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.

Subtopics

A2.01 Propulsion System Emissions and Noise Prediction and Reduction

Emissions

Current environmental concerns with subsonic and supersonic aircraft center around the impact of emissions on the Earth's climate. Carbon dioxide \( \text{CO}_2 \) and oxides of nitrogen \( \text{NO}_x \) 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 \( \text{NO}_x \) 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 \( \text{CO}_2 \) and \( \text{NO}_x \), 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 CO\textsubscript{2}, oxides of nitrogen (NO, NO\textsubscript{2}, NO\textsubscript{x}), 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 CO\textsubscript{2} and NO\textsubscript{x} 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 NO\textsubscript{x}, SO\textsubscript{x}, and HO\textsubscript{x}, 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.
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
Participating Center(s): ARC

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.

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.