N87-11200

AEROTHERMAL MODELING PROGRAM - PHASE II

Edward J. Mularz
NASA Lewis Research Center
Propulsion Laboratory, USARTL

Aircraft gas-turbine engine manufacturers have achieved substantial increases in performance of their engines in recent years. These performance increases are due largely to the use of advanced component designs and materials. The use of materials with higher temperature capabilities and the use of advanced liner cooling schemes have allowed the operation of the combustor at higher exit plane temperatures. Incorporating these improvements into the turbine engine has resulted in the hot-section parts being exposed to increasingly higher temperature and pressure levels. These levels produce an environment that is increasingly hostile to the hot-section components.

While the hot-section components account for only 20 percent of the engine's total weight, they account for nearly 60 percent of the engine's maintenance costs. The components most susceptible to damage have been shown to be the combustor liner and turbine airfoils. Clearly, the engine designer must increase efforts to reduce maintenance costs of these engine components if the United States engine manufacturers are to maintain their place in the competitive world aerospace market.

The predominant failure mode of aircraft gas-turbine combustors of sheet metal louver design has been identified as creep, low-cycle fatigue interaction or cracking. This cracking is caused by the thermal cycling of sections of the combustor liner where a large temperature gradient exists. To alleviate this failure mode, the thermal gradients within the entire combustor liner assembly must be significantly reduced. These gradients are generated by the local radiative and convective heat fluxes within the combustor. Therefore, a thorough understanding and characterization of these fluxes must be developed in order to determine current stress and temperature gradient limits and to design advanced, near-isothermal combustor liners.

To be able to predict the aerodynamic flow field of the combustor, the local heat fluxes, and, therefore, the liner life, several physical phenomena must be better understood. First, the aerothermal model chosen to analytically simulate the combustor must accurately predict the combustor's aerodynamic flow field. The previous, phase I effort of this program documented that current models can qualitatively predict the complex three-dimensional flow fields within a combustor. Quantitative modeling of these flows, however, requires the reduction of both computer execution times and the removal of numerical diffusion in the calculations. As more efficient numerical schemes appear, one can then effectively investigate areas such as scalar transport in the interaction of various flow streams and such as the development of the fuel spray and its interaction with the surrounding airstream.

The phase II effort is directed at improving the accuracy and validity of the analysis methods needed by designers of gas-turbine combustors. Following the successful development and validation of these improved analysis methods, the United States engine manufacturers can then proceed with confidence to incorporate these methods into their design systems. The use of these improved design systems should result in United States produced gas-turbine engines of superior performance and durability in the 1990's.

The overall objective of the Hot-Section Technology Aerothermal Modeling Program - Phase II is to improve the accuracy and utility of current aerothermal models for gas-turbine combustors. Three thrusts are identified:

(1) Improved numerical methods for turbulent viscous recirculating flows. - The three contractors from phase I all stated that improvements in accuracy and speed of convergence of combustor analytical models is necessary before the codes can become capable of producing quantitative, rather than qualitative, predictions of the combustor flow fields. In this effort improvements are being sought in both solution algorithms and differencing schemes. Present hybrid-upwind finite difference schemes possess excessive numerical diffusion errors which preclude accurate quantitative calculations. The advanced numerical techniques being considered should have improved efficiency (smaller error for the same computational time) over present codes.

(2) Flow interaction experiment. - The philosophy adopted in phase I was to assess the gas-turbine combustor aerothermal models using the constituent flow approach, that is, to evaluate submodels separately against simple flows which could be identified as relevant to the gas-turbine combustor. Among the examples of constituent flows against which the models were assessed were swirling flows and jets in crossflow. Although the performance of the models suggested that improvements are needed, notably with regard to eliminating false diffusion in three-dimensional calculations, it also was deemed appropriate to pursue a flow interactions experiment, with suitably defined and measured boundary conditions, against which state-of-the art and improved models could be evaluated. Consideration of the gas-turbine combustor suggests that the interaction of jets in a confined crossflow with a swirling flow would be an appropriate experiment in that this interaction is a characteristic of, and is expected to be important in, current and future gas-turbine engine combustion chambers. Such an experiment is underway with analytical modeling used to predict the results. Improvements to the physical model will be considered after the numerical and experimental results are analyzed.

(3) Fuel injector-air swirl characterization. - Fuel injection plays an important part in the design of combustors for gas-turbine engines. Durability can be reduced by nonuniformities produced at the fuel injector. Nonuniformities can produce hot streaks that overheat sections of turbine vanes, adversely affecting their life. Nonuniformities can also produce rich zones that increase soot and the radiative heat load that reduce the durability of the combustor liner. The ability to understand and model the fuel injection process plays a critical part in the design of high-performance, durable engines. Fuel injection is a complex phenomena, and initial formation of a fuel spray cannot be predicted or modeled in the vicinity of the fuel injector with the present analytical computer models. The sheets or ligaments of fuel break up into droplets downstream of the fuel injector. It is at this point that the two-phase flow field can begin to be modeled. To assess these models, however, a well-controlled experiment is needed to provide the benchmark data. Modern gas-turbine combustors typically use an air swirler-fuel injector combination to create an efficient burning zone. Previous fuel-injection experimental and analytical efforts have not included the interaction of the air swirler with the fuel injector. It is the purpose of this effort to perform experimental research on two-phase flow interactions to support analytical modeling of the dome region of the combustor. To establish that the experiments and data are appropriate, a sensiti-

vity analysis of the major variables is to be made using a state-of-the art model. After the sensitivity analysis, the experimental program will be carried out to generate data for an improved model. Should the experiment include taking data with unproven instrumentation (for example, individual droplet velocities with laser anemometry), an additional task will be to verify those measurements. Improvements to the physical model will be considered after the numerical and experimental results are analyzed.