Aeronautics Research

Aviation Safety Topic A1

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

- Discovery of Precursors to Safety Incidents.
- Assuring Safe Human-Systems Integration.
- Prognostic Algorithm Design for Safety Assurance.
- Vehicle Health Assurance.
- Crew-System Interactions and Decisions.
- Loss of Control Prevention, Mitigation, and Recovery.
- Engine Icing.
- Airframe Icing.
- Atmospheric Hazard Sensing & Mitigation.

AvSP includes three research projects:

- The System-wide Safety Assurance Technologies Project provides knowledge, concepts and methods to proactively manage increasing complexity in the design and operation of vehicles.
- Air transportation systems, including advanced approaches to enable improved and cost-effective verification and validation of flight-critical systems.

The Vehicle Systems Safety Technologies Project identifies risks and provides knowledge to avoid, detect, mitigate, and recover from hazardous flight conditions, and to maintain vehicle airworthiness and health. The Atmospheric Environment Safety Technologies Project investigates sources of risk and provides technology needed to help ensure safe flight in and around atmospheric hazards. NASA seeks highly innovative proposals that will complement its work in science and technologies that build upon and advance the Agency’s unique safety-related research capabilities vital to aviation safety. Additional information is available at [http://www.aeronautics.nasa.gov/programs_avsafe.htm](http://www.aeronautics.nasa.gov/programs_avsafe.htm).

Sub Topics:

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

Lead Center: LaRC

Participating Center(s): AFRC, GRC
NASA is concerned with the prevention of encounters with hazardous in-flight conditions and the mitigation of their effects when they do occur. Hazardous flight conditions of particular interest are: wake vortices, clear-air turbulence, in-flight icing, lightning, and low visibility. NASA is interested in new and innovative methods for detection, identification, evaluation, and monitoring of in-flight hazards to aviation. In the case of lightning, interest is centered on the mitigation and in-flight measurement of lightning damage, particularly to composite aircraft.

NASA seeks to foster research and development that leads to innovative new technologies and methods, or significant improvements in existing technologies, for in-flight hazard avoidance and mitigation. Technologies may take the form of tools, models, techniques, procedures, substantiated guidelines, prototypes, and devices. Proposed products may be for retrofit into current aircraft or for installation in future aircraft. Both manned and unmanned aircraft are of interest.

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

Under this subtopic, proposals are invited that explore new and improved sensors and sensor systems for the detection and monitoring of hazards to aircraft before they are encountered. With regard to hazardous lightning conditions, the emphasis is not on remote detection, but rather on developing systems that make aircraft more robust in a lightning environment or provide in-flight damage assessment or other hazard mitigating benefits. The scope of this subtopic does not include human factors and focused development of human interfaces, including displays and alerts. Primary emphasis is on airborne applications, but in some cases the development of ground-based sensor technology may be supported. Approaches that use multiple sensors in combination to improve hazard detection and quantification of hazard levels are also of interest.

Areas of particular interest to NASA at this time are described in more detail below. The list and details are provided as encouragement but are not intended to exclude other proposals that fit the scope of this subtopic.

**Turbulence and Wake Vortex**

- **Remote detection of kinetic air hazards** - The class of hazards including wake vortices, turbulence, and other hazards associated with air motion is referred to as kinetic air hazards. Within this class, wakes and turbulence are the highest priorities; however, NASA is particularly interested in sensor systems that can detect multiple hazards and thus provide greater utility. For example, air data systems are at times disabled by icing, and a multi-function, multi-hazard sensor that includes a robust alternative air data source would be a great asset in such conditions.

- **Airborne detection of wake vortices** - Airborne detection of wake vortices is considered challenging due to the fact that detection must be possible in nearly all weather conditions, in order to be practical, and because of the size and nature of the phenomena. In particular, NASA is interested in the ability to detect and measure wake vortex hazards for arbitrary viewing angles.

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

Lightning

- **Lightning Strike Protection** - NASA is investigating means for mitigating damage to aircraft, with a particular interest in protecting composite aircraft. Currently, an electrically-conductive screen protects composite aircraft by functioning as a Faraday shield and is intended to confine lightning and electromagnetic effects to the outside or outermost skin of the aircraft. The lightning strike protection system, hereafter referred to as the LSP, is incorporated in the coatings, layers, and structure that comprise the skin of the aircraft. NASA is most interested in LSP solutions that will be cost effective and light-weight.

- **Mitigation of lightning strike damage** - NASA is seeking solutions that will provide better protection from lightning damage by directing attachment points or lightning currents to safe or less hazardous areas and by reducing the susceptibility of the aircraft to thermal or other damage due to strikes.

- **In-flight lightning damage measurement and assessment** - A typical commercial aircraft is struck by lightning about once per year. At this time, composite aircraft that are struck in-flight are inspected upon landing for a damage assessment. Such assessments may be time-consuming and difficult. Innovations that will provide a measurement or damage detection system in the LSP are solicited. The objective would be to achieve a capability to have damage detection and assessment capability in the aircraft that will provide immediate information to the flight crew after a lightning attachment.

### A1.02 Inflight Icing Hazard Mitigation Technology

**Lead Center: GRC**

NASA is concerned with the prevention of encounters with hazardous in-flight conditions and the mitigation of their effects when they do occur. Under this subtopic, proposals are invited that explore new and dramatically improved technologies related to inflight airframe and engine icing hazards for manned and unmanned vehicles. Technologies of interest should address the detection, measurement, and/or the mitigation of the hazards of flight into supercooled liquid water clouds and flight into regions of high ice crystal density. With these emphases in mind, products and technologies that can be made affordable and capable of retrofit into the current aviation system and aircraft, as well as for use in the future are sought.

Areas of interest include, but are not limited to:

- **Non-destructive 3-D ice density measurements of ice accretions on wind tunnel wing models.** NASA has a need for non-optical methods to digitize ice shapes with rough external surfaces and internal voids as can occur with accretions on highly swept wings for comparison to computational simulations. Current methods based upon scanning with line-of-sight, visible-spectrum digitization methods have been found inadequate for many of these very complex ice shapes.
Remote and in-situ technologies that can accurately quantify the super-cooled liquid water environment in the volume surrounding an airport. Of primary interest are remote sensing technologies that can, by themselves or with other instruments, quantify the temperature, liquid water content, and cloud droplet size spectrum to allow the production of a 3-D icing hazard map of the terminal airspace. Low-cost, expendable in-situ instruments are also of interest for validating and calibrating these remotely sensed measurements.

A1.03 Flight Deck Interface Technologies for NextGen

Lead Center: LaRC

Public benefits derived from continued growth in the transport of passengers and cargo are dependent on the improvement of the intrinsic safety attributes of current and future air vehicles that will operate in NextGen. The Aviation Safety Program (AvSP) is addressing this challenge by conducting cutting-edge fundamental and applied research that will yield innovative algorithms, tools, concepts and technologies from the discipline level up to the subsystem and system level. As a part of the AvSP, the Vehicle System Safety Technology (VSST) Project has initiated a Technical Challenge (TC) toward the improvement of Crew Decision-Making and response in complex situations (CDM), in current-day and NextGen operations.

To address this TC, NASA seeks innovative flight deck interface research and technology that address the following major topic areas:

- The flight crew's needs for situation awareness/information in current-day and emerging NextGen operations. Research and technology development focused on novel display technologies and display methods that allow for new means of NextGen information portrayal and creating visual and aural interface methods to provide hazard and aircraft state awareness and protection during terminal maneuvering area operations.

- The development of flight deck interface technologies that assure pilot awareness and appropriate engagement (balancing awareness and workload) in current-day and emerging NextGen operations. Research and technology development to proactively address the potential impact of changing roles and responsibilities between the Air Navigation Services Providers (ANSP) and pilots as well as between the human and automation, and the robustness of these interfaces when responding to unexpected events.

- Integrated information management systems that assure the information needed by flight crews to make critical decisions is complete and not misleading. Research and technology development to better manage flight deck information during NextGen "Net-Centric" operations without overloading or underwhelming the operators/users.

- Understanding demographics and proficiency that impact human (pilot) decision-making. Research and technology development which addresses emerging pilot demographics and pilot proficiency standards to improve pilot decision-making and interactions with other human and automation
A1.04 Vehicle Level Diagnostics

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

This SBIR subtopic augments on-going activities in the Vehicle Systems Safety Technology (VSST) project within NASA’s Aviation Safety Program. Specifically, this subtopic addresses the “Maintain Vehicle Safety between Major Inspections” (MVS) technical challenge. The MVS technical challenge concentrates on capabilities to maintain vehicle safety between major inspection intervals with an emphasis on the subsystems of airframe, avionics, and propulsion. NASA is seeking proposals to combine information from, and within, the various subsystems to perform overall vehicle level diagnostics. The objective of this work is to provide an infrastructure to assess the health state of aircraft though the integration of full vehicle sensors and diagnostic information. Partnering with organizations that can provide relevant data is encouraged.

A1.05 Data Mining and Knowledge Discovery

Lead Center: ARC

The fulfillment of the SSAT project's goal requires the ability to transform vast amounts of data produced by aircraft and associated systems and people into actionable knowledge that will aid in detection, causal analysis, and prediction at levels ranging from the aircraft-level, to the fleet-level, and ultimately to the level of the national airspace. For this topic, we are especially interested in automated discovery of previously unknown precursors to aviation safety incidents involving human - automation interaction. We expect to gain knowledge on latent deficiencies in crew training, communication, and operations that is of paramount importance to future SSAT project goals and objectives. The incorporation of human performance will be invaluable to the success of this effort, and as such it will be important to use heterogeneous data from varied sources that are matched on a per-flight basis with flight-recorded data, such as radar track data, airport information, weather data, flight crew schedule information, maintenance information, and Air Safety Reports. This topic will develop revolutionary and first-of-a-kind methods and tools that incorporate the limitations of human performance throughout the design lifecycle of human-automation systems to increase safety and reduce validation costs in NextGen.

The focus of this effort will be on the fleet level or above. As such, the successful proposal will develop validated data mining and machine learning based methods to uncover systemic human-automation interaction issues that manifest at a much broader level than those incidents that occur within a single flight or for a single aircraft. Simulated data that is representative of the interactions between humans and automation found on flight systems and on data from real world aircraft and supporting ground-based systems should be used. The total of the data set under study should be at least 10 TB in size, and exhibit appropriate statistical and operational complexities found in real world human automation interactions. Furthermore, a deep knowledge of human-automation interaction from the human-factors perspective as well as the ability to create novel machine learning and data mining algorithms should be clearly demonstrated.

A1.06 Assurance of Flight-Critical Systems

Lead Center: ARC
Participating Center(s): LaRC

The purpose of this subtopic is to invest in mid- and long-term research to establish rigorous, systematic, scalable, and repeatable verification and validation methods for flight-critical systems, with a deliberate focus on safety for NextGen (http://www.ipdo.gov [2]). This subtopic targets NextGen safety activities and interests encompassing vehicles, vehicle systems, airspace, airspace concept of operations, and air traffic technologies, such as communication or guidance and navigation. Methods for assessing issues with technology, human performance and human-systems integration are all included in this sub-topic, nothing that multi-disciplinary research is required that does not focus on one type of component or phenomenon to the exclusion of other important drivers of safety.

Proposals are sought for the development of:

- Safety-case methods and supporting technologies capable of analyzing the system-wide safety properties suitable for civil aviation vehicles and for complex concepts of operation involving airborne systems, ground
systems, human operators and controllers.

- Technologies and mathematical models that enable rigorous, comprehensive analysis of novel integrated, and distributed, systems interacting through various mechanisms such as communication networks and human-automation and human-human interaction.
- Techniques, tools and policies to enable efficient and accurate analysis of safety aspects of software-intensive systems, ultimately reducing the cost of software V&V to the point where it no longer inhibits many safety innovations and NextGen developments.
- Tools and techniques that can facilitate the use of formal methods in V&V throughout the lifecycle such as graphical-based development environments (e.g., eclipse plug-ins for static analyzers, model checkers, or theorem provers) or tools facilitating translation from design formats used in industry to formal languages supporting automated reasoning.

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

In Phase II, a functional system shall be delivered to NASA for its retention and ownership.

Air Traffic Management Research and Development (ATM R&D) Topic A2

Air Traffic Management Research and Development (ATM R&D) NASA has two Programs conducting ATM R&D. The Airspace Systems Program (ASP) is investing in the development, validation and transfer of advanced innovative concepts, technologies and procedures to support the development of the Next Generation Air Transportation System (NextGen). The Integrated Systems Research Program (ISRP) is conducting research at an integrated system-level on promising concepts and technologies and exploring, assessing or demonstrating their benefits in a relevant environment. All the investments include coordination with other NASA Programs and partnerships with other government agencies and joint activities with the U.S. aeronautics industry and academia.

ASP develops and demonstrates future concepts, capabilities, and technologies that will enable major increases in air traffic management effectiveness, flexibility, and efficiency, while maintaining safety, to meet capacity and mobility requirements of NextGen. ISRP explores and assesses new vehicle concepts and enabling technologies through system-level experimentation and focuses specifically on maturing and integrating technologies in major vehicle systems/subsystems for accelerated transition to practical application. One of ISRP's projects is the Unmanned Aircraft Systems (UAS) Integration in the National Airspace System (NAS). The project's primary goal is to address technology development in five areas to reduce the technical barriers related to the safety and operational challenges of routine UAS operations in the NAS. These areas include seamless integration of separation assurance/sense and avoid interoperability, evaluating the workload impact to human UAS operators, demonstration of secure UAS command and control datalink, document requirements for and to create an appropriate test environment for evaluating UAS concepts.

The A2 topic area solicits concepts that can reduce the technical barriers related to the safety and operational challenges of routine UAS operations in the NAS.

Proposers interested in developing and validating innovative ATM concepts, technologies, and procedures to support the Next Generation Air Transportation System (NextGen) should refer to Select Topic E2.01, Air Traffic Management Research and Development.
A2.01 Unmanned Aircraft Systems Integration into the National Airspace System Research

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

The following subtopic is in support of the Unmanned Aircraft Systems (UAS) Integration in the National Airspace System (NAS) Project under the Integrated Systems Research Program (ISRP). There is an increasing need to fly UAS in the NAS to perform missions of vital importance to National Security and Defense, Emergency Management, Science, and to enable commercial applications. The UAS Integration in the NAS Project is structured under the following technical challenges:

- **Airspace Integration** - validate technologies and procedures for UAS to remain an appropriate distance from other aircraft, and to safely and routinely interoperate with NAS and NextGen Air Traffic Services (ATS).
- **Standards/Regulations** - validate minimum system and operational performance standards and certification requirements and procedures for UAS to safely operate in the NAS.
- **Relevant Test Environment** - develop an adaptable, scalable, and schedulable relevant test environment for validating concepts and technologies for UAS to safely operate in the NAS. The Federal Aviation Administration (FAA) regulations are built upon the condition of a pilot being in an aircraft.

There exist few, if any, regulations specifically addressing UAS today. The primary user of UAS to date has been the military. The technologies and procedures to enable seamless operation and integration of UAS in the NAS need to be developed, validated, and employed by the FAA through rule making and policy development.

The Project goal is to capitalize on NASA's unique capabilities and competencies by utilizing integrated system level tests in a relevant environment to eliminate or reduce critical technical barriers of integrating UAS into the NAS. The project is further broken down into five subprojects: Separation Assurance/Sense and Avoid Interoperability (SSI); Communications; Human Systems Integration; Certification; and Integrated Test and Evaluation. The fifth sub-project, Integrated Test and Evaluation, is responsible for developing a live, virtual, and constructive test environment for the other four subprojects. The first phase of the project includes the following:

- Conduct initial modeling, simulation, and flight testing.
- Complete early subproject-focused deliverables (spectrum requirements, comparative analysis of certification methodologies, etc.).
- Validate the key technical elements identified by this project.

The second phase includes the following:

- Conduct systems-level, integrated testing of concepts and/or capabilities that address barriers to routine access to the NAS.
- Provide methodologies for development of airworthiness requirements and data to support development of certification standards and regulatory guidance.
• Develop a body of evidence (including validated data, algorithms, analysis, and recommendations) to support key decision makers in establishing policy, procedures, standards and regulations, enabling routine UAS access in the NAS.

This solicitation seeks proposals, but is not limited, to develop:

• **Certified control and non-payload communications (CNPC) system** - Current civil UAS operations are significantly constrained by the lack of a standardized, certified control and non-payload communications (CNPC) system. The UAS CNPC system is to provide communications functions between the Unmanned Aircraft (UA) and the UA ground control station for such applications as: telecommands; non-payload telemetry; navigation aid data; air traffic control (ATC) voice relay; air traffic services (ATS) data relay; sense and avoid data relay; airborne weather radar data; and non-payload situational awareness video. New and innovative approaches to providing terrestrial and space-based high-bandwidth CNPC systems that are inexpensive, small, low latency, reliable, and secure offer opportunities for quantum jumps in UAS utility and capabilities. Of particular interest are:
  - Technologies for High power C-band amplifiers and highly linear C-band power amplifiers/linearization of high power C-band amplifiers.
  - Miniaturization of C-band radio components/systems.

• **A Synthetic Vision System for a ground control station (GCS)** - Integration of display technology that presents the visual environment external to the unmanned aircraft using computer-generated imagery in a manner analogous to how it would appear to the pilot in a manned aircraft. A synthetic vision system displays critical features of the environment external to the aircraft through a computer-generated image of the external scene topography using terrain and obstacle databases. Several research and technological developments have made synthetic vision systems possible. Fundamentally, these systems require only precise ownship location, a database, available graphics and computing capability and display media. In terms of safety benefits, synthetic vision may help to reduce many accident precursors including: Loss of awareness of vertical/ lateral path, terrain traffic, etc. Operational benefits may include transition from instruments to visual flight, non-normal and emergency situations, virtual visual self-spacing and station keeping capability, etc. SVS have been extensively studied and there is a vast body of knowledge on their application to manned aviation. Special interest is in the integration of a SVS into a UA ground control station to support operator in the loop, sense and avoid (SAA) functions for UAS operations in the NAS. Guidelines for sense and avoid requirements and functions are currently being developed by standards organizations (e.g., RTCA SC-203) and the FAA.

• **Weather information systems for GCS** - On-board, real-time graphic aviation weather information products have been developed and successfully implemented for manned cockpits. Their use is now widespread and their safety impact widely recognized. The applicability of such products for operators and ground control pilots to enhance situation awareness and improve mission planning and execution is of interest to NASA. Systems such as the NASA developed Aviation Weather Information (AWIN) system that included software, data and data-link applications, color weather graphics such as composite-radar mosaic, lightning-strike data, wind data, satellite images and forecasts could be integrated into a ground control station to provide pilots with weather awareness before and during mission execution. Improved weather awareness should allow aircrews to avoid most weather-related problems through both pre-flight and en-route planning. While the use of these systems has been explored for military UAS operations, their applicability to civil and public operations has not yet been explored.

• **Operator Displays for Sense and Avoid Systems** - While guidelines for the integration of UAS operations in the NAS are being developed new SAA systems are being designed to provide the ground control pilot with situation awareness and the ability to execute required ATC procedures. SAA systems provide UAS with the capability to avoid collisions and remain well clear of other aircraft by means of sensor systems and equipment specifically designed for this purpose. SAA systems consist of surveillance sensors, data communications, threat detection and/or resolution logic and the display of traffic information and/or resolution guidance/advice. Of interest is the development of display technologies to enable ground control
pilots to participate in any phase of the SAA process as indicated by operator procedures. These new technologies should utilize the vast experience and body of knowledge developed over the years for airborne/ground separation assurance systems, TCAS displays, and cockpit displays of traffic information. In addition, these new displays will exhibit unique and very challenging new problems associated with the nature of unmanned systems as well as the communication latencies and potential safety risks of failure conditions. Human factors considerations should be applied in the design of these systems.

- **Lost Communication Link Procedures and Operations** - The procedures followed by unmanned aircraft and their pilots when the command and control link is lost with the ground station are not standardized and frequently do not take into account ATC regulations. Each UAS appears to have custom-designed procedures for "lost link" despite the existence of well-established rules for pilots to follow when communication capability is lost. Research should establish a desired set of procedures to be followed that parallel the existing requirements, but departing from those where necessary to meet critical safety considerations. These procedures may be codified in technologies used by the unmanned aircraft or the pilot in the ground control station to maximize the predictability of the UAS' actions from an ATC perspective.

- **Safety Analysis and Methodologies** - UAS operations are untried in the civil NAS. Unlike other aircraft, there is not an extensive record of civil operations upon which to forecast the safety of UAS operations in the NAS. The introduction of UAS into the NAS raises many safety issues and concerns. Typically, anytime a new capability is added into the NAS, an Operational Safety Assessment (OSA) is performed by the FAA, to determine whether that introduction of new capability will enhance or detract from the safety of the NAS. As these UAS represent a wholly new operational system, traditional approaches cannot suffice. Research is needed to identify and develop new safety analysis approaches, as well as prognostic indicators and potential new safety metrics.

**Air Vehicle Technologies Topic A3**

The Vehicle Systems Technology topic solicits cutting-edge research in aeronautics to overcome technology barriers and challenges in developing highly efficient aircraft systems of the future, with limited impact to the environment. The primary objective is the development of innovative design tools, capabilities and technologies that provide design and system solutions and capabilities to meet the national goals in cleaner environment, reduced noise and highly energy efficient and revolutionary aircraft for the next generation (NextGen) air transportation system.

This topic solicits physics-based, multidisciplinary design, analysis and optimization tools and capabilities to facilitate assessment of new vehicle designs and their potential performance characteristics. These tools and capabilities will enable the best design solutions to meet the performance and environmental requirements and challenges, and technology innovations of future air vehicles. It also solicits research in revolutionary aircraft concepts; lightweight high strength structures and materials; more efficient propulsion systems; advanced concepts for high lift and low drag aircraft that meet the performance, efficiency and environmental requirements of future aircraft, and the goals of NextGen.

Beginning in FY12, this topic covers aircraft technologies formerly covered by the Fundamental Aeronautics topic
as well as ground and flight test technologies formerly covered by the Aeronautics Test topic. The re-structuring will emphasize development of tools, technologies, test techniques, and knowledge to meet metrics derived from a definitive set of Technical Challenges responsive to the goals of the National Aeronautics Research and Development Plan (2010) and the NASA Strategic Plan (2011).

- **Fixed Wing Vehicles** - Technologies and concepts for subsonic transport aircraft, propulsion system energy efficiency and environmental compatibility supported by enabling tools and methods. Targeted challenges include drag and weight reduction for fuselages and high aspect ratio wings, quiet high performance high-lift and propulsion systems, high performance clean, alternative-fuel burning gas generators, paradigm-changing hybrid-electric propulsion systems, innovative propulsion-airframe integration concepts.

- **Rotary Wing Vehicles** - Advanced Efficient Propulsion (multi-speed lightweight rotorcraft drive trains and variable speed efficient engines), Advanced Concepts and Configurations (aerodynamically efficient rotorcraft, NextGen configurations, and multi-fidelity design and analysis tools), and Community and Passenger Acceptance (NextGen operations and standards, and comfort and safety).

- **High Speed** - Focused on supersonic research, design, and boom mitigation techniques to achieve low boom strength and other elements that will help enable a low-boom experimental aircraft; System Integration Assessment; Supersonic Cruise Efficiency - Propulsion; Supersonic Cruise Efficiency-Airframe; Sonic Boom Modeling; and Jet Noise Research.

- **Aeronautical Sciences** - Broad, cross-cutting discipline research (e.g., some CFD and structures & materials research) that is pervasive across flight regimes, helps develop some low-level concepts and ideas, and provides program-level systems analysis capability to assess balance and impact of program-wide investments.

- **Aeronautics Test Technologies** - Focused on instrumentation, test measurement technology, test techniques, and facility development that apply to NASA aeronautics facilities to help in sustaining and improving our test capabilities at four NASA Centers: Ames Research Center, Dryden Flight Research Center, Glenn Research Center, and Langley Research Center. Classes of facilities include low speed, transonic, and supersonic wind tunnels, air-breathing engine test facilities, the Western Aeronautical Test Range (WATR), support and test bed aircraft, and simulation and loads laboratories.

Sub Topics:

**A3.01 Structural Efficiency - Airframe**

**Lead Center: LaRC**

**Materials and Structural Concepts for Aeroelastically-Tailored Aircraft Wings**

The Fixed Wing and High Speed projects are focused on development of enabling technologies and advanced concepts for subsonic and supersonic cruise transport category aircraft, respectively, demonstrated to TRL 4-6 in the 2025 time frame. Both projects require simultaneous reduction of weight and drag to achieve their respective performance objectives. For subsonic transport aircraft, lift-induced drag is approximately 40% of the total drag at cruise and can be directly addressed via increased wing aspect ratio. For supersonic flight, speed requirements dictate highly swept wings with a very thin airfoil section. Both of these wing geometries, with higher aspect ratio or thinner airfoil section, result in more flexible structure that can exhibit aeroelastic instability and thus require more complicated aeroelastic design, analysis and control. The traditional solution to these aeroelastic issues has been primarily to stiffen the wing by adding additional structure, thus creating a weight penalty. Solutions that favorably modify the aeroelastic response of thin or high aspect ratio wings with no or little weight increase are needed.
Furthermore, maneuverability of the vehicle is dependent upon the control authority achievable by wing-located control surfaces in traditional aircraft designs, and possibly actively tailorable portions of wings in more integrated aircraft designs. Designing the wing to have desired aeroelastic characteristics makes the wing amenable to minimal-input active control solutions to further modify the aeroelastic response. Using a building block approach in this research topic, the current solicitation focuses on materials and structural concepts for aeroelastically-tailored aircraft wings, while the more complex aeroservoelastic solution will be the subject of a future solicitation.

This solicitation topic seeks innovative materials and/or structural concepts and technologies for lightweight wings with aeroelastic tailoring, such as tailored bending and torsional stiffness as an example. Proposals should involve novel materials, processes and structural concepts with significant potential to improve the structural efficiency and reduce specific weight. Laboratory scale approaches may be proposed for proof of concept, but must be scalable to application across a broad range of fixed wing aircraft sizes and speeds.

Tailored stiffness may include spatial or temporal variations in stiffness achieved by a combination of passive stiffness tailoring of anisotropic or functionally graded materials, novel structural topologies, or active integrated elements to change structural and/or material properties. The use of existing design and analysis tools and techniques to the greatest extent possible is encouraged, as it is not the intent of this solicitation to develop new computational tools. Specifically, the following concepts and technologies are sought:

- Materials and processing routes to fabricate engineered materials with tailored material properties along all three axes.
- Aeroelastically-tailored structural concepts by which desired static or dynamic aeroelastic responses can be achieved.

Phase I: Identify candidate material systems and structural concepts that enable aeroelastic tailoring of wing structure for reduced weight, for example, variable bending and torsional stiffness. Assess the feasibility and benefits of the proposed concept, including scale-up, necessary material property quantification, and design trade studies. The studies must include quantification of expected structural weight benefits. Identify limiting factors and recommendations for further technology development to address the shortfalls. For novel material systems and structural concepts requiring development, conduct initial proof of concept computational studies and/or element tests.

Phase II: Perform scale-up of materials and processes as necessary, and produce a detailed structural design and hardware build of a subscale wing suitable for laboratory testing to assess structural performance of the concept. Structural testing of the subscale wing will be performed subsequently by NASA and is beyond the scope of the Phase II effort.
Innovative technologies and methods are necessary for the design and development of efficient, environmentally acceptable aircraft. In support of the Fundamental Aeronautics Program, improvements in noise prediction, measurement methods and control are needed for subsonic, transonic and supersonic vehicles targeted specifically at airframe noise sources and the interaction of airframe and engine noise. Innovations in the following specific areas are solicited:

- Fundamental and applied computational fluid dynamics techniques for aeroacoustic analysis, which can be adapted for design codes.
- Prediction of aerodynamic noise sources including those from airframe and sources which arise from significant interactions between airframe and propulsion systems.
- Prediction of sound propagation from the aircraft through a complex atmosphere to the ground. This should include interaction between noise sources and the airframe and its flow field.
- Innovative source identification techniques for airframe (e.g., landing gear, high lift systems) noise sources, including turbulence details related to flow-induced noise typical of separated flow regions, vortices, shear layers, etc.
- Concepts for active and passive control of aeroacoustic noise sources for conventional and advanced aircraft configurations, including adaptive flow control technologies, and noise control technology and methods that are enabled by advanced aircraft configurations, including integrated airframe-propulsion control methodologies.
- Development of synthesis and auditory display technologies for subjective assessments of aircraft community and interior noise, including sonic boom.

A3.03 Low Emissions/Clean Power

Lead Center: GRC

Proposals are sought which support electric propulsion of transport aircraft, which includes various hybrid electric concepts, such as gas turbine engine-battery combinations and turboelectric propulsion (turbine prime mover with electric distribution of power to propulsors). Turboelectric propulsion for aircraft applications will require high specific power (hp/lb or kW/kg) and high efficiency components. Cryogenic and superconducting components will be required to achieve high specific power and high efficiency. The cryogenic components include fully superconducting generators and motors (i.e., superconducting stators as well as rotors), cryogenic inverters and active rectifiers, and cryocoolers. Proposals related to the superconducting machines may include aspects of the machines themselves as well as low AC loss superconducting materials for the stator windings. Generators with at least 10 MW capacity and motors of 2 to 3 MW capacity are of interest. Technology is sought that can contribute to superconducting machines with specific power more than 10 hp/lb. Superconducting wires with filaments less than 10 micrometers in diameter are of interest. Ideas are also sought for achieving 2-3X increase in specific power for non-cryogenic motors through a multidisciplinary approach utilizing advanced motor designs, better materials, and new structural concepts. Ideas are also sought to address challenges related to high voltage power transmission in future hybrid electric aircraft. New modeling and simulation tools for hybrid electric aircraft propulsion systems are also of interest.
The challenge of energy-efficient flight has at its foundation aerodynamic efficiency, and at the foundation of aerodynamic efficiency is low drag. Drag can be broadly decomposed into four components: viscous or skin friction drag, lift-induced drag, wave or compressibility drag, and excrescence drag due to various protruding items such as antennae, wipers, lights, etc. The relative impact of these four forces depends upon the targeted flight regime and vehicle-specific design requirements. The first force, however, viscous skin friction, stands out as particularly significant across most classes of flight vehicles and effective measures for its control would have a major impact on flight efficiency. In particular, supersonic, low-boom flight and new generations of energy-efficient subsonic transport airplanes including high L/D strut-braced designs, the blended wing body (BWB), the so called "double-bubble" designs and other concepts with large expanses of surface area would benefit from effective viscous drag control.

Viscous skin friction can be classified as either laminar or turbulent. While the laminar case and its attendant laminar flow control (LFC) techniques remain important scientific and technological disciplines, the goal of high Reynolds number flight efficiency requires that the turbulent case receive renewed attention. In place of the first-principles-derived theoretical framework of the laminar flow stability problem, in the turbulence case we have a wide collection of experimental observations, data correlations, various CFD approaches requiring turbulence closure models and, at low Reynolds numbers, full direct numerical simulation of the Navier-Stokes equations (DNS). While such experimental and CFD-derived knowledge, has greatly increased our understanding of turbulent boundary layer physics over the past decades, key relationships between wall layer and outer layer dynamics essential to a full understanding remain to be identified and verified.

Inadequacies in our understanding of boundary layer turbulence increase reliance upon a more qualitative, physics-guided approach to discovery. For example, the experimental observation of reduced skin friction in the corners of triangular cross-section pipes led to the discovery of drag-reducing V-groove riblets (subsequently also associated with the skin of certain shark species). The quasi-periodic, low-speed streak structures observed in the near-wall layer of turbulent boundary layers led to the implementation of mechanically controlled spanwise waves or lateral oscillations of the wall to disrupt the processes associated with low speed streak bursting. Similar observations have either been made or suggested with respect to the stabilizing influence of convex and in-plane curvature; long length-to-diameter ratio particulates; passive, active and reactive wall motion; manipulation of the wall layer by various geometrical devices (e.g., vortex generators (VG) and large eddy breakup devices (LEBU)), and various weakly ionized gas (WIG) and magnetohydrodynamic/electrohydrodynamic (MHD/EHD) concepts. This solicitation is offered in this spirit of innovation based on experimental or computational observations guided by a basic, though not necessarily complete, physical understanding of the turbulent processes.

In order to stimulate innovation in the area of turbulent viscous drag reduction, proposals are sought subject to the following guidelines:

- Proposals shall address passive, active, or reactive concepts for external, attached, fully developed, turbulent boundary layer viscous drag reduction in air.
- Experimental, hardware-based proposals and theoretical/computational proposals based on realizable hardware are preferred.
- All practical physical concepts are acceptable including but not limited to: mechanical/electro-mechanical
actuators, weakly-ionized-gas (WIG) concepts, laser/microwave energy deposition, MHD/EHD devices, surface microstructure/geometry, embedded mechanical devices (VG's, LEBU's), wall mass transpiration, heat transfer, wall motion, wall curvature effects and pressure gradient (vehicle shaping).

- Significant enhancements or refinements of existing concepts and technologies are acceptable.
- First order assessment or technically plausible discussion of any net system energy saving claims shall be provided.
- Proof-of-concept experimental demonstrations are encouraged for Phase I where applicable but are not required.
- Target conditions are flight-relevant Reynolds numbers at either high subsonic (0.7<M<0.9) or low supersonic (M<~3) speeds. Proposals at lower Mach and Reynolds numbers shall provide discussion of a developmental path towards flight-relevant conditions but not necessarily inclusive of actual flight.

A3.05 Controls/Dynamics - Propulsion Systems

Lead Center: GRC
Participating Center(s): AFRC

Propulsion controls and dynamics research is being done under various projects in the Fundamental Aeronautics Program (FAP). For turbine engines, work on Distributed Engine Control (DEC) and Model-Based Engine Control (MBEC) is currently being done under the Subsonic Fixed Wing (SFW) project, and Active Combustion Control research is currently being done under the Supersonics (SUP) project. These 3 efforts are expected to transition to the new Aeronautics Sciences (AS) project in FY13. Aero-Propulsion-Servo-Elasticity (APSE) research will continue under the SUP project. Research activity on Controls/Dynamics for electric propulsion systems is expected to be initiated in FY13 under the reformulated Fixed Wing (FW) project. Propulsion control and dynamics technologies that help achieve the goals of FAP, in terms of: reducing emissions; increasing fuel efficiency; tool and technology development and validation to address challenges in High Speed flight; and enabling fast, efficient design and analysis of advanced aviation systems, are of interest. Proposed activities that are compatible with current propulsion controls and dynamics activities supported by the FAP will be given preference. Following technologies are of specific interest:

- **High Efficiency Robust Engine Control** - Typical current operating engine control logic is designed using SISO (Single Input Single Output) PI (Proportional+Integral) control. The control logic is designed to provide minimum guaranteed performance while maintaining adequate safety margins throughout the engine operating life. Additionally, the control logic provides control of variables of interest such as Thrust, Stall Margin etc. indirectly since these variables cannot be measured or are not measured in flight because of restrictions on sensor cost/placement/reliability etc. All this results in highly conservative control design with resulting loss in efficiency. NASA is currently conducting research in Model-Based Engine Control (MBEC) where-in an on-board real-time engine model, tuned to reflect current engine condition, is used to generate estimate of quantities of interest that are to be regulated or limited and these estimates are used to provide direct control of Thrust etc. Alternate methods such as Model Predictive Control, Adaptive Control, direct non-linear control, etc. which will achieve the same objectives as the current MBEC approach while providing practical application of the control logic in terms of operation with sensor noise, operation across varying atmospheric conditions, operation across varying engine health condition over the operating life, and real-time operation within engine control hardware limits, are of interest. The emphasis is on practical application of existing control methods rather than theoretical derivation of totally new concepts. Control design approaches that can accommodate small to medium engine component faults and can still provide desired performance with safe operation are of special interest. The pre-requisite for proposals for engine
control design methods is that the NASA C-MAPSS40k (Commercial Modular Aero-Propulsion System Simulation for 40,000 lb class thrust engine) be used for control design and evaluation. This simulation can only be used by U.S. citizens since it is subject to export control laws. Methods for real-time engine parameter identification using flight data are also of interest by themselves.

- **Distributed Engine Control** - Current engine control architectures impose limitations on the insertion of new control capabilities primarily due to weight penalties and reliability issues related to complex wiring harnesses. Obsolescence management is also a primary concern in these systems because of the unscheduled cost impact and recertification issues over the engine life cycle. NASA in collaboration with AFRL (Air Force Research Lab) has been conducting research in developing technologies to enable Distributed Engine Control (DEC) architectures. The current need is to develop a DEC test-bed which can be used to investigate a wide range of issues such as system robustness, stability and performance of various DEC architectures, the development of network communications requirements, network performance evaluation, robustness of DEC architectures to data transmission faults and impact on system performance. The tools just described must be compatible with the NASA C-MAPSS40k simulation software and easily integrated into the Hardware-in-the-Loop research facility currently being developed under a separate contract. Restrictions on access to these technologies require that any proposed effort will be limited to work being done by U.S. citizens.

- **Active Combustion Control** - The overall objective is to develop all aspects of control systems to enable safe operation of low emissions combustors throughout the engine operating envelope. Low emission combustors are prone to thermo-acoustic instabilities. So far NASA research in this area has focused on modulating the main or pilot fuel flow to suppress such instability. Advanced, ultra-low emissions combustors utilize multi-point (multi-location) injection to achieve a homogeneous, lean fuel/air mixture. There is new interest in using precise control of fuel flow in such a manner as to suppress or avoid thermo-acoustic instabilities. Miniature fuel metering devices (and possibly also fuel flow measurement devices) are needed that can be physically distributed to be close to the multi-point fuel injector in order to enable the control system to accurately place a given portion of the overall fuel flow to each of the fuel injection locations.

- **Aero-Propulso-Servo-Elasticity (APSE)** - The objective of NASA research effort in APSE is to develop a comprehensive dynamic propulsion system model that can be utilized for thrust dynamics and integrated APSE vehicle controls and performance studies, like vehicle ride quality and vehicle stability under typical vehicle maneuvering and atmospheric disturbances, for supersonic vehicles. Innovative approaches to dynamic modeling of supersonic external compression inlets; parallel flow path modeling of the compression and whole propulsion system to accurately model the distortion effects of flexible modes, maneuvering and atmospheric disturbances; and integration of dynamic propulsion models with aircraft simulations incorporating flexible modes, are of interest.

- **Electric Propulsion Systems** - The objective is to achieve the required increase in the specific power of high efficiency electric components to make a 10 mega-watt onboard power generation and/or utilization feasible for propulsion. Specific areas of interest are: advanced electric power control systems for energy management of battery and fuel cell systems including potentiostatic sensor array to determine battery state-of-charge (SOC) and battery cycle affected state lifetimes; advanced phase angle control systems for electric motors; and advanced power control systems for effective management of large multi-motor arrays designated for use in newer turbo-electric aircraft and embedded boundary layer electric propulsion systems.

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**A3.06 Physics-Based Conceptual Design Tools**

**Lead Center:** GRC  
**Participating Center(s):** LaRC
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. The aerospace flight vehicle conceptual design phase is 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. Often, the important primary aerospace vehicle design decisions at the conceptual design level (e.g., overall configuration selection) are still made using simple analyses and heuristics. Progress has been made recently in incorporating more physic-based analysis tools in the conceptual design process, especially in the aerodynamics area, and NASA has developed a capability that integrates several analysis tools and models in engineering architectures, such as ModelCenter and OpenMDAO. However, gaps still remain in many disciplines.

Developing higher order, high fidelity tools suitable for conceptual design is a difficult challenge. The first issue is analysis turnaround time. To perform the configuration trades and optimization typical of conceptual design, runtimes measured in seconds or minutes, instead of hours or days, are required. However, rapid analysis turn around time alone is insufficient. To be suitable for conceptual design, tools and methods are needed which accurately predict the "as-built" characteristics. Because it is not possible to model every detail of the design and account for all the underlying physics in the problem formulation, it is difficult to predict the "as-built" characteristics with physics-based methods alone. What is usually required is a combination of these methods with some semi-empirical corrections. Ignoring this aspect can lead to higher order tools which are lower fidelity (less accurate) than the lower order tools they are intended to replace. Another challenge in conceptual design is a lack of detailed design information. Lower order, empirical-based methods typically used in the past for conceptual design often require only gross design parameters as inputs. It is, therefore, not necessary to know design details to obtain a reasonable estimate of the design's performance. High-order, physics-based methods currently require detailed design knowledge to be useful. For example, whereas semi-empirical drag prediction tools provide estimates for wing drag without needing full 3-D geometry including an airfoil design, such detail is necessary to successfully utilize CFD tools. This gap in the analysis capability and the maturity of the design being analyzed limits the usefulness of the high order analysis in conceptual design. Physics-based tools for conceptual design must be developed which are consistent with the amount of design knowledge that is available at the conceptual design stage.

NASA continues to investigate the potential of advanced, innovative propulsion and aircraft to improve fuel efficiency (i.e. reduce CO₂ emissions) and to reduce the environmental footprint (noise and NOₓ) of future generations of commercial transports across the flight speed regime. As such, the agency's systems analysts need to have the best design/analysis tools possible. The intention of this sub-topic is to solicit proposals for robust, physics-based tools enabling unconventional configurations to be addressed in the conceptual design process. Specifically for 2012, the solicitation will center on new tools and methods that pertain to the propulsion system. Modeling areas where enhanced capabilities are desired include the following:

- Electric/Turbo-electric performance & weight estimation methodologies. Some examples:
  - Electric component performance/weight estimation.
  - Electric grid performance and analysis.
  - Thermal management analysis.
- Enhanced propulsion system performance & weight methodologies. Some examples:
  - Turbomachinery loss modeling.
  - "Rapid" boundary layer ingestion performance.
Physics-based component weight estimation.  
Engine controls & accessories weight/volume.  
High order environmental tools. Some examples:  
Sonic boom modeling.  
Combustion emission indices generation.  
Advanced (beyond ANOPP) acoustics models.  
Reduced order atmospheric chemistry/global mixing.

A3.07 Rotorcraft  
Lead Center: ARC  
Participating Center(s): GRC, LaRC  
The challenge of the Rotary Wing thrust of the NASA Fundamental Aeronautics Program is to develop and validate tools, technologies and concepts to overcome key barriers for rotary wing vehicles. Technologies of particular interest are as follows:

- **Modeling and Analysis for Conceptual Design and Sizing** - Tools are sought that enable rotorcraft conceptual design and sizing for a wide range of missions. Such tools should also enable systems studies to assess technology benefits. These tools typically model the various rotorcraft components using lower fidelity, approximate and/or empirically based models, and improvements in these tools can be made through developing more accurate rotorcraft component models that are appropriate for conceptual design. The development of methodologies, tools and techniques that include rotorcraft handling qualities during conceptual design is of particular interest with topics including: flight control architecture and handling qualities measures; rotorcraft configuration and data requirements; and methods for integration into conceptual design and sizing codes and analyses. Additional topics of interest include, but are not limited to: engine and drive system models over large rotor speed ranges; auto generation of airfoil tables and analysis and optimization of airfoil sections; noise estimation methods for rotor, engine and drive systems; and airspace performance analysis tools for rotorcraft.

- **Advanced Turboshaft Engines with Variable-Speed Power-Turbine Capability** - Research (modeling, computational work, experiments) that addresses variable-speed power turbine (VSPT) and gas-generator aerothermodynamic, mechanical, and materials challenges is sought. The Rotary Wing Project of the Fundamental Aeronautics Program performs research and development of engine/driveline technologies to enable large civil tilt-rotor vehicles with variable-speed-rotor capability. Options for achieving main-rotor speed variability include a variable-speed transmission and/or a variable-speed power turbine. Key challenges for turboshaft engines of future rotary wing vehicles include high-efficiency power-turbine performance over a wide variable-speed range (50%)

Proposals on other rotorcraft technologies will also be considered as resources and priorities allow, but the primary emphasis of the solicitation will be on the above two identified technical areas.
A3.08 Propulsion Efficiency - Turbomachinery Technology

Lead Center: GRC

There is a critical need for advanced turbomachinery and heat transfer concepts, methods and tools to enable NASA to reach its goals under the Fundamental Aeronautics Program. These goals include dramatic reductions in aircraft fuel burn, noise, and emissions, as well as an ability to achieve mission requirements for, Subsonic, Rotary Wing, and High Speed Project flight regimes and fundamental research under the Aeronautical Sciences Project. Turbomachinery includes rotating machinery in the high and low pressure spools, transition ducts, purge and bleed flows, casing and hub. In the compression system, advanced concepts and technologies are required to enable higher overall pressure ratio, high stage loading and wider operating range while maintaining or improving aerodynamic efficiency. Such improvements will enable reduced weight and part count, and will enable advanced variable cycle engines for various missions. In the turbine, the very high cycle temperatures demanded by advanced engine cycles place a premium on the cooling technologies required to ensure adequate life of the turbine component. Reduced cooling flow rates and/or increased cycle temperatures enabled by these technologies have a dramatic impact on the engine performance.

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

- Advanced instrumentation to enable time-accurate, detailed measurement of unsteady velocities, pressures and temperatures in three-dimensional flowfields such as found in turbomachinery components and transition ducts. This may include instrumentation and measurement systems capable of operating in conditions up to 900 °F and in the presence of shock-blade row interactions, as well as in high speed, transonic cascades. The instrumentation methods may include measurement probes, non-intrusive optical methods and post-processing techniques that advance the state-of-the-art in turbomachinery unsteady flowfield measurement for purposes of accurately resolving these complex flowfield. Instrumentation enabling measurements and characterization of unsteady turbulent flows at combustor exit temperatures that can be implemented in warm test rigs and actual engines is also included. Instrumentation specific to turbomachinery and heat transfer should be proposed under this subtopic.

- Advanced turbomachinery active and passive flow control concepts to enable increased high stage loading in single and multi-stage axial compressors while maintaining or improving aerodynamic efficiency and operability. Technologies are sought that would reduce dependence on traditional range extending techniques (such as variable inlet guide vane and variable stator geometry) in compression systems. These may include flow control techniques near the compressor end walls and on the rotor and stator blade surfaces. Technologies are sought to reduce turbomachinery sensitivity to tip clearance leakage effects where clearance to chord ratios may be on the order of 5% or above. Technologies are sought to eliminate flow separation in low pressure turbines and transition ducts, improve off-design operation and enable variable cycle operation.

- Novel turbine cooling concepts are sought to enable very high turbine cooling effectiveness especially considering the manufacturability of such concepts. These concepts may include film cooling concepts, internal cooling concepts, and innovative methods to couple the film and internal cooling designs. Concepts proposed should have the potential to be produced with current or forthcoming manufacturing techniques. The availability of advanced manufacturing techniques may actually enable improved cooling designs beyond the current state-of-the-art. Concepts are also sought for the cooling of ceramic-based turbine materials such as ceramic matrix composite (CMC) vanes and blades.
Computational technologies allowing accurate predictions of turbomachinery flows and heat transfer including active and passive flow control features. Advanced turbulence and LES models that can account for complex three-dimensional flows common in turbomachinery. Models of flow control devices that enable incorporating them in RANS based CFD codes. Particular interest is in CFD method based on overset moving grids that will enable flexibility in studies of small features as cooling holes and active and passive flow control devices.

A3.09 Ground and Flight Test Techniques and Measurement Technologies

Lead Center: AFRC

NASA is committed to effective support and execution of flight research. This includes developing test techniques that improve the control of in-flight test conditions, expanding measurement and analysis methodologies, and improving test data acquisition and management with sensors and systems that have fast response, low volume, minimal intrusion, and high accuracy and reliability. By using state-of-the-art flight test techniques along with novel measurement and data acquisition technologies, NASA will be able to conduct flight research more effectively and also meet the challenges presented by NASA's cutting edge research and development programs. NASA's Aeronautical Test Program (ATP) supports a variety of flight regimes and vehicle types ranging from civil transports, low-speed, to high-altitude long-endurance to supersonic and access-to-space. Therefore, this solicitation can cover a wide range of flight conditions and craft.

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

Flight research and test capability proposals should be relevant to the following NASA aeronautical test facilities: Western Aeronautical Test Range, Aero-Structures Flight Loads Laboratory, Flight Research Simulation Laboratory, and Research Test Bed Aircraft. Proposals should address innovative methods and technologies to extend the health, maintainability and test capabilities of these flight research support facilities. Areas of interest include:

- Multi-disciplinary nonlinear dynamic systems prediction, modeling, identification, simulation, and control of aerospace vehicles.
- Test techniques for conducting in-flight boundary layer flow visualization, shock wave propagation, Schlieren photography, near and far-field sonic boom determination, atmospheric modeling.
- Active flow control techniques for performance and acoustic noise reduction.
- Intelligent health monitoring for hybrid or all electric distributed propulsion systems.
- Methods for significantly extending the life of electric aircraft propulsion energy sources (e.g., batteries).
- Innovative acoustic noise reduction technology for structural and propulsion systems.
• Techniques for manufacturing lighter, thinner, and tougher engine fan blades than current state-of-the-art.

• Measurement technologies for steady & unsteady aerodynamic, aero-thermal dynamics, structural dynamics, stability & control, and propulsion system performance.

• Verification & Validation (V&V) of complex highly integrated flight systems including hardware-in-the-loop testing.

• Innovative techniques that enable safer operations of aircraft (e.g., non-destructive examination of composites through ultrasonic techniques).

Aviation External Hazard Sensor Technologies Topic A1.01

NASA is concerned with the prevention of encounters with hazardous in-flight conditions and the mitigation of their effects when they do occur. Hazardous flight conditions of particular interest are: wake vortices, clear-air turbulence, in-flight icing, lightning, and low visibility. NASA is interested in new and innovative methods for detection, identification, evaluation, and monitoring of in-flight hazards to aviation. In the case of lightning, interest is centered on the mitigation and in-flight measurement of lightning damage, particularly to composite aircraft.

NASA seeks to foster research and development that leads to innovative new technologies and methods, or significant improvements in existing technologies, for in-flight hazard avoidance and mitigation. Technologies may take the form of tools, models, techniques, procedures, substantiated guidelines, prototypes, and devices. Proposed products may be for retrofit into current aircraft or for installation in future aircraft. Both manned and unmanned aircraft are of interest.

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

Under this subtopic, proposals are invited that explore new and improved sensors and sensor systems for the detection and monitoring of hazards to aircraft before they are encountered. With regard to hazardous lightning conditions, the emphasis is not on remote detection, but rather on developing systems that make aircraft more robust in a lightning environment or provide in-flight damage assessment or other hazard mitigating benefits. The scope of this subtopic does not include human factors and focused development of human interfaces, including displays and alerts. Primary emphasis is on airborne applications, but in some cases the development of ground-based sensor technology may be supported. Approaches that use multiple sensors in combination to improve hazard detection and quantification of hazard levels are also of interest.

Areas of particular interest to NASA at this time are described in more detail below. The list and details are
provided as encouragement but are not intended to exclude other proposals that fit the scope of this subtopic.

**Turbulence and Wake Vortex**

- *Remote detection of kinetic air hazards* - The class of hazards including wake vortices, turbulence, and other hazards associated with air motion is referred to as kinetic air hazards. Within this class, wakes and turbulence are the highest priorities; however, NASA is particularly interested in sensor systems that can detect multiple hazards and thus provide greater utility. For example, air data systems are at times disabled by icing, and a multi-function, multi-hazard sensor that includes a robust alternative air data source would be a great asset in such conditions.

- *Airborne detection of wake vortices* - Airborne detection of wake vortices is considered challenging due to the fact that detection must be possible in nearly all weather conditions, in order to be practical, and because of the size and nature of the phenomena. In particular, NASA is interested in the ability to detect and measure wake vortex hazards for arbitrary viewing angles.

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

**Lightning**

- *Lightning Strike Protection* - NASA is investigating means for mitigating damage to aircraft, with a particular interest in protecting composite aircraft. Currently, an electrically-conductive screen protects composite aircraft by functioning as a Faraday shield and is intended to confine lightning and electromagnetic effects to the outside or outermost skin of the aircraft. The lightning strike protection system, hereafter referred to as the LSP, is incorporated in the coatings, layers, and structure that comprise the skin of the aircraft. NASA is most interested in LSP solutions that will be cost effective and light-weight.

- *Mitigation of lightning strike damage* - NASA is seeking solutions that will provide better protection from lightning damage by directing attachment points or lightning currents to safe or less hazardous areas and by reducing the susceptibility of the aircraft to thermal or other damage due to strikes.

- *In-flight lightning damage measurement and assessment* - A typical commercial aircraft is struck by lightning about once per year. At this time, composite aircraft that are struck in-flight are inspected upon landing for a damage assessment. Such assessments may be time-consuming and difficult. Innovations that will provide a measurement or damage detection system in the LSP are solicited. The objective would be to achieve a capability to have damage detection and assessment capability in the aircraft that will provide immediate information to the flight crew after a lightning attachment.
effects when they do occur. Under this subtopic, proposals are invited that explore new and dramatically improved technologies related to inflight airframe and engine icing hazards for manned and unmanned vehicles. Technologies of interest should address the detection, measurement, and/or the mitigation of the hazards of flight into supercooled liquid water clouds and flight into regions of high ice crystal density. With these emphases in mind, products and technologies that can be made affordable and capable of retrofit into the current aviation system and aircraft, as well as for use in the future are sought.

Areas of interest include, but are not limited to:

- Non-destructive 3-D ice density measurements of ice accretions on wind tunnel wing models. NASA has a need for non-optical methods to digitize ice shapes with rough external surfaces and internal voids as can occur with accretions on highly swept wings for comparison to computational simulations. Current methods based upon scanning with line-of-sight, visible-spectrum digitization methods have been found inadequate for many of these very complex ice shapes.

- Remote and in-situ technologies that can accurately quantify the super-cooled liquid water environment in the volume surrounding an airport. Of primary interest are remote sensing technologies that can, by themselves or with other instruments, quantify the temperature, liquid water content, and cloud droplet size spectrum to allow the production of a 3-D icing hazard map of the terminal airspace. Low-cost, expendable in-situ instruments are also of interest for validating and calibrating these remotely sensed measurements.

Sub Topics:
Flight Deck Interface Technologies for NextGen Topic A1.03
Public benefits derived from continued growth in the transport of passengers and cargo are dependent on the improvement of the intrinsic safety attributes of current and future air vehicles that will operate in NextGen. The Aviation Safety Program (AvSP) is addressing this challenge by conducting cutting-edge fundamental and applied research that will yield innovative algorithms, tools, concepts and technologies from the discipline level up to the subsystem and system level. As a part of the AvSP, the Vehicle System Safety Technology (VSST) Project has initiated a Technical Challenge (TC) toward the improvement of Crew Decision-Making and response in complex situations (CDM), in current-day and NextGen operations.

To address this TC, NASA seeks innovative flight deck interface research and technology that address the following major topic areas:

- The flight crew’s needs for situation awareness/information in current-day and emerging NextGen operations. Research and technology development focused on novel display technologies and display methods that allow for new means of NextGen information portrayal and creating visual and aural interface methods to provide hazard and aircraft state awareness and protection during terminal maneuvering area operations.

- The development of flight deck interface technologies that assure pilot awareness and appropriate engagement (balancing awareness and workload) in current-day and emerging NextGen operations. Research and technology development to proactively address the potential impact of changing roles and responsibilities between the Air Navigation Services Providers (ANSP) and pilots as well as between the human and automation, and the robustness of these interfaces when responding to unexpected events.

- Integrated information management systems that assure the information needed by flight crews to make
critical decisions is complete and not misleading. Research and technology development to better manage flight deck information during NextGen "Net-Centric" operations without overloading or underwhelming the operators/users.

- Understanding demographics and proficiency that impact human (pilot) decision-making. Research and technology development which addresses emerging pilot demographics and pilot proficiency standards to improve pilot decision-making and interactions with other human and automation

Sub Topics:
Vehicle Level Diagnostics Topic A1.04
This SBIR subtopic augments on-going activities in the Vehicle Systems Safety Technology (VSST) project within NASA's Aviation Safety Program. Specifically, this subtopic addresses the "Maintain Vehicle Safety between Major Inspections" (MVS) technical challenge. The MVS technical challenge concentrates on capabilities to maintain vehicle safety between major inspection intervals with an emphasis on the subsystems of airframe, avionics, and propulsion. NASA is seeking proposals to combine information from, and within, the various subsystems to perform overall vehicle level diagnostics. The objective of this work is to provide an infrastructure to assess the health state of aircraft though the integration of full vehicle sensors and diagnostic information. Partnering with organizations that can provide relevant data is encouraged.

Sub Topics:
Data Mining and Knowledge Discovery Topic A1.05
The fulfillment of the SSAT project's goal requires the ability to transform vast amounts of data produced by aircraft and associated systems and people into actionable knowledge that will aid in detection, causal analysis, and prediction at levels ranging from the aircraft-level, to the fleet-level, and ultimately to the level of the national airspace. For this topic, we are especially interested in automated discovery of previously unknown precursors to aviation safety incidents involving human - automation interaction. We expect to gain knowledge on latent deficiencies in crew training, communication, and operations that is of paramount importance to future SSAT project goals and objectives. The incorporation of human performance will be invaluable to the success of this effort, and as such it will be important to use heterogeneous data from varied sources that are matched on a per-flight basis with flight-recorded data, such as radar track data, airport information, weather data, flight crew schedule information, maintenance information, and Air Safety Reports. This topic will develop revolutionary and first-of-a-kind methods and tools that incorporate the limitations of human performance throughout the design lifecycle of human-automation systems to increase safety and reduce validation costs in NextGen.

The focus of this effort will be on the fleet level or above. As such, the successful proposal will develop validated data mining and machine learning based methods to uncover systemic human-automation interaction issues that manifest at a much broader level than those incidents that occur within a single flight or for a single aircraft. Simulated data that is representative of the interactions between humans and automation found on flight systems and on data from real world aircraft and supporting ground-based systems should be used. The total of the data set under study should be at least 10 TB in size, and exhibit appropriate statistical and operational complexities found in real world human automation interactions. Furthermore, a deep knowledge of human-automation interaction from the human-factors perspective as well as the ability to create novel machine learning and data mining algorithms should be clearly demonstrated.

Sub Topics:
Assurance of Flight-Critical Systems Topic A1.06
The purpose of this subtopic is to invest in mid- and long-term research to establish rigorous, systematic, scalable, and repeatable verification and validation methods for flight-critical systems, with a deliberate focus on safety for NextGen (http://www.jpdo.gov [2]). This subtopic targets NextGen safety activities and interests encompassing vehicles, vehicle systems, airspace, airspace concept of operations, and air traffic technologies, such as communication or guidance and navigation. Methods for assessing issues with technology, human performance and human-systems integration are all included in this sub-topic, nothing that multi-disciplinary research is required that does not focus on one type of component or phenomenon to the exclusion of other important drivers of safety.

Proposals are sought for the development of:
Safety-case methods and supporting technologies capable of analyzing the system-wide safety properties suitable for civil aviation vehicles and for complex concepts of operation involving airborne systems, ground systems, human operators and controllers.

Technologies and mathematical models that enable rigorous, comprehensive analysis of novel integrated, and distributed, systems interacting through various mechanisms such as communication networks and human-automation and human-human interaction.

Techniques, tools and policies to enable efficient and accurate analysis of safety aspects of software-intensive systems, ultimately reducing the cost of software V&V to the point where it no longer inhibits many safety innovations and NextGen developments.

Tools and techniques that can facilitate the use of formal methods in V&V throughout the lifecycle such as graphical-based development environments (e.g., eclipse plug-ins for static analyzers, model checkers, or theorem provers) or tools facilitating translation from design formats used in industry to formal languages supporting automated reasoning.

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

In Phase II, a functional system shall be delivered to NASA for its retention and ownership.

Sub Topics:

Unmanned Aircraft Systems Integration into the National Airspace System Research Topic A2.01

The following subtopic is in support of the Unmanned Aircraft Systems (UAS) Integration in the National Airspace System (NAS) Project under the Integrated Systems Research Program (ISRP). There is an increasing need to fly UAS in the NAS to perform missions of vital importance to National Security and Defense, Emergency Management, Science, and to enable commercial applications. The UAS Integration in the NAS Project is structured under the following technical challenges:

- **Airspace Integration** - validate technologies and procedures for UAS to remain an appropriate distance from other aircraft, and to safely and routinely interoperate with NAS and NextGen Air Traffic Services (ATS).

- **Standards/Regulations** - validate minimum system and operational performance standards and certification requirements and procedures for UAS to safely operate in the NAS.

- **Relevant Test Environment** - develop an adaptable, scalable, and schedulable relevant test environment for validating concepts and technologies for UAS to safely operate in the NAS. The Federal Aviation Administration (FAA) regulations are built upon the condition of a pilot being in an aircraft.

There exist few, if any, regulations specifically addressing UAS today. The primary user of UAS to date has been the military. The technologies and procedures to enable seamless operation and integration of UAS in the NAS need to be developed, validated, and employed by the FAA through rule making and policy development.

The Project goal is to capitalize on NASA’s unique capabilities and competencies by utilizing integrated system level tests in a relevant environment to eliminate or reduce critical technical barriers of integrating UAS into the NAS. The project is further broken down into five subprojects: Separation Assurance/Sense and Avoid Interoperability (SSI); Communications; Human Systems Integration; Certification; and Integrated Test and Evaluation. The fifth sub-project, Integrated Test and Evaluation, is responsible for developing a live, virtual, and constructive test environment for the other four subprojects. The first phase of the project includes the following:
• Conduct initial modeling, simulation, and flight testing.

• Complete early subproject-focused deliverables (spectrum requirements, comparative analysis of certification methodologies, etc.).

• Validate the key technical elements identified by this project.

The second phase includes the following:

• Conduct systems-level, integrated testing of concepts and/or capabilities that address barriers to routine access to the NAS.

• Provide methodologies for development of airworthiness requirements and data to support development of certification standards and regulatory guidance.

• Develop a body of evidence (including validated data, algorithms, analysis, and recommendations) to support key decision makers in establishing policy, procedures, standards and regulations, enabling routine UAS access in the NAS.

This solicitation seeks proposals, but is not limited, to develop:

• **Certified control and non-payload communications (CNPC) system** - Current civil UAS operations are significantly constrained by the lack of a standardized, certified control and non-payload communications (CNPC) system. The UAS CNPC system is to provide communications functions between the Unmanned Aircraft (UA) and the UA ground control station for such applications as: telecommands; non-payload telemetry; navigation aid data; air traffic control (ATC) voice relay; air traffic services (ATS) data relay; sense and avoid data relay; airborne weather radar data; and non-payload situational awareness video. New and innovative approaches to providing terrestrial and space-based high-bandwidth CNPC systems that are inexpensive, small, low latency, reliable, and secure offer opportunities for quantum jumps in UAS utility and capabilities. Of particular interest are:
  - Technologies for High power C-band amplifiers and highly linear C-band power amplifiers/linearization of high power C-band amplifiers.
  - Miniaturization of C-band radio components/systems.

• **A "Synthetic Vision System" for a ground control station (GCS)** - Integration of display technology that presents the visual environment external to the unmanned aircraft using computer-generated imagery in a manner analogous to how it would appear to the pilot in a manned aircraft. A "synthetic vision system" displays critical features of the environment external to the aircraft through a computer-generated image of the external scene topography using terrain and obstacle databases. Several research and technological developments have made synthetic vision systems possible. Fundamentally, these systems require only precise ownship location, a database, available graphics and computing capability and display media. In terms of safety benefits, synthetic vision may help to reduce many accident precursors including: Loss of awareness of vertical/ lateral path, terrain traffic, etc. Operational benefits may include transition from instruments to visual flight, non-normal and emergency situations, virtual visual self-spacing and station keeping capability, etc. SVS have been extensively studied and there is a vast body of knowledge on their application to manned aviation. Special interest is in the integration of a SVS into a UA ground control station to support operator in the loop, sense and avoid (SAA) functions for UAS operations in the NAS. Guidelines for sense and avoid requirements and functions are currently being developed by standards organizations (e.g., RTCA SC-203) and the FAA.
• **Weather information systems for GCS** - On-board, real-time graphic aviation weather information products have been developed and successfully implemented for manned cockpits. Their use is now widespread and their safety impact widely recognized. The applicability of such products for operators and ground control pilots to enhance situation awareness and improve mission planning and execution is of interest to NASA. Systems such as the NASA developed Aviation Weather Information (AWIN) system that included software, data and data-link applications, color weather graphics such as composite-radar mosaic, lightning-strike data, wind data, satellite images and forecasts could be integrated into a ground control station to provide pilots with weather awareness before and during mission execution. Improved weather awareness should allow aircrews to avoid most weather-related problems through both pre-flight and en-route planning. While the use of these systems has been explored for military UAS operations, their applicability to civil and public operations has not yet been explored.

• **Operator Displays for Sense and Avoid Systems** - While guidelines for the integration of UAS operations in the NAS are being developed new SAA systems are being designed to provide the ground control pilot with situation awareness and the ability to execute required ATC procedures. SAA systems provide UAS with the capability to avoid collisions and remain well clear of other aircraft by means of sensor systems and equipment specifically designed for this purpose. SAA systems consist of surveillance sensors, data communications, threat detection and/or resolution logic and the display of traffic information and/or resolution guidance/advice. Of interest is the development of display technologies to enable ground control pilots to participate in any phase of the SAA process as indicated by operator procedures. These new technologies should utilize the vast experience and body of knowledge developed over the years for airborne/ground separation assurance systems, TCAS displays, and cockpit displays of traffic information. In addition, these new displays will exhibit unique and very challenging new problems associated with the nature of unmanned systems as well as the communication latencies and potential safety risks of failure conditions. Human factors considerations should be applied in the design of these systems.

• **Lost Communication Link Procedures and Operations** - The procedures followed by unmanned aircraft and their pilots when the command and control link is lost with the ground station are not standardized and frequently do not take into account ATC regulations. Each UAS appears to have custom-designed procedures for "lost link" despite the existence of well-established rules for pilots to follow when communication capability is lost. Research should establish a desired set of procedures to be followed that parallel the existing requirements, but departing from those where necessary to meet critical safety considerations. These procedures may be codified in technologies used by the unmanned aircraft or the pilot in the ground control station to maximize the predictability of the UAS' actions from an ATC perspective.

• **Safety Analysis and Methodologies** - UAS operations are untried in the civil NAS. Unlike other aircraft, there is not an extensive record of civil operations upon which to forecast the safety of UAS operations in the NAS. The introduction of UAS into the NAS raises many safety issues and concerns. Typically, anytime a new capability is added into the NAS, an Operational Safety Assessment (OSA) is performed by the FAA, to determine whether that introduction of new capability will enhance or detract from the safety of the NAS. As these UAS represent a wholly new operational system, traditional approaches cannot suffice. Research is needed to identify and develop new safety analysis approaches, as well as prognostic indicators and potential new safety metrics.
The Fixed Wing and High Speed projects are focused on development of enabling technologies and advanced concepts for subsonic and supersonic cruise transport category aircraft, respectively, demonstrated to TRL 4-6 in the 2025 time frame. Both projects require simultaneous reduction of weight and drag to achieve their respective performance objectives. For subsonic transport aircraft, lift-induced drag is approximately 40% of the total drag at cruise and can be directly addressed via increased wing aspect ratio. For supersonic flight, speed requirements dictate highly swept wings with a very thin airfoil section. Both of these wing geometries, with higher aspect ratio or thinner airfoil section, result in more flexible structure that can exhibit aeroelastic instability and thus require more complicated aeroelastic design, analysis and control. The traditional solution to these aeroelastic issues has been primarily to stiffen the wing by adding additional structure, thus creating a weight penalty. Solutions that favorably modify the aeroelastic response of thin or high aspect ratio wings with no or little weight increase are needed. Furthermore, maneuverability of the vehicle is dependent upon the control authority achievable by wing-located control surfaces in traditional aircraft designs, and possibly actively tailorable portions of wings in more integrated aircraft designs. Designing the wing to have desired aeroelastic characteristics makes the wing amenable to minimal-input active control solutions to further modify the aeroelastic response. Using a building block approach in this research topic, the current solicitation focuses on materials and structural concepts for aeroelastically-tailored aircraft wings, while the more complex aeroservoelastic solution will be the subject of a future solicitation.

This solicitation topic seeks innovative materials and/or structural concepts and technologies for lightweight wings with aeroelastic tailoring, such as tailored bending and torsional stiffness as an example. Proposals should involve novel materials, processes and structural concepts with significant potential to improve the structural efficiency and reduce specific weight. Laboratory scale approaches may be proposed for proof of concept, but must be scalable to application across a broad range of fixed wing aircraft sizes and speeds.

Tailored stiffness may include spatial or temporal variations in stiffness achieved by a combination of passive stiffness tailoring of anisotropic or functionally graded materials, novel structural topologies, or active integrated elements to change structural and/or material properties. The use of existing design and analysis tools and techniques to the greatest extent possible is encouraged, as it is not the intent of this solicitation to develop new computational tools. Specifically, the following concepts and technologies are sought:

- Materials and processing routes to fabricate engineered materials with tailored material properties along all three axes.
- Aeroelastically-tailored structural concepts by which desired static or dynamic aeroelastic responses can be achieved.

Phase I: Identify candidate material systems and structural concepts that enable aeroelastic tailoring of wing structure for reduced weight, for example, variable bending and torsional stiffness. Assess the feasibility and benefits of the proposed concept, including scale-up, necessary material property quantification, and design trade studies. The studies must include quantification of expected structural weight benefits. Identify limiting factors and recommendations for further technology development to address the shortfalls. For novel material systems and structural concepts requiring development, conduct initial proof of concept computational studies and/or element tests.

Phase II: Perform scale-up of materials and processes as necessary, and produce a detailed structural design and hardware build of a subscale wing suitable for laboratory testing to assess structural performance of the concept. Structural testing of the subscale wing will be performed subsequently by NASA and is beyond the scope of the Phase II effort.
Sub Topics: Quiet Performance Topic A3.02
Innovative technologies and methods are necessary for the design and development of efficient, environmentally acceptable aircraft. In support of the Fundamental Aeronautics Program, improvements in noise prediction, measurement methods and control are needed for subsonic, transonic and supersonic vehicles targeted specifically at airframe noise sources and the interaction of airframe and engine noise. Innovations in the following specific areas are solicited:

• Fundamental and applied computational fluid dynamics techniques for aeroacoustic analysis, which can be adapted for design codes.

• Prediction of aerodynamic noise sources including those from airframe and sources which arise from significant interactions between airframe and propulsion systems.

• Prediction of sound propagation from the aircraft through a complex atmosphere to the ground. This should include interaction between noise sources and the airframe and its flow field.

• Innovative source identification techniques for airframe (e.g., landing gear, high lift systems) noise sources, including turbulence details related to flow-induced noise typical of separated flow regions, vortices, shear layers, etc.

• Concepts for active and passive control of aeroacoustic noise sources for conventional and advanced aircraft configurations, including adaptive flow control technologies, and noise control technology and methods that are enabled by advanced aircraft configurations, including integrated airframe-propulsion control methodologies.

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

Sub Topics: Low Emissions/Clean Power Topic A3.03
Proposals are sought which support electric propulsion of transport aircraft, which includes various hybrid electric concepts, such as gas turbine engine-battery combinations and turboelectric propulsion (turbine prime mover with electric distribution of power to propulsors). Turboelectric propulsion for aircraft applications will require high specific power (hp/lb or kW/kg) and high efficiency components. Cryogenic and superconducting components will be required to achieve high specific power and high efficiency. The cryogenic components include fully superconducting generators and motors (i.e., superconducting stators as well as rotors), cryogenic inverters and active rectifiers, and cryocoolers. Proposals related to the superconducting machines may include aspects of the machines themselves as well as low AC loss superconducting materials for the stator windings. Generators with at least 10 MW capacity and motors of 2 to 3 MW capacity are of interest. Technology is sought that can contribute to superconducting machines with specific power more than 10 hp/lb. Superconducting wires with filaments less than 10 micrometers in diameter are of interest. Ideas are also sought for achieving 2-3X increase in specific power for non-cryogenic motors through a multidisciplinary approach utilizing advanced motor designs, better materials, and new structural concepts. Ideas are also sought to address challenges related to high voltage power transmission in future hybrid electric aircraft. New modeling and simulation tools for hybrid electric aircraft propulsion systems are also of interest.
The challenge of energy-efficient flight has at its foundation aerodynamic efficiency, and at the foundation of aerodynamic efficiency is low drag. Drag can be broadly decomposed into four components: viscous or skin friction drag, lift-induced drag, wave or compressibility drag, and excrescence drag due to various protruding items such as antennae, wipers, lights, etc. The relative impact of these four forces depends upon the targeted flight regime and vehicle-specific design requirements. The first force, however, viscous skin friction, stands out as particularly significant across most classes of flight vehicles and effective measures for its control would have a major impact on flight efficiency. In particular, supersonic, low-boom flight and new generations of energy-efficient subsonic transport airplanes including high L/D strut-braced designs, the blended wing body (BWB), the so called "double-bubble" designs and other concepts with large expanses of surface area would benefit from effective viscous drag control.

Viscous skin friction can be classified as either laminar or turbulent. While the laminar case and its attendant laminar flow control (LFC) techniques remain important scientific and technological disciplines, the goal of high Reynolds number flight efficiency requires that the turbulent case receive renewed attention. In place of the first-principles-derived theoretical framework of the laminar flow stability problem, in the turbulence case we have a wide collection of experimental observations, data correlations, various CFD approaches requiring turbulence closure models and, at low Reynolds numbers, full direct numerical simulation of the Navier-Stokes equations (DNS). While such experimental and CFD-derived knowledge, has greatly increased our understanding of turbulent boundary layer physics over the past decades, key relationships between wall layer and outer layer dynamics essential to a full understanding remain to be identified and verified.

Inadequacies in our understanding of boundary layer turbulence increase reliance upon a more qualitative, physics-guided approach to discovery. For example, the experimental observation of reduced skin friction in the corners of triangular cross-section pipes led to the discovery of drag-reducing V-groove riblets (subsequently also associated with the skin of certain shark species). The quasi-periodic, low-speed streak structures observed in the near-wall layer of turbulent boundary layers led to the implementation of mechanically controlled spanwise waves or lateral oscillations of the wall to disrupt the processes associated with low speed streak bursting. Similar observations have either been made or suggested with respect to the stabilizing influence of convex and in-plane curvature; long length-to-diameter ratio particulates; passive, active and reactive wall motion; manipulation of the wall layer by various geometrical devices (e.g., vortex generators (VG) and large eddy breakup devices (LEBU)), and various weakly ionized gas (WIG) and magnetohydrodynamic/electrohydrodynamic (MHD/EHD) concepts. This solicitation is offered in this spirit of innovation based on experimental or computational observations guided by a basic, though not necessarily complete, physical understanding of the turbulent processes.

In order to stimulate innovation in the area of turbulent viscous drag reduction, proposals are sought subject to the following guidelines:

- Proposals shall address passive, active, or reactive concepts for external, attached, fully developed, turbulent boundary layer viscous drag reduction in air.
- Experimental, hardware-based proposals and theoretical/computational proposals based on realizable hardware are preferred.
- All practical physical concepts are acceptable including but not limited to: mechanical/electro-mechanical
actuators, weakly-ionized-gas (WIG) concepts, laser/microwave energy deposition, MHD/EHD devices, surface microstructure/geometry, embedded mechanical devices (VG's, LEBU's), wall mass transpiration, heat transfer, wall motion, wall curvature effects and pressure gradient (vehicle shaping).

- Significant enhancements or refinements of existing concepts and technologies are acceptable.
- First order assessment or technically plausible discussion of any net system energy saving claims shall be provided.
- Proof-of-concept experimental demonstrations are encouraged for Phase I where applicable but are not required.
- Target conditions are flight-relevant Reynolds numbers at either high subsonic (0.7<\textit{M}<0.9) or low supersonic (\textit{M}<~ 3) speeds. Proposals at lower Mach and Reynolds numbers shall provide discussion of a developmental path towards flight-relevant conditions but not necessarily inclusive of actual flight.

Sub Topics:
Controls/Dynamics - Propulsion Systems Topic A3.05

Propulsion controls and dynamics research is being done under various projects in the Fundamental Aeronautics Program (FAP). For turbine engines, work on Distributed Engine Control (DEC) and Model-Based Engine Control (MBEC) is currently being done under the Subsonic Fixed Wing (SFW) project, and Active Combustion Control research is currently being done under the Supersonics (SUP) project. These 3 efforts are expected to transition to the new Aeronautics Sciences (AS) project in FY13. Aero-Propulso-Servo-Elasticity (APSE) research will continue under the SUP project. Research activity on Controls/Dynamics for electric propulsion systems is expected to be initiated in FY13 under the reformulated Fixed Wing (FW) project. Propulsion control and dynamics technologies that help achieve the goals of FAP, in terms of: reducing emissions; increasing fuel efficiency; tool and technology development and validation to address challenges in High Speed flight; and enabling fast, efficient design and analysis of advanced aviation systems, are of interest. Proposed activities that are compatible with current propulsion controls and dynamics activities supported by the FAP will be given preference. Following technologies are of specific interest:

- **High Efficiency Robust Engine Control** - Typical current operating engine control logic is designed using SISO (Single Input Single Output) PI (Proportional+Integral) control. The control logic is designed to provide minimum guaranteed performance while maintaining adequate safety margins throughout the engine operating life. Additionally, the control logic provides control of variables of interest such as Thrust, Stall Margin etc. indirectly since these variables cannot be measured or are not measured in flight because of restrictions on sensor cost/placement/reliability etc. All this results in highly conservative control design with resulting loss in efficiency. NASA is currently conducting research in Model-Based Engine Control (MBEC) where-in an on-board real-time engine model, tuned to reflect current engine condition, is used to generate estimate of quantities of interest that are to be regulated or limited and these estimates are used to provide direct control of Thrust etc. Alternate methods such as Model Predictive Control, Adaptive Control, direct non-linear control, etc. which will achieve the same objectives as the current MBEC approach while providing practical application of the control logic in terms of operation with sensor noise, operation across varying atmospheric conditions, operation across varying engine health condition over the operating life, and real-time operation within engine control hardware limits, are of interest. The emphasis is on practical application of existing control methods rather than theoretical derivation of totally new concepts. Control design approaches that can accommodate small to medium engine component faults and can still provide desired performance with safe operation are of special interest. The pre-requisite for proposals for engine control design methods is that the NASA C-MAPSS40k (Commercial Modular Aero-Propulsion System Simulation for 40,000 lb class thrust engine) be used for control design and evaluation. This simulation can only be used by U.S. citizens since it is subject to export control laws. Methods for real-time engine parameter identification using flight data are also of interest by themselves.
• **Distributed Engine Control** - Current engine control architectures impose limitations on the insertion of new control capabilities primarily due to weight penalties and reliability issues related to complex wiring harnesses. Obsolescence management is also a primary concern in these systems because of the unscheduled cost impact and recertification issues over the engine life cycle. NASA in collaboration with AFRL (Air Force Research Lab) has been conducting research in developing technologies to enable Distributed Engine Control (DEC) architectures. The current need is to develop a DEC test-bed which can be used to investigate a wide range of issues such as system robustness, stability and performance of various DEC architectures, the development of network communications requirements, network performance evaluation, robustness of DEC architectures to data transmission faults and impact on system performance. The tools just described must be compatible with the NASA C-MAPSS40k simulation software and easily integrated into the Hardware-in-the-Loop research facility currently being developed under a separate contract. Restrictions on access to these technologies require that any proposed effort will be limited to work being done by U.S. citizens.

• **Active Combustion Control** - The overall objective is to develop all aspects of control systems to enable safe operation of low emissions combustors throughout the engine operating envelope. Low emission combustors are prone to thermo-acoustic instabilities. So far NASA research in this area has focused on modulating the main or pilot fuel flow to suppress such instability. Advanced, ultra-low emissions combustors utilize multi-point (multi-location) injection to achieve a homogeneous, lean fuel/air mixture. There is new interest in using precise control of fuel flow in such a manner as to suppress or avoid thermo-acoustic instabilities. Miniature fuel metering devices (and possibly also fuel flow measurement devices) are needed that can be physically distributed to be close to the multi-point fuel injector in order to enable the control system to accurately place a given proportion of the overall fuel flow to each of the fuel injection locations.

• **Aero-Propulsion- Servo-Elasticity** (APSE) - The objective of NASA research effort in APSE is to develop a comprehensive dynamic propulsion system model that can be utilized for thrust dynamics and integrated APSE vehicle controls and performance studies, like vehicle ride quality and vehicle stability under typical vehicle maneuvering and atmospheric disturbances, for supersonic vehicles. Innovative approaches to dynamic modeling of supersonic external compression inlets; parallel flow path modeling of the compression and whole propulsion system to accurately model the distortion effects of flexible modes, maneuvering and atmospheric disturbances; and integration of dynamic propulsion models with aircraft simulations incorporating flexible modes, are of interest.

• **Electric Propulsion Systems** - The objective is to achieve the required increase in the specific power of high efficiency electric components to make a 10 mega-watt onboard power generation and/or utilization feasible for propulsion. Specific areas of interest are: advanced electric power control systems for energy management of battery and fuel cell systems including potentiostatic sensor array to determine battery state-of-charge (SOC) and battery cycle affected state lifetimes; advanced phase angle control systems for electric motors; and advanced power control systems for effective management of large multi-motor arrays designated for use in newer turbo-electric aircraft and embedded boundary layer electric propulsion systems.

Sub Topics:

**Physics-Based Conceptual Design Tools Topic A3.06**

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. The aerospace flight vehicle conceptual design phase is 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. Often, the important primary aerospace vehicle design decisions at the conceptual design level (e.g., overall configuration selection) are still made using simple analyses and heuristics. Progress has been made recently in incorporating more physic-based analysis tools in the conceptual design process, especially in the aerodynamics area, and NASA has developed a capability that
integrates several analysis tools and models in engineering architectures, such as ModelCenter and OpenMDAO. However, gaps still remain in many disciplines.

Developing higher order, high fidelity tools suitable for conceptual design is a difficult challenge. The first issue is analysis turnaround time. To perform the configuration trades and optimization typical of conceptual design, runtimes measured in seconds or minutes, instead of hours or days, are required. However, rapid analysis turn around time alone is insufficient. To be suitable for conceptual design, tools and methods are needed which accurately predict the "as-built" characteristics. Because it is not possible to model every detail of the design and account for all the underlying physics in the problem formulation, it is difficult to predict the "as-built" characteristics with physics-based methods alone. What is usually required is a combination of these methods with some semi-empirical corrections. Ignoring this aspect can lead to higher order tools which are lower fidelity (less accurate) than the lower order tools they are intended to replace. Another challenge in conceptual design is a lack of detailed design information. Lower order, empirical-based methods typically used in the past for conceptual design often require only gross design parameters as inputs. It is, therefore, not necessary to know design details to obtain a reasonable estimate of the design's performance. High-order, physics-based methods currently require detailed design knowledge to be useful. For example, whereas semi-empirical drag prediction tools provide estimates for wing drag without needing full 3-D geometry including an airfoil design, such detail is necessary to successfully utilize CFD tools. This gap in the analysis capability and the maturity of the design being analyzed limits the usefulness of the high order analysis in conceptual design. Physics-based tools for conceptual design must be developed which are consistent with the amount of design knowledge that is available at the conceptual design stage.

NASA continues to investigate the potential of advanced, innovative propulsion and aircraft to improve fuel efficiency (i.e, reduce CO$_2$ emissions) and to reduce the environmental footprint (noise and NOx) of future generations of commercial transports across the flight speed regime. As such, the agency's systems analysts need to have the best design/analysis tools possible. The intention of this sub-topic is to solicit proposals for robust, physics-based tools enabling unconventional configurations to be addressed in the conceptual design process. Specifically for 2012, the solicitation will center on new tools and methods that pertain to the propulsion system. Modeling areas where enhanced capabilities are desired include the following:

- Electric/Turbo-electric performance & weight estimation methodologies. Some examples:
  - Electric component performance/weight estimation.
  - Electric grid performance and analysis.
  - Thermal management analysis.

- Enhanced propulsion system performance & weight methodologies. Some examples:
  - Turbomachinery loss modeling.
  - "Rapid" boundary layer ingestion performance.
  - Physics-based component weight estimation.
  - Engine controls & accessories weight/volume.

- High order environmental tools. Some examples:
  - Sonic boom modeling.
  - Combustion emission indices generation.
Advanced (beyond ANOPP) acoustics models.
Reduced order atmospheric chemistry/global mixing.

Sub Topics:
Rotorcraft Topic A3.07
The challenge of the Rotary Wing thrust of the NASA Fundamental Aeronautics Program is to develop and validate tools, technologies and concepts to overcome key barriers for rotary wing vehicles. Technologies of particular interest are as follows:

- **Modeling and Analysis for Conceptual Design and Sizing** - Tools are sought that enable rotorcraft conceptual design and sizing for a wide range of missions. Such tools should also enable systems studies to assess technology benefits. These tools typically model the various rotorcraft components using lower fidelity, approximate and/or empirically based models, and improvements in these tools can be made through developing more accurate rotorcraft component models that are appropriate for conceptual design. The development of methodologies, tools and techniques that include rotorcraft handling qualities during conceptual design is of particular interest with topics including: flight control architecture and handling qualities measures; rotorcraft configuration and data requirements; and methods for integration into conceptual design and sizing codes and analyses. Additional topics of interest include, but are not limited to: engine and drive system models over large rotor speed ranges; auto generation of airfoil tables and analysis and optimization of airfoil sections; noise estimation methods for rotor, engine and drive systems; and airspace performance analysis tools for rotorcraft.

- **Advanced Turboshaft Engines with Variable-Speed Power-Turbine Capability** - Research (modeling, computational work, experiments) that addresses variable-speed power turbine (VSPT) and gas-generator aerothermodynamic, mechanical, and materials challenges is sought. The Rotary Wing Project of the Fundamental Aeronautics Program performs research and development of engine/driveline technologies to enable large civil tilt-rotor vehicles with variable-speed-rotor capability. Options for achieving main-rotor speed variability include a variable-speed transmission and/or a variable-speed power turbine. Key challenges for turboshaft engines of future rotary wing vehicles include high-efficiency power-turbine performance over a wide variable-speed range (50%)

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

Sub Topics:
Propulsion Efficiency - Turbomachinery Technology Topic A3.08
There is a critical need for advanced turbomachinery and heat transfer concepts, methods and tools to enable NASA to reach its goals under the Fundamental Aeronautics Program. These goals include dramatic reductions in aircraft fuel burn, noise, and emissions, as well as an ability to achieve mission requirements for, Subsonic, Rotary Wing, and High Speed Project flight regimes and fundamental research under the Aeronautical Sciences Project. Turbomachinery includes rotating machinery in the high and low pressure spools, transition ducts, purge and bleed flows, casing and hub. In the compression system, advanced concepts and technologies are required to enable higher overall pressure ratio, high stage loading and wider operating range while maintaining or improving aerodynamic efficiency. Such improvements will enable reduced weight and part count, and will enable advanced variable cycle engines for various missions. In the turbine, the very high cycle temperatures demanded by advanced engine cycles place a premium on the cooling technologies required to ensure adequate life of the
turbine component. Reduced cooling flow rates and/or increased cycle temperatures enabled by these technologies have a dramatic impact on the engine performance.

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

- **Advanced instrumentation** to enable time-accurate, detailed measurement of unsteady velocities, pressures and temperatures in three-dimensional flowfields such as found in turbomachinery components and transition ducts. This may include instrumentation and measurement systems capable of operating in conditions up to 900 °F and in the presence of shock-blade row interactions, as well as in high speed, transonic cascades. The instrumentation methods may include measurement probes, non-intrusive optical methods and post-processing techniques that advance the state-of-the-art in turbomachinery unsteady flowfield measurement for purposes of accurately resolving these complex flowfield. Instrumentation enabling measurements and characterization of unsteady turbulent flows at combustor exit temperatures that can be implemented in warm test rigs and actual engines is also included. Instrumentation specific to turbomachinery and heat transfer should be proposed under this subtopic.

- **Advanced turbomachinery active and passive flow control concepts** to enable increased high stage loading in single and multi-stage axial compressors while maintaining or improving aerodynamic efficiency and operability. Technologies are sought that would reduce dependence on traditional range extending techniques (such as variable inlet guide vane and variable stator geometry) in compression systems. These may include flow control techniques near the compressor end walls and on the rotor and stator blade surfaces. Technologies are sought to reduce turbomachinery sensitivity to tip clearance leakage effects where clearance to chord ratios may be on the order of 5% or above. Technologies are sought to eliminate flow separation in low pressure turbines and transition ducts, improve off-design operation and enable variable cycle operation.

- **Novel turbine cooling concepts** are sought to enable very high turbine cooling effectiveness especially considering the manufacturability of such concepts. These concepts may include film cooling concepts, internal cooling concepts, and innovative methods to couple the film and internal cooling designs. Concepts proposed should have the potential to be produced with current or forthcoming manufacturing techniques. The availability of advanced manufacturing techniques may actually enable improved cooling designs beyond the current state-of-the-art. Concepts are also sought for the cooling of ceramic-based turbine materials such as ceramic matrix composite (CMC) vanes and blades.

- **Computational technologies** allowing accurate predictions of turbomachinery flows and heat transfer including active and passive flow control features. Advanced turbulence and LES models that can account for complex three-dimensional flows common in turbomachinery. Models of flow control devices that enable incorporating them in RANS based CFD codes. Particular interest is in CFD method based on overset moving grids that will enable flexibility in studies of small features as cooling holes and active and passive flow control devices.

**Sub Topics:**

- **Ground and Flight Test Techniques and Measurement Technologies**

NASA is committed to effective support and execution of flight research. This includes developing test techniques that improve the control of in-flight test conditions, expanding measurement and analysis methodologies, and improving test data acquisition and management with sensors and systems that have fast response, low volume, minimal intrusion, and high accuracy and reliability. By using state-of-the-art flight test techniques along with novel measurement and data acquisition technologies, NASA will be able to conduct flight research more effectively and also meet the challenges presented by NASA's cutting edge research and development programs. NASA's
Aeronautical Test Program (ATP) supports a variety of flight regimes and vehicle types ranging from civil transports, low-speed, to high-altitude long-endurance to supersonic and access-to-space. Therefore, this solicitation can cover a wide range of flight conditions and craft.

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

Flight research and test capability proposals should be relevant to the following NASA aeronautical test facilities: Western Aeronautical Test Range, Aero-Structures Flight Loads Laboratory, Flight Research Simulation Laboratory, and Research Test Bed Aircraft. Proposals should address innovative methods and technologies to extend the health, maintainability and test capabilities of these flight research support facilities. Areas of interest include:

- Multi-disciplinary nonlinear dynamic systems prediction, modeling, identification, simulation, and control of aerospace vehicles.
- Test techniques for conducting in-flight boundary layer flow visualization, shock wave propagation, Schlieren photography, near and far-field sonic boom determination, atmospheric modeling.
- Active flow control techniques for performance and acoustic noise reduction.
- Intelligent health monitoring for hybrid or all electric distributed propulsion systems.
- Methods for significantly extending the life of electric aircraft propulsion energy sources (e.g., batteries).
- Innovative acoustic noise reduction technology for structural and propulsion systems.
- Techniques for manufacturing lighter, thinner, and tougher engine fan blades than current state-of-the-art.
- Verification & Validation (V&V) of complex highly integrated flight systems including hardware-in-the-loop testing.
- Innovative techniques that enable safer operations of aircraft (e.g., non-destructive examination of composites through ultrasonic techniques).

Sub Topics: