NASA CR-159812

(NASA-CR-159812) CORE COMPRESSOR EXIT STAGE STUDY, 2 Final Report (Pratt and Whitney Aircraft Group) 90 p HC A05/MF A01 CSCL 21E

N80-23312

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G3/07 20299

CORE COMPRESSOR EXIT STAGE STUDY

II. FINAL REPORT

by

R.F. Behlke, E.A. Burdsall, E. Canal Jr. and N. D. Korn

October 1979

UNITED TECHNOLOGIES CORPORATION
Pratt & Whitney Aircraft Group
Commercial Products Division

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
NASA-Lewis Research Center
Contract NAS3-20578

FOREWORD

The study described herein was performed under NASA Contract NAS-3-20578 by the Pratt & Whitney Aircraft Group, Commercial Products Division, United Technologies Corporation, under the direction of Mr. N. T. Monsarrat, Program Manager. The NASA Project Manager was Mr. R. S. Ruggeri, NASA-Lewis Research Center, Fluid System Components Division, Fan and Compressor Branch. The work was performed during the period 20 October 1976 through 30 June 1979. The authors wish to acknowledge the participation and contributions in the fulfillment of this contract by Messrs. W. T. Hanley and H. A. Harmon of the Pratt & Whitney Aircraft Group and by Mr. C. L. Crockett of the United Technologies Research Center, Test Facilities Operations Group.

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SUMMARY

Tests were conducted on two three-stage compressors, designed with aspect ratios of 0.81 and 1.22, to acquire detailed overall aerodynamic performance data on the effects of aspect ratio in high hub-tip ratio stages, similar to those at the rear of advanced multistage compressors. Both compressors were designed for 15 percent surge margin. The 0.81 aspect ratio compressor (3S1) was designed for a higher pressure ratio than the 1.22 aspect ratio compressor (3S2) in recognition of the increased capability believed to exist at lower aspect ratios.

The test results showed that the 0.81 aspect ratio compressor exceeded its design surge margin by nine percent despite its higher design loading and demonstrated a peak adiabatic efficiency of 86.1 percent. The 1.22 aspect ratio compressor achieved a higher peak efficiency level (87.0 percent) than the 0.81 aspect ratio compressor, but fell short of its surge margin goal by three percent. The lower aspect ratio compressor exhibited greater efficiency in the endwall regions and a depressed efficiency in the midspan regions. The first stage of the lower aspect ratio compressor exhibited a stalled static pressure characteristic while all three stages of the higher aspect ratio compressor stalled uniformly but below their peak design level.

INTRODUCTION

Compressors for advanced aircraft turbofan engines must combine high efficiency with adequate stability margin in a compact, light-weight configuration. Pratt & Whitney Aircraft experience (ref. 1) with single and multistage compressors suggests that low aspect ratio airfoils have the potential to meet these requirements by combining high loading capability with previously developed low endwall loss technology. A test program was devised to determine the benefits of low aspect ratio in the high hub-tip ratio rear stage environment of an advanced multistage compressor. The aerodynamic configuration chosen for testing was based on the last three stages of the eight-stage, Advanced Multistage Axial Flow Compressor (AMAC) studied under a previous contract (ref. 2). A low Mach number three-stage rig was selected as the test vehicle.

This report presents the results of both the 0.81 aspect ratio (3S1) compressor and the 1.22 aspect ratio (3S2) compressor tests. Details of the design of each of these compressors are presented in ref. 3.

APPARATUS

AERODYNAMIC DESIGN

Two three-stage compressors, designated 3S1 and 3S2, were designed to demonstrate improved blading for the rear stages of highly loaded, advanced core compressors. A schematic of the 3S1 and 3S2 compressors is shown in Figure 1. The average aspect ratio of the 3S1 configuration was 0.81, the overall pressure ratio at design speed was 1.35, and the average diffusion factor (D Factor) was 0.529. The 3S2 configuration was similar to 3S1, but was designed for a fifty percent higher aspect ratio (1.22). The principal aerodynamic design parameters of the 3S1 and 3S2 compressors are given in Table I. The design mean wheel speed, tip diameter, and flow capacity were established to be compatible with the limitations of an existing test facility.

TABLE I

PRINCIPAL AERODYNAMIC DESIGN PARAMETERS

	3S1	3S2
Inlet Corrected Flow; kg/sec (lbm/sec)	4.30 (9.47)	4.30 (9.47)
Corrected Mean Wheel Speed, 50 percent Span; m/sec (ft/sec)	167 (547)	167 (547)
Pressure Ratio	1.357	1.324
Overall Adiabatic Efficiency, %	88.30	88.70
Aspect Ratio, Average	0.81	1.22
Solidity, Average	1.10	1.10
Inlet Hub-Tip Ratio	0.915	0.915
Exit Hub-Tip Ratio	0.915	0.915
Work Coefficient -E-, Average	0.702	0.644
Flow Coefficient - Cx/U, Average (50 percent Span)	0.440	0.444
D Factor, Average*	0.529	0.491
P/(Po-P), Average	0.497	0.467
Tip Clearance, Average cm (in.)	0.033 (0.013)	0.033 (0.013)
Reaction	0.517	0.517

*D Factor Average = Sum of mass average diffusion factors from streamline analysis for the various blade rows divided by the number of blade rows.

The aerodynamic design (see ref. 3) was performed in three steps. First, the analytical design system was adjusted to ensure performance agreement with data from tests of three-stage compressors similar to the 3S1 configuration. Next a preliminary design based on a meanline approach provided a rough flowpath and average aerodynamic quantities. Finally a detailed full-span design, which utilized a streamline calculation procedure, was used to set blading geometry and finalize flowpath dimensions. Circular arc mean camber line airfoils with a 65 series thickness distribution were chosen for all rows because of their excellent low Mach number performance characteristics.

MECHANICAL DESIGN

Compressor Rig

The basic mechanical design of the 3S1 and 3S2 compressor rigs (see ref. 3) consisted of an assembly of interlocking aluminum rings, which formed the compressor case, and a set of aluminum wheels, which were keyed to a central shaft and formed the compressor hub. The 3S1 compressor assembly is shown as the top half of the schematic in Figure 1 and 3S2 as the lower half. A rotating drum design consisting of a rotor assembly supported by bearings at the front and rear of the compressor was used for the inner portion of the rig. The rotor assembly consisted of a stack of aluminum rotor blade carrier and spacer wheels keyed to a central shaft threaded at both ends. The stator assembly consisted of a stack of interlocking stator vane carrier and spacer rings. The parts were secured in place by steel endplates clamped together by tie rods.

All blading was cast using an aluminum alloy material, A356-T6. Blading attachment was accomplished by means of a bolt, which secured the blade or vane to the blade or vane carrier. Typical rotor and cantilevered stator assemblies are shown in Figures 2 and 3, respectively.

Test Facility

The compressor test facility, located at the United Technologies Research Center, consists of the compressor drive system, the inlet and discharge flow ducting, and the data acquisition system. The drive system and compressor are located within a test cell. The operating controls, monitoring instrumentation, and data acquisition system are located in a separate control room.

The major components of the compressor drive system are a DC electric motor and a speed-increasing gearbox. An automatic speed control is utilized to maintain speed at a preset value.

Filtered ambient air is ducted into the test cell and through a plenum that provides uniform pressure and temperature distributions at the compressor inlet. A throttle downstream of the compressor controls the rate of airflow through the compressor. The flow is exhausted through a duct containing a silencer to reduce noise levels before discharging to the atmosphere. The facility is shown schematically in Figure 4.

The Computerized Precision Acquisition Sequencing System (COMPASS) is used for control, acquisition, and recording of the experimental data. Utilizing a minicomputer for control of the data acquisition sequences, COMPASS can acquire parameters that include identification information and calibration data, as well as analog and digital transducer data. The system is self calibrating via primary and secondary pressure and voltage standards and is capable of a pressure measurement accuracy of ±0.10 percent of full scale reading and a temperature measurement accuracy of ±0.14°C (±0.25°F).

INSTRUMENTATION AND CALIBRATION

Compressor Performance Instrumentation

Rig instrumentation was selected to obtain overall compressor performance. Wall static pressures were incorporated to evaluate individual rotor as well as individual stage characteristics relative to design values. Figure 5 shows the locations of the overall performance instrumentation as well as the location of the inter-blade row static pressure taps.

Compressor airflow was calculated from measured total and static pressures in an axial plane close to the bellmouth exit defined in Figure 1 as station 0. Total temperatures used in the calculation were obtained from probes at the compressor inlet instrumentation plane, station 1 (Figure 5). Prior to the rig test program, a detailed flow calibration was performed in which radial traverses in four circumferential locations were made at several flow rates. The data were integrated to establish the true flow at the rig inlet flow measuring plane. The true flow was then correlated with the flow calculated from the midspan instrumentation used during the tests and the correlation was used to establish a flow coefficient which was applied to all data, resulting in an accuracy within one percent of the true flow.

Compressor rotor speed was measured by means of a magnetic pickup. A tachometer converted the pulse rate from the pickup into rotor speed in rpm. Accuracy was within 0.1 percent.

Pressures from pole rakes in the inlet and discharge and from static pressure taps were sensed by gage type analog pressure transducers mounted in multiport scanning valves. These pneumatic switches were also used to apply known pressures produced by the calibration hardware to the appropriate pressure transducers. The accuracy of the pressure measurement system was 0.1 percent of full-scale reading.

All temperatures were measured by Chromel-Alumel Type K thermocouples. Each thermocouple wire was individually calibrated to establish its unique properties relative to the 1968 International Temperature Scale. The temperature measurement system is accurate to $\pm 0.14^{\circ}$C ($\pm 0.25^{\circ}$F).

Compressor inlet and exit total pressure and temperature radial rakes consisted of both five and four element probes. Thus, pressures and temperatures were sampled at nine radial locations. Typical pressure and temperature rakes are shown in Figures 6 and 7. The location, number, and type of performance instrumentation used are given in Table II.

TABLE II

PERFORMANCE INSTRUMENTATION COMPRESSORS 3S1 AND 3S2

Instr. Plane Location	Parameter Measured	Type, Quantity and Radial Location	Circumferential Position Angle - CW From TDC From Rear
Station 0 (Flow Measuring Station	P_o	8 miniature single keilhead probes located at midspan	45°, 90°, 135°, 180° 225°, 270°, 315°, 0°
	P	8 outer wall static taps	15°, 60°, 105°, 150° 195°, 240°, 285°, 330°
	P	8 inner wall static taps	15°, 60°, 105°, 150° 195°, 240°, 285°, 330°
Station 1 (Compressor Inlet)	P_o	3-five element rakes, keilhead sensors at 5, 20, 50, 80 and 95% span.	110°, 230°, 350°
		3-four element rakes, Keilhead sensors at 10, 30, 70, and 90% span.	50°, 170°, 290°
	T_o	6-five element rakes, T/C sensors at 5, 20, 50, 80 and 95% span.	35°, 95°, 155°, 215° 275°, 335°
		6-four element rakes, T/C sensors at 10, 30, 70, and 90% span.	5°, 65°, 125°, 185°, 245°, 305°
	P	6-outer wall static taps	20°, 80°, 140°, 200° 260°, 320°
		6-inner wall static taps	20°, 80°, 140°, 200° 260°, 320°
Station 2 (IGV-R1)	P	4-outer wall static taps	60°, 150°, 240°, 330°
Station 3 (R1-S1)	P	4-outer wall static taps	60°, 150°, 240°, 330°
Station 4 (S1-R2)	P	4-outer wall static taps	60°, 150°, 240°, 330°
Station 5 (R2-S2)	P	4-outer wall static taps	60°, 150°, 240°, 330°

TABLE II (Cont'd)

PERFORMANCE INSTRUMENTATION COMPRESSOR 3S1 AND 3S2

Instr. Plane Location	Parameter Measured	Type, Quantity and Radial Location	Circumferential Position Angle - CW From TDC From Rear
Station 6 (S2-R3)	P	4-outer wall static taps	60°, 150°, 240°, 330°
Station 7 (R3-S3)	P	4-outer wall static taps	60°, 150°, 240°, 330°
Station 8 (Downstream) of S3)	P	4-outer wall static taps	60°, 150°, 240°, 330°
Station 9 (Compressor Exit)	P_o*	6-five element rakes, keilhead sensors at 5, 20, 50, 80 and 95% span	5.5°, 66.6°, 121.0°, 182.1°, 243.4°, 304.0°
		6-four element rakes, keilhead sensors at 10, 30, 70, and 90% span	32.1°, [illegible], 156.3°, [illegible], 269.9°, 331.0°
	T_o*	6-five element rakes, T/C sensors at 5, 20, 50, 80 and 95% span	53.2°, 107.7°, 168.8°, 229.9°, 291.0°, 352.2°
		6-four element rakes, T/C sensors at 10, 30, 70 and 90% span.	18.8°, 79.9°, 141.0°, 202.1°, 256.6°, 317.7°
	P	6-outer wall static taps	12.1°, 73.2°, 131.0°, 192.1°, 249.9°, 311.0°
		6-inner wall static taps	12.1°, 73.2°, 131.0°, 192.1°, 249.9°, 311.0°

*This instrumentation was located circumferentially to access a discharge stator wake and vane gap.

Rig Safety Instrumentation

Instrumentation was incorporated to monitor rig and drive motor vibrations, bearing temperatures, rotor/case rub, vane/drum rub, and compressor surge.

PROCEDURES

TEST PROCEDURE

The test program consisted of a shakedown run, the performance program, a program to measure running tip clearance, and a data validity check to identify possible performance deterioration during the test program.

Shakedown tests were conducted to substantiate the mechanical integrity of the rig and to verify that the instrumentation hookup and the data acquisition and reduction systems were functioning properly.

The performance program consisted of obtaining six sets of speedlines at each of three separate speeds: 85, 100, and 105 percent of design speed. This procedure ensured statistically accurate average speedlines. In addition, surge points were obtained for each speed.

Dynamic rotor tip clearances were calculated from measurements of the long blade clearances at 18, 85, 100, and 105 percent rotor speed. Measurements were recorded for each rotor at six circumferential locations.

The data validity program consisted of six sets of speedlines at 100 percent of design speed to verify that overall compressor performance had not deteriorated during the test program.

DATA REDUCTION TECHNIQUES

Data reduction programs developed at Pratt & Whitney Aircraft were used to process the overall performance, stage performance, rotor performance, and radial profiles for the two compressors. Raw data from the test stand were recorded in millivolts on magnetic tape for subsequent processing. Preliminary processing converted the millivolt data into engineering units, applied wire calibrations to thermocouple readings, applied Mach number calibrations to pressure and temperature measurements, performed circumferential mass averaging, corrected the data to standard inlet conditions, calculated overall performance, and punched cards.

The punched cards produced by the data reduction program were used in two data-analysis programs. The first program modified flow and performance measurements by correcting for probe and inlet losses. This program provided corrected performance cards which were fed into a performance plotting and averaging program. Overall performance for each compressor was based upon the arithmetic average of six repeat speedlines each at 85, 100, and 105 percent of design speed. Spanwise profiles for each compressor were taken from the speedline closest in performance to the average. The second data analysis program calculated stage and rotor static pressure characteristics. The flow of information from test stand through analysis is shown in Figure 8. Details of the data correction and performance calculations are given in Appendix B.

RESULTS AND DISCUSSION

Overall performance, stage and rotor static pressure characteristics; and profiles of inlet and discharge spanwise pressure, temperature and efficiency are presented in this section. The 3S1 and 3S2 compressor test results are compared with each other and with design goals.

OVERALL PERFORMANCE

Overall Performance of 3S1 Compared With 3S2

The overall performance (pressure ratio and efficiency as functions of flow) for both the 3S1 and 3S2 compressors are compared in Figure 9. The characteristics shown for each compressor are averages of six repeat speedlines.

The 3S1 (0.81 aspect ratio) compressor had a one percent lower peak efficiency than the 3S2 configuration, but a greater peak pressure rise and a greater flow range and, as a consequence, a twelve percent higher surge margin. The lower aspect ratio compressor achieved a design speed peak overall adiabatic efficiency of 86.1 percent at a flow of 4.36 kg/sec (9.62 lbm/sec) and a pressure ratio of 1.346. The 1.22 aspect ratio compressor, 3S2, attained a design speed peak overall adiabatic efficiency of 87.0 percent at a flow of 4.35 kg/sec (9.58 lbm/sec) and a pressure ratio of 1.314. Overall performance at design speed is summarized in Table III for each compressor at design speed.

The efficiency of both compressors decreased when speed was increased, but the decrease was greater for the lower aspect ratio compressor. The peak efficiency of 3S1 dropped 0.9 percentage points between 85 percent and 105 percent of design speed. The 3S2 efficiency drop was 0.35 percentage points when speed was increased over the same range. Surge margin to peak efficiency was 24 percent for 3S1 and 12.4 percent for 3S2 at the design speed. Surge margin to the peak efficiency point increased as speed was increased for both compressors. The surge margin of 3S1 was 20.5 percent at 85 percent speed and 27.7 percent at 105 percent speed. Surge margin of 3S2 increased from 9.04 percent at 85 percent speed to 13.6 percent at 105 percent speed.

Because of fabrication tolerances, the measured average running clearance was 0.037 cm (0.014 in.) for the 3S1 compressor and 0.043 cm (0.017 in.) for the 3S2 configuration.

Plots of efficiency and pressure ratio versus corrected flow, efficiency versus pressure ratio, and temperature ratio versus corrected flow are presented for both compressors at 85, 100, and 105 percent of design speed in Figures 10 through 27. These plots display all of the performance program and deterioration check run data points. The scatter in efficiency measurements can be seen to be generally within ±0.35 percentage points. No deterioration of performance was noted for either the 3S1 or the 3S2 compressor.

TABLE III

OVERALL PERFORMANCE SUMMARY

	3S1		3S2	
	Test	Design	Test	Design
Inlet Corrected Flow,				
kg/sec	4.28	4.30	4.35	4.30
lbm/sec	9.43	9.47	9.58	9.47
Design Corrected Flow, %	99.58	100.0	101.16	100.0
Corrected Flow Per Unit Inlet Annulus Area,				
kg/m^2-sec	89.61	90.05	91.10	90.05
lbm/ft^2-sec	18.35	18.43	18.65	18.43
Pressure Ratio at Peak Efficiency	1.346	1.357	1.314	1.324
Surge Margin (From Peak Efficiency), %	24.0	15.0	12.4	15.0
Adiabatic Efficiency, %	86.1	88.3	87.0	88.7
Average Running Tip Clearance				
cm	0.0366	0.033	0.0427	0.033
in.	0.0144	0.013	0.0168	0.013
Average Tip Clearance/ Average Span	0.014	0.0126	0.0163	0.0126
Average Tip Clearance/ Average Chord	0.0112	0.0101	0.0199	0.0154

STAGE STATIC PRESSURE CHARACTERISTICS

Comparison Between 3S1 and 3S2 Compressors

The stage static pressure coefficient versus flow coefficient curves presented in Figures 28 and 29 display significant differences between the two compressors. The second and third stage of the 3S1 compressor produced about 10 percent greater peak pressure coefficient at design speed than the corresponding stages of the 3S2 compressor. This greater peak pressure ratio appears to be the source of the higher surge margin of the lower aspect ratio design. The first stage of 3S1 peaked prior to surge and differs from the other lower aspect ratio stages in that respect. The second and third stages of each compressor were subjected to more representative multistage conditions and should be more indicative of the performance potential for their respective aspect ratios in a multistage environment. All stages tested fell away slightly from their design pressure rise as surge flow was approached, but the extremely peaked nature of the first 3S1 stage characteristic suggests that it might be improved by rematching.

The 3S1 and 3S2 rotor characteristics are shown in Figure 28 through 33 for 85, 100, and 105 percent speed. The 100 percent speed characteristics of the 3S1 rotors and stages, Figure 28, are similar in shape and in relative level trends. The prematurely peaked first rotor appears to be the cause of the stalled first-stage characteristic. The second- and third-stage characteristics are below design level, possibly due to poor inlet conditions from the first stage, but closely follow the design shape. The first two 3S2 rotors, Figure 29, follow their respective stage design characteristic trends quite closely, but the last rotor shows a more vertically sloped pressure rise than either its design characteristic or the test characteristics of the other two stages. After the test it was discovered that the stator 3 leading edge static pressure tap used to determine the static pressure rise of the last stage rotor was located inside the vane row. It was concluded that this tap was measuring part of the stator pressure rise, producing excessively high values. The agreement of the three stage characteristics and the first and second rotor characteristics with design, and the mislocated static pressure tap makes it safe to assume that the third 3S2 rotor was also close to design.

Rotor and stage performance at 85 and 105 percent speed, Figures 30 through 33, shows the same trends as in the 100 percent speed results for both compressors.

Compessor 3S1 Characteristics Compared With Design

The static pressure-rise characteristics of the 3S1 compressor are compared with design values in Figures 28, 30 and 32 at 100, 85 and 105 percent design speed, respectively. The first stage is ten percent below its design peak pressure rise while the other two stages come close to meeting their design goals, but at a lower flow coefficient. This falloff of characteristic relative to design but eventual attainment of design level at lower flow coefficient implies an increase in blockage which delays the achievement of peak pressure level. The characteristic shapes for all three stages agree well with design from the highest flow point to the peak efficiency point (fifth data point from surge).

Compressor 3S2 Characteristics Compared With Design

The static pressure-rise characteristics of the 3S2 compressor are compared with design values in Figures 29, 31, and 33 at 100, 85, and 105 percent of design, respectively. All stages are close to their design intent at flows from wide open to peak efficiency (fourth point from surge) at all speeds. At flows below peak efficiency, however, the pressure characteristics are 'ow and prematurely peaked by the same amount relative to design in all three stages at all speeds. These data also show that although premature surge occurred at all speeds tested, all three stages appear to have surged/stalled at about the same time.

The weak first-stage characteristic, relative to the second and third stages, exhibited in the 3S1 test is not present in this uniform 3S2 result, but the peak pressure rise deficit in all three stages of the 3S2 produced significantly less surge margin.

SPANWISE PROFILES

Comparison of 3S1 and 3S2 Spanwise Profiles

Spanwise profiles of pressure ratio, temperature ratio, and efficiency indicate that an increased loading design at reduced aspect ratio flattens discharge radial pressure and temperature profiles and decreases endwall losses. Circumferentially mass averaged discharge radial profiles are shown for peak efficiency in Figure 34. The efficiency of 3S1 was improved in the endwalls, but the improvement was offset by a decrease in core-flow efficiency. Compared with 3S2, the 3S1 lower aspect ratio compressor showed an improvement of 2.4 percentage points in efficiency at the inner wall, a 0.4 percentage point improvement at the outer wall, and a decline in efficiency of 4.0 percentage points at 50 percent span.

Discharge profiles for the 3S1 compressor were significantly flatter than those of the higher aspect ratio compressor. The efficiency profiles of 3S2 was 11.5 percentage points greater at midspan than at the inner wall. In contrast, the efficiency of 3S1 varied by only five percentage points from midspan to either wall. In temperature profile, 3S2 varied about twice as much as 3S1 over the same spanwise extent. In pressure, while the magnitude of the spanwise variation was similar, the shapes were different. The pressure profile of the lower aspect ratio compressor, 3S1, was flat between 20 and 80 percent span while the profile of the higher aspect ratio compressor, 3S2, was peaked in the center.

At near surge, the exit profiles for both compressors tended to flatten and show more similarity than at peak efficiency, as shown in Figure 35. These data indicate that 3S2 demonstrated less root temperature rise near surge than at peak efficiency.

The flatter exit profiles for the 3S1 compressor at peak efficiency, and for both compressors as they were throttled toward surge, indicate that secondary mixing was taking place. The increase of this effect with longer chord and increased loading corresponds to classical secondary loss theories. The increased endwall efficiency with lower aspect ratio could be due to the transport of low momentum air to the depressed efficiency core. However, further testing is required to ascertain whether this core efficiency drop is an inherent efficiency penalty of low aspect ratio blading or a recoverable matching effect.

The slight waviness of the spanwise profiles in Figures 34 and 35 was caused by circumferential variations in the pressure and temperature, which were sampled by the 4 and 5 element probes used to form one composite spanwise profile. Although previous testing been determined that the instrumentation used accurately measures average performance, its use was not intended to produce high resolution circumferential and radial information.

Inlet pressure and temperature profiles at peak efficiency and near surge for both compressors are compared in Figures 36 and 37, respectively, and indicate no significant differences in inlet conditions between the two tests. Tabulations of additional spanwise inlet and exit pressure and temperature data for 3S1 and 3S2 compressor are presented in Appendix "C". These data are for performance points at 85, 100, and 105 percent speeds, being representative of the six repeated speed lines at each speed.

SUMMARY OF RESULTS

Two three stage compressors, representative of the rear stages of advanced compressors, were tested to evaluate the effect of blade aspect ratio on aerodynamic performance. The design aspect ratio of both blades and vanes was 0.81 for the compressor designated 3S1 and was 1.22 for the compressor designated 3S2. The test produced the following principal results.

1. The 0.81 aspect ratio compressor demonstrated 12 percent higher surge margin but 0.9 percentage points lower efficiency than a 1.22 aspect ratio compressor of similar design.

2. The lower aspect ratio compressor had higher efficiency in the endwall regions and flatter spanwise exit pressure and temperature profiles than the higher aspect ratio compressor.

3. The lower aspect ratio compressor exceeded its design surge margin goal by nine percentage points while the higher aspect ratio compressor was three percentage points low. This suggests that improved efficiency may be attainable at the lower aspect ratio by utilizing the demonstrated excess surge margin to redesign for a higher pressure ratio. In addition, the observed poor match of the first stage could be improved.

4. A secondary flow mixing process, which transports low momentum fluid from the endwall region to the core flow regions and is enhanced by increased chord and loading, could be responsible for the flattening of the profiles of 3S1 and both the increased endwall region efficiency and decreased midspan efficiency of 3S1 relative to 3S2. This mechanism could also explain the profile flattening for both compressors as surge is approached.

REFERENCES

1. Behlke, R. F., Brooky, J. D.; and Canal, E.: "Study of Blade Aspect Ratio on a Compressor Front Stage - Final Report," NASA CR-159556 PWA-5583-58, 1979.

2. Marman, H. V. and Marchant, R. D., "Preliminary Compressor Design Study for Advanced Multistage Axial Flow Compressors - Final Report," NASA CR-135091, PWA-5318, 1976.

3. Burdsall, E. A.; [illegible]al, E.; and Lyons, K. A., "Core Compressor Exit Stage Study - I Aerodynamic and Mechanical Design," NASA CR-159714, PWA-5561-55.

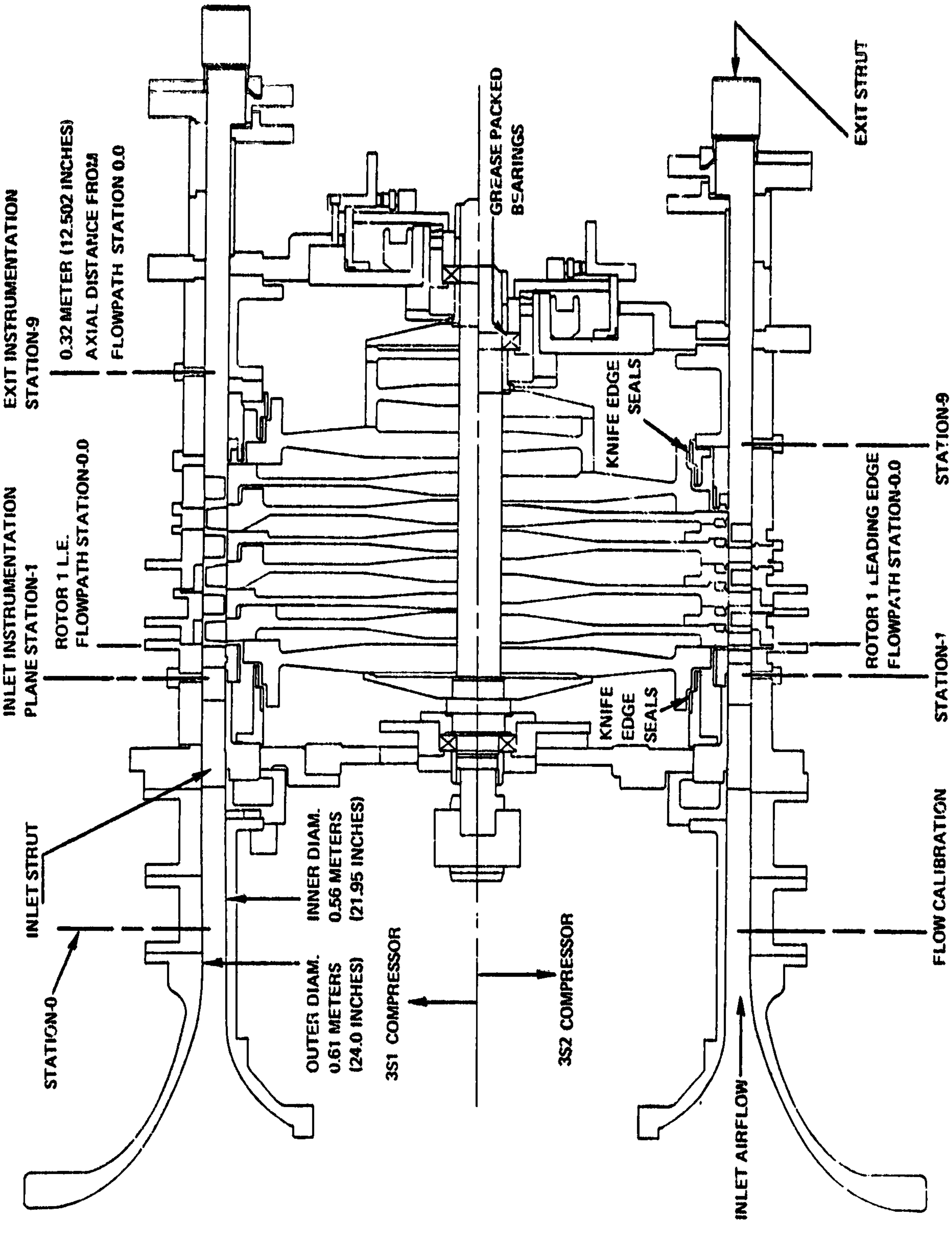

Figure 1 Schematic of the 3S1/3S2 Test Compressors

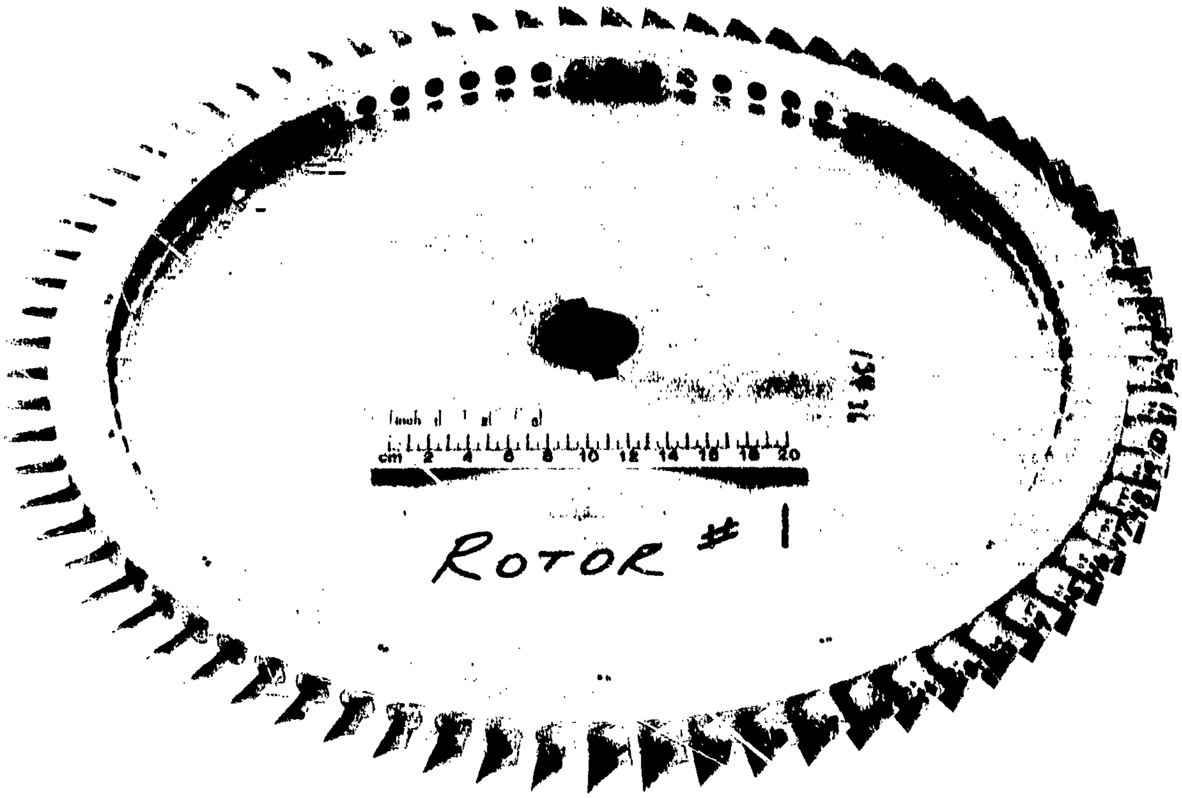

Figure 2 Photograph of a Typical Rotor Assembly

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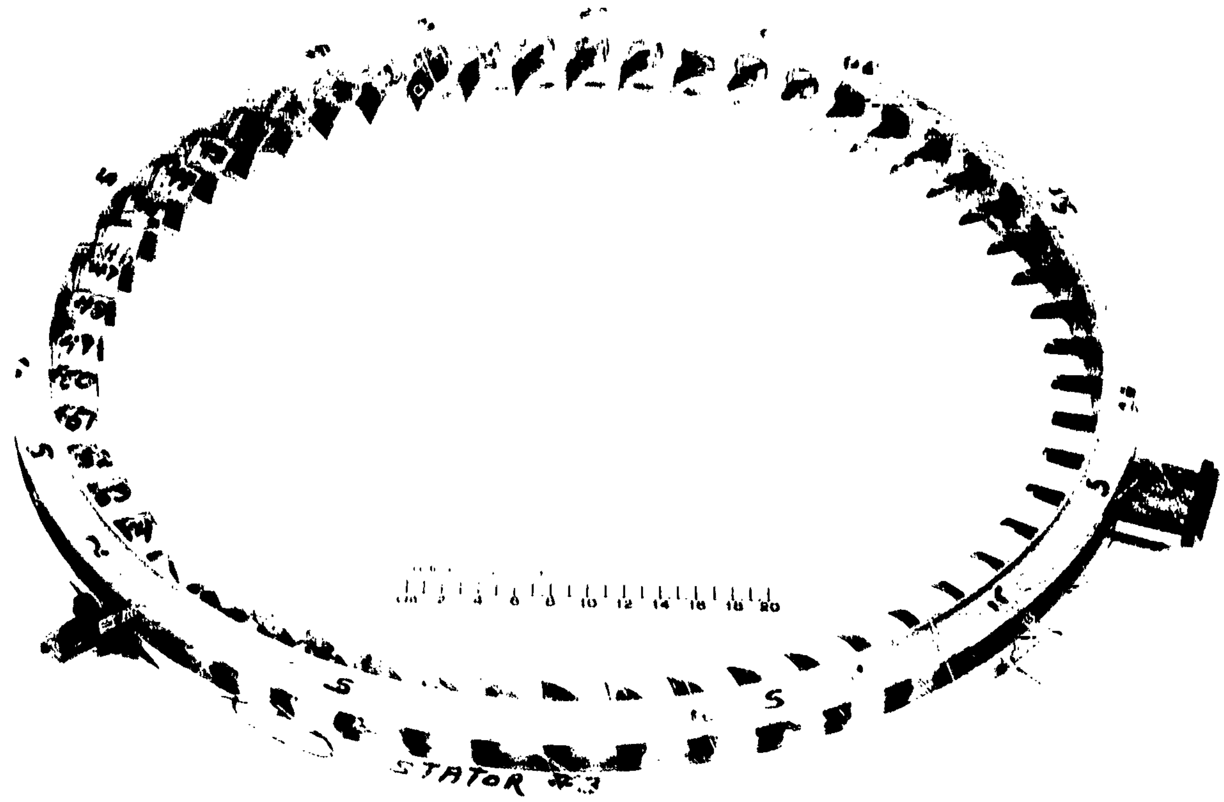

Figure 3 Photograph of a Typical Stator Assembly

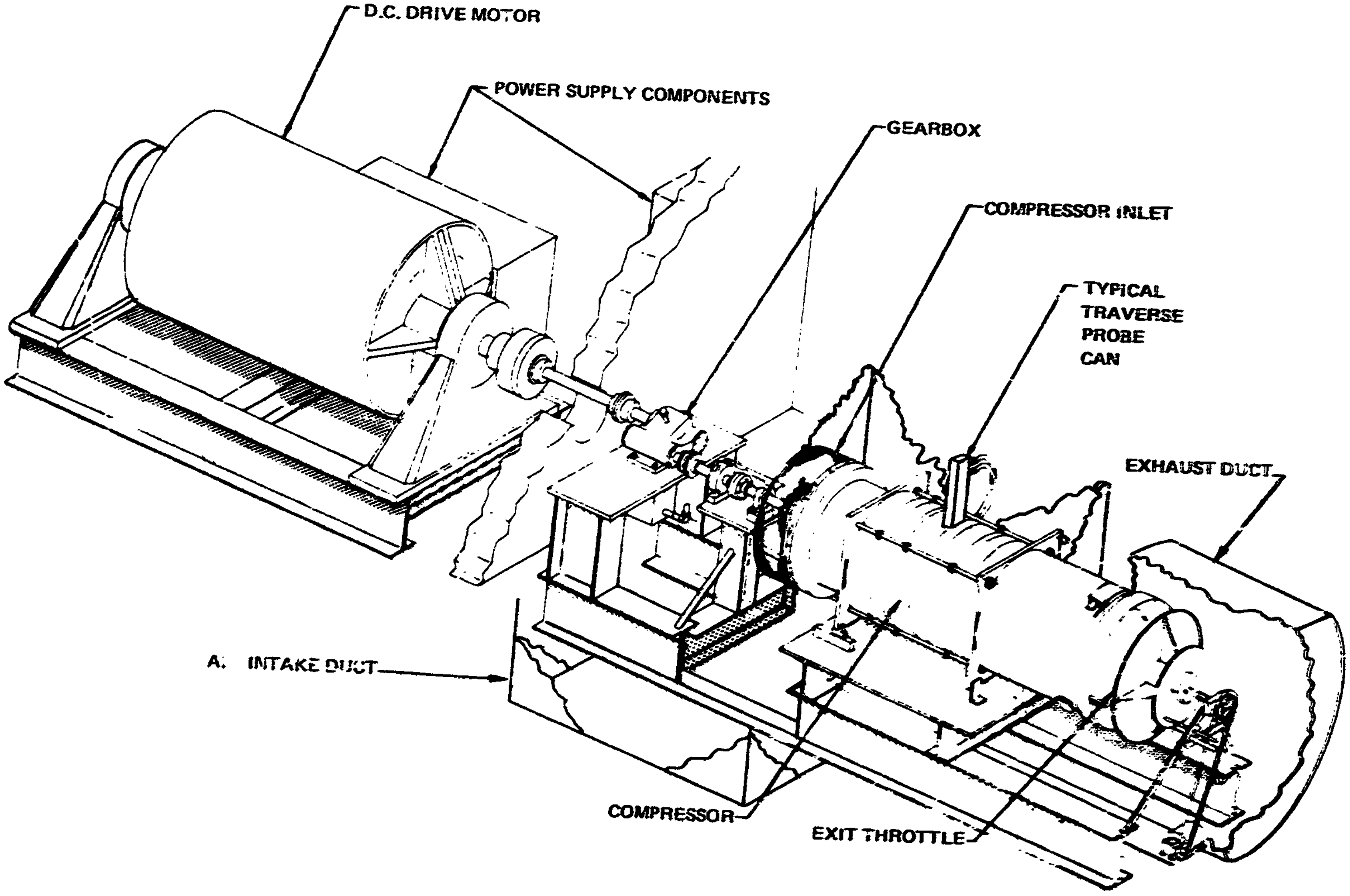

Figure 4 Three-Stage Axial-Flow Compressor Rig Facility

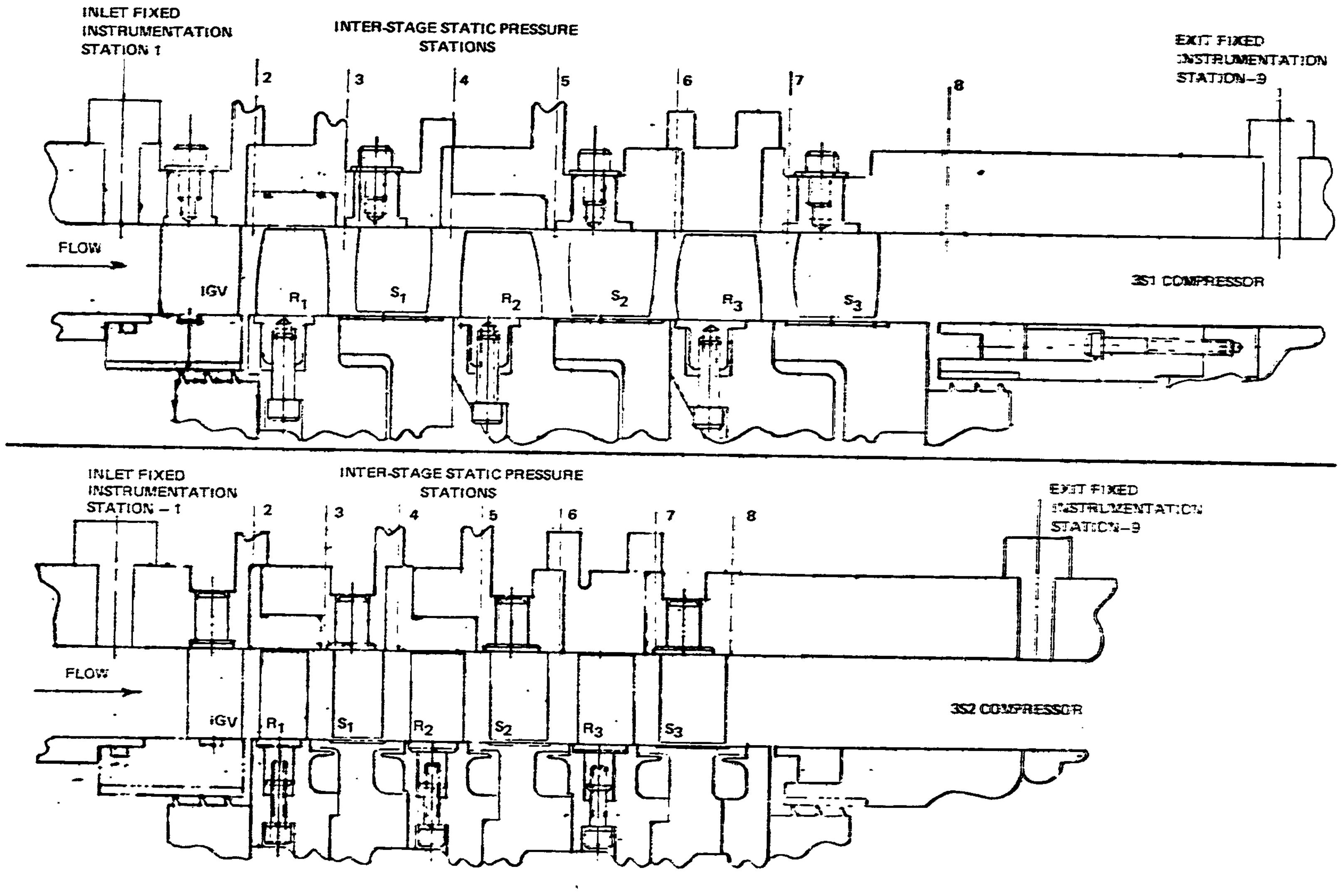

Figure 5 Axial Locations of Instrumentation Planes for the 3S1 and 3S2 Compressors

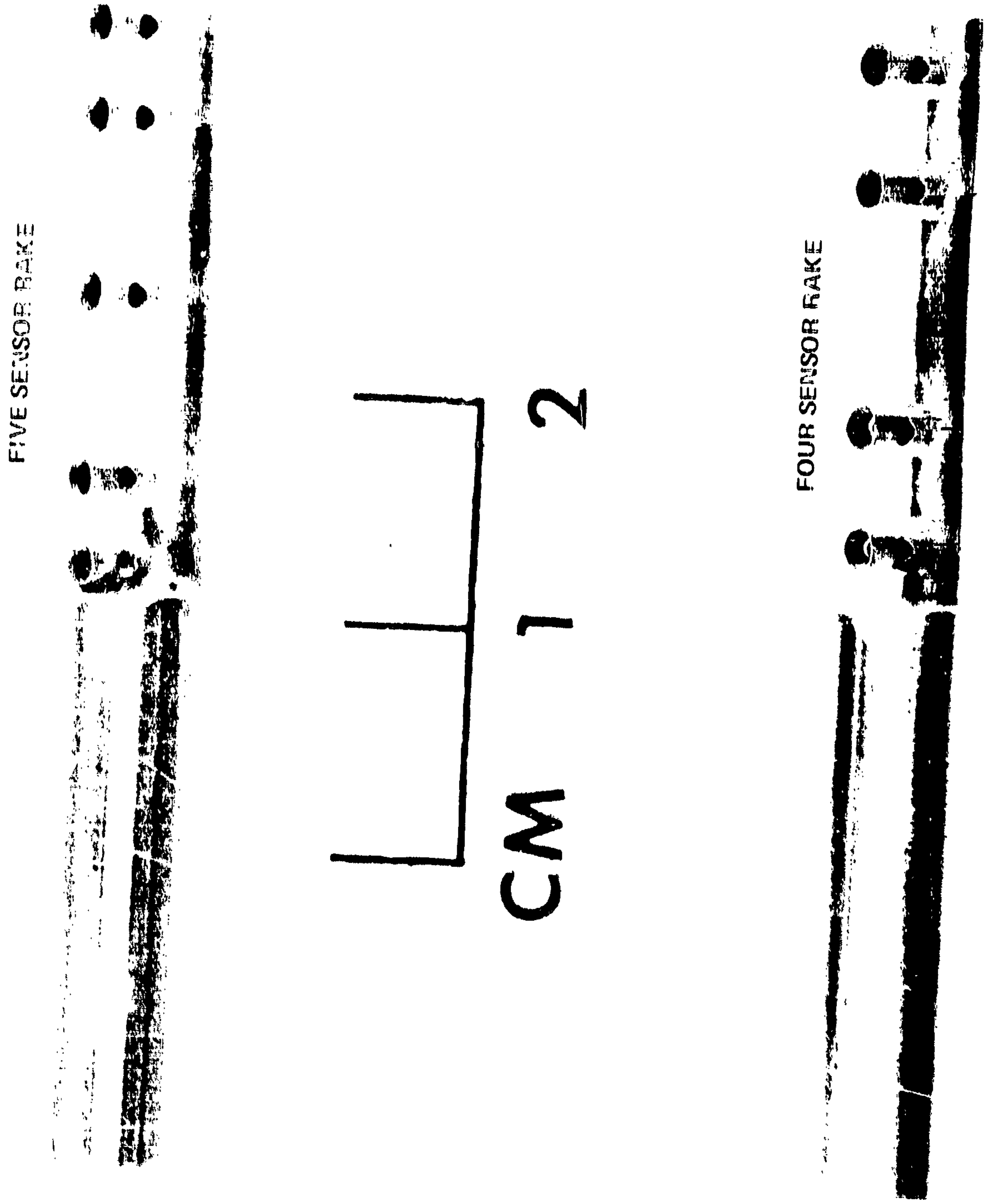

Figure 6 Typical Total Pressure Rakes

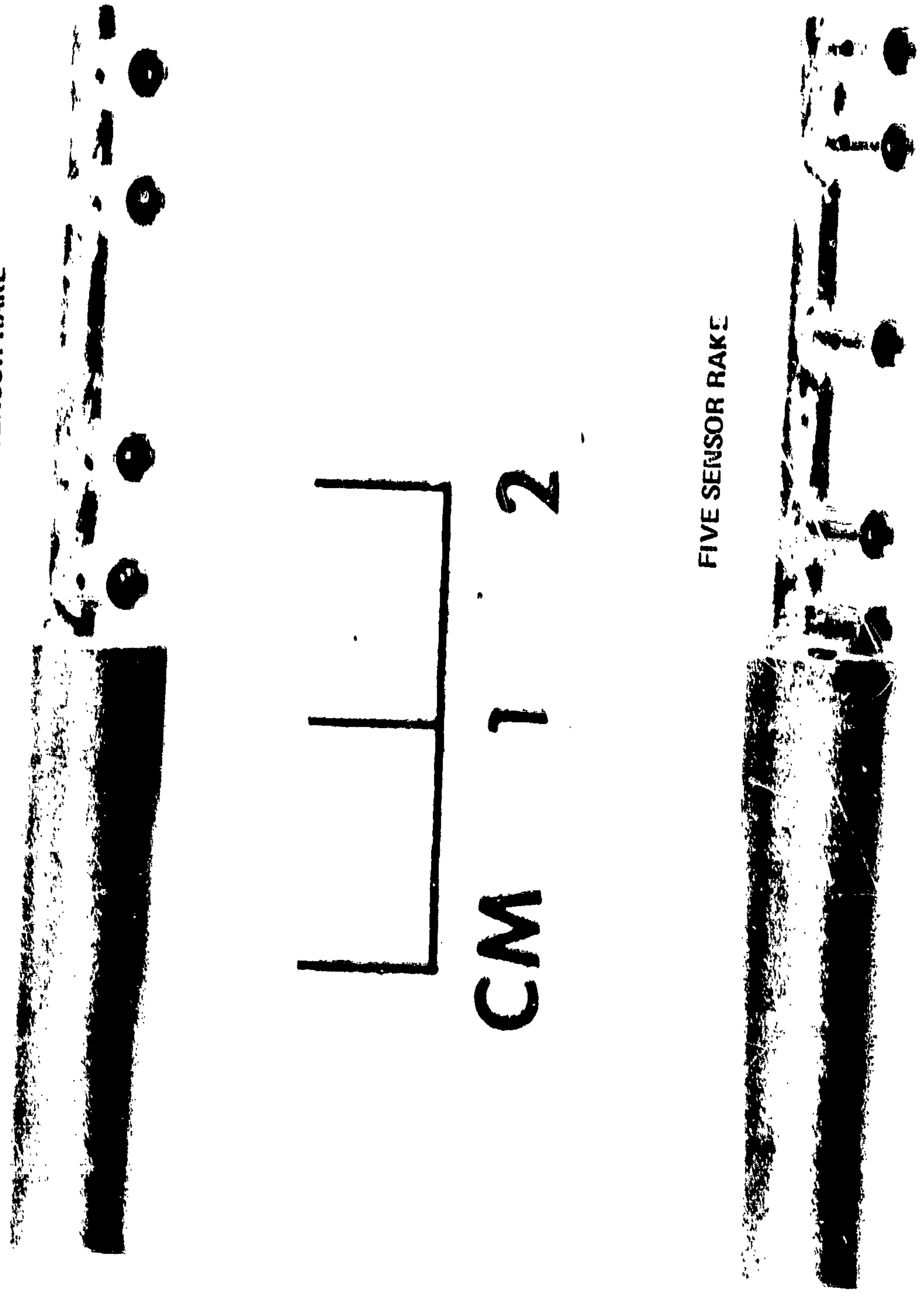

Figure 7 Typical Total Temperature Rakes

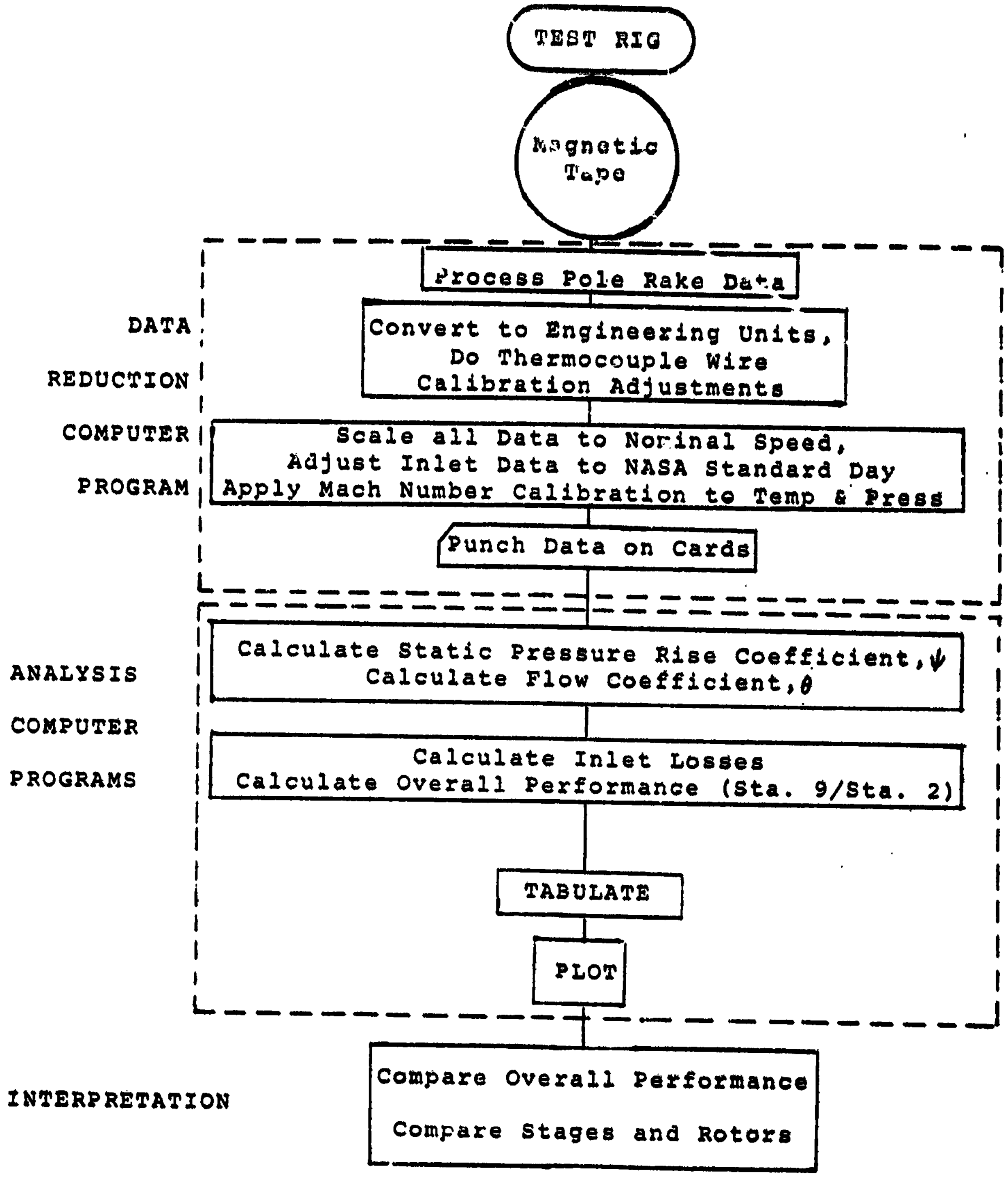

Figure 8 Data Analysis Flow Chart

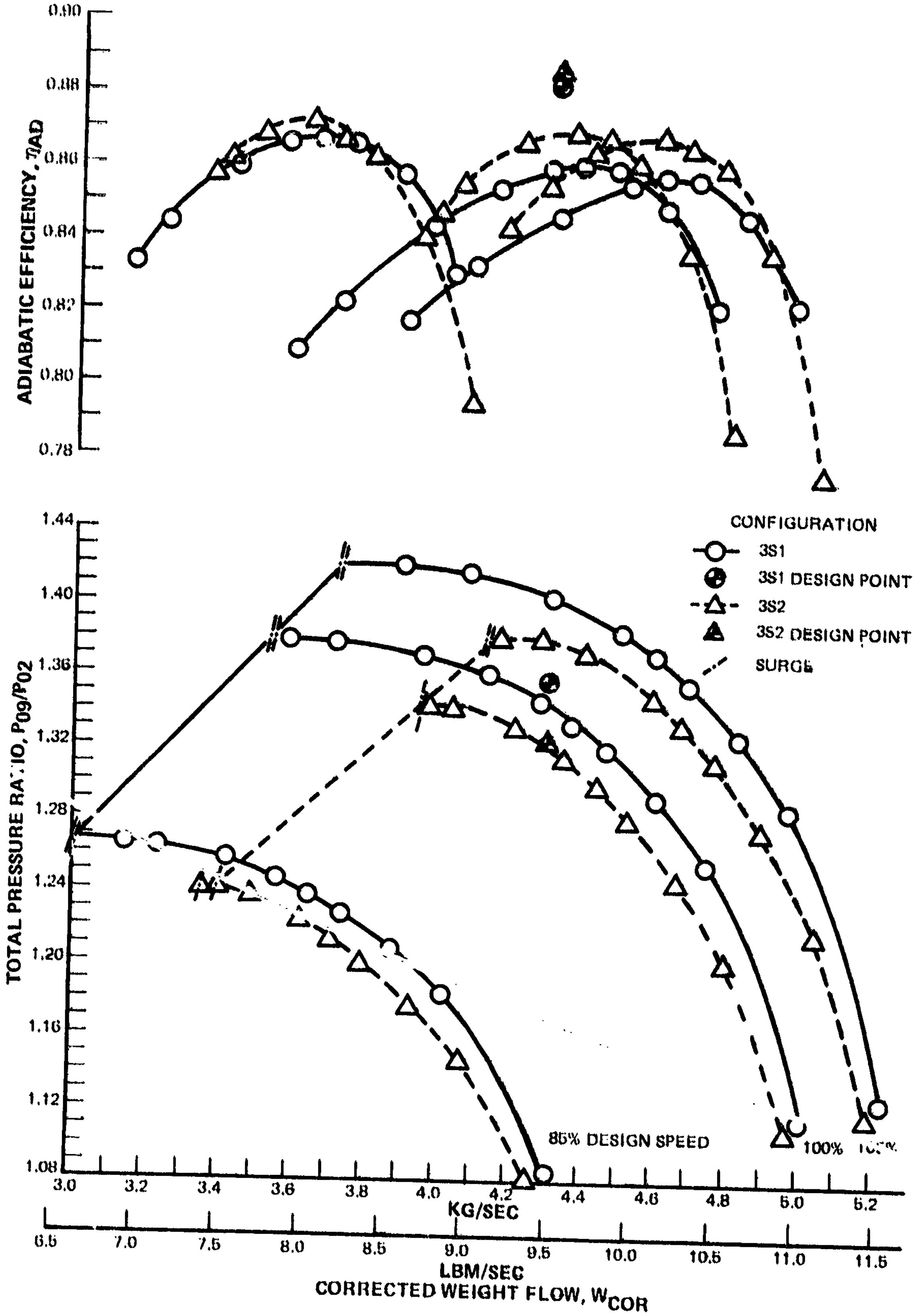

Figure 9 Comparison of 3S1 and 3S2 Overall Performance Based on Average of Six Repeat Test Speedlines

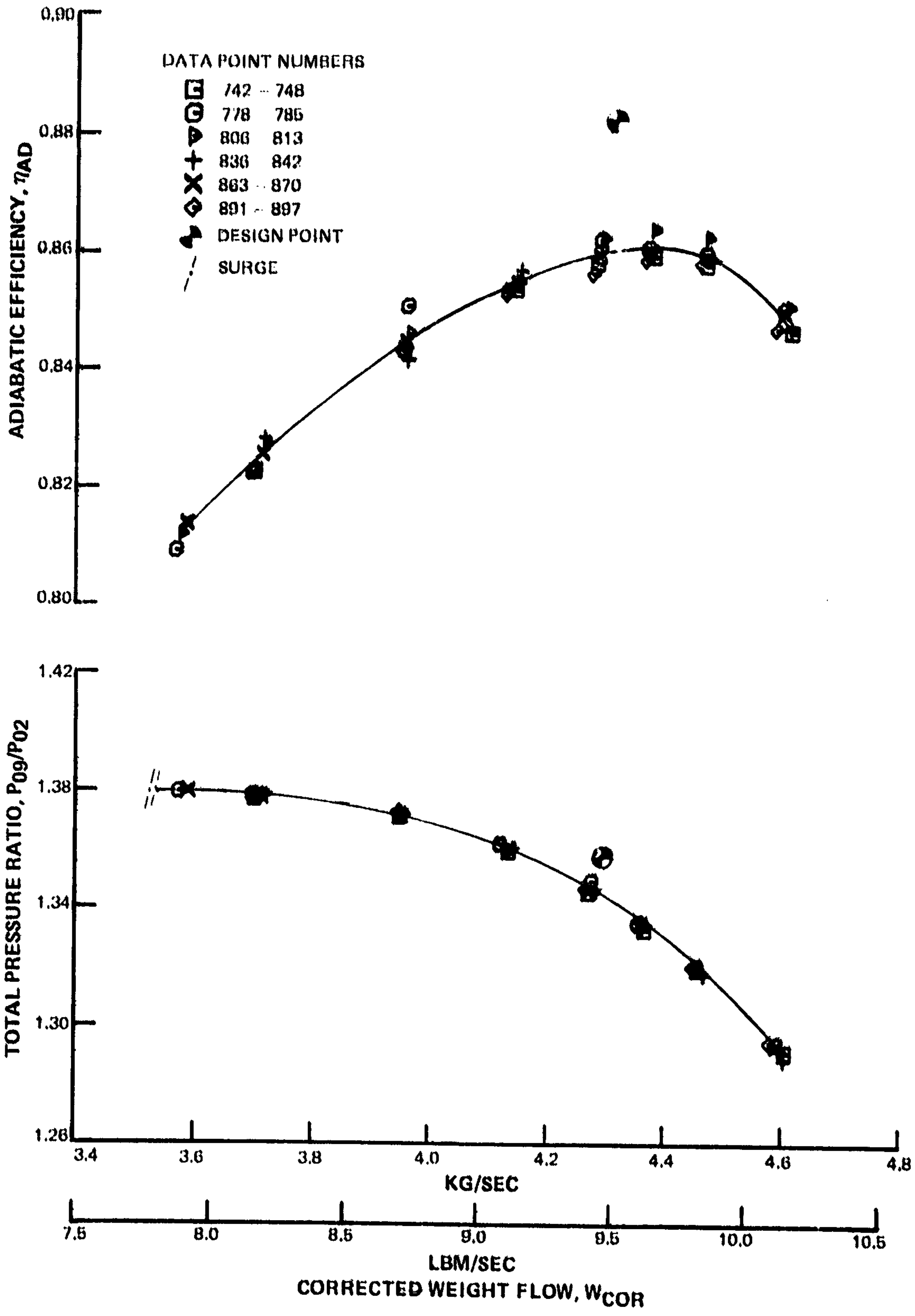

Figure 10 Adiabatic Efficiency and Pressure Ratio as Functions of Corrected Weight Flow for 3S1 Configuration at Design Speed

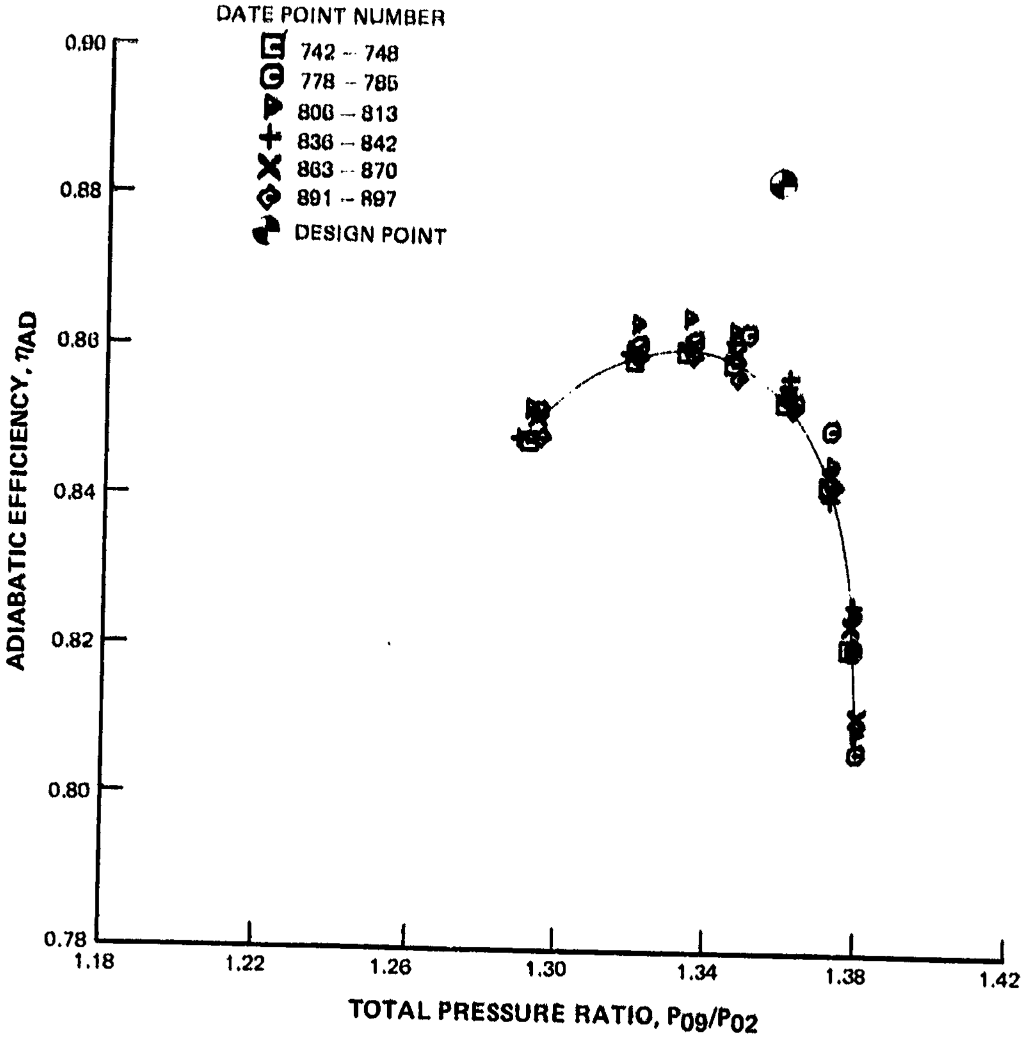

Figure 11 Adiabatic Efficiency as a Function of Pressure Ratio for 3S1 Configuration at Design Speed

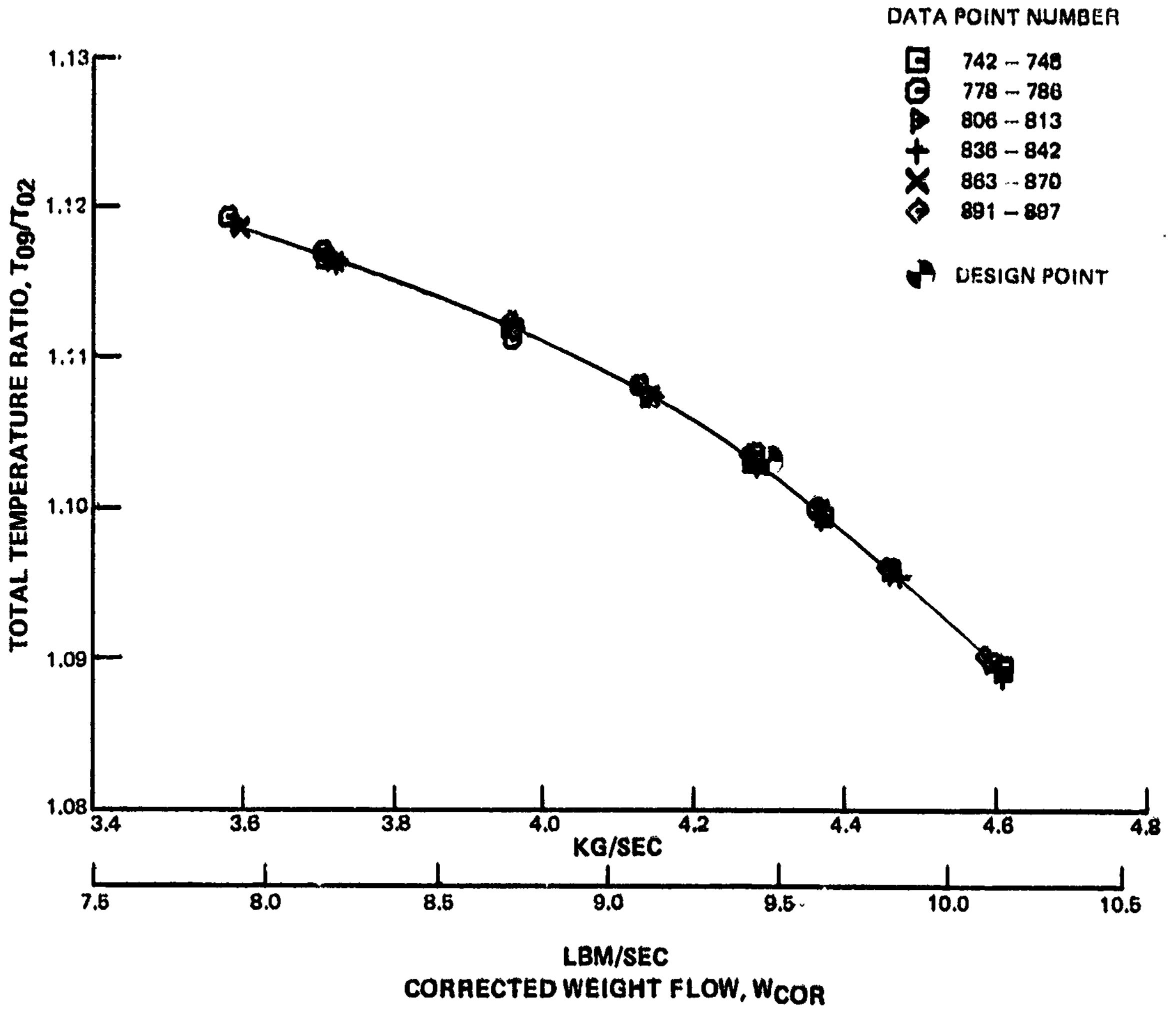

Figure 12 Total Temperature Ratio as a Function of Corrected Weight Flow for 3S1 Configuration at Design Speed

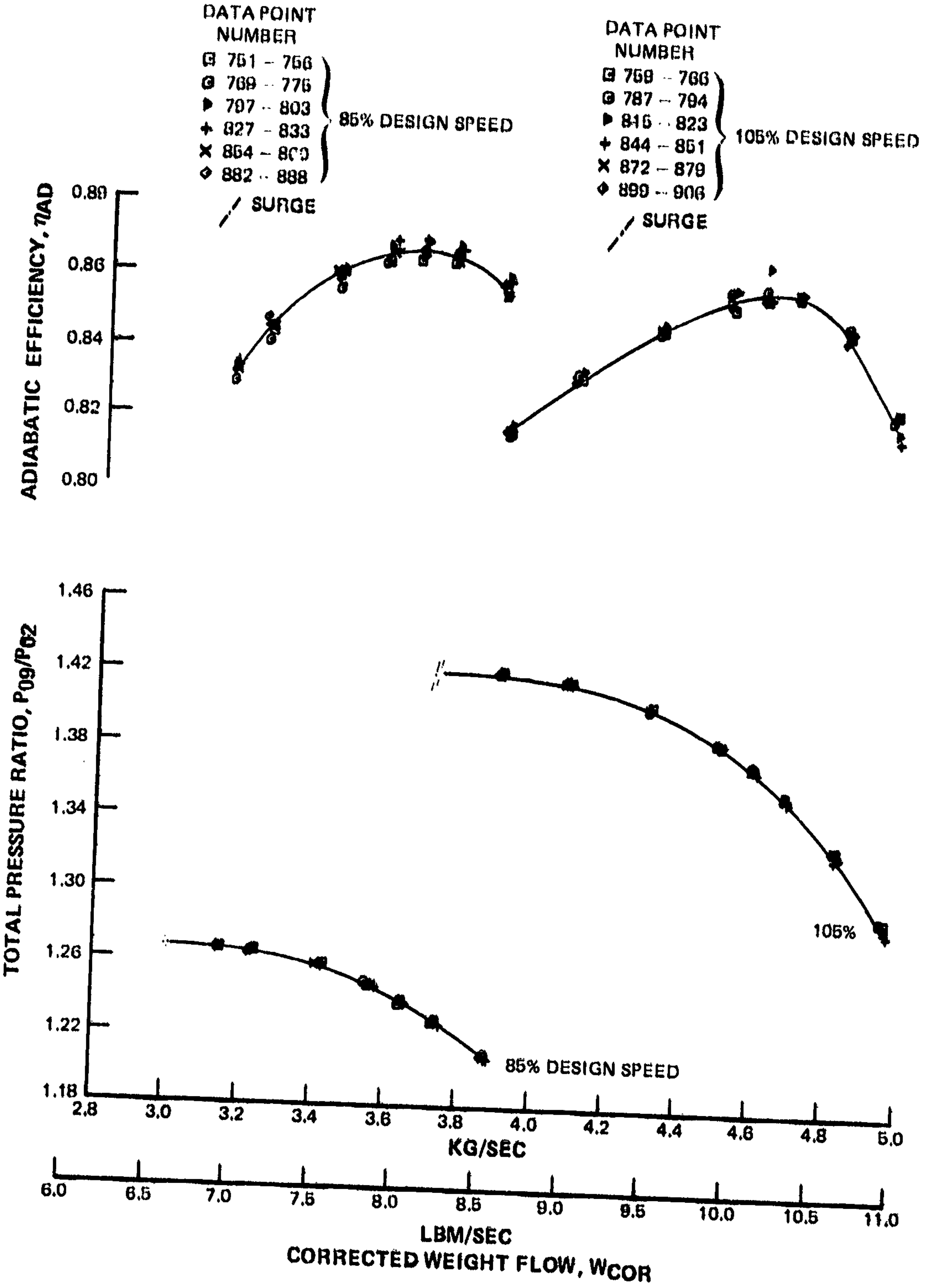

Figure 13 Pressure Ratio and Adiabatic Efficiency as Functions of Corrected Weight Flow for 3S1 Configuration at 85 and 105 Percent Design Speed

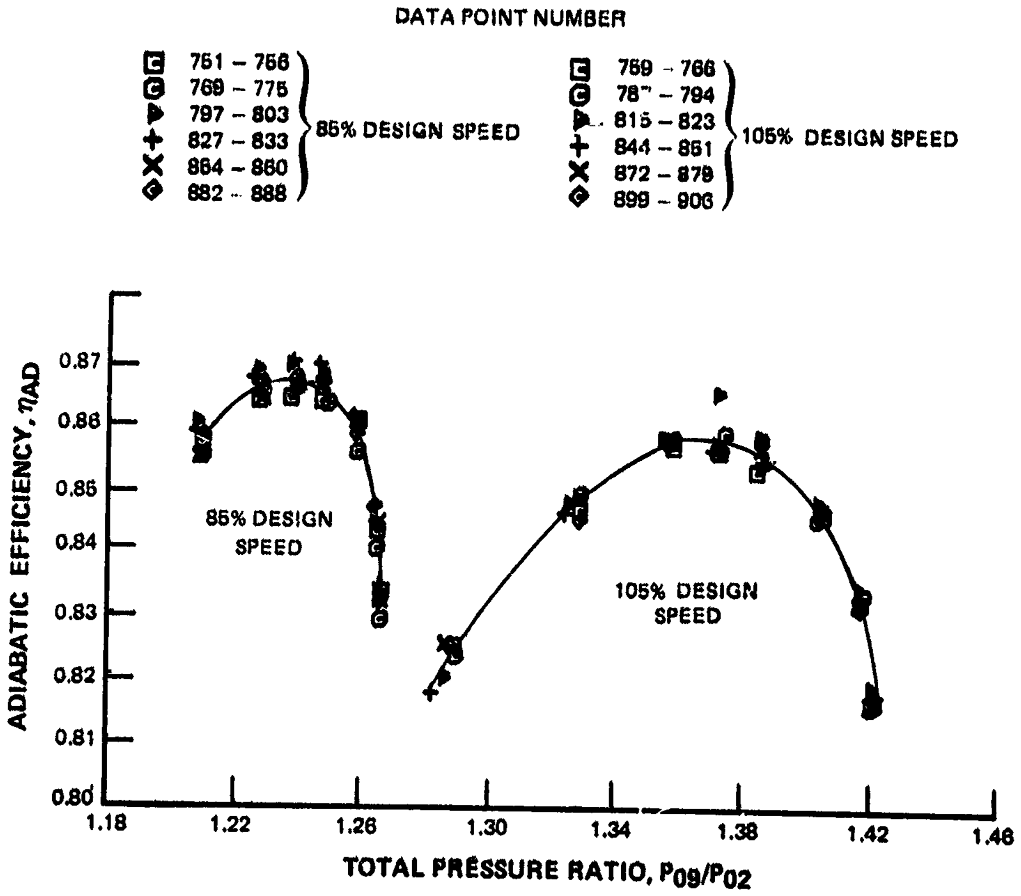

Figure 14 Adiabatic Efficiency as a Function of Pressure Ratio for 3S1 Configuration at 85 and 105 Percent Design Speed

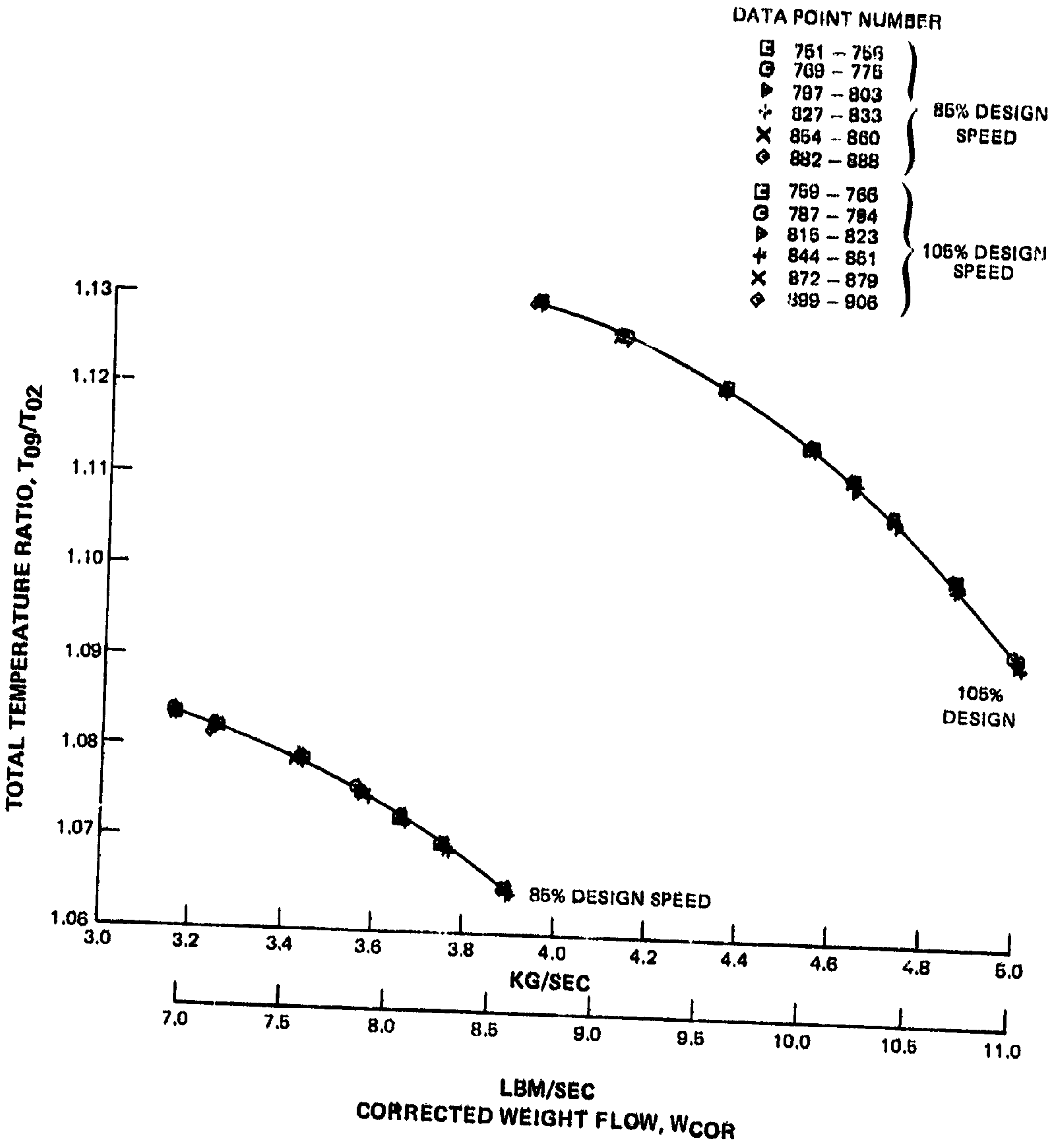

Figure 15 Temperature Ratio as a Function of Corrected Weight Flow for 3S1 Configuration at 85 and 105 Percent of Design Speed

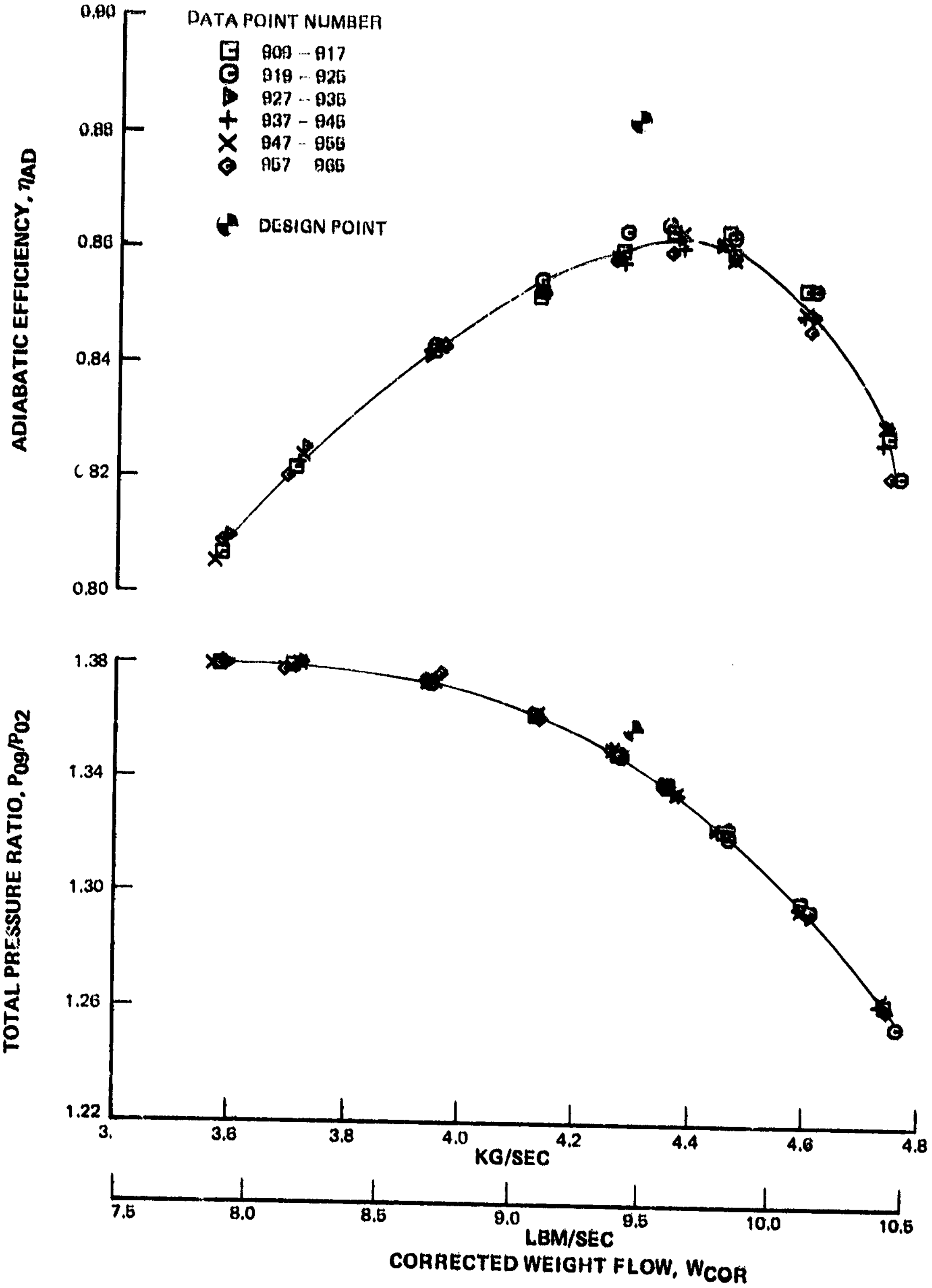

Figure 16 Adiabatic Efficiency and Pressure Ratio as Functions of Corrected Weight Flow for 3S1 Configuration at Design Speed - Deterioration Check

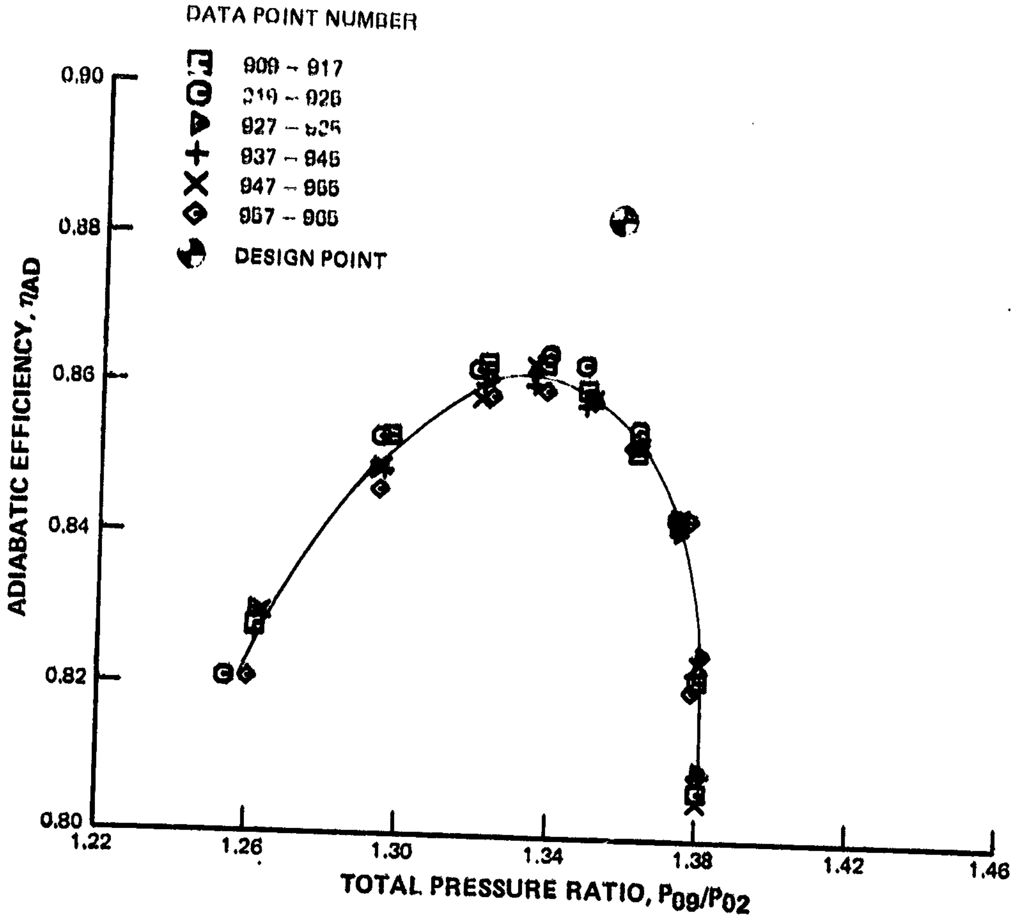

Figure 17 Adiabatic Efficiency as a Function of Pressure Ratio for 3S1 Configuration at Design Speed - Deterioration Check

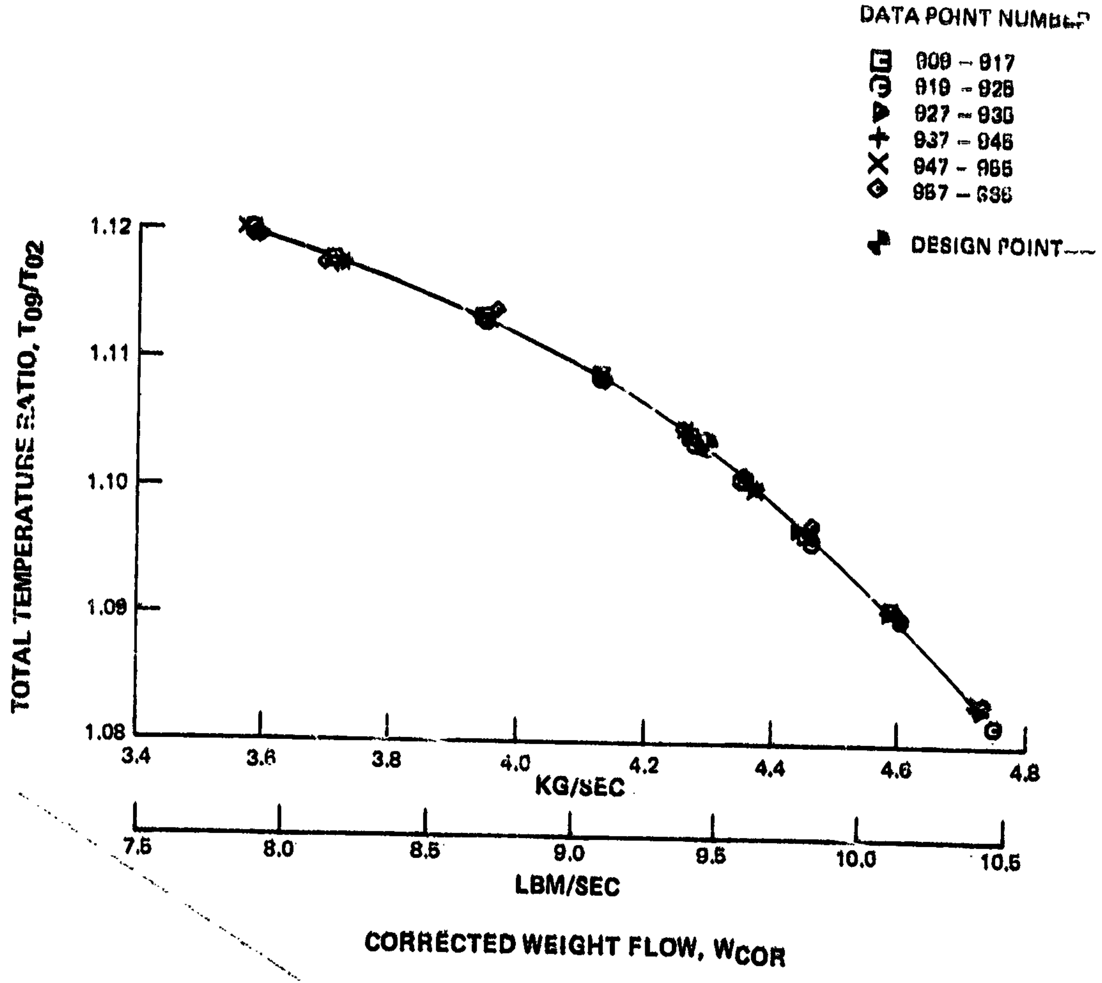

Figure 18 Temperature Ratio as Function of Corrected Weight Flow for 3S1 Configuration at Design Speed - Deterioration Check

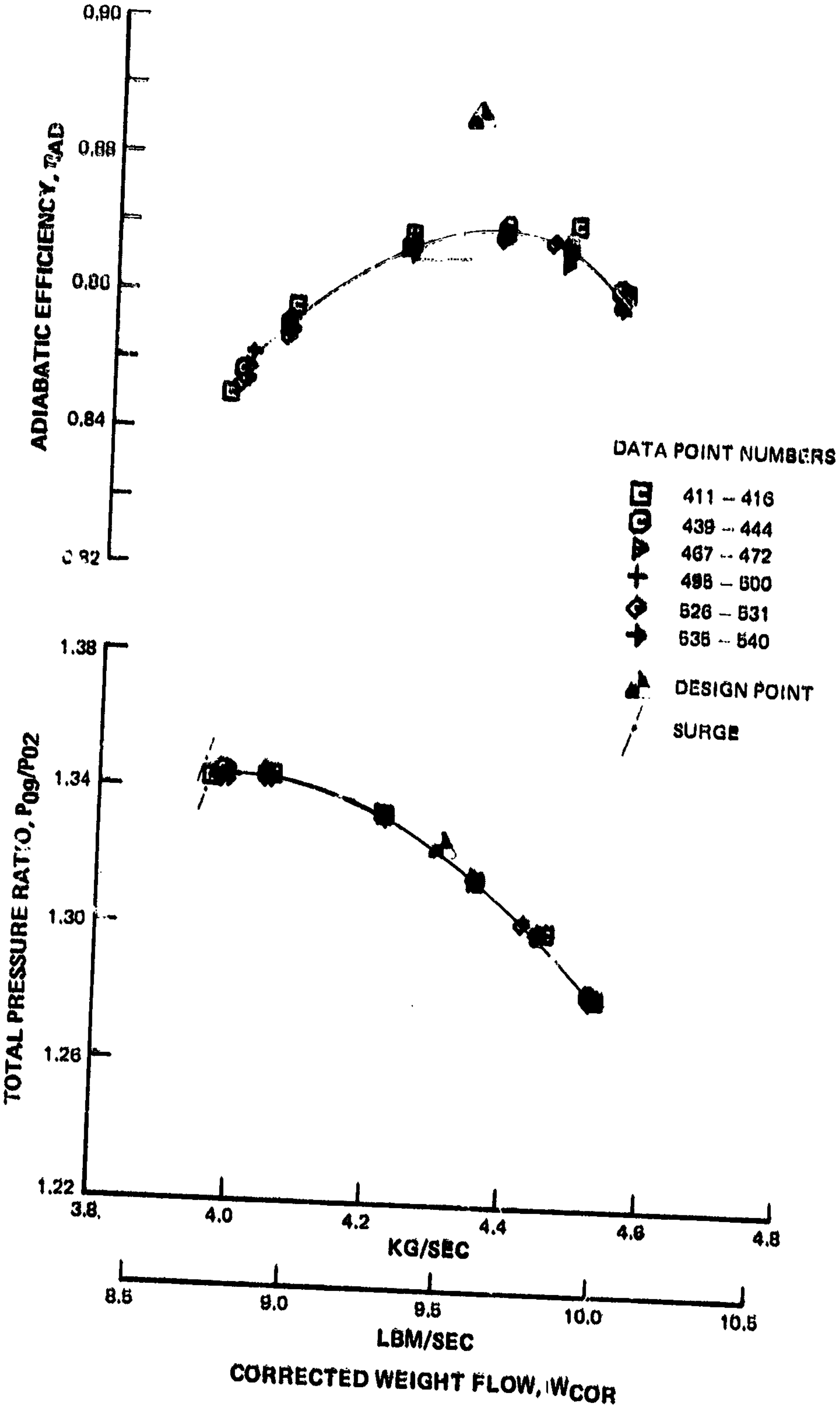

Figure 19 Adiabatic Efficiency and Pressure Ratio as Functions of Corrected Weight Flow for 3S2 Configuration at Design Speed

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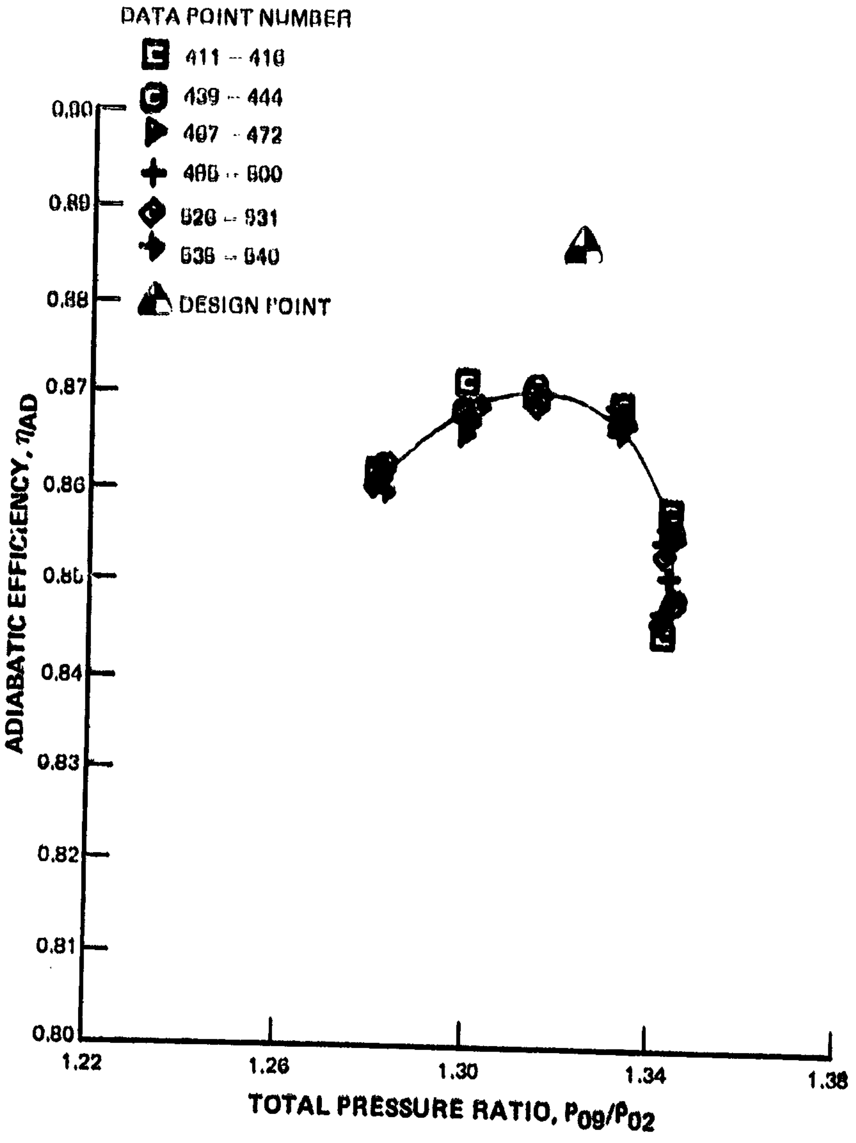

Figure 20 Adiabatic Efficiency as a Function of Pressure Ratio for 3S2 Configuration at Design Speed

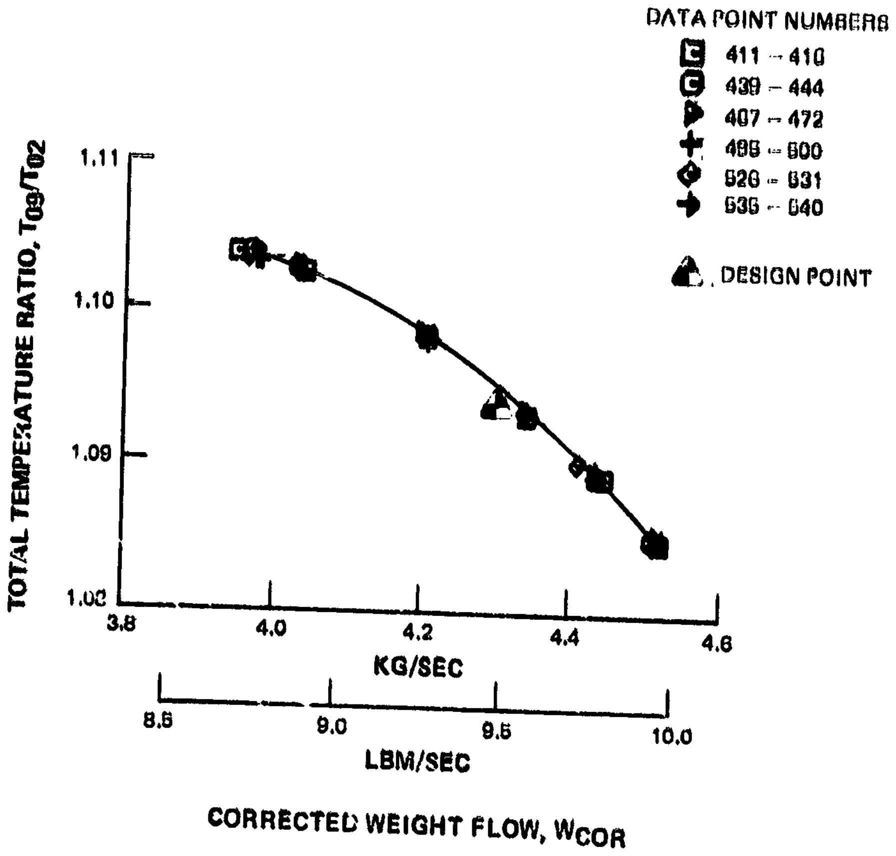

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Figure 21 Temperature Ratio as a Function of Corrected Weight Flow for 3S2 Configuration at Design Speed

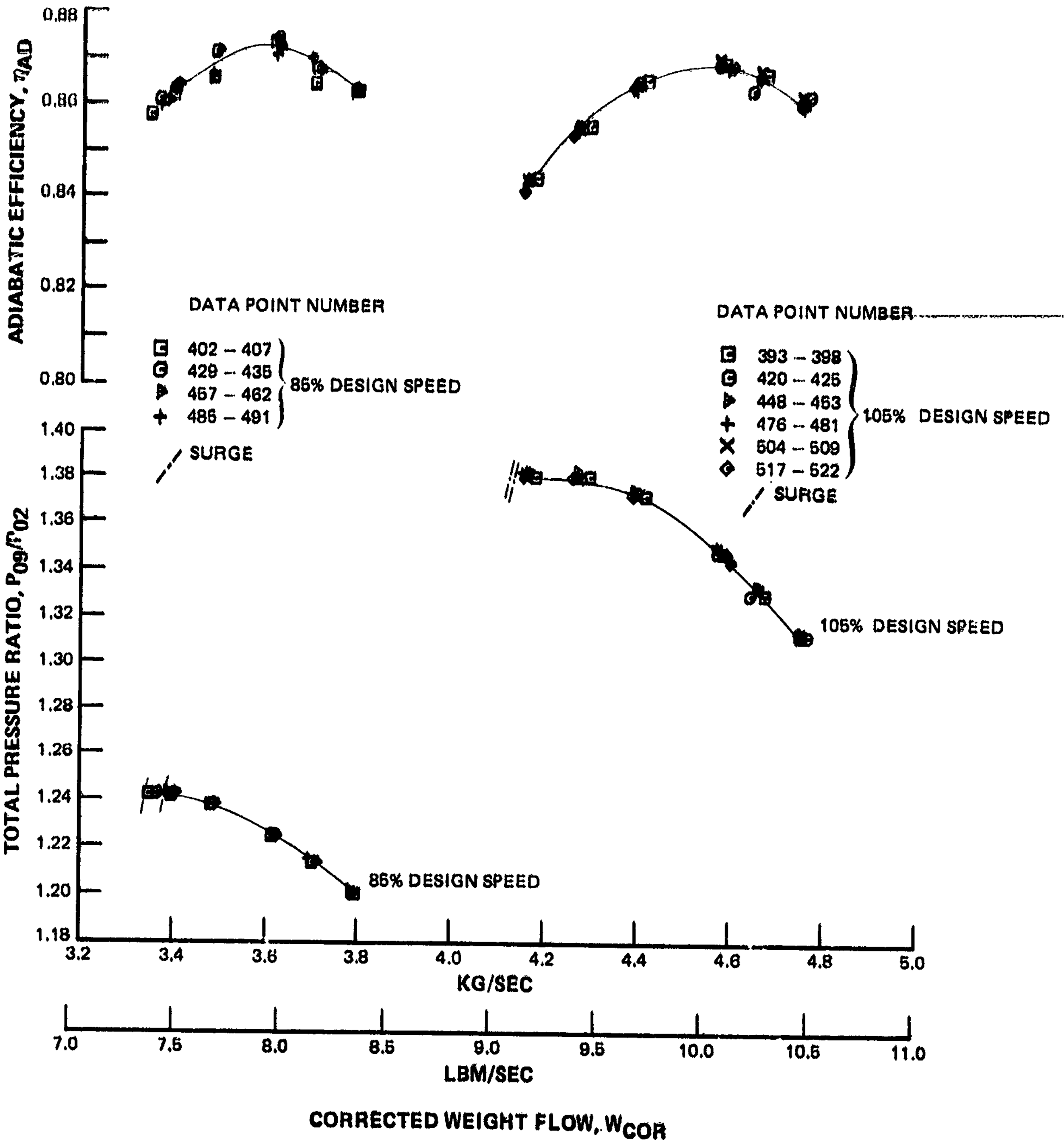

Figure 22 Adiabatic Efficiency and Pressure Ratio as Functions of Corrected Flow for 3S2 Configuration at 85 and 105 Percent of Design Speed

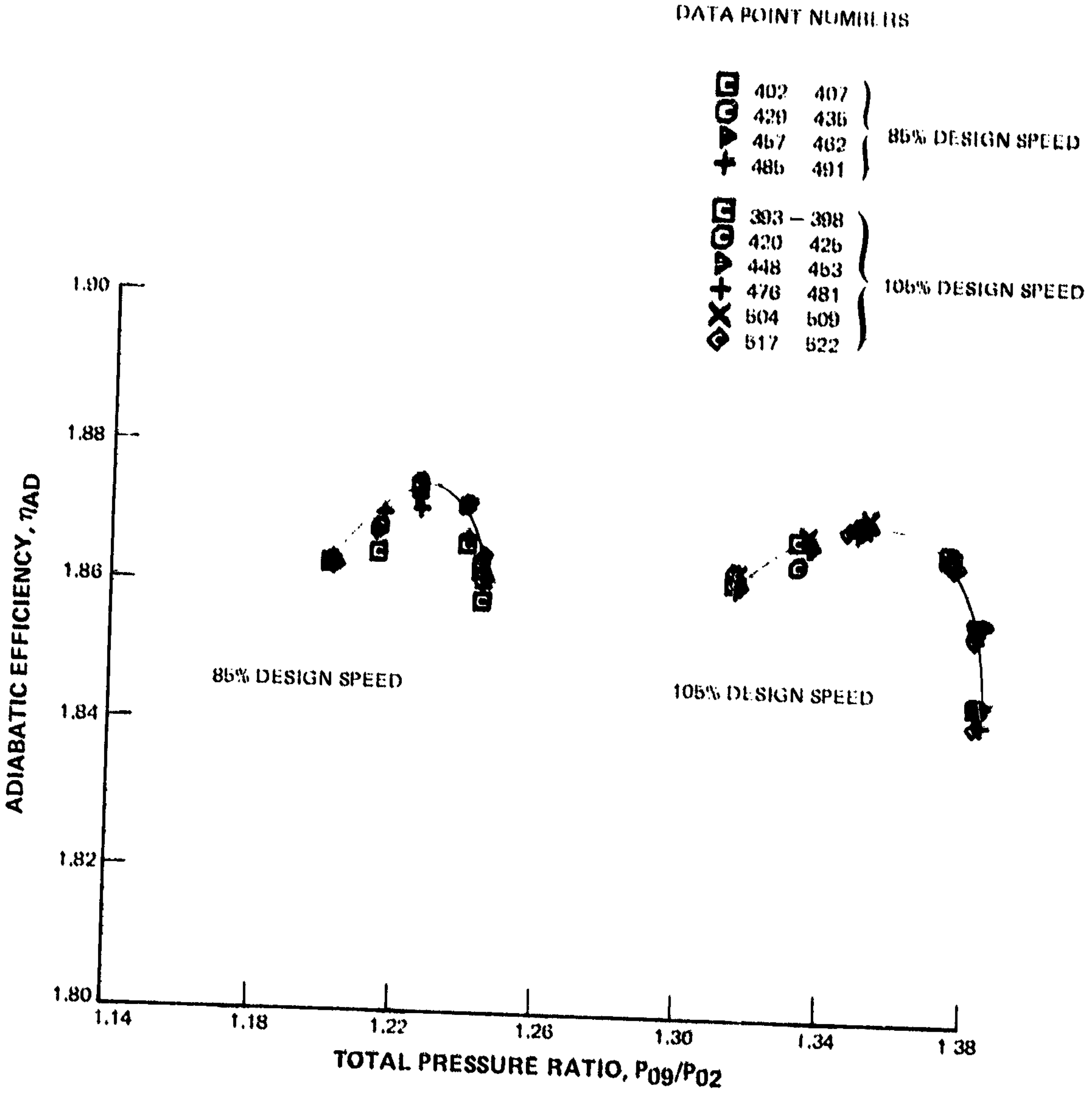

Figure 23 Adiabatic Efficiency as a Function of Pressure Ratio for 3S2 Configuration at 85 and 105 Percent of Design Speed

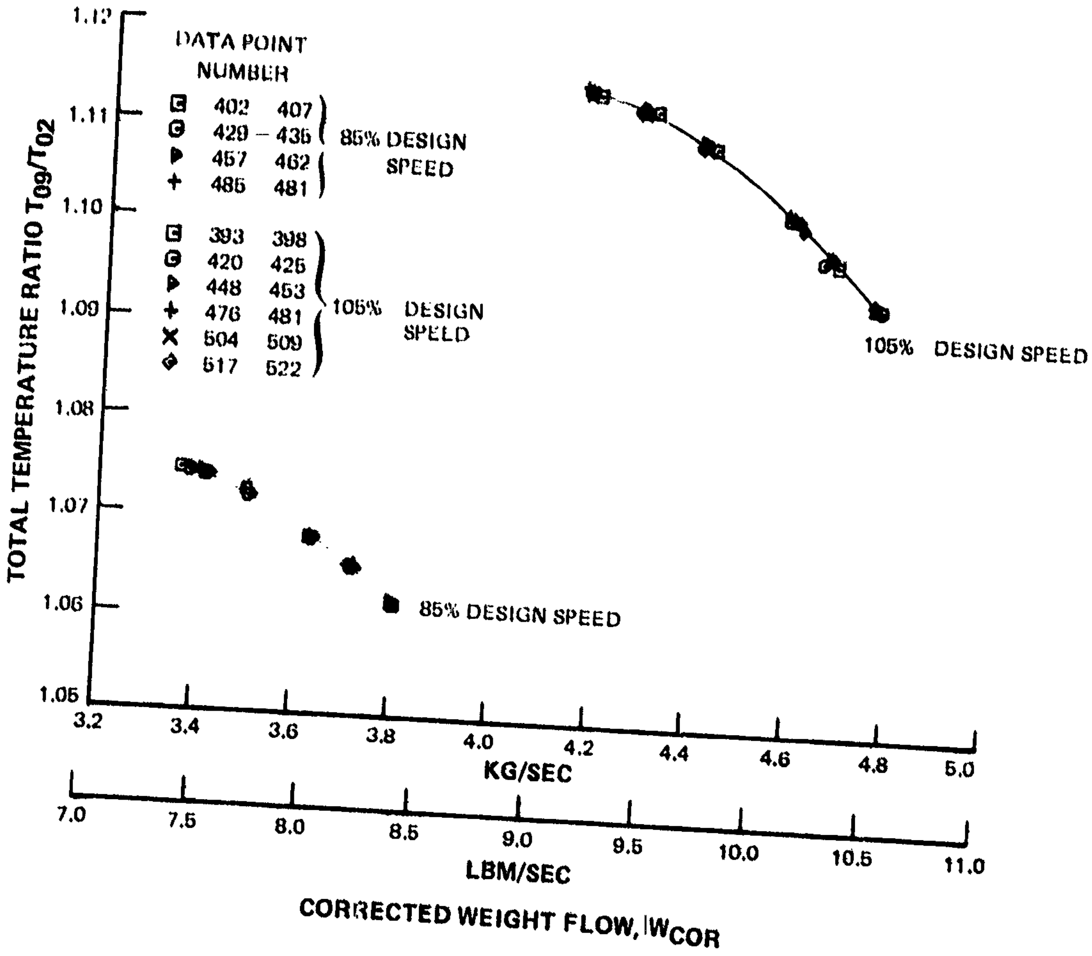

Figure 24 Temperature Ratio as a Function of Corrected Weight Flow for 3S2 Configuration at 85 and 105 Percent Design Speed

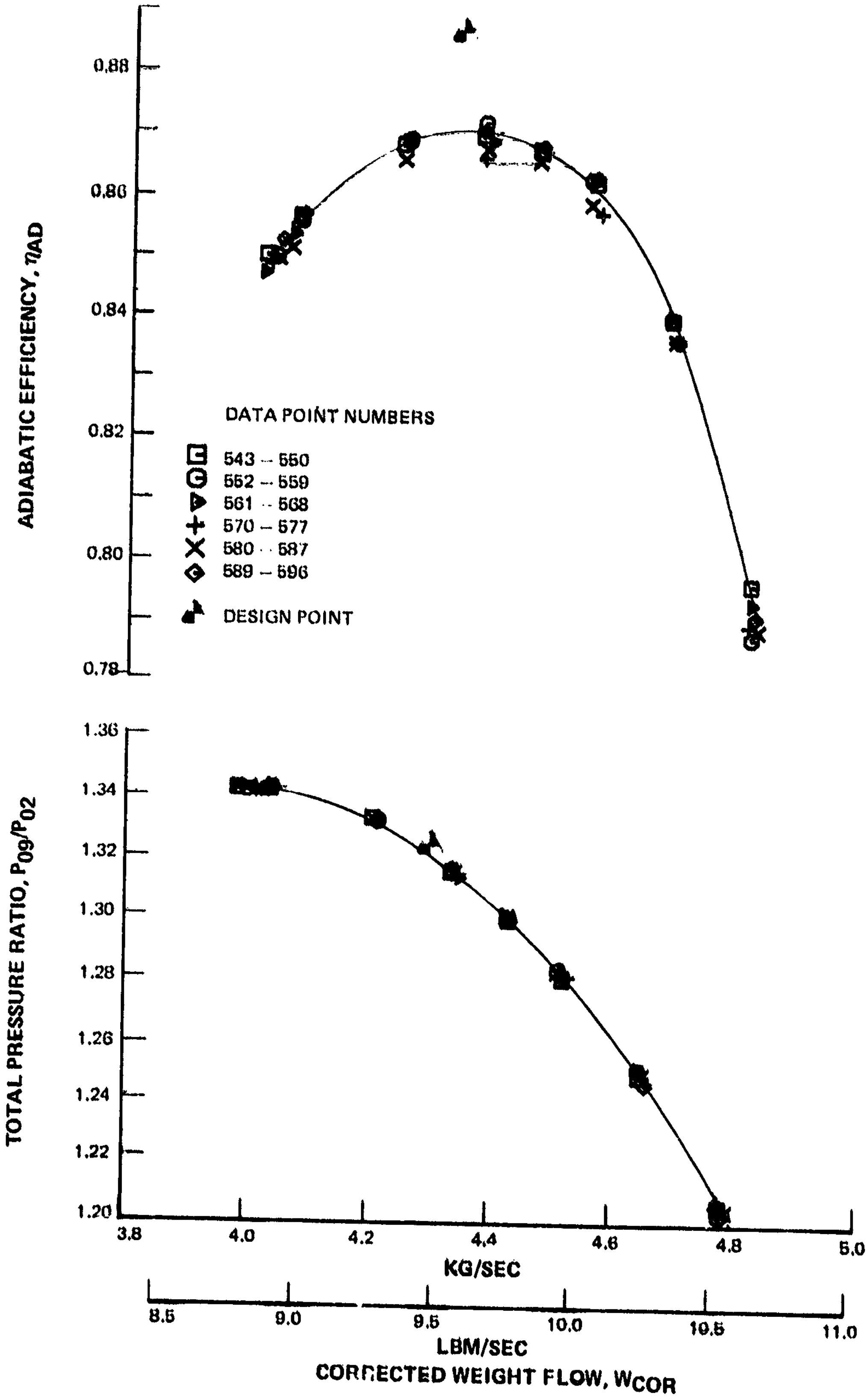

Figure 25 Adiabatic Efficiency and Pressure Ratio as Functions of Corrected Weight Flow for 3S2 Configuration at Design Speed - Deterioration Check

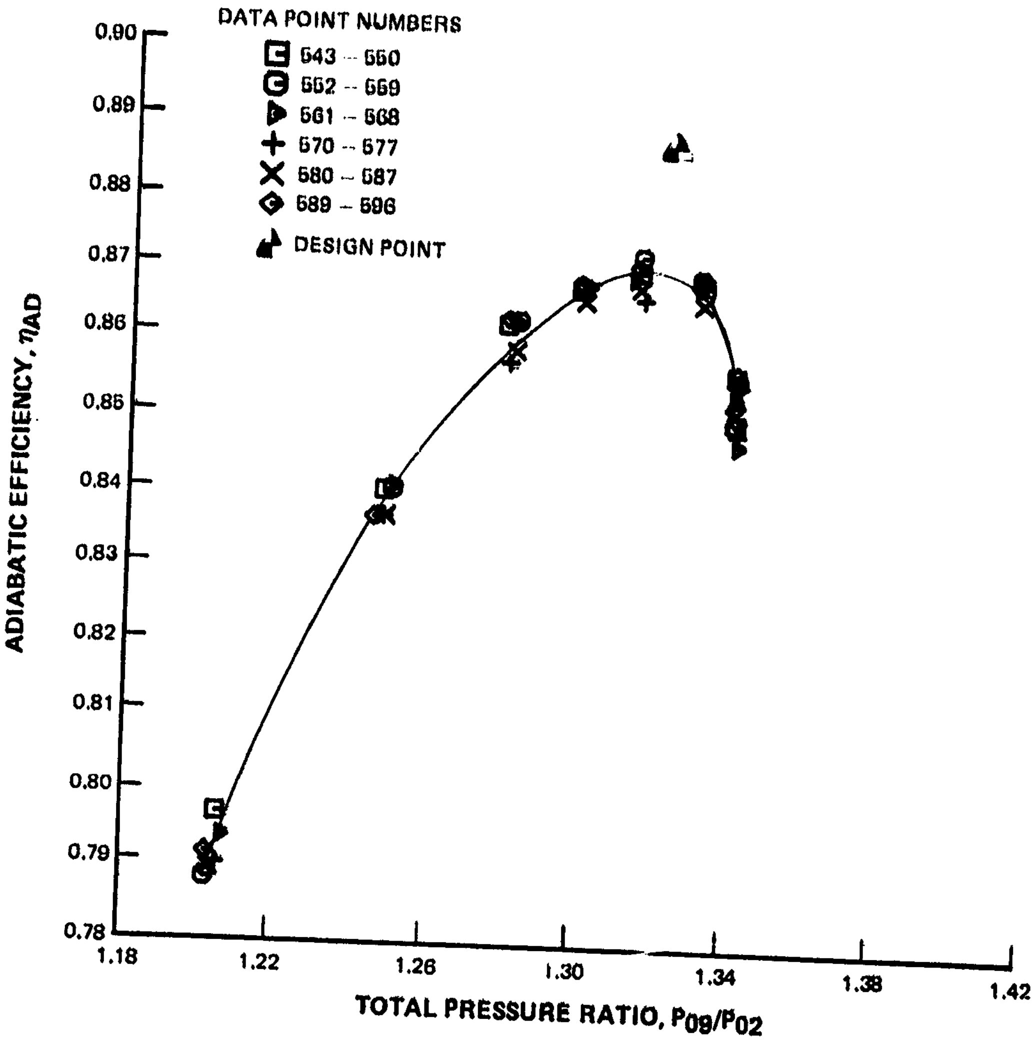

Figure 26 Adiabatic Efficiency as a Function of Pressure Ratio for 3S2 Configuration at Design Speed - Deterioration Check

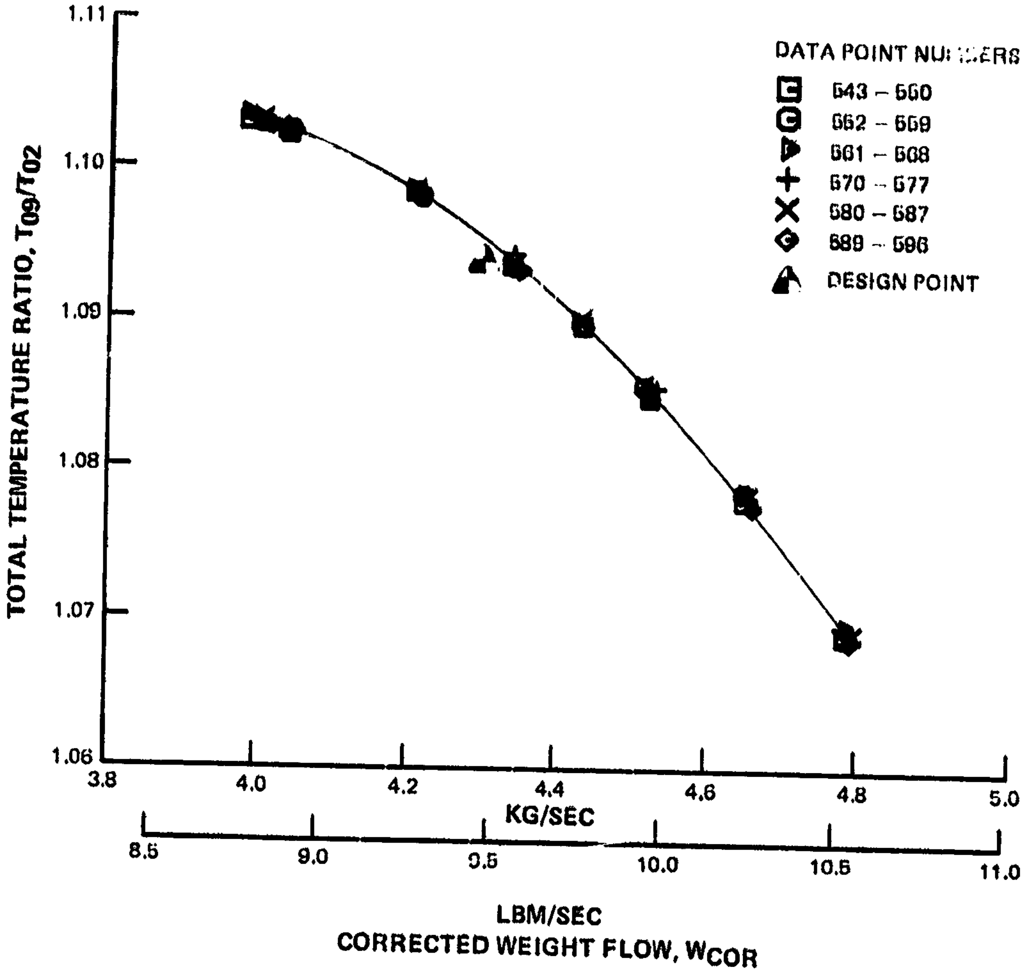

Figure 27 Temperature Ratio as a Function of Corrected Weight Flow for 3S2 Configuration at Design Speed - Deterioration Check

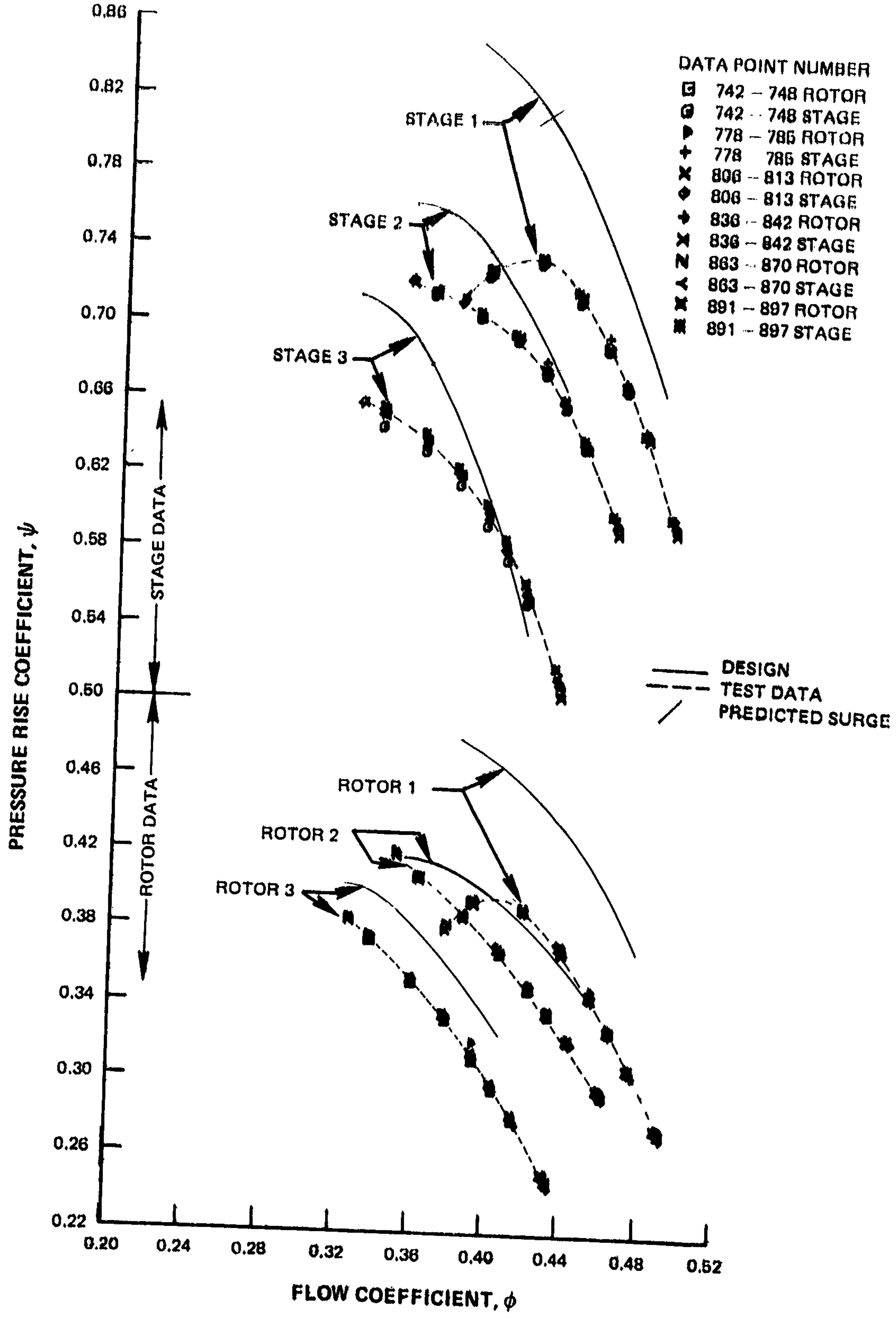

Figure 28 Pressure Rise Coefficient as a Function of Flow Coefficient for 3S1 Configuration at Design Speed

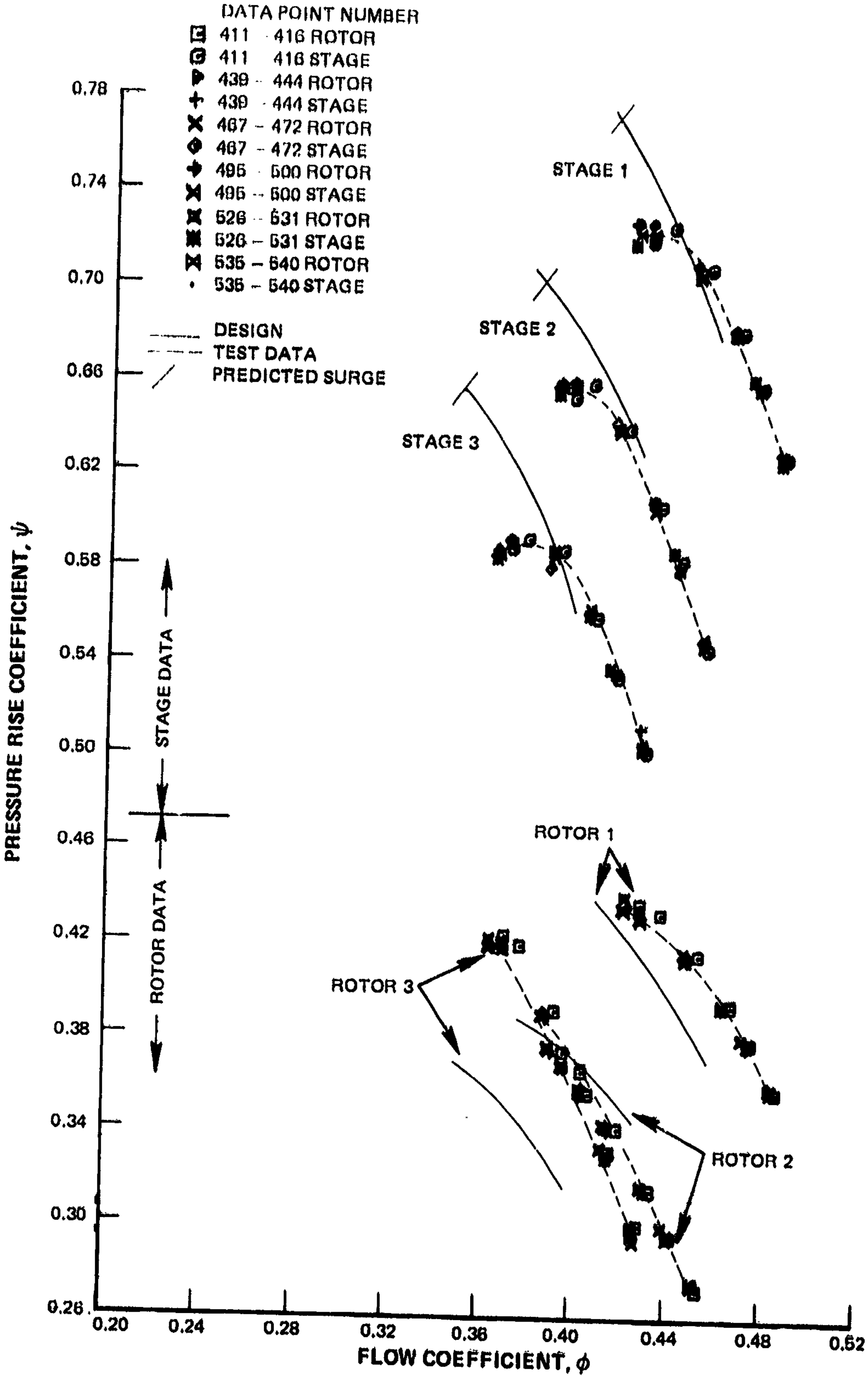

Figure 29 Pressure Rise Coefficient as a Function of Flow Coefficient for 3S2 Configuration at Design Speed

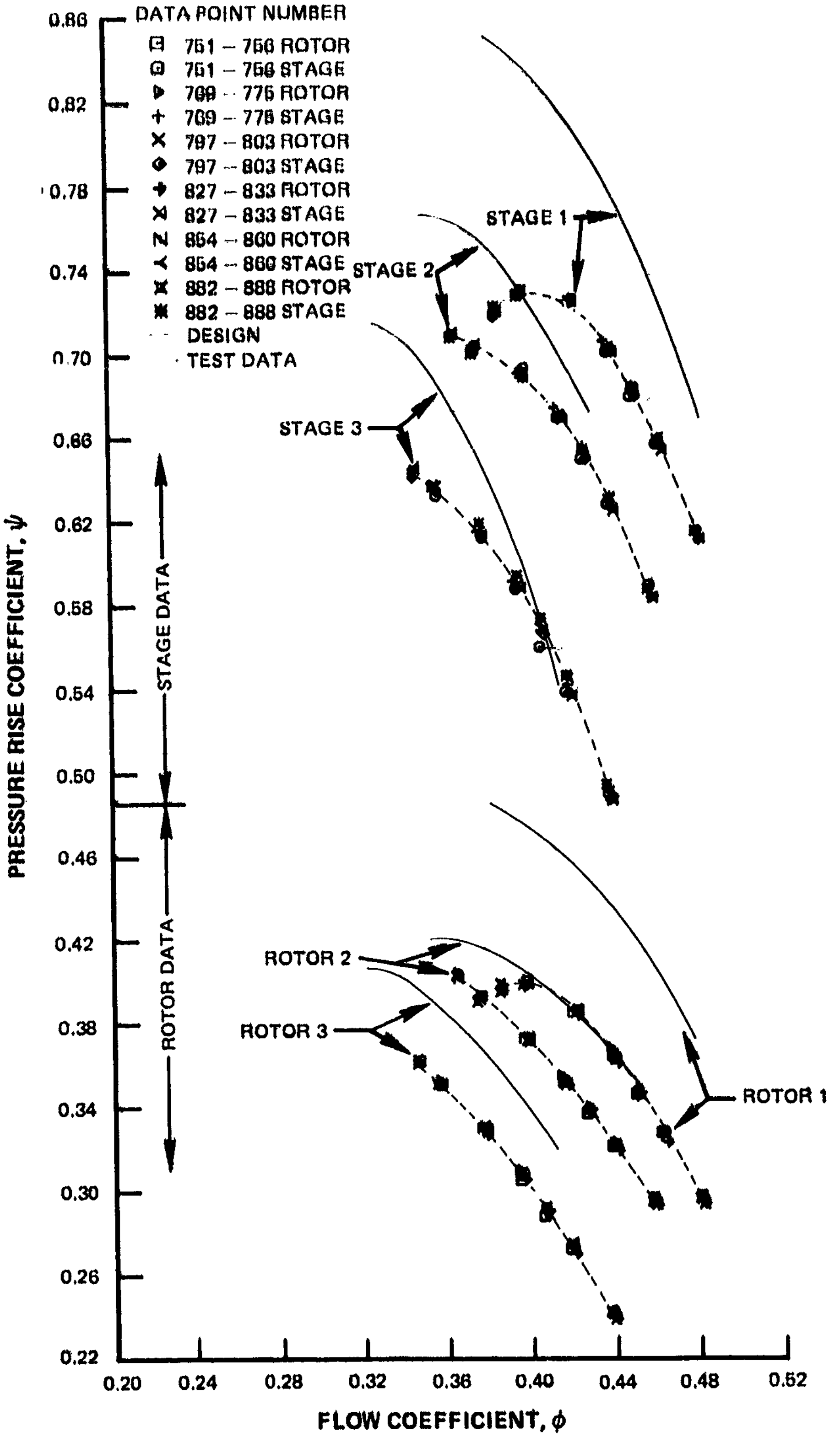

Figure 30 Pressure Rise Coefficient as a Function of Flow Coefficient for 3S1 Configuration at 85 Percent Design Speed

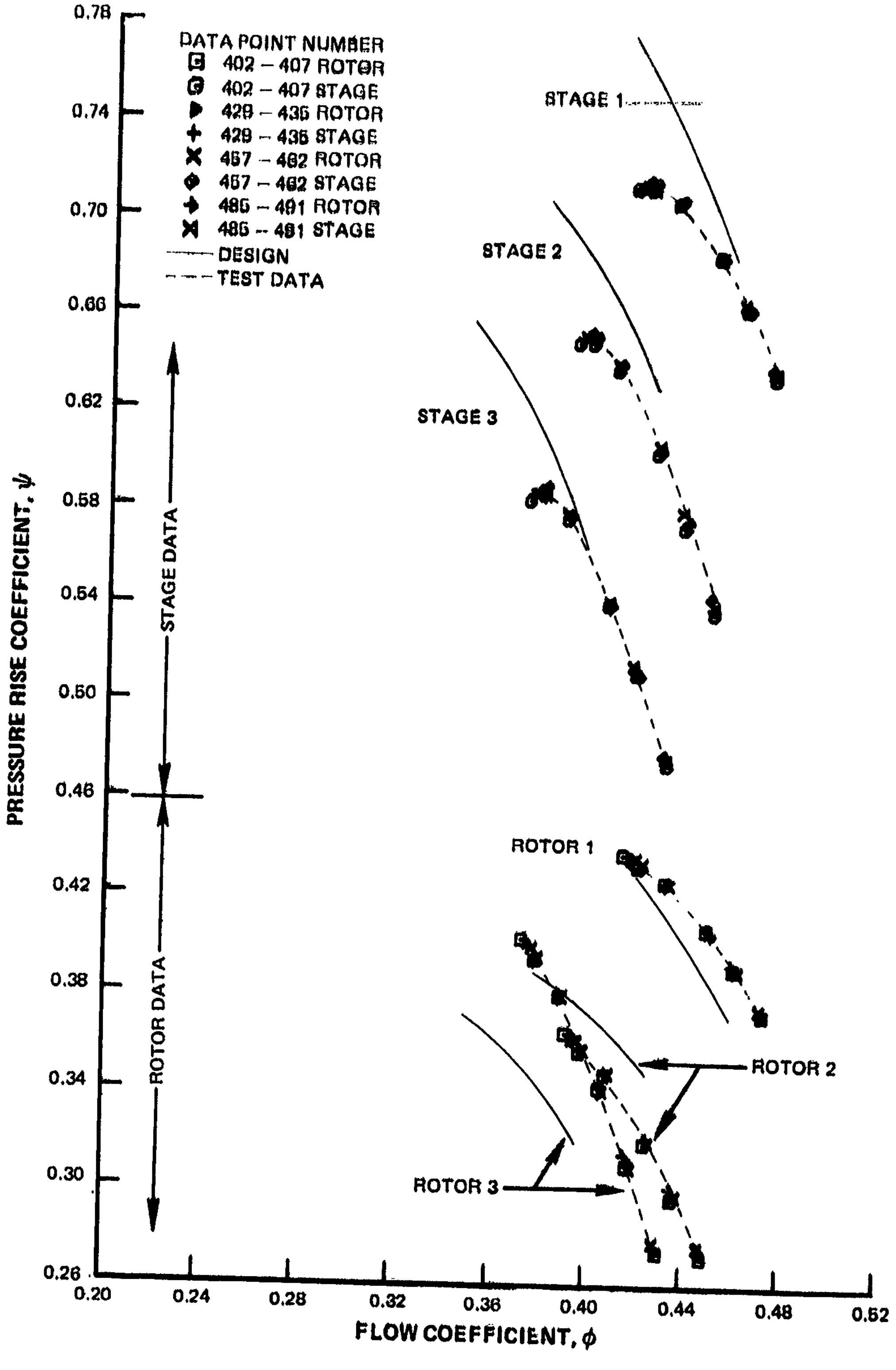

Figure 31 Pressure Rise Coefficient as a Function of Flow Coefficient for 3S2 Configuration at 85 Percent Design Speed

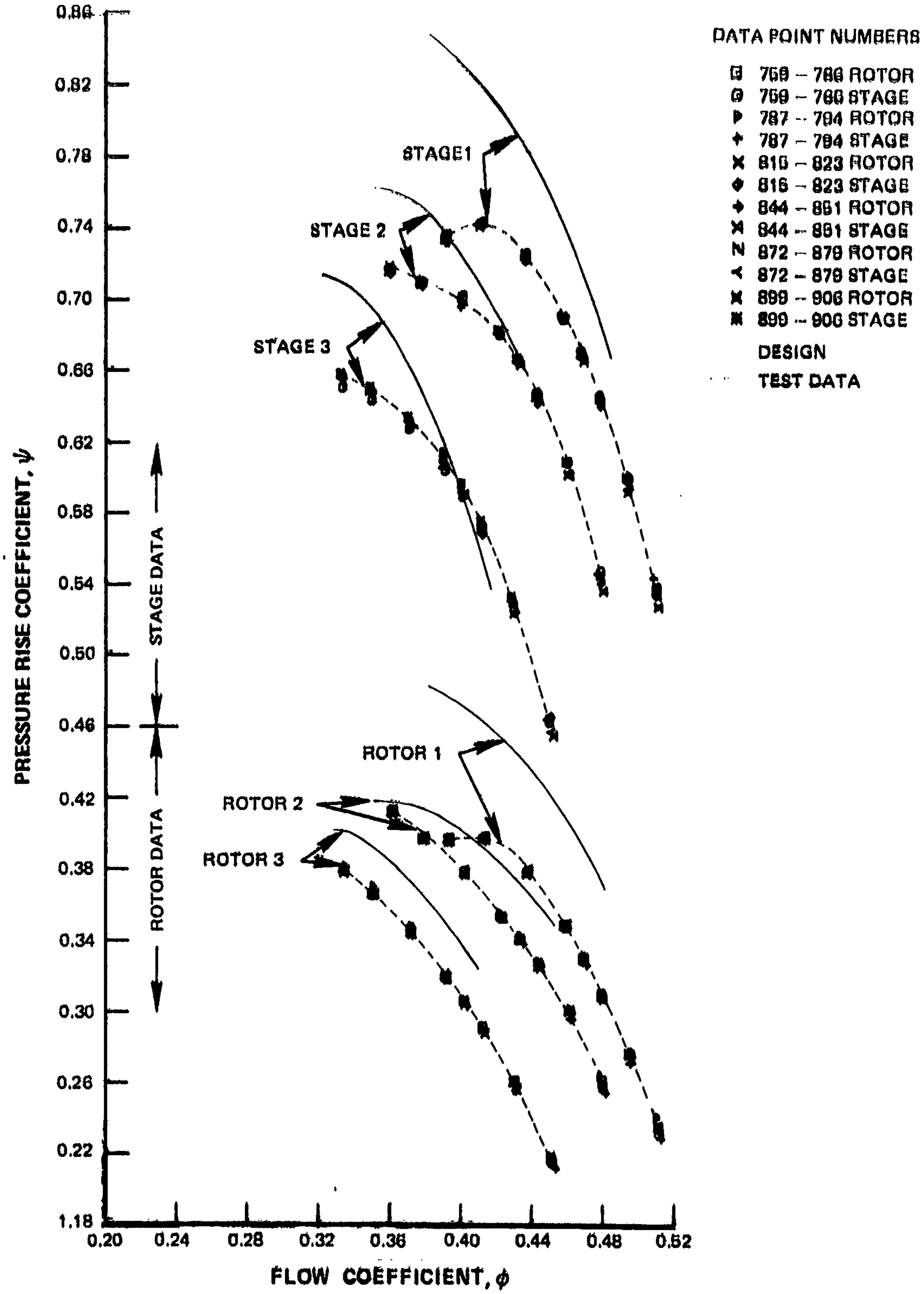

Figure 32 Pressure Rise Coefficient as a Function of Flow Coefficient for 3S1 Configuration at 105 Percent Design Speed

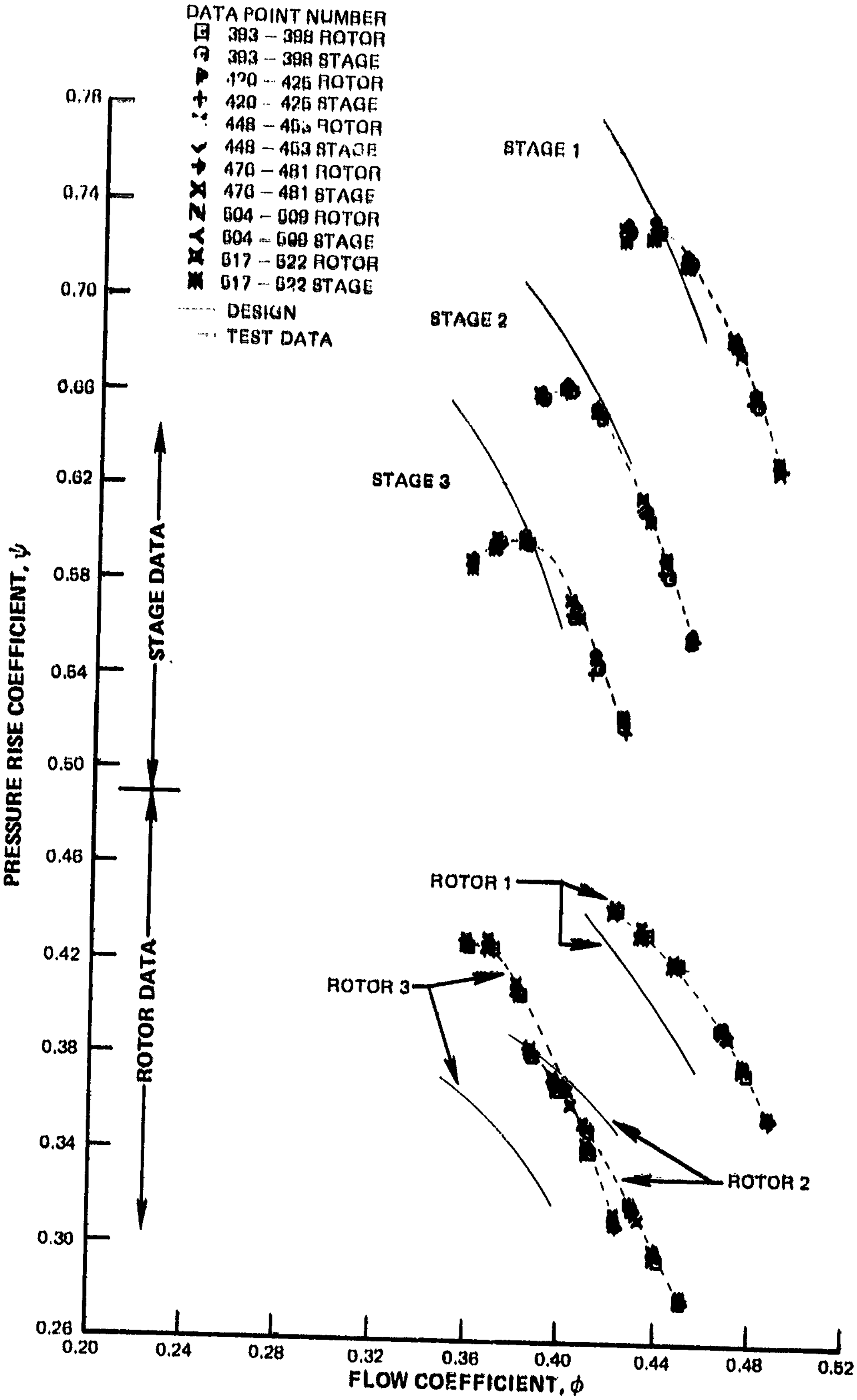

Figure 33 Pressure Rise Coefficient as a Function of Flow Coefficient for 3S2 Configuration at 105 Percent Design Speed

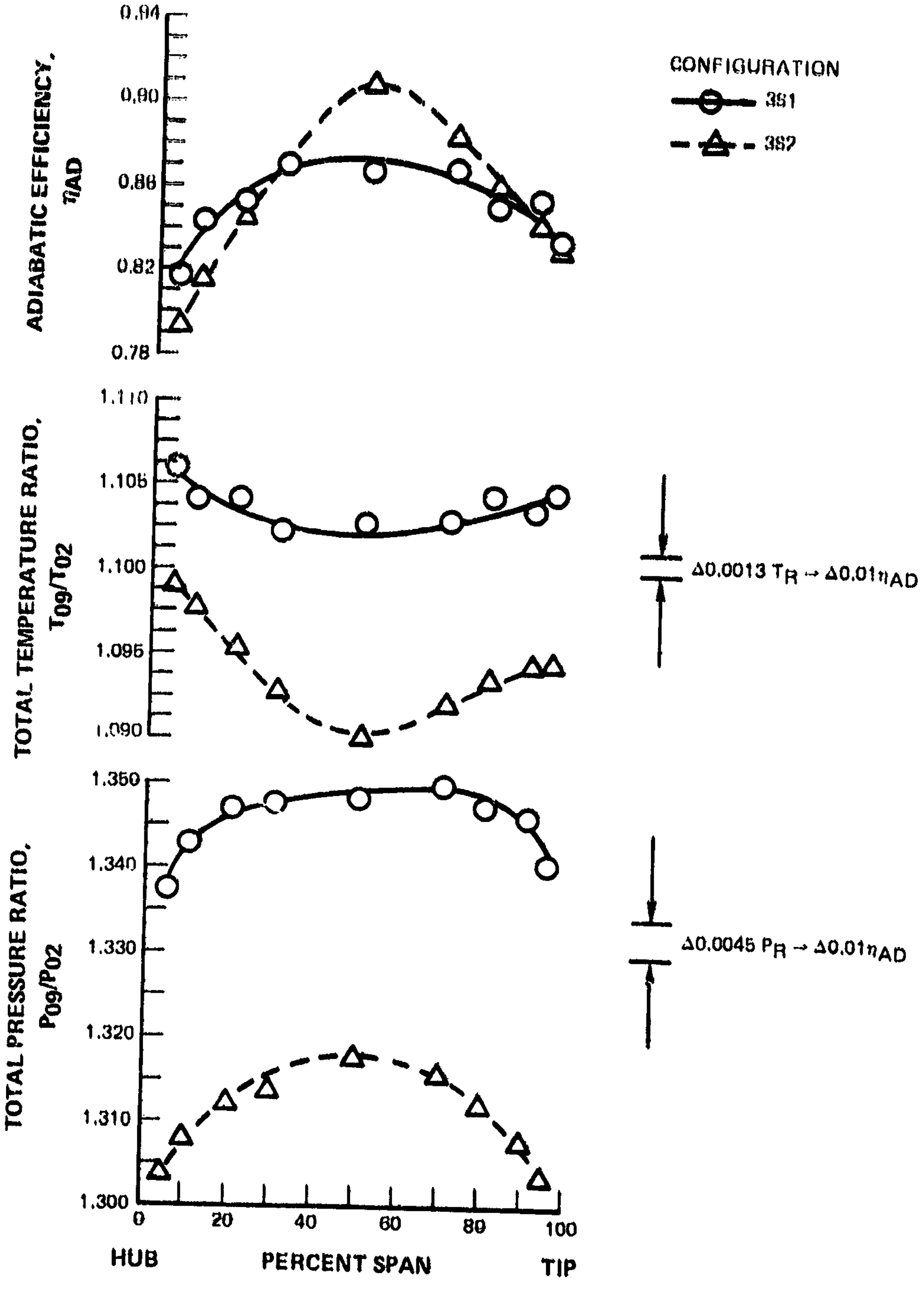

Figure 34 Adiabatic Efficiency, Temperature Ratio, and Pressure Ratio as Functions of Percent Span for 3S1 and 3S2 Configurations at Peak Efficiency; Design Speed

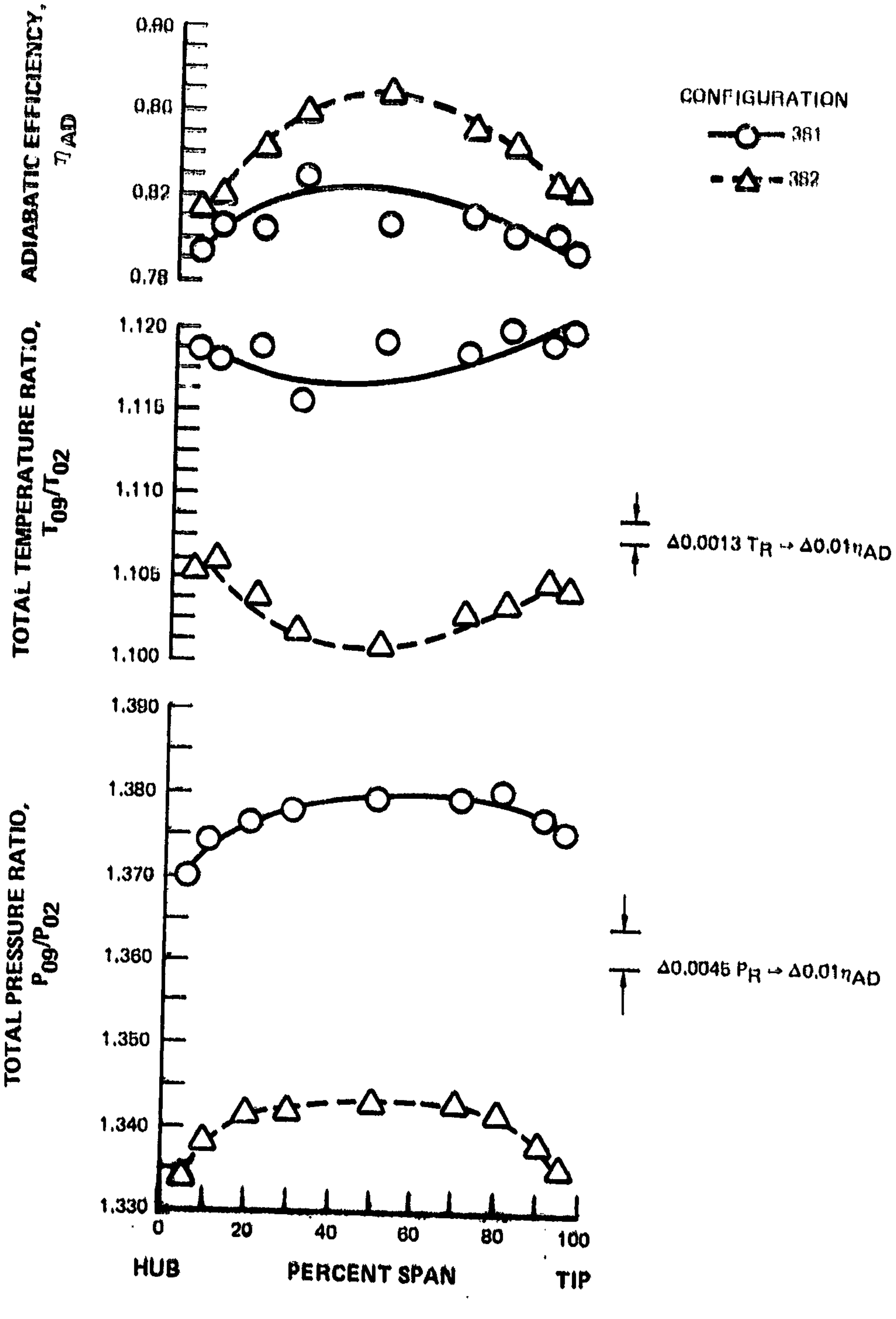

Figure 35 Adiabatic Efficiency, Temperature Ratio, and Pressure Ratio as Functions of Percent Span for 3S1 and 3S2 Configurations at Near Stall; Design Speed

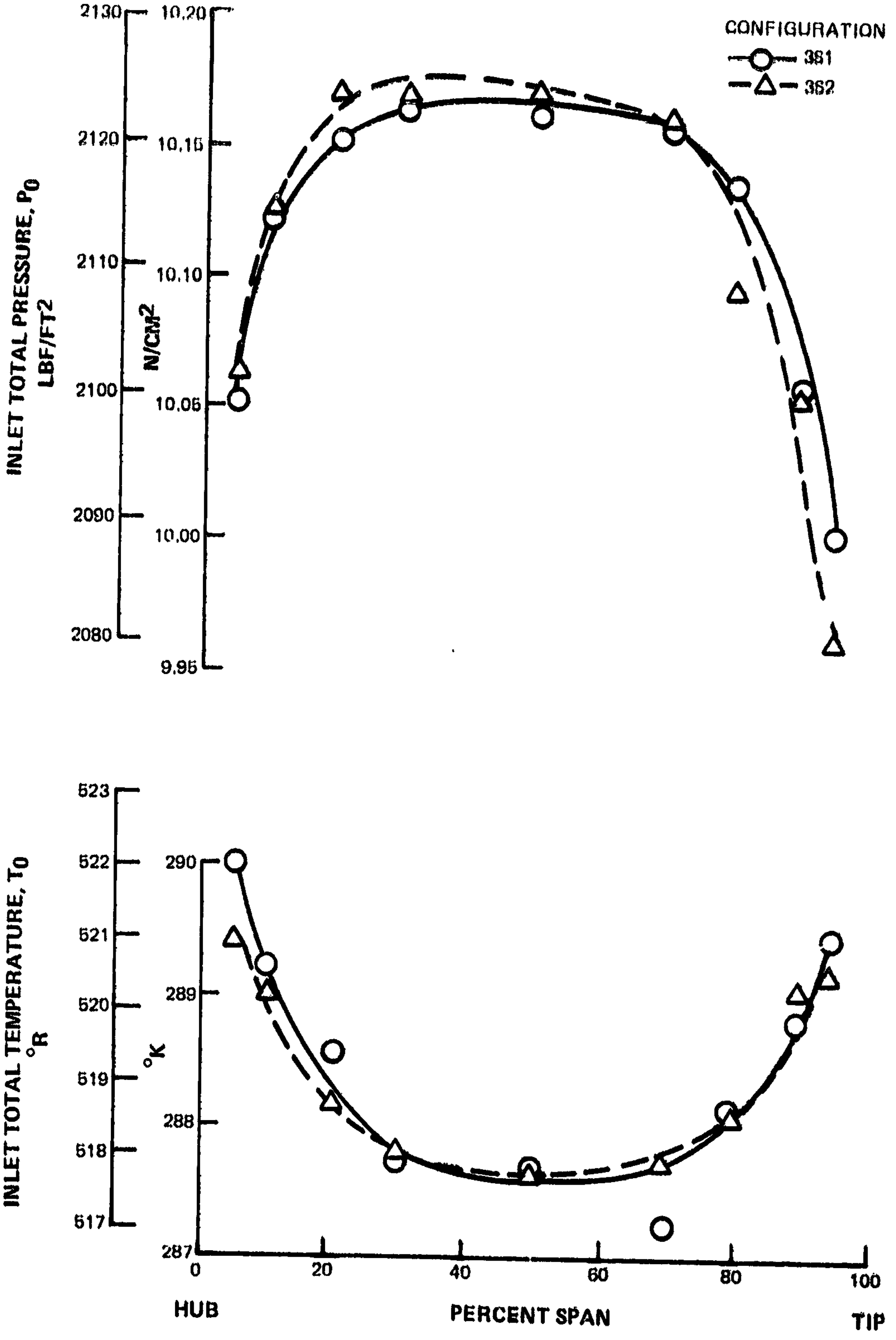

Figure 36 Inlet Total Pressure and Total Temperature as Functions of Percent Span for 3S1 and 3S2 Configurations at Peak Efficiency; Design Speed

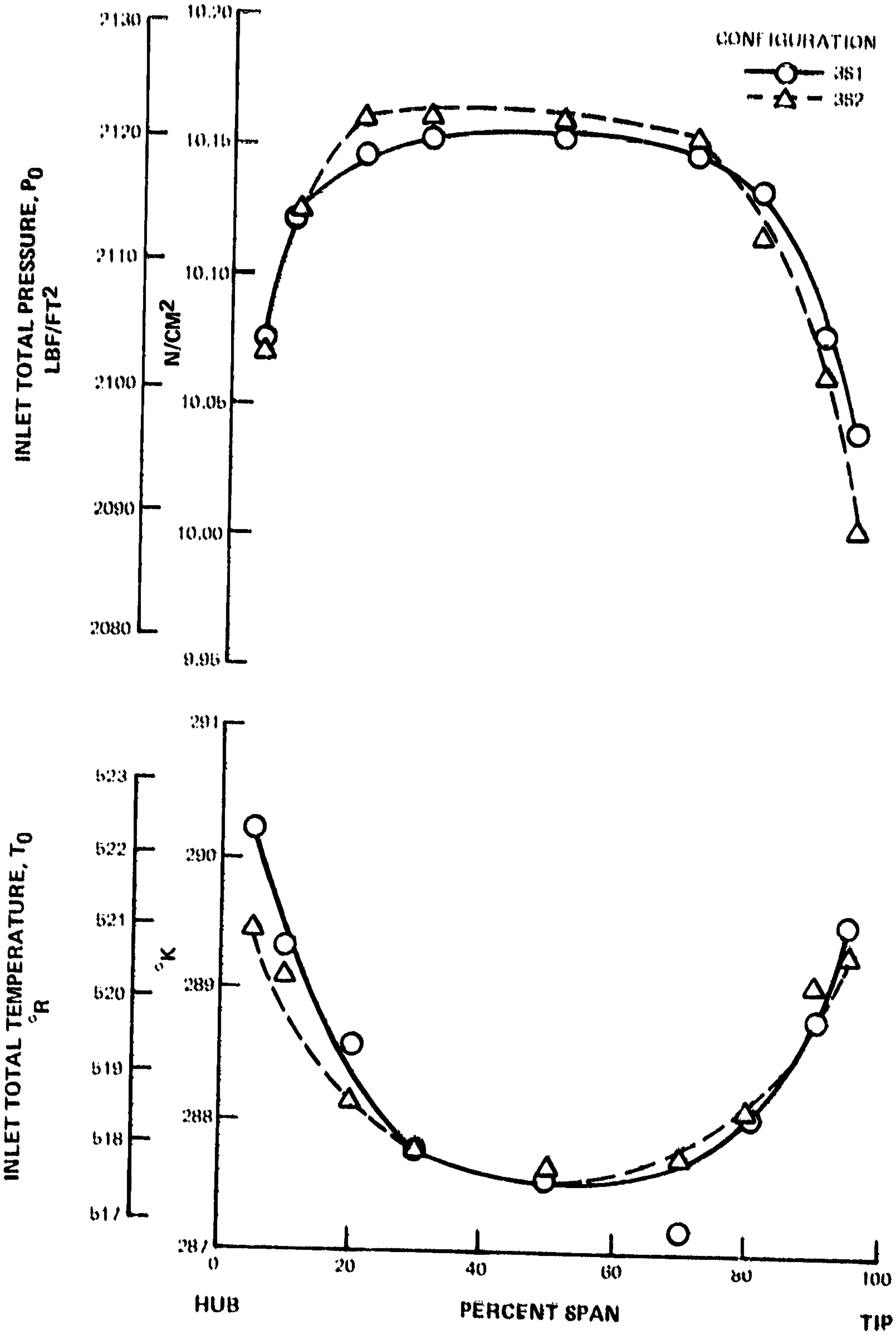

Figure 37 Inlet Total Pressure and Total Temperature as Functions of Percent Span for 3S1 and 3S2 Configurations at Near Surge; Design Speed

APPENDIX A

SYMBOLS AND ABBREVIATIONS

A	Area, meters ^{2} (feet^2)
ASP	Aerodynamic Set Point (rig speed and throttle setting)
b	Chord, cm (in.)
D	Diffusion factor for rotor: $D = 1 - \frac{V'_3}{V'_2} + \frac{r_3 V_{\theta 3} - r_2 V_{\theta 2}}{(r_2 + r_3)\sigma \; V'_2}$ for stator: $D = 1 - \frac{V_4}{V_3} + \frac{r_3 V_{\theta 3} - r_4 V_{\theta 4}}{(r_3 + r_4)\sigma \; V_3}$
E	Work Coefficient $E = \frac{U_3 V_{\theta 3} - U_2 V_{\theta 2}}{1/2 \; U_2^2}$
IGV	Inlet Guide Vane
N	Rotor Speed, revolutions per minute
P	Static Pressure (absolute), N/m^2 (lbf/ft^2)
P_o	Total or Stagnation Pressure (absolute), N/m^2 (lbf/ft^2)
Pr	Pressure Ratio
ΔP	Static Pressure Rise, N/m^2 (lbf/ft^2)
r	Radius, cm (in.)
s	Blade spacing (circumferential), cm (in.)
T	Temperature, K (°F)
Tr	Temperature Ratio
To	Total or Stagnation Temperature, K (°F)
U	Rotor tangential velocity, m/sec (ft/sec)
V	Air Velocity, m/sec (ft/sec)
W	Weight Flow, kg/sec (lbm/sec)
γ	Specific Heat Ratio
δ	Total Pressure/Standard Day Total Pressure
θ	Total Temperature/Standard Day Total Temperature
η	Efficiency
σ	Solidity, b/s
ρ	Density, kg/m^3 (lbm/ft^3)
ψ	Stage Static Pressure Rise Coefficient, (See App. B)
ϕ	Stage Flow Coefficient, (See App. B)

APPENDIX A (Cont'd)

Subscripts

ad	Adiabatic
an	Annulus
av	Average
cor	Corrected to Standard Day
m	Midspan
nom	Nominal
z	Axial Component
θ	Tangential Component
0	Total or Stagnation condition
1	Inlet Station
2	First Rotor Inlet
3	First Stator Inlet
4	Second Rotor Inlet
5	Second Stator Inlet
6	Third Rotor Inlet
7	Third Stator Inlet
9	Exit Station

Superscripts

'	Relative to Rotor
-	Mass Averaged

APPENDIX B

DATA REDUCTION EQUATIONS

DATA CORRECTION AND MASS AVERAGING

All measurements were corrected to the nominal test speed and NASA standard sea level inlet total pressure and temperature. Exit total temperature and pressure data at each radius were corrected using the relationships:

$$(1)\quad T_o = K_T \left\{ 1 + \left[\frac{T_{o,\ test}}{T_{o,\ inlet\ (mass\ av)}} - 1 \right] \left[\frac{N_{cor,\ nom}}{N_{cor,\ test}} \right]^2 \right\}$$

$$(2)\quad P_o = K_P \left\{ 1 + \left[\left(\frac{P_{o,\ test}}{P_{o,\ inlet\ (mass\ av)}} \right)^{\frac{\gamma-1}{\gamma}} - 1 \right] \left[\frac{N_{cor,\ nom}}{N_{cor,\ test}} \right]^2 \right\}^{\frac{\gamma}{\gamma-1}}$$

where, $K_T = 288.15K\ (518.69\ ^{o}R)$
$K_P = 10.1325 \times 10^4\ N/m^2\ (2116.22\ lbf/ft^2)$

Static pressures measured at the inner and outer case walls were corrected to ambient level using the relationship:

$$(3)\quad P = K_P \left\{ \frac{P_{test}}{P_{o,\ inlet(mass\ av)}} + \frac{2\gamma}{\gamma-1} \left[\left(\frac{P_{test}}{P_{o,\ inlet\ (mass\ av)}} \right)^{\frac{\gamma-1}{\gamma}} - 1 \right] \cdot \left(\frac{P_{test}}{P_{o,\ inlet\ (mass\ av)}} \right)^{\frac{1}{\gamma}} \left[\left(\frac{N_{cor,\ nom}}{N_{cor,\ test}} \right) - 1 \right] \right\}$$

where Mach number squared has been assumed small with respect to 1.0. The compressor inlet total pressure and temperature measurements were mass averaged radially and circumferentially for each test point in order to obtain the reference values in equations (1), (2), and (3). Corrected test speed, defined by $(N/\sqrt{\theta})_2$, was also obtained for each point.

The levels of inlet total pressure and temperature measurements were adjusted so that the radial and circumferential mass averages of all readings are equal to the standard values.

$$P_0 = K_P + P_0 - P_0 \text{ inlet (mass av)} \qquad (4)$$

$$T_0 = K_T + T_0 - T_0 \text{ inlet (mass av)} \qquad (5)$$

The corrected test values for total temperature and total pressure from the pole rakes at the inlet and exit stations were circumferentially and radially mass averaged to produce average values for calculating overall performance. A linear static pressure gradient between inner and outer cases at each circumferential location was used for the mass averaging. The corrected data were also mass averaged circumferentially at each radius to give composite radial distributions of temperature and pressure at the inlet and exit stations.

Compressor Overall Performance Computations

Pressure Ratio

Since the tests were intended to reproduce conditions which would be present in the latter stages of a core compressor, the overall performance was presented from upstream of the first rotor (station 2 of Figure 1) to the exit station (station 9). The overall pressure ratio based on the inlet to the first rotor was calculated as follows:

$$\frac{\bar{P}_{09}}{\bar{P}_{02}} = \frac{\bar{P}_{09}}{\bar{P}_{01}} \times \frac{1}{\bar{P}_{r,IGV} \times \bar{P}_{r,pole} \times \bar{P}_{r,strut}}$$

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where $\bar{P}_{09}$ = exit station mass-averaged total pressure

$\bar{P}_{02}$ = first rotor inlet mass-averaged total pressure

$\bar{P}_{01}$ = inlet station mass-averaged total pressure

$\bar{P}_{r,IGV}$ = total pressure ratio across the inlet guide vane

$\bar{P}_{r,pole}$ = total pressure ratio due to losses of inlet station and flow station pole rakes

$\bar{P}_{r,strut}$ = total pressure ratio due to inlet strut losses

All the inlet loss pressure ratios were calculated as functions of the inlet dynamic pressure calculated as a function of flow by:

For W_{cor} in kg/sec

$$\frac{P_o - P}{P_o} = 1.682842 \times 10^{-3} + W_{cor} \times (2.083418 \times 10^{-3} W_{cor} - 1.455674 \times 10^{-3})$$

For W_{cor} in lbm/sec

$$\frac{P_o - P}{P_o} = 1.682842 \times 10^{-3} + W_{cor} \times \left(4.28655 \times 10^{-4} W_{cor} - 6.602824 \times 10^{-4}\right)$$

$$\overline{P}_{r,IGV} = 1.0 - 0.01534 \left(\frac{P_o - P}{P_o}\right)$$

$$\overline{P}_{r,pole} = 1.0 - 0.035095 \left(\frac{P_o - P}{P_o}\right)$$

$$\overline{P}_{r,strut} = 1.0 - 0.001455 \left(\frac{P_o - P}{P_o}\right)$$

Temperature Ratio

Since no work is done ahead of the first rotor and heat loss through the cases is estimated to be negligible, the total temperature ratio is unchanged:

$$\frac{\overline{T}_{09}}{\overline{T}_{02}} = \frac{\overline{T}_{09}}{\overline{T}_{01}}$$

Adiabatic Efficiency

The adiabatic efficiency of the compressor was calculated by:

$$\eta_{ad} = \frac{\left(\overline{P}_{09}/\overline{P}_{02}\right)^{\frac{\gamma-1}{\gamma}} - 1.0}{(\overline{T}_{09}/\overline{T}_{02}) - 1.0}$$

where γ = the ratio of specific heats at the average temperature of the compressor.

Flow Rate

The flow rate was first calculated for the inlet flow calibration station (station 0) and then corrected to the inlet of the first rotor (station 2). An ideal flow rate was calculated from the average midspan total pressure measured at the flow calibration station, the average midspan static pressure at that station (obtained by linear interpolation between outer and inner wall measurements), and the mass averaged total temperature from all the measurements at station 1. The actual flow rate was then the product of the ideal flow rate and the flow coefficient. Thus

$$\left(W \frac{\sqrt{\theta}}{\delta}\right) = (W_{IDEAL}) \times (\text{Flow Coef.}) \frac{\sqrt{\dfrac{\bar{T}_{01}}{K_T}}}{\left(\dfrac{\bar{P}_{02}}{K_P}\right)}$$

Rotor and Stage Performance Based on Wall Static Pressures

Rotor and stage performance was computed separately for each of the three stages for each test point in terms of a static pressure rise coefficient and a flow coefficient. The static pressure rise coefficient is based on the kinetic energy the midspan flow would have if the air velocity were the same as the rotor velocity. The rotor static pressure rise coefficients are:

$$\psi_{\text{ROTOR 1}} = \frac{P_3 - P_2}{\dfrac{1/2 \ \rho_2 \ U_{m2}^2}{g}}$$

$$\psi_{\text{ROTOR 2}} = \frac{P_5 - P_4}{\dfrac{1/2 \ \rho_4 \ U_{m4}^2}{g}}$$

$$\psi \text{ ROTOR } 3 = \frac{P_7 - P_6}{\frac{1/2 \; \rho_6 \; U_{m6}^2}{g}}$$

where P = static pressure, N/m^2 (lbf/ft^2)

ρ = fluid density, Kg/m^3 (lbm/ft^3)

U_m = midspan rotor speed, m/sec (ft/sec)

and subscripts for P, ρ, and U_m correspond to station numbers in Figure 5.

Similarly, the stage static pressure rise coefficients are:

$$\psi \text{ STAGE } 1 = \frac{P_4 - P_2}{\frac{1/2 \; \rho_2 \; U_{m2}^2}{g}}$$

$$\psi \text{ STAGE } 2 = \frac{P_6 - P_4}{\frac{1/2 \; \rho_4 \; U_{m4}^2}{g}}$$

$$\psi \text{ STAGE } 3 = \frac{P_8 - P_6}{\frac{1/2 \; \rho_6 \; U_{m6}^2}{g}}$$

The flow coefficient used for both rotor and stage performance is the ratio of the axial velocity at the rotor inlet station to the midspan rotor speed.

$$\phi 1 = \frac{V_{z2}}{U_{m2}} ,$$

$$\phi 2 = \frac{V_{z4}}{U_{m2}} ,$$

$$\phi_3 = \frac{V_{z6}}{U_{m6}}$$

In order to calculate the fluid density values, the pressures and temperatures within the compressor were calculated based on assumptions of equal rotor pressure ratio and temperature ratio for each stage. Stator losses were assumed equal to the design values for every test point.

$$\bar{P}_{r,ROTOR} = \frac{\bar{P}_{03}}{\bar{P}_{02}} = \frac{\bar{P}_{05}}{\bar{P}_{04}} = \frac{\bar{P}_{07}}{\bar{P}_{06}}$$

$$= \left[\frac{\bar{P}_{09}/\bar{P}_{01}}{\dfrac{\bar{P}_{02}}{\bar{\bar{P}}_{01,DES}} \times \dfrac{\bar{P}_{04}}{\bar{\bar{P}}_{03,DES}} \times \dfrac{\bar{P}_{06}}{\bar{\bar{P}}_{05,DES}} \times \dfrac{\bar{P}_{08}}{\bar{\bar{P}}_{07,DES}}}\right]^{1/3}$$

$$\bar{T}_{r,ROTOR} = \bar{T}_{r,STAGE} = \left(\frac{\bar{\bar{T}}_{09}}{\bar{\bar{T}}_{01}}\right)^{1/3}$$

APPENDIX C

TABULATION OF INLET AND EXIT SPANWISE TEST DATA

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3S1 CONFIGURATION AT 85% DESIGN SPEED

ASP 882-888

ASP 882 WCOR = 3.87003 kg/sec (8.5320 lbm/sec)

% Span	5	10	20	30	50	70	80	90	95
Diam m	0.5601	0.5628	0.5679	0.5732	0.5836	0.5940	0.5992	0.6044	0.6070
ft	1.8377	1.8463	1.8633	1.8805	1.9147	1.9488	1.9658	1.9830	1.9915
P_O (inlet) N/m^2	100710	101257	101508	101575	101579	101550	101378	100745	100263
lbf/ft^2	2103.39	2114.81	2120.04	2121.45	2121.54	2120.92	2117.33	2104.12	2094.04
T_O (inlet) K	289.380	288.799	288.405	287.803	287.824	287.528	288.128	288.599	288.966
°R	520.879	519.834	519.125	518.042	518.079	517.546	518.627	519.475	520.135
P_O (exit) N/m^2	121630	122022	122390	122554	122708	122590	122407	121965	121750
lbf/ft^2	2540.30	2548.50	2556.19	2559.61	2562.83	2560.35	2556.53	2547.30	2542.81
T_O (exit) K	307.448	307.328	307.080	306.871	306.666	306.762	306.837	306.872	306.819
°R	553.402	553.186	552.739	552.363	551.995	552.167	552.303	552.366	552.270

ASP 883 WCOR = 3.73667 kg/sec (8.2380 lbm/sec)

% Span	5	10	20	30	50	70	80	90	95
Diam m	0.5601	0.5628	0.5679	0.5732	0.5836	0.5940	0.5992	0.6044	0.6070
ft	1.8377	1.8463	1.8633	1.8805	1.9147	1.9488	1.9658	1.9830	1.9915
P_O (inlet) N/m^2	100740	101270	101493	101559	101568	101535	101368	100749	100365
lbf/ft^2	2104.02	2115.08	2119.73	2121.11	2121.30	2120.62	2117.13	2104.20	2096.17
T_O (inlet) K	289.355	288.812	288.365	287.806	287.818	287.538	288.135	288.610	289.009
°R	520.835	519.857	519.052	518.047	518.069	517.564	518.639	519.493	520.212
P_O (exit) N/m^2	123526	123981	124275	124407	124628	124437	124255	124115	123646
lbf/ft^2	2579.90	2589.42	2595.55	2598.30	2602.92	2598.93	2595.14	2592.22	2582.42
T_O (exit) K	308.730	308.596	308.366	308.191	308.054	308.087	308.336	308.265	308.324
°R	555.710	555.458	555.055	554.739	554.493	554.552	555.000	554.873	554.978

3S1 CONFIGURATION AT 85% DESIGN SPEED (Cont'd)

ASP 884 W_{COR} = 3.64677 kg/sec (8.0398 lbm/sec)

% Span	5	10	20	30	50	70	80	90	95
Diam m	0.5601	0.5628	0.5679	0.5732	0.5836	0.5940	0.5992	0.6044	0.6070
Diam ft	1.8377	1.8463	1.8633	1.8805	1.9147	1.9488	1.9658	1.9830	1.9915
P_0 (inlet) N/m^2	100774	101268	101484	101540	101553	101520	101393	100756	100436
P_0 (inlet) lbf/ft^2	2104.71	2115.04	2119.54	2120.71	2121.00	2120.31	2117.64	2104.34	2097.65
T_0 (inlet) K	289.395	288.833	288.365	287.799	287.815	287.522	288.108	288.631	289.028
T_0 (inlet) °R	520.906	519.896	519.052	518.034	518.033	517.536	518.590	519.531	520.246
P_0 (exit) N/m^2	124646	125086	125391	125482	125709	125528	125370	125331	124752
P_0 (exit) lbf/ft^2	2603.29	2612.47	2618.86	2620.77	2625.51	2621.72	2618.43	2617.61	2605.52
T_0 (exit) K	309.574	309.373	309.212	308.937	308.964	308.949	309.300	309.149	309.299
T_0 (exit) °R	557.229	556.867	556.578	556.083	556.130	556.103	556.735	556.463	556.734

ASP 885 W_{COR} = 3.56159 kg/sec (7.8520 lbm/sec)

% Span	5	10	20	30	50	70	80	90	95
Diam m	0.5601	0.5628	0.5679	0.5732	0.5836	0.5940	0.5992	0.6044	0.6070
Diam ft	1.8377	1.8463	1.8633	1.8805	1.9147	1.9488	1.9658	1.9830	1.9915
P_0 (inlet) N/m^2	100788	101261	101475	101534	101542	101514	101371	100821	100467
P_0 (inlet) lbf/ft^2	2105.02	2114.90	2119.36	2120.59	2120.76	2120.17	2117.18	2105.70	2098.30
T_0 (inlet) K	289.396	288.862	288.357	287.836	287.768	286.433	288.120	288.618	289.013
T_0 (inlet) °R	520.908	519.948	519.038	518.100	517.979	515.575	518.611	519.508	520.219
P_0 (exit) N/m^2	125528	125974	126272	126330	126480	126408	126309	126279	125736
P_0 (exit) lbf/ft^2	2621.72	2631.03	2637.26	2638.47	2641.60	2640.09	2639.04	2637.40	2626.07
T_0 (exit) K	310.235	310.007	309.917	309.609	309.686	309.710	310.039	309.871	310.041
T_0 (exit) °R	558.419	558.008	557.846	557.291	557.430	557.473	558.056	557.764	558.070

3S1 CONFIGURATION AT 85% DESIGN SPEED (Cont'd)

ASP 886	W_{COR} = 3.41780 kg/sec (7.5350 lbm/sec)								
% Span	5	10	20	30	50	70	80	90	95
Diam									
m	0.5601	0.5628	0.5679	0.5732	0.5836	0.5940	0.5992	0.6044	0.6070
ft	1.8377	1.8463	1.8633	1.8805	1.9147	1.9488	1.9658	1.9830	1.9916
P_0 (inlet)									
N/m^2	100826	101265	101461	101520	101529	101497	101387	100831	100526
lbf/ft^2	2105.81	2114.98	2119.06	2120.30	2120.49	2119.83	2117.52	2105.92	2099.56
T_0 (inlet)									
K	289.453	288.873	288.367	287.787	287.786	287.505	288.111	288.652	289.076
°R	521.011	519.967	519.056	518.012	518.011	517.504	518.596	519.569	520.332
P_0 (exit)									
N/m^2	126627	127095	127290	127411	127383	127580	127420	127401	126939
lbf/ft^2	2644.68	2654.45	2658.53	2661.04	2660.47	2664.58	2661.24	2660.85	2651.19
T_0 (exit)									
K	311.232	310.937	310.946	310.646	310.747	310.816	311.106	310.945	311.116
°R	560.213	559.682	559.698	559.158	559.341	559.464	559.986	559.697	560.005

ASP 887	W_{COR} = 3.22398 kg/sec (7.1077 lbm/sec)								
% Span	5	10	20	30	50	70	80	90	95
Diam									
m	0.5601	0.5628	0.5679	0.5732	0.5836	0.5940	0.5992	0.6044	0.6070
ft	1.8377	1.8463	1.8633	1.8805	1.9147	1.9488	1.9658	1.9830	1.9915
P_0 (inlet)									
N/m^2	100906	101259	101452	101497	101506	101463	101377	100907	100628
lbf/ft^2	2107.48	2114.85	2118.89	2119.81	2120.00	2119.11	2117.32	2107.50	2101.68
T_0 (inlet)									
K	289.298	288.719	288.285	287.783	287.763	287.603	288.180	288.737	289.153
°R	520.733	519.690	518.909	518.005	517.969	517.682	518.720	519.722	520.471
P_0 (exit)									
N/m^2	127333	127677	127883	127996	127980	128097	128044	127868	127636
lbf/ft^2	2659.42	2666.60	2670.90	2673.27	2672.94	2675.37	2674.27	2670.60	2665.75
T_0 (exit)									
K	311.690	311.499	311.660	311.435	311.614	311.646	311.902	311.725	311.800
°R	561.037	560.694	560.983	560.578	560.901	560.958	561.419	561.101	561.235

3S1 CONFIGURATION AT 85% DESIGN SPEED (Cont'd)

ASP 888 W_{COR} = 3.13898 kg/sec (6.9203 lbm/sec)

% Span	5	10	20	30	50	70	80	90	95
Diam									
m	0.5601	0.5628	0.5679	0.5732	0.5836	0.5940	0.5992	0.6044	0.6070
ft	1.8377	1.8463	1.8633	1.8805	1.9147	1.9488	1.9658	1.9830	1.9915
P_0 (inlet)									
N/m^2	100921	101277	101443	101485	101497	101406	101366	100921	100663
lbf/ft^2	2107.78	2115.22	2118.70	2119.58	2119.82	2119.18	2117.09	2107.79	2102.19
T_0 (inlet)									
K	289.349	288.761	288.312	287.811	287.773	287.592	288.130	288.685	289.090
^oR	520.824	519.765	518.958	518.056	517.987	517.661	518.629	519.628	520.357
P_0 (exit)									
N/m^2	127643	127908	128173	128192	128207	128309	128271	128091	127881
lbf/ft^2	2665.90	2671.43	2676.96	2677.35	2677.67	2679.80	2615.26	2679.01	2670.87
T_0 (exit)									
K	312.281	312.120	312.239	312.029	312.227	312.226	312.495	312.340	312.447
^oR	562.101	561.811	562.025	561.648	562.004	562.002	562.486	562.208	562.400

3SI CONFIGURATION AT 100% DESIGN SPEED

ASP 863-870

ASP 863 W_{COR} = 4.5972 kg/sec (10.1352 lbm/sec)

% Span	5	10	20	30	50	70	80	90	95
Diam m	0.5601	0.5628	0.5679	0.5732	0.5836	0.5940	0.5992	0.6044	0.6070
ft	1.8377	1.8463	1.8633	1.8805	1.9147	1.9488	1.9658	1.9830	1.9915
P_0 (inlet) N/m²	100422	101183	101579	101683	101697	101654	101379	100529	99858
lbf/ft²	2097.37	2113.27	2121.54	2123.71	2124.00	2123.11	2117.35	2099.61	2085.59
T_0 (inlet) K	289.778	289.047	288.510	287.751	287.712	287.330	288.058	288.647	289.168
°R	521.596	520.281	519.314	517.949	517.877	517.190	518.500	519.560	520.499
P_0 (exit) N/m²	129676	130334	130849	131056	131254	131001	130818	130314	130049
lbf/ft²	2708.35	2722.10	2732.86	2737.18	2741.31	2736.03	2732.21	2721.68	2716.16
T_0 (exit) K	314.791	314.563	314.217	313.923	313.643	313.798	313.954	314.043	313.986
°R	566.620	566.208	565.586	565.056	564.553	564.831	565.113	565.273	565.171

ASP 864 W_{COR} = 4.4611 kg/sec (9.83511 lbm/sec)

% Span	5	10	20	30	50	70	80	90	95
Diam m	0.5601	0.5628	0.5679	0.5732	0.5836	0.5940	0.5992	0.6044	0.6070
ft	1.8377	1.8463	1.8633	1.8805	1.9147	1.9488	1.9658	1.9830	1.9915
P_0 (inlet) N/m²	100469	101206	101566	101668	101680	101622	101403	100537	99918
lbf/ft²	2098.36	2113.75	2121.27	2123.39	2123.65	2122.43	2117.85	2099.76	2086.80
T_0 (inlet) K	289.911	289.187	288.513	287.737	287.622	287.270	288.055	288.716	317.055
°R	521.836	520.534	519.319	517.922	517.717	517.082	518.495	519.685	570.713
P_0 (exit) N/m²	132328	132998	133448	133580	133860	133671	133340	133295	132528
lbf/ft²	2763.74	2777.74	2787.14	2789.90	2795.74	2791.80	2784.88	2783.93	2767.91
T_0 (exit) K	316.545	316.204	315.938	315.584	315.446	315.521	315.880	315.810	315.933
°R	569.778	569.162	568.683	568.046	567.799	567.934	568.580	568.454	568.674

JSI CONFIGURATION AT 100% DESIGN SPEED (Cont'd)

ASP 865 W_{COR} = 4.36656 kg/sec (9.62666 lbm/sec)

% Span	5	10	20	30	50	70	80	90	95
Diam									
m	0.5601	0.5628	0.5679	0.5732	0.5836	0.5940	0.5992	0.6044	0.6070
ft	1.8377	1.8463	1.8633	1.8805	1.9147	1.9488	1.9658	1.9830	1.9915
P_0 (inlet)									
N/m²	100501	101216	101556	101660	101667	101611	101399	100531	99984
lbf/ft²	2099.01	2113.95	2121.06	2123.22	2123.38	2122.20	2117.79	2099.65	2088.23
T_0 (inlet)									
K	289.985	289.198	288.515	287.710	287.615	287.222	288.041	288.764	317.166
°R	521.968	520.553	519.322	517.874	517.702	516.996	518.469	519.771	570.894
P_0 (exit)									
N/m²	133929	134576	135015	135099	135311	135251	134992	134882	134200
lbf/ft²	2797.19	2810.70	2819.87	2821.62	2826.05	2824.79	2819.39	2817.08	2802.85
T_0 (exit)									
K	317.685	317.271	317.109	316.632	316.650	316.710	317.147	316.975	317.211
°R	571.828	571.083	570.793	569.933	569.966	570.074	570.860	570.551	570.975

ASP 866 W_{COR} = 4.28008 kg/sec (9.43603 lbm/sec)

% Span	5	10	20	30	50	70	80	90	95
Diam									
m	0.5601	0.5628	0.5679	0.5732	0.5836	0.5940	0.5992	0.6044	0.6070
ft	1.8377	1.8463	1.8633	1.8805	1.9147	1.9488	1.9658	1.9830	1.9915
P_0 (inlet)									
N/m²	100541	101230	101540	101648	101653	101594	101384	100587	100040
lbf/ft²	2099.85	2114.25	2120.72	2122.98	2123.08	2121.84	2117.47	2100.81	2089.39
T_0 (inlet)									
K	289.975	289.179	288.516	287.690	287.627	287.216	288.063	288.761	289.406
°R	521.950	520.518	519.324	517.837	517.724	516.985	518.510	519.766	520.927
P_0 (exit)									
N/m²	135152	135152	136194	136292	136370	136449	136258	136057	135529
lbf/ft²	2822.72	2835.95	2844.49	2846.54	2848.17	2849.81	2845.82	2841.63	2830.59
T_0 (exit)									
K	318.605	318.097	320.839	317.494	317.626	317.668	318.105	317.898	318.186
°R	573.484	572.570	577.506	571.484	571.722	571.798	572.585	572.211	572.730

3S1 CONFIGURATION AT 100% DESIGN SPEED (Cont'd)

ASP 867 W_{COR} = 4.14178 kg/sec (9.13111 lbm/sec)

% Span	5	10	20	30	50	70	80	90	95
Diam									
m	0.5601	0.5628	0.5679	0.5732	0.5836	0.5940	0.5992	0.6044	0.6070
ft	1.8377	1.8463	1.8633	1.8805	1.9147	1.9488	1.9658	1.9830	1.9915
P_o (inlet)									
N/m^2	100598	101226	101538	101621	101630	101576	101391	100614	100141
lbf/ft^2	2101.04	2114.16	2120.67	2122.41	2122.60	2121.47	2117.61	2101.37	2091.49
T_o (inlet)									
K	290.033	289.261	288.491	287.698	287.590	287.206	288.023	288.804	289.436
°R	522.056	520.665	519.280	517.852	517.657	516.966	518.438	519.843	520.981
P_o (exit)									
N/m^2	136629	137239	137536	137730	137650	137931	137695	137504	137071
lbf/ft^2	2853.58	2866.31	2872.52	2876.56	2874.89	2880.76	2875.84	2871.85	2862.81
T_o (exit)									
K	319.783	319.258	319.350	318.798	318.911	318.941	319.330	319.115	319.371
°R	575.605	574.659	574.825	573.832	574.035	574.089	574.790	574.402	574.864

ASP 868 W_{COR} = 3.95810 kg/sec (8.72617 lbm/sec)

% Span	5	10	20	30	50	70	80	90	95
Diam									
m	0.5601	0.5628	0.5679	0.5732	0.5836	0.5940	0.5992	0.6044	0.6070
ft	1.8377	1.8463	1.8633	1.8805	1.9147	1.9488	1.9658	1.9830	1.9915
P_o (inlet)									
N/m^2	100626	101237	101518	101599	101606	101552	101364	100695	100227
lbf/ft^2	2102.63	2114.38	2120.25	2121.95	2122.10	2120.97	2117.05	2103.07	2093.30
T_o (inlet)									
K	290.073	289.167	288.580	287.656	287.616	287.187	288.050	288.757	289.417
°R	522.127	520.496	519.440	517.777	517.705	516.933	518.485	519.777	520.947
P_o (exit)									
N/m^2	138002	138441	138741	138884	138836	138965	138910	138592	138354
lbf/ft^2	2882.24	2891.42	2897.68	2900.67	2899.67	2902.35	2901.22	2894.56	2889.59
T_o (exit)									
K	320.805	320.441	320.581	320.138	320.316	320.214	320.611	320.370	320.594
°R	577.444	576.790	577.042	576.243	576.565	576.381	577.096	576.661	577.065

3S1 CONFIGURATION AT 100% DESIGN SPEED (Cont'd)

ASP 869 W_{COR} = 3.72177 kg/sec (8.20615 lbm/sec)

% Span	5	10	20	30	50	70	80	90	95
Diam m	0.5601	0.5628	0.5679	0.5732	0.5836	0.5940	0.5992	0.6044	0.6070
ft	1.8377	1.8463	1.8633	1.8805	1.9147	1.9488	1.9658	1.9830	1.9916
P_0 (inlet) N/m^2	100727	101270	101497	101565	101575	101522	101363	100778	100353
lbf/ft^2	2103.73	2115.08	2119.81	2121.25	2121.45	2120.35	2116.81	2104.81	2095.93
T_0 (inlet) K	290.104	289.217	288.518	287.717	287.592	287.189	288.021	288.742	317.213
°R	522.183	520.587	519.328	517.886	517.661	516.936	518.434	519.731	570.979
P_0 (exit) N/m^2	138642	139065	139341	139434	139569	139561	139647	139289	139141
lbf/ft^2	2895.62	2904.45	2910.21	2912.15	2914.98	2914.81	2916.60	2909.12	2906.04
T_0 (exit) K	321.770	321.553	321.743	321.403	321.731	321.527	321.934	321.674	321.872
°R	579.181	578.791	579.132	578.521	579.112	578.744	579.477	579.008	579.365

ASP 870 W_{COR} = 3.59742 kg/sec (7.93099 lbm/sec)

% Span	5	10	20	30	50	70	80	90	95
Diam m	0.5601	0.5628	0.5679	0.5732	0.5836	0.5940	0.5992	0.6044	0.6070
ft	1.8377	1.8463	1.8633	1.8805	1.9147	1.9488	1.9658	1.9830	1.9915
P_0 (inlet) N/m^2	100776	101248	101481	101545	101553	101509	101373	100715	100445
lbf/ft^2	2104.77	2114.63	2119.49	2120.83	2120.99	2120.07	2117.23	2103.48	2097.85
T_0 (inlet) K	290.187	289.298	288.525	287.743	287.517	287.143	288.026	288.765	289.507
°R	522.333	520.732	519.341	517.933	517.526	516.853	518.443	519.772	521.109
P_0 (exit) N/m^2	138797	134456	139477	139618	139780	139784	139868	139549	139386
lbf/ft^2	2898.85	2808.18	2913.05	2915.99	2919.39	2919.47	2921.22	2914.56	2911.16
T_0 (exit) K	322.351	322.152	322.403	321.471	322.517	322.348	322.758	322.505	322.738
°R	580.227	579.869	580.321	578.644	580.526	580.222	580.960	580.504	580.923

3S1 CONFIGURATION AT 105% DESIGN SPEED

ASP 872-879

ASP 872 W_{COR} = 4.96708 kg/sec (10.9506 lbm/sec)

% Span	5	10	20	30	50	70	80	90	95
Diam									
m	0.5601	0.5628	0.5679	0.5732	0.5836	0.5940	0.5992	0.6044	0.6070
ft	1.8377	1.8463	1.8633	1.8805	1.9147	1.9488	1.9658	1.9830	1.9915
P_o (inlet)									
N/m^2	100237	101133	101625	101767	101771	101699	101425	100330	99599
lbf/ft^2	2093.51	2112.21	2122.60	2125.46	2125.54	2124.04	2118.31	2095.45	2080.18
T_o (inlet)									
K	289.895	289.129	288.565	287.688	287.704	287.242	288.052	288.688	289.249
^oR	521.807	520.429	519.412	517.834	517.863	517.032	518.490	519.636	520.644
P_o (exit)									
N/m^2	128771	129352	130073	130360	130689	130324	130144	129342	129084
lbf/ft^2	2689.45	2701.59	2716.64	2722.63	2729.51	2721.89	2718.13	2701.37	2695.98
T_o (exit)									
K	315.149	314.924	314.576	313.644	313.977	314.159	314.146	314.241	314.077
^oR	567.265	566.859	566.228	564.556	565.155	565.483	565.458	565.629	565.335

ASP 873 W_{COR} = 4.82112 kg/sec (10.6288 lbm/sec)

% Span	5	10	20	30	50	70	80	90	95
Diam									
m	0.5601	0.5628	0.5679	0.5732	0.5836	0.5940	0.5992	0.6044	0.6070
ft	1.8377	1.8463	1.8633	1.8805	1.9147	1.9488	1.9658	1.9830	1.9915
P_o (inlet)									
N/m^2	100315	101167	101610	101734	101744	101665	101427	100391	99596
lbf/ft^2	2095.13	2112.92	2122.18	2124.76	2124.97	2123.32	2118.35	2096.72	2082.20
T_o (inlet)									
K	289.986	289.133	288.567	287.635	287.679	287.199	288.076	288.745	289.363
^oR	521.970	520.434	519.417	517.740	517.818	516.953	518.533	519.736	520.849
P_o (exit)									
N/m^2	133074	133804	134381	134557	134822	134572	134199	133964	133349
lbf/ft^2	2779.33	2794.58	2806.63	2810.30	2815.83	2810.61	2802.82	2797.91	2785.07
T_o (exit)									
K	317.703	317.444	317.007	316.742	316.431	316.637	316.853	316.941	316.917
^oR	571.861	571.394	570.609	570.131	569.570	569.942	570.330	570.489	570.447

3S1 CONFIGURATION AT 105% DESIGN SPEED (Cont'd)

ASP 874 W_{COR} = 4.68286 kg/sec (10.3240 lbm/sec)

% Span	5	10	20	30	50	70	80	90	95
Diam m	0.5601	0.5628	0.5679	0.5732	0.5836	0.5940	0.5992	0.6044	0.6070
ft	1.8377	1.8463	1.8633	1.8805	1.9147	1.9488	1.9658	1.9830	1.9915
P_0 (inlet) N/m^2	100382	101188	101591	101708	101717	101641	101434	100440	99760
lbf/ft^2	2096.52	2113.38	2121.78	2124.23	2124.43	2122.82	2118.51	2097.77	2083.75
T_0 (inlet) K	290.031	289.162	288.581	287.615	287.665	287.190	288.071	288.743	289.392
°R	522.055	520.486	519.441	517.703	517.792	516.937	518.524	519.733	520.901
P_0 (exit) N/m^2	135979	136703	137208	137327	137584	137525	137068	137040	136192
lbf/ft^2	2840.00	2855.11	2865.68	2868.16	2873.51	2872.28	2862.73	2862.31	2844.44
T_0 (exit) K	319.509	319.135	318.859	318.434	318.382	318.480	318.931	318.767	319.010
°R	575.112	574.438	573.942	573.176	573.083	573.259	574.071	573.776	574.213

ASP 875 W_{COR} = 4.59037 kg/sec (10.1201 lbm/sec)

% Span	5	10	20	30	50	70	80	90	95
Diam m	0.5601	0.5628	0.5679	0.5732	0.5836	0.5940	0.5992	0.6044	0.6070
ft	1.8377	1.8463	1.8633	1.8805	1.9147	1.9488	1.9658	1.9830	1.9915
P_0 (inlet) N/m^2	100405	101166	101581	101700	101703	101631	101423	100458	99880
lbf/ft^2	2097.01	2112.90	2121.56	2124.08	2124.13	2122.62	2118.27	2098.13	2086.05
T_0 (inlet) K	290.052	289.230	288.525	287.634	287.601	287.199	288.055	288.812	289.462
°R	522.089	520.610	519.341	517.737	517.677	516.954	518.513	519.856	521.028
P_0 (exit) N/m^2	137588	138309	138785	138883	139034	1390967	138756	138620	137924
lbf/ft^2	2873.60	2888.65	2898.61	2900.64	2903.81	2905.11	2897.99	2895.15	2880.61
T_0 (exit) K	320.754	320.252	320.095	319.548	319.614	319.696	320.175	319.953	320.280
°R	577.353	576.449	576.166	575.181	575.300	575.449	576.311	575.911	576.500

3S1 CONFIGURATION AT 105% DESIGN SPEED (Cont'd)

ASP 876 W_{COR} = 4.49399 kg/sec (9.9076 lbm/sec)

% Span	5	10	20	30	50	70	80	90	95
Diam									
m	0.5601	0.5628	0.5679	0.5732	0.5836	0.5940	0.5992	0.6044	0.6070
ft	1.8377	1.8463	1.8633	1.8805	1.9147	1.9408	1.9658	1.9830	1.9916
P_0 (inlet)									
N/m^2	100452	101183	101553	101676	101675	101627	101434	100533	99928
lbf/ft^2	2098.00	2113.27	2120.99	2123.56	2123.54	2122.53	2118.51	2099.68	2087.06
T_0 (inlet)									
K	290.065	289.265	288.483	287.663	287.558	287.199	288.056	288.841	289.520
°R	522.113	520.673	519.266	517.790	517.600	516.954	518.496	519.909	521.132
P_0 (exit)									
N/m^2	138974	139700	140106	140242	140254	140460	140173	140012	139398
lbf/ft^2	2902.54	2917.72	2926.20	2929.03	2929.28	2933.58	2927.58	2924.23	2911.41
T_0 (exit)									
K	321.856	321.264	321.254	320.023	320.789	320.866	321.298	321.079	321.385
°R	579.336	578.270	578.252	576.037	577.416	577.555	578.331	577.937	578.488

ASP 877 W_{COR} = 4.30493 kg/sec (9.4908 lbm/sec)

% Span	5	10	20	30	50	70	80	90	95
Diam									
m	0.5601	0.5628	0.5679	0.5732	0.5836	0.5940	0.5992	0.6044	0.6070
ft	1.8377	1.8463	1.8633	1.8805	1.9147	1.9498	1.9658	1.9830	1.9915
P_0 (inlet)									
N/m^2	100544	101197	101546	101647	101658	101590	101402	100585	100040
lbf/ft^2	2099.92	2113.56	2120.85	2122.95	2123.18	2121.76	2117.84	2100.78	2089.40
T_0 (inlet)									
K	290.144	289.274	288.519	287.661	287.581	287.142	288.023	288.816	289.526
°R	522.255	520.689	519.330	517.785	517.642	516.851	518.438	519.865	521.143
P_0 (exit)									
N/m^2	141073	141688	141965	142193	142085	142393	142136	141987	141479
lbf/ft^2	2946.39	2959.23	2965.01	2969.78	2967.53	2973.96	2968.59	2965.48	2954.86
T_0 (exit)									
K	323.393	322.816	323.007	322.409	322.634	322.561	323.024	322.753	323.012
°R	582.103	581.065	581.408	580.331	580.736	580.605	581.439	580.950	581.417

3S1 CONFIGURATION AT 105% DESIGN SPEED (Cont'd)

ASP 878 W_{COR} = 4.07446 kg/sec (8.9827 lbm/sec)

% Span	5	10	20	30	50	70	80	90	95
Diam									
m	0.5601	0.5628	0.5679	0.5732	0.5836	0.5940	0.5992	0.6044	0.6070
ft	1.8377	1.8463	1.8633	1.8805	1.9147	1.9488	1.9658	1.9830	1.9915
P_0 (inlet)									
N/m^2	100510	101222	101512	101610	101620	101560	101410	100657	100216
lbf/ft^2	2101.08	2114.08	2120.13	2122.17	2122.38	2121.14	2118.01	2102.27	2093.06
T_0 (inlet)									
K	290.192	289.276	288.486	287.662	287.536	287.126	288.077	288.829	289.611
^{o}R	522.342	520.692	519.270	517.787	517.561	516.822	518.534	519.888	521.295
P_0 (exit)									
N/m^2	142454	142927	143271	143359	143450	143507	143507	143180	142918
lbf/ft^2	2975.22	2985.10	2992.30	2994.13	2996.04	2997.23	2997.22	2990.39	2984.79
T_0 (exit)									
K	324.568	324.280	324.428	324.048	324.297	324.166	324.571	324.344	324.552
^{o}R	584.218	583.699	583.965	583.281	583.730	583.494	584.224	583.814	584.189

ASP 879 W_{COR} = 3.89543 kg/sec (8.5880 lbm/sec)

% Span	5	10	20	30	50	70	80	90	95
Diam									
m	0.5601	0.5628	0.5679	0.5732	0.5836	0.5940	0.5992	0.6044	0.6070
ft	1.8377	1.8463	1.8633	1.8805	1.9147	1.9488	1.9658	1.9830	1.9915
P_0 (inlet)									
N/m^2	100659	101234	101512	101586	101602	101549	101373	100716	100264
lbf/ft^2	2102.31	2114.32	2120.14	2121.58	2122.01	2120.91	2117.23	2103.50	2094.06
T_0 (inlet)									
K	290.333	289.422	288.507	287.688	287.451	287.059	288.051	288.845	289.702
^{o}R	522.597	520.955	519.308	517.835	517.408	516.702	518.488	519.916	521.459
P_0 (exit)									
N/m^2	142795	143267	143585	143693	143893	143918	143947	143654	143384
lbf/ft^2	2982.36	2992.21	2998.85	3001.10	3005.28	3005.80	3006.42	3000.30	2994.56
T_0 (exit)									
K	325.398	325.137	325.373	325.029	325.364	325.201	325.589	325.362	325.568
^{o}R	585.711	585.242	585.667	585.047	585.651	585.357	586.055	585.647	586.017

3S2 CONFIGURATION AT 86% DESIGN SPEED

ASP 457-462

ASP 457 W_{COR} = 3.7832 kg/sec (8.3406 lbm/sec)

% Span	5	10	20	30	50	70	80	90	95
Diam									
m	0.5601	0.5628	0.5679	0.5732	0.5836	0.5940	0.5992	0.6044	0.6070
ft	1.8377	1.8463	1.8633	1.8805	1.9147	1.9488	1.9658	1.9830	1.9915
P_0 (inlet)									
N/m^2	100849	101311	101616	101628	101616	101548	101084	100689	100081
lbf/ft^2	2106.29	2115.94	2122.30	2122.56	2122.31	2120.88	2111.20	2102.95	2090.24
T_0 (inlet)									
K	289.109	288.811	288.098	287.809	287.725	287.833	288.147	288.841	288.979
°R	520.397	519.859	518.576	518.056	517.905	518.100	518.665	519.913	520.162
P_0 (exit)									
N/m^2	120993	121344	121664	121693	121976	121734	121390	121129	120728
lbf/ft^2	2527.00	2534.34	2541.02	2541.62	2547.53	2542.48	2535.30	2529.35	2521.46
T_0 (exit)									
K	307.379	307.076	306.595	306.126	305.512	305.789	306.022	306.231	306.147
°R	553.283	552.736	551.871	551.026	549.921	550.420	550.839	551.215	551.065

ASP 458 W_{COR} = 3.7144 kg/sec (8.1890 lbm/sec)

% Span	5	10	20	30	50	70	80	90	95
Diam									
m	0.5601	0.5628	0.5679	0.5732	0.5836	0.5940	0.5992	0.6044	0.6070
ft	1.8377	1.8463	1.8633	1.8805	1.9147	1.9488	1.9658	1.9830	1.9915
P_0 (inlet)									
N/m^2	100858	101275	101605	101614	101605	101556	101103	100713	100126
lbf/ft^2	2106.48	2115.19	2122.07	2122.27	2122.07	2121.05	2111.60	2103.44	2091.19
T_0 (inlet)									
K	289.108	288.864	288.046	207.819	287.696	287.824	288.155	288.891	289.046
°R	520.394	519.956	518.483	518.074	517.853	518.034	518.679	520.003	520.282
P_0 (exit)									
N/m^2	122151	122481	122782	122891	123165	122870	122665	122319	122023
lbf/ft^2	2551.20	2558.08	2564.37	2566.64	2572.36	2566.20	2561.93	2554.68	2548.51
T_0 (exit)									
K	308.240	307.955	307.454	306.958	306.302	306.699	306.898	307.263	307.065
°R	554.832	554.319	553.418	552.524	551.343	552.058	552.416	553.074	552.717

3S2 CONFIGURATION AT 85% DESIGN SPEED (Cont'd)

ASP 459 W_{COR} = 3.6209 kg/sec (7.9960 lbm/sec)

% Span	5	10	20	30	50	70	80	90	95
Diam m	0.5601	0.5628	0.5679	0.5732	0.5836	0.5940	0.5992	0.6044	0.6070
ft	1.8377	1.8463	1.8633	1.8805	1.9147	1.9488	1.9658	1.9830	1.9915
P_o (inlet) N/m^2	100882	101318	101596	101603	101592	101520	101113	100741	100187
lbf/ft^2	2106.97	2116.08	2121.86	2122.04	2121.90	2120.31	2111.79	2104.03	2092.46
T_o (inlet) K	289.122	288.823	288.069	287.788	287.718	287.819	288.160	288.887	289.046
°R	520.419	519.882	518.525	518.018	517.892	518.074	518.688	519.996	520.282
P_o (exit) N/m^2	123249	123569	123867	124013	124285	124096	123834	123558	123236
lbf/ft^2	2574.13	2580.80	2587.03	2590.07	2595.76	2591.61	2586.34	2580.58	2573.86
T_o (exit) K	309.012	308.748	308.251	307.766	307.107	307.543	307.758	308.201	307.799
°R	556.222	555.747	554.351	553.978	552.792	553.578	533.964	554.762	554.038

ASP 460 W_{COR} = 3.4958 kg/sec (7.7070 lbm/sec)

% Snan	5	10	20	30	50	70	80	90	95
Diam m	0.5601	0.5628	0.5679	0.5732	0.5836	0.5940	0.5992	0.6044	0.6070
ft	1.8377	1.8463	1.8633	1.8805	1.9147	1.9488	1.9658	1.9830	1.9915
P_o (inlet) N/m^2	100926	101277	101583	101592	101578	101531	101072	100806	100228
lbf/ft^2	2107.90	2115.23	2121.61	2121.80	2121.51	2120.54	2110.95	2105.38	2093.31
T_o (inlet) K	289.178	288.826	288.057	287.773	287.676	287.810	288.179	288.957	289.123
°R	520.521	519.887	518.502	517.991	517.816	518.058	518.722	520.123	520.422
P_o (exit) N/m^2	124664	124949	125257	125360	125659	125542	125338	125068	124803
lbf/ft^2	2603.68	2609.63	2616.07	2618.21	2624.46	2622.01	2617.76	2612.11	2606.57
T_o (exit) K	310.116	309.873	309.431	308.859	308.296	308.716	309.024	308.982	309.235
°R	558.208	557.706	556.976	555.946	554.932	555.689	556.243	556.167	556.623

3S2 CONFIGURATION AT 85% DESIGN SPEED (Cont'd)

ASP 461 W_{COR} = 3.4113 kg/sec (7.5207 lbm/sec)

% Span	5	10	20	30	50	70	80	90	95
Diam									
m	0.5601	0.5628	0.5679	0.5732	0.5836	0.5940	0.5992	0.6044	0.6070
ft	1.8377	1.8463	1.8633	1.8805	1.9147	1.9488	1.9658	1.9830	1.9915
P_0 (inlet)									
N/m^2	100939	101286	101567	101575	101564	101514	101115	100779	100346
lbf/ft^2	2108.16	2115.41	2121.29	2121.45	2121.23	2120.18	2111.85	2104.82	2095.78
T_0 (inlet)									
K	289.169	288.856	288.049	287.802	287.682	287.794	288.166	288.916	289.114
°R	520.504	519.941	518.488	518.043	517.827	518.029	518.699	520.048	520.406
P_0 (exit)									
N/m^2	125177	125471	125764	125858	126057	125882	125782	125590	125337
lbf/ft^2	2614.39	2620.54	2626.64	2628.62	2632.77	2629.12	2627.03	2623.02	2617.73
T_0 (exit)									
K	310.509	310.251	309.820	309.306	308.860	309.295	309.589	309.807	309.797
°R	558.917	558.452	557.676	556.751	555.948	556.731	557.261	557.652	557.635

ASP 462 W_{COR} = 3.3900 kg/sec (7.4738 lbm/sec)

% Span	5	10	20	30	50	70	80	90	95
Diam									
m	0.5601	0.5628	0.5679	0.5732	0.5836	0.5940	0.5992	0.6044	0.6070
ft	1.8377	1.8463	1.8633	1.8805	1.9147	1.9488	1.9658	1.9830	1.9915
P_0 (inlet)									
N/m^2	100935	101293	101559	101564	101554	101506	101158	100782	100388
lbf/ft^2	2108.08	2115.56	2121.11	2121.23	2121.01	2120.00	2112.75	2104.38	2096.66
T_0 (inlet)									
K	289.176	288.879	288.025	287.791	287.662	287.796	288.173	288.947	289.144
°R	520.517	519.982	518.445	518.024	517.792	518.033	518.712	520.105	520.460
P_0 (exit)									
N/m^2	125244	125551	125832	125937	126093	125906	125824	125643	125394
lbf/ft^2	2615.78	2622.21	2628.08	2630.27	2633.52	2629.61	2627.90	2624.12	2618.92
T_0 (exit)									
K	310.625	310.358	309.923	309.392	309.009	309.444	309.716	309.954	309.921
°R	559.125	558.644	557.861	556.905	556.217	557.000	557.489	557.917	557.858

3S2 CONFIGURATION AT 100% DESIGN SPEED

ASP 495-500

ASP 495 WCOR = 4.5226 kg/sec (9.9707 lbm/sec)

% Span	5	10	20	30	50	70	80	90	95
Diam m	0.5601	0.5628	0.5679	0.5732	0.5836	0.5940	0.5992	0.6044	0.6070
ft	1.8377	1.8463	1.8633	1.8806	1.9147	1.9488	1.9658	1.9830	1.9915
P_0 (inlet) N/m^2	100603	101281	101730	101766	101755	101658	100997	100435	99529
lbf/ft^2	2100.31	2115.30	2124.81	2125.41	2125.21	2123.10	2109.37	2097.63	2078.72
T_0 (inlet) K	289.346	288.968	288.177	287.787	287.627	287.762	288.037	288.961	289.038
°R	520.823	520.143	518.719	518.016	517.729	517.972	518.467	520.129	520.269
P_0 (exit) N/m^2	128706	129176	129608	129659	130027	129755	129377	128938	128560
lbf/ft^2	2688.08	2697.92	2706.93	2707.99	2715.68	2710.00	2702.11	2692.95	2685.04
T_0 (exit) K	314.319	313.882	313.237	312.567	311.799	312.166	312.503	312.764	312.748
°R	565.775	564.988	563.826	562.621	561.238	561.899	562.505	562.975	562.947

ASP 496 WCOR = 4.4379 kg/sec (9.7839 lbm/sec)

% Span	5	10	20	30	50	70	80	90	95
Diam m	0.5601	0.5628	0.5679	0.5732	0.5836	0.5940	0.5992	0.6044	0.6070
ft	1.8377	1.8463	1.8633	1.8806	1.9147	1.9488	1.9658	1.9830	1.9915
P_0 (inlet) N/m^2	100630	101269	101734	101748	101744	101627	101011	100443	99606
lbf/ft^2	2101.71	2115.05	2124.76	2125.06	2124.98	2122.53	2109.66	2097.81	2080.32
T_0 (inlet) K	289.346	289.048	288.151	287.789	287.609	287.729	288.043	288.990	289.097
°R	520.822	520.286	518.672	518.020	517.697	517.913	518.478	520.182	520.375
P_0 (exit) N/m^2	130450	130925	131355	131500	131880	131610	131204	130737	130349
lbf/ft^2	2724.53	2734.43	2743.43	2746.45	2754.38	2748.75	2740.26	2730.51	2722.42
T_0 (exit) K	315.565	315.117	314.494	313.729	312.963	313.437	313.799	314.096	314.108
°R	568.017	567.211	566.089	564.712	563.333	564.187	564.839	565.373	565.395

3S2 CONFIGURATION AT 100% DESIGN SPEED (Cont'd)

ASP 497 W_{COR} = 4.3488 kg/sec (9.5876 lbm/sec)

% Span	5	10	20	30	50	70	80	90	95
Diam									
m	0.5601	0.5628	0.5679	0.5732	0.5836	0.5940	0.5992	0.6044	0.6070
ft	1.8377	1.8463	1.8633	1.8806	1.9147	1.9488	1.9658	1.9830	1.9915
P_0 (inlet)									
N/m^2	100645	101287	101729	101729	101721	101623	100987	100559	99642
lbf/ft^2	2102.02	2115.44	2124.67	2124.67	2124.50	2122.45	2109.16	2100.22	2081.08
T_0 (inlet)									
K	289.371	288.999	288.152	287.760	287.619	287.721	288.059	289.007	289.127
°R	520.868	520.199	518.674	517.968	517.714	517.898	518.506	520.212	520.428
P_0 (exit)									
N/m^2	131982	132416	132851	133005	133434	133250	132854	132416	132002
lbf/ft^2	2756.53	2765.57	2774.67	2777.89	2786.85	2783.00	2774.73	2765.58	2756.93
T_0 (exit)									
K	316.675	316.254	315.632	314.874	314.082	314.615	315.049	315.294	315.342
°R	570.015	569.258	568.138	566.773	565.347	566.307	567.088	567.529	567.615

ASP 498 W_{COR} = 4.2127 kg/sec (9.2874 lbm/sec)

% Span	5	10	20	30	50	70	80	90	95
Diam									
m	0.5601	0.5628	0.5679	0.5732	0.5836	0.5940	0.5992	0.6044	0.6070
ft	1.8377	1.8463	1.8633	1.8805	1.9147	1.9488	1.9658	1.9830	1.9915
P_0 (inlet)									
N/m^2	100692	101246	101690	101710	101698	101620	101019	100568	99756
lbf/ft^2	2103.00	2114.58	2123.86	2124.26	2124.01	2122.39	2109.84	2100.42	2083.46
T_0 (inlet)									
K	289.444	289.029	288.167	287.741	287.591	287.686	288.042	289.057	289.210
°R	520.999	520.253	518.701	517.934	517.663	517.835	518.476	520.303	520.578
P_0 (exit)									
N/m^2	133816	134171	134651	134716	135117	134854	134719	134293	134047
lbf/ft^2	2794.82	2802.24	2812.25	2813.62	2822.00	2816.50	2813.67	2804.78	2799.65
T_0 (exit)									
K	317.945	317.495	316.942	316.105	315.504	316.043	316.513	316.736	316.806
°R	572.301	571.491	570.495	568.989	567.907	568.878	569.724	570.125	570.250

3S2 CONFIGURATION AT 100% DESIGN SPEED (Cont'd)

ASP 499 W_{COR} = 4.0417 kg/sec (8.9104 lbm/sec)

% Span	5	10	20	30	50	70	80	90	95
Diam									
m	0.5601	0.5628	0.5679	0.5732	0.5836	0.5940	0.5992	0.6044	0.6070
ft	1.8377	1.8463	1.8633	1.8805	1.9147	1.9488	1.9658	1.9830	1.9915
P_0 (inlet)									
N/m^2	100715	101264	101643	101664	101654	101571	101144	100587	100012
lbf/ft^2	2103.48	2114.95	2122.86	2123.30	2123.09	2121.36	2112.48	2100.82	2088.80
T_0 (inlet)									
K	289.451	289.028	288.122	287.747	287.577	287.701	288.045	289.058	289.242
°R	521.012	520.251	518.619	517.944	517.638	517.862	518.481	520.304	520.636
P_0 (exit)									
N/m^2	135076	135516	135860	135941	136062	136089	135934	135566	135265
lbf/ft^2	2821.14	2830.32	2837.51	2839.21	2841.72	2842.30	2839.06	2831.38	2825.09
T_0 (exit)									
K	318.963	318.561	317.953	317.338	317.002	317.563	317.832	318.131	318.061
°R	574.134	573.410	572.316	571.208	570.604	571.613	572.098	572.635	572.510

ASP 500 W_{COR} = 3.9869 kg/sec (8.7896 lbm/sec)

% Span	5	10	20	30	50	70	80	90	95
Diam									
m	0.5601	0.5628	0.5679	0.5732	0.5836	0.5940	0.5992	0.6044	0.6071
ft	1.8377	1.8463	1.8633	1.8805	1.9147	1.9488	1.9658	1.9830	1.9915
P_0 (inlet)									
N/m^2	100716	101275	101620	101635	101630	101576	101203	100655	100068
lbf/ft^2	2103.51	2115.19	2122.38	2122.71	2122.60	2121.47	2113.69	2102.23	2089.98
T_0 (inlet)									
K	289.426	289.075	288.101	287.734	287.583	287.701	288.055	289.037	289.258
°R	520.967	520.335	518.581	517.921	517.649	517.861	518.499	520.266	520.665
P_0 (exit)									
N/m^2	135169	135594	135939	135978	136081	136089	135965	135606	135306
lbf/ft^2	2823.08	2831.96	2839.17	2839.97	2842.12	2842.29	2839.70	2832.21	2825.94
T_0 (exit)									
K	318.523	318.687	318.101	317.522	317.252	317.832	318.023	318.377	318.263
°R	573.342	573.637	572.582	571.539	571.053	572.098	572.441	573.078	572.873

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352 CONFIGURATION AT 105% DESIGN SPEED

ASP 504-509

ASP 504 W_{COR} = 4.7436 kg/sec (10.4578 lbm/sec)

% Span	5	10	20	30	50	70	80	90	95
Diam									
m	0.5601	0.5628	0.5679	0.5732	0.5836	0.5940	0.5992	0.6044	0.6070
ft	1.8377	1.8463	1.8633	1.8805	1.9147	1.9488	1.9658	1.9830	1.9915
P_o (inlet)									
N/m^2	100184	101247	101769	101791	101782	101705	101011	100391	99376
lbf/ft^2	2098.66	2114.59	2125.50	2125.96	2125.77	2124.17	2109.67	2096.73	2075.53
T_o (inlet)									
K	289.328	288.990	288.166	287.760	287.629	287.775	288.053	288.975	289.058
°R	520.786	520.178	518.695	517.963	517.728	517.991	518.491	520.151	520.300
P_o (exit)									
N/m^2	131906	132434	132899	132972	133383	133158	132653	132274	131762
lbf/ft^2	2754.93	2765.96	2775.67	2777.20	2785.78	2781.08	2770.53	2761.57	2751.92
T_o (exit)									
K	317.063	316.560	315.887	315.095	314.356	314.764	315.225	315.713	315.119
°R	570.708	569.804	568.592	567.167	565.837	566.571	567.400	568.278	567.210

ASP 505 W_{COR} = 4.6557 kg/sec (10.2642 lbm/sec)

% Span	5	10	20	30	50	70	80	90	95
Diam									
m	0.5601	0.5628	0.5679	0.5732	0.5836	0.5940	0.5992	0.6044	0.6070
ft	1.8377	1.8463	1.8633	1.8805	1.9147	1.9488	1.9658	1.9830	1.9915
P_o (inlet)									
N/m^2	100540	101261	101768	101790	101779	101661	101011	100373	99429
lbf/ft^2	2099.84	2114.89	2125.48	2125.94	2125.72	2123.25	2109.66	2096.34	2076.62
T_o (inlet)									
K	289.292	288.996	288.102	287.784	287.623	287.777	288.065	288.985	289.090
°R	520.725	520.193	518.583	518.012	517.721	517.998	518.517	520.173	520.362
P_o (exit)									
N/m^2	133811	134308	134790	134951	135350	135185	134603	134190	133613
lbf/ft^2	2794.71	2805.10	2815.17	2818.52	2826.86	2823.41	2811.25	2802.64	2790.58
T_o (exit)									
K	318.354	317.838	317.224	316.366	315.603	316.157	316.588	317.108	316.529
°R	573.037	572.109	571.003	569.459	568.086	569.082	569.858	570.795	569.753

3S2 CONFIGURATION AT 105% DESIGN SPEED (Cont'd)

ASP 606 W_{COR} = 4.6656 kg/sec (10.0554 lbm/sec)

% Span	5	10	20	30	50	70	80	90	95
Diam									
m	0.5601	0.5628	0.5679	0.5732	0.5836	0.5940	0.5992	0.6044	0.6070
ft	1.8377	1.8463	1.8633	1.8805	1.9147	1.9488	1.9658	1.9830	1.9915
P_0 (inlet)									
N/m^2	100574	101260	101749	101771	101764	101664	100992	100407	99511
lbf/ft^2	2100.55	2114.88	2125.08	2125.55	2125.39	2123.30	2109.28	2097.06	2078.34
T_0 (inlet)									
K	289.324	288.979	288.099	287.762	287.613	287.782	288.084	288.997	289.114
°R	520.784	520.162	518.579	517.972	517.704	518.008	518.551	520.194	520.405
P_0 (exit)									
N/m^2	135561	135995	136517	136658	137110	136839	136517	135993	135591
lbf/ft^2	2831.26	2840.34	2851.24	2854.18	2863.61	2857.96	2851.23	2840.29	2831.90
T_0 (exit)									
K	319.509	319.026	318.411	317.583	316.852	317.377	317.946	318.327	317.863
°R	575.116	574.246	573.139	571.650	570.333	571.278	572.303	572.989	572.153

ASP 507 W_{COR} = 4.3961 kg/sec (9.6917 lbm/sec)

% Span	5	10	20	30	50	70	80	90	95
Diam									
m	0.5601	0.5628	0.5679	0.5732	0.5836	0.5940	0.5992	0.6044	0.6070
ft	1.8377	1.8463	1.8633	1.8805	1.9147	1.9488	1.9658	1.9830	1.9915
P_0 (inlet)									
N/m^2	100520	101260	101721	101738	101727	101637	101004	100520	99643
lbf/ft^2	2101.51	2114.88	2124.50	2124.85	2124.63	2122.75	2109.53	2099.41	2081.09
T_0 (inlet)									
K	289.352	288.950	288.107	287.729	287.617	287.769	288.088	289.031	289.163
°R	520.833	520.110	518.593	517.912	517.710	517.985	518.558	520.255	528.493
P_0 (exit)									
N/m^2	137891	138321	138827	138906	139173	139062	138863	138449	138183
lbf/ft^2	2879.93	2888.90	2899.48	2901.13	2906.81	2904.39	2900.22	2891.57	2886.03
T_0 (exit)									
K	321.229	320.684	320.107	319.241	318.923	319.402	319.856	320.285	319.746
°R	578.212	577.232	576.193	574.633	574.061	574.924	575.741	576.513	575.542

352 CONFIGURATION AT 105% DESIGN SPEED (Cont'd)

ASP 508 WCOR = 4.2676 kg/sec (9.4085 lbm/sec)

% Span	5	10	20	30	50	70	80	90	95
Diam m	0.5601	0.5628	0.5679	0.5732	0.5836	0.5940	0.5992	0.6044	0.6070
ft	1.8377	1.8463	1.8633	1.8805	1.9147	1.9488	1.9658	1.9830	1.9915
P_o (inlet) N/m^2	100662	101236	101688	101704	101696	101611	101114	100477	99846
lbf/ft^2	2102.39	2114.36	2123.81	2124.15	2123.98	2122.21	2111.82	2098.52	2085.34
T_o (inlet) K	289.382	289.069	288.061	287.737	287.583	287.725	288.073	289.073	289.249
°R	520.887	520.325	518.510	517.927	517.649	517.904	518.531	520.331	520.648
P_o (exit) N/m^2	138779	139247	139619	139687	139858	139858	139715	139251	138962
lbf/ft^2	2898.47	2908.25	2916.02	2917.44	2921.01	2921.02	2918.03	2908.33	2902.29
T_o (exit) K	321.957	321.473	320.874	320.185	319.928	320.512	320.736	321.294	320.672
°R	579.523	578.651	577.574	576.333	575.870	576.922	577.324	578.329	577.209

ASP 509 WCOR = 4.1564 kg/sec (9.1633 lbm/sec)

% Span	5	10	20	30	50	70	80	90	95
Diam m	0.5601	0.5628	0.5679	0.5732	0.5836	0.5940	0.5992	0.6044	0.6070
ft	1.8377	1.8463	1.8633	1.8805	1.9147	1.9488	1.9658	1.9830	1.9915
P_o (inlet) N/m^2	100680	101248	101649	101658	101655	101607	101189	100559	99958
lbf/ft^2	2102.76	2114.61	2123.00	2123.13	2123.13	2122.12	2113.38	2100.22	2087.68
T_o (inlet) K	289.337	288.971	288.033	287.704	287.592	287.788	288.112	289.064	289.273
°R	520.806	520.147	518.460	517.867	517.666	518.018	518.601	520.315	520.691
P_o (exit) N/m^2	138991	139461	139799	139804	139931	139880	139713	139353	139027
lbf/ft^2	2902.91	2912.72	2919.77	2919.39	2922.54	2921.47	2917.98	2910.47	2903.66
T_o (exit) K	322.155	321.768	321.194	320.668	320.493	321.129	321.272	321.823	321.191
°R	579.879	579.183	578.149	577.203	576.888	578.032	578.290	579.282	578.143