Including Finite Surface Span Effects in Empirical Jet-Surface Interaction Noise Models

Cliff Brown

NASA Glenn Research Center

Clifford.A.Brown@nasa.gov

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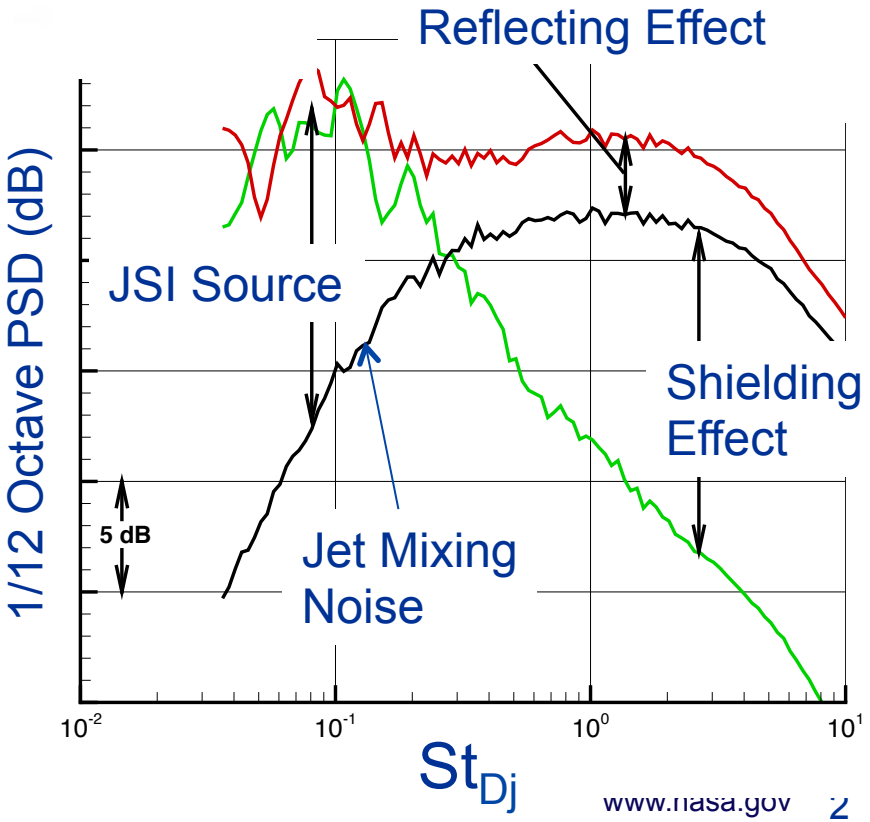
Jet-Surface Interaction (JSI) Noise

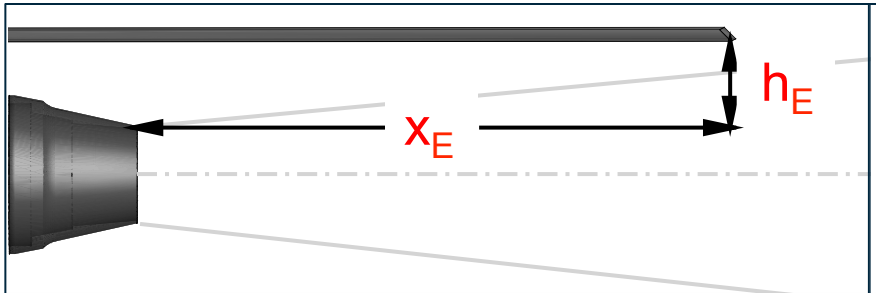
Noise created by the high-speed jet exhaust striking or passing near a solid surface

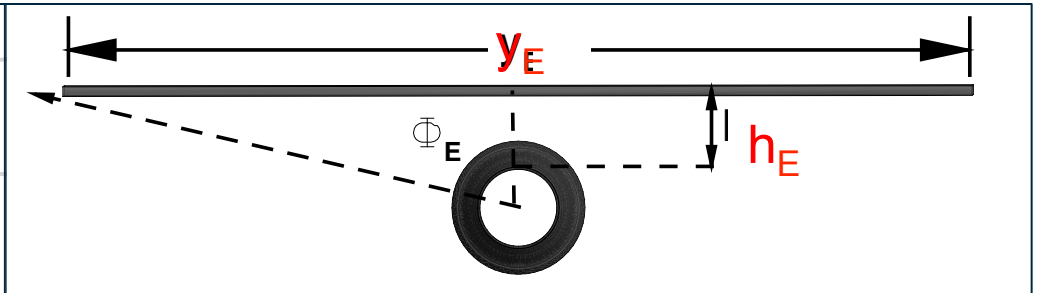
- Types of jet-surface interaction noise
  - Surface loading (“scrubbing”) noise
  - Trailing edge (“scattering”) noise
  - Surface vibration noise
- Measured far-field noise includes:
  - Jet-surface interaction noise sources
  - Jet mixing noise (isolated)
  - Shielding/Reflecting effect



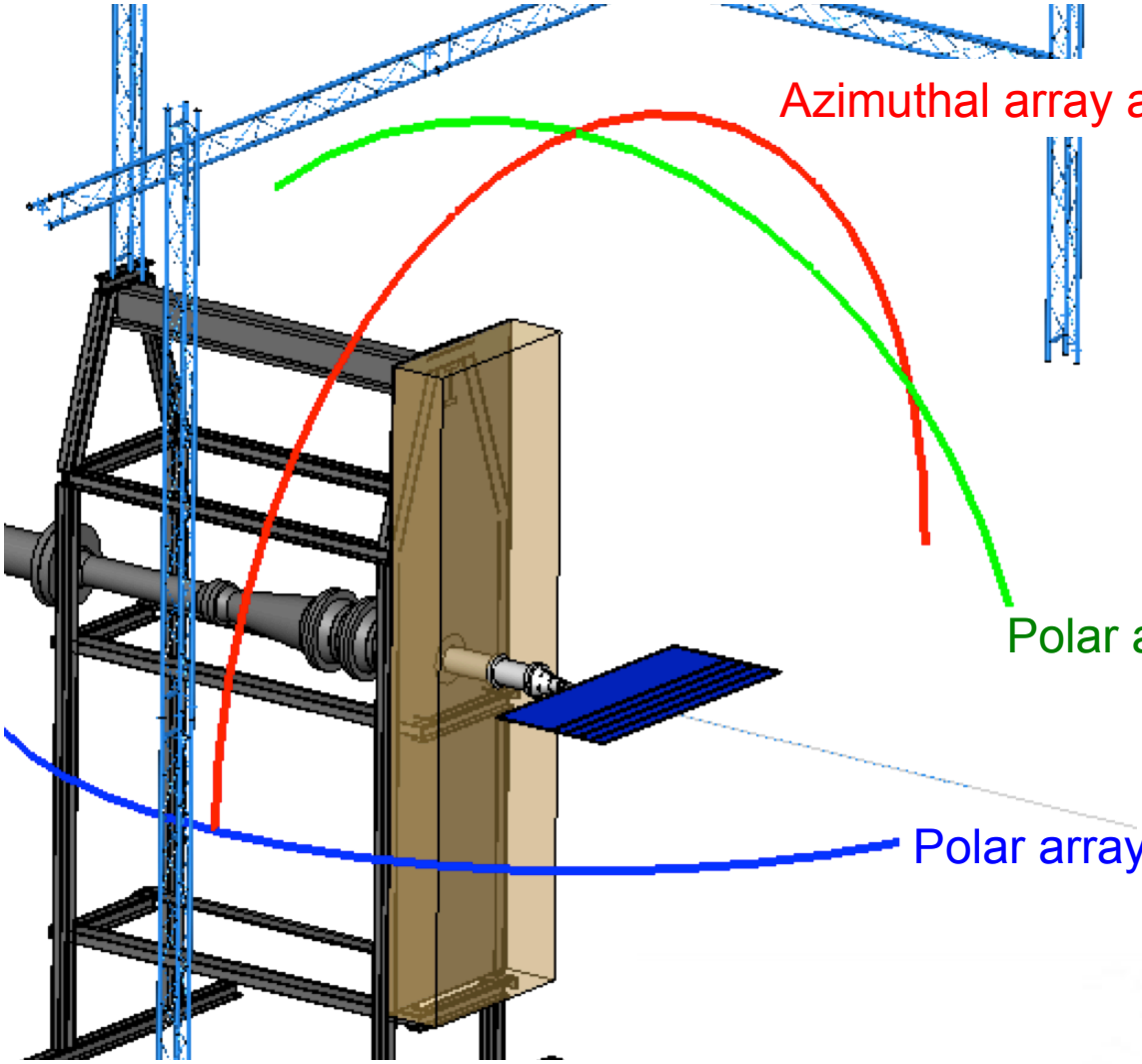
Experimental Database for Finite Span Models

1) Generic jet-surface geometry generally applicable to a wide range of aircraft configurations (subset of previous infinite span experiments)
   - ✓ Round D_e=2 *inch* nozzle (SMC000)
   - ✓ Flat plate with a beveled trailing edge, x_E = 4”, 12”
2) “Surface as a source” and “Surface as a shield” configurations
   - ✓ $0 \le h_E \le 5$ *inches*
3) Cover subsonic flight regime
   - ✓ M_a = 0.5, 0.7, 0.9, T_R = 1.0
4) Surface spans (yE) from infinite to yE < De
   - ✓ y_E = 1”, 2”, 4”, 6”, 12”, 24”
5) Cover range of polar and azimuthal angles
   - ✓ Representative “shielded” observers $50^o \le \theta \le 165^o$, $0^o \le \Phi \le 140^o$





Test Setup with Microphone Arrays

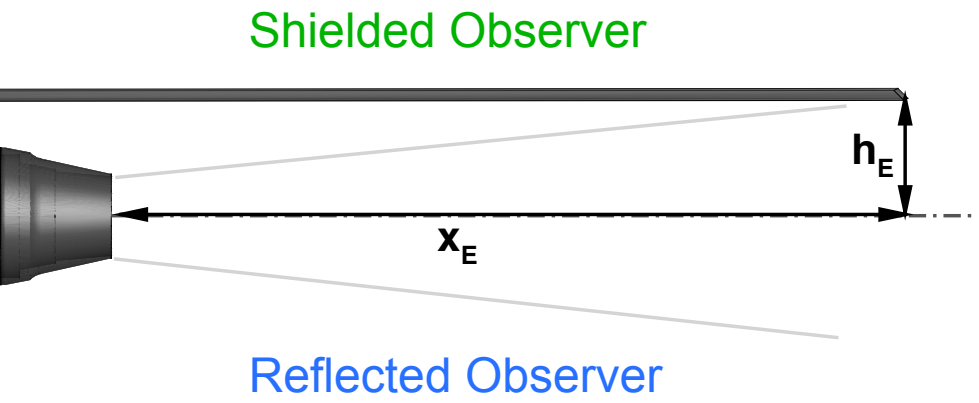


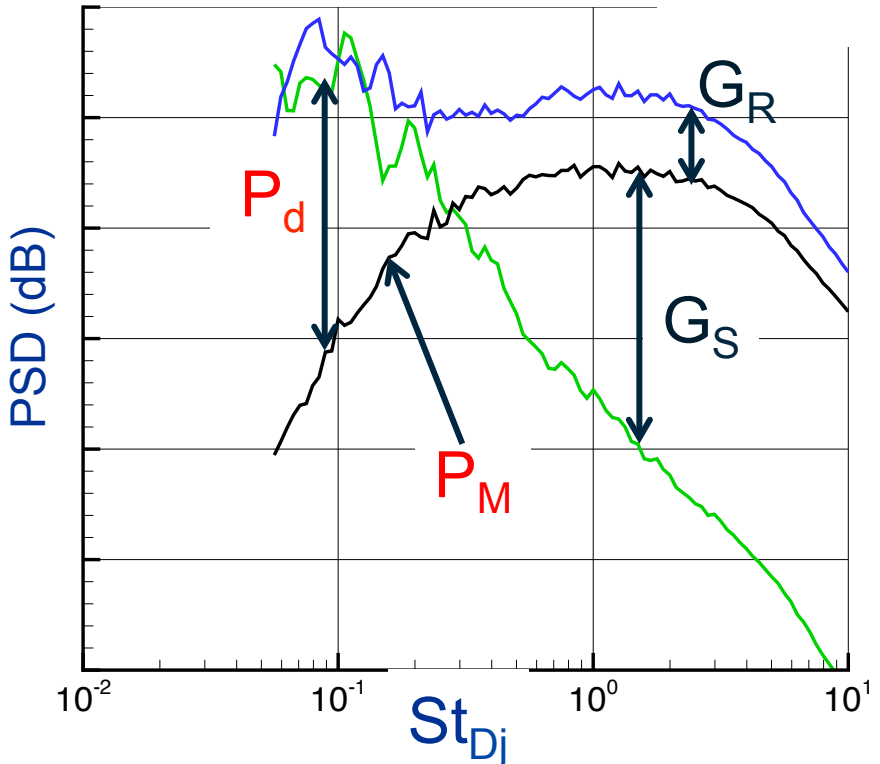
Empirical Model for Exhaust Noise

Model the mixing noise (P_m) and JSI (P_d) noise as separate sources with modifiers to account for other effects

$$PSD(M_a, T_R, x_E, h_E) = P_m(M_a, T_R, M_f) + G_{S/R}(M_a, T_R, x_{TE}, h) \oplus P_d(M_a, T_R, x_{TE}, h)$$

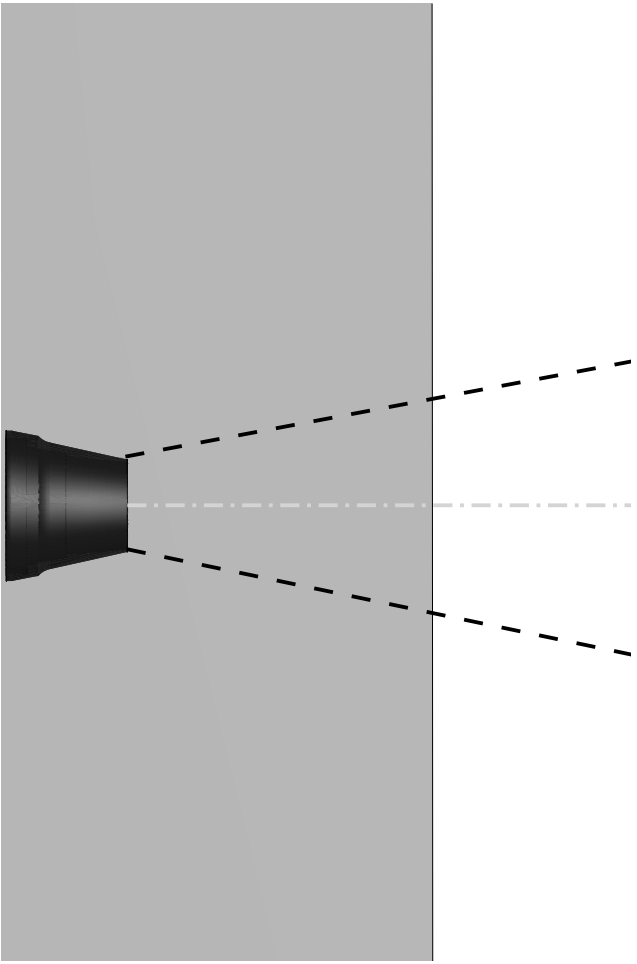
- $\oplus$ means to add power (anti-logarithmically)
- Simplifies process by allowing separate models for each source and effect





JSI Source Model – Infinite Span

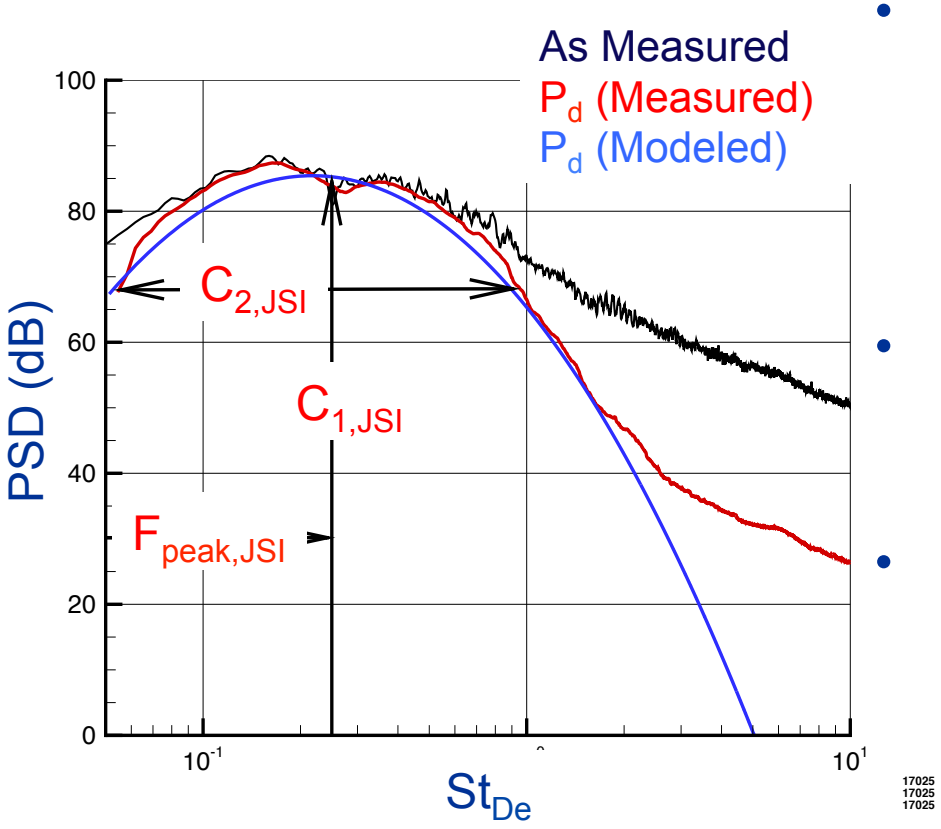
$$PSD(M_a,T_R) = P_m(M_a, T_R, M_f) + G_{S/R}(M_a, T_R, x_{TE}, h) \boldsymbol{+} P_d(M_a, T_R, x_E, h_E)$$



- Simplifications by assuming infinite span
  - Only one edge exposed to flow
  - Azimuthal angle not needed in modeling due to known dipole directivity
- Spectra determined by:
  1. Flow conditions at edge
  2. Length of trailing edge exposed to flow due to jet spread
- Assume a parabolic spectral shape
  - $P_{d,\theta=90} = C_{1,JSI}+C_{2,JSI}\log_{10}(f/F_{peak,JSI})^2$
  - Where $C_{1,JSI}$, $C_{2,JSI}$ and $F_{peak,JSI}$ are functions of M_a, T_R, x_E, h_E

JSI Source Model – Infinite Span

$$PSD_T(M_a,T_R,x_E,h_E) = P_m(M_a, T_R, M_f) + G_{S/R}(M_a, T_R, x_{TE}, h) \textbf{ ✚ } P_d(M_a, T_R, x_E, h_E)$$



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* More details in Brown, AIAA 2015-0229

JSI Source Model – Finite Span

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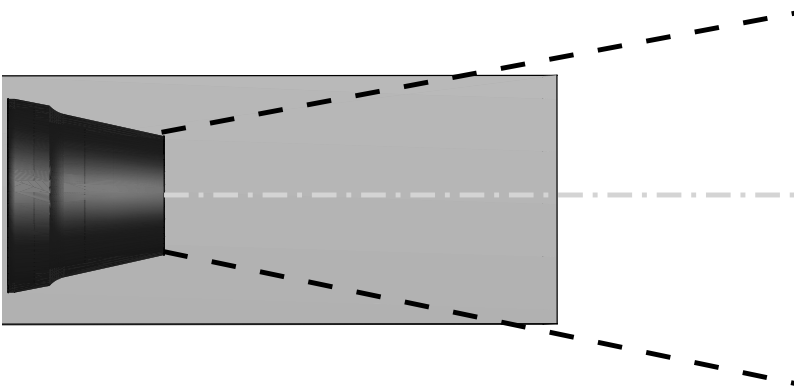
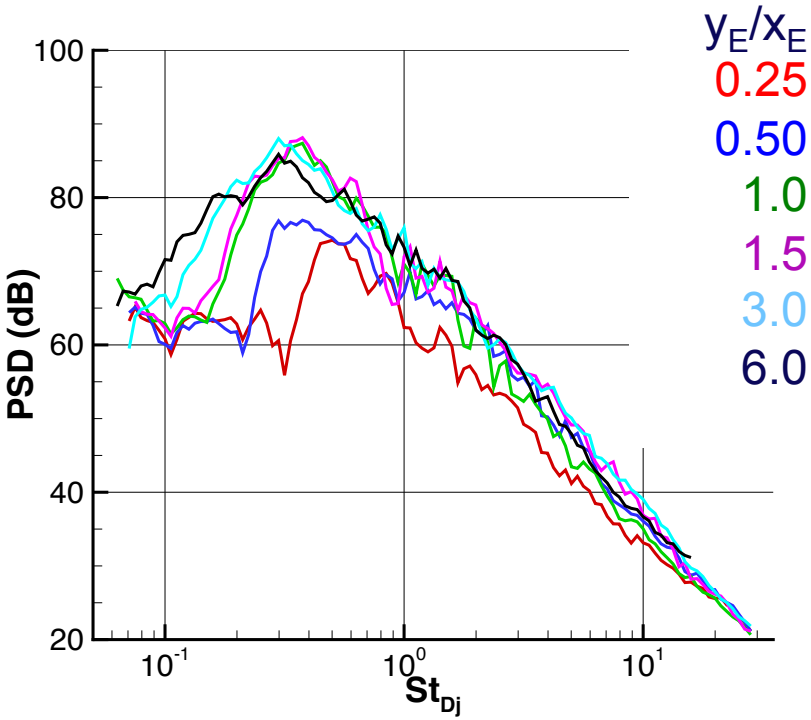


- Would like to modify infinite span model
  - Need to extend model over many (θ,Φ) observers
- Spectra determined by:
  1. Flow conditions at edge
  2. Length of trailing edge exposed
  3. Possible side edge effects
- Nondimensionalize span by length (y_E/x_E)
  - Jet spread over the length of the surface
  - Set a maximum at infinite span value

JSI Source Model – Finite Span

$$P_{d,\theta=90} = C_{1,JSI} C_{span,JSI} + C_{2,JSI} \log_{10}(f/F_{peak,JSI})^2$$



- $y_E/x_E \approx 1$ is equivalent to infinite span
- Effect of span is primarily on amplitude for $y_E > D_e$
  - Modify amplitude term $C_{1,JSI}$ in P_d model
  - Normalize peak amplitude by infinite span amplitude ➔ model finite span as percentage of infinite span
  - Peak amplitude may be difficult to determine so use OASPL

JSI Source Model – Finite Span

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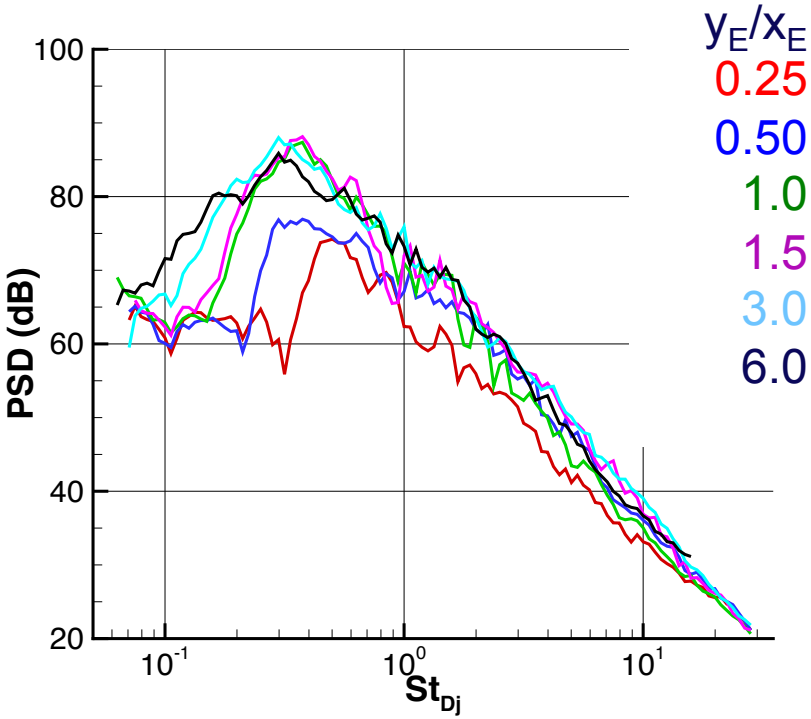

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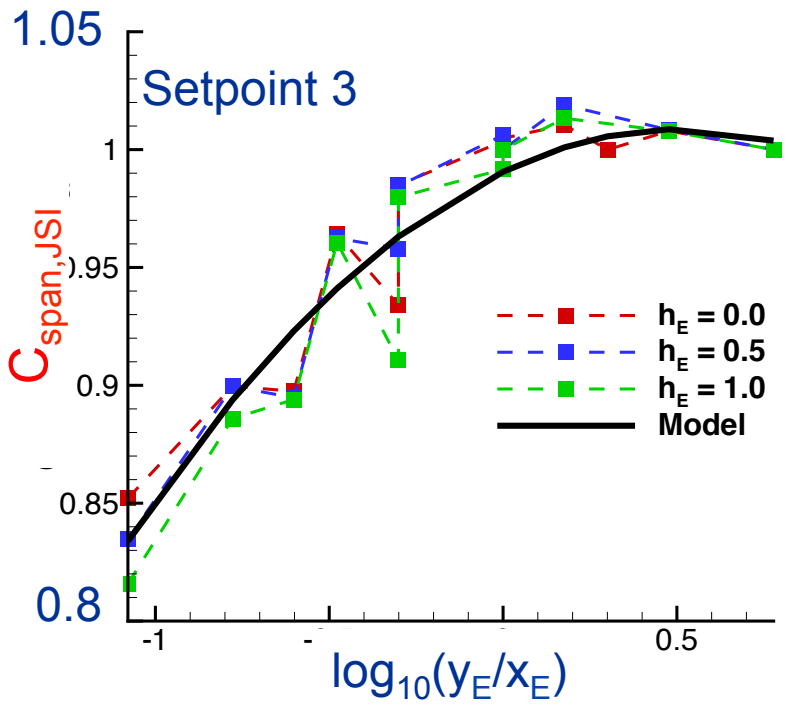
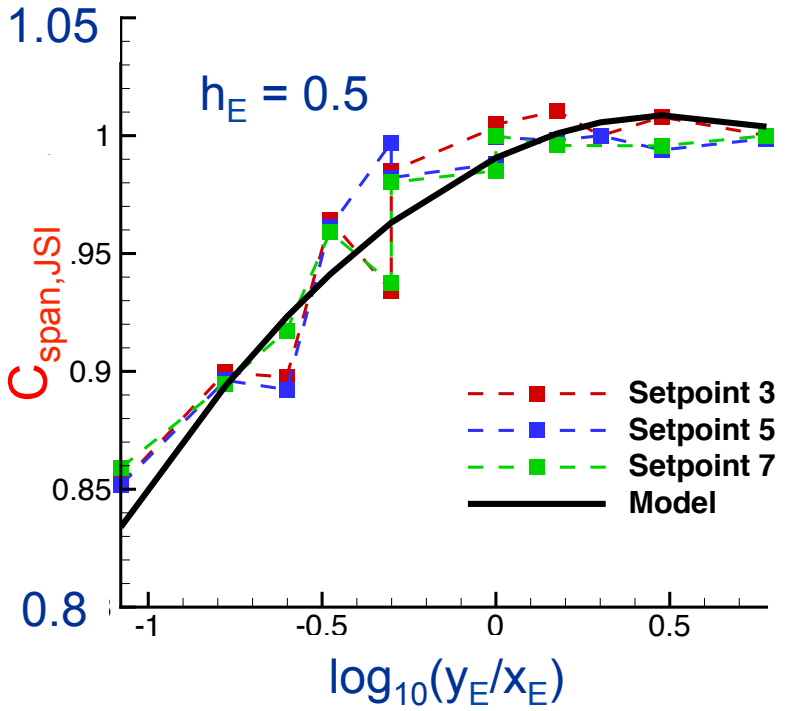
Finite span model is: $C_{span,JSI} = (OASPL_{FS}/OASPL_{IS}) = F(y_E/x_E)$

JSI Source Model – Finite Span

$$P_{d,\theta=90} = C_{1,JSI}(C_{span,JSI}) + C_{2,JSI}\log_{10}(f/F_{peak,JSI})^2$$

- Fit data to a quadratic function of $\log_{10}(y_E/x_E)$ using a least-squares fit
- Set maximum level $C_{span,JSI} = 1$ when $y_E/x_E > 1$
- $C_{span,JSI}(y_E/x_E) = -0.0691 * [\log_{10}(y_E/x_E)]^2 + 0.0707 * \log_{10}(y_E/x_E) + 0.9906$

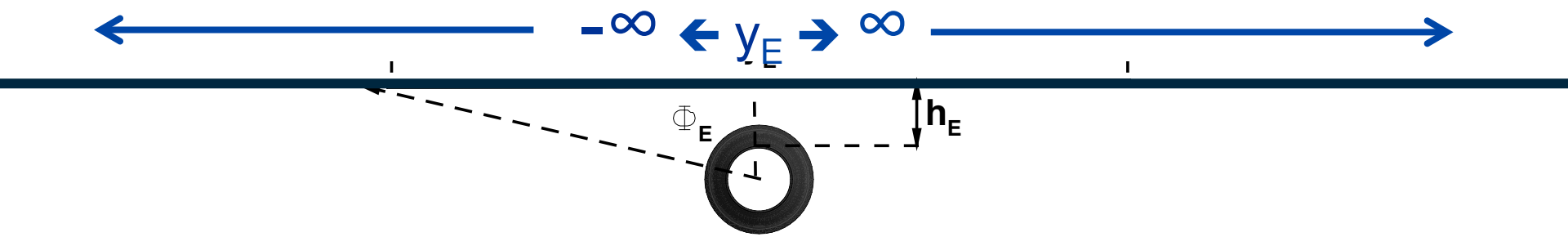




Shielding Model – Infinite Span

$$PSD(M_a,T_R) = P_m(M_a, T_R, M_f) + G_S(M_a, T_R, x_{TE}, h) + P_d(M_a, T_R, x_E, h_E)$$

- Simplifications by assuming infinite span
  - Azimuthal angle not needed – observer is on shielded or reflected side
- Effect spectral shape determined by:
  1. Source location relative to trailing edge location
  2. Observer polar angle
- Assume linear function of logarithmic frequency with maximum 0 dB
  - $G_{S,\Theta} = C_{1,S,\Theta} * \log_{10}(St_{De}) + C_{2,S,\theta}$
  - Where $C_{1,S,\theta}$ and $C_{2,S,\theta}$ are functions of M_a, T_R, x_E, h_E
  - And determined at each polar angle, θ, in the data set



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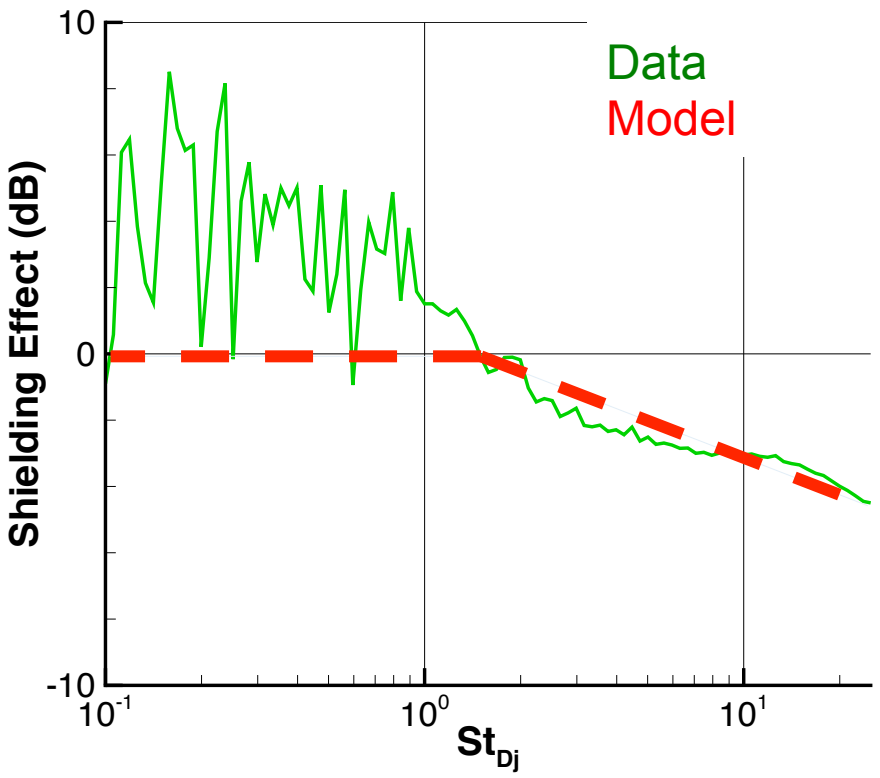
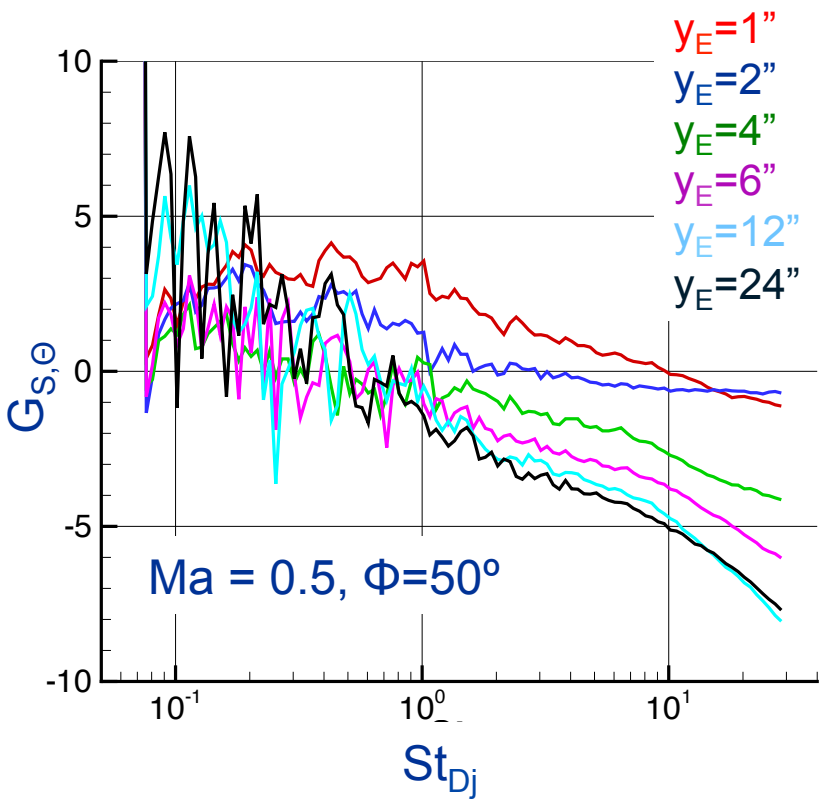


* More details in Brown, AIAA 2015-3128

JSI Source Model – Finite Span

$$G_{S,\Theta} = C_{span,S}[C_{1,S,\Theta} * \log_{10}(St_{De}) + C_{2,S,\theta}]$$

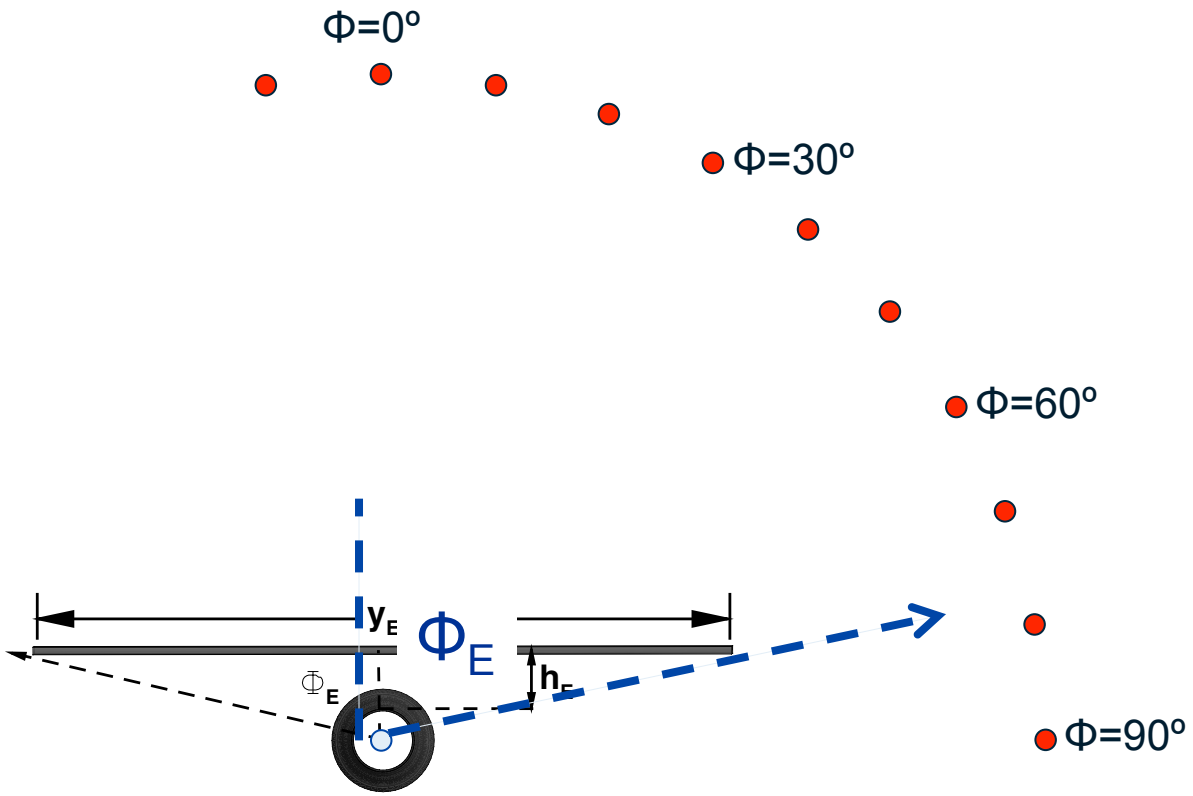


- Observer azimuthal angle required
- Effect of span is to decrease shielding as span decreases
  - Focus on amplitude changes to shift infinite span linear model
  - Normalize by infinite span ➔ model finite span as percentage of infinite span
  - Model at each azimuthal angle in dataset
  - Need independent variable that gives shielded versus unshielded observers

JSI Source Model – Finite Span

$$G_{S,\theta} = C_{span,S,\Phi}[C_{1,S,\Theta} * \log_{10}(St_{De}) + C_{2,S,\theta}]$$

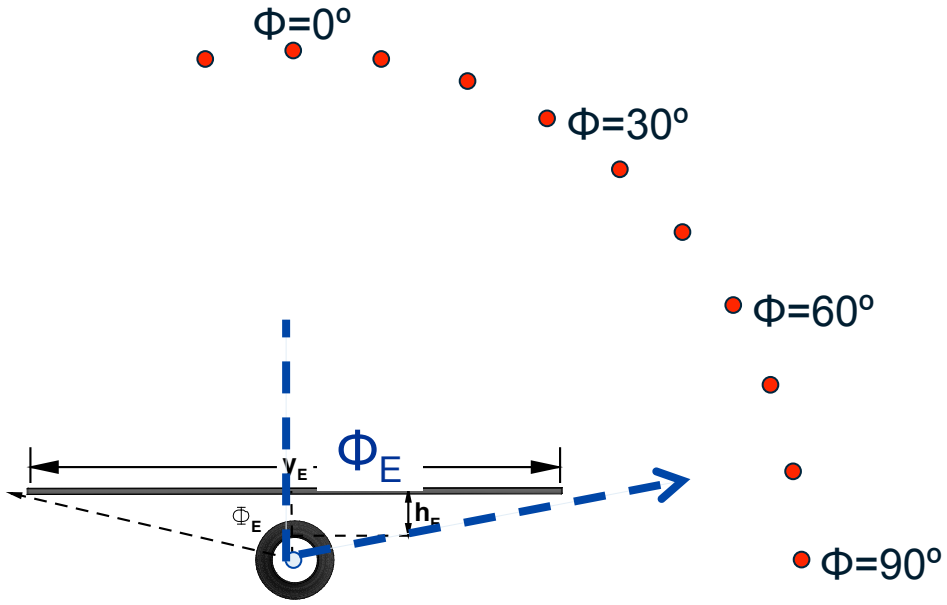
- $C_{span,S}$ is function of angle between centerline and spanwise edge, Φ_E
  - $\Phi_E = \tan^{-1}[(y_E/2) / (h_E + D_e/2)]$

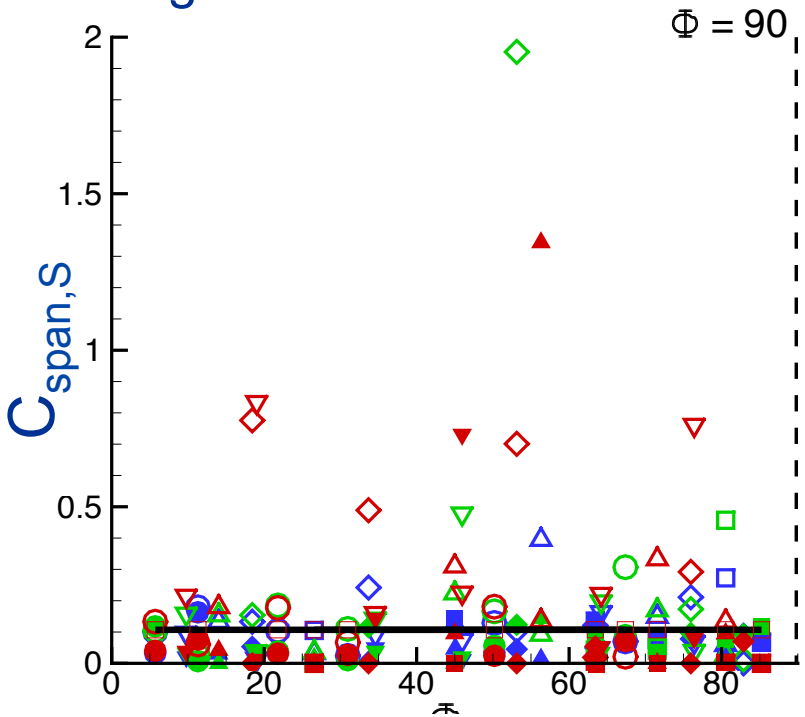


JSI Source Model – Finite Span

$$G_{S,\theta} = C_{span,S,\Phi}[C_{1,S,\Theta} * \log_{10}(St_{De}) + C_{2,S,\theta}]$$

- Observer Φ=90 is never shielded – use to establish scatter in data
  - Scatter may be uncertainty in data or due to other edge effects
  - Least-squares fit gives constant level around 0.1
- Use to restrict range of fit at other observer angles

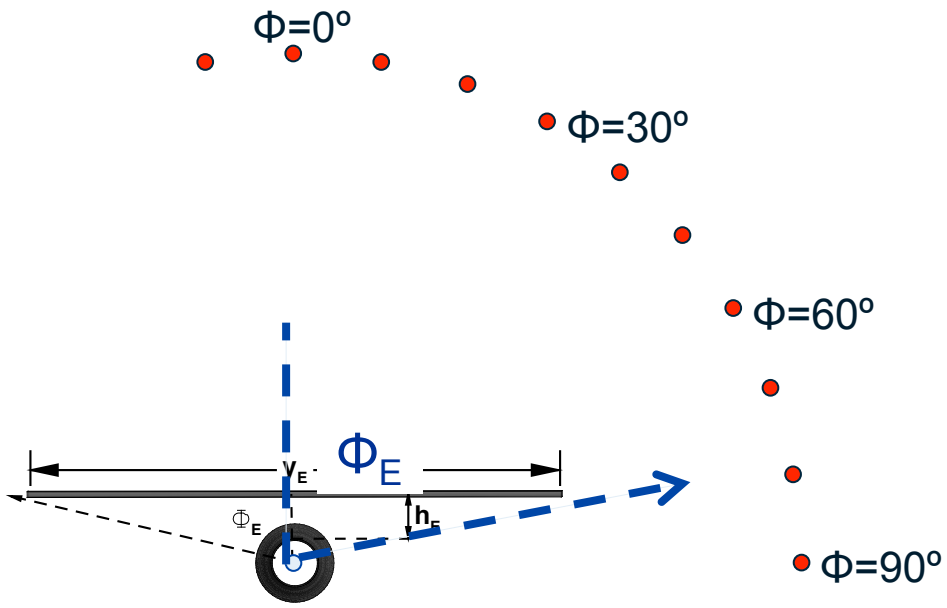


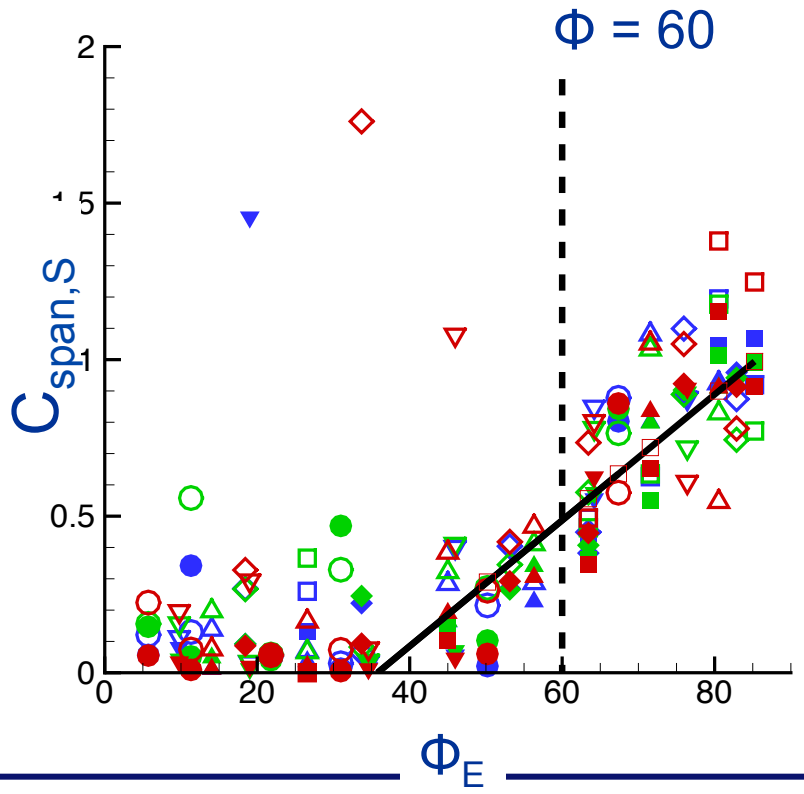


JSI Source Model – Finite Span

$$G_{S,\theta} = C_{span,S,\Phi}[C_{1,S,\Theta} * \log_{10}(St_{De}) + C_{2,S,\theta}]$$

- Restrict range to data statistically different from zero
- Perform linear least-squares fit so that:
  - $C_{span,S,\Phi} = S_{1,\Phi} * \Phi_E + S_{2,\Phi}$





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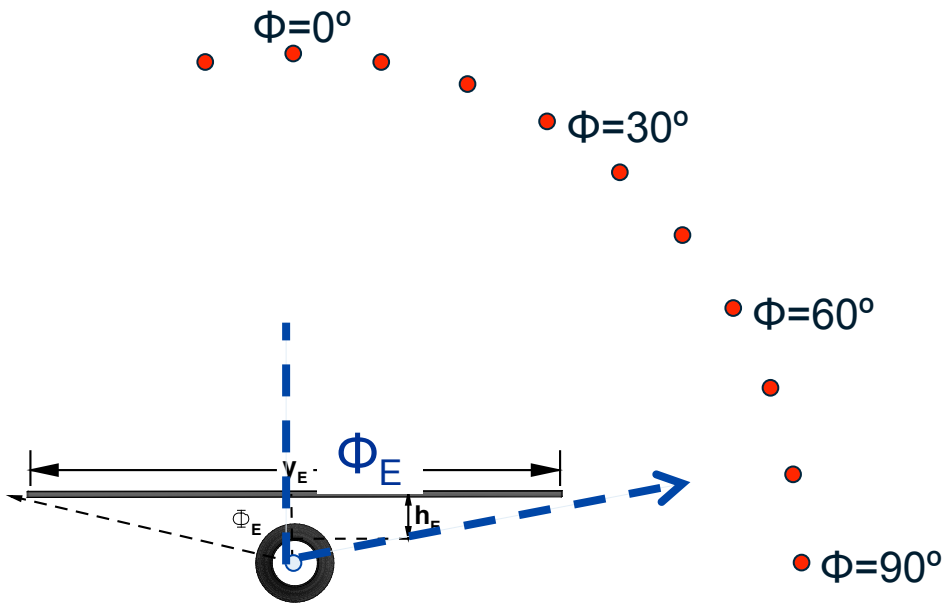

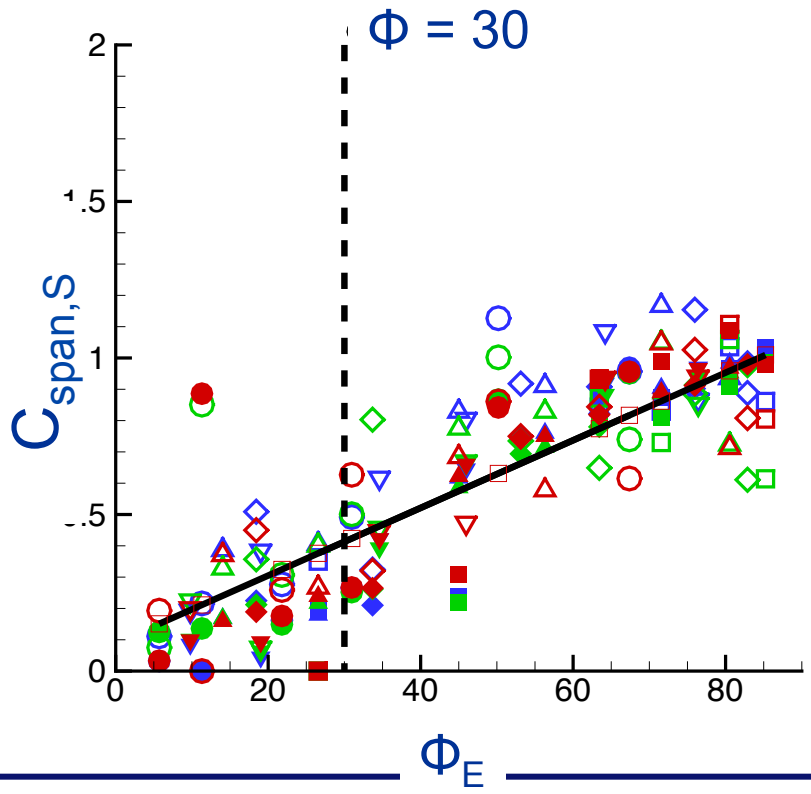

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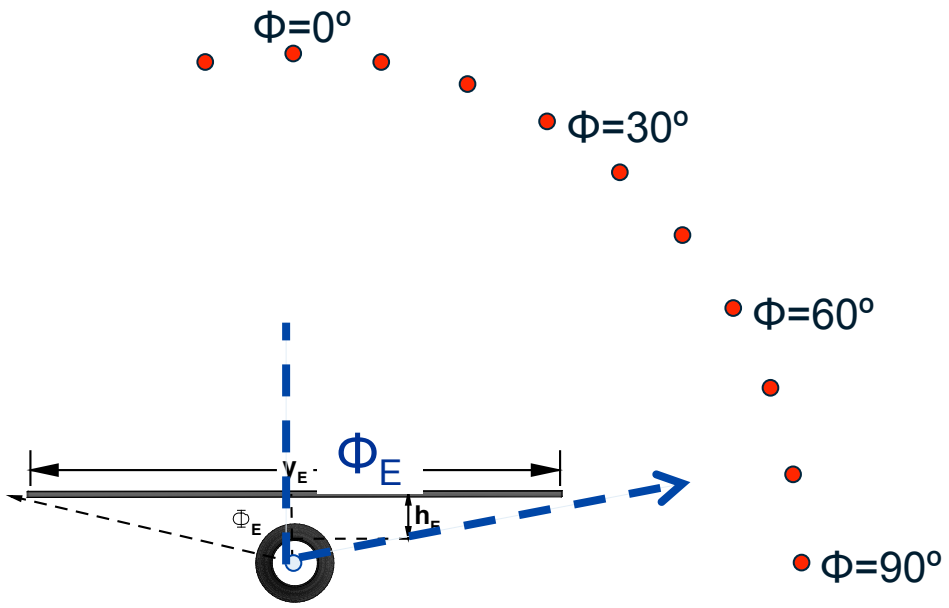
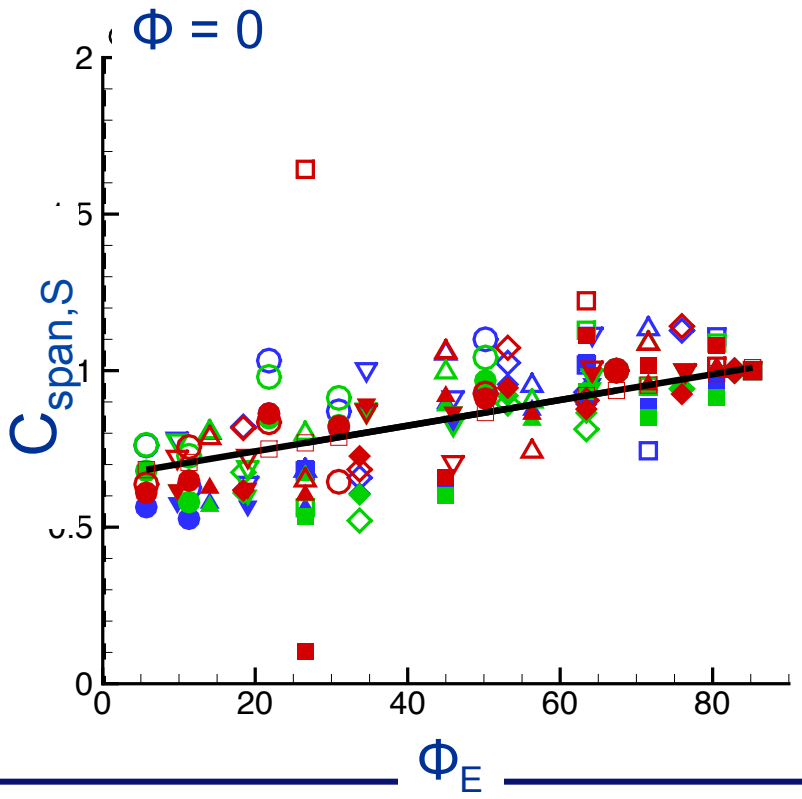
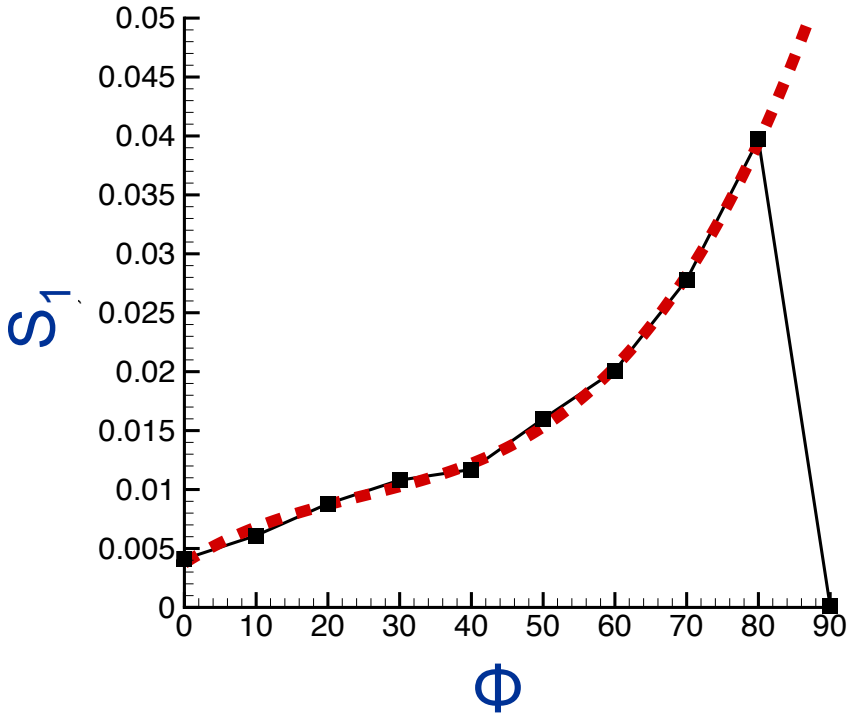


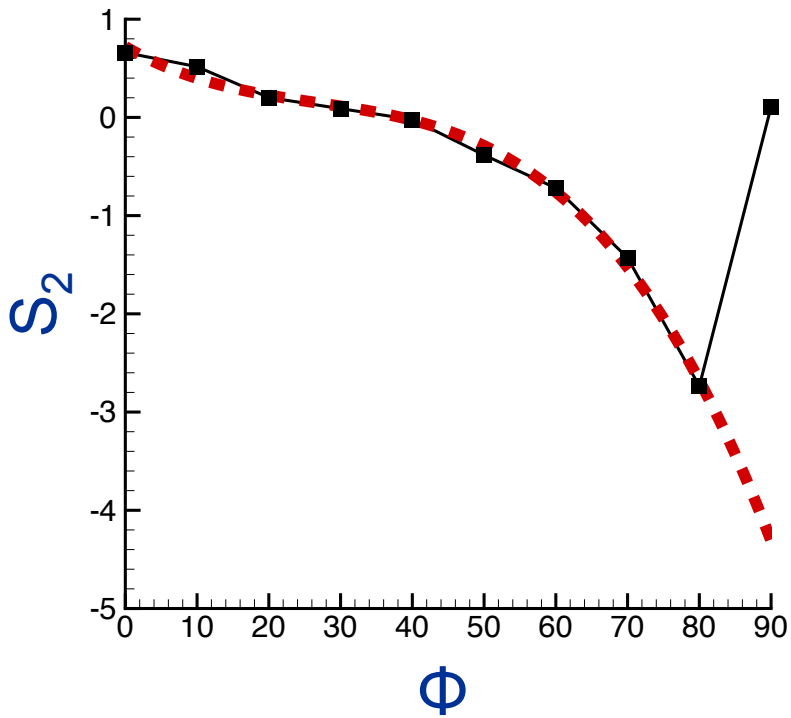


JSI Source Model – Finite Span

$$C_{span,S,\Phi} = S_{1,\Phi} * \Phi_E + S_{2,\Phi}$$

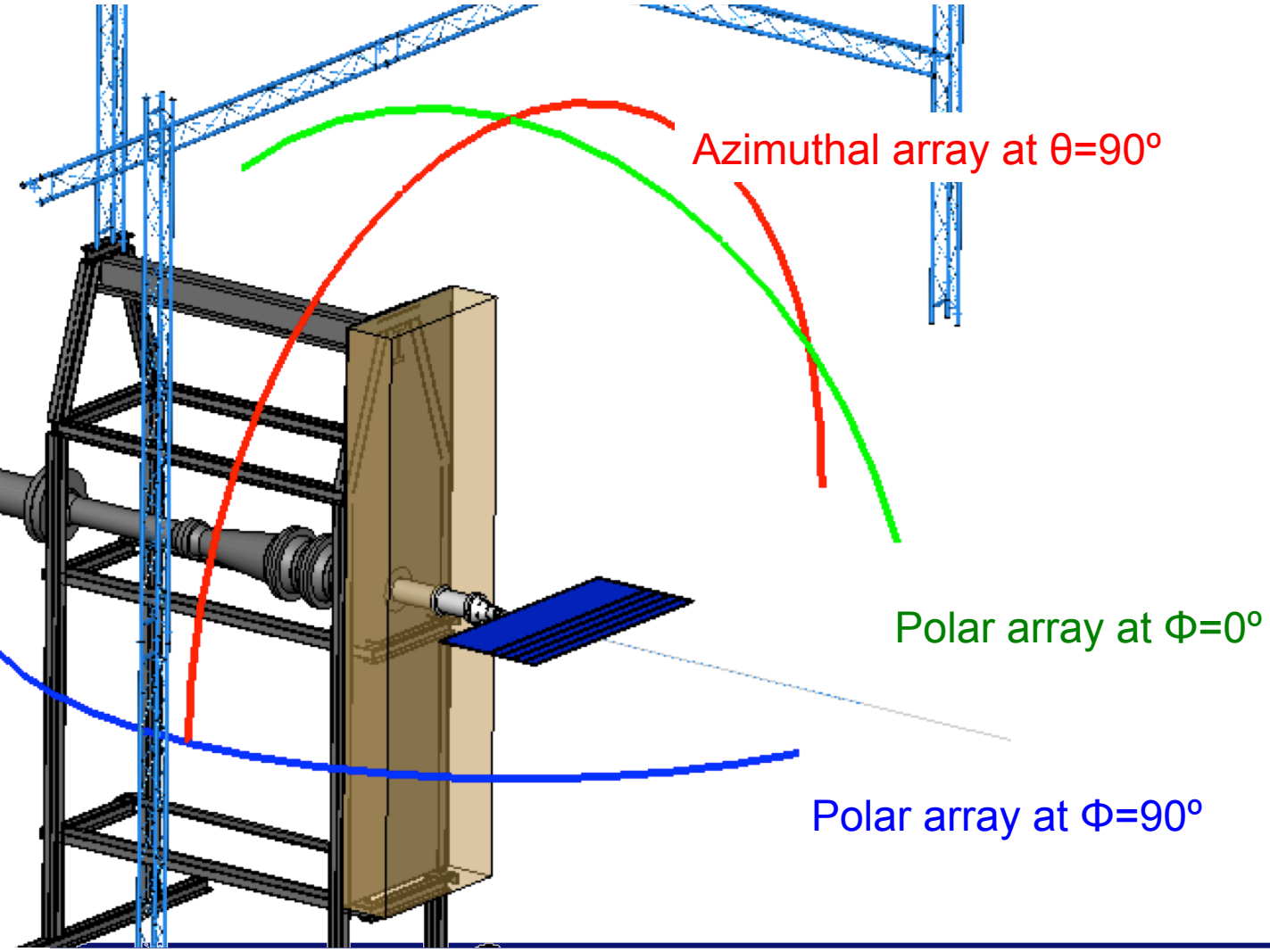
- Have coefficients $S_{1,\Phi}$ and $S_{2,\Phi}$ at Φ=10º increments
  - Can linearly interpolate between them for other observer angles
  - Or fit to a cubic polynomial for $0 \leq \Phi \leq 80$





Comparison to Data

$$PSD(M_a,T_R) = P_m(M_a, T_R, M_f) + G_S(M_a, T_R, x_{TE}, h) \boxplus P_d(M_a, T_R, x_E, h_E)$$



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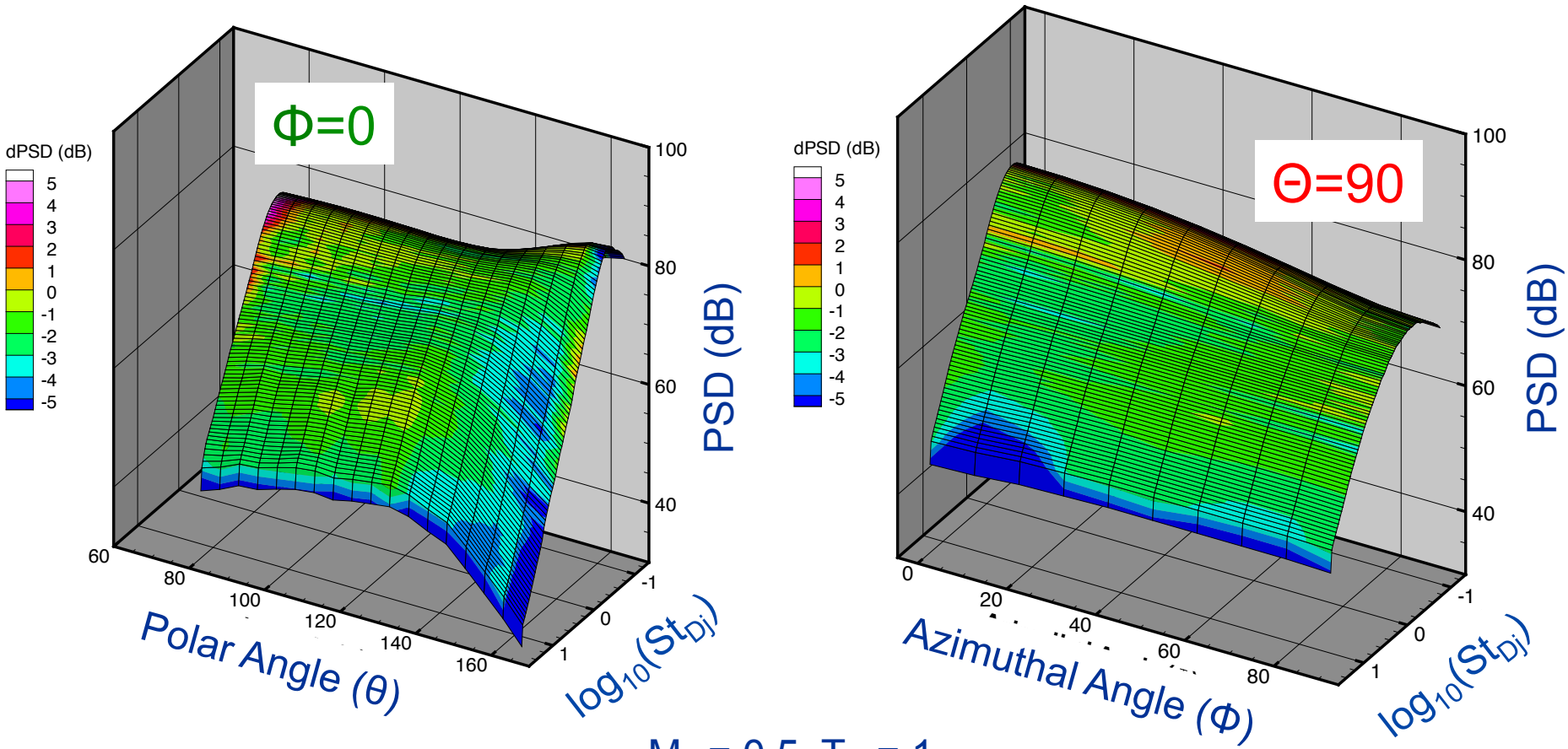


$M_a = 0.5, T_R = 1$
$x_E = 4, h_E = 0, y_E = 2$

Summary

- Empirical models have been developed to account for finite surface spans on the JSI source and shielding effect
- Models work by modifying the amplitude of the infinite span
  - Extends model over other angles not in dataset
  - Allows natural limits on effect to keep model bounded
- Models add dependency on azimuthal angle
- The finite span models remove one significant assumption from previous work
- These models will be added to existing ANOPP modules for system level aircraft noise predictions

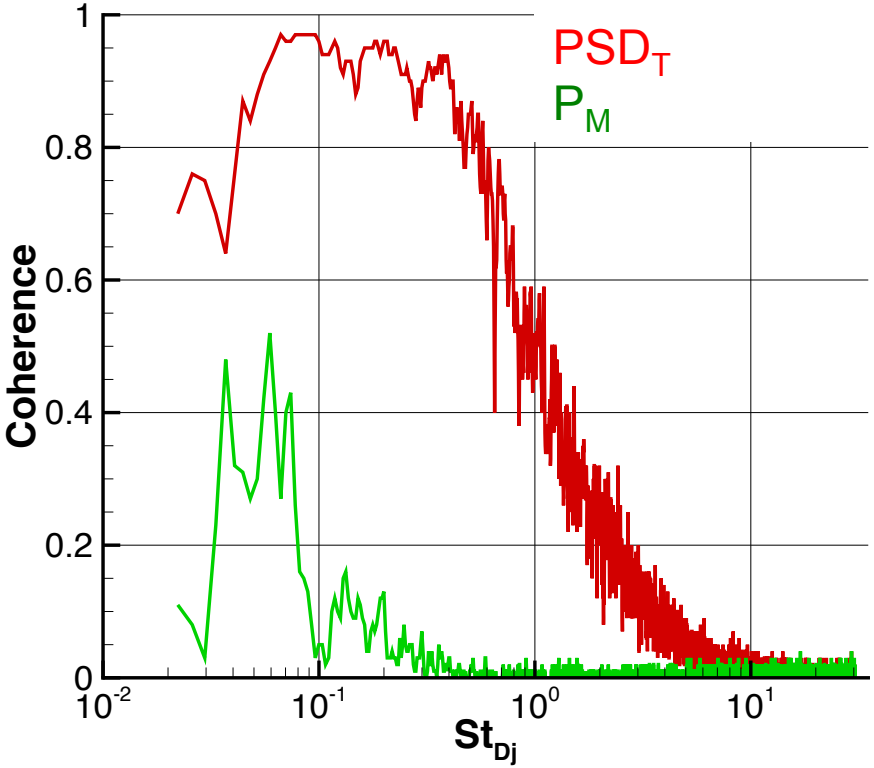
Extra Slides

Outline

- Define jet-surface interaction (JSI) noise
- Experimental database for model development
- Empirical JSI models for infinite span surfaces
- Correction models for finite span (JSI and shielding)
- Model verification
- Summary

Separating Noise Sources in Measured Data

- JSI noise is dominated by trailing edge noise
  - Approximated by a dipole point source at the trailing edge
  - JSI noise coherent across a range of polar angles where jet noise is not



Separating Noise Sources in Measured Data

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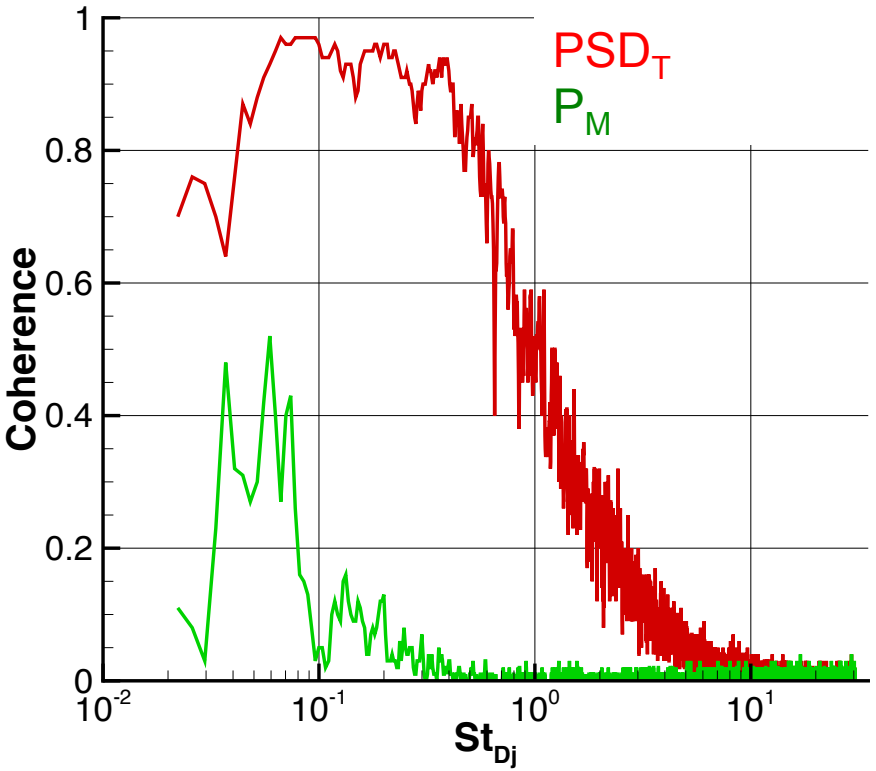
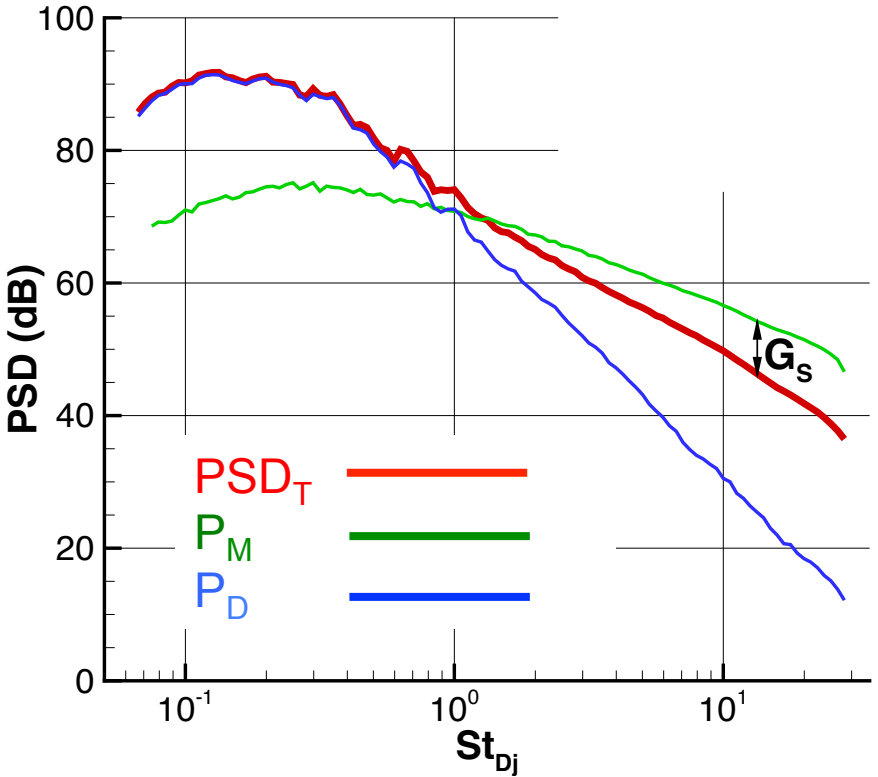
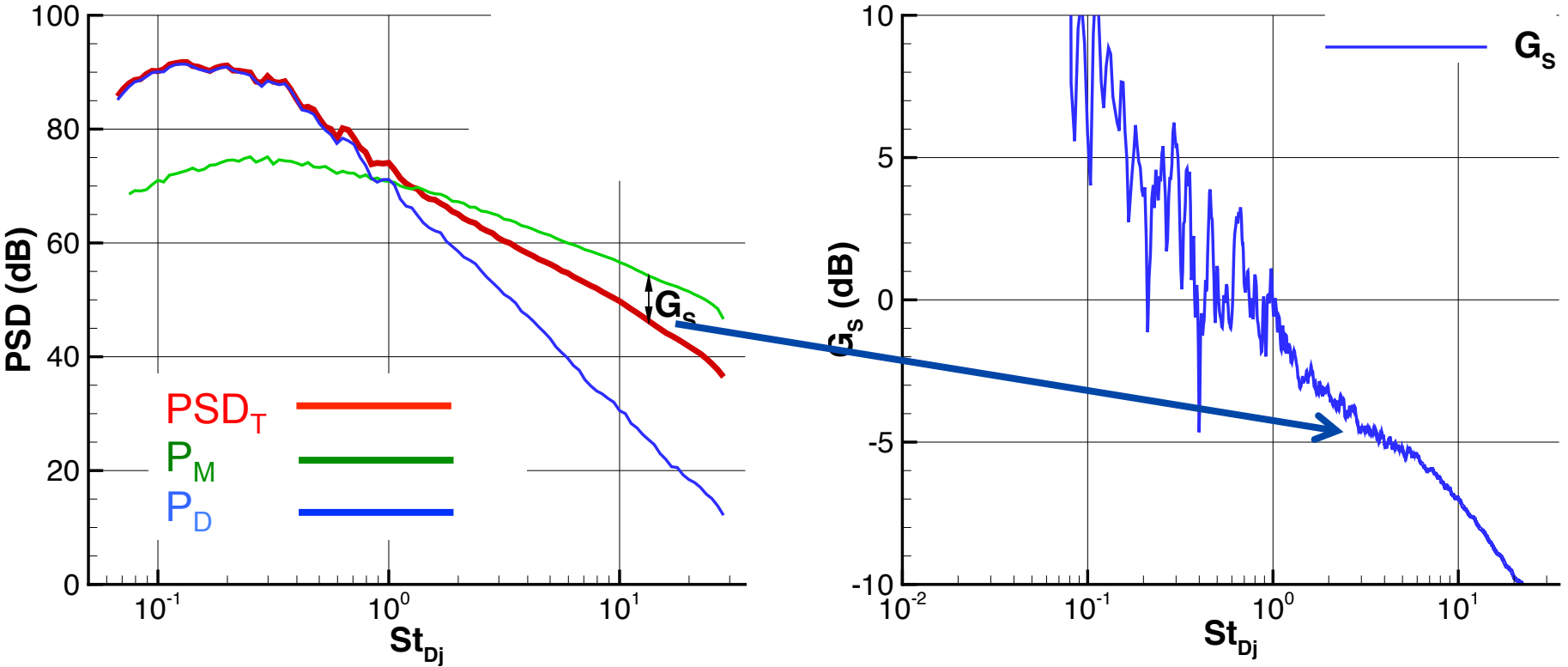
  - Approximated by a dipole point source at the trailing edge
  - JSI noise coherent across a range of polar angles where jet noise is not
- Use coherence (γ^2) to extract the jet-surface interaction noise (P_D) from the measured noise (PSD_T) → $P_D = \gamma^{2*}PSD_T$





Separating Noise Sources in Measured Data

- Shielding effect (G_S) is the difference between the mixing noise (P_M) and the measured noise (PSD_T) less the JSI (P_d) noise so: $G_S = (PSD_T \ominus P_d) - P_m$
- GS is the result of two spectral subtractions and, therefore, is subject to higher uncertainty



Surfaces with Microphone Arrays