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 catalytically, separated flows, and an unknown free-stream disturbance environment.

At heating rates encountered during hypersonic re-entry, the surface is ablating 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.