NASA is the Nation's leading government organization for civil aeronautical research. Within NASA's overall strategic plan Aeronautics has the goal to "Advance knowledge in the fundamental disciplines of aeronautics, and develop technologies for safer aircraft and higher capacity airspace systems." To address this goal NASA's Aeronautics Research Mission Directorate (ARMD) is organized into three separate Programs: Fundamental Aeronautics, Aviation Safety, and Airspace Systems.

The Fundamental Aeronautics Program is dedicated to the mastery and advancement of core aeronautics technologies across all flight regimes. NASA intends to invest broadly and deeply in these core competencies to produce knowledge, technology, and tools that are applicable across a broad range of air vehicles. The program encompasses cutting-edge, fundamental research in traditional aeronautical disciplines, as well as emerging fields with promising application to aeronautics. The overall program is long-term in scope as well as focused and integrated across disciplines. It is implemented through NASA's four research centers: the Ames Research Center, in Mountain View, California; the Dryden Flight Research Center in Edwards, California; the Glenn Research Center in Cleveland, Ohio; and the Langley Research Center in Hampton, Virginia.

To achieve these objectives NASA has defined a four-level approach to technology development: (1) conduct foundational research to further our fundamental understanding of the underlying physics and our ability model that physics, (2) leverage the foundational research to develop technologies and analytical tools focused on discipline-based solutions, (3) integrate methods and technologies to develop multi-disciplinary solutions, and (4) solve the aeronautics challenges for a broad range of air vehicles with system-level optimization, assessment and technology integration.

The Fundamental Aeronautics will provide for results yielding the following:

- Technology innovation and integrated, multidisciplinary analysis tools;
- Rapid evaluation of new concepts and technology;
- Accelerated application of new technology to a wide array of vehicles;
- Reduced environmental impact and increased public benefit of future aircraft: lower emissions, less noise, higher efficiency, and safer operation.

Structurally, program is composed of four focused thrust areas: hypersonic flight, supersonic flight, subsonic fixed-wing aircraft and subsonic rotary-wing aircraft. Each thrust area, in turn, addresses specific discipline, multi-discipline, sub-system and system level technology issues relevant to that flight regime. However, 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 Fundamental Aeronautics subtopics are organized by discipline, not by flight regime, with a special subtopic for rotary-wing issues. The full list of Fundamental Aeronautics subtopics are: (1) Materials and Structures, (2) Combustion, (3) Acoustics, (4) Aeroelasticity, (5) Aerodynamics, (6) Aero thermodynamics, (7) Control and Dynamics, (8) Experimental Capabilities and Flight Research, (9) Systems Analysis, Design and Optimization, and (10) Rotorcraft.
Each of the subsequent subtopic sections will describe the scope, key issues and technical content of the subtopic. It will also include the specific areas of interest spanning the four flight regimes. Individual proposals are not restricted to any one specific technical area or any single part of the full flight regime. They may address any or all areas included in a subtopic and may cover any or all parts of the entire flight regime.

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 research thrusts to enable the design and development of advanced future aircraft. In general, technologies of interest that cover the four research thrusts (Subsonic Fixed Wing, Subsonic Rotary Wing, Supersonic, Hypersonic) include: fundamental materials development and characterization, multifunctional materials and structures development, structural health monitoring and damage assessment science, validated structural analysis tools, and computational materials development tools. More specific information on materials and structures technologies of interest in this program is given below.

Proposals are sought that address specific design and development challenges associated with airframe and propulsion systems and directly support improvements to future subsonic fixed wing aircraft. The potential impact of the proposed technologies should be linked to improvements in aircraft performance indicators such as vehicle weight, noise, lift, drag, lifetime, and emissions. Specific technology areas where contributions are sought include, but are not limited to the following:

- Advanced materials design concepts and processing development (e.g., multifunctional materials concepts, innovative approaches to damage tolerant lightweight structural materials, lightweight materials concepts to mitigate lightning strike damage, hybrid materials approaches to multifunctionality and/or improved durability and damage tolerance, and high-temperature materials for propulsion system applications);
- Design methods for material and structural concepts (in particular, multifunctional concepts) including variable fidelity methods, uncertainty based design and optimization methods, multi-scale computational methods, and multi-physics modeling and simulation tools;
- Adaptive materials and structures concepts (e.g., environmentally responsive materials and structures, intrinsically load/strain sensing materials and structures, active and/or highly flexible structures, shape memory and self-healing materials, innovative non-parasitic in situ methods to detect damage, impact and structural dynamics);
- Concepts and techniques for advanced multifunctional and/or adaptive material and structures characterization and evaluation (including combinations of thermal and mechanical loading environments);
- Identification, development and verification of degradation and failure mechanisms/criteria, residual strength (and other critical residual properties) and life prediction methods, and damage science design and analysis methods;
- Advanced materials fabrication and processing methods and joining and assembly methods, for ceramics, metals and polymers and/or hybrids of these materials;
- Tribological surface sciences, and mechanical components including oil-free bearings and seals technologies.

Supersonics aircraft require durable and reliable materials and structures to provide continuous operation at speeds in excess of Mach 2. Specific technology areas where contributions are sought include:

- Oxidative fail-safe CMC, CMC structures for liners and airfoils;
Advanced engine containment prediction tools;
High temperature shape memory alloys;
Accelerated life prediction tools;
Rapid design methods for aircraft structures;
Novel hot acoustic absorber technologies are also of interest to address the sound problems with supersonic flights.

The ultra-high temperatures experienced by a hypersonic vehicle, coupled with storage challenges of advanced fuels requires advanced materials and structures technologies to enable safe reliable operation of the vehicles. Specific technology areas where contributions are sought include:

- Probabilistic design and lifing methods for high and cryogenic temperature materials;
- Design database development, structural joining techniques and characterization methods for advanced materials;
- Impact models for high and cryogenic temperature materials;
- Structurally integrated multifunctional thermal protection systems;
- Identification, development and verification of environmental and mechanical degradation and failure mechanisms, failure criteria, other design critical properties;
- Physics-based life prediction methods for advanced high temperature composites coupled with damage tolerant design and analysis methods;
- Computational materials development tools for durable high temperature materials;
- Development of composite material systems and coatings for significantly improved hypersonic environmental durability for increased mission lifetime;
- Development of durable structural sensor technology for extreme environments;
- Advanced thermal control structural and material systems through techniques to improve vehicle safety and decrease weight resulting from combined thermal and structural loads;
- Oxidation modeling;
- Modeling of high temperature composite structures manufacturing.

A2.02 Combustion for Aerospace Vehicles

Lead Center: GRC

Participating Center(s): LaRC

Combustion research will be 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 interest where research is solicited but is not restricted to includes:

- Validation data sets at appropriate conditions that can be used for physics-based model development;
- Detailed and reduced chemical kinetics mechanisms for practical fuels under rich and lean conditions for combustion calculations;
- Large Eddy Simulation submodels for reacting, multiphase flow simulations under realistic operating conditions;
- Turbulence-chemistry interaction models and validation data;
- Development of laser-based diagnostics and novel experimental techniques for measurements in reacting flows;
- Two-phase flow simulation models including liquid breakup and vaporization under subcritical and supercritical conditions;
- Combustion instability modeling and validation;
- Novel combustion simulation methodologies;
- Novel low emissions combustion concepts that enhance the state of the art in subsonic combustors;
- Active combustion control including high frequency actuators and sensors;
- Reformer technology and catalyst development for the processing of aviation fuels;
- Novel low emissions concepts suitable for low emissions operation at supersonic cruise conditions;
- 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.

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, 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 aero-acoustic analysis, which can be adapted for design codes;
- Prediction of aero-acoustic noise sources including engine and airframe noise sources 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;
- Computational and analytical structural acoustics techniques for aircraft and advanced aerospace vehicle interior noise prediction, particularly for use early in the airframe design process;
- Prediction and control of high-amplitude aero-acoustic loads on advanced aerospace structures and the resulting dynamic response and fatigue;
- Innovative source identification techniques for engine (fan, jet, combustor, or turbine noise) and airframe (landing gear, high lift systems) noise sources, including turbulence details related to flow-induced noise sources typical of jets, separated regions, vortices, shear layers, etc.;
- Concepts for active and passive control of aero-acoustic 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 advanced 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;
- Development and application of flight procedures for reducing community noise impact while maintaining or enhancing safety, capacity, and fuel efficiency.

A2.04 Aeroelasticity

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

The NASA Fundamental Aeronautics program has the goal to develop system-level capabilities that will enable the civilian and military designers to develop revolutionary systems, in particular by integrating methods and technologies to develop 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 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.
- Development of unique control concepts 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.

Flight regimes of interest in the Fundamental Aeronautics program include subsonic, supersonic, and hypersonic. The goal of the program is to develop validated physics-based multidisciplinary design, analysis, and optimization tools, integrated with technology development. Topics of interest include (but are not limited to) the following:
• Structure-induced noise, flutter and dynamic response prediction, stiffness and strength tailoring, propulsion-specific structures, quasi-static aeroelasticity. Fluid-structure interaction, validation methods, data processing and interpretation methods, probabilistic modeling, rapid modeling analysis development, 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. Stiffness and strength tailoring and actively controlled propulsion system core components (e.g. fan and turbine blades, vanes). High fidelity unsteady aeroelastic capability which utilize current and future computer capabilities effectively. Advanced turbomachinery active damping concept. Rapid, high-fidelity probabilistic aeroelastic modeling capability.

• Physics-based models for turbomachinery aeroelasticity related to highly separated flows, shedding, rotating stall, non-synchronous vibrations (NSV). Robust, fast-running, accelerated convergence, reduced-order CFD approaches to turbomachinery aeroelasticity for propulsion applications. Blade vibration measurement systems including closely spaced modes, blade-to-blade variations (mistuning) and system identification. Blade damping systems for metallic and composite blades, including passive and active damping methods.

• Aeroservoelasticity, including alternative control architectures, development and testing of control law concepts. Integrated tool set for fully coupled modeling and simulation of aeroservo thermoelasticity / flight dynamic (ASTE/FD) and propulsion effects. Development of CFD-based methods (reduced-order models) aeroservoelasticity models that can be used to predict and alleviate gust loads, ride quality issues, and flutter issues. Fast and accurate aeroelastic analysis methods to predict fan/compressor flutter vibrations in the presence of the inlet and neighboring blade rows. Vortical effects and nonlinear unsteady aerodynamics influence on the aeroelastic/ASE response of supersonic configurations.

• Lightweight structures under aerodynamic loads, with emphasis on aeroelastic phenomena in hypersonic domain. 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, 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 with an emphasis on the development of novel, practical, lightweight, low-energy actuators;
- Wake decay models capturing the relevant physics into the near, mid, and far fields;
- 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;
- 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

The accurate prediction of aerothermal environments is of crucial importance for meeting current goals of subsonic, supersonic and hypersonic thrust areas as well as supporting future missions of NASA by reducing uncertainties in design and development. Development of highly accurate tools to predict aerothermal environments and associated effects on vehicles is needed to enable advanced spacecraft for future missions.

Radiative heating has not been a critical issue for the Space Shuttle Orbiter due to its relatively low reentry velocities on the order of 7.5 km/s, or for other entry probes such as Genesis and Stardust due to their small sizes. However, the Crew Exploration Vehicle’s large size and high reentry velocities of approximately 10.5 km/s during lunar return missions make it imperative to study the phenomenon of shock layer radiation. Aerocapture missions to Titan, Neptune, and Venus also require the study of radiative heat transfer as well as of the internal structure and dynamics of the constituent gases.

Transition and turbulence effects are particularly complex in hypersonic flows because of the presence of shocks, real gas effects, non-smooth body surfaces with difficult-to-quantify roughness distributions, effects of nose bluntness, ablation, surface catalytic, separated flows, and an unknown free-stream disturbance environment.

At heating rates encountered during hypersonic re-entry, the surface is ablation and the interaction of ablation products blowing into the boundary layer induces new interactions (chemical reactions, radiation absorption) that have strong impacts on surface heating rates and integrated heat loads.

Aerothermal analyses and management are furthermore relevant to the design of advanced propulsion systems. The isolators and nozzles in both rocket-based and turbine-based combined cycle engines are critical components of future reusable hypersonic vehicles.
Major research and technological advances are required in order to develop Ultra-High Bypass Ratio engines and high power density cores. A better fundamental understanding coupled with the ability to accurately simulate the aerothermodynamics of highly loaded turbomachinery is needed, along with innovative ideas such as flow control for increasing fan and compressor work factors without sacrificing efficiency and operability. Improvements in turbine cooling effectiveness, secondary flow, and component matching are also important for high-pressure ratio engines.

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

- Computational methodologies for the analysis of radiation and its transport in the shock layer surrounding planetary entry vehicles;
- Advanced physics-based thermal and chemical non-equilibrium chemistry models;
- High-order accurate numerical methods and multi-scale models for Large Eddy Simulation of hypersonic transition and turbulence;
- Efficient implicit algorithms for the solution of stiff systems like those generated by high-order discretization methods;
- Studies of the interaction of gases in the shock layer with the ablating material making up the thermal protection system of the vehicle;
- Software tools for coupling radiation, non-equilibrium chemistry, Reynolds-averaged Navier-Stokes, and large eddy simulation codes to enable the design, development, and validation of mission configurations for entry into planetary atmospheres;
- Experiments and diagnostics to understand the characteristics of hypersonic flow fields, either in flight or in ground-based facilities;
- Computational and experimental technologies for the accurate prediction of combined cycle phenomena such as shock trains in isolators, inlet unstart, and thermal choke;
- Computational modeling to improve the accuracy of flow simulations for highly loaded turbomachinery;
- Innovative flow control methods, such as aspiration and bleed to reduce the losses associated with highly loaded turbomachinery;
- Assessment of the capabilities and deficiencies of currently available thermodynamics models and codes for the development of new physics based models;
- Development of active flow control devices such as Dielectric Barrier Discharge plasma actuators for application to turbomachinery flow control.

A2.07 Aircraft Control and Dynamics

**Lead Center: GRC**

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

Enabling advanced aircraft configurations for subsonic, supersonic and hypersonic flight, and high performance "Intelligent Engines" will require advancement in the state of the art of 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, enabling unique concepts of operations, lower emissions and noise, and safe operation over a wide operating envelope. 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 with enhanced control effectors and propulsion systems. Proposals for novel multidisciplinary nonlinear dynamic systems modeling, identification, and simulation for control objectives are encouraged. Control objectives include feasible and realistic boundary layer and laminar flow control, aeroelastic maneuver performance, and load control including smart actuation and active aerostructural concepts, active control of propulsion system components, and drag minimization for high efficiency and range performance. Technology needs specific to different flight regimes are summarized in the following:
For subsonic fixed wing aircraft, technologies of interest, with application to both flight and propulsion control, include: methods for development of dynamic models and simulations of the integrated component/control system being considered; defining actuation requirements for novel control approaches and developing prototype actuators; developing and applying innovative control methods and validating them through laboratory test and vehicle simulations as appropriate.

For supersonic flight, the technologies of interest include: methods for developing integrated dynamic models and simulation including flexibility effects and suitable for control design; novel control design methods for integrated aero-servo-elastic-propulsive 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) and efficient operation.

For hypersonic flight, the technologies of interest include: system dynamic models 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; hierarchical GNC (Guidance, Navigation and Control) architectures to enable trajectory shaping and control over a wide operating envelope with integrated flight/propulsion control; adaptive and robust control methods that can handle large modeling uncertainties; simulation test-beds for evaluating hypersonic concept vehicle control under various types of uncertainty, system-wide coupling and associated model mis-specification.

A2.08 Experimental Capabilities and Flight Research

Lead Center: AFRC
Participating Center(s): LaRC

Advances to the state of the art in both Experimental Capabilities and Flight Research are needed to support almost every aspect of the Fundamental Aeronautics programs under development in NASA. These tools will be used to generate experimental data for the creation and validation of advanced prediction models, as well as evaluate advanced concepts, both in the laboratory and in suitable facilities (e.g. wind tunnels, flight tests, etc.). New measurement techniques capable of measuring transient phenomena are needed to support acoustic noise model validation and turbulence measurements. Developing sensors capable of measuring environments in harsh environments (e.g. inside engines) are needed to support intelligent engine design. Proposals are sought for new flight testing technologies and capabilities in order facilitate evaluation of concepts at true flight conditions. More specific examples of research in this area are listed below.

Experimental Capabilities

Innovative technologies are sought that will advance current experimental capabilities and develop new measurement techniques to support other areas of Fundamental Aeronautics. These techniques will not only support traditional aeronautic measurements in wind tunnels, but also development of advanced concepts in areas such as structures and materials and propulsion design. Current experimental techniques are highly effective at measuring parameters under highly controlled conditions found in traditional wind tunnels and test chambers. What is necessary to support advanced designs is the ability to make continuous field, time-resolved measurements under conditions which are difficult to control. It is also highly desirable to reduce the setup and calibration effort associated with experimental measurement techniques. Some examples of research interests in this area may include but are not limited to:

- New capabilities for the assessing the properties of advanced lightweight materials under relevant flight loads combining mechanical, thermal, and pressure loads;
- Development and applications of novel high temperature MEMS sensors based on silicon carbide technology;
- Advanced testing techniques to address such phenomena as icing and scaling effects in wind tunnels;
- Development of high temporal resolution optical diagnostics (such as Particle Imaging Velocimetry)
capable of operating at frequencies up to 50 kHz;

- Development of advanced videogrammetric systems capable of characterizing the 3D shape of aerodynamic surfaces with high data acquisition rates and increased precision.

Flight Research
The Flight Research area solicits innovative flight research experiments that demonstrate breakthrough vehicle or system concepts, technologies, and operations in the real flight environment. This includes both test techniques and subsystems that will make flight research easier to achieve, as well as innovative vehicle system concepts at low maturity levels. The emphasis of this subtopic is the feasibility, development, and maturation of advanced flight research experiments that demonstrate advanced or revolutionary methodologies, technologies, and concepts. It seeks advanced flight techniques, operations, and experiments that promise significant leaps in vehicle performance, operation, safety, cost, and capability; and may require a demonstration or validation in an actual flight environment to fully characterize or validate it. Some examples of research interests in this area may include but are not limited to:

- Inflatable aero-structures;
- Innovative control surface-effectors;
- Innovative engine designs for UAVs;
- Noise reduction for Conventional Take-off and Landing/Short Take-off and Landing (CTOL/STOL) aircraft and engines;
- Aerodynamic systems optimization for planetary aircraft;
- Flexible system stability derivative identification;
- Innovative approaches to thermal protection that minimize aerodynamic performance degradation;
- Innovative approaches to structures, stability, control, and aerodynamics integration schemes;
- Innovative approaches to incorporation of UAV operations into commercial airspace.

This subtopic is intended to advance and demonstrate revolutionary concepts and is not intended to support evolutionary steps required in normal product development. Proposals should emphasize the need of flight research on a concept or technology as a necessary means of verifying or proving its worth; emphasis should also be given to multidisciplinary integration of advanced flight systems. The benefit of this effort will ultimately be more efficient aerospace vehicles, increased flight safety (particularly during flight research), and an increased understanding of the complex interactions between the vehicle or technology concept and the flight environment.

A2.09 Aircraft Systems Analysis, Design and Optimization

Lead Center: ARC

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
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.

Analyses 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 (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.
A2.10 Rotorcraft

Lead Center: ARC

Participating Center(s): AFRC, ARC, 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. Meeting this challenge will require innovative technologies and methods, with an emphasis on integrated, multidisciplinary, first-principle computational tools specifically applicable to the unique problems of rotary wing aircraft. Examples of technologies of interest are as follows.

Propulsion/Aeromechanics Integration: Encompassing dynamic and aerodynamic integration of rotorcraft. Including advanced configurations such as rotors operating at different speeds in hover and cruise (variable speed transmission/engine), high speed rotorcraft, and heavy lift rotorcraft. Possibly including on-blade active rotor control, or flow control for hub, blades, or engine inlet.

Super-Integrated Vehicle Management System: Integrated, broadband rotorcraft control system incorporating flight control system, engine control, airframe/drive train/rotor load control, active rotor control of vibration and noise, vehicle health management, and guidance for low noise operation. Including control design methodology development.

Integrated Rotorcraft Design: Advanced light weight structural and propulsion concepts with integrated functionality to achieve reduced interior noise, vibration, and maintenance/inspection requirements. Includes gear vibration transmission through the gear/shaft/bearing/structural system and structural bonding techniques that increase fatigue life while allowing for post-buckling load capability for thin sheet sandwich construction.

Integrated Rotorcraft Design: Interactional aeroacoustics, encompassing dynamic, aerodynamic, aeroacoustic interactions of one or more main rotors, tail rotors, airframe, wings, empennage, engine, drive system. Possibly including active flow control for hub or fuselage drag reduction, or active rotor control.

Integrated Experimental Systems: Unified experimental techniques, integrating methods to enable efficient, multi-parameter, simultaneous measurements for characterizing rotorcraft behavior. Including unsteady pressure, blade deformation and position, flow field measurements, measurements that track wake vortex strength and position.

Examples of rotorcraft unique aspects of the aeronautics disciplines are as follows.

Materials and Structures: Advanced light-weight structural concepts exploiting material hybridization, selective reinforcement and material and geometric tailoring to achieve increased performance and durability while reducing weight, cabin noise and manufacturing cost, with emphasis on structural concepts for high oscillatory load environment of rotorcraft structures. Characterization of composite material properties under impact loading and models of impact damage. Characterization and simulation of fatigue damage in composite materials, crack/delamination growth models for spectrum loading, and high cycle fatigue thresholds, in particular for unique design and operational aspects of structures for rotor blades.

Propulsion: Research is solicited to improve rotorcraft propulsion and the ability to design and predict its performance in the following general areas:

Propulsion system (drives, engines, controls) technologies to enable variable speed rotor systems. Specific focus areas may include: enabling concepts and techniques for wide operability propulsion systems and variable speed drive systems/transmissions. Engine compressor stall control, engine flow control concepts for wide operability, cooling and secondary flow concepts for wide operability and integrated controls and modeling to support wide operability are sought. In addition, concepts for controlling and enabling variable speed drives, lightweight
technologies and concepts and performance prediction capabilities for variable speed systems are sought.

Gearbox optimized propulsion systems in which both the engine and drive systems work together for improved performance. Specific concepts may include: dedicated gearbox lube systems coupled with oil-free engines; technologies to predict drive system windage losses and gear surface fatigue modeling; technologies to achieve lightweight propulsion such as composite propulsion structures and components; high power density electromechanical systems and efficient high power density propulsion concepts such as highly loaded components; engine flow control concepts; high temperature components; nano-composite components and other relevant propulsion system technologies. Propulsion system concepts must be focused on power range and operating environment required for rotorcraft.

**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. Rotor noise, including broadband, harmonic, blade-vortex interaction, high-speed impulsive; alternate tail rotor and auxiliary power concepts, rotor/tail rotor, and rotor/rotor interactional noise. 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.

**Aeroelasticity and Dynamics:** Advanced rotorcraft hub and blade concepts for improved stability and loads capability. High-fidelity, first-principles approaches to rotorcraft stability calculation, including finite state and reduced order aerodynamic modeling approaches. Vibration reduction methods and techniques, including utilization of on-blade active control, individual blade control, or nonrotating frame active and passive means.

**Aerodynamics:** Airloading of rotor blades, including unsteady, compressible, viscous flows and blade-vortex interaction; stall and dynamic stall; rotor wake formation, propagation, dissipation, and interactions; rotor wake geometry. Aerodynamics of rotorcraft airframes, including rotor hubs, airframe drag, rotor-airframe-wing interactions of tiltrotors and compound configurations. Performance, including force and power of isolated rotors and of rotorcraft systems with influence of interactions between components. Behavior of rotors and rotorcraft in maneuvers and high speed flight, and advanced configurations heavy lift and slowed-rotor rotorcraft. Advanced computational fluid dynamics methods, including turbulence behavior unique to rotary wings.

**Flight Dynamics and Controls:** Rotorcraft flight dynamics and handling qualities. Including hover and low-speed guidance and situational awareness augmentation; autorotation control and guidance; variable-speed rotor control; low-cost low-speed air data system; improved simulation of low-visibility conditions (brownout, whiteout); control concepts for redundant effectors; affordable tactile cueing for retrofit into civil rotorcraft; study of redundancy/reliability required to achieve low-cost single-pilot IFR certification; continuously-variable transmission (current technology is focused on discrete-speed, transmission, but continuously-variable is highly desirable; flight control mitigation of structure/power train/rotor frequency overlap with primary control frequencies; proprotor control to provide helicopter-like response in heave for tiltrotor helicopter-mode operations.

**Experimental Capabilities:** Instrumentation and techniques for assessing scale rotor blade boundary layer state (laminar, transition, turbulent) and/or profile in simulated hover and forward flight conditions, measurement systems for large-field rotor wake assessment, instrumentation and techniques to measure dynamic boundary layer transition on the fixed system (fuselage) during scale model wind tunnel testing, multi-parameter temporally-resolved flow diagnostic techniques for wind tunnel testing of model-scale rotors and engine acoustic testing, fast time response pressure sensitive paints, alternatives to conventional slip rings (e.g. optical slip rings, reliable telemetry methods), high temperature and pressure sensors for engine applications, high temperature proximity sensors for turbine blade clearance measurements, sensors and/or methods for high accuracy rotorcraft velocity measurement in very low speed forward flight.