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GAS FLOW ENVIRONMENTAL AND HEAT TRANSFER NONROTATING 3D PROGRAM

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OBJECTIVES

The experimental contract objective is to provide a complete set of "benchmark" quality data for the flow and heat transfer within a "large" rectangular turning duct. These data are to be used to evaluate and verify three-dimensional internal viscous flow models and computational codes. The analytical contract objective is to select such a computational code and define the capabilities of this code to predict the experimental results. Details of the proper code operation will be defined and improvements to the code modeling capabilities will be formulated.

The experimental and analytical efforts are being conducted under a coordinated multiphase contract. Phase one, the current work, is the study of internal flow in a rectangular, square cross-sectioned, 90° bend turning duct, and is planned as a 28 month investigation which started in April, 1982. Phase one is divided into the following five tasks: I. Design and Fabrication, II. Experimental Velocity Measurements, III. Experimental Heat Transfer, IV. Theoretical Analysis and Data Comparison, V. Reporting and Technical Data. Future work to be performed at NASA's option includes the investigation of flow over an airfoil cascade, with and without film cooling, inside the turning radius of the duct.

Separate but coordinated experimental and analytic approaches are in progress to attain the contract objectives.

APPROACH, EXPERIMENTAL

The experimental facility design features modular tunnel components which allow flow measurements every 15° in the 90° bend. The 25.4 cm (10 in) square cross section tunnel is designed with a 13 to 1 area ratio bell mouth contoured to provide uniform flow velocity and is powered by a variable speed, six-bladed fan. (See Figures 1 and 2). The tunnel is designed for incompressible flow and will produce Reynolds numbers of 0.2 to 2.0 X 10^6 at the entrance of the 90° bend for tunnel velocities of 6 to 30 m/sec (20 to 100 ft/sec). These two flow conditions provide laminar and fully turbulent boundary layer profiles at the entrance to the 90° bend. The facility is also designed for adiabatic wall testing with large thermal gradients in the air stream. Heated air will be provided by electric resistance heaters sized so that 100 KW will produce a minimum of 110°C (200°F) temperature increase in the air stream.

The primary instrumentation is designed for non-intrusive flow measurements utilizing a three-dimensional, laser velocimeter (LV) and wall static pressure and heat flux gages. The LV utilizes two color beams and Bragg diffraction beam splitting/frequency shifting to separate the three simultaneous, orthogonal, vector velocity components. The LV signal processors determine the digital values of velocity from the seed particles crossing the laser beam probe volume. To improve and speed up digital data acquisition, the LV processors are designed around an S-100

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bus Z-80 microprocessor which provides on-line, near-real time data reduction. This on-line data reduction capability will be used to assess the adequacy and precision of the data as it is acquired and recorded for off-line detailed analysis. Typical data output is shown in Figure 3. To qualify the measurements as "benchmark" data, the LV data will be compared with both pitot probe and hot wire anemometer measurements for flow conditions which permit comparisons.

CURRENT RESULTS AND PLANS, EXPERIMENTAL

All experimental hardware and instrumentation systems have been designed, fabricated, assembled, installed and checked out. Only the air heater remains to be fabricated, and only the heat flux measurement system remains to be checked . Extensive tunnel flow quality surveys have been completed in the inlet section following "benchmark" calibration of the LV system, pitot-static, and hot wire anemometer. All three measurement systems were calibrated against reference standards and were found to agree within $\pm$ 1% on the entrance section velocity. The LV system was calibrated with a spinning disk reference velocity at 20 m/sec. The pitot-static pressures were read on a precision slant manometer with 13mm of H_2O full scale. The hot-wire system was calibrated in a reference nozzle flow at 30.5 m/sec. Velocity surveys taken 50.8 cm (20 in) behind the bell mouth exit showed flat velocity profiles $\pm$ 0.5% mean velocity outside of the boundary layer. Laminar and turbulent boundary layers were measured at velocities of 4.5 m/sec and 19.4 m/sec, respectively as shown in Figure 4. Most significant finding was that the LV and hot-wire turbulence intensity measurements agreed within 10% or nominally 1% turbulence intensity. The mill bed traverse system has demonstrated repeated accuracy of $\pm$ 0.1mm on all three axis of movement. Both LV and probe positions are controlled by the computer driven mill bed.

Development of the flow seeding system was successfully completed during the LV system checkout. Phenolic micro-ballons of 2-5 micron size are sprayed in a slurry of alcohol and water into the air stream in front of the bell mouth. Uniform seed distribution was obtained in the test section with this system.

The experimental effort is progressing toward completion of flow measurements at the seven stations in the 90° duct for the unheated flow. A minimum of 300 spatial points in the duct half-plane are being surveyed for mean velocity, unsteady velocity and total pressure at each station. After completion of the unheated flow surveys at two Reynolds numbers, scheduled for 1 December 1983, the air heater and tunnel insulation will be installed for the adiabatic wall testing during the winter months when lower ambient temperatures will reduce tunnel wall temperatures. The experimental phase of this effort is scheduled for completion in May, 1983.

APPROACH, ANALYTICAL

The analytical approach involves, first, selecting a computer code capable of solving the Navier Stokes equations with turbulence models for three dimensional internal flow, and adapting it to the experimental geometry and flow conditions. After this, calculations are to be made for laminar flow conditions for unheated flow. Analysis of these calculations will define the grid size and stretching factors required for adequate resolution as well as the values of time steps and smoothing factors required for convergence. Also, any output and graphics capability required for comparison with data is to be developed during this phase. The adequacy of the code with respect to the differencing scheme, adaptability and convergence will be decided in this phase, by comparisons with published experimental and computational data and by grid sensitivity studies.

The next phase of the effort involves computation of heated laminar flows with adiabatic wall conditions. This calculation is important for determining maximum wall temperatures to be expected in the experiment. It will also be important in determining whether for the temperatures planned, the velocities will deviate sufficiently from the unheated case to provide an interesting flow.

The third phase involves detailed comparison with experiment for laminar flows with and without heat added. The resolution of the computer code will be the main aspect tested here. The heated case will involve adiabatic wall conditions.

The fourth phase involves computing turbulent flows corresponding to actual experimental conditions, with and without heat added. Particular attention will be paid to the treatment of heat transport in the turbulence model. Detailed comparisons with experiment will be made.

A final phase involves selective grid refinement in regions where high resolution is required so that a measure of the numerical truncation error can be obtained.

CURRENT RESULTS AND PLANS, ANALYTICAL

The code selected for the analytical study is a version of the Beam-Warming algorithm adapted to generalized coordinate systems by P. D. Thomas. It is very well documented and relatively easy to use. The original plan to use the "MINT" code developed by Briley and McDonald has not been followed due to our inability to obtain the code. Detailed comparisons of the results of our code, for a laminar flow case, with published results of the MINT code have been made. For comparable grids the codes gave similar results. These results have also been compared to published experimental results as shown in Figure 5. This comparison indicated a discrepency which appeared to be due to lack of adequate resolution in the computed results for both codes. This discrepency has been investigated by grid refinement studies. Further, the effect of the grid stretching factors on the solution has been determined. The time step size and smoothing factors have been determined which approximately optimize convergence for this case. A graphical display program has been written and used to simulate streamlines in the flow as shown in Figure 6. These results have been qualitatively compared with preliminary experimental results in a 1/3 scale duct.

A heated laminar flow case with adiabatic wall conditions was then computed. It was determined that the wall temperature at a point near the end of the bend would be close to the maximum inlet temperature, which occurs at the center of the duct. Computed total temperature profiles are shown in Figure 7. This result is important in determining the maximum allowable inlet temperature. For the temperature profile considered, which was close to that planned in the experiment, it was also determined that the velocity profiles would differ significantly from those of the unheated flow. Thus, the heated flow experiment would result in a qualitatively different flow, for the planned inlet temperatures, and the experiment would give useful results.

Currently, we are running unheated turbulent flow cases. Preliminary results are being studied to determine the sensitivity of the results to the turbulence model parameters. Detailed comparisons with experiment will be made for the laminar cases, with and without heating, as soon as they are available. We will then proceed with the comparisons for turbulent flow and additional grid refinement studies.

Experimental Facility

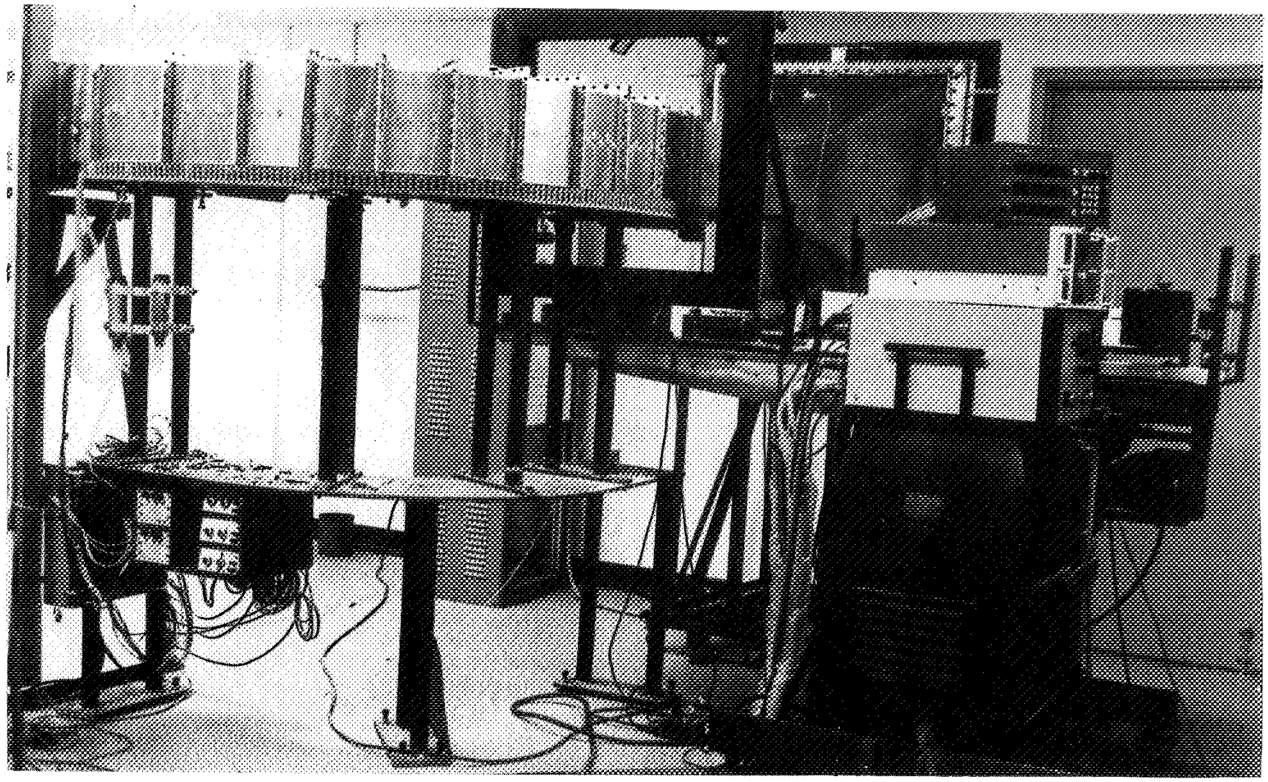

Figure 1.

LV and Pressure Instrumentation Detail

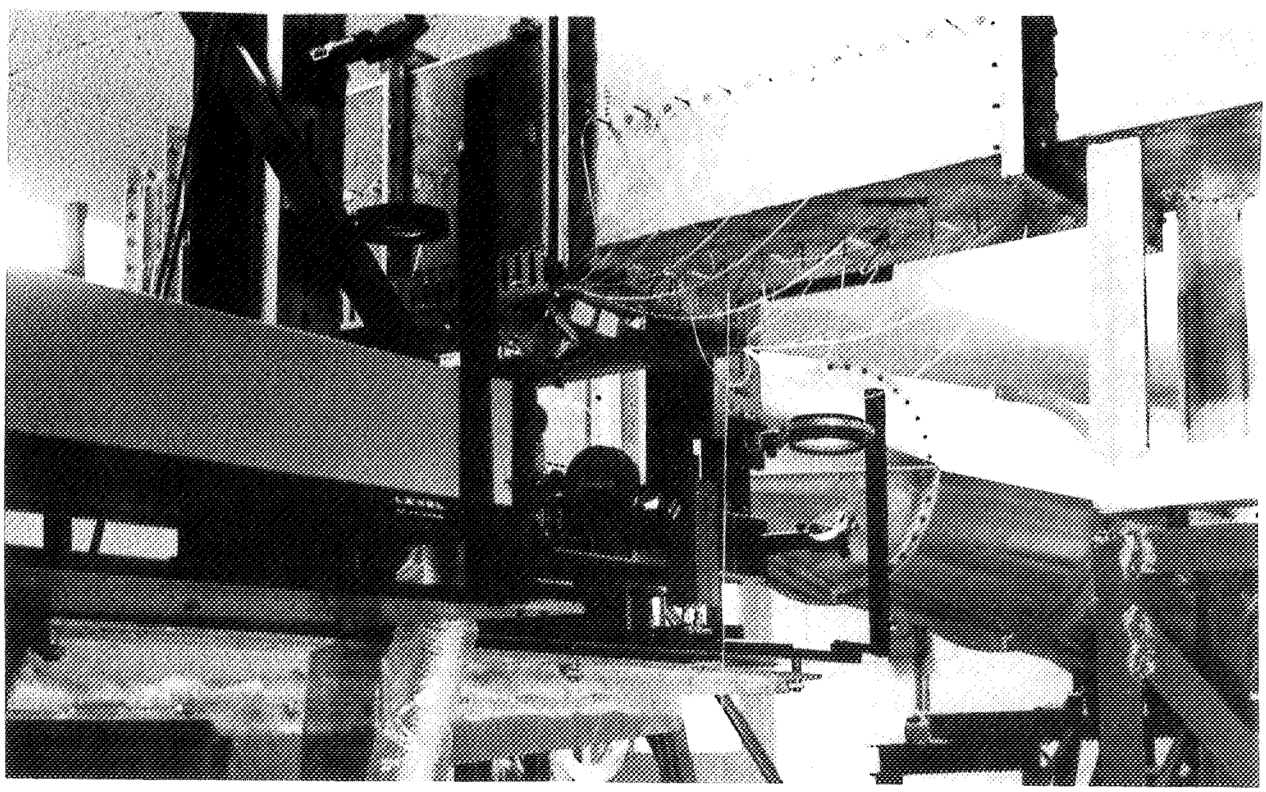

Figure 2.

Typical On-Line Data Display

	X Axial	Y Crosswise	Z Spanwise	Active modes
	(Active)	(Active)	(Active)	
Long Fringe Count	8	8	8	
Short Fringe Count	5	5	5	
Precount	2	3	3	
Clock Frequency	100.00	100.00	100.00	
High Pass Filter	1.2207E-02	2.0000E-01	1.0000E-01	XYZ
Fringe Period	46.100	36.030	15.360	
Maximum Aperiodicity	4.0000E+00	4.0000E+00	4.0000E+00	PRINT
Bias Frequency	-.60	.30	.23	PLOT
Platform position	-.0180	-.0100	-.0100	HDCOPY
Timer Rate	1.0E+03			
Sample Size	400			
Run Number	6			

			X	Y	Z
Vrms = 19.71	V	=	19.69	= .7315	= -.1691
SIGMArms = .3668	SIGMA	=	.3660	= .2300	= 6.1734E-02
% = 1.862		% =	1.859	% = 31.44	% = 36.50
Accepted = 271		=	348	= 326	= 381
Aperiodicity failures		=	52	= 74	= 19
High pass filter failures		=	0	= 0	= 0
Frequency		=	.1729	= .2797	= .2410

Correlation Coefficient = 5.42758E-02
Covariance = 2.82059E-04

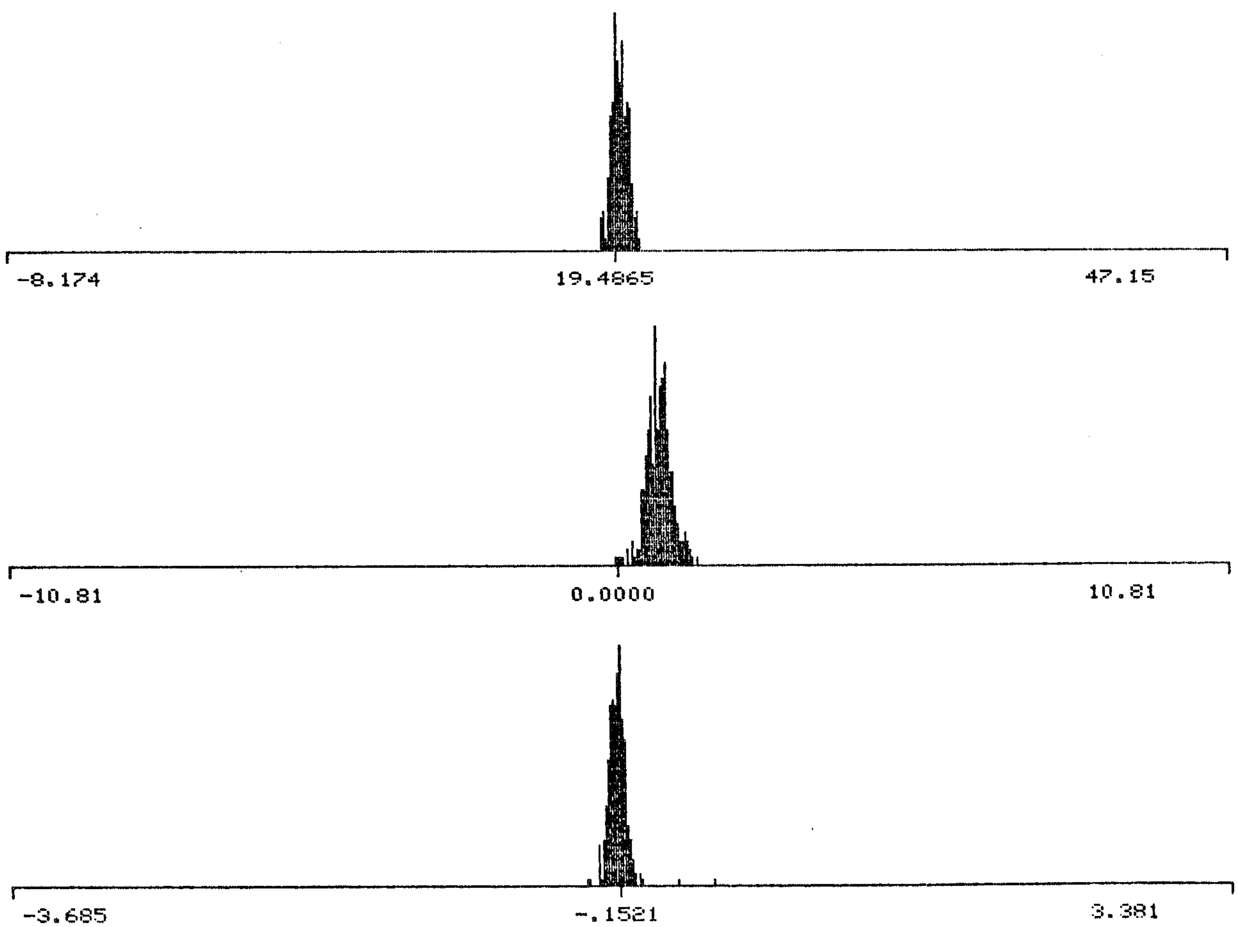

Figure 3.

Entrance Region Boundary Layer Profiles

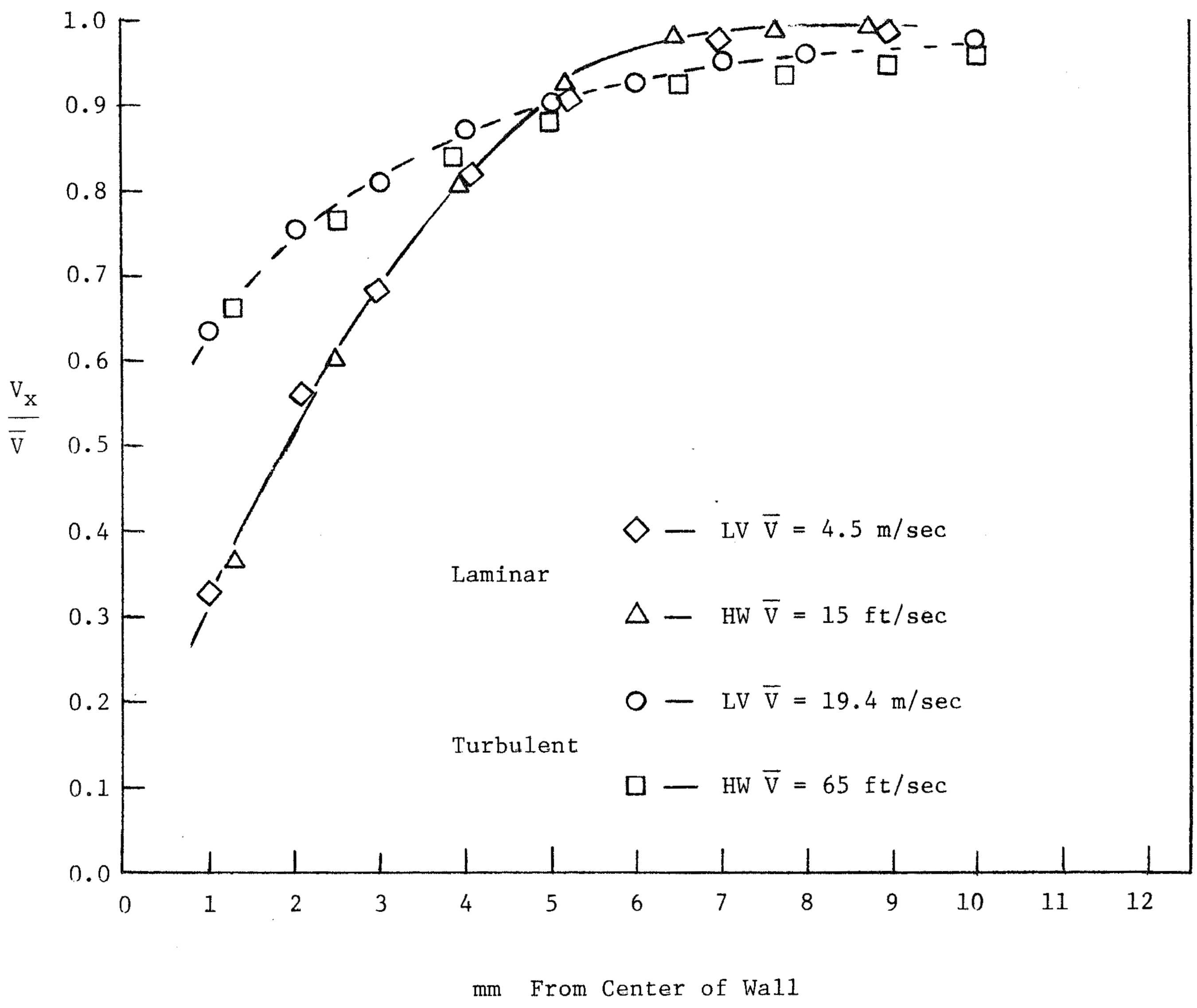

Figure 4

Axial Velocity Comparison Analytic/Experimental

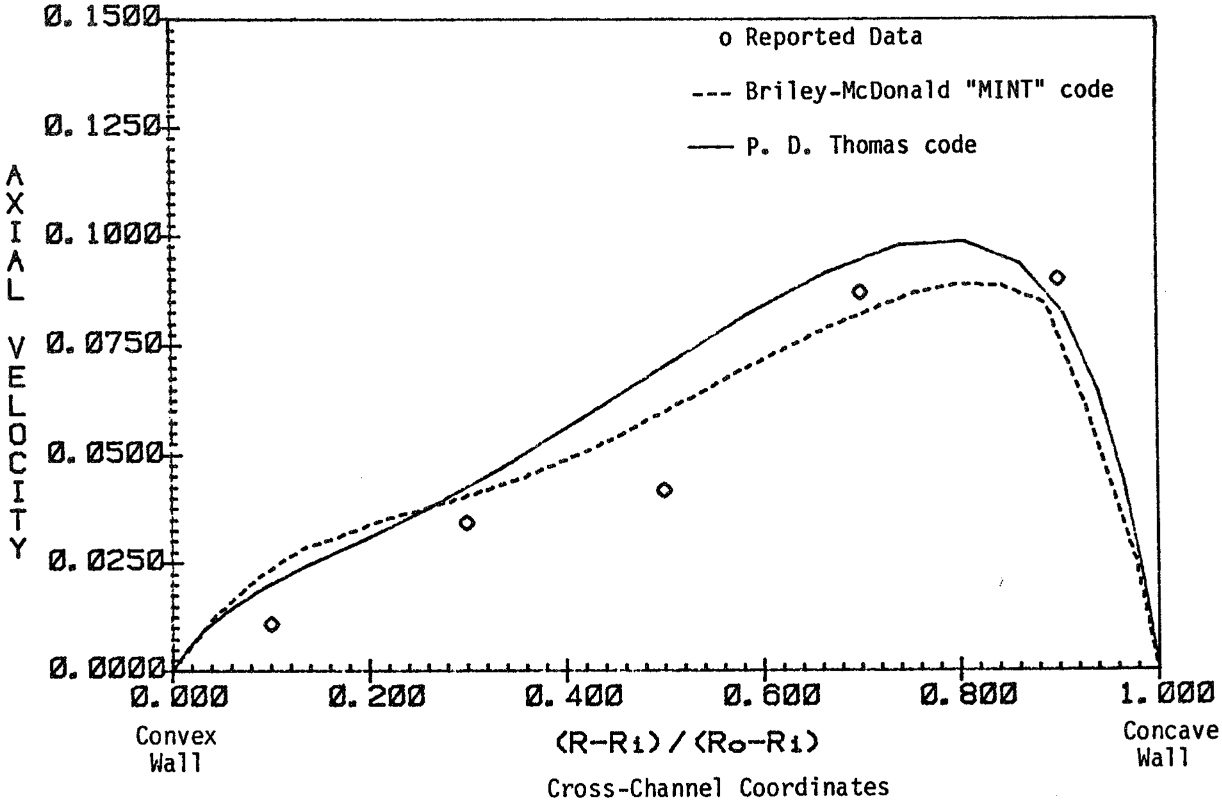

Figure 5.

Streamline Trace for Laminar Flow

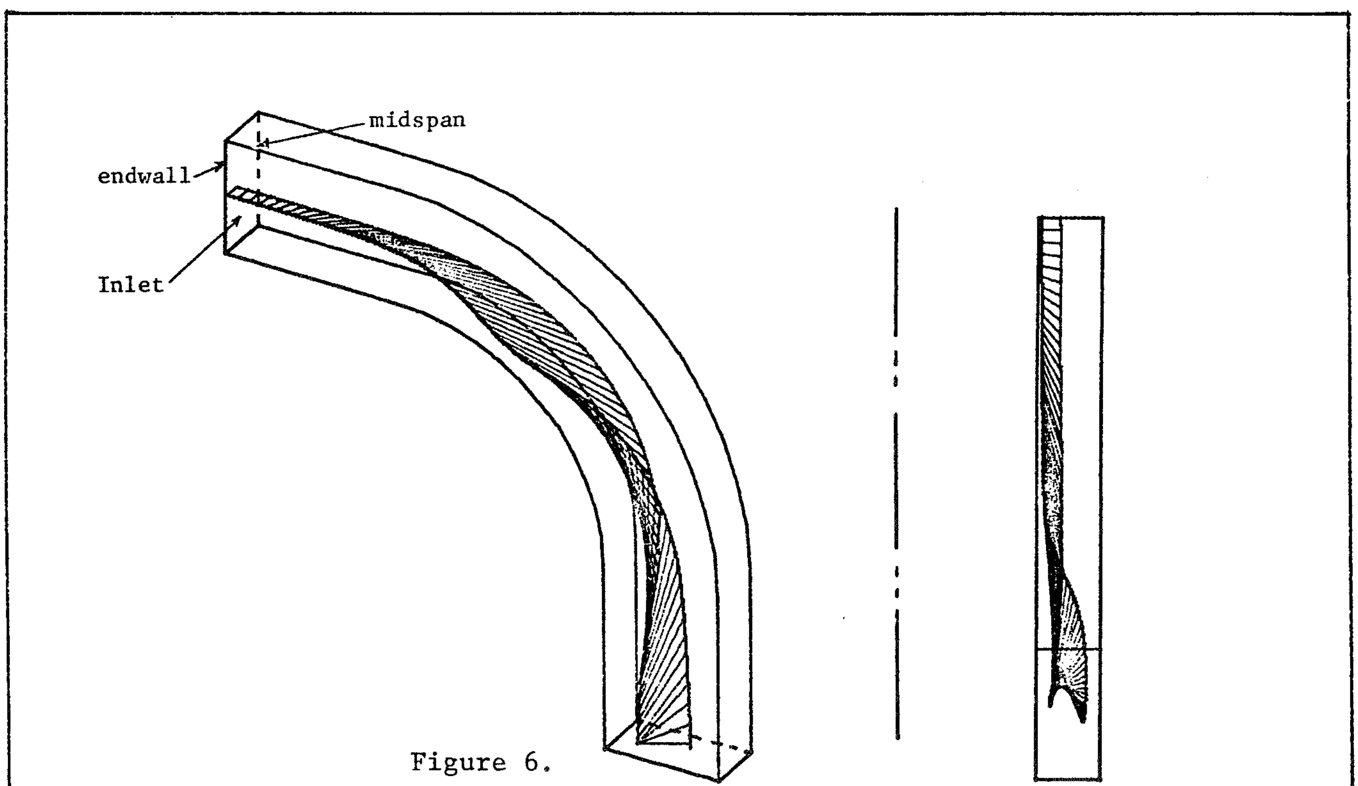

Figure 6.

Total Temperature Profile at Bend Exit
Laminar Flow, Adiabatic Wall

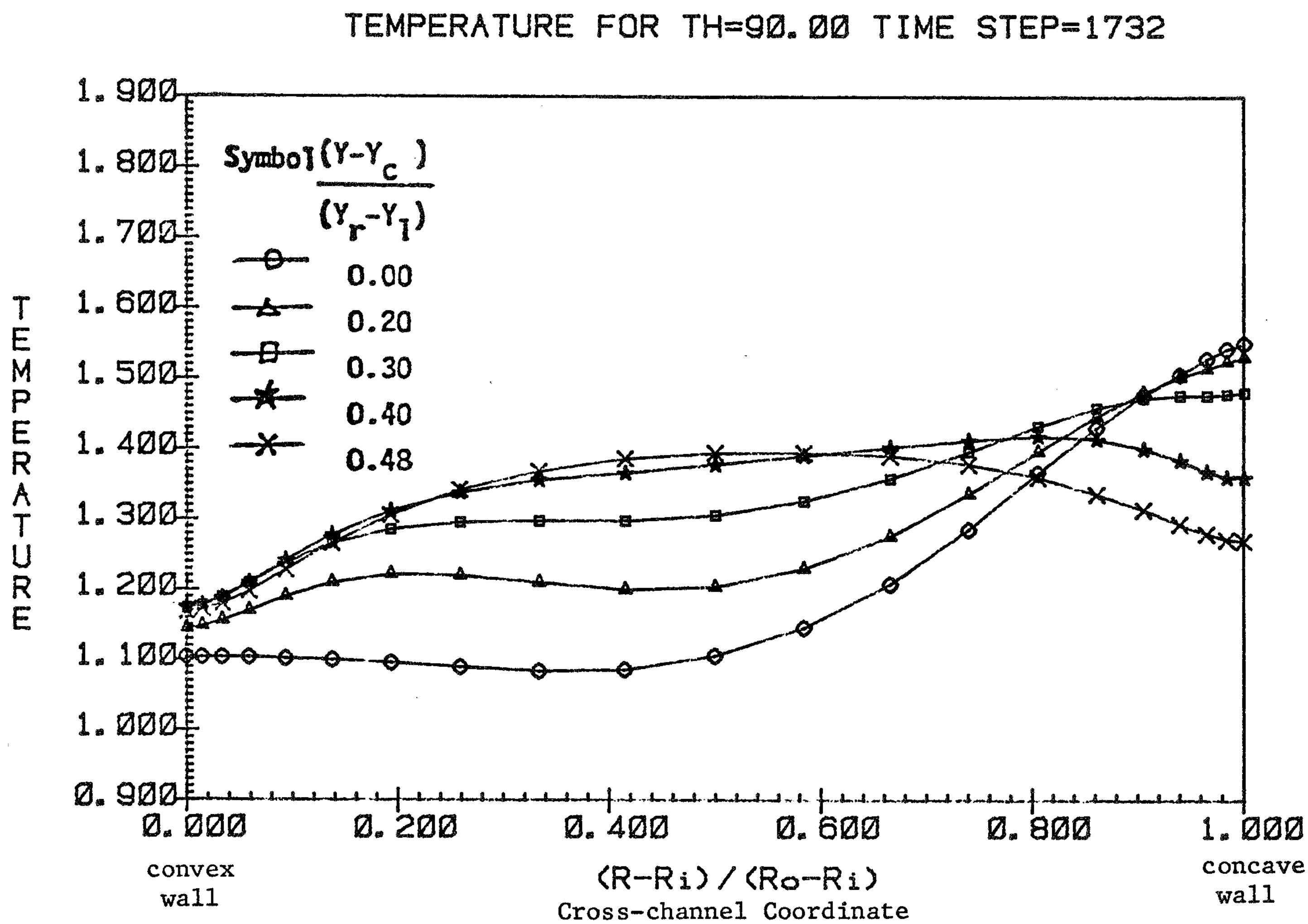

Figure 7.