



## NASA SBIR 2011 Phase I Solicitation

### A2 Fundamental Aeronautics

The Fundamental Aeronautics Program conducts cutting-edge research to achieve technological capabilities necessary to overcome national challenges in air transportation including reduced noise, emissions, and fuel consumption, increased mobility through a faster means of transportation, and the ability to ascend/descend through planetary atmospheres. These technological capabilities enable design solutions for performance and environmental challenges of future air vehicles. Research in revolutionary aircraft configurations, lighter and stronger materials, improved propulsion systems, and advanced concepts for high lift and drag reduction all target the efficiency and environmental compatibility of future air vehicles. The program develops physics-based, multidisciplinary design, analysis and optimization tools to enable evaluation of new vehicle designs and to assess the potential impact of design innovations on a vehicle's overall performance. The FA Program consists of four projects:

- Subsonic Fixed Wing addresses the challenge of enabling revolutionary energy efficiency improvements of subsonic/transonic transport aircraft that dramatically reduce harmful emissions and noise for sustained growth of the air transportation system. Improvements in prediction tools and new experimental methods. Noise prediction and reduction technologies for airframe and propulsion systems. Emissions reduction technologies and prediction tools. Improved vehicle performance through design and development of lightweight, multifunctional and durable structural components, low drag aerodynamic components, and higher bypass ratio engines with efficient power plants, and advanced aircraft configurations. Reduce take off and landing field length requirements. Multi-disciplinary design and analysis tools and processes.
- Subsonic Rotary Wing addresses the challenge of radically improving the transportation system using rotary wing vehicles by increasing speed, range, and payload while decreasing noise and emissions. Enable variable-speed rotor concepts. Contain the external noise within the landing area and reduce internal noise. Assess multiple active rotorcraft concepts. Advance technologies such as crashworthiness, safe operations in icing conditions, and condition based maintenance methodologies.
- Supersonics addresses the challenge of eliminating the environmental and performance barriers that prevent practical supersonic vehicles (cruise efficiency, noise and emissions, performance). Efficiency (supersonic cruise, light weight and durability at high temperature). Jet noise reduction relative to an unsuppressed jet. Light weight and durability at high temperature. Environmental challenges (airport noise, sonic boom, high altitude emissions). Performance challenges (aero-propulso-servo-elastic analysis and design, cruise lift/drag ratio). Multidisciplinary design, analysis and optimization challenges.
- Hypersonics addresses the challenge of enabling airbreathing access to space and high mass entry,

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descent, and landing into planetary atmospheres Fundamental research to enable very-high speed flight (for airbreathing launch vehicles) and Entry, Descent and Landing into planetary atmospheres High-temperature materials, thermal protection systems (single and multi-use), airbreathing propulsion, aerothermodynamics, multi-disciplinary analysis and design, guidance, navigation, and control, advanced experimental capabilities, and supersonic decelerator technologies Accurate predictive models for high-speed compressible flow including turbulence, heating, ablation, combustion, and their interactions in order to reduce the uncertainty in predictions of aerodynamic heat loads during the design of hypersonic vehicles Additional information: (<http://www.aeronautics.nasa.gov/fap/index.html>).

## Subtopics

### A2.01 Materials and Structures for Future Aircraft

Lead Center: GRC

Participating Center(s): AFRC, ARC, LaRC

Advanced materials and structures technologies are needed in all four of the NASA Fundamental Aeronautics Program research thrusts (Subsonics Fixed Wing, Subsonics Rotary Wing, Supersonics, and Hypersonics) to enable the design and development of advanced future aircraft. Proposals are sought that address specific design and development challenges associated with airframe and propulsion systems. These proposals should be linked to improvements in aircraft performance indicators such as vehicle weight, fuel consumption, noise, lift, drag, durability, and emissions. In general, the technologies of interest cover five research themes:

#### Fundamental Materials Development, Processing and Characterization

Innovative approaches to enhance the durability, processability, performance and reliability of advanced materials (metals, ceramics, polymers, composites, nanostructured materials, hybrids and coatings). In particular, proposals are sought in:

- Advanced high temperature materials for aircraft engine and airframe components and thermal protection systems, including advanced blade and disk alloys, ceramics and CMCs, polymers and PMCs, nanostructured materials, hybrid materials and coatings to improve environmental durability.
- New adaptive materials such as piezoelectric ceramics, shape memory alloys, shape memory polymers, and variable stiffness materials and methods to integrate these materials into airframe and/or aircraft engine structures to change component shape, dampen vibrations, and/or attenuate acoustic transmission through the structure.
- Multifunctional materials and structural concepts for engine and airframe structures, such as novel approaches to power harvesting and thermal management, lightning strike mitigating, self-sensing, and materials for wireless sensing and actuation.
- New high strength fibers, in particular low density, high strength and stiffness carbon fibers.
- Innovative processing methods to reduce component manufacturing costs and improve damage tolerance, performance and reliability of ceramics, shape memory alloys, polymers, composites, and hybrids, nanostructured and multifunctional materials and coatings.
- Development of joining and integration technologies including fasteners and/or chemical joining methods for ceramic-to-ceramic, metal-to-metal (with an emphasis on joining dissimilar forms of nickel base superalloys, e.g., powder metallurgy to cast or directionally solidified alloys), and metal-to-ceramic as well

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as solid state joining methods such as advanced friction stir welding.

- Innovative methods for the evaluation of advanced materials and structural concepts (in particular multifunctional and/or adaptive) under simulated operating conditions, including combinations of electrical, thermal and mechanical loads.
- Nondestructive evaluation (NDE) methods for the detection of as-fabricated flaws and in-service damage for textile polymeric, ceramic and metal matrix composites, nanostructured materials and hybrids. NDE methods that provide quantitative information on residual structural performance are preferred.

### **Structural Analysis Tools and Procedures**

Robust and efficient design methods and tools for advanced materials and structural concepts (in particular multifunctional and/or adaptive components) including variable fidelity methods, uncertainty based design and optimization methods, multi-scale computational modeling, and multi-physics modeling and simulation tools. In particular, proposals are sought in:

- Multiscale design tools for aircraft and engine structures that integrate novel materials, mechanism design, and structural subcomponent design into systems level designs.
- Life prediction tools for textile composites including fiber architecture modeling methods that enable the development of physics-based hierarchical analysis methods. Fiber architecture models that address yarn-to-yarn and ply-to-ply interactions covering a wide range of textile perform structures in either a relaxed or compressed deformation state as well as tools to predict debonding and delamination of through thickness reinforced (stitched, z-pinned) composites are of particular interest.
- Tools to predict durability and damage tolerance of new material forms including metallic-composite hybrids, friction stir-welded metallic materials and powder metallurgy-formed materials.
- Meso scale tools to guide materials placement to enable tailored load paths in multifunctional structures for enhanced damage tolerance.

### **Computational Materials Development Tools**

Methods to predict properties, damage tolerance, and/or durability of both airframe and propulsion materials, thermal protection systems and ablatives based upon chemistry and processing for conventional as well as functionally graded, nanostructured, multifunctional and adaptive materials. In particular proposals are sought in:

- Ab-initio methods that enable the development of coatings for multiple uses at temperatures above 3000°F in an air environment.
- Computational tool development for structure-property modeling of adaptive materials such as piezoelectric ceramics, shape memory alloys, shape memory polymers to characterize their physical and mechanical behavior under the influence of an external stimulus.
- Computational and analytical tools to enable molecular design of polymeric and/nanostructured materials with tailored multifunctional characteristics.
- Computational microstructural and thermodynamic analysis tools and technique development for designing

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new lightweight alloy compositions for subsonic airframe and engines from first principles, functionally graded (chemically or microstructurally) materials, and/or novel metals processing techniques to accelerate materials development and understanding of processing-structure-property relationships.

- Software tools to predict temperature dependent phase chemistries, volume fractions, shape and size distributions, and lattice parameters of phases in a broad range of nickel and iron-nickel based superalloys. Toolset should utilize thermodynamic and kinetic databases and models that are fully accessible, which allow modifications and user-input to expand experimental databases and refine model predictions.

### **Advanced Structural Concepts**

New concepts for airframe and propulsion components incorporating new light weight concepts as well as "smart" structural concepts such as those incorporating self-diagnostics with adaptive materials, multifunctional component concepts to reduce mass and improve durability and performance, lightweight, efficient drive systems and electric motors for use in advanced turboelectric propulsion systems for aircraft, and new concepts for robust thermal protection systems for high-mass planetary entry, descent and landing. In particular, proposals are sought in:

- Innovative structural concepts, materials, manufacturing and fabrication leading to reliable, entry descent and landing systems including deployable rigid and flexible heat shields and structurally integrated multifunctional systems. Of particular interest are high temperature honeycombs, hat stiffeners, rigid fibrous and foam insulators, as well as high temperature adhesives, films and fabrics for advanced flexible heat shields.
- New actuator concepts employing shape memory alloys.
- Advanced mechanical component technologies including self-lubricating coatings, oil-free bearings, and seals.
- Advanced material and component technologies to enable the development of mechanical and electrical drive system to enable the development of turboelectric propulsion systems, which utilize power from a single turbine engine generator to drive multiple propulsive fans. Innovative concepts are sought for AC-tolerant, low loss ( 1.5 T field and 500 Hz electrical frequency; and high efficiency (= 30% of Carnot), low mass (
- Novel structural designs for integrated fan cases that combine hardwall composite cases for blade containment with acoustic treatments as well as concepts that integrate the case with the fan inlet to maximize structural, acoustic attenuation and weight benefits.
- Innovative approaches to structural sensors for extreme environments (>1800Å°F) including the development and validation of improved methods (i.e., adhesives, plasma spraying techniques, etc.) for attaching sensors to advanced high-temperature materials as well as approaches to measure strain, temperature, heat flux and/or acceleration of structural components.

### **A2.02 Combustion for Aerospace Vehicles**

**Lead Center:** GRC

**Participating Center(s):** LaRC

Combustion research is critical for the development of future aerospace vehicles. Vehicles for subsonic and supersonic flight regimes will be required to emit extremely low amounts of gaseous and particulate emissions to

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satisfy increasingly stringent emissions regulations. Hypersonic vehicles require combustion systems capable of sustaining stable and efficient combustion in very high speed flow fields where fuel/air mixing must be accomplished very rapidly and residence times for combustion are extremely limited; a major challenge is developing scaling laws that will allow the size of scramjet engines to be increased by a factor of 10, i.e., to mass flow rates of 100 lbm/sec. Fundamental combustion research coupled with associated physics based model development of combustion processes will provide the foundation for technology development critical for aerospace vehicles. Combustion for aerospace vehicles typically involves multi-phase, multi-component fuel, turbulent, unsteady, 3D, reacting flows where much of the physics of the processes are not completely understood. CFD codes used for combustion do not currently have the predictive capability that is typically found for non reacting flows. Practical aerospace combustion concepts typically require very rapid mixing of the fuel and air with a minimum pressure loss to achieve complete combustion in the smallest volume. Reducing emissions may require combustor operation where combustion instability can be an issue and active control may be required. Areas of specific interest where research is solicited includes:

- Development of laser-based diagnostics and novel experimental techniques for measurements in reacting flows.
- Two-phase flow simulation models and validation data under supercritical conditions.
- Development of ultra-sensitive instruments for measuring gas turbine black carbon emissions at temperatures and pressures characteristic of commercial aircraft cruise altitudes.
- High frequency actuators (bandwidth ~1000 Hz) that can be used to modulate fuel flow at multiple fuel injection locations (with individual Flow Numbers of 3 to 5) with minimal fuel pressure drop for active combustion control.
- Combustion instability modeling and validation.
- Novel combustion simulation methodologies.
- Concepts that will allow the scaling of scramjet engines burning hydrogen and/or hydrocarbon fuels.

The following areas are of particular interest:

- The effect that size has on mixing, injection, and thermal loading losses.
- The effect of size on mixing and flame propagation.
- The effect of size on injection strategies.
- The scaling of ignition devices, flameholders, and mixing devices.
- The effect that the size and thickness of the incoming boundary layer has on ignition devices and flameholders.
- Whether there is a ratio between the size of inviscid stirring structures and turbulent structures that is optimal for rapid mixing.

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## **A2.03 Aero-Acoustics**

**Lead Center:** LaRC

**Participating Center(s):** ARC, GRC

Innovative technologies and methods are necessary for the design and development of efficient, environmentally acceptable airplanes, and advanced aerospace vehicles. In support of the Fundamental Aeronautics Program, improvements in noise prediction, measurement methods and control are needed for subsonic and supersonic vehicles, including fan, jet, turbomachinery, engine core, open rotor, propeller and airframe noise sources. In addition, improvements in prediction and control of noise transmitted through aerospace vehicle structures are needed to reduce noise impact on passengers and crew. Innovations in the following specific areas are solicited:

- Fundamental and applied computational fluid dynamics techniques for aeroacoustic analysis, which can be adapted for design codes.
- Prediction of aerodynamic noise sources including those from engine and airframe as well as sources, which arise from significant interactions between airframe and propulsion systems.
- Efficient prediction tools for turbine and combustor aeroacoustics.
- Efficient high-fidelity computational fluid dynamics tools for assessing aeroacoustic performance of installed high and low speed single- and counter-rotation propellers.
- Innovative source identification techniques for engine (e.g., fan, jet, combustor, or turbine noise) and for airframe (e.g., landing gear, high lift systems) noise sources, including turbulence details related to flow-induced noise typical of jets, separated flow regions, vortices, shear layers, etc.
- Concepts for active and passive control of aeroacoustic noise sources for conventional and advanced aircraft configurations, including adaptive flow control technologies, smart structures for nozzles and inlets, advanced acoustic liners, and noise control technology and methods that are enabled by advanced aircraft configurations, including integrated airframe-propulsion control methodologies.
- Prediction of near field sound propagation including interaction between noise sources and the airframe and its flow field and far field sound propagation (including sonic booms) from the aircraft through a complex atmosphere to the ground.
- Computational and analytical structural acoustics prediction techniques for aircraft and advanced aerospace vehicle interior noise, 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.
- Development of synthesis and auditory display technologies for subjective assessments of aircraft community and interior noise, including sonic boom.

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## **A2.04 Aeroelasticity**

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**Lead Center: LaRC**

**Participating Center(s): AFRC, ARC, GRC**

The NASA Fundamental Aeronautics program has the goal to develop system-level capabilities that will enable civilian and military designers to create revolutionary systems, in particular by integrating methods and technologies that incorporate multi-disciplinary solutions. Aeroelastic behavior of flight vehicles is a particularly challenging facet of that goal.

The program's work on aeroelasticity includes conduct of broad-based research and technology development to obtain a fundamental understanding of aeroelastic and unsteady-aerodynamic phenomena experienced by aerospace vehicles in subsonic, transonic, supersonic, and hypersonic speed regimes. The program content includes theoretical aeroelasticity, experimental aeroelasticity, and advanced aeroservoelastic concepts. Of interest are:

- Aeroelastic, aeroservoelastic, and unsteady aerodynamic analyses at the appropriate level of fidelity for the problem at hand.
- Aeroelastic, aeroservoelastic, and unsteady aerodynamic experiments to validate methodologies and to gain valuable insights available only through testing.
- Development of computational-fluid-dynamic, computational-aeroelastic, and computational-aeroservoelastic analysis tools that advance the state of the art in aeroelasticity through novel and creative application of aeroelastic knowledge.

The technical discipline of aeroelasticity is a critical ingredient necessary in the design process of a flight vehicle for ensuring freedom from catastrophic aeroelastic and aeroservoelastic instabilities. This discipline requires a thorough understanding of the complex interactions between a flexible structure and the unsteady aerodynamic forces acting on the structure and at times, active systems controlling the flight vehicle. Complex unsteady aerodynamic flow phenomena, particularly at transonic Mach numbers, are also very important because this is the speed regime most critical to encountering aeroelastic instabilities. In addition, aeroelasticity is presently being exploited as a means for improving the capabilities of high performance aircraft through the use of innovative active control systems using both aerodynamic and smart material concepts. Work to develop analytical and experimental methodologies for reliably predicting the effects of aeroelasticity and their impact on aircraft performance, flight dynamics, and safety of flight are valuable. Subjects to be considered include:

- Development of design methodologies that include CFD steady and unsteady aerodynamics, flexible structures, and active control systems.
- Development of methods to predict aeroelastic phenomena and complex steady and unsteady aerodynamic flow phenomena, especially in the transonic speed range. Aeroelastic phenomena of interest include flutter, buffet, buzz, limit cycle oscillations, divergence, and gust response; flow phenomena of interest include viscous effects, vortex flows, separated flows, transonic nonlinearities, and unsteady shock motions.
- Development of efficient methods to generate mathematical models of wind-tunnel models and flight vehicles for performing vibration, aeroelastic, and aeroservoelastic studies. Examples include (a) CFD-based methods (reduced-order models) for aeroservoelasticity models that can be used to predict and alleviate gust loads, ride quality issues, and flutter issues and (b) integrated tool sets for fully coupled modeling and simulation of aeroservoelastothermoelasticity / flight dynamic (ASTE/FD) and propulsion effects.

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- Development of physics-based models for turbomachinery aeroelasticity related to highly separated flows, shedding, rotating stall, and non-synchronous vibrations (NSV). This includes robust, fast-running, accelerated convergence, reduced-order CFD approaches to turbomachinery aeroelasticity for propulsion applications. Development of blade vibration measurement systems (including closely spaced modes, blade-to-blade variations (mistuning), and system identification) and blade damping systems for metallic and composite blades (including passive and active damping methods) are of interest.
  - Development of aeroservoelasticity concepts and models, including unique control concepts and architectures that employ smart materials embedded in the structure and/or aerodynamic control surfaces for suppressing aeroelastic instabilities or for improving performance.
  - Development of techniques that support simulations, ground testing, wind-tunnel tests, and flight experiments of aeroelastic phenomena.
  - Investigation and development of techniques that incorporate structure-induced noise, stiffness and strength tailoring, propulsion-specific structures, data processing and interpretation methods, non-linear and time-varying methods development, unstructured grid methods, additional propulsion systems-specific methods, dampers, multistage effects, non-synchronous vibrations, coupling effects on blade vibration, probabilistic aerodynamics and aeroelastics, actively controlled propulsion system core components (e.g., fan and turbine blades, vanes), and advanced turbomachinery active damping concepts.
  - Investigation and development of techniques that incorporate lightweight structures and flexible structures under aerodynamic loads, with emphasis on aeroelastic phenomena in the hypersonic domain. Investigation of high temperatures associated with high heating rates, resulting in additional complexities associated with varying thermal expansion and temperature dependent structural coefficients. Acquisition of data to verify analysis tools with these complexities.

## **A2.05 Aerodynamics**

**Lead Center:** LaRC

**Participating Center(s):** AFRC, ARC, GRC, JSC, MSFC

The challenge of flight has at its foundation the understanding, prediction, and control of fluid flow around complex geometries - aerodynamics. Aerodynamic prediction is critical throughout the flight envelope for subsonic, supersonic, and hypersonic vehicles - driving outer mold line definition, providing loads to other disciplines, and enabling environmental impact assessments in areas such as emissions, noise, and aircraft spacing.

In turn, high confidence prediction enables high confidence development and assessment of innovative aerodynamic concepts. This subtopic seeks innovative physics-based models and novel aerodynamic concepts, with an emphasis on flow control, applicable in part or over the entire speed regime from subsonic through hypersonic flight.

All vehicle classes will experience subsonic flight conditions. The most fundamental issue is the prediction of flow separation onset and progression on smooth, curved surfaces, and the control of separation. Supersonic and hypersonic vehicles will experience supersonic flight conditions. Fundamental to this flight regime is the sonic boom, which to date has been a barrier issue for a viable civil vehicle. Addressing boom alone is not a sufficient mission enabler however, as low drag is a prerequisite for an economically viable vehicle, whether only passing through the supersonic regime, or cruising there. Atmospheric entry vehicles and space access vehicles will experience hypersonic flight conditions. Reentry capsules and vehicles deploy multiple parachutes during descent and landing.

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Predicting the physics of unsteady flows in supersonic and subsonic speeds is important for the design of these deceleration systems. The gas-dynamic performance of decelerators for vehicles entering the atmospheres of planets in the solar system is not well understood. Reusable hypersonic vehicles will be designed such that the lower body can be used as an integrated propulsion system in cruise condition. Their performance is likely to suffer in off-design conditions, particularly acutely at transonic speeds. Advanced flow control technologies are needed to alleviate the problem.

This solicitation seeks proposals to develop and validate:

- Turbulence models and advanced computational techniques such as detached eddy, large eddy, or direct numerical simulations that capture the physics of separation onset at Reynolds numbers relevant to flight, where relevant to flight is dependent on a targeted vehicle class and mission profile.
- Boundary-layer transition models suitable for direct integration with state-of-the-art flow solvers.
- Active flow control concepts targeted at separation control, shock wave manipulation, and/or viscous drag reduction with an emphasis on the development of novel, practical, lightweight, low-energy actuators.
- Innovative aerodynamic concepts targeted at vehicle efficiency or control, including but not limited to concepts targeted at turbulent boundary skin friction drag reduction.
- Physics-based models for simultaneous low boom/low drag prediction and design.
- Aerodynamic concepts enabling simultaneous low boom and low drag objectives.
- Innovative methods to validate both flow models and aerodynamic concepts with an emphasis on aft-shock effects, which are hindered by conventional wind tunnel model mounting approaches.
- Uncertainty quantification methods suitable for use with state-of-the-art flow solvers.
- Accurate aerodynamic analysis and multidisciplinary design tools for multi-body flexible structures in the atmospheres of planets and moons including the Earth, Mars, and Titan.
- Advanced flow control technologies to alleviate off-design performance penalties for reusable hypersonic vehicles.

## **A2.06 Aerothermodynamics**

**Lead Center: ARC**

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

Development of hypersonic flight vehicles for airbreathing access to space and for planetary entry poses several design challenges. One of the primary obstacles is the large uncertainty in predictive capability of the aerothermal environment to which these vehicles are subjected. For airbreathing access to space vehicles, predictions of boundary layer transition to turbulence and shock boundary layer interactions in a turbulent flow regime are sources of large aerothermal uncertainty and require conservative assumptions. For planetary entry vehicles with either rigid or flexible thermal protection systems (TPS), sources of large aerothermal uncertainty in high enthalpy

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conditions also include the catalytic or ablative properties of the TPS. The fluid dynamic and thermochemical interactions of a rough ablating surface with the aerothermal environment leads to many poorly understood coupled phenomena such as early boundary layer transition, turbulent heating augmentation, catalytic heating, radiation absorption, etc. At high entry speeds and large vehicle sizes, shock layer radiation becomes a large component of the aeroheating, with an increasing fraction of the radiation produced in the poorly understood vacuum ultraviolet part of the spectrum. The low confidence in the predictive capability is apparent in high enthalpy flows that are often difficult to adequately reproduce in a ground test facility.

The model uncertainties require designers to resort to large margins, resulting in reduced mission capabilities and increased costs. Future science and human exploration missions to Mars and other planets will require dramatic improvements in our current capability to land large payloads safely on these worlds. Research in aerothermodynamics focuses on solving some of the most difficult challenges in hypersonic flight. These include the development of predictive models via experimental validation for shock layer radiation phenomena, non-equilibrium thermodynamic and transport properties, catalyticity, transition and turbulence, and ablation phenomena, as well as the development of new experimental datasets, especially in high enthalpy flow that can be used to validate theoretical and computational models.

Proposals suggesting innovative approaches to any of these problems are encouraged; specific areas of interest include:

- Advancement of NASA boundary layer transition tools, especially including high enthalpy effects.
- Development of shock turbulent boundary layer interaction models and validation with an experimental program.
- Development of radiation models supported by experimental validation in a laboratory (using shock tube, plasma torch, etc.) simulating extreme entry environments at Earth, Mars, Titan, and the Giant Planets.
- Development of high enthalpy RANS level turbulence models in a rough, ablating environment using experimentation or use of high fidelity computational techniques such as DNS or LES.
- Development of instrumentation for use in high-enthalpy flows to measure pressure, shear, radiation intensity, and off body flow quantities with enhanced capability such as high frequency measurements and/or high temperature tolerance.
- Development of tools and techniques that enable remote thermal imaging of entry vehicles with high temperature and spatial resolution, and lower uncertainty than the state-of-the art.
- Development of numerical techniques and computational tools that advance the start-of-the-art in computations of unsteady, turbulent separated flows with reasonable computational efficiency.

## **A2.07 Flight and Propulsion Control and Dynamics**

Lead Center: ARC

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

NASA is conducting fundamental aeronautic research to develop innovative ideas that can lead to next generation aircraft design concepts with improved aerodynamic efficiency, lower emissions, less fuel burn, and reduced noise and carbon footprints. To realize these potential benefits, innovative vehicle design concepts can exhibit many complex modes of interactions due to many different effects of flight physics such as aerodynamics, vehicle dynamics, propulsion, structural dynamics, and external environment in all three flight regimes. Advanced flight control strategies for innovative aircraft design concepts are seen as an enabling technology that can harvest potential benefits derived from these complex modes of interaction. The following technology areas are of particular interest:

### **Active Aeroelastic Wing Shape Tailoring for Aircraft Performance and Control**

Modern aircraft are increasingly designed with light-weight, flexible airframe structures. By employing distributed flight control surfaces, a modern wing structure (which implies aircraft wing, horizontal stabilizer, and vertical stabilizer) can be strategically tailored in-flight by actively controlling the wing shape so as to bring about certain desired vehicle characteristics. For example, active aeroelastic wing shape tailoring can be employed to control the wash-out distribution and wing deflection in such a manner that could result in improved aerodynamic performance such as reduced drag during cruise or increased lift during take-off. Another novel use of active aeroelastic wing shape tailoring is for flight control. By actively controlling flexible aerodynamic surfaces differentially or collectively, the motion of an aircraft can be controlled in all three stability axes. In high speed supersonic or hypersonic vehicles, effects of airframe-propulsion-structure interactions can be significant. Thus, propulsion control can play an integral role with active aeroelastic wing shape tailoring control in high speed flight regimes.

Technology development of active aeroelastic wing shape tailoring may include, but are not limited to the following:

- Innovative aircraft concepts that can significantly improve aerodynamic, performance and control by leveraging active aeroelastic wing shape tailoring.
- Sensor technology that will enable in-flight wing twist and deflection static and dynamic measurements for control development.
- Actuation methods that include novel modes of operation and concepts of actuation for actively controlling wing shape in-flight.
- Vehicle dynamic modeling capability that includes effects of aero-propulsive-servo-elasticity for vehicle control and dynamics.
- Integrated approaches for active aeroelastic wing shape tailoring control with novel control effector concepts that will provide multi-objective advanced optimal or adaptive control strategies to achieve simultaneously aerodynamic performance such as trim drag reduction, aeroelastic stabilization or mode suppression, and load limiting.

### **Gust Load Alleviation Control**

In a future NextGen operational concept, close separation between aircraft in super density operations could lead to more frequent wake vortex encounters. Airframe flexibility in modern aircraft will inherently lead to a potential increase in vehicle dynamic response to turbulence and wake vortices. Gust load alleviation control technology can improve ride qualities and reduce undesired structural dynamic loading on flexible airframes that could shorten aircraft service life. Gust load alleviation control technology can be either reactive or predictive. In a traditional reactive control framework, flight control systems can be designed to provide sufficient aerodynamic damping

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characteristics that suppress vehicle dynamic response as rapidly as possible upon a turbulence encounter. There is a trade off, however, between increased damping for mode suppression and command-following objectives of a flight control system. Large damping ratios, while desirable for mode suppression, may result in poor flight control performance.

Predictive control can provide a novel gust load alleviation strategy for future aircraft design with light-weight flexible structures. Novel look-ahead sensor technology can measure or estimate turbulent intensity to provide such information to a predictive gust load alleviation control system which in turn would dynamically reconfigure flight control surfaces as an aircraft enters a turbulent atmospheric region. Technology development of predictive gust load alleviation control may include, but are not limited to the following:

- Novel sensor methods for Optical Air Data Systems based on LIDAR or other novel detection methods that can measure near-field air turbulent velocity components directly in front of an aircraft in the order of one-body length scale to provide nearly instantaneous predictive capability to significantly improve the effectiveness of a gust load alleviation control system.
- Predictive gust load alleviation control approaches or other effective methods that can reliably reconfigure flight control surfaces dynamically based on the sensor information of the near-field turbulence to mitigate the vehicle structural dynamic response upon a turbulence encounter. The predictive control strategies should be cognizant of potential adverse effects due to potential latency issues that can counteract the objective of gust load alleviation, or potential structural mode interactions due to control input signals that may contain frequencies close to the natural frequencies of the airframe.

### **Advanced Control Concepts for Propulsion Systems**

Enabling high performance "Intelligent Engines" will require advancement in the state of the art of propulsion system control. Engine control architectures/methods need to be developed that provide a tighter bound control on engine parameters for improved propulsion efficiency while maintaining safe operation. The ability of the controller to maintain its designed improvement of engine operation over the entire life and particular health condition of the propulsion system is critical. The controller needs to adapt to the specific health conditions of each engine to eventually allow for a "personalized" control, which will maintain the most efficient operation throughout the engine lifetime and increase the useful operating life. Possible advanced engine control concepts could include:

- Direct nonlinear control design such as predictive model based methods to directly control engine thrust while maintaining safety limits such as stall margins.
- Model-Based Multivariable control to allow direct control of quantities of interest such as thrust, temperature and stall margins while using all available actuators for feedback.
- Adaptive control schemes to maintain robust performance with changing engine condition with usage.

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**Lead Center: LaRC**

**Participating Center(s): ARC, GRC**

One of the approaches to achieve the NASA Fundamental Aeronautics Program goals is to solve the aeronautics challenges for a broad range of air vehicles with system-level optimization, assessment and technology integration. The needs to meet this approach can be defined by three general themes:

- Variable Fidelity, Physics-Based Design/Analysis Tools.
- Technology Assessment and Integration.
- Evaluation of Advanced Concepts.

Current interdisciplinary design/analysis involves a multitude of tools not necessarily developed to work together, hindering their application to complete system design/analysis studies. NASA has developed a capability that integrates several conceptual design/analysis tools and models in ModelCenter. In addition, development work is continuing on a python-based, open-source architecture (OpenMDAO) that should serve as the long term solution for a multi-fidelity, multi-disciplinary optimization framework. Solicited topics are targeted around these three themes that will support this NASA research area.

### **Variable Fidelity, Physics-Based Design/Analysis Tools**

An integrated design process combines high-fidelity computational analyses from several disciplines with advanced numerical design procedures to simultaneously perform detailed Outer Mold Line (OML) shape optimization, structural sizing, active load alleviation control, multi-speed performance (e.g., low takeoff and landing speeds, but efficient transonic cruise), and/or other detailed-design tasks. Current practice still widely uses sequential, single-discipline optimization, at best coupling low-fidelity modeling of other relevant disciplines during the detailed design phase. Substantial performance improvements will be realized by developing closely integrated design procedures coupled with highest-fidelity analyses for use during detailed-design. Design procedures must enable rapid determination of sensitivities (gradients) of a design objective with respect to all design variables and constraints, choose search directions through design space without violating constraints, and make appropriate changes to the vehicle shape (ideally both external OML shape and internal structural element size). Solicitations are for integrated design optimization tools that find combinations of design variables from more than one discipline and can vary synergistically to produce superior performance compared to the results of sequential, single-discipline optimization or repeated cut-and-try analysis.

Research challenges include the engineering details needed to numerically zoom (i.e., numerical analysis at various levels of detail) between multi-fidelity components of the same discipline, as well as, multi-discipline components of the same fidelity. A major computer science challenge is developing boundary objects that will be reused in a wide variety of simulations. Proposals will be considered that enable coupling differing disciplines, numerical zooming within a single discipline, deploying large simulations and assembling and controlling secure or non-secure simulations.

### **Technology Assessment and Integration**

Improved analysis capability of integrated airframe and propulsion systems would allow more efficient designs to be created that would maximize efficiency and performance while minimizing both noise and emissions. Improved integrated system modeling should allow designers to consider trade-offs between various design and operating parameters to determine the optimum design for various classes of subsonic fixed wing aircraft ranging from personal aircraft to large transports. The modeling would also be beneficial if it had enough fidelity to enable it to

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analyze both conventional and unconventional systems. Current analysis tools capable of analyzing integrated systems are based on simplified physical and semi-empirical models that are not fully capable of analyzing aircraft and propulsion system parameters that would be required for new or unconventional systems.

Analysis tools are solicited that are capable of analyzing new and unconventional aircraft and propulsion integrated systems. These include:

- New combustor designs, alternate fuel operation, and the ability to estimate all emissions.
- Noise source models (e.g., fan, jet, turbine, core and airframe components). Analyses tools that are scalable, especially to small aircraft, are desired.

### **Evaluation of Advanced Concepts**

Conceptual design and analysis of unconventional vehicle concepts and technologies is needed for technology portfolio investment planning, development of advanced concepts to provide technology pull, and independent technical assessment of new concepts. This capability will enable "virtual expeditions through the design space" for multi-mission trade studies and optimization. This will require an integrated variable fidelity concept design system. The aerospace flight vehicle conceptual design phase is, in contrast to the succeeding preliminary and detail design phases, the most important step in the product development sequence, because of its predefining function. However, the conceptual design phase is the least well understood part of the entire flight vehicle design process, owing to its high level of abstraction and associated risk, its multidisciplinary design complexity, its permanent shortage of available design information, and its chronic time pressure to find solutions. Currently, the important primary aerospace vehicle design decisions at the conceptual design level (e.g., overall configuration selection) are still made using extremely simple analyses and heuristics. An integrated, variable fidelity system would have large benefits. Higher fidelity tools enabling unconventional configurations to be addressed in the conceptual design process are solicited.

## **A2.09 Rotorcraft**

**Lead Center:** ARC

**Participating Center(s):** GRC, LaRC

The challenge of the Subsonic Rotary Wing thrust of the NASA Fundamental Aeronautics Program is to develop validated physics-based multidisciplinary design-analysis-optimization tools for rotorcraft, integrated with technology development, enabling rotorcraft with advanced capabilities to fly as designed for any mission. Technologies of particular interest are as follows:

### **Experimental Capabilities: Instrumentation and Techniques for Rotor Blade Measurements**

Instrumentation and measurement techniques are encouraged for assessing scale rotor blade boundary layer state (e.g., laminar, transition, turbulent flow) in simulated hover and forward flight conditions, measurement systems for large-field rotor wake assessment, and fast-response pressure sensitive paints applicable to blade surfaces.

### **Acoustics: Interior and Exterior Rotorcraft Noise Generation, Propagation and Control**

Interior noise topics of interest include, but are not limited to, prediction and/or experimental methods that enhance the understanding of noise generation and transmission mechanisms for cabin noise sources (e.g., power-train noise), active and combined active/passive methods to reduce cabin noise, and novel structural systems or

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materials to reduce cabin noise without an excessive weight penalty. Exterior noise topics of interest include, but are not limited to, noise prediction methods that address the understanding of issues such as noise generation, propagation, and control. These methods may address topics such as novel or drastically improved source noise prediction methods, novel or drastically improved noise propagation methods (e.g., through the atmosphere) to understand and/or control noise sources and their impact on the community. Methods should address one or more of the major noise components such as: harmonic noise, broadband noise, blade-vortex interaction noise, high-speed impulsive noise, interactional noise, and/or low frequency noise (e.g., propagation, psychoacoustic effects, etc).

### **Rotorcraft Power Train System Improvements**

Health management of rotorcraft power trains is critical. Predictive, condition-based maintenance improves safety, decreases maintenance costs, and increases system availability. Topics of interest include algorithm development, software tools and innovative sensor technologies to detect and predict the health and usage of rotorcraft dynamic mechanical systems in the engine and drive system. Rotorcraft health management technologies can include tools to: increase fault detection coverage and decrease false alarm rates; detect onset of failure, isolate damage, and assess damage severity; predict remaining useful life and maintenance actions required; system models, material failure models and correlation of failure under bench fatigue, seeded fault test and fielded data; tools to correlate propulsion system operational parameters back to actual usage and component fatigue life; Also of interest are advanced gear technologies for rotorcraft transmissions.

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

## **A2.10 Propulsion Systems**

**Lead Center: GRC**

**Participating Center(s): GRC**

This subtopic is divided into three parts. The first part is the Turbomachinery and Heat Transfer and the second part is Developments Needed in Turbulence Modeling for Propulsion Flowpaths and third is Propulsion System Integration:

### **Turbomachinery and Heat Transfer**

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

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

- Advanced instrumentation to enable time-accurate, detailed measurement of unsteady velocities, pressures and temperatures in three-dimensional flowfields such as found in turbomachinery components. This may include instrumentation and measurement systems capable of operating in conditions up to 900 degrees F and in the presence of shock-blade row interactions, as well as in high speed, transonic cascades. The instrumentation methods may include measurement probes, non-intrusive optical methods

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and post-processing techniques that advance the state of the art in turbomachinery unsteady flowfield measurement for purposes of accurately resolving these complex flowfield.

- Advanced compressor flow control concepts to enable increased high stage loading in single and multi-stage axial compressors while maintaining or improving aerodynamic efficiency and operability. Technologies are sought that would reduce dependence on traditional range extending techniques (such as variable inlet guide vane and variable stator geometry) in compression systems. These may include flow control techniques near the compressor end walls and on the rotor and stator blade surfaces. Technologies are sought to reduce turbomachinery sensitivity to tip clearance leakage effects where clearance to chord ratios may be on the order of 5% or above.
- Novel turbine cooling concepts are sought to enable very high turbine cooling effectiveness especially considering the manufacturability of such concepts. These concepts may include film cooling concepts, internal cooling concepts, and innovative methods to couple the film and internal cooling designs. Concepts proposed should have the potential to be produced with current or forthcoming manufacturing techniques. The availability of advanced manufacturing techniques may actually enable improved cooling designs beyond the current state-of-the-art.

### **Developments Needed in Turbulence Modeling for Propulsion Flowpaths and Propulsion System Integration**

Flowpaths within propulsion systems are characterized by several aerodynamic and thermodynamic features which are very difficult for currently available computational fluid dynamics (CFD) methods to calculate accurately. Experiments alone are limited in their ability to provide detailed insights to the complex flow physics which occur in advanced propulsion-airframe integrated systems for future subsonic, supersonic and hypersonic applications. Therefore, the continued need for competent CFD methods to be used in conjunction with experiments is high. The one CFD modeling area that has remained the most challenging, yet most critical to the success of integrated propulsion system simulations is turbulence modeling. The flow features specific to the propulsion system components that provide the greatest turbulence modeling challenges include separated flows whether they be from subsonic diffusion or turbulent shock wave-boundary layer interactions, inlet/vehicle forebody boundary layer transition, unsteady flowfields resulting from incorporation of active flow control, strongly three-dimensional and curved flows in turbomachinery, turbulent-chemistry interactions from subsonic combustors to scramjets, and heat transfer.

Propulsion system integration challenges are encountered across all of the speed regimes from subsonic "N+3" vehicle concepts (with projected fuel burn benefits from boundary layer ingestion or distributed propulsion systems, for example), to supersonic "N+2" vehicle concepts with low-boom, high-performance inlets and nozzles integrated with variable cycle engine systems, to hypersonic reusable air-breathing launch vehicle concepts which incorporate integrated combined-cycle propulsion systems.

Proposals suggesting innovative approaches to any of these problems are encouraged; specific areas of interest include:

- Advancement of turbulence modeling for shock wave-boundary layer interactions.
- Advancement of Reynolds-stress closure models for propulsion flowpath analyses, including application of LES and or DNS for model development and validation.
- Development of mid-level CFD models for the interaction of turbulence and chemical reaction that give superior results to the simple models (e.g., Magnussen), but which do not require the large computational

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expense of the very complex models (e.g., PDF evolution methods).

- Advancement of boundary layer transition models, especially in cases of low freestream turbulence levels that occur in actual flight.
- Incorporation of NASA high-order accurate numerical methods (e.g., Flux Reconstruction) into propulsion CFD tools using both structured as well as unstructured meshes.
- Development of methods and software tools to quantify uncertainty as part of the CFD solution procedure.

Development of meaningful metrics that quantify the difference between computed solutions and experimental data and use the metrics to validate the CFD codes. Development of tools to enable rapid post-processing and assessment of CFD solutions, especially from NASA in-house CFD tools such as Wind-US and VULCAN (e.g., automatically interpolating numerical solutions to the measurement locations, generating "metrics of goodness" for parameters of interest, etc.).

Propulsion integration topics:

- Development of methodologies that provide installed nozzle performance, specifically conceptual level design/analysis methods, capable of addressing conventional and unconventional geometries. Geometries should be valid for subsonic, supersonic, and/or hypersonic flight applications. Documentation of methodologies should include: underlying theory and mathematical models, computational solution methods, source-code, validation data, and limitations.
- Technologies and/or concepts to enable integrated, high-performance, light-weight supersonic inlets and nozzles that have minimal impact on an aircraft's sonic boom signature.
- Development of supersonic inlet systems that are "Fail Safe" and require no net mass extraction (i.e., bleed) or mass injection to control the shock wave/boundary-layer separations that inevitably arise in any supersonic inlet.
- Shorter, accurate, robust inlet mass flow measurement systems to replace the classic cold pipe/mass flow plug and measure mass-flow with distorted inflow.