



NASA SBIR 2016 Phase I Solicitation

Aeronautics Research

Air Vehicle Technology Topic A1

The Air Vehicle Technology topic solicits cutting-edge research in aeronautics to overcome technology barriers and challenges in developing safe, new vehicles that will fly faster, cleaner, and quieter, and use fuel far more efficiently. The primary objective is the development of knowledge, technologies, tools, innovative concepts and capabilities needed as the Nation continues to experience growth in both domestic and international air transportation while needing to protect and preserve the environment. This topic solicits tools, technologies and capabilities to facilitate assessment of new vehicle designs and their potential performance characteristics. These tools, technologies and capabilities will enable:

- The best design solutions to meet performance and environmental requirements and challenges.
- Technology innovations for future air vehicles.

It also solicits focused research in revolutionary aircraft technologies enabling improved structural, aerodynamic, and propulsion efficiency and reduced noise and emissions while maintaining vehicle safety in order to meet the performance, efficiency and environmental requirements of future aircraft operating in the Next Gen airspace. This topic includes tools and technologies that contribute to meeting metrics derived from a definitive set of Technical Challenges responsive to the goals of the National Aeronautics Research and Development (R&D) Policy and Plan, the National Aeronautics R&D Test and Evaluation (T&E) Infrastructure Plan (2011), and the NASA Aeronautics Strategic Implementation Plan (2015). The topic focuses on the needs of NASA's Advanced Air Vehicles Program (AAVP) which consists of five projects, three that target a specific vehicle class/type, and two crosscutting projects focused on commonly encountered challenges associated with composite materials and capabilities necessary to enable advanced technology development.

- Advanced Air Transport Technologies (AATT) Project explores and develops technologies and concepts for improved energy efficiency and environmental compatibility of fixed wing, subsonic transports.
- Revolutionary Vertical Lift Technologies (RVLT) Project develops and validates tools, technologies, and concepts to overcome key barriers for rotary wing vehicles.
- Commercial Supersonics Technology (CST) Project enables tools and technologies and validation capabilities necessary to overcome environmental and performance barriers to practical civil supersonic airliners and sustains NASA competence in hypersonic air-breathing propulsion necessary to support the nearer-term Department of Defense (DoD) hypersonic mission.
- Advanced Composites (AC) Project focuses on reducing the timeline for development and certification of innovative composite materials and structures.
- Aeronautics Evaluation & Test Capabilities (AETC) Project sustains and enhances those specific research and test capabilities necessary to address and achieve the future air vehicles and operations as described above.

Sub Topics:

A1.01 Structural Efficiency - Aeroelasticity and Aeroservoelastic Control

Lead Center: LaRC

Participating Center(s): AFRC

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, 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.
- Development of techniques that support simulations, ground testing, wind-tunnel tests, and flight experiments for aerostructural control of aeroservoelastic phenomena.

A1.02 Quiet Performance - Propulsion Noise Reduction Technology

Lead Center: GRC

Participating Center(s): LaRC

To reduce noise emissions from aircraft, tools and technologies are needed to design aircraft that are both efficient and low noise. As such, developments/improvements in noise reduction technology, noise prediction tools, and flow & noise diagnostic methods are necessary to mitigate the environmental impact of aircraft noise. The focus of this call is on aircraft propulsion noise and innovations are solicited 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), and low-drag liners (i.e., liners that maintain current acoustic performance while reducing aerodynamic impact).

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- 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 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.

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

Lead Center: GRC

Participating Center(s): LaRC

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, 3-D, 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 Aerodynamic Efficiency - Active Flow Control Actuation Concepts

Lead Center: LaRC

Participating Center(s): AFRC

Active flow control (AFC) technology has the potential to be a key contributor to achieving NASA's aeronautics goal of revolutionizing the energy efficiency and environmental compatibility of fixed wing transport aircraft. Active flow control is the on-demand addition of energy into a boundary layer for maintaining, recovering, or improving vehicle performance. Since Prandtl's discovery of the boundary layer, AFC actuation methods have included steady mass transfer via suction or blowing, and unsteady perturbations created by zero net mass flux actuators, plasma actuators, and fluidic oscillators. Previous wind tunnel and flight tests demonstrated that this technology is capable of improving vehicle performance by reducing and/or eliminating separation and increasing circulation. When integrated into a transport aircraft, therefore, AFC would result in smaller control surfaces creating less drag and thereby less fuel consumption during flight. Widespread application of the technology on commercial transports, however, requires that AFC actuators and systems be energy-efficient, reliant, and robust. Another challenging aspect of the design of the actuation system involves understanding how and where to integrate the actuator into the vehicle. Computational tool development is also needed in parallel with actuator development to enable a more synergistic approach to active flow control system design thus maximizing the potential benefits of an AFC system.

This solicitation is for robust, energy-efficient, reliable actuation systems with the control authority needed to control turbulent separation thus improving circulation on simply hinged flaps systems and other aircraft control surfaces during the subsonic portion of the flight regime and/or to control shock induced separation on vehicles in cruise during the transonic portion of the flight regime.

Areas of specific interest where research is solicited include but are not limited to the following:

- Experimental or computational investigations aimed at control of turbulent boundary layer separation due to large adverse pressure gradients or shock/boundary layer interactions.
- Development of novel, energy-efficient, and robust actuators for controlling boundary layer separation.
- Development of computational tools to model the performance of a proposed actuator concept.
- Development of closed-loop active flow control systems with demonstrated improvements in AFC efficiency measured by the energy consumed by the AFC actuator.
- Experimental evaluation of realistic AFC actuators applied to separated flows.
- Experimental and computational studies that demonstrate the efficiency of the proposed actuation system.
- Development of computational tools to model the flowfield resulting from the application of active flow control on an airfoil or wing.

A1.05 Physics-Based Computational Tools - Stability and Control/High Lift Design Tools

Lead Center: LaRC

Participating Center(s): GRC

NASA continues to investigate the potential of advanced, innovative propulsion and airframe concepts to improve fuel efficiency and reduce the environmental footprint of future generations of commercial transports across the breadth of the flight speed regimes. Advanced concepts are viewed as potential options for helping to meet aggressive, long range (i.e., 'N+3' timeframe) fuel burn, noise, and emission reduction targets. Conceptual design and analysis of unconventional airframe and propulsion concepts and technologies is used within NASA for technology portfolio investment planning, development of advanced concepts to provide technology pull, and

independent technical assessment of new concepts, so the agency's systems analysts need the best conceptual design and analysis tools possible to support these efforts.

Historically, only empirical and semi-empirical analysis methods have been used during the conceptual design phase. These techniques work well for the conceptual design of conventional systems with parameters that reside within the historical databases used to develop the methodologies. However, these methods are not well suited for unconventional concepts, or even conventional concepts which reside outside of the database. Substantial progress has been made recently in incorporating more physics-based analysis tools in the conceptual design process, and NASA has developed a capability that integrates several analysis tools and models in engineering frameworks, such as ModelCenter and OpenMDAO, with a geometry-centric approach built around tools such as OpenVSP and GeoMACH. However, modeling gaps still remain in many disciplines.

Developing higher-order, more-accurate tools suitable for conceptual design is a difficult challenge. To perform the configuration trades and optimization typical in conceptual design, runtimes measured in seconds or minutes, instead of hours or days, are required. Additionally, because it is not possible to model every detail of the design and account for all the underlying physics in the problem formulation, it is difficult to predict the 'as-built' characteristics with physics-based methods alone. Finally, the gap between the analysis capability and the maturity of the design being analyzed currently limits the usefulness of high order analysis in conceptual design. Physics-based tools for conceptual design are needed which can rapidly and accurately predict the as-built characteristics of unconventional aircraft designs, while remaining consistent with the amount of design knowledge that is available at the conceptual design stage.

Sizing of an aircraft design can be strongly affected by its takeoff and landing characteristics, yet for both conventional and unconventional aircraft concepts it can be difficult to accurately estimate the aerodynamic performance in the high-lift configuration. In addition, many traditional methods of sizing aircraft controls surfaces and assuring acceptable handling qualities have lost their validity as more unconventional aircraft are being studied, and additional dynamic modes might become unstable. For FY2016, specific capabilities are being sought in the following areas:

- Methods for aerodynamic analysis, weight estimation, and design of aircraft high-lift systems.
 - Analysis of the aerodynamic performance of externally-blown flaps.
 - Robust prediction of maximum lift coefficient with flaps and slats extended.
 - Estimation of high-lift system weight as a function of design parameters.
 - Optimization of high-lift component design, trading aerodynamic performance and weight/complexity to minimize overall aircraft system weight, fuel burn and cost as an objective function.
- Methods for analysis of aircraft static and dynamic stability characteristics suitable for unconventional aircraft.
 - Physics-based sizing of tails and control surfaces that is more sensitive to aircraft design parameters than traditional tail volume coefficients.
 - Calculation of mass moments of inertia for the complete aircraft system throughout the full mission.
 - Simulation of the dynamics of unconventional aircraft configurations with tight coupling of propulsion and aerodynamics characteristics, including evaluation of active control systems.
 - Definition of handling qualities for unmanned aerial systems.

The desired capabilities are physics-based methods that are of higher order than traditional empirical methods, but can be applied in the conceptual design phase with limited requirements on the availability of detailed design information. Newly-developed methods and methods integration activities should include verification and validation of results, and will ideally address quantification of uncertainty and calculation of sensitivity derivatives for use in adjoint design.

A1.06 Vertical Lift - VL Measurement Techniques and Condition-Based Maintenance

Lead Center: ARC

Participating Center(s): GRC, LaRC

The Vertical Lift subtopic is primarily interested in the following two areas:

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- Health management of drive systems for vertical lift vehicle is critical to reliable operations and safety. Predictive Condition-Based Maintenance (CBM) improves safety, decreases maintenance costs, and increases system availability. A topic of interest in CBM includes analysis capabilities and models to simulate operating drive systems and components, including the modeling of realistic anomalies and faults that can help design and qualify CBM systems, and test their utility in making maintenance decisions. These CBM simulation capabilities should be of sufficient fidelity, demonstrated by validation and verification performance metrics, to allow development of CBM systems that include: differentiation between different failure modes, detection of onset and progression of failures, identification of the damaged component, assessment of damage severity, measurement of usage to predict remaining life, and recommendation of maintenance actions required. Proposals based only on novel post-processing of accelerometer data will not be considered for award.
 - Accurate measurements of lift systems and blade aerodynamics are key to developing and validating high-fidelity analyses and designing next-generation high-performance vertical lift systems. A topic of interest is instrumentation and measurement techniques for assessing blade boundary layer state (e.g., laminar flow, transition, turbulent flow) of a rotating blade system in hover and forward flight conditions. IR thermography is one technique for identifying transition but the technique typically requires heating (or cooling) the blade to enhance temperature differentials between the blade and the ambient air. Techniques, IR or non-IR, are sought that are non-intrusive or minimally non-intrusive. Both on-surface and off-surface techniques that can be efficiently applied to new or existing blades for testing in a wind tunnel or in flight are desired.

Proposals on other vertical lift technologies will also be considered however the primary emphasis of this solicitation will be on the above two identified technical areas.

A1.07 Propulsion Efficiency - Turbomachinery Technology for Reduced Fuel Burn

Lead Center: GRC

System and technology studies have indicated that advanced gas turbine propulsion will remain critical for future subsonic transports. Turbomachinery includes the rotating machinery in the high and low pressure spools, transition ducts, purge and bleed flows, casing and hub. We are interested in traditional gas turbine turbomachinery, as well as in innovative concepts as exo-skeletal engines, intercooled gas turbines, cooled cooling air, waste heat recovery, and other concepts.

NASA is looking for improvement in aeropropulsive efficiency. Areas of interest include: Improved components of current architectures and cycles, novel components and cycles to improve cycle limits, and novel architectures to improve mission efficiency limits.

In the compression system, advanced concepts and technologies are required to enable higher overall pressure ratio, high stage loading and wider operating range. 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's). Reduced cooling flow rates and/or increased cycle temperatures enabled by these technologies have a dramatic impact on the engine performance. Such improvements will enable reduced fuel burn, reduced weight and part count, and will enable advanced variable cycle engines for various missions.

Innovative proposals in the following turbomachinery and heat transfer areas are solicited:

- *Small core turbomachinery* - Higher fan Bypass Ratio (BPR) will require more compact engine core sizes rather than by growing the fan diameter, resulting in large tip/endwall and purge flow losses. Tip-leakage mitigation technologies for small-core turbomachinery and concept for circumvent the issue via innovative gas turbine designs. Desensitizing to losses due to tip leakage, secondary flows, seals, purge flows, and cooling air. Shorter transition ducts.
- *Optimized integrated combustor – turbine systems* - Integration concepts of combustor and turbine for improved overall and component performance are being sought.

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- *Flow control in turbomachinery* - Advanced turbomachinery active and passive flow control concepts to enable increased high stage loading in single and multi-stage axial compressors while maintaining or improving aerodynamic efficiency and operability. Technologies are sought that would reduce dependence on traditional range extending techniques (such as variable inlet guide vane and variable stator geometry) in compression systems. These may include flow control techniques near the compressor end walls and on the rotor and stator blade surfaces. Technologies are sought to reduce tip clearance leakage as well as rapid acting tip clearance control in compressors and turbines. Technologies are sought to eliminate flow separation in low pressure turbines and transition ducts, improve off-design operation and enable variable cycle operation.
 - *Cooling and thermal management* - Novel turbine cooling concepts are sought to enable very high turbine cooling effectiveness. The concepts are mainly for ceramic-based turbine materials such as ceramic matrix composite (CMC) vanes and blades. The availability of advanced manufacturing techniques may enable improved cooling designs beyond the current state-of-the-art. These concepts may include film cooling concepts, internal cooling concepts, and innovative methods to couple the film and internal cooling designs. Innovative high performance heat exchangers to cool the cooling air and for intercooling cycles are sought.
 - *Computational technologies for turbomachinery* - Computational technologies allowing accurate predictions of turbomachinery flows and heat transfer including active and passive flow control features and flow structures. Advanced turbulence and LES models that can account for complex three-dimensional flows common in turbomachinery. Models of flow control devices that enable incorporating them in RANS based CFD codes. Particular interest is in CFD method based on overset moving grids that will enable flexibility in studies of small features as cooling holes and active and passive flow control devices. Interfacing LES and RANS codes for unsteady rotating bounded flows. As engines get smaller, interaction issues dominate and CFD methods to enable simulation of the interactions are needed.

A1.08 Aeronautics Ground Test and Measurements Technologies

Lead Center: LaRC

Participating Center(s): GRC

NASA's ground-based test facilities, which include low speed, transonic, supersonic, and hypersonic wind tunnels, hypersonic propulsion integration test facilities, air-breathing engine test facilities, and simulation and loads laboratories, play an integral role in the design, development, evaluation, and analysis of advanced aerospace technologies and vehicles. In addition to design databases, 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 ground-based test facilities to enhance testing and measurement capability and improve utilization and efficiency. For this solicitation, NASA seeks proposals for innovative research and development in the following areas:

- *Force and Moment Balances* - Internal and external balances provide foundational data to evaluate aerodynamic performance and validate numerical solutions. To meet future testing and accuracy requirements, NASA is interested in new innovative balance designs for full- and semi-span test articles that incorporate new sensors, materials, manufacturing techniques, and calibration methods. Systems that are capable of transferring high pressure air and/or power across the balance and operating at high temperatures (up to 350F) are especially desired.
- *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 [1]. Non-intrusive measurement systems offering multi-component velocities, density, and pressure in the tunnel stream upstream and downstream of test articles are required to routinely quantify tunnel inflow and outflow conditions for the purposes of establishing boundary conditions for advanced numerical simulations. These systems should include provisions for combining these data into the regular stream of test data provided by a given facility.
- *Model Attitude and Position Monitoring* - Measurements of wind tunnel model attitude and position (e.g., roll, pitch, yaw angles and spatial coordinates X, Y, Z relative to a defined origin and coordinate system) are critical but are often difficult to make due to packaging constraints, model orientations where gravity based

sensors are not applicable, and test configurations that require multiple angle of attack systems. To address some of these limitations, optical, non-intrusive techniques are needed to provide real-time or near real-time measurements of model attitude at high data rates (10 Hz – 8kHz) and with sufficient accuracy ($0.005 \pm 0.0025^\circ$ in pitch $0.025 \pm 0.025^\circ$ in roll and yaw). The setup and calibration time required for these systems should be 4 hours or less to minimize the impact on tunnel operations. Many NASA wind tunnel facilities conduct tests at elevated temperatures (above 700° F) or at extremely low temperatures (-250° F). Displacement measurement components in actuator systems for the setting of hydraulic cylinder positions and other hardware used in test article support and positioning systems must operate routinely in these environments. Innovative designs and hardware solutions are desired to provide accurate and reliable performance at these extreme conditions.

- *Improved Operational Efficiencies and Data Throughput.* - Technologies are needed to significantly increase the amount of data acquired per test point, including simultaneous measurement of multiple flow parameters at high acquisition rates to capture rapidly evolving or oscillatory flow phenomena. Methods that exploit wireless sensor capabilities to reduce instrumentation cabling are of interest, including wireless strain gauge systems and technologies that can be applied for strain measurement on high speed rotating fan/rotor blades. Virtual environments that provide data fusion for real-time comparisons between wind tunnel data and computational results are also desired as well as technologies that integrate knowledge capture, training, and best practices for improved operational efficiencies, especially for activities that occur on an infrequent basis like calibration and characterization.

References:

- [1] - Slotnick, J., et al., "CFD Vision 2030 Study: A Path to Revolutionary Computational Aerosciences", NASA/CR-2014-218178, March 2014.

A1.09 Vehicle Safety - Inflight Icing Hazard Mitigation Technology

Lead Center: GRC

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 airframe and engine icing hazards for manned and unmanned vehicles. Technologies of interest should address the detection, measurement, and/or the mitigation of the hazards of flight into supercooled liquid water clouds and flight into regions of high ice crystal density. Of particular interest are technologies that can address emerging icing issues of advanced aircraft configurations (N+2/N+3 aircraft, as well as vertical lift and unmanned systems).

Integrated Flight Systems Topic A2

One of the greatest issues that NASA faces in transitioning advanced technologies into future aeronautics systems is the gap caused by the difference between the maturity level of technologies developed through fundamental research and the maturity required for technologies to be infused into future air vehicles and operational systems. Integrated Aviation Systems Program's (IASP) goal is to demonstrate integrated concepts and technologies to a maturity level sufficient to reduce risk of implementation for stakeholders in the aviation community. IASP conducts integrated system-level research on those promising concepts and technologies to explore, assess, and demonstrate the benefits in an operationally relevant environment. IASP matures and integrates technologies for accelerated transition to practical application, and supports the flight research needs across the ARMD strategic thrusts, the Programs, and all research phases of technology development. IASP consists of three projects, the Environmentally Responsible Aviation (ERA) Project, the UAS Integration in the National Airspace System (NAS) Project and the Flight Demonstrations and Capabilities Project (FDC).

The FDC Project consists of an integrated set of flight test capabilities and demonstrations. The flight test capabilities include the Dryden Aeronautical Test Range, and the aircraft required to support research flight tests and mission demands. The project capabilities also include the Armstrong Flight Research Center (AFRC) Simulation and Flight Loads Laboratories, which include a suite of ground-based laboratories that support flight

research and mission operations. These facilities and assets are able to perform tests covering the flight envelope from subsonic through hypersonic speeds and include unique capabilities ranging from simulating icing environments to modeling extreme dynamic situations.

NASA will demonstrate the feasibility and maturity of new technologies through flight tests, utilizing collaborative partnerships from across the aeronautical industry, and including international partners as appropriate. These activities support research within all six aeronautics strategic thrust areas.

Sub Topics:

A2.01 Flight Test and Measurements Technologies

Lead Center: AFRC

Participating Center(s): LaRC

NASA continues to see 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 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 electric propulsion, transonic civil transport, and supersonic civil transport. Therefore, this solicitation can cover a wide range of flight conditions and craft. NASA also requires improved measurement and analysis techniques for acquisition of realtime, in-flight data used to determine aerodynamic, structural, flight control, and propulsion system performance characteristics. These data will also be used to provide test conductors the information to safely expand the flight and test envelopes of aerospace vehicles and components. This requirement includes the development of sensors (both in-situ and remotely) to enhance the monitoring of test aircraft safety and atmospheric conditions during flight testing.

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:

- 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 include:

- 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 technique and/or system to enable high data rate, high volume IP based telemetry for flight test. Air-to-Air and Air-to-Ground communication.
- Improve time-constrained situational awareness and decision support via integrated secure cloud-based web services for real-time decision making.
- Intelligent health monitoring for hybrid and/or all electric distributed propulsion systems.
- Methods for significantly extending the life of electric aircraft propulsion energy sources (e.g., batteries, fuel cells, etc.).
- Test techniques for conducting quantitative in-flight boundary layer flow visualization, global surface pressure, shock wave propagation, Schlieren photography, near and far-field sonic boom determination, atmospheric modeling.
- Measurement technologies for in-flight steady & unsteady aerodynamics, juncture flow measurements, propulsion airframe integration, structural dynamics, stability & control, and propulsion system performance.

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- 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 operations of aircraft.

A2.02 Unmanned Aircraft Systems Technology

Lead Center: AFRC

Participating Center(s): GRC, LaRC

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 other known and 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 2016 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 reward. 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.

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- *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.
- 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.

Airspace Operations and Safety Topic A3

The Airspace Operations and Safety Program (AOSP) seeks innovative and feasible concepts and technologies to enable significant increases in the capacity and efficiency of the Next Generation Air Transportation System (NextGen) while maintaining or improving safety and environmental acceptability. AOSP activities and projects will target system-wide operational benefits of high impact for NextGen both in the arenas of airspace operations and safety management. Projects will be formulated with near-term end dates or deliberative evaluation points consistent with the accomplishment of program-defined Technical Challenges. AOSP aligns with the ARMD Strategic Thrusts of Safe and Efficient Growth in Global Aviation, Enable Real-Time System-Wide Safety Assurance, and Enable Assured Machine Autonomy for Aviation. Distribution of work area across the AOSP project structure is described below. AOSP is comprised of three projects:

- Airspace Technology Demonstrations (ATD).
- Shadow Mode Assessment Using Realistic Technologies for the National Airspace System (SMART-NAS).
- Test-Bed for Safe Trajectory-Based Operations, and Safe Autonomous Systems Operations (SASO).

The three projects are formulated to make major contributions to operational needs of the future through the development and research of foundational concepts and technologies and their analysis, integration, and maturation in relevant, system-level environments. Each of the projects are, much like the airspace system itself, highly integrated and require attention to critical system integration and transition interfaces with the NAS. The Airspace Technology Demonstrations (ATD) Project will accelerate the maturation of concepts and technologies to higher levels of maturity for transition to stakeholders, including research supporting the existing ATD-1:

- Interval Management - Terminal Area Precision Scheduling and Spacing effort.
- Integrated Arrivals/Departures/ Surface Operations.
- Applied Traffic Flow Management.
- Technologies for Assuring Safe Aircraft Energy and Attitude State (TASEAS).

The SMART-NAS Testbed for Safe Trajectory Based Operations Project will deliver an evaluation capability, critical to the ATM community, allowing full NextGen and beyond-NextGen concepts to be assessed and developed. This simulation and modeling capability will include the ability to assess multiple parallel universes, accepts data feeds, allows for live/virtual/constructive- distributed environment, and enable integrated examinations of concepts, algorithms, technologies, and NAS architectures. The Safe Autonomous System Operations (SASO) Project will develop autonomous system concepts and technologies; conduct demonstrations, and transfer application specific matured technologies to increase affordability, efficiency, mobility of goods and passengers, safety, and scalability and mix of airspace operations. Proposals for this topic will develop innovative feasible concepts and technologies to enable significant increases in the capacity, efficiency, scalability and cost effectiveness of the Next Generation Air Transportation System (NextGen) while maintaining or improving safety and environmental acceptability.

Sub Topics:

A3.01 Advanced Air Traffic Management Systems Concepts

Lead Center: ARC

Participating Center(s): LaRC

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 full integration of Unmanned Aerial Systems (UAS) 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.
- 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 time frame) functionality.

A3.02 Autonomy of the National Airspace Systems (NAS)

Lead Center: ARC

Participating Center(s): LaRC

Develop concepts or technologies focused on increasing the efficiency of the air transportation system within the mid-term operational paradigm (2025-2035 time frame), in areas that would culminate in autonomy products to improve mobility, scalability, efficiency, safety, and cost-competitiveness. Proposals in the followings areas in product-oriented research and development are sought, but are not limited to:

- Autonomous and safe Unmanned Aerial Vehicle (UAV) operations for the last and first 50 feet, under diverse weather conditions.
- Autonomous or increasing levels of autonomy for, or towards, any of the following:
 - Networked cockpit management.
 - Traffic flow management.
 - Airport management.
 - Metroplex management.

- Integrated Arrival/Departure/Surface operations.
- Low altitude airspace operations.
- 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.
 - Adaptive automation/human-system integration concepts, technologies and solutions that increase operator (pilot and or controller) efficiency and safety, and reduce workload to enable advances in air traffic movement and operations.

A3.03 Future Aviation Systems Safety

Lead Center: ARC

Participating Center(s): LaRC

The Aeronautics Research Mission Directorate (ARMD) has concluded the successful Aviation Safety Program (AvSP). The Airspace Operations and Safety Program (AOSP) is succeeding AvSP's significant achievements and stepping up to lead the ARMD research in the area of Real-Time System-Wide Safety Assurance (RSSA). As currently envisioned, ARMD sees its future, safety-related research focused in a forward looking, more comprehensive system-wide direction. ARMD's RSSA will focus on the current and future NAS, towards a gate-to-gate trajectory-based system capability that satisfies a full vision for NextGen and beyond. The ultimate vision for RSSA would enable the delivery of a progression of capabilities that accelerate the detection, prognosis and resolution of system-wide threats. Proposals under this sub-topic are sought, but not limited to, the following areas:

- Identify and characterize (causation, consequence, criticality) safety threats and anomalies that could and should be monitored for by an RSSA system. For each threat/anomaly, identify triggers, precursors, and data needed to analyze/determine if a trigger or precursor has occurred.
- 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 HMI concepts and technologies for alerting and resolution guidance delivery/visualization/execution to ensure timely avoidance or mitigation of predicted safety threats.
- Determine optimal human-machine function allocation for handling emerging safety threats, including threats communication, prioritization, alerting, and mitigation.
- 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.

Structural Efficiency - Aeroelasticity and Aeroservoelastic Control Topic A1.01

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, 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.
- Development of techniques that support simulations, ground testing, wind-tunnel tests, and flight experiments for aerostructural control of aeroservoelastic phenomena.

Sub Topics:

Quiet Performance - Propulsion Noise Reduction Technology Topic A1.02

To reduce noise emissions from aircraft, tools and technologies are needed to design aircraft that are both efficient and low noise. As such, developments/improvements in noise reduction technology, noise prediction tools, and flow & noise diagnostic methods are necessary to mitigate the environmental impact of aircraft noise. The focus of this call is on aircraft propulsion noise and innovations are solicited 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), and low-drag liners (i.e., liners that maintain current acoustic performance while reducing aerodynamic impact).
- 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 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.

Sub Topics:

Low Emissions/Clean Power - Combustion Technology/Emissions Measurement Techniques Topic A1.03
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, 3-D, 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.).

Sub Topics:

Aerodynamic Efficiency - Active Flow Control Actuation Concepts Topic A1.04
Active flow control (AFC) technology has the potential to be a key contributor to achieving NASA's aeronautics goal of revolutionizing the energy efficiency and environmental compatibility of fixed wing transport aircraft. Active flow control is the on-demand addition of energy into a boundary layer for maintaining, recovering, or improving vehicle performance. Since Prandtl's discovery of the boundary layer, AFC actuation methods have included steady mass transfer via suction or blowing, and unsteady perturbations created by zero net mass flux actuators,

plasma actuators, and fluidic oscillators. Previous wind tunnel and flight tests demonstrated that this technology is capable of improving vehicle performance by reducing and/or eliminating separation and increasing circulation. When integrated into a transport aircraft, therefore, AFC would result in smaller control surfaces creating less drag and thereby less fuel consumption during flight. Widespread application of the technology on commercial transports, however, requires that AFC actuators and systems be energy-efficient, reliable, and robust. Another challenging aspect of the design of the actuation system involves understanding how and where to integrate the actuator into the vehicle. Computational tool development is also needed in parallel with actuator development to enable a more synergistic approach to active flow control system design thus maximizing the potential benefits of an AFC system.

This solicitation is for robust, energy-efficient, reliable actuation systems with the control authority needed to control turbulent separation thus improving circulation on simply hinged flaps systems and other aircraft control surfaces during the subsonic portion of the flight regime and/or to control shock induced separation on vehicles in cruise during the transonic portion of the flight regime.

Areas of specific interest where research is solicited include but are not limited to the following:

- Experimental or computational investigations aimed at control of turbulent boundary layer separation due to large adverse pressure gradients or shock/boundary layer interactions.
- Development of novel, energy-efficient, and robust actuators for controlling boundary layer separation.
- Development of computational tools to model the performance of a proposed actuator concept.
- Development of closed-loop active flow control systems with demonstrated improvements in AFC efficiency measured by the energy consumed by the AFC actuator.
- Experimental evaluation of realistic AFC actuators applied to separated flows.
- Experimental and computational studies that demonstrate the efficiency of the proposed actuation system.
- Development of computational tools to model the flowfield resulting from the application of active flow control on an airfoil or wing.

Sub Topics:

Physics-Based Computational Tools - Stability and Control/High Lift Design Tools Topic A1.05
NASA continues to investigate the potential of advanced, innovative propulsion and airframe concepts to improve fuel efficiency and reduce the environmental footprint of future generations of commercial transports across the breadth of the flight speed regimes. Advanced concepts are viewed as potential options for helping to meet aggressive, long range (i.e., 'N+3' timeframe) fuel burn, noise, and emission reduction targets. Conceptual design and analysis of unconventional airframe and propulsion concepts and technologies is used within NASA for technology portfolio investment planning, development of advanced concepts to provide technology pull, and independent technical assessment of new concepts, so the agency's systems analysts need the best conceptual design and analysis tools possible to support these efforts.

Historically, only empirical and semi-empirical analysis methods have been used during the conceptual design phase. These techniques work well for the conceptual design of conventional systems with parameters that reside within the historical databases used to develop the methodologies. However, these methods are not well suited for unconventional concepts, or even conventional concepts which reside outside of the database. Substantial progress has been made recently in incorporating more physics-based analysis tools in the conceptual design process, and NASA has developed a capability that integrates several analysis tools and models in engineering frameworks, such as ModelCenter and OpenMDAO, with a geometry-centric approach built around tools such as OpenVSP and GeoMACH. However, modeling gaps still remain in many disciplines.

Developing higher-order, more-accurate tools suitable for conceptual design is a difficult challenge. To perform the configuration trades and optimization typical in conceptual design, runtimes measured in seconds or minutes, instead of hours or days, are required. Additionally, because it is not possible to model every detail of the design and account for all the underlying physics in the problem formulation, it is difficult to predict the 'as-built' characteristics with physics-based methods alone. Finally, the gap between the analysis capability and the maturity of the design being analyzed currently limits the usefulness of high order analysis in conceptual design. Physics-based tools for conceptual design are needed which can rapidly and accurately predict the as-built characteristics of unconventional aircraft designs, while remaining consistent with the amount of design knowledge that is available at the conceptual design stage.

Sizing of an aircraft design can be strongly affected by its takeoff and landing characteristics, yet for both conventional and unconventional aircraft concepts it can be difficult to accurately estimate the aerodynamic performance in the high-lift configuration. In addition, many traditional methods of sizing aircraft controls surfaces and assuring acceptable handling qualities have lost their validity as more unconventional aircraft are being studied, and additional dynamic modes might become unstable. For FY2016, specific capabilities are being sought in the following areas:

- Methods for aerodynamic analysis, weight estimation, and design of aircraft high-lift systems.
 - Analysis of the aerodynamic performance of externally-blown flaps.
 - Robust prediction of maximum lift coefficient with flaps and slats extended.
 - Estimation of high-lift system weight as a function of design parameters.
 - Optimization of high-lift component design, trading aerodynamic performance and weight/complexity to minimize overall aircraft system weight, fuel burn and cost as an objective function.
- Methods for analysis of aircraft static and dynamic stability characteristics suitable for unconventional aircraft.
 - Physics-based sizing of tails and control surfaces that is more sensitive to aircraft design parameters than traditional tail volume coefficients.
 - Calculation of mass moments of inertia for the complete aircraft system throughout the full mission.
 - Simulation of the dynamics of unconventional aircraft configurations with tight coupling of propulsion and aerodynamics characteristics, including evaluation of active control systems.
 - Definition of handling qualities for unmanned aerial systems.

The desired capabilities are physics-based methods that are of higher order than traditional empirical methods, but can be applied in the conceptual design phase with limited requirements on the availability of detailed design information. Newly-developed methods and methods integration activities should include verification and validation of results, and will ideally address quantification of uncertainty and calculation of sensitivity derivatives for use in adjoint design.

Sub Topics:

Vertical Lift - VL Measurement Techniques and Condition-Based Maintenance Topic A1.06

The Vertical Lift subtopic is primarily interested in the following two areas:

- Health management of drive systems for vertical lift vehicle is critical to reliable operations and safety. Predictive Condition-Based Maintenance (CBM) improves safety, decreases maintenance costs, and increases system availability. A topic of interest in CBM includes analysis capabilities and models to simulate operating drive systems and components, including the modeling of realistic anomalies and faults that can help design and qualify CBM systems, and test their utility in making maintenance decisions. These CBM simulation capabilities should be of sufficient fidelity, demonstrated by validation and verification performance metrics, to allow development of CBM systems that include: differentiation between different failure modes, detection of onset and progression of failures, identification of the damaged component, assessment of damage severity, measurement of usage to predict remaining life, and recommendation of maintenance actions required. Proposals based only on novel post-processing of accelerometer data will not be considered for award.
- Accurate measurements of lift systems and blade aerodynamics are key to developing and validating high-fidelity analyses and designing next-generation high-performance vertical lift systems. A topic of interest is instrumentation and measurement techniques for assessing blade boundary layer state (e.g., laminar flow, transition, turbulent flow) of a rotating blade system in hover and forward flight conditions. IR thermography is one technique for identifying transition but the technique typically requires heating (or cooling) the blade to enhance temperature differentials between the blade and the ambient air. Techniques, IR or non-IR, are sought that are non-intrusive or minimally non-intrusive. Both on-surface and off-surface techniques that can be efficiently applied to new or existing blades for testing in a wind tunnel or in flight are desired.

Proposals on other vertical lift technologies will also be considered however the primary emphasis of this solicitation will be on the above two identified technical areas.

Sub Topics:

Propulsion Efficiency - Turbomachinery Technology for Reduced Fuel Burn Topic A1.07

System and technology studies have indicated that advanced gas turbine propulsion will remain critical for future subsonic transports. Turbomachinery includes the rotating machinery in the high and low pressure spools,

transition ducts, purge and bleed flows, casing and hub. We are interested in traditional gas turbine turbomachinery, as well as in innovative concepts as exo-skeletal engines, intercooled gas turbines, cooled cooling air, waste heat recovery, and other concepts.

NASA is looking for improvement in aeropropulsive efficiency. Areas of interest include: Improved components of current architectures and cycles, novel components and cycles to improve cycle limits, and novel architectures to improve mission efficiency limits.

In the compression system, advanced concepts and technologies are required to enable higher overall pressure ratio, high stage loading and wider operating range. 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's). Reduced cooling flow rates and/or increased cycle temperatures enabled by these technologies have a dramatic impact on the engine performance. Such improvements will enable reduced fuel burn, reduced weight and part count, and will enable advanced variable cycle engines for various missions.

Innovative proposals in the following turbomachinery and heat transfer areas are solicited:

- *Small core turbomachinery* - Higher fan Bypass Ratio (BPR) will require more compact engine core sizes rather than by growing the fan diameter, resulting in large tip/endwall and purge flow losses. Tip-leakage mitigation technologies for small-core turbomachinery and concept for circumvent the issue via innovative gas turbine designs. Desensitizing to losses due to tip leakage, secondary flows, seals, purge flows, and cooling air. Shorter transition ducts.
- *Optimized integrated combustor – turbine systems* - Integration concepts of combustor and turbine for improved overall and component performance are being sought.
- *Flow control in turbomachinery* - Advanced turbomachinery active and passive flow control concepts to enable increased high stage loading in single and multi-stage axial compressors while maintaining or improving aerodynamic efficiency and operability. Technologies are sought that would reduce dependence on traditional range extending techniques (such as variable inlet guide vane and variable stator geometry) in compression systems. These may include flow control techniques near the compressor end walls and on the rotor and stator blade surfaces. Technologies are sought to reduce tip clearance leakage as well as rapid acting tip clearance control in compressors and turbines. Technologies are sought to eliminate flow separation in low pressure turbines and transition ducts, improve off-design operation and enable variable cycle operation.
- *Cooling and thermal management* - Novel turbine cooling concepts are sought to enable very high turbine cooling effectiveness. The concepts are mainly for ceramic-based turbine materials such as ceramic matrix composite (CMC) vanes and blades. The availability of advanced manufacturing techniques may enable improved cooling designs beyond the current state-of-the-art. These concepts may include film cooling concepts, internal cooling concepts, and innovative methods to couple the film and internal cooling designs. Innovative high performance heat exchangers to cool the cooling air and for intercooling cycles are sought.
- *Computational technologies for turbomachinery* - Computational technologies allowing accurate predictions of turbomachinery flows and heat transfer including active and passive flow control features and flow structures. Advanced turbulence and LES models that can account for complex three-dimensional flows common in turbomachinery. Models of flow control devices that enable incorporating them in RANS based CFD codes. Particular interest is in CFD method based on overset moving grids that will enable flexibility in studies of small features as cooling holes and active and passive flow control devices. Interfacing LES and RANS codes for unsteady rotating bounded flows. As engines get smaller, interaction issues dominate and CFD methods to enable simulation of the interactions are needed.

Sub Topics:

Aeronautics Ground Test and Measurements Technologies Topic A1.08

NASA's ground-based test facilities, which include low speed, transonic, supersonic, and hypersonic wind tunnels, hypersonic propulsion integration test facilities, air-breathing engine test facilities, and simulation and loads laboratories, play an integral role in the design, development, evaluation, and analysis of advanced aerospace technologies and vehicles. In addition to design databases, 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 ground-based test facilities to enhance testing and measurement capability and improve utilization and efficiency. For this solicitation, NASA seeks proposals for innovative research and development in the following areas:

- *Force and Moment Balances* - Internal and external balances provide foundational data to evaluate aerodynamic performance and validate numerical solutions. To meet future testing and accuracy requirements, NASA is interested in new innovative balance designs for full- and semi-span test articles that incorporate new sensors, materials, manufacturing techniques, and calibration methods. Systems that are capable of transferring high pressure air and/or power across the balance and operating at high temperatures (up to 350F) are especially desired.
- *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 [1]. Non-intrusive measurement systems offering multi-component velocities, density, and pressure in the tunnel stream upstream and downstream of test articles are required to routinely quantify tunnel inflow and outflow conditions for the purposes of establishing boundary conditions for advanced numerical simulations. These systems should include provisions for combining these data into the regular stream of test data provided by a given facility.
- *Model Attitude and Position Monitoring* - Measurements of wind tunnel model attitude and position (e.g., roll, pitch, yaw angles and spatial coordinates X, Y, Z relative to a defined origin and coordinate system) are critical but are often difficult to make due to packaging constraints, model orientations where gravity based sensors are not applicable, and test configurations that require multiple angle of attack systems. To address some of these limitations, optical, non-intrusive techniques are needed to provide real-time or near real-time measurements of model attitude at high data rates (10 Hz – 8kHz) and with sufficient accuracy ($0.005 \pm 0.0025^\circ$ in pitch $0.025 \pm 0.025^\circ$ in roll and yaw). The setup and calibration time required for these systems should be 4 hours or less to minimize the impact on tunnel operations. Many NASA wind tunnel facilities conduct tests at elevated temperatures (above 700° F) or at extremely low temperatures (-250° F). Displacement measurement components in actuator systems for the setting of hydraulic cylinder positions and other hardware used in test article support and positioning systems must operate routinely in these environments. Innovative designs and hardware solutions are desired to provide accurate and reliable performance at these extreme conditions.
- *Improved Operational Efficiencies and Data Throughput* - Technologies are needed to significantly increase the amount of data acquired per test point, including simultaneous measurement of multiple flow parameters at high acquisition rates to capture rapidly evolving or oscillatory flow phenomena. Methods that exploit wireless sensor capabilities to reduce instrumentation cabling are of interest, including wireless strain gauge systems and technologies that can be applied for strain measurement on high speed rotating fan/rotor blades. Virtual environments that provide data fusion for real-time comparisons between wind tunnel data and computational results are also desired as well as technologies that integrate knowledge capture, training, and best practices for improved operational efficiencies, especially for activities that occur on an infrequent basis like calibration and characterization.

References:

- [1] - Slotnick, J., et al., "CFD Vision 2030 Study: A Path to Revolutionary Computational Aerosciences", NASA/CR-2014-218178, March 2014.

Sub Topics:

Vehicle Safety - Inflight Icing Hazard Mitigation Technology Topic A1.09

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 airframe and engine icing hazards for manned and unmanned vehicles. Technologies of interest should address the detection, measurement, and/or the mitigation of the hazards of flight into supercooled liquid water clouds and flight into regions of high ice crystal density. Of particular interest are technologies that can address emerging icing issues of advanced aircraft configurations (N+2/N+3 aircraft, as well as vertical lift and unmanned systems).

Sub Topics:

Flight Test and Measurements Technologies Topic A2.01

NASA continues to see 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 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 electric propulsion, transonic civil transport, and supersonic civil transport. Therefore, this solicitation can cover a wide range of flight conditions and craft. NASA also requires improved measurement and analysis techniques for acquisition of realtime, in-flight data used to determine aerodynamic, structural, flight control, and propulsion system performance characteristics. These data will also be used to provide test conductors the information to safely expand the flight and test envelopes of aerospace vehicles and components. This requirement includes the development of sensors (both in-situ and remotely) to enhance the monitoring of test aircraft safety and atmospheric conditions during flight testing.

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:

- 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 include:

- 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 technique and/or system to enable high data rate, high volume IP based telemetry for flight test. Air-to-Air and Air-to-Ground communication.
- Improve time-constrained situational awareness and decision support via integrated secure cloud-based web services for real-time decision making.
- Intelligent health monitoring for hybrid and/or all electric distributed propulsion systems.
- Methods for significantly extending the life of electric aircraft propulsion energy sources (e.g., batteries, fuel cells, etc.).
- Test techniques for conducting quantitative in-flight boundary layer flow visualization, global surface pressure, shock wave propagation, Schlieren photography, near and far-field sonic boom determination, atmospheric modeling.
- Measurement technologies for in-flight steady & 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 operations of aircraft.

Sub Topics:

Unmanned Aircraft Systems Technology Topic A2.02

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 other known and 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 2016 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 reward. 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:

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- 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.
 - 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.

Sub Topics:

Advanced Air Traffic Management Systems Concepts Topic A3.01

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 full integration of Unmanned Aerial Systems (UAS) 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.
- 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 time frame) functionality.

Sub Topics:

Autonomy of the National Airspace Systems (NAS) Topic A3.02

Develop concepts or technologies focused on increasing the efficiency of the air transportation system within the mid-term operational paradigm (2025-2035 time frame), in areas that would culminate in autonomy products to improve mobility, scalability, efficiency, safety, and cost-competitiveness. Proposals in the followings areas in product-oriented research and development are sought, but are not limited to:

- Autonomous and safe Unmanned Aerial Vehicle (UAV) operations for the last and first 50 feet, under diverse weather conditions.
- Autonomous or increasing levels of autonomy for, or towards, any of the following:
 - Networked cockpit management.
 - Traffic flow management.
 - Airport management.
 - Metroplex management.
 - Integrated Arrival/Departure/Surface operations.
 - Low altitude airspace operations.
- 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.

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- 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.
 - Adaptive automation/human-system integration concepts, technologies and solutions that increase operator (pilot and or controller) efficiency and safety, and reduce workload to enable advances in air traffic movement and operations.

Sub Topics:

Future Aviation Systems Safety Topic A3.03

The Aeronautics Research Mission Directorate (ARMD) has concluded the successful Aviation Safety Program (AvSP). The Airspace Operations and Safety Program (AOSP) is succeeding AvSP's significant achievements and stepping up to lead the ARMD research in the area of Real-Time System-Wide Safety Assurance (RSSA). As currently envisioned, ARMD sees its future, safety-related research focused in a forward looking, more comprehensive system-wide direction. ARMD's RSSA will focus on the current and future NAS, towards a gate-to-gate trajectory-based system capability that satisfies a full vision for NextGen and beyond. The ultimate vision for RSSA would enable the delivery of a progression of capabilities that accelerate the detection, prognosis and resolution of system-wide threats. Proposals under this sub-topic are sought, but not limited to, the following areas:

- Identify and characterize (causation, consequence, criticality) safety threats and anomalies that could and should be monitored for by an RSSA system. For each threat/anomaly, identify triggers, precursors, and data needed to analyze/determine if a trigger or precursor has occurred.
- 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 HMI concepts and technologies for alerting and resolution guidance delivery/visualization/execution to ensure timely avoidance or mitigation of predicted safety threats.
- Determine optimal human-machine function allocation for handling emerging safety threats, including threats communication, prioritization, alerting, and mitigation.
- 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.

Sub Topics: