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GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION
SPONSORED PROJECT INITIATION

Date: October 26, 1976

Project Title: Wheelspace Cooling Test

Project No: E-25-666

Project Director: Dr. W. O. Winer

Sponsor: General Electric Co.;Gas Turbine Mfg.Dept.;Schenectady,NY 1234

Agreement Period: From 7/1/76 Until 12/31/76

Type Agreement: Service Agreement/P.O. No. 087-ETBM-71753 dated 10/6/76

Amount: $40,000 (Fixed Price)

Reports Required: Final Report

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Defense Priority Rating: N/A

Assigned to: Mechanical Engineering (School/Laboratory)

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SPONSORED PROJECT TERMINATION

Date: February 28, 1978

Project Title: Wheelspace Cooling Test

Project No: E-25-666

Project Director: Dr. W.O. Winer

Sponsor: General Electric Co.; Gas Turbine Mfg. Dept.
Schenectady, NY 12345

Effective Termination Date: 12/31/76 (fixed price)

Clearance of Accounting Charges: 12/31/76

Grant/Contract Closeout Actions Remaining:

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_ Final Fiscal Report

_ Final Report of Inventions

_ Govt. Property Inventory & Related Certificate

_ Classified Material Certificate

_ Other ______________

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CA-4 (3/76)

E-25-600

GEORGIA INSTITUTE OF TECHNOLOGY
School of Mechanical Engineering
Atlanta, Georgia

FINAL REPORT

GAS TURBINE WHEELSPACE SEALING STUDY

GENERAL ELECTRIC SERVICE AGREEMENT
P.O. #087-ETBM-71753

by

Ward O. Winer
Professor
and
Principal Investigator

David M. Sanborn
Associate Professor

Scott Bair
Research Engineer

Sponsored by

The General Electric Company
Large Gas Turbine Division
Schenectady, New York 12345

August, 1977

GAS TURBINE WHEELSPACE SEALING STUDY

FINAL REPORT

SUBMITTED TO

GENERAL ELECTRIC COMPANY
LARGE GAS TURBINE DIVISION
SCHENECTADY, NEW YORK 12345

SUBMITTED BY

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Professor
and
Principal Investigator

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Atlanta, Georgia 30332

August, 1977

Ward O. Winer, Professor
and Principal Investigator

SUMMARY

Due to the heat conducted through the wheel and stator of the turbine and the radial inflow of hot exhaust gases, high temperatures occur in the turbine wheelspace. Cooling of a turbine disk by compressed air from the compressor represents a loss of compressed burner inlet air. Therefore it is desirable to use the minimum cooling air, consistent with turbine wheel temperature limitations.

It is known that the geometry of the rotating seal, the rim spacing, the inner rotor-to-stator spacing, the radial seal clearance, the amount of rim flow and the wheelspeed can affect the wheelspace temperature.

The rate of wheelspace temperature decrease with increased cooling flowrate depends on the combination of seal geometry and operating conditions. The rotating seal geometry, rim spacing and the rotor-to-stator inner spacing play a major role in wheelspace cooling. It was also found that the effect of the radial clearance between the rotating and stationary seal, the amount of hot gas flow in the outer rim space and the wheelspeed on wheelspace temperature are less pronounced.

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CHAPTER I

CONCLUSIONS AND RECOMMENDATIONS

Conclusions drawn from the experimental results are:

1. The wheelspace temperature always decreases as the coolant supply increases. The rate of temperature decrease depends on the geometry of the rotating seal, the outer rim spacing, the radial seal clearance between the rotating and stationary seal, the inner rotor-to-stator spacing, the amount of rim flow and the wheelspeed.

2. When rotating seals PT18 and PT19 are used on the forward side of the wheel, the wheelspace temperature using PT18 seal is higher than using seal PT19. But the wheelspace pressure is higher with PT19 seal.

3. When rotating seal PT18 and PT18A are used on the aft side of the wheel, the wheelspace temperature and pressure using PT18-A seal are higher.

4. The effect of rim spacing on wheelspace temperature was significant. On either forward or aft side, where seal PT18 is used, smaller rim spacing causes lower wheelspace temperatures. However, the wheelspace pressure is not affected by the change in rim spacing. In neither case was hot gas in flow found at low coolant supply (0.13 lbm/sec). When PT19 seal was used on the forward side, the wheelspace temperatures reached a minimum at a rim spacing of 0.2 inch. Inflow of hot gases were always present at some locations when the rim

spacing is large (0.4 inch and 0.6 inch) regardless of the amount of cooling supply. The effect of rotor-to-stator inner spacing is also important. When PT18 seal is used on the forward side, lower wheel-space temperatures were obtained with smaller spacing. When PT18 is used on the aft side, a spacing of 1 inch resulted in minimum wheel-space temperatures. Also no inflow is present even at low coolant supply ($\sim$ 0.15 lbm/sec).

When seal PT18-A is used on the aft side, the rotor-to-stator inner spacing has no pronounced effect on wheelspace temperature.

5. For seals PT18 and PT19 wheelspace temperatures were minumum for a radial seal clearance of 0.1 inch but the variation of wheelspace temperature with radial clearance was small. For seal PT18A the effect of radial clearance was even less.

6. Finally, at a given seal geometry, increasing the wheelspeed results in a reduction of wheelspace temperature but the effect is small.

Rim flow effects wheelspace temperatures as expected with temperatures increasing with greater rim flow.

Of the variables studied the rim spacing and the inner rotor-stator spacing have the most pronounced effect on wheelspace temperatures.

CHAPTER II

TECHNICAL BACKGROUND

This investigation is a continuation of the Phase I large gas turbine wheelspace cooling studies [1]. Its objective is to determine experimentally the relationship among cooling air flowrate, seal geometry, wheelspeed and system temperatures to provide design criteria.

Many previous studies have been concerned with the fluid mechanics and heat transfer on a rotating disk. Several of these have been directed toward turbine design. A report by Hoeft [2] reviews wheelspace cooling for G.E. turbines through 1973. Bayley et al. [3] and Haynes et al. [4] studied the case of a shrouded disk. Owen, Haynes and Bayley [5] report a combined experimental and theoretical investigation of the heat transfer from an air cooled rotating disk. Chao and Grief [6], Metzger [7,8] and Koosintin et al. [9] also did related investigations.

The inflow of hot gases is governed by the static pressure difference in the radial direction on the stationary wall. This pressure difference is in part due to the centrifugal forces created by the fluid motion. It is found that the shape of the stationary wall surface as well as the rotating disk affect this pressure gradient, thus, the radial inflow of hot gases and outflow of cooling air. Uzkan studied different stationary wall geometry with and without radial through flow

[10 and 11]. The effect of the rotating wheel shape was also evaluated by him [12].

Uzkan's results gave insight into the fluid behavior on a rotating wheel and stationary wall. However, in order to apply his results to actual turbine design a complete housing must be present. This led Edelfelt [13,14] to continue Uzkan's investigation.

As the wall and/or the rotor geometry is changed, the drag forces as well as the static pressure are altered. In order to gain a better understanding of the fluid behavior between the turbine disk and its stationary wall on different geometry, Mani [15] made a series of experiments by varying the inlet condition, stator seals and overlapping stator and rotor seals. Mani found that overlapping seals are very effective in reducing the radial inflow at the rim, and reducing the axial clearance can reduce the critical throughflow. No penalty of torque increase was found with these changes.

In the study reported here a 40 inch diameter wheel is incorporated in a casing designed specifically to permit extensive changes in both rotating and stationary seal geometry. Both hot rim flow simulating working fluid and wheelspace cooling air are provided. Stationary blading is provided in the casing to turn the rim flow in such a way as to simulate direction and magnitude of hot rim flow over the seal area. The system is heavily instrumented for temperature and pressure measurements. Three rotating seals were employed. The system is highly flexible and could be used for further seal studies in addition to those reported here.

CHAPTER III

EQUIPMENT

Figure III-1 shows a schematic of the testing facilities at Georgia Tech employed in this study. A 40 inch diameter wheel with forward and aft rotating seals is mounted on two bearings in the walls of the housing. The wheel is driven by a propane fueled Chrysler Industrial engine through a 2 inch drive shaft. The engine and the drive shaft are connected by a belt and a Twin Disk hand operated dry clutch. The drive shaft is underneath the engine, supported by two pillow blocks and attached through a Lovejoy flexible coupling to the shaft of the wheel. The wheelspeed is varied continuously up to about 3000 rpm by adjusting the throttle of the engine. A Hasler manual tachometer held against the wheel shaft is used to measure the wheelspeed.

Hot air, simulating turbine working fluid, is supplied by a Worthington two-stage piston air compressor connected to a combustion chamber. An air-propane mixture is electrically ignited in the chamber. Propane supply, and hence temperature, is controlled pneumatically by a Taylor Instruments Temperature Controller. The hot air was typically supplied at 250F. The amount of hot air flow is controlled by a valve or by adjusting the compressor capacity. Air flowrate can be varied from 2 to 4 lbm/s. The flow rate through the combustion chamber is measured with an orifice plate flowmeter located upstream of the chamber. Fifteen heavy duty rubber hoses are used to provide distribution of hot air to the housing. The hot air is

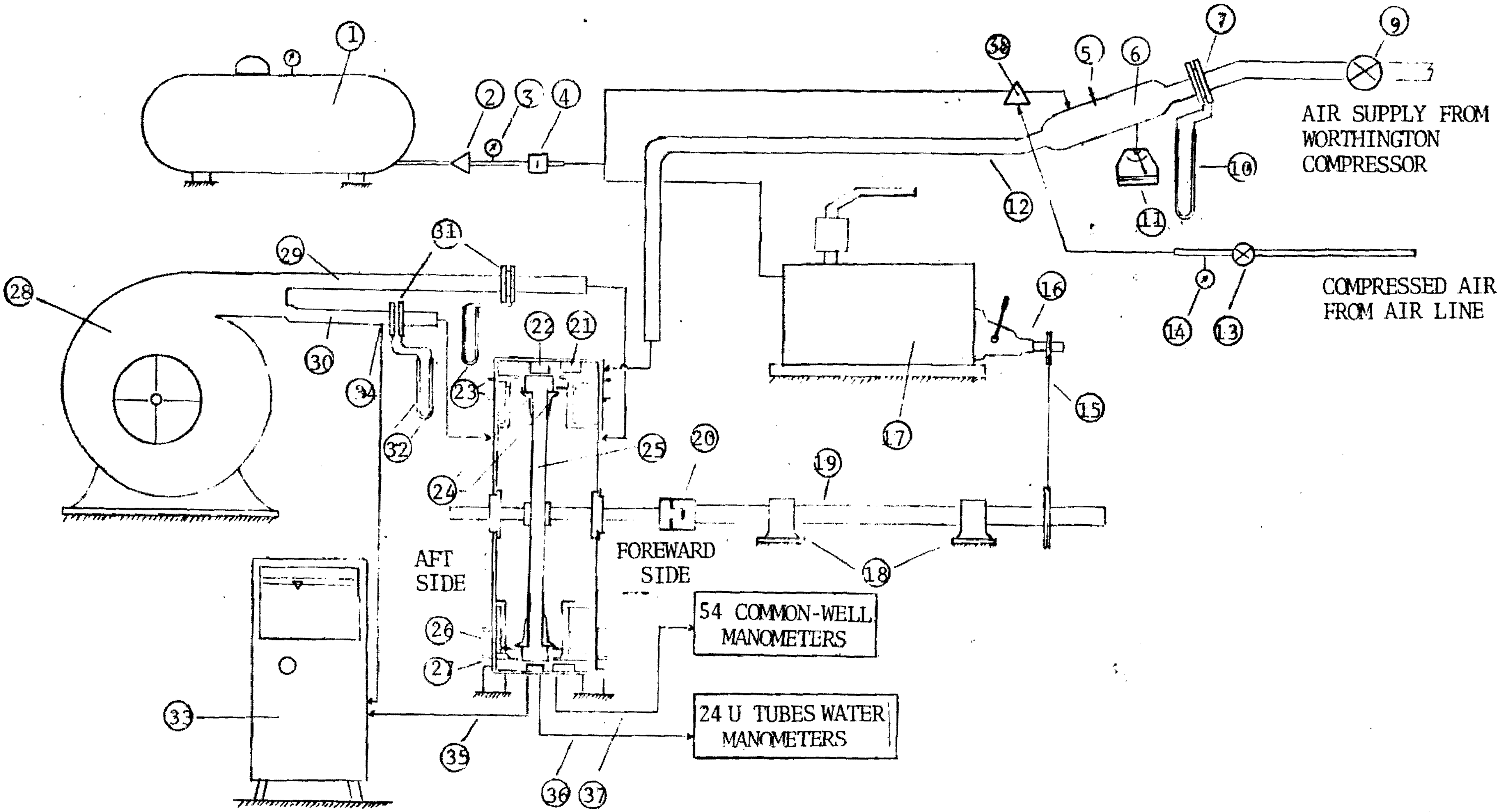


Figure III -1. General System Schematic

1. 500 gallon propane tank
2. Regulator
3. Pressure gage
4. Emergency switch
5. Spark plug
6. Combustion chamber
7. Orifice plate flowmeter
8. Control valve
9. Mercury manometer
10. Taylor instrument temperature controller
11. Hot air line
12. Air control valve
13. Air line pressure gage
14. Pulley and belt
15. Twin disc hand operated dry clutch
16. Chrysler industrial engine
17. Pillow blocks
18. 3-drive shaft
19. Lovejoy couplings
20. Nozzle
21. Buckets
22. Jack screws
23. Rotating seals (forward and aft)
24. Rotor
25. Radial seal
26. Rim seal
27. 10 hp centrifugal blower
28. Forward cooling air
29. Aft cooling air
30. Orifice plate flowmeters
31. Merian #3 fluid manometers
32. Leed-Northrup multipoint recorder
33. Thermocouple-cooling air temperature measurement
34. 56 thermocouples at different forward and aft wheel location
35. 24 pressure tap lines
36. 54 pressure tap lines
37. Pneumatic Taylor Instrument controller

KEY TO FIGURE III-1

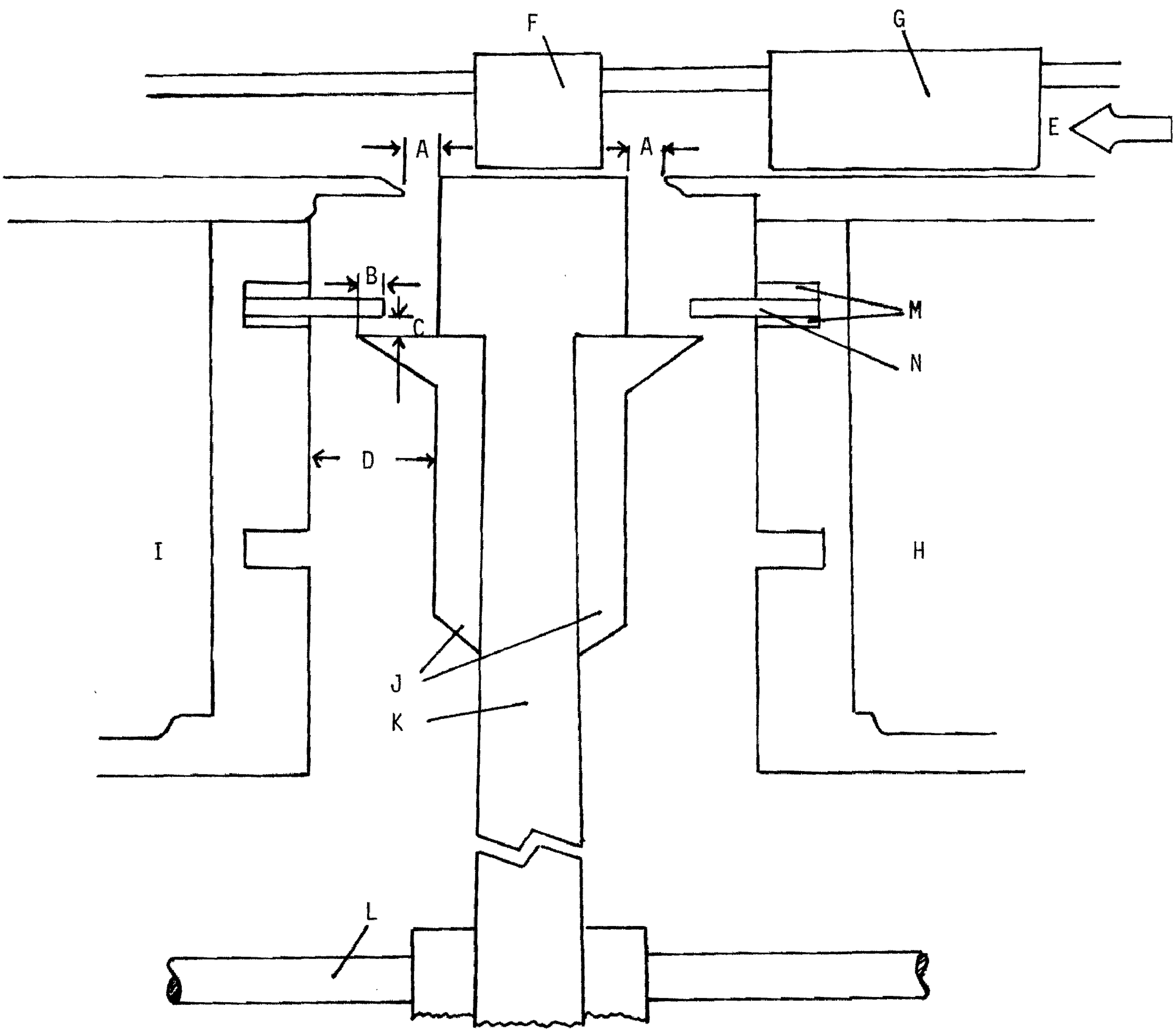
exhausted directly to the atmosphere from ten openings in the housing.

Cooling air is supplied by a 10 hp electric driven centrifugal blower through two ducts. An orifice plate flowmeter is placed in each of these ducts to measure the amount of air flow. Six flexible hoses, three on each duct, are used to provide cooling in the forward and aft sides of the housing. The blower provides air up to 1.3 lbm/s. The amount of air flow can be varied by restricting the inlet of the blower.

The hot air, cooling air and surrounding ambient air temperatures are measured with copper constantan thermocouples connected to a Leeds and Northrup multipoint recorder.

A detailed schematic of the wheelspace seal area is shown in Figure III-2 and the working drawings of the wheelspace apparatus are included in Appendix 1A. The 40 inch wheel acts as a rotor. The rotor-to-stator rim spacing (A in Figure III-2) can be varied from 0.1 inch to 0.6 inch by adjusting the jack bolts in the housing wall. The inner rotor-to-stator spacing (D in Figure III-2) can also be adjusted in the same manner from 0.75 inch to 1.5 inch. Seals and spacers of different width and thickness are available so that the radial seal clearances (C in Figure III-2) as well as the radial seal overlap (B in Figure III-2) can be varied. The radial seal clearance can vary from 0.05 inch to 0.20 inch. The radial seal overlap was held constant at 0.05 inch for all tests reported.

Stationary buckets at the axial position of the wheel and nozzles upstream to these buckets are present, so the flow behavior (direction and magnitude of the velocity) is comparable to that of an



A:	Rotor-to-Stator Rim Spacing	H:	Forward Stator
B:	Radial Seal Overlap (Constant at 0.05 inch)	I:	AFT Stator
C:	Radial Seal Clearance	J:	Rotating Seals
D:	Rotor-to-Stator Axial Inner Spacing	K:	40" Diameter Rotor
E:	Rim Gas Flow	L:	Wheelshaft
F:	Buckets	M:	Spacers
G:	Nozzles	N:	Radial Seal

Figure III-2. The Wheelspace Seal Nomenclature.

actual turbine wheel.

Mechanical drawings and photographs of the equipment are presented in Appendix 1.

Measurements

Thermocouple and pressure tap locations are designated by subscripts (T_{xyz} and P_{xyz}). The first subscript (x) indicates the axial location, the second (y) the radial position and the third (z) the circumferential position. The coordinates for the positions are shown in Figure III-3.

It is convenient to average the values of temperature or pressure from different circumferential positions for some discussions. When this is done two subscripts (x,y) are used indicating the axial and radial positions, and the value reported is the average of the circumferential locations for that x and y.

Temperature Measurements

Fifty-six copper-constantan thermocouples are used to measure the temperature at different locations. Twenty-eight are on the aft side and 28 on the forward side. These thermocouples are distributed radially at three circumferential positions 120^{o} apart. They are mounted on the wheelspace wall, radial seal area and axially along the crossflow space. Figure III-4 shows the locations schematically. Photographs in Appendix 1-B show typical temperature and pressure sensor installations.

By connecting the thermocouples to a Leeds and Northrup multi-point recorder the temperatures are obtained. Table III-2 indicates

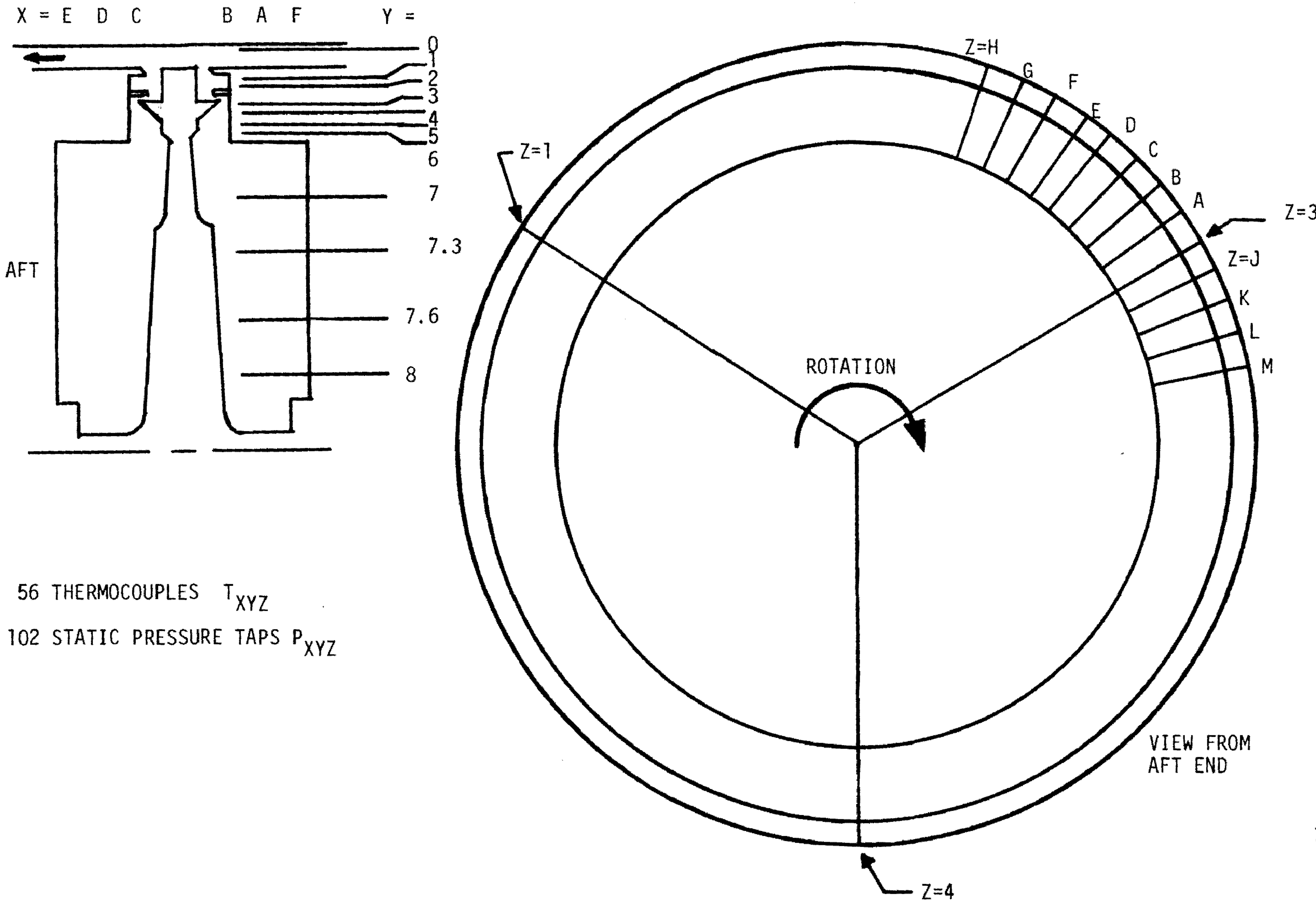


Figure III-3. Coordinate Location Definition for T/C and Pressure.

the relationship between recorder position and thermocouple locations.

Pressure Measurements

Seventy-eight static pressure taps are present. Thirty pressure taps are distributed radially along the wheelspace walls and axially along the rim flow space at two circumferential locations. Twenty-four pressure taps are placed circumferentially (12 forward and 12 aft) along the outer surface of the rim flow. These pressure taps are used to detect circumferential variations in the crossflow. Locations of these taps relative to the flow vanes are shown in Appendix 3-D.

The static pressures are read on two common-well manometers with reference to atmospheric pressure. Meriam No. 3 fluid with specific gravity of 2.95 is used as a measuring fluid. The manometers can not be read to an accuracy of better than $\pm$ 0.05 inch resulting in pressure accuracies of about $\pm$ 0.01 psi.

In addition to the above, there are 48 pressure taps placed in 24 pairs to measure the pressure difference across the radial seals. Twelve pairs are located in each of the forward and aft sections. They are located circumferentially along the radial seal. U-tube manometers are used to read the pressure difference. Figure III-4a&b also shows their locations.

Pressure and temperature data were entered into a computer file for analysis with the program presented in Appendix 2. A complete printout of the data for all tests is available but not included in this document.

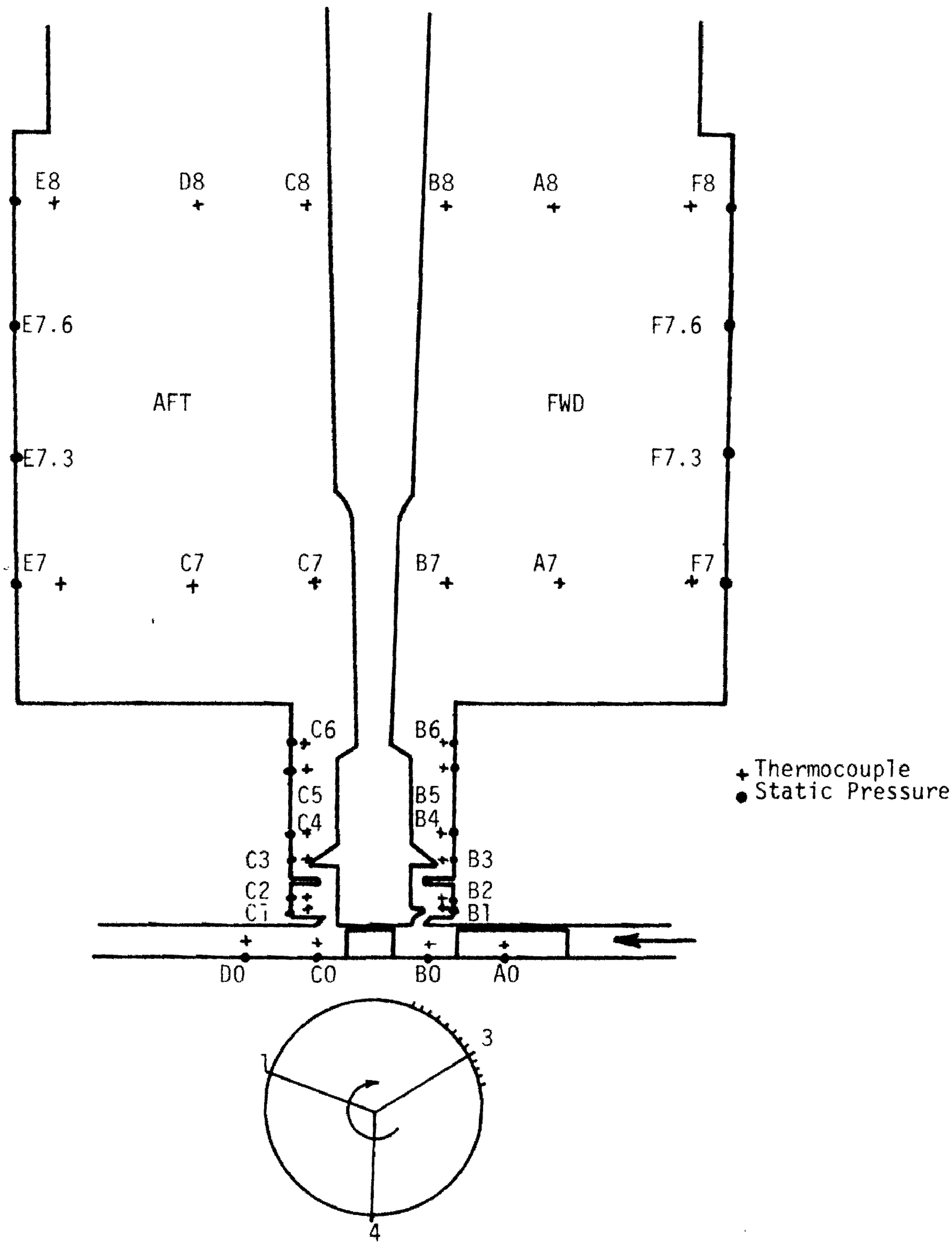
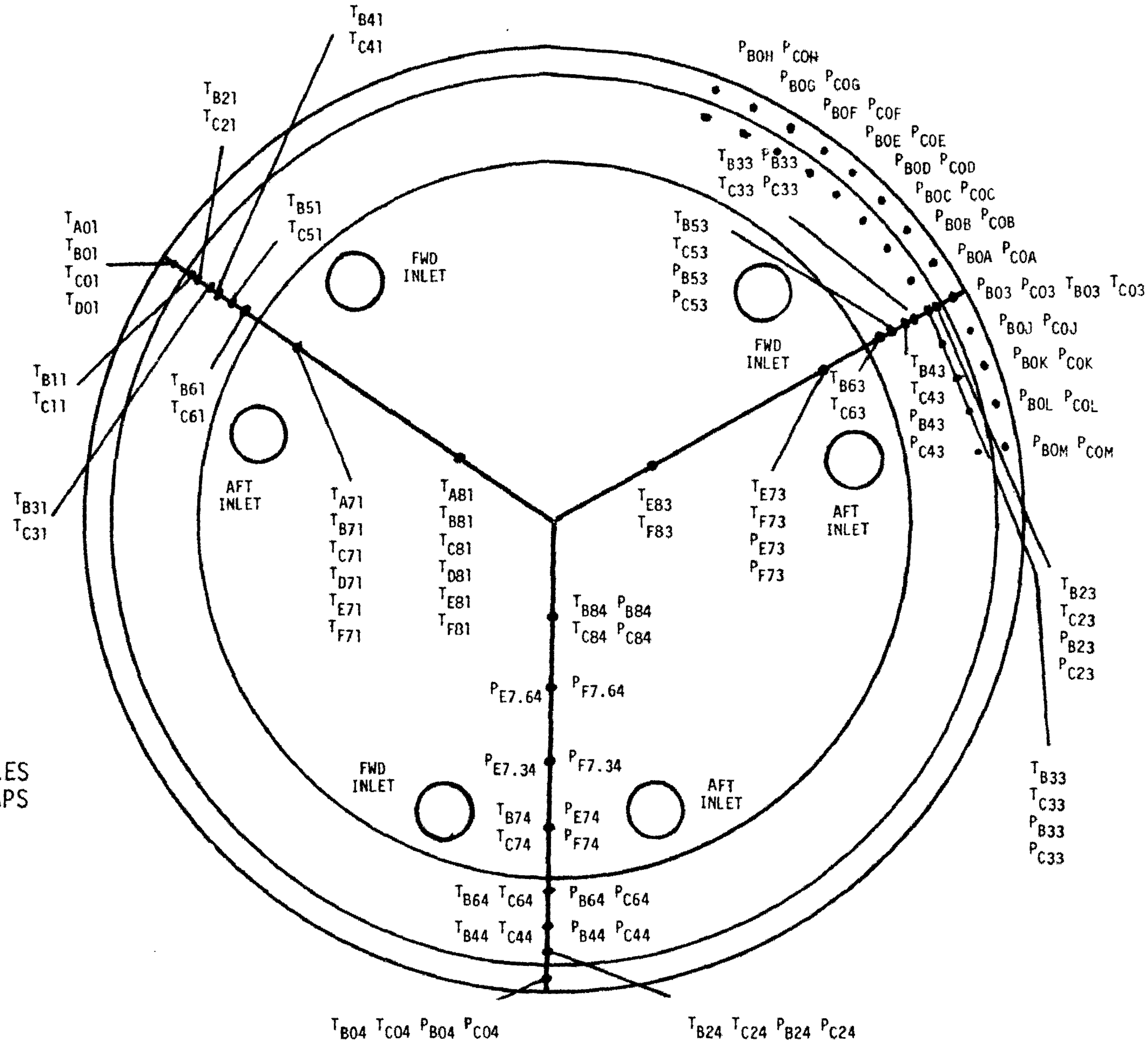


Figure III-4A. Instrumentation Sensor Location.



56 THERMOCOUPLES
102 PRESSURE TAPS

Figure III-4B. Instrumentation Sensor Location.

Table III-1. Thermocouple Identification - December 15, 1975.

RECORDER BANK	T/C	MACHINE LOCATION		BANK	T/C	LOCATION	
1	2	E73		4	1	C11	AFT
	2	D71			2	C31	
	4	C01			3	B61	
	5	C74			5	B63	
	6	C71			6	B64	
	7	C84	AFT		7	B51	
	8	C81			8	B53	
	9	E81			9	B41	
	10	E83			10	B43	
	11	D81			11	B44	
	12	F71			12	B31	FORWARD
2	1	F73		5	1	B33	
	3	A71			2	B21	
	4	B71			3	B23	
	5	B74	FORWARD		4	B24	
	6	F81			6	B11	
	7	B81			7	A01	
	8	F83			8	D01	AFT
	9	B84			9	B03	FORWARD
	10	A81			10	C03	AFT
	11	E71			11	B01	
	12	C44			12		FORWARD
3	1	C64		6	1	B04	
	2	C63			2	C04	AFT
	4	C61			3		
	5	C53			4		
	6	C51	AFT		5		
	7	C43			6		
	8	C41			7		
	9	C33			8		
	10	C24			9		
	11	C23			10	AMBIENT	
	12	C21			11	CROSS INLET	
					12	COOLING INLET 1/16/76	

Table III-2. Pressure Tap Location.

P_{C04}	P_{F73}	P_{C0K}	P_{B3M}	P_{C2M}
P_{B04}	P_{F74}	P_{C0L}	P_{B2M}	
P_{C03}	$P_{F7.34}$	P_{C0M}	P_{C3H}	
P_{B03}	$P_{F7.64}$	P_{B3H}	P_{C2H}	
P_{C13}	P_{F84}	P_{B2H}	P_{C3G}	
P_{C23}	P_{B0H}	P_{B3G}	P_{C2G}	
P_{C24}	P_{B0G}	P_{B2G}	P_{C3F}	
P_{C33}	P_{B0F}	P_{B3F}	P_{C2F}	
P_{C43}	P_{B0E}	P_{B2F}	P_{C3E}	
P_{C44}	P_{B0D}	P_{B3E}	P_{C2E}	
P_{C53}	P_{B0C}	P_{B2E}	P_{C310}	
P_{C64}	P_{B0B}	P_{B3D}	P_{C2D}	
P_{B13}	P_{B0H}	P_{B2D}	P_{C3C}	
P_{B23}	P_{B0J}	P_{B3C}	P_{C2C}	
P_{B24}	P_{B0K}	P_{B2C}	P_{C3B}	
P_{B33}	P_{B0L}	P_{B3B}	P_{C2B}	
P_{B43}	P_{B0M}	P_{B2B}	P_{C3A}	
P_{B44}	P_{C0H}	P_{B3A}	P_{C2A}	
P_{B53}	P_{C0G}	P_{B2A}	P_{C3J}	
	P_{C0F}			
P_{B64}	P_{C0E}	P_{B3J}	P_{C2J}	
P_{E73}	P_{C0D}	P_{B2J}	P_{C3K}	
P_{E74}	P_{C0C}	P_{B3K}	P_{C2K}	
$P_{E7.34}$	P_{C0B}	P_{B2K}	P_{C3L}	
$P_{E7.64}$	P_{C0A}	P_{B3L}	P_{C2L}	
P_{E84}	P_{C0J}	P_{B2L}	P_{C3M}	

CHAPTER IV

TEST PROCEDURE

Two test series were conducted, each with different seals on the rotor. Figure IV-1 shows the seal geometry for the two test series.

In both test series, studies of the effect of rim spacing, rim flow, inner rotor-stator spacing and radial seal clearance are made. In test series I, in addition to those four tests mentioned above, wheel speeds of 1200 rpm, 2200 rpm and 3000 rpm are also included. Table IV-1 describes the conditions employed.

Each test consists of varying the cooling flow from the maximum blower capacity to near zero. Four to six cooling flowrates are used in a test.

Experimental Procedure

The steps taken for each test are as follows: The propane, engine and compressor are turned on followed by igniting the air-propane mixture in the combustion chamber. Once hot air is obtained, the blower is turned on to supply cooling air. Due to the thermal transient, generally 15 minutes or longer is required for the system to reach steady state. The wheel speed is checked by means of a Hasler tachometer held against the shaft. Steady state is determined from the temperature readings on the multipoint recorder and the wheelspeed. Only steady state data are considered in the present studies.

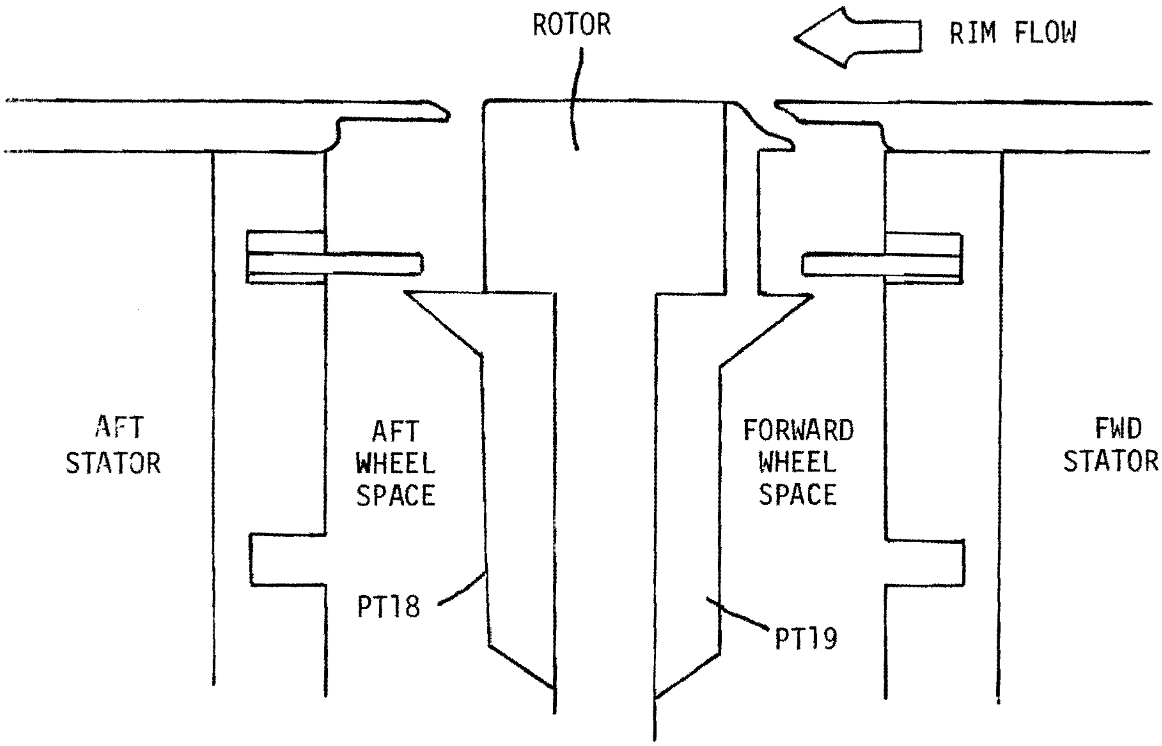


Figure IV-1A. Rotor Seal Geometry, Test Series I.

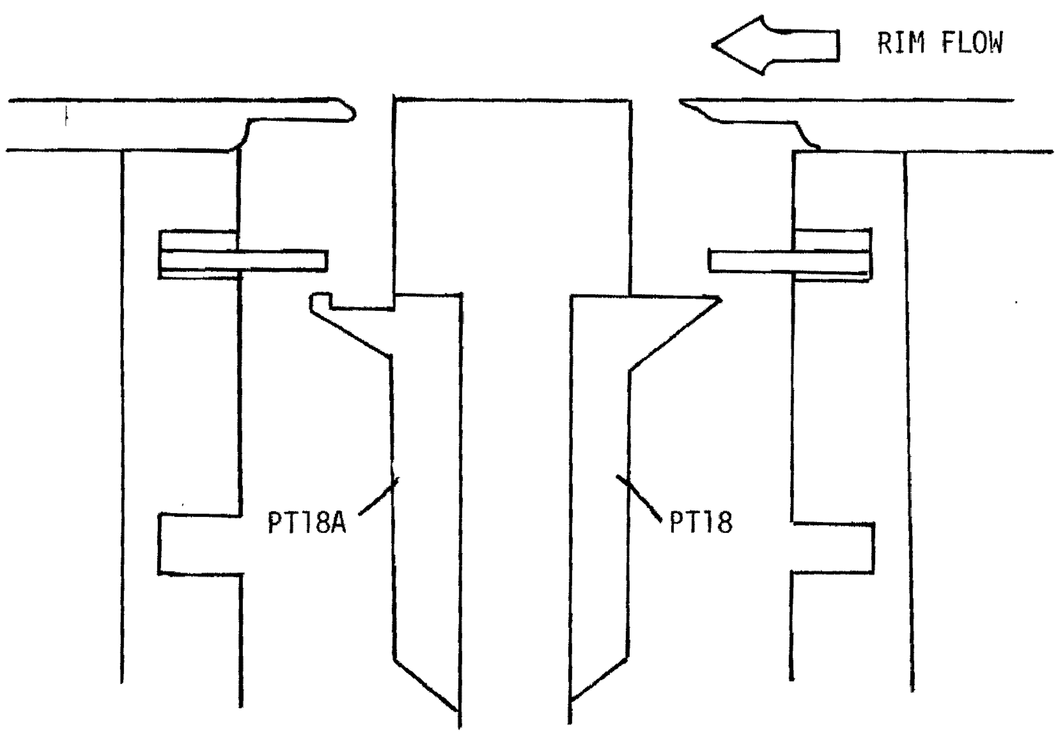


Figure IV -1B. Rotor Seal Geometry, Test Series II.

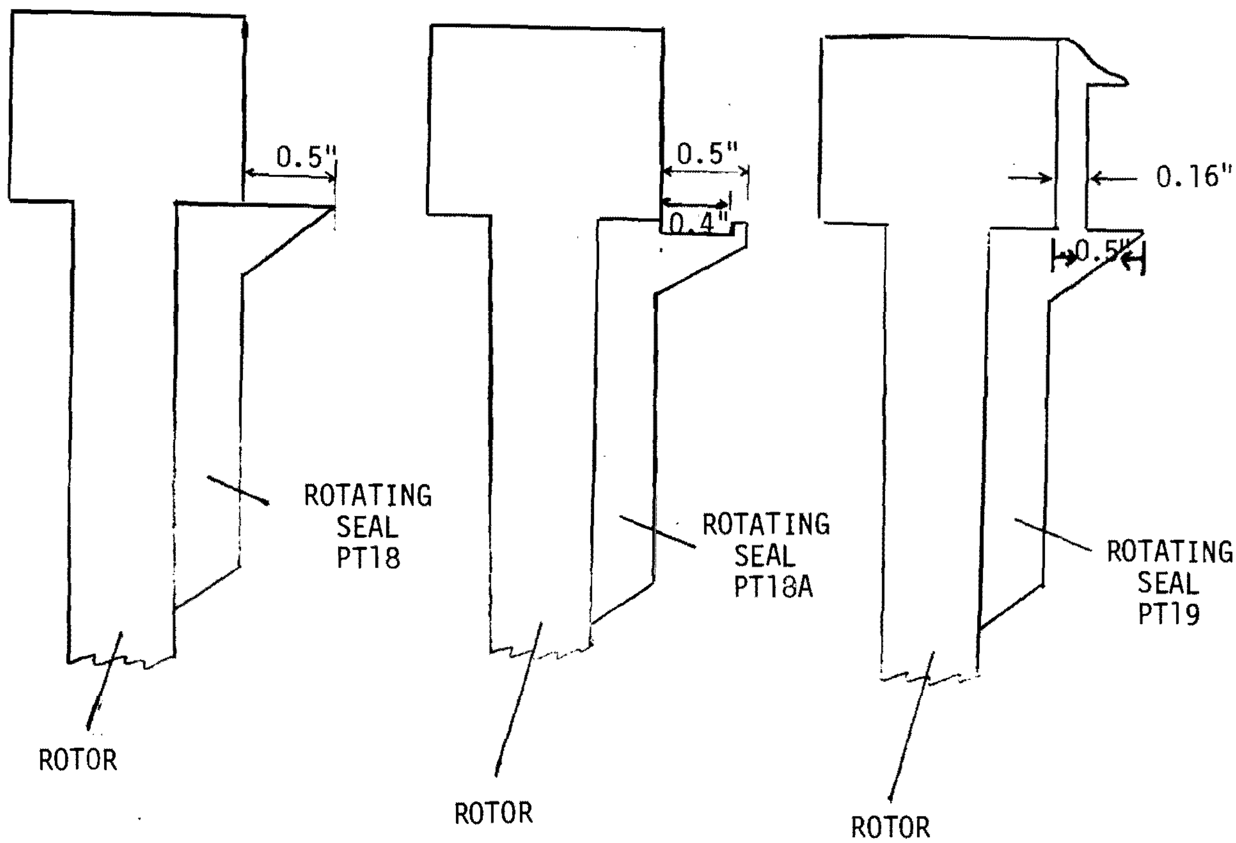


Figure IV-1C. Rotating Seals - PT18, PT18A and PT19.

Table IV - 1A. Test Description, Test Series I

TEST NUMBER	TEST EFFECT	RADIAL SEAL CLEARANCE[1] (IN.)	RIM AXIAL SPACING[2] (IN.)	ROTOR-STATOR INNER SPACING[3] (IN.)	RIM FLOW (LBM/SEC)	WHEEL SPEED (RPM)
F1A1	Baseline	0.1	0.2	1.0	4.0	2900, 3100
A3	Speed	0.1	0.2	1.0	4.0	2200, 2300
A5	Speed	0.1	0.2	1.0	4.0	1200, 1300
F2 A6	Rim Spacing	0.1	0.1	1.0	4.0	2880
F3 A7	Rim Spacing	0.1	0.4	1.0	4.0	2900, 3050
F4 A8	Rim Spacing	0.1	0.6	1.0	4.0	2535
F5 A9	Rim Flow	0.1	0.2	1.0	2.9	2900
F6 A10	Rim Flow	0.1	0.2	1.0	1.84	2910
A12	Rotor-Stator Inner Spacing	0.1	0.2	0.75	4.0	2900
A13	Rotor-Stator Inner Spacing	0.1	0.2	1.5	4.0	3150, 2500
F8 A14	Radial Seal Clearance	0.15	0.2	1.0	4.0	3000
F9	Radial Seal Clearance	0.05	0.2	1.0	4.0	3000

[1] C in Figure 3-2

[2] A in Figure 3-2

[3] D in Figure 3-2

Table IV-1B. Test Description, Test Series II

TEST NUMBER	TEST EFFECT	RADIAL SEAL CLEARANCE[1] (IN.)	RIM AXIAL SPACING[2] (IN.)	ROTOR-STATOR INNER SPACING[3] (IN.)	RIM FLOW (LBM/SEC)	WHEEL SPEED (RPM)
F10 A16	Baseline	0.1	0.2	1.0	4.0	2950, 3000
F11	Rim Spacing	0.1	0.1	1.0	4.0	2900
F12	Rim Spacing	0.1	0.4	1.0	4.0	2900
F13	Rim Spacing	0.1	0.6	1.0	4.0	2850
F14	Rim Flow	0.1	0.2	1.0	3.2	2850, 3000
F15	Rim Flow	0.1	0.2	1.0	1.87	2920
F17 A17	Inner Spacing	0.1	0.2	0.75	4.0	2800, 3000
F18 A18	Inner Spacing	0.1	0.2	1.5	4.0	2850
F19 A19	Radial Seal Clearance	0.2	0.2	1.0	4.0	2850
F20 A20	Radial Seal Clearance	0.15	0.2	1.0	4.0	2850
F21 A21	Radial Seal Clearance	0.05	1.2	1.0	4.0	2750

[1] C in Figure 3-2

[2] A in Figure 3-2

[3] D in Figure 3-2

Data Handling

The temperature data are non-dimensionalized according to the dimensionless temperature parameter:

$$\theta \equiv \frac{T - T_{cool}}{T_{hot} - T_{cool}}$$

where

T = local wheelspace temperature

T_{cool} = coolant inlet temperature

T_{hot} = hot air temperature at the inlet of the wheel.

This parameter can range from zero to one depending on whether the local temperature is the minimum or maximum possible, namely the cooling air temperature or hot cross flow temperature respectively. These dimensionless temperatures are further averaged over the three different circumferential locations having this same axial and radial positions. These dimensionless temperatures are presented in the form of plots in Appendix 3-A (Figures AT-1 to AT-23). Tables of these data are available but not included in this report.

The static pressure data determine the flow behavior and the wheelspace pressure. The data are taken directly from the experiment, entered into the computer and averaged from two circumferential positions for given axial and radial position. The results of the pressure measurements are given in psi and plots of the average pressure versus cooling flow are presented in Appendix 3-B, (Figures AP-1 to AP-23). Tables of these data are available but not included in this report.

The local radial flow across the seal is proportional to the square root of pressure difference across the seal for a given seal geometry. Therefore the pressure measured at radial positions 2 and 3 indicate the local direction of flow and the square root of the pressure difference represents the flow rate. The pressures measured at radial positions 2 and 3 are therefore converted into square roots of pressure difference with appropriate consideration of sign for direction of the flow (flow out of wheelspace is positive). These data are plotted in Appendix 3-C, (Figures AF-1 to AF-23). Tables of these data are available but not included in this report. The square root of the seal pressure difference can be used as an indicator of local seal flow only when the seal geometry is held constant (that is for test involving a given set of seals with common overlap and radial clearance).

Finally, the circumferential static pressure distribution at radial position 0 (the wall of the casing) is evaluated and presented in Appendix 3-D.

CHAPTER V

DISCUSSION OF RESULTS

The temperature and pressure in the wheelspace as well as the seal flow depend on six factors: the rotating seal geometry, the rim spacing between the rotor and stator, the inner rotor-to-stator spacing, the radial seal clearance between the disk rotating seal and the stator static seal, the amount of rim flow and the wheelspeed. The effect of each of these factors will be discussed in this section. Extensive details of pressures, temperatures, and seal pressure differences for each run will be found in the appendices of the report.

A high degree of accuracy in the results can not be expected due to the nature of the equipment and the presence of many outside factors that cannot be controlled during the experiment. A typical uncontrolled factor is the ambient temperature which influences cooling air supply temperature, heat transfer from the unit, and propane supply pressure. However, since the purpose of the experiment is to evaluate how the different factors affect the cooling of the turbine disk for actual turbine design, the trends in the data are of primary importance.

Most of the following discussion is based on position B4 and C4* for forward and aft sides respectively because this radial position

*Position B4 or C4 refer to the average of three circumferential positions B41, B43 and B44 for forward and C41, C43 and C44 for AFT position. (See Figure II-3B and position reference to B4 and/or C4).

is the outermost location in the wheelspace.

As expected the wheelspace temperature decreases as the supply of cooling air increases because the cooling air convects away the heat conducted through the wheel and the stator,and obstructs the inflow of hot gases from the rim flow.

For any given set of operating conditions the temperature in the forward wheelspace is higher than in the aft wheelspace. Figure V-1A shows this effect at radial position 4 in baseline tests F1A1 and F10A16. The same effect can be observed in radial positions 2, 3, 5 and 6 by comparing Figures AT1-B and AT13-A. The difference between forward and aft wheelspace temperatures for several other seal geometries are shown in Figures IV-1B, IV-1C and IV-1D. Consistently the temperatures at the forward wheelspace are higher than those in the aft wheelspace.

The lower aft wheelspace temperatures are due in part to the fact that the forward rim flow temperatures (T_{AO} and T_{BO}) are higher than the aft (T_{CO} and T_{DO}).

The rim flow temperature is reduced in the direction of flow as a result of cooling by the surfaces and mixing of lower temperature cooling air from the wheelspace. Therefore the amount of conduction heating of the forward wheelspace should be greater than the aft and any hot gas inflow in the forward wheelspace will have a greater influence on wheelspace temperatures than a comparable amount of inflow to the aft wheelspace.

Rotating Seal Geometry

Three rotating seal geometries were evaluated. Seals PT18 and

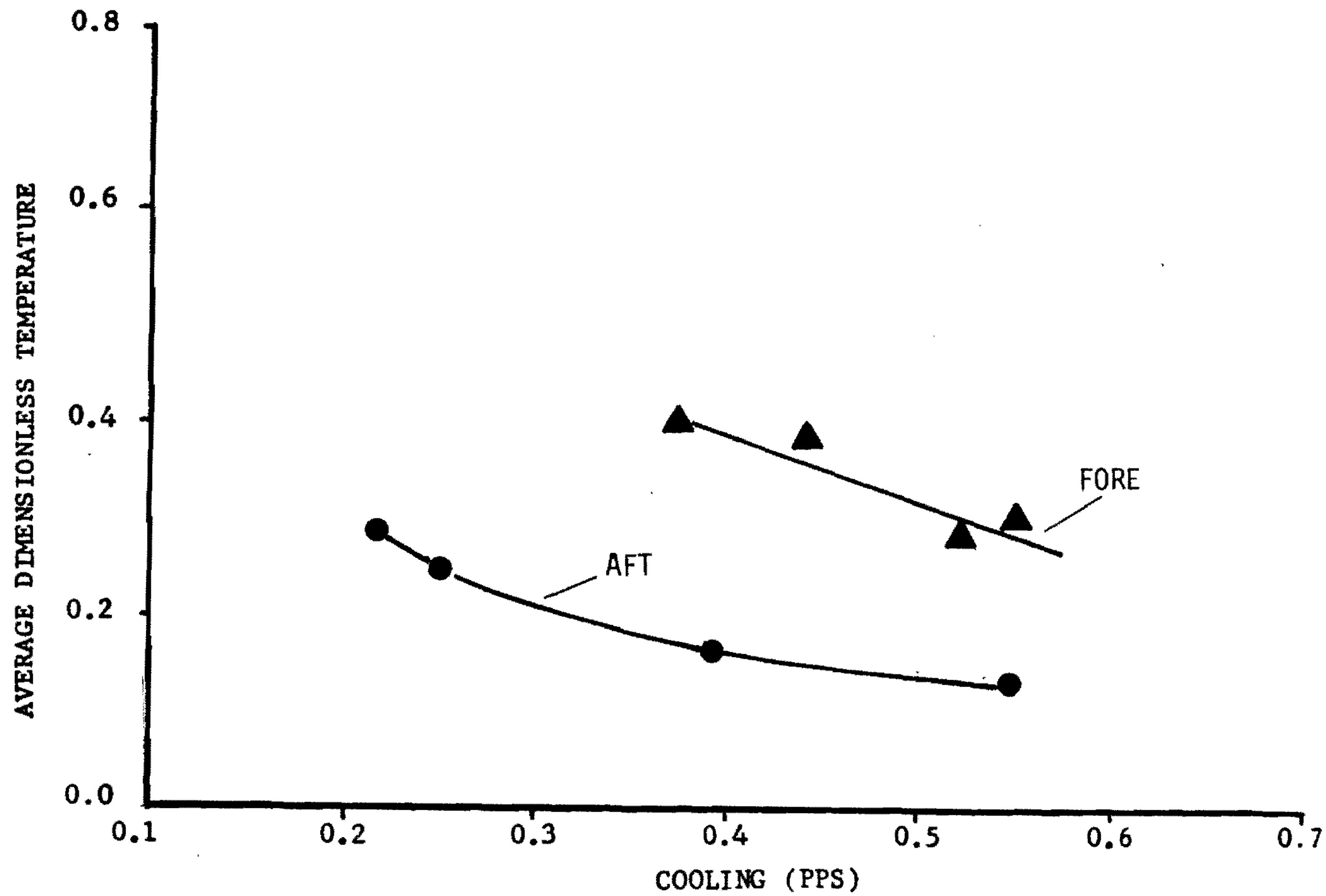


Figure V-1A. Wheelspace Temperature in Fore and Aft Position (B4 and C4) Tests F1A1 Baseline.

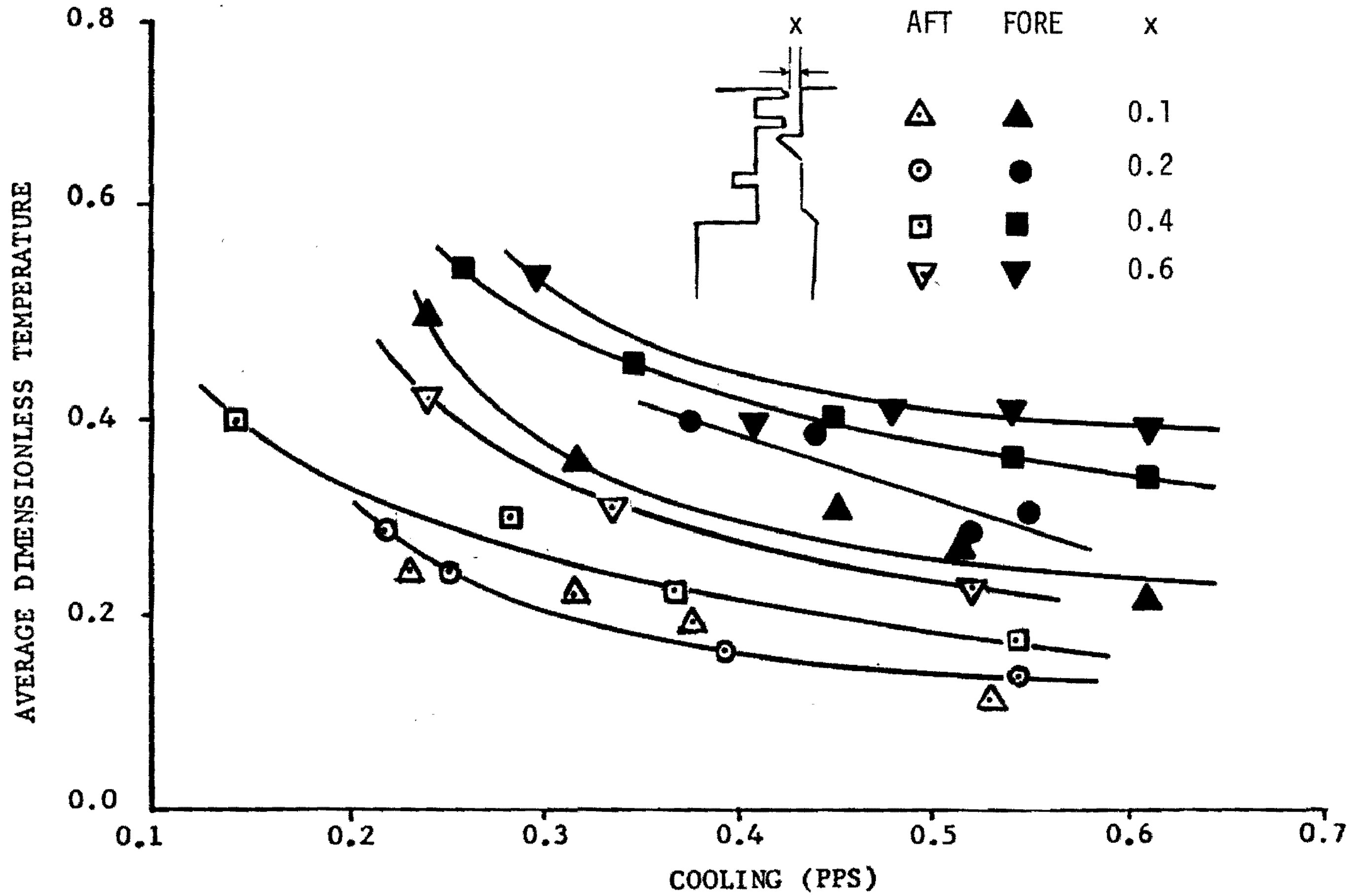


Figure V-1B. **Wheelspace Temperature in Fore and Aft Position for Several Rim Spacings (B4 and C4), Tests F1A1, F2A6, F3A7, F4A8.**

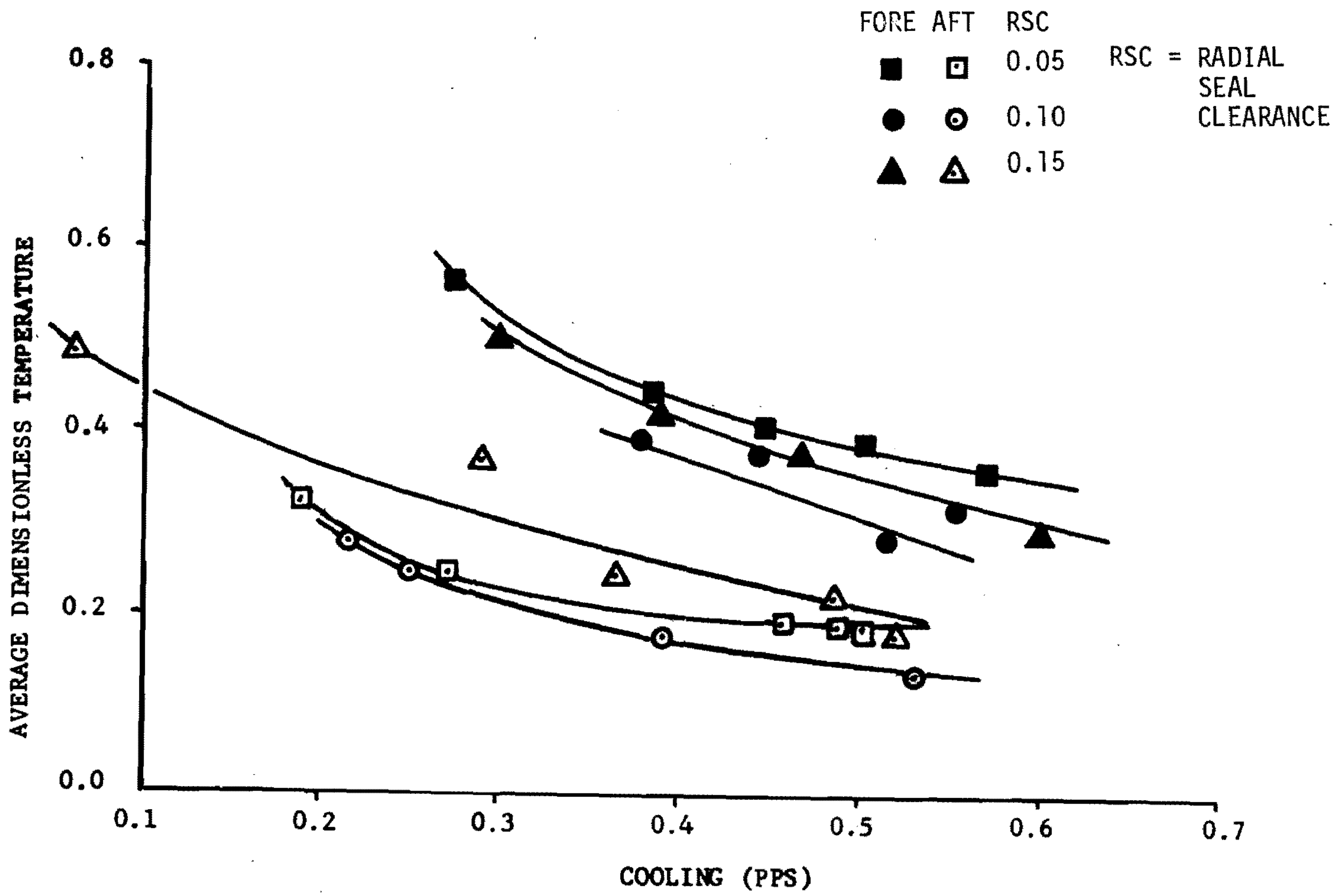


Figure V-1C. **Wheelspace Temperature in Fore and Aft Position for Several Radial Seal Clearances (B4 and C4), Tests F1A1, F8A14, F9A15.**

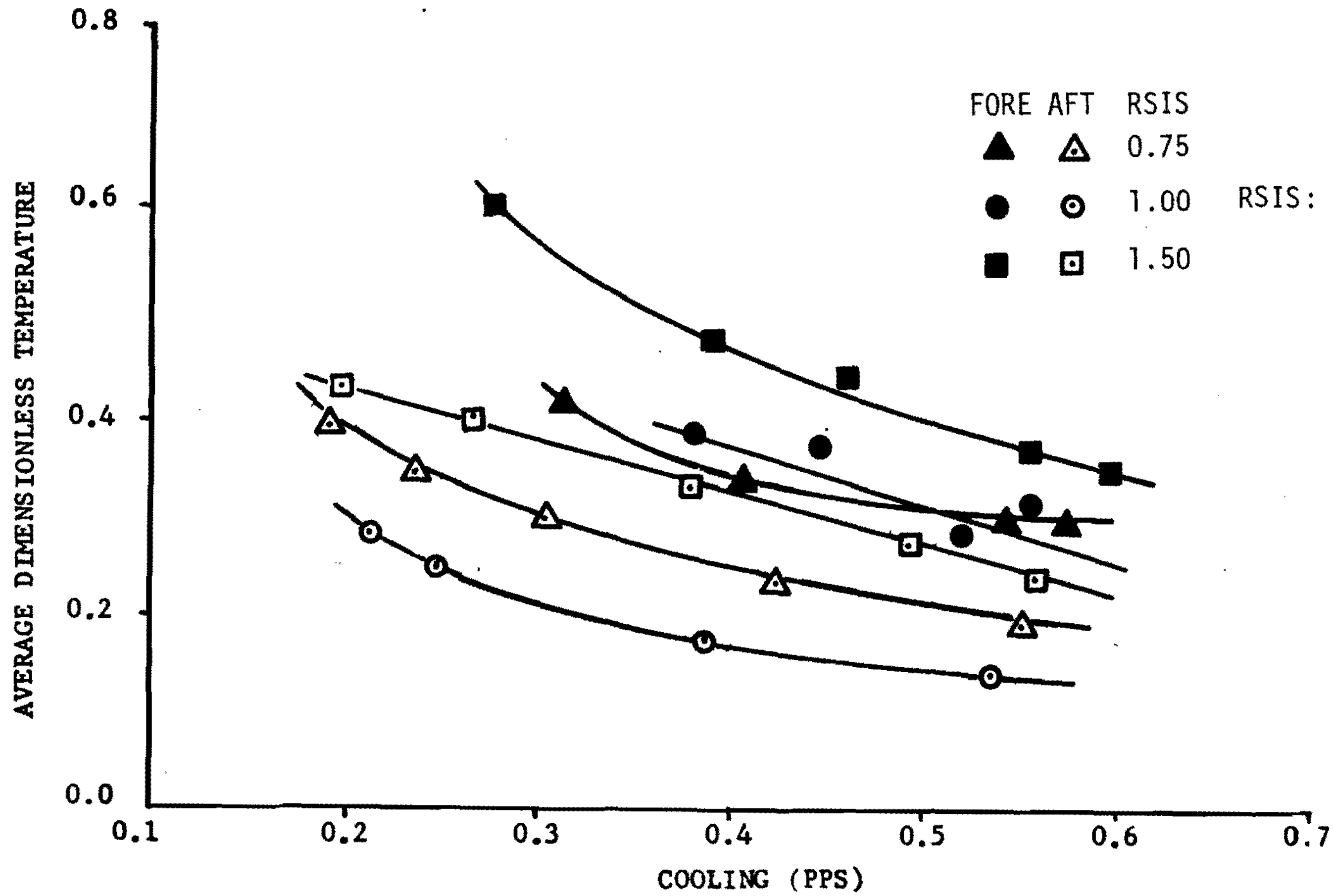


Figure V-1D. Wheelspace Temperature in Fore and Aft Position for Several Rotor-Stator Inner Spacings (B4 and C4), Tests F10A16, F17A17, F18A18.

PT19 were used on the forward side while on the aft side PT18 and PT18A were used (See Figure IV.2). To evaluate the effect of the rotating seal geometry the following conditions were employed: 3000 rpm wheelspeed, 4 lbm/s rim flow and rim spacing, radial seal clearance and rotor-to-stator inner spacing (A, C and D respectively in Figure III.2) of 0.2, 0.1 and 1.0 inches respectively.

On the forward side of the rotor, the wheelspace temperatures are higher when seal PT18 is used. Figure V.2 shows the temperature difference due to different rotating seal geometries at radial position B4. Curve I in Figure V.2 corresponds to seal PT19 while Curve II corresponds to PT18. For temperatures at different radial locations (B5, B6, B7, F7, A7, F8, A8 and B8) compare Figures AT1-A and AT13-A.

When using seal PT19, the wheelspace pressure is lower (See Figure V.2 for radial position B4 and for other radial positions compare Figures AP1-A and AP13-A), therefore, hot rim gas inflow* is found (Figure V.4) at low values of cooling supply (m_{cool}, $< \sim 0.4$ lbm/sec). Because of the presence of the lip on seal PT19, it creates greater resistance to coolant flow out of the wheelspace.

On the aft side of the rotor, wheelspace temperatures using seal PT18-A are higher than when using PT18. (See Figure V.5 or compare Figures AT1-B and AT13-B). The higher temperature is associated with the lower amount of local radial outflow (Figure V.7). The presence of the "step" in seal PT18A does not seem to influence the wheelspace pressure (Figure V-6) but does result in less coolant outflow.

*Positive $\sqrt{\Delta p}$ represents outflow, negative $\sqrt{\Delta p}$ represents inflow.

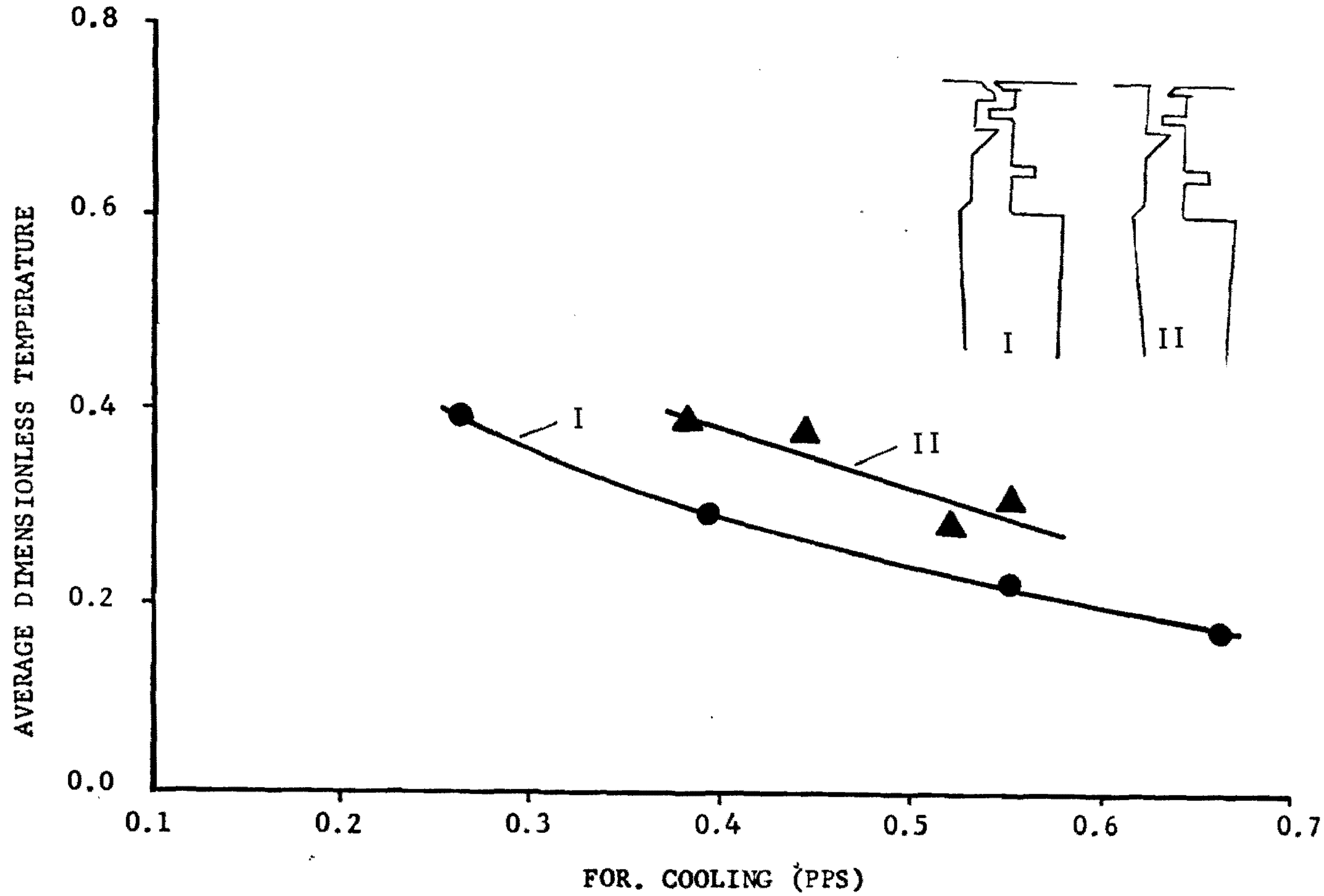


Figure V-2. Temperature at Position B4 for Forward Rotating Seal Geometry PT18 (II) and PT19 (I).

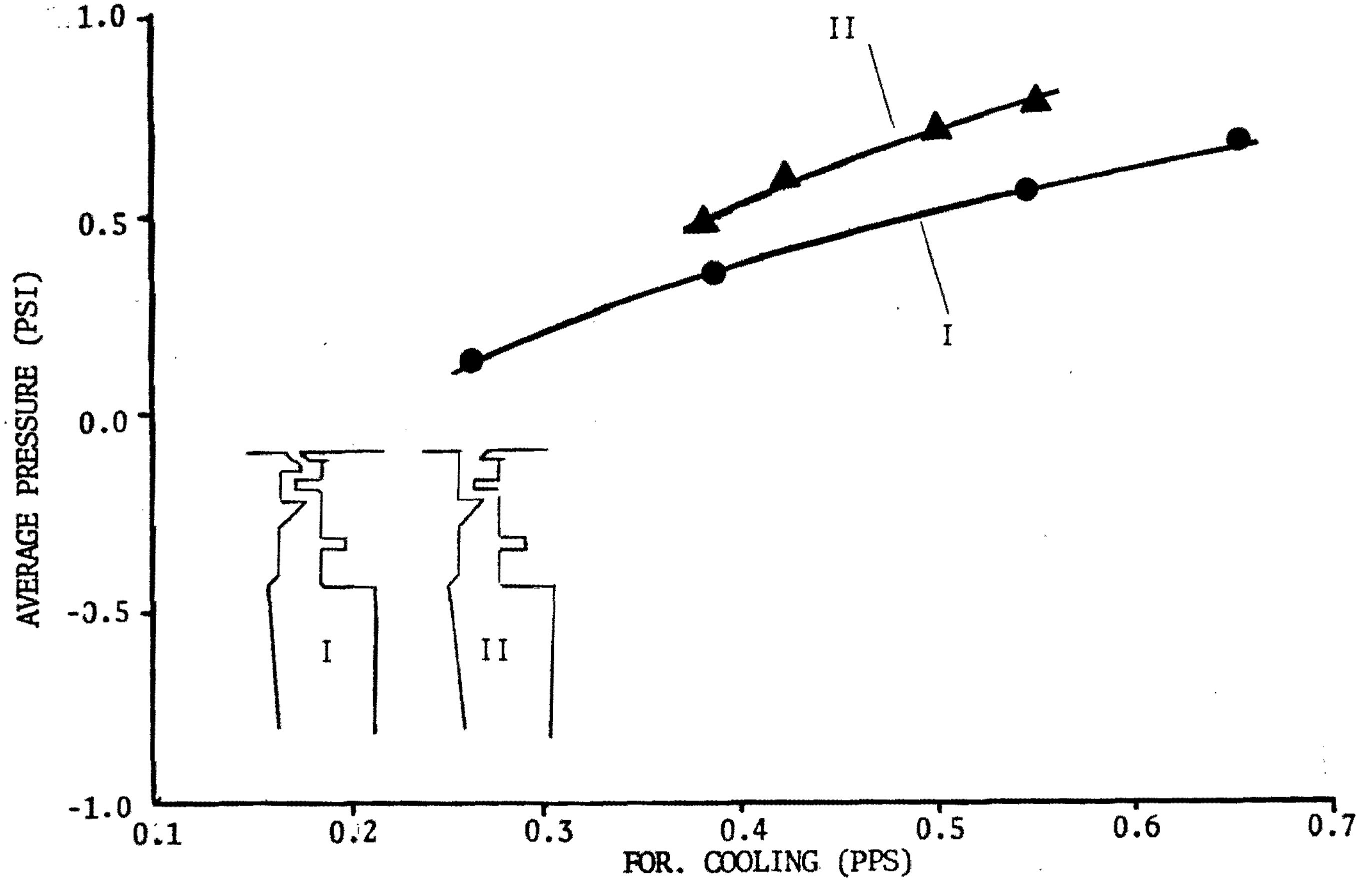


Figure V-3. Pressure at Position B4 for Forward Rotating Seal Geometry PT18 (II) and PT19 (I).

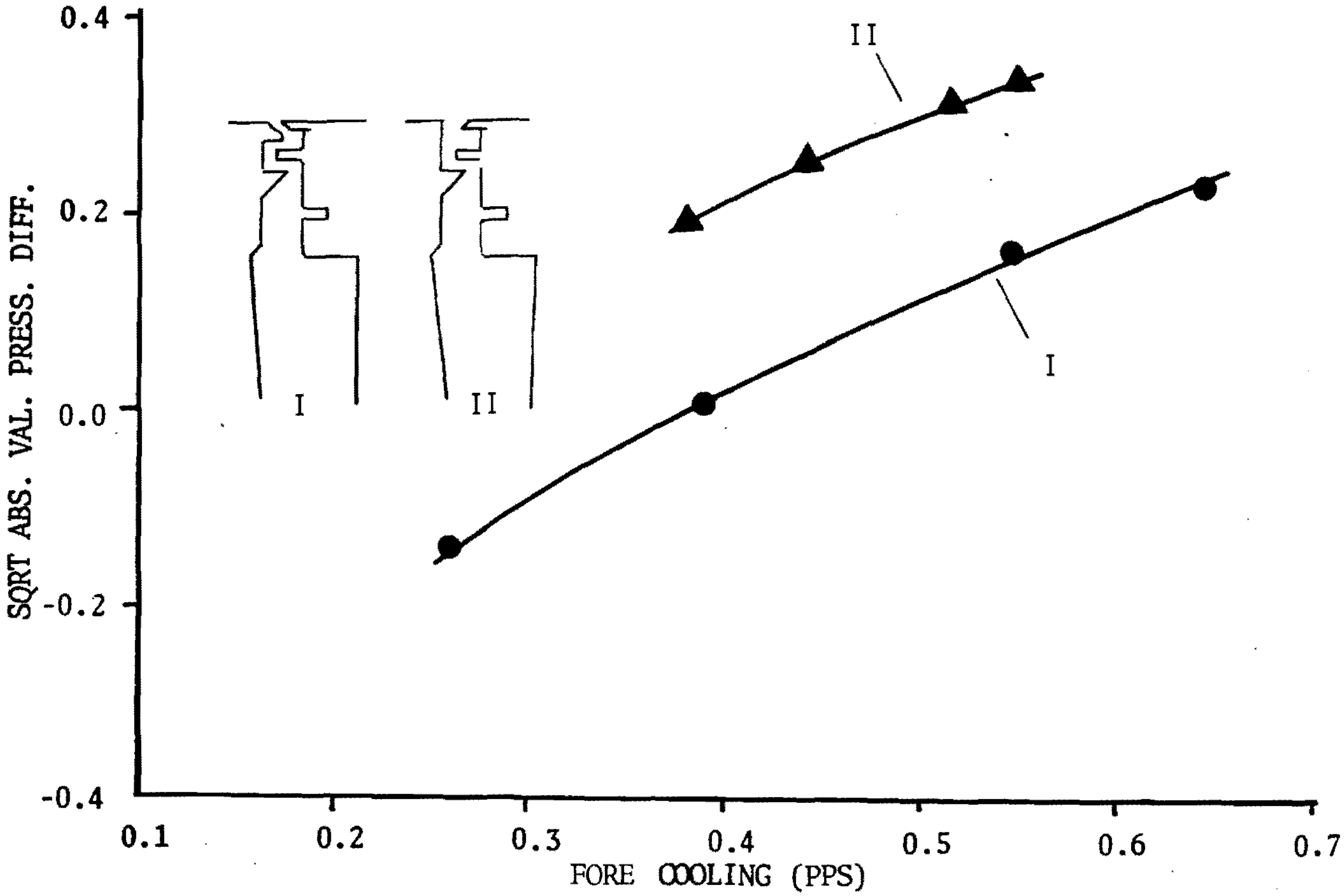


Figure V-4. Local Coolant Flow Across Radial Seal for Two Different Forward Rotating Seals, PT18 (II) and PT19 (I) (Circumferential Position 3).

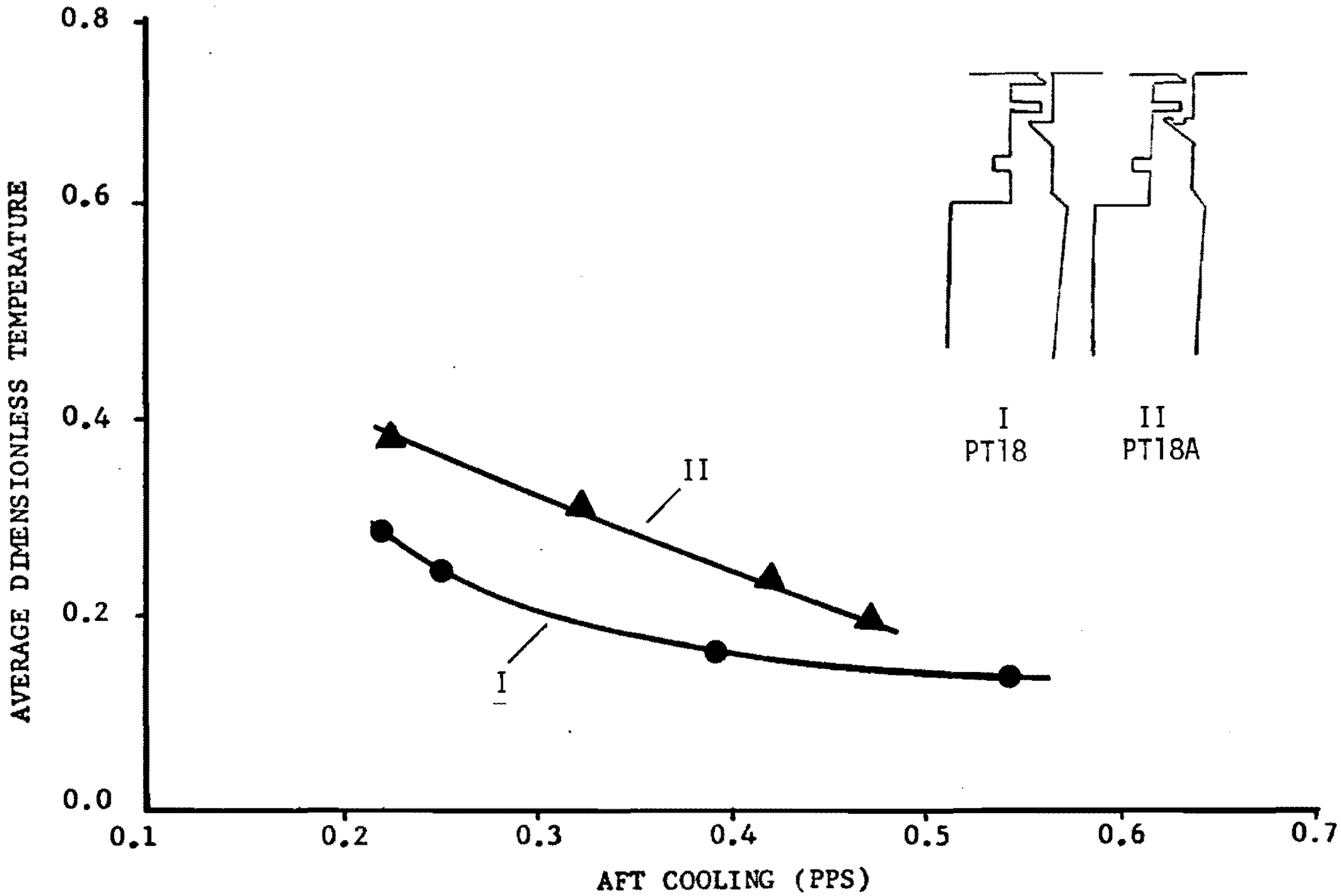


Figure V-5. Temperature at Position C4 for Aft Rotating Seals PT18 (I) and PT18A (II).

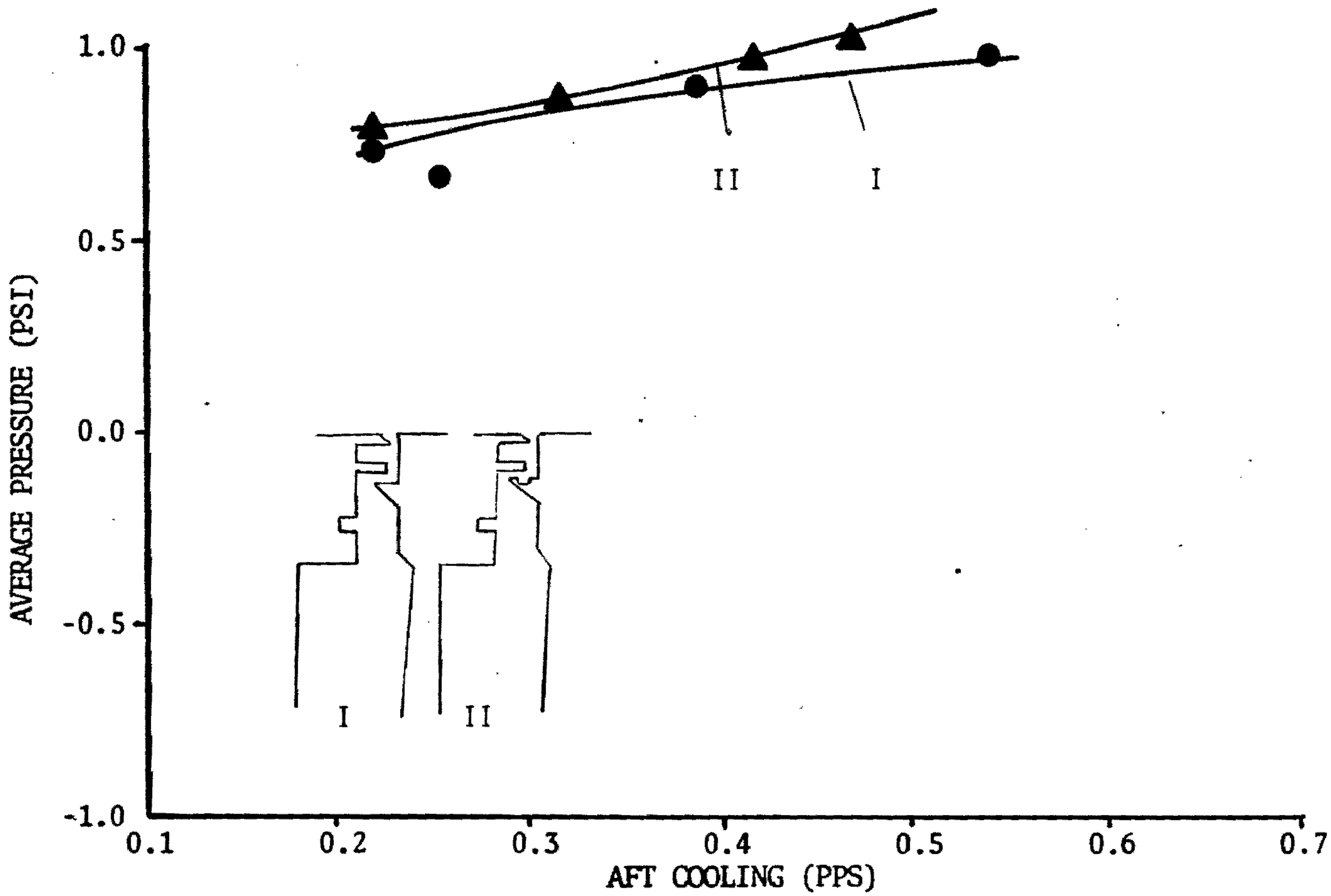


Figure V-6. Pressure at Position C4 for Aft Rotating Seals PT18 (I) and PT18A (II).

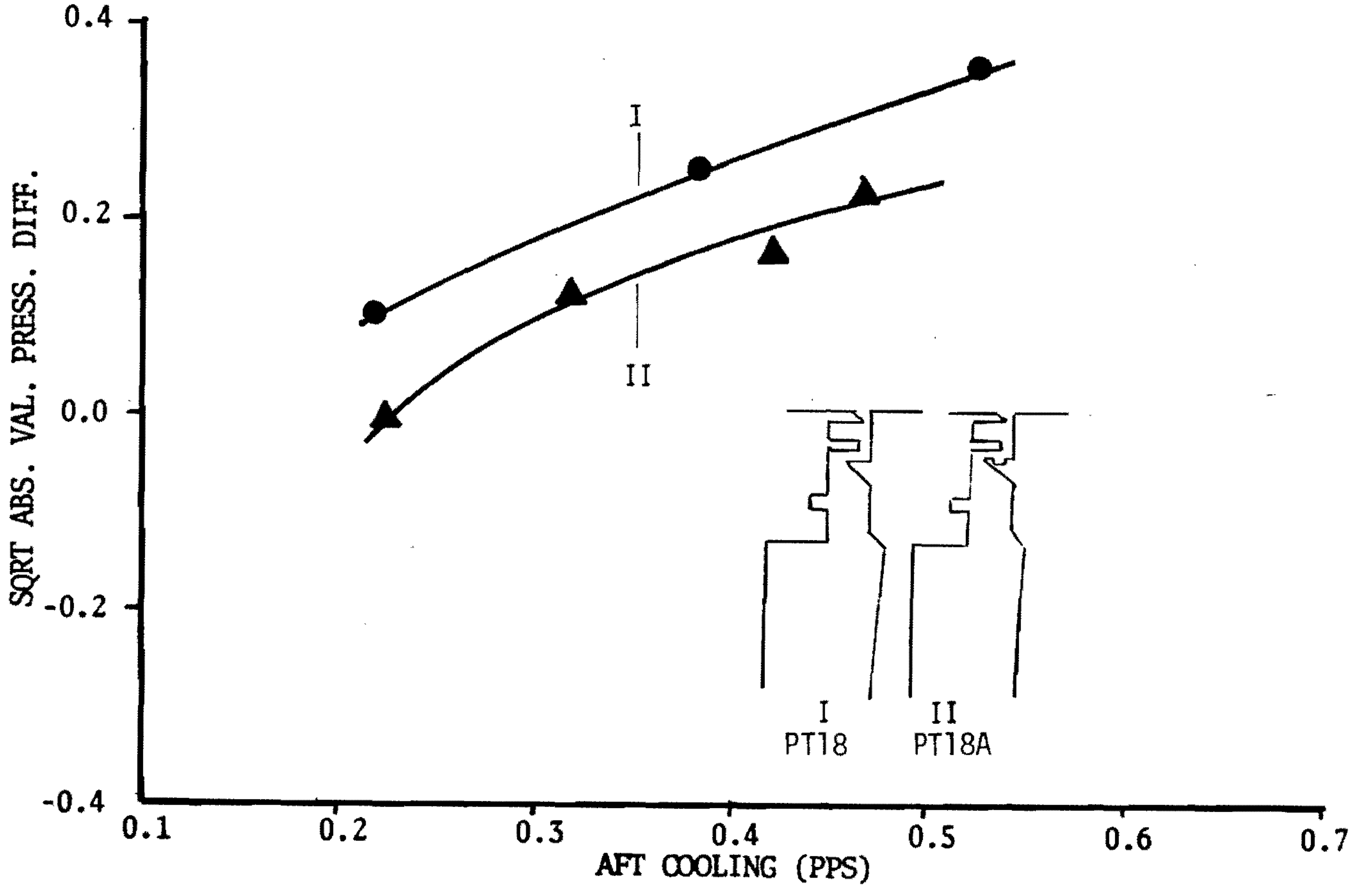


Figure V-7. **Local Coolant Flow Across Radial Seal and for Two Different Aft Rotating Seals, PT18 (I) and PT18A (II) Circumferential Position 3.**

Rim Spacing Effect

In order to see the effect of rim spacing (A in Figure III-2), two sets of experiments are run. On the forward side of the rotor rotating seals PT18 and PT19 are used. On the aft side seal PT18 is used. By holding the wheelspeed, rim flow, radial seal clearance and inner rotor-to-stator spacing constant, at 3000 rpm, 4 lbm/s., 0.1 inch and 1.0 inch respectively, the effect of rim spacing of 0.1, 0.2, 0.4 and 0.6 inches are evaluated.

When rotating seal PT18 is used, the wheelspace temperatures at either forward or aft positions are found to be higher for larger rim spacing. Figures V-8A and V-8B show the effect on wheelspace temperature of rim spacings at radial positions C2 and C4 respectively and Figure V-8C shows the forward temperatures at position B4. (Also see Figures AT1-B, AT4-B, AT5-B, AT6-B, AT13-A, AT14, AT15 and AT16). The wheelspace pressure and the local outflow of coolant is not affected by changing the rim spacings between the stator and the rotor. (See Figures V-9 to V-12, also see Figures AP1-B, AP4-B to AP6-B, AF1-B, AF4-B to AF6-B, AP13A, AP14 to AP16, and AF13-A, AF4 to AF6).

When rotating seal PT19 is used, decreasing the rim spacing to 0.2 inch lowers the wheelspace temperature at either radial position 2, or 4 but the further decrease in spacing seems to be detrimental (See Figures V-13A and V-13B, or compare Figures AT1-A and AT4-A to AT4-6 for rim spacing of 0.1 inch). The reversal in trend with reduced rim spacing is also seen for the wheelspace pressure (Figure V-15) and radial seal flow (Figure V-14).

Comparisons of Figure AT1-B and AT13-A, AT4-B and AT14, AT15-B

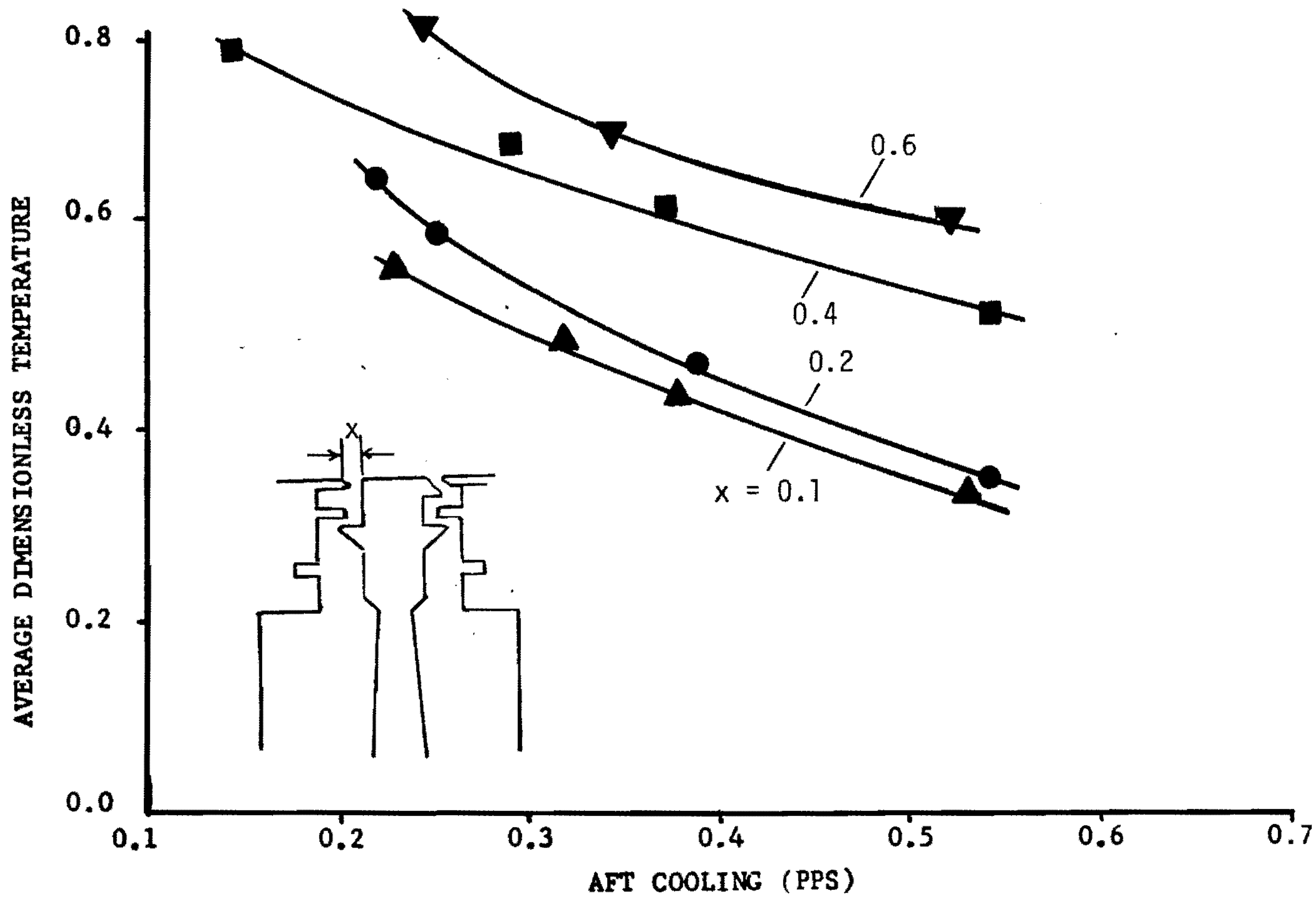


Figure V-8A. Rim Spacing Effect on Temperature, Seal PT18, Position C2.

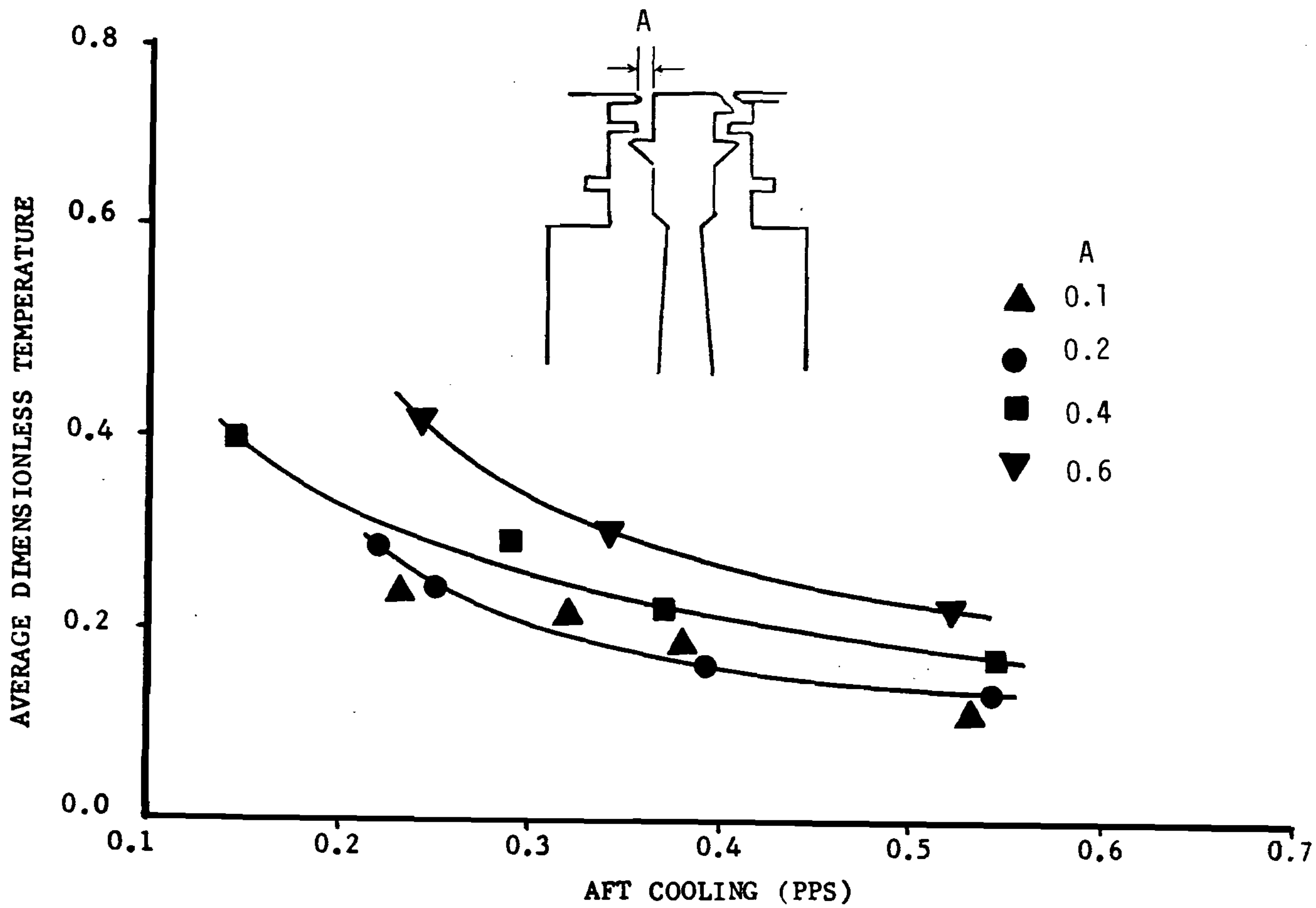


Figure V-8B. Rim Spacing Effect on Temperature, Seal PT18, Position C4.

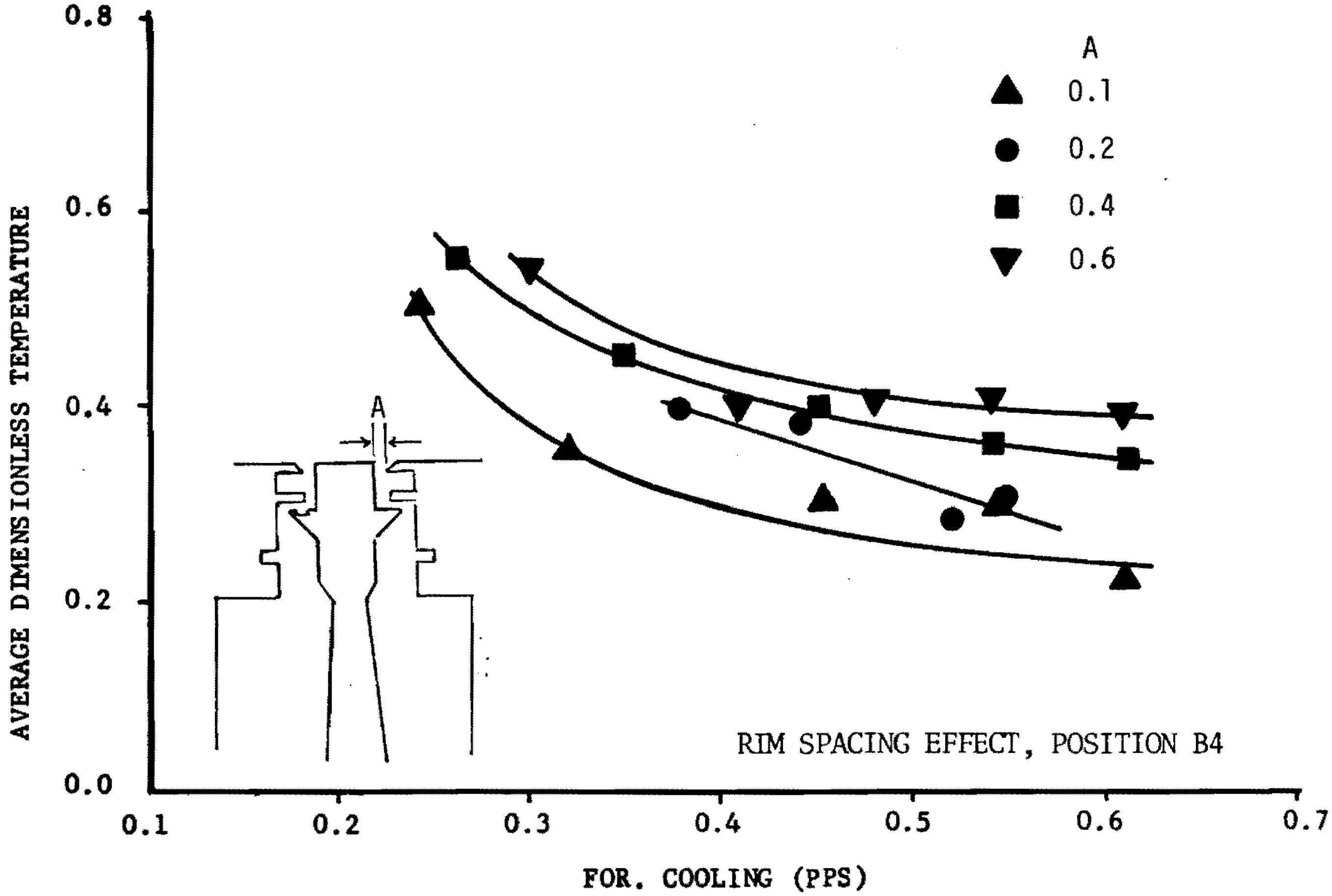


Figure V-8C. **Rim Spacing Effect on Temperature, Seal PT18, Position B4.**

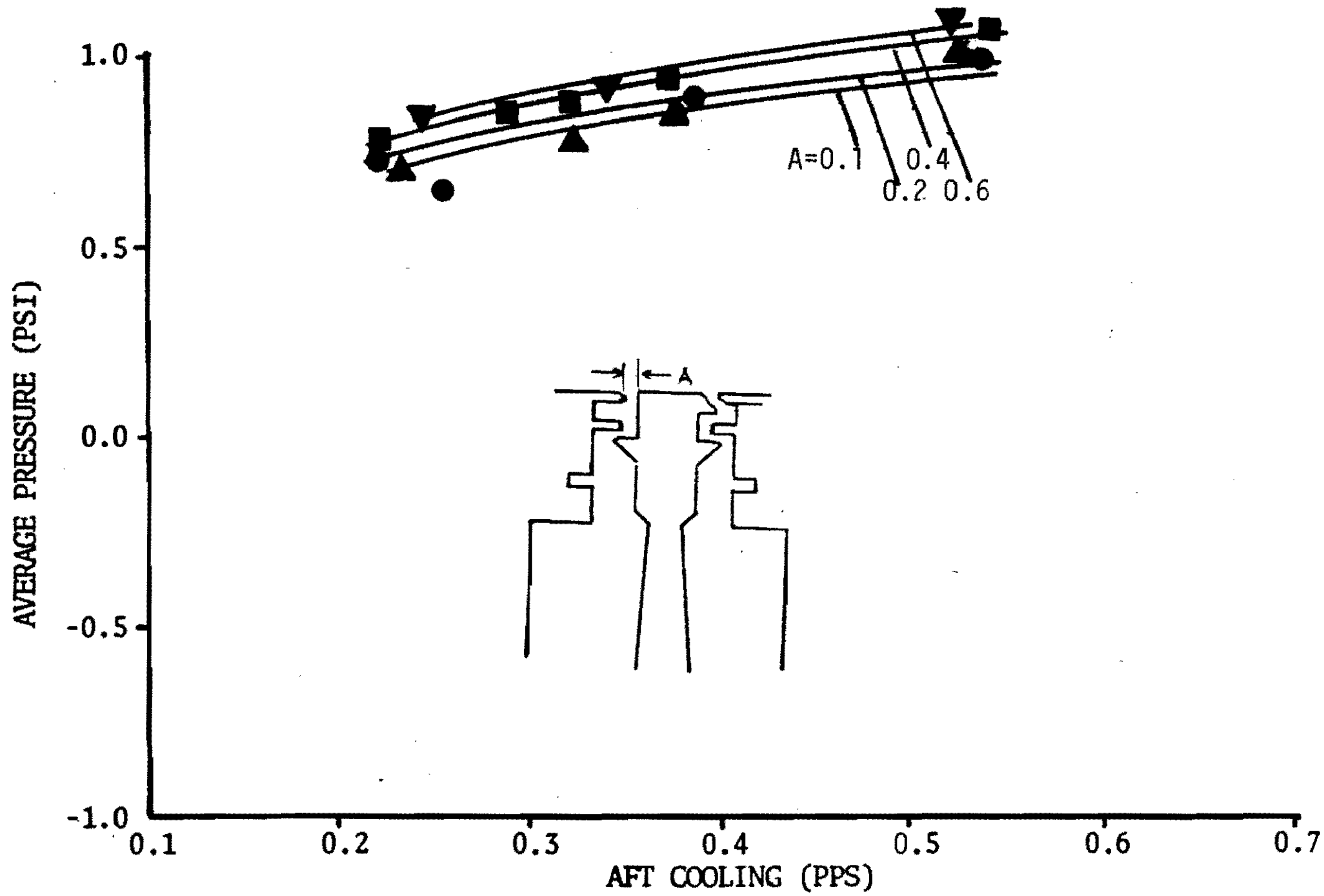


Figure V-9. Rim Spacing Effect on Pressure, Seal PT18, Position C4.

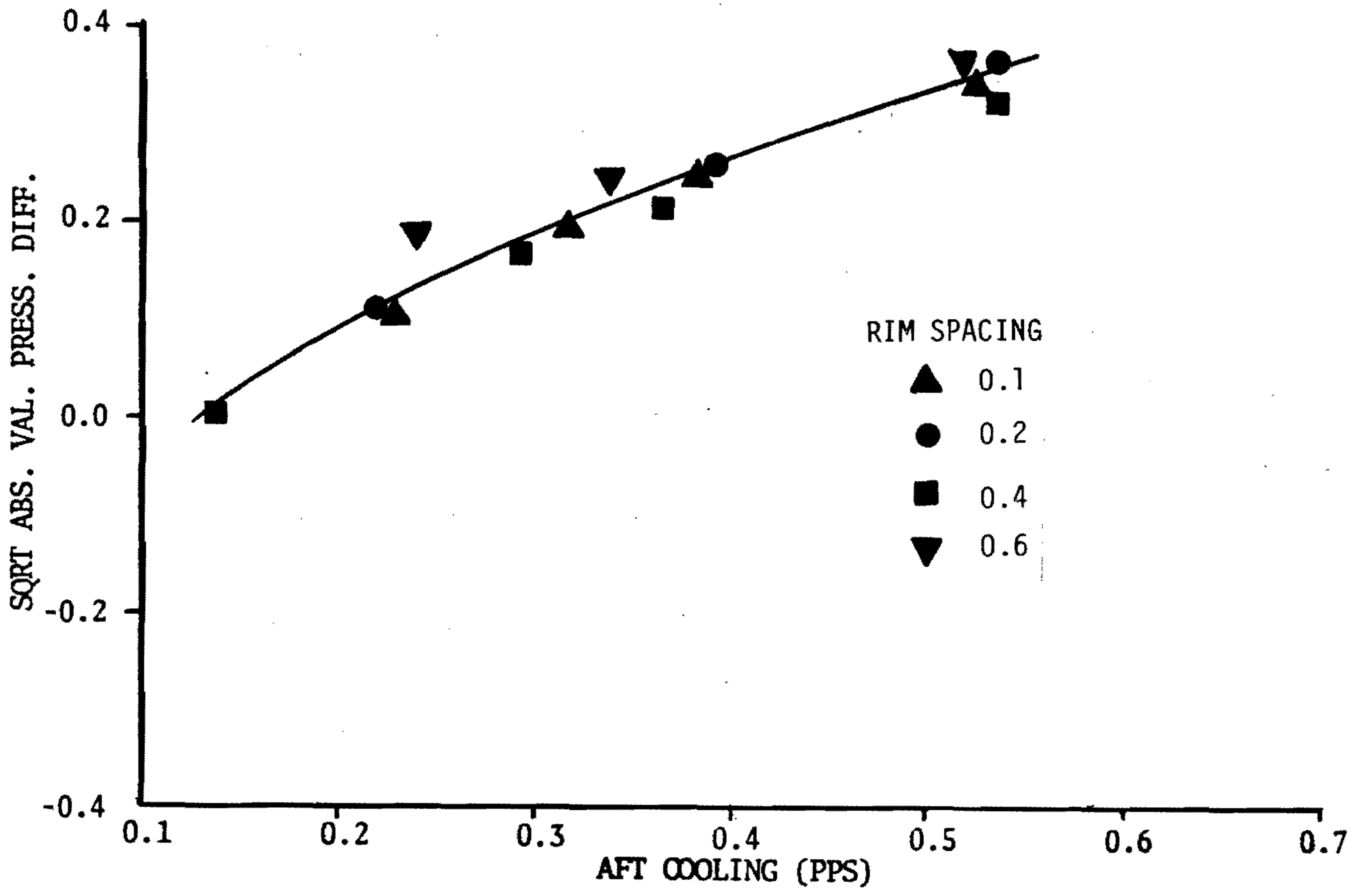


Figure V-10. Aft Local Flow Across the Radial Seal for Different Rim Spacing, Seal PT18, Position 3.

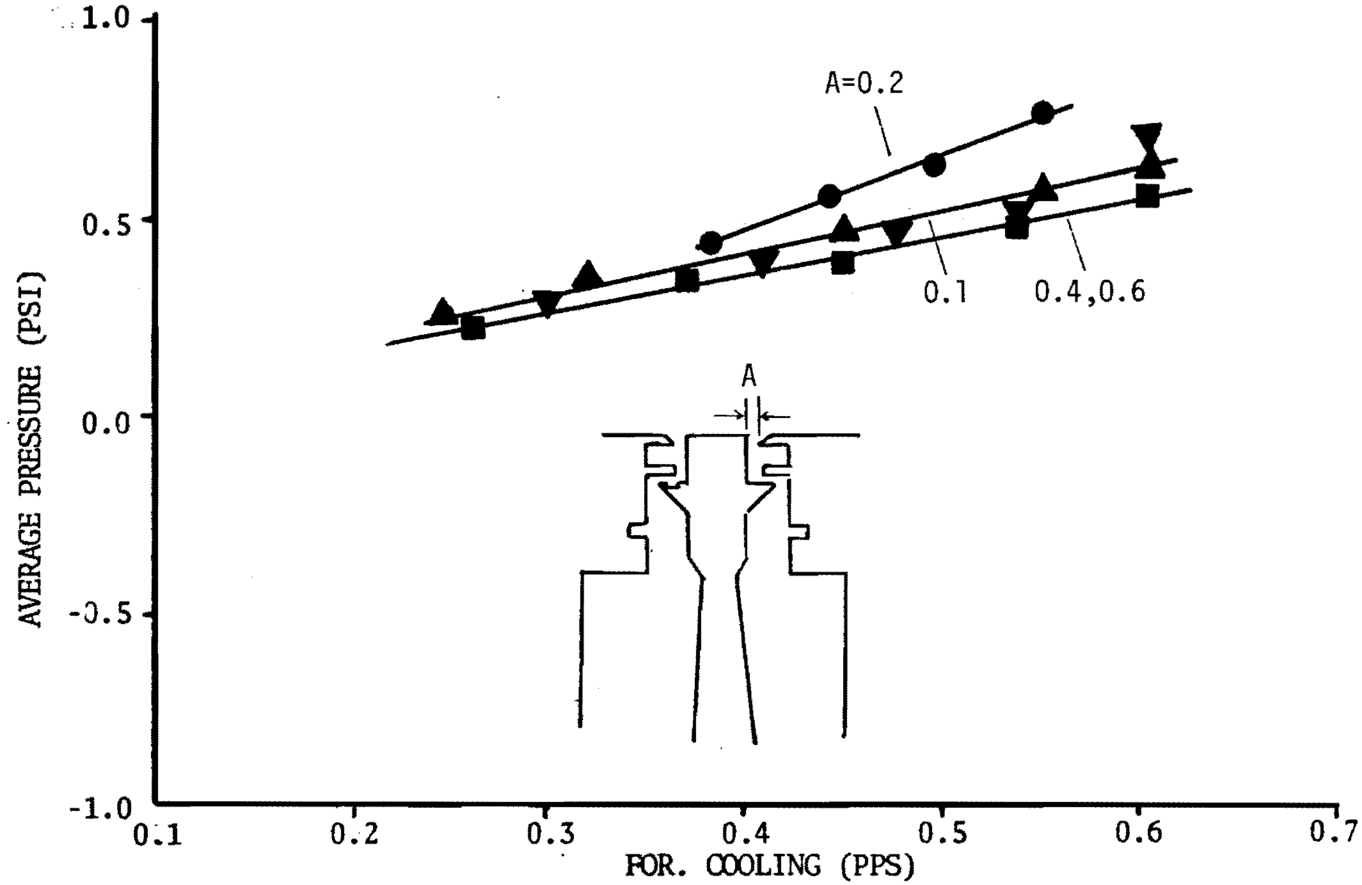


Figure V-11. **Rim Spacing Effect on Pressure, Seal PT18, Position B2.**

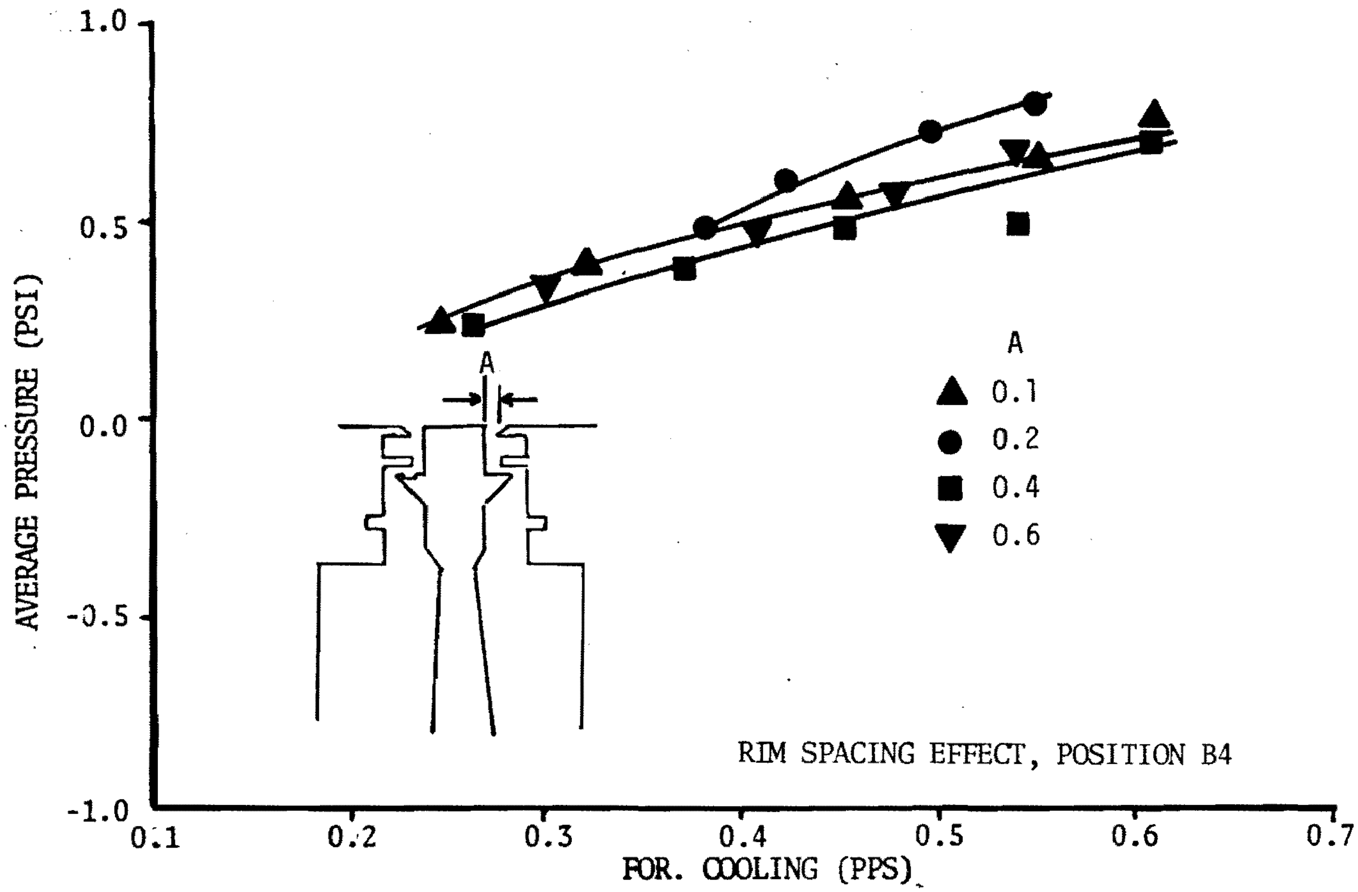


Figure V-12. **Rim Spacing Effect on Pressure, Seal PT18, Position B4.**

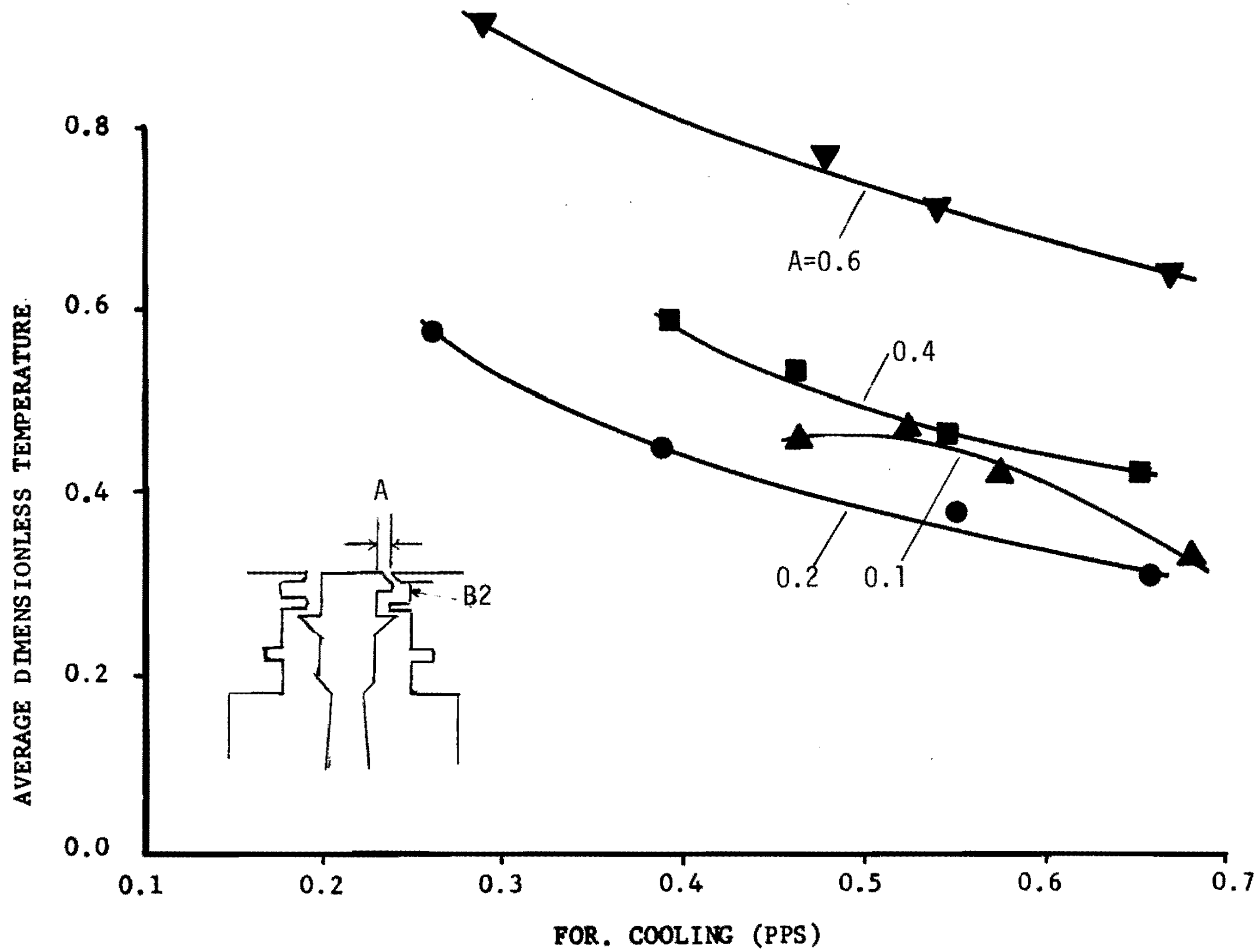


Figure V-13A. Rim Spacing Effect on Temperature, Seal PT19, Position B2.

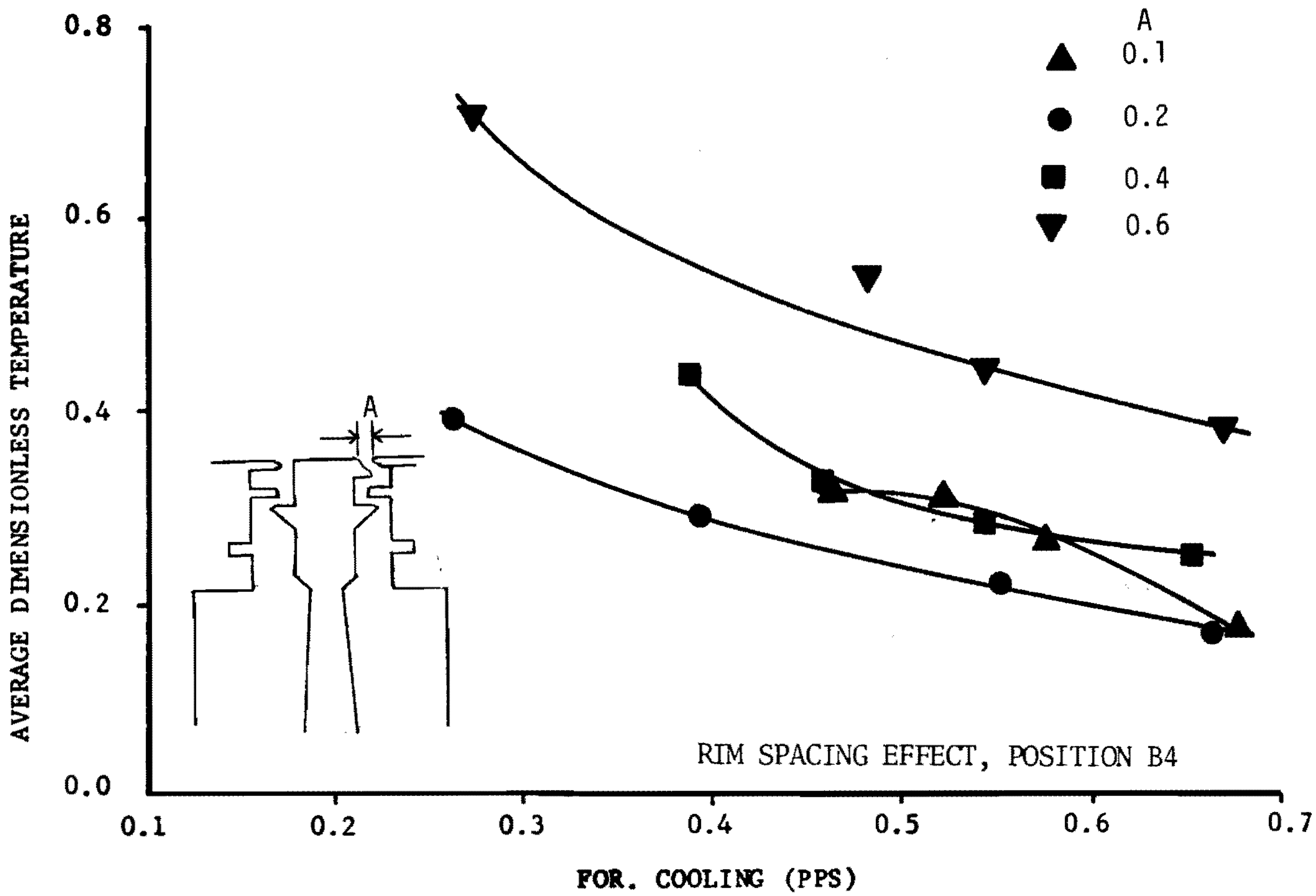


Figure V-13B. Rim Spacing Effect on Temperature, Seal PT19, Position B4.

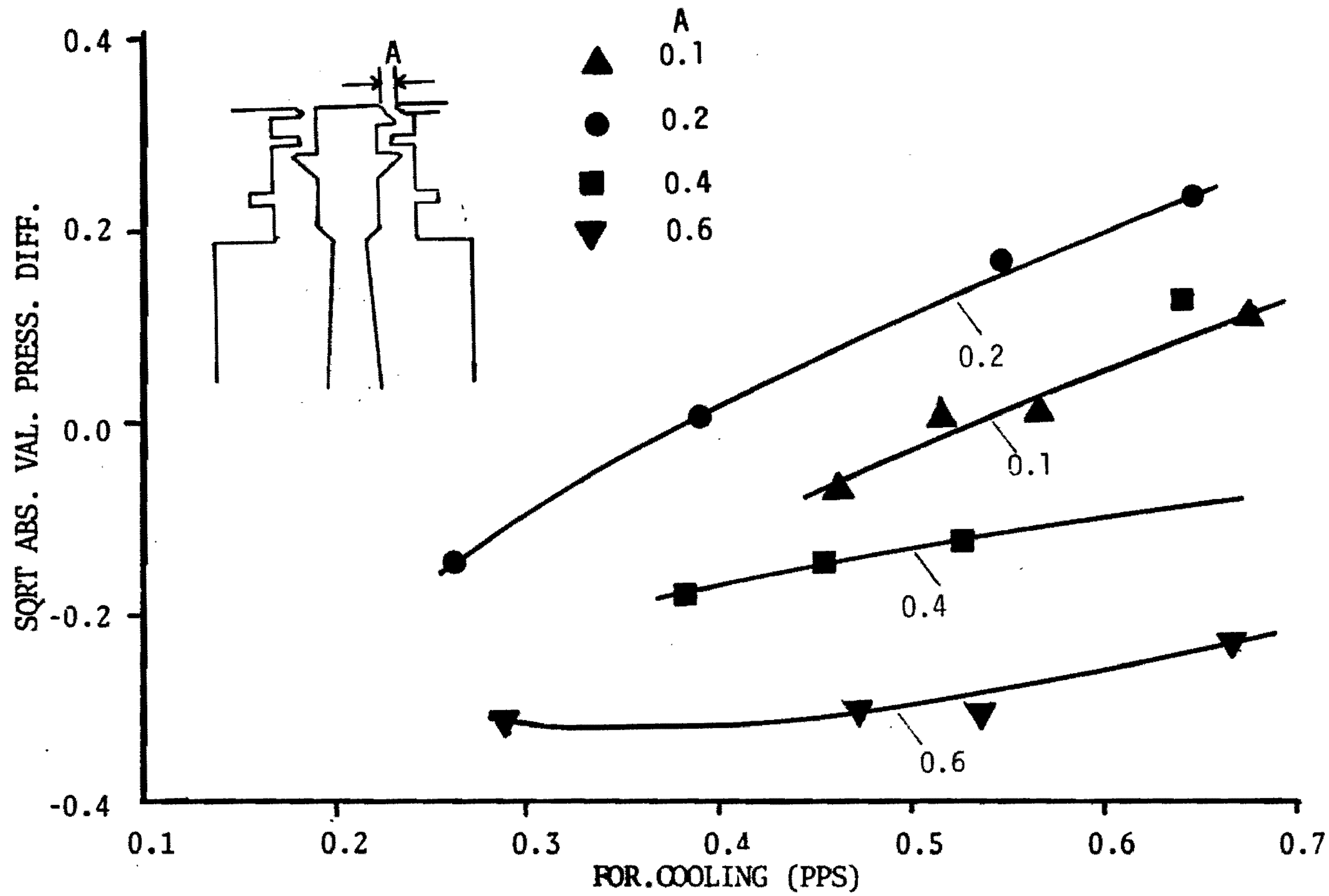


Figure V-14. Rim Spacing Effect on Forward Local Flow Across the Radial Seal, Seal PT19, Position 3.

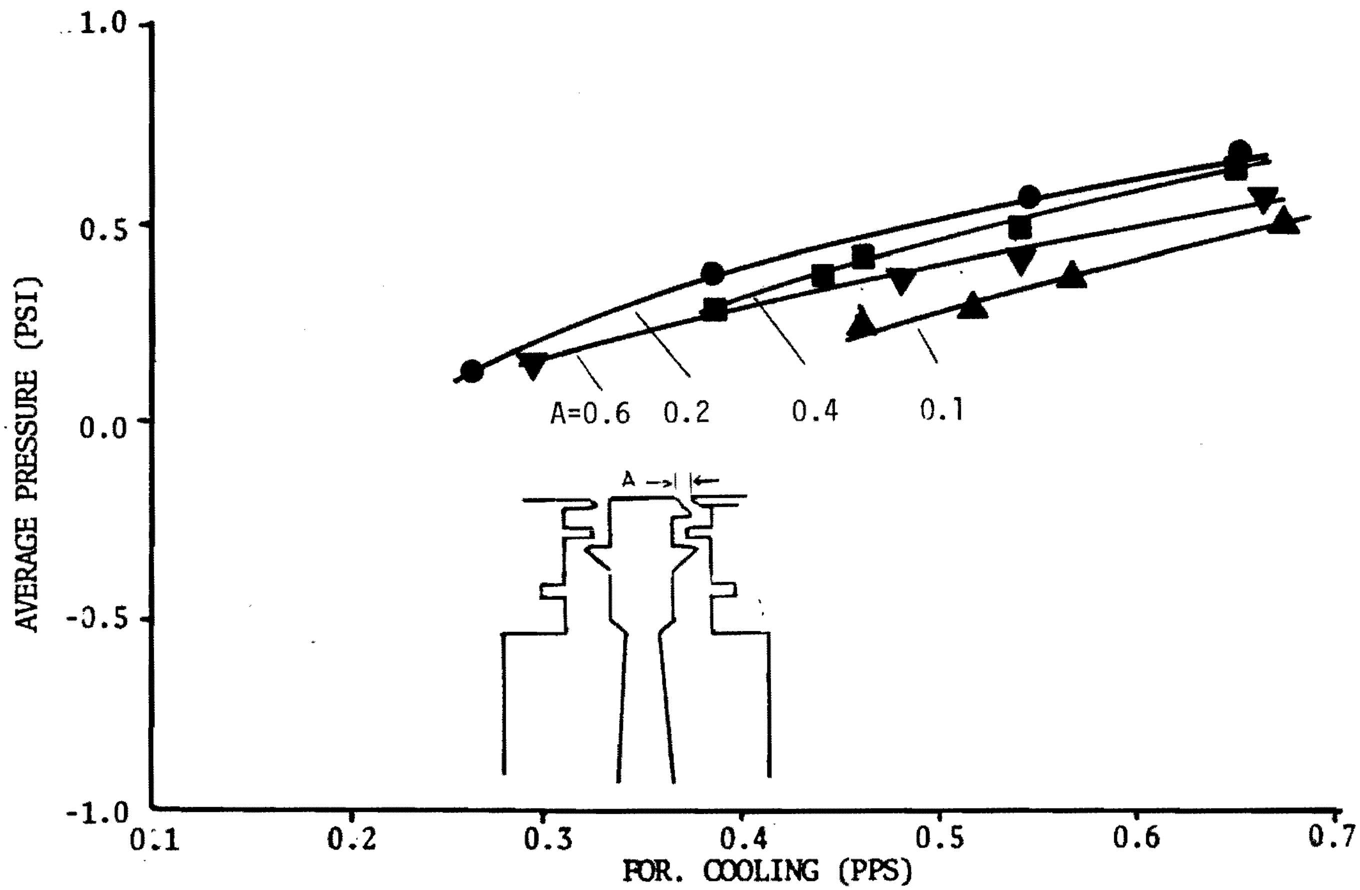


Figure V-15. Rim Spacing Effect on Pressure, Seal PT19, Position B4.

and AT15, and AT6-B and AT16 show they have the same slope for the forward and aft side of the wheel for a given rim spacing and rotating seal geometry. Therefore, the rim spacing plays an equally important role on the forward as well as the aft side of the wheel.

Rotor-to-Stator Inner Spacing

At a rim flow of 4 lbm/s, wheelspeed of 3000 rpm, radial seal clearance 0.1 inch, rim spacing 0.2 inch, the effect of inner rotor-to-stator spacing (D in Figure III-2) of 0.75 inch, 1.0 inch and 1.5 inch is evaluated. The forward seal employed is PT18 and the aft is PT18 or PT18-A.

On the forward side with seal PT18, wheelspace temperatures decrease for smaller rotor-to-stator inner spacings (Figure V-16). It is believed that the corresponding lower temperature at smaller spacing is a result of the changing character of the convection heat transfer from the stator as the spacing decreases. For a constant cooling flow a decrease in rotor-stator spacing increases the local velocity and hence the local convection coefficient. Comparisons of the effect of rotor-to-stator spacing for positions B2, B3, B5 and B6 can be made by examining Figures AT13-A, AT19-A and AT20-A.

On the aft side, using seal PT18, the temperature versus cooling curves for inner rotor-to-stator spacing of 1.5 inch, 0.75 inch, and 1.0 inch are shown in Figure V-17 for radial position C4. The lowest wheelspace temperature is for a 1.0 inch spacing. Figures AT1-B, AT9 and AT10 can be compared to see the rotor-to-stator inner spacing effect for position B2, B5, B6, B7, A7, F7, B8, A8 and F8. The above results show the temperature effect due to inner rotor-to-stator spacing is

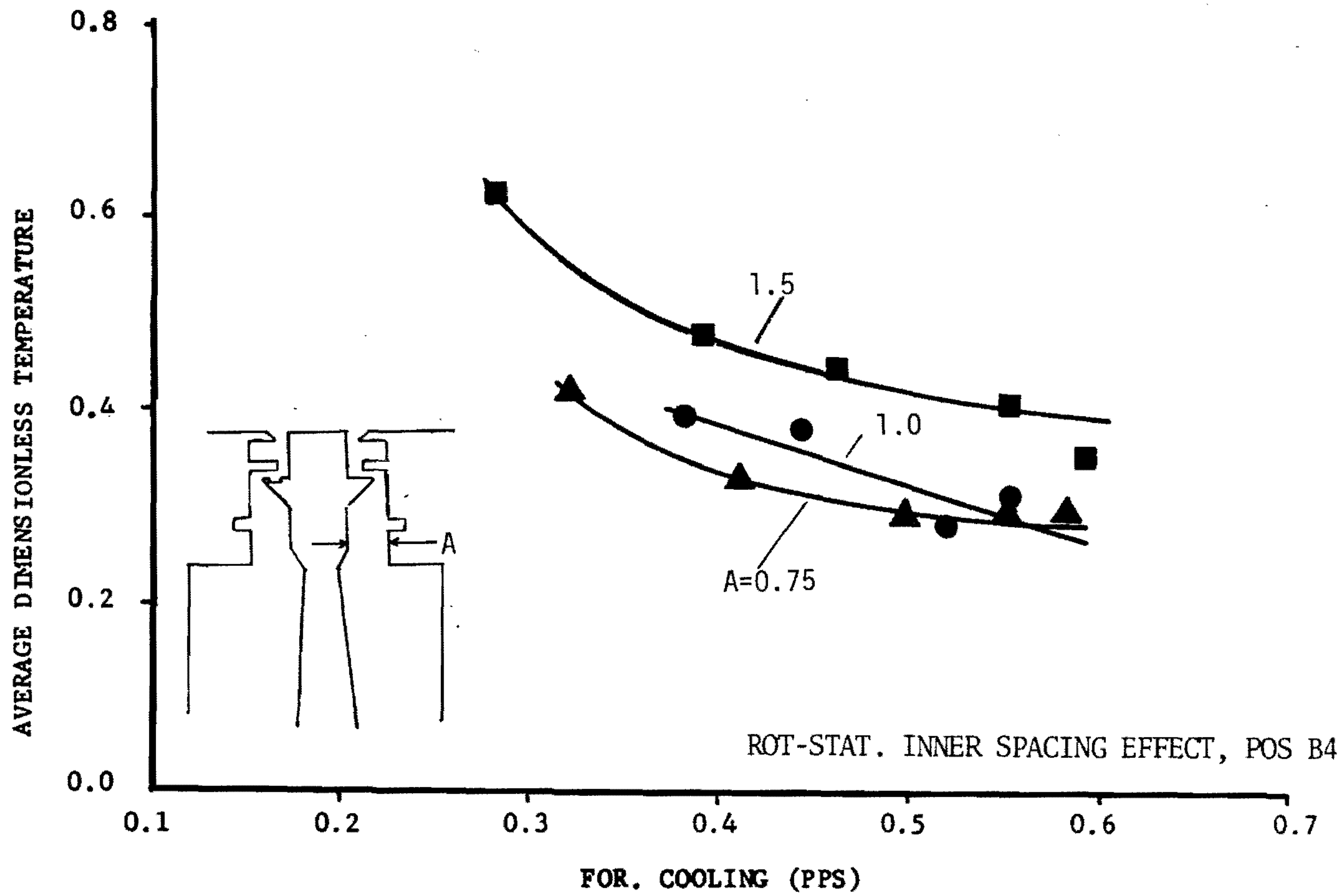


Figure V-16. Rotor-Stator Inner Spacing Effect on Temperature, Seal PT18, Position B4.

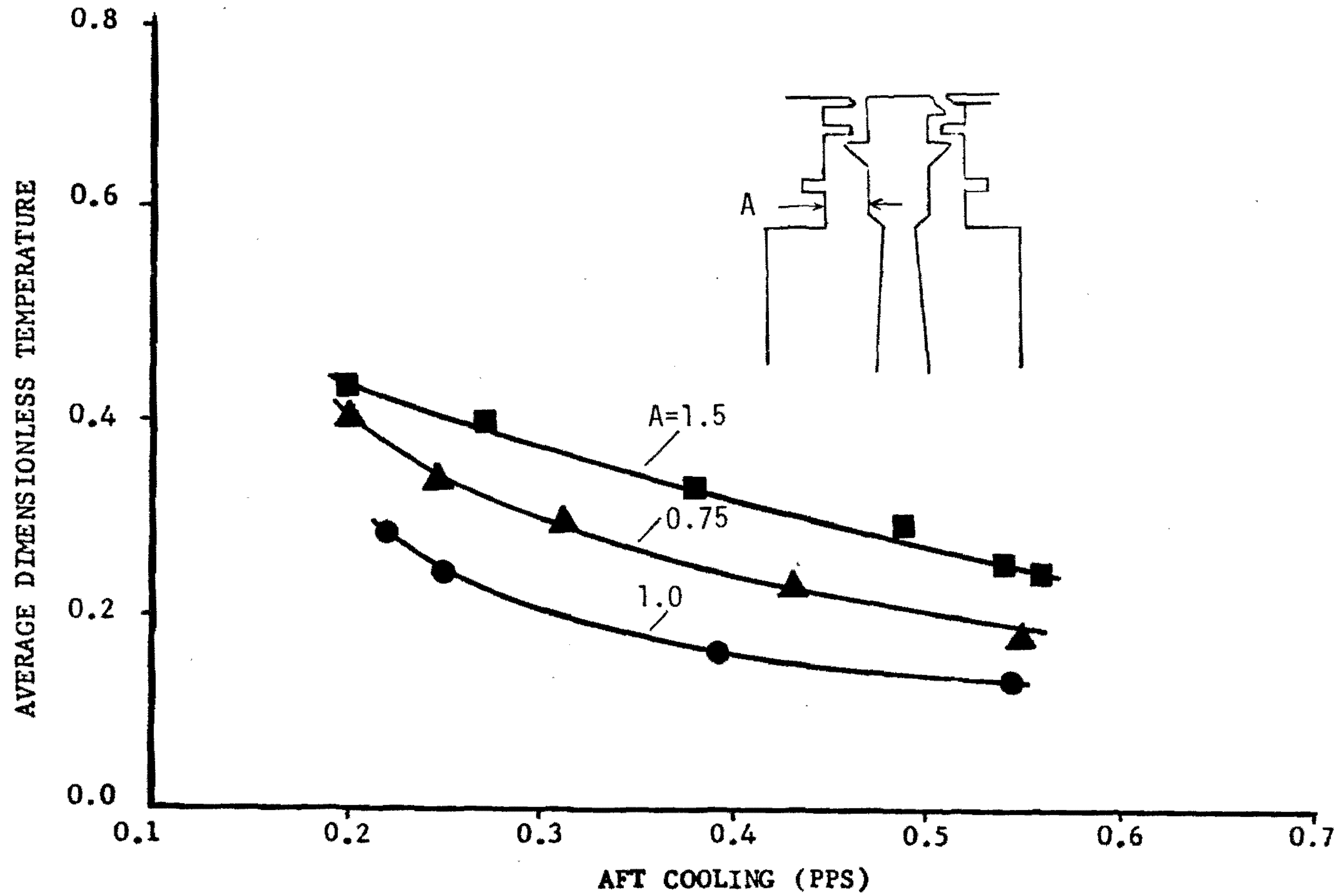


Figure V-17. Rotor-Stator Inner Spacing Effect on Temperature, Seal PT18, Position C4.

significant when seal PT18 is used. However, when using seal PT18-A, Figure V-18A and V-18B show the wheelspace temperature changes due to different inner spacings between the rotor and stator are negligible. Figures AT19-B and AT20-B are the results of rotor-to-stator spacings of 0.75 inch and 1.5 inch.

For all the above cases, on the forward or aft side of the wheel, the wheelspace pressure difference due to the different rotor-to-stator inner spacing is small. (See Figures V-19, V-20A and V-20B and compare Figures AP1-A, AP9 and AP10 and AP13, AP19 and AP20).

Comparison of Figures V-16, V-17, and V-18B with corresponding cooling outflow (square root of pressure difference) in Figures V-22A and V-21 and V-22B respectively seems to present an inconsistancy. It is expected that when more cooling outflow occurs the wheelspace temperature would be lower because (1) more cooling air is present to convect away the heat conducted through the wheel and stator, and (2) less hot gas would penetrate the wheelspace. However, this trend is not present in the data. No explanation for this inconsistancy is available at this time.

Radial Seal Clearance

The effect of radial seal clearance of 0.05 inch, 0.1 inch and 0.15 inch are evaluated. The experiments were run for several cooling supply rates, 4 lbm/s rim flow, 3000 rpm wheelspeed, 0.2 inch rim spacing and 1.0 inch rotor-to-stator inner spacings. PT18 and PT19 rotating seals are used on the forward side of the wheel and PT18 and PT18-A on the aft side. The results are presented in Figures V-23 to V-35.

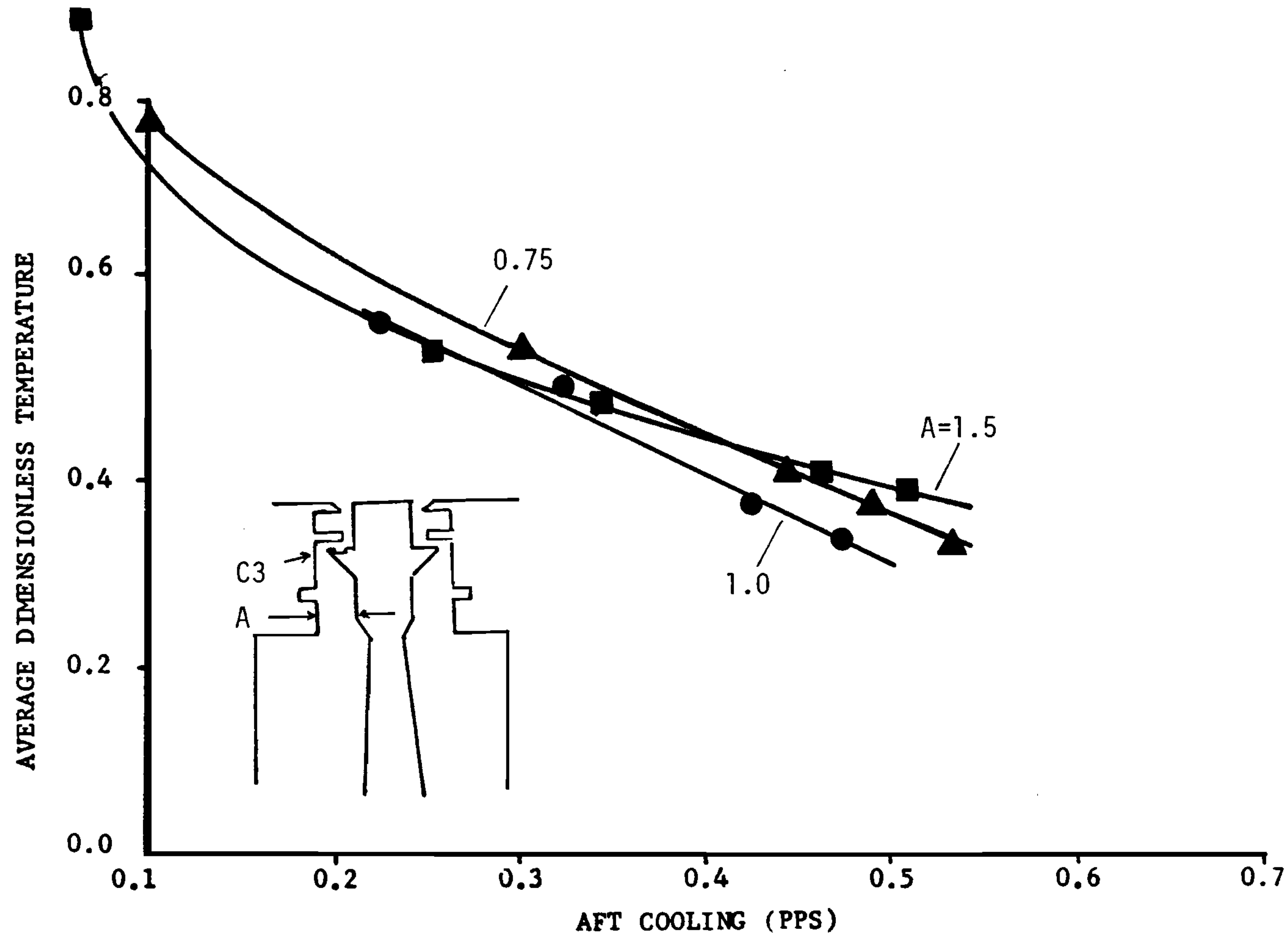


Figure V-18A. **Rotor-Stator Inner Spacing Effect on Temperature, Seal PT18A, Position C3.**

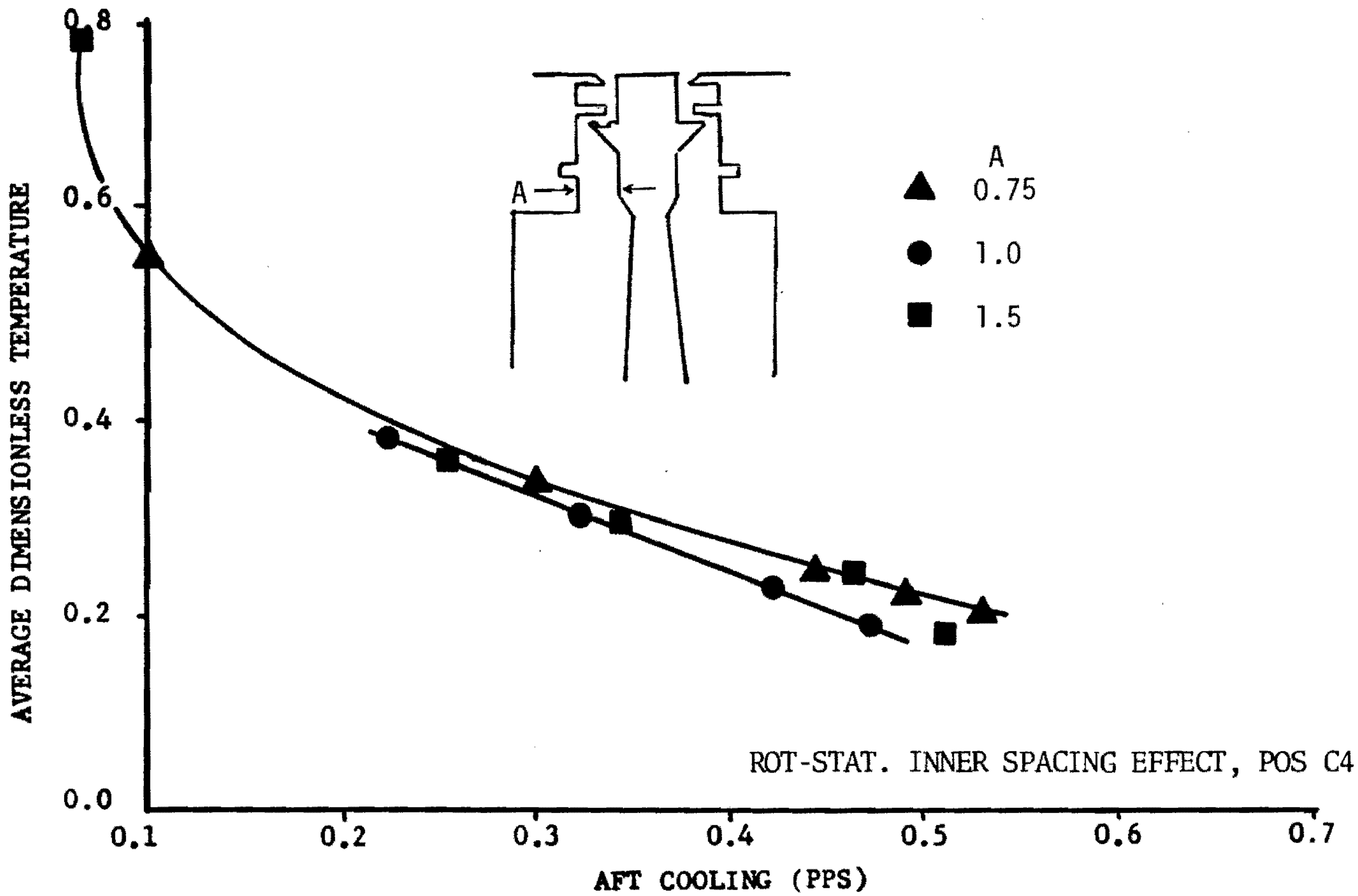


Figure V-18B. Rotor-Stator Inner Spacing Effect on Temperature, Seal PT18A, Position C4.

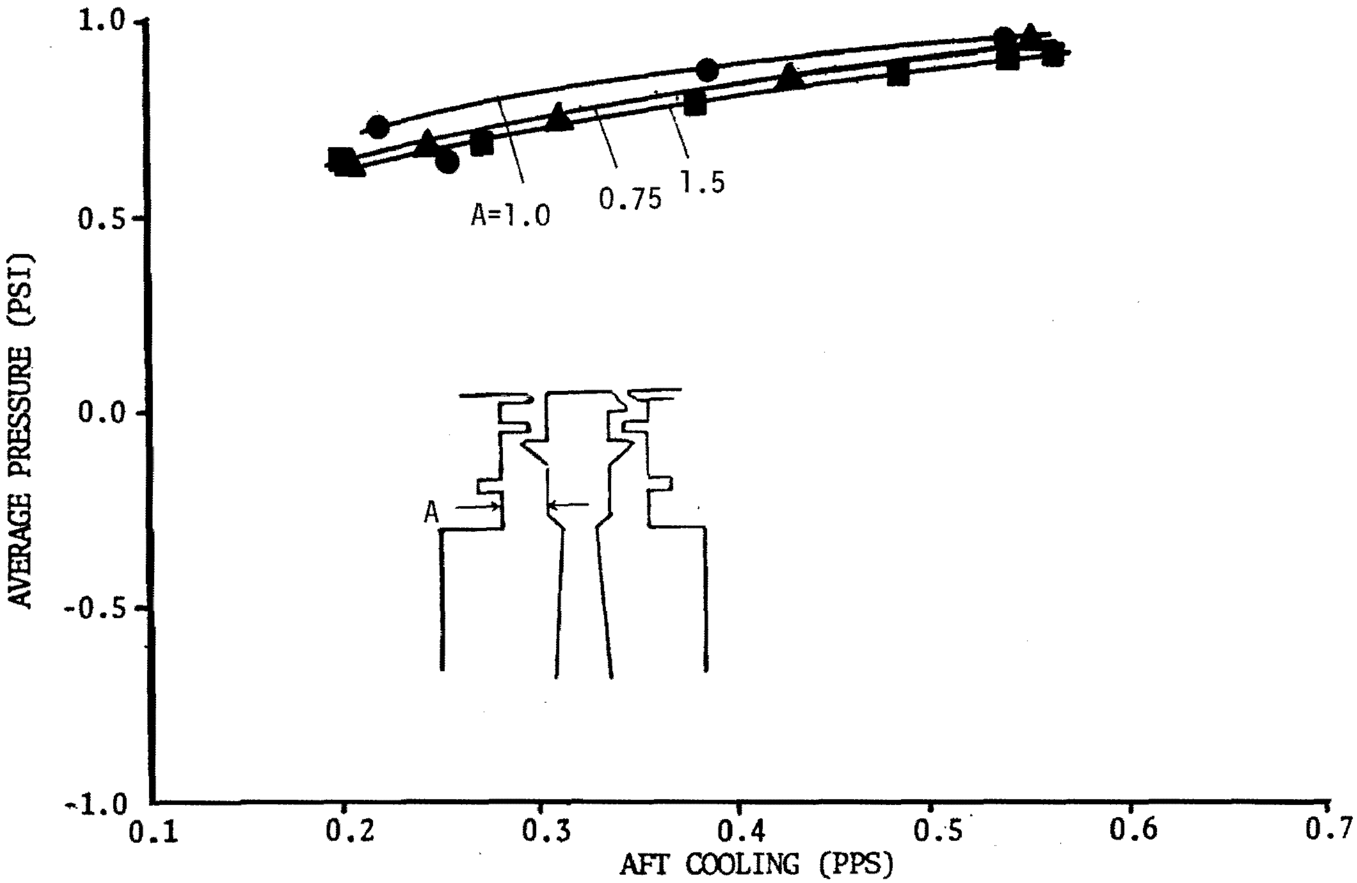


Figure V-19. Rotor-Stator Inner Spacing Effect on Pressure, Seal PT18, Position C3.

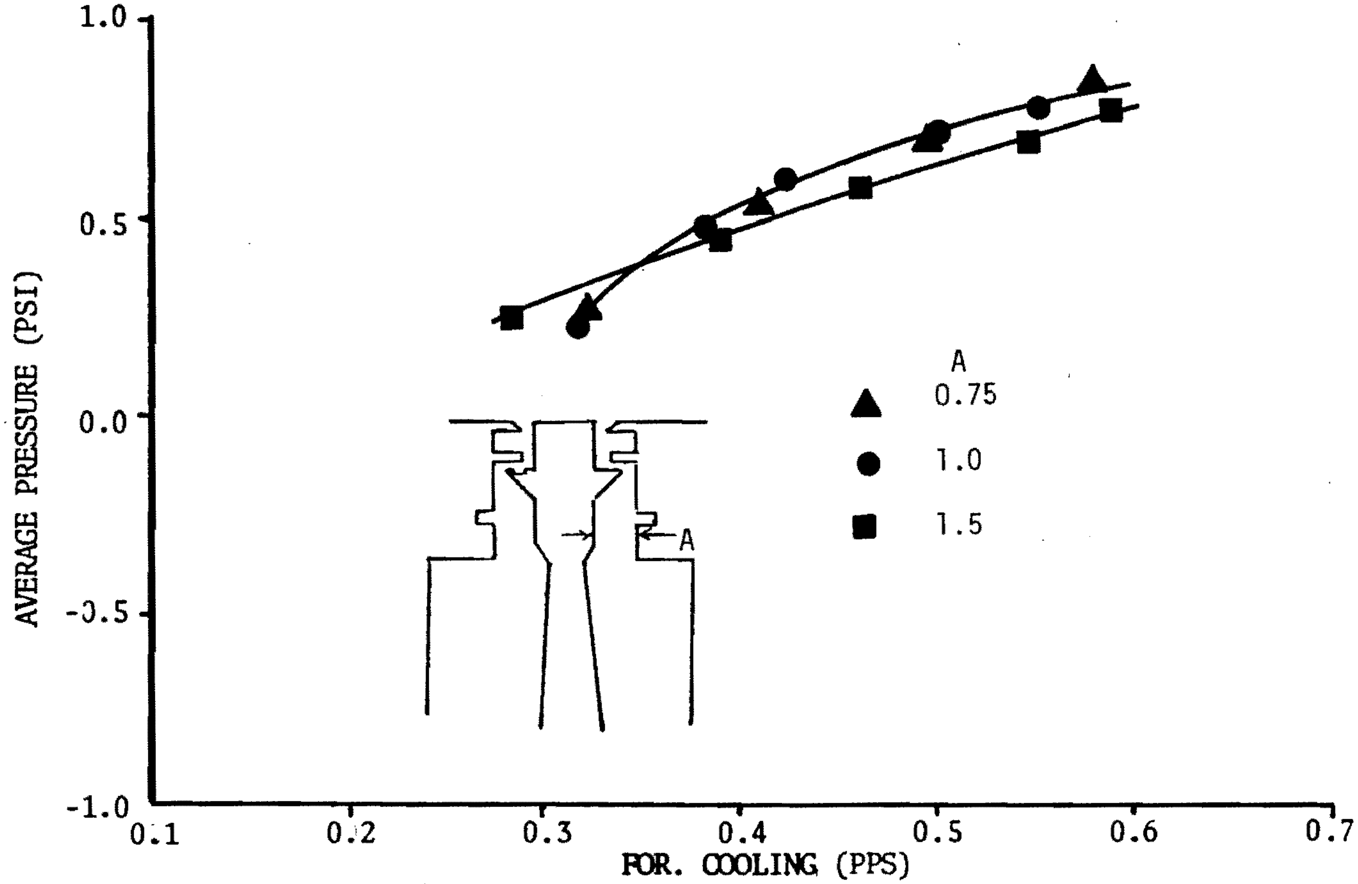


Figure V-20A. Rotor-Stator Inner Spacing Effect on Pressure, Seal PT18, Position B4.

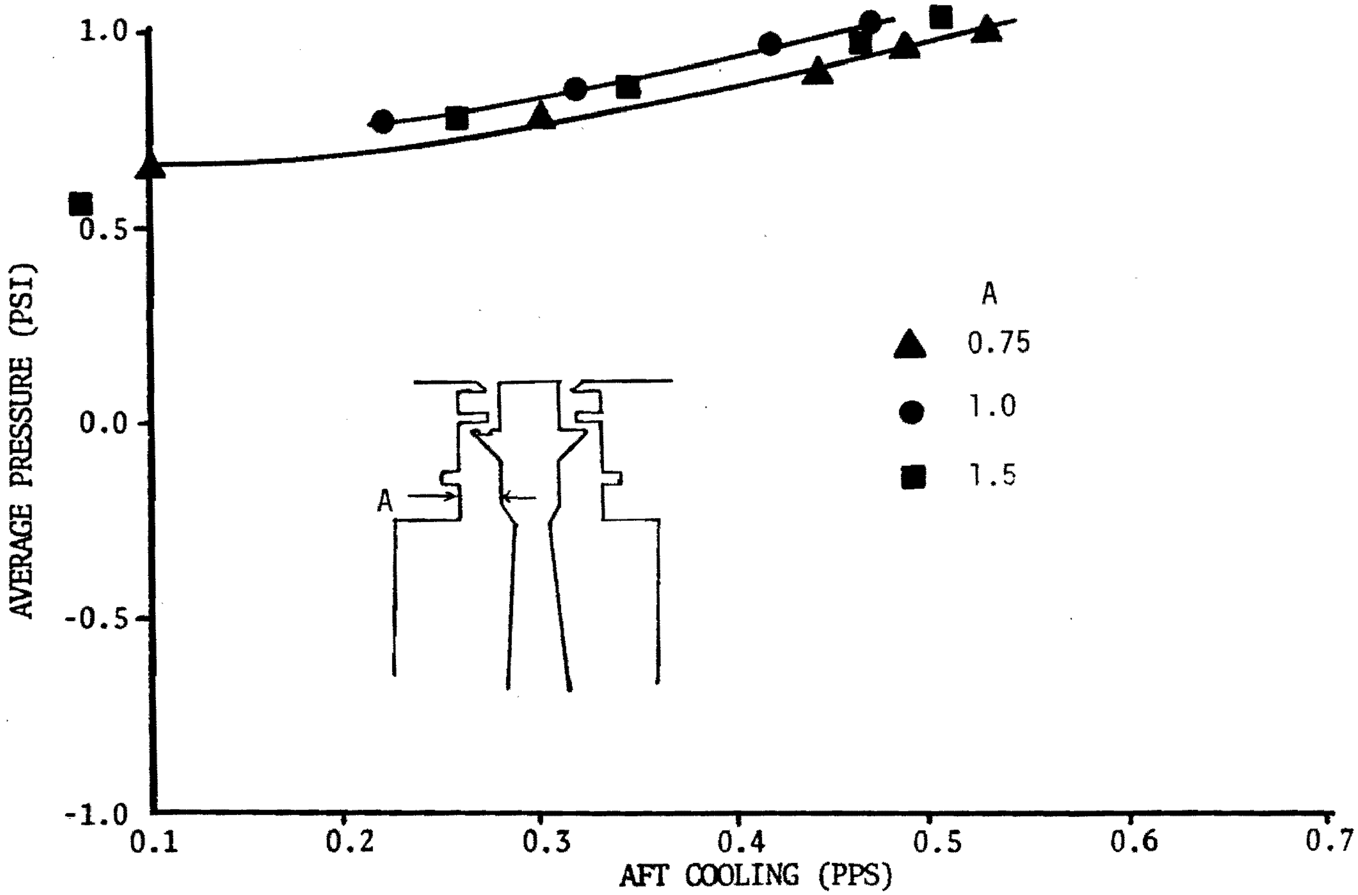


Figure V -20B. Rotor-Stator Inner Spacing Effect on Pressure, Seal PT18A, Position C4.

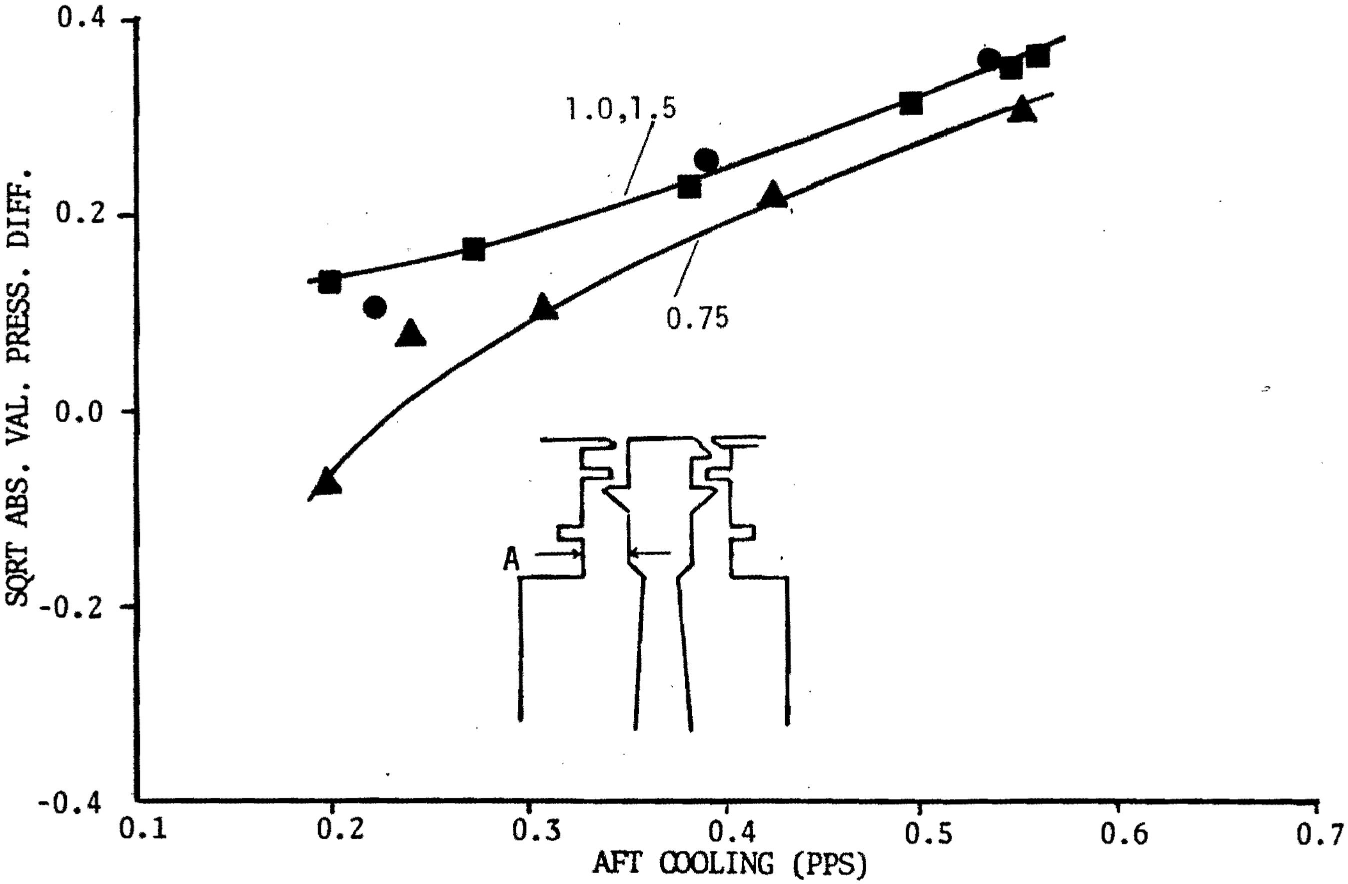


Figure V-21. Rotor-Stator Inner Spacing Effect on Aft Local Flow, Seal PT18, Position 3.

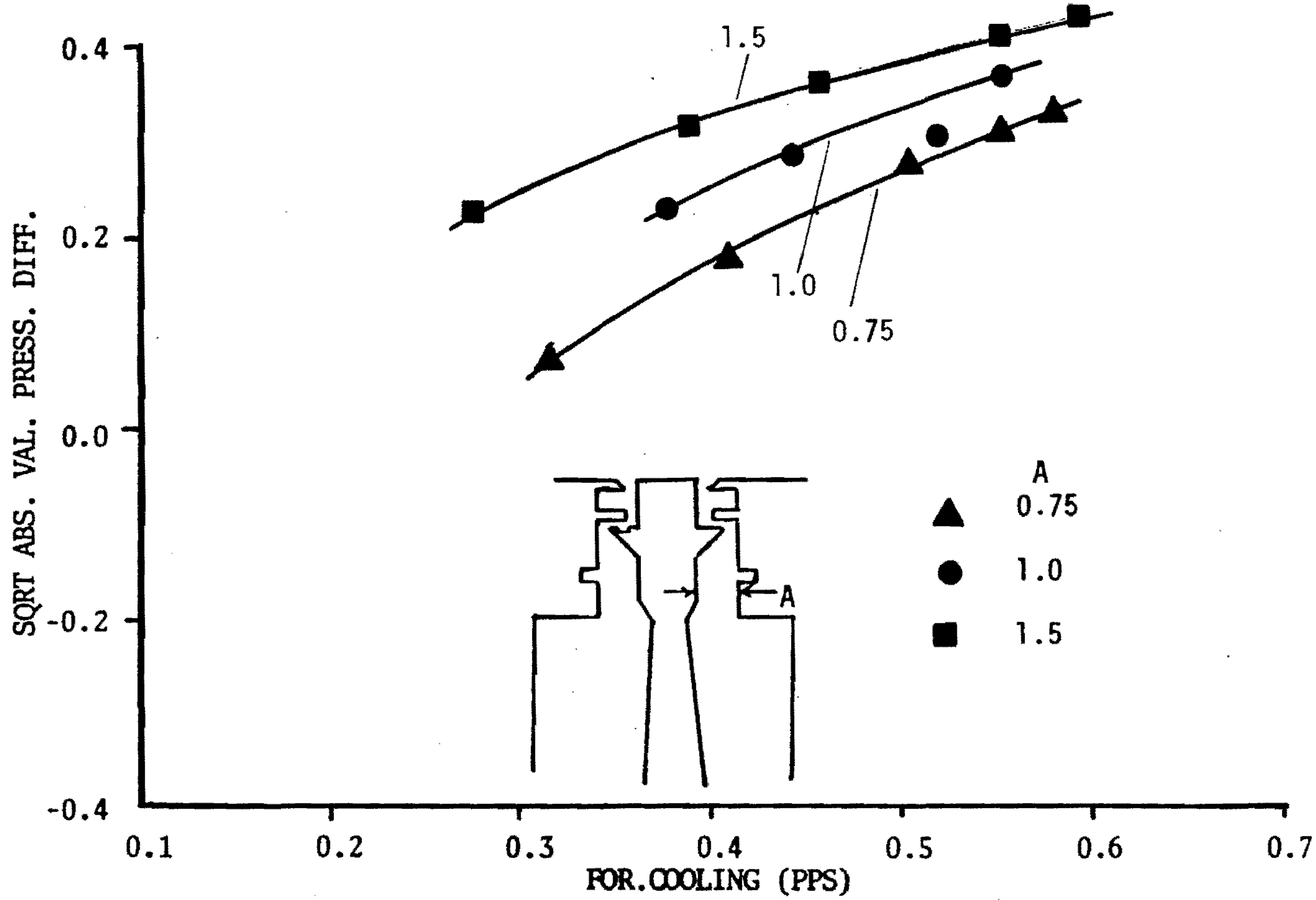


Figure V-22A. Rotor-Stator Inner Spacing Effect on Forward Local Flow, Seal PT18, Position 3.

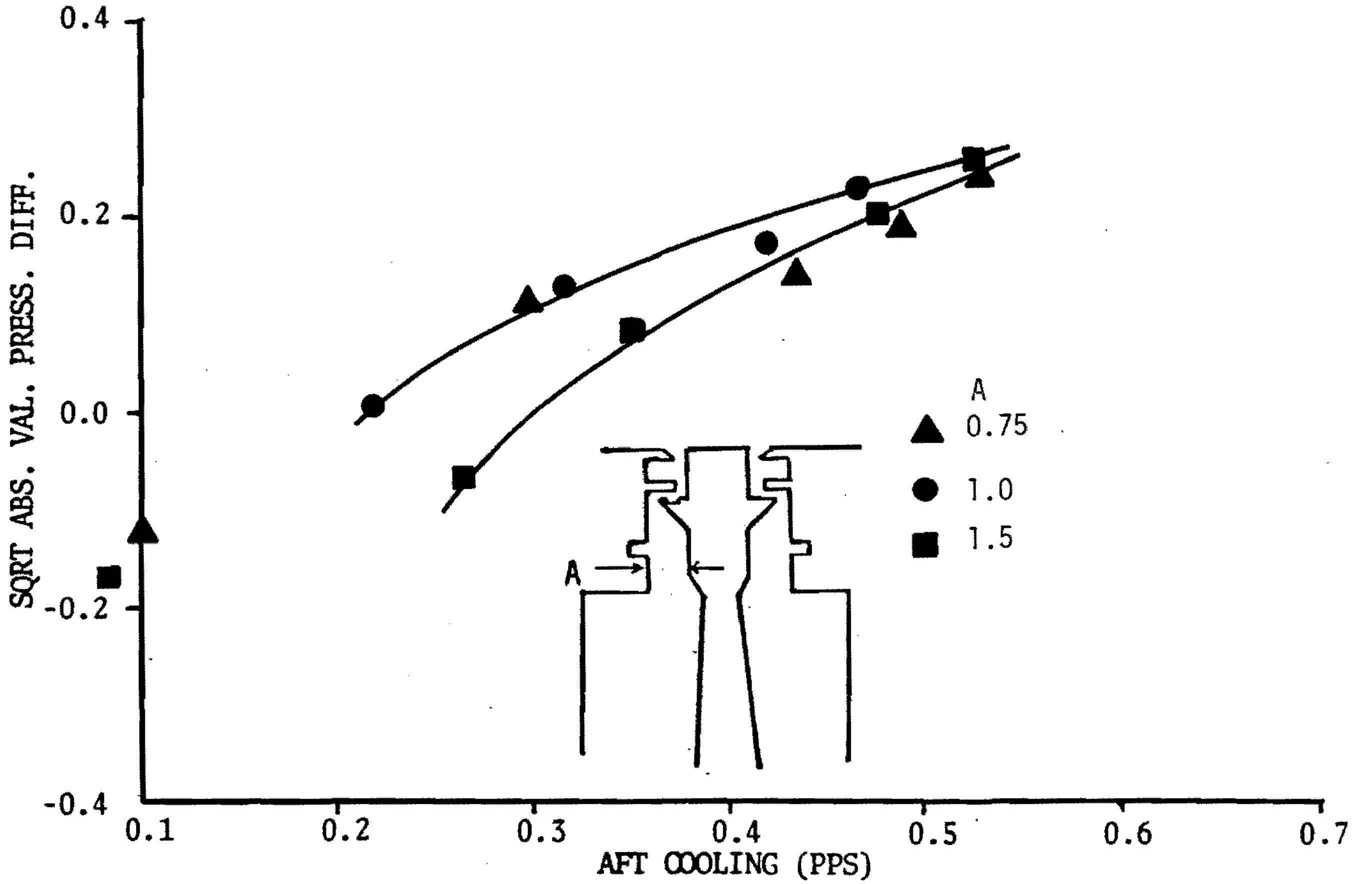


Figure V-22B. Rotor-Stator Inner Spacing Effect on Aft Local Flow, Seal PT18A, Position 3.

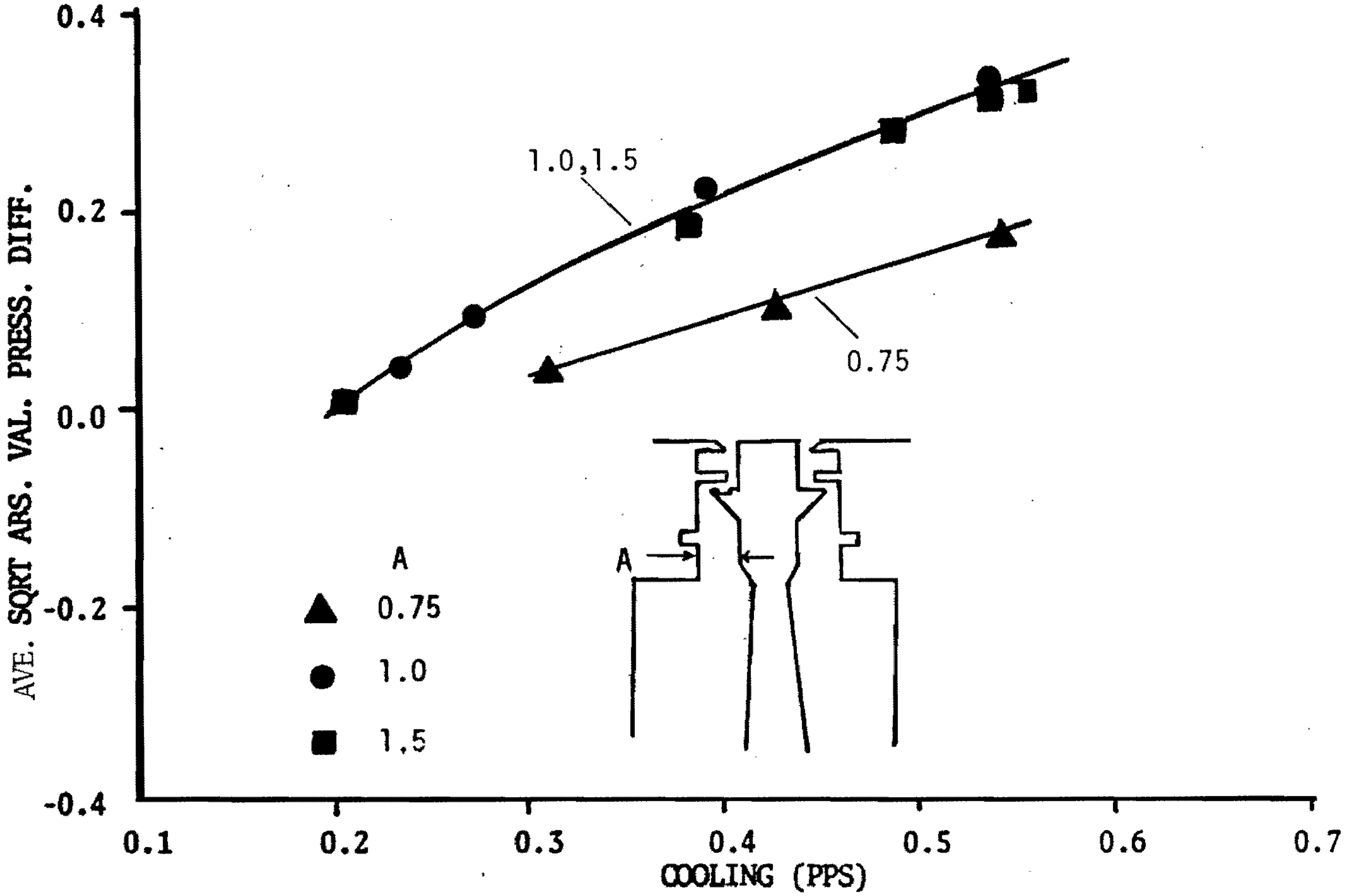


Figure V-22C. Rotor-Stator Inner Spacing Effect on Aft Average Local Flow, Seal PT18A.

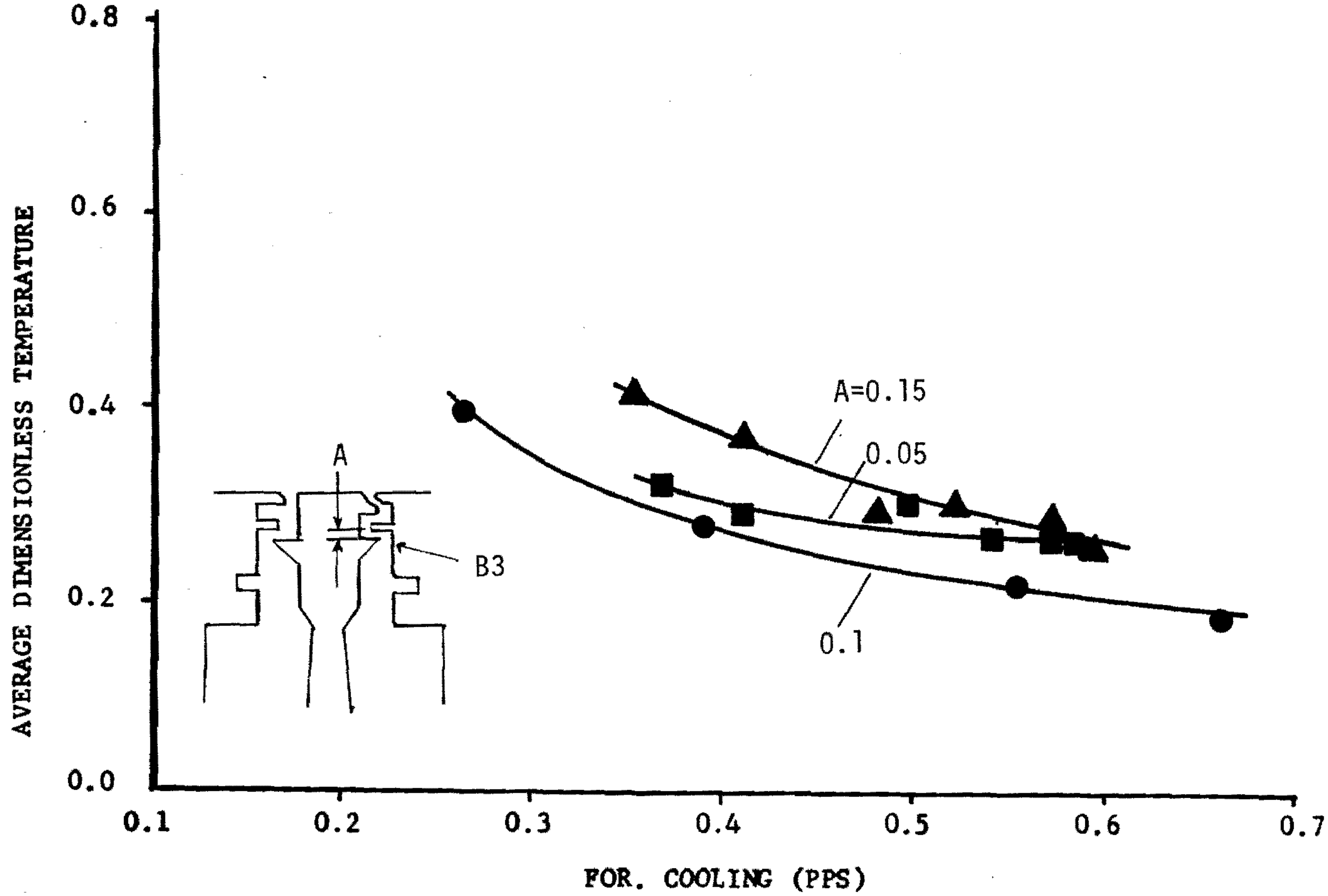


Figure V-23. Radial Seal Clearance Effect on Temperature, Seal PT19, Position B3.

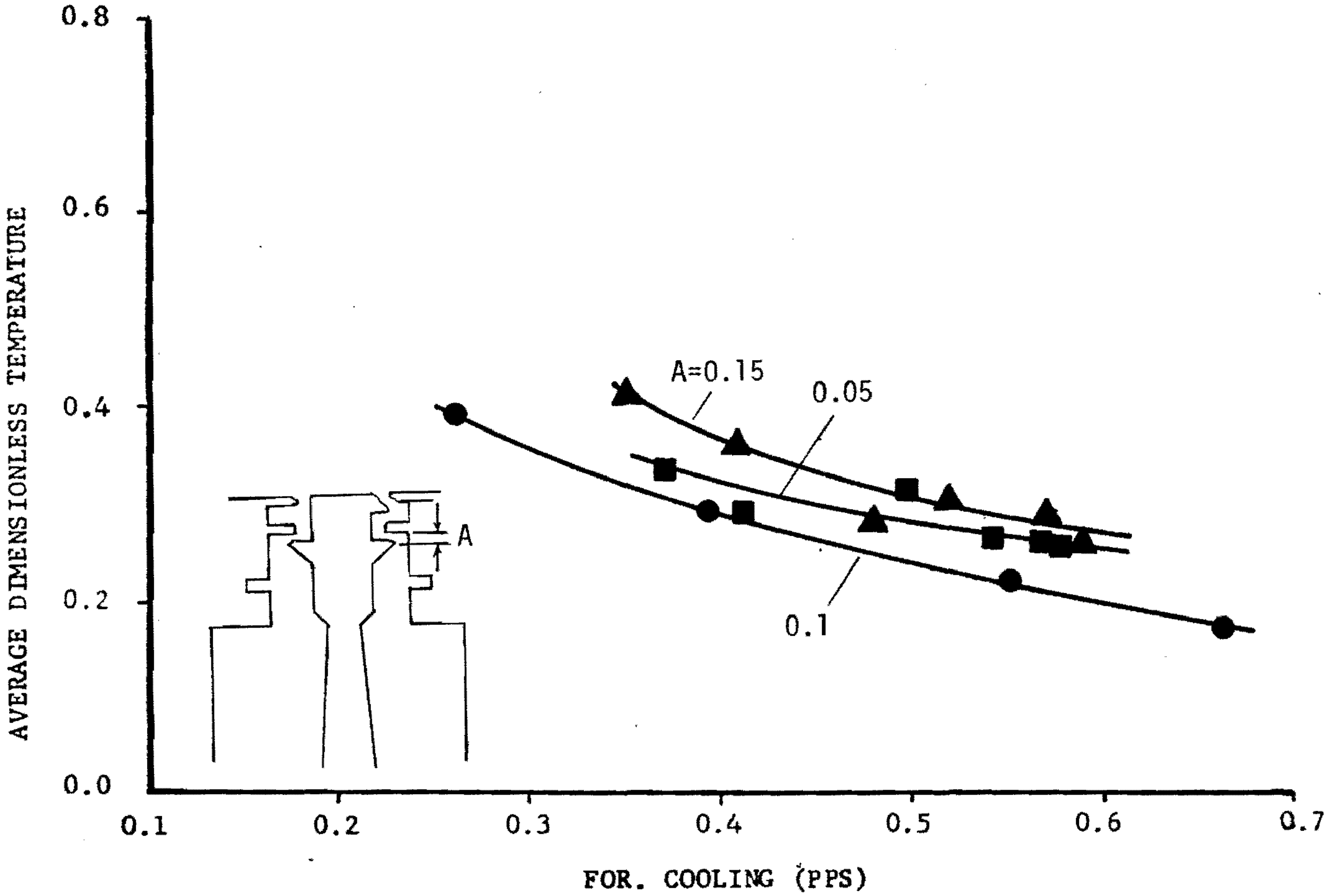


Figure V-24. Effect of Radial Seal Clearance on Temperature, Seal PT19, Position B4.

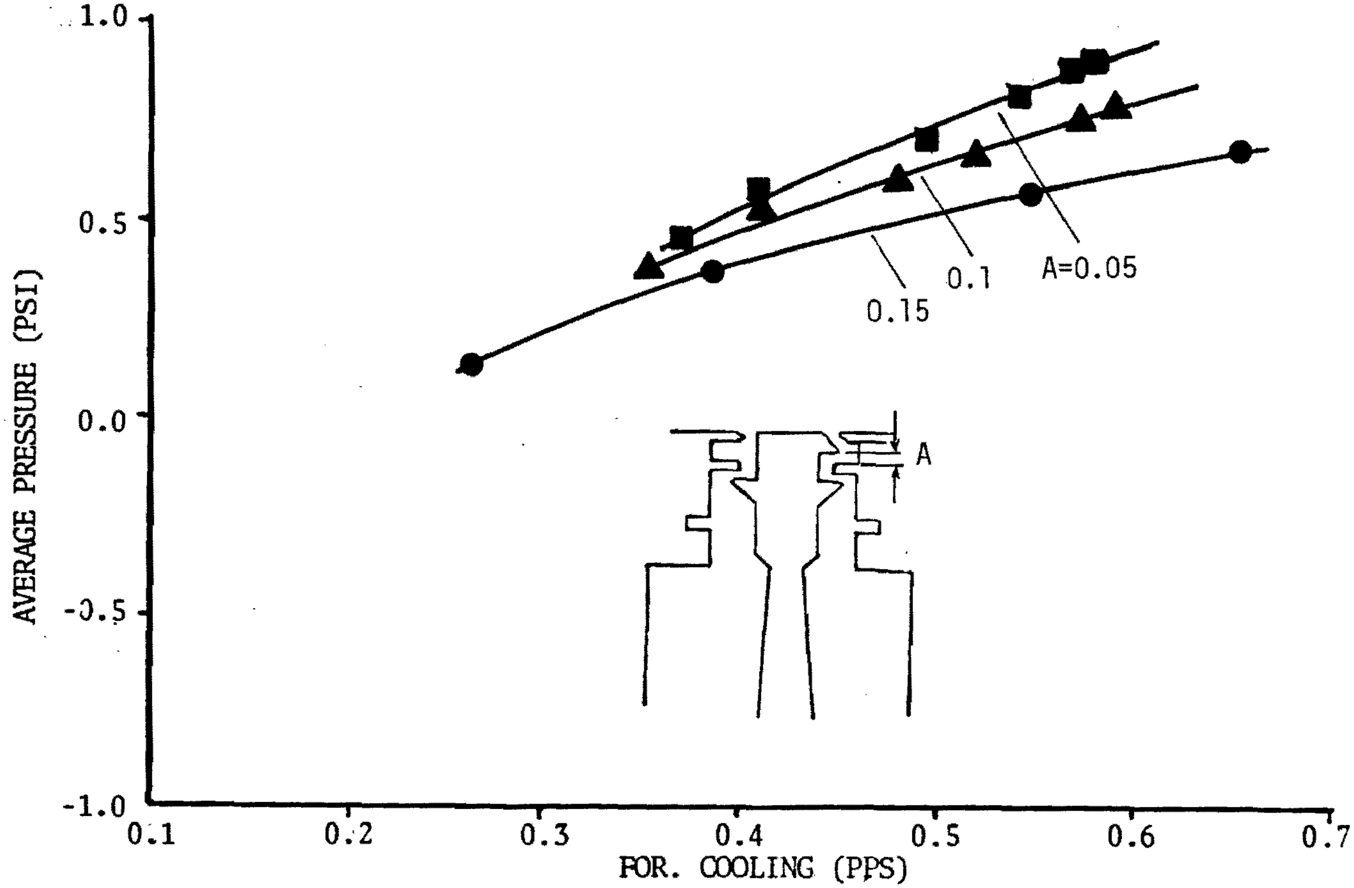


Figure V-25. Effect of Radial Seal Clearance on Pressure, Seal PT19, Position B4.

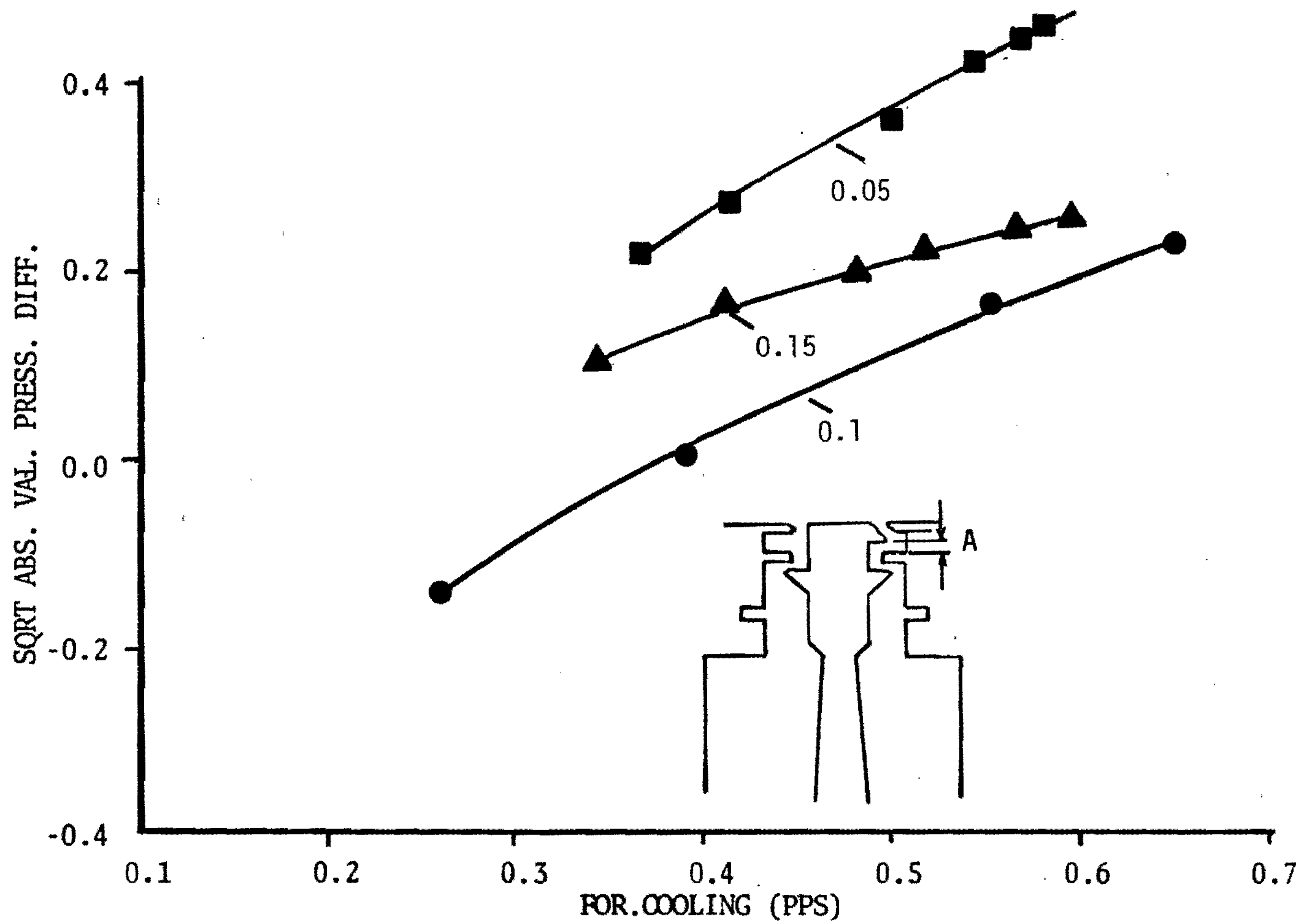


Figure V-26. Effect of Radial Seal Clearance on Forward Local Flow Across Radial Seal, Seal PT19, Position 3.

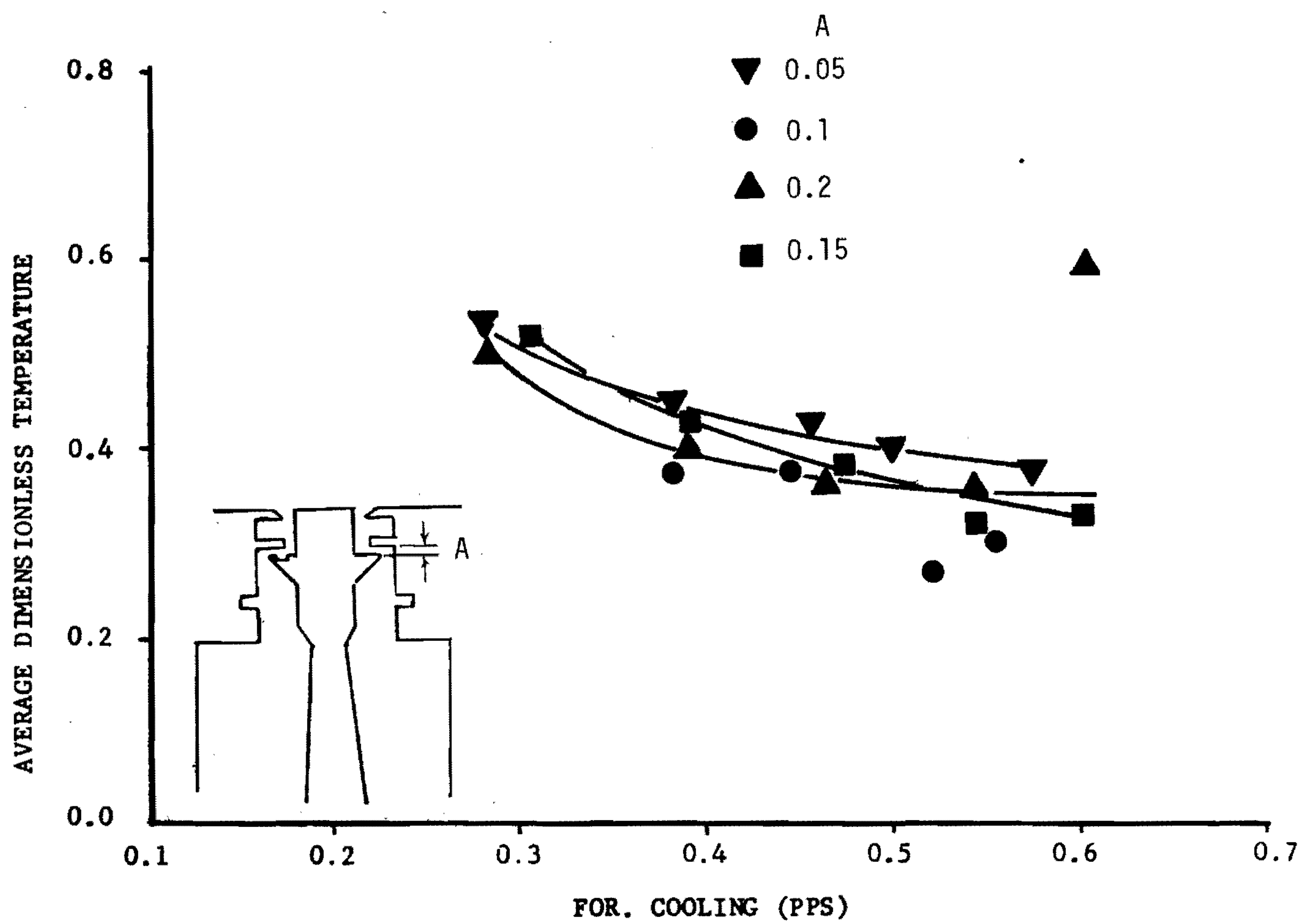


Figure V-27A. Effect of Radial Seal Clearance on Temperature, Seal PT18, Position B3.

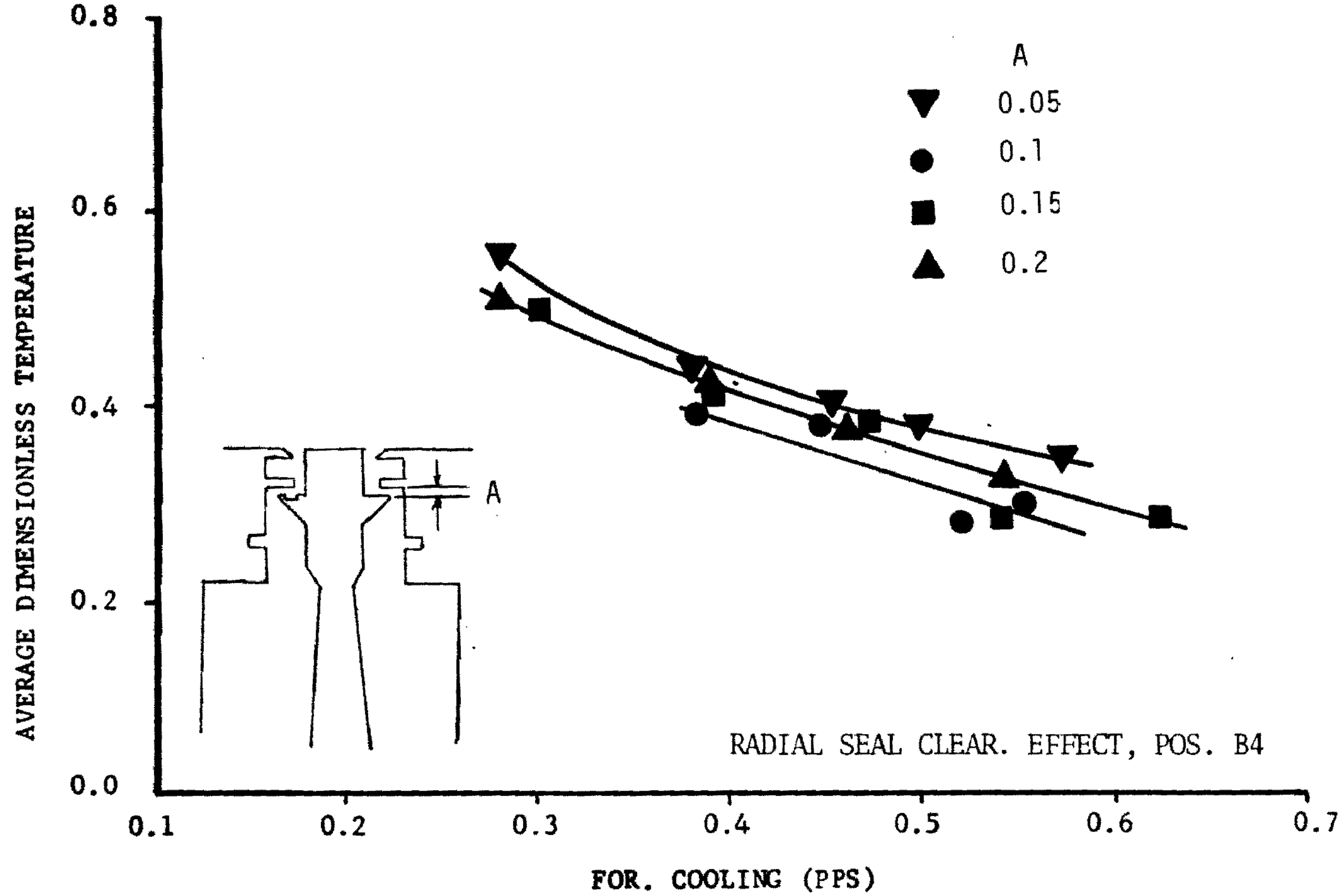


Figure V-27B. Effect of Radial Seal Clearance on Temperature, Seal PT18, Position B4.

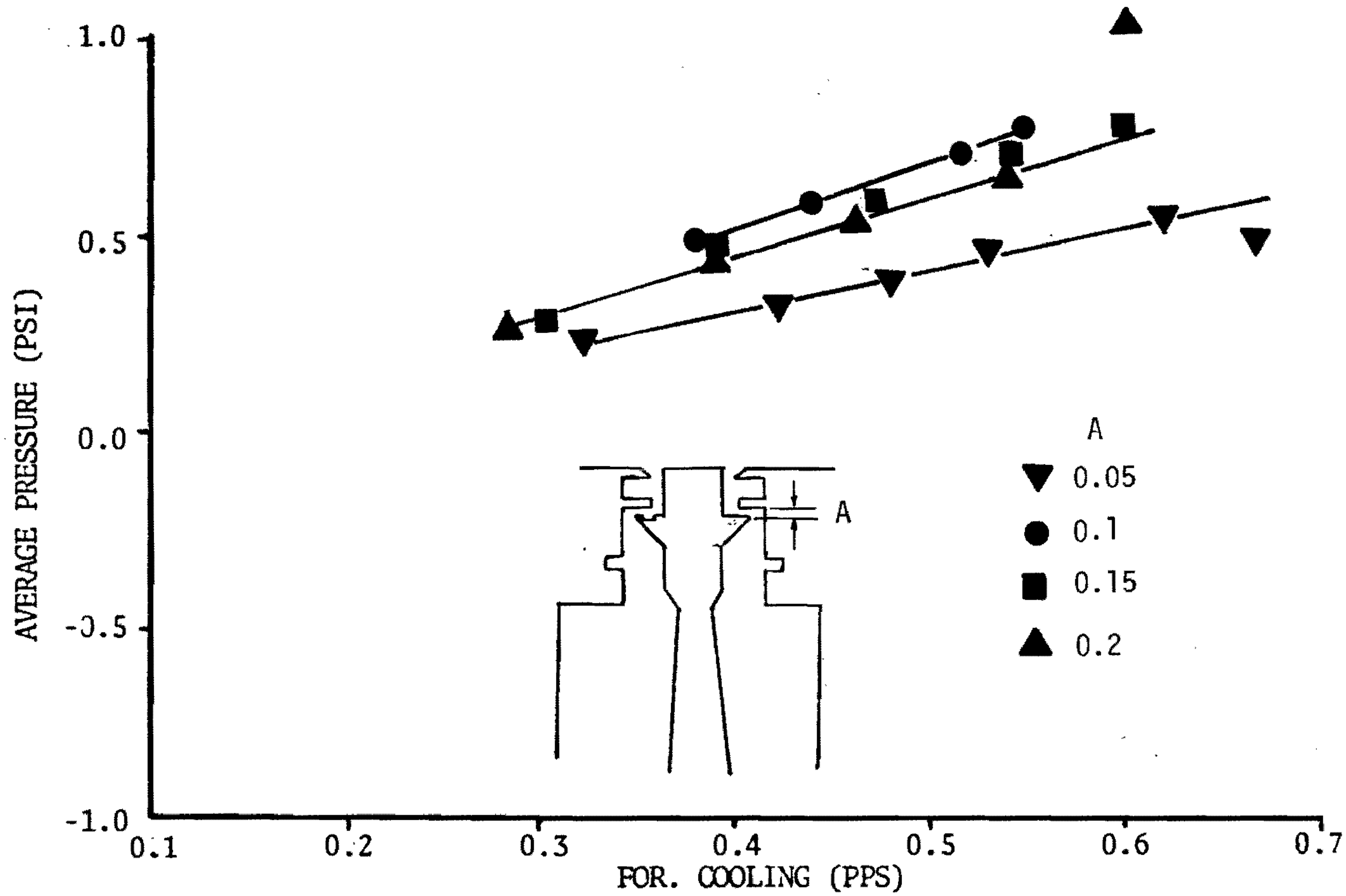


Figure V-28A. Effect of Radial Seal Clearance on Pressure, Seal PT18, Position B3.

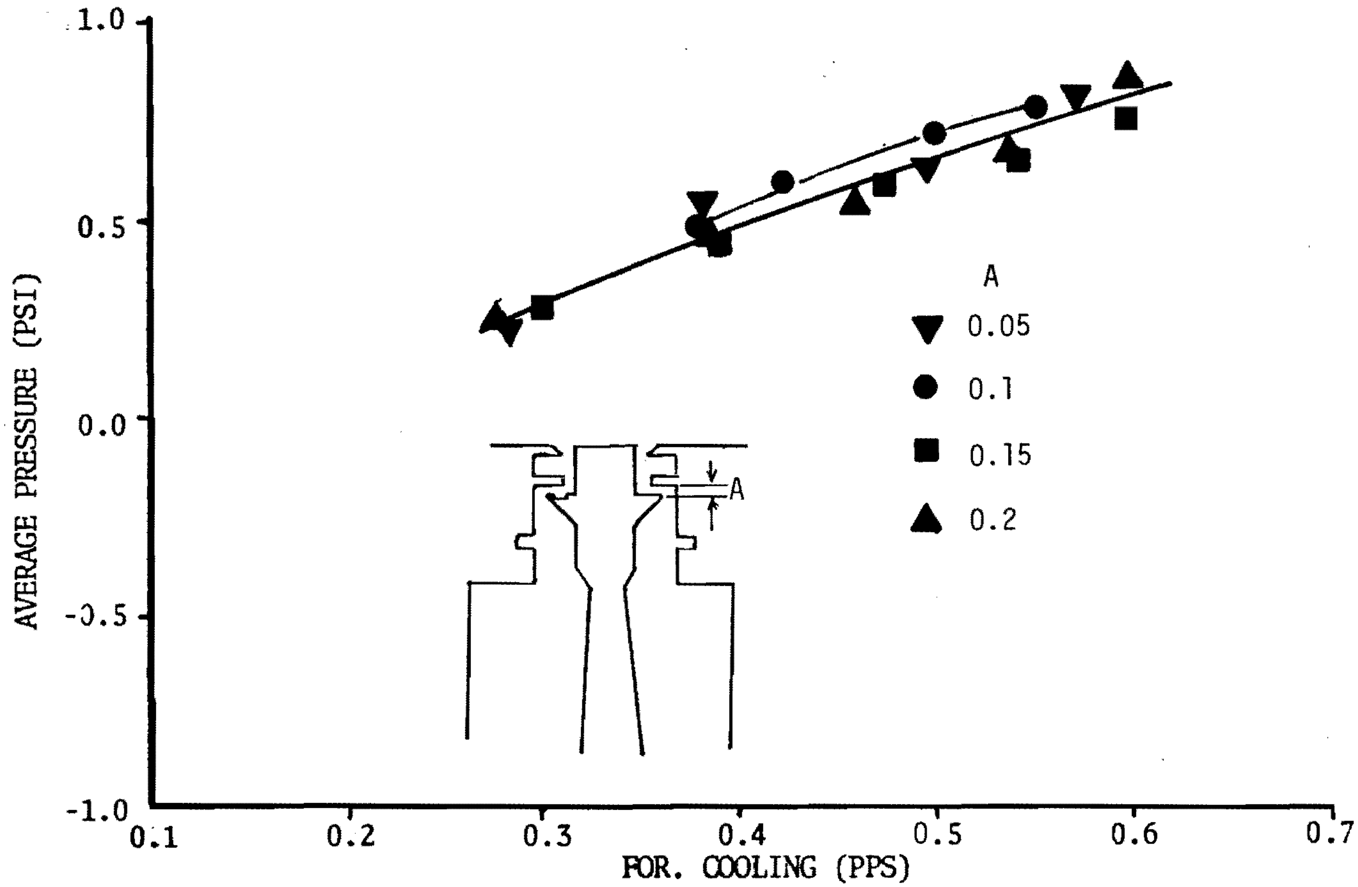


Figure V-28B. Effect of Radial Seal Clearance on Pressure, Seal PT18, Position B4.

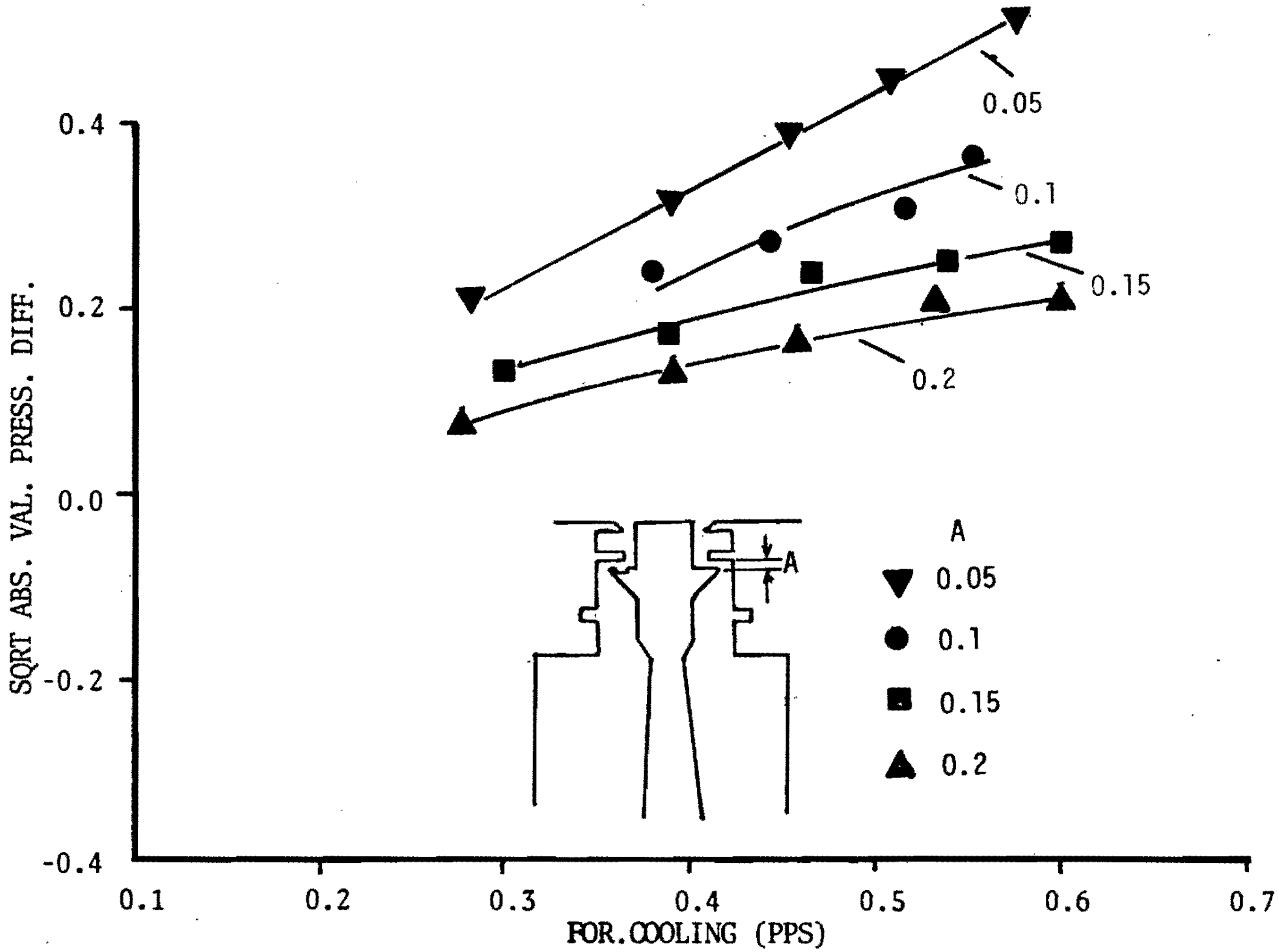


Figure V-29. Effect of Radial Seal Clearance on Forward Local Radial Seal Flow, Seal PT18, Position 3.

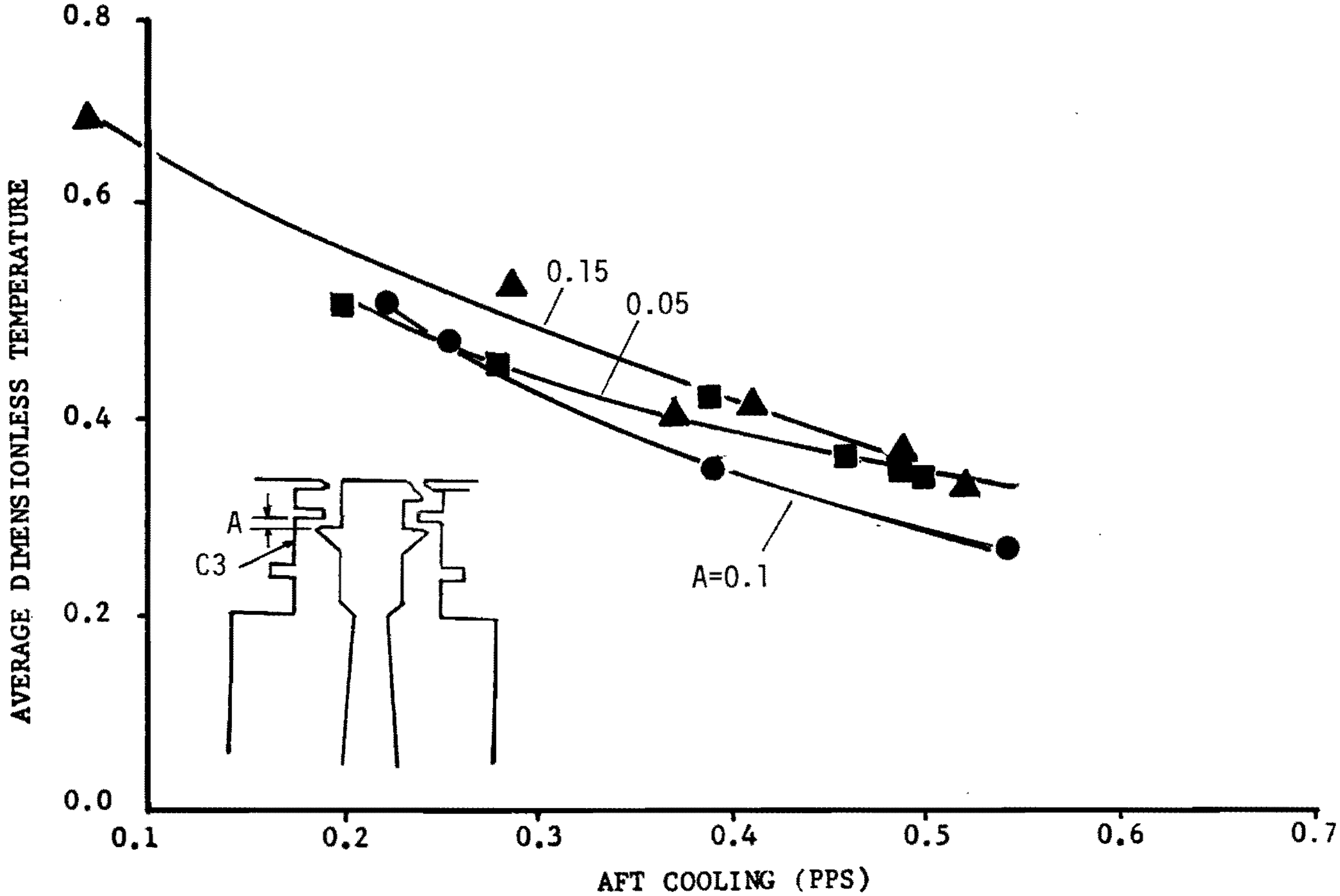


Figure V-30A. Effect of Radial Seal Clearance on Temperature, Seal PT18, Position C3.

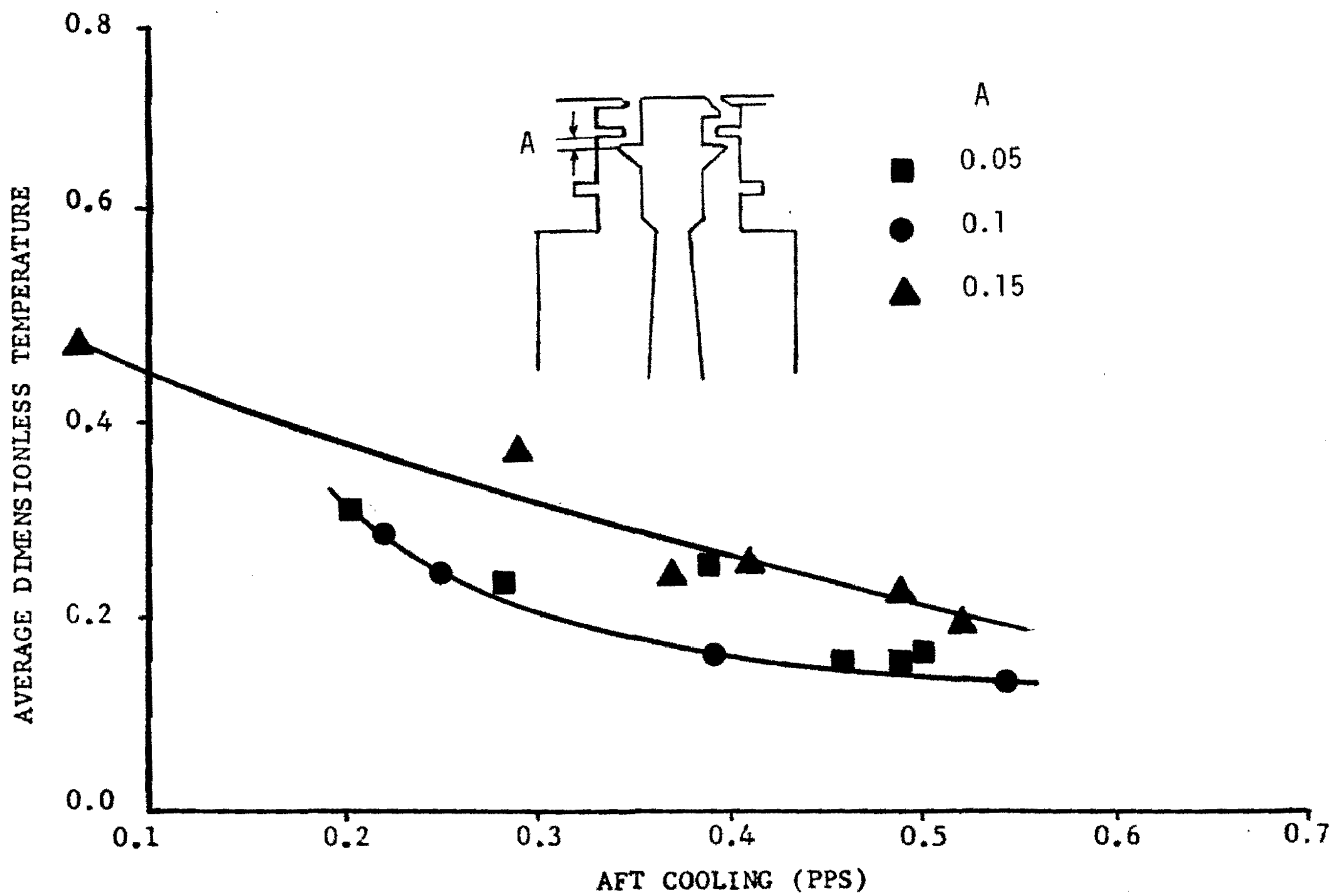


Figure V-30B. Effect of Radial Seal Clearance on Temperature, Seal PT18, Position C4.

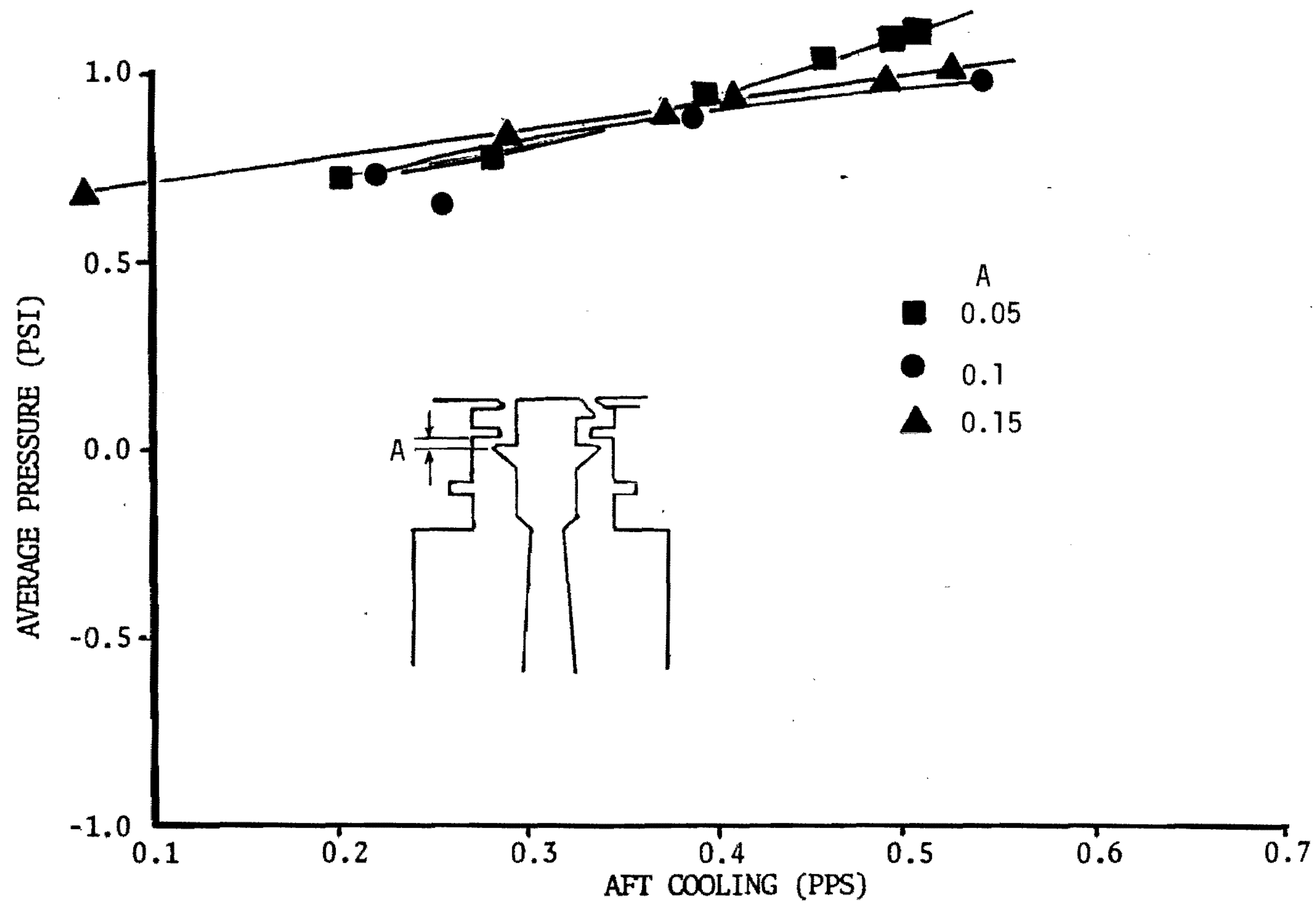


Figure V-31. Effect of Radial Seal Clearance on Pressure, Seal PT18, Position C4.

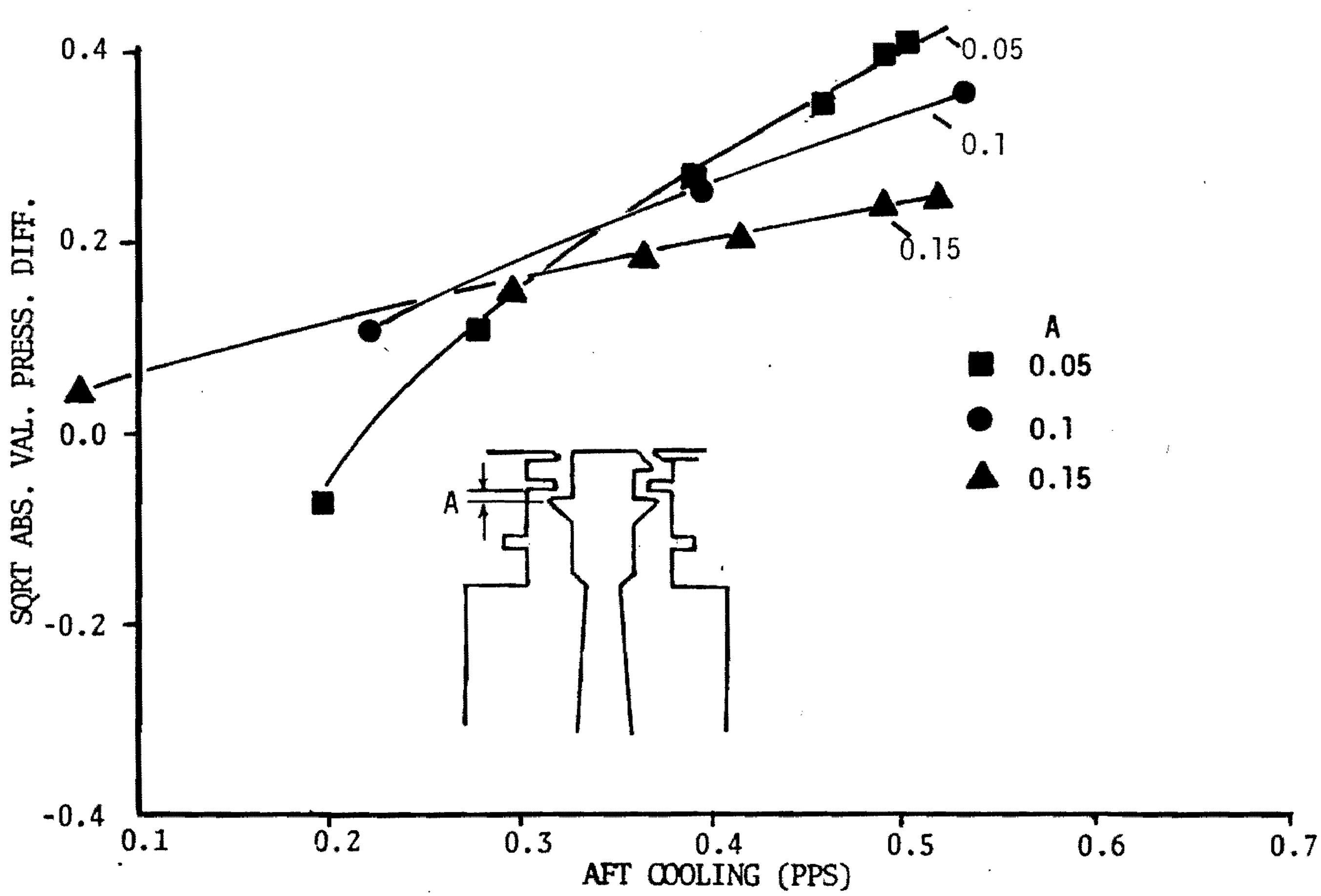


Figure V-32. Effect of Radial Seal Clearance on Aft Local Flow Across Radial Seal, Seal PT18, Position 3.

ect of
l PT8A

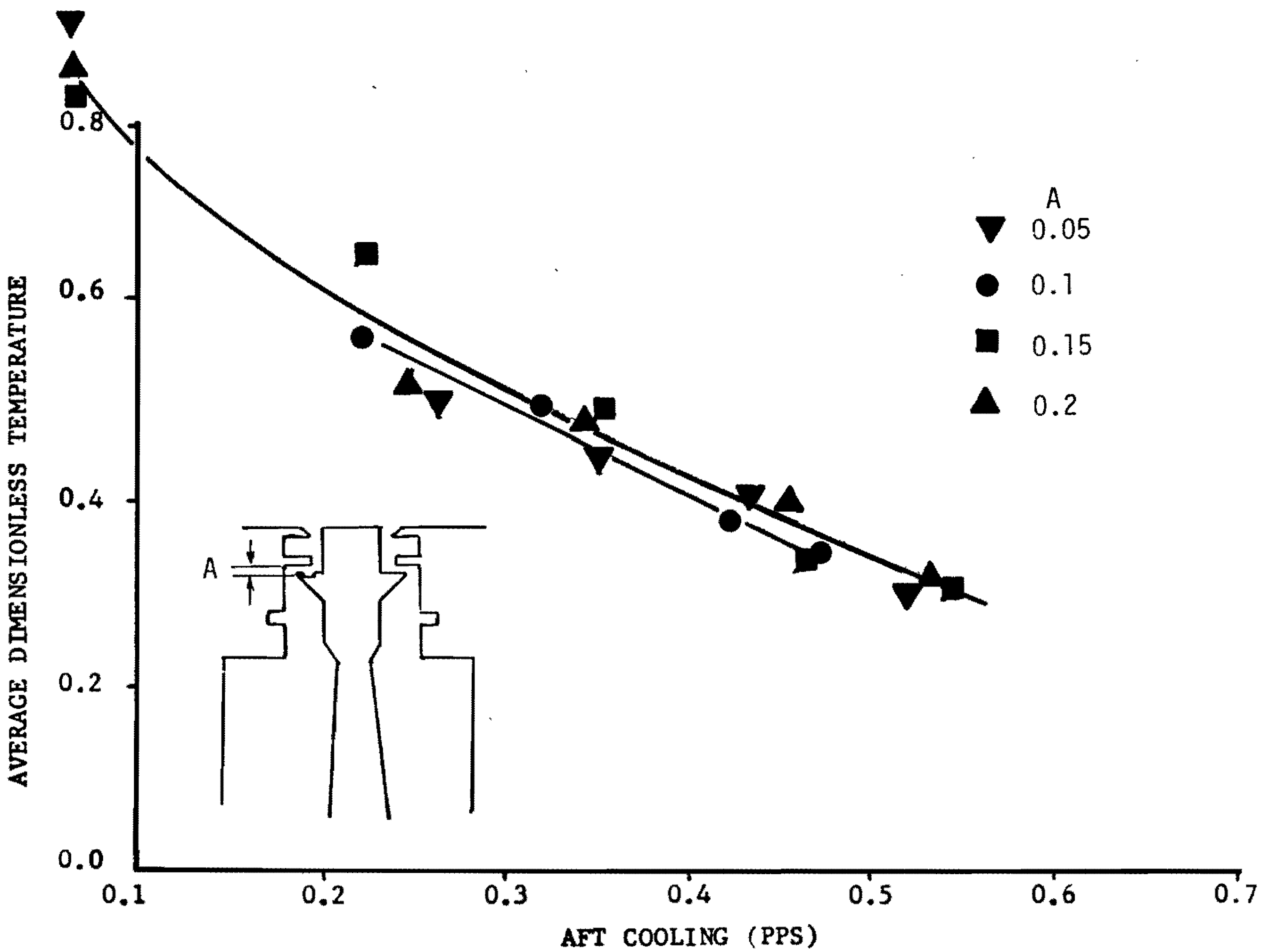


Figure V-33A. Effect of Radial Seal Clearance on Temperature, Seal PT8A, Position C3.

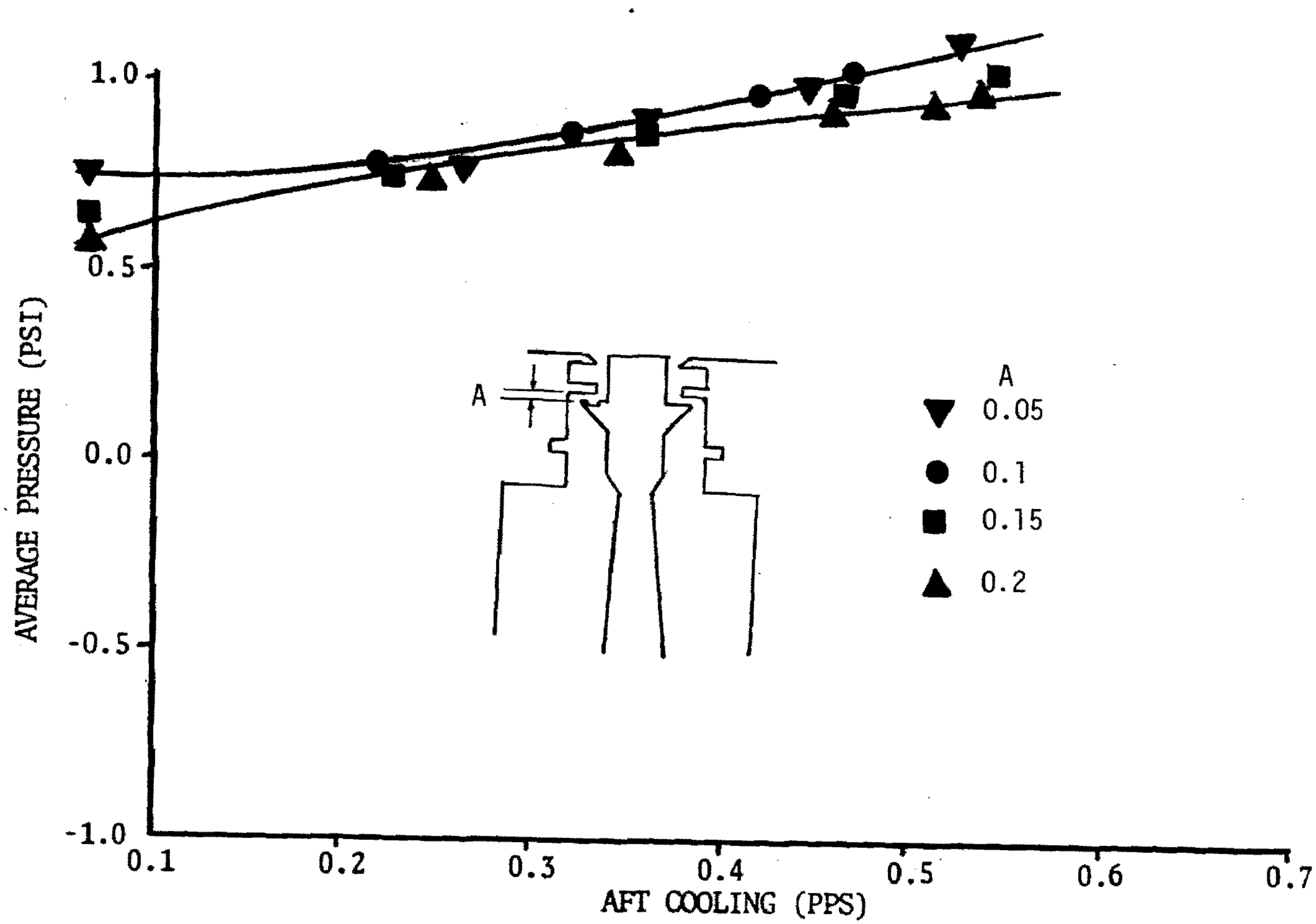


Figure V-34. Effect of Radial Seal Clearance on Pressure, Seal PT18A, Position C4.

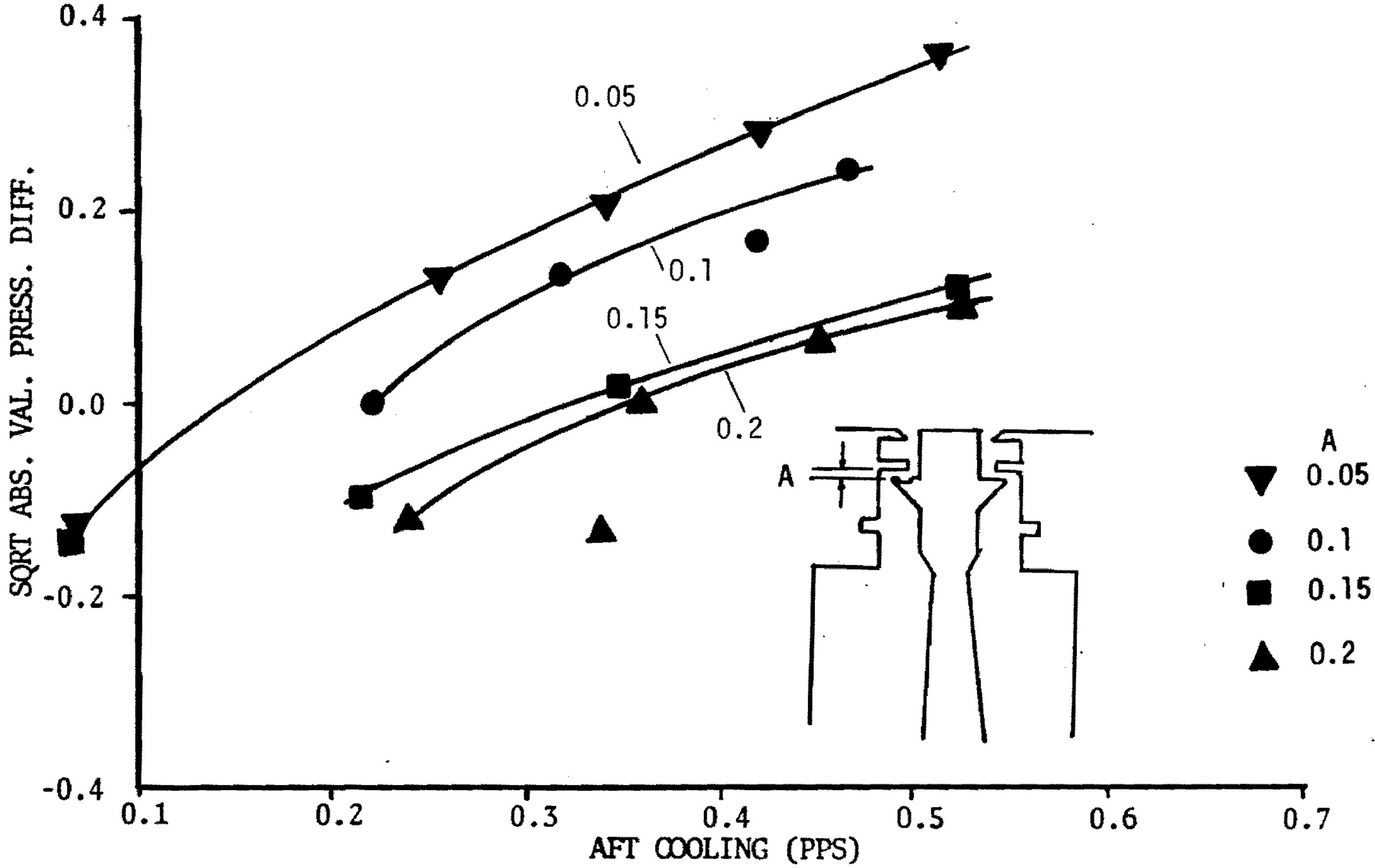


Figure V-35. Effect of Radial Seal Clearance on Aft Local Flow Across Radial Seal, Position 3.

With rotating seal PT19, lower wheelspace temperatures are obtained when the radial seal clearance is 0.1 inch (Figure V-23, V-24, for positions B3 and B4 for other positions compare Figures AT1-A, AT11-A and AT12-A). At a smaller gap (0.05 inch), the wheelspace temperatures and pressures are higher (Figure V-23, V-24 and V-25). Apparently the small flow area between the static and rotating seals obstruct the heated coolant from flowing out of the wheelspace creating a high wheelspace pressure as shown in Figure V-25 (or compare AP1-A, AP11-A and AP12-A). Therefore, as the coolant is heated due to the heat conducted through the rotor and stator, the temperatures in the wheelspace are higher.

When seal PT18 is used on the forward or aft side of the wheel, the effect of radial seal clearance is even less pronounced than with PT19. The difference in wheelspace temperatures or pressures is not significant for the range of gaps studied. Figures V-27, V-28, V-30 and V-31 show the temperature and pressure curves for radial positions 3 and 4. (Also see Figures AT13, AT21 to AT23 for temperatures and AP13, AP21 to AP23 for pressures at other radial positions.)

The results with PT18-A seal show no difference in temperature or pressure at positions C3 and C4 for different radial seal clearances (See Figures V-33 and V-34 and Figures AT13-B, AT21-B to AT23-B and AP13-B, AP31-B to AP23-B).

Comparing the results of radial seal clearance using seal PT18, PT18A and PT19, it is found that the lip on PT19 seal has an effect on the wheelspace temperature and pressure but not a large effect.

Figures V-26, V-29, V-32 and V-35 show $\sqrt{\Delta p}$ across the seal but must be viewed with caution in the case of varying the radial seal gap. The $\sqrt{\Delta p}$ was introduced as a useful indicator of local flow across the seal when the seal geometry is constant. However, comparisons can not be made from one curve to another in this case because the seal gap is being changed.

Within the range of this experiment, a 0.1 inch radial seal gap seems to result in the lowest wheelspace temperatures. But the radial seal clearance does not influence wheelspace temperatures to the extent that rim spacing and rotor-to-stator inner spacing do.

Rim Flow

At a wheelspeed of 3000 rpm, 0.2 inch rim spacing, 0.1 inch radial seal clearance, 1.0 inch inner rotor-to-stator spacing and using rotating seal PT18 on the aft side and PT18 or PT19 on the forward side, the effect of rim flow was studied.

Regardless of the rotating seal geometry in forward and aft locations, higher wheelspace pressures are present with higher rim flow (See Figures V-36, V-37 and V-38, also compare Figures AP1, AP7, AP8, AP13-A, AP17 and AP19). This is to be expected because with high rim flow, the rim area pressure is higher hence restricting the outflow of cooling air.

Similarly, when seal PT18 is used on the forward side, lower wheelspace temperatures (Figure V-39) and greater local coolant outflow (Figure V-40) are found with less rim flow. When this same seal is used on the aft side of the wheel, the variations in wheelspace temperatures and seal flow are not as pronounced (Figures V-41 and V-42).

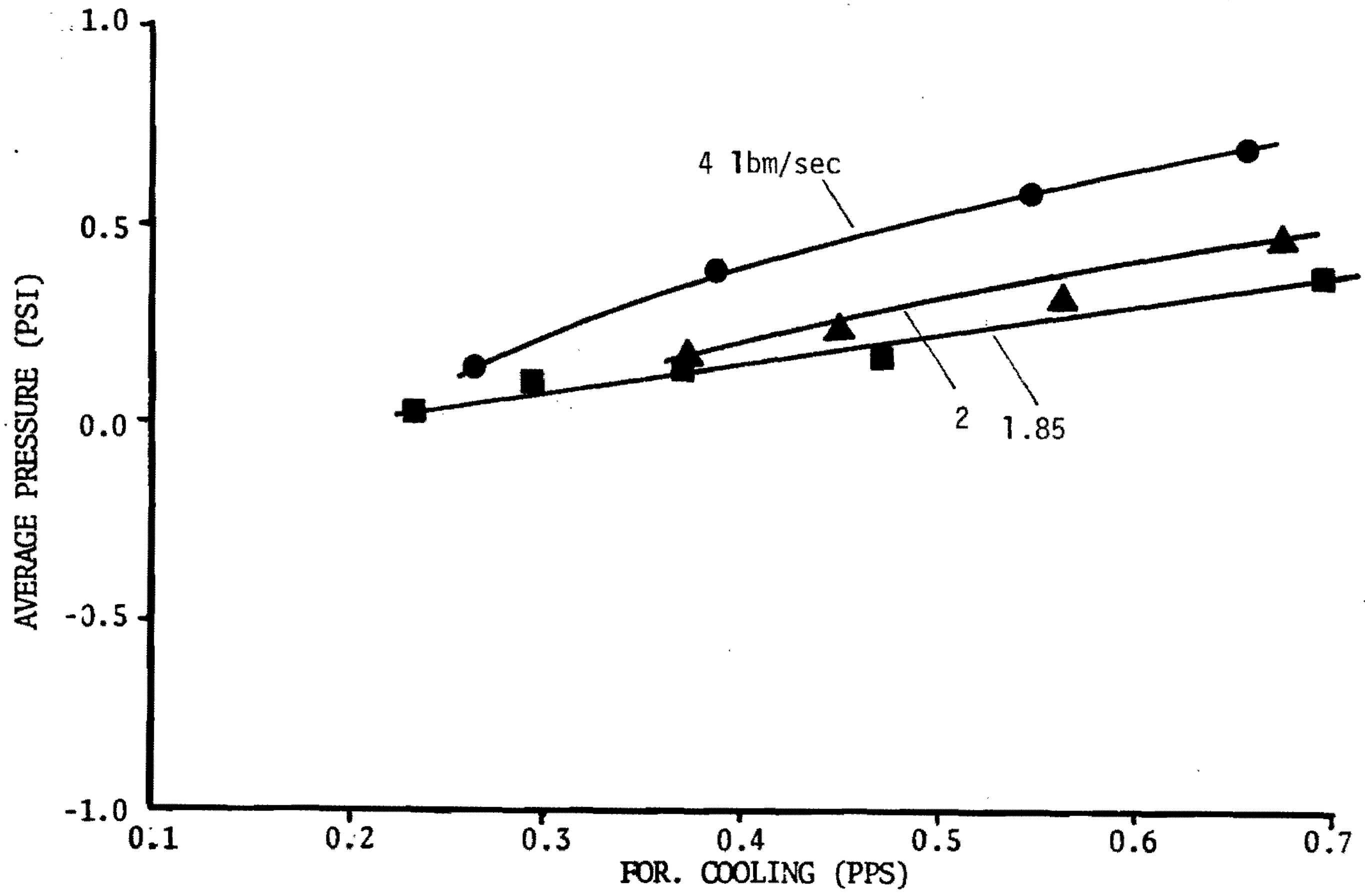


Figure V-36. **Effect of Rim Flow on Pressure, Seal PT19, Position B4.**

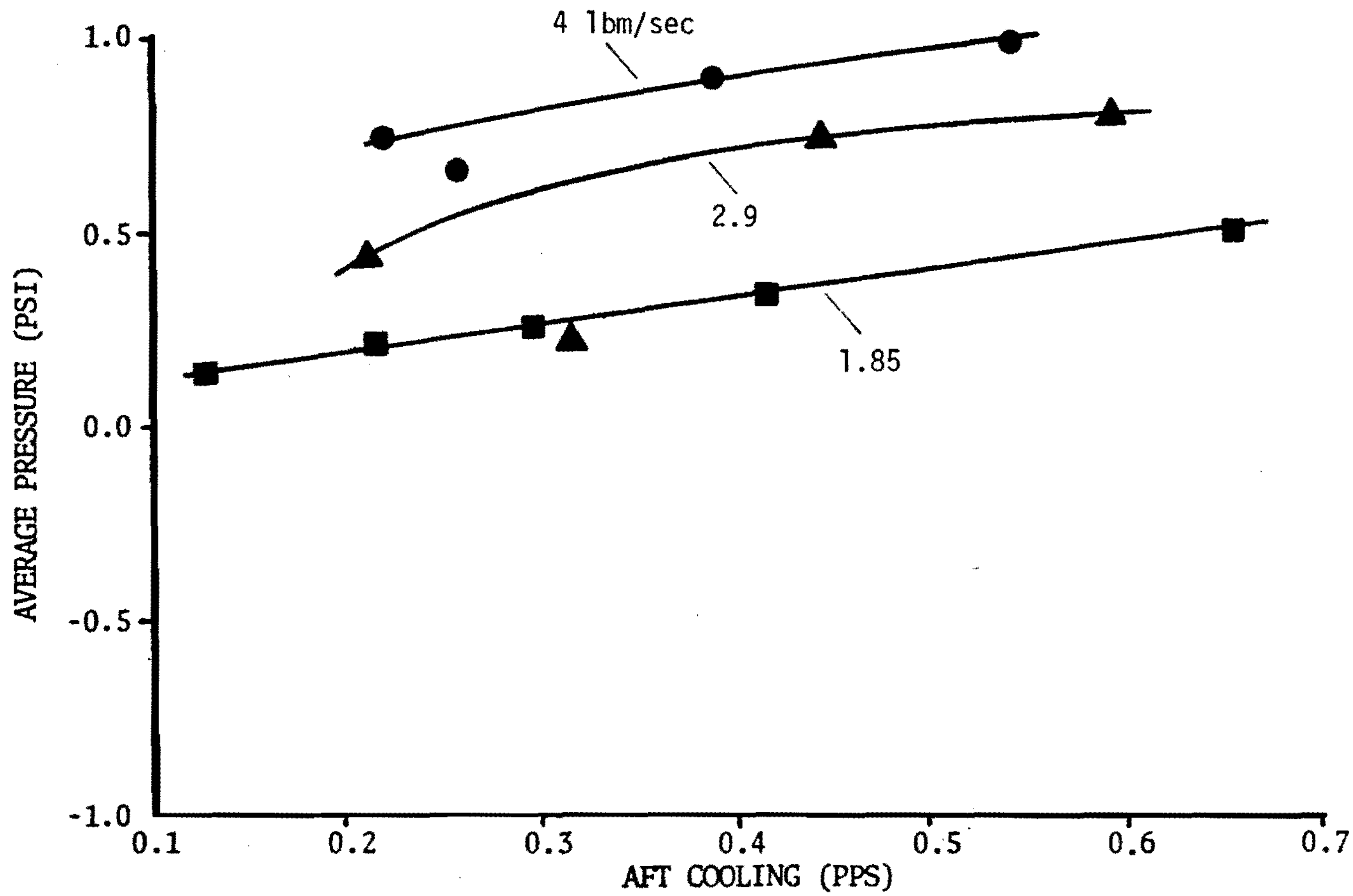


Figure V-37. Effect of Rim Flow on Pressure, Seal PT18, Position C4.

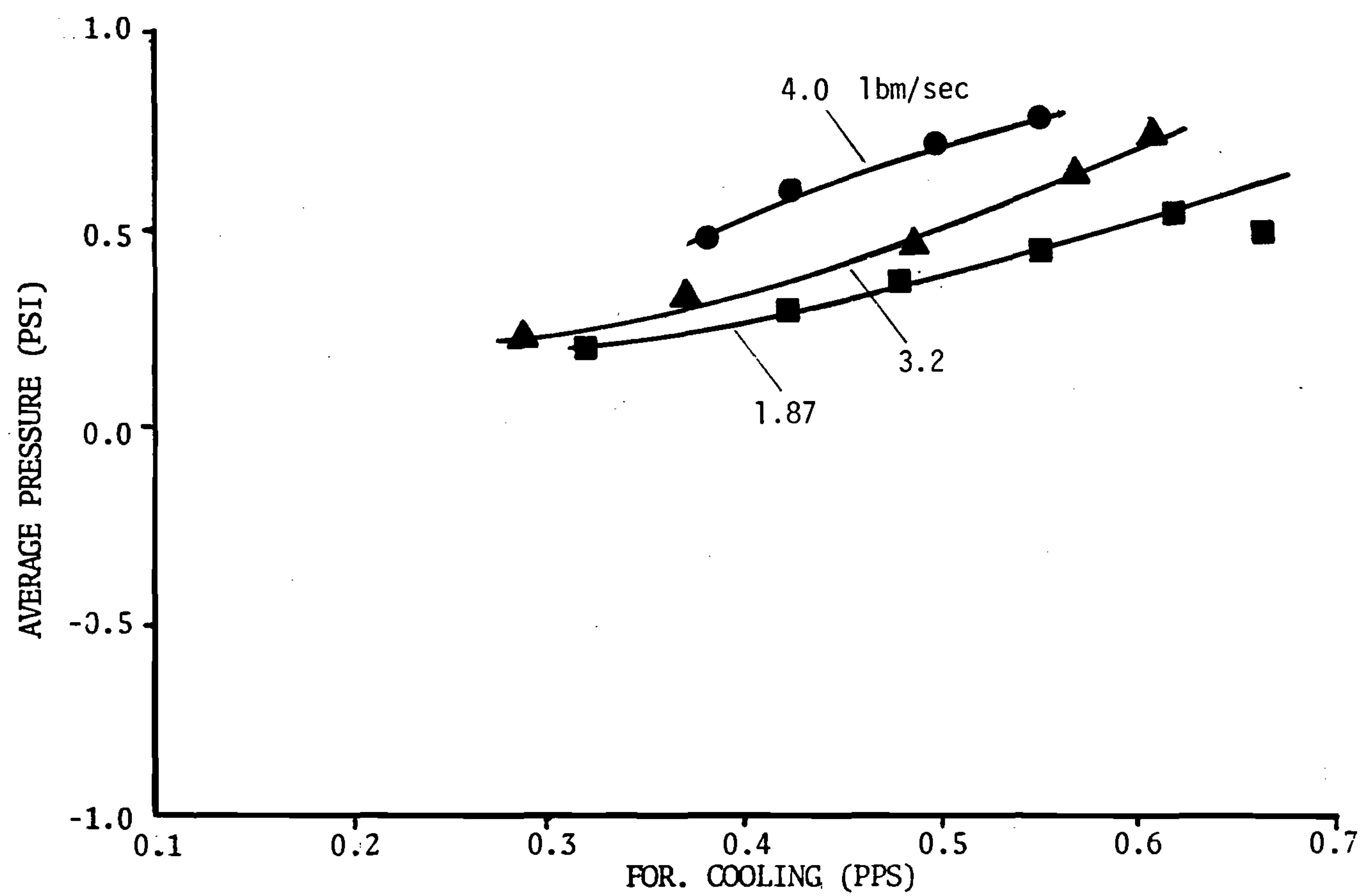


Figure V-38. Effect of Rim Flow on Pressure, Seal PT18, Position B4.

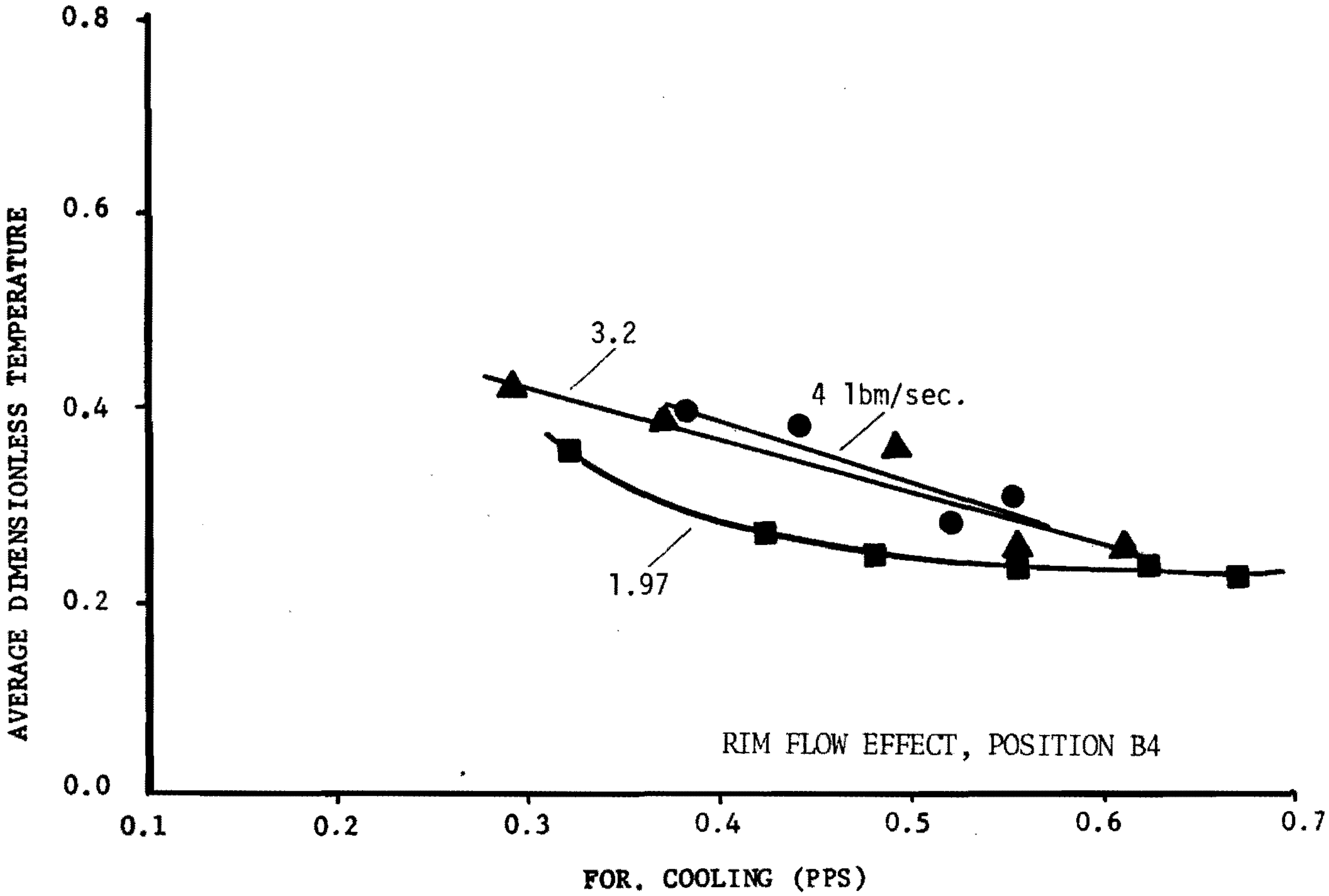


Figure V-39. Effect of Rim Flow on Temperature, Seal PT18, Position B4.

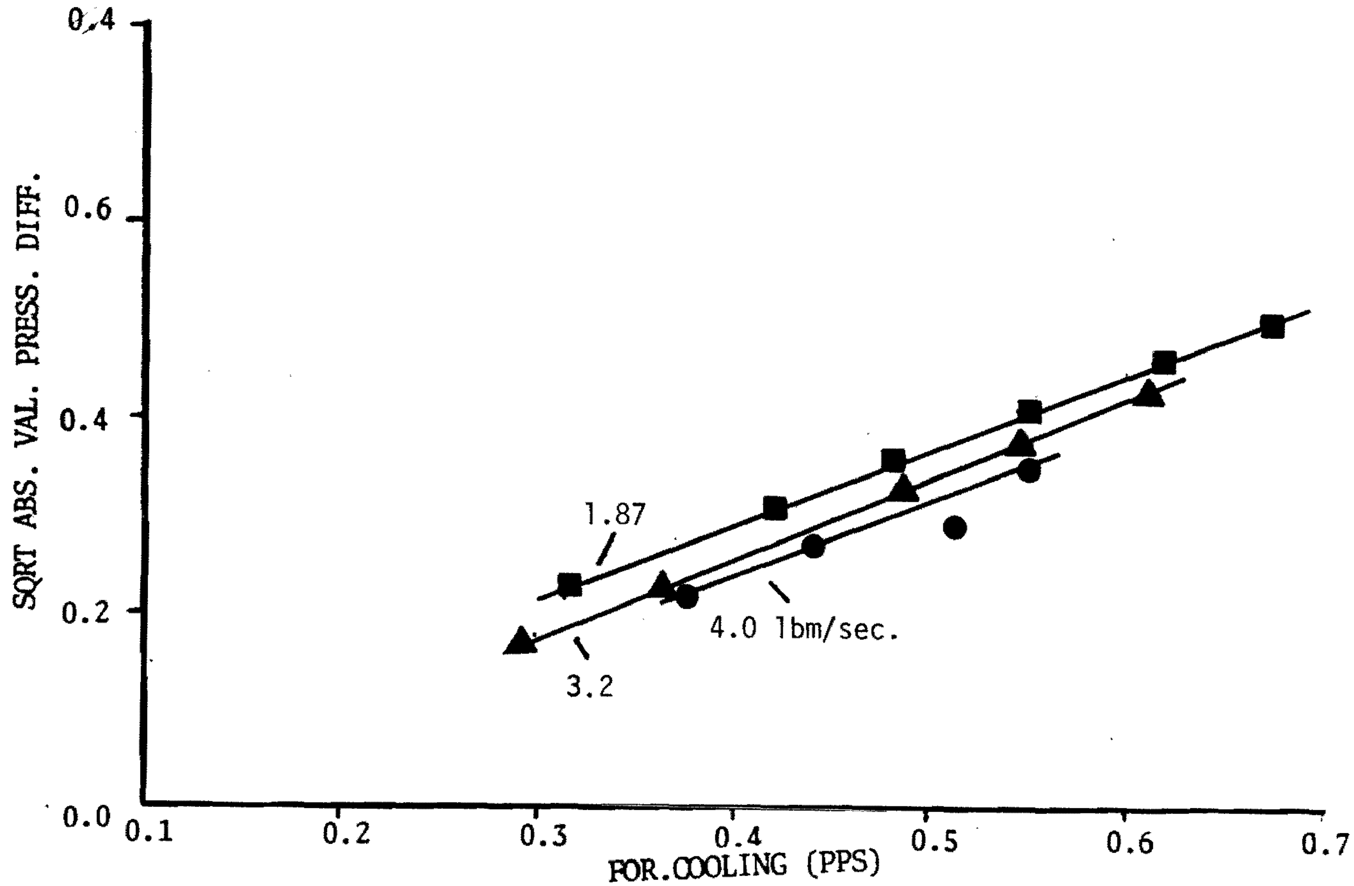


Figure V-40. Effect of Rim Flow on Forward Local Flow Across Radial Seal, Seal PT18, Position 3.

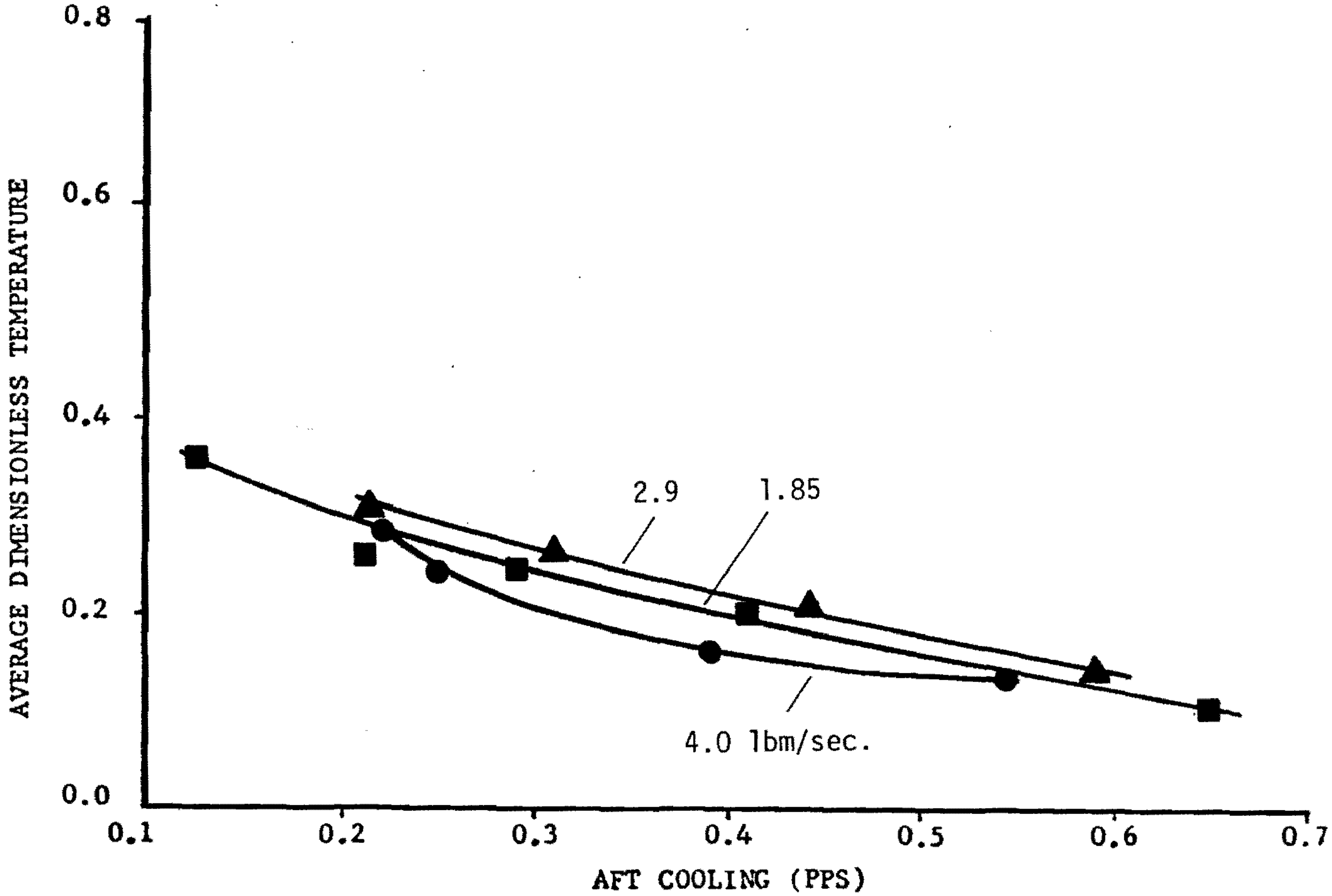


Figure V-41. Effect of Rim Flow on Temperature, Seal PT18, Position C4.

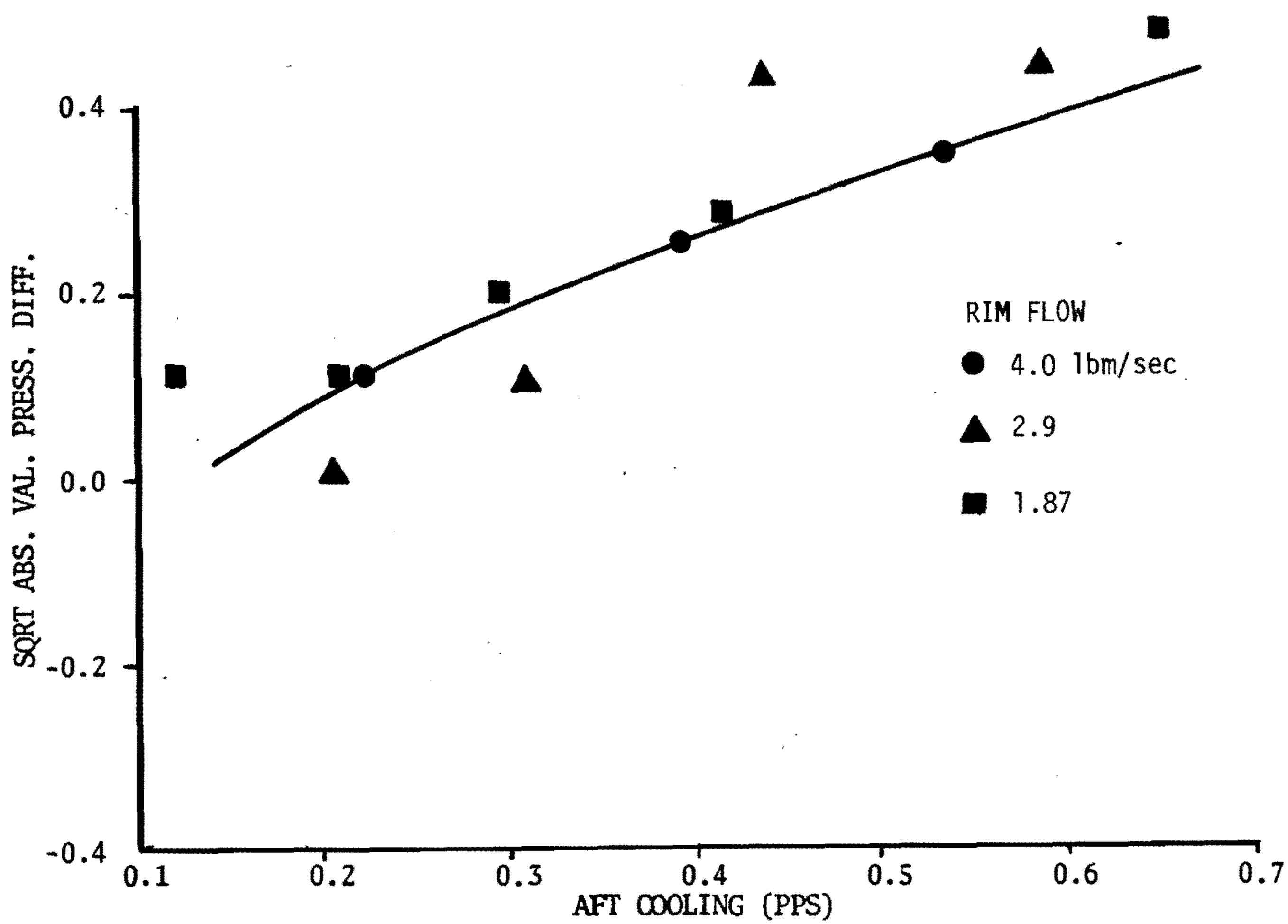


Figure V-42. Effect of Rim Flow on Aft Local Flow Across Radial Seal, Seal PT18, Position 3.

The case where rotating seal PT19 is used is shown in Figures V-43 and V-44. The effect of rim flow on wheelspace temperature is small in this case.

Wheel Speed Effect

By using seal PT18, rim spacing of 0.2 inch, radial seal clearance 0.1 inch, rotor-to-stator inner spacing of 1.0 inch and 4 lbm/s rim flow it is found that wheelspeeds from 1200 to 3000 RPM have little influence on wheelspace temperatures or pressures. (Figures V-45 and V-46 or compare AT1-B, AT2, AT3, AT1-B, AP-2 and AP-3).

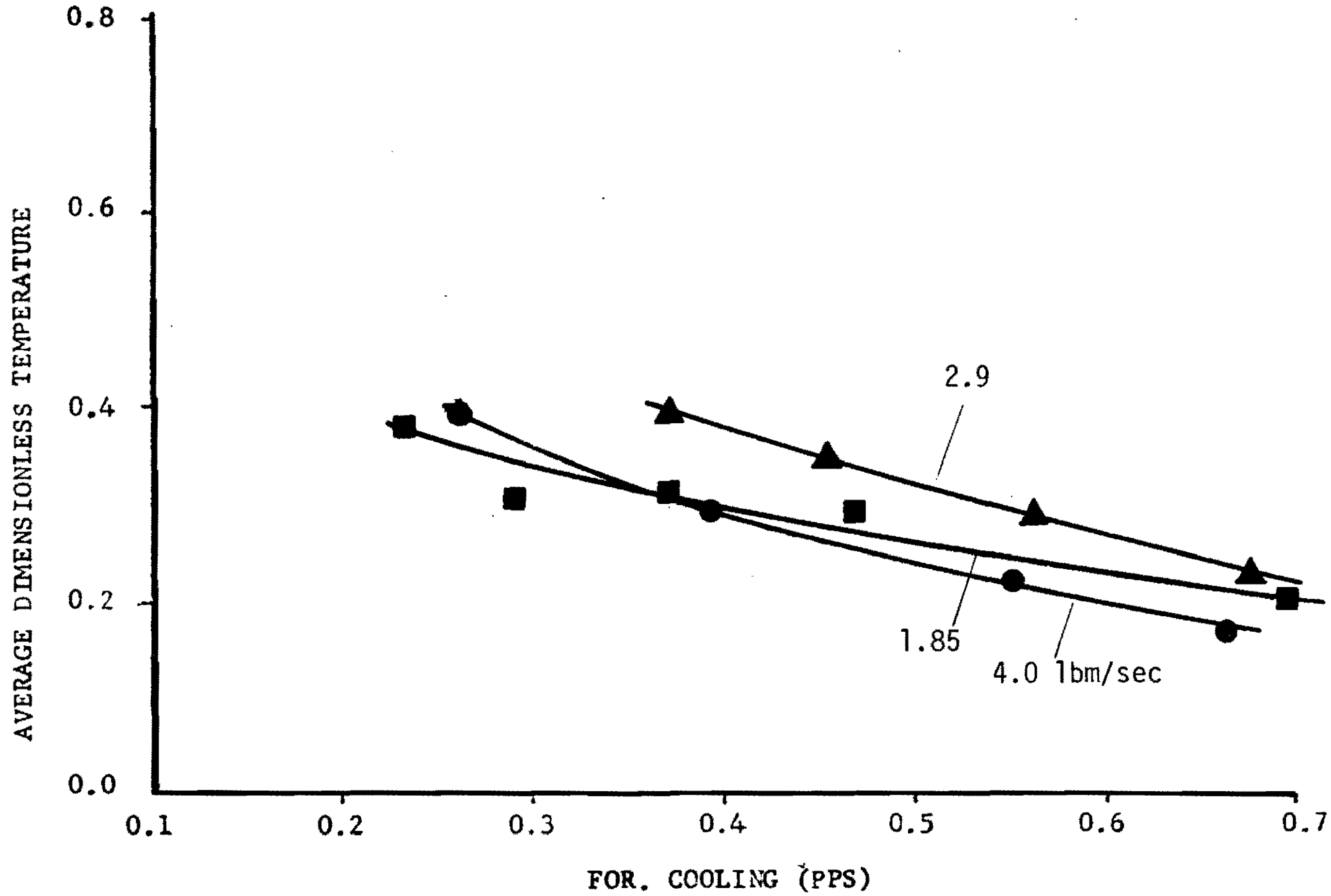


Figure V-43. Effect of Rim Flow on Temperature, Seal PT19, Position B4.

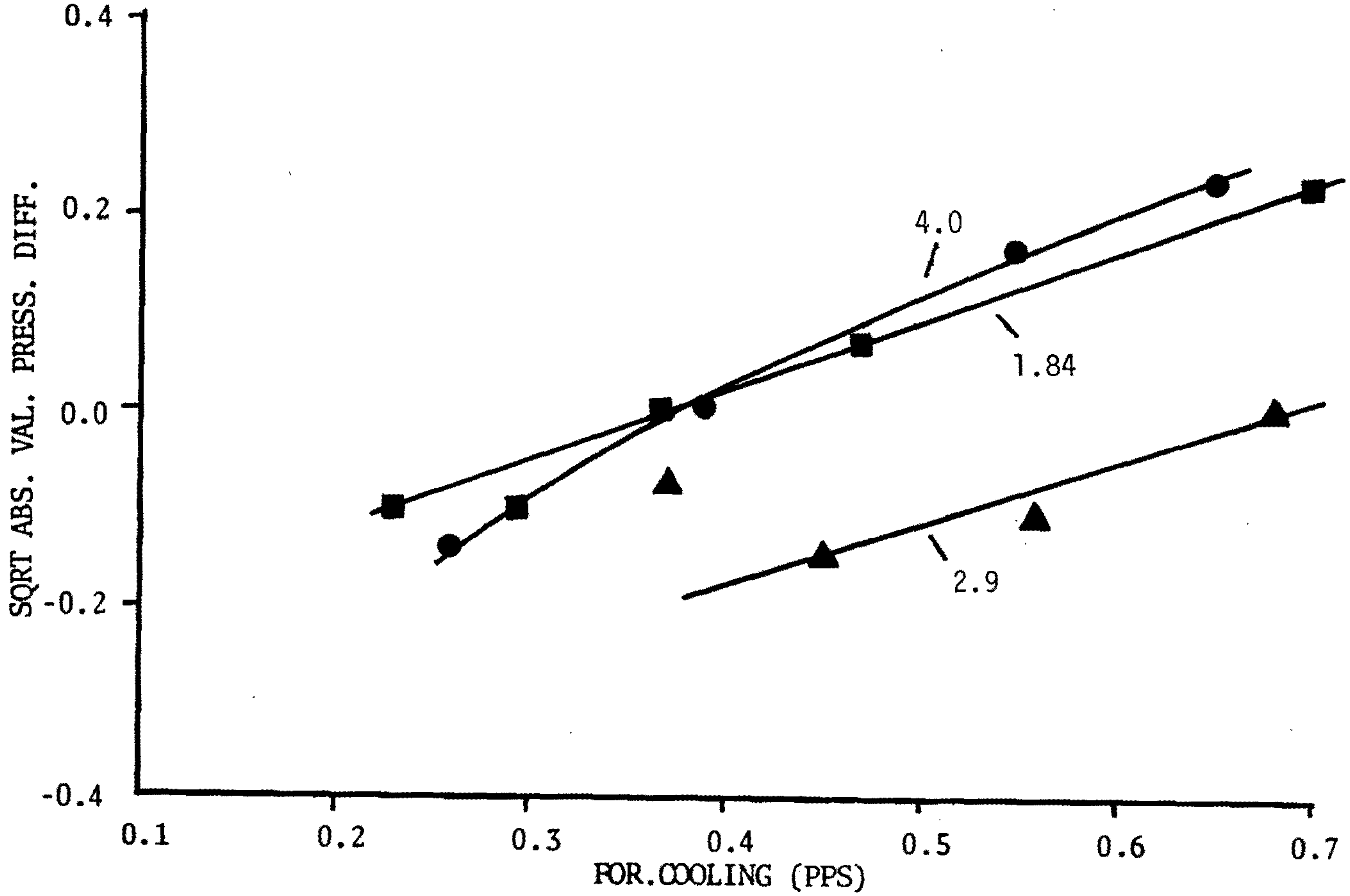


Figure V-44. Effect of Rim Flow on Forward Local Flow Across Radial Seal, Seal PT19, Position 3.

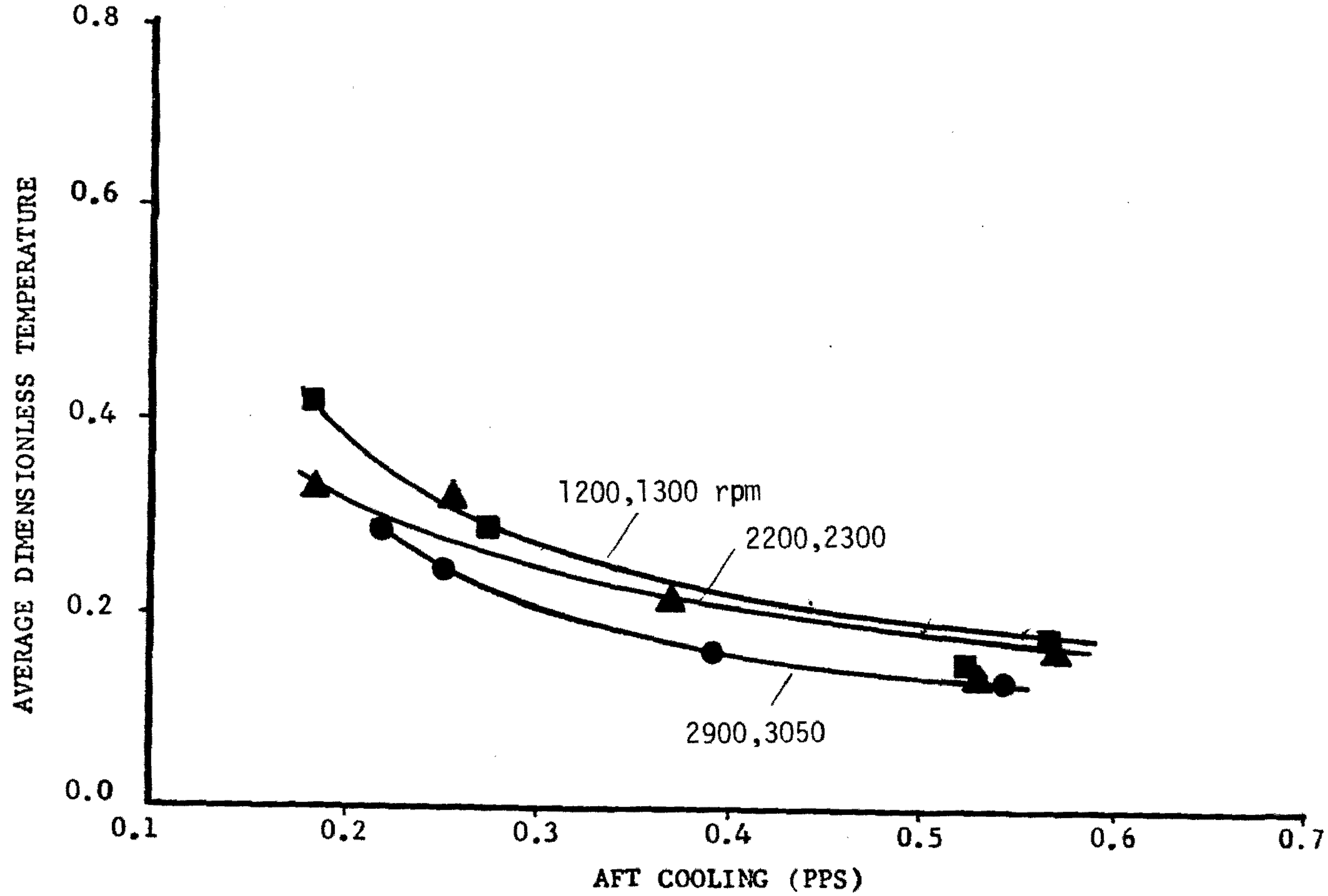


Figure V.-45. Effect of Wheelspeed on Temperature, Seal PT18, Position C4.

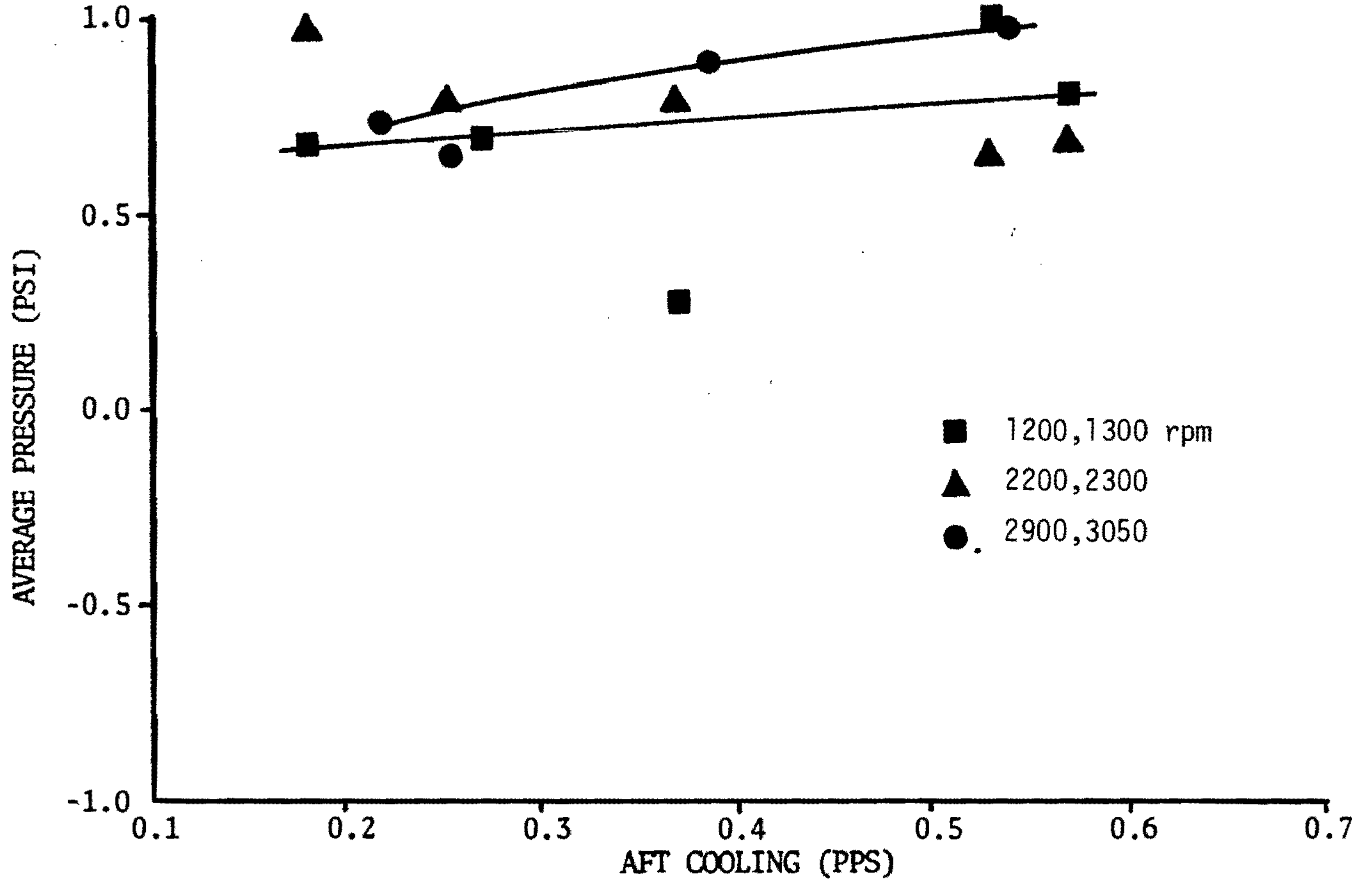


Figure V-46. Effect of Wheelspeed on Pressure, Seal PT18, Position C4.

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13. Edelfelt, I. H., "Experimental Investigation of the Flow between a Stationary Wall and a Rotating Disk with Throughflow and Axial Flow", General Electric Research and Development Center Report No. 71-C-010, December 1970.

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APPENDICES

LIST OF APPENDICES

APPENDIX I

COMPUTER PROGRAM WS1 FLOW CHART

```
C
C
C
C      PROGRAM WS1: ABSTRACT
C
C           THIS PROGRAM CALCULATES THE AVERAGE DIMENSIONLESS
C      TEMPERATURE AT DIFFERENT WHEEL LOCATION, AVERAGE WHEEL-
C      SPACE PRESSURE AND THE FLOW ACROSS A CIRCUNFERENTIAL
C      SEAL OF THE WHEEL. IT READS IN DATA TAKEN FROM THE
C      EXPERIMENT, SORTS THEM AND CONVERT THE DATAS TO THE
C      APPROPRIATE UNITS. ONCE CALCULATIONS ARE DONE, THE
C      ORGANIZED DATA WILL BE PRINTED OUT IN A FORM OF TABLES
C      AND BY USING LIBRARY SUBROUTINES PLOTTINGS OF DIMENSIONLESS
C      TEMPERATURE,AVERAGE PRESSURE AND SQUARE ROOT OF THE
C      ABSOLUTE VALUE OF THE PRESSURE ACROSS THE CIRCUNFERENTIAL
C      SEAL VERSUS COOLING ARE DONE.
C
C           THIS PROGRAM WILL HANDLE FORWARD TEST, AFT TEST OR
C      THE COMBINATION OF BOTH TO UP TO SIX RUNS. IT IS COMPOSED
C      OF A FOUR PARTS MAIN PROGRAM AND FIVE SUBROUTINES.
C
C      DICTIONARY OF PRIMARY VARIABLES USED IN THIS PROGRAM:
C
C      AA: RIM SEAL CLEARENCE
C      AMB: AMBIENT TEMPERATURE
C      AT: AFT TEMPERATURE
C      BC(I): PRESSURE TAPS LOCATIONS FOR FLOW ACROSS THE
C           CIRCUNFERENTIAL SEAL.
C      BF(I): PRESSURE TAPS LOCATIONS CIRCUNFERENTIALLY AT
C           "O" POSITION.
C      BP(I,J): CIRCUNFERENTIAL PRESSURES
C      BPC(I,J): CIRCUNFERENTIAL PRESSURES ACROSS SEAL
C      B3: PRESSURE DIFFERENCE B33-B23
C      CA(I): AFT COOLING
C      CC: RADIAL SEAL CLEARENCE
C      CF(I): FORWARD COOLING
C      CO: COMMENTS
C      COO: COOLING TEMPERATURE
C      CRO: HOT INLET TEMPERATURE
C      C3: AFT PRESSURE DIFFERENCE C33-C23
C      D(I,J): TEMPERATURE DATAS
C      DA: DATE
C      DD: ROTOR-STATOR AXIAL CLEARENCE
C      DF(I): THERMOCOUPLES LOCATION
C      DFO(I): SORTED THERMOCOUPLES LOCATION
C      DG(I): THERMOCOUPLES LOCATION, AVERAGE VALUES
C      DP(I): PRESSURE TAPS LOCATION
C      FAT: FORWARD AND AFT TEMPERATURES
C      FT: FORWARD TEMPERATURE
C      HF(I): CROSS FLOW
C      N(I): RUN NUMBER (PRESSURE)
C      NBA: NUMBER OF AFT RUNS (TANGENTIAL LOCATION)
C      NBF: NUMBER OF FORWARD RUNS (TANGENTIAL LOCATION)
C      NR: NUMBER OF RUNS
C      NRA: NUMBER OF AFT RUNS
       NRF: NUMBER OF FORWARD RUNS
C      NT(I): NUMBER OF RUNS (TEMPERATURE)
C      NTA: NUMBER OF AFT RUNS (TEMPERATURE)
C      NTF: NUMBER OF FORWARD RUNS (TEMPERATURE)
C      NTR: NUMBER OF RUNS (TEMPERATURE)
C      N1: NUMBER OF RUNS
C      P(I): PRESSURE AT DIFFERENT RADIAL LOCATION
```

```
C       PA(I,J): AVERAGE PRESSURE FROM 2 CIRCUNFERENTIAL POSITION
C       PD(I): PRESSURE TAPS DEFINITION
C       POF: SUBROUTINE, PRINT OUT FORWARD TEMPERATURES
C       RPM: WHEELSPEED
C       SB: PRESSURE TAPS IDENTIFICATION FOR PRESSURE DIFFERENTIAL
C            ACROSS THE RADIAL SEAL
C       T(I,J): DIMENSIONLESS TEMPERATURE
C       TA(I,J):AVERAGE DIMENSIONLESS TEMPERATURE FROM 3 CIRCUNFERENTIAL
C            POSITIONS
C       TN: TEST NUMBER
C       TT(I): CROSS TEMPERATURE
        PROGRAM MAIN(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
        DIMENSION RPM(6),HF(6),TT(6),CF(8),CA(8),N1(6),D(59,6),
       *NT(6),DS(59,6),T(59,6),TA(28,8),DF(59),DFO(59),DG(28)
        DIMENSION DP(30),P(30,6),N(6),PA(22,8),PD(22)
        DIMENSION BPF(12,6),BPA(12,6),BPCF(12,6),BPCA(12,6),BF(12),
       *BA(12),SBF(12,6),SBA(12,6),BCA(12),BCF(12)
        DIMENSION TN(7),DA(2),CO(7),ITITF(2),ITITA(2)
        DIMENSION AKF(6),AKA(6),BKF(6),BKA(6)
        DIMENSION IBUF(512)
C
C       PART I: GENERAL
C
C       THERMOCOUPLES IDENTIFICATION
C
        DATA DF/'C73','D71','C01','C74','C71','C84','C81',
       *'E81','C83','D81','F71','F73','A71','B71','B74',
       *'F81','B81','F83','B84','A81','E71','C44','C64',
       *'C63','C61','C53','C51','C43','C41','C33','C24','C23',
       *'C21','C11','C31','B61','B63','B64','B51','B53',
       *'B41','B43','B44','B31','B33','B21','B23','B24',
       *'B11','A01','D01','B03','C03','B01','B04','C04',
       *'AMB','CRO','COO'/
        DATA DFO/'A01','A71','A81','B01','B03','B04','B11','B21',
       *'B23','B24','B31','B33','B41','B43','B44','B51','B53',
       *'B61','B63','B64','B71','B74','B81','B84','F71','F73',
       *'F81','F83','C01','C03','C04','C11','C21','C23','C24',
       *'C31','C33','C41','C43','C44','C51','C53','C61','C63',
       *'C64','C71','C73','C74','C81','C83','C84','D01','D71',
       *'D81','E71','E81','AMB','CRO','COO'/
        DATA DG/ 'A0','A7','A8','B0','B1','B2','B3','B4','B5',
       *'B6','B7','B8','F7','F8','C0','C1','C2','C3','C4',
       *'C5','C6','C7','C8','D0','D7','D8','E7','E8'/
C
C       PRESSURE TAPS IDENTIFICATION
C
        DATA PD/'C0','C1','C2','C3','C4','C5','C6','E7','E7.3',
       *'E7.6','E8','B0','B1','B2','B3','B4','B5','B6','F7',
       *'F7.3','F7.6','F8'/
        DATA DP/'C04','B04','C03','B03','C13','C23','C24','C33',
       *'C43','C44','C53','C64','B13','B23','B24','B33',
       *'B43','B44','B53','B64','E73','E74','E7.34','E7.64',
       *'E84','F73','F74','F7.34','F7.64','F84'/
C
C       PRESSURE DIFFERENCE ACROSS TANGENTIAL SEAL IDENTIFICATION
C
        DATA BF/'BOH','BOG','BOF','BOE','BOD','BOC','BOB','BOA',
       *'BOJ','BOK','BOL','BOM'/
        DATA BA/'COH','COG','COF','COE','COD','COC','COB','COA',
       *'COJ','COK','COL','COM'/
        DATA BCF/'B3H-B2H','B3G-B2G','B3F-B2F','B3E-B2E',
       *'B3D-B2D','B3C-B2C','B3B-B2B','B3A-B2A','B3J-B2J',
       *'B3K-B2K','B3L-B2L','B3M-B2M'/
        DATA BCA/'C3H-C2H','C3G-C2G','C3F-C2F','C3E-C2E','C3D-C2D',
       *'C3C-C2C','C3B-C2B','C3A-C2A','C3J-C2J','C3K-C2K',
       *'C3L-C2L','C3M-C2M'/
```

```
      CALL PLOTS(IBUF,512,9,00)
      CALL PLOT(1.,1.,-3)
C
C     READ IN DATA
C
      READ(5,701) TN
  701 FORMAT(7A10)
      READ(5,702)DA
  702 FORMAT(2A10)
      READ*,AA,CC,DD
      READ(5,703)CO
  703 FORMAT(7A10)
      READ*,NRF,NRA
      IF(NRF.GE.NRA)GO TO 704
      NR=NRA
      GO TO 705
  704 NR=NRF
  705 READ*, (N1(I),I=1,NR)
      READ*, (RPM(I),I=1,NR)
      READ*, (HF(I),I=1,NR)
      READ*, (TT(I),I=1,NR)
      READ*, (CF(I),I=1,NRF)
      READ*, (CA(I),I=1,NRA)
C
C     CALCULATIONS
C
      DO 707 I=1,NRF
  707 CF(I)=.309*SQRT(CF(I))
      DO 708 I=1,NRA
  708 CA(I)=.309*SQRT(CA(I))
C
C     PRINT OUT 1
C
      WRITE(6,711)TN
  711 FORMAT(10X,T25,'TEST NUMBER:',T39,7A10)
      WRITE(6,712)DA
  712 FORMAT(1H ,/,T25,'DATE:',T32,2A10)
      WRITE(6,713)AA,CC,DD
  713 FORMAT(1H ,/,T25,'RIM SEAL CLEARENCE IN INCHES:',
     *T60,F4.2,//,T25,'RADIAL SEAL CLEARENCE IN INCHES:',
     *T60,F4.2,//,T25,'ROT-STAT AX. SEAL CLEAR.IN INCHES:',
     *T60,F4.2,/)
      WRITE(6,714)CO
  714 FORMAT(1H ,T25,'COMMENTS:',T35,7A10)
      WRITE(6,710)NRF,NRA
  710 FORMAT(/,T25,'NUMBER OF FORWARD RUNS:',T50,I1,//,
     *T25,'NUMBER OF AFT RUNS:',T50,I1,//)
      WRITE(6,715)(N1(I),I=1,NR)
  715 FORMAT(T3,'RUN NUMBER:',T25,6I8,/)
      WRITE(6,716)(RPM(I),I=1,NR)
  716 FORMAT(/,T3,'WHEEL SPEED IN RPM:',T25,6F8.0,/)
      WRITE(6,717)(HF(I),I=1,NR)
  717 FORMAT(/,T3,'CROSS FLOW IN PPS:',T25,6F8.2,/)
      WRITE(6,718)(TT(I),I=1,NR)
  718 FORMAT(/,T3,'CROSS TEMP.IN DEG F:',T25,6F8.0,/)
      IF(NRF.EQ.0)GO TO 720
      WRITE(6,719)(CF(I),I=1,NRF)
  719 FORMAT(/,T3,'FOR COOLING IN PPS:',T25,6F8.2,/)
  720 IF(NRA.EQ.0)GO TO 723
      WRITE(6,721)(CA(I),I=1,NRA)
  721 FORMAT(/,T3,'AFT COOLING IN PPS:',T25,6F8.2,/)
C
C     PART II: WHEEL TEMPERATURE
C
  723 READ*, NTF,NTA
      IF(NTF.GE.NTA)GO TO 731
```

```
      NTR=NTA
      GO TO 732
  731 NTR=NTF
  732 READ*, (NT(I),I=1,NTR)
      IF(NTF.EQ.0)GO TO 740
      IF(NTA.EQ.0)GO TO 741
C
C     FORWARD AND AFT TESTS
C
      DO 781 I=1,10
  781 READ*,(D(I,J),J=1,NTA)
      DO 782 I=11,20
  782 READ*,(D(I,J),J=1,NTF)
      DO 783 I=21,35
  783 READ*,(D(I,J),J=1,NTA)
      DO 784 I=36,50
  784 READ*,(D(I,J),J=1,NTF)
      READ*,(D(51,J),J=1,NTA)
      READ*,(D(52,J),J=1,NTF)
      READ*,(D(53,J),J=1,NTA)
      DO 785 I=54,55
  785 READ*,(D(I,J),J=1,NTF)
      READ*,(D(56,J),J=1,NTA)
      DO 786 I=57,59
  786 READ*,(D(I,J),J=1,NTR)
      CALL POF(DG,DS,DFO,T,TA,NTF,NT,D,CF,TN)
      CALL POA(DG,DS,DFO,T,TA,NTA,NT,D,CA,TN)
      GO TO 733
C
C     AFT TEST ONLY
C
  740 DO 761 I=1,10
  761 READ*,(D(I,J),J=1,NTA)
      DO 762 I=21,35
  762 READ*,(D(I,J),J=1,NTA)
      READ*,(D(51,J),J=1,NTA)
      READ*,(D(53,J),J=1,NTA)
      READ*,(D(56,J),J=1,NTA)
      DO 763 I=57,59
  763 READ*,(D(I,J),J=1,NTA)
      CALL POA(DG,DS,DFO,T,TA,NTA,NT,D,CA,TN)
      GO TO 733
C
C     FORWARD TEST ONLY
C
  741 DO 771 I=11,20
  771 READ*,(D(I,J),J=1,NTF)
      DO 772 I=36,50
  772 READ*,(D(I,J),J=1,NTF)
      READ*,(D(52,J),J=1,NTF)
      READ*,(D(54,J),J=1,NTF)
      READ*,(D(55,J),J=1,NTF)
      DO 773 I=57,59
  773 READ*,(D(I,J),J=1,NTF)
      CALL POF(DG,DS,DFO,T,TA,NTF,NT,D,CF,TN)
  733 READ*,NA,NF
C
C     PART III: WHEEL PRESSURE
C
      IF(NF.GE.NA)GO TO 1
      NR=NA
      GO TO 2
    1 NR=NF
    2 READ*,(N(I),I=1,NR)
      IF(NF.EQ.0)GO TO 301
      IF(NA.EQ.0)GO TO 302
```

```
C
C      FORWARD AND AFT TESTS
C
       READ*,((P(I1,I2),I2=1,NR),I1=1,30)
       DO 321 I=1,30
       DO 322 J=1,NR
   322 P(I,J)=.1065*P(I,J)
   321 CONTINUE
       CALL AFF(PA,PD,P,NF,CF,DP,AKF,BKF,CKF,B3,TN,ITITF)
       CALL APA(PA,PD,P,NA,CA,DP,AKA,BKA,CKA,C3,TN,ITITA)
       GO TO 320
C
C      FORWARD TEST ONLY
C
   302 READ*,(P(2,I2),I2=1,NF)
       READ*,(P(4,I2),I2=1,NF)
       DO 343 I1=13,20
   343 READ*,(P(I1,I2),I2=1,NF)
       DO 344 I1=26,30
   344 READ*,(P(I1,I2),I2=1,NF)
       DO 323 I=2,4,2
       DO 324 J=1,NF
   324 P(I,J)=.1065*P(I,J)
   323 CONTINUE
       DO 325 I=13,20
       DO 326 J=1,NF
   326 P(I,J)=.1065*P(I,J)
   325 CONTINUE
       DO 327 I=26,30
       DO 328 J=1,NF
   328 P(I,J)=.1065*P(I,J)
   327 CONTINUE
       CALL AFF(PA,PD,P,NF,CF,DP,AKF,BKF,CKF,B3,TN,ITITF)
       GO TO 320
C
C      AFT TEST ONLY
C
   301 READ*,(P(1,I2),I2=1,NA)
       READ*,(P(3,I2),I2=1,NA)
       DO 357 I1=5,12
   357 READ*,(P(I1,I2),I2=1,NA)
       DO 358 I1=21,25
   358 READ*,(P(I1,I2),I2=1,NA)
       DO 330 I=1,3,2
       DO 331 J=1,NA
   331 P(I,J)=.1065*P(I,J)
   330 CONTINUE
       DO 332 I=5,12
       DO 333 J=1,NA
   333 P(I,J)=.1065*P(I,J)
   332 CONTINUE
       DO 334 I=21,25
       DO 335 J=1,NA
   335 P(I,J)=.1065*P(I,J)
   334 CONTINUE
       CALL APA(PA,PD,P,NA,CA,DP,AKA,BKA,CKA,C3,TN,ITITA)
C
C      PART IV: FLOW ACROSS CIRCUNFERENCIAL SEAL
C
   320 READ*,NBF,NBA
       IF(NBF.EQ.0)GO TO 400
       IF(NBA.EQ.0)GO TO 401
C
C      FORWARD AND AFT TESTS
C
       WRITE(6,402)
```

```
  402 FORMAT('1',//,T26,'FORWARD PRESSURE')
      CALL TPAC(BPF,BPCF,NBF,CF,BF,SBF,BCF,AKF,BKF,CKF,B3,TN,ITITF)
      WRITE(6,403)
  403 FORMAT('1',//,T26,'AFT PRESSURE')
      CALL TPAC(BPA,BPCA,NBA,CA,BA,SBA,BCA,AKA,BKA,CKA,C3,TN,ITITA)
      GO TO 499
C
C     FORWARD TEST ONLY
C
  401 WRITE(6,402)
      CALL TPAC(BPF,BPCF,NBF,CF,BF,SBF,BCF,AKF,BKF,CKF,B3,TN,ITITF)
      GO TO 499
C
C     AFT TEST ONLY
C
  400 WRITE(6,403)
      CALL TPAC(BPA,BPCA,NBA,CA,BA,SBA,BCA,AKA,BKA,CKA,C3,TN,ITITA)
  499 CALL PLOT(0.,0.,999)
      STOP
      END
      SUBROUTINE TPAC(BP,BPC,N,C,B,SB,BC,AK,BK,CK,A3,TN,ITITL)
      DIMENSION BP(12,6),BPC(12,6),C(8),B(12),SB(12,6),BC(12)
      DIMENSION BK(6),AK(6),SAK(6)
      DIMENSION SB1(13,8),Y1(8)
      DIMENSION TN(7),ITITL(2)
      DO 452 I=1,12
  452 READ*,(BP(I,J),J=1,N),(BPC(I,J),J=1,N)
      DO 412 I=1,12
      DO 411 J=1,N
      BP(I,J)=.1065*BP(I,J)
      BPC(I,J)=.0361*BPC(I,J)
  411 CONTINUE
  412 CONTINUE
C
C     PRINT OUT TANGENTIAL PRESSURE
C
      WRITE(6,454)
  454 FORMAT('0',//,T25,'CIRCUNFERENTIAL PRESSURE (PSI)')
      WRITE(6,457)(C(I),I=1,N)
  457 FORMAT(//,T7,'COOLING (PPS):',T25,6F7.2,/)
      DO 455 I=1,8
  455 WRITE(6,456)B(I),(BP(I,J),J=1,N)
      WRITE(6,456)CK,(BK(J),J=1,N)
      DO 476 I=9,12
  476 WRITE(6,456)B(I),(BP(I,J),J=1,N)
  456 FORMAT(T7,A3,T25,6F7.2)
C
C     PRINT OUT ACROSS SEAL PRESSURE
C
      WRITE(6,461)
  461 FORMAT(//,T12,'PRESSURE DIFFERENCE ACROSS SEAL (PSI)')
      WRITE(6,457)(C(I),I=1,N)
      DO 462 I=1,8
  462 WRITE(6,463)BC(I),(BPC(I,J),J=1,N)
      WRITE(6,463)A3,(AK(J),J=1,N)
      DO 477 I=9,12
  477 WRITE(6,463)BC(I),(BPC(I,J),J=1,N)
  463 FORMAT(T7,A7,T25,6F7.2)
C
C     TAKE SQUARE ROOT OF PRESSURE DIFFERENCE
C
      DO 469 J=1,N
      DO 467 I=1,12
      IF(BPC(I,J).LT.0.0)GO TO 468
      SB(I,J)=SQRT(BPC(I,J))
      GO TO 467
```

```
  468 A=-BPC(I,J)
      AN=SQRT(A)
      SB(I,J)=-AN
  467 CONTINUE
  469 CONTINUE
  470 WRITE(6,471)
  471 FORMAT(//,T12,'SQUARE ROOT OF PRESSURE DIFFERENCE:')
      WRITE(6,457)(C(I),I=1,N)
      DO 480 J=1,N
      IF(AK(J).LT.0.0)GO TO 481
      SAK(J)=SQRT(AK(J))
      GO TO 480
  481 P=-AK(J)
      PN=SQRT(P)
      SAK(J)=-PN
  480 CONTINUE
      DO 472 I=1,8
  472 WRITE(6,473)BC(I),(SB(I,J),J=1,N)
      WRITE(6,473)A3,(SAK(J),J=1,N)
      DO 483 I=9,12
  483 WRITE(6,473)BC(I),(SB(I,J),J=1,N)
  473 FORMAT(T7,A7,T25,6F7.2)
      DO 11 J=1,N
      DO 10 I=1,8
   10 SB1(I,J)=SB(I,J)
      SB1(9,J)=SAK(J)
      DO 12 I=10,13
   12 SB1(I,J)=SB(I-1,J)
   11 CONTINUE
C
C     PLOT SQUARE ROOT OF ABSOLUTE PRESSURE VS COOLING
C
      DO 20 I=1,13
      SB1(I,N+1)=-.4
   20 SB1(I,N+2)=.2
      C(N+1)=.0 $ C(N+2)=.1
      Y1(N+1)=-.4 $ Y1(N+2)=.2
      CALL AXIS(0.,0.,ITITL,-17,7.,0.,0.0,.1)
      CALL AXIS(0.,0.,'SQRT PRESS. DIFF.',17,6.,90.,-.4,.2)
      N2=N+2
      DO 22 I=1,13
      DO 21 J=1,N2
      Y1(J)=SB1(I,J)
   21 CONTINUE
   22 CALL LINE(C,Y1,N,1,-1,I)
      CALL SYMBOL(.25,7.,.14,TN,0.0,25)
      CALL PLOT(9.,0.,-3)
      RETURN
      END
C
C     TEMPERATURE SUBROUTINES
C
C     PRINT OUT FORWARD
C
      SUBROUTINE POF(DG,DS,DFO,T,TA,NTF,NT,D,CF,TN)
      DIMENSION DG(28),DS(59,6),T(59,6),DFO(59),TA(28,8),NT(6),D(59,6),
     *CF(8)
      DIMENSION Y1(8)
      DIMENSION TN(7)
      DO 906 I=1,NTF
      DS(1,I)=D(50,I)
      DS(2,I)=D(13,I)
      DS(3,I)=D(20,I)
      DS(4,I)=D(54,I)
      DS(5,I)=D(52,I)
      DS(6,I)=D(55,I)
```

```
        DS(7,I)=D(49,I)
        DS(8,I)=D(46,I)
        DS(9,I)=D(47,I)
        DS(10,I)=D(48,I)
        DS(11,I)=D(44,I)
        DS(12,I)=D(45,I)
        DS(13,I)=D(41,I)
        DS(14,I)=D(42,I)
        DS(15,I)=D(43,I)
        DS(16,I)=D(39,I)
        DS(17,I)=D(40,I)
        DS(18,I)=D(36,I)
        DS(19,I)=D(37,I)
        DS(20,I)=D(38,I)
        DS(21,I)=D(14,I)
        DS(22,I)=D(15,I)
        DS(23,I)=D(17,I)
        DS(24,I)=D(19,I)
        DS(25,I)=D(11,I)
        DS(26,I)=D(12,I)
        DS(27,I)=D(16,I)
        DS(28,I)=D(18,I)
        DS(57,I)=D(57,I)
        DS(58,I)=D(58,I)
        DS(59,I)=D(59,I)
    906 CONTINUE
        WRITE(6,901)
    901 FORMAT(//,T10,'FOR. TEMP. AT FOLL WHEEL LOCATION (DEG F):',
       *//)
        WRITE(6,900)(CF(I),I=1,NTF)
    900 FORMAT(//,T7,'COOLING (PPS):',T25,6F7.2,/)
        DO 902 I=1,28
    902 WRITE(6,907)DFO(I),(DS(I,J),J=1,NTF)
    907 FORMAT(T7,A5,T25,6F7.0)
C
C       CALCULATIONS FOR DIMENSIONLESS TEMPERATURE
C
        DO 904 J=1,NTF
        DO 909 I=1,28
    909 T(I,J)=(DS(I,J)-DS(59,J))/(DS(58,J)-DS(59,J))
    904 CONTINUE
        WRITE(6,911)
    911 FORMAT(//,T10,'FORWARD DIMENSIONLESS TEMP DISTRIBUTION:'
       *)
        WRITE(6,900)(CF(I),I=1,NTF)
        DO 903 I=1,28
    903 WRITE(6,905)DFO(I),(T(I,J),J=1,NTF)
    905 FORMAT(T7,A5,T25,6F7.2)
C
C       TAKE AVERAGE DIMENSIONLESS TEMPERATURE
C
        DO 920 I=1,NTF
        DO 921 J=1,3
    921 TA(J,I)=T(J,I)
        TA(4,I)=(T(4,I)+T(5,I)+T(6,I))/3.
        TA(5,I)=T(7,I)
        TA(6,I)=(T(8,I)+T(9,I)+T(10,I))/3.
        TA(7,I)=(T(11,I)+T(12,I))/2.
        TA(8,I)=(T(13,I)+T(14,I)+T(15,I))/3.
        TA(9,I)=(T(16,I)+T(17,I))/2.
        TA(10,I)=(T(18,I)+T(19,I)+T(20,I))/3.
        TA(11,I)=(T(21,I)+T(22,I))/2.
        TA(12,I)=(T(23,I)+T(24,I))/2.
        TA(13,I)=(T(25,I)+T(26,I))/2.
        TA(14,I)=(T(27,I)+T(28,I))/2.
    920 CONTINUE
```

```
C
C      PRINT OUT DIMENSIONLESS TEMPERATURE
C
       WRITE(6,922)
   922 FORMAT(/,T10,'FORWARD AVE. DIMENSIONLESS TEMP DISTRIBUTION')
       WRITE(6,900)(CF(I),I=1,NTF)
       DO 923 I=1,14
   923 WRITE(6,905)DG(I),(TA(I,J),J=1,NTF)
C
C      PLOT FORWARD DIMENSIONLESS TEMPERATURE VS COOLING
C
       DO 10 I=1,14
       TA(I,NTF+1)=0.0
    10 TA(I,NTF+2)=.2
       CF(NTF+1)=0.0 $ CF(NTF+2)=.1
       Y1(NTF+1)=0.0 $ Y1(NTF+2)=.2
       CALL AXIS(0.,0.,'FOR. COOLING (PPS)',-18,7.,0.,0.0,.1)
       CALL AXIS(0.,0.,'DIMENS. TEMP.',15,5.,90.,0.0,.2)
       NTFP2=NTF+2
       DO 12 I=1,14
       DO 11 J=1,NTFP2
       Y1(J)=TA(I,J)
11     CONTINUE
12     CALL LINE(CF,Y1,NTF,1,-1,I)
       CALL SYMBOL(.25,6.,.14,TN,0.0,25)
       CALL PLOT(9.,0.,-3)
       RETURN
       END
C
C      PRINT OUT AFT
C
       SUBROUTINE POA(DG,DS,DFO,T,TA,NTA,NT,D,CA,TN)
       DIMENSION DG(28),DS(59,6),T(59,6),DFO(59),TA(28,8),NT(6),D(59,6),
      *CA(8)
       DIMENSION Y1(8)
       DIMENSION TN(7)
       DO 956 I=1,NTA
       DS(29,I)=D(3,I)
       DS(30,I)=D(53,I)
       DS(31,I)=D(56,I)
       DS(32,I)=D(34,I)
       DS(33,I)=D(33,I)
       DS(34,I)=D(32,I)
       DS(35,I)=D(31,I)
       DS(36,I)=D(35,I)
       DS(37,I)=D(30,I)
       DS(38,I)=D(29,I)
       DS(39,I)=D(28,I)
       DS(40,I)=D(22,I)
       DS(41,I)=D(27,I)
       DS(42,I)=D(26,I)
       DS(43,I)=D(25,I)
       DS(44,I)=D(24,I)
       DS(45,I)=D(23,I)
       DS(46,I)=D(5,I)
       DS(47,I)=D(1,I)
       DS(48,I)=D(4,I)
       DS(49,I)=D(7,I)
       DS(50,I)=D(9,I)
       DS(51,I)=D(6,I)
       DS(52,I)=D(51,I)
       DS(53,I)=D(2,I)
       DS(54,I)=D(10,I)
       DS(55,I)=D(21,I)
       DS(56,I)=D(8,I)
       DS(57,I)=D(57,I)
```

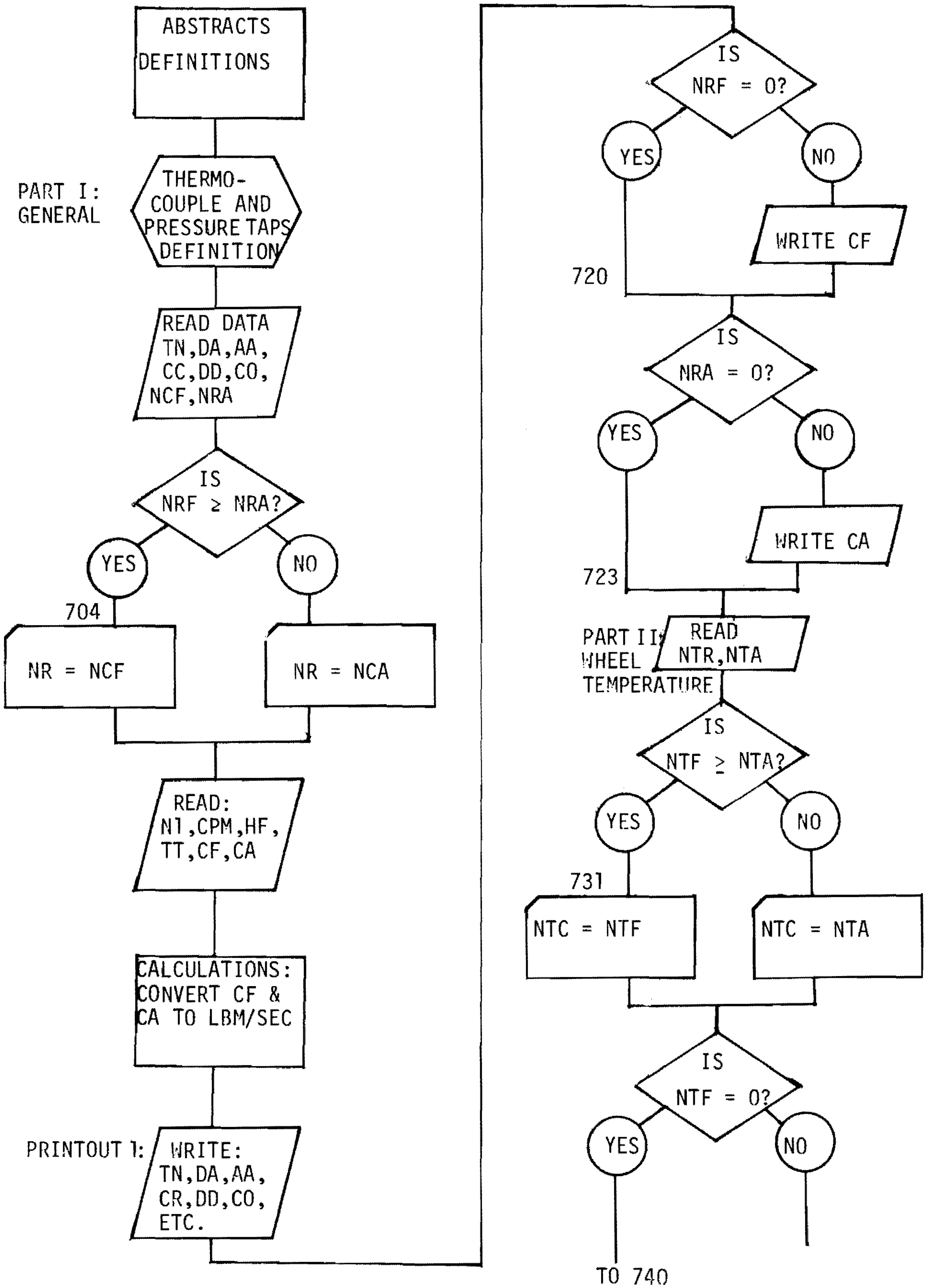
```
      DS(58,I)=D(58,I)
      DS(59,I)=D(59,I)
  956 CONTINUE
      WRITE(6,951)
  951 FORMAT(//,T10,'AFT TEMP AT FOLL.WHEEL LOCATION (DEG F):',//)
      WRITE(6,950)(CA(I),I=1,NTA)
  950 FORMAT(//,T7,'COOLING (PPS)',T25,6F7.2,/)
      DO 952 I=29,56
  952 WRITE(6,957)DFO(I),(DS(I,J),J=1,NTA)
  957 FORMAT(T7,A5,T25,6F7.0)
C
C     CALCULATION FOR DIMENSIONLESS TEMPERATURE
C
      DO 954 I=29,56
      DO 959 J=1,NTA
  959 T(I,J)=(DS(I,J)-DS(59,J))/(DS(58,J)-DS(59,J))
  954 CONTINUE
      WRITE(6,961)
  961 FORMAT(/,T10,'DIMENSIONLESS TEMP DISTRIBUTION:')
      WRITE(6,950)(CA(I),I=1,NTA)
      DO 953 I=29,56
  953 WRITE(6,955)DFO(I),(T(I,J),J=1,NTA)
  955 FORMAT(T7,A5,T25,6F7.2)
C
C     TAKE AVERAGE DIMENSIONLESS TEMPERATURE
C
      DO 970 I=1,NTA
      TA(15,I)=(T(29,I)+T(30,I)+T(31,I))/3.
      TA(16,I)=T(32,I)
      TA(17,I)=(T(33,I)+T(34,I)+T(35,I))/3.
      TA(18,I)=(T(36,I)+T(37,I))/2.
      TA(19,I)=(T(38,I)+T(39,I)+T(40,I))/3.
      TA(20,I)=(T(41,I)+T(42,I))/2.
      TA(21,I)=(T(43,I)+T(44,I)+T(45,I))/3.
      TA(22,I)=(T(46,I)+T(47,I)+T(48,I))/3.
      TA(23,I)=(T(49,I)+T(50,I)+T(51,I))/3.
      DO 980 J=24,28
  980 TA(J,I)=T(J+28,I)
  970 CONTINUE
C
C     PRINT OUT AVERAGE DIMENSIONLESS.TEMPERATURE
C
      WRITE(6,971)
  971 FORMAT(/,T10,'AFT AVERAGE DIMENSIONLESS TEMP DIST:')
      WRITE(6,950)(CA(I),I=1,NTA)
      DO 973 I=15,28
  973 WRITE(6,955)DG(I),(TA(I,J),J=1,NTA)
C
C     PLOT AFT DIMENSIONLESS TEMPERATURE VS COOLING
C
      DO 10 I=15,28
      TA(I,NTA+1)=0.0
   10 TA(I,NTA+2)=0.2
      CA(NTA+1)=.0 $ CA(NTA+2)=.1
      Y1(NTA+1)=0.0 $ Y1(NTA+2)=.2
      CALL AXIS(0.,0.,'AFT COOLING (PPS)',-17,7.,0.,0.0,.1)
      CALL AXIS(0.,0.,'DIMENS. TEMP.',15,5.,90.,0.0,.2)
      NTAP2=NTA+2
      DO 12 I=15,28
      I2=I-14
      DO 11 J=1,NTAP2
      Y1(J)=TA(I,J)
   11 CONTINUE
   12 CALL LINE(CA,Y1,NTA,1,-1,I2)
      CALL SYMBOL(.25,6.,.14,TN,0.0,25)
      CALL PLOT(9.,0.,-3)
```

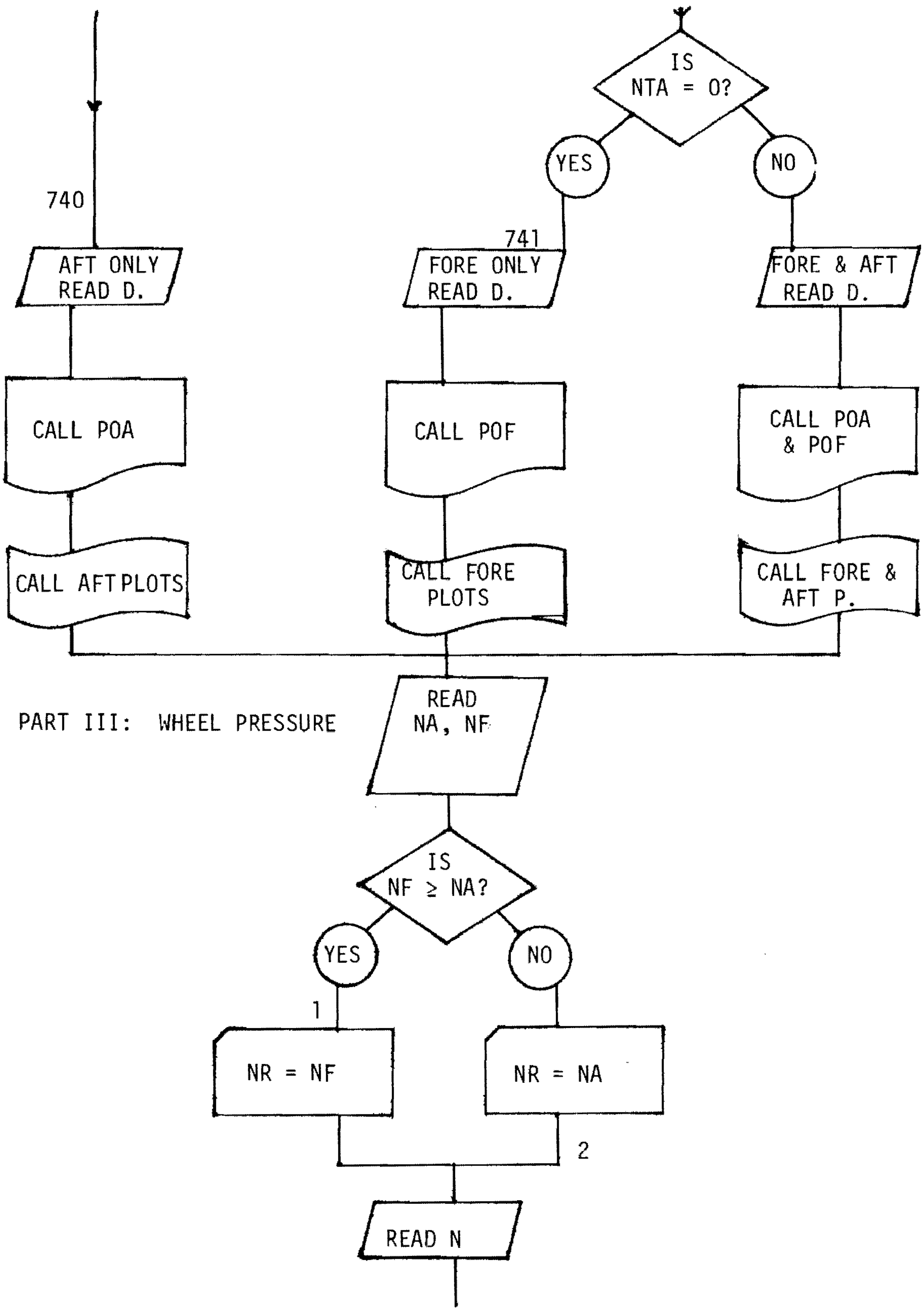
```
      RETURN
      END
C
C     PRESSURE SUBROUTINES
C
      SUBROUTINE APA(PA,PD,P,NA,CA,DP,AKA,BKA,CKA,C3,TN,ITITA)
      DIMENSION PA(22,8),PD(22),P(30,6),CA(6),DP(30)
      DIMENSION AKA(6),BKA(6)
      DIMENSION Y1(8)
      DIMENSION TN(7),ITITA(2)
C
C     PRINT OUT AFT
C
      WRITE(6,313)
  313 FORMAT(1H ,//,T12,'AFT PRESS. AT FOLL. WHEEL LOCATION (PSI):',//)
  310 FORMAT(//,T7,'COOLING (PPS):',T25,6F7.2,/)
  311 FORMAT(1H ,T7,A5,T25,6F7.2)
      WRITE(6,310)(CA(I),I=1,NA)
      WRITE(6,311) DP(1),(P(1,I1),I1=1,NA)
      WRITE(6,311) DP(3),(P(3,I1),I1=1,NA)
      DO 350 I=5,12
  350 WRITE(6,311) DP(I),(P(I,I1),I1=1,NA)
      DO 351 I=21,25
  351 WRITE(6,311) DP(I),(P(I,I1),I1=1,NA)
C
C     TAKE AVERAGE AFT PRESSURE
C
      DO 810 I=1,NA
      PA(1,I)=(P(3,I)+P(1,I))/2.
      PA(2,I)=P(5,I)
      PA(3,I)=(P(6,I)+P(7,I))/2.
      PA(4,I)=P(8,I)
      PA(5,I)=(P(9,I)+P(10,I))/2.
      PA(6,I)=P(11,I)
      PA(7,I)=P(12,I)
      PA(8,I)=(P(21,I)+P(22,I))/2.
      PA(9,I)=P(23,I)
      PA(10,I)=P(24,I)
      PA(11,I)=P(25,I)
  810 CONTINUE
      WRITE(6,801)
  801 FORMAT(1H ,//,T15,'AFT AVE.PRESS.(PPS)')
      WRITE(6,809)(CA(I),I=1,NA)
  809 FORMAT(//,T7,'COOLING (PSI):',T25,6F7.2,/)
      DO 803 I=1,11
  804 WRITE(6,802)PD(I),(PA(I,J),J=1,NA)
  802 FORMAT(1H ,T7,A5,T25,6F7.2)
  803 CONTINUE
      CKA='C03'
      C3='C33-C23'
      ITITA(1)='AFT COOLIN'
      ITITA(2)='G (PPS)'
      DO 31 J=1,NA
      BKA(J)=P(3,J)
      AKA(J)=P(8,J)-P(6,J)
   31 CONTINUE
C
C     PLOT AFT AVERAGE PRESSURE VS COOLING
C
      DO 10 I=1,11
      PA(I,NA+1)=-1.
   10 PA(I,NA+2)=.5
      CA(NA+1)=.0 $ CA(NA+2)=.1
      Y1(NA+1)=-1. $ Y1(NA+2)=.5
      CALL AXIS(0.,0.,'AFT COOLING (PPS)',-17,7.,0.,.0,.1)
      CALL AXIS(0.,0.,'AVE. PRESS. (PSI)',17,6.,90.,-1.,.5)
```

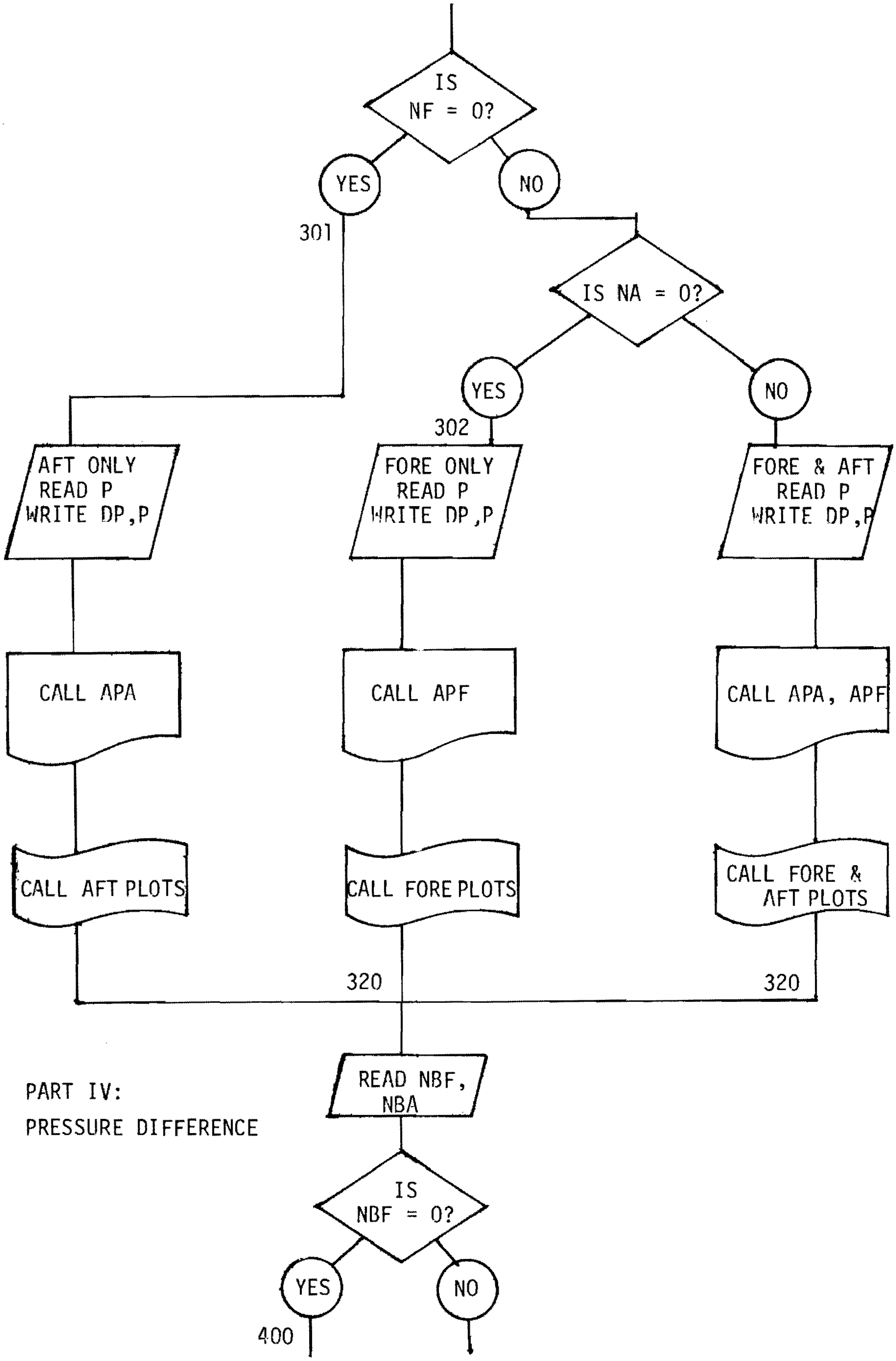
```
      K=NA+2
      DO 12 I=1,11
      DO 11 J=1,K
      Y1(J)=PA(I,J)
   11 CONTINUE
      CALL LINE(CA,Y1,NA,1,-1,I)
   12 CONTINUE
      CALL SYMBOL(.25,7.,.14,TN,0.0,25)
      CALL PLOT(9.,0.,-3)
      RETURN
      END
      SUBROUTINE APF(PA,PD,P,NF,CF,DP,AKF,BKF,CKF,B3,TN,ITITF)
      DIMENSION PA(22,8),PD(22),P(30,6),CF(8),DP(30)
      DIMENSION AKF(6),BKF(6)
      DIMENSION Y1(8)
      DIMENSION TN(7),ITITF(2)
C
C     PRINT OUT FORWARD
C
      WRITE(6,312)
  312 FORMAT(1H ,//,T12,'FORWARD PRESS AT FOLL WHEEL LOCATION (PSI)')
      WRITE(6,310)(CF(I),I=1,NF)
  310 FORMAT(//,T7,'COOLING (PPS):',T25,6F7.2,/)
      WRITE(6,311)DP(2),(P(2,I1),I1=1,NF)
      WRITE(6,311)DP(4),(P(4,I1),I1=1,NF)
      DO 341 I=13,20
  341 WRITE(6,311) DP(I),(P(I,I1),I1=1,NF)
      DO 342 I=26,30
  342 WRITE(6,311) DP(I),(P(I,I1),I1=1,NF)
  311 FORMAT(1H ,T7,A5,T25,6F7.2)
C
C     TAKE AVERAGE FORWARD PRESSURE
C
      DO 820 I=1,NF
      PA(12,I)=(P(4,I)+P(2,I))/2.
      PA(13,I)=P(13,I)
      PA(14,I)=(P(14,I)+P(15,I))/2.
      PA(15,I)=P(16,I)
      PA(16,I)=(P(17,I)+P(18,I))/2.
      PA(17,I)=P(19,I)
      PA(18,I)=P(20,I)
      PA(19,I)=(P(26,I)+P(27,I))/2.
      PA(20,I)=P(28,I)
      PA(21,I)=P(29,I)
      PA(22,I)=P(30,I)
  820 CONTINUE
      WRITE (6,811)
  811 FORMAT(1H ,//,T15,'FOR.AVE.PRESS.(PSI)')
      WRITE(6,815)(CF(I),I=1,NF)
  815 FORMAT(//,T7,'COOLING (PSI):',T25,6F7.2,/)
      DO 813 I=12,22
      WRITE(6,812) PD(I),(PA(I,J),J=1,NF)
  812 FORMAT(1H ,T7,A5,T25,6F7.2)
  813 CONTINUE
      CKF='B03'
      B3='B33-B23'
      ITITF(1)='FOR COOLIN'
      ITITF(2)='G (PPS)'
      DO 30 J=1,NF
      BKF(J)=P(4,J)
      AKF(J)=P(16,J)-P(14,J)
   30 CONTINUE
C
C     PLOT FORWARD AVERAGE PRESSURE VS COOLING
C
      DO 10 I=12,22
```

```
      PA(I,NF+1)=-1.
   10 PA(I,NF+2)=.5
      CF(NF+1)=.0 $ CF(NF+2)=.1
      Y1(NF+1)=-1. $ Y1(NF+2)=.5
      CALL AXIS(0.,0.,'FOR. COOLING (PPS)',-18,7.,0.,.0,.1)
      CALL AXIS(0.,0.,'AVE. PRESS. (PSI)',17,6.,90.,-1.,.5)
      K=NF+2
      DO 12 I=12,22
      DO 11 J=1,K
      Y1(J)=PA(I,J)
   11 CONTINUE
      I2=I-11
      CALL LINE(CF,Y1,NF,1,-1,I2)
   12 CONTINUE
      CALL SYMBOL(.25,7.,.14,TN,0.0,25)
      CALL PLOT(9.,0.,-3)
      RETURN
      END
```

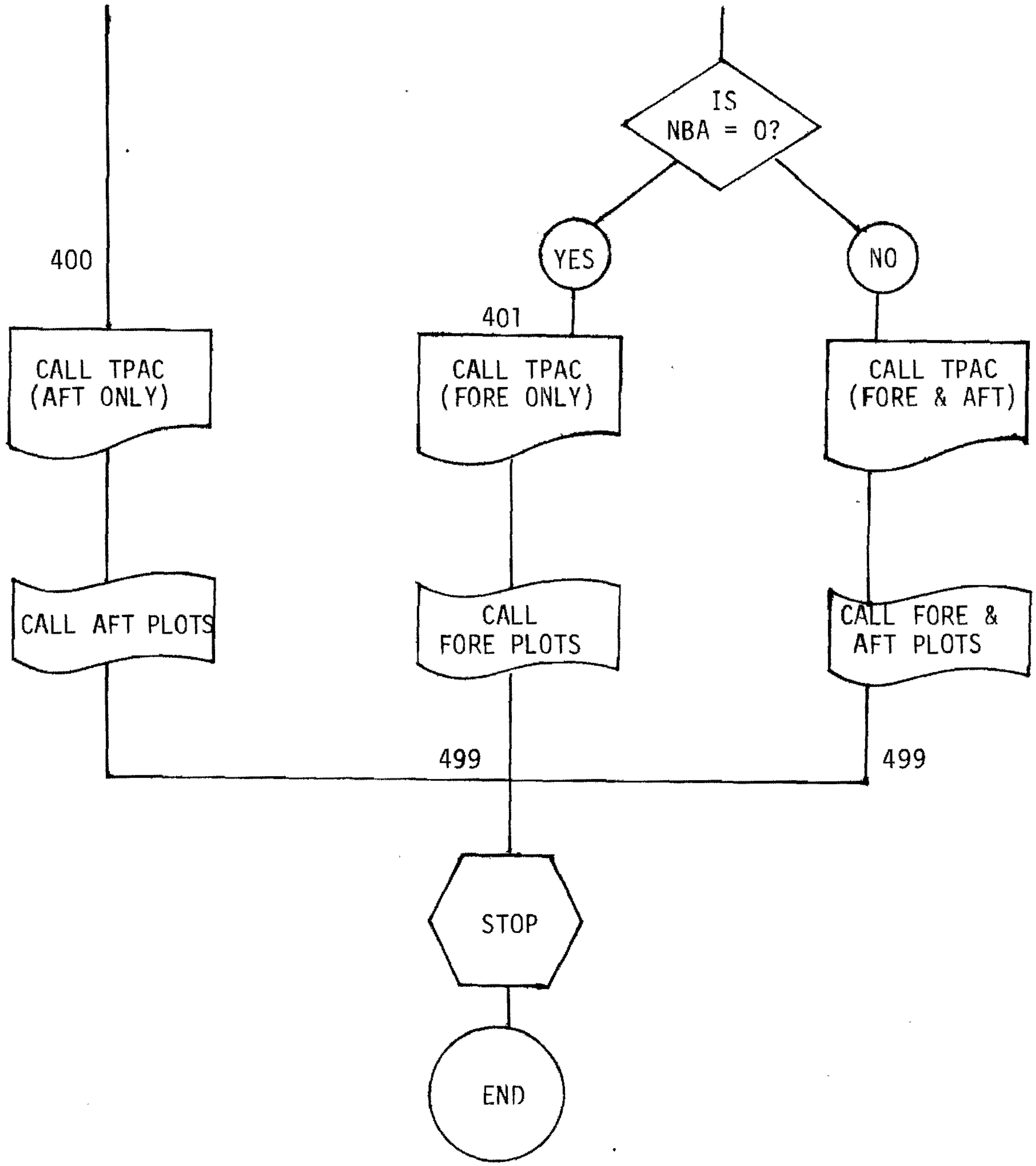
COMPUTER PROGRAM FLOW CHART




IS
NTA = 0?
YES
NO
740
741
AFT ONLY
READ D.
FORE ONLY
READ D.
FORE & AFT
READ D.
CALL POA
CALL POF
CALL POA
& POF
CALL AFT PLOTS
CALL FORE
PLOTS
CALL FORE &
AFT P.
PART III: WHEEL PRESSURE
READ
NA, NF
IS
NF ≥ NA?
YES
NO
1
NR = NF
NR = NA
2
READ N



PART IV:
PRESSURE DIFFERENCE


IS
NBA = 0?
YES
NO
400
401
CALL TPAC
(AFT ONLY)
CALL TPAC
(FORE ONLY)
CALL TPAC
(FORE & AFT)
CALL AFT PLOTS
CALL
FORE PLOTS
CALL FORE &
AFT PLOTS
499
499
STOP
END

APPENDIX II

GRAPHS OF TEMPERATURES, PRESSURES, AND SEAL PRESSURE DIFFERENTIALS AS A FUNCTION OF COOLING FLOW RATES FOR TESTS LISTED IN TABLE 5-1

LIST OF GRAPHS FROM APPENDIX 3A, 3B AND 3C

FIGURE NO. (PHASE I)

TEMPERATURE (AP. 3A)	PRESSURE (AP. 3B)	SORT P.O. (AP. 3C)	FORE	AFT	TEST NUMBER
AT1-A	AP1-A	AF1-A	X		F1A7 Baseline
AT1-B	AP1-B	AF1-B		X	F1A7 Baseline
AT2	AP2	AF2		X	A3 Speed Effect
AT3	AP3	AF3		X	A5 Speed Effect
AT4-A	AP4-A	AF4-A	X		F2A6 Rim Space
AT4-B	AP4-B	AF4-B		X	F2A6 Rim Space
AT5-A	AP5-A	AF5-A	X		F3A7 Rim Space
AT5-B	AP5-B	AF5-B		X	F3A7 Rim Space
AT6-A	AP6-A	AF6-A	X		F4A8 Rim Space
AT6-B	AP6-B	AF6-B		X	F4A8 Rim Space
AT7-A	AP7-A	AF7-A	X		F5A9 Rim Flow
AT7-B	AP7-B	AF7-B		X	F5A9 Rim Flow
AT8-A	AP8-A	AF8-A	X		F6A10 Rim Flow
AT8-B	AP8-B	AF8-B		X	F6A10 Rim Flow
AT9	AP9	AF9		X	A12 Rot. Stat.
AT10	AP10	AF10		X	A13 Rot. Stat.
AT11-A	AP11-A	AF11-A	X		F8A14 Radial Seal
AT11-B	AP11-B	AF11-B		X	F8A14 Radial Seal
AT12-A	AP12-A	AF12-A	X		F9A15 Radial Seal
AT12-B	AP12-B	AF12-B		X	F9A15 Radial Seal

FIGURE NO. (PHASE II)

TEMPERATURE (AP. 3A)	PRESSURE (AP. 3B)	SORT P.O. (AP. 3C)	FORE	AFT	TEST NUMBER
AT13-A	AP13-A	AF13-A	X		F10A16 Baseline
AT13-B	AP13-B	AF13-B		X	F10A16 Baseline
AT14	AP14	AF14	X		F11 Rim Space
AT15	AP15	AF15	X		F12 Rim Space
AT16	AP16	AF16	X		F13 Rim Space
AT17	AP17	AF17	X		F14 Rim Flow
AT18	AP18	AF18	X		F15 Rim Flow
AT19-A	AP19-A	AF19-A	X		F17A17 Inner
AT19-B	AP19-B	AF19-B		X	F17A17 Inner
AT20-A	AP20-A	AF20-A	X		F18A18 Inner
AT20-B	AP20-B	AF20-B		X	F18A18 Inner
AT21-A	AP21-A	AF21-A	X		F19A19 Radial
AT21-B	AP21-B	AF21-B		X	F19A19 Radial
AT22-A	AP22-A	AF22-A	X		F20A20 Radial
AT22-B	AP22-B	AF22-B		X	F20A20 Radial
AT23-A	AP23-A	AF23-A	X		F21A21 Radial
AT23-B	AP23-B	AF23-B		X	F21A21 Radial

APPENDIX IIIA

FIGURES AT1 - AT23

DIMENSIONLESS TEMPERATURE PLOTS

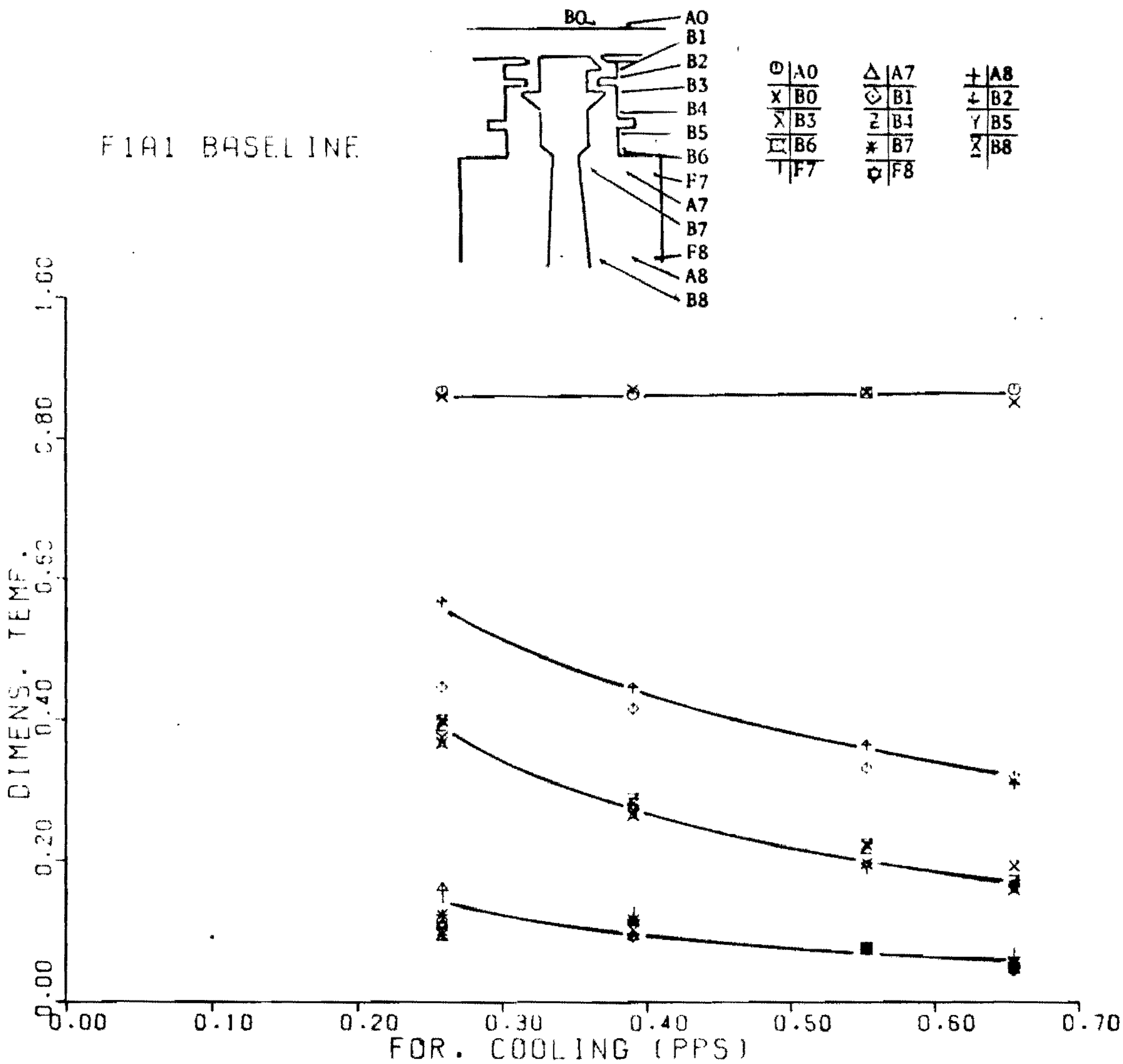

F1A1 BASELINE
BO
A0
B1
B2
B3
B4
B5
B6
F7
A7
B7
F8
A8
B8
A0
B0
B3
B6
F7
A7
B1
B4
B7
F8
A8
B2
B5
B8
DIMENS. TEMP.
0.00
0.20
0.40
0.60
0.80
1.00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
FOR. COOLING (PPS)

Figure AT1A

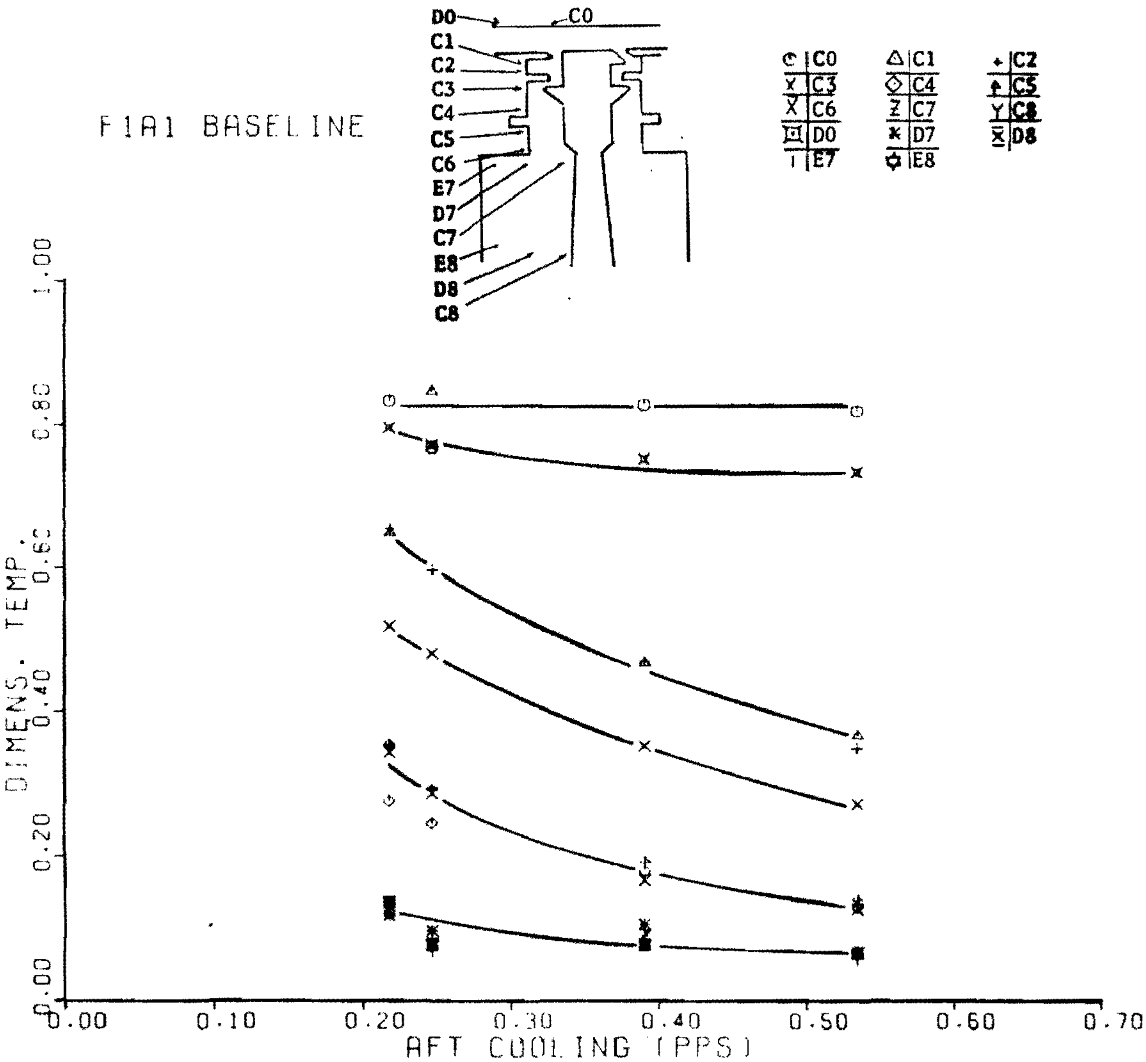

F1A1 BASELINE
D0
C0
C1
C2
C3
C4
C5
C6
E7
D7
C7
E8
D8
C8
C0
C1
C2
C3
C4
C5
C6
C7
C8
D0
D7
D8
E7
E8
DIMENS. TEMP.
0.00
0.20
0.40
0.60
0.80
1.00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
AFT COOLING (PPS)

Figure AT1B

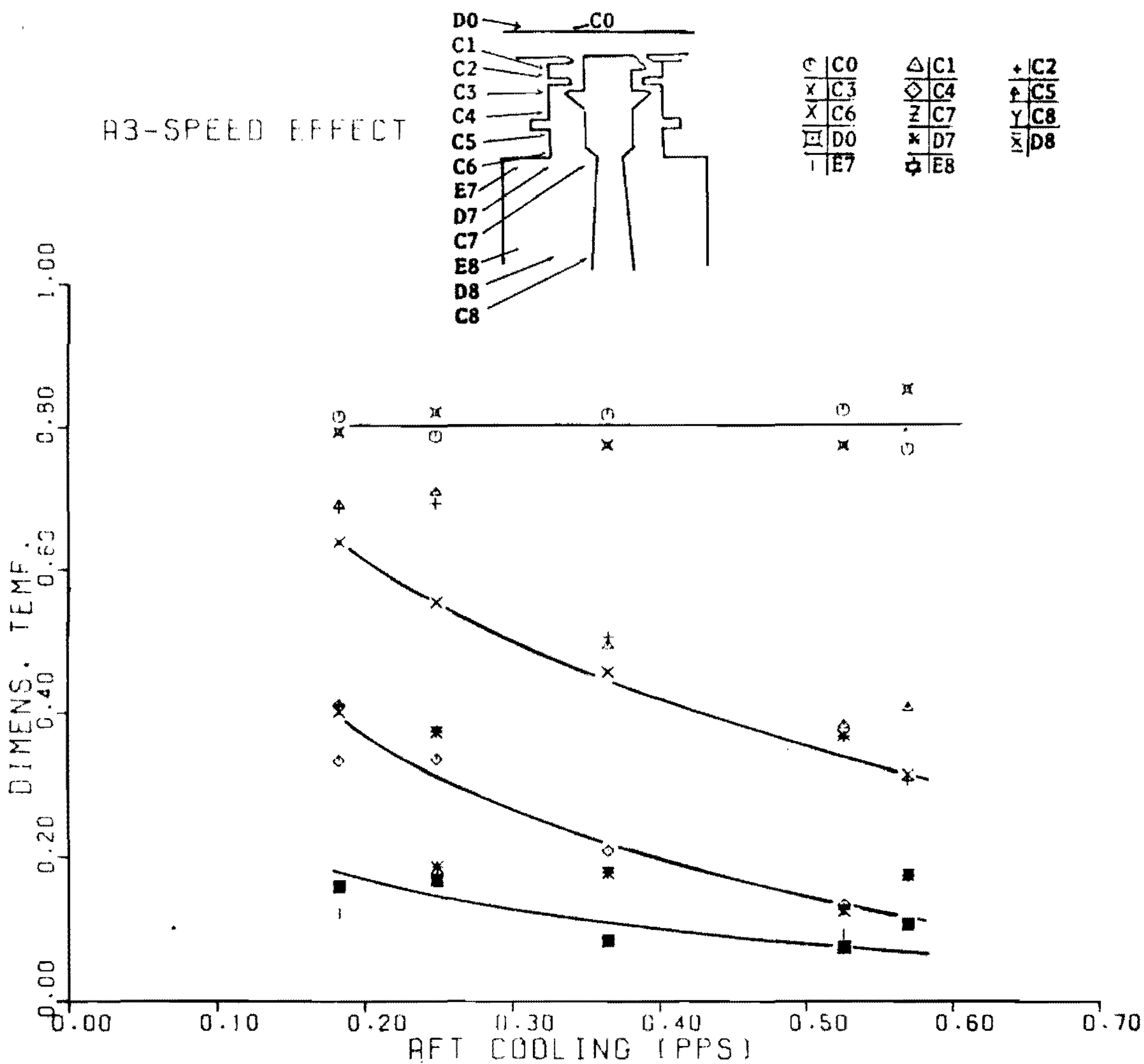

A3-SPEED EFFECT
D0
C0
C1
C2
C3
C4
C5
C6
E7
D7
C7
E8
D8
C8
C0
C1
C2
C3
C4
C5
C6
C7
C8
D0
D7
D8
E7
E8
DIMENS. TEMP.
0.00
0.20
0.40
0.60
0.80
1.00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
AFT COOLING (PPS)

Figure AT2

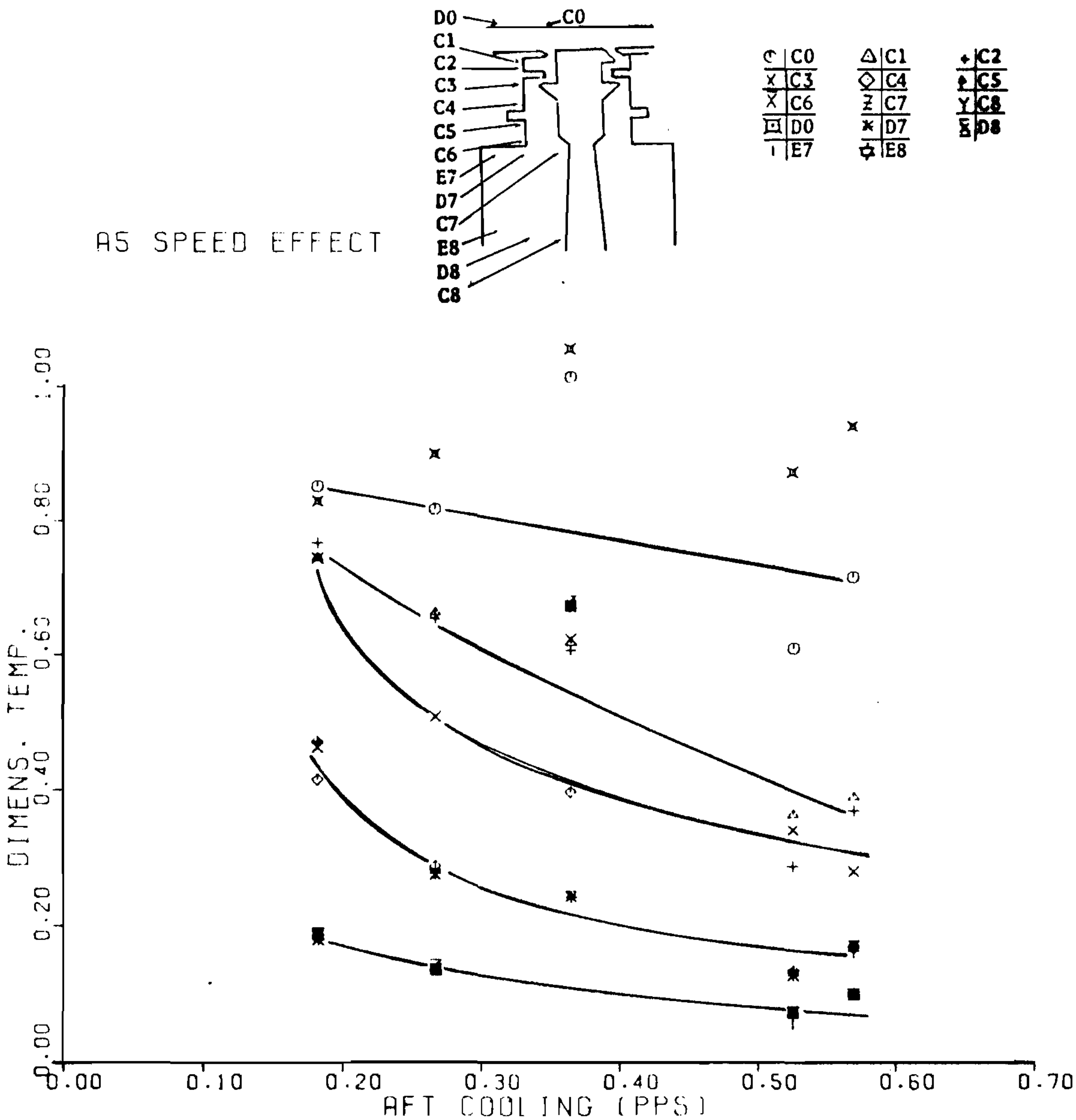

D0
C0
C1
C2
C3
C4
C5
C6
E7
D7
C7
E8
D8
C8
AS SPEED EFFECT
C0
C1
C2
C3
C4
C5
C6
C7
C8
D0
D7
D8
E7
E8
DIMENS. TEMP.
0.00
0.20
0.40
0.60
0.80
1.00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
AFT COOLING (PPS)

Figure AT3

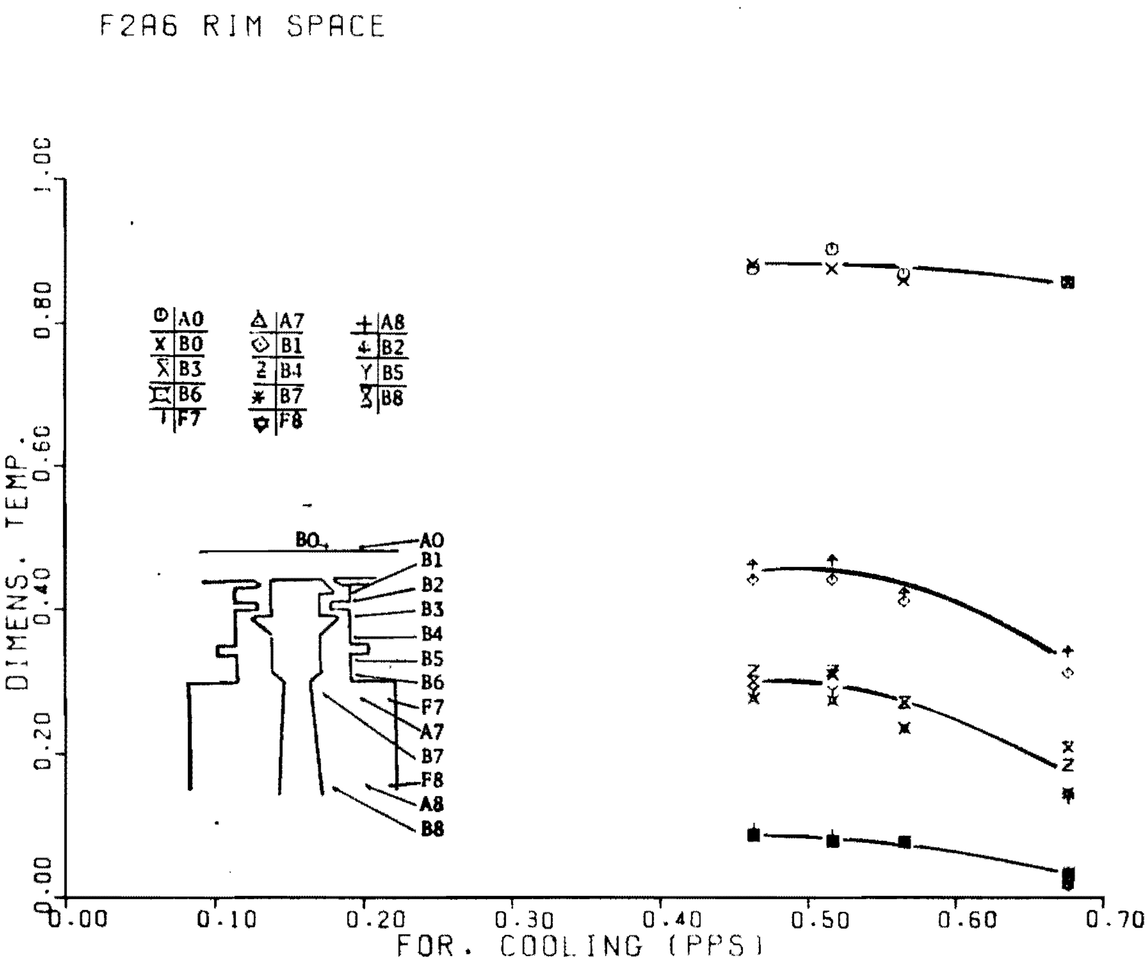

F2A6 RIM SPACE
DIMENS. TEMP.
FOR. COOLING (PPS)
0.00
0.20
0.40
0.60
0.80
1.00
0.10
0.30
0.50
0.70
A0
B0
B3
B6
F7
A7
B1
B4
B7
F8
A8
B2
B5
B8
B1
B2
B3
B4
B5
B6
F7
A7
B7
F8
A8
B8

Figure AT4A

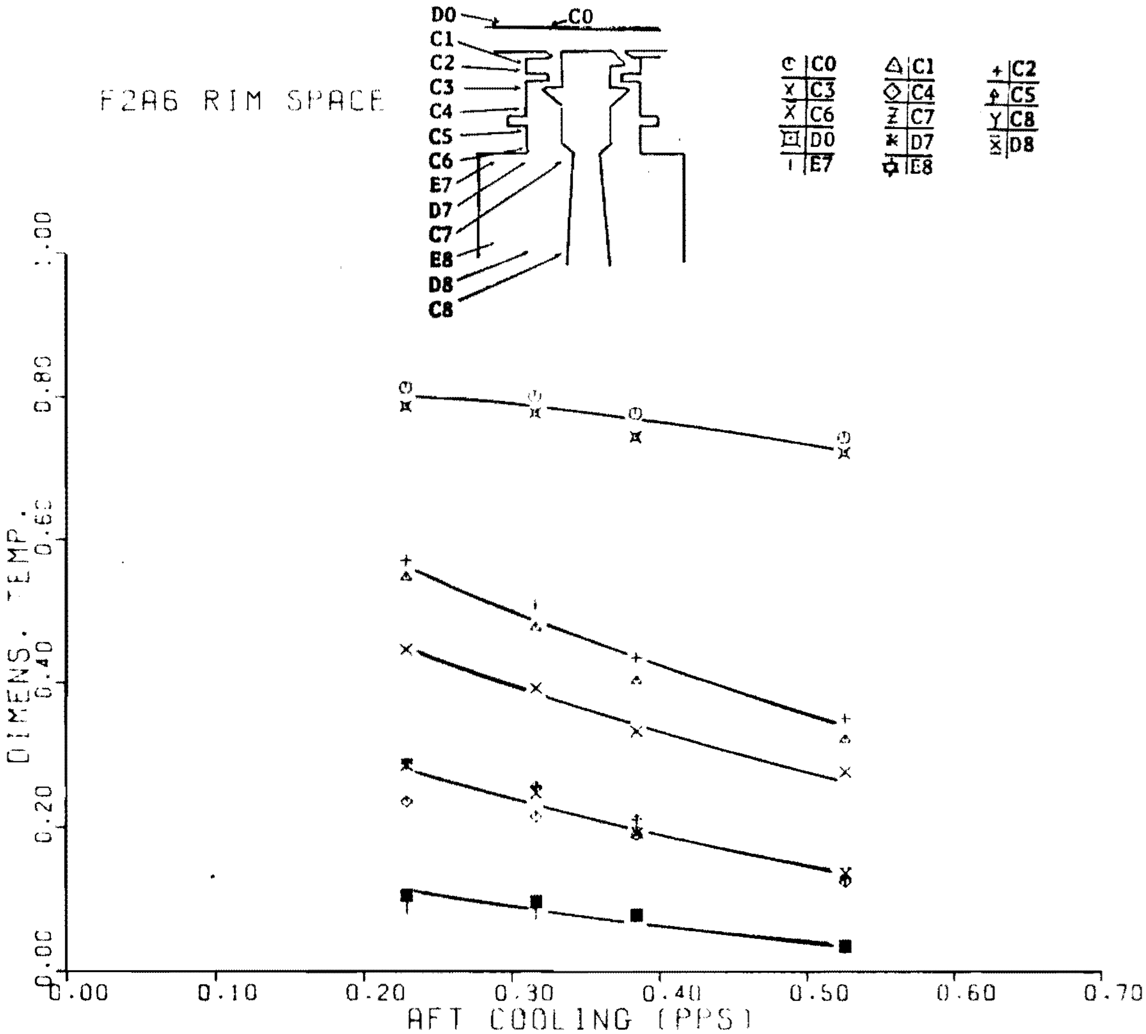

F2A6 RIM SPACE
D0
C0
C1
C2
C3
C4
C5
C6
E7
D7
C7
E8
D8
C8
C0
C1
C2
C3
C4
C5
C6
C7
C8
D0
D7
D8
E7
E8
DIMENS. TEMP.
0.00
0.20
0.40
0.60
0.80
1.00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
AFT COOLING (PPS)

Figure AT4-B

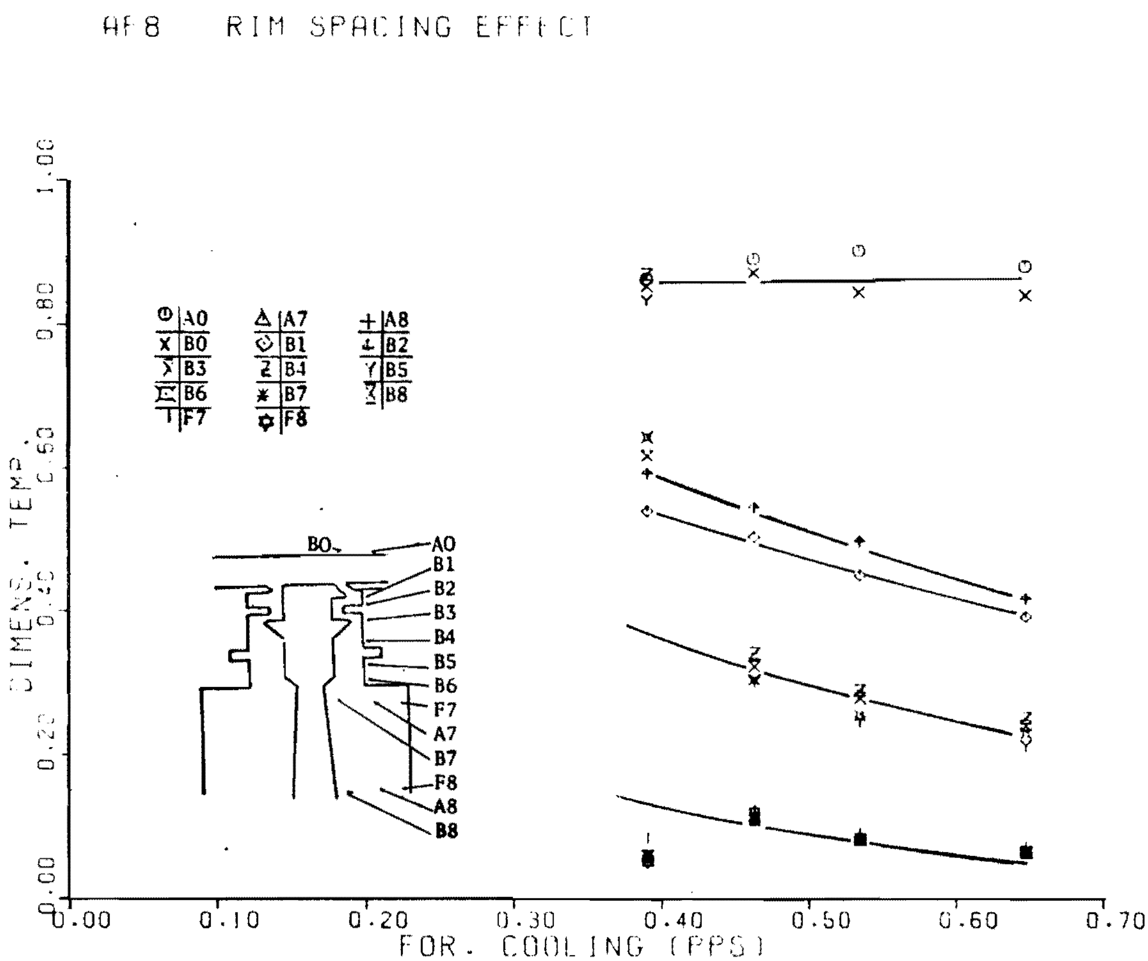

AF8 RIM SPACING EFFECT
A0
B0
B3
B6
F7
A7
B1
B4
B7
F8
A8
B2
B5
B8
BO
A0
B1
B2
B3
B4
B5
B6
F7
A7
B7
F8
A8
B8
DIMENS. TEMP.
0.00
0.20
0.40
0.60
0.80
1.00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
FOR. COOLING (PPS)

Figure AT-5A

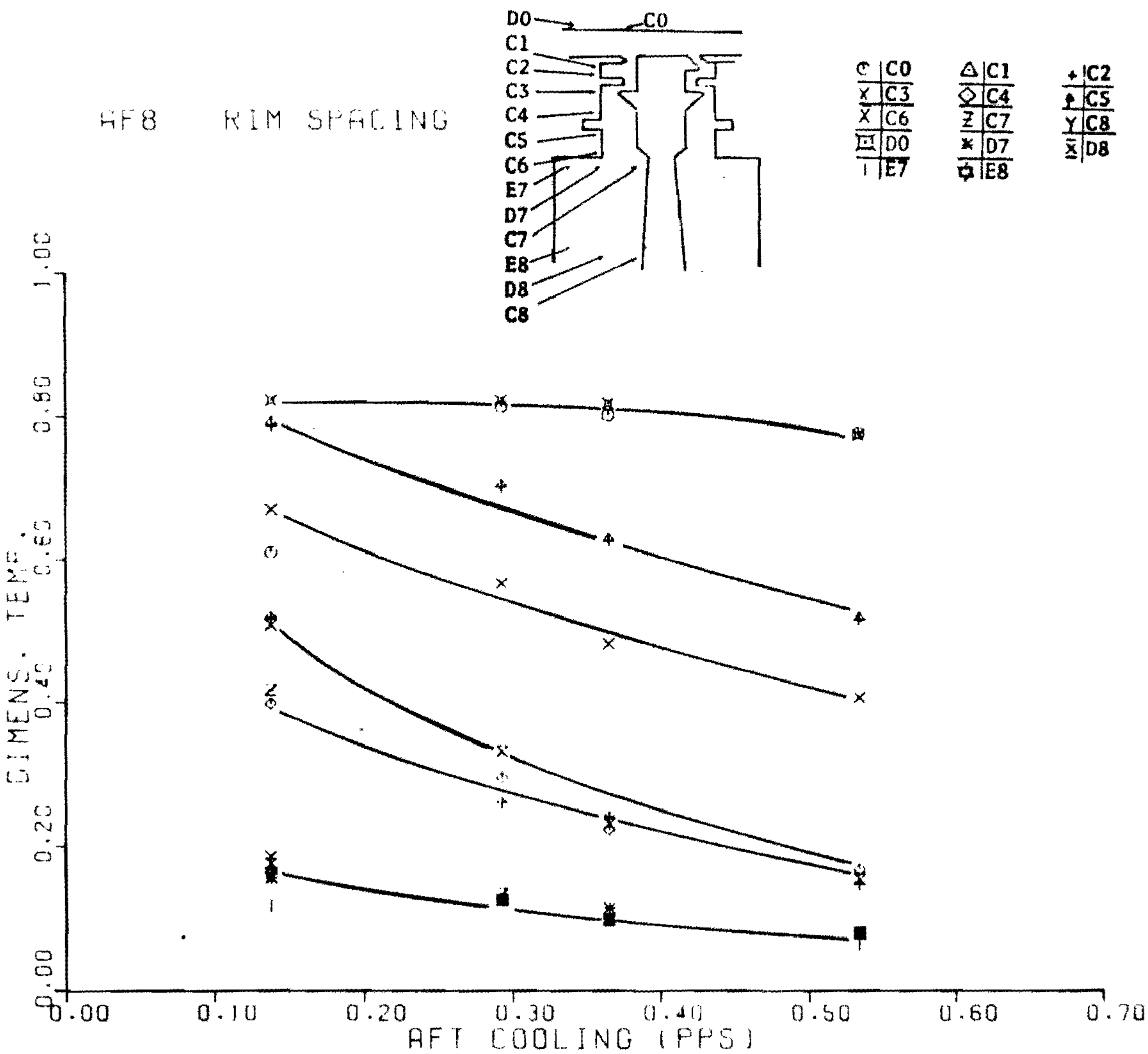

AF8 RIM SPACING
D0
C0
C1
C2
C3
C4
C5
C6
E7
D7
C7
E8
D8
C8
C0
C1
C2
C3
C4
C5
C6
C7
C8
D0
D7
D8
E7
E8
DIMENS. TEMP.
AFT COOLING (PPS)
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.20
0.40
0.60
0.80
1.00

Figure AT-5B

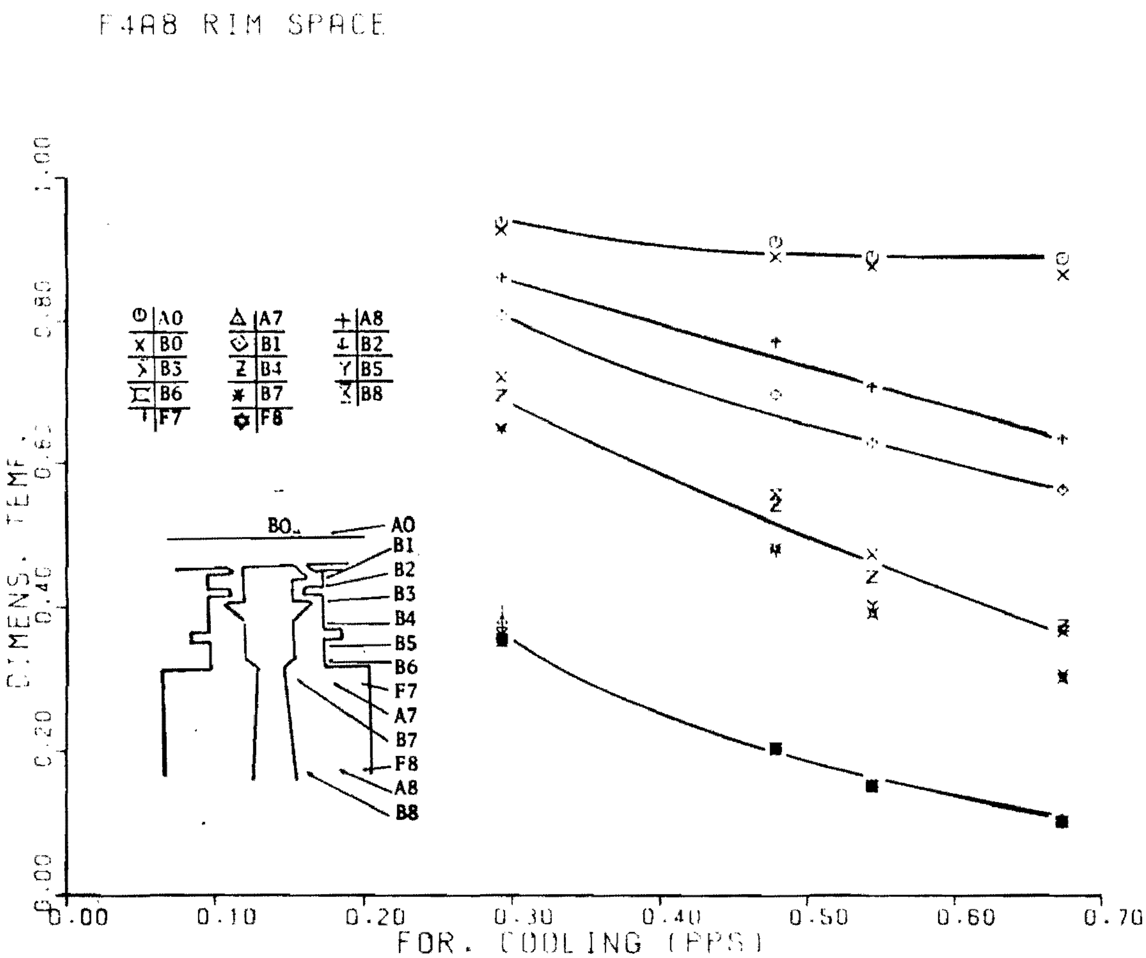

F4A8 RIM SPACE
A0
B0
B3
B6
F7
A7
B1
B4
B7
F8
A8
B2
B5
B8
B0
A0
B1
B2
B3
B4
B5
B6
F7
A7
B7
F8
A8
B8
DIMENS. TEMP.
0.00
0.20
0.40
0.60
0.80
1.00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
FOR. COOLING (PPS)

Figure AT-6A

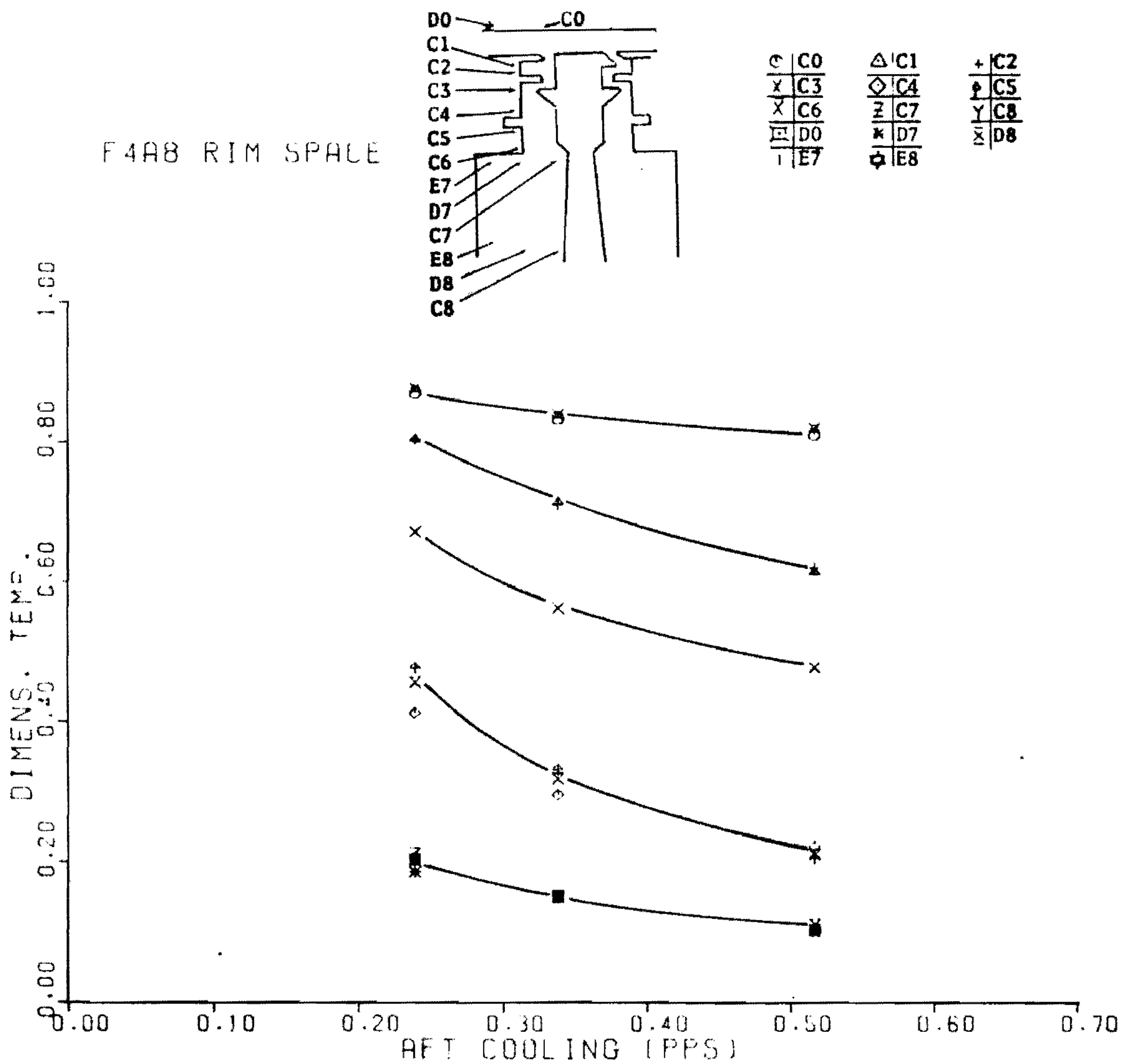

F4A8 RIM SPACE
D0
C0
C1
C2
C3
C4
C5
C6
E7
D7
C7
E8
D8
C8
C0
C1
C2
C3
C4
C5
C6
C7
C8
D0
D7
D8
E7
E8
DIMENS. TEMP.
AFT COOLING (PPS)
0.00
0.20
0.40
0.60
0.80
1.00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70

Figure AT-6C

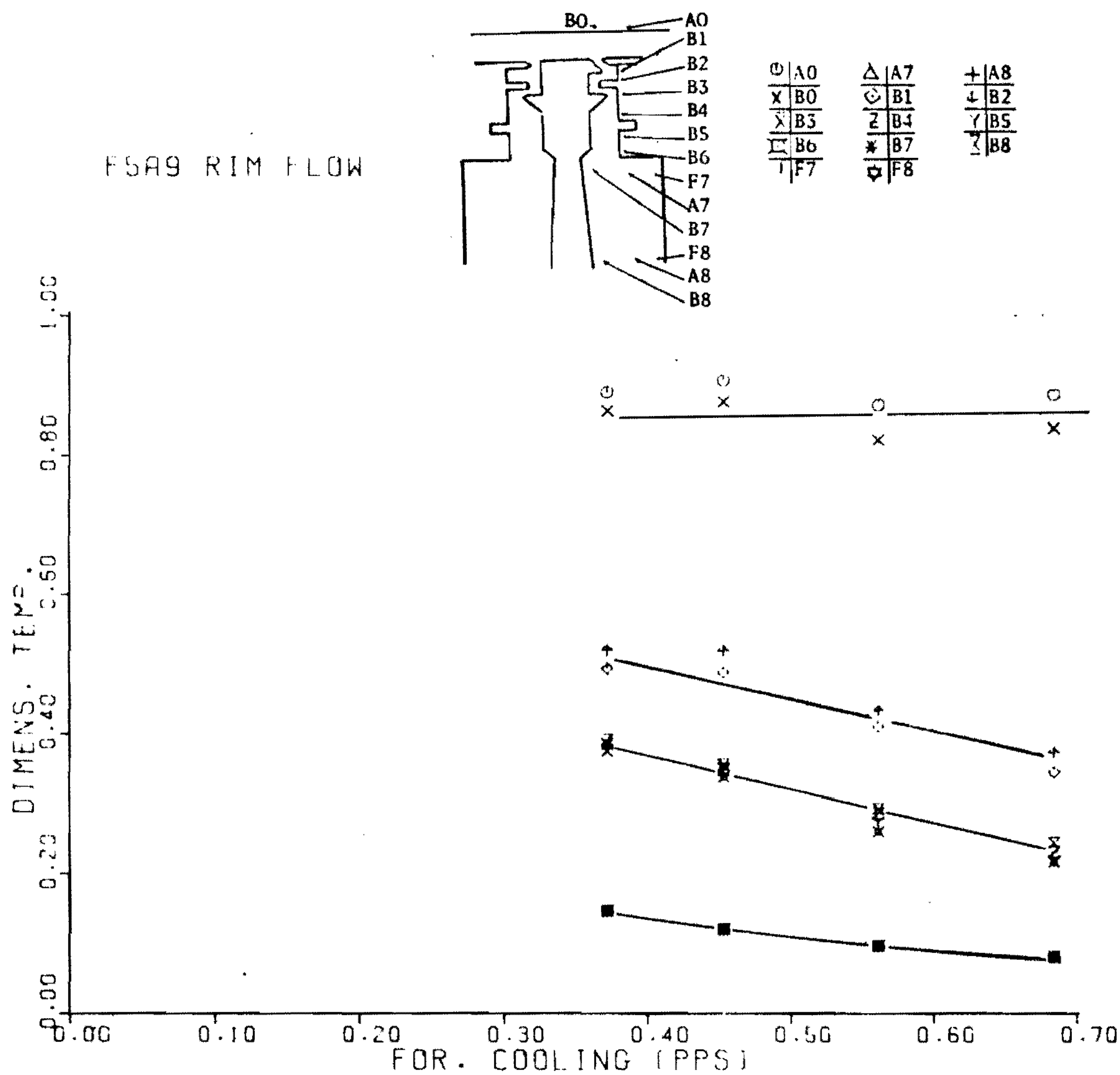

F5A9 RIM FLOW
BO.
A0
B1
B2
B3
B4
B5
B6
F7
A7
B7
F8
A8
B8
A0
B0
B3
B6
F7
A7
B1
B4
B7
F8
A8
B2
B5
B8
DIMENS. TEMP.
0.00
0.20
0.40
0.60
0.80
1.00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
FOR. COOLING (PPS)

Figure AT-7A

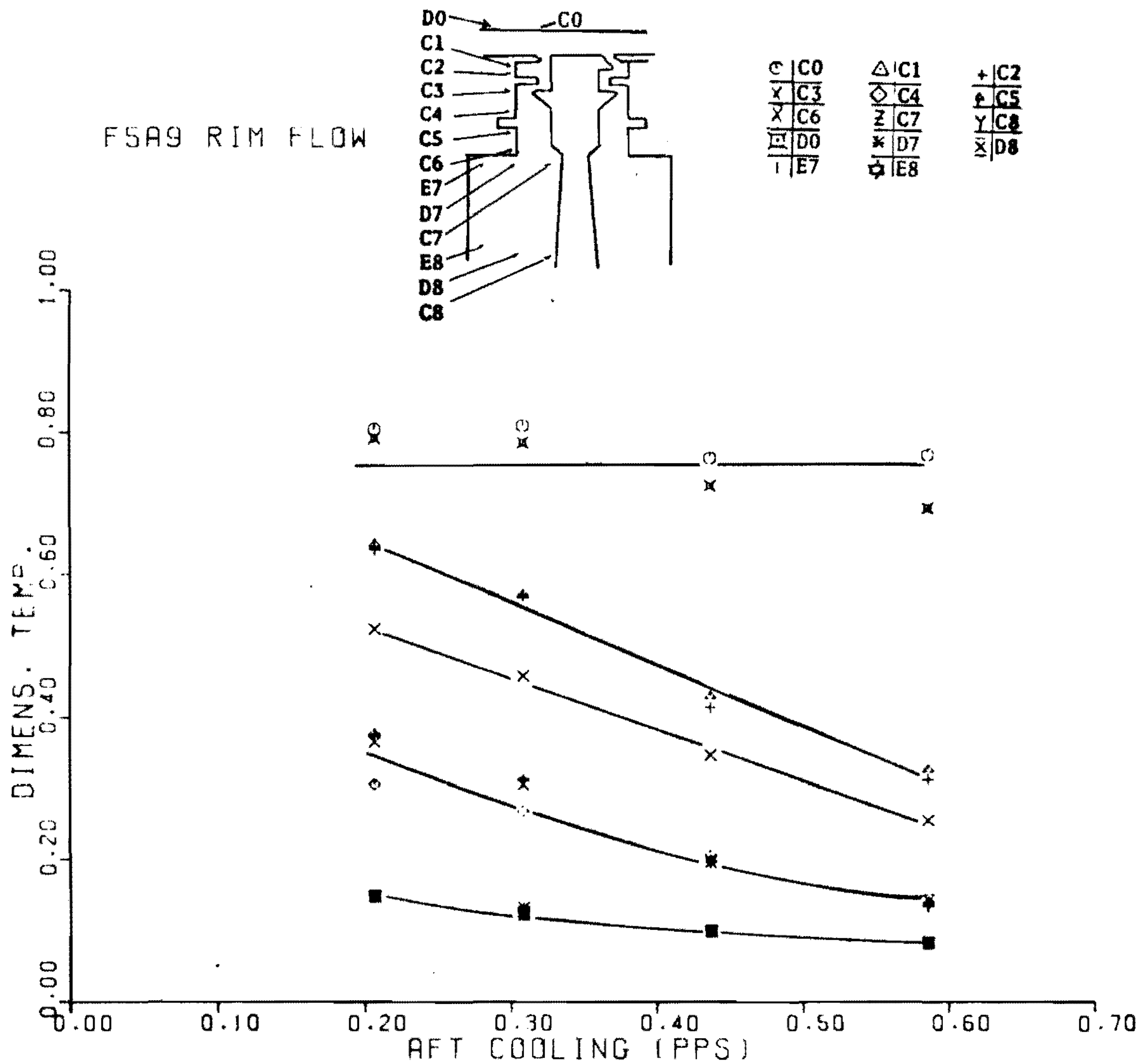

F5A9 RIM FLOW
D0
C0
C1
C2
C3
C4
C5
C6
E7
D7
C7
E8
D8
C8
C0
C1
C2
C3
C4
C5
C6
C7
C8
D0
D7
D8
E7
E8
DIMENS. TEMP.
AFT COOLING (PPS)
0.00
0.20
0.40
0.60
0.80
1.00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70

Figure AT-7B

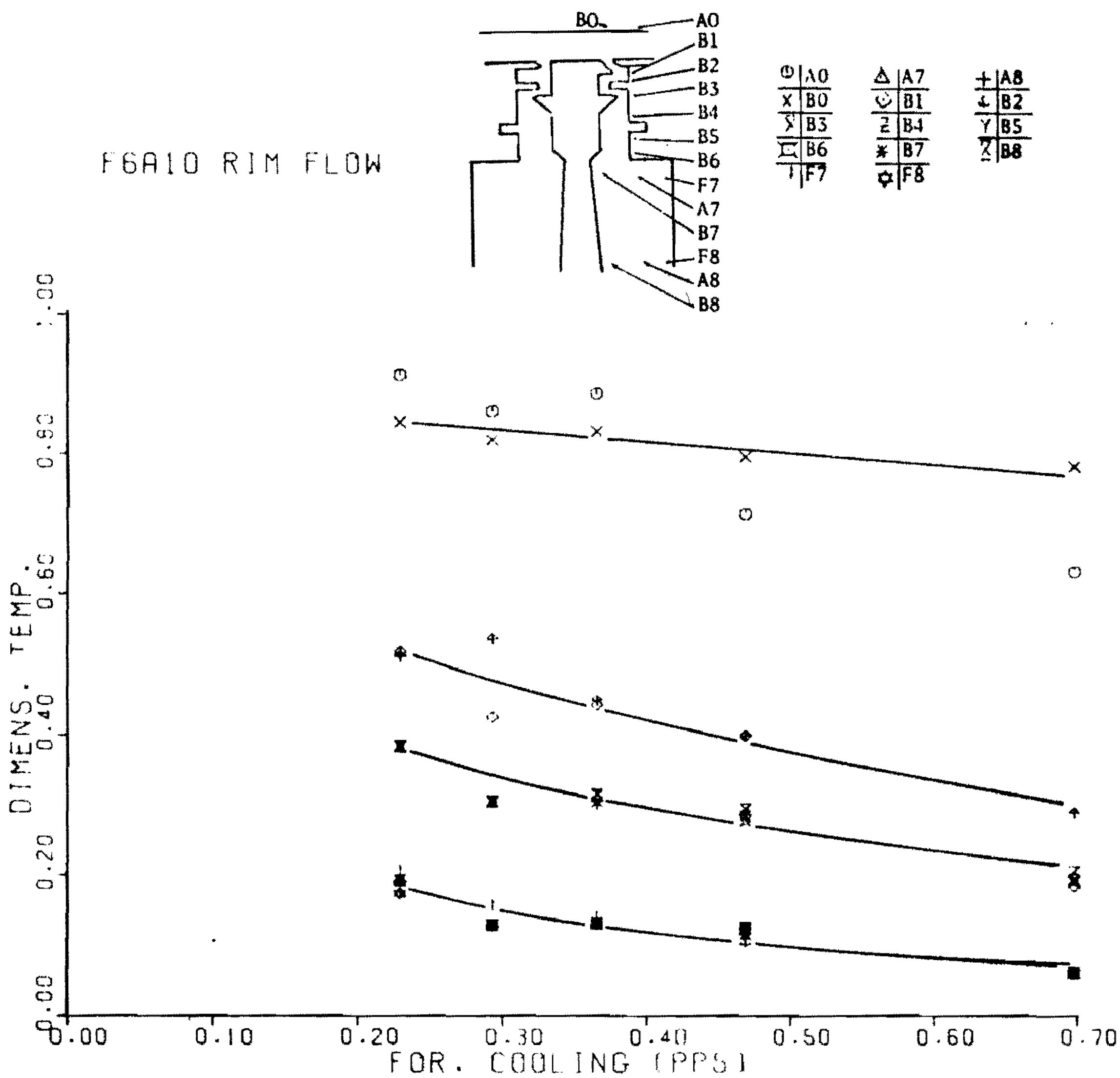

F6A10 RIM FLOW
B0
A0
B1
B2
B3
B4
B5
B6
F7
A7
B7
F8
A8
B8
A0
B0
B3
B6
F7
A7
B1
B4
B7
F8
A8
B2
B5
B8
DIMENS. TEMP.
0.00
0.20
0.40
0.60
0.80
1.00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
FOR. COOLING (PPS)

Figure AT-8A

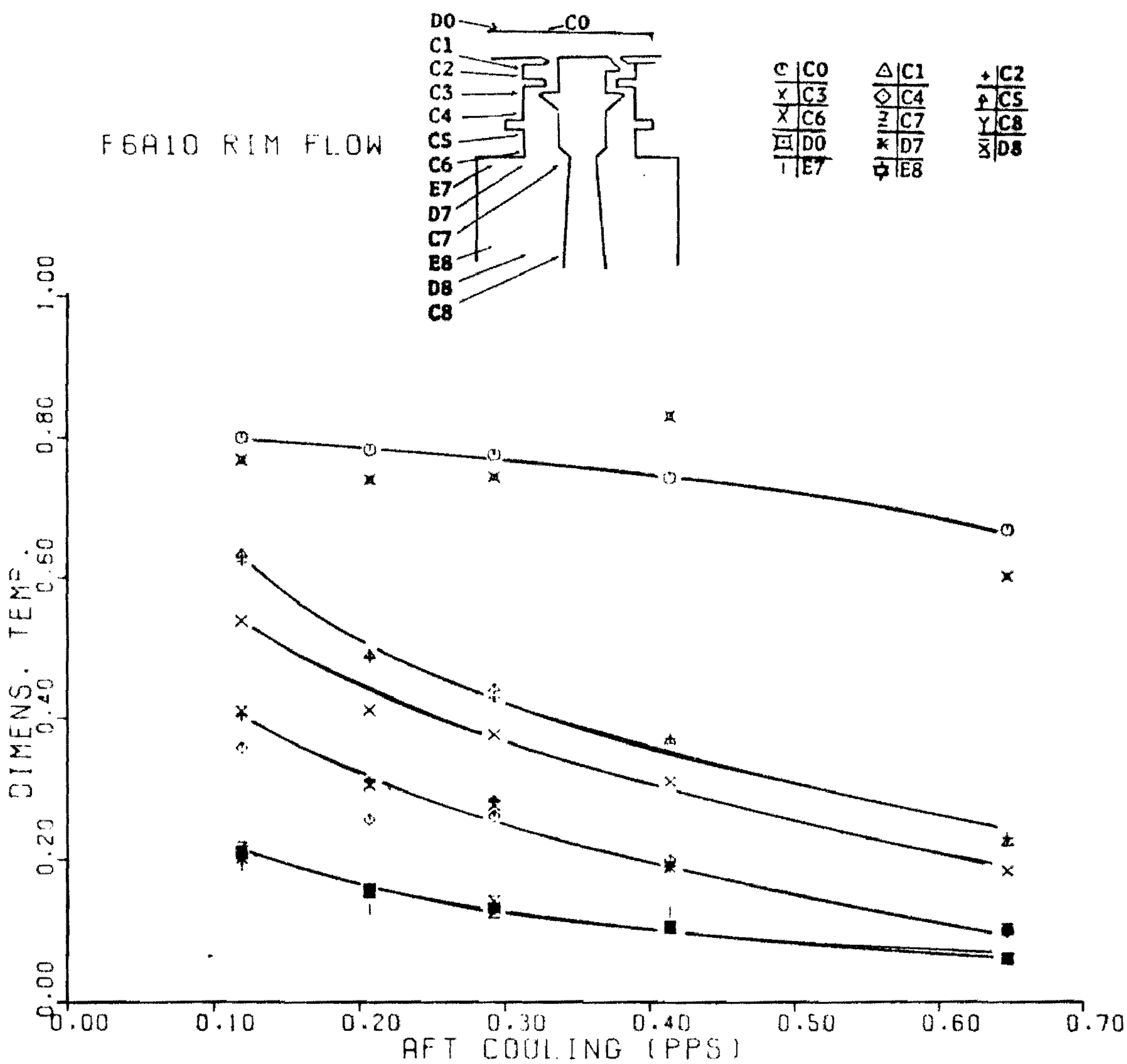

F6A10 RIM FLOW
D0
C0
C1
C2
C3
C4
C5
C6
E7
D7
C7
E8
D8
C8
C0
C3
C6
D0
E7
C1
C4
C7
D7
E8
C2
C5
C8
D8
DIMENS. TEMP.
0.00
0.20
0.40
0.60
0.80
1.00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
AFT COOLING (PPS)

Figure AT-8B

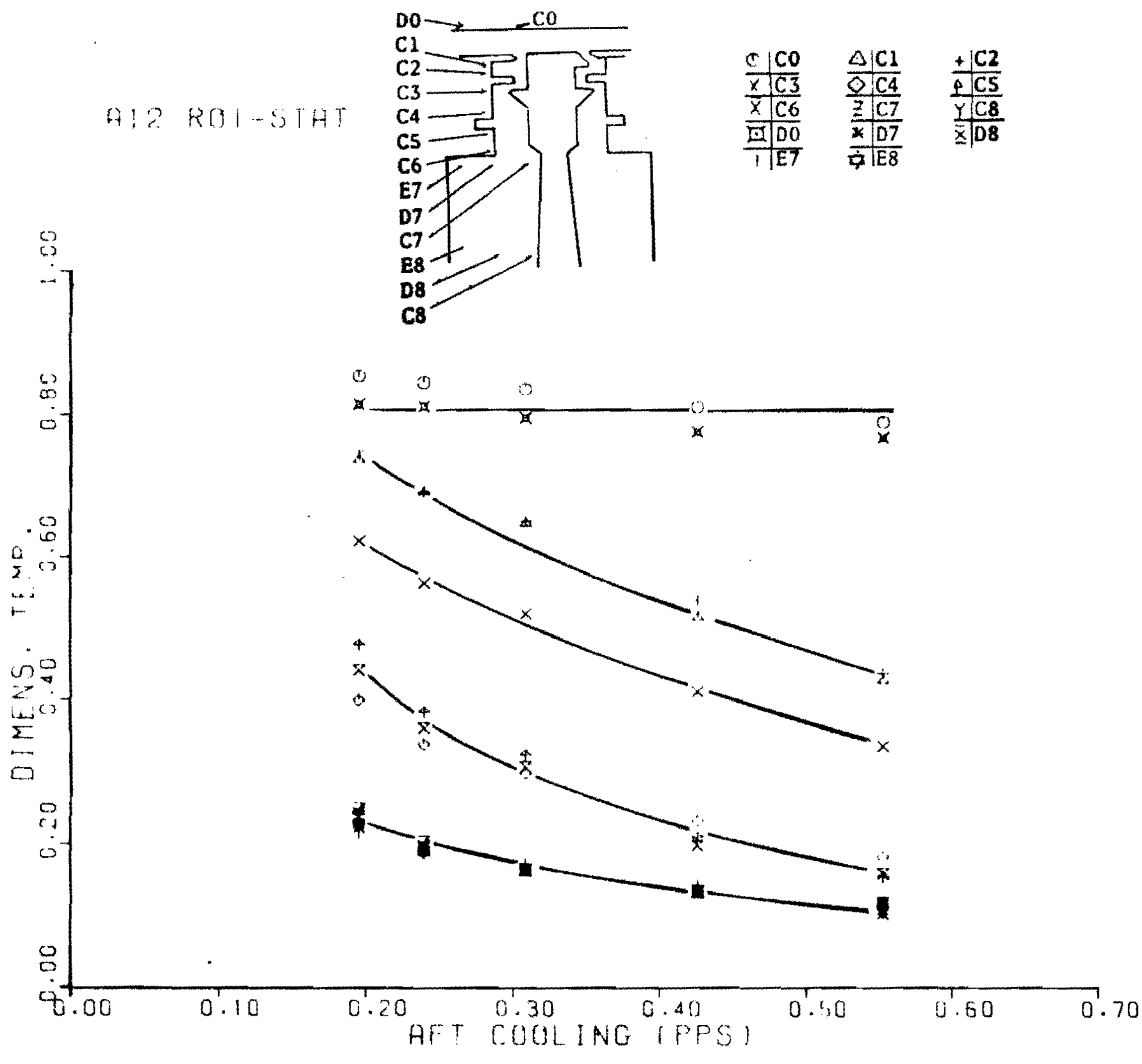

A12 ROT-STAT
D0
C0
C1
C2
C3
C4
C5
C6
E7
D7
C7
E8
D8
C8
C0
C1
C2
C3
C4
C5
C6
C7
C8
D0
D7
D8
E7
E8
DIMENS. TEMP.
0.00
0.20
0.40
0.60
0.80
1.00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
AFT COOLING (PPS)

Figure AT-9

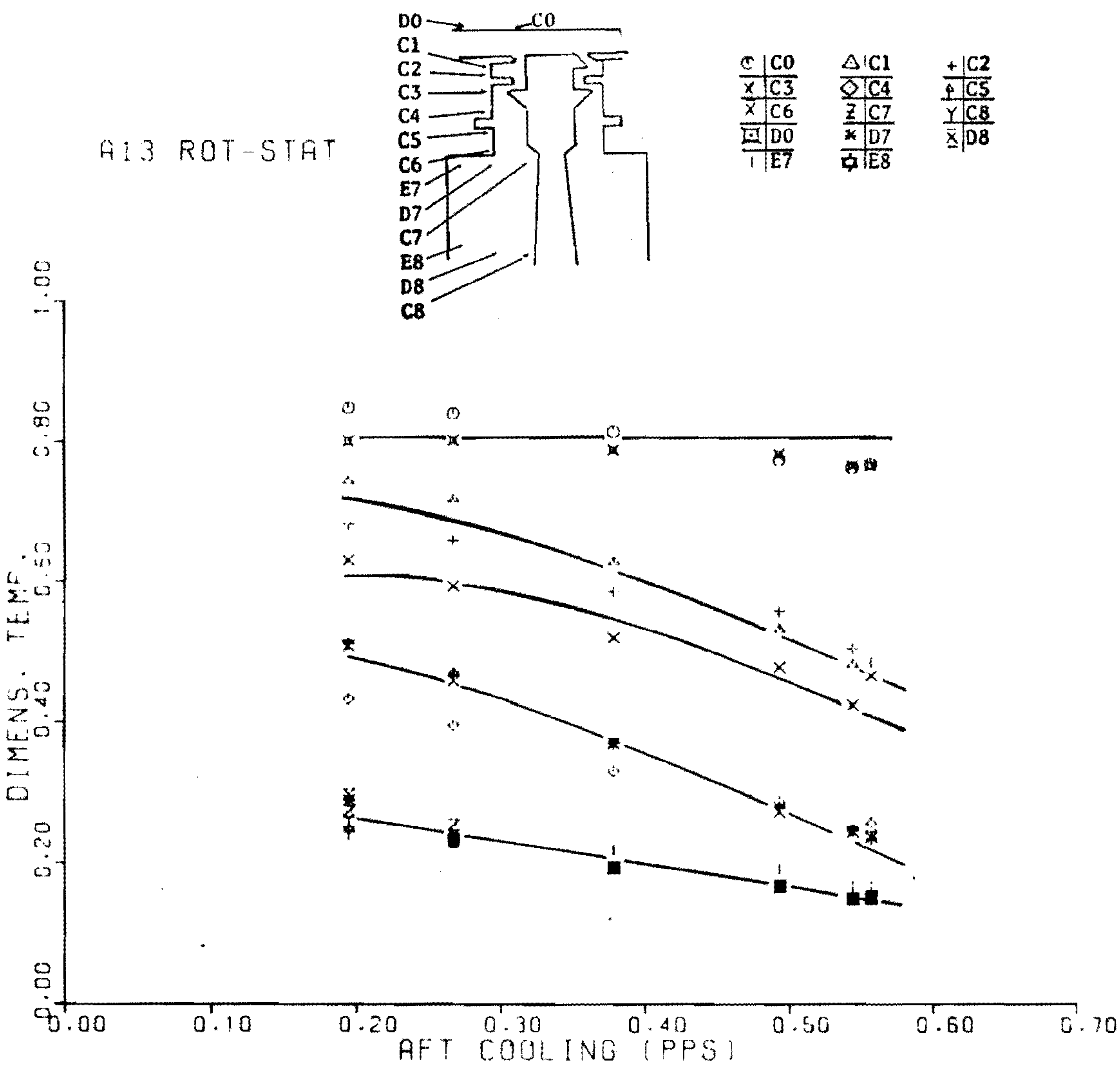

A13 ROT-STAT
D0
C0
C1
C2
C3
C4
C5
C6
E7
D7
C7
E8
D8
C8
C0
C1
C2
C3
C4
C5
C6
C7
C8
D0
D7
D8
E7
E8
DIMENS. TEMP.
0.00
0.20
0.40
0.60
0.80
1.00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
AFT COOLING (PPS)

Figure AT-10

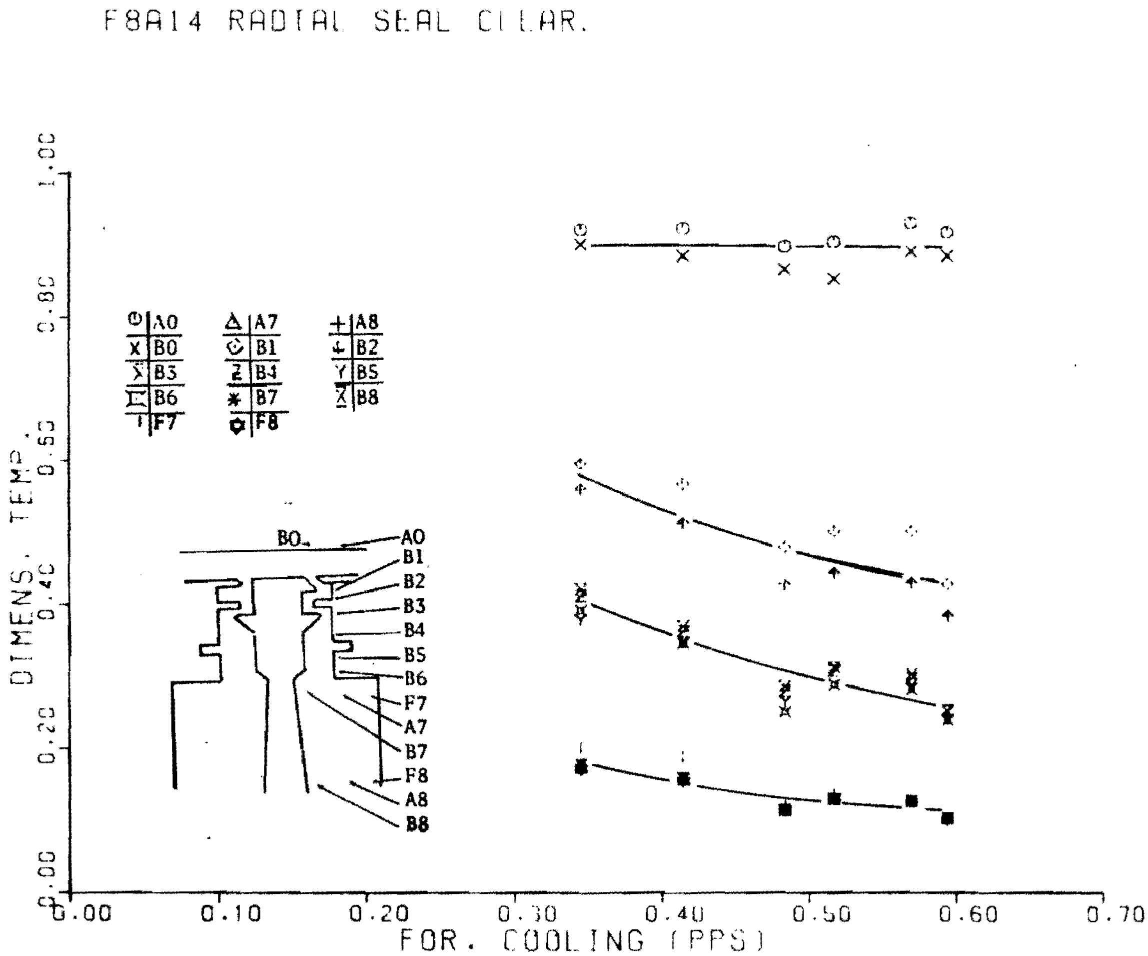


Figure AT-11A

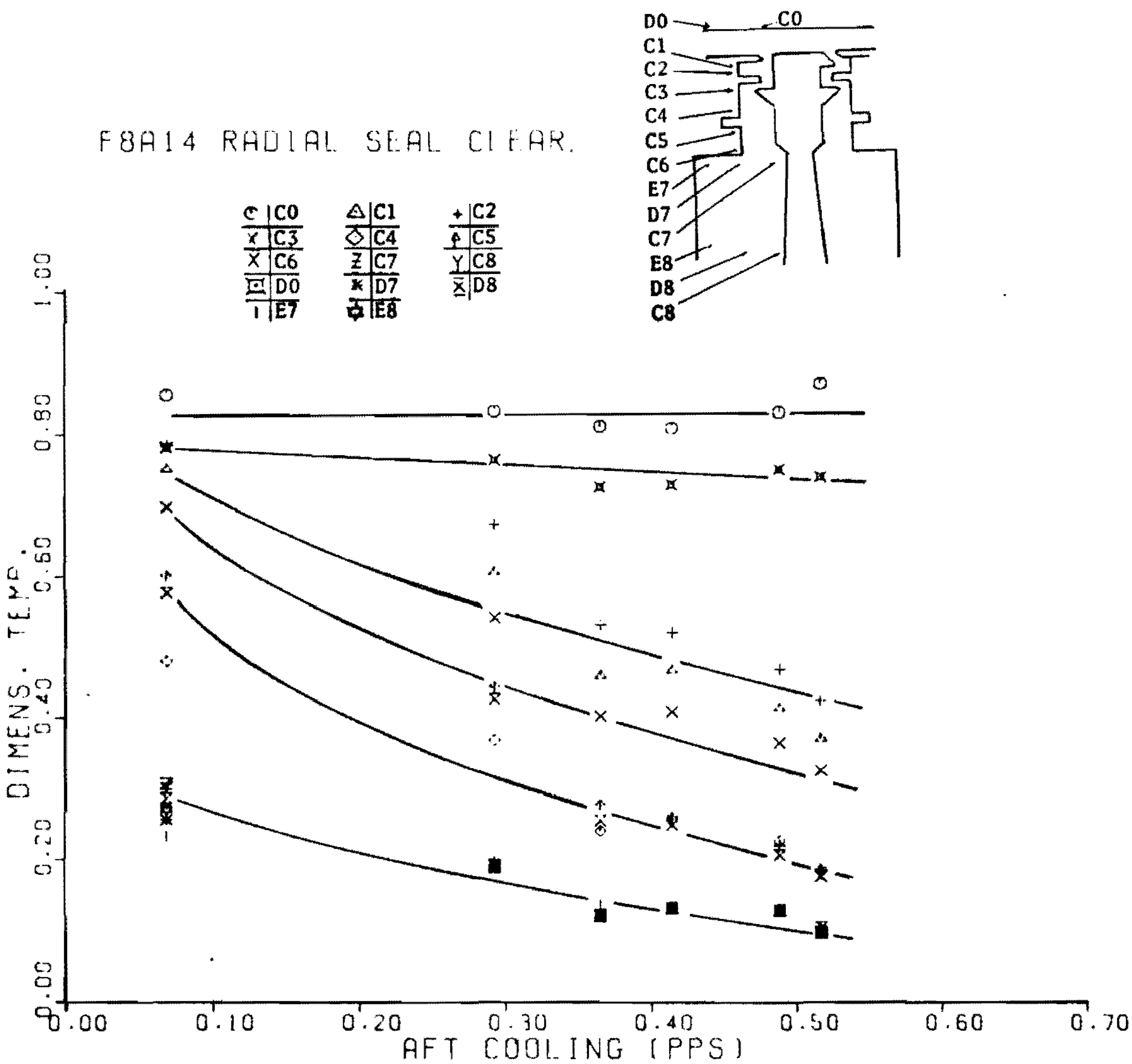


Figure AT-11B

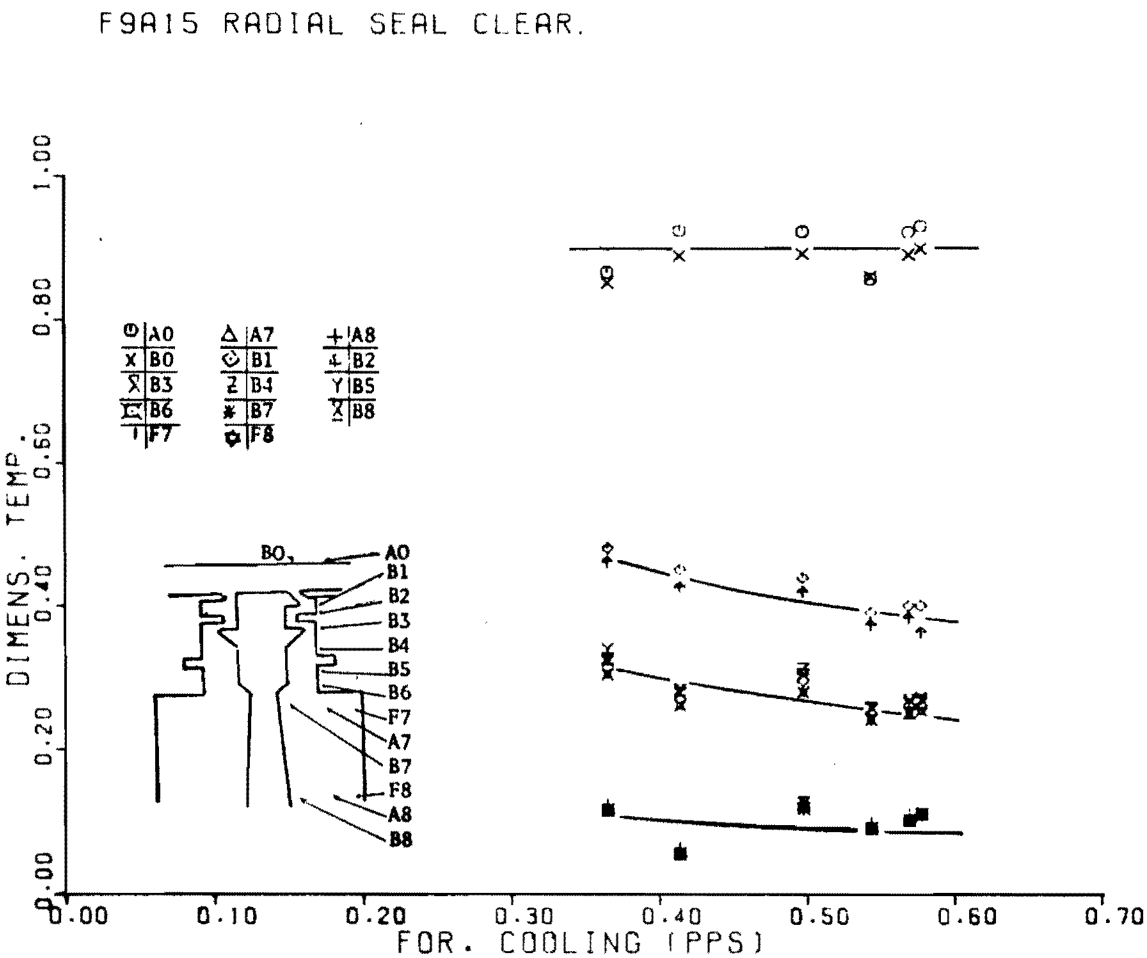


Figure AT-12A

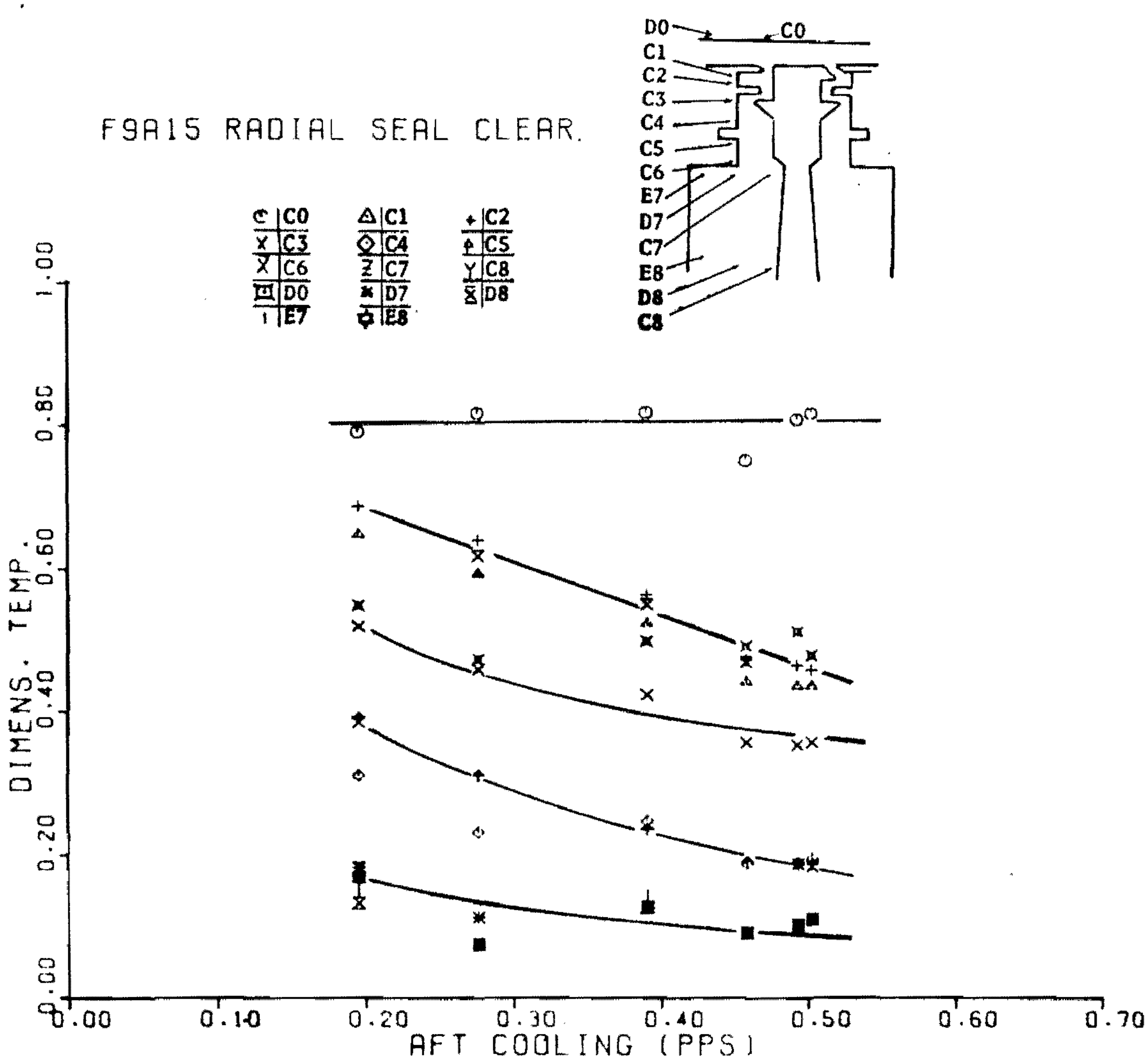


Figure AT-12B

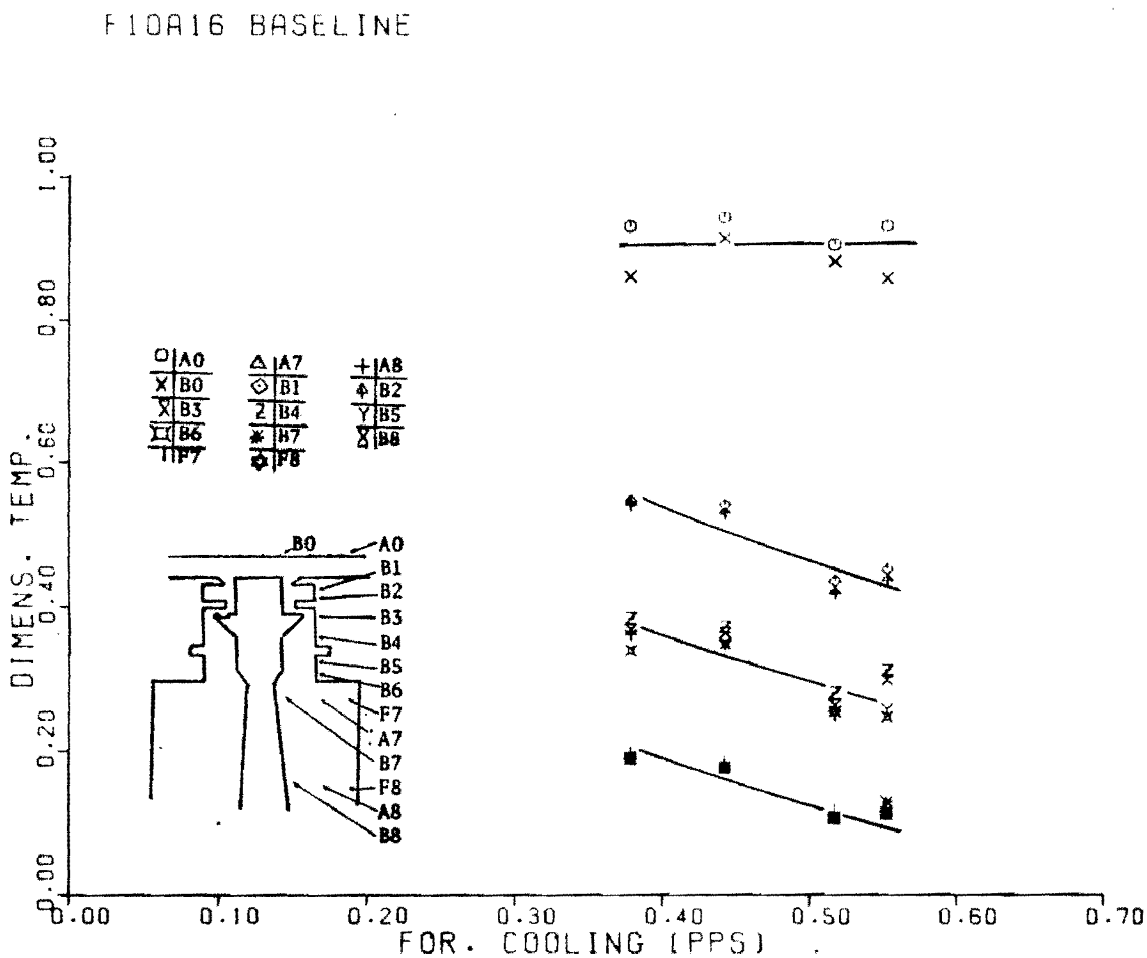


Figure AT-13A

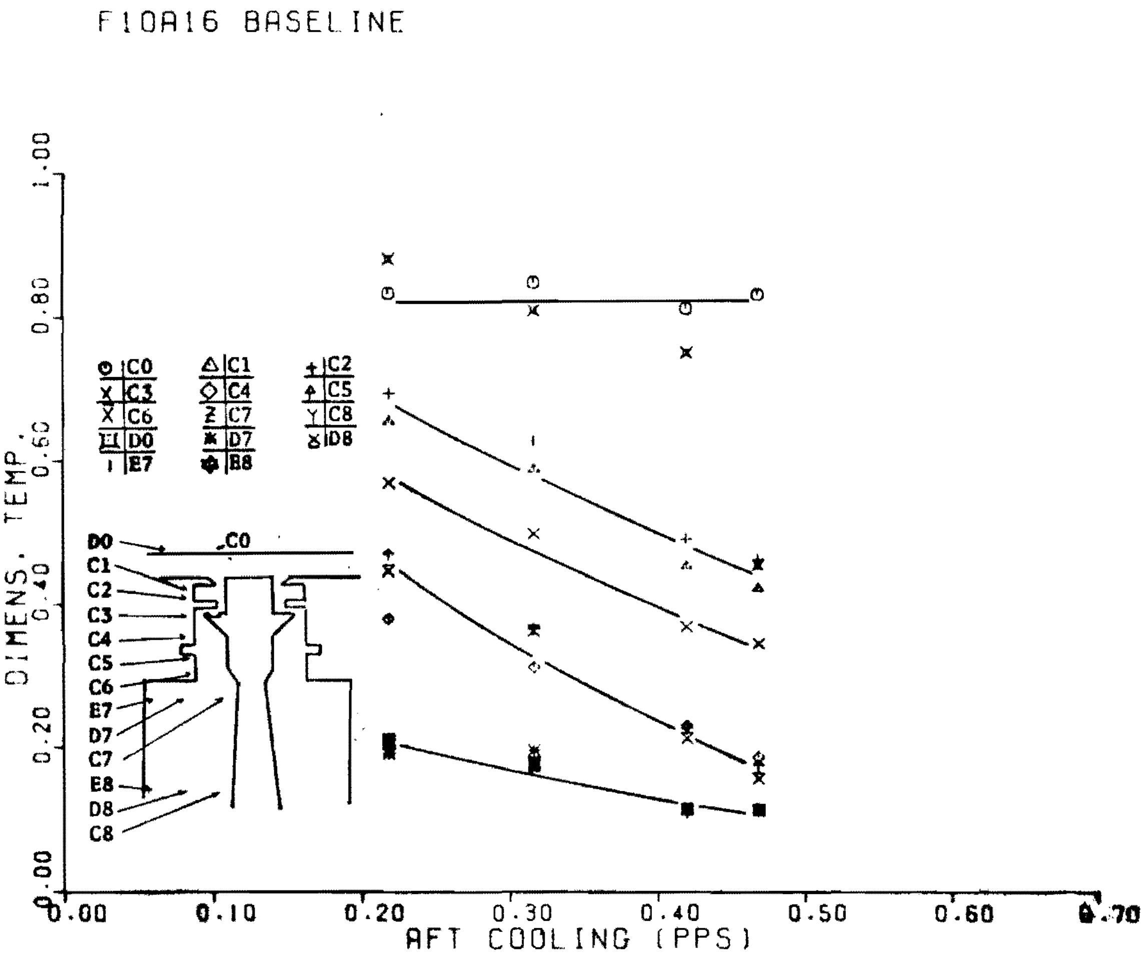


Figure AT-13B

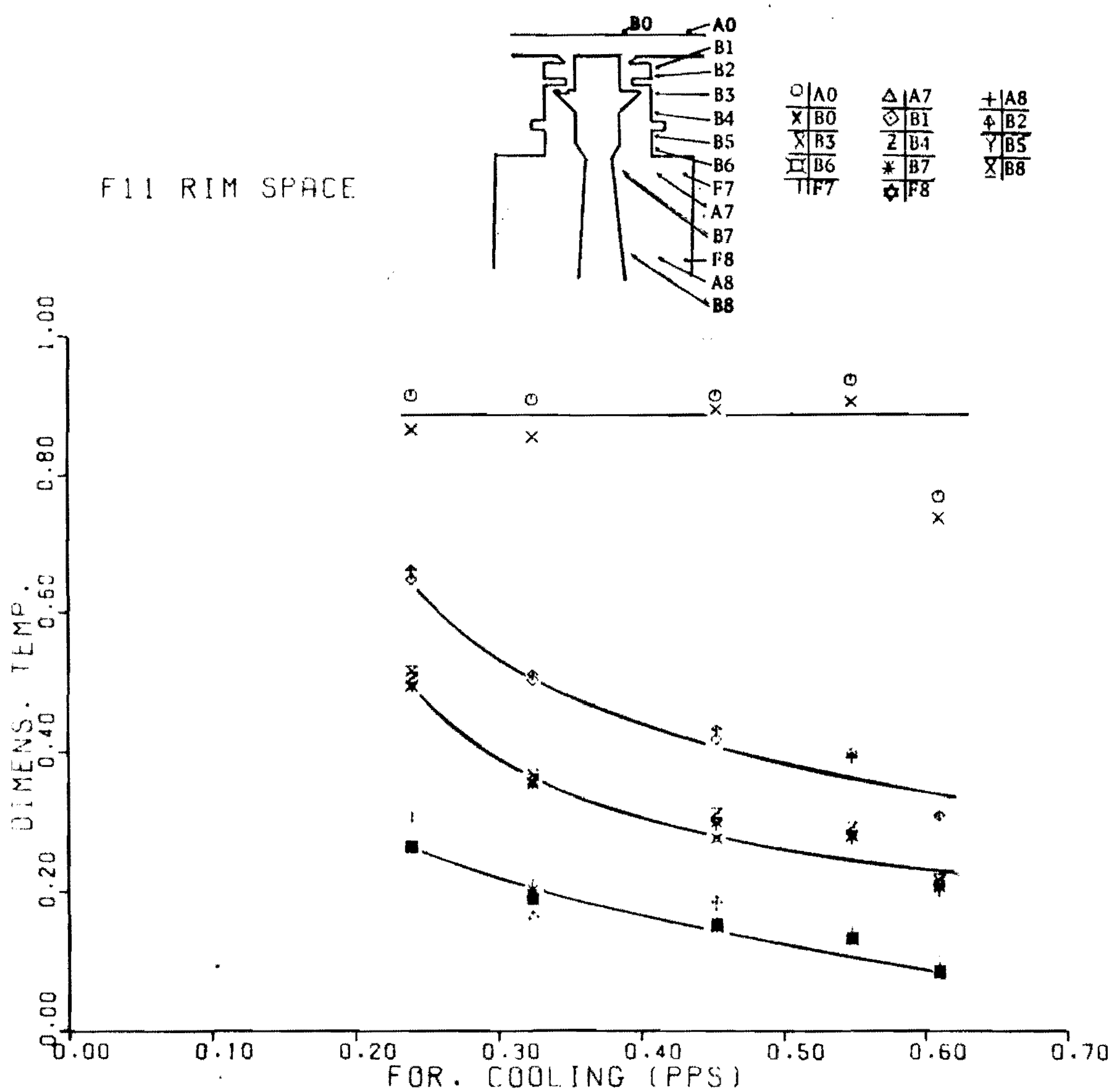

F11 RIM SPACE
B0
A0
B1
B2
B3
B4
B5
B6
F7
A7
B7
F8
A8
B8
A0
B0
B3
B6
F7
A7
B1
B4
B7
F8
A8
B2
B5
B8
DIMENS. TEMP.
0.00
0.20
0.40
0.60
0.80
1.00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
FOR. COOLING (PPS)

Figure AT-14

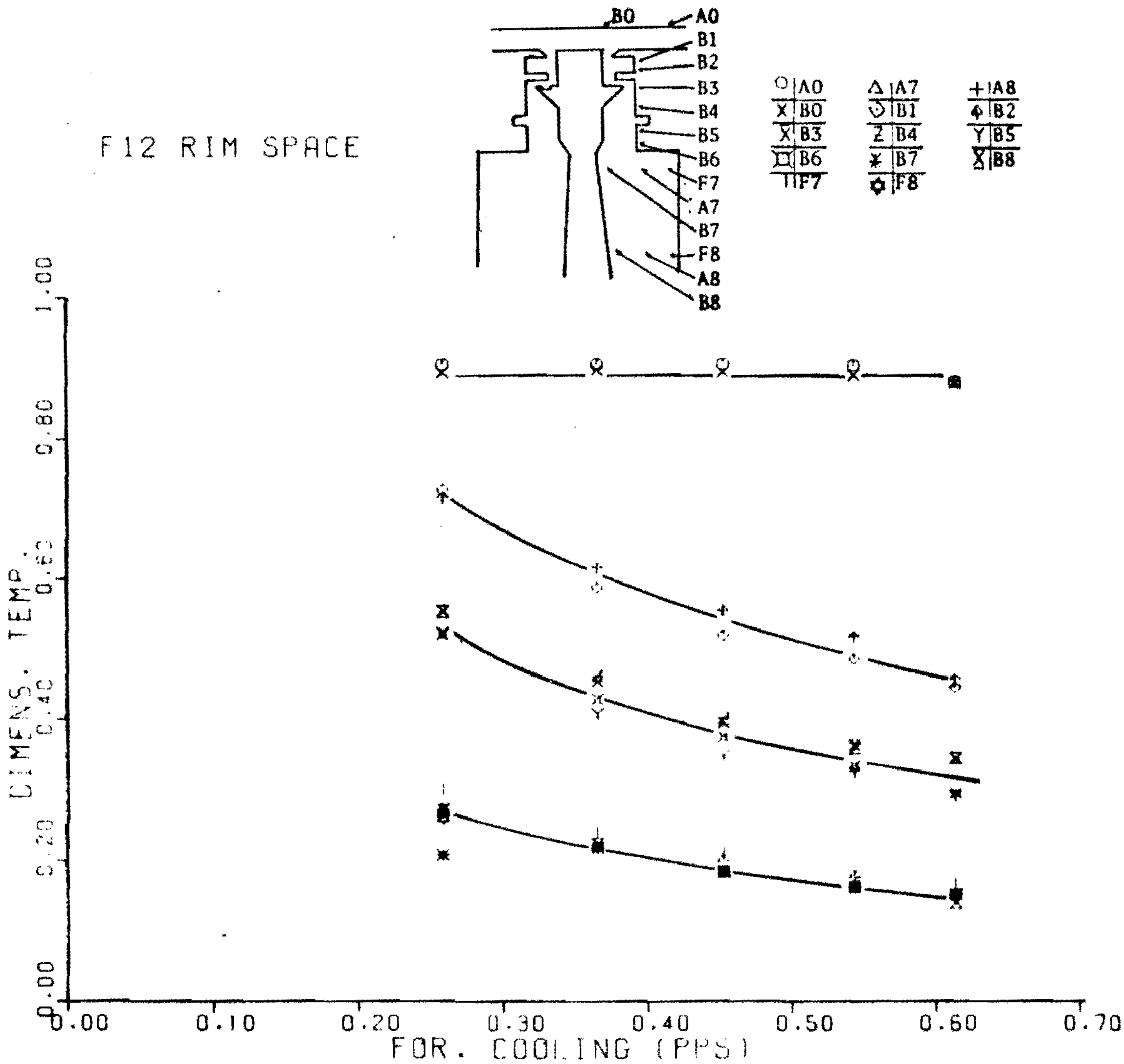

F12 RIM SPACE
B0
A0
B1
B2
B3
B4
B5
B6
F7
A7
B7
F8
A8
B8
A0
B0
B3
B6
F7
A7
B1
B4
B7
F8
A8
B2
B5
B8
DIMENS. TEMP.
0.00
0.20
0.40
0.60
0.80
1.00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
FOR. COOLING (PPS)

Figure AT-15

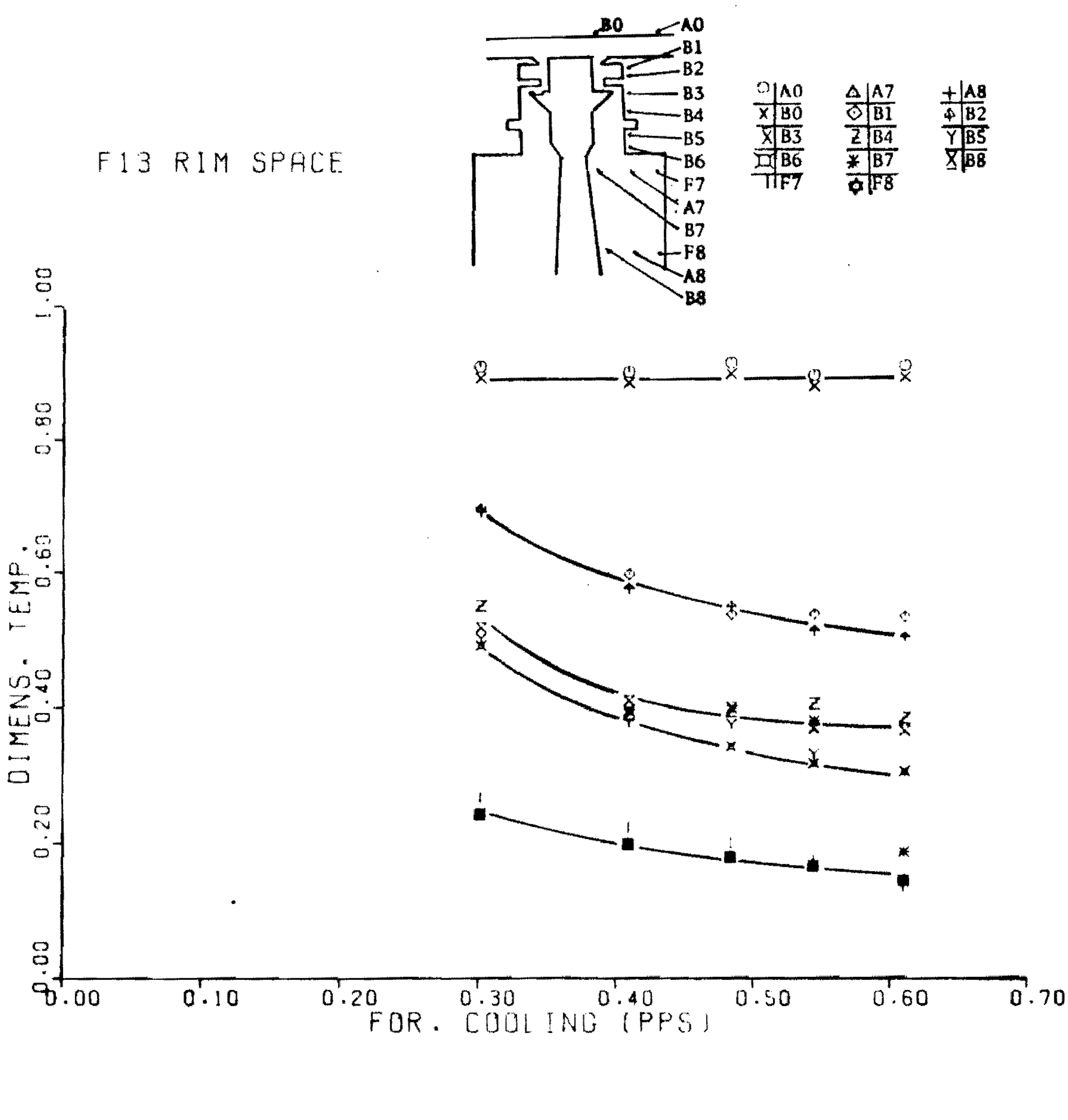

F13 RIM SPACE
B0
A0
B1
B2
B3
B4
B5
B6
F7
A7
B7
F8
A8
B8
A0
B0
B3
B6
F7
A7
B1
B4
B7
F8
A8
B2
B5
B8
DIMENS. TEMP.
0.00
0.20
0.40
0.60
0.80
1.00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
FOR. COOLING (PPS)

Figure AT-16

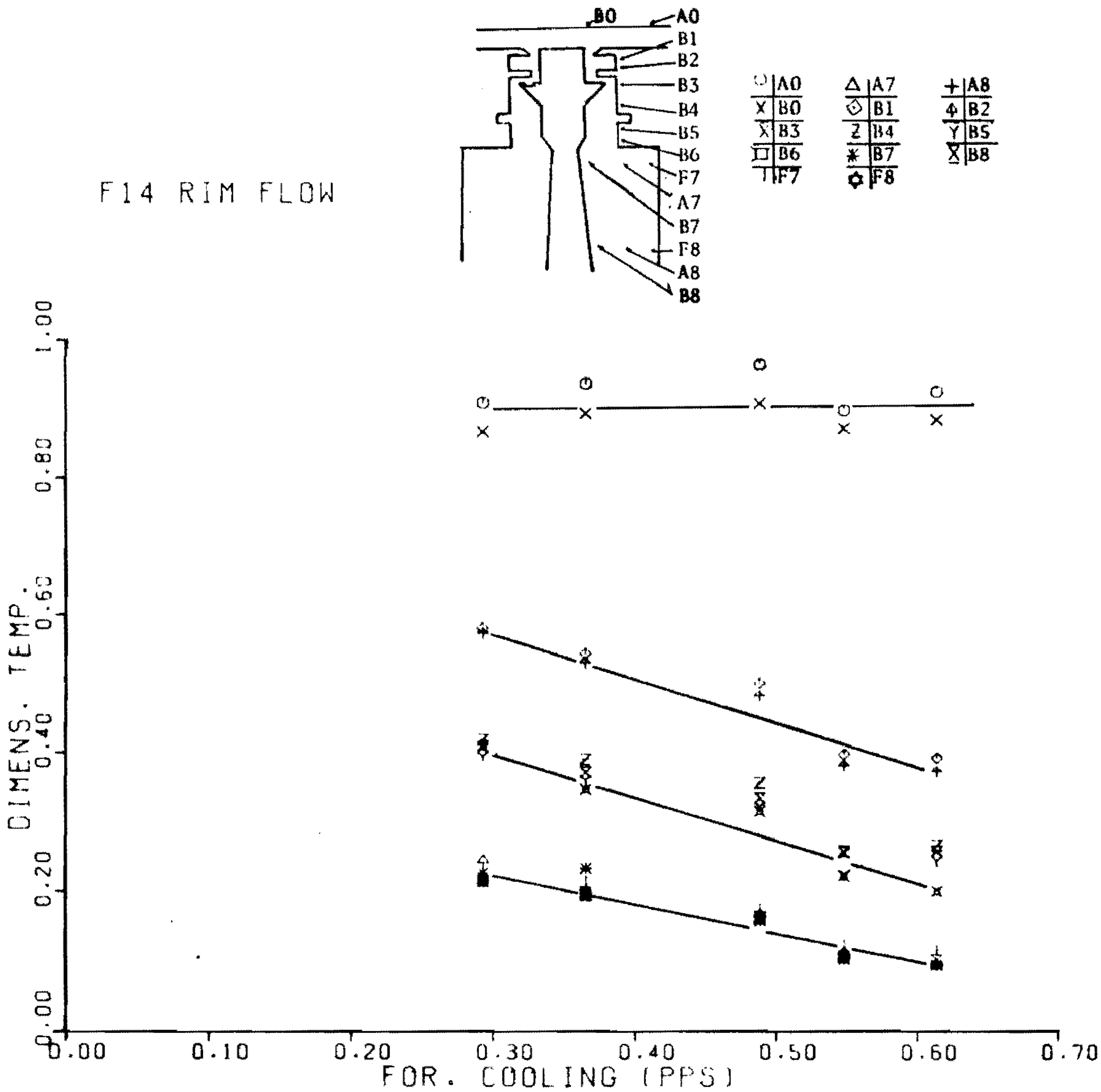

F14 RIM FLOW
B0
A0
B1
B2
B3
B4
B5
B6
F7
A7
B7
F8
A8
B8
A0
B0
B3
B6
F7
A7
B1
B4
B7
F8
A8
B2
B5
B8
DIMENS. TEMP.
0.00
0.20
0.40
0.60
0.80
1.00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
FOR. COOLING (PPS)

Figure AT-17

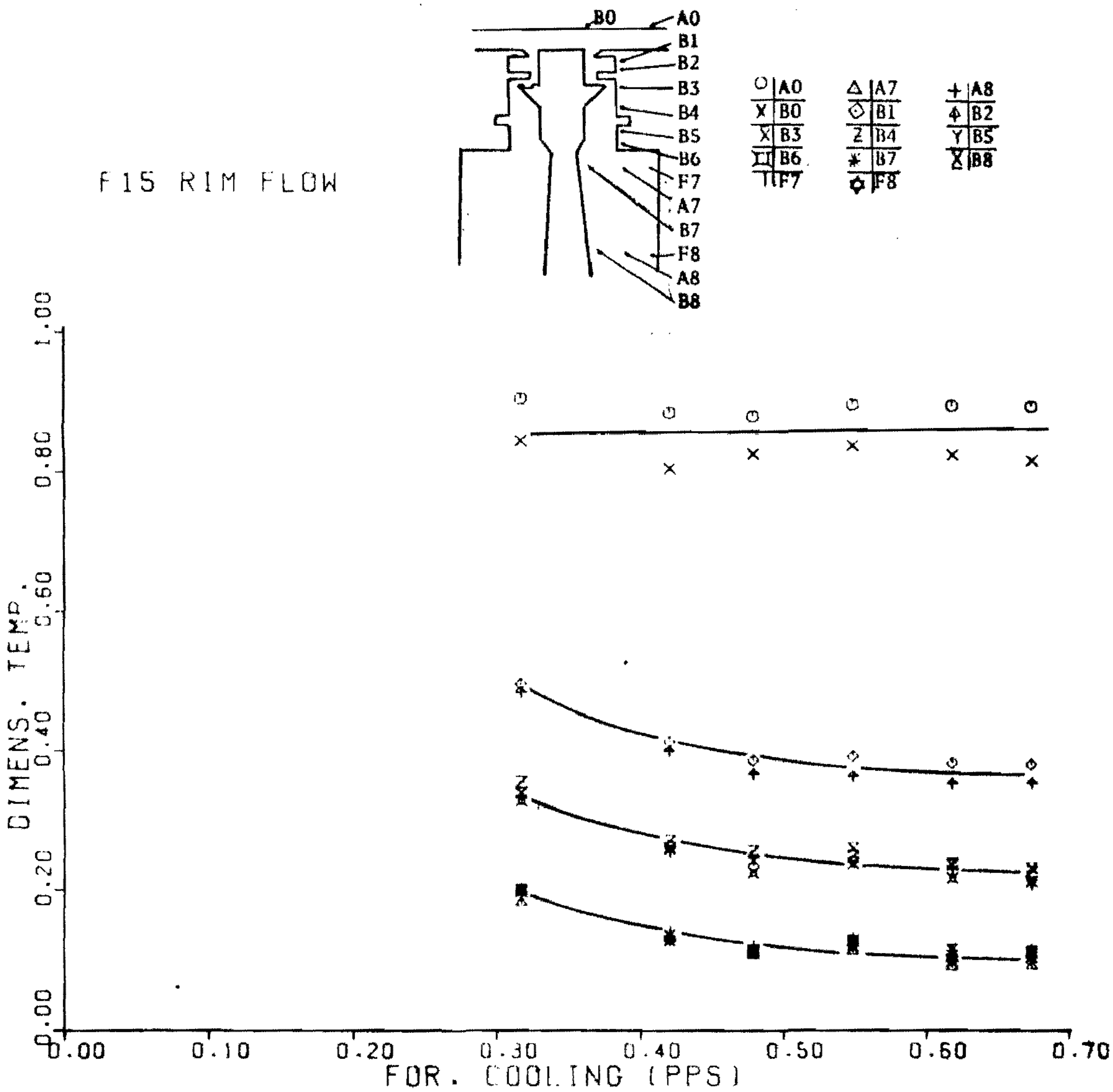

F15 RIM FLOW
B0
A0
B1
B2
B3
B4
B5
B6
F7
A7
B7
F8
A8
B8
A0
B0
B3
B6
F7
A7
B1
B4
B7
F8
A8
B2
B5
B8
DIMENS. TEMP.
0.00
0.20
0.40
0.60
0.80
1.00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
FOR. COOLING (PPS)

Figure AT-18

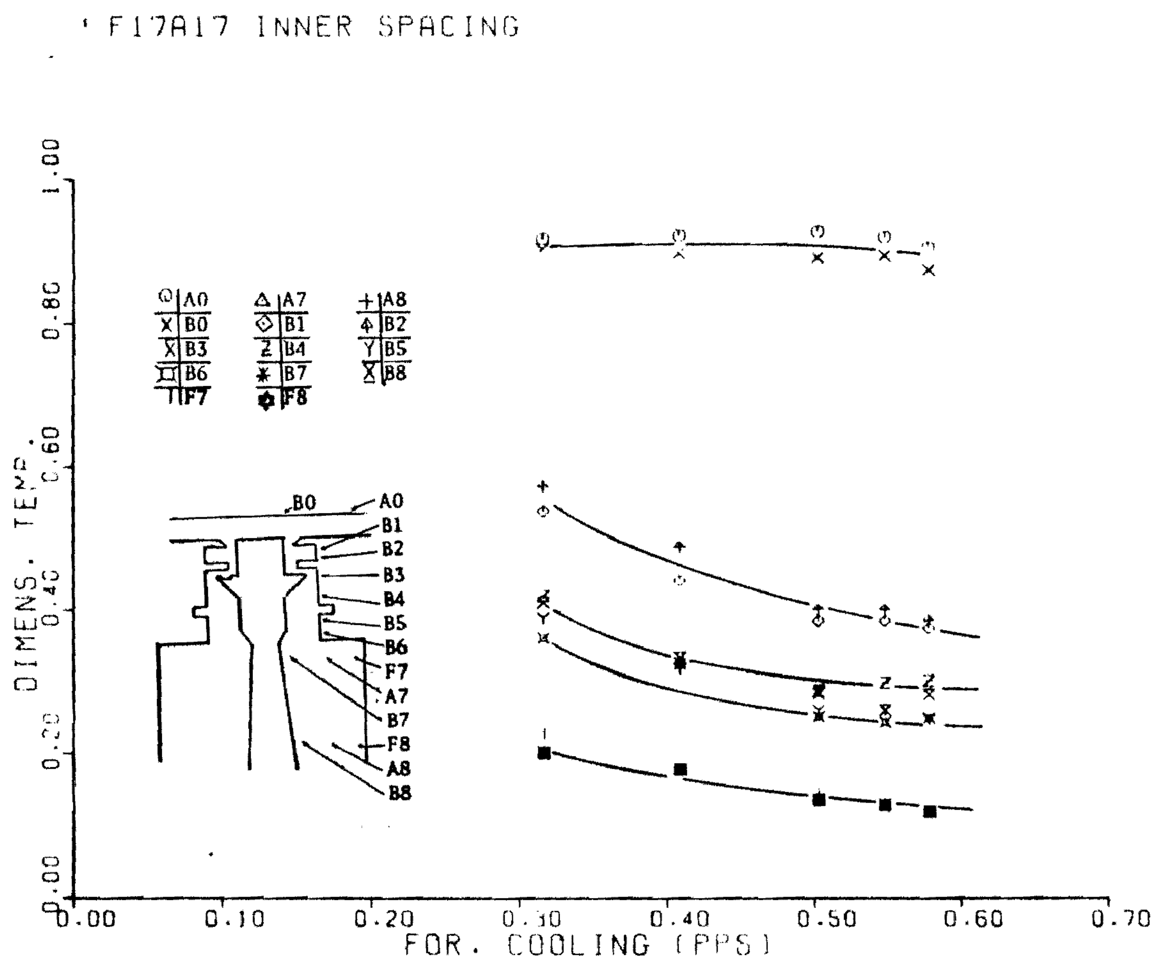


Figure AT-19A

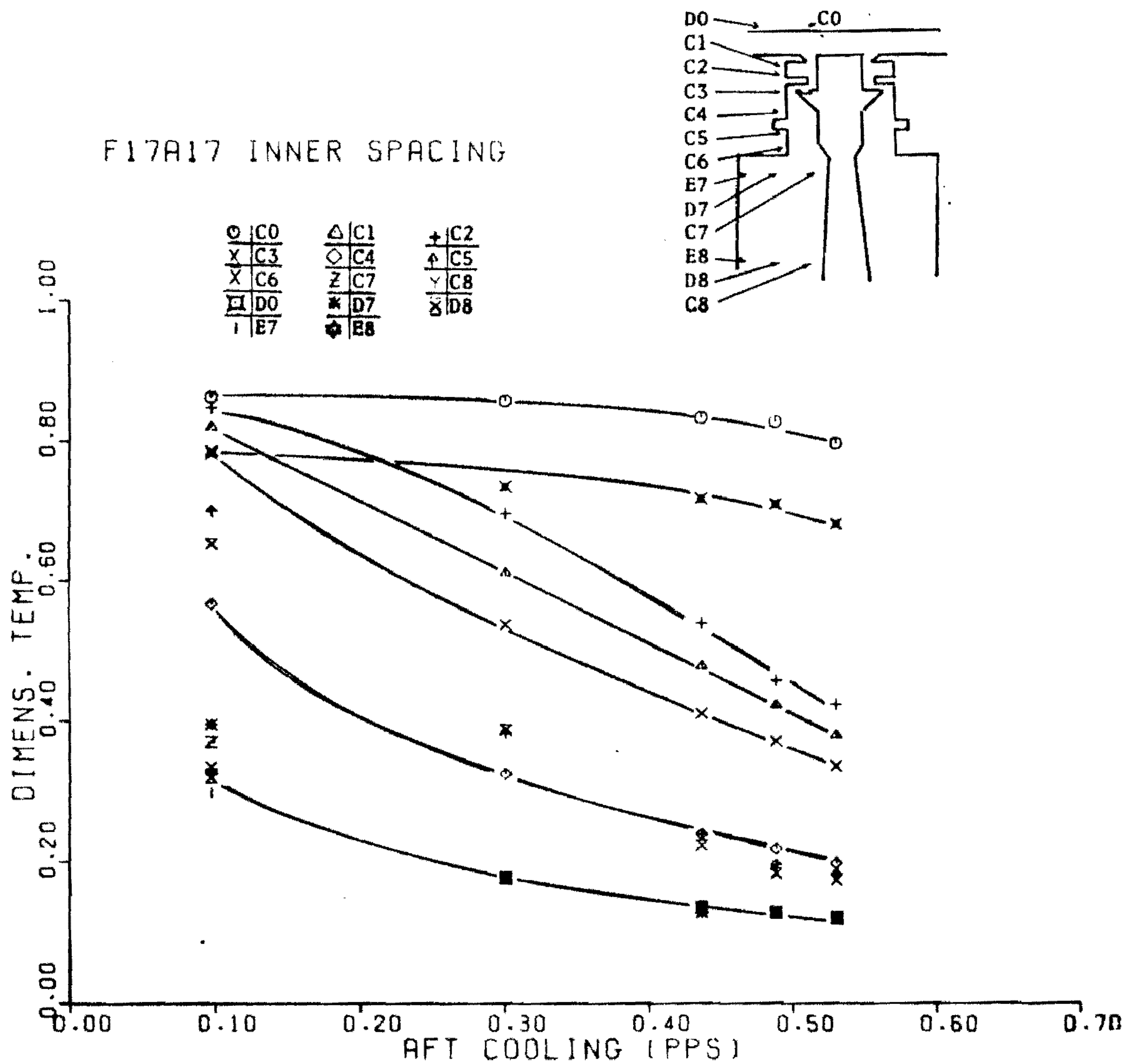


Figure AT-19B

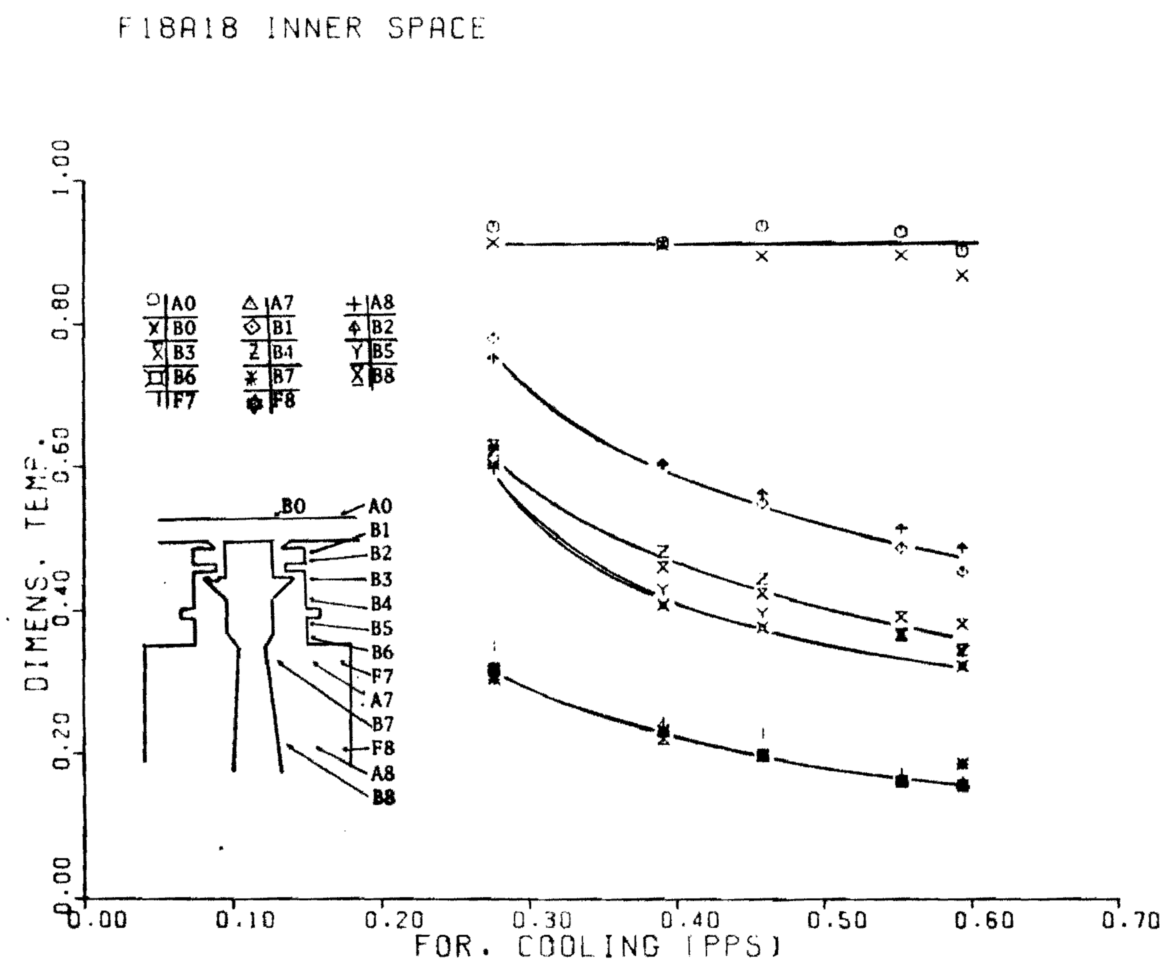


Figure AT-20A

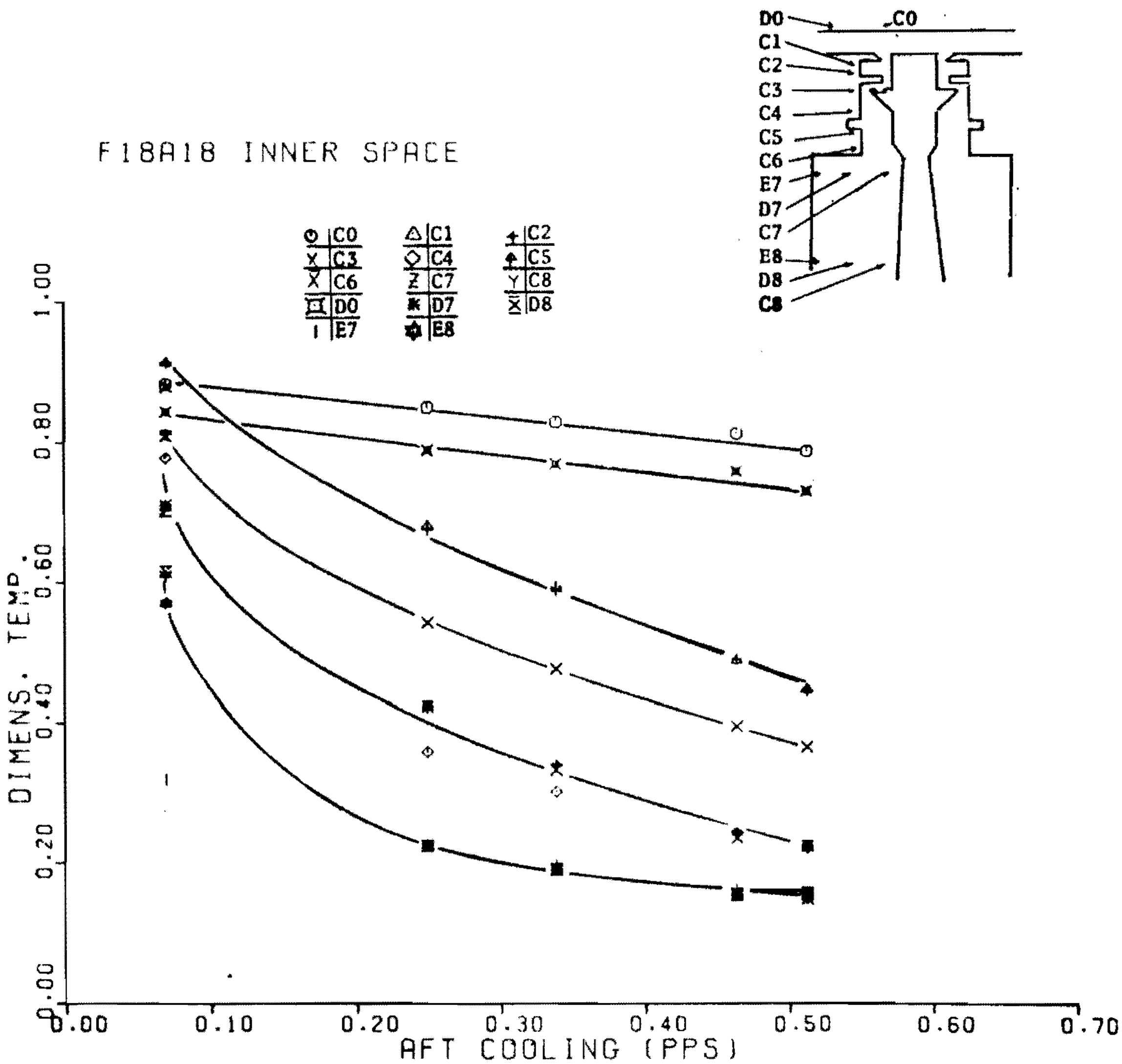


Figure AT-20B

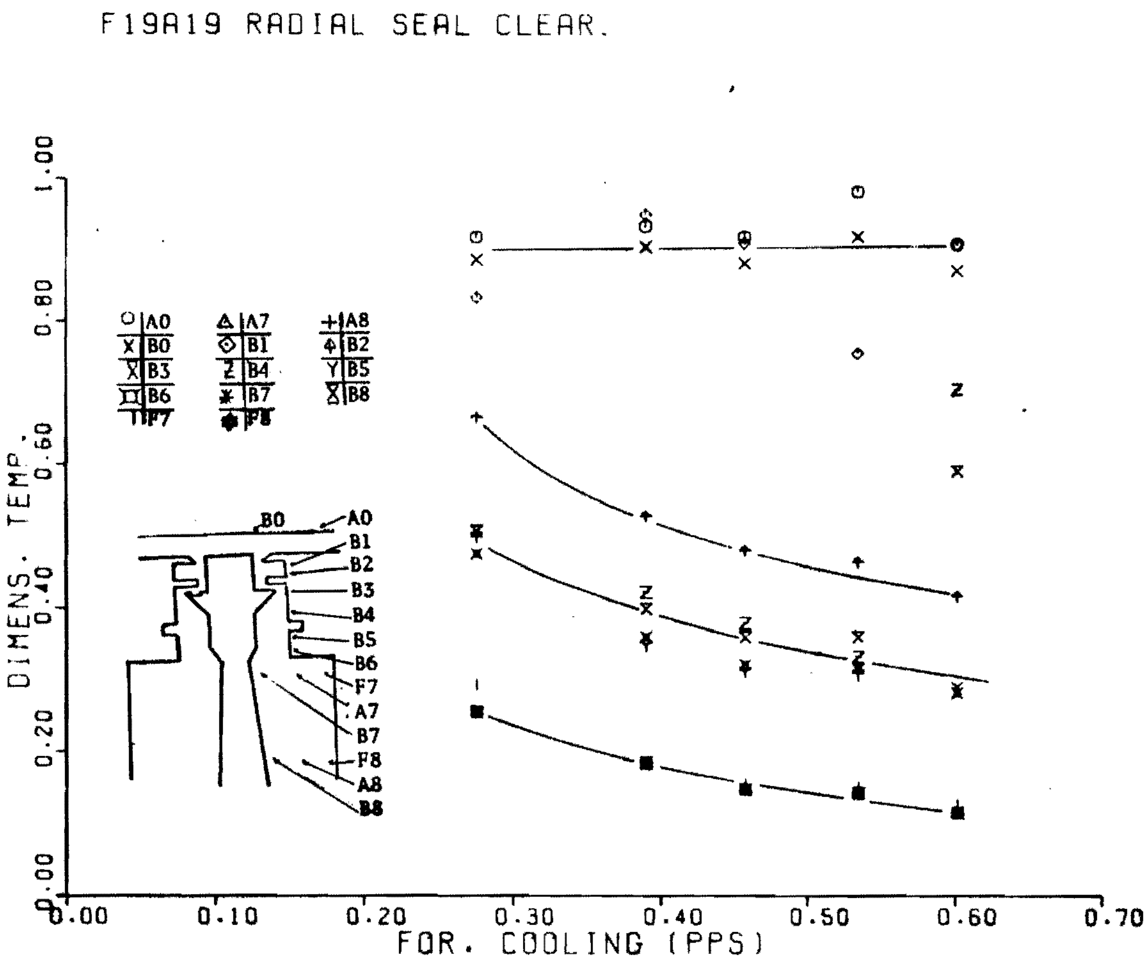


Figure AT-21A

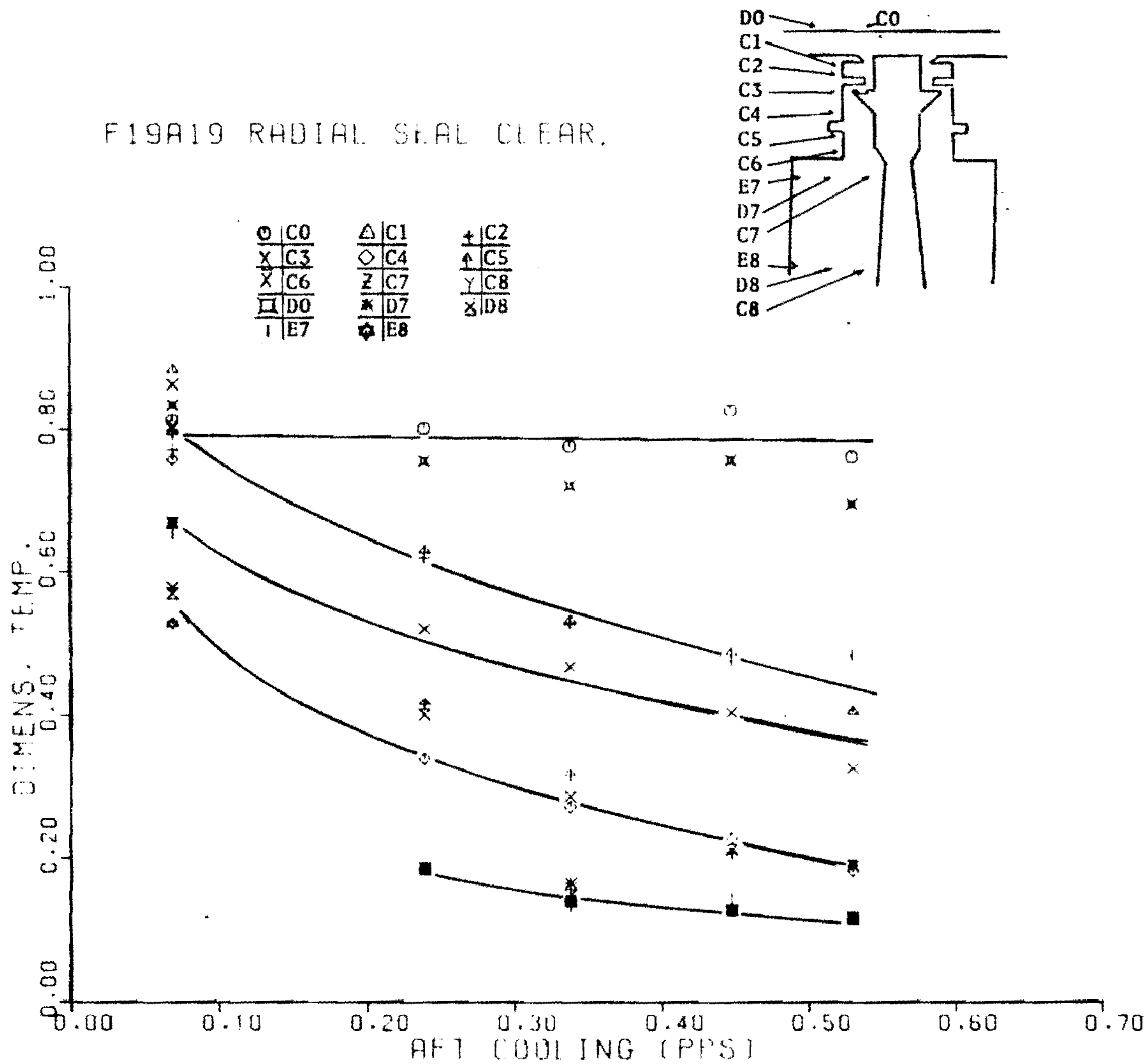


Figure AT-21B

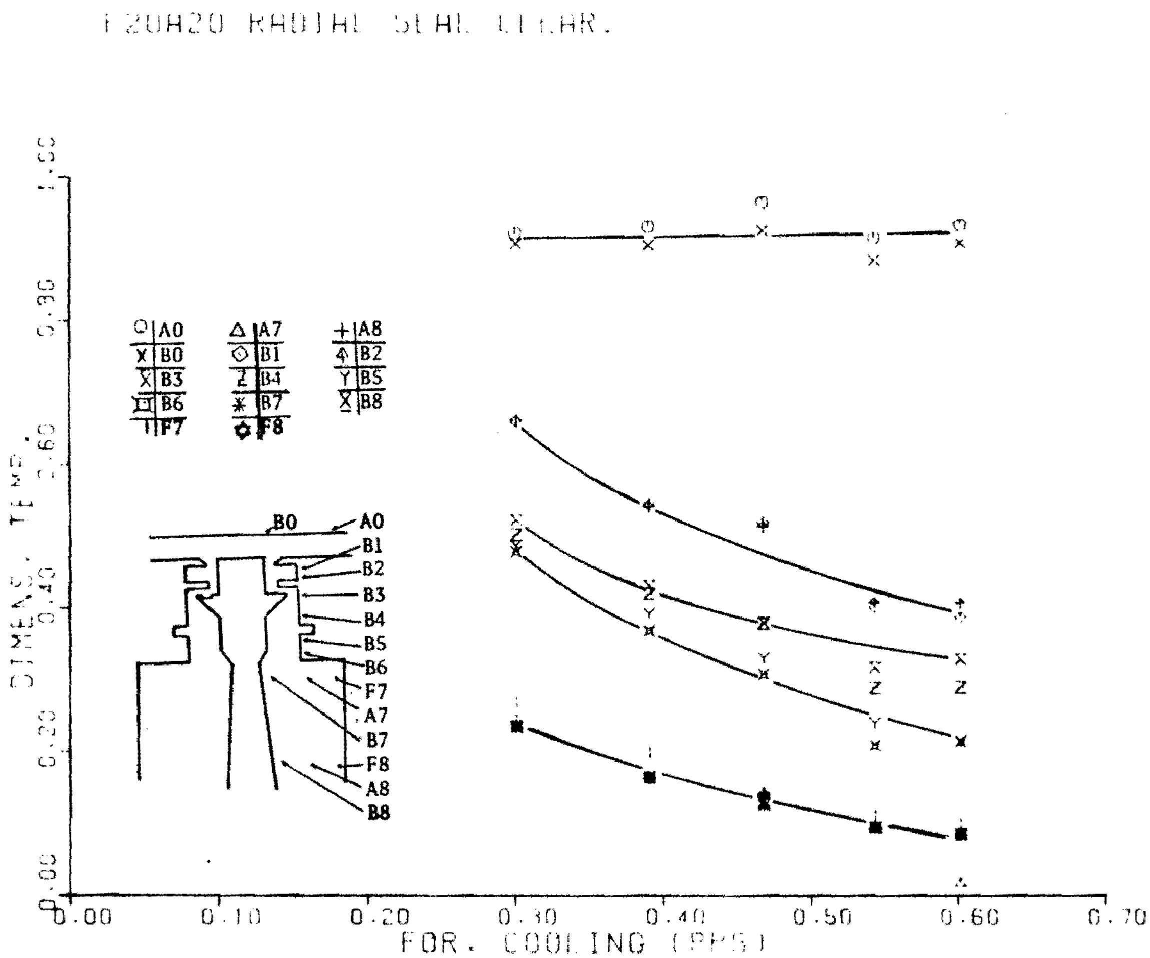


Figure AT-22A

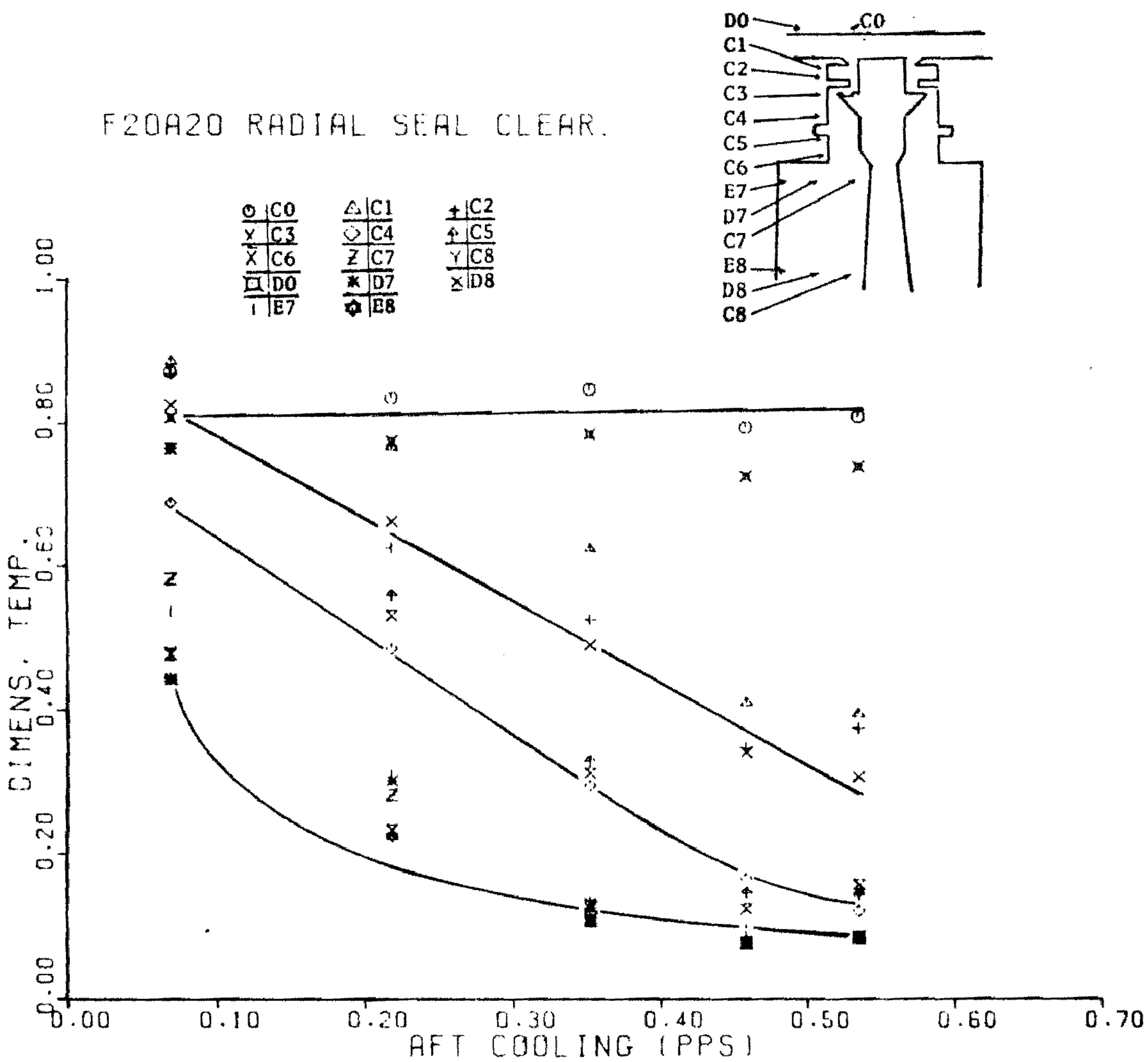


Figure AT-22B

F21A21 RADIAL SEAL CLEAR.

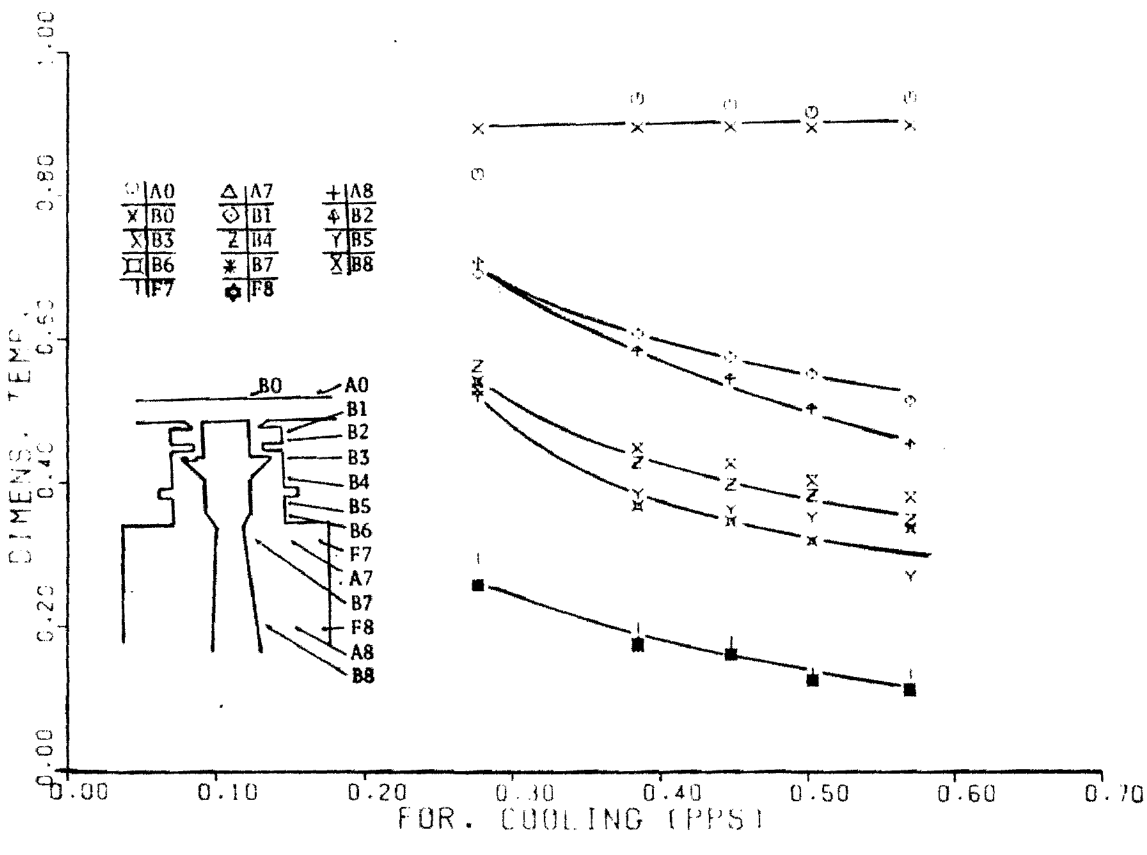


Figure AT-23A

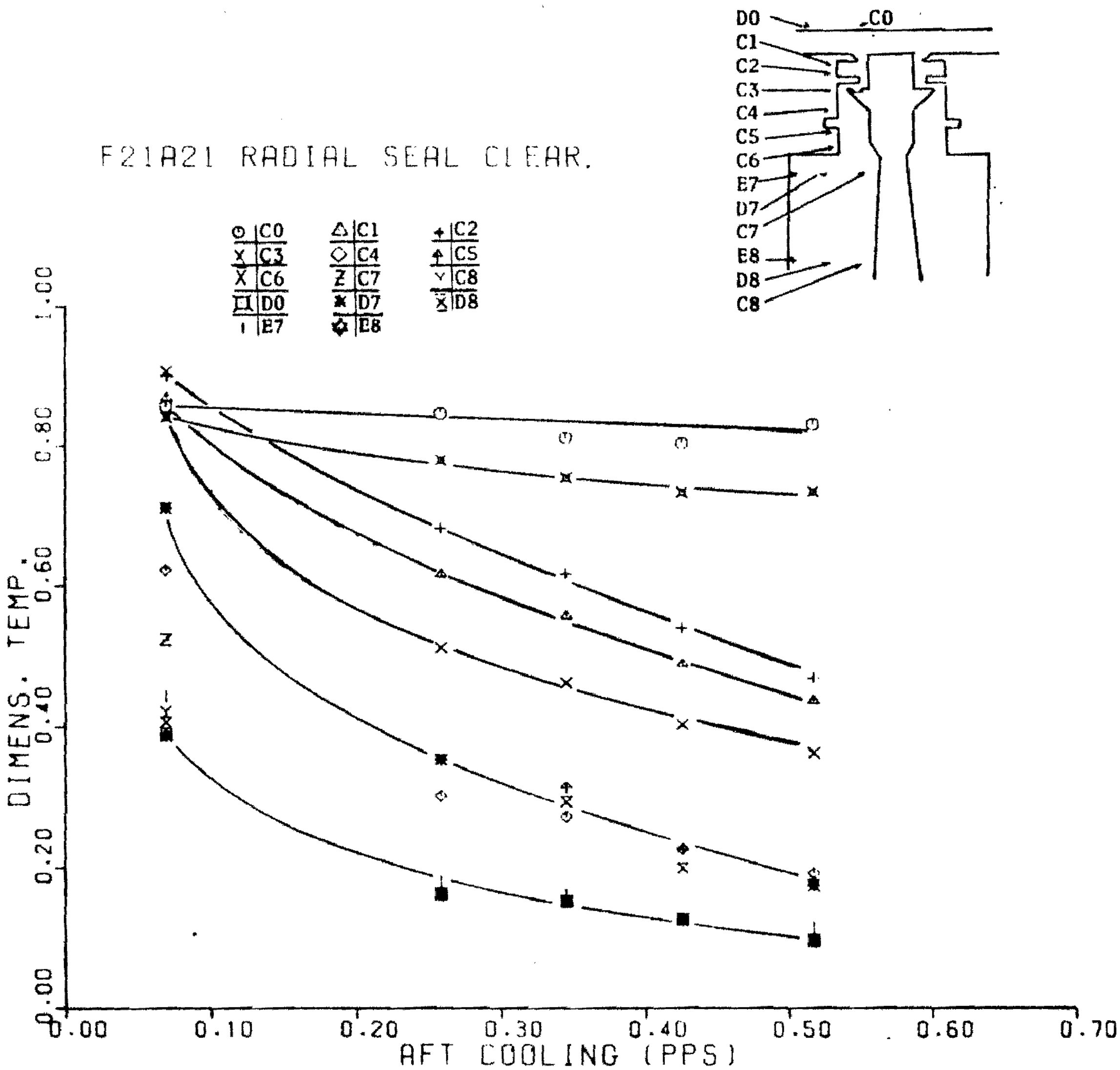


Figure AT-23B

APPENDIX IIIB

Figures AP1 - AP23

PRESSURE PLOTS

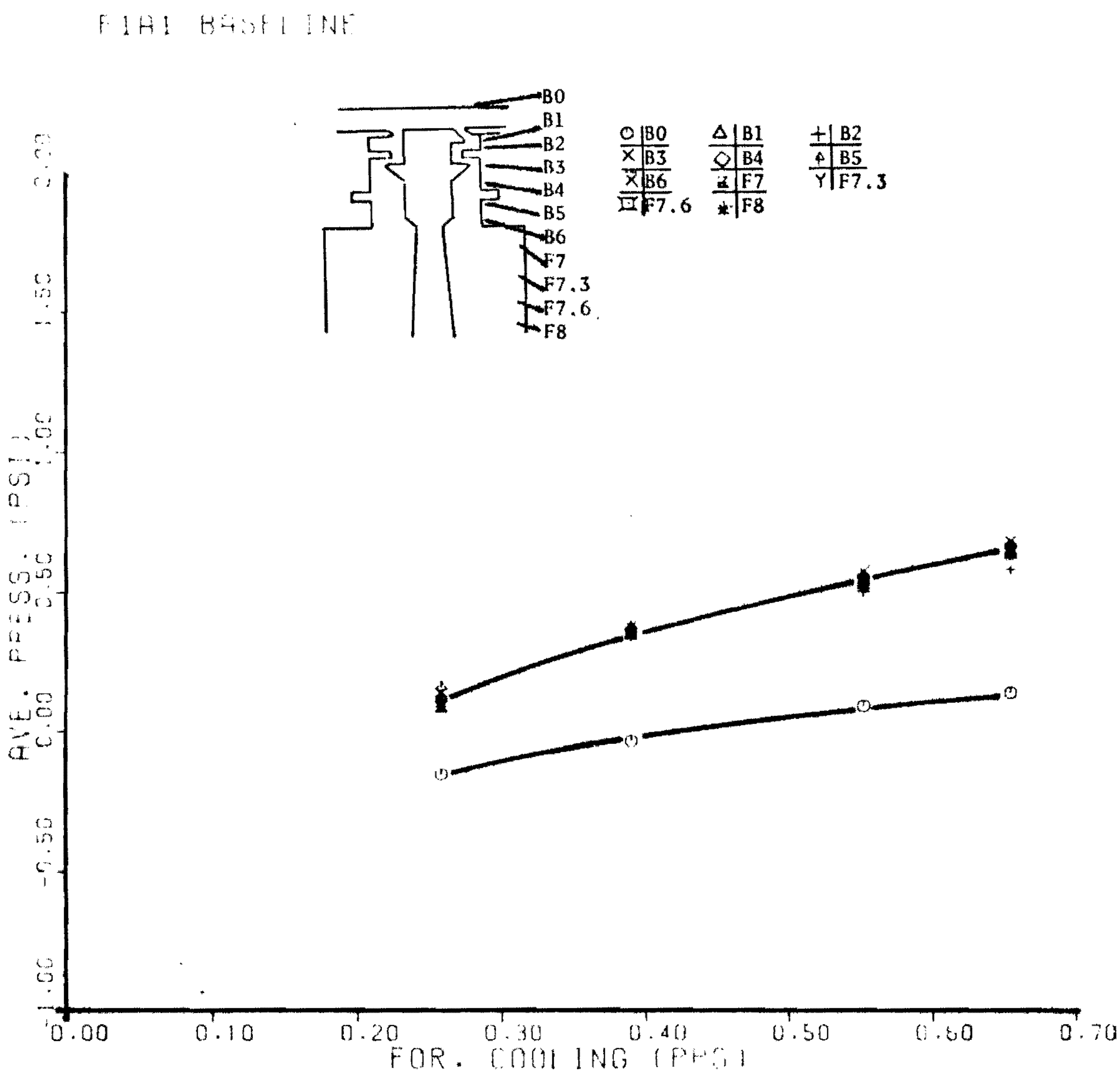

F1A1 BASELINE
B0
B1
B2
B3
B4
B5
B6
F7
F7.3
F7.6
F8
B0 B1 B2
B3 B4 B5
B6 F7 F7.3
F7.6 F8
AVE. PRESS. (PSI)
-1.00
-0.50
0.00
0.50
1.00
1.50
2.00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
FOR. COOLING (PPS)

Figure AP-1A

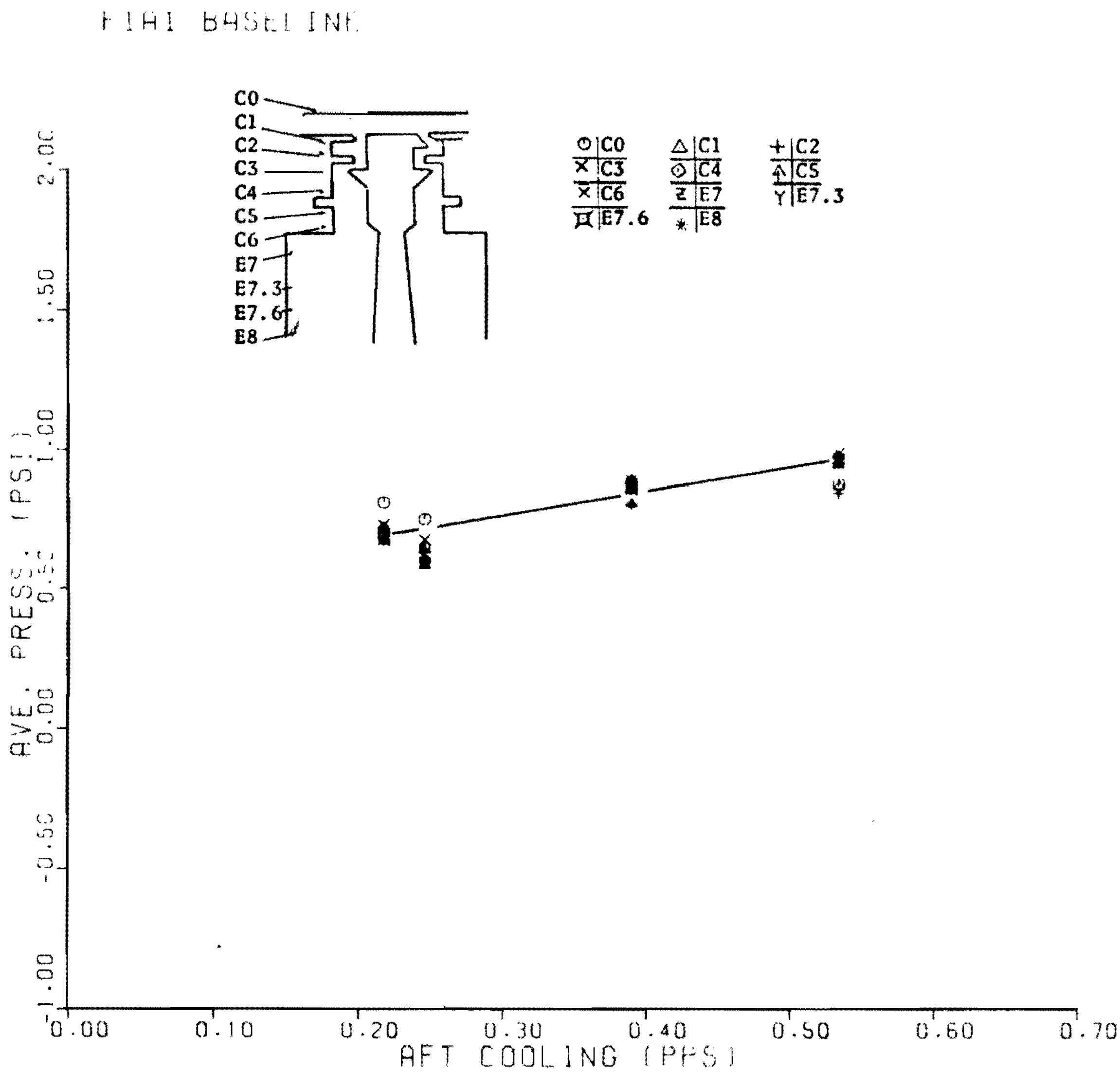

FIA1 BASELINE
C0
C1
C2
C3
C4
C5
C6
E7
E7.3
E7.6
E8
C0
C1
C2
C3
C4
C5
C6
E7
E7.3
E7.6
E8
AVE. PRESS. (PSI)
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
AFT COOLING (PPS)

Figure AP-1B

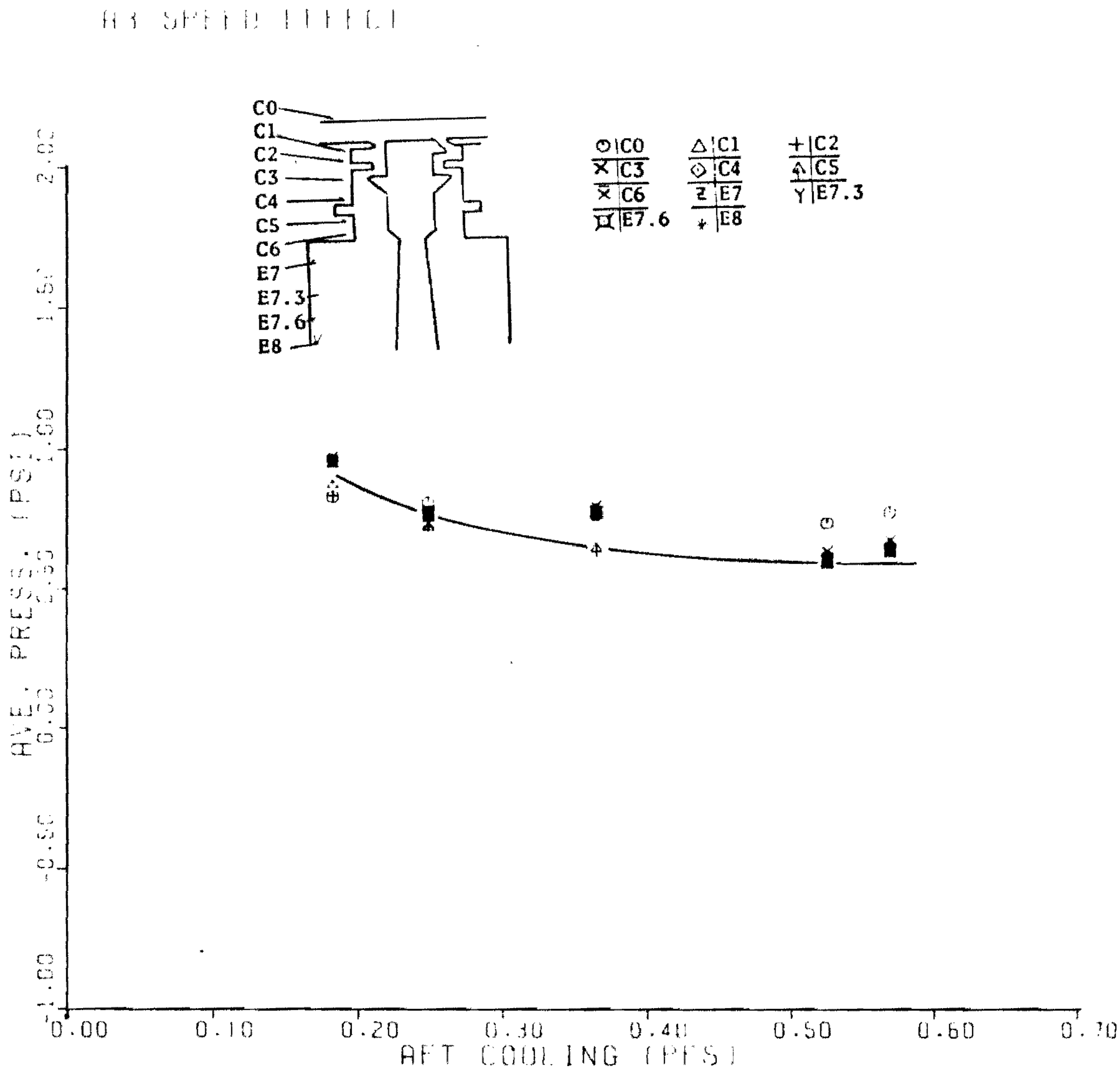


Figure AP-2

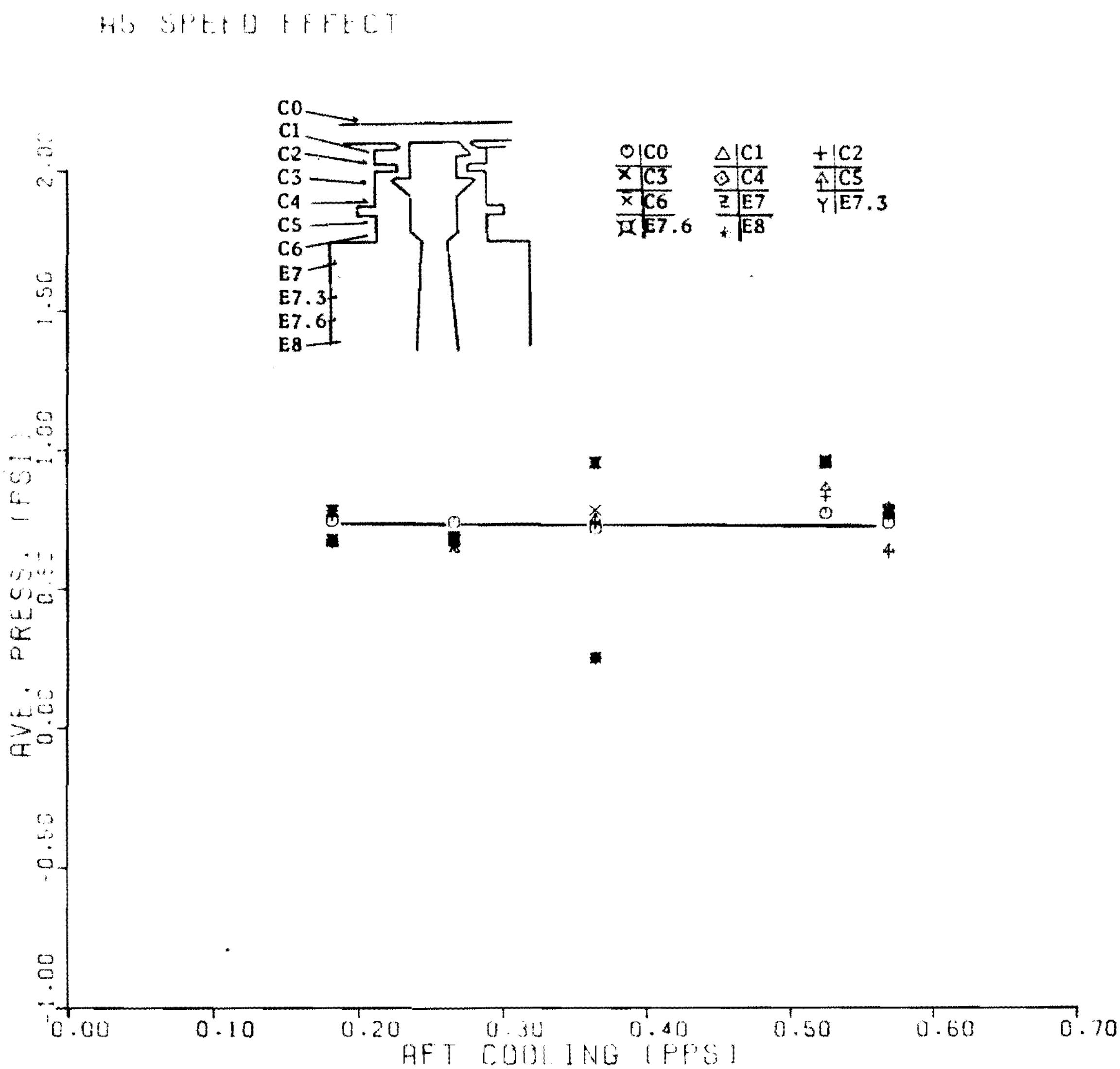

H5 SPEED EFFECT
C0
C1
C2
C3
C4
C5
C6
E7
E7.3
E7.6
E8
C0 C1 C2
C3 C4 C5
C6 E7 E7.3
E7.6 E8
AVE. PRESS. (PSI)
AFT COOLING (PPS)
0.00 0.10 0.20 0.30 0.40 0.50 0.60 0.70

Figure AP-3

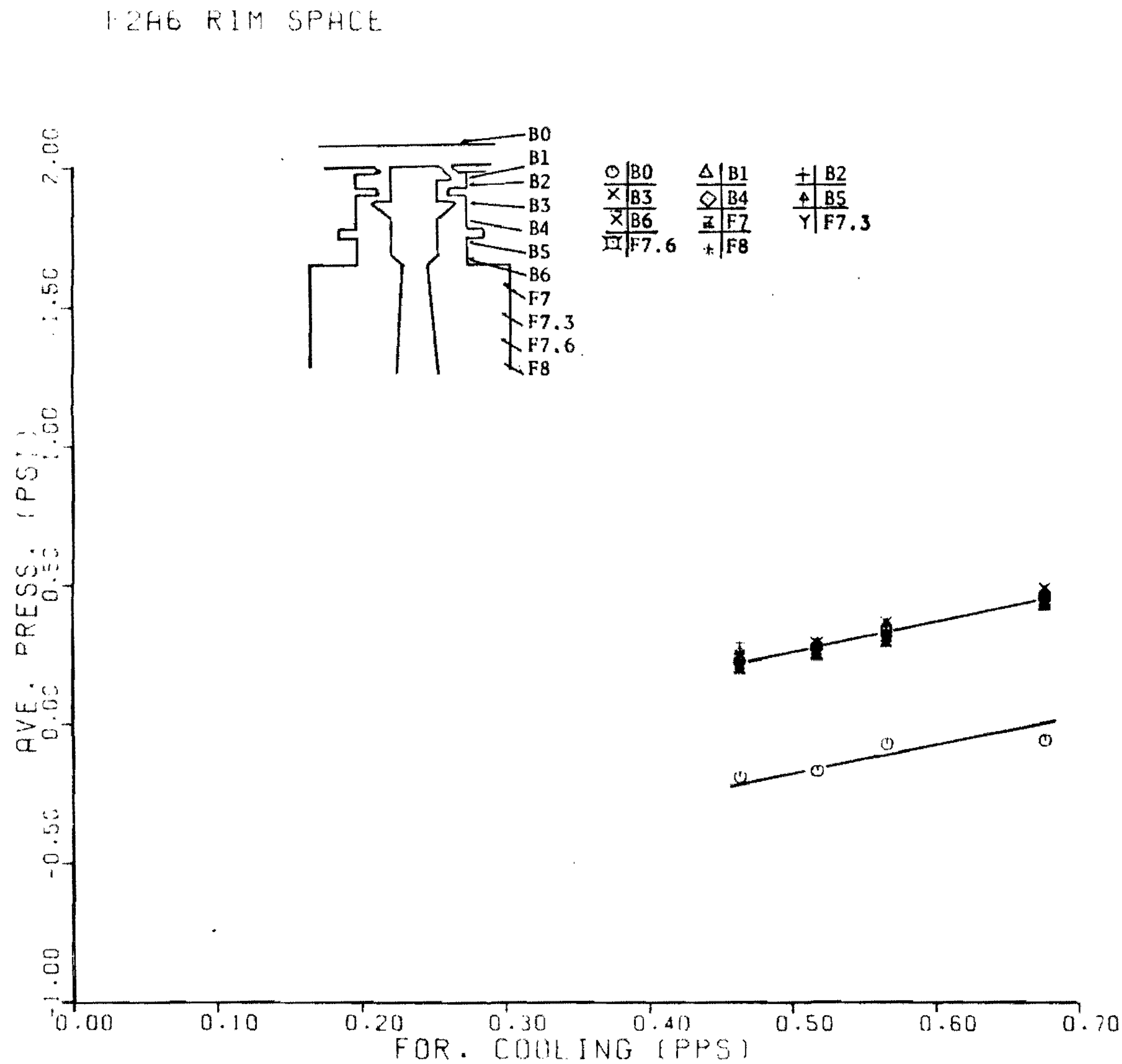

F2A6 RIM SPACE
B0
B1
B2
B3
B4
B5
B6
F7
F7.3
F7.6
F8
B0 B1 B2
B3 B4 B5
B6 F7 F7.3
F7.6 F8
AVE. PRESS. (PSI)
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
FOR. COOLING (PPS)

Figure AP-4A

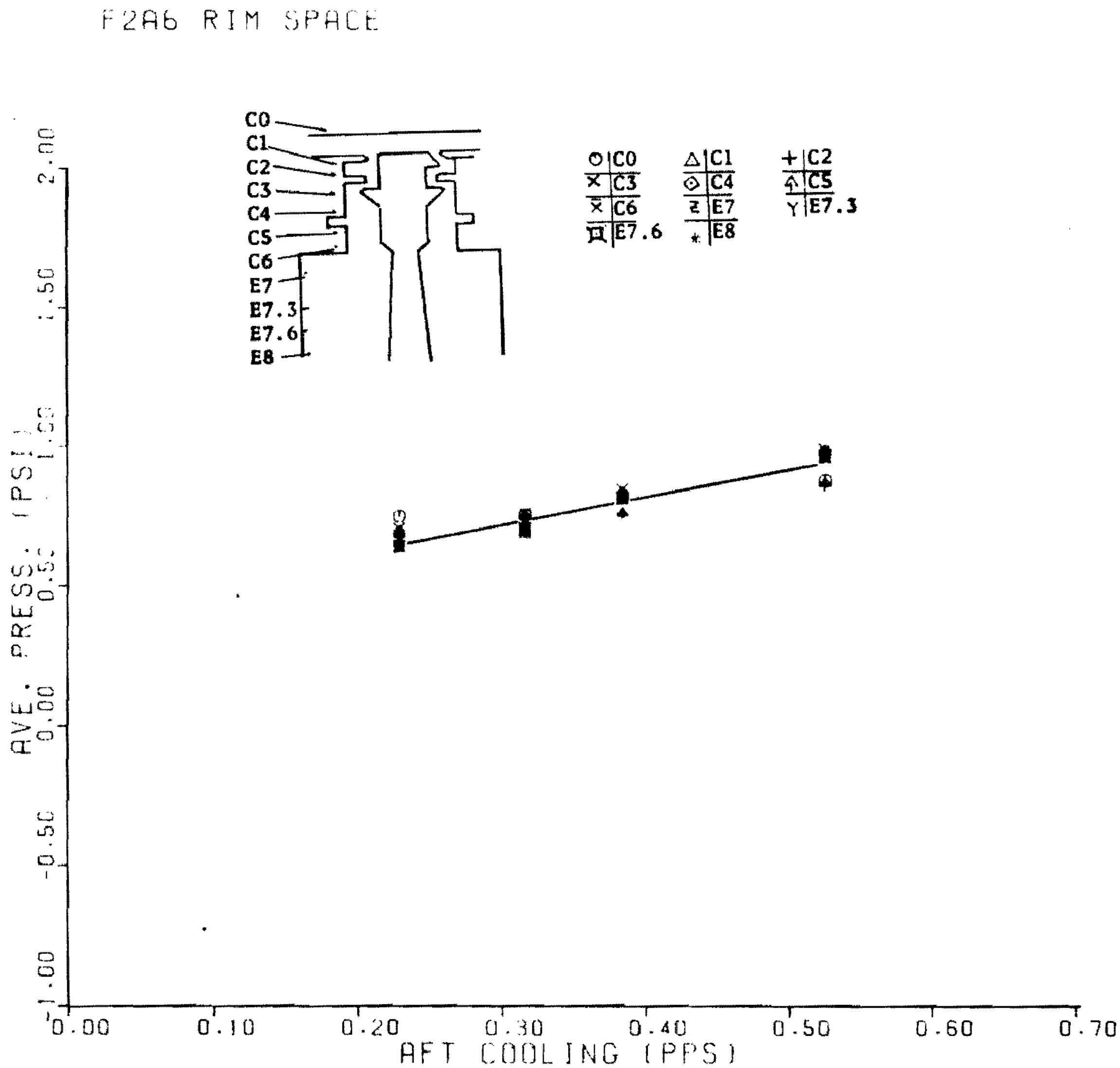

F2A6 RIM SPACE
C0
C1
C2
C3
C4
C5
C6
E7
E7.3
E7.6
E8
C0
C1
C2
C3
C4
C5
C6
E7
E7.3
E7.6
E8
AVE. PRESS. (PSI)
AFT COOLING (PPS)
-1.00
-0.50
0.00
0.50
1.00
1.50
2.00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70

Figure AP-4B

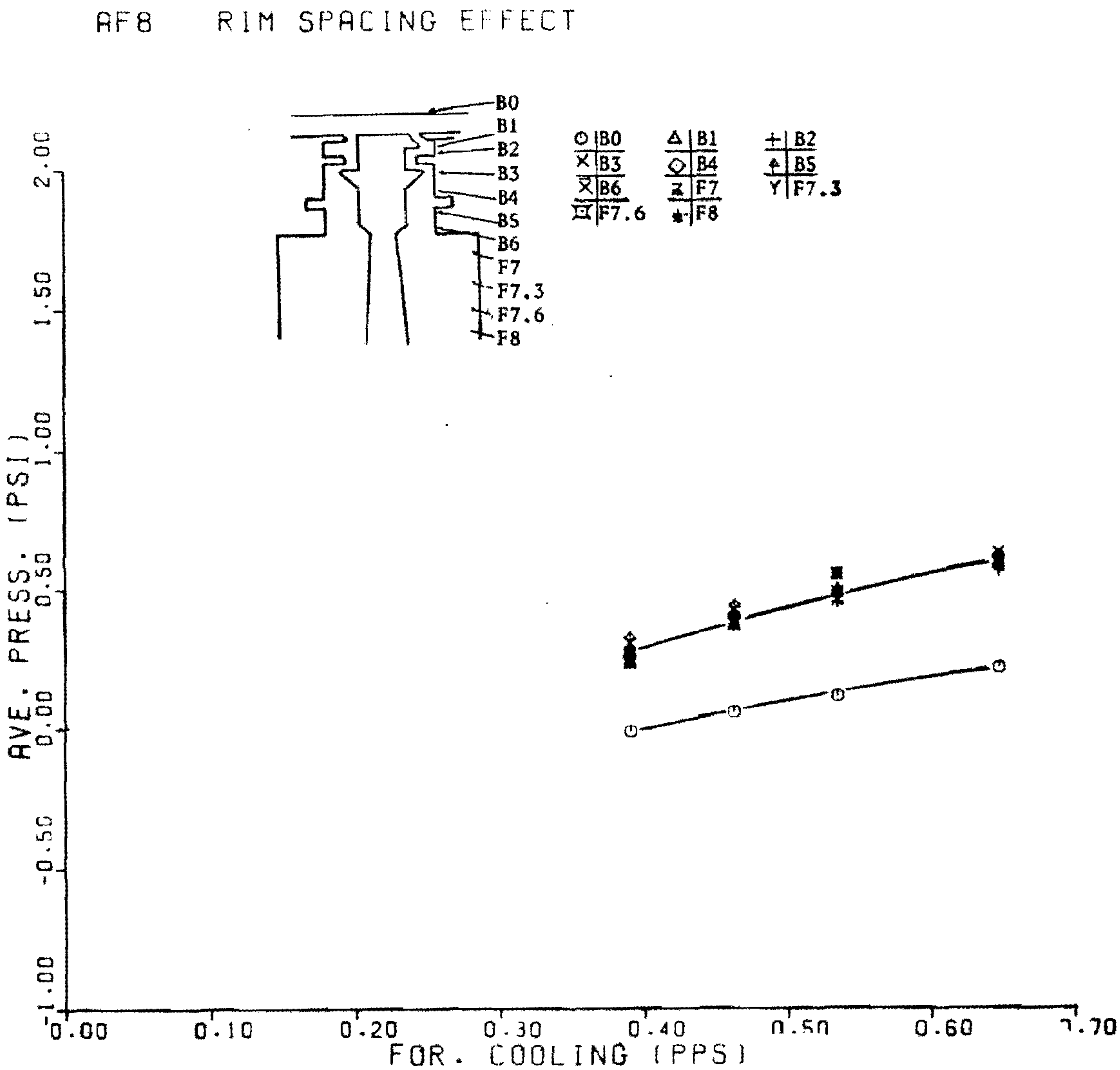
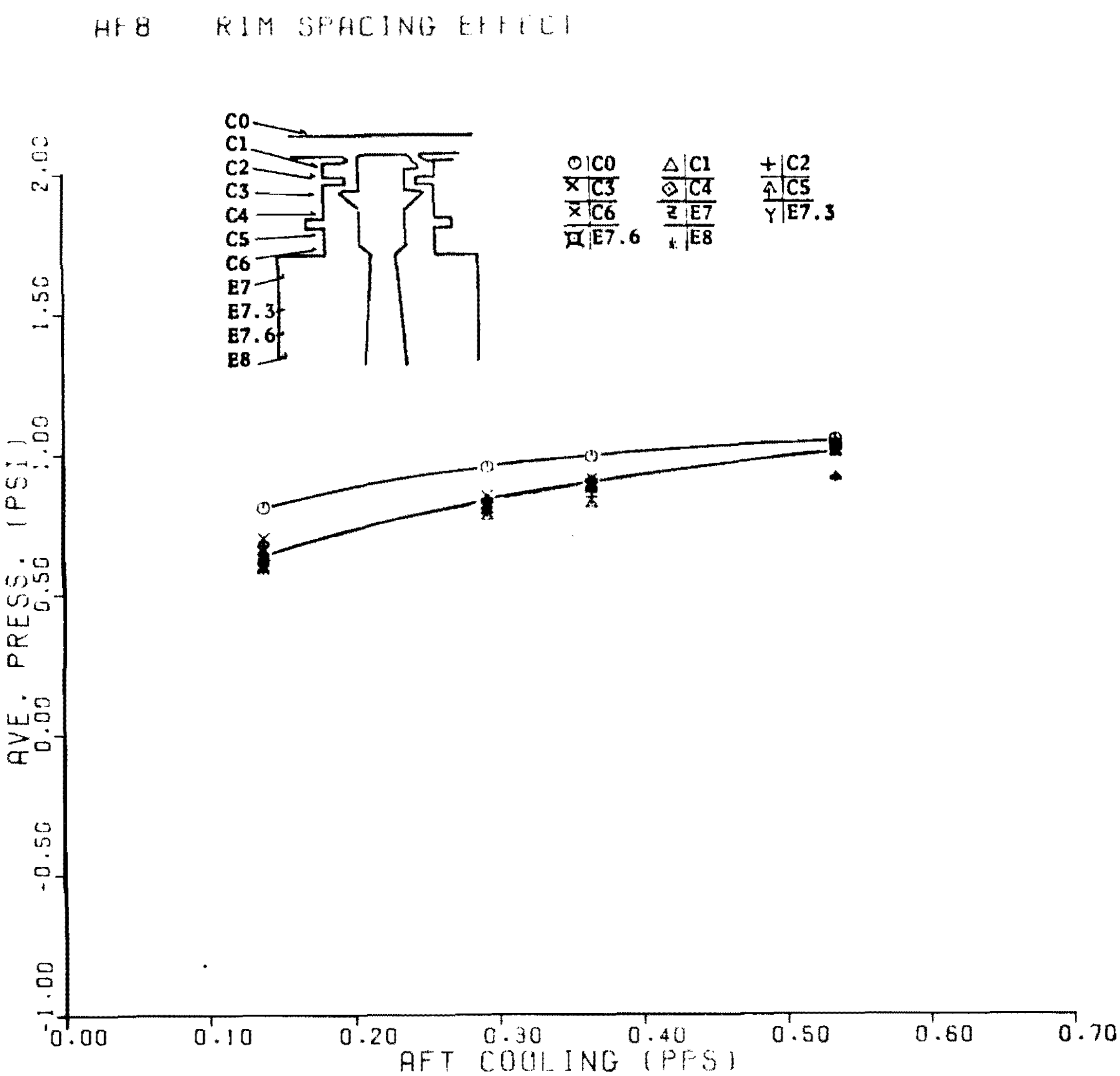

AF8 RIM SPACING EFFECT
B0
B1
B2
B3
B4
B5
B6
F7
F7.3
F7.6
F8
B0
B1
B2
B3
B4
B5
B6
F7
F7.3
F7.6
F8
AVE. PRESS. (PSI)
-1.00
-0.50
0.00
0.50
1.00
1.50
2.00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
FOR. COOLING (PPS)

Figure AP-5A



AF8 RIM SPACING EFFECT
C0
C1
C2
C3
C4
C5
C6
E7
E7.3
E7.6
E8
C0
C1
C2
C3
C4
C5
C6
E7
E7.3
E7.6
E8
AVE. PRESS. (PSI)
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
AFT COOLING (PPS)

Figure AP-5B

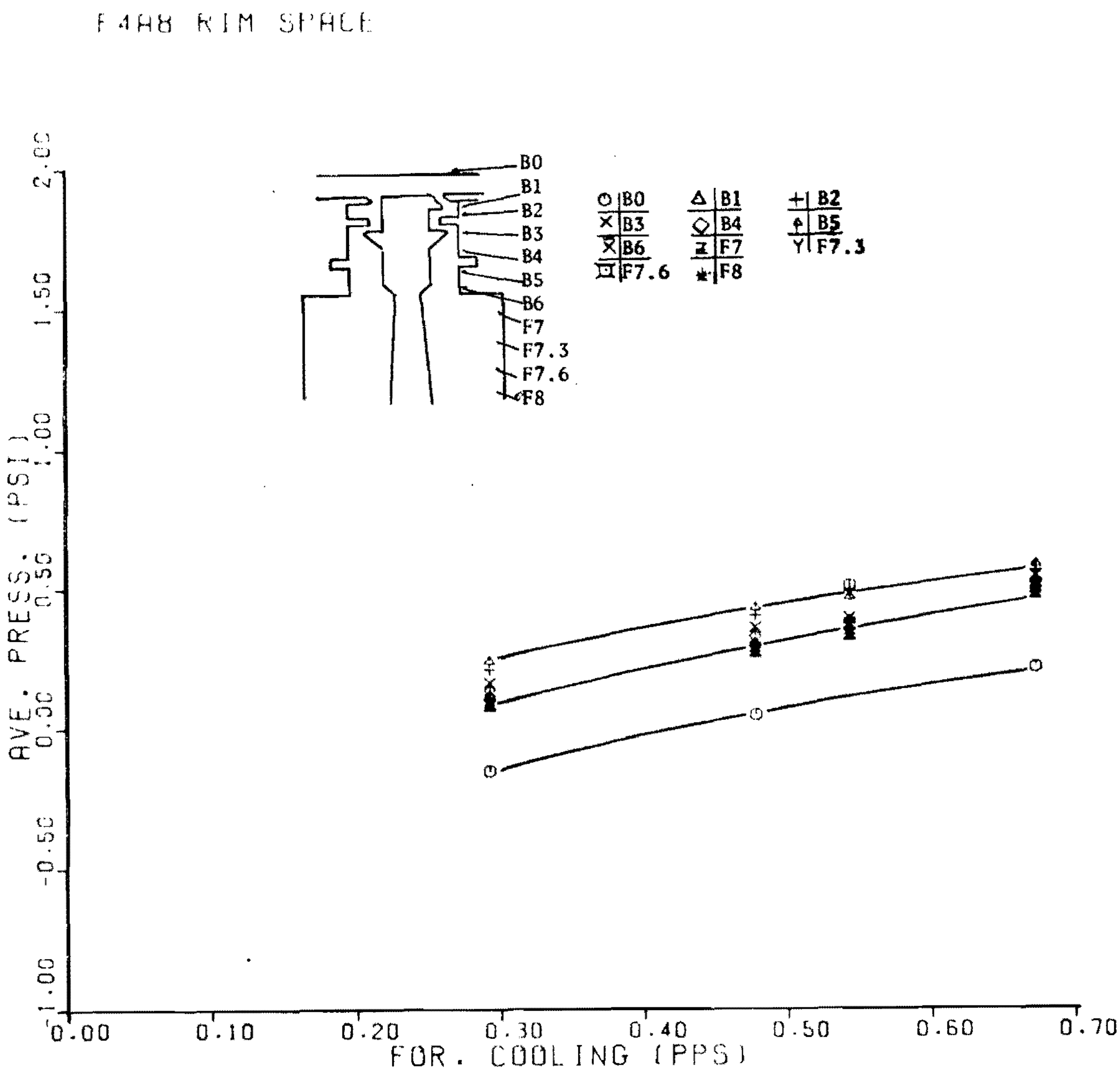

F4A8 RIM SPACE
B0
B1
B2
B3
B4
B5
B6
F7
F7.3
F7.6
F8
B0
B1
B2
B3
B4
B5
B6
F7
F7.3
F7.6
F8
AVE. PRESS. (PSI)
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
FOR. COOLING (PPS)

Figure AP-6A

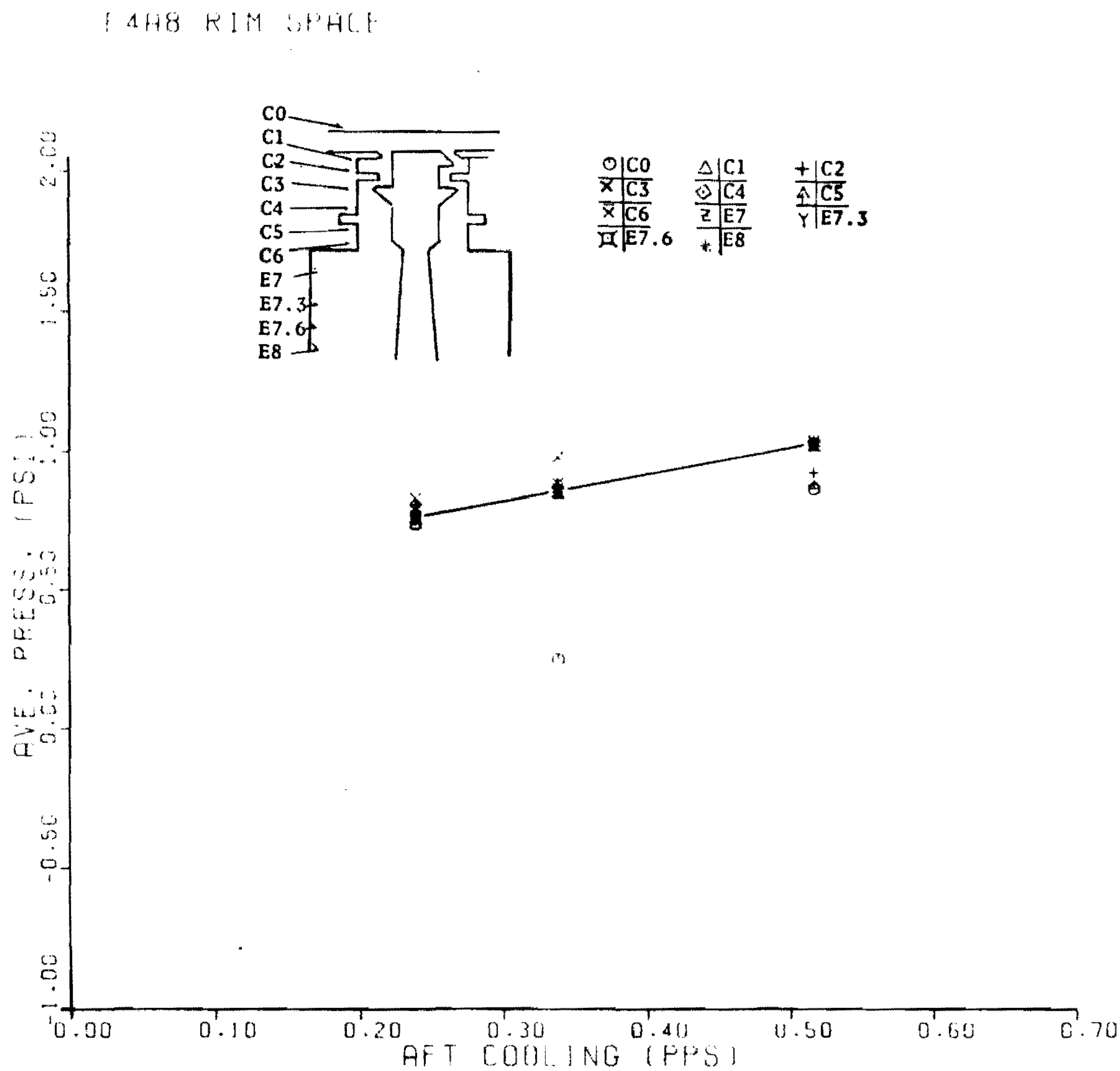
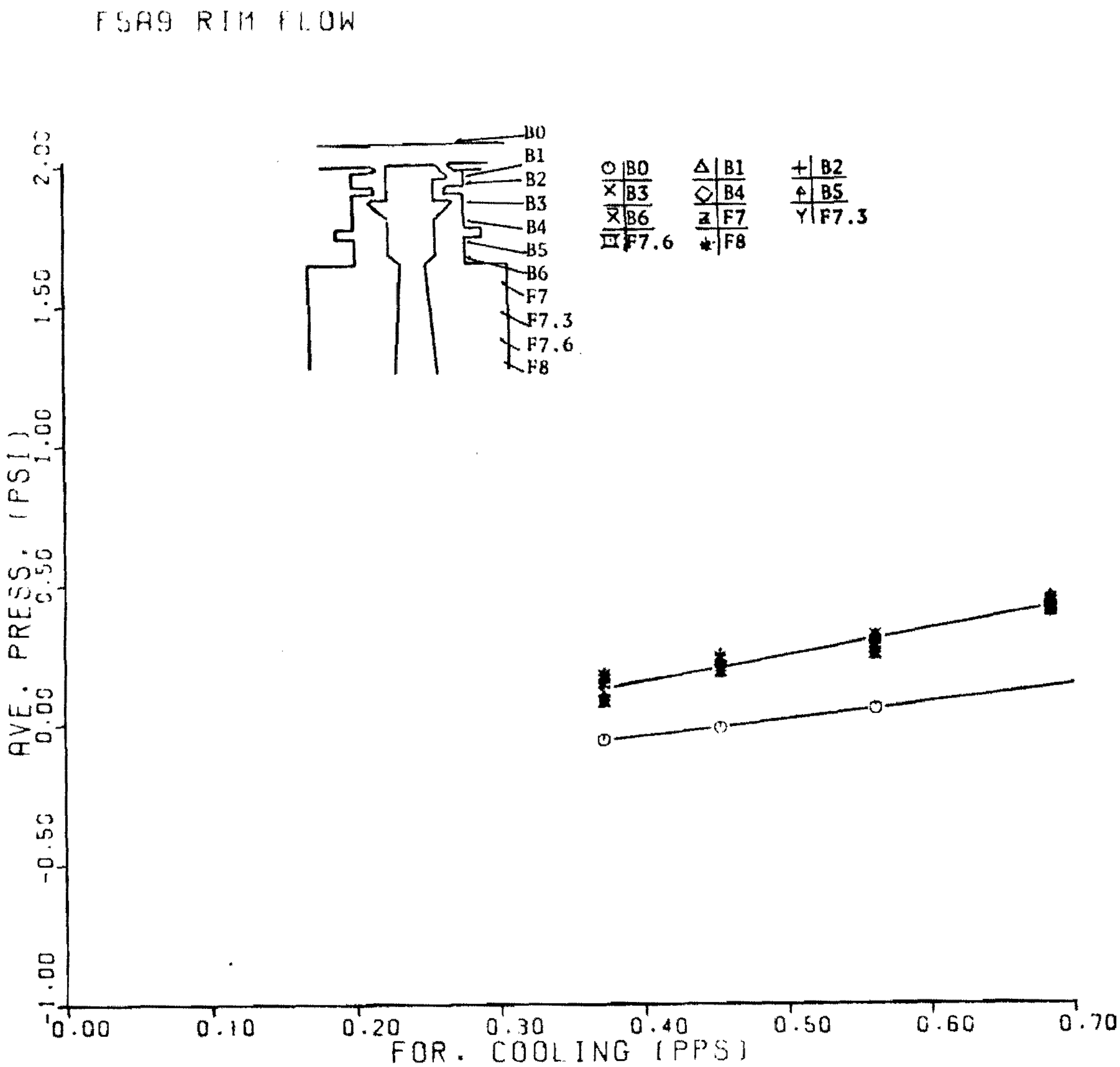

F4A8 RIM SPACE
C0
C1
C2
C3
C4
C5
C6
E7
E7.3
E7.6
E8
C0
C1
C2
C3
C4
C5
C6
E7
E7.3
E7.6
E8
AVE. PRESS. (PSI)
AFT COOLING (PPS)
-1.00
-0.50
0.00
0.50
1.00
1.50
2.00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70

Figure AP-6B



FSA9 RIM FLOW
B0
B1
B2
B3
B4
B5
B6
F7
F7.3
F7.6
F8
B0
B1
B2
B3
B4
B5
B6
F7
F7.3
F7.6
F8
AVE. PRESS. (PSI)
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
FOR. COOLING (PPS)

Figure AP-7A

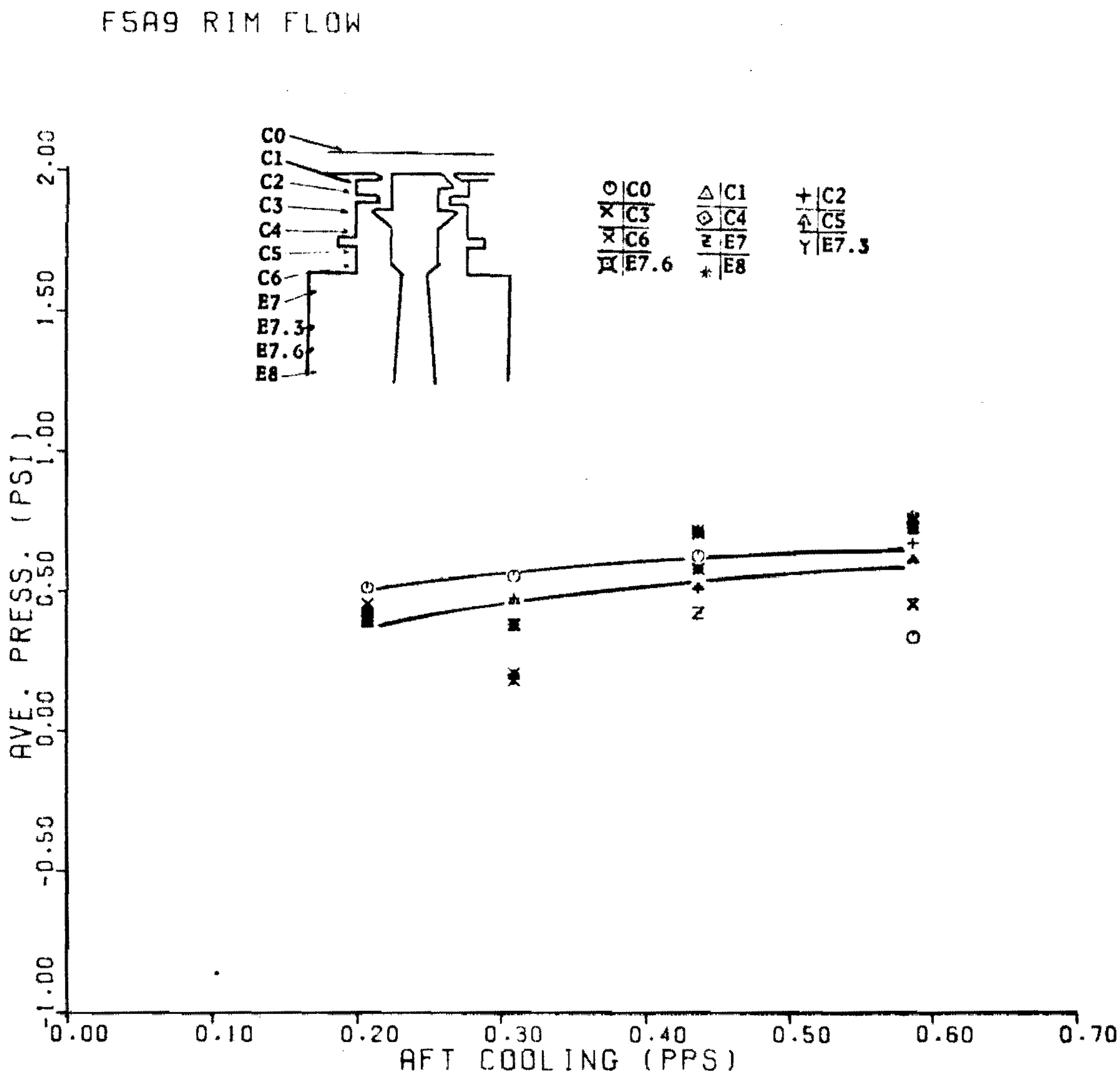

F5A9 RIM FLOW
C0
C1
C2
C3
C4
C5
C6
E7
E7.3
E7.6
E8
C0
C1
C2
C3
C4
C5
C6
E7
E7.3
E7.6
E8
AVE. PRESS. (PSI)
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
AFT COOLING (PPS)

Figure AP-7B

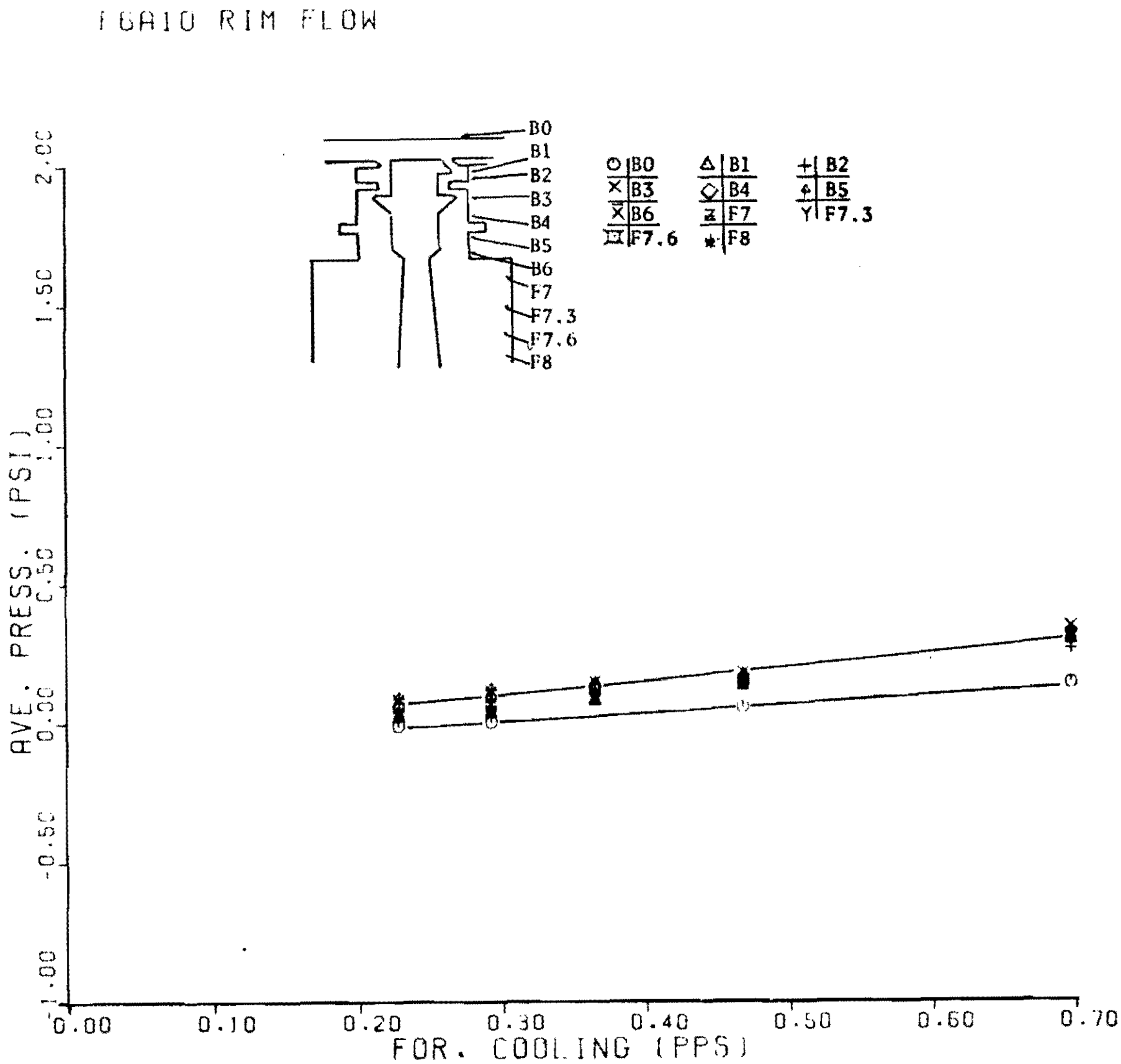

F6A10 RIM FLOW
B0
B1
B2
B3
B4
B5
B6
F7
F7.3
F7.6
F8
B0
B1
B2
B3
B4
B5
B6
F7
F7.3
F7.6
F8
AVE. PRESS. (PSI)
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
FOR. COOLING (PPS)

Figure AP-8A

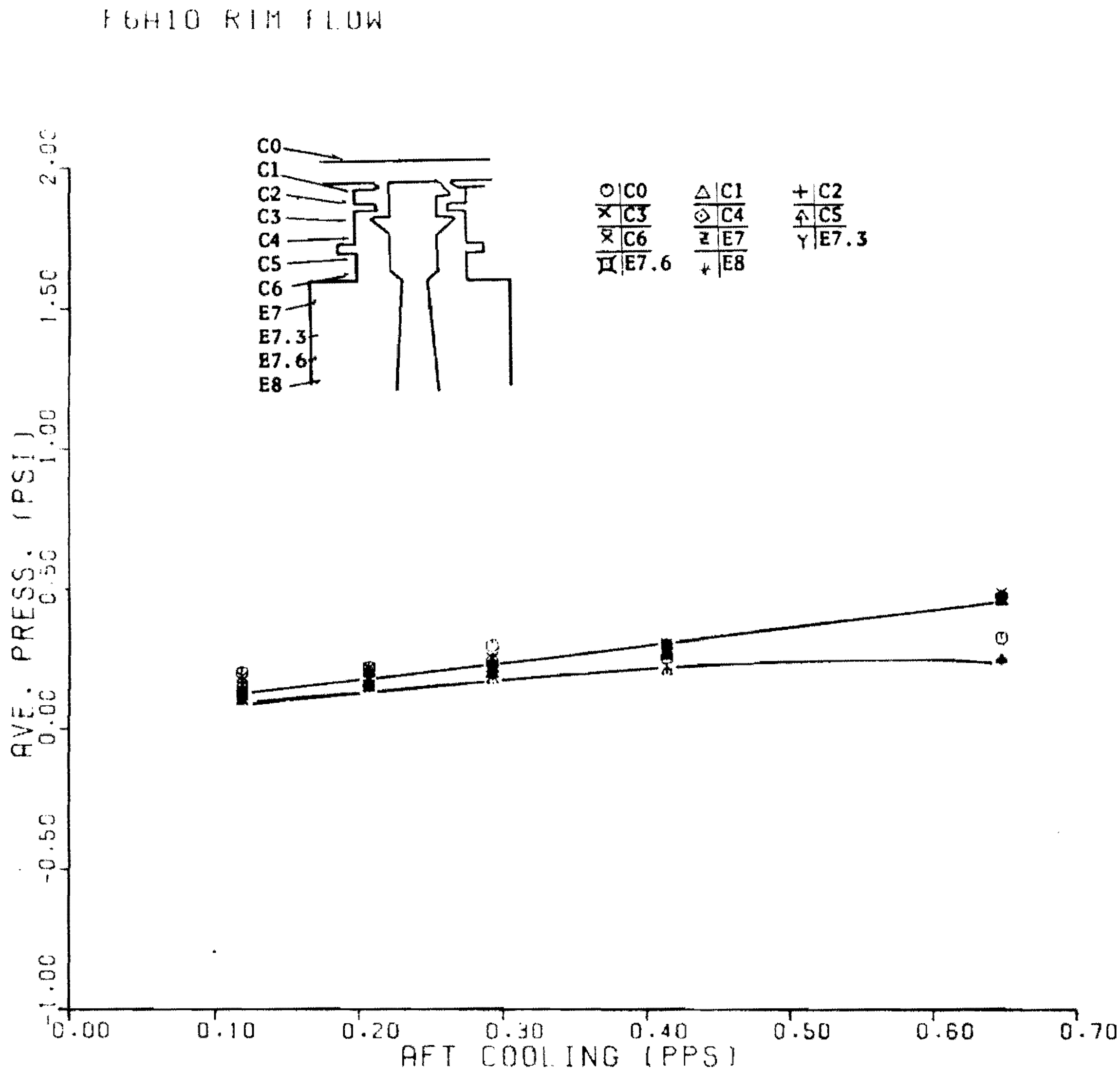

F6H10 RIM FLOW
C0
C1
C2
C3
C4
C5
C6
E7
E7.3
E7.6
E8
C0 C1 C2
C3 C4 C5
C6 E7 E7.3
E7.6 E8
AVE. PRESS. (PSI)
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00
0.00 0.10 0.20 0.30 0.40 0.50 0.60 0.70
AFT COOLING (PPS)

Figure AP-8B

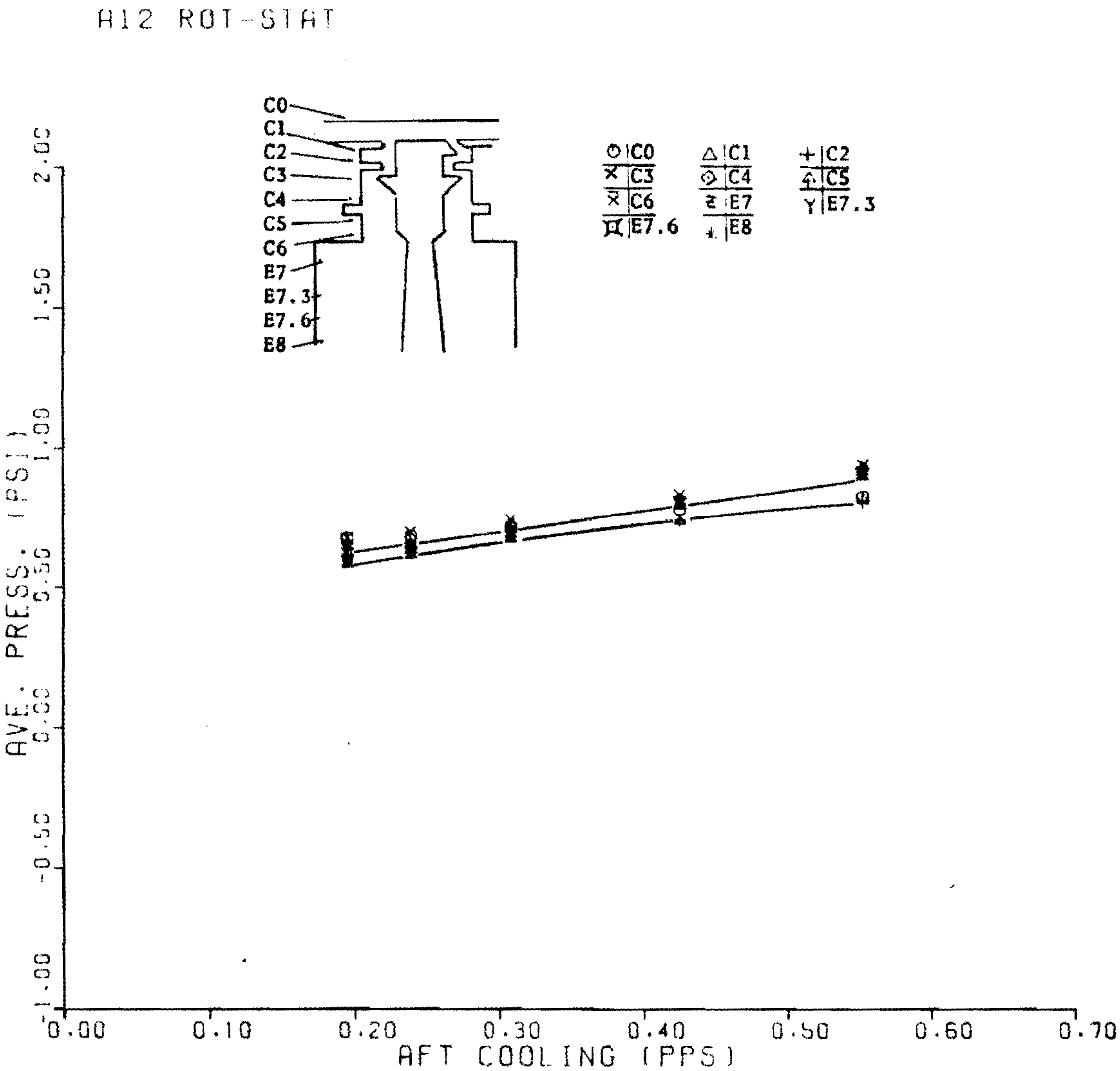
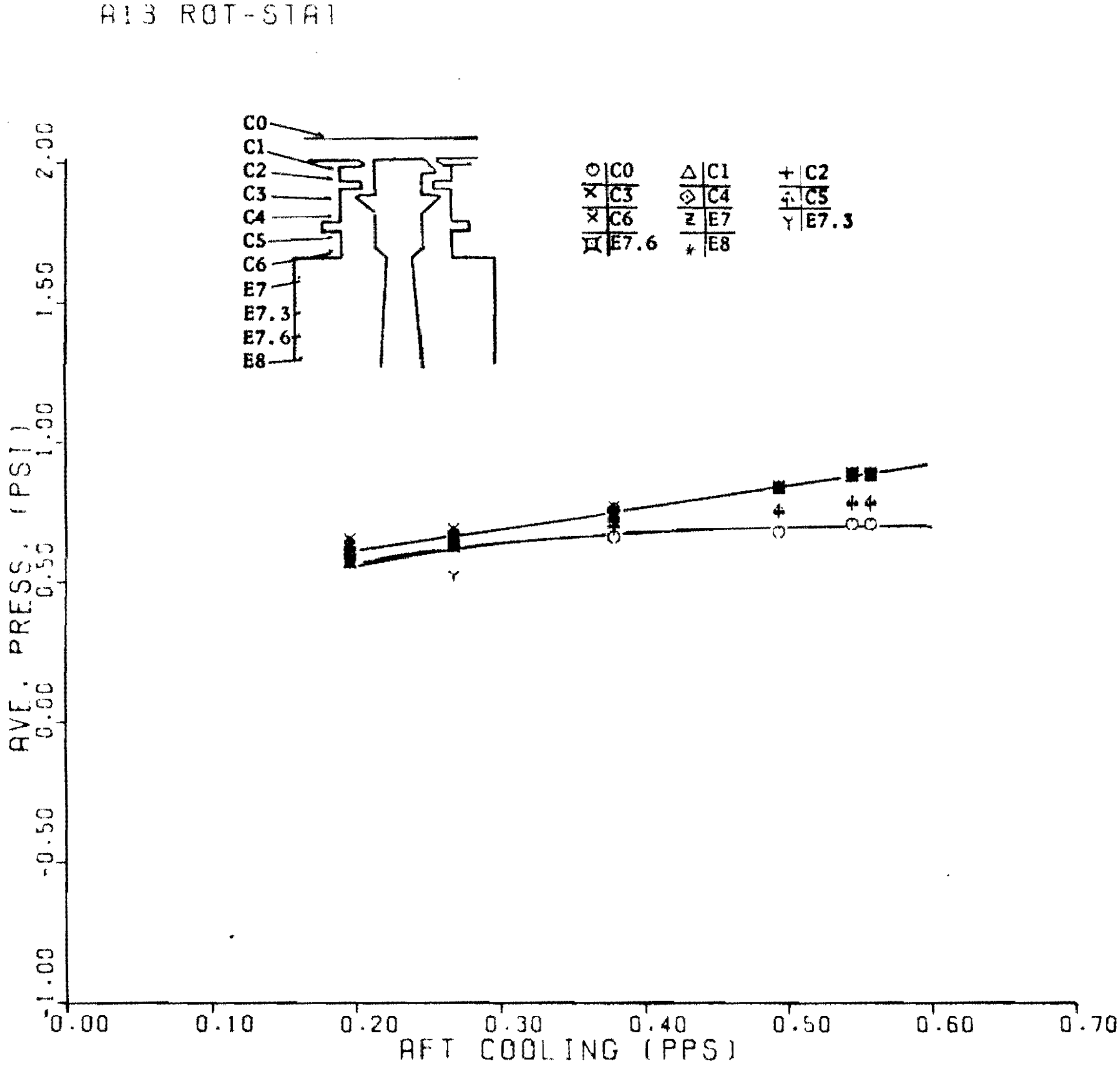

A12 ROT-STAT
C0
C1
C2
C3
C4
C5
C6
E7
E7.3
E7.6
E8
C0
C1
C2
C3
C4
C5
C6
E7
E7.3
E7.6
E8
AVE. PRESS. (PSI)
-1.00
-0.50
0.00
0.50
1.00
1.50
2.00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
AFT COOLING (PPS)

Figure AP-9



A13 ROT-STAT
C0
C1
C2
C3
C4
C5
C6
E7
E7.3
E7.6
E8
C0
C1
C2
C3
C4
C5
C6
E7
E7.3
E7.6
E8
AVE. PRESS. (PSI)
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
AFT COOLING (PPS)

Figure AP-10

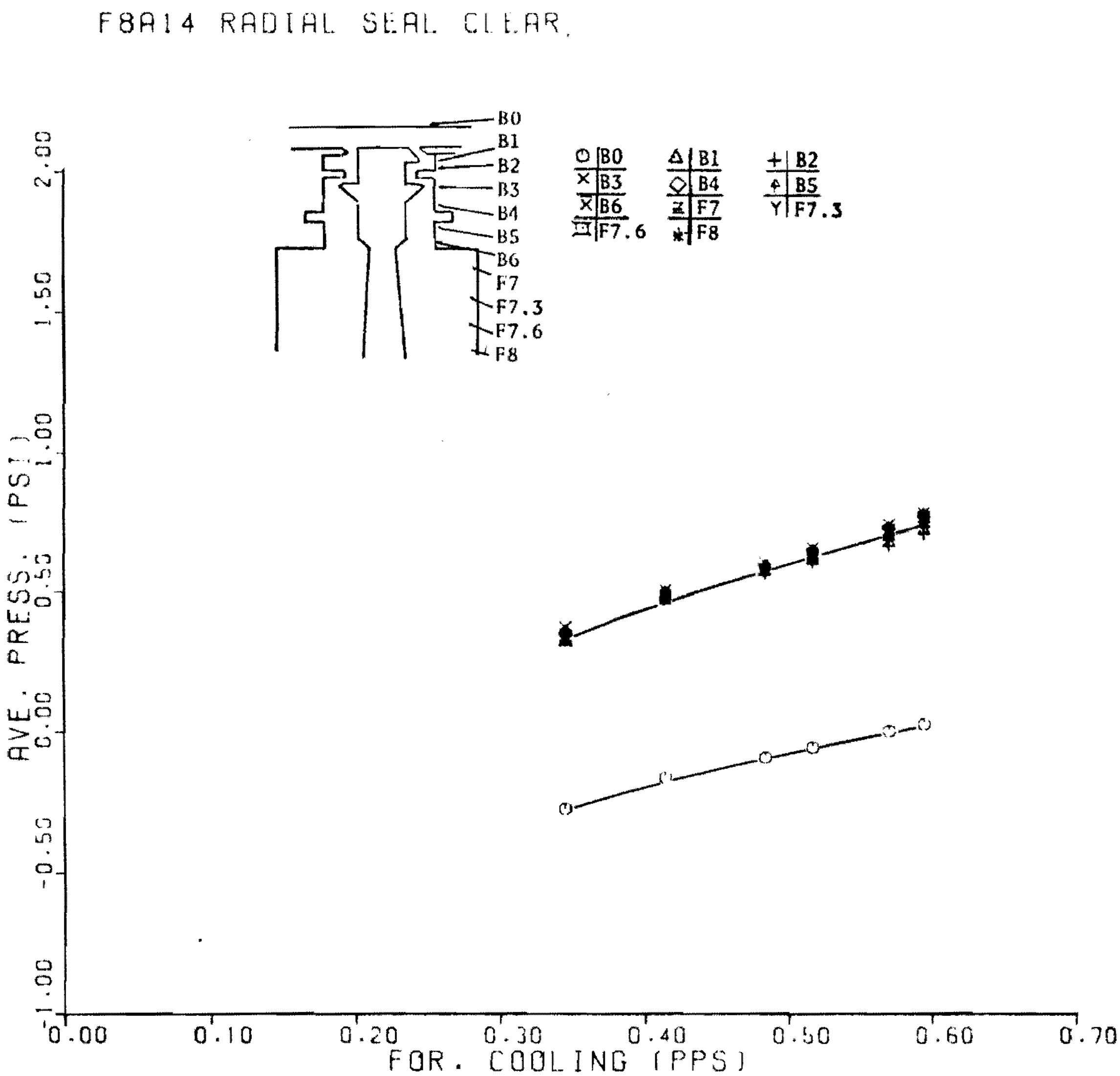


Figure AP-11A

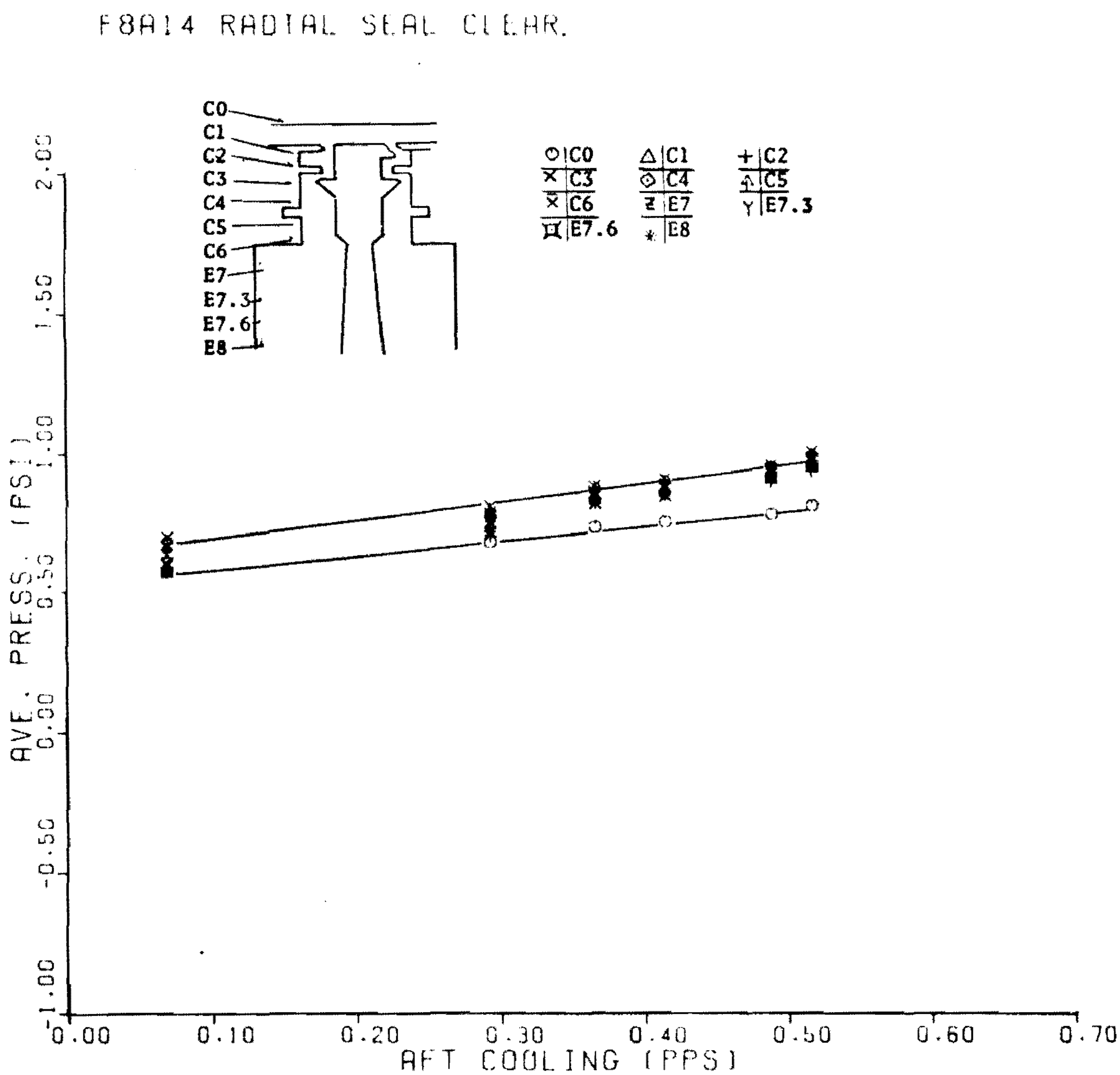


Figure AP-11B

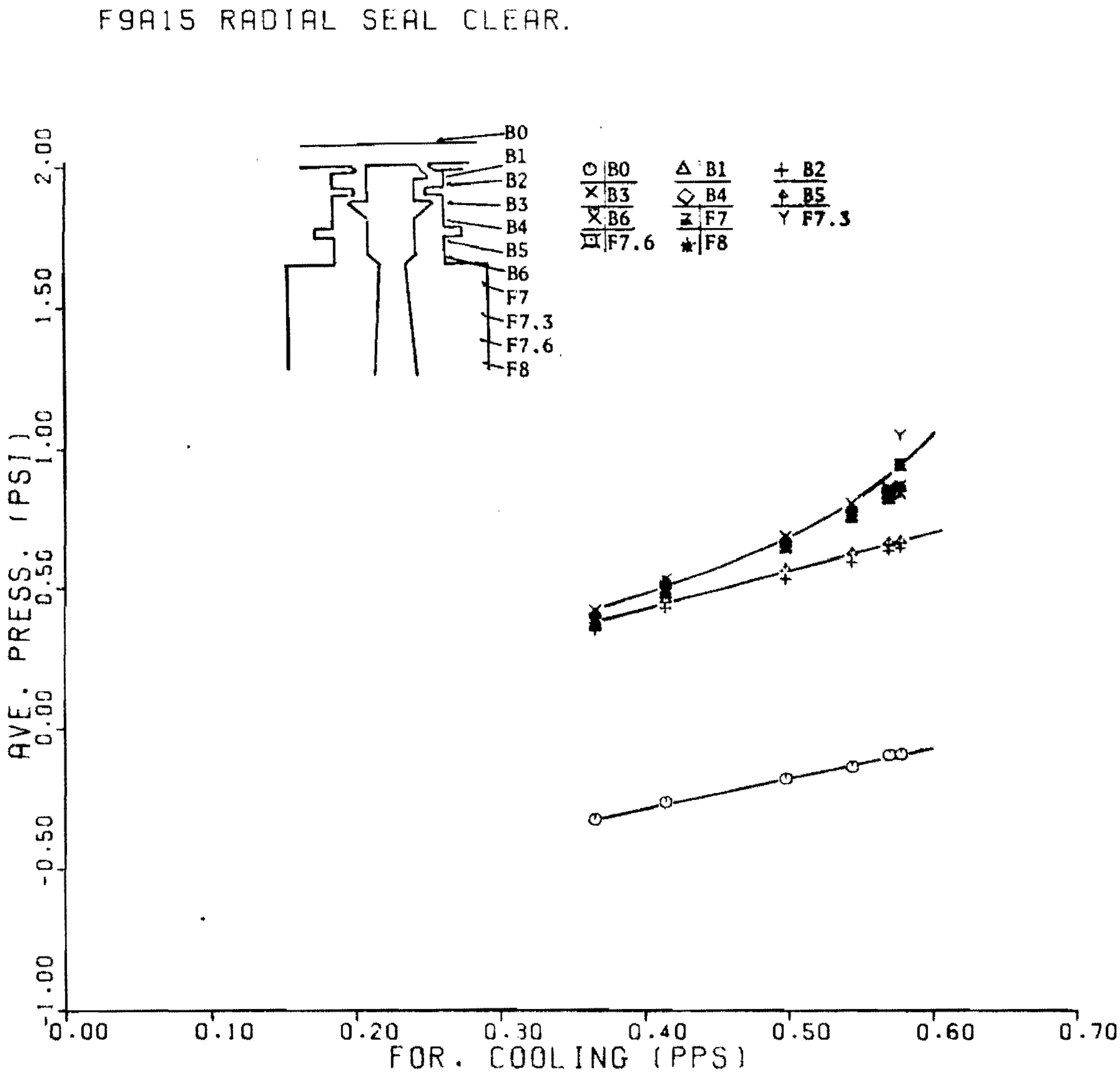


Figure AP-12A

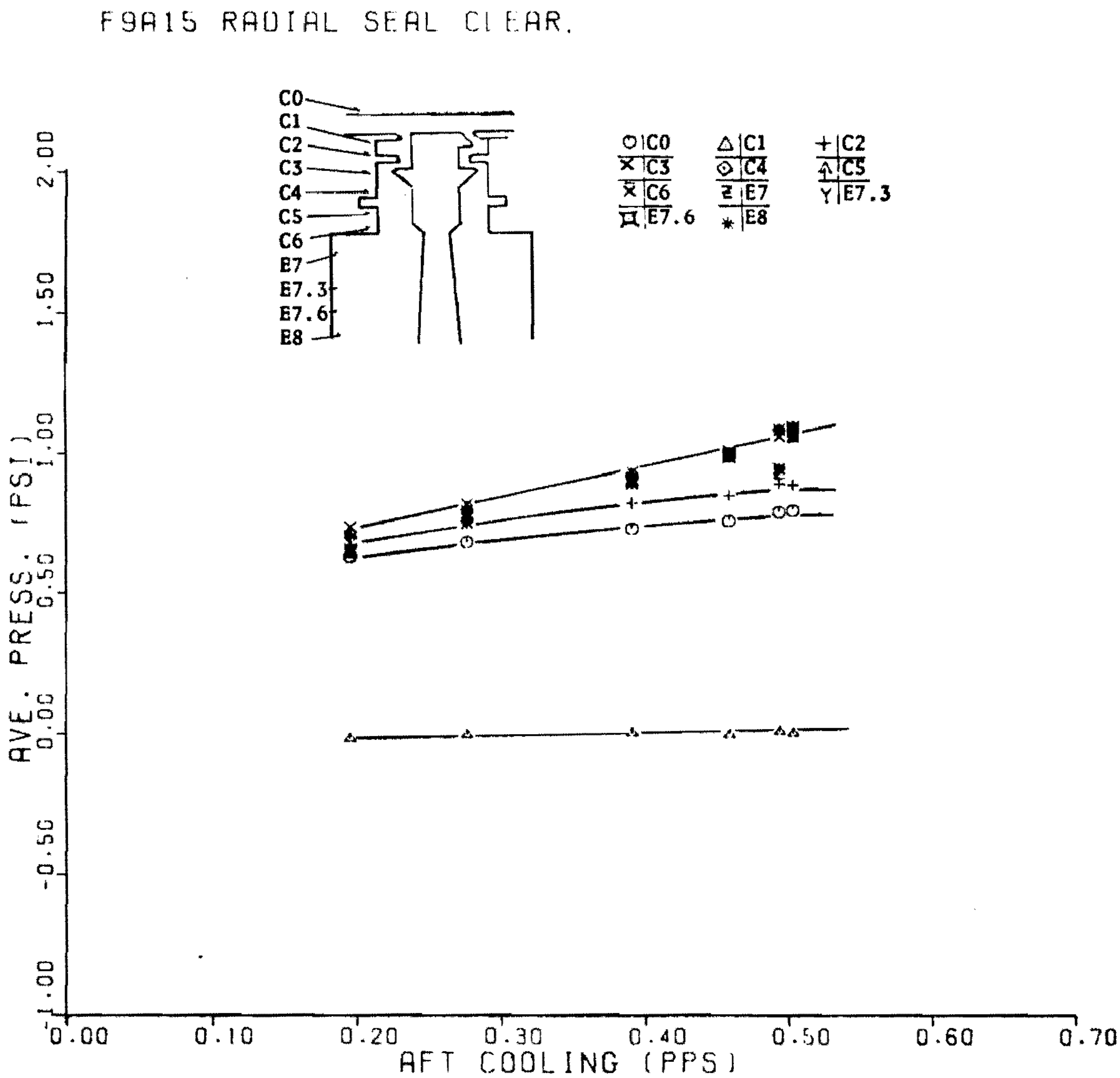


Figure AP-12B

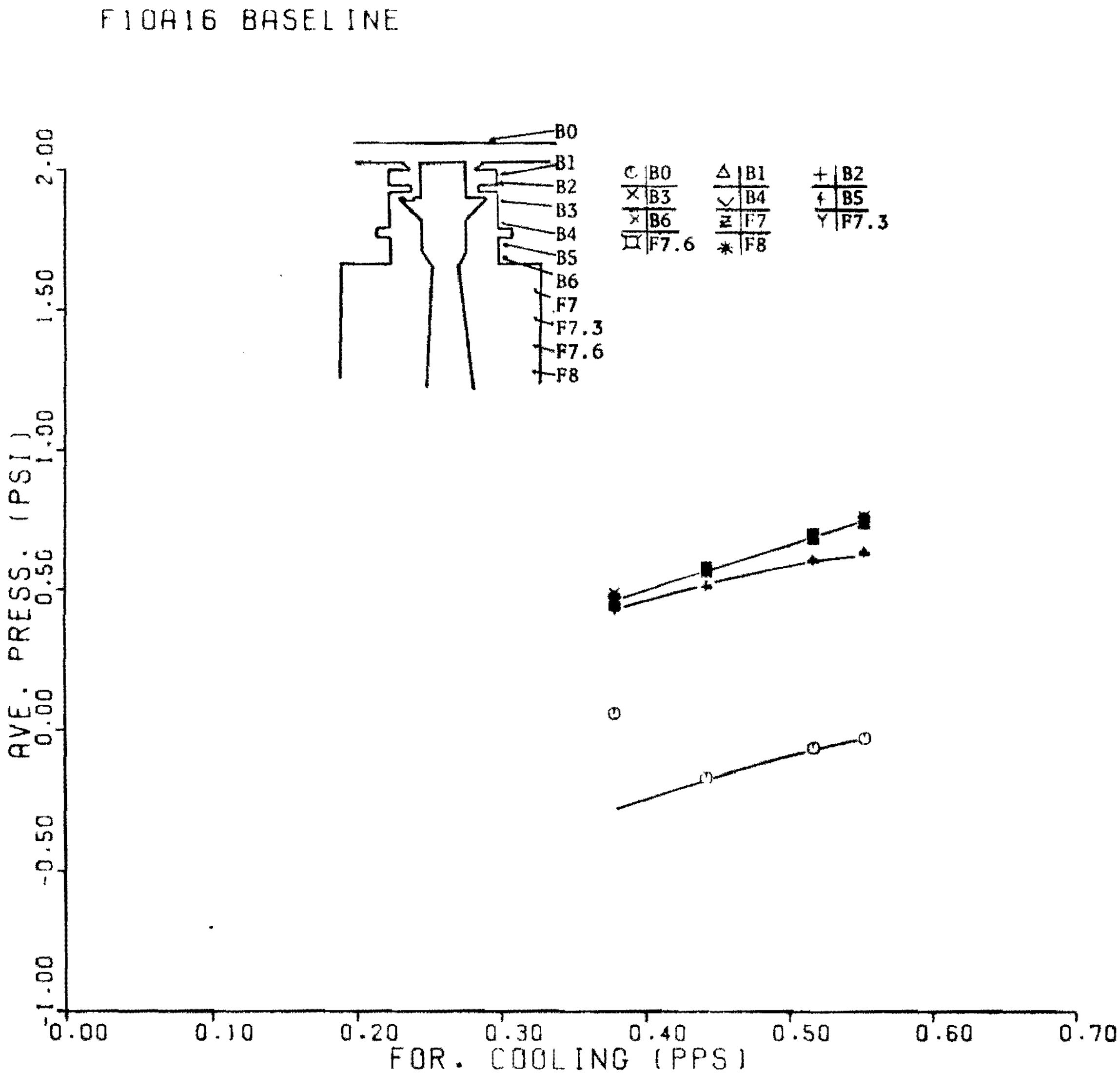


Figure AP-13A

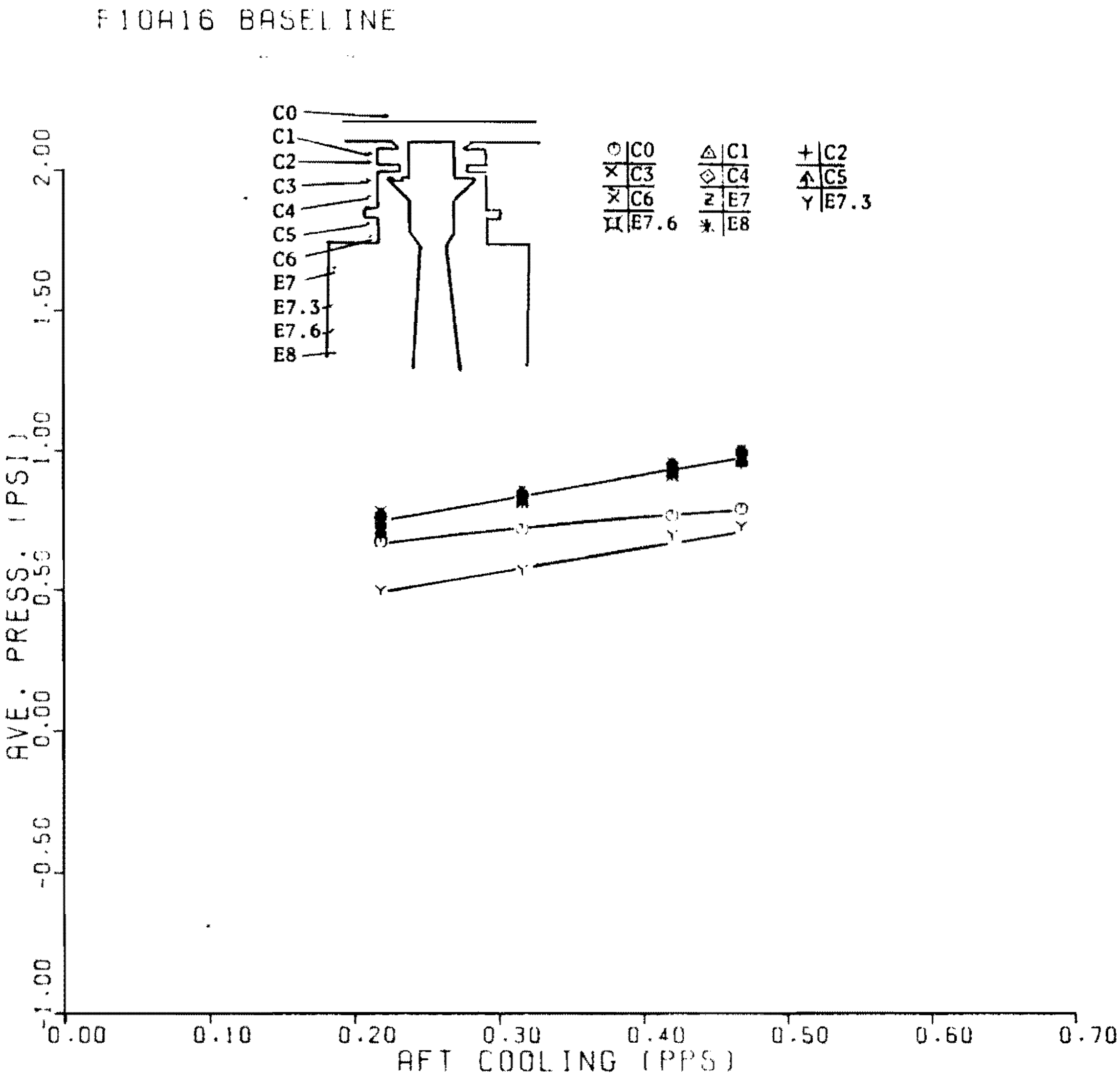


Figure AP-13B

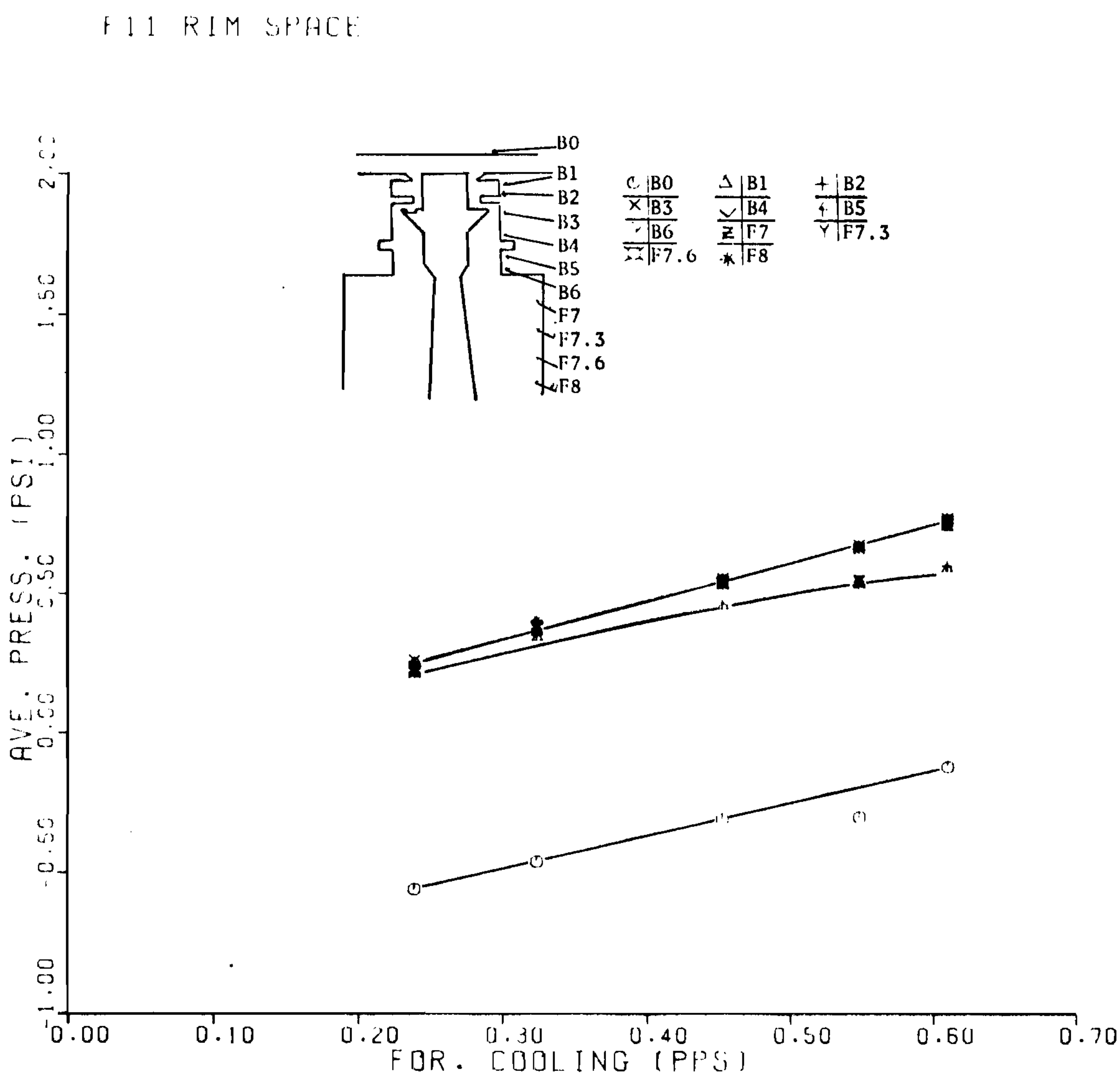

F11 RIM SPACE
B0
B1
B2
B3
B4
B5
B6
F7
F7.3
F7.6
F8
B0 B1 B2
B3 B4 B5
B6 F7 F7.3
F7.6 F8
AVE. PRESS. (PSI)
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00
0.00 0.10 0.20 0.30 0.40 0.50 0.60 0.70
FOR. COOLING (PPS)

Figure AP-14

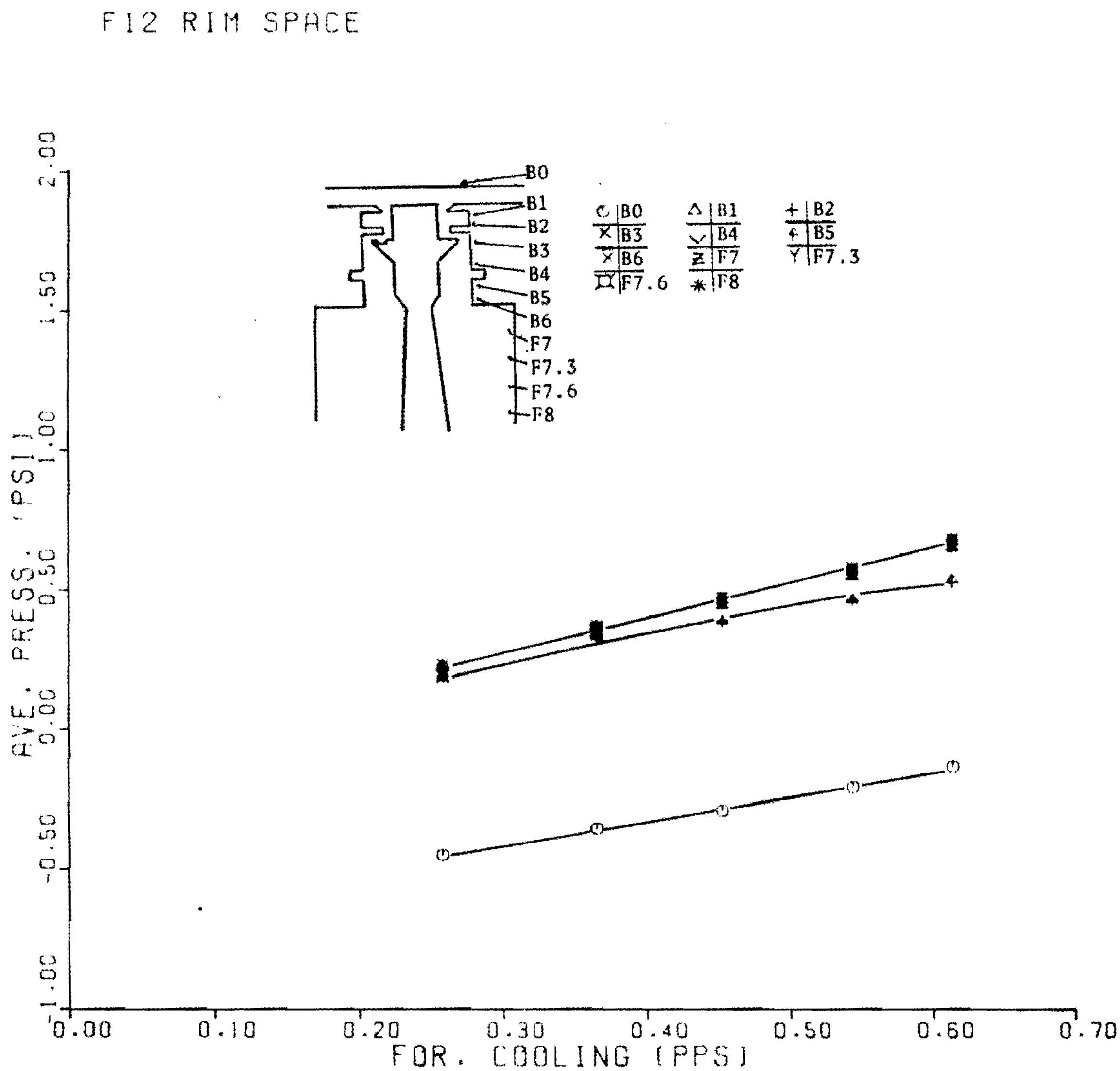

F12 RIM SPACE
B0
B1
B2
B3
B4
B5
B6
F7
F7.3
F7.6
F8
B0
B1
B2
B3
B4
B5
B6
F7
F7.3
F7.6
F8
AVE. PRESS. (PSI)
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
FOR. COOLING (PPS)

Figure AP-15

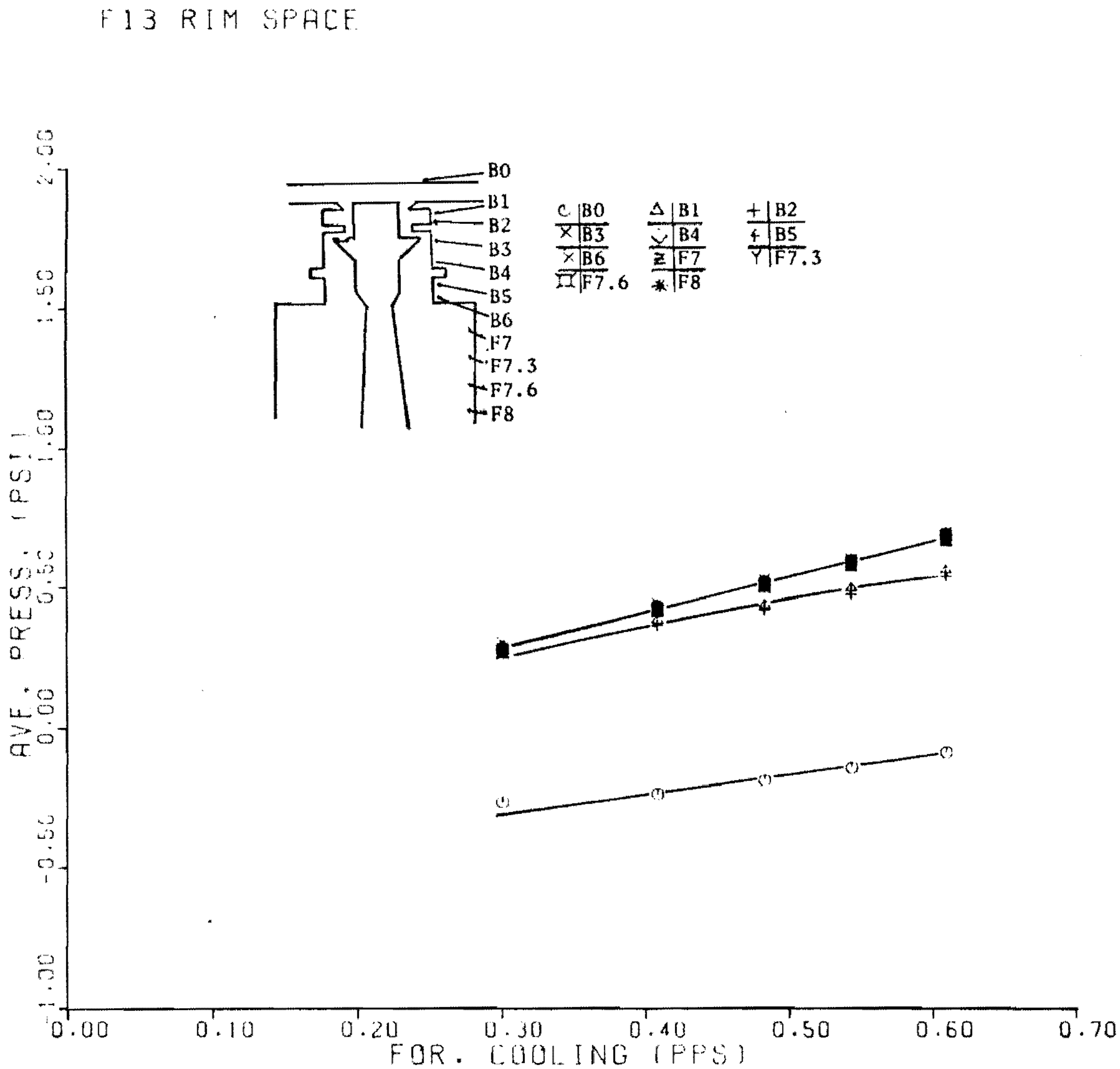

F13 RIM SPACE
B0
B1
B2
B3
B4
B5
B6
F7
F7.3
F7.6
F8
B0
B1
B2
B3
B4
B5
B6
F7
F7.3
F7.6
F8
AVE. PRESS. (PSI)
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
FOR. COOLING (PPS)

Figure AP-16

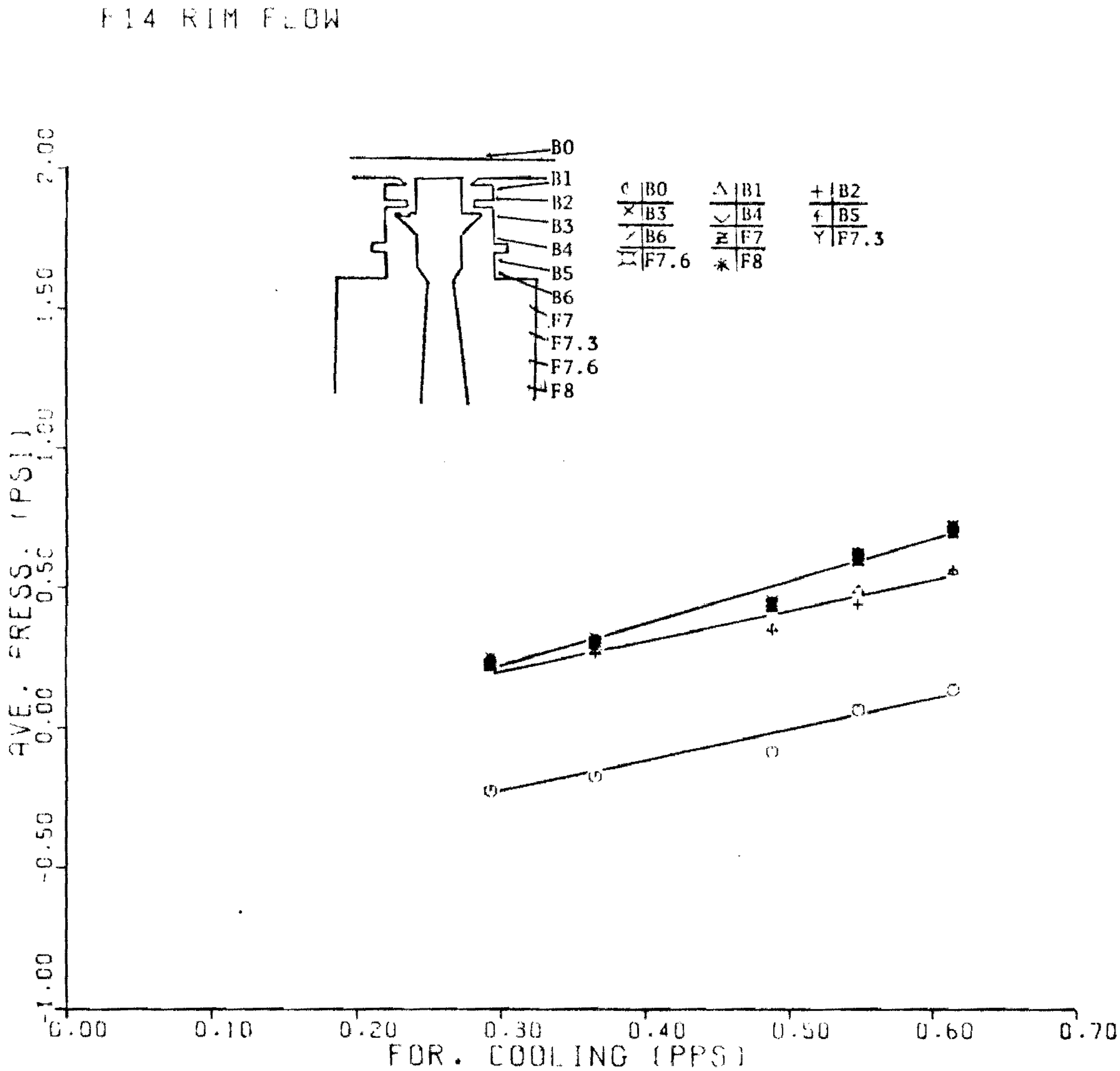
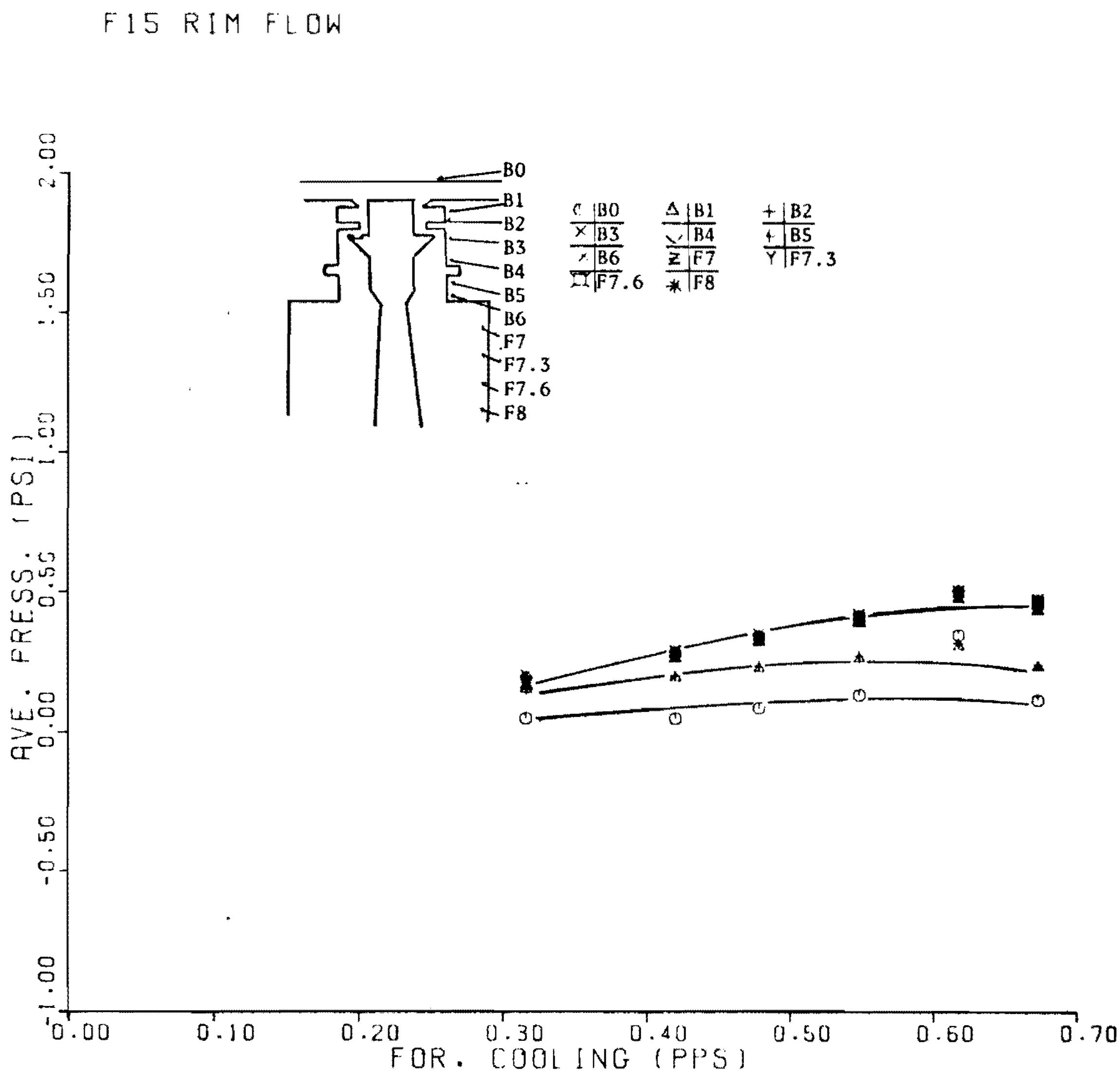

F14 RIM FLOW
B0
B1
B2
B3
B4
B5
B6
F7
F7.3
F7.6
F8
B0 B1 B2
B3 B4 B5
B6 F7 F7.3
F7.6 F8
AVE. PRESS. (PSI)
-1.00
-0.50
0.00
0.50
1.00
1.50
2.00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
FOR. COOLING (PPS)

Figure AP-17



F15 RIM FLOW
B0
B1
B2
B3
B4
B5
B6
F7
F7.3
F7.6
F8
B0
B1
B2
B3
B4
B5
B6
F7
F7.3
F7.6
F8
AVE. PRESS. (PSI)
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
FOR. COOLING (PPS)

Figure AP-18

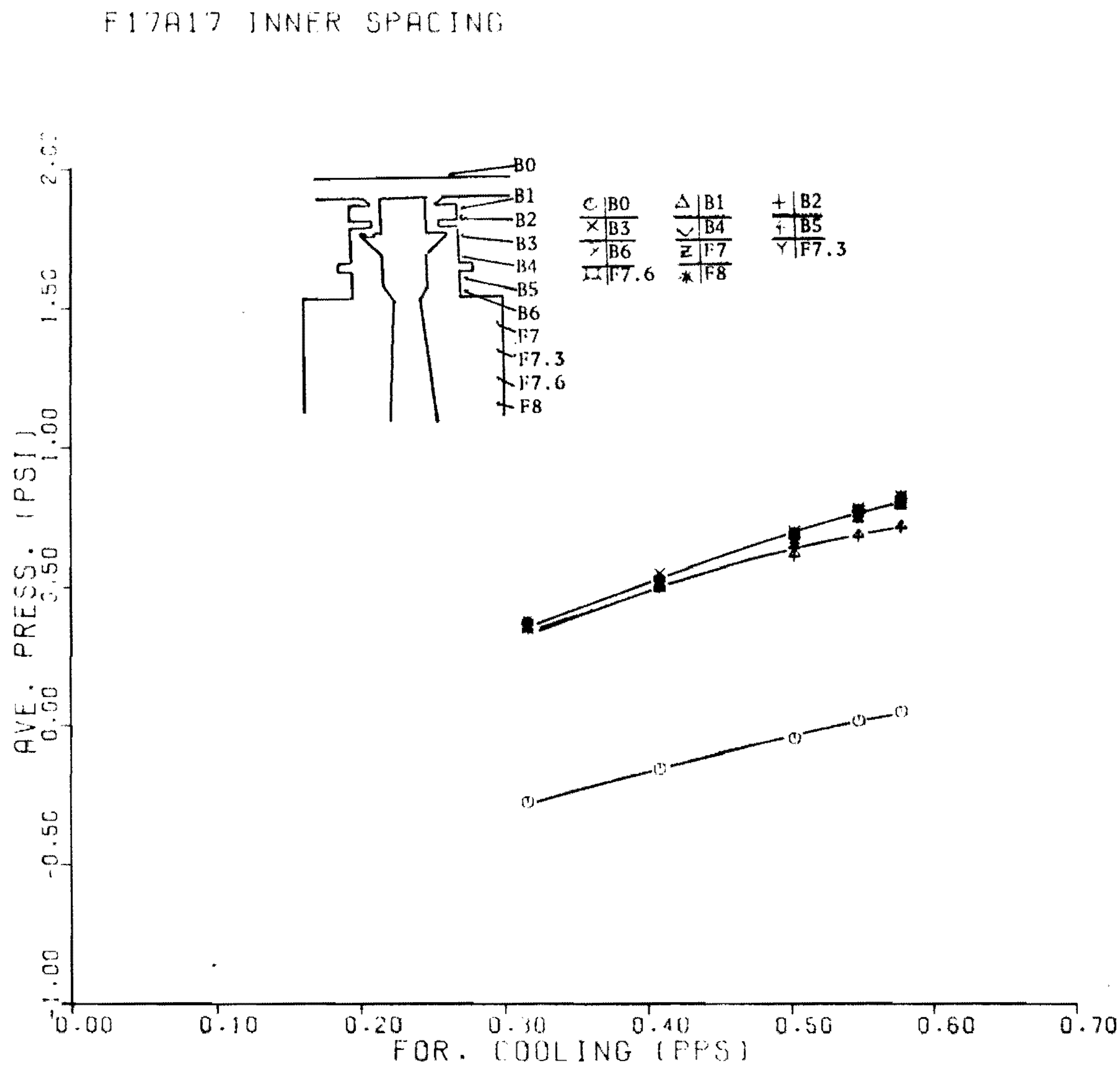


Figure AP-19A

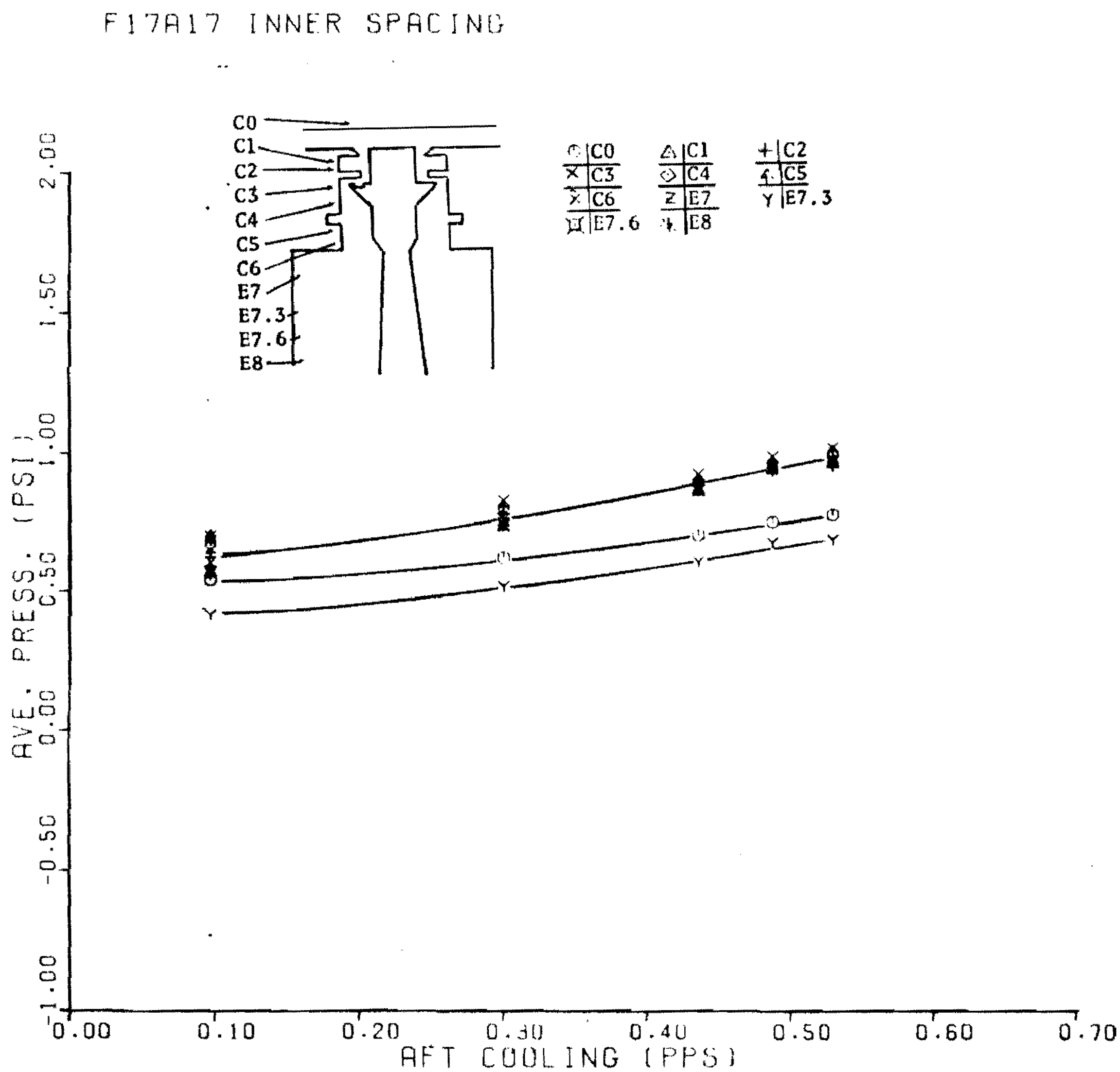


Figure AP-19B

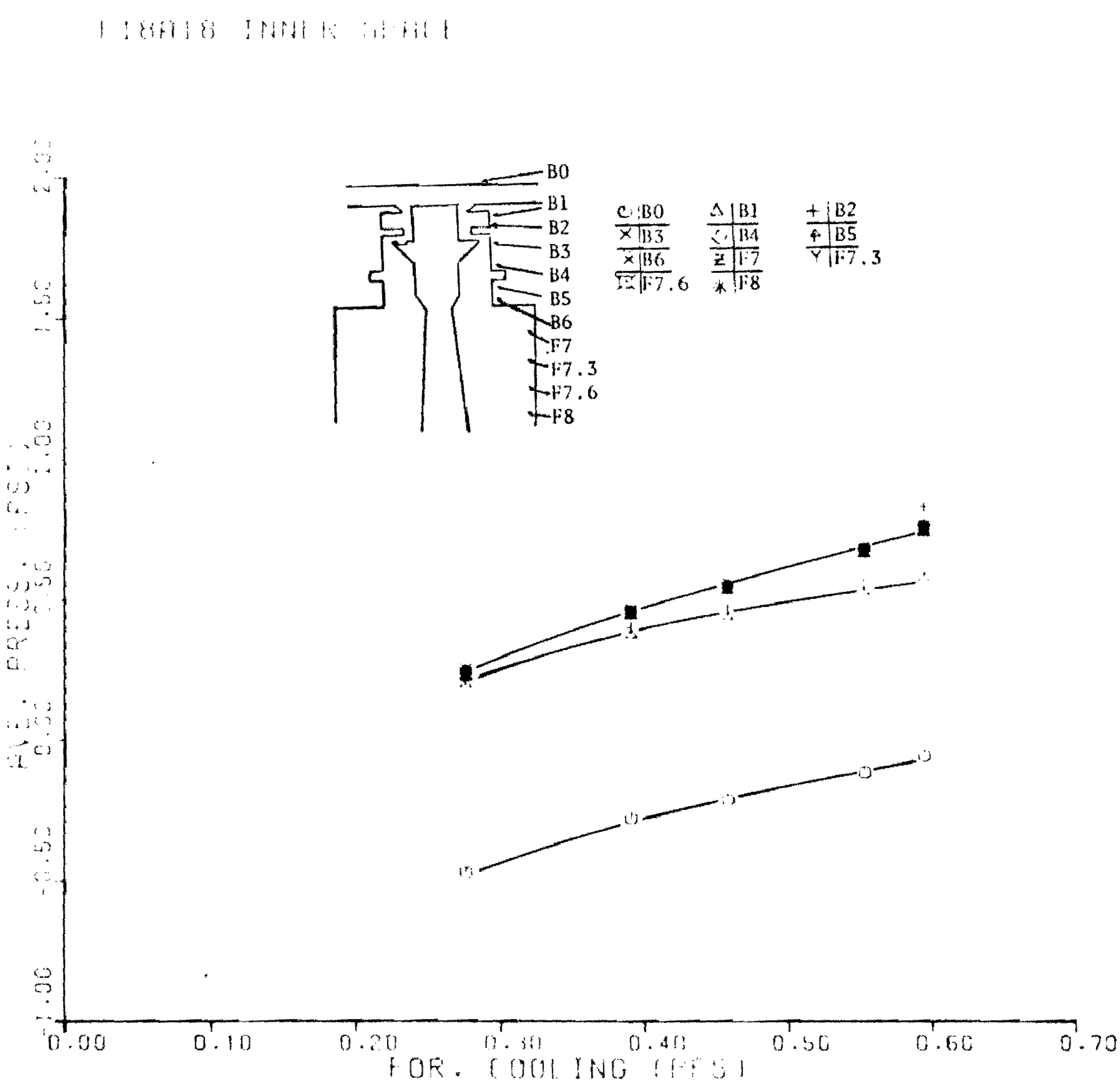


Figure AP-20A

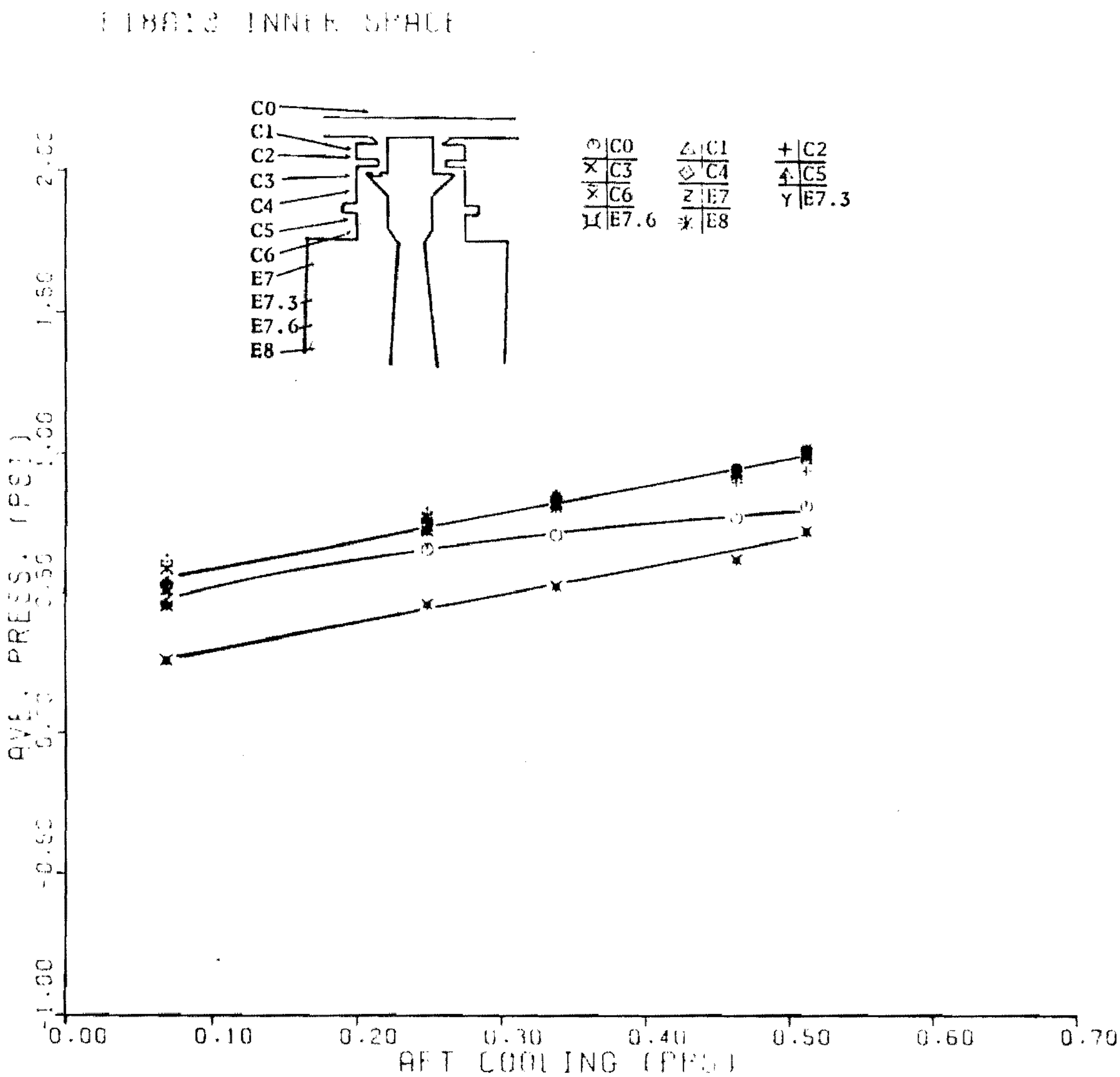


Figure AP-20B

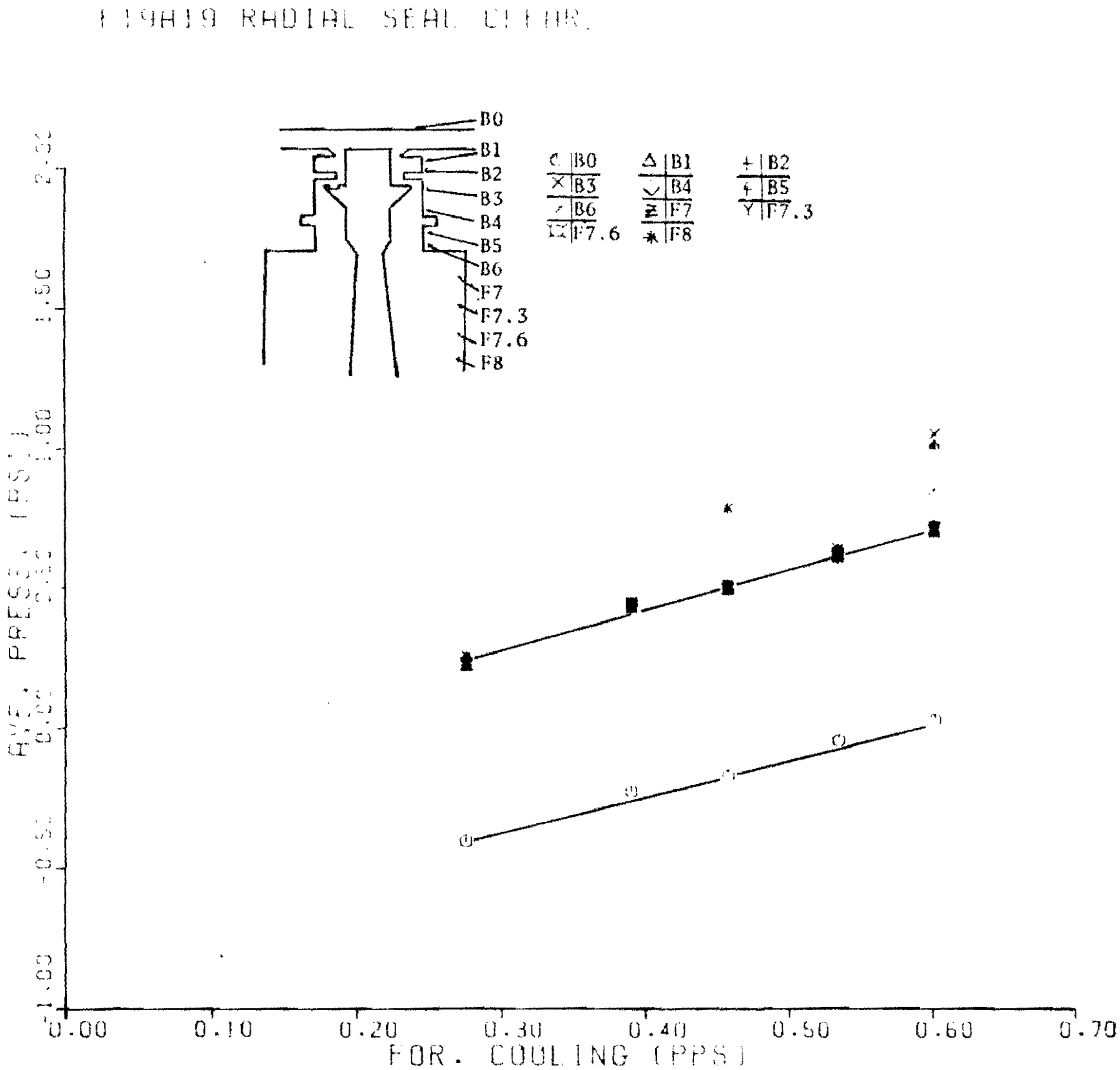


Figure AP-21A

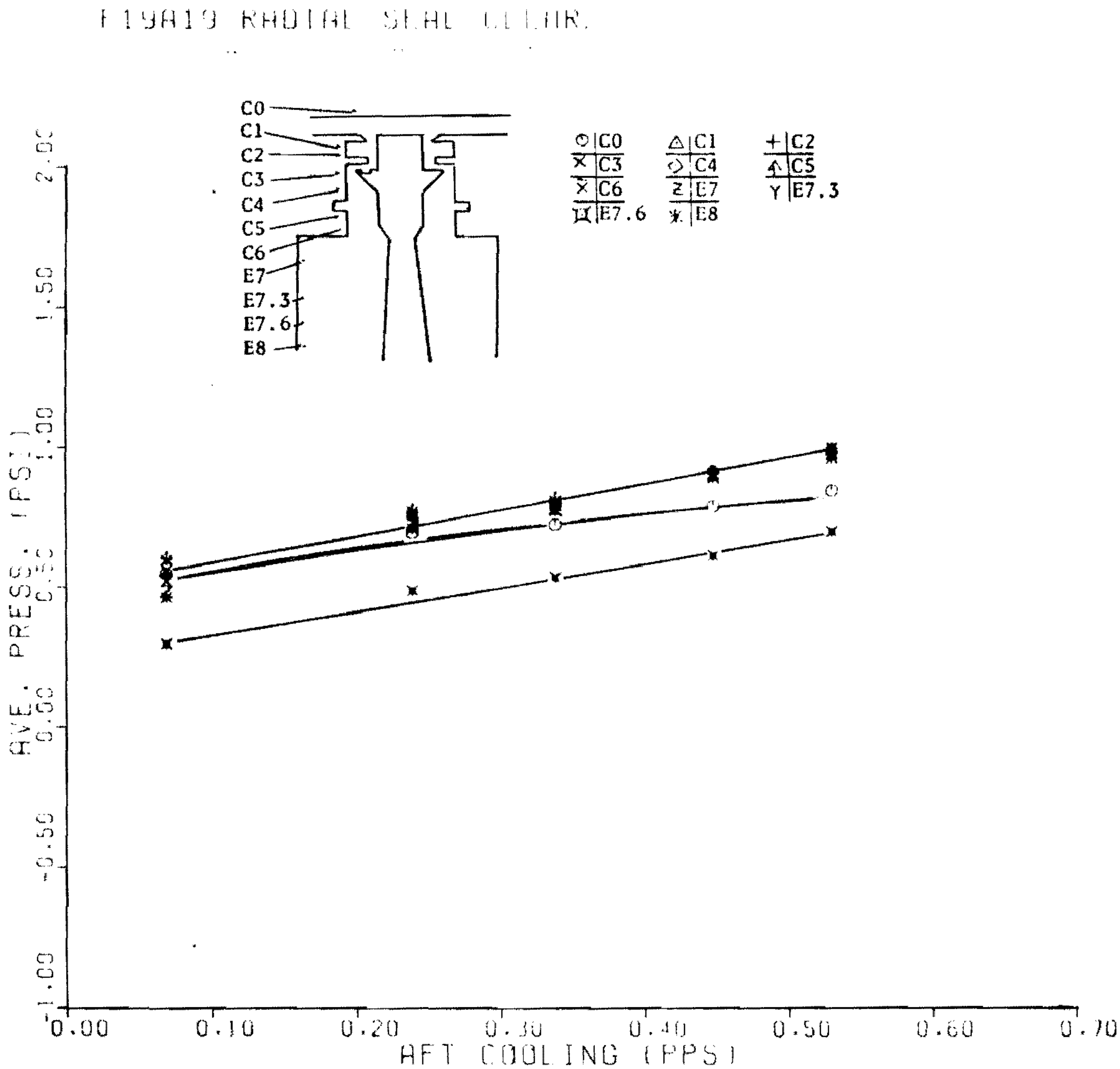


Figure AP-21B

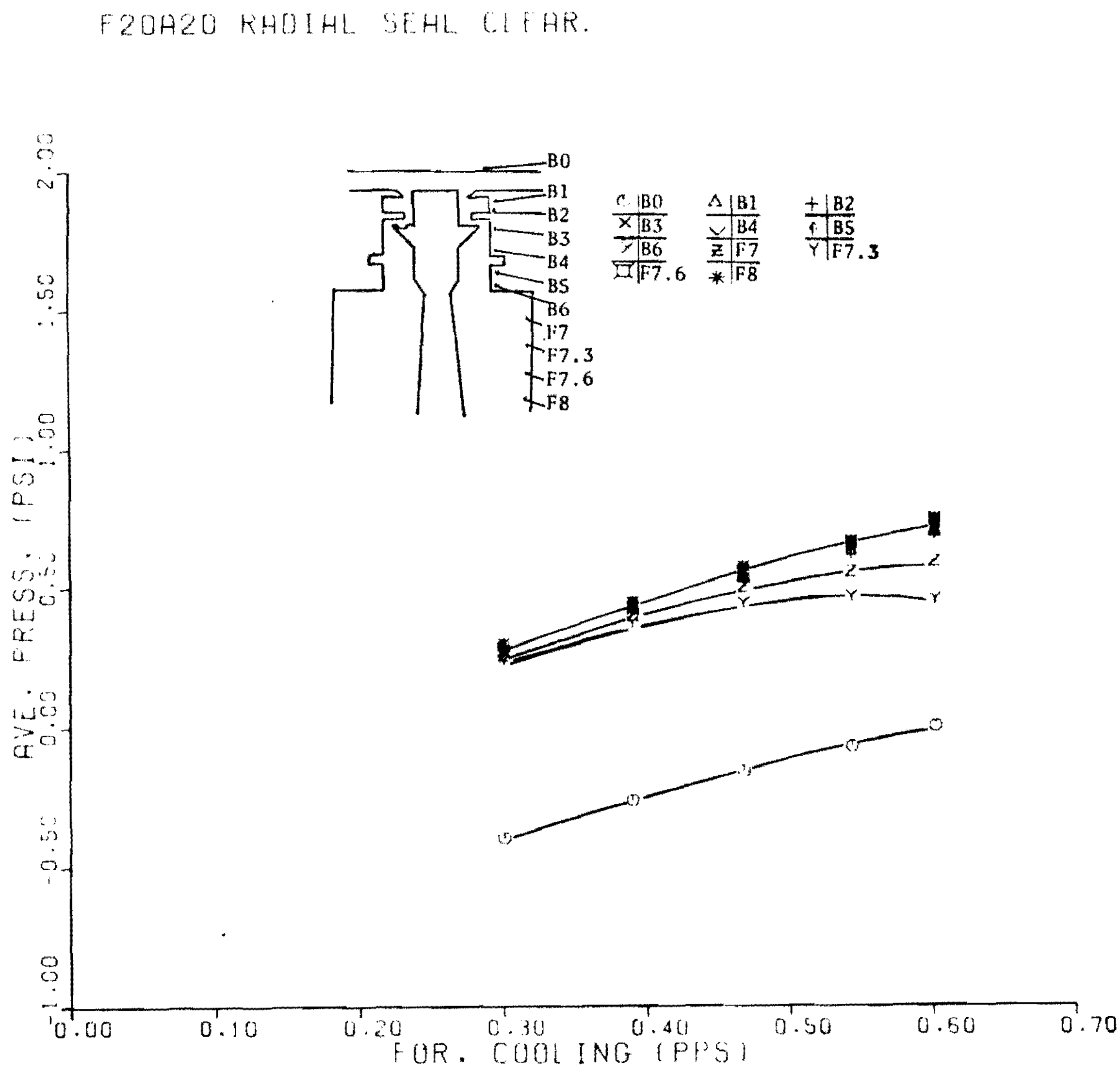


Figure AP-22A

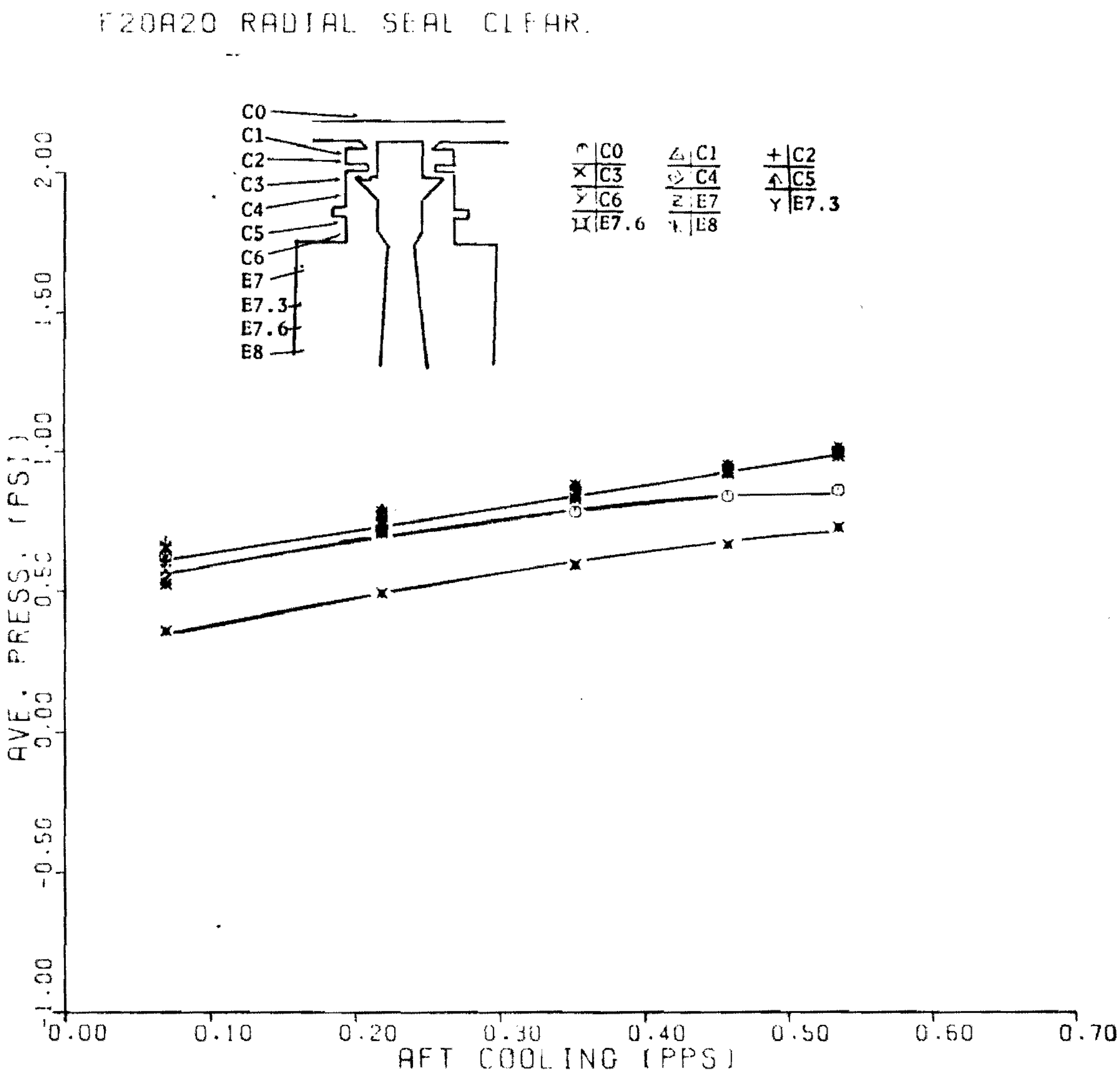


Figure AP-22B

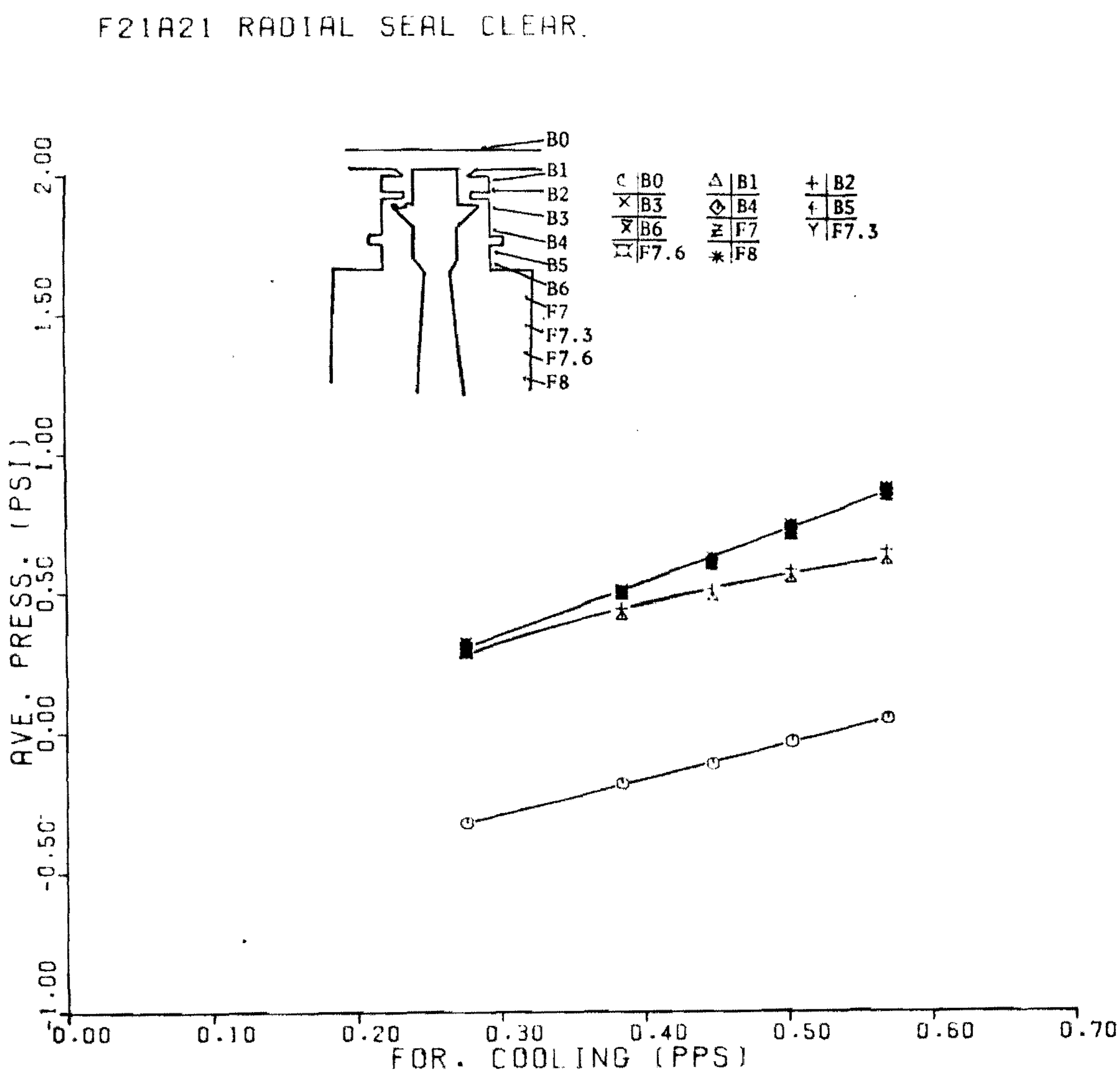


Figure AP-23A

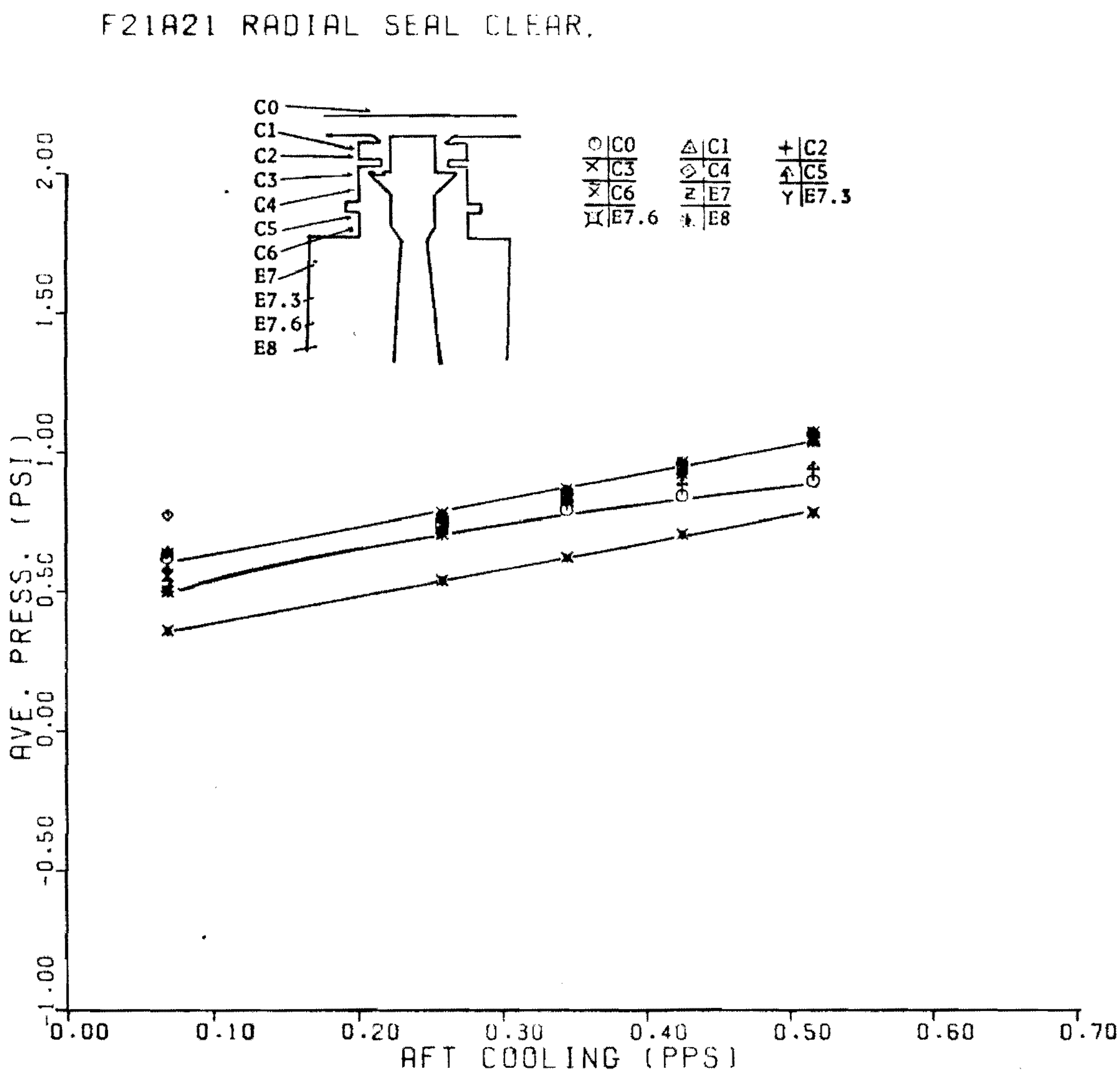


Figure AP-23B

APPENDIX IIIC

FIGURES AF1 - AF23

SEAL FLOW PLOT

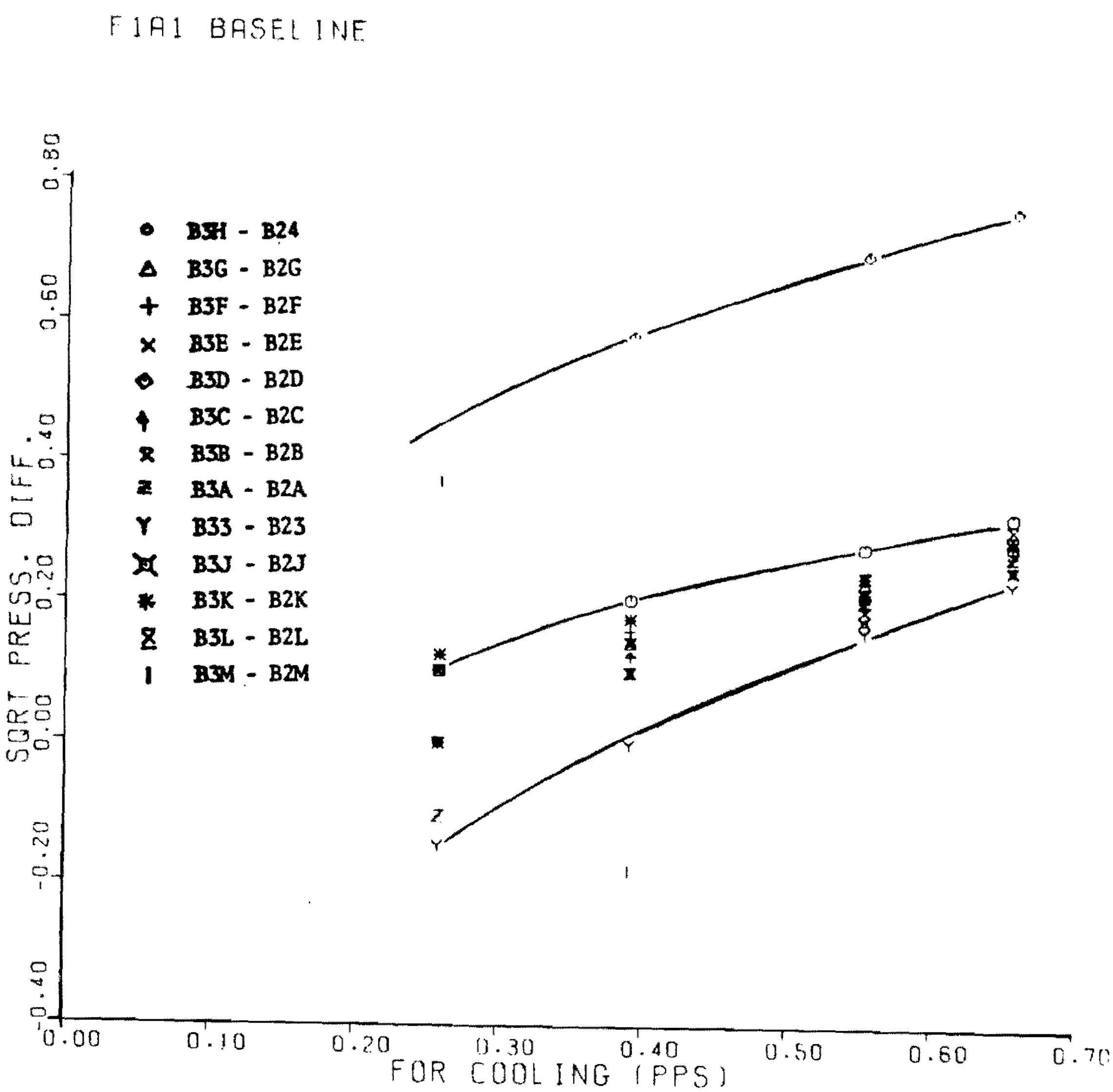

F1A1 BASELINE
SQRT PRESS. DIFF.
FOR COOLING (PPS)
B3H - B24
B3G - B2G
B3F - B2F
B3E - B2E
B3D - B2D
B3C - B2C
B3B - B2B
B3A - B2A
B33 - B23
B3J - B2J
B3K - B2K
B3L - B2L
B3M - B2M
0.80
0.60
0.40
0.20
0.00
-0.20
-0.40
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70

Figure AF1-A

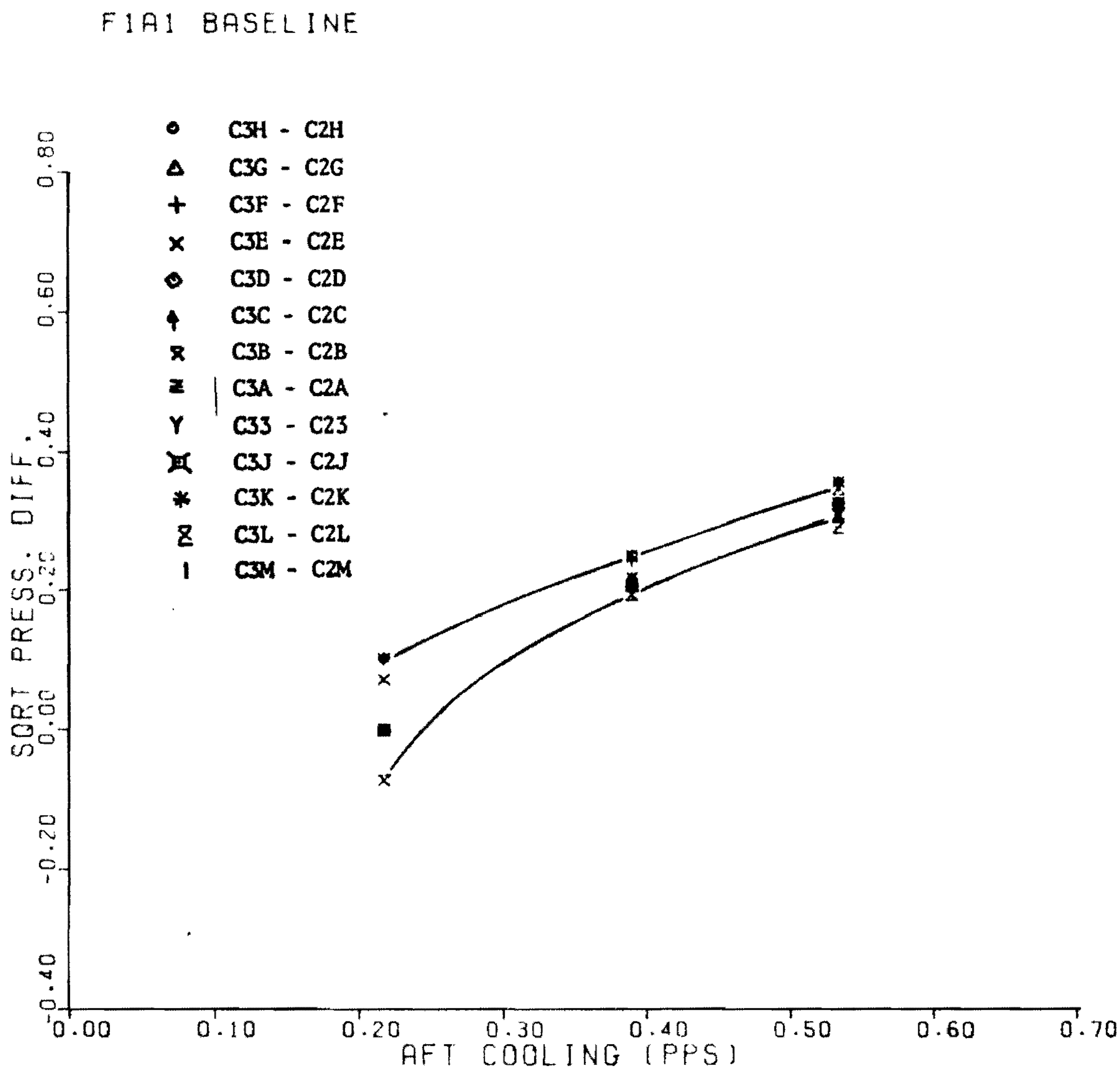

F1A1 BASELINE
C3H - C2H
C3G - C2G
C3F - C2F
C3E - C2E
C3D - C2D
C3C - C2C
C3B - C2B
C3A - C2A
C33 - C23
C3J - C2J
C3K - C2K
C3L - C2L
C3M - C2M
SQRT PRESS. DIFF.
0.80
0.60
0.40
0.20
0.00
-0.20
-0.40
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
AFT COOLING (PPS)

Figure AF-1B

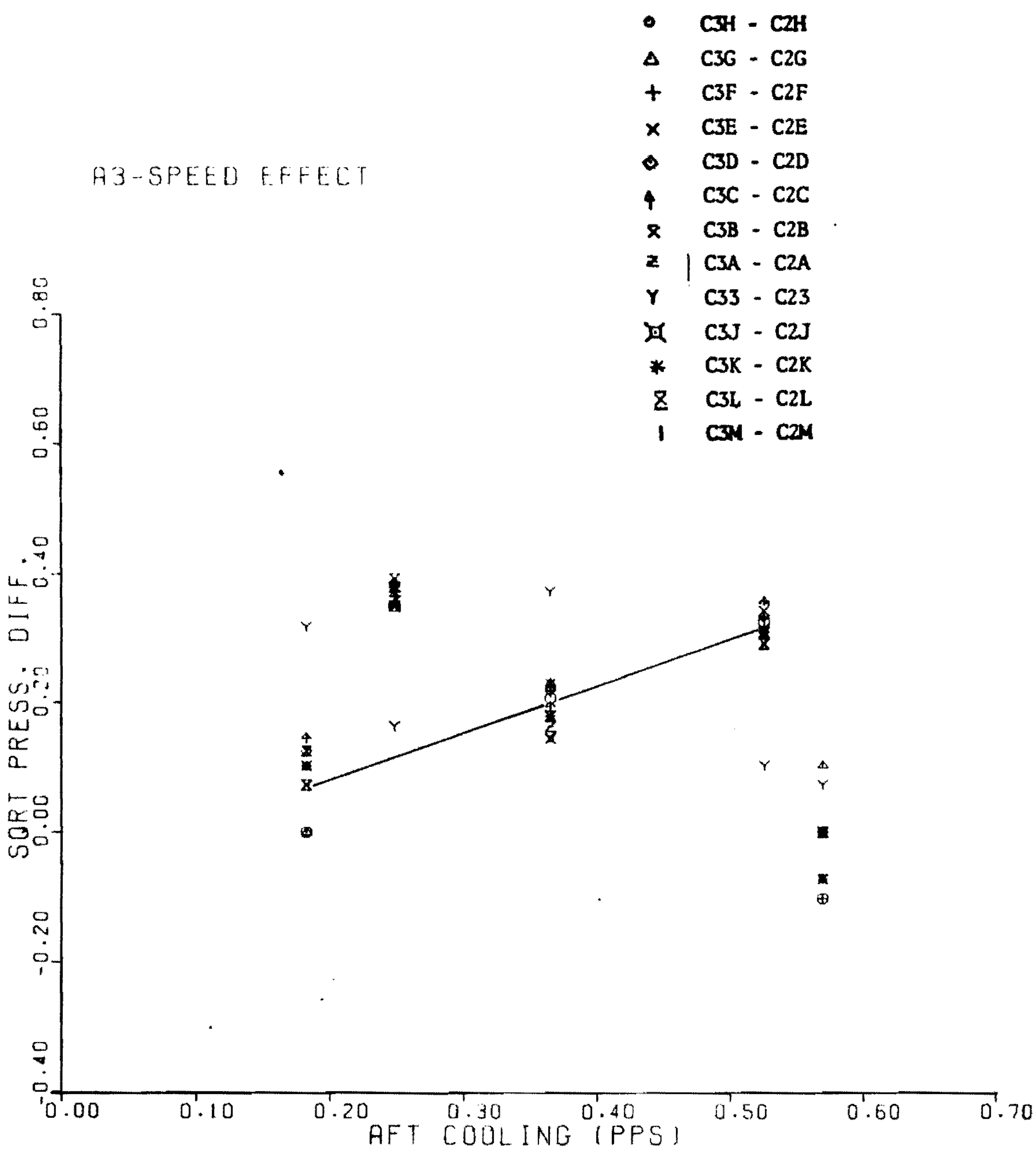

A3-SPEED EFFECT
C3H - C2H
C3G - C2G
C3F - C2F
C3E - C2E
C3D - C2D
C3C - C2C
C3B - C2B
C3A - C2A
C33 - C23
C3J - C2J
C3K - C2K
C3L - C2L
C3M - C2M
SQRT PRESS. DIFF.
0.80
0.60
0.40
0.20
0.00
-0.20
-0.40
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
AFT COOLING (PPS)

Figure AF-2

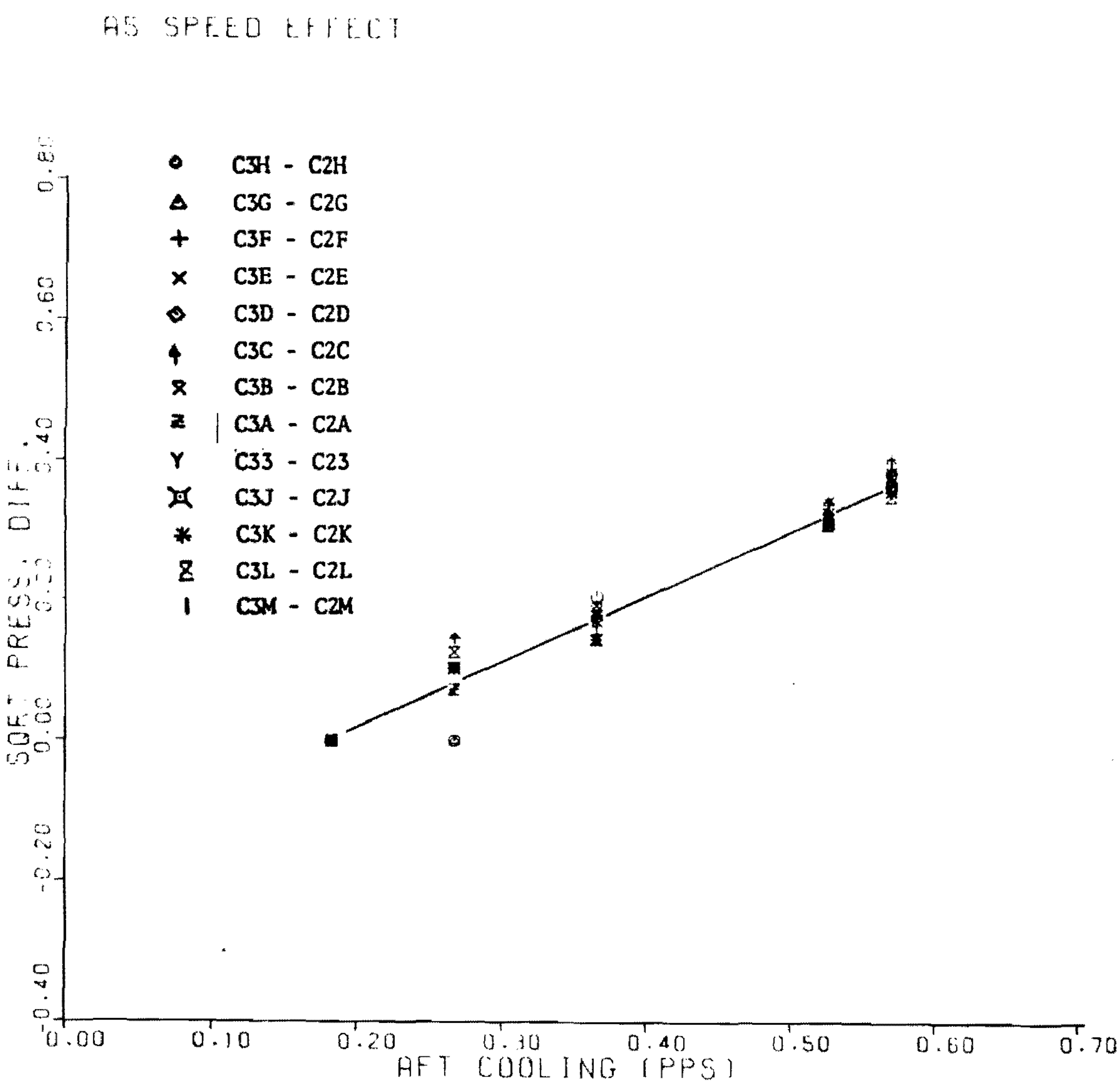
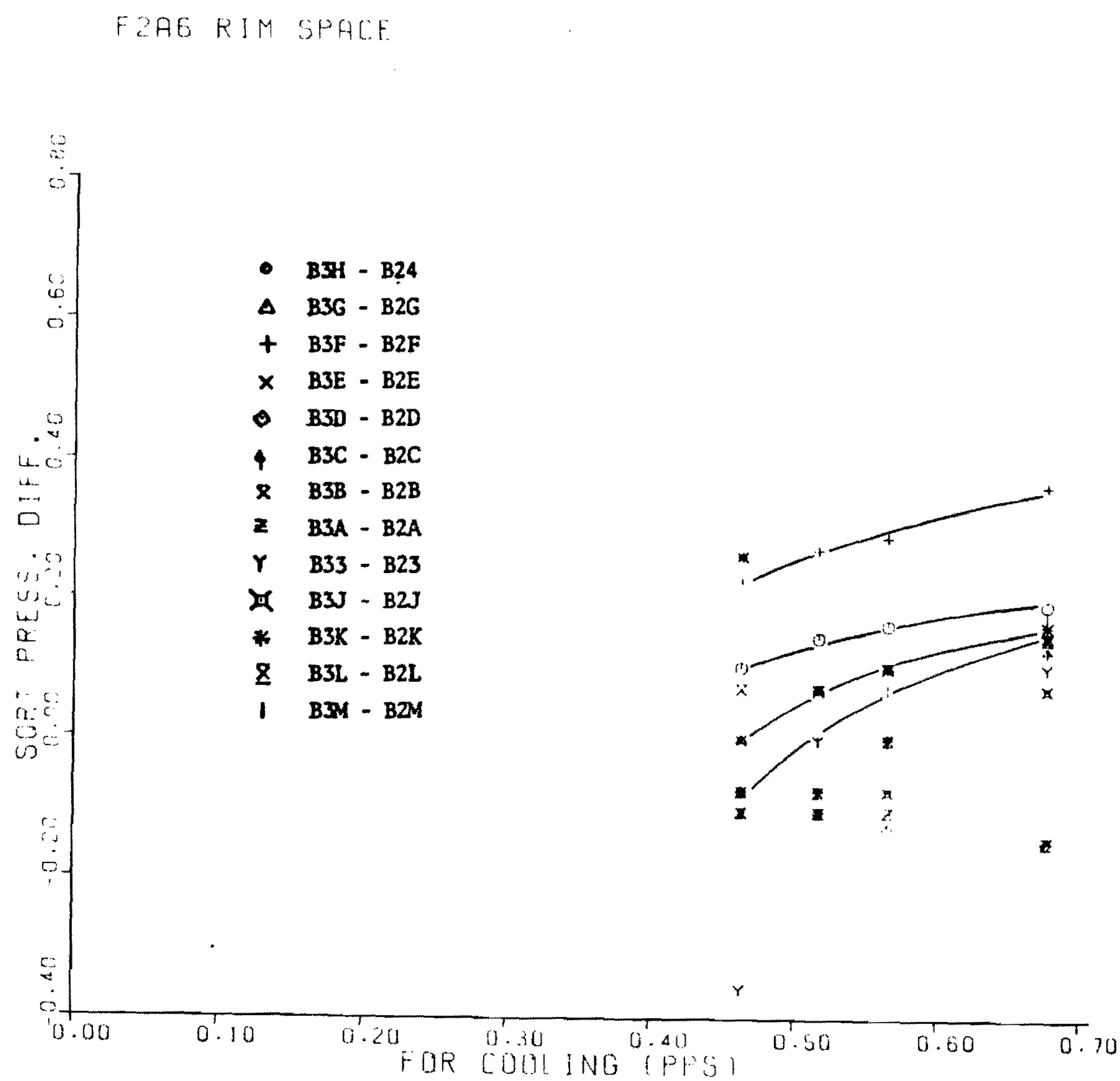
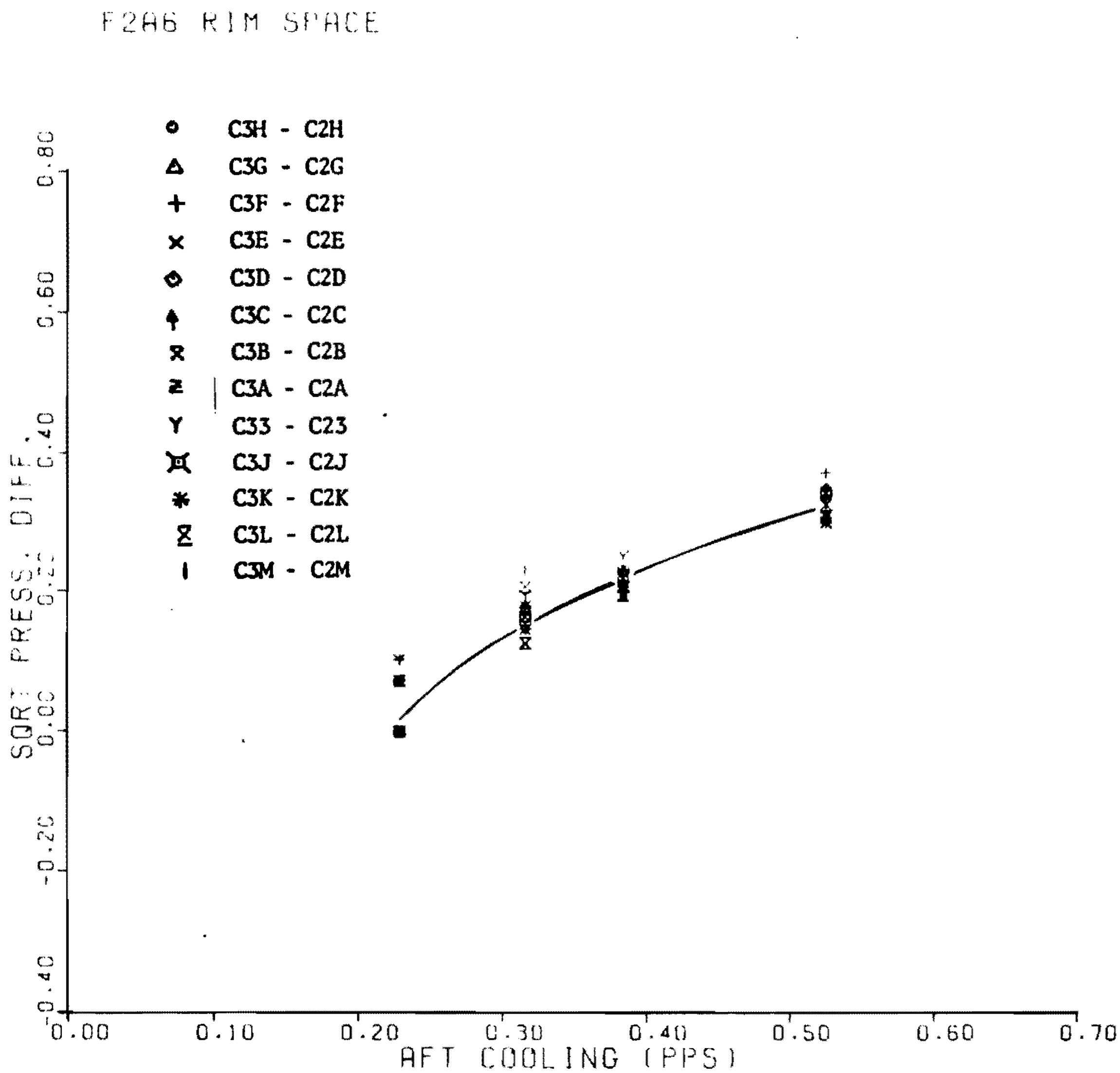

A5 SPEED EFFECT
C3H - C2H
C3G - C2G
C3F - C2F
C3E - C2E
C3D - C2D
C3C - C2C
C3B - C2B
C3A - C2A
C33 - C23
C3J - C2J
C3K - C2K
C3L - C2L
C3M - C2M
SOFT PRESS. DIFF.
0.80
0.60
0.40
0.20
0.00
-0.20
-0.40
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
AFT COOLING (PPS)

Figure AF-3



F2A6 RIM SPACE
B3H - B24
B3G - B2G
B3F - B2F
B3E - B2E
B3D - B2D
B3C - B2C
B3B - B2B
B3A - B2A
B33 - B23
B3J - B2J
B3K - B2K
B3L - B2L
B3M - B2M
SORT PRESS. DIFF.
FOR COOLING (PPS)

Figure AF-4A



F2A6 RIM SPACE
C3H - C2H
C3G - C2G
C3F - C2F
C3E - C2E
C3D - C2D
C3C - C2C
C3B - C2B
C3A - C2A
C33 - C23
C3J - C2J
C3K - C2K
C3L - C2L
C3M - C2M
SQRT PRESS. DIFF.
0.80
0.60
0.40
0.20
0.00
-0.20
-0.40
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
AFT COOLING (PPS)

Figure AF-4B

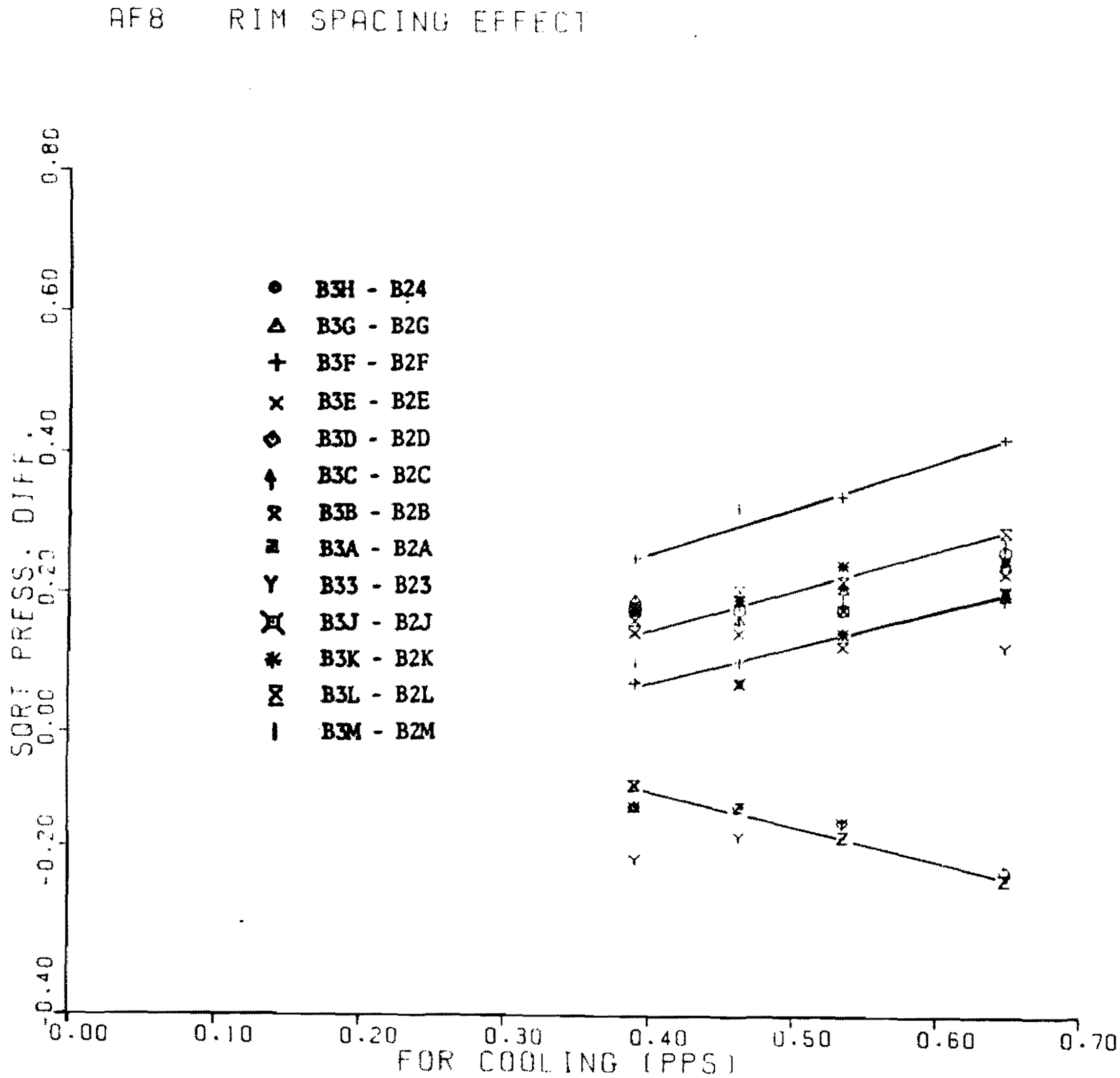

AF8 RIM SPACING EFFECT
B3H - B24
B3G - B2G
B3F - B2F
B3E - B2E
B3D - B2D
B3C - B2C
B3B - B2B
B3A - B2A
B33 - B23
B3J - B2J
B3K - B2K
B3L - B2L
B3M - B2M
SORT PRESS. DIFF.
FOR COOLING (PPS)
-0.40
-0.20
0.00
0.20
0.40
0.60
0.80
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70

Figure AF-5A

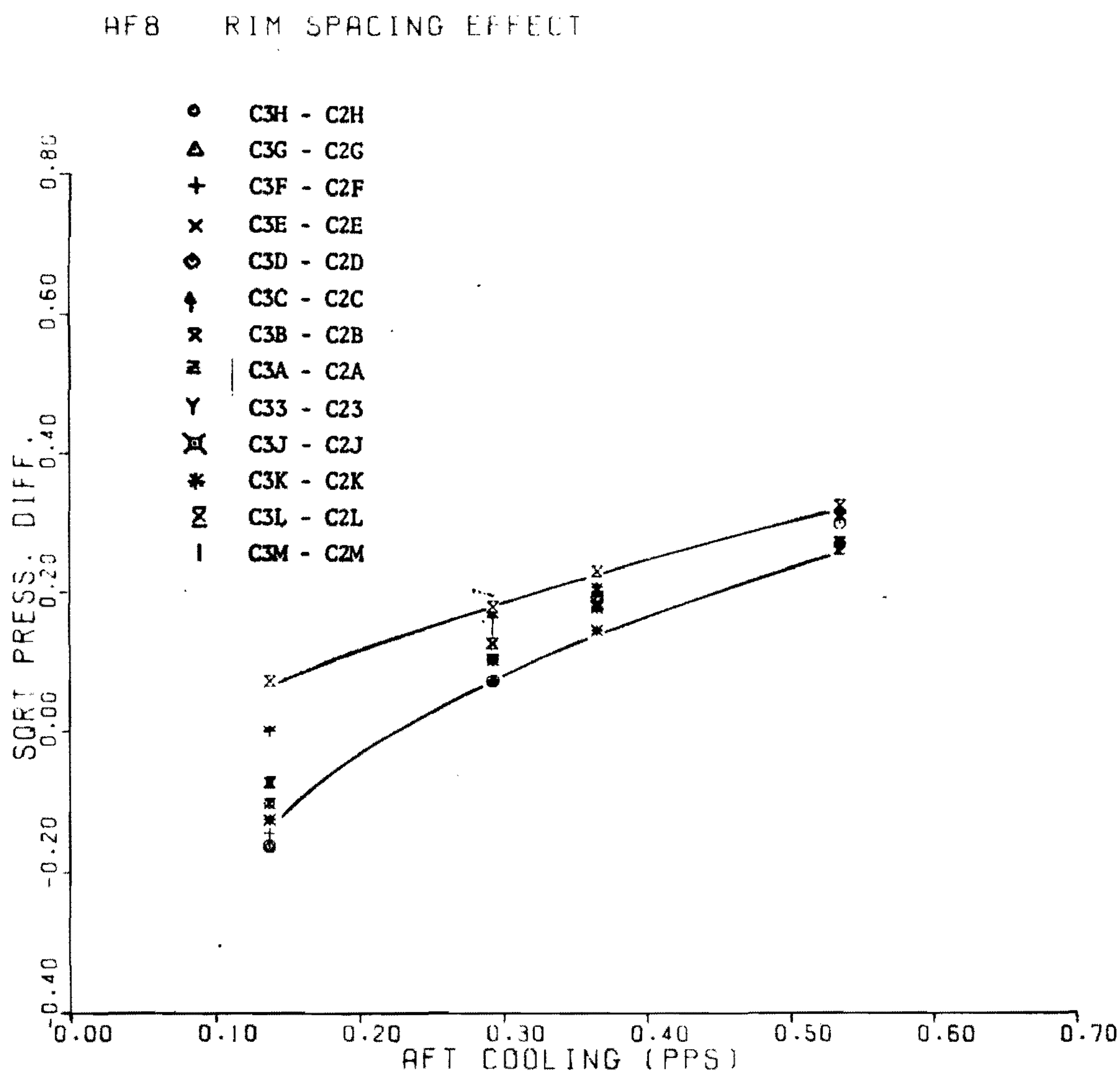

AF8 RIM SPACING EFFECT
C3H - C2H
C3G - C2G
C3F - C2F
C3E - C2E
C3D - C2D
C3C - C2C
C3B - C2B
C3A - C2A
C33 - C23
C3J - C2J
C3K - C2K
C3L - C2L
C3M - C2M
SQRT PRESS. DIFF.
AFT COOLING (PPS)
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
-0.40
-0.20
0.00
0.20
0.40
0.60
0.80

Figure AF-5B

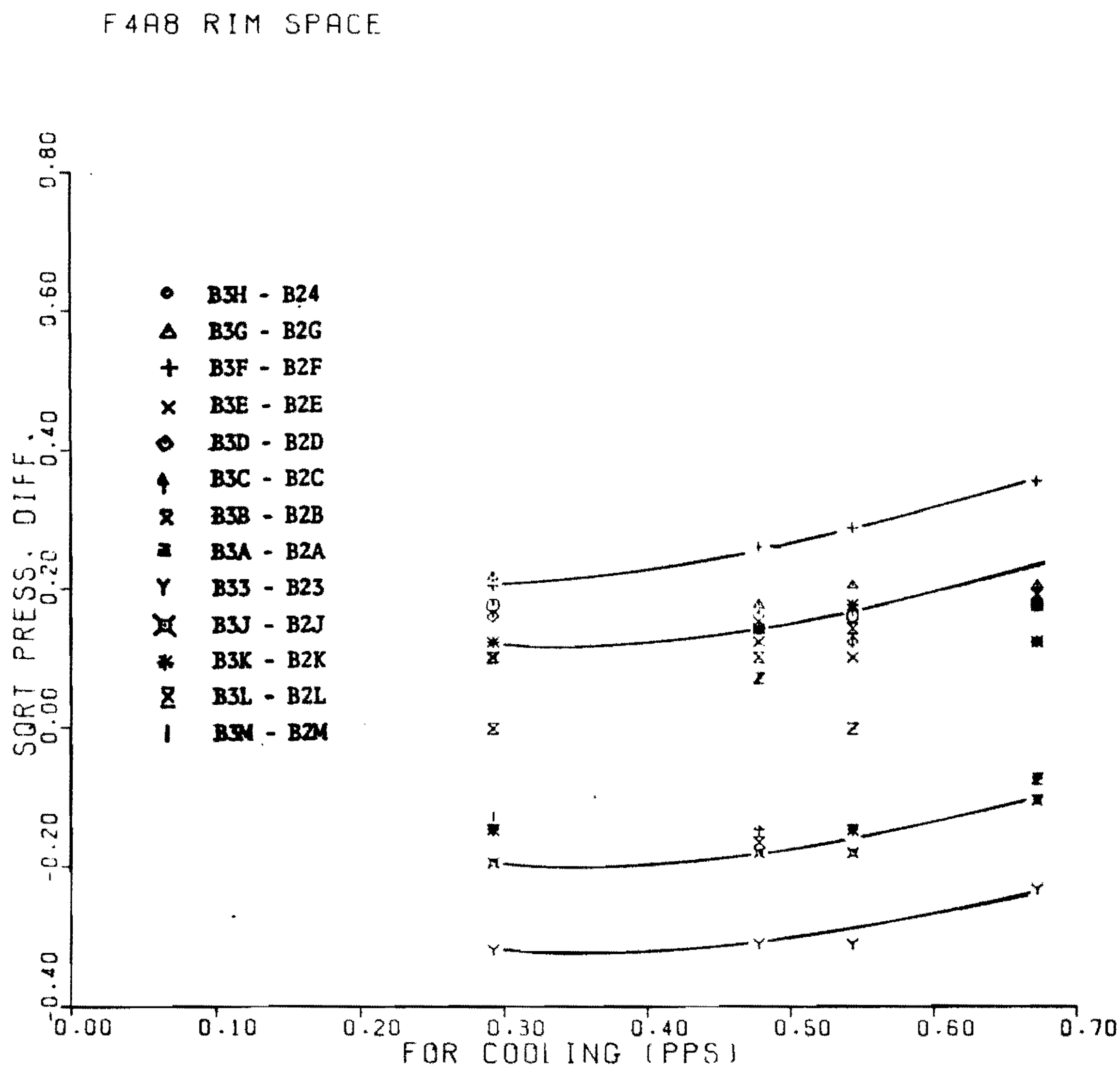

F4A8 RIM SPACE
B3H - B24
B3G - B2G
B3F - B2F
B3E - B2E
B3D - B2D
B3C - B2C
B3B - B2B
B3A - B2A
B33 - B23
B3J - B2J
B3K - B2K
B3L - B2L
B3M - B2M
SQRT PRESS. DIFF.
0.80
0.60
0.40
0.20
0.00
-0.20
-0.40
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
FOR COOLING (PPS)

Figure AF-6A

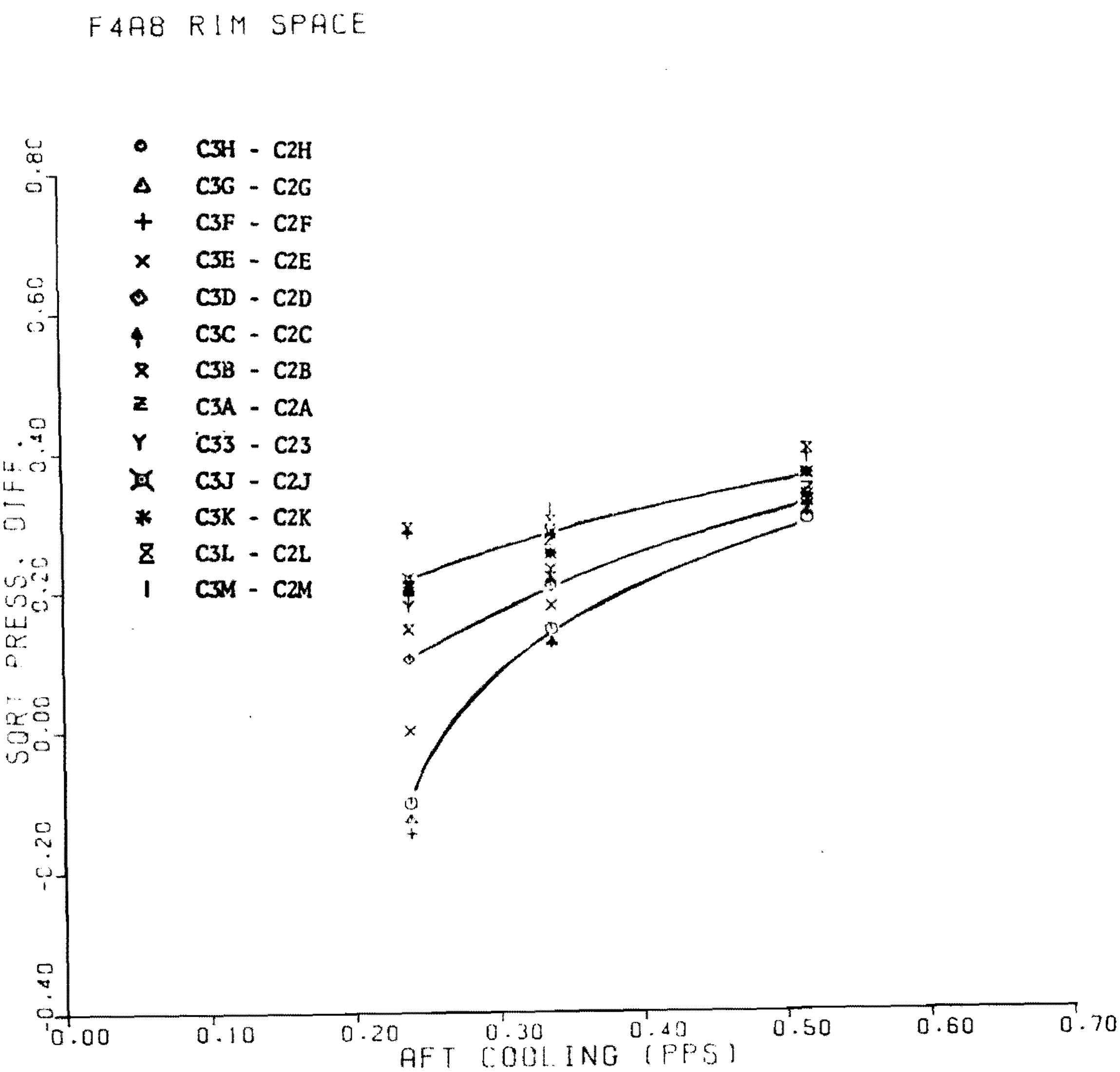

F4A8 RIM SPACE
C3H - C2H
C3G - C2G
C3F - C2F
C3E - C2E
C3D - C2D
C3C - C2C
C3B - C2B
C3A - C2A
C33 - C23
C3J - C2J
C3K - C2K
C3L - C2L
C3M - C2M
SORT PRESS. DIFF.
AFT COOLING (PPS)
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70

Figure AF-6B

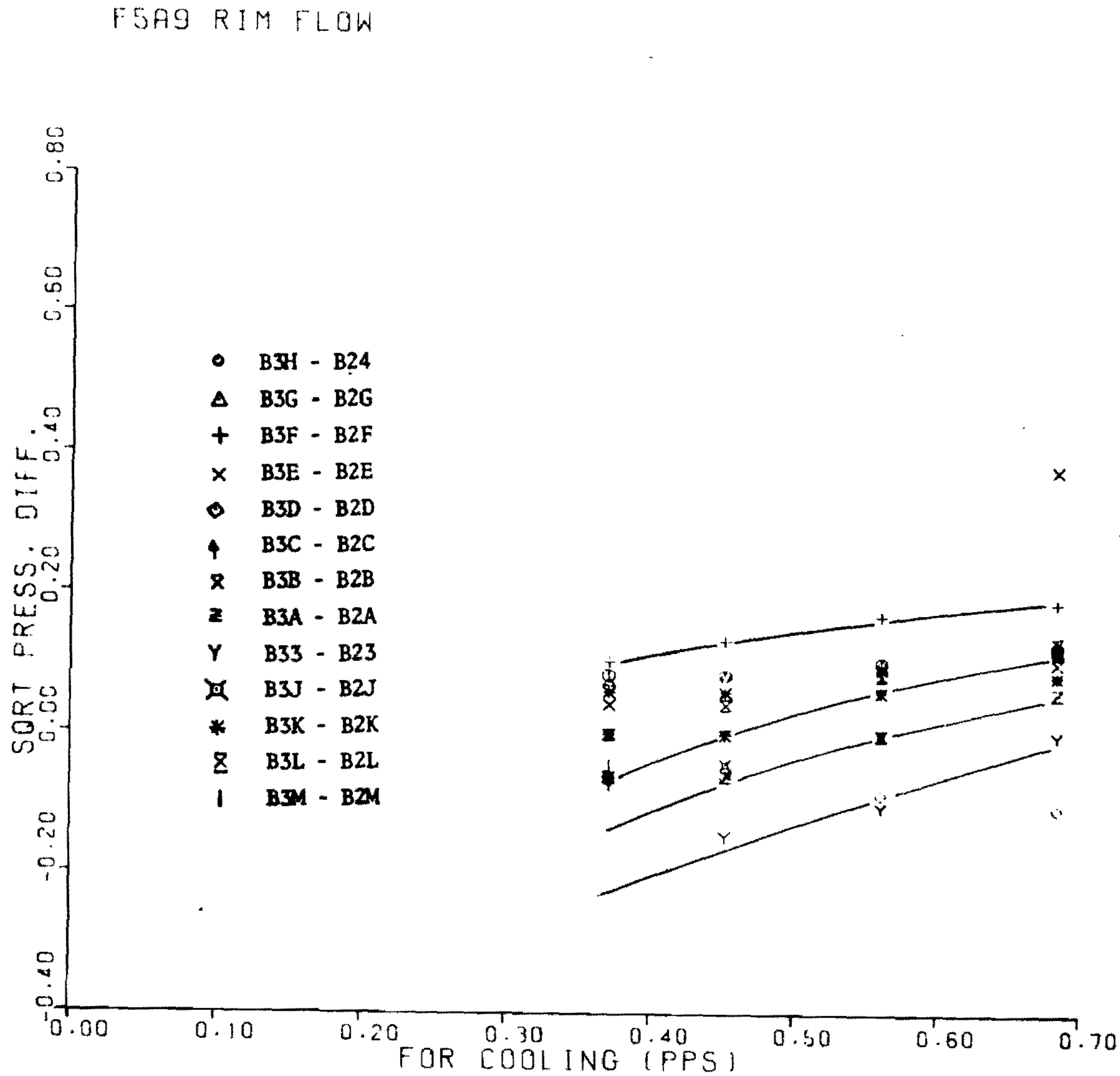

F5A9 RIM FLOW
SORT PRESS. DIFF.
FOR COOLING (PPS)
0.80
0.60
0.40
0.20
0.00
-0.20
-0.40
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
B3H - B24
B3G - B2G
B3F - B2F
B3E - B2E
B3D - B2D
B3C - B2C
B3B - B2B
B3A - B2A
B33 - B23
B3J - B2J
B3K - B2K
B3L - B2L
B3M - B2M

Figure AF-7A

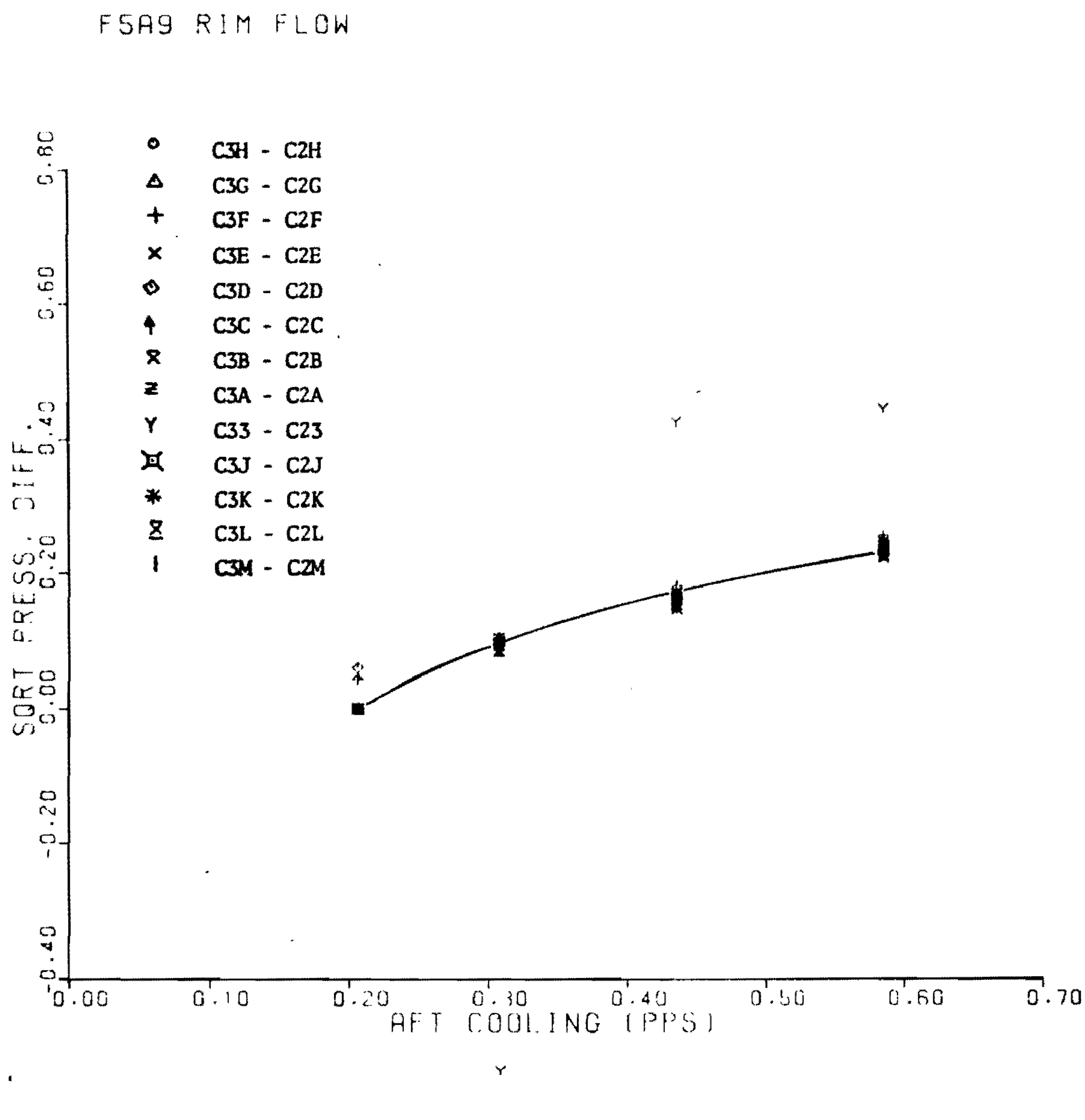

F5A9 RIM FLOW
C3H - C2H
C3G - C2G
C3F - C2F
C3E - C2E
C3D - C2D
C3C - C2C
C3B - C2B
C3A - C2A
C33 - C23
C3J - C2J
C3K - C2K
C3L - C2L
C3M - C2M
SQRT PRESS. DIFF.
0.80
0.60
0.40
0.20
0.00
-0.20
-0.40
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
AFT COOLING (PPS)

Figure AF-7B

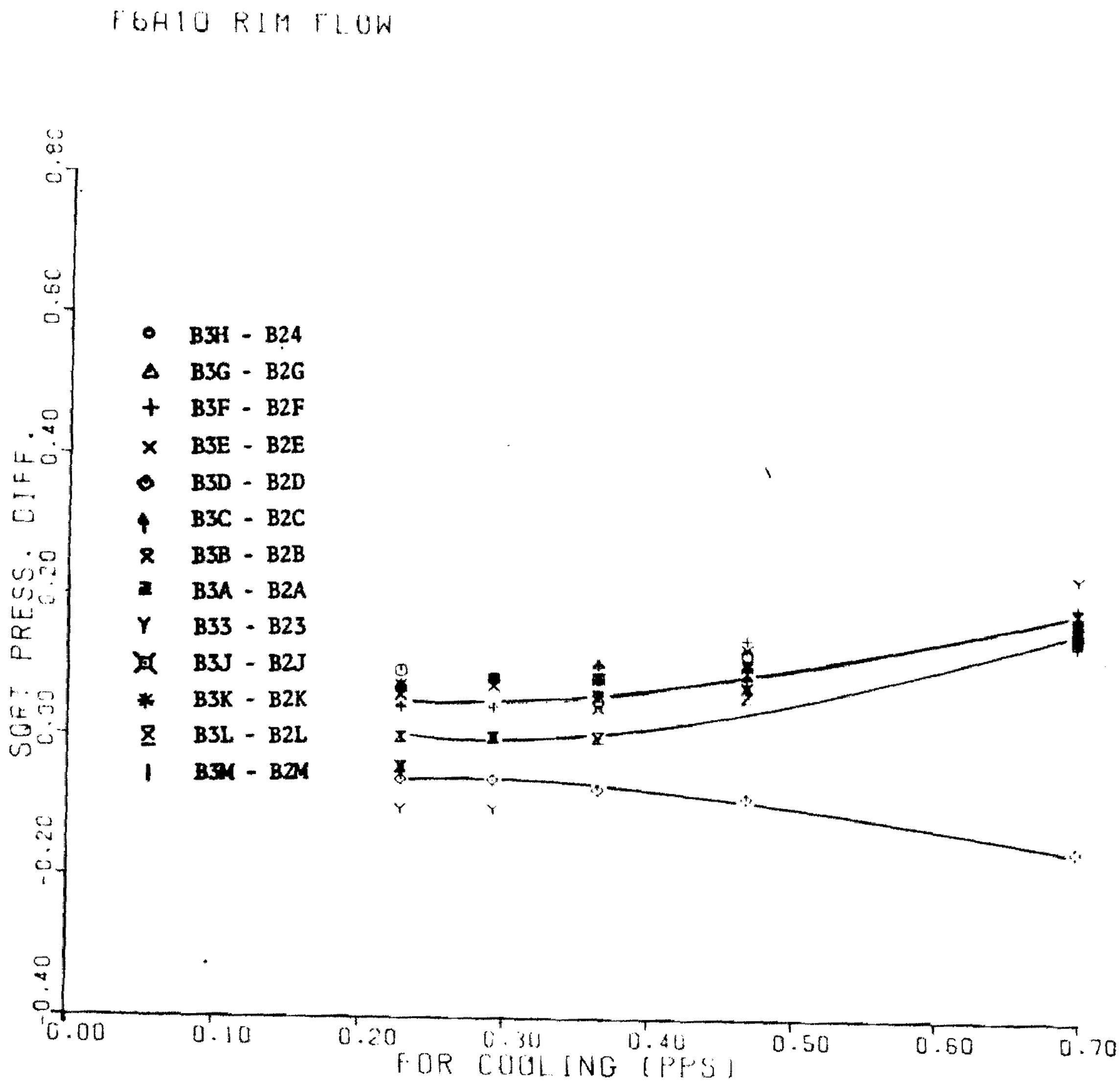

F6A10 RIM FLOW
SQRT PRESS. DIFF.
FOR COOLING (PPS)
0.80
0.60
0.40
0.20
0.00
-0.20
-0.40
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
B3H - B24
B3G - B2G
B3F - B2F
B3E - B2E
B3D - B2D
B3C - B2C
B3B - B2B
B3A - B2A
B33 - B23
B3J - B2J
B3K - B2K
B3L - B2L
B3M - B2M

Figure AF-8A

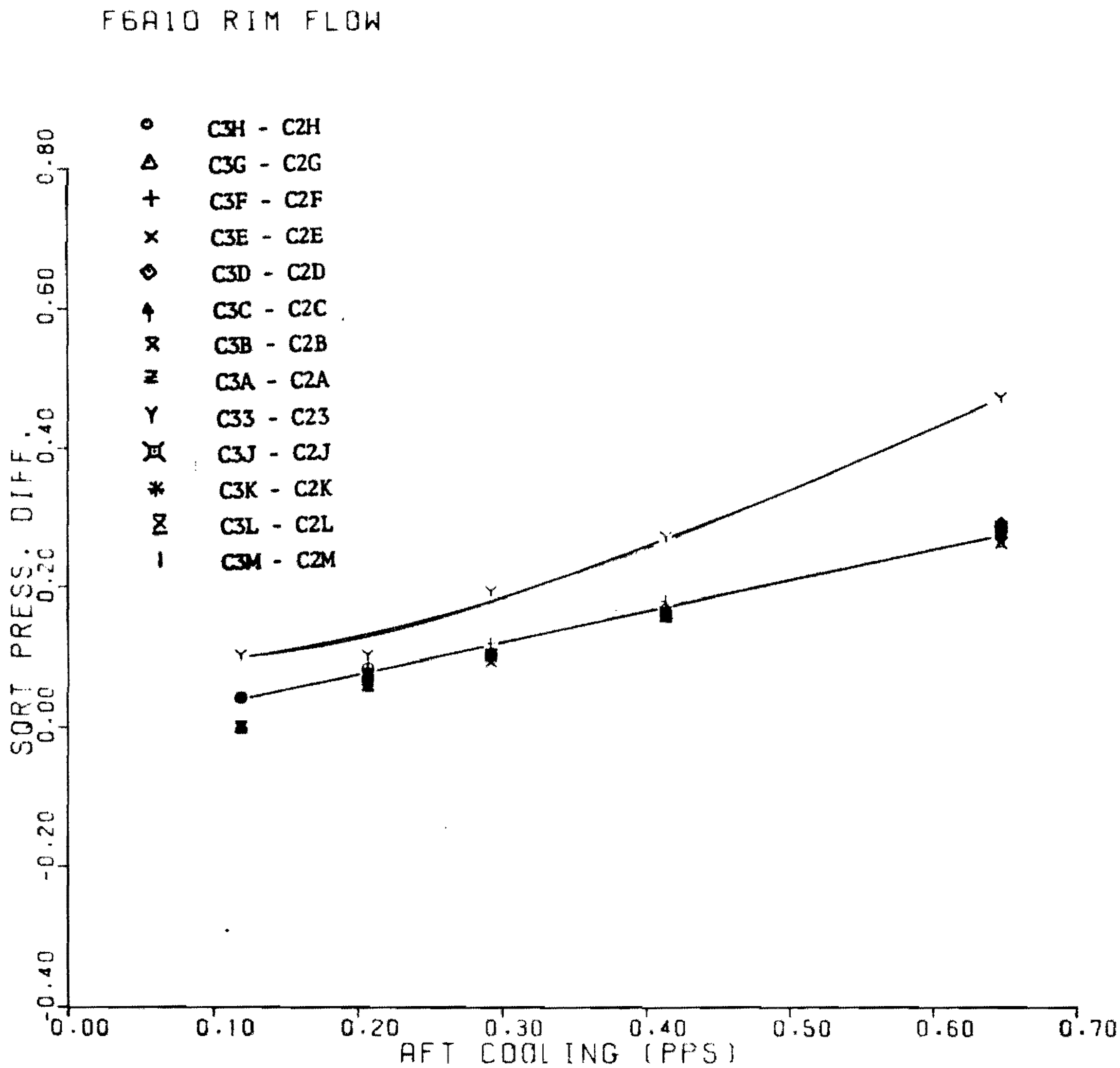

F6A10 RIM FLOW
C3H - C2H
C3G - C2G
C3F - C2F
C3E - C2E
C3D - C2D
C3C - C2C
C3B - C2B
C3A - C2A
C33 - C23
C3J - C2J
C3K - C2K
C3L - C2L
C3M - C2M
SORT PRESS. DIFF.
0.80
0.60
0.40
0.20
0.00
-0.20
-0.40
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
AFT COOLING (PPS)

Figure AF-8B

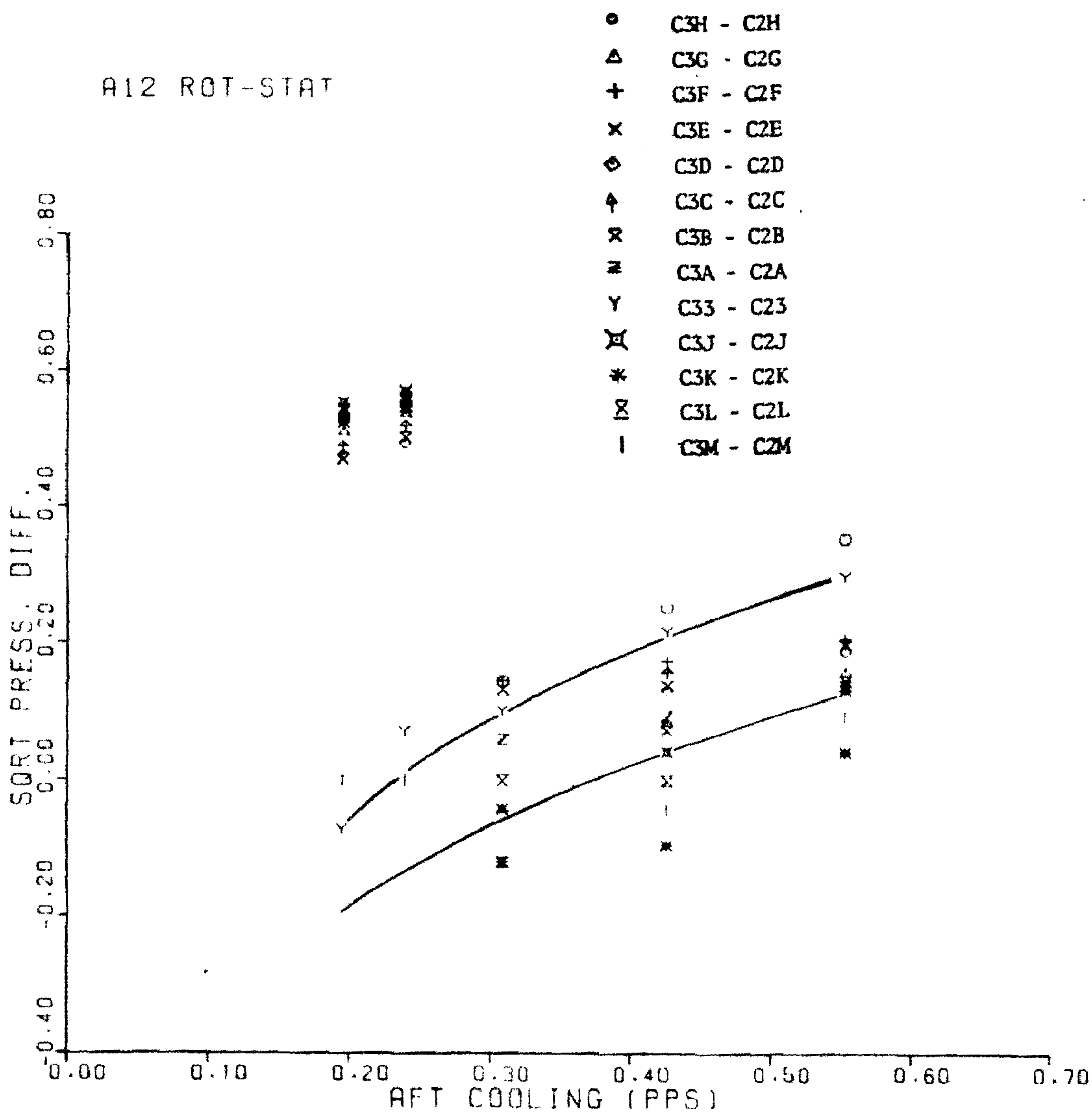

A12 ROT-STAT
C3H - C2H
C3G - C2G
C3F - C2F
C3E - C2E
C3D - C2D
C3C - C2C
C3B - C2B
C3A - C2A
C33 - C23
C3J - C2J
C3K - C2K
C3L - C2L
C3M - C2M
SQRT PRESS. DIFF.
-0.40
-0.20
0.00
0.20
0.40
0.60
0.80
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
AFT COOLING (PPS)

Figure AF-9

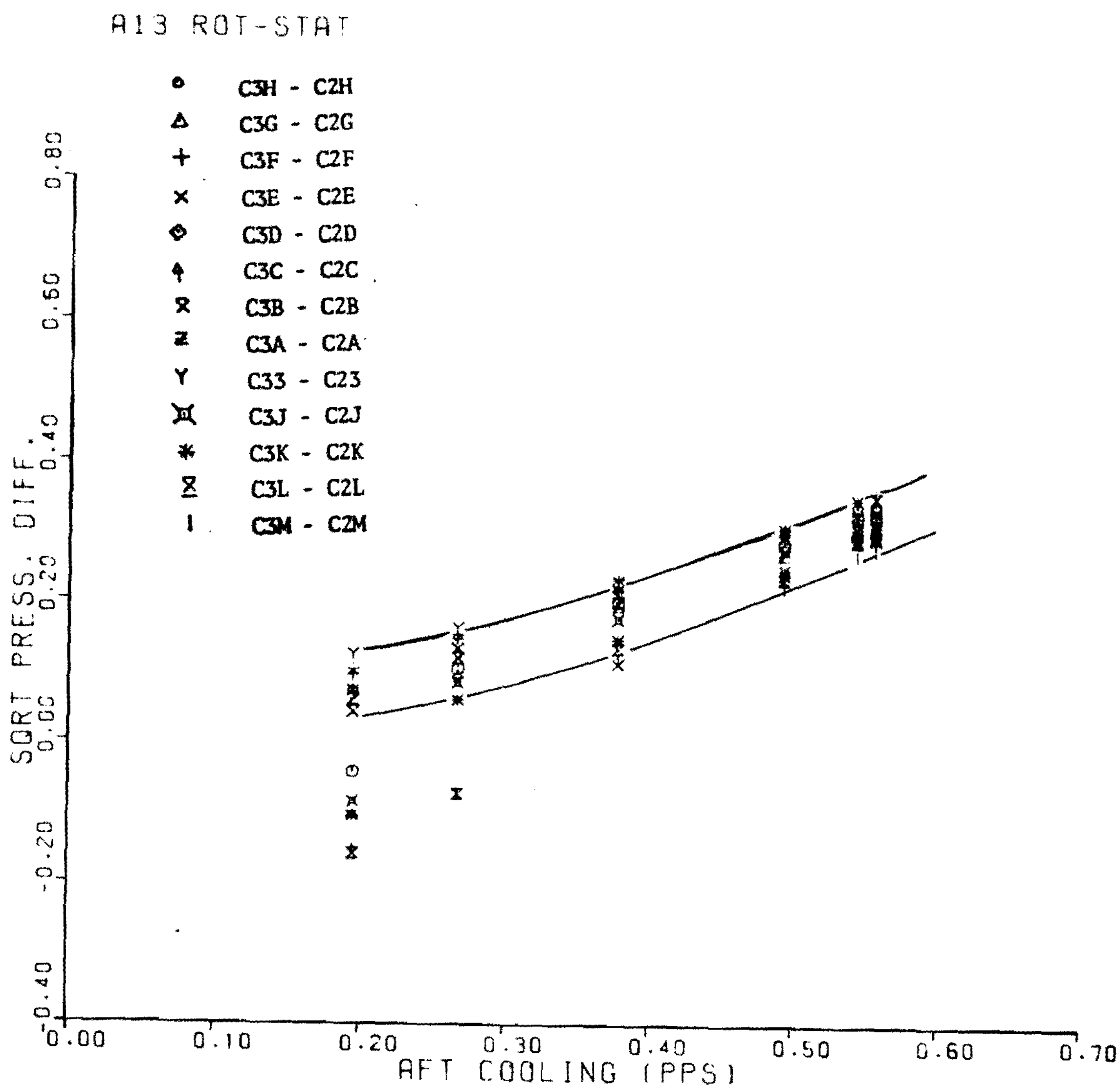

A13 ROT-STAT
C3H - C2H
C3G - C2G
C3F - C2F
C3E - C2E
C3D - C2D
C3C - C2C
C3B - C2B
C3A - C2A
C33 - C23
C3J - C2J
C3K - C2K
C3L - C2L
C3M - C2M
SQRT PRESS. DIFF.
-0.40
-0.20
0.00
0.20
0.40
0.60
0.80
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
AFT COOLING (PPS)

Figure AF-10

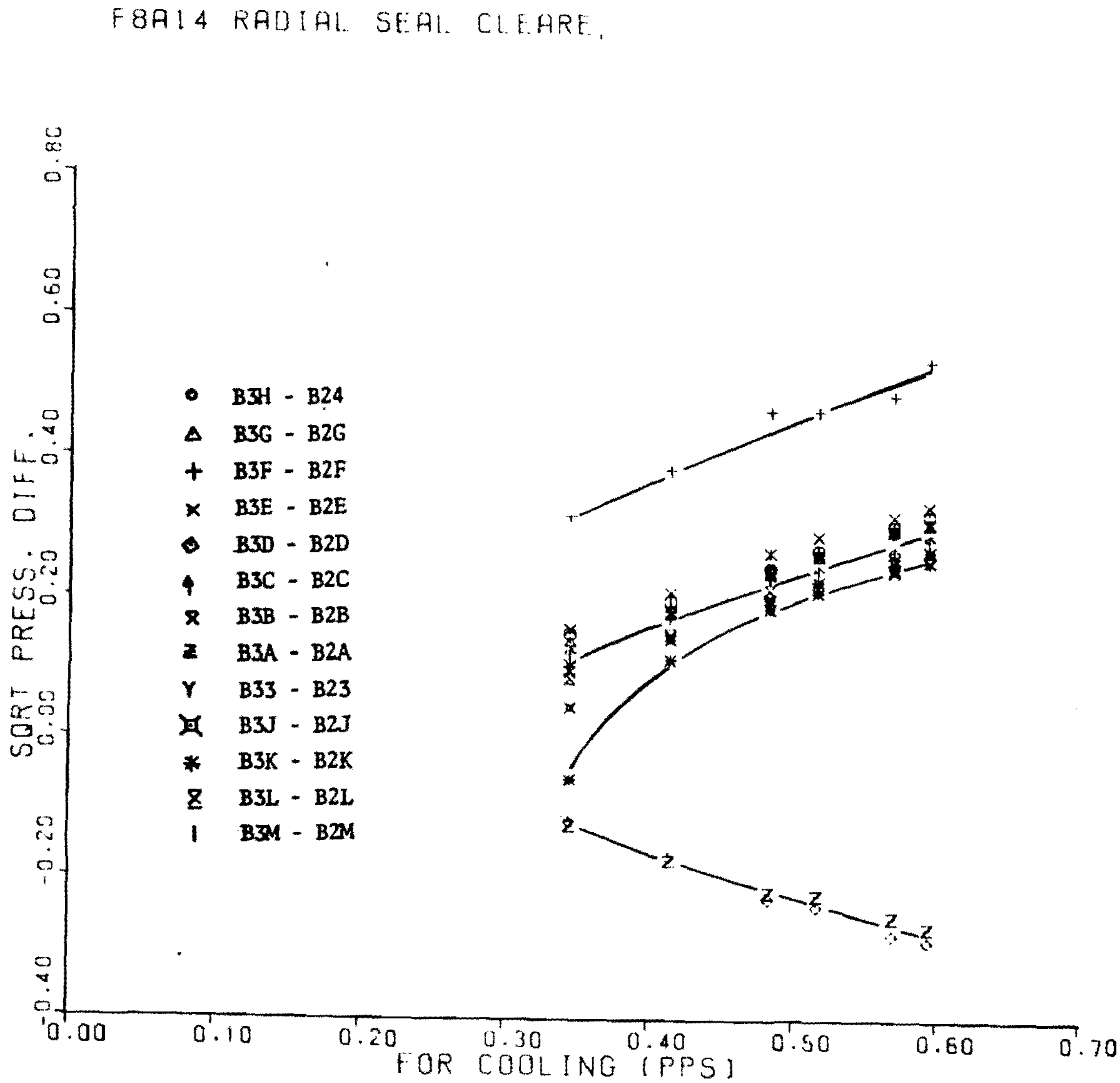


Figure AF-11A

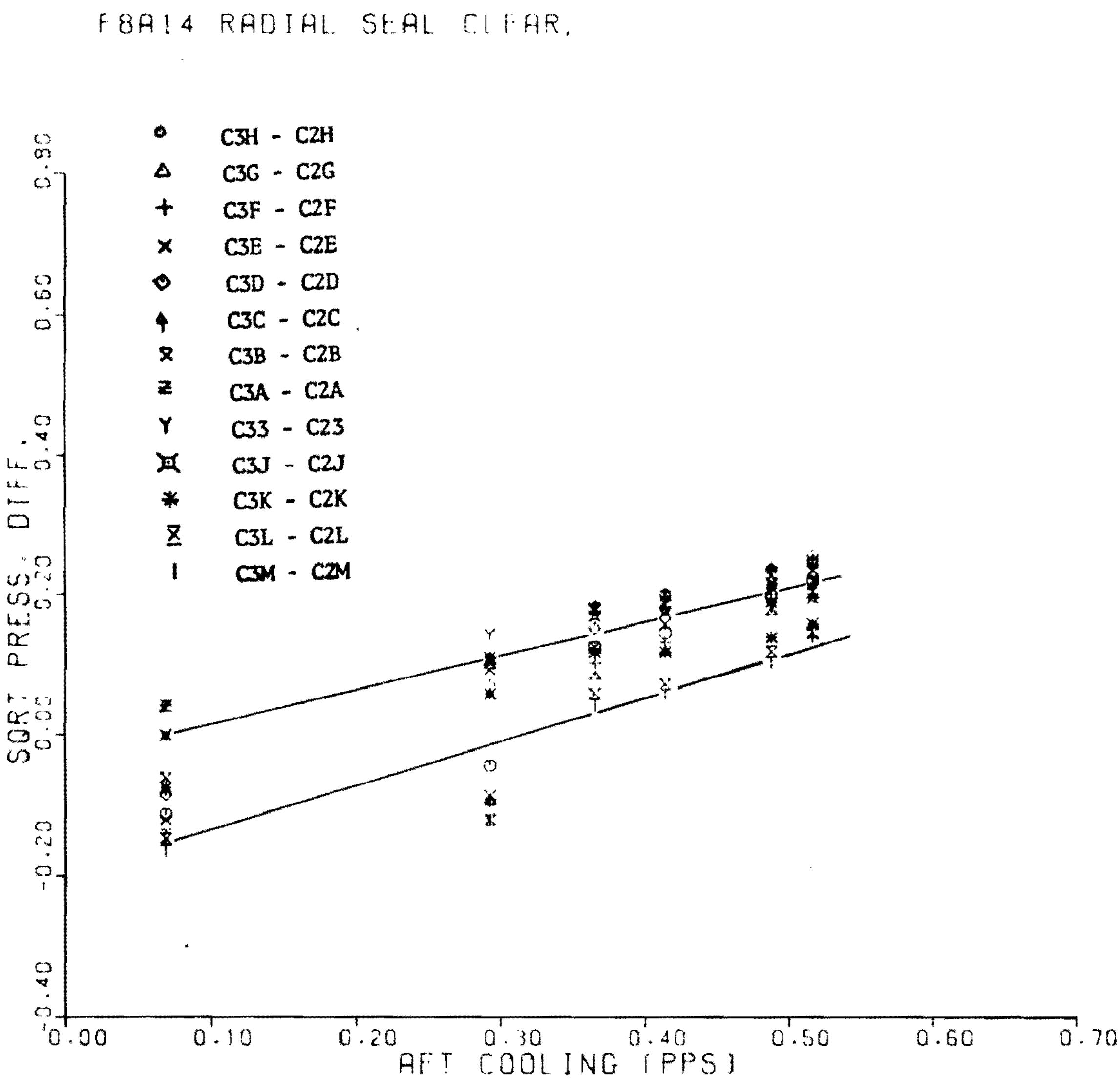


Figure AF-11B

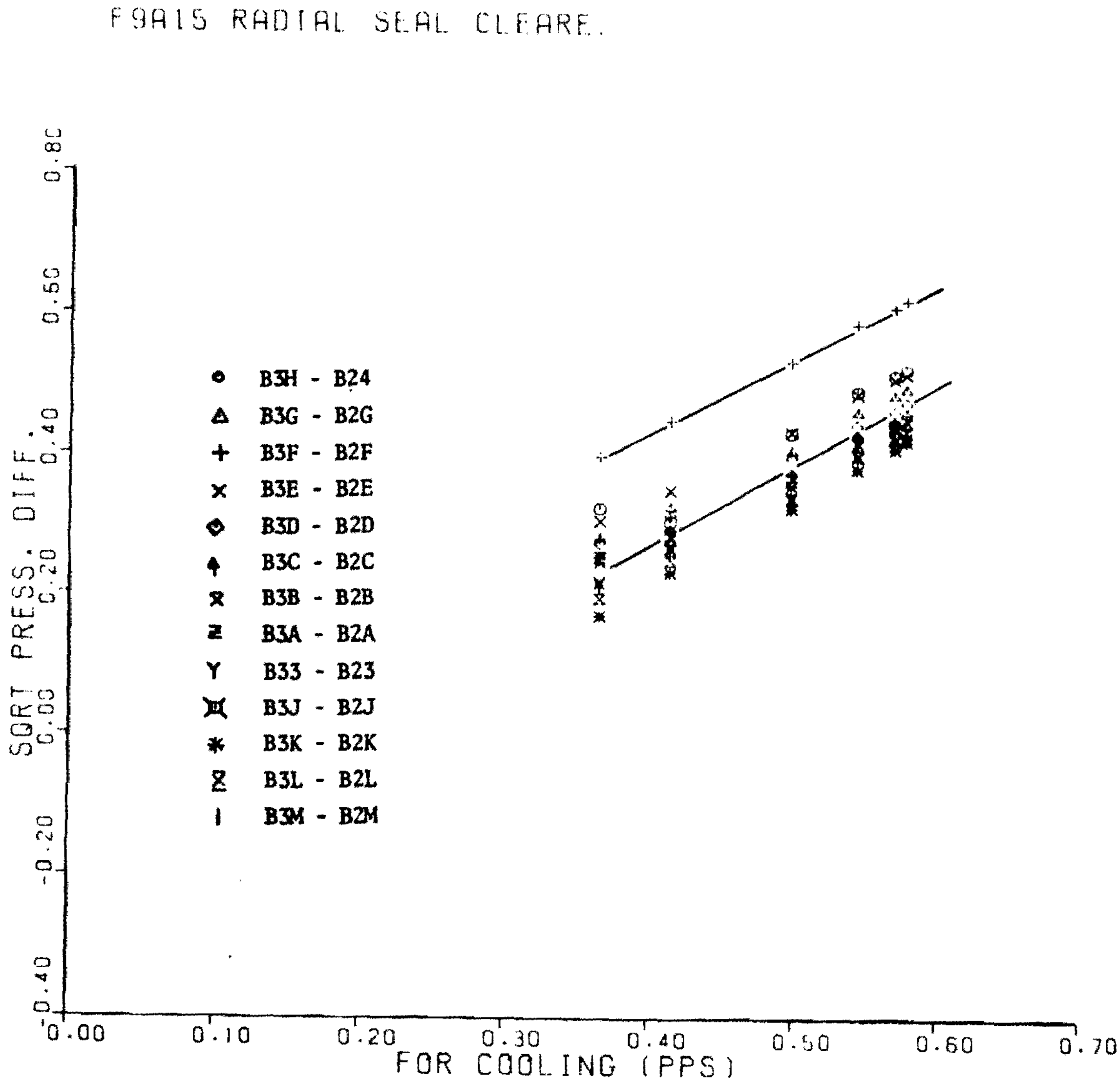


Figure AF-12A

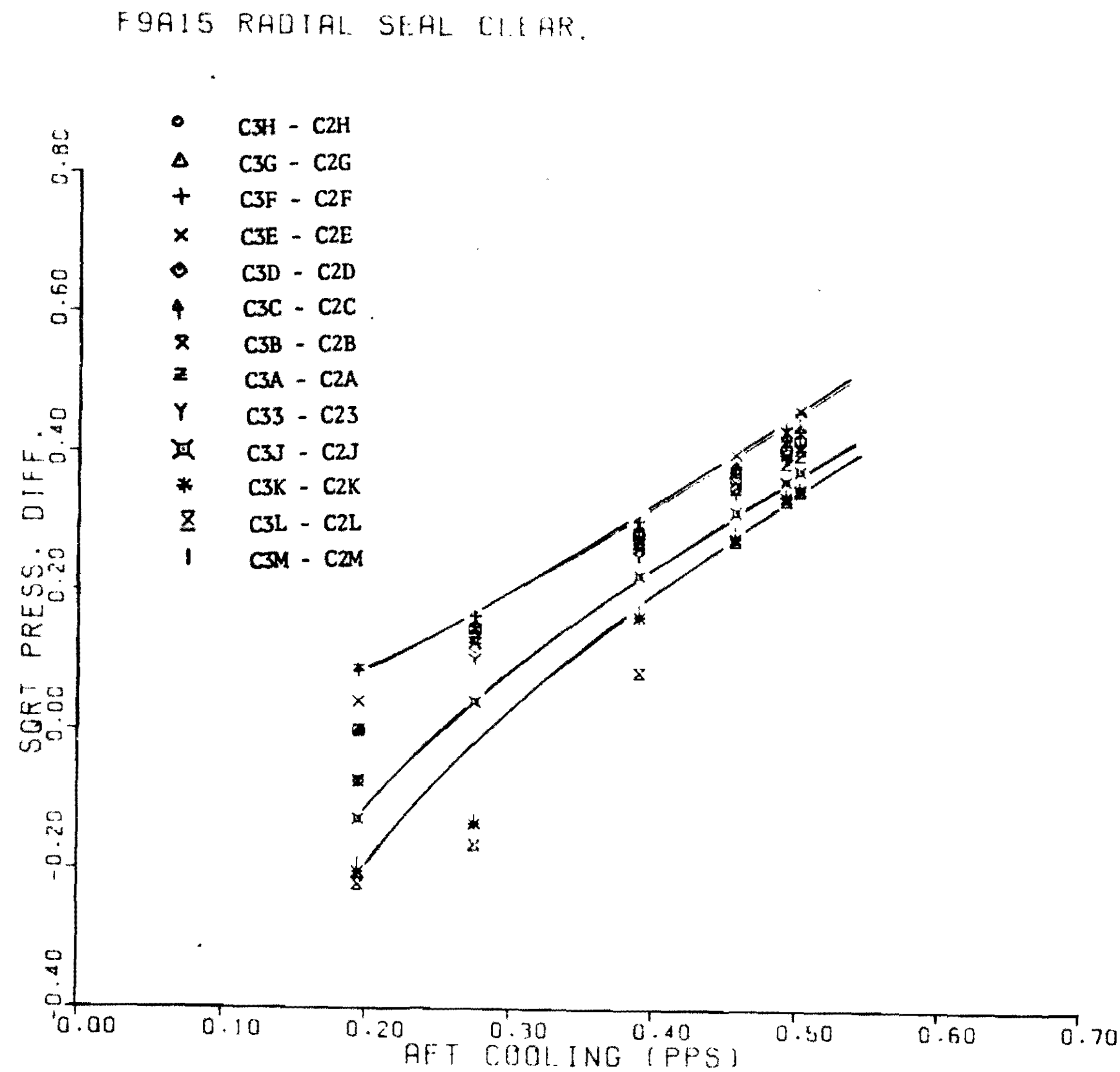


Figure AF-12B

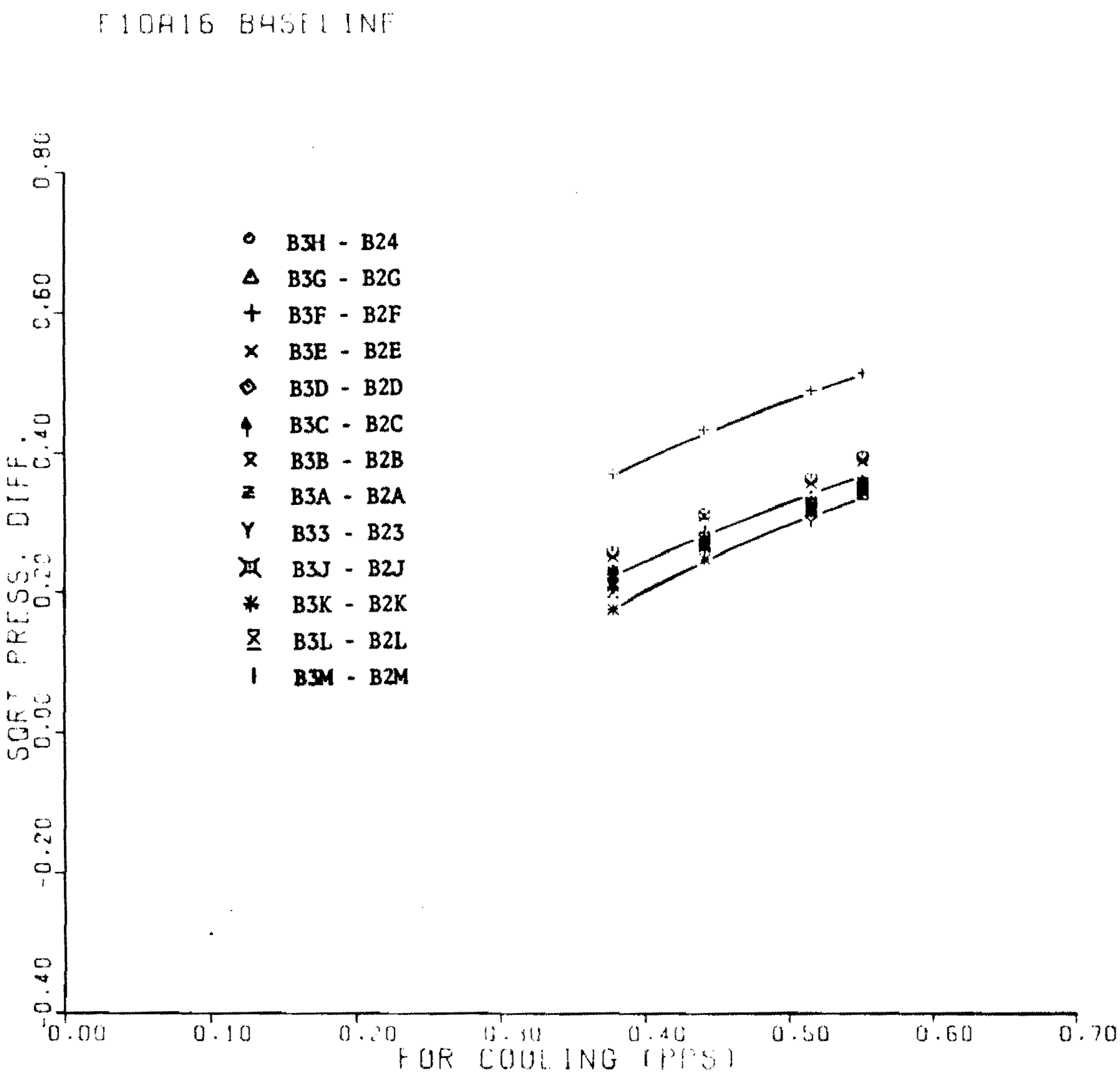


Figure AF-13A

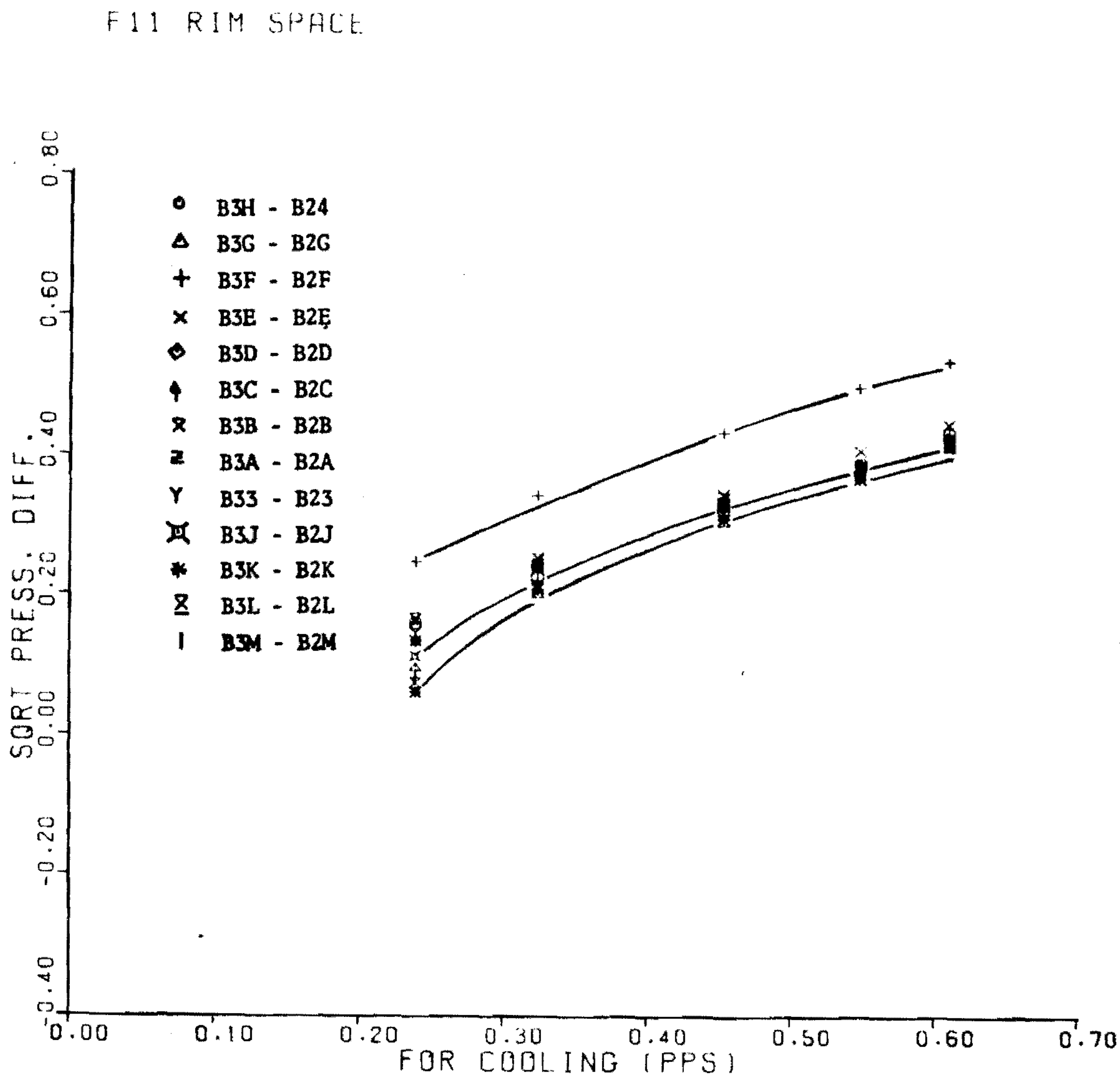

F11 RIM SPACE
B3H - B24
B3G - B2G
B3F - B2F
B3E - B2E
B3D - B2D
B3C - B2C
B3B - B2B
B3A - B2A
B33 - B23
B3J - B2J
B3K - B2K
B3L - B2L
B3M - B2M
SQRT PRESS. DIFF.
0.80
0.60
0.40
0.20
0.00
-0.20
-0.40
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
FOR COOLING (PPS)

Figure AF-14

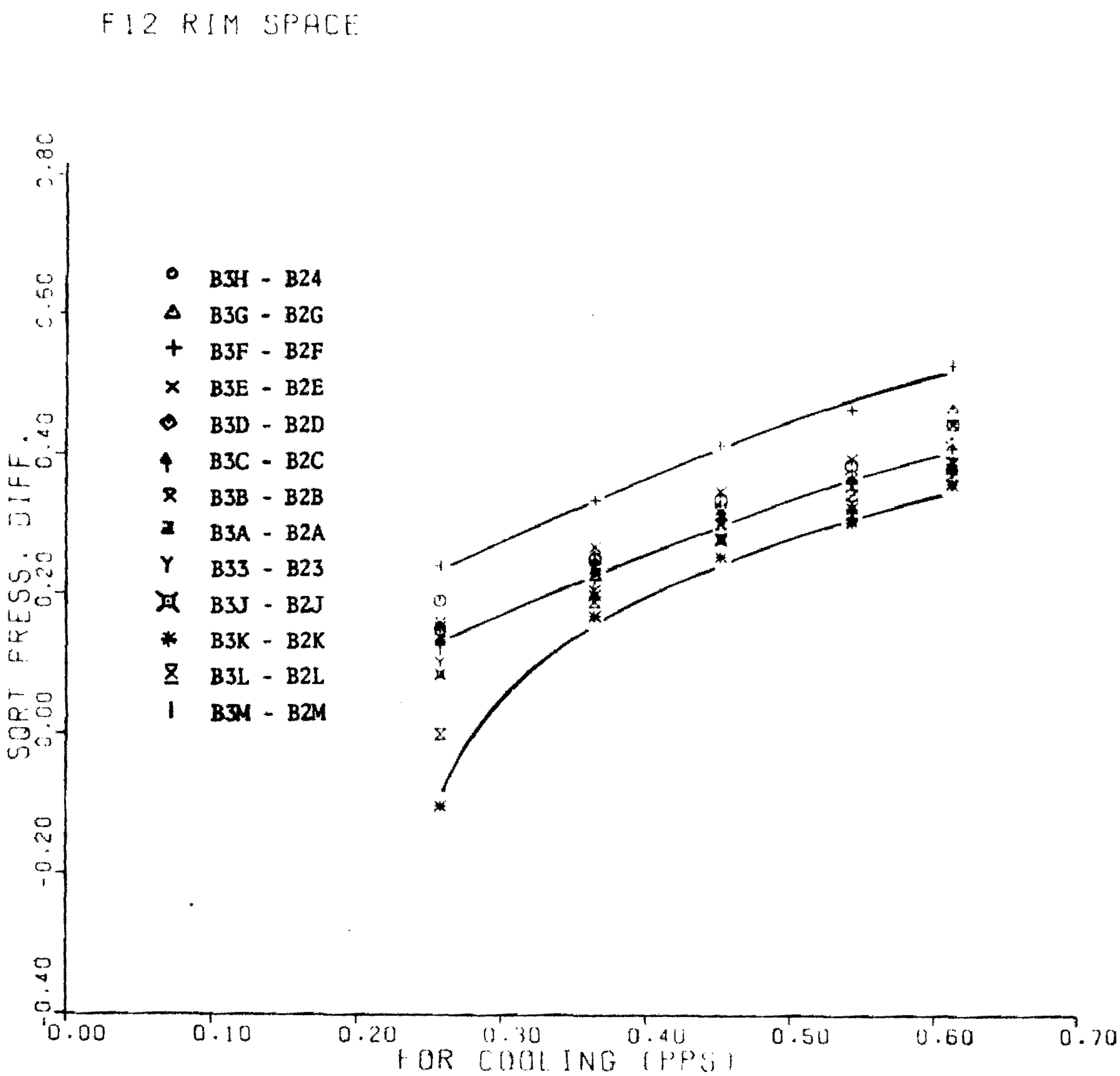
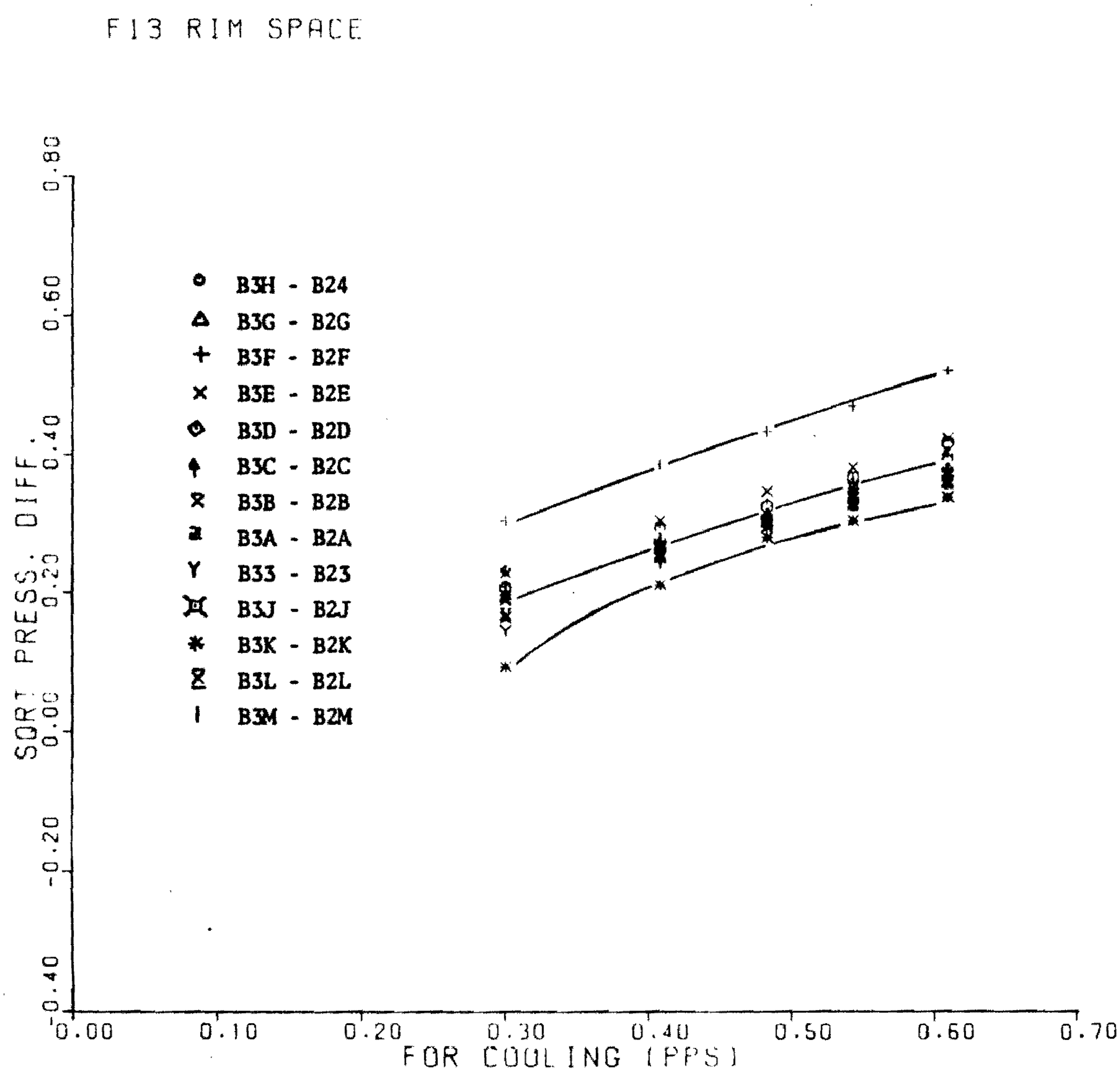
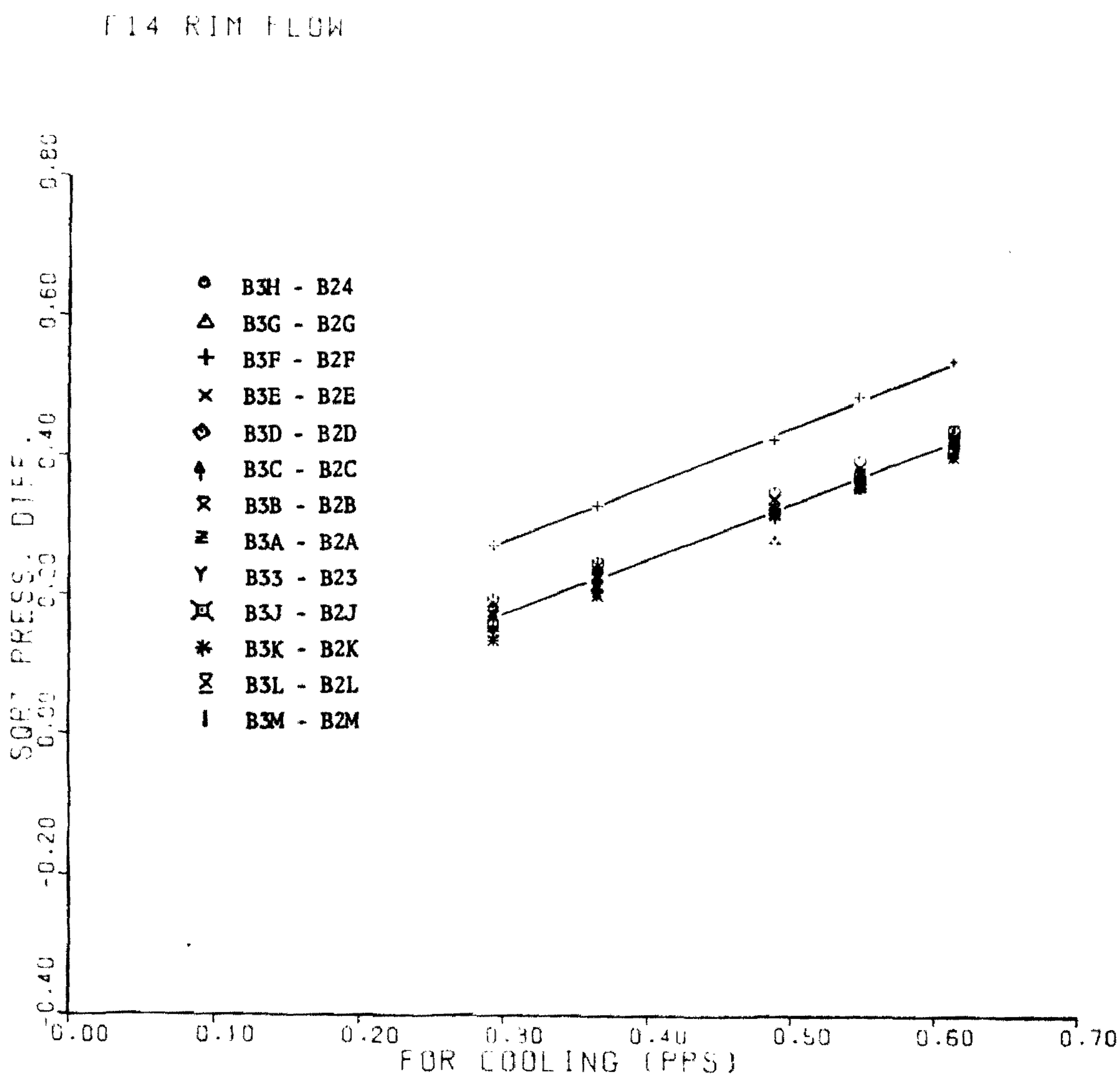

F12 RIM SPACE
B3H - B24
B3G - B2G
B3F - B2F
B3E - B2E
B3D - B2D
B3C - B2C
B3B - B2B
B3A - B2A
B33 - B23
B3J - B2J
B3K - B2K
B3L - B2L
B3M - B2M
SQRT PRESS. DIFF.
FOR COOLING (PPS)
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
-0.40
-0.20
0.20
0.40
0.60
0.80

Figure AF-15



F13 RIM SPACE
SORT PRESS. DIFF.
FOR COOLING (PPS)
0.80
0.60
0.40
0.20
0.00
-0.20
-0.40
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
B3H - B24
B3G - B2G
B3F - B2F
B3E - B2E
B3D - B2D
B3C - B2C
B3B - B2B
B3A - B2A
B33 - B23
B3J - B2J
B3K - B2K
B3L - B2L
B3M - B2M

Figure AF-16



F14 RIM FLOW
B3H - B24
B3G - B2G
B3F - B2F
B3E - B2E
B3D - B2D
B3C - B2C
B3B - B2B
B3A - B2A
B33 - B23
B3J - B2J
B3K - B2K
B3L - B2L
B3M - B2M
-0.40
-0.20
0.00
0.20
0.40
0.60
0.80
SQRT PRESS. DIFF.
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
FOR COOLING (PPS)

Figure AF-17

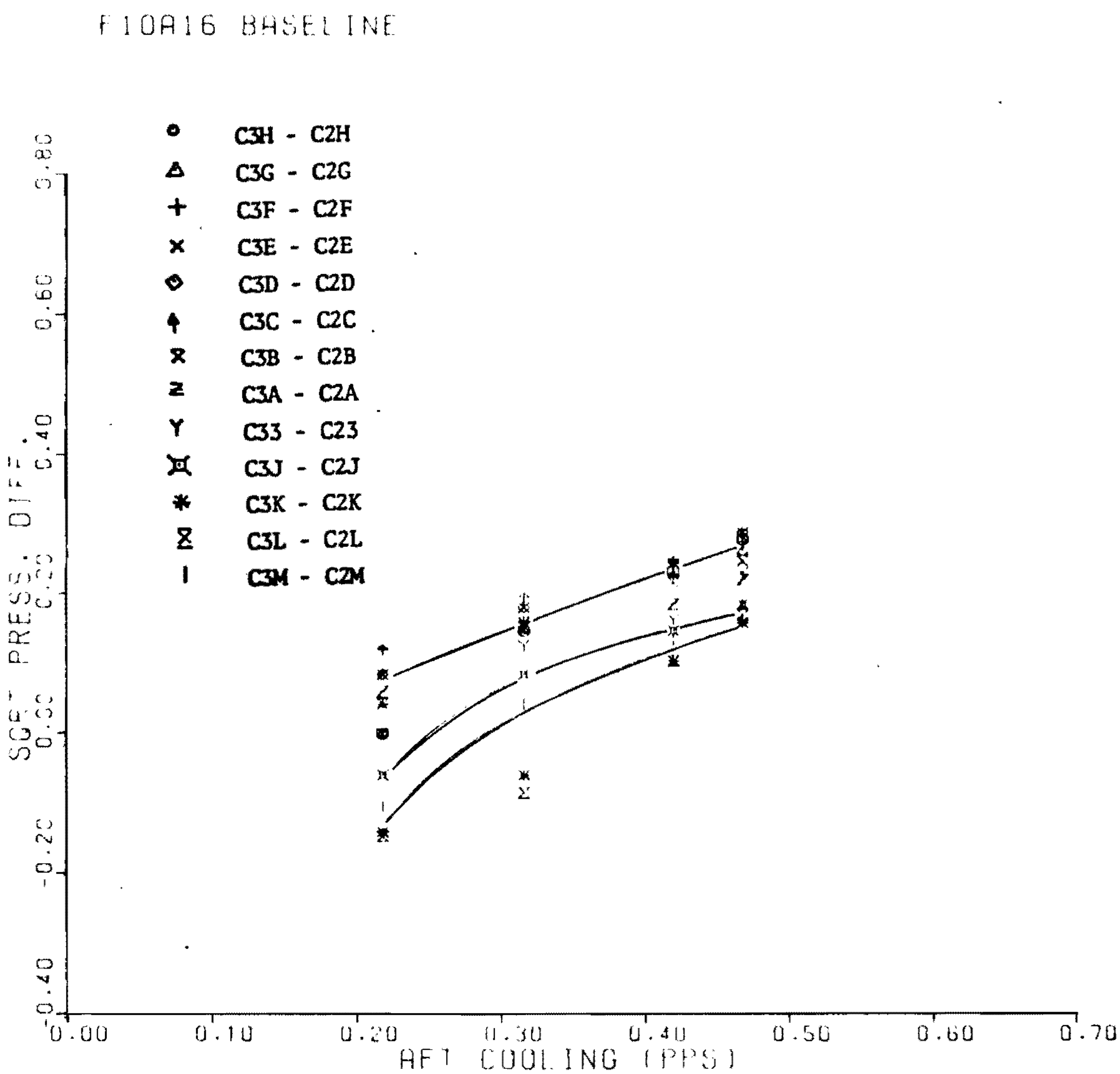
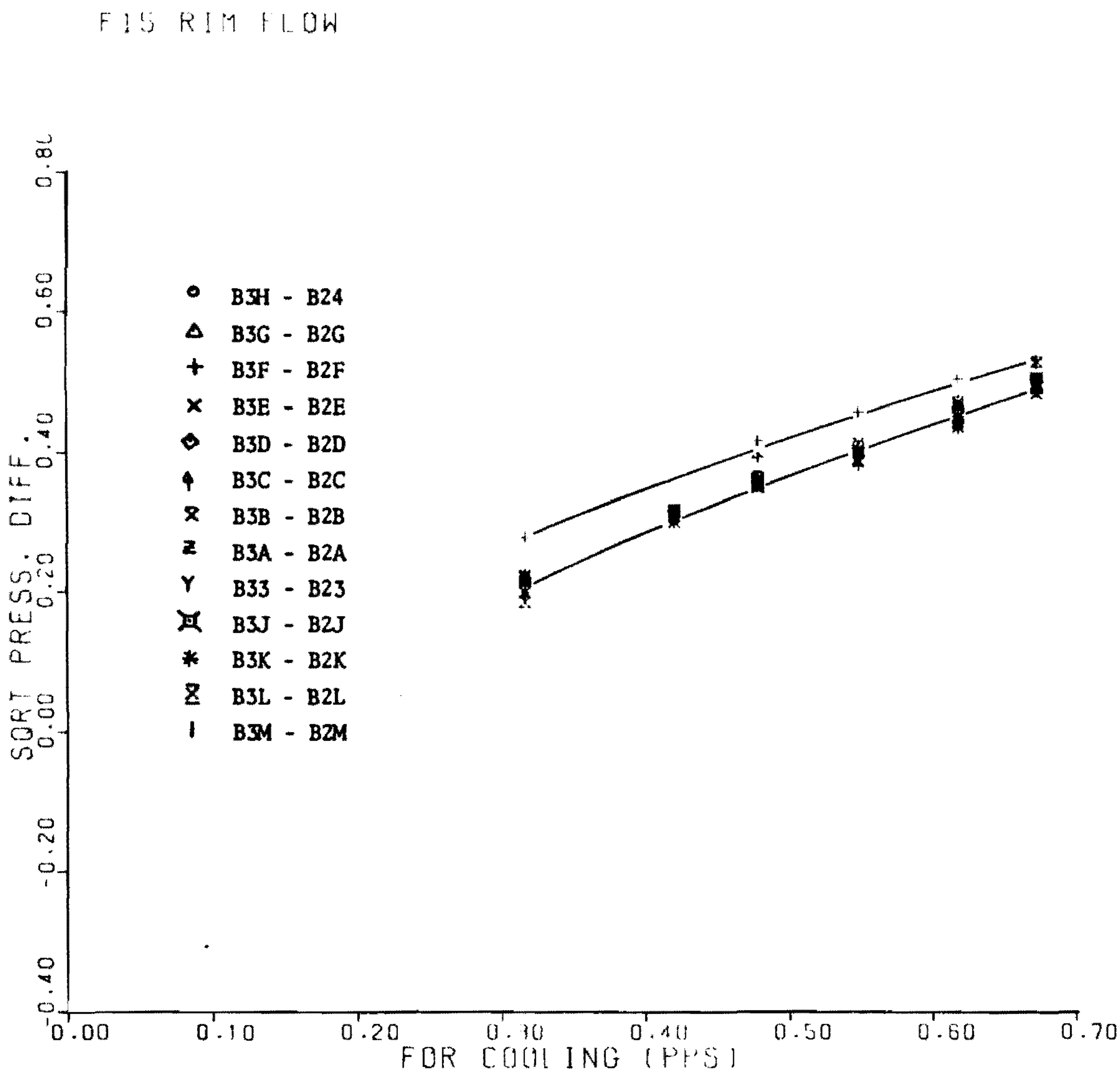


Figure AF-13B



F15 RIM FLOW
SQRT PRESS. DIFF.
0.80
0.60
0.40
0.20
0.00
-0.20
-0.40
B3H - B24
B3G - B2G
B3F - B2F
B3E - B2E
B3D - B2D
B3C - B2C
B3B - B2B
B3A - B2A
B33 - B23
B3J - B2J
B3K - B2K
B3L - B2L
B3M - B2M
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
FOR COOLING (PPS)

Figure AF-18

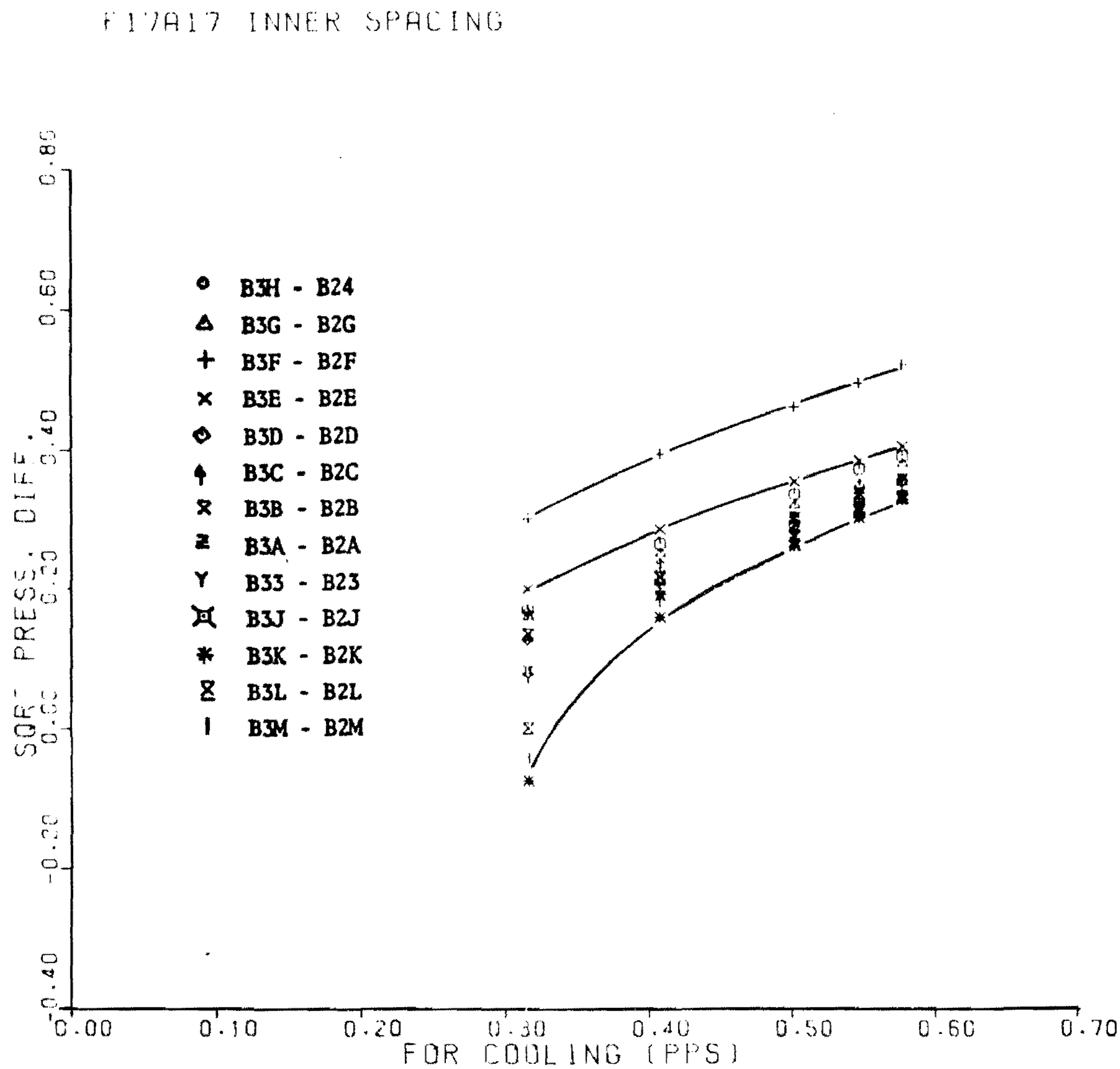


Figure AF-19A

F17A17 INNER SPACING

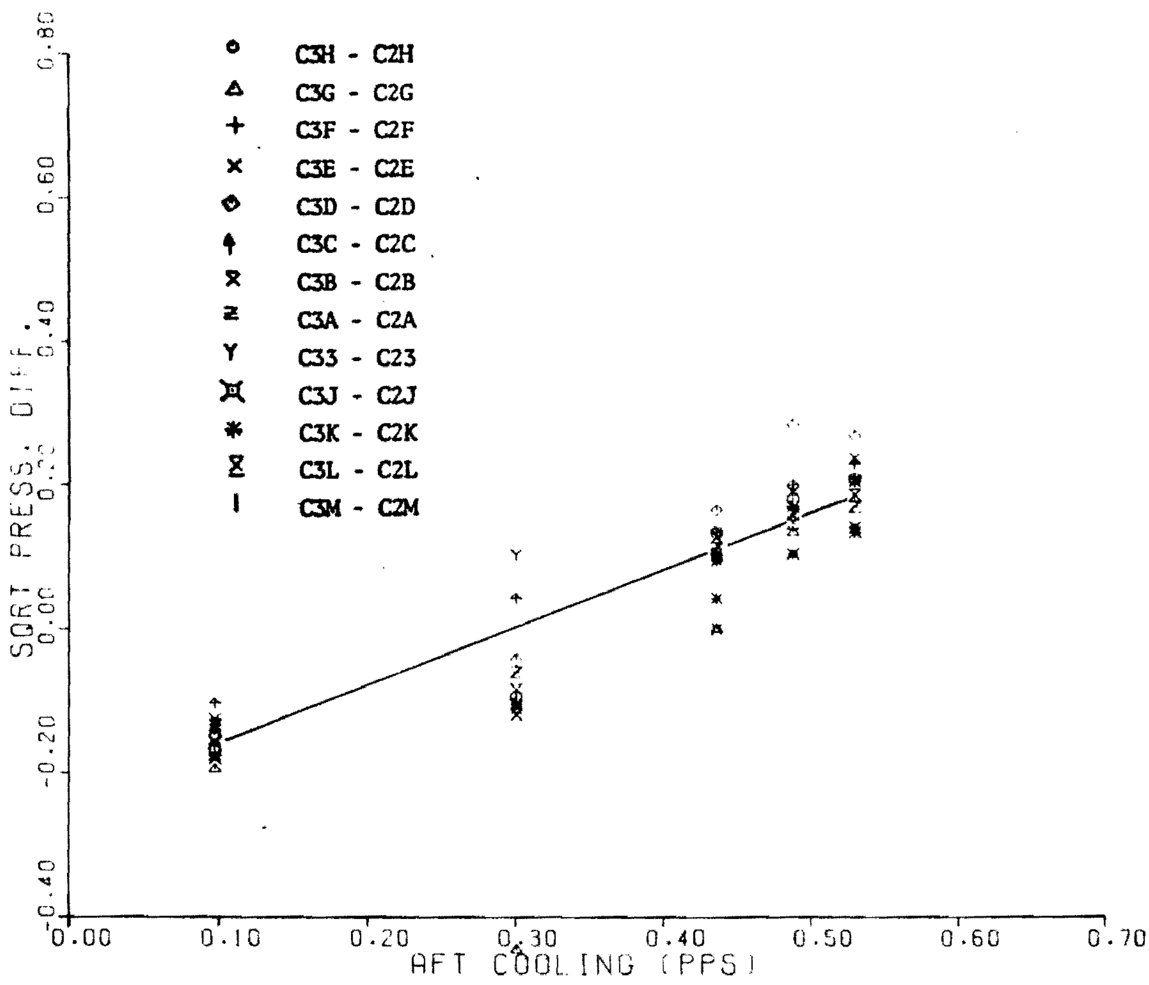


Figure AF-19B

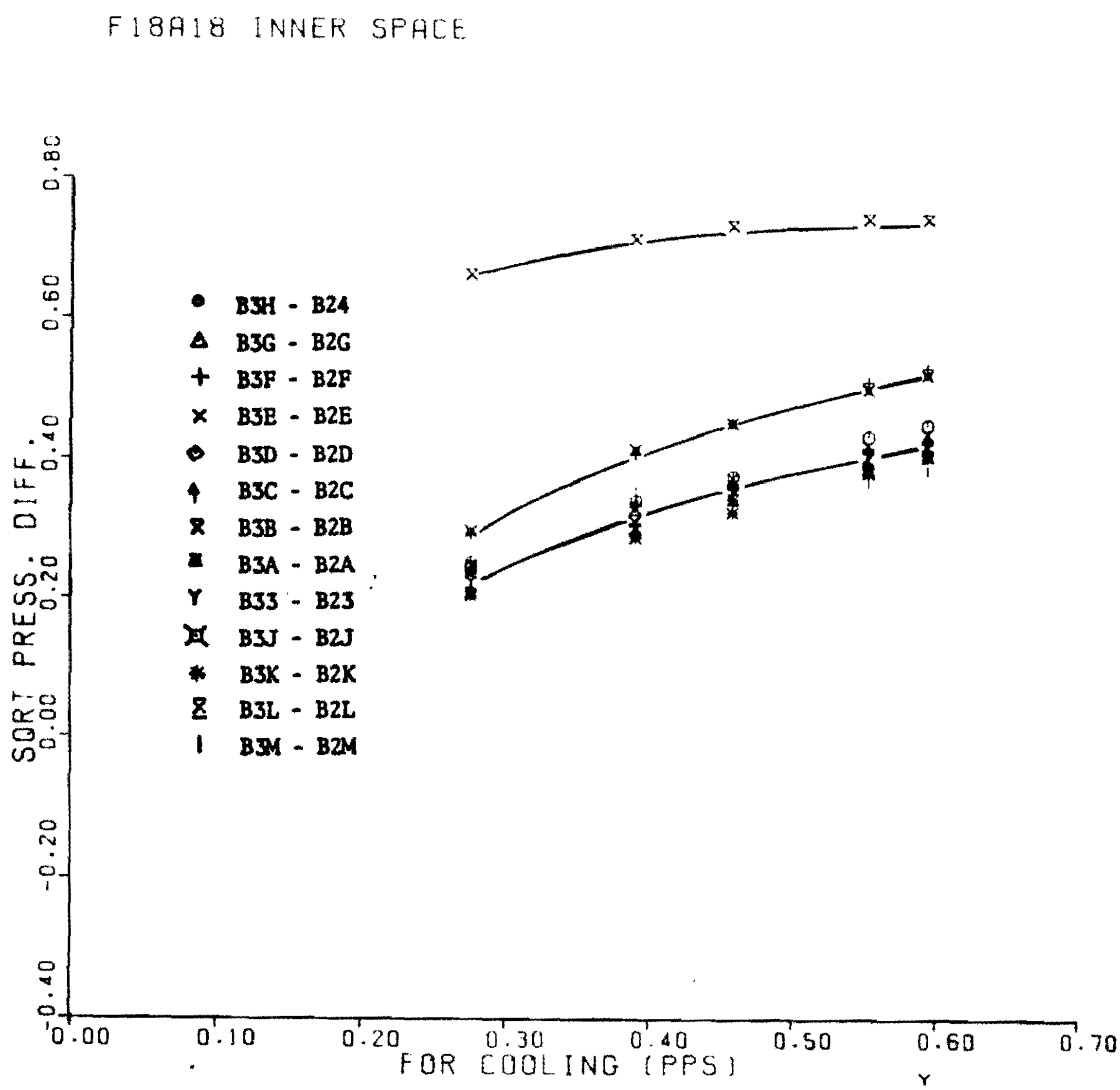


Figure AF-20A

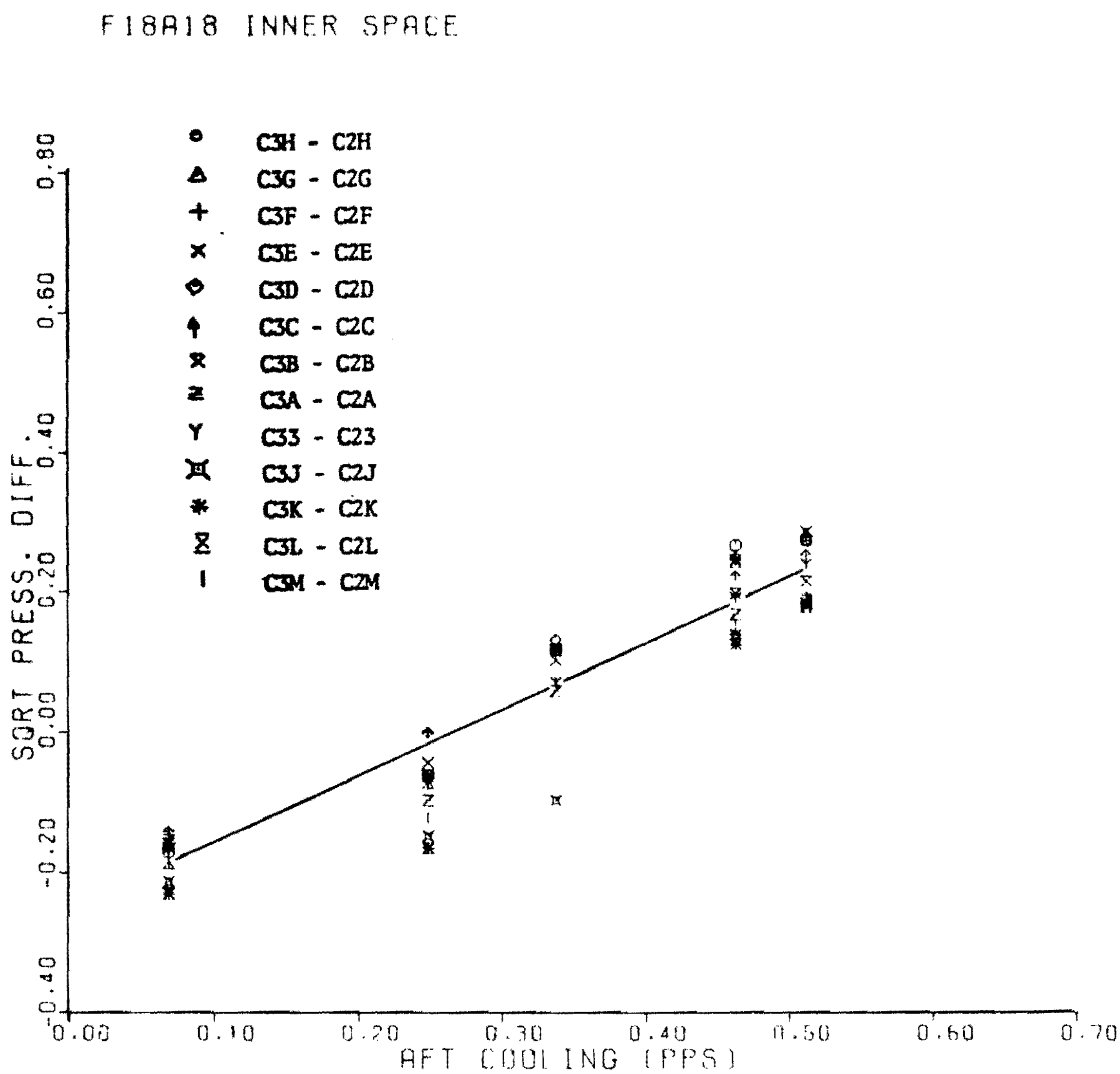


Figure AF-20B

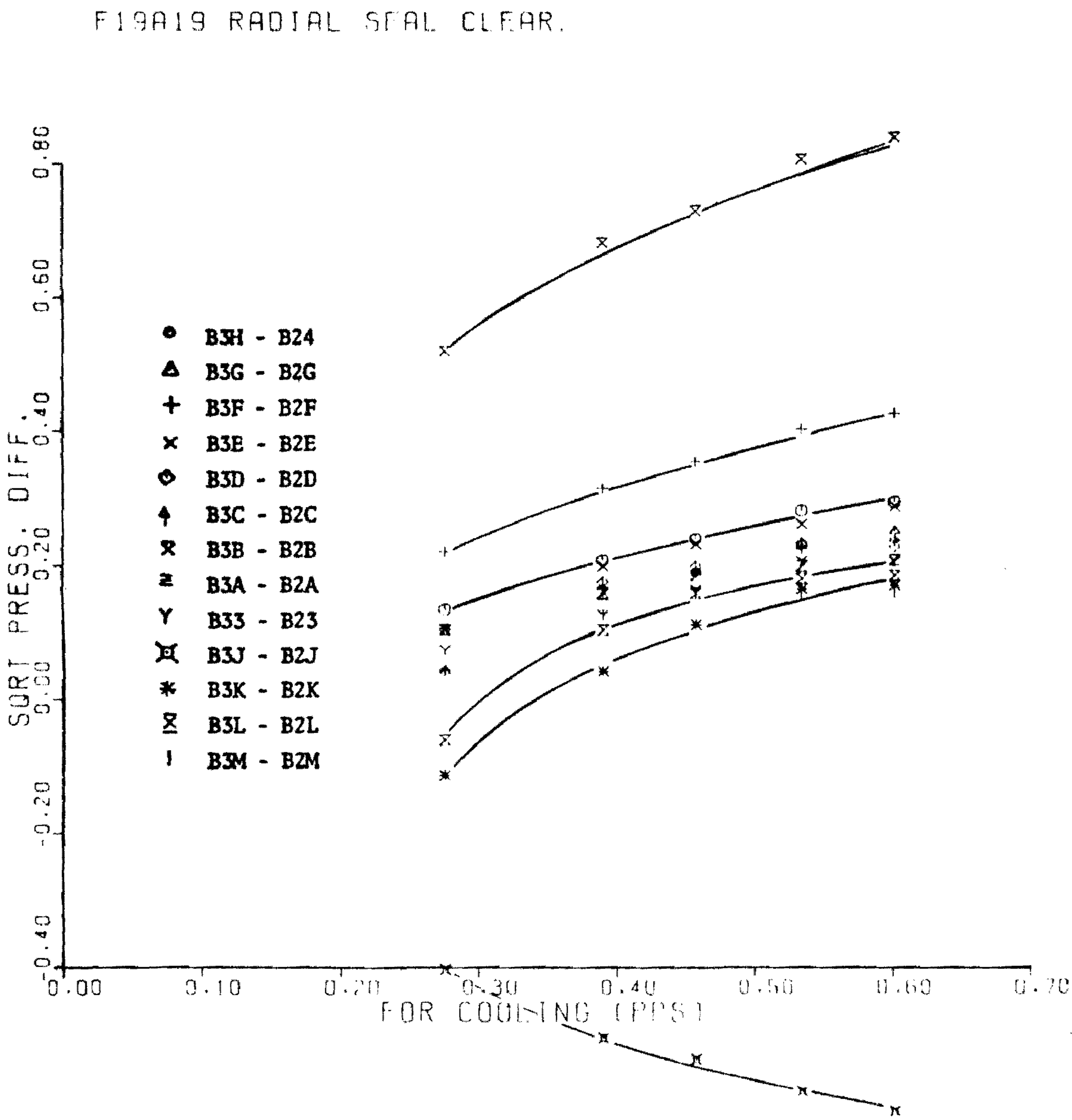


Figure AF-21A

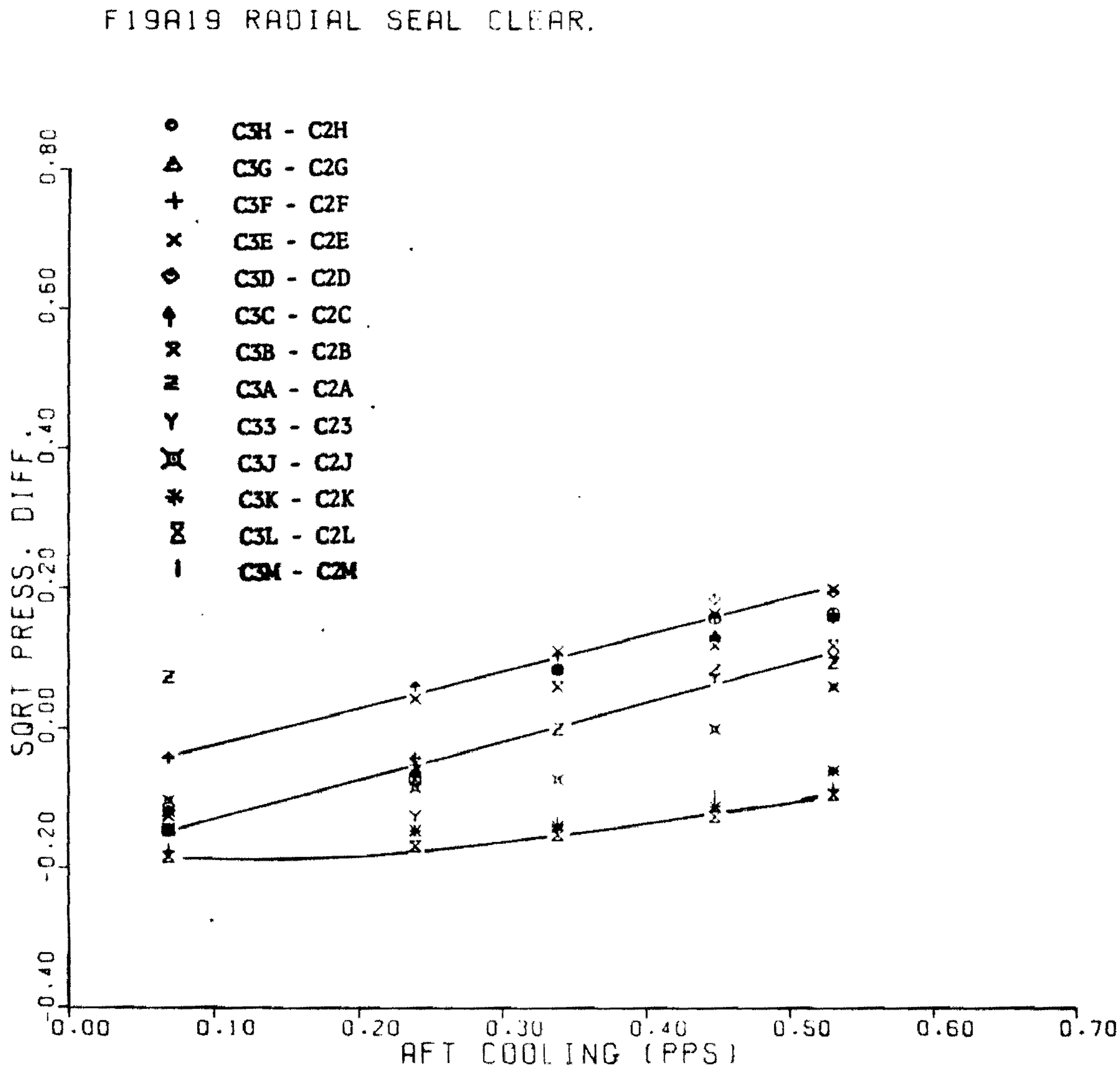


Figure AF-21B

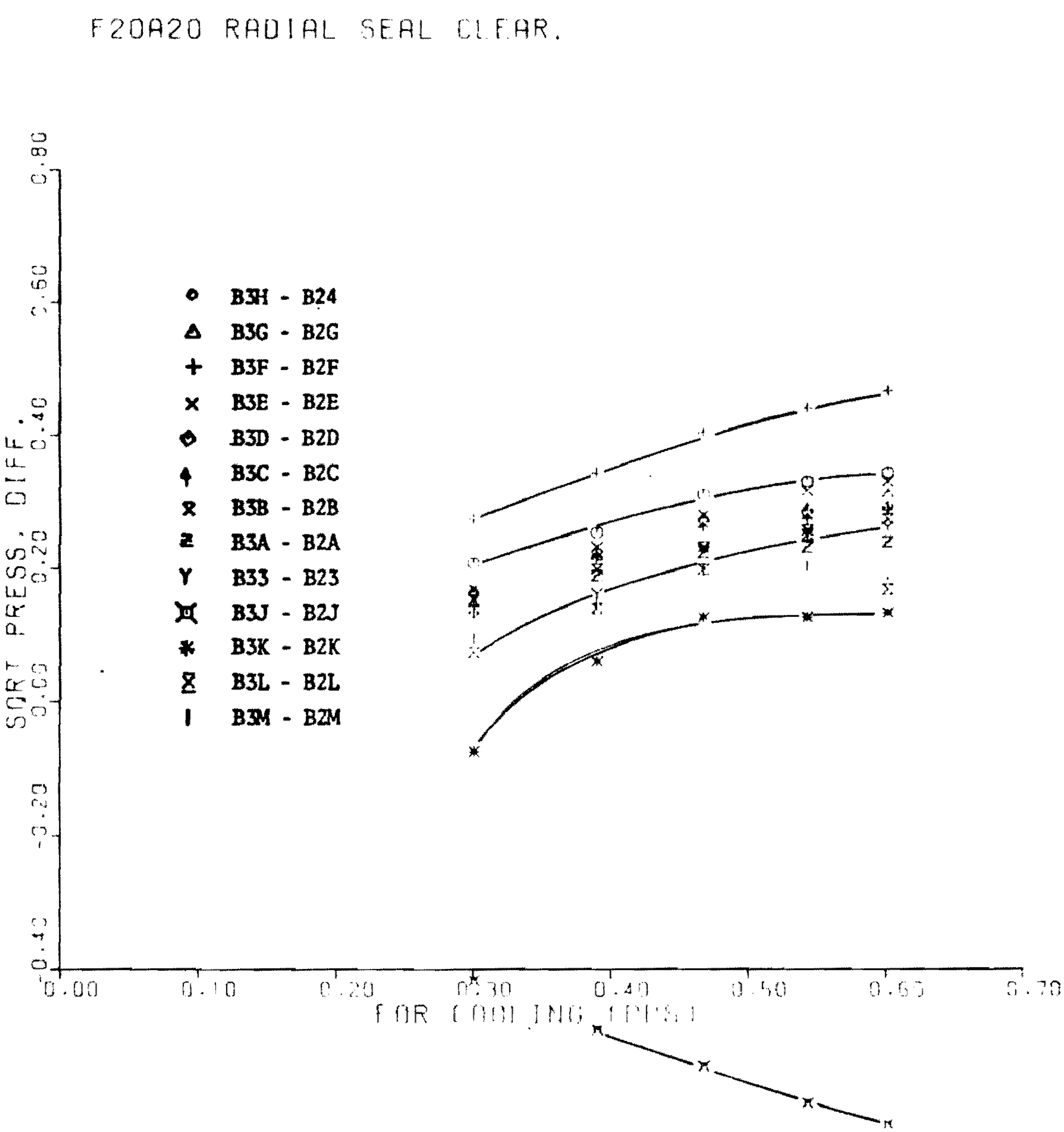


Figure AF-22A

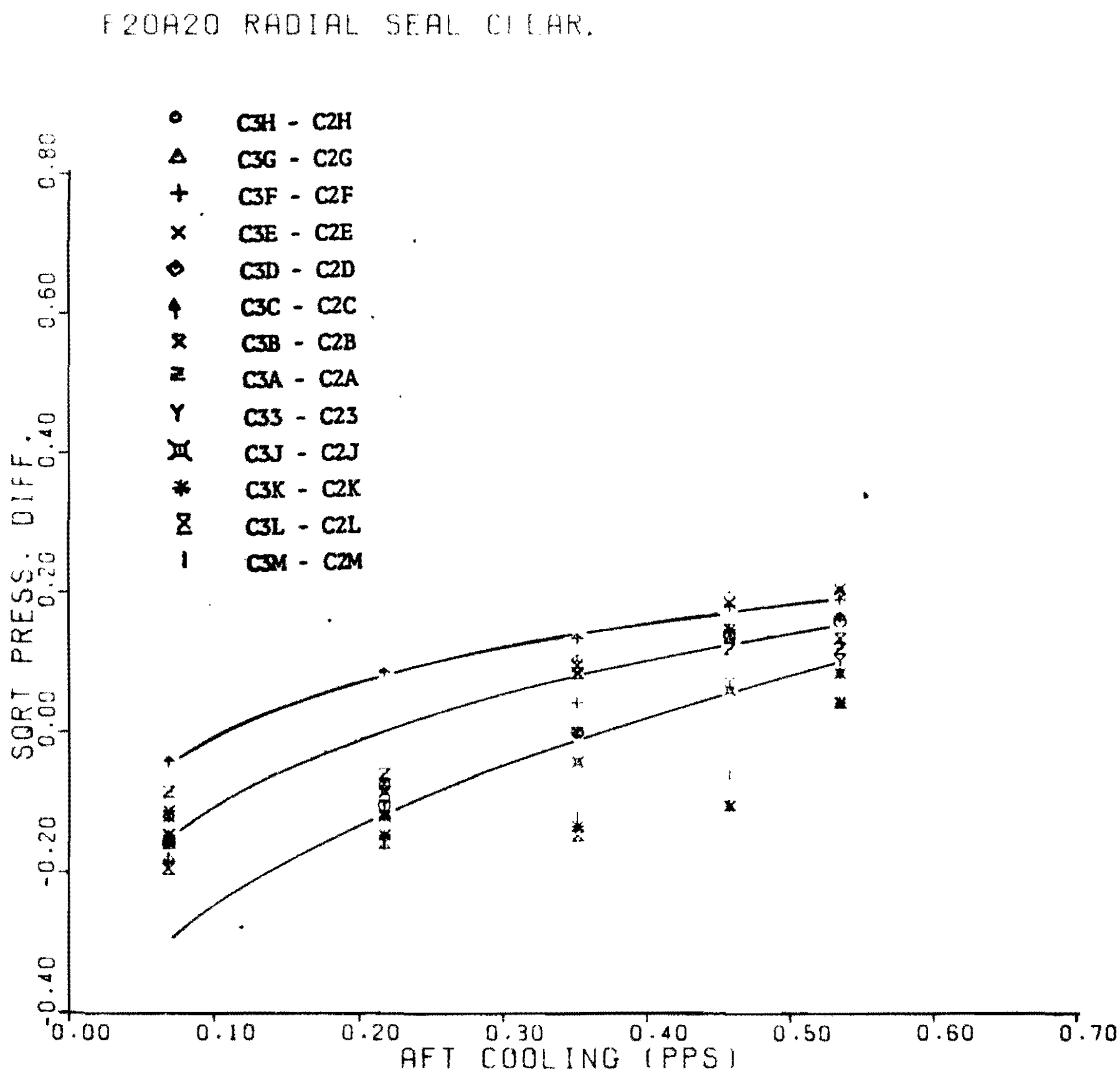


Figure AF-22B

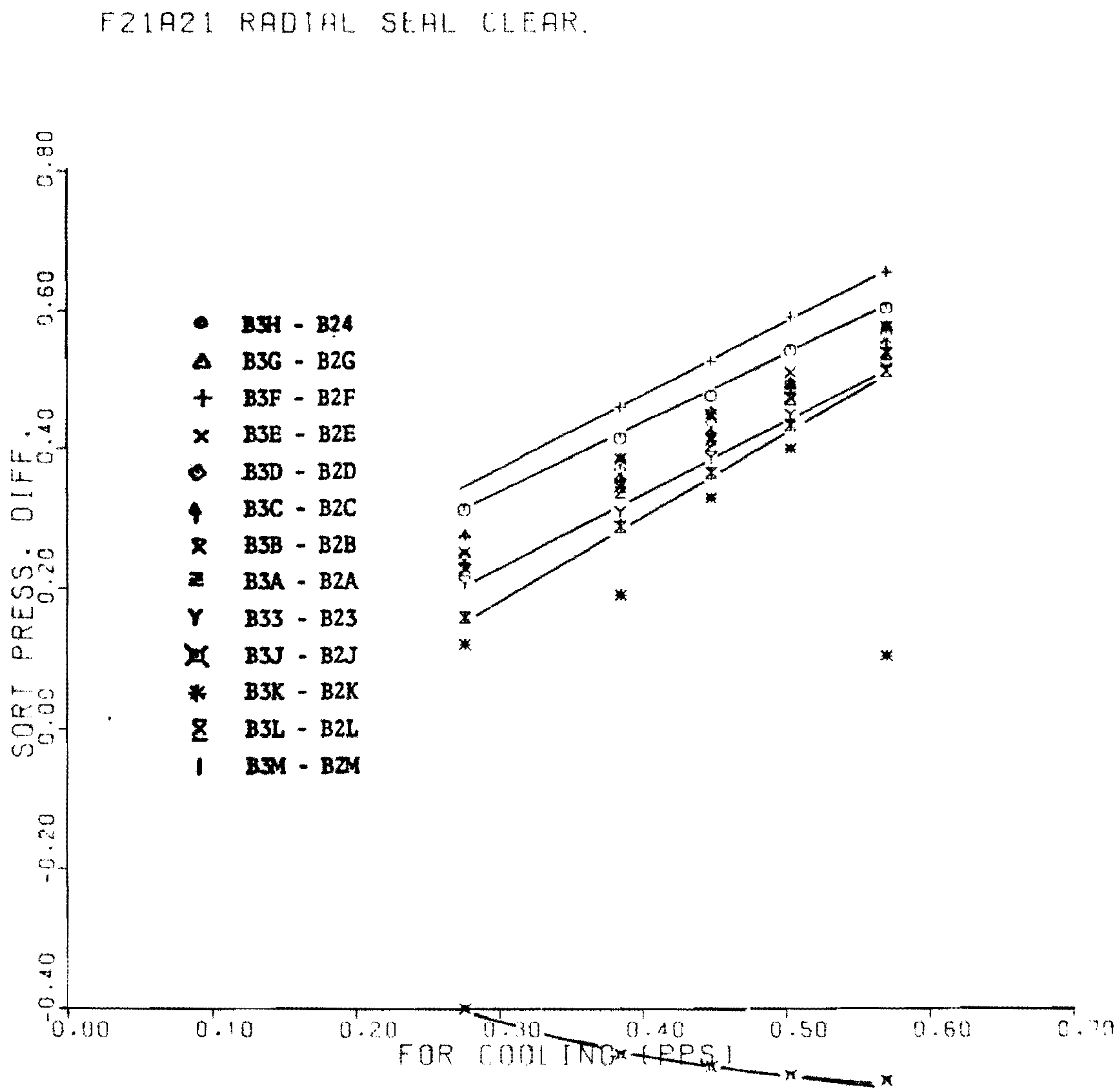


Figure AF-23A

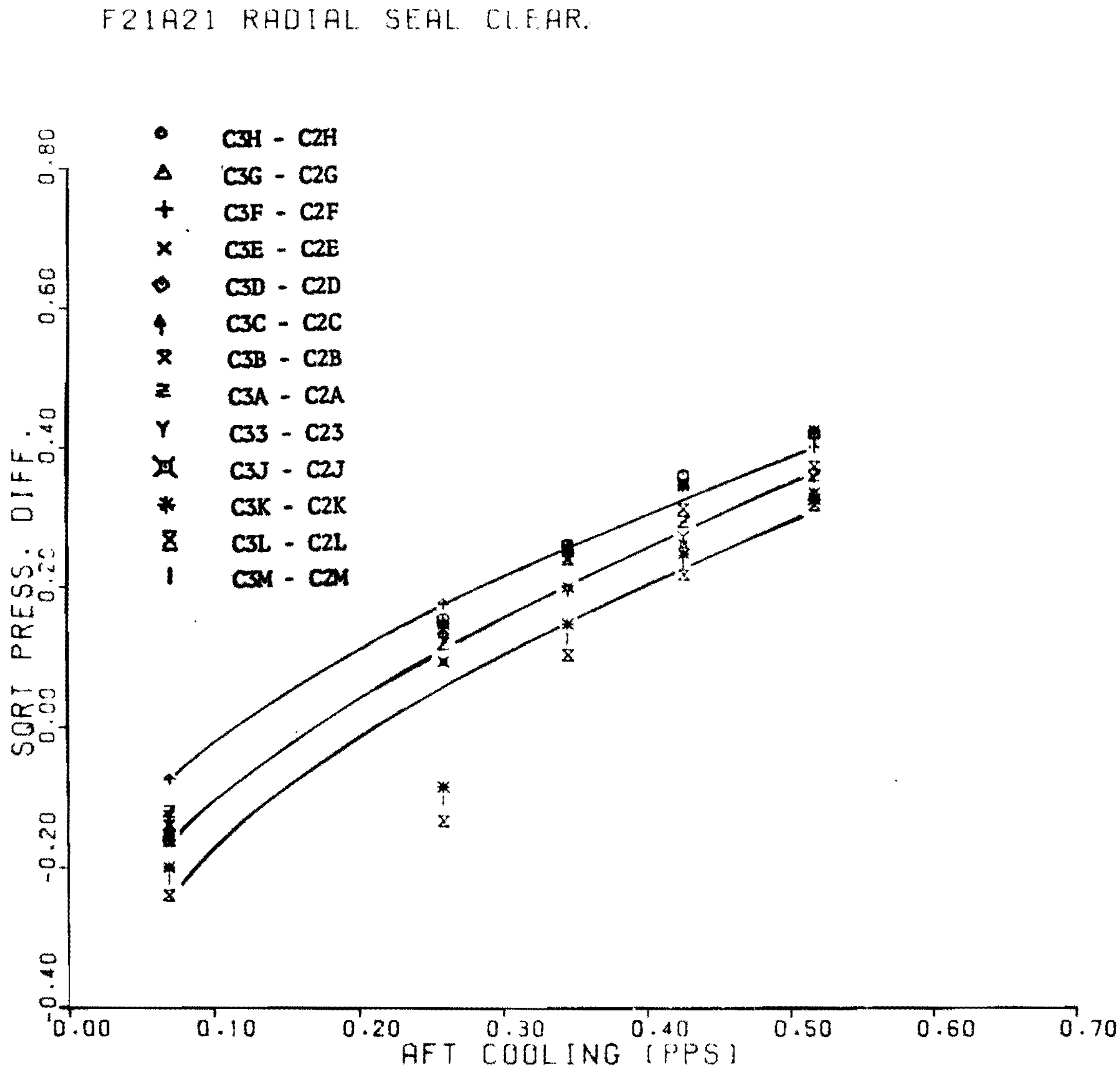


Figure AF-23B

APPENDIX IIID

OTHER SPACE PRESSURE DISTRIBUTION

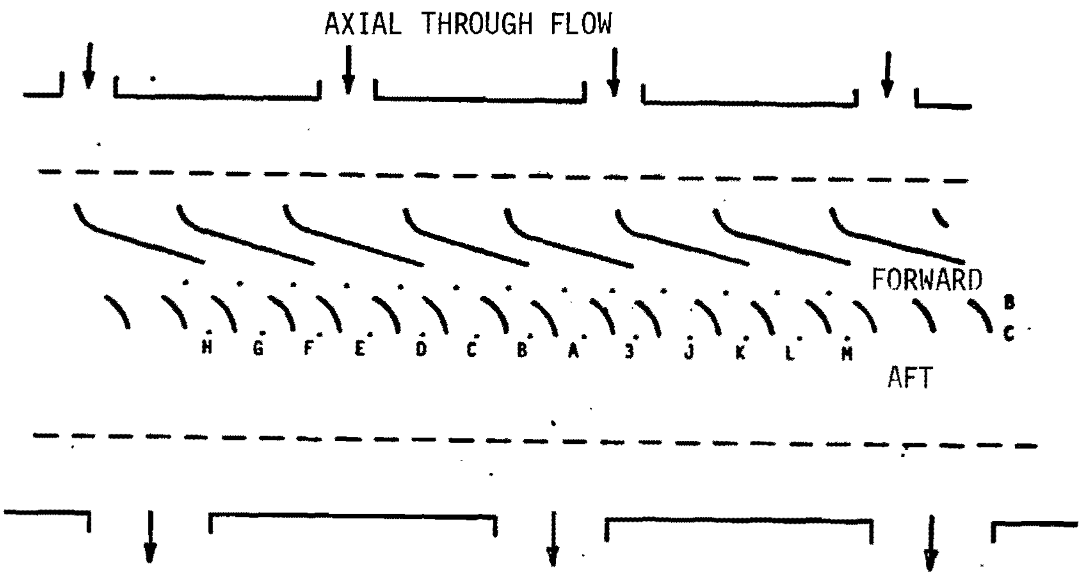


Figure IIID-1. The circumferential location of the pressure taps with respect to the buckets and nozzles at the wall of the casing

Figure IIID-2 and IIID-3 shows the circumferential pressure distribution on the forward and aft side respectively for different cooling rate for 4 lbm/sec axial throughflow and 3000 rpm wheelspeed. Pressures are gage pressure measured relative to ambient.

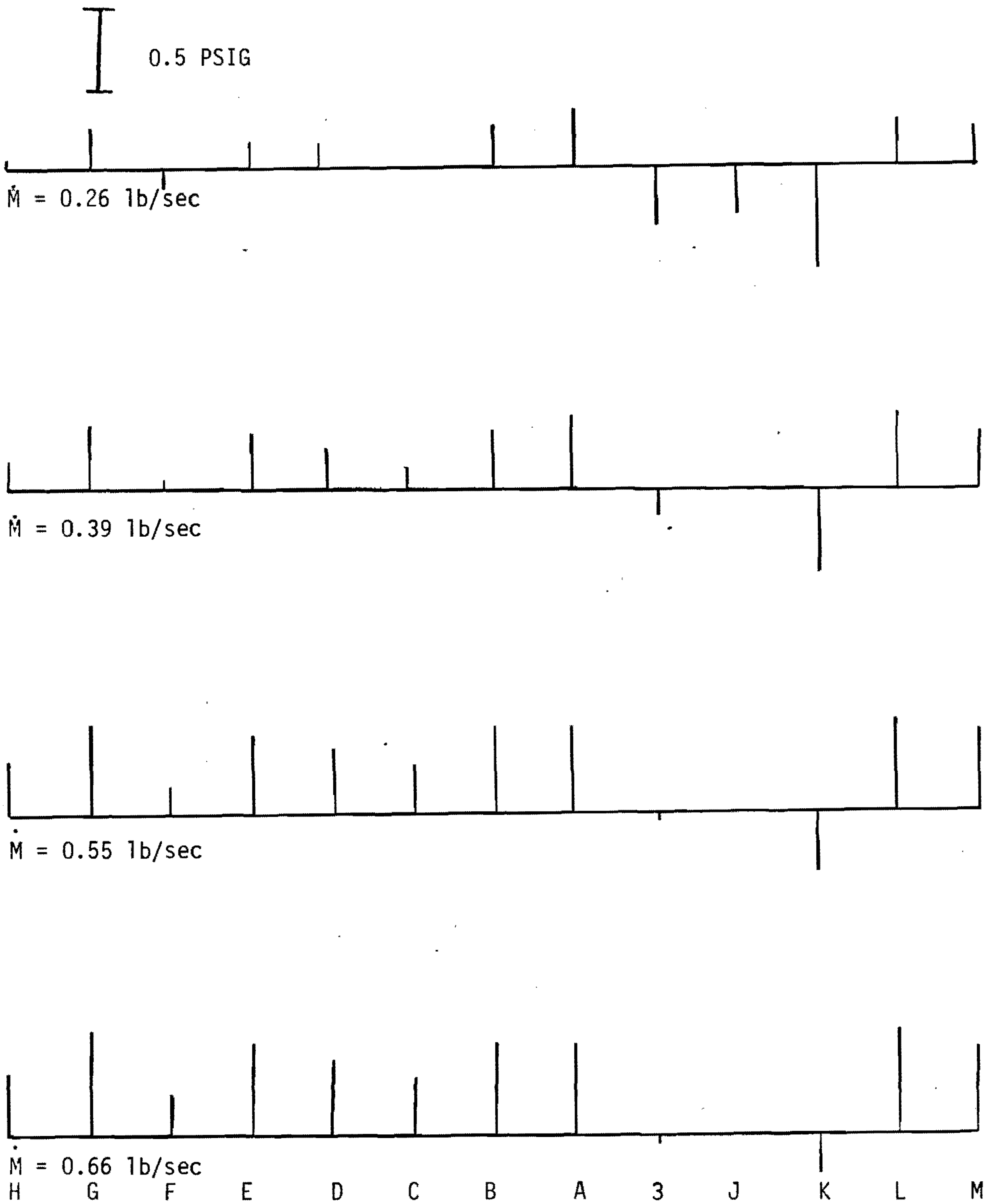


Figure IIID-2. Forward Outer Rim Circumferential Pressure Distribution for Various Cooling Flowrates.

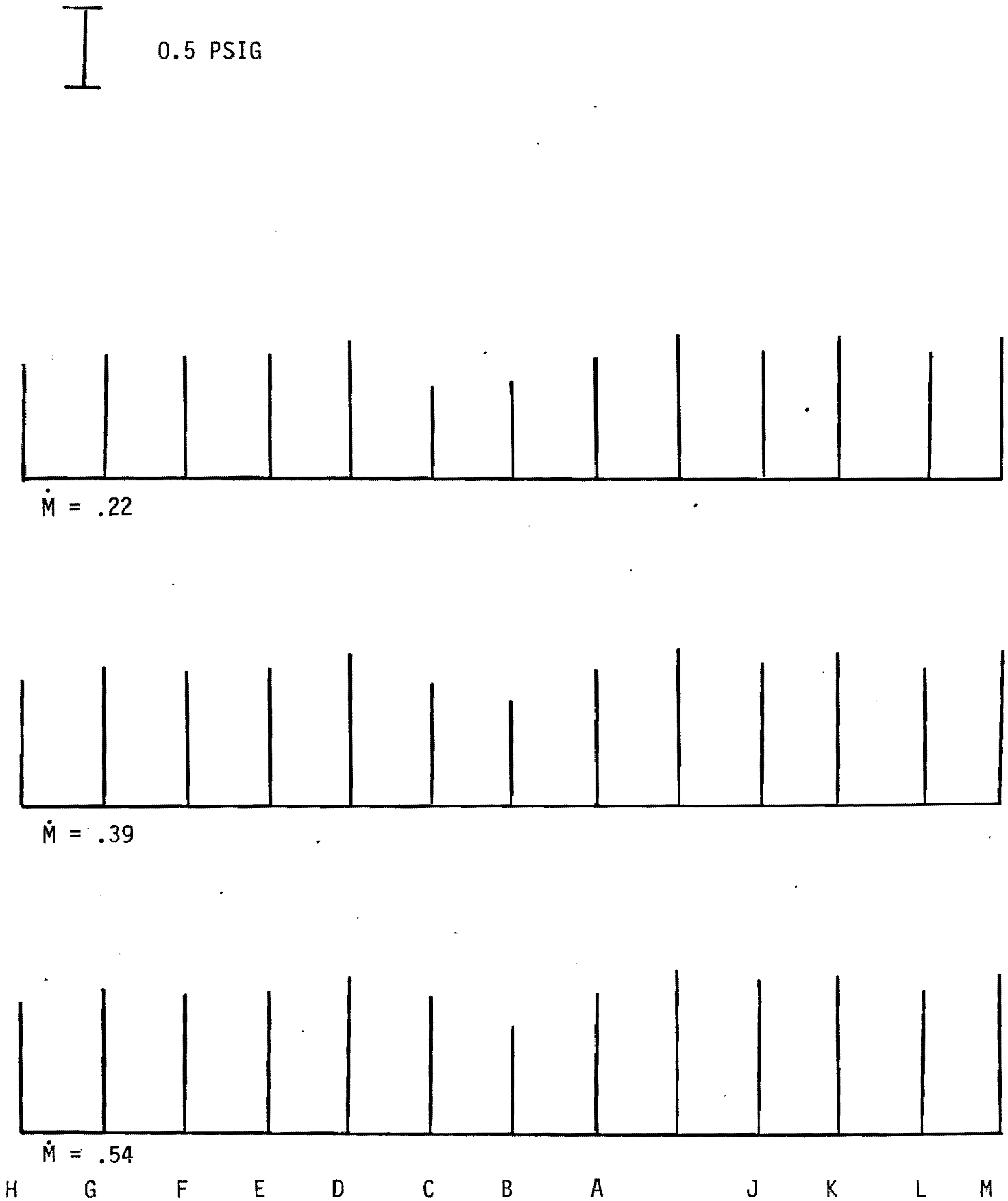


Figure IIID-3. Aft Outer Rim Circumferential Pressure Distribution for Various Cooling Flowrates.

APPENDIX IV-A

MECHANICAL DRAWINGS OF WHEELSPACE APPARATUS

MECHANICAL DRAWINGS OF WHEELSPACE APPARATUS

Number 10-5-523	Wheelspace Test Rig
Number 10-5-523-1	Wheelspace Test Rig
Number 10-5-523-2	Wheelspace Test Rig
Number 10-5-523-3	Wheelspace Test Rig
Number 10-5-523-4	Wheelspace Test Rig

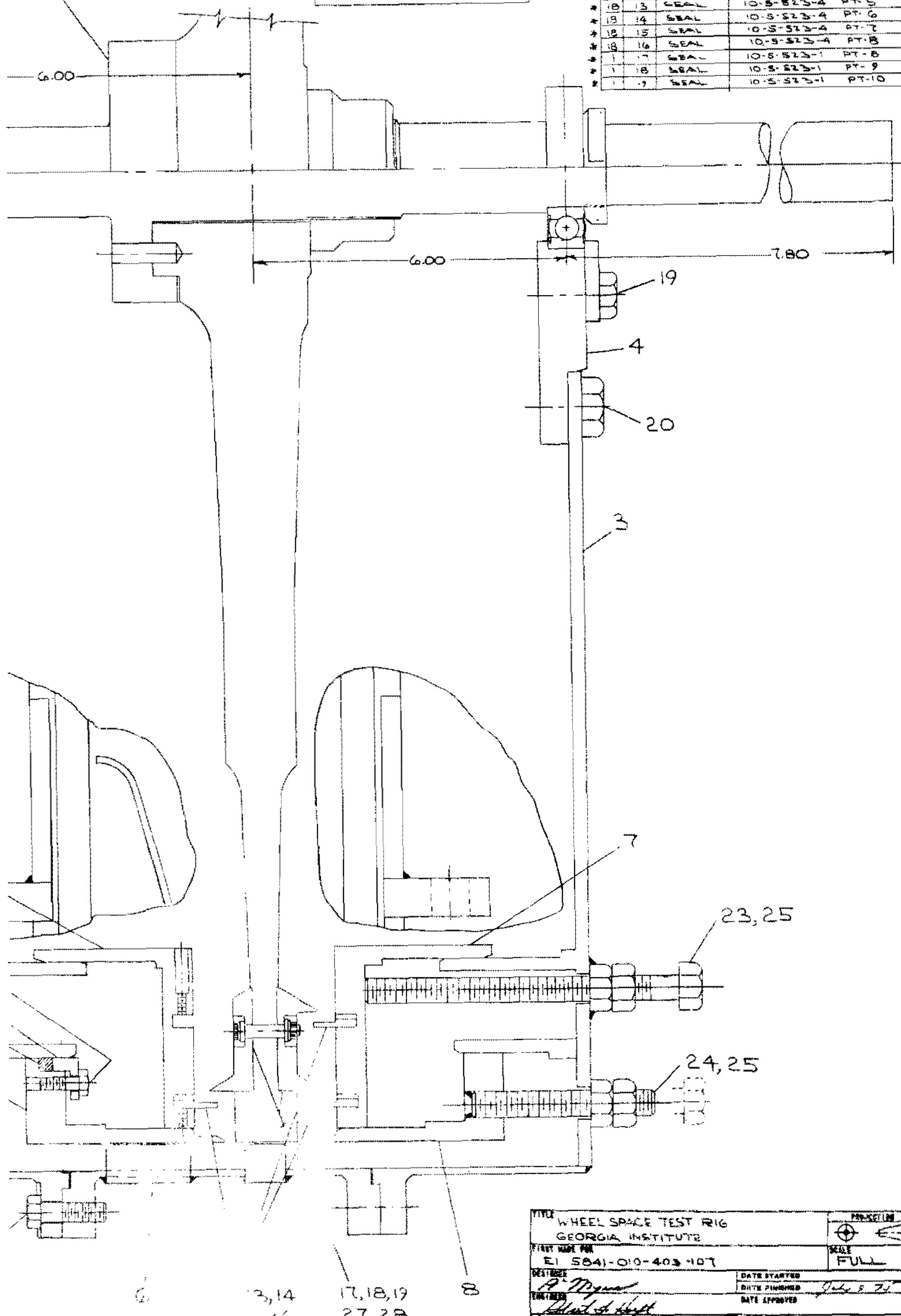
UNLESS OTHERWISE SPECIFIED USE THE FOLLOWING: APPLIED PRACTICES — SURFACES ✓

QTY	PT NO	NAME	IDENT
8	19	BOLT	.50-13×1.00LG ALLOY STL
16	20	BOLT	.625-11×1.00LG ALLOY STL
4	21	BOLT	.25-20×.75LG ALLOY STL
72	22	BOLT	.375-16×1.25LG ALLOY STL
6	23	BOLT	.50-13×6.00 (5.50" of THDS) ALLOY STL
6	24	BOLT	.50-13×3.50 (3.00" of THDS) ALLOY STL
18	25	NUT-HEX	.50-13 ALLOY STL
64	26	SCREW-SET	#6-32×.375LG - ALLOY STEEL
20	27	BOLT 12 PT	#10-32×1.00 LG ALLOY STL
20	28	NUT-12 PT	#10-32 ALLOY STL
1	29	PACKING	VENDOR: JOHN MANVILLE DESCRIPTION: CHEMPAC 2009 .25×.25×110LG

TITLE

FIRST MADE FOR

	QTY	PT NO	NAME	IDENTIFICATION
	1	1	ROTOR ASM	10-S-523-1 PT-1
	1	2	CASE-END	10-S-523-2 PT-2
	1	3	CASE-END	10-S-523-2 PT-3
	2	4	RETAINER-BRG	10-S-523-2 PT 4
	2	5	RETAINER-BRG	10-S-523-2 PT-5
	1	6	CASE-MID	10-S-523-3 PT-1
	2	7	RETAINER-SEAL	10-S-523-4 PT-1
	1	8	RETAINER-SEAL	10-S-523-4 PT-2
	1	9	RETAINER-SEAL	10-S-523-4 PT-3
	1	10	RETAINER-BLADE	10-S-523-4 PT-4
*	18	11	SPACER	10-S-523-4 PT-9
*	18	12	SPACER	10-S-523-4 PT-10
*	18	13	SEAL	10-S-523-4 PT-5
*	18	14	SEAL	10-S-523-4 PT-6
*	18	15	SEAL	10-S-523-4 PT-7
*	18	16	SEAL	10-S-523-4 PT-8
*	1	17	SEAL	10-S-523-1 PT-8
*	1	18	SEAL	10-S-523-1 PT-9
*	1	19	SEAL	10-S-523-1 PT-10



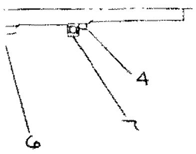
TITLE: WHEEL SPACE TEST RIG GEORGIA INSTITUTE	PROJECTION
FIRST MADE FOR: E1 5841-010-403-407	SCALE: FULL
DESIGNER: A. Myers	DATE STARTED / DATE FINISHED: July 8 71
ENGINEER: Robert A. Hoyt	DATE APPROVED
MATLS	AERO THERMO
MFG	Q A
GENERAL ELECTRIC — GAS TURBINE — REVIEW DATE	NO. 10-S-523 — REV.

REVISIONS

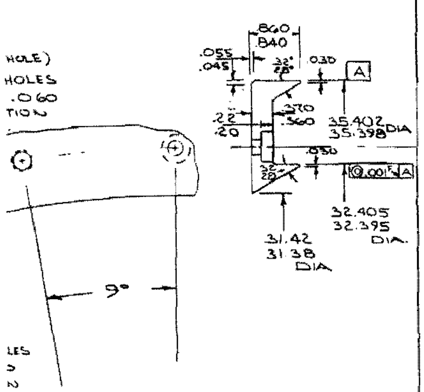
GENERAL ELECTRIC

9 10 11 12

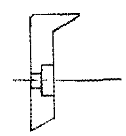
QTY	PT NO	NAME	IDENTIFICATION
1	1	ROTOR ASM	———
1	2	SHAFT	10-5-523-1 PT-2
1	3	WHEEL	10-5-523-1 PT-3
2	4	LOCKNUT	10-5-523-1 PT-4
1	5	DOWEL	.375 DIA × 1.25 LG ALLOY STL
1	6	NUT (1.938-16)	GE DWG 239A506 PT-7
2	7	BRG, BALL	VENDOR: NEW DEPARTURE BRISTOL CONN. DESCRIPTION– BRG. NO. - 97508 TYPE - 3000 I D - 1.5748 OD - 3.1496 WIDTH - .7087 TWO END SEALS



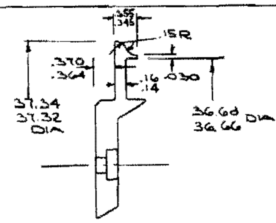
ASM



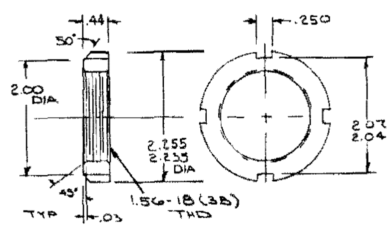
MATL - 4140 AISI
125✓



(9) OTHERWISE SAME AS PT-8



(10) OTHERWISE SAME AS PT-8

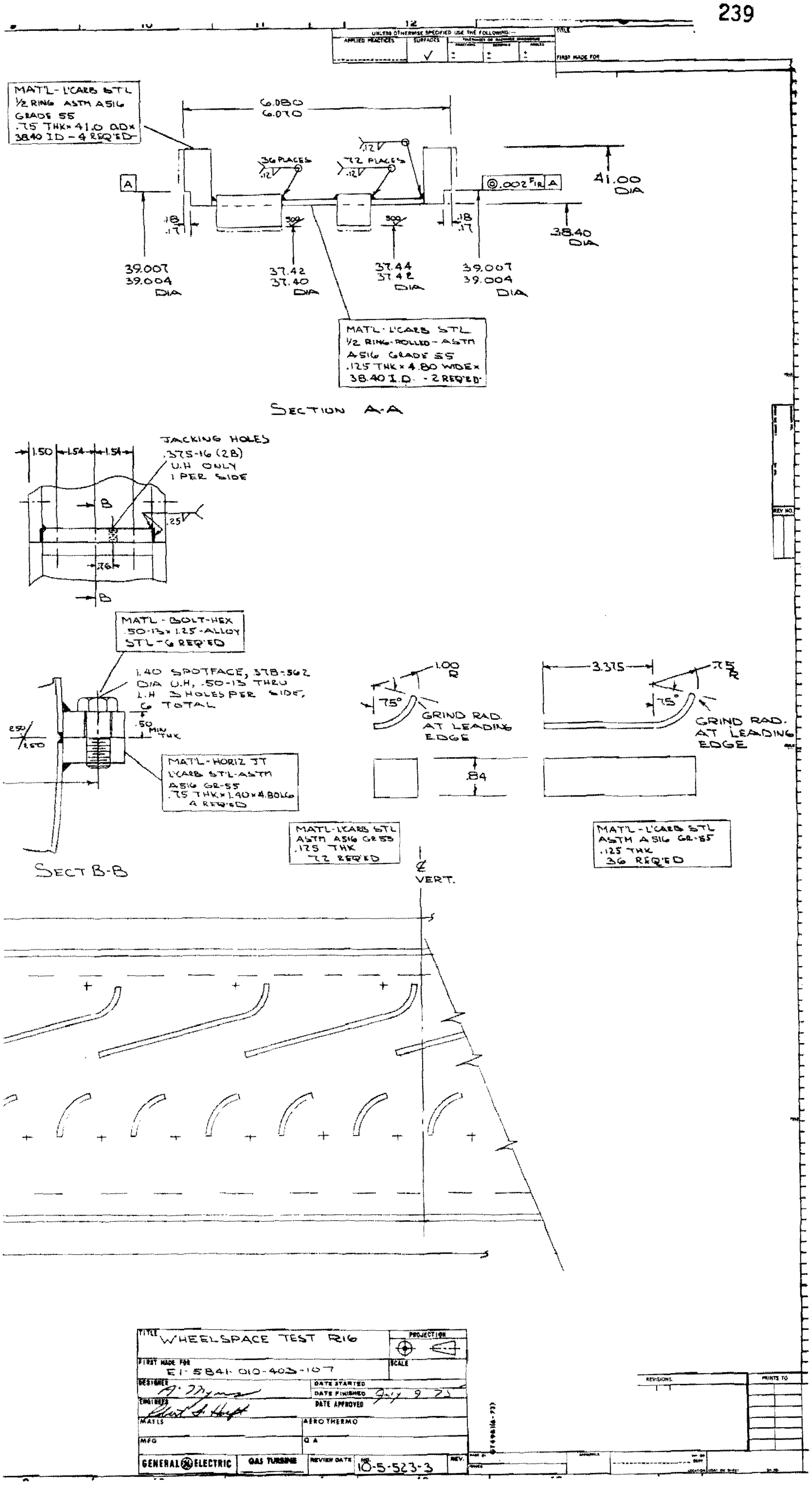


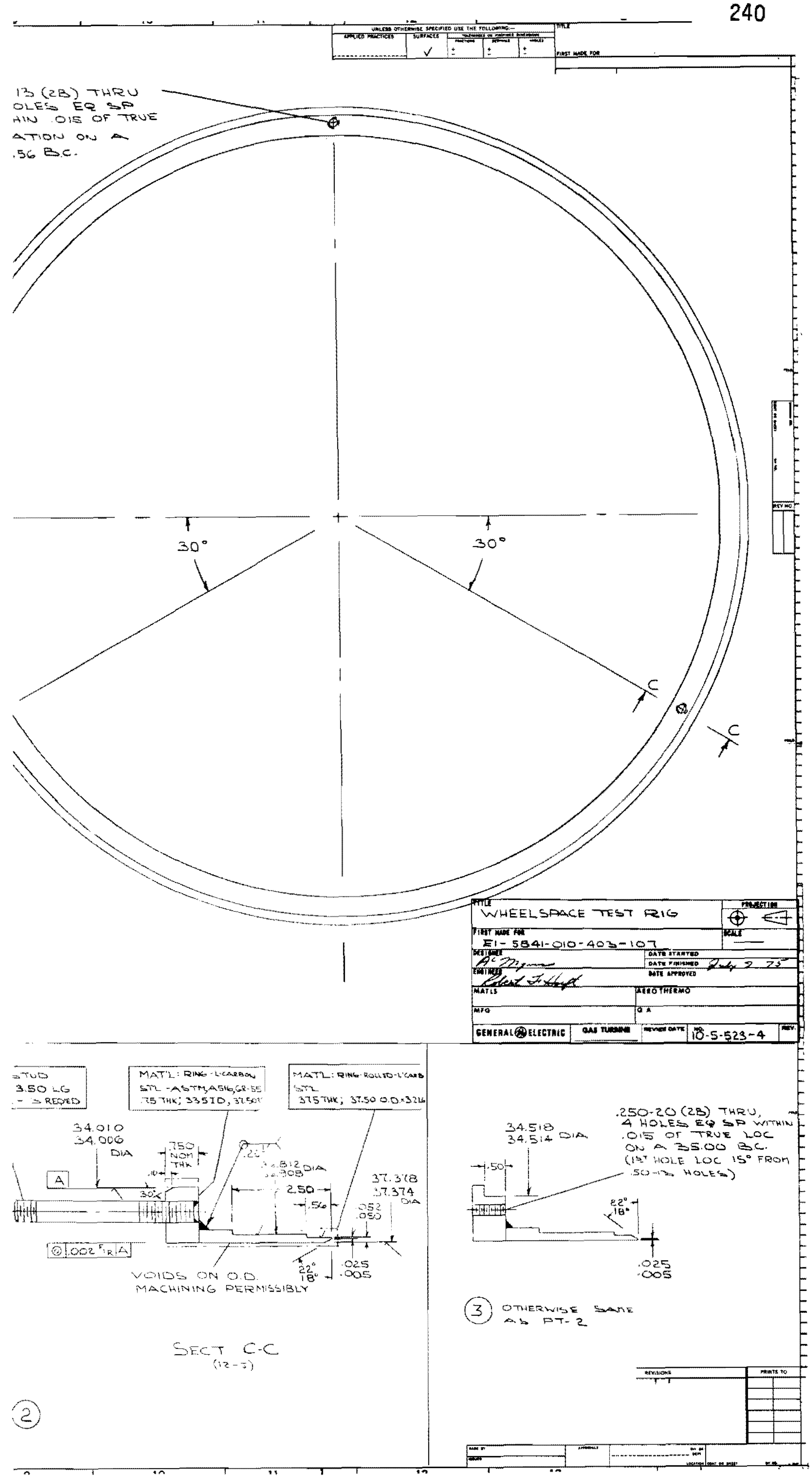
(4) LOCKNUT
MATL - 4140 AISI

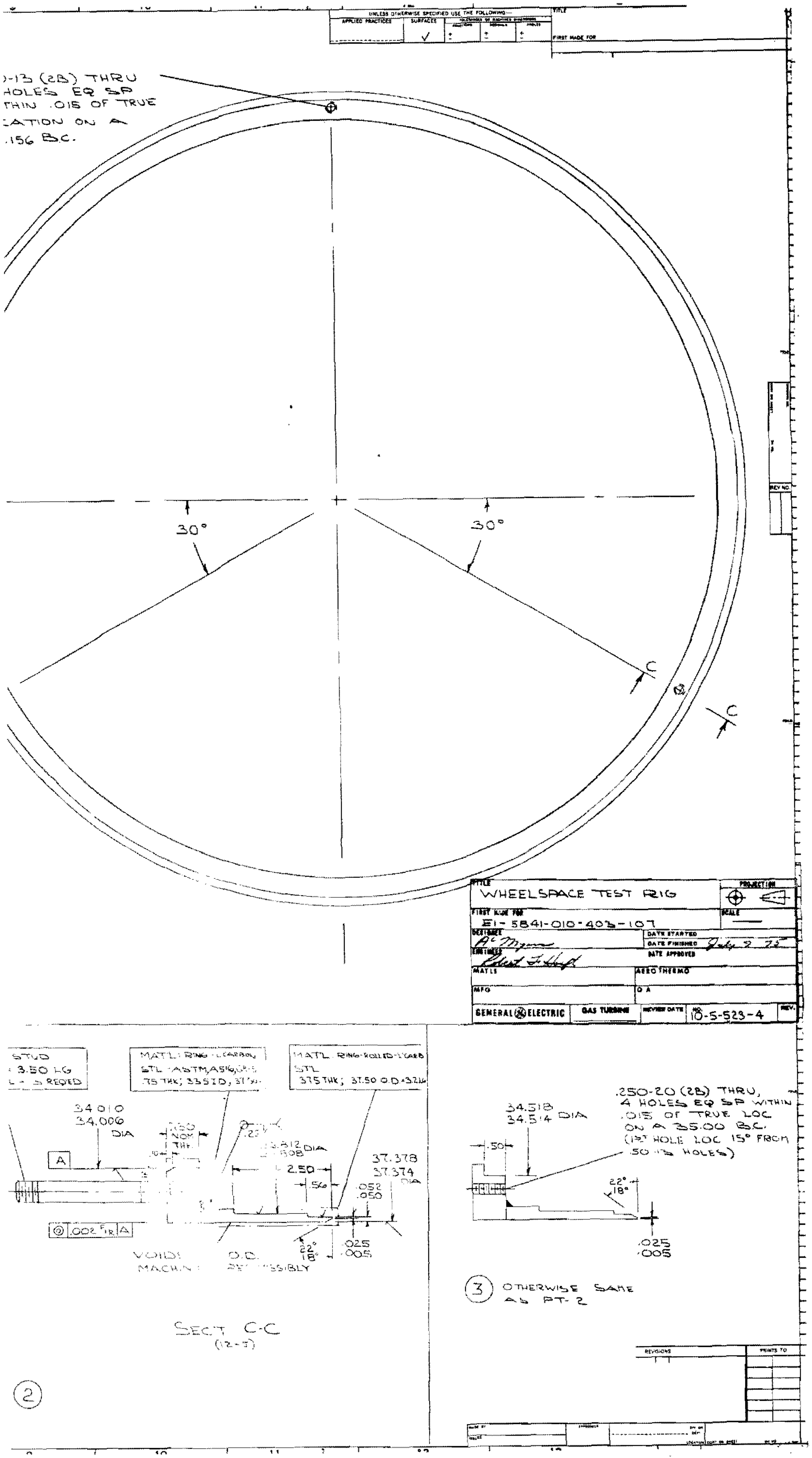
TITLE: WHEEL SPACE TEST RIG			PROJECTION
FIRST MADE FOR: E1-5841-010-403-107			SCALE
DESIGNER		DATE STARTED	
		DATE FINISHED	
ENGINEER		DATE APPROVED	
MATLS		AERO THERMO	
MFG		Q A	
GENERAL ELECTRIC	GAS TURBINE	REVIEW DATE	NO. 10-5-523-1 REV.

REVISIONS

PRINTS TO


MAT'L - L'CARB STL
1/2 RING ASTM A516
GRADE 55
.75 THK × 41.0 OD × 38.40 ID - 4 REQ'ED
6.080
6.070
.12
36 PLACES
72 PLACES
A
.002 FIR A
41.00 DIA
38.40 DIA
.18
.17
39.007
39.004
DIA
37.42
37.40
DIA
37.44
37.42
DIA
MAT'L - L'CARB STL
1/2 RING-ROLLED - ASTM
A516 GRADE 55
.125 THK × 4.80 WIDE × 38.40 I.D. - 2 REQ'ED
SECTION A-A
JACKING HOLES
.375-16 (2B)
U.H ONLY
1 PER SIDE
1.50
1.54
1.54
.25
.76
B
MATL - BOLT-HEX
.50-13 × 1.25 - ALLOY
STL - 6 REQ'ED
1.40 SPOTFACE, .378-.562
DIA U.H, .50-13 THRU
L.H 3 HOLES PER SIDE,
6 TOTAL
.50 MIN THK
MATL - HORIZ JT
L'CARB ST'L - ASTM
A516 GR-55
.75 THK × 1.40 × 4.806
4 REQ'ED
SECT B-B
1.00 R
75°
GRIND RAD.
AT LEADING
EDGE
.84
3.375
.75 R
75°
GRIND RAD.
AT LEADING
EDGE
MATL - L'CARB STL
ASTM A516 GR 55
.125 THK
72 REQ'ED
MATL - L'CARB STL
ASTM A516 GR-55
.125 THK
36 REQ'ED
℄ VERT.
WHEELSPACE TEST RIG
E1-5841-010-403-107
GENERAL ELECTRIC
GAS TURBINE
10-5-523-3


13 (2B) THRU
OLES EQ SP
HIN .015 OF TRUE
ATION ON A
.56 B.C.
30°
30°
C
C
WHEELSPACE TEST RIG
E1-5841-010-403-107
GENERAL ELECTRIC
GAS TURBINE
10-5-523-4
STUD
3.50 LG
REQ'D
MAT'L: RING-L'CARBON STL-ASTM A516, GR-55 .75 THK; 33.5 ID, 37.50 OD
MAT'L: RING-ROLLED-L'CARB STL .375 THK; 37.50 O.D.x32.16
34.010
34.006
DIA
A
.002 FIR A
VOIDS ON O.D. MACHINING PERMISSIBLY
SECT C-C
(12-3)
2
34.518
34.514 DIA
.250-20 (2B) THRU, 4 HOLES EQ SP WITHIN .015 OF TRUE LOC ON A 35.00 B.C. (1ST HOLE LOC 15° FROM .50-13 HOLES)
.025
.005
3 OTHERWISE SAME AS PT-2


UNLESS OTHERWISE SPECIFIED USE THE FOLLOWING
APPLIED PRACTICES
SURFACES
FIRST MADE FOR
-13 (2B) THRU
HOLES EQ SP
THIN .015 OF TRUE
CATION ON A
.156 B.C.
30°
30°
C
C
WHEELSPACE TEST RIG
PROJECTION
FIRST MADE FOR
E1-5841-010-403-107
SCALE
DESIGNER
DATE STARTED
DATE FINISHED
DATE APPROVED
ENGINEER
MATLS
AERO THERMO
MFG
Q A
GENERAL ELECTRIC
GAS TURBINE
REVIEW DATE
NO. 10-5-523-4
REV.
STUD
3.50 LG
3 REQ'D
MATL: RING - CARBON STL - ASTM A516 GR 5
.75 THK; 33.5 I.D.; 37.50
MATL: RING - ROLLED - CARB STL
.375 THK; 37.50 O.D. x 32.6
34.010
34.006
DIA
A
.002 FIR A
33.812
33.808 DIA
2.50
.56
37.378
37.374
DIA
.052
.050
22°
18°
.025
.005
VOIDS O.D.
MACHINE PERMISSIBLY
SECT C-C
(12-7)
2
.250-20 (2B) THRU,
4 HOLES EQ SP WITHIN
.015 OF TRUE LOC
ON A 35.00 B.C.
(1ST HOLE LOC 15° FROM
.50 HOLES)
34.518
34.514 DIA
.50
22°
18°
.025
.005
3
OTHERWISE SAME
AS PT-2
REVISIONS
PRINTS TO

APPENDIX IV-B

PHOTOGRAPHS OF WHEELSPACE APPARATUS

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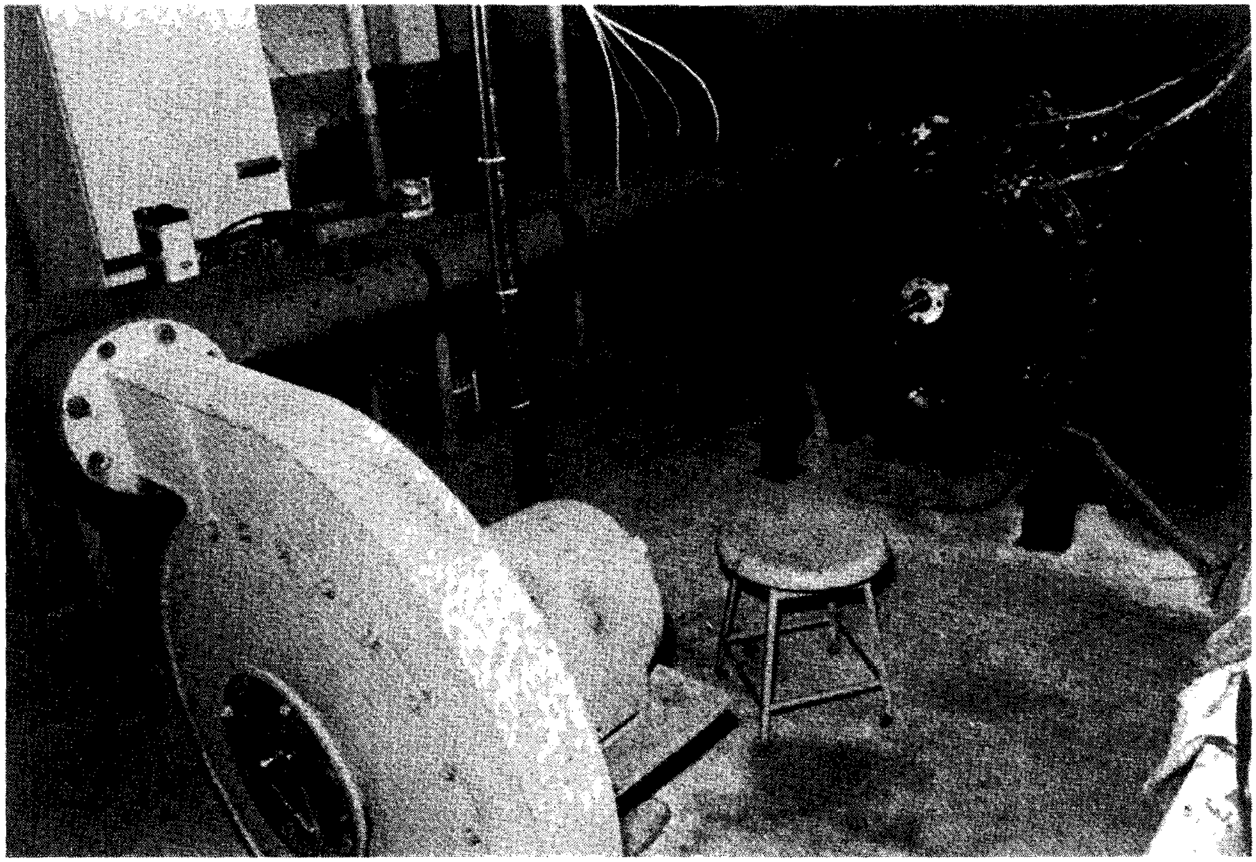

Figure B1. Overview of Wheelspace Test Facility. Wheelspace Apparature right background viewed from aft side, left foreground is blower to supply cooling air, drive engine behind wheelspace apparatus.

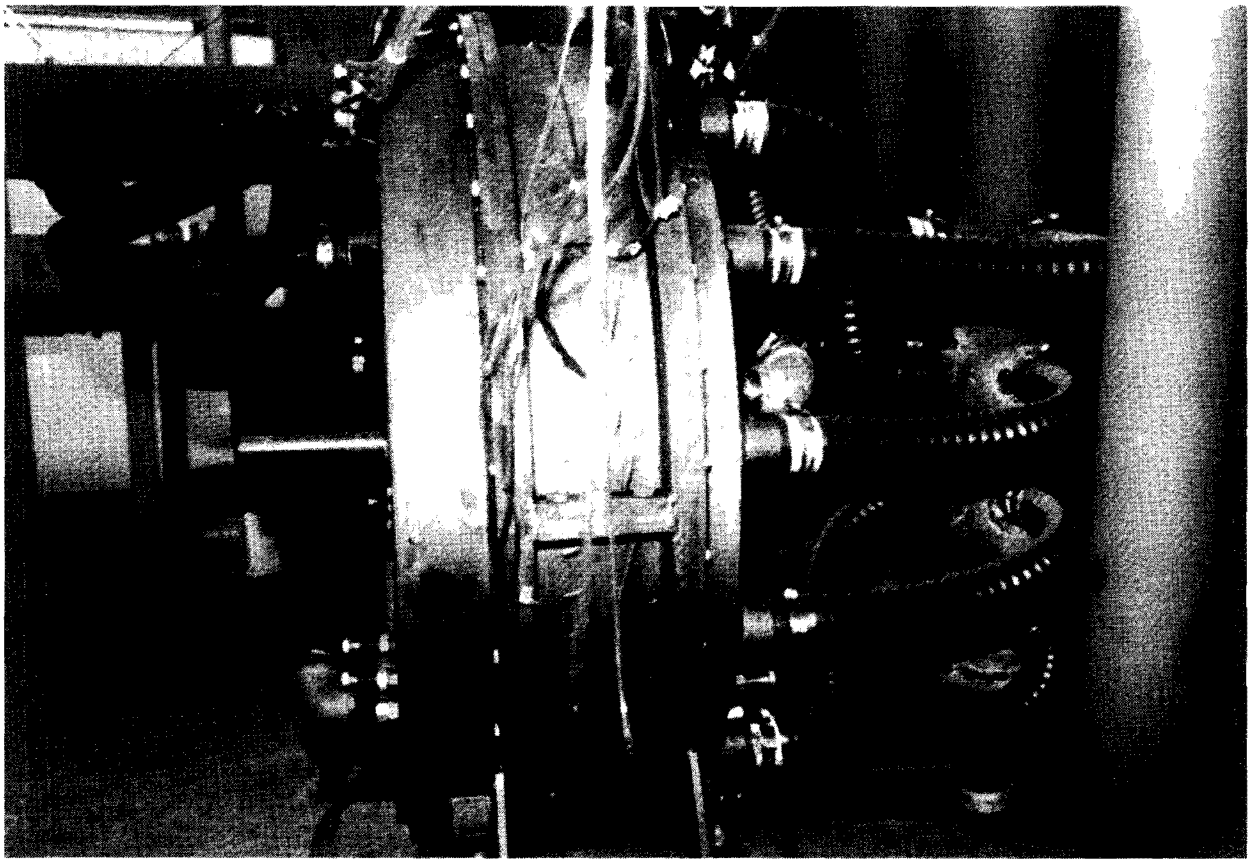

Figure B2. Side View of Wheelspace Test Apparatus. Rim flow enters on right and exits on left, forward wheelspace on right and aft on left, drive engine is on right.

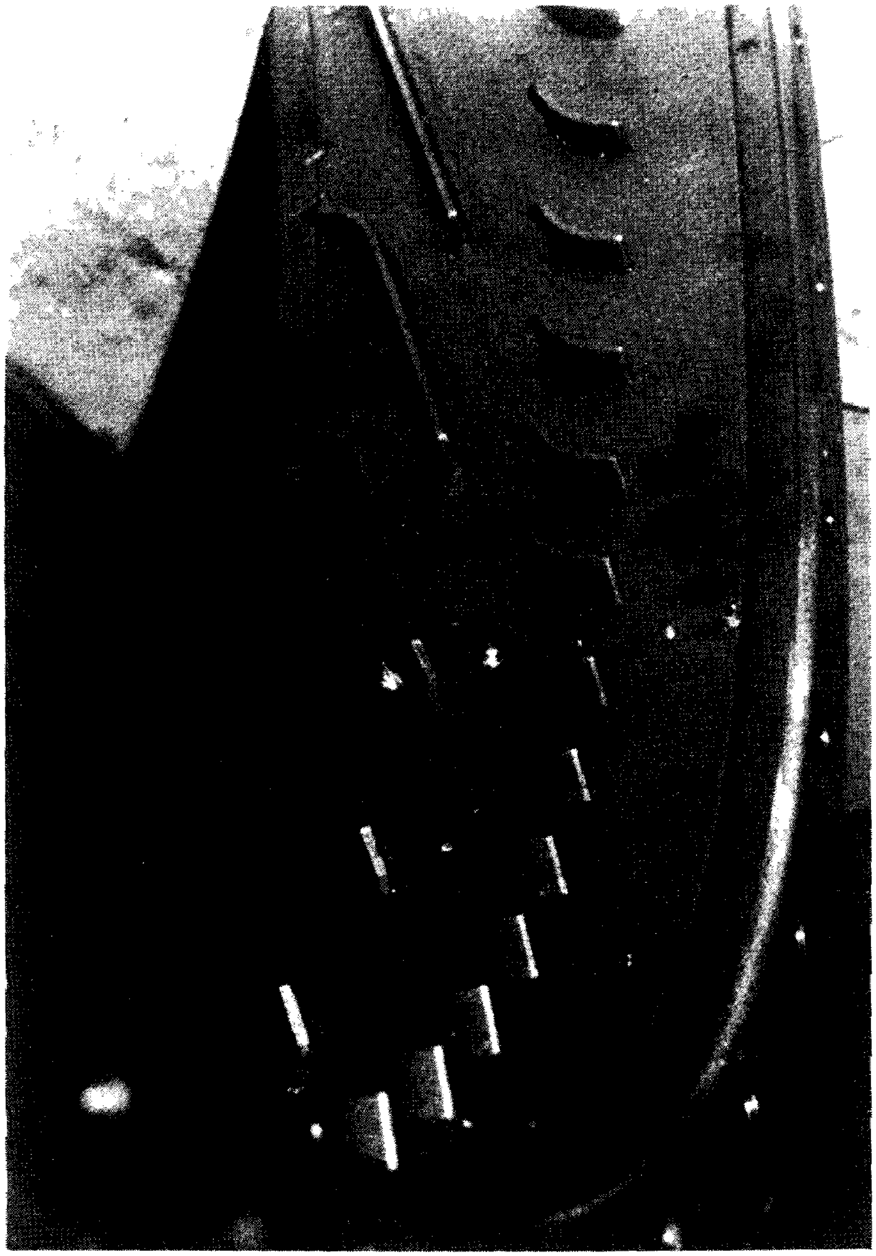

Figure B4. Rim Cover with Blades and Rim Flow Instrumentation. Nozzle blades on left and wheel turning blades on right, rim flow from left to right, rim flow instrumentation along a horizontal line in middle of picture.

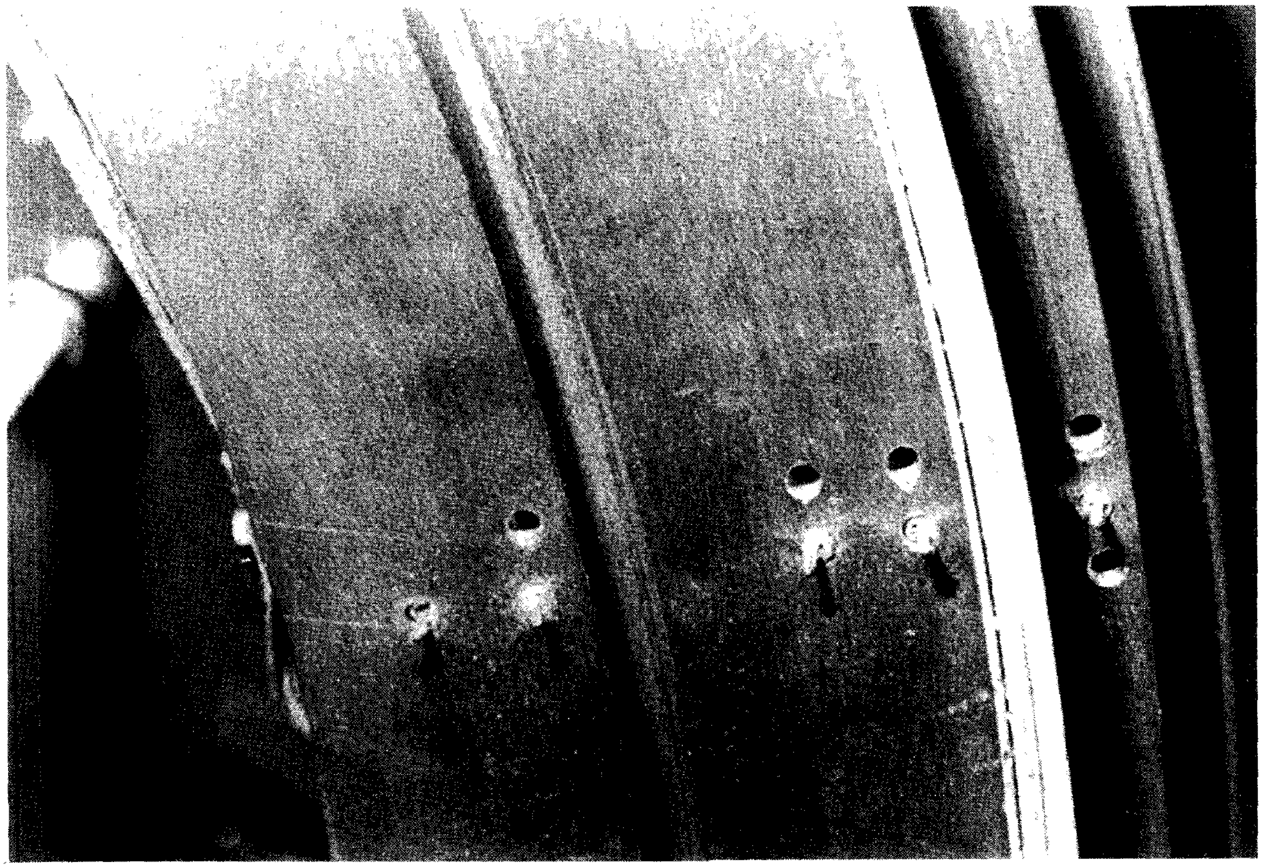

Figure B5. Seal Area Instrumentation. Radically distributed pressure taps and thermocouples in seal area typical of #3 circumferential position (forward or aft).