The Vehicle Systems Program (VSP) goal is to provide breakthrough technologies for significantly advanced future air vehicles. The approach is to develop these technologies and demonstrate them in flight to provide evidence of barrier breakthroughs. The benefits of these breakthrough technologies including opening more communities to air transportation, enabling new air transportation models by doubling vehicle speed capacity, eliminating aviation pollution, and enabling new science platforms. VSP will focus on four demonstration projects. The subsonic noise reduction project will start by demonstrating a 50% noise reduction compared to 1997 state of the art. The sonic boom reduction project will begin by demonstrating technology that could enable an acceptable sonic boom level. The high altitude, long endurance project will start by demonstrating a 14-day duration high-altitude aircraft. Finally, the zero emissions aircraft will begin by demonstrating an aircraft powered by hydrogen fuel cells.

Subtopics

A2.01 Noise Breakthrough Turbine-Based Propulsion Technologies

Lead Center: GRC

Future subsonic and supersonic aircraft may be required to achieve reduced noise levels up to 20 effective perceived noise levels (EPNdB) below FAR 36 Stage 3 certification levels without significant impacts to performance. The main emphasis of this subtopic is on high-risk, breakthrough technologies in order to reduce the technical risk associated with the development and deployment of new technologies in future commercial products. Subsonic noise reduction to date has predominantly been achieved via higher-bypass-ratio engines. With current practices, the nacelle diameter limit has physically been reached and engine noise is now comparable to airframe noise on approach. Engine noise reduction concepts proposed for subsonic applications must be compatible with low noise propulsion/airframe integration designs and continuous descent approach, low noise guidance flight procedures. Innovative noise reduction concepts need to be identified that provide economical alternatives to conventional propulsion systems.

Integrated, advanced propulsion systems with intelligent controls technologies will enable supersonic vehicles (up to Mach 2) having acceptable takeoff/landing noise and increased efficiency. Studies suggest that gas turbine engines with increased thrust-to-weight, bypass ratios, and decreased thrust specific fuel consumption are required to support quiet supersonic aircraft. NASA is interested in the development of advanced gas turbine engine concepts and key enabling technologies that can dramatically reduce the landing/take-off noise to an acceptable level, and which have the potential to dramatically improve the sustained cruise performance of a supersonic
aircraft. Concepts proposed for supersonic applications must not adversely impact the airframe configurations to reduce sonic boom intensity, especially with regard to the formation of shaped waves and the human response to shaped waves.

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

**Subsonic Propulsion System Technologies**

- Innovative source identification techniques for fan, jet, combustor, or turbine noise;
- Advanced turbine engine cycles to achieve effective very high-bypass-ratio with smaller diameter engines;
- Innovative technologies for reduction of fan, jet, combustor, or turbine noise; and
- Advanced sound attenuating liners, including active and passive control.

**Supersonic Propulsion System Technologies**

- Advanced turbine engine cycle concepts to achieve low takeoff/landing noise and high supersonic cruise efficiency, including high pressure, high bypass multiple spool cycles, inter-stage turbine burning, variable cycle engines;
- Advanced propulsion system technologies, including advanced integrated airframe-propulsion control methodologies, adaptive flow control technologies, smart structures for nozzles and inlets, inlet technologies for weight/ performance/ operability/ stability; and
- High temperature materials such as monolithic ceramics and nano materials, evaporatively cooled turbine blades, and counter rotating stages enable more compact engine cores, greater thermal efficiency, and higher thrust to weight ratios.

Proposals must show improvements to the state-of-the art and viable application to aircraft.

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**A2.02 Fuel Cell Technologies for Aircraft Propulsion & Power**

**Lead Center:** GRC  
**Participating Center(s):** AFRC

Fuel cells offer a promising technology for clean, efficient power generation important to both High Altitude Long Endurance (HALE) remotely piloted aircraft, and future envisioned environmentally friendly commercial transports. Both consumable fuel and regenerative fuel based fuel cells are of interest. The former type is applicable to both HALE and commercial transports, while the latter type is of interest for a solar-electric powered HALE capable of...
multi-month missions. The consumable fuel based fuel cell will likely use atmospheric air for the cathode gas, while the regenerative systems will likely use pure oxygen stored and regenerated on-board. For both applications, the focus of this subtopic is on hydrogen fuel based systems including liquid for consumable fuel systems and gaseous for regenerative fuel cell systems.

To realize these aircraft applications will require one or even two orders of magnitude improvement in unit power and power density (volume and weight) for the power generation system, and specifically the fuel cell stack, as compared to ground based systems. In addition, the systems are required to operate at altitude, including high altitudes (≥ 60,000 ft) for the HALE applications, and provide service life and reliability significantly greater than ground-based systems. Thus, NASA is seeking “break-through” technologies necessary for aircraft instead of evolutionary improvement to current state-of-the-art.

Technologies of specific interest include:

- Innovative fuel cell power systems demonstrating high specific power and high efficiency using consumed liquid hydrogen fuel with scalability to 100’s of kW and capable of high altitude operations;
- PEM stack demonstrating ≥ 2 kW/kg and ≥ 50% efficiency (LHV) with scalability to 100’s of kW;
- SOFC stack demonstrating ≥ 1 kW/kg and ≥ 50% efficiency (LHV) with scalability to 100’s of kW; and
- Innovative regenerative fuel cell energy storage systems and critical components (e.g., unitized fuel cell and electrolyzer stack, PEM or SOFC based systems, etc) demonstrating ≥ 600 watt-hr/kg and high round trip efficiency.

A2.03 Hydrogen Fuel Systems and Components for Aircraft Applications

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

Hydrogen is the most likely fuel to enable future zero emissions aircraft and High Altitude Long Endurance Remotely Operated Aircraft (HALE ROA). Due to the increased volume required for hydrogen systems as compared to current hydrocarbon fueled aircraft, key technologies are required to reduce feed system weight while maximizing propellant storage efficiency. To be a viable technology for future aircraft systems, hydrogen feed components most likely will require life cycles approaching 10,000+ with an expectation of 20+ years in service, a significant difference from current state-of-the-art for space flight systems. For HALE ROA systems, vehicle mass must be kept low enough for flights up to altitudes exceeding 60,000 ft. Insulation systems must be lightweight and designed for minimum maintenance. Hydrogen storage and feed systems can be either cryogenic or gaseous depending upon the vehicle configuration. Tank mass fraction requirements (mass of storage system/mass of hydrogen) for liquid hydrogen on the order of 15% are expected to meet mission requirements. Hydrogen tank systems applications will be expected to provide storage for flight vehicles for up to 14 days duration with cryogenic systems and 6 months for aircraft with gaseous hydrogen. System safety is a critical factor in the design and development of any hydrogen system. To ensure public safety it is important that highly-sensitive, low-power-use sensors and instrumentation are developed to identify and diagnose potential problems with the hydrogen systems.
Technology focus areas will include storage, distribution, and propellant conditions. Innovations are solicited in the following areas:

**Storage and Distribution Components**

- Lightweight, low thermal conductivity on-board cryogenic storage tanks, feed lines, valves, and relief devices;
- Lightweight, low thermal conductivity insulation for tanks and feed lines that requires minimal inspection and maintenance;
- Lightweight, low permeable gaseous hydrogen storage tanks and feed lines; and
- Low power, high-sensitivity sensors for hydrogen leak detection and condition monitoring.

**Propellant Conditioning Components and Technologies**

- Innovative methods to reduce the volume of stored hydrogen while minimizing system weight;
- Technologies for the reformation of hydrocarbon based fuels to hydrogen;
- Advanced technologies to minimize losses during loading and unloading of hydrogen, including autonomous operations, tank transfers, delivery to propulsion system, venting, and/or hydrogen recovery;
- Advanced technologies to minimize hydrogen losses and reduce energy requirements for system pre-chill, delivery to propulsion system, venting and/or hydrogen recovery, and long duration temperature.

Proposals must show improvements to the state-of-the-art and viable application to aircraft.

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**A2.04 Aircraft 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 aero acoustic analysis, which can be adapted for design codes;

• Simulation and prediction of aero acoustic noise sources particularly for airframe noise sources and situations with significant interactions between airframe and propulsion systems;

• Concepts for active and passive control of aero acoustic 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; and

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

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A2.05 Electric Drive Components, Power Management and Distribution Technologies

Lead Center: GRC

Participating Center(s): GSFC, JPL, JSC

Future environmentally harmonious aircraft propulsion systems may be driven by electric power. These new systems will likely be fueled by hydrogen stored as a cryogenic liquid. Like all flight systems, these new electric based propulsion concepts will require each component to be extremely lightweight, especially when compared to similar ground-based systems. Future specific power requirements for the entire propulsion system from power supply to electric motor could reach 20-kW/kg. The total electric power supplied for aircraft will be orders of magnitude higher than for existing flight-rated secondary electrical systems. Future high power electric systems present a number of challenges for application to volume and weight limited aircraft. NASA is interested in the development of innovative technologies that demonstrate the feasibility of high power densities (>5kW/kg) for electric power delivery and propulsion. Specific areas of interest include but are not limited to the following:

• High power density electric motors and actuators, including superconducting, cryogenic and non-cryogenic systems;
• Cryogenically cooled lightweight, possibly superconducting, high power transmission lines;

• Cryogenically cooled and non-cryogenic lightweight power conditioning and control technology including technologies for isolation of noise-sensitive avionics power busses from main propulsion power busses;

• Cryogenically cooled and non-cryogenic lightweight high voltage high power density power management components;

• Highly integrated dual function components and systems that have the potential to reduce overall vehicle and subsystem weight (e.g., power conductors that are integrated into the airframe structure, motors directly integrated into the fan/propeller structure);

• Advanced enabling technologies such as nanoelectronics, smart sensors, and actuators;

• Advanced diagnostics, health monitoring and control concepts, smart sensors, electronics and actuators for enabling self-diagnosis and prognosis, and self-reconfiguration capabilities;

• Concepts that integrate distributed sensing with actuation and control logic for micro-level control of parameters (such as propulsion system internal flows, electrical states, etc. that impact performance and environment).

Proposals must show improvements to the state-of-the-art and viable application to aircraft.

A2.06 Smart, Adaptive Aerospace Vehicles With Intelligence

Lead Center: ARC
Participating Center(s): LaRC

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, interacted 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.

There are a number of specific areas of interest:

- 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; and
- 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 Atmospheric 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, and
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, 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 to Prepare for 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, aero elastic
maneuver performance, and load control including smart actuation and active aero structural 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 (HALO) 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 aero elastic model**
identification for stability and performance monitoring and prediction in adaptive control;

- Self-learning control strategies for aero structural 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.