# NASA SBIR 2011 Phase I Solicitation

## A1 Aviation Safety

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 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).

## Subtopics

### 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). 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 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 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

**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 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:

- 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 (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/).

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 handing 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.

## A1.09 Integrated Vehicle Dynamics Modeling Methods for LOC Conditions

**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 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.

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

**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.

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.

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:

- 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 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 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 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 VVFCS element under the SSAT project in the Aviation Safety program.

VVFCS 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, VVFCS 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.