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COOLANT PASSAGE HEAT TRANSFER WITH ROTATION
A Progress Report on the Computational Aspects

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Turbine airfoils are subjected to increasingly higher heat loads which escalate the cooling requirements in order to satisfy life goals for the component materials. If turbine efficiency is to be maintained, however, cooling requirements should be as low as possible. To keep the quantity of cooling air bounded, a more efficient internal cooling scheme must be developed. One approach is to employ airfoils with multi-pass cooling passages that contain devices to augment internal heat transfer while limiting pressure drop. (fig. 1).

Design experience with multi-pass cooling passage airfoils has shown that a surplus of cooling air must be provided as a margin of safety. This increased cooling air leads to a performance penalty. Reliable methods for predicting the internal thermal and aerodynamic performance of multi-pass cooling passage airfoils would reduce or eliminate the need for the safety margin of surplus cooling air.

The objective of the program is to develop and verify improved analytical methods that will form the basis for design technology which will result in efficient turbine components with improved durability without sacrificing performance. The objective will be met by: 1) establishing a comprehensive experimental database that can form the basis of an empirical design system. 2) developing computational fluid dynamic techniques, and 3) analyzing the information in the database with both phenomenological modeling and mathemetical modeling to derive a suitable design and analysis procedure.

Currently, a design phase has been completed which defined a rotating experiment to simulate blade passage cooling. Models of blade internal geometries will be studied. The first model with instrumented smooth wall legs has been designed and is being fabricated. It is scheduled for testing in December, 1983. The subsequent models will have "rough" walls and will address passage aspect ratio changes. These tests will generate a database for the development of a design system.

The prediction of local coolant side heat transfer coefficients and coolant temperature rise and pressure drop in the cooling passages is difficult because of the three dimensional, elliptic nature of the flow, the effects of rotation, and the complex turbulence promoting devices. The analytical approach under consideration is based on the 3D-TEACH computer code being developed for gas turbine combustor applications by Pratt & Whitney Aircraft, (ref. 1).

The 3D-TEACH code is a generalized aerothermal fluid dynamic solver for three-dimensional, elliptic, turbulent, steady flows. The approach stays within the framework of continuum mechanics and uses a statistical description of turbulence, coupled with the accepted Eulerian description provided by the Navier-Strokes equations of motion. Closure to the resulting time-mean equations is provided by turbulence modeling of the eddy viscosity type. The modeled partial differential equations are manipulated into a general form that permits a single solution algorithm to be used for a numerical procedure. A hybird (upwind/central) finite differencing scheme is used to discretize the equations.

A version of the 3D-TEACH code has been modified to calculate fluid flow and heat transfer in rotating passages. In order to be able to apply the code with confidence to the experimental data generated in this program, it is essential to assess the suitability of the physical modeling used. To do this, the code is being exercised in flow situations similar to the turbine airfoil application, but simpler in nature. Such a procedure enables the weaknesses, if any, to be identified easily.

To test the behavior of the modified momentum equations flow in a rotating multi-pass passage (figure 1), was calculated. Flow patterns are made visible by the use of streak lines. Figure 2 shows flow at 600 RPM (0·174 Rossby Number) in two cross-sections of the passage. The development of a vortex pair in the outflow (away from axis of rotation) leg due to Coriolis forces can be seen clearly. The action of the sharp turns is to coalesce these vortices into a single vortex that dominates flow in the inflow leg. The observed behavior appears sensible.

The quantitative behavior in rotation was examined through reference 2. For example, a comparison of velocity profiles for the duct rotating at 165 R.P.M. is given in figure 3. Streakline flow visualization shows also the development of Coriolis vortices in the duct.

The ability of the code to calculate heat transfer in a rectangular duct with a sharp 180 degree bend was examined through reference 3. A comparison of calculated and measured Nusselt numbers for the various zones through the passage is given in figure 4 at two Reynolds numbers.

The behavior of the code thus far is pleasing, and the results of the comparisons with the verification experiments is very encouraging. Further investigations of these and other suitable experiments will continue to build confidence in the code. Use of more sophisticated turbulence modeling will also be explored. The developed code will then be applied to the measurements to be made as part of this program.

REFERENCES

1. Sturgress, G. J., "Aerothermal Modeling - Phase I Final Report," NASA Rept. CR. 168202, May 1983.

2. Moon, I.M., "Effects of Coriolis Force on the Turbulent Boundary Layer in Rotating Fluid Mechanics," M.I.T. Gas Turbine Lab. Report No. 74, June 1964.

3. Metzger, D. and Sahm, M., "Measured Heat Transfer in Smooth Rectangular Ducts with 180 Degree Sharp-Corners Turns," Arizona State University Tech. Rept. ERC-R-83003, January 1983.

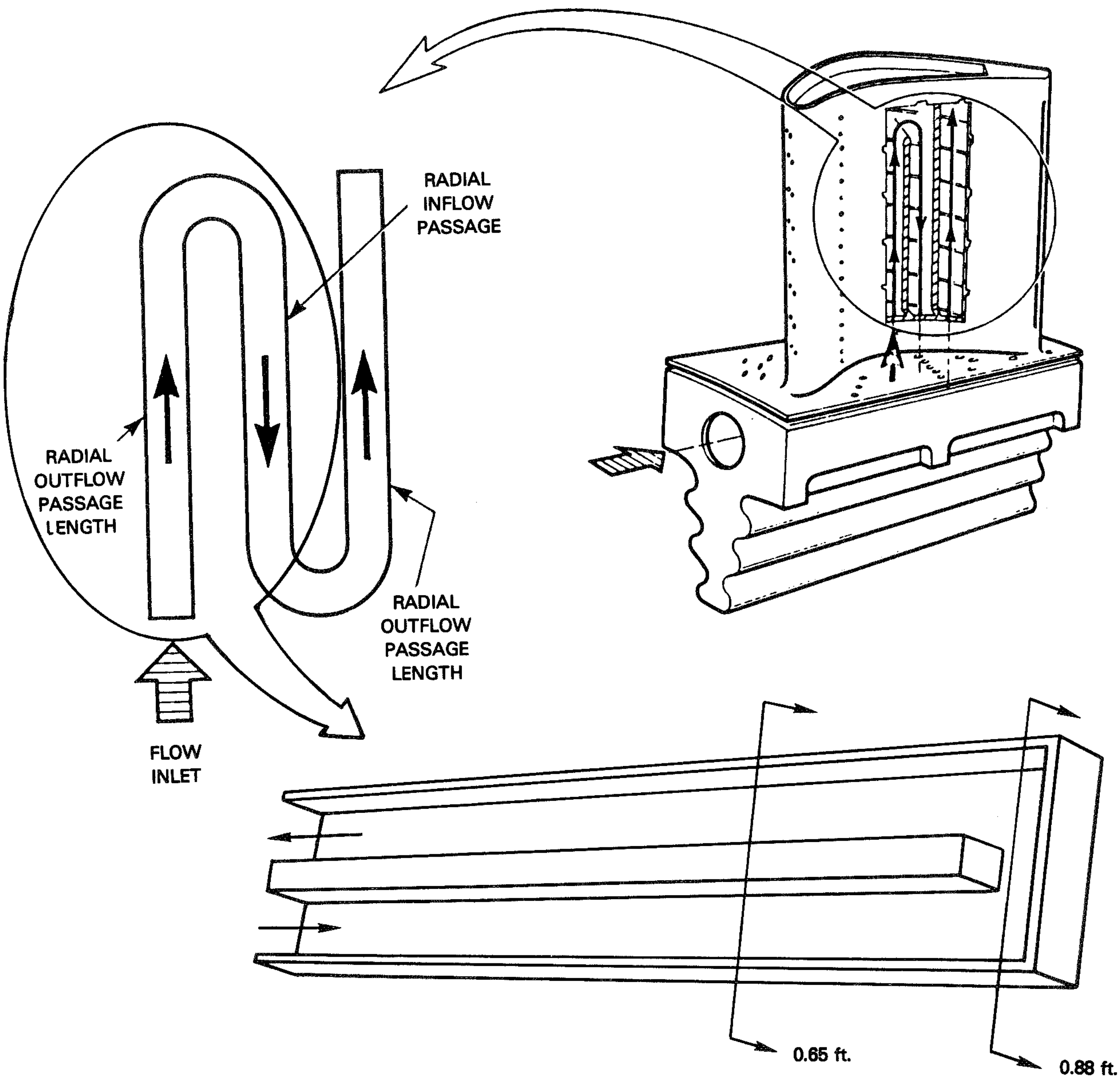

Figure 1 Schematic Of Coolant Passage

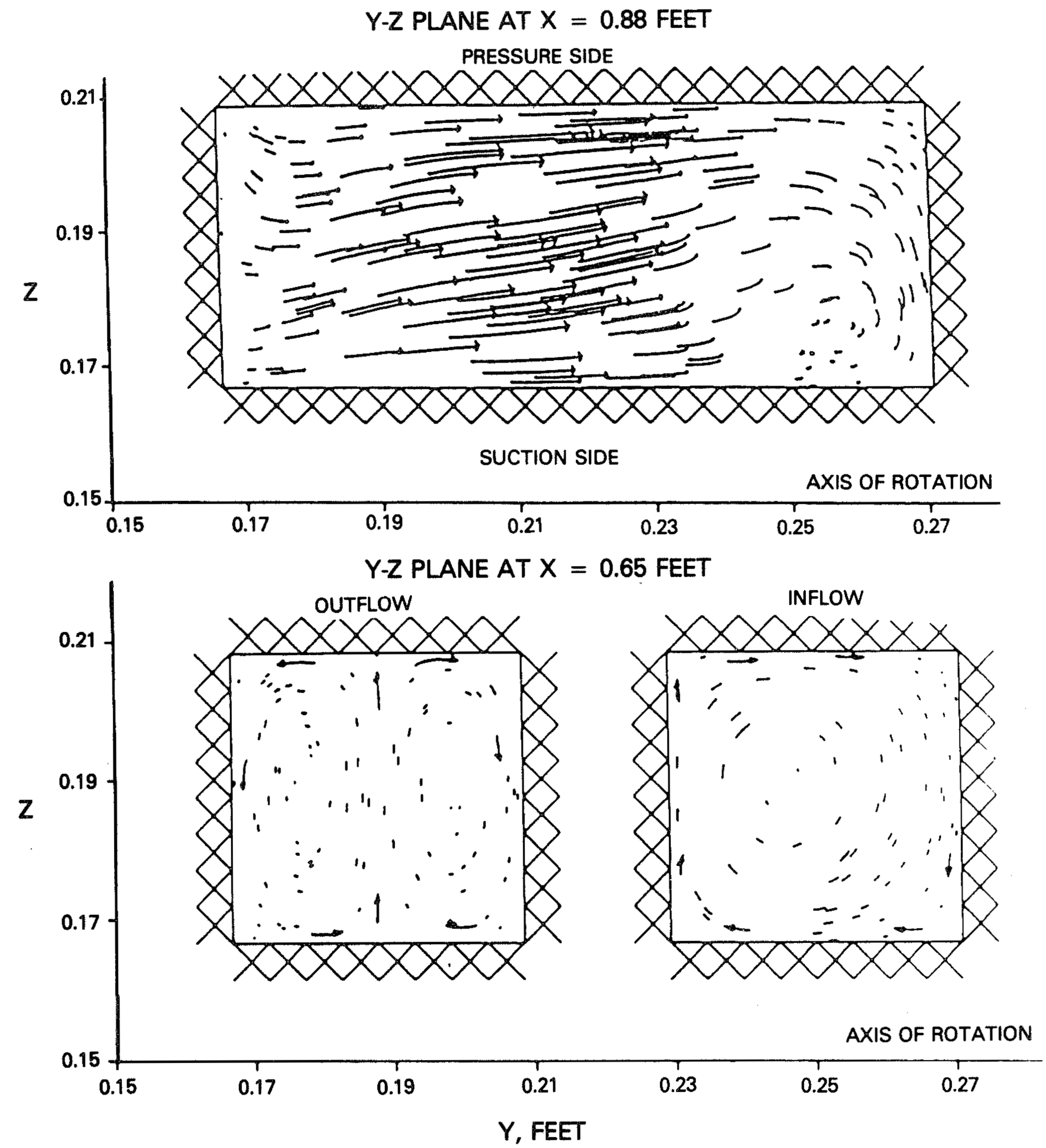

Figure 2 Test Of Momentum Equations Rotation at 600 R.P.M.

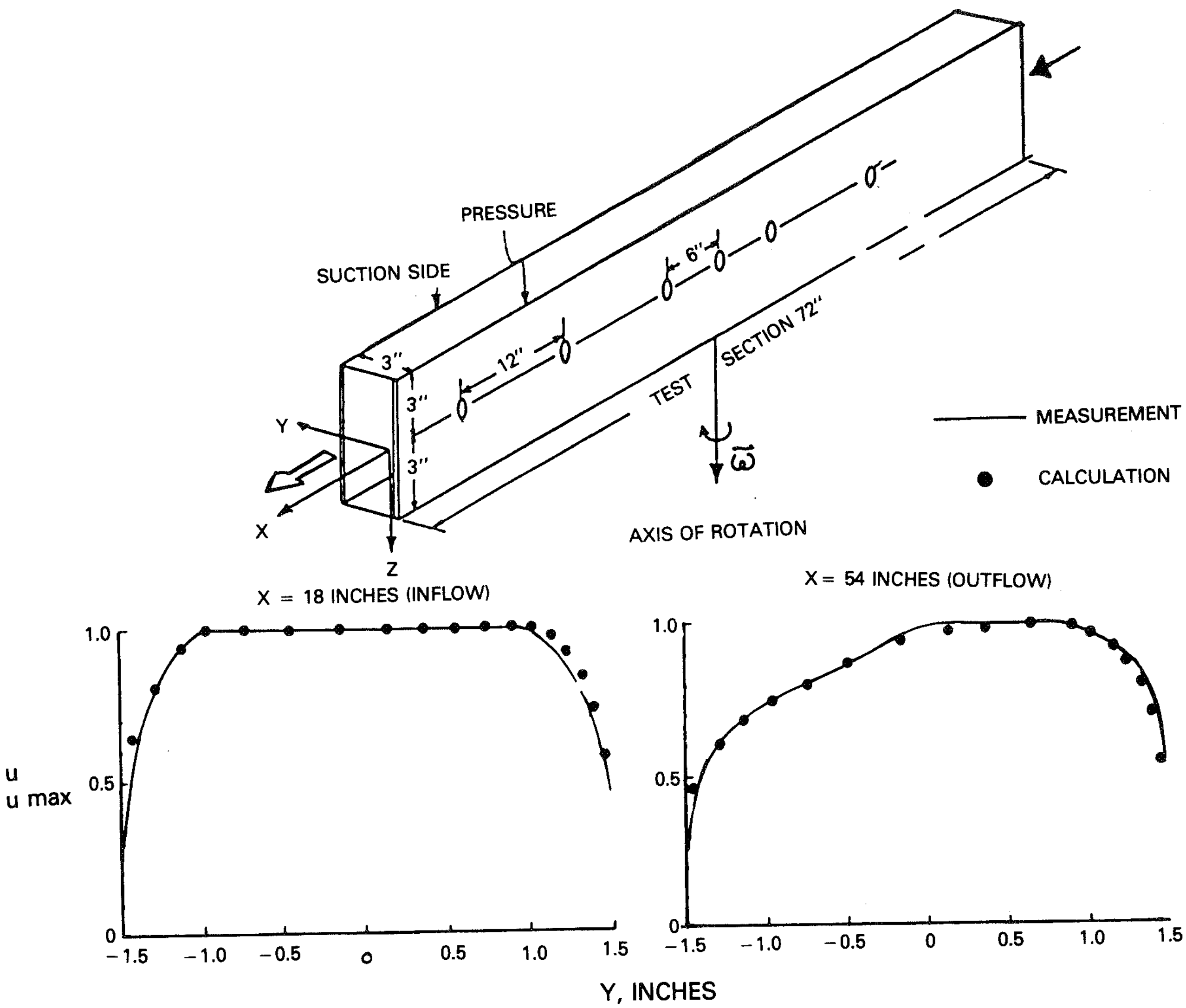

Figure 3 Axial Velocity Profile Development at 165 R.P.M. For Moon's Experiment

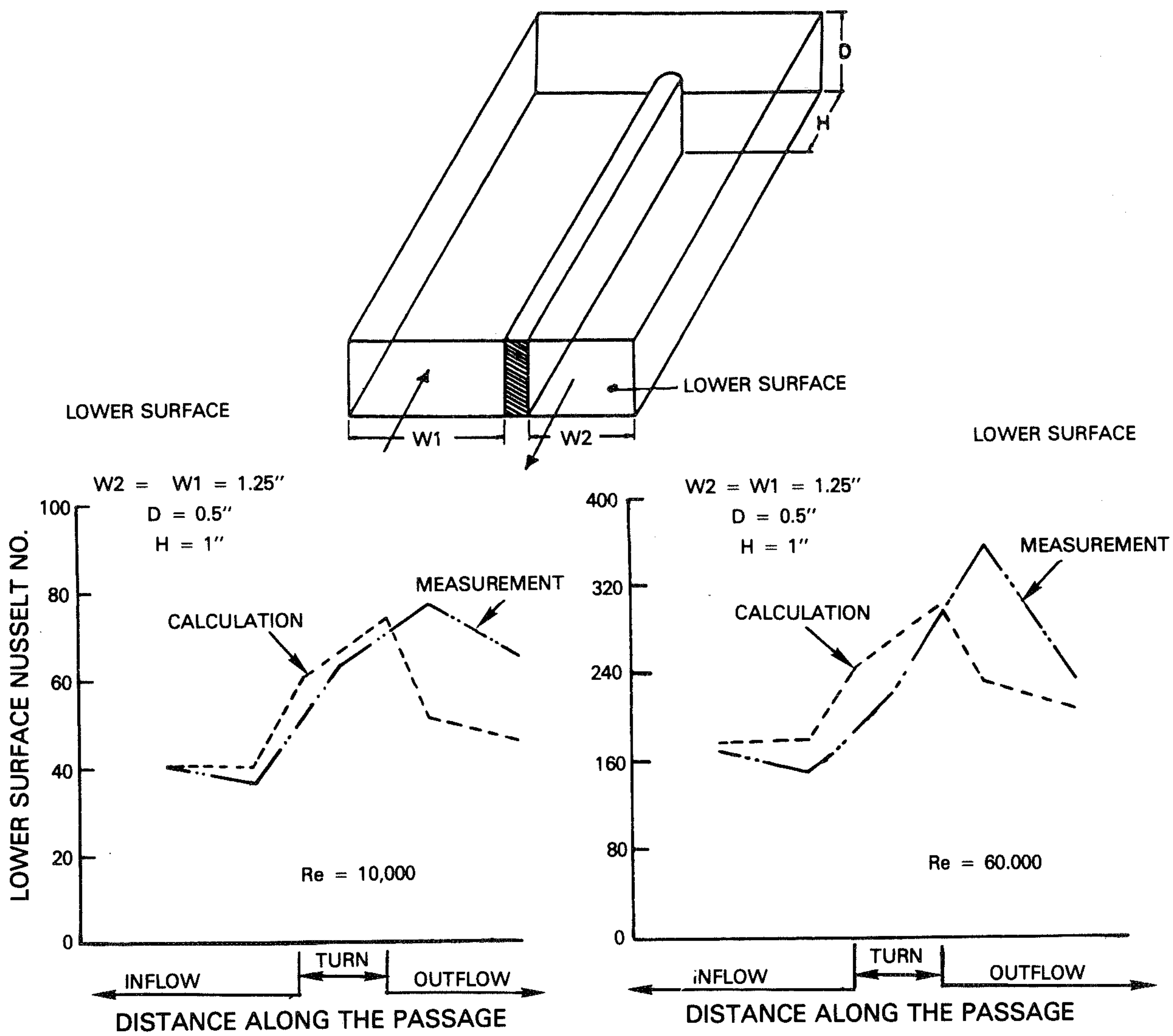

Figure 4 Heat Transfer In 180° Sharp Bend For Metzger's Experiment