NASA SBIR 2009 Phase I Solicitation

Aeronautics Research

Aviation Safety Topic A1

The Aviation Safety Program focuses on the Nation's future aviation safety challenges. This vigilance for safety must continue in order to meet the projected increases in air traffic capacity and realize the new capabilities envisioned for the Next Generation Air Transportation System (NextGen). The Aviation Safety Program will conduct research to improve the intrinsic safety attributes of legacy and future aircraft and their operations in the Next Generation Air Transportation system, and to eliminate safety-related technology barriers.

The program has focused on furthering our understanding of the fundamental questions that need to be addressed for mid- and long-term improvements to aviation safety through engineering analysis and technology design. The results at the fundamental level will be integrated at the discipline and multi-discipline levels to ultimately yield system-level integrated capabilities, methods, and tools for analysis, optimization, prediction, and design that will enable improved safety for a range of operating concepts, vehicle classes, and crew configurations. The Aviation Safety Program is divided into four complementary and highly interlinked projects:

- The Aircraft Aging and Durability Project performs foundational research in aging science that will ultimately yield multi-disciplinary analysis and optimization capabilities that will enable system-level integrated methods for the detection, prediction, and mitigation/management of aging-related hazards for future civilian and military aircraft.
- The Integrated Intelligent Flight Deck Project develops tools, methods, principles, guidelines, and technologies for revolutionary flight deck systems that enable transformations toward safer operations.
- The Integrated Resilient Aircraft Control Project conducts research to advance the state of aircraft flight control to provide onboard control resilience for ensuring safe flight in the presence of adverse conditions.
- The Integrated Vehicle Health Management Project develops validated tools, technologies and techniques for automated detection, diagnosis and prognosis that enable mitigation of adverse events during flight.

Examples areas of program interest include research directed at fundamental knowledge of legacy and future aircraft structures and systems durability; on-board detection, diagnosis, prognosis, prediction and mitigation of system failures and faults; monitoring vehicle and airspace issues to identify problems before they become accidents; understanding aircraft dynamics of current and future vehicles in damaged and upset conditions; robust control systems; aircraft guidance for emergency operation; airborne sensors and sensor systems for the detection and monitoring of external hazards to aircraft (e.g., in-flight icing conditions, wake vortices); design of robust collaborative work environments; effective and robust human-automation systems; and information management for effective decision making. In addition, general methods for dramatically advancing the community's capability for thorough, cost-effective and time-effective verification and validation of safety-critical systems are of interest to the program as a whole, including rigorous methods for validating design requirements for vehicles and aviation operations, verifying integrated and distributed aircraft and air traffic systems (including assumptions about human performance), and verifying software-intensive systems.

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 [1].
Sub Topics:

A1.01 Mitigation of Aircraft Aging and Durability-Related Hazards

Lead Center: GRC

Participating Center(s): ARC, LaRC

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 moisture-resistant resins and new surface treatments/primers. Novel chemistries are sought to improve the durability of aerospace adhesives with potential use on subsonic aircraft. This research opportunity is focused on the development of novel chemistries for coupling agents, surface treatments for adherends and their interfaces, leading to aerospace structural adhesives with improved durability. Work may involve chemical modification and testing of adhesives, coupling agents, surface treatments or combinations thereof and modeling to predict behavior and guide the synthetic approaches. Examples of adhesive characteristics to model and/or test may include, but are not limited to, hydrolytic stability of the interfacial chemistry, moisture permeability at the interface, and hydrophobicity of coupling agents and surface primers. Examples of adherends to model and/or test include carbon fiber/epoxy composites used in structural applications on subsonic aircraft, and aluminum, as well as their respective surface treatments. Additionally, proposals are sought for test techniques to fully characterize aging history and strain rate effects on thermoset and/or thermoplastic resins as well as on advanced composites manufactured of such resins and reinforced with 3D fiber preforms such as the triaxial braid used in advanced composite fan containment structures. Technology innovations may take the form of tools, models, algorithms, prototypes, and/or devices.

A1.02 Sensing and Diagnostic Capability for Aircraft Aging and Damage

Lead Center: LaRC

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

Many conventional nondestructive evaluation (NDE) techniques have been used for flaw detection, but have shown little potential for much broader application. One element in NASA's contribution to solving the problem of aging and damage processes in future vehicles is research to identify changes in fundamental material properties as indicators of material aging-related hazards before they become critical. Degraded and failing fiber composites can exhibit a number of micromechanisms such as fiber buckling and breakage, matrix cracking, and delamination.

Methodologies are being sought that allow engineers, using advanced modeling tools to predict the remaining useful life of components, the ability to make use of nondestructive evaluation (NDE) data more effectively. One proposed methodology would be an automated means of processing NDE data to extract defect characteristics (i.e. crack length and depth, or delamination size and location) and map these directly to a computer aided drafting model of the component being inspected. This model (which now contains defect information) could then be used by engineers to perform structural analysis on the component. A successful proposal should demonstrate the performance of the methodology proposed by using the data from at least one conventional NDE technique (i.e. Thermography, Ultrasonics, etc.) and a standard CAD drawing file format.

Additionally, actual NDE technologies are also being sought for the nondestructive characterization of age-related degradation in complex composite materials. Innovative and novel approaches to using NDE technologies to measure properties related to material aging (i.e. thermal diffusivity, elastic constants, density, microcrack formation, fiber buckling and breakage, etc.) in complex composite material systems, adhesively bonded/built-up and/or polymer-matrix composite sandwich structures. The anticipated outcome of successful proposals would be a both Phase 2 prototype NDE technology for the use of the developed technique to characterize age-related degradation and a demonstration of the technology showing its ability to measure a relevant material property in a carbon fiber/epoxy composite used for structural applications on subsonic aircraft.

A1.03 Prediction of Aging Effects

Lead Center: LaRC

Participating Center(s): ARC, GRC

In order to assess the long-term effects of potential hazards and aging-related degradation of new and emerging material systems/fabrication techniques, NASA is performing research to anticipate aging and to predict its effects on the designs of future aircraft. To support this predictive capability, structural integrity analytical tools, lifing methods, and material durability prediction tools are being developed. Physics-based and continuum-based models encapsulated as computational methods (software) are needed to provide the basis for these higher level (e.g., design) tools. Proposals are sought that apply innovative computational methods, models and analytic tools to the following specific applications:

- Probabilistic computational code is sought for improved structural analysis of complex metallic and composite airframe components. The methods used in 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.
- Software tools are needed to predict the onset and rates of type-II hot corrosion attack in nickel-based turbine disk superalloys that allow for prolonged disk operation at high temperatures. Typically hot corrosion of turbine alloys is a product of molten salt exposure and is manifested by a localized pitting corrosion attack. Prolonged high temperature exposures of turbine disk alloys to sulfur-rich low temperature melting eutectic salts can lead to an onset of Type II hot corrosion attack causing serious degradation to the durability of the turbine components.
- Computational software is sought to simulate of the response of advanced composite fan case/containment structures in aged conditions to jet engine fan blade-out events using impact mechanics and structural system dynamics modeling techniques.

The anticipated outcome of successful Phase 2 proposals would be analytic code (software) delivered to NASA suitable for use in material evaluation studies.

A1.04 Aviation External Hazard Sensor Technologies

Lead Center: LaRC

Participating Center(s): AFRC, GRC

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 [2]). The general approach to the development of airborne sensors for NextGen is to encourage the development of multi-use, adaptable, and affordable sensors. 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. This subtopic solicits technology that is focused on developing capabilities to detect and evaluate hazards. The development of human interfaces, including displays and alerts, is not within the scope of this subtopic 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, such as new sensor technologies in conjunction with existing X-band airborne radar, to improve hazard detection and quantification of hazard levels are of interest.

At this time, the following hazards are of particular interest: in-flight icing conditions, wake vortices, and turbulence. Proposals associated with sensor investigations addressing these hazards are encouraged, and some suggestions follow. Emphasis on vortices and icing is not intended to discourage proposals targeting other or additional hazards such as reduced visibility, terrain, airborne or ground obstacles, convective weather, gust fronts, cross winds, and wind shear.

To enable remote detection and classification of in-flight icing hazards for the future airspace system and emerging aircraft, NASA is soliciting proposals for the development of sensor systems for the detection of icing conditions. Examples include the following practical remote sensing systems:

- Low-cost, ground-based, vertical-pointing with potential scanning capability X-band radar that can operate unattended around the clock (24/7/365) and provide calibrated reflectivity and velocity data with hydrometer/cloud particle classification (based upon the reflectivity and velocity data).
- Low-cost, high-frequency (> 89 GHz) microwave or infrared radiometer technology capable of providing air temperature, water vapor, and liquid water measurements for both ground-based and airborne applications.

Wake vortex detection in the terminal area is of particular interest, because closer spacing between aircraft is necessary to facilitate the high-density operations expected in NextGen. 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. Proposed techniques shall provide range-resolved clear air wind and aerosol measurements in the near-IR wavelength region from 1.5 microns to 2.1 microns. Wind and aerosol measurement with

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.

A1.05 Crew Systems Technologies for Improved Aviation Safety

Lead Center: LaRC

NASA seeks highly innovative, crew-centered, technologies to improve aerospace system safety through the development of more effective joint human-automation systems in aviation. This is to be accomplished through increased awareness of operator and crew functional state (both in terms of functional readiness and in situ assessment), and through improved interactions among intelligent agents (human and automated). We seek proposals for the development of advanced technologies that:

- Effectively convey information and aid decision making to enable novel NextGen operational requirements (e.g., 4D trajectory-based operations, visual operations in non-visual meteorological conditions, etc. as described in http://www.faa.gov/about/initiatives/nextgen/media/NGIP_0130.pdf [3]);
- Foster the appropriate use of automation and complex information sources by, for example, conveying constraints on automation reliability and information certainty/timeliness;
- Support effective joint cognitive systems by improving the communication and collaboration among multiple intelligent agents (human and automated, proximal and remote), and provide assessment techniques and metrics for evaluating mixed H/A team performance;
- Characterize the operational status of the human crew members, effectively modulate this state, and/or effectively adapt interfaces and automation in response to functional status (e.g., situationally-aware display reconfiguration, aiding, and multi-modal presentation of information to maximize system performance and minimize information processing bottlenecks);
- Provide methods, metrics, and tools that help to assess the effectiveness of the above-mentioned technologies in human-in-the-loop simulation and/or flight studies.

Proposals should describe novel technologies with high potential to serve the objectives of the Robust Automation/Human Systems element of NASA's Aviation Safety Integrated Intelligent Flight Deck program (http://www.aeronautics.nasa.gov/avsafe/iifd/rahs.htm [4]). Successful Phase 1 proposals should culminate in a final report that specifies, and a Phase 2 proposal that would realize, technology that improves the effectiveness of joint human-automation systems in aviation, or improves the ability to assess effectiveness of such systems.

A1.06 Technologies for Improved Design and Analysis of Flight Deck Systems

Lead Center: ARC

Information complexity in flight deck systems is increasing exponentially, and flight deck designers need tools to understand, manage, and estimate the performance and safety characteristics of these systems early in the design process - this is particularly true due to the multi-disciplinary nature of these systems. NASA seeks innovative design methods and tools for representing the complex human-automation interactions that will be part of future flight deck 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 performance;
- Design tools and methods that improve the application of human-centered design principles to the design and certification of mixed human-automated systems;
- Tools and methods for modeling the complex information management systems required for future flight deck systems;
- Methods of data uncertainty estimation during the flight deck system design phase particularly as applied to predicting overall system integrity;
- Design and analysis methods or tools to better predict and assess human and system performance in relevant operational environments.

Proposals should describe novel design methods, metrics, and/or tools with high potential to serve the objectives of the System Design and Analysis element of NASA's Aviation Safety Integrated Intelligent Flight Deck program (http://www.aeronautics.nasa.gov/avsafe/iifd/sda.htm [5]). Successful Phase 1 proposals should culminate in a final report that specifies, and a Phase 2 proposal that would realize, tools that improve the design process for human-automation systems in aviation, 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.

A1.07 Adaptive Aeroservoelastic Suppression

Lead Center: AFRC

Participating Center(s): ARC, LaRC

NASA has initiated an Integrated Resilient Aircraft Control (IRAC) effort under the Aviation Safety Program. The main focus of the effort is to advance the state-of-the-art technology in adaptive controls to provide a design option that allows for increased resiliency to failures, damage, and upset conditions. These adaptive flight control systems will automatically adjust the control feedback and command paths to regain stability, maneuverability, and eventually a safe landing. One potential consequence of changing the control feedback and command paths is that an undesired aeroservoelastic (ASE) interaction could occur. The resulting limit cycle oscillation could result in structural damage or potentially total loss of vehicle control.

Current airplanes with non-adaptive control laws usually include roll-off or notch filters to avoid ASE interactions. These structural mode suppression filters are designed to provide 8 dB of gain attenuation at the structural mode frequency. Ground Vibration Testing (GVT), Structural Mode Interaction (SMI) testing, and finally full scale flight testing are performed to verify that no adverse ASE interactions occur. Until a significant configuration or control system change occurs, the structural mode suppression filters provide adequate protection.

When an adaptive system changes to respond to off-nominal rigid body behavior, the changes in control can affect the structural mode attenuation levels. In the case of a damaged vehicle, the frequency and damping of the structural modes can change. The combination of changing structural behavior with changing control system gains results in a system with a probability of adverse interactions that is very difficult to predict a priori. An onboard, measurement based method is needed to ensure that the system adjusts to attenuate any adverse ASE interaction before a sustained limit cycle and vehicle damage are encountered. This system must work in concert with the adaptive control system to allow the overall goal of re-gaining rigid body performance as much as possible without exacerbating the situation with ASE interactions.

A1.08 Engine Lifing and Prognosis for In-Flight Emergencies

Lead Center: GRC

The object of this research topic is to develop innovative methodologies and tools to determine the consumed life of an engine and the probability of an engine system failure for future operations.

Aircraft engine design and life are based on a theoretical operation flight profile that in practice is not seen by most engines in service. The ability to predict remaining engine life with a defined reliability in real time from sensor measurements is a condition precedent to emergency operation risk assessment. It is expected that this research will result in a demonstration of an integrated life monitoring and prognosis methodology that will utilize existing and under-development probabilistic codes for engine life usage and risk assessment for future operations that may require enhanced performance.

The expected outcome of the research will be an on-line simulation demonstration of an integrated engine life module for:

- Probabilistic engine life usage calculation.
- Methodologies for engine failure prediction for future operations.
- Risk assessment and trade-off tools for off-nominal operations.

NASA resources available for the research will be an engine component data base for turbine disks and blades, and probabilistic computer codes for life prediction and reliability.

A1.09 Pilot Interactions with Adaptive Control Systems under Off-Nominal Conditions

Lead Center: ARC

Participating Center(s): AFRC

Adaptive control is a promising control technology that can enhance flight safety and performance. Adaptive control has been demonstrated to provide improved performance in many unmanned aerial systems. When operated in an autonomous mode such as in an autopilot, the behavior of an adaptive flight control system can be modeled and simulated with a sufficient degree of repeatability.

The presence of a pilot working in a closed-loop fashion with an adaptive flight control presents an important problem that has not been well addressed. Adaptive control generally requires sufficiently rich input signals to improve parameter convergence, as the adaptive control system adapts to parametric changes in the vehicle dynamics or exogenous disturbances. The condition for rich input signals is known as persistent excitation. During adaptation under off-nominal conditions such as aircraft with damage, the pilot provides persistently exciting signals to the adaptive control system. There is generally a trade-off between adaptation and stability due to persistent excitation. With a high persistent excitation in the pilot inputs, the speed of adaptation increases and in theory better handling performance could be achieved. However, in practice, the high persistent excitation in the control signals can potentially cause significant cross-coupling between different flight control axes and or excite unmodeled dynamics such as aeroservoelastic modes. The overall effect of high persistent excitation could aggravate stability robustness of an adaptive flight control system with a pilot in the loop that results in poor handling qualities.

Another aspect of pilot interactions with an adaptive control system is the potential interactions between two adaptive elements in a closed-loop fashion, because the pilot can also be viewed as an adaptive control system with a learning ability. With the pilot adaptive element providing high persistently exciting inputs into an adaptive flight control system with a predetermined adaptation rate, the issue of stability can be important and difficult to assess.

To enable an adaptive flight control system to be operated with a pilot in the loop, it is necessary to develop new research techniques that can assess the effects of pilot interactions with an adaptive flight control system. These techniques should address pilot control responses via an adaptive model with features that can capture relevant interactions with an adaptive flight control system. Techniques for assessing pilot interactions via metrics that can quantify the pilot-vehicle system responses with an adaptive flight control system are also needed. Other aspects of the research can include new methods and tools that can provide an advisory function to limit the pilot control inputs in order to trade off between command-following performance and stability robustness.

Research in adaptive control methods will address the system requirements to provide good flying characteristics when the human operator closes the control loop. In the presence of damage, failures, etc. the adaptive system must trade the stability requirements with closed loop handling requirements. Methods for selecting the best achievable handling are needed. The adaptation system needs to find a good compromise between suppression of coupling between the axis (i.e. pitch into roll, etc.) and good in-axis behavior. Better metrics to assess cross-coupled (asymmetric) behavior are needed. These metrics could provide a quantitative measurement of the severity of a given failure, as well as a measure of the improvement due to adaptation. As the adaptation changes the flying characteristics of the vehicle, some means of informing the operator is required to ensure that the system is not overdriven by a pilot who is expecting nominal performance.

A1.10 Detection of Aircraft Anomalies

Lead Center: GRC

Participating Center(s): AFRC, ARC, LaRC

Adverse events that occur in aircraft can lead to potentially serious consequences if they go undetected. This effort is to develop the technologies, tools, and techniques to detect in-flight anomalies from adverse events. This involves the integration of novel sensor and advanced analytical technologies for airframe, propulsion systems, and other subsystems within the aircraft. The emphasis of this work is not on diagnosing the exact nature of the failure but on identifying its presence. Proposals are solicited that address aspects of the following topics:

- Analytical and data-driven technologies required to interpret the sensor data to enable the detection of fault and failure events;
- Methods to differentiate sensor failure from actual system or component failure;
- Characterizing, quantifying, and interpreting multi-sensor outputs; and
- New sensors, sensory materials and sensor systems that improve the detection of an adverse event or permit increased sensory coverage for an adverse event.

Emphasis is on novel methods to detect failures in electrical, electromechanical, electronic, structural, and propulsion systems. Along with these system failures, condition sensors are desired for both the detection of internal engine icing as well as composite aircraft lightning strikes (location and intensity). Where possible, a rigorous mathematical framework should be employed to ensure the detection rates and detection time constants are acceptable according to published baselines as characterized by statistical measures. Understanding and addressing validation issues are critical components of this effort.

A1.11 Diagnosis of Aircraft Anomalies

Lead Center: LaRC

Participating Center(s): AFRC, GRC, SSC

The capability to identify faults is critical to determining appropriate mitigation actions to maintain aircraft safety. This effort is to develop innovative methods and tools for the diagnosis of aircraft faults and failures. It includes the development of integrated technologies, tools, and techniques to determine the causal factors, nature, and severity of an adverse event and to distinguish that event from within a family of potential adverse events. These requirements go beyond standard fault isolation techniques. The emphasis is on the development of mathematically rigorous diagnostic technologies that are applicable to structures, propulsion systems, software, and other subsystems within the aircraft. Technologies developed must be able to perform diagnosis given heterogeneous and asynchronous signals coming from the health management components of the vehicle and integrating information from each of these components.

The ability to actively query health management systems, use advanced decision making techniques to perform the diagnosis, and then assess the severity using these techniques are critical. As an example, the mathematical rigor of the diagnosis and severity assessment could be treated through a Bayesian methodology since it allows for characterization and propagation of uncertainties through models of aircraft failure and degradation.

Both computational and prototype hardware implementations of the diagnostic capabilities are expected outcomes of this effort. Other methods could also be employed that appropriately model the uncertainties in the subsystem due to noise and other sources of uncertainty. The ability to actively query the underlying health management systems (whether they are related to detection or not) is critical to reducing the uncertainty in the diagnosis. As an example, if there is ambiguity in the diagnosis about the type and location of a particular failure in the aircraft structure, the diagnostic engine should be able to actively query that system or related systems to determine the true location and severity of the anomaly. Where possible, a rigorous mathematical framework should be employed to provide a rank ordered list of diagnoses, an assessment of the severity of each diagnosed event, along with a measure of the certainty in the diagnosis. Understanding and addressing the system integration and validation issues are critical components of this effort.

A1.12 Prognosis of Aircraft Anomalies

Lead Center: ARC

Participating Center(s): AFRC, GRC, LaRC

The ability to accurately and precisely predict the remaining useful life (RUL) of aircraft components and subsystems enables decision making and action taking that can avert or mitigate failures, thereby enhancing aircraft safety. Furthermore, it can improve operational efficiency by facilitating condition-based maintenance and reducing unscheduled maintenance. This effort here addresses the development of innovative methods, technologies, and tools for the prognosis of aircraft faults and failures. The assessment of the RUL could be used by other aircraft systems to place additional restrictions, such as a new operating envelope, on the flight control systems or it could be used by flight or maintenance personnel to take preventative actions. Areas of interest include developing methods for making predictions of RUL which take into account operational and environmental uncertainties (pure data-driven approaches are discouraged); physics-based models of degradation; generation of aging and degradation datasets on relevant components or subsystems; and development of validation and verification methodologies for prognostics.

Research should be conducted to demonstrate technical feasibility during Phase 1 and to show a path toward a Phase 2 technology demonstration. Proposals are solicited that address aspects of the following areas:

- RUL prediction techniques that address a set of fault modes for a device or component, for example by modeling the physics of the most critical fault modes and using (typically less accurate) data-driven methods for the remainder.
- Physics-based damage propagation models for one or more relevant aircraft subsystems such as composite or metallic airframe structures, engine turbomachinery and hot structures, avionics, electrical power systems, electromechanical systems, and electronics. Proposals that focus on technologies envisioned for next generation aircraft are strongly encouraged.
- 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. Methods can also consider the fusion of different techniques but must show how this helps to improve the uncertainty using appropriate metrics.
- Aircraft relevant testbeds that can generate aging and degradation datasets for the development and testing of prognostic techniques.
- Verification and validation methods for prognostic algorithms.

A1.13 Healing Material System Concepts for IVHM

Lead Center: LaRC

Participating Center(s): AFRC, ARC, GRC

The development of integrated multifunctional self-sensing, self-repairing structures will enable the next generation of light-weight, reliable and damage-tolerant aerospace vehicle designs. Prototype multifunctional composite and/or metallic structures are sought to meet these needs, as are concepts for their analytical and experimental interrogation. Specifically, structural and material concepts are sought to enable in situ monitoring and repair of service damage (e.g., cracks, delaminations) to improve structural durability and enhance safe operation of aerospace structural systems. Emphasis is placed on the development of new materials and systems for the mitigation of structural damage and/or new concepts for activation of healing mechanisms using new or existing materials. These advanced structural and material concepts must be robust, consider all known damage modes for specific material systems and be validated through experiment.

A1.14 Verification and Validation of Flight-Critical Systems

Lead Center: ARC

Participating Center(s): AFRC, LaRC

The purpose of this subtopic is to invest in mid- and long-term research to establish rigorous, systematic, scalable, and repeatable verification and validation methods for flight-critical systems, with a deliberate focus on safety for NextGen (http://www.jpdo.gov/nextgen.asp [6]). This subtopic targets NextGen safety activities and interests encompassing vehicles, vehicle systems, airspace, airspace concept of operations, and air traffic technologies, such as communication or guidance and navigation. Methods for assessing issues with technology, human performance and human-systems integration are all included in this sub-topic, nothing that multi-disciplinary research is required that does not focus on one type of component or phenomenon to the exclusion of other important drivers of safety.

Proposals are sought for the development of:

- Safety-case methods and supporting technologies capable of analyzing the system-wide safety properties suitable for civil aviation vehicles and for complex concepts of operation involving airborne systems, ground systems, human operators and controllers.
- Technologies and mathematical models that enable rigorous, comprehensive analysis of novel integrated, and distributed, systems interacting through various mechanisms such as communication networks and human-automation and human-human interaction.
- Techniques, tools and policies to enable efficient and accurate analysis of safety aspects of software-intensive systems, ultimately reducing the cost of software V&V to the point where it no longer inhibits many safety innovations and NextGen developments.

This subtopic is intended to address those flight-critical systems that directly conduct flight operations by controlling the aircraft, such as on-board avionics and flight deck systems, and safety-critical ground-based functions such as air traffic control and systems for communication, navigation and surveillance. It is not intended to cover V&V of computational models of physical systems (e.g., CFD codes or finite element analysis).

Fundamental Aeronautics Topic A2

The Fundamental Aeronautics Program (FAP) encompasses the principles of flight in any atmosphere, and at any speed. The program develops focused technological capabilities, starting with the most basic knowledge of underlying phenomena through validation and verification of advanced concepts and technologies at the component and systems level. Physics-based, multidisciplinary design, analysis, and optimization (MDAO) tools will be developed that make it possible to evaluate radically new vehicle designs and to assess, with known uncertainties, the potential impact of innovative technologies and concepts on a vehicle's overall performance. The development of advanced component technologies will realize revolutionary improvements in noise, emissions, and performance. The program also supports NASA's human and robotic exploration missions by advancing knowledge in aeronautical areas critical to planetary Entry, Descent, and Landing. NASA has defined a four-level approach to technology development: conduct foundational research to further our fundamental understanding of the underlying physics and our ability model that physics; leverage the foundational research to develop technologies and analytical tools focused on discipline-based solutions; integrate methods and technologies to develop multi-disciplinary solutions; and solve the aeronautics challenges for a broad range of air vehicles with system-level optimization, assessment and technology integration.

Structurally, the FAP is composed of four projects: hypersonic flight, supersonic flight, subsonic fixed-wing aircraft and subsonic rotary-wing aircraft.

Hypersonics

- Fundamental research in all disciplines to enable very-high speed flight (for airbreathing launch vehicles) and re-entry into planetary atmospheres;
- High-temperature materials, thermal protection systems, air-breathing propulsion, aero-thermodynamics, multi-disciplinary analysis and design, GNC, experimental capabilities.

Supersonics

- Eliminate environmental and performance barriers that prevent practical supersonic vehicles (cruise efficiency, noise and emissions, vehicle integration and control);
- Supersonic deceleration technology for Entry, Descent, and Landing into Mars.

Subsonic Fixed Wing (SFW)

- Develop revolutionary technologies and aircraft concepts with highly improved performance while satisfying strict noise and emission constraints;
- Focus on enabling technologies: acoustics predictions, propulsion/combustion, system integration, high-lift concepts, lightweight and strong materials, GNC.

Subsonic Rotary Wing (SRW)

- Improve civil potential of rotary wing vehicles (vs. fixed wing) while maintaining their unique benefits;
- Key advances in multiple areas through innovation in materials, aeromechanics, flow control, propulsion.

Each project addresses specific discipline, multi-discipline, sub-system and system level technology issues relevant to that flight regime. A key aspect of the Fundamental Aeronautics Program is that many technical issues are common across multiple flight regimes and may be best resolved in an integrated coordinated manner. As such, the FAP subtopics are organized by discipline, not by flight regime, with a special subtopic for rotary-wing issues.

Additional information: http://www.aeronautics.nasa.gov/fap/index.html [7]
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, noise, lift, drag, durability, and emissions. This subtopic is also a subtopic for the "Low-Cost and Reliable Access to Space (LCRATS)" topic. Proposals to this subtopic may gain additional consideration to the extent that they effectively address the LCRATS topic (See topic O5 under the Space Operations Mission Directorate). In general, the technologies of interest cover four research themes:

- **Fundamental materials development, processing and characterization -** new approaches to enhance the durability, processability, and reliability of advanced materials (metals, ceramics, polymers, composites, hybrids and coatings) with an emphasis on multifunctional and adaptive materials and structural concepts. In particular, proposals are sought in:
    - Textile ceramic matrix composite materials and structures and environmental barrier coatings capable of multi-use at 2700°F or greater for air vehicle propulsion and airframe applications.
    - 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.
    - Development of joining and integration technologies including fasteners and/or chemical joining methods for ceramic-to-ceramic, metal-to-metal, and metal-to-ceramic materials.
    - Development of variable stiffness materials to support adaptive, multifunctional structures concepts.
- **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 structures that integrate novel materials, mechanism design, and structural subcomponent design into systems level designs.
  - Life prediction tools for textile ceramic 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 preform structures in either a relaxed or compressed deformation state are of particular interest.

- **Computational materials development tools** - methods to predict properties of both airframe and propulsion materials based upon chemistry and process for conventional as well as nanostructured, multifunctional and adaptive materials.

  - Ab-initio methods that enable the development of refractory composite coating for multi-use at temperatures greater than 3000°F in an air environments.
  - Quantum chemistry, molecular dynamics, and mesoscale models for the design, characterization and optimization of ablation materials for radiation heating, thermal re-radiation, and catalytic effects.

- **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:

  - Microadaptive flow control for use in robust, efficient, low mass actuators with broad bandwidths. The identification and development of actuators that can operate in harsh environments (600-800°F) experienced in gas turbine engine compressors with the following features: (1) operational frequencies of 1000 to 10,000 Hz, (2) stroke or displacement >100?m, (3)capable of exerting forces >200 lbs.
  - Piezoelectric devices with the ability to convert strain energy into useable electric energy that can be integrated into aircraft designs for energy harvesting and or vibration damping including application to aircraft engine fan and compressor rotor blades. Requirement for these devices are power densities greater than or equal to 0.1 mW/cm^2. Novel approaches are sought to enable piezoelectric devices to operate in engine environment including typical stresses of fan/compressor blades and to have the durability for engine application.
  - Miniature thermoelectric devices for powering RF sensors for use in turbine engine compressors. Devices must be capable of operating at temperatures up to 600°C in oxidizing environments and capable of achieving power densities greater than or equal to 0.1 mW/cm^2. Prototype device demonstration is required showing functionality at 600° in air for 100 hours and delivering power output in excess of 10?W/cm^2.
  - Materials to support wireless sensing and actuating multifunctional structures.
  - Manufacturing and fabrication technologies leading to the development of lightweight structurally integrated thermal protection systems for space access and planetary entry, including high temperature honeycombs, hat-stiffeners, rigid fibrous and foam insulators.

- Advanced material and component technologies to enable the development of mechanical and electrical drive system to distribute power from a single engine core to drive multiple propulsive fans, in particular, AC-tolerant, low loss (1.5 T field and 500 Hz electrical frequency; and high efficiency (= 30% of Carnot), low mass (
- Novel structural design strategies for integrated fan cases that combine hardwall composite cases for blade containment with acoustic treatments. Concepts are also sought that also integrate the case with the fan inlet to maximize structural, acoustic attenuation and weight benefits.

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. 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 include:

- 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 determining the size-dependent mass of gas-turbine engine particle emissions;
- 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;
- Combustor and/or combustion physics and mechanisms, enhanced mixing concepts, ignition and flame holding, turbulent flame propagation, vitiated-test media and facility-contamination effects, hydrogen/hydrocarbon-air kinetic mechanisms, multi-phase combustion processes, and engine/propulsion component characterizations;
- Novel combustor concepts that advance/enhance the state-of-the-art in hypersonic propulsion to improve

system performance, operability, reliability and reduce cost. Both analytic and/or experimental efforts are encouraged, as well as collaborative efforts that leverage technology from on-going research activities;

- Computational and experimental technologies for the accurate prediction of combined cycle phenomena such as shock trains in isolators, inlet unstart, and thermal choke.

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, propfan, 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, crew and launch vehicle payloads. 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 and sources which arise from significant interactions between airframe and propulsion systems;
- Prediction of sound propagation (including sonic booms) from the aircraft through a complex atmosphere to the ground. This should include interaction between noise sources and the airframe and its flowfield;
- Computational and analytical structural acoustics prediction techniques for aircraft and advanced aerospace vehicle interior noise, particularly for use early in the airframe design process;
- Prediction and control of high-amplitude aeroacoustic loads on advanced aerospace structures and the resulting dynamic response and fatigue;
- 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, and noise control technology and methods that are enabled by advanced aircraft configurations, including integrated airframe-propulsion control methodologies;
- Technologies and techniques for active and passive interior noise control for aircraft and advanced aerospace vehicle structures;
- 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 the 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 assuring 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 aerodynamic flow phenomena, especially in the transonic speed range. Aeroelastic phenomena of interest include flutter, buffet, buzz, limit cycle oscillations, 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 aeroservothermoelasticity / 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

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 such as the new Crew Exploration Vehicle 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 capturing 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;
- 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.

A2.06 Aerothermodynamics

Lead Center: LaRC

Participating Center(s): AFRC, ARC, GRC

Development of accurate tools to predict aerothermal environments and their effects on space vehicles is critically important to achieving the goals of current NASA missions. These tools will also enable the development of advanced spacecraft for future missions by reducing uncertainties during design and development.

The large size and high re-entry velocity of the Crew Exploration Vehicle and the conditions encountered in proposed aerocapture missions to Titan, Neptune, and Venus require study of shock layer radiation phenomena, radiative heat transfer, and non-equilibrium thermodynamic and transport properties; these in turn require understanding of the internal structure and dynamics of the constituent gases.

Transition and turbulence effects are particularly complex in hypersonic flows, where unique problems are posed by shocks, real gas effects, body surfaces with complex and possibly time-dependent roughness, nose bluntness, ablation, surface catalyticity, separation, and an unknown free-stream disturbance environment.

At the heating rates encountered during hypersonic re-entry, surface ablation products blowing into the boundary layer introduce new interactions including chemical reactions and radiation absorption, that strongly affect surface heating rates and integrated heat loads.

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

- Computational analysis methods for radiation and radiation transport in the shock layer surrounding planetary entry vehicles;
- Advanced physics-based thermal and chemical non-equilibrium models for thermodynamics, transport, and radiation;
- Studies of the interactions of gases in the shock layer with ablating materials from the vehicle thermal protection system;
- Experimental methods and diagnostics to measure the characteristics of hypersonic flow fields, either in flight or in ground-based facilities;
- Software tools coupling radiation, non-equilibrium chemistry, Reynolds-averaged Navier-Stokes, and large eddy simulation codes to enable the design and validation of mission configurations for entry into planetary atmospheres.

A2.07 Flight and Propulsion Control and Dynamics

Lead Center: ARC

Participating Center(s): AFRC, GRC, LaRC

Enabling advanced aircraft configurations for subsonic, supersonic and hypersonic flight, and high performance engines will require advancement in the state-of-the art dynamic modeling and flight/propulsion control. Control methods need to be developed and validated for "optimal" and reliable performance of complex, unsteady, and nonlinear systems with significant modeling uncertainties while ensuring operational flexibility. New dynamic modeling and simulation techniques need to be developed to investigate dynamic performance issues and support development of control strategies for innovative aircraft configurations and propulsion systems. Technology needs specific to different flight regimes are summarized in the following:

Subsonic Fixed Wing Aircraft

Technologies of interest include: flying qualities design guidelines for civil transport aircraft and methods for evaluating the flying qualities of concept transport aircraft, including blended-wing-body and cruise efficient short takeoff and landing aircraft; active control techniques for subsystems within current and advanced engines that lead to improvements in propulsion system efficiency; definition of actuation requirements and characterization of transient behavior of flow control for active aerodynamic shaping; development of a modular, distributed control system architecture for unified propulsion/airframe control; toolset capable of assessing the controllability for a given control effector layout and determining the sizes of conventional control surfaces, horizontal tail and vertical tail necessary to meet control power requirements; novel control techniques for reducing system noise, emissions and fuel burn.

Supersonic Flight

Technologies of interest include: methods for developing integrated aeroservoelastic (ASE) models, including propulsion effects, suitable for simulation and control design; novel control design methods for integrated aero-propulsion-servo-elastic control leading to acceptable flying qualities over the operating flight envelope; novel, and feasible, takeoff and approach to landing procedures to accommodate the visibility challenges due to long forebodies; integrated inlet/engine control to ensure safe (no inlet unstart or compressor surge/stall) and efficient operation.

Hypersonic Flight

Technologies of interest include: system dynamic models pertaining to a dual-mode combustor based propulsion system (RAM/SCRAM) incorporating the essential coupled dynamic elements with varying fidelity for control design, analysis, and evaluation; methods for characterizing uncertainty in the dynamic models to enable control robustness evaluation; methods for dynamic modeling of hypersonic flow fields, both for external aerodynamics and internal flowpaths, and of heat release in scramjet flowpaths with appropriate fidelity for use in dynamic analysis and control design; hierarchical GNC (Guidance, Navigation and Control) architectures and energy management techniques to enable trajectory shaping and control over a wide operating envelope with integrated flight/propulsion control.

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

A2.08 Aircraft Systems Analysis, Design and Optimization

Lead Center: GRC

Participating Center(s): ARC, LaRC

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 four general themes:

1. Design Environment Development;

2. Variable Fidelity, Physics-Based Design/Analysis Tools;
3. Technology Assessment and Integration; and
4. 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. Multi-fidelity, multi-disciplinary optimization frameworks, such as Numerical Propulsion System Simulation (NPSS), have been developed by NASA but have limited capabilities to simulate complete vehicle systems. Solicited topics are aligned with these four themes that will support this NASA research area.

(1) Design Environment Development

Technology development is needed to provide complex simulation and modeling capabilities where the computer science details are transparent to the engineer. A framework environment is needed to provide a seamless integration environment where the engineer need not be concerned with where or how particular codes within the system level simulation will be run. Interfaces and utilities to define, setup, verify, determine the appropriate resources, and launch the system simulation are also needed.

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.

(2) 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.

(3) 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: (1) New combustor designs, alternate fuel operation, and the ability to estimate all emissions, and (2) Noise source models (e.g., fan, jet, turbine, core and airframe components). Analyses tools that are scalable, especially to small aircraft, are desired.

(4) 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:

Propulsion-Variable Speed Drive Systems/Transmissions

Technologies, and predictive capability, related to enabling concepts and techniques for variable speed drive systems/transmissions suitable for large rotorcraft application are encouraged. Specifically this would include concepts for controlling and enabling variable speed drives as well as lightweight and reliable drive system components. Efficient drive-system speed-variability on the order of 30-50% should be the focus of the proposed technologies and analysis tools.

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, fast-response pressure sensitive paints applicable to blade surfaces, and methods to measure the rotor tip path plane angle of attack, lateral and longitude flapping, and shaft angle in flight and in the wind tunnel. Very low airspeed measurement systems for flight vehicles.

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

Topics of interest include, but are not limited to, external noise prediction methods for manned and unmanned rotorcraft, improved acoustic propagation models, psychoacoustics analysis of rotorcraft noise, interior noise prediction methods and active/passive noise control applications for rotorcraft including engine and transmission noise reduction, advanced acoustic measurement systems for flight and wind tunnel applications, acoustic data acquisition/reduction/analysis, rotor noise reduction techniques, noise abatement flight operations. Methods, devices, concepts for rotorcraft, or specifically wing, airflow control for steep noise abatement approach operations and hover (low speed) download relief. Rotor noise including broadband, harmonic, blade-vortex interaction, and high-speed impulsive noise, as well as rotor/tail rotor and rotor/rotor interactional noise, are of interest. Frequency range includes not only audible range, but very low frequency rotational noise (blade-passage frequency below 20 Hz) as well. Optimized active/passive concepts and noise tailoring, including rotorcraft designs that are inherently designed for lower noise as a constraint.

Rotorcraft Diagnostics

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 and tools to detect and predict the health and usage of rotorcraft dynamic mechanical systems in the engine and drive system. Automatic rotor imbalance detection and rotor smoothing is also of interest. Additionally, rotorcraft health management technologies can include, but are not limited, 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; integration of health monitoring information with maintenance processes and procedures; data management and automated techniques to acquire/process diagnostic information; system models, material failure models and correlation of failure under bench fatigue, seeded fault test and fielded data; data collection/management for analysis of operational data; in-flight pilot cueing and warning of impending catastrophic events.

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 four identified technical areas.

A2.10 Propulsion Systems

Lead Center: GRC

This subtopic is divided into two parts. The first part is the Turbomachinery and Heat Transfer and the second part is Propulsion 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 drastic 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 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 design 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 are on the order of 5% or above.
- Advanced flow analysis tools to enable design optimization of highly loaded compression systems that can accurately predict aerodynamic efficiency and operability. This includes computer codes with updated models for losses, turbulence, and other models that can simulate the flow through turbomachinery components with advanced design features such as swept and bowed blade shapes, flow range extension techniques, such as flow control and transition control to maintain acceptable operability and efficiency.
- 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.
- Methods are sought to enable more efficient use of coolant air in the turbine through coolant flow modulation. These methods could consist of open-loop or closed-loop coolant flow modulation. Modulations could be high-frequency with frequencies on the order of the turbine blade passing frequency or longer time scales on the order of engine thermal transients. Development of methods to measure turbine local and/or average surface temperatures to enable the closed-loop capability will be considered. Feedback control of the coolant flow rates and/or methods to produce modulation in actual turbine thermal environments are desired. Finally, a description of how the proposed technology will work in a vision modulated turbine cooling turbine system will be needed.

Propulsion Integration

Proposals for Propulsion Integration will address engine and engine integration topics as outlined in this section in support of the Fundamental Aeronautics Program.

One objective of the Subsonic Fixed Wing Project is to develop verified analysis capabilities for the key technical issues related to integrating embedded propulsion systems for "N+2" hybrid wing/body configurations. These key technical issues include: inlet technologies for distorted engine inflows related to embedded engines with boundary layer ingestion; fan-face flow distortion and its effects on fan efficiency and operability, noise, flutter stability and aeromechanical stress and life; wide operability of the fan and core with a variable area nozzle; issues related to the implementation of a thrust vectoring variable area nozzle; and duct losses related to long flow paths associated with embedded engines. Specifically, proposals are sought to provide advanced technology, prediction methods and tools.

The supersonics project would like proposals to develop tools and propulsion technologies that will enable the design of high performance fans; high-efficiency, low-boom, and stable inlets; high-performance, low-noise exhaust nozzles; and intelligent sensors and actuators for supersonic aircraft. The supersonics project is interested in both computational and experimental research, aimed at evaluating and analyzing promising technologies as well as understanding the fundamental flow physics that will enable improved prediction methods.

A mission class of interest to the Hypersonics Project is Highly Reliable Reusable Launch Systems (HRRLS). The HRRLS mission was chosen to build on work started in NASA's Next Generation Launch Technology (NGLT) Program to provide new vehicle architectures and technologies to dramatically increase the reliability of future launch vehicles. The design of reusable entry vehicles that provide low-cost access to space is challenging in several technology areas. The development of hypersonic-unique air breathing propulsion systems and the integration of the propulsion system with the airframe impact vehicle performance and controllability and drive the need for an integrated physics-based design methodology.

For Propulsion Integration, topics will be solicited for two areas:

- Design concepts, actuators and analysis tools that enable:
    - High performance supersonic inlets and nozzles that have minimal impact on an aircraftÂ's sonic boom signature;
    - The control of shock wave boundary layer interactions and reduction of dynamic distortion in supersonic inlets;
    - Stable highly integrated supersonic inlets;
    - High pressure recovery, low distortion and low-weight subsonic diffusers;
    - Low weight systems for nozzle area control;
    - Thrust vectoring;
    - Practical, validated CFD models for flow control devices such as micro ramps, vaned vortex generators, air jets, or synthetic jets.

- Unsteady coupled Inlet / Fan Analysis Tools to investigate:
    - Engine transient affect on inlet unstart;
    - Mode transition for a hypersonic dual Turbine engine/RAM-SCRAM flowpath;
    - Inlet and fan aero/mechanical loads;
    - Engine/inlet control system development;
    - Distortion Tolerance.

Airspace Systems Topic A3

NASA's Airspace Systems (AS) Program is investing in the development of innovative concepts and technologies to support the development of the Next Generation Air Transportation System (NGATS is also commonly known as NextGen). NASA is working to develop, validate and transfer advanced concepts, technologies, and procedures through partnership with the Federal Aviation Administration (FAA) and other government agencies represented in the Joint Planning and Development Office (JPDO), and in cooperation with the U.S. aeronautics industry and academia. As such, the AS Program 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. The AS Program integrates the two projects, NextGen Airspace and NextGen Airportal, to directly address the fundamental research needs of NextGen vision in partnership with the member agencies of the JPDO. The NextGen Airspace Project develops and explores fundamental concepts and integrated solutions that address the optimal allocation of ground and air automation technologies necessary for NextGen. The project will 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 aircraft safely and efficiently through the NAS. The NextGen Airportal Project develops and validates algorithms, concepts, and technologies to increase throughput of the runway complex and achieve high efficiency in the use of airportal resources such as gates, taxiways, runways, and final approach airspace. NASA research in this project will lead to development of solutions that safely integrate surface and terminal area air traffic optimization tools and systems with 4-D trajectory operations. Ultimately, 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; and
- Maintain system safety and environmental protection.

Additional information is available at http://www.aeronautics.nasa.gov/programs_asp.htm [8].
Sub Topics:

A3.01 NextGen Airspace

Lead Center: ARC

Participating Center(s): AFRC, LaRC

The primary goal of the Airspace project is to develop integrated solutions for a safe, efficient, and high-capacity airspace system. Of particular interest is the development of core capabilities, including:

- Trajectory-based operations, which manages traffic using 4-dimensional trajectories to achieve increases in capacity and efficiency;
- Super-density operations, which maximizes the use of limited runways at the busiest airports;
- Weather assimilated into decision making, with emphasis on probabilistic weather;
- Equivalent visual operations, which will allow the system to maintain visual flight rule capacities in instrument flight rule conditions.

These core capabilities are required to enable key Airspace project functions such as Dynamic Airspace Configuration, Traffic Flow Management, Separation Assurance, and the overarching Evaluator that integrates these ATM functions over multiple planning intervals.

In order to meet these challenges, innovative and technically feasible approaches are sought to advance technologies in research areas relevant to NASA's NextGen Airspace effort. The general areas of primary interest are Dynamic Airspace Configuration, Traffic Flow Management, and Separation Assurance. Specific research topics for the Airspace project include:

- Four-dimensional trajectory modeling in the presence of uncertainty;
- Air/air and air/ground trajectory exchange interoperability;
- Trajectory uncertainty prediction and mitigation;
- Intent information requirements for separation assurance and super density operations;
- Airspace re-design techniques that improve capacity, including changing shape of current sectors and introducing new airspace classes;
- Pilot and controller procedures and decision support systems needed to facilitate dynamic airspace changes;
- Collaborative decision making techniques involving multiple agents;
- Integrated solutions of ATM functions over multiple planning intervals and across domains;
- Optimal allocation of separation assurance functions across humans and automation and air and ground

systems;

- Optimization techniques to address demand/capacity imbalances;
- New safety assessment methods for safety-critical air and ground automation technologies;
- Scheduling optimization for integrated arrival/departure/surface operations;
- Displays and procedures for very closely-spaced parallel approaches;
- Traffic complexity monitoring and prediction;
- Trajectory design and conformance monitoring;
- Weather assimilated into ATM decision-making;
- Environmental metrics and assessments of new concepts and technologies;
- The effect of new vehicles (including UAVs) on air traffic management;
- Gate-to-Gate modeling for NextGen concepts;
- Integration of UAVs into the NAS, including examination of the anticipated mix of UAV classes and capabilities (equipment, size, mission) in the next 20 years;
- The effect of traffic congestion on integration of UAVs into the NAS;
- Separation assurance responsibilities with regard to UAVs;
- The requirements for, and the development of, a simulation environment to test UAV integration in the NAS.

A3.02 NextGen Airportal

Lead Center: LaRC

Participating Center(s): AFRC, ARC

Airportal research focuses on key capabilities that will increase throughput of the airport environment, and that achieve the highest possible efficiencies in the use of airport resources such as terminal airspace, runways, taxiways, and gates. Of particular interest is the development of the following core capabilities within Airportal:

- Optimization of surface aircraft traffic;
- Dynamic airport configuration management (including the optimal balancing of Airportal resources for arrival, departure, and surface aircraft operations);
- Predictive models to enable mitigation of wake vortex hazards;
- New procedures for performing safe, closely spaced, and converging approaches at closer distances than are currently allowed;

- Modeling, simulation, and experimental validation research focused on single and multiple regional airports (metroplex);
- Other innovative opportunities for transformational improvements in Airportal/metroplex throughput.

Inherent to the ASP approach is the integration of airborne solutions within the overall surface management optimization scheme.

In order to meet these challenges, innovative and technically feasible approaches are sought to advance technologies in research areas relevant to NASA's Next Gen/Airportal effort. The general areas of interest are surface movement optimization, converging and parallel runway operations, safety risk assessment methodologies, and wake vortex solutions inside Metroplex boundaries. Specific research topics for Next Gen/Airportal include:

- Human/automation interface concepts and standards for flight crews and air traffic control personnel specific to surface/airportal operations;
- Integration of decision-support tools across different airspace domains;
- Advanced technologies and approaches to achieving 2-3X improvement in the throughput of airports and metroplexes;
- Automatic taxi clearance and aircraft control technologies;
- Scheduling algorithm for aircraft deicing and integration with a surface traffic decision-support tool;
- Collaborative decision making between airlines and airport traffic control tower personnel for optimized surface operations, including push back scheduling and management of airport surface assets;
- Real-time assessment of the performance of surface operations;
- Computationally efficient solution methods for surface traffic planning optimization problems;
- Automation concepts and technologies for handling off-nominal situations and failure recovery mechanism;
- Design of computer-human interface (CHI) for ground-based automated surface traffic management;
- 4D taxi clearances and air-ground trajectory negotiation for landing aircraft;
- Innovative concepts, technologies, and procedures for safely increasing throughput of runways, especially combinations of parallel, converging, and intersecting runways;
- Innovative concepts, technologies, and procedures to maintain airport runway throughput under off-nominal conditions such as zero-zero ceiling and visibility;
- Innovative ideas for very closely spaced parallel runway operations, including airborne spacing algorithms and wake vortex avoidance procedures;
- Algorithms for determining wake vortex encounters from aircraft flight data recorders;
- Wake vortex hazard research, especially: establishment of wake vortex encounter hazard threshold, encounter assessment tools, development of a wake vortex hazard metric, flight crew awareness and

response techniques;

- Fusion of data from weather sensors and models for automated input into atmospheric prediction models (e.g., Terminal Area Simulation SystemÂ-TASS) used for assessments of atmospheric hazards to aviation and for initializing wake vortex prediction software;
- Innovations in sensors for detection of wake vortices as well as with weather sensors in support of wake vortex predictions;
- Measurements of wind, temperature, and turbulence from departing and arriving aircraft;
- Radar simulation tools for wake vortices.

Note: The development of technologies for the airborne detection of wake vortices is covered in Subtopic A1.04.

Aeronautics Test Technologies Topic A4

NASA has implemented the Aeronautics Test Program (ATP) within its Aeronautics Research Mission Directorate (ARMD). The purpose of the ATP is to ensure 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) needs. Furthermore, ATP provides rate stability to the aforementioned user community. The ATP facilities are located at the NASA Research Centers, including at Ames Research Center, Dryden Flight Research Center, Glenn Research Center and Langley Research Center. Classes of facilities within the ATP include low speed wind tunnels, transonic wind tunnels, supersonic wind tunnels, hypersonic wind tunnels, hypersonic propulsion integration test facilities, air-breathing engine test facilities, the Western Aeronautical Test Range (WATR), support aircraft, 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. 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 [9].
Sub Topics:

A4.01 Ground Test Techniques and Measurement Technology

Lead Center: LaRC

Participating Center(s): ARC, GRC

NASA is strategically positioning its ground test facilities to meet the future testing needs for our nation. NASA's aeronautics and space research and development pushes the limits of technology, including the ground test facilities that are used to confirm theory and provide validation and verification of new technical concepts. By using state-of-the-art test measurement technologies, data acquisition, testing techniques and enhancing facility performance, NASA will be able to operate its facilities more efficiently and effectively and also be able to meet the challenges presented by NASA's cutting edge research and development programs. Therefore, 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 emphasis for this subtopic is in the area of test measurement technology. Examples of 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 Partical 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.). Areas of interest are in the subsonic, transonic, supersonic, and hypersonic speed regimes. Specialized areas may include cryogenic conditions, icing conditions, and rotating turbo machinery.

Proposals that lead to products or processes that are applicable specifically to the ATP facilities (see http://www.aeronautics.nasa.gov/atp [10]) 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 government-owned, industry and academic institution aerospace ground test facilities.

A4.02 Flight Test Techniques and Measurement Technology

Lead Center: AFRC

Participating Center(s): ARC, GRC

NASA's flight research is reliant on a combination of both ground and flight research facilities. By using state-of-the-art 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 scope of this subtopic is broad, with emphasis on emissions, noise, and performance. Research technologies applicable to this subtopic should address (but are not limited to) the following ground and flight facilities at Dryden: Western Aeronautical Test Range (WATR), Flight Loads Laboratory (FLL), Research Flight Simulation Hardware-in-the-Loop Simulation (HILS), Test bed and Support Aircraft (e.g. F-15, F-18, ER-2, Gulfstream-III, and Ikhana). In addition to the facilities, the following generic capabilities are desired that pertain to any of a variety of types of vehicles ranging from low-speed, to high-altitude long-endurance to supersonic, to hypersonic and access-to-space.

- Modeling, identification, simulation, and control of aerospace vehicles in flight research, flight sensors, sensor arrays and airborne instruments for flight research, and advanced aerospace flight concepts.

- Safer and more efficient design of advanced aerospace vehicles requires advancement in current predictive design and analysis tools. The goal is to develop more efficient software tools for predicting and understanding the response of an airframe under the simultaneous influences of structural dynamics, thermal dynamics, steady and unsteady aerodynamics, and the control system. The benefit of this effort will ultimately be an increased understanding of the complex interactions between the vehicle dynamics subsystems with an emphasis on flight research validation methods for control-oriented applications.

- Proposals for novel multidisciplinary nonlinear dynamic systems modeling, identification, and simulation for control objectives are encouraged. Control objectives include feasible and realistic boundary layer and laminar flow control, aeroelastic maneuver performance and load control (including smart actuation and active aerostructural concepts), autonomous health monitoring for stability and performance, and drag minimization for high efficiency and range performance.

- Real-time measurement techniques are needed to acquire aerodynamic, structural, control, and propulsion system performance characteristics in-flight and to safely expand the flight envelope of aerospace vehicles. This subtopic encompasses the development of sensors, sensor systems, sensor arrays, or instrumentation systems for improving the state-of-the-art in aircraft ground or flight research. This includes the development of sensors to enhance aircraft safety by determining atmospheric conditions. The goals are to improve the effectiveness of flight research by simplifying and minimizing sensor installation, measuring new parameters, improving the quality of measurements, minimizing the disturbance to the measured parameter from the sensor presence, deriving new information from conventional techniques, or combining sensor suites with embedded processing to add value to output information. These sensors and systems are required to have fast response, low volume, minimal intrusion, and high accuracy and reliability.

- This subtopic further solicits innovative flight research experiments that demonstrate breakthrough vehicle or system concepts, methodologies, technologies, and operations in the real flight environment and that are particularly related to separation and flow quality characterization in subsonic flight, shockwave propagation in supersonic flight, and small scale technology development in hypersonic flight. It further seeks advanced flight techniques, operations, and experiments that promise significant leaps in vehicle performance, operation, safety, cost, and capability; and that require a demonstration in an actual-flight environment to fully characterize or validate advances.

NASA is seeking highly innovative and viable research technologies that would increase efficiency or overcome limitations for flight research. Other areas of interest include: Verification & Validation techniques for non-deterministic and complex redundant systems; Design Tools integrated into the simulation environment for early research and validation; Flight Measurements & Data Acquisition; Skin Friction; Flight Hardened Systems & Miniaturization; Signal Processing & Reconfigurable Systems; Wireless technologies.

Mitigation of Aircraft Aging and Durability-Related Hazards Topic A1.01

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 moisture-resistant resins and new surface treatments/primers. Novel chemistries are sought to improve the durability of aerospace adhesives with potential use on subsonic aircraft. This research opportunity is focused on the development of novel chemistries for coupling agents, surface treatments for adherends and their interfaces, leading to aerospace structural adhesives with improved durability. Work may involve chemical modification and testing of adhesives, coupling agents, surface treatments or combinations thereof and modeling to predict behavior and guide the synthetic approaches. Examples of adhesive characteristics to model and/or test may include, but are not limited to, hydrolytic stability of the interfacial chemistry, moisture permeability at the interface, and hydrophobicity of coupling agents and surface primers. Examples of adherends to model and/or test include carbon fiber/epoxy composites used in structural applications on subsonic aircraft, and aluminum, as well as their respective surface treatments. Additionally, proposals are sought for test techniques to fully characterize aging history and strain rate effects on thermoset and/or thermoplastic resins as well as on advanced composites manufactured of such resins and reinforced with 3D fiber preforms such as the triaxial braid used in advanced composite fan containment structures. Technology innovations may take the form of tools, models, algorithms, prototypes, and/or devices.

Sub Topics:

Sensing and Diagnostic Capability for Aircraft Aging and Damage Topic A1.02

Many conventional nondestructive evaluation (NDE) techniques have been used for flaw detection, but have shown little potential for much broader application. One element in NASA's contribution to solving the problem of aging and damage processes in future vehicles is research to identify changes in fundamental material properties as indicators of material aging-related hazards before they become critical. Degraded and failing fiber composites can exhibit a number of micromechanisms such as fiber buckling and breakage, matrix cracking, and delamination.

Methodologies are being sought that allow engineers, using advanced modeling tools to predict the remaining useful life of components, the ability to make use of nondestructive evaluation (NDE) data more effectively. One proposed methodology would be an automated means of processing NDE data to extract defect characteristics (i.e. crack length and depth, or delamination size and location) and map these directly to a computer aided drafting model of the component being inspected. This model (which now contains defect information) could then be used by engineers to perform structural analysis on the component. A successful proposal should demonstrate the performance of the methodology proposed by using the data from at least one conventional NDE technique (i.e. Thermography, Ultrasonics, etc.) and a standard CAD drawing file format.

Additionally, actual NDE technologies are also being sought for the nondestructive characterization of age-related degradation in complex composite materials. Innovative and novel approaches to using NDE technologies to measure properties related to material aging (i.e. thermal diffusivity, elastic constants, density, microcrack formation, fiber buckling and breakage, etc.) in complex composite material systems, adhesively bonded/built-up and/or polymer-matrix composite sandwich structures. The anticipated outcome of successful proposals would be a both Phase 2 prototype NDE technology for the use of the developed technique to characterize age-related degradation and a demonstration of the technology showing its ability to measure a relevant material property in a carbon fiber/epoxy composite used for structural applications on subsonic aircraft.

Sub Topics:

Prediction of Aging Effects Topic A1.03

In order to assess the long-term effects of potential hazards and aging-related degradation of new and emerging material systems/fabrication techniques, NASA is performing research to anticipate aging and to predict its effects on the designs of future aircraft. To support this predictive capability, structural integrity analytical tools, lifing methods, and material durability prediction tools are being developed. Physics-based and continuum-based models encapsulated as computational methods (software) are needed to provide the basis for these higher level (e.g., design) tools. Proposals are sought that apply innovative computational methods, models and analytic tools to the following specific applications:

- Probabilistic computational code is sought for improved structural analysis of complex metallic and composite airframe components. The methods used in 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.
- Software tools are needed to predict the onset and rates of type-II hot corrosion attack in nickel-based turbine disk superalloys that allow for prolonged disk operation at high temperatures. Typically hot corrosion of turbine alloys is a product of molten salt exposure and is manifested by a localized pitting corrosion attack. Prolonged high temperature exposures of turbine disk alloys to sulfur-rich low temperature melting eutectic salts can lead to an onset of Type II hot corrosion attack causing serious degradation to the durability of the turbine components.
- Computational software is sought to simulate of the response of advanced composite fan case/containment structures in aged conditions to jet engine fan blade-out events using impact mechanics and structural system dynamics modeling techniques.

The anticipated outcome of successful Phase 2 proposals would be analytic code (software) delivered to NASA suitable for use in material evaluation studies.

Sub Topics:
Aviation External Hazard Sensor Technologies Topic A1.04
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 [2]). The general approach to the development of airborne sensors for NextGen is to encourage the development of multi-use, adaptable, and affordable sensors. 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. This subtopic solicits technology that is focused on developing capabilities to detect and evaluate hazards. The development of human interfaces, including displays and alerts, is not within the scope of this subtopic 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, such as new sensor technologies in conjunction with existing X-band airborne radar, to improve hazard detection and quantification of hazard levels are of interest.

At this time, the following hazards are of particular interest: in-flight icing conditions, wake vortices, and turbulence. Proposals associated with sensor investigations addressing these hazards are encouraged, and some suggestions follow. Emphasis on vortices and icing is not intended to discourage proposals targeting other or additional hazards such as reduced visibility, terrain, airborne or ground obstacles, convective weather, gust fronts, cross winds, and wind shear.

To enable remote detection and classification of in-flight icing hazards for the future airspace system and emerging aircraft, NASA is soliciting proposals for the development of sensor systems for the detection of icing conditions. Examples include the following practical remote sensing systems:

- Low-cost, ground-based, vertical-pointing with potential scanning capability X-band radar that can operate unattended around the clock (24/7/365) and provide calibrated reflectivity and velocity data with hydrometer/cloud particle classification (based upon the reflectivity and velocity data).
- Low-cost, high-frequency (> 89 GHz) microwave or infrared radiometer technology capable of providing air temperature, water vapor, and liquid water measurements for both ground-based and airborne applications.

Wake vortex detection in the terminal area is of particular interest, because closer spacing between aircraft is necessary to facilitate the high-density operations expected in NextGen. 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. Proposed techniques shall provide range-resolved clear air wind and aerosol measurements in the near-IR wavelength region from 1.5 microns to 2.1 microns. Wind and aerosol measurement with

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.

Sub Topics:

Crew Systems Technologies for Improved Aviation Safety Topic A1.05

NASA seeks highly innovative, crew-centered, technologies to improve aerospace system safety through the development of more effective joint human-automation systems in aviation. This is to be accomplished through increased awareness of operator and crew functional state (both in terms of functional readiness and in situ assessment), and through improved interactions among intelligent agents (human and automated). We seek proposals for the development of advanced technologies that:

- Effectively convey information and aid decision making to enable novel NextGen operational requirements (e.g., 4D trajectory-based operations, visual operations in non-visual meteorological conditions, etc. as described in http://www.faa.gov/about/initiatives/nextgen/media/NGIP_0130.pdf [3]);
- Foster the appropriate use of automation and complex information sources by, for example, conveying constraints on automation reliability and information certainty/timeliness;
- Support effective joint cognitive systems by improving the communication and collaboration among multiple intelligent agents (human and automated, proximal and remote), and provide assessment techniques and metrics for evaluating mixed H/A team performance;
- Characterize the operational status of the human crew members, effectively modulate this state, and/or effectively adapt interfaces and automation in response to functional status (e.g., situationally-aware display reconfiguration, aiding, and multi-modal presentation of information to maximize system performance and minimize information processing bottlenecks);
- Provide methods, metrics, and tools that help to assess the effectiveness of the above-mentioned technologies in human-in-the-loop simulation and/or flight studies.

Proposals should describe novel technologies with high potential to serve the objectives of the Robust Automation/Human Systems element of NASA's Aviation Safety Integrated Intelligent Flight Deck program (http://www.aeronautics.nasa.gov/avsafe/iifd/rahs.htm [4]). Successful Phase 1 proposals should culminate in a final report that specifies, and a Phase 2 proposal that would realize, technology that improves the effectiveness of joint human-automation systems in aviation, or improves the ability to assess effectiveness of such systems.

Sub Topics:
Technologies for Improved Design and Analysis of Flight Deck Systems Topic A1.06
Information complexity in flight deck systems is increasing exponentially, and flight deck designers need tools to understand, manage, and estimate the performance and safety characteristics of these systems early in the design process - this is particularly true due to the multi-disciplinary nature of these systems. NASA seeks innovative design methods and tools for representing the complex human-automation interactions that will be part of future flight deck 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 performance;
- Design tools and methods that improve the application of human-centered design principles to the design and certification of mixed human-automated systems;
- Tools and methods for modeling the complex information management systems required for future flight

deck systems;

- Methods of data uncertainty estimation during the flight deck system design phase particularly as applied to predicting overall system integrity;
- Design and analysis methods or tools to better predict and assess human and system performance in relevant operational environments.

Proposals should describe novel design methods, metrics, and/or tools with high potential to serve the objectives of the System Design and Analysis element of NASA's Aviation Safety Integrated Intelligent Flight Deck program (http://www.aeronautics.nasa.gov/avsafe/iifd/sda.htm [5]). Successful Phase 1 proposals should culminate in a final report that specifies, and a Phase 2 proposal that would realize, tools that improve the design process for human-automation systems in aviation, 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.

Sub Topics:
Adaptive Aeroservoelastic Suppression Topic A1.07
NASA has initiated an Integrated Resilient Aircraft Control (IRAC) effort under the Aviation Safety Program. The main focus of the effort is to advance the state-of-the-art technology in adaptive controls to provide a design option that allows for increased resiliency to failures, damage, and upset conditions. These adaptive flight control systems will automatically adjust the control feedback and command paths to regain stability, maneuverability, and eventually a safe landing. One potential consequence of changing the control feedback and command paths is that an undesired aeroservoelastic (ASE) interaction could occur. The resulting limit cycle oscillation could result in structural damage or potentially total loss of vehicle control.

Current airplanes with non-adaptive control laws usually include roll-off or notch filters to avoid ASE interactions. These structural mode suppression filters are designed to provide 8 dB of gain attenuation at the structural mode frequency. Ground Vibration Testing (GVT), Structural Mode Interaction (SMI) testing, and finally full scale flight testing are performed to verify that no adverse ASE interactions occur. Until a significant configuration or control system change occurs, the structural mode suppression filters provide adequate protection.

When an adaptive system changes to respond to off-nominal rigid body behavior, the changes in control can affect the structural mode attenuation levels. In the case of a damaged vehicle, the frequency and damping of the structural modes can change. The combination of changing structural behavior with changing control system gains results in a system with a probability of adverse interactions that is very difficult to predict a priori. An onboard, measurement based method is needed to ensure that the system adjusts to attenuate any adverse ASE interaction before a sustained limit cycle and vehicle damage are encountered. This system must work in concert with the adaptive control system to allow the overall goal of re-gaining rigid body performance as much as possible without exacerbating the situation with ASE interactions.

Sub Topics:
Engine Lifing and Prognosis for In-Flight Emergencies Topic A1.08
The object of this research topic is to develop innovative methodologies and tools to determine the consumed life

of an engine and the probability of an engine system failure for future operations.

Aircraft engine design and life are based on a theoretical operation flight profile that in practice is not seen by most engines in service. The ability to predict remaining engine life with a defined reliability in real time from sensor measurements is a condition precedent to emergency operation risk assessment. It is expected that this research will result in a demonstration of an integrated life monitoring and prognosis methodology that will utilize existing and under-development probabilistic codes for engine life usage and risk assessment for future operations that may require enhanced performance.

The expected outcome of the research will be an on-line simulation demonstration of an integrated engine life module for:

- Probabilistic engine life usage calculation.
- Methodologies for engine failure prediction for future operations.
- Risk assessment and trade-off tools for off-nominal operations.

NASA resources available for the research will be an engine component data base for turbine disks and blades, and probabilistic computer codes for life prediction and reliability.

Sub Topics:
Pilot Interactions with Adaptive Control Systems under Off-Nominal Conditions Topic A1.09
Adaptive control is a promising control technology that can enhance flight safety and performance. Adaptive control has been demonstrated to provide improved performance in many unmanned aerial systems. When operated in an autonomous mode such as in an autopilot, the behavior of an adaptive flight control system can be modeled and simulated with a sufficient degree of repeatability.

The presence of a pilot working in a closed-loop fashion with an adaptive flight control presents an important problem that has not been well addressed. Adaptive control generally requires sufficiently rich input signals to improve parameter convergence, as the adaptive control system adapts to parametric changes in the vehicle dynamics or exogenous disturbances. The condition for rich input signals is known as persistent excitation. During adaptation under off-nominal conditions such as aircraft with damage, the pilot provides persistently exciting signals to the adaptive control system. There is generally a trade-off between adaptation and stability due to persistent excitation. With a high persistent excitation in the pilot inputs, the speed of adaptation increases and in theory better handling performance could be achieved. However, in practice, the high persistent excitation in the control signals can potentially cause significant cross-coupling between different flight control axes and or excite unmodeled dynamics such as aeroservoelastic modes. The overall effect of high persistent excitation could aggravate stability robustness of an adaptive flight control system with a pilot in the loop that results in poor handling qualities.

Another aspect of pilot interactions with an adaptive control system is the potential interactions between two adaptive elements in a closed-loop fashion, because the pilot can also be viewed as an adaptive control system with a learning ability. With the pilot adaptive element providing high persistently exciting inputs into an adaptive flight control system with a predetermined adaptation rate, the issue of stability can be important and difficult to assess.

To enable an adaptive flight control system to be operated with a pilot in the loop, it is necessary to develop new research techniques that can assess the effects of pilot interactions with an adaptive flight control system. These techniques should address pilot control responses via an adaptive model with features that can capture relevant interactions with an adaptive flight control system. Techniques for assessing pilot interactions via metrics that can quantify the pilot-vehicle system responses with an adaptive flight control system are also needed. Other aspects of the research can include new methods and tools that can provide an advisory function to limit the pilot control inputs in order to trade off between command-following performance and stability robustness.

Research in adaptive control methods will address the system requirements to provide good flying characteristics when the human operator closes the control loop. In the presence of damage, failures, etc. the adaptive system must trade the stability requirements with closed loop handling requirements. Methods for selecting the best achievable handling are needed. The adaptation system needs to find a good compromise between suppression of coupling between the axis (i.e. pitch into roll, etc.) and good in-axis behavior. Better metrics to assess cross-coupled (asymmetric) behavior are needed. These metrics could provide a quantitative measurement of the severity of a given failure, as well as a measure of the improvement due to adaptation. As the adaptation changes the flying characteristics of the vehicle, some means of informing the operator is required to ensure that the system is not overdriven by a pilot who is expecting nominal performance.

Sub Topics:

Detection of Aircraft Anomalies Topic A1.10

Adverse events that occur in aircraft can lead to potentially serious consequences if they go undetected. This effort is to develop the technologies, tools, and techniques to detect in-flight anomalies from adverse events. This involves the integration of novel sensor and advanced analytical technologies for airframe, propulsion systems, and other subsystems within the aircraft. The emphasis of this work is not on diagnosing the exact nature of the failure but on identifying its presence. Proposals are solicited that address aspects of the following topics:

- Analytical and data-driven technologies required to interpret the sensor data to enable the detection of fault and failure events;
- Methods to differentiate sensor failure from actual system or component failure;
- Characterizing, quantifying, and interpreting multi-sensor outputs; and
- New sensors, sensory materials and sensor systems that improve the detection of an adverse event or permit increased sensory coverage for an adverse event.

Emphasis is on novel methods to detect failures in electrical, electromechanical, electronic, structural, and propulsion systems. Along with these system failures, condition sensors are desired for both the detection of internal engine icing as well as composite aircraft lightning strikes (location and intensity). Where possible, a rigorous mathematical framework should be employed to ensure the detection rates and detection time constants are acceptable according to published baselines as characterized by statistical measures. Understanding and addressing validation issues are critical components of this effort.

Sub Topics:

Diagnosis of Aircraft Anomalies Topic A1.11

The capability to identify faults is critical to determining appropriate mitigation actions to maintain aircraft safety. This effort is to develop innovative methods and tools for the diagnosis of aircraft faults and failures. It includes the development of integrated technologies, tools, and techniques to determine the causal factors, nature, and severity of an adverse event and to distinguish that event from within a family of potential adverse events. These requirements go beyond standard fault isolation techniques. The emphasis is on the development of mathematically rigorous diagnostic technologies that are applicable to structures, propulsion systems, software, and other subsystems within the aircraft. Technologies developed must be able to perform diagnosis given heterogeneous and asynchronous signals coming from the health management components of the vehicle and integrating information from each of these components.

The ability to actively query health management systems, use advanced decision making techniques to perform the diagnosis, and then assess the severity using these techniques are critical. As an example, the mathematical rigor of the diagnosis and severity assessment could be treated through a Bayesian methodology since it allows for characterization and propagation of uncertainties through models of aircraft failure and degradation.

Both computational and prototype hardware implementations of the diagnostic capabilities are expected outcomes of this effort. Other methods could also be employed that appropriately model the uncertainties in the subsystem due to noise and other sources of uncertainty. The ability to actively query the underlying health management systems (whether they are related to detection or not) is critical to reducing the uncertainty in the diagnosis. As an example, if there is ambiguity in the diagnosis about the type and location of a particular failure in the aircraft structure, the diagnostic engine should be able to actively query that system or related systems to determine the true location and severity of the anomaly. Where possible, a rigorous mathematical framework should be employed to provide a rank ordered list of diagnoses, an assessment of the severity of each diagnosed event, along with a measure of the certainty in the diagnosis. Understanding and addressing the system integration and validation issues are critical components of this effort.

Sub Topics:

Prognosis of Aircraft Anomalies Topic A1.12

The ability to accurately and precisely predict the remaining useful life (RUL) of aircraft components and subsystems enables decision making and action taking that can avert or mitigate failures, thereby enhancing aircraft safety. Furthermore, it can improve operational efficiency by facilitating condition-based maintenance and reducing unscheduled maintenance. This effort here addresses the development of innovative methods, technologies, and tools for the prognosis of aircraft faults and failures. The assessment of the RUL could be used by other aircraft systems to place additional restrictions, such as a new operating envelope, on the flight control systems or it could be used by flight or maintenance personnel to take preventative actions. Areas of interest include developing methods for making predictions of RUL which take into account operational and environmental uncertainties (pure data-driven approaches are discouraged); physics-based models of degradation; generation of aging and degradation datasets on relevant components or subsystems; and development of validation and verification methodologies for prognostics.

Research should be conducted to demonstrate technical feasibility during Phase 1 and to show a path toward a Phase 2 technology demonstration. Proposals are solicited that address aspects of the following areas:

- RUL prediction techniques that address a set of fault modes for a device or component, for example by modeling the physics of the most critical fault modes and using (typically less accurate) data-driven methods for the remainder.
- Physics-based damage propagation models for one or more relevant aircraft subsystems such as composite or metallic airframe structures, engine turbomachinery and hot structures, avionics, electrical power systems, electromechanical systems, and electronics. Proposals that focus on technologies envisioned for next generation aircraft are strongly encouraged.
- 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. Methods can also consider the fusion of different techniques but must show how this helps to improve the uncertainty using appropriate metrics.
- Aircraft relevant testbeds that can generate aging and degradation datasets for the development and testing of prognostic techniques.
- Verification and validation methods for prognostic algorithms.

Sub Topics:
Healing Material System Concepts for IVHM Topic A1.13
The development of integrated multifunctional self-sensing, self-repairing structures will enable the next generation of light-weight, reliable and damage-tolerant aerospace vehicle designs. Prototype multifunctional composite and/or metallic structures are sought to meet these needs, as are concepts for their analytical and experimental interrogation. Specifically, structural and material concepts are sought to enable in situ monitoring and repair of service damage (e.g., cracks, delaminations) to improve structural durability and enhance safe operation of aerospace structural systems. Emphasis is placed on the development of new materials and systems for the mitigation of structural damage and/or new concepts for activation of healing mechanisms using new or existing materials. These advanced structural and material concepts must be robust, consider all known damage modes for specific material systems and be validated through experiment.

Sub Topics:
Verification and Validation of Flight-Critical Systems Topic A1.14
The purpose of this subtopic is to invest in mid- and long-term research to establish rigorous, systematic, scalable, and repeatable verification and validation methods for flight-critical systems, with a deliberate focus on safety for NextGen (http://www.jpdo.gov/nextgen.asp [6]). This subtopic targets NextGen safety activities and interests encompassing vehicles, vehicle systems, airspace, airspace concept of operations, and air traffic technologies, such as communication or guidance and navigation. Methods for assessing issues with technology, human performance and human-systems integration are all included in this sub-topic, nothing that multi-disciplinary research is required that does not focus on one type of component or phenomenon to the exclusion of other

important drivers of safety.

Proposals are sought for the development of:

- Safety-case methods and supporting technologies capable of analyzing the system-wide safety properties suitable for civil aviation vehicles and for complex concepts of operation involving airborne systems, ground systems, human operators and controllers.
- Technologies and mathematical models that enable rigorous, comprehensive analysis of novel integrated, and distributed, systems interacting through various mechanisms such as communication networks and human-automation and human-human interaction.
- Techniques, tools and policies to enable efficient and accurate analysis of safety aspects of software-intensive systems, ultimately reducing the cost of software V&V to the point where it no longer inhibits many safety innovations and NextGen developments.

This subtopic is intended to address those flight-critical systems that directly conduct flight operations by controlling the aircraft, such as on-board avionics and flight deck systems, and safety-critical ground-based functions such as air traffic control and systems for communication, navigation and surveillance. It is not intended to cover V&V of computational models of physical systems (e.g., CFD codes or finite element analysis).

Sub Topics:
Materials and Structures for Future Aircraft Topic A2.01
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, noise, lift, drag, durability, and emissions. This subtopic is also a subtopic for the "Low-Cost and Reliable Access to Space (LCRATS)" topic. Proposals to this subtopic may gain additional consideration to the extent that they effectively address the LCRATS topic (See topic O5 under the Space Operations Mission Directorate). In general, the technologies of interest cover four research themes:

- **Fundamental materials development, processing and characterization** - new approaches to enhance the durability, processability, and reliability of advanced materials (metals, ceramics, polymers, composites, hybrids and coatings) with an emphasis on multifunctional and adaptive materials and structural concepts. In particular, proposals are sought in:

- Textile ceramic matrix composite materials and structures and environmental barrier coatings capable of multi-use at 2700°F or greater for air vehicle propulsion and airframe applications.
- 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.
- Development of joining and integration technologies including fasteners and/or chemical joining methods for ceramic-to-ceramic, metal-to-metal, and metal-to-ceramic materials.
- Development of variable stiffness materials to support adaptive, multifunctional structures concepts.

- **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 structures that integrate novel materials, mechanism design, and structural subcomponent design into systems level designs.
    - Life prediction tools for textile ceramic 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 preform structures in either a relaxed or compressed deformation state are of particular interest.
- **Computational materials development tools** - methods to predict properties of both airframe and propulsion materials based upon chemistry and process for conventional as well as nanostructured, multifunctional and adaptive materials.
    - Ab-initio methods that enable the development of refractory composite coating for multi-use at temperatures greater than 3000°F in an air environments.
    - Quantum chemistry, molecular dynamics, and mesoscale models for the design, characterization and optimization of ablation materials for radiation heating, thermal re-radiation, and catalytic effects.
- **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:
    - Microadaptive flow control for use in robust, efficient, low mass actuators with broad bandwidths. The identification and development of actuators that can operate in harsh environments (600-800°F) experienced in gas turbine engine compressors with the following features: (1) operational frequencies of 1000 to 10,000 Hz, (2) stroke or displacement >100?m, (3)capable of exerting forces >200 lbs.

- Piezoelectric devices with the ability to convert strain energy into useable electric energy that can be integrated into aircraft designs for energy harvesting and or vibration damping including application to aircraft engine fan and compressor rotor blades. Requirement for these devices are power densities greater than or equal to 0.1 mW/cm^2. Novel approaches are sought to enable piezoelectric devices to operate in engine environment including typical stresses of fan/compressor blades and to have the durability for engine application.

- Miniature thermoelectric devices for powering RF sensors for use in turbine engine compressors. Devices must be capable of operating at temperatures up to 600°C in oxidizing environments and capable of achieving power densities greater than or equal to 0.1 mW/cm^2. Prototype device demonstration is required showing functionality at 600° in air for 100 hours and delivering power output in excess of 10?W/cm^2.

- Materials to support wireless sensing and actuating multifunctional structures.

- Manufacturing and fabrication technologies leading to the development of lightweight structurally integrated thermal protection systems for space access and planetary entry, including high temperature honeycombs, hat-stiffeners, rigid fibrous and foam insulators.

- Advanced material and component technologies to enable the development of mechanical and electrical drive system to distribute power from a single engine core to drive multiple propulsive fans, in particular, AC-tolerant, low loss (1.5 T field and 500 Hz electrical frequency; and high efficiency (= 30% of Carnot), low mass (
- Novel structural design strategies for integrated fan cases that combine hardwall composite cases for blade containment with acoustic treatments. Concepts are also sought that also integrate the case with the fan inlet to maximize structural, acoustic attenuation and weight benefits.

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. 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 include:

- 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 determining the size-dependent mass of gas-turbine engine particle emissions;

- 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;

- Combustor and/or combustion physics and mechanisms, enhanced mixing concepts, ignition and flame holding, turbulent flame propagation, vitiated-test media and facility-contamination effects, hydrogen/hydrocarbon-air kinetic mechanisms, multi-phase combustion processes, and engine/propulsion component characterizations;

- Novel combustor concepts that advance/enhance the state-of-the-art in hypersonic propulsion to improve system performance, operability, reliability and reduce cost. Both analytic and/or experimental efforts are encouraged, as well as collaborative efforts that leverage technology from on-going research activities;

- Computational and experimental technologies for the accurate prediction of combined cycle phenomena such as shock trains in isolators, inlet unstart, and thermal choke.

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, propfan, 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, crew and launch vehicle payloads. 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 and sources which arise from significant interactions between airframe and propulsion systems;

- Prediction of sound propagation (including sonic booms) from the aircraft through a complex atmosphere to the ground. This should include interaction between noise sources and the airframe and its flowfield;

- Computational and analytical structural acoustics prediction techniques for aircraft and advanced aerospace vehicle interior noise, particularly for use early in the airframe design process;

- Prediction and control of high-amplitude aeroacoustic loads on advanced aerospace structures and the resulting dynamic response and fatigue;

- 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, and noise control technology and methods that are enabled by advanced aircraft configurations, including integrated airframe-propulsion control methodologies;

- Technologies and techniques for active and passive interior noise control for aircraft and advanced aerospace vehicle structures;
- 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 the 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 assuring 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 aerodynamic flow phenomena, especially in the transonic speed range. Aeroelastic phenomena of interest include flutter, buffet, buzz, limit cycle oscillations, 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 aeroservothermoelasticity / 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.

Sub Topics:

Aerodynamics Topic A2.05

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 such as the new Crew Exploration Vehicle 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 capturing 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;
- 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.

Sub Topics:

Aerothermodynamics Topic A2.06

Development of accurate tools to predict aerothermal environments and their effects on space vehicles is critically important to achieving the goals of current NASA missions. These tools will also enable the development of advanced spacecraft for future missions by reducing uncertainties during design and development.

The large size and high re-entry velocity of the Crew Exploration Vehicle and the conditions encountered in proposed aerocapture missions to Titan, Neptune, and Venus require study of shock layer radiation phenomena, radiative heat transfer, and non-equilibrium thermodynamic and transport properties; these in turn require understanding of the internal structure and dynamics of the constituent gases.

Transition and turbulence effects are particularly complex in hypersonic flows, where unique problems are posed by shocks, real gas effects, body surfaces with complex and possibly time-dependent roughness, nose bluntness, ablation, surface catalyticity, separation, and an unknown free-stream disturbance environment.

At the heating rates encountered during hypersonic re-entry, surface ablation products blowing into the boundary layer introduce new interactions including chemical reactions and radiation absorption, that strongly affect surface heating rates and integrated heat loads.

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

- Computational analysis methods for radiation and radiation transport in the shock layer surrounding planetary entry vehicles;
- Advanced physics-based thermal and chemical non-equilibrium models for thermodynamics, transport, and radiation;
- Studies of the interactions of gases in the shock layer with ablating materials from the vehicle thermal protection system;
- Experimental methods and diagnostics to measure the characteristics of hypersonic flow fields, either in flight or in ground-based facilities;
- Software tools coupling radiation, non-equilibrium chemistry, Reynolds-averaged Navier-Stokes, and large eddy simulation codes to enable the design and validation of mission configurations for entry into planetary atmospheres.

Sub Topics:
Flight and Propulsion Control and Dynamics Topic A2.07
Enabling advanced aircraft configurations for subsonic, supersonic and hypersonic flight, and high performance engines will require advancement in the state-of-the art dynamic modeling and flight/propulsion control. Control methods need to be developed and validated for "optimal" and reliable performance of complex, unsteady, and nonlinear systems with significant modeling uncertainties while ensuring operational flexibility. New dynamic modeling and simulation techniques need to be developed to investigate dynamic performance issues and support development of control strategies for innovative aircraft configurations and propulsion systems. Technology needs specific to different flight regimes are summarized in the following:

Subsonic Fixed Wing Aircraft

Technologies of interest include: flying qualities design guidelines for civil transport aircraft and methods for evaluating the flying qualities of concept transport aircraft, including blended-wing-body and cruise efficient short takeoff and landing aircraft; active control techniques for subsystems within current and advanced engines that lead to improvements in propulsion system efficiency; definition of actuation requirements and characterization of transient behavior of flow control for active aerodynamic shaping; development of a modular, distributed control system architecture for unified propulsion/airframe control; toolset capable of assessing the controllability for a given control effector layout and determining the sizes of conventional control surfaces, horizontal tail and vertical tail necessary to meet control power requirements; novel control techniques for reducing system noise, emissions and fuel burn.

Supersonic Flight

Technologies of interest include: methods for developing integrated aeroservoelastic (ASE) models, including propulsion effects, suitable for simulation and control design; novel control design methods for integrated aero-propulsion-servo-elastic control leading to acceptable flying qualities over the operating flight envelope; novel, and feasible, takeoff and approach to landing procedures to accommodate the visibility challenges due to long forebodies; integrated inlet/engine control to ensure safe (no inlet unstart or compressor surge/stall) and efficient operation.

Hypersonic Flight

Technologies of interest include: system dynamic models pertaining to a dual-mode combustor based propulsion system (RAM/SCRAM) incorporating the essential coupled dynamic elements with varying fidelity for control design, analysis, and evaluation; methods for characterizing uncertainty in the dynamic models to enable control robustness evaluation; methods for dynamic modeling of hypersonic flow fields, both for external aerodynamics and internal flowpaths, and of heat release in scramjet flowpaths with appropriate fidelity for use in dynamic analysis and control design; hierarchical GNC (Guidance, Navigation and Control) architectures and energy management techniques to enable trajectory shaping and control over a wide operating envelope with integrated flight/propulsion control.

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

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 four general themes:

1. Design Environment Development;
2. Variable Fidelity, Physics-Based Design/Analysis Tools;
3. Technology Assessment and Integration; and
4. 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. Multi-fidelity, multi-disciplinary optimization frameworks, such as Numerical Propulsion System Simulation (NPSS), have been developed by NASA but have limited capabilities to simulate complete vehicle systems. Solicited topics are aligned with these four themes that will support this NASA research area.

(1) Design Environment Development

Technology development is needed to provide complex simulation and modeling capabilities where the computer science details are transparent to the engineer. A framework environment is needed to provide a seamless integration environment where the engineer need not be concerned with where or how particular codes within the system level simulation will be run. Interfaces and utilities to define, setup, verify, determine the appropriate resources, and launch the system simulation are also needed.

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.

(2) 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.

(3) 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: (1) New combustor designs, alternate fuel operation, and the ability to estimate all emissions, and (2) Noise source models (e.g., fan, jet, turbine, core and airframe components). Analyses tools that are scalable, especially to small aircraft, are desired.

(4) 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:

Propulsion-Variable Speed Drive Systems/Transmissions

Technologies, and predictive capability, related to enabling concepts and techniques for variable speed drive systems/transmissions suitable for large rotorcraft application are encouraged. Specifically this would include concepts for controlling and enabling variable speed drives as well as lightweight and reliable drive system components. Efficient drive-system speed-variability on the order of 30-50% should be the focus of the proposed technologies and analysis tools.

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, fast-response pressure sensitive paints applicable to blade surfaces, and methods to measure the rotor tip path plane angle of attack, lateral and longitude flapping, and shaft angle in flight and in the wind tunnel. Very low airspeed measurement systems for flight vehicles.

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

Topics of interest include, but are not limited to, external noise prediction methods for manned and unmanned rotorcraft, improved acoustic propagation models, psychoacoustics analysis of rotorcraft noise, interior noise prediction methods and active/passive noise control applications for rotorcraft including engine and transmission noise reduction, advanced acoustic measurement systems for flight and wind tunnel applications, acoustic data acquisition/reduction/analysis, rotor noise reduction techniques, noise abatement flight operations. Methods, devices, concepts for rotorcraft, or specifically wing, airflow control for steep noise abatement approach operations and hover (low speed) download relief. Rotor noise including broadband, harmonic, blade-vortex interaction, and high-speed impulsive noise, as well as rotor/tail rotor and rotor/rotor interactional noise, are of interest. Frequency range includes not only audible range, but very low frequency rotational noise (blade-passage frequency below 20 Hz) as well. Optimized active/passive concepts and noise tailoring, including rotorcraft designs that are inherently designed for lower noise as a constraint.

Rotorcraft Diagnostics

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 and tools to detect and predict the health and usage of rotorcraft dynamic mechanical systems in the engine and drive system. Automatic rotor imbalance detection and rotor smoothing is also of interest. Additionally, rotorcraft health management technologies can include, but are not limited, 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; integration of health monitoring information with maintenance processes and procedures; data management and automated techniques to acquire/process diagnostic information; system models, material failure models and correlation of failure under bench fatigue, seeded fault test and fielded data; data collection/management for analysis of operational data; in-flight pilot cueing and warning of impending catastrophic events.

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 four identified technical areas.

Sub Topics:
Propulsion Systems Topic A2.10
This subtopic is divided into two parts. The first part is the Turbomachinery and Heat Transfer and the second part is Propulsion 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 drastic 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 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 design 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 are on the order of 5% or above.

- Advanced flow analysis tools to enable design optimization of highly loaded compression systems that can accurately predict aerodynamic efficiency and operability. This includes computer codes with updated models for losses, turbulence, and other models that can simulate the flow through turbomachinery components with advanced design features such as swept and bowed blade shapes, flow range extension techniques, such as flow control and transition control to maintain acceptable operability and efficiency.

- 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.

- Methods are sought to enable more efficient use of coolant air in the turbine through coolant flow modulation. These methods could consist of open-loop or closed-loop coolant flow modulation. Modulations could be high-frequency with frequencies on the order of the turbine blade passing frequency or longer time scales on the order of engine thermal transients. Development of methods to measure turbine local and/or average surface temperatures to enable the closed-loop capability will be considered. Feedback control of the coolant flow rates and/or methods to produce modulation in actual turbine thermal environments are desired. Finally, a description of how the proposed technology will work in a vision modulated turbine cooling turbine system will be needed.

Propulsion Integration

Proposals for Propulsion Integration will address engine and engine integration topics as outlined in this section in support of the Fundamental Aeronautics Program.

One objective of the Subsonic Fixed Wing Project is to develop verified analysis capabilities for the key technical issues related to integrating embedded propulsion systems for "N+2" hybrid wing/body configurations. These key technical issues include: inlet technologies for distorted engine inflows related to embedded engines with boundary layer ingestion; fan-face flow distortion and its effects on fan efficiency and operability, noise, flutter stability and aeromechanical stress and life; wide operability of the fan and core with a variable area nozzle; issues related to the implementation of a thrust vectoring variable area nozzle; and duct losses related to long flow paths associated with embedded engines. Specifically, proposals are sought to provide advanced technology, prediction methods and tools.

The supersonics project would like proposals to develop tools and propulsion technologies that will enable the design of high performance fans; high-efficiency, low-boom, and stable inlets; high-performance, low-noise exhaust nozzles; and intelligent sensors and actuators for supersonic aircraft. The supersonics project is interested in both computational and experimental research, aimed at evaluating and analyzing promising technologies as well as understanding the fundamental flow physics that will enable improved prediction methods.

A mission class of interest to the Hypersonics Project is Highly Reliable Reusable Launch Systems (HRRLS). The HRRLS mission was chosen to build on work started in NASA's Next Generation Launch Technology (NGLT)

Program to provide new vehicle architectures and technologies to dramatically increase the reliability of future launch vehicles. The design of reusable entry vehicles that provide low-cost access to space is challenging in several technology areas. The development of hypersonic-unique air breathing propulsion systems and the integration of the propulsion system with the airframe impact vehicle performance and controllability and drive the need for an integrated physics-based design methodology.

For Propulsion Integration, topics will be solicited for two areas:

- Design concepts, actuators and analysis tools that enable:
    - High performance supersonic inlets and nozzles that have minimal impact on an aircraftÂ's sonic boom signature;
    - The control of shock wave boundary layer interactions and reduction of dynamic distortion in supersonic inlets;
    - Stable highly integrated supersonic inlets;
    - High pressure recovery, low distortion and low-weight subsonic diffusers;
    - Low weight systems for nozzle area control;
    - Thrust vectoring;
    - Practical, validated CFD models for flow control devices such as micro ramps, vaned vortex generators, air jets, or synthetic jets.
- Unsteady coupled Inlet / Fan Analysis Tools to investigate:
    - Engine transient affect on inlet unstart;
    - Mode transition for a hypersonic dual Turbine engine/RAM-SCRAM flowpath;
    - Inlet and fan aero/mechanical loads;
    - Engine/inlet control system development;
    - Distortion Tolerance.

Sub Topics:
NextGen Airspace Topic A3.01
The primary goal of the Airspace project is to develop integrated solutions for a safe, efficient, and high-capacity airspace system. Of particular interest is the development of core capabilities, including:

- Trajectory-based operations, which manages traffic using 4-dimensional trajectories to achieve increases in capacity and efficiency;
- Super-density operations, which maximizes the use of limited runways at the busiest airports;
- Weather assimilated into decision making, with emphasis on probabilistic weather;
- Equivalent visual operations, which will allow the system to maintain visual flight rule capacities in instrument flight rule conditions.

These core capabilities are required to enable key Airspace project functions such as Dynamic Airspace Configuration, Traffic Flow Management, Separation Assurance, and the overarching Evaluator that integrates these ATM functions over multiple planning intervals.

In order to meet these challenges, innovative and technically feasible approaches are sought to advance technologies in research areas relevant to NASA's NextGen Airspace effort. The general areas of primary interest are Dynamic Airspace Configuration, Traffic Flow Management, and Separation Assurance. Specific research topics for the Airspace project include:

- Four-dimensional trajectory modeling in the presence of uncertainty;
- Air/air and air/ground trajectory exchange interoperability;
- Trajectory uncertainty prediction and mitigation;
- Intent information requirements for separation assurance and super density operations;
- Airspace re-design techniques that improve capacity, including changing shape of current sectors and introducing new airspace classes;
- Pilot and controller procedures and decision support systems needed to facilitate dynamic airspace changes;
- Collaborative decision making techniques involving multiple agents;
- Integrated solutions of ATM functions over multiple planning intervals and across domains;
- Optimal allocation of separation assurance functions across humans and automation and air and ground systems;
- Optimization techniques to address demand/capacity imbalances;
- New safety assessment methods for safety-critical air and ground automation technologies;
- Scheduling optimization for integrated arrival/departure/surface operations;
- Displays and procedures for very closely-spaced parallel approaches;

- Traffic complexity monitoring and prediction;
- Trajectory design and conformance monitoring;
- Weather assimilated into ATM decision-making;
- Environmental metrics and assessments of new concepts and technologies;
- The effect of new vehicles (including UAVs) on air traffic management;
- Gate-to-Gate modeling for NextGen concepts;
- Integration of UAVs into the NAS, including examination of the anticipated mix of UAV classes and capabilities (equipment, size, mission) in the next 20 years;
- The effect of traffic congestion on integration of UAVs into the NAS;
- Separation assurance responsibilities with regard to UAVs;
- The requirements for, and the development of, a simulation environment to test UAV integration in the NAS.

Sub Topics:
NextGen Airportal Topic A3.02
Airportal research focuses on key capabilities that will increase throughput of the airport environment, and that achieve the highest possible efficiencies in the use of airport resources such as terminal airspace, runways, taxiways, and gates. Of particular interest is the development of the following core capabilities within Airportal:

- Optimization of surface aircraft traffic;
- Dynamic airport configuration management (including the optimal balancing of Airportal resources for arrival, departure, and surface aircraft operations);
- Predictive models to enable mitigation of wake vortex hazards;
- New procedures for performing safe, closely spaced, and converging approaches at closer distances than are currently allowed;
- Modeling, simulation, and experimental validation research focused on single and multiple regional airports (metroplex);
- Other innovative opportunities for transformational improvements in Airportal/metroplex throughput.

Inherent to the ASP approach is the integration of airborne solutions within the overall surface management optimization scheme.

In order to meet these challenges, innovative and technically feasible approaches are sought to advance technologies in research areas relevant to NASA's Next Gen/Airportal effort. The general areas of interest are surface movement optimization, converging and parallel runway operations, safety risk assessment methodologies, and wake vortex solutions inside Metroplex boundaries. Specific research topics for Next Gen/Airportal include:

- Human/automation interface concepts and standards for flight crews and air traffic control personnel specific to surface/airportal operations;
- Integration of decision-support tools across different airspace domains;
- Advanced technologies and approaches to achieving 2-3X improvement in the throughput of airports and metroplexes;
- Automatic taxi clearance and aircraft control technologies;
- Scheduling algorithm for aircraft deicing and integration with a surface traffic decision-support tool;
- Collaborative decision making between airlines and airport traffic control tower personnel for optimized surface operations, including push back scheduling and management of airport surface assets;
- Real-time assessment of the performance of surface operations;
- Computationally efficient solution methods for surface traffic planning optimization problems;
- Automation concepts and technologies for handling off-nominal situations and failure recovery mechanism;
- Design of computer-human interface (CHI) for ground-based automated surface traffic management;
- 4D taxi clearances and air-ground trajectory negotiation for landing aircraft;
- Innovative concepts, technologies, and procedures for safely increasing throughput of runways, especially combinations of parallel, converging, and intersecting runways;
- Innovative concepts, technologies, and procedures to maintain airport runway throughput under off-nominal conditions such as zero-zero ceiling and visibility;
- Innovative ideas for very closely spaced parallel runway operations, including airborne spacing algorithms and wake vortex avoidance procedures;
- Algorithms for determining wake vortex encounters from aircraft flight data recorders;
- Wake vortex hazard research, especially: establishment of wake vortex encounter hazard threshold, encounter assessment tools, development of a wake vortex hazard metric, flight crew awareness and response techniques;
- Fusion of data from weather sensors and models for automated input into atmospheric prediction models (e.g., Terminal Area Simulation SystemÂ-TASS) used for assessments of atmospheric hazards to aviation and for initializing wake vortex prediction software;
- Innovations in sensors for detection of wake vortices as well as with weather sensors in support of wake vortex predictions;
- Measurements of wind, temperature, and turbulence from departing and arriving aircraft;
- Radar simulation tools for wake vortices.

Note: The development of technologies for the airborne detection of wake vortices is covered in Subtopic A1.04.

Sub Topics:

Ground Test Techniques and Measurement Technology Topic A4.01

NASA is strategically positioning its ground test facilities to meet the future testing needs for our nation. NASA's aeronautics and space research and development pushes the limits of technology, including the ground test facilities that are used to confirm theory and provide validation and verification of new technical concepts. By using state-of-the-art test measurement technologies, data acquisition, testing techniques and enhancing facility performance, NASA will be able to operate its facilities more efficiently and effectively and also be able to meet the challenges presented by NASA's cutting edge research and development programs. Therefore, 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 emphasis for this subtopic is in the area of test measurement technology. Examples of 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 Partical 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.). Areas of interest are in the subsonic, transonic, supersonic, and hypersonic speed regimes. Specialized areas may include cryogenic conditions, icing conditions, and rotating turbo machinery.

Proposals that lead to products or processes that are applicable specifically to the ATP facilities (see http://www.aeronautics.nasa.gov/atp [10]) 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 government-owned, industry and academic institution aerospace ground test facilities.

Sub Topics:

Flight Test Techniques and Measurement Technology Topic A4.02

NASA's flight research is reliant on a combination of both ground and flight research facilities. By using state-of-the-art 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 scope of this subtopic is broad, with emphasis on emissions, noise, and performance. Research technologies applicable to this subtopic should address (but are not limited to) the following ground and flight facilities at Dryden: Western Aeronautical Test Range (WATR), Flight Loads Laboratory (FLL), Research Flight Simulation Hardware-in-the-Loop Simulation (HILS), Test bed and Support Aircraft (e.g. F-15, F-18, ER-2, Gulfstream-III, and Ikhana). In addition to the facilities, the following generic capabilities are desired that pertain to any of a variety of types of vehicles ranging from low-speed, to high-altitude long-endurance to supersonic, to hypersonic and access-to-space.

- Modeling, identification, simulation, and control of aerospace vehicles in flight research, flight sensors, sensor arrays and airborne instruments for flight research, and advanced aerospace flight concepts.
- Safer and more efficient design of advanced aerospace vehicles requires advancement in current predictive design and analysis tools. The goal is to develop more efficient software tools for predicting and understanding the response of an airframe under the simultaneous influences of structural dynamics, thermal dynamics, steady and unsteady aerodynamics, and the control system. The benefit of this effort will ultimately be an increased understanding of the complex interactions between the vehicle dynamics subsystems with an emphasis on flight research validation methods for control-oriented applications.
- Proposals for novel multidisciplinary nonlinear dynamic systems modeling, identification, and simulation for control objectives are encouraged. Control objectives include feasible and realistic boundary layer and laminar flow control, aeroelastic maneuver performance and load control (including smart actuation and active aerostructural concepts), autonomous health monitoring for stability and performance, and drag minimization for high efficiency and range performance.
- Real-time measurement techniques are needed to acquire aerodynamic, structural, control, and propulsion system performance characteristics in-flight and to safely expand the flight envelope of aerospace vehicles. This subtopic encompasses the development of sensors, sensor systems, sensor arrays, or instrumentation systems for improving the state-of-the-art in aircraft ground or flight research. This includes the development of sensors to enhance aircraft safety by determining atmospheric conditions. The goals are to improve the effectiveness of flight research by simplifying and minimizing sensor installation, measuring new parameters, improving the quality of measurements, minimizing the disturbance to the measured parameter from the sensor presence, deriving new information from conventional techniques, or combining sensor suites with embedded processing to add value to output information. These sensors and systems are required to have fast response, low volume, minimal intrusion, and high accuracy and reliability.
- This subtopic further solicits innovative flight research experiments that demonstrate breakthrough vehicle or system concepts, methodologies, technologies, and operations in the real flight environment and that are particularly related to separation and flow quality characterization in subsonic flight, shockwave propagation in supersonic flight, and small scale technology development in hypersonic flight. It further seeks advanced flight techniques, operations, and experiments that promise significant leaps in vehicle performance, operation, safety, cost, and capability; and that require a demonstration in an actual-flight environment to fully characterize or validate advances.

NASA is seeking highly innovative and viable research technologies that would increase efficiency or overcome limitations for flight research. Other areas of interest include: Verification & Validation techniques for non-deterministic and complex redundant systems; Design Tools integrated into the simulation environment for early research and validation; Flight Measurements & Data Acquisition; Skin Friction; Flight Hardened Systems & Miniaturization; Signal Processing & Reconfigurable Systems; Wireless technologies.

Sub Topics: