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HOST TURBINE HEAT TRANSFER SUBPROJECT OVERVIEW

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The HOST turbine heat transfer subproject is maturing with all programs in place and many bearing fruit. The accomplishments are interesting, varied, and in abundance as will be seen at this workshop. The experimental data base are leading the analyses slightly, particularly in the nonrotating area of research (figs. 1 and 2). This situation is somewhat by tradition and somewhat by design.

The experimental part of the turbine heat transfer subproject consists of six large experiments, which will be highlighted in this overview, and three of somewhat more modest scope. Three of the large experiments were conducted in the stationary frame of reference and are at or near completion. One of the initial efforts was the stator airfoil heat-transfer program conducted at Allison Gas-Turbine Division. The non-film-cooled and the showerhead-film-cooled data have already been reported. Highlights of the data are shown in figure 3. The gill-region film-cooling effort is currently underway. The investigation of secondary flows in a 90° curved duct, conducted at the University of Tennessee Space Institute, has also been completed. The first phase examined flows with a relatively thin inlet boundary layer and low free-stream turbulence. The second phase studied a thicker inlet boundary layer and higher free-stream turbulence. A comparison of analytical and experimental cross-flow velocity vectors is shown for the 60° plane in figure 4. Two experiments were also conducted at Lewis in the high-pressure facility. One examined full-coverage film-cooled vanes, and the other, advanced instrumentation. Reports on some of these results were published last year.

The other three large experimental efforts were conducted in a rotating reference frame. An experiment to obtain gas-path airfoil heat-transfer coefficients in the large, low-speed turbine at United Technologies Research Center has been completed. Single-stage data with both high- and low-inlet turbulence were taken in phase I. The second phase examined a one and one-half stage turbine and focused on the second vane row. Under phase III aerodynamic quantities such as interrow time-averaged and rms values of velocity, flow angle, inlet turbulence, and surface pressure distribution were measured.

Coolant passage heat-transfer data in a rotating frame are also being obtained at Pratt & Whitney/United Technologies Research Center. Experiments with smooth wall serpentine passages and with skewed turbulators have been completed. Some results of the effect of rotation and heat transfer are shown in figure 5 for the smooth-wall case. An experiment with turbulators normal to the flow will be started this year.

The final large experiment will be conducted at Lewis in the warm-core turbine. This facility, which fully scales a modern turbine stage, is being modified for laser anemometry access to the vane and blade passages. Research will

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begin in 1987. Once intended to be a step on the way to the high-pressure turbine, this rig is now the main verification rig in the turbine heat-transfer subproject.

The three smaller and somewhat more fundamental experiments are directed at important mechanisms. Two are being conducted by Arizona State University. The first, on impingement cooling, is complete; the second, on tip region heat transfer simulation, is providing excellent data. An experiment on the heat-transfer effects of large-scale, high-intensity turbulence, similar to that found at combustor exits, is also underway at Stanford University.

The analytic efforts in the turbine-heat-transfer subproject are characterized by efforts to adapt existing codes and analyses to turbine heat transfer. In general these codes and analyses were well established before HOST became involved; however, the applications were not for turbine heat transfer, and extensive revision has often been required. In some cases the analytic and experimental work were part of the same contract.

The well-known STAN5 boundary-layer code was modified by Allison Gas Turbine Division to define starting points and transition to turbulent flow to accommodate their data, with and without film cooling, as well as data in the literature.

United Technologies Research Center assessed its three-dimensional boundary layer code and modified it to allow for easier application of turbine type inviscid edge conditions. The same code is being modified for use as a two-dimensional unsteady code in order to analyze the rotor-stator interaction data.

The also well-known three-dimensional Navier-Stokes TEACH code has been modified by Pratt & Whitney to incorporate rotational terms. The modified code has been delivered to NASA Lewis and work has begun on it here.

A fully elliptic three-dimensional Navier-Stokes code has been under development at Scientific Research Associates (SRA) for many years. It was primarily directed at inlets and nozzles. SRA, first as a subcontractor to Allison Gas Turbine Division and now as a prime contractor, has been modifying the code for turbine applications. This includes grid work for turbine airfoils, adding an energy equation and turbulence modeling, and improved user friendliness. The code has been installed on the Lewis Cray XMP, and a first report on its use for turbine heat-transfer has been published. A comparison with the Allison nonrotating experimental data is shown in figure 6.

Finally, a fundamental study on numerical turbulence modeling, directed specifically at the airfoil in the turbine environment, is underway at the University of Minnesota.

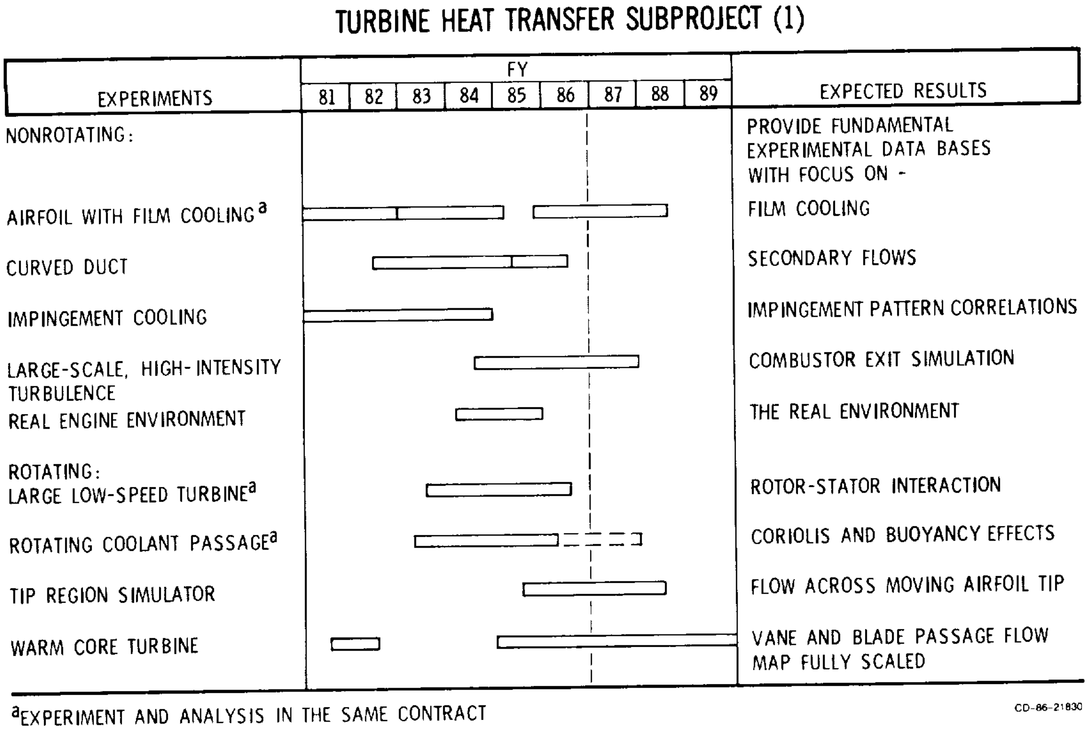

Figure 1

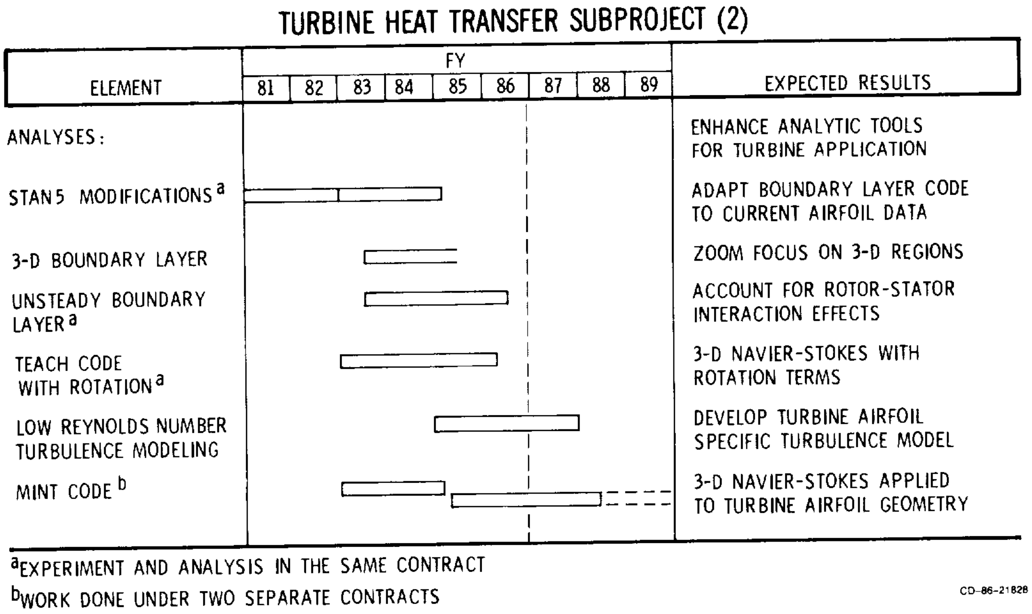

Figure 2

GAS-SIDE HEAT TRANSFER WITH LEADING EDGE FILM COOLING

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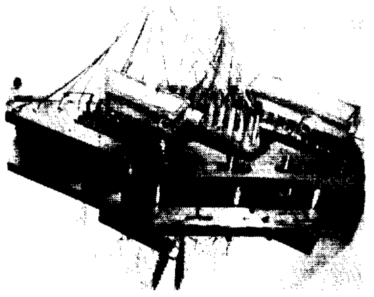
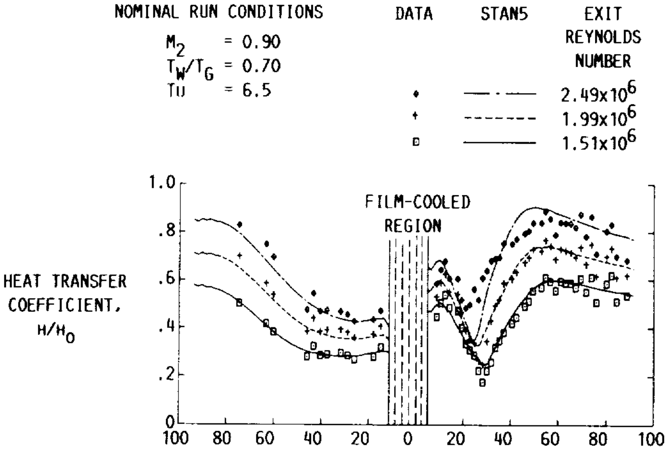
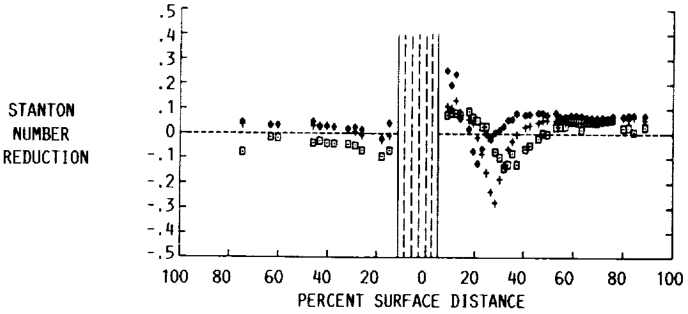

CASCADE TEST FACILITY



EXPERIMENTAL/ANALYTICAL COMPARISON WITHOUT FILM COOLING



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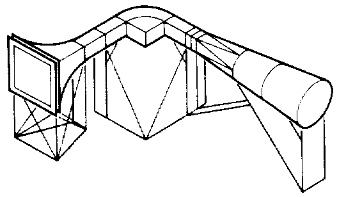
STANTON NUMBER REDUCTION WITH LEADING EDGE FILM COOLING

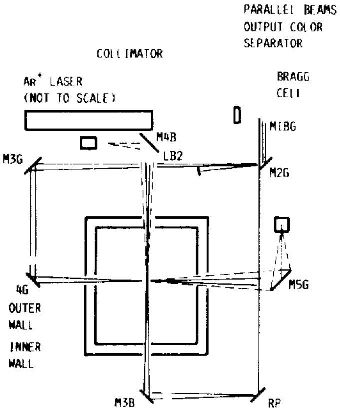
Figure 3

THREE-DIMENSIONAL FLOW FIELD SIMULATING TURBINE PASSAGES

CURVED-DUCT FACILITY

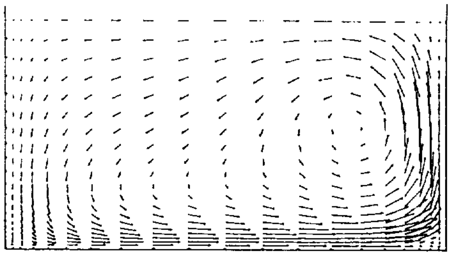


3-D LV OPTICAL SYSTEM



CROSSFLOW VELOCITY AT 60°

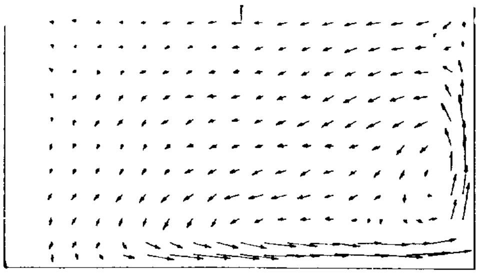
EXPERIMENTAL-ANALYTICAL COMPARISON



PRESSURE SURFACE

P.D. THOMAS CODE RESULTS

SUCTION SURFACE



LOW REYNOLDS NUMBER DATA

Figure 4

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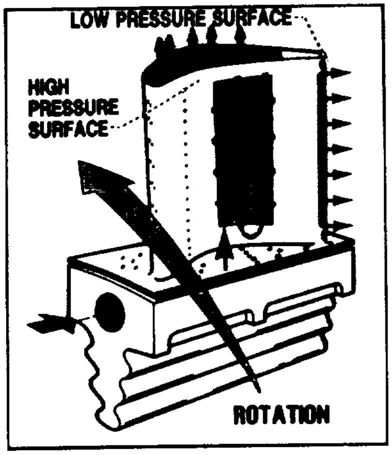
EFFECT OF ROTATION ON COOLANT PASSAGE HEAT TRANSFER

HEAT TRANSFER IN MULTIPASS GEOMETRIES IS ALREADY VERY COMPLEX. ROTATION INTRODUCES ADDITIONAL FIRST-ORDER EFFECTS WHICH MUST BE CORRECTLY UNDERSTOOD AND MODELED



HEAT TRANSFER IN SMOOTH-WALLED TEST MODEL

RADIALLY OUTWARD FLOW, FIRST LEG; Re ≈ 25,000; Δ T = 80°F

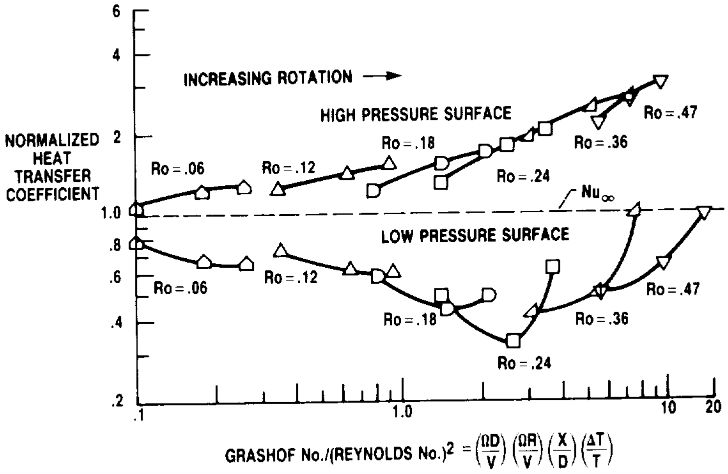


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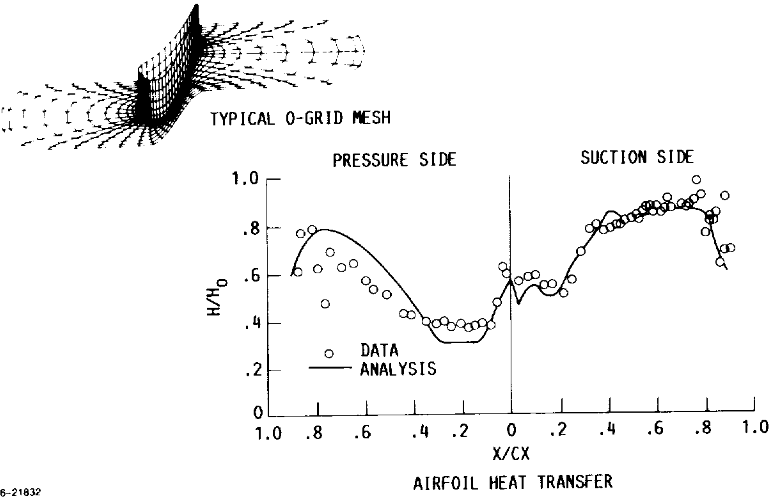
Figure 5

CALCULATION OF AIRFOIL HEAT TRANSFER USING A FULL NAVIER-STOKES CODE



AIRFOIL HEAT TRANSFER

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Figure 6