Aeronautics Research

A1.01 Aeroelasticity and Aeroservoelastic Control

Lead Center: GRC
Participating Center(s): AFRC

Scope Title
Aeroelasticity and Aeroservoelasticity for Advanced Configurations

Scope Description
The technical discipline of aeroelasticity is a critical ingredient necessary in the design process of a flight vehicle for maintaining optimal performance while ensuring freedom from aeroelastic and aeroservoelastic instabilities. This discipline requires a thorough understanding of the complex interactions between a flexible structure and the steady and unsteady aerodynamic forces acting on the structure, with interactive control systems for flight vehicle performance and stability. These fundamental aeronautics work is focused on active/adaptive aerostructural control for lightweight flexible structures, specifically related to load distribution, flutter prediction and suppression, gust load prediction and alleviation, and aeroservoelasticity for Ultra-Efficient and Supersonic Commercial Vehicles.

The program's work on aeroservoelasticity includes conduct of broad-based research and technology development to obtain a fundamental understanding of aeroelastic and unsteady aerodynamic phenomena experienced by aerospace vehicles in subsonic, transonic, supersonic, and hypersonic speed regimes.

The program content includes theoretical aeroelasticity, experimental aeroelasticity, and advanced aeroservoelastic concepts. Of interest are:

- Aeroelastic, aeroservoelastic, and unsteady aerodynamic analyses at the appropriate level of fidelity for the problem at hand.
- Aeroelastic, aeroservoelastic, and unsteady aerodynamic experiments to validate methodologies and to gain valuable insights available only through testing.
- Development of computational fluid dynamic (CFD), computational aeroelastic, and computational aeroservoelastic analysis tools that advance the state of the art in aeroservoelasticity through novel and creative application of aeroelastic knowledge.

Specific subjects to be considered include:

- Development of aerostructural control design methodologies that include CFD steady and unsteady aerodynamics, flexible structures, and active control systems.
- Development of efficient methods to generate mathematical models of wind tunnel models and flight
vehicles for performing aeroservoelastic studies.

- Development of CFD-based methods (reduced-order models) for aeroservoelastic models and simulation that can be used to predict gust loads, ride quality issues, flight dynamics stability, and aerostructural control issues.
- Development of novel aeroservoelastic sensing and control approaches, including active/adaptive control concepts and architectures that employ smart materials embedded in the structure and aerodynamic sensing and control schemes for suppressing aeroelastic instabilities and improving performance.
- Development of techniques that support simulations, ground testing, wind tunnel tests, and flight experiments for aerostructural control of aeroservoelastic phenomena.

**Expected TRL or TRL Range at completion of the Project**

3 to 5

**Primary Technology Taxonomy**

**Level 1**

TX 15 Flight Vehicle Systems

**Level 2**

TX 15.1 Aerosciences

**Desired Deliverables of Phase I and Phase II**

- Hardware
- Software

**Desired Deliverables Description**

This subtopic seeks technologies for

- Development of CFD, computational aeroelastic, and computational aeroservoelastic analysis tools that advance the state of the art in aeroservoelasticity through novel and creative application of aeroelastic knowledge.
- Development of aerostructural control design methodologies that include CFD steady and unsteady aerodynamics, flexible structures, and active control systems.
- Development of efficient methods to generate mathematical models of wind tunnel models and flight vehicles for performing aeroservoelastic studies.
- Development of CFD-based methods (reduced-order models) for aeroservoelastic models and simulation that can be used to predict gust loads, ride quality issues, flight dynamics stability, and aerostructural control issues.
- Development of novel aeroservoelastic sensing and control approaches, including active/adaptive control concepts and architectures that employ smart materials embedded in the structure and aerodynamic sensing and control schemes for suppressing aeroelastic instabilities and improving performance.
- Development of techniques that support simulations, ground testing, wind tunnel tests, and flight experiments for aerostructural control of aeroservoelastic phenomena.

**Expected Phase I and Phase II Deliverables:**

**Phase I:** Develop the infrastructure for the analysis tool(s), methods, methodologies, and/or simulation/test techniques, then demonstrate/verify feasibility via prototype or proof of concept.

**Phase II:** Complete development of the Phase 1 effort, demonstrating/verifying the tool(s), methods, methodologies, and/or simulation/test techniques via model(s)/structure(s) of appropriate complexity and interest to NASA.
State of the Art and Critical Gaps

Aeroelastic prediction and testing methods must evolve and expand together with new and emerging aircraft, structural, and material concepts. The use of lightweight flexible structures, the development of new airframes (truss-braced wings, blended-wing bodies, etc.), and the intentional exploitation of aeroelastic response phenomena require a comprehensive understanding of the aeroelasticity involved if they are to succeed. Both enhancements to current methodologies/codes and new methodologies/codes that enable evaluation and understanding of new concepts are needed to keep pace with the state of the art in vehicle technology and to fill critical gaps in understanding those vehicles. Code development and performance prediction typically lag vehicle conceptual development, so while the most popular computational methods in use today, which were developed under Small Business Innovation Research (SBIR) awards, work well for yesterday's configurations, they will have to be modified or rethought entirely to capture the behavior of today's and tomorrow's evolutionary and revolutionary vehicles.

Relevance / Science Traceability

Predicting the aeroelastic response of emerging evolutionary and revolutionary vehicle concepts is not an easy task. Aeroelastic prediction and testing methods must evolve and expand with the concepts themselves, which include new vehicle configurations, new structures, and new materials. The use of lightweight flexible structures, the development of new airframes (truss-braced wings, blended-wing bodies, etc.), and the intentional exploitation of aeroelastic response phenomena require a comprehensive understanding of the aeroelasticity involved if they are to succeed. The Boeing 787, for example, has the most flexible wing of any transport built thanks to composites and aggressive aeroelastic optimization of the structure. Some specific NASA programs/projects/topics that will greatly benefit from the expansion of aeroelastic knowledge, tools, and test techniques are under the Aeronautics Research Mission Directorate (ARMD), including (a) the Advanced Air Vehicles Program (AAVP), specifically, the Aerosciences Evaluation and Test Capabilities (AETC) project, the Advanced Air Transportation Technologies (AATT) project with the Performance Adaptive Aeroelastic Wing (PAAW) and Passive Aeroelastically- Tailored Wing (PATW) subprojects, and the Commercial Supersonic Technology (CST) project; (b) the Transformative Aeronautics Concepts Program (TACP), specifically, the Convergent Aeronautics Solutions (CAS) project and the Transformational Tools and Technologies (TTT) project; (c) the Integrated Aviation Systems Program (IASP), specifically, the Flight Demonstrations and Capabilities (FDC) project; (d) N+3; (e) the X-56A flight project; and (f) the work with new ultra-efficient and supersonic commercial vehicles.

References

Links to program/project websites:

1. ARMD's Advanced Air Vehicles Program (AAVP): [https://www.nasa.gov/aeroresearch/programs/aavp](https://www.nasa.gov/aeroresearch/programs/aavp) [1]
2. ARMD's Transformative Aeronautics Concepts Program: [https://www.nasa.gov/aeroresearch/programs/tacp](https://www.nasa.gov/aeroresearch/programs/tacp) [2]

Information related to evolutionary and revolutionary flight vehicle concepts/configurations that are on the drawing board or already being tested:

3. Joined Wing: [https://www.nasa.gov/centers/langley/multimedia/iotw-tdt-wing.html](https://www.nasa.gov/centers/langley/multimedia/iotw-tdt-wing.html) [7]
A1.02 Quiet Performance - Aircraft Propulsion Noise

Lead Center: GRC

Participating Center(s): LaRC

Scope Title

Aircraft Propulsion Noise

Scope Description

Innovative methods and technologies are necessary for the design and development of efficient and environmentally acceptable aircraft. In particular, the impact of aircraft noise on communities around airports is the predominant limiting factor on the growth of the nation's air transportation system. 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. In support of the Advanced Air Vehicles Program (AAVP), Integrated Aviation Systems Program (IASP), and Transformative Aeronautics Concepts Program (TACP), improvements in propulsion noise prediction, diagnostics, and reduction are needed for subsonic and supersonic aircraft. Innovations in the following areas are solicited:

Prediction:

- High-fidelity fan and turbine broadband noise prediction models, fan and turbine 3D acoustic transmission models for tone and broadband noise.
- Accurate models for prediction of installed noise for jet-surface interaction, fan inlet distortion, and open rotors.

Diagnostics:

- Tools/technologies for quantitative characterization of fan in-duct broadband noise in terms of its spatial and temporal content.
- Phased array and acoustical holography techniques to measure realistic propulsion noise sources in low signal-to-noise ratio wind tunnel environments.
- Characterization of fundamental jet noise sources and structures.

Reduction:

- Advanced liners including broadband liners (i.e., liners capable of appreciable sound absorption over at least two octaves) and low-frequency liners (i.e., liners with optimum absorption frequencies half of the current ones but without increasing liner depth).
- Low noise propulsor concepts that are significantly quieter than the current generation fans and open rotors.
- Concepts for active control of broadband noise sources including fan, open rotor, jet, compressor, combustor, and turbine.
- Adaptive flow and noise control technologies including smart structures for inlets, nozzles, and low-drag liners.
- Concepts to mitigate the effects of distorted inflow on propulsor noise.

Expected TRL or TRL Range at completion of the Project
Primary Technology Taxonomy

Level 1

TX 01 Propulsion Systems

Level 2

TX 01.3 Aero Propulsion

Desired Deliverables of Phase I and Phase II

- Research
- Analysis
- Prototype
- Hardware
- Software

Desired Deliverables Description

Tools and technologies that enable prediction, diagnostics, and reduction of propulsion noise at component or system level for subsonic and supersonic aircraft. Phase I deliverables can include: (1) demonstration of the utility of new tools for predicting realistic model problems in propulsion noise, (2) proof-of-concept demonstration of advanced noise diagnostic techniques for propulsion noise identification and characterization, and (3) laboratory demonstration of propulsion noise reduction concepts or technologies. Phase II deliverables can include maturation of such tools, capabilities, and technologies for realistic propulsion components or systems.

State of the Art and Critical Gaps

Efficient high-fidelity computational tools that enable timely evaluations of multiple engine configurations 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 fan, combustor, and turbine. 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 for aircraft.

Relevance / Science Traceability

AAVP: The Advanced Air Transport Technology (AATT) and Commercial Supersonic Technology (CST) Projects would benefit from more accurate propulsion noise prediction capabilities, more robust propulsion noise diagnostic tools, and more effective propulsion noise reduction technologies. These could lead to quieter propulsion systems that can help reduce the aircraft noise footprint at landing and takeoff. New engine architectures and new airframe-engine integration concepts could also benefit from an infusion of new tools and technologies to assess their acoustic performance in early design stages.

TACP: The Transformational Tools and Technologies (TTT) Project would benefit from tool developments to enhance the ability to consider acoustic considerations earlier in the aircraft propulsion system design process. The TTT Project would also benefit from the development and demonstration of simple material systems, such as advanced liner concepts with reduced drag or adaptive material and/or structures that reduce propulsion noise, as these component technologies could have application in numerous vehicle classes in the AAVP portfolio, including subsonic and supersonic transports and, potentially, vertical lift vehicles.

References
A1.03 Low Emissions/Clean Power - Environmentally Responsible Propulsion

Lead Center: GRC

Participating Center(s): LaRC

Scope Title

Environmentally Responsible Propulsion - Aircraft Combustor Tools and Technologies

Scope Description

Innovative tools and technologies are required to address several challenges to improving combustor operability and durability and minimizing the impact of aircraft emissions on human health and the environment. Overcoming these challenges is important to both next-generation subsonic aircraft and potential future high-speed commercial aircraft. Particulate matter emissions from aircraft gas turbine engines, consisting primarily of ultrafine soot, contribute to adverse health and climate impacts, and new international standards on nonvolatile particulate matter emissions will start in 2023. Next-generation single-aisle aircraft are pushing towards smaller engine cores and higher overall pressure ratios, leading to challenges in combustor cooling design. Future high-speed (supersonic) aircraft also face significant combustor cooling challenges due to the need for maximizing the air available to combust with the fuel (to provide ultralow emissions of oxides of nitrogen that mitigate ozone depletion at stratospheric cruise altitudes) while operating at the harshest thermal condition during long-duration cruise. Conventional gas turbine engines operating at higher overall pressure ratios and future hybrid-electric or high-speed aircraft concepts that use the fuel as a heat sink may experience fuel injection behavior outside of current understanding and modeling capabilities. Aviation goals to reduce climate impacts from aviation will drive increased use and blending ratios of sustainable aviation fuels. To address these challenges, innovations in the following specific areas are solicited:

- Nonintrusive optical techniques to measure near-wall velocities, temperature, and/or turbulence variables for experiments with liquid-spray injection operating over a range of pressures (1 atm to at least 30 atm).
- Tools and technologies to improve combustor durability and optimize cooling in the combustor for smaller core subsonic application and/or long-duration cruise supersonic applications.
- Approaches that tightly couple convection, conduction, and radiation heat transfer in a computationally efficient manner applicable to time-accurate eddy-resolving simulations of combustion flows with liquid-spray injection.
- Fuel-sensitive soot-precursor chemistry models applicable to Jet-A and various blending ratios of Jet-A with sustainable aviation fuels.
- For multicomponent hydrocarbon fuels (conventional jet fuel and sustainable aviation fuels), models for the transition from two-phase (liquid-vapor regime with surface tension) behavior to a single-phase behavior (where no surface tension exists) that may be encountered for fuels injected into high-pressure and high-temperature combustor chamber conditions, and/or for heated fuels.

Development of measurement techniques for characterizing aircraft engine particle emissions in the 10- to 200-nm particle diameter size range and their interactions with contrails and contrail-cirrus clouds. Complete instrument systems are desired, including features such as remote/unattended operation and data acquisition and minimum size, weight, and power consumption. Instrument prototypes as a deliverable in Phase II proposals and/or
field demonstrations are encouraged. Desired measurement capabilities include:

- Size-dependent number and mass concentrations at 1-Hz time resolution that differentiate volatile/nonvolatile particles or elemental/organic carbon fractions, consistent with the measurement definitions given by the standard SAE ARP6320A ([https://www.sae.org/standards/content/arp6320a/][13]). Note that the ARP is referenced only for measurement referencing and terminology; this subtopic seeks proposals for research-grade instruments that go significantly beyond the current state of the art and the baseline measurement requirements of the ARP.
- Open-path, aircraft cloud probes suitable for measuring the number and size distribution of near-field small contrail ice crystals down to a nominal 0.1- to 0.3-µm diameter lower size limit.
- Aircraft-mounted water vapor, dew point, or relative humidity probe with small enough size, weight, and power footprint that it would be suitable for integration on a commercial aircraft. Instrument should be optimized for upper tropospheric ambient measurements (nominally 20-ppm minimum sensitivity for water vapor, -40 to -70 °C static air temperature, 150- to 300-mbar static air pressure).
- Aircraft-mounted temperature probe suitable for measuring static air temperature with accuracy at or better than 0.1 °C under upper tropospheric flight conditions.
- Measurements carried out at high sample line pressures relevant for sector combustor studies and low pressures relevant for flight studies.

**Expected TRL or TRL Range at completion of the Project**

2 to 5

**Primary Technology Taxonomy**

**Level 1**

TX 01 Propulsion Systems

**Level 2**

TX 01.3 Aero Propulsion

**Desired Deliverables of Phase I and Phase II**

- Research
- Analysis
- Prototype
- Software
- Hardware

**Desired Deliverables Description**

A major deliverable will be computer simulation software to predict the best and most effective combustor configurations. Sensor development for monitoring engine emissions would be another deliverable.

Phase I should successfully demonstrate fabrication/testing of a laboratory breadboard system, overcoming a major system or subsystem technical hurdle, or foundational work that lays the groundwork for the Phase II work plan, which should be summarized in the Phase I report.

Phase II deliverables such as instrument prototypes and/or field demonstrations are highly encouraged.

**State of the Art and Critical Gaps**

Combustion involves multiphase, multicomponent fuel, turbulent, unsteady, 3D, reacting flows where much of the physics of the processes are not completely understood. Computational fluid dynamics (CFD) codes used for combustion do not currently have the predictive capability that is typically found for nonreacting flows. Low-
emissions combustion concepts require very rapid mixing of the fuel and air with a minimum pressure loss to achieve complete combustion in the smallest volume. Areas of specific interest where research is solicited include:

- Development of laser-based diagnostics for quantitative spatially and temporally resolved measurements of fuel/air ratio in reacting flows at elevated pressure.
- Development of optical techniques for soot measurement and characterization for combustor flametube and sector tests (non-prevaporized liquid combustion, fuel Jet-A, pressures 3 to 80 atm; flame temperatures up to 2,250 K, soot diameters on the order of 10 to 100 nm)
- Development of ultrasensitive instruments for determining the size-dependent mass of combustion-generated particle emissions.
- Low-emissions combustor concepts for small high-pressure engine cores.

Relevance / Science Traceability

All of Aeronautics Research Mission Directorate (ARMD), Transformational Tools and Technologies (TTT), etc.

Achieving low emissions and finding new pathways to cleaner power are critical for the development of future air vehicles. Vehicles for subsonic and supersonic flight regimes will be required to operate on a variety of certified aircraft fuels and emit extremely low amounts of gaseous and particulate emissions to satisfy increasingly stringent emissions regulations. Future vehicles will be more fuel efficient, which will result in smaller engine cores operating at higher pressures. Future combustors will also likely employ lean-burn concepts, which are more susceptible to combustion instabilities.

Infusion/Commercial Potential: These developments will impact future aircraft engine combustor designs (lower emissions, improve operability, control instabilities) and may have commercial applications in other gas-turbine-based industries, such as power generation and industrial burners. The modeling and results can be and will be employed in current and future hydrocarbon rocket engine designs (improving combustion efficiency, ignition, stability, etc.).

References

- Procedure for the Continuous Sampling and Measurement of Non-Volatile Particulate Matter Emissions from Aircraft Turbine Engines (ARP6320): https://www.sae.org/standards/content/arp6320/ [16]

A1.04 Electrified Aircraft Propulsion

Lead Center: GRC

Participating Center(s): AFRC, LaRC

Scope Title

Electrified Aircraft Propulsion (EAP)
Scope Description

Technical proposals are sought for the development of enabling power systems, that will be required for aircraft using turboelectric, hybrid-electric, or all-electric power generation as part of the propulsion system. This subtopic is targeted towards megawatt-class vehicles. For the 100- to 200-kW realm targeted to electric vertical takeoff and landing (eVTOL) vehicles, please go to subtopic A1.06: Vertical Lift Technology for Urban Air Mobility -Electric Motor Fault Mitigation Technology.

Specifically, novel developments are sought in these areas:

- Superconducting wire or cables compatible with the NASA High Efficiency Megawatt Motor (HEMM) and at a temperature of 62 K that have properties exceeding: engineering current density >205 A/mm², cost per performance <$1.10/(A-m), and shear stress in all three axis >20 MPa. Information on HEMM can be found in the publication “High Efficiency Megawatt Motor Preliminary Design”, Jansen et al. https://ntrs.nasa.gov/citations/20190029589 [17]
- Lightweight alternating current (AC) and direct current (DC) electrical fault management systems and protective devices (such as circuit breakers). Technology should scale to aircraft circuits operating in the 1,000- to 3,000-V range at 500 to 2,000 A. Prototypes can be built at the 100- to 500-V at 10- to 100-A range or at full scale. The circuit breaker technology proposals will be evaluated on the metrics of: speed to isolate circuit, specific power (kW/kg), and efficiency (1- (W loss/ W conducted)). The performance objective is to exceed 200 kW/kg and 99.5% at full scale.
- Converters (inverters/rectifiers) used to convert AC to AC frequency AC to DC. Technology should scale to aircraft circuits operating in the 1,000- to 3,000-V range at 500 to 2,000 A. Prototypes can be built at the 100- to 500-V at 10- to 100-A range or at full scale. The converters will be evaluated on the metrics of specific power (kW/kg) and efficiency with objective to exceed 20 kW/kg and 99.5% at full scale.
- Electric machines for aircraft propulsion used for direct-drive propulsion of fans or propellers or as generators coupled to internal combustion engines, turboprops, or turbofans. Technology should scale to aircraft applications in the 1- to 5-MW range. The electric machines will be evaluated on the metrics of: specific power (kW/kg) and efficiency with objective to exceed 20 kW/kg and 98% at full scale.

Expected TRL or TRL Range at completion of the Project

2 to 6

Primary Technology Taxonomy

Level 1

TX 01 Propulsion Systems

Level 2

TX 01.3 Aero Propulsion

Desired Deliverables of Phase I and Phase II

- Research
- Analysis
- Prototype
- Hardware
- Software

Desired Deliverables Description

Deliverables vary considerably within the subtopic, but ideally proposals would identify a technology pull area (with a market size estimate), how the proposed idea addresses the needs of the technology pull area and then deliver a combination of analysis and prototypes that substantiate the idea's merit. For Phase I, it is desirable that the
The proposed innovation clearly demonstrates that it is commercially feasible and addresses NASA's needs. Deliverables for a Phase II should be focused on the maturation, development, and demonstration of the proposed technical innovation.

**State of the Art and Critical Gaps**

The critical technical need is for lightweight, high-efficiency motors, distribution systems, and fault management. Typically, the weight needs to be reduced by a factor of 2 to 3 and efficiency needs to be improved. Higher efficiency reduces losses and makes thermal management more achievable in an aircraft.

Technologies that address these gaps enable EAP, which 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.

**Relevance / Science Traceability**

EAP is an area of strong and growing interest in the Aeronautics Research Mission Directorate (ARMD). There are emerging vehicle level efforts in urban on-demand mobility, the X-57 electric airplane being built to demonstrate EAP advances applicable to thin and short haul aircraft markets, and an ongoing technology development subproject to enable EAP for single-aisle aircraft. Additionally, NASA is starting the new Electrified Powertrain Flight Demonstration (EPFD) project to enable a megawatt-class aircraft.

Key outcomes NASA intends to achieve in this area are:

- **Outcome for 2015 to 2025:** Markets will begin to open for electrified small aircraft.
- **Outcome for 2025 to 2035:** Certified small-aircraft fleets enabled by EAP will provide new mobility options. The decade may also see initial application of EAP on large aircraft.
- **Outcome for >2035:** The prevalence of small-aircraft fleets with electrified propulsion will provide improved economics, performance, safety, and environmental impact, while growth in fleet operations of large aircraft with cleaner, more efficient alternative propulsion systems will substantially contribute to carbon reduction.

Projects working in the vehicle aspects of EAP include:

- **Advanced Air Vehicles Program (AAVP)/Advanced Air Transport Technology (AATT) Project**
- **Integrated Aviation Systems Program (IASP)/Flight Demonstrations and Capabilities (FDC) Project**
- **AAVP/Revolutionary Vertical Lift Technology (RVLT) Project**
- **Transformative Aeronautics Concepts Program (TACP)/Convergent Aeronautics Solutions (CAS) Project**
- **TACP/Transformational Tools and Technologies (TTT) Project**

**References**

- EAP is called out as a key part of Thrust 3 in the ARMD strategic plan: [https://www.nasa.gov/aeroresearch/strategy](https://www.nasa.gov/aeroresearch/strategy) [18]
- Overview of NASA's EAP Research for Large Subsonic Aircraft: [https://ntrs.nasa.gov/search.jsp?R=20170006235](https://ntrs.nasa.gov/search.jsp?R=20170006235) [19]
- “High Efficiency Megawatt Motor Preliminary Design”, Jansen et al. [https://ntrs.nasa.gov/citations/20190029589](https://ntrs.nasa.gov/citations/20190029589) [21]

**A1.05 Computational Tools and Methods**

Lead Center: GRC
Unstructured Meshes for Scale-Resolving Simulations

Computational fluid dynamics (CFD) plays an important role in the design and development of a vast array of aerospace vehicles, from commercial transports to space systems. With the ever-increasing computational power, usage of higher fidelity, fast CFD tools and processes will significantly improve the aerodynamic performance of airframe and propulsion systems, as well as greatly reduce nonrecurring costs associated with ground-based and flight testing. Historically, the growth of CFD accuracy has allowed NASA and other organizations, including commercial companies, to reduce wind tunnel and single engine component tests. Going forward, increased CFD fidelity for complete vehicle or engine configurations holds the promise of significantly reducing development costs, by enabling certification by analysis (CbA). Confidence in fast, accurate CFD and multidisciplinary analysis tools allow engineers to reach out of their existing design space and accelerate technology maturation schedules. Uncertainty quantification is a key technology in enhancing confidence in the prediction capability of the computational tools. NASA’s CFD Vision 2030 Study (https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20140003093.pdf [22]) highlighted the many shortcomings in the existing computational technologies used for conducting high-fidelity simulations, including multidisciplinary analysis and optimization, and made specific recommendations for investments necessary to overcome these challenges. A more recent study provided a long-term vision and a technology development roadmap to enable CbA for aircraft and engine certification (see https://ntrs.nasa.gov/citations/20210015404 [23]).

During the current cycle, proposals are solicited in the following mesh generation area for CFD simulations:

Unstructured Meshes for Scale-Resolving Simulations: Mesh generation for high-fidelity simulations is a critical area of research. The focused grid-related area for which proposals are being solicited is automated and scalable mesh generation for wall-modeled large eddy simulations (WMLES). Unstructured approaches can be used to discretize highly complex flow configurations but, in addition to automation, there is need to generate the mesh robustly and efficiently regardless of geometric complexity. The mesh quality aspect is especially critical for scale-resolving simulations where numerical methods benefit significantly from element regularity and alignment for accuracy considerations, while maintaining an optimal number of cells for solver efficiency. Isotropic meshing is preferred and a combination of hex grid (near solid boundaries) and tetrahedral (further away) may provide the best compromise between solution accuracy and solver efficiency. The goal of the solicited work is to encourage development of such mesh generation software that can be interfaced and integrated with NASA CFD solvers. The requirements for the solicited mesh software include: (1) it should be able to efficiently handle arbitrarily complex geometries; (2) the software should be Message Passing Interface (MPI) parallel, scalable to billion+ cell meshes as are typical for NASA applications; (3) the mesh generation process needs to take a water-tight bounding volume definition as input, where the surface of the bounding volume can be marked with prescribed mesh resolution(s), in addition to any user-prescribed volume refinement metrics (such as adjoint-based error metrics, prescribed volumes, etc.). Such mesh technology has the potential to drastically improve turnaround time for scale-resolving simulations for complex configurations and enabling wider use of high-fidelity CFD analysis for challenging turbulent flow problems. This research effort is expected to enable NASA solvers to interface with the resulting tool. The meshing tool should be designed to perform well on the emerging high-performance computing hardware. An additional area of research may include adaptive mesh refinement while a WMLES is progressing. Demonstration of mesh generation coupled with NASA CFD solvers (e.g., the unstructured grid code FUN3D) is considered essential for the solicited research.

Expected TRL or TRL Range at completion of the Project

3 to 6

Primary Technology Taxonomy

Level 1
TX 15 Flight Vehicle Systems

Level 2

TX 15.1 Aerosciences

Desired Deliverables of Phase I and Phase II

- Software
- Research
- Analysis

Desired Deliverables Description

Phase I:

1. Demonstrate fully automated unstructured mesh generation for canonical geometries as proof of concept.
2. Demonstrate accuracy and efficiency of the developed capability, using a NASA CFD solver (e.g., FUN3D).
3. Provide an executable of the mesh generation code and an Application Programming Interface (API) to interface with NASA solvers for independent testing.

Phase II:

1. Further develop the mesh generation capability for WMLES and demonstrate on more complex topologies (e.g., NASA Common Research High-Lift Model (HLPW-4 configuration), NASA juncture flow model, multistream chevron nozzle (TMP17)).
2. Demonstrate solution accuracy.
3. Demonstrate weak and strong scaling of the mesh generation software pushing the capability limits.
5. Deliver executable of mesh generation solver along with the API to NASA for its internal use.

State of the Art and Critical Gaps

NASA's CFD Vision 2030 Study identified several impediments in computational technologies and this solicitation addresses one of those related to application of scale-resolving simulations needed for expanding the scope of application of CFD across the aircraft flight envelope, particularly in the prediction of maximum lift. This solicitation also addresses meshing needs to enable such computations.

Relevance / Science Traceability

Various programs and projects of NASA missions use CFD for advanced aircraft concepts, launch vehicle design, and planetary entry vehicles. The developed technology will enable design decisions by Aeronautics Research Mission Directorate (ARMD) and Human Exploration and Operations Mission Directorate (HEOMD).

References

- NASA’s CFD Vision 2030 Study: https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20140003093.pdf [22]
- FUN3D: https://software.nasa.gov/software/LAR-19638-1 [25]
Scope Title

Unstructured Mesh Generation for Icing

Scope Description

Computational fluid dynamics (CFD) plays an important role in the design and development of a vast array of aerospace vehicles, from commercial transports to space systems. With the ever-increasing computational power, usage of higher fidelity, fast CFD tools and processes will significantly improve the aerodynamic performance of airframe and propulsion systems, as well as greatly reduce nonrecurring costs associated with ground-based and flight testing. Historically, the growth of CFD accuracy has allowed NASA and other organizations, including commercial companies, to reduce wind tunnel and single-engine component tests. Going forward, increased CFD fidelity for complete vehicle or engine configurations holds the promise of significantly reducing development costs, by enabling certification by analysis (CbA). Confidence in fast, accurate CFD and multidisciplinary analysis tools allow engineers to reach out of their existing design space and accelerate technology maturation schedules. Uncertainty quantification is a key technology in enhancing confidence in the prediction capability of the computational tools. NASA’s CFD Vision 2030 Study (https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20140003093.pdf [22]) highlighted the many shortcomings in the existing computational technologies used for conducting high-fidelity simulations, including multidisciplinary analysis and optimization, and made specific recommendations for investments necessary to overcome these challenges. A more recent study provided a long-term vision and a technology development roadmap to enable CbA for aircraft and engine certification (see https://ntrs.nasa.gov/citations/20210015404 [23]).

During the current cycle, proposals are solicited in mesh generation for the following CFD application.

Unstructured Mesh Generation for Icing: Another topic for which proposals are solicited is the study of icing effect on aircraft performance. Icing plays an important role in aircraft design and the certification process and, therefore, modeling and quantification of icing effects on aerodynamic performance (e.g., aircraft CLmax) is required, as pointed out in the CbA report referred to previously. This solicitation invites proposals for grid generation with imposed icing shapes to enable high-fidelity CFD analysis of relevant configurations. The objective is to use the developed capability with NASA unstructured grid CFD solvers and, therefore, the proposer will address such coupling along with the capability demonstration. The proposer will collect available icing data and use it to demonstrate the unstructured grid capability as well as simulate icing effect on aerodynamic performance particularly during high-lift flight configuration. Breakdown of the proposed work, including the strategy for capability demonstration, will be a critical factor in the evaluation process. The goal of this research is to provide an automated, efficient, and accurate tool for the intended purpose. Deliverables must include an Application Programming Interface (API) to interface the meshing tool with NASA CFD solvers, in particular FUN3D.

Expected TRL or TRL Range at completion of the Project

3 to 6

Primary Technology Taxonomy

Level 1

TX 15 Flight Vehicle Systems

Level 2

TX 15.1 Aerosciences

Desired Deliverables of Phase I and Phase II

- Analysis
- Research
- Software
Desired Deliverables Description

Phase I:

1. Demonstrate fully automated unstructured mesh generation for canonical wing geometries as proof of concept.
2. Demonstrate accuracy and efficiency of the developed capability, using a NASA CFD solver (e.g., FUN3D), for prediction of icing effect.
3. Provide an executable of the mesh generation code and an API to interface with NASA solvers for independent testing.

Phase II:

1. Further develop the mesh generation capability including icing and demonstrate on more complex topologies (high-lift applications are of particular interest).
2. Demonstrate solution accuracy.
3. Deliver executable of mesh generation tool, including icing effect, along with the API to couple with NASA unstructured grid solvers.

State of the Art and Critical Gaps

NASA's CFD Vision 2030 Study identified several impediments in computational technologies and this solicitation addresses one of those related to application of scale-resolving simulations needed for expanding the scope of application of CFD across the aircraft flight envelope, particularly in the prediction of maximum lift. NASA's more recent study "A Guide for Aircraft Certification by Analysis" identified the need for computation of icing effects on aerodynamic performance. This solicitation also addresses meshing needs to enable such computations.

Relevance / Science Traceability

Various programs and projects of NASA missions use CFD for advanced aircraft concepts, launch vehicle design, and planetary entry vehicles. The developed technology will enable design decisions by Aeronautics Research Mission Directorate (ARMD) and Human Exploration and Operations Mission Directorate (HEOMD).

References

- NASA's CFD Vision 2030 Study: https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20140003093.pdf [22]
- NASA's Aircraft Certification by Analysis Study: https://ntrs.nasa.gov/citations/20210015404 [23]

A1.06 Vertical Lift Technology for Urban Air Mobility -Electric Motor Fault Mitigation Technology

Lead Center: GRC

Participating Center(s): AFRC, ARC, LaRC

Scope Title

Electric Vertical Takeoff and Landing (eVTOL) Electric Motor Fault Mitigation Technologies
Scope Description

The expanding Urban Air Mobility (UAM) vehicle industry has generated a significant level of enthusiasm among aviation designers and manufacturers, resulting in numerous vehicle configurations. Most of the prototype UAM vehicles have more than 4 rotors or propellers, have electric propulsion, carry 2 to 6 passengers, fly more like a helicopter (vertical take-off and landing) than a fixed-wing aircraft and will fly relatively close to the ground and near buildings. There are many technical challenges facing industry’s development of safe, quiet, reliable, affordable, comfortable, and certifiable UAM vehicles and vehicle operations. One of those challenges is the subject of this SBIR subtopic, namely, safe, and reliable operation of electric motors (100- to 200-kW class) for eVTOL vehicles to accomplish UAM mission (numerous daily operations; hover-cruise-hover loading cycle) [Ref. 1].

[Megawatt electric propulsion systems for CTOL transport aircraft is addressed in the A1.04 Electrified Aircraft Propulsion subtopic.]

The application of the requested technologies should be relevant to the NASA Revolutionary Vertical Lift Technology (RVLT) Project’s reference concept vehicles [Refs. 2-3], which embody the key vehicle characteristics of the UAM vehicle configurations being designed throughout industry. Technologies proposed for this solicitation should be relevant to 100-kW-class motor-rotor powertrain elements with scalability in the 20- to 500-kW class. Due to the power levels envisioned for UAM vehicles, most will require high-voltage (>540 V) bus operation, with the corresponding high-voltage direct current (DC) protection devices to ensure safe systems [Ref. 4].

Through this solicitation, NASA is seeking advanced technologies supporting electric/hybrid-electric propulsion for the advance air mobility and specifically the UAM mission (concept of operations) in the areas of:

- **Electric Machine/Motor Fault Detection and Fault Mitigation:** This solicitation is seeking technology advancements that will address the fault detection and fault mitigation for electric machines used in eVTOL vehicle propulsion systems. There are several key faults that are typical for electric machines: electrical, mechanical, and magnetic. Through this Small Business Innovative Research (SBIR) solicitation, technologies are being sought that would preclude common electric machine faults and/or detect and mitigate the faults to ensure safe vehicle operations. Technologies targeting the mitigation of turn-to-turn and turn-to-ground stator short circuit faults in a permanent magnet aircraft generator and/or motor are of especially high interest. Technologies are sought that either allow a motor/generator to continue operating in the event of a stator short circuit or enable quick shut down of the motor/generator before the fault enters a thermal runaway condition.

- **Electric Motor Performance Improvement Technology:** Single Fluid Motor with High Power Density and High Reliability: Novel and innovative efforts are sought to develop high-performance electric drive motors that utilize a fluid as both the motor coolant and bearing lubricant. Vertical lift propulsion using electric motors to drive rotors and/or propellers offer the potential for lightweight and high efficiency partly through the elimination of ancillary systems found on conventional aircraft. Amongst these systems are hydraulic fluids and lubricating oils. For example, a direct-drive electric motor or those that utilize noncontact magnetic gearing (i.e., flux modulation machines) [Refs. 5-9] could function without lubricating oil provided their bearings could operate solely using the water-based coolants used for motor thermal management. Conventional steel-based ball and roller bearings are susceptible to corrosion and wear when operated using water. NASA has developed newly emerging NiTi (nickel-titanium) alloy bearings [Refs. 10-11] that are impervious to corrosion and have been shown to operate reliably when immersed in water. While a single-fluid electric motor utilizing oil could be conceived, the high viscosity of oils and their low heat capacity tend to limit electric motor power density. It is further recognized that magnetic, electrical, and rotordynamic characteristics of such machines are critical to success and are influenced by material selections. The use of emerging bearing material technologies, such as NiTi and ceramics, for bearings to operate well using a single fluid (such as water, water-based with additives, or appropriate dielectric fluid) [Refs. 12-13] could provide needed tribological, thermal, and electrical performance while achieving power density and reliability comparable to existing conventional designs. However, proposers will need to consider and address several considerations including bearing wear, bearing fatigue, strategy for robustness to debris carried by the fluid stream (including debris arising from bearing fatigue or wear), and bearing stiffness as these will influence the rotor-shaft-bearing subsystem. This topic specifically seeks electric motors using liquid-lubricated bearings. Electric motor concepts using grease-lubricated bearings are not within the scope of this topic.
Expected TRL or TRL Range at completion of the Project

2 to 4

Primary Technology Taxonomy

Level 1

TX 01 Propulsion Systems

Level 2

TX 01.3 Aero Propulsion

Desired Deliverables of Phase I and Phase II

- Analysis
- Research
- Prototype

Desired Deliverables Description

Phase I of the SBIR should develop design concepts for specific technology advancements supported by analytical studies including modeling and simulation. Phase I effort should establish Phase II goals and should quantify projections of technology performance in the detection and mitigation of motor faults.

Phase II of the SBIR should further develop the designs and validate achievement of goals through additional analysis, modeling, and simulation and through system/component functionality experiments. Phase II incorporates experiments with aircraft relevant hardware available commercially or through partnership with an aircraft component supplier and modified with innovative technology from this SBIR effort.

State of the Art and Critical Gaps

There are over 200 UAM vehicle concepts in varying stages of development. The immediate focus of the vehicle developers is overcoming obstacles on the path to certification. The public has experience flying in large transport and regional fixed-wing aircraft and are calibrated to associated safety levels for commercial air transportation. Detailed certification requirements for UAM vehicles are still under development by the relevant certifying authorities. For UAM aircraft, research is needed that addresses safety and reliability expectations of the traveling public and certifying authorities for the UAM mission. The concepts of operations for the UAM mission consists of numerous flights per day with power system/powertrain loading associated with vertical flight (hover) and forward flight for each flight. This concept of operations establish unique safety and reliability challenges for the power system/powertrain. Technology advancements are required to achieve these challenges.

Relevance / Science Traceability

This subtopic is relevant to the Aeronautics Research Mission Directorate (ARMD) Revolutionary Vertical Lift Technology (RVLT) Project under the Advanced Air Vehicle Program. The goal of the RVLT Project is to develop and validate tools, technologies, and concepts to overcome key barriers for vertical lift vehicles. The project scope encompasses technologies that address noise, speed, mobility, payload, efficiency, environment, and safety for both conventional and nonconventional vertical lift configurations. This subtopic directly aligns with the mission goals and scope in addressing safety and reliability of nonconventional vertical lift configurations. RVLT along with other ARMD projects are pursuing technologies, tools, and research that will enable new aviation markets to address the operational and vehicle requirements for the advance air mobility missions and specifically the UAM (air taxi) mission for VTOL vehicles.

References


A1.08 Aeronautics Ground Test and Measurement Technologies

Lead Center: GRC

Participating Center(s): ARC, GRC

Scope Title

Electromagnetic Interference (EMI) Detection and Mitigation in Higher Voltage/Higher Power Applications

Scope Description

NASA is developing electric-powered aircraft under both the Electrified Aircraft Propulsion Technologies (EAPT) and Revolutionary Vertical Lift Technology (RVLT) projects, where testbeds are being used to investigate system interactions and power quality (PQ) to feed associated standards for these classes of vehicles. NASA is also working with the Federal Aviation Administration (FAA) to provide pertinent data for drafting of the certification processes. As part of the testbed development, NASA is in need of EMI and PQ test equipment for higher voltage/higher power applications, which does not currently exist. Additionally, NASA is investigating the use of fiber-Bragg-grating- (FBG-) based temperature sensors for monitoring temperatures in electric-powered vehicles, both in the electric motors and in the aircraft thermal management systems being developed. While the fiber optic sensing of temperature is immune to EMI, the interrogators used to send the broadband pulses of light down the fiber and process the reflected return signals to measure the temperature at the FBG locations along the fiber are...
currently not immune to EMI. The objective of the Small Business Innovation Research (SBIR) subtopic is twofold: first to develop EMI and PQ test equipment, and secondly, to develop EMI immune optical interrogators for use on electrified aircraft. For RVLT applications, the requirements are to develop EMI equipment (power amplifiers, isolation transformers, ripple and surge injection units, etc.) and power equipment (power amplifiers, isolation transformers, fault injection units, dynamic load banks, and wide bandwidth emulators/power supplies) capable of testing systems/loads with operating voltages of at least 650 Vdc (1 kV preferred), 150 A (300 A preferred), with minimum bandwidths of direct current (DC) to 250 kHz (although may vary depending on application), and operating up to altitudes of 15,000 ft. The 250 kHz is of interest for investigation of EMI noise. For EAPT applications, the requirements are to develop similar EMI and power equipment capable of testing systems/loads with operating voltages of at least 1 kVdc and 1 kA, with a bandwidth of DC to 50 kHz and operating at altitudes up to 35,000 ft. EAPT also seeks to develop optical interrogators with a nominal optical bandwidth of at least 40 nm and a high spectral resolution (1 pm) that are immune to EAPT-specified level of EMI above. These high-EMI environments are endemic to both ground- and flight-based hybrid electric systems, and, hence, will have applicability to both test regimes. Initial systems for ground testing will not be constrained by weight, however, future flight-based systems should also be designed for minimized system weight and size.

**Expected TRL or TRL Range at completion of the Project**

4 to 6

**Primary Technology Taxonomy**

**Level 1**

TX 01 Propulsion Systems

**Level 2**

TX 01.3 Aero Propulsion

**Desired Deliverables of Phase I and Phase II**

- Research
- Analysis
- Prototype
- Hardware

**Desired Deliverables Description**

The desired deliverables for Phase I would be, at a minimum, detailed design and analysis of proposed equipment. An added benefit would be the build of breadboard units to validate the proposed approach. The desired deliverables for Phase II would be prototype hardware validated through test.

**State of the Art and Critical Gaps**

EMI and PQ test equipment for these higher voltage/higher power applications does not exist. With the advent of electrified aircraft efforts, this type of test equipment will be critical in evaluating safety and system interaction aspects for the myriad of designs being proposed for the urban air mobility market.

**Relevance / Science Traceability**

This scope ties directly to Aeronautics Research Mission Directorate (ARMD) via the RVLT project by providing technology critical for evaluating architectures under investigation at NASA, and most likely would also have application to the larger aircraft testbed under development through EAPT.

**References**

ARMD Strategic Implementation Plan: [https://www.nasa.gov/aeroresearch/strategy](https://www.nasa.gov/aeroresearch/strategy) [18]
Scope Title

Flow Diagnostics for High-Speed Flows

Scope Description

Spatially and temporally resolved, molecular-based diagnostics are sought for high-speed wind tunnel flows (supersonic, hypersonic), both with and without combustion. Improved measurement capabilities are needed for velocity, temperature, density, and/or species concentrations in harsh wind tunnel environments, from short-duration (~msec) to long-duration (~min) flow facilities. Measurement systems should be reliable and robust and preferably would be able to be implemented in multiple wind tunnel facilities and facility types including blowdown tunnels, combustion-heated tunnels, shock tubes, shock tunnels, and arc jets. Planar or volumetric, spatially resolved measurements are preferred. Ability to measure multiple parameters simultaneously is desirable. The ability to time-resolve unsteady flows so that frequency spectra of the measured phenomena can be obtained is also desirable. Measurement systems should be validated against accepted standards (thermocouples, calibration flames, etc.) to determine measurement accuracy and precision. Proposals should project anticipated accuracies and precisions of the proposed measurement system(s) based on prior cited or demonstrated work.

One area of emphasis is measurement of temperature, water vapor concentrations, and velocity at the nozzle exit of large (up to 8-ft diam.) hypersonic tunnels to quantify facility performance and to determine test article inflow conditions. Such flow fields may contain water droplets and the size, quantity, and distribution of these droplets is also of interest to NASA. Measurements are needed at high repetition rates (tens of kilohertz) and should be able to operate continuously or repeatedly for a duration of several minutes to obtain appropriate amount of data to improve statistical error and provide detailed information about the time varying nature of these flow fields. The technologies described above are all critical for evaluating and analyzing high-speed vehicle concepts and technologies in support of several different NASA missions.

Expected TRL or TRL Range at completion of the Project

4 to 7

Primary Technology Taxonomy

Level 1

TX 13 Ground, Test, and Surface Systems

Level 2

TX 13.X Other Ground, Test, and Surface Systems

Desired Deliverables of Phase I and Phase II

- Hardware
- Prototype
- Analysis
- Research
- Software

Desired Deliverables Description

The deliverables for the Phase I research should include proof of concept of proposed idea along with a design for the comprehensive system that would be developed in Phase II, including detailed analysis of the expected performance (spatial resolution, time response, accuracy, precision, etc.). The expected deliverables at the end of the Phase II effort is a usable system to be deployed in a NASA facility and training for NASA personnel. Demonstration of the measurement system in a NASA facility would be beneficial and strongly encouraged.
State of the Art and Critical Gaps

There are very limited technologies for measuring nozzle exit conditions in hypersonic facilities. Some systems exist but there have been very limited applications. A technology that can measure nozzle exit conditions could also be used for engine inlet and outflow conditions as well. A promising technology was developed and used to study aircraft engine outflow plumes using Air Force Small Business Innovation Research (SBIR) support. This included using an array of laser beams to perform absorption spectroscopy at the exit of a J-85 jet engine. Temperature and water vapor concentrations were measured over an ~1- by 1-m area. A gap in this technology is that the gas velocity, a highly desirable parameter, was not measured. Another gap that exists is the need expressed by facility managers and customers at some of the larger combustion-heated hypersonic facilities at NASA to measure water vapor droplet size and concentration (water droplets are an undesirable consequence of combustion heating and can affect engine performance).

Relevance / Science Traceability

The target application of this technology is in facilities like the 8-Foot High-Temperature Tunnel at NASA Langley. However, the technology also has other applications such as measuring inflow or outflow for engines being tested at NASA Glenn. The technology could also be applied to measure inflow conditions in other types of facilities like shock tube and shock tunnels as well as conventional aeronautical testing facilities.

References

ARMD Strategic Implementation Plan: https://www.nasa.gov/aeroresearch/strategy [18]

A2.01 Flight Test and Measurement Technologies

Lead Center: HQ

Participating Center(s): ARC, GRC, LaRC

Scope Title

Flight Test and Measurement Technologies

Scope 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 and industry’s cutting-edge research and development programs.

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 solicitation can cover 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 technologies 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.

Areas of interest emphasizing flight test and measurement technologies include:

- Measurement technologies for in-flight steady and unsteady aerodynamics, juncture flow measurements, propulsion airframe integration, structural dynamics, stability, and control including related to turbulence, and propulsion system performance in order to validate and improve flight modeling for next-generation vertical takeoff and landing (VTOL) vehicles.
- Advancement of miniaturization or portability of in situ and/or onboard sensing and/or integrated secured remote services for use in real-time decision making.
- Prognostic and intelligent vehicle health monitoring for hybrid and/or all-electric propulsion systems using an adaptive embedded control systems. Note: Only sensors to detect failures and for vehicle health monitoring will be considered. Proposals relating to flight control changes and other algorithms that respond to health issues and damage detected by sensors are covered under Subtopic A2.02 and will be rejected in this subtopic.
- Improved ruggedized single-longitudinal mode wideband 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 optics sensing system (FOSS).
- Sensing technologies, such as wireless sensors, that can be used for flight test instrumentation and flight modeling verification for manned and unmanned aircraft. Emphasis should be on developing a variety of specialized low-profile sensors that are capable of participating in a synchronized, high data rate, and high data volume diverse wireless sensor measurement network with a capability to deliver time-stamped/encrypted data to a central node. For example, an interrogation unit should support the wireless sensor itself and communicate with the flight unit. This area also includes wireless (nonintrusion) power transferring techniques and/or wirelessly powering remote sensors.

The emphasis here is for articles to be developed for flight test and flight test facility needs.

The technologies developed for this subtopic directly address the technical challenges in the Aeronautics Research Mission Directorate (ARMD) Integrated Aviation Systems Program (IASP) and the Electrified Powertrain Flight Demonstration (EPFD) and FDC Projects. The FDC Project conducts complex flight research demonstrations to support multiple ARMD programs. FDC is seeking to enhance flight research and test capabilities necessary to address and achieve the ARMD strategic plan. Technologies for this subtopic could also support Advanced Air Vehicle Program (AAVP) projects: Commercial Supersonic Technology (CST) and Revolutionary Vertical Lift Technology (RVLT), as well as the Aerosciences Evaluation and Test Capabilities (AETC) Portfolio Office.

For technologies focused on ground testing or operations, please consider submitting to subtopic A1.08 Aeronautics Ground Test and Measurement Technologies, as ground testing technologies will be considered out of scope for this A2.01 subtopic.

For technologies with space-only applications, please consider submitting to a related space subtopic as space-only technologies will be considered out of scope for this A2.01 subtopic.

Proposals relating to flight control changes and other algorithms that respond to health issues and damage detected by sensors are covered under subtopic A2.02 and will be rejected in this subtopic.

Proposals that focus solely on flight vehicle development rather than focusing on technologies applicable to flight test and measurement will be considered out of scope for the A2.01 subtopic.

Expected TRL or TRL Range at completion of the Project

3 to 6
Primary Technology Taxonomy

Level 1

TX 15 Flight Vehicle Systems

Level 2

TX 15.2 Flight Mechanics

Desired Deliverables of Phase I and Phase II

- Research
- Analysis
- Prototype
- Hardware
- Software

Desired Deliverables Description

For a Phase I effort, the small business is expected to develop a proof-of-concept demonstration of a technology and 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.

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 or software that is suitable to work in ground testing and can be proven, via relevant environment testing, to be working in flight environment. This relevant environment testing would satisfy NASA's technical readiness level expectations at the end of Phase II.

State of the Art and Critical Gaps

Current atmospheric flight systems cover a large range of uses from point-to-point drones to high-performance small aircraft, to large transports, 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. Known gaps include wireless instrumentation for flight, advanced telemetry technique, intelligent internal state monitoring for air and space vehicles, techniques for studying sonic booms, 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 secure telemetry of data to ensure informed operation of the flight system.

Relevance / Science Traceability

The technologies developed for this subtopic directly address the technical and capability challenges in ARMD’s FDC Project. FDC conducts complex flight research demonstrations to support different ARMD programs. FDC is seeking to enhance flight research and test capabilities necessary to address and achieve ARMD’s strategic plan. Also, they could support IASP and EPFD projects as well as CST and RVLT projects and the AETC Portfolio Office.

References

- NASA’s Low-Boom Flight Demonstration mission: [https://www.nasa.gov/X59](https://www.nasa.gov/X59) [28]
- NASA Armstrong Fact Sheet: NASA X-57
  Maxwell: [https://www.nasa.gov/centers/armstrong/news/FactSheets/FS-109.html](https://www.nasa.gov/centers/armstrong/news/FactSheets/FS-109.html) [29]
- NASA Armstrong Fact Sheet: Fiber Optic Sensing
A2.02 Enabling Aircraft Autonomy

Lead Center: HQ

Participating Center(s): ARC, GRC, LaRC

Scope Title

Enabling Aircraft Autonomy

Scope Description

The increased use of automation on aircraft offers significant advantages over traditional manned aircraft for applications that are dangerous to humans, long in duration, and/or require a fast response and high degree of precision. Some examples include remote sensing, disaster response, delivery of goods, industrial inspection, and agricultural support. Advanced autonomous functions in aircraft can enable greater capabilities and promise greater economic and operational advantages. Some of these advantages include a higher degree of resilience to off-nominal conditions, the ability to adapt to dynamic situations, and less reliance on humans during operations.

There are many barriers that are restricting greater use and application of autonomy in air vehicles. These barriers include, but are not limited to, the lack of methods, architectures, and tools that enable:

- Cognition and multiobjective decision making.
- Cost-effective, resilient, and self-organizing communications.
- Prognostics, survivability, and fault tolerance.
- Verification and validation technology and certification approaches.

NASA and the aviation industry are involved in research that would greatly benefit from breakthroughs in autonomous capabilities that could eventually enable the Advanced Air Mobility (AAM) mission. A few of the areas of research and missions are listed below:

- Remote missions utilizing one or more unmanned aircraft systems (UAS) would benefit from autonomous planning algorithms that can coordinate and execute a mission with minimal human oversight.
- Detect and avoid algorithms, sensor fusion techniques, robust trajectory planners, and contingency management systems can enable AAM and higher levels of UAS integration into the National Airspace System (NAS).
- Fault detection, diagnostics, and prognostics capabilities can inform autonomous contingency management systems.

This subtopic is intended to break through these and other barriers with innovative and high-risk research, enabling greater use of autonomy in NASA research, civil aviation, and, ultimately, the emerging AAM market. It is important to note that any proposals for UAS development and sensors for vehicle health/failure detection will not be
The following two research areas are the primary focus, and any submissions must show a strong relevance to these areas to be considered.

- **Prognostics, survivability, and fault tolerance:** Techniques are required that can understand vehicle health and critical failures, anticipate failures, and autonomously replan or execute emergency landings safely. Prognostics technologies capable of providing accurate predictions in a computationally constrained environment, such as that expected for small vehicles, are also needed. Examples include, but are not limited to, new, efficient approaches and algorithms and hybrid edge/cloud approaches. Proposals for vehicle health and failure detection are covered under Subtopic A151 and will be rejected under this subtopic.
- **Verification and validation technology and certification approaches:** New methods of verification, validation, and certification need to be developed to enable application of complex systems to be certified for use in the NAS. Proposed research could include novel hardware and/or software architectures that expedite or enable alternates to traditional verification and validation requirements. Proposals should reference material on emerging standards for autonomy certification, including the American Society for Testing and Materials (ASTM) autonomy guidelines and emerging Federal Aviation Administration (FAA) considerations for small aircraft, UAS, and UAM. For example, proposals could reference standards coming out of ASTM AC377.

**Expected TRL or TRL Range at completion of the Project**

3 to 6

**Primary Technology Taxonomy**

**Level 1**

TX 10 Autonomous Systems

**Level 2**

TX 10.X Other Autonomous Systems

**Desired Deliverables of Phase I and Phase II**

- Research
- Analysis
- Prototype
- Hardware
- Software

**Desired Deliverables Description**

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

- A technology demonstration in a simulation environment that clearly shows the benefits of the technology developed.
- 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.
- A written plan to continue the technology development and/or to infuse the technology. This may be part of the final report.

**Phase II deliverables should include, but are not limited to:**
A useable/workable prototype of the technology (or software program), such as toolboxes, integrated hardware prototypes, training databases, or development/testing environments, are highly desired. A technology demonstration in a relevant flight environment that clearly shows the benefits of the technology developed. 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. There should be evidence of infusing the technology or a clear written plan for near-term infusion of the technology. This may be part of the final report.

State of the Art and Critical Gaps

Current autonomous systems have limited capabilities, have poor perception of the environment, require human oversight, and need special clearances to fly in the NAS. Future autonomous systems with higher degrees of autonomy will be able to freely fly in the NAS but will require certifiable software that ensure a high degree of safety assurance. Additionally, advanced sensors and more sophisticated algorithms that can plan around other UAS/AAM vehicles and obstacles will be needed. Therefore, the technologies that will be required to advance the state of the art are as follows:

1. A certification process for complex nondeterministic algorithms.
2. Prognostics, vehicle health, and sensor fusion algorithms.
3. Decision making and cooperative planning algorithms.
4. Secure and robust communications.

Relevance / Science Traceability

This subtopic is relevant to the NASA Aeronautics Research Mission Directorate (ARMD) Strategic Thrust 5 and Strategic Thrust 6.

- Airspace Operations and Safety Program (AOSP): [https://www.nasa.gov/aeroresearch/programs/aosp](https://www.nasa.gov/aeroresearch/programs/aosp) [34]
- Integrated Aviation Systems Program (IASP): [https://www.nasa.gov/aeroresearch/programs/iasp](https://www.nasa.gov/aeroresearch/programs/iasp) [35]

References

- Explore Flight: We're with You When You Fly: [https://nari.arc.nasa.gov/aero-autonomy](https://nari.arc.nasa.gov/aero-autonomy) [39]

A2.03 Advanced Air Mobility (AAM) Integration

Lead Center: HQ

Participating Center(s): LaRC
Scope Title

Support Community AAM and Community Engagement Planning

Scope Description

AAM is a concept for safe, sustainable, affordable, and accessible aviation for transformational local and intraregional missions. AAM includes many potential mission types (e.g., passenger transport, aerial work, and cargo transport) that may be accomplished with many different aircraft types (e.g., manned, and unmanned; conventional, short, and/or vertical takeoff and landing; all electric and hybrid electric; etc.) and are envisioned to bring aviation into people’s daily lives. Although passenger-carrying urban air mobility (UAM) is an AAM mission with much investment, other AAM missions, including but not limited to “thin haul”/regional air mobility, small package delivery, and medical transport, are also of interest. Responses to this subtopic are not limited to strictly any single AAM mission.

The AAM ecosystem can be viewed as being comprised of three pillars: vehicle, airspace, and community. For this discussion community consists of governmental decision makers and those that support them. Significant investment is being made in local vehicle manufacturing companies, and some investment is being made into local airspace companies, while local and tribal AAM planning entities are having to prioritize their AAM efforts amongst their other funding obligations.

The integration of AAM into a multimodal transportation system is a complicated endeavor involving leveraging existing infrastructure, working with existing and new stakeholders in an evolving regulatory environment. The purpose of this SBIR is to energize an industry around supporting the local community AAM planning efforts while recognizing that these local communities may not have the resources to conduct the planning needed to enable AAM at UAM maturity level-4 (UML-4) on the timeline desired by the entities in the other two pillars. Activities proposed by companies desiring to enter this market shall fill a gap in the communities’ current planning efforts.

Three areas of near-term community need have surfaced from NASA conversations with state and city departments of transportation. These include (1) meeting AAM educational and outreach needs, (2) support for planning demonstrations, and (3) AAM system planning.

Educational: A clear and pressing need for education of both local decision makers and the local flying and nonflying public has been identified. The goal of companies proposing to this Small Business Innovation Research (SBIR) would be to enable a robust and cost-conscious capability available to local decision makers to support them effectively providing a broad range of materials at various levels of detail for their use when engaging entities such as local city councils, mayors, planning boards, and infrastructure planning teams. The company would also be able to provide materials and be able to support organizations that directly engage with and inform the public such as Metropolitan Planning Organizations (MPOs), science museums, and Science, Technology, Education, and Mathematics (STEM)-focused organizations. The company should also be capable of providing materials and outreach capabilities not readily available to these organizations, such as locally targeted virtual reality simulations of AAM operations. The company should also have a detailed and sustained familiarity with the local or state culture, nuances, customs, and values to be able to provide a long-term resource to these planning officials and to be able to craft outreach materials that connect citizens with information and in ways relevant to their local situation. Phase I would be to begin executing the plan in the proposal and developing the materials described as part of the plan. Ideally, the plan would include an initial target local partner (customer). Phase I would also include identifying and contacting a regional or statewide customer base. Phase II would be to provide services to these regional or statewide customers and cementing relationships and a sustainable business.

AAM Demonstrations: Conducting AAM demonstrations is a complicated and involved process that could be markedly easier with expertise associated with having experience and the federal relationships in conducting previous demonstrations. This SBIR would be focused on maturing a company’s capability to support local decision makers in the planning and execution of local AAM demonstrations. These demonstrations would ideally be focused on “public-good” missions. The capability should include development and analysis of use case(s) or compelling missions, identification and forming the stakeholders needed to execute a demonstration into an effective team, the capability to develop and execute the local outreach necessary for a successful demonstration, knowledge of the local and federal regulations and decision makers critical for the successful execution of the
demonstration, and the development and execution of a demonstration that achieves the desired goals whether they are a one-time demonstration or to enable a sustainable capability. Phase I would be to develop a generic plan that can be tailored for each demonstration customer and to compile case studies from previous AAM case studies that would provide lessons learned for future demonstrations and be available for incorporation into the generic plan. Phase I would also identify several localities seeking to conduct or already planning demonstrations. Phase II would be to support a certain number of these efforts in whichever stage they are currently in. Phase II would also include providing overviews to other localities interested in conducting demonstrations with the goal of beginning to build a sustainable customer base.

AAM System Planning Support: Planning for an urban, regional, or statewide passenger or large cargo carrying AAM system is a significantly complicated endeavor. It includes possessing the relevant subject matter expertise, the ability to conduct economic and demand analysis, system modeling and trade analysis, and to be able to provide decision makers either the tools to make those decisions or the material necessary to support the decision-making process. An AAM system could be a system of urban vertiports or a statewide system leveraging existing general aviation airports supplemented by new vertiports. This planning capability is not expected to be a short-term endeavor but could potentially span multiple years from the development of a plan, through its initial construction and updating planning assumptions and analysis as the system matures. The purpose of this SBIR is to create and support the development of companies focused and able to provide long-term, local AAM planning support. A locally focused and long-term strategy would enable the building of long-term partnerships and relationships with local stakeholders including academic entities, business groups, and local and regional planning officials along with an awareness of and appreciation for local culture, customs, and values. Phase I of this SBIR would be to plan the structure needed, obtain the expertise, and identify the data sources needed to conduct AAM system planning for the locality identified in the proposal. Phase II would be to begin to support the locally needed long-term planning efforts.

Proposers seeking funding for aircraft design and individual aircraft operations should submit to vehicle technology subtopic in A1 and proposers seeking airspace design and operations funding should submit to A3 subtopics.

**Expected TRL or TRL Range at completion of the Project**

1 to 6

**Primary Technology Taxonomy**

**Level 1**

TX 11 Software, Modeling, Simulation, and Information Processing

**Level 2**

TX 11.X Other Software, Modeling, Simulation, and Information Processing

**Desired Deliverables of Phase I and Phase II**

- Analysis
- Prototype
- Hardware
- Software

**Desired Deliverables Description**

Deliverables are further detailed in each scope.

Phase I Deliverables would include development of initial materials to support (1) meeting AAM educational and outreach needs, (2) support for planning demonstrations, and (3) AAM system planning. Phase I would also include identifying and making contact with a regional or statewide customer base.

Phase II would be to provide services to these regional or statewide customers for education, demonstration
planning, or AAM system planning as applicable.

State of the Art and Critical Gaps

Current transportation planning is focused on either airport-based aviation or ground transportation. There are few resources for AAM planning and planning for AAM to be integrated into these modes of transportation. There is a dearth of small businesses that can bring deep local knowledge and the potential for long-term relationships to these communities. These 3 areas have been identified as near-term critical gaps as part of the partnership with 5 departments of transportation. The timing is also ideal to get these companies up and running as demonstrations are currently being planned and executed and the first electric vertical takeoff and landing (eVTOL) aircraft are expected to be certified in 2024.

Relevance / Science Traceability

This subtopic is relevant to the Aeronautics Research Mission Directorate (ARMD) AAM Mission and the 8 projects supporting that mission.

References

- NASA's National Aeronautics Committee briefings: https://www.nasa.gov/aeroresearch/aero-nac-committee [40]
- https://www.nasa.gov/aeroresearch/one-word-change-expands-nasas-vision-for-future-airspace/ [41]
- UAM UML-4 ConOps https://sti.nasa.gov/ [42]
- FAA UAM ConOps 1.0 https://nari.arc.nasa.gov/sites/default/files/attachments/UAM_ConOps_v1.0.pdf [43]

Scope Title

Reconfigurable Vertiport Surface Marking

Scope Description

AAM is a concept for safe, sustainable, affordable, and accessible aviation for transformational local and intraregional missions. AAM includes many potential mission types (e.g., passenger transport, aerial work, and cargo transport) that may be accomplished with many different aircraft types (e.g., manned, and unmanned; conventional, short, and/or vertical takeoff and landing; all electric and hybrid electric; etc.) and are envisioned to bring aviation into people's daily lives. Although passenger-carrying urban air mobility (UAM) is an AAM mission with much investment, other AAM missions, including but not limited to “thin haul”/regional air mobility, small package delivery, and medical transport, are also of interest. Responses to this subtopic are not limited to strictly any single AAM mission.

AAM at UAM maturity level-4 (UML-4) envisions multiple vehicle types utilizing multiple vertiports variously configured from one to multiple landing pads. It is also envisioned that these vehicle types will mature as more experience is gained to achieve safety and performance improvements. Additionally, the Federal Aviation Administration (FAA) is currently working on the design advisory circular for these vehicles, and while the planned 2022 engineering brief will meet early needs, definitive design guidance is likely several years away. These and many more factors will impact the markings on vertiport surfaces. While airports are well served by fixed pavement markings, future vertiports could achieve the needed degree of flexibility with reconfigurable Touchdown and Lift Off (TLOF) and Final Approach and Takeoff (FATO) areas markings. Reconfigurable surface markings could also serve to assist with the control of embarking and debarking passengers.

Expected TRL or TRL Range at completion of the Project
Primary Technology Taxonomy

Level 1

TX 12 Materials, Structures, Mechanical Systems, and Manufacturing

Level 2

TX 12.X Other Manufacturing, Materials, and Structures

Desired Deliverables of Phase I and Phase II

- Research
- Analysis
- Prototype

Desired Deliverables Description

Phase I of this Small Business Innovation Research (SBIR) would be to design a vertiport surface meeting current surface performance criterion that also incorporates reconfigurable markings. Phase II of this effort would be to manufacture and demonstrate this surface and begin the process to obtain FAA approval for utilization at future vertiports.

State of the Art and Critical Gaps

Currently surface markings at airports and heliports are painted on the surface and not reconfigurable without significant effort. Vertiports capable of servicing passengers do not currently exist in the U.S. as design criteria does not exist and no electric vertical takeoff and landing (eVTOL) have been certified.

Relevance / Science Traceability

With the issuance of the FAA's vertiport design advisory circular not expected until 2025, many entities are hesitant to invest significant resources in infrastructure that has the potential to not meet future standards, requirements, or regulations. The ability to have a vertiport surface that is reconfigurable would reduce the risk for vertiport surfaces to not meet future standards, requirements, or regulations; increase safety; allow vertiport configurations that are specific to a vehicle type; and reduce the cost associated with reconfiguring markings to meet future updated standards, requirements, or regulations.

References

- FAA Airport Technology Research & Development Branch Home Page: https://www.airporttech.tc.faa.gov/Airport-R-D [46]
Low-Altitude Meteorological Information Supplemental Data Service

Scope Description

Currently low-level AAM operations operate either under visual line of sight or under a waiver for beyond visual line of sight (BVLOS). Frequently, if local, approved weather stations, e.g., at an airport located a distance from the operations, reports instrument meteorological conditions (IMC), the entire area is assumed to be under IMC for BVLOS flights. Often, the planned route or area of AAM operations is under visual flight rules (VFR) conditions even though the weather station is reporting IMC or critical weather conditions. The use of data from not currently aviation-approved sensors to identify current local conditions that can be correlated to the data from the selected weather sensor could determine conditions when the certified weather sensor is reporting IMC and the intended area or route of flight is under VFR conditions. For example, the weather at Monterey Bay Regional Airport in California is 0 vertical feet and 0 mi horizontally with no wind and an operator wishes to fly a cargo delivery from Carmel Valley where they can see at least 1,000 ft and 3 mi and their weather station says winds are 5 to 7 kn to a customer in Big Sur, where the customer verifies that the weather is also 1,000 ft and 3 mi with similar winds. The weather between the Valley and Big Sur is not serviced by an approved aviation weather station, but several traffic cameras along the proposed route show the tops of local buildings, images of buildings 3 mi in the distance, and the local vegetation relatively motionless. The operator could utilize this information to determine if the weather-based risk to the flight is acceptable and within the limits of their operating waiver and perform the mission. In a second similar case except where the winds at the regional airport were 15 kn and the traffic cameras show local vegetation moving significantly, the operator could then determine that the winds along the route could exceed the operating limits of the aircraft and determine that the risk is too high and not perform the mission. This effort would determine that there is not a high degree of correlation of visibility between the airport and the local surrounding areas but that there was a high degree of correlation between the winds at the airport and those in the surrounding area.

Another potential scenario is around winds aloft. It could be feasible to deploy enough wind lidars to determine with a high degree of accuracy the winds aloft all along a specific route. An effort under this Small Business Innovation Research (SBIR) scope would be to correlate winds speeds aloft with ground winds speeds. This would allow for the deployment of expensive wind lidars and other sensing equipment during initial installation of weather sensing networks to be gradually replaced with less expensive sensors that could utilize this information to provide aloft wind speed information that could be validated at specific points by airborne traffic instead of continuing to maintain an expensive sensing network. It would also identify situations where correlations start to break down or are not possible, for example, around a thunderstorm.

Given the highly localized nature of this effort, it is anticipated that to be effectively commercialized, the location for the research would need to be in conjunction with either current small unmanned aerial systems (sUAS) operations or a passenger/large cargo carrying AAM demonstration/planned early operation that would have a high likelihood of potential customers for the capability/data.

Expected TRL or TRL Range at completion of the Project

1 to 3

Primary Technology Taxonomy

Level 1

TX 11 Software, Modeling, Simulation, and Information Processing

Level 2

TX 11.4 Information Processing

Desired Deliverables of Phase I and Phase II

- Research
Analysis
Prototype
Software
Hardware

Desired Deliverables Description

Phase I will deliver a plan to identify selected reference stations (weather or other sensors, e.g., camera) with accessible access to past and present data, potential low-level routes or areas either being used or planned for early AAM operations (suAS or vehicles sized to carry passengers), and obtain past reports or plan to develop a collection of adverse weather conditions that can be correlated to topography or pilot reports in the vicinity of the reference stations, low-level routes, and areas. The plan should also outline the methodology to be more fully developed during Phase II and identify opportunities to conduct Phase II investigations in multiple localities.

Phase II would be to collect the data identified in Phase I, refine and execute the methodology outlined in Phase I, and implement that methodology to evaluate whether the conditions along the routes/within the areas satisfy VFR or other conditions when the reference stations are reporting IMC or other conditions.

State of the Art and Critical Gaps

Currently there are a limited number of sensors beyond airports that are able to provide actual weather conditions to aircraft flying in the areas envisioned by AAM operations. Installing infrastructure of equal capabilities across the entire U.S. would be prohibitively expensive. This supplemental service would serve to leverage the existing sensors in combination with data correlated from past observations to be able to predict specified routes or areas are accessible to low-level flight when heights of cloud bases at selected reference stations reach specified values. For the winds aloft case, they are currently measured by balloons or onboard aircraft sensors. This results in few, specific point measurements versus a broader data set that would support denser operations.

Relevance / Science Traceability

Current suAS operations are largely using risk-based methodologies to determine whether their vehicles can safely fly in weather conditions provided by a limited number of sensors. This effort would provide a methodology that would provide additional data to inform these risk-based decisions.

References

- NASA UAM ConOps: https://sti.nasa.gov/ [42]

Scope Title

Multipurpose AAM Sensor Networks

Scope Description

AAM is a concept for safe, sustainable, affordable, and accessible aviation for transformational local and intraregional missions. AAM includes many potential mission types (e.g., passenger transport, aerial work, and cargo transport) that may be accomplished with many different aircraft types (e.g., manned and unmanned; conventional, short, and/or vertical takeoff and landing; all electric and hybrid electric; etc.) and are envisioned to bring aviation into people’s daily lives. Although passenger-carrying urban air mobility (UAM) is an AAM mission with much investment, other AAM missions, including but not limited to “thin haul”/regional air mobility, small package delivery, and medical transport, are also of interest. Responses to this subtopic are not limited to strictly any single AAM mission.

At UAM maturity level-4 (UML-4), it is envisioned there will be multiple sensor types networked to perform the functions necessary for safe and efficient movement of passengers and cargo. These networks include sensors for navigation, surveillance, and weather. Types of sensors will include radars, lidars, anemometers, thermometers, and the novel use of sensors such as traffic cameras. Independent sensors could be purchased, installed, and
networked to satisfy each need, however, this would be inefficient and expensive. Localities are also investing funds in installing significant networks for both citizen internet connectivity and other efforts such as connected vehicles. This effort is to identify the opportunities and drawbacks associated with multipurpose usage of sensors and networks.

**Expected TRL or TRL Range at completion of the Project**

1 to 3

**Primary Technology Taxonomy**

**Level 1**

TX 08 Sensors and Instruments

**Level 2**

TX 08.X Other Sensors and Instruments

**Desired Deliverables of Phase I and Phase II**

- Research
- Analysis
- Prototype
- Software

**Desired Deliverables Description**

Effort under Phase I of this Small Business Innovation Research (SBIR) would be to collect or catalog performance requirements and capabilities for navigation, surveillance, weather, and other sensors that could potentially perform multiple functions. The effort would also catalog the existing or planned networks supporting these sensors. This would include the use of radars for both aircraft surveillance and precipitation or lidars to determine navigational performance or wind turbulence. Exploration of novel sensors would include the identification of sensors supporting other uses that could benefit AAM operations such as traffic cameras for determining visibility and sensors supporting other forms of transportation such as Advanced Road Weather Information System (ARWIS) to provide temperature and potential surface icing conditions. Phase I would also identify sensors existing or being planned for near-term installation that could be leveraged for future demonstrations.

Phase II of this effort would be to leverage existing AAM activities to investigate the potential incorporation of additional AAM functionality while utilizing current or planned sensors. Potential activities could include the Ohio Department of Transportation (DOT) Route 33 Active Traffic Management (ATM) efforts, Minnesota’s extensive ARWIS system, or North Central Texas Collaborative Adaptive Sensing of Atmosphere (CASA), or its Arlington Entertainment district demonstration. Efforts in Phase II would also identify potential additional benefits achievable through these sensors such as counter drone capability or weather warning alerting to the local community.

**State of the Art and Critical Gaps**

Current state of the art is to identify and utilize either customized or purpose built sensors targeted to meet the requirements for the system they are supporting. While this results in high performance capability, these networks are both expensive to install and maintain and difficult to upgrade with new and innovative technologies and capabilities. This SBIR would be a start at closing the gap between attempting to fund expensive single purpose systems and installing affordable capable systems with shorter return on investments and more amenable to upgrading.

**Relevance / Science Traceability**

Information collected during this phase should also be targeted to inform the ATM-X AAM X series simulations and potential automated vertiport functions being investigated by the High Density Vertiport subproject within the AAM
A2.04 AERONAUTICAL INFORMATION SYSTEM SECURITY (AISS): Aircraft Systems

Lead Center: HQ

Scope Title

Onboard Noninvasive Intrusion Detection Systems

Scope Description

To accommodate the anticipated diversity and complexity of operations in the future National Airspace System (NAS), the system must be more digitally connected, but by being connected this provides more pathways for hackers into the NAS and its systems, increasing the likelihood that an aircraft will be hacked. With new entrants, such as Unmanned Aircraft Systems (UAS) and Advanced Air Mobility (AAM), they will rely on third party services to operate. There is a need to detect safety events and safety threats caused by hackers to increase the ability of the systemwide safety assurance to perform its functions. The increased assurance will play a critical role in how quickly new operations and new vehicles can be safely integrated with NAS operations. NASA is developing ground and vehicle based In-Time System-Wide Safety Assurance (ISSA) capabilities to monitor, assess and mitigate safety threats, and this SBIR will address the detection of cybersecurity threats that will cause safety threats, to both commercial and emerging operations. The eventual goal is for these capabilities to be integrated into an In-Time Aviation Safety Management System (IASMS) capable of system-level safety assessment.

This subtopic seeks technologies to enhance cybersecurity monitoring and assessment capabilities for air-vehicle-based systems. This may include cyber related ISSA tools or techniques that fit within the architecture being developed by NASA or it may include a separate cybersecurity device that performs monitor-assess functions whose outputs may be integrated with a larger IASMS at some future point. Proposal areas include, design architectures, and development and/or demonstration in the following areas, with an emphasis on onboard flight cyber safety:

- Onboard system monitoring and assessing with reporting both locally and to off-board operations centers.
- Interfacing to the larger network systems monitoring and assessing with reporting, both locally and to operations centers.
- Integration of individual monitor-assessing instances into the greater system-of-system approach, either standalone or as a capability of safety ISSA architectures.

From a functionality point of view, each instance of the monitor-predict entity, a combination of entities, or the systemwide ISSA may perform one or more of these functions:

- Monitor: detect anomalies or deviations from normal operations.
- Assess: localization; determine attack target, provide analysis to forecast the probability of events.
- Report: onboard, off board, and logging.
- Mitigate: when mitigation is possible, mitigate incidents without loss of operational and prioritize corrective actions for onboard operators/systems.
Given the developing Advanced Air Mobility (AAM) and traditional aviation systems, several possible analytical approaches may be possible. These include:

- Digital Twin: analytical combinations of on onboard and off-board models.
- Attestation: provable by observation methodologies.
- Traffic monitoring: monitoring of aviation bus data, network data, or other data flows.
- MDAO: multidisciplinary design analysis optimization.
- Artificial intelligence/machine learning: i.e., “teach” a model to adapt itself to defenses as they engage.

**Expected TRL or TRL Range at completion of the Project**

2 to 5

**Primary Technology Taxonomy**

**Level 1**

TX 08 Sensors and Instruments

**Level 2**

TX 08.3 In-Situ Instruments/Sensor

**Desired Deliverables of Phase I and Phase II**

- Hardware
- Software
- Analysis
- Prototype
- Research

**Desired Deliverables Description**

**Phase I:**

- Analysis and architectures for onboard cyber anomaly monitoring system, to include aviation buses and other data flows.
- Analysis and architectures for predictive analysis of cyber anomalies.
- Reporting capabilities to operations centers.

**Phase II:**

- Analysis and architectures for systemwide cyber anomaly monitoring including node and aggregation methods.
- Mitigation: analysis and design of cyber-resilience methodologies that include mitigation incidents without loss of mission success.
- Prioritize corrective actions for operators/systems.
- Propose a demonstration system implementation including hardware, software, testing, and validation.

**State of the Art and Critical Gaps**

There are clear limitations to near term adoption of these new cyber technologies into the National Airspace System (NAS) or the AAM equivalent. These include:
Current aviation communication technologies, certified for use in the NAS, are severely limited in bandwidth and constrained to specific functions. This makes concepts that may move large amounts of data between air vehicles and the ground difficult to implement.

In-time data prediction can be computer processing unit (CPU) intensive. The onboard capabilities of Unmanned Aircraft Systems (UAS) and AAM-type vehicles may not provide significant onboard processing capabilities.

Data needed for the prediction of aviation cyber events is not well understood or data is difficult to obtain or synthesize.

Data needed for aviation cybersecurity machine learning methodologies is also difficult to obtain and validate. Attempts to use information technology (IT) ground-based systems as surrogates for aviation systems may not yield reliable comparisons.

Relevance / Science Traceability

As our world becomes more digitally connected, there are increasing opportunities for cyber-attacks across all domains. Aviation is no exception.

Communication links and maintenance loads are susceptible to viruses and other attacks. Most communication systems in the aircraft are not protected via authentication or by encryption and with newer systems that rely on commercial standards like Ethernet and Internet Protocols (IP) vulnerability to cyber threats increases. It is possible to send data to an aircraft via the communications link and if the messages are formatted properly, they will be acted up by the onboard systems, potentially causing Denial of Service attack or affecting other systems by disrupting processes. This SBIR focuses on air vehicle cybersecurity and seeks proposals for observation of nominal system states, assessment and reporting of off-nominal traffic, and mitigation of off-nominal operations.

References


A3.01 Advanced Air Traffic Management System Concepts

Lead Center: ARC

Participating Center(s): LaRC

Scope Title

Advanced Air Traffic Management (ATM) System Concepts

Scope Description

This subtopic addresses contributions towards ATM systems and concepts with potential application in the near-future (2025 to 2030) National Airspace System (NAS). The subtopic seeks proposals that can apply novel and innovative technologies and concepts towards addressing established ATM challenges of improving efficiency, capacity, and throughput while minimizing negative environmental impact, maintaining or improving safety, and/or accelerating the implementation of NASA technologies in the current and future NAS.

Given the recent coronavirus pandemic and the dramatic impact to the airlines and U.S. aviation industry as a
whole, this solicitation also seeks proposals that can apply novel and innovative concepts, technologies, and capabilities towards enabling the U.S. air transportation system to recover from the recent negative impacts of reduced traffic demand.

The NASA technologies that are being researched and developed for the future NAS include, but are not limited to: Integrated Arrival, Departure, and Surface (IADS) capabilities, routing and rerouting around weather from ground-based and cockpit-based systems, tools enabling trajectory-based operations (TBO), and capabilities that can be integrated with a fully realized Unmanned Aircraft Systems Traffic Management (UTM) system for a wide range of commercial and public use.

Technologies, concepts, models, algorithms, architectures, and tools are sought in this solicitation to bridge the gap from NASA’s research and development (R&D) to operational implementation, and should address such nearer term ATM challenges as:

- Safe, end-to-end TBO.
- Enabling and integrating existing independent systems and domains, and increasingly diverse and unconventional operations (gradually enabling the future integration of large unmanned vehicles, unconventional commercial airline business models, space traffic management, and subsonic and supersonic vehicles).
- Applying elements of the service-based architecture concept being pioneered in the UTM domain.

**Expected TRL or TRL Range at completion of the Project**

1 to 4

**Primary Technology Taxonomy**

**Level 1**

TX 16 Air Traffic Management and Range Tracking Systems

**Level 2**

TX 16.3 Traffic Management Concepts

**Desired Deliverables of Phase I and Phase II**

- Research
- Analysis
- Prototype
- Software

**Desired Deliverables Description**

Technologies that can advance safe and efficient growth in global operations (Aeronautics Research Mission Directorate (ARMD) Thrust 1 Goal) that can be incorporated into existing and future NASA concepts.

Phase I deliverables may take the form of a prototype/proof-of-concept decision support tool, automation and/or service, a proof-of-concept demonstration of the underlying architecture, and/or validation of the approach taken, which shows focus on a particular aspect or use case of the R&D challenge being investigated.

Phase II deliverables would presumably take the form of higher TRL tools/decision support services that convincingly demonstrate a solution to the proposed R&D challenge.

**State of the Art and Critical Gaps**
State of the Art: NASA has been researching advanced air transportation concepts and technologies to improve commercial operations in the NAS.

Critical Gaps: Significant challenges remain in integrating air transportation technologies across different domains and operators (e.g., airport surface and terminal area; airport authority and air navigation service providers; etc.), providing comprehensive strategic scheduling and traffic management technologies, enabling concepts that will allow for increased demand and complexity of operations, and enabling recovery from the global-pandemic-induced air transportation system impacts.

Relevance / Science Traceability

Airspace Operations and Safety Program (AOSP) within ARMD.

Successful technologies in this subtopic have helped to advance the air traffic management/airspace operations objectives of the Program and enable successful technology transfer to external stakeholders (including the Federal Aviation Administration and the air transportation industry).

References

1. Airspace Operations and Safety Program (AOSP): https://www.nasa.gov/aeroresearch/programs/aosp [34]

A3.02 Increasing Autonomy in the National Airspace System (NAS)

Lead Center: ARC

Participating Center(s): LaRC

Scope Title

Human-Autonomy Teaming in the National Airspace System (NAS)

Scope Description

In current airspace operations, human operators occupy extensive decision-making capabilities and perform the most significant roles in the National Airspace System (NAS). As more autonomous system capabilities are introduced in air transportation, a critical research question for future airspace operations is the appropriate allocation of tasks and functions for the human operators and future autonomous systems, as they seamlessly team together to achieve common goals.

This collaboration between the human-operator and the autonomous technology, also known as “human-autonomy teaming,” is the primary focus of this subtopic.

NASA’s future concepts of air transportation (2030 and beyond) are anticipated to increasingly rely on autonomy, artificial intelligence, and machine learning, to maintain operational efficiency and safety, dynamically accommodating changes to environmental and operational conditions. The future concepts will significantly expand the capabilities of airspace operations and vehicle management to ensure safe, secure, and equitable operations, assuming seamless, integrated, flexible, and robust systems, resilient and resistant to cyber-attack. The future concepts include traditional and nontraditional vehicle types and operations, along with diverse airspace domains and mission types, and a service-based architecture to provide user services, as appropriate. Examples of such service-based systems include those demonstrated within NASA’s Unmanned Aircraft Systems Traffic Management (UTM) and the Air Traffic Management – eXploration (ATM-X) Urban Air Mobility (UAM) Projects.
This subtopic seeks proposals that will apply novel and innovative solutions to technologies, methods, and approaches to developing tools and/or technologies that will enable successful human-autonomy teaming in the future NAS (2030 and beyond).

Proposals that do not address or consider the human operator’s interaction with future, autonomous, NAS technologies will be rejected.

**Expected TRL or TRL Range at completion of the Project**

1 to 4

**Primary Technology Taxonomy**

**Level 1**

TX 16 Air Traffic Management and Range Tracking Systems

**Level 2**

TX 16.3 Traffic Management Concepts

**Desired Deliverables of Phase I and Phase II**

- Research
- Analysis
- Prototype
- Software

**Desired Deliverables Description**

Technologies that can advance safe and efficient growth in global operations (Aeronautics Research Mission Directorate (ARMD) Thrust 1 Goal) as well as developing autonomy applications for aviation (as under ARMD Thrust 6).

Phase I deliverables may take the form of a prototype/proof-of-concept decision support tool, automation and/or service, a proof-of-concept demonstration of the underlying architecture, and/or validation of the approach taken, which shows focus on a particular aspect or use case of the research and development (R&D) challenge being investigated. Phase II deliverables would presumably take the form of higher TRL tools/decision support services that convincingly demonstrate a solution to the proposed R&D challenge.

**State of the Art and Critical Gaps**

State of the Art: NASA has been researching advanced air transportation concepts and technologies to improve commercial operations in the NAS. Autonomy is the focus of increased ARMD interest as evidenced in Thrust 6, Assured Autonomy for Aviation Transformation. Airspace Operations and Safety Program (AOSP) research is increasingly applying autonomous technologies and capabilities towards air transportation challenges. These technologies and capabilities may address limited solutions to targeted problems.

Critical Gaps: The growth of data sciences and autonomy/artificial intelligence technologies continue to have great potential to benefit the development of a more autonomous air transportation system. This is needed to accommodate the increasing demand and diversity of air transportation missions and operations. The interpretation and use of data-science-based information by human operators and decision makers, continues to be of interest.

This subtopic is focused on the human-autonomy teaming of the airspace operations in the future NAS. Proposals that do not address the human operator interaction with future NAS technologies will be declined.

**Relevance / Science Traceability**
Relevance to AOSP.

Successful technologies in this subtopic have helped to advance the air traffic management/airspace operations objectives of the AOSP Program. The technologies also introduce new autonomy/artificial intelligence/data science methods and approaches to air transportation problems for current and near-future application, and show where such approaches are/are not appropriate to advance airspace operations.

References:

1. Airspace Operations and Safety Program (AOSP): [https://www.nasa.gov/aeroresearch/programs/aosp](https://www.nasa.gov/aeroresearch/programs/aosp) [34]

Scope Title

A3.03 Future Aviation Systems Safety

Lead Center: ARC

Participating Center(s): LaRC

Scope Description

Public benefits derived from continued growth in the transport of passengers and cargo are dependent on the improvement of the intrinsic safety attributes of the Nation’s and the world’s current and future air transportation system. Recent developments to address increasing demand for access to the airspace include: increased use of automation and autonomy to enhance system capabilities; airspace systems with tightly coupled air and ground functionality; cloud computing-based technologies used to perform functions or services; other widely distributed functions across ground, air, and space environments; increasingly integrated aircraft systems; and novel vehicle capabilities for both traditional and advanced air mobility (AAM) operations such as Unmanned Aircraft Systems (UAS) and Urban Air Mobility (UAM). These revolutionary changes are leading to greater system complexity, and current methods of ensuring that airspace and vehicle designs meet desired safety levels will likely not scale to these levels of complexity (Aeronautics R&D Plan, p. 30). The Airspace Operations and Safety Program (AOSP) is addressing this challenge with a major area of focus on In-Time System-Wide Safety Assurance (ISSA).

Understanding and predicting systemwide safety concerns of the airspace system and the vehicles flying in it, as envisioned in future aviation systems, is paramount. Thus, a proactive approach to managing system safety requires that once a new system, technology, procedure, or training is introduced, that operators have: (1) the ability to monitor the system continuously and to extract and fuse information from diverse data sources to identify emergent anomalous behaviors through health monitoring of systemwide functions and (2) the ability to reliably predict probabilities of the occurrence of hazardous events and of their safety risks. Specifically, AOSP's System-Wide Safety (SWS) Project is developing an In-Time Aviation Safety Management System (IASMS), a scalable and distributed system approach to address aviation safety needs. Based on ISSA building blocks, IASMS services, functions, and capabilities (SFCs) are architecturally structured to “Monitor—Assess—Mitigate” operational safety risks. For definition, services are systems that produce safety-relevant information, functions produce safety-relevant outputs or data needed to compute safety-relevant metrics, and capabilities provide safety-relevant benefits that may leverage services and functions. IASMS SFCs are envisioned to include increasingly automated and autonomous functionality to adapt and scale to the increasing complexity of aviation operations, necessitating new approaches to assure autonomous functionality. Therefore, proposals focused on assurance of autonomy for operational systems will also be considered for award. Additionally, due to the increasingly digital transformation of the airspace system and nature of the IASMS, one research area of high interest is methods for monitoring, assessing, and mitigating cybersecurity vulnerabilities and attacks. Innovative approaches and methods are sought that monitor/assess/mitigate vulnerabilities before they can be exploited by malicious actors. Proposed innovations
are sought that can be easily incorporated into the IASMS. Proposals that lack a technology/function that can be integrated into the concept of an IASMS will be declined.

Specifically, this subtopic seeks the following types of proposals, whose technologies can be integrated into IASMS:

- Proposals to address the safety-critical risks identified in beyond visual-line-of-sight (BVLOS) operations in small and large UAS, including but not limited to risks such as:
  - Flight outside of approved airspace.
  - Unsafe proximity to people/property.
  - Critical system failure (including loss of command and control (C2) link, loss or degraded Global Positioning System (GPS), loss of power, and engine failure).
  - Loss-of-control (i.e., outside the envelope or flight control system failure).
  - Any potential cybersecurity or cyber-physical attack affecting any or all operations within the UAS airspace system.

- Proposals supporting the research and development of ISSA objectives:
  - To detect and identify systemwide safety anomalies, precursors, and margins.
  - To develop the safety-data-focused architecture, data exchange model, and data collection mechanisms.
  - To enable simulations to investigate flight risk in attitude and energy aircraft state awareness.

- Proposals supporting safety prognostic decision support tools, automation, techniques, strategies, and protocols:
  - To support real-time safety assurance (including in-time monitoring of safety requirements).
  - That consider operational context, as well as operator state, traits, and intent.
  - For integrated prevention, mitigation, and recovery plans with information uncertainty and system dynamics in a UAS and trajectory-based operations (TBO) environment.
  - To enable transition from a dedicated pilot in command or operator for each aircraft (as required per current regulations) to single-pilot operations.
  - To enable efficient management of multiple unmanned and AAM aircraft in civil operations.
  - To assure safety of air traffic applications through verification and validation (V&V) tools and techniques used during certification and throughout the product lifecycle.

- Proposals supporting assurance of highly automated and increasingly autonomous systems that support safety-critical functions. Specific focus includes:
  - Identification and development of new technologies that enable increasingly autonomous air safety services. Each new technology should be accompanied by examples of the services it enables.
  - Technologies that overcome the limitations of current V&V capabilities with respect to new increasingly autonomous systems. For example, new testing techniques sufficient for deploying machine learning (ML)-enabled systems.
  - Determination of where current certification standards (such as DO-178C) fail to address assurance needs for these technologies or fail to consider V&V results associated with the new technologies.
  - Development of use cases demonstrating novel certification approaches, such as Overarching Properties or safety cases, that enable the certification of increasingly autonomous systems.
  - Development of use cases demonstrating the assurance of cyber-physical-human systems that accommodate shifting roles and responsibilities between humans and automation.

- Cybersecurity resiliency requiring availability and integrity of critical functions including:
  - Rapid detection of incidents to enable remediation.
  - Automatic remediation actions to restore sufficient network or application services to support mission essential functions.
  - Information resilience for shared airspace status.
  - Reliable delivery and authentication of important messages.
  - Security management systems, security management frameworks, or information security management systems.
  - Resilient voice, data, and precision navigation and timing.

- Proposals that develop, apply, and assure IASMS services, functions, and/or capabilities to emergency response missions using aerospace vehicle operations. Operations may include but are not limited to: wildfire fighting, hurricane disaster relief and recovery, search and rescue, medical courier, and security operations.
  - SFCs should address one or more hazards highlighted in previous sections or identified through
hazard analysis. Proposers are encouraged to leverage prior NASA work in this area.

Expected TRL or TRL Range at completion of the Project:

1 to 3

Primary Technology Taxonomy:
Level 1: TX 16 Air Traffic Management and Range Tracking Systems
Level 2: TX 16.1 Safe All Vehicle Access

Desired Deliverables of Phase I and Phase II:

- Research
- Analysis
- Prototype
- Software

Desired Deliverables Description:
Technologies that can advance the goals of safe air transportation operations that can be incorporated into existing and future NASA concepts.

Desired deliverables for Phase I include development of multiple concepts/approaches, tradeoffs analyses, and proof-of-concept demonstrations.

Desired deliverables for Phase II include development of functional prototypes, integration of prototypes into existing and future NASA concepts, and demonstration of the prototype in a realistic environment.

State of the Art and Critical Gaps:

State of the art: Recent developments to address increasing air transportation demand are leading to greater system complexity, including airspace systems with tightly coupled air and ground functions as well as widely distributed and integrated aircraft systems. Current methods of ensuring that designs meet desired safety levels will likely not scale to these levels of complexity (Aeronautics R&D Plan, p. 30). AOSP is addressing this challenge with a major area of focus on ISSA.

Critical gaps: A proactive approach to managing system safety requires: (1) the ability to monitor the system continuously and to extract and fuse information from diverse data sources to identify emergent anomalous behaviors after new technologies, procedures, and training are introduced and (2) the ability to reliably predict probabilities of the occurrence of hazardous events and of their safety risks. Also, with the addition of UAM/AAM concepts, and increasing development of UAS Traffic Management (UTM), the safety research needs to expand to include these various missions and vehicles.

Relevance / Science Traceability:
Successful technologies in this subtopic will advance the safety of the air transportation system. The AOSP safety effort focuses on proactively managing safety through continuous monitoring and extracting relevant information from diverse data sources and identifying anomalous behaviors to help predict hazardous events and evaluate safety risk. This subtopic contributes technologies towards those objectives.

References:

1. Airspace Operations and Safety Program (AOSP): [https://www.nasa.gov/aeroresearch/programs/aosp](https://www.nasa.gov/aeroresearch/programs/aosp) [34]
A3.04 Nontraditional Airspace Operations and Aerial Wildfire Response

Lead Center: ARC
Participating Center(s): LaRC

Scope Title
Nontraditional Airspace Operations

Scope Description
NASA is exploring airspace operations incorporating unmanned vehicles and novel operations occurring in all airspaces (controlled and uncontrolled), with a goal to safely and efficiently integrate with existing operations and mission types. NASA's research to enable unmanned vehicles to be safely and fully integrated into existing airspace structures (or lack thereof) has already demonstrated the potential benefits and capabilities of a service-based architecture (such as that developed for the Unmanned Aircraft Systems Traffic Management (UTM) Research and Development (R&D) evaluations), and has led to new procedures, equipage and operating requirements, and policy recommendations, to enable widespread, harmonized, and equitable execution of diverse unmanned missions.

This scope is focused on Urban Air Mobility (UAM)/Advanced Air Mobility (AAM) airspace operations only and is not accepting proposals specific to other nontraditional operations. In addition, proposals that focus only on cyber-resiliency solutions without proposing specific UAM/AAM services, will be declined.

This subtopic seeks proposals to continue to adapt the UTM concept elements for application to UAM/AAM including:

- Service-based architecture designs that enable dense and/or increasingly complex UAM operations.
- Dynamic route planning that considers changing environmental conditions, vehicle performance and endurance, and airspace congestion and traffic avoidance.
- Dynamic scheduling for on-demand access to constrained resources and interaction between vehicles with starkly different performance and control characteristics.
- Integration of emergent users with legacy users, large commercial transport, including pass-through to and from ultrahigh altitudes and interactions around major airports.
- Operational concepts for fleet and network management, market need and growth potential for future operations, and airspace integration.
- Identification of potential certification approaches for new vehicles operations (such as electric vertical takeoff and landing).

Future service-based architectures also require resiliency to cyberattacks to ensure safe and robust operations that maintain expected levels of safety, as well as accommodating changes to environmental and operational conditions. Therefore, proposals should incorporate cyber-resiliency methods, tools, or capabilities, or address cyber-resiliency as part of the proposed effort, but proposals focused exclusively on cybersecurity will be declined.

Expected TRL or TRL Range at completion of the Project:
1 to 4
Primary Technology Taxonomy:
Level 1: TX 16 Air Traffic Management and Range Tracking Systems
Level 2: TX 16.3 Traffic Management Concepts

Desired Deliverables of Phase I and Phase II:

- Research
- Analysis
- Prototype
- Software

Desired Deliverables Description:

Technologies that can advance safe and efficient growth in global operations (Aeronautics Research Mission Directorate (ARMD) Thrust 1 Goal) as well as developing autonomy applications for aviation (as under ARMD Thrust 6), that are specifically applicable to UAM operations, and address post-pandemic recovery, as appropriate.

Phase I deliverables may take the form of a prototype/proof-of-concept decision support tool, automation and/or service, a proof-of-concept demonstration of the underlying architecture, and/or validation of the approach taken, which shows focus on a particular aspect or use case of the R&D challenge being investigated.

Phase II deliverables would presumably take the form of higher TRL tools/decision support services that convincingly demonstrate a solution to the proposed R&D challenge.

State of the Art and Critical Gaps:

Current state of the art - Nontraditional airspace operations: NASA has been researching advanced air transportation concepts and technologies to improve commercial operations in the National Airspace System and has been applying this expertise, as well as a service-based architecture and concepts pioneered for UTM, towards UAM/AAM.

Critical gaps - Nontraditional airspace operations: Significant challenges remain to fully develop the UAM/AAM airspace concept of operations, including integrating air transportation technologies across different domains and operators; providing comprehensive, strategic scheduling and traffic management technologies; and enabling concepts that will allow for scaling demand and complexity of operations. This subtopic is focused on the Airspace Operations of the UAM/AAM concept only. Proposals must have clear application to UAM/AAM airspace operations. Proposals that focus on UAM/AAM vehicle capabilities, or onboard vehicle technologies or systems, will be declined. Proposals that are specific to other nontraditional operations (such as, but not limited to, space traffic management, automated air cargo, UTM, and ultrahigh altitude), without clear application to UAM/AAM, will be declined.

Relevance / Science Traceability:

Airspace Operations and Safety Program (AOSP).

Air Traffic Management-eXploration (ATM-X) Project.

Successful technologies in this subtopic will help NASA pioneer UAM concepts and technologies. The technologies also incorporate new autonomy/artificial intelligence/data science methods and approaches to air transportation problems for current and near-future application.

References:

1. Airspace Operations and Safety Program (AOSP): [https://www.nasa.gov/aeroresearch/programs/aosp][34]
2. NASA Ames Aviation Systems Division publications:
### Scope Title

Aviation Operations for Wildfire Response

### Scope Description

In the United States, wildfires are becoming increasingly severe and costly in terms of acreage burned, property damage, and most importantly, lives lost. Wildfire frequency and intensity is escalating, inducing budgetary, personnel, and equipment challenges. Furthermore, California and other western states have been facing persistent drought conditions and much hotter temperatures, which are fueling wildfire intensity and duration. These alarming trends have made it urgent to recognize how wildfires could be better predicted, mitigated, and managed.

NASA has a history of contributions to wildfire and other disaster management including remote sensing, instrumentation, mapping, data fusion, and prediction. More recently, the NASA Aeronautics Research Mission Directorate (ARMD) has been investigating capabilities to help manage wildfire suppression and mitigation efforts through technologies for coordination of airspace operations for wildfire management.

NASA ARMD has recently made significant contribution to enable widespread use of small unmanned aircraft systems (sUAS) by developing air traffic management capabilities for low-altitude unmanned vehicle operations, called UAS Traffic Management (UTM). This work is being expanded to safely and efficiently integrate larger Urban Air Mobility (UAM) vehicles and operations with existing operations and mission types. NASA recognizes the value these capabilities could provide when applied to the aerial wildfire management domain.

Current applications of aviation to wildfire management include deployment of smokejumpers to a fire, transport of firefighters, equipment and supplies, fire retardant or water drop, reconnaissance of fire locations and fire behavior, and supervision of air tactical operations.

Current challenges of aerial wildfire management include: existing airspace management techniques are manual and cannot accommodate the demand for new types of aircraft (e.g., unmanned aircraft); aerial firefighting is limited to acceptable visual conditions (no night operations); monitoring and remote sensing missions are intermittent, flown outside of active fire-fighting or available periodically from satellite assets; and there is a lack of reliable, resilient, and secure data communications for quick information dissemination to support effective decision making.

NASA is seeking technologies to:

- Provide an extension to the UTM network considering the unique needs and characteristics of wildfire disaster situations and the response to combat them.
- Provide capabilities that address UAS integration to aerial wildfire management but also have the potential to represent a dynamic airspace for coordination of multiple manned and unmanned vehicles.
- Increase the capacity of available communications, reduce the latency of data transfer, and provide a persistent network for the use of UAS and other aviation assets by emergency responders.
- Provide airspace coordination and resource tracking for a common operating picture for situational awareness.
- Ensure highest safety and efficiency of operations.

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

1 to 5
Primary Technology Taxonomy:
Level 1: TX 16 Air Traffic Management and Range Tracking Systems
Level 2: TX 16.3 Traffic Management Concepts

Desired Deliverables of Phase I and Phase II:

- Research
- Analysis
- Prototype
- Software

Desired Deliverables Description:

Phase I deliverables may include prototype/proof-of-concept decision support tool, automation and/or service, a proof-of-concept demonstration of the underlying architecture, and/or validation of the approach taken, which shows focus on a particular aspect or use case of the research and development challenge being investigated.

Phase II deliverables would presumably take the form of higher TRL tools/decision support services that convincingly demonstrate a solution to the proposed research and development challenge.

State of the Art and Critical Gaps:

The current state of the art for coordination of aerial firefighting is a manual process that must be coordinated across multiple entities, often bringing multiple aerial assets to wildfire fighting environment. Advanced tools and techniques are required to address the following gaps:

- Existing airspace management process very manual and slow.
- Awareness of aircraft operations conducted by visual monitoring and radio communication.
- Unmanned systems are not easily integrated into aerial fire suppression operations.
- Operations are limited by visibility and no operations are conducted at night when fires often die back.
- Surveillance images are captured and disseminated only every 4 hours.
- Intermittent communication can delay effective response.
- Conditions can rapidly change requiring timely information for effective decision making.
- Decision makers for emergency response are overloaded with data.
- Information requirements differ for various roles within the disaster response.

Tools and data are often spread across numerous applications.

Relevance / Science Traceability:

Due to climate change, wildfires are becoming increasingly more frequent and severe. Fire seasons are longer, lasting 6 to 8 months and in some cases are year-round. The 2020 fire season was the worst in recorded history, burning over 4 million acres of land, destroying more than 8,500 structures, and killing more than 30 people. The economic impact of these fires is in the hundreds of billions of dollars and results in lasting societal impact. The annual cost of fire suppression has soared from roughly $425 million per year in 1999 to $1.6 billion in 2019.

Recently, President Biden and Vice President Harris met with Governors from western states, Cabinet officials, and private sector partners to discuss specific actions the public and private sector are each taking to strengthen prevention, preparedness, mitigation, and response efforts to protect communities across our country from wildfires and their devastating impacts. The President directed a number of actions, in close coordination with State and local governments and the private sector, to ensure the Federal Government can most effectively protect public safety and deliver assistance to our people in times of urgent need.

References:
1. Airspace Operations and Safety Program (AOSP): [https://www.nasa.gov/aeroresearch/programs/aosp](https://www.nasa.gov/aeroresearch/programs/aosp) [34]
2. NASA Ames Aviation Systems Division publications:  
   [https://aviationsystems.arc.nasa.gov/publications/index.shtml](https://aviationsystems.arc.nasa.gov/publications/index.shtml) [52]
3. NASA Ames Aviation Systems Division: [https://aviationsystems.arc.nasa.gov/index.shtml](https://aviationsystems.arc.nasa.gov/index.shtml) [53]
4. ARMD Strategic Implementation Plan: [https://www.nasa.gov/aeroresearch/strategy](https://www.nasa.gov/aeroresearch/strategy) [18]