EFFECTS OF INLET DISTORTION ON A STATIC PRESSURE PROBE MOUNTED ON THE ENGINE HUB IN AN F-15 AIRPLANE

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SUMMARY

Knowledge of the pressure conditions at the engine face is important for the efficient control of an air-breathing engine. However, there are many problems encountered in obtaining good engine face pressure data. In a special study, a single static measurement located upstream of the engine hub in the stream flow was found to provide a pressure signal suitable for engine control.

A probe for measuring fan inlet static pressure (PS2) was designed for and mounted on the hub of the left F100-PW-100 turbofan engine installed in the F-15 test aircraft for flight evaluation at the NASA Ames Research Center Dryden Flight Research Facility (ARC-DFRF) (ref. 1). This same probe was also evaluated on the hub of another F100 engine in the NASA Lewis Research Center (LeRC) altitude facility (ref. 2). The probe is currently being used as a static pressure sensor for a digital engine control system (ref. 3).

WHY IS PS2 NEEDED?

Fan inlet total pressure (PT2) is a critical control parameter, so how is it measured? Using a single PT2 probe would be acceptable for uniform flow conditions but when the flow is distorted the PT2 measurement varies significantly across the engine face. An alternative is to use a multiple probe rake array; however, this array is complex and expensive to install. One alternative is a static pressure measurement mounted on the engine hub to provide a total-to-static pressure ratio, which is a function of airflow. Digital controls can calculate airflow, and hence PT2, but what are the effects of distortion on PS2? And are they correlatable? This paper attempts to answer these questions.

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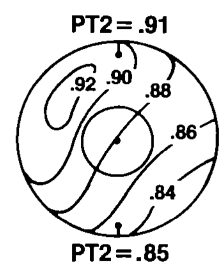
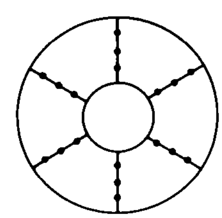
Why PS2?

- PT2 (Engine Face Total Pressure) is a critical engine control parameter

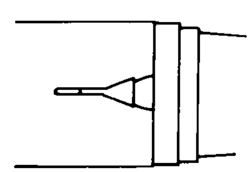


- Measure PT2 with a single probe ?
  - OK for uniform flow
  - For distorted flow, PT2= ?

- Measure PT2 with a multiprobe rake ?
  - Great PT2 data
  - Complex
  - Expensive



- Use an indirect measurement ?
  - Static pressure measured on hub mounted probe provides a total-to-static pressure ratio which is only a function of airflow
  - Digital controls can calculate airflow, and hence, PT2
  - Distortion effects ?



PS2 PROBE AND PT2 RAKE ON F100 ENGINE

A closeup photo of the F100-PW-100 engine face shows the PS2 static probe mounted on the hub center. The PT2 probes, of which there are 35, can be seen mounted in seven of the inlet guide vanes. The 35-probe seven-rake array of total pressure probes at the engine face provides the data needed to determine total pressure recovery and to calculate various distortion factors. The distortion factors are:

DTMM = (PT2MAX - PT2MIN)/PT2AVG

$K\theta$ = engine manufacturers' cicumferential distortion factor

KRA2 = engine manufacturers' radial distortion factor

KA2 = $K\theta$ + b(KRA2)
where b is a weighting factor (function of airflow)

The equations for these distortion factors are given in reference 4.

PS2 Probe and PT2 Rakes on F100 Engine

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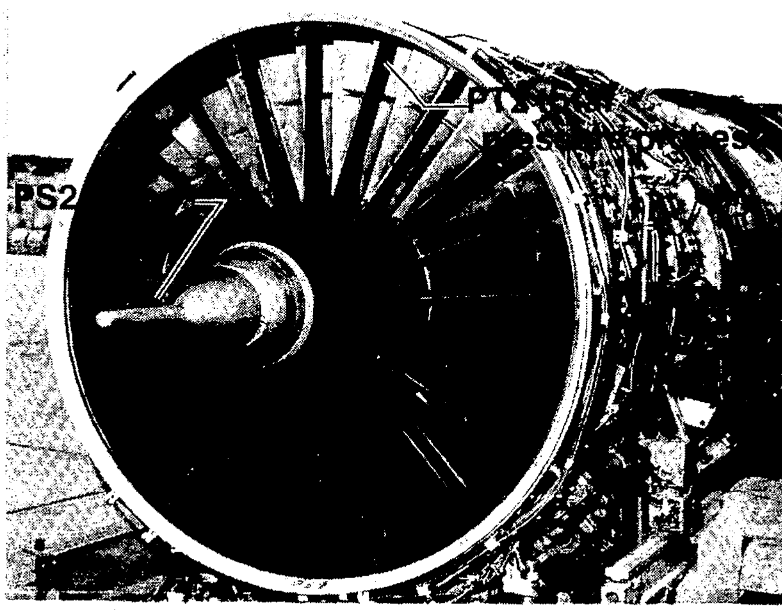

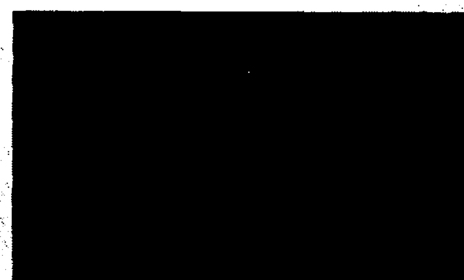

PRESSURE INSTRUMENTATION

The schematic of the pressure instrumentation is shown below. In order to increase the accuracy of all of the results, the engine face pressures were measured with differential pressure transducers. Pressure accuracy was approximately 1 percent. Reference pressure was obtained from an inlet wall static pressure tap and was stabilized by the use of a pressure reservoir. The reference pressure was measured with a highly accurate digital quartz pressure transducer. All transducers were located in an environment that was temperature controlled. The resulting accuracy was estimated to be ±1 percent. The PS2 pressure was measured with three differential transducers, and the measurements were averaged for improved accuracy. With a pressure accuracy of 1 percent, calculated distortion factor accuracy was 3 percent (ref. 5). The long lines between pressure probes and transducers resulted in the data being usable for steady-state information only.

PS2 and PT2 Pressure Measurement System

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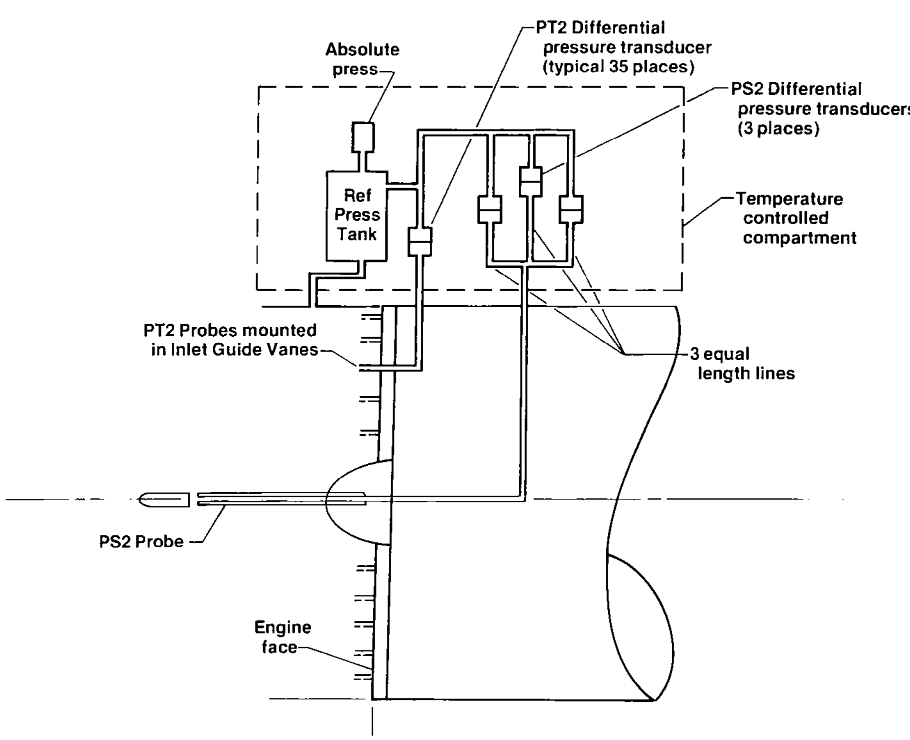

F-15 INLET

The F-15 aircraft has two side-mounted inlets of a two-dimensional horizontal ramp design. The inlets provide external compression with three ramps and feature variable capture area by rotating the inlet about a transverse hinge point at the lower cowl lip. The ramps and bypass doors are automatically scheduled by the air inlet controllers. For the distortion data presented in this paper, the third inlet ramp was controlled manually in flight to vary the third ramp angle in increments. The third ramp is shown in the "down" position. As the third ramp angle is increased, the inlet throat area is decreased, the inlet Mach number is increased, and the distortion at the engine face is increased until the engine stalls.

F-15 Inlet

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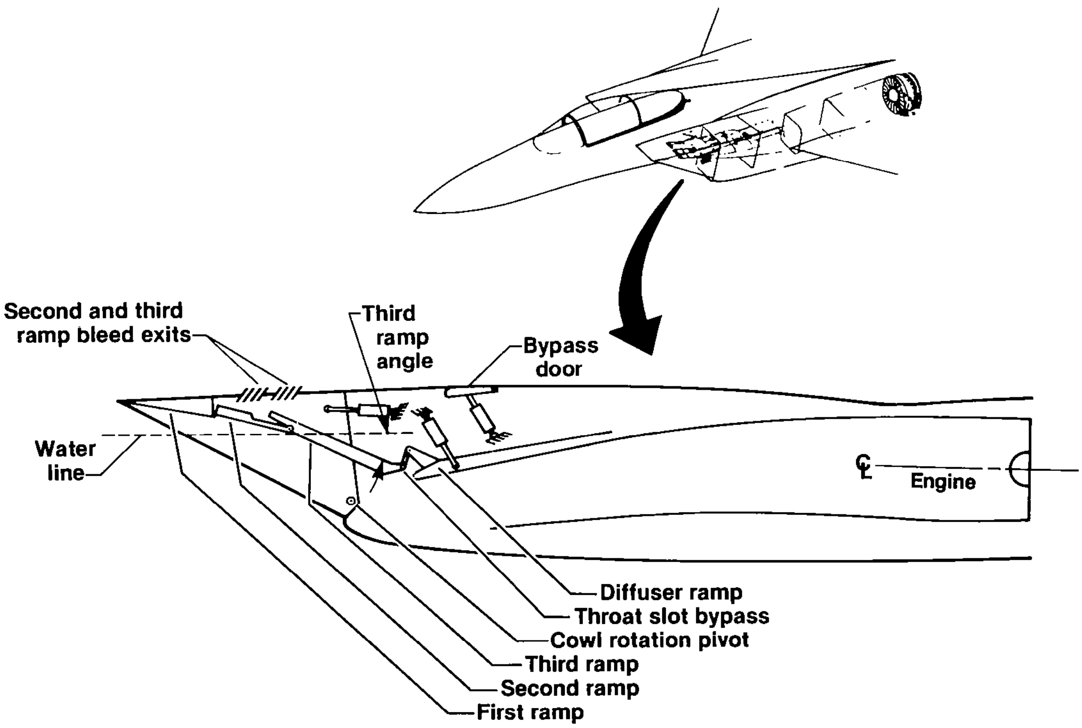

PT2 CALCULATION

On those systems that do not have engine face PT2 measurements, the PT2 can be calculated as schematically shown below. Engine corrected airflow (WAC2) is obtained from the engine pumping curve by the input of fan-corrected rotor speed and engine pressure ratio. The DEEC logic contains a table of PT2/PS2 as a function of airflow, so entering the table with airflow and PS2, PT2 can be obtained. Since engine pressure ratio (EPR) requires the PT2 measurements, an iterative procedure is required.

PT2 Calculation

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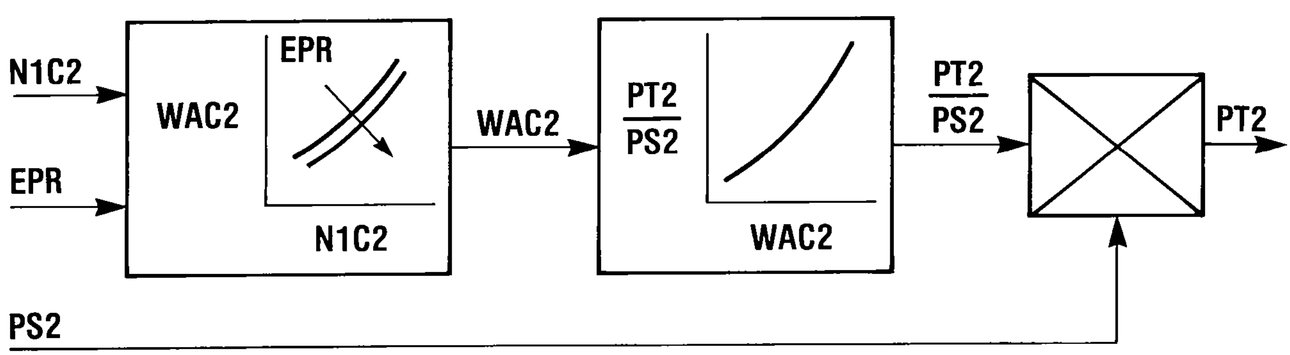

$\overline{\text{PT2}}$/PS2 AT LOW DISTORTION

The PS2 static pressure probe was tested in an altitude facility on an F100 engine and in the inlet of an F-15 airplane while in flight. Steady-state low distortion data, obtained over a range of engine throtle settings at Mach 0.9 and 40,000 ft, was compared with low distortion data obtained on a different engine in an altitude facility (ref. 6). The data from flight and the altitude facility compared $\overline{\text{PT2}}$/PS2 pressure ratio with corrected engine airflow (WAC2) and showed no measurable shift in $\overline{\text{PT2}}$/PS2. Other flight test conditions, including Mach number excursions and maximum load factor turns, also correlated with previous altitude facility test results.

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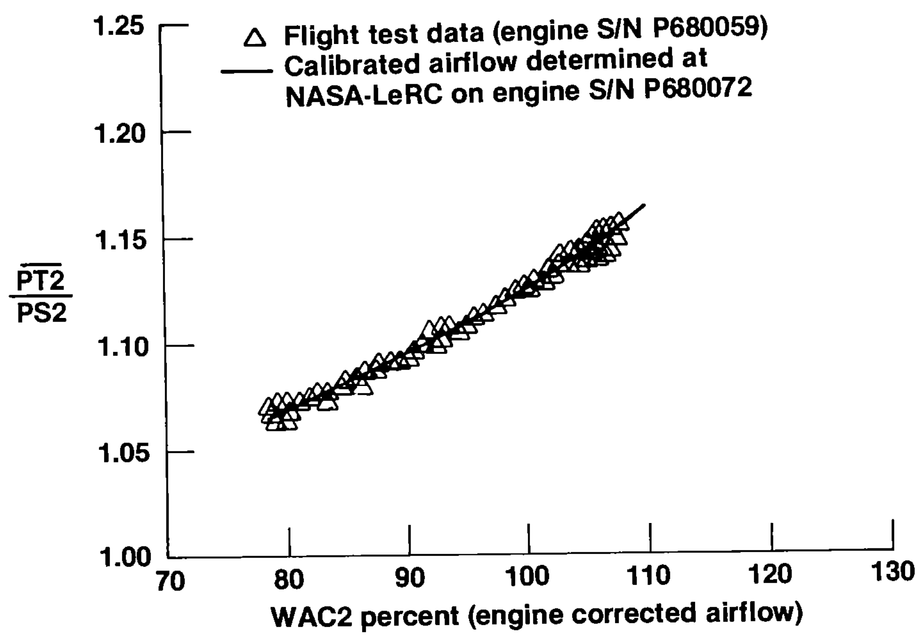
Low Distortion Flight Conditions



INDUCED DISTORTION

Increased levels of distortion were desired to evaluate effects on the $\overline{PT2}/PS2$ relationship. Increased levels of distortion in the inlet were induced during flight test by lowering the inlet third ramp in a series of steps, with each step being held for about 10 sec. With increasing third ramp angle, the inlet throat area was reduced, causing the inlet throat Mach number to increase. The $\overline{PT2}/PS2$ pressure ratio also gradually increased until engine stall occurred. Four of these tests were conducted at Mach 0.8 and 0.9 at altitudes of 30,000 and 40,000 ft.

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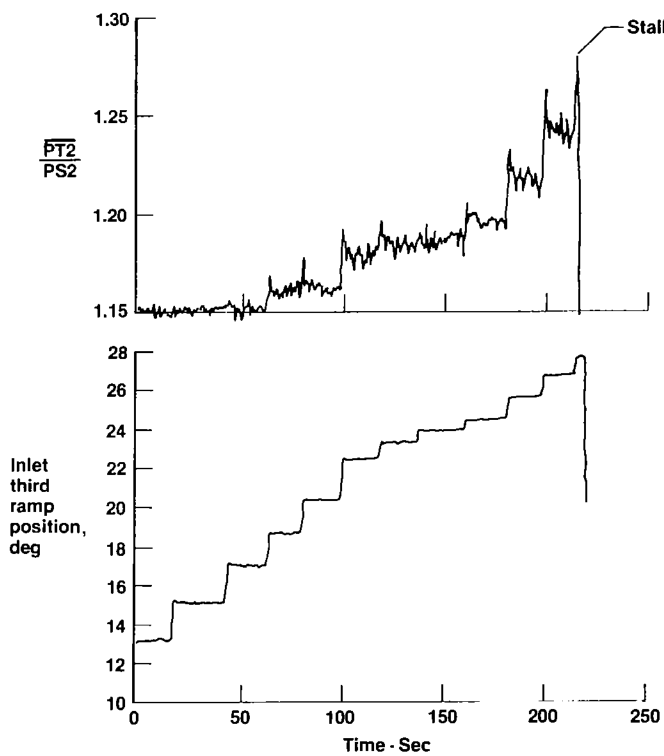
$\overline{PT2}/PS2$ Variation with Ramp Step Inputs



INCREASING INLET THIRD RAMP ANGLE

A typical data run showing a plot of all of the distortion factors and the pressure ratios versus inlet third ramp angle is given below. The distortion factor (DTMM), circumferential distortion factor (Kθ), and overall distortion factor (KA2) increase with increasing third ramp angle, while the radial distortion factor (KRA2) changes very little. The engine face pressure ratio $\overline{PT2}$/PS2 gradually increases with increasing third ramp angle while the fan inlet total pressure recovery ($\overline{PT2}$)/free stream total pressure (PTINF) decreases.

Typical Ramp Excursion

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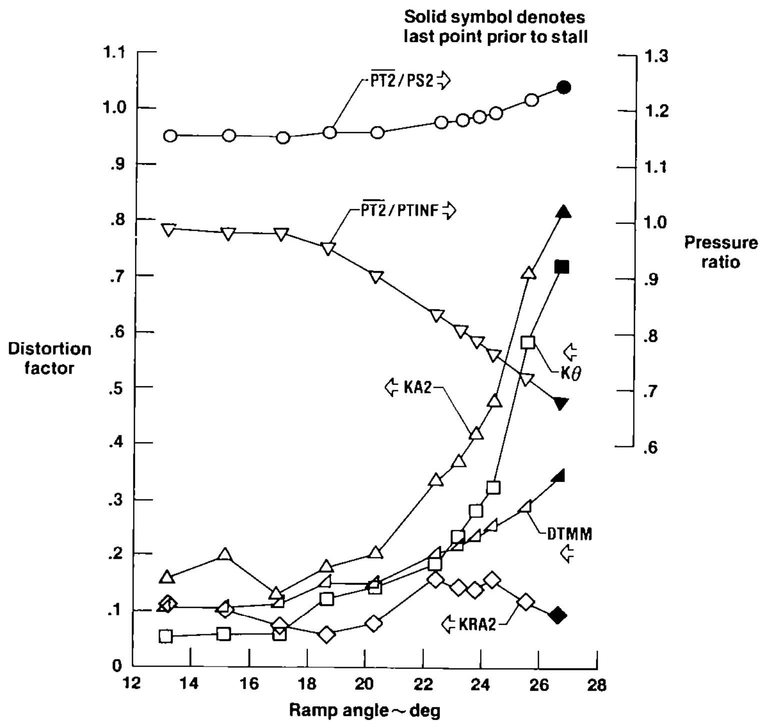
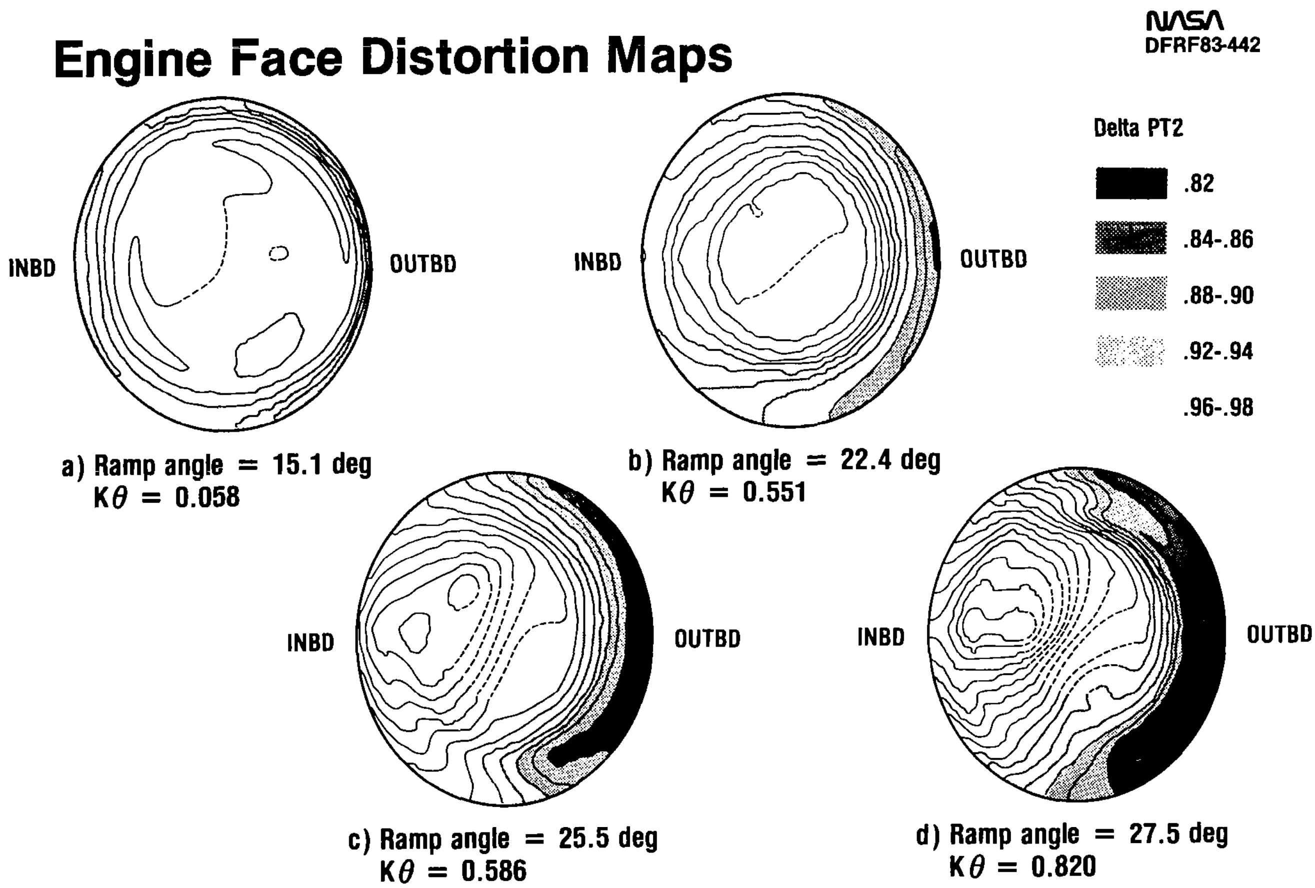


The compressor face distortion maps, illustrated below, show increasing pressure distortion as the inlet third ramp angle is increased. The pressure patterns change from the relatively symmetrical shapes of low distortion to a classical 180° distortion pattern seen just before engine stall and depicted in figure (d). These 180° distortion patterns have relatively large pressure gradients across the engine face with high pressure on the inboard side and low pressure on the outboard side. These distortion maps are a graphical presentation of the pressure distributions at the engine face. The calculated distortion factors Kθ, KA2, and DTMM, however, provide numerical values that can be better evaluated and compared.



a) Ramp angle = 15.1 deg
$K\theta = 0.058$

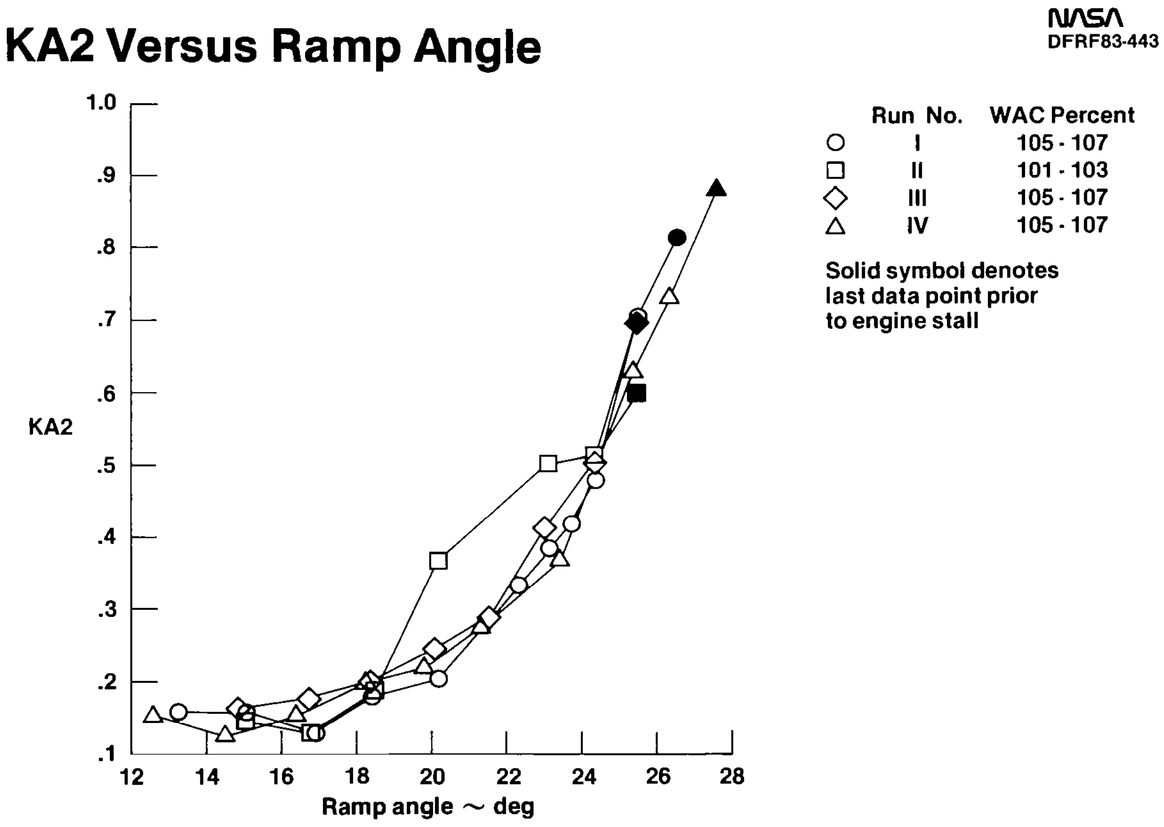
b) Ramp angle = 22.4 deg
$K\theta = 0.551$

c) Ramp angle = 25.5 deg
$K\theta = 0.586$

d) Ramp angle = 27.5 deg
$K\theta = 0.820$

KA2 VERSUS RAMP ANGLE

When the distortion factor data from each of the four ramp excursions are combined on one plot, the repeatable nature of each of the distortion factors is shown. The KA2 distortion factor increases very rapidly and goes to large values with increasing inlet third-ramp angle. The three tests (I, III, and IV), run at maximum airflow, show excellent agreement. Run II was conducted at a slightly lower airflow, and deviates from the other three runs.



Kθ VERSUS RAMP ANGLE

The circumferential distortion factor Kθ also increases rapidly at the higher third ramp angles, and minor differences between the four runs are seen. DTMM increases less than Kθ and is not shown.

Kθ Versus Ramp Angle

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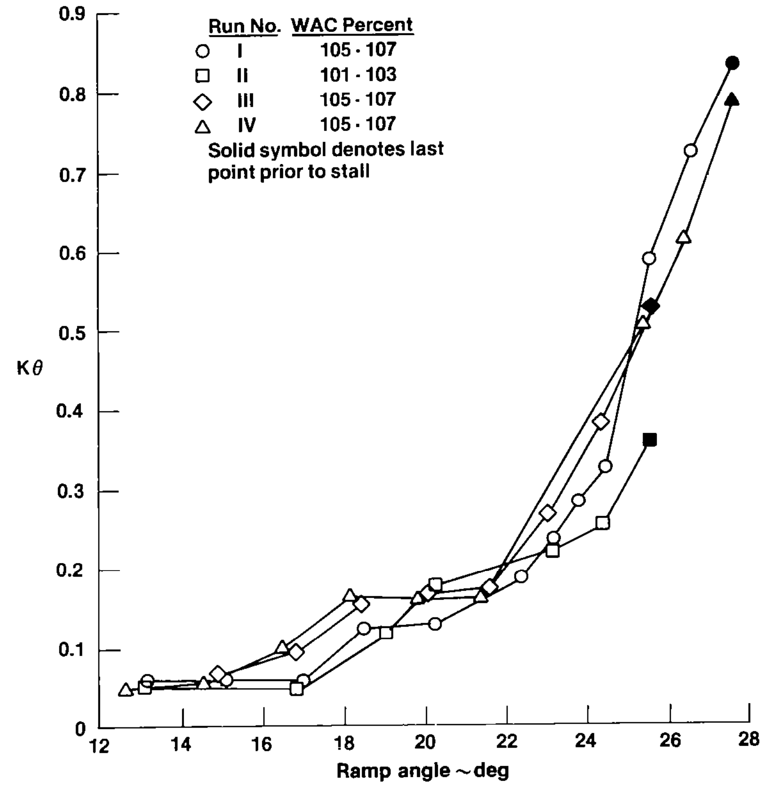
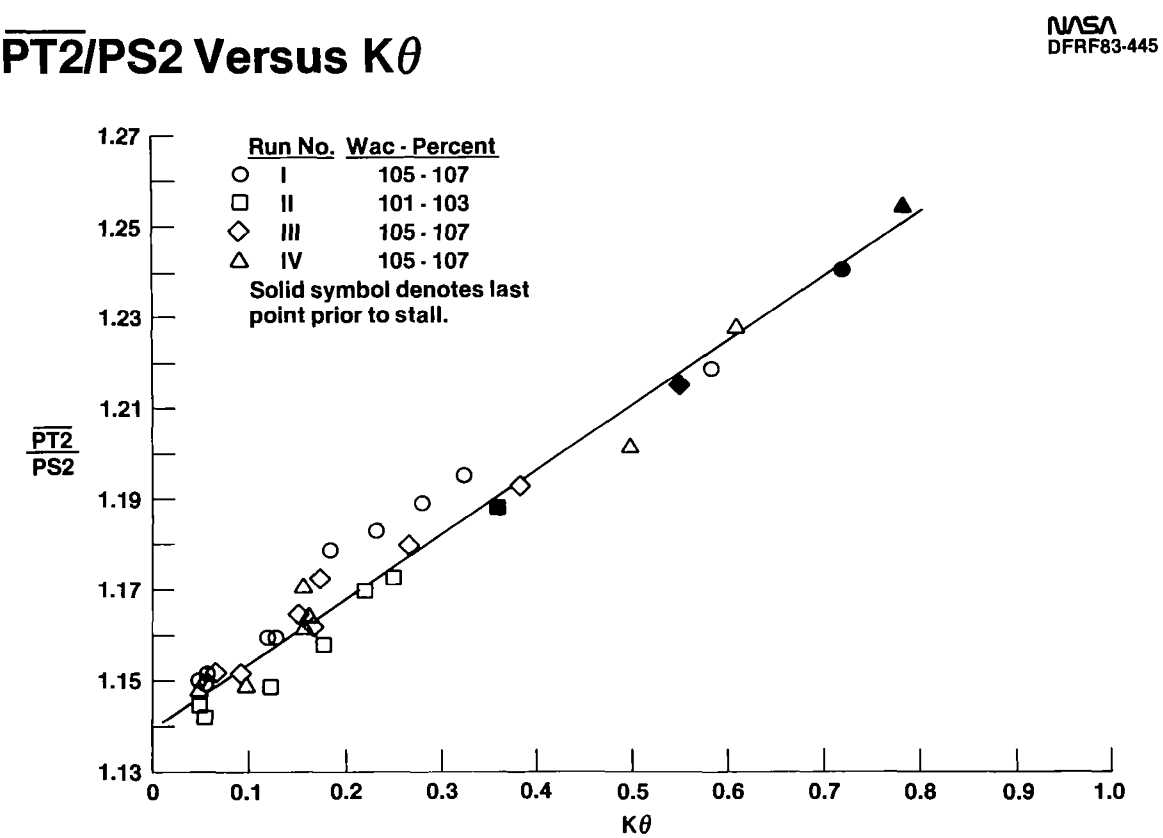


Kθ VERSUS $\overline{PT2}/PS2$

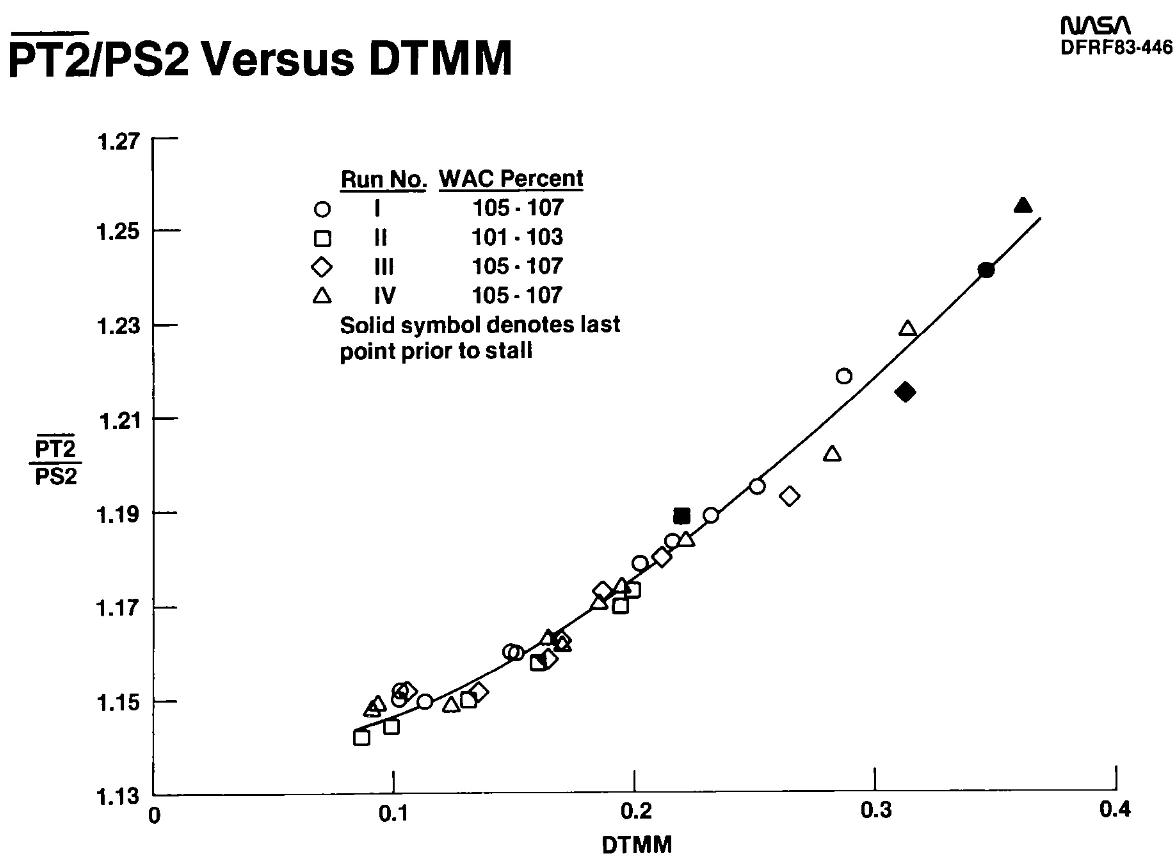
When the pressure ratio $\overline{PT2}/PS2$ is compared against the distortion factors, a definite correlation exists for all except the radial distortion factor KRA2. The circumferential distortion factor Kθ, shown below, exhibits a good linear correlation with $\overline{PT2}/PS2$ for all four tests. The effects of free-stream Mach number, altitude, or airflow differences are not evident in the data.

$\overline{PT2}/PS2$ Versus $K\theta$



DTMM VERSUS $\overline{PT2}/PS2$

The distortion factor DTMM also shows good correlation, with no apparent effect of free-stream Mach number, altitude, or airflow differences for the four tests conducted.



EFFECT OF DISTORTION ON EPR

As distortion increases, the engine without the DEEC control logic remains at about a constant EPR, whereas the engine operating with PS2 input to DEEC will compensate by downtrimming the engine. When the Kθ distortion increases to about 0.8, EPR is reduced by about 10 percent, thus effectively downtrimming the engine by about 10 percent and automatically helping the engine avoid stall.

Effect of Kθ on EPR

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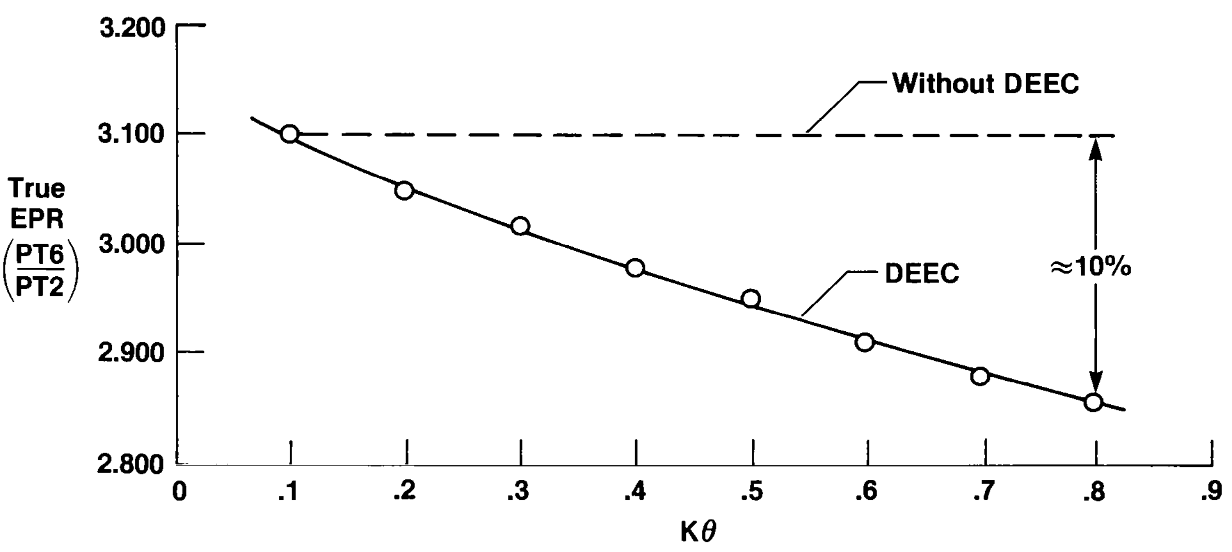

CONCLUSIONS

1. For low distortion conditions, the ratio of engine face total pressure to static pressure agreed well with previous altitude facility data.

2. During tests in which the inlet throat area was reduced, large amounts of circumferential distortion occurred, but only small amounts of radial distortion occurred.

3. The ratio of engine face total pressure to static pressure correlated well with the distortion factors $K\theta$, KA2, and DTMM.

4. The PS2 probe can be useful as an engine control parameter as part of an algorithm to provide automatic compensation for distortion.

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