Jet-Surface Interaction – High Aspect Ratio Nozzle Test Test Summary

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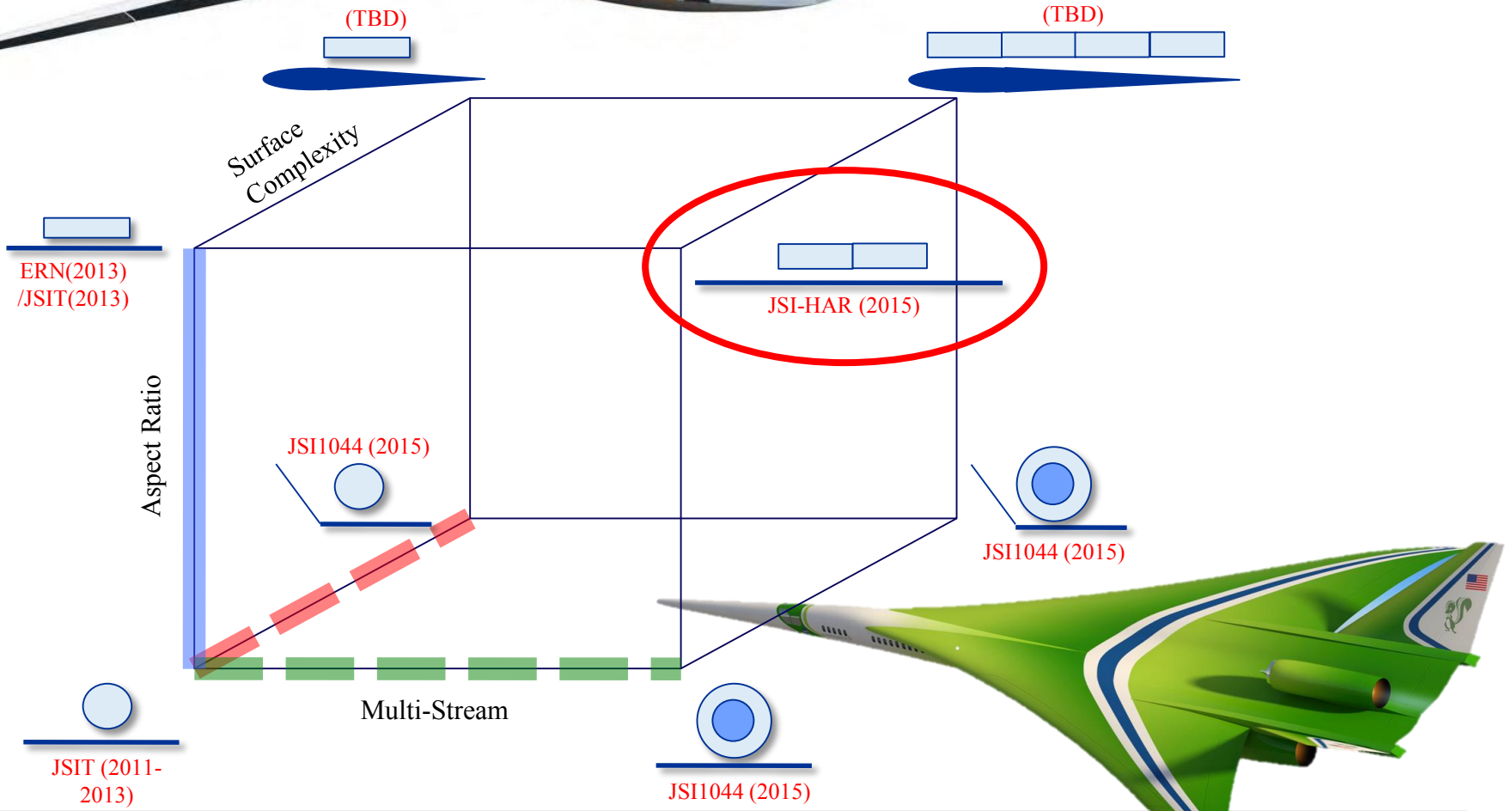
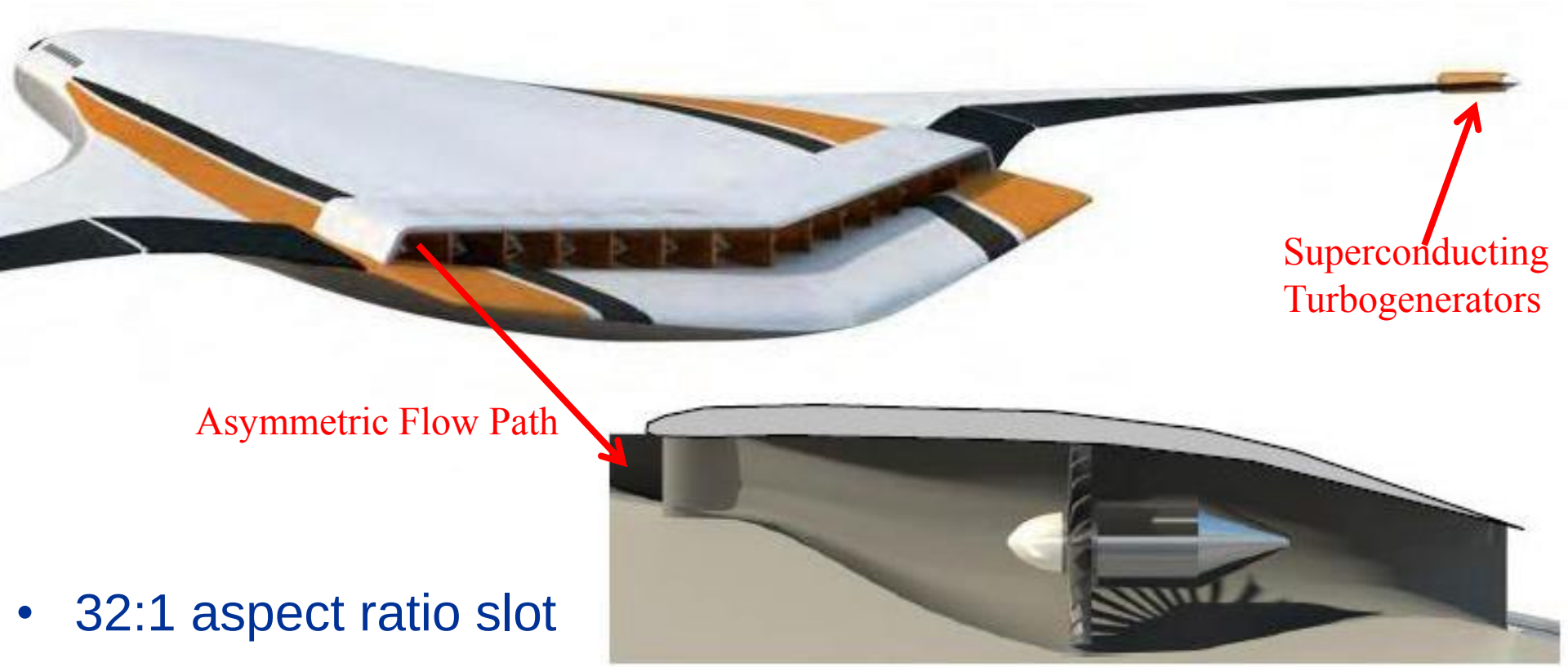
Jet-Surface Interaction Noise Test Programs



* Covered by AATT and CST Projects

Motivation:
Turbo-electric Distributed Propulsion Concept (TeDP)



- 32:1 aspect ratio slot
- Divided into 2:1 at exit
- Electric fan has low pressure ratio, low temperature ratio
- Aft deck extends (estimated) 1-4 slot heights downstream

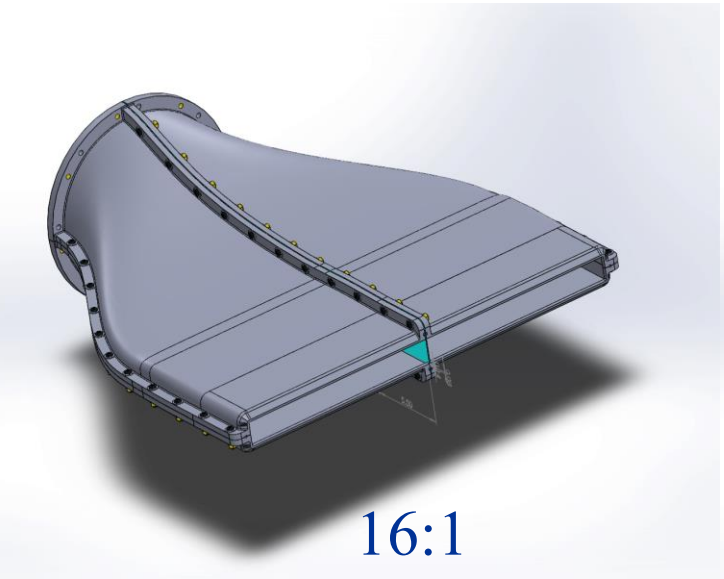
* Kim et. al., AIAA 2015-3805

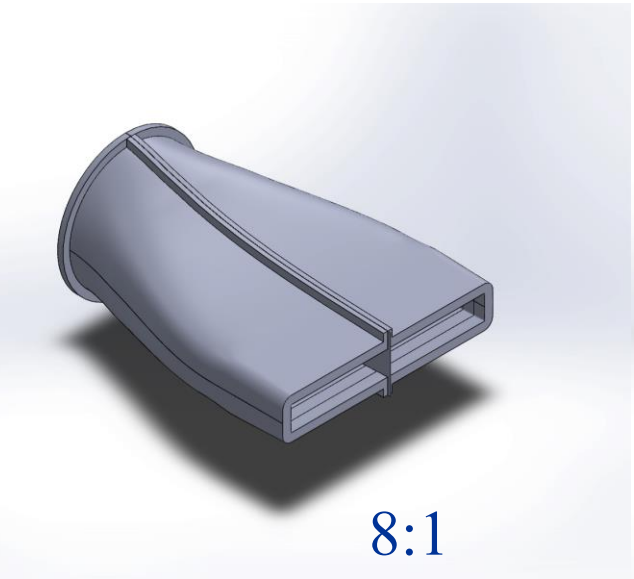
Goals for JSI-HAR

1. Extend current database to larger aspect ratio nozzles
2. Verify / connect current small-scale database to larger-scale rectangular nozzles near surfaces
3. Acquire data suitable for creating / validating empirical jet-surface interaction noise models
4. Investigate the effect of nozzle septa on the jet-mixing and jet-surface interaction noise sources

Test Plan

1. Design and test 3 nozzles (listed by priority):
   1. 16:1 aspect ratio – extend current database to higher aspect ratios
   2. 8:1 aspect ratio – verify/connect small-scale database to larger-scale
   3. 12:1 aspect ratio – midpoint to allow a second-order modeling





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   1. 16:1 aspect ratio – extend current database to higher aspect ratios
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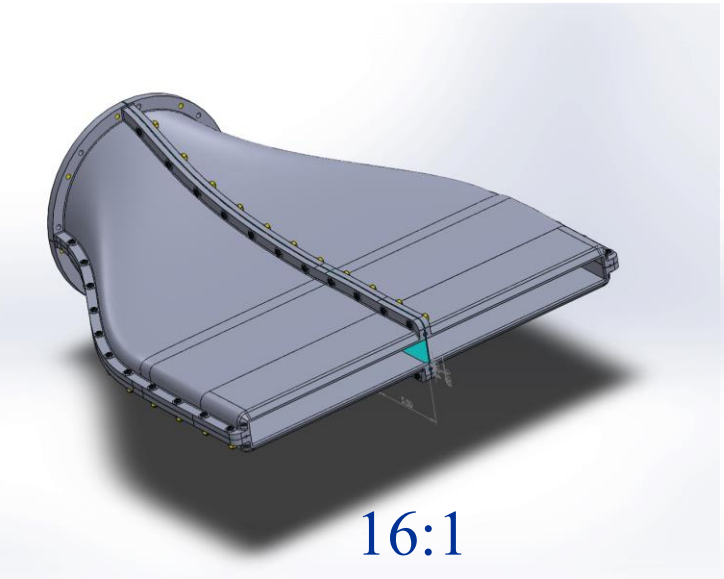
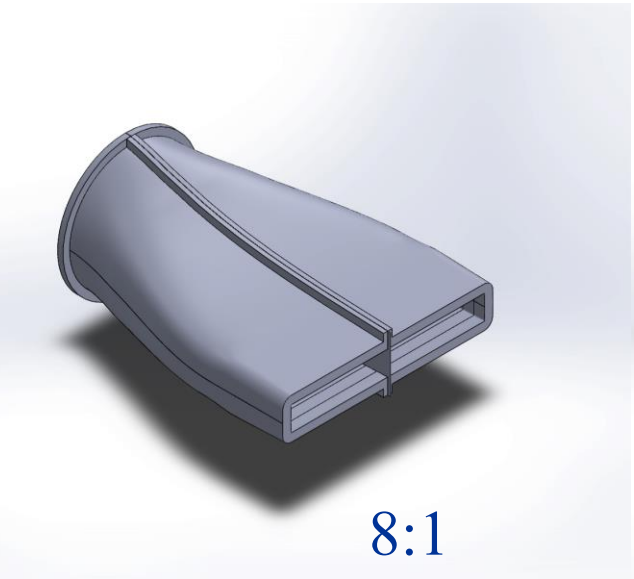
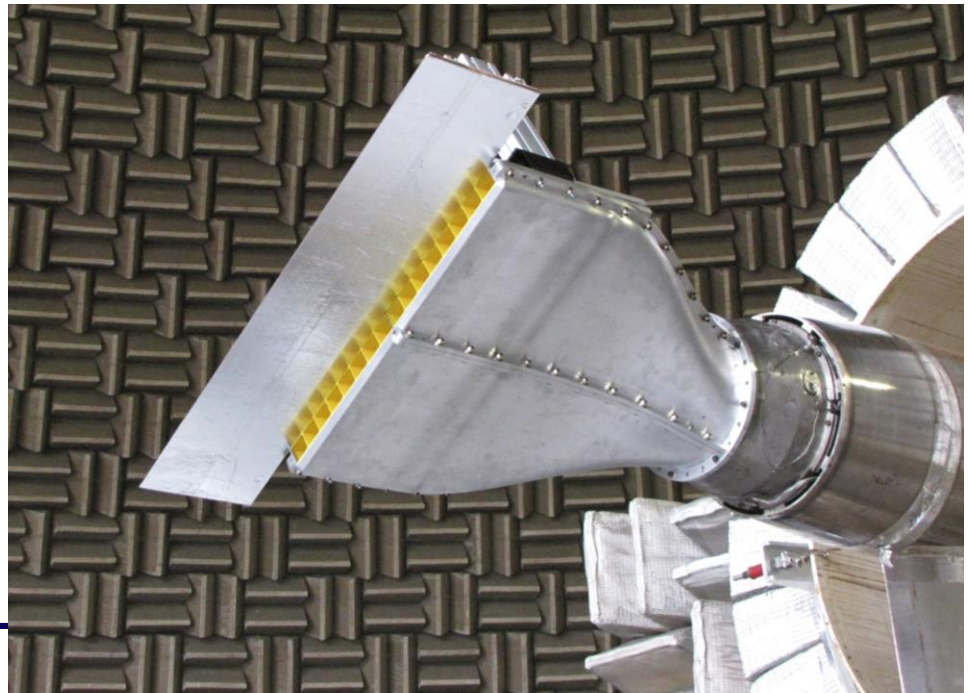




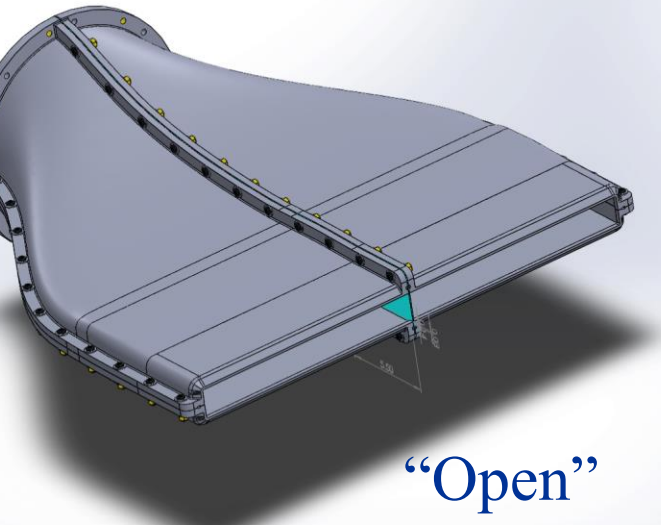
Test Plan

1. Design and test 16:1, ~~8:1, 12:1~~ aspect ratio nozzles
2. Add aft decks / surfaces onto nozzles
    1. Acquire data for modeling JSI source and shielding effect

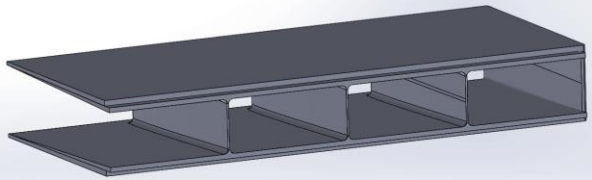


Test Plan

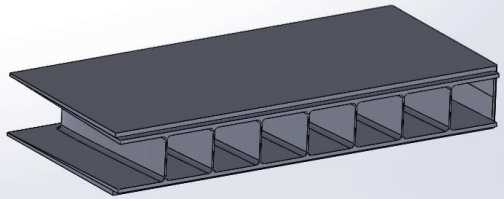
1. Design and test 16:1, ~~8:1, 12:1~~ aspect ratio nozzles
2. Add aft decks / surfaces onto nozzles
3. Design and test nozzle septa inserts
    1. “Open” no septa insert – effect of aspect ratio on jet mixing noise
    2. 2:1 / 7 septa inserts – similar to the TeDP concept
    3. 1:1 / 15 septa insert – effect of varying number of septa
    4. ~~Other variations~~



“Open”

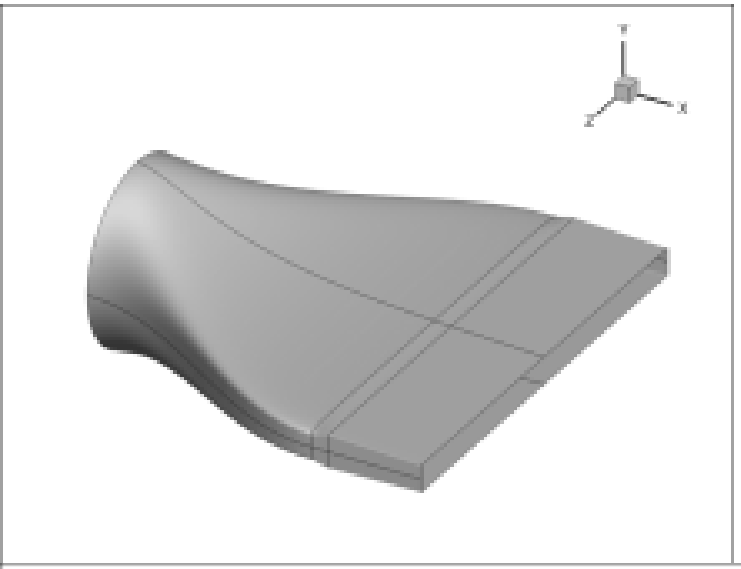


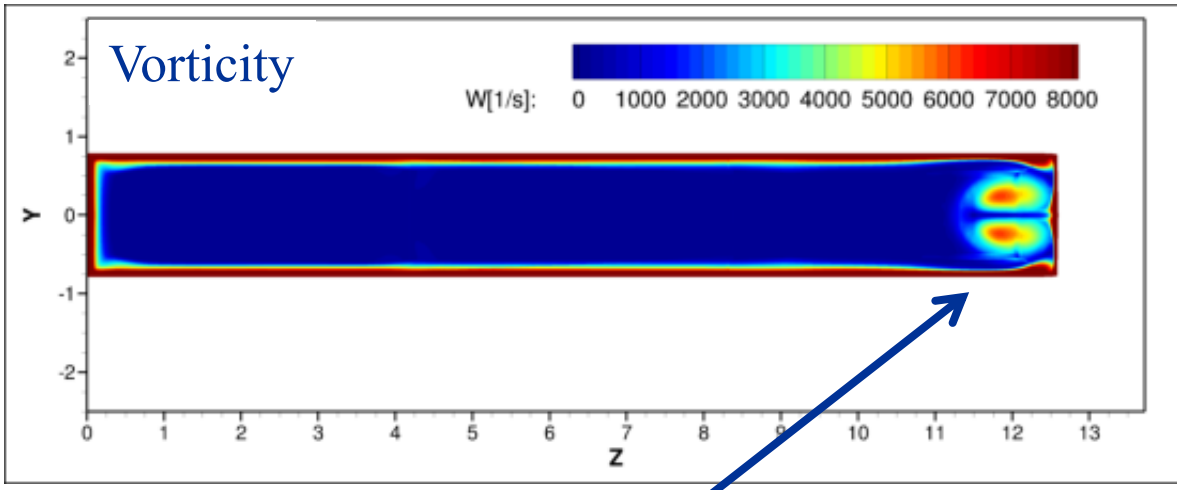
2:1 / 7 septa

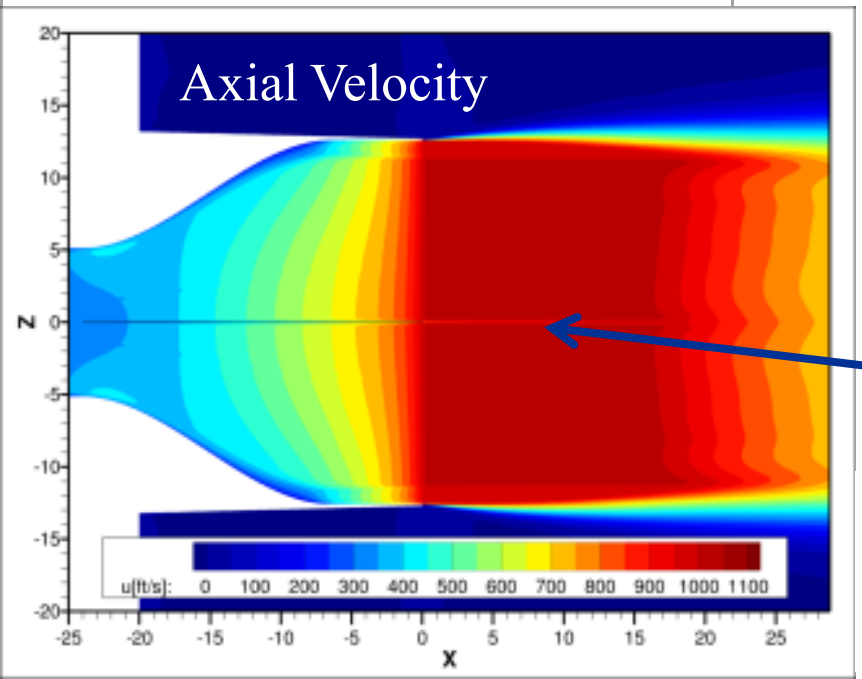


1:1 / 15 septa

16:1 Nozzle Design







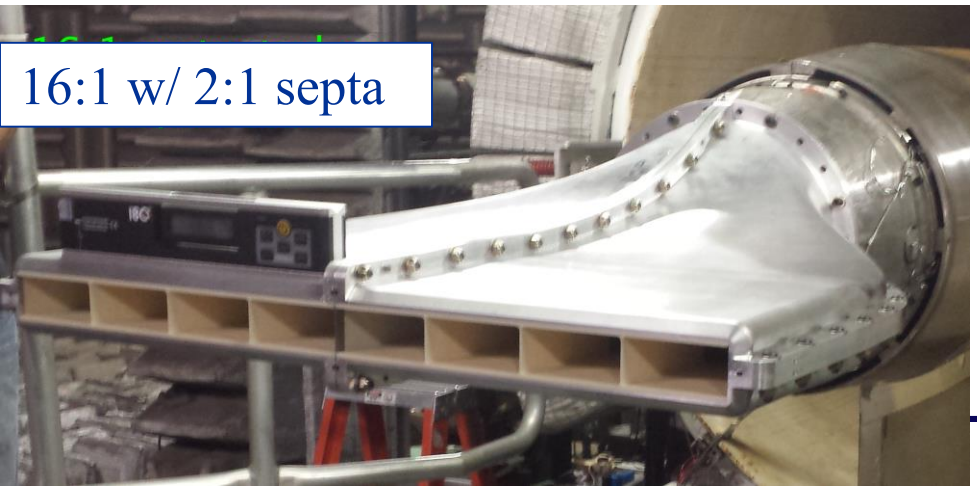
- Significant vorticity near corners
- Attached flow along outboard edge of major axis (BL thickness still significant)
- No normal shocks at nozzle exit
- Continuous area contraction helps
- Significant wake from center vane (added for structural support)

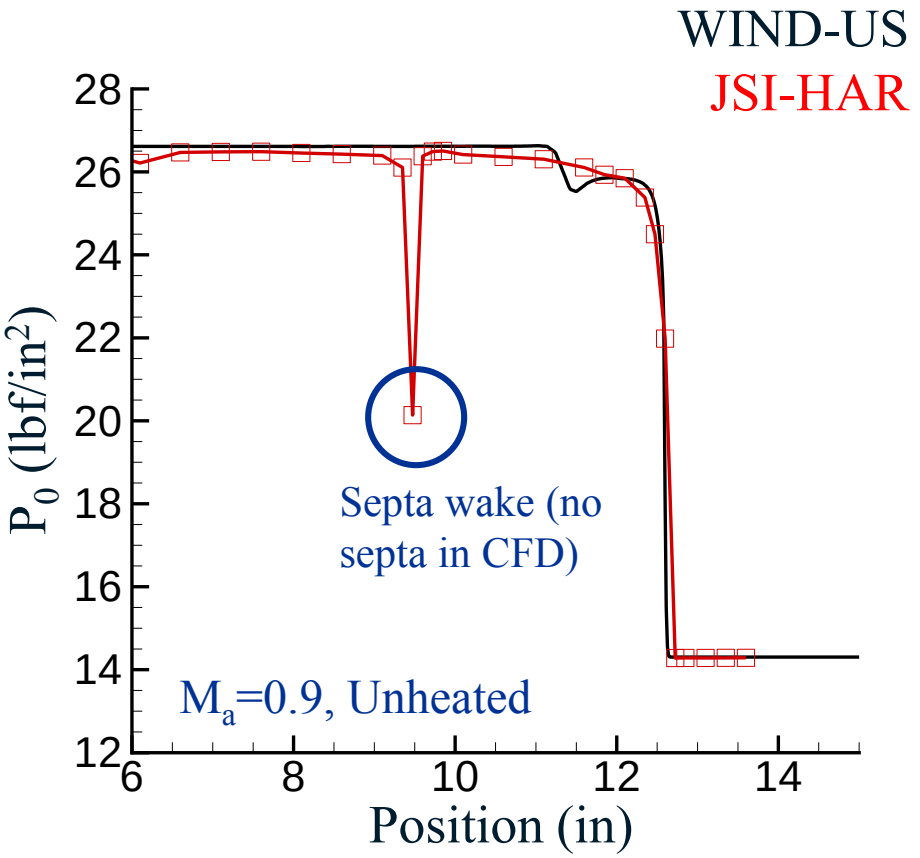
* Brown & Dippold, TWG Fall 2015

* Dippold, V., "Design and Analyses of High Aspect Ratio Nozzle for Distributed Propulsion Acoustics Measurements", AIAA Aviation 2016 Conference

Flow Profile at Nozzle Exit

- 2:1 / 7 septa insert installed for JSI-HAR but not in WIND-US
- Total pressure measured 0.25” downstream of nozzle exit
- No indication of vortex in JSI-HAR
  - 1 Hz averaged pressure data would not likely pick this up even if present
- Flat profile between septa
- Losses slightly higher in JSI-HAR data



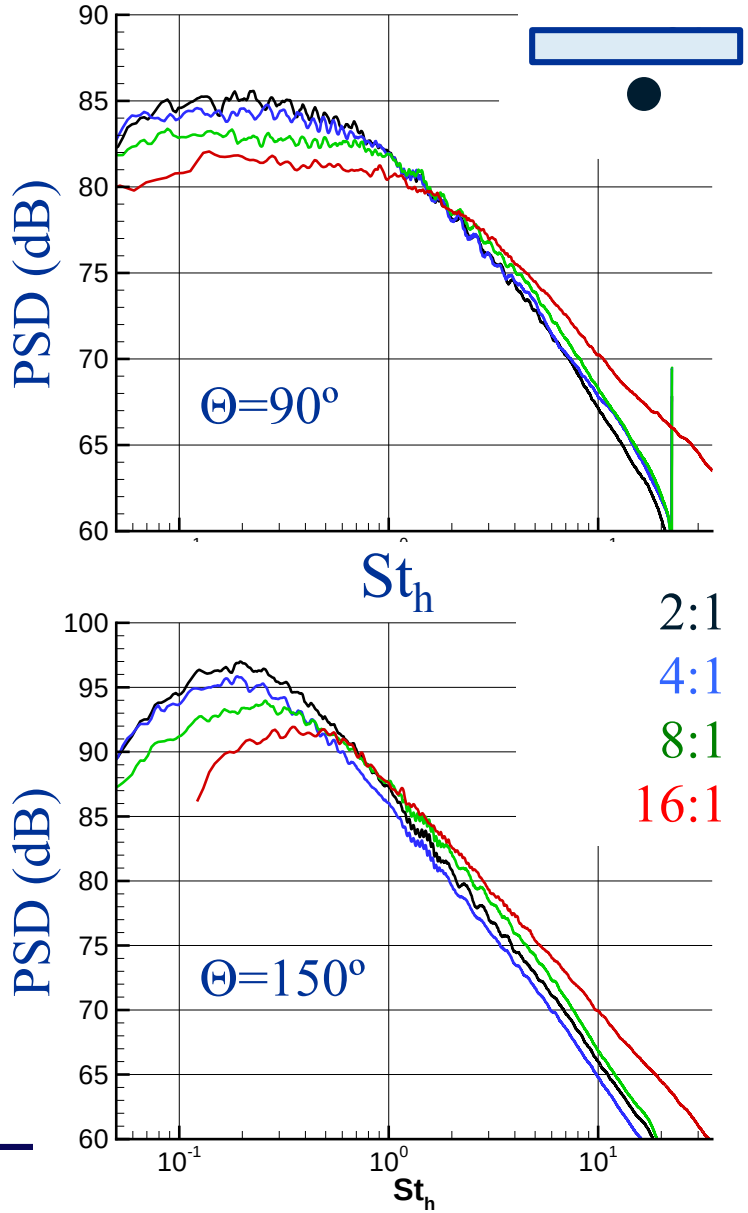


Goals for JSI-HAR

1. Extend current database to larger aspect ratio nozzles
2. Verify / connect current small-scale database to larger-scale rectangular nozzles near surfaces
3. Acquire data suitable for creating / validating empirical jet-surface interaction noise models
4. Investigate the effect of nozzle septa on the jet-mixing and jet-surface interaction noise sources

Extend to Higher Aspect Ratios

- Compare spectra to:
  - Show effect of nozzle aspect ratio
  - Connect to existing database via trends
- Similar to TeDP jet exit condition
  - Mach 0.7, unheated
- Nozzles with different sizes
  - 2:1, 4:1, 8:1 -> Area = 3.57 in^2
  - 16:1 -> Area = 33.7 in^2
- Scale:
  - Frequency as Strouhal number based on nozzle height
  - Distance to 100 equivalent jet diameter
- Trends follow from small to large scale across test programs



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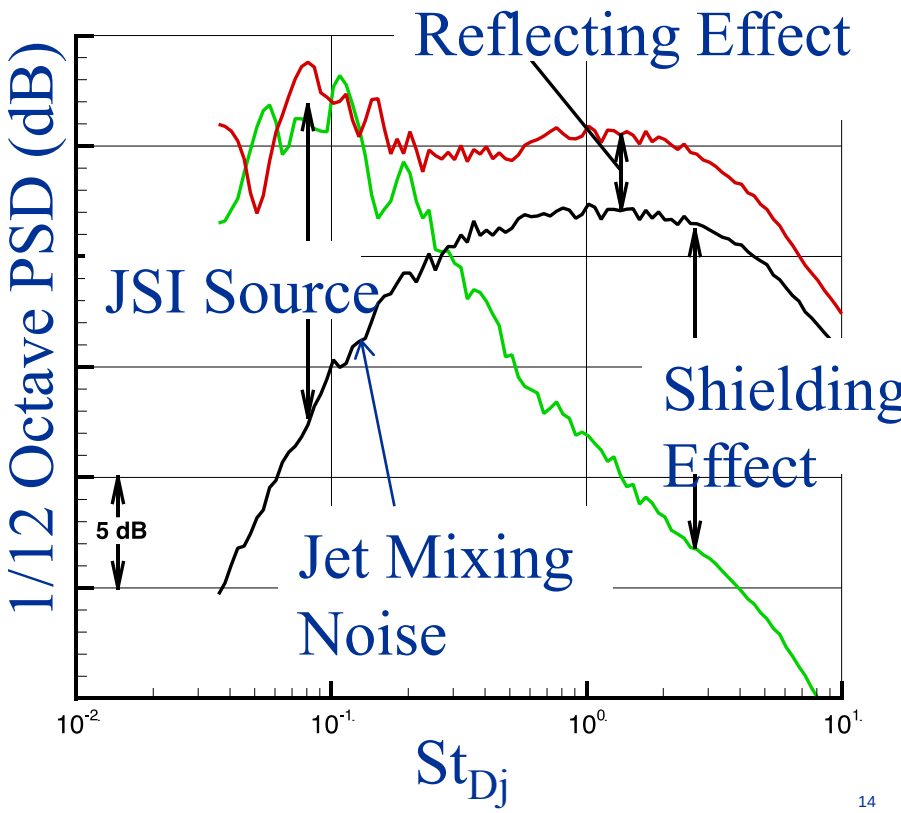
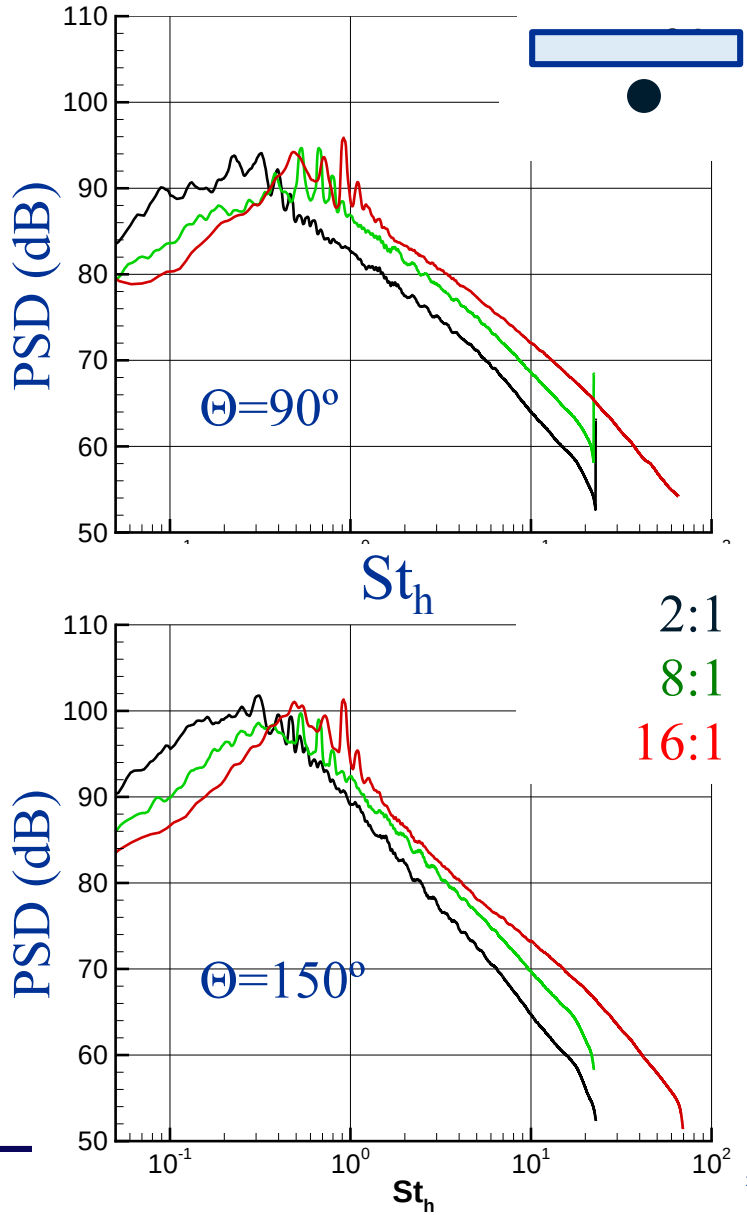
Jet-Surface Interaction (JSI) Noise Sources and Effects

- Measured far-field noise includes:
  - Jet-surface interaction noise sources
  - Jet mixing noise (isolated)
  - Shielding/Reflecting effect
- Types of JSI noise sources
  - Surface loading (“scrubbing”) noise
  - Trailing edge (“scattering”) noise
  - Surface vibration noise
- Data acquired for surface lengths x_E/h = 0.83, 2, 4, 6, 8, zero standoff



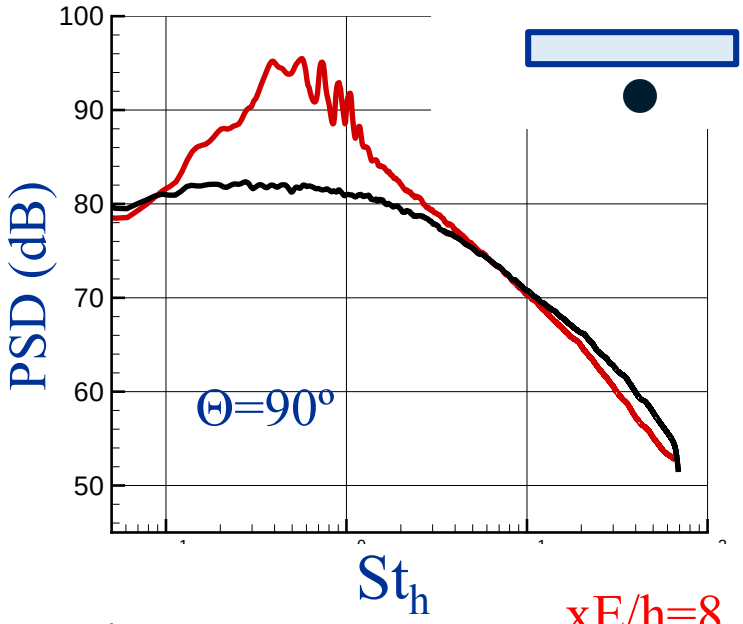
Extend to Larger Scale

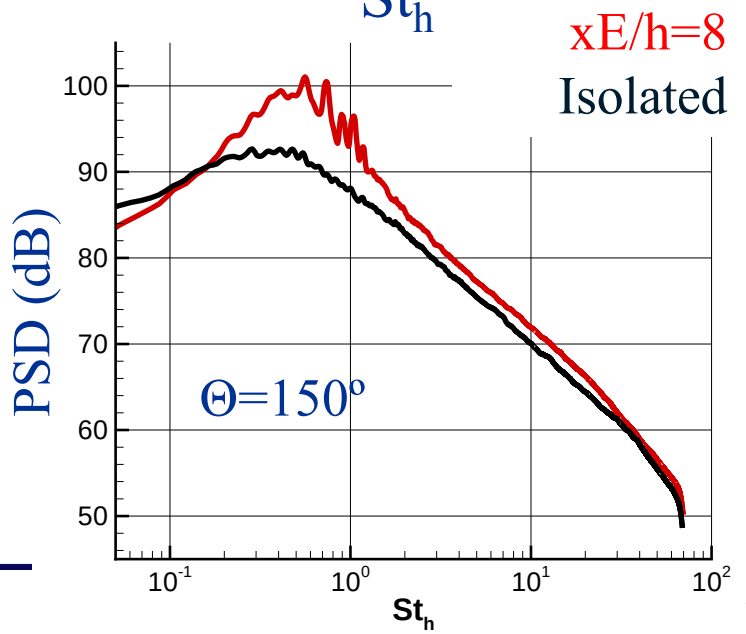
- Compare spectra to:
  - Effect surface at increase aspect ratios
  - Connect to existing database via trends
- Similar to TeDP jet exit condition
  - Mach 0.7, unheated
- Surface length, $x_E/h = 6$
- Scale:
  - Frequency as Strouhal number based on nozzle height
  - Distance to 100 equivalent jet diameter
- Trends follow from small to large scale across test programs



Noise Impact of Surface

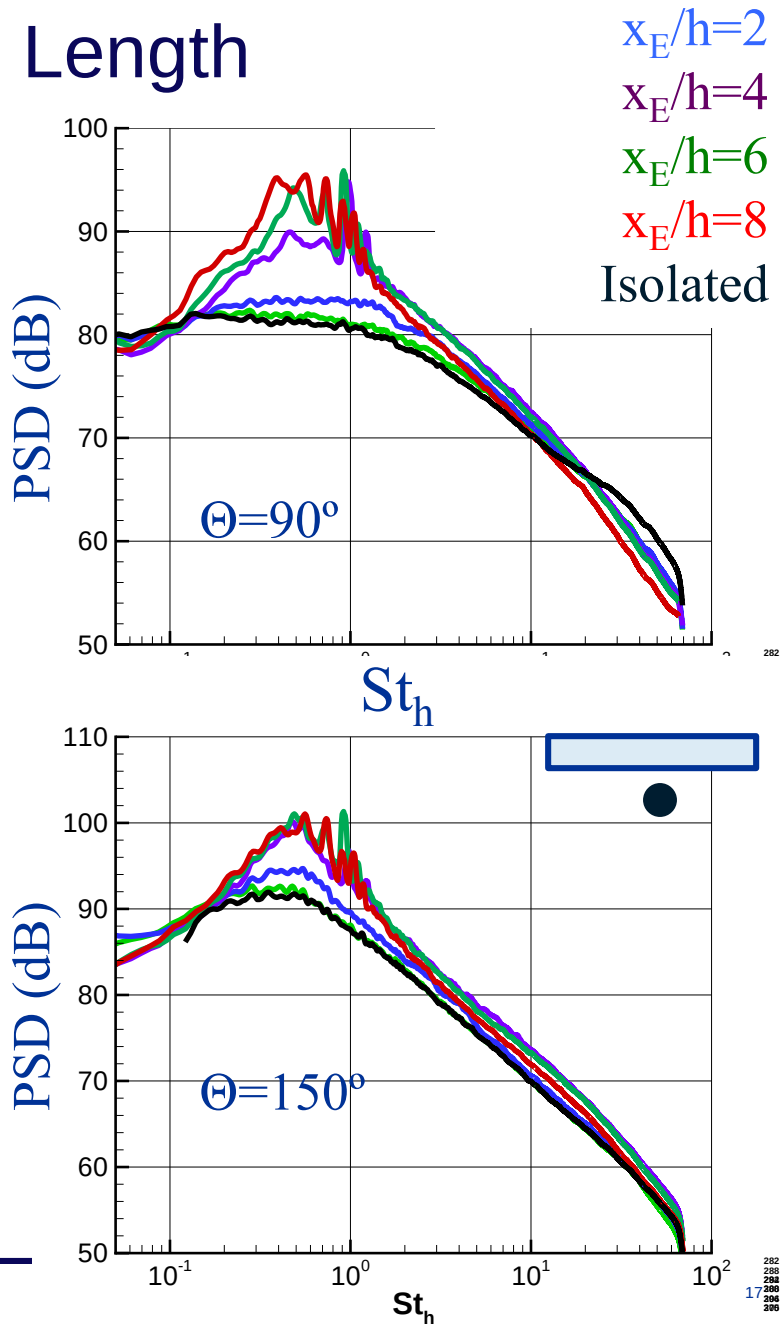
- Compare spectra to:
  - Show effect of adding surface
- Similar to TeDP jet exit condition
  - Mach 0.7, unheated
- Aspect ratio 16:1
- Surface length, x_E = 8h
- JSI source maybe large relative to shielding
- Model to full-scale factor matters





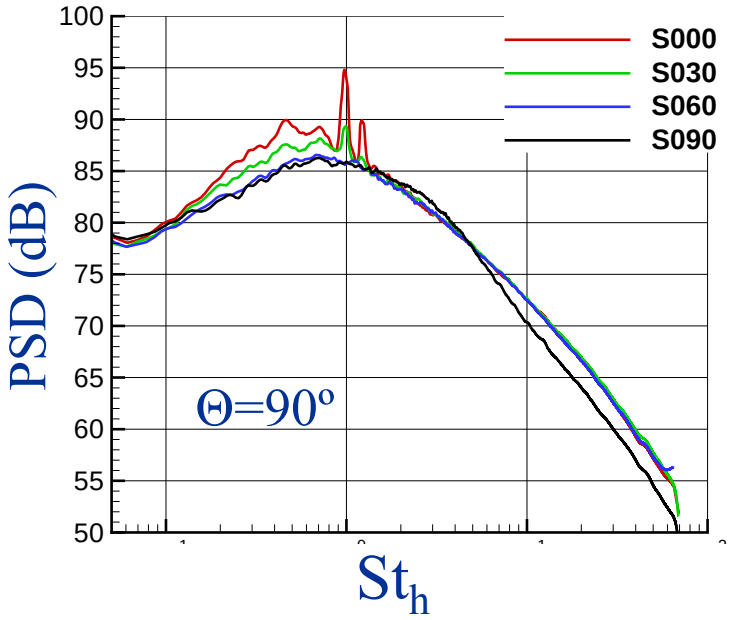
Noise Impact of Surface Length

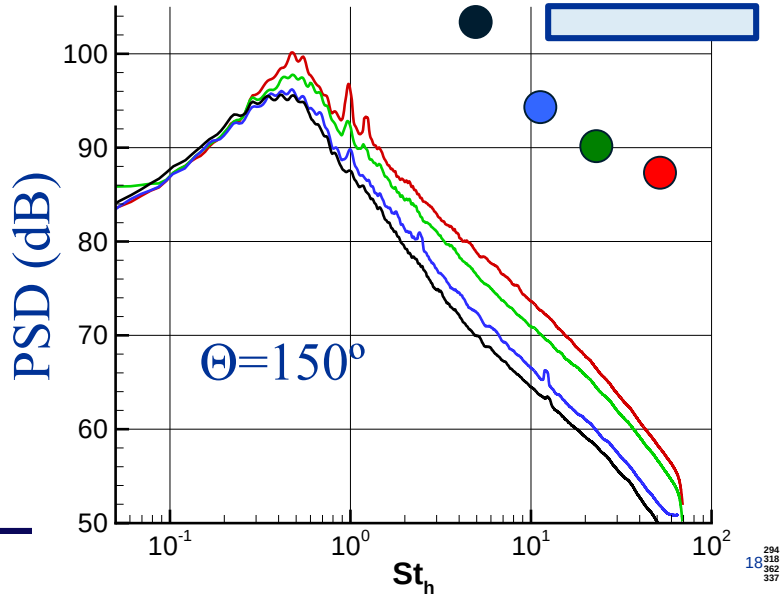
- Compare spectra to:
  - Show effect of surface length
- Similar to TeDP jet exit condition
  - Mach 0.7, unheated
- Aspect ratio 16:1
- Shorter surface may give high frequency shielding with smaller low frequency penalty at 90º
- All surfaces produce more high frequency noise than isolated at 150º



Noise Impact of Observer Azimuthal Angle

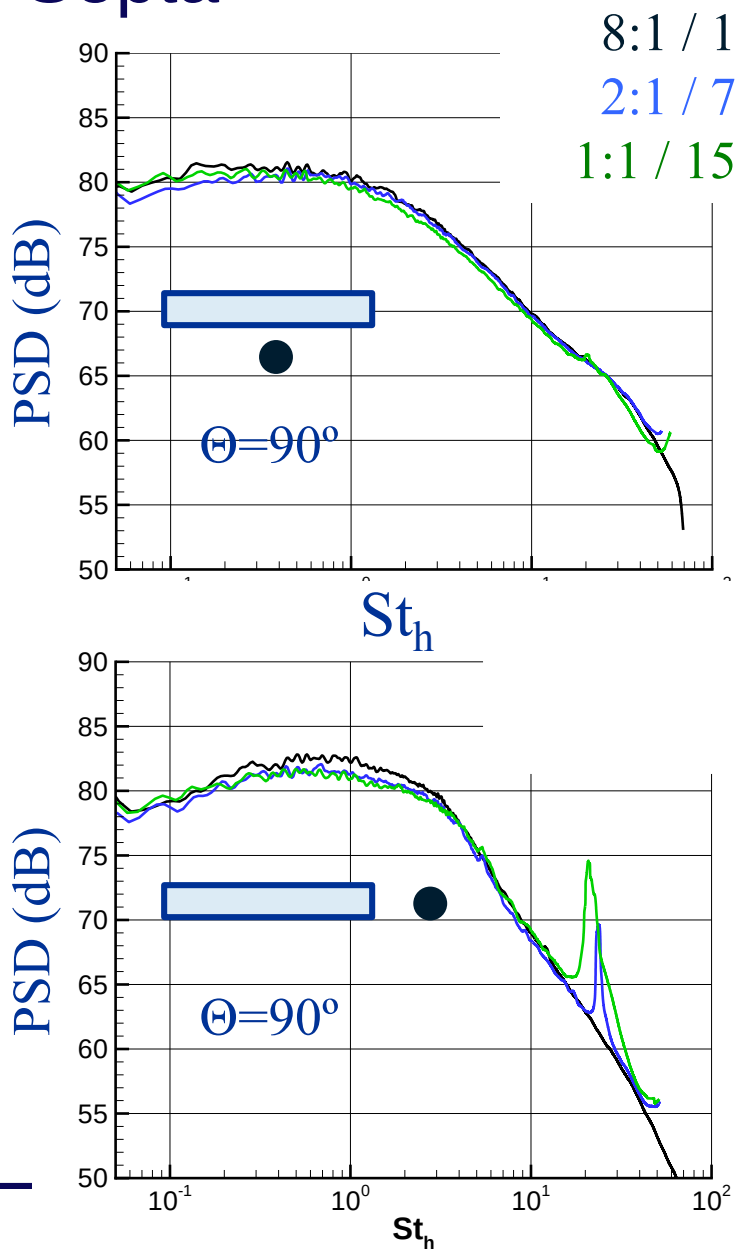
- Compare spectra to:
  - Show effect sideline
- Similar to TeDP jet exit condition
  - Mach 0.7, unheated
- 16:1, $x_E/h = 4$
- Significant changes at downstream observer angles as azimuthal angle changes





Noise Impact of Nozzle Septa

- Compare spectra to:
  - Show effect nozzle septa
- Similar to TeDP jet exit condition
  - Mach 0.7, unheated
- 16:1, no surface
- Septa create tone to major axis observer that grows with number of septa



Summary of JSI-HAR

1. Extend current database to larger aspect ratio nozzles
   - Acquired data with 16:1 nozzle
2. Verify / connect current small-scale database to larger-scale rectangular nozzles near surfaces
   - Trends with and without surfaces appear to follow from previous work
3. Acquire data suitable for creating / validating empirical jet-surface interaction noise models
   - Acquired data over a range of surface lengths
4. Investigate the effect of nozzle septa on the jet-mixing and jet-surface interaction noise sources
   - Data acquired with 3 septa configurations

- What's next?

Goals for JSI-HAR

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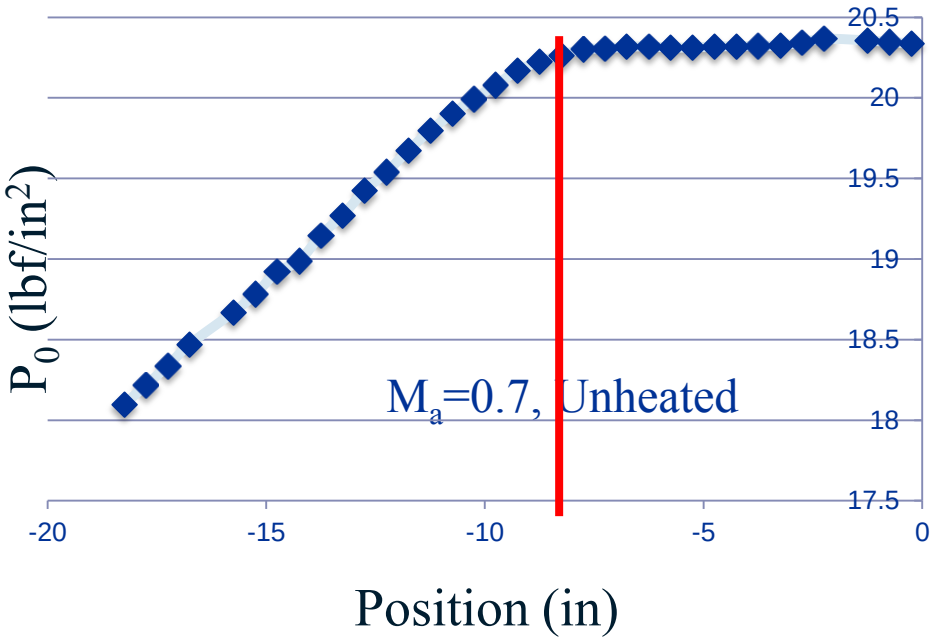
JSI Source and Effect Modeling

- Empirical models have been developed for round nozzles near surfaces
- First-order modeling for rectangular nozzles based on these round nozzle models suggest:
  - Scaling distances and frequency on nozzle height
  - Adjusting potential core length
- Jet potential core length is nondimensionalizing parameter
  - Data were acquired with 16:1 nozzle to estimate potential core length

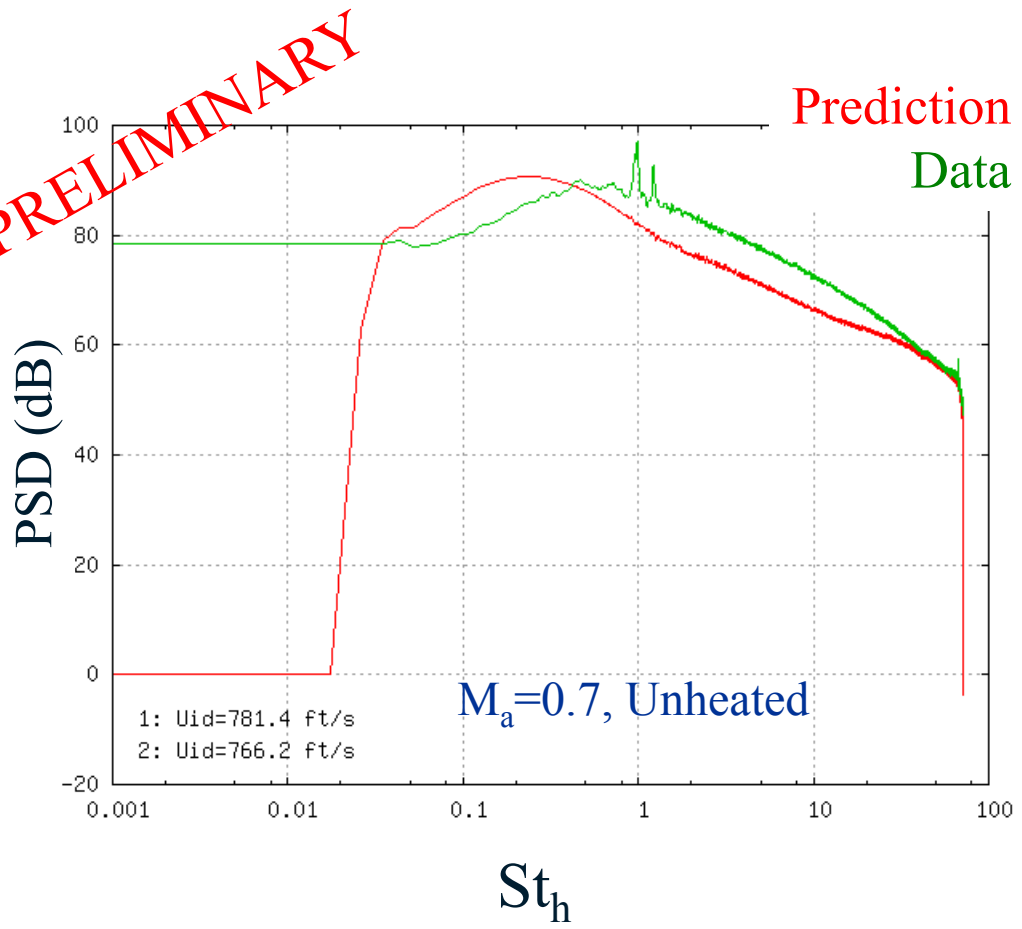
Jet Potential Core Length

- JSI source and shielding effect models both depend on jet potential core length (x_C)
- Surface length in model is x_E/x_C
- Jet potential core length is approximately 7.75” for Ma=0.7, unheated jet
- Model for round jet would give $x_C/D_e \approx 5.13$
- If rectangular nozzle scales by h instead of D_e, $x_C/h \approx 5.13 \rightarrow x_C \approx 7.7$”



Jet Potential Core Length

- Modeled prediction with adjusted scaling parameters for rectangular nozzles
- Peak frequency shift
- Approximate right peak amplitude (JSI source driven)
- Spectral shape off at high frequencies
- More development needed!



Questions?

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Summary

- A round-to-rectangular convergent nozzle with aspect ratio 16:1 was designed for acoustic measurements
  - Minimized potential noise sources from: (1) internal flow separation and (2) shock cells
- 16:1 aspect ratio nozzle fabricated for testing
  - Inserts to simulate TeDP concept details (septa) rapid prototyped
- Pressure traverse at nozzle exit shows expected flow profile
- Preliminary analysis of noise data consistent with previous experiments
  - JSI noise source prominent at low frequencies
  - Shielding at only the highest frequencies
- Test on-going through October
  - Baseline (no septa), 2:1 / 7 Septa inserts planned

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