National Aeronautics and Space Administration

The Aerodynamic Performance of an Over-the-Rotor Liner with Circumferential Grooves on a High Bypass Ratio Turbofan Rotor

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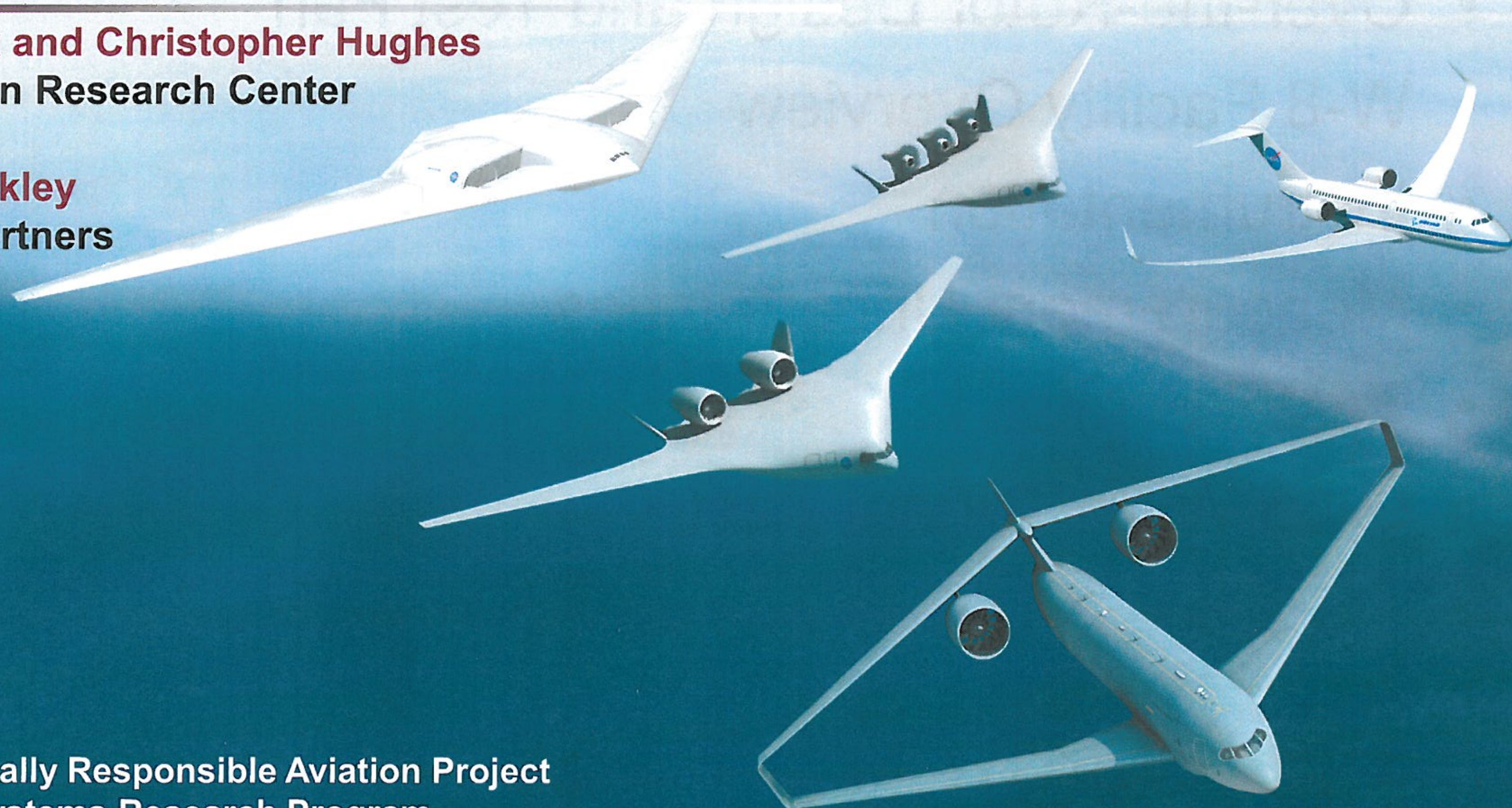
James Buckley
Vantage Partners



Environmentally Responsible Aviation Project
Integrated Systems Research Program

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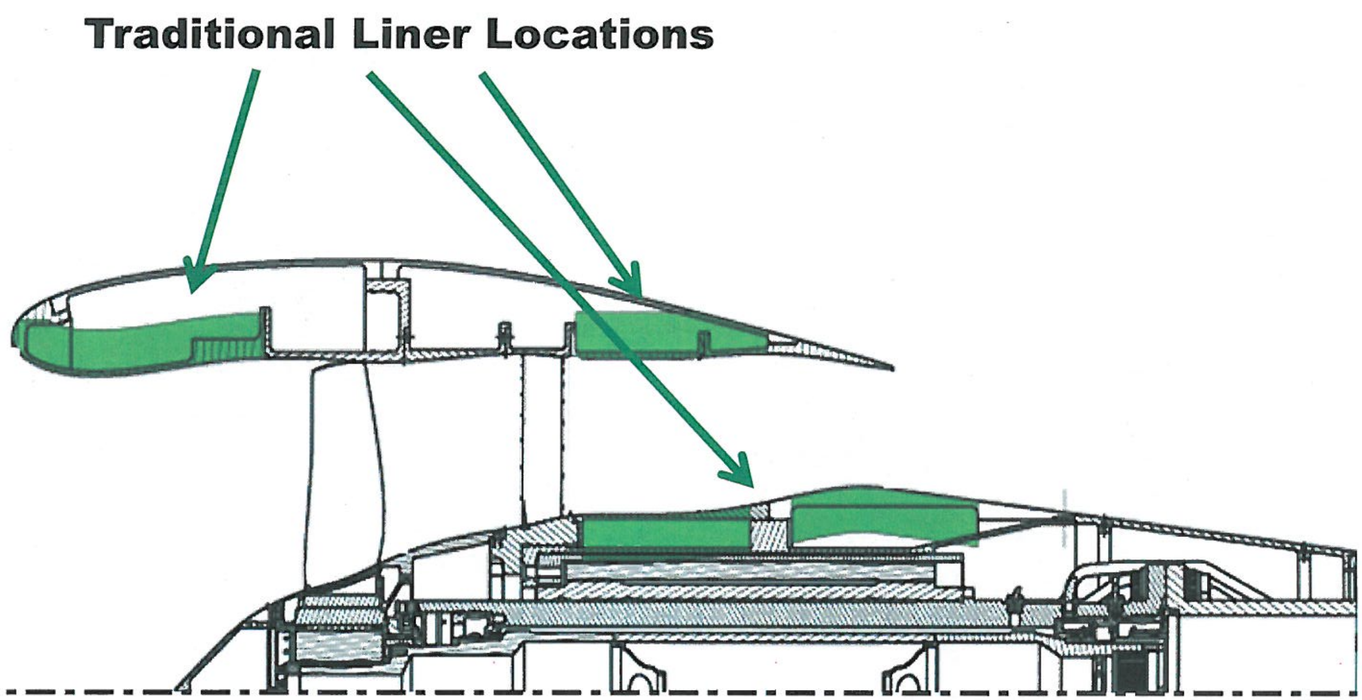
Outline

- Over-the-Rotor Treatment Development at NASA
- Over-the-Rotor Design and Test Fan
- W-8 Facility Overview
- Instrumentation
- Measurement Uncertainties
- Test Results
- 9x15 Wind Tunnel Test

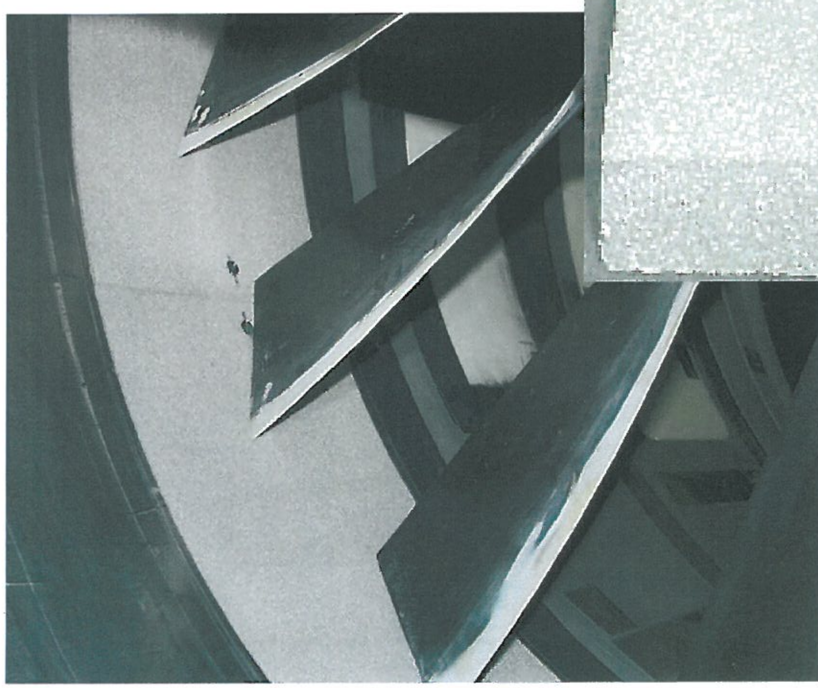
Over-the-Rotor Acoustic Treatments

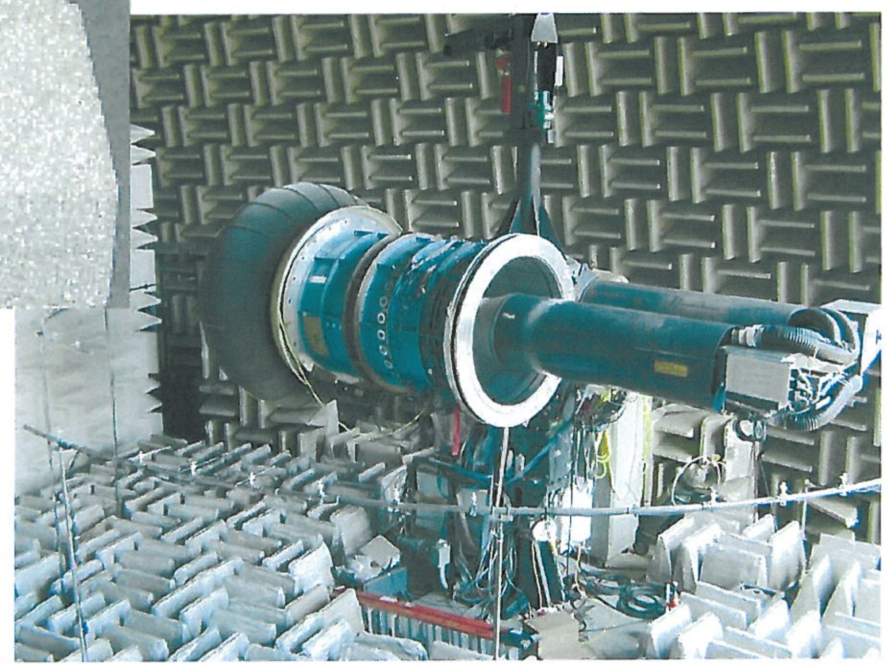


Foam Metal Over-the-Rotor Liner on a Low Speed Fan

Sutliff and Jones, AIAA 2008-2897

- A foam metal liner was installed directly over-the-rotor as well as about a chord forward and aft of the rotor.
- Up to 4dB of broadband attenuation was achieved.
- The liner altered the tip flow and increased the size and strength of the rotor tip vortex.
- Fan performance cannot be evaluated on this low speed fan.



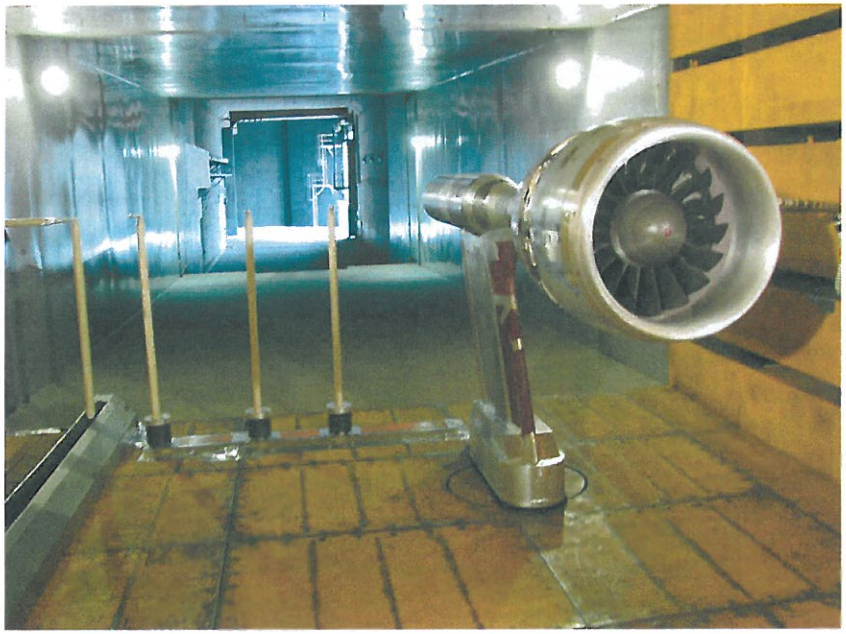


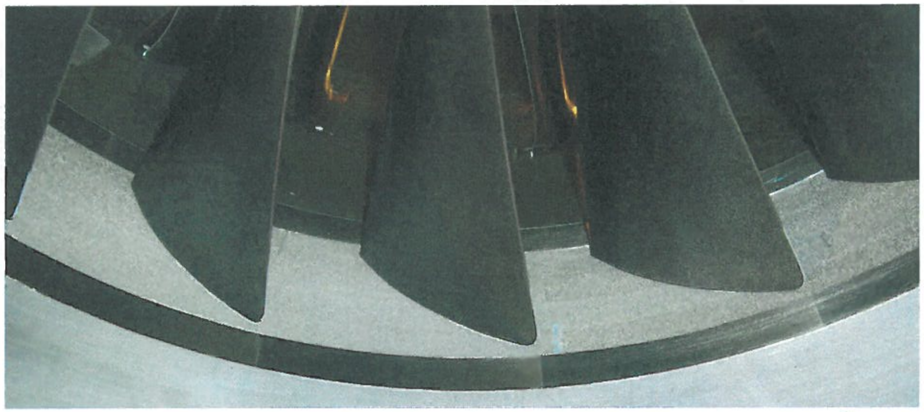
The Advanced Ducted Propulsor Test in the 9x15 Wind Tunnel

Elliott, Woodward, and Podboy, AIAA 2009-3140

Hughes and Gazzaniga, AIAA 2009-3139

- A foam metal liner was installed directly over-the-rotor and behind a perforated sheet.
- The broadband noise reduction resulted in a 1 dB reduction in overall acoustic power level.
- The treatment caused a 3.75% to 8.75% loss in efficiency compared to a hardwall baseline case.
- The composite fan blades were damaged by pressure fluctuations through the perforated plated.

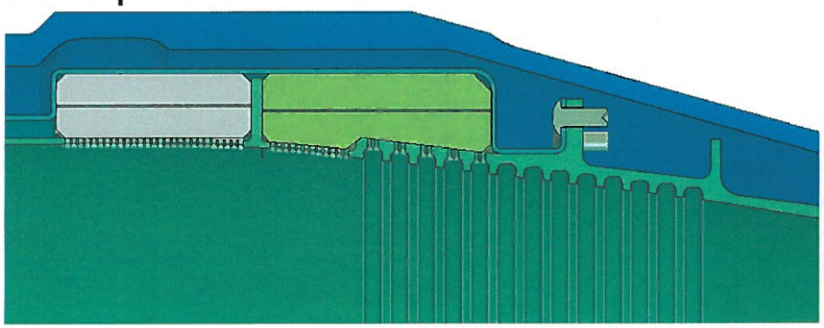


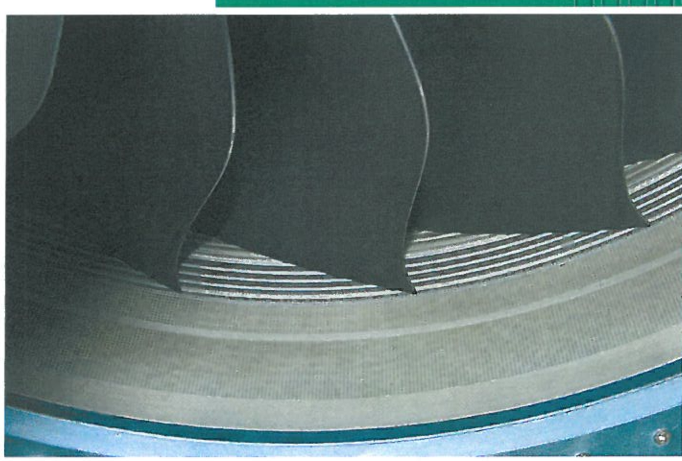


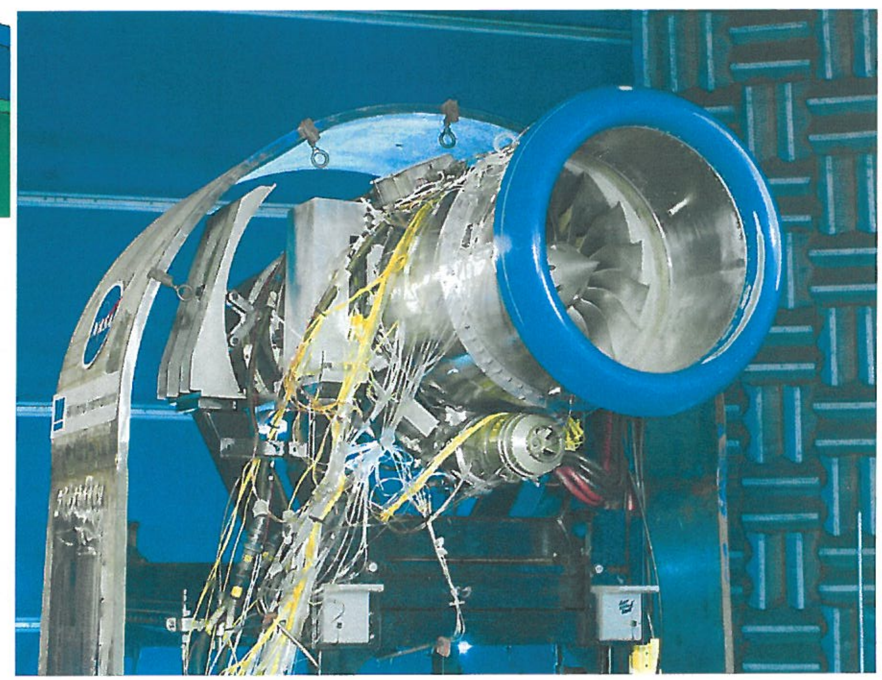
Williams International FJ44-3A Static Engine Test

Sutliff, Elliott, Jones and Hartley, AIAA 2009-3141

- Foam metal liner was installed behind a perforated plate in the inlet
- The over-the-rotor section covered the forward 1/3 of the blade chord and was installed behind circumferential grooves.
- 5dB inlet acoustic power level attenuation (2.5dB overall)
- Up to a 2% loss in performance
- Acoustic performance was reduced at sonic tip speeds



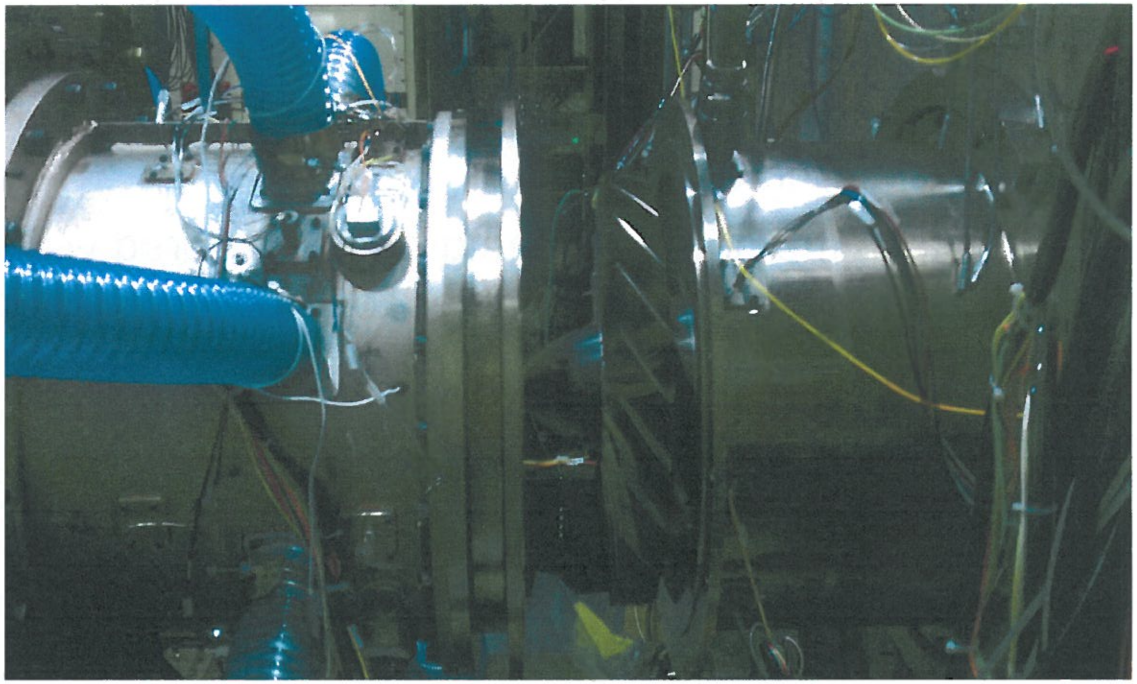




Source Diagnostic Test Hardware

- The Source Diagnostic Test hardware was tested in a rotor alone configuration in the 9x15 wind tunnel and the W-8 Single Stage Axial Compressor Facility in the early 2000's
- R4 Fan: 22 blades
- 12,657 RPMc design speed and pressure ratio of 1.5
- Testing at part speed was used to simulate a lower pressure ratio fan at subsonic tip Mach numbers.

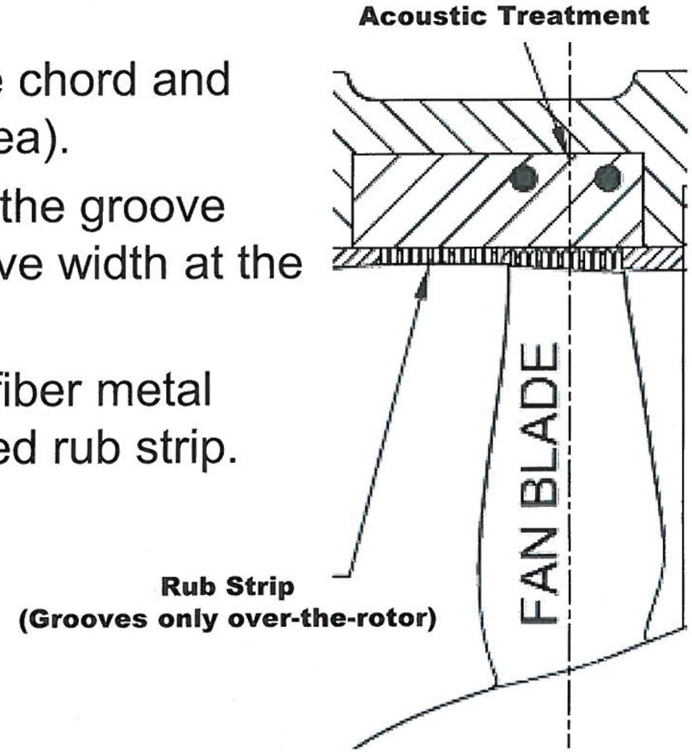
% Design Speed	RPM_c	Nominal Mass Flow, lb_c/sec
50.0%	6329	46.8
61.7%	7809	57.7
65.0%	8227	60.9
70.0%	8860	65.8
77.5%	9809	73.2
87.5%	11075	83.6



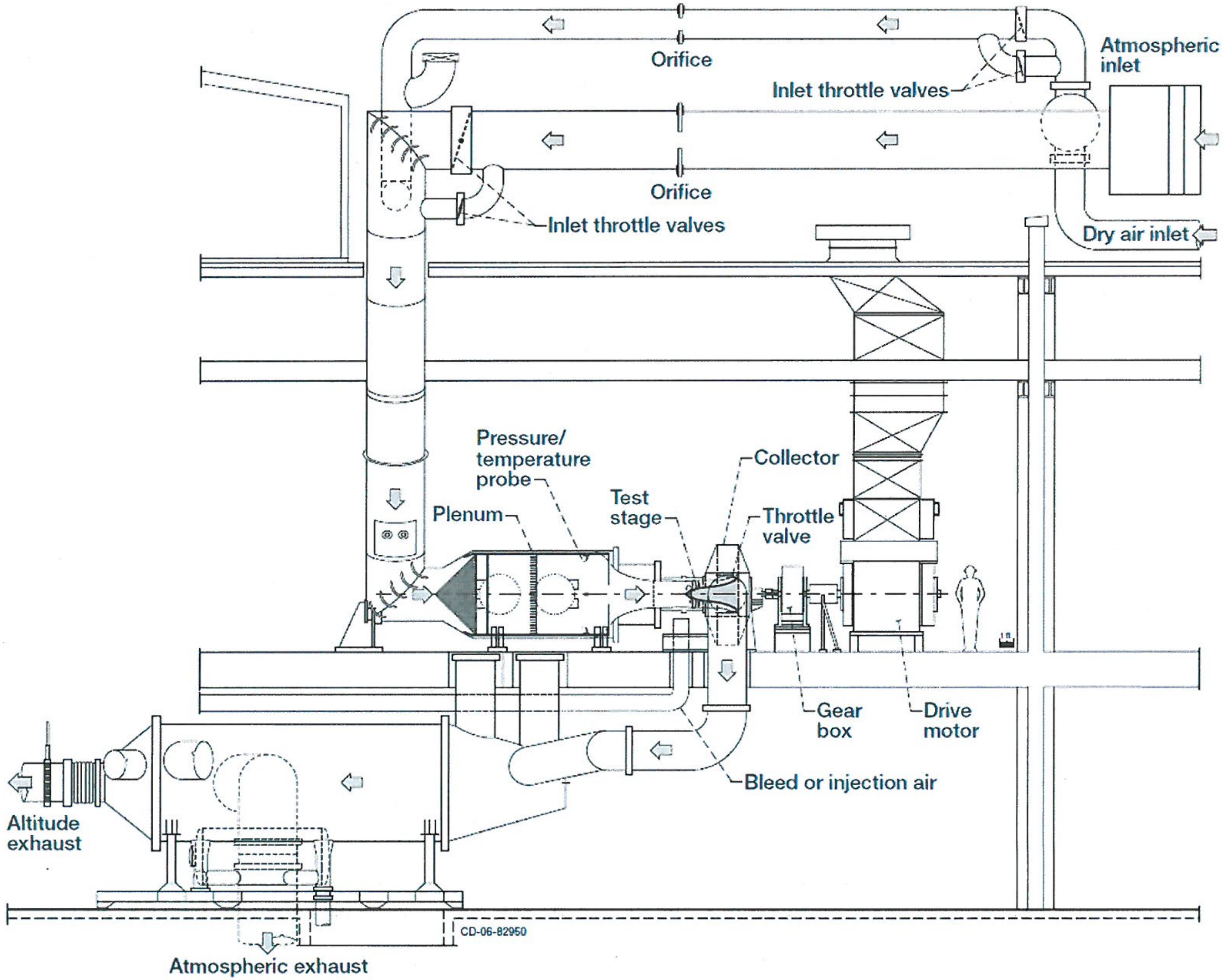
Over-the-Rotor Liner Design

- Acoustic design by Mike Jones (NASA Langley Research Center)
- Aerodynamic design by Dan Tweedt (AP Solutions)
- Hardware design by Jim Buckley (Vantage Partners)

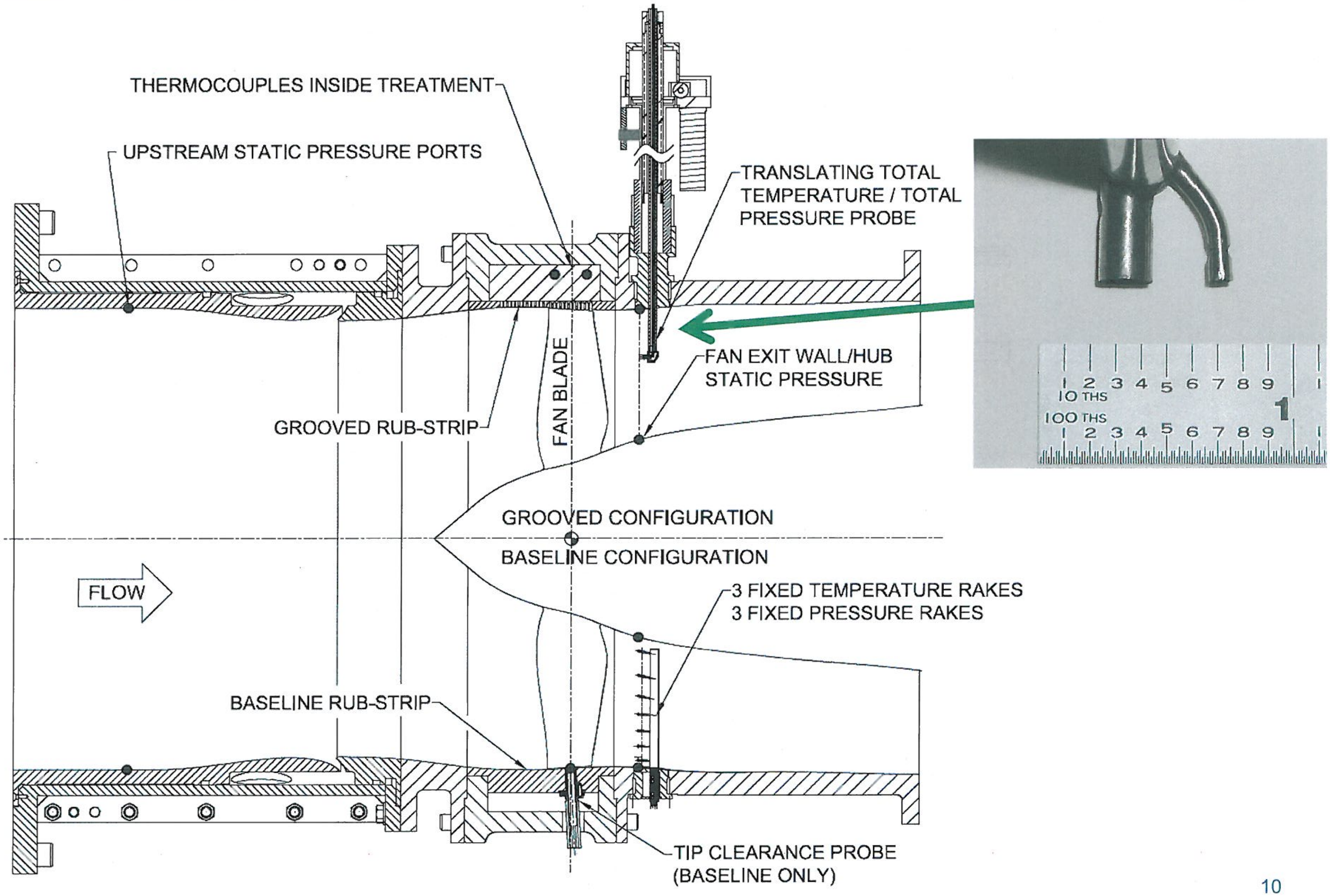
- The circumferential grooves cover the entire blade chord and have about 67% open area (groove width/ total area).
- The depth of the grooves vary from about 2 times the groove width at the rotor leading edge to 3 times the groove width at the rotor trailing edge.
- Slots in the bottom of the grooves covered with a fiber metal screen allow acoustic waves to through the grooved rub strip.



W-8: Single-Stage Axial Compressor Facility

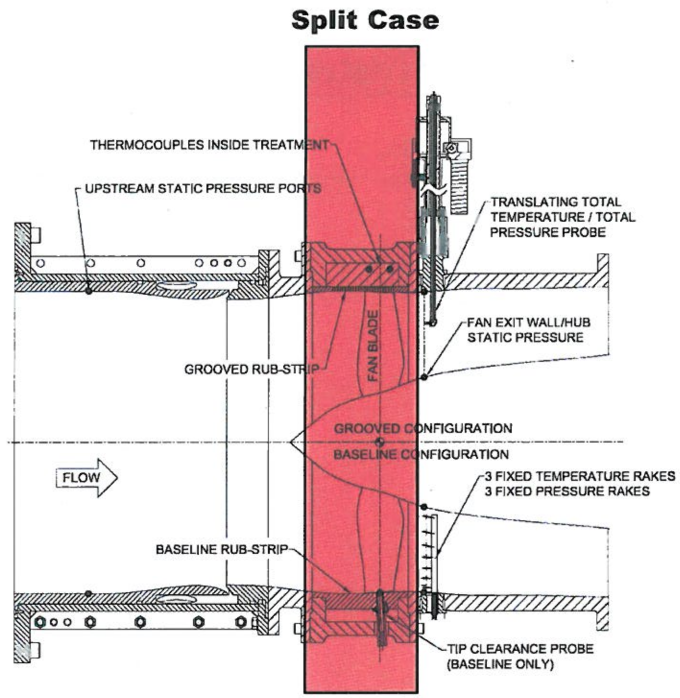


Test Hardware and Instrumentation



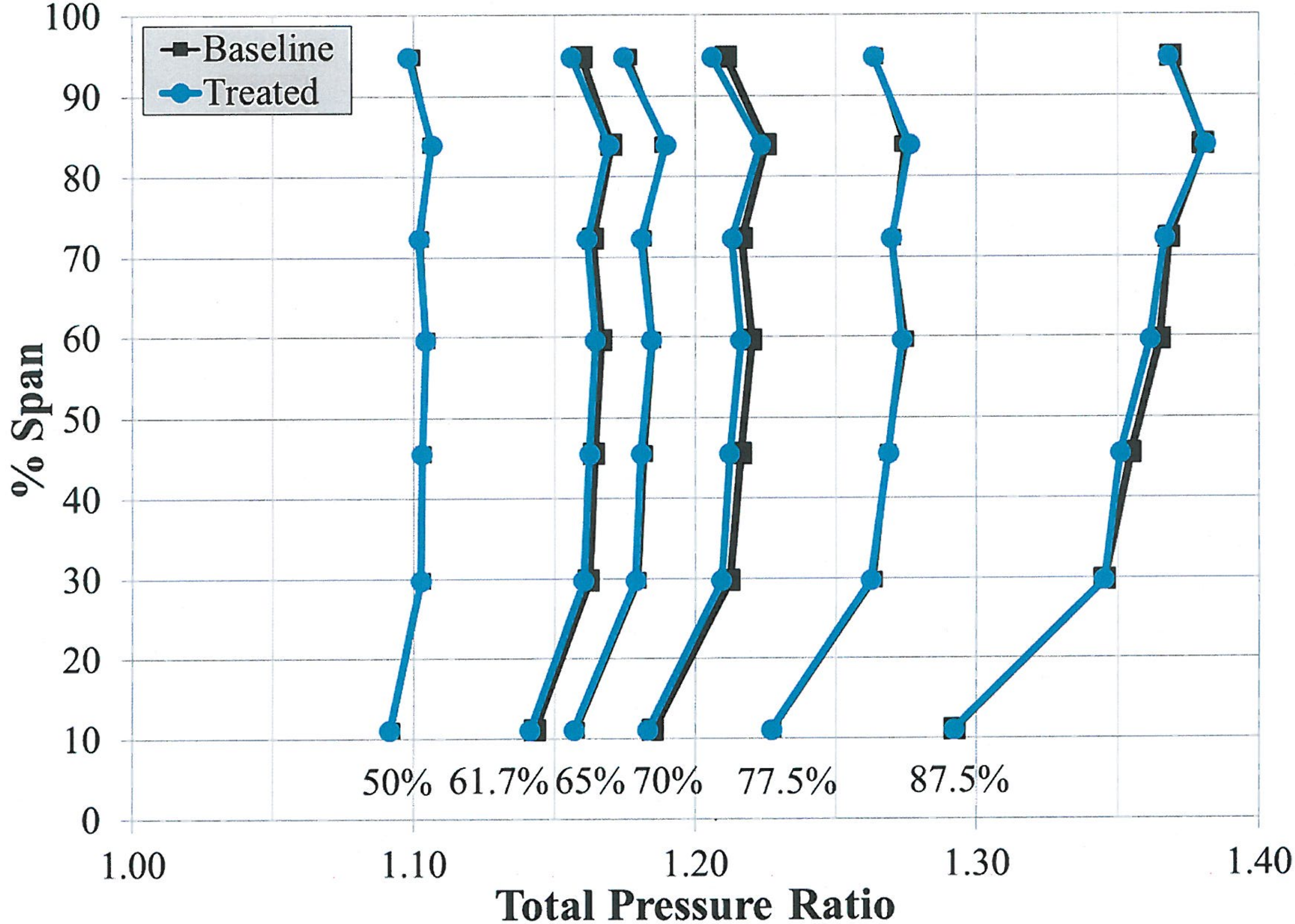
Measurement Uncertainties

- When the desired result is a Δ between two configurations, bias errors can be minimized by reducing the differences between the two configurations.
- Precision errors, some bias errors, and nonlinear errors cannot be reduced.
- The remaining errors could only be estimated from the experimental results.

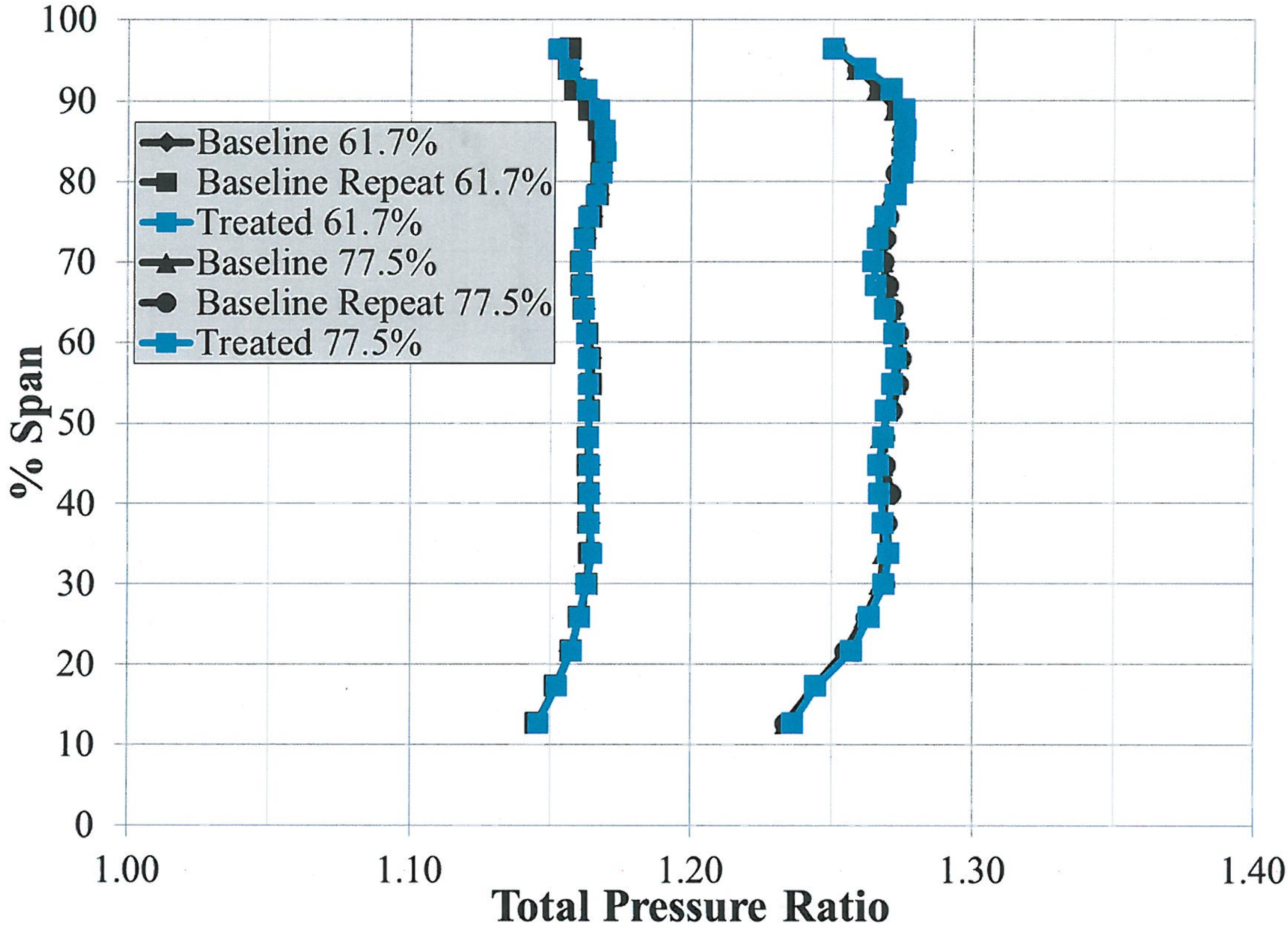


		Fan Total Pressure Ratio (PR) Relative Errors		Fan Total Temperature Ratio (TR) Relative Errors		Fan Adiabatic Efficiency (FAE) Relative Errors	
% Design Speed	RPM_c	Absolute Uncertainty, %	Repeatability, %	Absolute Uncertainty, %	Repeatability, %	Absolute Uncertainty, %	Repeatability, %
61.7%	7809	±0.52	±0.04	±16.0	±0.03	±13.9	±0.77
77.5%	9809	±0.31	±0.06	±10.7	±0.04	±8.9	±0.65
87.5%	11075	±0.23	±0.11	±8.4	±0.07	±7.2	±0.60

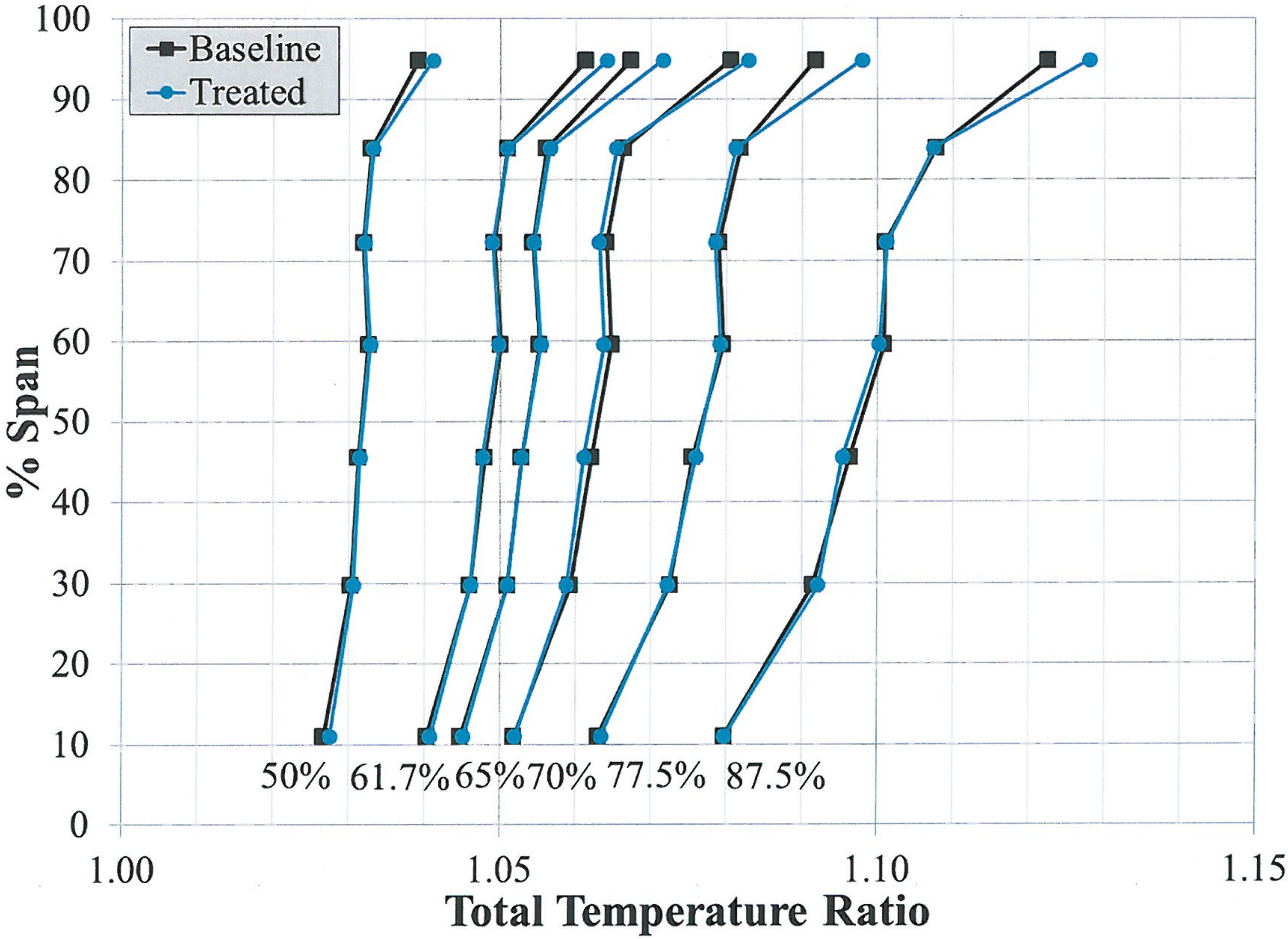
Rake Averaged Fan Pressure Ratio



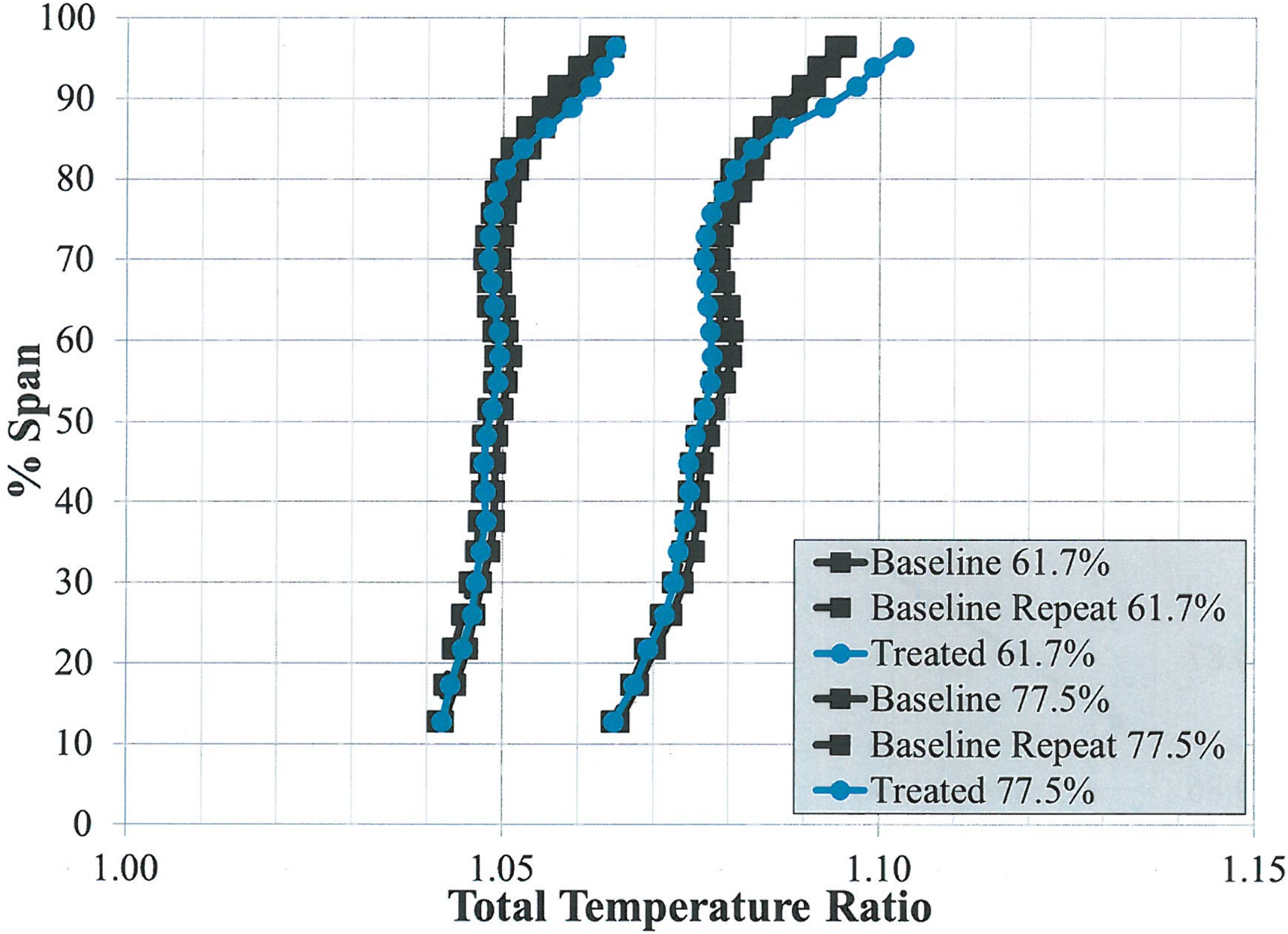
Total Pressure Probe Survey



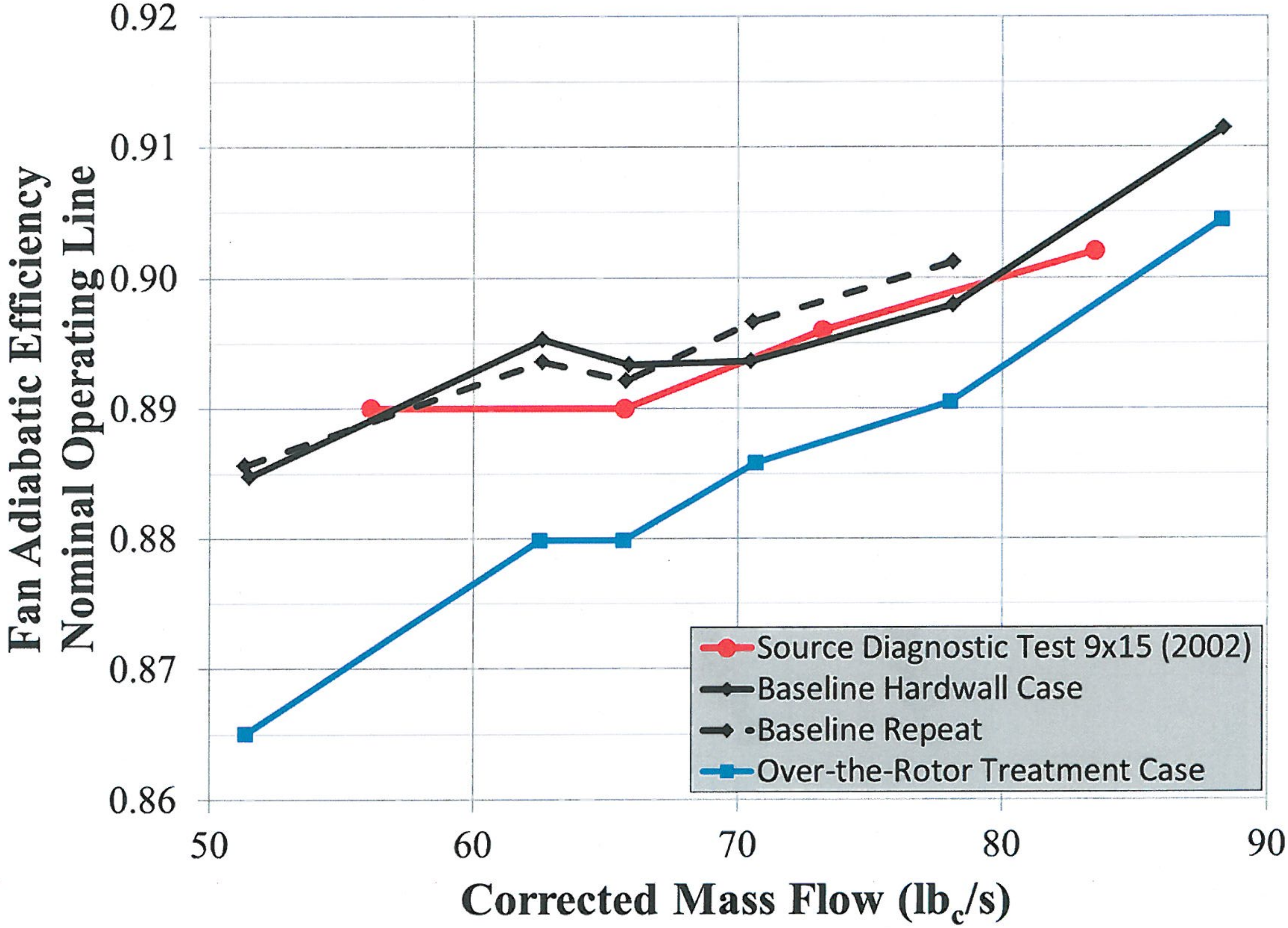
Rake Averaged Fan Temperature Ratio



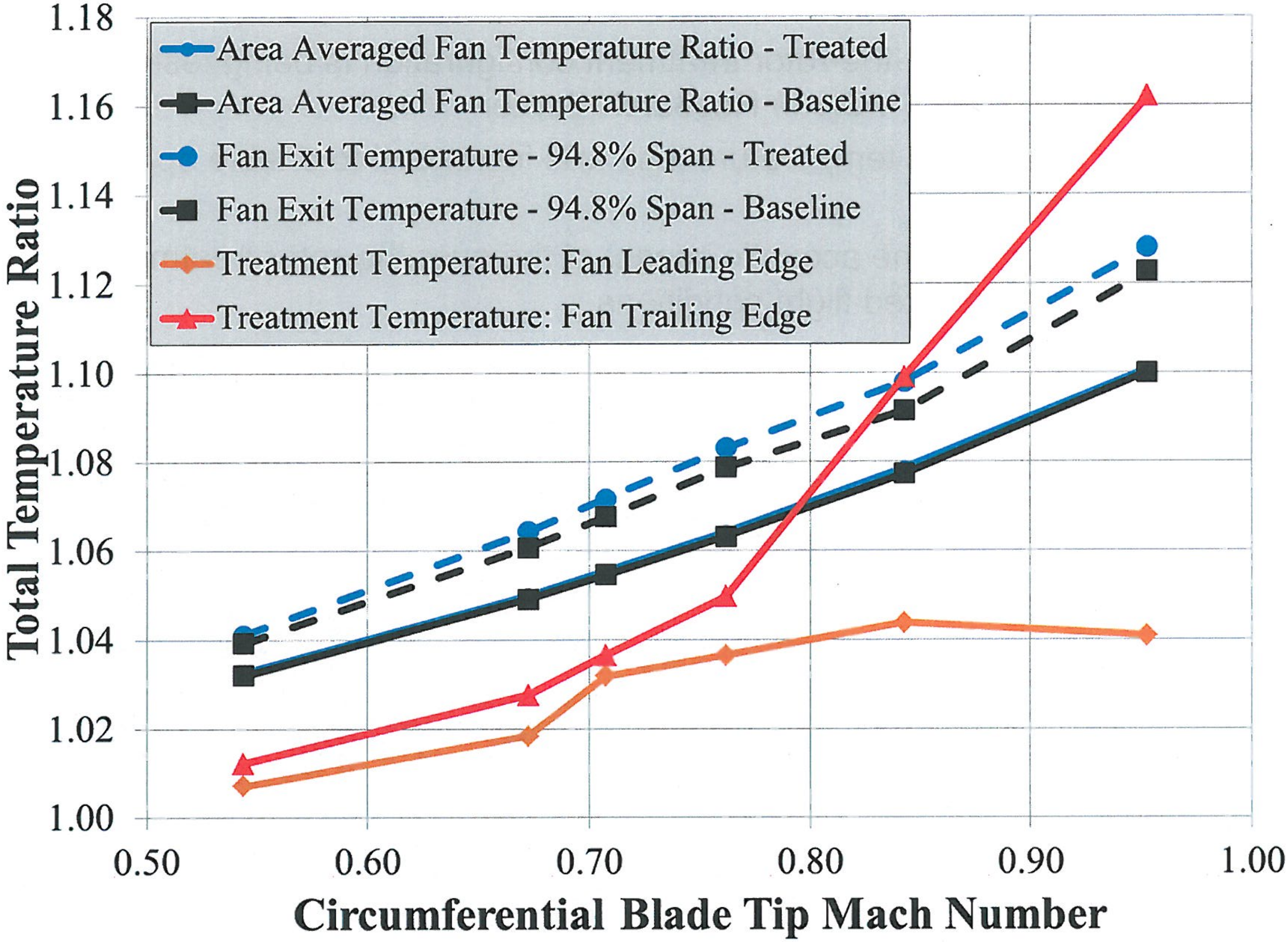
Total Temperature Probe Survey



Fan Adiabatic Efficiency (Nominal Operating Line)

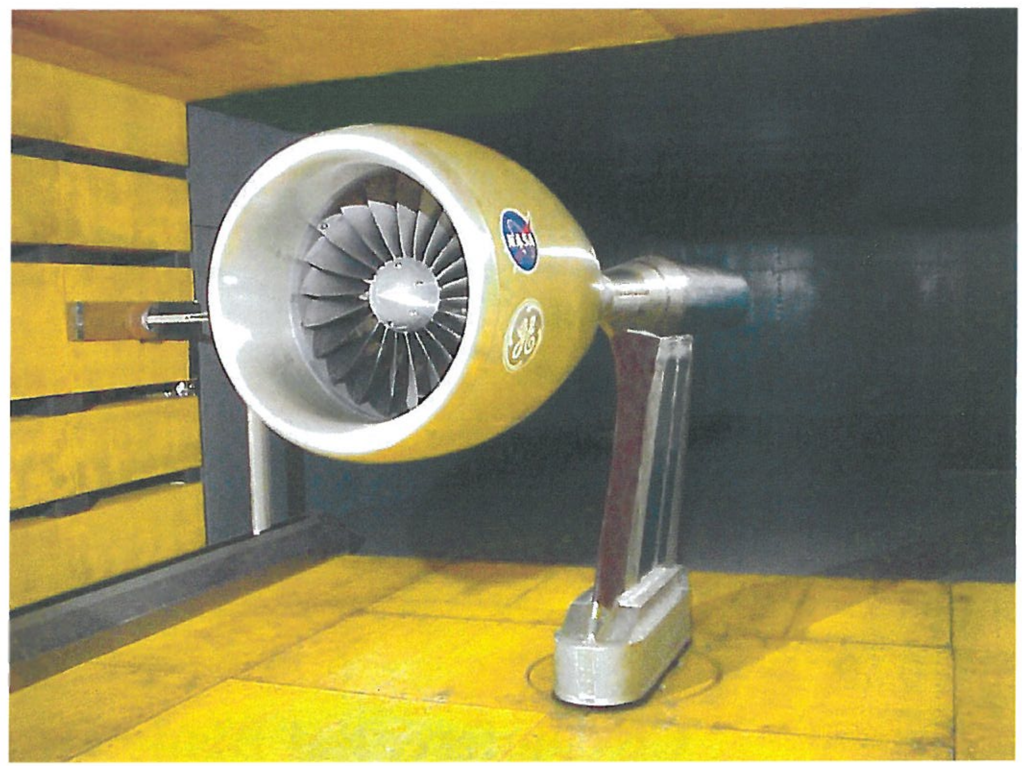


Acoustic Treatment Temperatures



9x15 Wind Tunnel Test

- Currently, the same over-the-rotor treatment configuration is being tested in the 9x15 wind tunnel at NASA Glenn Research Center
- The acoustic treatment's temperature limit was increased to enable operation at higher fan speeds.
- The efficiency loss and the acoustic impact of the over-the-rotor treatment will be determined at simulated flight conditions.



Summary

- An over-the-rotor acoustic treatment concept was designed and tested in the W-8 Single Stage Axial Compressor Facility.
- No significant change in pressure ratio was seen, but an increase in temperature near the blade tips was seen.
- The performance loss due to the over-the-rotor treatment, in terms of fan adiabatic efficiency, varied from 0.75% to 2% over the range of conditions tested.
- When the fan tip speed approached sonic conditions, the acoustic treatment temperature increased dramatically.
- The efficiency loss and the acoustic impact of the over-the-rotor treatment will be determined at simulated flight conditions in the 9x15 wind tunnel.