National Aeronautics and Space Administration

Fundamental Aeronautics Program

Supersonics Project

Jet Noise Reduction Potential from Emerging Variable Cycle Technologies

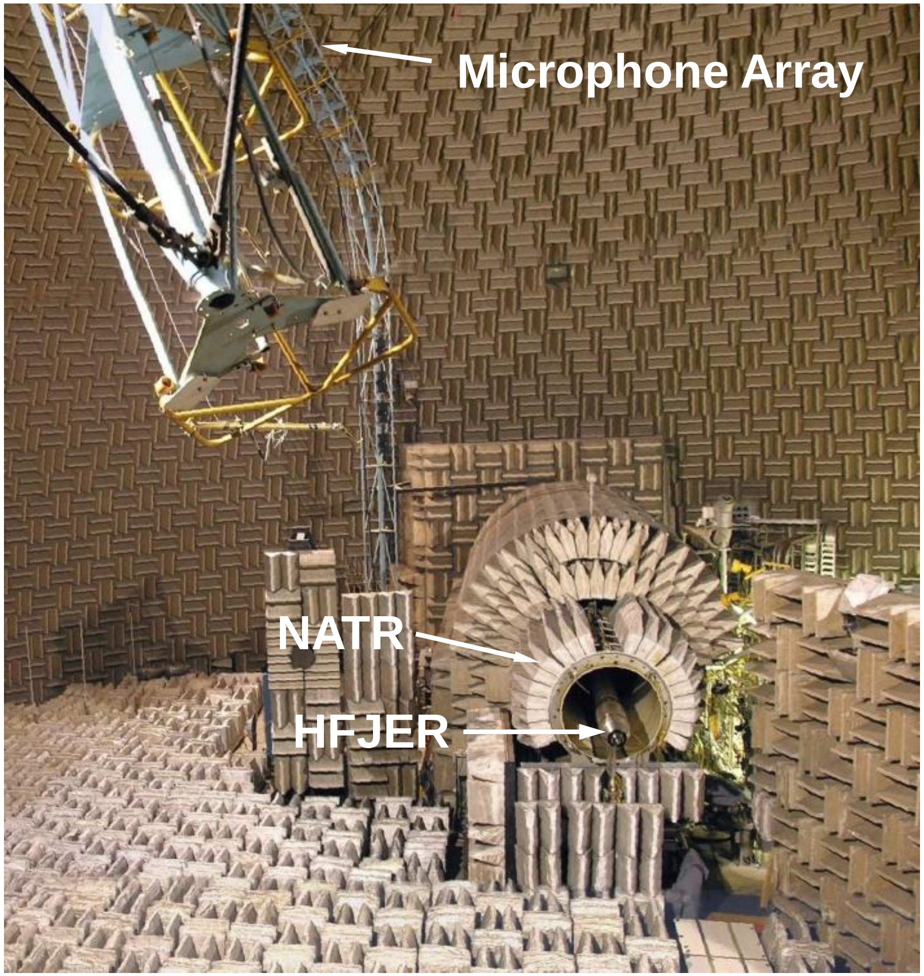
Brenda Henderson, James Bridges, Mark Wernet
NASA Glenn Research Center

48th AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit
July 29 – August 1, 2012
Atlanta, Georgia

Purpose of Study

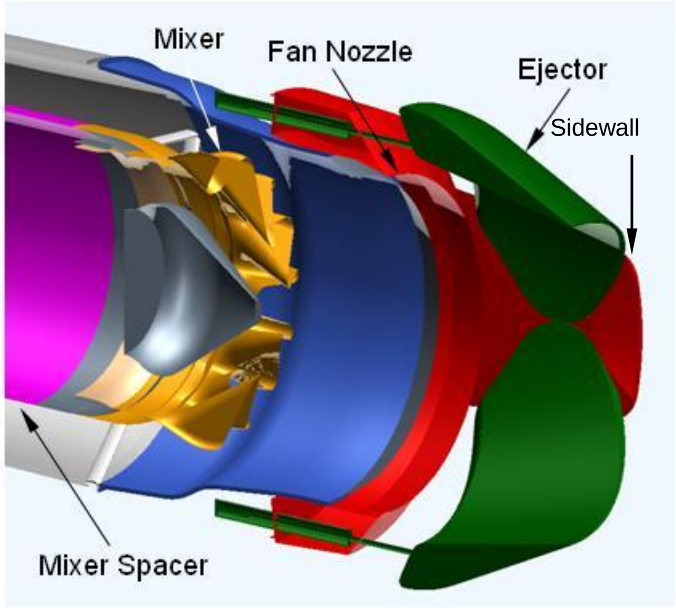
- Investigate the noise reduction potential of emerging technologies for N+2 supersonic aircraft
  - Enter service 2018 - 2020
  - 35 – 70 passengers
  - Mach 1.6 – 1.8 cruise speeds
  - Noise levels 10 – 20 EPNdB (cumulative) below FAA Stage 3
- Hardware designed and fabricated by Lockheed Martin, Rolls-Royce Liberty Works (RRLW), and General Electric Global Research (GEGR)
- Concepts tested at the Aero-Acoustic Propulsion Laboratory at NASA Glenn Research Center

Aero-Acoustic Propulsion Laboratory (AAPL)

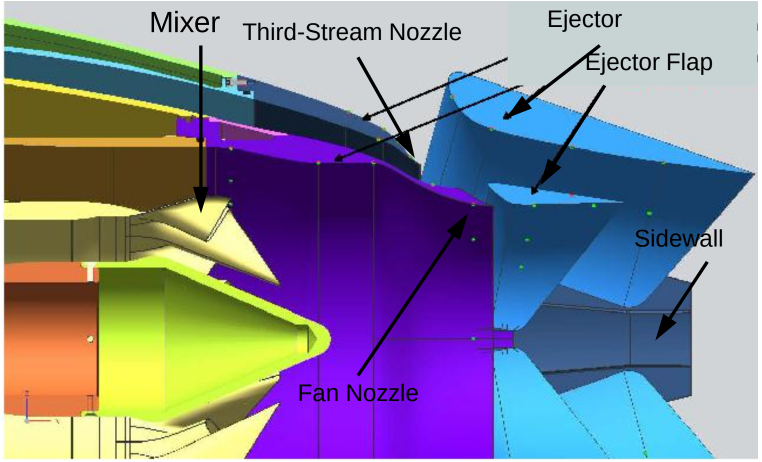


- AAPL
  - 65 foot geodesic dome
  - 45 foot microphone arc – 24 elements
- Nozzle Acoustic Test Rig (NATR)
  - 53 inch simulated flight stream
  - Maximum Mach number = 0.35
- High Flow Jet Exit Rig (HFJER)
  - 3-stream capability (3rd stream new)
  - Independent pressure control on all streams
  - Independent temperature control on fan and core streams
  - Fan and third-stream temperatures the same

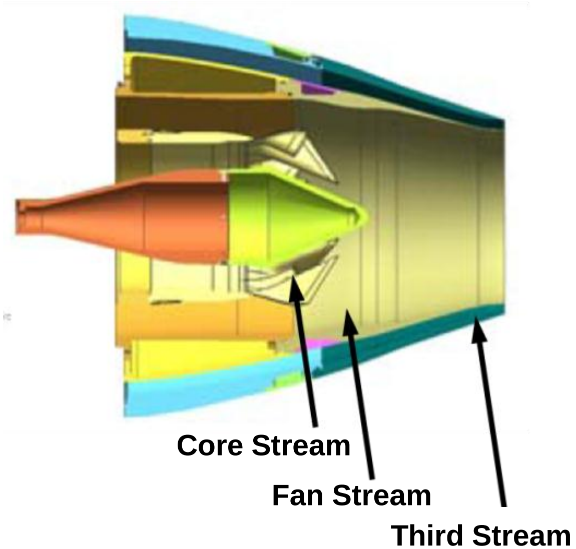
RRLW Hardware



HVC Hardware



N+2 HVC Hardware



N+2 HVC Baseline Hardware

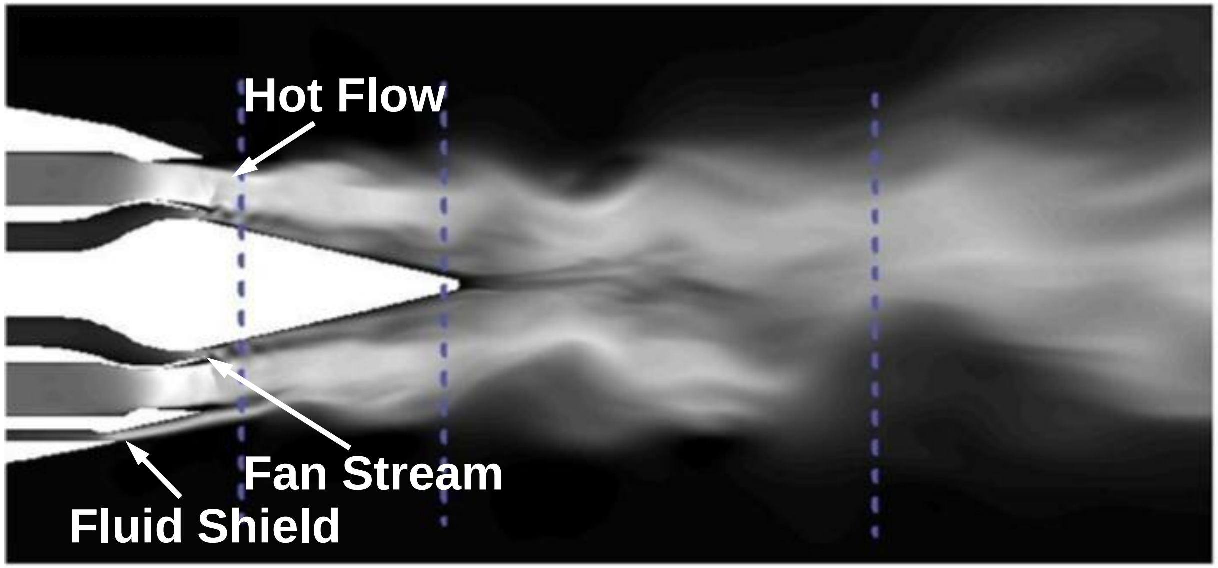
RRLW Cycle Points

NPR_c	NPR_f	NTR_c $TT_c/Tamb$	NTR_f $TT_f/Tamb$	M_{fj}
1.6000	1.6000	2.9000	1.2900	0.00
1.8000	1.8000	2.9000	1.2900	0.00
1.6000	1.8000	2.6900	1.2900	0.00
1.6000	1.8000	3.0500	1.2000	0.00
1.6000	1.8000	2.9000	1.1000	0.00
1.6000	1.6000	2.9000	1.2900	0.30
1.8000	1.8000	2.9000	1.2900	0.30
1.6000	1.8000	2.6900	1.2900	0.30
1.6000	1.8000	3.0500	1.2000	0.30
1.6000	1.8000	2.9000	1.1000	0.30

- HVC cycle points (N+2 HVC cycle points similar the NPR_t slightly below NPR_f)
- M_{fj} – free jet Mach number
- NPR – nozzle pressure ratio
- NTR – nozzle temperature ratio

Subsonic Exhausts

GEGR Hardware

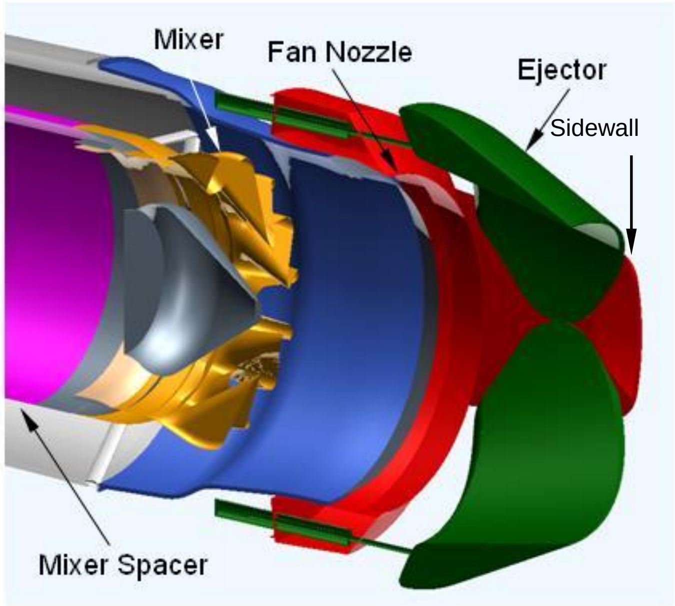


Exhaust speeds at high subsonic or low supersonic conditions

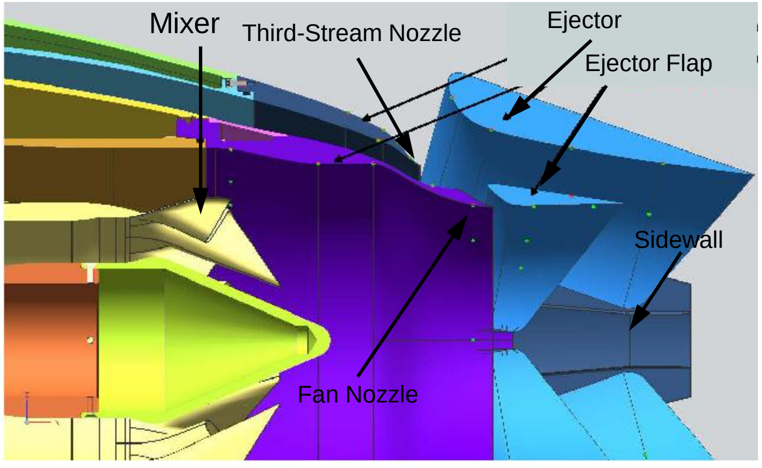
Experiments

- Far-field acoustics
- PIV
- Phased array
- Oil-film visualization

RRLW Model Results

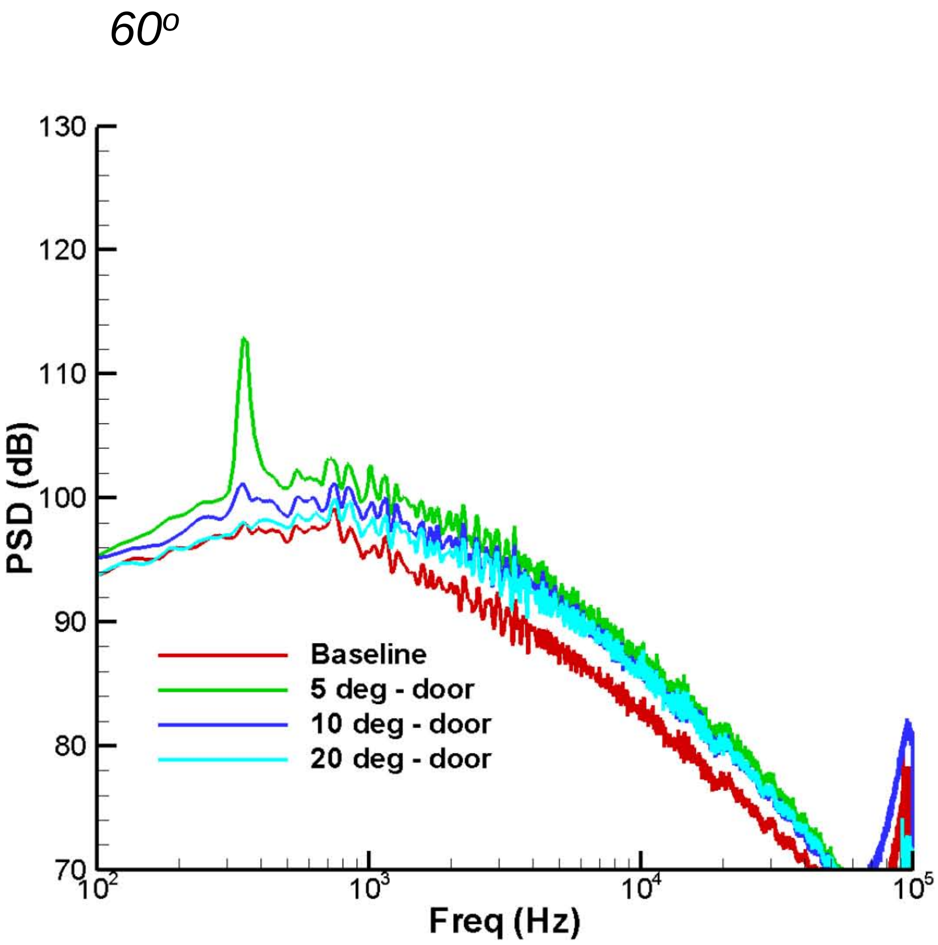


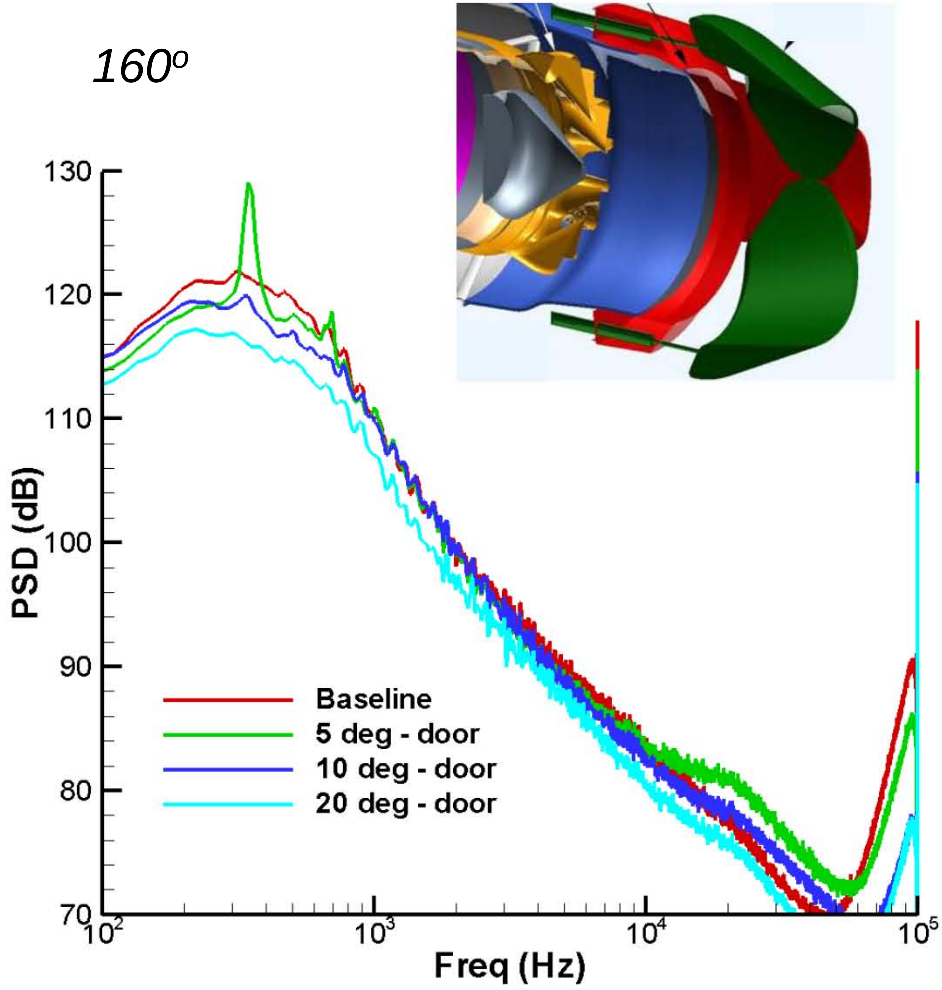
HVC



N+2 HVC

HVC Acoustic Results – $M_{fj} = 0.0$

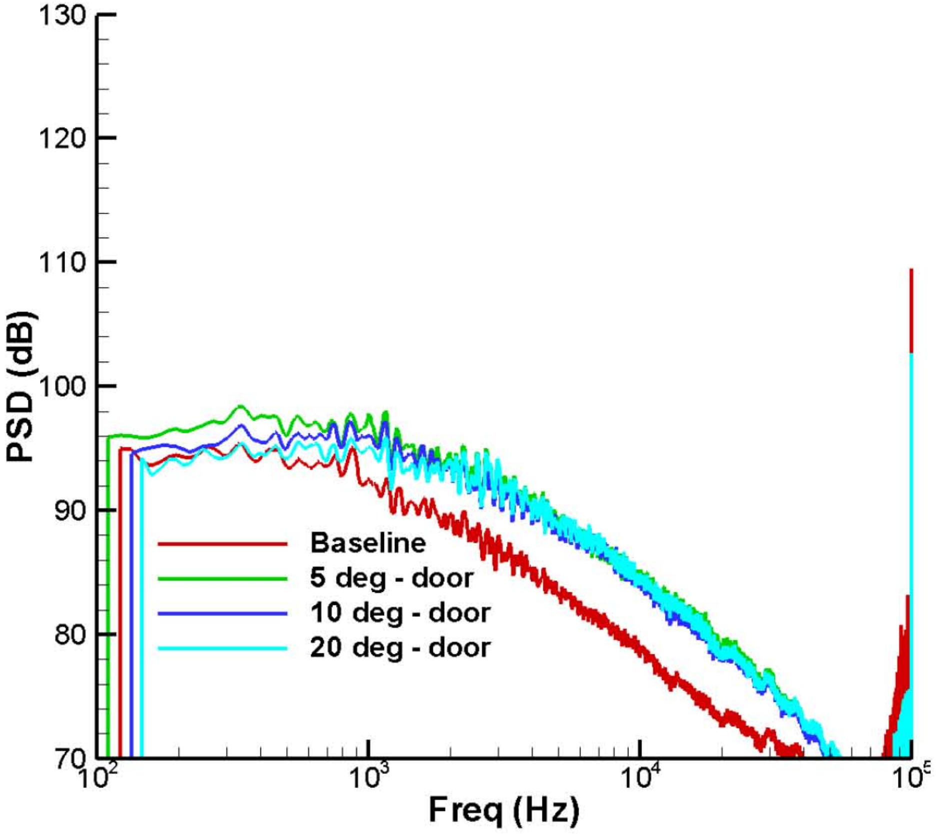




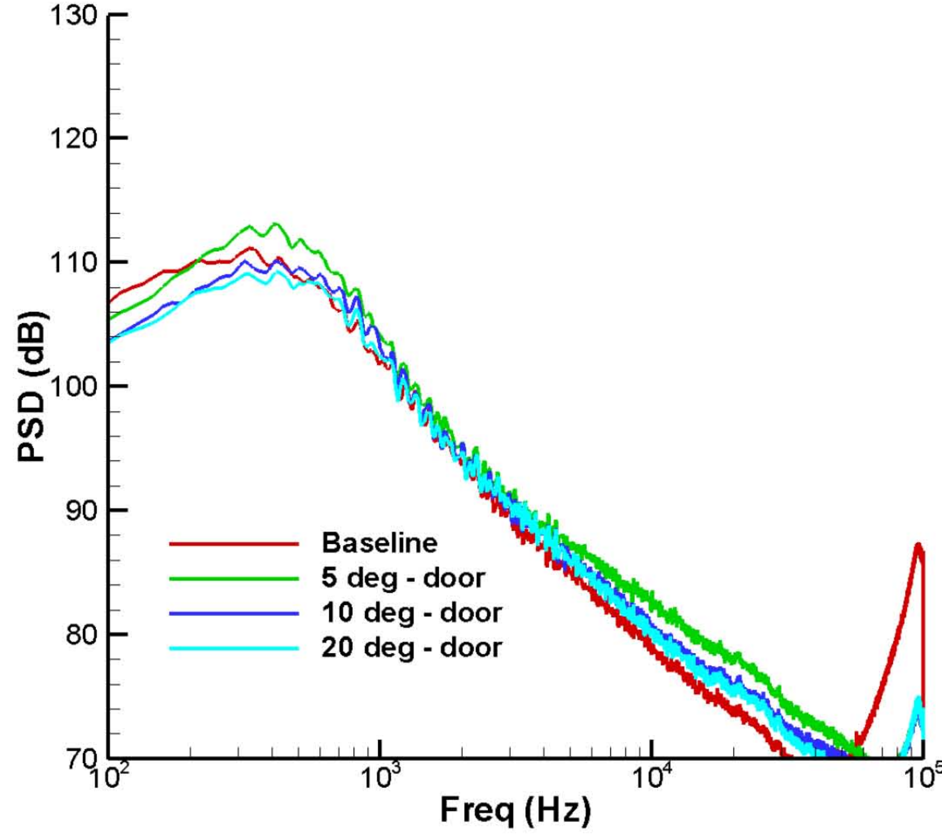
- Tone produced as smallest door angle
- Acoustic levels for baseline nozzle lower than HVC model in forward quadrant

HVC Acoustic Results – M_{fj} = 0.3

60º



160º

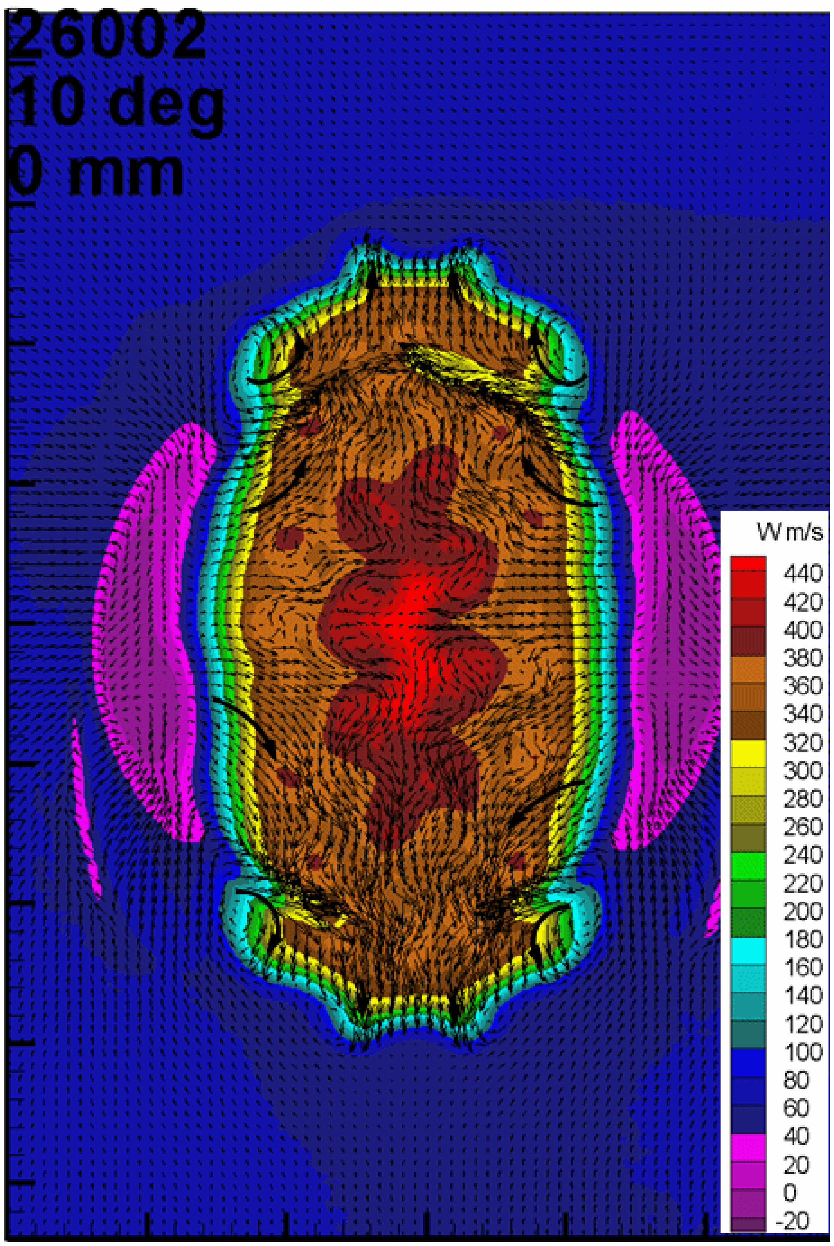


- In forward quadrant acoustic levels for baseline nozzle lower than HVC model
- In peak noise direction, acoustic levels for baseline nozzle lower than HVC at mid and high frequencies

HVC Cross-Stream PIV Results

$NPR_c = 1.60$
$NPR_b = 1.80$
$TT_c = 1472R$
$TT_b = 700R$
$M_{fj} = 0.2$

10^o Door

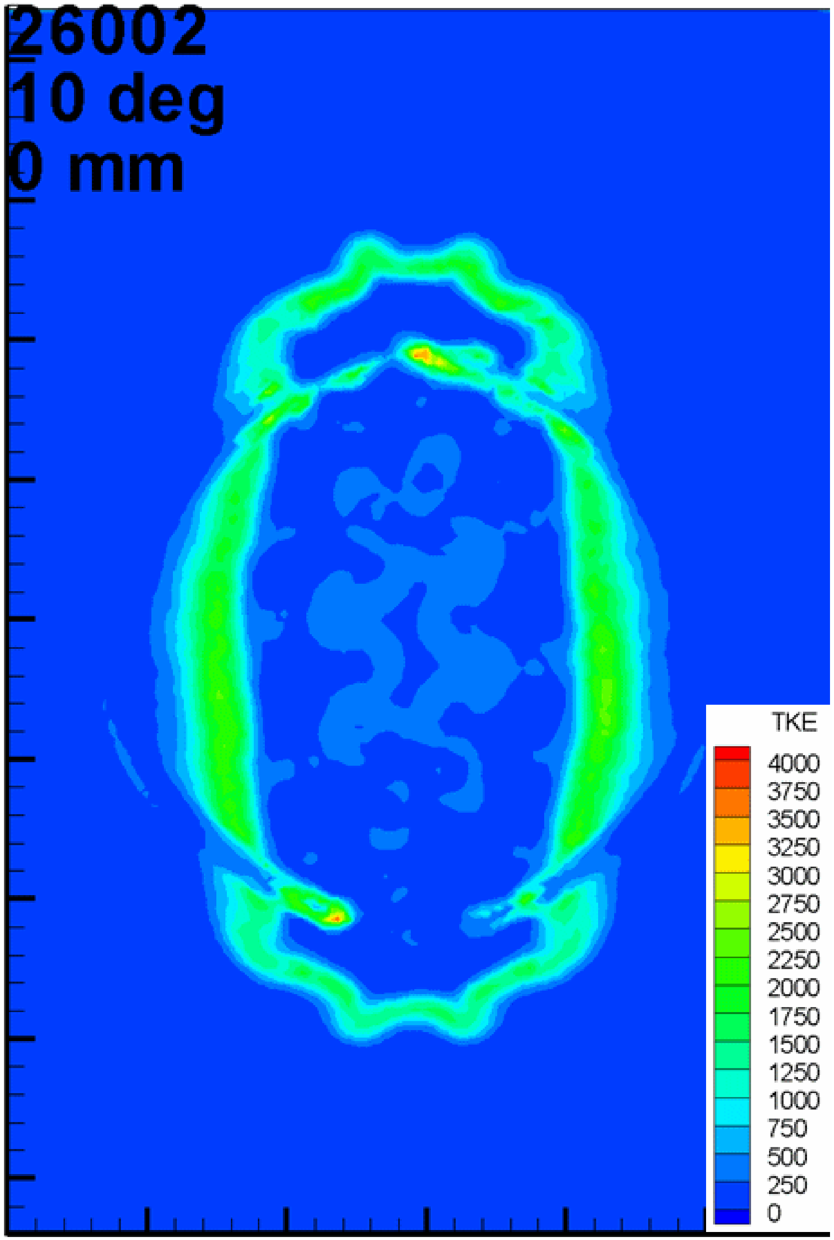


- Cross-stream mean axial velocity
- Purple is velocity below free stream
- Separation behind ejector doors
- Strong vortices set up by door-sidewall interface

HVC Cross-Stream PIV Results

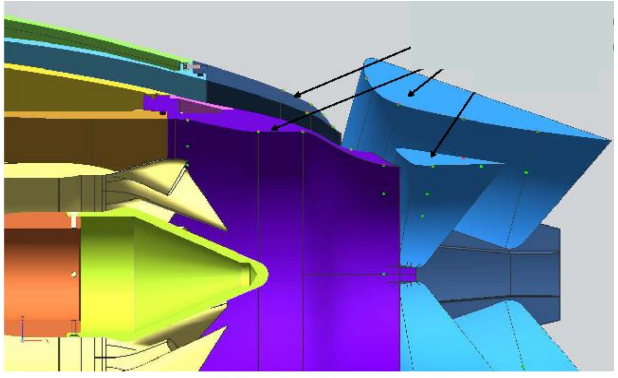
$NPR_c = 1.60$
$NPR_b = 1.80$
$TT_c = 1472R$
$TT_b = 700R$
$M_{fj} = 0.2$

10º Door

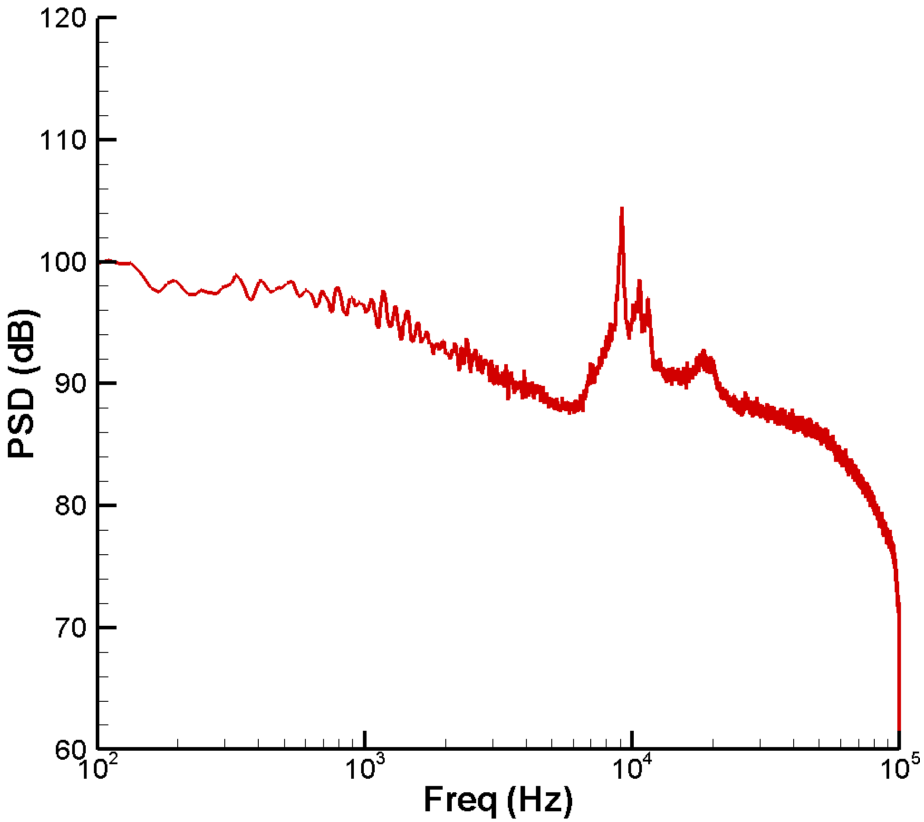


- Cross-stream TKE
- Strong vortices set up by door-sidewall interface stretches/augments shear layer turbulence downstream

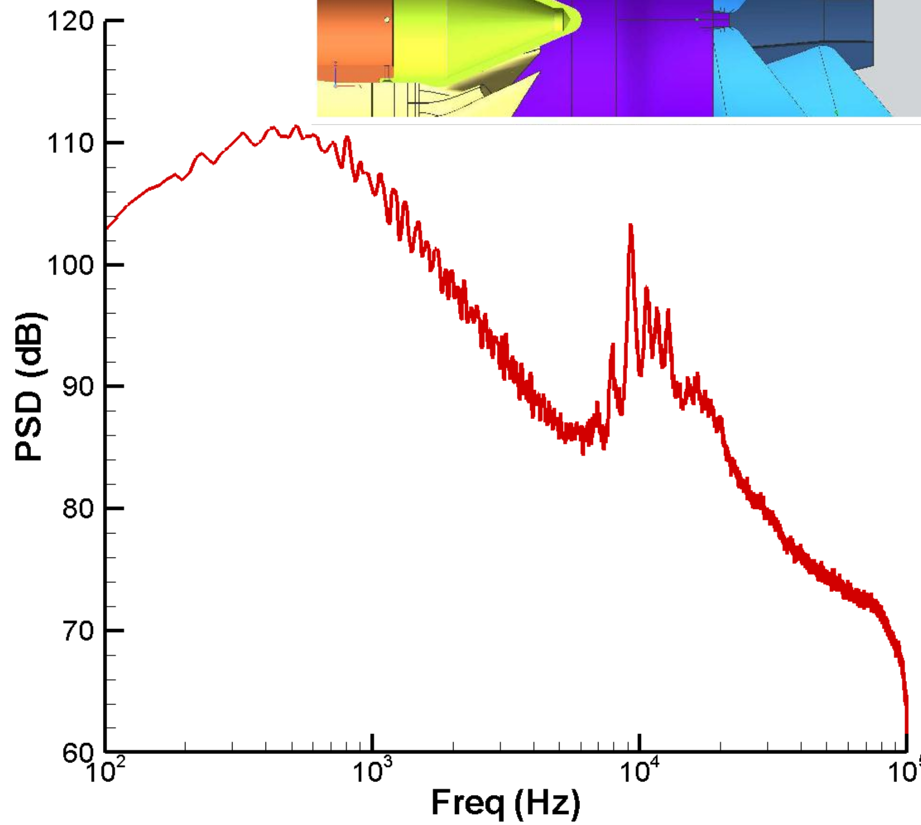
N+2 HVC Acoustic Results – M_{fj} = 0.3



90^o



150^o

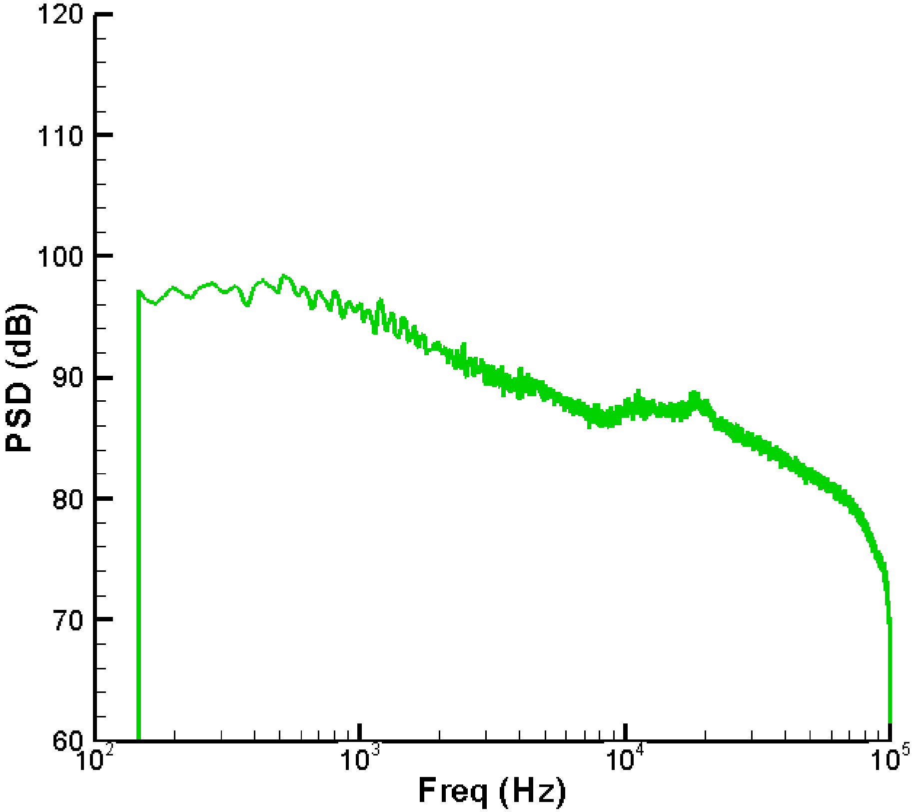


Multiple discrete-frequency tones produced by N+2 HVC model in as-built configuration

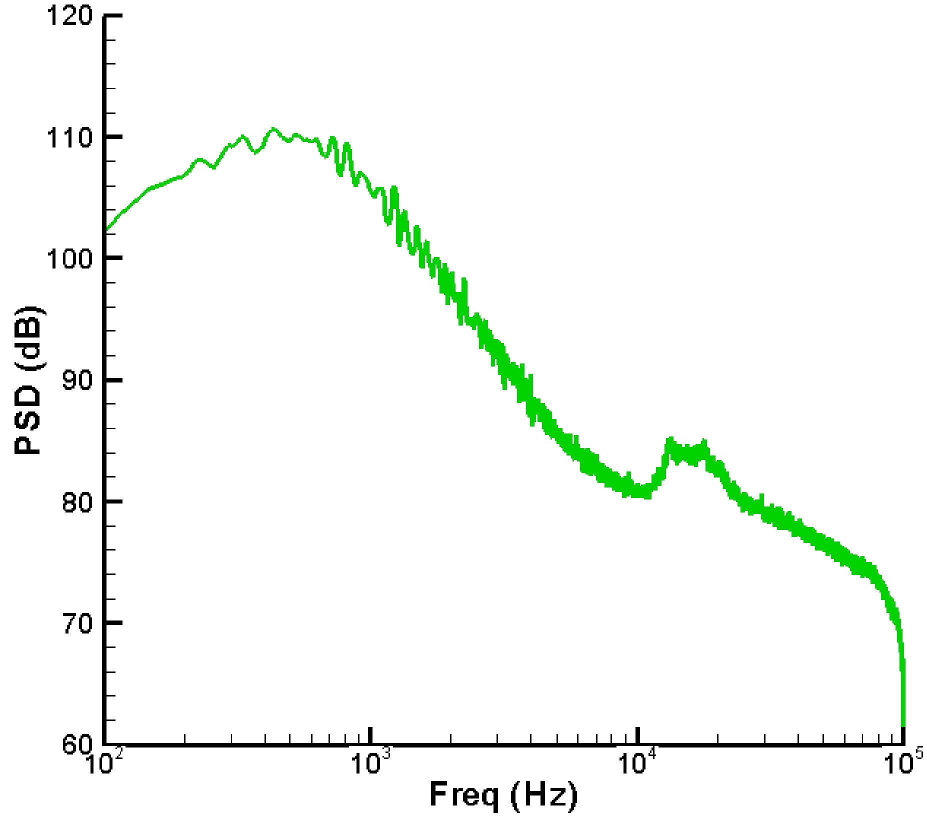
N+2 HVC Acoustic Results – M_{fj} = 0.3

Covered Ejector Flap

90°



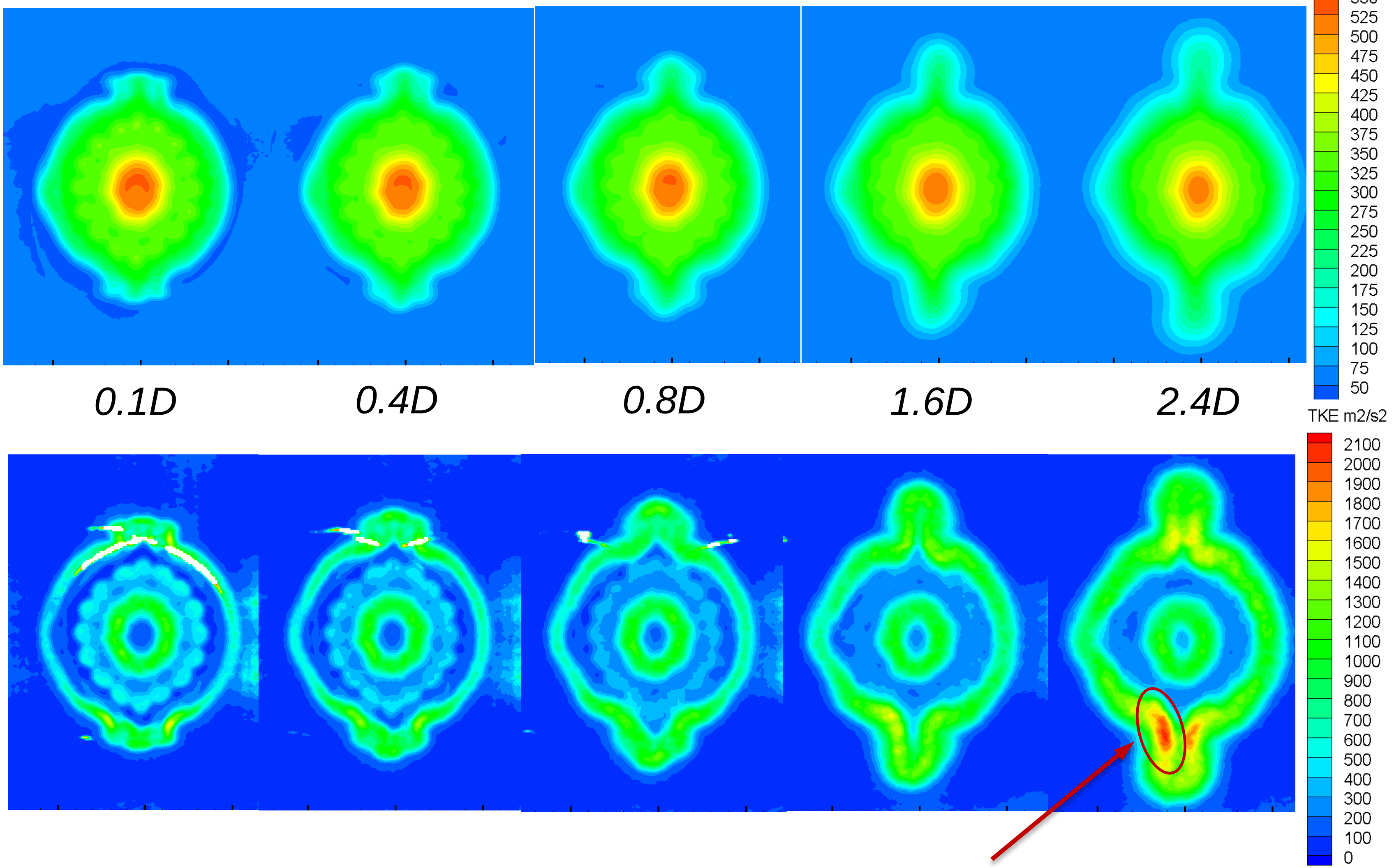
150°



Discrete-frequency tones reduced by covering ejector flap

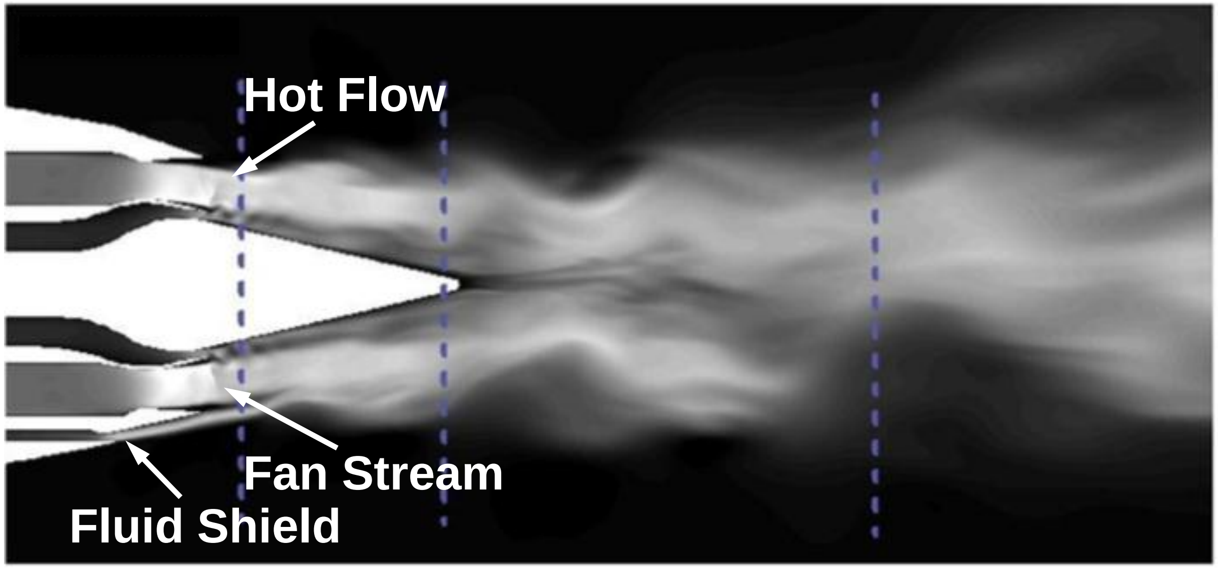
N+2 HVC PIV Results – $M_{fj} = 0.2$

Covered Ejector Flap



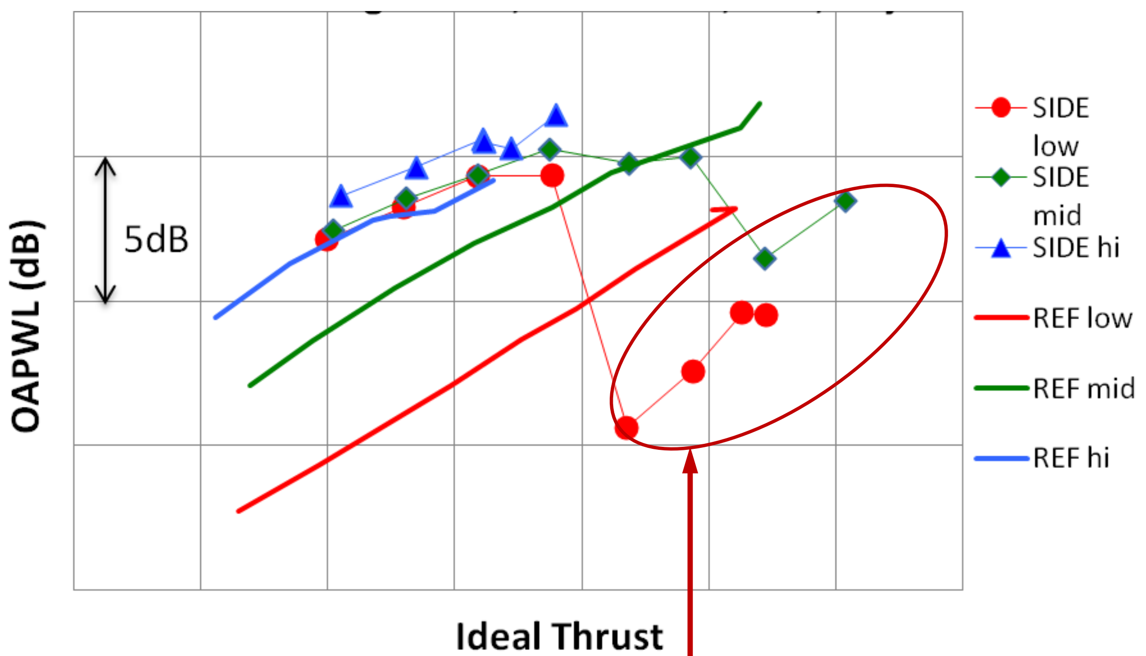
Highest measured TKE levels in regions downstream of ejector/sidewall corners

GEGR Model Results



GEGR Acoustic Results – $M_{fj} = 0.3$

Inverted Velocity Profile – No Fluid Shield

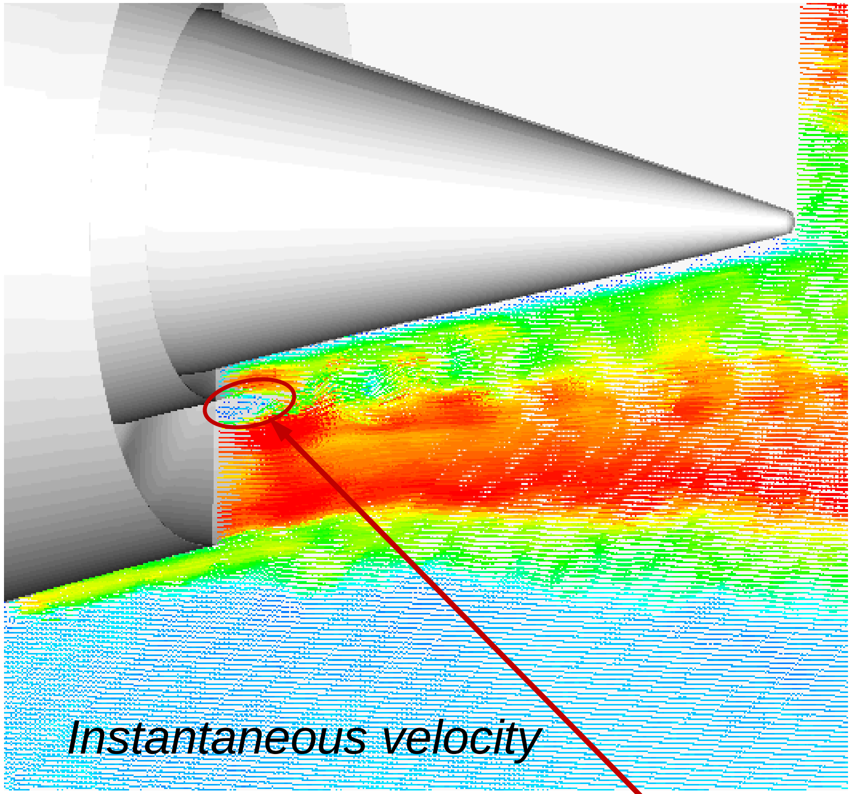


OAPWL for GEGR model lower than reference at high NPRs

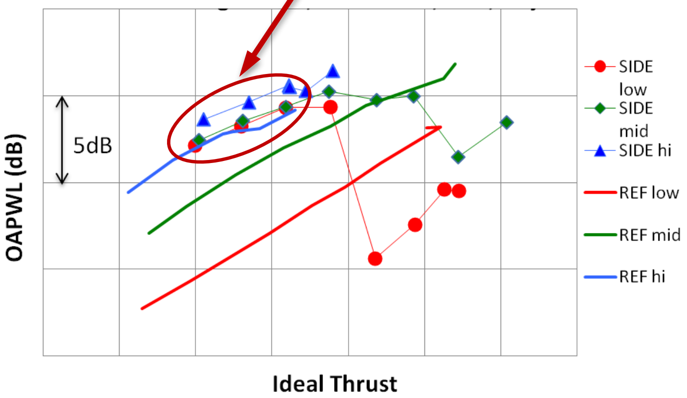
Fluid shield provided ≤ 1 dB additional reduction

GEGR PIV Results – M_{fj} = 0.3

Inverted Velocity Profile and Fluid Shield



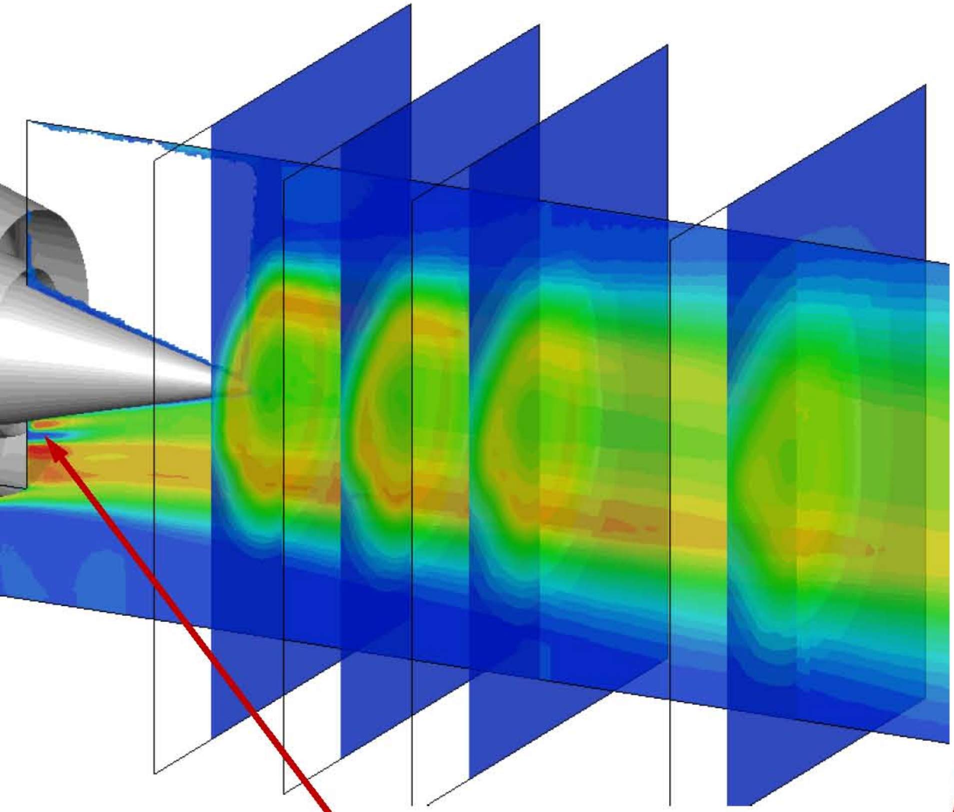
Representative PIV result for low NPR



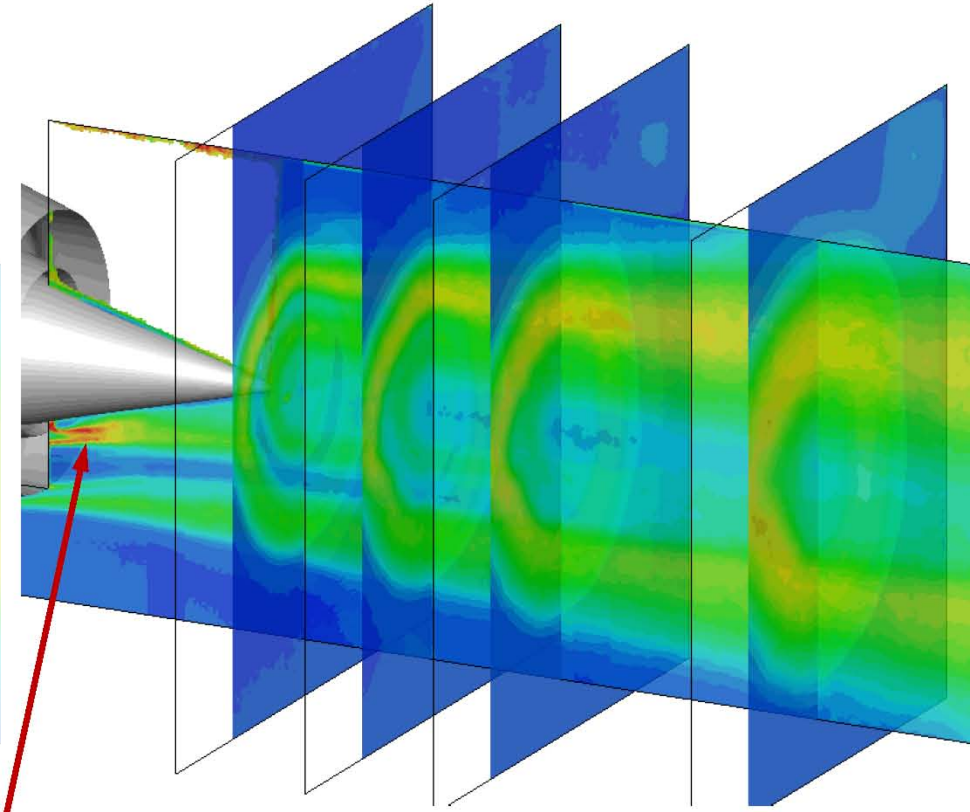
Flow separates from divergent nozzle regions

GEGR Streamwise PIV Results – $M_{fj} = 0.3$

Inverted Velocity Profile and Fluid Shield



Mean Velocity

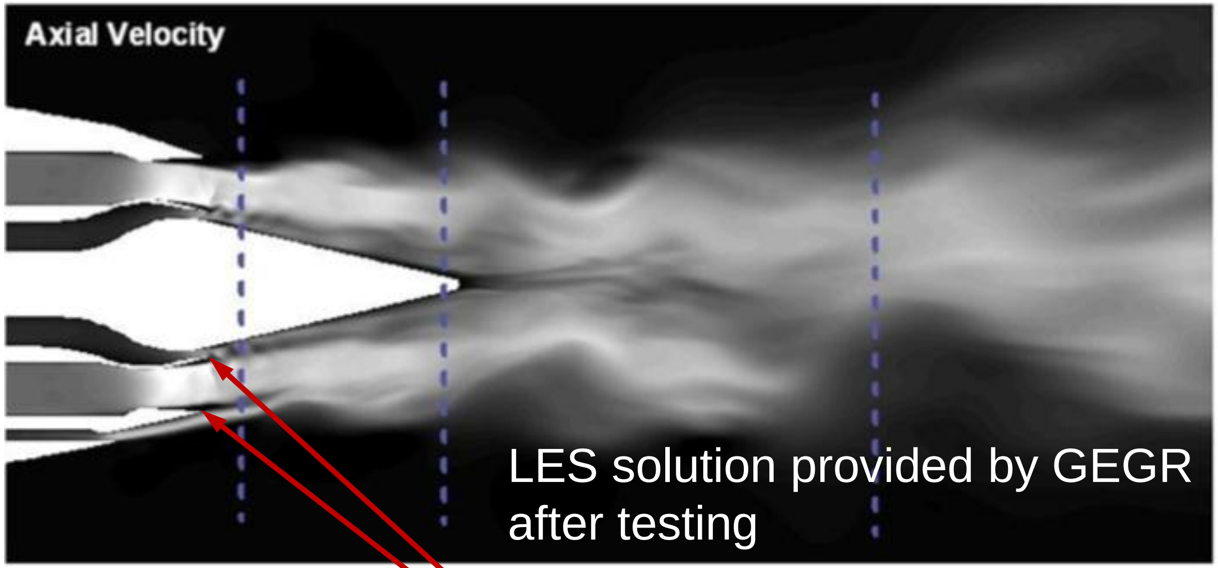


RMS Turbulent Velocity

- Low mean velocity and high rms turbulent velocity near separation region
- Asymmetry introduced by fluid shield

GEGR LES Results – M_{fj} = 0.3

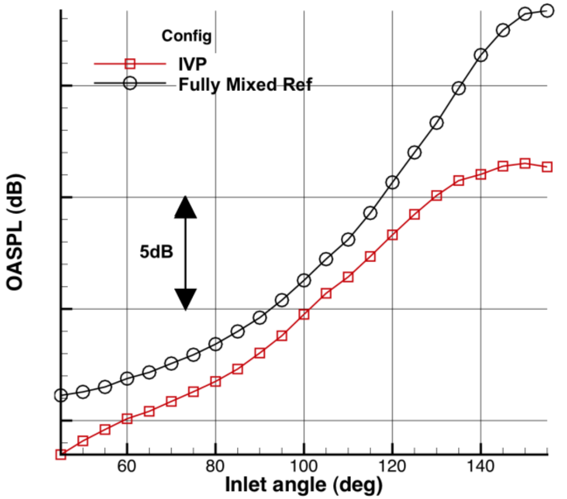
Inverted Velocity Profile and Fluid Shield

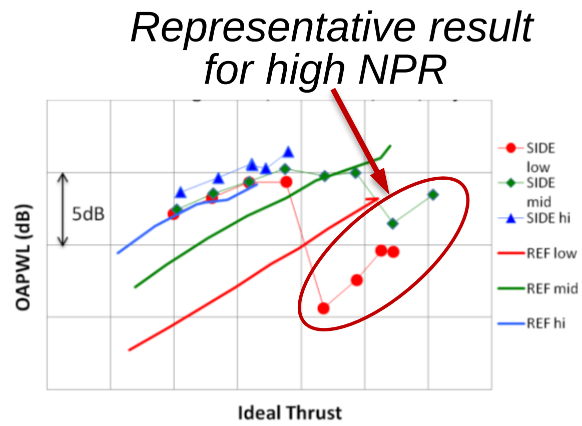


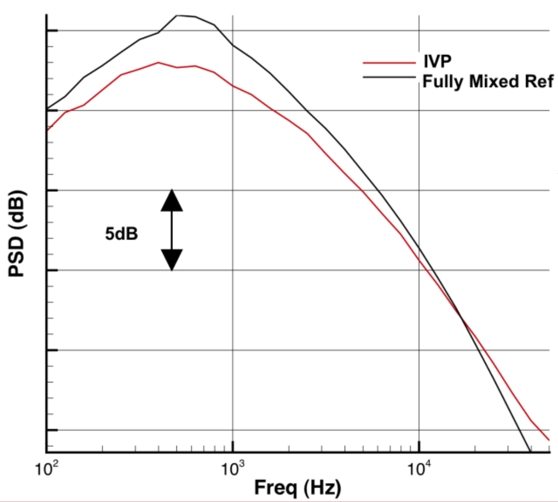
Flow separation found in CFD solution after testing

GEGR Acoustic Results (High NPR – M_{fj} = 0.3

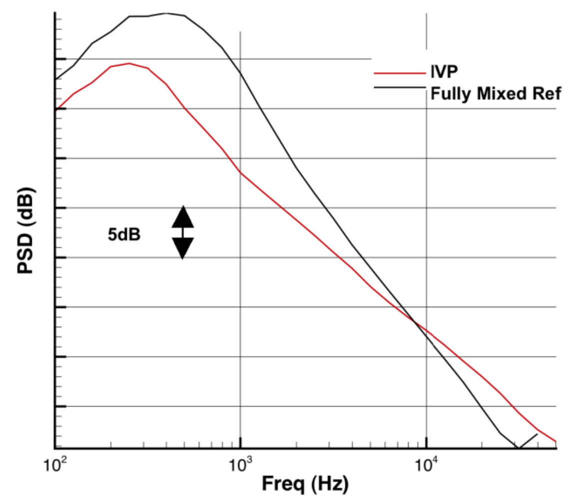
Inverted Velocity Profile - No Fluid Shield







90°



150°

GEGR produces up to 5 dB reduction at low-mid frequencies and slight increase in noise levels at high frequencies

Conclusions

- All complex exhaust concepts suffered from separation for some cycle conditions
- Initial RANS CFD used to select flow lines did not detect flow separation
- Subsequent LES CFD has detected separation in GEGR model
- Separation degraded acoustic performance of all models

Abstract

Acoustic and flow-field experiments were conducted on exhaust concepts for the next generation supersonic, commercial aircraft. The concepts were developed by Lockheed Martin (LM), Rolls-Royce Liberty Works (RRLW), and General Electric Global Research (GEGR) as part of an N+2 (next generation forward) aircraft system study initiated by the Supersonics Project in NASA's Fundamental Aeronautics Program. The experiments were conducted in the Aero-Acoustic Propulsion Laboratory at the NASA Glenn Research Center. The exhaust concepts utilized ejectors, inverted velocity profiles, and fluidic shields. One of the ejector concepts was found to produce stagnant flow within the ejector and the other ejector concept produced discrete-frequency tones that degraded the acoustic performance of the model. The concept incorporating an inverted velocity profile and fluid shield produced overall-sound-pressure-level reductions of 6 dB relative to a single stream nozzle at the peak jet noise angle for some nozzle pressure ratios. Flow separations in the nozzle degraded the acoustic performance of the inverted velocity profile model at low nozzle pressure ratios.