



## NASA SBIR 2011 Phase I Solicitation

### Aeronautics Research

#### Aviation Safety Topic A1

The Aviation Safety Program conducts fundamental research and technology development of known and predicted safety concerns as the nation transitions to the Next Generation Air Transportation System (NextGen). Future challenges to maintaining aviation safety arise from expected significant increases in air traffic, continued operation of legacy vehicles, introduction of new vehicle concepts, increased reliance on automation, and increased operating complexity. Further design challenges also exist where safety barriers may prevent the technical innovations necessary to achieve NextGen capacity and efficiency goals. The program seeks capabilities furthering the practice of proactive safety management and design methodologies and solutions to predict and prevent safety issues, to monitor for them in-flight and mitigate against them should they occur, to analyze and design them out of complex system behaviors, and to constantly analyze designs and operational data for potential hazards. AvSP's top ten technical challenges are:

- Assurance of Flight Critical Systems.
- Discovery of Safety Issues.
- Automation Design Tools.
- Prognostic Algorithm Design.
- Vehicle Health Assurance.
- Crew-System Interactions and Decisions.
- Loss of Control Prevention, Mitigation, and Recovery.
- Engine Icing.
- Airframe Icing.
- Atmospheric Hazard Sensing and Mitigation.

AvSP includes three research projects:

The System-wide Safety Assurance Technologies Project provides knowledge, concepts and methods to proactively manage increasing complexity in the design and operation of vehicles and the air transportation

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systems, including advanced approaches to enable improved and cost-effective verification and validation of flight-critical systems.

The Vehicle Systems Safety Technologies Project provides knowledge, concepts and methods to avoid, detect, mitigate, and recover from hazardous flight conditions, and to maintain vehicle airworthiness and health.

The Atmospheric Environment Safety Technologies Project investigates sources of risk and provides technology needed to help ensure safe flight in and around atmospheric hazards.

NASA seeks highly innovative proposals that will complement its work in science and technologies that build upon and advance the Agency's unique safety-related research capabilities vital to aviation safety. Additional information is available at ([http://www.aeronautics.nasa.gov/programs\\_avsafe.htm](http://www.aeronautics.nasa.gov/programs_avsafe.htm) [1]).

Sub Topics:

### **A1.01 Aviation External Hazard Sensor Technologies**

**Lead Center:** LaRC

**Participating Center(s):** ARC

NASA is concerned with new and innovative methods for detection, identification, evaluation, and monitoring of in-flight hazards to aviation. NASA seeks to foster research and development that leads to innovative new technologies and methods, or significant improvements in existing technologies, for in-flight hazard avoidance and mitigation. Technologies may take the form of tools, models, techniques, procedures, substantiated guidelines, prototypes, and devices.

A key objective of the NASA Aviation Safety Program is to support the research of technology, systems, and methods that will facilitate transformation of the National Airspace System to Next Generation Air Transportation System (NextGen) (information available at [www.jpdo.gov](http://www.jpdo.gov) [2]). The general approach to the development of airborne sensors for NextGen is to encourage the development of multi-use, adaptable, and effective sensors that will have a strong benefit to safety. The greatest impact will result from improved sensing capability in the terminal area, where higher density and more reliable operations are required for NextGen.

Under this subtopic, proposals are invited that explore new and improved sensors and sensor systems for the detection and monitoring of hazards to aircraft before they are encountered. The scope of this subtopic does not include human factors and development of human interfaces, including displays and alerts, except where explicitly requested in association with special topics. Primary emphasis is on airborne applications, but in some cases the development of ground-based sensor technology may be supported. Approaches that use multiple sensors in combination to improve hazard detection and quantification of hazard levels are also of interest.

At this time, there are some areas of particular interest to NASA, and these are described below. They are provided as encouragement but not intended to exclude other proposals that fit this subtopic. These areas of interest include two specific hazards to aircraft and specific advancements in fundamental radar technology. The interest in radar technology can be considered to be independent of the interest in the two hazards. While NASA is interested in all aviation hazards, wake vortices and turbulence are of particular interest. Proposals associated with remote sensing investigations addressing these hazards are encouraged. This emphasis is not intended to discourage proposals targeting other or additional hazards such as reduced visibility, terrain, airborne obstacles, volcanic ash, convective weather, lightning, gust fronts, cross winds, and wind shear.

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Airborne detection of wake vortices is considered challenging due to the fact that detection must be possible in nearly all weather conditions, in order to be practical, and because of the size and nature of the phenomena. Proposals are encouraged for the development of novel coherent and direct detection lidar systems and associated components that allow accurate meteorological wind and aerosol measurements suitable for wake vortex characterization. Lidar development includes, but is not limited to, novel transceiver architectures, efficient signal processing methodologies, wake processing algorithms and real time data reduction and display schemes. Improvements in size, weight, range, system efficiency, sensitivity, and reliability based on emerging technologies are desired.

NASA has made a major investment in the development of new and enhanced technologies to enable detection of turbulence to improve aviation safety. Progress has been made in efforts to quantify hazard levels from convectively induced turbulence events and to make these quantitative assessments available to civil and commercial aviation. NASA is interested in expanding these prior efforts to take advantage of the newly developing turbulence monitoring technologies, particularly those focused on clear air turbulence (CAT). NASA welcomes proposals that explore the methods, algorithms and quantitative assessment of turbulence for the purpose of increasing aviation safety and augmenting currently available data in support of NextGen operations.

In order to detect and/or discriminate some meteorological hazards, future radars will need multi-frequency and/or polarimetric capabilities. NASA seeks new system/component designs and hazard detection applications for airborne weather radars based upon extending the current design to incorporate multi-frequencies and/or polarimetric capabilities. In addition, the current generation of weather radar is fundamentally limited by its ability to scan the airspace; consequently, NASA is seeking novel designs and enhancements to produce electronically scanned antennas/radars.

## **A1.02 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 technologies 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. With these emphases in mind, products and technologies that can be made affordable and capable of retrofit into the current aviation system and aircraft, as well as for use in the future are sought.

Areas of interest include, but are not limited to:

- Non-destructive digitization of ice accretions on wind tunnel wing models. NASA has a need for methods to digitize ice shapes with rough external surfaces and internal voids as can occur with accretions on highly

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swept wing. Current methods based upon scanning with line-of-sight optical digitization methods have been found inadequate for these ice shapes.

- New instruments are needed utilizing innovative concepts to measure ice-crystal/liquid water mixed phase clouds in ground test facilities and in flight. Cloud properties of interest include: crystal/droplet temperature, material phase, particle size, speed, cloud liquid-water content, ice-water content, air temperature, and humidity. Non-intrusive measurement techniques capable of providing the spatial distribution of these properties across an engine duct with a diameter of at least 3 feet are particularly of interest.
- New instruments or measurement techniques are also needed for the detailed study of the ice accretion process on wing surfaces and internal engine components. Properties of particular interest are heat transfer, accretion extent, and ice density. The measurement of these properties needs to be non-interfering.

### **A1.03 Durable Propulsion Components**

**Lead Center: GRC**

The mitigation and management of aging and durability-related hazards in future civilian and military aircraft will require advanced materials, concepts, and techniques. NASA is engaged in the research of materials (metals, ceramics, and composites) and characterization/validation test techniques to mitigate aging and durability issues and to enable advanced material suitability and concepts.

Proposals are sought for the development of physics-based probabilistic fatigue life models for powder metallurgy disk superalloys, which include both crystal plasticity and surface environmental damage modes. The models would capture the evolution of fatigue damage due to crystallographic slip within multiple grains of variable orientation and size, as well as damage due to environmental interactions at the surfaces of compressor and turbine powder metallurgy superalloy disks. This research opportunity is focused on quantifying, modeling and validating each of these damage modes during simple cyclic and dwell fatigue cycles, and then later for simulated service in aerospace gas turbine engine disk materials. Work may involve use of uniform gage and notched fatigue specimens to simulate key disk features, potentially utilizing varied disk surface finish conditions and associated residual stress and cold work. The simulated load history and temperature gas turbine engine conditions should approximate turbine service history reflective of the new generation of gas turbine engines and include the effect of superimposed dwell cycles. NASA will be an active participant in Phase I of the research effort by providing superalloy disk sections, for the proposer to machine into specimens, mechanically test, analyze, and model evolution of these damage modes. Technology innovations may take the form of the unique quantification of the effect of service history on these damage modes, and include analytical modeling descriptions of the evolution of these parameters as a function of simulated service history. The technology innovations may also include models and algorithms extrapolating this damage to service conditions outside of those tested during the program.

### **A1.04 Airframe Design and Sustainment**

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**Lead Center: LaRC**

**Participating Center(s): AFRC, GRC**

Conventional aircraft airframe structures have achieved a high level of reliability through decades of experience, incremental technology changes, and an empirically based building block design methodology. Emerging and next generation aircraft will employ new lightweight materials and structural concepts that have very different characteristics than our current experience base. One element in NASA's effort to ensure the integrity of future vehicles is research to improve the reliability of airframe structures through enhanced computational methods to predict structural integrity and life, and validating correlation between computational models and the as-manufactured and as-maintained aircraft structure.

NASA seeks tools and methods for improved understanding and prediction of structural response, and experimental methods for measuring and evaluating the performance of new airframe structural designs. Specific areas of interest include the following:

- Improved structural analysis methods for complex metallic and composite airframe components using novel multi-scale as well as global-local computational codes. The methods used for these solutions need to detail the initiation and progression of damage to determine accurate estimates of residual life and or strength of complex airframe structures. Robust numerical algorithms are required to simulate the nonlinear behavior of damage progression coupled with geometric and material nonlinearity.
- Correlation between computational models and airframe structures:
  - Experimental methods for detailed characterization of as-manufactured structures relative to the as-designed configuration, to identify deviations in geometry, material application, and possibly identify manufacturing anomalies.
  - Advanced experimental methods for full-field assessment of strain during structural or flight tests for the purpose of validating computational models, and identifying hot-spots in the structure that are not represented in the models. Ease of application on built-up structures will be a significant factor.
  - Technologies to measure residual stresses in structures resulting from manufacturing processes and fit-up during structural assembly, as these residual stresses may severely compromise design margins.
- Repair technology for metallic or composite structures:
  - Novel approaches to arrest damage and return structural integrity (other than replacement, grind out, scarf, or bonded or bolted doublers).
  - Validation of structural repair: technology to interrogate an applied repair to validate the design of the repair, and correct application of the repair. The intent will be to determine whether the repair performs as expected to return structural integrity.

Technology innovations may take the form of tools, models, algorithms, and devices.

All proposals should discuss means for verification and validation of proposed methods and tools in operationally

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valid, or end-user, contexts.

### **A1.05 Sensing and Diagnostic Capabilities for Degradation in Aircraft Materials and Structures**

**Lead Center:** LaRC

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

Many conventional nondestructive evaluation (NDE) and integrated vehicle health management (IVHM) techniques have been used for flaw detection, but have shown little potential for much broader application. One element in NASA's effort to ensure the integrity of future vehicles is research to identify changes in fundamental material properties as indicators of material aging-related hazards before they become critical. For example, composites can exhibit a number of micromechanisms such as fiber buckling and breakage, matrix cracking and delaminations as precursor to failure. For complex metallic components an inability to determine residual stress state limits the validity of predictions of the fatigue life of the component.

To further these goals, NDE and IVHM technologies are being sought for the nondestructive characterization of age-related degradation in complex materials and structures. Innovative and novel approaches to using NDE technologies to measure properties related to manufacturing defects, flaws, and material aging. Measurement techniques, models, and analysis methods related to quantifying material thermal properties, elastic properties, density, microcrack formation, fiber buckling and breakage, etc. in complex composite material systems, adhesively bonded/built-up and/or polymer-matrix composite sandwich structures are of particular interest. Other NDE and IVHM technologies being sought are those that enable the quantitative assessment of the strength of an adhesive region of bonded joints and repairs or enable the rapid inspection of large area structures. The anticipated outcome of successful proposals would be both a Phase II prototype technology for the use of the developed technique and a demonstration of the technology showing its ability to measure a relevant material property or structural damage in the advanced materials and structures in subsonic aircraft.

### **A1.06 Propulsion Health State Assessment and Management**

**Lead Center:** GRC

**Participating Center(s):** AFRC

The emphasis for this subtopic is on propulsion system health management, in order to predict, prevent, or accommodate safety-significant malfunctions and damage. Past advances in this area have helped improve the reliability and safety of aircraft propulsion systems; however, propulsion system component failures are still a contributing factor in numerous aircraft accidents and incidents. Advances in technology are sought which help to further reduce the occurrence of and/or mitigate the effects of safety-significant propulsion system malfunctions and damage. Specifically the following are sought: propulsion health management technologies such as instrumentation, sensors, health monitoring algorithms, and fault accommodating logic, which will detect, diagnose, prevent, assess, and allow recovery from propulsion system malfunctions, degradation, or damage. Specific technologies of interest include:

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- Self-awareness and diagnosis of gas path, combustion, and overall engine state (containment systems and rotating and static components), and fault-tolerant system architectures.
  - Analytical and data-driven techniques for diagnosing incipient faults in the presence deterioration, engine-to-engine variation, and transient operating conditions.
  - Innovative sensing techniques for the cost-effective assessment of turbomachinery health in harsh high-temperature environments including high temperature sensors including fiber optic and Microsystems, rotatodynamics monitoring, energy harvesting, communication, and packaging.
  - Prognostic techniques for the accurate assessment of remaining component life while in-flight.

### **A1.07 Avionics Health State Assessment and Management**

**Lead Center:** ARC

**Participating Center(s):** LaRC

Shielded twisted-pair cables are already in common use on-board aircraft and spacecraft, and are destined to be ubiquitous in the all-electric aircraft designs of the future. At present, however, easy to use commercially available connector interfaces between this type of cable and electrical test equipment (such as oscilloscopes, network analyzers, or handheld diagnostic units) are not readily available, and custom-built test fixtures are the norm. Given the widespread use of this cable type in other commercial wiring applications such as DSL, NASA is investing in the research and development of a commercial-grade product to address this need. Proposals are therefore sought for the design of a novel electrical connector system (or small portable interface board) that can interface the coaxial SMA (or 2.9 mm) ports of typical high-end electrical test equipment with a shielded twisted-pair (STP) cable (2 inner conductors surrounded by a shield). The design should provide two 50 ohm coaxial SMA (or 2.9 mm) inputs, each used to individually excite the common and differential modes of the cable, and one output connection to the STP cable itself. In addition, the design should minimize the mode cross coupling caused by the connector in the frequency range of interest (0-10 GHz). Finally, a critical part of the design must include a calibration method and set of calibration standards for obtaining a high-quality Vector Network Analyzer (VNA) based measurement (using a standard VNA) of the 4 port 4x4 S-parameter matrix covering the differential and common mode ports on each end of the TSP cable from 0-10 GHz.

Proposals should address the design and the numerical verification of the connector and calibration standards in Phase I, with the experimental validation and the prototype construction reserved for Phase II. Use of a commercial electromagnetics simulator such as COMSOL is strongly encouraged. While the design does not need to be compact or inexpensive at this stage, any obvious impediments to its subsequent miniaturization or commercialization will be considered a serious weakness.

### **A1.08 Crew Systems Technologies for Improved Aviation Safety**

**Lead Center:** LaRC

The NASA Aviation Safety program aims to model and develop integrated crew-system interaction (ICS) concepts and to subsequently evaluate this concept in a relevant operational environment in comparison to state-of-the-art.

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NASA seeks proposals for novel technologies and evaluation tools with high potential to support an ICSI with effective crew-system interactions in the context of NextGen operational requirements (e.g., 4D trajectory-based operations, visual operations in non-visual meteorological conditions, etc.) and assumptions (e.g., net-centric information management environment) (NextGen described in <http://www.faa.gov/nextgen/> [3]).

To improve these interactions, we seek interventions that proactively identify and mitigate NextGen flight deck risks; address documented crew-related causal factors in accidents; and improve the ability to unobtrusively, effectively, and sensitively evaluate and model crew and crew-automation system performance. In particular, we seek proposals for the development of advanced technologies that address:

- Crew challenges associated with piloting terminal area 4D Trajectory-Based Operations in Instrument Meteorological Conditions (IMC).
- Displays, decision-support, and automation interaction under off-nominal conditions; in particular in that lead to spatial disorientation and loss of energy state awareness leading to loss-of-control (LOC).
- The appropriate levels of integrity for new classes of information to be made available to the crew as a result of NextGen's net centric information management environment.
- Pilot proficiency in increasingly automated flight decks (e.g., manual handling skill erosion).
- Optimal methods for information presentation as distributed over time and display space for multiple operators to maximize crew information processing and coordination.
- Appropriate trust in, and therefore use of, automation and complex information sources by, for example, conveying constraints on automation reliability and information certainty/timeliness.
- Effective joint cognitive system design and evaluation with multiple intelligent agents (human and automated, proximal and remote).
- Improved oculometer, neurophysiological, or other sensors and/or data integration methods that would improve the ability to characterize operator functional status in real time.
- Improved human-system interaction through effectively modulating operator state, and/or effectively adapting interfaces and automation in response to this functional status.
- Evaluation of adaptive and adaptable crew-system interfaces.
- A priori assessment of human error likelihood and consequence in NextGen scenarios

Phase I proposals that demonstrate relevance to the NASA Aviation Safety Program's VSST and/or SSAT programs, include a detailed resource-loaded schedule, literature-based justification, highly competent staffing, prescription for Phase II work, and clear path to commercialization or utilization in NASA programs are most valued.

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**Lead Center: LaRC**

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

Effective characterization of LOC conditions requires inclusion of the flight dynamics effects from multiple disciplines, including aerodynamics, structures, propulsion, and aeroelasticity. However, the types of data and data sets obtained from modeling in these various disciplines can be quite disparate, even within a discipline (e.g., wind-tunnel static versus dynamic data versus CFD flow-field data), and is exacerbated when we consider the non-linear parts of the flight envelope. Further, disciplines have varying levels of sensitivity to certain flight conditions.

Of interest are software tools that could take such disparate types of information and provide methods to manage and integrate them in a single environment to provide flight-dynamics-relevant implications. Examples include translating thrust response into force and moment increments to superimpose on the nominal aerodynamics, or applying aerodynamic load distributions to key structural components to define flight envelope boundaries based on structural load limits. Such tools can also be useful in highlighting flight conditions where data sets overlap and thus may provide good integrated model fidelity, versus conditions where fidelity may be limited, helping provide guidance on where research emphasis should be placed. Overall, concepts should be aimed at facilitating integrated model implementation into a flight simulation environment.

### **A1.10 Advanced Dynamic Testing Capability for Abnormal Flight Conditions**

**Lead Center: LaRC**

The goal of developing a comprehensive methodology for obtaining appropriate aerodynamic math models for flight vehicles over a greatly expanded flight envelope requires a more general formulation of the aerodynamic model that more accurately characterizes nonlinear steady and unsteady aerodynamics. This leads to greater demands in the development of dynamic test techniques and correspondingly more demands on test facility capabilities. This topic is for the design and software for a prototype dynamic test rig for wind or water tunnel application, with guidance for scaling up to large facilities. The concept should be aimed at providing high-automation and productivity for arbitrary, programmable, multi-axis motions, and should consider the following test capabilities that are considered an important subset of possible motions for characterizing vehicle dynamics characteristics under abnormal flight conditions: conventional single-axis forced oscillation; constant-rate motion through the use of square and triangle waveforms; steady and oscillatory coning motions; inclined axis coning; coupled, multi-axis motion; and wide-band inputs, such as Schroeder sweeps. Design should include considerations for mitigating blockage and interference effects.

### **A1.11 Transport Aircraft Simulator Motion Fidelity For Abnormal Flight Conditions**

**Lead Center: LaRC**

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

Piloted simulation remains an important enabling tool for a wide variety of research aimed at commercial aviation safety. Over the past decade, significant advances in aerodynamic modeling of large transport airplanes at high angles of attack are providing new capabilities for prediction of flight behavior in off-nominal or out-of-envelope conditions. As a result, piloted simulation is now being considered for flight training specifically aimed at stall and

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post-stall conditions. In addition, other technology areas focused on the problem of loss-of-control accidents, such as advanced controls and crew systems, now stand to benefit from this enhanced simulation capability.

Simulator motion often plays an important role in simulator fidelity. For example, hexapod motion systems are commonly used for airline flight training and are justified by the increased transfer of training with the added realism of cockpit accelerations. However, it is recognized that all motion systems have limitations and therefore maneuvers must be designed to stay within the limits of the system's capabilities and range of effectiveness. The problem of aircraft upsets and loss-of-control typically involves large-amplitude motions due to extended excursions in vehicle attitudes and angular rates, and the desire to emulate the resulting accelerations has added a new challenge to simulator motion fidelity. A response to this need has been proposals for new motion systems that provide sustained cockpit accelerations that are possible during upset events. Over the past decade, limited research has been conducted on the effects of motion on upset training (both ground-based and in-flight simulation) and one approach has involved analysis of pilot performance with various types of training.

This subtopic requests a broad study of the requirements and capabilities for simulator motion systems across the range of current and proposed systems, including fixed-base, hexapod, continuous-g and in-flight simulation. It is intended that this research be aimed at large-amplitude motions and address simulation facility requirements for research and training or other uses for a broad range of applications and technologies. In addition, proposals for new or enhanced motion cueing systems are encouraged if justified by this study.

Desired outcomes of this research include but are not limited to the following:

- Analysis of motion system requirements and cueing algorithms for large-amplitude maneuvers, including out-of-envelope or loss-of-control events for large transport airplanes.
- A comparison of maneuver envelopes for current and proposed simulator motion devices.
- Analysis of the state-of-the-art of motion systems that includes anticipated new requirements.
- Physiological considerations for transfer of fidelity and realism of cockpit motion environments.
- Benefits of various motion capabilities based on physiological factors, transfer of training, and other criteria as appropriate.
- Integration of aerodynamic buffet effects and other cockpit noise and vibration sources.
- Any other topics that are considered necessary to advance the state-of-the-art and utility of motion systems. for large amplitude maneuvers.
- Long-term recommended research and potential advantages of advanced simulator motion fidelity.

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**Lead Center: GRC**

**Participating Center(s): LaRC**

In current aircraft, the flight and propulsion controls are designed independently and pilots manually integrate them through manipulation of the cockpit controls. Although the pilot manages these individual systems well under normal conditions, an integrated design approach would be able to achieve maximum benefit from these systems under abnormal conditions, especially for energy management and coordinated control for upset prevention and recovery. NextGen operations might also benefit, especially relative to 4-D trajectory management. If properly integrated up front in the flight control design, the propulsion system could be an effective flight control actuator. However, in order to optimally integrate the two systems, the engine performance must be known. The propulsion performance is dependent on operating condition, and many safety constraints make it highly nonlinear. Thus it is necessary to have a system that can continuously predict the engine performance and constraints at the current operating condition and communicate this to the flight control system to facilitate optimal flight and propulsion integration. Ideally, the flight control system should be able to treat the propulsion system as a linear time-varying constrained system for real-time control purposes. Including the propulsion system in the flight control design provides another degree of freedom for the designer, and because the propulsion system is such a powerful actuator, it is one that potentially enhances upset prevention and recovery. Developing the ability to use the propulsion system to augment the flight control while still providing traditional pilot interaction with the cockpit controls can improve maneuverability and safety transparently.

Under this research subtopic, an approach to predicting, and communicating engine dynamic response that facilitates integrated flight and propulsion control would be developed. This is a prerequisite to utilizing the engines as flight control actuators to improve maneuverability and aid in upset prevention and recovery.

Potential NASA resources:

Commercial Modular Aero-Propulsion System Simulation40k (C-MAPSS40k) and Generic Transport Model (GTM).

### **A1.13 Advanced Upset Protection System**

**Lead Center: AFRC**

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

One of the common causes for Loss of control (LOC) is the crew's lack of awareness of the current energy state relative to the current mission phase and inappropriate response to a low or high-energy state. Technologies to prevent the development of an inappropriate energy state via manual aids and automatic approaches are crucial for the prevention of loss of control.

In large airplanes, energy management refers to the ability to know and control the complex combination of the aircraft's airspeed and speed trend, altitude and vertical speed, configuration, and thrust. For example, near-terminal operations (takeoff and landing) require precise control of airspeed to achieve optimum performance while maintaining safe stall margin, and altitude management is critical for approaches. The penalty for improper energy management can be de-stabilized approaches, excessive pilot workload leading to distraction, and ultimately inadequate altitude or airspeed to recover from a loss-of-control event (e.g., stall). Many loss-of-control incidents/accidents can be attributed to improper management of airspeed, especially those leading to aerodynamic stall or departure from controlled flight.

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Under this research subtopic, an envelope protection system would be developed to prevent low and high energy states based on the aircraft's current mission phase objectives. The envelope protection system should investigate the automatic use of the propulsion system, landing gear and secondary flight controls to maintain energy state. Methods to display information on system status to the pilot should also be considered to prevent adverse pilot interaction with the envelope protection system. Use on both current and NextGen aircraft should also be considered.

#### **A1.14 Detection, Identification, and Mitigation of Sensor Failures**

**Lead Center:** LaRC

**Participating Center(s):** AFRC, ARC

Faults related to aircraft sensing systems have been a major cause of loss-of-control accidents and incidents. For example, an airspeed sensing system fault is suspected of setting into motion a chain of events that resulted in the loss of Air France flight 447 (June 2009); a faulty altimeter is suspected in the stall and crash of Turkish Airline flight 1951 (February 2009); and faulty angle-of-attack sensing is suspected of causing violent uncommanded motion in Qantas Flight 72 (October 2008). Sensor redundancy is essential to ensure safety and reliability of the flight systems; however, redundancy alone may not be sufficient to avoid problems due to common mode failures across redundant sensors (such as suspected Pitot tube icing in all airspeed sensors). Therefore, research is needed to utilize all information available from multiple- possibly diverse- sensors in order to rapidly detect and isolate sensor faults in real time. The research would involve information fusion across multiple sensors, detection of erroneous behavior within a sensor or sensor suite, and mitigation of information loss through algorithmic redundancy and design to estimate the lost information from a failed sensor. The aim of the research would be to develop technology to prevent loss of control due to sensing system faults.

#### **A1.15 Unmanned Vehicle Design for Loss-of-Control Flight Research**

**Lead Center:** LaRC

**Participating Center(s):** AFRC

Recent advances in unmanned vehicle systems have enabled subscale flight testing using remotely piloted or autonomous vehicles to obtain high fidelity estimates of key aircraft performance parameters. An important requirement for obtaining relevant dynamic flight data from subscale vehicles is to apply dynamic scaling to the aircraft, so as to provide scaled inertial and mass properties, as well as geometric similitude.

The use of these vehicles is of particular interest in aviation safety studies because they allow exploration into unusual flight attitudes and upset conditions that are difficult to test in full scale aircraft due to structural limits and other safety concerns. Models of the stall and departure characteristics, as can be identified through flight testing, are needed to improve both aircraft training simulators as well as allow the design of control systems to reduce loss-of-control accidents.

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Proposals are sought for a subscale civil transport vehicle design for remotely operated flight testing that allows a wide range of vehicle configurations. The vehicle should be modular in construction to emulate configurations representative of both conventional tail jet transports with under-wing engines and T-tail transports with rear mounted engines. In addition, the design should allow ballasting to achieve a range of target inertias and center of gravity locations. The ability to introduce flexible components for aeroelastic effects, as well components to model structural and control surface failures are also of interest.

Proposals should address construction methods that allow tradeoffs in costs and complexity while maintaining structural integrity required for loss-of-control flight testing. Control surfaces should be distributed to provide redundancy and allow for experiments involving actuator failures and in-flight dynamic simulation. Vehicle size should be consistent with commercially available turbine engines and allow road transport with manual field assembly.

#### **A1.16 Validation Methods for Safety-Critical Systems Operating under LOC Conditions**

**Lead Center:** LaRC

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

Validation of future complex integrated systems designed to ensure flight safety under off-nominal conditions associated with aircraft loss of control is a significant challenge. Future systems will ensure vehicle flight safety by integrating vehicle health management functions, resilient control functions, flight safety assessment and prediction functions, and crew interface and variable autonomy functions. Each of these functions is characterized by algorithmic diversity that must be addressed in the validation process. Vehicle health management involves diagnostic and prognostic algorithms that utilize stochastic decision-based reasoning and extensive information processing and data fusion. Resilient control functions can involve adaptive control algorithms that utilize time-varying parameters and/or hybrid system switching. Flight safety management may involve diagnostic and prognostic reasoning algorithms as well as control theoretic algorithms. Crew interface functions involve displays that are human-factors-based and require information processing and reasoning, and variable autonomy will require assessment and reasoning algorithms. Onboard modeling functions will involve system identification algorithms and databases. Normal operating conditions of the future may extend beyond current-day operational limits. Moreover, safe operation under off-nominal conditions that could lead to loss-of-control events will be a focus of the system design. In particular, operation under abnormal flight conditions, external hazards and disturbances, adverse onboard conditions, and key combinations of these conditions will be a major part of the operational complexity required for future safety-critical systems. Future air transportation systems must also be considered under operational complexity, such as requirements for dense all-weather operations, self separation of aircraft, and mixed capabilities of aircraft operating in the same airspace, including current and future vehicle configurations as well as piloted and autonomous vehicles.

System validation is a confirmation that the algorithms are performing the intended function under all possible operating conditions. The validation process must be capable of identifying potentially problematic regions of operation (and their boundaries) and exposing system limitations - particularly for operation under off-nominal and hazardous conditions related to loss of control. New methods, metrics, and software tools must be established for algorithms that cannot be thoroughly evaluated using existing methods. Innovative research proposals are sought to address any of the following areas:

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- Analytical Validation Methods.
  - Predictive Capability Assessment Methods.
  - Real-Time (or Run-Time) Validation Methods.

Analytical validation methods are comprised of a set of analytical methods and tools that facilitate the accurate prediction of system properties under various operating and off-nominal conditions. A wide variety of analytical methods will be needed to evaluate stability and performance of various and dissimilar system functions, robustness to adverse and abnormal conditions, and reliability under errors, faults, failures, and damage. These methods and software tools will be utilized offline and prior to implementation in representative avionics system software and hardware. These methods will enable analysis under a wide range of conditions, and be used to facilitate nonlinear simulation-based and experimental evaluations under selected potentially problematic conditions in order to expose system deficiencies and limitations over a very large operational space. Analytical methods and tools applicable to determining stability, performance, robustness, and reliability of nonlinear, time-varying, and/or hybrid systems involving control theoretic, diagnostic/prognostic, and/or reasoning systems are sought.

Predictive capability assessment is an evaluation of the validity and level of confidence that can be placed in the validation process and results under nominal and off-nominal conditions (and their associated boundaries). The need for this evaluation arises from the inability to fully evaluate these technologies under actual loss-of-control conditions. A detailed disclosure is required of model, simulation, and emulation validity for the off-nominal conditions being considered in the validation, interactions that have been neglected, assumptions that have been made, and uncertainties associated with the models and data. Cross-correlations should be utilized between analytical, simulation and ground test, and flight test results in order to corroborate the results and promote efficiency in covering the very large space of operational and off-nominal conditions being evaluated. The level of confidence in the validation process and results must be established for subsystem technologies as well as the fully integrated system. This includes an evaluation of error propagation effects across subsystems, and an evaluation of integrated system effectiveness in mitigating off-nominal conditions and preventing cascading errors, faults, and failures across subsystems. Metrics for performing this evaluation are also needed. Uncertainty-based and/or statistical-based methods and tools that enable the determination of level of confidence in the validation of uncertain systems operating under extreme conditions are sought.

Real-time (or run-time) validation methods are needed for the onboard monitoring of crucial system properties whose violation could compromise safety of flight. These properties might include closed-loop stability, robustness margins, or underlying theoretical assumptions that must not be violated. This information could be used as part of a real-time safety-of-flight assessment system for the vehicle. Real-time methods and software tools are sought that enable onboard validation of nonlinear, time-varying, and reasoning systems.

## **A1.17 Data Mining and Knowledge Discovery**

**Lead Center: ARC**

The fulfillment of the SSAT project's goal requires the ability to transform the vast amount of data produced by the

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aircraft and associated systems and people into actionable knowledge that will aid in detection, causal analysis, and prediction at levels ranging from the aircraft-level, to the fleet-level, and ultimately to the level of the national airspace. The vastness of this data means that data mining methods must be efficient and scalable so that they can return results quickly. Additionally, much of this data will be distributed among multiple systems. Data mining methods that can operate on the distributed data directly are critical because centralizing large volumes of data is typically impractical. However, these methods must be provably able to return the same results as what a comparable method would return if the data could be centralized because this is a critical part of verifying and validating these algorithms, which is important for aviation safety applications. Additionally, algorithms that can learn in an online fashion---can learn from new data in incremental fashion without having to re-learn from the old data---will be important to allow deployed algorithms to update themselves as the national airspace evolves. The data is also heterogeneous: it consists of text data (e.g., aviation safety reports), discrete sequences (e.g., pilot switches, phases of flight), continuous time-series data (e.g., flight-recorded data), radar track data, and others. Data mining methods that can operate on such diverse data are needed because no one data source is likely to be sufficient for anomaly detection, causal analysis, and prediction.

This topic will yield efficient and scalable data-driven algorithms for anomaly detection, causal analysis, and prediction that are able to operate at levels ranging from the aircraft level to the fleet level. To that end, the methods must be able to efficiently learn from vast historical time-series datasets (at least 10 TB) that are heterogeneous (contain continuous, discrete, and/or text data). Distributed data-driven algorithms that provably return the same results as a comparable method that requires data to be centralized are also of great interest. Online algorithms that can update their models in incremental fashion are also of great interest for this subtopic.

## **A1.18 Prognostics and Decision Making**

**Lead Center:** ARC

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

The benefit of prognostics will be realized by converting remaining life estimates and dynamically changing context information into actionable decisions. These decisions can then be enacted at the appropriate level, depending on the prognostic time horizon and safety criticality of the affected area. In particular, information about RUL could be used either reflexively, through resource re-allocation, through mission replanning, or through appropriate maintenance action.

To maximize the impact, it is necessary to provide an accurate and precise prognostic output, carefully manage uncertainty, and provide an appropriate contingency. This effort addresses the development of innovative methods, technologies, and tools for the prognosis of aircraft faults and failures in aircraft systems and how to decide on remedial actions.

Areas of interest include the development of methods for estimation of RUL, which take into account future operational and environmental conditions; for dealing with inherent uncertainties; for building physics-based models of degradation; for generation of example aging and degradation datasets on relevant components or subsystems; and for development of validation and verification methodologies for prognostics.

Research should be conducted to demonstrate technical feasibility during Phase I and to show a path toward a

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Phase II technology demonstration. Proposals are solicited that address aspects of the following areas:

- Novel RUL prediction techniques that improve accuracy, precision, and robustness of RUL output, for example through the fusion of different methods.
- Uncertainty representation and management (reduction of prediction uncertainty bounds) methods. Proposers are encouraged to consider uncertainties due to measurement noise, imperfect models and algorithms, as well as uncertainties stemming from future anticipated loads and environmental conditions.
- Contingency management methods that act on predictive information. Particular interest is for methods that address the medium-and long term prognostic horizons.
- Verification and validation methods for prognostic algorithms.
- Aircraft relevant test beds that can generate aging and degradation datasets for the development and testing of prognostic techniques.

All methods should be demonstrated on a set of fault modes for a device or component such as composite airframe structures, engine turbomachinery and hot structures, avionics, electrical power systems, or electronics. Prognostic performance needs to be measured on benchmark data sets using prognostic metrics for accuracy, precision, and robustness. Metrics should include prognostic horizon (PH), alpha-lambda, relative accuracy (RA), convergence, and R\_delta.

### **A1.19 Technologies for Improved Design and Analysis of Safety-Critical Dynamic Systems**

**Lead Center: ARC**

The NASA Aviation Safety program seeks proposals to support the development of robust human interactive, dynamic, safety-critical systems. The aviation Safety program is particularly interested in methods and tools that support predictive analysis of Human - Automation Interaction of mixed initiative systems in complex environments.

Information complexity in aviation systems is increasing exponentially, and designers and evaluators of these systems need tools to understand, manage, and estimate the performance and safety characteristics early in the design process. NASA seeks innovative design methods and tools for representing the complex human-automation interactions that will be part of future safety-critical, dynamic, mixed initiative systems. In addition, NASA seeks tools and methods for estimating, measuring, and/or evaluating the performance of these designs throughout the lifecycle from preliminary design to operational use - with an emphasis on the early stages of conceptual design. Specific areas of interest include the following:

- Computational/modeling approaches to support determining appropriate human-automation function allocations with respect to safety and reliability. Specifically these methods should focus on metrics that

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describe the robustness and resilience of a proposed human - automation function allocation.

- Analysis tools and methods that improve the application of human-centered design principles to the design and certification of mixed human-automated systems.
- Design and analysis methods or tools to better predict and assess human and system performance in relevant operational environments (e.g., future generations of air traffic management) , particularly in regards to procedural errors. Specifically, this work should include performance estimates that account for differences in training and proficiency.
- Analysis tools to support the use of mixed initiative systems in off-nominal conditions.
- Tools that provide validated human performance analysis early in the design process.

Proposals should describe novel design methods, metrics, and/or tools with high potential to serve the objectives of the Human Systems Solutions element of NASA's Aviation Safety Program's System-wide Safety Assurance Technologies project. Successful Phase I proposals should provide a literature review that on which the proposed work is based, a detailed schedule, and should culminate in a final report that specifies, and a Phase II proposal that would realize, tools that improve the analysis process for human-automation systems in aerospace, or improves the ability to assess effectiveness of such systems during the design phase. All proposals should discuss means for verification and validation of proposed methods and tools in operationally valid, or end-user, contexts.

## **A1.20 Verification and Validation of Flight-Critical Systems**

**Lead Center: ARC**

**Participating Center(s): AFRC, LaRC**

The Aviation Safety program has been put in charge of addressing the JPDO concerns that current V&V techniques are not sufficient to verify and validate NextGen. This is reflected in the VVFC element under the SSAT project in the Aviation Safety program.

VVFC has four major themes:

- Argument-based safety assurance, which aims at unifying and formalizing how V&V results for ground and airborne software systems are folded into a safety argument for certification.
- Distributed Systems, which aims at developing guidance on the V&V of distributed applications, e.g., communication topologies, mixed-criticality architectures, and fault tolerance schemes.
- Authority and Autonomy, which explores the modeling and analysis of authority problems in the NAS when viewed as a distributed system within which automation and humans interact.
- Software-intensive systems, which focuses on early, formal methods for the V&V of software systems.

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This year, VVFC is interested in technologies that can be transitioned (meaning that tools are made available) to industry in the following areas:

- Run-time monitoring.
- Safety case.
- Static analysis.
- Code libraries implementing fundamental technologies that can be used in formal method research, such as:
  - Memory and time efficient decision procedures.
  - Memory and time efficient abstractions for static analysis.

## Fundamental Aeronautics Topic A2

The Fundamental Aeronautics Program conducts cutting-edge research to achieve technological capabilities necessary to overcome national challenges in air transportation including reduced noise, emissions, and fuel consumption, increased mobility through a faster means of transportation, and the ability to ascend/descend through planetary atmospheres. These technological capabilities enable design solutions for performance and environmental challenges of future air vehicles. Research in revolutionary aircraft configurations, lighter and stronger materials, improved propulsion systems, and advanced concepts for high lift and drag reduction all target the efficiency and environmental compatibility of future air vehicles. The program develops physics-based, multidisciplinary design, analysis and optimization tools to enable evaluation of new vehicle designs and to assess the potential impact of design innovations on a vehicle's overall performance. The FA Program consists of four projects:

- Subsonic Fixed Wing addresses the challenge of enabling revolutionary energy efficiency improvements of subsonic/transonic transport aircraft that dramatic reduce harmful emissions and noise for sustained growth of the air transportation system Improvements in prediction tools and new experimental methods Noise prediction and reduction technologies for airframe and propulsion systems Emissions reduction technologies and prediction tools Improved vehicle performance through design and development of lightweight, multifunctional and durable structural components, low drag aerodynamic components, and higher bypass ratio engines with efficient power plants, and advanced aircraft configurations Reduce take off and landing field length requirements Multi-disciplinary design and analysis tools and processes.
- Subsonic Rotary Wing addresses the challenge of radically improving the transportation system using

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rotary wing vehicles by increasing speed, range, and payload while decreasing noise and emissions. Enable variable-speed rotor concepts Contain the external noise within the landing area and reduce internal noise Assess multiple active rotorcraft concepts Advance technologies such as crashworthiness, safe operations in icing conditions, and condition based maintenance methodologies.

- Supersonics addresses the challenge of eliminating the environmental and performance barriers that prevent practical supersonic vehicles (cruise efficiency, noise and emissions, performance) Efficiency (supersonic cruise, light weight and durability at high temperature) Jet noise reduction relative to an unsuppressed jet Light weight and durability at high temperature) Environmental challenges (airport noise, sonic boom, high altitude emissions) Performance challenges (aero-propulso-servo-elastic analysis and design, cruise lift/drag ratio) Multidisciplinary design, analysis and optimization challenges.
- Hypersonics addresses the challenge of enabling airbreathing access to space and high mass entry, descent, and landing into planetary atmospheres Fundamental research to enable very-high speed flight (for airbreathing launch vehicles) and Entry, Descent and Landing into planetary atmospheres High-temperature materials, thermal protection systems (single and multi-use), airbreathing propulsion, aerothermodynamics, multi-disciplinary analysis and design, guidance, navigation, and control, advanced experimental capabilities, and supersonic decelerator technologies Accurate predictive models for high-speed compressible flow including turbulence, heating, ablation, combustion, and their interactions in order to reduce the uncertainty in predictions of aerodynamic heat loads during the design of hypersonic vehicles Additional information: (<http://www.aeronautics.nasa.gov/fap/index.html> [4]).

Sub Topics:

## **A2.01 Materials and Structures for Future Aircraft**

**Lead Center: GRC**

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

Advanced materials and structures technologies are needed in all four of the NASA Fundamental Aeronautics Program research thrusts (Subsonics Fixed Wing, Subsonics Rotary Wing, Supersonics, and Hypersonics) to enable the design and development of advanced future aircraft. Proposals are sought that address specific design and development challenges associated with airframe and propulsion systems. These proposals should be linked to improvements in aircraft performance indicators such as vehicle weight, fuel consumption, noise, lift, drag, durability, and emissions. In general, the technologies of interest cover five research themes:

### **Fundamental Materials Development, Processing and Characterization**

Innovative approaches to enhance the durability, processability, performance and reliability of advanced materials (metals, ceramics, polymers, composites, nanostructured materials, hybrids and coatings). In particular, proposals are sought in:

- Advanced high temperature materials for aircraft engine and airframe components and thermal protection systems, including advanced blade and disk alloys, ceramics and CMCs, polymers and PMCs, nanostructured materials, hybrid materials and coatings to improve environmental durability.
- New adaptive materials such as piezoelectric ceramics, shape memory alloys, shape memory polymers, and variable stiffness materials and methods to integrate these materials into airframe and/or aircraft engine structures to change component shape, dampen vibrations, and/or attenuate acoustic transmission through the structure.
- Multifunctional materials and structural concepts for engine and airframe structures, such as novel approaches to power harvesting and thermal management, lightning strike mitigating, self-sensing, and materials for wireless sensing and actuation.

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- New high strength fibers, in particular low density, high strength and stiffness carbon fibers.
  - Innovative processing methods to reduce component manufacturing costs and improve damage tolerance, performance and reliability of ceramics, shape memory alloys, polymers, composites, and hybrids, nanostructured and multifunctional materials and coatings.
  - Development of joining and integration technologies including fasteners and/or chemical joining methods for ceramic-to-ceramic, metal-to-metal (with an emphasis on joining dissimilar forms of nickel base superalloys, e.g., powder metallurgy to cast or directionally solidified alloys), and metal-to-ceramic as well as solid state joining methods such as advanced friction stir welding.
  - Innovative methods for the evaluation of advanced materials and structural concepts (in particular multifunctional and/or adaptive) under simulated operating conditions, including combinations of electrical, thermal and mechanical loads.
  - Nondestructive evaluation (NDE) methods for the detection of as-fabricated flaws and in-service damage for textile polymeric, ceramic and metal matrix composites, nanostructured materials and hybrids. NDE methods that provide quantitative information on residual structural performance are preferred.

### **Structural Analysis Tools and Procedures**

Robust and efficient design methods and tools for advanced materials and structural concepts (in particular multifunctional and/or adaptive components) including variable fidelity methods, uncertainty based design and optimization methods, multi-scale computational modeling, and multi-physics modeling and simulation tools. In particular, proposals are sought in:

- Multiscale design tools for aircraft and engine structures that integrate novel materials, mechanism design, and structural subcomponent design into systems level designs.
- Life prediction tools for textile composites including fiber architecture modeling methods that enable the development of physics-based hierarchical analysis methods. Fiber architecture models that address yarn-to-yarn and ply-to-ply interactions covering a wide range of textile perform structures in either a relaxed or compressed deformation state as well as tools to predict debonding and delamination of through thickness reinforced (stitched, z-pinned) composites are of particular interest.
- Tools to predict durability and damage tolerance of new material forms including metallic-composite hybrids, friction stir-welded metallic materials and powder metallurgy-formed materials.
- Meso scale tools to guide materials placement to enable tailored load paths in multifunctional structures for enhanced damage tolerance.

### **Computational Materials Development Tools**

Methods to predict properties, damage tolerance, and/or durability of both airframe and propulsion materials, thermal protection systems and ablatives based upon chemistry and processing for conventional as well as functionally graded, nanostructured, multifunctional and adaptive materials. In particular proposals are sought in:

- Ab-initio methods that enable the development of coatings for multiple uses at temperatures above 3000°F in an air environment.

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- Computational tool development for structure-property modeling of adaptive materials such as piezoelectric ceramics, shape memory alloys, shape memory polymers to characterize their physical and mechanical behavior under the influence of an external stimulus.
  - Computational and analytical tools to enable molecular design of polymeric and/nanostructured materials with tailored multifunctional characteristics.
  - Computational microstructural and thermodynamic analysis tools and technique development for designing new lightweight alloy compositions for subsonic airframe and engines from first principles, functionally graded (chemically or microstructurally) materials, and/or novel metals processing techniques to accelerate materials development and understanding of processing-structure-property relationships.
  - Software tools to predict temperature dependent phase chemistries, volume fractions, shape and size distributions, and lattice parameters of phases in a broad range of nickel and iron-nickel based superalloys. Toolset should utilize thermodynamic and kinetic databases and models that are fully accessible, which allow modifications and user-input to expand experimental databases and refine model predictions.

### **Advanced Structural Concepts**

New concepts for airframe and propulsion components incorporating new light weight concepts as well as "smart" structural concepts such as those incorporating self-diagnostics with adaptive materials, multifunctional component concepts to reduce mass and improve durability and performance, lightweight, efficient drive systems and electric motors for use in advanced turboelectric propulsion systems for aircraft, and new concepts for robust thermal protection systems for high-mass planetary entry, descent and landing. In particular, proposals are sought in:

- Innovative structural concepts, materials, manufacturing and fabrication leading to reliable, entry descent and landing systems including deployable rigid and flexible heat shields and structurally integrated multifunctional systems. Of particular interest are high temperature honeycombs, hat stiffeners, rigid fibrous and foam insulators, as well as high temperature adhesives, films and fabrics for advanced flexible heat shields.
- New actuator concepts employing shape memory alloys.
- Advanced mechanical component technologies including self-lubricating coatings, oil-free bearings, and seals.
- Advanced material and component technologies to enable the development of mechanical and electrical drive system to enable the development of turboelectric propulsion systems, which utilize power from a single turbine engine generator to drive multiple propulsive fans. Innovative concepts are sought for AC-tolerant, low loss ( 1.5 T field and 500 Hz electrical frequency; and high efficiency (= 30% of Carnot), low mass (
- Novel structural designs for integrated fan cases that combine hardwall composite cases for blade containment with acoustic treatments as well as concepts that integrate the case with the fan inlet to maximize structural, acoustic attenuation and weight benefits.
- Innovative approaches to structural sensors for extreme environments (>1800°F) including the development and validation of improved methods (i.e., adhesives, plasma spraying techniques, etc.) for attaching sensors to advanced high-temperature materials as well as approaches to measure strain, temperature, heat flux and/or acceleration of structural components.

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## A2.02 Combustion for Aerospace Vehicles

Lead Center: GRC

Participating Center(s): LaRC

Combustion research is critical for the development of future aerospace vehicles. Vehicles for subsonic and supersonic flight regimes will be required to emit extremely low amounts of gaseous and particulate emissions to satisfy increasingly stringent emissions regulations. Hypersonic vehicles require combustion systems capable of sustaining stable and efficient combustion in very high speed flow fields where fuel/air mixing must be accomplished very rapidly and residence times for combustion are extremely limited; a major challenge is developing scaling laws that will allow the size of scramjet engines to be increased by a factor of 10, i.e., to mass flow rates of 100 lbm/sec. Fundamental combustion research coupled with associated physics based model development of combustion processes will provide the foundation for technology development critical for aerospace vehicles. Combustion for aerospace vehicles typically involves multi-phase, multi-component fuel, turbulent, unsteady, 3D, reacting flows where much of the physics of the processes are not completely understood. CFD codes used for combustion do not currently have the predictive capability that is typically found for non reacting flows. Practical aerospace combustion concepts typically require very rapid mixing of the fuel and air with a minimum pressure loss to achieve complete combustion in the smallest volume. Reducing emissions may require combustor operation where combustion instability can be an issue and active control may be required. Areas of specific interest where research is solicited includes:

- Development of laser-based diagnostics and novel experimental techniques for measurements in reacting flows.
- Two-phase flow simulation models and validation data under supercritical conditions.
- Development of ultra-sensitive instruments for measuring gas turbine black carbon emissions at temperatures and pressures characteristic of commercial aircraft cruise altitudes.
- High frequency actuators (bandwidth ~1000 Hz) that can be used to modulate fuel flow at multiple fuel injection locations (with individual Flow Numbers of 3 to 5) with minimal fuel pressure drop for active combustion control.
- Combustion instability modeling and validation.
- Novel combustion simulation methodologies.
- Concepts that will allow the scaling of scramjet engines burning hydrogen and/or hydrocarbon fuels.

The following areas are of particular interest:

- The effect that size has on mixing, injection, and thermal loading losses.
- The effect of size on mixing and flame propagation.
- The effect of size on injection strategies.

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- The scaling of ignition devices, flameholders, and mixing devices.
  - The effect that the size and thickness of the incoming boundary layer has on ignition devices and flameholders.
  - Whether there is a ratio between the size of inviscid stirring structures and turbulent structures that is optimal for rapid mixing.

### **A2.03 Aero-Acoustics**

**Lead Center:** LaRC

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

Innovative technologies and methods are necessary for the design and development of efficient, environmentally acceptable airplanes, and advanced aerospace vehicles. In support of the Fundamental Aeronautics Program, improvements in noise prediction, measurement methods and control are needed for subsonic and supersonic vehicles, including fan, jet, turbomachinery, engine core, open rotor, propeller and airframe noise sources. In addition, improvements in prediction and control of noise transmitted through aerospace vehicle structures are needed to reduce noise impact on passengers and crew. Innovations in the following specific areas are solicited:

- Fundamental and applied computational fluid dynamics techniques for aeroacoustic analysis, which can be adapted for design codes.
- Prediction of aerodynamic noise sources including those from engine and airframe as well as sources, which arise from significant interactions between airframe and propulsion systems.
- Efficient prediction tools for turbine and combustor aeroacoustics.
- Efficient high-fidelity computational fluid dynamics tools for assessing aeroacoustic performance of installed high and low speed single- and counter-rotation propellers.
- Innovative source identification techniques for engine (e.g., fan, jet, combustor, or turbine noise) and for airframe (e.g., landing gear, high lift systems) noise sources, including turbulence details related to flow-induced noise typical of jets, separated flow regions, vortices, shear layers, etc.
- Concepts for active and passive control of aeroacoustic noise sources for conventional and advanced aircraft configurations, including adaptive flow control technologies, smart structures for nozzles and inlets, advanced acoustic liners, and noise control technology and methods that are enabled by advanced aircraft configurations, including integrated airframe-propulsion control methodologies.
- Prediction of near field sound propagation including interaction between noise sources and the airframe and its flow field and far field sound propagation (including sonic booms) from the aircraft through a complex atmosphere to the ground.
- Computational and analytical structural acoustics prediction techniques for aircraft and advanced aerospace vehicle interior noise, particularly for use early in the airframe design process;
- Technologies and techniques for active and passive interior noise control for aircraft and advanced aerospace vehicle structures. Prediction and control of high-amplitude aeroacoustic loads on advanced aerospace structures and the resulting dynamic response and fatigue.

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- Development of synthesis and auditory display technologies for subjective assessments of aircraft community and interior noise, including sonic boom.

## **A2.04 Aeroelasticity**

**Lead Center:** LaRC

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

The NASA Fundamental Aeronautics program has the goal to develop system-level capabilities that will enable civilian and military designers to create revolutionary systems, in particular by integrating methods and technologies that incorporate multi-disciplinary solutions. Aeroelastic behavior of flight vehicles is a particularly challenging facet of that goal.

The program's work on aeroelasticity 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 aeroelasticity through novel and creative application of aeroelastic knowledge.

The technical discipline of aeroelasticity is a critical ingredient necessary in the design process of a flight vehicle for ensuring freedom from catastrophic aeroelastic and aeroservoelastic instabilities. This discipline requires a thorough understanding of the complex interactions between a flexible structure and the unsteady aerodynamic forces acting on the structure and at times, active systems controlling the flight vehicle. Complex unsteady aerodynamic flow phenomena, particularly at transonic Mach numbers, are also very important because this is the speed regime most critical to encountering aeroelastic instabilities. In addition, aeroelasticity is presently being exploited as a means for improving the capabilities of high performance aircraft through the use of innovative active control systems using both aerodynamic and smart material concepts. Work to develop analytical and experimental methodologies for reliably predicting the effects of aeroelasticity and their impact on aircraft performance, flight dynamics, and safety of flight are valuable. Subjects to be considered include:

- Development of design methodologies that include CFD steady and unsteady aerodynamics, flexible structures, and active control systems.
- Development of methods to predict aeroelastic phenomena and complex steady and unsteady

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aerodynamic flow phenomena, especially in the transonic speed range. Aeroelastic phenomena of interest include flutter, buffet, buzz, limit cycle oscillations, divergence, and gust response; flow phenomena of interest include viscous effects, vortex flows, separated flows, transonic nonlinearities, and unsteady shock motions.

- Development of efficient methods to generate mathematical models of wind-tunnel models and flight vehicles for performing vibration, aeroelastic, and aeroservoelastic studies. Examples include (a) CFD-based methods (reduced-order models) for aeroservoelasticity models that can be used to predict and alleviate gust loads, ride quality issues, and flutter issues and (b) integrated tool sets for fully coupled modeling and simulation of aeroservoelastocity / flight dynamic (ASTE/FD) and propulsion effects.
- Development of physics-based models for turbomachinery aeroelasticity related to highly separated flows, shedding, rotating stall, and non-synchronous vibrations (NSV). This includes robust, fast-running, accelerated convergence, reduced-order CFD approaches to turbomachinery aeroelasticity for propulsion applications. Development of blade vibration measurement systems (including closely spaced modes, blade-to-blade variations (mistuning), and system identification) and blade damping systems for metallic and composite blades (including passive and active damping methods) are of interest.
- Development of aeroservoelasticity concepts and models, including unique control concepts and architectures that employ smart materials embedded in the structure and/or aerodynamic control surfaces for suppressing aeroelastic instabilities or for improving performance.
- Development of techniques that support simulations, ground testing, wind-tunnel tests, and flight experiments of aeroelastic phenomena.
- Investigation and development of techniques that incorporate structure-induced noise, stiffness and strength tailoring, propulsion-specific structures, data processing and interpretation methods, non-linear and time-varying methods development, unstructured grid methods, additional propulsion systems-specific methods, dampers, multistage effects, non-synchronous vibrations, coupling effects on blade vibration, probabilistic aerodynamics and aeroelastics, actively controlled propulsion system core components (e.g., fan and turbine blades, vanes), and advanced turbomachinery active damping concepts.
- Investigation and development of techniques that incorporate lightweight structures and flexible structures under aerodynamic loads, with emphasis on aeroelastic phenomena in the hypersonic domain. Investigation of high temperatures associated with high heating rates, resulting in additional complexities associated with varying thermal expansion and temperature dependent structural coefficients. Acquisition of data to verify analysis tools with these complexities.

## **A2.05 Aerodynamics**

**Lead Center:** LaRC

**Participating Center(s):** AFRC, ARC, GRC, JSC, MSFC

The challenge of flight has at its foundation the understanding, prediction, and control of fluid flow around complex geometries - aerodynamics. Aerodynamic prediction is critical throughout the flight envelope for subsonic, supersonic, and hypersonic vehicles - driving outer mold line definition, providing loads to other disciplines, and enabling environmental impact assessments in areas such as emissions, noise, and aircraft spacing.

In turn, high confidence prediction enables high confidence development and assessment of innovative aerodynamic concepts. This subtopic seeks innovative physics-based models and novel aerodynamic concepts, with an emphasis on flow control, applicable in part or over the entire speed regime from subsonic through hypersonic flight.

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All vehicle classes will experience subsonic flight conditions. The most fundamental issue is the prediction of flow separation onset and progression on smooth, curved surfaces, and the control of separation. Supersonic and hypersonic vehicles will experience supersonic flight conditions. Fundamental to this flight regime is the sonic boom, which to date has been a barrier issue for a viable civil vehicle. Addressing boom alone is not a sufficient mission enabler however, as low drag is a prerequisite for an economically viable vehicle, whether only passing through the supersonic regime, or cruising there. Atmospheric entry vehicles and space access vehicles will experience hypersonic flight conditions. Reentry capsules and vehicles deploy multiple parachutes during descent and landing. Predicting the physics of unsteady flows in supersonic and subsonic speeds is important for the design of these deceleration systems. The gas-dynamic performance of decelerators for vehicles entering the atmospheres of planets in the solar system is not well understood. Reusable hypersonic vehicles will be designed such that the lower body can be used as an integrated propulsion system in cruise condition. Their performance is likely to suffer in off-design conditions, particularly acutely at transonic speeds. Advanced flow control technologies are needed to alleviate the problem.

This solicitation seeks proposals to develop and validate:

- Turbulence models and advanced computational techniques such as detached eddy, large eddy, or direct numerical simulations that capture the physics of separation onset at Reynolds numbers relevant to flight, where relevant to flight is dependent on a targeted vehicle class and mission profile.
- Boundary-layer transition models suitable for direct integration with state-of-the-art flow solvers.
- Active flow control concepts targeted at separation control, shock wave manipulation, and/or viscous drag reduction with an emphasis on the development of novel, practical, lightweight, low-energy actuators.
- Innovative aerodynamic concepts targeted at vehicle efficiency or control, including but not limited to concepts targeted at turbulent boundary skin friction drag reduction.
- Physics-based models for simultaneous low boom/low drag prediction and design.
- Aerodynamic concepts enabling simultaneous low boom and low drag objectives.
- Innovative methods to validate both flow models and aerodynamic concepts with an emphasis on aft-shock effects, which are hindered by conventional wind tunnel model mounting approaches.
- Uncertainty quantification methods suitable for use with state-of-the-art flow solvers.
- Accurate aerodynamic analysis and multidisciplinary design tools for multi-body flexible structures in the atmospheres of planets and moons including the Earth, Mars, and Titan.
- Advanced flow control technologies to alleviate off-design performance penalties for reusable hypersonic vehicles.

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## A2.06 Aerothermodynamics

Lead Center: ARC

Participating Center(s): AFRC, GRC, LaRC

Development of hypersonic flight vehicles for airbreathing access to space and for planetary entry poses several design challenges. One of the primary obstacles is the large uncertainty in predictive capability of the aerothermal environment to which these vehicles are subjected. For airbreathing access to space vehicles, predictions of boundary layer transition to turbulence and shock boundary layer interactions in a turbulent flow regime are sources of large aerothermal uncertainty and require conservative assumptions. For planetary entry vehicles with either rigid or flexible thermal protection systems (TPS), sources of large aerothermal uncertainty in high enthalpy conditions also include the catalytic or ablative properties of the TPS. The fluid dynamic and thermochemical interactions of a rough ablating surface with the aerothermal environment leads to many poorly understood coupled phenomena such as early boundary layer transition, turbulent heating augmentation, catalytic heating, radiation absorption, etc. At high entry speeds and large vehicle sizes, shock layer radiation becomes a large component of the aeroheating, with an increasing fraction of the radiation produced in the poorly understood vacuum ultraviolet part of the spectrum. The low confidence in the predictive capability is apparent in high enthalpy flows that are often difficult to adequately reproduce in a ground test facility.

The model uncertainties require designers to resort to large margins, resulting in reduced mission capabilities and increased costs. Future science and human exploration missions to Mars and other planets will require dramatic improvements in our current capability to land large payloads safely on these worlds. Research in aerothermodynamics focuses on solving some of the most difficult challenges in hypersonic flight. These include the development of predictive models via experimental validation for shock layer radiation phenomena, non-equilibrium thermodynamic and transport properties, catalycity, transition and turbulence, and ablation phenomena, as well as the development of new experimental datasets, especially in high enthalpy flow that can be used to validate theoretical and computational models.

Proposals suggesting innovative approaches to any of these problems are encouraged; specific areas of interest include:

- Advancement of NASA boundary layer transition tools, especially including high enthalpy effects.
- Development of shock turbulent boundary layer interaction models and validation with an experimental program.
- Development of radiation models supported by experimental validation in a laboratory (using shock tube, plasma torch, etc.) simulating extreme entry environments at Earth, Mars, Titan, and the Giant Planets.
- Development of high enthalpy RANS level turbulence models in a rough, ablating environment using experimentation or use of high fidelity computational techniques such as DNS or LES.
- Development of instrumentation for use in high-enthalpy flows to measure pressure, shear, radiation intensity, and off body flow quantities with enhanced capability such as high frequency measurements and/or high temperature tolerance.
- Development of tools and techniques that enable remote thermal imaging of entry vehicles with high temperature and spatial resolution, and lower uncertainty than the state-of-the art.
- Development of numerical techniques and computational tools that advance the start-of-the-art in computations of unsteady, turbulent separated flows with reasonable computational efficiency.

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## **A2.07 Flight and Propulsion Control and Dynamics**

**Lead Center:** ARC

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

NASA is conducting fundamental aeronautic research to develop innovative ideas that can lead to next generation aircraft design concepts with improved aerodynamic efficiency, lower emissions, less fuel burn, and reduced noise and carbon footprints. To realize these potential benefits, innovative vehicle design concepts can exhibit many complex modes of interactions due to many different effects of flight physics such as aerodynamics, vehicle dynamics, propulsion, structural dynamics, and external environment in all three flight regimes. Advanced flight control strategies for innovative aircraft design concepts are seen as an enabling technology that can harvest potential benefits derived from these complex modes of interaction. The following technology areas are of particular interest:

### **Active Aeroelastic Wing Shape Tailoring for Aircraft Performance and Control**

Modern aircraft are increasingly designed with light-weight, flexible airframe structures. By employing distributed flight control surfaces, a modern wing structure (which implies aircraft wing, horizontal stabilizer, and vertical stabilizer) can be strategically tailored in-flight by actively controlling the wing shape so as to bring about certain desired vehicle characteristics. For example, active aeroelastic wing shape tailoring can be employed to control the wash-out distribution and wing deflection in such a manner that could result in improved aerodynamic performance such as reduced drag during cruise or increased lift during take-off. Another novel use of active aeroelastic wing shape tailoring is for flight control. By actively controlling flexible aerodynamic surfaces differentially or collectively, the motion of an aircraft can be controlled in all three stability axes. In high speed supersonic or hypersonic vehicles, effects of airframe-propulsion-structure interactions can be significant. Thus, propulsion control can play an integral role with active aeroelastic wing shape tailoring control in high speed flight regimes.

Technology development of active aeroelastic wing shape tailoring may include, but are not limited to the following:

- Innovative aircraft concepts that can significantly improve aerodynamic, performance and control by leveraging active aeroelastic wing shape tailoring.
- Sensor technology that will enable in-flight wing twist and deflection static and dynamic measurements for control development.
- Actuation methods that include novel modes of operation and concepts of actuation for actively controlling wing shape in-flight.
- Vehicle dynamic modeling capability that includes effects of aero-propulsive-servo-elasticity for vehicle control and dynamics.
- Integrated approaches for active aeroelastic wing shape tailoring control with novel control effector concepts that will provide multi-objective advanced optimal or adaptive control strategies to achieve simultaneously aerodynamic performance such as trim drag reduction, aeroelastic stabilization or mode suppression, and load limiting.

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## **Gust Load Alleviation Control**

In a future NextGen operational concept, close separation between aircraft in super density operations could lead to more frequent wake vortex encounters. Airframe flexibility in modern aircraft will inherently lead to a potential increase in vehicle dynamic response to turbulence and wake vortices. Gust load alleviation control technology can improve ride qualities and reduce undesired structural dynamic loading on flexible airframes that could shorten aircraft service life. Gust load alleviation control technology can be either reactive or predictive. In a traditional reactive control framework, flight control systems can be designed to provide sufficient aerodynamic damping characteristics that suppress vehicle dynamic response as rapidly as possible upon a turbulence encounter. There is a trade off, however, between increased damping for mode suppression and command-following objectives of a flight control system. Large damping ratios, while desirable for mode suppression, may result in poor flight control performance.

Predictive control can provide a novel gust load alleviation strategy for future aircraft design with light-weight flexible structures. Novel look-ahead sensor technology can measure or estimate turbulent intensity to provide such information to a predictive gust load alleviation control system which in turn would dynamically reconfigure flight control surfaces as an aircraft enters a turbulent atmospheric region. Technology development of predictive gust load alleviation control may include, but are not limited to the following:

- Novel sensor methods for Optical Air Data Systems based on LIDAR or other novel detection methods that can measure near-field air turbulent velocity components directly in front of an aircraft in the order of one-body length scale to provide nearly instantaneous predictive capability to significantly improve the effectiveness of a gust load alleviation control system.
- Predictive gust load alleviation control approaches or other effective methods that can reliably reconfigure flight control surfaces dynamically based on the sensor information of the near-field turbulence to mitigate the vehicle structural dynamic response upon a turbulence encounter. The predictive control strategies should be cognizant of potential adverse effects due to potential latency issues that can counteract the objective of gust load alleviation, or potential structural mode interactions due to control input signals that may contain frequencies close to the natural frequencies of the airframe.

## **Advanced Control Concepts for Propulsion Systems**

Enabling high performance "Intelligent Engines" will require advancement in the state of the art of propulsion system control. Engine control architectures/methods need to be developed that provide a tighter bound control on engine parameters for improved propulsion efficiency while maintaining safe operation. The ability of the controller to maintain its designed improvement of engine operation over the entire life and particular health condition of the propulsion system is critical. The controller needs to adapt to the specific health conditions of each engine to eventually allow for a "personalized" control, which will maintain the most efficient operation throughout the engine lifetime and increase the useful operating life. Possible advanced engine control concepts could include:

- Direct nonlinear control design such as predictive model based methods to directly control engine thrust while maintaining safety limits such as stall margins.
- Model-Based Multivariable control to allow direct control of quantities of interest such as thrust, temperature and stall margins while using all available actuators for feedback.

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- Adaptive control schemes to maintain robust performance with changing engine condition with usage.

## **A2.08 Aircraft Systems Analysis, Design and Optimization**

**Lead Center:** LaRC

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

One of the approaches to achieve the NASA Fundamental Aeronautics Program goals is to solve the aeronautics challenges for a broad range of air vehicles with system-level optimization, assessment and technology integration. The needs to meet this approach can be defined by three general themes:

- Variable Fidelity, Physics-Based Design/Analysis Tools.
- Technology Assessment and Integration.
- Evaluation of Advanced Concepts.

Current interdisciplinary design/analysis involves a multitude of tools not necessarily developed to work together, hindering their application to complete system design/analysis studies. NASA has developed a capability that integrates several conceptual design/analysis tools and models in ModelCenter. In addition, development work is continuing on a python-based, open-source architecture (OpenMDAO) that should serve as the long term solution for a multi-fidelity, multi-disciplinary optimization framework. Solicited topics are targeted around these three themes that will support this NASA research area.

### **Variable Fidelity, Physics-Based Design/Analysis Tools**

An integrated design process combines high-fidelity computational analyses from several disciplines with advanced numerical design procedures to simultaneously perform detailed Outer Mold Line (OML) shape optimization, structural sizing, active load alleviation control, multi-speed performance (e.g., low takeoff and landing speeds, but efficient transonic cruise), and/or other detailed-design tasks. Current practice still widely uses sequential, single-discipline optimization, at best coupling low-fidelity modeling of other relevant disciplines during the detailed design phase. Substantial performance improvements will be realized by developing closely integrated design procedures coupled with highest-fidelity analyses for use during detailed-design. Design procedures must enable rapid determination of sensitivities (gradients) of a design objective with respect to all design variables and constraints, choose search directions through design space without violating constraints, and make appropriate changes to the vehicle shape (ideally both external OML shape and internal structural element size). Solicitations are for integrated design optimization tools that find combinations of design variables from more than one discipline and can vary synergistically to produce superior performance compared to the results of sequential, single-discipline optimization or repeated cut-and-try analysis.

Research challenges include the engineering details needed to numerically zoom (i.e., numerical analysis at various levels of detail) between multi-fidelity components of the same discipline, as well as, multi-discipline components of the same fidelity. A major computer science challenge is developing boundary objects that will be reused in a wide variety of simulations. Proposals will be considered that enable coupling differing disciplines, numerical zooming within a single discipline, deploying large simulations and assembling and controlling secure or non-secure simulations.

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## Technology Assessment and Integration

Improved analysis capability of integrated airframe and propulsion systems would allow more efficient designs to be created that would maximize efficiency and performance while minimizing both noise and emissions. Improved integrated system modeling should allow designers to consider trade-offs between various design and operating parameters to determine the optimum design for various classes of subsonic fixed wing aircraft ranging from personal aircraft to large transports. The modeling would also be beneficial if it had enough fidelity to enable it to analyze both conventional and unconventional systems. Current analysis tools capable of analyzing integrated systems are based on simplified physical and semi-empirical models that are not fully capable of analyzing aircraft and propulsion system parameters that would be required for new or unconventional systems.

Analysis tools are solicited that are capable of analyzing new and unconventional aircraft and propulsion integrated systems. These include:

- New combustor designs, alternate fuel operation, and the ability to estimate all emissions.
- Noise source models (e.g., fan, jet, turbine, core and airframe components). Analyses tools that are scalable, especially to small aircraft, are desired.

## Evaluation of Advanced Concepts

Conceptual design and analysis of unconventional vehicle concepts and technologies is needed for technology portfolio investment planning, development of advanced concepts to provide technology pull, and independent technical assessment of new concepts. This capability will enable "virtual expeditions through the design space" for multi-mission trade studies and optimization. This will require an integrated variable fidelity concept design system. The aerospace flight vehicle conceptual design phase is, in contrast to the succeeding preliminary and detail design phases, the most important step in the product development sequence, because of its predefining function. However, the conceptual design phase is the least well understood part of the entire flight vehicle design process, owing to its high level of abstraction and associated risk, its multidisciplinary design complexity, its permanent shortage of available design information, and its chronic time pressure to find solutions. Currently, the important primary aerospace vehicle design decisions at the conceptual design level (e.g., overall configuration selection) are still made using extremely simple analyses and heuristics. An integrated, variable fidelity system would have large benefits. Higher fidelity tools enabling unconventional configurations to be addressed in the conceptual design process are solicited.

### A2.09 Rotorcraft

**Lead Center:** ARC

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

The challenge of the Subsonic Rotary Wing thrust of the NASA Fundamental Aeronautics Program is to develop validated physics-based multidisciplinary design-analysis-optimization tools for rotorcraft, integrated with technology development, enabling rotorcraft with advanced capabilities to fly as designed for any mission. Technologies of particular interest are as follows:

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### **Experimental Capabilities: Instrumentation and Techniques for Rotor Blade Measurements**

Instrumentation and measurement techniques are encouraged for assessing scale rotor blade boundary layer state (e.g., laminar, transition, turbulent flow) in simulated hover and forward flight conditions, measurement systems for large-field rotor wake assessment, and fast-response pressure sensitive paints applicable to blade surfaces.

### **Acoustics: Interior and Exterior Rotorcraft Noise Generation, Propagation and Control**

Interior noise topics of interest include, but are not limited to, prediction and/or experimental methods that enhance the understanding of noise generation and transmission mechanisms for cabin noise sources (e.g., power-train noise), active and combined active/passive methods to reduce cabin noise, and novel structural systems or materials to reduce cabin noise without an excessive weight penalty. Exterior noise topics of interest include, but are not limited to, noise prediction methods that address the understanding of issues such as noise generation, propagation, and control. These methods may address topics such as novel or drastically improved source noise prediction methods, novel or drastically improved noise propagation methods (e.g., through the atmosphere) to understand and/or control noise sources and their impact on the community. Methods should address one or more of the major noise components such as: harmonic noise, broadband noise, blade-vortex interaction noise, high-speed impulsive noise, interactional noise, and/or low frequency noise (e.g., propagation, psychoacoustic effects, etc).

### **Rotorcraft Power Train System Improvements**

Health management of rotorcraft power trains is critical. Predictive, condition-based maintenance improves safety, decreases maintenance costs, and increases system availability. Topics of interest include algorithm development, software tools and innovative sensor technologies to detect and predict the health and usage of rotorcraft dynamic mechanical systems in the engine and drive system. Rotorcraft health management technologies can include tools to: increase fault detection coverage and decrease false alarm rates; detect onset of failure, isolate damage, and assess damage severity; predict remaining useful life and maintenance actions required; system models, material failure models and correlation of failure under bench fatigue, seeded fault test and fielded data; tools to correlate propulsion system operational parameters back to actual usage and component fatigue life; Also of interest are advanced gear technologies for rotorcraft transmissions.

Proposals on other rotorcraft technologies will also be considered as resources and priorities allow, but the primary emphasis of the solicitation will be on the above three identified technical areas.

## **A2.10 Propulsion Systems**

**Lead Center:** GRC

**Participating Center(s):** GRC

This subtopic is divided into three parts. The first part is the Turbomachinery and Heat Transfer and the second part is Developments Needed in Turbulence Modeling for Propulsion Flowpaths and third is Propulsion System Integration:

### **Turbomachinery and Heat Transfer**

There is a critical need for advanced turbomachinery and heat transfer concepts, methods and tools to enable NASA to reach its goals in the various Fundamental Aeronautics projects. These goals include dramatic reductions in aircraft fuel burn, noise, and emissions, as well as an ability to achieve mission requirements for Subsonic Rotary Wing, Subsonic Fixed Wing, Supersonics, and Hypersonics Project flight regimes. In the compression system, advanced concepts and technologies are required to enable higher overall pressure ratio, high stage loading and wider operating range while maintaining or improving aerodynamic efficiency. Such improvements will enable reduced weight and part count, and will enable advanced variable cycle engines for various missions. 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. Reduced cooling flow rates and/or increased cycle temperatures enabled by these technologies have a dramatic impact on the engine performance.

Proposals are sought in the turbomachinery and heat transfer area to provide the following specific items:

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- Advanced instrumentation to enable time-accurate, detailed measurement of unsteady velocities, pressures and temperatures in three-dimensional flowfields such as found in turbomachinery components. This may include instrumentation and measurement systems capable of operating in conditions up to 900 degrees F and in the presence of shock-blade row interactions, as well as in high speed, transonic cascades. The instrumentation methods may include measurement probes, non-intrusive optical methods and post-processing techniques that advance the state of the art in turbomachinery unsteady flowfield measurement for purposes of accurately resolving these complex flowfield.
  - Advanced compressor 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 turbomachinery sensitivity to tip clearance leakage effects where clearance to chord ratios may be on the order of 5% or above.
  - Novel turbine cooling concepts are sought to enable very high turbine cooling effectiveness especially considering the manufacturability of such concepts. These concepts may include film cooling concepts, internal cooling concepts, and innovative methods to couple the film and internal cooling designs. Concepts proposed should have the potential to be produced with current or forthcoming manufacturing techniques. The availability of advanced manufacturing techniques may actually enable improved cooling designs beyond the current state-of-the-art.

### **Developments Needed in Turbulence Modeling for Propulsion Flowpaths and Propulsion System Integration**

Flowpaths within propulsion systems are characterized by several aerodynamic and thermodynamic features which are very difficult for currently available computational fluid dynamics (CFD) methods to calculate accurately. Experiments alone are limited in their ability to provide detailed insights to the complex flow physics which occur in advanced propulsion-airframe integrated systems for future subsonic, supersonic and hypersonic applications. Therefore, the continued need for competent CFD methods to be used in conjunction with experiments is high. The one CFD modeling area that has remained the most challenging, yet most critical to the success of integrated propulsion system simulations is turbulence modeling. The flow features specific to the propulsion system components that provide the greatest turbulence modeling challenges include separated flows whether they be from subsonic diffusion or turbulent shock wave-boundary layer interactions, inlet/vehicle forebody boundary layer transition, unsteady flowfields resulting from incorporation of active flow control, strongly three-dimensional and curved flows in turbomachinery, turbulent-chemistry interactions from subsonic combustors to scramjets, and heat transfer.

Propulsion system integration challenges are encountered across all of the speed regimes from subsonic "N+3" vehicle concepts (with projected fuel burn benefits from boundary layer ingestion or distributed propulsion systems, for example), to supersonic "N+2" vehicle concepts with low-boom, high-performance inlets and nozzles integrated with variable cycle engine systems, to hypersonic reusable air-breathing launch vehicle concepts which incorporate integrated combined-cycle propulsion systems.

Proposals suggesting innovative approaches to any of these problems are encouraged; specific areas of interest include:

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- Advancement of turbulence modeling for shock wave-boundary layer interactions.
  - Advancement of Reynolds-stress closure models for propulsion flowpath analyses, including application of LES and or DNS for model development and validation.
  - Development of mid-level CFD models for the interaction of turbulence and chemical reaction that give superior results to the simple models (e.g., Magnussen), but which do not require the large computational expense of the very complex models (e.g., PDF evolution methods).
  - Advancement of boundary layer transition models, especially in cases of low freestream turbulence levels that occur in actual flight.
  - Incorporation of NASA high-order accurate numerical methods (e.g., Flux Reconstruction) into propulsion CFD tools using both structured as well as unstructured meshes.
  - Development of methods and software tools to quantify uncertainty as part of the CFD solution procedure.

Development of meaningful metrics that quantify the difference between computed solutions and experimental data and use the metrics to validate the CFD codes. Development of tools to enable rapid post-processing and assessment of CFD solutions, especially from NASA in-house CFD tools such as Wind-US and VULCAN (e.g., automatically interpolating numerical solutions to the measurement locations, generating "metrics of goodness" for parameters of interest, etc.).

Propulsion integration topics:

- Development of methodologies that provide installed nozzle performance, specifically conceptual level design/analysis methods, capable of addressing conventional and unconventional geometries. Geometries should be valid for subsonic, supersonic, and/or hypersonic flight applications. Documentation of methodologies should include: underlying theory and mathematical models, computational solution methods, source-code, validation data, and limitations.
- Technologies and/or concepts to enable integrated, high-performance, light-weight supersonic inlets and nozzles that have minimal impact on an aircraft's sonic boom signature.
- Development of supersonic inlet systems that are "Fail Safe" and require no net mass extraction (i.e., bleed) or mass injection to control the shock wave/boundary-layer separations that inevitably arise in any supersonic inlet.
- Shorter, accurate, robust inlet mass flow measurement systems to replace the classic cold pipe/mass flow plug and measure mass-flow with distorted inflow.

NASA's Airspace Systems Program (ASP) is investing in the development, validation and transfer of advanced innovative concepts, technologies and procedures to support the development of the Next Generation Air Transportation System (NextGen). This investment includes partnerships with other government agencies represented in the Joint Planning and Development Office (JPDO), including the Federal Aviation Administration (FAA) and joint activities with the U.S. aeronautics industry and academia. As such, ASP will develop and demonstrate future concepts, capabilities, and technologies that will enable major increases in air traffic management effectiveness, flexibility, and efficiency, while maintaining safety, to meet capacity and mobility requirements of NextGen. ASP integrates the two projects NextGen Concepts and Technology Development (CTD) and NextGen Systems Analysis Integration and Evaluation (SAIE), to directly address the fundamental research needs of NextGen vision in partnership with the member agencies of the JPDO. The CTD develops and explores fundamental concepts, algorithms, and air-borne and ground-based technologies to increase capacity and throughput of the national airspace system, to address demand-capacity imbalances, and achieve high efficiency in the use of resources such as airports, en route and terminal airspace. The SAIE Project is responsible for facilitating the Research and Development maturation of integrated concepts through evaluation in relevant environments, providing integrated solutions, characterizing airspace system problem spaces, defining innovative approaches, and assessing the potential system impacts and design ramifications of the program's portfolio. Together, the projects will also focus NASA's technical expertise and world-class facilities to address the question of where, when, how and the extent to which automation can be applied to moving air traffic safely and efficiently through the NAS and technologies that address optimal allocation of ground and air technologies necessary for NextGen. Additionally, the roles and responsibilities of humans and automation influence in the ATM will be addressed by both projects. Key objectives of NASA's AS Program are to:

- Improve mobility, capacity, efficiency and access of the airspace system.
- Improve collaboration, predictability, and flexibility for the airspace users.
- Enable accurate modeling and simulation of air transportation systems.
- Accommodate operations of all classes of aircraft.
- Maintain system safety and environmental protection.

Sub Topics:

### **A3.01 Concepts and Technology Development (CTD)**

**Lead Center:** ARC

**Participating Center(s):** AFRC, LaRC

The Concepts and Technology Development (CTD) Project supports NASA Airspace Systems Program objectives by developing gate-to-gate concepts and technologies intended to enable significant increases in the capacity and efficiency of the Next Generation Air Transportation System (NextGen), as defined by the Joint Planning and Development Office (JPDO).

The CTD project develops and explores fundamental concepts, algorithms, and technologies to increase throughput of the National Airspace System (NAS) and achieve high efficiency in the use of resources such as airports, en route and terminal airspace. The CTD research is concerned with conducting algorithm development, analyses and fast-time simulations, identifying and defining infrastructure requirements, field test requirements, and conducting field tests.

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Innovative and technically feasible approaches are sought to advance technologies in research areas relevant to NASA's CTD effort. The general areas of primary interest are:

### **Traffic Flow Management**

- Flow management to mitigate large-scale climate disruptions, such as volcanic ash, or other natural disaster phenomena.

### **Super Density Operations**

- Environmental and traffic efficiency metrics and assessments to compare different super-density operations concepts and technologies.
- Application of environmental and traffic efficiency metrics specifically for congested airspace or mixed equipage scenarios.
- Cost-effective integration of advanced speed control capabilities into the cockpit to enable environmentally friendly super density operations.

### **Separation Assurance**

- Develop and demonstrate a prototype capability to output real-time schedules (e.g., from Traffic Management Advisor ) from current operational en route computers (e.g., ERAM and/or Host) to an external system to support trajectory-based operations research and simulation.

### **Trajectory Design**

- Trajectory design and conformance monitoring for surface, terminal area, and en route.
- Trajectory implementation/execution in flight deck automation and automated air traffic control.
- Innovative methods to improve individual aircraft (surface, climb, descent and cruise) trajectories and air traffic operations to reduce the environmental impact.

### **Dynamic Airspace Configuration**

- Flexible/adaptable airspace boundaries for NextGen operations in both en route and terminal airspace.
- Generic-airspace operations, including airspace design attributes and human factors considerations such as procedures and decision support tools.

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- Tubes-in-the-sky operational concept development, including air/ground equipage requirements and design of a dynamic tube network.
  - Dynamic airspace allocation to facilitate operations of UAVs and/or commercial space vehicles in the national airspace system .

## **Human Factors**

- Design considerations for Tower/surface controller tools.
- Graphical user-interface systems for air traffic management/flight deck and ground-based automation simulation and testing applications.

## **Weather**

- Common situational awareness between flight deck and ground automation systems for weather avoidance (may be related to 4D weather cube)
- Integrating weather products into decision support tools
- Airspace capacity estimation in presence of weather
- Means for creating realistic, consistent 3-D weather objects/imagery across numerous automation systems (e.g., a flight simulator out-the-window scene, cockpit radar display, airline operations weather display, ground radar image of the same weather object).

## **Atmospheric Hazards**

- Development of wake vortex detection and hazard metric tools.
- Wake modeling and sensing capabilities implemented into the flight deck for airborne aircraft separation and spacing.
- Development of enroute wake turbulence identification and mitigation tools, processes, and systems.
- Novel, compact, and field-deployable laser remote sensing technologies for measuring meteorological parameters (e.g., wind, temperature, pressure, and turbulence) at ranges >1km in support of characterization of aircraft generated wake vortices.

## **Methods and Methodologies**

- Algorithms and methods to satisfy multi-criteria design needs in air traffic management.
- Integrated hardware/software tool for accelerating general optimization tasks.
- Applying novel computing concepts to ATM problems.

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- Experimental methodology, including scenario development, for incorporating rare events in realistic and dynamic human-in-the-loop air traffic management research, and methods for analyzing cause and effect in post experiment data.
  - Stand-alone graphical user interface capabilities for data collection and processing of meteorological remote sensing technologies.

## **Other**

- Derived sensor information from both ground-based radar trackers and ADS-B information for derivation of airspeed and local wind information.

### **A3.02 Systems Analysis Integration Evaluation (SAIE)**

**Lead Center:** LaRC

**Participating Center(s):** AFRC, ARC

SAIE will provide systems level analysis of the NAS characteristics, constraints, and demands such that a suite of capacity-increasing concepts and technologies for system solutions are enabled and facilitated, integrated, evaluated and demonstrated. SAIE is responsible for characterizing airspace system problem spaces, defining innovative approaches, assessing the potential system-level benefits, impacts and safety.

Specific innovative research topics being sought by SAIE include:

#### **Airspace System Level Concepts Development**

- NextGen airspace system safety assessment, graceful degradation, fault tolerant, and recovery concepts and methodologies.
- System level capacity and environmental (e.g., CO<sub>2</sub>, NO<sub>x</sub> emissions and noise) improvement concepts and assessments and methodologies.
- System level NextGen assessments, concepts and methodologies that incorporate and/or inform future vehicle and fleet designs.
- Autonomous and distributed system concepts.
- Concepts that study system-wide effects of various functional allocations.
- Revolutionary airspace system concepts, designs and methodologies.

#### **Trajectory Modeling and Uncertainty Prediction**

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- Analysis of growth of uncertainty as a function of look-ahead time on different phases of flight.
  - Development of methods to determine, for a target concept/system, the TP accuracy needed to be able to achieve the minimum acceptable system/concept performance as well as identify sources of errors.
  - Development of methods for managing/reducing trajectory uncertainty to meet specified performance requirements.
  - Identify critical aircraft behavior data for exchange for interoperability.
  - Innovative methods to improve individual aircraft (surface, climb, descent and cruise) trajectories and air traffic operations to reduce the environmental impact.

### **Roles and Responsibilities in NextGen**

- Systems analysis concepts, assessments and methodologies to optimize air-ground and automation functional allocation for NextGen (e.g., functional allocation options between human/machine and among AOC, flight deck and service provider).
- Airspace systems-level concepts, assessments and methodologies using increasing levels of autonomy.

### **Modeling and Simulation (should be relevant to NASA Airspace Program objectives)**

- Develop new methods that help in assessing and designing airspace to improve system level performance (e.g., increase capacity, reduce complexity, optimize or improve performance of the air transportation network architecture).
- Explicit methodologies relevant to applications can include:
  - Rigorous predictive modeling of uncertainty in various parts of the system and its propagation.
  - Multiobjective decision making algorithms for all aspects of decision making and optimization in the system.
  - Model/dimension reduction for improved computational tractability.
  - Methods for managing multiscale phenomena in the NAS.
  - Methods for quantifying and managing complexity and uncertainty.
  - Methods for assessing the necessary balance between predictability and flexibility in the system, especially in the presence of autonomy.

The Aeronautics Test Program (ATP) ensures the long term availability and health of NASA's major wind tunnels/ground test facilities and flight operations/test infrastructure that support NASA, DoD and U.S. industry research and development (R&D) and test and evaluation (T&E) requirements. Furthermore, ATP provides rate stability to the aforementioned user community. The ATP facilities are located at four NASA Centers made up of the Ames Research Center, Dryden Flight Research Center, Glenn Research Center and Langley Research Center. Classes of facilities within the ATP include low speed, transonic, supersonic, and hypersonic wind tunnels, hypersonic propulsion integration test facilities, air-breathing engine test facilities, the Western Aeronautical Test Range (WATR), support & test bed aircraft, and the simulation and loads laboratories. A key component of ensuring a test facility's long-term viability is to implement and continually improve on the efficiency and effectiveness of that facility's operations along with developing new technologies to address the nation's future aerospace challenges. To operate a facility in this manner requires the use of state-of-the-art test technologies and test techniques, creative facility performance capability enhancements, and novel means of acquiring test data. NASA is soliciting proposals in the areas of instrumentation, test measurement technology, test techniques and facility development that apply to the ATP facilities to help in achieving the ATP goals of sustaining and improving our test capabilities. Proposals that describe products or processes that are transportable across multiple facility classes are of special interest. The proposals will also be assessed for their ability to develop products that can be implemented across government-owned, industry and academic institution test facilities. Additional information: <http://www.aeronautics.nasa.gov/atp/index.html> [5].

Sub Topics:

#### **A4.01 Ground Test Techniques and Measurement Technology**

**Lead Center: LaRC**

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

NASA is seeking highly innovative and commercially viable test measurement technologies, test techniques, and facility performance technologies that would increase efficiency, capability, productivity for ground test facilities. The types of technology solutions sought, but not limited to, are: skin friction measurement techniques; improved flow transition and quality detection methodologies; non-intrusive measurement technologies for velocity, pressure, temperature, and strain measurements; force balance measurement technology development; and improvement of current cutting edge technologies, such as Particle Based Velocimetry (LDV, PIV), Pressure Sensitive Paint (PSP), and focusing acoustic measurements that can be used more reliably in a production wind tunnel environment. Instrumentation solutions used to characterize ground test facility performance are being sought in the area of aerodynamics performance characterization (flow quality, turbulence intensity, mach number measurement, etc.). Of interest are subsonic, transonic, supersonic, and hypersonic speed regimes. Specialized areas may include cryogenic conditions, icing conditions, and rotating turbo machinery. Proposals that are applicable specifically to the ATP facilities (see <http://www.aeronautics.nasa.gov/atp> [6]) and across multiple facility classes are especially important. The proposals will also be assessed for their ability to develop products that can be used in other aerospace ground test facilities.

#### **A4.02 Flight Test Techniques and Measurement Technology**

**Lead Center: AFRC**

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

NASA's flight research and test facilities are reliant on a combination of both ground and flight research capabilities. By using state-of-the-art flight test techniques, measurement and data acquisition technologies, NASA will be able to operate its flight research facilities more effectively and also meet the challenges presented by NASA's cutting edge research and development programs. The Aeronautical Test Program pertains to a variety of flight regimes and vehicle types ranging from civil transports, low-speed, to high-altitude long-endurance to supersonic, to hypersonic and access-to-space.

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The scope of this subtopic is broad. Flight research and test capabilities should address (but are not limited to) the following NASA aeronautical test facilities: Aeronautical Test Range, Aero-Structures Flight Loads Laboratory, Flight Research Simulation Laboratory, and Research Test Bed Aircraft. Proposals should address innovative methods and technologies to extend the health, maintainability and test capabilities of these flight research support facilities.

NASA is committed to improve the ATP effectiveness to support and conduct flight research. This includes developing test techniques that improve the control of both ground-based and 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.

NASA requires improved measurement and analysis techniques for acquisition of real-time, in-flight data used to determine aerodynamic, structural, flight control, and propulsion system performance characteristics. These data will also be used to provide test conductors the information to safely expand the flight and test envelopes of aerospace vehicles and components. This requirement includes the development of sensors to enhance the monitoring of test aircraft safety and atmospheric conditions during flight testing.

Areas of interest include:

- Multi-disciplinary nonlinear dynamic systems prediction, modeling, identification, simulation, and control of aerospace vehicles.
- Test techniques for conducting in-flight boundary layer flow visualization, shock wave propagation, Schlieren photography, near and far-field sonic boom determination, atmospheric modeling.
- Measurement technologies for steady & unsteady aerodynamic, aero-thermal dynamics, structural dynamics, stability & control, and propulsion system performance.
- Verification & Validation (V&V) of complex highly integrated flight systems including hardware-in-the-loop testing.
- Manufacturability, affordability, and performance of small upper-stage booster technologies for small- & nano-satellites.
- Innovative techniques that enable safer operations of aircraft (e.g., non destructive examination of composites through ultrasonic techniques).

Also of interest to NASA are innovative methods and analysis techniques to improve the correlation of data from ground test to flight test.

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## Integrated System Research Project (ISRP) Topic A5

The Integrated Systems Research Program (ISRP), a new program effort that began in FY10, will conduct research at an integrated system-level on promising concepts and technologies and explore, assess or demonstrate their benefits in a relevant environment. The integrated system-level research in this program will be coordinated with on-going long-term, foundational research within the three other research programs, as well as efforts within other Federal Government agencies. As the NextGen evolves to meet the projected growth in demand for air transportation, researchers must address the national challenges of mobility, capacity, safety, and energy and the environment in order to meet the expected growth in air traffic. In particular, the environmental impacts of noise and emissions are a growing concern and could limit the ability of the system to accommodate growth. ISRP will explore and assess new vehicle concepts and enabling technologies through system-level experimentation to simultaneously reduce fuel burn, noise and emissions, and will focus specifically on maturing and integrating technologies in major vehicle systems/subsystems for accelerated transition to practical application. ISRP is comprised of two projects - the Environmentally Responsible Aviation (ERA) Project and the Unmanned Aircraft Systems (UAS) Integration in the National Airspace System (NAS) Project. Environmentally Responsible Aviation (ERA) The project's primary goal is to select vehicle concepts and technologies that can simultaneously reduce fuel burn, noise and emissions; it contains three subprojects: Airframe Technology, Propulsion Technology and Vehicle Systems Integration.

- Testing unconventional aircraft configurations that have higher lift to drag ratio, reduced drag and reduced noise around airports.
- Achieving drag reduction through laminar flow.
- Developing composite (nonmetallic) structural concepts to reduce weight and improve fuel burn; and
- Testing advanced, fuel-flexible combustor technologies that can reduce engine NOx emissions. The Unmanned Aircraft Systems (UAS) Integration in the National Airspace System (NAS) The project's primary goal is to address technology development in several areas to reduce the technical barriers related to the safety and operational challenges of UAS routine operations in the NAS.
- Separation Assurance - Safely and seamlessly integrate UAS into NextGen separation assurance through demonstrate of 4DT applications that result in the same or fewer losses of separation as traditional separation services.
- Human Systems Integration - Demonstrate reduced workload of UAS pilots by advanced interface design and automation; Collect Human in the Loop (HITL) data to apply to computational model that provides for 100% situational awareness of aircraft within 5 nm and 1200 ft; and Develop at standard against which to assess UAS ground control stations.
- Communication - Demonstrate a secure UAS command and control datalink which meets communication confidentiality, availability and integrity requirements and which meets FAA communication latency requirements. Certification - Document applicability of possible certification method meeting airworthiness requirements for the full range of UAS and collect UAS-specific data in a civil context to support development of standards and regulations.

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- Integrated Test and Evaluation - Creation of an appropriate test environment; Integration of the technical research to probe and evaluate the concepts; and Coordination and prioritization of facility and aircraft schedules.

Sub Topics:

### **A5.01 UAS Integration in the NAS**

**Lead Center: AFRC**

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

The following subtopic is in support of the Unmanned Aircraft Systems (UAS) Integration in the National Airspace System (NAS) Project under ISRP. There is an increasing need to fly UAS in the NAS to perform missions of vital importance to National Security and Defense, Emergency Management, Science, and to enable Commercial Applications. UAS are unable to routinely access the NAS today due to a lack of:

- Automated separation assurance integrated with collision avoidance systems.
- Robust communication technologies.
- Robust human systems integration.
- Standardized safety and certification.

The Federal Aviation Administration (FAA) regulations are built upon the condition of a pilot being in aircraft. There exist few, if any, regulations specifically addressing UAS today. The primary user of UAS to date has been the military. The technologies and procedures to enable seamless operation and integration of UAS in the NAS need to be developed, validated, and employed by the FAA through rule making and policy development. The Project goal is to develop capabilities that reduce technical barriers related to the safety and operational challenges associated with enabling routine UAS access to the NAS. This goal will be accomplished through a two-phased approach based on development of system-level integration of key concepts, technologies and/or procedures, and demonstrations of integrated capabilities in an operationally relevant environment. The project is further broken down into five subprojects: Separation Assurance; Communications; Human Systems Integration; Certification; and Integrated Test and Evaluation. The fifth sub-project, Integrated Test and Evaluation, integrates the other four subprojects. The Phase I technical objectives include:

- Developing a gap analysis between current state of the art and NextGen Concept of Operations.
- Validating the key technical elements identified by the project requirements.
- Initial modeling, simulation, and flight testing.
- Completion of subproject Phase I deliverables (Spectrum requirements, comparative analysis of certification methodologies, etc.) and continue Phase II preparation (infrastructure, tools, etc.).

The Phase II technical objectives include:

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- Providing regulators with a methodology for developing airworthiness requirements for UAS, and data to support development of certifications standards and regulatory guidance.
  - Providing systems-level, integrated testing of concepts and/or capabilities that address barriers to routine access to the NAS, through simulation and flight testing, address issues including separation assurance, communications requirements, and Human Systems Integration in operationally relevant environments.

This solicitation seeks proposals to develop:

- Desktop Simulation System for Rapid Collection of Human-in-the-Loop Simulation Data. Study, design and build a desktop human-in-the-loop simulation system that integrates UAS ground control stations, unmanned vehicles, manned aircraft, and controller interfaces to rapidly evaluate concepts for separation assurance, separation algorithms, procedures for off-nominal conditions, and other research questions. In addition, investigate training requirements and verification methods for the quality of the data, the types of tasks for which such a system could provide meaningful data, and the architecture required to ensure scalability. The simulation system could be based on the Multi Aircraft Control System (MACS), which already includes all those elements except the UAS ground control station. An initial implementation could include a single human operator with all other agents simulated, while advanced implementations would connect several instances of the simulator to capture interactions between human controllers, pilots and UAS operators.
- UAS Model Construction from Real-time Surveillance Data. In order to improve trajectory predictions for aircraft types without detailed models, a real-time system identification process is needed to automatically construct propulsion and aerodynamics models from available Air Traffic Control (ATC) surveillance data (primary or secondary radar, ADS-B, etc.) while the aircraft is in flight. Initial work would establish what real-time surveillance data is required for a model of sufficient fidelity to reliably predict aircraft trajectories ten or more minutes into the future and over tens of thousands of vertical feet, and what types of aircraft maneuvers would provide maximum observability of the unknown parameters (e.g., the vehicle's response to commanded doublets in altitude at max climb/descent speed or step changes in commanded aircraft velocity as observed by radar or ADS-B). These maneuvers would be commanded of the UAS by ATC to improve a poorly understood vehicle model in real-time. Model construction could also be done with archived surveillance data as a first step, but real-time construction is the preferred ultimate outcome.
- Certified control and non-payload communications (CNPC) system. Current civil UAS operations are significantly constrained by the lack of a standardized, certified control and non-payload communications (CNPC) system. The UAS CNPC system is to provide communications functions between the Unmanned Aircraft (UA) and the UA ground control station for such applications as: telecommands; non-payload telemetry; navigation aid data; air traffic control (ATC) voice relay; air traffic services (ATS) data relay; sense and avoid data relay; airborne weather radar data; and non-payload situational awareness video. New and innovative approaches to providing terrestrial and space-based high-bandwidth CNPC systems that are inexpensive, small, low latency, reliable, and secure offer opportunities for quantum jumps in UAS utility and capabilities. Of particular interest are technologies for the enhancement/improvement of CNPC performance for UAS operations in urban locations, taking into account the propagation, reflection/refraction and shadowing/blockage environment encountered in the urban environment.
- System for Rapid Automated UAS Mission Planning. UAS mission planning is currently a very cumbersome and time-consuming activity that involves a highly manual process. In order to provide better UAS integration in the NAS, an automated mission planning system is required with the following capabilities:
  - During the pre-flight mission phase, automation is needed to identify emergency landing sites, ditch sites, and develop UAS responses to contingency events at all points along the route commensurate with UAS platform performance.

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- During the in-flight mission phase, automation is needed to assess and integrate real-time weather information, such as that provided via Flight Information Services - Broadcast (FIS-B), to dynamically re-plan the route for safe navigation. This includes fuel planning and weather assessment capabilities to select and fly to appropriate alternate destination airfields.
  - During the in-flight mission phase, automation is needed to assess real-time route deviations/changes imposed by Air Traffic Control (ATC). The assessment would consider fuel, weather and emergency landing/ditch site constraints to verify the route change is supportable and safe.

#### Aviation External Hazard Sensor Technologies Topic A1.01

NASA is concerned with new and innovative methods for detection, identification, evaluation, and monitoring of in-flight hazards to aviation. NASA seeks to foster research and development that leads to innovative new technologies and methods, or significant improvements in existing technologies, for in-flight hazard avoidance and mitigation. Technologies may take the form of tools, models, techniques, procedures, substantiated guidelines, prototypes, and devices.

A key objective of the NASA Aviation Safety Program is to support the research of technology, systems, and methods that will facilitate transformation of the National Airspace System to Next Generation Air Transportation System (NextGen) (information available at [www.jpdo.gov](http://www.jpdo.gov) [2]). The general approach to the development of airborne sensors for NextGen is to encourage the development of multi-use, adaptable, and effective sensors that will have a strong benefit to safety. The greatest impact will result from improved sensing capability in the terminal area, where higher density and more reliable operations are required for NextGen.

Under this subtopic, proposals are invited that explore new and improved sensors and sensor systems for the detection and monitoring of hazards to aircraft before they are encountered. The scope of this subtopic does not include human factors and development of human interfaces, including displays and alerts, except where explicitly requested in association with special topics. Primary emphasis is on airborne applications, but in some cases the development of ground-based sensor technology may be supported. Approaches that use multiple sensors in combination to improve hazard detection and quantification of hazard levels are also of interest.

At this time, there are some areas of particular interest to NASA, and these are described below. They are provided as encouragement but not intended to exclude other proposals that fit this subtopic. These areas of interest include two specific hazards to aircraft and specific advancements in fundamental radar technology. The interest in radar technology can be considered to be independent of the interest in the two hazards. While NASA is interested in all aviation hazards, wake vortices and turbulence are of particular interest. Proposals associated with remote sensing investigations addressing these hazards are encouraged. This emphasis is not intended to discourage proposals targeting other or additional hazards such as reduced visibility, terrain, airborne obstacles, volcanic ash, convective weather, lightning, gust fronts, cross winds, and wind shear.

Airborne detection of wake vortices is considered challenging due to the fact that detection must be possible in

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nearly all weather conditions, in order to be practical, and because of the size and nature of the phenomena. Proposals are encouraged for the development of novel coherent and direct detection lidar systems and associated components that allow accurate meteorological wind and aerosol measurements suitable for wake vortex characterization. Lidar development includes, but is not limited to, novel transceiver architectures, efficient signal processing methodologies, wake processing algorithms and real time data reduction and display schemes. Improvements in size, weight, range, system efficiency, sensitivity, and reliability based on emerging technologies are desired.

NASA has made a major investment in the development of new and enhanced technologies to enable detection of turbulence to improve aviation safety. Progress has been made in efforts to quantify hazard levels from convectively induced turbulence events and to make these quantitative assessments available to civil and commercial aviation. NASA is interested in expanding these prior efforts to take advantage of the newly developing turbulence monitoring technologies, particularly those focused on clear air turbulence (CAT). NASA welcomes proposals that explore the methods, algorithms and quantitative assessment of turbulence for the purpose of increasing aviation safety and augmenting currently available data in support of NextGen operations.

In order to detect and/or discriminate some meteorological hazards, future radars will need multi-frequency and/or polarimetric capabilities. NASA seeks new system/component designs and hazard detection applications for airborne weather radars based upon extending the current design to incorporate multi-frequencies and/or polarimetric capabilities. In addition, the current generation of weather radar is fundamentally limited by its ability to scan the airspace; consequently, NASA is seeking novel designs and enhancements to produce electronically scanned antennas/radars.

#### Sub Topics:

##### Inflight Icing Hazard Mitigation Technology Topic A1.02

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 technologies 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. With these emphases in mind, products and technologies that can be made affordable and capable of retrofit into the current aviation system and aircraft, as well as for use in the future are sought.

Areas of interest include, but are not limited to:

- Non-destructive digitization of ice accretions on wind tunnel wing models. NASA has a need for methods to digitize ice shapes with rough external surfaces and internal voids as can occur with accretions on highly swept wing. Current methods based upon scanning with line-of-sight optical digitization methods have been found inadequate for these ice shapes.
- New instruments are needed utilizing innovative concepts to measure ice-crystal/liquid water mixed phase clouds in ground test facilities and in flight. Cloud properties of interest include: crystal/droplet temperature, material phase, particle size, speed, cloud liquid-water content, ice-water content, air temperature, and humidity. Non-intrusive measurement techniques capable of providing the spatial distribution of these

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properties across an engine duct with a diameter of at least 3 feet are particularly of interest.

- New instruments or measurement techniques are also needed for the detailed study of the ice accretion process on wing surfaces and internal engine components. Properties of particular interest are heat transfer, accretion extent, and ice density. The measurement of these properties needs to be non-interfering.

#### Sub Topics:

##### Durable Propulsion Components Topic A1.03

The mitigation and management of aging and durability-related hazards in future civilian and military aircraft will require advanced materials, concepts, and techniques. NASA is engaged in the research of materials (metals, ceramics, and composites) and characterization/validation test techniques to mitigate aging and durability issues and to enable advanced material suitability and concepts.

Proposals are sought for the development of physics-based probabilistic fatigue life models for powder metallurgy disk superalloys, which include both crystal plasticity and surface environmental damage modes. The models would capture the evolution of fatigue damage due to crystallographic slip within multiple grains of variable orientation and size, as well as damage due to environmental interactions at the surfaces of compressor and turbine powder metallurgy superalloy disks. This research opportunity is focused on quantifying, modeling and validating each of these damage modes during simple cyclic and dwell fatigue cycles, and then later for simulated service in aerospace gas turbine engine disk materials. Work may involve use of uniform gage and notched fatigue specimens to simulate key disk features, potentially utilizing varied disk surface finish conditions and associated residual stress and cold work. The simulated load history and temperature gas turbine engine conditions should approximate turbine service history reflective of the new generation of gas turbine engines and include the effect of superimposed dwell cycles. NASA will be an active participant in Phase I of the research effort by providing superalloy disk sections, for the proposer to machine into specimens, mechanically test, analyze, and model evolution of these damage modes. Technology innovations may take the form of the unique quantification of the effect of service history on these damage modes, and include analytical modeling descriptions of the evolution of these parameters as a function of simulated service history. The technology innovations may also include models and algorithms extrapolating this damage to service conditions outside of those tested during the program.

#### Sub Topics:

##### Airframe Design and Sustainment Topic A1.04

Conventional aircraft airframe structures have achieved a high level of reliability through decades of experience, incremental technology changes, and an empirically based building block design methodology. Emerging and next generation aircraft will employ new lightweight materials and structural concepts that have very different characteristics than our current experience base. One element in NASA's effort to ensure the integrity of future vehicles is research to improve the reliability of airframe structures through enhanced computational methods to predict structural integrity and life, and validating correlation between computational models and the as-manufactured and as-maintained aircraft structure.

NASA seeks tools and methods for improved understanding and prediction of structural response, and experimental methods for measuring and evaluating the performance of new airframe structural designs. Specific areas of interest include the following:

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- Improved structural analysis methods for complex metallic and composite airframe components using novel multi-scale as well as global-local computational codes. The methods used for these solutions need to detail the initiation and progression of damage to determine accurate estimates of residual life and or strength of complex airframe structures. Robust numerical algorithms are required to simulate the nonlinear behavior of damage progression coupled with geometric and material nonlinearity.
  - Correlation between computational models and airframe structures:
    - Experimental methods for detailed characterization of as-manufactured structures relative to the as-designed configuration, to identify deviations in geometry, material application, and possibly identify manufacturing anomalies.
    - Advanced experimental methods for full-field assessment of strain during structural or flight tests for the purpose of validating computational models, and identifying hot-spots in the structure that are not represented in the models. Ease of application on built-up structures will be a significant factor.
    - Technologies to measure residual stresses in structures resulting from manufacturing processes and fit-up during structural assembly, as these residual stresses may severely compromise design margins.
  - Repair technology for metallic or composite structures:
    - Novel approaches to arrest damage and return structural integrity (other than replacement, grind out, scarf, or bonded or bolted doublers).
    - Validation of structural repair: technology to interrogate an applied repair to validate the design of the repair, and correct application of the repair. The intent will be to determine whether the repair performs as expected to return structural integrity.

Technology innovations may take the form of tools, models, algorithms, and devices.

All proposals should discuss means for verification and validation of proposed methods and tools in operationally valid, or end-user, contexts.

#### Sub Topics:

Sensing and Diagnostic Capabilities for Degradation in Aircraft Materials and Structures Topic A1.05  
Many conventional nondestructive evaluation (NDE) and integrated vehicle health management (IVHM) techniques have been used for flaw detection, but have shown little potential for much broader application. One element in NASA's effort to ensure the integrity of future vehicles is research to identify changes in fundamental material properties as indicators of material aging-related hazards before they become critical. For example, composites can exhibit a number of micromechanisms such as fiber buckling and breakage, matrix cracking and delaminations as precursor to failure. For complex metallic components an inability to determine residual stress state limits the validity of predictions of the fatigue life of the component.

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To further these goals, NDE and IVHM technologies are being sought for the nondestructive characterization of age-related degradation in complex materials and structures. Innovative and novel approaches to using NDE technologies to measure properties related to manufacturing defects, flaws, and material aging. Measurement techniques, models, and analysis methods related to quantifying material thermal properties, elastic properties, density, microcrack formation, fiber buckling and breakage, etc. in complex composite material systems, adhesively bonded/built-up and/or polymer-matrix composite sandwich structures are of particular interest. Other NDE and IVHM technologies being sought are those that enable the quantitative assessment of the strength of an adhesive region of bonded joints and repairs or enable the rapid inspection of large area structures. The anticipated outcome of successful proposals would be both a Phase II prototype technology for the use of the developed technique and a demonstration of the technology showing its ability to measure a relevant material property or structural damage in the advanced materials and structures in subsonic aircraft.

#### Sub Topics:

##### Propulsion Health State Assessment and Management Topic A1.06

The emphasis for this subtopic is on propulsion system health management, in order to predict, prevent, or accommodate safety-significant malfunctions and damage. Past advances in this area have helped improve the reliability and safety of aircraft propulsion systems; however, propulsion system component failures are still a contributing factor in numerous aircraft accidents and incidents. Advances in technology are sought which help to further reduce the occurrence of and/or mitigate the effects of safety-significant propulsion system malfunctions and damage. Specifically the following are sought: propulsion health management technologies such as instrumentation, sensors, health monitoring algorithms, and fault accommodating logic, which will detect, diagnose, prevent, assess, and allow recovery from propulsion system malfunctions, degradation, or damage. Specific technologies of interest include:

- Self-awareness and diagnosis of gas path, combustion, and overall engine state (containment systems and rotating and static components), and fault-tolerant system architectures.
- Analytical and data-driven techniques for diagnosing incipient faults in the presence deterioration, engine-to-engine variation, and transient operating conditions.
- Innovative sensing techniques for the cost-effective assessment of turbomachinery health in harsh high-temperature environments including high temperature sensors including fiber optic and Microsystems, rotatodynamics monitoring, energy harvesting, communication, and packaging.
- Prognostic techniques for the accurate assessment of remaining component life while in-flight.

#### Sub Topics:

##### Avionics Health State Assessment and Management Topic A1.07

Shielded twisted-pair cables are already in common use on-board aircraft and spacecraft, and are destined to be ubiquitous in the all-electric aircraft designs of the future. At present, however, easy to use commercially available connector interfaces between this type of cable and electrical test equipment (such as oscilloscopes, network analyzers, or handheld diagnostic units) are not readily available, and custom-built test fixtures are the norm. Given the widespread use of this cable type in other commercial wiring applications such as DSL, NASA is investing in the research and development of a commercial-grade product to address this need. Proposals are therefore sought for the design of a novel electrical connector system (or small portable interface board) that can interface the coaxial SMA (or 2.9 mm) ports of typical high-end electrical test equipment with a shielded twisted-pair (STP) cable

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(2 inner conductors surrounded by a shield). The design should provide two 50 ohm coaxial SMA (or 2.9 mm) inputs, each used to individually excite the common and differential modes of the cable, and one output connection to the STP cable itself. In addition, the design should minimize the mode cross coupling caused by the connector in the frequency range of interest (0-10 GHz). Finally, a critical part of the design must include a calibration method and set of calibration standards for obtaining a high-quality Vector Network Analyzer (VNA) based measurement (using a standard VNA) of the 4 port 4x4 S-parameter matrix covering the differential and common mode ports on each end of the TSP cable from 0-10 GHz.

Proposals should address the design and the numerical verification of the connector and calibration standards in Phase I, with the experimental validation and the prototype construction reserved for Phase II. Use of a commercial electromagnetics simulator such as COMSOL is strongly encouraged. While the design does not need to be compact or inexpensive at this stage, any obvious impediments to its subsequent miniaturization or commercialization will be considered a serious weakness.

#### Sub Topics:

##### Crew Systems Technologies for Improved Aviation Safety Topic A1.08

The NASA Aviation Safety program aims to model and develop integrated crew-system interaction (ICSI) concepts and to subsequently evaluate this concept in a relevant operational environment in comparison to state-of-the-art. NASA seeks proposals for novel technologies and evaluation tools with high potential to support an ICSI with effective crew-system interactions in the context of NextGen operational requirements (e.g., 4D trajectory-based operations, visual operations in non-visual meteorological conditions, etc.) and assumptions (e.g., net-centric information management environment) (NextGen described in <http://www.faa.gov/nextgen/> [3]).

To improve these interactions, we seek interventions that proactively identify and mitigate NextGen flight deck risks; address documented crew-related causal factors in accidents; and improve the ability to unobtrusively, effectively, and sensitively evaluate and model crew and crew-automation system performance. In particular, we seek proposals for the development of advanced technologies that address:

- Crew challenges associated with piloting terminal area 4D Trajectory-Based Operations in Instrument Meteorological Conditions (IMC).
- Displays, decision-support, and automation interaction under off-nominal conditions; in particular in that lead to spatial disorientation and loss of energy state awareness leading to loss-of-control (LOC).
- The appropriate levels of integrity for new classes of information to be made available to the crew as a result of NextGen's net centric information management environment.
- Pilot proficiency in increasingly automated flight decks (e.g., manual handling skill erosion).
- Optimal methods for information presentation as distributed over time and display space for multiple operators to maximize crew information processing and coordination.
- Appropriate trust in, and therefore use of, automation and complex information sources by, for example, conveying constraints on automation reliability and information certainty/timeliness.
- Effective joint cognitive system design and evaluation with multiple intelligent agents (human and

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automated, proximal and remote).

- Improved oculometer, neurophysiological, or other sensors and/or data integration methods that would improve the ability to characterize operator functional status in real time.
- Improved human-system interaction through effectively modulating operator state, and/or effectively adapting interfaces and automation in response to this functional status.
- Evaluation of adaptive and adaptable crew-system interfaces.
- A priori assessment of human error likelihood and consequence in NextGen scenarios

Phase I proposals that demonstrate relevance to the NASA Aviation Safety Program's VSST and/or SSAT programs, include a detailed resource-loaded schedule, literature-based justification, highly competent staffing, prescription for Phase II work, and clear path to commercialization or utilization in NASA programs are most valued.

#### Sub Topics:

Integrated Vehicle Dynamics Modeling Methods for LOC Conditions Topic A1.09  
Effective characterization of LOC conditions requires inclusion of the flight dynamics effects from multiple disciplines, including aerodynamics, structures, propulsion, and aeroelasticity. However, the types of data and data sets obtained from modeling in these various disciplines can be quite disparate, even within a discipline (e.g., wind-tunnel static versus dynamic data versus CFD flow-field data), and is exacerbated when we consider the non-linear parts of the flight envelope. Further, disciplines have varying levels of sensitivity to certain flight conditions.

Of interest are software tools that could take such disparate types of information and provide methods to manage and integrate them in a single environment to provide flight-dynamics-relevant implications. Examples include translating thrust response into force and moment increments to superimpose on the nominal aerodynamics, or applying aerodynamic load distributions to key structural components to define flight envelope boundaries based on structural load limits. Such tools can also be useful in highlighting flight conditions where data sets overlap and thus may provide good integrated model fidelity, versus conditions where fidelity may be limited, helping provide guidance on where research emphasis should be placed. Overall, concepts should be aimed at facilitating integrated model implementation into a flight simulation environment.

#### Sub Topics:

Advanced Dynamic Testing Capability for Abnormal Flight Conditions Topic A1.10  
The goal of developing a comprehensive methodology for obtaining appropriate aerodynamic math models for flight vehicles over a greatly expanded flight envelope requires a more general formulation of the aerodynamic model that more accurately characterizes nonlinear steady and unsteady aerodynamics. This leads to greater demands in the development of dynamic test techniques and correspondingly more demands on test facility capabilities. This topic is for the design and software for a prototype dynamic test rig for wind or water tunnel application, with guidance for scaling up to large facilities. The concept should be aimed at providing high-automation and productivity for arbitrary, programmable, multi-axis motions, and should consider the following test capabilities that are considered an important subset of possible motions for characterizing vehicle dynamics characteristics under abnormal flight conditions: conventional single-axis forced oscillation; constant-rate motion through the use of square and triangle waveforms; steady and oscillatory coning motions; inclined axis coning; coupled, multi-axis motion; and wide-band inputs, such as Schroeder sweeps. Design should include considerations for mitigating blockage and interference effects.

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#### Sub Topics:

##### Transport Aircraft Simulator Motion Fidelity For Abnormal Flight Conditions Topic A1.11

Piloted simulation remains an important enabling tool for a wide variety of research aimed at commercial aviation safety. Over the past decade, significant advances in aerodynamic modeling of large transport airplanes at high angles of attack are providing new capabilities for prediction of flight behavior in off-nominal or out-of-envelope conditions. As a result, piloted simulation is now being considered for flight training specifically aimed at stall and post-stall conditions. In addition, other technology areas focused on the problem of loss-of-control accidents, such as advanced controls and crew systems, now stand to benefit from this enhanced simulation capability.

Simulator motion often plays an important role in simulator fidelity. For example, hexapod motion systems are commonly used for airline flight training and are justified by the increased transfer of training with the added realism of cockpit accelerations. However, it is recognized that all motion systems have limitations and therefore maneuvers must be designed to stay within the limits of the system's capabilities and range of effectiveness. The problem of aircraft upsets and loss-of-control typically involves large-amplitude motions due to extended excursions in vehicle attitudes and angular rates, and the desire to emulate the resulting accelerations has added a new challenge to simulator motion fidelity. A response to this need has been proposals for new motion systems that provide sustained cockpit accelerations that are possible during upset events. Over the past decade, limited research has been conducted on the effects of motion on upset training (both ground-based and in-flight simulation) and one approach has involved analysis of pilot performance with various types of training.

This subtopic requests a broad study of the requirements and capabilities for simulator motion systems across the range of current and proposed systems, including fixed-base, hexapod, continuous-g and in-flight simulation. It is intended that this research be aimed at large-amplitude motions and address simulation facility requirements for research and training or other uses for a broad range of applications and technologies. In addition, proposals for new or enhanced motion cueing systems are encouraged if justified by this study.

Desired outcomes of this research include but are not limited to the following:

- Analysis of motion system requirements and cueing algorithms for large-amplitude maneuvers, including out-of-envelope or loss-of-control events for large transport airplanes.
- A comparison of maneuver envelopes for current and proposed simulator motion devices.
- Analysis of the state-of-the-art of motion systems that includes anticipated new requirements.
- Physiological considerations for transfer of fidelity and realism of cockpit motion environments.
- Benefits of various motion capabilities based on physiological factors, transfer of training, and other criteria as appropriate.
- Integration of aerodynamic buffet effects and other cockpit noise and vibration sources.
- Any other topics that are considered necessary to advance the state-of-the-art and utility of motion

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systems. for large amplitude maneuvers.

- Long-term recommended research and potential advantages of advanced simulator motion fidelity.

#### Sub Topics:

##### Propulsion System Performance Prediction for Integrated Flight and Propulsion Control Topic A1.12

In current aircraft, the flight and propulsion controls are designed independently and pilots manually integrate them through manipulation of the cockpit controls. Although the pilot manages these individual systems well under normal conditions, an integrated design approach would be able to achieve maximum benefit from these systems under abnormal conditions, especially for energy management and coordinated control for upset prevention and recovery. NextGen operations might also benefit, especially relative to 4-D trajectory management. If properly integrated up front in the flight control design, the propulsion system could be an effective flight control actuator. However, in order to optimally integrate the two systems, the engine performance must be known. The propulsion performance is dependent on operating condition, and many safety constraints make it highly nonlinear. Thus it is necessary to have a system that can continuously predict the engine performance and constraints at the current operating condition and communicate this to the flight control system to facilitate optimal flight and propulsion integration. Ideally, the flight control system should be able to treat the propulsion system as a linear time-varying constrained system for real-time control purposes. Including the propulsion system in the flight control design provides another degree of freedom for the designer, and because the propulsion system is such a powerful actuator, it is one that potentially enhances upset prevention and recovery. Developing the ability to use the propulsion system to augment the flight control while still providing traditional pilot interaction with the cockpit controls can improve maneuverability and safety transparently.

Under this research subtopic, an approach to predicting, and communicating engine dynamic response that facilitates integrated flight and propulsion control would be developed. This is a prerequisite to utilizing the engines as flight control actuators to improve maneuverability and aid in upset prevention and recovery.

Potential NASA resources:

Commercial Modular Aero-Propulsion System Simulation40k (C-MAPSS40k) and Generic Transport Model (GTM).

#### Sub Topics:

##### Advanced Upset Protection System Topic A1.13

One of the common causes for Loss of control (LOC) is the crew's lack of awareness of the current energy state relative to the current mission phase and inappropriate response to a low or high-energy state. Technologies to prevent the development of an inappropriate energy state via manual aids and automatic approaches are crucial for the prevention of loss of control.

In large airplanes, energy management refers to the ability to know and control the complex combination of the aircraft's airspeed and speed trend, altitude and vertical speed, configuration, and thrust. For example, near-terminal operations (takeoff and landing) require precise control of airspeed to achieve optimum performance while maintaining safe stall margin, and altitude management is critical for approaches. The penalty for improper energy management can be de-stabilized approaches, excessive pilot workload leading to distraction, and ultimately

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inadequate altitude or airspeed to recover from a loss-of-control event (e.g., stall). Many loss-of-control incidents/accidents can be attributed to improper management of airspeed, especially those leading to aerodynamic stall or departure from controlled flight.

Under this research subtopic, an envelope protection system would be developed to prevent low and high energy states based on the aircraft's current mission phase objectives. The envelope protection system should investigate the automatic use of the propulsion system, landing gear and secondary flight controls to maintain energy state. Methods to display information on system status to the pilot should also be considered to prevent adverse pilot interaction with the envelope protection system. Use on both current and NextGen aircraft should also be considered.

#### Sub Topics:

##### Detection, Identification, and Mitigation of Sensor Failures Topic A1.14

Faults related to aircraft sensing systems have been a major cause of loss-of-control accidents and incidents. For example, an airspeed sensing system fault is suspected of setting into motion a chain of events that resulted in the loss of Air France flight 447 (June 2009); a faulty altimeter is suspected in the stall and crash of Turkish Airline flight 1951 (February 2009); and faulty angle-of-attack sensing is suspected of causing violent uncommanded motion in Qantas Flight 72 (October 2008). Sensor redundancy is essential to ensure safety and reliability of the flight systems; however, redundancy alone may not be sufficient to avoid problems due to common mode failures across redundant sensors (such as suspected Pitot tube icing in all airspeed sensors). Therefore, research is needed to utilize all information available from multiple- possibly diverse- sensors in order to rapidly detect and isolate sensor faults in real time. The research would involve information fusion across multiple sensors, detection of erroneous behavior within a sensor or sensor suite, and mitigation of information loss through algorithmic redundancy and design to estimate the lost information from a failed sensor. The aim of the research would be to develop technology to prevent loss of control due to sensing system faults.

#### Sub Topics:

##### Unmanned Vehicle Design for Loss-of-Control Flight Research Topic A1.15

Recent advances in unmanned vehicle systems have enabled subscale flight testing using remotely piloted or autonomous vehicles to obtain high fidelity estimates of key aircraft performance parameters. An important requirement for obtaining relevant dynamic flight data from subscale vehicles is to apply dynamic scaling to the aircraft, so as to provide scaled inertial and mass properties, as well as geometric similitude.

The use of these vehicles is of particular interest in aviation safety studies because they allow exploration into unusual flight attitudes and upset conditions that are difficult to test in full scale aircraft due to structural limits and other safety concerns. Models of the stall and departure characteristics, as can be identified through flight testing, are needed to improve both aircraft training simulators as well as allow the design of control systems to reduce loss-of-control accidents.

Proposals are sought for a subscale civil transport vehicle design for remotely operated flight testing that allows a wide range of vehicle configurations. The vehicle should be modular in construction to emulate configurations representative of both conventional tail jet transports with under-wing engines and T-tail transports with rear mounted engines. In addition, the design should allow ballasting to achieve a range of target inertias and center of

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gravity locations. The ability to introduce flexible components for aeroelastic effects, as well components to model structural and control surface failures are also of interest.

Proposals should address construction methods that allow tradeoffs in costs and complexity while maintaining structural integrity required for loss-of-control flight testing. Control surfaces should be distributed to provide redundancy and allow for experiments involving actuator failures and in-flight dynamic simulation. Vehicle size should be consistent with commercially available turbine engines and allow road transport with manual field assembly.

Sub Topics:

Validation Methods for Safety-Critical Systems Operating under LOC Conditions Topic A1.16

Validation of future complex integrated systems designed to ensure flight safety under off-nominal conditions associated with aircraft loss of control is a significant challenge. Future systems will ensure vehicle flight safety by integrating vehicle health management functions, resilient control functions, flight safety assessment and prediction functions, and crew interface and variable autonomy functions. Each of these functions is characterized by algorithmic diversity that must be addressed in the validation process. Vehicle health management involves diagnostic and prognostic algorithms that utilize stochastic decision-based reasoning and extensive information processing and data fusion. Resilient control functions can involve adaptive control algorithms that utilize time-varying parameters and/or hybrid system switching. Flight safety management may involve diagnostic and prognostic reasoning algorithms as well as control theoretic algorithms. Crew interface functions involve displays that are human-factors-based and require information processing and reasoning, and variable autonomy will require assessment and reasoning algorithms. Onboard modeling functions will involve system identification algorithms and databases. Normal operating conditions of the future may extend beyond current-day operational limits. Moreover, safe operation under off-nominal conditions that could lead to loss-of-control events will be a focus of the system design. In particular, operation under abnormal flight conditions, external hazards and disturbances, adverse onboard conditions, and key combinations of these conditions will be a major part of the operational complexity required for future safety-critical systems. Future air transportation systems must also be considered under operational complexity, such as requirements for dense all-weather operations, self separation of aircraft, and mixed capabilities of aircraft operating in the same airspace, including current and future vehicle configurations as well as piloted and autonomous vehicles.

System validation is a confirmation that the algorithms are performing the intended function under all possible operating conditions. The validation process must be capable of identifying potentially problematic regions of operation (and their boundaries) and exposing system limitations - particularly for operation under off-nominal and hazardous conditions related to loss of control. New methods, metrics, and software tools must be established for algorithms that cannot be thoroughly evaluated using existing methods. Innovative research proposals are sought to address any of the following areas:

- Analytical Validation Methods.
- Predictive Capability Assessment Methods.
- Real-Time (or Run-Time) Validation Methods.

Analytical validation methods are comprised of a set of analytical methods and tools that facilitate the accurate

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prediction of system properties under various operating and off-nominal conditions. A wide variety of analytical methods will be needed to evaluate stability and performance of various and dissimilar system functions, robustness to adverse and abnormal conditions, and reliability under errors, faults, failures, and damage. These methods and software tools will be utilized offline and prior to implementation in representative avionics system software and hardware. These methods will enable analysis under a wide range of conditions, and be used to facilitate nonlinear simulation-based and experimental evaluations under selected potentially problematic conditions in order to expose system deficiencies and limitations over a very large operational space. Analytical methods and tools applicable to determining stability, performance, robustness, and reliability of nonlinear, time-varying, and/or hybrid systems involving control theoretic, diagnostic/prognostic, and/or reasoning systems are sought.

Predictive capability assessment is an evaluation of the validity and level of confidence that can be placed in the validation process and results under nominal and off-nominal conditions (and their associated boundaries). The need for this evaluation arises from the inability to fully evaluate these technologies under actual loss-of-control conditions. A detailed disclosure is required of model, simulation, and emulation validity for the off-nominal conditions being considered in the validation, interactions that have been neglected, assumptions that have been made, and uncertainties associated with the models and data. Cross-correlations should be utilized between analytical, simulation and ground test, and flight test results in order to corroborate the results and promote efficiency in covering the very large space of operational and off-nominal conditions being evaluated. The level of confidence in the validation process and results must be established for subsystem technologies as well as the fully integrated system. This includes an evaluation of error propagation effects across subsystems, and an evaluation of integrated system effectiveness in mitigating off-nominal conditions and preventing cascading errors, faults, and failures across subsystems. Metrics for performing this evaluation are also needed. Uncertainty-based and/or statistical-based methods and tools that enable the determination of level of confidence in the validation of uncertain systems operating under extreme conditions are sought.

Real-time (or run-time) validation methods are needed for the onboard monitoring of crucial system properties whose violation could compromise safety of flight. These properties might include closed-loop stability, robustness margins, or underlying theoretical assumptions that must not be violated. This information could be used as part of a real-time safety-of-flight assessment system for the vehicle. Real-time methods and software tools are sought that enable onboard validation of nonlinear, time-varying, and reasoning systems.

#### Sub Topics:

##### Data Mining and Knowledge Discovery Topic A1.17

The fulfillment of the SSAT project's goal requires the ability to transform the vast amount of data produced by the aircraft and associated systems and people into actionable knowledge that will aid in detection, causal analysis, and prediction at levels ranging from the aircraft-level, to the fleet-level, and ultimately to the level of the national airspace. The vastness of this data means that data mining methods must be efficient and scalable so that they can return results quickly. Additionally, much of this data will be distributed among multiple systems. Data mining methods that can operate on the distributed data directly are critical because centralizing large volumes of data is typically impractical. However, these methods must be provably able to return the same results as what a comparable method would return if the data could be centralized because this is a critical part of verifying and validating these algorithms, which is important for aviation safety applications. Additionally, algorithms that can learn in an online fashion---can learn from new data in incremental fashion without having to re-learn from the old data---will be important to allow deployed algorithms to update themselves as the national airspace evolves. The data is also heterogeneous: it consists of text data (e.g., aviation safety reports), discrete sequences (e.g., pilot switches, phases of flight), continuous time-series data (e.g., flight-recorded data), radar track data, and others. Data mining methods that can operate on such diverse data are needed because no one data source is likely to be sufficient for anomaly detection, causal analysis, and prediction.

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This topic will yield efficient and scalable data-driven algorithms for anomaly detection, causal analysis, and prediction that are able to operate at levels ranging from the aircraft level to the fleet level. To that end, the methods must be able to efficiently learn from vast historical time-series datasets (at least 10 TB) that are heterogeneous (contain continuous, discrete, and/or text data). Distributed data-driven algorithms that provably return the same results as a comparable method that requires data to be centralized are also of great interest. Online algorithms that can update their models in incremental fashion are also of great interest for this subtopic.

Sub Topics:

Prognostics and Decision Making Topic A1.18

The benefit of prognostics will be realized by converting remaining life estimates and dynamically changing context information into actionable decisions. These decisions can then be enacted at the appropriate level, depending on the prognostic time horizon and safety criticality of the affected area. In particular, information about RUL could be used either reflexively, through resource re-allocation, through mission replanning, or through appropriate maintenance action.

To maximize the impact, it is necessary to provide an accurate and precise prognostic output, carefully manage uncertainty, and provide an appropriate contingency. This effort addresses the development of innovative methods, technologies, and tools for the prognosis of aircraft faults and failures in aircraft systems and how to decide on remedial actions.

Areas of interest include the development of methods for estimation of RUL, which take into account future operational and environmental conditions; for dealing with inherent uncertainties; for building physics-based models of degradation; for generation of example aging and degradation datasets on relevant components or subsystems; and for development of validation and verification methodologies for prognostics.

Research should be conducted to demonstrate technical feasibility during Phase I and to show a path toward a Phase II technology demonstration. Proposals are solicited that address aspects of the following areas:

- Novel RUL prediction techniques that improve accuracy, precision, and robustness of RUL output, for example through the fusion of different methods.
- Uncertainty representation and management (reduction of prediction uncertainty bounds) methods. Proposers are encouraged to consider uncertainties due to measurement noise, imperfect models and algorithms, as well as uncertainties stemming from future anticipated loads and environmental conditions.
- Contingency management methods that act on predictive information. Particular interest is for methods that address the medium-and long term prognostic horizons.
- Verification and validation methods for prognostic algorithms.
- Aircraft relevant test beds that can generate aging and degradation datasets for the development and testing of prognostic techniques.

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All methods should be demonstrated on a set of fault modes for a device or component such as composite airframe structures, engine turbomachinery and hot structures, avionics, electrical power systems, or electronics. Prognostic performance needs to be measured on benchmark data sets using prognostic metrics for accuracy, precision, and robustness. Metrics should include prognostic horizon (PH), alpha-lambda, relative accuracy (RA), convergence, and R\_delta.

Sub Topics:

Technologies for Improved Design and Analysis of Safety-Critical Dynamic Systems Topic A1.19  
The NASA Aviation Safety program seeks proposals to support the development of robust human interactive, dynamic, safety-critical systems. The aviation Safety program is particularly interested in methods and tools that support predictive analysis of Human - Automation Interaction of mixed initiative systems in complex environments.

Information complexity in aviation systems is increasing exponentially, and designers and evaluators of these systems need tools to understand, manage, and estimate the performance and safety characteristics early in the design process. NASA seeks innovative design methods and tools for representing the complex human-automation interactions that will be part of future safety-critical, dynamic, mixed initiative systems. In addition, NASA seeks tools and methods for estimating, measuring, and/or evaluating the performance of these designs throughout the lifecycle from preliminary design to operational use - with an emphasis on the early stages of conceptual design. Specific areas of interest include the following:

- Computational/modeling approaches to support determining appropriate human-automation function allocations with respect to safety and reliability. Specifically these methods should focus on metrics that describe the robustness and resilience of a proposed human - automation function allocation.
- Analysis tools and methods that improve the application of human-centered design principles to the design and certification of mixed human-automated systems.
- Design and analysis methods or tools to better predict and assess human and system performance in relevant operational environments (e.g., future generations of air traffic management) , particularly in regards to procedural errors. Specifically, this work should include performance estimates that account for differences in training and proficiency.
- Analysis tools to support the use of mixed initiative systems in off-nominal conditions.
- Tools that provide validated human performance analysis early in the design process.

Proposals should describe novel design methods, metrics, and/or tools with high potential to serve the objectives of the Human Systems Solutions element of NASA's Aviation Safety Program's System-wide Safety Assurance Technologies project. Successful Phase I proposals should provide a literature review that on which the proposed work is based, a detailed schedule, and should culminate in a final report that specifies, and a Phase II proposal that would realize, tools that improve the analysis process for human-automation systems in aerospace, or improves the ability to assess effectiveness of such systems during the design phase. All proposals should discuss means for verification and validation of proposed methods and tools in operationally valid, or end-user, contexts.

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Sub Topics:

Verification and Validation of Flight-Critical Systems Topic A1.20

The Aviation Safety program has been put in charge of addressing the JPDO concerns that current V&V techniques are not sufficient to verify and validate NextGen. This is reflected in the VVFC element under the SSAT project in the Aviation Safety program.

VVFC has four major themes:

- Argument-based safety assurance, which aims at unifying and formalizing how V&V results for ground and airborne software systems are folded into a safety argument for certification.
- Distributed Systems, which aims at developing guidance on the V&V of distributed applications, e.g., communication topologies, mixed-criticality architectures, and fault tolerance schemes.
- Authority and Autonomy, which explores the modeling and analysis of authority problems in the NAS when viewed as a distributed system within which automation and humans interact.
- Software-intensive systems, which focuses on early, formal methods for the V&V of software systems.

This year, VVFC is interested in technologies that can be transitioned (meaning that tools are made available) to industry in the following areas:

- Run-time monitoring.
- Safety case.
- Static analysis.
- Code libraries implementing fundamental technologies that can be used in formal method research, such as:
  - Memory and time efficient decision procedures.
  - Memory and time efficient abstractions for static analysis.

Sub Topics:

Materials and Structures for Future Aircraft Topic A2.01

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Advanced materials and structures technologies are needed in all four of the NASA Fundamental Aeronautics Program research thrusts (Subsonics Fixed Wing, Subsonics Rotary Wing, Supersonics, and Hypersonics) to enable the design and development of advanced future aircraft. Proposals are sought that address specific design and development challenges associated with airframe and propulsion systems. These proposals should be linked to improvements in aircraft performance indicators such as vehicle weight, fuel consumption, noise, lift, drag, durability, and emissions. In general, the technologies of interest cover five research themes:

### **Fundamental Materials Development, Processing and Characterization**

Innovative approaches to enhance the durability, processability, performance and reliability of advanced materials (metals, ceramics, polymers, composites, nanostructured materials, hybrids and coatings). In particular, proposals are sought in:

- Advanced high temperature materials for aircraft engine and airframe components and thermal protection systems, including advanced blade and disk alloys, ceramics and CMCs, polymers and PMCs, nanostructured materials, hybrid materials and coatings to improve environmental durability.
- New adaptive materials such as piezoelectric ceramics, shape memory alloys, shape memory polymers, and variable stiffness materials and methods to integrate these materials into airframe and/or aircraft engine structures to change component shape, dampen vibrations, and/or attenuate acoustic transmission through the structure.
- Multifunctional materials and structural concepts for engine and airframe structures, such as novel approaches to power harvesting and thermal management, lightning strike mitigating, self-sensing, and materials for wireless sensing and actuation.
- New high strength fibers, in particular low density, high strength and stiffness carbon fibers.
- Innovative processing methods to reduce component manufacturing costs and improve damage tolerance, performance and reliability of ceramics, shape memory alloys, polymers, composites, and hybrids, nanostructured and multifunctional materials and coatings.
- Development of joining and integration technologies including fasteners and/or chemical joining methods for ceramic-to-ceramic, metal-to-metal (with an emphasis on joining dissimilar forms of nickel base superalloys, e.g., powder metallurgy to cast or directionally solidified alloys), and metal-to-ceramic as well as solid state joining methods such as advanced friction stir welding.
- Innovative methods for the evaluation of advanced materials and structural concepts (in particular multifunctional and/or adaptive) under simulated operating conditions, including combinations of electrical, thermal and mechanical loads.
- Nondestructive evaluation (NDE) methods for the detection of as-fabricated flaws and in-service damage for textile polymeric, ceramic and metal matrix composites, nanostructured materials and hybrids. NDE methods that provide quantitative information on residual structural performance are preferred.

### **Structural Analysis Tools and Procedures**

Robust and efficient design methods and tools for advanced materials and structural concepts (in particular multifunctional and/or adaptive components) including variable fidelity methods, uncertainty based design and optimization methods, multi-scale computational modeling, and multi-physics modeling and simulation tools. In particular, proposals are sought in:

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- Multiscale design tools for aircraft and engine structures that integrate novel materials, mechanism design, and structural subcomponent design into systems level designs.
  - Life prediction tools for textile composites including fiber architecture modeling methods that enable the development of physics-based hierarchical analysis methods. Fiber architecture models that address yarn-to-yarn and ply-to-ply interactions covering a wide range of textile perform structures in either a relaxed or compressed deformation state as well as tools to predict debonding and delamination of through thickness reinforced (stitched, z-pinned) composites are of particular interest.
  - Tools to predict durability and damage tolerance of new material forms including metallic-composite hybrids, friction stir-welded metallic materials and powder metallurgy-formed materials.
  - Meso scale tools to guide materials placement to enable tailored load paths in multifunctional structures for enhanced damage tolerance.

### **Computational Materials Development Tools**

Methods to predict properties, damage tolerance, and/or durability of both airframe and propulsion materials, thermal protection systems and ablatives based upon chemistry and processing for conventional as well as functionally graded, nanostructured, multifunctional and adaptive materials. In particular proposals are sought in:

- Ab-initio methods that enable the development of coatings for multiple uses at temperatures above 3000°F in an air environment.
- Computational tool development for structure-property modeling of adaptive materials such as piezoelectric ceramics, shape memory alloys, shape memory polymers to characterize their physical and mechanical behavior under the influence of an external stimulus.
- Computational and analytical tools to enable molecular design of polymeric and/nanostructured materials with tailored multifunctional characteristics.
- Computational microstructural and thermodynamic analysis tools and technique development for designing new lightweight alloy compositions for subsonic airframe and engines from first principles, functionally graded (chemically or microstructurally) materials, and/or novel metals processing techniques to accelerate materials development and understanding of processing-structure-property relationships.
- Software tools to predict temperature dependent phase chemistries, volume fractions, shape and size distributions, and lattice parameters of phases in a broad range of nickel and iron-nickel based superalloys. Toolset should utilize thermodynamic and kinetic databases and models that are fully accessible, which allow modifications and user-input to expand experimental databases and refine model predictions.

### **Advanced Structural Concepts**

New concepts for airframe and propulsion components incorporating new light weight concepts as well as "smart" structural concepts such as those incorporating self-diagnostics with adaptive materials, multifunctional component concepts to reduce mass and improve durability and performance, lightweight, efficient drive systems and electric motors for use in advanced turboelectric propulsion systems for aircraft, and new concepts for robust thermal protection systems for high-mass planetary entry, descent and landing. In particular, proposals are sought in:

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- Innovative structural concepts, materials, manufacturing and fabrication leading to reliable, entry descent and landing systems including deployable rigid and flexible heat shields and structurally integrated multifunctional systems. Of particular interest are high temperature honeycombs, hat stiffeners, rigid fibrous and foam insulators, as well as high temperature adhesives, films and fabrics for advanced flexible heat shields.
  - New actuator concepts employing shape memory alloys.
  - Advanced mechanical component technologies including self-lubricating coatings, oil-free bearings, and seals.
  - Advanced material and component technologies to enable the development of mechanical and electrical drive system to enable the development of turboelectric propulsion systems, which utilize power from a single turbine engine generator to drive multiple propulsive fans. Innovative concepts are sought for AC-tolerant, low loss ( 1.5 T field and 500 Hz electrical frequency; and high efficiency (= 30% of Carnot), low mass (
  - Novel structural designs for integrated fan cases that combine hardwall composite cases for blade containment with acoustic treatments as well as concepts that integrate the case with the fan inlet to maximize structural, acoustic attenuation and weight benefits.
  - Innovative approaches to structural sensors for extreme environments (>1800°F) including the development and validation of improved methods (i.e., adhesives, plasma spraying techniques, etc.) for attaching sensors to advanced high-temperature materials as well as approaches to measure strain, temperature, heat flux and/or acceleration of structural components.

#### Sub Topics:

##### Combustion for Aerospace Vehicles Topic A2.02

Combustion research is critical for the development of future aerospace vehicles. Vehicles for subsonic and supersonic flight regimes will be required to emit extremely low amounts of gaseous and particulate emissions to satisfy increasingly stringent emissions regulations. Hypersonic vehicles require combustion systems capable of sustaining stable and efficient combustion in very high speed flow fields where fuel/air mixing must be accomplished very rapidly and residence times for combustion are extremely limited; a major challenge is developing scaling laws that will allow the size of scramjet engines to be increased by a factor of 10, i.e., to mass flow rates of 100 lbm/sec. Fundamental combustion research coupled with associated physics based model development of combustion processes will provide the foundation for technology development critical for aerospace vehicles. Combustion for aerospace vehicles typically involves multi-phase, multi-component fuel, turbulent, unsteady, 3D, reacting flows where much of the physics of the processes are not completely understood. CFD codes used for combustion do not currently have the predictive capability that is typically found for non reacting flows. Practical aerospace combustion concepts typically require very rapid mixing of the fuel and air with a minimum pressure loss to achieve complete combustion in the smallest volume. Reducing emissions may require combustor operation where combustion instability can be an issue and active control may be required. Areas of specific interest where research is solicited includes:

- Development of laser-based diagnostics and novel experimental techniques for measurements in reacting flows.
- Two-phase flow simulation models and validation data under supercritical conditions.

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- Development of ultra-sensitive instruments for measuring gas turbine black carbon emissions at temperatures and pressures characteristic of commercial aircraft cruise altitudes.
  - High frequency actuators (bandwidth ~1000 Hz) that can be used to modulate fuel flow at multiple fuel injection locations (with individual Flow Numbers of 3 to 5) with minimal fuel pressure drop for active combustion control.
  - Combustion instability modeling and validation.
  - Novel combustion simulation methodologies.
  - Concepts that will allow the scaling of scramjet engines burning hydrogen and/or hydrocarbon fuels.

The following areas are of particular interest:

- The effect that size has on mixing, injection, and thermal loading losses.
- The effect of size on mixing and flame propagation.
- The effect of size on injection strategies.
- The scaling of ignition devices, flameholders, and mixing devices.
- The effect that the size and thickness of the incoming boundary layer has on ignition devices and flameholders.
- Whether there is a ratio between the size of inviscid stirring structures and turbulent structures that is optimal for rapid mixing.

#### Sub Topics:

##### Aero-Acoustics Topic A2.03

Innovative technologies and methods are necessary for the design and development of efficient, environmentally acceptable airplanes, and advanced aerospace vehicles. In support of the Fundamental Aeronautics Program, improvements in noise prediction, measurement methods and control are needed for subsonic and supersonic vehicles, including fan, jet, turbomachinery, engine core, open rotor, propeller and airframe noise sources. In addition, improvements in prediction and control of noise transmitted through aerospace vehicle structures are needed to reduce noise impact on passengers and crew. Innovations in the following specific areas are solicited:

- Fundamental and applied computational fluid dynamics techniques for aeroacoustic analysis, which can be adapted for design codes.
- Prediction of aerodynamic noise sources including those from engine and airframe as well as sources, which arise from significant interactions between airframe and propulsion systems.
- Efficient prediction tools for turbine and combustor aeroacoustics.
- Efficient high-fidelity computational fluid dynamics tools for assessing aeroacoustic performance of installed high and low speed single- and counter-rotation propellers.

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- Innovative source identification techniques for engine (e.g., fan, jet, combustor, or turbine noise) and for airframe (e.g., landing gear, high lift systems) noise sources, including turbulence details related to flow-induced noise typical of jets, separated flow regions, vortices, shear layers, etc.
  - Concepts for active and passive control of aeroacoustic noise sources for conventional and advanced aircraft configurations, including adaptive flow control technologies, smart structures for nozzles and inlets, advanced acoustic liners, and noise control technology and methods that are enabled by advanced aircraft configurations, including integrated airframe-propulsion control methodologies.
  - Prediction of near field sound propagation including interaction between noise sources and the airframe and its flow field and far field sound propagation (including sonic booms) from the aircraft through a complex atmosphere to the ground.
  - Computational and analytical structural acoustics prediction techniques for aircraft and advanced aerospace vehicle interior noise, particularly for use early in the airframe design process;
  - Technologies and techniques for active and passive interior noise control for aircraft and advanced aerospace vehicle structures. Prediction and control of high-amplitude aeroacoustic loads on advanced aerospace structures and the resulting dynamic response and fatigue.
  - Development of synthesis and auditory display technologies for subjective assessments of aircraft community and interior noise, including sonic boom.

#### Sub Topics:

##### Aeroelasticity Topic A2.04

The NASA Fundamental Aeronautics program has the goal to develop system-level capabilities that will enable civilian and military designers to create revolutionary systems, in particular by integrating methods and technologies that incorporate multi-disciplinary solutions. Aeroelastic behavior of flight vehicles is a particularly challenging facet of that goal.

The program's work on aeroelasticity 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 aeroelasticity through novel and creative application of aeroelastic knowledge.

The technical discipline of aeroelasticity is a critical ingredient necessary in the design process of a flight vehicle for ensuring freedom from catastrophic aeroelastic and aeroservoelastic instabilities. This discipline requires a thorough understanding of the complex interactions between a flexible structure and the unsteady aerodynamic

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forces acting on the structure and at times, active systems controlling the flight vehicle. Complex unsteady aerodynamic flow phenomena, particularly at transonic Mach numbers, are also very important because this is the speed regime most critical to encountering aeroelastic instabilities. In addition, aeroelasticity is presently being exploited as a means for improving the capabilities of high performance aircraft through the use of innovative active control systems using both aerodynamic and smart material concepts. Work to develop analytical and experimental methodologies for reliably predicting the effects of aeroelasticity and their impact on aircraft performance, flight dynamics, and safety of flight are valuable. Subjects to be considered include:

- Development of design methodologies that include CFD steady and unsteady aerodynamics, flexible structures, and active control systems.
- Development of methods to predict aeroelastic phenomena and complex steady and unsteady aerodynamic flow phenomena, especially in the transonic speed range. Aeroelastic phenomena of interest include flutter, buffet, buzz, limit cycle oscillations, divergence, and gust response; flow phenomena of interest include viscous effects, vortex flows, separated flows, transonic nonlinearities, and unsteady shock motions.
- Development of efficient methods to generate mathematical models of wind-tunnel models and flight vehicles for performing vibration, aeroelastic, and aeroservoelastic studies. Examples include (a) CFD-based methods (reduced-order models) for aeroservoelasticity models that can be used to predict and alleviate gust loads, ride quality issues, and flutter issues and (b) integrated tool sets for fully coupled modeling and simulation of aeroservoelastocity / flight dynamic (ASTE/FD) and propulsion effects.
- Development of physics-based models for turbomachinery aeroelasticity related to highly separated flows, shedding, rotating stall, and non-synchronous vibrations (NSV). This includes robust, fast-running, accelerated convergence, reduced-order CFD approaches to turbomachinery aeroelasticity for propulsion applications. Development of blade vibration measurement systems (including closely spaced modes, blade-to-blade variations (mistuning), and system identification) and blade damping systems for metallic and composite blades (including passive and active damping methods) are of interest.
- Development of aeroservoelasticity concepts and models, including unique control concepts and architectures that employ smart materials embedded in the structure and/or aerodynamic control surfaces for suppressing aeroelastic instabilities or for improving performance.
- Development of techniques that support simulations, ground testing, wind-tunnel tests, and flight experiments of aeroelastic phenomena.
- Investigation and development of techniques that incorporate structure-induced noise, stiffness and strength tailoring, propulsion-specific structures, data processing and interpretation methods, non-linear and time-varying methods development, unstructured grid methods, additional propulsion systems-specific methods, dampers, multistage effects, non-synchronous vibrations, coupling effects on blade vibration, probabilistic aerodynamics and aeroelastics, actively controlled propulsion system core components (e.g., fan and turbine blades, vanes), and advanced turbomachinery active damping concepts.
- Investigation and development of techniques that incorporate lightweight structures and flexible structures under aerodynamic loads, with emphasis on aeroelastic phenomena in the hypersonic domain. Investigation of high temperatures associated with high heating rates, resulting in additional complexities associated with varying thermal expansion and temperature dependent structural coefficients. Acquisition of data to verify analysis tools with these complexities.

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The challenge of flight has at its foundation the understanding, prediction, and control of fluid flow around complex geometries - aerodynamics. Aerodynamic prediction is critical throughout the flight envelope for subsonic, supersonic, and hypersonic vehicles - driving outer mold line definition, providing loads to other disciplines, and enabling environmental impact assessments in areas such as emissions, noise, and aircraft spacing.

In turn, high confidence prediction enables high confidence development and assessment of innovative aerodynamic concepts. This subtopic seeks innovative physics-based models and novel aerodynamic concepts, with an emphasis on flow control, applicable in part or over the entire speed regime from subsonic through hypersonic flight.

All vehicle classes will experience subsonic flight conditions. The most fundamental issue is the prediction of flow separation onset and progression on smooth, curved surfaces, and the control of separation. Supersonic and hypersonic vehicles will experience supersonic flight conditions. Fundamental to this flight regime is the sonic boom, which to date has been a barrier issue for a viable civil vehicle. Addressing boom alone is not a sufficient mission enabler however, as low drag is a prerequisite for an economically viable vehicle, whether only passing through the supersonic regime, or cruising there. Atmospheric entry vehicles and space access vehicles will experience hypersonic flight conditions. Reentry capsules and vehicles deploy multiple parachutes during descent and landing. Predicting the physics of unsteady flows in supersonic and subsonic speeds is important for the design of these deceleration systems. The gas-dynamic performance of decelerators for vehicles entering the atmospheres of planets in the solar system is not well understood. Reusable hypersonic vehicles will be designed such that the lower body can be used as an integrated propulsion system in cruise condition. Their performance is likely to suffer in off-design conditions, particularly acutely at transonic speeds. Advanced flow control technologies are needed to alleviate the problem.

This solicitation seeks proposals to develop and validate:

- Turbulence models and advanced computational techniques such as detached eddy, large eddy, or direct numerical simulations that capture the physics of separation onset at Reynolds numbers relevant to flight, where relevant to flight is dependent on a targeted vehicle class and mission profile.
- Boundary-layer transition models suitable for direct integration with state-of-the-art flow solvers.
- Active flow control concepts targeted at separation control, shock wave manipulation, and/or viscous drag reduction with an emphasis on the development of novel, practical, lightweight, low-energy actuators.
- Innovative aerodynamic concepts targeted at vehicle efficiency or control, including but not limited to concepts targeted at turbulent boundary skin friction drag reduction.
- Physics-based models for simultaneous low boom/low drag prediction and design.
- Aerodynamic concepts enabling simultaneous low boom and low drag objectives.
- Innovative methods to validate both flow models and aerodynamic concepts with an emphasis on aft-shock effects, which are hindered by conventional wind tunnel model mounting approaches.
- Uncertainty quantification methods suitable for use with state-of-the-art flow solvers.
- Accurate aerodynamic analysis and multidisciplinary design tools for multi-body flexible structures in the atmospheres of planets and moons including the Earth, Mars, and Titan.

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- Advanced flow control technologies to alleviate off-design performance penalties for reusable hypersonic vehicles.

Sub Topics:

Aerothermodynamics Topic A2.06

Development of hypersonic flight vehicles for airbreathing access to space and for planetary entry poses several design challenges. One of the primary obstacles is the large uncertainty in predictive capability of the aerothermal environment to which these vehicles are subjected. For airbreathing access to space vehicles, predictions of boundary layer transition to turbulence and shock boundary layer interactions in a turbulent flow regime are sources of large aerothermal uncertainty and require conservative assumptions. For planetary entry vehicles with either rigid or flexible thermal protection systems (TPS), sources of large aerothermal uncertainty in high enthalpy conditions also include the catalytic or ablative properties of the TPS. The fluid dynamic and thermochemical interactions of a rough ablating surface with the aerothermal environment leads to many poorly understood coupled phenomena such as early boundary layer transition, turbulent heating augmentation, catalytic heating, radiation absorption, etc. At high entry speeds and large vehicle sizes, shock layer radiation becomes a large component of the aeroheating, with an increasing fraction of the radiation produced in the poorly understood vacuum ultraviolet part of the spectrum. The low confidence in the predictive capability is apparent in high enthalpy flows that are often difficult to adequately reproduce in a ground test facility.

The model uncertainties require designers to resort to large margins, resulting in reduced mission capabilities and increased costs. Future science and human exploration missions to Mars and other planets will require dramatic improvements in our current capability to land large payloads safely on these worlds. Research in aerothermodynamics focuses on solving some of the most difficult challenges in hypersonic flight. These include the development of predictive models via experimental validation for shock layer radiation phenomena, non-equilibrium thermodynamic and transport properties, catalycity, transition and turbulence, and ablation phenomena, as well as the development of new experimental datasets, especially in high enthalpy flow that can be used to validate theoretical and computational models.

Proposals suggesting innovative approaches to any of these problems are encouraged; specific areas of interest include:

- Advancement of NASA boundary layer transition tools, especially including high enthalpy effects.
- Development of shock turbulent boundary layer interaction models and validation with an experimental program.
- Development of radiation models supported by experimental validation in a laboratory (using shock tube, plasma torch, etc.) simulating extreme entry environments at Earth, Mars, Titan, and the Giant Planets.
- Development of high enthalpy RANS level turbulence models in a rough, ablating environment using experimentation or use of high fidelity computational techniques such as DNS or LES.
- Development of instrumentation for use in high-enthalpy flows to measure pressure, shear, radiation intensity, and off body flow quantities with enhanced capability such as high frequency measurements and/or high temperature tolerance.

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- Development of tools and techniques that enable remote thermal imaging of entry vehicles with high temperature and spatial resolution, and lower uncertainty than the state-of-the art.
  - Development of numerical techniques and computational tools that advance the start-of-the-art in computations of unsteady, turbulent separated flows with reasonable computational efficiency.

#### Sub Topics:

##### Flight and Propulsion Control and Dynamics Topic A2.07

NASA is conducting fundamental aeronautic research to develop innovative ideas that can lead to next generation aircraft design concepts with improved aerodynamic efficiency, lower emissions, less fuel burn, and reduced noise and carbon footprints. To realize these potential benefits, innovative vehicle design concepts can exhibit many complex modes of interactions due to many different effects of flight physics such as aerodynamics, vehicle dynamics, propulsion, structural dynamics, and external environment in all three flight regimes. Advanced flight control strategies for innovative aircraft design concepts are seen as an enabling technology that can harvest potential benefits derived from these complex modes of interaction. The following technology areas are of particular interest:

#### **Active Aeroelastic Wing Shape Tailoring for Aircraft Performance and Control**

Modern aircraft are increasingly designed with light-weight, flexible airframe structures. By employing distributed flight control surfaces, a modern wing structure (which implies aircraft wing, horizontal stabilizer, and vertical stabilizer) can be strategically tailored in-flight by actively controlling the wing shape so as to bring about certain desired vehicle characteristics. For example, active aeroelastic wing shape tailoring can be employed to control the wash-out distribution and wing deflection in such a manner that could result in improved aerodynamic performance such as reduced drag during cruise or increased lift during take-off. Another novel use of active aeroelastic wing shape tailoring is for flight control. By actively controlling flexible aerodynamic surfaces differentially or collectively, the motion of an aircraft can be controlled in all three stability axes. In high speed supersonic or hypersonic vehicles, effects of airframe-propulsion-structure interactions can be significant. Thus, propulsion control can play an integral role with active aeroelastic wing shape tailoring control in high speed flight regimes.

Technology development of active aeroelastic wing shape tailoring may include, but are not limited to the following:

- Innovative aircraft concepts that can significantly improve aerodynamic, performance and control by leveraging active aeroelastic wing shape tailoring.
- Sensor technology that will enable in-flight wing twist and deflection static and dynamic measurements for control development.
- Actuation methods that include novel modes of operation and concepts of actuation for actively controlling wing shape in-flight.
- Vehicle dynamic modeling capability that includes effects of aero-propulsive-servo-elasticity for vehicle control and dynamics.
- Integrated approaches for active aeroelastic wing shape tailoring control with novel control effector concepts that will provide multi-objective advanced optimal or adaptive control strategies to achieve

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simultaneously aerodynamic performance such as trim drag reduction, aeroelastic stabilization or mode suppression, and load limiting.

### **Gust Load Alleviation Control**

In a future NextGen operational concept, close separation between aircraft in super density operations could lead to more frequent wake vortex encounters. Airframe flexibility in modern aircraft will inherently lead to a potential increase in vehicle dynamic response to turbulence and wake vortices. Gust load alleviation control technology can improve ride qualities and reduce undesired structural dynamic loading on flexible airframes that could shorten aircraft service life. Gust load alleviation control technology can be either reactive or predictive. In a traditional reactive control framework, flight control systems can be designed to provide sufficient aerodynamic damping characteristics that suppress vehicle dynamic response as rapidly as possible upon a turbulence encounter. There is a trade off, however, between increased damping for mode suppression and command-following objectives of a flight control system. Large damping ratios, while desirable for mode suppression, may result in poor flight control performance.

Predictive control can provide a novel gust load alleviation strategy for future aircraft design with light-weight flexible structures. Novel look-ahead sensor technology can measure or estimate turbulent intensity to provide such information to a predictive gust load alleviation control system which in turn would dynamically reconfigure flight control surfaces as an aircraft enters a turbulent atmospheric region. Technology development of predictive gust load alleviation control may include, but are not limited to the following:

- Novel sensor methods for Optical Air Data Systems based on LIDAR or other novel detection methods that can measure near-field air turbulent velocity components directly in front of an aircraft in the order of one-body length scale to provide nearly instantaneous predictive capability to significantly improve the effectiveness of a gust load alleviation control system.
- Predictive gust load alleviation control approaches or other effective methods that can reliably reconfigure flight control surfaces dynamically based on the sensor information of the near-field turbulence to mitigate the vehicle structural dynamic response upon a turbulence encounter. The predictive control strategies should be cognizant of potential adverse effects due to potential latency issues that can counteract the objective of gust load alleviation, or potential structural mode interactions due to control input signals that may contain frequencies close to the natural frequencies of the airframe.

### **Advanced Control Concepts for Propulsion Systems**

Enabling high performance "Intelligent Engines" will require advancement in the state of the art of propulsion system control. Engine control architectures/methods need to be developed that provide a tighter bound control on engine parameters for improved propulsion efficiency while maintaining safe operation. The ability of the controller to maintain its designed improvement of engine operation over the entire life and particular health condition of the propulsion system is critical. The controller needs to adapt to the specific health conditions of each engine to eventually allow for a "personalized" control, which will maintain the most efficient operation throughout the engine lifetime and increase the useful operating life. Possible advanced engine control concepts could include:

- Direct nonlinear control design such as predictive model based methods to directly control engine thrust while maintaining safety limits such as stall margins.

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- Model-Based Multivariable control to allow direct control of quantities of interest such as thrust, temperature and stall margins while using all available actuators for feedback.
  - Adaptive control schemes to maintain robust performance with changing engine condition with usage.

#### Sub Topics:

Aircraft Systems Analysis, Design and Optimization Topic A2.08

One of the approaches to achieve the NASA Fundamental Aeronautics Program goals is to solve the aeronautics challenges for a broad range of air vehicles with system-level optimization, assessment and technology integration. The needs to meet this approach can be defined by three general themes:

- Variable Fidelity, Physics-Based Design/Analysis Tools.
- Technology Assessment and Integration.
- Evaluation of Advanced Concepts.

Current interdisciplinary design/analysis involves a multitude of tools not necessarily developed to work together, hindering their application to complete system design/analysis studies. NASA has developed a capability that integrates several conceptual design/analysis tools and models in ModelCenter. In addition, development work is continuing on a python-based, open-source architecture (OpenMDAO) that should serve as the long term solution for a multi-fidelity, multi-disciplinary optimization framework. Solicited topics are targeted around these three themes that will support this NASA research area.

#### **Variable Fidelity, Physics-Based Design/Analysis Tools**

An integrated design process combines high-fidelity computational analyses from several disciplines with advanced numerical design procedures to simultaneously perform detailed Outer Mold Line (OML) shape optimization, structural sizing, active load alleviation control, multi-speed performance (e.g., low takeoff and landing speeds, but efficient transonic cruise), and/or other detailed-design tasks. Current practice still widely uses sequential, single-discipline optimization, at best coupling low-fidelity modeling of other relevant disciplines during the detailed design phase. Substantial performance improvements will be realized by developing closely integrated design procedures coupled with highest-fidelity analyses for use during detailed-design. Design procedures must enable rapid determination of sensitivities (gradients) of a design objective with respect to all design variables and constraints, choose search directions through design space without violating constraints, and make appropriate changes to the vehicle shape (ideally both external OML shape and internal structural element size). Solicitations are for integrated design optimization tools that find combinations of design variables from more than one discipline and can vary synergistically to produce superior performance compared to the results of sequential, single-discipline optimization or repeated cut-and-try analysis.

Research challenges include the engineering details needed to numerically zoom (i.e., numerical analysis at various levels of detail) between multi-fidelity components of the same discipline, as well as, multi-discipline components of the same fidelity. A major computer science challenge is developing boundary objects that will be reused in a wide variety of simulations. Proposals will be considered that enable coupling differing disciplines, numerical zooming within a single discipline, deploying large simulations and assembling and controlling secure or non-secure simulations.

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## Technology Assessment and Integration

Improved analysis capability of integrated airframe and propulsion systems would allow more efficient designs to be created that would maximize efficiency and performance while minimizing both noise and emissions. Improved integrated system modeling should allow designers to consider trade-offs between various design and operating parameters to determine the optimum design for various classes of subsonic fixed wing aircraft ranging from personal aircraft to large transports. The modeling would also be beneficial if it had enough fidelity to enable it to analyze both conventional and unconventional systems. Current analysis tools capable of analyzing integrated systems are based on simplified physical and semi-empirical models that are not fully capable of analyzing aircraft and propulsion system parameters that would be required for new or unconventional systems.

Analysis tools are solicited that are capable of analyzing new and unconventional aircraft and propulsion integrated systems. These include:

- New combustor designs, alternate fuel operation, and the ability to estimate all emissions.
- Noise source models (e.g., fan, jet, turbine, core and airframe components). Analyses tools that are scalable, especially to small aircraft, are desired.

## Evaluation of Advanced Concepts

Conceptual design and analysis of unconventional vehicle concepts and technologies is needed for technology portfolio investment planning, development of advanced concepts to provide technology pull, and independent technical assessment of new concepts. This capability will enable "virtual expeditions through the design space" for multi-mission trade studies and optimization. This will require an integrated variable fidelity concept design system. The aerospace flight vehicle conceptual design phase is, in contrast to the succeeding preliminary and detail design phases, the most important step in the product development sequence, because of its predefining function. However, the conceptual design phase is the least well understood part of the entire flight vehicle design process, owing to its high level of abstraction and associated risk, its multidisciplinary design complexity, its permanent shortage of available design information, and its chronic time pressure to find solutions. Currently, the important primary aerospace vehicle design decisions at the conceptual design level (e.g., overall configuration selection) are still made using extremely simple analyses and heuristics. An integrated, variable fidelity system would have large benefits. Higher fidelity tools enabling unconventional configurations to be addressed in the conceptual design process are solicited.

### Sub Topics:

#### Rotorcraft Topic A2.09

The challenge of the Subsonic Rotary Wing thrust of the NASA Fundamental Aeronautics Program is to develop validated physics-based multidisciplinary design-analysis-optimization tools for rotorcraft, integrated with technology development, enabling rotorcraft with advanced capabilities to fly as designed for any mission. Technologies of particular interest are as follows:

#### **Experimental Capabilities: Instrumentation and Techniques for Rotor Blade Measurements**

Instrumentation and measurement techniques are encouraged for assessing scale rotor blade boundary layer state (e.g., laminar, transition, turbulent flow) in simulated hover and forward flight conditions, measurement systems for large-field rotor wake assessment, and fast-response pressure sensitive paints applicable to blade surfaces.

#### **Acoustics: Interior and Exterior Rotorcraft Noise Generation, Propagation and Control**

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Interior noise topics of interest include, but are not limited to, prediction and/or experimental methods that enhance the understanding of noise generation and transmission mechanisms for cabin noise sources (e.g., power-train noise), active and combined active/passive methods to reduce cabin noise, and novel structural systems or materials to reduce cabin noise without an excessive weight penalty. Exterior noise topics of interest include, but are not limited to, noise prediction methods that address the understanding of issues such as noise generation, propagation, and control. These methods may address topics such as novel or drastically improved source noise prediction methods, novel or drastically improved noise propagation methods (e.g., through the atmosphere) to understand and/or control noise sources and their impact on the community. Methods should address one or more of the major noise components such as: harmonic noise, broadband noise, blade-vortex interaction noise, high-speed impulsive noise, interactional noise, and/or low frequency noise (e.g., propagation, psychoacoustic effects, etc).

### **Rotorcraft Power Train System Improvements**

Health management of rotorcraft power trains is critical. Predictive, condition-based maintenance improves safety, decreases maintenance costs, and increases system availability. Topics of interest include algorithm development, software tools and innovative sensor technologies to detect and predict the health and usage of rotorcraft dynamic mechanical systems in the engine and drive system. Rotorcraft health management technologies can include tools to: increase fault detection coverage and decrease false alarm rates; detect onset of failure, isolate damage, and assess damage severity; predict remaining useful life and maintenance actions required; system models, material failure models and correlation of failure under bench fatigue, seeded fault test and fielded data; tools to correlate propulsion system operational parameters back to actual usage and component fatigue life; Also of interest are advanced gear technologies for rotorcraft transmissions.

Proposals on other rotorcraft technologies will also be considered as resources and priorities allow, but the primary emphasis of the solicitation will be on the above three identified technical areas.

Sub Topics:

Propulsion Systems Topic A2.10

This subtopic is divided into three parts. The first part is the Turbomachinery and Heat Transfer and the second part is Developments Needed in Turbulence Modeling for Propulsion Flowpaths and third is Propulsion System Integration:

#### **Turbomachinery and Heat Transfer**

There is a critical need for advanced turbomachinery and heat transfer concepts, methods and tools to enable NASA to reach its goals in the various Fundamental Aeronautics projects. These goals include dramatic reductions in aircraft fuel burn, noise, and emissions, as well as an ability to achieve mission requirements for Subsonic Rotary Wing, Subsonic Fixed Wing, Supersonics, and Hypersonics Project flight regimes. In the compression system, advanced concepts and technologies are required to enable higher overall pressure ratio, high stage loading and wider operating range while maintaining or improving aerodynamic efficiency. Such improvements will enable reduced weight and part count, and will enable advanced variable cycle engines for various missions. 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. Reduced cooling flow rates and/or increased cycle temperatures enabled by these technologies have a dramatic impact on the engine performance.

Proposals are sought in the turbomachinery and heat transfer area to provide the following specific items:

- Advanced instrumentation to enable time-accurate, detailed measurement of unsteady velocities, pressures and temperatures in three-dimensional flowfields such as found in turbomachinery components. This may include instrumentation and measurement systems capable of operating in conditions up to 900 degrees F and in the presence of shock-blade row interactions, as well as in high speed, transonic cascades. The instrumentation methods may include measurement probes, non-intrusive optical methods and post-processing techniques that advance the state of the art in turbomachinery unsteady flowfield measurement for purposes of accurately resolving these complex flowfield.

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- Advanced compressor 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 turbomachinery sensitivity to tip clearance leakage effects where clearance to chord ratios may be on the order of 5% or above.
  - Novel turbine cooling concepts are sought to enable very high turbine cooling effectiveness especially considering the manufacturability of such concepts. These concepts may include film cooling concepts, internal cooling concepts, and innovative methods to couple the film and internal cooling designs. Concepts proposed should have the potential to be produced with current or forthcoming manufacturing techniques. The availability of advanced manufacturing techniques may actually enable improved cooling designs beyond the current state-of-the-art.

### **Developments Needed in Turbulence Modeling for Propulsion Flowpaths and Propulsion System Integration**

Flowpaths within propulsion systems are characterized by several aerodynamic and thermodynamic features which are very difficult for currently available computational fluid dynamics (CFD) methods to calculate accurately. Experiments alone are limited in their ability to provide detailed insights to the complex flow physics which occur in advanced propulsion-airframe integrated systems for future subsonic, supersonic and hypersonic applications. Therefore, the continued need for competent CFD methods to be used in conjunction with experiments is high. The one CFD modeling area that has remained the most challenging, yet most critical to the success of integrated propulsion system simulations is turbulence modeling. The flow features specific to the propulsion system components that provide the greatest turbulence modeling challenges include separated flows whether they be from subsonic diffusion or turbulent shock wave-boundary layer interactions, inlet/vehicle forebody boundary layer transition, unsteady flowfields resulting from incorporation of active flow control, strongly three-dimensional and curved flows in turbomachinery, turbulent-chemistry interactions from subsonic combustors to scramjets, and heat transfer.

Propulsion system integration challenges are encountered across all of the speed regimes from subsonic "N+3" vehicle concepts (with projected fuel burn benefits from boundary layer ingestion or distributed propulsion systems, for example), to supersonic "N+2" vehicle concepts with low-boom, high-performance inlets and nozzles integrated with variable cycle engine systems, to hypersonic reusable air-breathing launch vehicle concepts which incorporate integrated combined-cycle propulsion systems.

Proposals suggesting innovative approaches to any of these problems are encouraged; specific areas of interest include:

- Advancement of turbulence modeling for shock wave-boundary layer interactions.
- Advancement of Reynolds-stress closure models for propulsion flowpath analyses, including application of LES and or DNS for model development and validation.
- Development of mid-level CFD models for the interaction of turbulence and chemical reaction that give superior results to the simple models (e.g., Magnussen), but which do not require the large computational expense of the very complex models (e.g., PDF evolution methods).

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- Advancement of boundary layer transition models, especially in cases of low freestream turbulence levels that occur in actual flight.
  - Incorporation of NASA high-order accurate numerical methods (e.g., Flux Reconstruction) into propulsion CFD tools using both structured as well as unstructured meshes.
  - Development of methods and software tools to quantify uncertainty as part of the CFD solution procedure.

Development of meaningful metrics that quantify the difference between computed solutions and experimental data and use the metrics to validate the CFD codes. Development of tools to enable rapid post-processing and assessment of CFD solutions, especially from NASA in-house CFD tools such as Wind-US and VULCAN (e.g., automatically interpolating numerical solutions to the measurement locations, generating "metrics of goodness" for parameters of interest, etc.).

Propulsion integration topics:

- Development of methodologies that provide installed nozzle performance, specifically conceptual level design/analysis methods, capable of addressing conventional and unconventional geometries. Geometries should be valid for subsonic, supersonic, and/or hypersonic flight applications. Documentation of methodologies should include: underlying theory and mathematical models, computational solution methods, source-code, validation data, and limitations.
- Technologies and/or concepts to enable integrated, high-performance, light-weight supersonic inlets and nozzles that have minimal impact on an aircraft's sonic boom signature.
- Development of supersonic inlet systems that are "Fail Safe" and require no net mass extraction (i.e., bleed) or mass injection to control the shock wave/boundary-layer separations that inevitably arise in any supersonic inlet.
- Shorter, accurate, robust inlet mass flow measurement systems to replace the classic cold pipe/mass flow plug and measure mass-flow with distorted inflow.

Sub Topics:

Concepts and Technology Development (CTD) Topic A3.01

The Concepts and Technology Development (CTD) Project supports NASA Airspace Systems Program objectives by developing gate-to-gate concepts and technologies intended to enable significant increases in the capacity and efficiency of the Next Generation Air Transportation System (NextGen), as defined by the Joint Planning and Development Office (JPDO).

The CTD project develops and explores fundamental concepts, algorithms, and technologies to increase throughput of the National Airspace System (NAS) and achieve high efficiency in the use of resources such as airports, en route and terminal airspace. The CTD research is concerned with conducting algorithm development, analyses and fast-time simulations, identifying and defining infrastructure requirements, field test requirements, and

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conducting field tests.

Innovative and technically feasible approaches are sought to advance technologies in research areas relevant to NASA's CTD effort. The general areas of primary interest are:

### **Traffic Flow Management**

- Flow management to mitigate large-scale climate disruptions, such as volcanic ash, or other natural disaster phenomena.

### **Super Density Operations**

- Environmental and traffic efficiency metrics and assessments to compare different super-density operations concepts and technologies.
- Application of environmental and traffic efficiency metrics specifically for congested airspace or mixed equipage scenarios.
- Cost-effective integration of advanced speed control capabilities into the cockpit to enable environmentally friendly super density operations.

### **Separation Assurance**

- Develop and demonstrate a prototype capability to output real-time schedules (e.g., from Traffic Management Advisor ) from current operational en route computers (e.g., ERAM and/or Host) to an external system to support trajectory-based operations research and simulation.

### **Trajectory Design**

- Trajectory design and conformance monitoring for surface, terminal area, and en route.
- Trajectory implementation/execution in flight deck automation and automated air traffic control.
- Innovative methods to improve individual aircraft (surface, climb, descent and cruise) trajectories and air traffic operations to reduce the environmental impact.

### **Dynamic Airspace Configuration**

- Flexible/adaptable airspace boundaries for NextGen operations in both en route and terminal airspace.
- Generic-airspace operations, including airspace design attributes and human factors considerations such

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as procedures and decision support tools.

- Tubes-in-the-sky operational concept development, including air/ground equipage requirements and design of a dynamic tube network.
- Dynamic airspace allocation to facilitate operations of UAVs and/or commercial space vehicles in the national airspace system .

## **Human Factors**

- Design considerations for Tower/surface controller tools.
- Graphical user-interface systems for air traffic management/flight deck and ground-based automation simulation and testing applications.

## **Weather**

- Common situational awareness between flight deck and ground automation systems for weather avoidance (may be related to 4D weather cube)
- Integrating weather products into decision support tools
- Airspace capacity estimation in presence of weather
- Means for creating realistic, consistent 3-D weather objects/imagery across numerous automation systems (e.g., a flight simulator out-the-window scene, cockpit radar display, airline operations weather display, ground radar image of the same weather object).

## **Atmospheric Hazards**

- Development of wake vortex detection and hazard metric tools.
- Wake modeling and sensing capabilities implemented into the flight deck for airborne aircraft separation and spacing.
- Development of enroute wake turbulence identification and mitigation tools, processes, and systems.
- Novel, compact, and field-deployable laser remote sensing technologies for measuring meteorological parameters (e.g., wind, temperature, pressure, and turbulence) at ranges >1km in support of characterization of aircraft generated wake vortices.

## **Methods and Methodologies**

- Algorithms and methods to satisfy multi-criteria design needs in air traffic management.
- Integrated hardware/software tool for accelerating general optimization tasks.

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- Applying novel computing concepts to ATM problems.
  - Experimental methodology, including scenario development, for incorporating rare events in realistic and dynamic human-in-the-loop air traffic management research, and methods for analyzing cause and effect in post experiment data.
  - Stand-alone graphical user interface capabilities for data collection and processing of meteorological remote sensing technologies.

## **Other**

- Derived sensor information from both ground-based radar trackers and ADS-B information for derivation of airspeed and local wind information.

### Sub Topics:

#### Systems Analysis Integration Evaluation (SAIE) Topic A3.02

SAIE will provide systems level analysis of the NAS characteristics, constraints, and demands such that a suite of capacity-increasing concepts and technologies for system solutions are enabled and facilitated, integrated, evaluated and demonstrated. SAIE is responsible for characterizing airspace system problem spaces, defining innovative approaches, assessing the potential system-level benefits, impacts and safety.

Specific innovative research topics being sought by SAIE include:

### **Airspace System Level Concepts Development**

- NextGen airspace system safety assessment, graceful degradation, fault tolerant, and recovery concepts and methodologies.
- System level capacity and environmental (e.g., CO<sub>2</sub>, NO<sub>x</sub> emissions and noise) improvement concepts and assessments and methodologies.
- System level NextGen assessments, concepts and methodologies that incorporate and/or inform future vehicle and fleet designs.
- Autonomous and distributed system concepts.
- Concepts that study system-wide effects of various functional allocations.
- Revolutionary airspace system concepts, designs and methodologies.

### **Trajectory Modeling and Uncertainty Prediction**

- Analysis of growth of uncertainty as a function of look-ahead time on different phases of flight.

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- Development of methods to determine, for a target concept/system, the TP accuracy needed to be able to achieve the minimum acceptable system/concept performance as well as identify sources of errors.
  - Development of methods for managing/reducing trajectory uncertainty to meet specified performance requirements.
  - Identify critical aircraft behavior data for exchange for interoperability.
  - Innovative methods to improve individual aircraft (surface, climb, descent and cruise) trajectories and air traffic operations to reduce the environmental impact.

### **Roles and Responsibilities in NextGen**

- Systems analysis concepts, assessments and methodologies to optimize air-ground and automation functional allocation for NextGen (e.g., functional allocation options between human/machine and among AOC, flight deck and service provider).
- Airspace systems-level concepts, assessments and methodologies using increasing levels of autonomy.

### **Modeling and Simulation (should be relevant to NASA Airspace Program objectives)**

- Develop new methods that help in assessing and designing airspace to improve system level performance (e.g., increase capacity, reduce complexity, optimize or improve performance of the air transportation network architecture).
- Explicit methodologies relevant to applications can include:
  - Rigorous predictive modeling of uncertainty in various parts of the system and its propagation.
  - Multiobjective decision making algorithms for all aspects of decision making and optimization in the system.
  - Model/dimension reduction for improved computational tractability.
  - Methods for managing multiscale phenomena in the NAS.
  - Methods for quantifying and managing complexity and uncertainty.
  - Methods for assessing the necessary balance between predictability and flexibility in the system, especially in the presence of autonomy.

#### **Sub Topics:**

Ground Test Techniques and Measurement Technology Topic A4.01

NASA is seeking highly innovative and commercially viable test measurement technologies, test techniques, and facility performance technologies that would increase efficiency, capability, productivity for ground test facilities.

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The types of technology solutions sought, but not limited to, are: skin friction measurement techniques; improved flow transition and quality detection methodologies; non-intrusive measurement technologies for velocity, pressure, temperature, and strain measurements; force balance measurement technology development; and improvement of current cutting edge technologies, such as Particle Based Velocimetry (LDV, PIV), Pressure Sensitive Paint (PSP), and focusing acoustic measurements that can be used more reliably in a production wind tunnel environment. Instrumentation solutions used to characterize ground test facility performance are being sought in the area of aerodynamics performance characterization (flow quality, turbulence intensity, mach number measurement, etc.). Of interest are subsonic, transonic, supersonic, and hypersonic speed regimes. Specialized areas may include cryogenic conditions, icing conditions, and rotating turbo machinery. Proposals that are applicable specifically to the ATP facilities (see <http://www.aeronautics.nasa.gov/atp> [6]) and across multiple facility classes are especially important. The proposals will also be assessed for their ability to develop products that can be used in other aerospace ground test facilities.

#### Sub Topics:

##### Flight Test Techniques and Measurement Technology Topic A4.02

NASA's flight research and test facilities are reliant on a combination of both ground and flight research capabilities. By using state-of-the-art flight test techniques, measurement and data acquisition technologies, NASA will be able to operate its flight research facilities more effectively and also meet the challenges presented by NASA's cutting edge research and development programs. The Aeronautical Test Program pertains to a variety of flight regimes and vehicle types ranging from civil transports, low-speed, to high-altitude long-endurance to supersonic, to hypersonic and access-to-space.

The scope of this subtopic is broad. Flight research and test capabilities should address (but are not limited to) the following NASA aeronautical test facilities: Aeronautical Test Range, Aero-Structures Flight Loads Laboratory, Flight Research Simulation Laboratory, and Research Test Bed Aircraft. Proposals should address innovative methods and technologies to extend the health, maintainability and test capabilities of these flight research support facilities.

NASA is committed to improve the ATP effectiveness to support and conduct flight research. This includes developing test techniques that improve the control of both ground-based and 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.

NASA requires improved measurement and analysis techniques for acquisition of real-time, in-flight data used to determine aerodynamic, structural, flight control, and propulsion system performance characteristics. These data will also be used to provide test conductors the information to safely expand the flight and test envelopes of aerospace vehicles and components. This requirement includes the development of sensors to enhance the monitoring of test aircraft safety and atmospheric conditions during flight testing.

#### Areas of interest include:

- Multi-disciplinary nonlinear dynamic systems prediction, modeling, identification, simulation, and control of aerospace vehicles.

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- Test techniques for conducting in-flight boundary layer flow visualization, shock wave propagation, Schlieren photography, near and far-field sonic boom determination, atmospheric modeling.
  - Measurement technologies for steady & unsteady aerodynamic, aero-thermal dynamics, structural dynamics, stability & control, and propulsion system performance.
  - Verification & Validation (V&V) of complex highly integrated flight systems including hardware-in-the-loop testing.
  - Manufacturability, affordability, and performance of small upper-stage booster technologies for small- & nano-satellites.
  - Innovative techniques that enable safer operations of aircraft (e.g., non destructive examination of composites through ultrasonic techniques).

Also of interest to NASA are innovative methods and analysis techniques to improve the correlation of data from ground test to flight test.

#### Sub Topics:

##### UAS Integration in the NAS Topic A5.01

The following subtopic is in support of the Unmanned Aircraft Systems (UAS) Integration in the National Airspace System (NAS) Project under ISRP. There is an increasing need to fly UAS in the NAS to perform missions of vital importance to National Security and Defense, Emergency Management, Science, and to enable Commercial Applications. UAS are unable to routinely access the NAS today due to a lack of:

- Automated separation assurance integrated with collision avoidance systems.
- Robust communication technologies.
- Robust human systems integration.
- Standardized safety and certification.

The Federal Aviation Administration (FAA) regulations are built upon the condition of a pilot being in aircraft. There exist few, if any, regulations specifically addressing UAS today. The primary user of UAS to date has been the military. The technologies and procedures to enable seamless operation and integration of UAS in the NAS need to be developed, validated, and employed by the FAA through rule making and policy development. The Project goal is to develop capabilities that reduce technical barriers related to the safety and operational challenges associated with enabling routine UAS access to the NAS. This goal will be accomplished through a two-phased approach based on development of system-level integration of key concepts, technologies and/or procedures, and demonstrations of integrated capabilities in an operationally relevant environment. The project is further broken

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down into five subprojects: Separation Assurance; Communications; Human Systems Integration; Certification; and Integrated Test and Evaluation. The fifth sub-project, Integrated Test and Evaluation, integrates the other four subprojects. The Phase I technical objectives include:

- Developing a gap analysis between current state of the art and NextGen Concept of Operations.
- Validating the key technical elements identified by the project requirements.
- Initial modeling, simulation, and flight testing.
- Completion of subproject Phase I deliverables (Spectrum requirements, comparative analysis of certification methodologies, etc.) and continue Phase II preparation (infrastructure, tools, etc.).

The Phase II technical objectives include:

- Providing regulators with a methodology for developing airworthiness requirements for UAS, and data to support development of certifications standards and regulatory guidance.
- Providing systems-level, integrated testing of concepts and/or capabilities that address barriers to routine access to the NAS, through simulation and flight testing, address issues including separation assurance, communications requirements, and Human Systems Integration in operationally relevant environments.

This solicitation seeks proposals to develop:

- Desktop Simulation System for Rapid Collection of Human-in-the-Loop Simulation Data. Study, design and build a desktop human-in-the-loop simulation system that integrates UAS ground control stations, unmanned vehicles, manned aircraft, and controller interfaces to rapidly evaluate concepts for separation assurance, separation algorithms, procedures for off-nominal conditions, and other research questions. In addition, investigate training requirements and verification methods for the quality of the data, the types of tasks for which such a system could provide meaningful data, and the architecture required to ensure scalability. The simulation system could be based on the Multi Aircraft Control System (MACS), which already includes all those elements except the UAS ground control station. An initial implementation could include a single human operator with all other agents simulated, while advanced implementations would connect several instances of the simulator to capture interactions between human controllers, pilots and UAS operators.
- UAS Model Construction from Real-time Surveillance Data. In order to improve trajectory predictions for aircraft types without detailed models, a real-time system identification process is needed to automatically construct propulsion and aerodynamics models from available Air Traffic Control (ATC) surveillance data (primary or secondary radar, ADS-B, etc.) while the aircraft is in flight. Initial work would establish what real-time surveillance data is required for a model of sufficient fidelity to reliably predict aircraft trajectories ten or more minutes into the future and over tens of thousands of vertical feet, and what types of aircraft maneuvers would provide maximum observability of the unknown parameters (e.g., the vehicle's response to commanded doublets in altitude at max climb/descent speed or step changes in commanded aircraft velocity as observed by radar or ADS-B). These maneuvers would be commanded of the UAS by ATC to

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improve a poorly understood vehicle model in real-time. Model construction could also be done with archived surveillance data as a first step, but real-time construction is the preferred ultimate outcome.

- Certified control and non-payload communications (CNPC) system. Current civil UAS operations are significantly constrained by the lack of a standardized, certified control and non-payload communications (CNPC) system. The UAS CNPC system is to provide communications functions between the Unmanned Aircraft (UA) and the UA ground control station for such applications as: telecommands; non-payload telemetry; navigation aid data; air traffic control (ATC) voice relay; air traffic services (ATS) data relay; sense and avoid data relay; airborne weather radar data; and non-payload situational awareness video. New and innovative approaches to providing terrestrial and space-based high-bandwidth CNPC systems that are inexpensive, small, low latency, reliable, and secure offer opportunities for quantum jumps in UAS utility and capabilities. Of particular interest are technologies for the enhancement/improvement of CNPC performance for UAS operations in urban locations, taking into account the propagation, reflection/refraction and shadowing/blockage environment encountered in the urban environment.
- System for Rapid Automated UAS Mission Planning. UAS mission planning is currently a very cumbersome and time-consuming activity that involves a highly manual process. In order to provide better UAS integration in the NAS, an automated mission planning system is required with the following capabilities:
  - During the pre-flight mission phase, automation is needed to identify emergency landing sites, ditch sites, and develop UAS responses to contingency events at all points along the route commensurate with UAS platform performance.
  - During the in-flight mission phase, automation is needed to assess and integrate real-time weather information, such as that provided via Flight Information Services - Broadcast (FIS-B), to dynamically re-plan the route for safe navigation. This includes fuel planning and weather assessment capabilities to select and fly to appropriate alternate destination airfields.
  - During the in-flight mission phase, automation is needed to assess real-time route deviations/changes imposed by Air Traffic Control (ATC). The assessment would consider fuel, weather and emergency landing/ditch site constraints to verify the route change is supportable and safe.

Sub Topics:

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