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16. Abstract

The flight testing of an inlet static pressure noseboom probe and instrumented inlet case produced results consistent with sea-level and altitude stand testing. The F-15 flight test verified the basic relationship of total to static pressure ratio versus corrected airflow and automatic distortion downmatch with the engine pressure ratio control mode. Additionally, the backup control inlet case statics demonstrated sufficient accuracy for backup control fuel flow scheduling, and the station 6 manifolded production probe was in agreement with the flight test station 6 total pressure probes.

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SUMMARY

The NASA-DFRC flight test has provided inflight verification for the Digital Electronic Engine Control (DEEC) Engine Pressure Ratio (EPR) Control Mode. This test was conducted concurrently with shuttle tile testing, which resulted in flight restrictions and omission of some planned test points. High Mach number points and aircraft maneuvers were the omitted parts. The data recorded under the flight restrictions included Mach number excursions to 1.4, altitude climbs to 47,000 feet, several upper left hand corner steady-state conditions, and several high distortion points. Over this range of test conditions, the correlation of inlet total to static pressure as a function of corrected airflow (PT/PS vs WACC) agrees with previous sea level and altitude data. Additionally, DEEC automatic downmatch for distortion was substantiated with high levels of inlet distortion induced by the aircraft inlet 3rd ramp.

INTRODUCTION

Inlet total to static pressure ratio (PT/PS) is used with the digital electronic engine control (DEEC) for closed loop control of engine pressure ratio (EPR). An engine inlet noseboom probe is used to sense inlet static pressure (PS2) which is then used to calculate inlet total pressure (PT2). This calculation is done by means of a curve read in the DEEC logic, PT/PS versus corrected airflow (WACC). The calculated PT2, together with sensed station 6 total pressure from the production PT6 probe (PT6M), provides EPR feedback to the engine control. The accuracy of the elements involved in determining EPR feedback determines the accuracy of EPR scheduling with the DEEC.

In early sea-level testing with the PS2 noseboom probe, a definite shift in the relationship of PT/PS versus WACC was evident for inlet distortion. This shift was in a favorable direction for the EPR control mode. With distortion, PT/PS is increased at a given airflow, and this increase will result in downtrimming EPR from the control schedule. This automatic distortion downmatch with the DEEC EPR control mode provides additional fan stall margin when compared to constant EPR scheduling.

The level of automatic distortion downmatch is dependent on the level of inlet distortion and the static pressure profile generated at the noseboom port location. The noseboom is located on the engine centerline. Previous to this flight test, there were no data available with inlet centerline static pressure measurements. This flight test was therefore needed to provide inflight verification of the expected automatic distortion downmatch as well as verification of the PT/PS correlation.

The flight test used a prototype PS2 noseboom probe and a specially designed engine inlet case containing 34 kielheaded total pressure probes. Figure 1 shows the PS2 noseboom probe mounted on the flight test engine. The instrumented inlet case is shown in greater detail in Figure 2. This hardware was used in previous testing at NASA-LeRC.

Figure 1. PS2 Noseprobe Installed on an F100-PW-100 Engine

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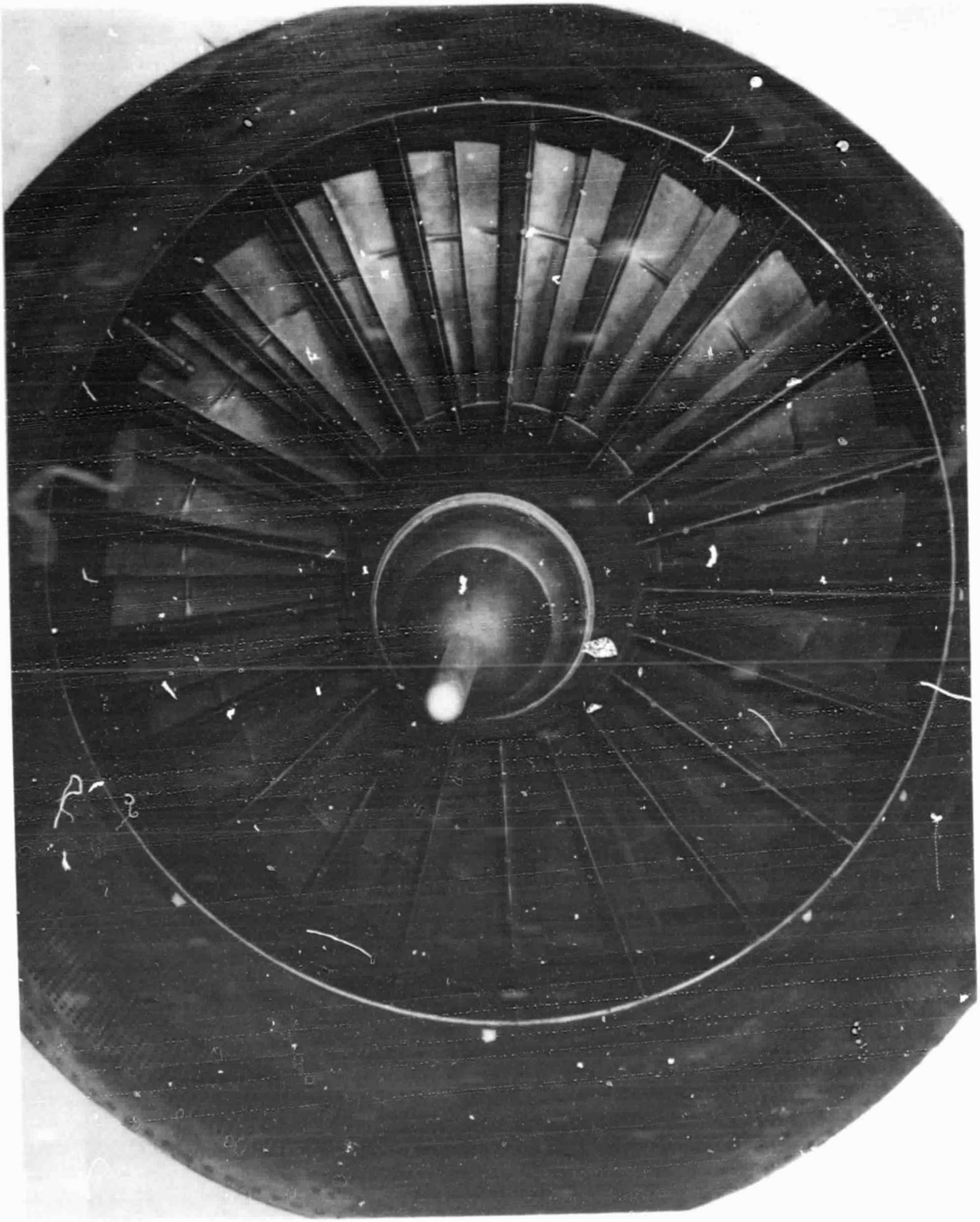

Figure 2. Photo of PS2 Engine Noseprobe

TEST PROCEDURE

An instrumented inlet case, 34 total pressure probes, and the DEEC PS2 nose cone probe were used to determine the PT/PS ratio, and corrected airflow was determined from corrected fan speed. The speed flow correlation used for this test was in agreement with the NASA-LeRC airflow calibration of the flight test engine.

The shuttle tile testing imposed several restrictions on the flight test. The flight test was accomplished under the following restrictions:

- o Dynamic Pressure Limit = 600 psf
- o Yaw Angle Limit = $\pm$ 1 degree
- o Pitch Angle Limit = $\pm$ 10 degrees
- o Load Factor = + 3 / − 1
- o Mach Number Limits = 1.5

Flight test points obtained were:

- o 200 and 400 knots climbs to 47,000 feet, including descents.
- o Mach number excursions to 1.2 and 1.4 at 30,000 and 40,000 feet, respectively.
- o Maneuver points at Mach number/altitude conditions 0.9/40K, 0.8/35K, 0.7/35K, 0.6/30K, 1.4/30K, and 0.8/30K.
- o Part power steady-state points at 0.9/40K conditions.
- o Third ramp induced distortion at conditions 0.9/40K, 0.9/30K, 0.8/40K, and 0.8/30K.

Flight test points not obtained due to shuttle tile restrictions:

- o Maximum maneuvers at 0.8/30K and 0.8/50K, Mach number/altitude conditions.
- o Constant inlet pressure altitude climbs from 30,000 feet to 50,000 feet at both 10 psia and 16 psia inlet pressure.
- o Third ramp induced distortion at 1.4/50K, Mach number/altitude conditions.
- o Maximum pitch andle or "g" load at conditions 50,000 feet altitude and Mach numbers 0.6, 0.8, 0.9, 1.2, 1.4, 1.8, 2.2; 40,000 feet altitude and Mach numbers 0.6, 0.8, 0.9, 1.2, 1.4, 1.8; and 30,000 feet altitude and Mach numbers 0.4, 0.6, 0.8, 0.9, 1.2, 1.4.

PT/PS CORRELATION - NONDISTORTED

The present correlation, PT/PS vs WACC, was derived from sea level testing and adjusted after altitude tests at NASA-LeRC. Figure 3 shows excellent agreement between flight test data and previous data from NASA-LeRC. The 1/2 percent difference at high airflows, indicated in Figure 3, may result from a speed flow calibration that is slightly high. The speed flow curve used to determine airflow agreed with the flight test engine airflow calibration at NASA-LeRC. However, NASA-LeRC airflow measurements were approximately two percent higher than sea level measurements for engine P0072.

A 1/2 percent low pressure bias was defined from P0072 test results. Flight test results show no consistent similar bias.

Originally, the flight test plans included excursions to 2.2 Mach number and maneuvers to maximum aircraft pitch and yaw angles. However, since the PS2 test was accomplished concurrently with shuttle tile testing, these extreme conditions were not permitted because of the shuttle tile test configuration.

The allowable aircraft maneuvers produced relatively low inlet distortion, about 1/3 of the distortion level produced with a 180 degree moderate distortion screen. These relatively low distortion levels produce little shift in the PT/PS correlation. Figure 4 shows the maximum allowed maneuvers produced no measurable shift in PT/PS.

Mach number excursions, steady-state settings at various conditions, and part power points at 0.9/40K all show similar agreement with previous test results. Figures 5, 6 and 7 present these results

DISTORTION DOWNMATCH

During flight test, the aircraft inlet 3rd ramp was lowered to induce high levels of engine inlet distortion. The levels of distortion generated were, in most cases, enough to cause engine stall. Previous comparisons of distortion from a full down 3rd ramp show this distortion level to be approximately equal to distortion generated at aircraft departure conditions.

Figure 8 shows the shift in PT/PS at constant airflow for increments of 3rd ramp position. The difference between measured PT/PS and PT/PS from the DEEC schedule determines how much the DEEC EPR control mode would downmatch for the induced distortion. As shown in the figure, the downmatch would be as much as 11.4 percent for 27.5 degrees of ramp position.

Figure 9 compares the shift in PT/PS from 3rd ramp distortion to the shift produced at extreme aircraft pitch and yaw during F-16 model inlet tests. This figure shows up to 10 percent shift caused by either method of inlet distortion.

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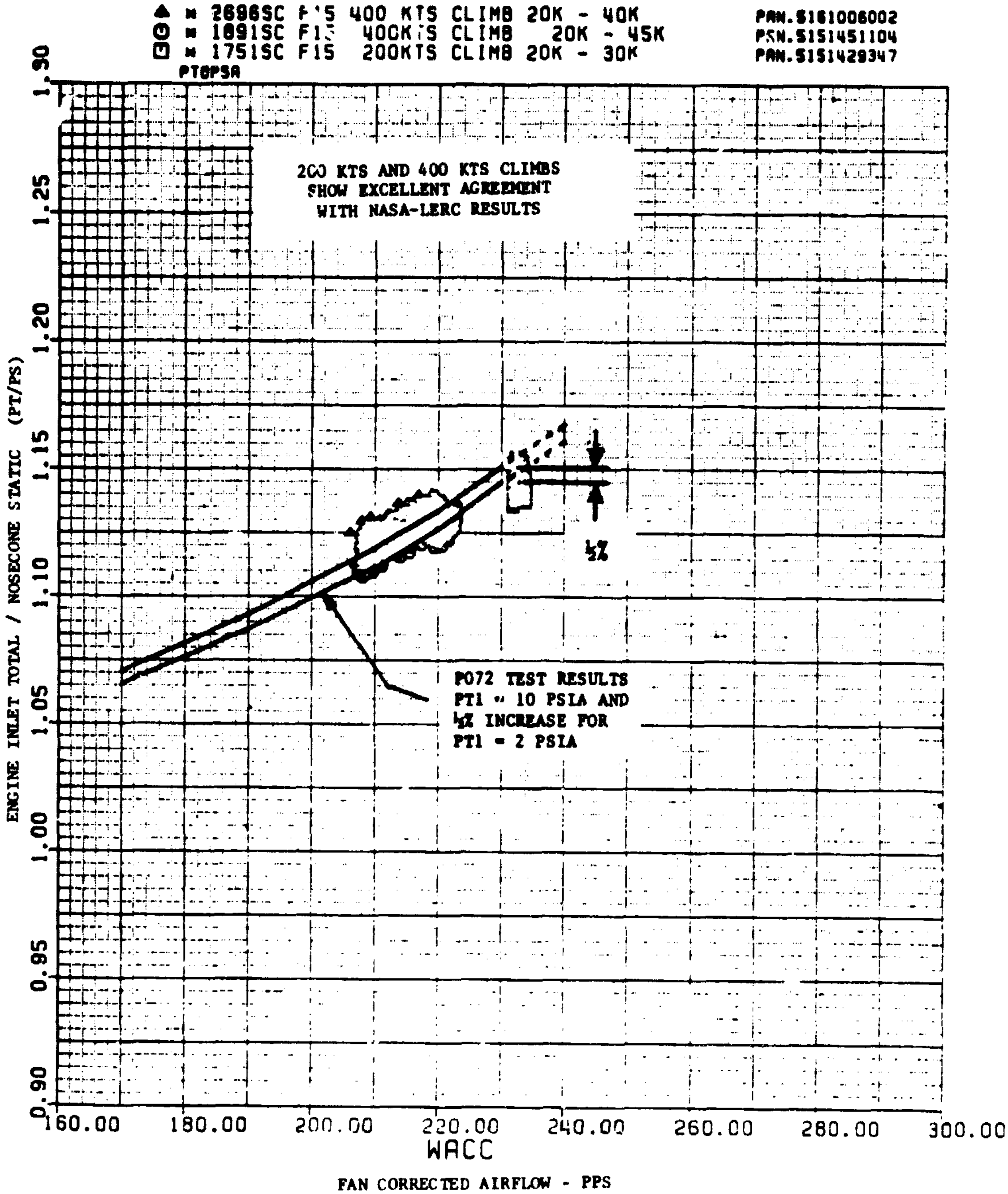

Figure 3. 200 Kts and 400 Kts Climbs Show Excellent Agreement With NASA-LeRC Results

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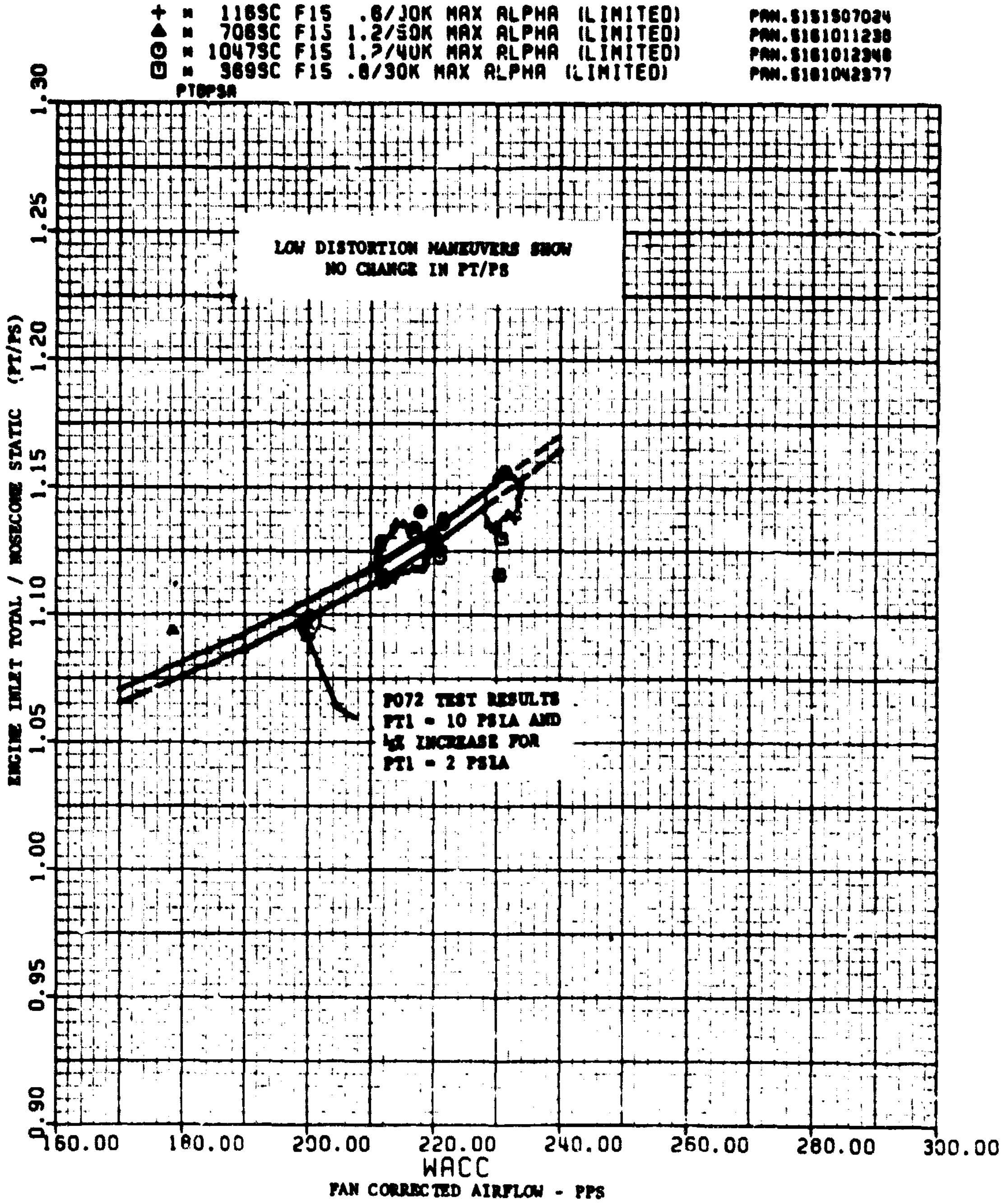

Figure 4. Low Distortion Maneuvers Show No Change in PT/PS

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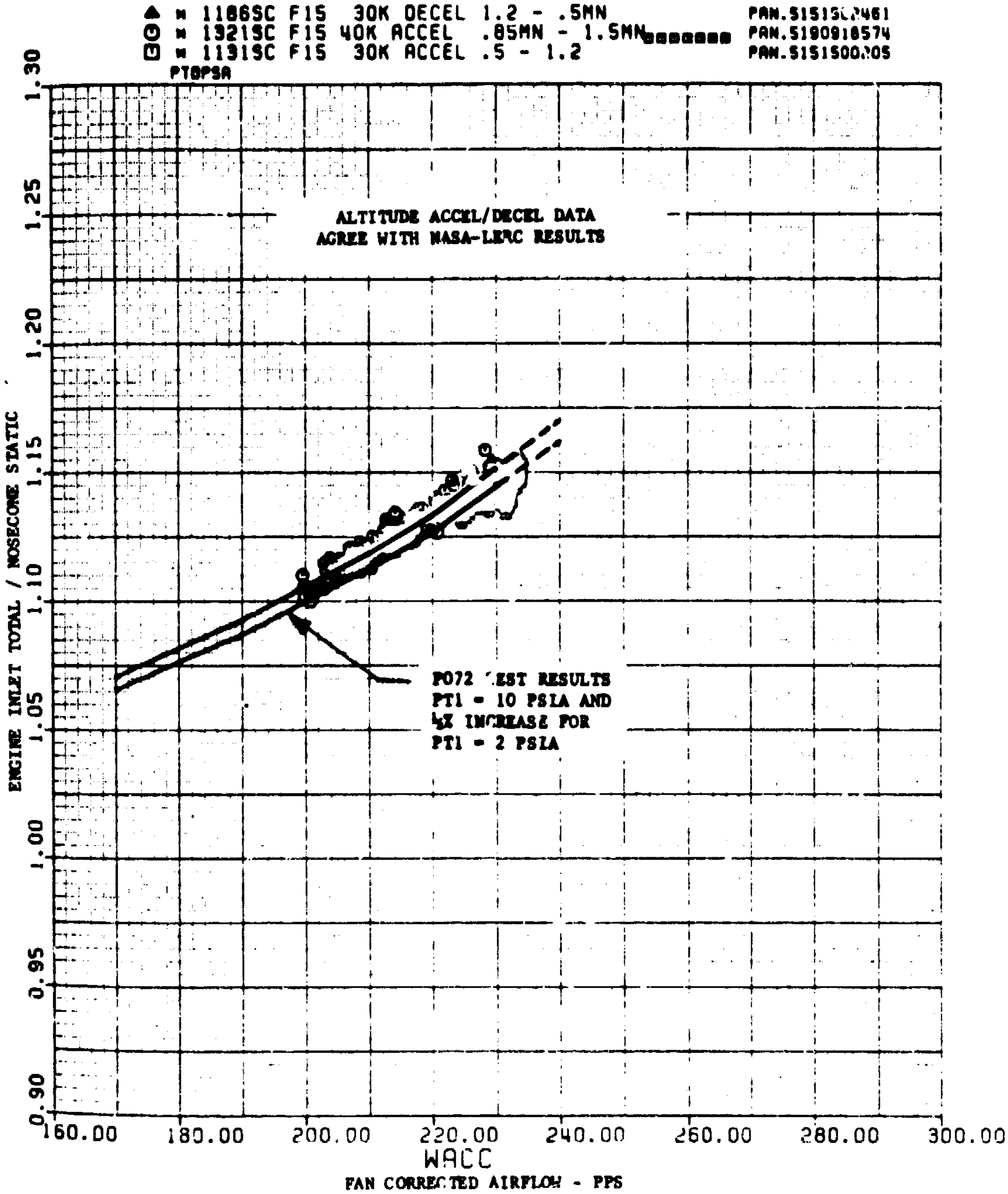

Figure 5. Altitude Accel/Decel Data Agree With NASA-LeRC Results

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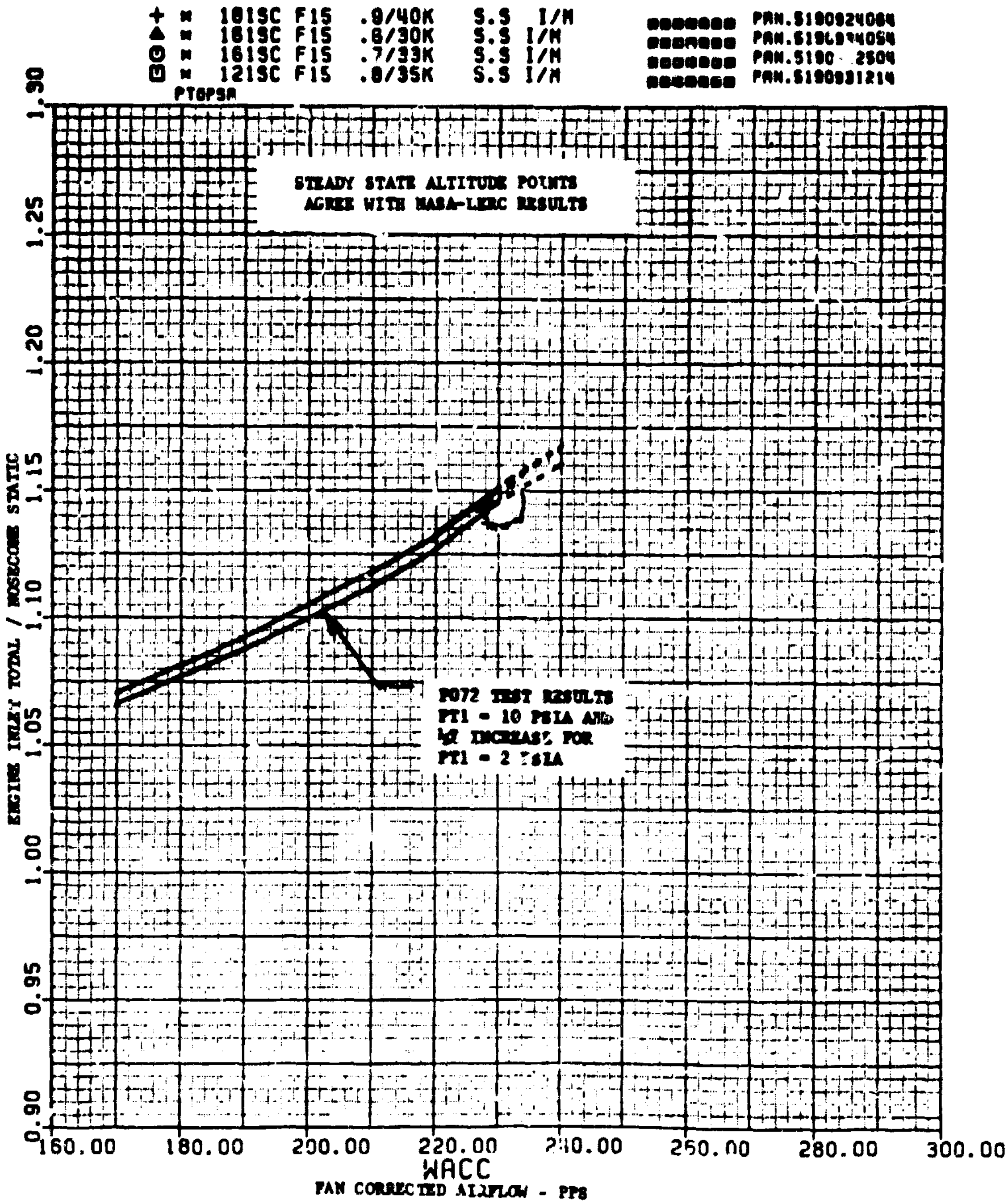

Figure 6. Steady-State Altitude Points Agree With NASA-LeRC Results

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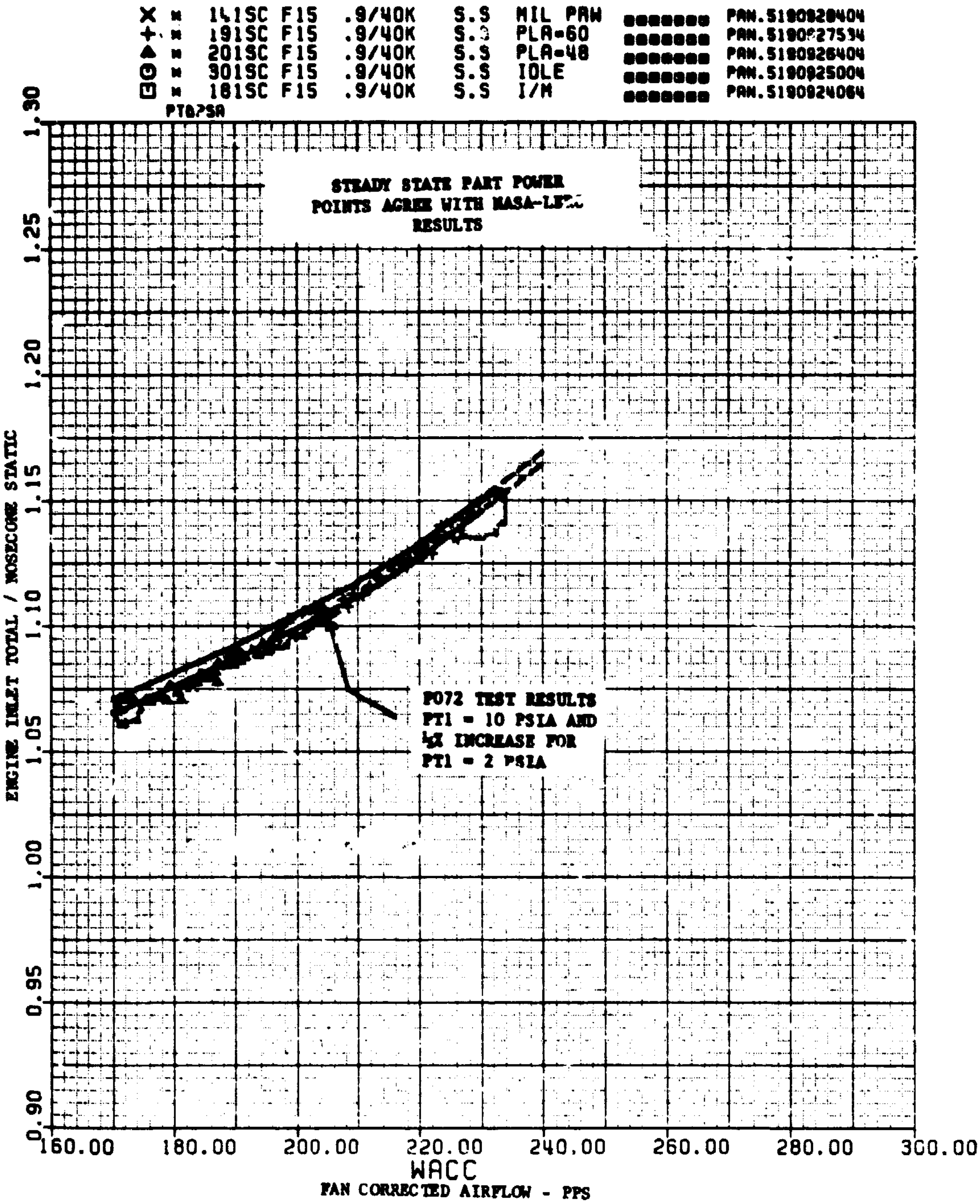

Figure 7. Steady-State Part Power Points Agree With NASA-LeRC Results

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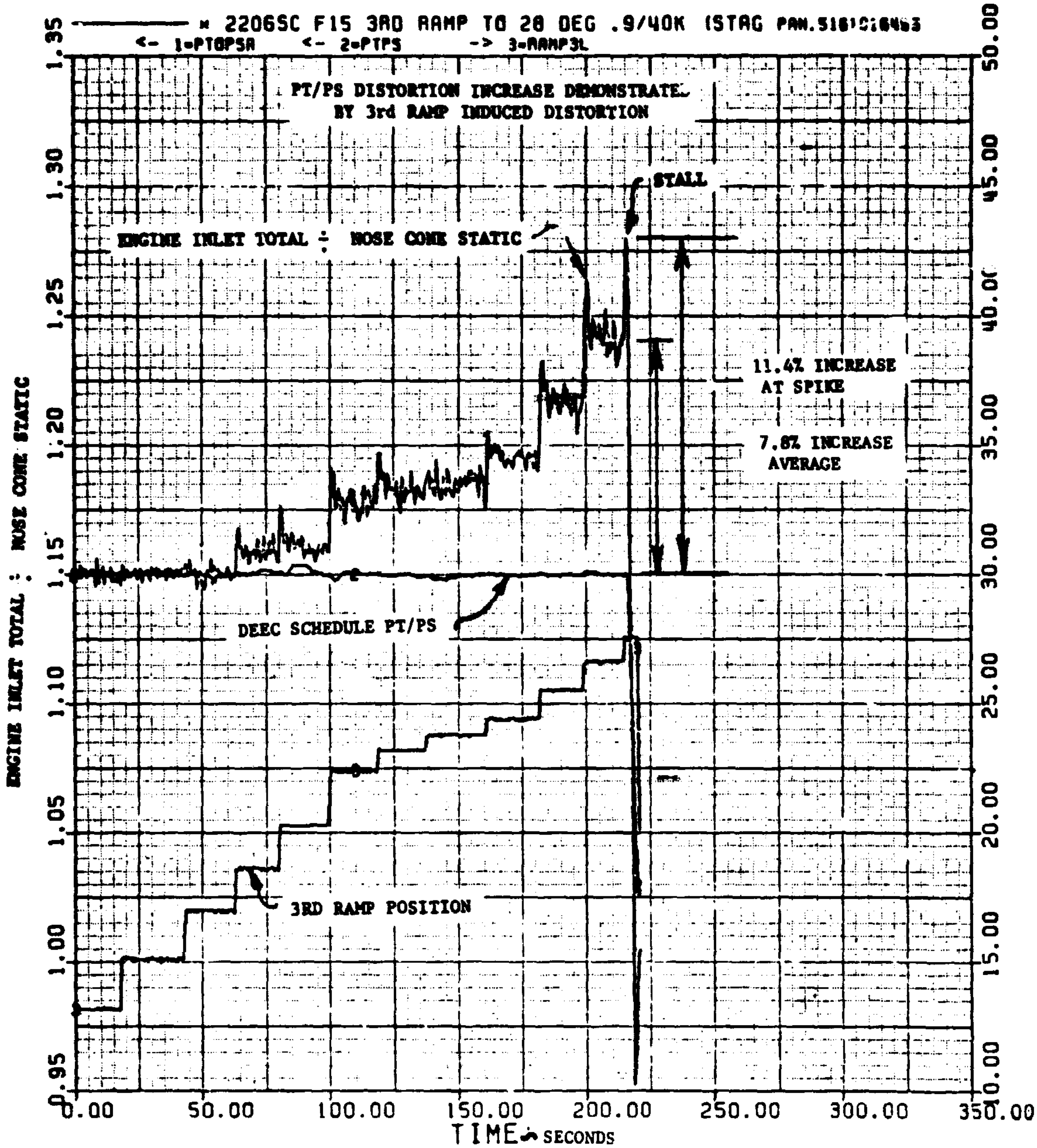

Figure 8. PT/PS Distortion Increase Demonstrated by 3rd Ramp Induced Distortion

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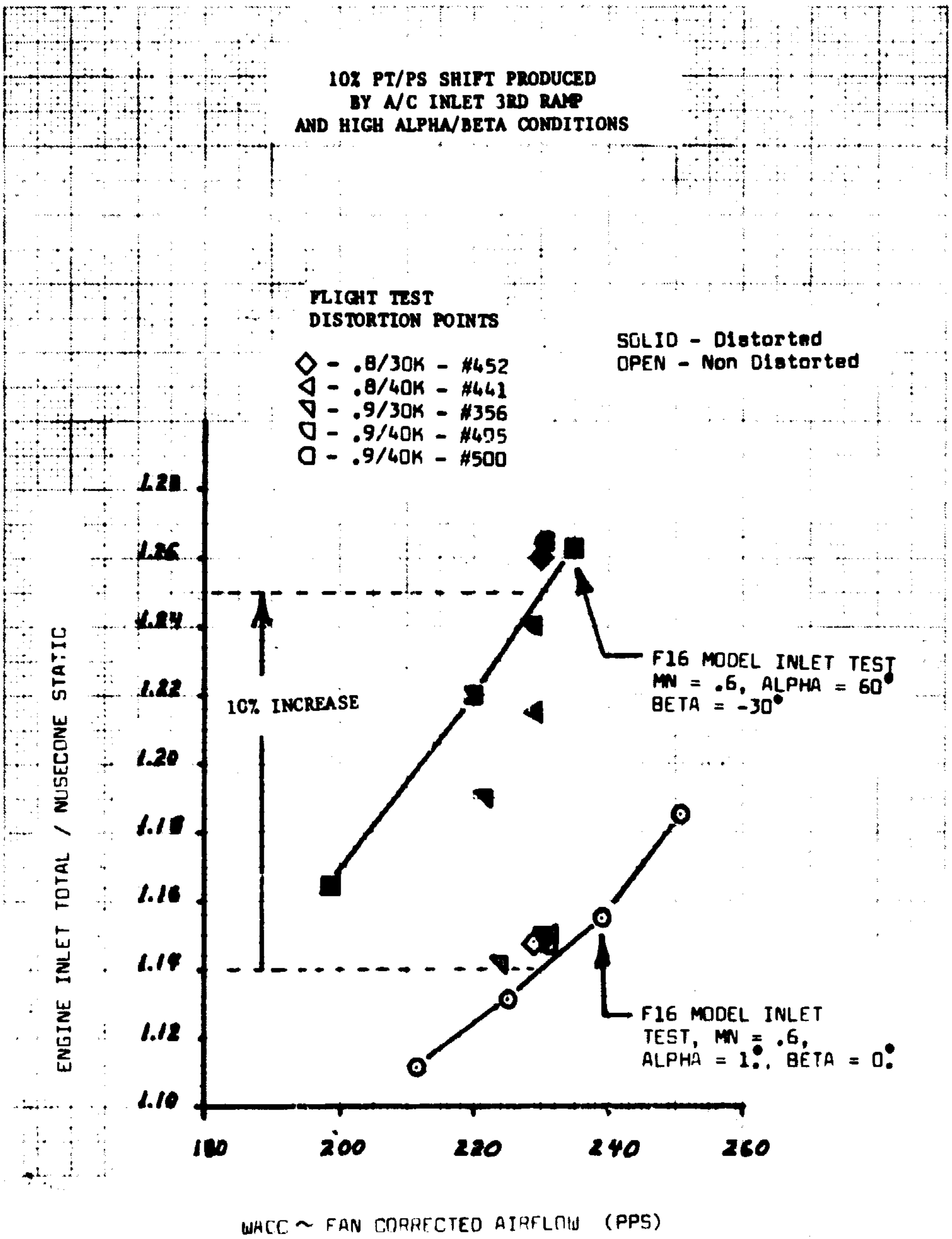

Figure 9. Ten Percent PT/PS Shift Produced by A/C Inlet 3rd Ramp and High Alpha/Beta Conditions

PT6 PRODUCTION PROBE CORRELATION

Flight test data were used to check the correlation of the production probe measurements to average station 6 pressure. The average station 6 pressure was determined by a 6 rake 30 probe average. As shown in Figure 10, the production probe PT6 agrees closely with average PT6 over a wide range of pressure. The error between the production probe and average pressure is shown in Figure 11. As shown in Figure 11, the production probe measurements would be corrected by the present DEEC correction schedule to within 0.3 percent, nominally, of average PT6.

INLET CASE STATIC PRESSURE

The total to static pressure ratio correlation using the inlet case static pressure compared favorably with previous correlations. Figure 12 shows the correlation for several flight conditions compared to previous results at NASA-LeRC. As Figure 12 shows, variations of total to inlet case static pressure were four percent for the flight test data. This variation was checked for correlation with pressure, but was found to be inconsistent with the pressure bias identified at NASA-LeRC. Data from several different flights indicate a possible flight-to-flight instrumentation shift for the inlet case static pressure measurements.

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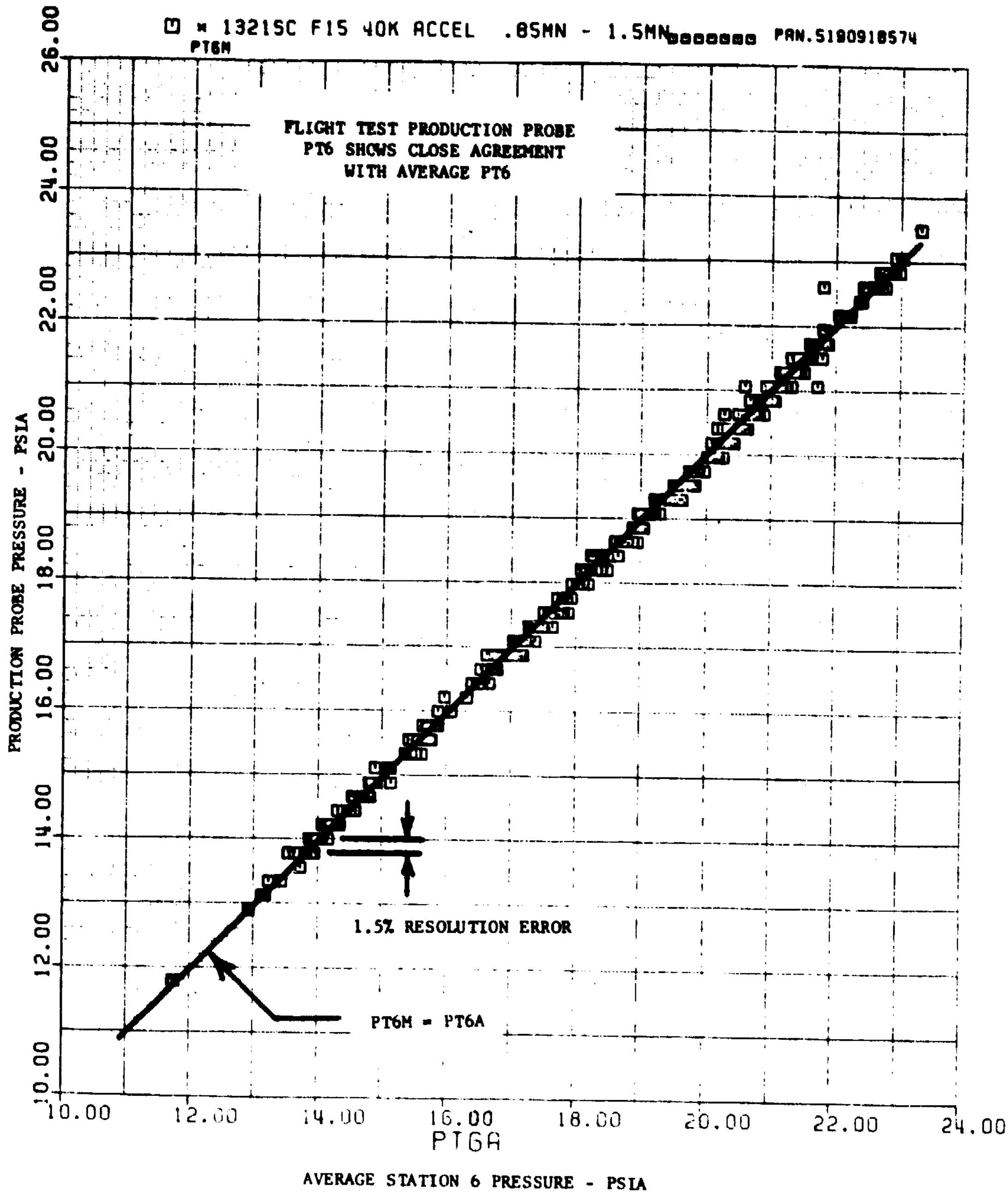

Figure 10. Flight Test Production Probe PT6 Shows Close Agreement With Average PT6

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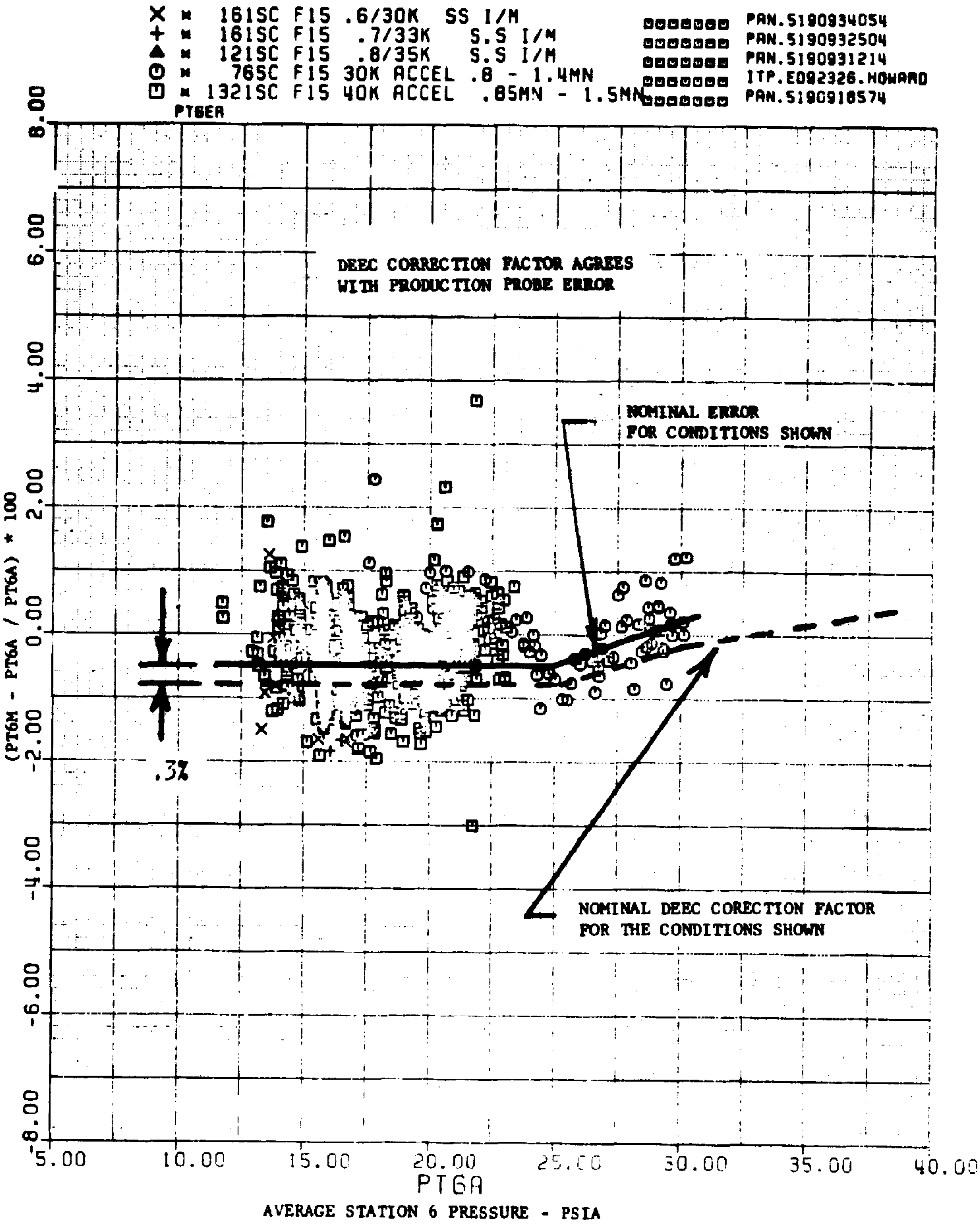

Figure 11. DEEC Correction Factor Agrees With Production Probe Error

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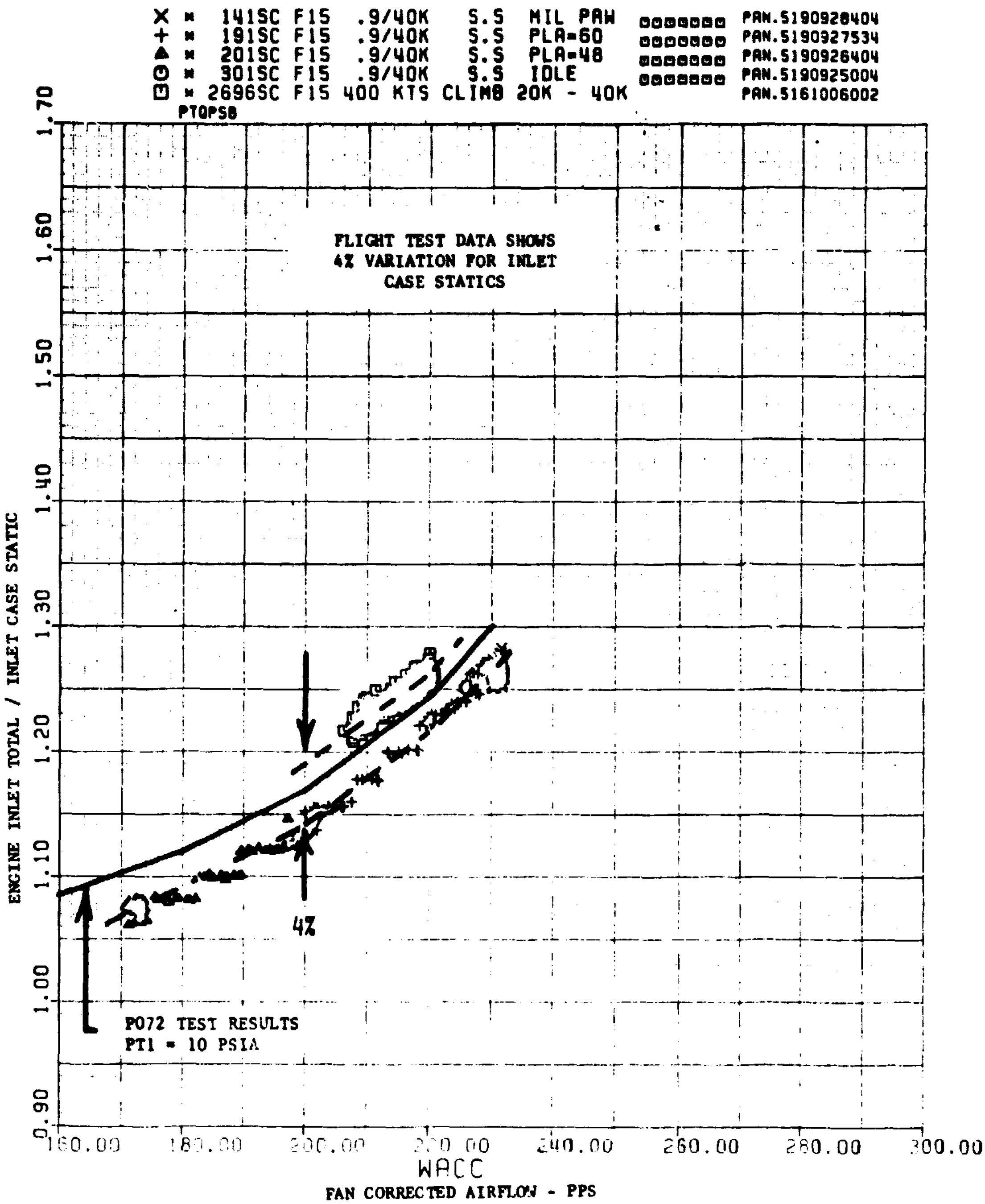

Figure 12. Flight Test Data Shows Four Percent Variation for Inlet Case Statics

CONCLUSIONS

- o The DEEC correlation of inlet total to static pressure ratio versus corrected airflow (PT/PS vs WACC) was substantiated to a Mach number of 1.4 and to altitudes of 47,000 feet. The flight test data show agreement within 1/2 percent of previous data from altitude tests at NASA-LeRC.

- o DEEC EPR mode automatic downmatch for distortion was substantiated by high distortion levels induced by the aircraft inlet 3rd ramp. The 3rd ramp induced distortion produced PT/PS shifts from 4 to 10 percent. These distortion levels are comparable to distortion created at aircraft departure conditions which produced up to 10 percent shift in PT/PS during F-16 model inlet tests.

- o The correlation of production probe PT6 with average station 6 pressure was in excellent agreement with previous sea level and altitude tests.

- o The proposed backup control inlet case pressures produced a total to static pressure ratio correlation in agreement with previous tests at NASA-LeRC.