Jet-Surface Interaction – High Aspect Ratio Nozzle Test Nozzle Design and Preliminary Data

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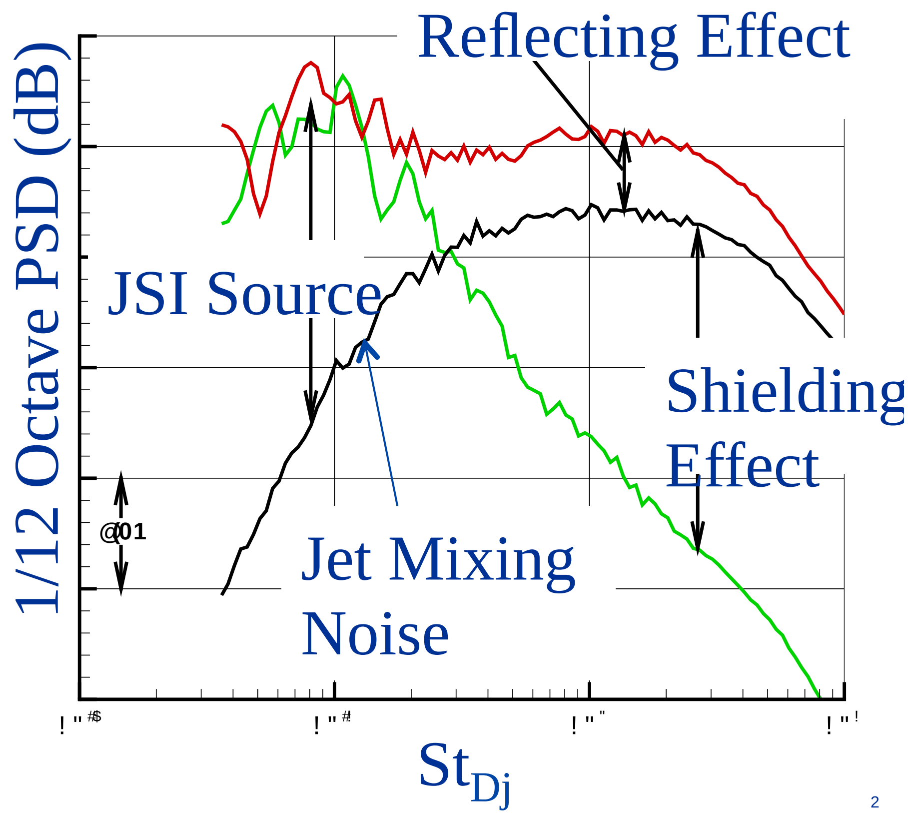
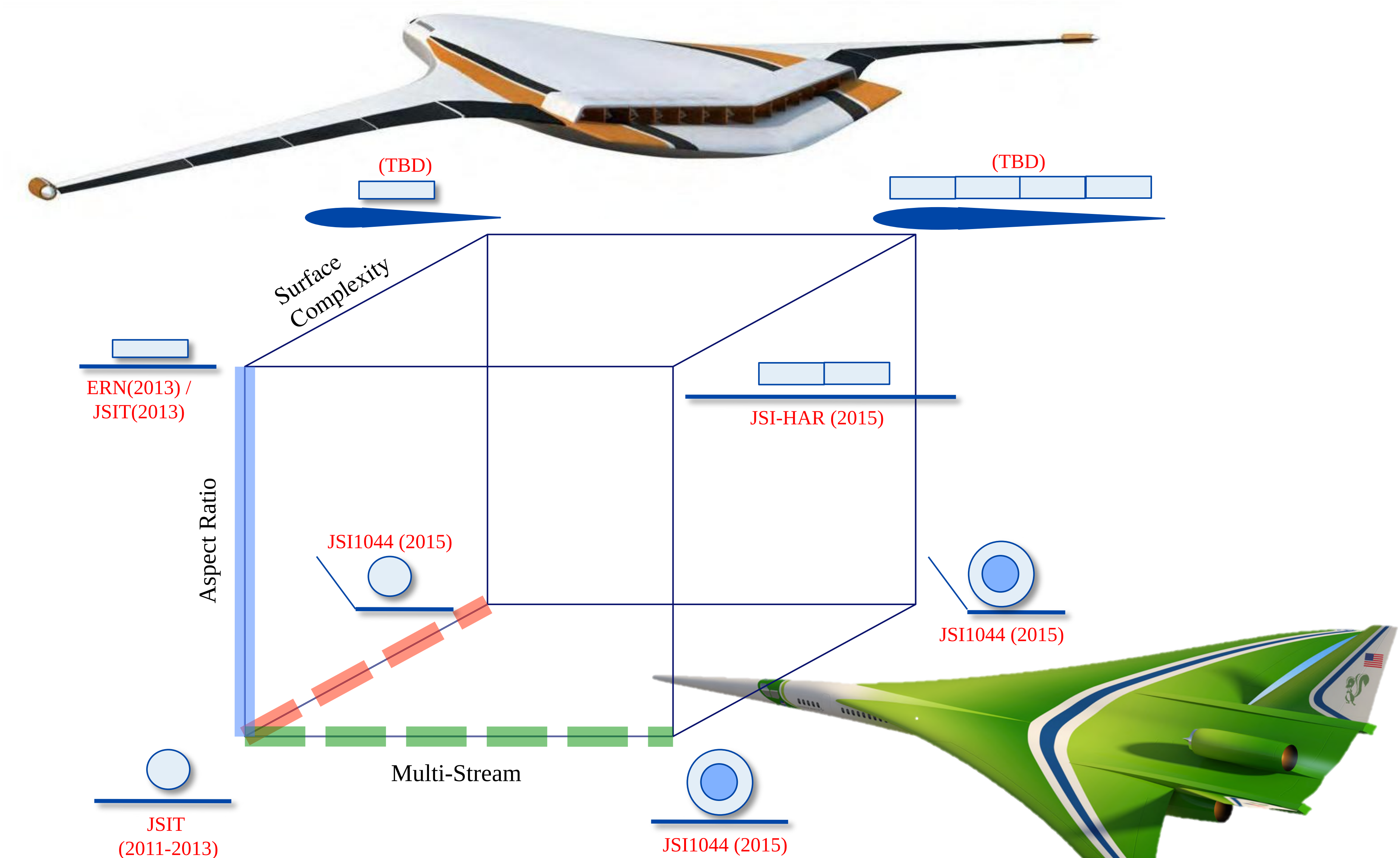
Jet-Surface Interaction (JSI) Noise Sources and Effects

- 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

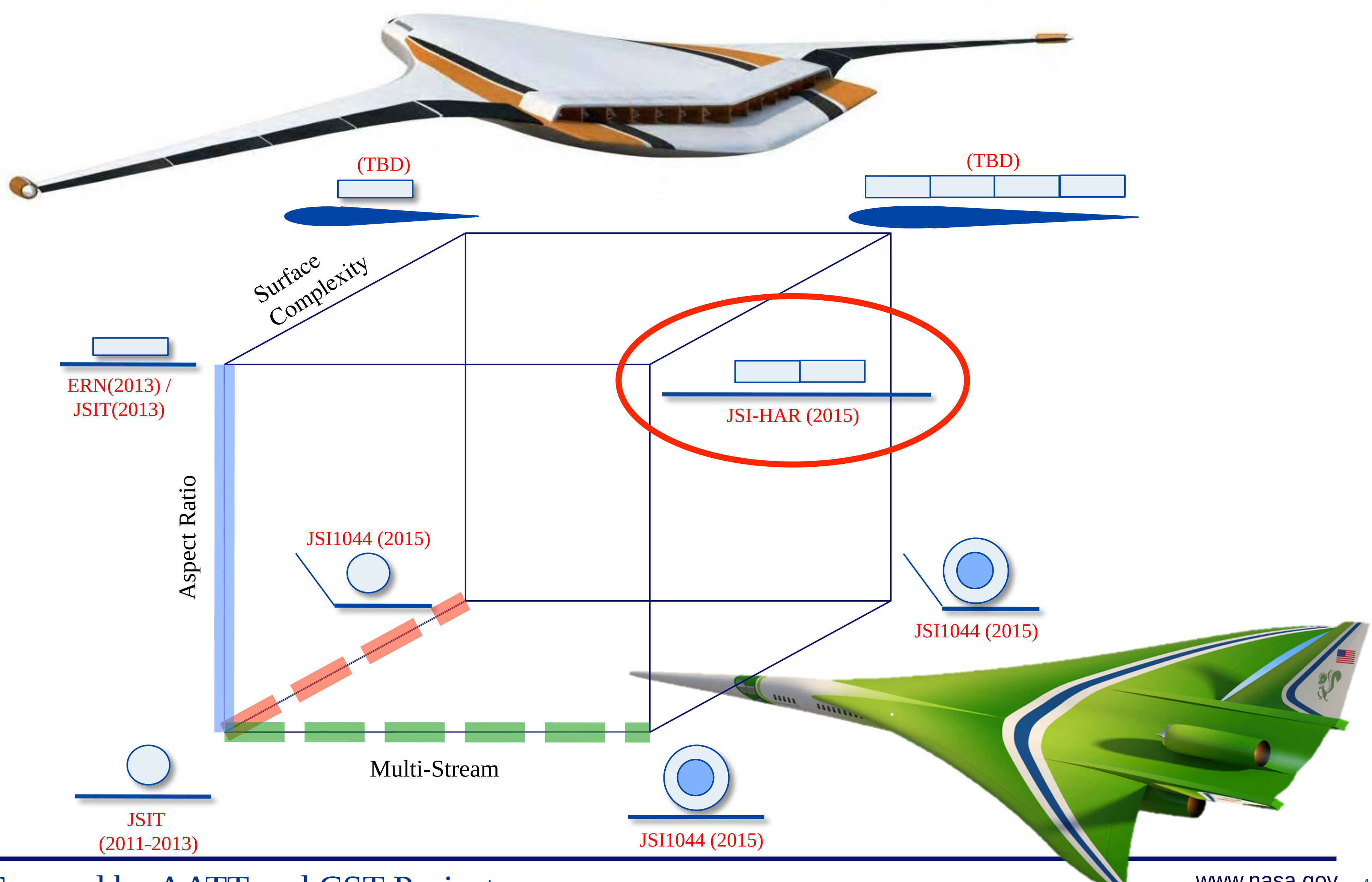


Jet-Surface Interaction Noise Test Programs



* Covered by AATT and CST Projects

Jet-Surface Interaction Noise Test Programs



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Turbo-electric Distributed Propulsion Concept

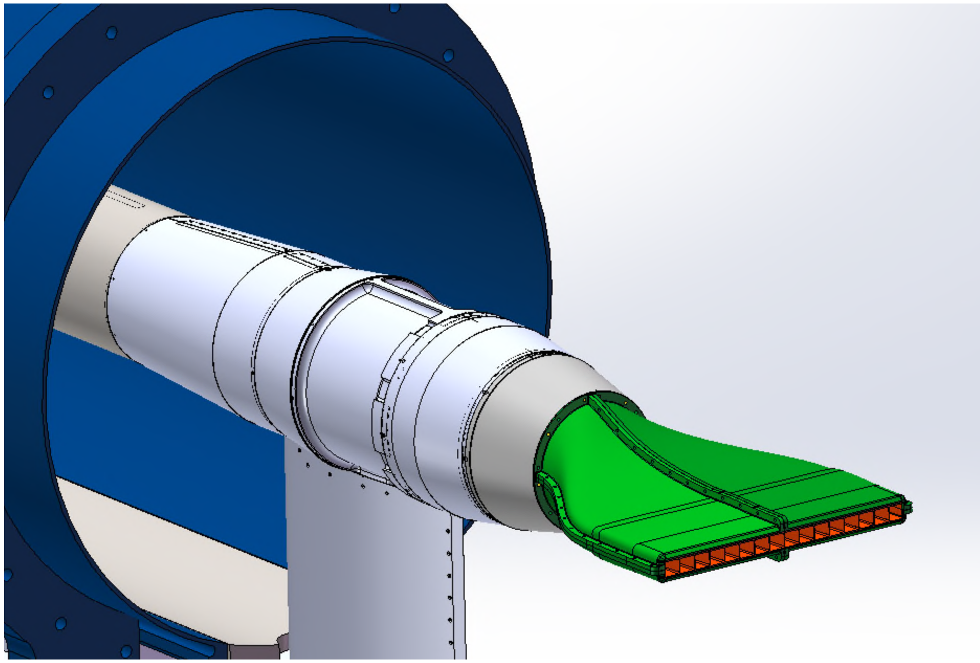
Asymmetric Flow Path

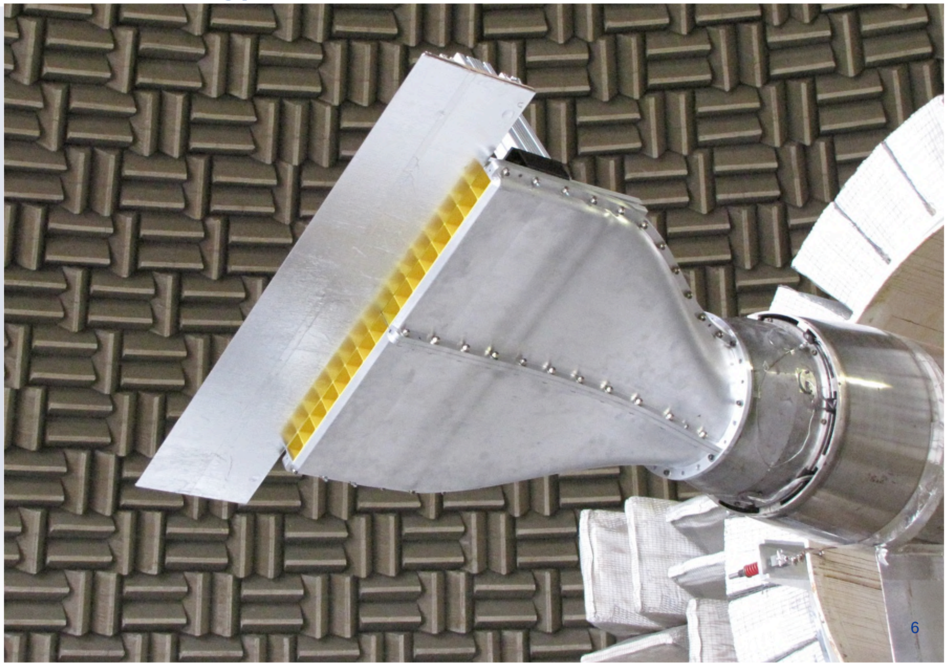
- 32:1 aspect ratio slot
- Divided into 2:1 at exit
- Electric fan has low pressure ratio, low temperature ratio
  - Test conditions 1.2 ! NPR ! 1.86, TTR = 1
- Aft deck extends (estimated) 1-4 slot heights downstream

* Kim et. al., AIAA 2015-3805

Nozzle Design for JSI-HAR Testing

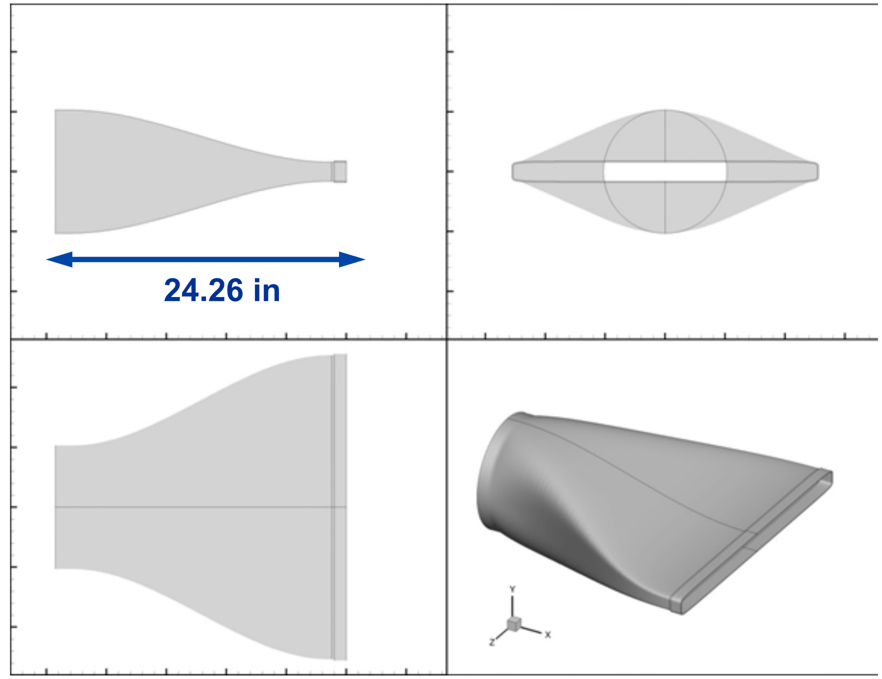
- Problem specific to model scale testing
  - TeDP has other issues but each fan is round to approximately 2:1 aspect ratio
- Limited by flow rate and scale factor to 16:1 aspect ratio
- Must transition from round to rectangular
  - Low noise - minimize internal flow separations and exit shocks
  - Uniform flow profile at exit
  - Minimize nozzle length and weight
- Allow parametric variations of septa/internal flow
  - Rapid prototyped plastic inserts (not load bearing)

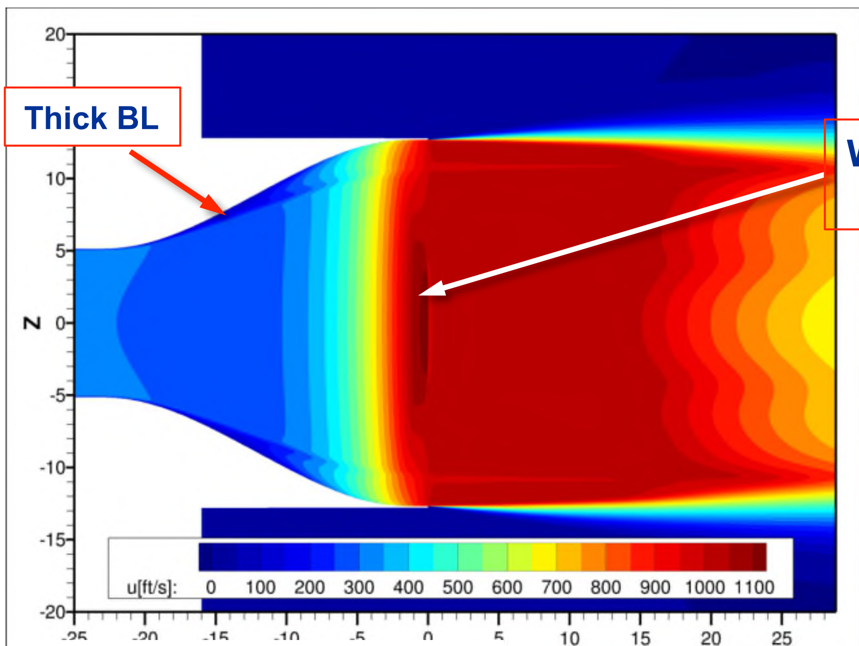


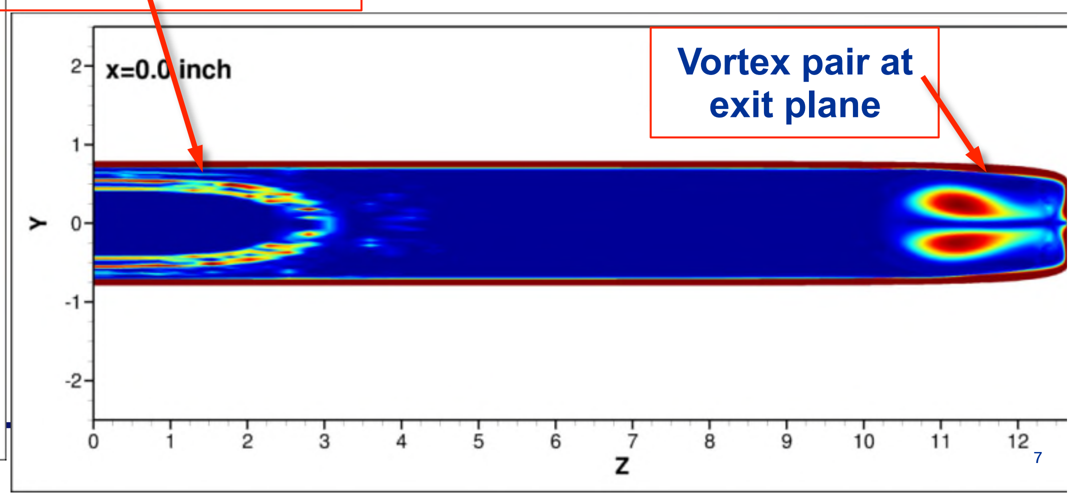


First Efforts Using SUPIN

- SUPIN* is a parametric inlet design tool
  - Assume “backward” inlet is a nozzle
- Observations:
  - Lines not always smooth near inflow.
  - Thick boundary layers and separation along side walls as major axis spread.
  - Normal shock along centerline
- Greater control to parameterize nozzle designs required (SUPIN is not for nozzles!)



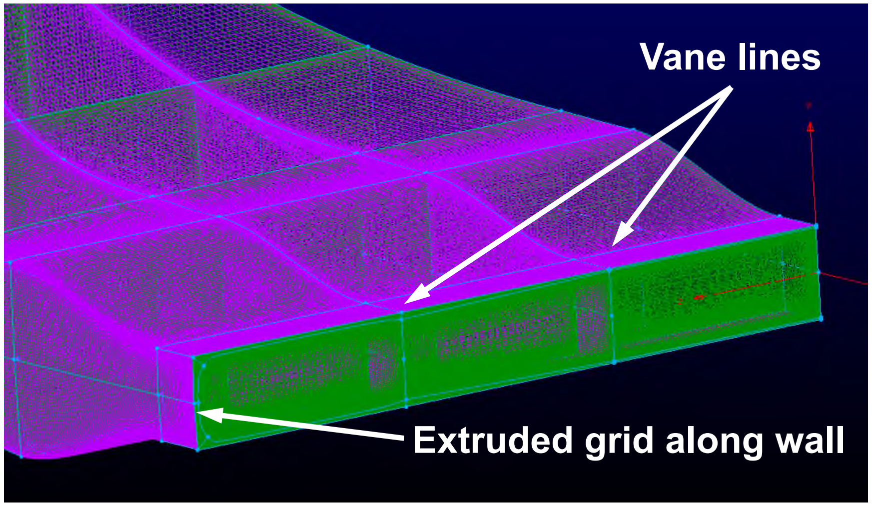




* AIAA Paper 2012-0016

CFD for Design Evaluation

- Wind-US v4 used for all simulations presented here.
  - General purpose, compressible Reynolds-Averaged Navier-Stokes solver
  - SST turbulence model used
  - Steady flow simulations, i.e. constant CFL number
- Flow conditions:
  - Quiescent Freestream: p_∞=14.3 psi; M_∞=0.01
  - NPR=1.861 " M_{jet}=0.98 (M_a=0.9)
  - Unheated Jet: T_0=529.64°R (TTR=1)
- Grid:
  - 9 – 24.5 million cells
- Simulations performed on NAS:
  - 5 Ivy Bridge nodes (20 cores/node)
  - Converged solution < 60 hours total wall time.

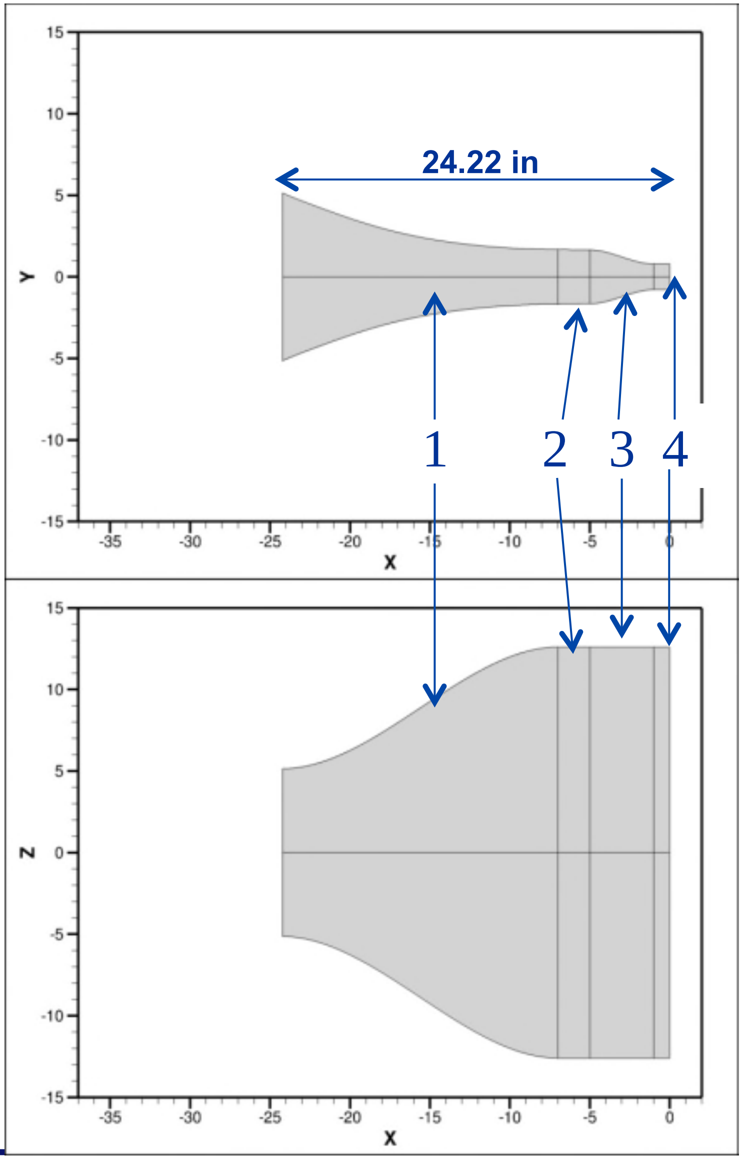


Next Approach: Parameterized Nozzle Design

•" Idea: Transition flow in segments rather than all at once to gain greater control over design
  –" Created new code to generate flow lines

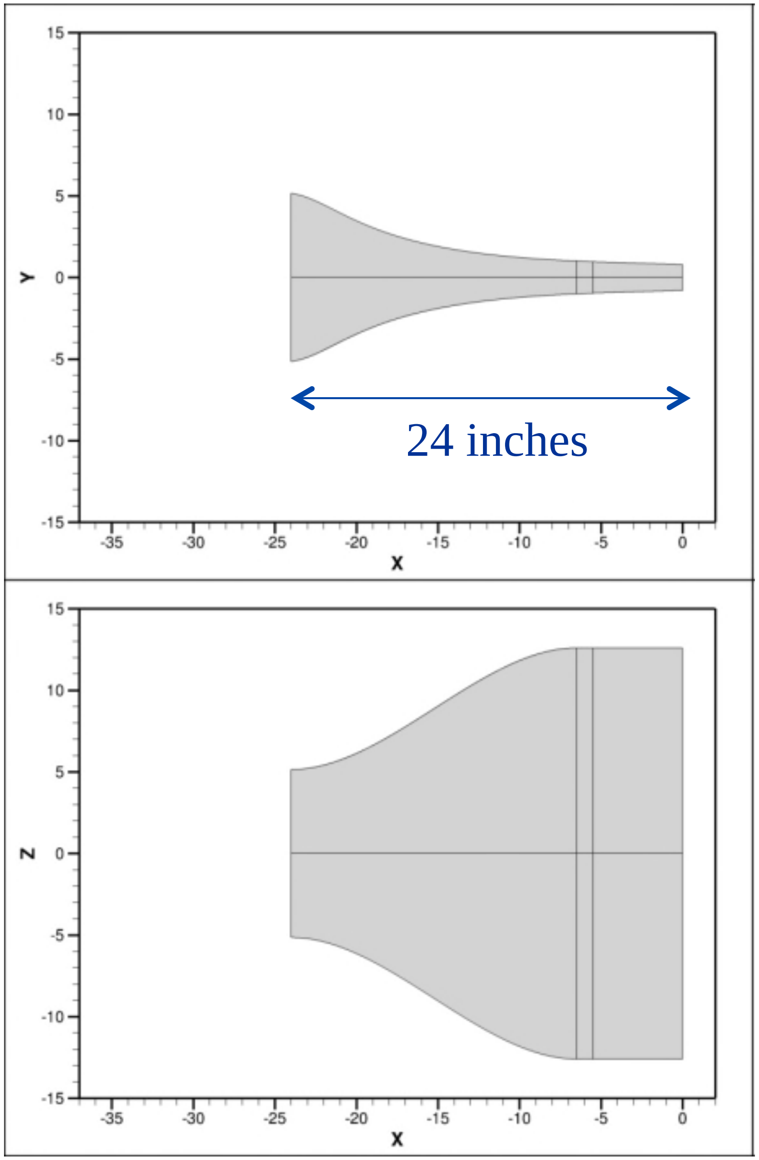
•" Example: Four segments
  1." Transition from circular to order 10 superellipse; grow major axis to nozzle exit width via cubic polynomial; maximum divergence angle<33°; constant area
  2." Transition from order 10 superellipse to order 100 via exponential function; constant area
  3." Contract area to nozzle exit area using cubic polynomial for minor axis
  4." Constant area and shape to nozzle exit to accommodate septa inserts

•" Include capability to add turning vanes
  –" Minimize BL growth and flow separation by distributing flow out to side walls as major axis grows.
  –" Modeled vanes with inviscid boundary condition (infinitely thin, slip surface) for ease of gridding and improved run time during design evaluation stage

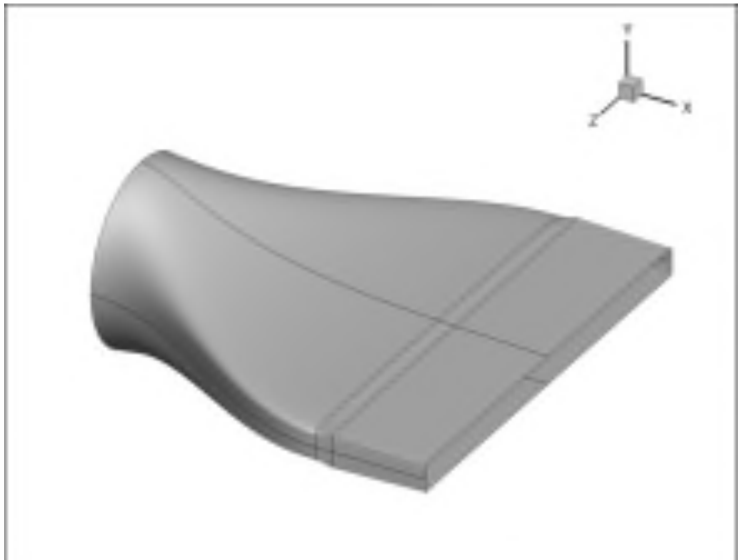


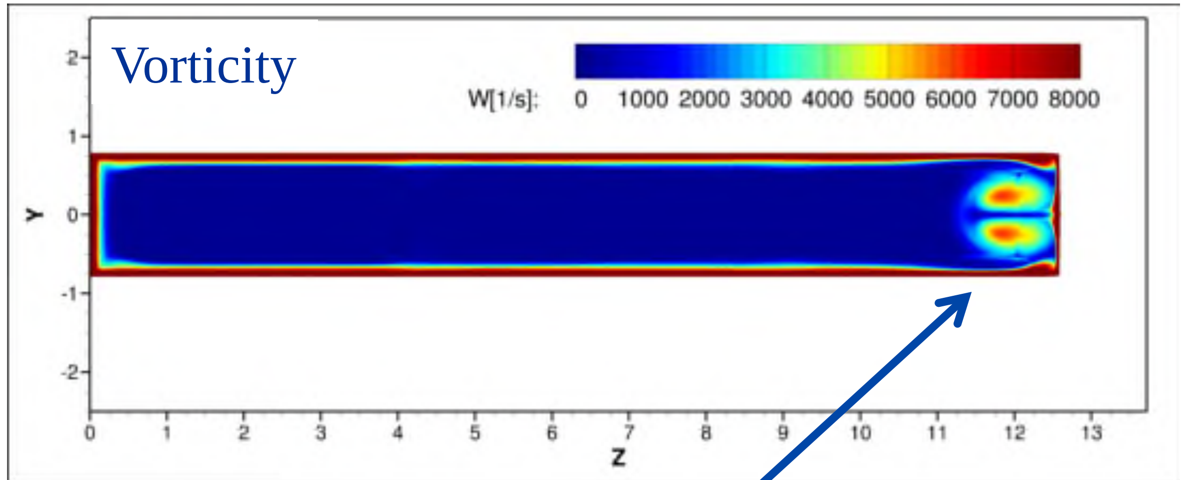
Final Design: A16-10

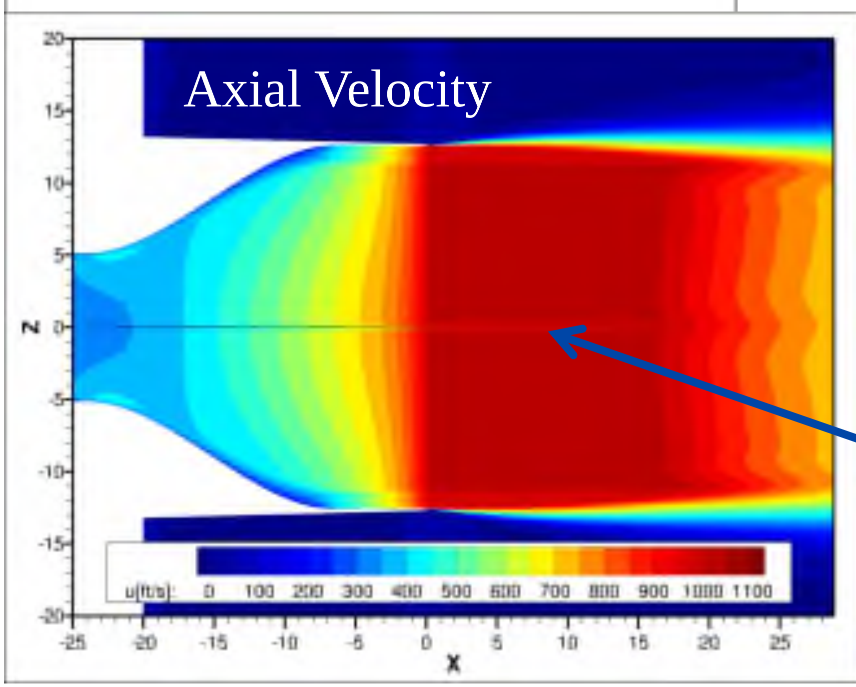
- Three segments:
  1. Transition from circular to order 10 superellipse; grow major axis to nozzle exit width via cubic polynomial; maximum divergence angle<33°; linear area contraction through segment 2 (80% of total)
  2. Transition from order 10 superellipse to order 100 via exponential function; continues linear area contraction from segment 1 (80% or total); constant major axis length
  3. Linear area contraction (20% of total) with constant major axis length and constant superellipse order; longer segment length (5.5 inches) to accommodate septa inserts
- No turning vanes
  - CFD showed turning vanes did not do much once outer flow lines were refined
  - CFD showed significant wakes from turning vanes
  - Center vane retained for structural support



A16-10: Design Evaluation



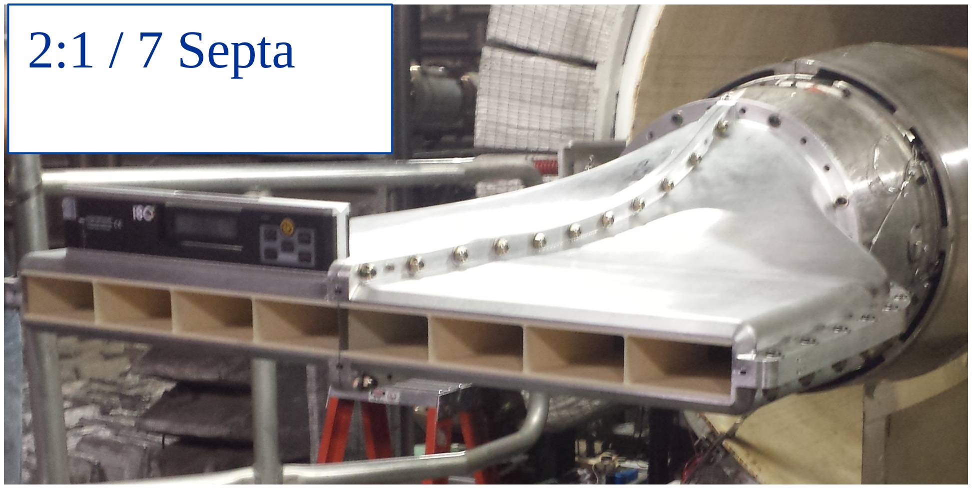


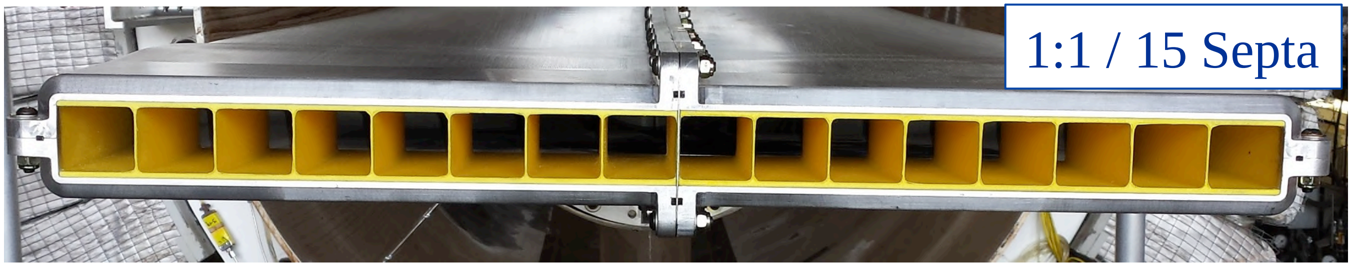


- Significant vorticity near corners
- Attached flow along outboard edge of major axis (BL thickness still significant)
- No normal shocks at nozzle exit
- Continuous area contraction helps
- Significant wake from center vane (added for structural support)

Septa Inserts

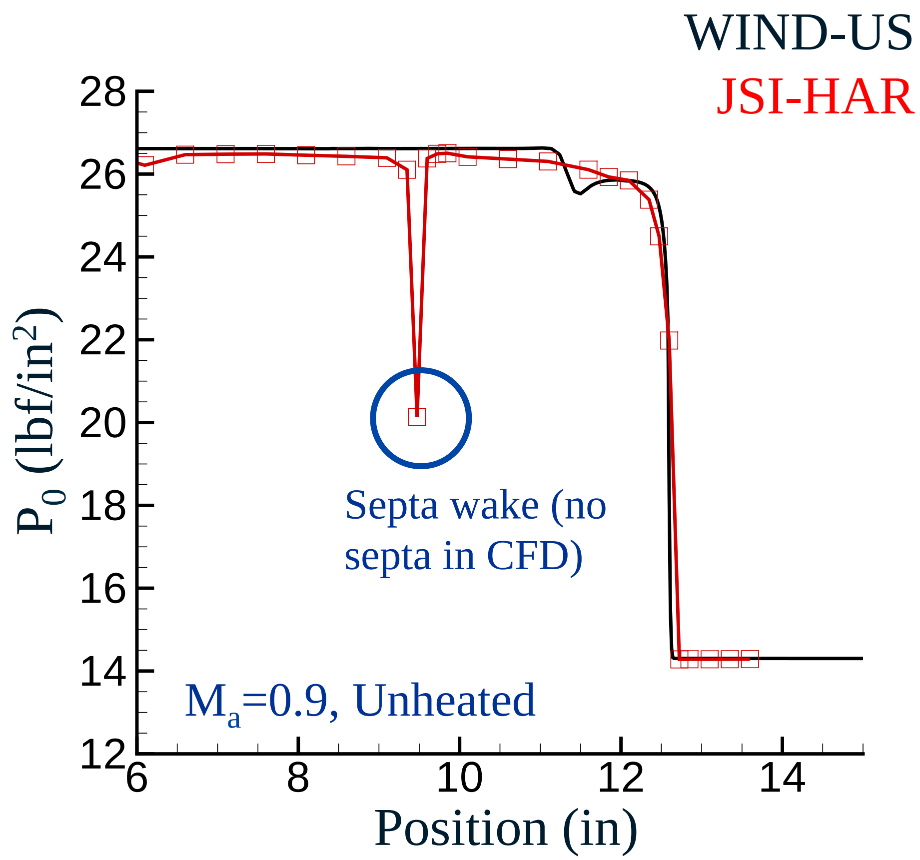
- Inserts are rapid prototyped using solid ABS plastic
- Inserts sit in small recess
- Septa are airfoil shaped
  - NACA0003, chord = 6”
  - R=1 mm leading edge fillet, R=0.5 mm trailing edge fillet
  - 2 mm fillet at root and stem
- Half airfoil at center vane around sheet metal

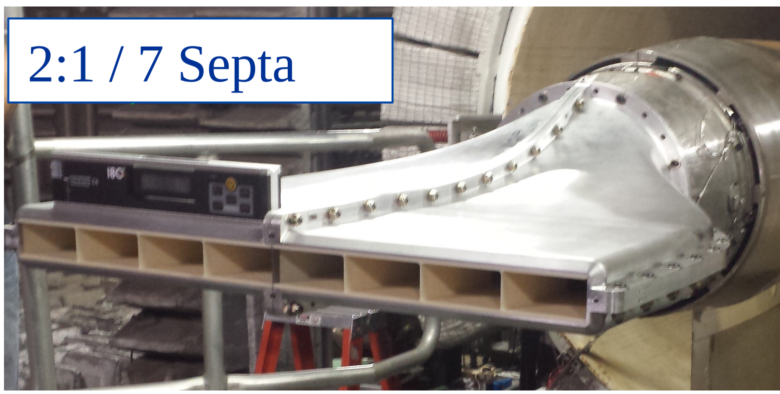




Flow Profile at Nozzle Exit (1)

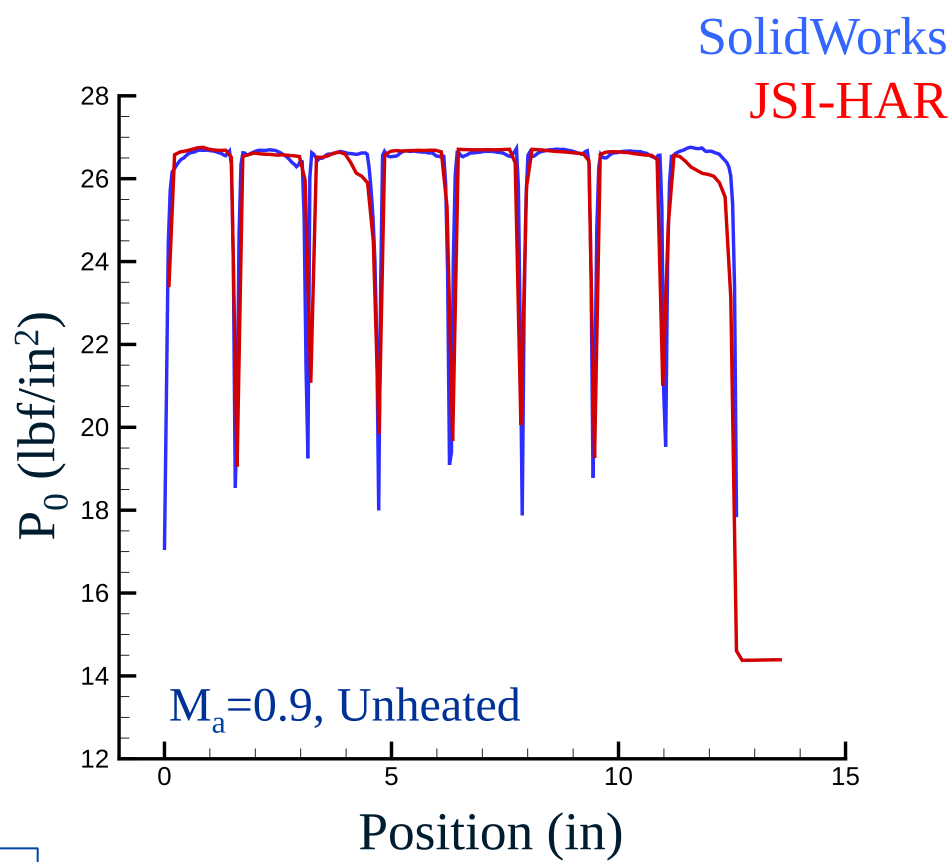
- 2:1 / 7 septa insert installed for JSI-HAR but not in WIND-US
- Total pressure measured 0.25" downstream of nozzle exit
- No indication of vortex in JSI-HAR data
  - 1 Hz averaged pressure data would not likely pick this up even if present
- Flat profile between septa
- Losses slightly higher in JSI-HAR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

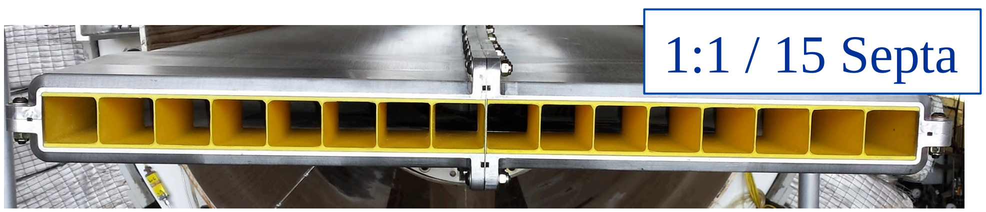




Flow Profile at Nozzle Exit (2)

- 1:1 / 15 septa insert in both
- Total pressure measured 0.25” downstream of nozzle exit
- More losses at nozzle edge in JSI-HAR than predicted
- Deeper wake deficits in SolidWorks result
  - JSI-HAR probe may not be directly behind septa
- Reasonable comparison for approximately 2 hours invested in SolidWorks simulation

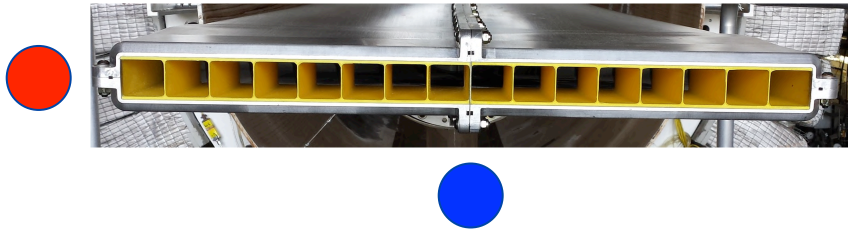


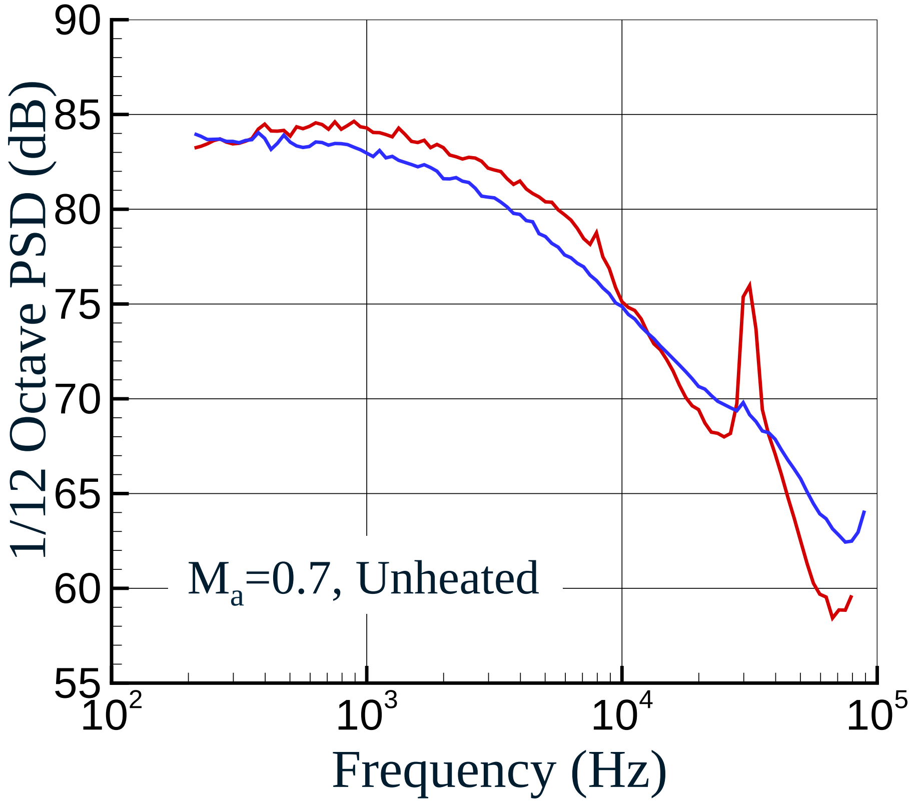


* Thanks to Dennis Eck, AAPL Facility Engineer, for SolidWorks result

Far-Field Noise – 1:1 / 15 Septa

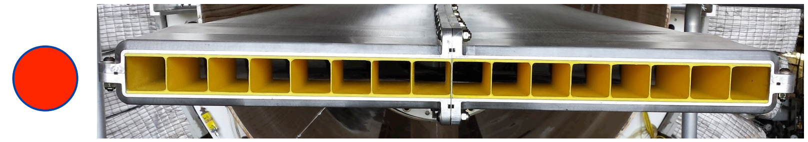
- Spectra: 1-ft lossless at # =90º
- No surface
- Increased broadband noise on minor axis
- High frequency tonal content
  - Strouhal shedding from septa



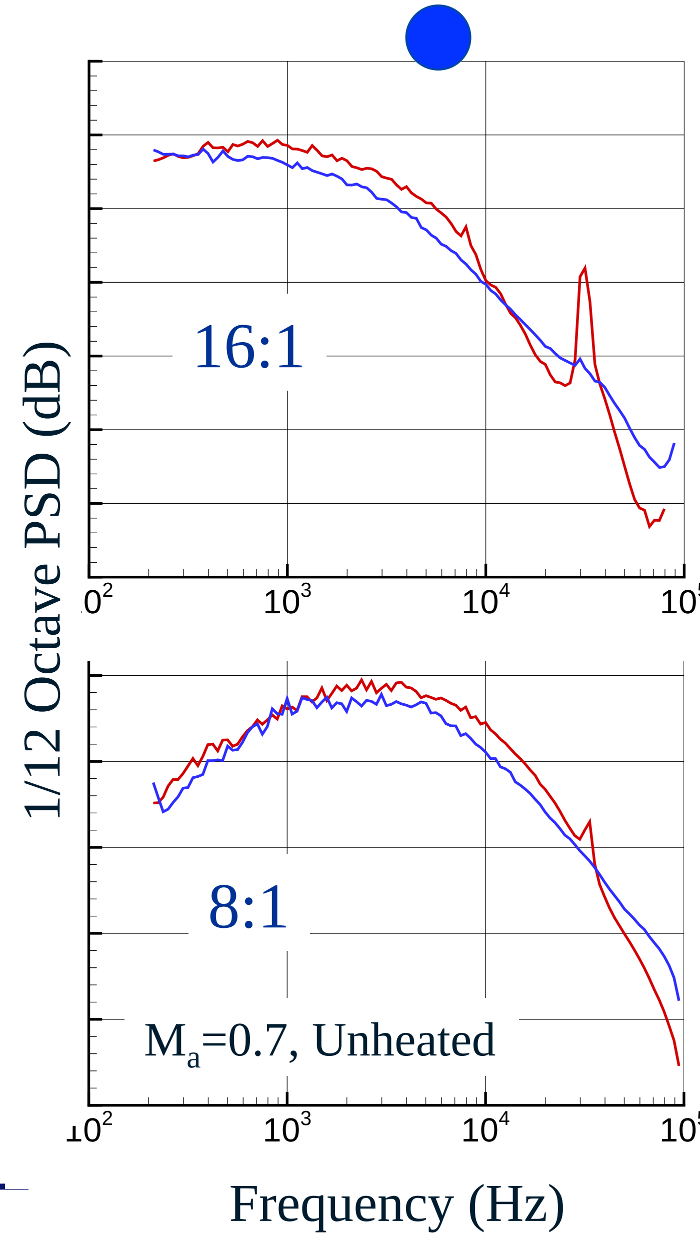


* Bridges, AIAA 2015-3119

Far-Field Noise – 1:1 / 15 Septa



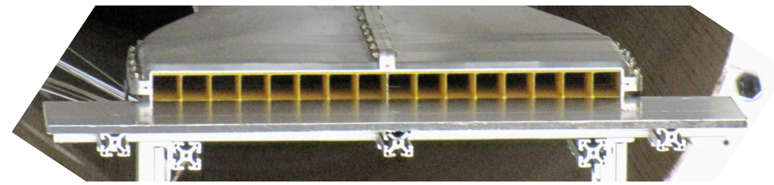
- Spectra: 1-ft lossless at # =90º
- 8:1 smaller scale but similar septa width*
- Trends follow from 8:1 to 16:1
  - Increased broadband noise on minor axis
  - Stourhal shedding from septa gives high frequency tonal content
- Planning additional septa for 16:1 to separate aspect ratio from septa effects

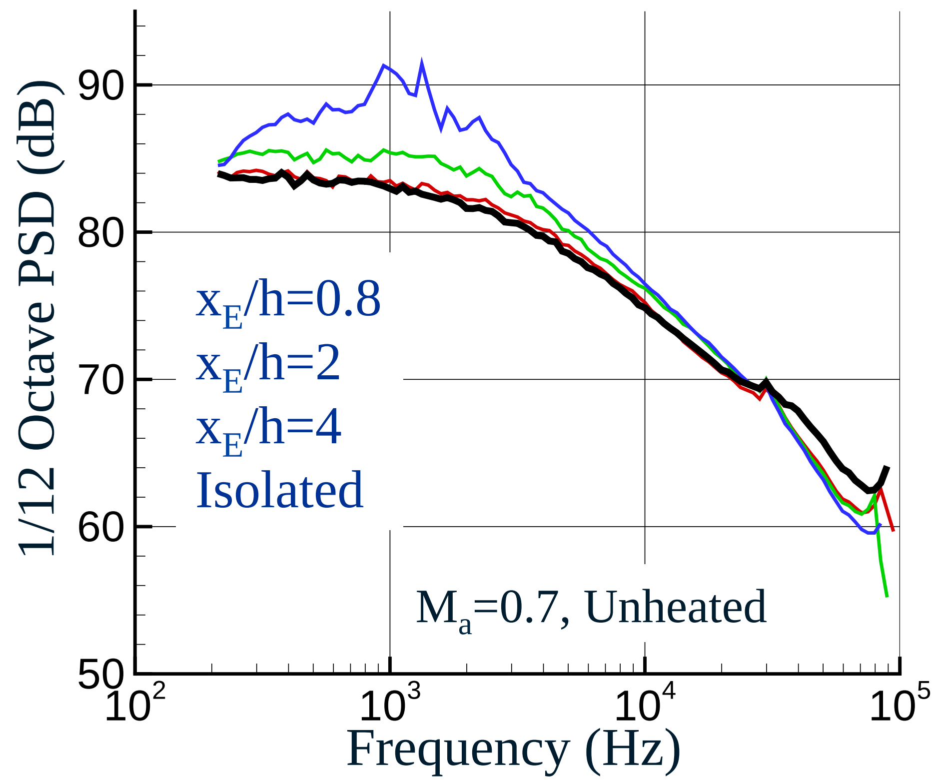


* Bridges, AIAA 2015-3119

Far-Field Noise – 1:1 / 15 Septa with Surface

- Spectra: 1-ft lossless at # =90º
- JSI noise source increasing with longer surfaces
  - Follows previously observed trends
- Shielding only at the higher frequencies
  - Approximate scale factor 25:1 based on slot height (h)
  - JSI noise very low frequency at full-scale (acoustic loading)
  - Shielding could benefit EPNL when taken to full-scale





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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