



## NASA SBIR 2009 Phase I Solicitation

### A2 Fundamental Aeronautics

The Fundamental Aeronautics Program (FAP) encompasses the principles of flight in any atmosphere, and at any speed. The program develops focused technological capabilities, starting with the most basic knowledge of underlying phenomena through validation and verification of advanced concepts and technologies at the component and systems level. Physics-based, multidisciplinary design, analysis, and optimization (MDAO) tools will be developed that make it possible to evaluate radically new vehicle designs and to assess, with known uncertainties, the potential impact of innovative technologies and concepts on a vehicle's overall performance. The development of advanced component technologies will realize revolutionary improvements in noise, emissions, and performance. The program also supports NASA's human and robotic exploration missions by advancing knowledge in aeronautical areas critical to planetary Entry, Descent, and Landing. NASA has defined a four-level approach to technology development: conduct foundational research to further our fundamental understanding of the underlying physics and our ability model that physics; leverage the foundational research to develop technologies and analytical tools focused on discipline-based solutions; integrate methods and technologies to develop multi-disciplinary solutions; and solve the aeronautics challenges for a broad range of air vehicles with system-level optimization, assessment and technology integration.

Structurally, the FAP is composed of four projects: hypersonic flight, supersonic flight, subsonic fixed-wing aircraft and subsonic rotary-wing aircraft.

#### Hypersonics

- Fundamental research in all disciplines to enable very-high speed flight (for airbreathing launch vehicles) and re-entry into planetary atmospheres;
- High-temperature materials, thermal protection systems, air-breathing propulsion, aero-thermodynamics, multi-disciplinary analysis and design, GNC, experimental capabilities.

#### Supersonics

- Eliminate environmental and performance barriers that prevent practical supersonic vehicles (cruise

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efficiency, noise and emissions, vehicle integration and control);

- Supersonic deceleration technology for Entry, Descent, and Landing into Mars.

### **Subsonic Fixed Wing (SFW)**

- Develop revolutionary technologies and aircraft concepts with highly improved performance while satisfying strict noise and emission constraints;
- Focus on enabling technologies: acoustics predictions, propulsion/combustion, system integration, high-lift concepts, lightweight and strong materials, GNC.

### **Subsonic Rotary Wing (SRW)**

- Improve civil potential of rotary wing vehicles (vs. fixed wing) while maintaining their unique benefits;
- Key advances in multiple areas through innovation in materials, aeromechanics, flow control, propulsion.

Each project addresses specific discipline, multi-discipline, sub-system and system level technology issues relevant to that flight regime. A key aspect of the Fundamental Aeronautics Program is that many technical issues are common across multiple flight regimes and may be best resolved in an integrated coordinated manner. As such, the FAP subtopics are organized by discipline, not by flight regime, with a special subtopic for rotary-wing issues.

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, noise, lift, drag, durability, and emissions. This subtopic is also a subtopic for the "Low-Cost and Reliable Access to Space (LCRATS)" topic. Proposals to this subtopic may gain additional consideration to the extent that they effectively address the LCRATS topic (See topic O5 under the Space Operations Mission Directorate). In general, the technologies of interest cover four research themes:

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- **Fundamental materials development, processing and characterization** - new approaches to enhance the durability, processability, and reliability of advanced materials (metals, ceramics, polymers, composites, hybrids and coatings) with an emphasis on multifunctional and adaptive materials and structural concepts. In particular, proposals are sought in:
    - Textile ceramic matrix composite materials and structures and environmental barrier coatings capable of multi-use at 2700Å°F or greater for air vehicle propulsion and airframe applications.
    - 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.
    - Development of joining and integration technologies including fasteners and/or chemical joining methods for ceramic-to-ceramic, metal-to-metal, and metal-to-ceramic materials.
    - Development of variable stiffness materials to support adaptive, multifunctional structures concepts.
  
  - **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 structures that integrate novel materials, mechanism design, and structural subcomponent design into systems level designs.
    - Life prediction tools for textile ceramic 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 preform structures in either a relaxed or compressed deformation state are of particular interest.
  
  - **Computational materials development tools** - methods to predict properties of both airframe and propulsion materials based upon chemistry and process for conventional as well as nanostructured, multifunctional and adaptive materials.
    - Ab-initio methods that enable the development of refractory composite coating for multi-use at temperatures greater than 3000Å°F in an air environments.
    - Quantum chemistry, molecular dynamics, and mesoscale models for the design, characterization and optimization of ablation materials for radiation heating, thermal re-radiation, and catalytic effects.
  
  - **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:
    - Microadaptive flow control for use in robust, efficient, low mass actuators with broad bandwidths. The identification and development of actuators that can operate in harsh environments (600-800Å°F) experienced in gas turbine engine compressors with the following features: (1)
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operational frequencies of 1000 to 10,000 Hz, (2) stroke or displacement  $>100\frac{1}{2}$ m, (3) capable of exerting forces  $>200$  lbs.

- Piezoelectric devices with the ability to convert strain energy into useable electric energy that can be integrated into aircraft designs for energy harvesting and or vibration damping including application to aircraft engine fan and compressor rotor blades. Requirement for these devices are power densities greater than or equal to  $0.1 \text{ mW/cm}^2$ . Novel approaches are sought to enable piezoelectric devices to operate in engine environment including typical stresses of fan/compressor blades and to have the durability for engine application.
- Miniature thermoelectric devices for powering RF sensors for use in turbine engine compressors. Devices must be capable of operating at temperatures up to  $600\text{Å}^\circ\text{C}$  in oxidizing environments and capable of achieving power densities greater than or equal to  $0.1 \text{ mW/cm}^2$ . Prototype device demonstration is required showing functionality at  $600\text{Å}^\circ$  in air for 100 hours and delivering power output in excess of  $10\frac{1}{2}\text{W/cm}^2$ .
- Materials to support wireless sensing and actuating multifunctional structures.
- Manufacturing and fabrication technologies leading to the development of lightweight structurally integrated thermal protection systems for space access and planetary entry, including high temperature honeycombs, hat-stiffeners, rigid fibrous and foam insulators.
- Advanced material and component technologies to enable the development of mechanical and electrical drive system to distribute power from a single engine core to drive multiple propulsive fans, in particular, AC-tolerant, low loss ( 1.5 T field and 500 Hz electrical frequency; and high efficiency (= 30% of Carnot), low mass (
- Novel structural design strategies for integrated fan cases that combine hardwall composite cases for blade containment with acoustic treatments. Concepts are also sought that also integrate the case with the fan inlet to maximize structural, acoustic attenuation and weight benefits.

## **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 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. 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 include:

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- 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 determining the size-dependent mass of gas-turbine engine particle emissions;
  - 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;
  - Combustor and/or combustion physics and mechanisms, enhanced mixing concepts, ignition and flame holding, turbulent flame propagation, vitiated-test media and facility-contamination effects, hydrogen/hydrocarbon-air kinetic mechanisms, multi-phase combustion processes, and engine/propulsion component characterizations;
  - Novel combustor concepts that advance/enhance the state-of-the-art in hypersonic propulsion to improve system performance, operability, reliability and reduce cost. Both analytic and/or experimental efforts are encouraged, as well as collaborative efforts that leverage technology from on-going research activities;
  - Computational and experimental technologies for the accurate prediction of combined cycle phenomena such as shock trains in isolators, inlet unstart, and thermal choke.

### **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, propfan, 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, crew and 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;
- Prediction of aerodynamic noise sources including those from engine and airframe and sources which arise from significant interactions between airframe and propulsion systems;
- Prediction of sound propagation (including sonic booms) from the aircraft through a complex atmosphere to the ground. This should include interaction between noise sources and the airframe and its flowfield;

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- Computational and analytical structural acoustics prediction techniques for aircraft and advanced aerospace vehicle interior noise, particularly for use early in the airframe design process;
  - Prediction and control of high-amplitude aeroacoustic loads on advanced aerospace structures and the resulting dynamic response and fatigue;
  - 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, and noise control technology and methods that are enabled by advanced aircraft configurations, including integrated airframe-propulsion control methodologies;
  - Technologies and techniques for active and passive interior noise control for aircraft and advanced aerospace vehicle structures;
  - Development of synthesis and auditory display technologies for subjective assessments of aircraft community and interior noise, including sonic boom.

## **A2.04 Aeroelasticity**

**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 the 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 assuring 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

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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, 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 aeroservoelastocity / flight dynamic (ASTE/FD) and propulsion effects.
- 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

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,

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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 such as the new Crew Exploration Vehicle deploy multiple parachutes during descent and landing. 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 capturing 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;
- 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.

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## **A2.06 Aerothermodynamics**

**Lead Center:** LaRC

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

Development of accurate tools to predict aerothermal environments and their effects on space vehicles is critically important to achieving the goals of current NASA missions. These tools will also enable the development of advanced spacecraft for future missions by reducing uncertainties during design and development.

The large size and high re-entry velocity of the Crew Exploration Vehicle and the conditions encountered in proposed aerocapture missions to Titan, Neptune, and Venus require study of shock layer radiation phenomena, radiative heat transfer, and non-equilibrium thermodynamic and transport properties; these in turn require understanding of the internal structure and dynamics of the constituent gases.

Transition and turbulence effects are particularly complex in hypersonic flows, where unique problems are posed by shocks, real gas effects, body surfaces with complex and possibly time-dependent roughness, nose bluntness, ablation, surface catalyticity, separation, and an unknown free-stream disturbance environment.

At the heating rates encountered during hypersonic re-entry, surface ablation products blowing into the boundary layer introduce new interactions including chemical reactions and radiation absorption, that strongly affect surface heating rates and integrated heat loads.

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

- Computational analysis methods for radiation and radiation transport in the shock layer surrounding planetary entry vehicles;
- Advanced physics-based thermal and chemical non-equilibrium models for thermodynamics, transport, and radiation;
- Studies of the interactions of gases in the shock layer with ablating materials from the vehicle thermal protection system;
- Experimental methods and diagnostics to measure the characteristics of hypersonic flow fields, either in flight or in ground-based facilities;
- Software tools coupling radiation, non-equilibrium chemistry, Reynolds-averaged Navier-Stokes, and large eddy simulation codes to enable the design and validation of mission configurations for entry into planetary atmospheres.

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

**Lead Center:** ARC

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

Enabling advanced aircraft configurations for subsonic, supersonic and hypersonic flight, and high performance engines will require advancement in the state-of-the art dynamic modeling and flight/propulsion control. Control methods need to be developed and validated for "optimal" and reliable performance of complex, unsteady, and nonlinear systems with significant modeling uncertainties while ensuring operational flexibility. New dynamic modeling and simulation techniques need to be developed to investigate dynamic performance issues and support development of control strategies for innovative aircraft configurations and propulsion systems. Technology needs specific to different flight regimes are summarized in the following:

### **Subsonic Fixed Wing Aircraft**

Technologies of interest include: flying qualities design guidelines for civil transport aircraft and methods for evaluating the flying qualities of concept transport aircraft, including blended-wing-body and cruise efficient short takeoff and landing aircraft; active control techniques for subsystems within current and advanced engines that lead to improvements in propulsion system efficiency; definition of actuation requirements and characterization of transient behavior of flow control for active aerodynamic shaping; development of a modular, distributed control system architecture for unified propulsion/airframe control; toolset capable of assessing the controllability for a given control effector layout and determining the sizes of conventional control surfaces, horizontal tail and vertical tail necessary to meet control power requirements; novel control techniques for reducing system noise, emissions and fuel burn.

### **Supersonic Flight**

Technologies of interest include: methods for developing integrated aeroservoelastic (ASE) models, including propulsion effects, suitable for simulation and control design; novel control design methods for integrated aero-propulsion-servo-elastic control leading to acceptable flying qualities over the operating flight envelope; novel, and feasible, takeoff and approach to landing procedures to accommodate the visibility challenges due to long forebodies; integrated inlet/engine control to ensure safe (no inlet unstart or compressor surge/stall) and efficient operation.

### **Hypersonic Flight**

Technologies of interest include: system dynamic models pertaining to a dual-mode combustor based propulsion system (RAM/SCRAM) incorporating the essential coupled dynamic elements with varying fidelity for control design, analysis, and evaluation; methods for characterizing uncertainty in the dynamic models to enable control robustness evaluation; methods for dynamic modeling of hypersonic flow fields, both for external aerodynamics and internal flowpaths, and of heat release in scramjet flowpaths with appropriate fidelity for use in dynamic analysis and control design; hierarchical GNC (Guidance, Navigation and Control) architectures and energy management techniques to enable trajectory shaping and control over a wide operating envelope with integrated flight/propulsion control.

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

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## **A2.08 Aircraft Systems Analysis, Design and Optimization**

**Lead Center:** GRC

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

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 four general themes:

1. Design Environment Development;
2. Variable Fidelity, Physics-Based Design/Analysis Tools;
3. Technology Assessment and Integration; and
4. 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. Multi-fidelity, multi-disciplinary optimization frameworks, such as Numerical Propulsion System Simulation (NPSS), have been developed by NASA but have limited capabilities to simulate complete vehicle systems. Solicited topics are aligned with these four themes that will support this NASA research area.

### **(1) Design Environment Development**

Technology development is needed to provide complex simulation and modeling capabilities where the computer science details are transparent to the engineer. A framework environment is needed to provide a seamless integration environment where the engineer need not be concerned with where or how particular codes within the system level simulation will be run. Interfaces and utilities to define, setup, verify, determine the appropriate resources, and launch the system simulation are also needed.

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.

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

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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.

### **(3) 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 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: (1) New combustor designs, alternate fuel operation, and the ability to estimate all emissions, and (2) Noise source models (e.g., fan, jet, turbine, core and airframe components). Analyses tools that are scalable, especially to small aircraft, are desired.

### **(4) 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.

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## **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:

### **Propulsion-Variable Speed Drive Systems/Transmissions**

Technologies, and predictive capability, related to enabling concepts and techniques for variable speed drive systems/transmissions suitable for large rotorcraft application are encouraged. Specifically this would include concepts for controlling and enabling variable speed drives as well as lightweight and reliable drive system components. Efficient drive-system speed-variability on the order of 30-50% should be the focus of the proposed technologies and analysis tools.

### **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, fast-response pressure sensitive paints applicable to blade surfaces, and methods to measure the rotor tip path plane angle of attack, lateral and longitude flapping, and shaft angle in flight and in the wind tunnel. Very low airspeed measurement systems for flight vehicles.

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

Topics of interest include, but are not limited to, external noise prediction methods for manned and unmanned rotorcraft, improved acoustic propagation models, psychoacoustics analysis of rotorcraft noise, interior noise prediction methods and active/passive noise control applications for rotorcraft including engine and transmission noise reduction, advanced acoustic measurement systems for flight and wind tunnel applications, acoustic data acquisition/reduction/analysis, rotor noise reduction techniques, noise abatement flight operations. Methods, devices, concepts for rotorcraft, or specifically wing, airflow control for steep noise abatement approach operations and hover (low speed) download relief. Rotor noise including broadband, harmonic, blade-vortex interaction, and high-speed impulsive noise, as well as rotor/tail rotor and rotor/rotor interactional noise, are of interest. Frequency range includes not only audible range, but very low frequency rotational noise (blade-passage frequency below 20 Hz) as well. Optimized active/passive concepts and noise tailoring, including rotorcraft designs that are inherently designed for lower noise as a constraint.

### **Rotorcraft Diagnostics**

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 and tools to detect and predict the health and usage of rotorcraft dynamic mechanical systems in the engine and drive system. Automatic rotor imbalance detection and rotor smoothing is also of interest. Additionally, rotorcraft health management technologies can include, but are not limited, 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; integration of health monitoring information with maintenance processes and procedures; data management and automated techniques to acquire/process diagnostic

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information; system models, material failure models and correlation of failure under bench fatigue, seeded fault test and fielded data; data collection/management for analysis of operational data; in-flight pilot cueing and warning of impending catastrophic events.

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 four identified technical areas.

## **A2.10 Propulsion Systems**

**Lead Center: GRC**

This subtopic is divided into two parts. The first part is the Turbomachinery and Heat Transfer and the second part is Propulsion 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 drastic 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 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 design 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 are on the order of 5% or above.
- Advanced flow analysis tools to enable design optimization of highly loaded compression systems that can accurately predict aerodynamic efficiency and operability. This includes computer codes with updated models for losses, turbulence, and other models that can simulate the flow through turbomachinery components with advanced design features such as swept and bowed blade shapes, flow range extension techniques, such as flow control and transition control to maintain acceptable operability and efficiency.

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- 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.
  - Methods are sought to enable more efficient use of coolant air in the turbine through coolant flow modulation. These methods could consist of open-loop or closed-loop coolant flow modulation. Modulations could be high-frequency with frequencies on the order of the turbine blade passing frequency or longer time scales on the order of engine thermal transients. Development of methods to measure turbine local and/or average surface temperatures to enable the closed-loop capability will be considered. Feedback control of the coolant flow rates and/or methods to produce modulation in actual turbine thermal environments are desired. Finally, a description of how the proposed technology will work in a vision modulated turbine cooling turbine system will be needed.

### **Propulsion Integration**

Proposals for Propulsion Integration will address engine and engine integration topics as outlined in this section in support of the Fundamental Aeronautics Program.

One objective of the Subsonic Fixed Wing Project is to develop verified analysis capabilities for the key technical issues related to integrating embedded propulsion systems for "N+2" hybrid wing/body configurations. These key technical issues include: inlet technologies for distorted engine inflows related to embedded engines with boundary layer ingestion; fan-face flow distortion and its effects on fan efficiency and operability, noise, flutter stability and aeromechanical stress and life; wide operability of the fan and core with a variable area nozzle; issues related to the implementation of a thrust vectoring variable area nozzle; and duct losses related to long flow paths associated with embedded engines. Specifically, proposals are sought to provide advanced technology, prediction methods and tools.

The supersonics project would like proposals to develop tools and propulsion technologies that will enable the design of high performance fans; high-efficiency, low-boom, and stable inlets; high-performance, low-noise exhaust nozzles; and intelligent sensors and actuators for supersonic aircraft. The supersonics project is interested in both computational and experimental research, aimed at evaluating and analyzing promising technologies as well as understanding the fundamental flow physics that will enable improved prediction methods.

A mission class of interest to the Hypersonics Project is Highly Reliable Reusable Launch Systems (HRRLS). The HRRLS mission was chosen to build on work started in NASA's Next Generation Launch Technology (NGLT) Program to provide new vehicle architectures and technologies to dramatically increase the reliability of future launch vehicles. The design of reusable entry vehicles that provide low-cost access to space is challenging in several technology areas. The development of hypersonic-unique air breathing propulsion systems and the integration of the propulsion system with the airframe impact vehicle performance and controllability and drive the need for an integrated physics-based design methodology.

For Propulsion Integration, topics will be solicited for two areas:

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- Design concepts, actuators and analysis tools that enable:
    - High performance supersonic inlets and nozzles that have minimal impact on an aircraft's sonic boom signature;
    - The control of shock wave boundary layer interactions and reduction of dynamic distortion in supersonic inlets;
    - Stable highly integrated supersonic inlets;
    - High pressure recovery, low distortion and low-weight subsonic diffusers;
    - Low weight systems for nozzle area control;
    - Thrust vectoring;
    - Practical, validated CFD models for flow control devices such as micro ramps, vaned vortex generators, air jets, or synthetic jets.
  
  - Unsteady coupled Inlet / Fan Analysis Tools to investigate:
    - Engine transient affect on inlet unstart;
    - Mode transition for a hypersonic dual Turbine engine/RAM-SCRAM flowpath;
    - Inlet and fan aero/mechanical loads;
    - Engine/inlet control system development;
    - Distortion Tolerance.