NASA SBIR 2004 Phase I Solicitation

Aerospace Technology

Aviation Safety and Security Topic A1

The worldwide commercial aviation accident rate has been nearly constant over the past two decades. Although the rate is very low, increasing traffic over the years may result in the absolute number of accidents also increasing. Without improvements, doubling or tripling of air traffic by 2017 could lead to 50 or more major accidents a year. This number of accidents would have an unacceptable impact on the air transportation system. The goal of NASA's Aviation Safety and Security Program (AvSSP) is to develop and demonstrate technologies that contribute to a reduction in the fatal aviation accident rate. Research and technology will address accidents involving hazardous weather, controlled flight into terrain, human-error caused accidents and incidents, and mechanical or software malfunctions. The Program will also develop and integrate information technologies needed to build a safer aviation system and provide information for the assessment of situations and trends that indicate unsafe conditions before they lead to accidents. NASA researchers are also looking at ways to adapt aviation technologies already being developed to improve aviation security. The AvSSP is focusing on areas where NASA expertise could make a significant contribution to security: 1) the hardening of aircraft and their systems, 2) secure airspace operation technologies, 3) improved systems to screen passenger and cargo information, and 4) sensors designed to better detect threats. NASA seeks highly innovative proposals that will complement its work in Aviation Safety and Security in the following subtopic areas:

Sub Topics:

A1.01 Crew Systems Technologies for Improved Aviation Safety

Lead Center: LaRC

NASA takes a crew-centered approach to improving aviation safety and, therefore, specifically investigates human error roots of accidents and incidents to identify the basis for innovating crew-centered automation and interface technologies. These technologies must be evaluated sensitively and in operationally-valid contexts. NASA develops evaluation methodologies and tools to sensitively and robustly assess aviation safety technologies. Finally, to ensure adoption, NASA investigates how innovative aviation safety technologies can be effectively used in airspace operations and be supported by pilot procedures and instruction.

NASA seeks highly innovative technologies to improve airspace safety with a crew-centered focus. Such advanced technologies may meet these goals by ensuring appropriate situation awareness; facilitating and extending human perception, information interpretation, and response planning and selection; counteracting human information processing limitations, biases, and error-tendencies; assisting in response planning and execution; and ensuring individuals have access to use the airspace system as appropriate. In addition, NASA seeks tools and methods for measuring and assessing pilots' and collaborating operators' performance in complex, dynamic systems. Technologies may take the form of tools, models, operational procedures, instructional systems, prototypes, and devices for use in the flight deck, elsewhere by pilots, or by those who design systems for crew use. Technologies should have a high potential for emerging as marketable products, of which there are a number of examples:
- Novel technologies to improve information presentation;
- Intelligent systems monitoring and alerting technologies for improved failure mode identification, recovery, and threat mitigation;
- Designs for human-error prevention, detection, and mitigation;
- Decision-support tools and methods to improve communication, collaborative and distributive decision-making;
- Data fusion technologies to integrate disparate sources of flight-related information for improved situation awareness and appropriate workload modulation;
- Support for crew response planning and selection;
- Computational approaches to determine and appropriately modulate crew engagement, workload, and situation awareness;
- Human-centered information technologies to improve the performance of less-experienced pilots and pilot populations with special requirements;
- Avionics designers and/or certification specialist tools to improve the application of human-centered principles;
- Human-error reliability approaches to analyzing flight deck displays, decision aids, and procedures, and designs that consider presentation of uncertain data; and
- Individual and team performance metrics, analysis methods, and tools to better evaluate and certify human and system performance for use in operational airspace environments, simulation, and model-based analyses.

A1.02 Aviation Safety and Security: Fire, Icing and Propulsion-Safe and Secure CNS Aircraft Systems

Lead Center: GRC

NASA is concerned with the prevention of hazardous conditions and the mitigation of their effects when they do occur. One particular emphasis is on the prevention and suppression of in-flight fire and explosions, as well as fuel tank explosions and post-crash fires. Aircraft fires represent a small number of actual accident causes, but the number of fatalities due to in-flight, post-crash, and on-ground fires is large.

A second emphasis is on mitigating the safety risk and collateral damage due to unexpected failures of rotating components. Although the FAA mandates a blade containment and rotor unbalance requirement (FAR Part 33, Section 33.94) as part of the airworthiness standards for turbine aircraft engines, there are substantial potential (aircraft-engine) system benefits to be gained by enabling safety assured, lighter weight, lower cost, and more damage-tolerant designs for engine case/containment systems and associated (primary load path) structures.
A third emphasis for this subtopic is on propulsion system health management, in order to prevent or accommodate safety-significant malfunctions and damage. Past advances in this area have helped improve the reliability and safety of aircraft propulsion systems; however, propulsion system component failures are still a contributing factor in numerous aircraft accidents and incidents. Advances in technology are sought which help to further reduce the occurrence of and/or mitigate the effects of safety-significant propulsion system malfunctions and damage.

A fourth emphasis is to increase the level of safety for all aircraft flying in the atmospheric icing environment. To maximize the level of safety, aircraft must be capable of handling all possible icing conditions by either avoiding or tolerating the conditions. Proposals are invited that lead to innovative new approaches or significant improvements in existing technologies for in-flight icing conditions avoidance (icing weather information systems) or tolerance (airframe and engine ice protection systems and design tools).

A final emphasis for this subtopic is protection and hardening of the aircraft’s communication, navigation and surveillance (CNS) systems, as well as enabling new aviation security applications through improved air-to-ground data link communications. Technology is needed to harden the CNS systems, both onboard and air-to-ground, and to provide next-generation airborne, ground- and space-based surveillance systems.

With these emphases in mind, products and technologies that can be made affordable and retrofitable within the current aviation system, as well as for use in the future, are sought:

- Technology for prevention and suppression of potential in-flight fires in fuel tanks, cargo bays, insulation, and other inaccessible locations due to accidents or deliberate acts.
- Technology to provide fuel tank vapor flammability reduction and onboard oxygen generation.
- Technology to minimize fire hazards in crashes and to prevent or delay fires.
- Advanced material or structural configuration concepts to prevent catastrophic failures of engine components, or to ensure fragment containment.
- Computational tools for analyzing blade-loss events and designing structural components and systems accordingly.
- Health management technologies such as instrumentation, ground and on-wing nondestructive inspection, health monitoring algorithms, and fault accommodating logic, which will predict, diagnose, prevent, assess, and allow recovery from propulsion system malfunctions or damage.
- Ground and airborne radome technologies for microwave wavelength radar and radiometers that remain clear of liquid water and ice in all weather situations.
- *In situ* icing environment measurement systems that can provide practical, very low-cost validation data for emerging icing weather information systems and atmospheric modeling. Measured information must include location, altitude, cloud liquid water content, temperature, and ideally cloud particle sizing and phase information. Solutions envisioned would use radiosonde-based systems.
- Ice protection and detection technology submittal must provide significant improvements over current systems or address new design needs. Areas of improvement can be considered to be: efficient thermal protection systems, including composite wing or structures applications, wide area ice detection, detection that serves both ground and in-flight applications, and de-icing systems that operate at near anti-icing
performance. Any submittal must be cost competitive to current technologies.

- Next generation capabilities for remote monitoring of onboard systems and the aircraft environment.
- Secure onboard information processing, computing and air/ground networking.
- Technologies to harden aircraft communication, navigation, and surveillance systems against abnormality and deliberate attack.

A1.03 Technologies for Improved Aviation Security

Lead Center: LaRC
Participating Center(s): ARC

Following the attacks on September 11, 2001, NASA recognized that it now shared the responsibility for improving homeland security. The NASA Strategic Plan includes requirements to enable a more secure air transportation system and to create a more secure world by investing in technologies and collaborating with other agencies, industry, and academia. NASA’s role in civil aeronautics has always been to develop high-risk, high-payoff technologies to meet critical national aviation challenges, and ensuring the security of the nation from terrorist attacks is a high priority national challenge.

NASA aims to develop and advance technologies that will reduce the vulnerability of the Air Transportation System (ATS) to threats or hostile acts, and identify and inform users of potential vulnerabilities in a timely fashion. Specific technical focus areas include system-wide security risk assessment and incident precursor identification; enhanced flight procedures and onboard systems to protect critical infrastructures and key assets and enable the safe recovery of a seized aircraft; definition of directed energy threats to the aircraft and on/off-board systems that will provide surveillance and countermeasures of these threats; integrated adaptive control systems to detect and compensate for vehicle damage; hardened and security-enhanced aircraft networks and data links; remote monitoring of the aircraft environment and systems; new materials for composite fire and explosive resistant fuselage structures; advanced, airborne, in situ detection of chemical and biological terror agents; and commercial aircraft fuel tank inerting. Technologies under development are intended for the next-generation ATS, however, issues such as retrofitting, certification, system implementation, and cost-benefit analysis must be considered during the technology development process.

NASA seeks highly innovative and commercially viable technologies that will improve aviation security by addressing threats to air vehicles, as well as the ATS. Specific areas of focus include: preventing aircraft from being used as a weapon of mass destruction (WMD); protection from man-portable air defense systems (ManPADS) and electromagnetic energy (EME) attacks; light-weight, fire- and explosive-resistant composite materials; explosive resistant fuel systems, ground-based decision support tools needed to monitor airspace security concerns; reporting systems to monitor security violations; secure encrypted data link systems, intrusion-tolerant communications networks and communications systems to support emerging aviation security applications; tools to support real-time management of security information; and chemical and biological sensor development. Technologies may take the form of tools, models, techniques, procedures, substantiated guidelines, prototypes, and devices:
• Intelligent systems monitoring and alerting technologies;
• Technologies that enable secure communications, navigation, and surveillance onboard the aircraft;
• Secure communications systems to support emerging aviation security applications;
• Onboard and ground surveillance and interception systems for aircraft immunity to electromagnetic interference and electromagnetic pulse intrusions;
• Technologies and methods to provide accurate information and guidance to enable pilot avoidance of protected airspace, maintain positive identity verification of aircraft operators, determine pilot intent, and deny flight control access to unauthorized persons;
• Flight control systems that accommodate vehicle damage relative to changes in aircraft stability, control, and structural load characteristics;
• Material systems, fuselage structural concepts, and fuel systems that are resistant to fire and explosions;
• Fuel system technologies that prevent or minimize in-flight vulnerability of civil transport aircraft due to small arms or man-portable defense systems type projectiles;
• Decision-support tools and methods to improve communication, collaborative, and distributive decision-making;
• Data fusion technologies for integrating disparate sources of flight-related information;
• Computational approaches to monitoring crew health, stress level, state of duress, and performance; and
• Validation methods and tools for advanced safety and security critical systems.

A1.04 Automated On-Line Health Management and Data Analysis

Lead Center: AFRC
Participating Center(s): ARC

Online health monitoring is a critical technology for improving transportation safety in the 21st century. Safe, affordable, and more efficient operation of aerospace vehicles requires advances in online health monitoring of vehicle subsystems and information monitoring from many sources over local and wide area networks. Online health monitoring is a general concept involving signal-processing algorithms designed to support decisions related to safety, maintenance, or operating procedures. The concept of online health monitoring emphasizes algorithms that minimize the time between data acquisition and decision-making.

This subtopic seeks solutions for online aircraft subsystem health monitoring. Solutions should exploit multiple computers communicating over standard networks where applicable. Solutions can be designed to monitor a specific subsystem or a number of systems simultaneously. Resulting commercial products might be implemented in a distributed decision-making environment such as onboard diagnostics and management systems, or maintenance and inspection networks of potentially global proportion.
Proposers should discuss who the users of resulting products would be, e.g., research/test/development; manufacturing; maintenance depots; flight crew; Unmanned Aerial Vehicles/Remotely Operated Aircraft (UAV/ROA) aircraft operators; airports; flight operations or mission control; or airlines. Proposers are encouraged to discuss data acquisition, processing, and presentation components in their proposal. Proposals that focus solely on sensor development should not be submitted to this subtopic. Such proposals should be addressed to sensor development subtopics such as the Flight Sensors, Sensor Arrays and Airborne Instruments for Flight Research subtopic.

Examples of desired solutions targeted by this subtopic follow:

- Real-time autonomous sensor validity monitors;
- Flight control system or flight path diagnostics for predicting loss of control;
- Automated testing and diagnostics of mission-critical avionics;
- Structural fatigue, life cycle, static, or dynamic load monitors;
- Automated nondestructive evaluation for faulty structural components;
- Electrical system monitoring and fire prevention;
- Applications that exploit wireless communication technology to reduce costs;
- Model-reference or model-updating schemes based on measured data, which operate autonomously;
- Proactive maintenance schedules for rocket or turbine engines, including engine life-cycle monitors;
- Predicting or detecting any equipment malfunction;
- Middleware or software toolkits to lower the cost of developing online health monitoring applications; and
- Innovative solutions for harvesting, managing, archival, and retrieval of aerospace vehicle health data.

Vehicle Systems Topic A2

The Vehicle Systems Program is about Outcomes for the Public Good: Environmentally Friendly Aircraft, Air Vehicles for Public Mobility, Superior Air Power, and New Aeronautical Missions. Vehicle Systems does this by looking at three objectives: transportation system concepts, vehicle capabilities, and enabling technologies. The Vehicle Systems Program is developing revolutionary technologies at the laboratory, component, or subsystem level. The majority of the resources are allocated for fundamental research to find breakthrough technologies
through three projects: Tailored Lightweight Structures, Robust Reliability, and Electric Hybrid Propulsion. These projects develop the fundamental technologies needed to enable the change state in aeronautics. Existing and newfound knowledge is refined through field tests through three more projects: Efficient Aerodynamic Configurations, Ultra-Efficient Engine Technology, and Quiet Aircraft Technology. These projects focus on the integration of these technologies into subsystems and systems that can be developed with industry partners into highly used products. To measure the overall progress, Vehicle Systems accelerates the technology integration and maturation through two Vehicle Sector Integration Projects: Strategic Vehicle Architectures and Flight and System Demonstrations. The Strategic Vehicle Architectures Project conducts system level integration studies, and the Flight and Systems Demonstrations Project conducts concept development and research flight-testing.

Sub Topics:

**A2.01 Propulsion System Emissions and Noise Prediction and Reduction**

**Lead Center: GRC**

**Emissions**

Current environmental concerns with subsonic and supersonic aircraft center around the impact of emissions on the Earth’s climate. Carbon dioxide (CO₂) and oxides of nitrogen (NOₓ) are the major emitters of concern coming from commercial aircraft engines. Current state-of-the-art engines and combustors in most subsonic aircraft are fuel-efficient and meet the 1996 ICAO nitrogen oxide (NOₓ) limits, but may not able to meet the future stringent regulations. Recent observations of aircraft exhaust contrails (from both subsonic and supersonic flights) have resulted in growing concern over aerosol, particulate, and sulfur levels in the fuel. In particular, aerosols and particulates from aircraft are suspected of producing high altitude clouds, which could adversely affect the Earth’s climatology. Advanced concepts research for reducing CO₂ and NOₓ, and analytical and experimental research in characterization (intrusive and non-intrusive) and control (through component design, controls, and/or fuel additives) of gaseous, liquid, and particulates of aircraft exhaust emissions is sought. Specific aircraft operating conditions of interest include the landing-takeoff cycle, as well as the in-flight portion of the mission. There are a number of areas of particular interest:

- New concepts for reducing CO₂, oxides of nitrogen (NO, NO₂, NOₓ), unburned hydrocarbons; carbon monoxide, particulate, and aerosols emitters (novel propulsion concepts, injector designs to improve fuel mixing, catalysts, additives, etc.)

- New fuels for commercial aircraft that minimize CO₂ and NOₓ emissions

- Innovative active control concepts for emission minimization with an integrated systems focus including emission modeling for control, sensing, and actuation requirements, control logic development, and experimental validation are of interest.

- New instrumentation techniques are needed for the measurement of engine emissions such as NOₓ, SOₓ, and HOₓ, atomic oxygen and hydrocarbons in combustion facilities and engines. Size, size distributions, reactivity, and constituents of aerosols and particulates are needed, as are temperature, pressure, density, and velocity measurements. Optical techniques that provide 2-D and 3-D data; time history measurements; and thin film, fiber optic, and micro-electrical-mechanical systems (MEMS)-based sensors are of interest.

**Noise**

Engine noise reduction technologies are required in the areas of propulsion source noise, nacelle aeroacoustics, and engine/airframe integration. Some of the key technologies needed to achieve these goals are revolutionary propulsion systems for reduced noise without significant increases in cost and emissions. Noise reduction concepts need to be identified that provide economical alternatives to conventional propulsion systems. NASA is soliciting proposals in one or more of the following areas for propulsion system noise reduction:
Innovative acoustic source identification techniques for turbomachinery noise: The technique shall be described for a relevant source. Plans for a Phase II demonstration should be included for the Phase I proposal. A simple source may be used where the solution is known to demonstrate the technique. A clear explanation on how the technique can be applied to turbofan engines should be included. The technique should be capable of identifying sources contributing to dominant engine components, such as fan and jet noise.

Fan Noise: The technique shall be capable of separating fan sources such as fan-alone versus fan/stator interaction for both tones and broadband noise. Sufficient resolution is needed to determine the location of the dominant sources on the aerodynamic surfaces. Jet Noise: The technique shall be capable of locating both internal and external mixing noise for dual-flow nozzles found in modern turbofans. Innovative turbofan source reduction techniques. Methods shall emphasize noise reduction methods for fan, jet, and core components without compromising performance for turbofan engines. A resulting engine system that incorporates one or more of the proposed methods should be capable of reducing perceived noise levels anywhere from 10 to 20 effective perceived noise level (EPNdB) relative to FAR 36, Stage 3 certification levels.

Revolutionary propulsion concepts for lower emissions and noise (proposed as alternatives to turbofan engines). Feasibility studies shall be done that demonstrate the potential for 20 EPNdB engine noise reduction relative to FAR 36, Stage 3 certification levels and 90% reduction in NO\textsubscript{x} emissions standards relative to current International Civil Aviation Organization (ICAO) regulations for commercial aircraft concepts.

Enabling technologies shall be identified for future research.

A2.02 Electric and Intelligent Propulsion Technologies for Environmentally Harmonious Aircraft

Lead Center: GRC

Electric aircraft propulsion and power systems have the potential to completely eliminate harmful emissions from aircraft while at the same time improving energy efficiency. Major strides have been achieved in the development of fuel cells, especially in the automotive field. NASA is pursuing the application of fuel cell technology for both aircraft power and propulsion. There are still major technical advances required to make a commercially viable electric aircraft a reality, but this goal now appears to be achievable, possibly even in the nearer term. To achieve the realization of environmentally harmonious 21st century air vehicles, innovations are needed to enable highly efficient, low cost, power dense (weight and volume) electric aircraft propulsion and power systems.

Technical areas of interest in electric aircraft propulsion and power include, but are not limited to, fuel cells, power management, power conditioning, power distribution, actuators, motors and drive systems, sensors and fuel storage (especially hydrogen). Highly integrated dual function components and systems that have the potential to reduce overall vehicle and subsystem weight are of special interest (e.g., power conductors that are integrated into the airframe structure, motors directly integrated into the fan/propeller structure). Synergistic use of onboard cryogenic hydrogen fuel is also of interest. Both component and system level technologies are solicited. Proposals must show improvements to the state-of-the-art and viable application to aircraft.
Implementation of intelligent propulsion concepts requires advancements in the area of robust control synthesis techniques and automated diagnostics, and development of advanced enabling technologies such as nanoelectronics, smart sensors, and actuators. Attention will also need to be paid to integration of the active component control and diagnostics technologies with the control of the overall propulsion system. This will require moving from the current analog control systems to distributed control architectures.

Intelligent propulsion technologies that address electric, turbine, jet and/or hybrid aerospace propulsion systems are of interest. Proposals focusing on development of advanced diagnostics, health monitoring and control concepts, smart sensors, electronics and actuators for enabling self-diagnosis and prognosis, and self-reconfiguration capabilities are being sought. Concepts of special interest include those that integrate distributed sensing with actuation and control logic for micro-level control of parameters (such as propulsion system internal flows that impact performance and environment). Novel instrumentation approaches that provide valuable information for development and validation of technologies for self-diagnosis, prognosis, and reconfiguration are also of interest.

A2.03 Revolutionary Technologies and Components for Propulsion Systems

Lead Center: GRC

NASA seeks highly innovative concepts for propulsion systems and components for advanced high-speed aerospace vehicles to support missions, such as access to space, global cruise, and high-speed transports. The main emphasis in this subtopic is on high-risk, breakthrough technologies in order to revolutionize aerospace propulsion over a broad flight spectrum, up to Mach 8. Proposals offering significant advancements in critical components and designs for propulsion systems and subsystems are sought. Specific technical areas include the following:

- Advanced cooling concepts that minimize coolant penalties can include innovative cooling systems, fuel cooling of the combustor, and endothermic fuels and/or fuel additives to increase the heat-sink capacity or cooling capacity of fuels.
- Innovative concepts relating to the combustion process, including fuel injectors, piloting, flame holding techniques for increased performance and decreased emissions, techniques to identify the onset of combustion instability in lean-burn and/or rich-burn, low NOₓ combustor, ramjet combustion and active and passive combustion controls in order to extend the operability of the combustion components to a wider range of operating conditions.
- New inlet concepts to meet functional airflow needs of high Mach number propulsion. For instance, a variable geometry, supersonic, mixed compression inlet. Compatibility with turbomachinery and mode transition across the speed range should be addressed. Special attention should be given to combustor demands along a realistic flight corridor. This flight corridor must be compatible with turbine engine thermal-structure limits.
- New techniques to improve the aerodynamic performance and operability of the inlet, including highly offset subsonic diffusers and designs for boundary layer control, minimizing engine unstart susceptibility, and techniques to identify and control the onset of mode transition between different propulsion concepts within the same internal flow path or dual flow paths.
• New controllable and reliable nozzle concepts with optimum expansion efficiency and thrust vectoring capability, including a computational nozzle design methodology to study various geometries and chemistry effects.

• Enabling technologies of components and subsystems that allow turbomachinery to operate at high-speed flight conditions. Specific examples include 1) a lightweight, high-pressure ratio compressor which must be protected or removed from the extremely high temperature primary air stream; 2) applications of micro-electrical-mechanical systems (MEMS) that demonstrate the potential to enhance the performance and reduce the cost and weight; and 3) innovative inlet flow conditioning.

• New concepts for combined or combination cycles, in particular those including turbine propulsion. Alternate engine cycles that meet a unique mission requirement (e.g., global reach, access to space, etc.), including pulse detonation, ramjets, scramjets, and rockets. Proposals can also include development of unique components required for the maturation of alternate propulsion cycles, such as inlets, diffusers, nozzles, air valves, fuel injectors, combustors, etc.

• Innovative integration technologies among components or subsystems that significantly improve the performance or reduce the cost of the overall propulsion systems are sought. This includes new collaborative and concurrent engineering tools for analysis and design. These tools could reduce the need for empiricism, thus facilitating early evaluation of interactions among propulsion components. "Intelligent" design tools, based on technologies such as evolutionary algorithms and neural networks, are also of interest. All design/analysis tool proposals must include a propulsion technology development application.

A2.04 Airframe Systems Noise Prediction and Reduction

Lead Center: LaRC

Innovative technologies and methods are necessary for the design and development of efficient, environmentally acceptable airplanes, rotorcraft, and advanced aerospace vehicles. In support of the goal of the Quiet Aircraft Technology Project for reduced noise impact on community residents, improvements in noise prediction and control are needed for jet, propeller, rotor, fan, turbomachinery, and airframe noise sources. In addition, improvements in prediction and control of noise transmitted through aerospace vehicle structures are needed to reduce noise impact on aircraft passengers and crew and on launch vehicle payloads. Innovations in the following specific areas are solicited:

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

• Simulation and prediction of aeroacoustic noise sources particularly for airframe noise sources and situations with significant interactions between airframe and propulsion systems.

• Concepts for active and passive control of aeroacoustic noise sources for conventional and advanced aircraft configurations.

• Innovative active and passive acoustic treatment concepts for engine nacelle liners and concepts for high-intensity acoustic sources, which can be used to characterize engine nacelle liner materials.

• Reduction technologies and prediction methods for rotorcraft and advanced propeller aerodynamic noise.
• Development of synthesis and auditory display technologies for subjective assessments of aircraft community and interior noise.

• Development and application of flight procedures for reducing community noise impact of rotorcraft and subsonic and future supersonic commercial aircraft while maintaining safety, capacity, and fuel efficiency.

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

• Technologies and techniques for active and passive interior noise control for aircraft and advanced aerospace vehicle structures.

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

A2.05 Revolutionary Materials and Structures Technology for Propulsion and Power Components

Lead Center: GRC

This subtopic addresses structural and mechanical components, subsystems and advanced materials for Aerospace Propulsion and Power Systems. Proposals are sought for innovative and commercially viable concepts that address objectives such as lighter weight, reduced operational costs, lower noise, lower emissions, higher temperature capability, increased efficiency and/or operational margin, greater safety and reliability, and more time on-station for aircraft, satellites, and power equipment.

One focus is on problems related to structural and mechanical components and subsystems that operate at high temperatures, in hostile aero-thermo-chemical environments or space environments, and at high stresses under cyclic loading conditions. Interests include magnetic, foil, and fluid film bearings, tribological coatings, seals, transmissions, noise reduction, flight weight electric motors, rotating equipment, aeroelasticity, ballistic impacts, fatigue, fracture, life prediction, probabilistic methods, and structural health monitoring (diagnostics and prognosis).

A second focus addresses advanced materials, their development, and their application to primary propulsion systems such as aircraft gas turbines, rocket and turbine-based combined cycle engines, and rocket engines as well as auxiliary power sources in aircraft and space vehicles. Materials of interest include any classes especially those used in propulsion systems such as high-temperature polymers and composites, metals including titanium alloys and nickel-based super alloys, ceramics and ceramic matrix composites, and coatings for these, and processes for their economical and reliable preparation.

A2.06 Smart, Adaptive Aerospace Vehicles With Intelligence

Lead Center: LaRC
This subtopic emphasizes the roles of aerodynamics, aero thermodynamics, adaptive software, vehicle dynamics in nonlinear flight regimes, and advanced instrumentation in research directed towards the identification, development and validation of enabling technologies that support the design of future, autonomous aerospace vehicle and platform concepts for aviation safety, and security vehicle systems. Some of the vehicle attributes envisioned by this subtopic include: a) "Smart" vehicle attributes—using advanced sensor technologies, flight vehicle systems are "highly aware" of onboard health and performance parameters, as well as the external flow field and potential threat environments; b) "Adaptive" vehicle attributes—flight avionics systems are reconfigurable, structural elements are self-repairing, flight control surfaces and/or effectors respond to changing flight parameters and/or vehicle system performance degradation; and c) "Intelligent" vehicle attributes—vehicle onboard processing and artificial intelligence technologies, interfaced with advanced vehicle structural component and subcomponent designs and appropriate actuating devices, reacts rapidly and effectively to changing performance demands and/or external flight and security threat environments. Future air vehicles with the above attributes will manage complexity, "know" themselves, continuously tune themselves, adapt to unpredictable conditions, prevent and recover from failures, and provide a safe environment.

For atmospheric vehicles and platforms, both military and civil applications are sought, while for aviation applications, emphasis is placed on configurations that enable the discovery of new aviation safety and security concepts. Concepts and corresponding enabling technologies are sought which expand the traditional boundaries of conventional piloted vehicles categories such as General Aviation (GA) or Personal Air Vehicles (PAV), as well as significantly advance the state-of-the-art in remotely operated vehicle classes such as Long-Endurance Sensing Platforms (LESP), Unmanned Aerial Vehicles (UAV) or Unmanned Combat Aerial Vehicles (UCAV) as they can relate to aviation safety and security. Furthermore, for Earth applications, special emphasis is placed on research proposals that attempt to provide solutions for a future state in which revolutionary vehicles operate in a highly integrated airspace including hub and spoke, point-to-point, long-haul, unmanned aircraft, green aircraft, as well as a future state where air vehicle designs reflect a high level of integration in performance, safety and security, airspace capacity, environmental impact and cost factors.

Specific areas of interest are:

- Conceptual flight vehicle/platform designs featuring variable levels of vehicle and airspace requirements integration, and/or smart, intelligent, and adaptive flight vehicle capabilities, as demonstrated by state-of-the-art systems analyses methods to determine enabling technologies and resulting impacts on future system integrated performance, environmental impact, and safety and security issues.

- New algorithms for predicting vehicle loads and response using minimal vehicle state information.

- Novel optimization methodologies to support conceptual design studies for highly-integrated flight vehicle and air space concepts and/or smart, intelligent and adaptive flight vehicle capabilities, which demonstrate appropriate design variable selection, scaling techniques, suitable cost functions, and improved computational efficiency.

- Physics-based modeling and simulation tools of multiple vehicle classes and corresponding airspace operations aspects to support scenario-based planning and requirements definition of highly integrated vehicle and airspace capacity concepts, including investigations of the potential use of virtual/immersive simulations on future engineering decision making processes.

- Micro-scale wireless communications, health monitoring, energy harvesting, and power-distribution technologies for large arrays of vehicle-embedded MEMS sensors and actuators.
A2.07 Revolutionary Flight Concepts

Lead Center: AFRC

This subtopic solicits innovative flight test experiments that demonstrate breakthrough vehicle or system concepts, technologies, and operations in the real flight environment. The emphasis of this subtopic is the feasibility, development, and maturation of advanced flight research experiments that demonstrate advanced or revolutionary methodologies, technologies, and concepts. It seeks advanced flight techniques, operations, and experiments that promise significant leaps in vehicle performance, operation, safety, cost, and capability; and may require a demonstration or validation in an actual flight environment to fully characterize or validate it.

The scope of this subtopic is broad and includes advanced flight experiments that accelerate the understanding, research, and development of advanced technologies and unconventional operational concepts. Examples extend to (but are not limited to) such things as inflatable aero-structures (new designs or innovative applications, new manufacturing methods, new materials, new in-flight inflation methods, and new methods for analysis of inflation dynamics), innovative control surface effectors (micro-surfaces, embedded boundary-layer control effectors, micro-actuators), innovative engine designs for UAV aircraft, alternative engines/motors/concepts, alternative fuels research (hydrocarbon, hydrogen, or regenerative), sonic boom reduction, noise reduction for Conventional Take-off and Landing/Short Take-off and Landing (CTOL/STOL) aircraft and engines, advanced mass transportation concepts, retrofit threat detection capabilities for civil transports, damage mitigation concepts, streamlining airport operations concepts, retrofitting existing airports for next generation airliners, alternative external vision systems, shroudless launch of aerodynamic shapes on the front of ELVs, aerodynamic systems optimization for planetary aircraft (Venus, Mars, Io, and/or Titan), flexible system stability derivative identification, innovative approaches to thermal protection that minimize aerodynamic performance degradation, innovative approaches to structures, stability, control, and aerodynamics integration schemes, and innovative approaches to incorporation of UAV operations into commercial airspace. This subtopic is intended to advance and demonstrate revolutionary concepts and is not intended to support evolutionary steps required in normal product development. Proposals should emphasize the need of flight testing a concept or technology as a necessary means of verifying or proving its worth; emphasis should also be given to multidisciplinary integration of advanced flight systems. The benefit of this effort will ultimately be more efficient aerospace vehicles, increased flight safety (particularly during flight research), and an increased understanding of the complex interactions between the vehicle or technology concept and the flight environment.

A2.08 Modeling, Identification, and Simulation for Control of Aerospace Vehicles in Flight Test

Lead Center: AFRC

Safer and more efficient design of advanced aerospace vehicles requires advancement in current predictive design and analysis tools. The goal of this subtopic is to develop more efficient software tools for predicting and understanding the response of an airframe under the simultaneous influence of structural dynamics, thermal dynamics, steady and unsteady aerodynamics, and the control system. The benefit of this effort will ultimately be an increased understanding of the complex interactions between the vehicle dynamical subsystems with an emphasis towards flight test validation methods for control-oriented applications. Proposals for novel multidisciplinary nonlinear dynamic systems modeling, identification, and simulation for control objectives are encouraged. Control objectives include feasible and realistic boundary layer and laminar flow control, aeroelastic maneuver performance, and load control including smart actuation and active aerostructural concepts, autonomous
health monitoring for stability and performance, and drag minimization for high efficiency and range performance. Methodologies should pertain to any of a variety of types of vehicles, such as Unmanned Aerospace Vehicles/Remotely Operated Aircraft (UAV/ROA), and flight regimes ranging from low-speed High-Altitude Long-Endurance (HALE) to hypersonic and access-to-space aerospace vehicles. Proposals should address one or more of the following:

- Accurate prediction with validation of steady and unsteady pressure, stress, and thermal loads;
- Effective multidisciplinary dynamics analysis algorithms with flight-test correlation capability conducive to validation with test data, such as with finite-element aeroservoelastic computations;
- Time-accurate simulation systems from nonlinear multidisciplinary dynamics models with applications toward flight-testing, such as with reduced-order CFD-based methods;
- Novel and efficient schemes for control-oriented identification of nonlinear aeroservoelastic dynamics from test data with provisions for uncertainty estimation and model correlation;
- Online and autonomous model update schemes for loads, aerodynamic, and aeroelastic model identification for stability and performance monitoring and prediction in adaptive control;
- Self-learning control strategies for aerostructural vehicles and development of enhanced real-time controls software and hardware for long-term onboard systems operation;
- Integration of modeling, analysis, simulation, and identification techniques for control objectives in a unified, compatible manner; and
- Innovative high-performance facilities for integrated simulation and graphical interface, or virtual reality systems, for multidisciplinary aerospace systems.

A2.09 Flight Sensors and Airborne Instruments for Flight Research

Lead Center: AFRC

Real-time measurement techniques are needed to acquire aerodynamic, structural, and propulsion system performance characteristics in flight and to safely expand the flight envelope of aerospace vehicles. The scope of this subtopic is the development of sensors or instrumentation systems for improving the state-of-the-art in aircraft flight testing. This includes the development of sensors to enhance aircraft safety by determining atmospheric conditions. The goals are to improve the effectiveness of flight testing by simplifying and minimizing sensor installation, measuring new parameters, improving the quality of measurements, and minimizing the disturbance to the measured parameter from the sensor presence or deriving new information from conventional techniques. This subtopic solicits proposals for improving airborne sensors and instrumentation systems in all flight regimes. These sensors and systems are required to have fast response, low volume, minimal intrusion and high accuracy and reliability. Innovative concepts are solicited in the areas that follow below.

Vehicle Condition Monitoring
Sensor development in support of vehicle health and performance monitoring includes the monitoring of aerodynamic, structural, propulsion, electrical, pneumatic, hydraulic, navigation, control, and communication subsystems. Proposals that focus solely on health management algorithms and systems integration should be addressed in the Automated Online Health Management and Data Analysis subtopic.

**Vehicle Environmental Monitoring**

Sensor development in support of vehicle environmental monitoring includes the following:

- Non-intrusive air data parameters (airspeed, air temperature, ambient and stagnation pressures, Mach number, air density, and flow angle);
- Off-surface flow field measurement and/or visualization (laminar, vortical, and separated flow, turbulence) zero to 50 meters from the aircraft;
- Boundary layer flow field, surface pressure distribution, acoustics or skin friction measurements or visualization; and
- Unusually small, light and low-power instrumentation for use on miniature aircraft and high altitude long endurance vehicles.

**Airspace Systems Topic A3**

NASA’s Airspace Systems (AS) program is investing in the development of revolutionary improvements and modernization for the air traffic management (ATM) system. The AS Program will enable new aircraft, new aircraft technologies and air traffic technology to safely maximize operational efficiency, flexibility, predictability, and access into airspace systems. The major challenges are to accommodate projected growth in air traffic while preserving and enhancing safety; provide all airspace system users more flexibility and efficiency in the use of airports, airspace, and aircraft; reduce system delays; enable new modes of operation that support the FAA commitment to "Free Flight" and maintain pace with a continually evolving technical environment and provides for doorstep-to-destination transportation developments. AS Program objectives are:

- Improve mobility, capacity, efficiency and access of the airspace system;
- Improve collaboration, predictability and flexibility for the airspace users;
- Enable modeling and simulation of air transportation systems;
- Enable runway-independent aircraft and general aviation operations; and
- Maintain system safety and environmental protection.

NASA is working to develop, validate, and transfer advanced concepts, technologies and procedures through partnership with the Federal Aviation Administration (FAA), other government agencies, and in cooperation with the U.S. aeronautics industry.

**Sub Topics:**
A3.01 Next Generation Air-Traffic Management Systems

Lead Center: ARC

Participating Center(s): AFRC

The challenges in Air Traffic Management (ATM) are to create the next generation system and to develop the optimal plan for transitioning to the future system. This system should be one that (1) economically moves people and goods from origin to destination on schedule, (2) operates without fatalities or injuries resulting from system or human errors or terrorist intervention, (3) seamlessly supports the operation of unmanned aerial vehicles (UAVs) or remotely operated aircraft (ROAs), (4) is environmentally compatible, and (5) supports an integrated national transportation system and is harmonized with global transportation. This can only be achieved by developing ATM concepts characterized by increased automation and distributed responsibilities. It requires a new look at the way airspace is managed and the automation of some controller functions, thereby intensifying the need for a careful integration of machine and human performance. As these new automated and distributed systems are developed, security issues need to be addressed as early in the design phase as possible.

To meet these challenges, innovative and economically attractive approaches are sought to advance technologies in the following areas:

- Decision support tools (DST) to assist pilots, controllers, and dispatchers in all parts of the airspace (surface, terminal, en route, command center)
- Integration of DST across different airspace domains
- Next generation simulation and modeling capability—models of uncertainty and complexity, National Airspace System (NAS) operational performance, economic impact
- Distributed decision making
- Security of advanced ATM systems
- System robustness and safety—sensor failure, threat mitigation, health monitoring
- Weather modeling and improved trajectory estimation for traffic management applications
- Role of data exchange and data link in collaborative decision-making
- Modeling of the NAS
- Distributed complex, real-time simulations—components with different levels of fidelity, human-in-the-loop decision agents
- Integrated ATM/aircraft systems that reduce noise and emissions
- Automation concepts for advanced ATM systems and methodologies that address transitioning to more automated systems
- Application of methodologies from other domains to address ATM research issues
- Intelligent software architecture
- Runway-independent (e.g., Vertical Take-off Landing [VTOL], Short Take-off and Landing [STOL], and Vertical/Short Take-off and Landing [V/STOL]) aircraft technologies required to meet national air transportation needs, to satisfy requirements for airline productivity, passenger acceptance, and community friendliness, and autonomous operations
- Automated, real-time detect, see, and avoid operations
- Intermodal transportation technologies
- Each of the abovementioned technologies and other technologies specifically fostering the operation of unpiloted aircraft within NAS under control of the ATM system, including, but not limited to, innovative control, navigation, and surveillance (CNS) concepts; also considering high altitude, long endurance operations.

Crew Systems Technologies for Improved Aviation Safety Topic A1.01

NASA takes a crew-centered approach to improving aviation safety and, therefore, specifically investigates human error roots of accidents and incidents to identify the basis for innovating crew-centered automation and interface technologies. These technologies must be evaluated sensitively and in operationally-valid contexts. NASA develops evaluation methodologies and tools to sensitively and robustly assess aviation safety technologies. Finally, to ensure adoption, NASA investigates how innovative aviation safety technologies can be effectively used in airspace operations and be supported by pilot procedures and instruction.

NASA seeks highly innovative technologies to improve airspace safety with a crew-centered focus. Such advanced
technologies may meet these goals by ensuring appropriate situation awareness; facilitating and extending human perception, information interpretation, and response planning and selection; counteracting human information processing limitations, biases, and error-tendencies; assisting in response planning and execution; and ensuring individuals have access to use the airspace system as appropriate. In addition, NASA seeks tools and methods for measuring and assessing pilots’ and collaborating operators’ performance in complex, dynamic systems. Technologies may take the form of tools, models, operational procedures, instructional systems, prototypes, and devices for use in the flight deck, elsewhere by pilots, or by those who design systems for crew use. Technologies should have a high potential for emerging as marketable products, of which there are a number of examples:

- Novel technologies to improve information presentation;
- Intelligent systems monitoring and alerting technologies for improved failure mode identification, recovery, and threat mitigation;
- Designs for human-error prevention, detection, and mitigation;
- Decision-support tools and methods to improve communication, collaborative and distributive decision-making;
- Data fusion technologies to integrate disparate sources of flight-related information for improved situation awareness and appropriate workload modulation;
- Support for crew response planning and selection;
- Computational approaches to determine and appropriately modulate crew engagement, workload, and situation awareness;
- Human-centered information technologies to improve the performance of less-experienced pilots and pilot populations with special requirements;
- Avionics designers and/or certification specialist tools to improve the application of human-centered principles;
- Human-error reliability approaches to analyzing flight deck displays, decision aids, and procedures, and designs that consider presentation of uncertain data; and
- Individual and team performance metrics, analysis methods, and tools to better evaluate and certify human and system performance for use in operational airspace environments, simulation, and model-based analyses.

Sub Topics:
Aviation Safety and Security: Fire, Icing and Propulsion-Safe and Secure CNS Aircraft Systems Topic A1.02
NASA is concerned with the prevention of hazardous conditions and the mitigation of their effects when they do occur. One particular emphasis is on the prevention and suppression of in-flight fire and explosions, as well as fuel tank explosions and post-crash fires. Aircraft fires represent a small number of actual accident causes, but the number of fatalities due to in-flight, post-crash, and on-ground fires is large.

A second emphasis is on mitigating the safety risk and collateral damage due to unexpected failures of rotating components. Although the FAA mandates a blade containment and rotor unbalance requirement (FAR Part 33,
Section 33.94) as part of the airworthiness standards for turbine aircraft engines, there are substantial potential (aircraft-engine) system benefits to be gained by enabling safety assured, lighter weight, lower cost, and more damage-tolerant designs for engine case/containment systems and associated (primary load path) structures.

A third emphasis for this subtopic is on propulsion system health management, in order to prevent or accommodate safety-significant malfunctions and damage. Past advances in this area have helped improve the reliability and safety of aircraft propulsion systems; however, propulsion system component failures are still a contributing factor in numerous aircraft accidents and incidents. Advances in technology are sought which help to further reduce the occurrence of and/or mitigate the effects of safety-significant propulsion system malfunctions and damage.

A fourth emphasis is to increase the level of safety for all aircraft flying in the atmospheric icing environment. To maximize the level of safety, aircraft must be capable of handling all possible icing conditions by either avoiding or tolerating the conditions. Proposals are invited that lead to innovative new approaches or significant improvements in existing technologies for in-flight icing conditions avoidance (icing weather information systems) or tolerance (airframe and engine ice protection systems and design tools).

A final emphasis for this subtopic is protection and hardening of the aircraft’s communication, navigation and surveillance (CNS) systems, as well as enabling new aviation security applications through improved air-to-ground data link communications. Technology is needed to harden the CNS systems, both onboard and air-to-ground, and to provide next-generation airborne, ground- and space-based surveillance systems.

With these emphases in mind, products and technologies that can be made affordable and retrofitable within the current aviation system, as well as for use in the future, are sought:

- Technology for prevention and suppression of potential in-flight fires in fuel tanks, cargo bays, insulation, and other inaccessible locations due to accidents or deliberate acts.
- Technology to provide fuel tank vapor flammability reduction and onboard oxygen generation.
- Technology to minimize fire hazards in crashes and to prevent or delay fires.
- Advanced material or structural configuration concepts to prevent catastrophic failures of engine components, or to ensure fragment containment.
- Computational tools for analyzing blade-loss events and designing structural components and systems accordingly.
- Health management technologies such as instrumentation, ground and on-wing nondestructive inspection, health monitoring algorithms, and fault accommodating logic, which will predict, diagnose, prevent, assess, and allow recovery from propulsion system malfunctions or damage.
- Ground and airborne radome technologies for microwave wavelength radar and radiometers that remain clear of liquid water and ice in all weather situations.
- In situ icing environment measurement systems that can provide practical, very low-cost validation data for emerging icing weather information systems and atmospheric modeling. Measured information must include location, altitude, cloud liquid water content, temperature, and ideally cloud particle sizing and phase.
information. Solutions envisioned would use radiosonde-based systems.

- Ice protection and detection technology submittal must provide significant improvements over current systems or address new design needs. Areas of improvement can be considered to be: efficient thermal protection systems, including composite wing or structures applications, wide area ice detection, detection that serves both ground and in-flight applications, and de-icing systems that operate at near anti-icing performance. Any submittal must be cost competitive to current technologies.

- Next generation capabilities for remote monitoring of onboard systems and the aircraft environment.

- Secure onboard information processing, computing and air/ground networking.

- Technologies to harden aircraft communication, navigation, and surveillance systems against abnormality and deliberate attack.

Sub Topics:
Technologies for Improved Aviation Security Topic A1.03

Following the attacks on September 11, 2001, NASA recognized that it now shared the responsibility for improving homeland security. The NASA Strategic Plan includes requirements to enable a more secure air transportation system and to create a more secure world by investing in technologies and collaborating with other agencies, industry, and academia. NASA's role in civil aeronautics has always been to develop high-risk, high-payoff technologies to meet critical national aviation challenges, and ensuring the security of the nation from terrorist attacks is a high priority national challenge.

NASA aims to develop and advance technologies that will reduce the vulnerability of the Air Transportation System (ATS) to threats or hostile acts, and identify and inform users of potential vulnerabilities in a timely fashion. Specific technical focus areas include system-wide security risk assessment and incident precursor identification; enhanced flight procedures and onboard systems to protect critical infrastructures and key assets and enable the safe recovery of a seized aircraft; definition of directed energy threats to the aircraft and on/off-board systems that will provide surveillance and countermeasures of these threats; integrated adaptive control systems to detect and compensate for vehicle damage; hardened and security-enhanced aircraft networks and data links; remote monitoring of the aircraft environment and systems; new materials for composite fire and explosive resistant fuselage structures; advanced, airborne, in situ detection of chemical and biological terror agents; and commercial aircraft fuel tank inerting. Technologies under development are intended for the next-generation ATS, however, issues such as retrofitting, certification, system implementation, and cost-benefit analysis must be considered during the technology development process.

NASA seeks highly innovative and commercially viable technologies that will improve aviation security by addressing threats to air vehicles, as well as the ATS. Specific areas of focus include: preventing aircraft from being used as a weapon of mass destruction (WMD); protection from man-portable air defense systems (ManPADS) and electromagnetic energy (EME) attacks; light-weight, fire- and explosive-resistant composite materials; explosive resistant fuel systems, ground-based decision support tools needed to monitor airspace security concerns; reporting systems to monitor security violations; secure encrypted data link systems, intrusion-tolerant communications networks and communications systems to support emerging aviation security applications; tools to support real-time management of security information; and chemical and biological sensor development. Technologies may take the form of tools, models, techniques, procedures, substantiated guidelines, prototypes, and devices:
Intelligent systems monitoring and alerting technologies;
Technologies that enable secure communications, navigation, and surveillance onboard the aircraft;
Secure communications systems to support emerging aviation security applications;
Onboard and ground surveillance and interception systems for aircraft immunity to electromagnetic interference and electromagnetic pulse intrusions;
Technologies and methods to provide accurate information and guidance to enable pilot avoidance of protected airspace, maintain positive identity verification of aircraft operators, determine pilot intent, and deny flight control access to unauthorized persons;
Flight control systems that accommodate vehicle damage relative to changes in aircraft stability, control, and structural load characteristics;
Material systems, fuselage structural concepts, and fuel systems that are resistant to fire and explosions;
Fuel system technologies that prevent or minimize in-flight vulnerability of civil transport aircraft due to small arms or man-portable defense systems type projectiles;
Decision-support tools and methods to improve communication, collaborative, and distributive decision-making;
Data fusion technologies for integrating disparate sources of flight-related information;
Computational approaches to monitoring crew health, stress level, state of duress, and performance; and
Validation methods and tools for advanced safety and security critical systems.

Sub Topics:
Automated On-Line Health Management and Data Analysis Topic A1.04

Online health monitoring is a critical technology for improving transportation safety in the 21st century. Safe, affordable, and more efficient operation of aerospace vehicles requires advances in online health monitoring of vehicle subsystems and information monitoring from many sources over local and wide area networks. Online health monitoring is a general concept involving signal-processing algorithms designed to support decisions related to safety, maintenance, or operating procedures. The concept of online health monitoring emphasizes algorithms that minimize the time between data acquisition and decision-making.

This subtopic seeks solutions for online aircraft subsystem health monitoring. Solutions should exploit multiple computers communicating over standard networks where applicable. Solutions can be designed to monitor a specific subsystem or a number of systems simultaneously. Resulting commercial products might be implemented in a distributed decision-making environment such as onboard diagnostics and management systems, or maintenance and inspection networks of potentially global proportion.

Proposers should discuss who the users of resulting products would be, e.g., research/test/development; manufacturing; maintenance depots; flight crew; Unmanned Aerial Vehicles/Remotely Operated Aircraft (UAV/ROA) aircraft operators; airports; flight operations or mission control; or airlines. Proposers are encouraged to discuss data acquisition, processing, and presentation components in their proposal. Proposals that focus solely on
sensor development should not be submitted to this subtopic. Such proposals should be addressed to sensor development subtopics such as the Flight Sensors, Sensor Arrays and Airborne Instruments for Flight Research subtopic.

Examples of desired solutions targeted by this subtopic follow:

- Real-time autonomous sensor validity monitors;
- Flight control system or flight path diagnostics for predicting loss of control;
- Automated testing and diagnostics of mission-critical avionics;
- Structural fatigue, life cycle, static, or dynamic load monitors;
- Automated nondestructive evaluation for faulty structural components;
- Electrical system monitoring and fire prevention;
- Applications that exploit wireless communication technology to reduce costs;
- Model-reference or model-updating schemes based on measured data, which operate autonomously;
- Proactive maintenance schedules for rocket or turbine engines, including engine life-cycle monitors;
- Predicting or detecting any equipment malfunction;
- Middleware or software toolkits to lower the cost of developing online health monitoring applications; and
- Innovative solutions for harvesting, managing, archival, and retrieval of aerospace vehicle health data.

Sub Topics:

**Propulsion System Emissions and Noise Prediction and Reduction Topic A2.01**

**Emissions**

Current environmental concerns with subsonic and supersonic aircraft center around the impact of emissions on the Earth's climate. Carbon dioxide (CO$_2$) and oxides of nitrogen (NO$_x$) are the major emittants of concern coming from commercial aircraft engines. Current state-of-the-art engines and combustors in most subsonic aircraft are fuel-efficient and meet the 1996 ICAO nitrogen oxide (NO$_x$) limits, but may not able to meet the future stringent regulations. Recent observations of aircraft exhaust contrails (from both subsonic and supersonic flights) have resulted in growing concern over aerosol, particulate, and sulfur levels in the fuel. In particular, aerosols and particulates from aircraft are suspected of producing high altitude clouds, which could adversely affect the Earth's climatology. Advanced concepts research for reducing CO$_2$ and NO$_x$, and analytical and experimental research in characterization (intrusive and non-intrusive) and control (through component design, controls, and/or fuel additives) of gaseous, liquid, and particulates of aircraft exhaust emissions is sought. Specific aircraft operating conditions of interest include the landing-takeoff cycle, as well as the in-flight portion of the mission. There are a number of areas of particular interest:
• New concepts for reducing CO₂, oxides of nitrogen (NO, NO₂, NOₓ), unburned hydrocarbons; carbon monoxide, particulate, and aerosols emittants (novel propulsion concepts, injector designs to improve fuel mixing, catalysts, additives, etc.)

• New fuels for commercial aircraft that minimize CO₂ and NOₓ emissions

• Innovative active control concepts for emission minimization with an integrated systems focus including emission modeling for control, sensing, and actuation requirements, control logic development, and experimental validation are of interest.

• New instrumentation techniques are needed for the measurement of engine emissions such as NOₓ, SOₓ, and HOₓ, atomic oxygen and hydrocarbons in combustion facilities and engines. Size, size distributions, reactivity, and constituents of aerosols and particulates are needed, as are temperature, pressure, density, and velocity measurements. Optical techniques that provide 2-D and 3-D data; time history measurements; and thin film, fiber optic, and micro-electrical-mechanical systems (MEMS)-based sensors are of interest.

Noise

Engine noise reduction technologies are required in the areas of propulsion source noise, nacelle aeroacoustics, and engine/airframe integration. Some of the key technologies needed to achieve these goals are revolutionary propulsion systems for reduced noise without significant increases in cost and emissions. Noise reduction concepts need to be identified that provide economical alternatives to conventional propulsion systems. NASA is soliciting proposals in one or more of the following areas for propulsion system noise reduction:

• Innovative acoustic source identification techniques for turbomachinery noise: The technique shall be described for a relevant source. Plans for a Phase II demonstration should be included for the Phase I proposal. A simple source may be used where the solution is known to demonstrate the technique. A clear explanation on how the technique can be applied to turbofan engines should be included. The technique should be capable of identifying sources contributing to dominant engine components, such as fan and jet noise.

• Fan Noise: The technique shall be capable of separating fan sources such as fan-alone versus fan/stator interaction for both tones and broadband noise. Sufficient resolution is needed to determine the location of the dominant sources on the aerodynamic surfaces. Jet Noise: The technique shall be capable of locating both internal and external mixing noise for dual-flow nozzles found in modern turbofans. Innovative turbofan source reduction techniques. Methods shall emphasize noise reduction methods for fan, jet, and core components without compromising performance for turbofan engines. A resulting engine system that incorporates one or more of the proposed methods should be capable of reducing perceived noise levels anywhere from 10 to 20 effective perceived noise level (EPNdB) relative to FAR 36, Stage 3 certification levels.

• Revolutionary propulsion concepts for lower emissions and noise (proposed as alternatives to turbofan engines). Feasibility studies shall be done that demonstrate the potential for 20 EPNdB engine noise reduction relative to FAR 36, Stage 3 certification levels and 90% reduction in NOₓ emissions standards relative to current International Civil Aviation Organization (ICAO) regulations for commercial aircraft concepts.

Enabling technologies shall be identified for future research.
Electric and Intelligent Propulsion Technologies for Environmentally Harmonious Aircraft Topic A2.02

Electric aircraft propulsion and power systems have the potential to completely eliminate harmful emissions from aircraft while at the same time improving energy efficiency. Major strides have been achieved in the development of fuel cells, especially in the automotive field. NASA is pursuing the application of fuel cell technology for both aircraft power and propulsion. There are still major technical advances required to make a commercially viable electric aircraft a reality, but this goal now appears to be achievable, possibly even in the nearer term. To achieve the realization of environmentally harmonious 21st century air vehicles, innovations are needed to enable highly efficient, low cost, power dense (weight and volume) electric aircraft propulsion and power systems.

Technical areas of interest in electric aircraft propulsion and power include, but are not limited to, fuel cells, power management, power conditioning, power distribution, actuators, motors and drive systems, sensors and fuel storage (especially hydrogen). Highly integrated dual function components and systems that have the potential to reduce overall vehicle and subsystem weight are of special interest (e.g., power conductors that are integrated into the airframe structure, motors directly integrated into the fan/propeller structure). Synergistic use of onboard cryogenic hydrogen fuel is also of interest. Both component and system level technologies are solicited. Proposals must show improvements to the state-of-the-art and viable application to aircraft.

Implementation of intelligent propulsion concepts requires advancements in the area of robust control synthesis techniques and automated diagnostics, and development of advanced enabling technologies such as nanoelectronics, smart sensors, and actuators. Attention will also need to be paid to integration of the active component control and diagnostics technologies with the control of the overall propulsion system. This will require moving from the current analog control systems to distributed control architectures.

Intelligent propulsion technologies that address electric, turbine, jet and/or hybrid aerospace propulsion systems are of interest. Proposals focusing on development of advanced diagnostics, health monitoring and control concepts, smart sensors, electronics and actuators for enabling self-diagnosis and prognosis, and self-reconfiguration capabilities are being sought. Concepts of special interest include those that integrate distributed sensing with actuation and control logic for micro-level control of parameters (such as propulsion system internal flows that impact performance and environment). Novel instrumentation approaches that provide valuable information for development and validation of technologies for self-diagnosis, prognosis, and reconfiguration are also of interest.

Revolutionary Technologies and Components for Propulsion Systems Topic A2.03

NASA seeks highly innovative concepts for propulsion systems and components for advanced high-speed aerospace vehicles to support missions, such as access to space, global cruise, and high-speed transports. The main emphasis in this subtopic is on high-risk, breakthrough technologies in order to revolutionize aerospace propulsion over a broad flight spectrum, up to Mach 8. Proposals offering significant advancements in critical components and designs for propulsion systems and subsystems are sought. Specific technical areas include the following:

- Advanced cooling concepts that minimize coolant penalties can include innovative cooling systems, fuel cooling of the combustor, and endothermic fuels and/or fuel additives to increase the heat-sink capacity or cooling capacity of fuels.
• Innovative concepts relating to the combustion process, including fuel injectors, piloting, flame holding techniques for increased performance and decreased emissions, techniques to identify the onset of combustion instability in lean-burn and/or rich-burn, low NO$_x$ combustor, ramjet combustion and active and passive combustion controls in order to extend the operability of the combustion components to a wider range of operating conditions.

• New inlet concepts to meet functional airflow needs of high Mach number propulsion. For instance, a variable geometry, supersonic, mixed compression inlet. Compatibility with turbomachinery and mode transition across the speed range should be addressed. Special attention should be given to combustor demands along a realistic flight corridor. This flight corridor must be compatible with turbine engine thermal-structure limits.

• New techniques to improve the aerodynamic performance and operability of the inlet, including highly offset subsonic diffusers and designs for boundary layer control, minimizing engine unstart susceptibility, and techniques to identify and control the onset of mode transition between different propulsion concepts within the same internal flow path or dual flow paths.

• New controllable and reliable nozzle concepts with optimum expansion efficiency and thrust vectoring capability, including a computational nozzle design methodology to study various geometries and chemistry effects.

• Enabling technologies of components and subsystems that allow turbomachinery to operate at high-speed flight conditions. Specific examples include 1) a lightweight, high-pressure ratio compressor which must be protected or removed from the extremely high temperature primary air stream; 2) applications of micro-electrical-mechanical systems (MEMS) that demonstrate the potential to enhance the performance and reduce the cost and weight; and 3) innovative inlet flow conditioning.

• New concepts for combined or combination cycles, in particular those including turbine propulsion. Alternate engine cycles that meet a unique mission requirement (e.g., global reach, access to space, etc.), including pulse detonation, ramjets, scramjets, and rockets. Proposals can also include development of unique components required for the maturation of alternate propulsion cycles, such as inlets, diffusers, nozzles, air valves, fuel injectors, combustors, etc.

• Innovative integration technologies among components or subsystems that significantly improve the performance or reduce the cost of the overall propulsion systems are sought. This includes new collaborative and concurrent engineering tools for analysis and design. These tools could reduce the need for empiricism, thus facilitating early evaluation of interactions among propulsion components. "Intelligent" design tools, based on technologies such as evolutionary algorithms and neural networks, are also of interest. All design/analysis tool proposals must include a propulsion technology development application.

Sub Topics:

Airframe Systems Noise Prediction and Reduction Topic A2.04
Innovative technologies and methods are necessary for the design and development of efficient, environmentally acceptable airplanes, rotorcraft, and advanced aerospace vehicles. In support of the goal of the Quiet Aircraft Technology Project for reduced noise impact on community residents, improvements in noise prediction and control are needed for jet, propeller, rotor, fan, turbomachinery, and airframe noise sources. In addition, improvements in prediction and control of noise transmitted through aerospace vehicle structures are needed to reduce noise impact on aircraft passengers and crew and on launch vehicle payloads. Innovations in the following specific areas are solicited:
• Fundamental and applied computational fluid-dynamics techniques for aeroacoustic analysis, which can be adapted for design codes.

• Simulation and prediction of aeroacoustic noise sources particularly for airframe noise sources and situations with significant interactions between airframe and propulsion systems.

• Concepts for active and passive control of aeroacoustic noise sources for conventional and advanced aircraft configurations.

• Innovative active and passive acoustic treatment concepts for engine nacelle liners and concepts for high-intensity acoustic sources, which can be used to characterize engine nacelle liner materials.

• Reduction technologies and prediction methods for rotorcraft and advanced propeller aerodynamic noise.

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

• Development and application of flight procedures for reducing community noise impact of rotorcraft and subsonic and future supersonic commercial aircraft while maintaining safety, capacity, and fuel efficiency.

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

• Technologies and techniques for active and passive interior noise control for aircraft and advanced aerospace vehicle structures.

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

Sub Topics:

Revolutionary Materials and Structures Technology for Propulsion and Power Components Topic A2.05

This subtopic addresses structural and mechanical components, subsystems and advanced materials for Aerospace Propulsion and Power Systems. Proposals are sought for innovative and commercially viable concepts that address objectives such as lighter weight, reduced operational costs, lower noise, lower emissions, higher temperature capability, increased efficiency and/or operational margin, greater safety and reliability, and more time on-station for aircraft, satellites, and power equipment.

One focus is on problems related to structural and mechanical components and subsystems that operate at high temperatures, in hostile aero-thermo-chemical environments or space environments, and at high stresses under cyclic loading conditions. Interests include magnetic, foil, and fluid film bearings, tribological coatings, seals, transmissions, noise reduction, flight weight electric motors, rotating equipment, aeroelasticity, ballistic impacts, fatigue, fracture, life prediction, probabilistic methods, and structural health monitoring (diagnostics and prognosis).

A second focus addresses advanced materials, their development, and their application to primary propulsion systems such as aircraft gas turbines, rocket and turbine-based combined cycle engines, and rocket engines as well as auxiliary power sources in aircraft and space vehicles. Materials of interest include any classes especially those used in propulsion systems such as high-temperature polymers and composites, metals including titanium alloys and nickel-based super alloys, ceramics and ceramic matrix composites, and coatings for these, and processes for their economical and reliable preparation.
Sub Topics:
Smart, Adaptive Aerospace Vehicles With Intelligence Topic A2.06
This subtopic emphasizes the roles of aerodynamics, aerothermodynamics, adaptive software, vehicle dynamics in nonlinear flight regimes, and advanced instrumentation in research directed towards the identification, development and validation of enabling technologies that support the design of future, autonomous aerospace vehicle and platform concepts for aviation safety, and security vehicle systems. Some of the vehicle attributes envisioned by this subtopic include: a) "Smart" vehicle attributes—using advanced sensor technologies, flight vehicle systems are "highly aware" of onboard health and performance parameters, as well as the external flow field and potential threat environments; b) "Adaptive" vehicle attributes—flight avionics systems are reconfigurable, structural elements are self-repairing, flight control surfaces and/or effectors respond to changing flight parameters and/or vehicle system performance degradation; and c) "Intelligent" vehicle attributes—vehicle onboard processing and artificial intelligence technologies, interfaced with advanced vehicle structural component and subcomponent designs and appropriate actuating devices, reacts rapidly and effectively to changing performance demands and/or external flight and security threat environments. Future air vehicles with the above attributes will manage complexity, "know" themselves, continuously tune themselves, adapt to unpredictable conditions, prevent and recover from failures, and provide a safe environment.

For atmospheric vehicles and platforms, both military and civil applications are sought, while for aviation applications, emphasis is placed on configurations that enable the discovery of new aviation safety and security concepts. Concepts and corresponding enabling technologies are sought which expand the traditional boundaries of conventional piloted vehicles categories such as General Aviation (GA) or Personal Air Vehicles (PAV), as well as significantly advance the state-of-the-art in remotely operated vehicle classes such as Long-Endurance Sensing Platforms (LESP), Unmanned Aerial Vehicles (UAV) or Unmanned Combat Aerial Vehicles (UCAV) as they can relate to aviation safety and security. Furthermore, for Earth applications, special emphasis is placed on research proposals that attempt to provide solutions for a future state in which revolutionary vehicles operate in a highly integrated airspace including hub and spoke, point-to-point, long-haul, unmanned aircraft, green aircraft, as well as a future state where air vehicle designs reflect a high level of integration in performance, safety and security, airspace capacity, environmental impact and cost factors.

Specific areas of interest are:

- Conceptual flight vehicle/platform designs featuring variable levels of vehicle and airspace requirements integration, and/or smart, intelligent, and adaptive flight vehicle capabilities, as demonstrated by state-of-the-art systems analyses methods to determine enabling technologies and resulting impacts on future system integrated performance, environmental impact, and safety and security issues.

- New algorithms for predicting vehicle loads and response using minimal vehicle state information.

- Novel optimization methodologies to support conceptual design studies for highly-integrated flight vehicle and air space concepts and/or smart, intelligent and adaptive flight vehicle capabilities, which demonstrate appropriate design variable selection, scaling techniques, suitable cost functions, and improved computational efficiency.

- Physics-based modeling and simulation tools of multiple vehicle classes and corresponding airspace operations aspects to support scenario-based planning and requirements definition of highly integrated vehicle and airspace capacity concepts, including investigations of the potential use of virtual/immersive simulations on future engineering decision making processes.

- Micro-scale wireless communications, health monitoring, energy harvesting, and power-distribution technologies for large arrays of vehicle-embedded MEMS sensors and actuators.
Sub Topics:  
Revolutionary Flight Concepts Topic A2.07
This subtopic solicits innovative flight test experiments that demonstrate breakthrough vehicle or system concepts, technologies, and operations in the real flight environment. The emphasis of this subtopic is the feasibility, development, and maturation of advanced flight research experiments that demonstrate advanced or revolutionary methodologies, technologies, and concepts. It seeks advanced flight techniques, operations, and experiments that promise significant leaps in vehicle performance, operation, safety, cost, and capability; and may require a demonstration or validation in an actual flight environment to fully characterize or validate it.

The scope of this subtopic is broad and includes advanced flight experiments that accelerate the understanding, research, and development of advanced technologies and unconventional operational concepts. Examples extend to (but are not limited to) such things as inflatable aero-structures (new designs or innovative applications, new manufacturing methods, new materials, new in-flight inflation methods, and new methods for analysis of inflation dynamics), innovative control surface effectors (micro-surfaces, embedded boundary-layer control effectors, micro-actuators), innovative engine designs for UAV aircraft, alternative engines/motors/concepts, alternative fuels research (hydrocarbon, hydrogen, or regenerative), sonic boom reduction, noise reduction for Conventional Take-off and Landing/Short Take-off and Landing (CTOL/STOL) aircraft and engines, advanced mass transportation concepts, retrofit threat detection capabilities for civil transports, damage mitigation concepts, streamlining airport operations concepts, retrofitting existing airports for next generation airliners, alternative external vision systems, shroudless launch of aerodynamic shapes on the front of ELVs, aerodynamic systems optimization for planetary aircraft (Venus, Mars, Io, and/or Titan), flexible system stability derivative identification, innovative approaches to thermal protection that minimize aerodynamic performance degradation, innovative approaches to structures, stability, control, and aerodynamics integration schemes, and innovative approaches to incorporation of UAV operations into commercial airspace. This subtopic is intended to advance and demonstrate revolutionary concepts and is not intended to support evolutionary steps required in normal product development. Proposals should emphasize the need of flight testing a concept or technology as a necessary means of verifying or proving its worth; emphasis should also be given to multidisciplinary integration of advanced flight systems. The benefit of this effort will ultimately be more efficient aerospace vehicles, increased flight safety (particularly during flight research), and an increased understanding of the complex interactions between the vehicle or technology concept and the flight environment.

Sub Topics:  
Modeling, Identification, and Simulation for Control of Aerospace Vehicles in Flight Test Topic A2.08
Safer and more efficient design of advanced aerospace vehicles requires advancement in current predictive design and analysis tools. The goal of this subtopic is to develop more efficient software tools for predicting and understanding the response of an airframe under the simultaneous influence of structural dynamics, thermal dynamics, steady and unsteady aerodynamics, and the control system. The benefit of this effort will ultimately be an increased understanding of the complex interactions between the vehicle dynamical subsystems with an emphasis towards flight test validation methods for control-oriented applications. Proposals for novel multidisciplinary nonlinear dynamic systems modeling, identification, and simulation for control objectives are encouraged. Control objectives include feasible and realistic boundary layer and laminar flow control, aeroelastic maneuver performance, and load control including smart actuation and active aerostructural concepts, autonomous health monitoring for stability and performance, and drag minimization for high efficiency and range performance. Methodologies should pertain to any of a variety of types of vehicles, such as Unmanned Aerospace Vehicles/Remotely Operated Aircraft (UAV/ROA), and flight regimes ranging from low-speed High-Altitude Long-Endurance (HALE) to hypersonic and access-to-space aerospace vehicles. Proposals should address one or more of the following:
• Accurate prediction with validation of steady and unsteady pressure, stress, and thermal loads;

• Effective multidisciplinary dynamics analysis algorithms with flight-test correlation capability conducive to validation with test data, such as with finite-element aeroservoelastic computations;

• Time-accurate simulation systems from nonlinear multidisciplinary dynamics models with applications toward flight-testing, such as with reduced-order CFD-based methods;

• Novel and efficient schemes for control-oriented identification of nonlinear aeroservoelastic dynamics from test data with provisions for uncertainty estimation and model correlation;

• Online and autonomous model update schemes for loads, aerodynamic, and aeroelastic model identification for stability and performance monitoring and prediction in adaptive control;

• Self-learning control strategies for aerostructural vehicles and development of enhanced real-time controls software and hardware for long-term onboard systems operation;

• Integration of modeling, analysis, simulation, and identification techniques for control objectives in a unified, compatible manner; and

• Innovative high-performance facilities for integrated simulation and graphical interface, or virtual reality systems, for multidisciplinary aerospace systems.

Sub Topics:

Flight Sensors and Airborne Instruments for Flight Research Topic A2.09
Real-time measurement techniques are needed to acquire aerodynamic, structural, and propulsion system performance characteristics in flight and to safely expand the flight envelope of aerospace vehicles. The scope of this subtopic is the development of sensors or instrumentation systems for improving the state-of-the-art in aircraft flight testing. This includes the development of sensors to enhance aircraft safety by determining atmospheric conditions. The goals are to improve the effectiveness of flight testing by simplifying and minimizing sensor installation, measuring new parameters, improving the quality of measurements, and minimizing the disturbance to the measured parameter from the sensor presence or deriving new information from conventional techniques. This subtopic solicits proposals for improving airborne sensors and instrumentation systems in all flight regimes. These sensors and systems are required to have fast response, low volume, minimal intrusion and high accuracy and reliability. Innovative concepts are solicited in the areas that follow below.

Vehicle Condition Monitoring

Sensor development in support of vehicle health and performance monitoring includes the monitoring of aerodynamic, structural, propulsion, electrical, pneumatic, hydraulic, navigation, control, and communication subsystems. Proposals that focus solely on health management algorithms and systems integration should be addressed in the Automated Online Health Management and Data Analysis subtopic.

Vehicle Environmental Monitoring

Sensor development in support of vehicle environmental monitoring includes the following:
- Non-intrusive air data parameters (airspeed, air temperature, ambient and stagnation pressures, Mach number, air density, and flow angle);

- Off-surface flow field measurement and/or visualization (laminar, vortical, and separated flow, turbulence) zero to 50 meters from the aircraft;

- Boundary layer flow field, surface pressure distribution, acoustics or skin friction measurements or visualization; and

- Unusually small, light and low-power instrumentation for use on miniature aircraft and high altitude long endurance vehicles.

Sub Topics:

Next Generation Air-Traffic Management Systems Topic A3.01

The challenges in Air Traffic Management (ATM) are to create the next generation system and to develop the optimal plan for transitioning to the future system. This system should be one that (1) economically moves people and goods from origin to destination on schedule, (2) operates without fatalities or injuries resulting from system or human errors or terrorist intervention, (3) seamlessly supports the operation of unmanned aerial vehicles (UAVs) or remotely operated aircraft (ROAs), (4) is environmentally compatible, and (5) supports an integrated national transportation system and is harmonized with global transportation. This can only be achieved by developing ATM concepts characterized by increased automation and distributed responsibilities. It requires a new look at the way airspace is managed and the automation of some controller functions, thereby intensifying the need for a careful integration of machine and human performance. As these new automated and distributed systems are developed, security issues need to be addressed as early in the design phase as possible.

To meet these challenges, innovative and economically attractive approaches are sought to advance technologies in the following areas:

- Decision support tools (DST) to assist pilots, controllers, and dispatchers in all parts of the airspace (surface, terminal, en route, command center)
- Integration of DST across different airspace domains
- Next generation simulation and modeling capability—models of uncertainty and complexity, National Airspace System (NAS) operational performance, economic impact
- Distributed decision making
- Security of advanced ATM systems
- System robustness and safety—sensor failure, threat mitigation, health monitoring
- Weather modeling and improved trajectory estimation for traffic management applications
- Role of data exchange and data link in collaborative decision-making
- Modeling of the NAS
- Distributed complex, real-time simulations—components with different levels of fidelity, human-in-the-loop decision agents
- Integrated ATM/aircraft systems that reduce noise and emissions
- Automation concepts for advanced ATM systems and methodologies that address transitioning to more automated systems
- Application of methodologies from other domains to address ATM research issues
- Intelligent software architecture
- Runway-independent (e.g., Vertical Take-off Landing [VTOL], Short Take-off and Landing [STOL], and Vertical/Short Take-off and Landing [V/STOL]) aircraft technologies required to meet national air transportation needs, to satisfy requirements for airline productivity, passenger acceptance, and community friendliness, and autonomous operations
- Automated, real-time detect, see, and avoid operations
- Intermodal transportation technologies
• Each of the abovementioned technologies and other technologies specifically fostering the operation of unpiloted aircraft within NAS under control of the ATM system, including, but not limited to, innovative control, navigation, and surveillance (CNS) concepts; also considering high altitude, long endurance operations.

Sub Topics: