Progress Report and Renewal Proposal for

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Entitled:

EXPERIMENTAL INVESTIGATION OF THE THREE-DIMENSIONAL
BOUNDARY LAYER ON A ROTATING DISK

Principal Investigator:

John K. Eaton
Associate Professor

Submitted by:

Thermosciences Division
Department of Mechanical Engineering
Stanford University
Stanford, California 94305-3030

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OBJECTIVES

The overall objective of the research program is to develop new physical understanding and predictive capability of heat transfer in three-dimensional turbulent boundary layers (3DTBL). Earlier phases of this work examined the flow and heat transfer effects of longitudinal vortices embedded in two-dimensional turbulent boundary layers and the heat transfer in a pressure-driven three-dimensional boundary layer. The objectives of the present study are to develop a detailed understanding of the turbulence structure and heat transfer characteristics of the 3DTBL formed on the surface of a rotating disk. In addition, a second experiment was carried out to examine the development of longitudinal vortices in a pressure-driven 3DTBL with the primary purpose being to assess the longevity of longitudinal vortices in flows where a sheet of longitudinal vorticity is also present.

PROGRESS TO DATE

Rotating Disk Flow

All progress to date on the rotating disk flow has been in the area of facility development. An entirely new facility is being developed for this experiment requiring construction of a new lab and installation of all the required equipment.

The primary piece of equipment is the one meter diameter rotating disk apparatus sketched in Figure 1. It consists of a nominally 0.5 inch thick aluminum tool-plate disk mounted on a vertical spindle. The spindle is belt driven at speeds up to 1100 RPM achieving a Reynolds number slightly in excess of one million at a non-dimensional radius of 0.8. The disk was Blanchard ground then polished on its own spindle to achieve a smooth surface with axial runout of less than 0.0015 inches.

Measurements of the heat transfer and flow behavior will be made on the upper surface of this disk. The flow's on the upper and lower surfaces are isolated from each other by an annular shroud extending from the tip of the disk to a radius of approximately 0.8 meters. The lower surface is enclosed forming a heated cavity which can be used to reduce thermal conduction through the disk during heat transfer measurements. The rotating disk apparatus is instrumented with a tachometer to accurately measure the disk's speed. A set of instrument grade slip rings have also been installed for use during the heat transfer measurements.

The instrumentation for the first stage of the fluid mechanics measurements is now nearly complete. Measurement techniques for this stage will include a three-hole yaw probe and both single and multiple-wire hotwire anemometers. A three-degree-of-freedom traverse mechanism (axial, radial, and rotation about probe axis) has been installed and connected to the laboratory computer. This traverse was designed to carry the standard probes used in our previous 3DTBL experiments. A new calibration method for hotwire probes was required since the disk flow does not have a uniform freestream flow. In the past, we have calibrated our probes in the freestream of our wind tunnel by varying the velocity under computer control. For the disk flow, we have developed a portable jet apparatus which can be placed on the disk and will supply a computer-controlled velocity and temperature at the probe position. This allows rapid calibration of the probe without removing it from the traverse mechanism. The calibration jet has been so successful, that two more have already been built by our colleagues.

The experiment will also include laser Doppler anemometer (LDA) measurements of the velocity profiles and Reynolds stresses. The original proposal was to extend an existing single-component laser Doppler anemometer system to two-component operation for this experiment. However, we felt that a fiber-optic based two-component system would be easier to use and considerably more flexible. The budget was rearranged and additional Stanford funds were used allowing the purchase of a TSI fiber-optic LDA system with 190 mm diameter optics. The large diameter optics will provide the excellent spatial resolution required for this experiment. The new optical components have not yet arrived but a traverse mechanism has been purchased and installation should be relatively quick.

Vortices in Three-Dimensional Boundary Layer

An issue that arose during our previous DOE sponsored studies on longitudinal vortices embedded in two-dimensional boundary layers was the effect of mean flow three dimensionality on the vortex development. A typical pressure-driven 3DTBL includes a concentrated sheet of longitudinal vorticity near the surface and a more diffuse, oppositely-signed sheet of longitudinal vorticity in the outer layer. The question then was: How does a rolled up longitudinal vortex interact with a distributed sheet of vorticity? This of course has implications for real-world problems where longitudinal vortices are often embedded in three-dimensional boundary layers. The experiment is also relevant to our basic understanding of 3DTBL's. Unsteady and localized longitudinal vortices are key features of natural two-dimensional boundary layers. Anderson and Eaton (1989) hypothesized that Reynolds stresses are suppressed in 3DTBL's because the mean flow longitudinal vorticity interferes with the longitudinal vortices of the turbulence.

The experiments were conducted in the three-dimensional wedge flow apparatus previously used for 3DTBL studies by Anderson and Eaton (1989) and Abrahamson and Eaton (1990). Longitudinal vortices were injected using half-delta wing vortex generators mounted on the test wall in the two-dimensional region of the test section. The vortices then flowed into the strongly three-dimensional flow above the wedge. Extensive measurements were made using a five-hole probe and a cross wire anemometer.

Two cases were examined, one in which the sign of the longitudinal vorticity was the same as the near-wall vorticity in the 3DTBL (labelled Case 2) and one in which the vortex sign was opposite (labelled Case 1). The measurements are documented in the attached paper and summarized here. The principle finding was that vortices of both signs were attenuated more rapidly than vortices embedded in two-dimensional boundary layers. Case 1 vortices were attenuated much more rapidly than Case 2 vortices. In fact, the boundary layer perturbation caused by Case 1 vortices was nearly gone by the end of our test section. The reasons for the attenuation are two-fold. First, the boundary layer three dimensionality strains the vortex, spreading its concentrated vorticity and also helping to eliminate axial velocity perturbations. Secondly, the Case 1 vortex ingests opposite sign vorticity from the near wall layer. These conclusions are based primarily on the mean flow data. Extensive turbulence data were also acquired but have not been fully analyzed to date.

PLANNED WORK

The next step in the disk flow work is to acquire time-averaged probe data for several different Reynolds numbers. This will be followed by installation of the laser Doppler anemometer and acquisition of additional time-averaged data. Work on the temporal features of the turbulence is expected to begin late in the second year of the program.

Design and fabrication of the heat transfer measurement surface is expected to begin during Summer 1990. The basic hardware for this has been purchased. A new PhD student, Mr. Chris Elkins, will be joining us from CalTech to work on the project.

The main effort on the vortex/boundary layer interaction flow is in data analysis. Both a major report and a journal paper describing this work will be prepared.

BUDGET

An updated budget for the next two years of the program is attached. There will be no remaining funds at the end of the current year.

REFERENCES

Anderson, S.D., and J.K. Eaton, "Reynolds Stress Development in Pressure-Driven Three-Dimensional Turbulent Boundary Layers," J. Fluid Mech., Vol. 202, 1989, pp. 263-294.

Abrahamson, S.D., and J.K. Eaton, "Heat Transfer through a Pressure-Driven Three-Dimensional Boundary Layer," AIAA/ASME Thermophysics and Heat Transfer Conference, Seattle, June 1990.

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