The Aviation Safety Program focuses on the Nation's aviation safety challenges of the future. 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 (NGATS). The Aviation Safety Program will conduct research to improve the intrinsic safety attributes of future aircraft and to eliminate safety-related technology barriers. The program is focusing on a foundational approach to advancing knowledge in core disciplines (e.g., fluid dynamics, computational methods, material science), which in turn is used to build integrated multidisciplinary system-level models, tools, and technologies.

This approach focuses on furthering our understanding of the underlying physics, chemistry, materials, etc., of aeronautics phenomena when broken down to these most basic elements. 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 missions, vehicle classes, and crew configurations.

Example areas of program interest include research directed at the detection, prediction and mitigation/management of aging-related hazards of future civilian and military aircraft; designs of revolutionary adaptive flight decks; in-flight prognosis of aircraft health, preventative and adaptive systems for in-flight operability; informed logistics and maintenance graceful recovery from in-flight failures; software safety assurance and formal verification methods for safety-critical systems; as well as system-level integrated resilient control technologies.

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.

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 for mitigation of aging and durability issues and to enable advanced material suitability and concepts. Proposals are sought for innovations in these mitigation technologies:
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.

Concepts for autonomous self-healing of composite aerospace structures. NASA is interested only in passive approaches, i.e., approaches that do not require sensors or external energy to activate the healing process. Desired performance objectives include improved compression-after-impact performance and retarded/arrested damage growth. To be competitive with lightweight traditional (non-healing) aerospace structures, self-healing concepts must not introduce extensive passive weight, such as a reservoir tank of resin, etc.

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 Crew Systems Technologies for Improved Aviation Safety

Lead Center: LaRC

Participating Center(s): ARC

NASA seeks highly innovative and crew-centered technologies to improve aerospace system safety. Such advanced technologies may meet this goal by ensuring appropriate situation awareness: facilitating and extending human perception, information interpretation, and response planning and selection; counteracting human information processing limitations, biases, and error-tendencies; assisting in response planning and execution; and fostering successful, closely-coupled joint cognitive human/automation systems. NASA requires improved methods and tools for characterizing current and future users of aerospace systems, and tailoring designs to users. Such advanced technologies must be evaluated sensitively in operationally-valid contexts. Therefore, NASA also seeks tools and methods for ascertaining, measuring and evaluating aerospace system operator performance in advance aviation contexts, and how this performance is reflected in system performance.

Technologies may take the form of tools, models, operational procedures, instructional systems, prototypes, and/or devices for use in the flight deck, elsewhere by pilots, or by those who design systems for crew use. Specific topical areas of interest include the following:

- Intelligent systems monitoring and alerting technologies for improved failure mode identification, recovery,
and threat mitigation;

- Designs for human-error prevention, detection, and mitigation;
- Support for crew response planning and selection;
- New sensors and/or new associated algorithms for determining operator states of attention, awareness, engagement, and intent;
- Approaches that appropriately modulate crew attention, engagement, workload, and situation awareness;
- Human-centered technologies to improve the performance of less-experienced operators and of pilots from special population groups;
- Human-error reliability approaches to analyzing flight deck displays, decision aids, procedures, and human/automation integration policies;
- Presentation and aiding concepts for the display and use of data with spatial or temporal uncertainty and of integrated streams of data with various levels of integrity;
- Naturalistic dialog approaches for interacting with aircraft systems and external agents in flight;
- Individual and team performance metrics, analysis methods, and tools to better evaluate and certify human and system performance for use in operational environments, simulation, and model-based analyses with focus on sequential behavior analysis.

A1.03 Aviation External Hazard Sensor Technologies

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

NASA is concerned with new and innovative methods for airborne detection, identification, and evaluation of in-flight hazards to aviation. These hazards may include weather and other atmospheric phenomena, terrain, traffic, and runway contamination. Examples of hazards include: icing conditions, convective weather, wind shear, wind gusts, turbulence, volcanic ash, hail, low visibility, wake vortices, lightning, terrain, air traffic, runway incursions, man-made obstacles, and wet/icy runways. Proposals are invited that lead to innovative new technologies and approaches or significant improvements in existing technologies for in-flight hazard avoidance.

Technologies may take the form of tools, models, techniques, procedures, substantiated guidelines, prototypes, and devices. Although the emphasis is on airborne hazard detection, prediction, and avoidance, the following are also of interest: the sharing of information to support hazard avoidance by other aircraft; multi-sensor and multi-source hazard information utilization; collaborative decision-making; updates to terrain/obstacle databases; and provision of observations for input to weather models and forecast/now-cast products. Examples include:

- New and improved airborne forward-looking sensor systems;
- Data fusion technologies for integrating disparate sources of flight-related information with on-board and off-
board sensor data to detect and evaluate aviation hazards;

- Innovative technologies and methods to detect, predict, and quantify hazards in order to provide accurate information and guidance to enable avoidance of hazards or to instigate strategies for mitigation; and

- Decision-support tools and methods to improve collaborative and distributive decision-making.

While this subtopic is focused on remote detection and avoidance of hazards, the same systems that provide for avoidance can be utilized for mitigation and escape. Proposals that explore these applications in addition to avoidance are welcome.

A1.04 Adaptive Flight Control

Lead Center: ARC

Participating Center(s): AFRC, GRC, LaRC

Small Business Innovative Research in adaptive flight control should address stability and performance, maneuverability, and safe landing of aircraft in adverse conditions (e.g., faults and failures, damage, and environmental upsets). This includes analysis and design methods for adaptive/intelligent reconfigurable control by developing practical and theoretic metrics. The approach must be able to address the following:

- Unmodeled dynamics (e.g., aeroelastic modes);

- Parametric uncertainty (e.g., stability and control derivative variations due to aerodynamic changes);

- Time-scale separation inherent in different actuators (e.g., slow engines as actuators);

- Nonlinear dynamic nature of the actuator response including time lag (e.g., engine variable spool-up time and actuator rate limiting);

- Stability of adaptive control methods in the presence of unmodeled dynamics and exogenous disturbances (e.g., wind shear and atmospheric turbulence).

Effective adaptive control methods need to be developed to mitigate multiple faults, failures, and damage conditions under uncertain (and potentially deteriorating) conditions. These methods include but are not limited to the following:

- Multi-objective adaptive optimal control;

- Aeroservoelastic mode filtering adaptive control;

- Direct adaptive control;
• Indirect adaptive control;
• Hybrid (direct and indirect) adaptive control.

These methods must be capable of achieving good performance (e.g., rise time, gain and phase margins, and command tracking) under adverse conditions while obeying system constraints (e.g., load limits and actuator rate saturation).

Innovative proposals are sought which can address the areas above and provide substantial improvements, in capability and range of applicability, over existing commercial technology.

A1.05 Data Mining for Integrated Vehicle Health Management

Lead Center: ARC
Participating Center(s): AFRC, GRC, LaRC

Innovative data mining technologies are being solicited to incorporate within systems and continuous risk management processes covering the life cycles of aircraft and their related ground support systems as well as spacecraft, in particular the Orion Crew Exploration Vehicle and the Aries launch vehicle and their related ground support systems. The life cycle includes design, development, integration, testing, operation (nominal and off-nominal), maintenance, enhancement (upgrades), and failure analysis.

Relevant technologies include those that:

• Detect anomalies and faults;
• Detect trends;
• Discover similarities;
• Infer models from data;
• Detect topics from text;
• Classify instances or events;
• Fuse data from multiple sources;
• Display data mining results in an intuitive manner.

To achieve the above capabilities, relevant technologies are expected to meet a subset of the following criteria:
• Perform automated learning, both supervised and unsupervised;
• Permit the user to define the search criteria and heuristics;
• Support a mixed-initiative approach combining automated learning and user search control;
• Perform real-time analyses on continuous streams of data;
• Perform off-line analyses on static databases;
• Process one or more data types including numeric sequences, character sequences, English free-form text, image sequences, and combinations of these forms;
• Perform real-time analyses on continuous streams of data;
• Perform on-demand, scheduled, or triggered analyses on periodic and/or aperiodic data streams;
• Perform off-line analyses on static databases.

NASA has a broad range of potential applications for these technologies. The following list provides a few examples:

• Enhance diagnostic and prognostic capabilities of an onboard integrated health management system;
• Perform clustering and topic identification on reports from a Problem Reporting and Corrective Action system;
• Detect faults from image sequences;
• Enhance acceptance tests to reduce false positive and false negative classifications;
• Enhance information-based security systems by detecting anomalies;
• Improve the design process by discovering similar applicable designs given requirements;
• Support analyses that assess risk of component or system failure.

Proposals are expected to identify commercial state-of-the-art technology that will be extended as well as the relevant research that will be implemented as the result of an award.
A1.06 Sensing and Diagnostic Capability

Lead Center: GRC

Participating Center(s): ARC, LaRC

One element in NASA's contribution to solving the problem of aging and damage processes in future vehicles is research to identify aging-related hazards before they become critical. In order to provide early detection of these processes and hazards, new sensing and diagnostic capabilities to support nondestructive evaluation (NDE) systems are needed, as well as associated computational techniques and maintenance methods. Proposals are sought that provide innovations in sensing technologies and diagnostic solutions for these specific structural, material, and systems problems:

- 'Virtual' inspections on both monolithic homogeneous materials (i.e., metals) and composite materials using computational NDE tools. 'Virtual' inspections would include determining the size of flaws detectable with a particular technique, the parameters needed for inspections on a particular structure, or determining if a technique is applicable for a particular inspection. Techniques modeled could include (but are not limited to) terahertz imaging, thermography, ultrasonics, eddy current or radiographics.

- Chafing of wiring insulation is the primary reason for wire failure in both military and commercial aircraft. Computational methods are being solicited for analyzing data from nondestructive inspection techniques to detect and characterize chafing as early as possible, thus enabling useful life predictions.

- Hard shell composite fan containment components that include sandwich structures. Of interest are practical large-area rapid inspection and/or health monitoring methods that can monitor the bulk interior as well as the surface of the component over significant distances as the component goes through its service life. Techniques could include (but are not limited to) ultrasonic guided waves that interrogate the bulk while traveling laterally along the component surface, acoustic emission systems, and robust pressure-sensitive film systems that can visually record impacts and impact paths while surviving the service and impact conditions.

- Increased use of composite structure and components in aircraft will create new challenges for visual inspection which still constitutes 80-90% of all inspections. Because surface indicators of damage or delamination may be subtle or barely visible, NASA is interested in technologies and techniques that can enhance visual detectibility in the operational environment. Such innovations could include (but are not limited to) treatments of the composite materials, enhancements to the work environment, or job aids for visual inspectors or maintenance technicians (outside the realm of NDE systems). Desireable features include ease of use and minimal change to the operational process.

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

A1.07 Advanced Health Management for Aircraft Subsystems

Lead Center: GRC

Participating Center(s): AFRC, ARC, LaRC

The purpose of this solicitation is to seek highly innovative and commercially viable technologies that will improve aircraft safety for current and future civilian and military aircraft, and to overcome aircraft safety technological barriers that would otherwise constrain the full realization of the Next Generation Air Transportation System
(NGATS). Specifically, this subtopic seeks technologies in support of the Integrated Vehicle Health Management Project (IVHM) that will contribute to the reduction of aircraft system and component failures and malfunctions that cause and contribute to aircraft accidents and incidents.

The goal of IVHM is to develop technologies to determine system/component degradation and damage early enough to prevent or gracefully recover from in-flight failures in both the near-future and next-generation air transportation systems. These technologies will enable nearly continuous on-board situational awareness of the vehicle health state for use by the flight crew, ground crew, and maintenance depot. To achieve this, NASA will advance the state-of-the-art technology in on-board health state assessment to enable the continuous diagnosis and prognosis of the integrated vehicle's health status. To help meet this goal, NASA seeks innovative technology development activities in the following areas:

- **Airframe Health Management** - including self-awareness and prognosis, anomaly detection and identification, and in-flight damage, degradation and failure mitigation;

- **Propulsion Health Management** - including self-awareness and prognosis of gas path, combustion, and overall engine state (containment systems and rotating and static components), and fault-tolerant system architectures;

- **Aircraft Systems Health Management** - including state-awareness and prognosis of landing gear, hydraulic and pneumatic systems, electrical and power systems, fuel and lubrication systems, avionics/communications, navigation, surveillance/flight critical and flight management systems, and robust, distributed, fault-tolerant, self-recoverable architectures for flight critical aircraft applications;

- **Environmental Hazard Management** - including the prevention, detection, and mitigation of hazards such as ice accretion, lightning strikes, EMI/EMC, and ionizing radiation, as well as the direct and indirect effects of these hazards;

- **IVHM Architectures and Databases** - including system design, analysis and optimization, information management, data flow and communication, control and reconfiguration, architecture development and validation, and database development and management;

- **Validation and Predictive Capability Assessment** - including analysis, simulation, ground testing, flight testing, environmental testing, and software assurance.

NASA's IVHM research will ultimately yield integrated, multi-disciplinary analysis and optimization capabilities that enable system-level designs providing graceful recovery from in-flight failures, computationally efficient tools for in-flight prognosis of aircraft health including integrated predictive and sensor capabilities, and preventative and adaptive systems for in-flight operability and informed logistics and maintenance. Innovative technology solutions are being sought for the following IVHM technical challenges:

- Large-scale distributed anomaly, fault, malfunction, degradation, and failure detection with data/decision/information fusion (multiple sensors, actuators, and processing nodes);

- Prevention, detection, isolation, and mitigation of multiple independent/correlated anticipated and unanticipated failures (modeling of correlated failures and system/vehicle effects, diagnosis and prognosis, real-time processing and decision-making for very large state spaces, and health state reasoning);
Adaptive diagnostic and prognostic algorithms (adapts as systems and components age, are repaired, or replaced);

- Analytical methods to set local decision criteria so that global performance criteria are met (multi-dimensional optimization);

- Performance optimization in distributed systems (high probability of detection, low probability of false alarm);

- Vehicle-wide state and function monitoring of systems and structures (including digital avionics, auto-flight and control, propulsion, hydraulic, mechanical, pneumatic, electrical, and power generation and distribution systems);

- Large-scale distributed adaptive fault-tolerant processing architecture that is robust in adverse operating environments (EMI/EMC, ionizing radiation, low/high temperatures);

- Distributed hierarchical threat-tolerant self-healing embedded sensors and systems (embedded self-recovery mechanisms, adaptive, programmable and reconfigurable devices);

- Technology integration, verification, and validation (diagnostic and prognostic flight, airframe, and propulsion systems, environmental hazard management, advanced sensors and system architectures, Verification and Validation (V&V) with predictive capability).

Technology innovations may take the form of tools, models, algorithm, prototypes, and/or devices.

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**A1.08 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, computational methods, and validation techniques are needed to provide the basis for these higher level (e.g., design) tools. Proposals are sought that apply innovative methods, models and analytic tools to these specific applications:

- Improved structural analysis of complex metallic and composite airframe components through the use of novel multi-scale as well as global-local analytical codes. The methods used for these solutions need to detail the initiation and progression of damage to determine accurate estimates of residual life and or strength of complex airframe structures.

- Type II 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. Tools and models are needed to predict the onset
and the rates of hot corrosion attack in these types of alloys.

- Simulation of the response to jet engine fan blade-out events of advanced composite fan case/containment structures in aged conditions, using relevant impact mechanics and structural system dynamics modeling techniques.

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

A1.09 Integrated Avionics Systems for Small Scale Remotely Operated Vehicles

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

Small scale remotely operated vehicles are becoming an increasingly attractive option for experimental research in flight dynamics, vehicle state assessment, and automatic flight control as well as a growing number of commercial applications. Small scale vehicles (nominally 20 lbs to 80 lbs total weight) place constraints on the amount of on-board avionics that can be accommodated and these systems can benefit from integration of components. For flight research activities key avionic systems are:

- Inertial navigation units which combine gyroscopic measurements with GPS position data;
- The capabilities to implement an autopilot fail-safe should RF uplink be lost;
- The ability to log instrumentation data from analog, pulse-width and serial stream inputs;
- The ability to read and generate serial-port data streams for RF communication systems;
- Telemetry systems to provide for both ground-based piloting and real-time data downlink.

When used as experimental research test beds the requirements for data quality (resolution, bandwidth, linearity, etc.) are often higher than would be derived just for automated flight operations on the vehicle itself. Although existing commercial technology can individually address each of these areas, an integrated high-fidelity system that is commensurate with the low-power, low-weight, and EMI sensitive environment of subscale remotely piloted vehicles is not available. For safety of flight a fail-safe autopilot should be able to recover vehicle stability from a range of entry conditions and also have GPS waypoint return-and-hold or full auto landing capability. Programmability of the avionics unit is important to allow the system to be extended to a wide range of platforms, application environments, and experimental requirements. Telemetry systems are flight critical for remotely piloted vehicles and therefore must have high reliability in addition to meeting bandwidth requirements imposed by the data downlink from a fully instrumented vehicle.

Innovative system concepts are sought which can address some or all of the areas above and provide substantial improvements, in capability and range of applicability, over existing commercial technology.
A1.10 Adaptive Structural Mode 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.

Adaptive, reconfigurable structural mode suppression methods that address the following are needed:

- Suppression of all ASE interactions with no a priori knowledge of structural modes;
- Minimal interference/interaction with rigid body controller;
- Implementable in a real-time flight control processor.

Research areas of interest include, but are not limited to, the following:

- Adaptive filtering techniques;
- Self-tuning notch filters;
• ASE modeling and predictive techniques;
• Online margin measurement techniques;
• Online identification of structural vibrations;
• Global stability proofs for adaptive systems.

A1.11 Universal Enabling IVHM Technologies in Architecture, System Integration, Databases, and Verification and Validation

Lead Center: LaRC
Participating Center(s): AFRC, ARC, GRC

A vehicle-wide Integrated Vehicle Health Management (IVHM) Project system must be information rich with embedded monitoring and diagnostic/prognostic functions that will penetrate deeper and with smaller granularity into physical components and structures. This will necessitate the development of safety-critical, real-time, distributed, embedded sensing and computing system design, development, integration, and assessment capability for applications with huge numbers of sensing and computing nodes which are networked and dynamically reconfigurable in response to changing physical conditions, modes of operation, failures, damage, and environmental disturbances. Furthermore, the development of advanced anomaly detection, prognostic, and diagnostic architectures will be required. The architecture will be designed to optimize multi-dimensional/objective criteria, enable optimal adaptive redundancy management, support large-scale data, decision, and information fusion, and meet safety, cost, and performance criteria for the IVHM system. However, the development of such a vehicle-wide system must be done by many teams of different disciplines at different locations. Therefore, a standard project database is needed that stores and manages test data, failure statistics, fault modes and effects, diagnostic and prognostic models, simulations, and related documentation for all the systems, subsystems, and components that are part of the complex system for which an IVHM system is being developed.

The IVHM database must also allow for seamless integration with a variety of IVHM algorithms, including data mining, machine learning, and exploratory data analysis tools, in order to enable algorithm development and knowledge discovery using the same database of historical data. The IVHM database will be owned and operated by NASA and will be provided as a service to the aircraft industry, U.S. government, and the R&D community. The database will provide industry standard access controls to protect proprietary data rights as well as to ensure compliance with ITAR and EAR restrictions. Additionally, design tools/decision support systems that enable the design of aircraft while accounting for the sensing, processing, and data mining/analysis needs of IVHM is vital. These tools/systems must enable the designers and the analysts/discipline specialists to work together, rather than as separate entities, and must allow IVHM system design, including study of IVHM system tradeoffs, at the early aircraft design stage.

In order to ensure the safe and reliable application of IVHM technologies to civil aviation, advances in verification and validation (V&V) processes and underlying methods and tools are needed to assure the safety of systems that will become increasingly complex and nondeterministic. Advances are needed in compositional verification that will enable the safe integration of complex adaptive systems with strong guarantees of integrity, fault-tolerance, partitioning, and real-time. New tools, methods, and processes are needed for the V&V of diagnostic algorithms with non-deterministic behavior. The goal of the V&V research is to enable compelling evidence that required system properties are guaranteed by the composition of constituent parts, and to develop tools, methods and processes that mitigate concerns about design validity, safety, and reliability for complex, nondeterministic software-intensive systems.
A1.12 Technologies for Improvement Design and Analysis of Flight Deck Automation

Lead Center: ARC
Participating Center(s): LaRC

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 flight deck systems. NASA seeks innovative design methods and tools for representing the complex human-automation interactions that will be part of future adaptive 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. Specific areas of interest include the following:

- Computational 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 with respect to overall system integrity;

• Design and analysis methods or tools to better predict and assess human and system performance in relevant operational environments;

• Tools to extract information from analog information flows and transform to usable information content.

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

A1.13 On-Board Flight Envelope Estimation for Unimpaired and Impaired Aircraft

Lead Center: LaRC

Participating Center(s): AFRC, ARC, GRC

A primary goal of the NASA Aviation Safety Program is to develop technology for safe aircraft operation under different types of anomaly. Anomalies may occur in a variety of forms such as failed actuators, failed sensors, damaged surfaces or abrupt changes in aerodynamics or large changes in aerodynamics during upsets. As part of the Aviation Safety Program research, the Integrated Resilient Aircraft Control (IRAC) Project is investigating advanced control system concepts to provide greater aircraft resiliency to adverse events. The goal of the IRAC project is to arrive at a set of validated multidisciplinary aircraft control design tools and techniques for enabling safe flight in the presence of adverse conditions.

Research on advanced technical approaches (such as direct and indirect adaptive control) has focused on accomplishing stability and safe operability under anomaly. To be able to effectively develop and apply such methods, it is highly desirable, if not essential, to characterize the anomaly and assess the limits of operation of the impaired vehicle. Control application without regard to the vehicle impairment or adverse condition could have significant detrimental consequences. In particular, it would be desirable to characterize and isolate the anomalous condition, and then estimate the level of controllability, limits of maneuverability, and achievable flight envelope of the vehicle. This SBIR topic will develop analytical tools and prototype software to assess the ability of the vehicle to accomplish safe operation under specified anomalous conditions. Specific technology areas where contributions are sought include, but are not limited to, the following:

• Adaptive mathematical framework for control-centric onboard aircraft models that can accommodate real-time changes to subsystem dynamics;

• Real-time system identification capability for updating an onboard vehicle model with adaptive structure to
satisfy sub-system constraints under adverse conditions;

- Real-time fault diagnostic and prognostics capability needed in adaptive flight, propulsion, structural control application;

- Real-time control power map identification with inclusion of aircraft sub-system constraints under adverse conditions;

- Real-time dynamic flight envelope identification and prediction capability;

- Metrics and assessment models for safety-of-flight diagnostics and prognostics.

Fundamental Aeronautics Topic A2

NASA is the Nation's leading government organization for civil aeronautical research. Within NASA's overall strategic plan, Aeronautics has the goal to "Advance knowledge in the fundamental disciplines of aeronautics and develop technologies for safer aircraft and higher capacity airspace systems." To address this goal, NASA's Aeronautics Research Mission Directorate (ARMD) is organized into three separate Programs: Fundamental Aeronautics, Aviation Safety, and Airspace Systems.

The Fundamental Aeronautics Program encompasses cutting-edge research in traditional aeronautical disciplines, as well as emerging fields with promising application to aeronautics. The overall program is long-term in scope as well as focused and integrated across disciplines. It is implemented through NASA's four research centers: the Ames Research Center, in Mountain View, California; the Dryden Flight Research Center in Edwards, California; the Glenn Research Center in Cleveland, Ohio; and the Langley Research Center in Hampton, Virginia.

To achieve these objectives NASA has defined a four-level approach to technology development: (1) conduct foundational research to further our fundamental understanding of the underlying physics and our ability model that physics, (2) leverage the foundational research to develop technologies and analytical tools focused on discipline-based solutions, (3) integrate methods and technologies to develop multi-disciplinary solutions, and (4) solve the aeronautics challenges for a broad range of air vehicles with system-level optimization, assessment and technology integration.

The Fundamental Aeronautics Program will provide for results yielding the following:
- Technology innovation and integrated, multidisciplinary analysis tools;
- Rapid evaluation of new concepts and technology;
- Accelerated application of new technology to a wide array of vehicles;
- Reduced environmental impact and increased public benefit of future aircraft through lower emissions, less noise, higher efficiency, and safer operation.

Structurally, the program is composed of four projects: hypersonic flight, supersonic flight, subsonic fixed-wing aircraft and subsonic rotary-wing aircraft. Each project, in turn, addresses specific discipline, multi-discipline, sub-system and system level technology issues relevant to that flight regime. However, 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 Fundamental Aeronautics subtopics are organized by discipline, not by flight regime, with a special subtopic for rotary-wing issues.

The full list of Fundamental Aeronautics subtopics are: (1) Materials and Structures for Future Aircraft, (2) Combustion for Aerospace Vehicles, (3) Aero-Acoustics, (4) Aeroelasticity, (5) Aerodynamics, (6) Aerothermodynamics, (7) Flight and Propulsion Control and Dynamics, (8) Experimental Capabilities and Flight Research, (9) Aircraft Systems Analysis, Design and Optimization, and (10) Rotorcraft. Each of the subsequent subtopic sections will describe the scope, key issues and technical content of the subtopic. It will also include the specific areas of interest spanning the four flight regimes. Individual proposals are not restricted to any one specific technical area or any single part of the full flight regime. They may address any or all areas included in a subtopic and may cover any or all parts of the entire flight regime.

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 Programs research thrusts to enable the design and development of advanced future aircraft. In general, technologies of interest that cover the four research thrusts (Subsonic Fixed Wing, Subsonic Rotary Wing, Supersonic, Hypersonic) include:

- Fundamental materials development and characterization;
- Multifunctional materials and structures development;
- Life prediction and damage modeling;
- Validated structural analysis tools; and
- Computational materials development tools.
More specific information on materials and structures technologies of interest in this program is given below.

Subsonic Fixed Wing Aircraft

Proposals are sought that address specific design and development challenges associated with airframe and propulsion systems and directly support improvements to future subsonic fixed wing aircraft. The potential impact of the proposed technologies should be linked to improvements in aircraft performance indicators such as vehicle weight, noise, lift, drag, lifetime, and emissions. Specific technology areas where contributions are sought include, but are not limited to, the following:

- Advanced materials design concepts and processing development (e.g., multifunctional materials concepts, innovative approaches to damage tolerant lightweight structural materials, lightweight materials concepts to mitigate lightning strike damage, hybrid materials approaches to multifunctionality and/or improved durability and damage tolerance, and high-temperature materials for propulsion system applications);

- Design methods for material and structural concepts (in particular, multifunctional concepts) including variable fidelity methods, uncertainty based design and optimization methods, multi-scale computational methods, and multi-physics modeling and simulation tools;

- Adaptive materials and structures concepts (e.g., environmentally responsive materials and structures, intrinsically load/strain sensing materials and structures, active and/or highly flexible structures, shape memory and self-healing materials, innovative non-parasitic in situ methods to detect damage, impact and structural dynamics);

- Concepts and techniques for advanced multifunctional and/or adaptive material and structures characterization and evaluation (including combinations of thermal and mechanical loading environments);

- Identification, development and verification of degradation and failure mechanisms/criteria, residual strength (and other critical residual properties) and life prediction methods, and damage science design and analysis methods;

- Advanced materials fabrication and processing methods and joining and assembly methods, for ceramics, metals and polymers and/or hybrids of these materials;

- Tribological surface sciences, and mechanical components including oil-free bearings, seals technologies, and mechanical and electrical drive system to distribute engine power from a single engine core to drive multiple fans.

Supersonic Aircraft

Supersonic aircraft require durable and reliable materials and structures to provide continuous operation at speeds in excess of Mach 2. Specific technology areas where contributions are sought include:
• Oxidative fail-safe CMC, CMC structures for liners and airfoils;
• Advanced engine containment prediction tools;
• High temperature shape memory alloys;
• Accelerated life prediction tools;
• Rapid design methods for aircraft structures;
• Novel hot acoustic absorber technologies are also of interest to address the sound problems with supersonic flights.

**Hypersonic Vehicle**

The ultra-high temperatures and extreme environments experienced by a hypersonic or re-entry vehicle requires advanced materials and structures technologies to enable safe reliable vehicle operation. Specific technology areas where contributions are sought include:

• Physics-based life prediction methods for advanced high-temperature composites that support integrated structural design and analysis methods;
• SQL based software development tools for advanced material design database management;
• Advanced thermal protection systems using innovative structural and material concepts to improve vehicle safety and decrease weight including structurally integrated multifunctional systems;
• Advanced technology for enhanced thermal management, self sensing, and self healing of high-temperature materials;
• Design, development, analysis, and verification of advanced structural joining techniques for high-temperature composite airframe or propulsion structures;
• Computational materials development tools for durable high-temperature materials;
• Development of composite material systems and coatings for significantly improved hypersonic environmental durability for increased mission lifetimes;
• Development of durable structural sensor technology for extreme environments (> 1800 °F);
• Innovative structural concepts and materials leading to reliable high-mass planetary entry, decent, and landing systems.
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 interest where research is solicited, but is not restricted to, includes:

- Development of laser-based diagnostics and novel experimental techniques for measurements in reacting flows;
- Adaptive approaches for chemical kinetics in efficient combustion calculations;
- Two-phase flow simulation models and validation data under subcritical, superheated, and 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;
- High frequency/temperature sensors for active combustion control;
- Combustion instability modeling and validation;
- Novel combustion simulation methodologies;
- Novel low emissions combustion concepts that enhance the state-of-the-art in subsonic combustors;
- Novel low emissions concepts suitable for low emissions operation at supersonic cruise conditions;
- Alternative fuels for aerospace applications;
- Reformer technology and catalyst development for the processing of aviation fuels;
- 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, 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 aero-acoustic analysis, which can be adapted for design codes;

• Prediction of aero-acoustic noise sources including engine and airframe noise sources 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 techniques for aircraft and advanced aerospace vehicle interior noise prediction, particularly for use early in the airframe design process;

• Prediction and control of high-amplitude aero-acoustic 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 airframe (e.g., landing gear, high lift systems) noise sources, including turbulence details related to flow-induced noise sources typical of jets, separated regions, vortices, shear layers, etc.;

• Concepts for active and passive control of aero-acoustic 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 advanced 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;
Development and application of flight procedures for reducing community noise impact while maintaining or enhancing safety, capacity, and fuel efficiency.

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 develop revolutionary systems, in particular by integrating methods and technologies to develop 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
Flight regimes of interest in the Fundamental Aeronautics Program include subsonic, supersonic, and hypersonic. The goal of the program is to develop validated physics-based multidisciplinary design, analysis, and optimization tools, integrated with technology development. Topics of interest include, but are not limited to, the following:

- Structure-induced noise, flutter and dynamic response prediction, stiffness and strength tailoring, propulsion-specific structures, quasi-static aeroelasticity. Fluid-structure interaction, validation methods, data processing and interpretation methods, probabilistic modeling, rapid modeling analysis development, 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. Stiffness and strength tailoring and actively controlled propulsion system core components (e.g., fan and turbine blades, vanes). High fidelity unsteady aeroelastic capability which utilize current and future computer capabilities effectively. Advanced turbomachinery active damping concept. Rapid, high-fidelity probabilistic aeroelastic modeling capability.

- Physics-based models for turbomachinery aeroelasticity related to highly separated flows, shedding, rotating stall, non-synchronous vibrations (NSV). Robust, fast-running, accelerated convergence, reduced-order CFD approaches to turbomachinery aeroelasticity for propulsion applications. Blade vibration measurement systems including closely spaced modes, blade-to-blade variations (mistuning) and system identification. Blade damping systems for metallic and composite blades, including passive and active damping methods.

- Aeroservoelasticity, including alternative control architectures, development and testing of control law concepts. Integrated tool set for fully coupled modeling and simulation of aeroservothermoelasticity/flight dynamic (ASTE/FD) and propulsion effects. Development of CFD-based methods (reduced-order models) aeroservoelasticity models that can be used to predict and alleviate gust loads, ride quality issues, and flutter issues. Fast and accurate aeroelastic analysis methods to predict fan/compressor flutter vibrations in the presence of the inlet and neighboring blade rows. Vortical effects and nonlinear unsteady aerodynamics influence on the aeroelastic/ASE response of supersonic configurations.

- Lightweight structures and flexible structures under aerodynamic loads, with emphasis on aeroelastic phenomena in hypersonic domain. 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 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;

• 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, and to enable the development of advanced spacecraft for future missions by reducing uncertainties during design and development.

Radiative heating was not critical for the Space Shuttle Orbiter, due to its relatively low re-entry velocity, or for entry probes such as Genesis and Stardust, due to their small size. However, the large size and high reentry velocity of the Crew Exploration Vehicle make it imperative to study shock layer radiation phenomena. The conditions encountered in proposed aerocapture missions to Titan, Neptune, and Venus also require study of 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 special problems are posed by shocks, real gas effects, non-smooth body surfaces with complex and possibly time-dependent roughness distribution, nose bluntness, ablation, surface catalyticity, separation, and the unknown free-stream disturbance environment.

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

Aerothermal analyses and management are also relevant to the design of advanced propulsion systems. A better
fundamental understanding coupled with the ability to accurately simulate the aerothermodynamics of highly loaded turbomachinery is needed, along with innovative ideas such as flow control for increasing fan and compressor work factors without sacrificing efficiency and operability. Improvements in turbine cooling effectiveness, secondary flow management, and component matching are also important for high-pressure ratio engines.

Proposals suggesting innovative approaches to any of these issues are of interest. 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, development, and validation of mission configurations for entry into planetary atmospheres;
- Computational modeling to improve the accuracy of flow simulations for highly loaded turbomachinery;
- Innovative flow control methods, such as aspiration and bleed, to reduce the losses associated with highly loaded turbomachinery;
- Development of active flow control devices such as Dielectric Barrier Discharge plasma actuators for application to turbomachinery flow control.

A2.07 Flight and Propulsion Control and Dynamics

Lead Center: GRC

Participating Center(s): AFRC, ARC, LaRC

Enabling advanced aircraft configurations for subsonic, supersonic and hypersonic flight, high performance "Intelligent 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, enabling unique concepts of operations, lower emissions and noise, and safe operation over a wide operating envelope. 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 with enhanced control effectors and
propulsion systems. 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, active control of propulsion system components, and drag minimization for high efficiency and range performance. Technology needs specific to different flight regimes are summarized in the following:

**Subsonic Fixed Wing Aircraft**

Technologies of interest, with application to both flight and propulsion control, include: methods for development of dynamic models and simulations of the integrated component/control system being considered; defining actuation requirements for novel control approaches and developing prototype actuators; developing and applying innovative control methods and validating them through laboratory test and vehicle simulations as appropriate.

**Supersonic Flight**

Technologies of interest include: methods for developing integrated dynamic models and simulation including flexibility effects and suitable for control design; novel control design methods for integrated aero-servo-elastic-propulsive 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) and efficient operation.

**Hypersonic Flight**

Technologies of interest include: system dynamic models 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; hierarchical GNC (Guidance, Navigation and Control) architectures to enable trajectory shaping and control over a wide operating envelope with integrated flight/propulsion control; adaptive and robust control methods that can handle large modeling uncertainties; simulation test beds for evaluating hypersonic concept vehicle control under various types of uncertainty, system wide coupling and associated model misspecification.

**A2.08 Experimental Capabilities and Flight Research**

Lead Center: AFRC
Participating Center(s): ARC, LaRC
This subtopic is intended to solicit technologies for the following:

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, aerelastic 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. Methodologies should pertain to any of a variety of types of vehicles ranging from low-speed, high-altitude, long-endurance to hypersonic and access-to-space aerospace vehicles.

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. The scope of this subtopic is 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. This topic solicits proposals for improving airborne sensors and sensor instrumentation systems in all flight regimes - particularly transonic and hypersonic. 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 test experiments that demonstrate breakthrough vehicle or system concepts, technologies, and operations in the real flight environment. The emphasis of this subtopic is the feasibility, development, and maturation of advanced flight research experiments that demonstrate advanced or revolutionary methodologies, technologies, and concepts, particularly related to separation characterization in subsonic flight, shockwave propagation in supersonic flight, and small scale technology development in hypersonic flight. It 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.
A2.09 Aircraft Systems Analysis, Design and Optimization

Lead Center: ARC

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

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.

Analyses 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.

A2.10 Rotorcraft

Lead Center: ARC

Participating Center(s): AFRC, ARC, 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. Meeting this challenge will require innovative technologies and methods, with an emphasis on integrated, multidisciplinary, first-principle computational tools specifically applicable to the unique problems of rotary wing aircraft. Examples of technologies of interest are as follows:

**Propulsion/Aeromechanics Integration:** Encompassing dynamic and aerodynamic integration of rotorcraft including advanced configurations such as rotors operating at different speeds in hover and cruise (variable speed transmission/engine), high speed rotorcraft, and heavy lift rotorcraft. Possibly including on-blade active rotor control, or flow control for hub, blades, or engine inlet.

**Super-Integrated Vehicle Management System:** Integrated, broadband rotorcraft control system incorporating flight control system, engine control, airframe/drive train/rotor load control, active rotor control of vibration and noise, vehicle health management, and guidance for low noise operation. Including control design methodology development.

**Integrated Rotorcraft Design:** Advanced light weight structural and propulsion concepts with integrated functionality to achieve reduced interior noise, vibration, and maintenance/inspection requirements. This includes gear vibration transmission through the gear/ shaft/bearing/structural system and structural bonding techniques that increase fatigue life while allowing for post-bucking load capability for thin sheet sandwich construction.
**Integrated Rotorcraft Design:** Interactional aeroacoustics, encompassing dynamic, aerodynamic, aeroacoustic interactions of one or more main rotors, tail rotors, airframe, wings, empennage, engine, drive system. Possibly including active flow control for hub or fuselage drag reduction, or active rotor control.

**Integrated Experimental Systems:** Unified experimental techniques, integrating methods to enable efficient, multi-parameter, simultaneous measurements for characterizing rotorcraft behavior. Including unsteady pressure, blade deformation and position, flow field measurements, measurements that track wake vortex strength and position.

Examples of rotorcraft unique aspects of the aeronautics disciplines are as follows:

**Materials and Structures:** Advanced light-weight structural concepts exploiting material hybridization, selective reinforcement and material and geometric tailoring to achieve increased performance and durability while reducing weight, cabin noise and manufacturing cost, with emphasis on structural concepts for high oscillatory load environment of rotorcraft structures. Characterization of composite material properties under impact loading and models of impact damage. Characterization and simulation of fatigue damage in composite materials, crack/delamination growth models for spectrum loading, and high cycle fatigue thresholds, in particular for unique design and operational aspects of structures for rotor blades.

**Propulsion:** Research is solicited to improve rotorcraft propulsion and the ability to design and predict its performance in the following general areas:

Propulsion system (drives, engines, controls) technologies to enable variable speed rotor systems. Specific focus areas may include: enabling concepts and techniques for wide operability propulsion systems and variable speed drive systems/transmissions. Engine compressor stall control, engine flow control concepts for wide operability, cooling and secondary flow concepts for wide operability and integrated controls and modeling to support wide operability are sought. In addition, concepts for controlling and enabling variable speed drives, lightweight technologies and concepts and performance prediction capabilities for variable speed systems are sought.

Gearbox optimized propulsion systems in which both the engine and drive systems work together for improved performance. Specific concepts may include: dedicated gearbox lube systems coupled with oil-free engines; technologies to predict drive system windage losses and gear surface fatigue modeling; technologies to achieve
lightweight propulsion such as composite propulsion structures and components; high power density electromechanical systems and efficient high power density propulsion concepts such as highly loaded components; engine flow control concepts; high temperature components; nano-composite components and other relevant propulsion system technologies. Propulsion system concepts must be focused on power range and operating environment required for rotorcraft.

**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. Rotor noise, including broadband, harmonic, blade-vortex interaction, high-speed impulsive; alternate tail rotor and auxiliary power concepts, rotor/tail rotor, and rotor/rotor interactional noise. 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.

**Aeroelasticity and Dynamics:** Advanced rotorcraft hub and blade concepts for improved stability and loads capability. High-fidelity, first-principles approaches to rotorcraft stability calculation, including finite state and reduced order aerodynamic modeling approaches. Vibration reduction methods and techniques, including utilization of on-blade active control, individual blade control, or nonrotating frame active and passive means.

**Aerodynamics:** Airloading of rotor blades, including unsteady, compressible, viscous flows and blade-vortex interaction; stall and dynamic stall; rotor wake formation, propagation, dissipation, and interactions; rotor wake geometry. Aerodynamics of rotorcraft airframes, including rotor hubs, airframe drag, rotor-airframe-wing interactions of tiltrotors and compound configurations.Performance, including force and power of isolated rotors and of rotorcraft systems with influence of interactions between components. Behavior of rotors and rotorcraft in maneuvers and high speed flight, and advanced configurations heavy lift and slowed-rotor rotorcraft. Advanced computational fluid dynamics methods, including turbulence behavior unique to rotary wings.

**Flight Dynamics and Controls:** Rotorcraft flight dynamics and handling qualities. Including hover and low-speed guidance and situational awareness augmentation; autorotation control and guidance; variable-speed rotor control; low-cost low-speed air data system; improved simulation of low-visibility conditions (e.g., brownout, whiteout); control concepts for redundant effectors; affordable tactile cueing for retrofit into civil rotorcraft; study of redundancy/reliability required to achieve low-cost single-pilot IFR certification; continuously-variable transmission (current technology is focused on discrete-speed, transmission, but continuously-variable is highly desirable; flight control mitigation of structure/power train/rotor frequency overlap with primary control frequencies; proprotor control to provide helicopter-like response in heave for tilt rotor helicopter-mode operations.
**Experimental Capabilities**: Instrumentation and techniques for assessing scale rotor blade boundary layer state (e.g., laminar, transition, turbulent) and/or profile in simulated hover and forward flight conditions, measurement systems for large-field rotor wake assessment, instrumentation and techniques to measure dynamic boundary layer transition on the fixed system (fuselage) during scale model wind tunnel testing, multi-parameter temporally-resolved flow diagnostic techniques for wind tunnel testing of model-scale rotors and engine acoustic testing, fast time response pressure sensitive paints, alternatives to conventional slip rings (e.g., optical slip rings, reliable telemetry methods), high temperature and pressure sensors for engine applications, high temperature proximity sensors for turbine blade clearance measurements, sensors and/or methods for high accuracy rotorcraft velocity measurement in very low speed forward flight.

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**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). 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 the NGATS. The AS Program integrates the two projects, NGATS ATM Airspace and NGATS ATM Airportal, to directly address the fundamental research needs of NGATS vision in partnership with the member agencies of the JPDO. The NGATS ATM Airspace Project develops and explores fundamental concepts and integrated solutions that address the optimal allocation of ground and air automation technologies necessary for NGATS. 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 NGATS ATM Airportal Project develops and validates algorithms, concepts, and technologies to increase throughput of the runway complex and achieve high efficiency in the use of airport 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.

Sub Topics:

A3.01 Next Generation Air Transportation System - Airspace

Lead Center: ARC

Participating Center(s): AFRC, LaRC

The primary goal of the NASA Next Generation Air Transportation System (NGATS) Airspace effort is to develop integrated solutions for a safe, efficient, and high-capacity airspace system. Of particular interest is the development of core capabilities, including: (1) Performance-based services, which will enable higher levels of performance in proportion with user equipage level; (2) Trajectory-based operations, which is the basis for changing the way traffic is managed in the system to achieve increases in capacity and efficiency; (3) Super-density operations, which maximizes the use of limited runways at the busiest airports; (4) Weather assimilated into decision making; (5) 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 NGATS-Airspace functions such as Dynamic Airspace Configuration, Traffic Flow Management, Separation Assurance, and the overarching Evaluator that integrates these air traffic management (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 NGATS-Airspace effort. The general areas of primary interest are Dynamic Airspace Configuration, Traffic Flow Management, and Separation Assurance. Specific research topics for NGATS-Airspace include:

- 4D trajectory based operations;
- Air/ground automation concepts and technologies;
- Airspace modeling and simulation techniques;
- Automated separation assurance;
- Collaborative decision making techniques involving multiple agents;
- Equivalent visual operations;
- "Evaluator" integrated solutions of ATM functions over multiple planning intervals;
- Human factors for ATM;
- Locus of control across humans and automation;
- Multi-aircraft flow and airspace optimization;
- Performance based services;
- Safety analysis methods;
- Spacing and sequencing management;
- Super density terminal area operations;
- Traffic complexity monitoring and prediction;
- Traffic flow management concepts/techniques;
- Trajectory design and conformance;
- Weather assimilated into ATM decision-making.

A3.02 Next Generation Air Transportation - Airportal

Lead Center: LaRC

Participating Center(s): ARC

The Airportal research of NASA's Airspace Systems (AS) Program focuses on key capabilities that will increase throughput of the airportal environment and achieve the highest possible efficiencies in the use of airportal resources such as runways, taxiways, terminal airspace, and gates. The primary capabilities addressed are: (1) Super-density operations, (2) Equivalent visual operations, and (3) Aircraft trajectory-based operations.

Super-density operations will include conflict detection and resolution for closely spaced approaches, reduced aircraft wake vortex separation standards, and less restrictive run-way/taxiway operations. Additional mechanisms to increase the feasible density of operations will also be considered.

Equivalent visual operations will provide aircraft with the critical information needed to maintain safe distances from other aircraft during non-visual conditions, including a capability to operate at "visual performance" levels on the airport surface during low-visibility conditions. Advances in equivalent visual operations for the airportal air navigation service provider are also of interest.

Aircraft trajectory-based operations will utilize 4D trajectories (aircraft path from block-to-block, including path along the ground, and also including the time component) as the basis for planning and executing system operations.
NASA’s AS Program has identified the following Next Generation Air Transportation System (NGATS) Airportal research activities: Optimization of surface traffic; Dynamic airport configuration management (including the optimal balancing of airportal resources for arrival, departure, and surface operations); Predictive models to enable avoidance of wake vortex hazards; New procedures for performing safe, closely spaced and converging approaches at closer distances than are currently allowed; and modeling, simulation, and experimental validation research focused on single and multiple regional airports; and other innovative opportunities for transformational improvements in airportal/metroplex throughput. Inherent within the AS Program 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 NGATS-Airportal effort. The general areas of interest are surface management optimization, converging and parallel runway operations, safety risk assessment methodologies, and wake vortex solutions. Specific research topics for NGATS-Airportal include:

- Airborne spacing algorithms and wake avoidance procedures for airports with closely spaced runways;
- Automated separation assurance and runway/taxiway incursion prevention algorithms;
- Automatic taxi clearance and aircraft control technologies;
- Characterization of wake vortex and atmospheric hazards to flight in terms of aircraft and flight crew responses;
- Collaborative decision making between airlines and air traffic control tower personnel for optimized surface operations, including push back scheduling and management of airport surface assets;
- Dynamic airport configuration management;
- High resolution CFD and real-time modeling of wake vortex strength and location;
- Human/automation interaction and performance standards;
- Integration of decision-support tools across different airspace domains;
- Methodologies and/or algorithms to estimate environmental impacts of increased traffic on the surface and in the terminal airspace, and to reduce the environmental impacts under increased levels of traffic;
- Methodologies to estimate and assess the risk of transformational airspace operations for which little historical risk data may exist and for which operations may be constrained by the potential for extremely rare events;
- Modeling and simulation of single airport operations for validating taxi planning concepts;
- Optimized 4D trajectory generation and conformance monitoring for surface and terminal airspace operations, including departure and arrival planning for individual flights;
- Scheduling algorithm for aircraft deicing and integration with a surface traffic decision-support tool;
- Surface and terminal airspace traffic modeling and simulation of multiple regional airports;
Virtual towers;

Other technologies and approaches to achieving 2-3X improvement in the throughput of airports/metroplexes.

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.

Sub Topics:

A4.01 Test Measurement Technology

Lead Center: GRC

Participating Center(s): ARC, LaRC
NASA is concerned with operating its flight test aircraft with new and innovative flight test measurement methods. By using state-of-the-art test measurement technologies and novel means of acquiring test data, NASA will be able to operate its flight test aircraft and test-beds more effectively and also meet the challenges presented by NASA's cutting edge research and development programs. NASA's missions and programs push the limits of technology which places greater demands on its flight test-beds. These flight test-beds are often used in conjunction with
ground test facilities to confirm theory and provide verification and validation of new technologies. Therefore, NASA is seeking highly innovative and commercially viable test measurement technologies that would increase efficiency or overcome test limitations for flight research.

Flight test vehicles operate over a wide range of environmental conditions including among others: variable ambient pressure (the result of altitude changes), variable temperature (the result of altitude and airspeed changes), and vibration and acceleration (the result of engine vibration and dynamic flight maneuvers). In addition, weight, volume, and power requirements are at a premium because of limited space, power, and weight carrying capacity.

The first emphasis for this subtopic is in the area of flight test techniques. Factors in flight test techniques include, but are not limited to: methods for achieving accurate and repeatable flight test conditions (e.g., altitude, airspeed, flow quality, or turbulence intensity). Reconfigurable systems, alternative power sources, and novel methods for onboard data processing, storage, real-time access and RF data transmission are of interest. Technologies are also being requested to aid in multi-aircraft co-operative test techniques to enable chase aircraft to probe flow fields and visualize shock patterns around target aircraft.

The second emphasis for this subtopic is in the area of flight test measurement technology. Examples of the types of technology solutions sought are: data acquisition system improvements and miniaturization, skin friction experimental measurement techniques, and improved flow transition measurement techniques. Special emphasis is placed on new or novel, non-intrusive measurement technologies for pressure, temperature, and force measurements, and force measurement (balance) technology. Also, techniques that could facilitate shortening test measurement installation and setup times would be of interest such as methodologies that minimize the wiring infrastructure and other aircraft installation requirements would be applicable. Another area of interest is in test data conversions to different domains or data compression to reduce the volume of information that must be transmitted over existing telemetry links. It should be understood that all of these technologies must be capable of operating under extremes of temperature, pressure, and vibration typical in the flight environment.

Proposals that lead to products or processes that are applicable specifically to the ATP facilities and across multiple flight test-beds are especially important. Test-beds can be broadly categorized throughout a range of flight regimes encompassing hypersonic (e.g., orbital, sub-orbital, Phoenix missile), supersonic (e.g., F-15, F-16, F-18), and subsonic Fixed-Wing aircraft (e.g., ER2, G3, Predator-B). All platforms have a variety of different Mach/Altitude flight envelopes.
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 for mitigation of aging and durability issues and to enable advanced material suitability and concepts. Proposals are sought for innovations in these mitigation technologies:

- 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.

- Concepts for autonomous self-healing of composite aerospace structures. NASA is interested only in passive approaches, i.e., approaches that do not require sensors or external energy to activate the healing process. Desired performance objectives include improved compression-after-impact performance and retarded/arrested damage growth. To be competitive with lightweight traditional (non-healing) aerospace structures, self-healing concepts must not introduce extensive passive weight, such as a reservoir tank of resin, etc.

- 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:

Crew Systems Technologies for Improved Aviation Safety Topic A1.02
NASA seeks highly innovative and crew-centered technologies to improve aerospace system safety. Such advanced technologies may meet this goal by ensuring appropriate situation awareness: facilitating and extending human perception, information interpretation, and response planning and selection; counteracting human information processing limitations, biases, and error-tendencies; assisting in response planning and execution; and fostering successful, closely-coupled joint cognitive human/automation systems. NASA requires improved methods and tools for characterizing current and future users of aerospace systems, and tailoring designs to users. Such advanced technologies must be evaluated sensitively in operationally-valid contexts. Therefore, NASA also seeks tools and methods for ascertaining, measuring and evaluating aerospace system operator performance in advance aviation contexts, and how this performance is reflected in system performance.
Technologies may take the form of tools, models, operational procedures, instructional systems, prototypes, and/or devices for use in the flight deck, elsewhere by pilots, or by those who design systems for crew use. Specific topical areas of interest include the following:

- Intelligent systems monitoring and alerting technologies for improved failure mode identification, recovery, and threat mitigation;
- Designs for human-error prevention, detection, and mitigation;
- Support for crew response planning and selection;
- New sensors and/or new associated algorithms for determining operator states of attention, awareness, engagement, and intent;
- Approaches that appropriately modulate crew attention, engagement, workload, and situation awareness;
- Human-centered technologies to improve the performance of less-experienced operators and of pilots from special population groups;
- Human-error reliability approaches to analyzing flight deck displays, decision aids, procedures, and human/automation integration policies;
- Presentation and aiding concepts for the display and use of data with spatial or temporal uncertainty and of integrated streams of data with various levels of integrity;
- Naturalistic dialog approaches for interacting with aircraft systems and external agents in flight;
- Individual and team performance metrics, analysis methods, and tools to better evaluate and certify human and system performance for use in operational environments, simulation, and model-based analyses with focus on sequential behavior analysis.

Sub Topics:
Aviation External Hazard Sensor Technologies Topic A1.03
NASA is concerned with new and innovative methods for airborne detection, identification, and evaluation of in-flight hazards to aviation. These hazards may include weather and other atmospheric phenomena, terrain, traffic, and runway contamination. Examples of hazards include: icing conditions, convective weather, wind shear, wind gusts, turbulence, volcanic ash, hail, low visibility, wake vortices, lightning, terrain, air traffic, runway incursions, man-made obstacles, and wet/icy runways. Proposals are invited that lead to innovative new technologies and approaches or significant improvements in existing technologies for in-flight hazard avoidance.

Technologies may take the form of tools, models, techniques, procedures, substantiated guidelines, prototypes, and devices. Although the emphasis is on airborne hazard detection, prediction, and avoidance, the following are also of interest: the sharing of information to support hazard avoidance by other aircraft; multi-sensor and multi-source hazard information utilization; collaborative decision-making; updates to terrain/obstacle databases; and provision of observations for input to weather models and forecast/now-cast products. Examples include:
• New and improved airborne forward-looking sensor systems;

• Data fusion technologies for integrating disparate sources of flight-related information with on-board and off-board sensor data to detect and evaluate aviation hazards;

• Innovative technologies and methods to detect, predict, and quantify hazards in order to provide accurate information and guidance to enable avoidance of hazards or to instigate strategies for mitigation; and

• Decision-support tools and methods to improve collaborative and distributive decision-making.

While this subtopic is focused on remote detection and avoidance of hazards, the same systems that provide for avoidance can be utilized for mitigation and escape. Proposals that explore these applications in addition to avoidance are welcome.

Sub Topics:
Adaptive Flight Control Topic A1.04
Small Business Innovative Research in adaptive flight control should address stability and performance, maneuverability, and safe landing of aircraft in adverse conditions (e.g., faults and failures, damage, and environmental upsets). This includes analysis and design methods for adaptive/intelligent reconfigurable control by developing practical and theoretic metrics. The approach must be able to address the following:

• Unmodeled dynamics (e.g., aeroelastic modes);

• Parametric uncertainty (e.g., stability and control derivative variations due to aerodynamic changes);

• Time-scale separation inherent in different actuators (e.g., slow engines as actuators);

• Nonlinear dynamic nature of the actuator response including time lag (e.g., engine variable spool-up time and actuator rate limiting);

• Stability of adaptive control methods in the presence of unmodeled dynamics and exogenous disturbances (e.g., wind shear and atmospheric turbulence).

Effective adaptive control methods need to be developed to mitigate multiple faults, failures, and damage conditions under uncertain (and potentially deteriorating) conditions. These methods include but are not limited to the following:

• Multi-objective adaptive optimal control;

• Aeroservoelastic mode filtering adaptive control;
• Direct adaptive control;
• Indirect adaptive control;
• Hybrid (direct and indirect) adaptive control.

These methods must be capable of achieving good performance (e.g., rise time, gain and phase margins, and command tracking) under adverse conditions while obeying system constraints (e.g., load limits and actuator rate saturation).

Innovative proposals are sought which can address the areas above and provide substantial improvements, in capability and range of applicability, over existing commercial technology.

Sub Topics:
Data Mining for Integrated Vehicle Health Management Topic A1.05
Innovative data mining technologies are being solicited to incorporate within systems and continuous risk management processes covering the life cycles of aircraft and their related ground support systems as well as spacecraft, in particular the Orion Crew Exploration Vehicle and the Aries launch vehicle and their related ground support systems. The life cycle includes design, development, integration, testing, operation (nominal and off-nominal), maintenance, enhancement (upgrades), and failure analysis.

Relevant technologies include those that:

• Detect anomalies and faults;
• Detect trends;
• Discover similarities;
• Infer models from data;
• Detect topics from text;
• Classify instances or events;
• Fuse data from multiple sources;
• Display data mining results in an intuitive manner.

To achieve the above capabilities, relevant technologies are expected to meet a subset of the following criteria:
• Perform automated learning, both supervised and unsupervised;
• Permit the user to define the search criteria and heuristics;
• Support a mixed-initiative approach combing automated learning and user search control;
• Perform real-time analyses on continuous streams of data;
• Perform off-line analyses on static databases;
• Process one or more data types including numeric sequences, character sequences, English free-form text, image sequences, and combinations of these forms;
• Perform real-time analyses on continuous streams of data;
• Perform on-demand, scheduled, or triggered analyses on periodic and/or aperiodic data streams;
• Perform off-line analyses on static databases.

NASA has a broad range of potential applications for these technologies. The following list provides a few examples:

• Enhance diagnostic and prognostic capabilities of an onboard integrated health management system;
• Perform clustering and topic identification on reports from a Problem Reporting and Corrective Action system;
• Detect faults from image sequences;
• Enhance acceptance tests to reduce false positive and false negative classifications;
• Enhance information-based security systems by detecting anomalies;
• Improve the design process by discovering similar applicable designs given requirements;
• Support analyses that assess risk of component or system failure.

Proposals are expected to identify commercial state-of-the-art technology that will be extended as well as the relevant research that will be implemented as the result of an award.

Sub Topics:
Sensing and Diagnostic Capability Topic A1.06
One element in NASA's contribution to solving the problem of aging and damage processes in future vehicles is research to identify aging-related hazards before they become critical. In order to provide early detection of these processes and hazards, new sensing and diagnostic capabilities to support nondestructive evaluation (NDE) systems are needed, as well as associated computational techniques and maintenance methods. Proposals are
sought that provide innovations in sensing technologies and diagnostic solutions for these specific structural, material, and systems problems:

- "Virtual" inspections on both monolithic homogeneous materials (i.e., metals) and composite materials using computational NDE tools. "Virtual" inspections would include determining the size of flaws detectable with a particular technique, the parameters needed for inspections on a particular structure, or determining if a technique is applicable for a particular inspection. Techniques modeled could include (but are not limited to) terahertz imaging, thermography, ultrasonics, eddy current or radiographics.

- Chafing of wiring insulation is the primary reason for wire failure in both military and commercial aircraft. Computational methods are being solicited for analyzing data from nondestructive inspection techniques to detect and characterize chafing as early as possible, thus enabling useful life predictions.

- Hard shell composite fan containment components that include sandwich structures. Of interest are practical large-area rapid inspection and/or health monitoring methods that can monitor the bulk interior as well as the surface of the component over significant distances as the component goes through its service life. Techniques could include (but are not limited to) ultrasonic guided waves that interrogate the bulk while traveling laterally along the component surface, acoustic emission systems, and robust pressure-sensitive film systems that can visually record impacts and impact paths while surviving the service and impact conditions.

- Increased use of composite structure and components in aircraft will create new challenges for visual inspection which still constitutes 80-90% of all inspections. Because surface indicators of damage or delamination may be subtle or barely visible, NASA is interested in technologies and techniques that can enhance visual detectibility in the operational environment. Such innovations could include (but are not limited to) treatments of the composite materials, enhancements to the work environment, or job aids for visual inspectors or maintenance technicians (outside the realm of NDE systems). Desirable features include ease of use and minimal change to the operational process.

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

Sub Topics:
Advanced Health Management for Aircraft Subsystems Topic A1.07
The purpose of this solicitation is to seek highly innovative and commercially viable technologies that will improve aircraft safety for current and future civilian and military aircraft, and to overcome aircraft safety technological barriers that would otherwise constrain the full realization of the Next Generation Air Transportation System (NGATS). Specifically, this subtopic seeks technologies in support of the Integrated Vehicle Health Management Project (IVHM) that will contribute to the reduction of aircraft system and component failures and malfunctions that cause and contribute to aircraft accidents and incidents.

The goal of IVHM is to develop technologies to determine system/component degradation and damage early enough to prevent or gracefully recover from in-flight failures in both the near-future and next-generation air transportation systems. These technologies will enable nearly continuous on-board situational awareness of the vehicle health state for use by the flight crew, ground crew, and maintenance depot. To achieve this, NASA will advance the state-of-the-art technology in on-board health state assessment to enable the continuous diagnosis and prognosis of the integrated vehicle’s health status. To help meet this goal, NASA seeks innovative technology development activities in the following areas:
• Airframe Health Management - including self-awareness and prognosis, anomaly detection and identification, and in-flight damage, degradation and failure mitigation;

• Propulsion Health Management - including self-awareness and prognosis of gas path, combustion, and overall engine state (containment systems and rotating and static components), and fault-tolerant system architectures;

• Aircraft Systems Health Management - including state-awareness and prognosis of landing gear, hydraulic and pneumatic systems, electrical and power systems, fuel and lubrication systems, avionics/communications, navigation, surveillance/flight critical and flight management systems, and robust, distributed, fault-tolerant, self-recoverable architectures for flight critical aircraft applications;

• Environmental Hazard Management - including the prevention, detection, and mitigation of hazards such as ice accretion, lightning strikes, EMI/EMC, and ionizing radiation, as well as the direct and indirect effects of these hazards;

• IVHM Architectures and Databases - including system design, analysis and optimization, information management, data flow and communication, control and reconfiguration, architecture development and validation, and database development and management;

• Validation and Predictive Capability Assessment - including analysis, simulation, ground testing, flight testing, environmental testing, and software assurance.

NASA's IVHM research will ultimately yield integrated, multi-disciplinary analysis and optimization capabilities that enable system-level designs providing graceful recovery from in-flight failures, computationally efficient tools for in-flight prognosis of aircraft health including integrated predictive and sensor capabilities, and preventative and adaptive systems for in-flight operability and informed logistics and maintenance. Innovative technology solutions are being sought for the following IVHM technical challenges:

• Large-scale distributed anomaly, fault, malfunction, degradation, and failure detection with data/decision/information fusion (multiple sensors, actuators, and processing nodes);

• Prevention, detection, isolation, and mitigation of multiple independent/correlated anticipated and unanticipated failures (modeling of correlated failures and system/vehicle effects, diagnosis and prognosis, real-time processing and decision-making for very large state spaces, and health state reasoning);

• Adaptive diagnostic and prognostic algorithms (adapts as systems and components age, are repaired, or replaced);

• Analytical methods to set local decision criteria so that global performance criteria are met (multi-dimensional optimization);

• Performance optimization in distributed systems (high probability of detection, low probability of false alarm);

• Vehicle-wide state and function monitoring of systems and structures (including digital avionics, auto-flight and control, propulsion, hydraulic, mechanical, pneumatic, electrical, and power generation and distribution systems);
- Large-scale distributed adaptive fault-tolerant processing architecture that is robust in adverse operating environments (EMI/EMC, ionizing radiation, low/high temperatures);

- Distributed hierarchical threat-tolerant self-healing embedded sensors and systems (embedded self-recovery mechanisms, adaptive, programmable and reconfigurable devices);

- Technology integration, verification, and validation (diagnostic and prognostic flight, airframe, and propulsion systems, environmental hazard management, advanced sensors and system architectures, Verification and Validation (V&V) with predictive capability).

Technology innovations may take the form of tools, models, algorithm, prototypes, and/or devices.

Sub Topics:
Prediction of Aging Effects Topic A1.08
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, computational methods, and validation techniques are needed to provide the basis for these higher level (e.g., design) tools. Proposals are sought that apply innovative methods, models and analytic tools to these specific applications:

- Improved structural analysis of complex metallic and composite airframe components through the use of novel multi-scale as well as global-local analytical codes. The methods used for these solutions need to detail the initiation and progression of damage to determine accurate estimates of residual life and or strength of complex airframe structures.

- Type II 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. Tools and models are needed to predict the onset and the rates of hot corrosion attack in these types of alloys.

- Simulation of the response to jet engine fan blade-out events of advanced composite fan case/containment structures in aged conditions, using relevant impact mechanics and structural system dynamics modeling techniques.

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

Sub Topics:
Integrated Avionics Systems for Small Scale Remotely Operated Vehicles Topic A1.09
Small scale remotely operated vehicles are becoming an increasingly attractive option for experimental research in flight dynamics, vehicle state assessment, and automatic flight control as well as a growing number of commercial
applications. Small scale vehicles (nominally 20 lbs to 80 lbs total weight) place constraints on the amount of on-board avionics that can be accommodated and these systems can benefit from integration of components. For flight research activities key avionic systems are:

- Inertial navigation units which combine gyroscopic measurements with GPS position data;
- The capabilities to implement an autopilot fail-safe should RF uplink be lost;
- The ability to log instrumentation data from analog, pulse-width and serial stream inputs;
- The ability to read and generate serial-port data streams for RF communication systems;
- Telemetry systems to provide for both ground-based piloting and real-time data downlink.

When used as experimental research test beds the requirements for data quality (resolution, bandwidth, linearity, etc.) are often higher than would be derived just for automated flight operations on the vehicle itself. Although existing commercial technology can individually address each of these areas, an integrated high-fidelity system that is commensurate with the low-power, low-weight, and EMI sensitive environment of subscale remotely piloted vehicles is not available. For safety of flight a fail-safe autopilot should be able to recover vehicle stability from a range of entry conditions and also have GPS waypoint return-and-hold or full auto landing capability. Programmability of the avionics unit is important to allow the system to be extended to a wide range of platforms, application environments, and experimental requirements. Telemetry systems are flight critical for remotely piloted vehicles and therefore must have high reliability in addition to meeting bandwidth requirements imposed by the data downlink from a fully instrumented vehicle.

Innovative system concepts are sought which can address some or all of the areas above and provide substantial improvements, in capability and range of applicability, over existing commercial technology.

Sub Topics:

Adaptive Structural Mode Suppression Topic A1.10
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.

Adaptive, reconfigurable structural mode suppression methods that address the following are needed:

- Suppression of all ASE interactions with no a priori knowledge of structural modes;
- Minimal interference/interaction with rigid body controller;
- Implementable in a real-time flight control processor.

Research areas of interest include, but are not limited to, the following:

- Adaptive filtering techniques;
- Self-tuning notch filters;
- ASE modeling and predictive techniques;
- Online margin measurement techniques;
- Online identification of structural vibrations;
- Global stability proofs for adaptive systems.

Sub Topics:

Universal Enabling IVHM Technologies in Architecture, System Integration, Databases, and Verification and Validation Topic A1.11

A vehicle-wide Integrated Vehicle Health Management (IVHM) Project system must be information rich with embedded monitoring and diagnostic/prognostic functions that will penetrate deeper and with smaller granularity into physical components and structures. This will necessitate the development of safety-critical, real-time, distributed, embedded sensing and computing system design, development, integration, and assessment capability for applications with huge numbers of sensing and computing nodes which are networked and dynamically reconfigurable in response to changing physical conditions, modes of operation, failures, damage, and environmental disturbances. Furthermore, the development of advanced anomaly detection, prognostic, and diagnostic architectures will be required. The architecture will be designed to optimize multi-dimensional/objective criteria, enable optimal adaptive redundancy management, support large-scale data, decision, and information fusion, and meet safety, cost, and performance criteria for the IVHM system. However, the development of such a vehicle-wide system must be done by many teams of different disciplines at different locations. Therefore, a standard project database is needed that stores and manages test data, failure statistics, fault modes and effects, diagnostic and prognostic models, simulations, and related documentation for all the systems, subsystems, and
components that are part of the complex system for which an IVHM system is being developed.

The IVHM database must also allow for seamless integration with a variety of IVHM algorithms, including data mining, machine learning, and exploratory data analysis tools, in order to enable algorithm development and knowledge discovery using the same database of historical data. The IVHM database will be owned and operated by NASA and will be provided as a service to the aircraft industry, U.S. government, and the R&D community. The database will provide industry standard access controls to protect proprietary data rights as well as to ensure compliance with ITAR and EAR restrictions. Additionally, design tools/decision support systems that enable the design of aircraft while accounting for the sensing, processing, and data mining/analysis needs of IVHM is vital. These tools/systems must enable the designers and the analysts/discipline specialists to work together, rather than as separate entities, and must allow IVHM system design, including study of IVHM system tradeoffs, at the early aircraft design stage.

In order to ensure the safe and reliable application of IVHM technologies to civil aviation, advances in verification and validation (V&V) processes and underlying methods and tools are needed to assure the safety of systems that will become increasingly complex and nondeterministic. Advances are needed in compositional verification that will enable the safe integration of complex adaptive systems with strong guarantees of integrity, fault-tolerance, partitioning, and real-time. New tools, methods, and processes are needed for the V&V of diagnostic algorithms with non-deterministic behavior. The goal of the V&V research is to enable compelling evidence that required system properties are guaranteed by the composition of constituent parts, and to develop tools, methods and processes that mitigate concerns about design validity, safety, and reliability for complex, nondeterministic software-intensive systems.

Proposals are sought that advance the state-of-the-art in architecture, system integration, databases, and V&V technologies that will facilitate the deployment of IVHM systems that satisfy safety and performance requirements. The potential impact of the proposed technologies should be linked to improvements in large-scale systems design, deployment, safety and reliability, quality and performance. Specific technology areas where contributions are sought include, but are not limited to the following:

- Design tools/decision support systems that account for the needs of IVHM, including sensing, processing, data collection, onboard data mining, and fault diagnostics and prognostics algorithms.

- A project database that stores and manages test data, failure statistics, fault modes and effects, diagnostic and prognostic models, simulations, and related documentation for all the systems, subsystems, and components. The IVHM database must also allow for seamless integration with a variety of IVHM algorithms, including data mining, machine learning, and exploratory data analysis tools, in order to enable algorithm development and knowledge discovery using the same database of historical data.

- Advances in compositional verification supported by High Confidence Real-Time Operating Systems (RTOS), Middleware (MW), and/or Virtual Machines (VM) that may be independently designed and verified. Desired system properties include dynamic re-allocation of computational resources; correct and consistent disambiguation of fault syndromes, particularly with respect to segregating faults within the computational infrastructure from faults in other vehicle systems; and graceful evolution of system capabilities, with minimum adverse effects due to parts and software obsolescence.

- New tools, methods, and processes for verification and validation of diagnostic algorithms with non-deterministic behavior. A desired outcome from this research effort would be a demonstration of the relevance of the tools, methods, and processes towards flight software acceptance as applied to a specific non-deterministic algorithm (e.g., neural network, genetic algorithm, fuzzy rule-based inference, etc.).
Sub Topics:
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 flight deck systems. NASA seeks innovative design methods and tools for representing the complex human-automation interactions that will be part of future adaptive 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. Specific areas of interest include the following:

- Computational 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 with respect to overall system integrity;
- Design and analysis methods or tools to better predict and assess human and system performance in relevant operational environments;
- Tools to extract information from analog information flows and transform to usable information content.

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

Sub Topics:
On-Board Flight Envelope Estimation for Unimpaired and Impaired Aircraft Topic A1.13
A primary goal of the NASA Aviation Safety Program is to develop technology for safe aircraft operation under different types of anomaly. Anomalies may occur in a variety of forms such as failed actuators, failed sensors, damaged surfaces or abrupt changes in aerodynamics or large changes in aerodynamics during upsets. As part of the Aviation Safety Program research, the Integrated Resilient Aircraft Control (IRAC) Project is investigating advanced control system concepts to provide greater aircraft resiliency to adverse events. The goal of the IRAC project is to arrive at a set of validated multidisciplinary aircraft control design tools and techniques for enabling safe flight in the presence of adverse conditions.

Research on advanced technical approaches (such as direct and indirect adaptive control) has focused on accomplishing stability and safe operability under anomaly. To be able to effectively develop and apply such
methods, it is highly desirable, if not essential, to characterize the anomaly and assess the limits of operation of the impaired vehicle. Control application without regard to the vehicle impairment or adverse condition could have significant detrimental consequences. In particular, it would be desirable to characterize and isolate the anomalous condition, and then estimate the level of controllability, limits of maneuverability, and achievable flight envelope of the vehicle. This SBIR topic will develop analytical tools and prototype software to assess the ability of the vehicle to accomplish safe operation under specified anomalous conditions. Specific technology areas where contributions are sought include, but are not limited to, the following:

- Adaptive mathematical framework for control-centric onboard aircraft models that can accommodate real-time changes to subsystem dynamics;
- Real-time system identification capability for updating an onboard vehicle model with adaptive structure to satisfy sub-system constraints under adverse conditions;
- Real-time fault diagnostic and prognostics capability needed in adaptive flight, propulsion, structural control application;
- Real-time control power map identification with inclusion of aircraft sub-system constraints under adverse conditions;
- Real-time dynamic flight envelope identification and prediction capability;
- Metrics and assessment models for safety-of-flight diagnostics and prognostics.

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 Programs research thrusts to enable the design and development of advanced future aircraft. In general, technologies of interest that cover the four research thrusts (Subsonic Fixed Wing, Subsonic Rotary Wing, Supersonic, Hypersonic) include:

- Fundamental materials development and characterization;
- Multifunctional materials and structures development;
- Life prediction and damage modeling;
- Validated structural analysis tools; and
- Computational materials development tools.
More specific information on materials and structures technologies of interest in this program is given below.

**Subsonic Fixed Wing Aircraft**

Proposals are sought that address specific design and development challenges associated with airframe and propulsion systems and directly support improvements to future subsonic fixed wing aircraft. The potential impact of the proposed technologies should be linked to improvements in aircraft performance indicators such as vehicle weight, noise, lift, drag, lifetime, and emissions. Specific technology areas where contributions are sought include, but are not limited to, the following:

- Advanced materials design concepts and processing development (e.g., multifunctional materials concepts, innovative approaches to damage tolerant lightweight structural materials, lightweight materials concepts to mitigate lightning strike damage, hybrid materials approaches to multifunctionality and/or improved durability and damage tolerance, and high-temperature materials for propulsion system applications);

- Design methods for material and structural concepts (in particular, multifunctional concepts) including variable fidelity methods, uncertainty based design and optimization methods, multi-scale computational methods, and multi-physics modeling and simulation tools;

- Adaptive materials and structures concepts (e.g., environmentally responsive materials and structures, intrinsically load/strain sensing materials and structures, active and/or highly flexible structures, shape memory and self-healing materials, innovative non-parasitic in situ methods to detect damage, impact and structural dynamics);

- Concepts and techniques for advanced multifunctional and/or adaptive material and structures characterization and evaluation (including combinations of thermal and mechanical loading environments);

- Identification, development and verification of degradation and failure mechanisms/criteria, residual strength (and other critical residual properties) and life prediction methods, and damage science design and analysis methods;

- Advanced materials fabrication and processing methods and joining and assembly methods, for ceramics, metals and polymers and/or hybrids of these materials;

- Tribological surface sciences, and mechanical components including oil-free bearings, seals technologies, and mechanical and electrical drive system to distribute engine power from a single engine core to drive multiple fans.

**Supersonic Aircraft**

Supersonic aircraft require durable and reliable materials and structures to provide continuous operation at speeds in excess of Mach 2. Specific technology areas where contributions are sought include:
Oxidative fail-safe CMC, CMC structures for liners and airfoils;

Advanced engine containment prediction tools;

High temperature shape memory alloys;

Accelerated life prediction tools;

Rapid design methods for aircraft structures;

Novel hot acoustic absorber technologies are also of interest to address the sound problems with supersonic flights.

**Hypersonic Vehicle**

The ultra-high temperatures and extreme environments experienced by a hypersonic or re-entry vehicle requires advanced materials and structures technologies to enable safe reliable vehicle operation. Specific technology areas where contributions are sought include:

- Physics-based life prediction methods for advanced high-temperature composites that support integrated structural design and analysis methods;

- SQL based software development tools for advanced material design database management;

- Advanced thermal protection systems using innovative structural and material concepts to improve vehicle safety and decrease weight including structurally integrated multifunctional systems;

- Advanced technology for enhanced thermal management, self sensing, and self healing of high-temperature materials;

- Design, development, analysis, and verification of advanced structural joining techniques for high-temperature composite airframe or propulsion structures;

- Computational materials development tools for durable high-temperature materials;

- Development of composite material systems and coatings for significantly improved hypersonic environmental durability for increased mission lifetimes;

- Development of durable structural sensor technology for extreme environments (> 1800 °F);

- Innovative structural concepts and materials leading to reliable high-mass planetary entry, decent, and landing systems.
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 interest where research is solicited, but is not restricted to, includes:

- Development of laser-based diagnostics and novel experimental techniques for measurements in reacting flows;
- Adaptive approaches for chemical kinetics in efficient combustion calculations;
- Two-phase flow simulation models and validation data under subcritical, superheated, and 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;
- High frequency/temperature sensors for active combustion control;
- Combustion instability modeling and validation;
- Novel combustion simulation methodologies;
- Novel low emissions combustion concepts that enhance the state-of-the-art in subsonic combustors;
- Novel low emissions concepts suitable for low emissions operation at supersonic cruise conditions;
- Alternative fuels for aerospace applications;
- Reformer technology and catalyst development for the processing of aviation fuels;
- 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, 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 aero-acoustic analysis, which can be adapted for design codes;
- Prediction of aero-acoustic noise sources including engine and airframe noise sources 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 techniques for aircraft and advanced aerospace vehicle interior noise prediction, particularly for use early in the airframe design process;
- Prediction and control of high-amplitude aero-acoustic 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 airframe (e.g., landing gear, high lift systems) noise sources, including turbulence details related to flow-induced noise sources typical of jets, separated regions, vortices, shear layers, etc.;
- Concepts for active and passive control of aero-acoustic 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 advanced 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;
- Development and application of flight procedures for reducing community noise impact while maintaining or enhancing safety, capacity, and fuel efficiency.

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 develop revolutionary systems, in particular by integrating methods and technologies to develop 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.
- Development of unique control concepts 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.

Flight regimes of interest in the Fundamental Aeronautics Program include subsonic, supersonic, and hypersonic. The goal of the program is to develop validated physics-based multidisciplinary design, analysis, and optimization tools, integrated with technology development. Topics of interest include, but are not limited to, the following:
• Structure-induced noise, flutter and dynamic response prediction, stiffness and strength tailoring, propulsion-specific structures, quasi-static aeroelasticity. Fluid-structure interaction, validation methods, data processing and interpretation methods, probabilistic modeling, rapid modeling analysis development, 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. Stiffness and strength tailoring and actively controlled propulsion system core components (e.g., fan and turbine blades, vanes). High fidelity unsteady aeroelastic capability which utilize current and future computer capabilities effectively. Advanced turbomachinery active damping concept. Rapid, high-fidelity probabilistic aeroelastic modeling capability.

• Physics-based models for turbomachinery aeroelasticity related to highly separated flows, shedding, rotating stall, non-synchronous vibrations (NSV). Robust, fast-running, accelerated convergence, reduced-order CFD approaches to turbomachinery aeroelasticity for propulsion applications. Blade vibration measurement systems including closely spaced modes, blade-to-blade variations (mistuning) and system identification. Blade damping systems for metallic and composite blades, including passive and active damping methods.

• Aeroservoelasticity, including alternative control architectures, development and testing of control law concepts. Integrated tool set for fully coupled modeling and simulation of aeroservothermoelasticity/flight dynamic (ASTE/FD) and propulsion effects. Development of CFD-based methods (reduced-order models) aeroservoelasticity models that can be used to predict and alleviate gust loads, ride quality issues, and flutter issues. Fast and accurate aeroelastic analysis methods to predict fan/compressor flutter vibrations in the presence of the inlet and neighboring blade rows. Vortical effects and nonlinear unsteady aerodynamics influence on the aeroelastic/ASE response of supersonic configurations.

• Lightweight structures and flexible structures under aerodynamic loads, with emphasis on aeroelastic phenomena in hypersonic domain. 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 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;
- 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 aero thermal environments and their effects on space vehicles is critically important to achieving the goals of current NASA missions, and to enable the development of advanced spacecraft for future missions by reducing uncertainties during design and development.
Radiative heating was not critical for the Space Shuttle Orbiter, due to its relatively low re-entry velocity, or for entry probes such as Genesis and Stardust, due to their small size. However, the large size and high reentry velocity of the Crew Exploration Vehicle make it imperative to study shock layer radiation phenomena. The conditions encountered in proposed aerocapture missions to Titan, Neptune, and Venus also require study of 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 special problems are posed by shocks, real gas effects, non-smooth body surfaces with complex and possibly time-dependent roughness distribution, nose bluntness, ablation, surface catalyticity, separation, and the unknown free-stream disturbance environment.

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

Aerothermal analyses and management are also relevant to the design of advanced propulsion systems. A better fundamental understanding coupled with the ability to accurately simulate the aerothermodynamics of highly loaded turbomachinery is needed, along with innovative ideas such as flow control for increasing fan and compressor work factors without sacrificing efficiency and operability. Improvements in turbine cooling effectiveness, secondary flow management, and component matching are also important for high-pressure ratio engines.

Proposals suggesting innovative approaches to any of these issues are of interest. 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, development, and validation of mission configurations for entry into planetary atmospheres;

• Computational modeling to improve the accuracy of flow simulations for highly loaded turbomachinery;

• Innovative flow control methods, such as aspiration and bleed, to reduce the losses associated with highly loaded turbomachinery;

• Development of active flow control devices such as Dielectric Barrier Discharge plasma actuators for application to turbomachinery flow control.

Sub Topics:
Flight and Propulsion Control and Dynamics Topic A2.07
Enabling advanced aircraft configurations for subsonic, supersonic and hypersonic flight, high performance "Intelligent 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, enabling unique concepts of operations, lower emissions and noise, and safe operation over a wide operating envelope. 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 with enhanced control effectors and propulsion systems. 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, active control of propulsion system components, and drag minimization for high efficiency and range performance. Technology needs specific to different flight regimes are summarized in the following:

Subsonic Fixed Wing Aircraft

Technologies of interest, with application to both flight and propulsion control, include: methods for development of dynamic models and simulations of the integrated component/control system being considered; defining actuation requirements for novel control approaches and developing prototype actuators; developing and applying innovative control methods and validating them through laboratory test and vehicle simulations as appropriate.

Supersonic Flight

Technologies of interest include: methods for developing integrated dynamic models and simulation including flexibility effects and suitable for control design; novel control design methods for integrated aero-servo-elastic-propulsive 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) and efficient operation.
Hypersonic Flight

Technologies of interest include: system dynamic models 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; hierarchical GNC (Guidance, Navigation and Control) architectures to enable trajectory shaping and control over a wide operating envelope with integrated flight/propulsion control; adaptive and robust control methods that can handle large modeling uncertainties; simulation test beds for evaluating hypersonic concept vehicle control under various types of uncertainty, system wide coupling and associated model misspecification.

Sub Topics:
   Experimental Capabilities and Flight Research Topic A2.08
This subtopic is intended to solicit technologies for the following:

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. Methodologies should pertain to any of a variety of types of vehicles ranging from low-speed, high-altitude, long-endurance to hypersonic and access-to-space aerospace vehicles.

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. The scope of this subtopic is 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. This topic solicits proposals for improving airborne sensors and sensor instrumentation systems in all flight regimes - particularly transonic and hypersonic. 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 test experiments that demonstrate breakthrough vehicle or system concepts, technologies, and operations in the real flight environment. The emphasis of this subtopic is the feasibility, development, and maturation of advanced flight research experiments that demonstrate advanced or revolutionary methodologies, technologies, and concepts, particularly related to separation characterization in subsonic flight, shockwave propagation in supersonic flight, and small scale technology development in hypersonic flight. It 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.

Sub Topics:

Aircraft Systems Analysis, Design and Optimization Topic A2.09

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

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.
Analyses 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 A2.10

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. Meeting this challenge will require innovative technologies and methods, with an emphasis on integrated, multidisciplinary, first-principle computational tools specifically applicable to the unique problems of rotary wing aircraft. Examples of technologies of interest are as follows:

**Propulsion/Aeromechanics Integration:** Encompassing dynamic and aerodynamic integration of rotorcraft including advanced configurations such as rotors operating at different speeds in hover and cruise (variable speed transmission/engine), high speed rotorcraft, and heavy lift rotorcraft. Possibly including on-blade active rotor control, or flow control for hub, blades, or engine inlet.

**Super-Integrated Vehicle Management System:** Integrated, broadband rotorcraft control system incorporating
flight control system, engine control, airframe/drive train/rotor load control, active rotor control of vibration and noise, vehicle health management, and guidance for low noise operation. Including control design methodology development.

**Integrated Rotorcraft Design:** Advanced light weight structural and propulsion concepts with integrated functionality to achieve reduced interior noise, vibration, and maintenance/inspection requirements. This includes gear vibration transmission through the gear/shaft/bearing/structural system and structural bonding techniques that increase fatigue life while allowing for post-bucking load capability for thin sheet sandwich construction.

**Integrated Rotorcraft Design:** Interactional aeroacoustics, encompassing dynamic, aerodynamic, aeroacoustic interactions of one or more main rotors, tail rotors, airframe, wings, empennage, engine, drive system. Possibly including active flow control for hub or fuselage drag reduction, or active rotor control.

**Integrated Experimental Systems:** Unified experimental techniques, integrating methods to enable efficient, multi-parameter, simultaneous measurements for characterizing rotorcraft behavior. Including unsteady pressure, blade deformation and position, flow field measurements, measurements that track wake vortex strength and position.

Examples of rotorcraft unique aspects of the aeronautics disciplines are as follows:

**Materials and Structures:** Advanced light-weight structural concepts exploiting material hybridization, selective reinforcement and material and geometric tailoring to achieve increased performance and durability while reducing weight, cabin noise and manufacturing cost, with emphasis on structural concepts for high oscillatory load environment of rotorcraft structures. Characterization of composite material properties under impact loading and models of impact damage. Characterization and simulation of fatigue damage in composite materials, crack/delamination growth models for spectrum loading, and high cycle fatigue thresholds, in particular for unique design and operational aspects of structures for rotor blades.

**Propulsion:** Research is solicited to improve rotorcraft propulsion and the ability to design and predict its performance in the following general areas:

Propulsion system (drives, engines, controls) technologies to enable variable speed rotor systems. Specific focus
areas may include: enabling concepts and techniques for wide operability propulsion systems and variable speed drive systems/transmissions. Engine compressor stall control, engine flow control concepts for wide operability, cooling and secondary flow concepts for wide operability and integrated controls and modeling to support wide operability are sought. In addition, concepts for controlling and enabling variable speed drives, lightweight technologies and concepts and performance prediction capabilities for variable speed systems are sought.

Gearbox optimized propulsion systems in which both the engine and drive systems work together for improved performance. Specific concepts may include: dedicated gearbox lube systems coupled with oil-free engines; technologies to predict drive system windage losses and gear surface fatigue modeling; technologies to achieve lightweight propulsion such as composite propulsion structures and components; high power density electromechanical systems and efficient high power density propulsion concepts such as highly loaded components; engine flow control concepts; high temperature components; nano-composite components and other relevant propulsion system technologies. Propulsion system concepts must be focused on power range and operating environment required for rotorcraft.

**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. Rotor noise, including broadband, harmonic, blade-vortex interaction, high-speed impulsive; alternate tail rotor and auxiliary power concepts, rotor/tail rotor, and rotor/rotor interactional noise. 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.

**Aeroelasticity and Dynamics:** Advanced rotorcraft hub and blade concepts for improved stability and loads capability. High-fidelity, first-principles approaches to rotorcraft stability calculation, including finite state and reduced order aerodynamic modeling approaches. Vibration reduction methods and techniques, including utilization of on-blade active control, individual blade control, or nonrotating frame active and passive means.

**Aerodynamics:** Airloading of rotor blades, including unsteady, compressible, viscous flows and blade-vortex interaction; stall and dynamic stall; rotor wake formation, propagation, dissipation, and interactions; rotor wake geometry. Aerodynamics of rotorcraft airframes, including rotor hubs, airframe drag, rotor-airframe-wing interactions of tiltrotors and compound configurations. Performance, including force and power of isolated rotors and of rotorcraft systems with influence of interactions between components. Behavior of rotors and rotorcraft in maneuvers and high speed flight, and advanced configurations heavy lift and slowed-rotor rotorcraft. Advanced computational fluid dynamics methods, including turbulence behavior unique to rotary wings.
Flight Dynamics and Controls: Rotorcraft flight dynamics and handling qualities. Including hover and low-speed guidance and situational awareness augmentation; autorotation control and guidance; variable-speed rotor control; low-cost low-speed air data system; improved simulation of low-visibility conditions (e.g., brownout, whiteout); control concepts for redundant effectors; affordable tactile cueing for retrofit into civil rotorcraft; study of redundancy/reliability required to achieve low-cost single-pilot IFR certification; continuously-variable transmission (current technology is focused on discrete-speed, transmission, but continuously-variable is highly desirable; flight control mitigation of structure/power train/rotor frequency overlap with primary control frequencies; proprotor control to provide helicopter-like response in heave for tilt rotor helicopter-mode operations.

Experimental Capabilities: Instrumentation and techniques for assessing scale rotor blade boundary layer state (e.g., laminar, transition, turbulent) and/or profile in simulated hover and forward flight conditions, measurement systems for large-field rotor wake assessment, instrumentation and techniques to measure dynamic boundary layer transition on the fixed system (fuselage) during scale model wind tunnel testing, multi-parameter temporally-resolved flow diagnostic techniques for wind tunnel testing of model-scale rotors and engine acoustic testing, fast time response pressure sensitive paints, alternatives to conventional slip rings (e.g., optical slip rings, reliable telemetry methods), high temperature and pressure sensors for engine applications, high temperature proximity sensors for turbine blade clearance measurements, sensors and/or methods for high accuracy rotorcraft velocity measurement in very low speed forward flight.

Sub Topics:
Next Generation Air Transportation System - Airspace Topic A3.01
The primary goal of the NASA Next Generation Air Transportation System (NGATS) Airspace effort is to develop integrated solutions for a safe, efficient, and high-capacity airspace system. Of particular interest is the development of core capabilities, including: (1) Performance-based services, which will enable higher levels of performance in proportion with user equipage level; (2) Trajectory-based operations, which is the basis for changing the way traffic is managed in the system to achieve increases in capacity and efficiency; (3) Super-density operations, which maximizes the use of limited runways at the busiest airports; (4) Weather assimilated into decision making; (5) 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 NGATS-Airspace functions such as Dynamic Airspace Configuration, Traffic Flow Management, Separation Assurance, and the overarching Evaluator that integrates these air traffic management (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 NGATS-Airspace effort. The general areas of primary interest are Dynamic Airspace Configuration, Traffic Flow Management, and Separation Assurance. Specific research topics for NGATS-Airspace include:
Sub Topics:

Next Generation Air Transportation - Airportal Topic A3.02

The Airportal research of NASA’s Airspace Systems (AS) Program focuses on key capabilities that will increase throughput of the airportal environment and achieve the highest possible efficiencies in the use of airportal resources such as runways, taxiways, terminal airspace, and gates. The primary capabilities addressed are: (1) Super-density operations, (2) Equivalent visual operations, and (3) Aircraft trajectory-based operations.

Super-density operations will include conflict detection and resolution for closely spaced approaches, reduced aircraft wake vortex separation standards, and less restrictive run-way/taxiway operations. Additional mechanisms
to increase the feasible density of operations will also be considered.

Equivalent visual operations will provide aircraft with the critical information needed to maintain safe distances from other aircraft during non-visual conditions, including a capability to operate at "visual performance" levels on the airport surface during low-visibility conditions. Advances in equivalent visual operations for the airport air navigation service provider are also of interest.

Aircraft trajectory-based operations will utilize 4D trajectories (aircraft path from block-to-block, including path along the ground, and also including the time component) as the basis for planning and executing system operations.

NASA’s AS Program has identified the following Next Generation Air Transportation System (NGATS) Airportal research activities: Optimization of surface traffic; Dynamic airport configuration management (including the optimal balancing of airportal resources for arrival, departure, and surface operations); Predictive models to enable avoidance of wake vortex hazards; New procedures for performing safe, closely spaced and converging approaches at closer distances than are currently allowed; and modeling, simulation, and experimental validation research focused on single and multiple regional airports; and other innovative opportunities for transformational improvements in airportal/metroplex throughput. Inherent within the AS Program 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 NGATS-Airportal effort. The general areas of interest are surface management optimization, converging and parallel runway operations, safety risk assessment methodologies, and wake vortex solutions. Specific research topics for NGATS-Airportal include:

- Airborne spacing algorithms and wake avoidance procedures for airports with closely spaced runways;
- Automated separation assurance and runway/taxiway incursion prevention algorithms;
- Automatic taxi clearance and aircraft control technologies;
- Characterization of wake vortex and atmospheric hazards to flight in terms of aircraft and flight crew responses;
- Collaborative decision making between airlines and air traffic control tower personnel for optimized surface operations, including push back scheduling and management of airport surface assets;
- Dynamic airport configuration management;
- High resolution CFD and real-time modeling of wake vortex strength and location;
- Human/automation interaction and performance standards;
- Integration of decision-support tools across different airspace domains;
- Methodologies and/or algorithms to estimate environmental impacts of increased traffic on the surface and in the terminal airspace, and to reduce the environmental impacts under increased levels of traffic;
- Methodologies to estimate and assess the risk of transformational airspace operations for which little historical risk data may exist and for which operations may be constrained by the potential for extremely rare events;
- Modeling and simulation of single airport operations for validating taxi planning concepts;
- Optimized 4D trajectory generation and conformance monitoring for surface and terminal airspace operations, including departure and arrival planning for individual flights;
- Scheduling algorithm for aircraft deicing and integration with a surface traffic decision-support tool;
- Surface and terminal airspace traffic modeling and simulation of multiple regional airports;
- Virtual towers;
- Other technologies and approaches to achieving 2-3X improvement in the throughput of airportals/metroplexs.

Sub Topics:
Test Measurement Technology Topic A4.01
NASA is concerned with operating its ground test facilities with new and innovative methods for test measurement technology and with continually improving on the efficiency and effectiveness of operation of its ground test facilities. 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 technologies. By using state-of-the-art test measurement technologies, novel means of acquiring test data, test techniques and creative facility performance capability enhancements, 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 or overcome research and development technology barriers for ground test facilities.

The first 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: data acquisition system improvements; skin friction experimental measurement techniques; improved flow transition detection methodologies; new or novel, non-intrusive measurement technologies for pressure, temperature, and force measurements; and force measurement (balance) technology development. Solutions are also sought with regards to the instrumentation used to characterize ground test facility performance. This could be in the area of aerodynamics performance characterization (flow quality, turbulence intensity, etc.) or, for example, in the case of specialty facilities, the
The measurement of high ice water content conditions in an icing wind tunnel.

The second emphasis for this subtopic is in the area of test techniques and facility performance technologies. Examples of the types of technology solutions that are being sought, but not limited to, are expanded operating envelope, enhanced or rapid characterization of facility performance, improved dynamic (forced oscillation) test capability at transonic and supersonic speeds, and improved flow transition detection methodologies.

Proposals that lead to products or processes that are applicable specifically to the ATP facilities 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:
Test Techniques and Facility Development Topic A4.02
NASA is concerned with operating its flight test aircraft with new and innovative flight test measurement methods. By using state-of-the-art test measurement technologies and novel means of acquiring test data, NASA will be able to operate its flight test aircraft and test-beds more effectively and also meet the challenges presented by NASA’s cutting edge research and development programs. NASA’s missions and programs push the limits of technology which places greater demands on its flight test-beds. These flight test-beds are often used in conjunction with ground test facilities to confirm theory and provide verification and validation of new technologies. Therefore, NASA is seeking highly innovative and commercially viable test measurement technologies that would increase efficiency or overcome test limitations for flight research.

Flight test vehicles operate over a wide range of environmental conditions including among others: variable ambient pressure (the result of altitude changes), variable temperature (the result of altitude and airspeed changes), and vibration and acceleration (the result of engine vibration and dynamic flight maneuvers). In addition, weight, volume, and power requirements are at a premium because of limited space, power, and weight carrying capacity.

The first emphasis for this subtopic is in the area of flight test techniques. Factors in flight test techniques include, but are not limited to: methods for achieving accurate and repeatable flight test conditions (e.g., altitude, airspeed, flow quality, or turbulence intensity). Reconfigurable systems, alternative power sources, and novel methods for onboard data processing, storage, real-time access and RF data transmission are of interest. Technologies are also being requested to aid in multi-aircraft co-operative test techniques to enable chase aircraft to probe flow fields and visualize shock patterns around target aircraft.
The second emphasis for this subtopic is in the area of flight test measurement technology. Examples of the types of technology solutions sought are: data acquisition system improvements and miniaturization, skin friction experimental measurement techniques, and improved flow transition measurement techniques. Special emphasis is placed on new or novel, non-intrusive measurement technologies for pressure, temperature, and force measurements, and force measurement (balance) technology. Also, techniques that could facilitate shortening test measurement installation and setup times would be of interest such as methodologies that minimize the wiring infrastructure and other aircraft installation requirements would be applicable. Another area of interest is in test data conversions to different domains or data compression to reduce the volume of information that must be transmitted over existing telemetry links. It should be understood that all of these technologies must be capable of operating under extremes of temperature, pressure, and vibration typical in the flight environment.

Proposals that lead to products or processes that are applicable specifically to the ATP facilities and across multiple flight test-beds are especially important. Test-beds can be broadly categorized throughout a range of flight regimes encompassing hypersonic (e.g., orbital, sub-orbital, Phoenix missile), supersonic (e.g., F-15, F-16, F-18), and subsonic Fixed-Wing aircraft (e.g., ER2, G3, Predator-B). All platforms have a variety of different Mach/Altitude flight envelopes.

Sub Topics: