Noise Prediction Module for Offset Stream Nozzles

A Modern Design of Experiments (MDOE) analysis of data acquired for an offset stream technology was presented. The data acquisition and concept development were funded under a Supersonics NRA NNX07AC62A awarded to Dimitri Papamoschou at University of California, Irvine. The technology involved the introduction of airfoils in the fan stream of a bypass ratio (BPR) two nozzle system operated at transonic exhaust speeds. The vanes deflected the fan stream relative to the core stream and resulted in reduced sideline noise for polar angles in the peak jet noise direction. Noise prediction models were developed for a range of vane configurations. The models interface with an existing ANOPP module and can be used or future system level studies.

National Aeronautics and Space Administration

Fundamental Aeronautics Program

Supersonics Project

Noise Prediction Module for Offset Stream Nozzles

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Data supplied under NRA NNX07AC62A by Dimitri Papamoschou
University of California, Irvine

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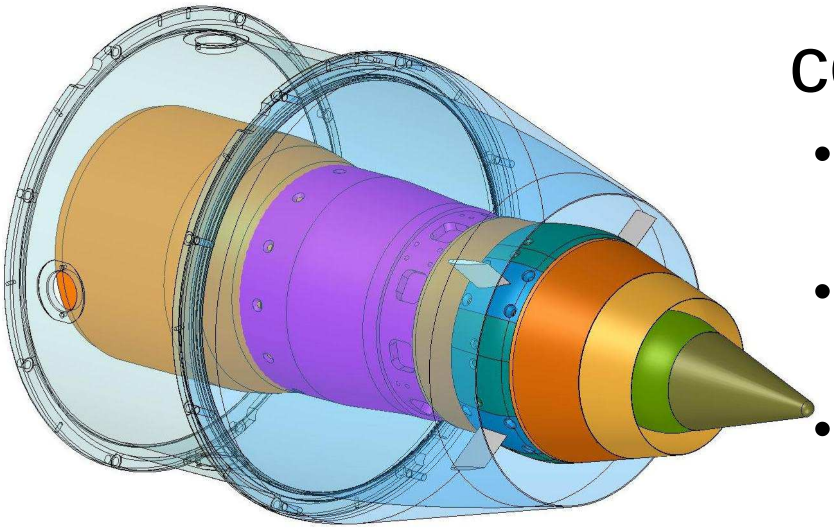
Purpose of Vanes

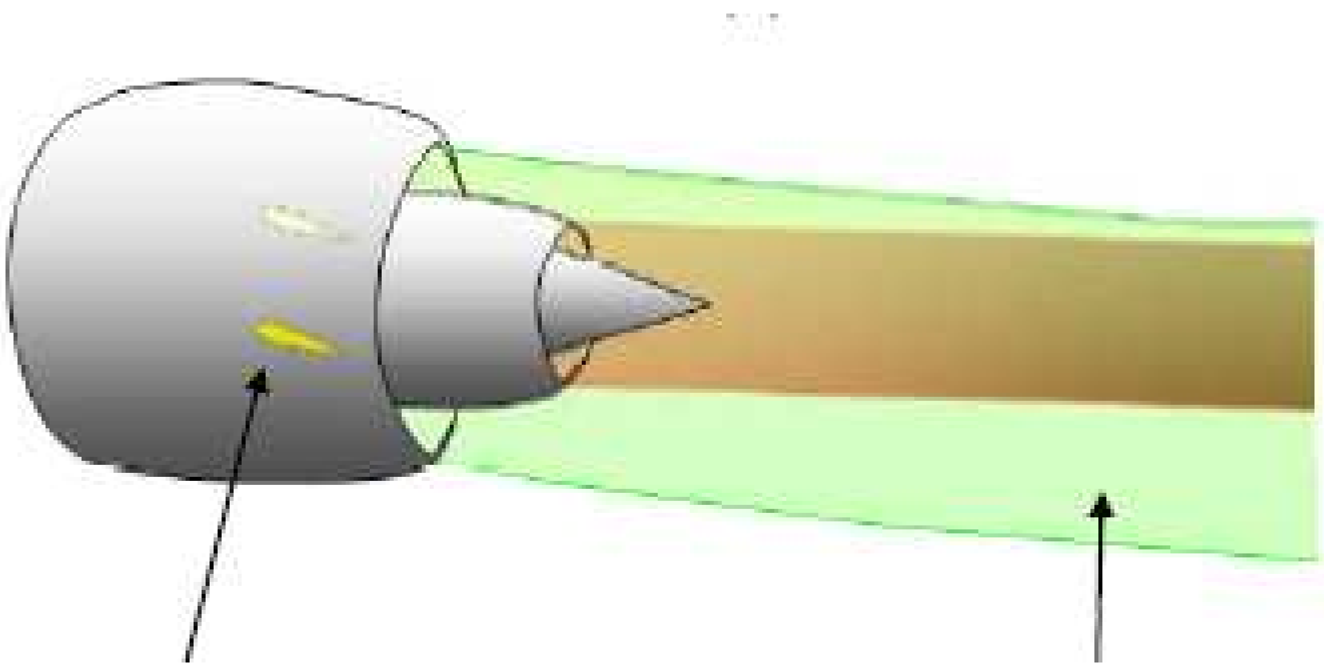


Move fan stream relative to core stream

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

Papamoschou, D. (2004), “New method for jet noise reduction in turbofan engines,” AIAA J., 11 (42), 2245 – 2253.

Purpose of Vanes



Vanes in Fan Stream

Thickened Layer of Fan Flow

Courtesy of Dimitri Papamoschou

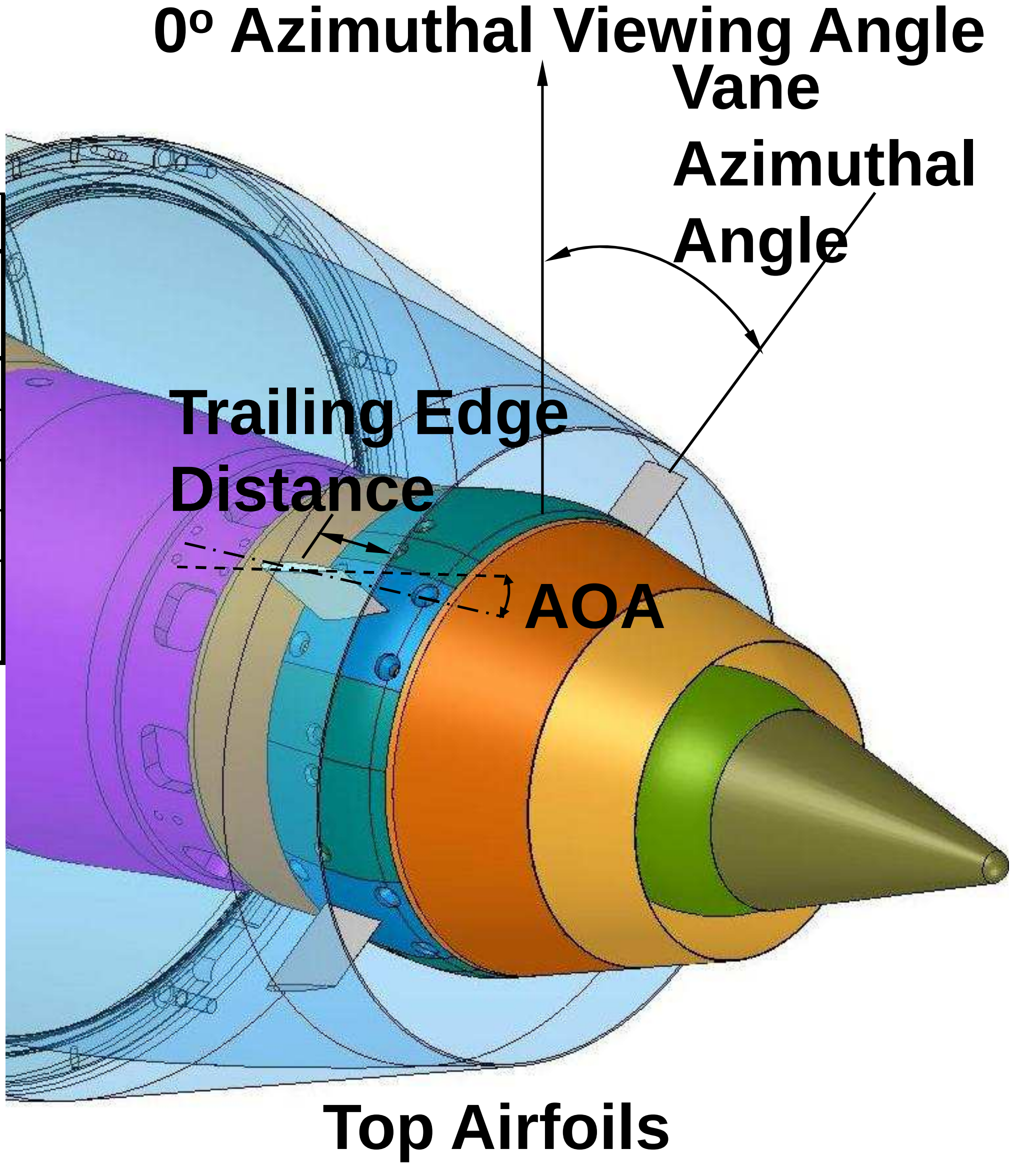
Objectives

- Using MDOE techniques
  – Perform parametric study
  – Model sideline noise reduction in 1/3 octave bands
- Use coefficients from MDOE analysis in existing ANOPP module

Parametric Study

Parametric Study				
Parameter	**Unit**	**Low Level**	**High Level**	**Center**
AOA Top	deg	5	10	7.5
AOA Bottom	deg	5	10	7.5
Azimuthal Top	deg	120	150	135
Azimuthal Bottom	deg	60	90	75
Trailing Edge Distance	fraction of chord	-0.5	-0.75	-0.625

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

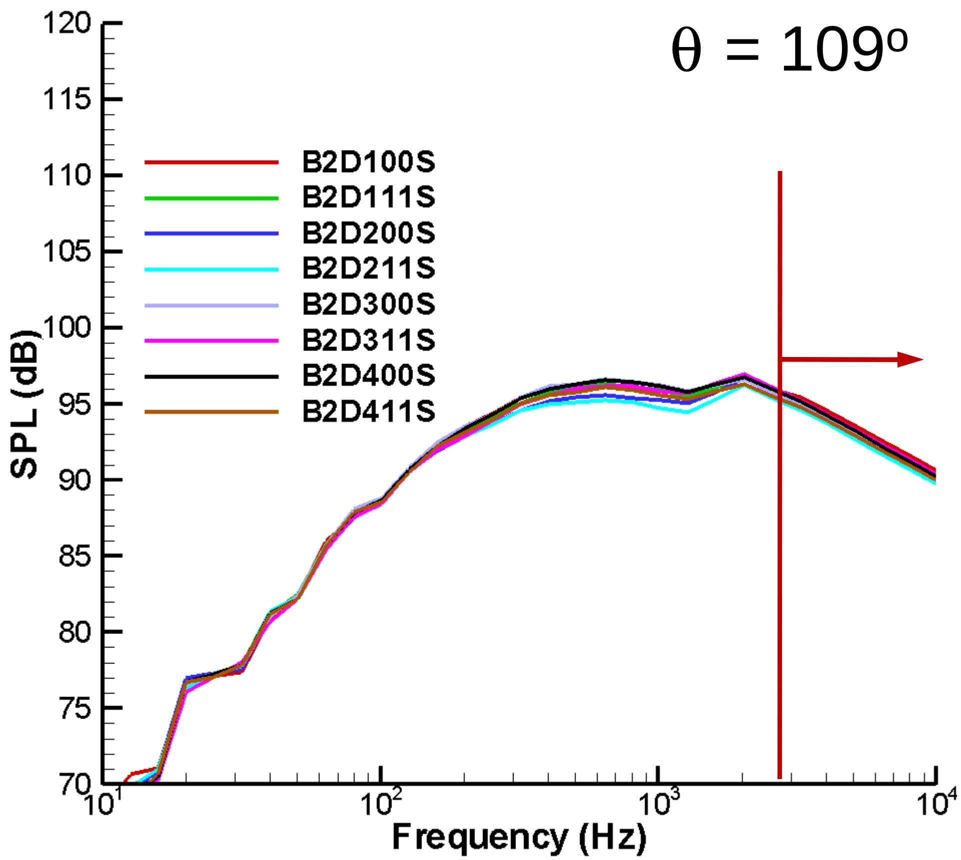


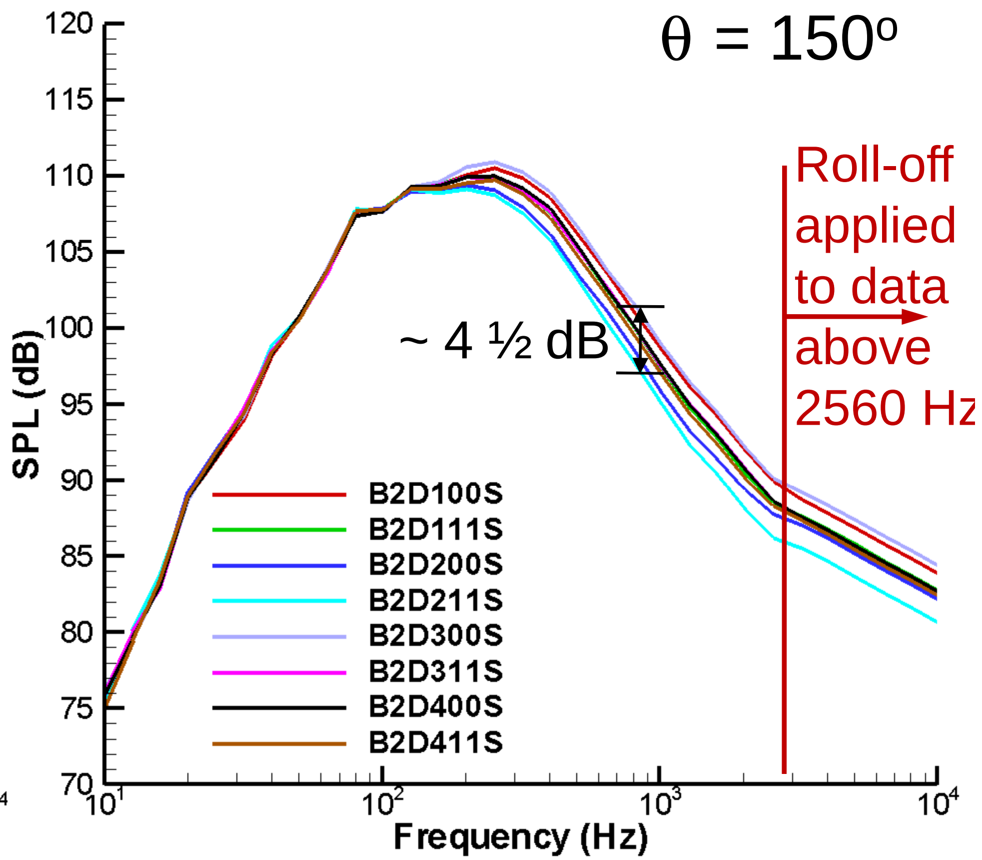
Cycle Points

Cycle	M_p	U_p (m/s)	M_s	U_s (m/s)	BPR
A	0.840	431.8	0.788	273.5	1.83
B	1.003	530.1	0.959	333.2	1.91
C	1.126	606.4	1.086	377.8	1.94
D	1.180	640.3	1.140	397.2	1.96

Data presented are for sideline azimuthal viewing angles

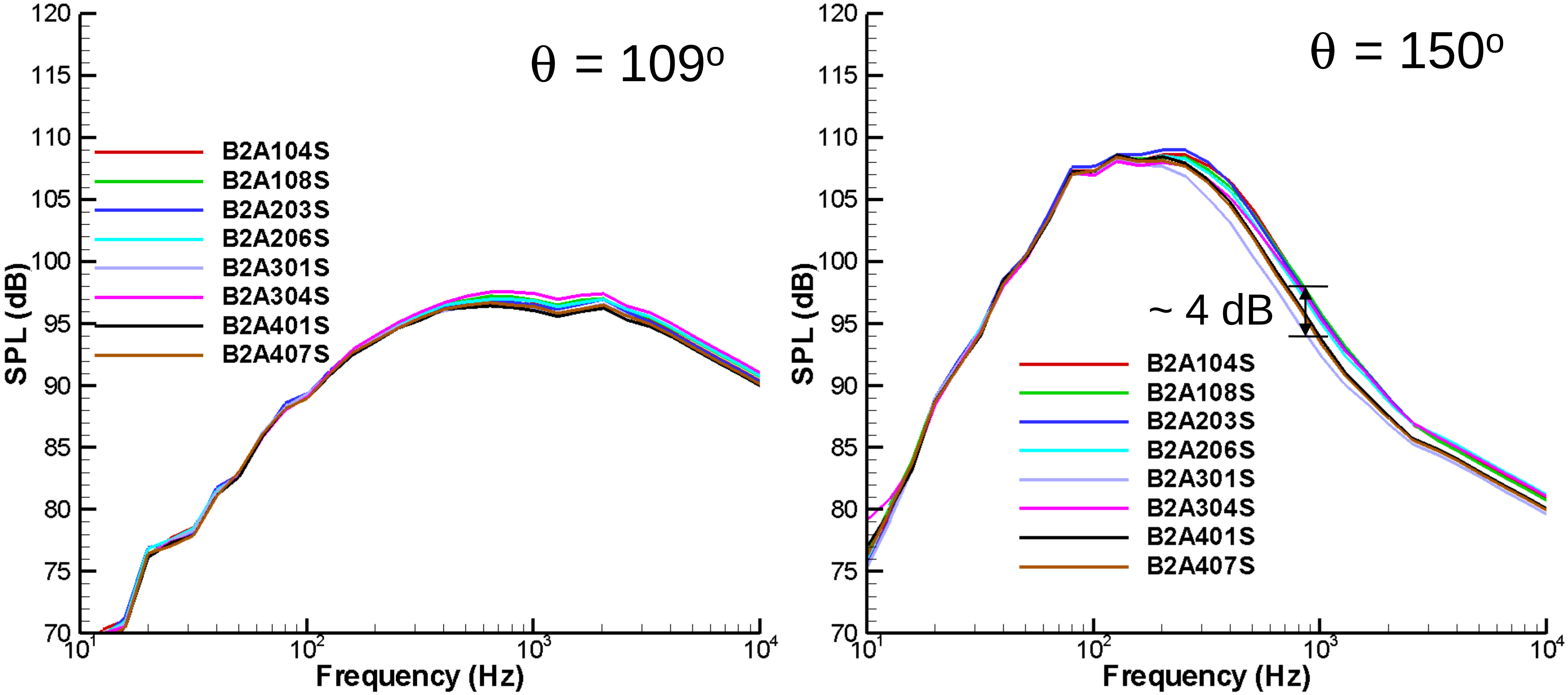
Baseline Repeats – Cycle Point D





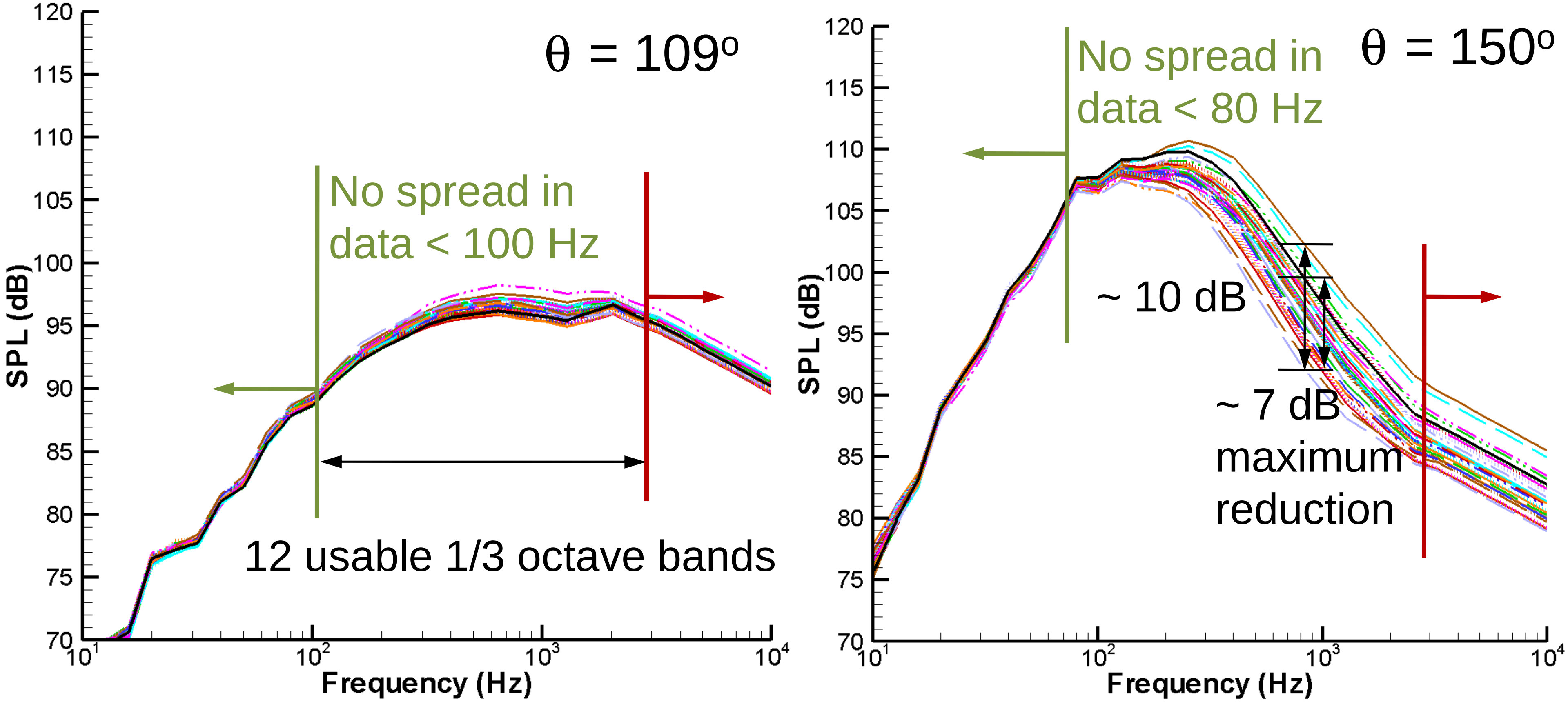
- 37.5 scale factor
- 1 foot lossless data
- 1/3 octave
- Representative data spread

Center Point Repeats – Cycle Point D



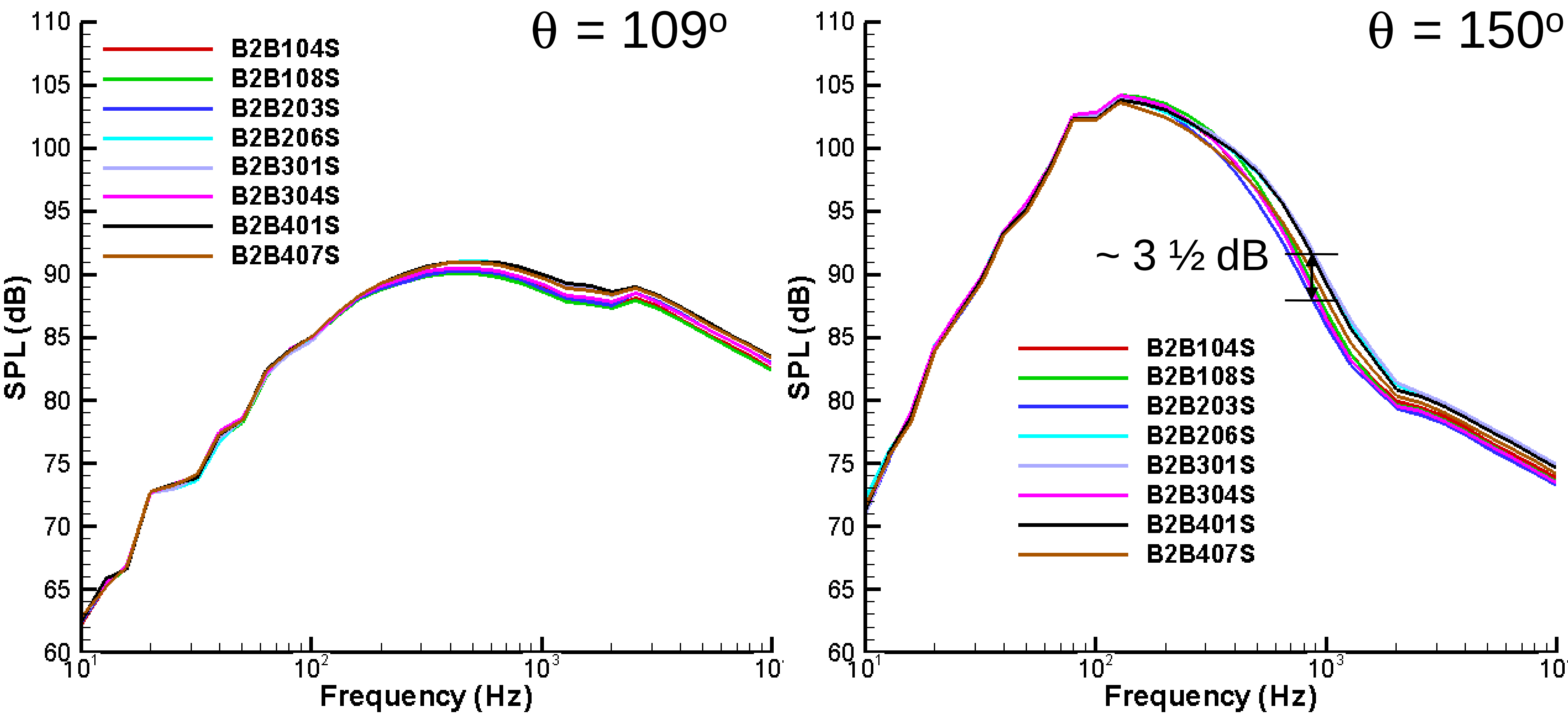
- Representative data spread for A, B, D cycles
- Block effects not significant A, B, D cycles
- Data spread for center point is generally less than that for baseline

Impact of Vane Design – Cycle Point D

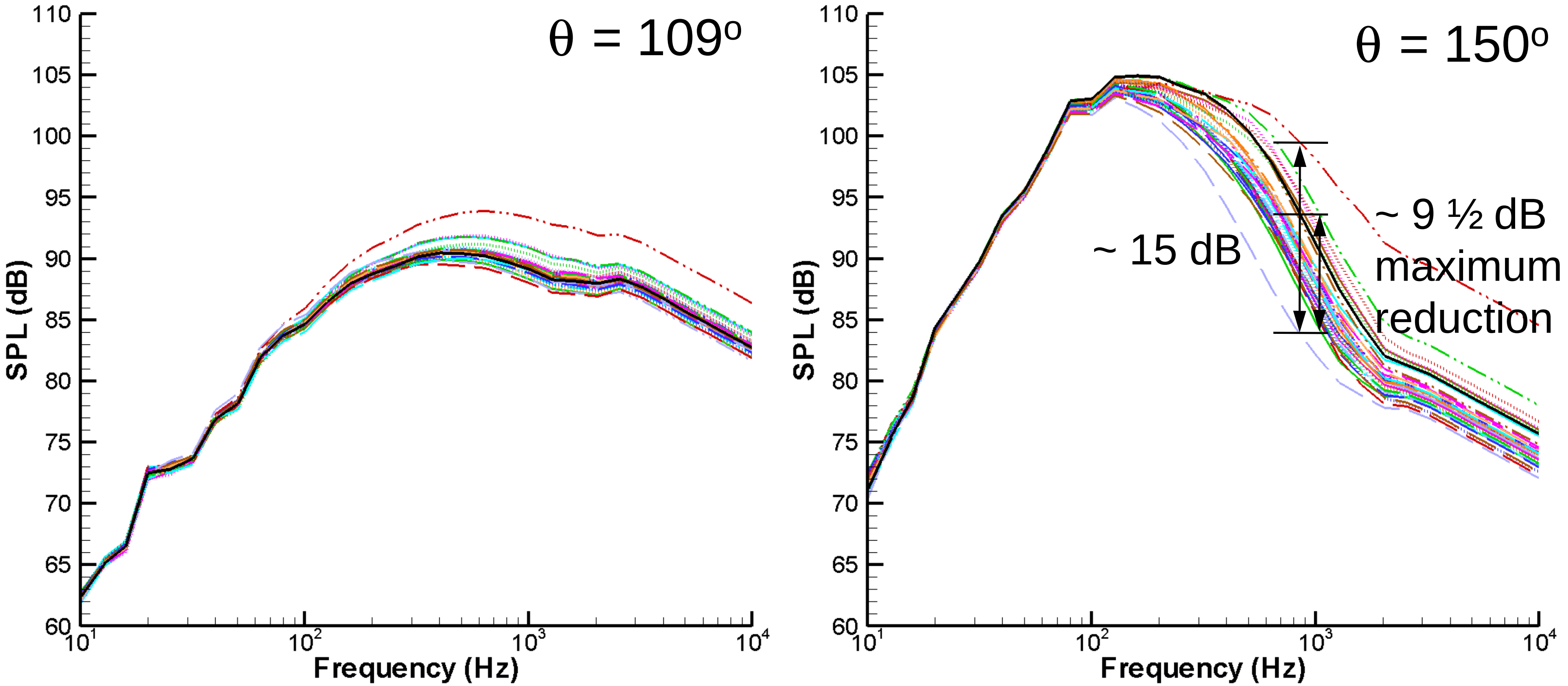


- Vanes slightly increase noise for angles ≤ 90º
- Vanes have significant impact in peak jet noise direction

Center Point - Cycle Point B



Impact of Vane Design – Cycle Point B



- Vanes have significant impact in peak jet noise direction

Models Developed from MDOE Analysis

- Cycle points A, B, C*, D
- Predicts noise reduction in 12 usable 1/3 octave bands
- 20^{o} incremented polar angles
- Models only completed for sideline azimuthal viewing angles
- Design optimized with noise reduction in representative band

General Prediction Equation

$NR_{1/3} = Mean + Co_A * A + Co_B * B + Co_C * C + Co_D * D + Co_E * E$ Main Effects

$+Co_{AB} * AB + Co_{AC} * AC + Co_{AD} * AD + Co_{AE} * AE + Co_{BC} * BC +$
$Co_B * BD + Co_{BE} * BE + Co_{CD} * CD + Co_{CE} * CE + Co_{DE} * DE$

2-Way Interactions

$+ Co_{ABC} * ABC + Co_{ABD} * ABD + Co_{ABE} * ABE + Co_{ACD} * ACD +$
$Co_{ACE} * ACE + Co_{BCD} * BCD + Co_{BCE} * BCE + Co_{BDE} * BDE +$
$Co_{CDE} * CDE$

3-Way Interactions

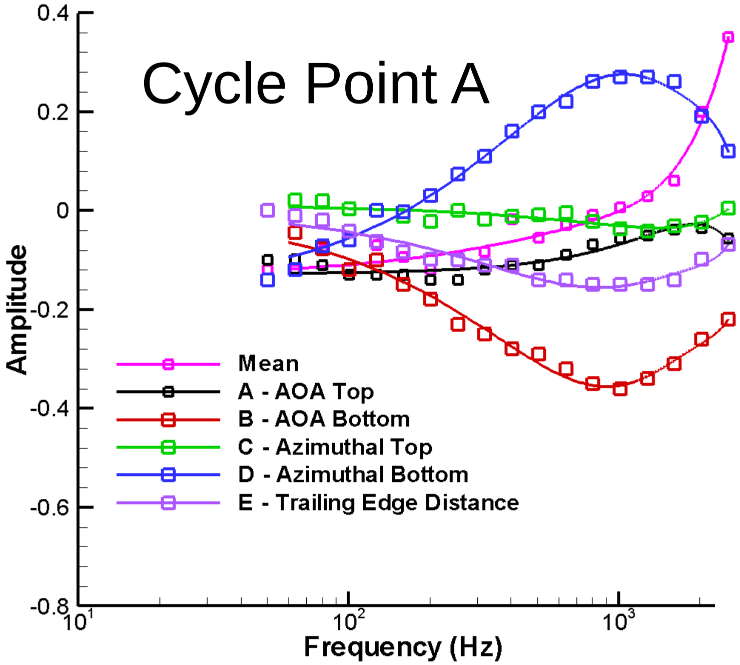
$+ Co_{ABCD} * ABCD + Co_{ABCE} * ABCE + Co_{ABDE} * ABDE + Co_{ACDE} *$
$ACDE + Co_{BCDE} * BCDE + Co_{ABCDE} * ABCDE$

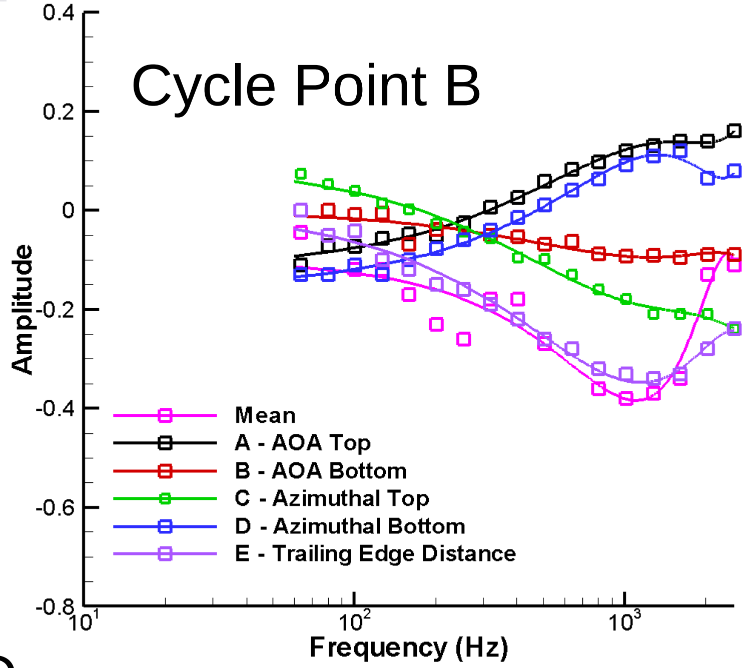
4 & 5-Way Interactions

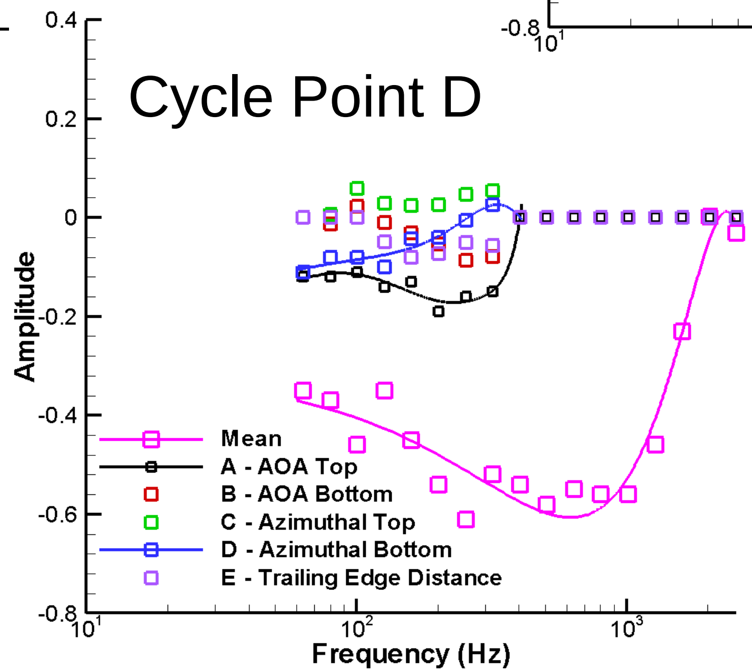
- $NR_{1/3}$ = Noise reduction in each 1/3 octave band = $Baseline_{1/3}$ – $Vane_{1/3}$
- A = Angle of attack top
- B = Angle of attack bottom
- C = Azimuthal top
- D = Azimuthal bottom
- E = Trailing edge distance

Variables are normalized

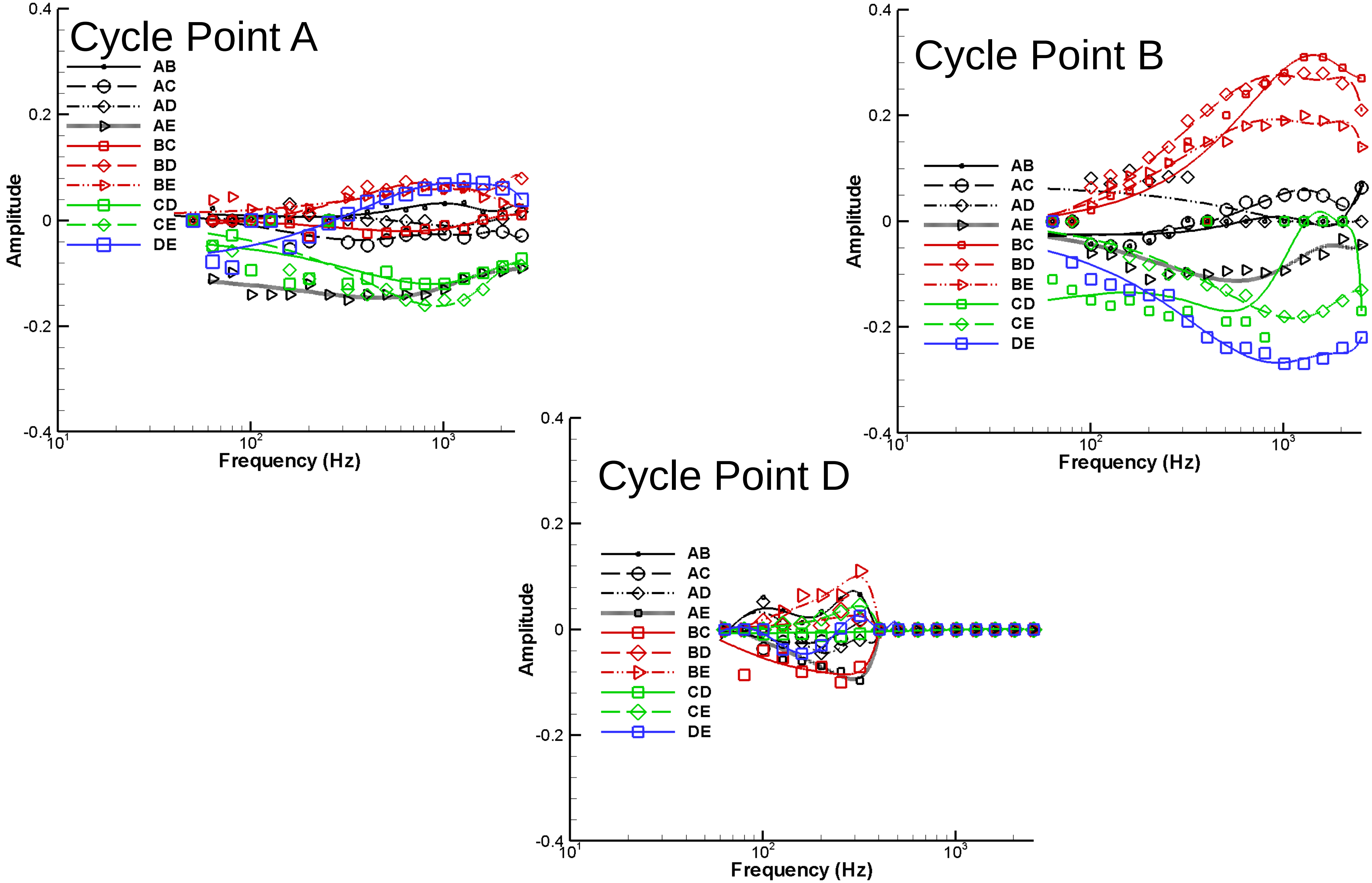
Models at 109º – Main Effects



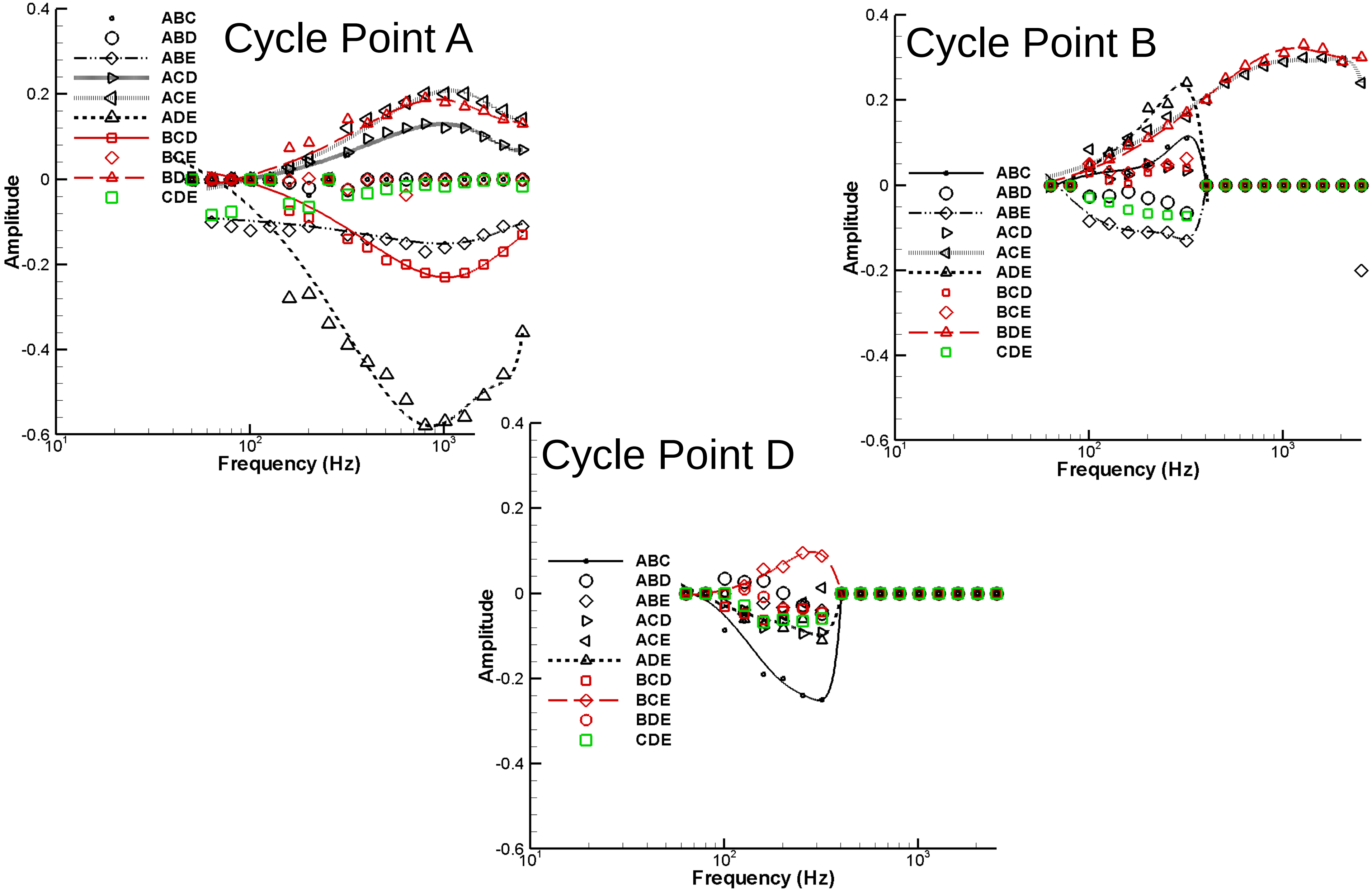




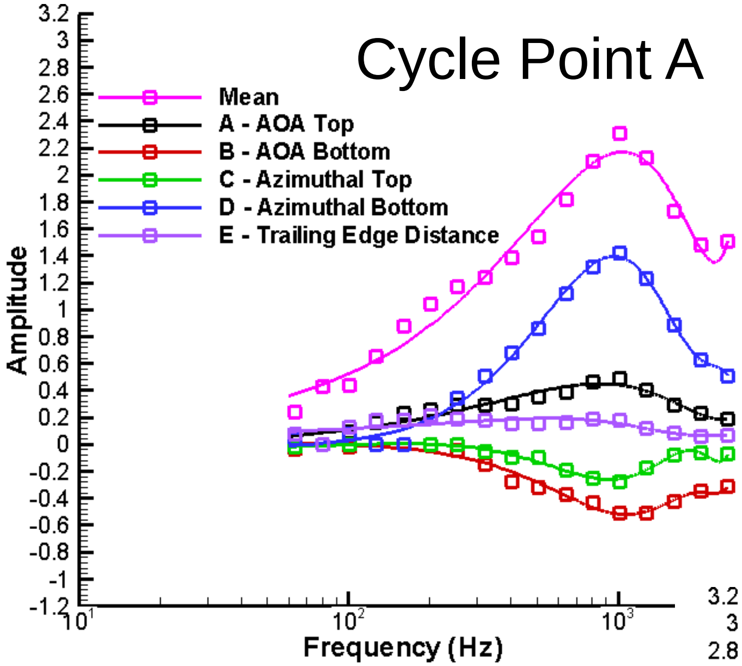
Models at 109º – 2 Way Interactions

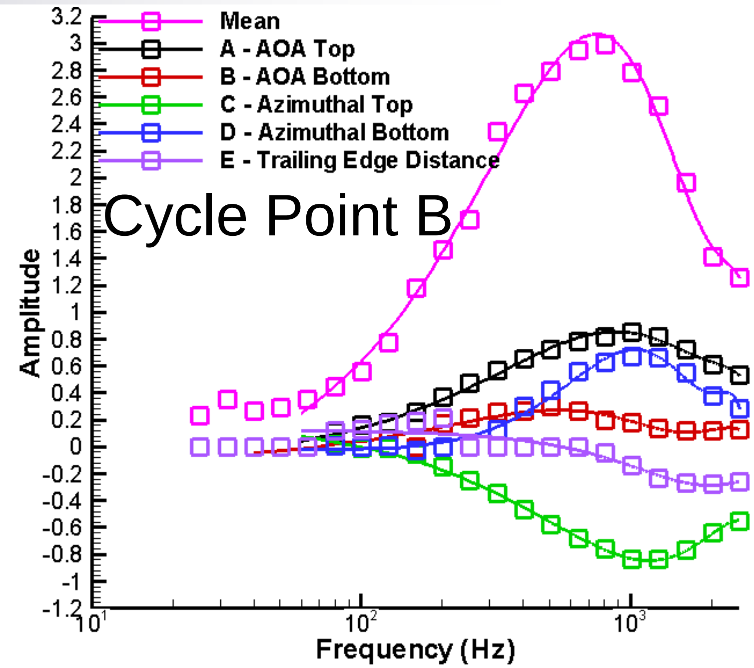


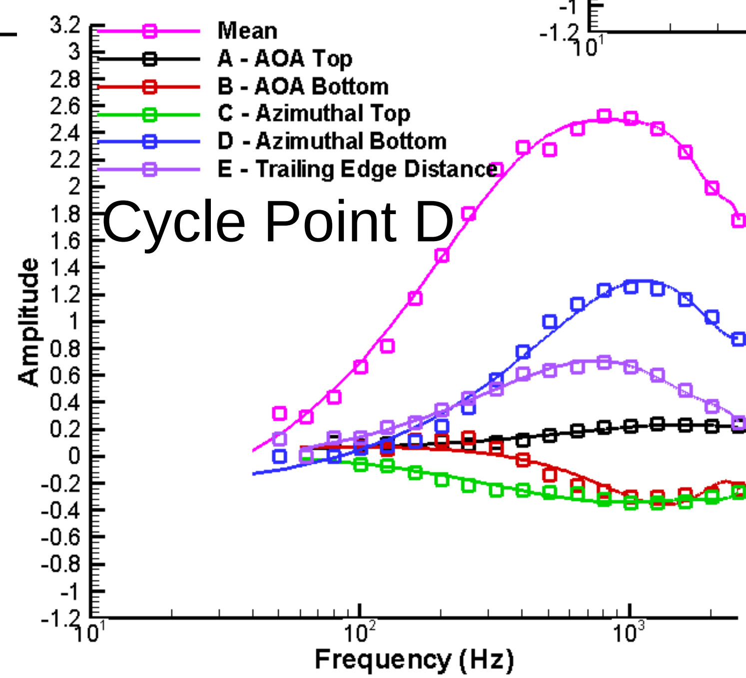
Models at 109º – 3 Way Interactions



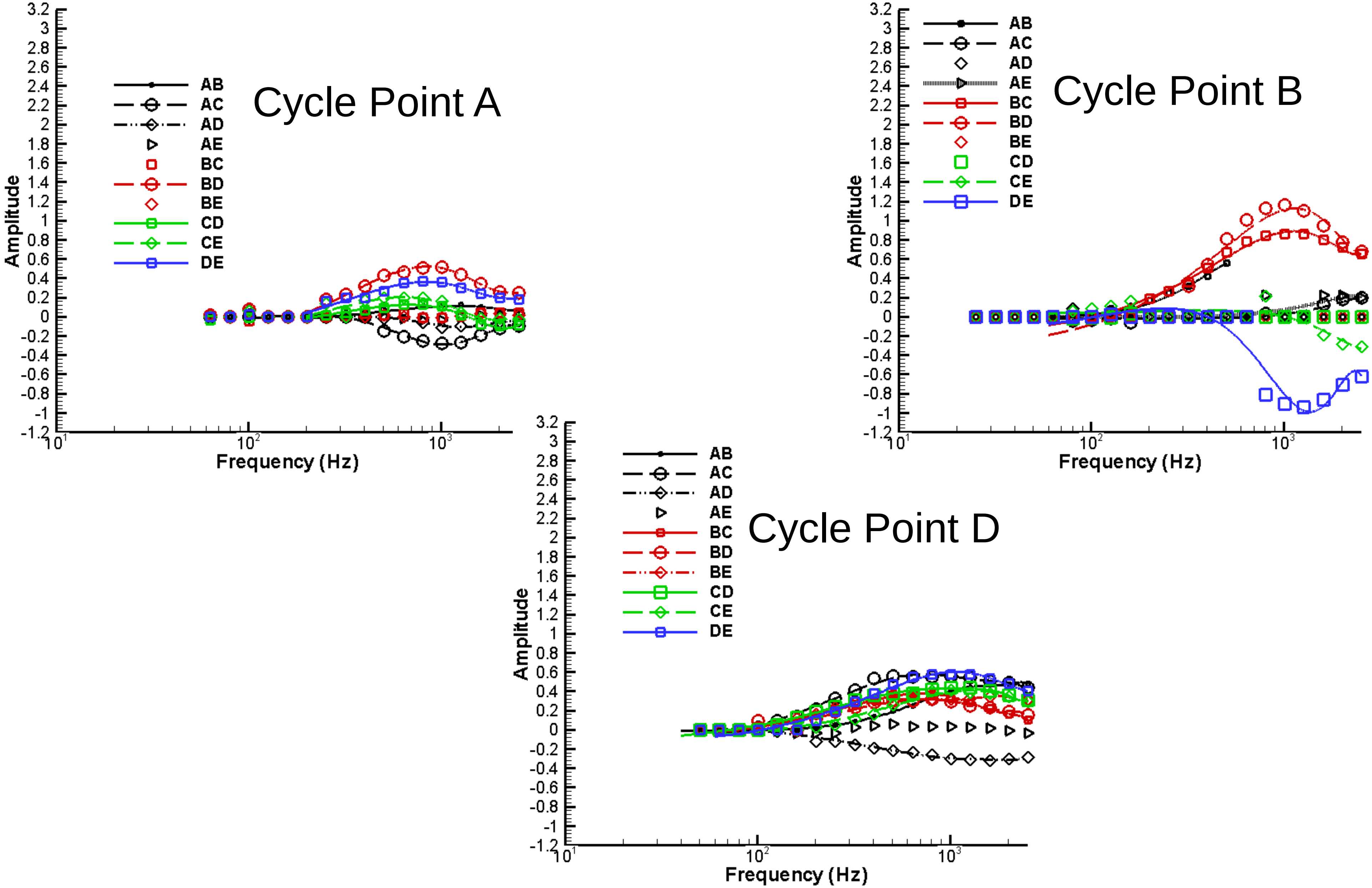
Models at 150º – Main Effects



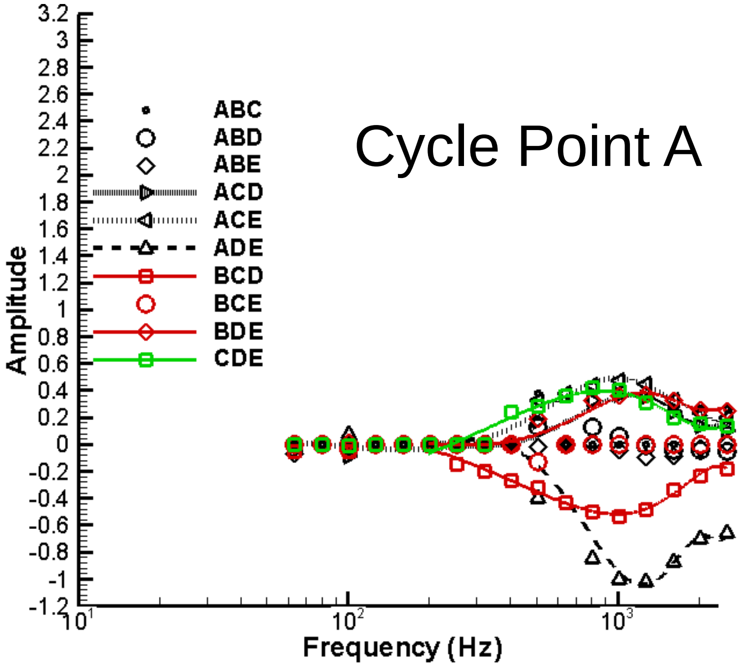


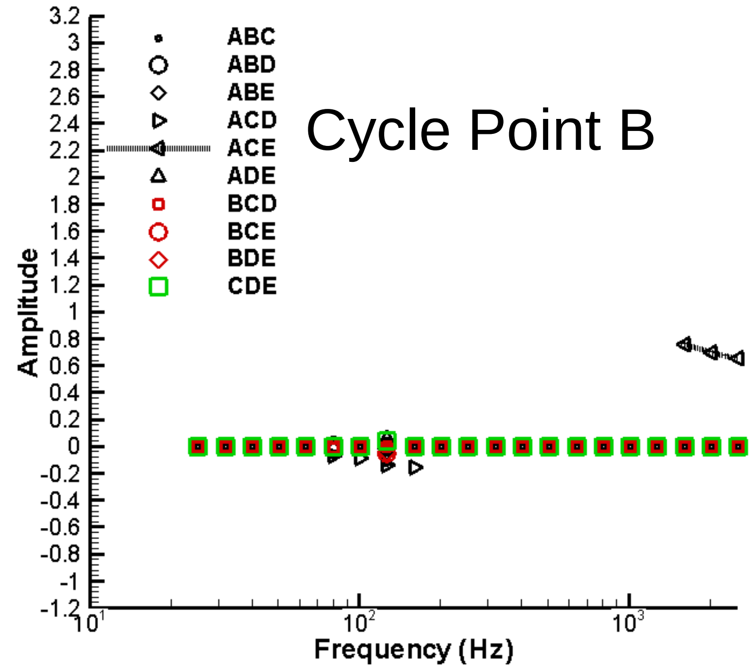


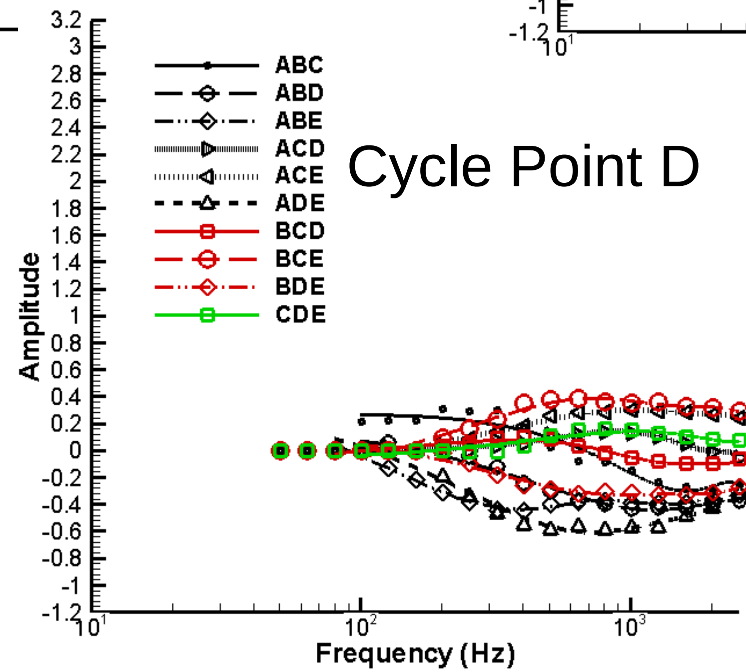
Models at 150º – 2 Way Interactions



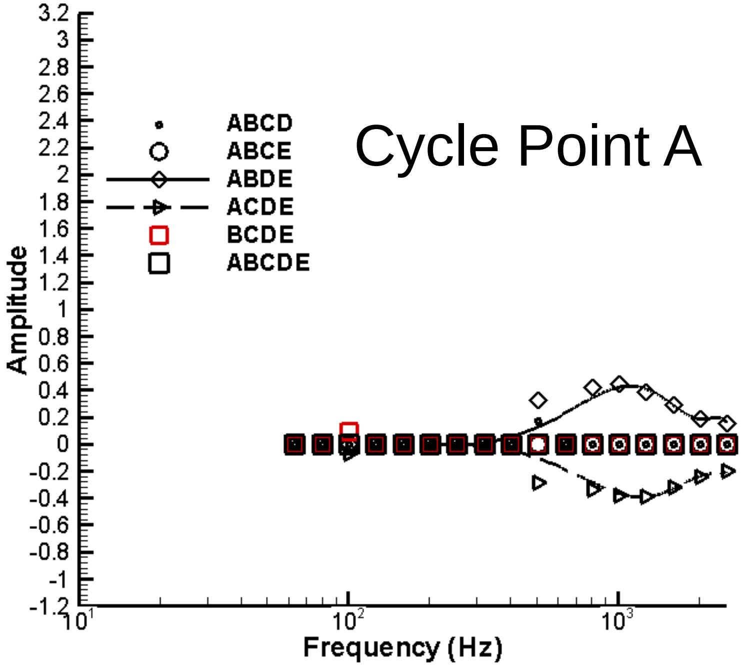
Models at 150º – 3 Way Interactions

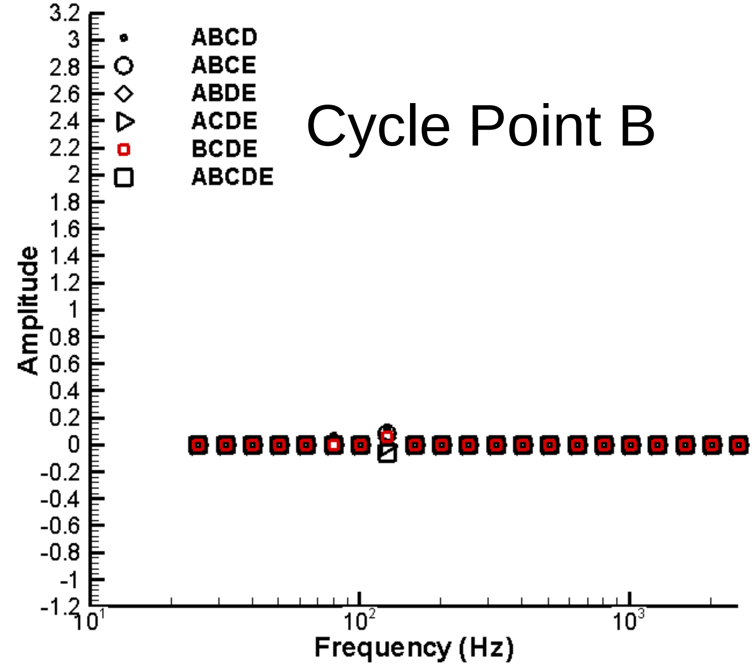


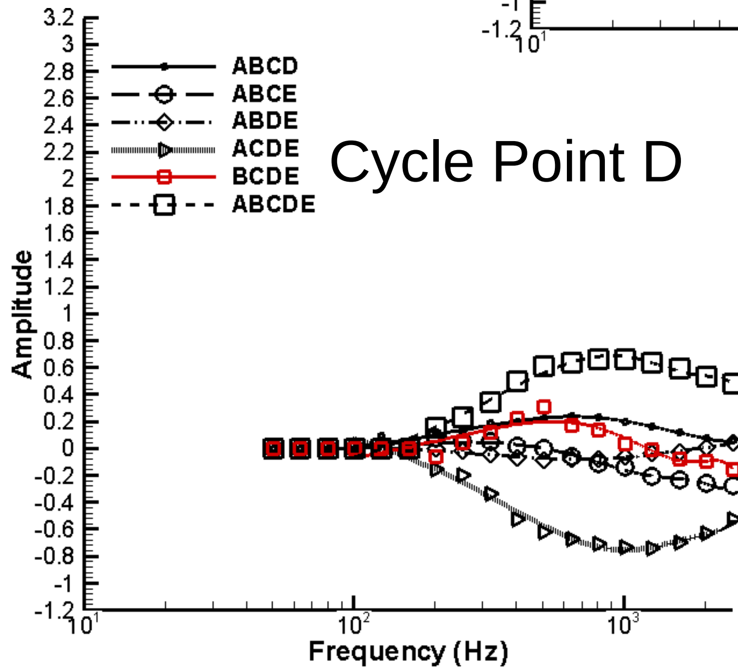




Models at 150º – 4 Way Interactions

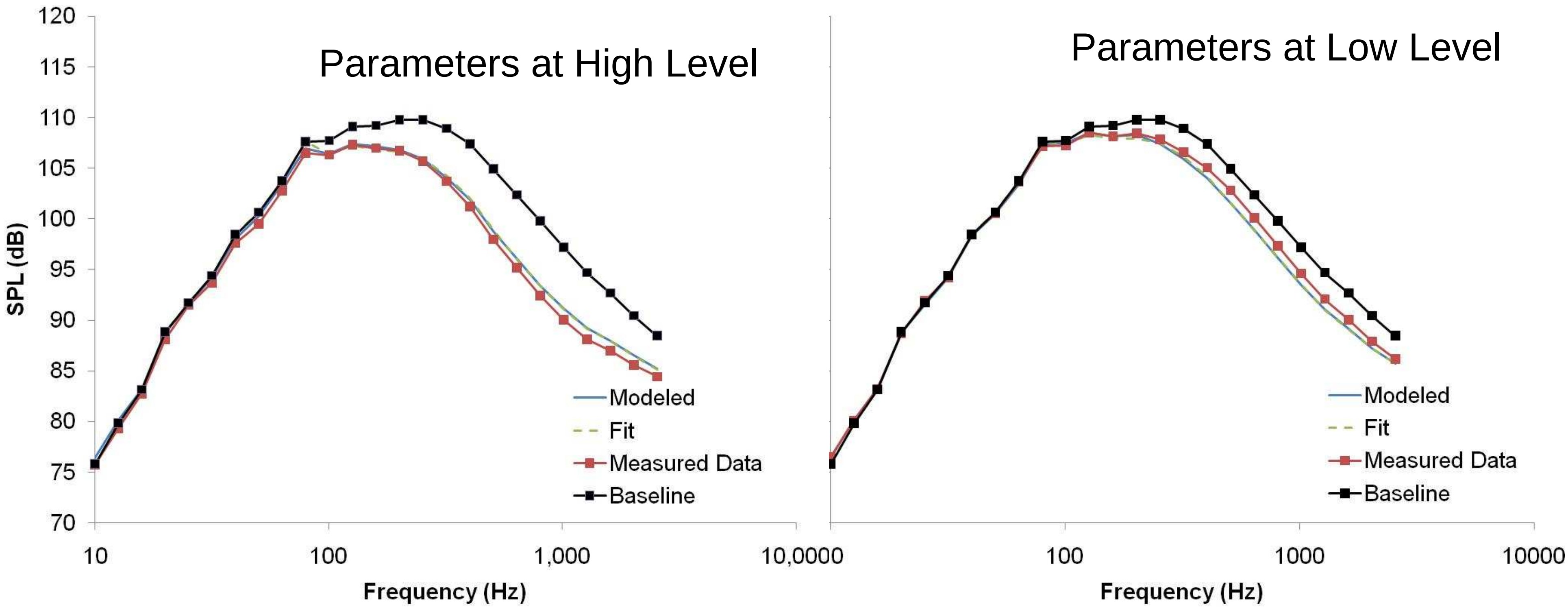




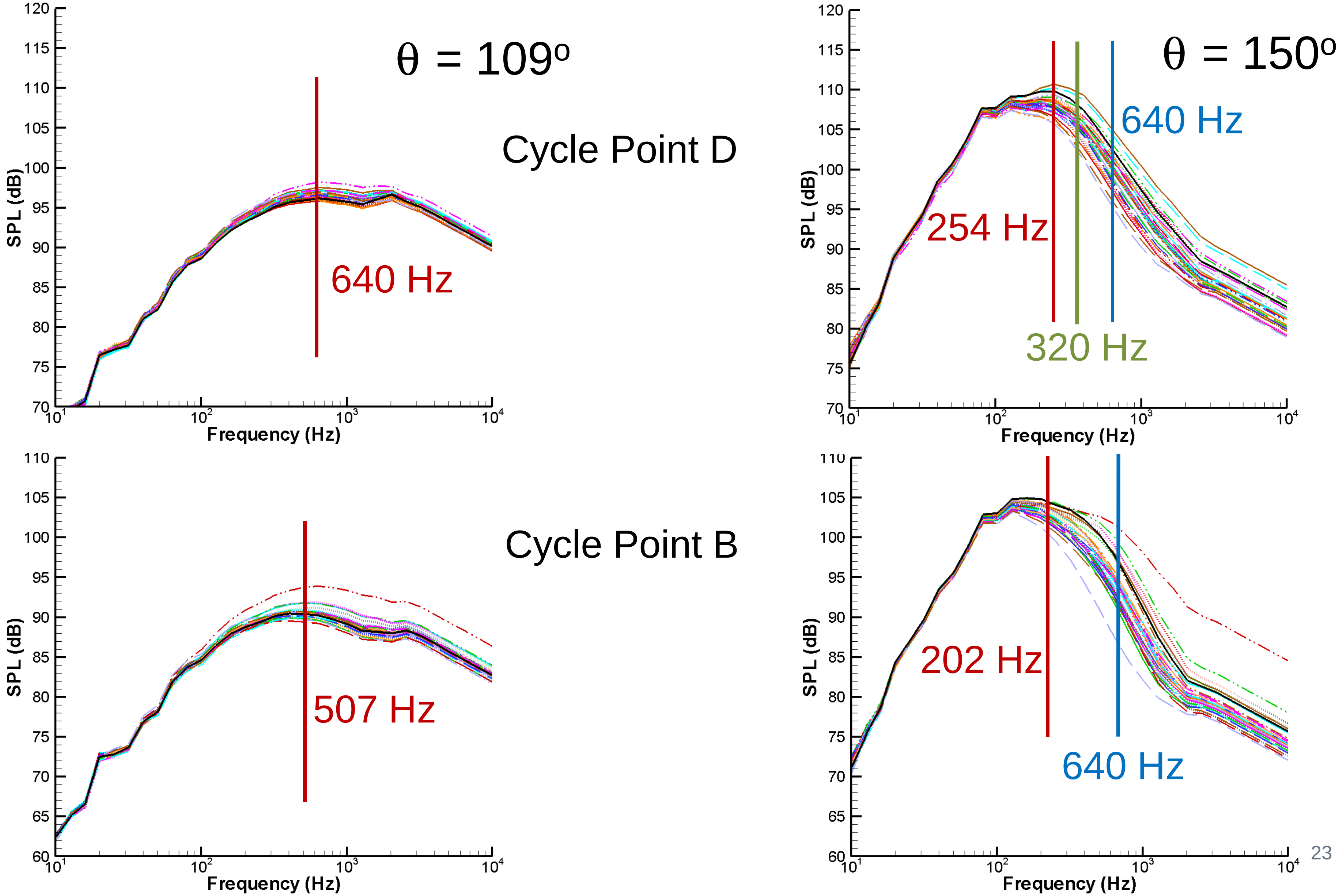


Models

θ = 150º

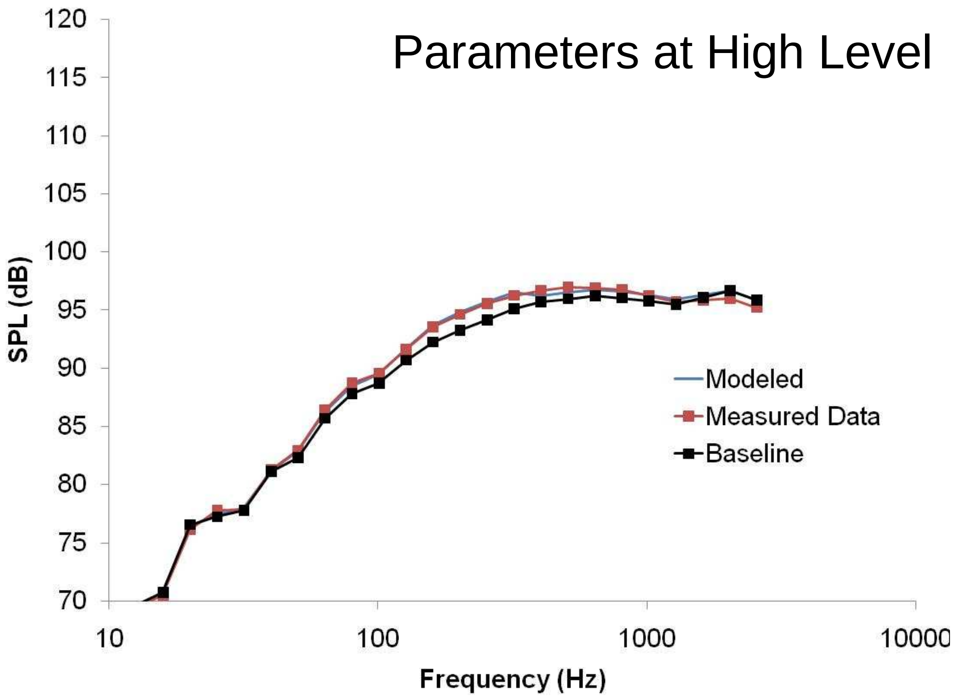


Optimization

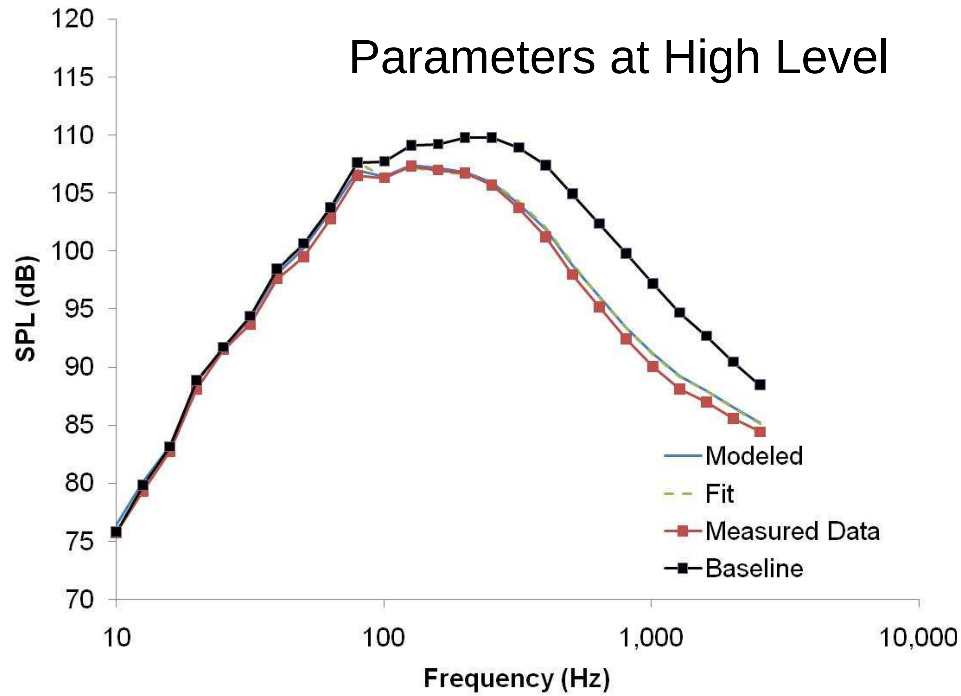


Optimization – Cycle Point D

θ = 109º



θ = 150º



- No curvature in any band for 150º

Conclusions

- Vanes have little impact on noise at upstream angles
- Vanes can reduce noise in peak jet noise direction
- General ANOPP module created for MDOE studies
  - 20º incremented polar angles
  - Models for sideline viewing angle
  - No curvature in models at large polar angles

NASA