FR-20710-6

SSME ALTERNATE TURBOPUMP DEVELOPMENT PROGRAM (HPFTP)

VERIFICATION COMPLETE REPORT
EXIT STRUT AERODYNAMIC DESIGN
DVS 30 DR NO. 3.1.2.2.4.1, VM NO. 4.1.2.4 A

JULY 1989

Prepared under
NASA Contract NAS8-36801
DRL Sequence No. SE12
WBS No. 1.5.1.2

Prepared for
George C. Marshall Space Flight Center
National Aeronautics and Space Administration
Marshall Space Flight Center, Al 35812

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ATD Project Manager

UNITED TECHNOLOGIES PRATT&WHITNEY

(NASA-CR-183755) SSME ALTERNATE TURBOPUMP DEVELOPMENT PROGRAM (HPFTP). VERIFICATION COMPLETE REPORT: EXIT STRUT AERODYNAMIC DESIGN DVS 30 DR NO. 3.1.2.2.4.1, VM NO. 4.1.2.4 A (PWA) 33 p

N90-70030

Unclas

00/20 0233357

Printed in the United

PRATT & WHITNEY AIRCRAFT GROUP
Government Products Division

FLORIDA TECHNICAL DATA

TRACEABILITY NUMBER		
YEAR	SERIES	JOB NO.

DISTRIBUTION

TITLE A.T.D. Fuel Pump Drive Turbine TAD Exit Strut Aerodynamic Design

REPORT NUMBER

ISSUE DATE April 4, 1989

ENGINE MODEL SSME Alternate Turbo-Pump Development

REF. COMPUTER PROGRAM W703, P824, T862, V310, V081, G693 (DECK NO.)

LAYOUT NO. 86WA134 CHANGE

WRITTEN BY X. A. Montesdeoca

X. A. Montesdeoca

RESUME

This report summarizes the aerodynamic design of a common strut for the SSME A.T.D. HPFTP turbine exhaust flowpath.

Notes:

1. The aerodynamic design point is the 109% power condition given in Design Table 0387.B dated 4/10/87.

2. A common strut with a maximum thickness of 0.6" was designed. The 15 struts were grouped into 5 different stagger angles, 4 will house cooling tubes.

3. One strut with a thickness of 0.78" was required to house an optical pyrometer. The strut was designed with a maximum thickness of 0.857" so that it may be staggered and aligned with its neighbors.

4. The final configuration minimizes the transverse pressure gradient at the turbine exit, the number of different strut staggers, and the number of casting tools to be fabricated.

5. W703 analysis predicts a 31% decrease in the transverse pressure gradient ($\Delta P/Q$) at the turbine exit relative to the Rocketdyne Phase II configuration.

NOTE: INCLUDE DESIGN POINT CONDITIONS IN RESUME, WHEN APPLICABLE.

Complete analysis details can be found in Design Notebook 18 Volume 1.

APPROVED BY (FIRST LEVEL SUPERVISION) (SECOND LEVEL SUPERVISION)

PWA 10927 REV 10-78

HPFTP Turbine Aerodynamic Design

The High Pressure Fuel Turbopump (HPFTP) turbine aerodynamic design is based on the requirements defined by the Interface Control Document (ICD) and by the Power Balance Model, Table 387B. Performance Table 387B was used for the turbine aerodynamic design because its turbine flow capacities are consistent with the baseline turbine nozzle flow test results conducted on Pratt & Whitney's test stand, E-6, in December, 1986.

A conventional pressure-compounded, 2-stage turbine was chosen because of its inherent high efficiency over a wide range of steady-state operating conditions. No exit guide vane is required for the small (18 degrees) exit swirl angle. The high airfoil gas bending loads in the HPFTP turbine required thin wall, hollow airfoil sections, with larger moments of inertia, in order to reduce the airfoil bending stresses. The HPFTP turbine design has a mean diameter wheel speed of 1482 ft/sec which is compatible with allowable disk and root attachment stress criteria. This wheel speed also provides a high design point wheel speed to gas velocity ratio, assuring that there will not be a significant efficiency loss at minimum power level (MPL) operation. The design point velocity ratio, (0.55) is conservative, ensuring minimal aerodynamic risk. The design speed of approximately 36,500 rpm selected for the HPFTP was primarily set by the pump hydrodynamics. The height of the turbine annulus was selected to limit the last stage blade root centrifugal stress to 46,000 psi. This annulus size yielded a favorable exit Mach number of 0.18 and a low exit swirl angle of 18 degrees, therefore, this rpm was satisfactory to the performance, stress, and exit Mach number requirements of the turbine.

The methodology associated with the design of the HPFTP starts with the meanline design analysis. This analysis is based on the assumption that the flow through the turbine can be represented by the flow at the center of the flow passage. This simplified approach permits selection of the number of stages required, the mean diameter of the flow passage, and the annulus area. Included in the analysis is an estimate of the aerodynamic efficiency. This prediction system uses the physical laws of aerodynamics and correlations from rig and engine data to estimate profile loss, secondary loss, blade tip leakage, and shock and incidence losses based on the geometry and aerodynamic parameters of the turbine. An interactive graphic flowpath design system is used, in conjunction with the optimum meanline design, to generate candidate flowpath configurations.

The streamline design analysis is used to optimize the radial variation in the velocity triangles, once the average conditions are selected from the meanline analysis. This analysis calculates the flow characteristics at numerous radial locations and at the inlet and exit of each airfoil row. Once the meanline and streamline analyses have been used to optimize the velocity triangles throughout the turbine, 2 dimensional (2-D) airfoil sections are designed. These airfoil sections are designed to achieve contours that provide the desired amount of flow turning without permitting the flow to separate from

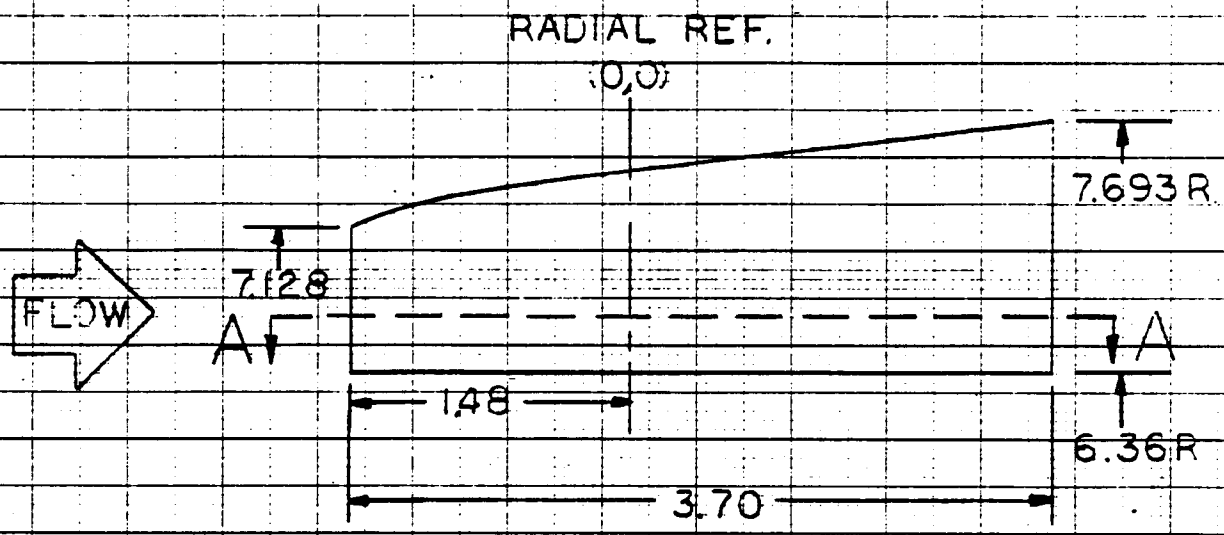
the airfoil surface. This process involves determining the static pressure distributions and boundary layer parameters along the airfoil surfaces and endwalls. An interactive graphics airfoil design system is used to identify adverse static pressure gradients such that the airfoil contour can be modified appropriately. After the 2-D airfoils are estimated at several spanwise locations, they are radially faired and combined with a preliminary endwall definition. An inviscid multi-stage 3-D flow analysis is then used to refine and optimize the entire flowpath configuration.

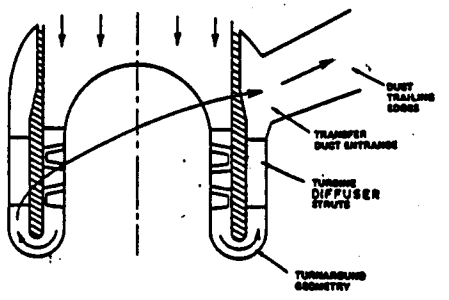
All turbine airfoil, endwall, inlet, and exit flow passage surfaces are contoured and refined as a system. The multi-stage feature enables a complete evaluation of potential changes to an individual surface contour during the design process. This assessment includes, not only flow property changes around the component being modified, but also around all upstream and downstream components in the complete turbine system. Improved performance and reduced risk result from this global optimization capability.

This report contains:

- Hot elevation diagrams for each airfoil
- 3-D airfoil plots
- 2-D airfoil section plots
- Tabulated airfoil section coordinates
- A plot of hot gaging dimensions versus radius
- A plot of percent change in flow area versus airfoil rotation
- A plot of stress versus span
- 3-D airfoil static pressure distributions
- Airfoil Ps/PT and Mach number contours
- A plot of suction surface boundary layer friction coefficient versus surface distance

SSME HPFTP EXIT DIFFUSER STRUT





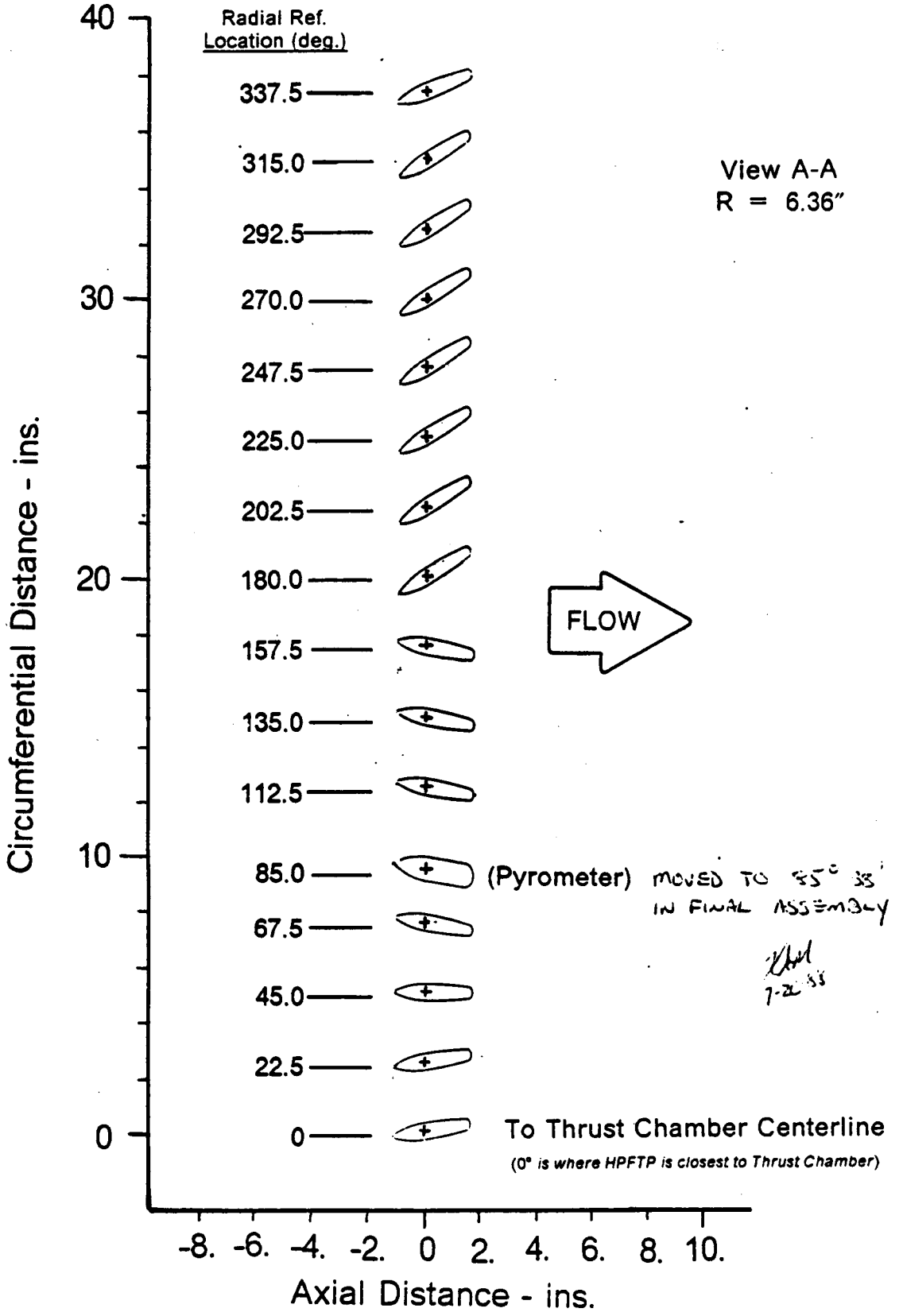
NOTES:

1. STRUT IS CONSTANT SECTION, STACKED ABOUT RADIAL REF.
2. TOTAL NUMBER OF STRUTS IS 16 (15 COMMON STRUTS WITH MAX THICKNESS OF 0.6" AND ONE 0.857" THICK TO MAKE THE ORIGINAL PERIMETER.
3. ALL DIMENSIONS ARE HOT.
4. MATERIAL IS AVA 1487. DENSITY ≈ 0.311 #/IN³
5. REFER TO PREVIOUS PAGE FOR A LIST OF PE24 AIRFOIL FILES.
6. REFERENCE LAYOUT L-86WA 119 (OUTER ENDWALL DEFINED IN COLD DIMENSIONS)

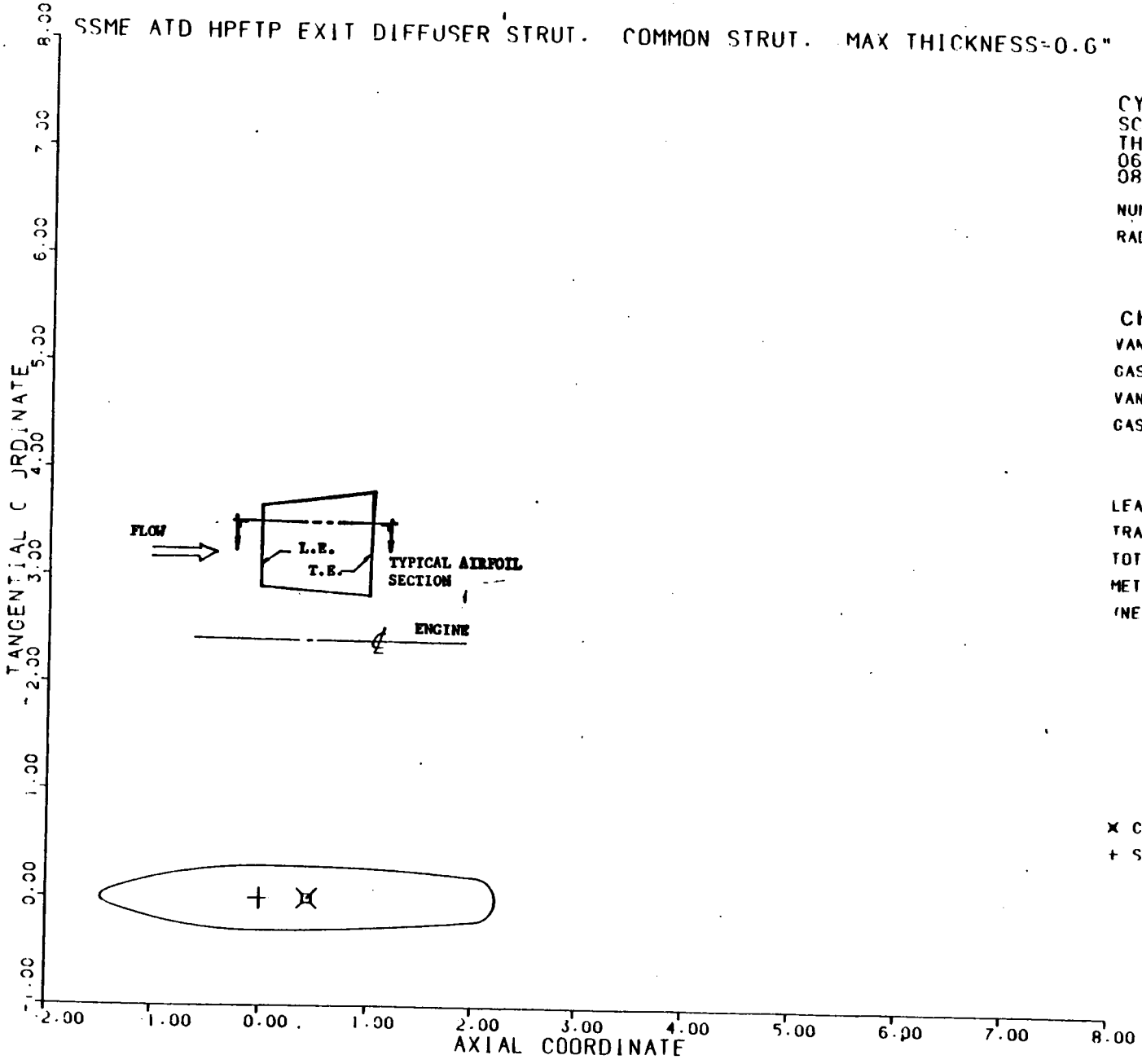
XAM. 6-3-88

46 1320
K+E 10 X 10 TO 1/2 INCH 7 X 10 INCHES KEUFFEL & ESSER CO. MADE IN U.S.A.

SSME ATD HPFTP
Exit Diffuser Strut Configuration



SSME ATD HPFTP EXIT DIFFUSER STRUT. COMMON STRUT. MAX THICKNESS=0.6"

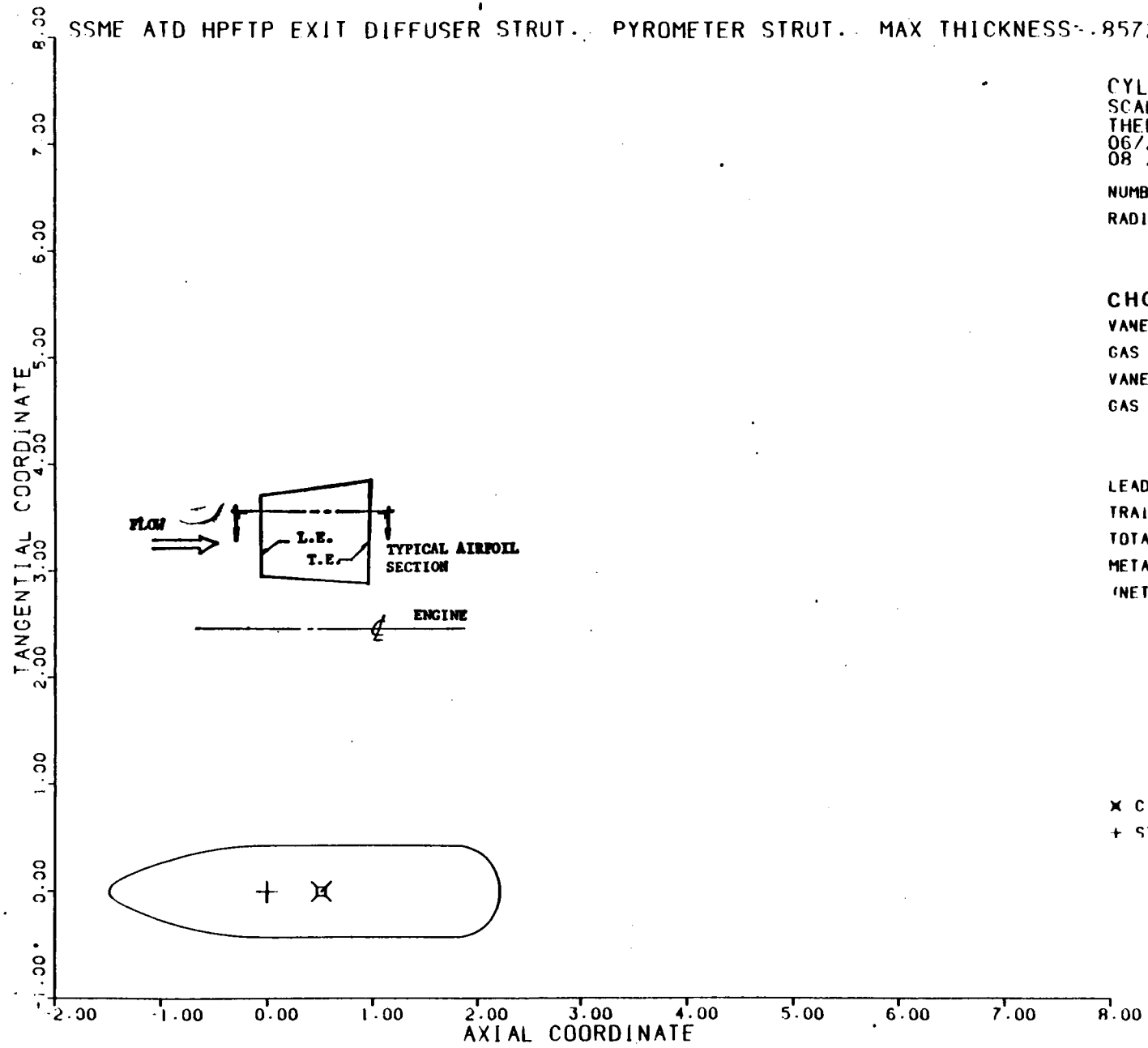


CYLINDRICAL
SCALE 1.0
THERMAL SHRINK FACTOR 1.000000
06/21/88
08.29.48

NUMBER OF VANES	15	
RADIUS (HOT)	6.360	INCHES
CHORD	3.7000	INCHES
VANE INLET ANGLE	90.000	DEGREES
GAS INLET ANGLE		DEGREES
VANE EXIT ANGLE	90.000	DEGREES
GAS EXIT ANGLE		DEGREES
LEADING EDGE RADIUS	0.0431	INCHES
TRAILING EDGE RADIUS	0.2012	INCHES
TOTAL AREA (SOLID)	1.7785	SQ. IN.
METAL AREA (NET, UNCOATED)	1.7785	SQ. IN.

	X	Y
✖ C.C.	0.4433	0.0000
+ STACKING LINE	0.0000	0.0000

SSME ATD HPFTP EXIT DIFFUSER STRUT. PYROMETER STRUT. MAX THICKNESS=.8572"

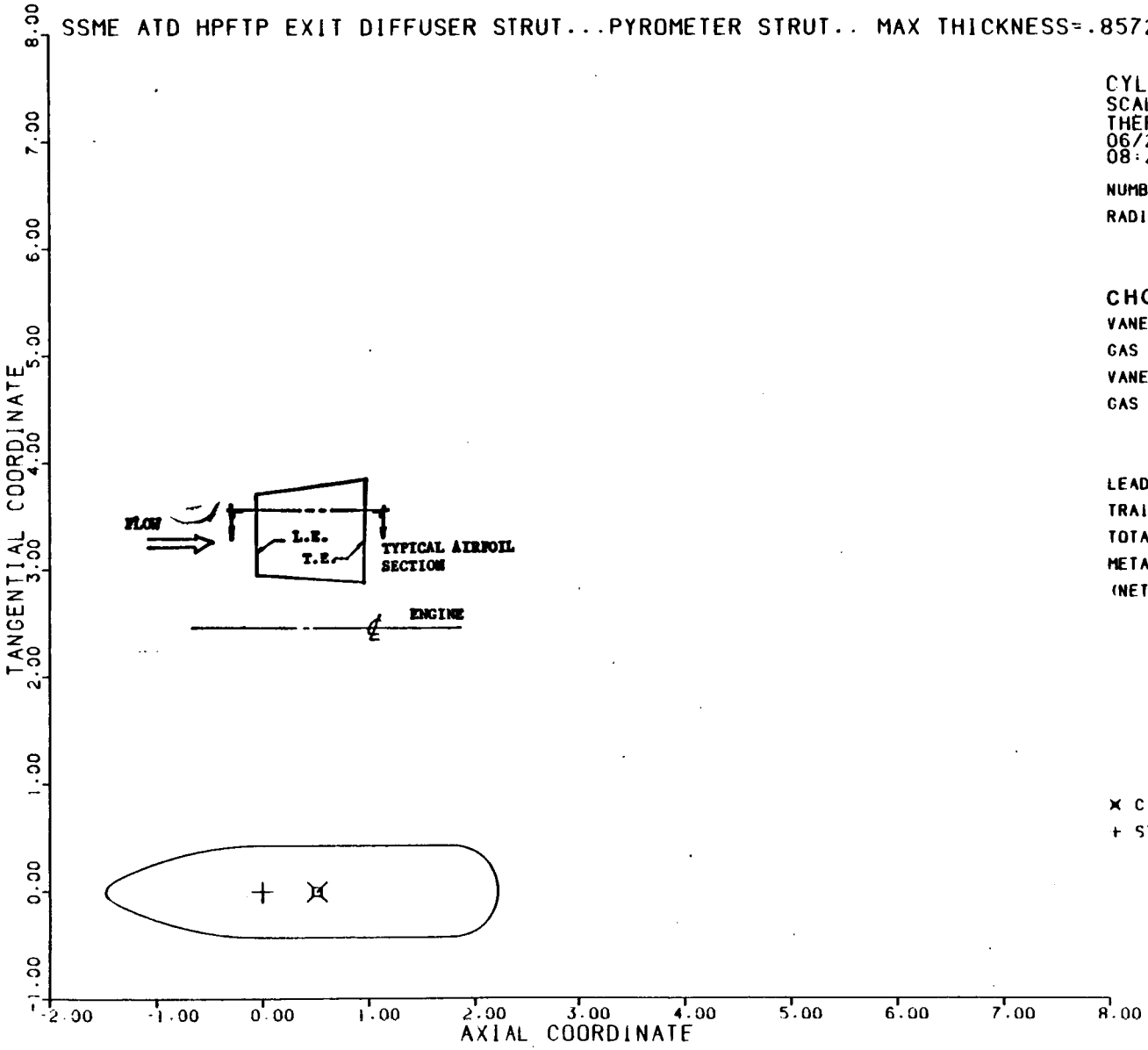


CYLINDRICAL
SCALE 1.0
THERMAL SHRINK FACTOR 1.000000
06/21/88
08 28:37

NUMBER OF VANES	1	
RADIUS (HOT)	6.360	INCHES
CHORD	3.7000	INCHES
VANE INLET ANGLE	90.000	DEGREES
GAS INLET ANGLE		DEGREES
VANE EXIT ANGLE	90.000	DEGREES
GAS EXIT ANGLE		DEGREES
LEADING EDGE RADIUS	0.0765	INCHES
TRAILING EDGE RADIUS	0.4225	INCHES
TOTAL AREA (SOLID)	2.7293	SQ. IN.
METAL AREA (NET, UNCOATED)	2.7293	SQ. IN.

	X	Y
X C.C.	0.5132	0.0000
+ STACKING LINE	0.0000	0.0000

SSME ATD HPFTP EXIT DIFFUSER STRUT...PYROMETER STRUT.. MAX THICKNESS=.8572"

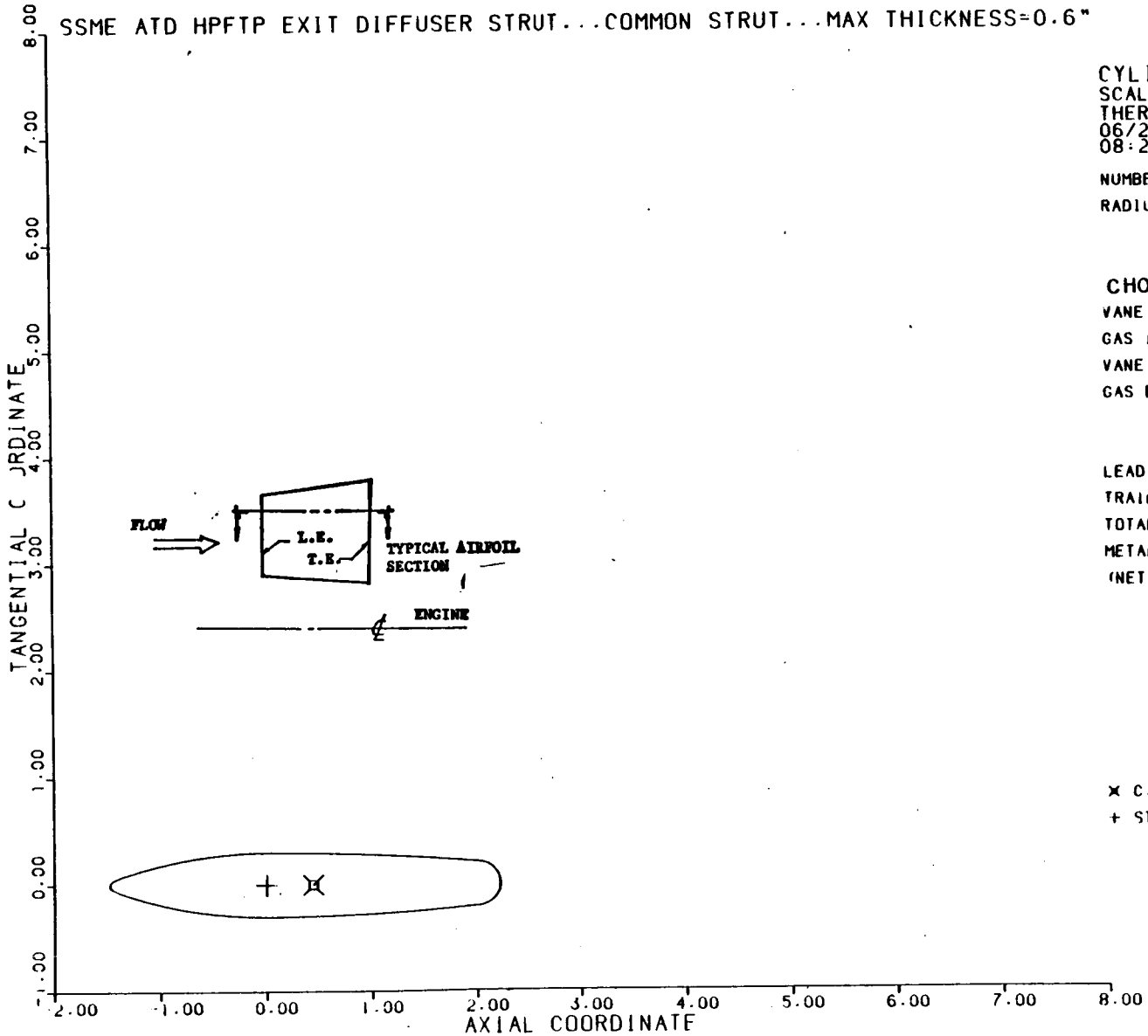


CYLINDRICAL
SCALE 1.0
THERMAL SHRINK FACTOR 1.000000
06/21/88
08:28:37

NUMBER OF VANES	1	
RADIUS (HOT)	6.360	INCHES
CHORD	3.7000	INCHES
VANE INLET ANGLE	90.000	DEGREES
GAS INLET ANGLE		DEGREES
VANE EXIT ANGLE	90.000	DEGREES
GAS EXIT ANGLE		DEGREES
LEADING EDGE RADIUS	0.0765	INCHES
TRAILING EDGE RADIUS	0.4225	INCHES
TOTAL AREA (SOLID)	2.7293	SQ. IN.
METAL AREA (NET. UNCOATED)	2.7293	SQ. IN.

	X	Y
× C.C.	0.5132	0.0000
+ STACKING LINE	0.0000	0.0000

SSME ATD HPFTP EXIT DIFFUSER STRUT...COMMON STRUT...MAX THICKNESS=0.6"



CYLINDRICAL
SCALE 1.0
THERMAL SHRINK FACTOR 1.000000
06/21/88
08:29:48

NUMBER OF VANES	15	
RADIUS (HOT)	6.360	INCHES
CHORD	3.7000	INCHES
VANE INLET ANGLE	90.000	DEGREES
GAS INLET ANGLE		DEGREES
VANE EXIT ANGLE	90.000	DEGREES
GAS EXIT ANGLE		DEGREES
LEADING EDGE RADIUS	0.0431	INCHES
TRAILING EDGE RADIUS	0.2012	INCHES
TOTAL AREA (SOLID)	1.7785	SQ. IN.
METAL AREA (NET, UNCOATED)	1.7785	SQ. IN.

	X	Y
× C.C.	0.4433	0.0000
+ STACKING LINE	0.0000	0.0000

SSME ATD HPFTP ENDWALL DEFINITION FOR TURBINE EXHAUST CASE

X-INNER	R-INNER	X-OUTER	R-OUTER	
5.4350	6.3600	5.4350	7.0360	TAD EXIT/DIFFUSER INLET
4.9316	6.3600	4.9316	7.0840	
4.8493	6.3600	4.8493	7.1040	
4.7670	6.3600	4.7670	7.1280	DIFFUSER STRUT LEADING EDGE
4.7485	6.3600	4.7485	7.1360	
4.7208	6.3600	4.7208	7.1460	
4.6745	6.3600	4.6745	7.1670	
4.5820	6.3600	4.5820	7.1990	
4.4896	6.3600	4.4896	7.2260	
4.3971	6.3600	4.3971	7.2500	
4.2122	6.3600	4.2122	7.2900	
4.0272	6.3600	4.0272	7.3240	
3.8423	6.3600	3.8423	7.3530	
3.6573	6.3600	3.6573	7.3780	
3.3983	6.3600	3.3983	7.4095	
3.1392	6.3600	3.1392	7.4410	
2.8802	6.3600	2.8802	7.4725	
2.6212	6.3600	2.6212	7.5040	
2.3622	6.3600	2.3622	7.5355	
2.1031	6.3600	2.1031	7.5670	
1.8441	6.3600	1.8441	7.5985	
1.5851	6.3600	1.5851	7.6300	
1.3260	6.3600	1.3260	7.6615	
1.0670	6.3600	1.0670	7.6930	DIFFUSER STRUT TRAILING EDGE

NOTE:

1. FOR REFERENCE ONLY!

2. X-VALUES CORRESPOND TO THE HOT FLOWPATH BY R.J.R. WHICH SHOWS THE TURBINE, 180 DEGREE TURN-AROUND DUCT AND THE DIFFUSER STRUTS.

3. OUTER ENDWELL (R-OUTER) PER GEORGE COX (CFD) DEFINITION.

EXTERNAL C: JUR TITLE - RJRP824 COMMON...R.J.ROMEY...5-18- ..COMMON TAD STRUT...STRUT 3...ZETA = 0.0
TD 0 TD REV. 0 PART NO. EMD NO. DATE 06/03/88 TIME 10:06:57 CYLINDRICAL
SUBTITLE HOT RADIUS = 6.36000 COLD RADIUS = 6.31000 THERMAL SHRINK FACTOR = 1.00000

PRETWIST NOT USED FOR TD PRINTOUT.

PCT X	X TOP	Y TOP	(CIRCLE)	X BOT	Y BOT	(CIRCLE)
0.0	-1.48000	-0.02664	0.00000	-1.48000	0.02664	0.00000
0.010	-1.44300	-0.04543		-1.44300	0.04543	
0.020	-1.40600	-0.06421		-1.40600	0.06421	
0.030	-1.36900	-0.07855		-1.36900	0.07855	
0.040	-1.33200	-0.09097		-1.33200	0.09097	
0.050	-1.29500	-0.10262		-1.29500	0.10262	
0.060	-1.25800	-0.11394		-1.25800	0.11394	
0.070	-1.22100	-0.12497		-1.22100	0.12497	
0.080	-1.18400	-0.13566		-1.18400	0.13566	
0.090	-1.14700	-0.14596		-1.14700	0.14596	
0.100	-1.11000	-0.15591		-1.11000	0.15591	
0.125	-1.01750	-0.17926		-1.01750	0.17926	
0.150	-0.92500	-0.20047		-0.92500	0.20047	
0.175	-0.83250	-0.21957		-0.83250	0.21957	
0.200	-0.74000	-0.23659		-0.74000	0.23659	
0.225	-0.64750	-0.25155		-0.64750	0.25155	
0.250	-0.55500	-0.26446		-0.55500	0.26446	
0.275	-0.46250	-0.27536		-0.46250	0.27536	
0.300	-0.37000	-0.28426		-0.37000	0.28426	
0.325	-0.27750	-0.29120		-0.27750	0.29120	
0.350	-0.18500	-0.29610		-0.18500	0.29610	
0.375	-0.09250	-0.29894		-0.09250	0.29894	
0.400	-0.00000	-0.30010		-0.00000	0.30010	
0.425	0.09250	-0.30004		0.09250	0.30004	
0.450	0.18500	-0.29929		0.18500	0.29929	
0.475	0.27750	-0.29826		0.27750	0.29826	
0.500	0.37000	-0.29691		0.37000	0.29691	
0.525	0.46250	-0.29513		0.46250	0.29513	
0.550	0.55500	-0.29293		0.55500	0.29293	
0.575	0.64750	-0.29034		0.64750	0.29034	
0.600	0.74000	-0.28735		0.74000	0.28735	
0.625	0.83250	-0.28396		0.83250	0.28396	
0.650	0.92500	-0.28017		0.92500	0.28017	
0.675	1.01750	-0.27598		1.01750	0.27598	
0.700	1.11000	-0.27139		1.11000	0.27139	
0.725	1.20250	-0.26640		1.20250	0.26640	
0.750	1.29500	-0.26102		1.29500	0.26102	
0.775	1.38750	-0.25525		1.38750	0.25525	
0.800	1.48000	-0.24903		1.48000	0.24903	
0.825	1.57250	-0.24237		1.57250	0.24237	
0.850	1.66500	-0.23545		1.66500	0.23545	
0.875	1.75750	-0.22831		1.75750	0.22831	
0.900	1.85000	-0.22027		1.85000	0.22027	
0.910	1.88700	-0.21667		1.88700	0.21667	
0.920	1.92400	-0.21322		1.92400	0.21322	
0.930	1.96100	-0.21036		1.96100	0.21036	
0.940	1.99800	-0.20805		1.99800	0.20805	
0.950	2.03500	-0.20433		2.03500	0.20433	
0.960	2.07200	-0.19653		2.07200	0.19653	
0.970	2.10900	-0.18180		2.10900	0.18180	
0.980	2.14600	-0.15771		2.14600	0.15771	
0.990	2.18300	-0.11772	-0.11627	2.18300	0.11772	0.11627
1.000	2.22000	-0.07723	0.00000	2.22000	0.07723	0.00000

L.E. CIRCLE (X,Y,R)	-1.43689	0.00000	0.04311
T.E. CIRCLE (X,Y,R)	2.01882	0.00000	0.20118
L.E. TOP TANG. PT. (X,Y)	-1.45660	-0.03834	
L.E. BOTTOM TANG. PT. (X,Y)	-1.45660	0.03834	
T.E. TOP TANG. PT. (X,Y)	2.17029	-0.13240	
T.E. BOTTOM TANG. PT. (X,Y)	2.17029	0.13240	
NOSE POINT (X,Y)	-1.48000	0.00000	
TAIL POINT (X,Y)	2.22000	0.00000	
NET CROSS-SECT. AREA (EXCL. COATING)	1.77851		
CTR. OF GRAV. (INCL. COATING) (X,Y)	0.44335	0.00000	
RAD. REF. PT. (X,Y)	0.0	0.0	
INLET ANGLE (DEG.)	90.000		
INLET WEDGE ANGLE (DEG.)	54.417		
EXIT ANGLE (DEG.)	90.000		
EXIT WEDGE ANGLE (DEG.)	97.683		
CHORD	3.70000		
NO. OF FOILS	15		

EXTERNAL C JUR TITLE - RJRP824 COMMON...R.J.ROMEY...5-18- ..COMMON TAD STRUT...STRUT 3...ZETA = 0.0
TD 0 TD REV. 0 PART NO. EMD NO. DATE 06/03/88 TIME 10:06:57 CYLINDRICAL
SUBTITLE HOT RADIUS = 7.03200 COLD RADIUS = 6.95750 THERMAL SHRINK FACTOR = 1.00000

PRETWIST NOT USED FOR TD PRINTOUT.

PCT X	X TOP	Y TOP	(CIRCLE)	X BOT	Y BOT	(CIRCLE)
0.0	-1.48000	-0.02664	0.00000	-1.48000	0.02664	0.00000
0.010	-1.44300	-0.04543		-1.44300	0.04543	
0.020	-1.40600	-0.06421		-1.40600	0.06421	
0.030	-1.36900	-0.07855		-1.36900	0.07855	
0.040	-1.33200	-0.09097		-1.33200	0.09097	
0.050	-1.29500	-0.10262		-1.29500	0.10262	
0.060	-1.25800	-0.11394		-1.25800	0.11394	
0.070	-1.22100	-0.12497		-1.22100	0.12497	
0.080	-1.18400	-0.13566		-1.18400	0.13566	
0.090	-1.14700	-0.14596		-1.14700	0.14596	
0.100	-1.11000	-0.15591		-1.11000	0.15591	
0.125	-1.01750	-0.17926		-1.01750	0.17926	
0.150	-0.92500	-0.20047		-0.92500	0.20047	
0.175	-0.83250	-0.21957		-0.83250	0.21957	
0.200	-0.74000	-0.23659		-0.74000	0.23659	
0.225	-0.64750	-0.25155		-0.64750	0.25155	
0.250	-0.55500	-0.26446		-0.55500	0.26446	
0.275	-0.46250	-0.27536		-0.46250	0.27536	
0.300	-0.37000	-0.28426		-0.37000	0.28426	
0.325	-0.27750	-0.29120		-0.27750	0.29120	
0.350	-0.18500	-0.29610		-0.18500	0.29610	
0.375	-0.09250	-0.29894		-0.09250	0.29894	
0.400	-0.00000	-0.30010		-0.00000	0.30010	
0.425	0.09250	-0.30004		0.09250	0.30004	
0.450	0.18500	-0.29929		0.18500	0.29929	
0.475	0.27750	-0.29826		0.27750	0.29826	
0.500	0.37000	-0.29691		0.37000	0.29691	
0.525	0.46250	-0.29513		0.46250	0.29513	
0.550	0.55500	-0.29293		0.55500	0.29293	
0.575	0.64750	-0.29034		0.64750	0.29034	
0.600	0.74000	-0.28735		0.74000	0.28735	
0.625	0.83250	-0.28396		0.83250	0.28396	
0.650	0.92500	-0.28017		0.92500	0.28017	
0.675	1.01750	-0.27598		1.01750	0.27598	
0.700	1.11000	-0.27139		1.11000	0.27139	
0.725	1.20250	-0.26640		1.20250	0.26640	
0.750	1.29500	-0.26102		1.29500	0.26102	
0.775	1.38750	-0.25525		1.38750	0.25525	
0.800	1.48000	-0.24903		1.48000	0.24903	
0.825	1.57250	-0.24237		1.57250	0.24237	
0.850	1.66500	-0.23545		1.66500	0.23545	
0.875	1.75750	-0.22831		1.75750	0.22831	
0.900	1.85000	-0.22027		1.85000	0.22027	
0.910	1.88700	-0.21667		1.88700	0.21667	
0.920	1.92400	-0.21322		1.92400	0.21322	
0.930	1.96100	-0.21036		1.96100	0.21036	
0.940	1.99800	-0.20805		1.99800	0.20805	
0.950	2.03500	-0.20433		2.03500	0.20433	
0.960	2.07200	-0.19653		2.07200	0.19653	
0.970	2.10900	-0.18180		2.10900	0.18180	
0.980	2.14600	-0.15771		2.14600	0.15771	
0.990	2.18300	-0.11772	-0.11627	2.18300	0.11772	0.11627
1.000	2.22000	-0.07723	0.00000	2.22000	0.07723	0.00000

L.E. CIRCLE (X,Y,R)	-1.43689	0.00000	0.04311
T.E. CIRCLE (X,Y,R)	2.01882	0.00000	0.20118
L.E. TOP TANG. PT. (X,Y)	-1.45660	-0.03834	
L.E. BOTTOM TANG. PT. (X,Y)	-1.45660	0.03834	
T.E. TOP TANG. PT. (X,Y)	2.17029	-0.13240	
T.E. BOTTOM TANG. PT. (X,Y)	2.17029	0.13240	
NOSE POINT (X,Y)	-1.48000	0.00000	
TAIL POINT (X,Y)	2.22000	0.00000	
NET CROSS-SECT. AREA (EXCL. COATING)	1.77851		
CTR. OF GRAV. (INCL. COATING) (X,Y)	0.44335	0.00000	
RAD. REF. PT. (X,Y)	0.0	0.0	
INLET ANGLE (DEG.)	90.000		
INLET WEDGE ANGLE (DEG.)	54.417		
EXIT ANGLE (DEG.)	90.000		
EXIT WEDGE ANGLE (DEG.)	97.683		
CHORD	3.70000		
NO. OF FOILS	15		

EXTERNAL C JUR TITLE - RJRP824 COMMON...R.J.ROWEY...5-18- ...COMMON TAD STRUT...STRUT 3...ZETA = 0.0
TD 0 TD REV. 0 PART NO. EMD NO. DATE 06/03/88 TIME 10:06:57 CYLINDRICAL
SUBTITLE HOT RADIUS = 7.70400 COLD RADIUS = 7.60500 THERMAL SHRINK FACTOR = 1.00000

PRETWIST NOT USED FOR TD PRINTOUT.

PCT X	X TOP	Y TOP	(CIRCLE)	X BOT	Y BOT	(CIRCLE)
0.0	-1.48000	-0.02664	0.00000	-1.48000	0.02664	0.00000
0.010	-1.44300	-0.04543		-1.44300	0.04543	
0.020	-1.40600	-0.06421		-1.40600	0.06421	
0.030	-1.36900	-0.07855		-1.36900	0.07855	
0.040	-1.33200	-0.09097		-1.33200	0.09097	
0.050	-1.29500	-0.10262		-1.29500	0.10262	
0.060	-1.25800	-0.11394		-1.25800	0.11394	
0.070	-1.22100	-0.12497		-1.22100	0.12497	
0.080	-1.18400	-0.13566		-1.18400	0.13566	
0.090	-1.14700	-0.14596		-1.14700	0.14596	
0.100	-1.11000	-0.15591		-1.11000	0.15591	
0.125	-1.01750	-0.17926		-1.01750	0.17926	
0.150	-0.92500	-0.20047		-0.92500	0.20047	
0.175	-0.83250	-0.21957		-0.83250	0.21957	
0.200	-0.74000	-0.23659		-0.74000	0.23659	
0.225	-0.64750	-0.25155		-0.64750	0.25155	
0.250	-0.55500	-0.26446		-0.55500	0.26446	
0.275	-0.46250	-0.27536		-0.46250	0.27536	
0.300	-0.37000	-0.28426		-0.37000	0.28426	
0.325	-0.27750	-0.29120		-0.27750	0.29120	
0.350	-0.18500	-0.29610		-0.18500	0.29610	
0.375	-0.09250	-0.29894		-0.09250	0.29894	
0.400	-0.00000	-0.30010		-0.00000	0.30010	
0.425	0.09250	-0.30004		0.09250	0.30004	
0.450	0.18500	-0.29929		0.18500	0.29929	
0.475	0.27750	-0.29826		0.27750	0.29826	
0.500	0.37000	-0.29691		0.37000	0.29691	
0.525	0.46250	-0.29513		0.46250	0.29513	
0.550	0.55500	-0.29293		0.55500	0.29293	
0.575	0.64750	-0.29034		0.64750	0.29034	
0.600	0.74000	-0.28735		0.74000	0.28735	
0.625	0.83250	-0.28396		0.83250	0.28396	
0.650	0.92500	-0.28017		0.92500	0.28017	
0.675	1.01750	-0.27598		1.01750	0.27598	
0.700	1.11000	-0.27139		1.11000	0.27139	
0.725	1.20250	-0.26640		1.20250	0.26640	
0.750	1.29500	-0.26102		1.29500	0.26102	
0.775	1.38750	-0.25525		1.38750	0.25525	
0.800	1.48000	-0.24903		1.48000	0.24903	
0.825	1.57250	-0.24237		1.57250	0.24237	
0.850	1.66500	-0.23545		1.66500	0.23545	
0.875	1.75750	-0.22831		1.75750	0.22831	
0.900	1.85000	-0.22027		1.85000	0.22027	
0.910	1.88700	-0.21667		1.88700	0.21667	
0.920	1.92400	-0.21322		1.92400	0.21322	
0.930	1.96100	-0.21036		1.96100	0.21036	
0.940	1.99800	-0.20805		1.99800	0.20805	
0.950	2.03500	-0.20433		2.03500	0.20433	
0.960	2.07200	-0.19653		2.07200	0.19653	
0.970	2.10900	-0.18180		2.10900	0.18180	
0.980	2.14600	-0.15771		2.14600	0.15771	
0.990	2.18300	-0.11772	-0.11627	2.18300	0.11772	0.11627
1.000	2.22000	-0.07723	0.00000	2.22000	0.07723	0.00000

L.E. CIRCLE (X,Y,R)	-1.43689	0.00000	0.04311
T.E. CIRCLE (X,Y,R)	2.01882	0.00000	0.20118
L.E. TOP TANG. PT. (X,Y)	-1.45660	-0.03834	
L.E. BOTTOM TANG. PT. (X,Y)	-1.45660	0.03834	
T.E. TOP TANG. PT. (X,Y)	2.17029	-0.13240	
T.E. BOTTOM TANG. PT. (X,Y)	2.17029	0.13240	
NOSE POINT (X,Y)	-1.48000	0.00000	
TAIL POINT (X,Y)	2.22000	0.00000	
NET CROSS-SECT. AREA (EXCL. COATING)	1.77851		
CTR. OF GRAV. (INCL. COATING) (X,Y)	0.44335	0.00000	
RAD. REF. PT. (X,Y)	0.0	0.0	
INLET ANGLE (DEG.)	90.000		
INLET WEDGE ANGLE (DEG.)	54.417		
EXIT ANGLE (DEG.)	90.000		
EXIT WEDGE ANGLE (DEG.)	97.683		
CHORD	3.70000		
NO. OF FOILS	15		

EXTERNAL (OUR TITLE - RJRP824 PYRO...R.J.ROWEY...5-28-8. .MAX THICKNESS = .8572"...STRUT 5...Z= -7.65
TD 0 TD REV. 0 PART NO. EMD NO. DATE 06/09/88 TIME 14:13:42 CYLINDRICAL
SUBTITLE HOT RADIUS = 6.36000 COLD RADIUS = 6.31000 THERMAL SHRINK FACTOR = 1.00000

PRETHIST NOT USED FOR TD PRINTOUT.

PCT X	X TOP	Y TOP	(CIRCLE)	X BOT	Y BOT	(CIRCLE)
0.0	-1.48000	-0.03877	0.00000	-1.48000	0.03877	0.00000
0.010	-1.44300	-0.06613		-1.44300	0.06613	
0.020	-1.40600	-0.09347		-1.40600	0.09347	
0.030	-1.36900	-0.11435		-1.36900	0.11435	
0.040	-1.33200	-0.13244		-1.33200	0.13244	
0.050	-1.29500	-0.14937		-1.29500	0.14937	
0.060	-1.25800	-0.16576		-1.25800	0.16576	
0.070	-1.22100	-0.18167		-1.22100	0.18167	
0.080	-1.18400	-0.19705		-1.18400	0.19705	
0.090	-1.14700	-0.21184		-1.14700	0.21184	
0.100	-1.11000	-0.22608		-1.11000	0.22608	
0.125	-1.01750	-0.25936		-1.01750	0.25936	
0.150	-0.92500	-0.28945		-0.92500	0.28945	
0.175	-0.83250	-0.31640		-0.83250	0.31640	
0.200	-0.74000	-0.34032		-0.74000	0.34032	
0.225	-0.64750	-0.36127		-0.64750	0.36127	
0.250	-0.55500	-0.37930		-0.55500	0.37930	
0.275	-0.46250	-0.39448		-0.46250	0.39448	
0.300	-0.37000	-0.40686		-0.37000	0.40686	
0.325	-0.27750	-0.41650		-0.27750	0.41650	
0.350	-0.18500	-0.42326		-0.18500	0.42326	
0.375	-0.09250	-0.42714		-0.09250	0.42714	
0.400	-0.00000	-0.42850		-0.00000	0.42850	
0.425	0.09250	-0.42860		0.09250	0.42860	
0.450	0.18500	-0.42860		0.18500	0.42860	
0.475	0.27750	-0.42860		0.27750	0.42860	
0.500	0.37000	-0.42860		0.37000	0.42860	
0.525	0.46250	-0.42860		0.46250	0.42860	
0.550	0.55500	-0.42860		0.55500	0.42860	
0.575	0.64750	-0.42860		0.64750	0.42860	
0.600	0.74000	-0.42860		0.74000	0.42860	
0.625	0.83250	-0.42860		0.83250	0.42860	
0.650	0.92500	-0.42860		0.92500	0.42860	
0.675	1.01750	-0.42860		1.01750	0.42860	
0.700	1.11000	-0.42860		1.11000	0.42860	
0.725	1.20250	-0.42860		1.20250	0.42860	
0.750	1.29500	-0.42860		1.29500	0.42860	
0.775	1.38750	-0.42860		1.38750	0.42860	
0.800	1.48000	-0.42860		1.48000	0.42860	
0.825	1.57250	-0.42860		1.57250	0.42860	
0.850	1.66500	-0.42850		1.66500	0.42850	
0.875	1.75750	-0.42638		1.75750	0.42638	
0.900	1.85000	-0.42431		1.85000	0.42431	
0.910	1.88700	-0.41746		1.88700	0.41746	
0.920	1.92400	-0.40733		1.92400	0.40733	
0.930	1.96100	-0.39355		1.96100	0.39355	
0.940	1.99800	-0.37556		1.99800	0.37556	
0.950	2.03500	-0.35275		2.03500	0.35275	
0.960	2.07200	-0.32416		2.07200	0.32416	
0.970	2.10900	-0.28807		2.10900	0.28807	
0.980	2.14600	-0.24124		2.14600	0.24124	
0.990	2.18300	-0.17486	-0.17291	2.18300	0.17486	0.17291
1.000	2.22000	-0.10769	0.00000	2.22000	0.10769	0.00000

L.E. CIRCLE (X,Y,R)	-1.40346	0.00000	0.07654
T.E. CIRCLE (X,Y,R)	1.79747	0.00000	0.42253
L.E. TOP TANG. PT. (X,Y)	-1.44985	-0.06088	
L.E. BOTTOM TANG. PT. (X,Y)	-1.44985	0.06088	
T.E. TOP TANG. PT. (X,Y)	2.17015	-0.19910	
T.E. BOTTOM TANG. PT. (X,Y)	2.17015	0.19910	
NOSE POINT (X,Y)	-1.48000	0.00000	
TAIL POINT (X,Y)	2.22000	0.00000	
NET CROSS-SECT. AREA (EXCL. COATING)	2.72931		
CTR. OF GRAV. (INCL. COATING) (X,Y)	0.51319	0.00000	
RAD. REF. PT. (X,Y)	0.0	0.0	
INLET ANGLE (DEG.)	90.000		
INLET WEDGE ANGLE (DEG.)	74.604		
EXIT ANGLE (DEG.)	90.000		
EXIT WEDGE ANGLE (DEG.)	123.775		
CHORD	3.70000		
NO. OF FOILS	1		

EXTERNAL (OUR TITLE - RJRP824 PYRO...R.J.ROWEY...5-28-8. .MAX THICKNESS = .8572"...STRUT 5...Z= -7.65
TD 0 TD REV. 0 PART NO. EMD NO. DATE 06/09/88 TIME 14:13:42 CYLINDRICAL
SUBTITLE HOT RADIUS = 7.02650 COLD RADIUS = 6.95220 THERMAL SHRINK FACTOR = 1.00000

PRETHIST NOT USED FOR TD PRINTOUT.

PCT X	X TOP	Y TOP	(CIRCLE)	X BOT	Y BOT	(CIRCLE)
0.0	-1.48000	-0.03877	0.00000	-1.48000	0.03877	0.00000
0.010	-1.44300	-0.06613		-1.44300	0.06613	
0.020	-1.40600	-0.09347		-1.40600	0.09347	
0.030	-1.36900	-0.11435		-1.36900	0.11435	
0.040	-1.33200	-0.13244		-1.33200	0.13244	
0.050	-1.29500	-0.14937		-1.29500	0.14937	
0.060	-1.25800	-0.16576		-1.25800	0.16576	
0.070	-1.22100	-0.18167		-1.22100	0.18167	
0.080	-1.18400	-0.19705		-1.18400	0.19705	
0.090	-1.14700	-0.21184		-1.14700	0.21184	
0.100	-1.11000	-0.22608		-1.11000	0.22608	
0.125	-1.01750	-0.25936		-1.01750	0.25936	
0.150	-0.92500	-0.28945		-0.92500	0.28945	
0.175	-0.83250	-0.31640		-0.83250	0.31640	
0.200	-0.74000	-0.34032		-0.74000	0.34032	
0.225	-0.64750	-0.36127		-0.64750	0.36127	
0.250	-0.55500	-0.37930		-0.55500	0.37930	
0.275	-0.46250	-0.39448		-0.46250	0.39448	
0.300	-0.37000	-0.40686		-0.37000	0.40686	
0.325	-0.27750	-0.41650		-0.27750	0.41650	
0.350	-0.18500	-0.42326		-0.18500	0.42326	
0.375	-0.09250	-0.42714		-0.09250	0.42714	
0.400	-0.00000	-0.42850		-0.00000	0.42850	
0.425	0.09250	-0.42860		0.09250	0.42860	
0.450	0.18500	-0.42860		0.18500	0.42860	
0.475	0.27750	-0.42860		0.27750	0.42860	
0.500	0.37000	-0.42860		0.37000	0.42860	
0.525	0.46250	-0.42860		0.46250	0.42860	
0.550	0.55500	-0.42860		0.55500	0.42860	
0.575	0.64750	-0.42860		0.64750	0.42860	
0.600	0.74000	-0.42860		0.74000	0.42860	
0.625	0.83250	-0.42860		0.83250	0.42860	
0.650	0.92500	-0.42860		0.92500	0.42860	
0.675	1.01750	-0.42860		1.01750	0.42860	
0.700	1.11000	-0.42860		1.11000	0.42860	
0.725	1.20250	-0.42860		1.20250	0.42860	
0.750	1.29500	-0.42860		1.29500	0.42860	
0.775	1.38750	-0.42860		1.38750	0.42860	
0.800	1.48000	-0.42860		1.48000	0.42860	
0.825	1.57250	-0.42860		1.57250	0.42860	
0.850	1.66500	-0.42850		1.66500	0.42850	
0.875	1.75750	-0.42638		1.75750	0.42638	
0.900	1.85000	-0.42431		1.85000	0.42431	
0.910	1.88700	-0.41746		1.88700	0.41746	
0.920	1.92400	-0.40733		1.92400	0.40733	
0.930	1.96100	-0.39355		1.96100	0.39355	
0.940	1.99800	-0.37556		1.99800	0.37556	
0.950	2.03500	-0.35275		2.03500	0.35275	
0.960	2.07200	-0.32416		2.07200	0.32416	
0.970	2.10900	-0.28807		2.10900	0.28807	
0.980	2.14600	-0.24124		2.14600	0.24124	
0.990	2.18300	-0.17486	-0.17291	2.18300	0.17486	0.17291
1.000	2.22000	-0.10769	0.00000	2.22000	0.10769	0.00000

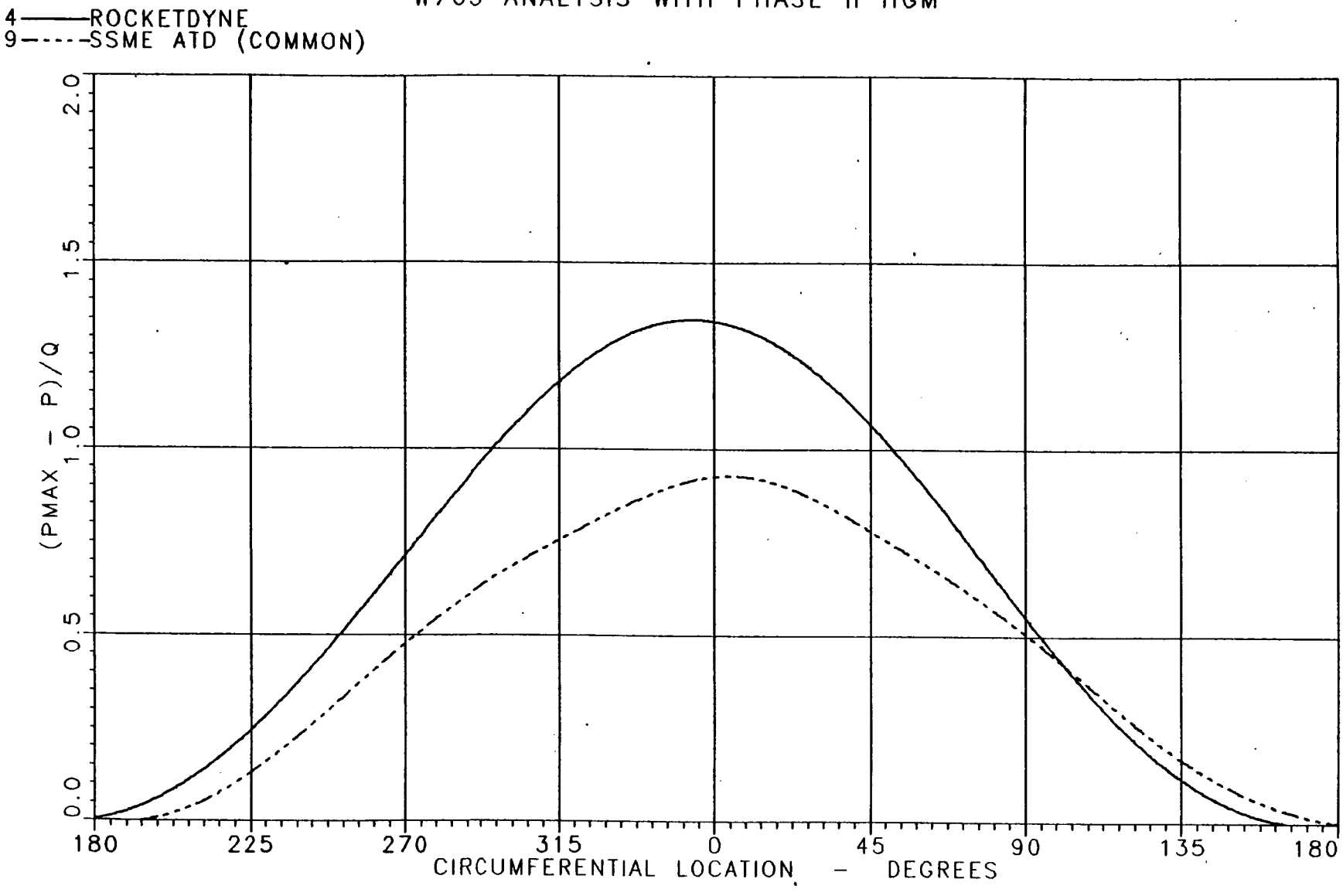
L.E. CIRCLE (X,Y,R)	-1.40346	0.00000	0.07654
T.E. CIRCLE (X,Y,R)	1.79747	0.00000	0.42253
L.E. TOP TANG. PT. (X,Y)	-1.44985	-0.06088	
L.E. BOTTOM TANG. PT. (X,Y)	-1.44985	0.06088	
T.E. TOP TANG. PT. (X,Y)	2.17015	-0.19910	
T.E. BOTTOM TANG. PT. (X,Y)	2.17015	0.19910	
NOSE POINT (X,Y)	-1.48000	0.00000	
TAIL POINT (X,Y)	2.22000	0.00000	
NET CROSS-SECT. AREA (EXCL. COATING)	2.72931		
CTR. OF GRAV. (INCL. COATING) (X,Y)	0.51319	0.00000	
RAD. REF. PT. (X,Y)	0.0	0.0	
INLET ANGLE (DEG.)	90.000		
INLET WEDGE ANGLE (DEG.)	74.604		
EXIT ANGLE (DEG.)	90.000		
EXIT WEDGE ANGLE (DEG.)	123.775		
CHORD	3.70000		
NO. OF FOILS	1		

EXTERNAL L OUR TITLE - RJRP824 PYRO...R.J.ROWEY...5-28-8. .MAX THICKNESS = .8572"...STRUT 5...Z= -7.65
TD 0 TD REV. 0 PART NO. EMD NO. DATE 06/09/88 TIME 14:13:42 CYLINDRICAL
SUBTITLE HOT RADIUS = 7.69300 COLD RADIUS = 7.59440 THERMAL SHRINK FACTOR = 1.00000

PRETWIST NOT USED FOR TD PRINTOUT.

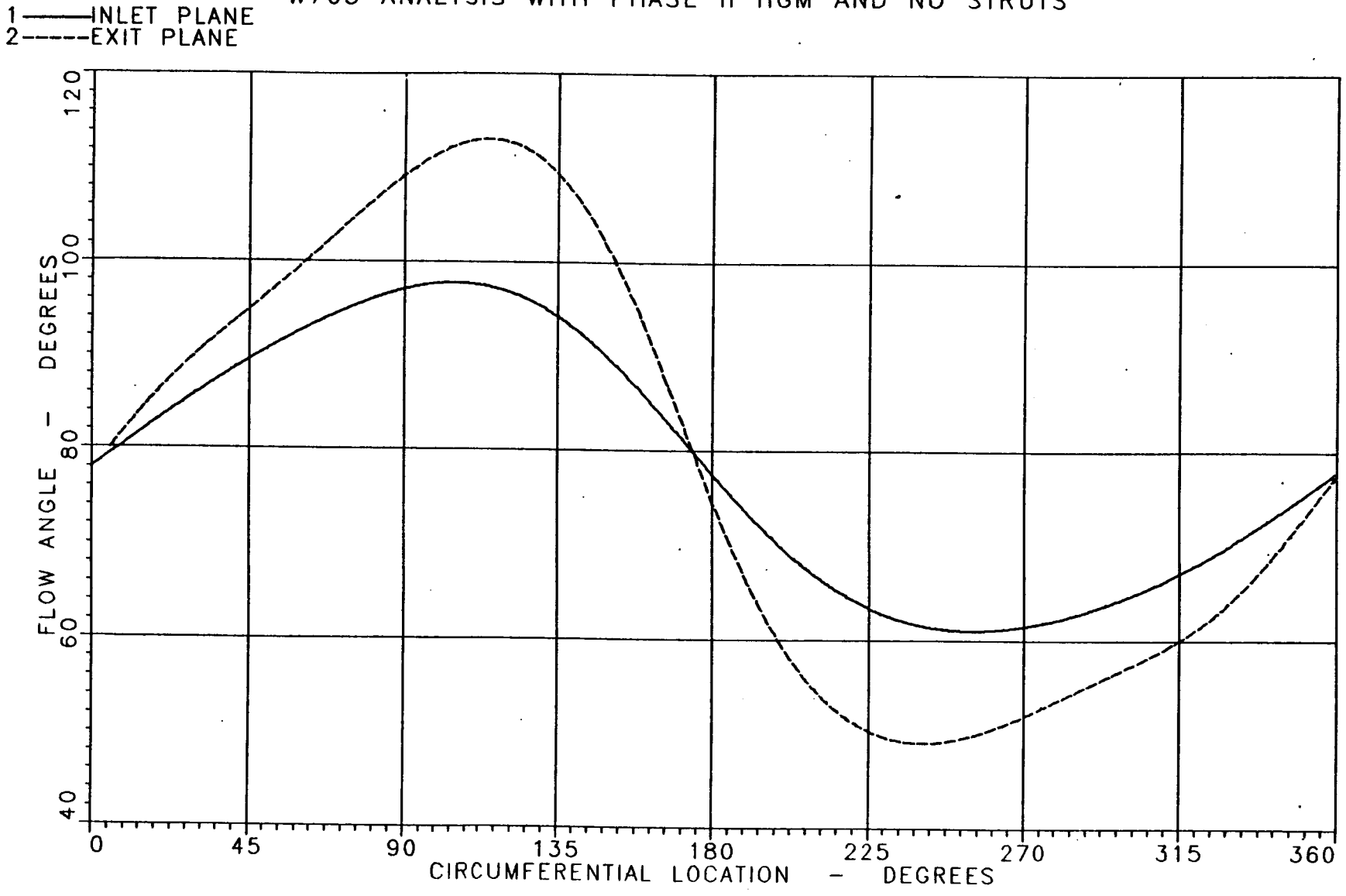
PCT X	X TOP	Y TOP	(CIRCLE)	X BOT	Y BOT	(CIRCLE)				
0.0	-1.48000	-0.03877	0.00000	-1.48000	0.03877	0.00000				
0.010	-1.44300	-0.06613		-1.44300	0.06613					
0.020	-1.40600	-0.09347		-1.40600	0.09347					
0.030	-1.36900	-0.11435		-1.36900	0.11435					
0.040	-1.33200	-0.13244		-1.33200	0.13244					
0.050	-1.29500	-0.14937		-1.29500	0.14937					
0.060	-1.25800	-0.16576		-1.25800	0.16576					
0.070	-1.22100	-0.18167		-1.22100	0.18167		L.E. CIRCLE (X,Y,R)	-1.40346	0.00000	0.07654
0.080	-1.18400	-0.19705		-1.18400	0.19705		T.E. CIRCLE (X,Y,R)	1.79747	0.00000	0.42253
0.090	-1.14700	-0.21184		-1.14700	0.21184					
0.100	-1.11000	-0.22608		-1.11000	0.22608		L.E. TOP TANG. PT. (X,Y)	-1.44985	-0.06088	
0.125	-1.01750	-0.25936		-1.01750	0.25936		L.E. BOTTOM TANG. PT. (X,Y)	-1.44985	0.06088	
0.150	-0.92500	-0.28945		-0.92500	0.28945		T.E. TOP TANG. PT. (X,Y)	2.17015	-0.19910	
0.175	-0.83250	-0.31640		-0.83250	0.31640		T.E. BOTTOM TANG. PT. (X,Y)	2.17015	0.19910	
0.200	-0.74000	-0.34032		-0.74000	0.34032					
0.225	-0.64750	-0.36127		-0.64750	0.36127		NOSE POINT (X,Y)	-1.48000	0.00000	
0.250	-0.55500	-0.37930		-0.55500	0.37930		TAIL POINT (X,Y)	2.22000	0.00000	
0.275	-0.46250	-0.39448		-0.46250	0.39448					
0.300	-0.37000	-0.40686		-0.37000	0.40686		NET CROSS-SECT. AREA (EXCL. COATING)	2.72931		
0.325	-0.27750	-0.41650		-0.27750	0.41650					
0.350	-0.18500	-0.42326		-0.18500	0.42326					
0.375	-0.09250	-0.42714		-0.09250	0.42714		CTR. OF GRAV. (INCL. COATING) (X,Y)	0.51319	0.00000	
0.400	-0.00000	-0.42850		-0.00000	0.42850		RAD. REF. PT. (X,Y)	0.0	0.0	
0.425	0.09250	-0.42860		0.09250	0.42860		INLET ANGLE (DEG.)	90.000		
0.450	0.18500	-0.42860		0.18500	0.42860		INLET WEDGE ANGLE (DEG.)	74.604		
0.475	0.27750	-0.42860		0.27750	0.42860		EXIT ANGLE (DEG.)	90.000		
0.500	0.37000	-0.42860		0.37000	0.42860		EXIT WEDGE ANGLE (DEG.)	123.775		
0.525	0.46250	-0.42860		0.46250	0.42860		CHORD	3.70000		
0.550	0.55500	-0.42860		0.55500	0.42860		NO. OF FOILS	1		
0.575	0.64750	-0.42860		0.64750	0.42860					
0.600	0.74000	-0.42860		0.74000	0.42860					
0.625	0.83250	-0.42860		0.83250	0.42860					
0.650	0.92500	-0.42860		0.92500	0.42860					
0.675	1.01750	-0.42860		1.01750	0.42860					
0.700	1.11000	-0.42860		1.11000	0.42860					
0.725	1.20250	-0.42860		1.20250	0.42860					
0.750	1.29500	-0.42860		1.29500	0.42860					
0.775	1.38750	-0.42860		1.38750	0.42860					
0.800	1.48000	-0.42860		1.48000	0.42860					
0.825	1.57250	-0.42860		1.57250	0.42860					
0.850	1.66500	-0.42850		1.66500	0.42850					
0.875	1.75750	-0.42638		1.75750	0.42638					
0.900	1.85000	-0.42431		1.85000	0.42431					
0.910	1.88700	-0.41746		1.88700	0.41746					
0.920	1.92400	-0.40733		1.92400	0.40733					
0.930	1.96100	-0.39355		1.96100	0.39355					
0.940	1.99800	-0.37556		1.99800	0.37556					
0.950	2.03500	-0.35275		2.03500	0.35275					
0.960	2.07200	-0.32416		2.07200	0.32416					
0.970	2.10900	-0.28807		2.10900	0.28807					
0.980	2.14600	-0.24124		2.14600	0.24124					
0.990	2.18300	-0.17486	-0.17291	2.18300	0.17486	0.17291				
1.000	2.22000	-0.10769	0.00000	2.22000	0.10769	0.00000				

PRATT & WHITNEY
SSME ATD FUEL PUMP TURBINE
TRANSVERSE PRESSURE GRADIENT AT TURBINE EXIT
W703 ANALYSIS WITH PHASE II HGM



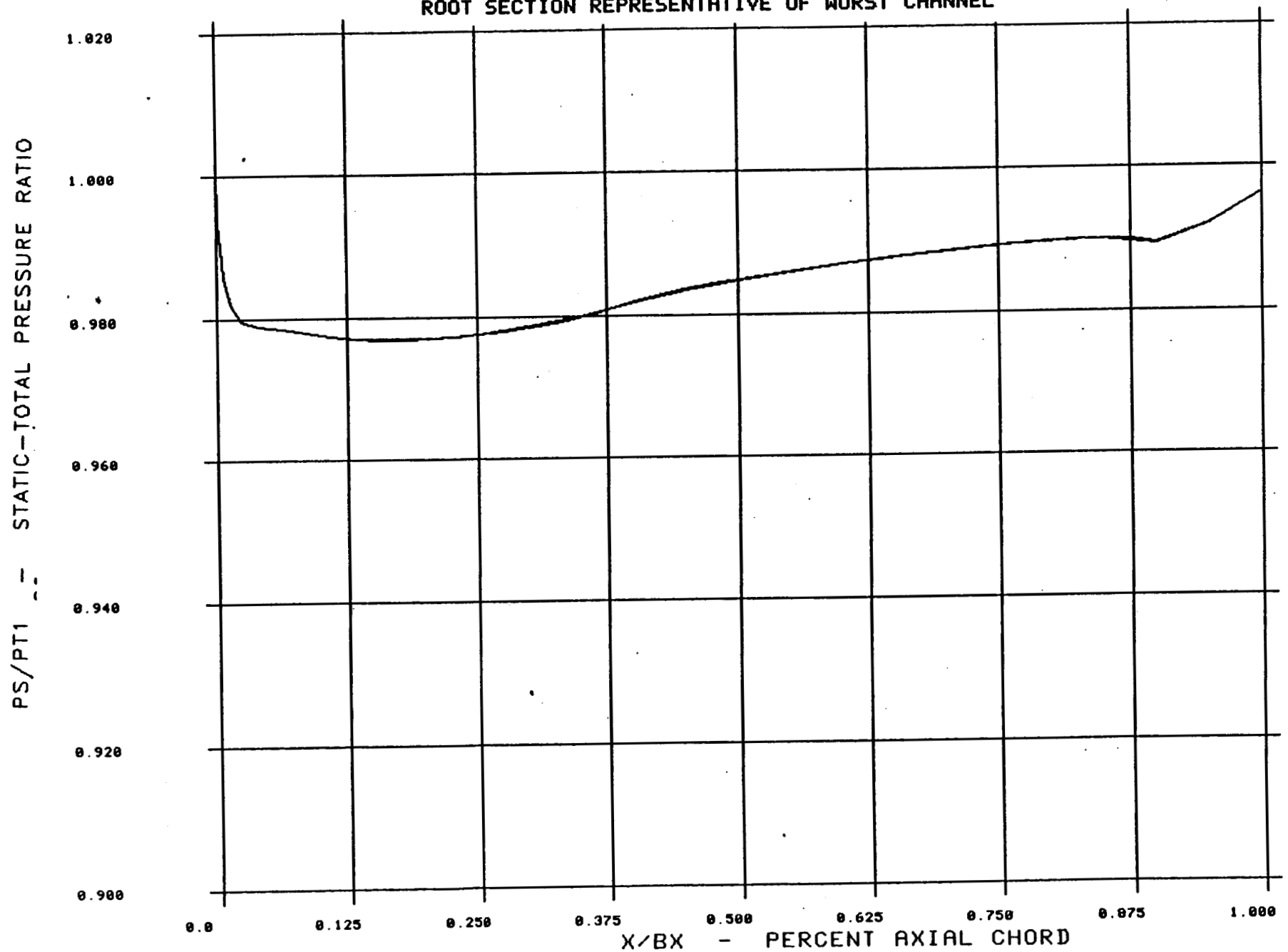
06/20/88
XAM

PRATT & WHITNEY
SSME ATD FUEL PUMP TURBINE
W703 ANALYSIS WITH PHASE II HGM AND NO STRUTS

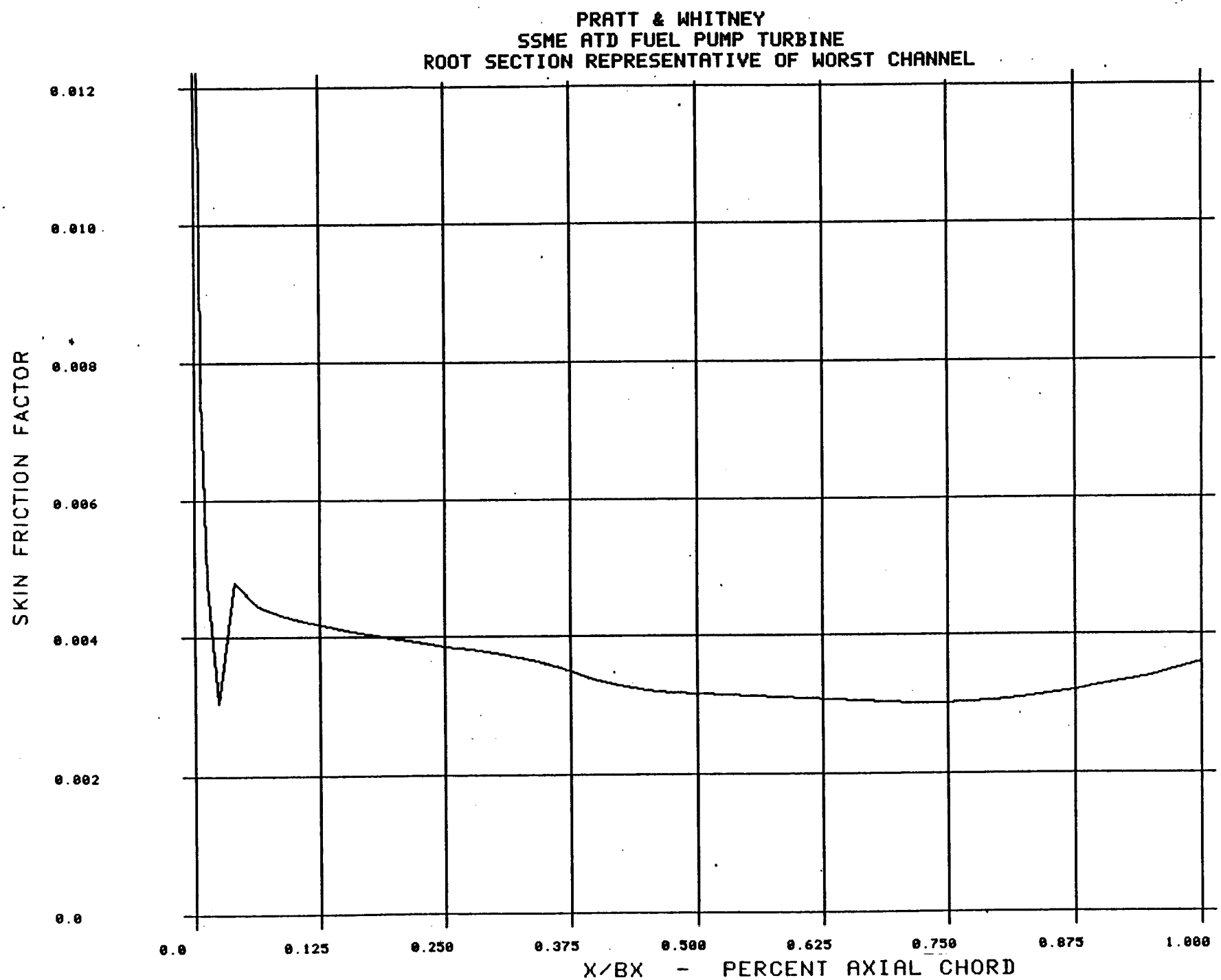


06/21/88
XAM

PRATT & WHITNEY
SSME ATD FUEL PUMP TURBINE
2-D PRESSURE DISTRIBUTION (T862)
ROOT SECTION REPRESENTATIVE OF WORST CHANNEL

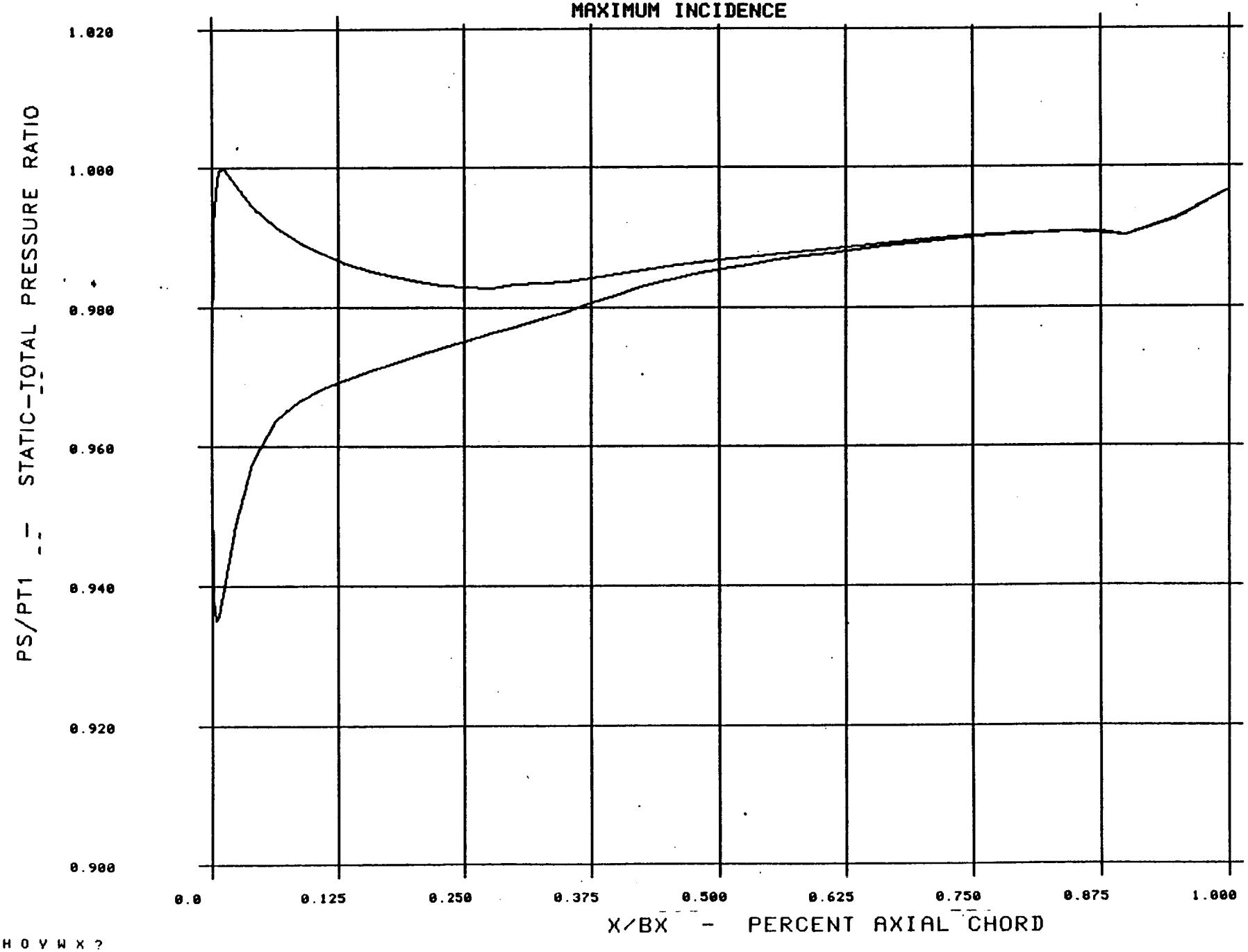


B F H O V W X ?

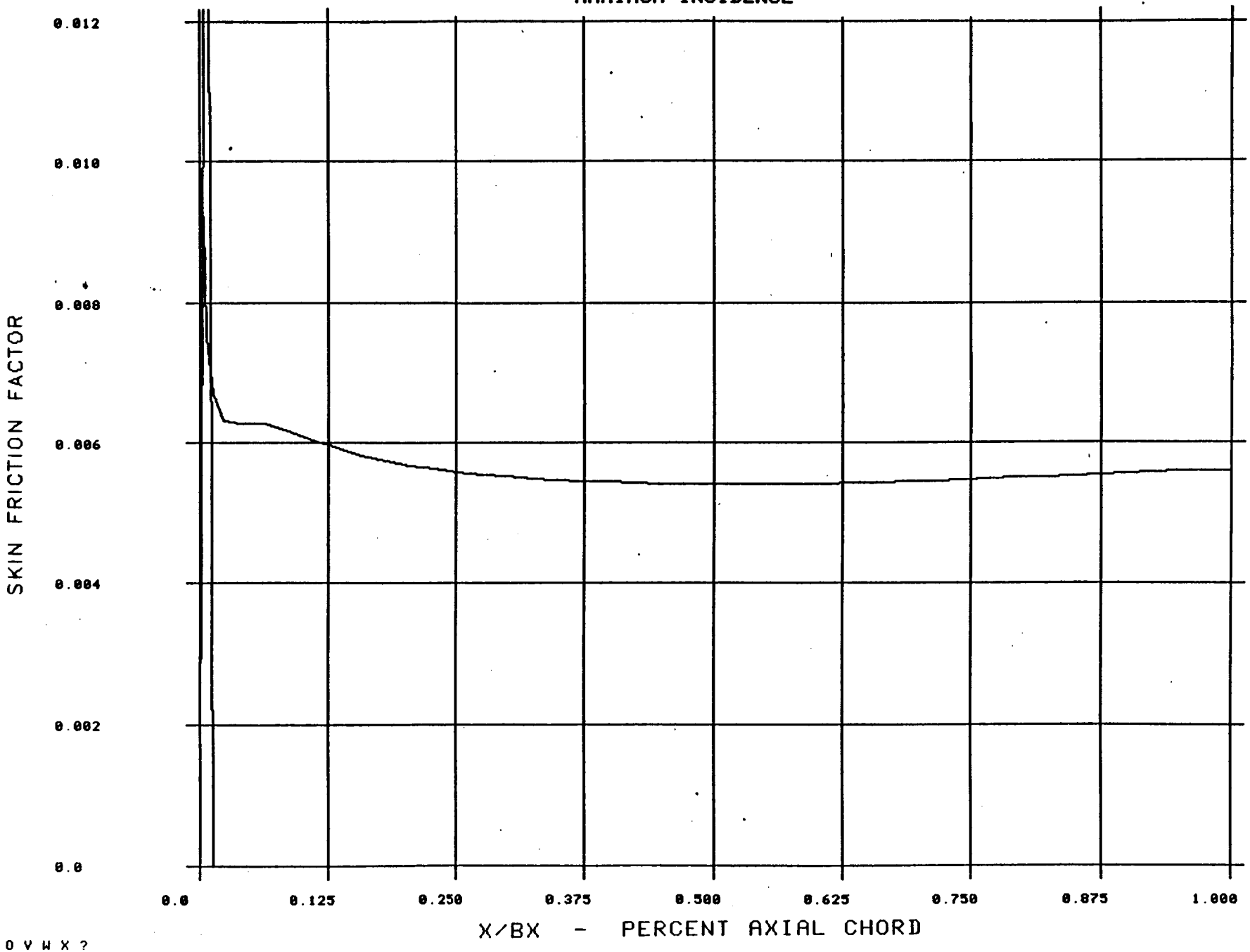

PRATT & WHITNEY
SSME ATD FUEL PUMP TURBINE
ROOT SECTION REPRESENTATIVE OF WORST CHANNEL
SKIN FRICTION FACTOR
0.012
0.010
0.008
0.006
0.004
0.002
0.0
0.0
0.125
0.250
0.375
0.500
0.625
0.750
0.875
1.000
X/BX - PERCENT AXIAL CHORD

B F H O V W X ?

PRATT & WHITNEY
SSME ATD FUEL PUMP TURBINE
2-D PRESSURE DISTRIBUTION (T862)
ROOT SECTION REPRESENTATIVE OF WORST CHANNEL
MAXIMUM INCIDENCE

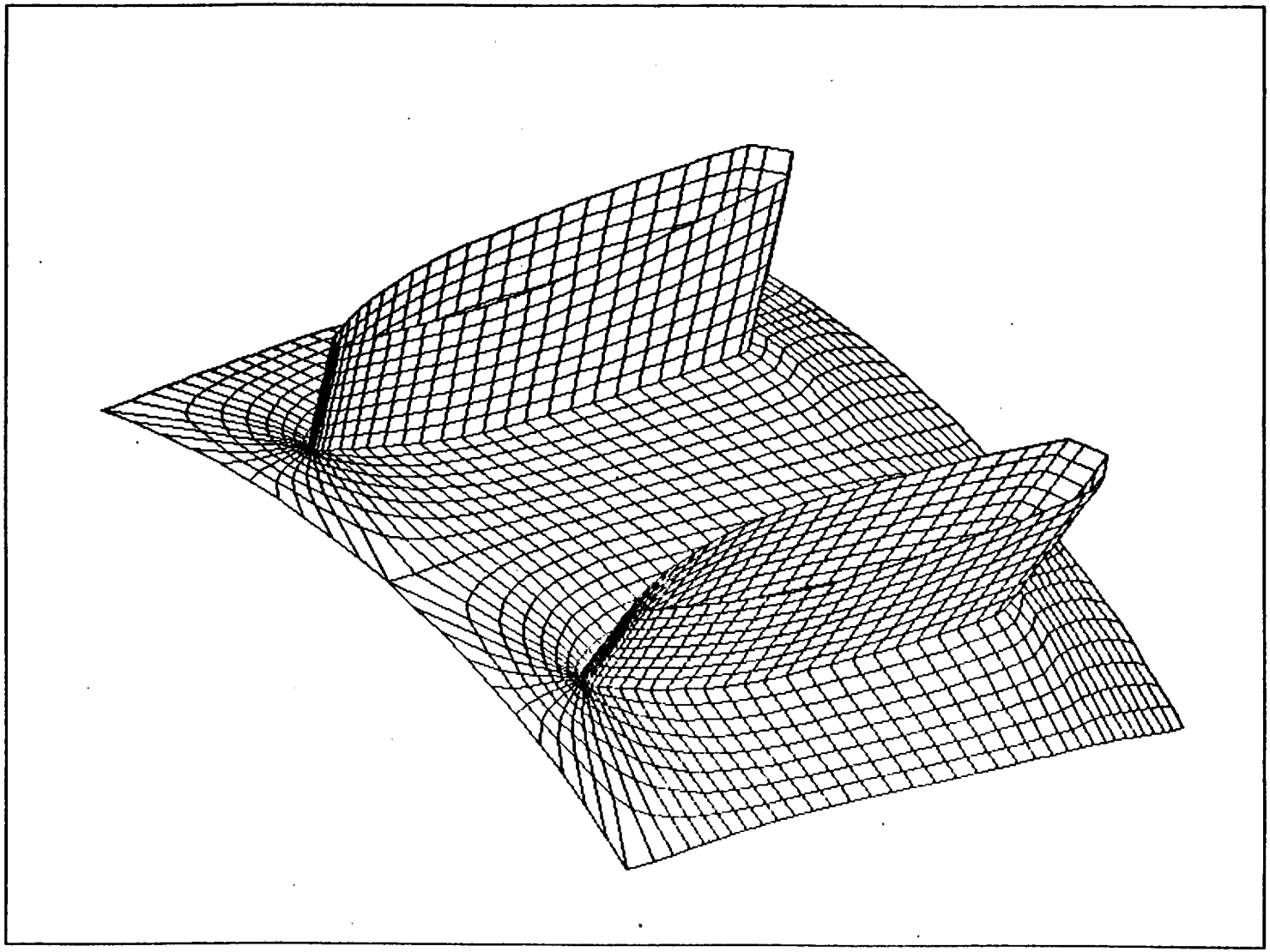


PRATT & WHITNEY
SSME ATD FUEL PUMP TURBINE
ROOT SECTION REPRESENTATIVE OF WORST CHANNEL
MAXIMUM INCIDENCE

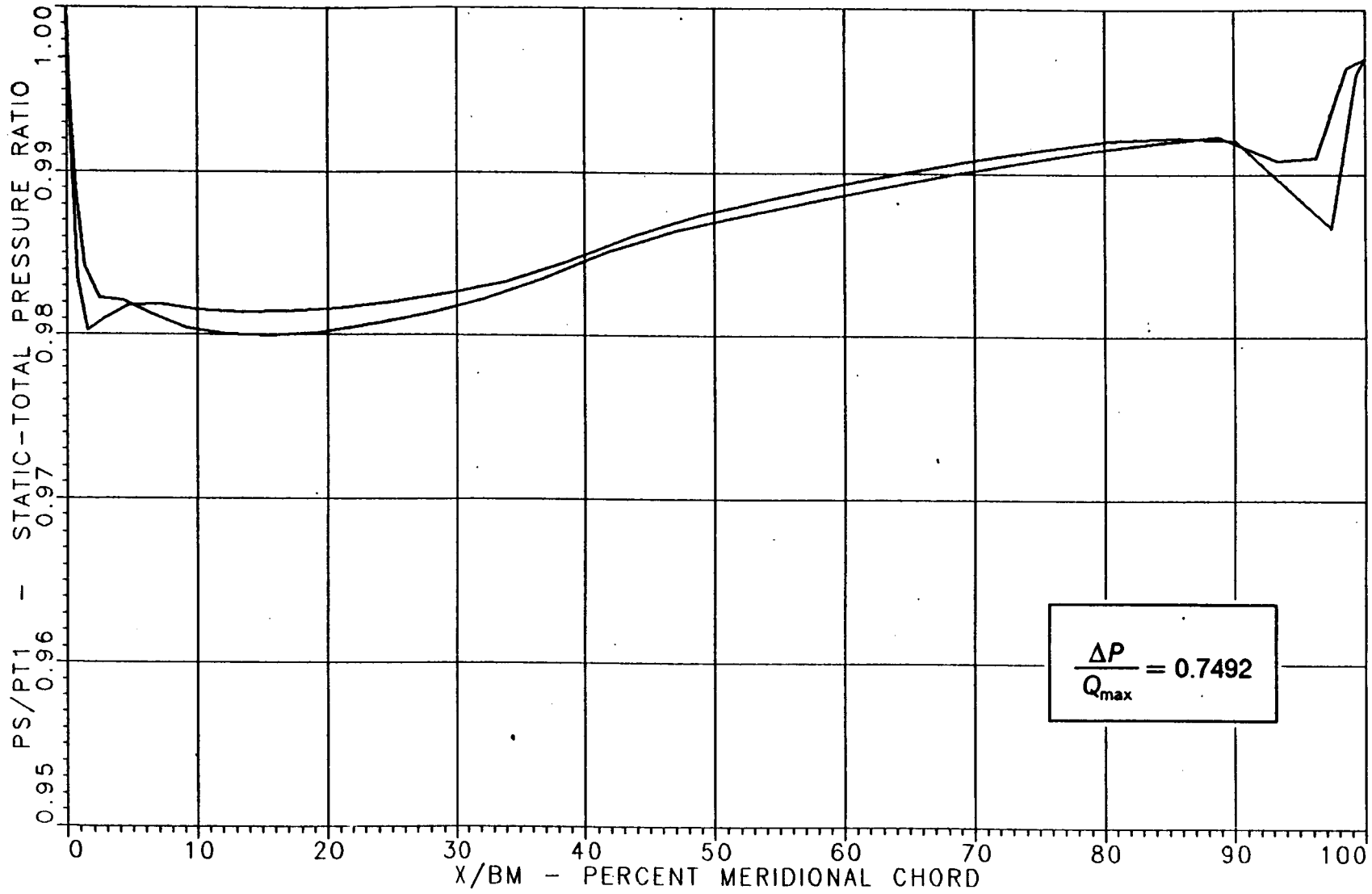


B F H O V W X ?

Pratt & Whitney
SSME ATD Fuel Pump Turbine
3D Mesh For Exit Diffuser Strut
Worst Channel

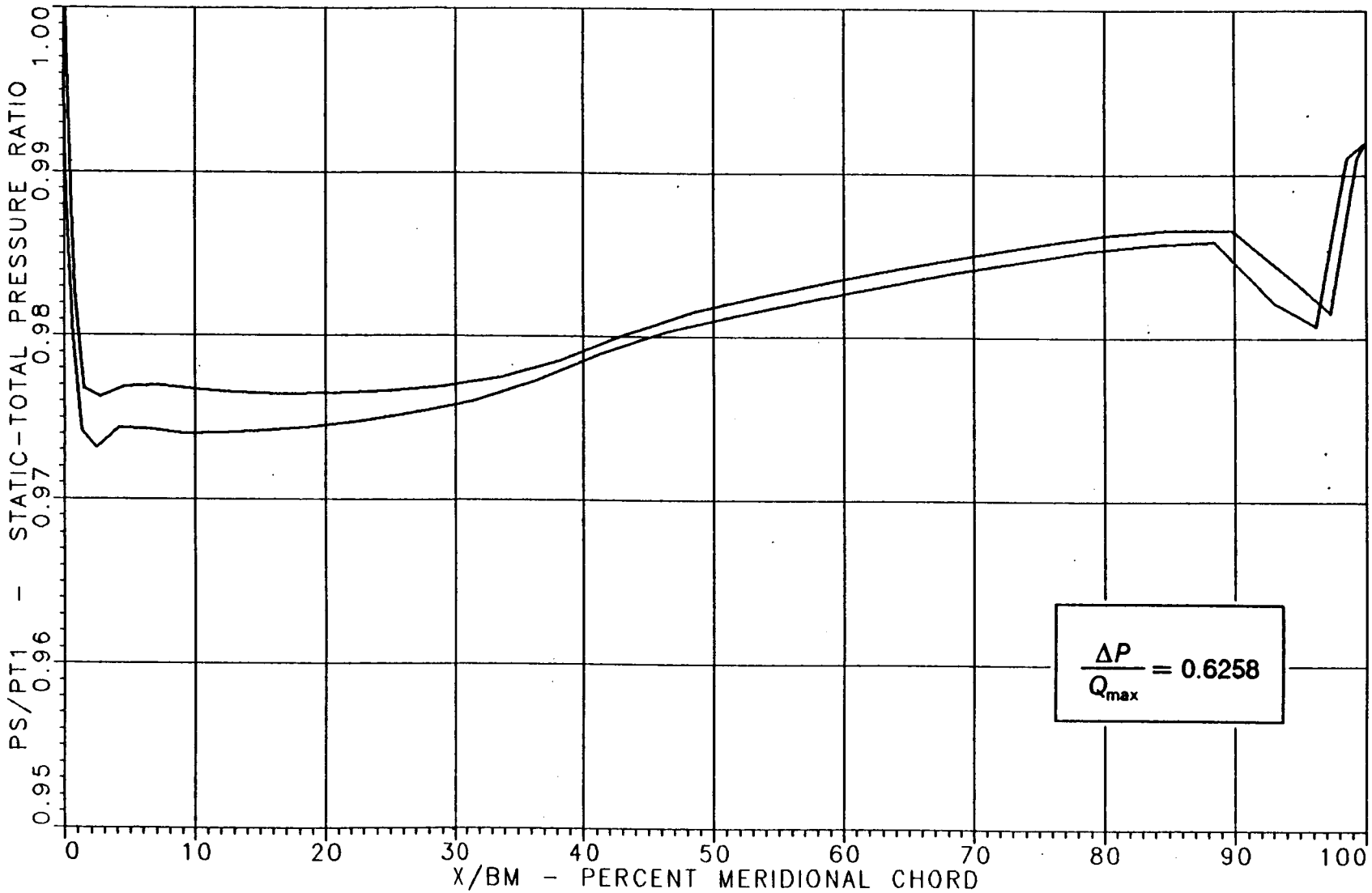


Pratt & Whitney
SSME ATD Fuel Pump Turbine
3D Pressure Distribution (V310)
Root Section Representative of Worst Channel



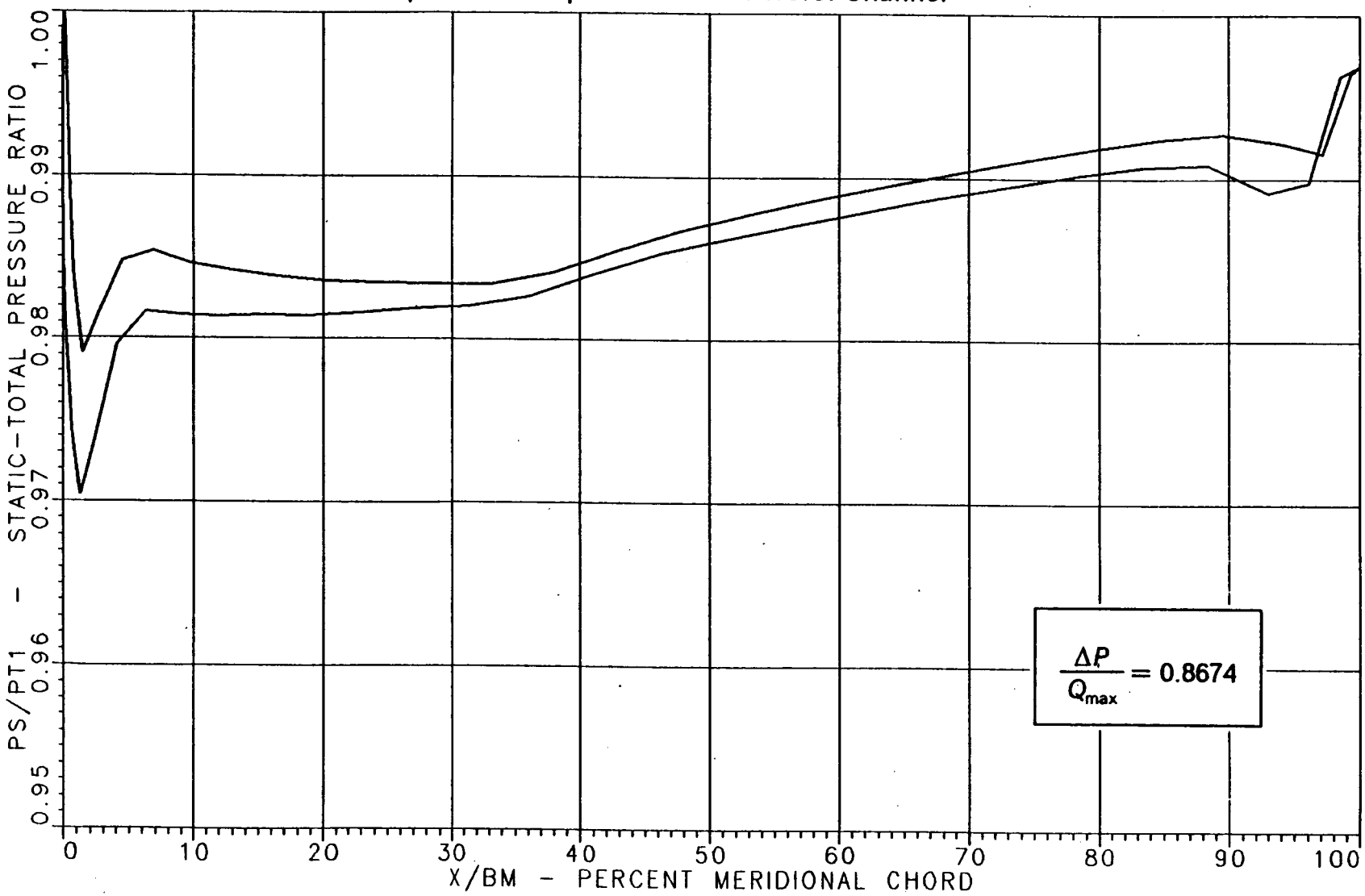
06/08/88
XAM

Pratt & Whitney
SSME ATD Fuel Pump Turbine
3D Pressure Distribution (V310)
Mean Section Representative of Worst Channel



06/08/88
XAM

Pratt & Whitney
SSME ATD Fuel Pump Turbine
3D Pressure Distribution (V310)
Tip Section Representative of Worst Channel



06/08/88
XAM

P/PT CONTOURS 06/14/8811:14:15

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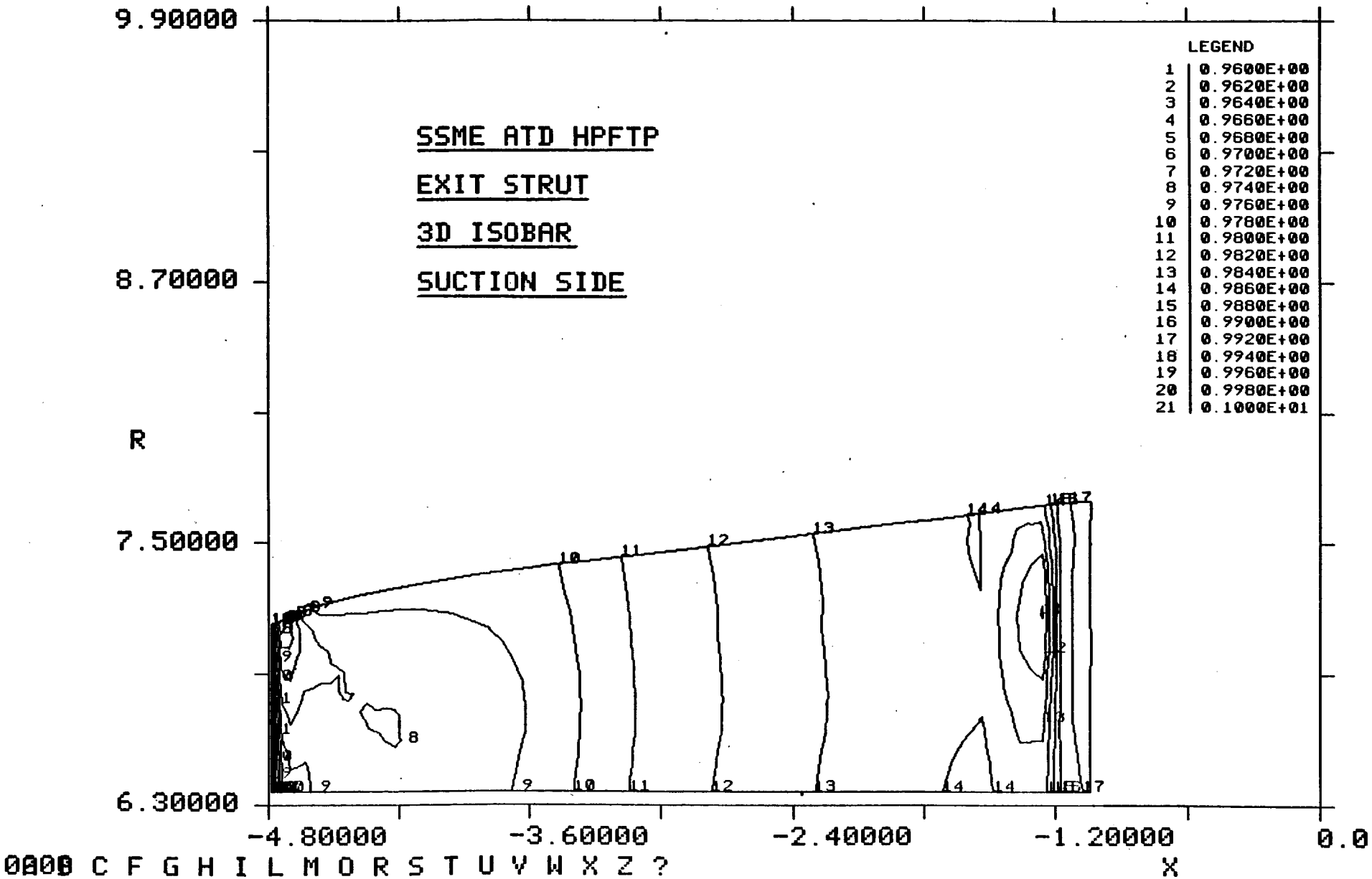
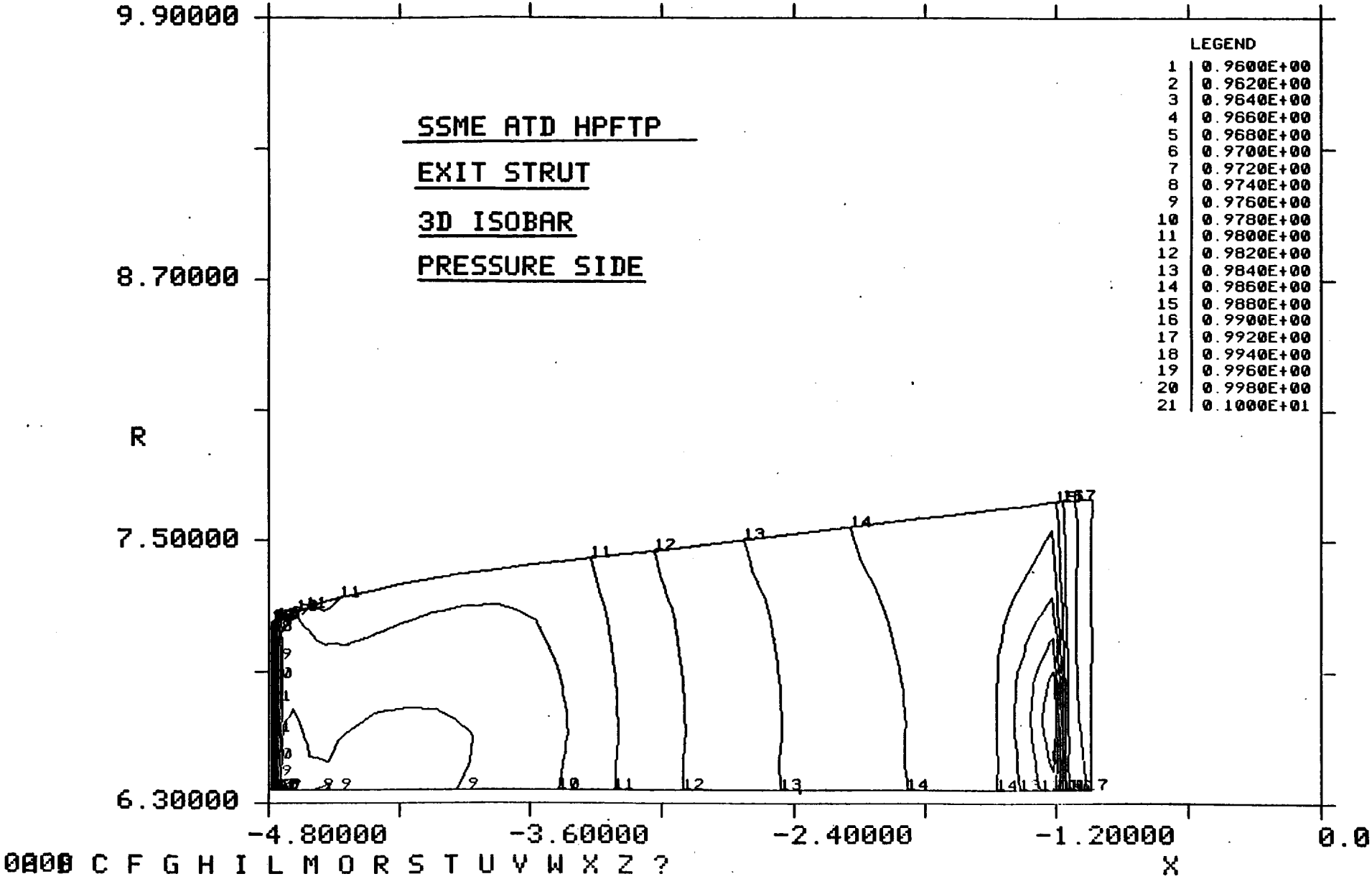


0000 C F G H I L M O R S T U V W X Z ?

P/PT CONTOURS 06/14/8811:20:56

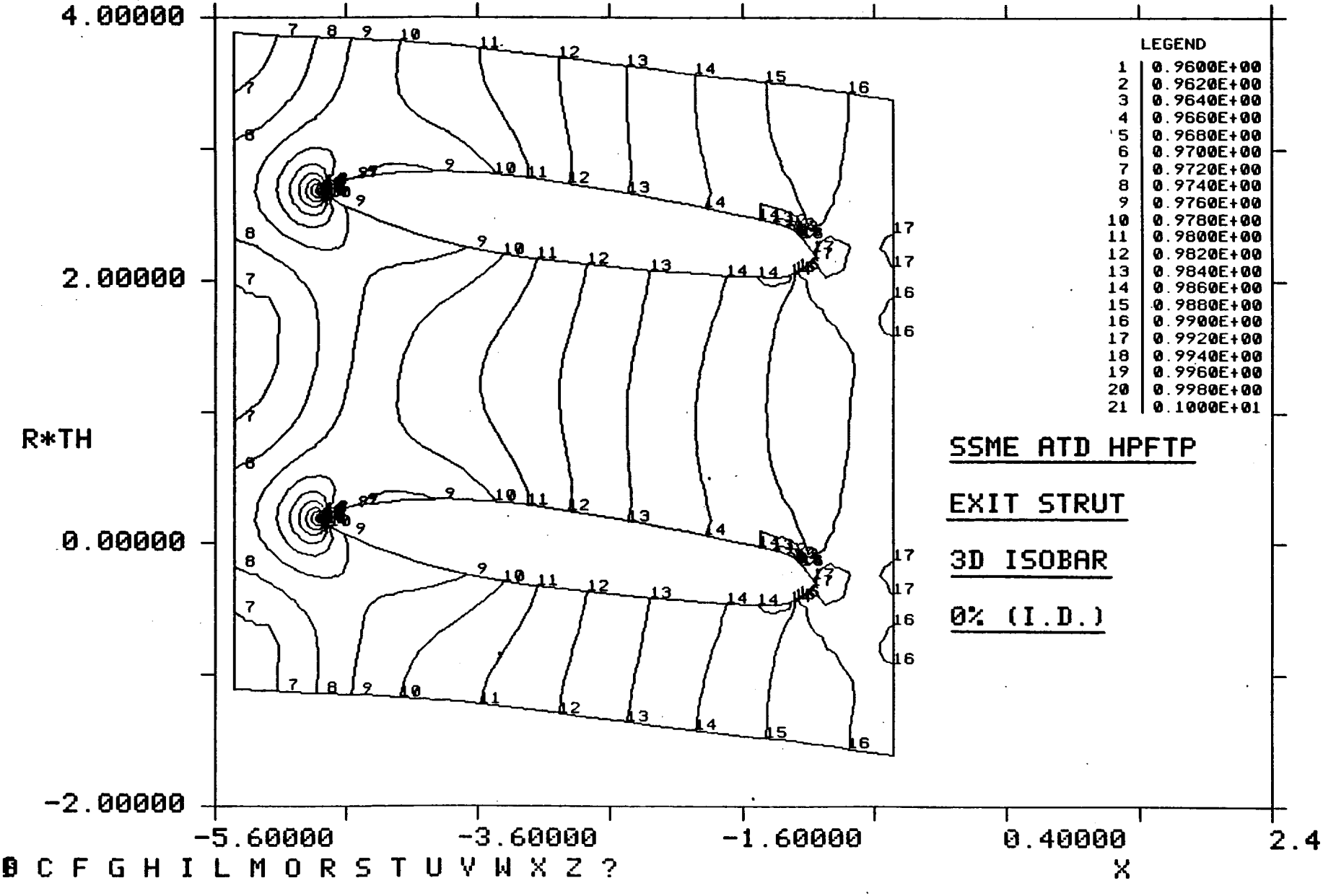
JSLICE= 1 NI 3D CYLINDRICAL C-GRID COMMON DIFFUSER STRUT...ZETA=-7.65



0000 C F G H I L M O R S T U V W X Z ?

P/PT CONTOURS 06/14/8810:39:24

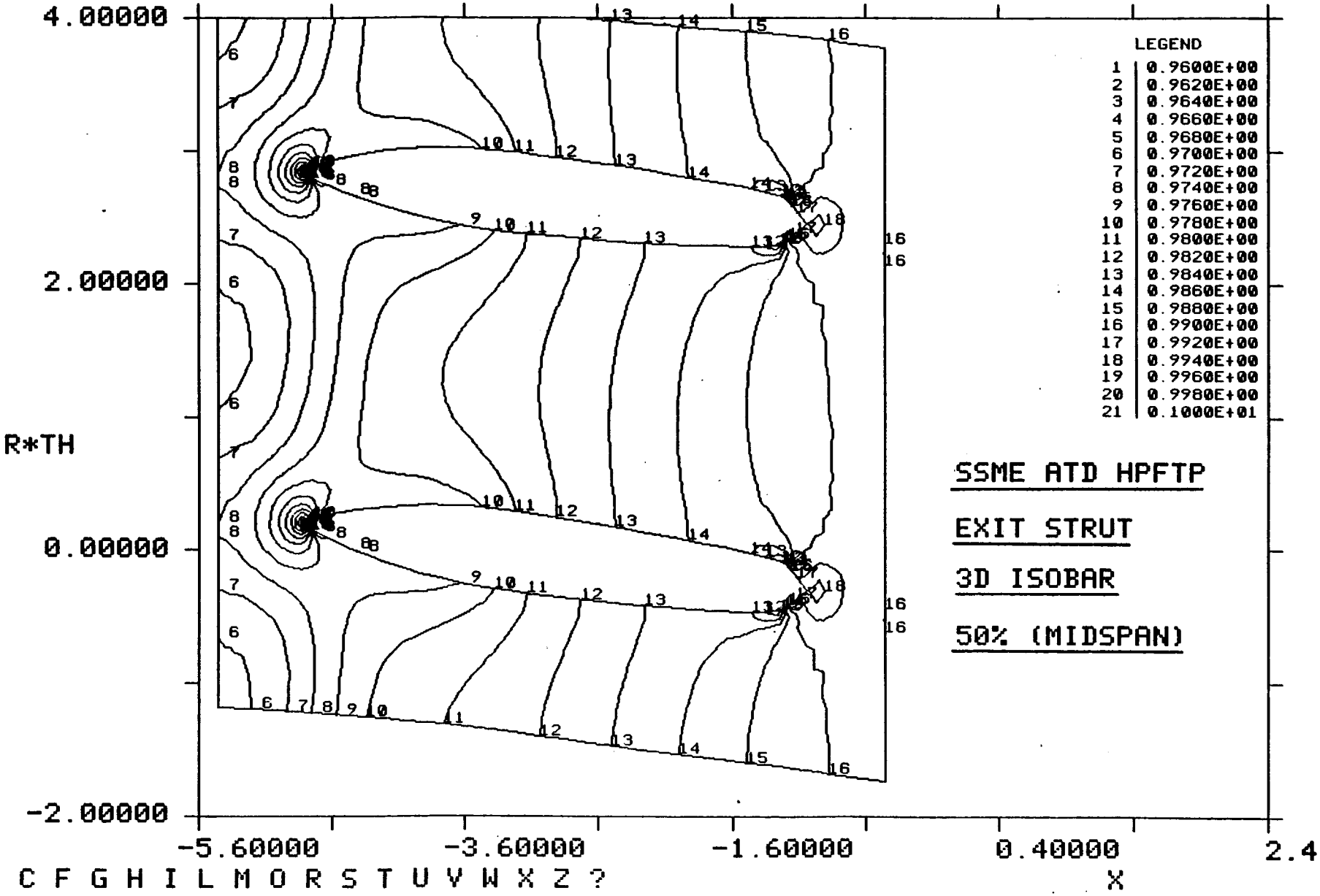
KSLICE= 1 NI 3D CYLINDRICAL C-GRID COMMON DIFFUSER STRUT...ZETA=-7.65



0000 C F G H I L M O R S T U V W X Z ?

P/PT CONTOURS 06/14/8810:59:49

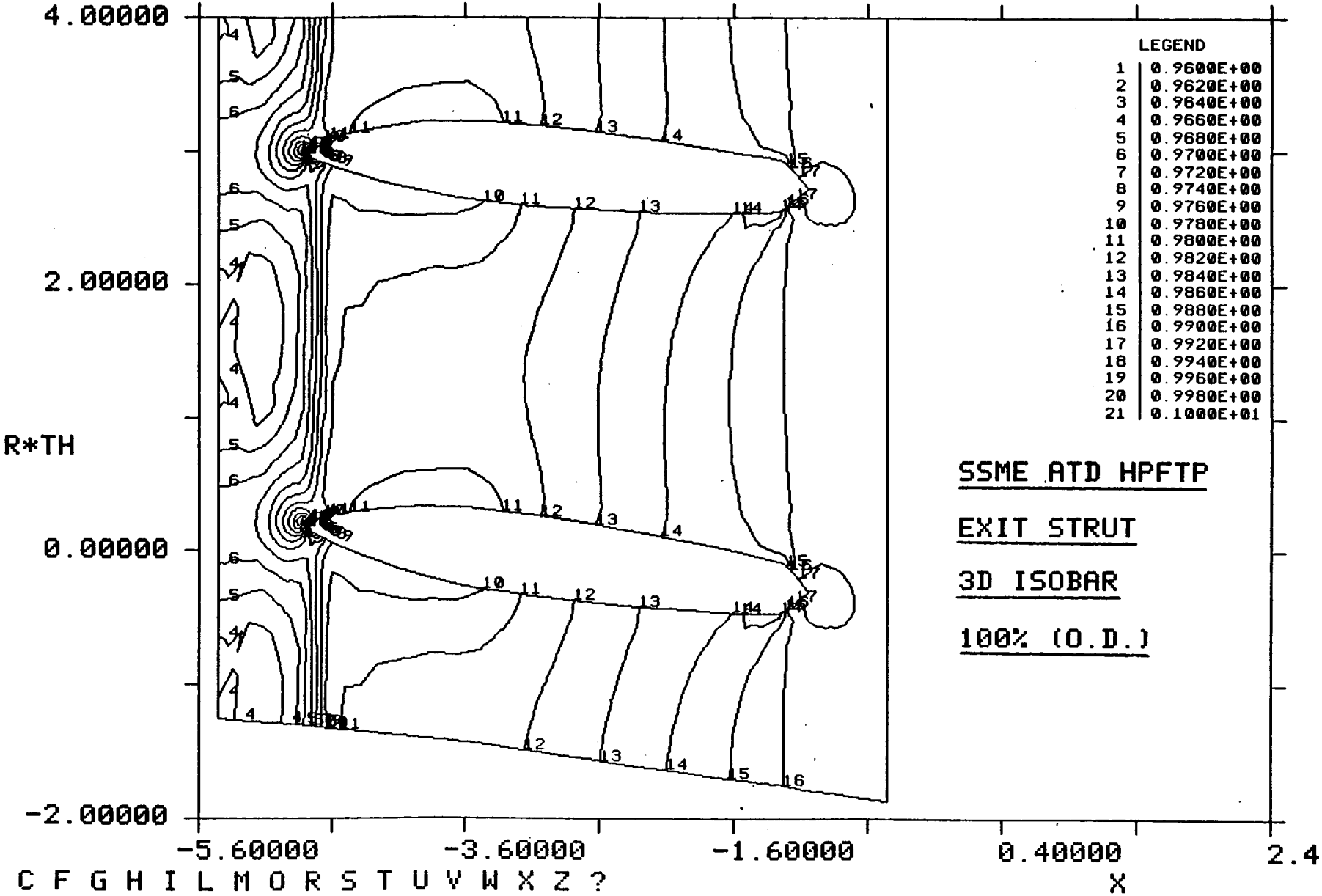
KSLICE= 5 NI 3D CYLINDRICAL C-GRID COMMON DIFFUSER STRUT...ZETA=-7.65



0 0 0 B C F G H I L M O R S T U V W X Z ?

P/PT CONTOURS 06/14/8811:04:09

KSLICE= 9 NI 3D CYLINDRICAL C-GRID COMMON DIFFUSER STRUT...ZETA=-7.65



0000 C F G H I L M O R S T U V W X Z ?