Aeroelasticity and Aeroservoelastic Control

Lead Center: LaRC

Participating Center(s): AFRC

Technology Area: TA15 Aeronautics

Scope Title
Aeroelasticity and Aeroservoelasticity for Advanced Configurations

Scope Description
The technical discipline of aeroelasticity is a critical ingredient necessary in the design process of a flight vehicle for maintaining optimal performance while ensuring freedom from aeroelastic and aeroservoelastic instabilities. This discipline requires a thorough understanding of the complex interactions between a flexible structure and the steady and unsteady aerodynamic forces acting on the structure, with interactive control systems for flight vehicle performance and stability. Predicting the aeroelastic response of emerging evolutionary and revolutionary vehicle concepts, which include new vehicle configurations, new structures, and/or new materials, is not an easy task. Aeroelastic prediction and testing methods must evolve and expand together with these vehicle concepts. The use of lightweight flexible structures, the development of new airframes, and the intentional exploitation of aeroelastic response phenomena require a comprehensive understanding of the aeroelasticity involved if they are to succeed. Both enhancements to current methodologies/codes and new methodologies/codes that enable evaluation and understanding of new concepts are needed to keep pace with the state of the art in vehicle technology and to fill critical gaps in understanding these complex vehicles.

The fundamental aeronautics work for the Aeroelasticity and Aeroservoelastic Control Subtopic is focused on active/adaptive aerostructural control for lightweight flexible structures, specifically related to load distribution, flutter prediction and suppression, gust load prediction and alleviation, and aeroservoelasticity for Ultra-Efficient and Supersonic Commercial Vehicles. The program’s work on aeroservoelasticity includes conduct of broad-based research and technology development to obtain a fundamental understanding of aeroelastic and unsteady-aerodynamic phenomena experienced by aerospace vehicles in subsonic, transonic, supersonic, and hypersonic speed regimes. The subtopic content includes theoretical aeroelasticity, experimental aeroelasticity, and advanced aeroservoelastic concepts. Of interest are:

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

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

References

Links to program/project websites:


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


3) Joined Wing: https://www.nasa.gov/centers/langley/multimedia/iotw-tdt-wing.html [7]


Expected TRL or TRL range at completion of the project: 3 to 5

A1.02 Quiet Performance - Aircraft Propulsion Noise

Lead Center: LaRC

Participating Center(s): LaRC

Technology Area: TA15 Aeronautics

Scope Description
Innovative methods and technologies are necessary for the design and development of efficient, environmentally acceptable aircraft. In particular, for passenger aircraft, 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/fees are employed, and increased potential for air traffic growth on a global scale.

Therefore, in support of the Advanced Air Vehicles Program (AAVP), Integrated Aviation Systems Program (IASP), and Transformative Aeronautics Concepts Program (TACP), improvements in technologies and methods for aircraft propulsion noise prediction, diagnostics, and reduction for both subsonic and supersonic aircraft are sought. Innovations in the following specific areas are solicited:

**Noise Reduction**

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

**Noise Prediction**

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

**Noise Diagnostics**

- Tools/Technologies for quantitative characterization of fan in-duct broadband noise in terms of its spatial and temporal content;
- Phased array and acoustical holography techniques to measure realistic propulsion noise sources in low-signal-to-noise ratio wind tunnel environments;
- Characterization of fundamental jet noise sources and structures;
- Innovative measurement of radiated acoustic fields from aeroacoustic sources;
- Novel and robust combustion noise measurement techniques.

**References**


**Expected TRL or TRL range at completion of the project:** 2 to 5.

**Desired Deliverables of Phase II**
Desired Deliverables Description

Concepts and technologies that demonstrate a potential for engine component noise reduction, or demonstrate characteristics that could be incorporated into a more sophisticated noise control solution for aircraft engines.

State of the Art and Critical Gaps

Current state-of-the-art solutions for propulsion noise reduction rely heavily on relatively modest changes to the engine architecture and/or passive noise reduction technologies such as acoustic liners, blade/vane count optimization, or vane sweep and/or lean. They do not incorporate advanced materials, adaptive mechanisms, or active noise control systems that can modify the acoustic performance of the component(s) of interest based on the noise state of the engine or aircraft. Such materials, mechanisms, and systems are currently at various stages of maturity, but in general they have not been sufficiently developed to meet certifiability, reliability, and robustness criteria. Novel material systems that could be applied to engine component noise sources are needed, such as shape memory alloy actuators, or active or adaptive systems. High-fidelity numerical tools are beginning to be used for predicting engine component noise. However, they remain too resource-intensive for routine use for design and analysis work. Medium-fidelity prediction tools that can be used for rapid-turn-around evaluations at design and analysis stages are highly desirable. Advanced flow and noise diagnostic techniques that can provide more direct linkage between the noise generating flow features and/or provide more detailed spatio-temporal descriptions of the sound field are also much needed.

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.

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.

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

Lead Center: LaRC

Participating Center(s): LaRC

Technology Area: TA15 Aeronautics

Scope Description

Environmentally Responsible Propulsion allows high turbine engine performance with lower pollution and quiet engines.

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

Development of measurement techniques for characterizing aircraft engine particle emissions in the 10 to 200 nanometer (nm) particle diameter size range including:

- Absorbing aerosol standard for the quantitative calibration of optically-based soot mass sensors
- Size-dependent mass concentrations of volatile (e.g., hydrocarbons, sulfuric acid) and non-volatile particles (e.g., black carbon or soot)
- Measurements carried out at high sample line pressures relevant for sector combustor studies and low pressures relevant for flight studies

Environmentally Responsible Propulsion includes all of the following potential research areas:
- Detectors (see also Sensors); Conversion; Generation; Sources (Renewable, Nonrenewable); Characterization; Models & Simulations (see also Testing & Evaluation); Thermal Imaging (see also Testing & Evaluation); Fluids; Metallics; Nanomaterials; Organics/Biomaterials/Hybrids.

References

https://www.nasa.gov/aeroresearch/programs/tacp/ttt [12]

https://www.nasa.gov/aeroresearch/programs [13]

NASA Glenn Combustor Facilities: https://www1.grc.nasa.gov/facilities/erb/combustor/ [14]


Expected TRL or TRL range at completion of the project: 2 to 5.

Desired Deliverables of Phase II

Prototype, Analysis, Software, Research

Desired Deliverables Description

A major deliverable will be computer simulation software to predict the best and most effective combustor configurations. Another deliverable would be prototype flow control devices to control combustor efficiency. Sensor development for monitoring engine emissions and sound levels would be another deliverable.

State of the Art and Critical Gaps

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

- Development of laser-based diagnostics for quantitative spatially and temporally resolved measurements of fuel/air ratio in reacting flows at elevated pressure.
- Development of ultra-sensitive instruments for determining the size-dependent mass of combustion generated particle emissions.
- Low emissions combustor concepts for small high pressure engine cores.
- Development of miniature high-frequency fuel modulation valve for combustion instability control able to withstand the surrounding high-temperature air environment.

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

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

A1.04 Electrified Aircraft Propulsion

Lead Center: LaRC

Participating Center(s): AFRC, LaRC

Technology Area: TA15 Aeronautics

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 which use turbo-electric, hybrid electric or all electric power generation as part of the propulsion system. A related STTR topic (T15.03) for electric aircraft propulsion energy storage is offered in parallel. Turbo-electric, 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 and cycle life >10,000 cycles. This subtopic seeks energy solutions in the Technology Readiness Level (TRL) 3-5 range, appropriate for near-term applications. Proposers working on lower TRL energy storage technologies with a research institution partner should consider proposing to the "Electrified Aircraft Propulsion Energy Storage" subtopic in the STTR solicitation.
- Additive manufacturing solutions for the seamless integration of thermal management technology within the Electrified Aircraft Propulsion (EAP) powertrain, airframe, thermal sources and sinks to minimize system mass and thermal impedance through a tight airframe integration scheme that potentially provides a multi-functional structure solution (load bearing and thermal transport).
- High voltage lightweight fault management devices with individual device rating of 600-3000 V DC, 200-1000 A.
- 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.
- Lightweight electrical insulation materials/composites for high altitude, high voltage power transmission with dielectric breakdown strength (V/m) of the insulation minimally 2.5 times that of the operating electric field stress (V/m) at the conductor surface, high resistivity (1019 to 106 ?×cm), low dialectic dissipation factor (tan ?), Insulation Class H (180? C) to Class C (>240 ?C), moisture resistant, good mechanical properties and improved thermal conductivity, above 0.5 W/m*K.
- Additive manufacturing processes and advanced materials for future generation electric motor designs and windings which provide lower costs, compact designs (>25% volume reduction), lighter weight (>30%
reduction), advanced cooling/improved thermal conductivity, multi-materials and/or greatly improved material or component properties which 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.

References:

Electrified Aircraft Propulsion (EAP) is called out as a key part of Thrust 4 in the Aeronautics Research Mission Directorate (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]

Expected TRL or TRL range at completion of the project: 2 to 6

Desired Deliverables of Phase II

Prototype, Analysis, Hardware, Software, Research

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.

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 2-3 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 600V. 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 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:

Electrified Aircraft Propulsion (EAP) is an area of strong and growing interest in 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 sub-project to enable EAP for single aisle aircraft. Additionally, NASA is formulating a MW-level EAP flight demo this year.

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:
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 non-recurring 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 allows engineers to reach out of their existing design space and accelerate technology maturation schedules. 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]) highlighted the many shortcomings in the existing computational technologies used for conducting high-fidelity simulations and made specific recommendations for investments necessary to overcome these challenges.

One area of research is scale-resolving numerical simulations, which are playing an increasing role in CFD analysis of new and existing aerodynamic configurations at off-design conditions. It is well-known that traditional steady-state Reynolds Averaged Navier-Stokes (RANS) analysis performs poorly in separated boundary layers and shear layers. Time-accurate Wall-Modeled Large Eddy Simulation (WMLES) and hybrid RANS-LES have demonstrated increased accuracy for a subset of these flows where large scale fluctuations are computationally resolved while the near-wall small scale fluctuations are modeled. Since RANS can accurately compute attached flow regions, it is desirable from a computational cost perspective to initiate scale resolving simulations just upstream of the separated flow regions. However, unsteady disturbances must be added to kick-start scale resolving simulations but an accurate and robust approach to accomplish that is lacking. The goal of this solicitation is to overcome this deficiency. One approach is to insert synthetic turbulent eddies at the start of the scale-resolving flow domain to effectively "trip" the flow. Several methods have been reported in the literature to generate these turbulent fluctuations, but these are not general enough to apply to realistic aircraft configurations, do not evolve into resolved physical turbulent structures in a reasonable amount of time/space, or cause large acoustic fluctuations rendering them inapplicable to aero-acoustic analysis.

An ideal turbulence generator for embedded scale-resolving simulations targeting hybrid RANS-LES and wall-modeled LES would satisfy the following criteria:

- Easy to implement/apply to general aircraft/rockets configurations locally embedded within a larger CFD domain
- Use existing upstream RANS data (e.g., using the Spalart-Allmaras turbulence model), such as velocity profile and estimated Reynolds stresses, and little to nothing else in terms of user parameters
- Develop into realistic turbulence under 10-15 boundary layer thickness from the plane (or volume) where it is applied (based on first order statistics and two-point correlations)
- Require little to no change to an existing scale-resolving flow solver independent of grid paradigm
Properly handle the inner region of hybrid RANS-LES and WMLES simulations leading to fast skin friction recovery within 10-15 boundary layer thickness

Create negligible acoustic fluctuations (i.e., smaller than magnitude of attached wall-bounded turbulence)

What is being solicited is a “plug and play” software module that could be easily inserted in an independent CFD solver (e.g., a NASA code) to provide necessary input for scale resolving simulations. The awardee will demonstrate the software tool for carefully selected relevant test cases, before delivering it to NASA.

References

https://www.nasa.gov/aeroresearch/programs/aavp [1]


Expected TRL or TRL range at completion of the project: 3 to 6

Desired Deliverables of Phase II

Analysis, Software, Research

Desired Deliverables Description

The deliverable will be a software tool that could be used in conjunction with computational fluid dynamic solvers to perform scale resolving simulations that are relevant to NASA missions, particularly the Aeronautics Research Mission Directorate (ARMD) where this capability is needed for flow control applications, aircraft maximum lift prediction and certification by analysis. The awardee will demonstrate the developed computational tool on relevant aerodynamic configurations before delivering it to NASA.

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 computational fluid dynamics for advanced aircraft concepts, launch vehicle design and planetary entry vehicles. The developed technology will enable design decisions by ARMD and Human Exploration and Operations Mission Directorate (HEOMD).

A1.06 Vertical Lift Technology and Urban Air Mobility

Lead Center: LaRC

Participating Center(s): AFRC, ARC, GRC

Technology Area: TA15 Aeronautics

Scope Title

Vertical Takeoff and Landing (VTOL) Urban Air Mobility (UAM) Ride Quality

Scope Description

Urban air mobility (UAM) is a concept for air transportation around metropolitan areas consisting of passenger-carrying operations. An emerging UAM market will require a high density of vertical takeoff and landing (VTOL)
operations for on-demand, affordable, quiet and fast transportation in a scalable and conveniently-accessible “vertiport” network. UAM is envisioned to provide increased mobility within a given metropolitan area by traveling faster, and using shorter and more direct routing as compared to ground vehicles.

The expanding 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 2-6 passengers, fly more like a helicopter (vertical take-off and landing) than a fixed-wing aircraft and will fly relatively close to the ground and near buildings. There are many unknowns as to how the industry will mature but technical barriers may be secondary to the challenge of attracting passengers to fly in these new aircraft that are unconventional in appearance and operations.

A critical challenge for UAM market growth is to gain public acceptance that UAM VTOL aircraft are: 1) as safe, or safer than, commercial air travel and automotive transportation, and 2) as comfortable as conventional modes of transportation.

The solicitation will address likely obstacles to passenger acceptance of UAM vehicles. Passenger acceptance concerns include feeling safe, vehicle motion, noise and vibration, availability and access, passenger well-being, concern for the environment and others. Some of these concerns are highlighted in Ref. 1, and in a recent study funded by NASA (Ref. 2) below.

Phase I of the SBIR should review these passenger acceptance concerns and propose mitigation strategies.

Phase II of the SBIR should include development and demonstration of strategies for improving the passenger experience for VTOL UAM vehicles.

References


Expected TRL or TRL range at completion of the project: 2 to 4

Desired Deliverables of Phase II

Prototype, Analysis, Research

Desired Deliverables Description

Strategies that address the safety and comfort expectations of UAM vehicle passengers.

State of the Art and Critical Gaps

There are approximately 150 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 ground transportation (cars, trains, buses) and are calibrated to the comfort levels (motion, noise, vibration, air conditioning, heating, lighting, etc.) associated with these modes of transportation. Multirotor UAM vehicles will fly more like a helicopter and as a consequence, will likely have more or different motion, vibration and noise transmitted into the cabin. For UAM aircraft, research is needed that 1) addresses the safety and comfort expectations of the passengers and crew, and 2) provides vehicle design strategies for improving passenger comfort.

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 scope
encompasses technologies that address noise, speed, mobility, payload, efficiency, environment and safety for both conventional and non-conventional vertical lift configurations. This subtopic directly aligns with the mission, goals and scope in addressing safety of non-conventional vertical lift configurations.

A1.07 Propulsion Efficiency - Turbomachinery Technology for High Power Density Turbine-Engines

Lead Center: LaRC

Participating Center(s): AFRC

Technology Area: TA15 Aeronautics

Scope Description

NASA is looking for improvement in aeropropulsive power density and efficiency in support of its Strategic Thrust in the area of Ultra-Efficient Subsonic Transports. Focus is on small core turbofan engines for next-generation and future large commercial transport aircraft, conventional as well as electrified. The subtopic is closely aligned with NASA Aeronautics programs in the areas of Compact Gas Turbine (CGT) and Electrified Aircraft Propulsion (EAP), and will augment the corresponding Advanced Air Transport Technology (AATT) Project's Technical Challenges. Technical Challenges are targeted technology development areas. Main areas of interest include: Improved efficiency of small core engines, integrated thermal management, innovative cycles, use of artificial intelligence (AI) for turbomachinery components design and optimization, and efficient turbomachinery for EAP, including large electric power extraction in serial-hybrid electrified aircraft and efficient turbine-engines for power generation. The improvements will help airlines to reduce costs by reduced fuel burn. Future electrified airplanes that rely on turbine engines as their energy sources will also be able to maximize their advantages over conventional propulsion.

The detailed areas solicited and the corresponding specific technologies sought include:

1. Small-core engines efficiency improvements:
   1. Desensitizing performance to losses due to tip leakage, secondary flows, seals, purge flows and cooling air
   2. Compact transition ducts
   3. Active and passive flow control for improved airfoil performance and reduce tip clearance losses
   4. Innovative turbine shrouding to circumvent tip clearance loss generation

2. Turbofan thermal management:
   1. Compact thermal management systems using multi-functional structures and additive manufacturing
   2. Integrated thermal management of turbofan-electric components for more-electric and hybrid-electric aircraft
   3. Turbine high effectiveness cooling and loss reduction
   4. Innovative aviation-weight compact heat exchangers for cooling the cooling air and associated heat recovery or rejection

3. Optimized integrated combustor – turbine systems:
   1. Integration concepts of combustor and turbine for improved overall and component performance

4. Innovative methods for turbomachinery design and aero thermal analysis
   1. Automating design of turbomachinery components using AI
   2. Automated turbomachinery computational fluid dynamics (CFD) grid generation using AI
   3. CFD models for turbomachinery unsteady flows including transition and separation for accurate loss prediction
   4. Components performance maps generation using Artificial Intelligence (AI) and Machine Learning (ML)
   5. Use of additive manufacturing to enable designs and improvements not possible with conventional manufacturing processes
   6. Remote non-contact dynamic temperature mapping in the presence of significant radiative background. Surface temperature mapping tools including efficient image processing algorithms are sought that will be compatible with silicon carbide based components with or without low thermal expansion oxide environmental barrier coating
7. Capability of fast full-wheel, unsteady, multi-stage, CFD for compressor and turbine components for aerothermal analysis

5. Innovative engine cycles as improvements alternatives to conventional engines
   1. Closed cycles for thermal management and primary propulsion (e.g., supercritical CO2 Brayton cycles, organic fluid Rankine cycles, etc.)
   2. Turbofan waste heat recovery and utilization

6. Efficient and light-weight turbomachinery for EAP and More Electric Aircraft
   1. Turbomachinery for high power extraction from turbofans. The desire is to enable larger than 20% of low pressure spool power at altitude cruise to be extracted as shaft power. The power is to electric generator(s) to provide power to electric motor-driven propulsors (example: STARC-ABL concept). Design of turbomachinery components and optimization of extraction from low- and high-pressure spools is sought.
   2. Efficiency improvements of small turboshaft engines powering turbo-generators/range-extenders used in regional EAP aircraft concepts. Small turboshafts suffer from low efficiency, and design of high effectiveness aviation-weight improvements are sought. Ideas to consider include recuperation using light-weight heat exchangers and concepts employing multifunctional and additive manufacturing approaches.

References

Links:

https://www.nasa.gov/aeroresearch/strategy [16]
https://www.nasa.gov/aeroresearch/ [20]

Summary:

NASA Strategic Plan 2018:

- Strategic Goal 3: Address National Challenges and Catalyze Economic Growth
  - Strategic Objective 3.2: Transform Aviation Through Revolutionary Technology Research, Development and Transfer

Aeronautics Research Mission Directorate (ARMD) New Strategic Thrust 3: Ultra Efficient Subsonic Transports - Thrust description: Realize revolutionary improvements in economics and environmental performance for subsonic transports with opportunities to transition to alternative propulsion and energy

Expected TRL or TRL range at completion of the project: 1 to 4

Desired Deliverables of Phase II

Prototype, Analysis, Hardware, Software, Research

Desired Deliverables Description

The objective of this subtopic solicitation is to develop technologies that contribute to increasing the power density of future turbofan engines. The deliverables of Phase I will be feasibility assessment of innovative ideas in the form of results of numerical studies, software tools, results of experiments, or tests of demonstration prototypes. Projects showing successful feasibility may be selected for further development under Phase II.

The scope of turbomachinery includes the rotating machinery in the high and low pressure spools, transition ducts, purge and bleed flows, casing and hub. It also includes turbomachinery aspects of EAP concepts where a turbine engine is the power source. The latter includes hybrid-electric turbofan power extraction and efficiency improvements of small turbine engine powering turbogenerator/ range-extenders. This topic address only aerothermal aspects of turbomachinery. Materials, controls and other areas are not included in this subtopic and may be solicited under separate subtopics.
This solicitation’s desire is to focus on the turbofan engine core, but unique novel ideas relevant to the whole engine are also sought.

**State of the Art and Critical Gaps**

System and technology studies have indicated that advanced gas turbine propulsion will remain critical for next-generation and future subsonic transports.

The main interest of this solicitation is in turbofan engines. Turbofans will be relevant for next-generation and future conventionally powered aircraft. They will also be relevant as power sources of future electrified airplanes.

Impressive advancements were made in turbofan technologies that increased their efficiency and performance. Most recent upcoming near term technologies being incorporated in engines as the GE9X and Rolls Royce SuperFan intend to include overall pressure-ratio (OPR) of 60, large diameter fans with low blade count and low fan pressure-ratio, bypass ratio of order 11, advanced booster designs, highly 3D airfoil designs, high compressor pressure ratio in the range of 27, application of CMC (Carbon Matrix Composites) materials in hot sections and more. Despite these advances, there is potential for additional improvements; they are possible and needed for future aircraft architecture and concepts.

In the turbine, the very high cycle temperatures demanded by advanced engine cycles place a premium on the cooling technologies required to ensure adequate life of the turbine component. New capabilities as well as challenges are provided with expected increased use of ceramic matrix composites (CMC). Presently, engines are overcooled because of uncertainty in hot section flow uniformity caused by hot streaks. Reduced cooling flow rates and/or increased cycle temperatures enabled by these technologies have a dramatic impact on the engine performance.

In the compression system, advanced concepts and technologies are required to increase stage loading and widen operating range. Interrelated to the turbine, the cooling flow presently result in high penalty caused by the typical 20% bleed air ratio; the goal is to reduce it to 5%. OPR may be increased to the order of 100. As result the overall thermal efficiency can be increased by 10-15%. Aerothermal improvements not only will improve performance, but also will lead to reduced weight and increase the core specific power.

Engines are currently designed in a time-consuming iterative manner taking several months for a complete system. AI and ML approaches are expected to speed up the process and lead to optimized designs maximizing the efficiency and power density and take it down to a matter of hours and days.

NASA and industry are actively working on electrified aircraft concepts. Many of these concepts employ turbine-engines as power sources. The impact on the turbomachinery requirement and design needs to be addressed, which, in turn, will impact the viability of the EAP concepts.

Finally, innovative methods for engine waste heat recovery and re-utilization will increase the effective engine efficiency. And alternatives to the conventional open Brayton cycle may also lead to revolutionary propulsion system, or at least to improvements of existing systems.

**Relevance / Science Traceability**

The solicited topics are directly relevant to NASA’ Aeronautics project goals in the area of high power density cores - to lead to realizing revolutionary improvements in economics and environmental performance for subsonic transports with opportunities to transition to alternative propulsion and energy.

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

Lead Center: LaRC

Participating Center(s): ARC, GRC
Technology Area: TA15 Aeronautics

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 for application in NASA's aeroscience ground test facilities that can revolutionize testing and measurement capabilities and improve utilization and efficiency. Tools and technologies that can be applied in NASA's portfolio of large-scale ground test facilities are of primary interest. For this solicitation, NASA seeks proposals for innovative research and development in the following areas:

**Non-Intrusive Temperature Measurements of Super-Cooled Water Droplets and Ice Crystals**

Non-intrusive ice and super-cooled water particle temperature measurement techniques are sought for NASA's Icing Test Facilities, the Propulsion Systems Laboratory and the Icing Research Tunnel.

Accurate temperature measurements of individual ice particles and super-cooled water droplets within an icing cloud in NASA icing test facilities is a key capability to enable technologies for the advancement of engine and airframe icing simulation tools. For engine icing facilities, this is important for characterizing the particle cloud entering the engine being tested and understanding the temperature history of the liquid droplets when they transition to ice crystals. For airframe icing, this is important for understanding the thermodynamic state of super-cooled large water droplets at the test section location. Proper validation of experimental simulations and computational models of ice accretion processes requires that the test facility be able to continuously measure and monitor the icing cloud particle/water droplet temperature at multiple locations simultaneously and non-intrusively.

**Cryogenic Shear Measurements**

Shear stress measurements are needed to validate computational tools that ultimately will be used to support the certification of aerospace vehicles by analysis. Shear stress is an important parameter for characterizing the interaction between a fluid and a surface over which it is moving. Quantitative measurements of shear stress provide information about the surface conditions on a model and help determine the location where features such as flow separation occur. Currently, shear stress is measured at discrete locations using sensors and probes; however, global (2D) measurements are also needed to help determine measurement locations for these sensors a priori and to provide Computational Fluid Dynamics (CFD) code validation data. Robust systems are sought to enable measurements on simple and complex geometries and configurations at both room temperature and cryogenic conditions (down to 80 Kelvin).

**Wind Tunnel Characterization**

Wind tunnel tests required to enable the CFD2030 Vision and support Certification by Analysis will need to have boundary conditions in the wind tunnel properly measured and documented. NASA is seeking non-intrusive measurement systems that can be installed permanently within NASA's larger facilities to document the test section inflow and/or outflow conditions. Specific flow parameters of interest include pressure, velocity, temperature, and density. Target facilities include the 11-Foot Wind Tunnel at NASA Ames Research Center, the 9x15 Low-Speed Wind Tunnel at NASA Glenn Research Center and the 14x22 Subsonic Tunnel at NASA Langley Research Center. These facilities feature large test sections with considerable optical access and are highly utilized. Another target facility is the Langley 8-foot High Temperature Tunnel (HTT), a combustion-heated, high-enthalpy supersonic wind tunnel having water vapor and water droplets in the free-stream flow. For this facility, desired measurements include gas temperature, velocity, water vapor concentration, as well as droplet size and the concentration and distributions thereof.

**References**

https://www.nasa.gov/aeroresearch/programs/aavp/aetc/ground-facilities [21]

https://ntrs.nasa.gov/search.jsp?R=20140003093 [22]
A1.09 Inflight Icing Hazard Mitigation Technology

Lead Center: LaRC

Technology Area: TA15 Aeronautics

Scope Title
Sensing and Mitigation of Icing Conditions

Scope Description
All-weather sensing and mitigation is a future challenge for electric vehicles, both electric vertical take-off and landing (eVTOL) operating in the urban air mobility (UAM) mission and unmanned aerial systems (UAS) in current and future mission profiles. The primary focus is on icing but other weather hazards including wind, reduced visibility, lightning and degradation of Global Positioning System (GPS) may also be addressed. Characterize the conditions which create ice accretions on a UAS and/or eVTOL (either a class or a specific aircraft) across the anticipated operational envelope, and analyze the ice shapes using simulation tools and ground test methods. Map performance degradation to atmospheric conditions obtained from flight test and/or atmospheric simulations. In-situ characterization of icing conditions using existing or new instruments or techniques must address the weight and power constraints expected for a class or specific vehicle. Ground-based remote sensing of icing conditions must be suitable for various vertiport sites, based on commercial instruments and/or data services.

References


Expected TRL or TRL range at completion of the project: 3 to 5.

Desired Deliverables of Phase II

Prototype, Analysis

Desired Deliverables Description

Deliverables may include some or all of the following: design or prototype of a multi-sensor suite for weather hazard identification, characterization of expected icing conditions along with associated performance degradation, and/or novel algorithms for identification of weather hazards.

State of the Art and Critical Gaps

All-weather operations are important for vertical lift air vehicles, which have missions that require operating in weather at altitude. Formation of ice over lifting surfaces can affect aerodynamic performance.

Detection and avoidance of icing is a key technology for acceptance and certification, for both manned and unmanned vehicles. Unplanned icing incidents have already occurred involving unmanned aerial systems undertaking current missions. Icing detection requires a broad database of icing encounters for validation. This
requires a significant campaign of testing in icing wind tunnels and in flight.

Atmospheric characterization is another key part of detection and avoidance. A vehicle must not only detect that it is in icing but also quantify the severity of the icing and any decision that must be made in a timely manner. Remote sensing methods, whether from a terminal area sensor or from a forward-looking sensor on the vehicle, are not currently capable of meeting these requirements. Current aviation weather research mostly involves either ground-level or cruise altitudes, since this is where current commercial aviation operation takes place. However, Unmanned Aerial Vehicles (UAVs) and eVTOLs may operate at low altitudes (within a few hundred feet altitude), where complex meteorological events can occur that are not well represented in prior weather research.

Relevance / Science Traceability

All-weather sensing and mitigation is a particular challenge for electric vehicles, both eVTOL operating in the UAM mission and UAVs operating in current and future mission profiles. Mitigation through detection and avoidance is especially critical for systems which already have stringent power and weight requirements.

A1.10 Hypersonic/High Speed Technology - Seals and Thermal Barriers

Lead Center: LaRC

Participating Center(s): LaRC

Technology Area: TA15 Aeronautics

Scope Title
Development of High Temperature, Wear-Resistant Coatings for Seals and Thermal Barriers

Scope Description

Future high speed vehicles will require high temperature, dynamic seals and thermal barriers around movable surfaces to minimize the ingestion of hot gases through sealed interfaces and protect underlying temperature-sensitive structures. Locations include around the edges and along the hinge lines of movable control surfaces (e.g., flaps, rudders), panels, and doors. The seals must operate in high heat flux, oxidizing environments and restrict the flow of hot gases at temperatures on the order of 2000° F. They must be flexible enough to accommodate distorted sealing surfaces while remaining in contact with them to create an effective seal. In some locations, they may also have to limit applied loads against sealing surfaces that are fragile or covered with delicate protective coatings. The seals must also be sufficiently durable to meet required life goals. They must resist damage as they are rubbed over rough, distorted sealing surfaces without incurring excessive increases in leakage due to wear. In some locations the seals may have to seal against rough thermal protection system (TPS) materials without sticking to their surfaces. Previous testing has shown that coatings on flexible fabrics can potentially improve seal durability. The objective of this opportunity is to identify and/or develop high temperature, wear-resistant coatings for seals and thermal barriers and evaluate their durability under representative operating conditions.

References

https://www.nasa.gov/aeroresearch/programs/aavp/ht [23]

Expected TRL or TRL range at completion of the project: 1 to 5

Desired Deliverables of Phase II

Prototype, Analysis, Hardware, Research

Desired Deliverables Description

Deliverables include development, production, demonstration and evaluation of high temperature, wear-resistant
coatings for seals and thermal barriers with key demonstrations/evaluations of their durability under representative operating conditions.

**State of the Art and Critical Gaps**

State-of-the-art seals and thermal barriers are often fabricated out of flexible, high-temperature ceramic fibers and fabrics to help minimize seal compression loads and to allow them to accommodate variable gap geometries and distorted sealing surfaces. However, these materials can become damaged when they are rubbed against adjacent sealing surfaces, especially in dynamic applications. This can lead to higher leak rates and increases in temperature near critical components thereby requiring the seals to be replaced, often after a limited number of missions.

**Relevance / Science Traceability**

This subtopic relates to the Hypersonics project within Aeronautics Research Mission Directorate (ARMD). Materials development is a long lead-time research area, and engaging innovation across a wider community through SBIR provides time to develop technologies that can be enabling for future hypersonic vehicles.

**Scope Title**

Development of High Temperature Elastomer for Use in Seal Applications at 700°F or greater

**Scope Description**

Future high-speed vehicles will require high temperature, low leakage seals to minimize the ingestion of hot gases through sealed interfaces and protect underlying temperature-sensitive structures (mostly static interfaces). The objective of this opportunity is to identify and/or develop a high temperature elastomer that can be formed (e.g., molded, extruded) into various seal geometries for use at temperatures of 700°F or greater. Upon successful identification/development of the elastomer, test specimens will be fabricated and evaluated under representative operating conditions.

**References**

https://www.nasa.gov/aeroresearch/programs/aavp/ht [23]

**Expected TRL or TRL range at completion of the project:** 1 to 5

**Desired Deliverables of Phase II**

Prototype, Analysis, Hardware, Research

**Desired Deliverables Description**

Deliverables include development, production, demonstration and evaluation of a high temperature elastomer that can be formed (e.g., molded, extruded) into various seal geometries for use at temperatures of 700°F or greater with key demonstrations/evaluations of sealing capability under representative operating conditions.

**State of the Art and Critical Gaps**

Low leakage seals such as O-rings are often made of elastomers because these materials exhibit little plastic flow and rapid, nearly complete recovery from an extending or compressing force. However, even the most heat-resistant elastomers have maximum continuous use temperature limits of about 600°F. Current heat-resistant elastomers have maximum continuous use temperature limits of about 600°F at which point they begin to break down and cease to function as an effective seal.

**Relevance / Science Traceability**
This subtopic relates to the Hypersonics project within ARMD. Materials development is a long lead-time research area, and engaging innovation across a wider community through SBIR provides time to develop technologies that can be enabling for future hypersonic vehicles.

**Note:** This subtopic solicits proposals in high temperature sealing needs which require, dynamic, static and/or barrier needs. Proposers working on hot structures should consider proposing to the H5.02 - Hot Structure Technology for Aerospace Vehicles subtopic in the Human Exploration and Operations Mission Directorate.

### A2.01 Flight Test and Measurement Technologies

**Lead Center:** AFRC

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

**Technology Area:** TA15 Aeronautics

**Scope Description**

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

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 on-board, 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.
- Methods for accurately estimating and significantly extending the life of electric aircraft propulsion energy source (e.g., batteries, fuel cells, etc.).
- 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 (non-intrusion) 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, airframes and the associated subsystems development for use in all areas of flight tests and missions, e.g., X-planes testing, hypersonic testing, science missions, etc.

The emphasis of this subtopic is on 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), the Electrified Powertrain Flight Demonstration (EPFD) and Flight Demonstrations and Capabilities (FDC) projects. The FDC 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 AAVP - Aeronautic Evaluation & Test.

References

https://sbir.nasa.gov/ [24]
https://www.nasa.gov/centers/armstrong/news/FactSheets/FS-108-AFRC.html [27]
https://www.nasa.gov/centers/armstrong/features/shock_and_awesome.html [28]
https://technology-afrc.ndc.nasa.gov/featurestory/fiber-optic-sensing [29]

Expected TRL or TRL range at completion of the project: 1 to 6

Desired Deliverables of Phase II

Prototype, Analysis, Hardware, Software, Research

Desired Deliverables Description

For a Phase I effort, at least 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 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 Electrified Powertrain Flight Demonstration Project, Advanced Air Vehicle Projects (AAVP) - Commercial Supersonic Technology (CST), and AAVP - Aeronautic Evaluation & Test.

**A2.02 Unmanned Aircraft Systems (UAS) Technologies**

Lead Center: AFRC

Participating Center(s): ARC, GRC, LaRC

Technology Area: TA15 Aeronautics

**Scope Title**

Enabling Autonomy

**Scope Description**

Unmanned Aircraft Systems (UAS) offer significant advantages over manned aircraft for applications which are dangerous to humans, long in duration, requiring fast response and high degree of precision. Some examples include remote sensing, disaster response, delivery of goods, industrial inspection and agricultural support. Additionally, UAS may eventually be capable of safely transporting passengers, which can increase operational flexibility. The addition of autonomy to UAS enables 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 UAS. These barriers include, but are not limited to, the lack of methods, architectures and tools that enable:

- The verification, validation and certification of complex and/or nondeterministic systems
- Sensing, perception, cognition and decision-making
- Cost-effective, resilient and self-organizing communications
- Improved survivability in degraded or off-nominal conditions

NASA and the aviation industry are involved in research that would greatly benefit from breakthroughs in UAS capabilities that could eventually enable the new Urban Air Mobility market. A few of the areas of research and missions are listed below.
Remote sensing missions utilizing one or more 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 Urban Air Mobility (UAM) and higher levels of UAS integration into the national airspace.

This solicitation is intended to break through these and other barriers with innovative and high-risk research.

The Integrated Aviation Systems Program's work on UAS technology for the FY 2020 NASA SBIR solicitation is focused on tackling these barriers to enable greater use of UAS in NASA research, in civil aviation use and ultimately in the emerging UAM market. The following four research areas are the primary focus of this solicitation, but other closely related areas will also be considered for award. The primary research areas are:

- Verification, Validation and Certification - 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.
- Sensing, Perception, Cognition and Decision Making - Technologies need to be developed that provide the ability of UAS to detect and extract internal and external information of the vehicle, transform the raw data into information that can be understood by machines or humans, and recognize patterns and make decisions based on the data and patterns.
- 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 cyber-physical attacks. Several key areas of interest are Resilient Position Navigation and Timing (RPNT) for GPS denied/degraded environments, mesh/self-organizing networks, and quantum communication technologies, in particular, quantum repeaters and quantum key distribution methods.
- Improved survivability in degraded or off-nominal conditions - Vehicle health monitoring techniques and contingency management algorithms that will mitigate risk to people and assets on the ground or in the air.

It is important to note that some technologies such as quantum communications can be utilized in many areas and it is recommended that the scope of such proposals be tailored to unmanned aircraft.

References

1) [https://www.hq.nasa.gov/office/aero/pdf/armd-strategic-implementation-plan.pdf][30]
2) [https://www.nasa.gov/sites/default/files/atoms/files/nac_tie_aug2018_tfong_tagged.pdf][31]

Expected TRL or TRL range at completion of the project: 3 to 6

Desired Deliverables of Phase II

Prototype, Analysis, Hardware, Software, Research

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 UAS application.
- A technology demonstration in a simulation environment which clearly shows the benefits of the technology.
developed.

- A written plan to continue the technology development and/or to infuse the technology into the UAS market. 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 into UAS application.
- A technology demonstration in a relevant flight environment which clearly shows the benefits of the technology developed.
- There should be evidence of infusing the technology into the UAS market or a clear written plan for near term infusion of the technology into the UAS market. 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/UAM 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 non-deterministic algorithms
2. Sensors (LIDAR, GPS, etc.) 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) [2]
- [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]

A3.01 Advanced Air Traffic Management System Concepts

Lead Center: ARC

Participating Center(s): LaRC

Technology Area: TA15 Aeronautics

Scope Description

This subtopic addresses contributions towards Air Traffic Management (ATM) systems and concepts with potential application in the near-future National Airspace System (2025-2030). 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, and maintaining or improving safety and/or which can accelerate the implementation of NASA technologies in the current and future National
Airspace System (NAS).

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, subsonic and supersonic vehicles)
- Applying elements of the service-based architecture concept being pioneered in the UTM domain

References

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

Expected TRL or TRL range at completion of the project: 1 to 4

Desired Deliverables of Phase II

Prototype, Analysis, Software, Research

Desired Deliverables Description

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

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 National Airspace System.

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.

Relevance / Science Traceability

Airspace Operations and Safety Program (AOSP) within Aeronautics Research Mission Directorate (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).

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

Lead Center: ARC
Participating Center(s): LaRC

Technology Area: TA15 Aeronautics

Scope Description

NASA’s future concepts for air transportation will significantly expand the capabilities of airspace and vehicle management and are anticipated to increasingly rely on autonomy and/or artificial intelligence to ensure safe 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 novel vehicle types: Unmanned Aircraft Systems (UAS), Urban Air Mobility (UAM), supersonic vehicles and space transportation vehicles
- All airspace domains and operations: airport, metroplex, en route, regional/national traffic flow management, integration of multiple domains, on-demand aircraft and operations, and non-towered airports, vertiports, spaceports, ramps and airline operations centers
- All mission types: commercial passenger, cargo transport, emergency response, surveillance, security, etc.

Further, the future concepts accommodate changes to a diverse range of environmental and operational conditions while maintaining expected safety levels.

This subtopic focuses on the future air transportation system (beyond 2025) including a widespread service-based architecture, as demonstrated within the NASA Unmanned Aircraft Systems Traffic Management (UTM) model, as appropriate.

This subtopic seeks proposals that will apply novel and innovative techniques, methods and approaches, to developing tools and/or technologies that will enable the successful transition to, or be an integral component of, the eventual realization of an autonomously operating airspace system in all airspace domains, from one in which human operators and decision-makers play a significant role.

Research and Development (R&D) challenges related to either transition or end-state autonomous airspace include:

- Transition of largely human-centric systems to human-autonomy teaming systems
- Autonomy/autonomous technologies and concepts for trajectory management and efficient/safe traffic flows
- Weather and environment-integrated flight planning, rerouting, and execution
- Fleet, crew and operator management to reduce the total cost of operations
- Graceful, manageable degradation in off-nominal conditions

This subtopic is also particularly interested in proposals focused on the application of advanced data science, and non-traditional data or information sources, towards Air Traffic Management (ATM) problems while incorporating meaningful ATM domain knowledge for more sophisticated results.

References

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

Expected TRL or TRL range at completion of the project: 1 to 4

Desired Deliverables of Phase II

Prototype, Analysis, Software, Research

Desired Deliverables Description

Technologies that can advance safe and efficient growth in global operations (ARMD Thrust 1 Goal) as well as developing autonomy applications for aviation (as under ARMD Thrust 6).
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 National Airspace System. 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 autonomy technologies and capabilities towards air transportation challenges. These may be more limited solutions to targeted problems.

Critical Gaps: Data sciences and autonomy/artificial intelligence technologies continue to be growing areas that have great potential to benefit the development of a more autonomous air transportation system, which is expected to be needed to accommodate the increasing demand and diversity of air transportation missions and operations.

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.

A3.03 Future Aviation Systems Safety

Lead Center: ARC

Participating Center(s): LaRC

Technology Area: TA15 Aeronautics

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 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). 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). 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.

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. Such systems would include the emergent effects of increased use of automation and autonomy to enhance system capabilities, efficiency and performance beyond current, human-based systems, through health monitoring of system-wide functions that are integrated across distributed ground, air, and space systems. Emerging highly automated and even autonomous operations, such as those envisioned for unmanned aircraft systems (UAS) and urban air mobility (UAM) will play a major role in future airspace systems. In particular, operating beyond the operator’s visual line-of-sight (BVLOS) and near or over populated areas are topics of concern. Safety-critical risks include (1) flight outside of approved airspace, (2) unsafe proximity to people/property, (3) critical system failure (including loss of command and control (C2) link, loss or degraded GPS, loss of power, and engine failure); (4) loss-of-control (i.e., outside the envelope or flight control system failure).

Tools are being sought for use in creating prototypes of ISSA capabilities. The ultimate vision for ISSA is the
delivery of a progression of capabilities that accelerate the detection, prognosis and resolution of system-wide threats.

Proposals under this subtopic are sought, but are not limited to, development and/or demonstration in the following areas (with an emphasis on safety applications):

- Data collection architecture, data exchange model and data collection mechanism (for example via UTM TCL-4).
- Data mining tools and techniques to detect and identify anomalies and precursors to safety threats system-wide.
- Tools and techniques to assess and predict safety margins system-wide to assure airspace safety.
- Prognostic decision support tools and techniques capable of supporting real-time safety assurance.
- Verification and validation (V&V) tools and techniques for assuring the safety of air traffic applications during certification and throughout their lifecycles, and techniques for supporting the in-time monitoring of safety requirements during operation.
- Products to address technologies, simulation capabilities and procedures for reducing flight risk in areas of attitude and energy aircraft state awareness.
- Decision support tools and automation that will reduce safety risks on the airport surface for normal operations and during severe weather events.
- Alerting strategies/protocols/techniques that consider operational context, as well as operator state, traits and intent.
- Methodologies and tools for integrated prevention, mitigation and recovery plans with information uncertainty and system dynamics in a UAS and in a trajectory-based operations (TBO) environment.
- Strategies for optimal human-machine coordination for real-time hazard mitigation.
- Methods and technologies enabling transition from a dedicated pilot-in-command or operator for each aircraft (as required per current regulations) to single operators safely and efficiently managing multiple unmanned and UAM aircraft in civil operations.
- Measurement methods and metrics for human-machine team performance and mitigation resolution.
- System-level performance models and metrics that include interdependencies and relationships among human and machine system elements.

References

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

https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/aero-rdplan-2010.pdf [34]

Expected TRL or TRL range at completion of the project: 1 to 3

Desired Deliverables of Phase II

Prototype, Analysis, Software, Research

Desired Deliverables Description

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

State of the Art and Critical Gaps

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

Critical Gaps: A proactive approach to managing system safety requires (1) the ability to monitor the system continuously and to extract and fuse information from diverse data sources to identify emergent anomalous...
behaviors after new technologies, procedures, and training are introduced; and (2) the ability to reliably predict probabilities of the occurrence of hazardous events and of their safety risks. Also, with the addition of UAM concepts, and increasing development of 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 pro-actively 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.

A3.04 Non-Traditional Airspace Operations

Lead Center: ARC

Participating Center(s): LaRC

Technology Area: TA15 Aeronautics

Scope Description

In addition to pioneering air traffic management research and development in conventional, commercial and traditional airspace environments, 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, equitable execution of diverse unmanned missions.

This subtopic welcomes proposals continuing to support and develop the UTM concept which seeks technologies to enable safe, heterogeneous (manned/unmanned) operations including, but not limited to, the following:

- To demonstrate the scalability of the UTM concept to potentially 10M+ users/operators
- To enable low size, weight, and power sense-and-avoid technologies
- The development of UTM-focused track and locate functions
- Autonomous and safe Unmanned Aircraft Systems (UAS) operations for the last and first 50 feet under diverse weather conditions

This subtopic also welcomes proposals supporting the Urban Air Mobility (UAM) concept, which seeks technologies including, but not limited to, the following:

- Service-based architecture designs that enable dense urban mobility operations and/or increasingly complex operations at ultra-high altitudes
- Dynamic route planning that considers changing environmental conditions, vehicle performance and endurance, 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 ultra-high altitudes and interactions around major airports
- Operational concepts for future vehicle and missions, including vehicle performance, vehicle 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 take-
off-and landing)

References

https://www.nasa.gov/aeroresearch/programs/aosp [32]
https://www.aviationsystemsdivision.arc.nasa.gov/publications/index.shtml [35]
https://www.aviationsystemsdivision.arc.nasa.gov/index.shtml [36]
https://www.nasa.gov/aeroresearch/strategy [16]

Expected TRL or TRL range at completion of the project: 1 to 4

Desired Deliverables of Phase II

Prototype, Analysis, Software, Research

Desired Deliverables Description

Technologies that can advance safe and efficient growth in global operations (ARMD Thrust 1 Goal) as well as developing autonomy applications for aviation (as under ARMD Thrust 6), that are specifically applicable to UTM and/or UAM operations.

State of the Art and Critical Gaps

Current state of the art: The proposed research and development area previously resided as a subset of existing subtopic (A3.02) Autonomy of the National Airspace System (NAS). This has made this subtopic too unwieldy in trying to capture both fundamental research supporting increasing autonomy in the NAS as well as technologies that can support or expand existing efforts in unmanned vehicles research, in particular UAS Traffic Management (UTM) and Urban Air Mobility (UAM) areas.

The state-of-the-art also covers the initial stages of UTM and UAM technology development.

Critical gaps: As identified in the Scope description, technologies are needed to expand from NASA-developed prototype testing conditions to technologies that would enable broader system capabilities, and achieve increased system robustness, scalability and agility to meet various mission needs.

Relevance / Science Traceability

Airspace Operations and Safety Program (AOSP)

Air Traffic Management eXploration (ATM-X) Project

Unmanned Aircraft Systems Traffic Management (UTM) Project

Successful technologies in this subtopic will help NASA pioneer UTM and 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.