Detailed Measurements in the SSME High Pressure Fuel Turbine with Smooth Rotor Blades

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Abstract

Several tests of the Rocketdyne configuration of the Space Shuttle Main Engine (SSME) High Pressure Fuel Turbopump (HPFTP) Turbine have been completed in the Turbine Test Equipment (TTE) at Marshall Space Flight Center. The tests involved using scaled performance parameters and model measurements to predict the performance of the turbine. The overall performance has been the primary objective of the tests to date, but more detailed measurements are also of interest. During the most recent test of the Rocketdyne configuration of the HPFTP turbine with smooth rotor blades, several different measurement techniques were used to study the turbine inlet and exit velocity profiles, boundary layer thicknesses, turbulence intensities, etc. Data has been obtained using various hot film probes and three-hole cobra probes. Laser Velocimeter measurements were also made. The test plan and test data will be presented and discussed as well as lessons learned on how to obtain the various types of data.

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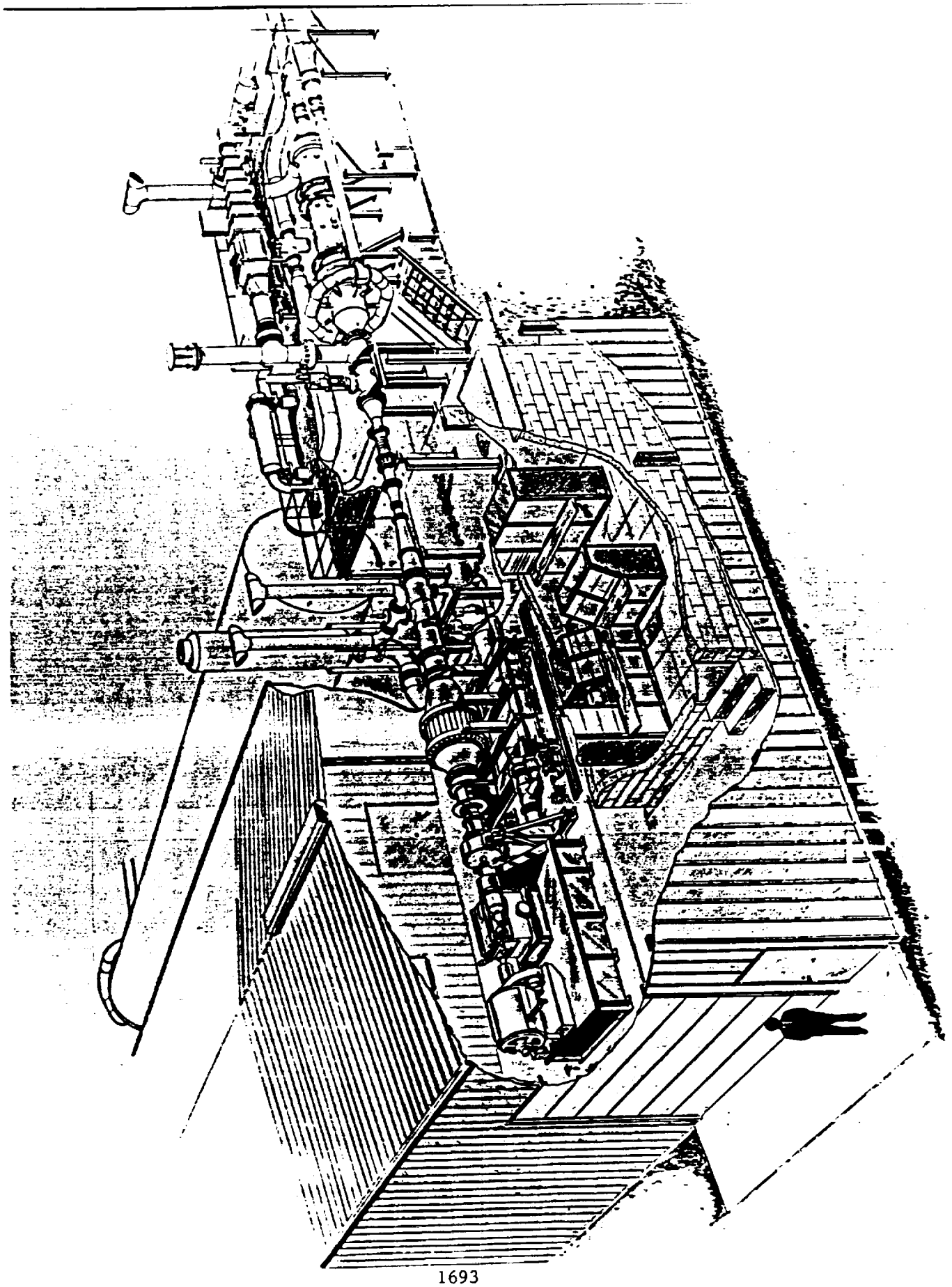
Outline

- Test Objectives
- Facility Description
- Model Description
- Instrumentation
- Test Plan
- Preliminary Test Results
- Conclusions

Test Objectives

- Develop and demonstrate techniques for making hot film probe, cobra probe, and laser velocimeter measurements in turbine flows
- Determine rake blockage effects on turbine performance
- Document fuel turbine acoustic environment
- Measure turbine inlet and exit velocity profiles, turbulence intensities, and boundary layer thicknesses
- Determine effect of Reynolds number on measurements



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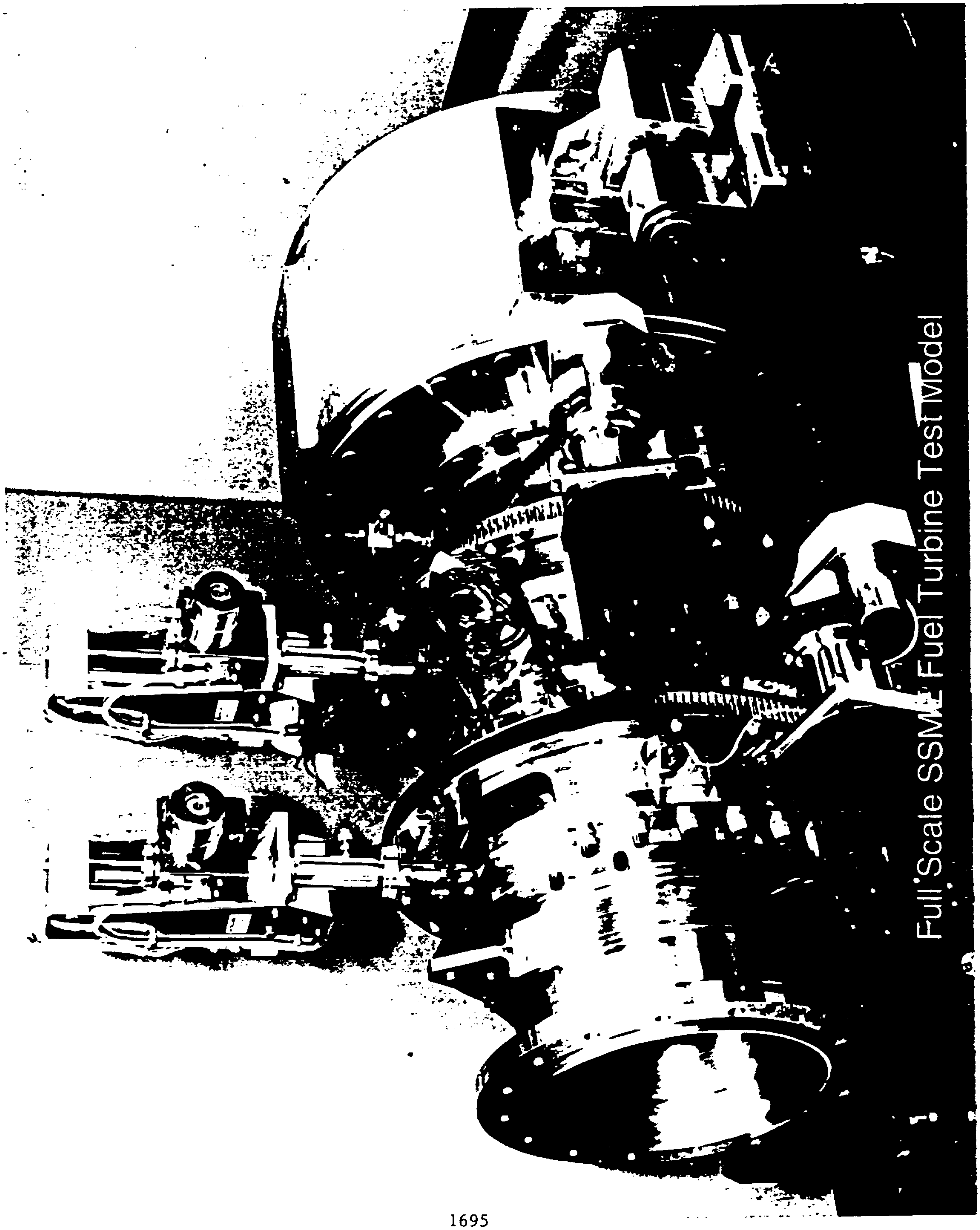
TTE Facts

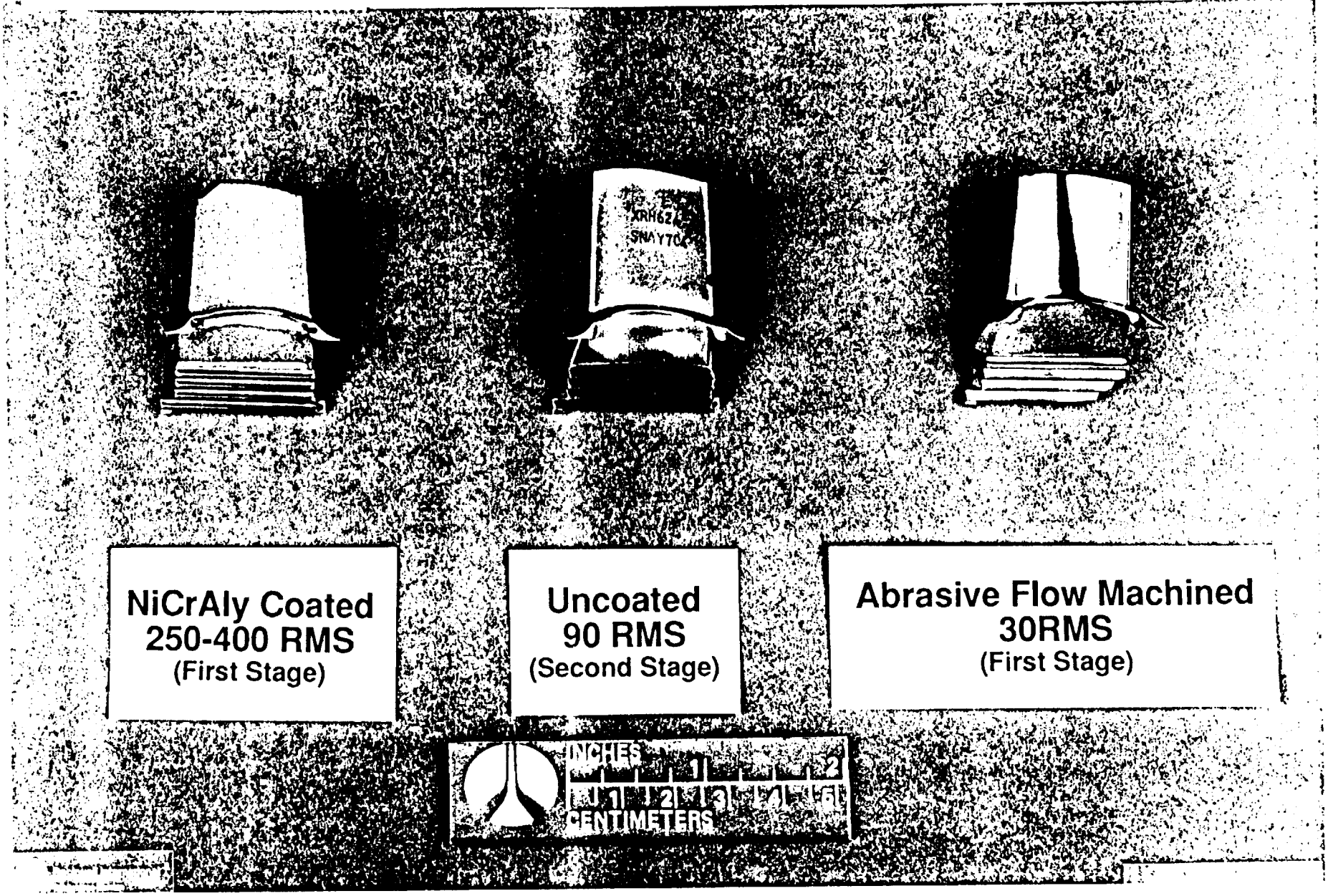
- Blowdown Facility (run times depend on inlet pressure)
- Regenerative Thermal Matrix Heater
- Herschel Venturi (large and small)
- Torquemeter (30, 500, 1000 ft-lb shafts)
- Gearbox (2:1, 1:1, 1:2)
- Dynamometer (600 HP continuous)
- Control Parameters -- Po, To, N, Pr
- Data Acquisition
  - Pressure Systems, Inc. (PSI) System
  - Hewlett-Packard (HP) 3852S data acquisition system
  - VAX -- database and data analysis

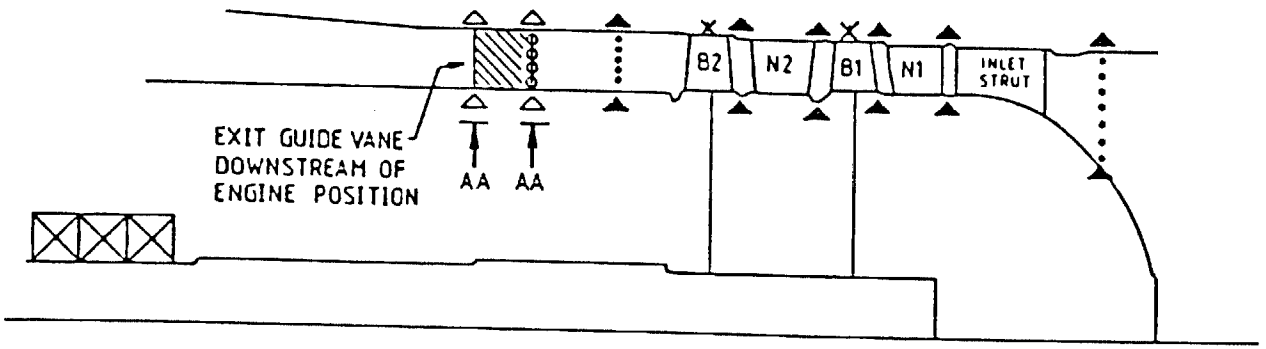


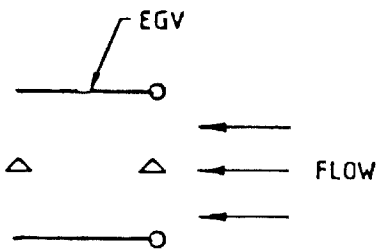
Phase IA Configuration

- Fully bladed two stage SSME fuel turbine test article
- Disk coolant flows not simulated
- Platform seal leakages not simulated
- Turbine exit circumferential pressure gradient not simulated
- Exit guide vanes downstream of engine position

COMPARISON OF COATED, UNCOATED, & POLISHED SSME HPFTP TURBINE BLADES







VIEW AA-AA

x Tip Clearance (3 Circumferential)
▲ Gas Path Wall (8 Circumferential)
• Rotating Ring (Continuously Variable through 90°)
o Fixed Exit (6 Circumferential)
△ Exit Static (12 Circumferential)

Phase IA Instrumentation

Instrumentation

- Inlet Spool

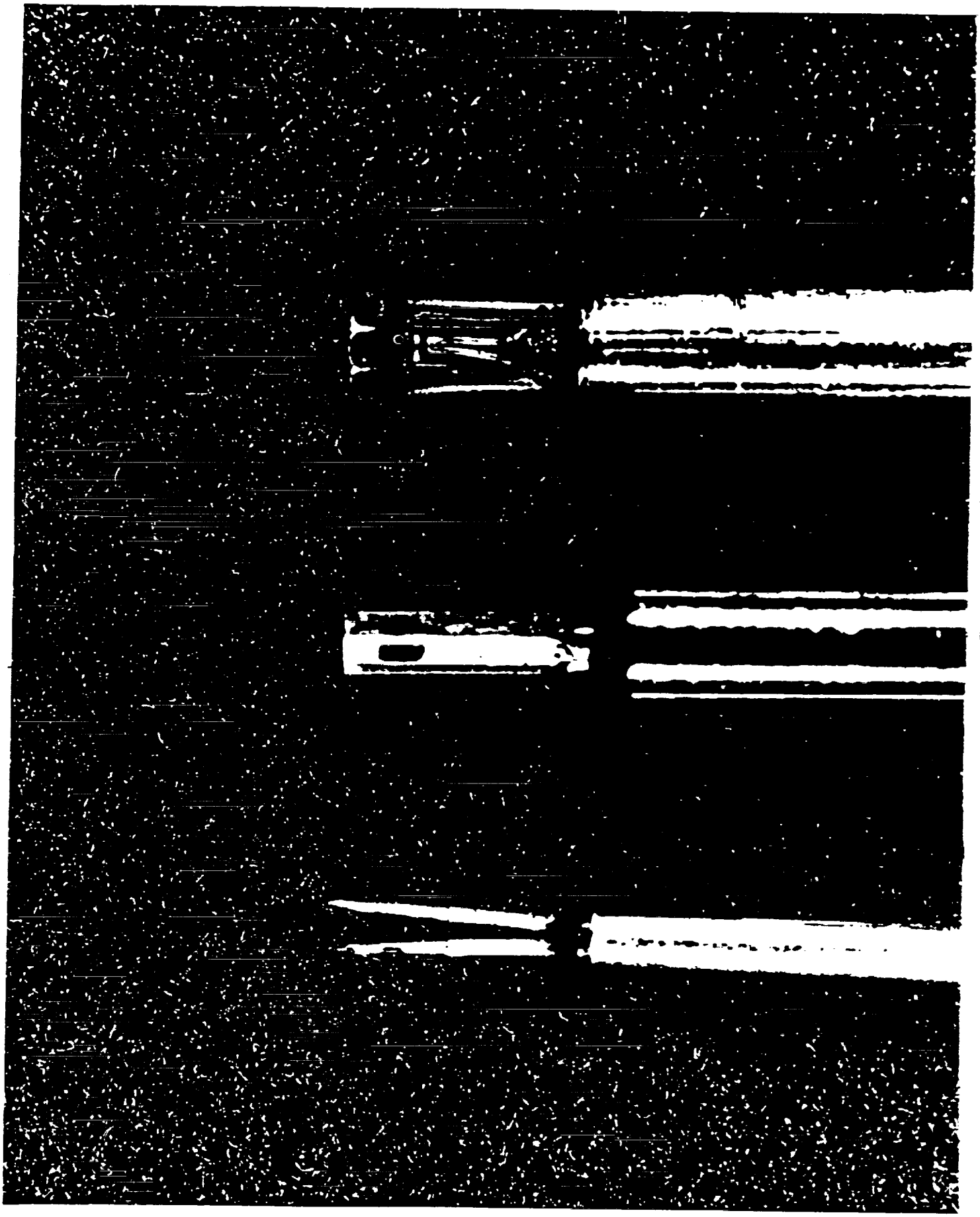
  Acoustic Pressure
  One Radial Actuator Tower (Cobra or Hot Film Probe)

- Turbine Inlet

  Acoustic Pressure
  Two Radial Actuator Towers (Cobra and Hot Film Probe)
  Laser Mounting Bracket
  Laser Window

- Turbine Exit

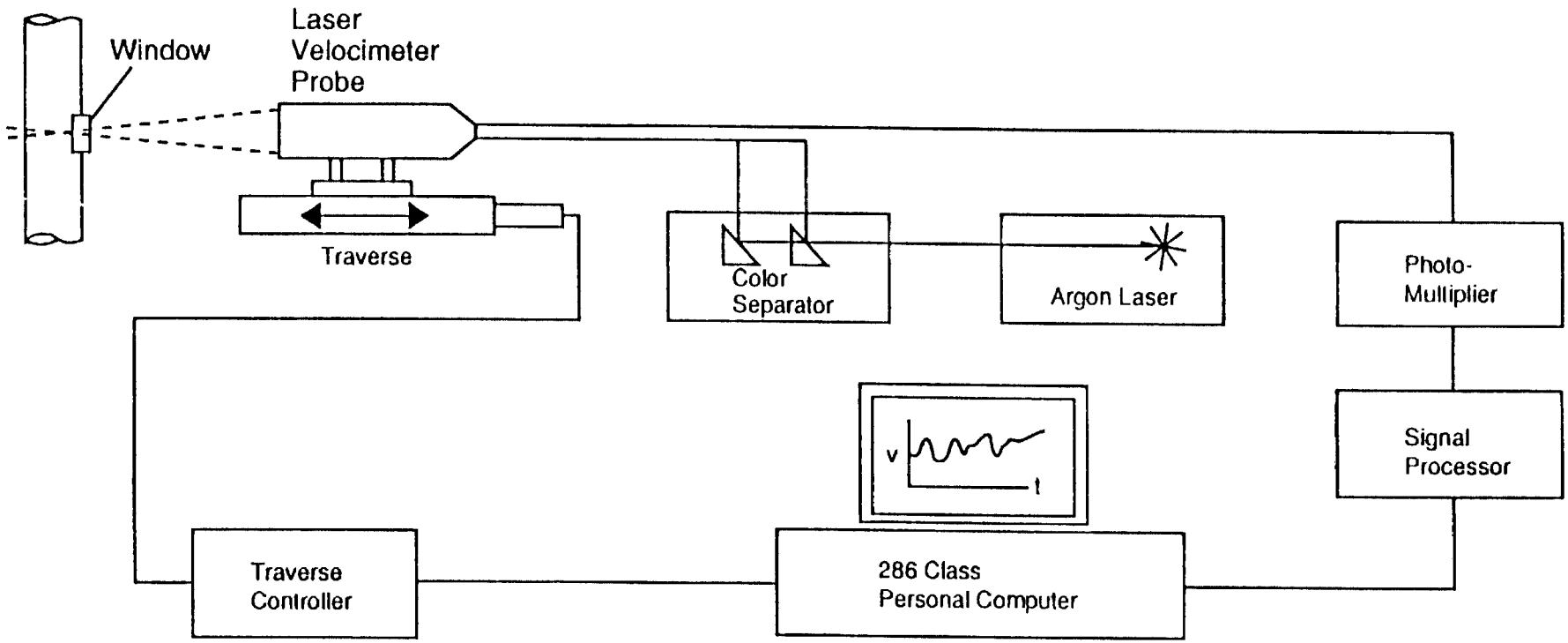
  Acoustic Pressure
  Two Radial Actuator Towers (Cobra and Hot Film Probe)
  Laser Mounting Bracket
  Laser Window

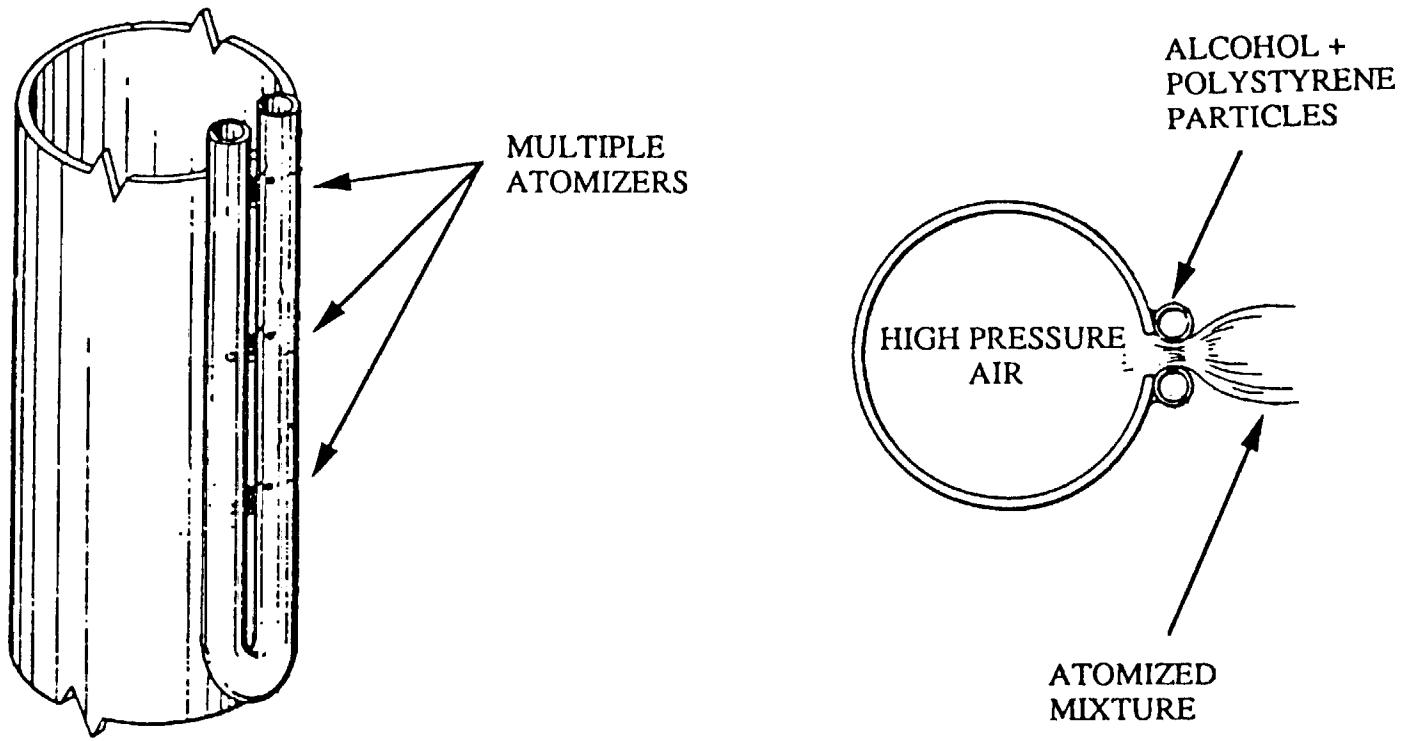


Spatial Resolution of Measurements

Instrument	Measurement Resolution		Comments
	Radially (in)	Circumferentially (in)	
Rotadata Cobra Probe	0.040	0.120	Probe head dimensions
Hot Film Probe (1260A-10)	0.001	0.050	Film diameter and width
Hot Film Probe (1234 HW)	0.040	0.040	Film diameter and width
LV Probe	0.197	0.008	Control volume size

LASER VELOCIMETER SYSTEM SCHEMATIC





SEEGMILLER ATOMIZER

Test Plan

I. Checkout

A. Static Pressure Checks
B. Check LV Bracket Vibration
C. Reestablish Design Point (104% Power Level) Performance
D. Determine Rake Blockage Effects at Design Point
E. Prepare Acoustic Pressure Data Acquisition System

II. Develop and Demonstrate Techniques

A. Establish Hot Film Probe Insertion Technique
B. Verify use of Cobra Probes to Obtain Velocities
C. Establish LV Seeding Method and Positioning

Test Plan (continued)

III. Measurements at Design Point

A. Measure Velocity Profiles
B. Measure Turbulence Intensities
C. Measure Boundary Layer Thicknesses
D. Obtain Acoustic Pressure Data

IV. Measurement at Off-Design Points

A. Verify Rake Blockage Effects Off-Design
B. Measure Velocity Profiles
C. Measure Turbulence Intensities
D. Measure Boundary Layer Thicknesses
E. Obtain Acoustic Pressure Data

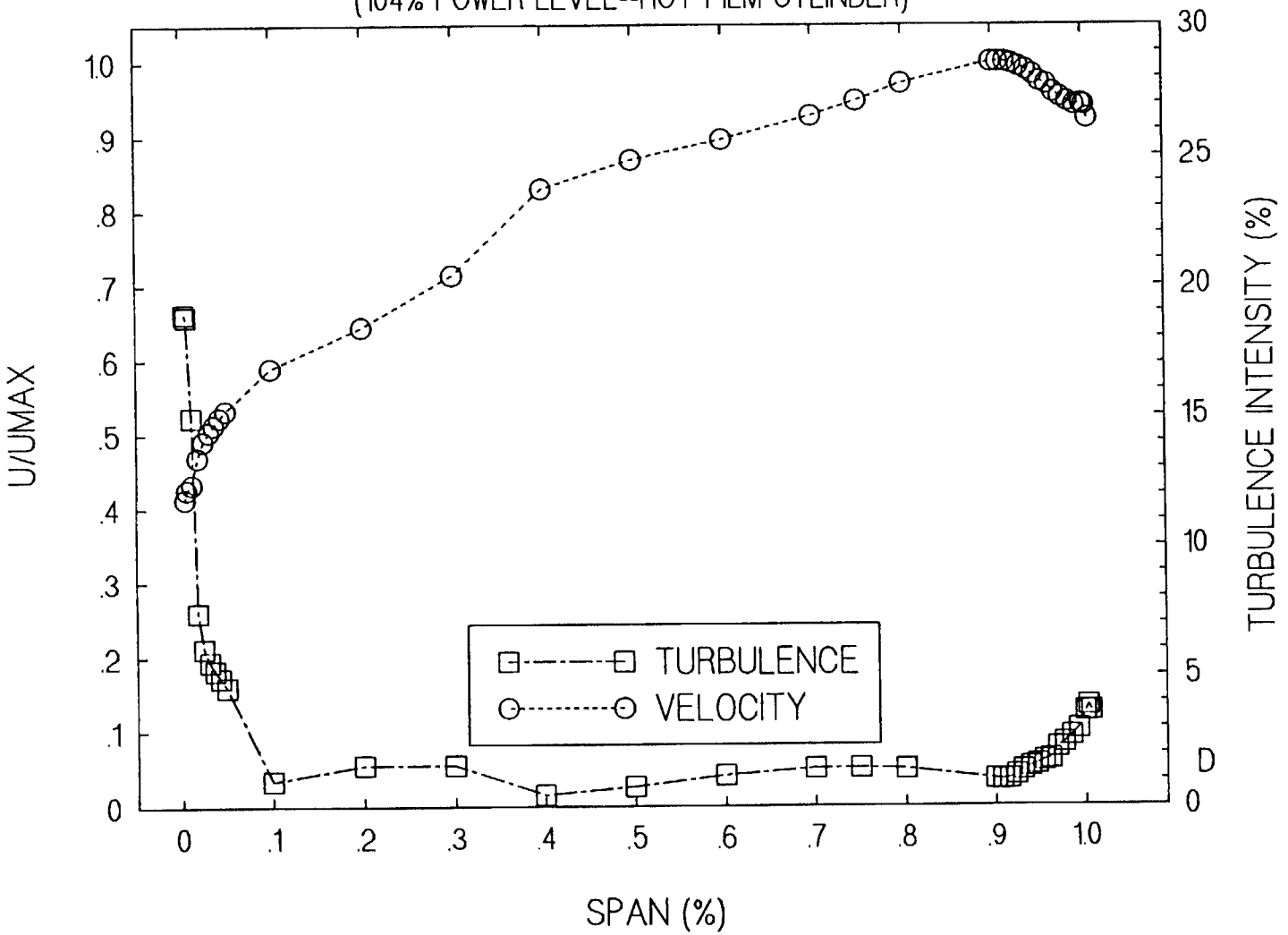
V. Determine Re Effect on Measurements

Laser Velocimeter Results

- Developed successful model/LV probe mounting design (minimal vibrations)
- Seeding successful at 50 psia with one hole seeder
- Overall poor signal to noise ratio
  - Minimize all reflections
  - Increase laser power
  - Investigate other seeding possibilities
- Separate test being planned to further improve LV measurements

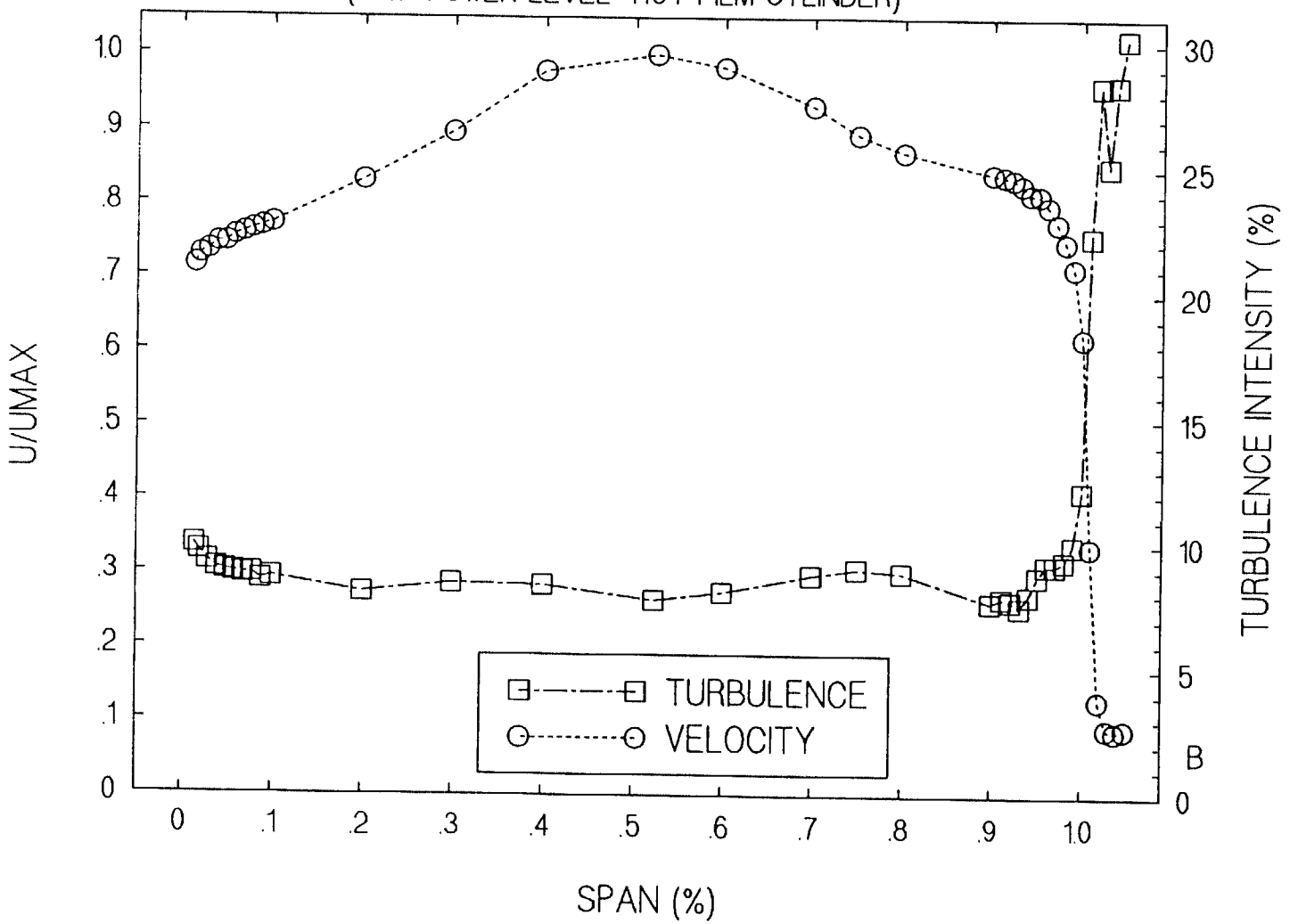
SSME HPFT INLET VELOCITY PROFILE AND TURBULENCE INTENSITY

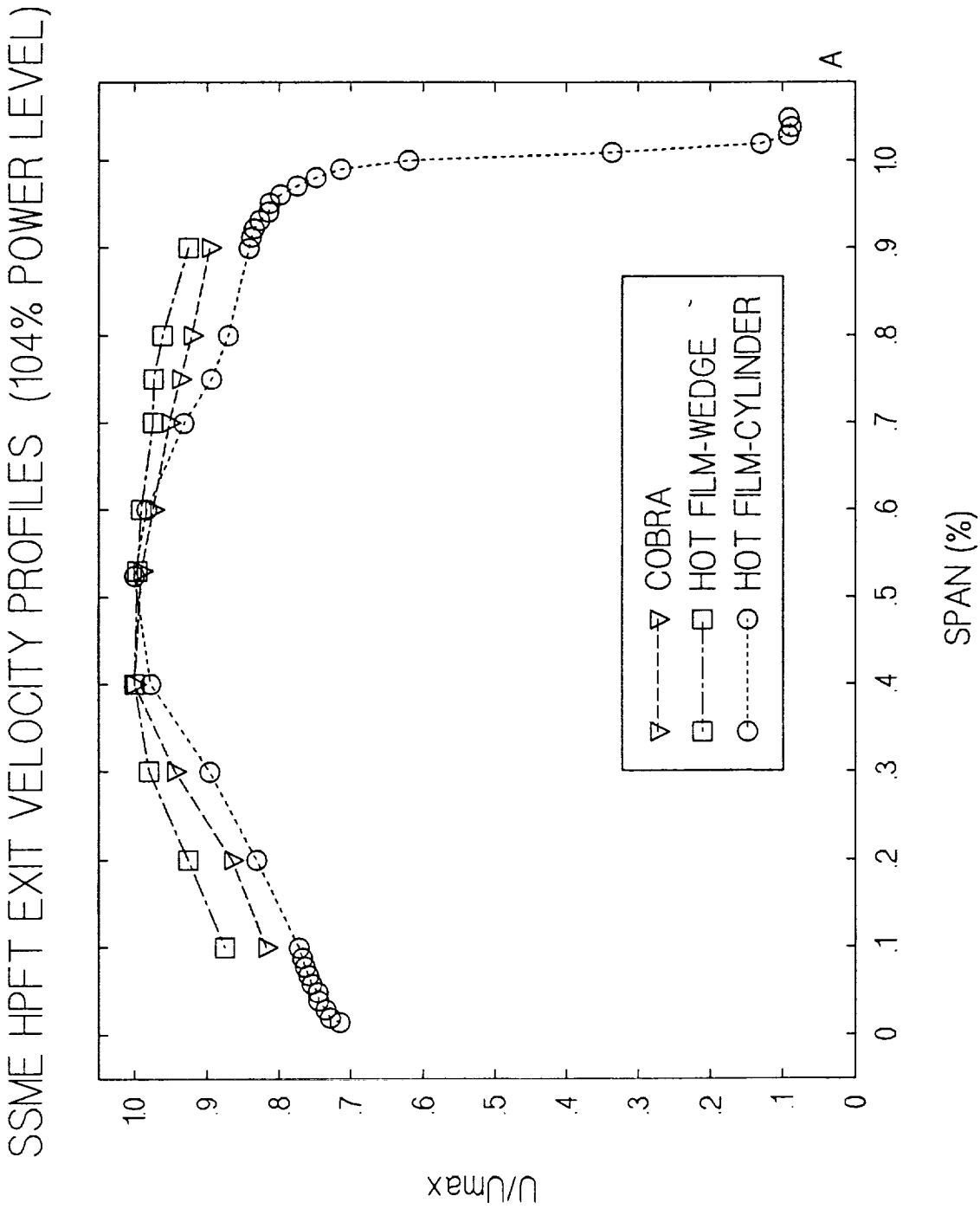
(104% POWER LEVEL--HOT FILM-CYLINDER)



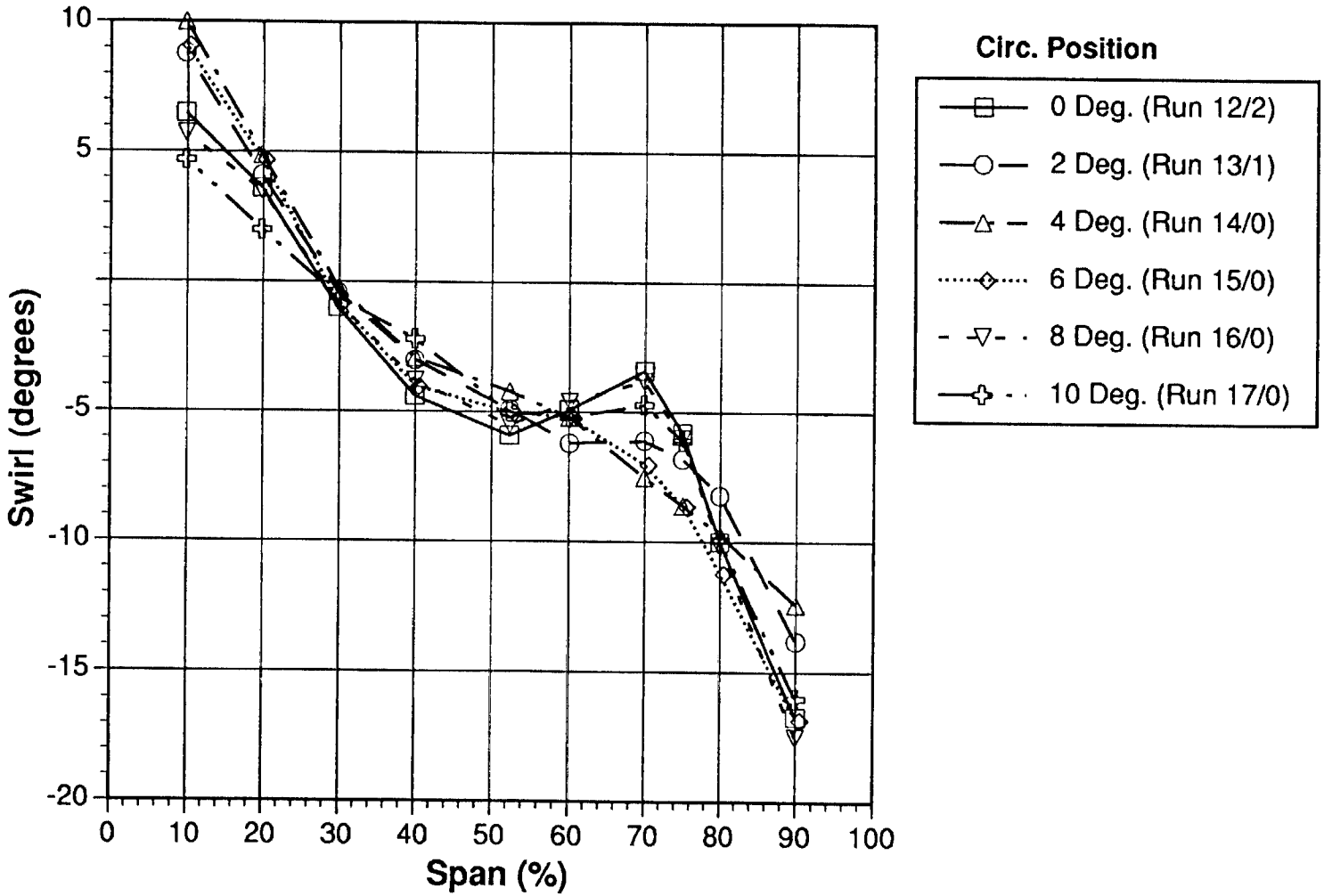
SSME HPFT EXIT VELOCITY PROFILE AND TURBULENCE INTENSITY

(104% POWER LEVEL--HOT FILM-CYLINDER)



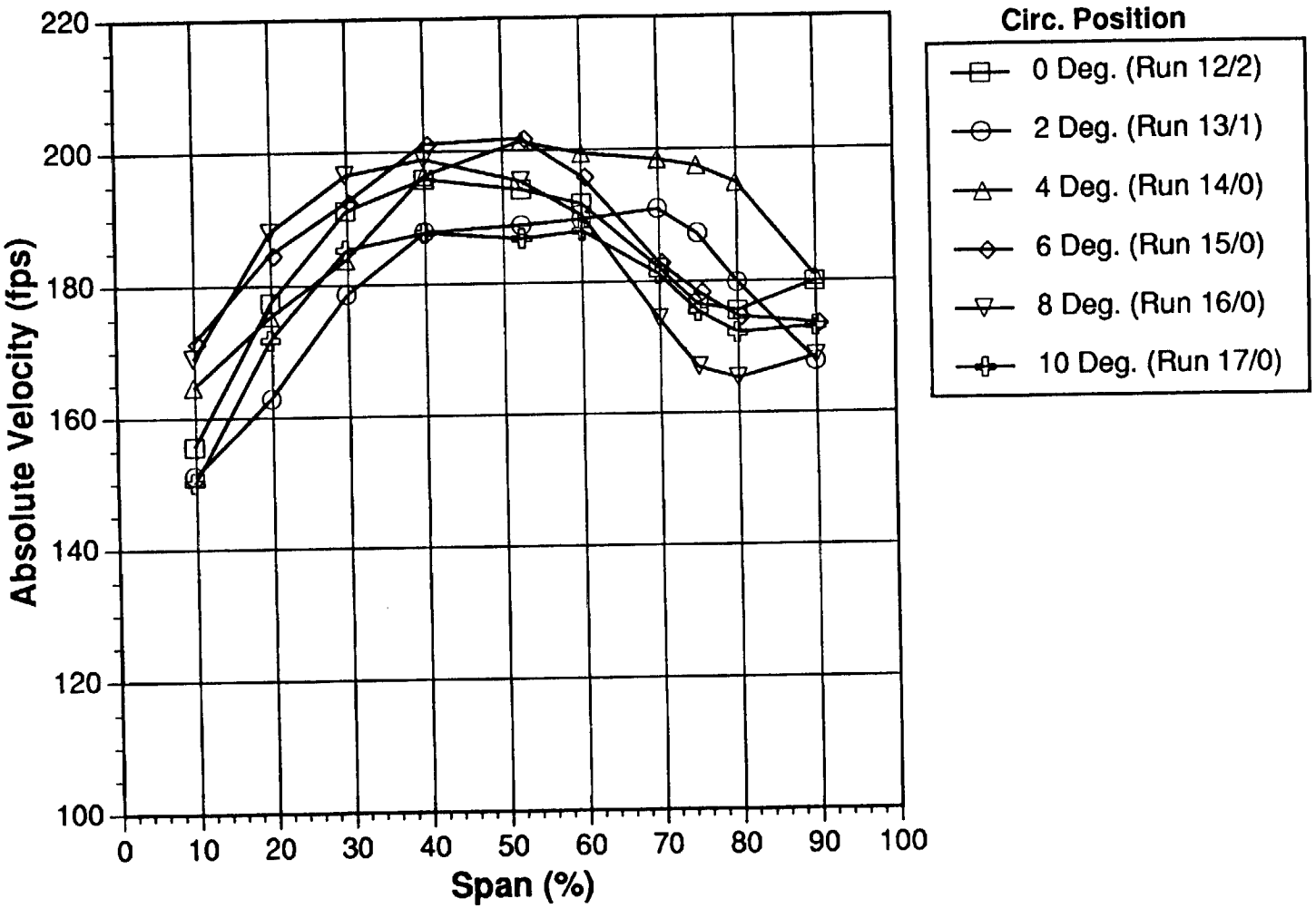

SSME HPFT EXIT VELOCITY PROFILES (104% POWER LEVEL)
U/Umax
SPAN (%)
A
COBRA
HOT FILM-WEDGE
HOT FILM-CYLINDER
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0

SSME HPFT Exit Swirl Versus Span and Circumferential Position (104% Power Level)



Note: Positive swirl is clockwise looking from turbine inlet to exit.

SSME HPFT Exit Velocity Versus Span and Circumferential Position (104% Power Level)



Conclusions

- Hot film probe insertion technique established
- Developed successful model/LV probe mounting design
- Seeding and LV measurements marginally successful
- Good agreement between cobra and hot film velocity profiles
- Measured turbine inlet and exit turbulence intensities (hot film)
- Measured turbine inlet and exit boundary layer thicknesses (hot film)
- Rake blockage effects appear minimal but analysis continuing
- Acoustic pressure data currently being analyzed by ED33
- Data collected to study Reynolds number effects on measurements