https://ntrs.nasa.gov/search.jsp?R=20110011259 2019-08-30T15:24:54+00:00Z

Highly Variable Cycle Nozzle Concept: Validation of Flow and Noise Predictions

Results from experimental and numerical studies of highly Variable Cycle (HVC) exhaust model were presented. The model was designed and fabricated under a Supersonics NRA awarded to Rolls-Royce. The model had a lobed mixer for the core stream nozzle, and elliptic fan stream nozzle, and an ejector. Experiments included far-field acoustic array, phased array, and Particle Image Velocimetry (PIV) measurements. Numerical studies included flow simulations using the WIND-US code and far-field acoustic solutions using an acoustic analogy developed by Goldstein (2003) and Leib and Goldstein (2011). Far-field acoustic measurements showed increased noise levels over the round baseline nozzle when using non-static forward flight conditions. Phased array measurements showed noise sources near the ejector doors when tones were produced for small ejector door positions. Ejector door separation identified in the experiments was reproduced in the numerical flow simulations. Acoustic solutions were unable to match levels measured in the peak jet noise direction indicating additional development work is needed to predict noise from highly three-dimensional flows.

National Aeronautics and Space Administration

Highly Variable Cycle Nozzle Concept: Validation of Flow and Noise Predictions

Supersonics Project

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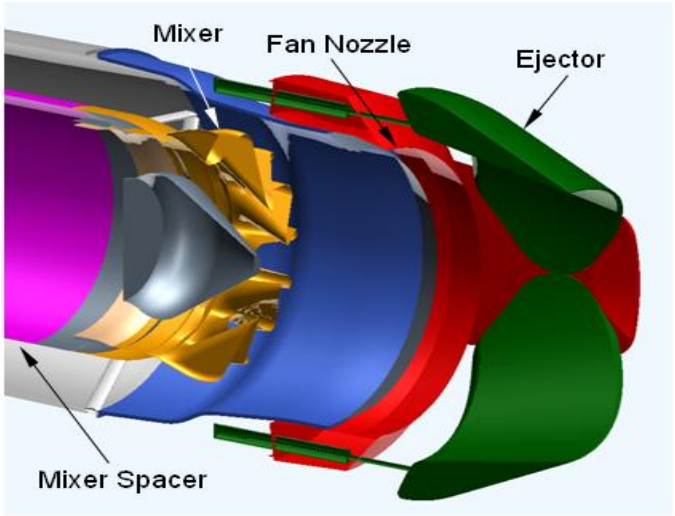
Franco Frate, Stewart Leib, Rick Bozak

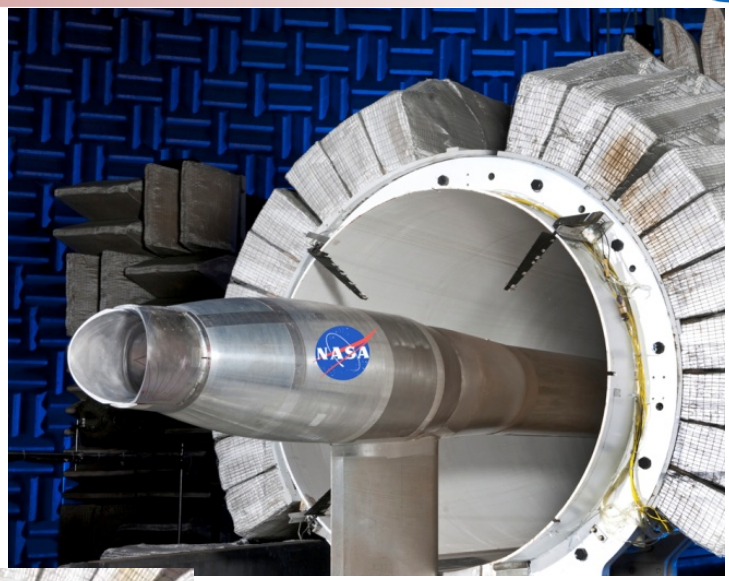
NASA Glenn Research Center

2011 Technical Conference
March 15-17, 2011
Cleveland, Ohio

Model



HVC Model



Baseline

HVC model designed and fabricated by Rolls-Royce under Supersonics NRA

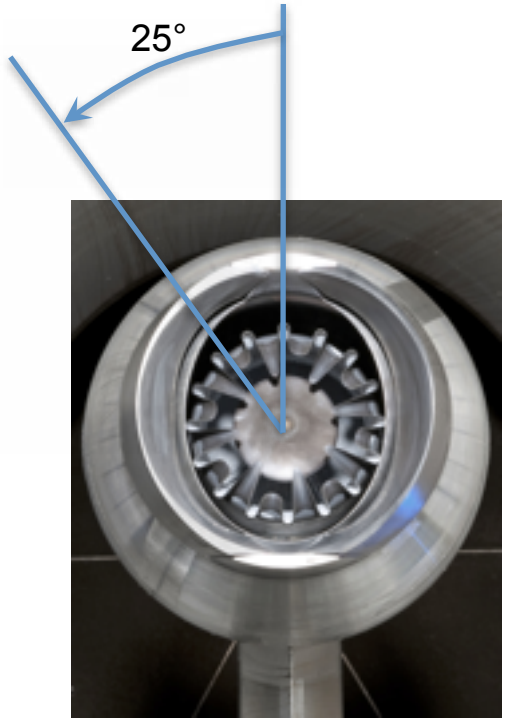
Studies

- Experiments
  - Far-field acoustics
  - PIV
    - Cross-stream stereo
    - Streamwise
  - Phased array
- Numerical Studies
  - CFD
  - Acoustic calculations

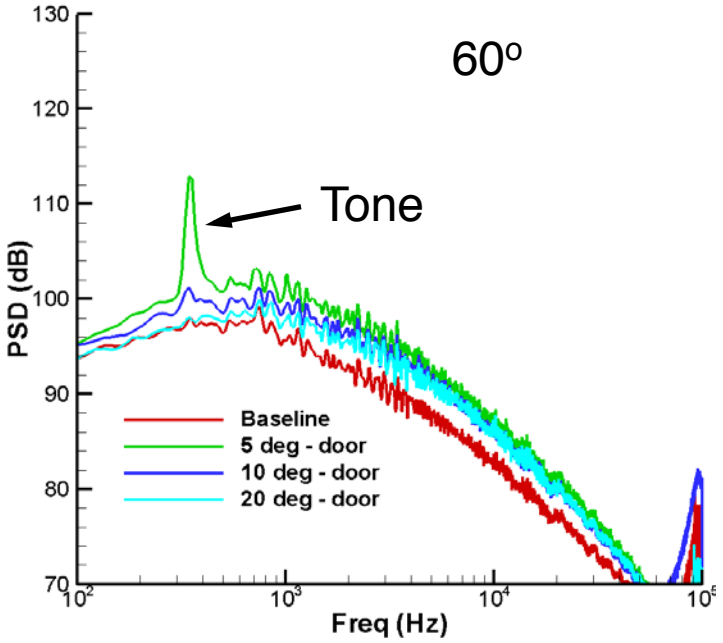
Cycle Points

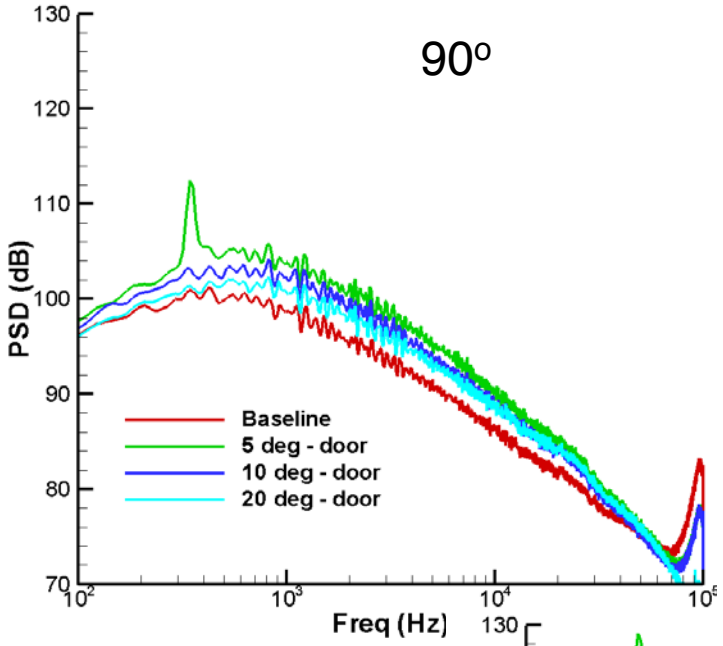
Setpoint	NPRc	NPRb	NTRc TTc/Tamb	NTRb TTf/Tamb	FJ Mach #
17010	1.6000	1.6000	2.9000	1.2900	0.00
19010	1.8000	1.8000	2.9000	1.2900	0.00
26010	**1.6000**	**1.8000**	**2.6900**	**1.2900**	**0.00**
28010	1.6000	1.8000	3.0500	1.2000	0.00
24000	1.6000	1.8000	2.9000	1.1000	0.00
17013	1.6000	1.6000	2.9000	1.2900	0.30
19013	1.8000	1.8000	2.9000	1.2900	0.30
26013	**1.6000**	**1.8000**	**2.6900**	**1.2900**	**0.30**
28013	**1.6000**	**1.8000**	**3.0500**	**1.2000**	**0.30**
24003	1.6000	1.8000	2.9000	1.1000	0.30

Far-field observer orientation

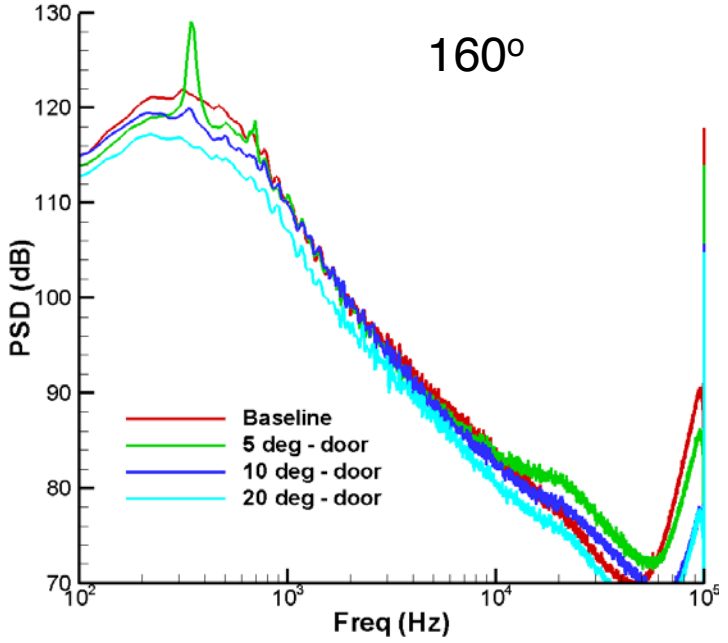


Acoustic Results - No Free Jet



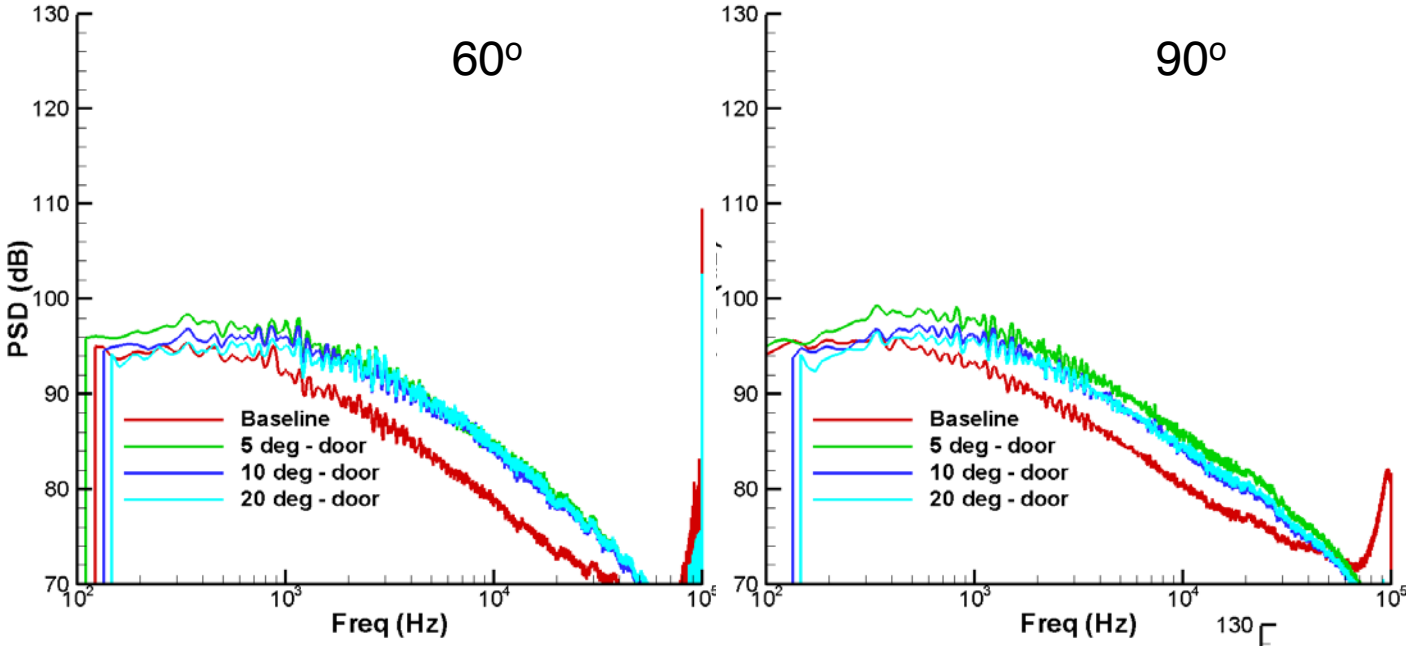


$NPR_c = 1.60$
$NPR_b = 1.80$
$NTR_c = 2.69$
$NTR_b = 1.29$
$M_{fj} = 0.0$



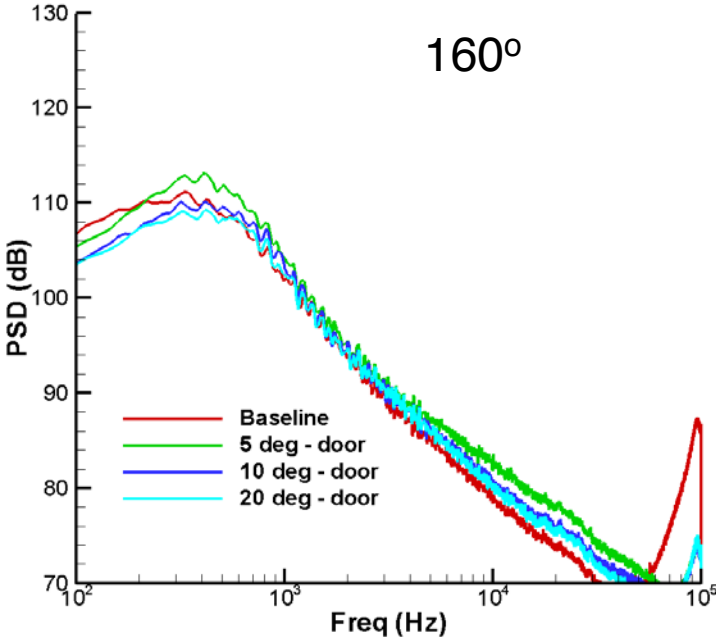
- Tones produced at small door angles and no free jet
- Noise decreases with increasing door angle
- Ejector increases noise at small and broadside observation angles
- Ejector decreases noise at peak jet noise angle

Acoustic Results – M_{fj} = 0.3

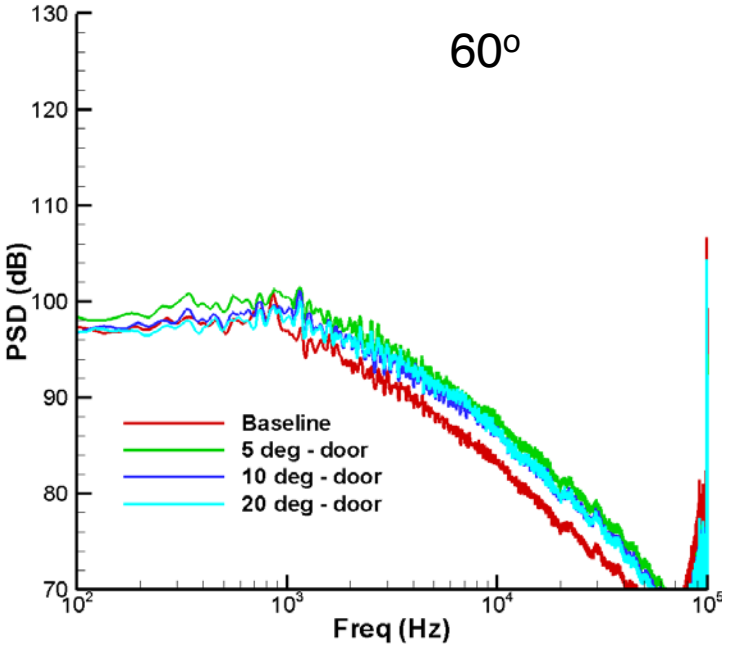


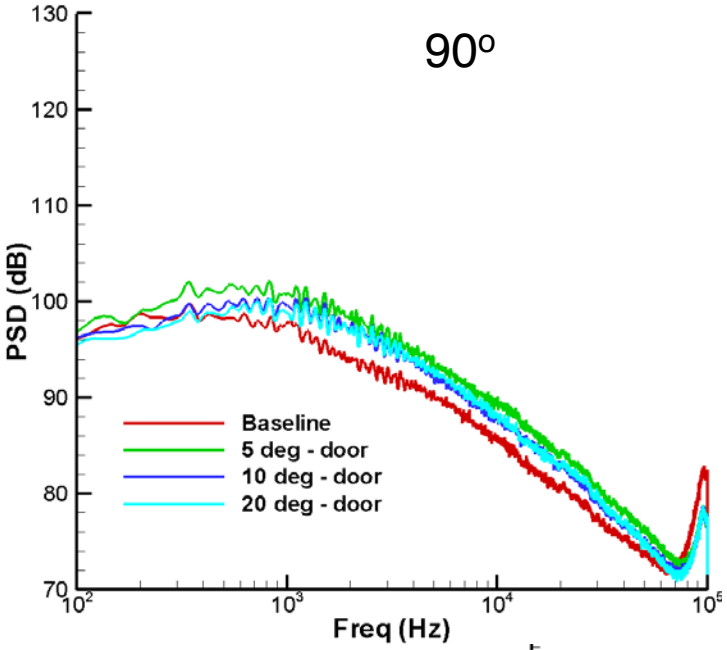
NPR_c = 1.60
NPR_b = 1.80
NTR_c = 2.69
NTR_b = 1.29
M_{fj} = 0.3

- Tones usually not present for M_{fj} = 0.3
- Ejector increases noise at small and broadside observation angles
- 10° and 20° door positions produce similar noise levels at small and broadside observation angles
- Noise levels for baseline and ejector are similar in peak jet noise direction



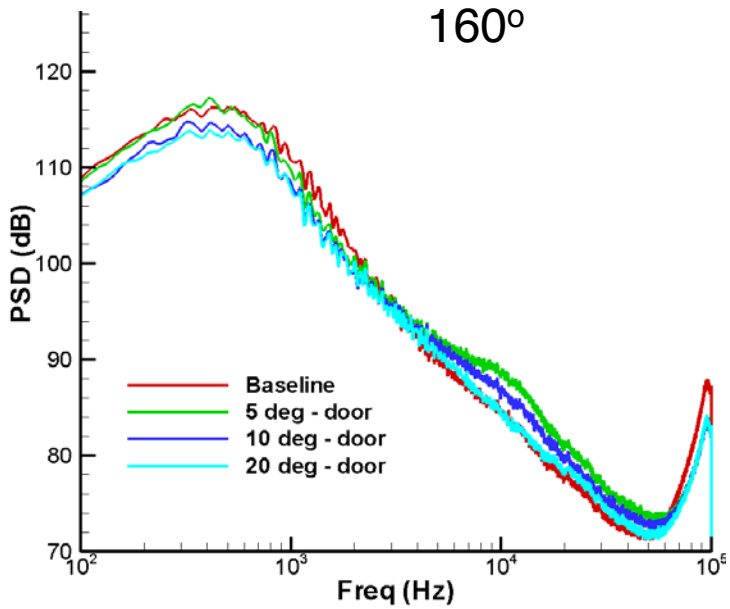
Acoustic Results – High Setpoint





$NPR_c = 1.60$
$NPR_b = 1.80$
$NTR_c = 3.05$
$NTR_b = 1.29$
$M_{fj} = 0.3$

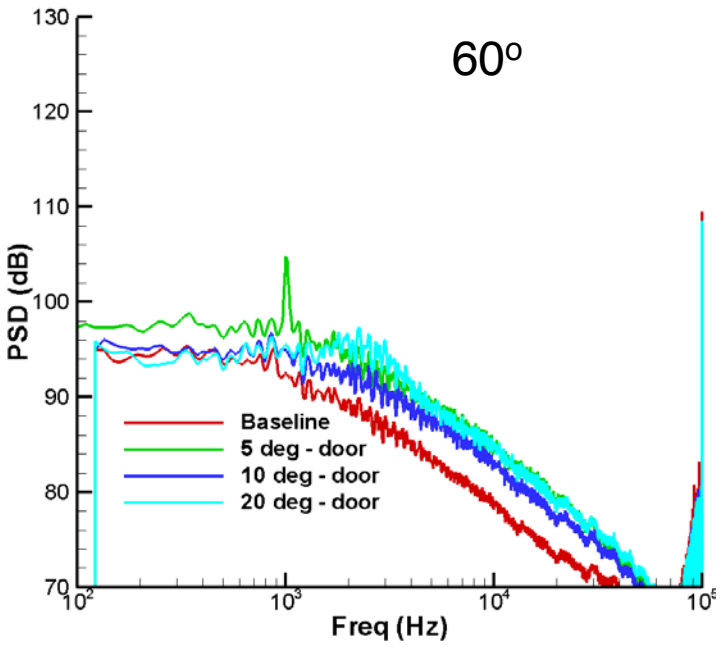
- 10^o and 20^o door positions decrease low-frequency noise at peak jet noise angle

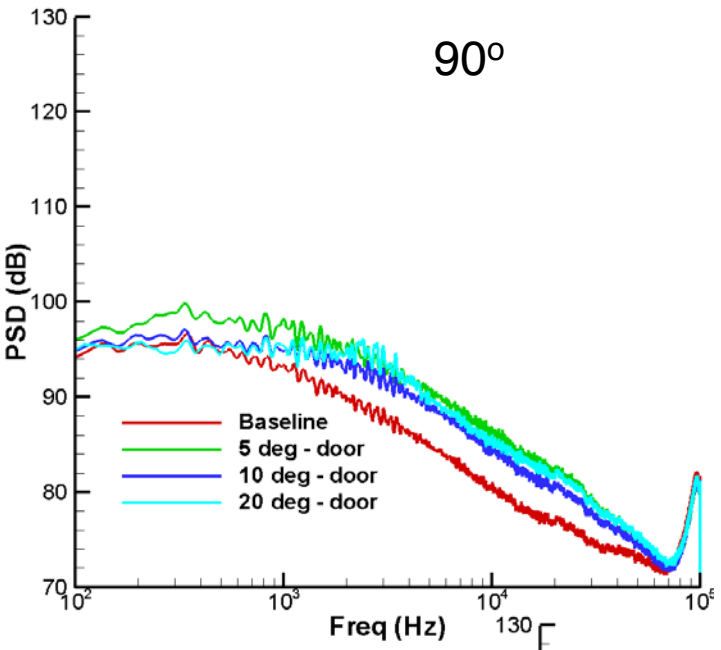


EPNL

	EPNL (EPNdB)@Mf=0.3		
Setpoint	10 deg	20 deg	Baseline
17010	92.25	91.55	92.1
19010	96.63	95.35	96.48
26010	94.25	92.94	92.93
24000	95.28	93.03	91.28
28010	97.12	96.34	97.36
17013	86.48	86.72	83.91
19013	90.93	90.79	88.83
26013	87.81	87.64	84.82
28013	91.98	91.81	90.43
24003	86.36	86.43	83.5

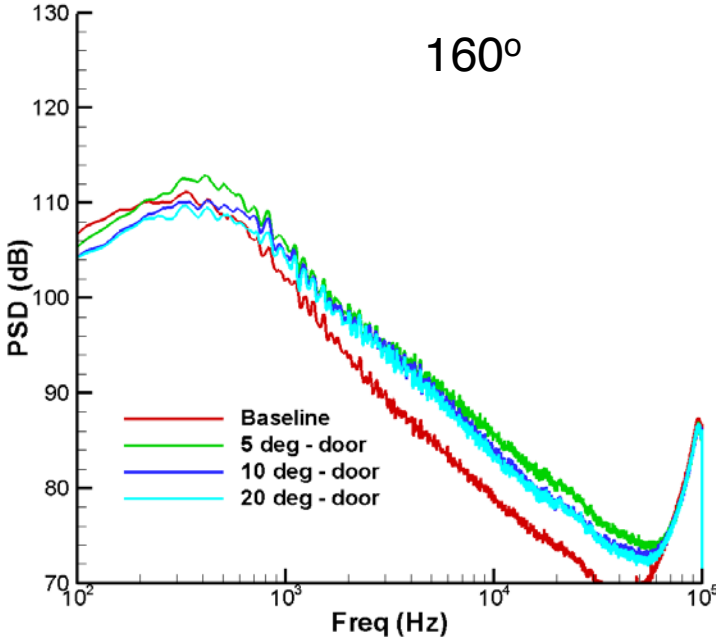
Acoustic Results – Doors in Microphone Plane





$NPR_c = 1.60$
$NPR_b = 1.80$
$NTR_c = 3.05$
$NTR_b = 1.29$
$M_{fj} = 0.3$

- Tones occur for small door angles with forward flight
- At upstream observation angles, 10° door position has lowest noise levels
- Ejector increases noise

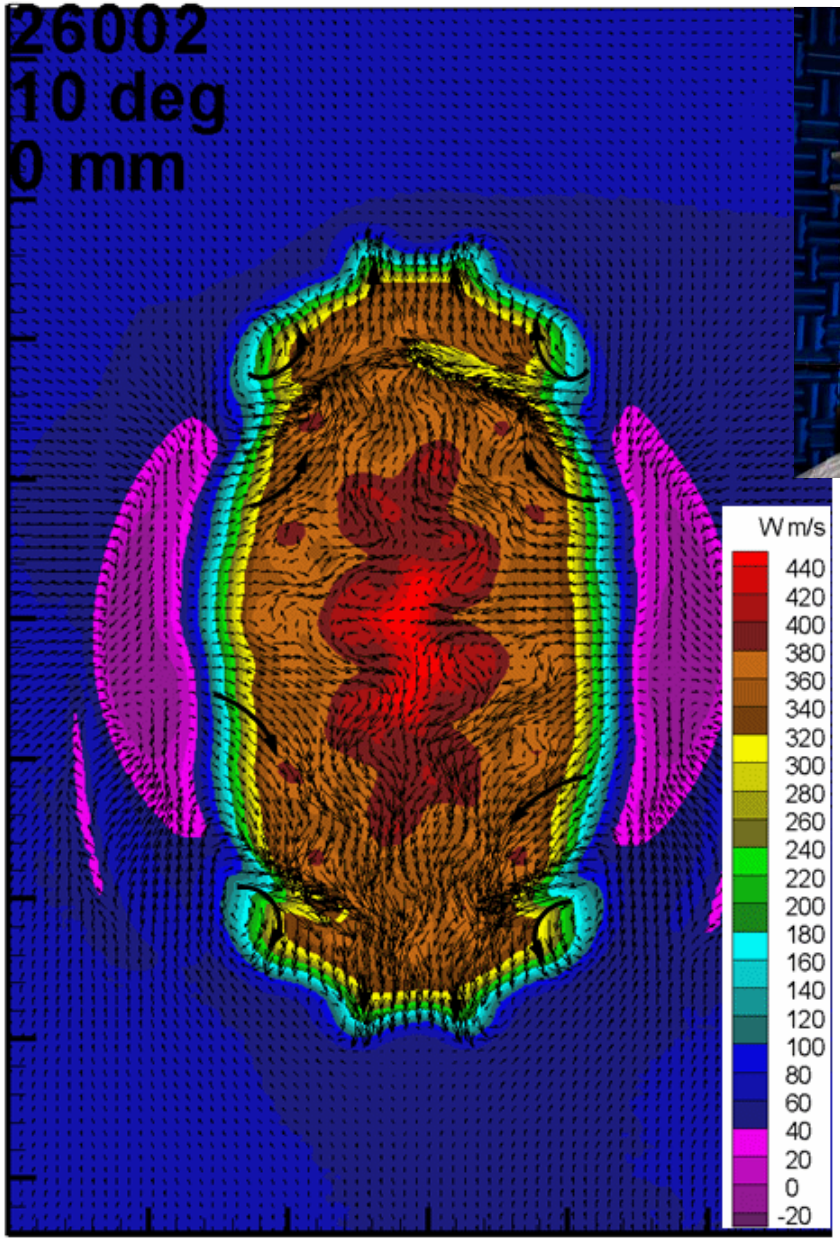


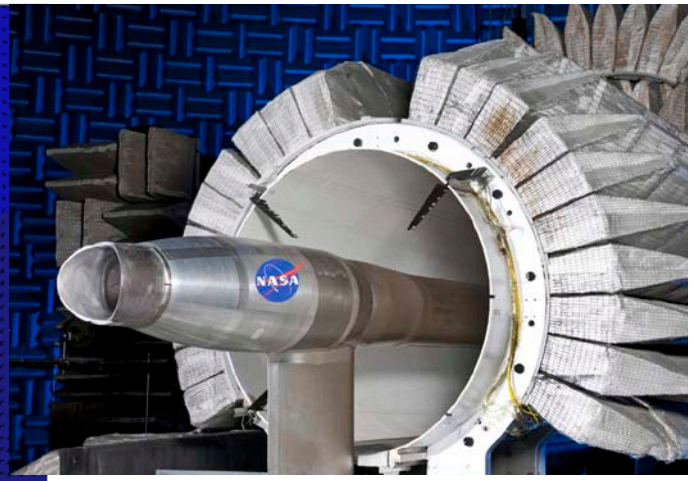
Far-field Acoustic Summary

- Tones occur for small door angles
- Ejector increases EPNL for simulated forward flight conditions
- Acoustic spectra shows azimuthal (model clocking) variation

PIV Results – 10° Door Position

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

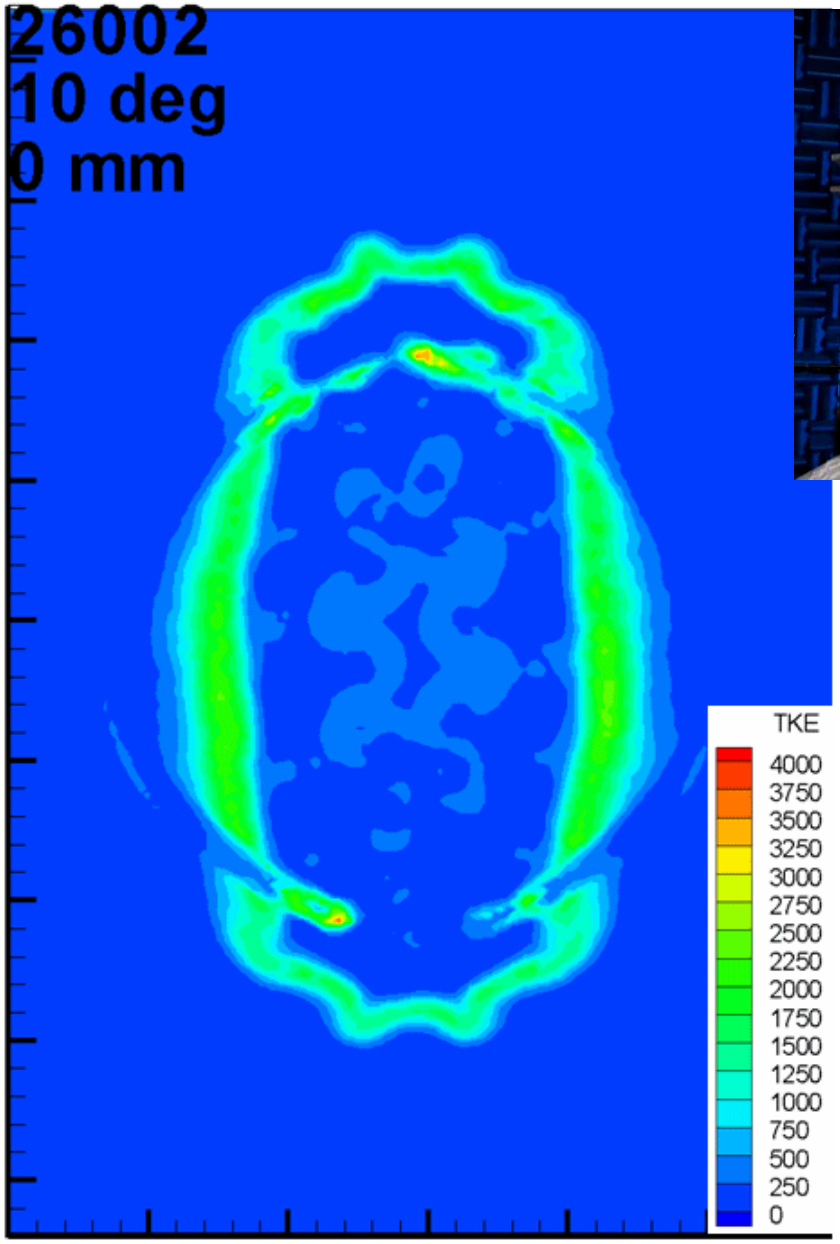


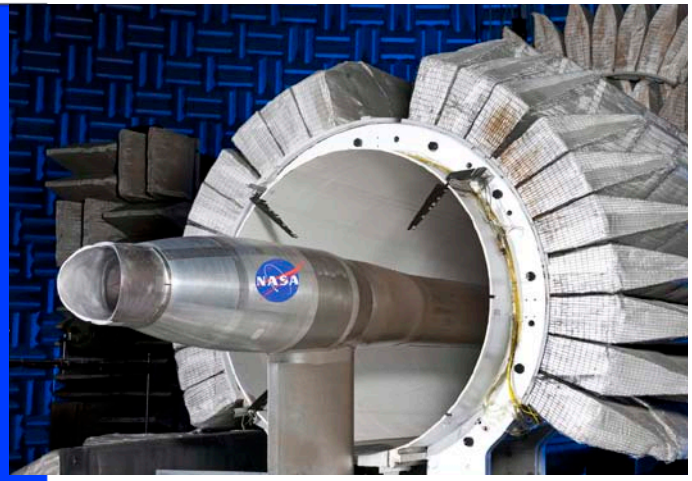


- Cross-stream cuts
  - color=mean axial velocity
  - vectors=cross-stream velocity
- Purple is velocity below freestream
- Separation behind ejector doors
- Strong vortices set up by door-sidewall interface

PIV Results – 10° Door Position

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

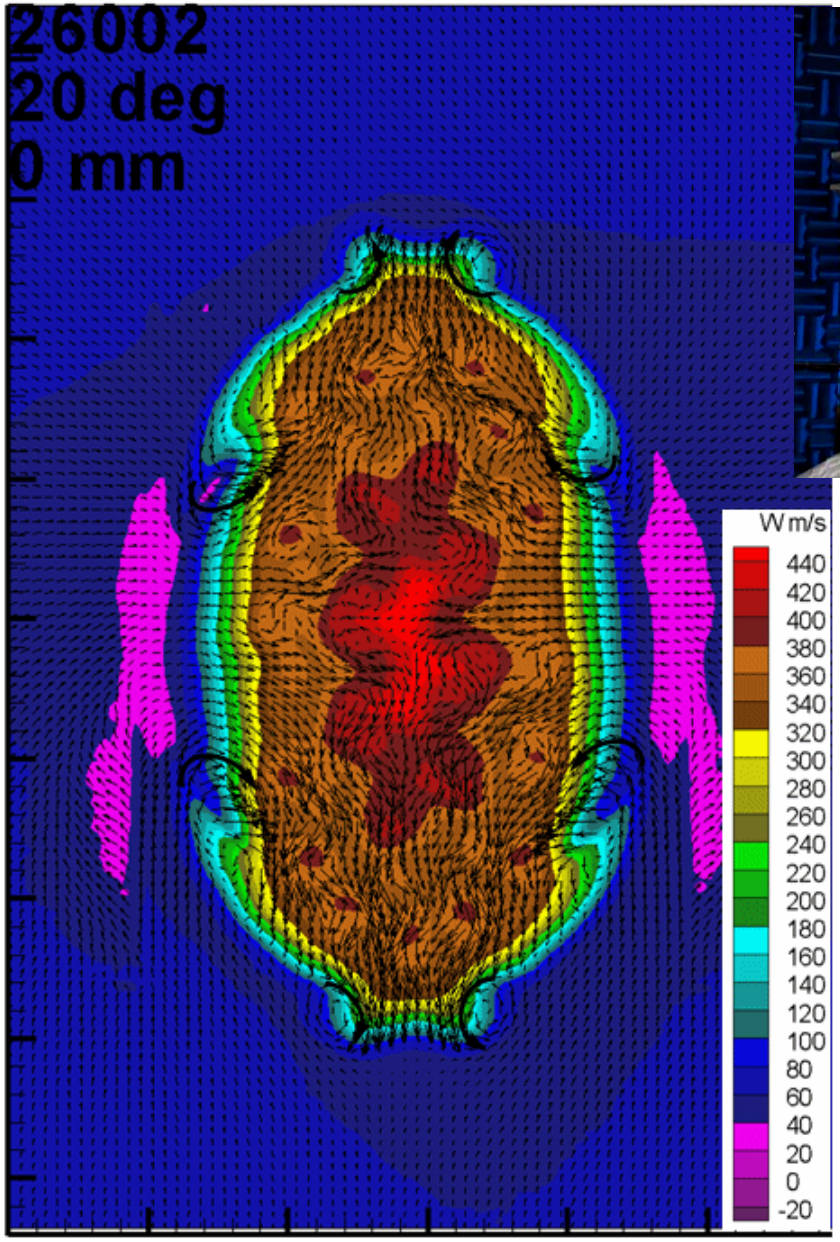


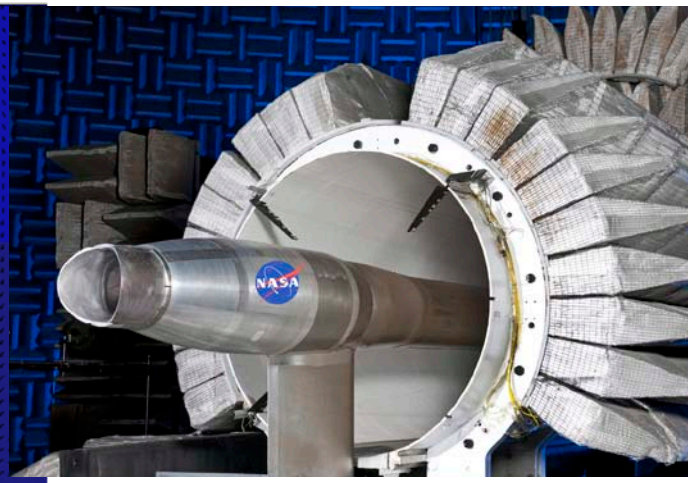


- Cross-stream cuts
  - color=turbulent kinetic energy
  - Peak tke > 3000 m^2/s^2
- Strong vortices set up by door-sidewall interface stretches/ augments shear layer turbulence downstream

PIV Results – 20° Door Position

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

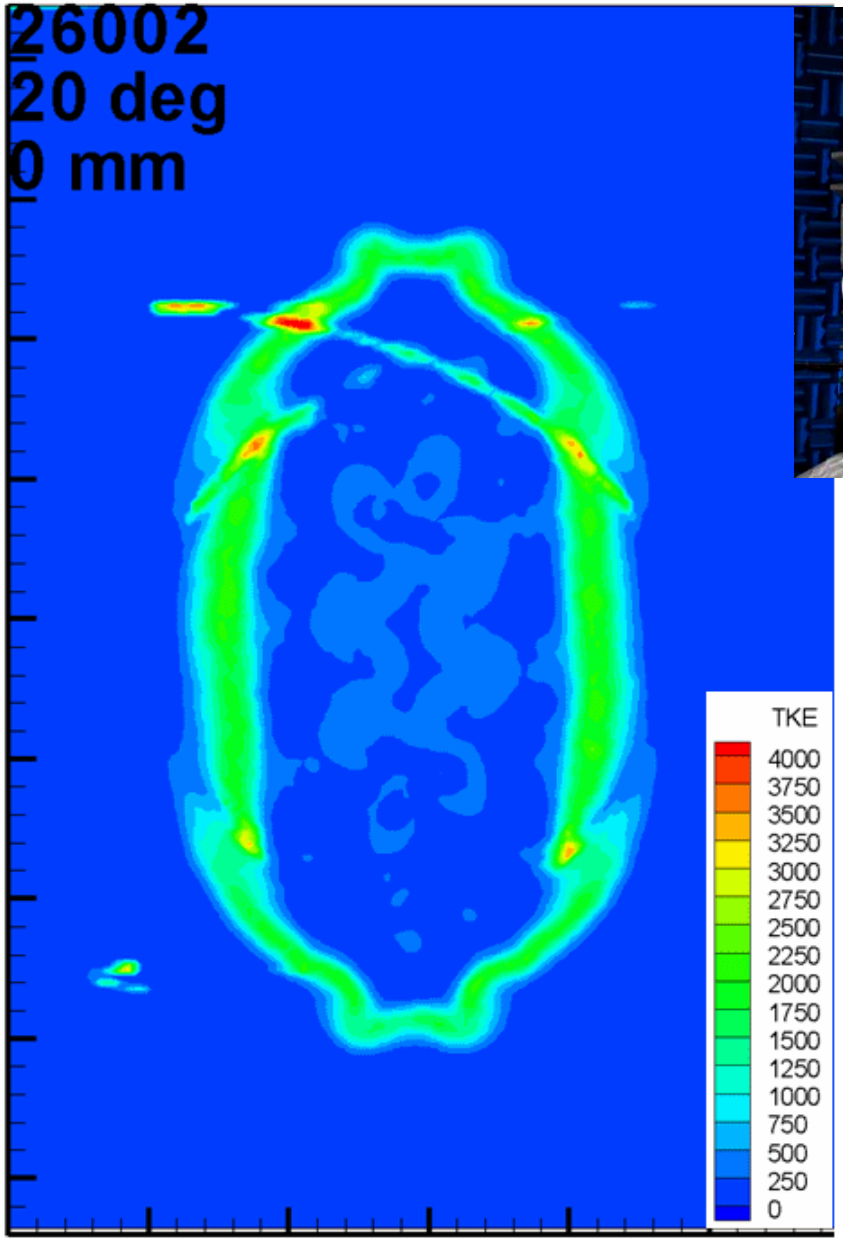


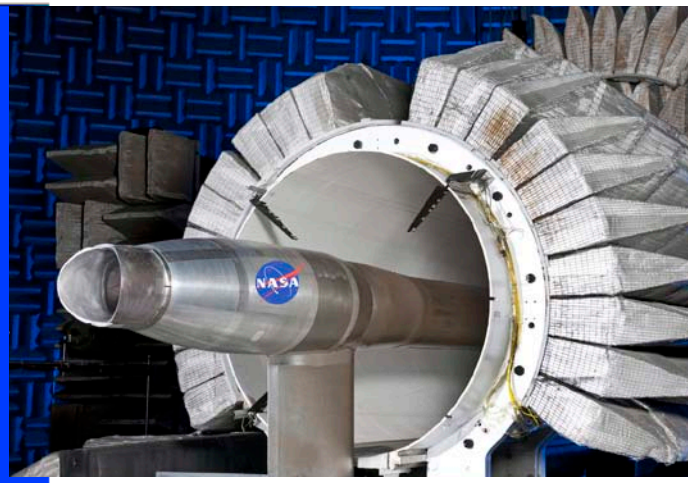


- Results similar to those obtained at 10°

PIV Results – 20° Door Position

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

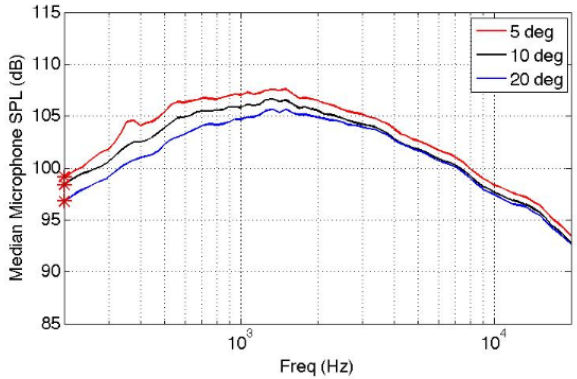


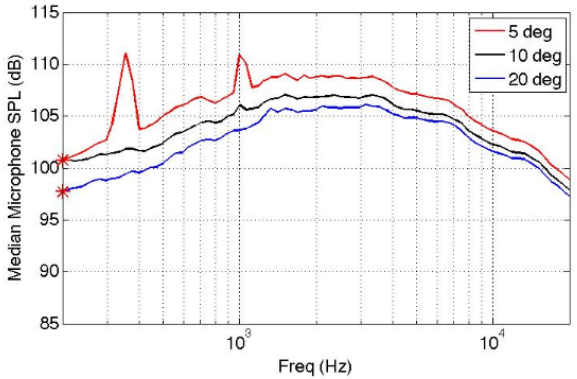


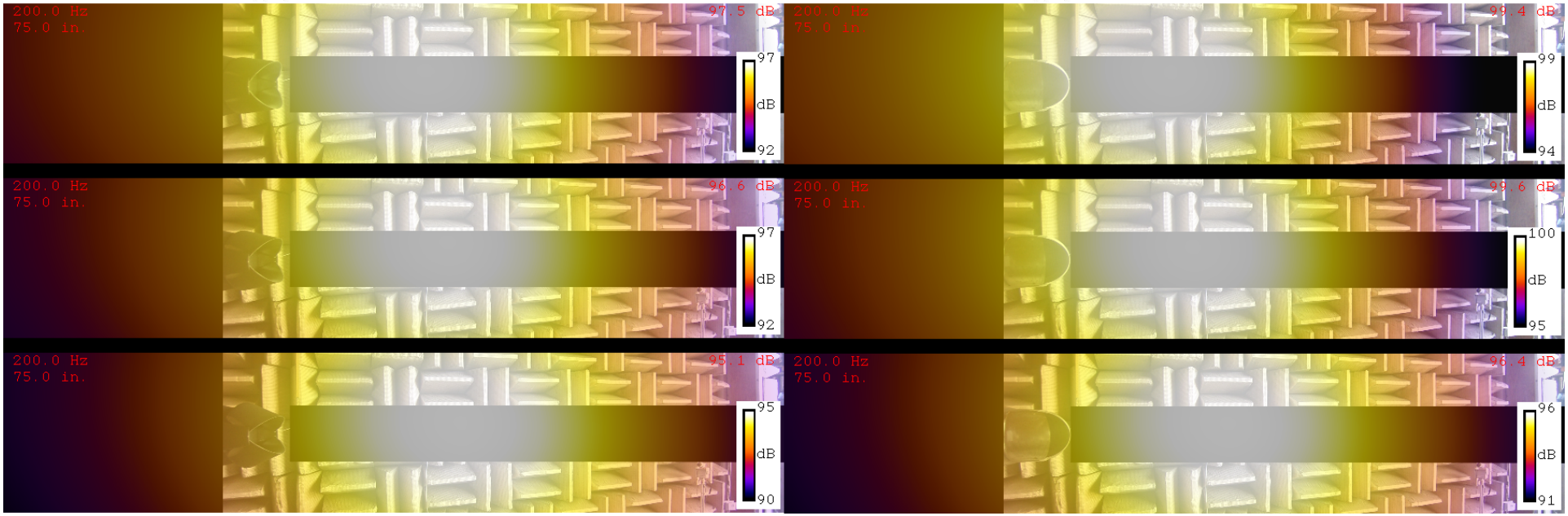
- Results similar to those obtained at 10°

Phased Array Results – No Free Jet

$NPR_c = 1.60$ $NPR_b = 1.80$ $NTR_c = 2.69$ $NTR_b = 1.29$ $M_{fj} = 0.0$





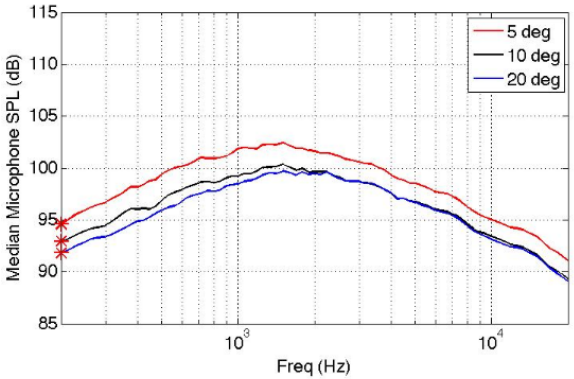


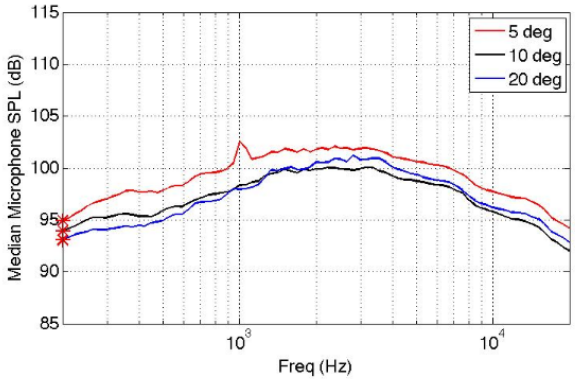
Sidewall Toward Array

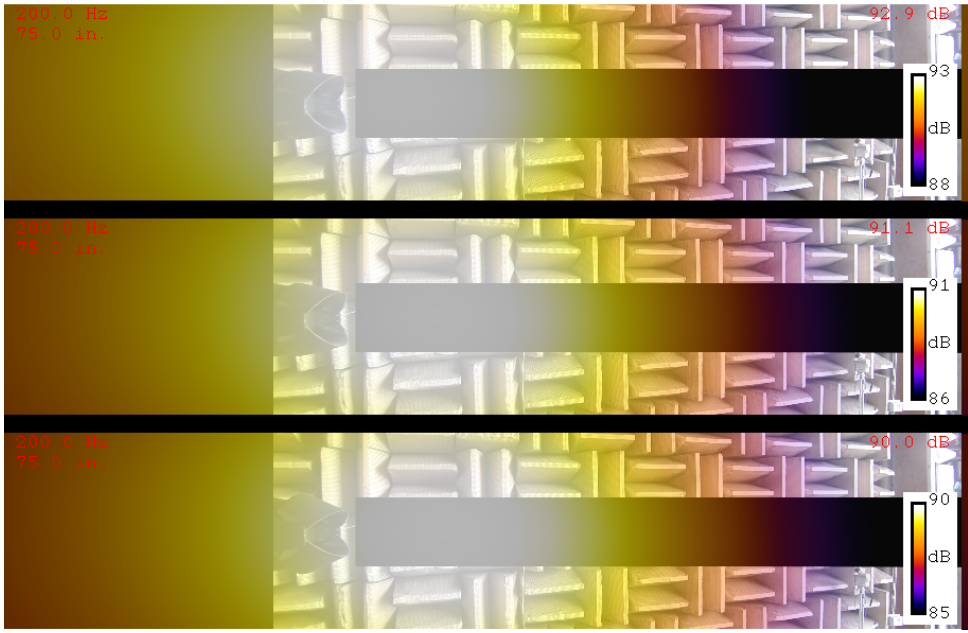
Ejector Door Toward Array

Phased Array Results – Mfj = 0.3 Jet

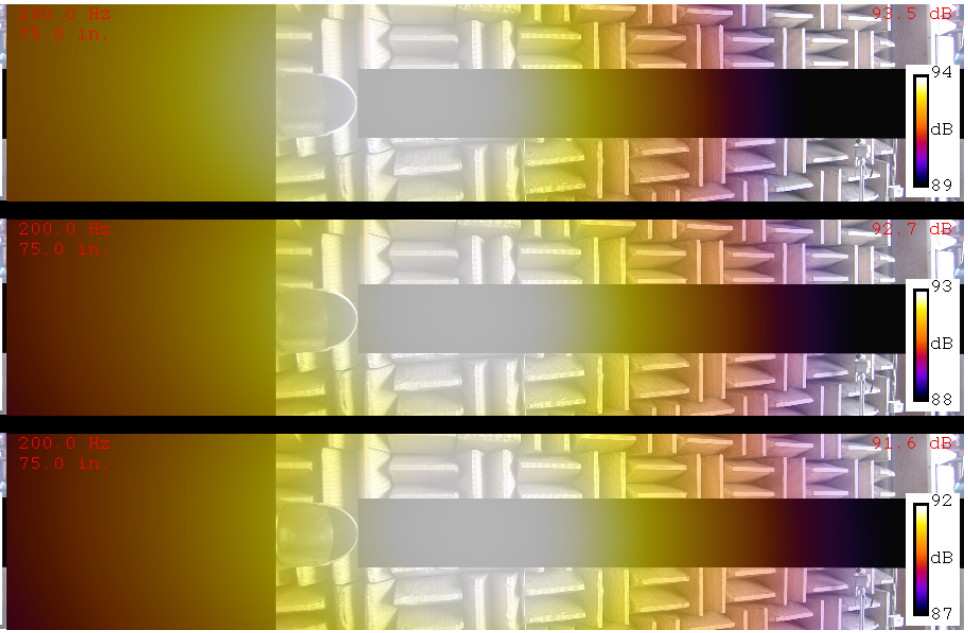
$NPR_c = 1.60$ $NPR_b = 1.80$ $NTR_c = 2.69$ $NTR_b = 1.29$ $M_{fj} = 0.3$





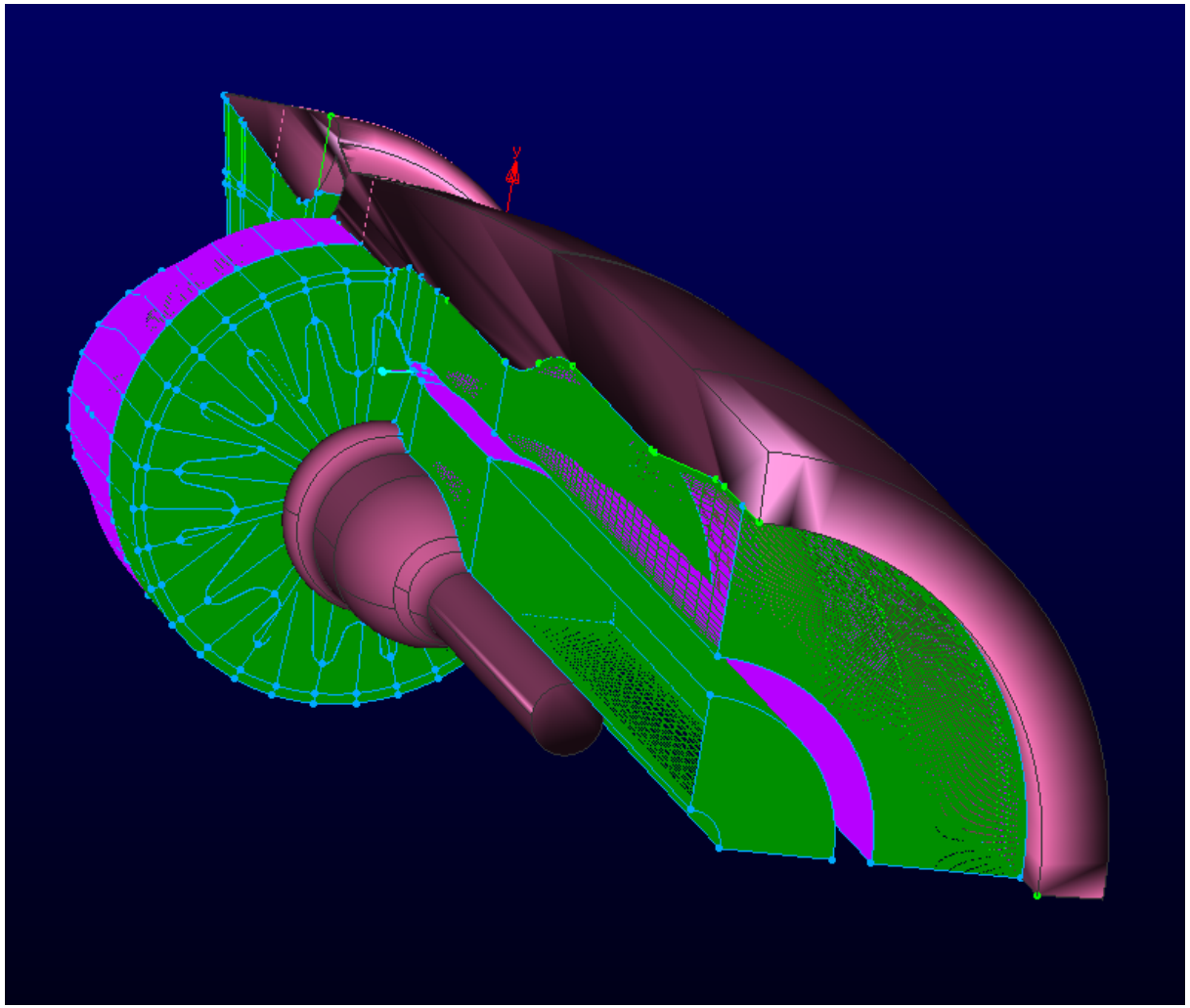


Sidewall Toward Array



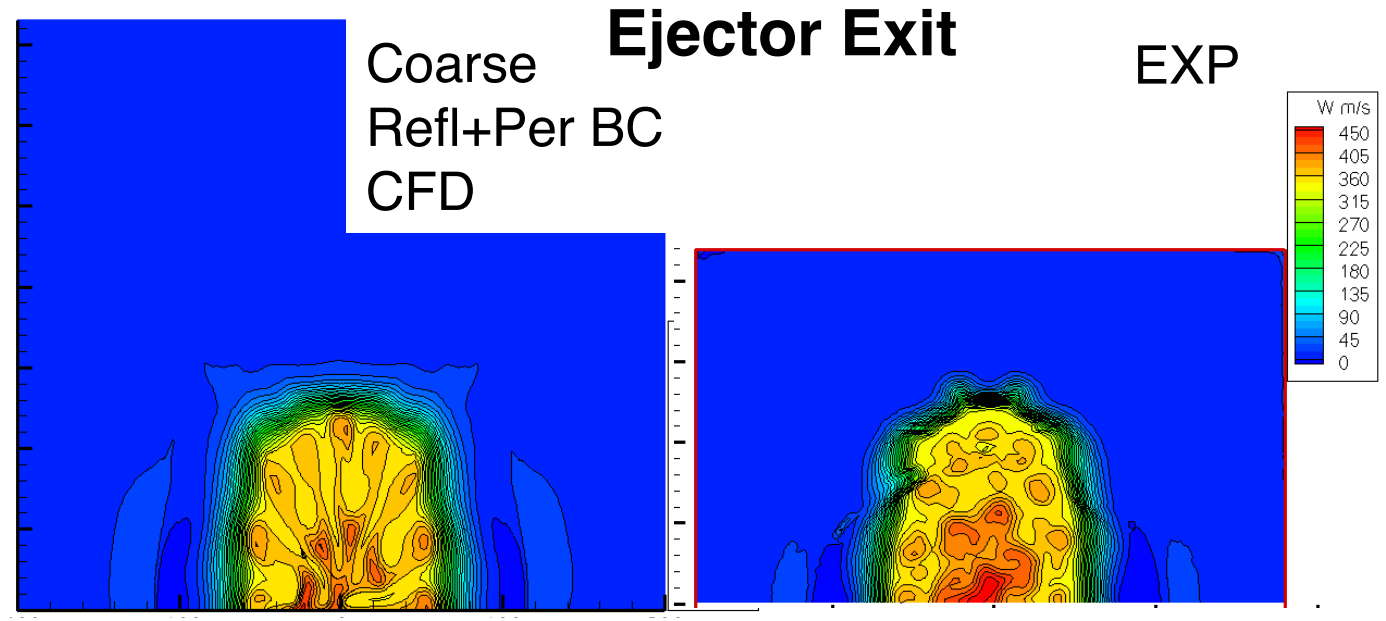
Ejector Door Toward Array

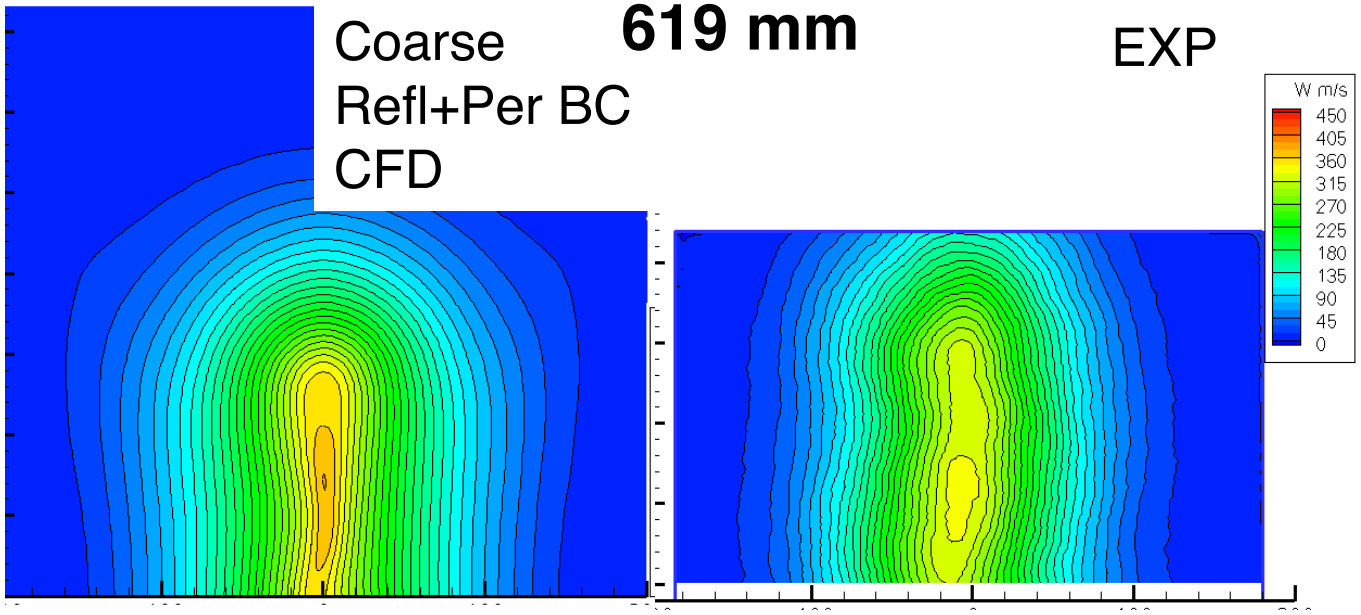
CFD Solutions



- Wind–US Code 3.139
- Simulated 180^{o} periodic BC's inside nozzle; ~ 8M gridpts
- Mentor SST turbulence model
- Jet conditions same as those in PIV
- M_{fj} = 0.03
- 10^{o} door

Mean Flow CFD Solutions





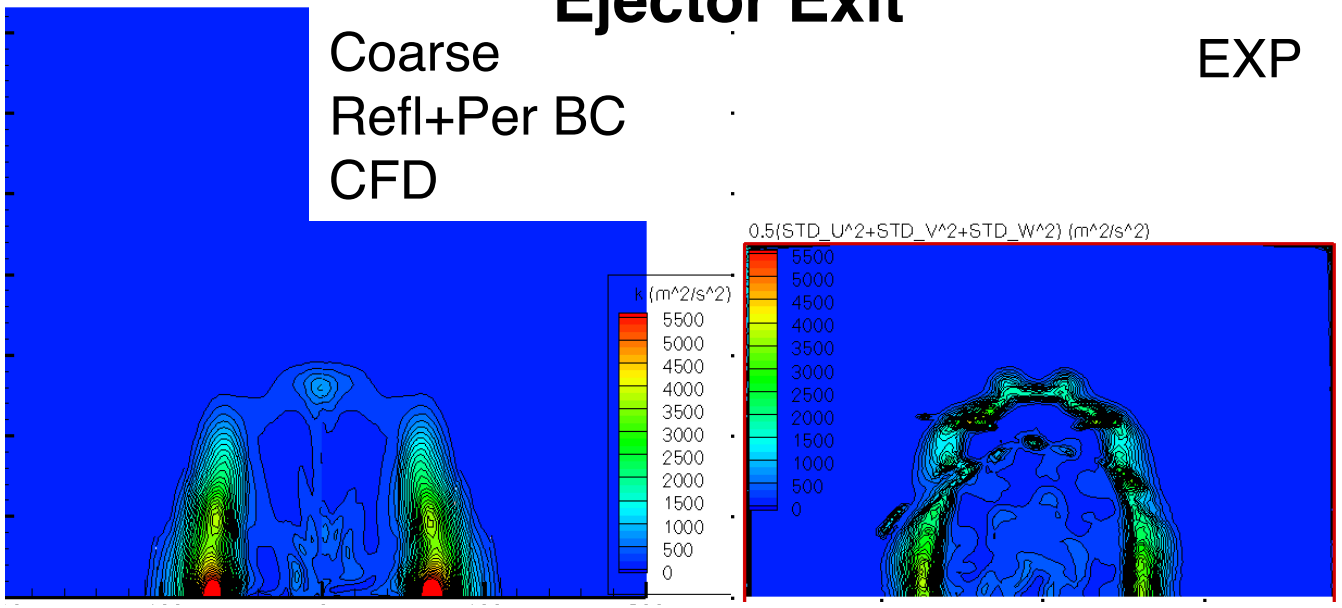
Calculated mean flow close to measured values

Turbulent CFD Solutions

Ejector Exit

Coarse
Refl+Per BC
CFD

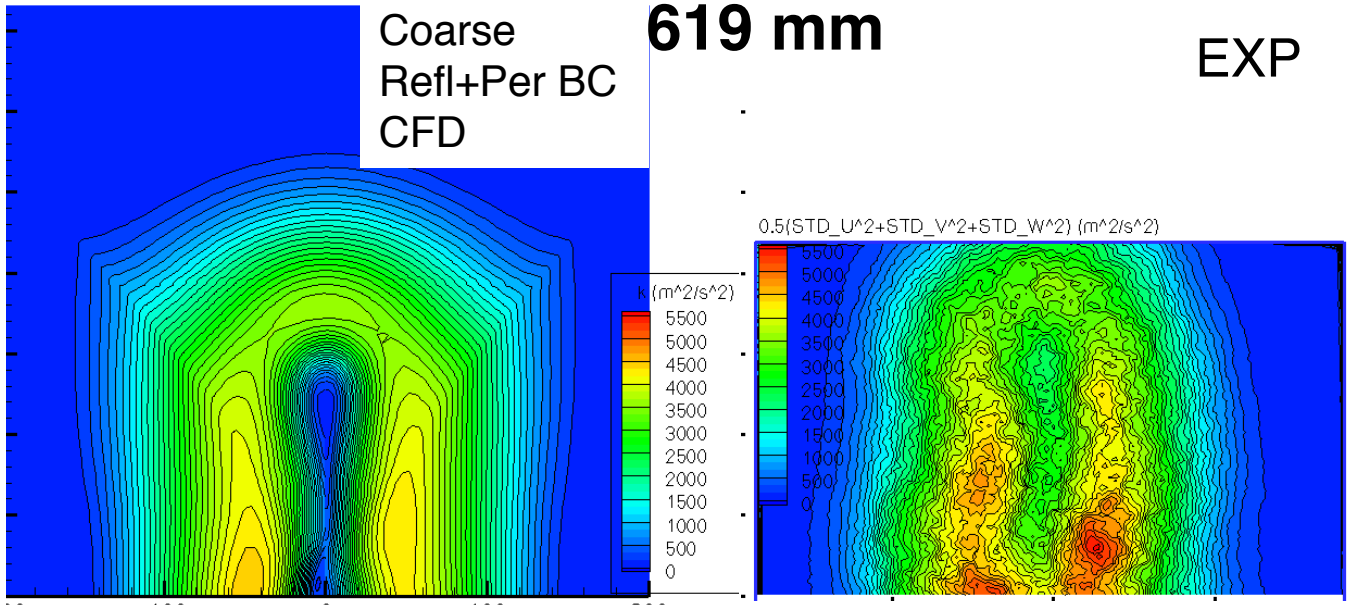
EXP



619 mm

Coarse
Refl+Per BC
CFD

EXP



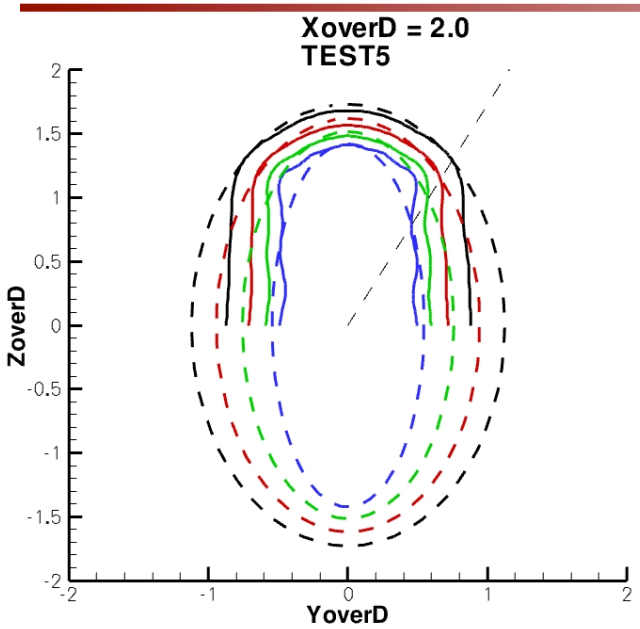
Calculated TKE

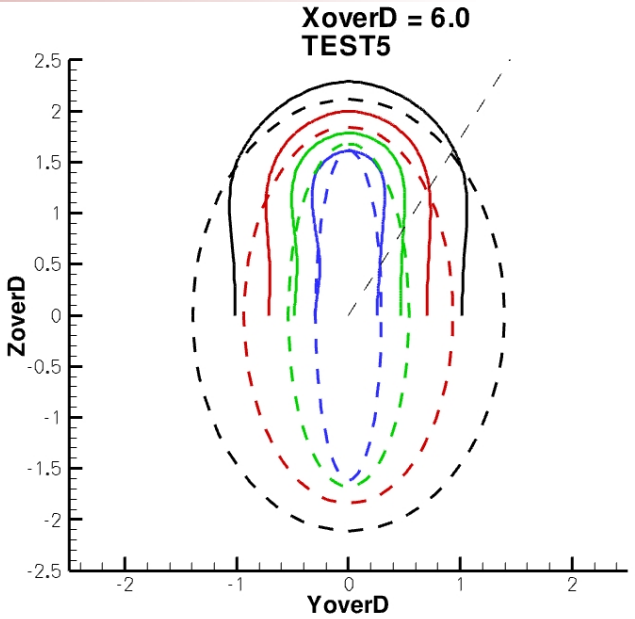
- High at exit
- Low downstream

Prediction of External Turbulent Mixing

- Acoustic Analogy Approach -- Goldstein (2003) formulation
- Weakly non-parallel mean flow
  - Lilley-like equation for propagation
  - Approximation for Green's function for elliptic/ rectangular jets
- Source term is hybrid (space-time/frequency) source model of Leib and Goldstein (2011)

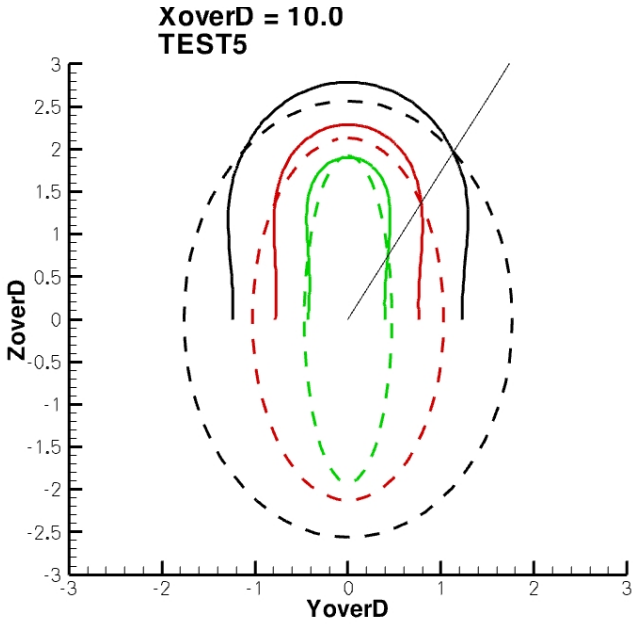
Mean Flow Predictions for Acoustic Calculations

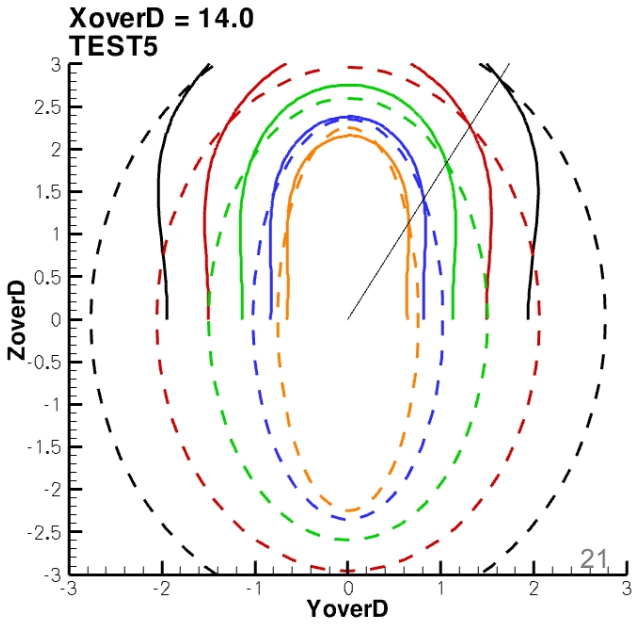




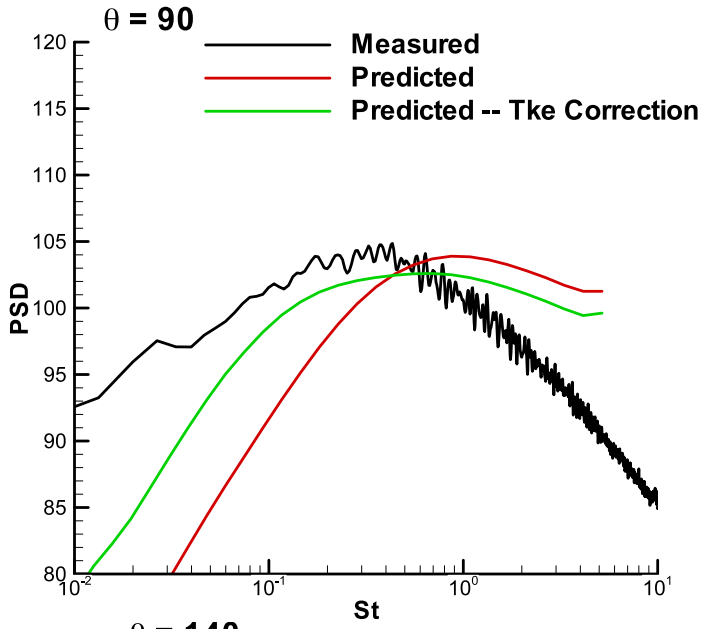
Plots of contours of Mean acoustic Mach number in axial slices

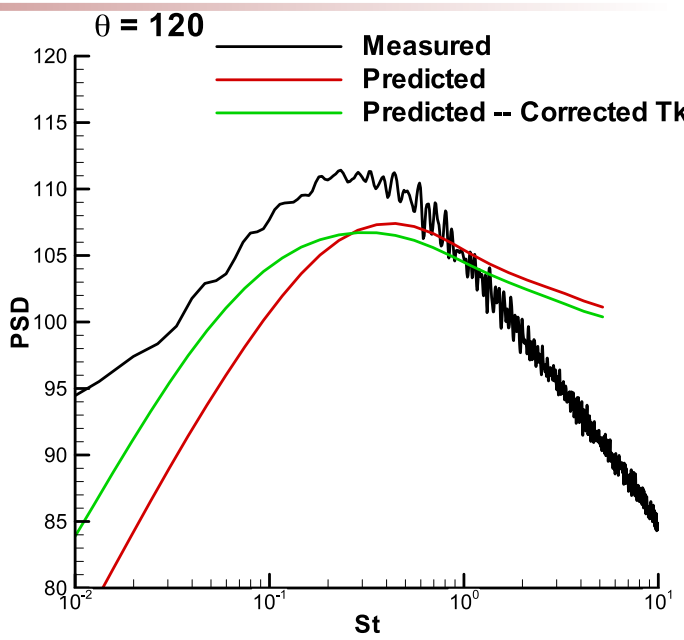
Solid – RANS
Dashed – Model

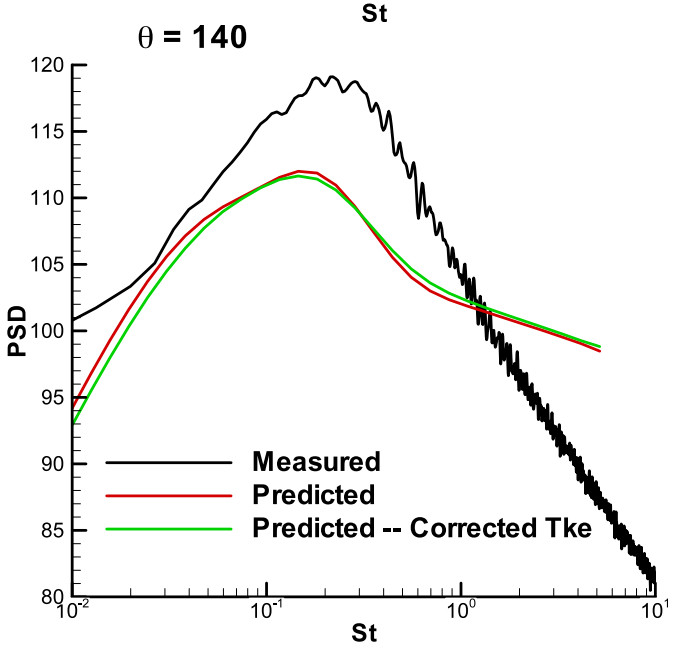




Acoustic Calculations







- External turbulent jet mixing noise only
  - No account for internally generated noise.
- Flow is heated
  - Source model does not contain velocity-enthalpy or enthalpy-enthalpy source terms.

Conclusions

- Diagnostic tools adequate for evaluating design
- CFD tools can predict flow separation
- Acoustic prediction tools need refinement