

OVERVIEW OF AEROTHERMODYNAMIC LOADS DEFINITION STUDY

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INTRODUCTION

For a number of years now, NASA has been conducting the Advanced Earth-to-Orbit (AETO) Propulsion Technology Program, now part of the Civil Space Technology Initiative (CSTI) Program. The program objective is to provide the knowledge, understanding, and design methodology that will allow the development of advanced earth-to-orbit propulsion systems with high performance, extended service life, automated operations, and diagnostics for in-flight health monitoring. This program supports both current and future engine and vehicle developments. The technology needs of the current Space Shuttle Main Engine (SSME) have thus far provided the main focus for the AETO efforts. Organizationally, the program has been divided into technology working groups made up of people from both the Marshall Space Flight Center and the Lewis Research Center. The focus of this report is the Lewis effort under the Fluid and Gas Dynamics working group, the Aerothermodynamic Loads Definition Study.

The objective of the Aerothermodynamic Loads Definition Study is to develop methods to more accurately predict the operating environment in advanced ETO propulsion systems, such as the Space Shuttle Main Engine (SSME) powerhead. Development of time averaged and time-dependent, three dimensional viscous computer codes as well as experimental verification and engine diagnostic testing are considered to be essential in achieving that objective. Time-averaged, nonsteady, and transient operating loads must all be well defined in order to accurately predict powerhead life.

The approach taken under this study consists of two parts: 1) to modify/apply/disseminate existing computational fluid dynamics (CFD) tools in response to current needs, and 2) to develop new technology that will enable more accurate computation of the time-averaged and unsteady aerothermodynamic loads in reusable space propulsion systems. The new technology development effort is further divided into three parts: 1) new computer code development, 2) experiments to provide data for physical models required by the codes, and 3) experiments to provide data for validating the codes. With the more accurate aerothermodynamic loads predictions providing boundary conditions to improve structural and fatigue life analyses, the goal of improved durability will be met.

The Aerothermodynamic Loads Definition Study was begun in October, 1983. The initial effort involved the use of existing CFD tools to analyze problems in the SSME fuel and oxidizer turbopump turbines, the fuel turbine turnaround duct, the fuel side preburner and the main injector LOX posts. Results of those efforts have been presented previously and will not be discussed here. What follows is a description of the currently active tasks and their status.



H4(a). UNSTEADY VISCOUS MULTI-BLADE-ROW TURBINE ANALYSIS

In this task, the objective is to develop a numerical simulation capability for unsteady viscous flow and heat transfer in interacting turbine blade rows.

The numerical simulation of unsteady viscous flows in turbines can provide much useful information on the factors effecting performance and life of these requires a means of reducing the three-dimensional, nonperiodic, multi-row problem remains intractable, a quasi-three dimensional treatment can be used to analyze much of the flow over the midspan portion of the turbine passage.

Existing turbulence models are being modified to incorporate known relevant unsteady flow effects. These models will be developed using unsteady boundary layer codes and then implemented in a highly efficient quasi 3D rotor-stator interaction code previously developed under this task. The resulting analysis will then be tested against data obtained from a low-speed turbine under task H4(e).

H4(b). Computation of 3D FLOW WITH HEAT TRANSFER

In this task, the objective is to develop an accurate, efficient numerical analysis of steady 3D viscous flow and heat transfer in turbine blade rows.

The approach being taken is to modify a 3D viscous turbomachinery code (RVC3D) to include an advanced turbulence model and increased resolution of near-wall gradients and to validate and upgrade the code by application to suitable 3D data sets. Figure 1 shows a preliminary comparison of experiment and computed results of endwall heat transfer using this code.

H4(e). 3D STATOR-ROTOR BLADE FLOW EXPERIMENTS

The objective of this task is to investigate the steady and unsteady 3D viscous flow field in an axial turbine stage, including stator-rotor interaction, mixing effects, blade and endwall boundary layers, and temperature gradient effects on secondary flow development. This work is being done in the Pennsylvania State University Axial Flow Turbine Research Facility.

A progress report will be presented later in this session.

H4(m). TURBULENCE MODELING FOR PROTEUS TURBOMACHINERY APPLICATION

The objective of this task is to develop the capability to predict turbulent flow losses and heat transfer in turbines typical of ETO propulsion systems using a 3D Navier-Stokes Code. Existing turbulence models are inadequate or require empirical tuning to generate reasonable results. Current effort is focused on the effect of turbulence on flow near the leading edge of turbine blades. Figure 2 shows computed effect of upstream vortices on surface temperature near the leading edge of a turbine blade.

H5(a). IMPROVED MODELING, PREBURNER FLOW

In this task, the objective is to obtain steady state reacting hydrogen data of mean and fluctuating velocities and concentrations and to compare benchmark data with predictions from computer models and evaluate turbulence-chemistry interactions.

Computations of the 3D flow in the advanced turbopump turbines requires knowledge of the condition of the gases exiting the burner. Current models for predicting those conditions are inadequate. Fluctuating concentration and velocity data can now be obtained with laser diagnostics. These measurements are necessary to determine the unmixedness of the reacting flow and the reaction rates. The measurements are also necessary for differentiating between the various computer models.

For this task, a team of computer modelers and experimentalist have defined the measurements required to verify turbulent-reacting flow models. Existing optical techniques will be used to make measurements within the shear layer-two component LDV, fluorescence for OH and temperature, and TiCl₄ for seeding and H₂O concentration.

The facility is now operational. Figure 3 is a photo of the rig, showing the laser beams being used to make measurements.

H5(f). HIGH REYNOLDS NUMBER AND UNSTEADY HEAT TRANSFER EXPERIMENT

In this task, the objective is to develop a fundamental understanding of the effects of high Reynolds number and Reynolds number variations, and also upstream unsteadiness, on heat transfer in turbulent boundary layers typical of turbine airfoils in the SSME turbopump turbines.

In order to be able to predict the surface pressure and temperature distributions within engine flow passages, and accurate turbulence and unsteadiness model is needed. Data in the proper range of Reynolds number and disturbance frequency are necessary for accurate modeling. A new in-house experimental rig, shown schematically in figure 4 has been built in which the major features of an SSME turbine airfoil are simulated, particularly the Reynolds number. A particular feature of the rig is the ability to span the Reynolds number range from conventional gas turbine levels up to SSME levels.

Figure 5 shows a comparison of preliminary measurements and computations of surface pressure and heat transfer coefficients. The facility is currently being modified, and tests will be continuing.

H5(g). UNSTEADY HEAT TRANSFER ANALYSIS

In this task, the objective is to formulate analytic models to aid in the prediction of the unsteady aero-thermal loads expected in the SSME turbopump turbines.

The ability to predict the aero-thermal loads in the turbine unsteady flow environment is an essential input to the ability to predict life and durability. There are two aspects to the unsteadiness which occurs on turbine blades. The first is due to free stream turbulence and wakes shed from upstream vanes and blades. The second is due to laminar/turbulent boundary layer transition which occurs some distance downstream from the blade leading edge. The transition effect on concave surface is being addressed in this research program.

For the boundary layer transition experiments, and experimental approach is being used to study the effects of concave curvature, which occurs on the pressure side of the SSME turbine airfoils, on the transition process.

LSVT23 IMPROVED AERO AND HEAT TRANSFER PREDICTION

In this task, the objective is to improve the calculation of the aerodynamic environment in low aspect ratio turbines and experimentally obtain the unsteady surface heat transfer response to a temperature disturbance.

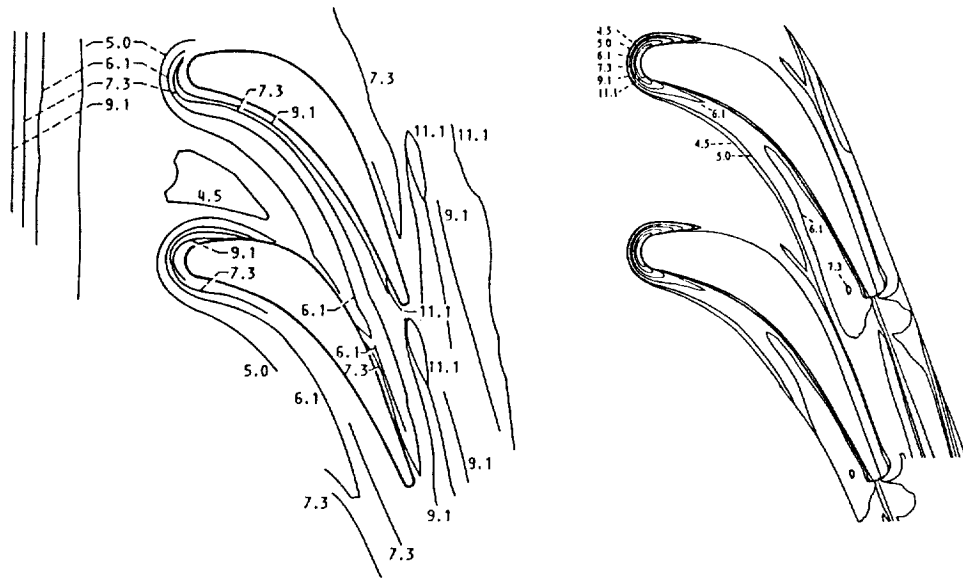
Knowledge of the local flow environment of turbine vanes and blades is essential for the accurate prediction of turbine temperature and heat transfer rates. In addition, the response of the turbine blade surfaces to rapid changes in stagnation temperature is unknown. Improved steady and unsteady heat transfer prediction is required for improved life and for turbine efficiency. An existing quasi-3D computer code will be activated at Calspan and used to compute pressure distributions over stator/rotor surfaces, substantially reducing the uncertainty in the aerodynamic environment and providing a reliable base for heat transfer predictions. The experimental phase will use actual SSME fuel turbine hardware, instrumented for time resolved heat transfer and pressure measurements.

A detailed description of the latest results under this task will be presented in another paper at this meeting.

SUMMARY

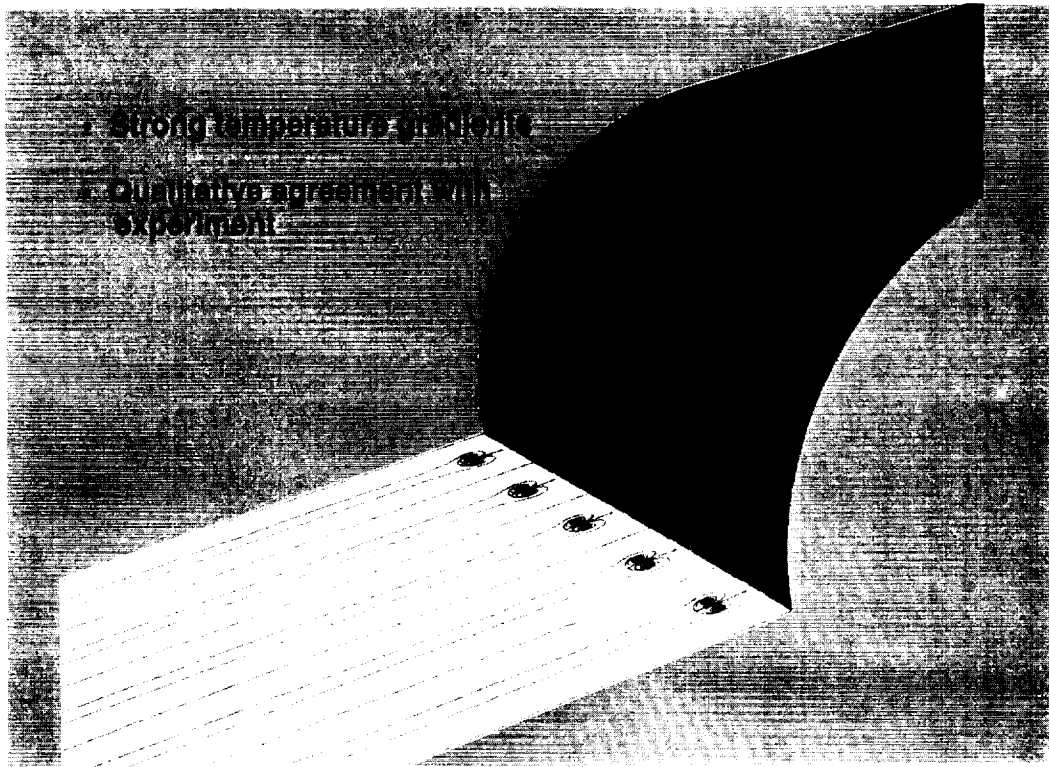
Significant progress is being made in the Aerothermodynamic Loads Definition Study, particularly in the turbomachinery area, where there is a distinct overlap between the ETO efforts and research in the aeronautical gas turbine field. The continuing work under this program will provide the knowledge, understanding and design methodology that will allow the development of advanced earth-to-orbit propulsion systems with high performance, extended service life, automated operations, and diagnostics for in-flight health monitoring.

Experimental and Computed Endwall Heat Transfer Contours of Stanton Number $\times 10^3$

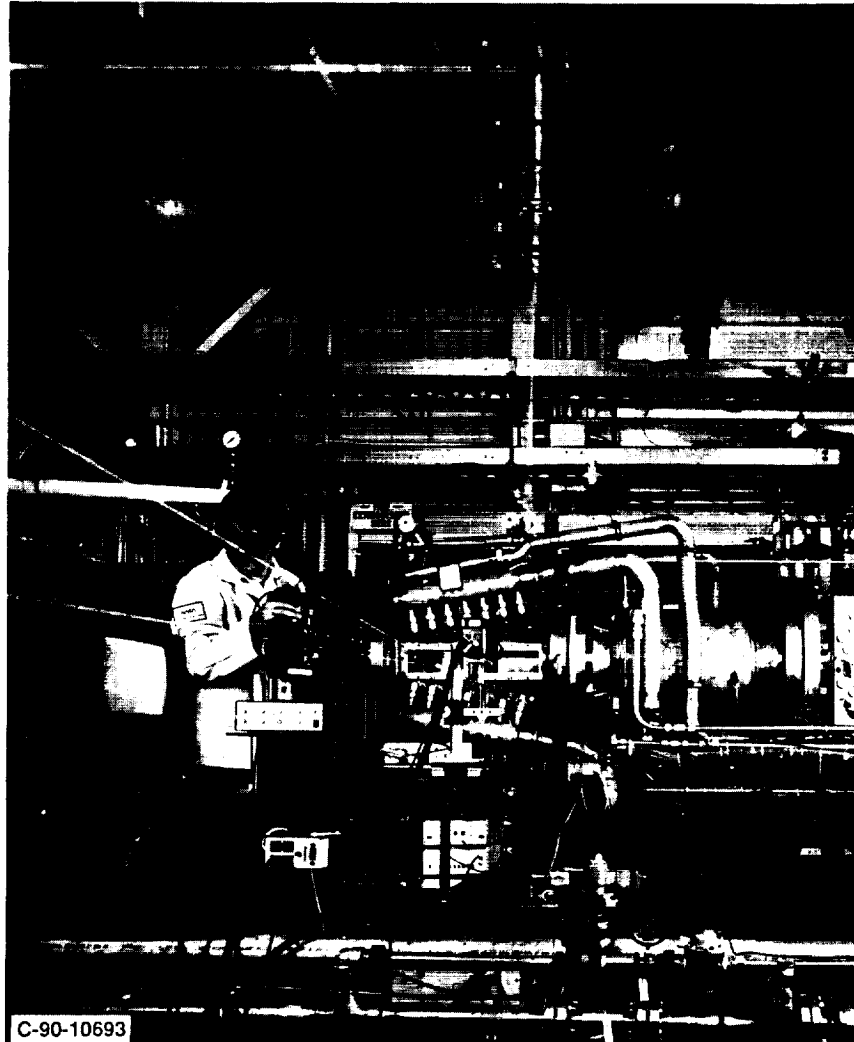


Experiment (data of Boyle and Russell) 3D Calculation (RVC3D)

Cylindrical Leading Edge Temperature Distribution Computed Effect of Free Stream Vortices



Reacting Shear Layer Facility



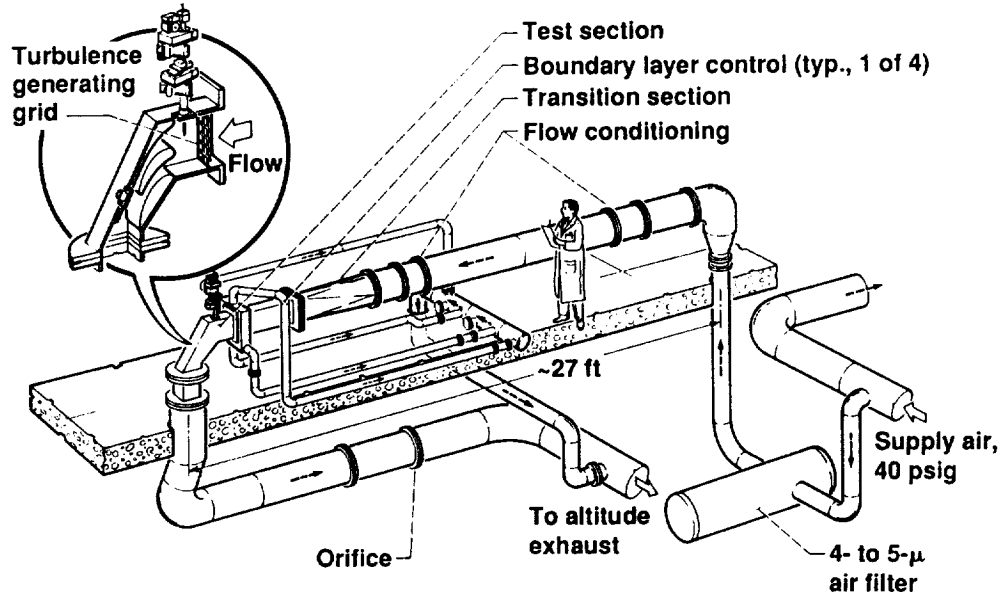
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ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

High Reynolds Number Heat Transfer Rig

Reynolds Number up to 7,500,000

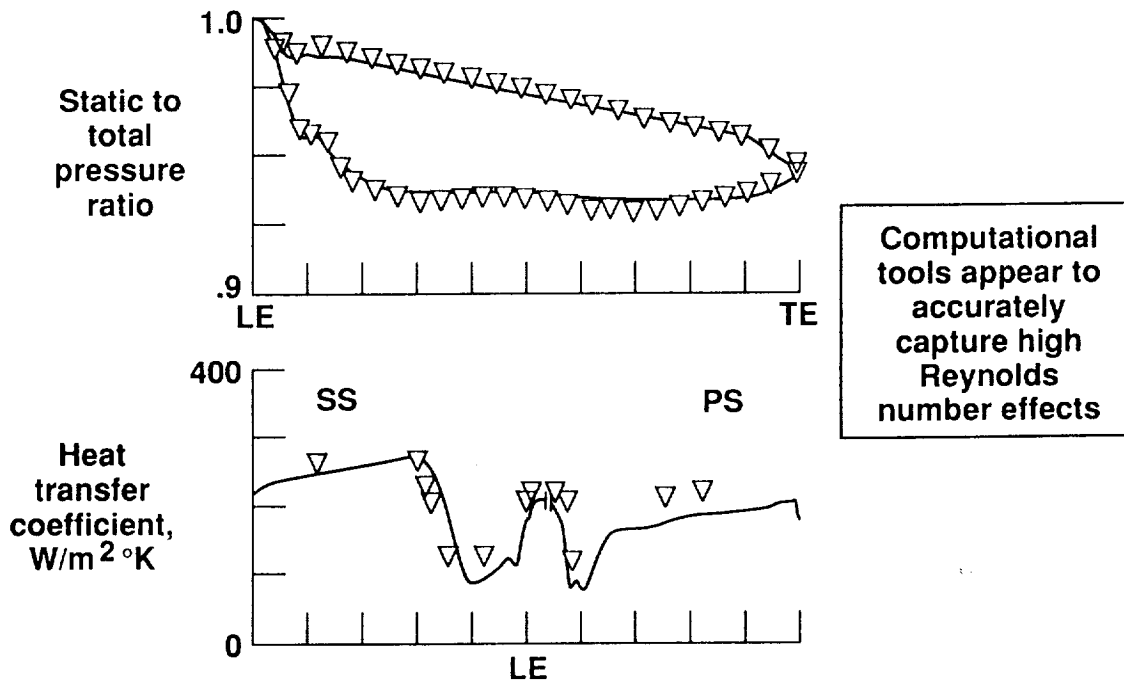
Test section cutaway



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High Reynolds Number Heat Transfer

Comparison of Measured and Computed Blade Surface Relative Pressure and Heat Transfer Coefficient



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