HIGHLY VARIABLE CYCLE EXHAUST MODEL TEST (HVC10)

Results from acoustic and flow-field studies using the Highly Variable Cycle Exhaust (HVC) model were presented. The model consisted of a lobed mixer on the core stream, an elliptic nozzle on the fan stream, and an ejector. For baseline comparisons, the fan nozzle was replaced with a round nozzle and the ejector doors were removed from the model. Acoustic studies showed far-field noise levels were higher for the HVC model with the ejector than for the baseline configuration. Results from Particle Image Velocimetry (PIV) studies indicated that large flow separation regions occurred along the ejector doors, thus restricting flow through the ejector. Phased array measurements showed noise sources located near the ejector doors for operating conditions where tones were present in the acoustic spectra.

Highly Variable Cycle Exhaust Model Test (HVC10)

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NASA Glenn Research Center

Acoustics Technical Working Group Meeting

Langley, VA

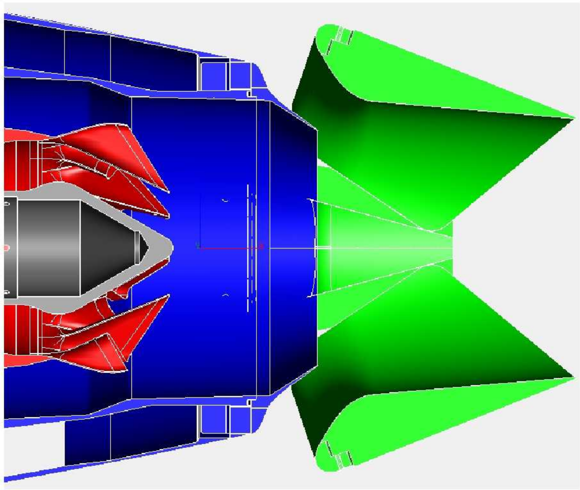
22 October 2010

Research supported by Fundamental Aero Program/Supersonics Project

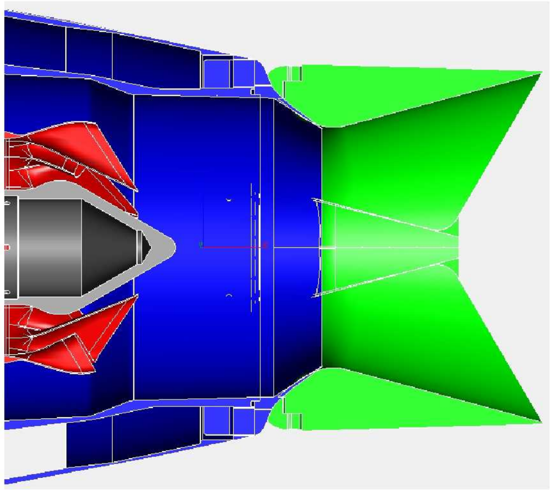
Motivation

- In 2008, Supersonics Project was looking for high-fidelity model of low-noise nozzle concept
  - Technology development
  - Application of noise prediction tools
- Rolls Royce Liberty Works won NRA for next generation Highly Variable Cycle Nozzle (HVC)
  - Variable geometry included sliding mixer, variable A8 primary nozzle, and variable A9 nozzle exit area.
  - Ejector to provide few dB suppression over conventional nozzle.
  - Model tested only in subsonic (takeoff) mixer/A8 configuration with variable A9.

Takeoff



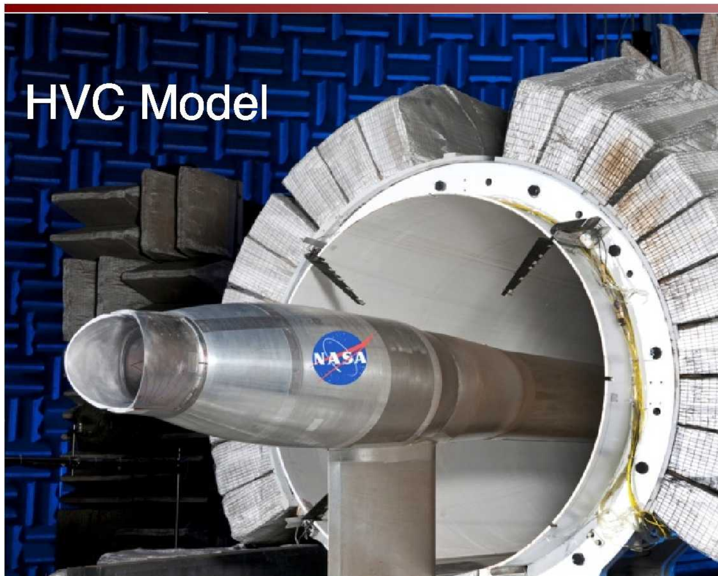
Cruise



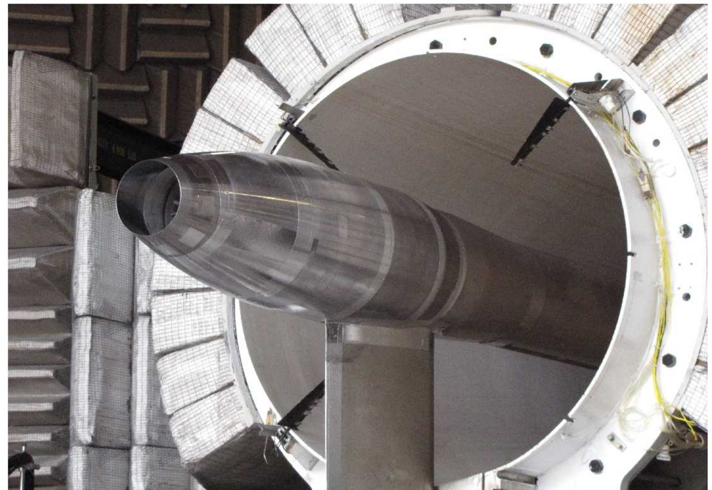
Design Experience

- In 2002 a proprietary test of two similar concepts from Rolls Royce and from Pratt & Whitney both suffered ejector resonance (howl).
- Neither design was supported by CFD.
- Subsequent CFD by Rolls Royce showed massive separation inside ejector.
- Significant effort was expended by Liberty Works under 2008 NASA NRA to improve ejector performance. Other significant differences were in mixer design and A8 throat geometry.
- CFD did not indicate separation in final design in takeoff, transonic, or cruise configurations. Fabrication was approved.

Models



Baseline Nozzle

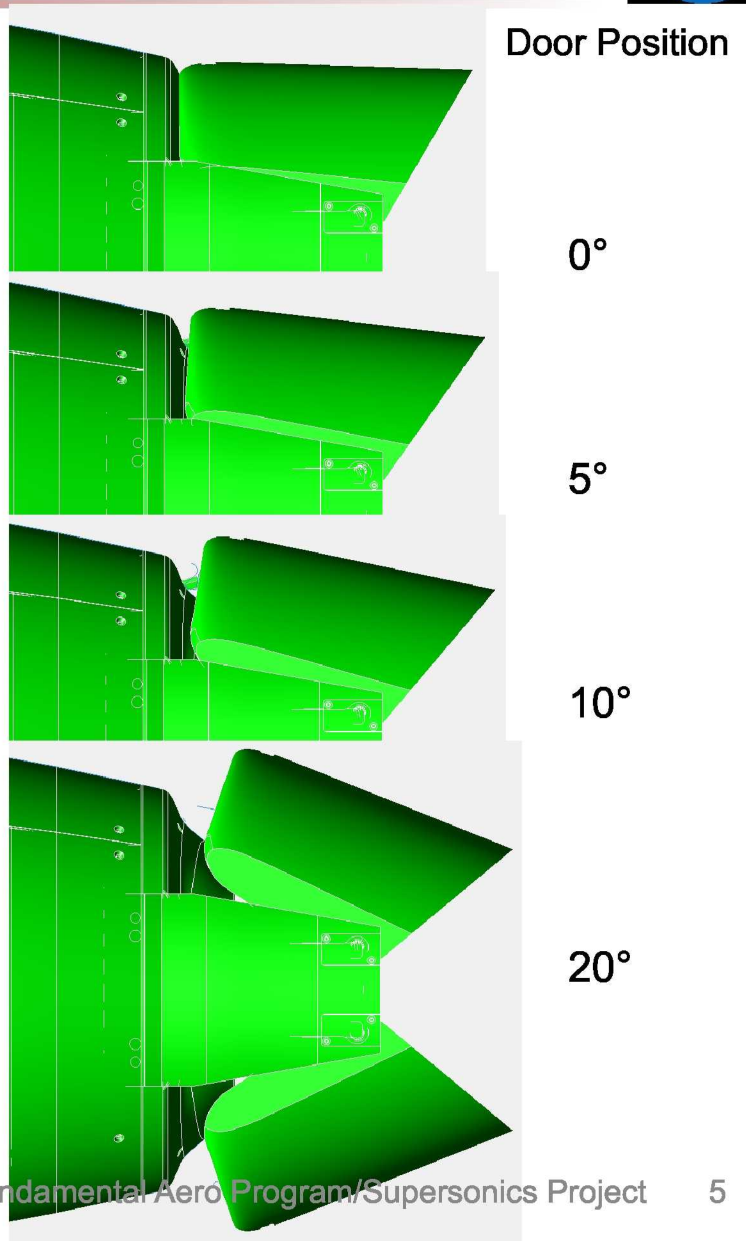


- Tests conducted on Nozzle Acoustic Test Rig (NATR) at NASA Glenn AeroAcoustic Propulsion Lab
  - Acoustic tests in April 2010.
  - PIV, phased array tests in July-Aug 2010.

Experiments

- Configurations
  - HVC Ejector door angle
  - Baseline convergent nozzle

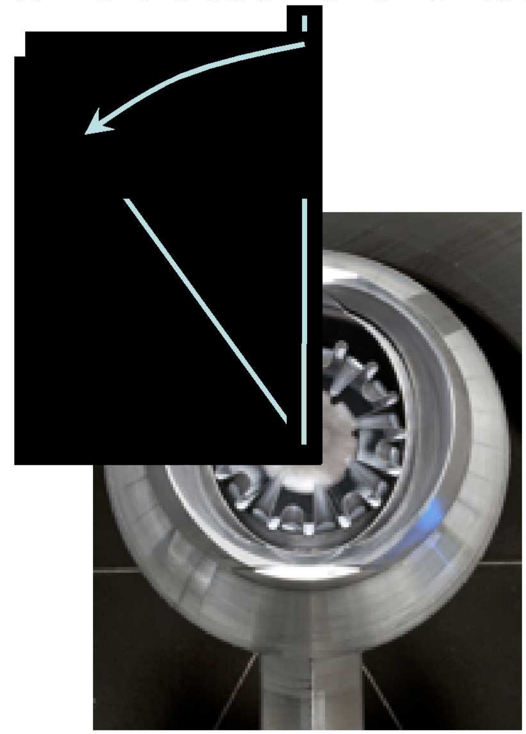
- Instrumentation systems
  - Far-field acoustics
  - PIV
    - Cross-stream stereo
    - Streamwise
  - Phased array
  - Pressure taps



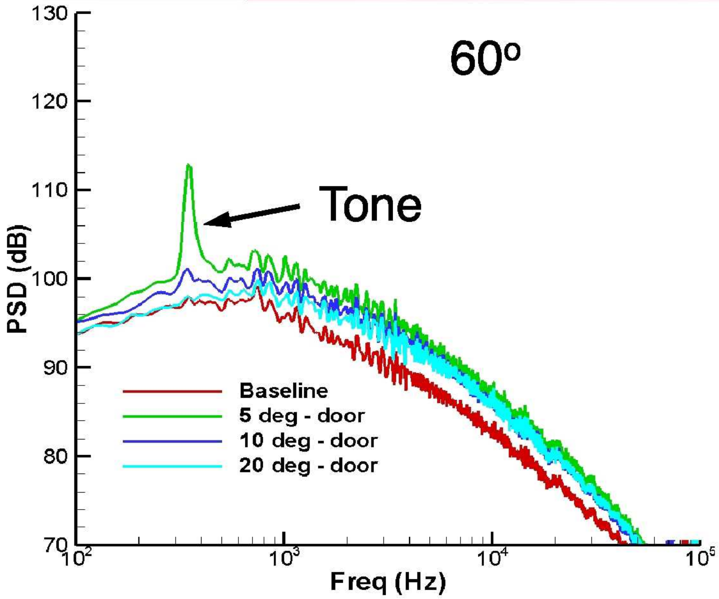
Cycle Points

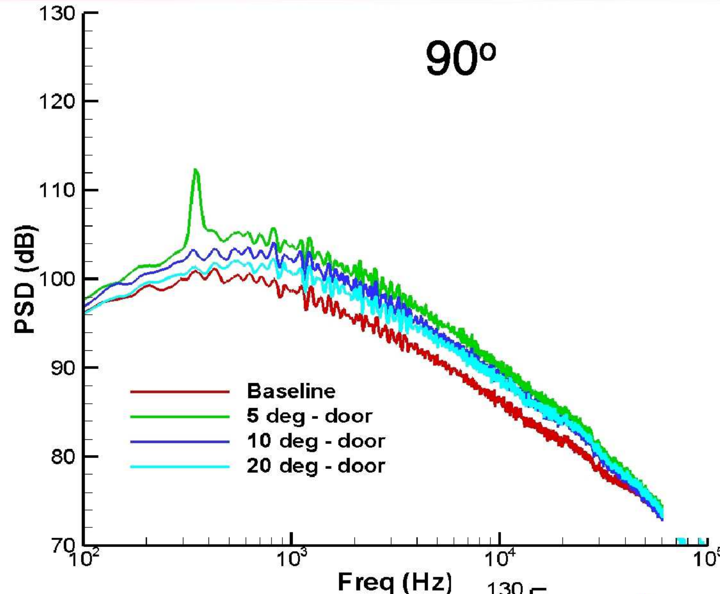
Setpoint	NPRc	NPRb	NTRc TTc/Tamb	NTRb TTf/Tamb	FJ Mach #
17010	1.6000	1.6000	2.9000	1.2900	0.00
19010	1.8000	1.8000	2.9000	1.2900	0.00
26010	**1.6000**	**1.8000**	**2.6900**	**1.2900**	**0.00**
28010	1.6000	1.8000	3.0500	1.2000	0.00
24000	1.6000	1.8000	2.9000	1.1000	0.00
17013	1.6000	1.6000	2.9000	1.2900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

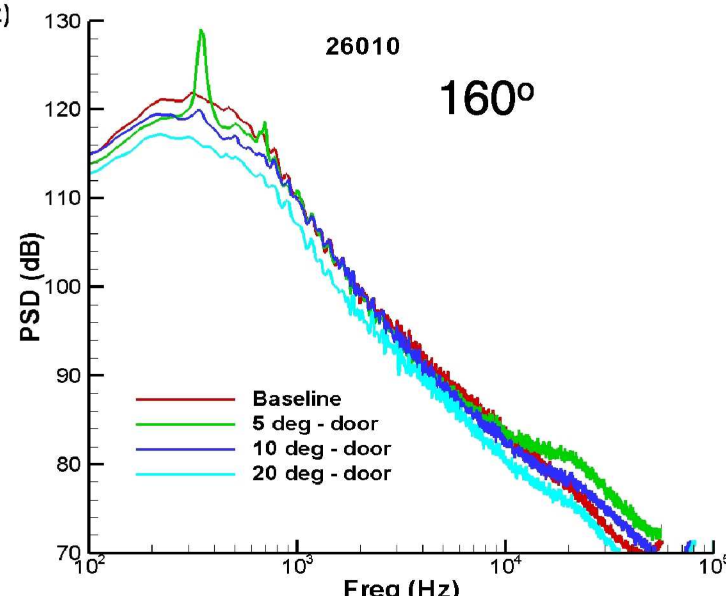


Acoustic Results—M_{fj} = 0.0 (Static)



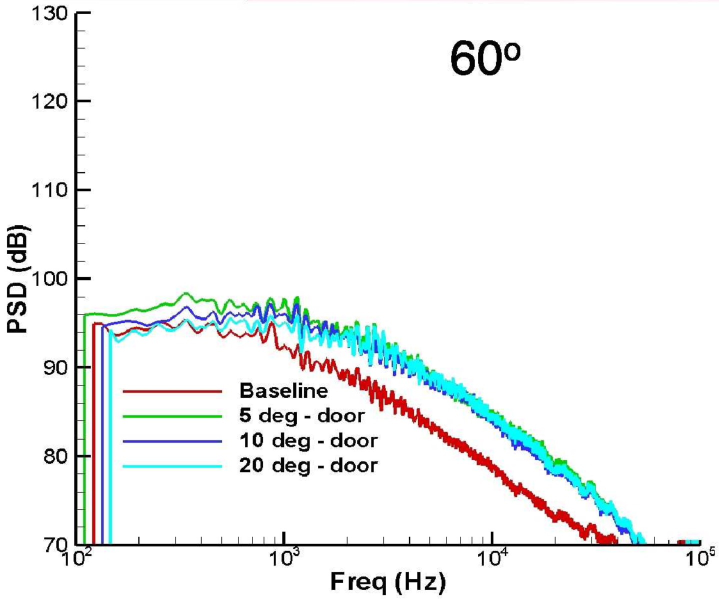


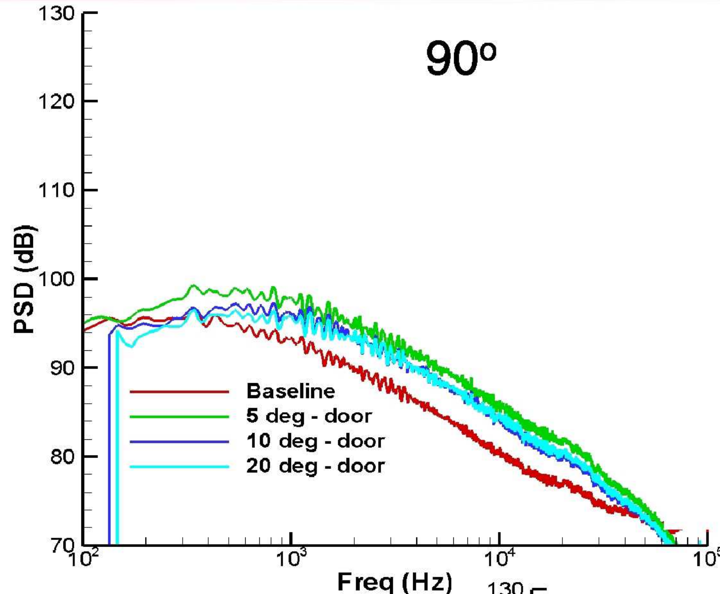
NPR_c = 1.60
NPR_b = 1.80
NTR_c = 2.69
NTR_b = 1.29
M_{fj} = 0.0



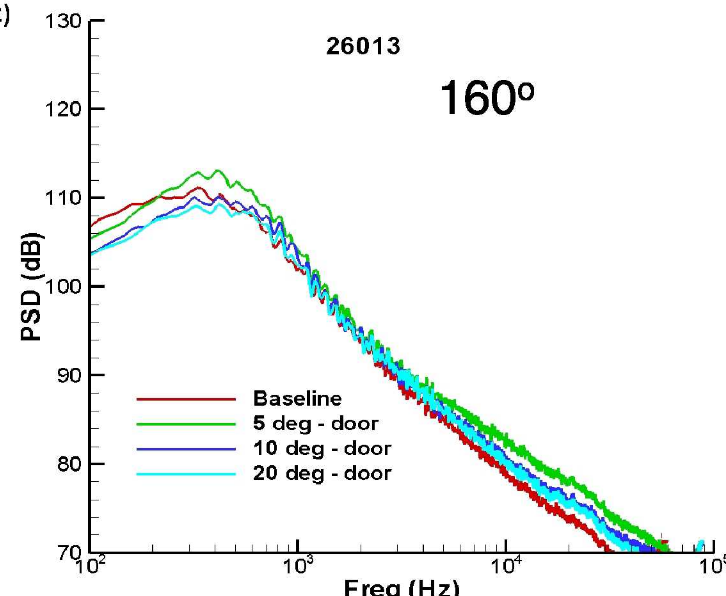
- Tones produced at small door angles and no free jet
- Noise decreases with increasing door angle
- Ejector increases noise at small and broadside observation angles
- Ejector decreases noise at peak jet noise angle

Acoustic Results—M_{fj} = 0.3



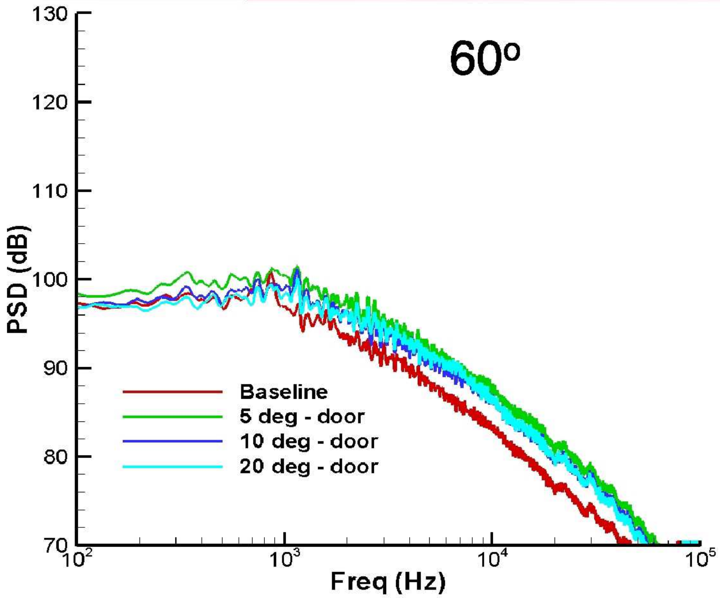


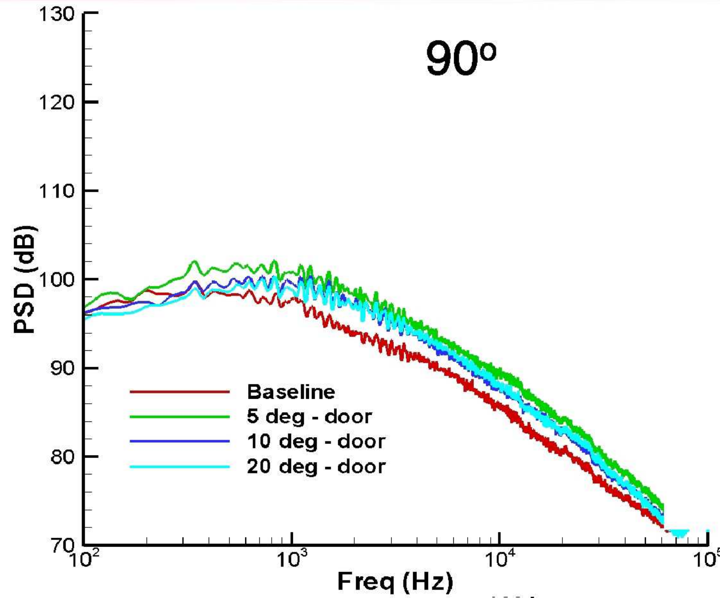
NPR_c = 1.60
NPR_b = 1.80
NTR_c = 2.69
NTR_b = 1.29
M_{fj} = 0.3



- 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

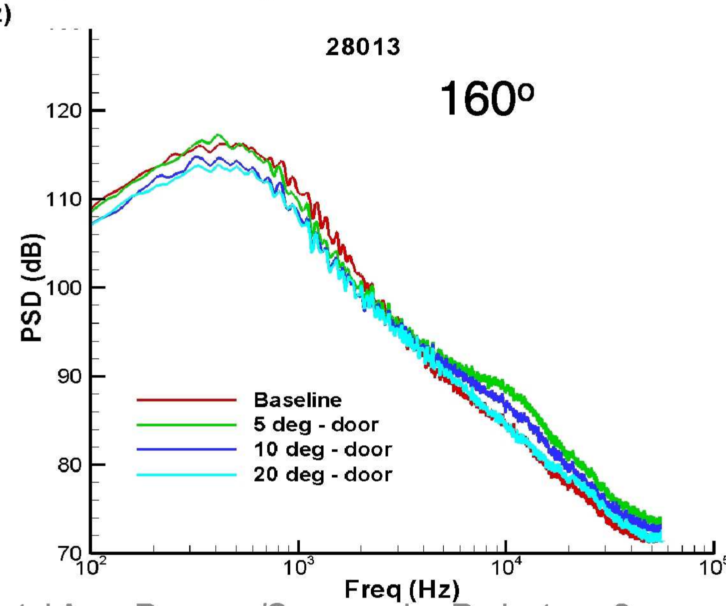
Acoustic Results—M_{fj} = 0.3—Highest Setpoint





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

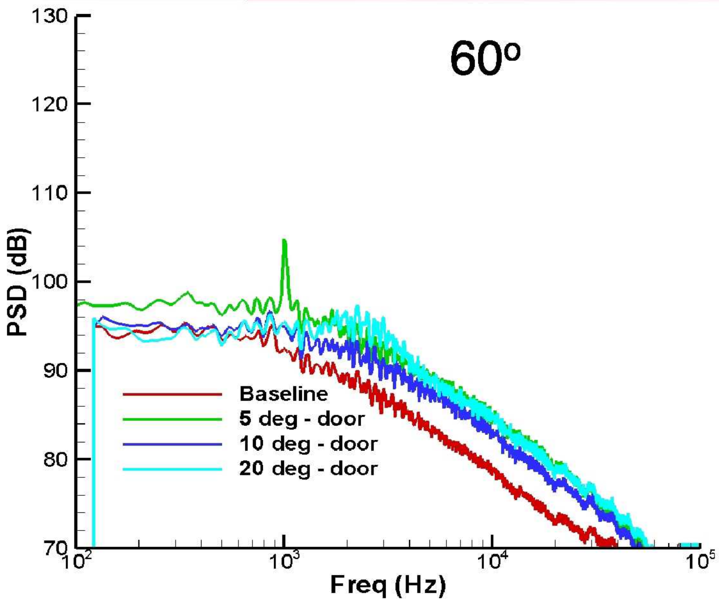
- 10° and 20° door positions decrease low-frequency noise at peak jet noise angle

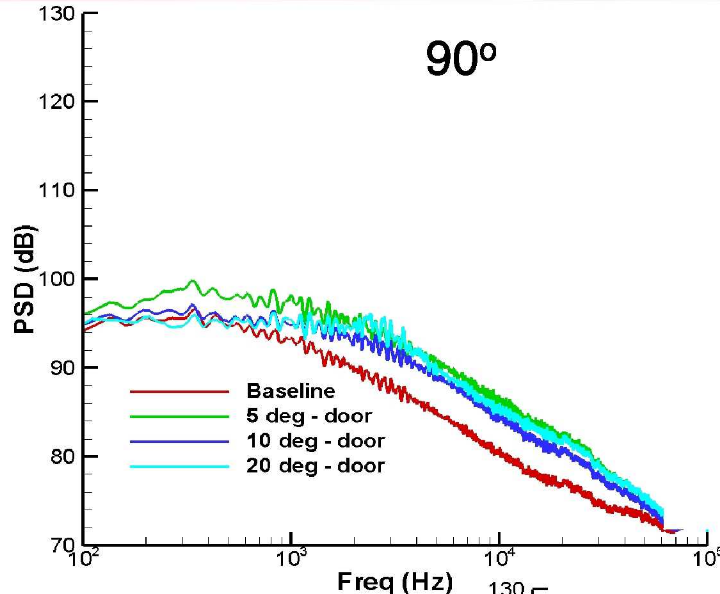


EPNL

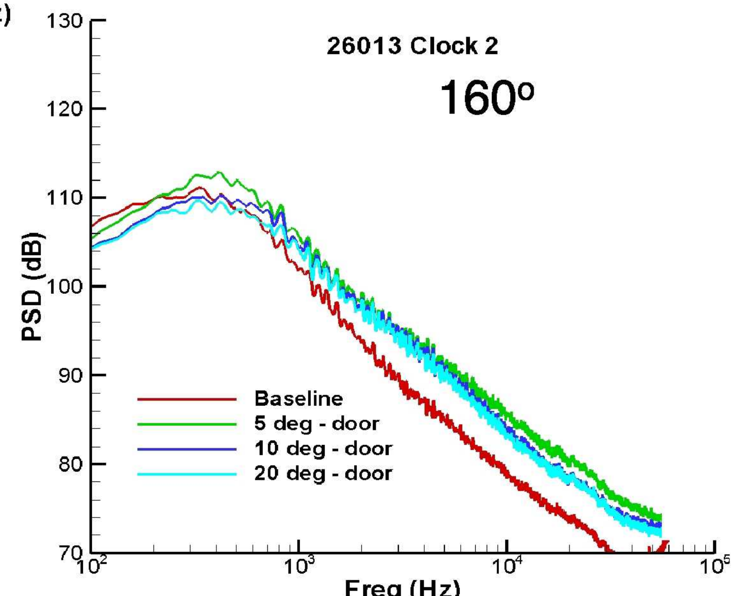
Condition		EPNL (EPNdB)@Mf=0.3		
Flight Speed	**Setpoint**	**10 deg**	**20 deg**	**Baseline**
Static Mfj=0.0	17010	92.25	91.55	92.1
	19010	96.63	95.35	96.48
	26010	**94.25**	**92.94**	**92.93**
	24000	95.28	93.03	91.28
	28010	97.12	96.34	97.36
Forward Flight Mfj=0.3	17013	86.48	86.72	83.91
	19013	90.93	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



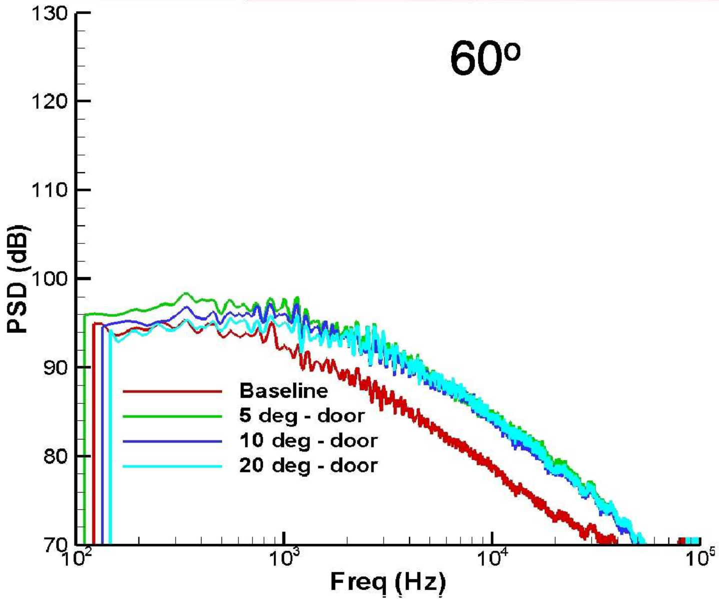


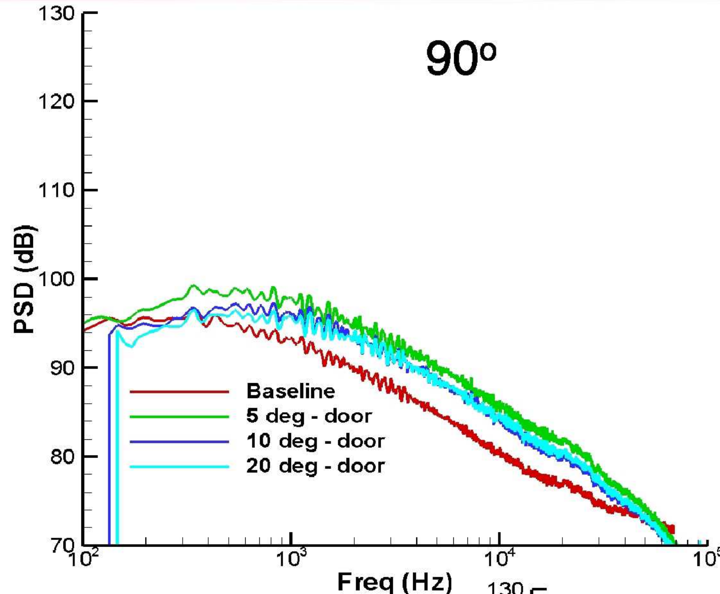
$NPR_c = 1.60$
$NPR_b = 1.80$
$NTR_c = 3.05$
$NTR_b = 1.29$
$M_{fj} = 0.3$



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

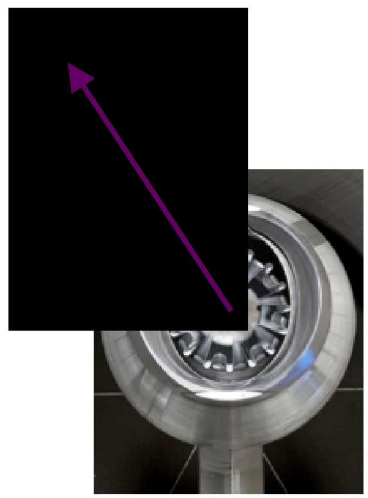
Acoustic Results—Azimuthal Directivity

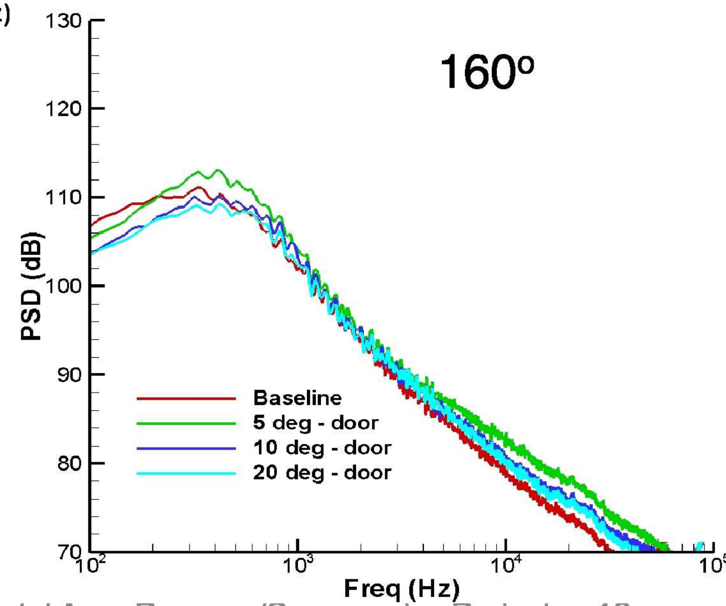




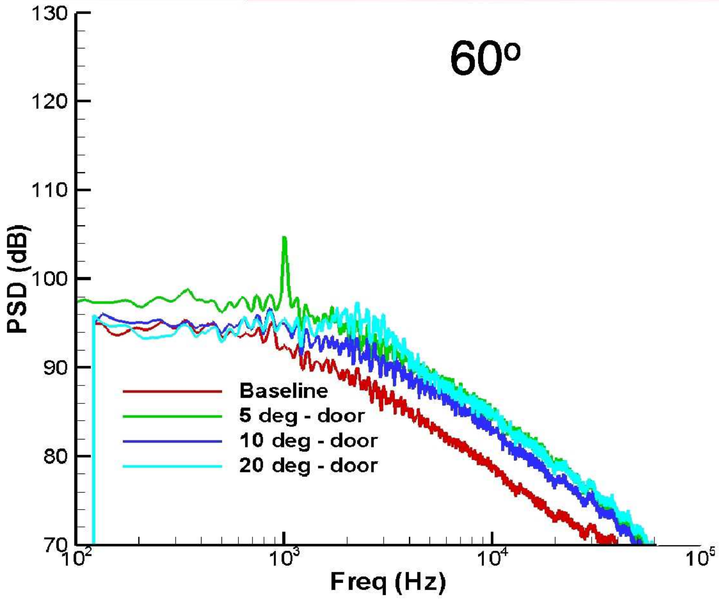
NPR_c = 1.60
NPR_b = 1.80
NTR_c = 2.69
NTR_b = 1.29
M_{fj} = 0.3

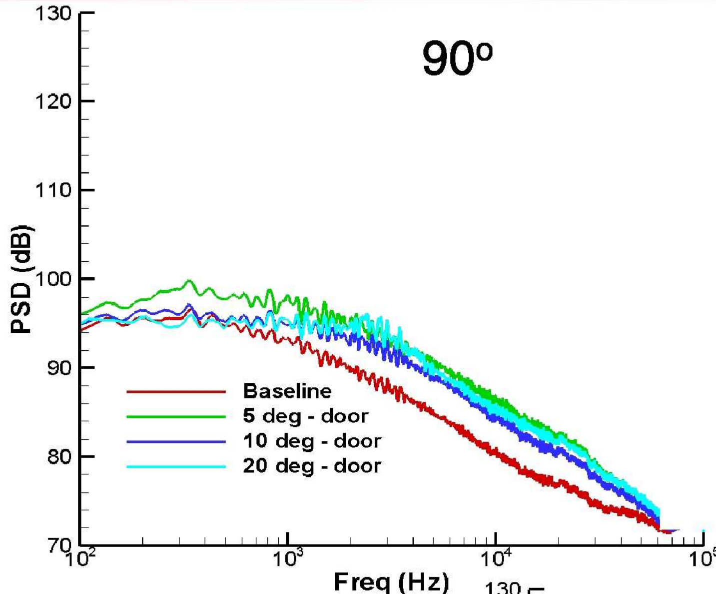
- Noise increased in plane of ejector opening:
  - Tones for small door angles.
  - High frequencies increase at far aft angles.
- At upstream observation angles, 10° door position has lowest noise levels.





Acoustic Results—Azimuthal Directivity





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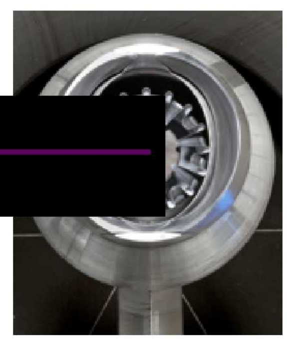
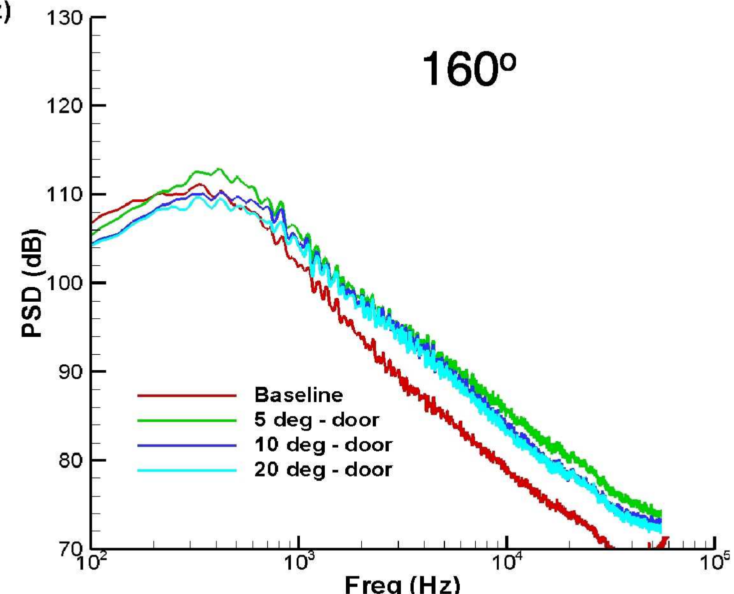
$NTR_c = 2.69$
$NTR_b = 1.29$
$M_{fj} = 0.3$

- Noise increased in plane of ejector opening:
  - Tones for small door angles.
  - High frequencies increa[redacted] far aft angles.
- At upstream observation angles, 10° door position has lowest noise levels.





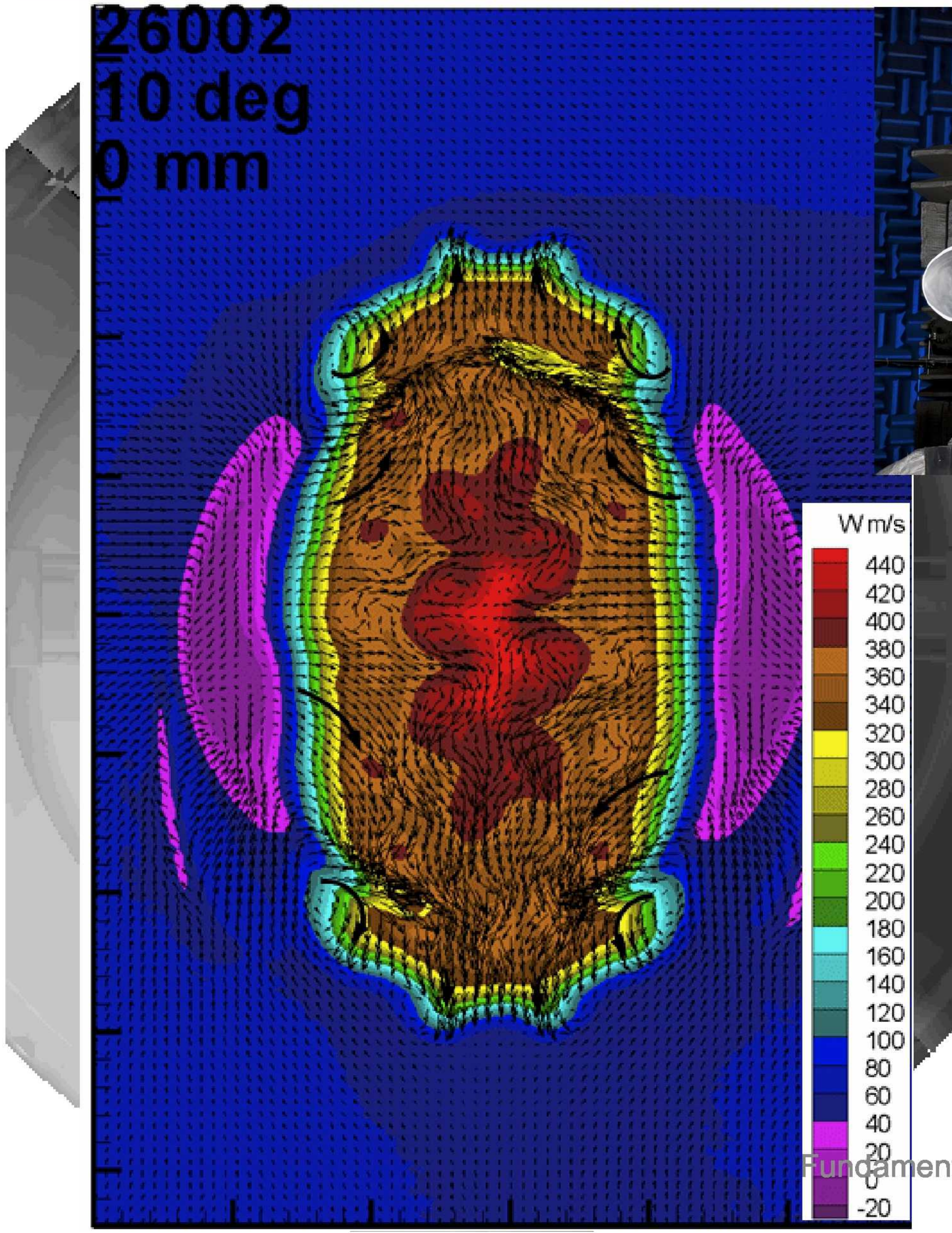
Acoustic Summary

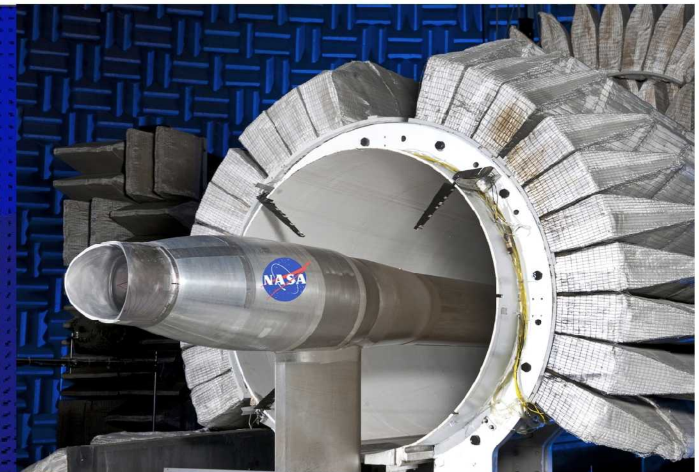
- Ejector increases EPNL for simulated forward flight conditions
- Tones occur for small door angles
  - Strong tone at static condition
  - Weaker, higher frequency tones in plane of ejector opening even at flight.
- Acoustic spectra shows small azimuthal (model clocking) variation
  - Ejector door opening azimuth (below aircraft) louder than sidewall azimuth.
  - Mostly due high frequency broadband noise.

PIV Results—10° Door Position

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

Axial planes
x/D=0.01
0.52
0.78
1.05
1.31
1.96
2.58





- Cross-stream cuts
  - color=mean axial velocity
  - vectors=cross-stream velocity
- Pink is velocity below freestream
- Note elliptic A8 and A9.
- Separation downstream of ejector doors
- Strong vortices set up by door-sidewall interface augment ellipticity.

PIV Results—10° Door Position

$NPR_c = 1.60$
$NPR_b = 1.80$
$TT_c = 1472R$
$TT_b = 700R$
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Axial planes
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0.52
0.78
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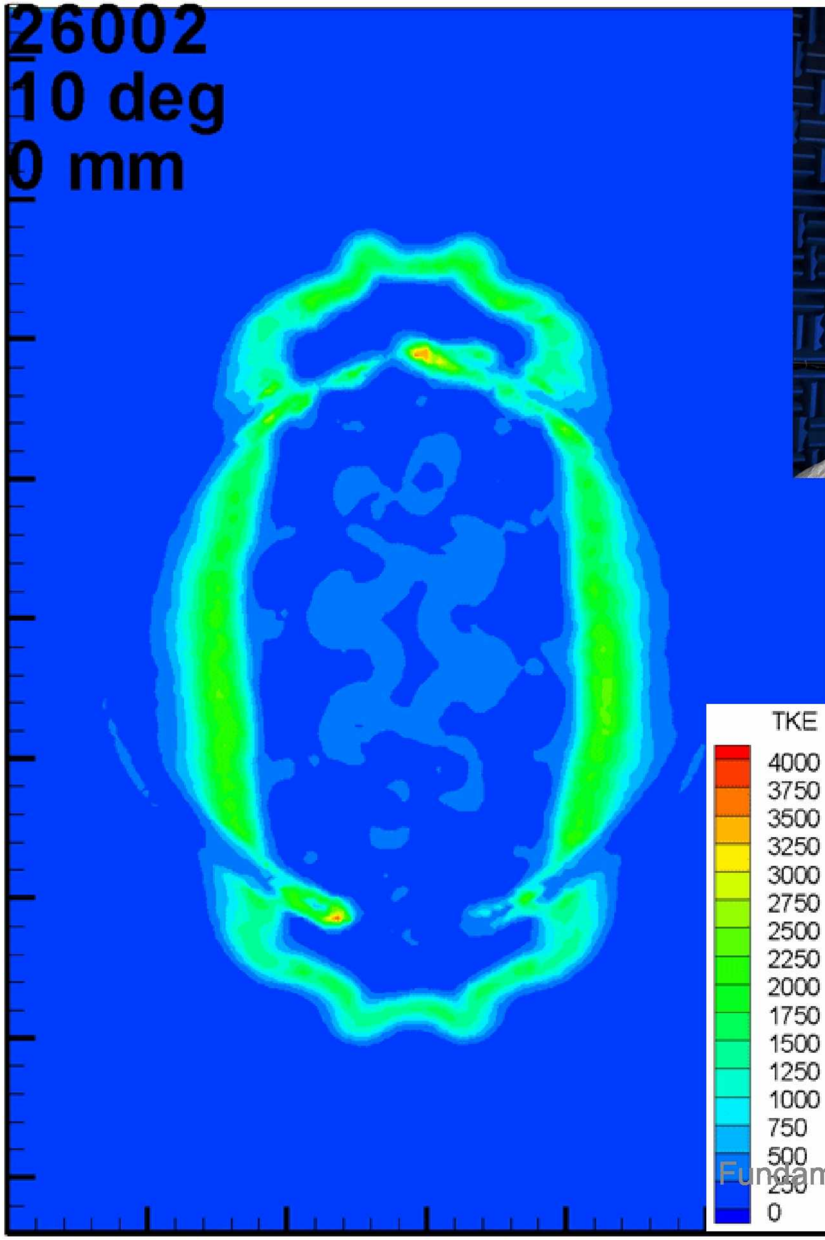
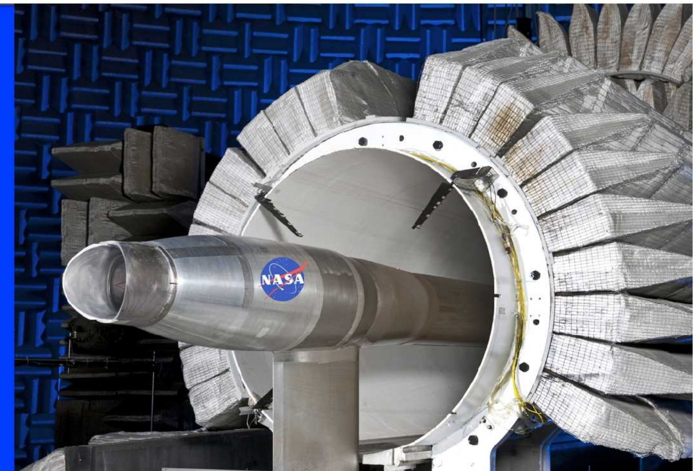


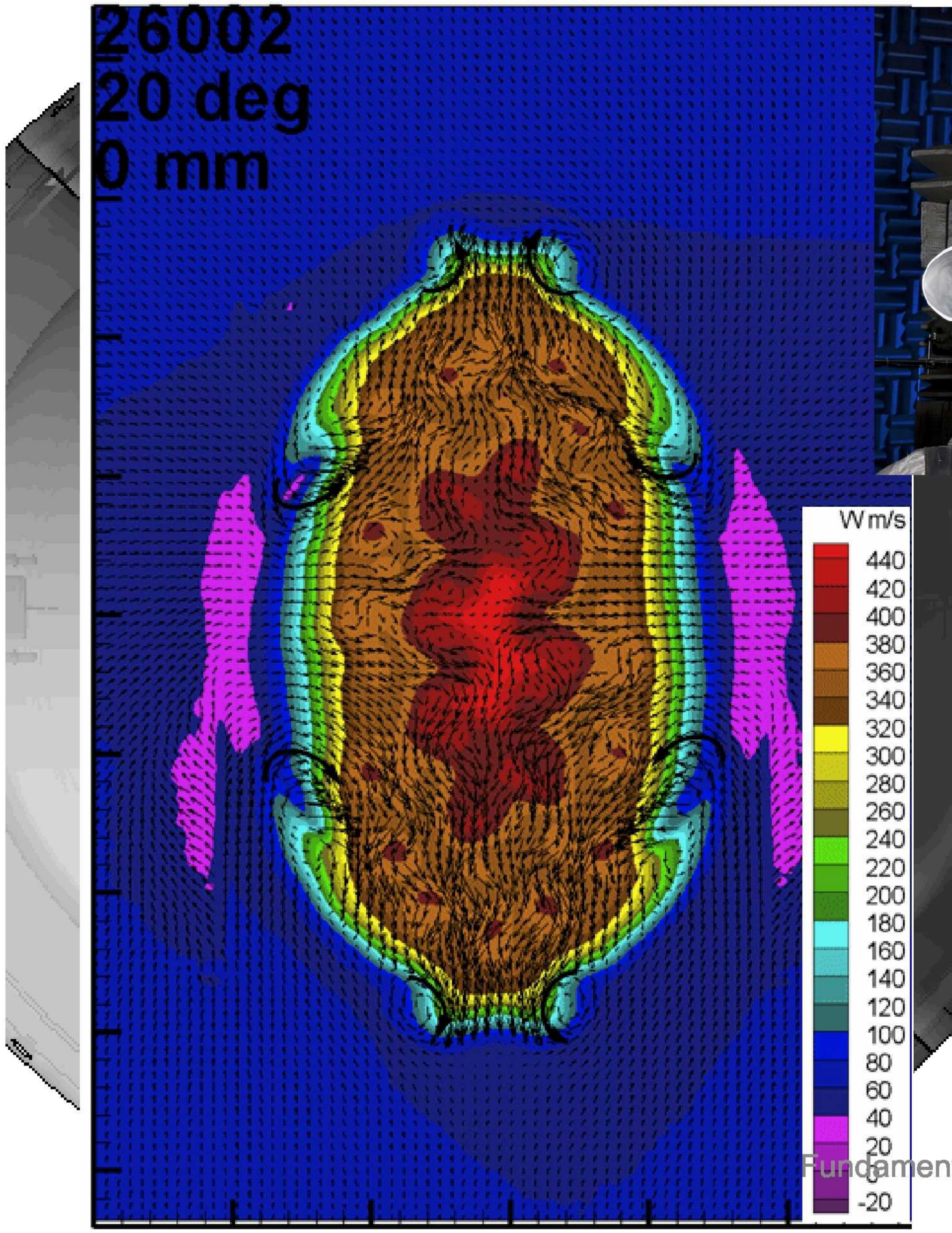


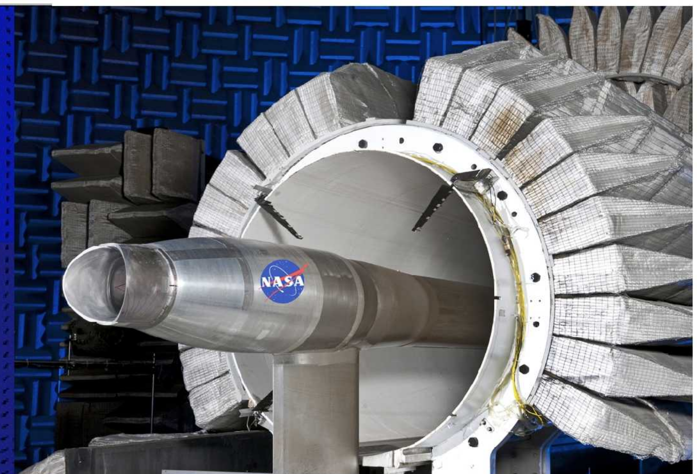
- Cross-stream cuts
  - color=turbulent kinetic energy
  - Peak tke > 3000 m^2/s^2
- Strong vortices set up by door-sidewall interface stretches/augments shear layer turbulence downstream

PIV Results—20° Door Position

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

Axial planes
x/D=0.01
0.52
0.78
1.05
1.31
1.96
2.58



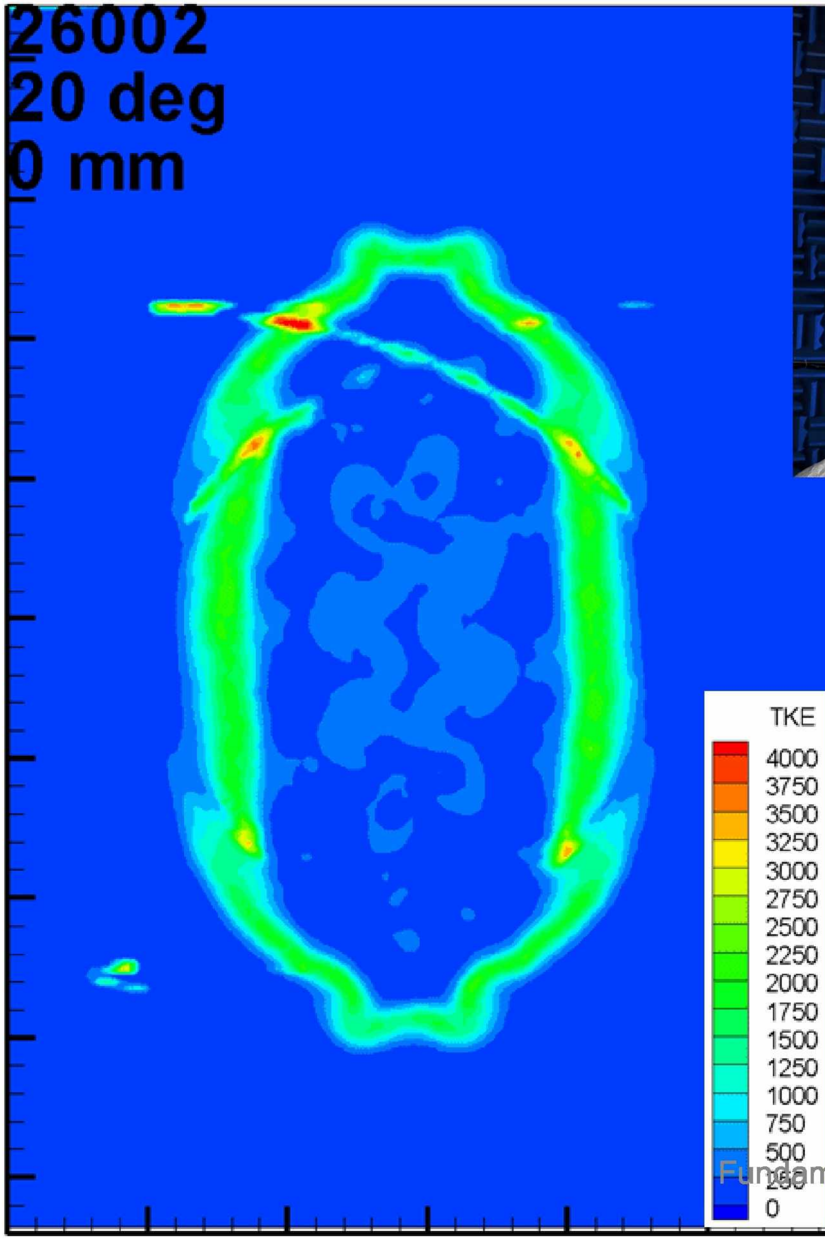


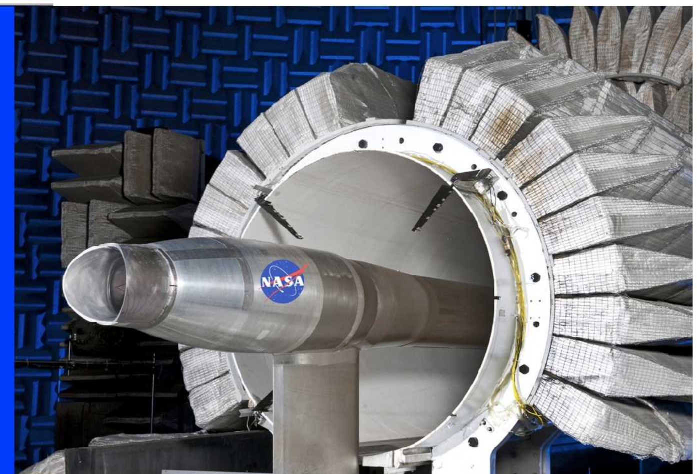
- Results similar to those obtained at 10°
- A9 more elliptic.

PIV Results—20° Door Position

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

Axial planes
x/D=0.01
0.52
0.78
1.05
1.31
1.96
2.58



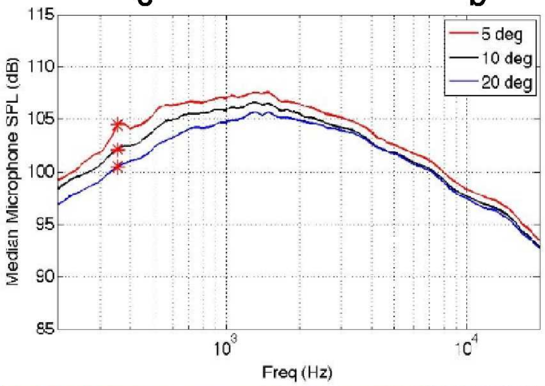


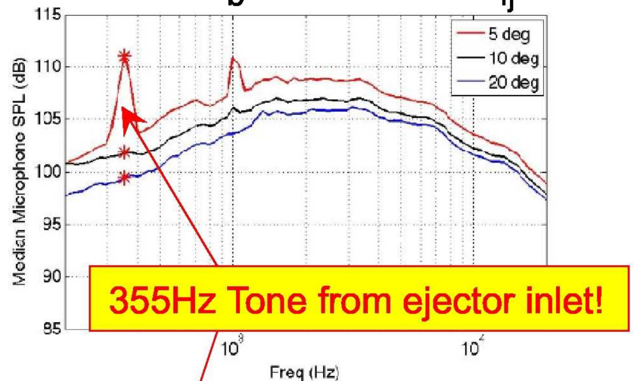
- Results similar to those obtained at 10°

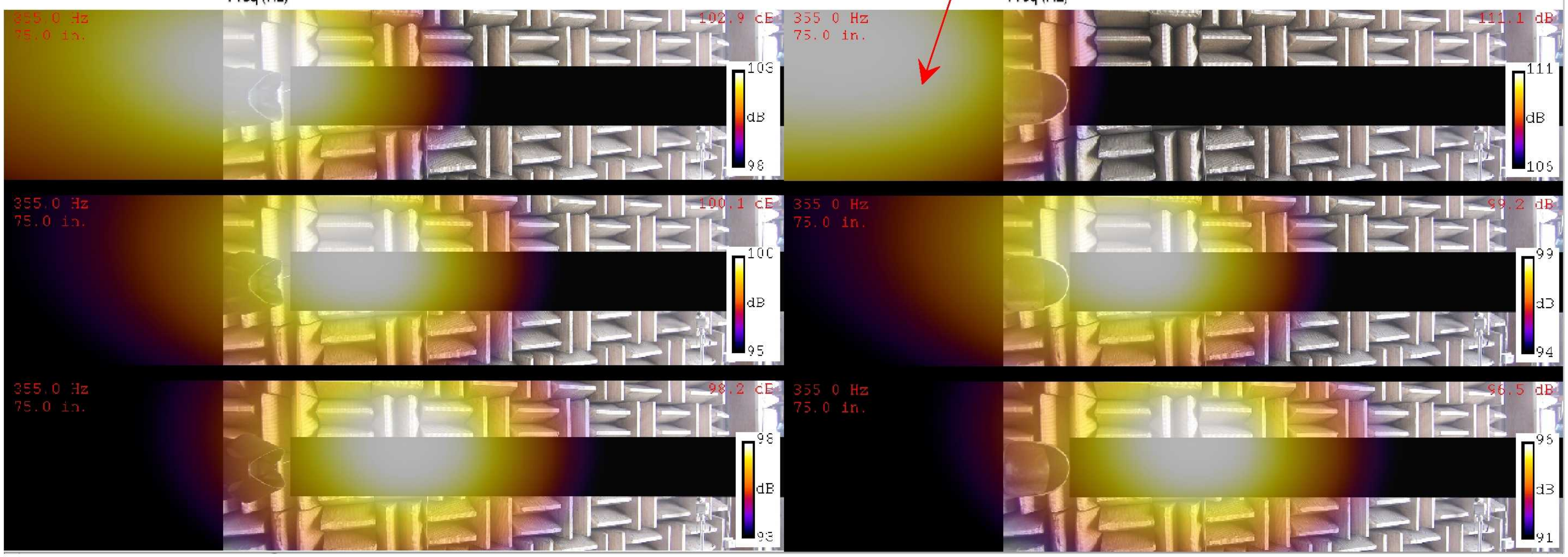
Impromptu Flow Vis upon combustor startup

Phased Array Results – M_{fj} = 0.0 (static)

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



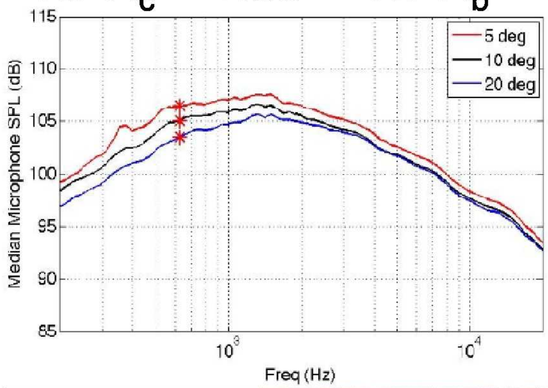


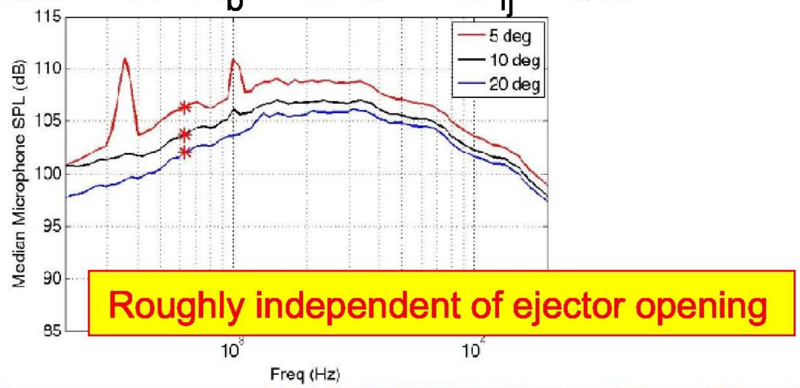


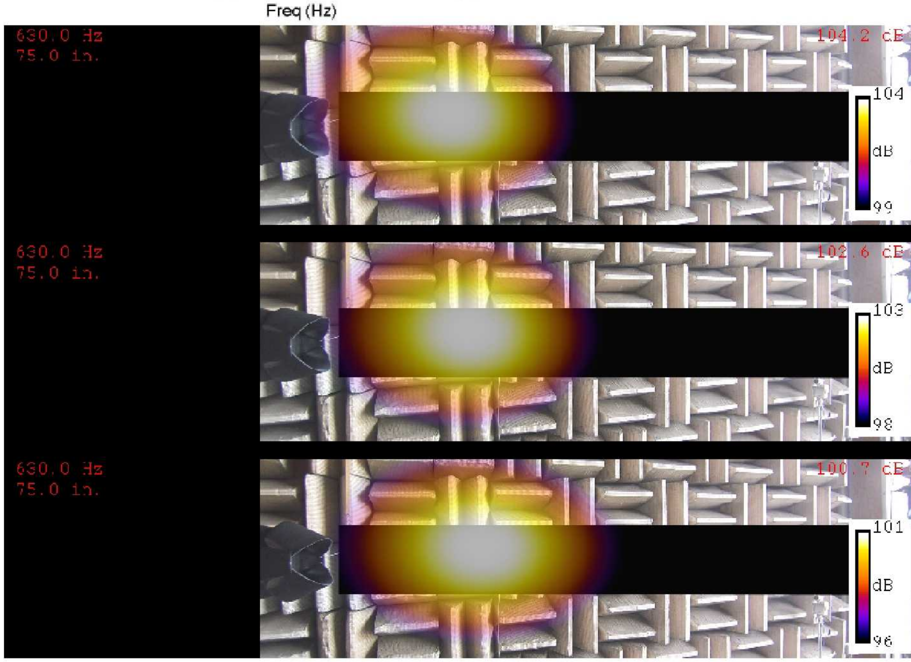
Sidewall Toward Array **355Hz** Ejector Door Toward Array

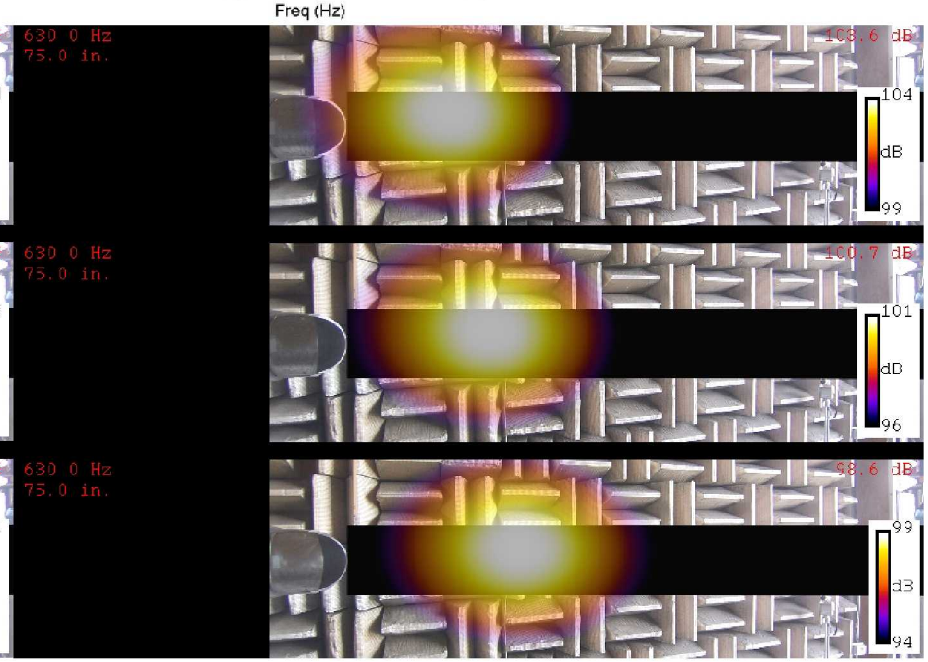
Phased Array Results – M_{fj} = 0.0 (static)

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





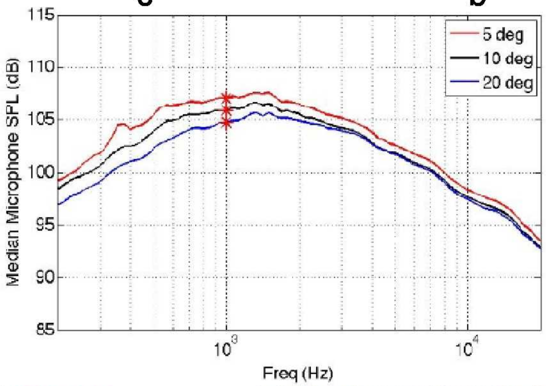


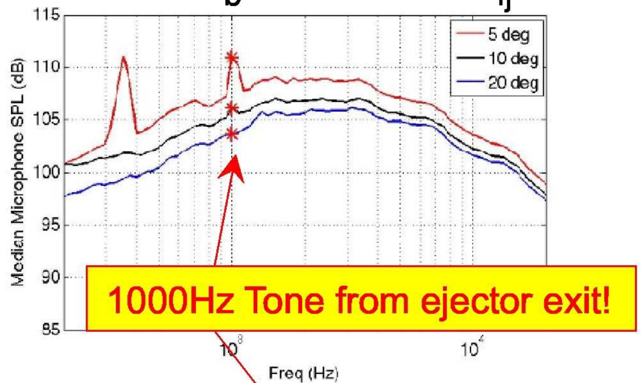


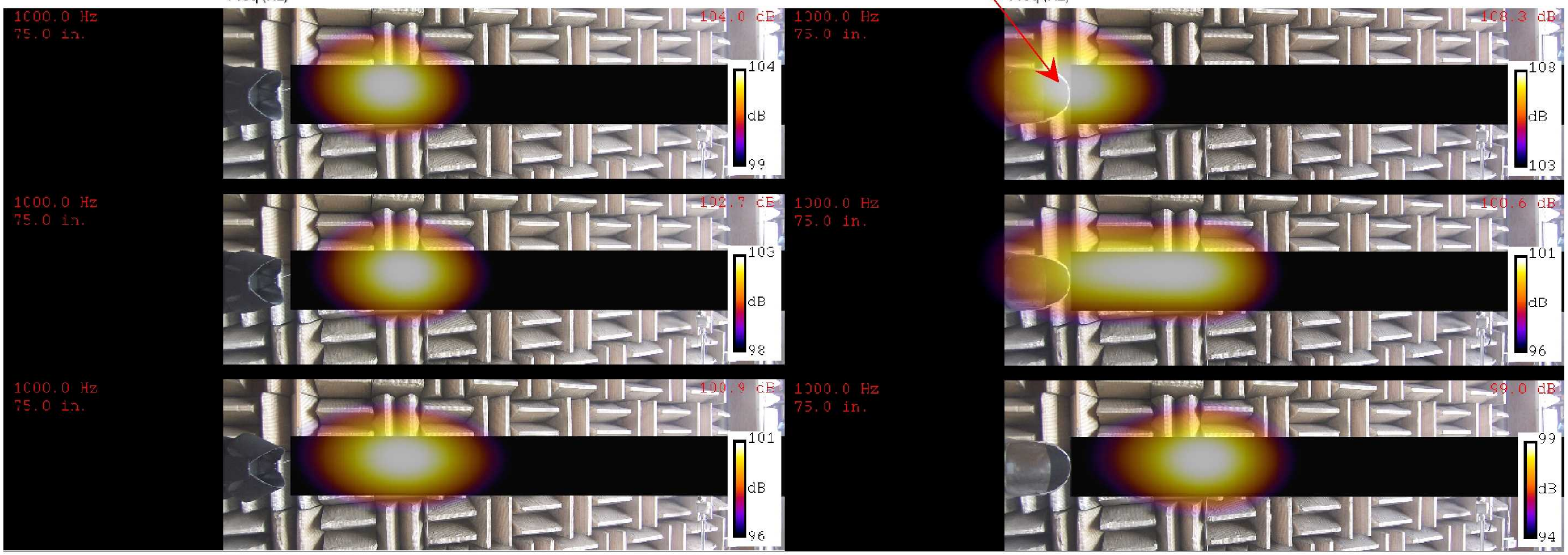
Sidewall Toward Array **630Hz** Ejector Door Toward Array

Phased Array Results – M_{fj} = 0.0 (static)

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



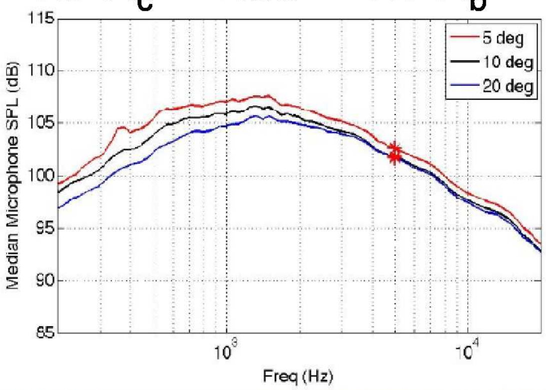


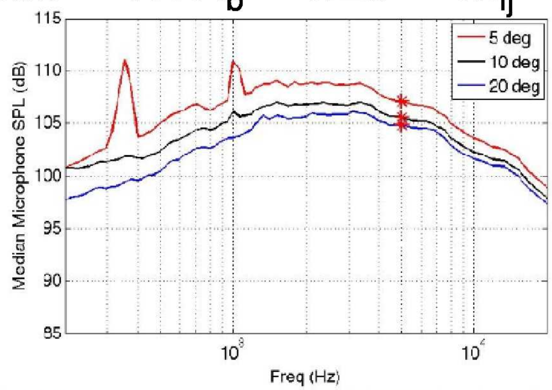


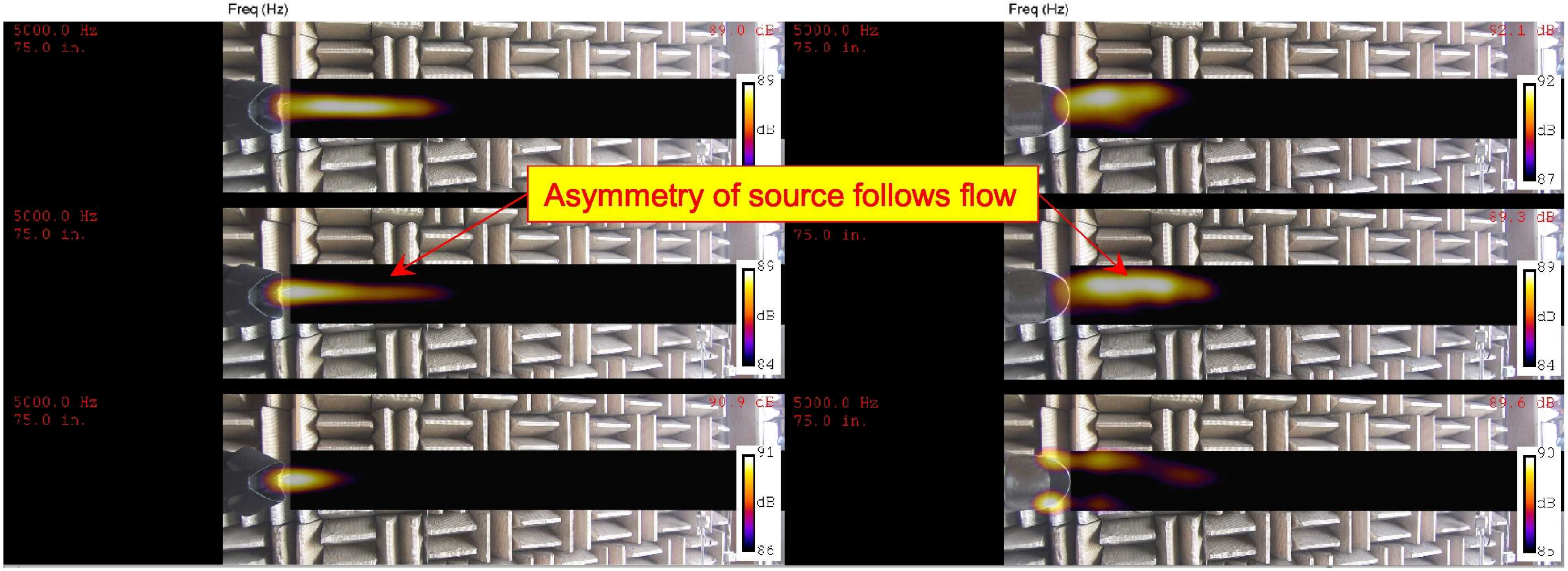
Sidewall Toward Array **1000Hz** Ejector Door Toward Array

Phased Array Results – M_{fj} = 0.0 (static)

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







Sidewall Toward Array **5000Hz** Ejector Door Toward Array

Summary

- Tones occur primarily for small ejector door angles
  - Strongest tone at static condition; source located at the ejector inlet
  - Other tones present with flight near the ejector door trailing edge
- Revised design did confine tones to small door opening positions
- Relative to convergent nozzle
  - Ejector decreases noise for static conditions with large door openings.
  - Ejector increases noise for all forward flight conditions.
- Flow downstream of ejector openings separated, increasing shear
- Large-scale vortices generated at edges of inlets coupled with elliptic A8 throat creates strongly non-axisymmetric plume, stretching/augmenting shear layer turbulence downstream.