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Progress Report
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**STRUCTURE AND MODELLING OF THE THREE-DIMENSIONAL
BOUNDARY LAYER ON A ROTATING DISK**

by John K. Eaton

Progress

The objectives of this research are to develop an improved understanding of the effects of mean flow three dimensionality on boundary layer flow and heat transfer. The specific problem of interest, the flow on a large rotating disk in an otherwise quiescent environment was selected for its geometric simplicity and for its relevance to rotating machinery design.

During the past year, there has been progress on two fronts. We have completed a visualization study of the boundary layer structure using our water flow apparatus. We had previously used two-point correlation measurements in our air-flow apparatus to develop a hypothesis explaining the reduction of vertical mixing which occurs in three dimensional boundary layers. We surmised that longitudinal vortices near the surface of the disk are affected differently by the crossflow depending on the sign of the cross flow. The overall effect of this is that the strength of so-called bursts of low-momentum fluid away from the wall are attenuated by the cross flow. This conclusion was tenuous because it was based only on two-point measurements. During the past year, we replicated the rotating disk flow in a water-tank apparatus. This required development of a special device to remove the angular momentum from the fluid flowing off the disk surface. Laser-doppler anemometry was used to measure the mean velocity profile and the single-point turbulence statistics. These statistics showed excellent agreement with the air-flow results indicating that we had correctly replicated the flow conditions. Hydrogen bubble flow visualization was then performed. This required the development of a system to magnify the images since the actual structures were on the order of 2 mm in diameter. High speed movies were analyzed on a frame by frame basis to examine bursts produced by longitudinal vortices. Longitudinal vortices of either sign were found to be equally prevalent. However, the bursts produced by one sign were found to be strongly attenuated in agreement with our earlier hypothesis. These results indicate that the heat transfer rate through the boundary layer should be reduced relative to a two-dimensional boundary layer, a hypothesis that will be investigated in the coming year.

Progress was also made on measurements of the heat transfer rate using the air flow system. As reported previously, a composite disk is being used to measure the heat transfer coefficient with approximately constant heat flux boundary conditions. The disk consists of an aluminum toolplate base, a layer of balsa insulation, foil heaters, and a thin steel surface plate. Much of our effort this year has been on reducing uncertainties in the measurements. The biggest problem is in precisely calculating the back losses since the disk has a fairly strong radial temperature gradient. A two-dimensional finite element method was developed to calculate the back losses given the measured temperature distributions on the steel surface plate and the aluminum sub disk. This calculation reduced the uncertainty but not to an acceptable level. A feedback control system was then developed to control the air temperature in the cavity below the disk. This system uses active cooling and controlled heating of the cavity to hold its temperature fixed to within 0.3 C. This has reduced the overall uncertainty by decreasing the time it takes the

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apparatus to approach steady state and thereby reducing the effects of ambient temperature drift.

Heat transfer measurements have been acquired at disk speeds up to 800 RPM giving Reynolds numbers up to 600,000. Both laminar and turbulent boundary layer conditions have been investigated. The laminar flow results agree well with previous measurements validating the experimental techniques. Extensive measurements were not available for turbulent heat transfer from a spinning disk. The results do agree well with a correlation proposed by Tadros and Erian based on a small set of data. Extension of the measurements to higher Reynolds number is proving difficult due to balancing problems. Our present efforts are devoted to precisely balancing the apparatus to run at speeds up to 1200 RPM.

Plans for 1994

The work will focus on the heat transfer experiments during the coming year. Assuming that the balancing problems can be solved the heat transfer data will be extended to a Reynolds number of approximately one million. This Reynolds number will give a broad region of turbulent flow covering over 2/3 of the disk radius. This should even further reduce the already low uncertainty since the temperature will be more uniform over the disk surface. In addition to the heat transfer coefficient, temperature profiles will also be measured for a range of Reynolds numbers.

The major effort will be in measuring the turbulent heat flux. The question to be answered is: How does the heat flux in the three dimensional flow compare to that in a two dimensional boundary layer. If our hypothesis stated above is correct we would expect reduced turbulent heat flux. Most of the work will be in developing the experimental technique to measure the turbulent heat flux. We will use a combination of a cold-wire temperature probe with a velocity measuring instrument, either a cross-wire anemometer or a laser Doppler velocimeter. The first effort will be in developing the miniature temperature sensor to be used. This will be a resistance thermometer made from 2.5 micron diameter tungsten wire. A digital filter will be developed to improve the probe's frequency response using standard techniques. This will then be placed in close proximity to the velocity measurement volume to form the turbulent heat flux. The turbulent heat flux results will be compared to standard turbulence models to determine if suppression of turbulence transport has occurred. This latter effort is likely to take place during the third year of the grant.

Students Supported

The grant partially supported three students during the year. Dr. Chisin Chiang who did the water flow experiment completed his Ph.D. in June 1993. He has gone on to a postdoctoral position at UCSD. Mr. Chris Elkins is performing the heat transfer experiments. He was supported through June by an ONR fellowship and is now fully supported by the grant. Ms. Debora Compton was partially supported by the grant. She is developing a very high resolution LDA system to be used to explore the near wall layers in more detail.

Publications

Chiang, C. and J.K. Eaton "An Experimental Investigation of Corotating Disks and Single Disk Flow Structures" Rept. MD-62, Dept. of Mechanical Engrg., Stanford U., June, 1993.

Chiang, C. and J.K. Eaton "An Experimental Study of the Effects of Three-Dimensionality on the Near Wall Turbulence Structures using Flow Visualization," submitted to Experiments in Fluids.

Littell, H.S. and J.K. Eaton "Turbulence Characteristics of the Boundary Layer on a Rotating Disk" accepted for publication in Journal of Fluid Mechanics.

Elkins, C.J. and J.K. Eaton "Heat Transfer Measurements in the Boundary Layer on a Rotating Disk" to be presented at AIAA/ASME Thermophysics and Heat Transfer Conference, June, 1994.

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