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RPR 161-04

BOUNDARY LAYER SIMULATION IMPROVEMENT

Progress Report
for

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on

Contract NAS8-36551

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Prepared for

National Aeronautics and Space Administration
George C. Marshall Space Flight Center
Marshall Space Flight Center, AL 35812

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BACKGROUND

The objective of the study is to advance the current Boundary Layer Integral Matrix Procedure - Version J (BLIMPJ) with regard to the previously-modeled calculation methods accounting for surface roughness, relaminarization, condensed phase, and thick boundary layer effects. Current analytical limitations will be relaxed to permit more realistic wall and flow conditions and to use appropriate turbulence models with specific emphasis for the projected Orbit Transfer Vehicle (OTV) engine application. The updates will be incorporated into the BLIMPJ computer program, and the modified program will be made operational on the MSFC CRAY computer system. An additional objective of this effort is to conduct experimental feasibility studies to find out how to obtain quality test data with advanced instrumentation for concept verification purposes.

STATUS OF TASKS

During the reporting period, work concentrated on Tasks 1, 2, and 4. The status of work on all tasks is provided in Table 1. In addition to the tasks reported here, an abstract was submitted to JANNAF for presentation at the upcoming Combustion meeting.

WALL ROUGHNESS

The variable surface roughness option has been added to BLIMPJ and the checkout of this option is continuing. The application of surface roughness over two separate regions of the OTV nozzle was reported in RPR 161-02. From the figures provided in this report it was demonstrated that, in regions away from the throat, the surface roughness option produced an increase in the heat flux distribution. Figures 1 and 2 show the heat flux distribution in the throat region where variable roughness was introduced. From these figures it can be seen that the heat flux does not maintain the slope of the heat flux distribution as it does in the other regions of the nozzle. The cause of this observation is not yet understood but work will continue in this area until it is resolved.

ROUGHNESS DATA FOR THE 60° - 15° CONICAL NOZZLE

The Two-Dimensional Kinetic (TDK) computer code was run on REMTECH's MicroVAX II computer for the 60° half-angle of convergence nozzle as mentioned in RPR 161-03. Analysis of the pressure data generated on the VAX version of TDK showed two slope discontinuities on both sides of nozzle throat. In order to see if the accuracy of the nozzle data generated by TDK would be improved, the UNIVAC version of TDK was run and the resulting theoretical data transferred to the VAX for use with BLIMPJ. Figure 3 shows a comparison of the TDK pressure ratio data generated by these two computers. It was seen that the upstream discontinuity was removed, whereas the discontinuity at the downstream geometrical attachment point remained. The TDK (theoretical) results were then used as input for BLIMPJ. BLIMPJ was run for four experimental nozzle wall roughness values. These values are smooth wall, 120 rms (1×10^{-5}ft), 175 rms (1.4583×10^{-5}ft), and 325 rms (2.70833 x

10^{-5}ft). Figures 4 through 7 show the comparisons of the BLIMPJ (theoretical) film coefficients and the experimentally measured film coefficients. The experimental data is documented in NASA Technical Note, NASA TN D-5887. The method of roughening the nozzle in this experiment was through sand blasting. The range of roughness in the nozzle was measured to be within ±10 percent of the normal value. The smooth wall film coefficients in Figure 4 show good agreement over the full length of the nozzle. The rough wall film coefficients show good agreement along the length of the nozzle except in the throat region. In this region, the theoretical values are as much as 28 percent higher than the experimental values. This difference can be partially attributed to the accuracy of the roughness measurements (±10 percent) and the accuracy of the heat-flux measurements (within 10 percent).

RELAMINARIZATION

The above NASA document also contains low chamber pressure data (30 psi and 75 psi) for which the turbulent boundary layer flow has been claimed to relaminarize. It has also been mentioned that the wall roughness tends to reduce relaminarization. A quick study using BLIMPJ suggested that the measured film coefficient data lay in between fully turbulent and fully laminar calculations. The initial attempts to turn on the relaminarization flag did not yield good comparison with data. Some of the problems were due to the pressure discontinuities that have been alluded to earlier. However, work will continue to validate the relaminarization option currently coded in BLIMPJ.

THRUST DECREMENT CALCULATION

Work began on development of a methodology for linking the TDK and BLIMPJ computer codes in order to perform thrust loss calculations and, later, optimizations. The first task was to modify the TDK code so that the temporary direct access file which contains the nozzle flow data would be saved for later use. The second task was to write a computer program that could use this direct access file to calculate the necessary data required to perform the thrust loss calculations in BLIMPJ. To facilitate talking about this code we will call it the Near-Wall Profile (NWP) code.

Figures 8 and 9 are samples of the data generated by NWP. NWP performs a series of operations. First it identifies and stores the data associated with the points on a streamline, and secondly it interpolates the data from the streamlines that correspond to a specified X. The interpolated data for which profiles can be determined include pressure, density and velocity. Figure 9 shows six profiles that were generated using NWP. These profiles are for constant values of X and include data from all stored streamlines. Modifications are currently being added to NWP include limiting profiles to the boundary layer region and calculating profiles along lines normal to the nozzle wall.

In generating the profiles with NWP it was found that two important factors must be considered when creating the direct access data file with TDK. One factor to consider is that it is necessary to extend the input wall profile well beyond the nozzle exit plane in order to calculate data throughout the exit plane boundary layer region. The other important point to remember is that TDK over-writes the data in the direct access data file if the numer of data points exceeds the default (50000) and/or namelist input value of IDMAX.

PLANNED ACTIVITIES

1. Check-out of roughness modules will be completed.
2. The iteration procedure coupling TDK and BLIMPJ will be completed.
3. Work on relaminarization will be continued.

TASK		FORMULATED	CODED	COMPLETED
1	<u>Wall roughness</u>			
	o Treatment of up to three sections with smooth/rough wall surfaces	●	●	●
	o Ccncept check-out	O		
2	<u>Relaminarization</u>			
	o Wall roughness effect and strong regenerative cooling	O	O	
	o Freestream turbulence impact			
	o Turbulence model mcdification			
	o Ccncept check-out			
3	<u>Condensed Phase</u>			
	o Treatment of up to three sections with different ccndensed phase loading			
	o Turbulence model representation			
	o Concept check-out			
4	<u>Thrust Decrement Calculation</u>			
	o Coupling of TDK results with new BLIMP concept	O	O	
	o Thrust loss optimization			
	o Concept check-out			
5	<u>Experimental Feasibility Studies</u>			
	o Identification of thrust chamber testing to obtain adequate data in support of wall roughness, relamin-arization, condensed phase, thick boundary layer			
6	<u>Instrumentation</u>			
	o Screening of instruments for B.L. testing for accuracy, location, complexity, manufacturer and cost			

o In Progress
● Completed

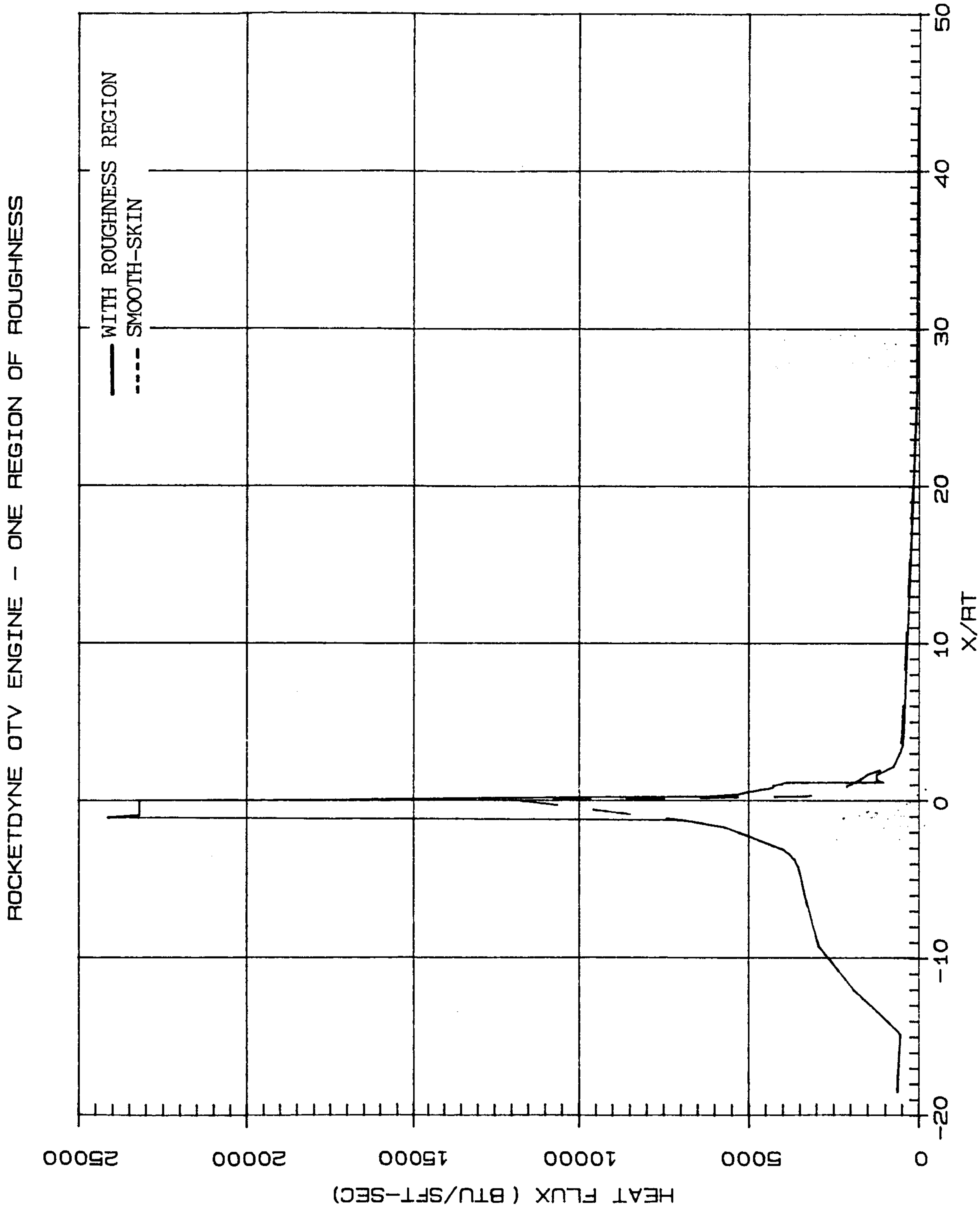

Fig. 1 Heat Flux Distribution in the OTV Nozzle with One Region of Roughness (RK = 0.00125 ft.) at the Throat

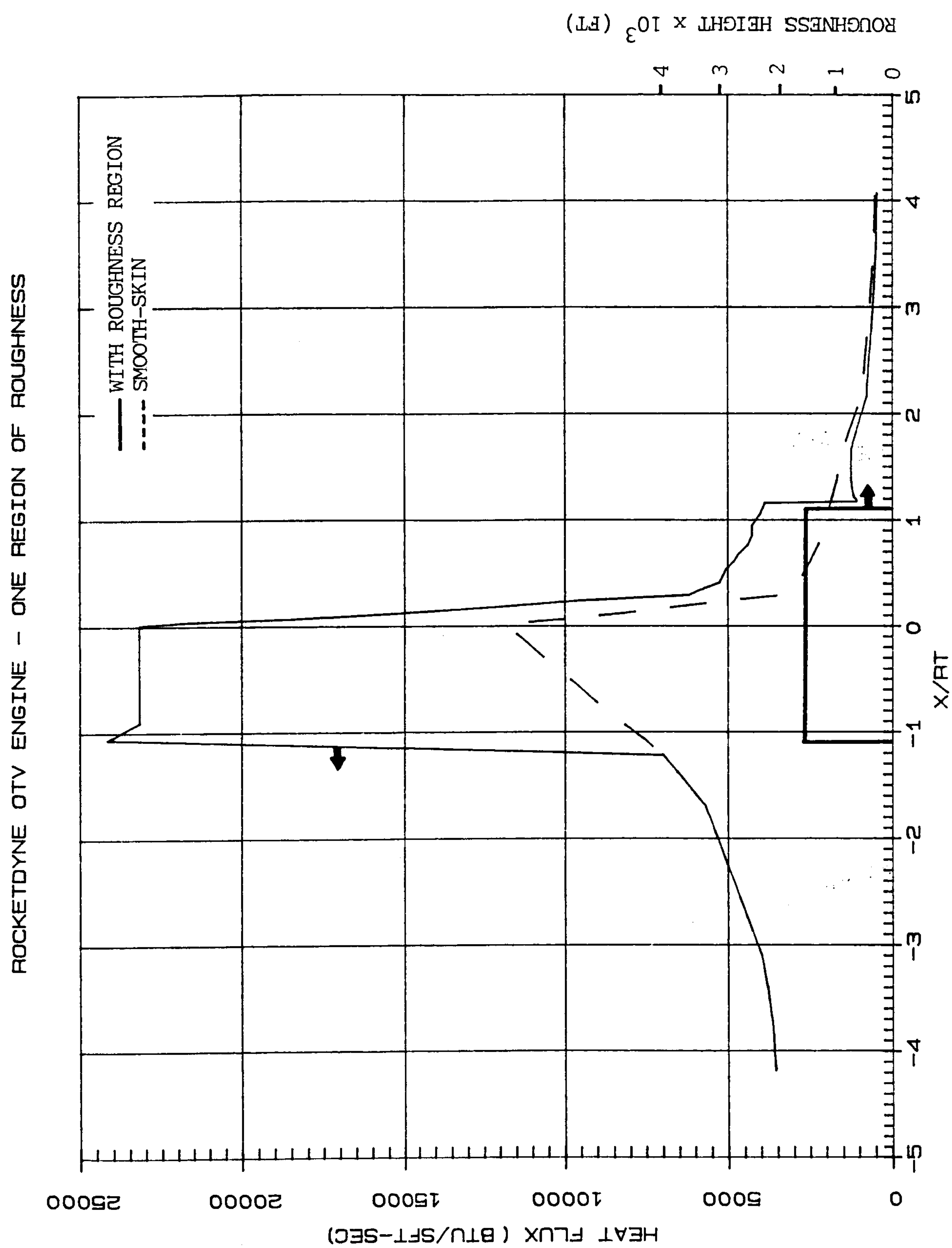

Fig. 2 Heat Flux Distribution in a Limited Portion of the OTV Nozzle Encompassing a Roughness Region (RK = 0.00125 ft.) - (Expanded Scale)

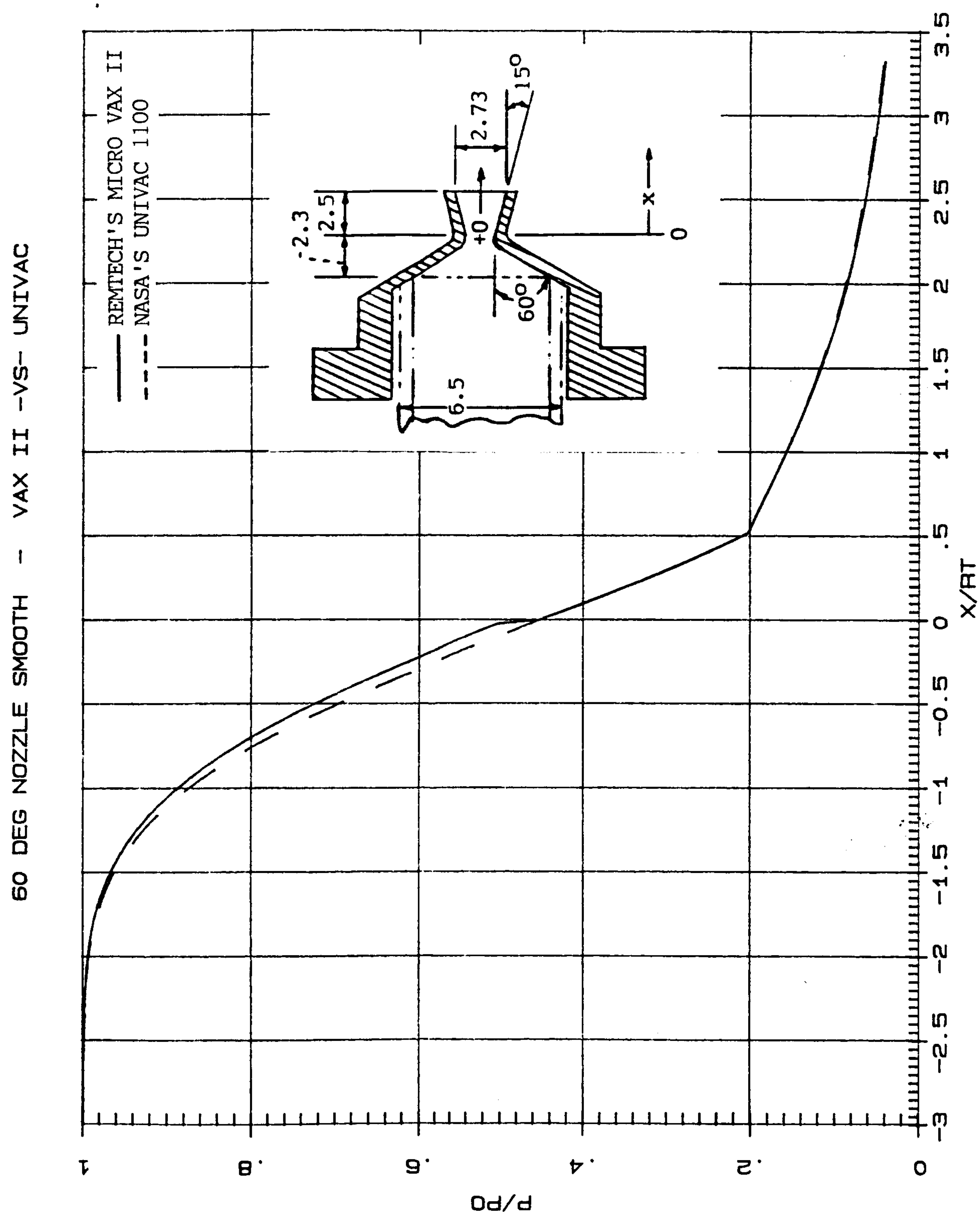

Fig. 3 Pressure Ratio vs. Normalized Axial Distance Calculated by TDK

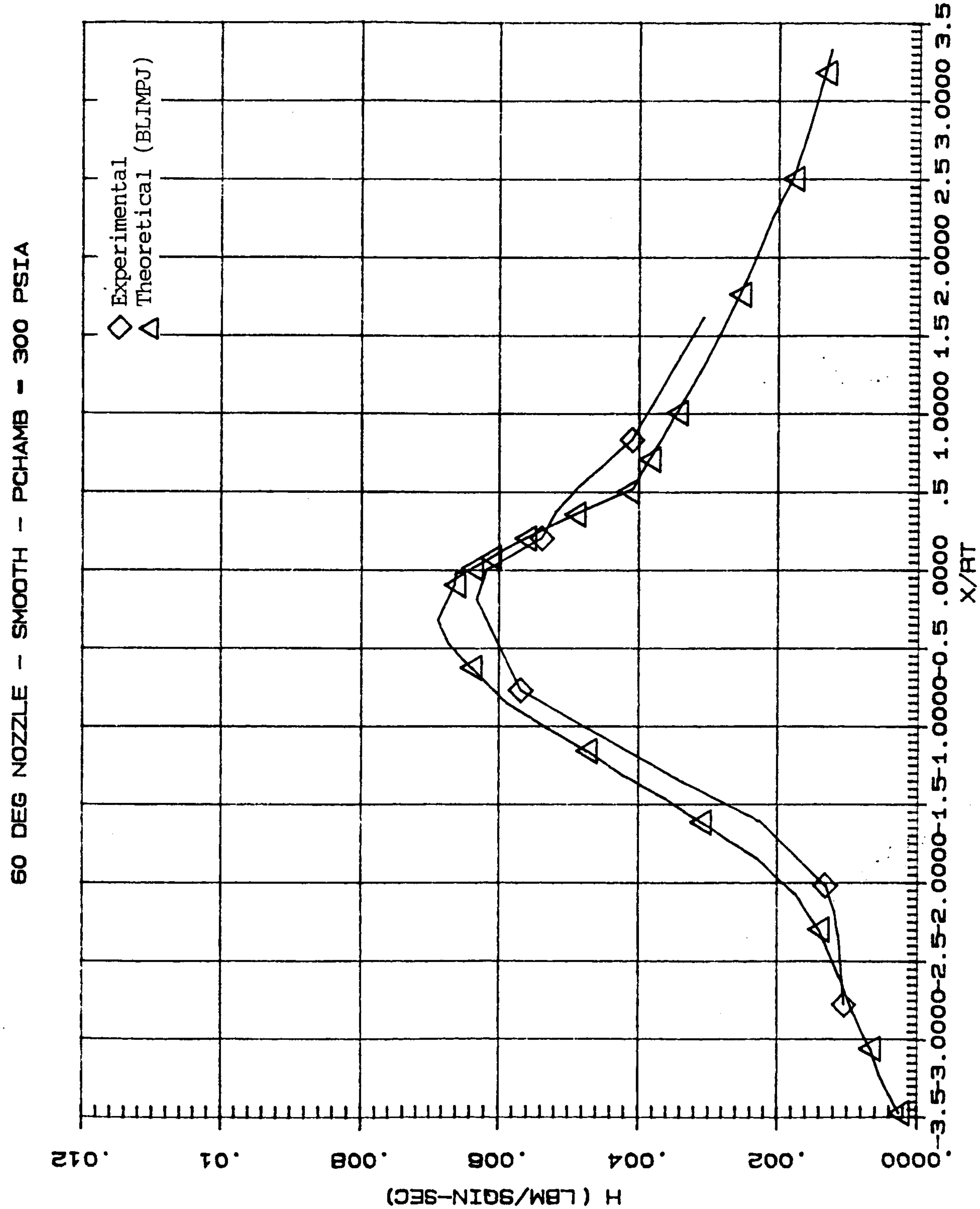

Fig. 4 Film Coefficient vs. Normalized Axial Distance - Smooth Wall

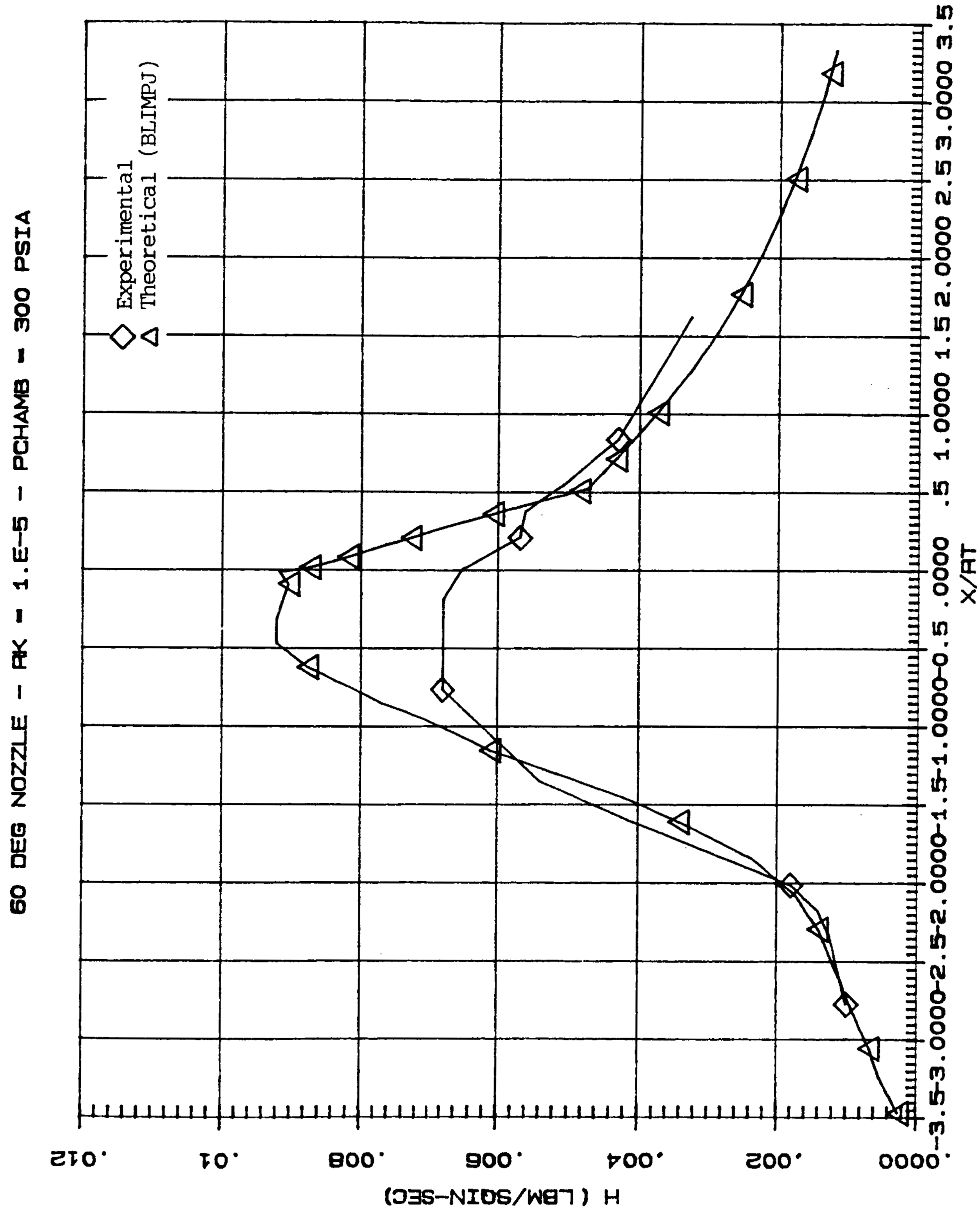

Fig. 5 Film Coefficient vs. Normalized Axial Distance - Rough Wall (RK = 1.0×10^{-5} ft)

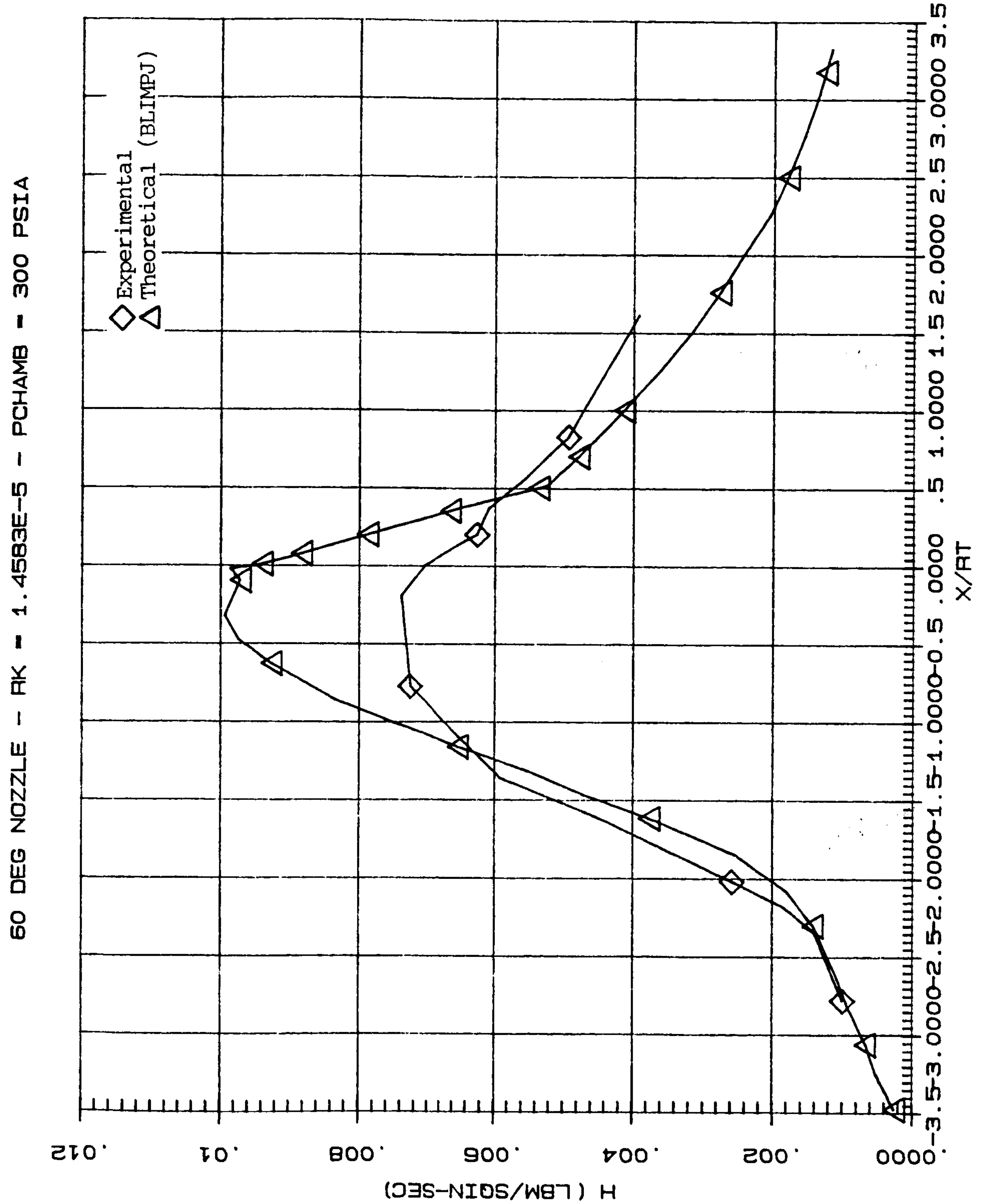

Fig. 6 Film Coefficient vs. Normalized Axial Distance - Rough Wall (RK = 1.4583 x 10^{-5} Ft)

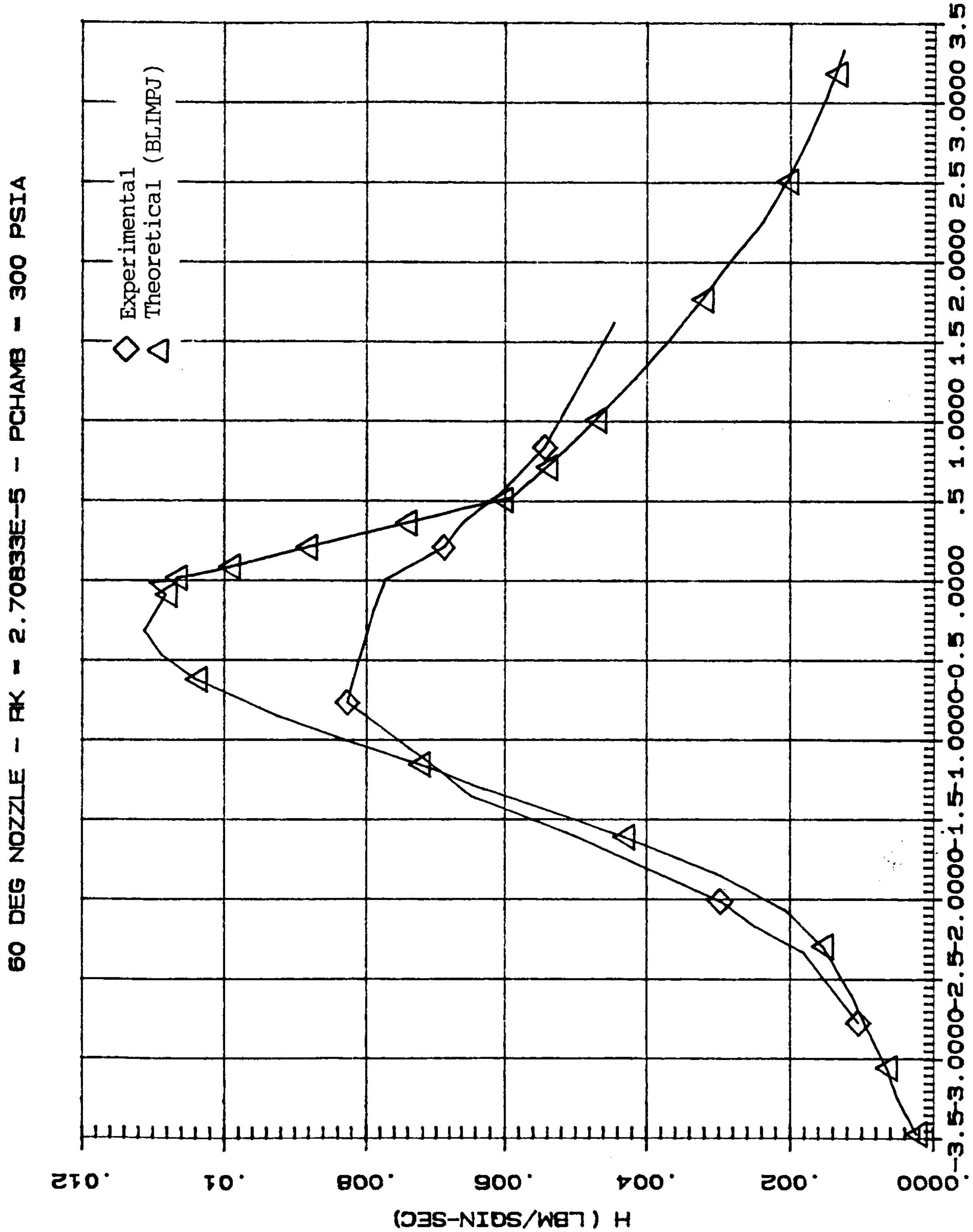

Fig. 7 Film Coefficient vs. Normalized Axial Distance - Rough Wall (RK = 2.70833 x 10^{-5} Ft)

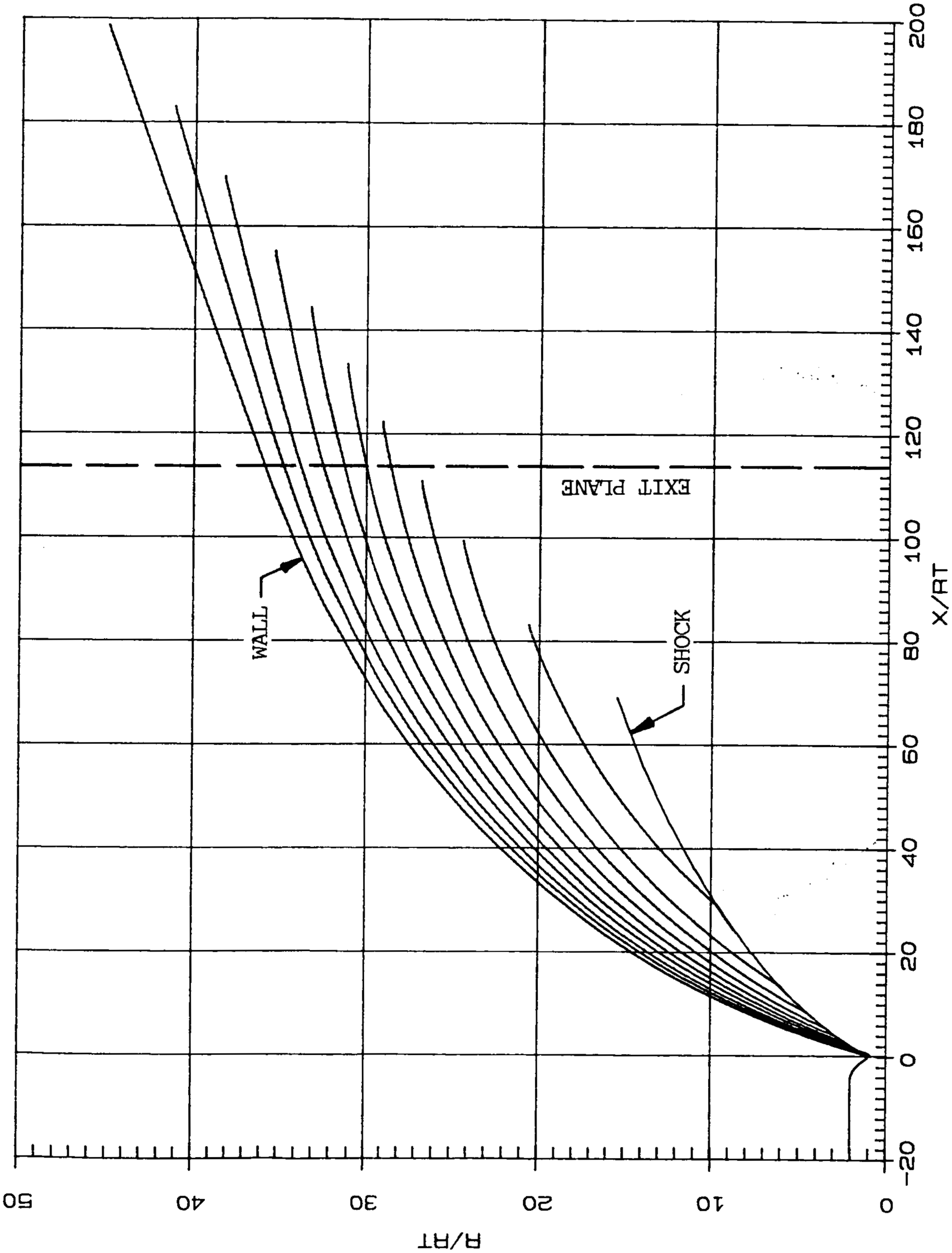

Fig. 8 Streamlines in Near-Wall Region of the OTV Nozzle

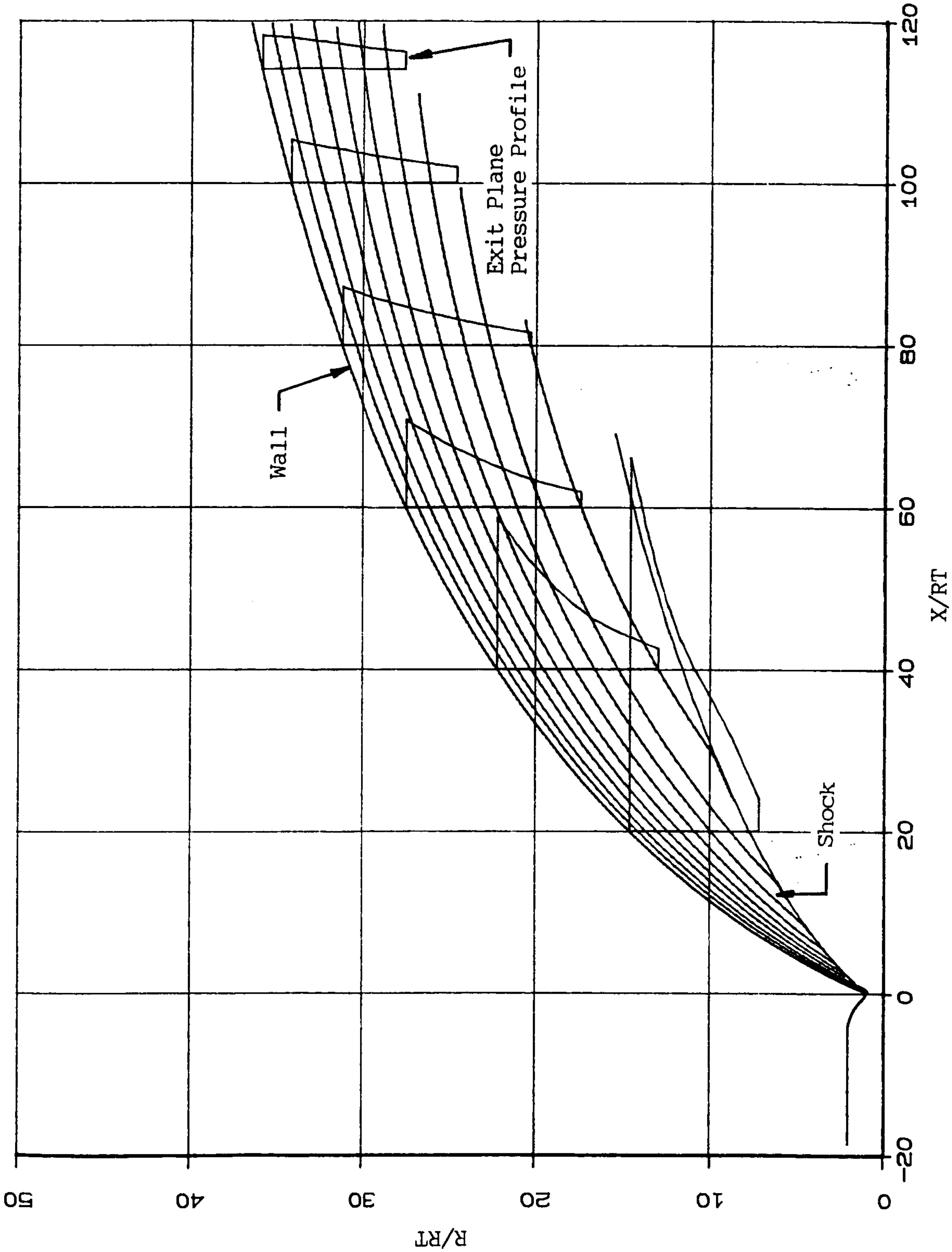

Fig. 9 Pressure Profiles in Near-wall Region of the OTV Nozzle