A Design of Experiments Investigation of Offset Streams for Supersonic Jet Noise Reduction

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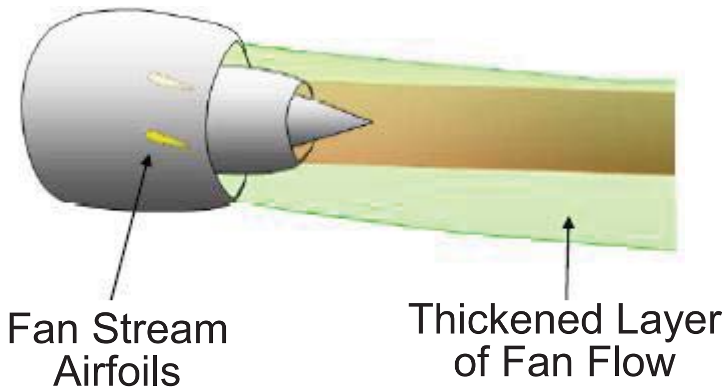
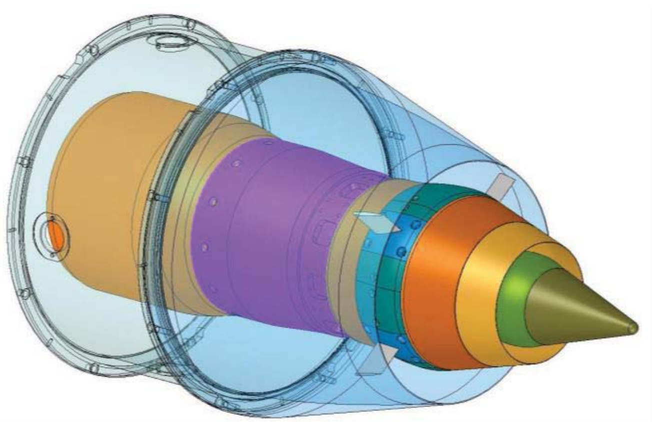
Purpose of Airfoils





Offset fan stream relative to core stream

- Lengthen secondary potential core on observation side of jet
- Reduce convective Mach number of the instability waves
- Reduce acoustic radiation associated with instability waves
- Alter turbulent kinetic energy

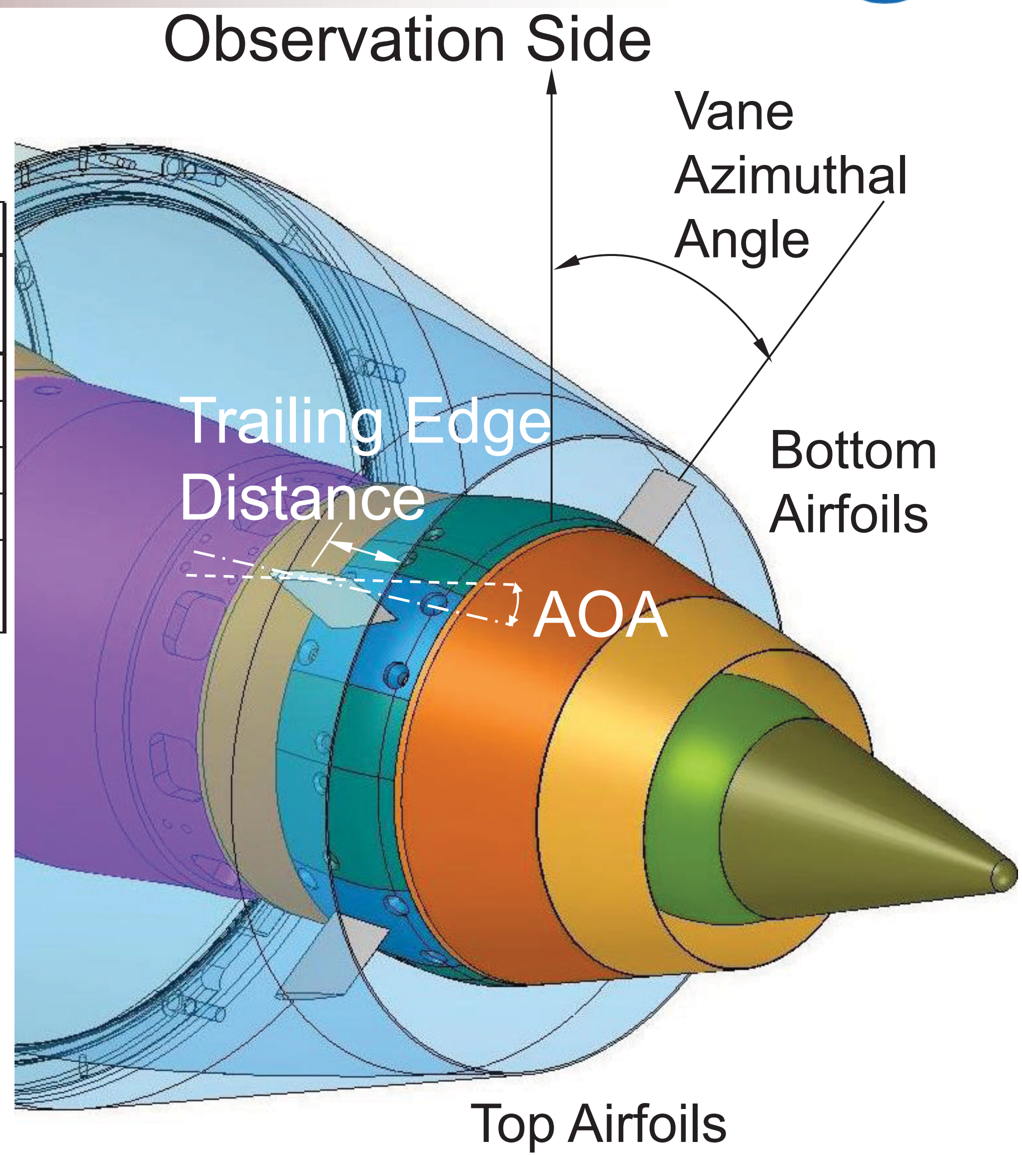
Objectives

- Perform a Design of Experiments (DoE) over large parametric range
- Using results of DoE, develop noise reduction models
  - Models will be used in NASA's Aircraft Noise Prediction Program (ANOPP)
  - Predictive capability will be used in future CFD study to understand flow-field leading to minimum noise

Parametric Study

Parametric Study				
Parameter	**Unit**	**Low Level**	**High Level**	**Center**
AOA Top (A)	deg	5	10	7.5
AOA Bottom (B)	deg	5	10	7.5
Azimuthal Top (C)	deg	120	150	135
Azimuthal Bottom (D)	deg	60	90	75
Trailing Edge Distance (E)	fraction of chord	-0.75	-0.50	-0.625

- Two level full factorial design
- Four data blocks
- Two center points/block
- Two baseline points/block

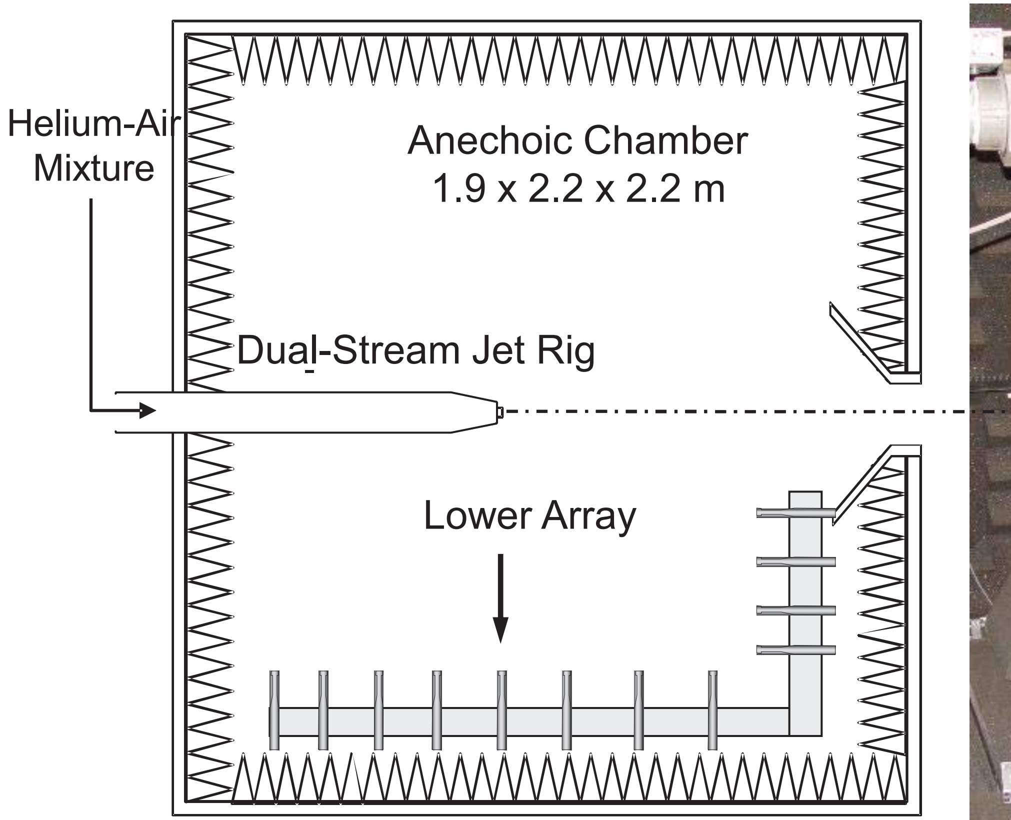


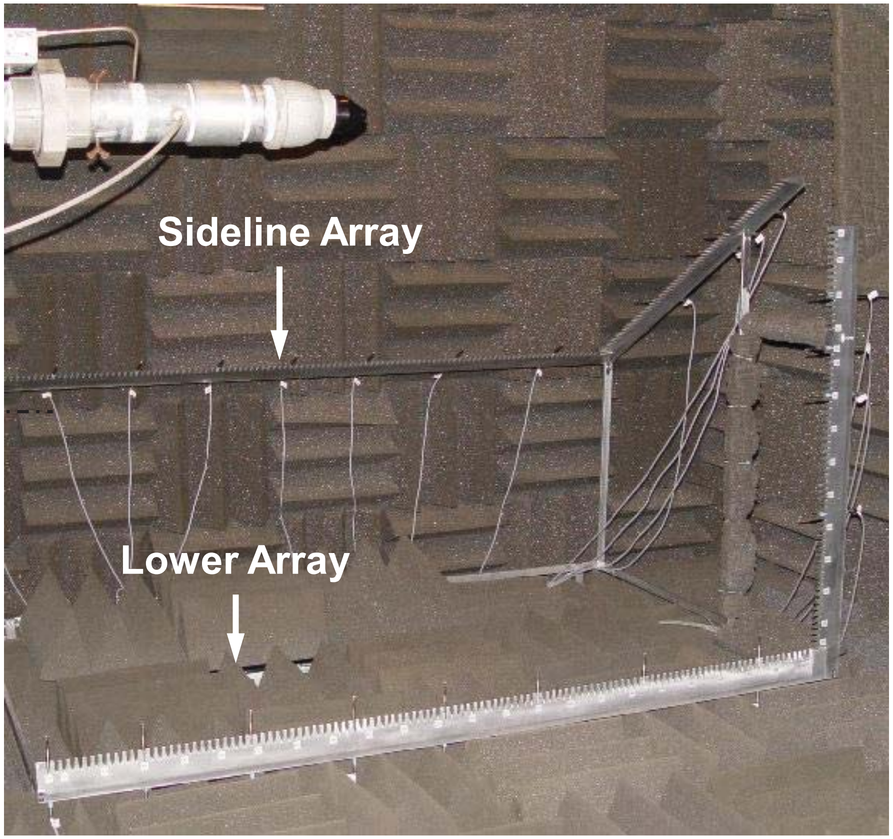
Cycle Points

Cycle	M_p	U_p (m/s)	M_s	U_s (m/s)	BPR
01	0.84	432	0.79	274	1.83
02	1.00	530	0.96	333	1.91
03	1.13	606	1.09	378	1.94
04	1.19	640	1.14	397	1.96

- Bypass ratio two nozzle system
- Cycle points based on system studies

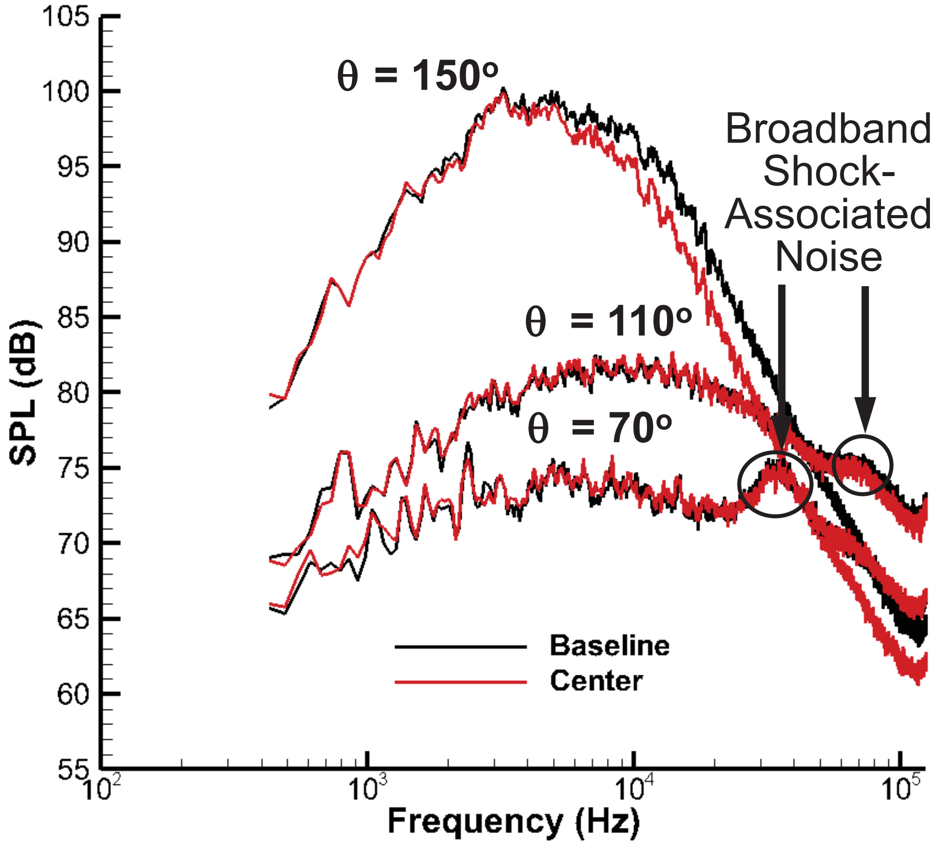
Experiments



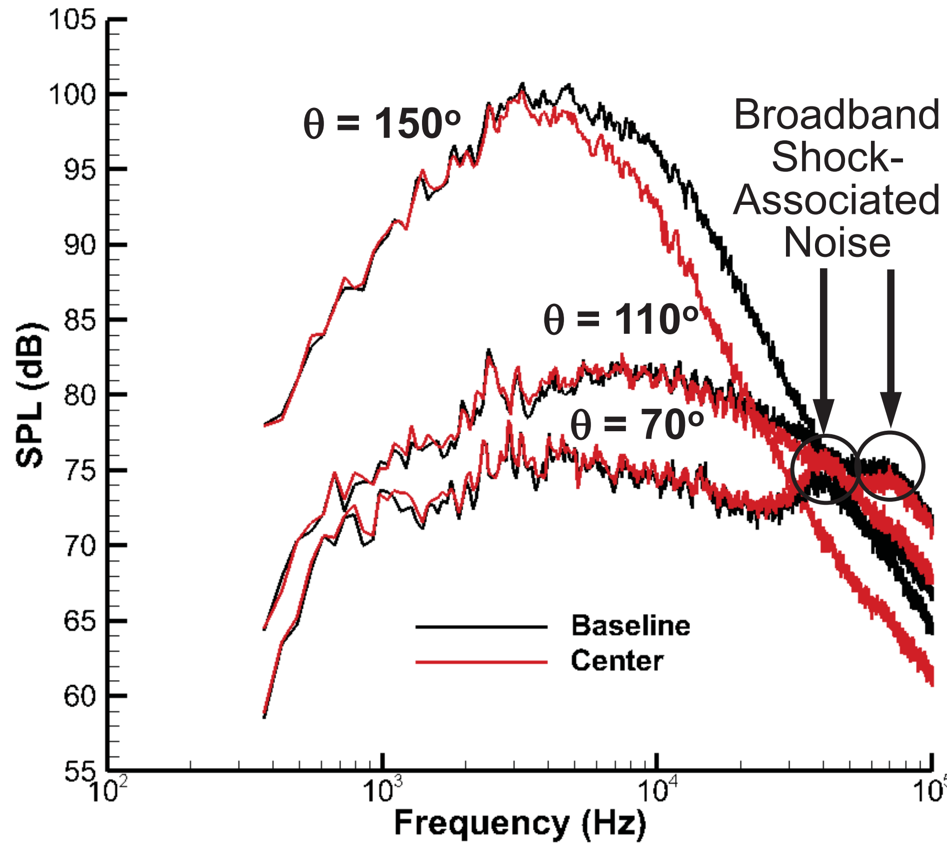


University of California, Irvine's Aeroacoustics Facility

Narrowband Results – Cycle 04

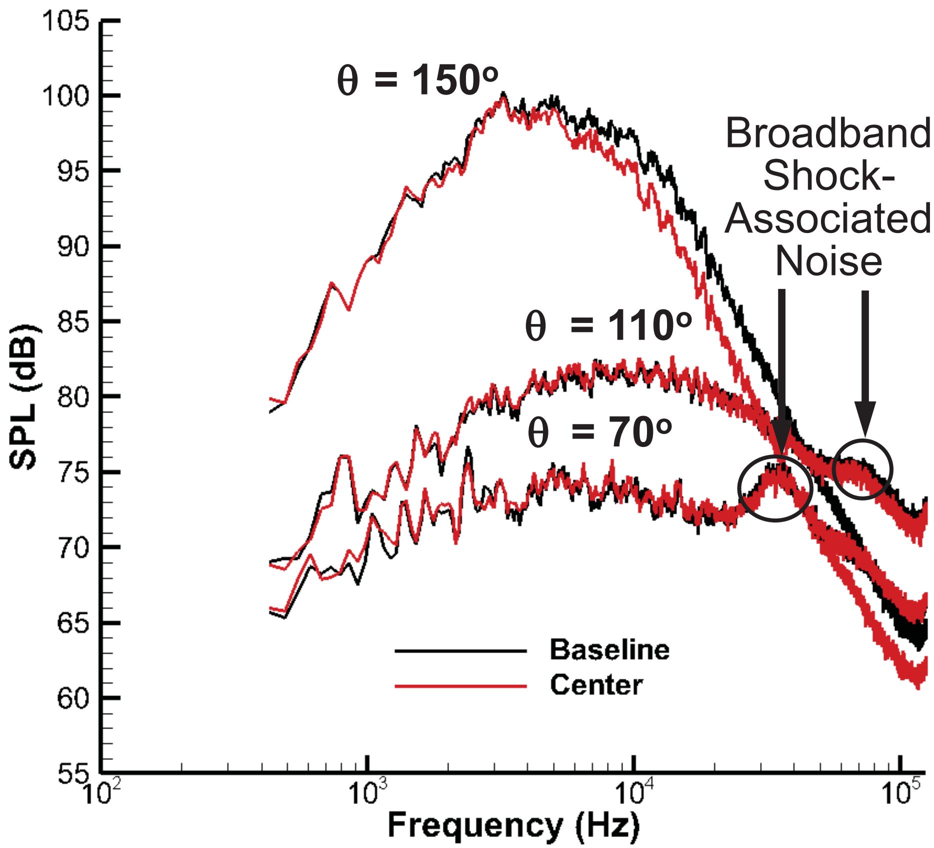


Sideline Array

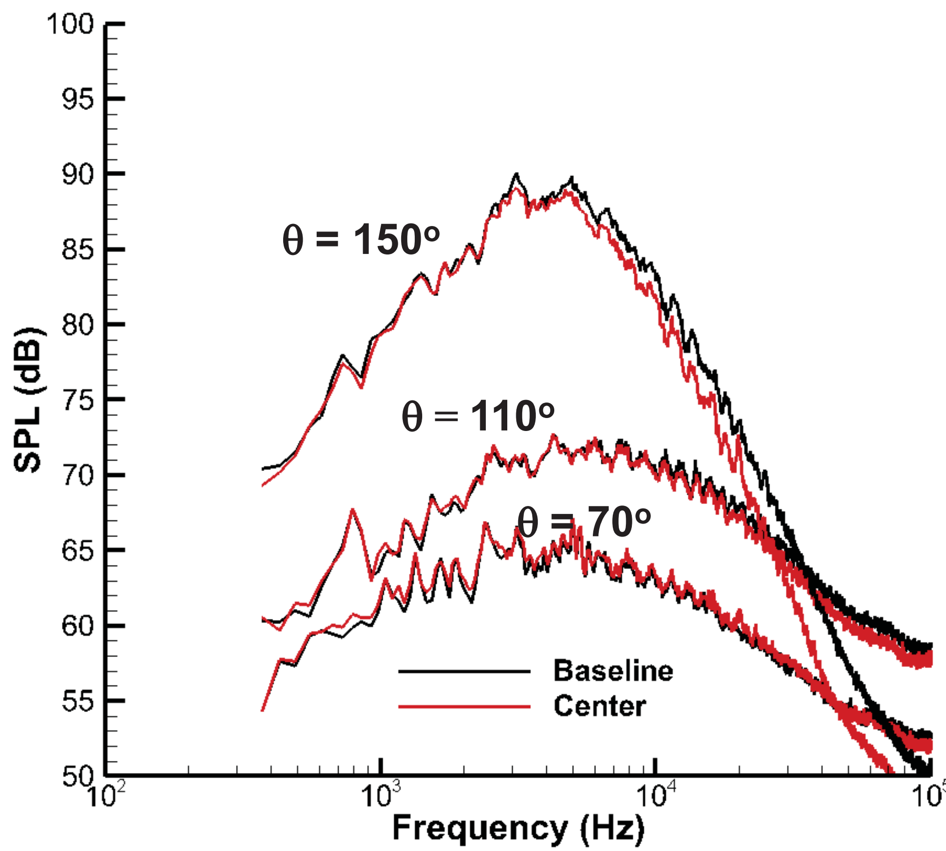


Lower Array

Narrowband Results – Sideline Array



Cycle 04



Cycle 01

Cycle Points

Cycle	M_p	U_p (m/s)	M_s	U_s (m/s)	BPR
01	0.84	432	0.79	274	1.83
02	1.00	530	0.96	333	1.91
03	1.13	606	1.09	378	1.94
04	1.19	640	1.14	397	1.96

Takeoff Condition

Model

$$(NR_{\frac{1}{3}} + k)^{\alpha} = Mean + CO_A A + CO_B B + CO_C C + CO_D D + CO_E E +$$

$$CO_{AB}AB + CO_{AC}AC + CO_{AD}AD + CO_{AE}AE + CO_{BC}BC +$$

$$CO_{BD}BD + CO_{BE}BE + CO_{CD}CD + CO_{CE}CE + CO_{DE}DE$$

$$+ CO_{ABC}ABC + CO_{ABD}ABD + CO_{ABE}ABE + CO_{ACD}ACD$$

$$+ CO_{ACE}ACE + CO_{ADE}ADE + CO_{BCD}BCD + CO_{BCE}BCE$$

$$+ CO_{BDE}BDE + CO_{CDE}CDE +$$

$$4\ Way\ Interactions + 5\ Way\ Interactions$$

1/3 Octave Bands
- Model Scale 37.5

Model Coefficients

NR = Base - Vane

Coded Parameter Levels

Low Level = -1

High Level = +1

Parameter	Low Level	High Level
AOA Top (A)	5	10
AOA Bottom (B)	5	10
Azimuthal Top (C)	120	150
Azimuthal Bottom (D)	60	90
Trailing Edge Distance (E)	-0.75	-0.50

1/3 Octave Band Results – Lower

Parametric Study				
Parameter	**Unit**	**Low Level**	**High Level**	**Center**
AOA Top (A)	deg	5	10	7.5
AOA Bottom (B)	deg	5	10	7.5
Azimuthal Top (C)	deg	120	150	135
Azimuthal Bottom (D)	deg	60	90	75
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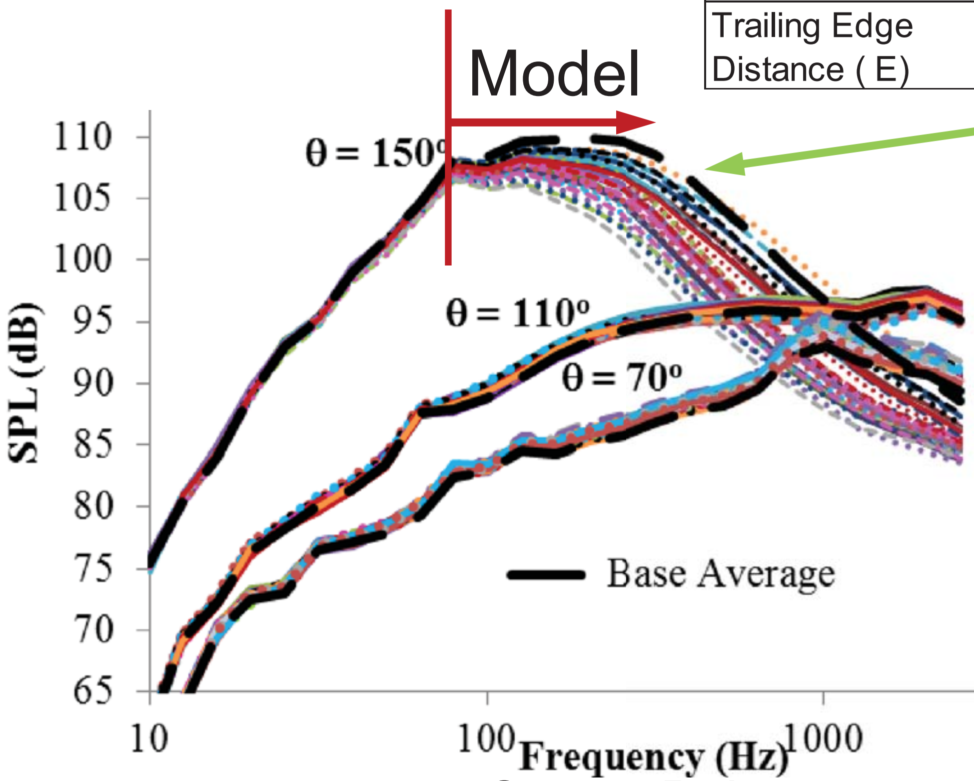
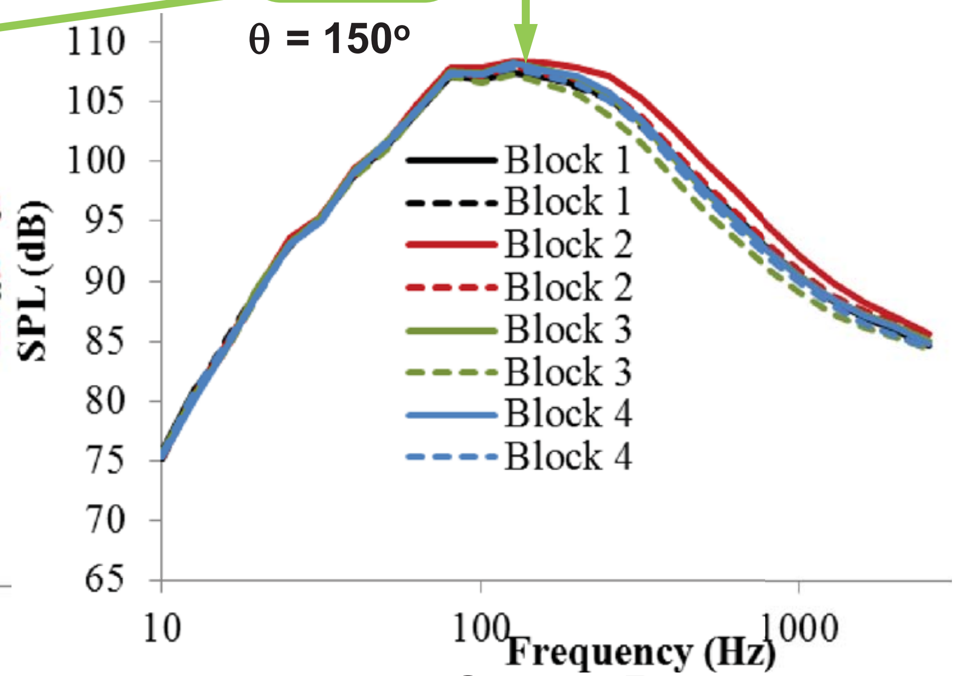


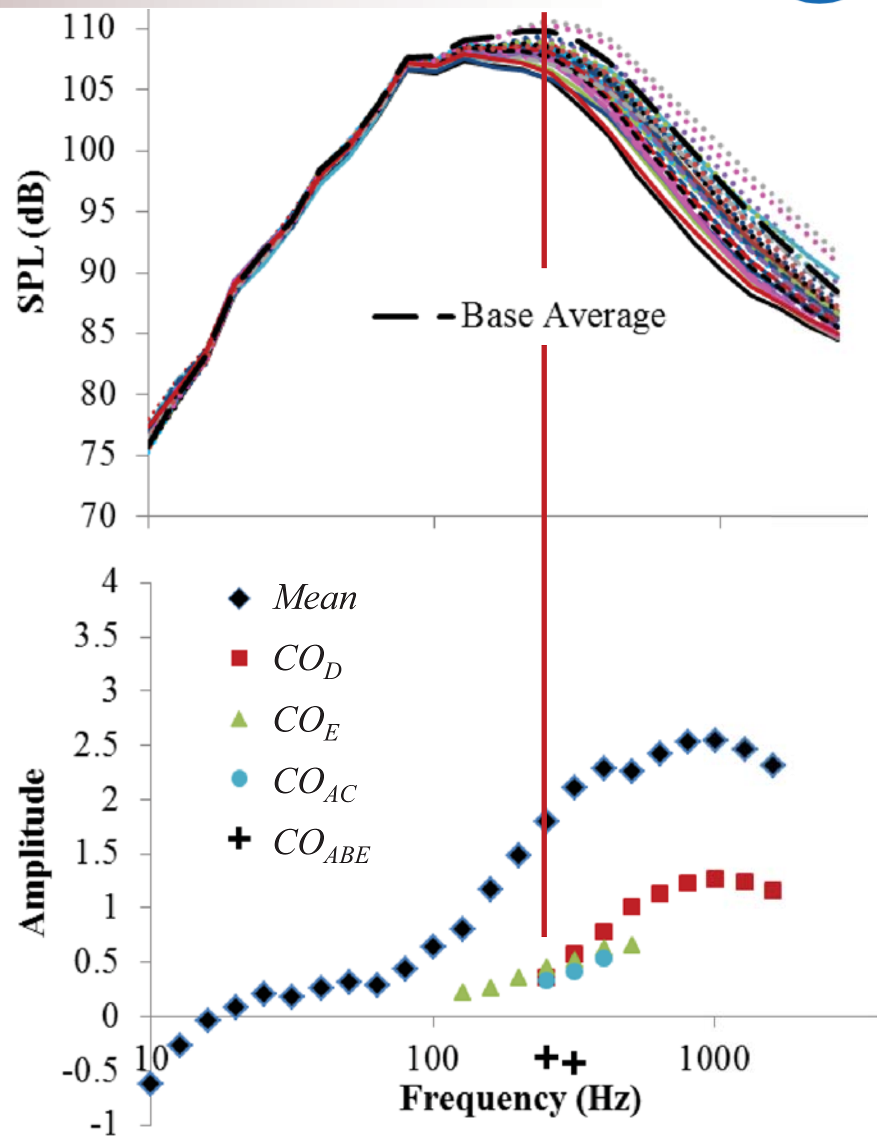
Corner Points



Center Repeats

Sideline Model – Peak Polar Angle

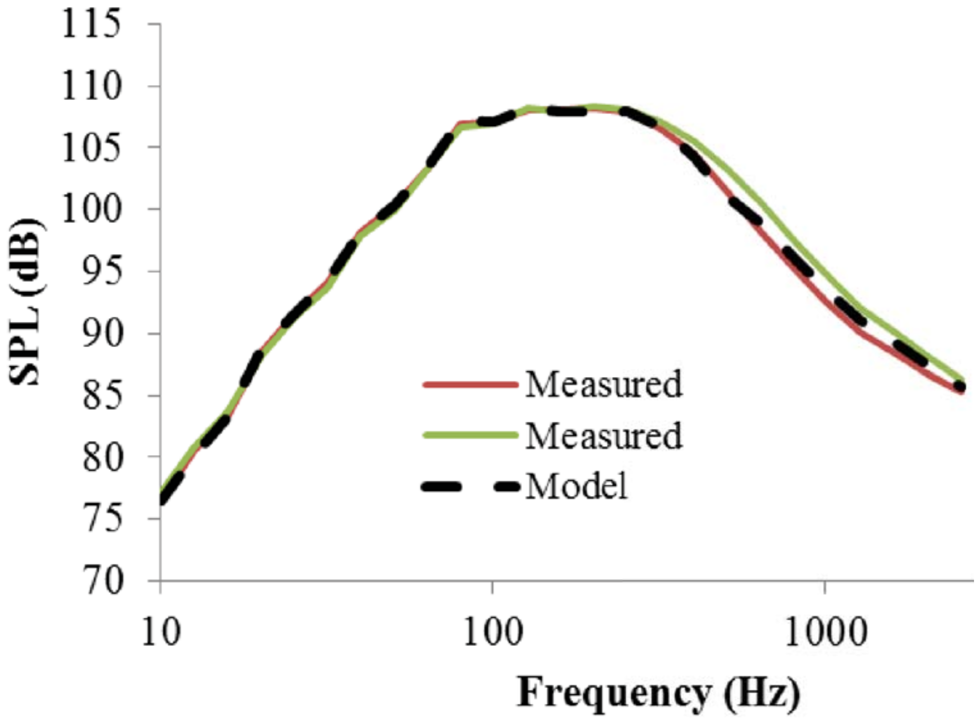
Parameter	Low Level	High Level
AOA Top (A)	5	10
AOA Bottom (B)	5	10
Azimuthal Top (C)	120	150
Azimuthal Bottom (D)	60	90
Trailing Edge Distance (E)	-0.75	-0.50



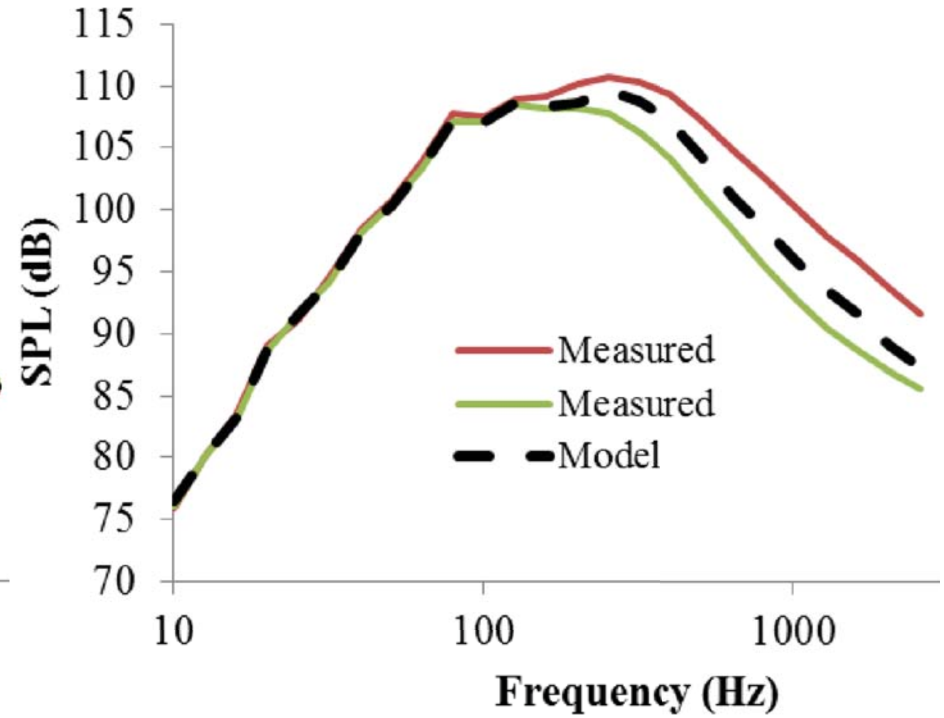
Main Effects
- Azimuthal Angle Bottom
- Trailing Edge Distance

Interaction Effects
- AOA Top, Azimuthal Top
- AOA Top, AOA Bottom, Trailing Edge Distance

Sideline Model Comparison



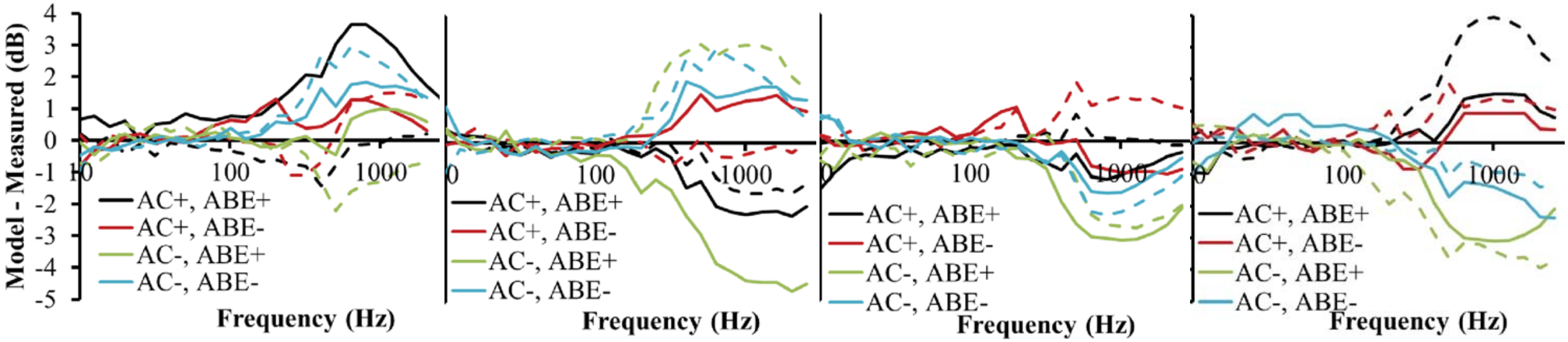
Best



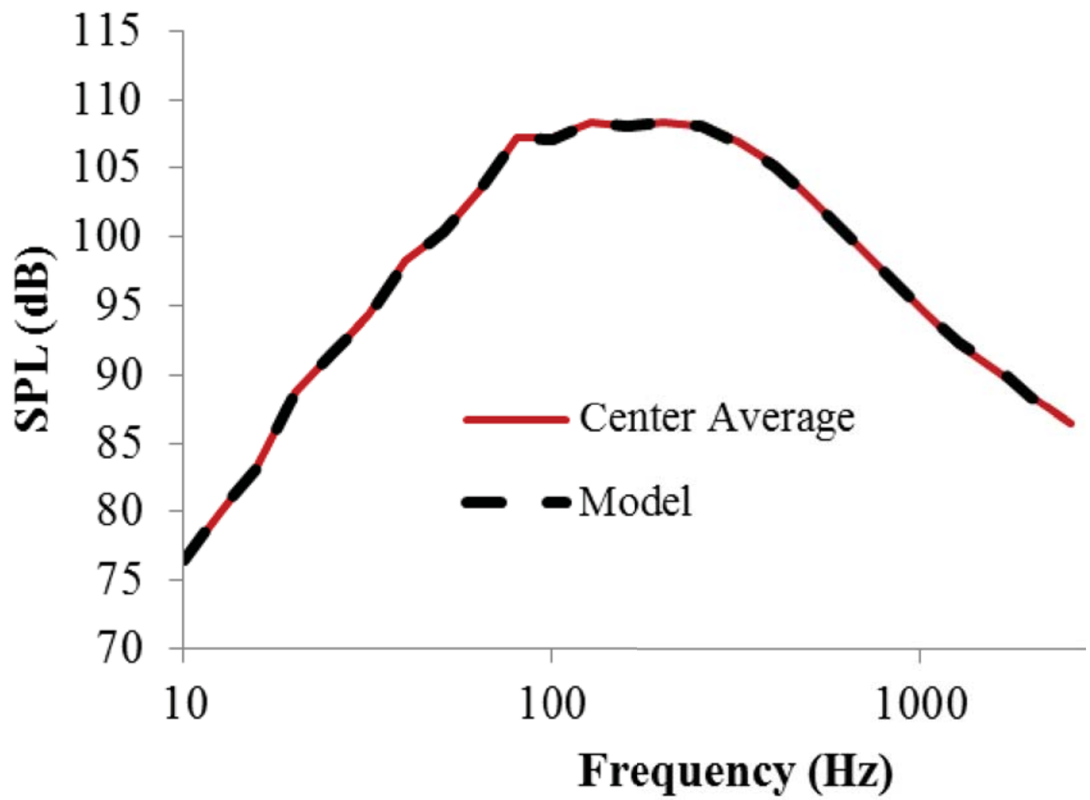
Worst

Differences in measured and modeled levels for all but one configuration are within data spread for center configurations

Sideline Model Comparison



Sideline Model Comparison - Center



Model fits Center Point data – no curvature

Lower Model – Peak Polar Angle

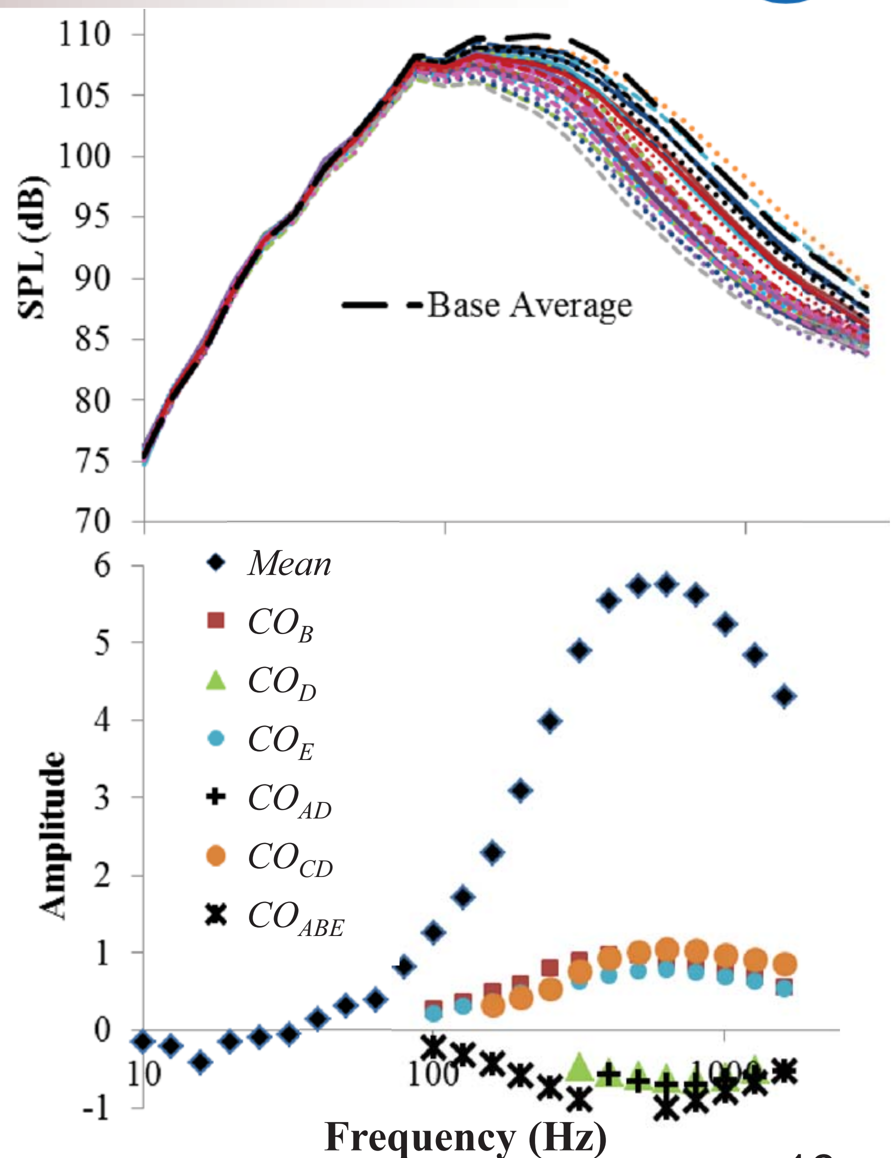
Parameter	Low Level	High Level
AOA Top (A)	5	10
AOA Bottom (B)	5	10
Azimuthal Top (C)	120	150
Azimuthal Bottom (D)	60	90
Trailing Edge Distance (E)	-0.75	-0.50

Main Effects

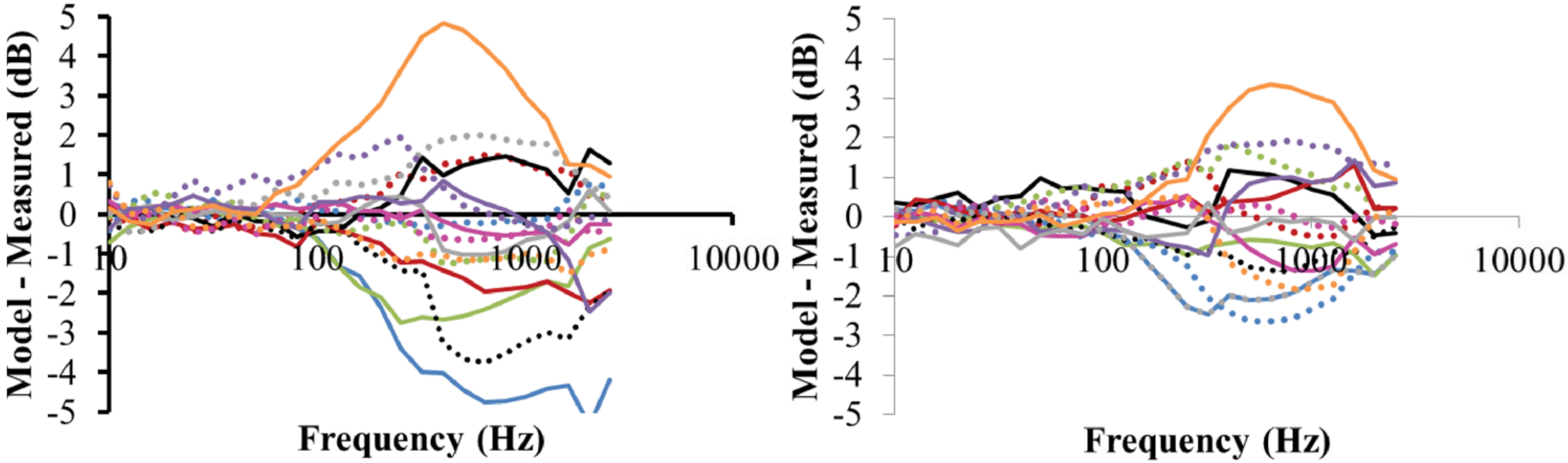
- AOA Bottom
- Azimuthal Angle Bottom
- Trailing Edge Distance

Interaction Effects

- AOA Top, Azimuthal Angle Bottom
- Azimuthal Angle Top, Azimuthal Angle Bottom
- AOA Top, AOA Bottom, Trailing Edge Distance

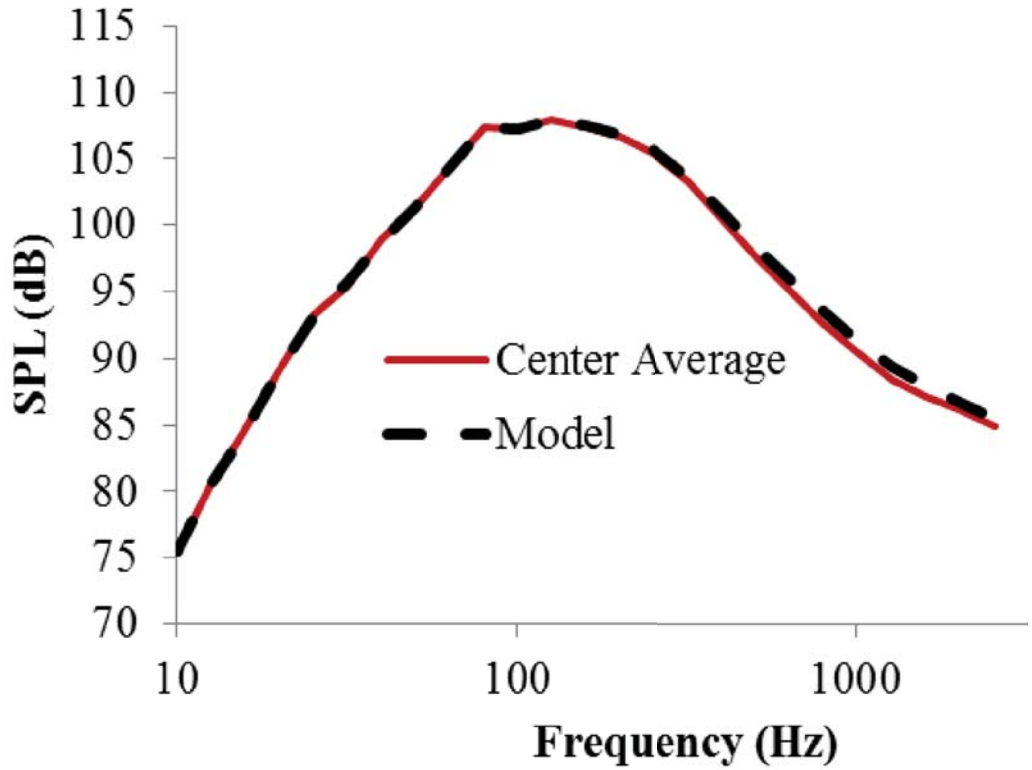


Lower Model Comparison



Differences in measured and modeled levels for all but two configuration are within data spread for center configurations

Lower Model Comparison - Center



Model fits Center Point data – no curvature

Conclusions

- Fan airfoil inserts reduce noise in the peak-jet-noise direction on the “thick” side of the fan stream
- Noise reduction for the Lower Array is greater than that for the Sideline Array
- Noise reduction is greater at high power settings than low power settings
- For the Sideline Array, bottom airfoil azimuthal angle has the greatest impact on mid- and low-frequency acoustic radiation
- For the Lower Array, bottom airfoil AOA and azimuthal angle as well as airfoil trailing edge distance impact mid- and high-frequency acoustic radiation
- Interaction terms are important in models developed for both azimuthal arrays
- Models are now available for NASA’s Aircraft Noise Prediction Program (ANOPP)

Future Work

- Optimized (for low noise) configuration will be determined from the models
- RANS solutions for the optimized design will be obtained
- Other techniques for obtaining the optimized flow-field will be investigated