



NASA SBIR 2011 Phase I Solicitation

A2.10 Propulsion Systems

Lead Center: GRC

Participating Center(s): GRC

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

Turbomachinery and Heat Transfer

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

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

- Advanced instrumentation to enable time-accurate, detailed measurement of unsteady velocities, pressures and temperatures in three-dimensional flowfields such as found in turbomachinery components. This may include instrumentation and measurement systems capable of operating in conditions up to 900 degrees F and in the presence of shock-blade row interactions, as well as in high speed, transonic cascades. The instrumentation methods may include measurement probes, non-intrusive optical methods and post-processing techniques that advance the state of the art in turbomachinery unsteady flowfield measurement for purposes of accurately resolving these complex flowfield.
- Advanced compressor flow control concepts to enable increased high stage loading in single and multi-stage axial compressors while maintaining or improving aerodynamic efficiency and operability. Technologies are sought that would reduce dependence on traditional range extending techniques (such as

variable inlet guide vane and variable stator geometry) in compression systems. These may include flow control techniques near the compressor end walls and on the rotor and stator blade surfaces. Technologies are sought to reduce turbomachinery sensitivity to tip clearance leakage effects where clearance to chord ratios may be on the order of 5% or above.

- Novel turbine cooling concepts are sought to enable very high turbine cooling effectiveness especially considering the manufacturability of such concepts. These concepts may include film cooling concepts, internal cooling concepts, and innovative methods to couple the film and internal cooling designs. Concepts proposed should have the potential to be produced with current or forthcoming manufacturing techniques. The availability of advanced manufacturing techniques may actually enable improved cooling designs beyond the current state-of-the-art.

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

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

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

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

- Advancement of turbulence modeling for shock wave-boundary layer interactions.
- Advancement of Reynolds-stress closure models for propulsion flowpath analyses, including application of LES and or DNS for model development and validation.
- Development of mid-level CFD models for the interaction of turbulence and chemical reaction that give superior results to the simple models (e.g., Magnussen), but which do not require the large computational expense of the very complex models (e.g., PDF evolution methods).
- Advancement of boundary layer transition models, especially in cases of low freestream turbulence levels that occur in actual flight.
- Incorporation of NASA high-order accurate numerical methods (e.g., Flux Reconstruction) into propulsion

CFD tools using both structured as well as unstructured meshes.

- Development of methods and software tools to quantify uncertainty as part of the CFD solution procedure.

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

Propulsion integration topics:

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