Integration of Flight Control with Aircraft Multidisciplinary Design Optimization

Scope Description:

Successful design tools for advanced aircraft concepts typically require close interaction among the various design disciplines involved: aerodynamics, structures, propulsion, flight control, etc. This is particularly true for advanced modern transports such as the Boeing 787 and nontraditional aircraft concepts currently being studied at NASA, such as the Transonic Truss-Braced Wing or the blended wing body, where the level of coupling across the various disciplines can be very complex. It has been shown that substantial benefits could be realized by including many of these disciplines within a single multidisciplinary design optimization (MDO) process, rather than optimizing each discipline in isolation. Furthermore, nontraditional flight control design philosophies are becoming increasingly more common as the aircraft industry is responding to the new urban air mobility (UAM) market. The NASA X-57, for example, could employ many modes of flight control distributed throughout the aircraft enabled by distributed electric propulsion. Thus, integration of flight control into an aircraft MDO process can produce more advanced aircraft design capabilities through improved and integrated methods and tools.

This subtopic seeks proposals that develop new methods and tools that enable the inclusion of flight control in an aircraft MDO process. The proposed control approach should directly contribute to aircraft overall design objectives, such as fuel burn, aircraft takeoff gross weight, or other aircraft performance metrics. The resulting tightly coupled MDO environment should be capable of handling the interactions among relevant disciplines, such as structures, aerodynamics, flight control (including the control effector design parameters and actuator weight/power), and propulsion. Design variables may include structural details (e.g., skin thickness, structural layout, and materials), aerodynamic details (planform shape, jig twist, and airfoil shape distributions), control law details (type, objective function, and control gains), control effector and sensor design parameters (size, layout, locations, and quantity), propulsion design parameters (thrust distribution, integrated allocation, and scheduling), etc. The control law may be parameterized in such a way that the resulting parameters are suitable to a numerical optimizer. Control design tools may utilize advanced distributed sensors such as fiber optic shape sensors or surface pressure sensors to achieve improved aircraft design objectives.

Appropriate design constraints should be imposed within the integrated MDO tool to ensure proper aerodynamic limits, such as stall and buffet; structural limits, such as maneuver and gust load response and flutter margins; as
well as control-centric constraints, such as stability margins, control actuator power and authority, position and rate limits, and sensor and actuator requirements that dictate controllability and observability.

Applications of these integrated MDO approaches could be implemented for realistic and relevant aircraft configurations to demonstrate the impact of the proposed methods. Performance gains should be actively derived from the system response to a control policy such as cruise-drag optimization, gust load alleviation, flutter suppression, flight-propulsion control, and multiobjective flight control. To integrate flight control into an MDO environment with a large number of design variables and constraints, new tools that would enable increased computational efficiency, such as adjoint-based optimization, are of interest using appropriate-fidelity aircraft models capable of capturing nonlinear aerodynamics. The proposed tools could be stand-alone or added capabilities to available open-sourced NASA MDO environments.

This subtopic does not seek proposals that propose vehicle conceptual design and analysis studies or control methods that have no clear transition paths to commercial applications.

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

**Primary Technology Taxonomy:**
- Level 1: TX 15 Flight Vehicle Systems
- Level 2: TX 15.6 Vehicle Concepts

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

**Desired Deliverables Description:**
For Phase I, the deliverables include flight control integrated MDO methods and tools.

For Phase II, the deliverables include more mature and validated flight control integrated MDO methods and tools which are to be integrated with open-sourced NASA MDO environments.

**State of the Art and Critical Gaps:**

Increasingly, more advanced aircraft concepts utilize innovative flight control design philosophies, such as the modern Boeing 787 with trailing edge variable camber, and Airbus A350 with adaptive drooped hinge flaps, as well as a wide variety of UAM aircraft design concepts with distributed electric propulsion. The current state of the art in research does not usually consider integration of flight control systems into an aircraft MDO process. Some low-level research effort of addressing flight control integration in an MDO process exists within the Aeronautics Research Mission Directorate (ARMD) Advanced Air Transport Technology (AATT) Project, but the effort does not consider a wide range of integration of flight control systems including actuators, sensors, and flight control laws. This critical research gap area could be filled by this subtopic.

**Relevance / Science Traceability:**

Under the NASA Advanced Air Vehicle Program (AAVP), the AATT Project is conducting research in distributed electric propulsion and adaptive wing technologies. Both of these research elements could benefit from this subtopic. Also, under the NASA AAVP, the Revolutionary Vertical Lift Technologies (RVLT) Project is conducting research in the area of UAM aircraft using distributed electric propulsion for electrical vertical takeoff and landing (eVTOL). This subtopic could complement the research conducted under the RVLT Project.

**References:**
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 noise prediction and noise control are needed for subsonic, transonic, and supersonic vehicles targeted. Solutions are sought that target airframe noise sources and the noise sources due to the aerodynamic and acoustic interaction of the airframe and engines. Innovations in the following specific areas are solicited:

- Prediction and/or mitigation of aerodynamic noise sources including those from the airframe, propulsion-airframe interactions, or aeroacoustic integration effects associated with high-aspect ratio truss-braced vehicles.
- Concepts for active and passive control of broadband aeroacoustic noise sources for conventional, truss-braced, and other advanced aircraft configurations. Technologies of interest include adaptive flow control and noise control enabled by advanced aircraft configurations, including integrated airframe-propulsion control methodologies.
- Innovative design approaches or technologies, including acoustic liner or porous surface concepts, to reduce airframe noise sources and/or propulsion/airframe aeroacoustic interactions. However, engine nacelle liner applications are
specifically excluded.

- System-level noise prediction methodologies for operational aspects (as opposed to certification conditions) of high-aspect ratio, truss-braced subsonic transports, or technology variants thereof.
- Fundamental and applied computational fluid dynamics techniques for aeroacoustic analysis which can be adapted for design purposes.
- Prediction and/or mitigation of aerodynamic noise sources including those from the airframe and those that arise from significant interactions between airframe and high-bypass ratio and/or small-core propulsion systems.
- Prediction of sound propagation from the aircraft through a complex atmosphere to the ground. This should include interactions between noise sources and the airframe and its flow field.
- Innovative source identification techniques for airframe (e.g., landing gear and high-lift systems) noise sources, including turbulence details related to flow-induced noise typical of separated flow regions, vortices, shear layers, etc.

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

- Research
- Analysis
- Prototype
- Hardware
- Software

**Desired Deliverables Description:**

Concepts, technologies, and tools that enable rapid assessment of the noise impact of novel engine/airframe configurations, mitigate component noise issues associated with novel aircraft configurations, and/or aid in the development and optimization of noise control approaches for component noise sources that enable new aircraft configurations such as truss-braced wing and small-core turbofan engines.

Phase I deliverables can include laboratory demonstrations that establish proof of concept of noise reduction technologies, or applications of novel computational tools with limited scope that demonstrate the potential for success on problems of greater scope.

Phase II deliverables can include system or subsystem demonstrations concurrent with the establishment of a realistic path to concept production, or incorporation of novel computational tools into existing modeling toolchains with validation cases to document capabilities.

**State of the Art and Critical Gaps:**

State-of-the-art technologies for noise reduction on conventional transport aircraft are generally passive and do not incorporate advanced material systems or adaptive mechanisms that can modify their performance based on the
noise state of the vehicle. Advanced material systems for airframe noise control are still in their infancy, especially in the context of certifiability and robustness. Novel material systems that could be applied to component noise sources on the aircraft are needed, such as shape memory alloy actuators, or active or adaptive systems. In addition, future aircraft designs, such as high-aspect ratio, truss-braced configurations, are envisioned that either leverage noise benefits of complex geometrical configurations or introduce noise challenges with engine/airframe integration. Efficient computational tools that enable rapid-turn evaluations of multiple configurations at the design stage are lacking. Numerical methods to study complex engine/airframe configurations are complex and difficult to leverage at the aircraft design stage where configuration details are not specified. Improvements to numerical methods and models for studying the noise aspects of advanced airframe configurations, including engine integration, would ease consideration of acoustics in the design, rather than leaving acoustics to the late design stage where noise control solutions are costly and less effective. Improved tools would also enable more rapid evaluation and development of novel noise control approaches that may be needed for these novel aircraft configurations.

Relevance / Science Traceability:

AAVP: The Advanced Air Transport Technology (AATT) and Commercial Supersonic Technology (CST) Projects would benefit from noise reduction technologies that could reduce the aircraft noise footprint at landing and takeoff. Configurations with novel engine placement, such as above the fuselage, can reduce the noise footprint, but technologies are needed to efficiently model the performance and noise impacts of these novel engine installations. In addition, novel configurations and technologies such as truss-braced wing and small-core turbofan engines will introduce new noise challenges that must be addressed to enable their successful deployment.

TACP: The Transformational Tools and Technologies (TTT) Project would benefit from tool developments to enhance the ability to consider acoustics earlier in the aircraft 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 noise, as these component technologies could have application in numerous vehicle classes in the AAVP portfolio, including subsonic and supersonic transports as well as vertical lift vehicles.

References:

AAVP - Advanced Air Transport Technology (AATT) Project: [https://www.nasa.gov/aeroresearch/programs/aavp/aatt][3]

AAVP - Commercial Supersonic Technology (CST) Project: [https://www.nasa.gov/aeroresearch/programs/aavp/cst][5]

TACP - Transformational Tools and Technologies (TTT) Project: [https://www.nasa.gov/aeroresearch/programs/tacp/ttt][6]
Materials and structures research and development (R&D) contributes to NASA's ability to achieve its long-term aeronautics goals, including the development of advanced propulsion systems. Proposals are sought for advanced materials and structures technologies that will be enabling for new propulsion systems for subsonic transport vehicles with high levels of thermal, transmission, and propulsive efficiency. Integrated computational and experimental approaches are needed that can reduce the time necessary for development, testing, and validation of new materials systems and components.

Advanced high-pressure-ratio compact gas turbine engines will include components of sufficiently compact size that new approaches to processing and advanced manufacturing will be needed. Temperature capability, thermomechanical performance, environmental durability, reliability, and cost-effectiveness are important considerations.

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

Proposals emphasizing modeling can address topics which shall address gaps in that 2040 vision. The range of topics could include data management, data analytics, machine learning, linkage and integration across spatiotemporal scales, and characterization of materials over their lifecycle. Proposals may address any material class associated with aeronautics propulsion for subsonic transport vehicles, multiscale modeling and measurements, multiscale optimization methods, and verification and validation of models and methods. However, approaches should rely on iterative, predictive methods that integrate experiments and simulations to describe the behavior and response of materials at various length and time scales.

Technology areas of interest this year include:

- Computational materials and multiscale modeling tools, including methods to predict properties, and/or durability of propulsion materials based upon chemistry and processing for conventional as well as functionally graded, nanostructured, multifunctional, and adaptive materials.
- Robust and efficient methods/tools to design and model advanced propulsion system materials and structures at all scale levels, including approaches that are adaptable for a multiscale framework.
- Multiscale design tools that integrate novel materials, mechanism design, and structural subcomponent design into system level designs.
- Advancing technology for ceramic matrix composites (CMCs) and their environmental barrier coatings (EBCs) for gas turbine engine components operating at 1,482 °C (2,700 °F) or higher. Focus areas include increased thermomechanical durability, increased resistance to environmental interactions,
cost-effectiveness of processing and manufacturing, and improved approaches to component fabrication and integration. Computational tools and integrated experimental/computational methods are sought, including models/tools to predict degradation and failure mechanisms.

- Additive manufacturing and other advanced processing/manufacturing approaches for structural components or materials to enable improved engine efficiency through decreasing weight and/or improving component design, properties, and performance.
- In support of future aircraft with hybrid electric or all electric propulsion systems, advanced cross-cutting materials technologies are needed. For example: (1) soft magnetic material with high magnetic saturation and/or lower losses for 100 to 300 kHz operation, (2) hard magnetic materials with an energy product greater than neodymium iron boron, (3) conductors for power cables with a specific resistivity less than copper or aluminum, and (4) novel materials systems and structures to enable functionality, such as power harvesting, thermal management, self-sensing, and actuation.
- Design and development of unique materials such as shape memory alloys and high entropy alloys for subsonic transport vehicle propulsion system structures and components.
- Propulsion aeromechanics, damping devices, and analysis and mistuning analysis for turbomachinery rotating blades.

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

Primary Technology Taxonomy:
Level 1: TX 12 Materials, Structures, Mechanical Systems, and Manufacturing
Level 2: TX 12.1 Materials

Desired Deliverables of Phase I and Phase II:

- Research
- Analysis
- Prototype
- Software

Desired Deliverables Description:

NASA's intent is to select proposals that have the potential to move a critical technology beyond Phase II SBIR funding and transition it to Phase III, where NASA's aeronautics programs, another Government agency, or a commercial entity in the aeronautics sector can fund further maturation as-needed, leading to actual usage in an enhanced propulsion system. The Phase I outcome should establish the scientific, technical, and commercial feasibility of the proposed innovation in fulfillment of NASA needs. Phase I should demonstrate advancement of a specific technology, supported by analytical and experimental studies that are documented in a final report. Phase IIs could yield: (1) models supported with experimental data, (2) software related to a model that was developed, (3) a material system or subcomponent that has been demonstrated to have better properties/performance (ability to operate at a higher temperature, carry more current, etc.), and (4) modeling tools for incorporation in software, etc. that can be infused into a NASA project or lead to commercialization of the technology. Consequently, Phase II efforts are strengthened when they include a partnership with a potential end-user of the technology.

State of the Art and Critical Gaps:

This subtopic would support R&D on advanced materials and structures technologies.
that will be enabling for new propulsion systems for subsonic transport vehicles with high levels of thermal, transmission, and propulsive efficiency. The needs are specified in the scope description. One of the major NASA Glenn Research Center core competencies is Materials and Structures for Extreme Environments. This subtopic supports that type of research—enabling materials and structures research that allows more efficient propulsion systems.

In general, integrated computational and experimental approaches are needed that can reduce the time necessary for development, testing, and validation of new materials systems and components. The increased use of various types of modeling to improve R&D effectiveness and enable more rapid and revolutionary materials design has been identified as critical. NASA recently conducted a study that identified critical cultural changes and gaps facing the multiscale modeling community.

For future aircraft with hybrid electric or all electric propulsion systems, advanced materials technology is needed for power components including electric machines and power cables.

Advanced high-pressure-ratio compact gas turbine engines will include components of sufficiently compact size that new approaches to processing and advanced manufacturing will be needed. Improvements in temperature capability, thermomechanical performance, environmental durability, reliability, and cost-effectiveness are important considerations.

Relevance / Science Traceability:

Aeronautics Research Mission Directorate (ARMD) projects that would/could support each of the specified areas of interest are listed below, along with advocates for the technologies. The technologies would lead to improved propulsion efficiencies (subsonic transport vehicles).

- Computational materials and multiscale modeling tools, including methods to predict properties, and/or durability of propulsion materials based upon chemistry and processing for conventional as well as functionally graded, nanostructured, multifunctional, and adaptive materials. TTT (Transformational Tools and Technology) Project.
- Robust and efficient methods/tools to design and model advanced propulsion system materials and structures at all scale levels, including approaches that are adaptable for a multiscale framework. TTT Project.
- Multiscale design tools that integrate novel materials, mechanism design, and structural subcomponent design into system level designs. TTT Project.
- Advancing technology for CMCs and their EBCs for gas turbine engine components operating at 1,482 °C (2,700 °F) or higher. TTT and AATT (Advanced Air Transport Technology) Projects.
- Additive manufacturing and other advanced processing/manufacturing approaches for structural components or materials to enable improved engine efficiency through decreasing weight and/or improving component design, properties, and performance. TTT Project.
- Soft magnetic material with high magnetic saturation and/or lower losses for 100 to 300 kHz operation, hard magnetic materials with an energy product greater than neodymium iron boron, conductors with a specific resistivity less than copper or aluminum, and cable insulation materials with increased dielectric breakdown
strength, and significantly higher thermal conductivity (?1 W/m·K) and resistance to ageing effects such as corona, ozone, humidity, and dust operating at greater than 3 kV. TTT, AATT, CAS (Convergent Aeronautics Solutions) Projects/HGEP (Hybrid Gas-Electric Propulsion) subproject.

- Novel materials systems and structures to enable functionality, such as power harvesting, thermal management, self-sensing, and actuation. Approaches may include use of nanotechnology and novel processing to tailor and control properties such as thermal conductivity, electrical conductivity, thermoelectric response, microstructure and porosity, and shape-memory behavior. TTT Project.
- Design and development of unique materials such as shape-memory alloys and high-entropy alloys for aeronautics structures and components. TTT and CAS Projects.
- Propulsion aeromechanics, damping devices, and analysis and mistuning analysis for turbomachinery rotating blades. TTT Project/AATT - UPAI (Unconventional Propulsion Airframe Integration)

References:


HGEP:
https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20170004515.pdf [8]

Hybrid Electric Propulsion:
https://www1.grc.nasa.gov/aeronautics/hep/ [9]

TTT:

CAS:
https://www.nasa.gov/aeroresearch/programs/tacp/cas [12]
https://nari.arc.nasa.gov/ [13]
https://www.nasa.gov/aeroresearch/programs/tacp [14]
https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20170006909.pdf [15]

A1.04 Electrified Aircraft Propulsion

Lead Center: ARC

Participating Center(s): AFRC, LaRC

Scope Title:
Electrified Aircraft Propulsion

Scope Description:

Proposals are sought for the development of energy storage, propulsion airframe integration, power distribution, thermal, tools/modeling approaches, electric machines, and electrical power conversion that will be required for aircraft that use turboelectric, hybrid electric, or all-electric power generation as part of the propulsion system. Turboelectric, hybrid electric, and all-electric power generation, as well as distributed propulsive power, have been identified as candidate transformative aircraft configurations with reduced fuel consumption/energy use and emissions. However, components and management methods for power generation, distribution, and conversion are not currently available in the high power ranges with the necessary efficiency, power density, electrical stability, and safety required for thin haul/short haul or transport-class aircraft. Novel developments are sought in:

- Energy storage systems with specific energy >400 Whr/kg at the system level under continuous 2C rate discharge conditions, with cycle life >10,000 cycles. Materials or strategies to promote rapid charging are desirable. This subtopic seeks energy solutions in the Technology Readiness Level (TRL) 3 to 5 range, appropriate for near-term applications.

- Lightweight electrical insulation materials/composites for high-altitude, high-voltage power transmission with dielectric breakdown strength (V/m) of the insulation minimally 2.5× that of the operating electric field stress at the conductor surface (operating voltages expected to be 1 to 20 kV), high resistivity at high temperature (>10^6 up to 10^20 ?•cm), low dielectric dissipation factor (tan ?), insulation Class C with operating temperature performance 220 to 400 ?C, moisture resistant, good mechanical properties (low creep under high-voltage stresses) and with thermal conductivity ?1 up to 10 W/m•K.

- Innovative tools for the design and analysis of airframe-integrated, high-performance distributed electric propulsion (DEP) inlet/fan systems and the resulting effect on: (1) distortion and swirl at the aerodynamic interface plane (AIP), (2) fan efficiency, stability, and structural robustness, and (3) operation of adjacent flow paths for DEP inlet/fan concepts and/or boundary layer ingestion (BLI) aircraft.

- Additive manufacturing processes and advanced materials for future generation MW-class electric motor designs and windings, which provide lower costs, compact designs (>25% volume reduction), lighter weight (>30% reduction), advanced cooling/improved thermal conductivity, multimaterials and/or greatly improved material or component properties that significantly contribute toward improved electric machine performance. Maintaining electrical insulating and lifetime properties over repetitive thermal cycling, along with being resistant to corona effects, is of interest.

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 topic, 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 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 power distribution systems and energy storage that have flight-critical reliability. 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. Another need for medium to large aircraft is the ability to operate at voltages above 600 V. This capability results in reduced weight, however, is called out specifically because it impacts all of the power system components.

Technologies that address these gaps enable Electrified Aircraft Propulsion (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 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 Demo (EPFD) project to enable a MW-class aircraft.

Key outcomes NASA intends to achieve in this area are:

- Outcome for 2015-2025: markets will begin to open for electrified small aircraft.
- Outcome for 2025-2035: certified small-aircraft fleets enabled by electrified aircraft propulsion will provide new mobility options. The decade may also see initial application of electrified aircraft propulsion 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 that 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) [16]

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) [17]

NASA X-57 Project: [https://www.nasa.gov/aeroresearch/X-57/technical/index.html](https://www.nasa.gov/aeroresearch/X-57/technical/index.html) [18]
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. 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 [19]) 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.

High-quality mesh generation was recognized by the Vision Study as a bottleneck in the CFD workflow as it impacts both the solution accuracy and the time to solution. Therefore, improved mesh technology is a continued need for high-fidelity simulations and proposals are solicited in two focused areas related to the overall grid generation theme. First, adaptive mesh capabilities have been very successful in unstructured and Cartesian grid paradigms, but application to structured overset grids have been limited to mesh refinement based on solution gradients which leads to too many grid points for full-scale three-dimensional configurations. Mesh redistribution algorithms use a fixed number of grid points, and locally refine (and coarsen) the mesh to equally distribute the error. This allows the "best" solution for a fixed computation cost with respect to the defined error metric. Adaptive mesh redistribution algorithms are needed for structured
overlapping grids that are robust in that given a valid structured overlapping grid system with no negative volumes, no orphan points, and a valid error-metric field, the redistributed mesh must also have no negative volumes and no orphans. The error metrics need to be based on solution and geometric gradients, solution Hessian, and adjoint-based error measures for achieving accurate lift and drag, pressure signatures, resolved turbulent kinetic energy, etc. These error-metric fields should be able to be read in and/or computed internally from an existing CFD solution. The error metric should be relevant to the CFD analysis being performed and the redistributed mesh should minimize the error with respect to the chosen metric. Finally, the cost of the redistribution algorithm (excluding the computation of the error-metric field in the case of an adjoint-based error metric) should only be a small percentage of the cost of a steady-state Reynolds-averaged Navier-Stokes (RANS) CFD solve on the structured overlapping grid being analyzed, less than 10%. Many private companies utilize NASA-structured overset grid tools such as Chimera Grid Tools and OVERFLOW, and several mesh generation software companies continue to develop and enhance their own structured grid generation capabilities. The addition of a solution- (or adjoint-) based adaptive mesh redistribution software package will have a large impact on reducing the generation of accurate overset grids, database generation, reduce uncertainty in computed solutions, and provide quantitative measures of solution error. This will impact the quality of CFD analysis being performed and lead to better products by industry.

The second 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 a 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. 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 turn-around 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.
Another focused area of research and development within this subtopic is the prediction of aeroelastic effects with uncertainty quantification. Application of computational aeroelastic simulations involving complex flow fields (e.g., flow separation) toward practical engineering applications is hindered by many factors beyond the large computational cost. The large volume of output data must be postprocessed nondeterministically, and new data-based methods are required to adequately understand the output, and further draw connections between the flow and events/mechanisms of interest, such as aeroelastic flutter. These methods may include machine learning, nonlinear transforms, classical parameters indicative of flutter onset (e.g., aerodynamic center location and generalized aerodynamic forces), higher-order statistical characterizations, etc. In addition to statistical flow outputs, the inputs to the flow simulations are often uncertain as well; methods are then required to propagate these uncertainties through the flow simulation in a cost-effective manner, and properly accommodate the uncertainties in the data-driven postprocessing methods. A possible and desired outcome is a toolbox of nonintrusive software that wraps around aeroelastic CFD simulations. Included in the envisioned work and products are uncertainty quantification- (UQ-) based postprocessing tools that would serve to guide an analysis team to characterize flutter onset (among other aeroelastic phenomena) in a nondeterministic manner. Phase I demonstrations of the UQ methodologies and tools on a single NASA-FUN3D flutter problem are desired. Phase II efforts would require more complete development of an automated and user-friendly toolbox. The awardees could then wrap the developed UQ tools around other CFD/aeroelastic solvers for commercialization.

In summary, proposals are being solicited in the above three focused areas under this subtopic. Successful awardees in all three research areas should note that it is NASA's intention to use developed software tools with NASA's CFD solvers. Therefore, fully functional application programming interfaces (APIs) will be required as deliverables.

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:
For focused area 1, the suggested research and development (including deliverable) during Phase I and II include:

Phase I:

- Single-zone demonstrations using airfoil geometry for O-grid or C-grid topologies with precomputed error-metric scalar/vector fields.
- Structured multiblock (without overset) grid for wing geometry.
- Structured overset grids for the wing geometry.
- Demonstrate capability of grid redistribution with up to 200 million grid cells within 20 minutes of wall-clock time.
- Provide an executable or an API for independent assessment by NASA teams.

Phase II:

- Collaborate with NASA team to develop API for coupled RANS-based grid adaptation.
- Assessment on four open-source complex structured grids: (1) Drag Prediction Workshop 6 (Wing-body-nacelle-pylon), (2) nozzle with baseline ramp (5th AIAA Propulsion Aerodynamics Workshop), (3) Sonic-Boom Prediction Workshop (C608 geometry), and (4) High Lift Prediction Workshop (HLPW-4).
- Demonstrate distributed memory strong scalability on grid sizes up to 1 billion with granularity at 500,000 points per core in under 5 minutes of wall-clock time.

For focused area 2, the suggested research and development during Phase I and II include:

Phase I:

- Given a bounding surface mesh (tri/quad/poly), demonstrate fully automated body-fitted polyhedral volume mesh generation for canonical geometries as proof of concept.
- Ability to export grid in CFD General Notation System (CGNS) (version greater than 4.1) file format.
- Demonstrate required cell quality metrics:
  - For each face, vector connecting the left and right cell centroids are aligned with face normal.
  - For each face, face centroid is half-way between left and right cell centroids.
- User defined refinement criteria should allow for:
  - Spatially varying wall-distance specified on the surface.
  - Minimum cell-centroid to face-centroid distance criteria specified by the user.
- Provide executable to NASA teams for preliminary testing.

Phase II:

- Demonstrations on three complex topologies: (1) HLPW-4, (2) Benchmark for Airframe Noise Computations (BANC-4) landing gear (PDCC-NLG), and (3)
Multistream Chevron nozzle (TMP17) satisfying the requirements established in Phase I.

- Performance assessment on a HLPW-4 geometry:
  - Demonstrate distributed memory weak scaling up to 10 billion cells at better than 10 million cells per core hour.
  - Demonstrate strong scaling on 10 billion cells mesh up to a granularity of 100,000 cells per core.
- Demonstrate the ability to conform to a user specified set of cell centroids.
- Develop API in collaboration with NASA CFD code developers.
- Demonstrate ability to regrid based on modified refinement criteria accessible through the API.

For focused area 3, demonstrations of the UQ methodologies and tools on a single NASA-FUN3D flutter problem are desired during Phase I. Phase II efforts would require more complete development of an automated and user-friendly toolbox.

**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.

**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:**

- [https://www.nasa.gov/aeroresearch/programs/aavp](https://www.nasa.gov/aeroresearch/programs/aavp) [2]
- [https://www.nasa.gov/aeroresearch/programs/tacp](https://www.nasa.gov/aeroresearch/programs/tacp) [14]
- NASA’s CFD Vision 2030 Study: [https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20140003093.pdf](https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20140003093.pdf) [19]

**A1.06 Vertical Lift Technology and Urban Air Mobility**

Lead Center: ARC

Participating Center(s): AFRC, ARC, LaRC

**Scope Title:**

**Electric Vertical Takeoff and Landing (eVTOL) Electric Propulsion Safety and Reliability**

**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. The majority 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 takeoff 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, safety and reliability of the electric power system and electric powertrain for these UAM /eVTOL vehicles.

This solicitation is seeking advancements in technologies that will improve the safety and reliability of the electrical power system/powertrain of UAM vehicles. There are three areas of main interest for this solicitation focused on the safety and reliability of the electrical power/powertrain system: (1) prognostic and diagnostic technologies for electric motors, (2) fault protection of high-voltage power system, and (3) advancements in thermal management technologies for electric motor systems. Based on industrial motor research and field data, use of continuous monitoring of conditions, such as temperature and vibration, can reduce the failure rate of motors by about two-thirds [Ref. 1]. This conclusion is based on data from large motors, but the physics of aviation motor degradation may be similar and future service experience may produce a similar overall trend. Due to the power levels envisioned for UAM vehicles, most will require high voltage (>540 V) operation, with the corresponding high-voltage direct current (DC) protection devices to ensure safe systems [Ref. 2]. Advancements in thermal management technologies, noted below, are also of interest given that temperature influences the overall safety and reliability of the power/powertrain system.

The application of the requested technologies should be relevant to the NASA Revolutionary Vertical Lift Technology (RVLT) project’s reference concept vehicles [Refs. 3-4], 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.

Through this solicitation, NASA is seeking advanced technologies supporting UAM electric/hybrid-electric propulsion in the areas of:

- **Prognostic/diagnostic technologies:** Operational performance diagnostics and prognostics technologies for electric motors and motor controllers to improve life and reliability of the system and reduce unscheduled maintenance for improved affordability. Technologies of interest related to motors/motor controllers include novel sensor and/or sensing technologies, data analysis algorithms, and methods to classify, fuse, or otherwise combine multiple sources of information for diagnostics, prognostics, and remaining useful life assessments. Proposers should consider the anticipated vehicle usage that will require differing motor power requirements for different phases of likely UAM flight profiles and maneuvers (power transients). The proposers should quantify any additional mass and/or power required (for example, mass of any additional sensors and associated cabling). Solutions that add minimal or no extra mass are of higher value and interest. The topic scope for the operational performance diagnostics and prognostics technologies is limited to the powertrain, motor controllers, and associated supporting systems for lubrication and cooling. The scope does not include batteries, fuel cells, fuel burning engines, avionics, communications equipment, or airframe structures.

- **High-voltage protection devices:** The high voltages expected in these systems will require properly rated protection devices. These do not currently exist for aeronautics-rated applications. While DC and alternating current (AC) architectures are both under consideration by designers, the focus here is on DC systems as these are the first being investigated by NASA. For this call, advanced technology high-voltage protection devices proposed should be applicable for systems with these characteristics: Voltage of 540 to 1,000 V, 100 to 200 A continuous operation with <5 msec clearing time. Other aspects of interest are current-limiting capability, high efficiency, and high reliability.

- **Thermal management technologies:** Lightweight, durable, and efficient thermal management solutions for 100 kW continuous-class electric motors are sought. Preferable are solution technologies that could be scaled and applied to aviation motors in a continuous power range of 20 to 500 kW. The most prevalent motor topology proposed and studied for this application are the permanent magnet motor family. Both passive and active approaches for thermal management may be applicable. Examples of technologies sought include integrated channels in rotor components, integrated heat pipes, and solutions enabled by additive manufacturing. Intended outcomes are effective and invasive solutions for motor rotors and windings with minimal mass and efficiency penalty. Solutions that demonstrate an improvement in reliability of the cooling system will be given extra consideration. Proposals should address the continuous motor specific power enabled by the innovations and the associated mass and efficiency penalties.
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 that address safety and reliability supported by analytical studies including modeling and simulation. Phase I effort should establish Phase II goals and should quantify projections of improvements to safety, reliability, and unscheduled maintenance assuming success of Phase II goals.

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 aircraft 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.

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.

References:

Electric Power Generation Via Thermionic Conversion for Hypersonic Applications

Lead Center: ARC

Participating Center(s): GRC

Scope Title:

Thermionic Energy Harvesting

Scope Description:

When employing a nonrotating propulsive device (engine), conventional generators for electrical power are not generally a viable design option; therefore, an alternative option is to utilize direct thermal-to-electric power conversion methods. One such technique is thermionic energy extraction applied to the primary flow path. Thermionic devices have been shown to be efficient in exploiting extreme temperature differentials, like those that typically characterize hypersonic flight environments, and also have a higher/larger energy density than that of standard batteries. The applications of thermionic devices in hypersonic vehicles are numerous, and broaden the design space, since 10 to 100 kW/m² of electrical power are compatible with realistic hardware implementation strategies. Significant, prior efforts in the 1960s, by both the U.S. and Soviet Union, were explored for space applications, but hypersonic atmospheric applications have not been extensively investigated.

For hypersonic atmospheric applications, the operational environments, relevant to the thermionic conversion process, are characterized by free-stream flight trajectories having dynamic pressures bounded by 750 to 3,500 (lbf/ft)/ft, and internal-flow path, peak static temperatures associated with adiabatic-flame temperatures (of a combusting hydrocarbon/air stoichiometric mixture). Additionally, volumetric and weight constraints of a novel thermionic device need to be competitive, and/or exceed, existing state-of-the-art battery technology in order to create viable design alternatives for system-design exploration. Although U.S. governmental restrictions typically apply to hypersonic-flight systems, this is not deemed to be a limiting factor in this Phase I activity, due to the low TRL; however, this issue will need to be further addressed during a Phase II award cycle, via coordination with appropriate U.S. governmental and industrial entities.

Expected TRL or TRL Range at completion of the Project: 1 to 3

Primary Technology Taxonomy:
Level 1: TX 03 Aerospace Power and Energy Storage
Level 2: TX 03.X Other Aerospace Power and Energy Storage

Desired Deliverables of Phase I and Phase II:

- Research
- Analysis
- Prototype

Desired Deliverables Description:

Phase I - Design of a testable prototype, capable of generating a few W/cm².

Phase II - Generation of experimental data in a relevant test environment with a thermionic device to quantify basic performance parameters and initiate scaling study.

State of the Art and Critical Gaps:
The specifics of designing a device with acceptable work functions for both emitter and collector surfaces is a significant technical issue. Additionally, manufacturing a volumetrically efficient device is not codified.

**Relevance / Science Traceability:**

The applications of power generator in harsh environments is relevant to atmospheric flight and numerous other commercial applications associated with energy conversion needs.

**References:**


(4) SECOND INTERNATIONAL CONFERENCE ON THERMIONIC ELECTRICAL POWER GENERATION, Stresa, Italy - May 27-31, 1968.

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**A1.08 Aeronautics Ground Test and Measurement Technologies**

Lead Center: ARC

Participating Center(s): ARC, GRC

**Scope Title:**

**Boundary Layer Velocity Profile Measurement On Models in Wind Tunnels**

**Scope Description:**

NASA's aeroscience ground test facilities include wind tunnels, air-breathing engine test facilities, and simulation and loads laboratories. They play an integral role in the design, development, evaluation, and analysis of advanced aerospace technologies and vehicles. These facilities provide critical data and fundamental insight required to understand complex phenomena and support the advancement of computational tools for modeling and simulation. The primary objective of the Aeronautics Ground Test and Measurements Technologies subtopic is to develop innovative tools and technologies that can be applied in NASA's aeroscience ground test facilities to revolutionize testing and measurement capabilities and improve utilization and efficiency. Of primary interest are technologies which can be applied to NASA’s portfolio of large-scale ground test facilities.

Spatially and temporally resolved velocity measurements are sought to study boundary layers on test articles in NASA’s large-scale ground test facilities. Proposed measurement capabilities could be used to measure boundary layer thickness, velocity profiles, and transition from laminar to turbulent flow, as well as detecting flow separation that could potentially be used for flow control. Measurement systems should be reliable and robust enough to be implemented in various wind tunnel facilities such as the National Transonic Facility, the 11-Foot Transonic Unitary Plan Facility, the Transonic Dynamics Tunnel, and 8- by 6-Foot Supersonic Wind Tunnel. These facilities operate using a variety of media, including air, nitrogen, and other gases such as R134a.

Technology for measuring boundary layers on models in cryogenic wind tunnels is relatively undeveloped so innovative techniques which can operate at cryogenic conditions are especially of interest. In one potential application in a transonic cryogenic wind tunnel, the boundary layer thickness can be as small as 0.1 mm (e.g., on a wing) but could be as large as 10 mm (e.g., on a fuselage). In this same application, the flow velocity could range from -50 to 200 m/sec. While light projection and remote detection capabilities will be considered, fiber optic light
delivery could be advantageous, particularly if the fiber optic transmission could utilize an existing pressure tap (or multiple taps) in the wind tunnel model. Scattering from light transmitted by a fiber optic embedded in the model could be detected by a remote, high magnification detection system or locally on the model (though that would result in additional cost to modify the wind tunnel model, which is less attractive).

Discrete sensor systems could be proposed that both transmit and collect light from a single location. Considerations for selection include the following: the ability to measure at multiple spatial locations, with higher spatial resolution, with higher temporal resolution, over a wider range of conditions, with higher accuracy and higher precision, and probes with potential for measuring multiple parameters (multiple velocity components or temperature, density, or other). Molecular- and particle-based approaches will also be considered. Such a sensor may have medical or industrial applications. Plans for device calibration and risk mitigation should be provided. Expected accuracy, precision, and spatial and temporal resolution should be estimated.

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

**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:**

- Prototype
- Hardware

**Desired Deliverables Description:**

Phase I: The desired deliverable would be a detailed system design for measuring thin boundary layers on model surfaces in both air and cryogenic conditions. This concept or system design should preferably be verified by simulation or testing and capable of being developed into a prototype system as part of a Phase II effort.

Phase II: Desired deliverables include a prototype system to measure boundary layers on a representative aerodynamic surface at room and cryogenic temperatures, a robust process for calibrating the system, and well-documented results from functional/operation tests including quantified uncertainty. It is anticipated that the technology would be demonstrated in a NASA ground-based test facility as part of the Phase II effort or shortly thereafter under Phase III funding.

**State of the Art and Critical Gaps:**

As NASA continues in the quest to advance computational methods and predictive tools as part of CFD 2030, one of the nemeses to significant advancement and validation is the lack of velocity information in the boundary layer. At both low and high speeds, making this measurement requires probe-based systems to be positioned close to the surface or optical-based systems to be focused near the surface. This is quite challenging due to (1) the thickness of the boundary layer, which can be as small as 0.1 mm, (2) conditions on the surface of the test article, (3) vibration of the test article, and (4) drastic temperature changes in the wind tunnel, which can range from room temperature to as low as -200 °C at cryogenic temperatures. There is currently no measurement system available to measure thin boundary layers, especially at cryogenic conditions, and NASA’s inability to obtain this critical data in ground-based facilities at near-flight Reynolds numbers limits the validation of numerical simulations and predictive tools for use in design and certification by analysis. The proposed technology could possibly have application on flight vehicles and in the medical field as well.

**Relevance / Science Traceability:**

The Transformational Tools and Technologies Project would use this technology to provide critical data to validate computational tools at near-flight Reynolds numbers as it pursues technical challenges to realize the CFD 2030 Vision and enable new aerospace vehicles to be certified by analysis. The technology would also have application for tests supporting the Advanced Air Transport Technology Project, the Commercial Supersonic Technology Project, the Revolutionary Vertical Lift Technology Project, and the Aerosciences Evaluation and Test Capabilities (AETC) Portfolio.
Measurement Technologies for Vertical Lift Configurations and Concepts

Scope Description:

NASA is currently evaluating new vertical lift configurations and concepts to enable Advanced Air Mobility (AAM). The measurement capabilities needed for AAM research are varied depending on whether model- or full-scale test articles are involved, whether wind tunnel or flight testing is conducted, and whether customized or off-the-shelf hardware is utilized. Nevertheless, vertical lift concepts will require new methods of providing real-time or near real-time measurements of rotor blade and vehicle performance including blade surface pressure distributions, boundary layer transition, rotor performance and blade position, rpm/phasing measurements, rotor control positions (cyclic pitch and flapping) and off-body flow field measurements for examining multiblade vortex interactions and wake/fuselage interaction. Current capabilities for obtaining these data are limited due to lower sampling rates and spatial resolutions using remote sensing. Technologies are needed to (1) increase the temporal and spatial resolutions of remotely sensed/wireless measurements and (2) bring these remotely sensed/wireless measurements onboard the vehicle or test article, where possible, to allow data to be efficiently acquired across a range of operational envelopes. Instrumentation that can be embedded in the blades and fuselage or added to off-the-shelf vehicle or model hardware with efficient data telemetry are desired.

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

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:

- Prototype
- Hardware
- Research

Desired Deliverables Description:

Phase I: The desired deliverable would be a detailed system design to enable remotely sensed/wireless measurements of blade surface pressure distributions, boundary layer transition, rotor performance and blade position, and off-body measurements. The system should enable efficient acquisition of performance data across the operating envelope of a representative AAM vehicle or model.

Phase II: Desired deliverables for Phase II include demonstration of a prototype system on a representative AAM vehicle, model, or test stand of the offeror’s choosing or in collaboration with NASA during a Revolutionary Vertical Lift Technology- (RVLT-) sponsored test.

State of the Art and Critical Gaps:

As part of the AAM mission, NASA is seeking to develop vehicle concepts and technologies to define requirements and standards that address key challenges such as safety, affordability, passenger acceptability, noise, automation, etc. Evaluation of these concepts and technologies will inherently depend on the same type of vehicle performance data typically used to assess the performance of larger-scale vehicles. Unfortunately, the same measurement techniques used for larger-scale vehicles are not directly applicable to AAM vehicles due to the reduced scale and unique design. As such, new measurement capabilities are needed that can be applied or added to vehicles or models during and after development.
Relevance / Science Traceability:

This technology would help fulfill the vision of the Revolutionary Vertical Lift Technology (RVLT) Project to create a future where vertical takeoff and landing (VTOL) configurations operate quietly, safely, efficiently, affordably, and routinely as an integral part of everyday life. This scope has been endorsed by the RVLT Project Manager as well as the Technical Leads in RVLT for Validation Test Campaigns.

The system might also have application to other types of flight and ground-based testing within the NASA Enterprise. This would fall under the purview of the Aerosciences Evaluation and Test Capabilities (AETC) Project.

References:

https://www.nasa.gov/aam [23]


A1.09 Vehicle Sensor Systems to Enable Situational Awareness

Lead Center: ARC

Participating Center(s): AFRC, ARC, LaRC

Scope Title:

Technologies to Enable Situational Awareness for Autonomous as well as Increasingly Autonomous Air Vehicles

Scope Description:

Achieving a vision for a safer and more efficient National Airspace System (NAS) with increasing traffic and the introduction of new vehicle types and unpiloted vehicles requires increasingly intelligent vehicle systems able to respond to complex and changing environments in a resilient and trustworthy manner. Future air vehicles, especially autonomous vehicles and those that support Advanced Air Mobility (AAM), must operate with a high degree of awareness of their own well-being, and possess the integrated intelligence to efficiently conduct operations while providing warning of off-nominal states. A vehicle’s capability to independently assure safety may be the only recourse in some situations, and for piloted vehicles addresses the recurring issue of inappropriate crew response. Internal to the vehicle, predictive maintenance reduces maintenance cost and vehicle down time through improved vehicle availability and throughput. Understanding the vehicle state also has impact on vehicle performance, efficiency, and environmental impact. External to the vehicle, vehicle awareness of the environment and ability to detect potential hazards in the surrounding airspace is crucial to the overall safety of the NAS and a vehicle’s ability to meet flight objectives.

This subtopic seeks technologies to enable intelligent vehicle systems, including subsystem and avoidance technologies, with an internal and external situational awareness to assure safety; optimize mission completion, efficiency and performance in nominal conditions; and respond to off-nominal conditions. The emphasis is on piloted vehicles augmented with autonomous capabilities, as well as increasingly autonomous unmanned air vehicles (including AAM). This subtopic includes vertical lift vehicles in general, but excludes sensor systems specifically designed for monitoring powertrain health; such proposals should propose to A1.06. Vertical Lift Technology and Urban Air Mobility. Situational awareness of new or alternate vehicle configurations, including distributed and hybrid electric propulsion, are also of interest. Areas of interest include:
• Sensing and perception technologies that provide the ability of the vehicle to
detect and extract internal and external vehicle information.
• Information fusion technologies to integrate information from multiple, disparate
sources and evaluate that information to determine health and operational state.
• Onboard hardware and software systems that are modular, scalable, redundant,
high reliability, and secure with minimal vehicle impact.
• Diagnostic technologies that provide critical markers trending to unsafe state.
• Networked sensors and algorithms to provide necessary vehicle full-field state information ranging from the component level to the subsystem and system level.
• Integrated systems technologies that enable the diagnosis of multiple hazards,
while effectively dealing with uncertainties and unexpected conditions.
• Approaches that enable improved in-flight vehicle state safety awareness with
adaptive methods to achieve improved efficiency, performance, and reduced
environmental impact.
• Methods that significantly enhance the fidelity and relevance of information
provided to ground systems by the vehicle in-flight for use in on-demand
maintenance.
• Perception software capabilities including multispectrum sensor fusion, real-time
perception system assurance software, and wake detection.
• Low-SWaP-C (size, weight, power, and cost) detection hardware that can detect
objects at far distances, e.g., 1,500 ft to 3 nmi, including visual cameras, infrared
(IR) cameras, event cameras, gated camera, Lidar, radar, and sonic hardware.
• Highly reliable vehicle navigation technologies (position, orientation, and rotational
and translational velocities) robust against Global Positioning System (GPS) denial/failures and responsive to the external environment.

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 10.1 Situational and Self Awareness

Desired Deliverables of Phase I and Phase II:

• Prototype
• Hardware
• Software

Desired Deliverables Description:

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

• A final report clearly stating the technology challenge addressed, the state of the
technology before the work was begun, the state of technology after the work was
completed, the innovations that were made during the work period, the remaining
barriers in the technology challenge, a plan to overcome the remaining barriers,
and a plan to infuse the technology developments into applications.
• A technology demonstration that clearly shows the benefits of the technology developed.
• A written plan to continue the technology development and/or to infuse the technology. This may be part of the final report.
• Resulting products can include hardware, software, demonstrations, reports, products, components, and integrated systems.

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

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

State of the Art and Critical Gaps:

It is predominately left to pilots (not the vehicle) to interpret current state and infer future states based on experience and expertise. Commercial Aviation Software Team (CAST), Federal Aviation Administration (FAA), National Transportation Safety Board (NTSB), and the National Research Council (NRC) have called for research on systems that can predict the state of the aircraft, including the state of autonomous systems, to provide notifications of trending to unsafe states. In order for there to be trust in autonomy, vehicle situational awareness needs to be tailored for independent autonomous systems without human intervention. Significant new capabilities are needed to enable safe vehicle operation in the airspace independent of human intervention. Sensing systems as intended here not only include the sensing element itself, but may also include the supporting technologies necessary to provide a meaningful measurement. Such supporting include hardware (e.g., networking capability) but also software (e.g., sensor fusion).

There has been development in internal vehicle component health management technology with some adoption; integrated subsystem/vehicle system full-field health management is limited and do not presently enable a completely autonomous vehicle system. Further, measurement and monitoring technologies need to be adapted with the introduction of new vehicle types to provide information relevant to understanding the specific vehicle state. The objective is to provide sufficient, dependable information with limited vehicle impact to enable, e.g., time appropriate cognition and decision making. [For Unmanned Aircraft Systems (UAS) vehicles, proposals involving such cognition and decision making can be submitted to Subtopic A2.02. Unmanned Aircraft Systems (UAS) Technologies.]

Relevant to AAM, current exterior perception technologies are focused on specific domains that are not relevant to AAM. AAM applications fly faster and in a less cluttered environment than automobiles. Nominal operations are expected to be at speeds between 40 and 200 mph and altitudes below 5,000 ft over a range under a few hundred miles. They also fly at a lower altitude than commercial airlines, making them more susceptible to weather conditions, while resulting in a more obstacle-rich environment. Most perception systems and software are currently focused on the auto industry where required ranges are shorter and update rates need to be faster, or they are designed for extremely low SWaP unmanned aerial vehicles (UAVs) that do not have passenger carrying safety requirements. Known gaps include the following: maintaining an aviation-grade safety assurance of perception systems, reaching the required detection distances, detection of objects in low-contrast/degraded environments,
and detection and knowledge of hyperlocal weather phenomena.

**Relevance / Science Traceability:**

This technology development is directly relevant to the NASA Aeronautics Research Mission Directorate (ARMD) Thrust 6 Autonomy Roadmap in order to allow more intelligent vehicle systems, and has strong relevance to NASA autonomy activities. NASA also plans to have an increasing role in the expanding market of AAM. Autonomy applications will only be able to make decisions as good as the information and insight at hand. The approach is to mature technology through this subtopic for ongoing implementation into NASA missions and commercial applications. This subtopic will also help define the limits of commercially available technology to meet the needs of increasingly intelligent systems to operate autonomously and in new transportation paradigms.

Autonomy is also a core capability increasingly relevant across a range of NASA mission directorates. For Science Mission Directorate (SMD) and Space Technology Mission Directorate (STMD), autonomy is central to planetary exploration and Earth monitoring, enabling more capable missions that provide improved science without the burden of human intervention. For example, the capability of an autonomous probe to maintain operations in uncertain or unforeseen conditions without human intervention can be critical to the success of the mission. Vehicle situational awareness may be mandatory in remote missions where it is difficult for a human to be in the loop in a timely manner. Likewise, the safety of the astronauts in a manned mission may depend on appropriate vehicle response to rapidly changing conditions.

**References:**

1. ARMD Strategic Thrust 6: Assured Autonomy for Aviation Transformation, Vision and Roadmap, M.Ballin, June 2016, [https://nari.arc.nasa.gov/thrust6](https://nari.arc.nasa.gov/thrust6) [24]
2. [https://www.nasa.gov/aam](https://www.nasa.gov/aam) [23]
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 also meet the challenges presented by NASA and industry’s cutting edge research and development programs.

NASA’s Flight Demonstrations and Capabilities 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. This subtopic supports innovative flight platform development for use in flight testing, science missions, and related subsystems development.

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:

- High-efficiency digital telemetry techniques and/or systems to enable high data rate and high-volume telemetry for flight test. This includes air-to-air and air-to-ground communication.
- Architecture and tools for high-integrity data capture and fusion.
- Real-time integration of multiple data sources from onboard, off-board, satellite, and ground-based measurement equipment.
- Advanced in situ/onboard sensing and/or integrated secured remote services for use in real-time decision making.
- Prognostic and intelligent health monitoring for hybrid and/or all-electric propulsion systems using an adaptive embedded control system.
- Test techniques, including optical-based measurement methods that capture data in various spectra, for conducting quantitative in-flight boundary layer flow visualization, schlieren photography, near and far-field sonic boom determination, and atmospheric modeling as well as measurements of global surface pressure.
and shock wave propagation.

- Measurement technologies for in-flight steady and unsteady aerodynamics, juncture flow measurements, propulsion airframe integration, structural dynamics, stability and control, and propulsion system performance.
- Improved rugged wideband fiber optic sweeping laser system design for optical frequency domain reflectometry containing no moving parts, to be operated onboard NASA's wide range of aircraft. Improved development of polarization insensitive fiber measurements using optical frequency domain reflectometry.
- Wireless sensors, sensing technologies, and telecommunication methods that can be used for flight test instrumentation applications 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 data to a central node. This area of technologies also includes wireless (nonintrusion) power transferring techniques and/or wirelessly powering remote sensors.
- Innovative measurement methods that utilize intelligent sensors for autonomous remote sensing in support of advanced flight testing.
- Fast imaging spectrometry that captures all dimensions (spatial/spectral/temporal) and can be used on unmanned aerial systems (UAS) platforms.
- Innovative new flight platforms and associated subsystem development for use in all areas of flight tests.

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 Flight Demonstrations and Capabilities (FDC) projects. The FDC Project conducts complex flight research demonstration to support multiple ARMD programs. FDC is seeking to enhance flight research and test capabilities necessary to address and achieve the ARMD Strategic plan. They could also support Advanced Air Vehicle Program (AAVP) projects: Commercial Supersonic Technology (CST) and Advanced Air Vehicles Program (AAVP) - Aerosciences Evaluation and Test Capabilities (AETC) Project.

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 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:** 2 to 6

**Primary Technology Taxonomy:**
- Level 1: TX 15 Flight Vehicle Systems
- Level 2: TX 15.X Other Flight Vehicle Systems

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

**Desired Deliverables Description:**

For a Phase I effort, at a minimum, a report is desired that describes the effort's successes, failures, and the proposed path ahead.

For a Phase II effort, the small business should show a maturation of the idea or technology that allows for a presentation of detailed influential analysis or a thorough demonstration at least, and most ideally a delivery of a prototype that includes beta-style or better hardware or software.

**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 IASP and FDC projects. 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 Strategic plan. Also, they could support IASP and EPFD projects, and AAVP CST project and Aerosciences Evaluation and Test Capabilities (AETC) Project.

**References:**

[https://sbir.nasa.gov/](https://sbir.nasa.gov/) [25]


[https://www.nasa.gov/centers/armstrong/news/FactSheets/FS-109.html](https://www.nasa.gov/centers/armstrong/news/FactSheets/FS-109.html) [27]

[https://www.nasa.gov/centers/armstrong/research/X-56/index.html](https://www.nasa.gov/centers/armstrong/research/X-56/index.html) [28]

A2.02 Enabling Aircraft Autonomy

Lead Center: AFRC

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 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 more capability and promises 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 multi-objective 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). A few of the areas of research and missions are listed below:

- Remote missions utilizing one or more unmanned aircraft system (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 that can enable AAM and higher levels of UAS integration into the national airspace
- Fault detection, diagnostics, and prognostics capabilities to inform autonomous contingency management systems.

This solicitation is intended to break through these and other barriers with innovative and high-risk research.
The Integrated Aviation Systems Program's FY2021 SBIR solicitation is focused on tackling these barriers to enable greater use of autonomy in NASA research, in civil aviation use, and, ultimately, in the emerging AAM market. The following four research areas are the primary focus of this solicitation, and any submissions must show a strong relevance to these areas to be considered. The primary research areas are:

- **Cognition and multi-objective decision making**—Technologies need to be developed that transform the raw data into actionable information and make decisions based on this information. Detect and avoid in the national airspace utilizing multiple sensors is an example of one challenge this particular research is attempting to address. Artificial intelligence-based methods such as machine learning will be considered if it provides a novel approach.

- **Cost-effective, resilient, and self-organizing communications**—Methods that ensure reliable, trusted-source communications with increasingly complex and interconnected systems are needed to minimize the impact of infrastructure outages (e.g., Global Positioning System (GPS) or ground station) and that are resilient against both internal and external cyberphysical attacks. Several key areas of interest are:
  - Resilient wireless communications in the presence of jamming, terrain, or weather caused interference.
  - Quantum communication technologies, in particular, quantum repeaters and quantum key distribution methods.

- **Prognostics, survivability, and fault tolerance**—Techniques that can understand vehicle health, critical failures, can 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. Examples include, but are not limited to, new, efficient approaches and algorithms and hybrid edge/cloud approaches.

- **Verification and validation technology and certification approaches**—New methods of verification, validation, and certification need to be developed which enable application of complex systems to be certified for use in the National Airspace System (NAS). Proposed research could include novel hardware and/or software architectures that enable alternate or expedite traditional verification and validation requirements. Proposals should reference material on emerging standards for autonomy certification, including ASTM autonomy guidelines and emerging Federal Aviation Administration (FAA) considerations for small aircraft, UAS, and Urban Air Mobility (UAM).

It is important to note that any proposals for UAS development will not be considered unless it can demonstrate strong relevance to aforementioned research interests.
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 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 technology demonstration in a simulation environment that clearly shows the benefits of the technology developed.
- A written plan to continue the technology development and/or to infuse the technology. This may be part of the final report.

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

- A final report clearly stating the technology challenge addressed, the state of the technology before the work was begun, the state of technology after the work was completed, the innovations that were made during the work period, the remaining barriers in the technology challenge, a plan to overcome the remaining barriers, and a plan to infuse the technology developments.
- A technology demonstration in a relevant flight environment that clearly shows the benefits of the technology developed.
- 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, 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 technology 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 NASA ARMD’s Strategic Thrust 5 and Strategic Thrust 6.

- [https://www.nasa.gov/aeroresearch/programs/tacp](https://www.nasa.gov/aeroresearch/programs/tacp) [14]
- [https://www.nasa.gov/aeroresearch/programs/aosp](https://www.nasa.gov/aeroresearch/programs/aosp) [32]
- [https://www.nasa.gov/aeroresearch/programs/iasp](https://www.nasa.gov/aeroresearch/programs/iasp) [33]

References:
[https://www.hq.nasa.gov/office/aero/pdf/armd-strategic-implementation-plan.pdf](https://www.hq.nasa.gov/office/aero/pdf/armd-strategic-implementation-plan.pdf) [34]

A2.03 Advanced Air Mobility (AAM) Integration
Lead Center: AFRC
Participating Center(s): LaRC

Scope Title:

AAM Community Integration - Weather Infrastructure Testbed

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.

Although limited manned, passenger-carrying UAM and other air taxi operations occur today, this market is ripe to expand as technologies such as electric propulsion and increasing autonomy converge enabling novel aircraft with enhanced capabilities. With time, the small unmanned aerial systems (sUAS) market and manned UAM and air taxi...
markets may converge into a broader AAM market including both manned and unmanned vehicles. To start down
the path to enabling this, ARMD has proposed an organizational framework, identified a set of barriers organized
according to this framework that must be overcome to enable this market, and has identified NASA’s potential
contributions to overcome these market impeding barriers.

The AAM framework consists of five pillars: (1) aircraft design, (2) individual aircraft operations, (3) airspace design,
(4) airspace and fleet operations, and (5) community integration. This solicitation focuses specifically on the
community integration pillar (Refs 1-3, 6-8). 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 the A3 topic.

- Scope 1 Weather Data Infrastructure Testbed—Weather data sensors are part of the weather infrastructure
proposed in the UAM Maturity Level 4 (UML-4) ecosystem ConOps (concept of operations) (Refs 4 and 8). These
sensors provide current weather conditions. The data they collect is an input into the UAM system for use by
vehicle and vertiport operators and Providers of Services/UTM Supplemental Service Providers (PSUs/USSes) (Ref 6)
and will also be utilized to validate forecasting models. This testbed should consider the innovative use of existing
and new, fixed and mobile, and nontraditional weather sensors as part of the architecture; testing and validation
of the accuracy of the sensors and data; new weather forecast techniques and/or ultrahigh spatial and temporal
resolution weather forecast models tailored for UAM; and/or the assimilation of weather data from these sensors into
weather models. The effort should consider the work being done by ASTM’s F38 WK73142 (Ref 5) and work towards
a goal of increasing measurement density and scalability while incentivizing private sector companies to install
weather sensing equipment, data delivery, and receive payment for the data by local government(s) and commercial
Weather Supplemental Data Service Providers (SDSP) to improve UML-4 weather situational awareness
and predictions. Phase I would also identify potential localities interested in hosting and utilizing the data
from this testbed. Phase II would be to build the testbed in at least one locality and market for additional
customers beyond those identified in Phase I.

Expected TRL or TRL Range at completion of the Project: 2 to 6
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:
- Software
- Hardware
- Analysis
- Research
- Prototype

Desired Deliverables Description:

Phase I of this SBIR would be focused on the development of an aviation metropolitan based weather sensing and
prototype testbed architecture to support addressing the challenges associated with future UAM and AAM weather
infrastructure. Phase I would also identify potential localities interested in hosting and utilizing the data from this
testbed.

Phase II would be to build the testbed in at least one locality and market for additional customers beyond those
identified in Phase I.

State of the Art and Critical Gaps:

The AAM marketplace is assessed at a UML-0 (see references). Technologies are needed to progress towards the
desired UML-4 level where this model of travel is affordable to the general public.

Relevance / Science Traceability:

AAM Mission Office.

This subtopic is relevant to the Aeronautics Research Mission Directorate (ARMD) AAM Mission and the eight projects supporting that mission. 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 the A3 topic.

References:

1. NASA's National Aeronautics Committee briefings:
   https://www.nasa.gov/aeroresearch/aero-nac-committee [36]
3. https://www.nasa.gov/aeroresearch/one-word-change-expands-nasas-vision-for-future-airspace/ [37]
4. Reference: Urban Weather section from the UAM UML-4 ConOps
   https://nari.arc.nasa.gov/sites/default/files/attachments/4%203%206%20Weather--CIWG%20version.pdf [38]
6. FAA UAM ConOps 1.0 https://nari.arc.nasa.gov/sites/default/files/attachments/UAM_ConOps_v1.0.pdf [40]
7. National Academies Report:
   https://www.nap.edu/catalog/25646/advancing-aerial-mobility-a-national-blueprint [41]

Scope Title:

AAM Community Integration - Urban Planning Simulation

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.

Although limited manned, passenger-carrying UAM and other air taxi operations occur today, this market is ripe to expand as technologies such as electric propulsion and increasing autonomy converge enabling novel aircraft with enhanced capabilities. With time, the small unmanned aerial systems (sUAS) market and manned UAM and air taxi markets may converge into a broader AAM market including both manned and unmanned vehicles. To start down the path to enabling this, ARMD has proposed an organizational framework, identified a set of barriers organized according to this framework that must be overcome to enable this market, and has identified NASA's potential contributions to overcome these market impeding barriers.

The AAM framework consists of five pillars: (1) aircraft design, (2) individual aircraft operations, (3) airspace design, (4) airspace and fleet operations, and (5) community integration. This solicitation focuses specifically on the community integration pillar (Refs 1-3, 6-8). 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 the A3 topic.

- Urban Planning Simulation – Develop or modify an existing city or urban planning gaming software to incorporate the ability to realistically simulate a multimodal transportation system that includes AAM transportation as an additional mode of transportation in a U.S. metropolitan area. (Ref 2)

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

Primary Technology Taxonomy:
Level 1: TX 11 Software, Modeling, Simulation, and Information Processing
Level 2: TX 11.3 Simulation

Desired Deliverables of Phase I and Phase II:

- Software

Desired Deliverables Description:

Phase I would focus on the identification of the specific gaming software, gaining the appropriate permissions, researching the constraints associated with UAM/AAM and planned Concept of Operations (Ref 2 and 6), planning the software modifications, and developing a schedule for updates and release of the updated software.

Phase II would be the software and graphics modification and release of the updated software in accordance with the Phase I plan.

State of the Art and Critical Gaps:

Multiple urban planning games currently exist.

Relevance / Science Traceability:

AAM Mission Office.

This subtopic is relevant to the Aeronautics Research Mission Directorate (ARMD) AAM Mission and the eight projects supporting that mission. 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 the A3 topic.

References:

1. NASA's National Aeronautics Committee briefings: https://www.nasa.gov/aeroresearch/aero-nac-committee [36]
3. https://www.nasa.gov/aeroresearch/one-word-change-expands-nasas-vision-for-future-airspace/ [37]
4. Reference: Urban Weather section from the UAM UML-4 ConOps https://nari.arc.nasa.gov/sites/default/files/attachments/4%203%206%20Weather--CIWG%20version.pdf [38]
6. FAA UAM ConOps 1.0 https://nari.arc.nasa.gov/sites/default/files/attachments/UAM_ConOps_v1.0.pdf [40]
AAM Community Integration

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.

Although limited manned, passenger-carrying UAM and other air taxi operations occur today, this market is ripe to expand as technologies such as electric propulsion and increasing autonomy converge enabling novel aircraft with enhanced capabilities. With time, the small unmanned aerial systems (sUAS) market and manned UAM and air taxi markets may converge into a broader AAM market including both manned and unmanned vehicles. To start down the path to enabling this, ARMD has proposed an organizational framework, identified a set of barriers organized according to this framework that must be overcome to enable this market, and has identified NASA’s potential contributions to overcome these market impeding barriers.

Th AAM framework consists of five pillars: (1) aircraft design, (2) individual aircraft operations, (3) airspace design, (4) airspace and fleet operations, and (5) community integration. This solicitation focuses specifically on the community integration pillar (Refs 1-3, 6-8). 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 the A3 topic.

- The integration of AAM into a multi-modal transportation system is a complicated endeavor involving leveraging existing infrastructure, working with existing and new stakeholders in an evolving regulatory environment. The results from this SBIR would form the nucleus of a set of tools that could be utilized by local community stakeholders to support the planning, public acceptance, and analysis of various design options to incorporate AAM into the local or regional transportation system.

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

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:

Phase I would be to identify initial needed types of data sets e.g., local zoning data and existing and needed tools, a plan to assemble or build the tools and incorporate the needed datasets, and create a business plan to market a planning suite of tools to localities to assist them to develop plans and assess the potential benefits of various site selection options and demand potential for various options for integration into the existing multimodal transportation systems. The integration of AAM into a multi-modal transportation system is a complicated endeavor involving leveraging existing infrastructure, working with existing and new stakeholders in an evolving regulatory environment. The results from this SBIR would form the nucleus of a set of tools that could be utilized by local community stakeholders to support the planning, public acceptance, and analysis of various design options to incorporate AAM into the local or regional transportation system.
Phase II would be to execute the plans developed in Phase I.

State of the Art and Critical Gaps:

NASA has developed decision support tools for the National Airspace System. This effort would leverage that experience to support local communities.

Relevance / Science Traceability:

This subtopic is relevant to the Aeronautics Research Mission Directorate (ARMD) AAM Mission and the eight projects supporting that mission. 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 the A3 topic.

References:

1. NASA’s National Aeronautics Committee briefings: [36]
   https://www.nasa.gov/aeroresearch/aero-nac-committee
3. https://www.nasa.gov/aeroresearch/one-word-change-expands-nasas-vision-for-future-airspace/ [37]
4. Reference: Urban Weather section from the UAM UML-4 ConOps
   https://nari.arc.nasa.gov/sites/default/files/attachments/4%20203%20Weather--CIWG%20version.pdf [38]
5. ASTM WK731142 [39]
6. FAA UAM ConOps 1.0 https://nari.arc.nasa.gov/sites/default/files/attachments/UAM_ConOps_v1.0.pdf [40]
7. National Academies Report: [41]
   https://www.nap.edu/catalog/25646/advancing-aerial-mobility-a-national-blueprint

Scope Title:

AAM Community Integration - Multimode Transportation Information Integration

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.

Although limited manned, passenger-carrying UAM and other air taxi operations occur today, this market is ripe to expand as technologies such as electric propulsion and increasing autonomy converge enabling novel aircraft with enhanced capabilities. With time, the small unmanned aerial systems (sUAS) market and manned UAM and air taxi markets may converge into a broader AAM market including both manned and unmanned vehicles. To start down the path to enabling this, Aeronautics Research Mission Directorate (ARMD) has proposed an organizational framework, identified a set of barriers organized according to this framework that must be overcome to enable this
market, and has identified NASA’s potential contributions to overcome these market impeding barriers.

The AAM framework consists of five pillars: (1) aircraft design, (2) individual aircraft operations, (3) airspace design, (4) airspace and fleet operations, and (5) community integration. This solicitation focuses specifically on the community integration pillar (Refs 1-3, 6-8). 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 the A3 topic.

- This effort would be to design and develop an innovative Multimodal Information Management System (MIMS) that includes AAM as one element of a Smart City transportation data management system.

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

- Prototype
- Hardware
- Software

Desired Deliverables Description:

Phase I would be to identify the system requirements, physical infrastructure including interfaces, data architecture and sources, security and data assurance measures needed for the system, and public and private partners.

Phase II would be to build the planned system and market it to several localities.

State of the Art and Critical Gaps:

Some systems exist e.g., Los Angeles has a scooter tracking system and app for their Department of Transportation and many localities have apps for their metros e.g. Washington DCs, Metro app. This would be a comprehensive multimodal system.

Relevance / Science Traceability:

This subtopic is relevant to the Aeronautics Research Mission Directorate (ARMD) AAM Mission and the eight projects supporting that mission. 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 the A3 topic.

References:

1. NASA’s National Aeronautics Committee briefings: https://www.nasa.gov/aeroresearch/aero-nac-committee [36]
3. https://www.nasa.gov/aeroresearch/one-word-change-expands-nasas-vision-for-future-airspace/ [37]
4. Reference: Urban Weather section from the UAM UML-4 ConOps https://nari.arc.nasa.gov/sites/default/files/attachments/4%203%206%20Weather--CIWG%20version.pdf [38]
6. FAA UAM ConOps 1.0 https://nari.arc.nasa.gov/sites/default/files/attachments/UAM_ConOps_v1.0.pdf [40]
7. National Academies Report:

A3.01 Advanced Air Traffic Management System Concepts
Lead Center: ARC
Participating Center(s): LaRC

Scope Title:
Advanced Air Traffic Management System Concepts

Scope Description:
This subtopic addresses contributions towards Air Traffic Management (ATM) systems and concepts with potential application in the near-future (2025-2030) 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:

https://www.nasa.gov/aeroresearch/programs/aosp [32]
Lead Center: ARC

Participating Center(s): LaRC

Scope Title:

Increasing Autonomy in the National Airspace System (NAS)

Scope Description:

NASA’s future concepts for air transportation (2030 and beyond) will significantly expand the capabilities of airspace and vehicle management and are anticipated to increasingly rely on autonomy and artificial intelligence and machine learning to ensure safe, secure, and equitable operations. Such future concepts propose a seamless, integrated, flexible, and robust set of systems that are anticipated to include traditional as well as nontraditional vehicle types and operations, diverse airspace domains and mission types, and a service-based architecture to provide user services as those demonstrated within NASA’s Unmanned Aircraft Systems Traffic Management (UTM) Project, as appropriate. Future concepts will require resilient, cyber-attack-resistant systems to ensure safe and robust operations that maintain expected levels of safety, as well as accommodate changes to environmental and operational conditions.

Human operators currently perform the most significant roles in decision making in the National Airspace System (NAS). The appropriate allocation of functions as humans team with autonomy (and even current automation) is a critical research question as more autonomous systems are introduced. To address these research challenges, this subtopic seeks proposals that will apply novel and innovative techniques, methods, and approaches to developing tools and/or technologies that will enable successful human-autonomy teaming in the future NAS.

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 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 rejected.

Relevance / Science Traceability:

Airspace Operations and Safety Program (AOSP).

Successful technologies in this subtopic have helped to advance the air traffic management/airspace operations objectives of the 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:

https://www.nasa.gov/aeroresearch/programs/aosp [32]

A3.03 Future Aviation Systems Safety

Lead Center: ARC

Participating Center(s): LaRC

Scope Title:

Future Aviation Systems Safety

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 include: increased use of automation and autonomy to enhance system capabilities, airspace systems with tightly coupled air and ground functions, 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 vehicles and mission types, such as Unmanned Aircraft Systems (UAS) and Advanced Air Mobility (AAM). 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 system-wide 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 system-wide 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), to address aviation system safety needs. Based on ISSA building blocks, its
Functional capabilities are architecturally structured to “Monitor—Assess—Mitigate” operational safety risks. One application area of high interest is 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 IASMS will be rejected.

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

1. 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.

2. Proposals supporting the research and development of ISSA objectives:
   - To detect and identify system-wide 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.

3. 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.

4. 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.

**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:**
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 Urban Air Mobility (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:

https://www.nasa.gov/aeroresearch/programs/aosp [32]

https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/aero-rdplan-2010.pdf [42]
A3.04 Nontraditional Airspace Operations

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 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 subtopic seeks proposals to continue to adapt the UTM concept elements for application to Urban Air Mobility (UAM)/Advanced Air Mobility (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 incorporating cyber-resiliency methods, tools, or capabilities, or address cyber-resiliency as part of the proposed effort are also being solicited.

New this year, this solicitation is focused on UAM/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 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:
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: 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: 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 rejected. 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 rejected.

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:

https://www.nasa.gov/aeroresearch/programs/aosp [32]
https://www.aviationsystemsdivision.arc.nasa.gov/publications/index.shtml [43]
https://www.aviationsystemsdivision.arc.nasa.gov/index.shtml [44]
https://www.nasa.gov/aeroresearch/strategy [16]