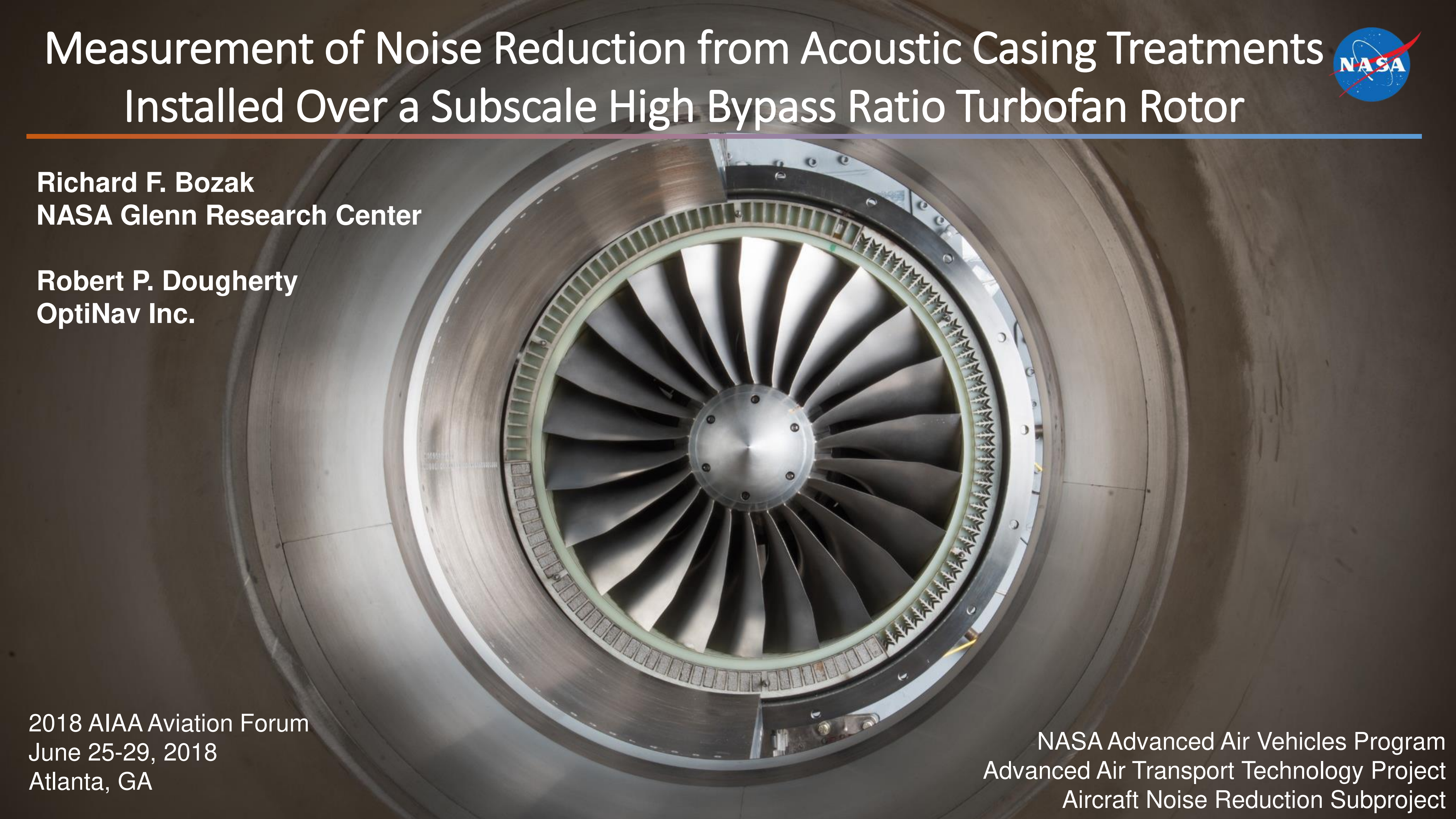
Measurement of Noise Reduction from Acoustic Casing Treatments Installed Over a Subscale High Bypass Ratio Turbofan Rotor



Richard F. Bozak
NASA Glenn Research Center

Robert P. Dougherty
OptiNav Inc.

2018 AIAA Aviation Forum
June 25-29, 2018
Atlanta, GA

NASA Advanced Air Vehicles Program
Advanced Air Transport Technology Project
Aircraft Noise Reduction Subproject

Outline

☐ Background

☐ Approach

☐ W-8 Acoustic Casing Treatment Test

☐ In-duct Mode Power Decomposition

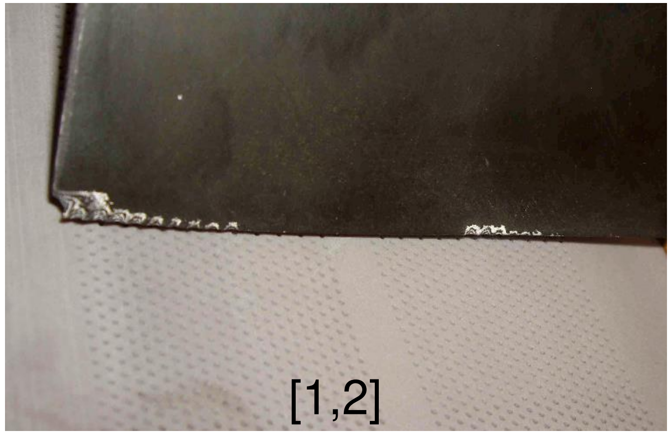
☐ Noise Reduction Results

☐ Summary

Background

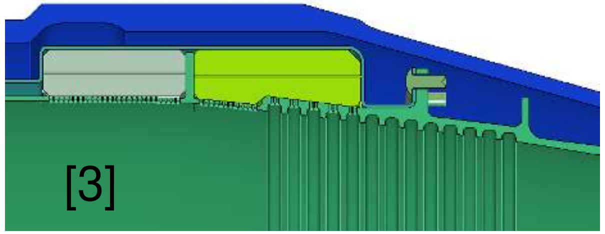
Installation of Acoustic Treatments Directly Over-the-Rotor

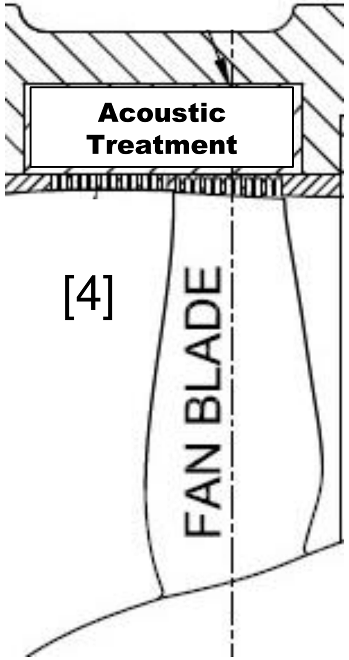
- Composite blade damage
- High treatment temperatures
- 4-9% loss in fan efficiency
- 1dB reduction in OAPWL



Inclusion of Circumferential Grooves between Rotor and Treatment [3,4]

- Reduces magnitude of BPF pressure waves on the treatment
- Significantly reduces aerodynamic performance losses
- Up to 5dB inlet acoustic power level reduction





1. Hughes, C., and Gazzaniga, J., “Effect of Two Advanced Noise Reduction Technologies on the Aerodynamic Performance of an Ultra High Bypass Ratio Fan,” AIAA 2009-3139.
2. Elliott, D., Woodward, R., and Podboy, G., “Acoustic Performance of Novel Fan Noise Reduction Technologies for a High Bypass Model Turbofan at Simulated Flight Conditions,” AIAA 2009-3140.
3. Sutliff, D. L., Jones M. J., and Hartley, T. C., “High-Speed Turbofan Noise Reduction Using Foam-Metal Liner Over-the-Rotor,” Journal of Aircraft, Vol. 50, No. 5, 2013, pp. 1491-1503.
4. Bozak R., Hughes C., and Buckley, J., “The Aerodynamic Performance of an Over-the-Rotor Liner With Circumferential Grooves on a High Bypass Turbofan Rotor,” GT2013-95114, 2013.

Approach

Overall Objective: To improve upon acoustic and aerodynamic performance acoustic casing treatments by further understanding their effect in the over-the-rotor environment and incorporating lessons learned from previous tests.

2015: Normal Incidence Tube (NIT) Test

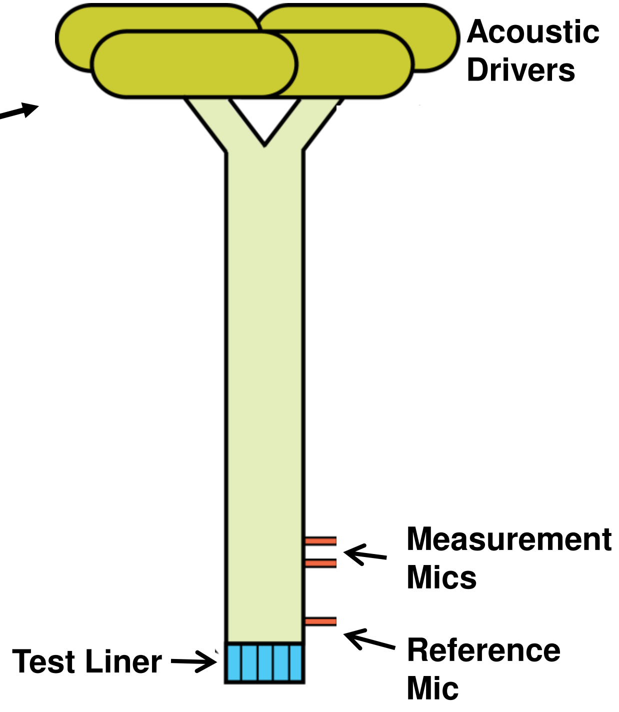
2016: Advanced Noise Control Fan (ANCF) Test*

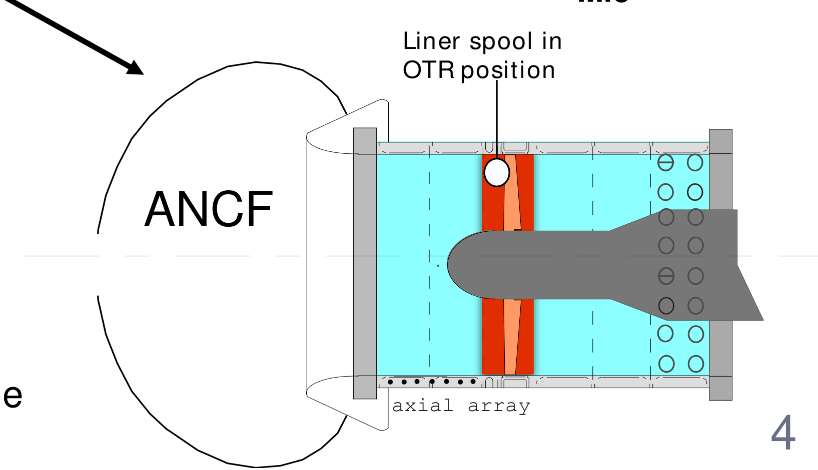
2017: W-8 Acoustic Casing Treatment Test

In order to facilitate the understanding of scaling between facilities, the same treatment geometries tested in each facility. **Not geometrically scaled.*

- Treatment depths limited to 1” to aid measurements in all facilities.
- Future testing is expected to demonstrate scalability.

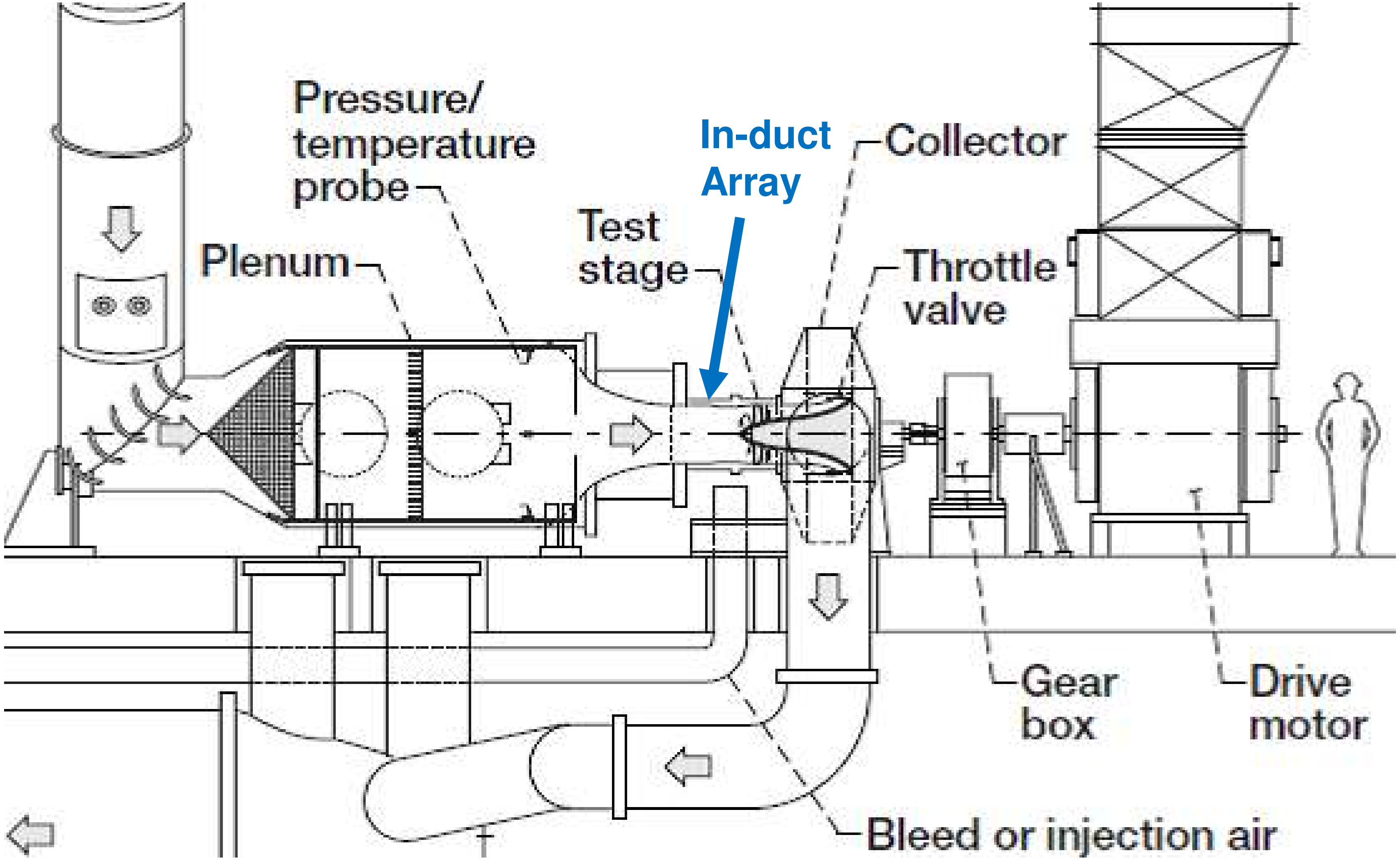
Normal Incidence Tube (NIT)





*Gazella et al., “Evaluating the Acoustic Benefits of Over-the-Rotor Acoustic Treatments Installed on the Advanced Noise Control Fan,” AIAA 2017-3872.

W-8 Single Stage Axial Compressor Facility



- Internal flow propulsor facility
- Electric drive motor provides up to 7000 hp, 21,240 RPM
- Mass Flows up to 100 lb_m/sec
- 22” Rotor Alone or Stage Fan Models
- Dual Flow or Bypass only
- Atmospheric or Altitude Exhaust Capability

SDT/R4 Fan Hardware

- The Source Diagnostic Test hardware was tested in a rotor alone configuration in NASA's 9x15 low speed wind tunnel (LSWT)[1] and the W-8 Single Stage Axial Compressor Facility[2] in the early 2000's.

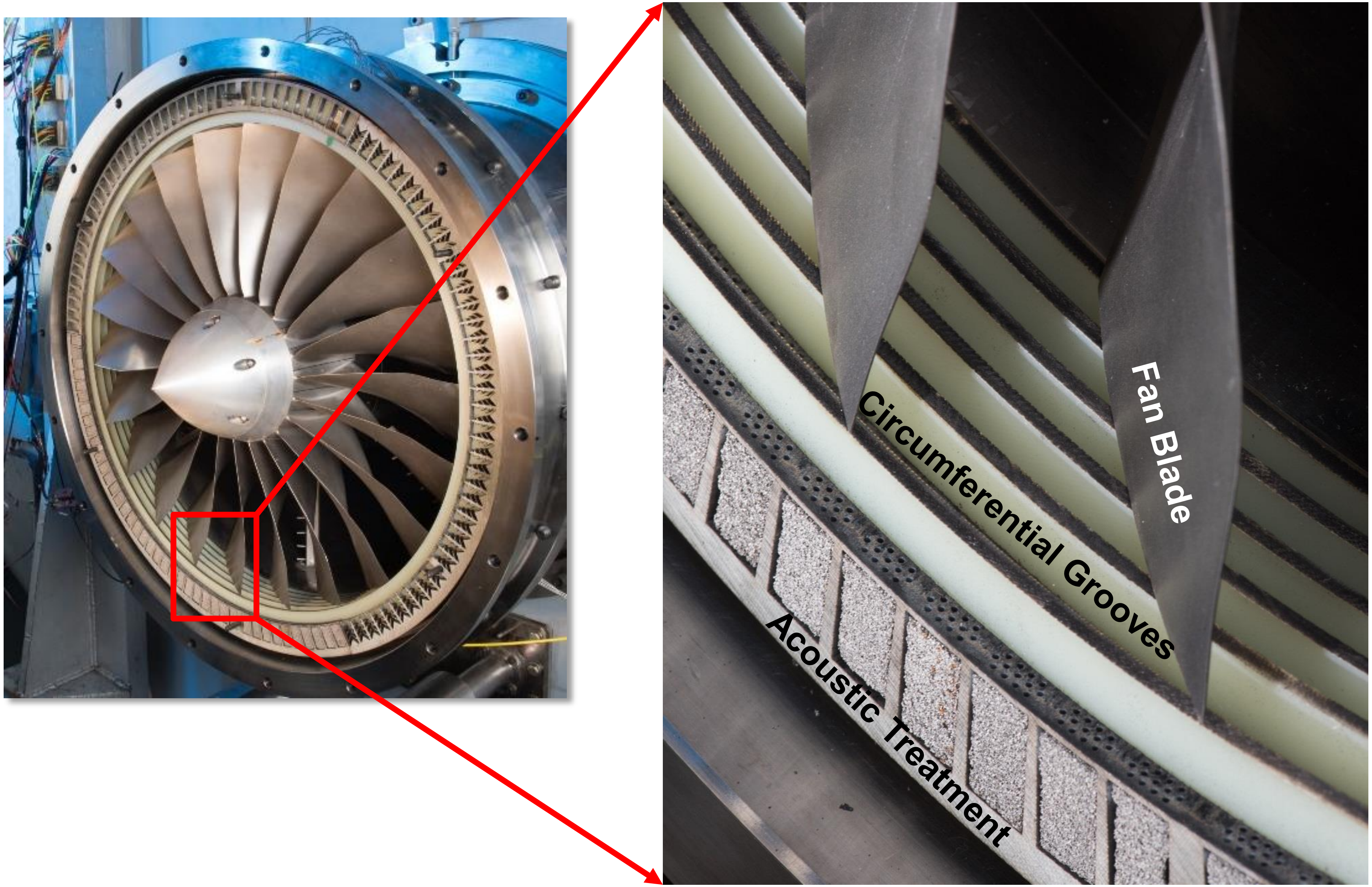
Parameter	**Value**
No. of Fan Blades	22
Fan Tip Diameter	22 in. (0.56m)
Hub/tip Ratio	0.30
Fan Design Pressure Ratio	1.50

Set Point Conditions		Fan Conditions	
% Fan Speed	Corrected Fan Speed, rpmc	Fan Inlet Axial Mach no.	Fan Tip Mach no.
50.0%	6,329	0.236	0.596
60.0%	7,594	0.286	0.718
61.7%	7,809	0.296	0.739
70.0%	8,860	0.343	0.843
77.5%	9,809	0.389	0.940
80.0%	10,126	0.407	0.974
87.5%	11,075	0.460	1.075
95.0%	12,024	0.523	1.183
100.0%	12,657	0.569	1.259

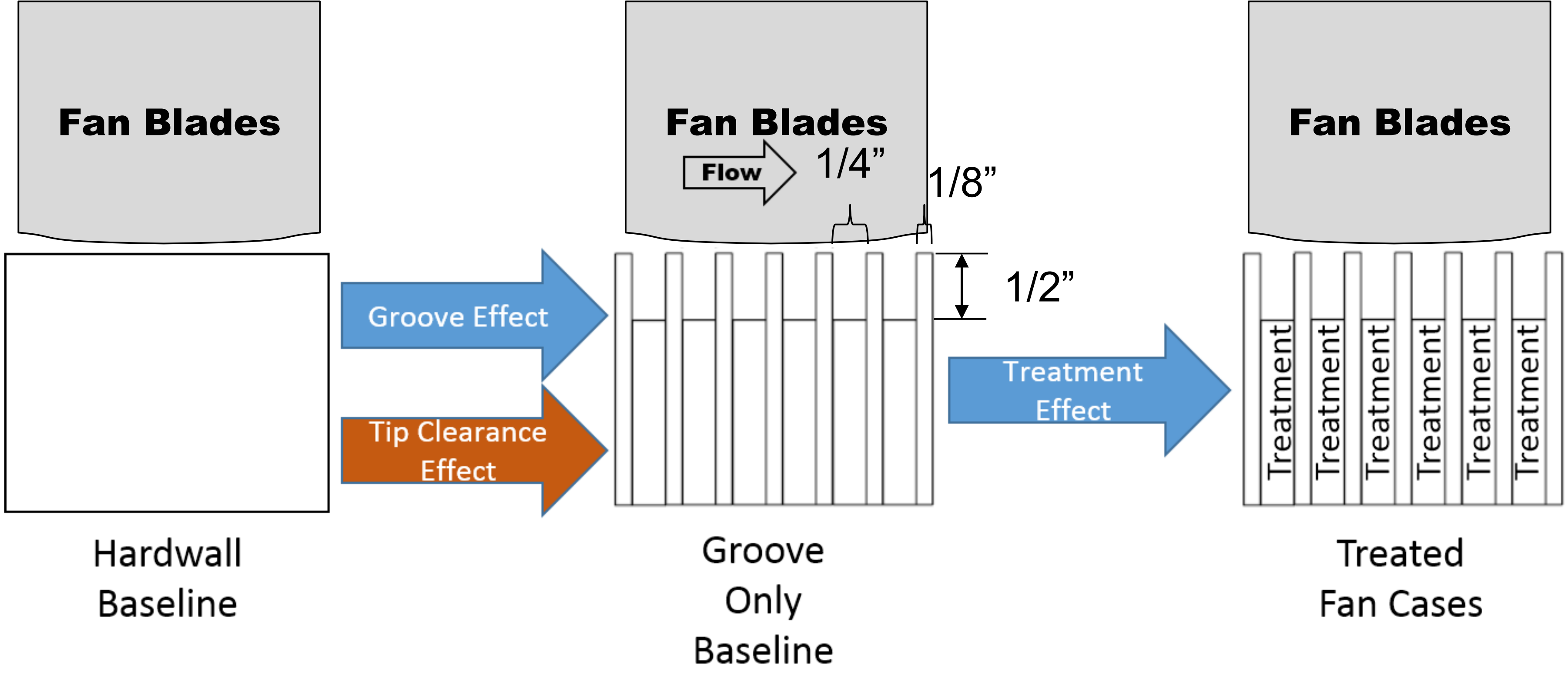
[1] Hughes, Christopher E., Jeracki, Robert J., and Miller, Christopher J., "Fan Noise Source Diagnostic Test – Rotor Alone Aerodynamic Performance Results," AIAA 2002-2426 or NASA TM 2005-211681.

[2] Van Zante, Dale E., Podboy, Gary G., Miller, Christopher J., Thorp, Scott A., "Testing and Performance Verification of a High Bypass Ratio Turbofan Rotor in an Internal Flow Component Test Facility," GT2007-27246.

Over-the-Rotor Acoustic Casing Treatment Design



Experimental Approach



Fan Blades

Flow

1/4”

1/8”

1/2”

Groove Effect

Tip Clearance Effect

Treatment Effect

Treatment

Treatment

Treatment

Treatment

Treatment

Treatment

Hardwall Baseline

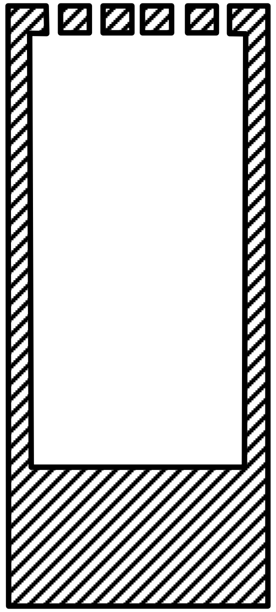
Groove Only Baseline

Treated Fan Cases

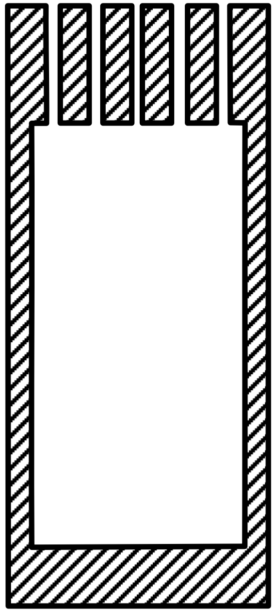
Effective Treatment L/D = 0.068

Acoustic Treatment Concepts

Empty
Chamber

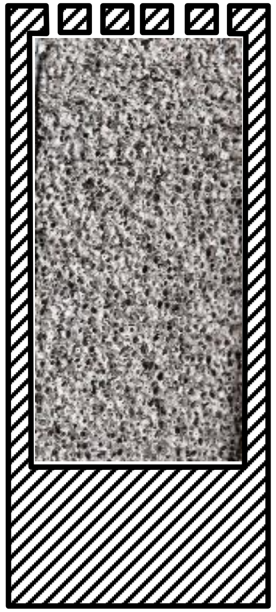


Thick
Perforate



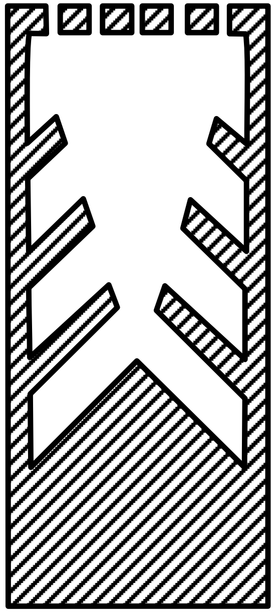
¼” Perforate
Thickness

Foam
Metal



FeCrAlY
80ppi 8%

Expansion
Chamber

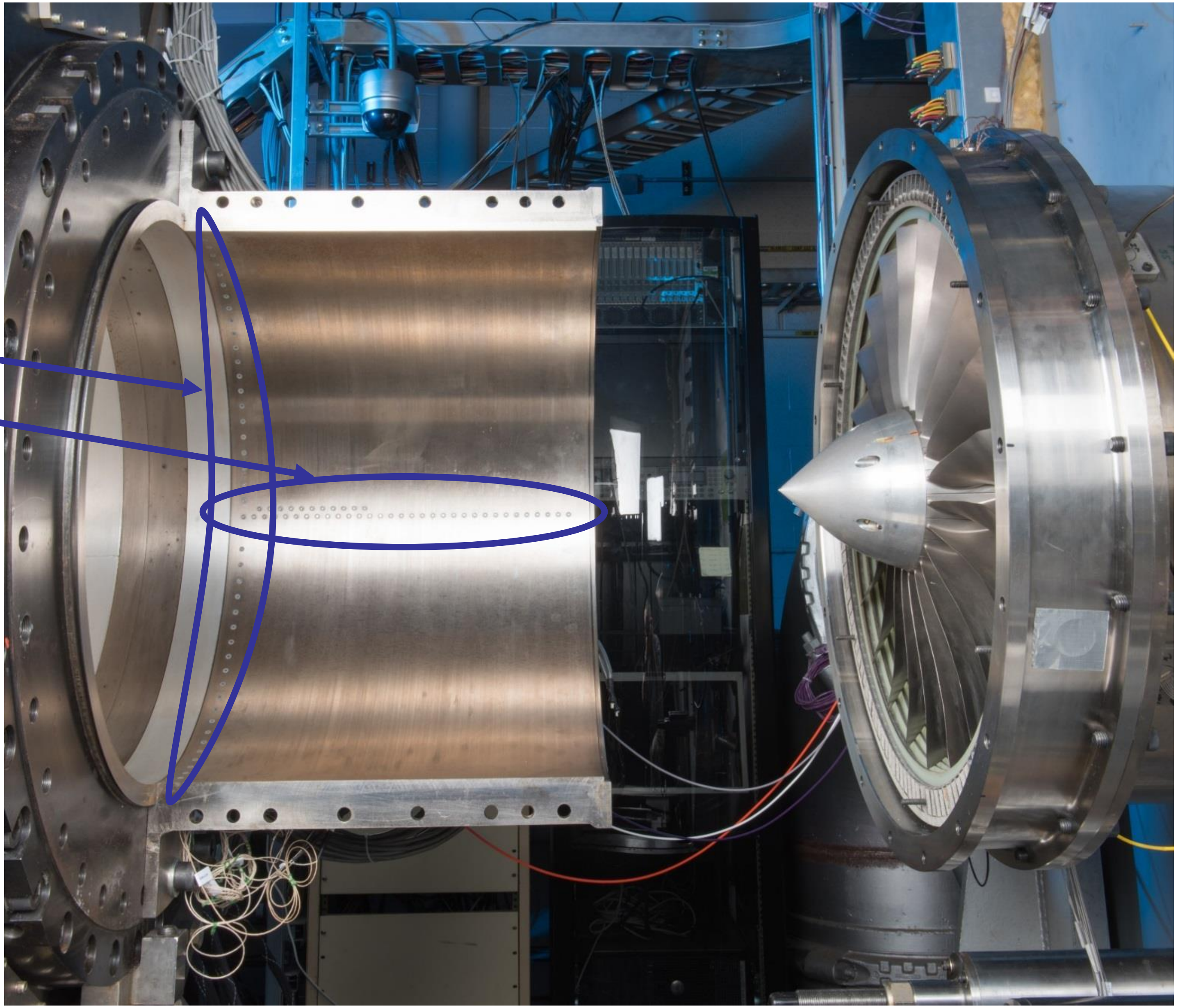


Fins to Aid
Expansion of
Pressure Waves

Unless specified otherwise, all treatments have a 0.035” diameter perforate, 10% open area, 0.060” perforate thickness, and a 1” chamber depth.

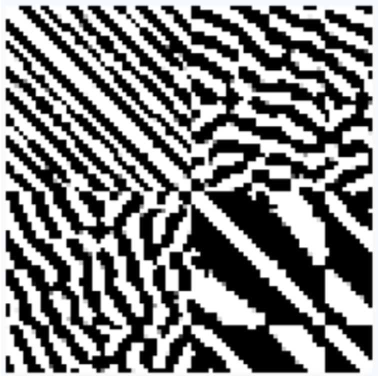
W-8 Acoustic Instrumentation: Inlet In-duct Array

- 22-inch constant area inlet duct
- 85 sensors
  - Kulite® 25PSIA
  - Installed into nylon inserts
- T-Array
  - ½ Circle, 4° Spacing
  - Long Axial
  - Staggered Short Axial



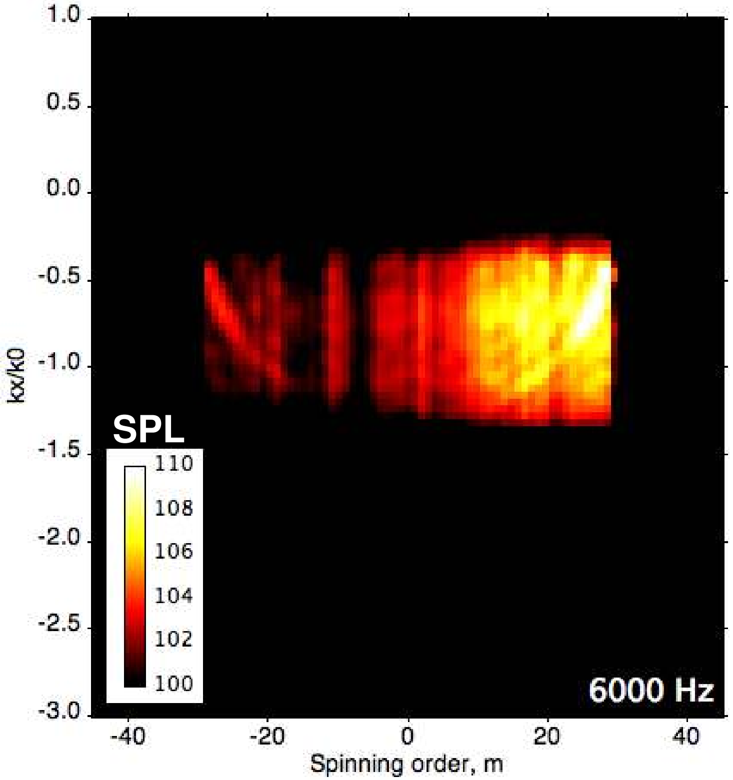
In-duct Array Data Processing to In-duct Modal Sound Power Level

Cross-Spectral Matrix



Quantitative Beamforming

Duct Wavenumber Space Sound Pressure Level (SPL)

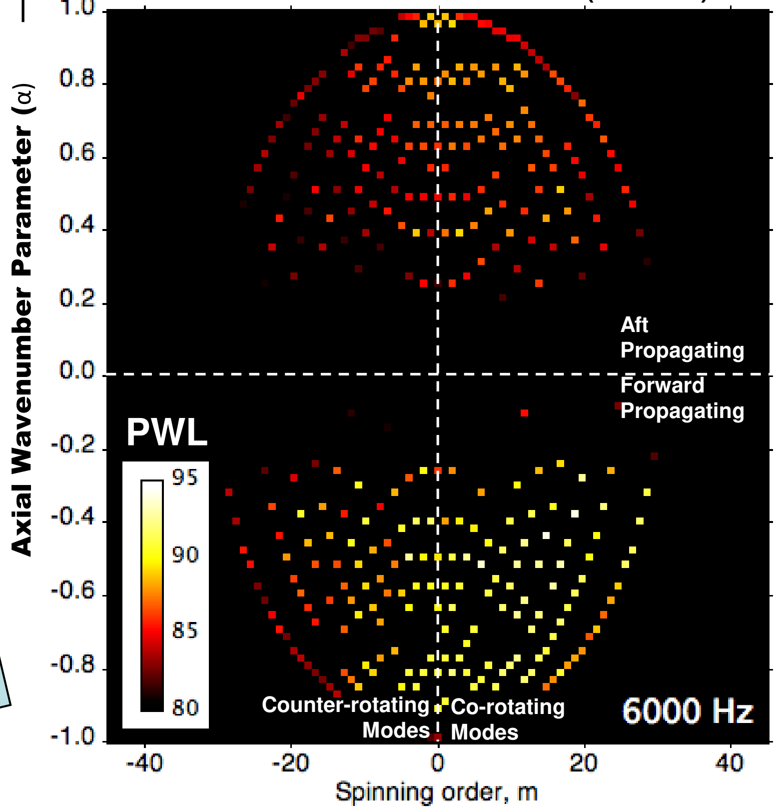


Mode Power Conversion

Axial Wavenumber Parameter

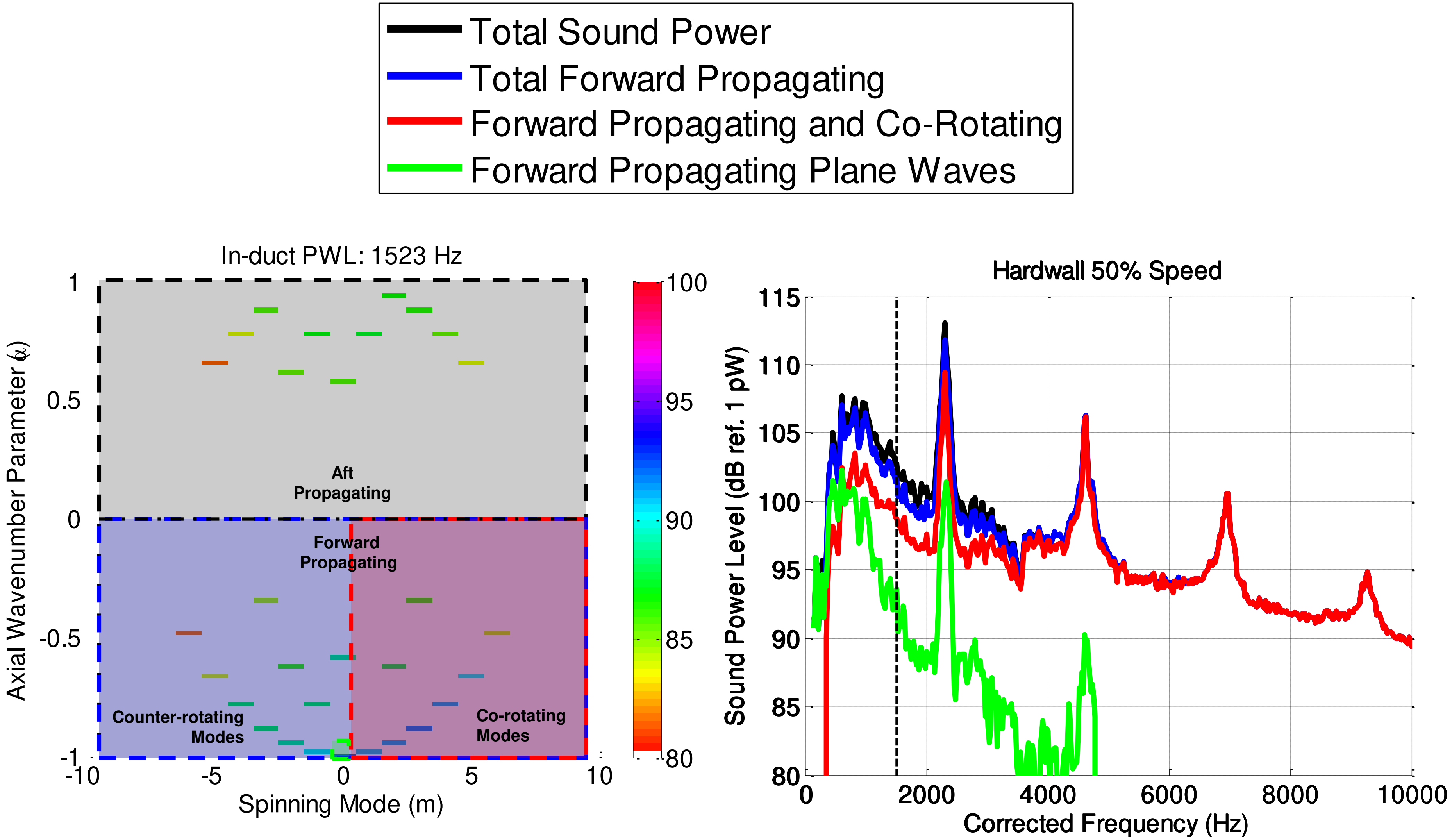
$$\alpha = \pm\sqrt{1-(1-M^2)\left(\frac{k_N}{k_0}\right)^2}$$

Modal Sound Power Levels (PWL)

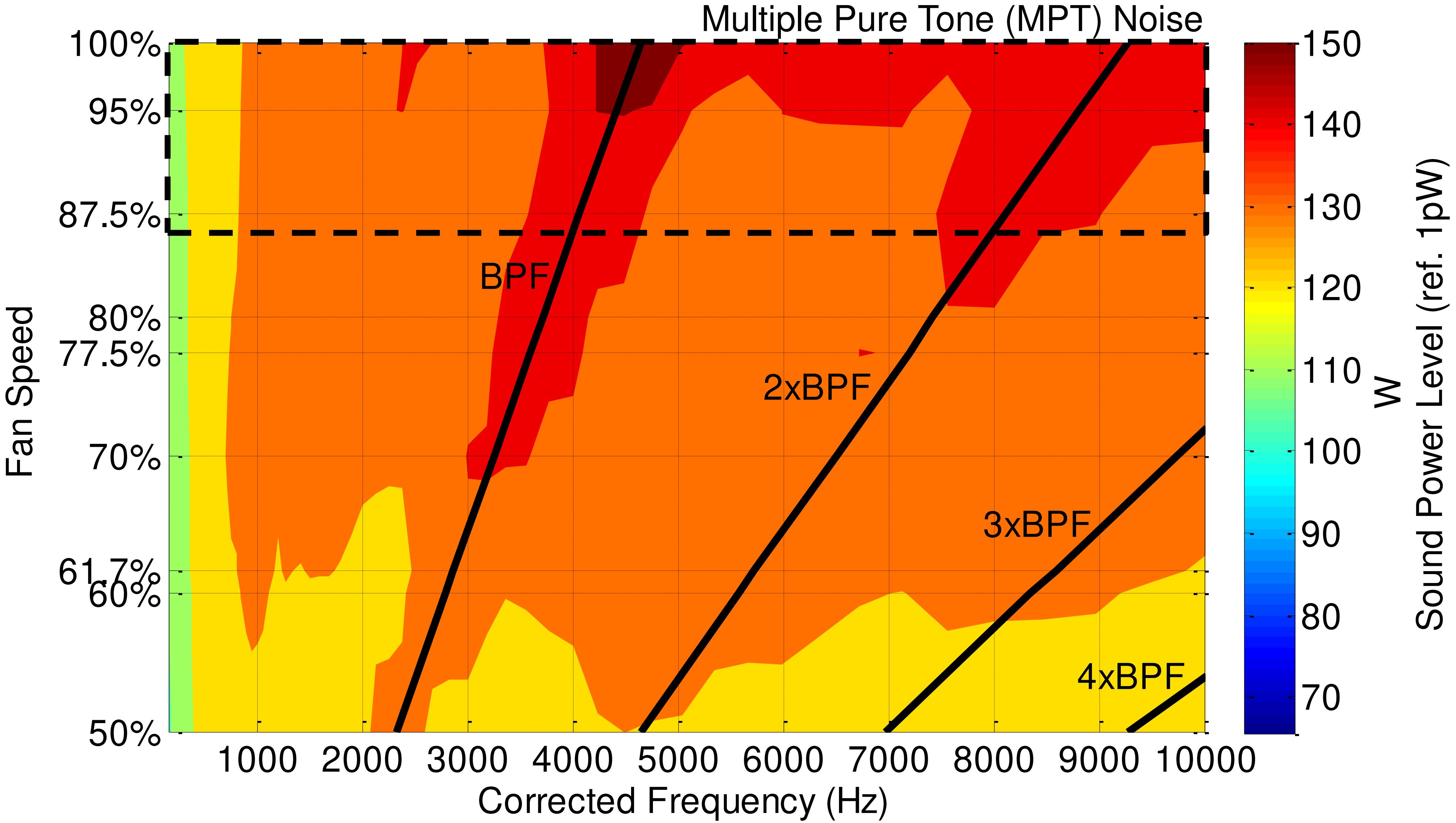


Dougherty, R. P., and Bozak, R. F., "Two-dimensional Modal Beamforming in Wavenumber Space for Duct Acoustics", 2018 Aviation, to be published.

In-duct Modal Decomposition

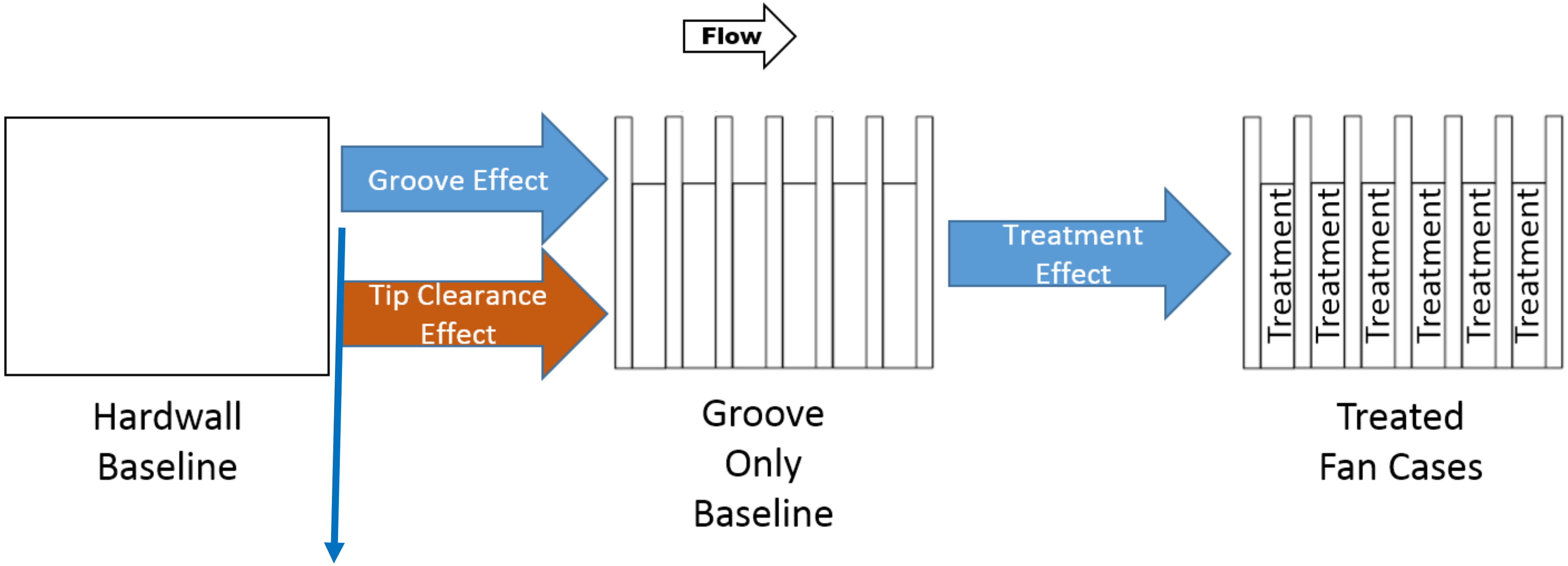


Hardwall Rotor Alone In-duct Sound Power Level Characteristics



- Data presented as 1/12 Octave In-duct Sound Power Levels ref. 1pW
- Frequencies have been corrected to standard day

Evaluation of Results



Hardwall Baseline

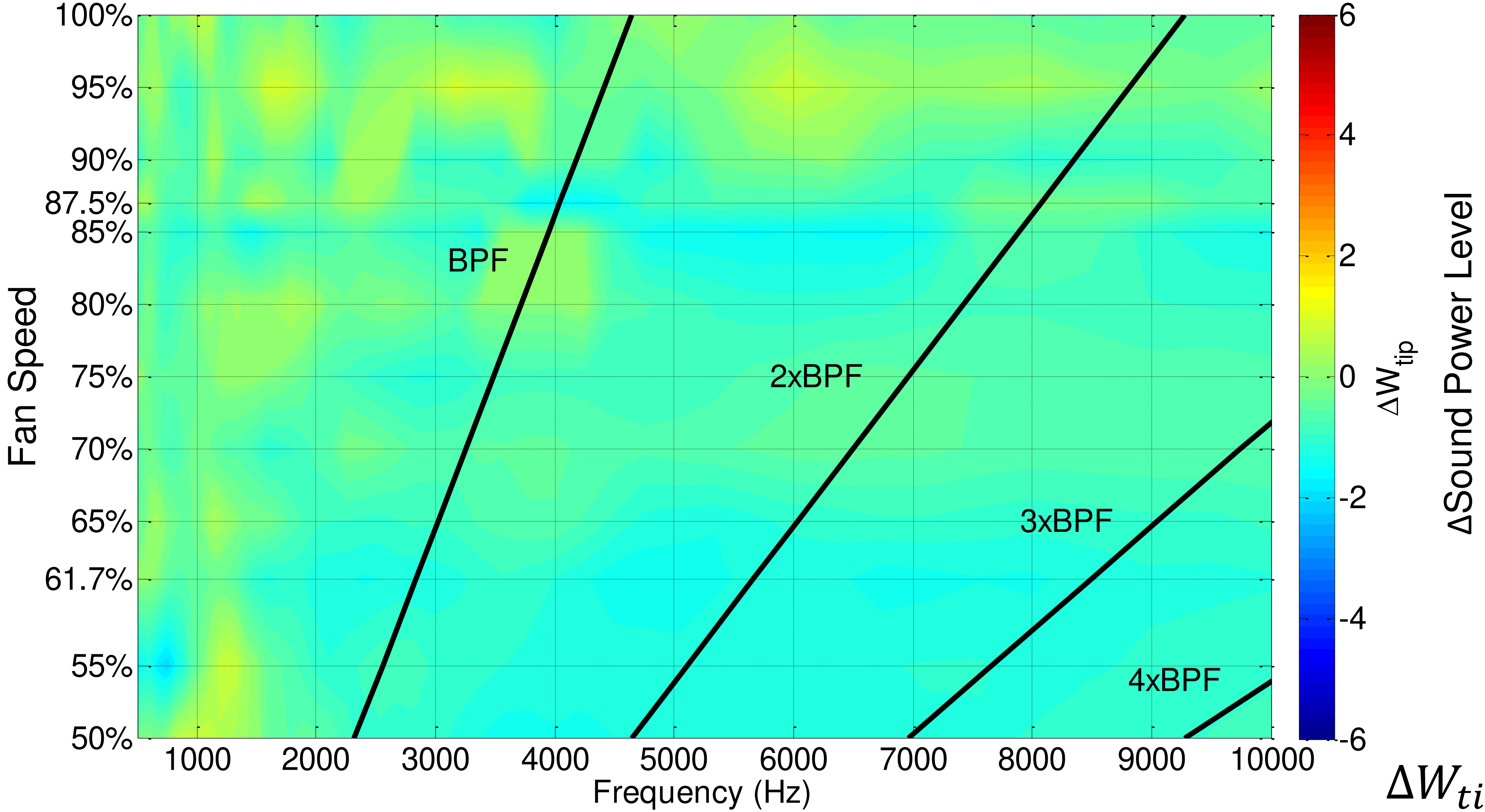
Groove Only Baseline

Treated Fan Cases

$$\Delta W_{grooves} = W_{grooves} - W_{hardwall} + \Delta W_{tip}$$

$$\Delta W_{tip} = W_{0.000"} - W_{0.030"}$$

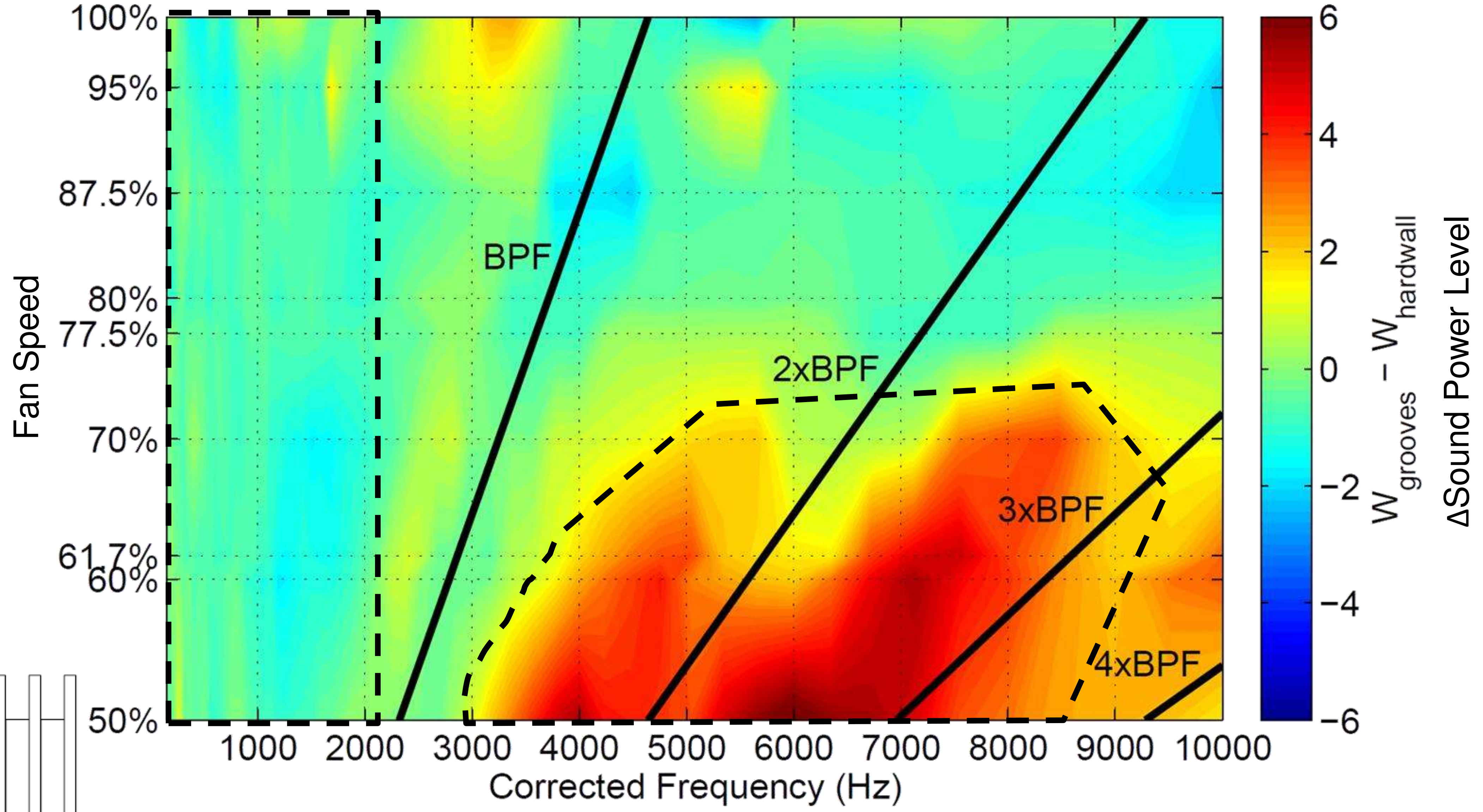
Effect of Tip Clearance (from far-field 9x15 LSWT data*)

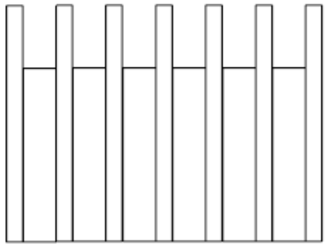


$$\Delta W_{tip} = W_{0.000"} - W_{0.030"}$$

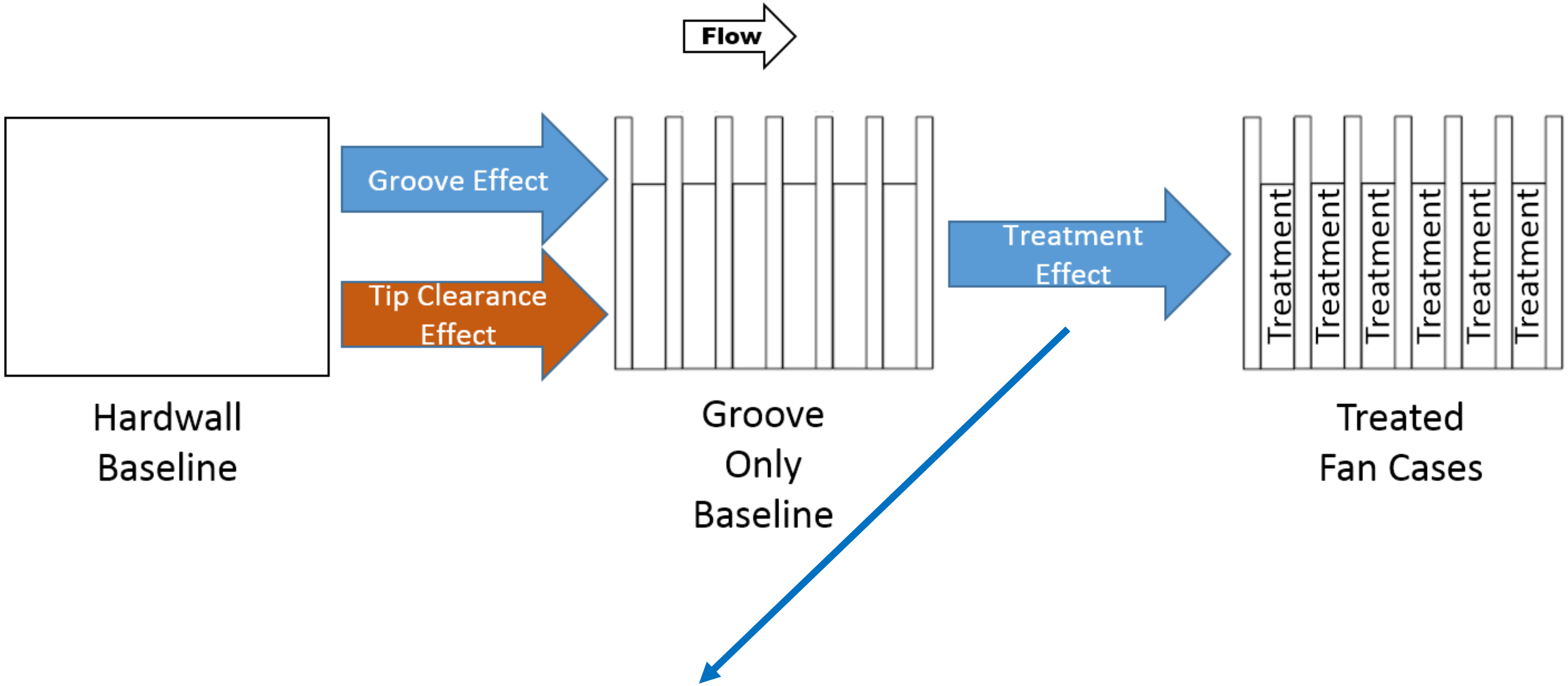
*Hughes, C. E., Woodward, R. P., and Podboy, G. G., ‘Effect of Tip Clearance on Fan Noise and Aerodynamic Performance,’ AIAA 2005-2875, AIAA/CEAS Aeroacoustic Conference, Monterey, CA, May 2005.

Effect of Circumferential Grooves and Tip Clearance



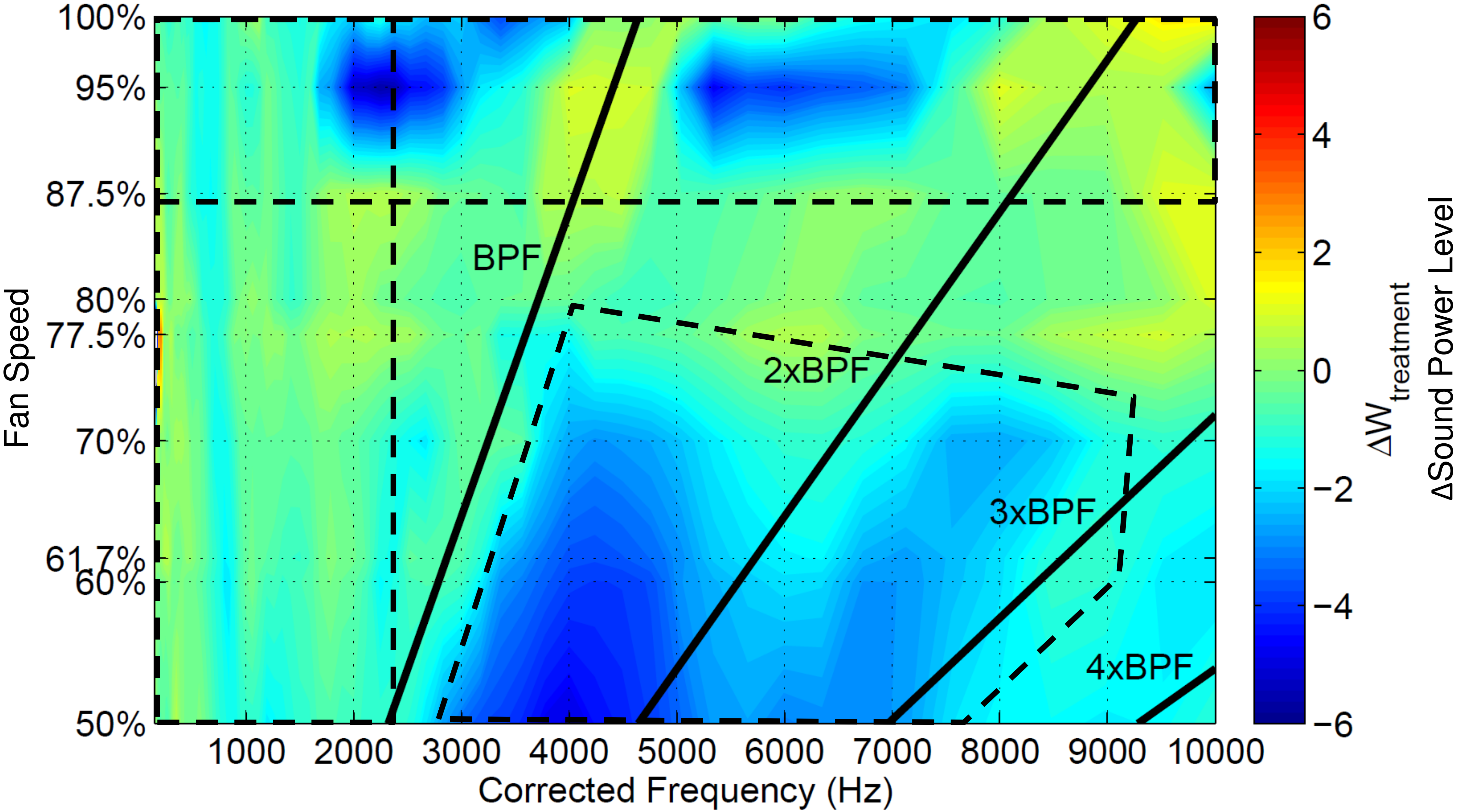


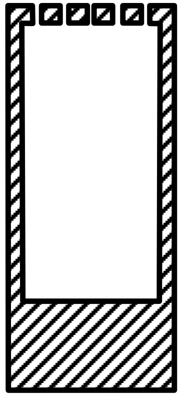
Evaluation of Treatment Performance



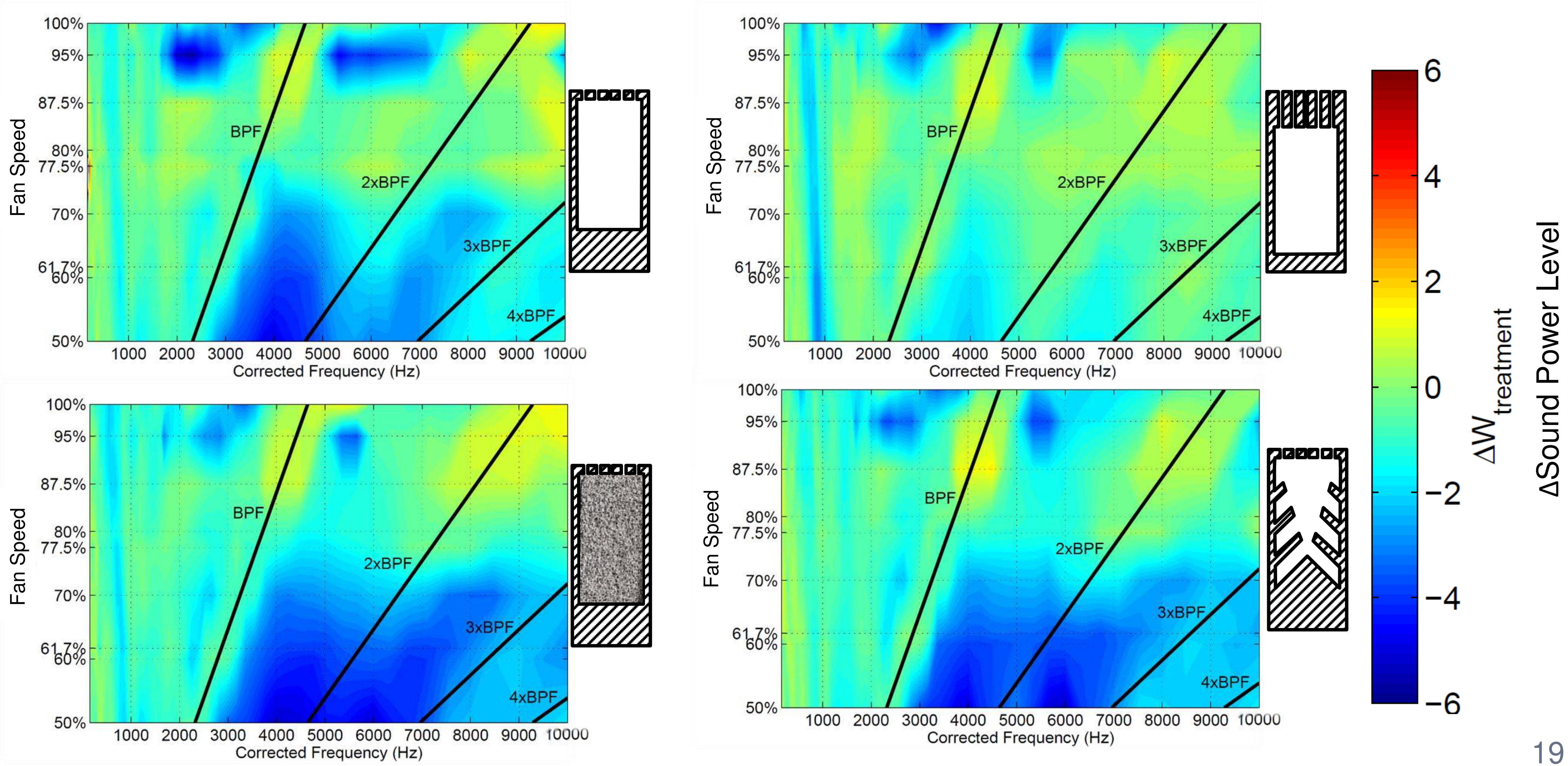
$$\Delta W_{treatment} = W_{treatment} - W_{grooves}$$

Empty Chamber Treatment Impact on Forward Propagating Modes

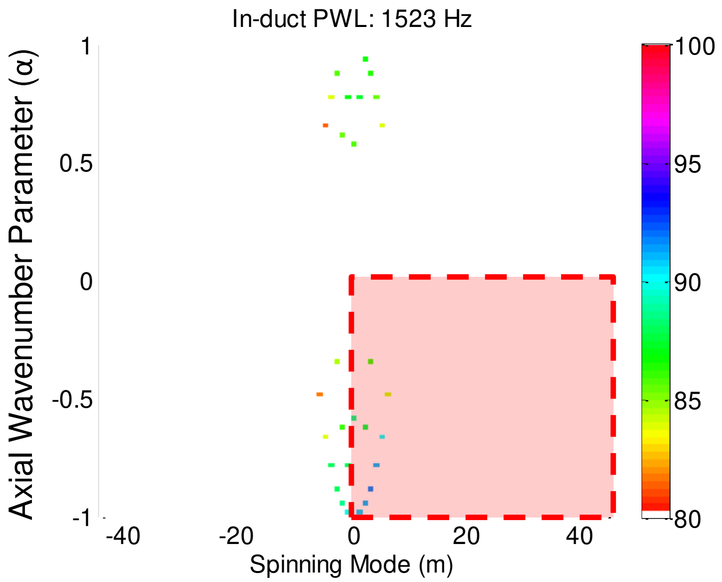


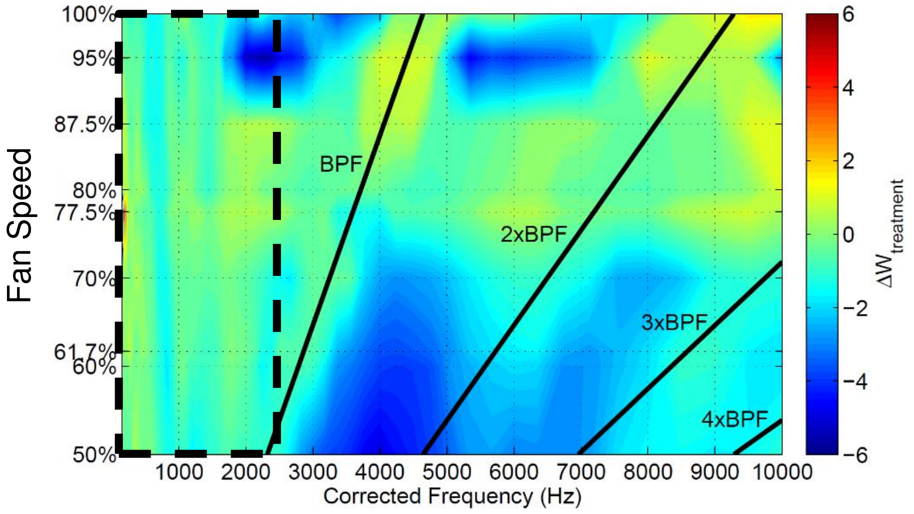


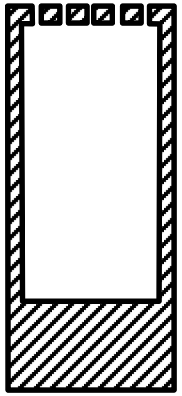
Treatment Impact on Forward Propagating Modes

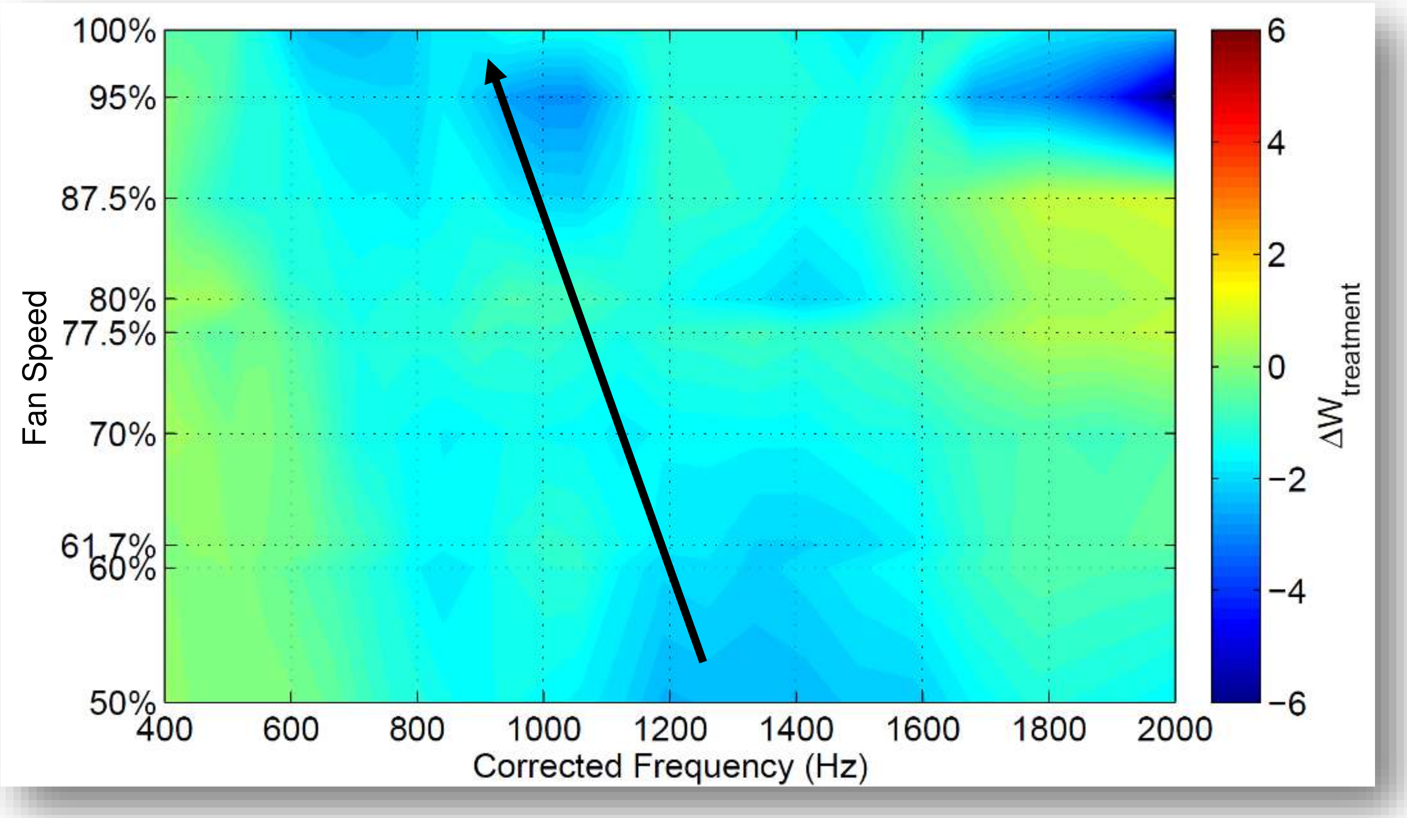


Treatment Impact on Co-rotating and Forward Propagating Modes

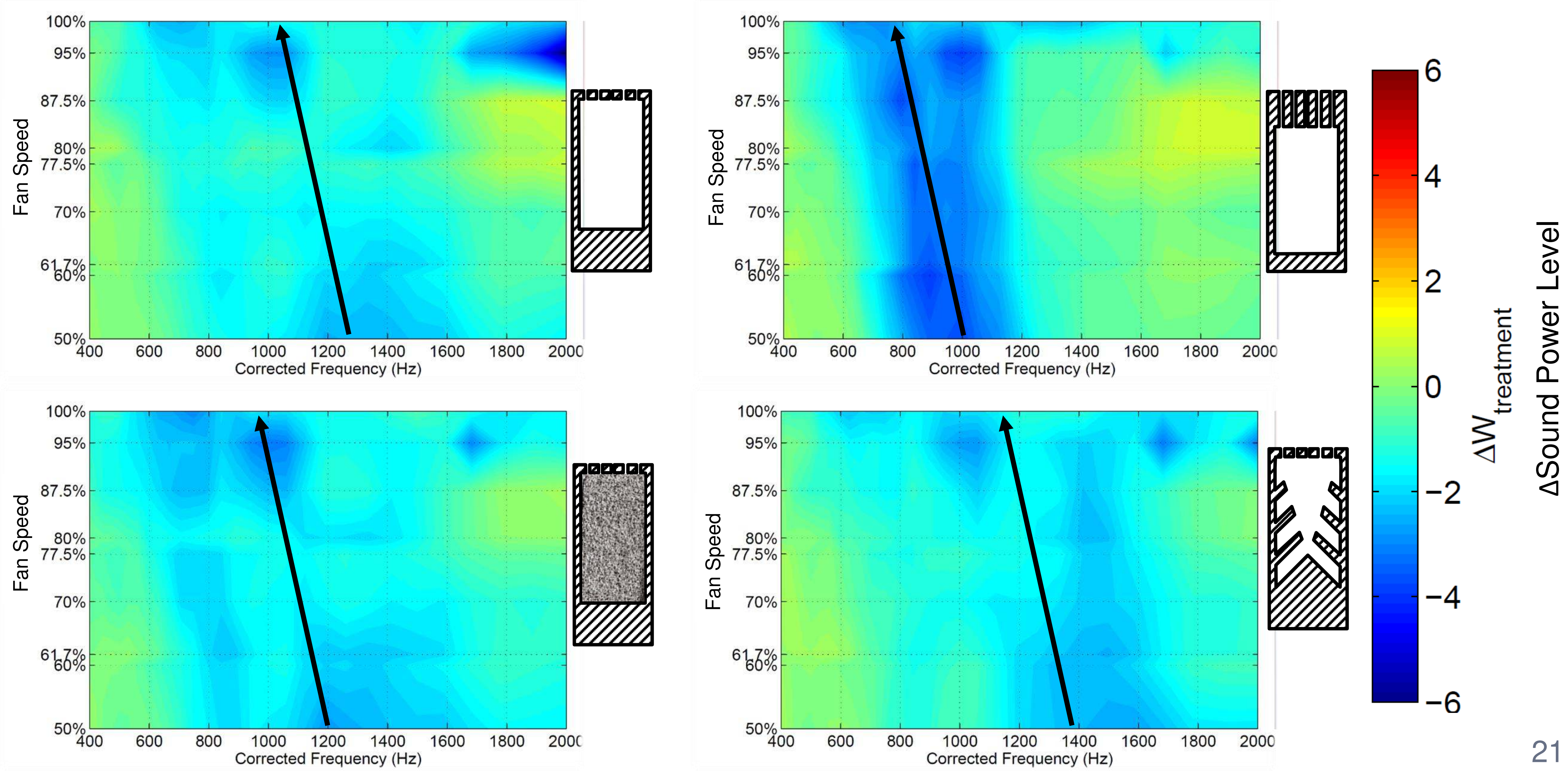








Treatment Impact on Co-Rotating and Forward Propagating Modes



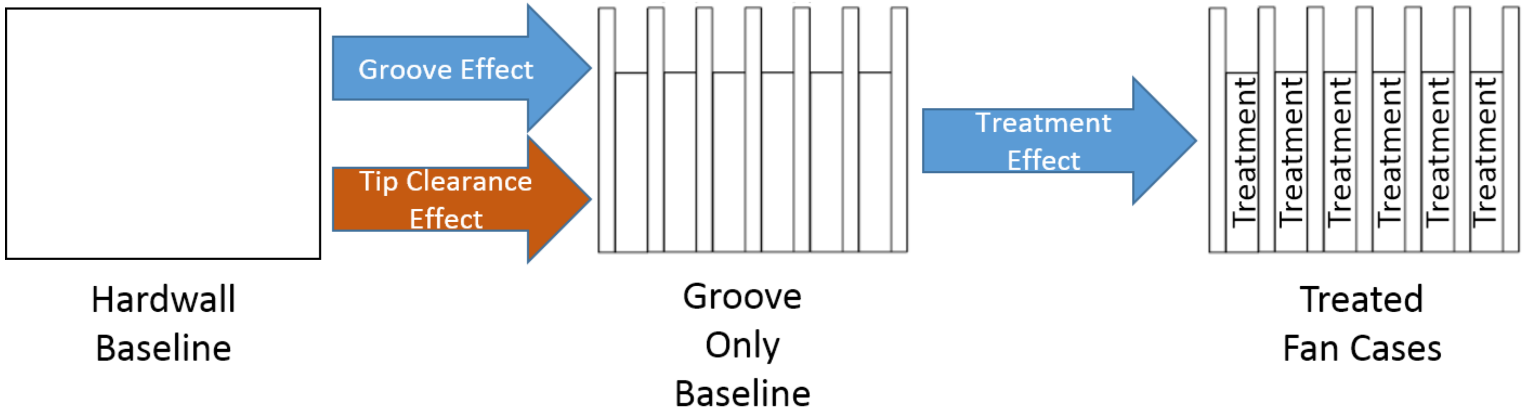
Summary of Results

	Groove Effect	**Treatment Effect**	**Total Effect**
In-duct Sound Power Level (dB)	$\Delta W_{grooves}$	$\Delta W_{treatment}$	ΔW_{total}
Forward Propagating Modes	– 1.6dB	– 1-2dB	– 2.6-3.6dB
Co-rotating Forward Propagating Modes	– 1.7dB	– 1.8-2.9dB	– 3.5-4.6dB
Circumferential Groove Noise (4-8kHz)	+ 7.6dB	– 1.5-5dB	+ 2.6-6.1dB

Treatment Impact to Forward Propagating Noise Sources (Rotor-Stator Noise)

Treatment Impact to Rotor Noise Sources

Circumferential Groove Impact Requires Further Investigation



Summary

- ❑ Acoustic measurements of a turbofan rotor were acquired for the first time in the W-8 facility at NASA GRC with an inlet in-duct array to determine the potential noise reduction of acoustic casing treatments.

- ❑ The total effect was measured to be 2.5-4.5dB reduction at low frequencies, but a 2.5-6dB penalty at higher frequencies.

- ❑ Circumferential grooves were found to reduce rotor noise up to 1.7dB under 3 kHz for all fan speeds, and increase noise by up to 7.6dB between 4-8 kHz at low fan speeds (<77.5%).

- ❑ Acoustic treatments at the bottoms of circumferential grooves are expected to reduce all forward propagating modes by 1-2dB and rotor noise by 2-3dB.

- ❑ Acoustic treatments also reduced MPT noise by 3-4dB, but increased BPF tones by 1-2dB.

- ❑ Further investigation and understanding of the acoustic impact of fan casing treatments, such as circumferential grooves, has the potential to improve over-the-rotor acoustic casing treatment performance up to 3-5dB.

Acknowledgments

- NASA Research team:
  - Mike Jones
  - Dan Sutliff
  - Doug Nark

- W-8 facility team

- Hardware Design:
  - Jim Buckley (Vantage Partners, LLC)
  - John Jones (ZIN Technologies Inc.)

- Advanced Air Transport Technology Project of NASA’s Advanced Air Vehicle Program