



NASA SBIR 2018 Phase I Solicitation

Aeronautics Research

A1.01 Structural Efficiency - Aeroelasticity and Aeroservoelastic Control

Lead Center: GRC

Participating Center(s): AFRC

Technology Area: TA15 Aeronautics

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. This fundamental aeronautics work is focused on active/adaptive aerostructural control for lightweight flexible structures, specifically related to load distribution, flutter prediction and suppression, gust load prediction and alleviation, and aeroservoelasticity for Ultra-Efficient and Supersonic Commercial Vehicles.

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

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

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

Specific subjects to be considered include:

- Development of aerostructural control design methodologies that include CFD steady and unsteady aerodynamics, flexible structures, and active control systems.
 - Development of efficient methods to generate mathematical models of wind-tunnel models and flight vehicles for performing aeroservoelastic studies.
 - Development of CFD-based methods (reduced-order models) for aeroservoelasticity models and simulation that can be used to predict gust loads, ride quality issues, flight dynamics stability, and aerostructural control issues.
 - Development of novel aeroservoelasticity 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.
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- Development of techniques that support simulations, ground testing, wind-tunnel tests, and flight experiments for aerostructural control of aeroservoelastic phenomena.

Links to program/project websites:

- ARMD's Advanced Air Vehicles Program (AAVP) - <https://www.nasa.gov/aeroresearch/programs/aavp> [1].
- ARMD's Flight Demonstrations and Capabilities (FDC) project under the Integrated Aviation Systems Program (IASP) - <https://www.nasa.gov/aeroresearch/programs/iasp/fdc> [2].
- X-56 Flight Project - <https://www.nasa.gov/centers/armstrong/research/X-56/index.html> [3].

A1.02 Quiet Performance - Propulsion Noise Reduction Technology

Lead Center: GRC

Participating Center(s): LaRC

Technology Area: TA15 Aeronautics

Aircraft noise reduction in general, and propulsion noise in particular, are areas of active research under the Advanced Air Transport Technology (AATT) Project and Commercial Supersonic Technology (CST) Project. In support of these projects environmental goals, innovations are sought in the following areas:

Noise Reduction:

- Advanced liners including broadband liners (i.e., liners capable of appreciable sound absorption over at least two octaves), low-frequency liners (i.e., liners with optimum absorption frequencies half of the current ones but without increasing liner depth), low-drag liner concepts that provide the same or better acoustic performance compared to those in use today, and high-temperature liners for reducing engine core noise.
- Low-noise propulsor concepts that are significantly quieter than the current generation turbofans and open rotors.
- Concepts for active control of broadband noise sources including fan, open rotor, jet, compressor, combustor, and turbine.
- Adaptive flow and noise control technologies for reducing propulsion noise including smart structures for inlets and nozzles.
- Concepts to mitigate the effects of distorted inflow on propulsor noise.

Noise Prediction:

- High-fidelity fan, compressor and turbine broadband noise prediction models, 3D fan and turbine acoustic transmission models for tone and broadband noise.
- Low-order, efficient and robust 3D noise models for engine noise sources (i.e., fan, jet, and core).
- 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.
- Techniques for measuring 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.

A1.03 Low Emissions/Clean Power - Combustion Technology/Emissions Measurement Techniques

Lead Center: GRC

Participating Center(s): LaRC

Technology Area: TA15 Aeronautics

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.

Combustion involves multi-phase, multi-component fuel, turbulent, unsteady, 3D, reacting flows where much of the physics of the processes are not completely understood. 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.

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 Supersonic Technology - Reduce Take-off and Landing Noise

Lead Center: GRC

Technology Area: TA15 Aeronautics

This solicitation is aimed at further exploring technologies that reduce landing and take-off noise while maintaining range and sonic boom within acceptable levels. This may include innovations in propulsion design, propulsion-airframe integration, vehicle operations, and high-lift airframe elements. A concept vehicle with low-boom configurations such as those identified in the above references is desired; however, other operational concepts, for example those not involving overland supersonic flight may be considered if there is an overlap in technology benefits.

The following list summarizes the topics for which proposals are sought in this solicitation. Details for each topic area are provided in the following section:

- Topic 2.1 - Innovative High Lift Concepts for Highly Swept Supersonic Wings.
- Topic 2.2 - Alternative Variable Propulsion Architectures.

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- Topic 2.3 - Efficient Optimization of Supersonic Nozzles to Minimize Jet Noise.

Topic 2.1 - Innovative High Lift Concepts for Highly Swept Supersonic Wings.

Objective

This topic seeks innovative high lift concept proposals that would enable takeoff and landing noise levels that meet certification requirements (consistent with those of the subsonic fleet), have minimal to no impact on supersonic performance, and are compatible with low-boom vehicle designs. Each concept should include a preliminary assessment of its performance at takeoff/landing speeds, its component noise, and an assessment of its impact on likely laminar flow requirements.

Approach

The high-lift system is an integral part of the take-off, landing, stall recovery, and low-altitude maneuvering segments of a supersonic aircraft's mission. Low-aspect ratio, thin, highly swept wings typical of supersonic aircraft generally do not perform well at low speed and present challenges to designing a high lift system. For modern supersonic aircraft, high lift systems not only need to enable good takeoff and landing performance, but also need to be quiet and stow so as to not interfere with natural laminar flow leading-edge design approaches that may be under consideration. Any high-lift system should also delay or reduce undesirable pitch characteristics.

Modern supersonic aircraft may have to meet the same low-noise requirements near an airport that subsonic aircraft do. Therefore, high-lift systems must have good performance to get the aircraft as high as possible over the "cutback" measurement point, and be low-noise for the approach-to-landing measurement point. An estimate of component noise will be required for all proposed high lift concepts and the basis of that estimate provided. As an example, continuous mold-line flaps have been investigated for subsonic aircraft and may be also be applicable on supersonic aircraft. Therefore, the subsonic studies would serve as a basis for the estimate of the component noise in a supersonic application. If there are no relevant studies for a particular concept, a proposal for such a study should be included.

Wing leading-edge laminar flow design technology may include a sufficiently small wing leading-edge radius (to manage supersonic attachment-line flow transition associated with leading-edge boundary-layer contamination/stability) as well as certain leading-edge treatments (to manage insect/debris contamination and cross-flow transition). Technology enabling wing leading-edge radius variations ranging from a large radius for use at low-speed conditions to a small radius for use at supersonic conditions may be considered. The leading-edge high-lift system shall minimize any steps/gaps/sealing issues when stowed for the supersonic cruise configuration. The trailing-edge high-lift system is not a concern for the laminar flow wing design, but still needs to address steps/gaps/sealing issues to minimize drag for supersonic cruise efficiency requirements. Although a subtle distinction, the laminar-flow requirement only applies to the supersonic cruise conditions; for low-speed conditions, a turbulent high-lift wing configuration may be more robust and preferable to meet these challenging high-lift requirements.

Ideas considered in previous supersonic research efforts (which had L/D requirements, but not low-noise or laminar-friendly requirements) included simply-hinged leading- and trailing-edge flaps. Questions remain regarding the adequacy of the performance of these concepts, given the more stringent criteria stated above.

Under a prior NRA contract, a baseline commercial passenger concept was developed for the Commercial Supersonic Technology Project. This representative mid-term configuration can be used to evaluate the proposed high lift concepts.

The proposed approach should involve multiple stages of activity if more than one concept is being investigated. During initial studies open trade spaces are encouraged. Through quarterly technical interchanges with the NASA team, it is anticipated that a down-select or prioritization of the most viable concepts will occur and will be more fully developed through CFD or experimental studies.

Outcome:

This effort will result in:

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- A suite of high-lift concepts, evaluated for low-speed performance (L/D), component noise, and “laminar-friendliness.” The most promising of these concepts will subsequently be used for experimental or high-fidelity computational proof-of-concept investigations on a relevant supersonic transport wing geometry.
 - Complete documentation of findings and relevant comparisons.
 - Recommendations for follow-on studies.

References:

1. H. R. Welge, J. Bonet, T. Magee, D. Chen, S. Hollowell, A. Kutzman, A. Mortlock, J. Stengle, C. Nelson, E. Adamson, S. Baughcum, R. Britt, G. Miller, and J. Tai, “N+2 supersonic concept development and systems integration”, CR-2010-216842, NASA, 2010.

<https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20100030607.pdf> [4]

Topic 2.2: Alternative Variable Propulsion Architectures

Objective

The objective of this subtopic is to explore one or more alternative variable propulsion concepts capable of a two-fold variability in effective bypass ratio with minimal compromise of supersonic cruise performance. The work will consider three-dimensional inlet and nozzle geometries and perform analysis of key propulsion efficiency trades, flight envelope operability, and propulsion noise at the Landing Take-Off phases of flight.

Background

To satisfy the increasing stringency of commercial Landing/Take-Off (LTO) noise, efficient supersonic cruise propulsion systems would ideally operate at high mass flow for take-off (low jet velocity) and safely transition to high specific thrust (high jet velocity) for supersonic operation. In recent decades, variable cycle technologies have afforded a measure of success in this pursuit, with some compromise in propulsion system weight and complexity [1]. Most recently, tip-fan versions of a variable cycle engine have been explored as a way to invoke higher fan mass flows at take-off with higher installed specific thrust for cruise³. Additional alternative concepts have also been expressed (e.g., mixer-ejector nozzles, supplemental mechanical/electric fans, or other concepts) to reconcile the dichotomy of high flow acoustic take-off with efficient supersonic cruise. Historically, however, all such variable propulsion systems have suffered size, weight, and realizability issues adversely affecting vehicle integration and cruise range performance. Furthermore, development of a propulsion system with such unique operating characteristics has challenged the economics of limited production supersonic vehicles.

While a number of such variable propulsion concepts have been contemplated for commercial supersonics to date, many have yet to be explored with modern analysis tools/methods or at a sufficiently credible level of detail or with an eye toward reducing uncertainty. Lack of realistic geometry including inlet, nozzle, and vehicle integration have oversimplified or obviated issues with such concepts as flow valves and moving surfaces that transition throughout the flight envelope. In addition to new concepts, use of modern design methods may allow reconsideration of some alternative propulsion architectures but with greater design realism in overcoming prior associated technical roadblocks. Vehicle integration for low sonic boom and supersonic drag has also been a major issue impacting the utility of high flow propulsion concepts as these considerations value minimizing nacelle cross-sectional area or fineness ratio. Correspondingly, engine/accessories packaging, inlet and nozzle interfaces, and integration with endemic features of supersonic vehicles must be considered (e.g., highly swept thin wings, propulsion in-board or aft-fuselage mounting and boundary-layer diversion).

Approaches

A set of metrics, including mass flow variability, cruise efficiency, range, and airport noise should be developed to evaluate alternative variable propulsion architectures. Promising alternative variable propulsion architectures should be evaluated using low-fidelity system analysis on a representative supersonic aircraft mission. Low-boom aircraft concepts, such as those referenced in published system studies⁴⁻¹⁰ may be used as a point of departure. Furthermore, propulsion approaches that modify existing or more “conventional” propulsion architectures are of key interest for achieving large changes in effective bypass ratio or specific thrust in an economical approach.

In their search for innovative concepts, proposers are encouraged to seek partnerships with non-traditional industries, large and small engine manufacturers, and universities with capabilities to explore credible levels of

detail and reduced uncertainty.

Outcome

A final report (non-proprietary and proprietary (if required) versions) is expected at the conclusion of this effort showing at least one conceptual propulsion configuration with a two-fold variability in effective bypass ratio, capable of powering a representative Mach 1.4-1.8 commercial supersonic transport sized for range of at least 4000 nautical miles and 8 - 90 passengers. The following items should be included in the final report:

- One to a few alternative variable propulsion concepts, investigated to a credible design level and accompanied by supporting trade studies of key design parameters.
- Engine cross-section(s) including outer dimensions and component weights (at a minimum).
- Three-dimensional geometry representations of inlet, nozzle and key components, with appropriate characterization for use in propulsion system model(s).
- Propulsion system model(s) (preferably in NPSS) and assumptions, with recommendations for further development of key technologies or components.
- Installed propulsion performance throughout a representative flight operating envelope.
- Low-fidelity acoustic analysis of the selected concept(s), reflective of the LTO trajectory for the representative vehicle.

References:

1. Berton, Jeffery J, et al "A Comparative Propulsion System Analysis for the High-Speed Civil Transport". NASA/TM—2005-213414. Glenn Research Center, Cleveland, Ohio. <https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20050123580.pdf> [5].
2. Pratt & Whitney West Palm Beach, Florida & General Electric Aircraft Engines Cincinnati, Ohio. "Critical Propulsion Components Volume 1: Summary, Introduction, and Propulsion Systems Studies". NASA/CR—2005-213584/VOL1. <https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20050185247.pdf> [6].
3. Dennis L. Huff, Brenda S. Henderson, Jeff J. Berton, and Jonathan A. Seidel. "Perceived Noise Analysis for Offset Jets Applied to Commercial Supersonic Aircraft", 54th AIAA Aerospace Sciences Meeting, AIAA SciTech Forum, (AIAA 2016-1635).
4. John Morgenstern, et al, "Final Report for the Advanced Concept Studies for Supersonic Commercial Transports Entering Service in the 2030 to 2035 Period, N+3 Supersonic Program", NASA/CR—2010-216796, NASA, 2010. <https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20100036507.pdf> [7].
5. H. R. Welge, et.al., "N+2 Supersonic Concept Development and Systems Integration", CR-2010-216842, NASA, 2010. <https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20100030607.pdf> [4].
6. H. Robert Welge, et al, "N+3 Advanced Concept Studies for Supersonic Commercial Transport Aircraft Entering Service in the 2030-2035 Period", NASA/CR—2011-217084, NASA, 2011. <https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20110010973.pdf> [8].
7. Todd E. Magee, et al, "System-Level Experimental Validations for Supersonic Commercial Transport Aircraft Entering Service in the 2018-2020 Time Period Phase I Final Report", NASA/CR—2013-217797, NASA, 2013. <https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20130011026.pdf> [9].
8. John Morgenstern, et al, "Advanced Concept Studies for Supersonic Commercial Transports Entering Service in the 2018 to 2020 Period Phase I Final Report", NASA/CR—2013-217820, NASA, 2013. <https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20130010174.pdf> [10].
9. John Morgenstern, et al, "Advanced Concept Studies for Supersonic Commercial Transports Entering Service in the 2018-2020 Period Phase II", NASA/CR—2015-218719, NASA, 2015. <https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20150015837.pdf> [11].
10. Todd E. Magee, et al, "System-Level Experimental Validations for Supersonic Commercial Transport Aircraft Entering Service in the 2018-2020 Time Period", NASA/CR—2015-218983, NASA, 2015. <https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20160000771.pdf> [12].

Topic 2.3: Efficient Optimization of Supersonic Nozzles to Minimize Jet Noise

Objective

The objective of this subtopic is to apply optimization methodology to problems in aeroacoustics, specifically to minimize jet noise of future commercial supersonic nozzle designs and installations.

Background

Currently, predicting the noise of a non-axisymmetric jet requires either time-accurate computation using Large Eddy Simulation, which is very expensive but potentially very accurate, or Reynolds-Averaged Navier-Stokes (RANS) CFD and acoustic source modeling, which is cheaper but has failed to provide absolute accuracies needed for design. The latter methods have demonstrated the capability to predict trends in noise from variations in nozzle geometry, however, and this capability may be harnessed to do optimization of nozzle geometries to minimize the jet noise. In the time-average methods, the flow solution can be obtained from a RANS-based CFD code, the noise produced from the flow can be computed using an established NASA code, and the transformation of the sound spectra to that of an overhead flight and its EPNL metric is given in FAA documentation.

Approach

The vision is that RANS-based methods which predict the noise of an engine nozzle for a given flow condition can be applied in optimization to reduce noise by varying the nozzle shape and/or installation. A successful effort would utilize NASA jet noise prediction knowledge and tools, determine viable optimization strategies and methods that are appropriate for these tools, and demonstrate the system by applying it to a nozzle design problem of interest to NASA.

Using a suitable optimization methodology, the proposer would develop a coupled Computational Fluid Dynamics-Computational Aero-acoustics (CFD-CAA) optimization system to find the minimum EPNL metric for a given set of geometric design parameters that describe the nozzle shape. It is expected the process would be suitable for designing three-dimensional, multi-stream, and unconventional nozzle concepts. Given the dependence on high-fidelity RANS computations for jet noise prediction, an efficient optimization process that utilizes gradient information (e.g. a continuous or discrete adjoint approach) is desired. Ideally, the CFD-CAA system will be developed to leverage and/or easily interface with adjoint-capable CFD codes like NASA's Fully Unstructured Navier-Stokes 3D (FUN3D)3 framework, or similar. Analytical derivatives for the calculations transforming the predicted noise spectra to the EPNL metric have been described in Reference 5.

Ultimately, the optimization strategy developed in this task will need to be implemented in an existing design and optimization framework. This framework is not the objective of the task. The success of the method chosen will depend upon ability to manipulate the given prediction codes with an emphasis on computational time, preferably being done on an engineering workstation-class computer, but could include the use of NASA supercomputer resources. The development effort is envisioned to consist of three phases. Phase I would include a survey of optimization methods that might be applied to the current prediction methods and a down-select of approaches to be pursued. Phase II would include development of the optimization method chosen and a simple demonstration of feasibility. Phase III would include demonstration of the system applied to a nozzle relevant to NASA.

Outcome

This effort will result in:

- A documented exploration of the application of optimization methods to future commercial supersonic nozzles and installations.
- At least one method being demonstrated with enough documentation to be implemented within a NASA design framework.
- An optimized design based on a NASA-originated nozzle suitable for validation in scale-model testing.
- Any codes derived from or integrated with government-furnished codes would be included as deliverables.

References:

1. Khavaran, Abbas; Bridges, James E, and Georgiadis, Nicholas, "Prediction of Turbulence-Generated Noise in Unheated Jets (Part 1: JeNo Technical Manual (Version 1))", NASA/TM 2005-213827, NASA 2005. <https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20050207369.pdf> [13].
2. Khavaran, Abbas; Wolter, John D, and Koch Danielle, "Prediction of Turbulence-Generated Noise in Unheated Jets (Part 2: JeNo Technical Manual (Version 1))", NASA/TM 2009-231827, NASA 2009. <https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20090020362.pdf> [14].

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3. Biedron, R., Derlaga, J., Gnoffo, P., Hammond, D., Jones, W., Kleb, B., Lee-Rausch, E., Nielsen, E., Park, M., Rumsey, C., Thomas, J., and Wood, W., "FUN3D Manual: 13.0," NASA TM-2016-219330, 2016. <https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20160010563.pdf> [15].
 4. Leib, Stewart, J. and Goldstein, Marvin E., "Hybrid Source Modeling for Predicting High-Speed Jet Noise," AIAA Journal, Vol. 49, No. 7, pp. 1324-1335, 2011.
 5. Lopes, L. V., "Robust Acoustic Objective Functions and Sensitivities in Adjoint-Based Design Optimizations and the Propagation of Uncertainty in Noise Computations," AIAA Paper 2017-1673, Jan. 2017.

A1.05 Computational Tools and Methods

Lead Center: GRC

Participating Center(s): ARC, GRC

Technology Area: TA15 Aeronautics

The CFD Vision 2030 Study (<https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20140003093.pdf> [16]) highlighted the many shortcomings in the existing technologies used for conducting high-fidelity simulations, and made specific recommendations for investments necessary to overcome these challenges. Areas of research that help to significantly reduce CFD workflow are the subject of this solicitation. It was recognized that the generation of meshes suitable for high-accuracy CFD simulations constitutes a principal bottleneck in the simulation workflow process as it requires significant human intervention. As more capable high performance computing (HPC) hardware enables higher resolution simulations, fast, reliable mesh generation and adaptivity will become more problematic. The other area of research pertains to extracting knowledge of physical relevance from computed and experimental data from wind tunnels and flight.

To enable accurate CFD solutions for complex configurations, proposals are solicited for generating unstructured and mixed-element meshes for accurate flow solutions. The new capability will be demonstrated for configurations of interest to NASA aeronautics (<http://www.aeronautics.nasa.gov/programs.htm> [17]) in terms of accuracy, speed and robustness. Of particular interest is the NASA juncture flow model (AIAA Paper 2016-1557) for which grids suitable for unsteady flow simulations (e.g., large eddy simulation (LES) and wall-modeled LES) needs to be generated. Another potential test case is the aircraft landing gear requiring hybrid RANS/LES solutions. The metrics for success are the quality and speed of grid generation. The proposers must present a convincing case that the proposed approach has the potential for dramatic decrease in CFD workflow time while generating quality grids that would produce physically relevant results. Proposers should also specify how the grid quality will be determined.

The second area of research for which proposals are solicited pertain to merging of high-fidelity CFD simulations with other aerodynamic data. With wind tunnel and flight testing still expected to play a key role in the aerospace system design process, methods to merge and assimilate CFD simulation data with other experimental/computational data sources to create an integrated database, including some measure of confidence level and/or uncertainty of all (or individual) portions of the database, are required. Currently, the merging of large amounts of experimental and variable fidelity computational data is mostly carried out through experience and intuition using fairly unsophisticated tools. Well-founded mathematically and statistically-based approaches are required for merging such data, for eliminating outlier numerical solutions as well as experimental points, and for generally quantifying the level of uncertainties throughout the data base.

Phase I research is expected to develop the technology and demonstrate it on relatively simpler configurations, while Phase II will increase the technology readiness level and include demonstration for more complex flow configurations.

A1.06 Vertical Lift Technology and Urban Air Mobility

Lead Center: GRC

Participating Center(s): AFRC, LaRC

Technology Area: TA15 Aeronautics

Urban air mobility (UAM) is a concept for immediate and flexible air transportation within a metropolitan area consisting of passenger-carrying operations. UAM passengers can select a trip origin, destination and timing without being aggregated with many other air travelers. 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. It is envisioned that UAM will provide increased mobility within a given metropolitan area by flying faster, and using shorter (< 100 miles) and more direct routing as compared to ground vehicles. UAM vehicles are assumed to require various degrees of autonomous operations to reach their full potential as the concepts are implemented and the market develops.

A series of workshops with NASA, FAA, academia, and industry were held over the past few years to discuss the potential benefits and challenges of UAM. The outcomes of these workshops, including technology roadmaps, are available at <http://www.nianet.org/ODM/roadmap.htm> [18]. Growth of UAM is dependent on affordable, low-noise VTOL configurations, which may be enabled by electric aircraft propulsion technologies, and the ability of these vehicles to operate within densely populated urban areas in most weather conditions including low altitude operations in rain, ice, wind, and turbulence.

The Vertical Lift Technology and Urban Air Mobility subtopic is primarily interested in innovative technologies focused on passenger-carrying UAM vehicles that include:

- Development and demonstration of technologies for vertical lift Urban Air Mobility (UAM) vehicle airframes and propulsion systems, including validated modeling and analysis tools and prototype demonstrations, that show benefits in terms of operating cost, noise, safety, weight, efficiency, emissions, fuel consumption, and/or reliability based on the vehicle mission, operating environment, and system status. Examples include:
 - Reconfigurable power and energy management system technologies.
 - Distributed electric propulsion and airframe technologies and associated design tools.
 - Technologies to enable operations in most weather conditions including rain, ice, wind, and turbulence.
 - Computationally efficient modeling tools capable of modeling sound propagation in an urban environment for creating auralizations of UAM vehicles.

A1.07 Electrified Aircraft Propulsion & Concepts

Lead Center: GRC

Participating Center(s): AFRC, LaRC

Technology Area: TA15 Aeronautics

Proposals are sought for the development of enabling power systems, turbofan engines, range extenders, electric machines, batteries, power converters, electrical fault management systems, protective devices (such as circuit breakers), and related materials that will be required for future thin/short haul aviation or commercial transport vehicles which use turboelectric, hybrid electric, or all electric power generation as part of the propulsion system. Electrified Aircraft Propulsion work for urban air mobility (UAM) should be proposed against subtopic A1.06 Vertical Lift Technology and Urban Air Mobility. 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: aircraft power systems operating at or above 1000V, turbofan engines in which >20% of power is extracted electrically, range extenders which consume fuel and produce electricity with significantly higher efficiency than available turbogenerator or diesel generators, batteries and other energy storage systems with specific energy >400Whr/kg at the system level and cycle life >10,000 cycles, electric machines (motors/generators) with efficiency >98% and specific power >13 kW/kg, converters (inverters/rectifiers) with efficiency >99% and specific power >19kW/kg, light weight AC and DC electrical fault management systems

and protective devices (such as circuit breakers), soft magnetic material with high magnetic saturation and/or lower losses for 100kHz-300kHz 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 (? 1W/m-K) and resistance to ageing effects such as corona, ozone, humidity and dust operating at greater than 3kV. Individual components should target the 15kW-3MW size range and would be combined into power systems in the range of 200kW-10MW total power.

Areas of particular interest this year are: turbofans in which >20% of power is extracted electrically, range extenders which burn fuel and produce electricity with significantly higher efficiency than available turbogenerator or diesel generators, and light weight AC and DC electrical fault management systems.

A1.08 Aeronautics Ground Test and Measurement Technologies

Lead Center: GRC

Participating Center(s): ARC, GRC

Technology Area: TA15 Aeronautics

NASA's aerospace 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 aerospace 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 [1]. For this solicitation, NASA seeks proposals for innovative research and development in the following areas:

- *Wind Tunnel Calibration and Characterization* - Capabilities for wind tunnel calibration and characterization are critical for overall enhancement of facilities and will play a critical role in achieving the CFD 2030 Vision [2]. Systems that can provide planar or volumetric measurements of flow quantities such as velocity, density, temperature, and pressure in the airflow upstream, around, and downstream of test articles are required to quantify tunnel inflow and outflow conditions and specify boundary conditions for numerical simulations.
- *Model Attitude, Position and/or Shape Sensing* - Measurements of test article attitude and position (e.g., roll, pitch, and yaw angles and spatial coordinates X, Y, Z of a wind tunnel model or other structure under test) are critical but are often difficult to make due to packaging constraints and model orientations where gravity based sensors are not applicable. To address some of these limitations, optical and non-optical techniques are needed to provide real-time or near real-time measurements of model attitude at data rates of up to 100 Hz and with sufficient accuracy (0.005± 0.0025 degrees in pitch 0.025±0.025 degrees in roll and yaw). For some applications, dynamic surface shape measurement techniques are needed at rates exceeding 10 kHz.
- *Technologies for Engine Simulators* - The need to assess aerodynamic performance at higher system levels with respect to fuel-burn and noise has created a great demand for propulsion-airframe integration (PAI) testing. Such tests use engine simulators which generate properly-scaled flows in the model. Currently, PAI tests can be quite expensive due to issues related to the integration of the simulator into the model, reliability, complexity of the calibration, and the high-pressure air and/or power which must cross the force and moment balance. NASA seeks innovative propulsion simulators that are more compact and capable of recreating the speed and volume of actual propulsion systems, including approach and landing conditions for the assessment of airframe noise. Hydraulic, pneumatic, electric, or hybrid approaches are solicited. NASA also seeks innovative measurement systems and techniques for monitoring and evaluating the performance of these simulators. Of interest are systems that can measure loads on individual blades for studies involving boundary layer ingestion, and balances capable of transferring high pressure air and/or power across the balance and operating at high temperatures (up to 350° F).

In addition to the areas listed above, proposals for especially innovative measurement systems and techniques which are broadly applicable to common problems in aerodynamic ground testing will also be considered.

[1] <https://www.nasa.gov/aeroresearch/programs/aavp/aetc/ground-facilities> [19].

[2] <https://ntrs.nasa.gov/search.jsp?R=20140003093> [20].

A1.09 Vehicle Safety - Inflight Icing Hazard Mitigation Technology

Lead Center: GRC

Technology Area: TA15 Aeronautics

NASA is concerned with the prevention of encounters with hazardous in-flight conditions and the mitigation of their effects when they do occur. Under this subtopic, proposals are invited that explore new and dramatically improved icing mitigation technologies and research tools related to inflight icing hazards for manned and unmanned vehicles. Of particular interest are technologies that can address emerging icing issues applicable to future On-Demand Mobility vehicles. Taken together, these hazards require a systems-level approach for integration with the airframe, propulsion system and control/avionics system. Technologies of interest should address the detection, measurement, and/or the mitigation of the hazards of flight into supercooled liquid water clouds and regions of freezing rain/drizzle. These technologies include but are not limited to on-board remote-sensing of environment, sensing of local environment, system identification, adaptive control and threat mitigation/protection, as well as new, very-low-power, ice-protection systems.

A1.10 Hypersonic Seal Technology Development

Lead Center: GRC

Participating Center(s): GRC

Technology Area: TA15 Aeronautics

NASA is developing advanced high temperature seals for a variety of applications. 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. To stay in contact with opposing sealing surfaces, the seals must remain resilient after repeated loading as the high-temperature surfaces around them move. Seal preloading elements, in various spring-like forms, can be incorporated within or behind a seal to provide the required resiliency. Spring tubes knitted from high temperature wire materials have been used inside high temperature seals, but they have been shown to lose resiliency and take on a permanent set at temperatures as low as 1200° F. Compression springs, canted coil springs, wave springs, and other unique configurations have all been evaluated as preload devices behind a seal with varying levels of success. For each design, though, material selection was a driving factor in the amount of resiliency exhibited by each type of seal preload device. Therefore, unique combinations of materials and designs will be required to achieve improved resiliency at the higher temperatures anticipated for future seal applications. NASA is interested in developing spring-like devices made of ceramic materials (e.g., silicon nitride) to use as preloading-seal elements applicable to these challenging environments. The overall goal is to develop seals that remain in contact with opposing sealing surfaces at higher temperatures for longer periods of time than current state of the art designs thus making them more reusable.

A2.01 Flight Test and Measurement Technologies

Lead Center: AFRC

Participating Center(s): ARC, GRC, LaRC

Technology Area: TA15 Aeronautics

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, expanding measurement and analysis methodologies, and improving 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's 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 also 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 ground and flight testing, science missions and related subsystems development.

Flight test and measurement technologies proposals should significantly enhance the capabilities of major government and industry flight test facilities comparable to the following NASA aeronautical test facilities:

- Dryden Aeronautical Test Range.
- Aero-Structures Flight Loads Laboratory.
- Flight Research Simulation Laboratory.
- Research Test Bed Aircraft.

Proposals should address innovative methods and technologies to reduce costs and extend the health, maintainability, communication and test techniques of these types of flight research support facilities.

- Areas of interest emphasizing flight test and measurement technologies include the following:
- High performance, real time reconfigurable software techniques for data acquisition and processing associated with IP based commands and/or IP based data input/output streams.
- High efficiency digital telemetry techniques and/or systems to enable high data rate, high volume IP based 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.
- Innovative cybersecurity protocols for safe transmission of measurement data.
- Improved time-constrained situational awareness and decision support via integrated, secure, cloud-based web services for 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 & control, and propulsion system performance.
- Miniaturized fiber optic-fed measurement systems with low power requirements are desirable for migration to small business class jets or UAS platforms.
- Innovative techniques that enable safer operation of aircraft.
- Wireless sensor/sensing technologies and telecommunication that can be used for flight test instrumentation applications for manned and unmanned aircraft. This includes wireless (non-intrusion) power transferring techniques and/or wirelessly powering remote sensors. Innovative measurement

methods that exploit autonomous remote sensing measurement technologies for supporting advanced flight testing.

- Fast imaging spectrometry that captures all dimensions (spatial/spectral/temporal) and can be used on 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 work is on flight test and flight test facility needs.

A2.02 Unmanned Aircraft Systems (UAS) Technologies

Lead Center: AFRC

Participating Center(s): ARC, GRC, LaRC

Technology Area: TA15 Aeronautics

Unmanned Aircraft Systems (UAS) offer advantages over manned aircraft for applications which are dangerous to humans, long in duration, require great precision, and require quick reaction. Examples of such applications include remote sensing, disaster response, delivery of goods, agricultural support, and many others that are known or yet to be discovered. In addition, the future of UAS promises great economic and operational advantages by requiring less human participation, less human training, an ability to take-off and land at any location, and the ability to react to dynamic situations.

NASA is involved in research that would greatly benefit from breakthroughs in UAS capabilities. Flight research of basic aerodynamics and advanced aero-vehicle concept would be revolutionized with an ability of UAS teams to cooperate and interact while making real time decisions based upon sensor data with little human oversight. Commercial industry would likewise be revolutionized with such abilities.

There are multiple technological barriers that are restricting greater use and application of UAS in NASA research and in civil aviation. These barriers include, but are not limited to, the lack of methods, architectures, and tools which enable:

- The verification, validation, and certification of complex and/or nondeterministic systems.
- Humans to operate multiple UAS with minimal oversight.
- Multi-vehicle cooperation and interoperability.
- High level machine perception, cognition, and decision-making.
- Inexpensive secure and reliable communications.

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 2018 NASA SBIR solicitation is focused on breaking through barriers to enable greater use of UAS in NASA research and in civil aviation use. The following five 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 inexpensive 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. Proposed research could include novel hardware and software architectures that enable or circumvent traditional verification and validation requirements.
- *Operation of Multiple UAS with Minimal Human Oversight* - Novel methods, software, and hardware that enable the operation of multiple UAS by a single human with minimal oversight need to be developed which ensure robust and safe operations. Proposed research could include novel hardware and software architectures which provide guarantees of safe UAS operations.
- *Multi-Vehicle Cooperation and Interoperability* - Technologies that enable UAS to interact in teams, including legacy vehicles, need to be developed. This includes technologies that enable UAS to negotiate

with others to find optimal routes, optimal task allocations, and optimal use of resources. Proposed research could include hardware and software architectures which enable UAS to operate in large cooperative and interactive teams.

- *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 abstract information which can be understood by machines or humans, and recognize patterns and make decisions based on the data and patterns.
- *Inexpensive, Reliable, and Secure Communications* - Inexpensive methods which ensure reliable and secure communications for increasingly interconnected and complex networks need to be developed that are immune from sophisticated cyber-physical attacks.

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.

A3.01 Advanced Air Traffic Management Systems Concepts

Lead Center: ARC

Participating Center(s): LaRC

Technology Area: TA15 Aeronautics

This subtopic addresses user needs and performance capabilities, trajectory-based operations, and the optimal assignment of humans and automation to air transportation system functions, gate-to-gate concepts and technologies to increase capacity and throughput of the National Airspace System (NAS), and achieving high efficiency in using aircraft, airports, en-route and terminal airspace resources, while accommodating an increasing variety of missions and vehicle types, including wide-spread integration of UAS and ODM operations. Examples of concepts or technologies that are sought include:

- Verification and validation methods and capabilities to enable safe, end-to-end NextGen Trajectory-Based Operations (TBO) functionality and seamless UAS operations, as well as other future aviation system concepts and architectures.
- Performance requirements, functional allocation definitions, and other critical data for integrated, end-to-end NextGen TBO functionality, and seamless UAS operations, as well as other future aviation system concepts and architectures.

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- Prognostic safety risk management solutions and concepts for emergent risks.
 - TBO concepts and enabling technology solutions that leverage revolutionary capabilities and that enable capacity, throughput, and efficiency gains within the various phases of gate-to-gate operations.
 - Networked/cloud-based systems to increase system predictability and reduce total cost of National Airspace System operations.

It is envisioned that the outcome of these concepts and technologies will provide greater system-wide safety, predictability, and reliability through full NextGen (2025-2035 timeframe) functionality.

A3.02 Increasing Autonomy in the National Airspace Systems (NAS) (not vehicles)

Lead Center: ARC

Participating Center(s): LaRC

Technology Area: TA15 Aeronautics

NASA's research envisions future concepts for air transportation that will significantly expand the current nature of airspace and vehicle management with an increasing reliance on autonomy technologies. Growing numbers of operations and a wider range of vehicle performance and mission goals will not be realizable in the current airspace system, and it is expected that a new service-based architecture, with features derived from NASA's Unmanned Aircraft System (UAS) Traffic Management (UTM) model, will provide the flexibility to support future use cases while establishing the necessary constraints to ensure safe and equitable operations. New technologies will be used to empower user decision making and collaboration with other users and the Air Navigation Service Provider. NASA's near-term goal for UTM itself is the development and demonstration of the concept to safely enable low-altitude airspace and UAS operations within the next five years. For the longer-term (10 to 15 years in the future), the goal is to safely enable the anticipated dramatic increase in density of all low-altitude airspace operations. NASA is partnered with other government agencies, industry, and academia, to perform the research, development, testing, and implementation of UTM.

This subtopic addresses the application of autonomy towards improving mobility, scalability, efficiency, safety, and cost-competitiveness, with particular attention towards the needs of emergent users and their operations (e.g., frequent, domestic supersonic flights, and commercial space launches to Urban Air Mobility and regional air-taxi operations) and enabling human operators to efficiently and effectively manage civilian low-altitude unmanned aircraft system (UAS) operations (UAS traffic management, or UTM) across a range of potential use cases (e.g., public safety/search and rescue, infrastructure inspection/surveillance, agricultural applications, cargo delivery, hobbyist, etc.). Proposals in the following areas are sought, but are not limited to:

- Autonomous or increasing levels of autonomy for, or towards, managing networked vehicle cockpits in all airspace domains (e.g., airport, metroplex, en route, regional/national traffic flow management, integration of multiple domains, on-demand aircraft and operations, and non-towered airports and vertiports).
- Autonomy (or self-management) -based architectures for the entirety, or parts, of airspace operations.
- Autonomous systems to produce any of the following system capabilities:
 - Prognostics, data mining, and data discovery to identify opportunities for improvement in airspace operations.
 - Weather-integrated flight planning, rerouting, and execution.
 - Fleet, crew, and airspace management to reduce the total cost of operations.
 - Predictions of unsafe conditions for vehicles, airspace, or dispatch operations.
 - Performance driven, all-operations, human-autonomy teaming management.
 - Verification and validation tools for increasingly autonomous operations.
 - Machine learning and/or self-learning algorithms for Shadow Mode Assessment using Realistic Technologies for the National Airspace System (NAS).
 - Autonomy/autonomous technologies and concepts for trajectory management and efficient/safe traffic flows.
- 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

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- 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.
 - Autonomous and safe UAS operations for the last and first 50 feet, under diverse weather conditions.
 - 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 (such as electric vertical take-off-and landing-VTOL).
 - Technologies to demonstrate the scalability of the UTM concept to potentially 10M+ users/operators.
 - The development of low size, weight, and power sense-and-avoid technologies for safe, heterogeneous (manned/unmanned) aircraft operations in the National Airspace System.
 - The development of UTM-focused track and locate functions.

A3.03 Future Aviation Systems Safety

Lead Center: ARC

Participating Center(s): LaRC

Technology Area: TA15 Aeronautics

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 real-time system-wide safety assurance (RSSA). A proactive approach to managing system safety requires:

- 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.
- 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 as envisioned by NextGen is paramount. Such a system 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 autonomous operations such as those envisioned for UAS and on-demand air mobility (ODM) 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:

- Flight outside of approved airspace.
- Unsafe proximity to people/property.
- Critical system failure (including loss of C2 link, loss or degraded GPS, loss of power, and engine failure).
- Loss-of-control (i.e., outside the envelope or flight control system failure).

Tools are being sought for use in creating prototypes of RSSA capabilities. The ultimate vision for RSSA 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 not limited to, these areas (with an emphasis on safety applications):

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- Develop data collection architecture, data exchange model and data collection mechanism (for example via UTM TCL-4).
 - Develop and demonstrate data mining tools and techniques to detect and identify anomalies and precursors to safety threats system-wide.
 - Develop and demonstrate tools and techniques to assess and predict safety margins system-wide to assure airspace safety.
 - Develop and demonstrate prognostic decision support tools and techniques capable of supporting real-time safety assurance.
 - Develop and demonstrate V&V tools and techniques for assuring the safety of air traffic applications during certification and throughout their lifecycles, and, techniques for supporting the real-time monitoring of safety requirements during operation.
 - Develop and demonstrate products to address technologies, simulation capabilities and procedures for reducing flight risk in areas of attitude and energy aircraft state awareness.
 - Develop and demonstrate decision support tools and automation that will reduce safety risks on the airport surface for normal operations and during severe weather events.
 - Develop and demonstrate alerting strategies/protocols/techniques that consider operational context, as well as operator state, traits, and intent.
 - Develop methodologies and tools for integrated prevention, mitigation, and recovery plans with information uncertainty and system dynamics in a UAS and in a TBO environment.
 - Develop and demonstrate strategies for optimal human-machine coordination for real-time hazard mitigation.
 - Develop and demonstrate 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 ODM aircraft in civil operations.
 - Develop measurement methods and metrics for human-machine team performance and mitigation resolution.
 - Develop system-level performance models and metrics that include interdependencies and relationships among human and machine system elements.
-