9- by 15-Foot Low Speed Wind Tunnel Acoustic Improvements Expanded Overview

Acoustics Branch Point-of-Contact: David Stephens

April 2016

Executive Summary

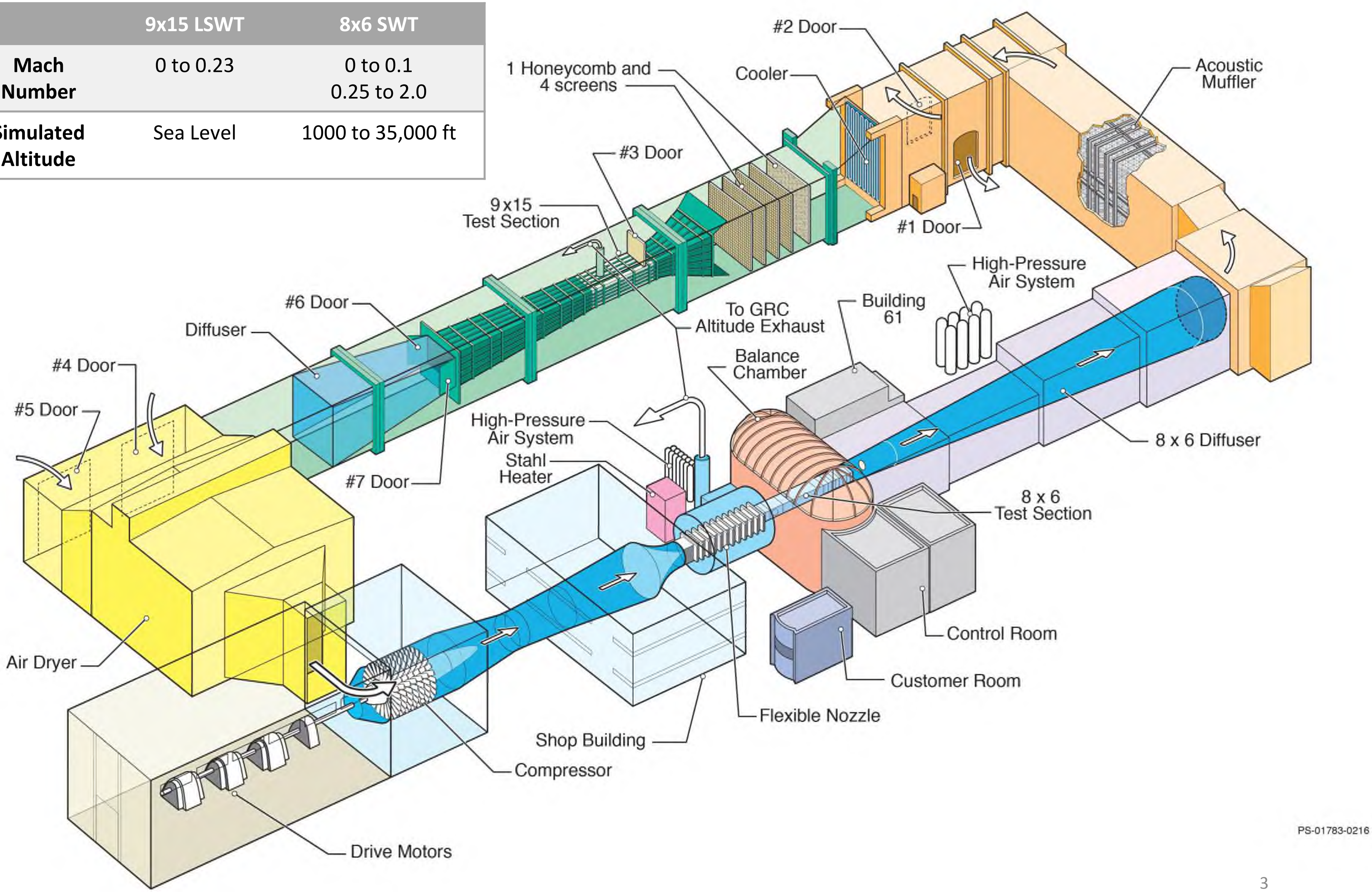
The 9- by 15-Foot Low Speed Wind Tunnel (9x15 LSWT) at NASA Glenn Research Center was built in 1969 in the return leg of the 8- by 6-Foot Supersonic Wind Tunnel (8x6 SWT). The 8x6 SWT was completed in 1949 and acoustically treated to mitigate community noise issues in 1950. This treatment included the addition of a large muffler downstream of the 8x6 SWT test section and diffuser.

The 9x15 LSWT was designed for performance testing of V/STOL aircraft models, but with the addition of the current acoustic treatment in 1986 the tunnel been used principally for acoustic and performance testing of aircraft propulsion systems. The present document describes an anticipated acoustic upgrade to be completed in 2017.

8x6/9x15 Facility Manager : David Stark

Unique facility for testing propulsors

	9x15 LSWT	8x6 SWT
Mach Number	0 to 0.23	0 to 0.1 0.25 to 2.0
Simulated Altitude	Sea Level	1000 to 35,000 ft



Fan/Propulsor Testing in 9x15 Tunnel

- The GRC 9x15 Low Speed Wind Tunnel has been extensively used to study and acoustically characterize nearly all of the NASA/Industry propulsor concepts over the past 20 years.

- Except for maintenance, the acoustic treatment has remained essentially unchanged in 20+ years.

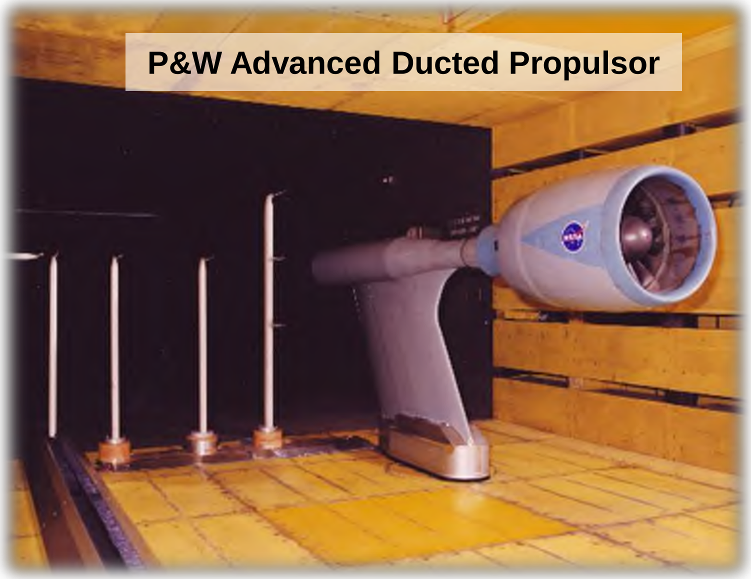
Honeywell Turbofan with Acoustic Liners

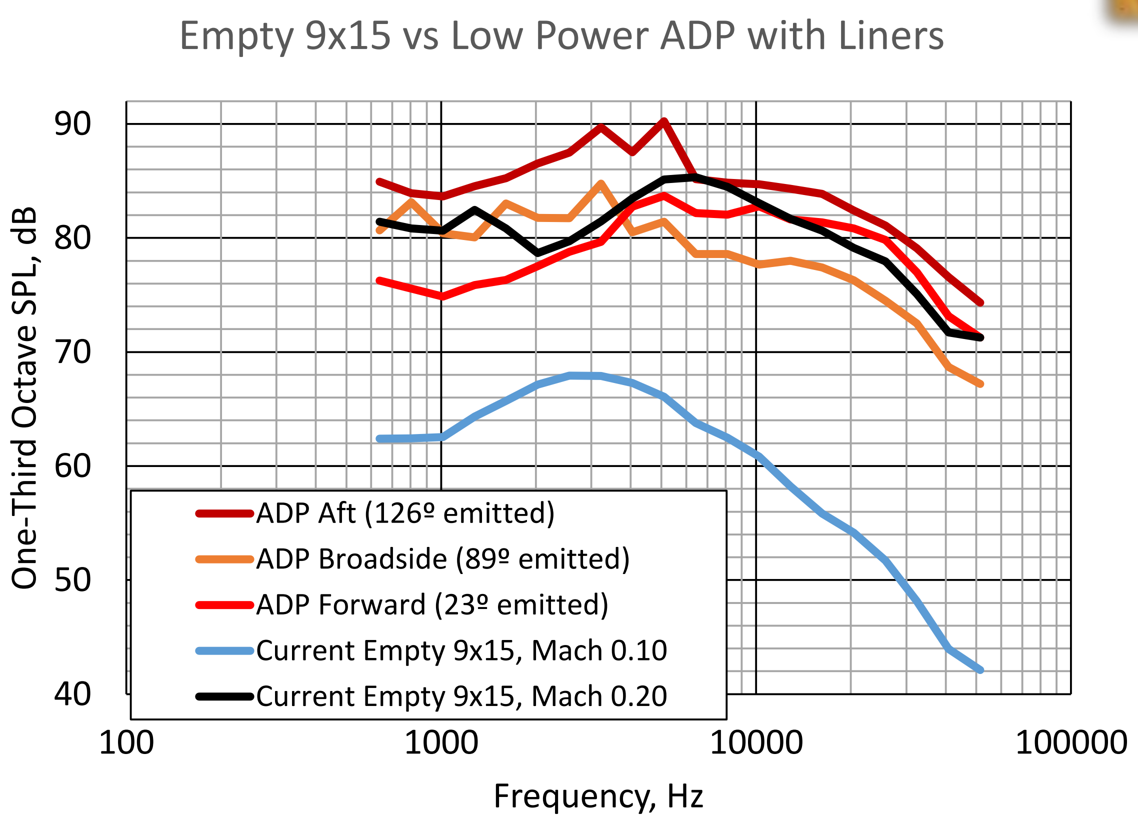

P&W Geared Turbofan


NASA/GE Open Rotor

Testing quiet fans requires a quiet wind tunnel

- Historically this has been done by testing a Mach 0.1, which is below true take-off and landing speeds.





- Future fans may be even quieter
  - Low tip speed
  - Low pressure ratio
  - Acoustic liners
- Open rotors and other concept fans require testing at higher tunnel speeds than Mach 0.1

Support from NASA Agency and Center Levels

- Preliminary assessment by Jacobs Technology, Inc performed in 2012
  - Funded by Environmentally Responsible Aviation
- Initial FY15 NASA funding resulted in initiation of 9x15 Design contract that resulted in completion of a 30% design review.
- Additional funding in FY15 from NASA GRC, NASA AETC project and NASA Augmentation funded a 9x15 Design/Build contract which began in September 2015 from the 30% design point. The FY15 funding provided 60% of the total project Design/Build cost.
- FY16 funding from NASA GRC and NASA AETC is currently being approved by Congress through the FY16 NASA Operating Plan and this funding will provide the remaining 9x15 Design/Build funding.

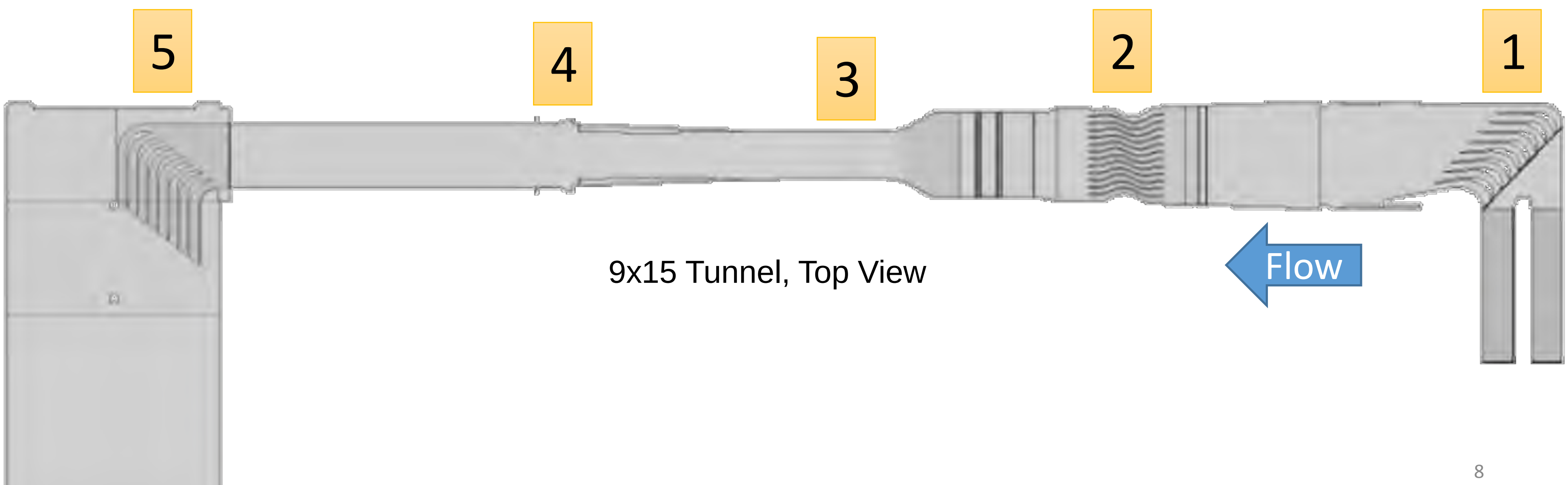
Anticipated Schedule

- December 2015 – Final pre-construction aerodynamic calibration of 8x6 and 9x15 test sections
- January 2016 – Final pre-construction background noise measurement of 9x15 test section
- September 30, 2016 – Boundary layer ingestion test in 8x6 tunnel ends
- October 31, 2016 – Wind Tunnel Shutdown for Start of Site Work
  - Both 8x6 and 9x15 shut down
- September 4, 2017 – Acceptance Testing Begins
  - Acceptance testing for 8x6 and 9x15 test sections
- September 29, 2017 – Tunnel Ready for Testing

Planned Wind Tunnel Renovation

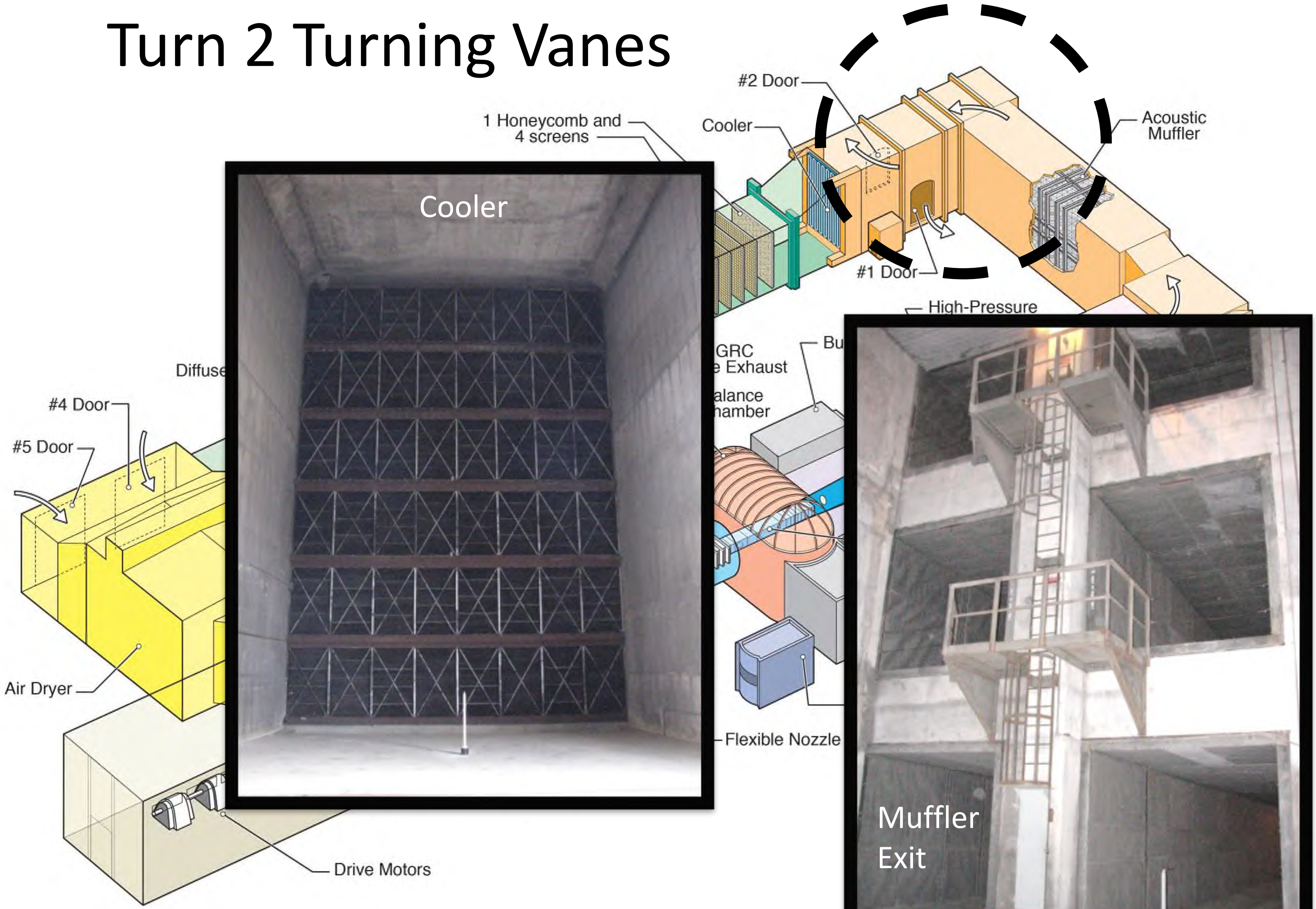
Complementary but discrete improvements

1. Add fairings and turning vanes to turn 2
2. Add acoustic baffles downstream of doors 1 & 2
3. Replace test section flow surfaces, remove slots
4. Reshape diffuser and add acoustic treatment
5. Add turning vanes to turn 3



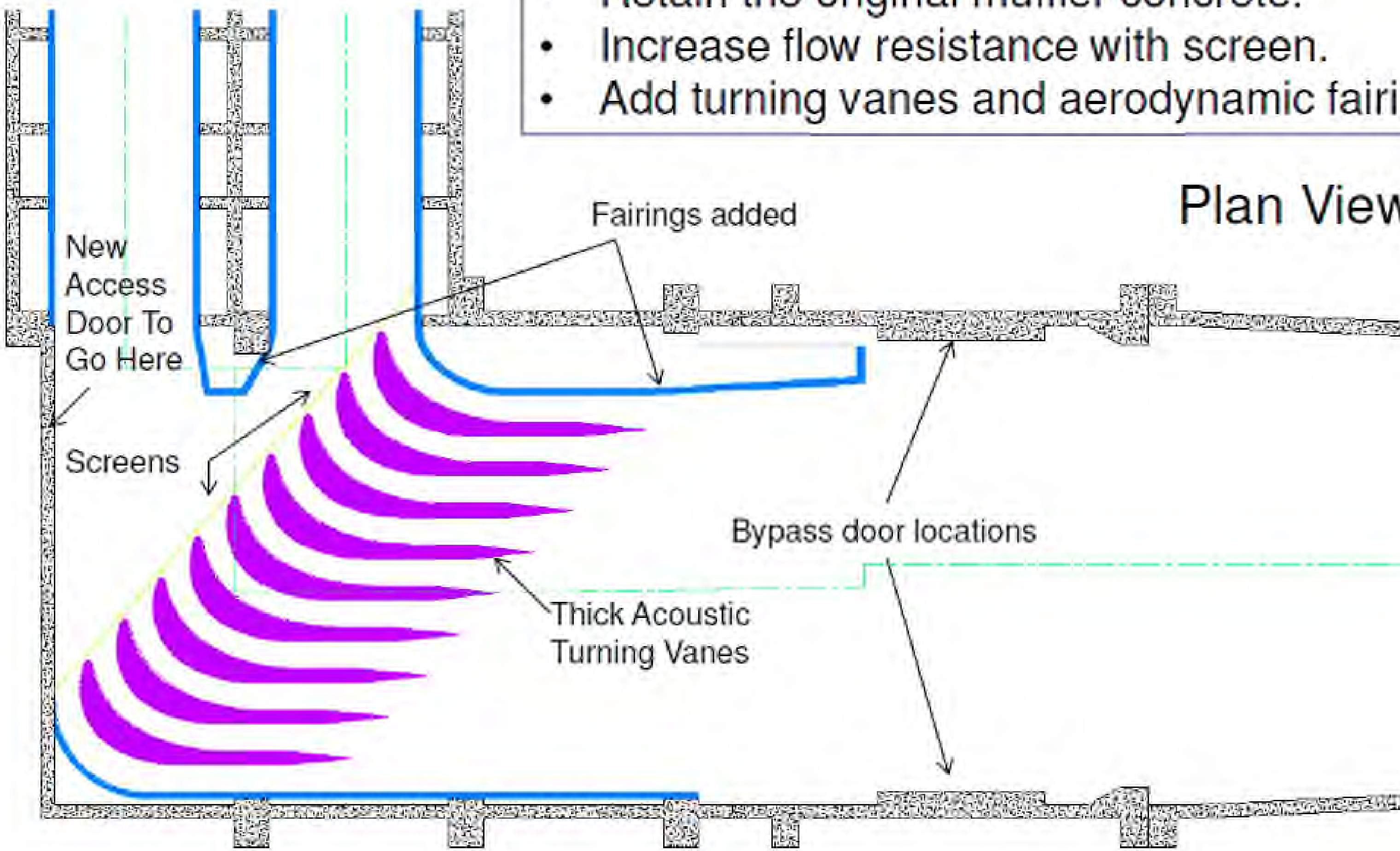
9x15 Tunnel, Top View

Turn 2 Turning Vanes



Improvements to Turn 2

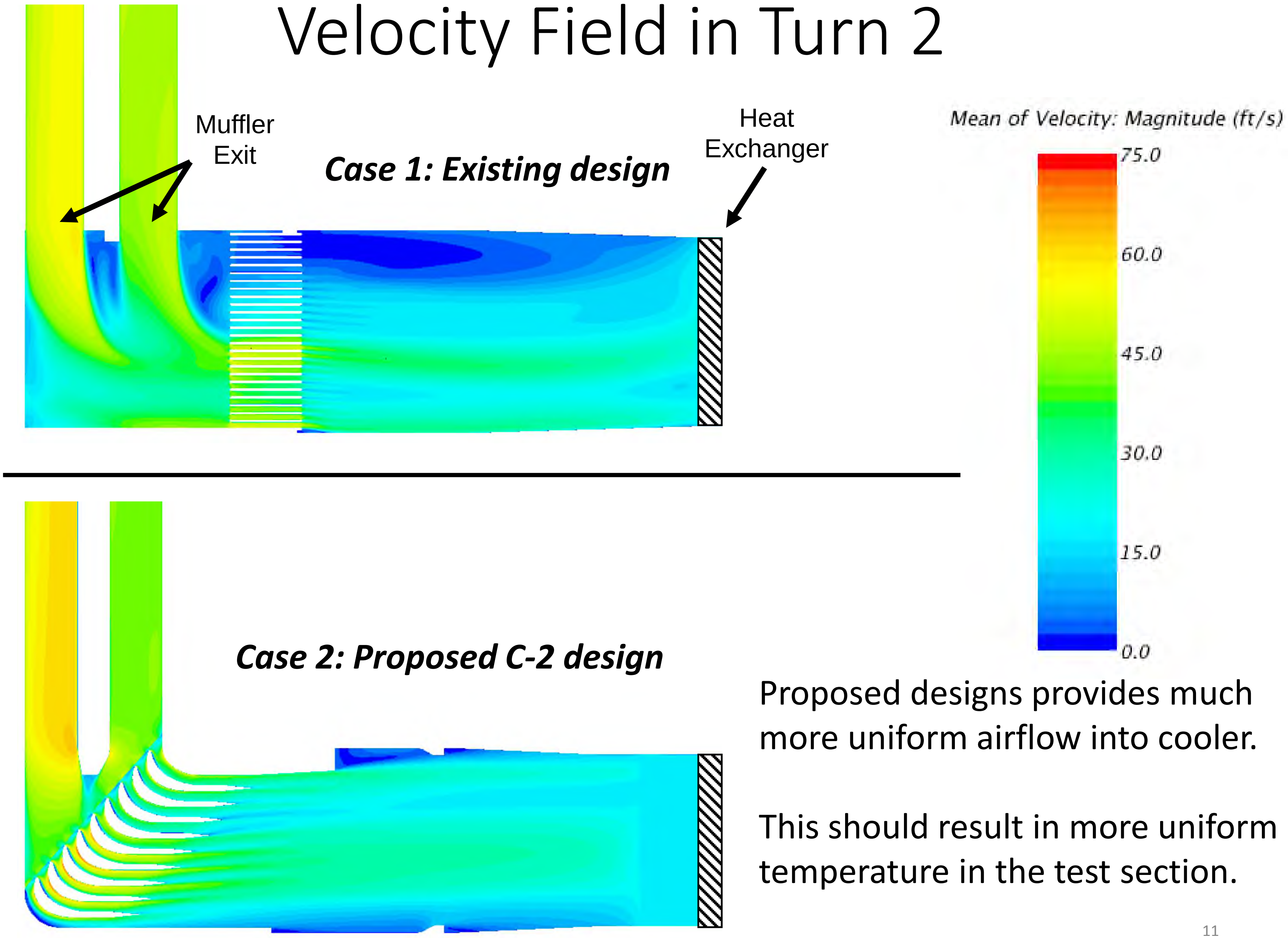
- Retain the original muffler concrete.
- Increase flow resistance with screen.
- Add turning vanes and aerodynamic fairings.



9x15 Wind Tunnel Upgrade-3

JACOBS

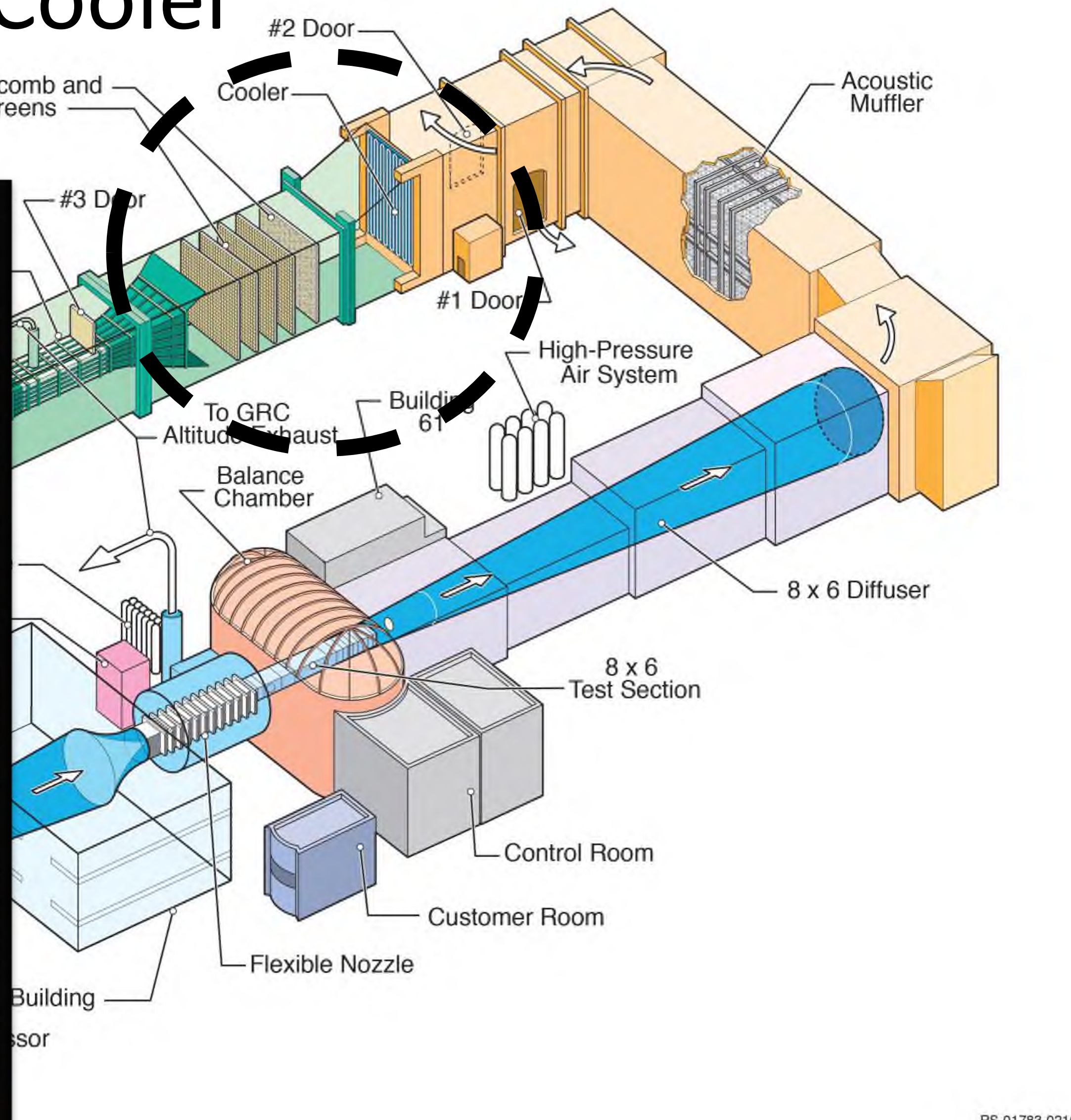
Velocity Field in Turn 2



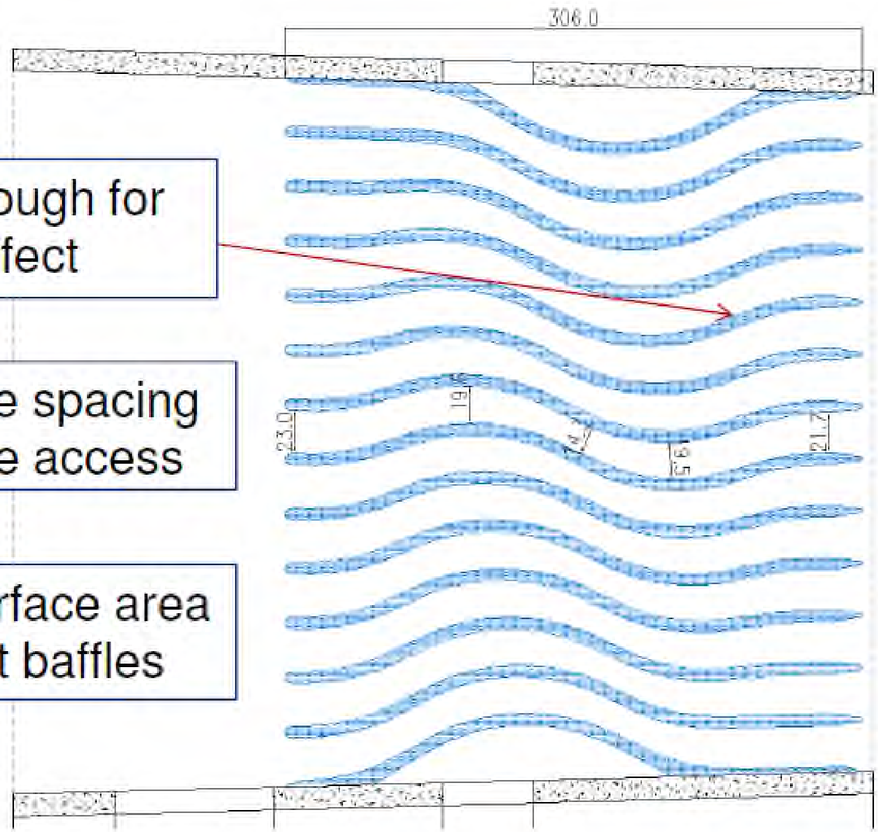
Proposed designs provides much more uniform airflow into cooler.

This should result in more uniform temperature in the test section.

Downstream of Cooler



Design of Serpentine Baffles



No see-through for beaming effect

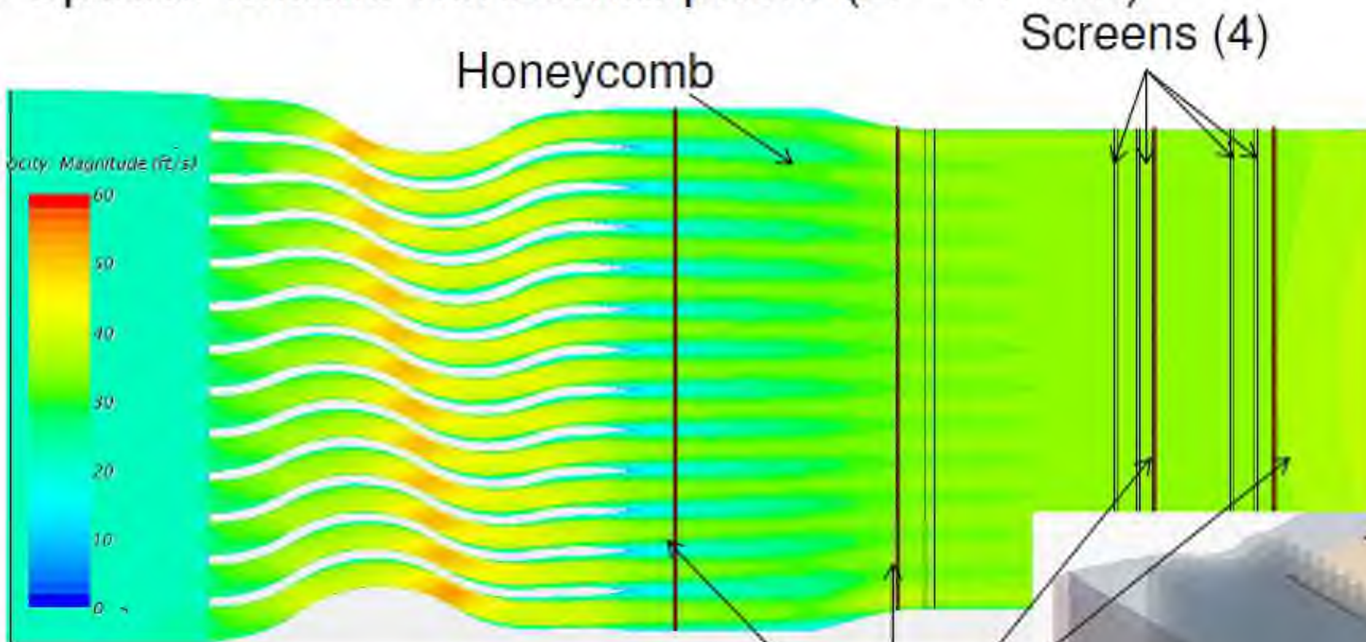
14.3" min. baffle spacing for maintenance access

15% reduction in surface area compared to straight baffles

Unit: Inches

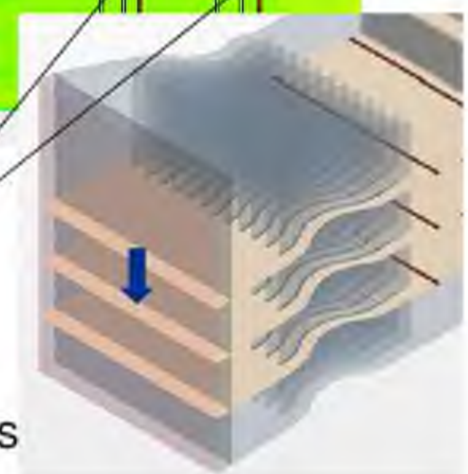
Velocity Solution

Flow Speed: Middle horizontal plane (Z = 17.3 ft)

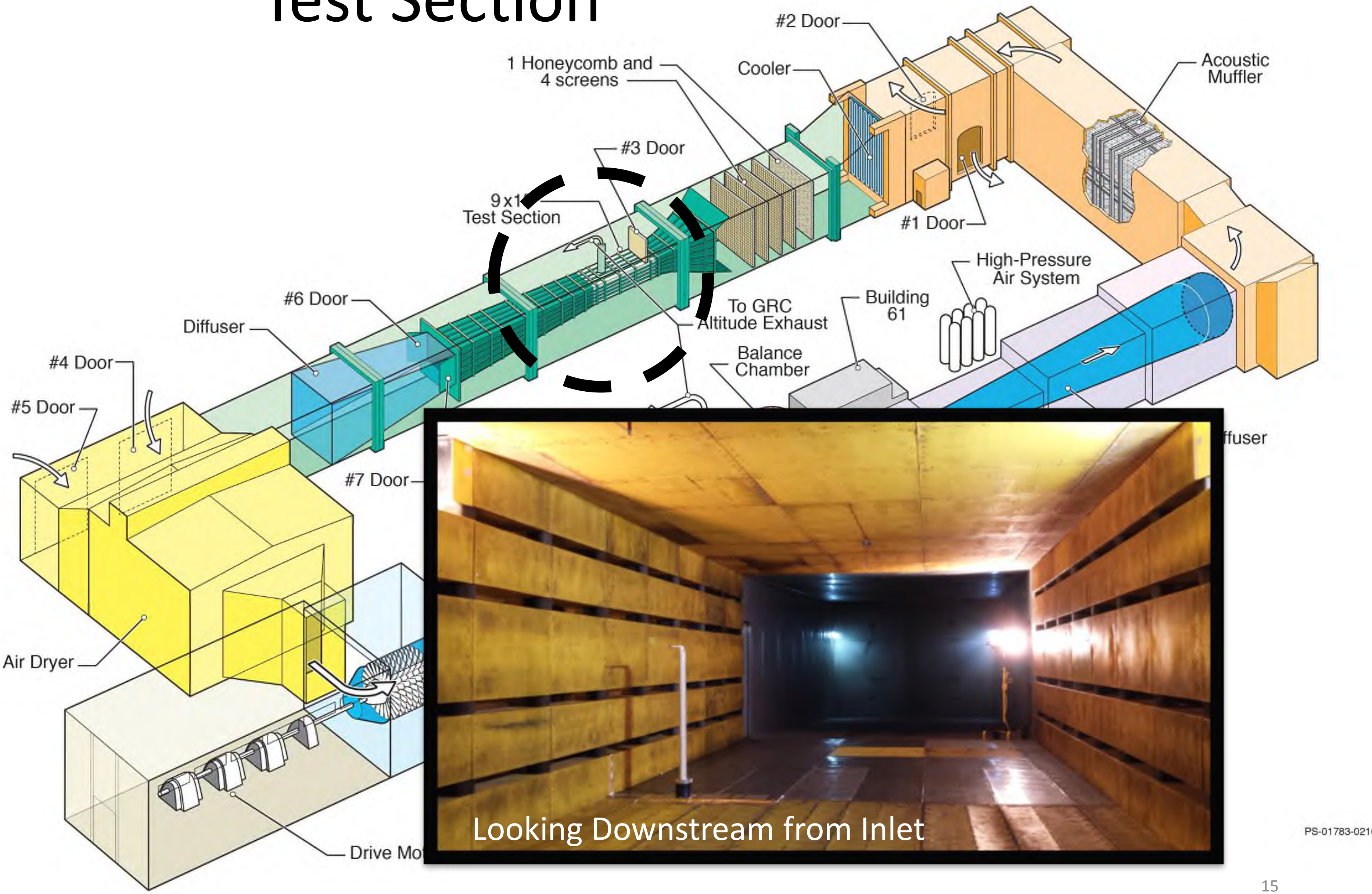


- Velocity variation reflects the passage geometry of commonality
- Attached flow throughout the baffles
- Mild velocity deviation in the wake

Flow Survey Locations



Test Section



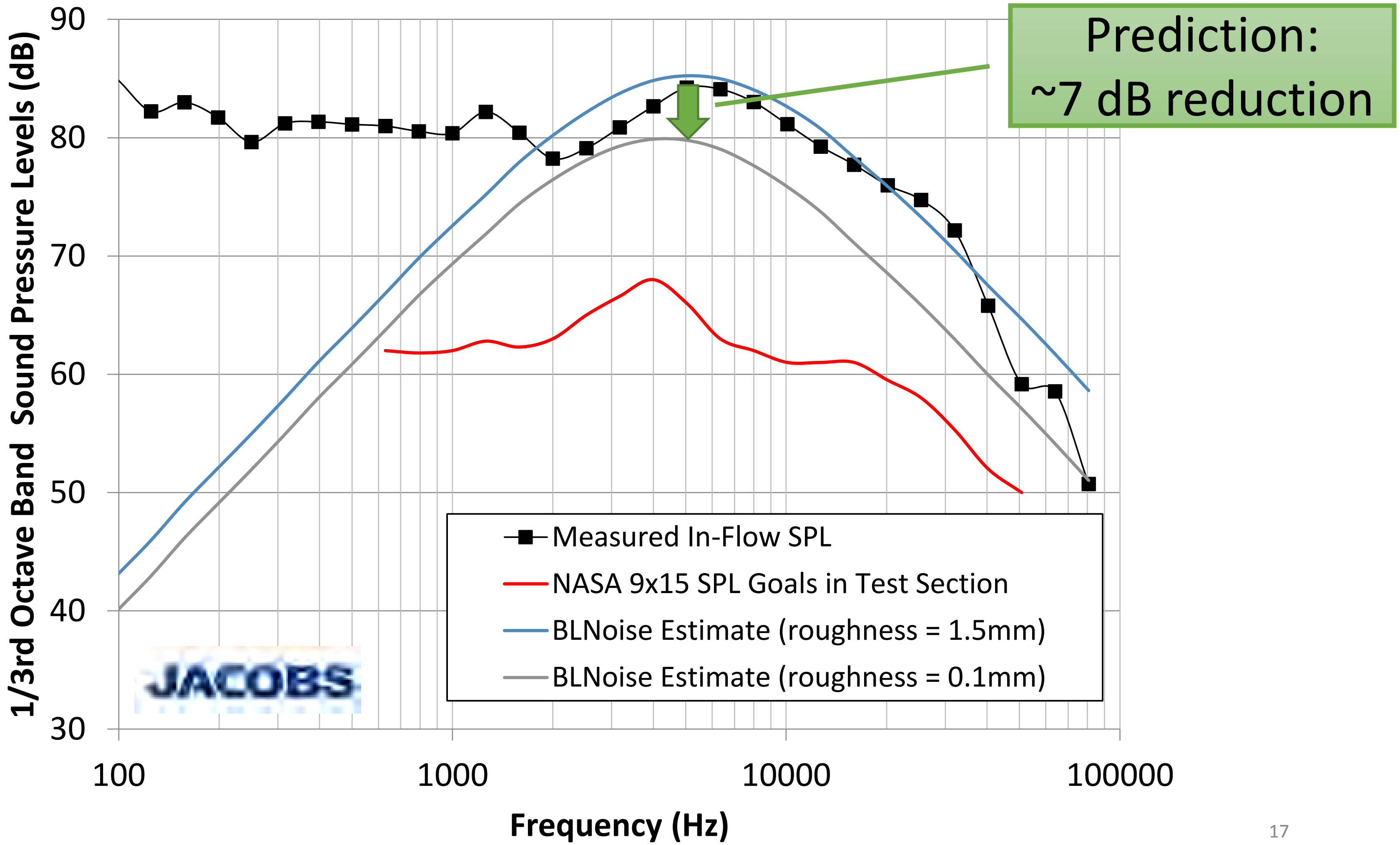
Current 9x15 Test Section

- The test section surface is perforated steel over a bulk Kevlar absorber
  - Facing plate is 16 ga, 1/8” holes, 40 percent open
- The acoustic treatment is built as dozens of individual boxes
  - There are slots in both walls, and many seams throughout the tunnel
- The 2012 study by Jacobs concluded that the majority of the noise in the 9x15 test section above 2 kHz is due to boundary layer flow over perforated steel surface

Test Section Perforated Metal (Current)

From Summer 2012 Study

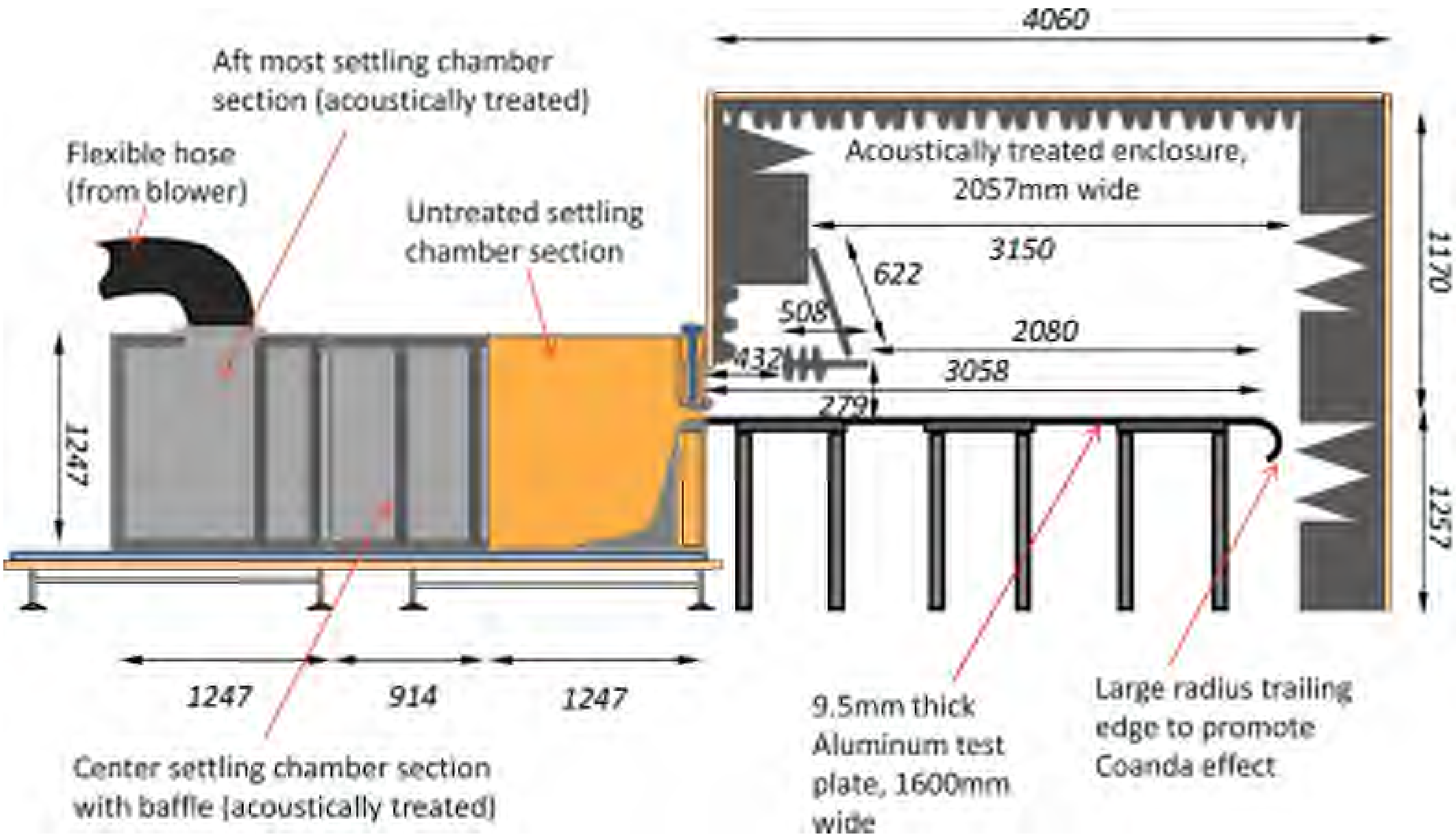
Jacobs concluded that the noise in the 9x15 test section above 2 kHz is due to airflow over the perforated steel tunnel walls



Proposal to improve the 9x15

- Jacobs estimated a 7 dB reduction in roughness noise is possible by replacing the current wind tunnel surface with a woven glass fiber cloth, lowering roughness from 1.5mm to 0.1mm (not including seams)
- It is a synthetic fabric made of flat weave bonded to a coated perforated metal sheet
- Sample shown →

Roughness Noise Facility at Virginia Tech

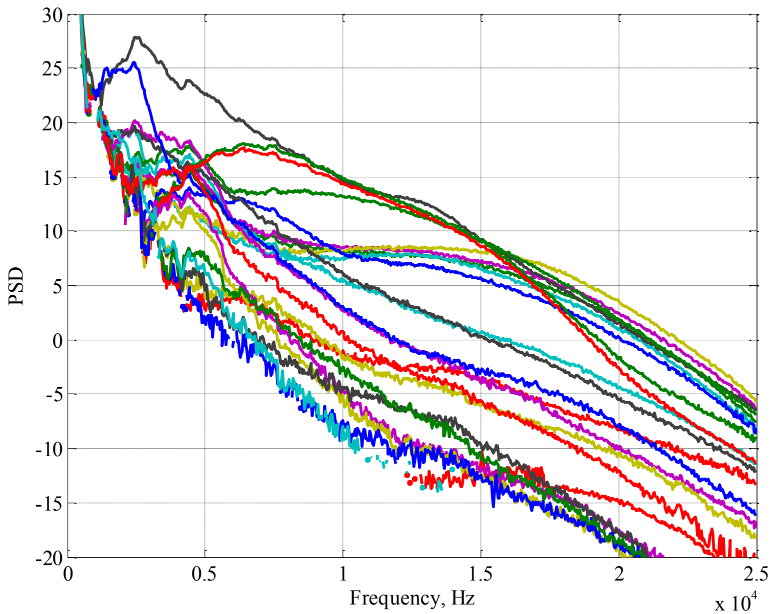


Inside Virginia Tech Facility 2014

Test section modification successful, allowing flush mounted samples with deep acoustic treatment below.

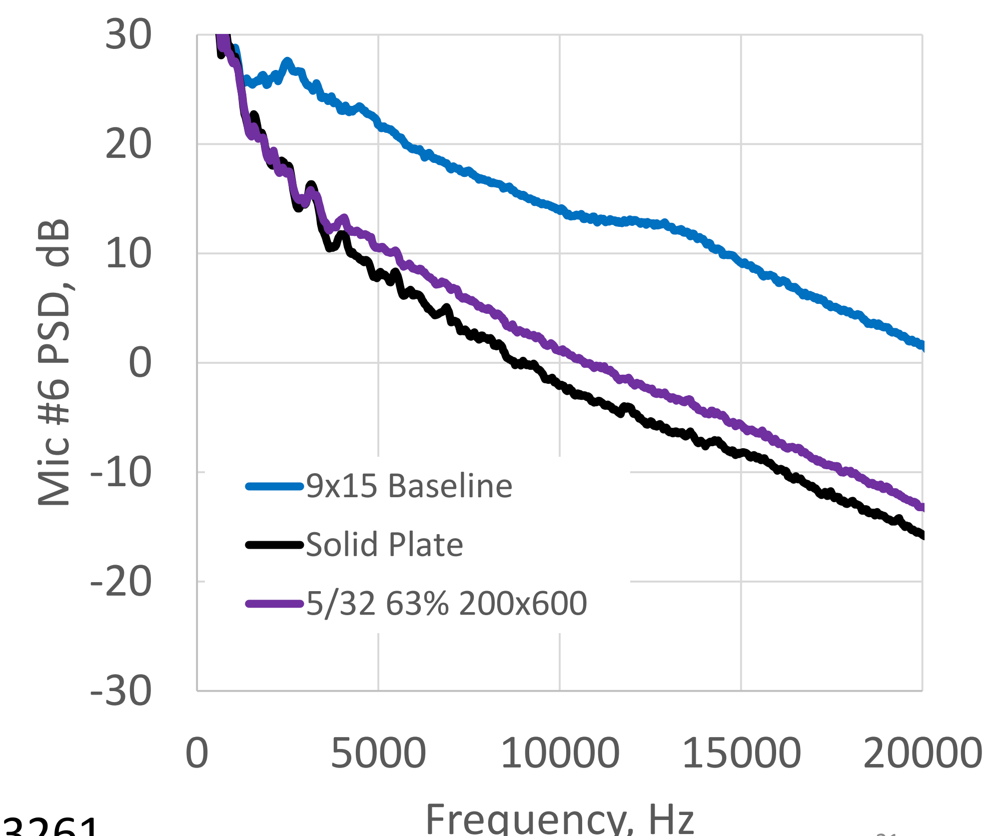
Extensive roughness noise testing at Virginia Tech to find quiet surface

- More than 30 samples tested
- Combinations of
  - Perforate (hole size, % open, thickness)
  - Covering (glass cloth, wire mesh)



- Very wide range of results
- For more information, see AIAA-2015-3261

Substantial noise benefit possible by replacing current test section flow surface



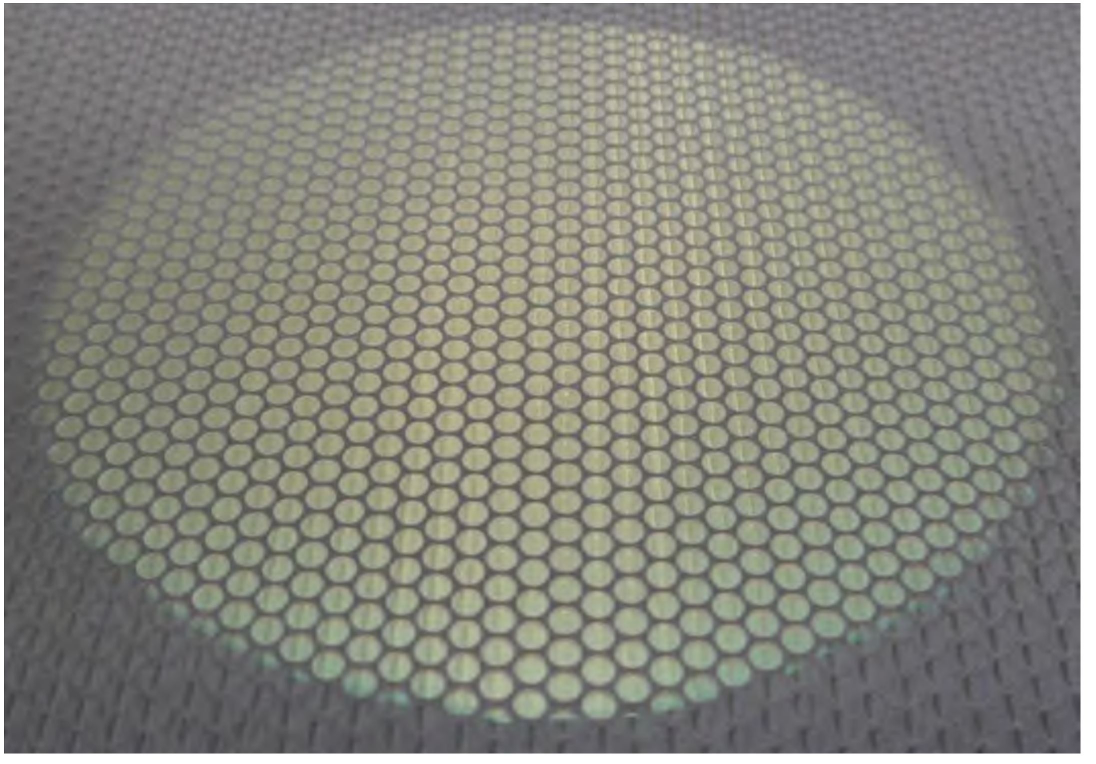
Diffusion Bonded Plates

Diffusion bonded plates (DBP) are produced by combining perforated sheet metal with fine wire cloth. These materials are joined in a vacuum furnace under heat and mechanical load in a process called diffusion bonding.

The function of the DBP is to allow passage of sound waves into bulk absorber material, while producing minimal self-noise under grazing flow.

DBP Details:

- 5/32” holes on 3/16” centers (63% open area) 16-gauge perforated sheet metal
- 200x600 Twilled Dutch Weave wire cloth
- 304 stainless steel cloth and plate
- Wire cloth “dimples” (depressions over perforations) approx. 0.005” deep
- Flow resistivity ~12 CGS Rayls

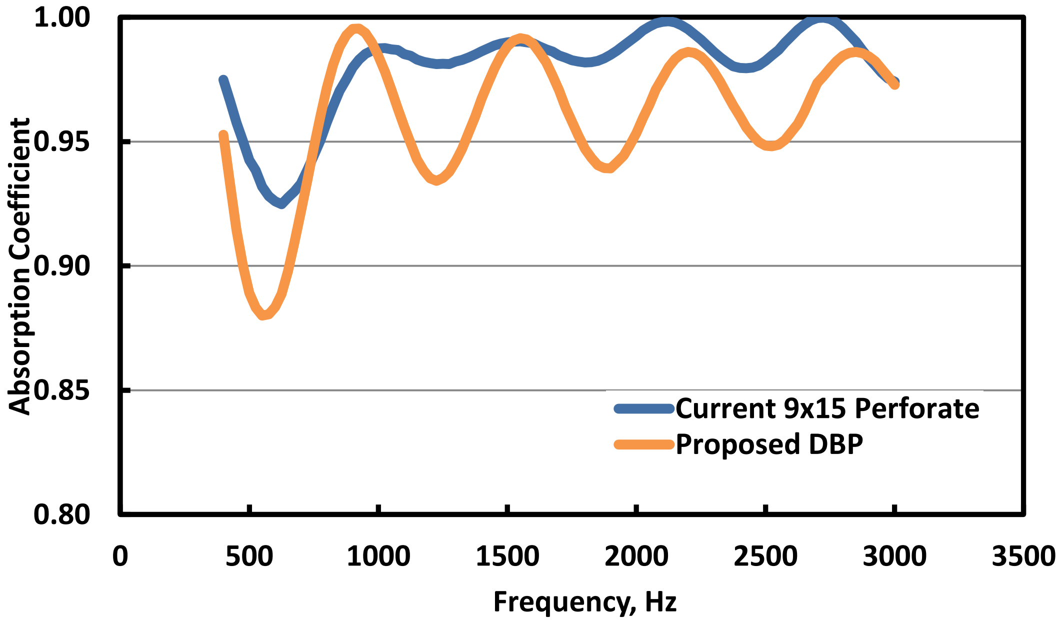


Goal: Minimal impact to anechoic quality

- Lower self noise AND maintain anechoic quality
- Impact of wire cloth over perforate has been investigated, examples given in next four slides
  - LaRC Normal Incidence Tube
  - Riverbank Acoustical Laboratory
  - Glenn Acoustical Testing Laboratory
  - LaRC Curved Duct Test Rig
- Testing of reinforced panels in GRC Acoustics Lab is pending
- Anechoic quality of test section to be assessed by external contractor according to ISO 26101 during July 2016

NASA Langley Normal Incidence Tube

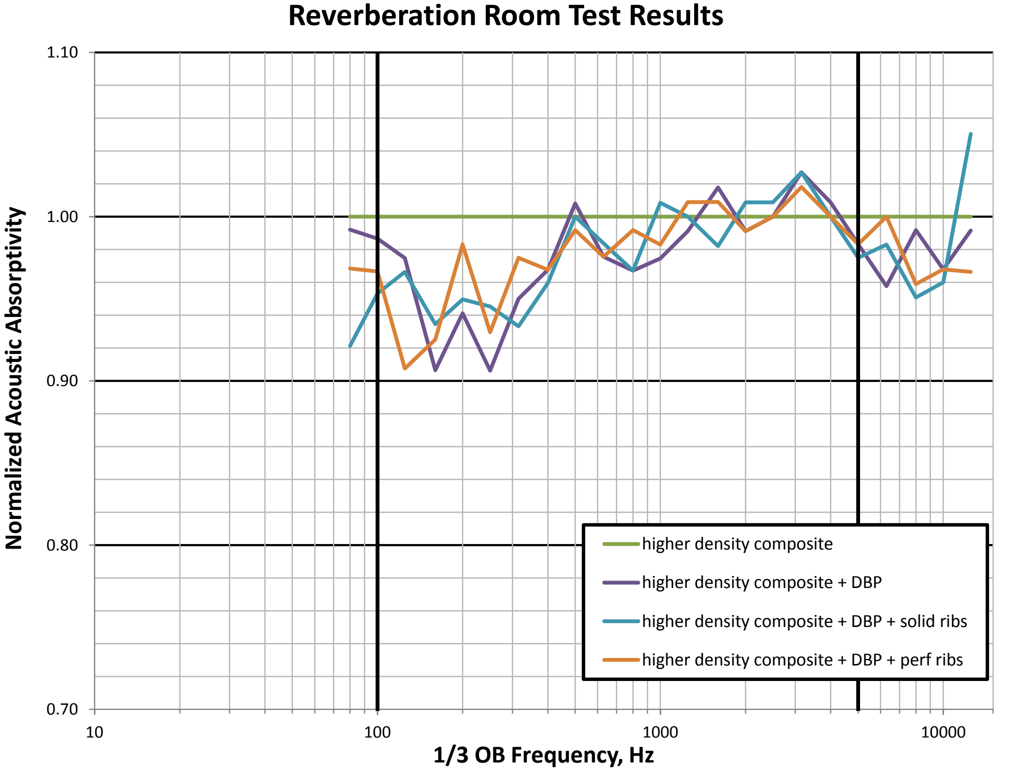
- Established facility
- Built for liner testing
- Limited to 3000 Hz, plane waves
- Ripples due to depth of bulk absorber



Langley Normal Incidence Tube

Reverberation room test at Riverbank Acoustical Laboratory

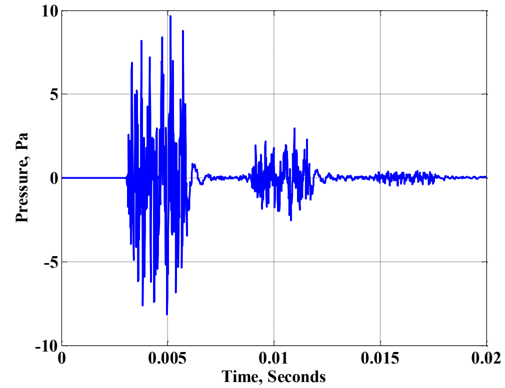
Six configurations were tested, with variation in bulk absorber density, with and without perforated panel covering and with different panel rib arrangements.

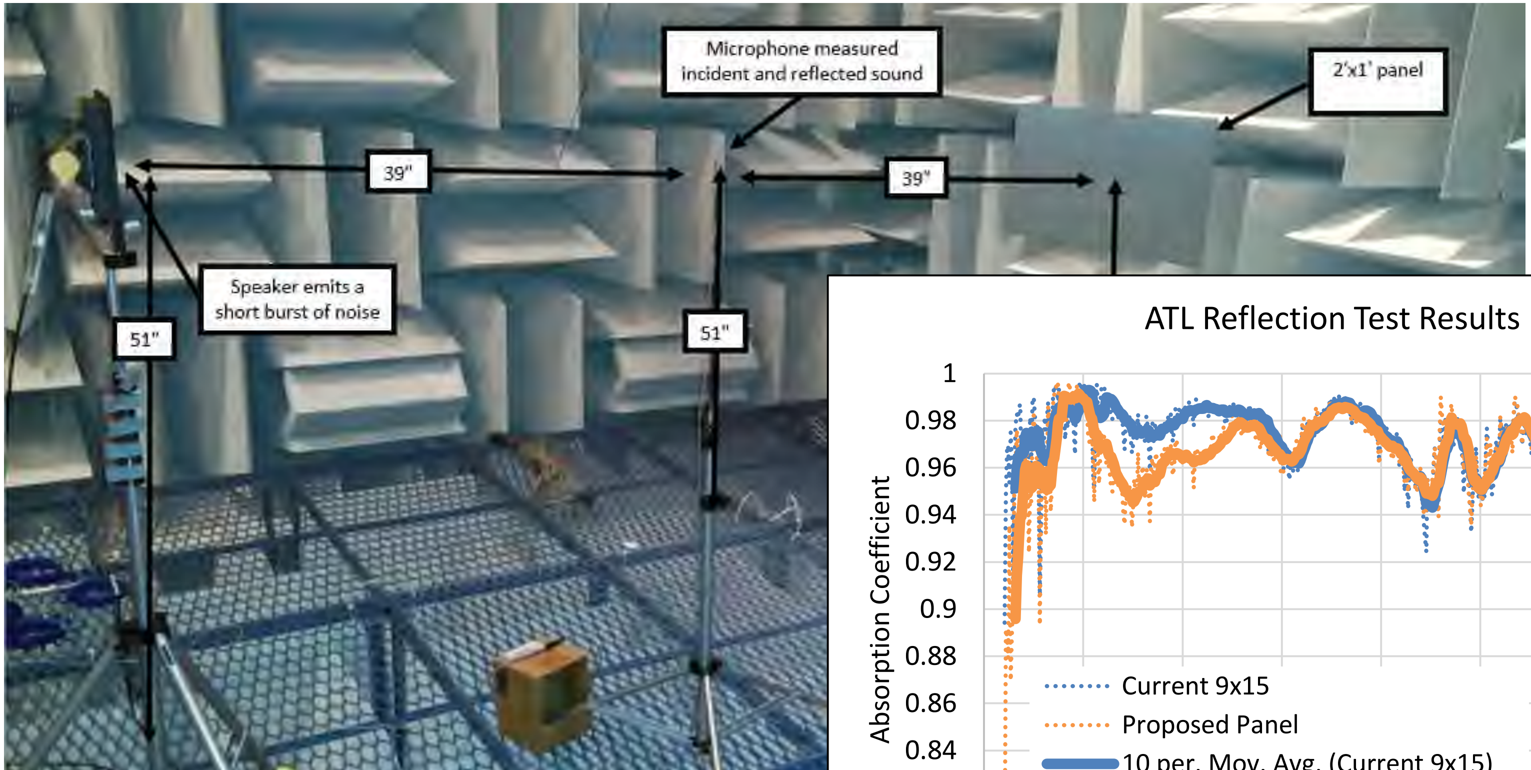


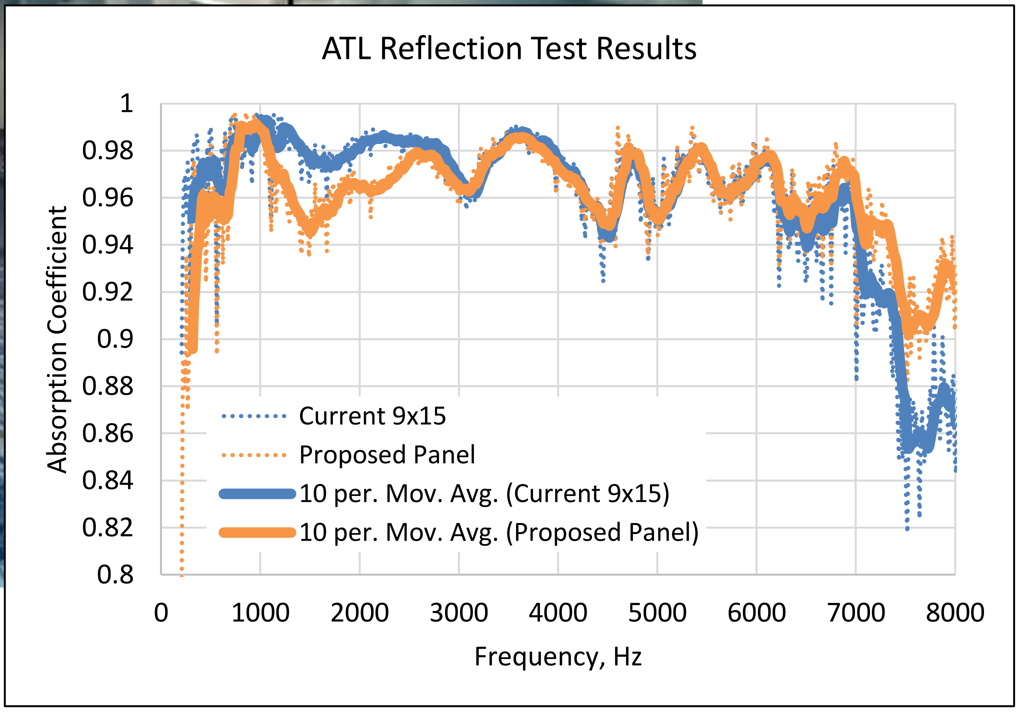
The DBP causes < 3% absorption reduction above 400 Hz.

Reflection Test at NASA Glenn Acoustical Testing Laboratory

- Not limited in frequency range
- Accurate positioning a challenge

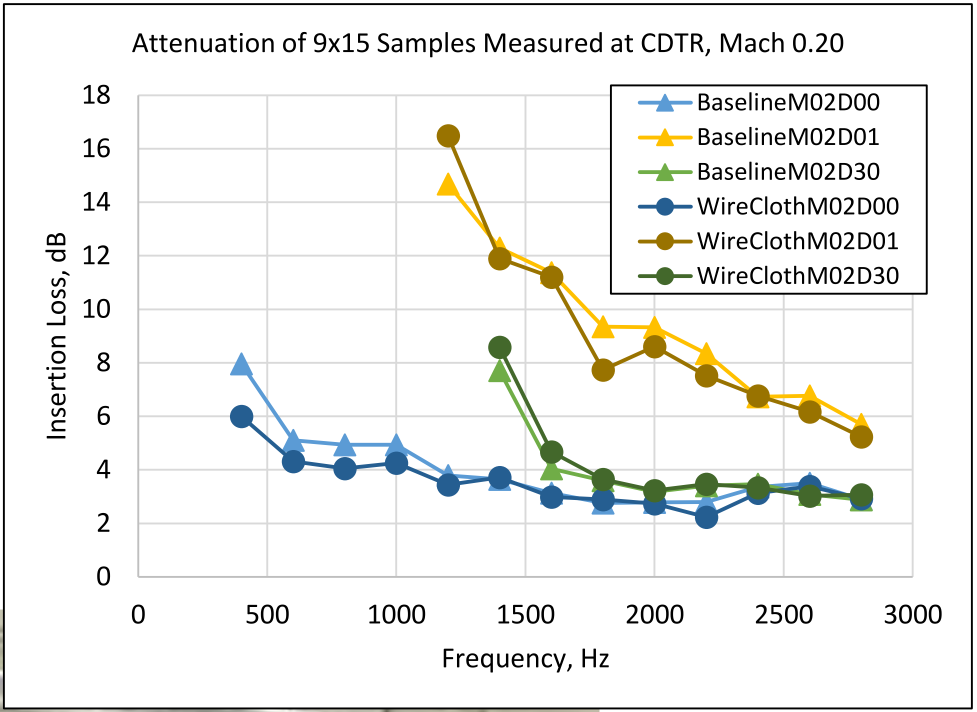


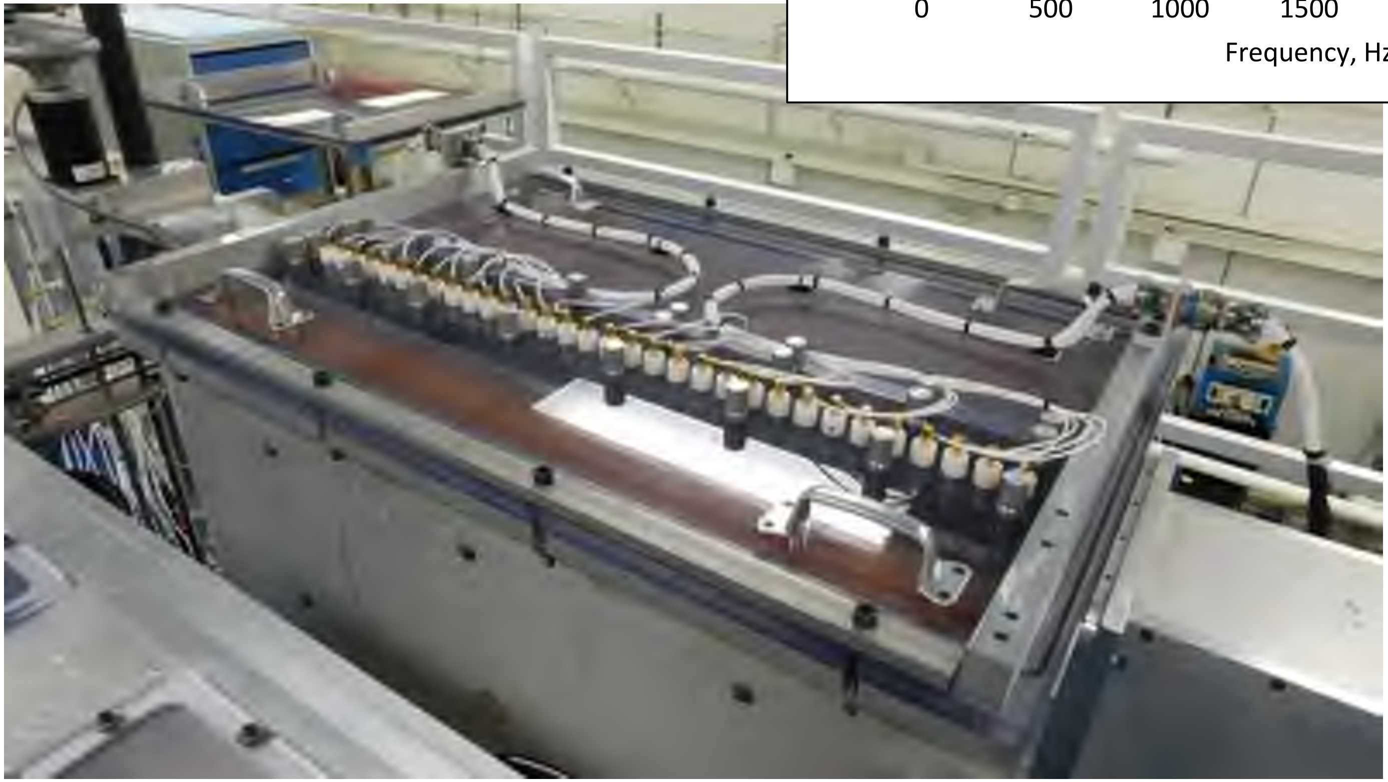




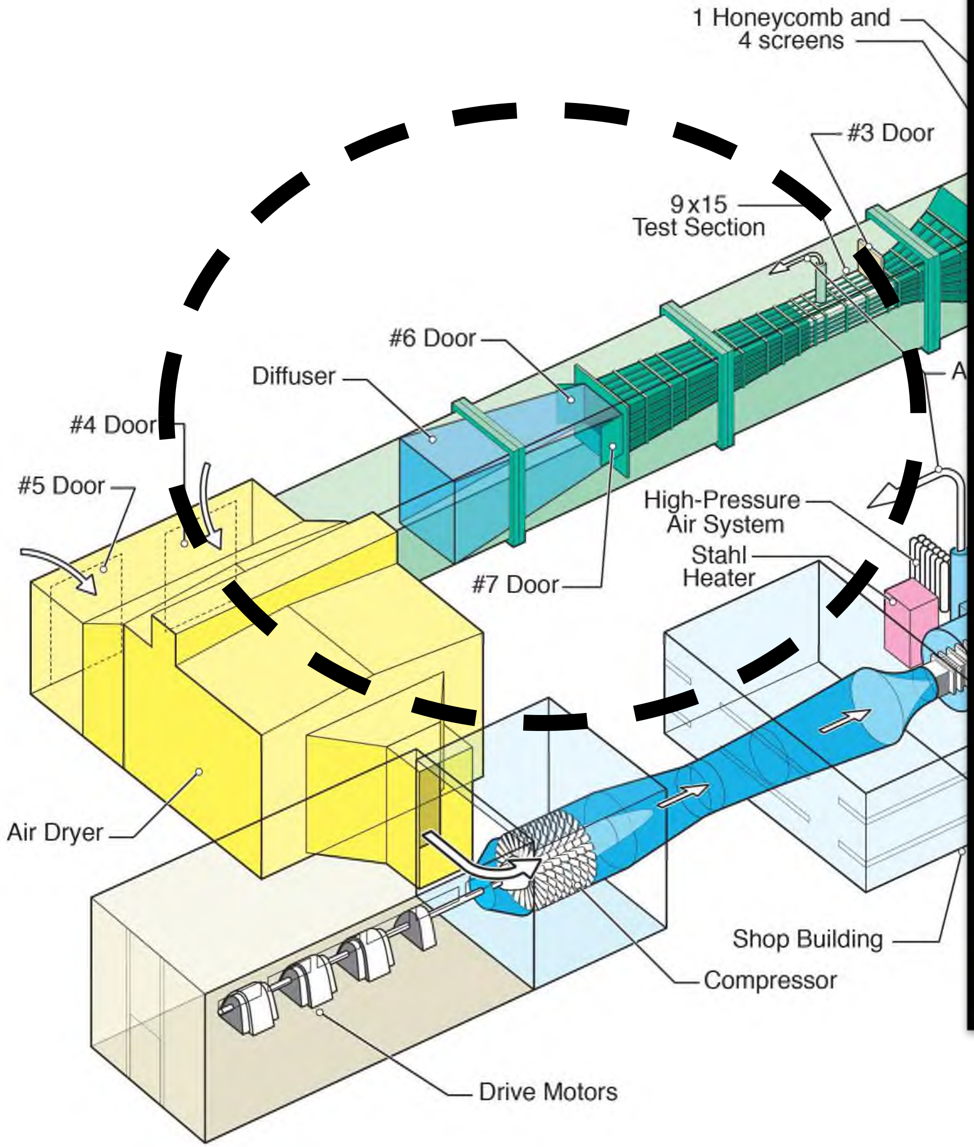
NASA Langley Curved Duct Test Rig

- Engine liner test with flow
- Rectangular duct modes
- Limited to 3000 Hz





Diffuser



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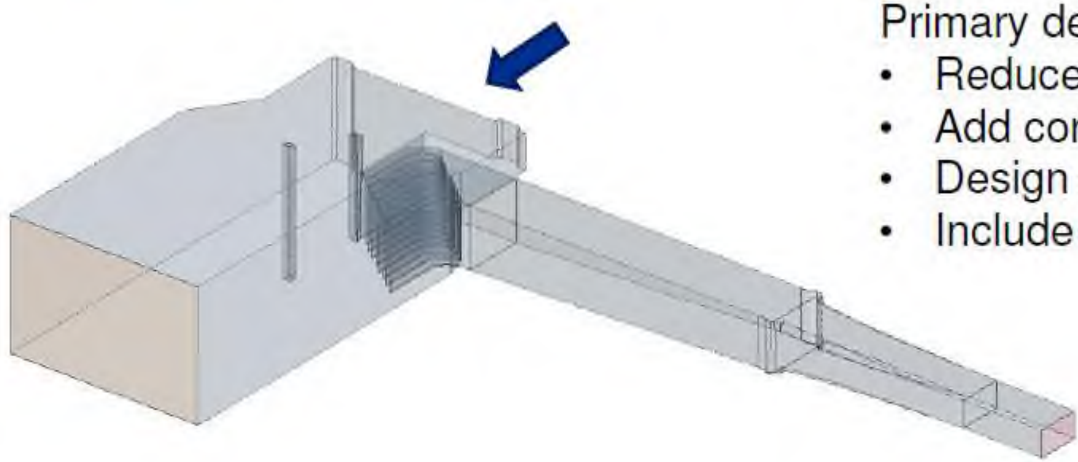
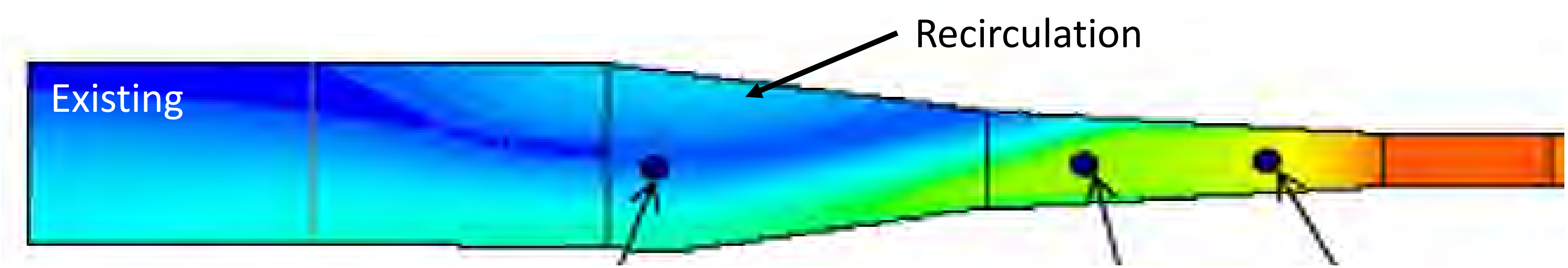
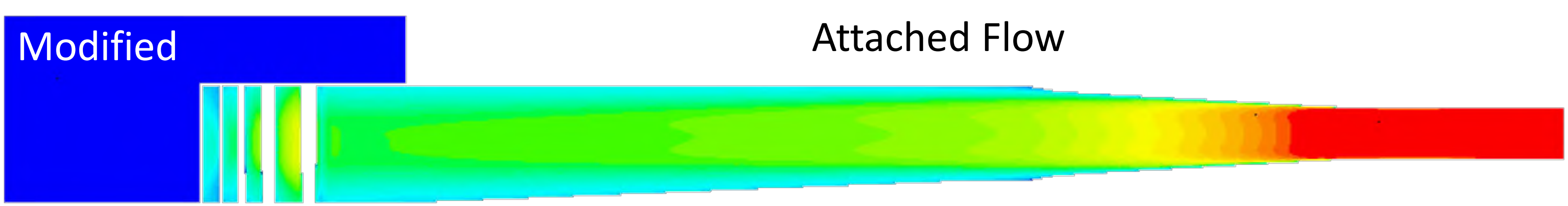
Design of Modified Diffuser



Primary design features:

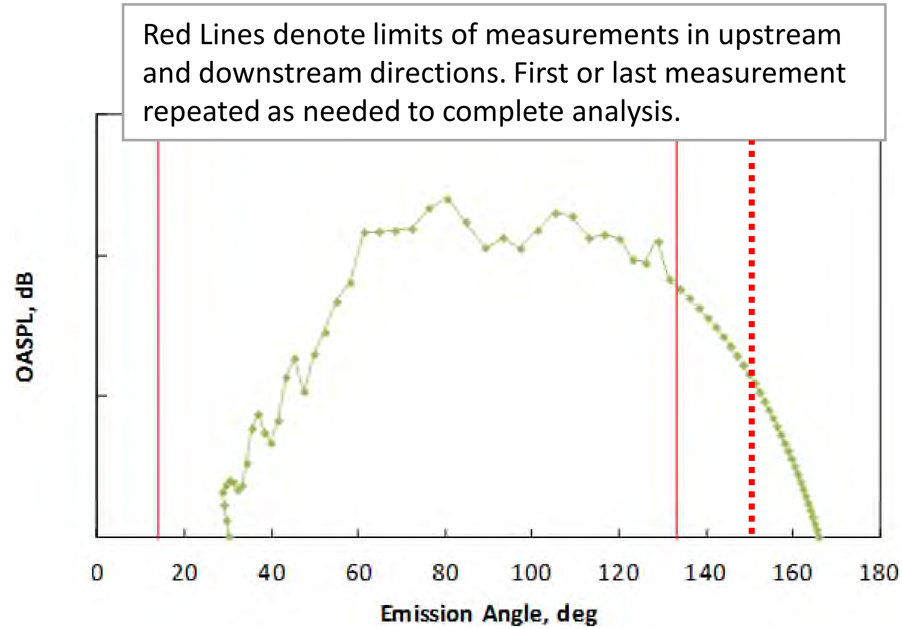
- Reduce overall area ratio.
- Add corner fillets.
- Design strategic flow separation.
- Include corner 3 turning vanes.

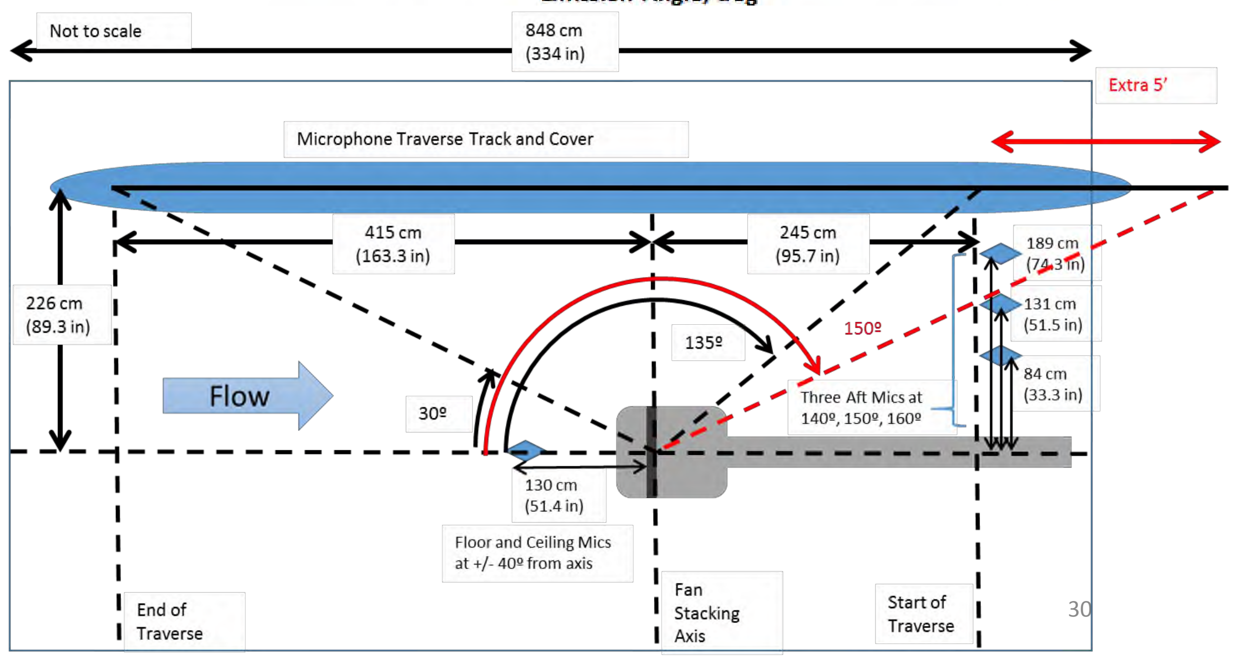




Test Section to be lengthened 5-feet into diffuser

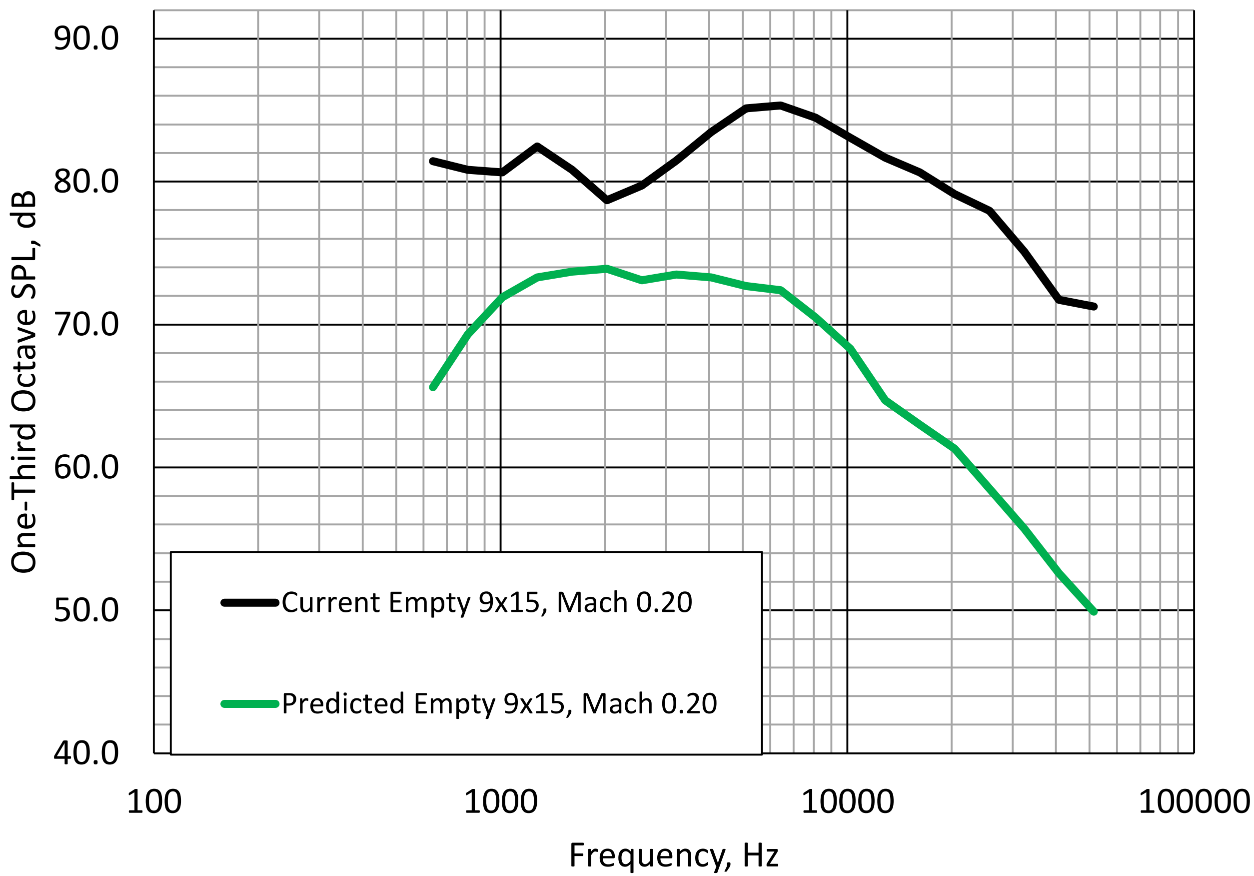
- Current test section length restricts aft measurement angles
- Floor mounted microphones are a marginal solution
- This can have a significant impact on EPNL calculations
- The addition of a 5-foot straight extension into the current diffuser will enable measurement to 150º geometric from upstream





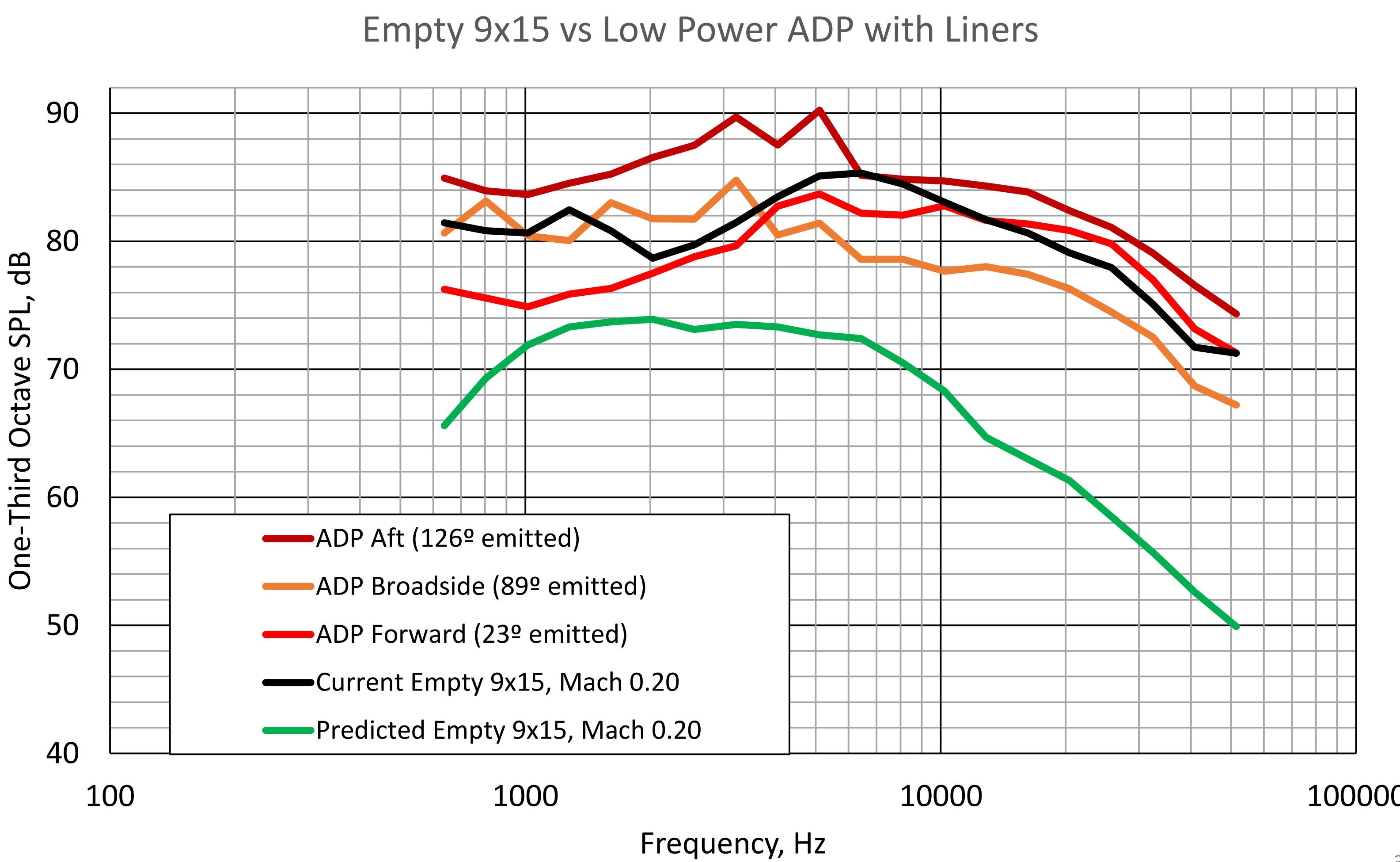
Anticipated Improvement to 9x15 noise levels after all 5 upgrades

Frequency	Empty Tunnel, (2012)	Jacobs Prediction
630	81.4	65.6
794	80.8	69.3
1000	80.6	71.9
1260	82.5	73.3
1587	80.8	73.7
2000	78.7	73.9
2520	79.7	73.1
3175	81.5	73.5
4000	83.5	73.3
5040	85.1	72.7
6350	85.3	72.4
8000	84.5	70.5
10079	83.1	68.3
12699	81.7	64.7
16000	80.6	63.0
20159	79.1	61.3
25398	77.9	58.5
32000	75.1	55.7
40317	71.7	52.6
50797	71.3	49.9



Acceptance criteria: No less than 3 dB from prediction

Relative to P&W Advanced Ducted Propulsor (ADP) Model Fan Measurements



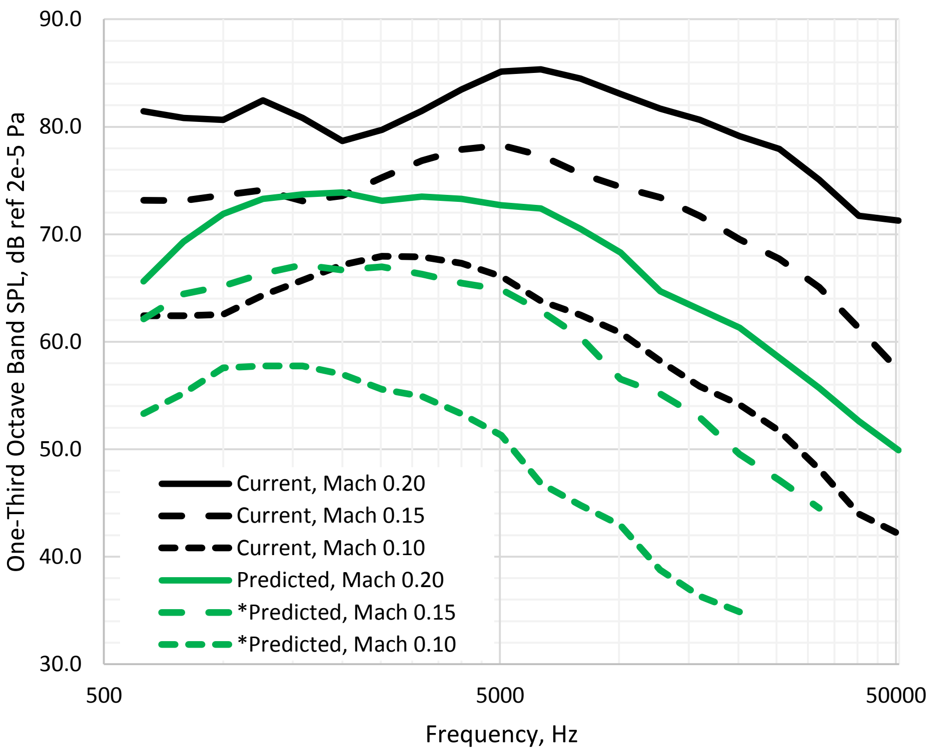
Summary

- GRC responding to industry feedback on 9x15 background noise level requirements
- Design and build contract in place to implement changes to 9x15 for improvements and funding identified and going through approvals
- The work to date by suggests substantial reductions in background that will improve signal-to-noise required in future systems
- Additional work on measurement and signal processing are expected to create additional signal-to-noise headroom

Additional Materials

Noise Predictions for Other Mach Numbers

Frequency	Current Mach 0.10	Current Mach 0.15	Current Mach 0.20	Predicted Mach 0.10*	Predicted Mach 0.15*	Predicted Mach 0.20
630	62.4	73.1	81.4	53.3	62.1	65.6
794	62.4	73.1	80.8	55.2	64.4	69.3
1000	62.5	73.6	80.6	57.6	65.2	71.9
1260	64.3	74.1	82.5	57.7	66.3	73.3
1587	65.7	73.1	80.8	57.8	67.1	73.7
2000	67.1	73.6	78.7	57.0	66.7	73.9
2520	67.9	75.3	79.7	55.6	67.0	73.1
3175	67.9	76.8	81.5	54.9	66.3	73.5
4000	67.3	77.9	83.5	53.3	65.5	73.3
5040	66.1	78.3	85.1	51.3	64.9	72.7
6350	63.8	77.3	85.3	46.8	62.9	72.4
8000	62.5	75.6	84.5	44.8	60.4	70.5
10079	60.8	74.4	83.1	42.9	56.5	68.3
12699	58.2	73.4	81.7	38.8	55.1	64.7
16000	55.8	71.7	80.6	36.3	53.0	63.0
20159	54.1	69.5	79.1	34.9	49.5	61.3
25398	51.7	67.7	77.9		47.1	58.5
32000	48.1	65.0	75.1		44.5	55.7
40317	44.0	61.3	71.7			52.6
50797	42.1	57.3	71.3			49.9



* Provided prediction is for Mach 0.20, scaled to other Mach numbers by NASA. The prediction was scaled in frequency by the Mach number ratio and in amplitude to mimic the current noise.