Presentation

NASA Fundamental Aeronautics Program Technical Conference

Cleveland, OH,

March 15-17, 2011

Experimental Measurement of Transonic Fan Wake Response to Uniform and Simulated Boundary Layer Ingesting Inlet Flows

Dr. Walter F. O'Brien
J. Bernard Jones Professor of Mechanical Engineering
Mr. Anthony M. Ferrar
Graduate Research Assistant
Virginia Tech
Blacksburg, VA

Mr. David Arend
Aerospace Engineer
NASA Glenn Research Center
Cleveland, OH

Research in partnership with
NASA and the United Aircraft Research Laboratories

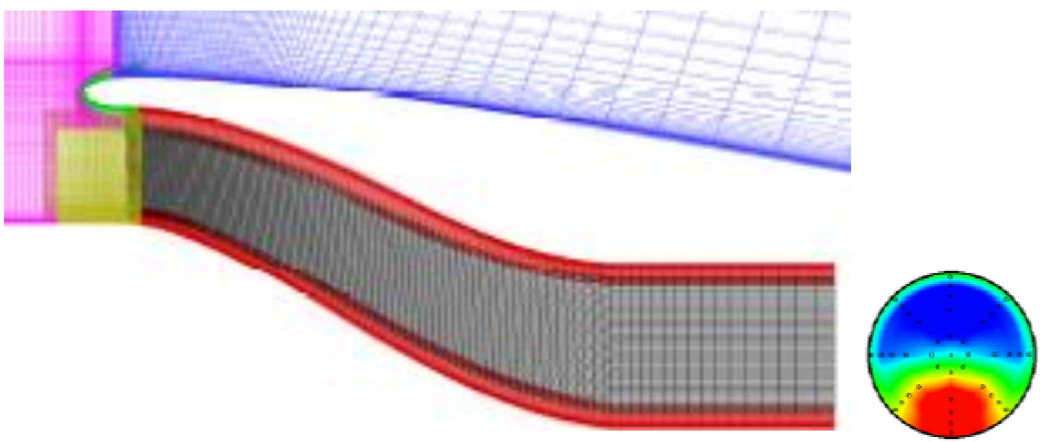
United Technologies Research Center

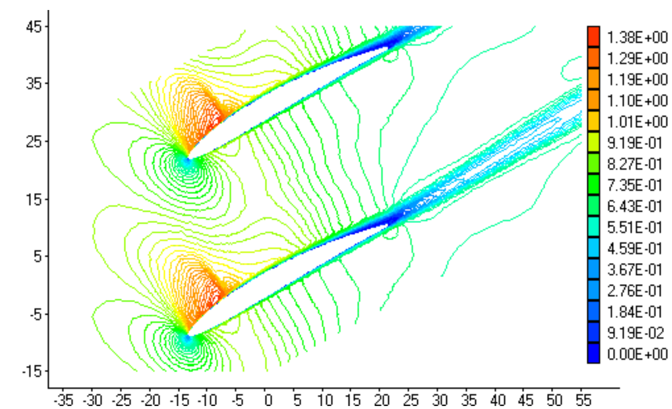
VirginiaTech
Invent the Future

Introduction

- BWB Aircraft with embedded engines and BLI inlets offer attractive advantages in terms of reduced noise from engines and increased range and fuel economy
- The BLI inlet produces inlet distortion patterns that can reduce fan performance and stall margin, and can produce undesirable forced responses

NASA

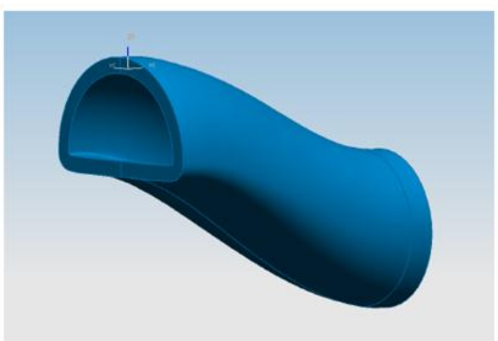


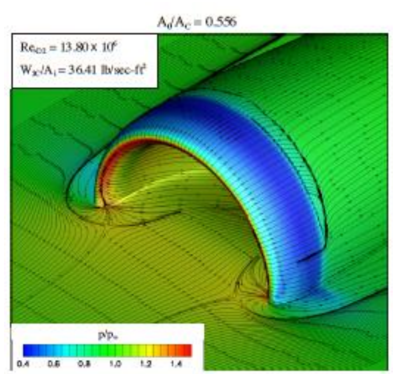


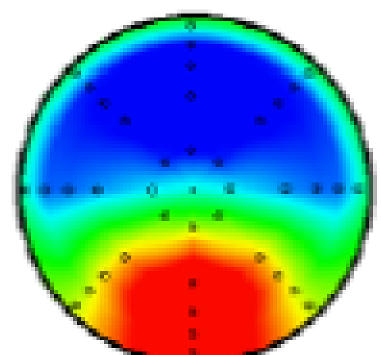
xOptimum

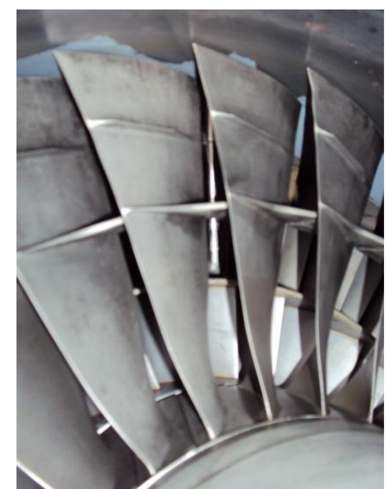
Introduction

- Knowledge of the dynamic response of fan flow when subjected to flow distortions of the type produced by BLI inlets is important for the design of distortion tolerant fans
- This project is investigating fan response to flow distortion by measuring the response of the fan of a JT15D engine to a flow pattern following the results of the NASA “Inlet A” BLI wind tunnel tests





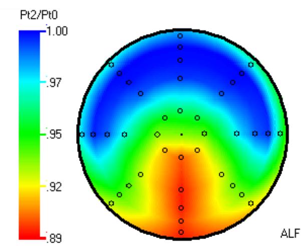




Ref. -Berrier et. al. “High Reynolds Number Investigation of a Flush-Mounted S-Duct Inlet with Large Amounts of Boundary Layer Ingestion” NASA/TP-2005-213766

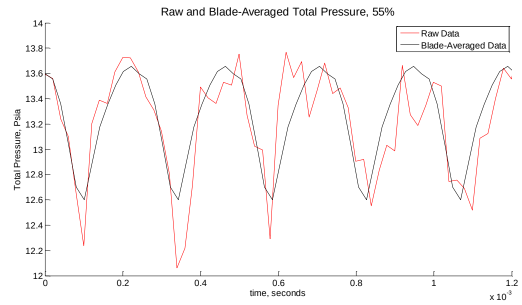
Research Plan

- Construct an inlet system and flow measurement apparatus for the Virginia Tech JT15D
  - Impose the desired flow distortion on the fan
  - Measure the dynamic effects of distortion on the fan flow
    - Blade wake structure
    - Flow turbulence level
- Perform research program to construct the required rig and make measurements

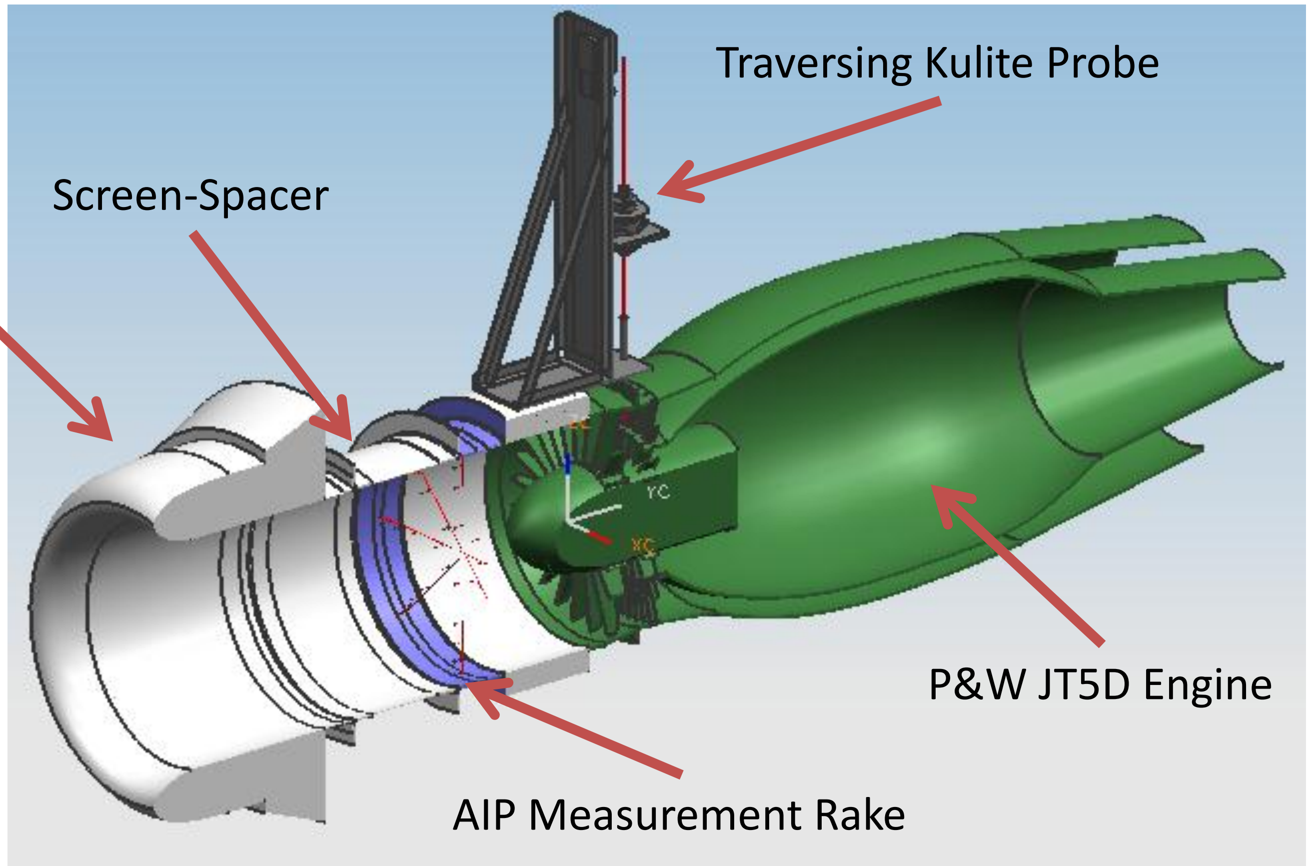


Research Plan Details

1. Measure clean inlet fan response
2. Develop P_0 distortion screen
3. Measure distorted inlet fan response
4. Data processing
   - Fan blade wake structure
   - Flow turbulence level



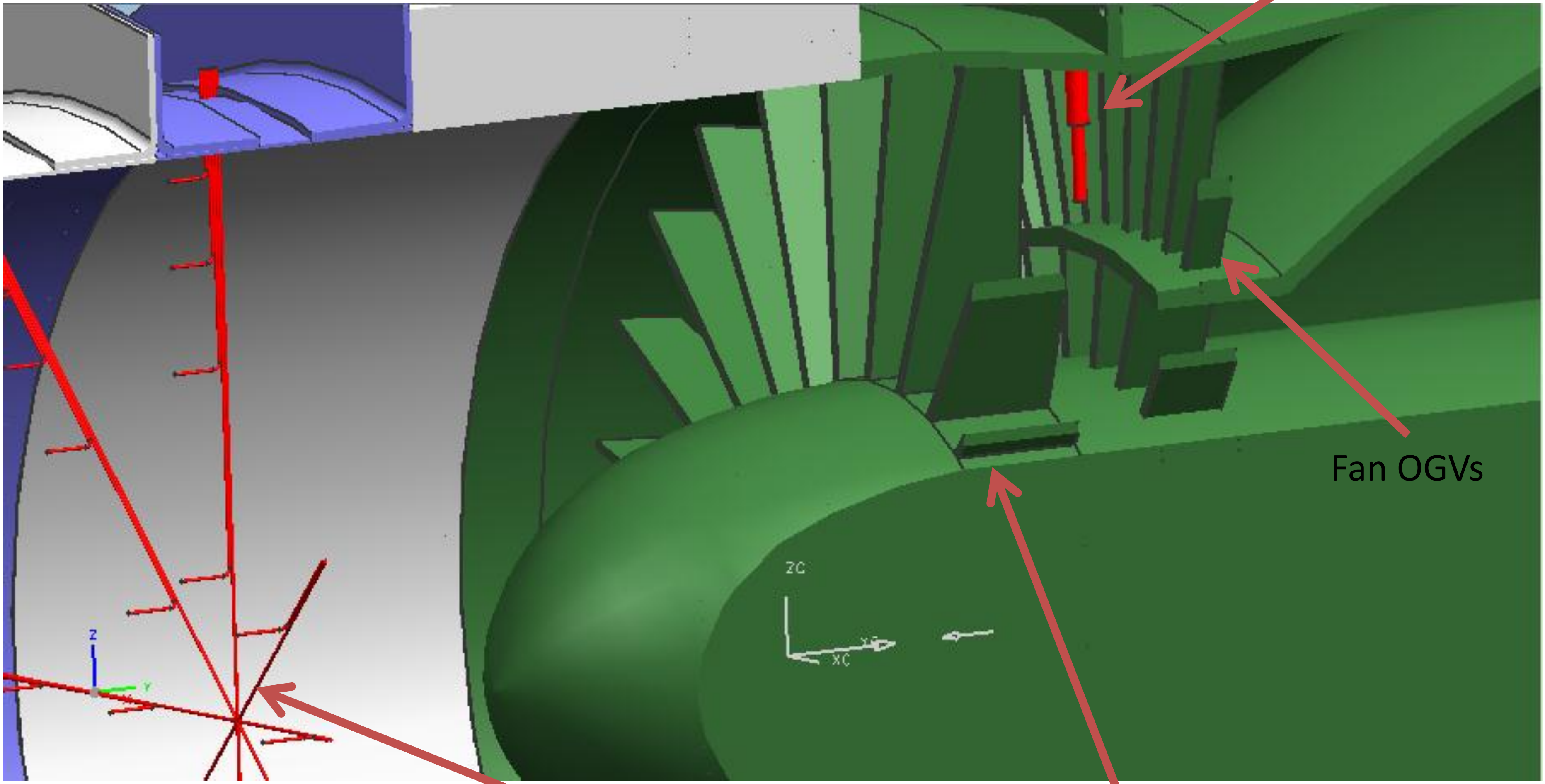
Clean Inlet Experiment



Initial clean inlet experiments have shown uniform flow entering the engine and measured unsteady fan blade wake details

Flow Probe and AIP Rake

Traversing Kulite Probe

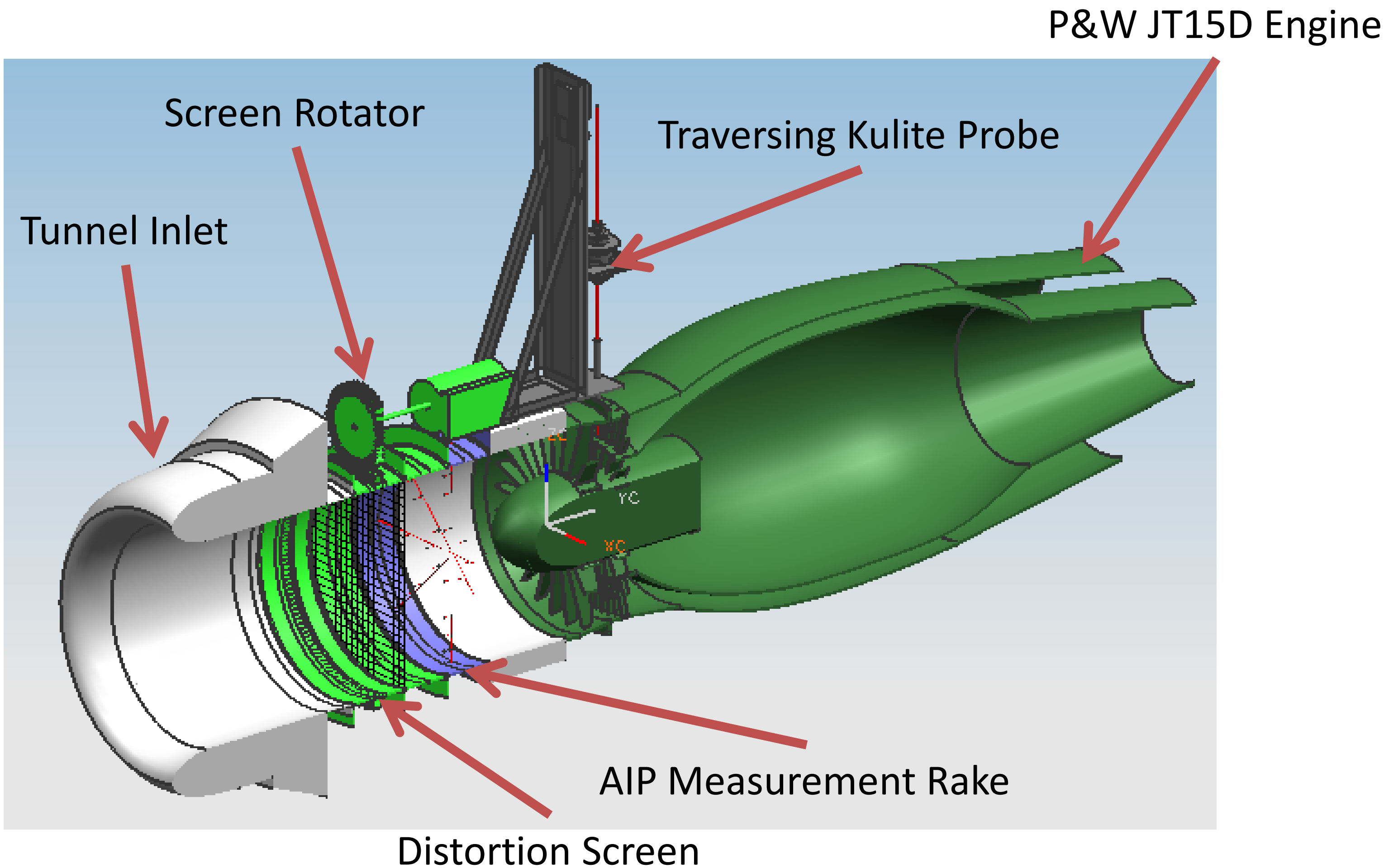


Fan OGVs

AIP Measurement Rake

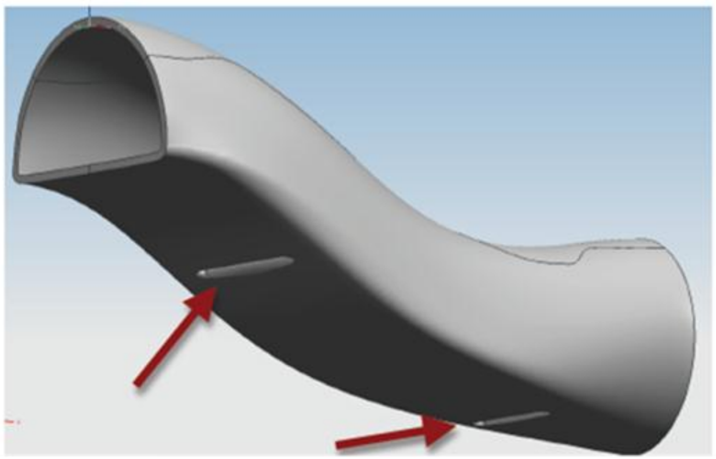
P&W JT5D Fan

Distorted Inlet Experiment

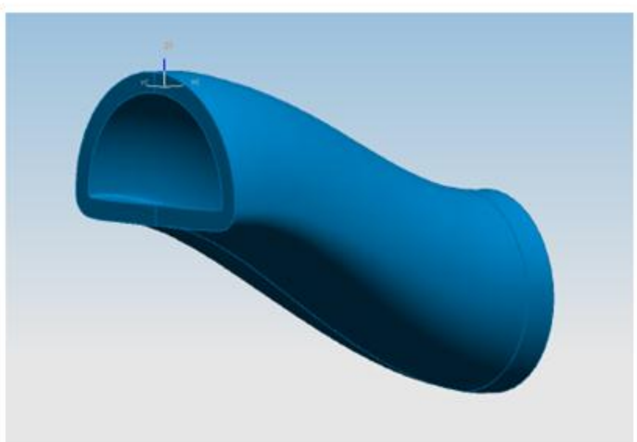


Typical Serpentine Inlet Distortion Patterns

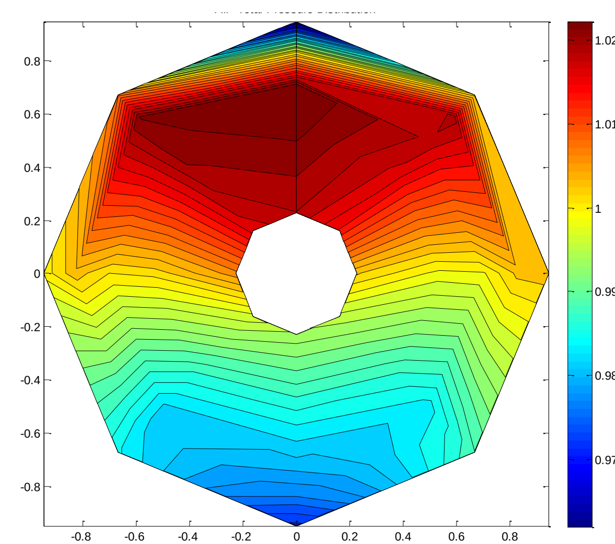
Measured S-Duct distortions

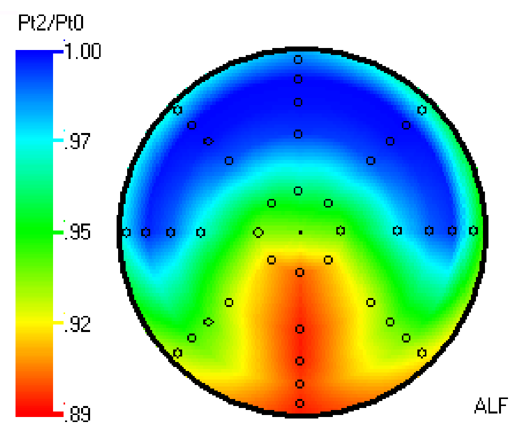


CAD model of UTRC BLI S-Duct



CAD model of NASA BLI S-Duct



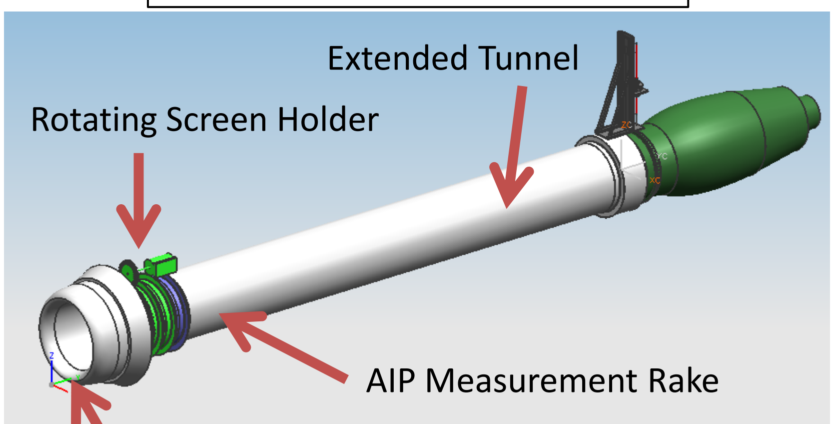


Ref. -Ferrar et. al. “Active Control of Flow in Serpentine Inlets for Blended Wing-Body Aircraft” AIAA-2009-4901

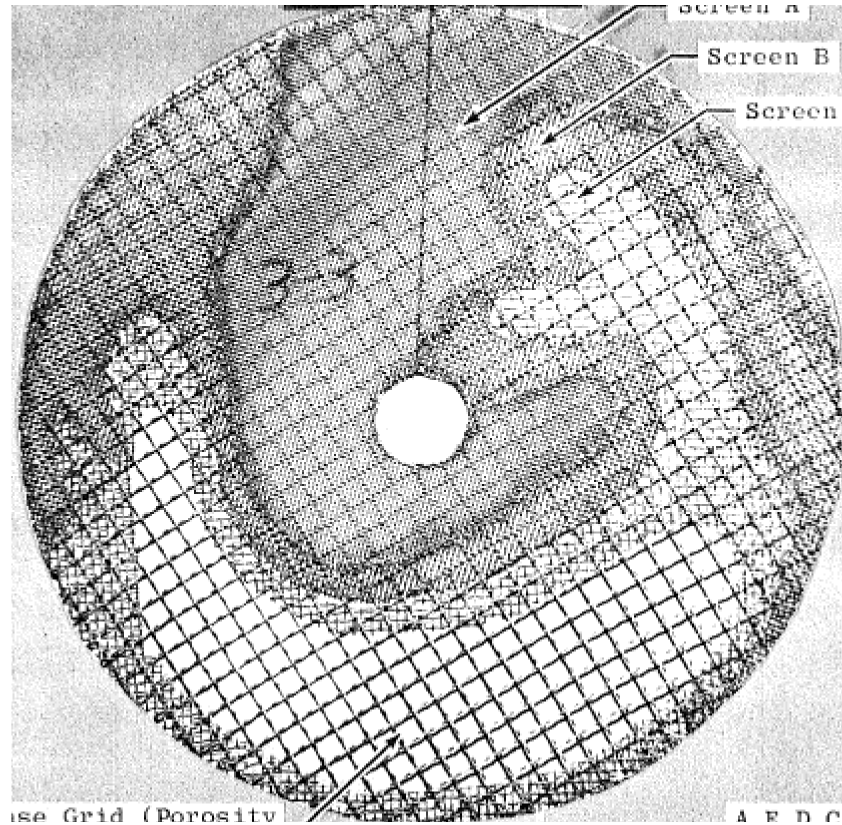
Screen Construction and Calibration Method

- Single-layer screen consisting of varying density sections with supporting grid
    - Performance of multi-layer screens is difficult to predict
- Each screen section is welded to adjacent sections

Screen Calibration Tunnel



Tunnel Inlet



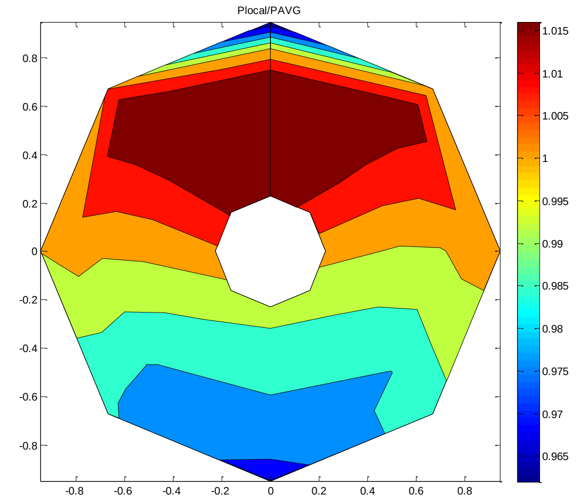
Ref. –Overall, B. W., 'A Procedure for the design of complex distortion screen patterns for producing specified steady-state total pressure profiles at the inlet of turbine engines," AEDC-TR-72-10, 1972

Screen Design Methodology

- Uses a pattern of varying density screens to generate desired P_0 profile
- Iterative development process:
  - Compute ideal screen design
  - Measure profile created by screen and compare to desired profile
  - Iterate on screen design until desired profile is achieved

Design Method Details:

1. Contour plot of desired profile determines outline of each screen section
2. Porosity of each screen section is determined using mass flow and desired P_0 to compute required area blockage
3. Construct screen as a single-layer, supported by a backing grid



Sample profile contour plot

AIP Steady P_0 Measurement System

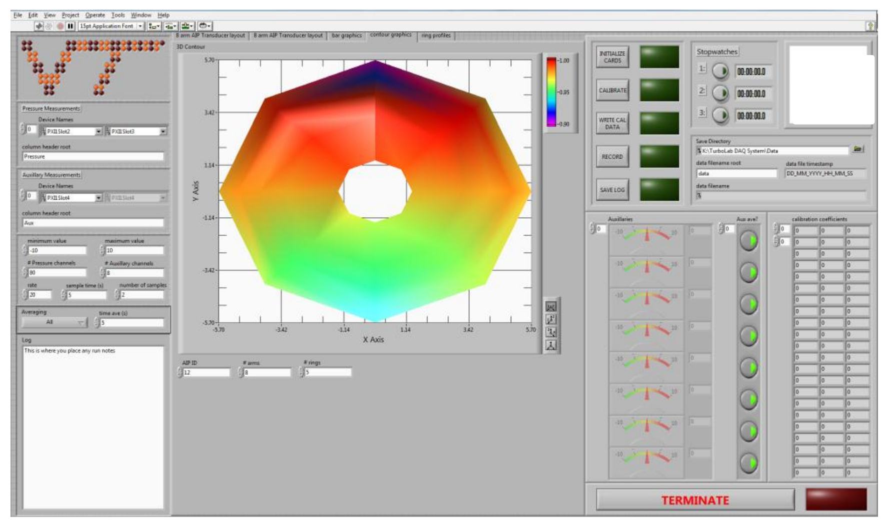
Experiment
- -60 probe AIP rake
- -Various static taps

(80x) Omega PX139
- -5psi transducers

NI-SCB68 Pin Block

NI-PXI 6225 DAQ
- -40 Differential Channels
- -16-bit, 250 kS/s

NI LabView VI

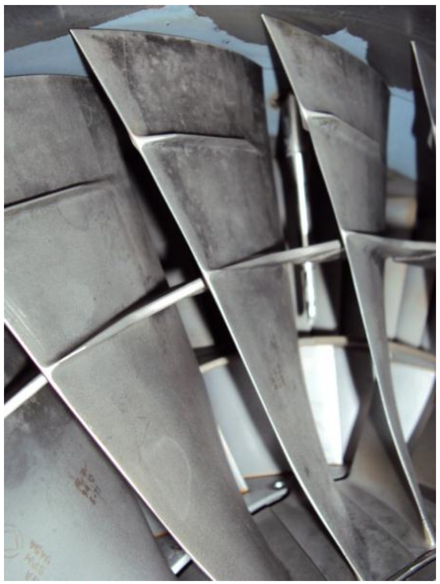


AIP Rake in JT15D Engine

- 60 Probe pressure rake currently installed on VT P&W JT15D
- Installed in Nov. 2010 and has successfully completed 7 engine runs up to full speed

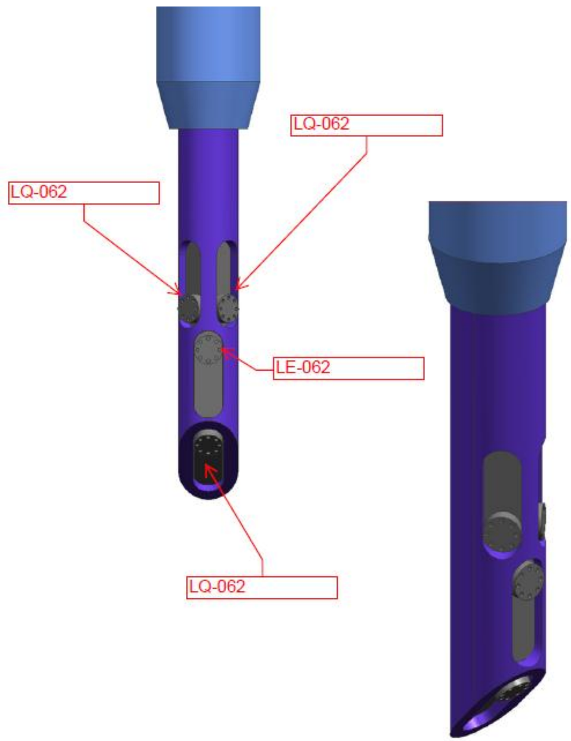
High-Response Kulite P_0 Measurement System

Experiment
-JT15D Fan



Eddy Current Sensor and optical key-phasor

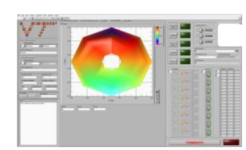
Kulite Total Pressure Probe
-(1x) Kulite LE-062
-(3x) Kulite LQ-062



NI-SCB68 Pin Block

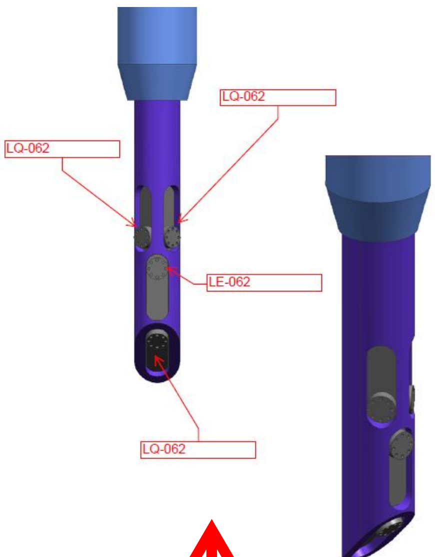
NI-PXI 6254 DAQ
- 1 MS/s, 16-bit
- 16 differential ch.

NI LabView VI

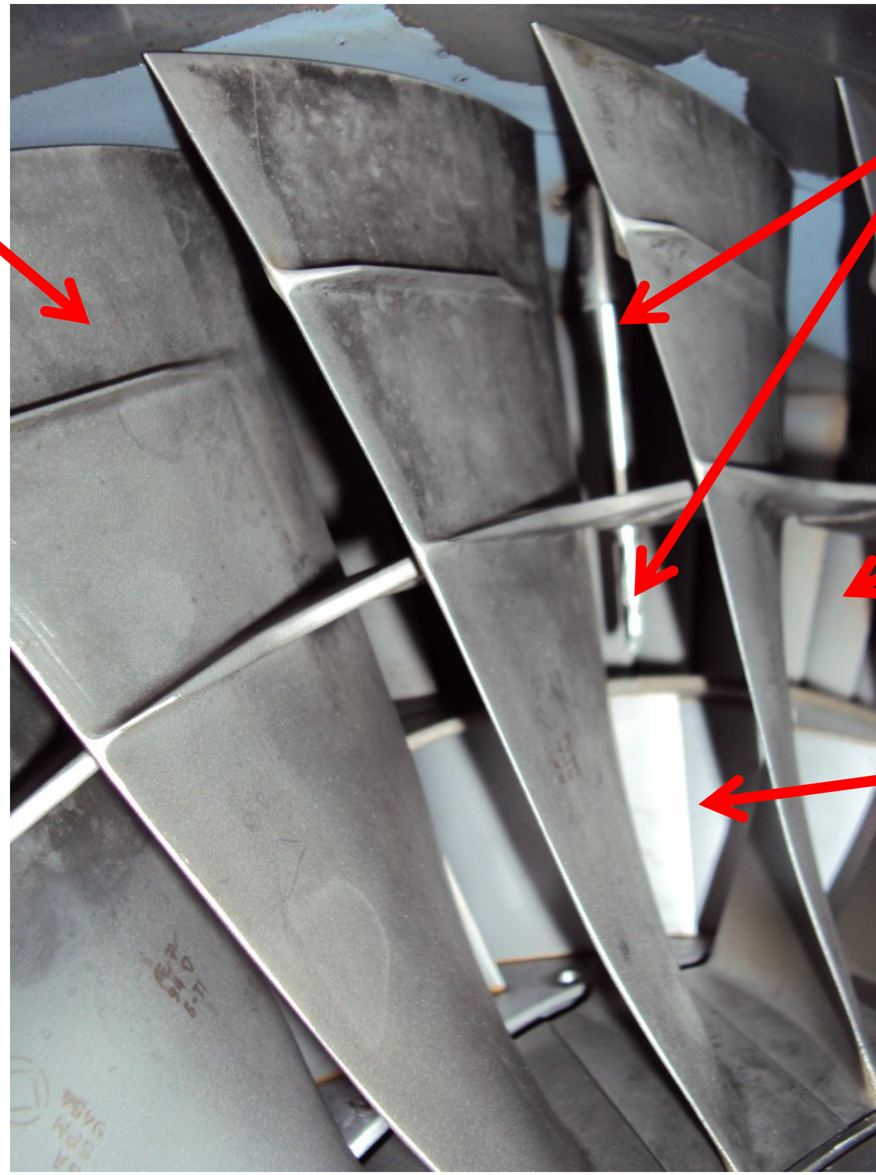


High Response Total Pressure Probe Behind Fan

JT15-D Fan



Kulite Probe Detail



Kulite Probe

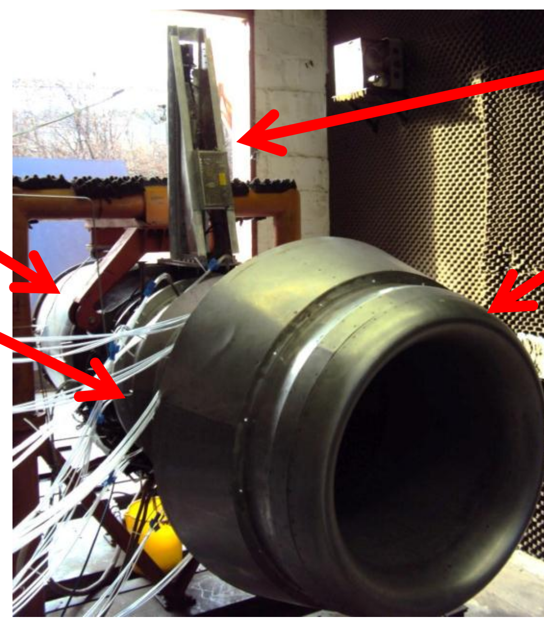
Fan Bypass OGV

Fan Core OGV

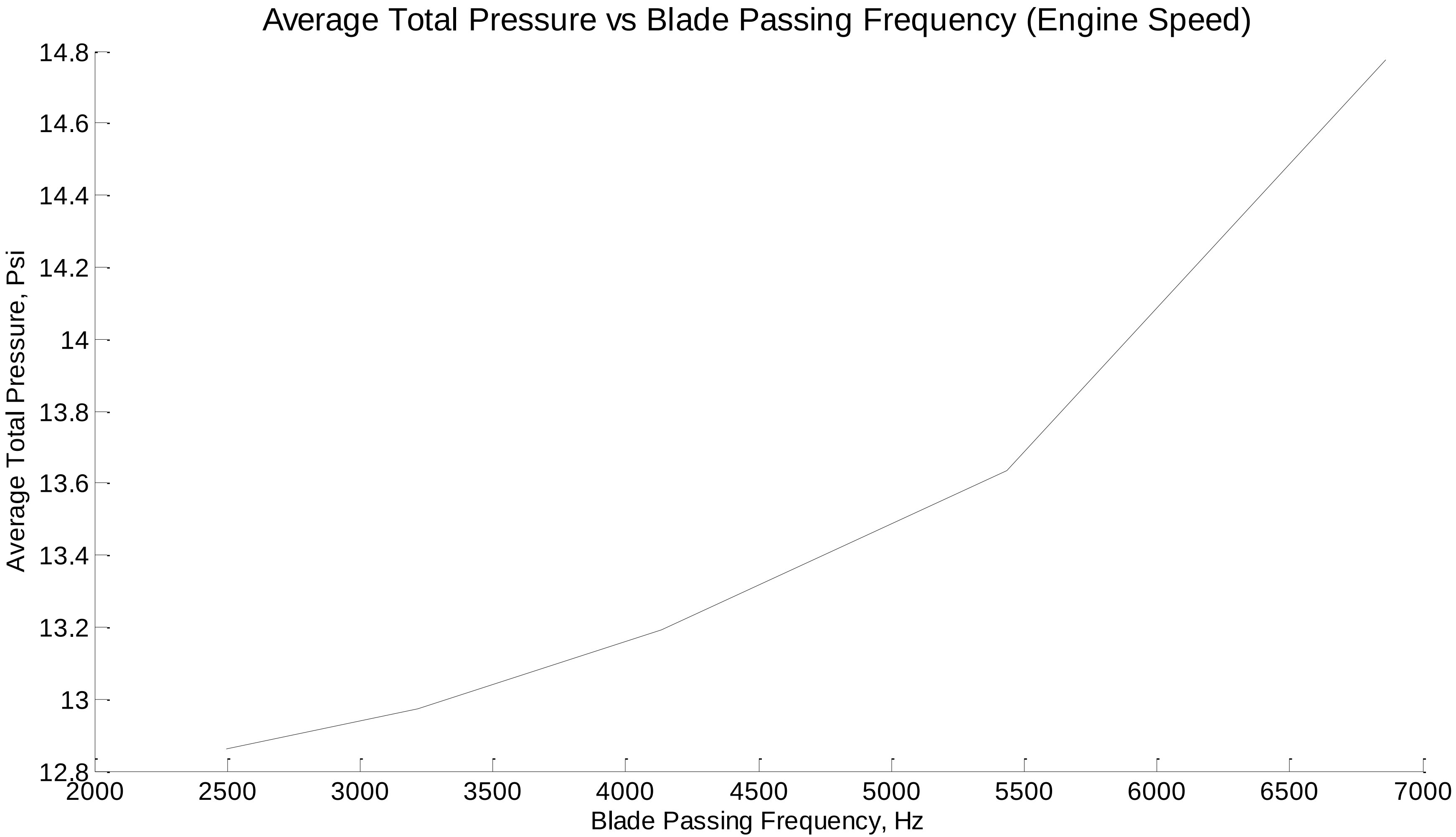
Preliminary High Response Flow Measurements

Test Cases

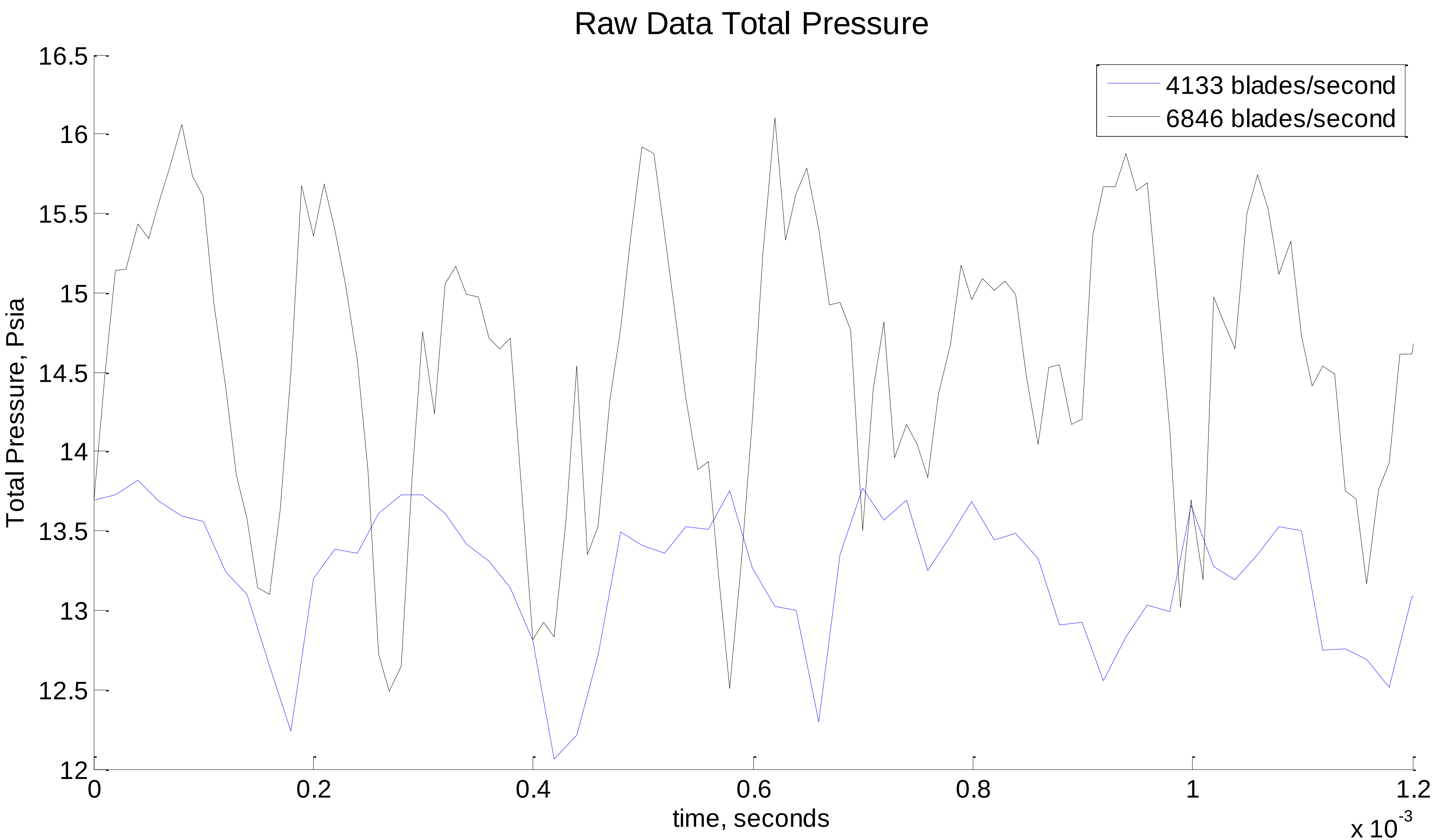
Fan Speed (% of maximum)	Blade Passing Frequency (Hz)	Sample Frequency (Hz)	Samples Per Blade Passing
34%	2495	50000	20.0401
43%	3216	50000	15.5473
55%	4133	50000	12.0977
72%	5435	50000	9.1996
92%	6863	50000	7.2854
92%	6846	100000	14.6071



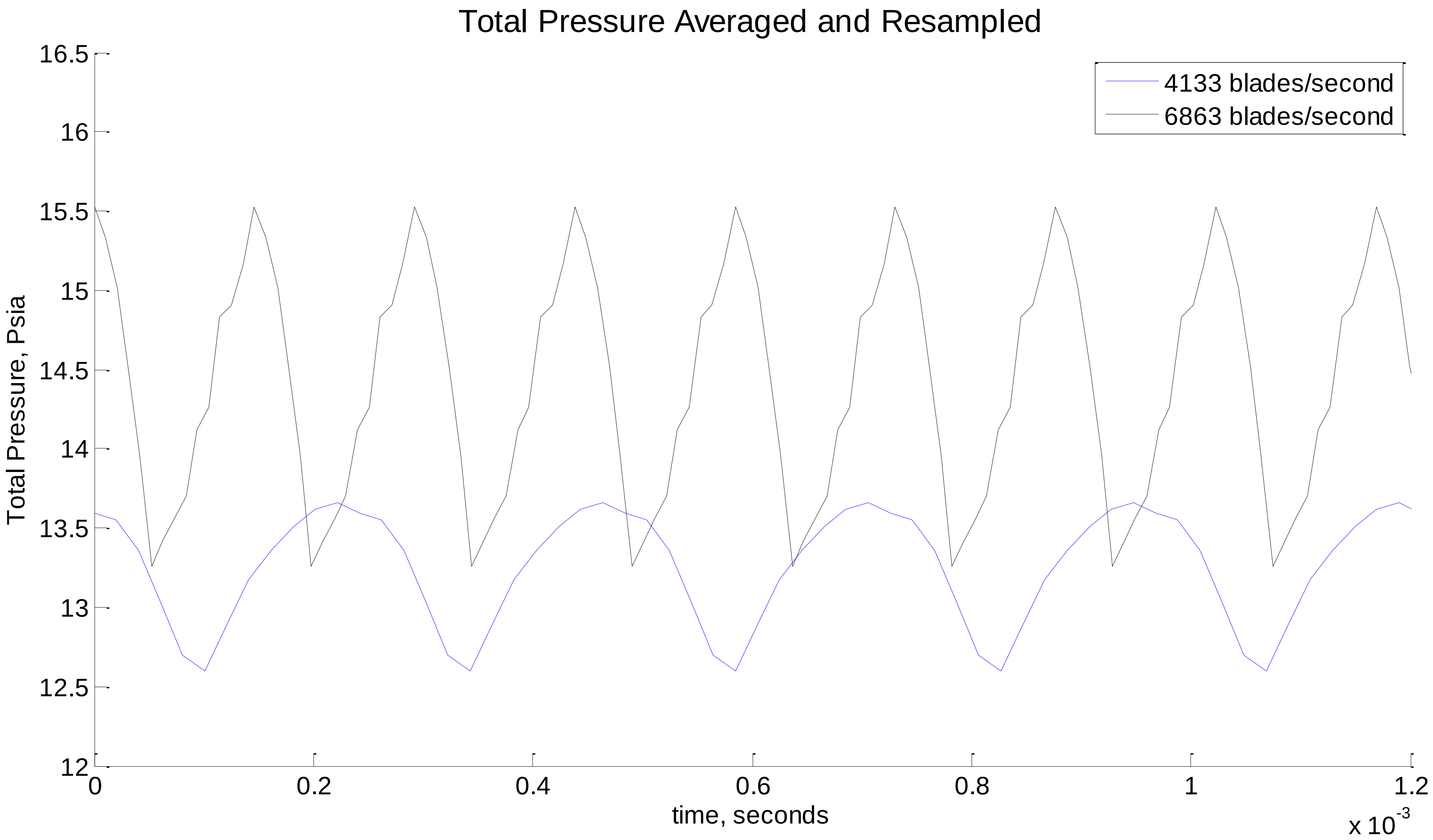
Average Total Pressure Measurements



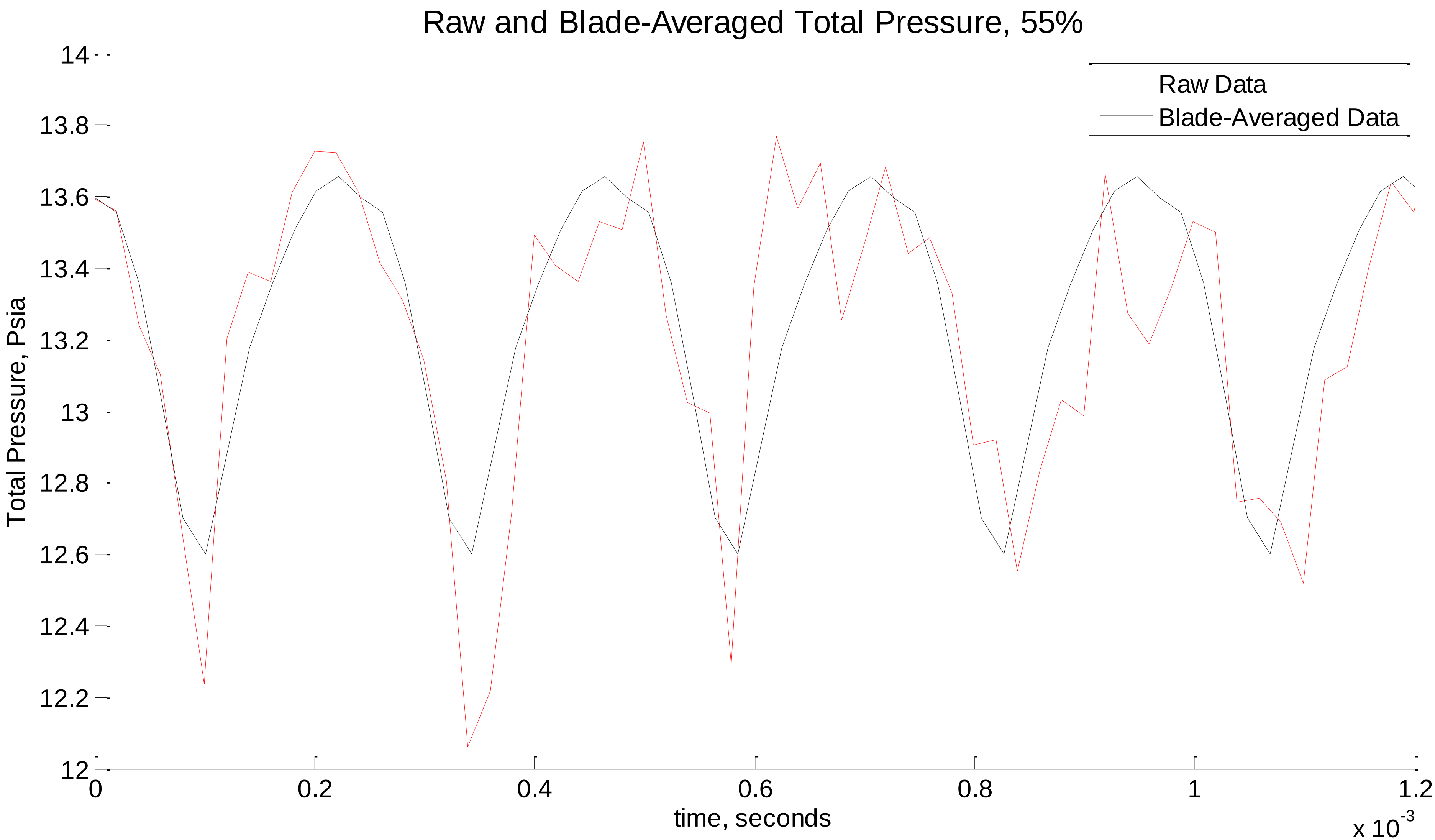
Dynamic Pressure Measurements



Dynamic Pressure Measurements

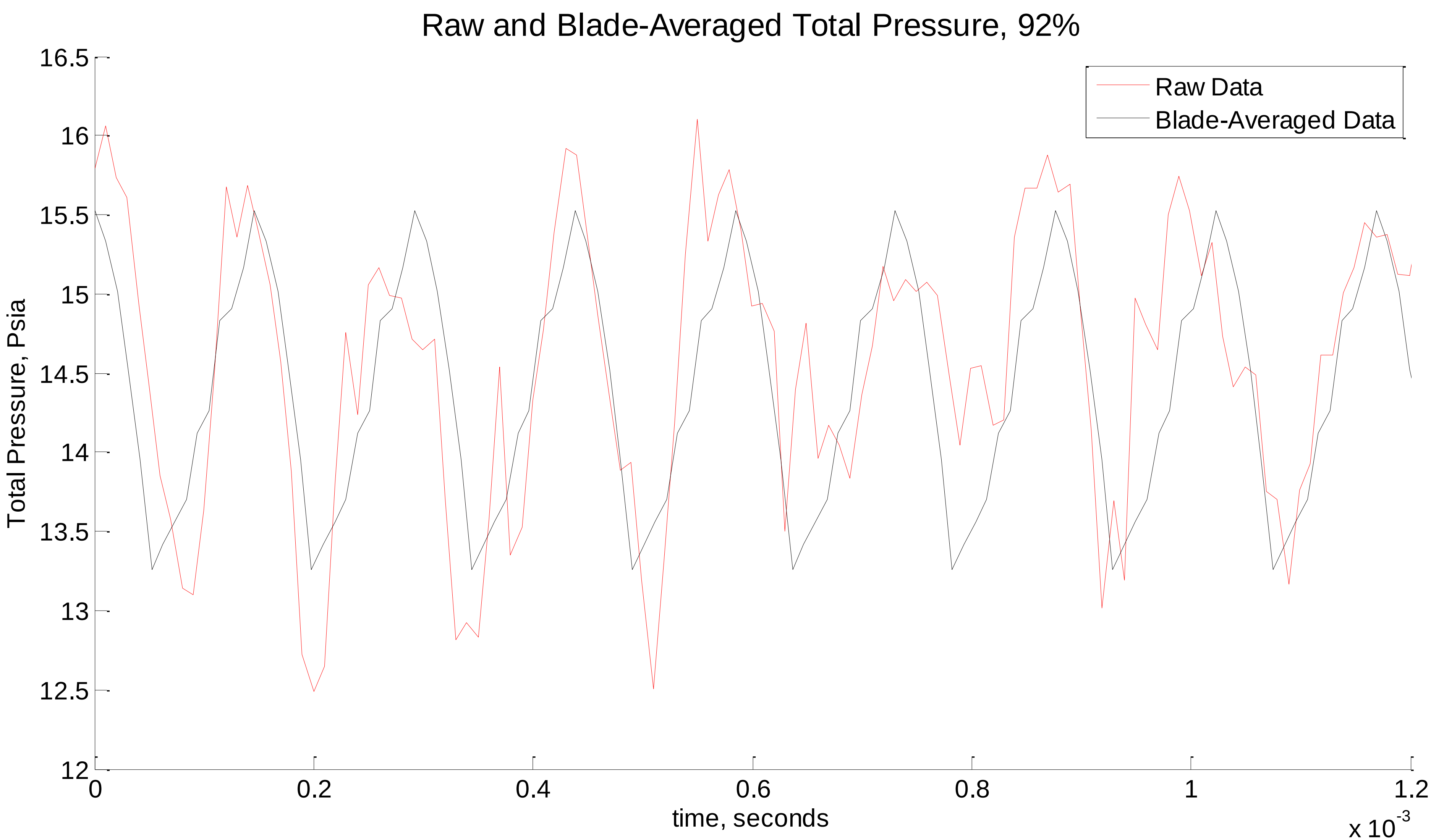


Dynamic Pressure Measurements



4133 Blades per second

Dynamic Pressure Measurements



6863 Blades per second

Progress and Future Plans

- Clean Inlet Test
  - → Inlet
  - → AIP rake
  - → JT15D engine
  - → Traversing high-response total pressure probe
    - → Kulite Transducers

- Screen Development
  - → Extended wind tunnel
  - → Design/Construct screen
  - – Measure screen performance
  - – Modify screen

- Distorted Inlet Test
  - – Screen close to fan
  - – AIP rake
  - – JT15D engine
  - – Traversing high-response total pressure probe

- Data processing

Summary

- Research Program is on track to provide new insights into fan response to distorted inflows as produced by BLI inlets
- Supports UTRC and NASA efforts in distortion-tolerant fan design and tests.