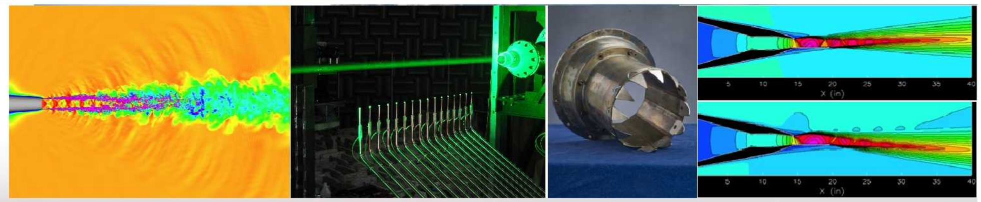
Fluidic Injection for Jet Noise Reduction

Brenda Henderson
NASA Glenn Research Center

Investigations into fluidic injection for jet noise reduction began over 50 years ago. Studies have included water and air injection for the reduction of noise in scale model jets and jet engines and water injection for the reduction of excess overpressures on the Space Shuttle at lift-off. Injection systems have included high pressure microjets as well as larger scale injectors operating at pressures that can be achieved in real jet engines. An historical perspective highlighting noise reduction potential is presented for injection concepts investigated over the last 50 years. Results from recent investigations conducted at NASA are presented for supersonic and subsonic dual-stream jets. The noise reduction benefits achieved through fluidic contouring using an azimuthally controlled nozzle will be discussed.

National Aeronautics and Space Administration

Fluidic Injection for Jet Noise Reduction



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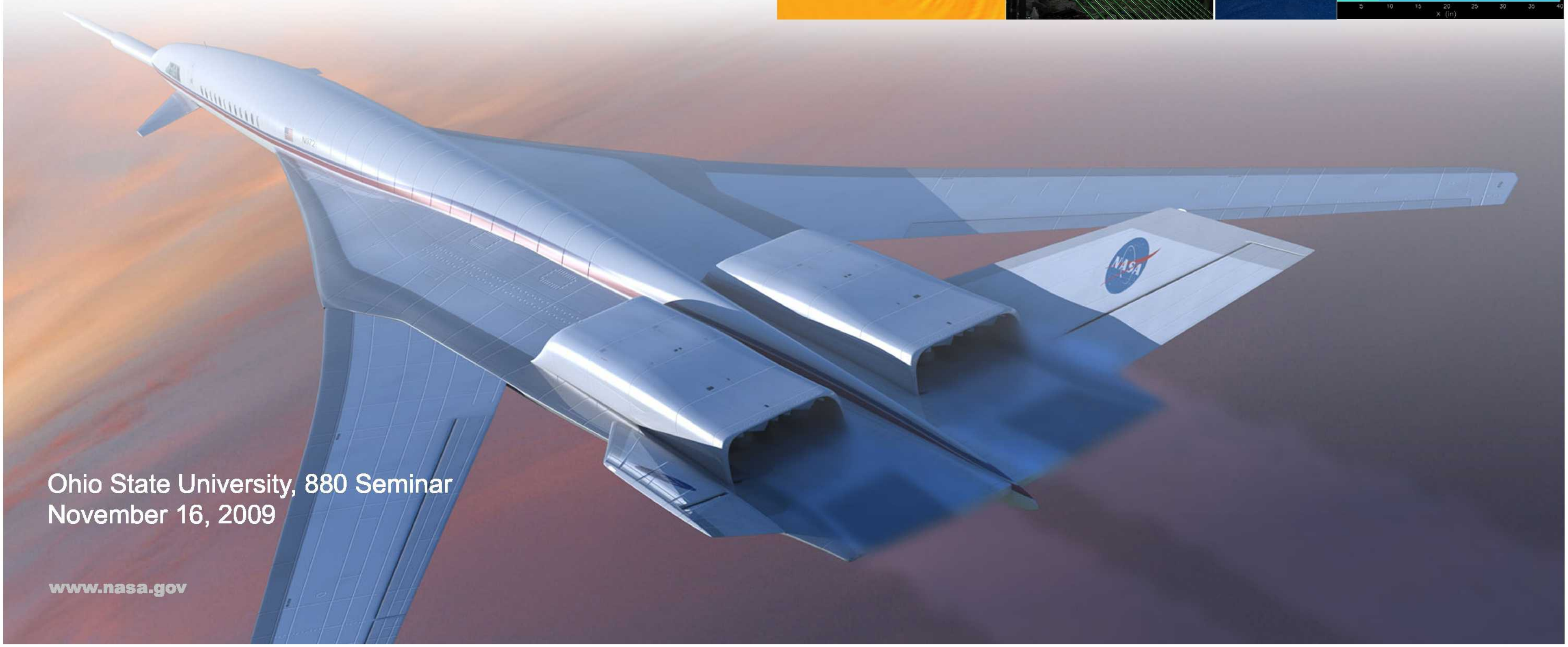


Ohio State University, 880 Seminar
November 16, 2009

www.nasa.gov

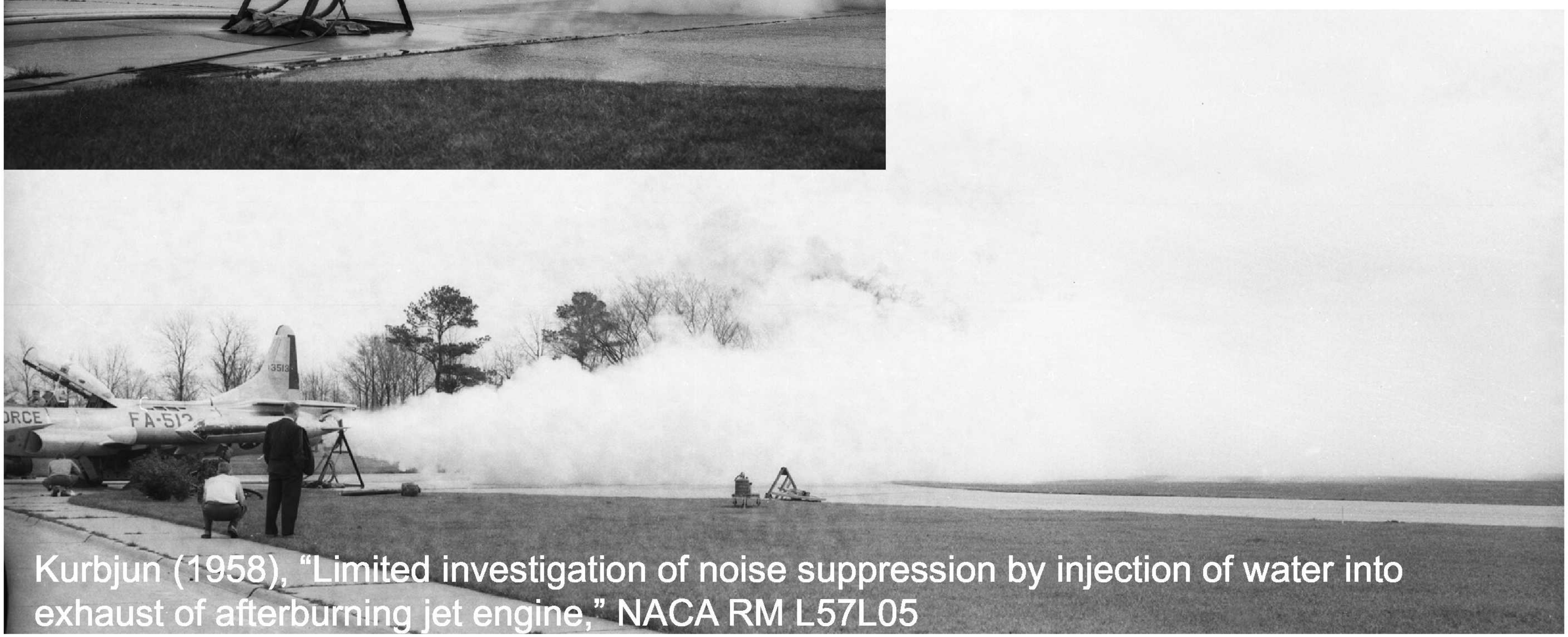
Overview

- Brief history of fluidic injection
  - Water and air
- NASA's acoustic measurements since 2002 on air injection
  - Generation I nozzles
  - Generation II nozzles

  With Goodrich Aerostructures
  - Generation III nozzles
- NASA's flow-field measurements - 2009
- Concluding remarks

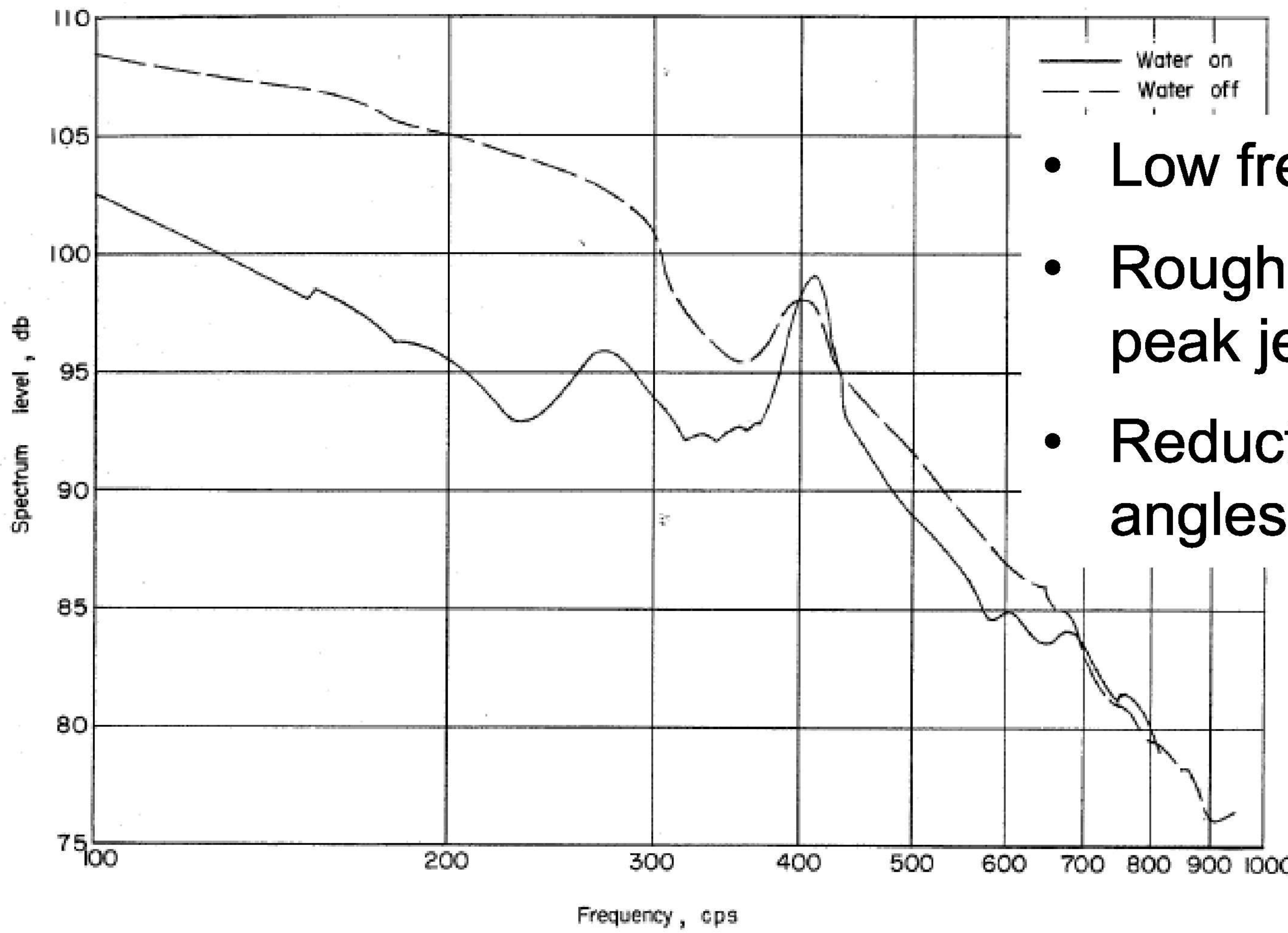
First Experiments – Kurbjun (1958)

- Engine produced 8000 lb thrust with afterburning
- 880 gallons of water/minute at 100 psig



Kurbjun (1958), “Limited investigation of noise suppression by injection of water into exhaust of afterburning jet engine,” NACA RM L57L05

Results from Kurbjun (1958)



150º, 150 feet

- Low frequency reduction
- Roughly 6 dB OASPL in peak jet noise direction
- Reductions at other angles much smaller

First Patent – Lilley (1961)

July 4, 1961 G. M. LILLEY 2,990,905

JET NOISE SUPPRESSION MEANS

Filed May 8, 1958

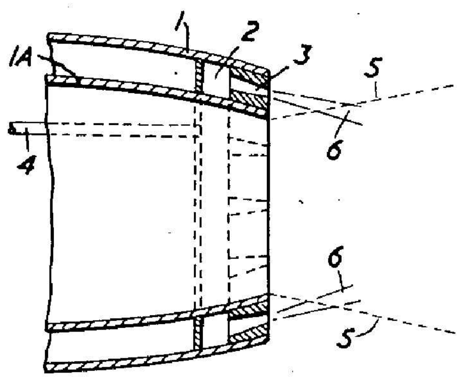


FIG. 1.

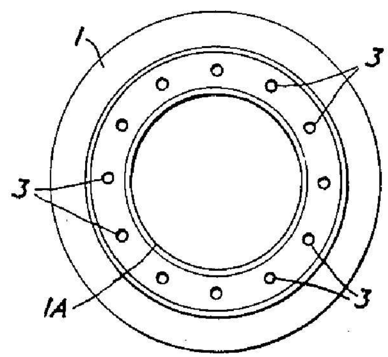


FIG. 2.

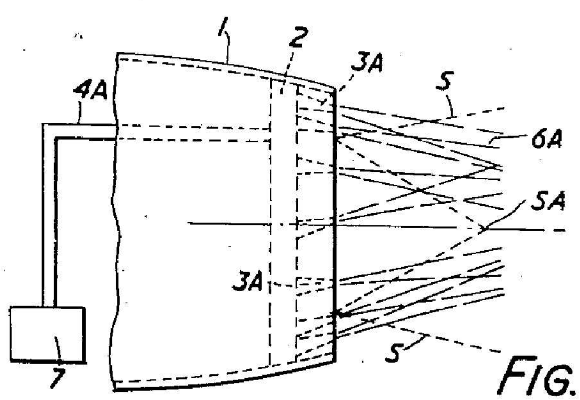


FIG. 3.

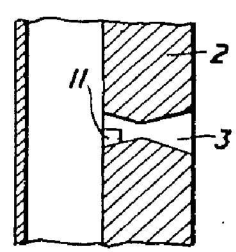
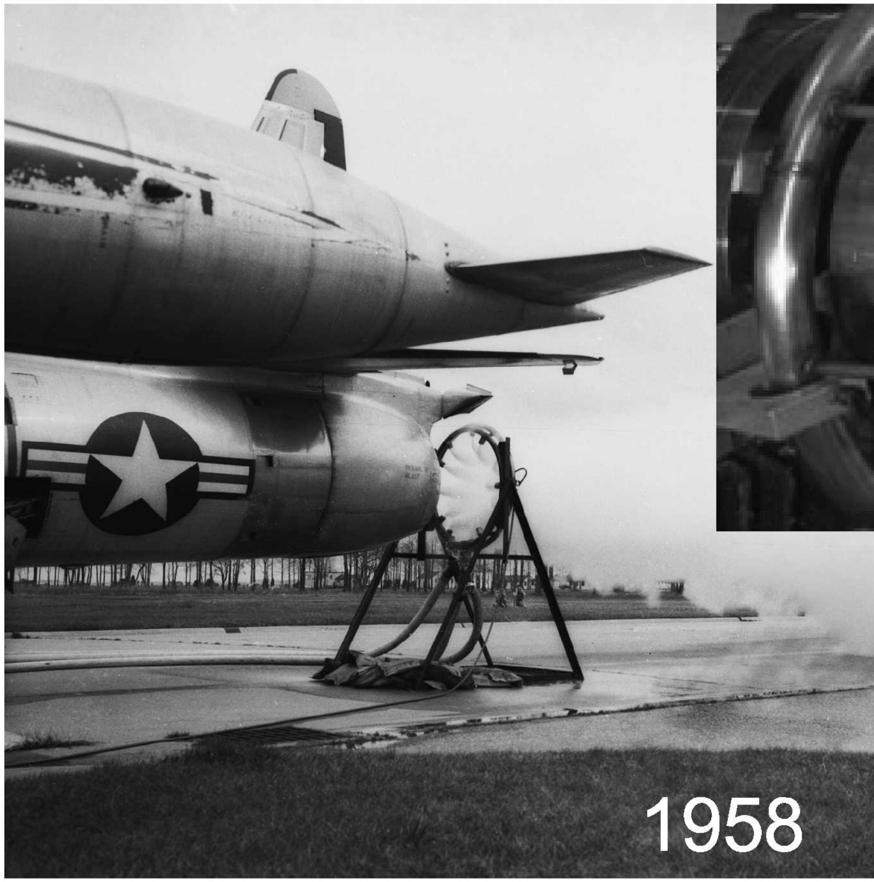


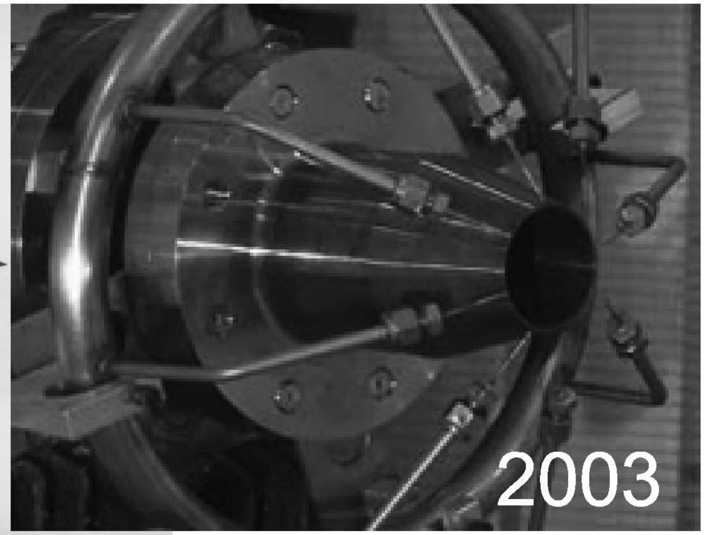
FIG. 6.

Reduction of jet noise through

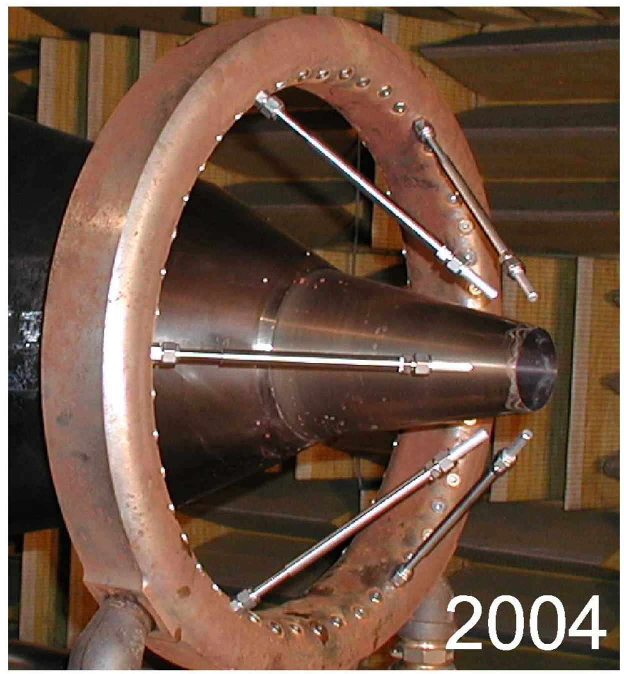
- Enhanced mixing
- Restricted formation of large eddies

40 - 50 Years Later





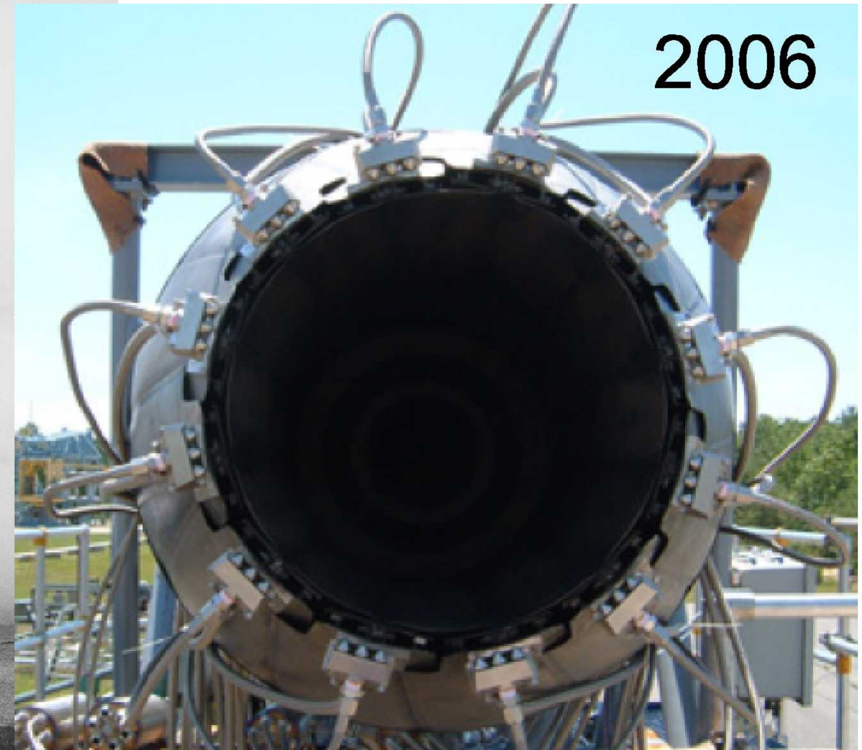
Krothapalli, A., Venkatakrishnan, L., Lourenco, L., Greska, B., and Elavarasan, R. (2003), "Turbulence and noise suppression of a high-speed jet by water injection," J. Fluid Mech. 491, 131-159.



Norum, T. (2004), "Reductions in multi-component noise by water injection," AIAA-2004-2976

Water

40 – 50 Years Later



Water and Air

Greska, B., Krothapalli, A., Seiner, J., Jansen, B., and Ukeiley, L. (2005), "The effects of microjet injection on an F404 jet engine," AIAA-2005-3047

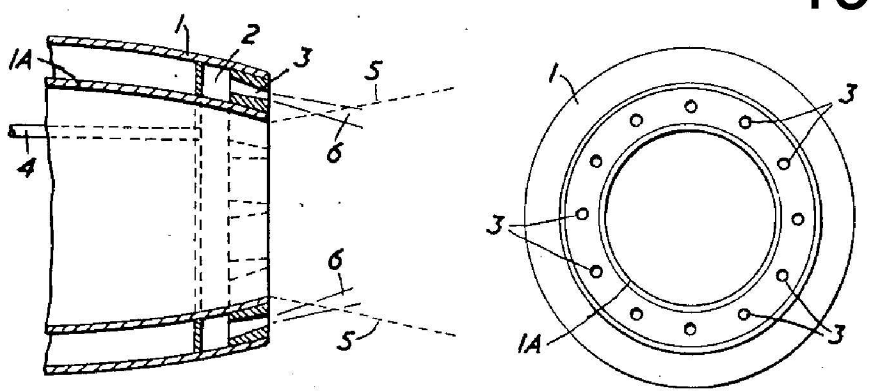
40 - 50 Years Later

G. M. LILLEY

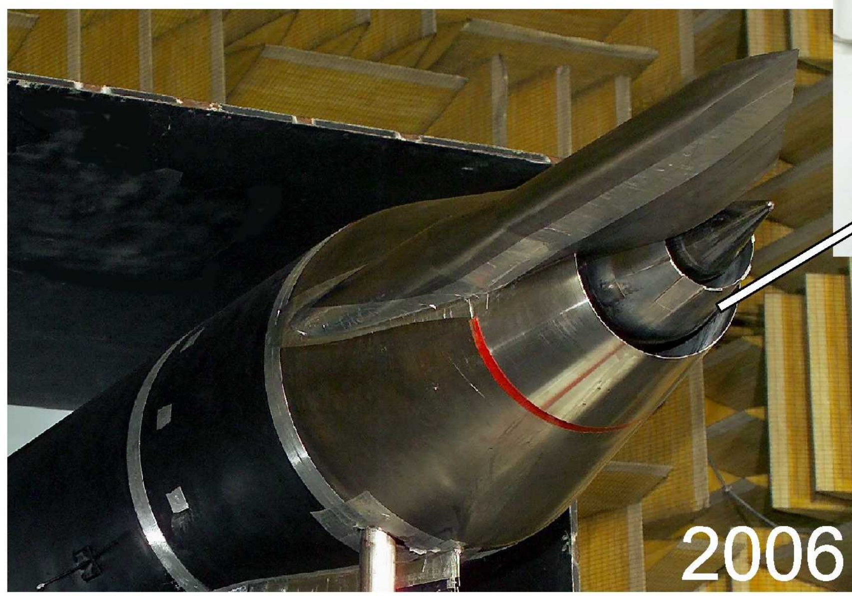
JET NOISE SUPPRESSION MEANS

Filed May 8, 1958

1961



Henderson, B., Kinzie, K., Whitmire, J., and Abeysinghe, A. (2006), “Aeroacoustic improvements of fluidic chevron nozzles,” AIAA-2006-2706



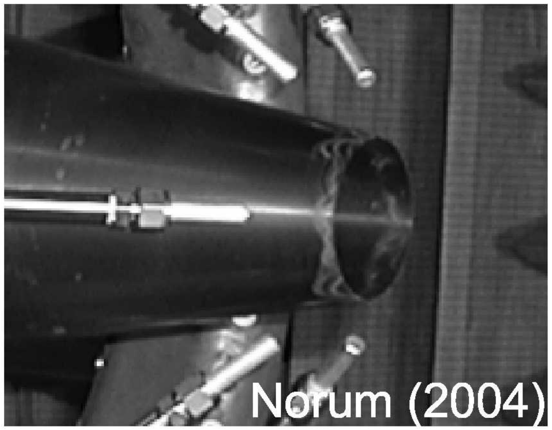
Air

What Have We Learned?

Air and Water

- Penetration into primary jet is a function of momentum ratio
- High pressure microjet systems are more effective at reducing noise than low pressure systems with larger injectors
  - High pressure systems – usually operate above 300 psia
  - No strict definition of 'microjet'

Microjet System



Low Pressure, Large Injector System

What Have We Learned?

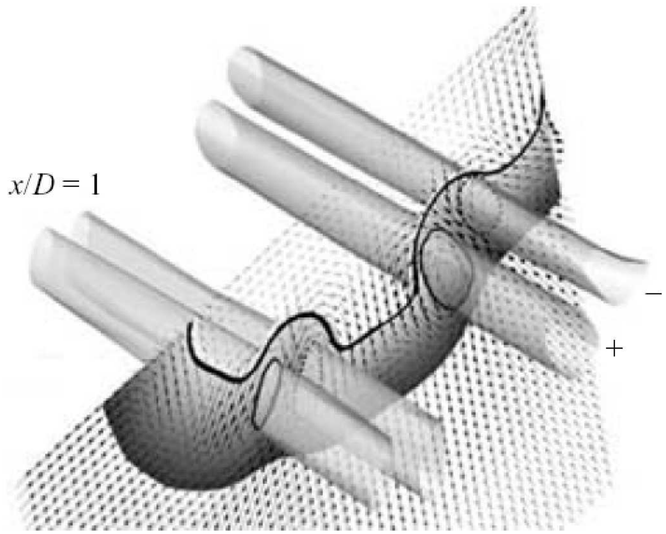
Water

- Reduces jet velocity through momentum transfer
- Reduces jet temperature through evaporation
- Modifies turbulence
- Often more effective at reducing noise in cold jet than in hot jets
- Effectively reduces overpressures in Shuttle lift-off environment – MFR can be > 100%

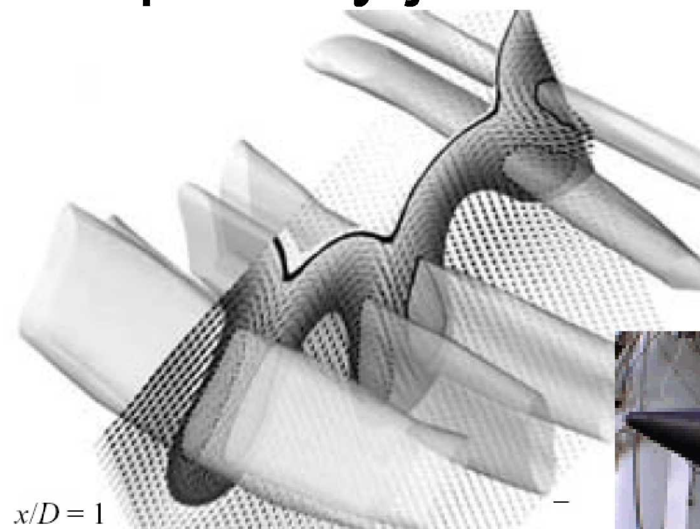
What Have We Learned?

Air

- Counter-rotating vortices are created in primary jet
  - Alters mixing characteristics of primary jet
  - Alters turbulence of primary jet



Microjet Injection



Chevron

Alkislar, M. B., Krothapalli, A., and Butler, G. W. (2007), “The effect of streamwise vortices on the aeroacoustics of a Mach 0.9 jet,” J. Fluid Mech. **578**, 139-169.

What Have We Learned?

Air

- Reductions in low frequency noise can be offset by increases in high frequency noise for dual stream jets
  - 1 EPNdB – studies limited
- Limited studies conducted for dual stream supersonic jets

Henderson, B. (2009), "Fifty years of fluidic injection for jet noise reduction," Int. J. of Aeroacoustics **9**, 91 – 122.

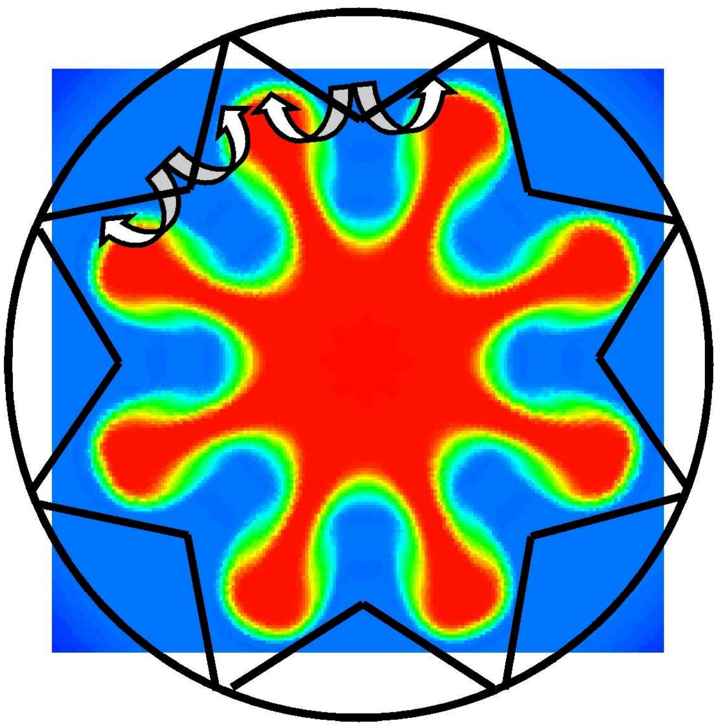
Overview

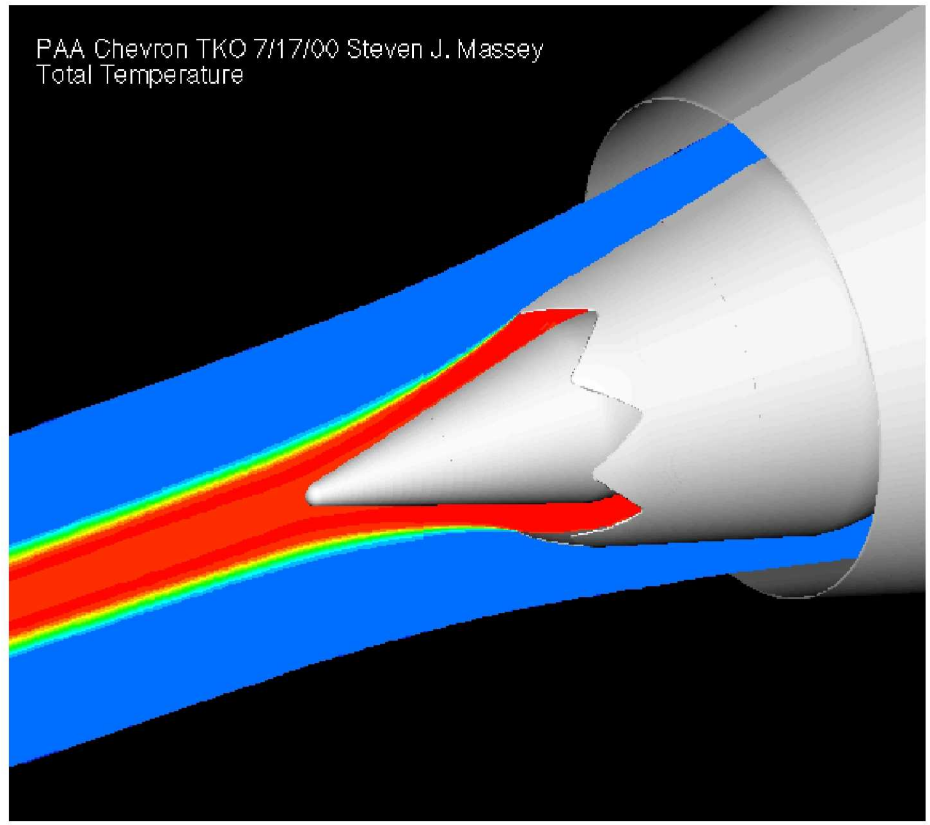
- Brief history of fluidic injection
  - Water and air
- NASA's acoustic measurements since 2002 on air injection
  - Subsonic dual-stream jets
    - Generation I nozzles
    - Generation II nozzles

With Goodrich Aerostructures

  - Supersonic jets – Generation II and III
- NASA's flow-field measurements - 2009
- Concluding remarks

Motivation for NASA Experiments

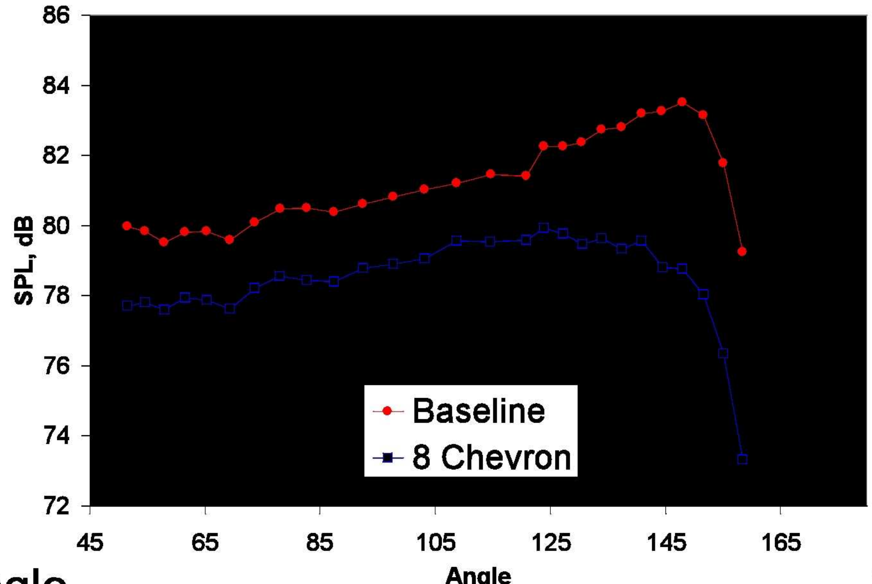




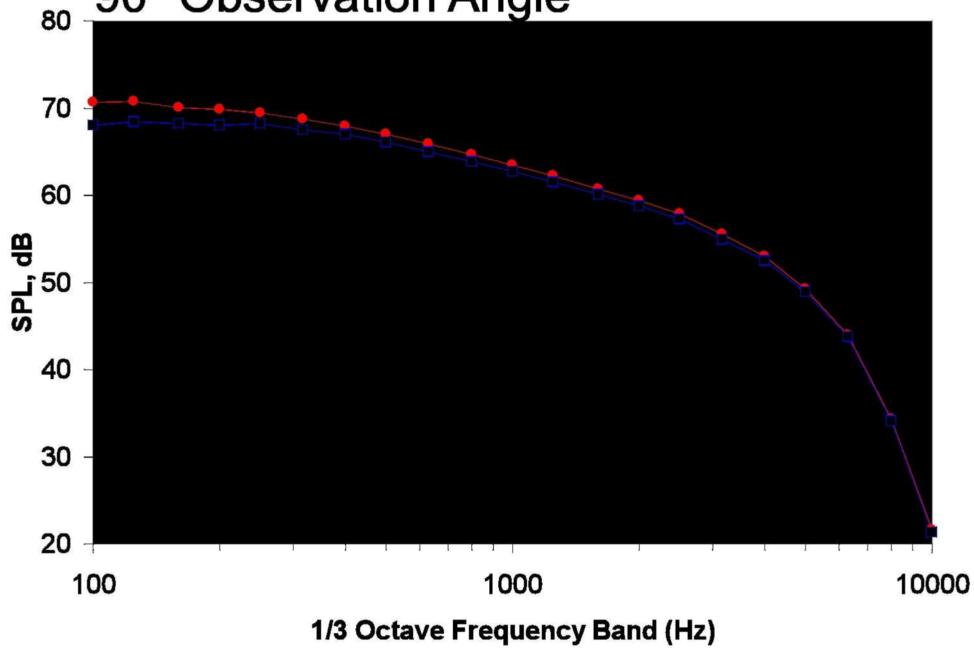
- Enhanced mixing shortens potential core and reduces low frequency acoustic radiation

Mechanical Chevron Noise Reduction

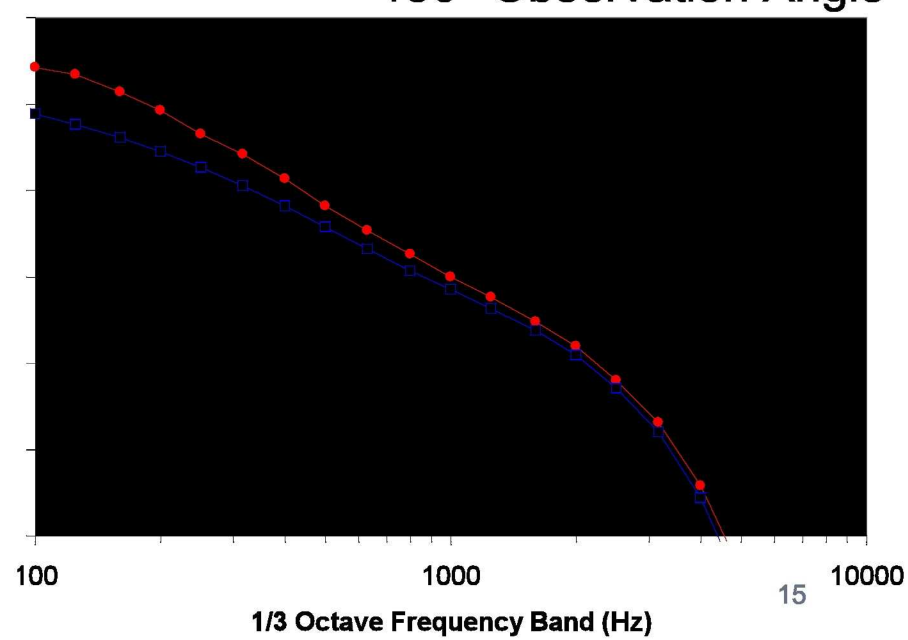
OASPL



90° Observation Angle

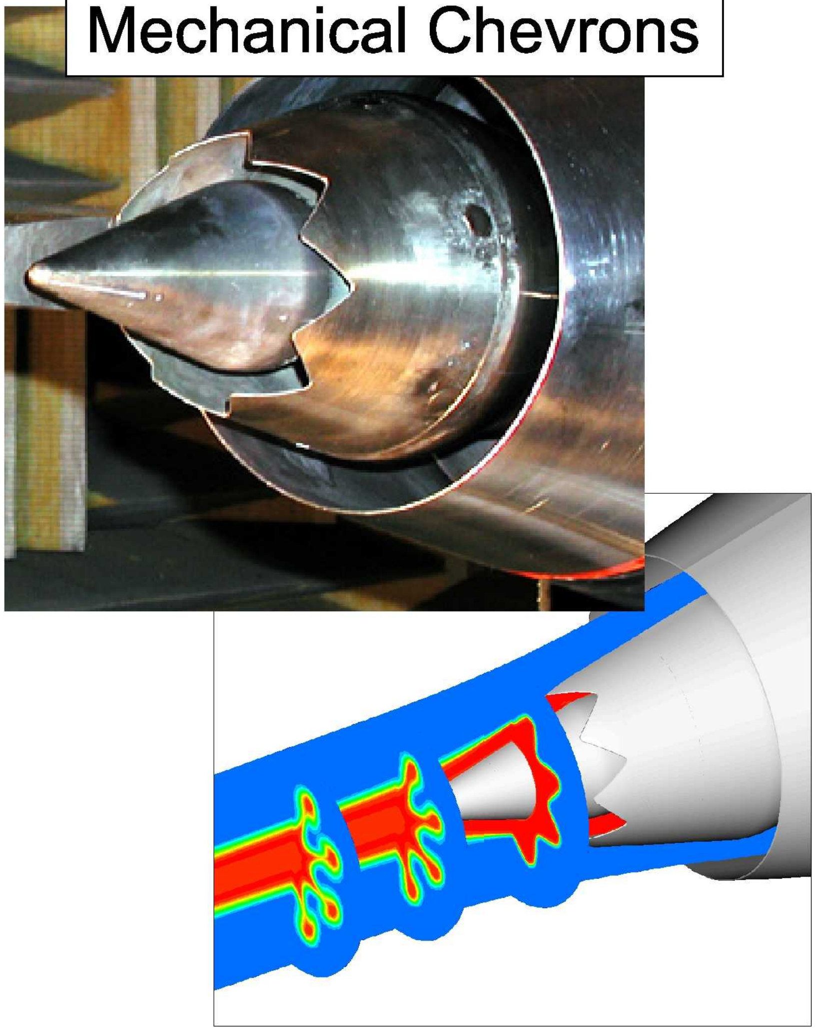


150° Observation Angle

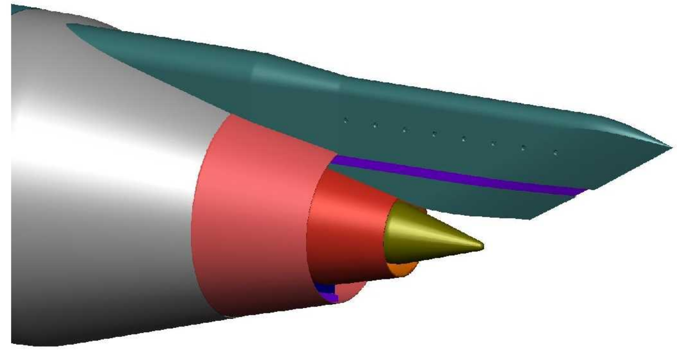


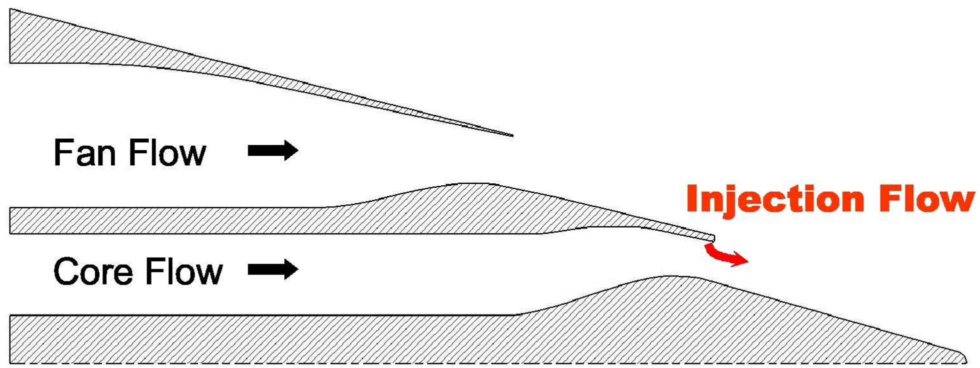
Can Mixing Be Achieved Another Way?

Mechanical Chevrons

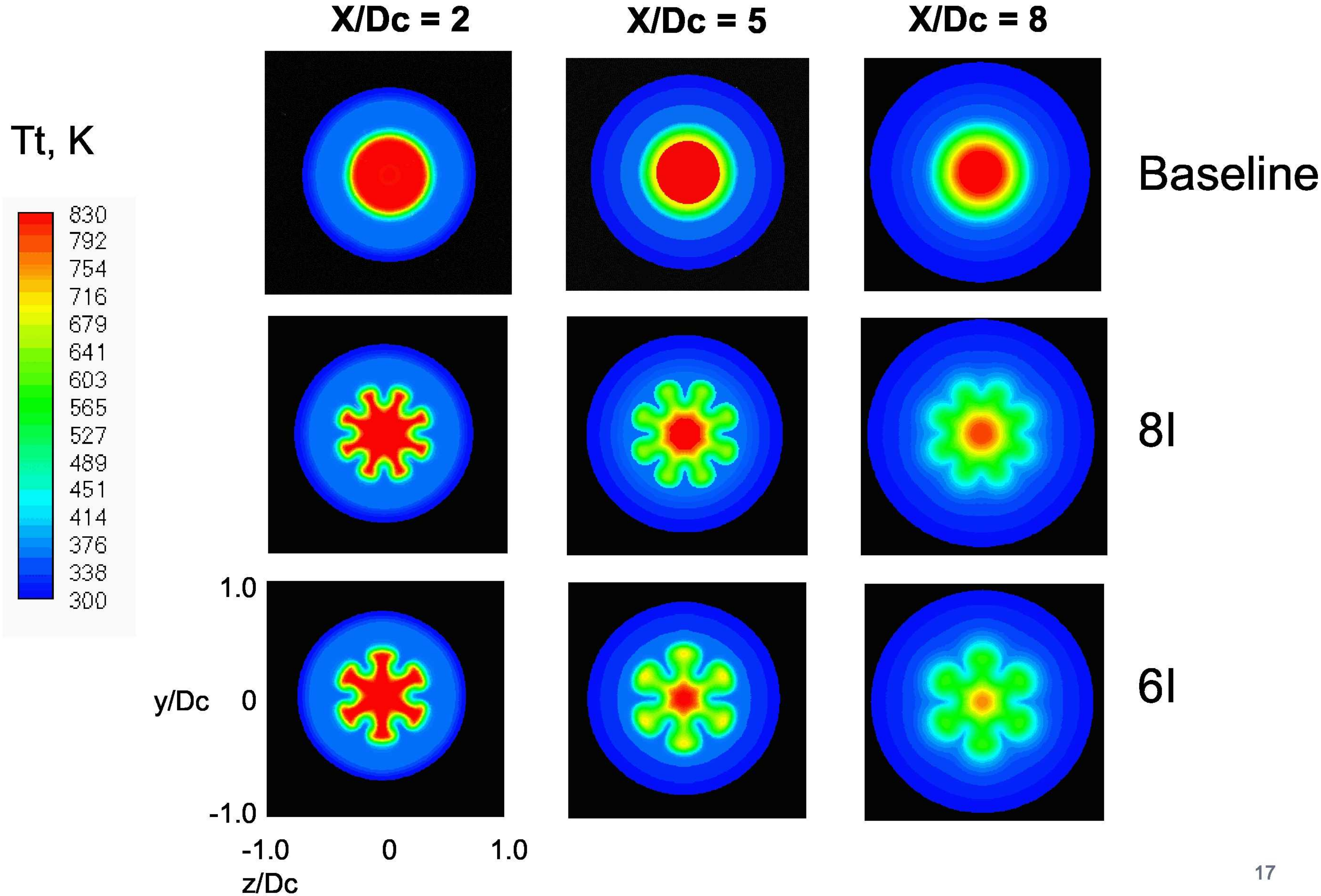


Fluidic Chevrons

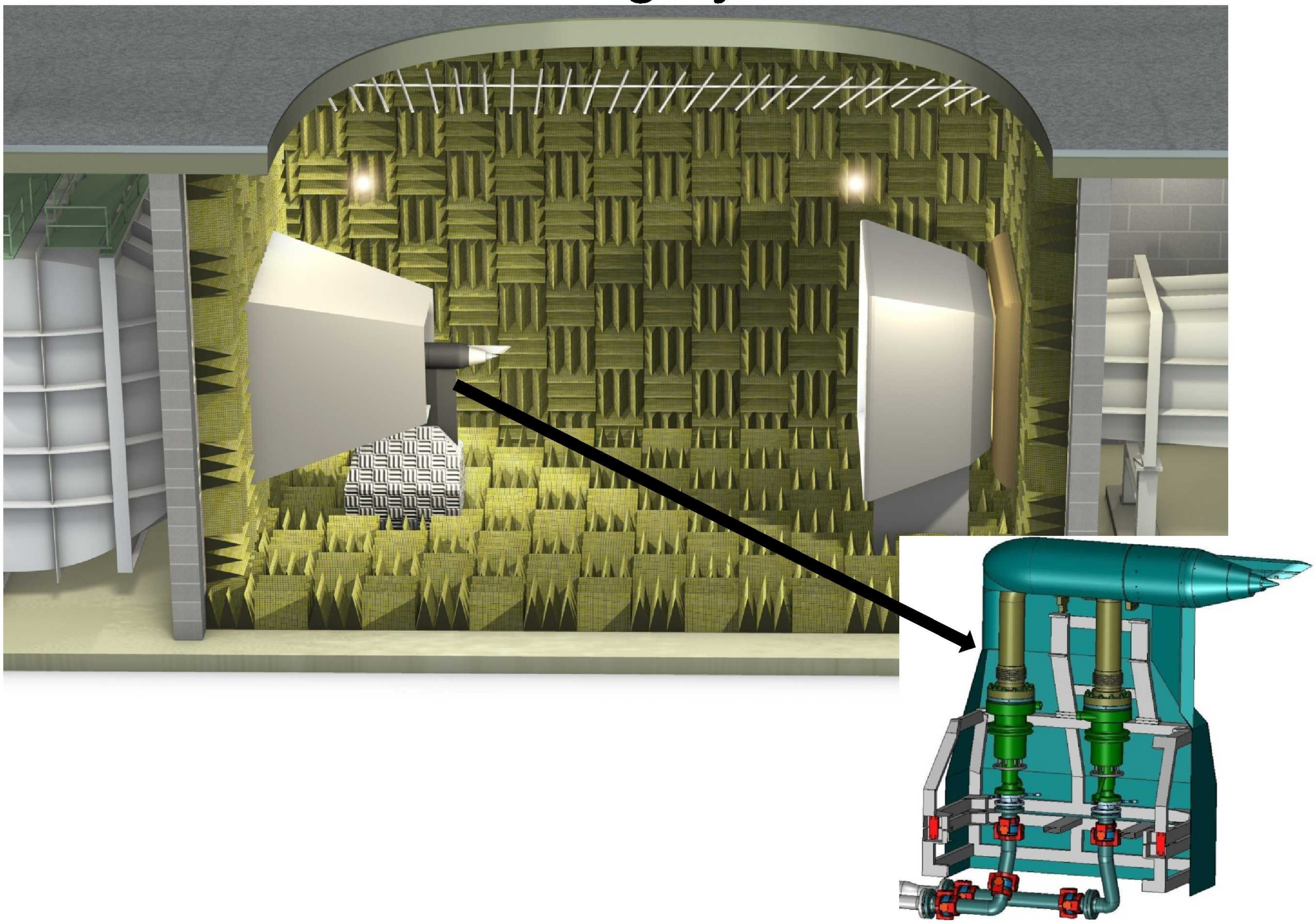




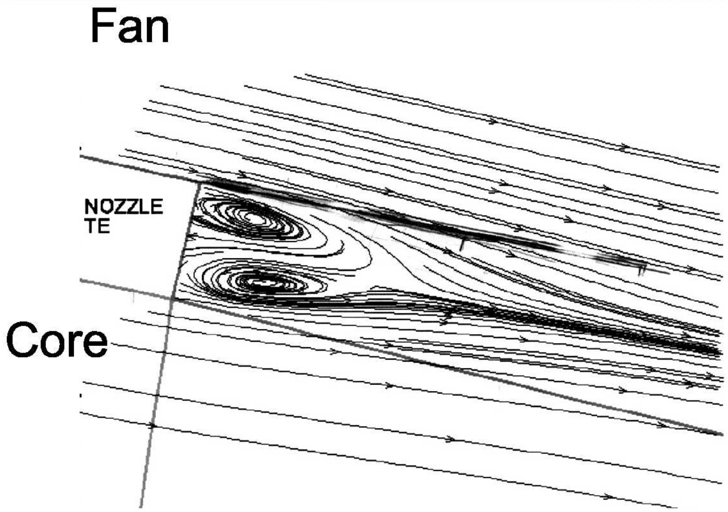
Total Temperature Contours

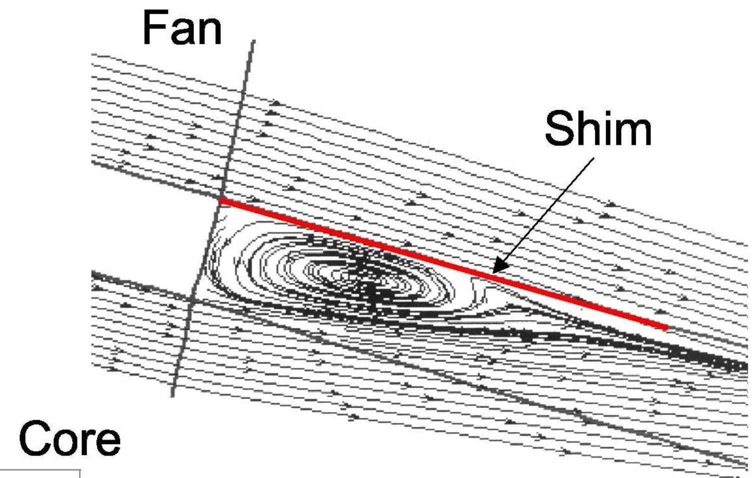


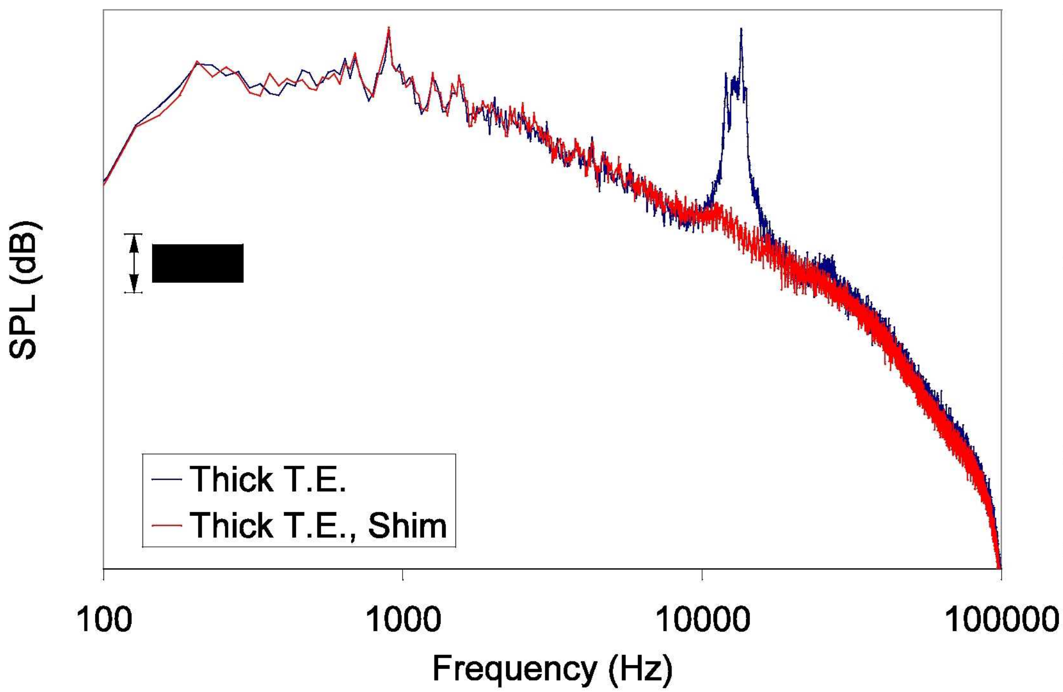
Low Speed Aeroacoustics Wind Tunnel Langley



Generation I Air Injection Nozzles





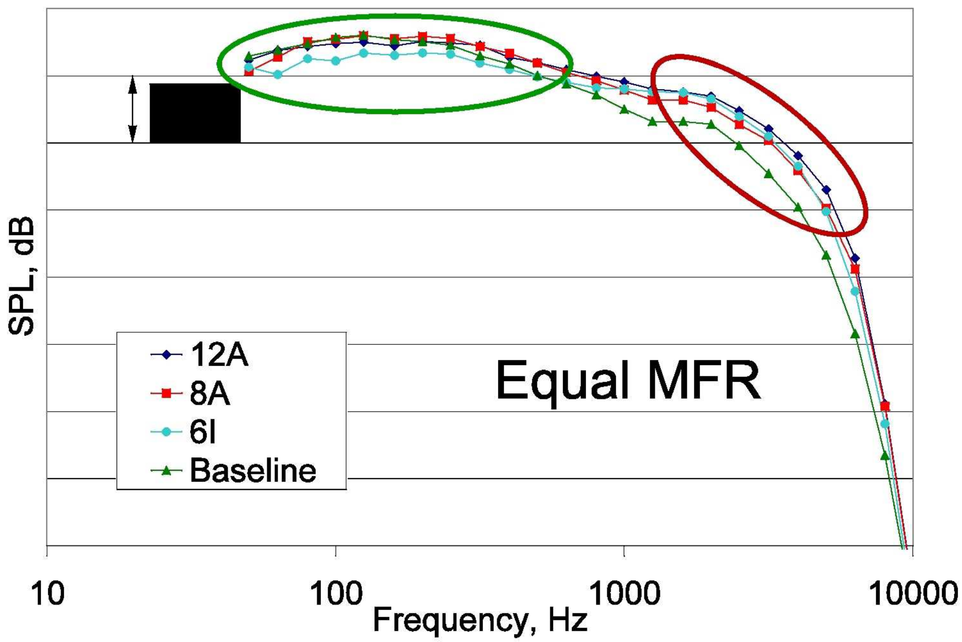


Gen I Nozzles

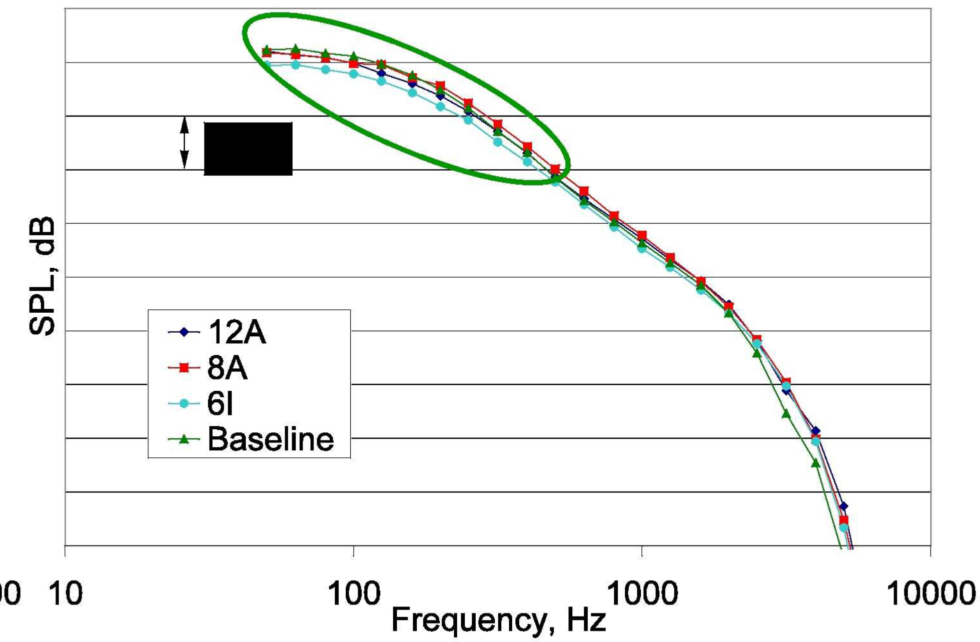
- Common plenum
- Exhaust slots
- No control over flow angle
- Thick trailing edges
- Inflow and alternating nozzles

Generation I Noise Characteristics

- Low frequency reductions offset by high frequency increases on an EPNL basis



$\theta = 90^o$



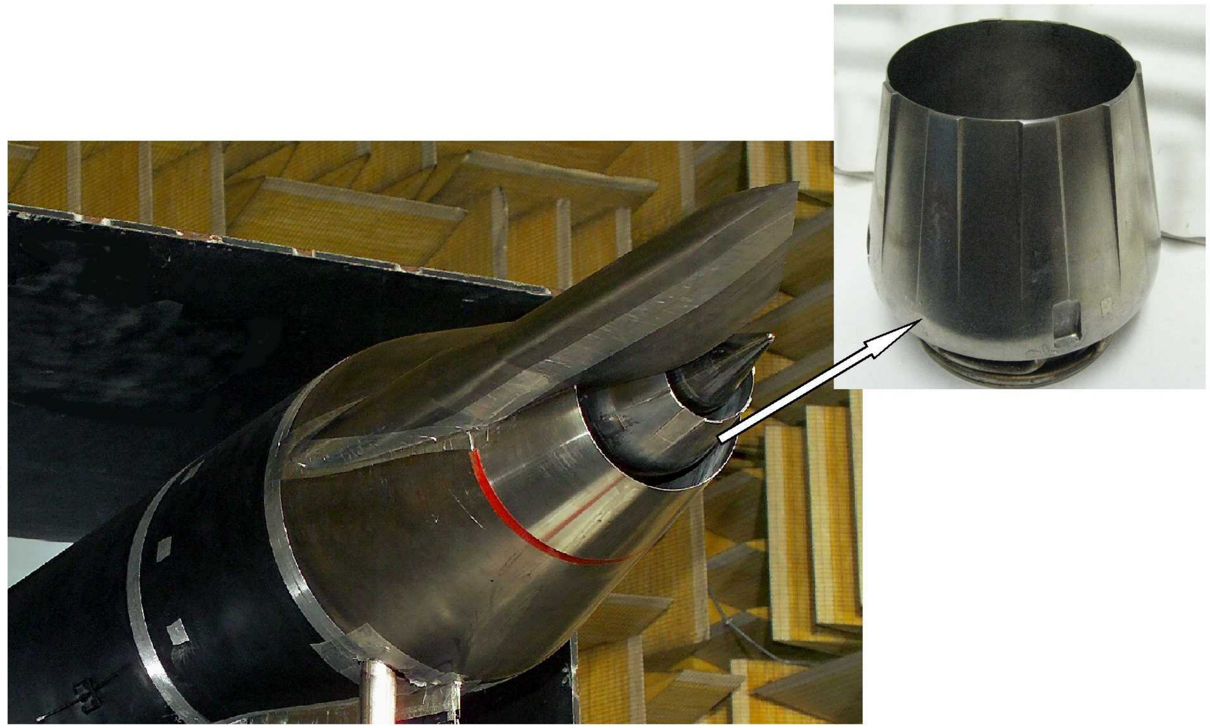
$\theta = 140^o$

Representative takeoff conditions at $M_{fj} = 0.28$

Generation II Nozzles

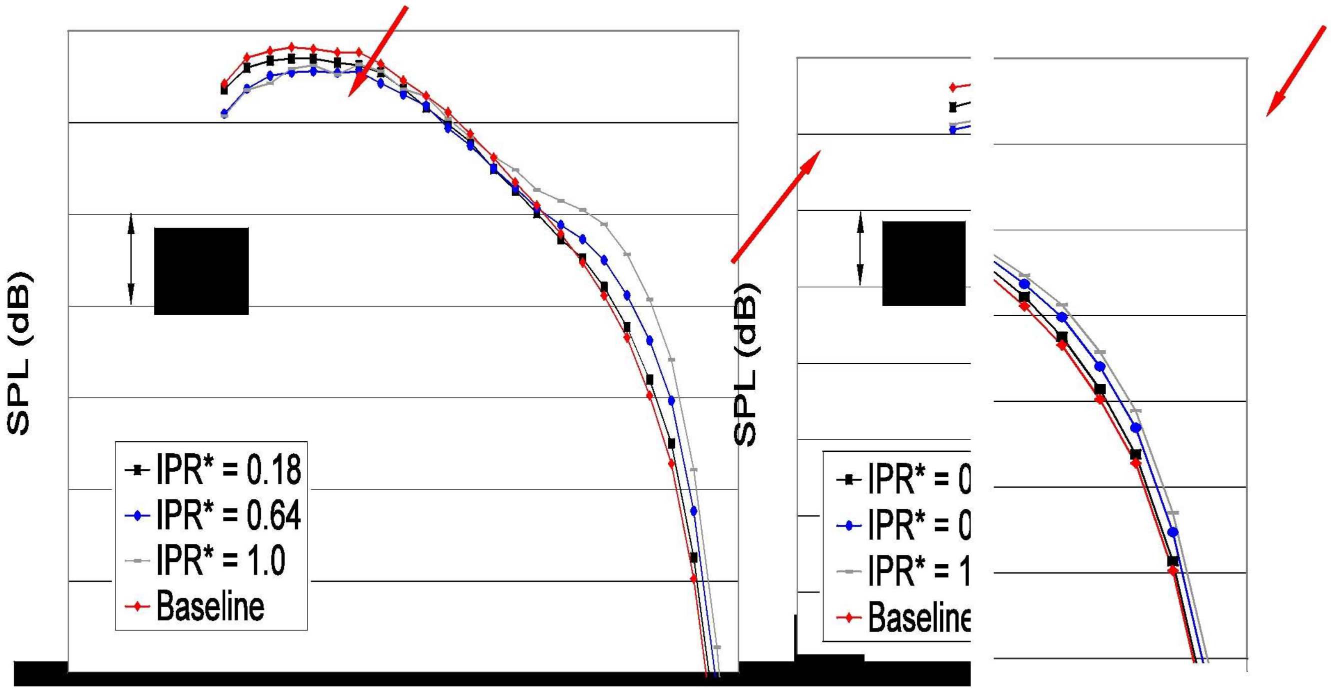
Gen II Nozzles

- Common plenum
- Contoured channels
- Exhaust slots near nozzle trailing edges
- Thin trailing edges between injection ports
- All 6 inflow injectors
    - Steep & shallow
    - Short & long
    - Perforated



Generation II Steep Injectors

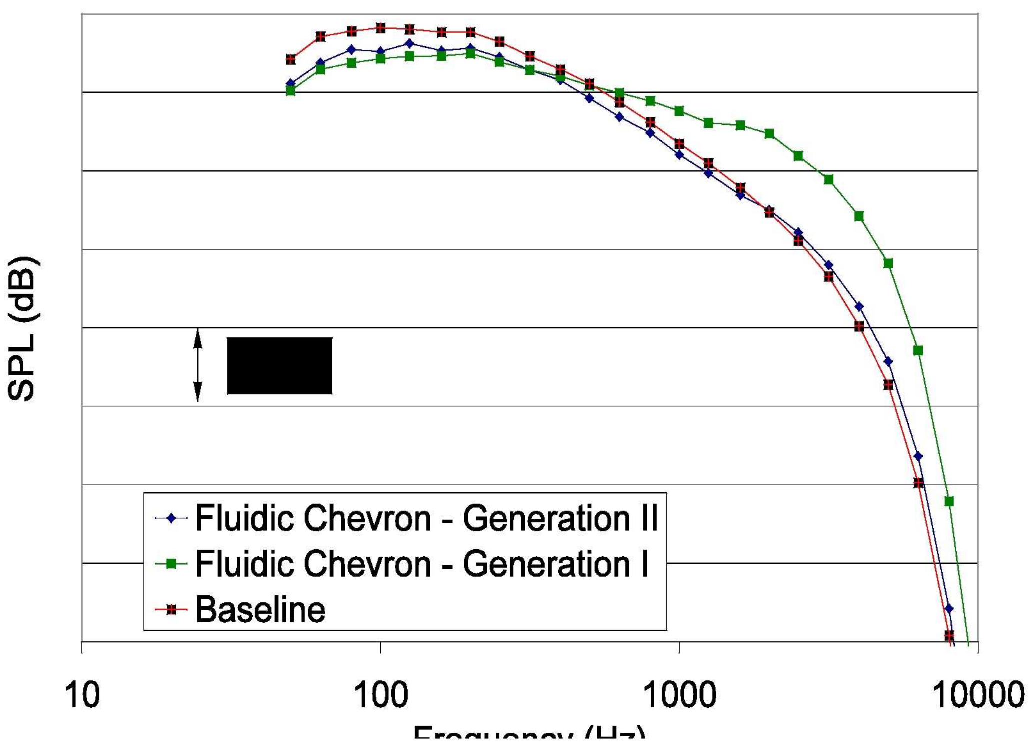
- Increasing IPR reduces low frequency noise and increases high frequency at small observation angles



$\theta = 90^o$ $\theta = 140^o$

Representative takeoff conditions at M_{fj} = 0.28

Comparison with Generation I Nozzles

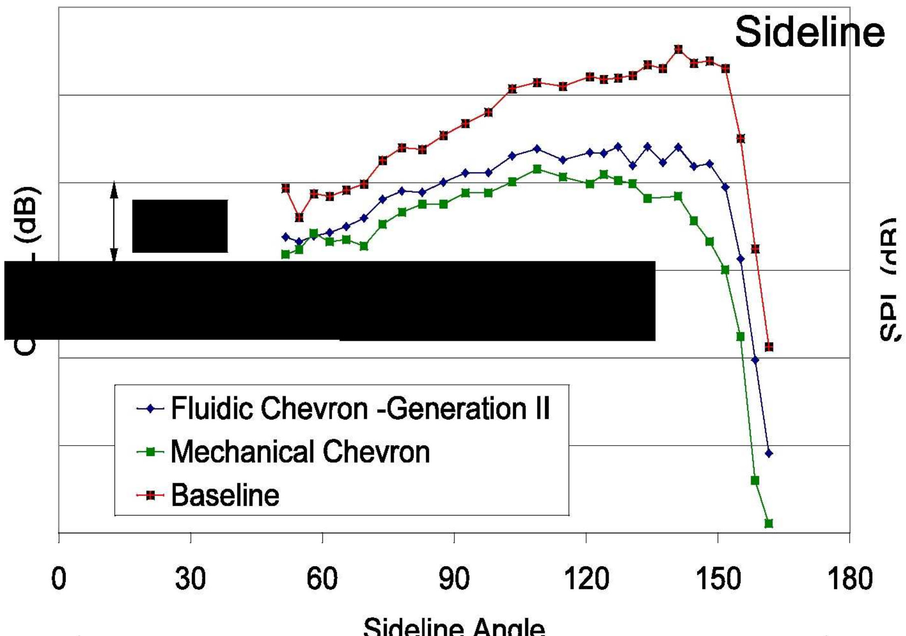


$\theta = 90^o$

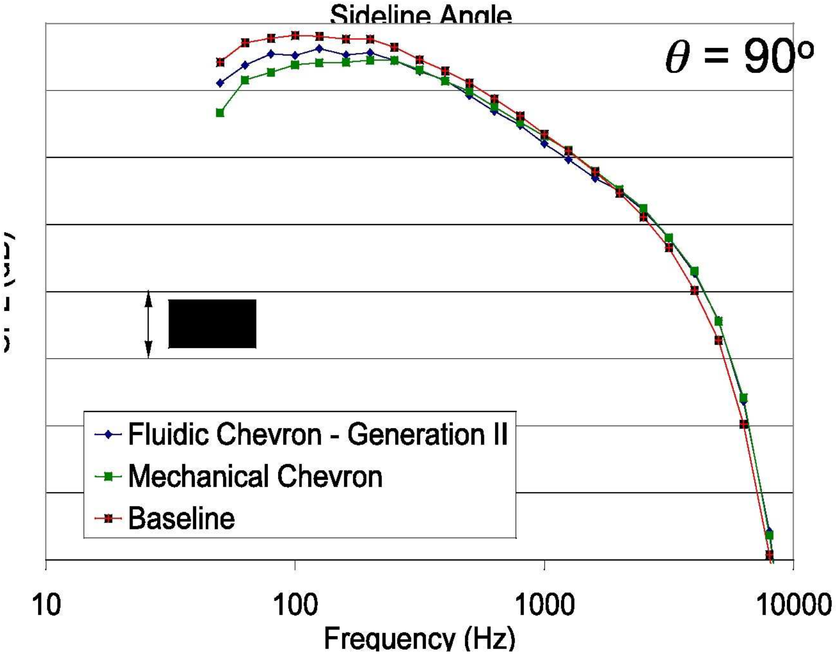
Improved Acoustic Characteristics

- Controlled injection angle
- Thin nozzle trailing edges
- Controlled injection location

Comparison with Mechanical Chevrons

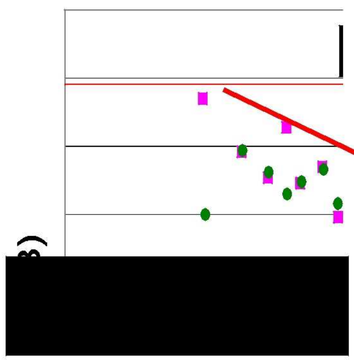


Configuration	ΔEPNdB
Fluidic Chevron	0.8
Mechanical Chevron	1.1



Noise reduction characteristics are approaching those of the mechanical chevron after two generations of development

Noise Reduction Characteristics



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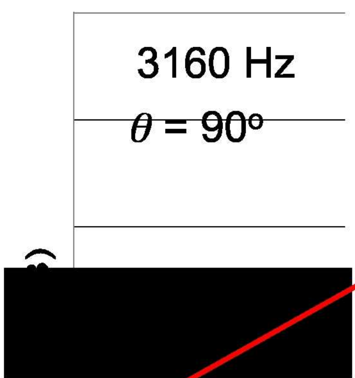

[redacted]

Noise Reduction Approach

- Decrease low frequency noise with increased perpendicular velocity
- Control high frequency noise with reduced perpendicular momentum

Overview

- Brief history of fluidic injection
  - Water and air
- NASA's acoustic measurements since 2002 on air injection
  - Subsonic dual-stream jets
    - Generation I nozzles
    - Generation II nozzles

  With Goodrich Aerostructures
  - Supersonic jets – Generation II and III
- NASA's flow-field measurements - 2009
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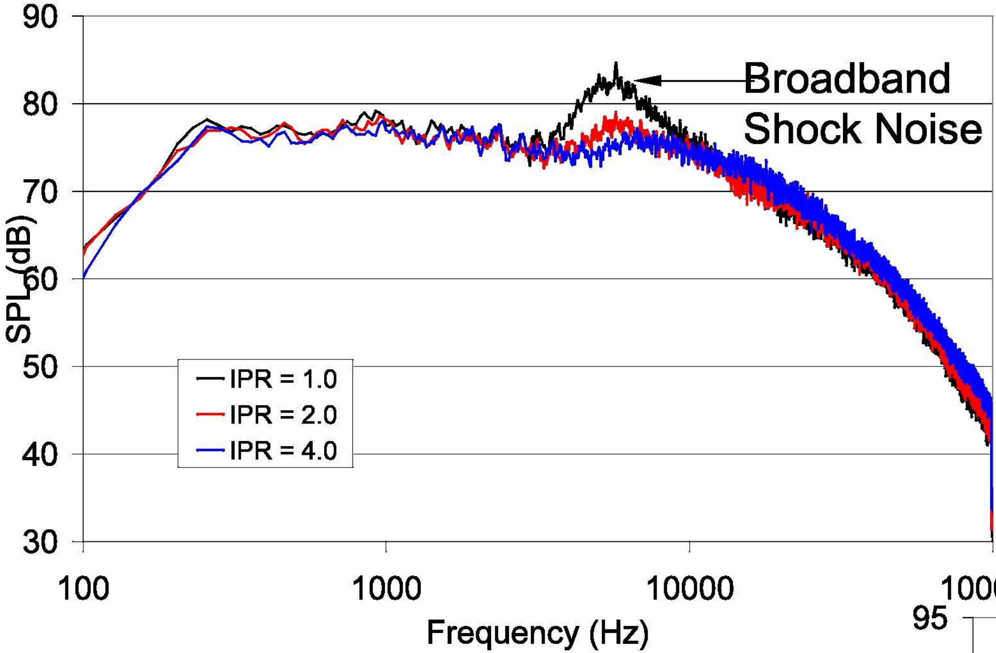
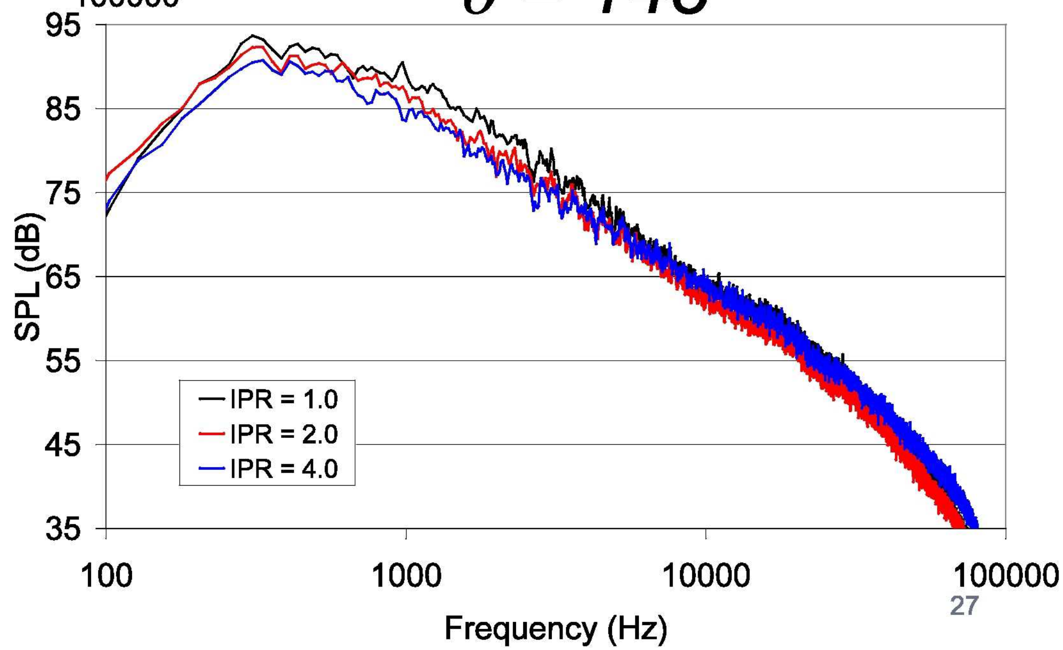
Single Supersonic Stream - Gen II



$\theta = 61^o$

Increasing IPR reduces shock noise and mixing noise

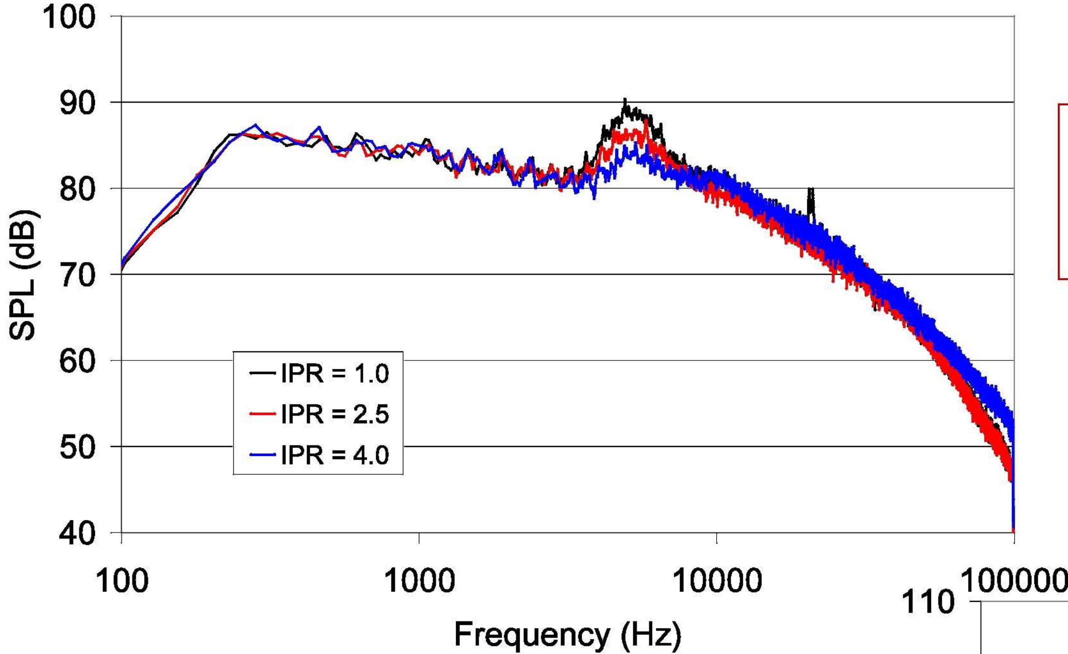
$\theta = 148^o$



$NPR_c = 2.17$

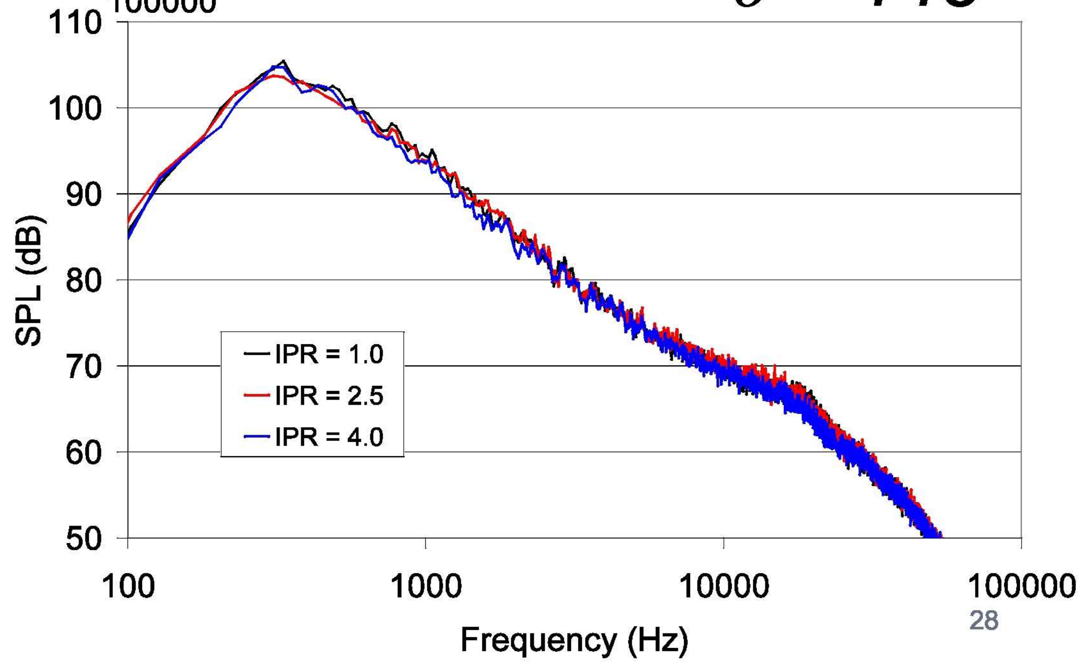
Cold

Supersonic Fan, Transonic Core–Gen II



Increasing IPR decreases shock noise

$\theta = 148^o$



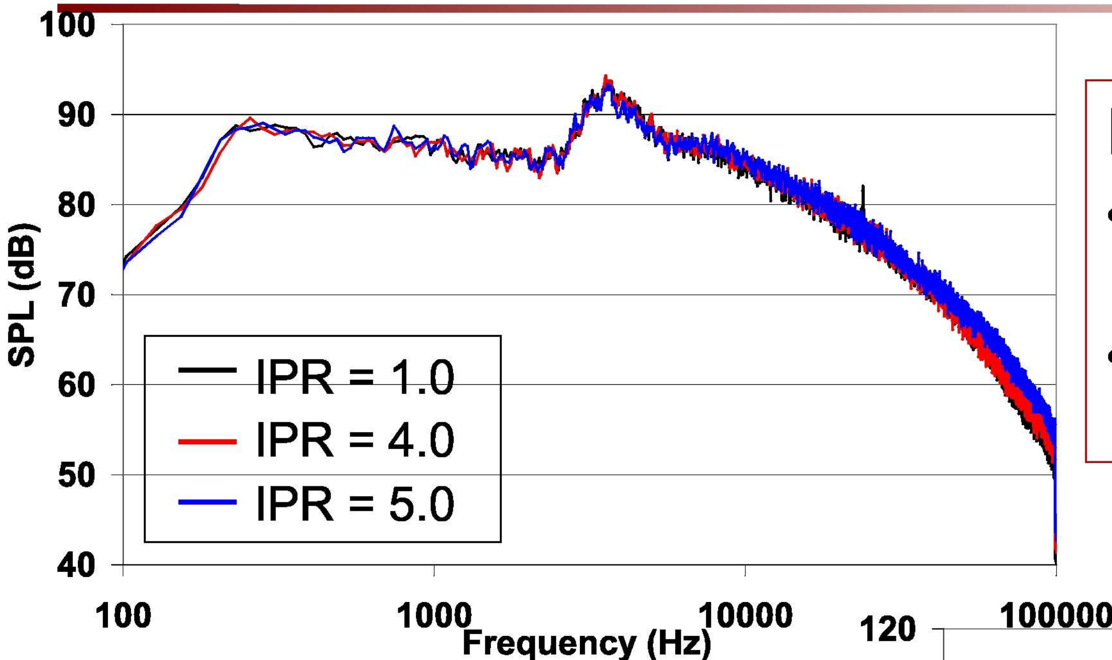
$\theta = 61^o$

$NPR_c = 1.61$

$NPR_f = 2.23$

Hot Core

Supersonic Fan, Transonic Core–Gen II

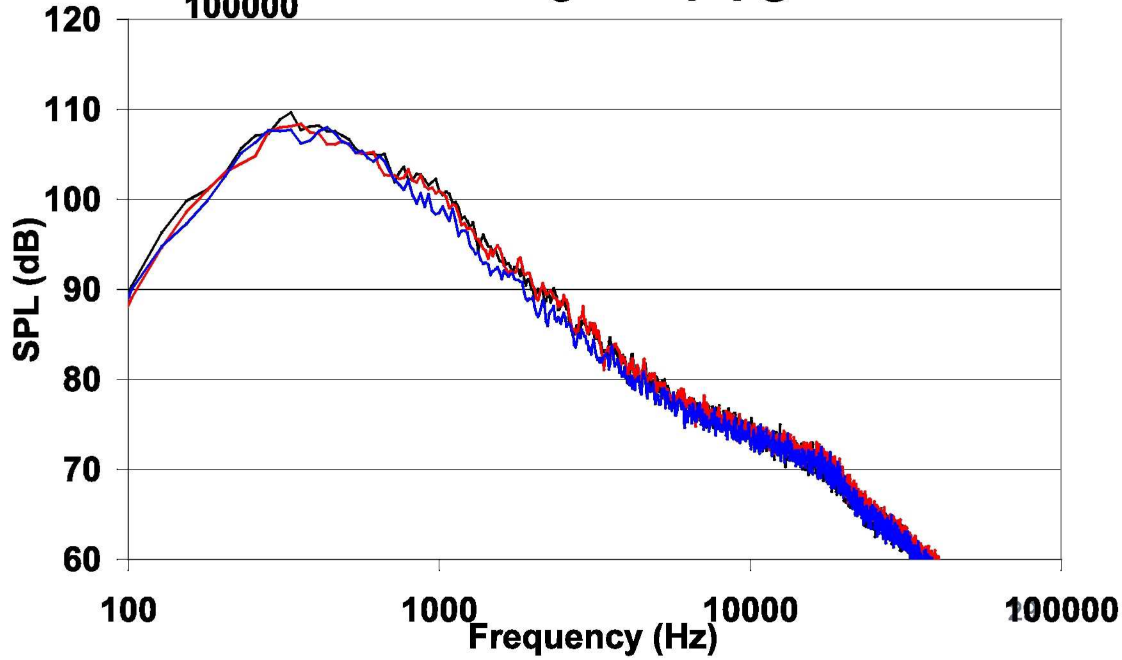


$\theta = 61^o$

Increasing IPR

- Has no impact on broadband shock noise
- Slightly reduces noise at peak jet noise angle

$\theta = 148^o$



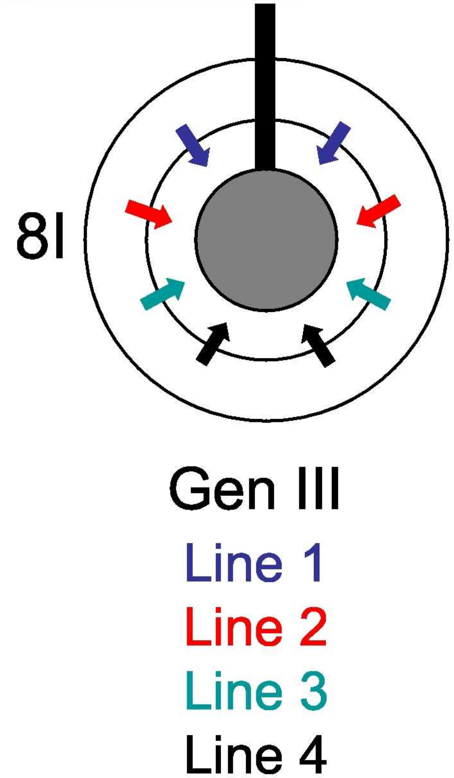
$NPR_c = 1.82$

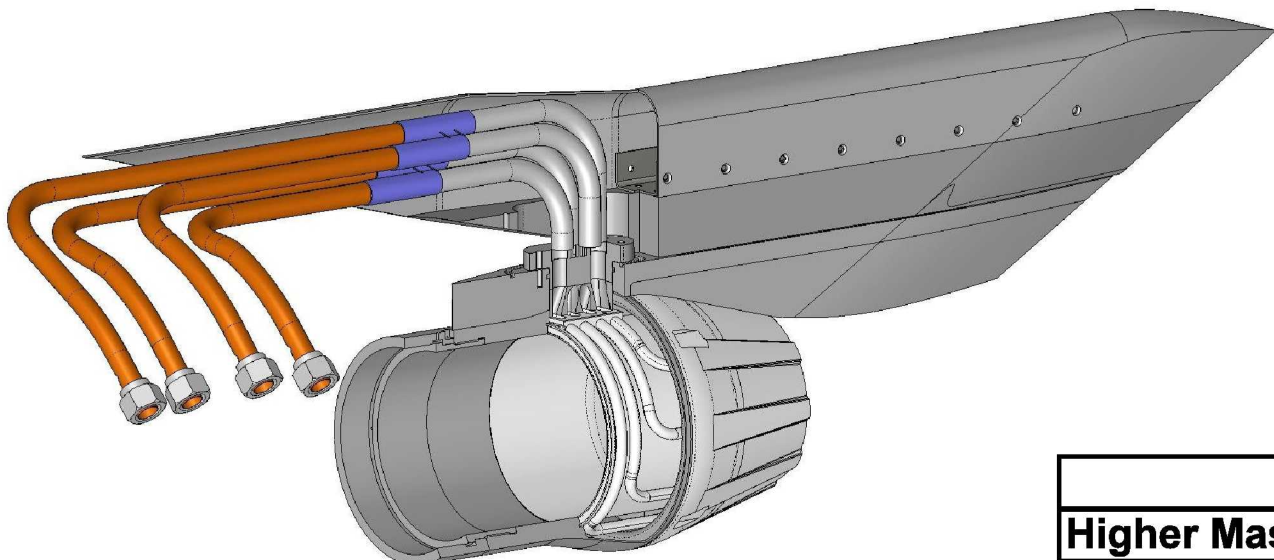
$NPR_f = 2.35$

Hot Core

Generation III Nozzle Azimuthally Controlled

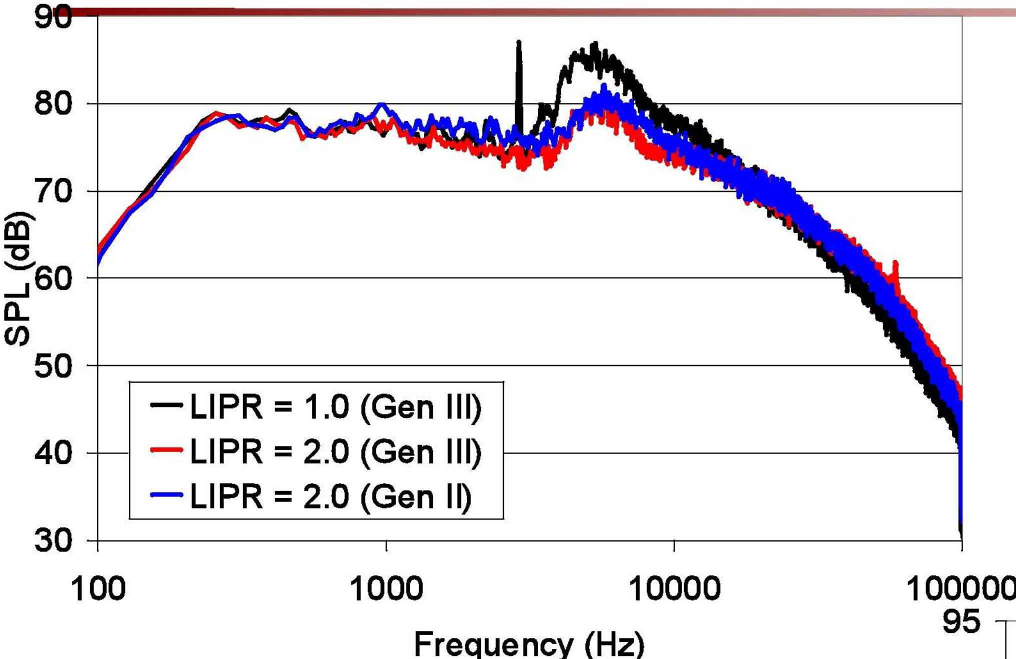
- 8 Inflow injectors
  - 4 pairs independently controlled
- No common plenum





	Gen II	Gen III
Higher Mass Flow	●	
Steeper Injection Angle		●
Greater # of Injectors		●
Azimuthal Control		●

Single Supersonic Stream – Gen II & III



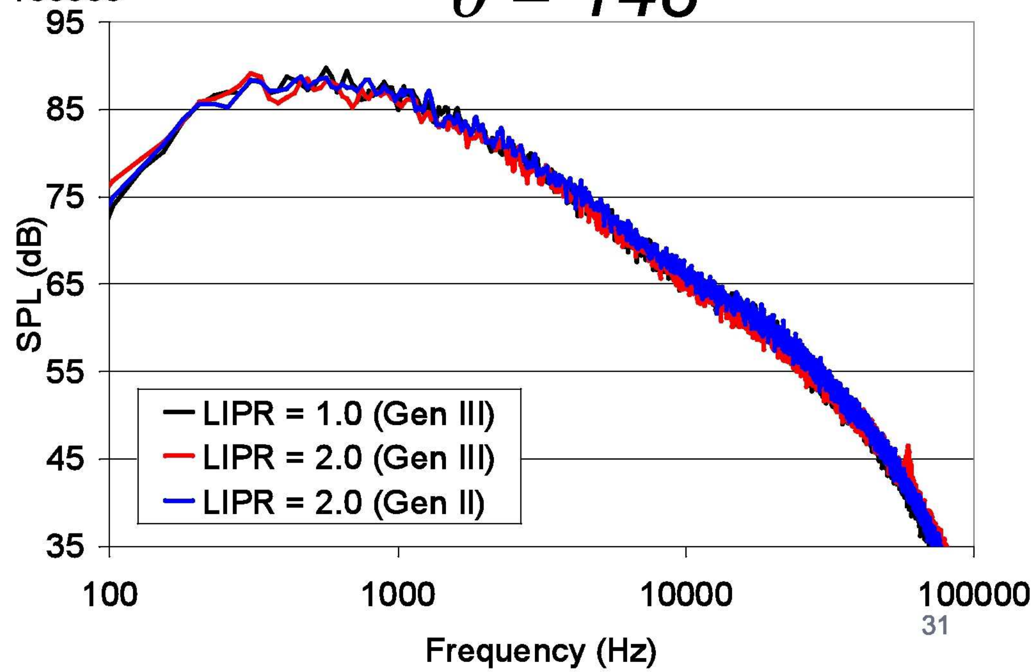
$\theta = 61^o$

$NPR_c = 2.18$
Cold

Similar shock noise reductions for Gen II and III

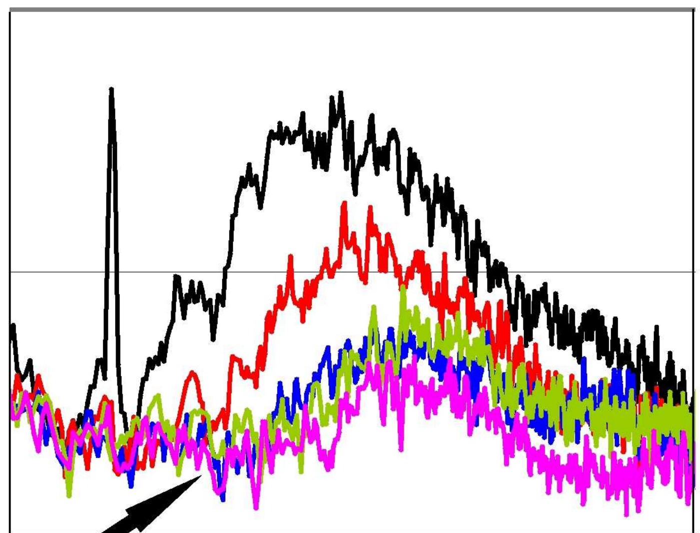
$MFR_{injectGenIII} = 0.8\%$
$MFR_{injectGenII} = 1.9\%$

$\theta = 148^o$

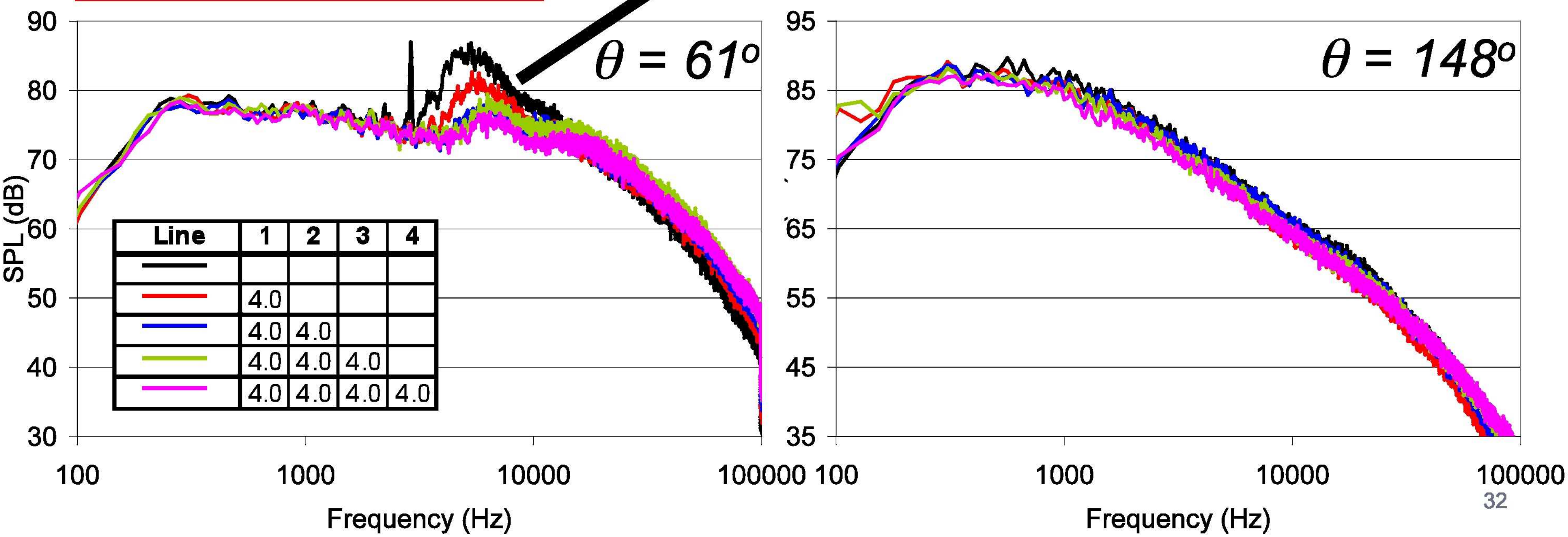


Effect of Azimuthal Control

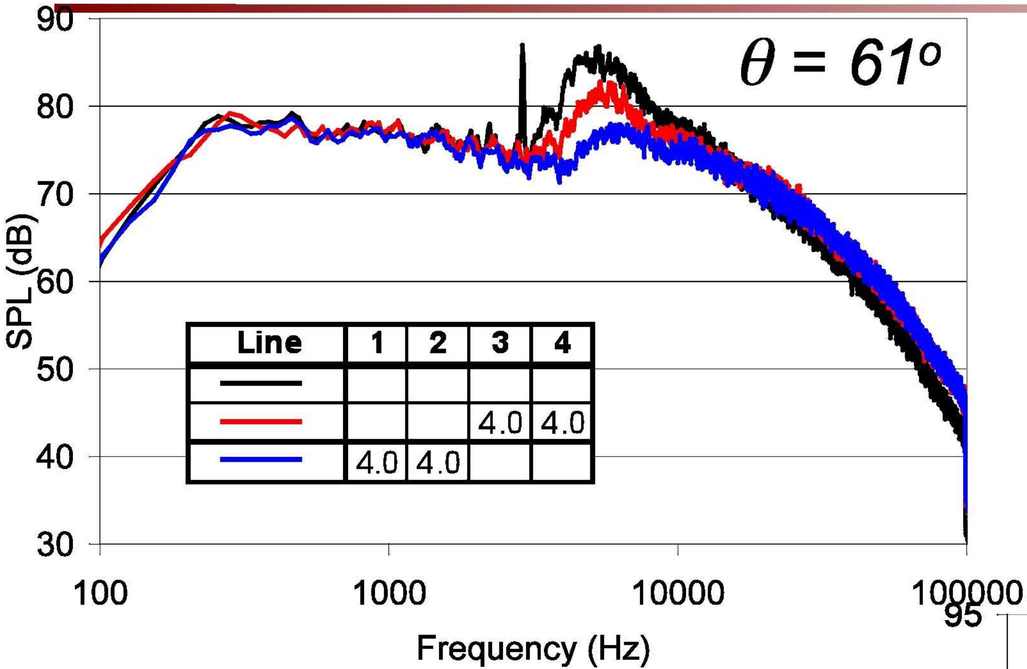
- One injection line needed for significant shock noise reduction
- Some mixing noise reduction with four lines



$NPR_c = 2.18$

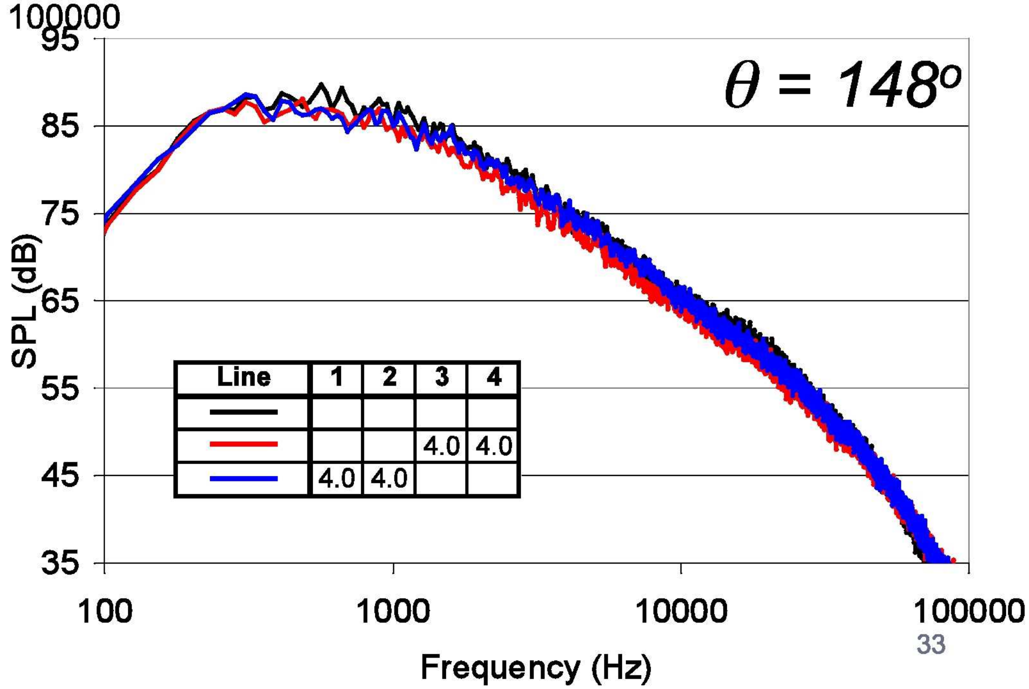


Effect of Azimuthal Control

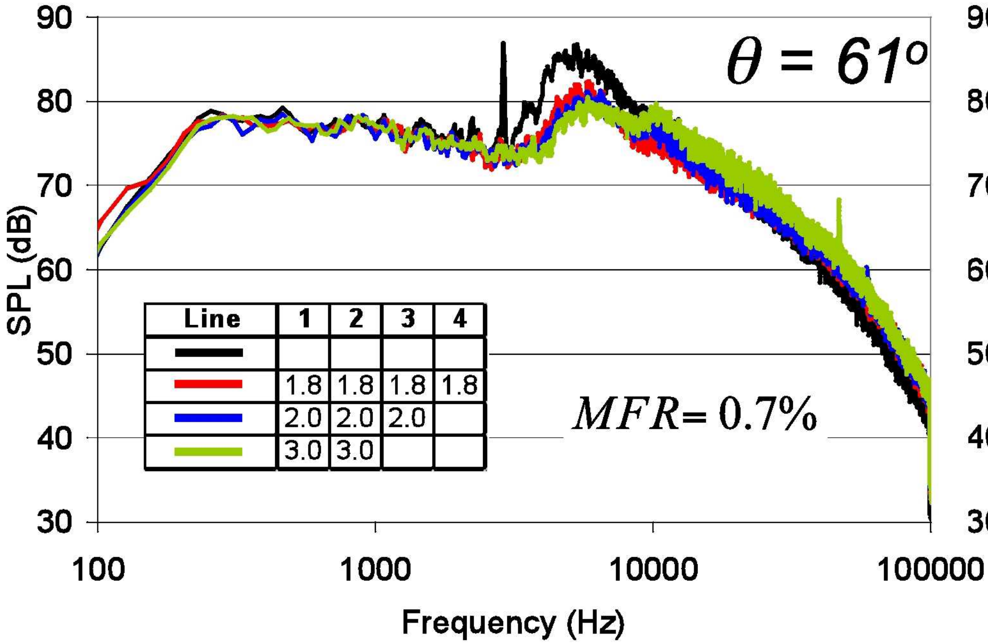


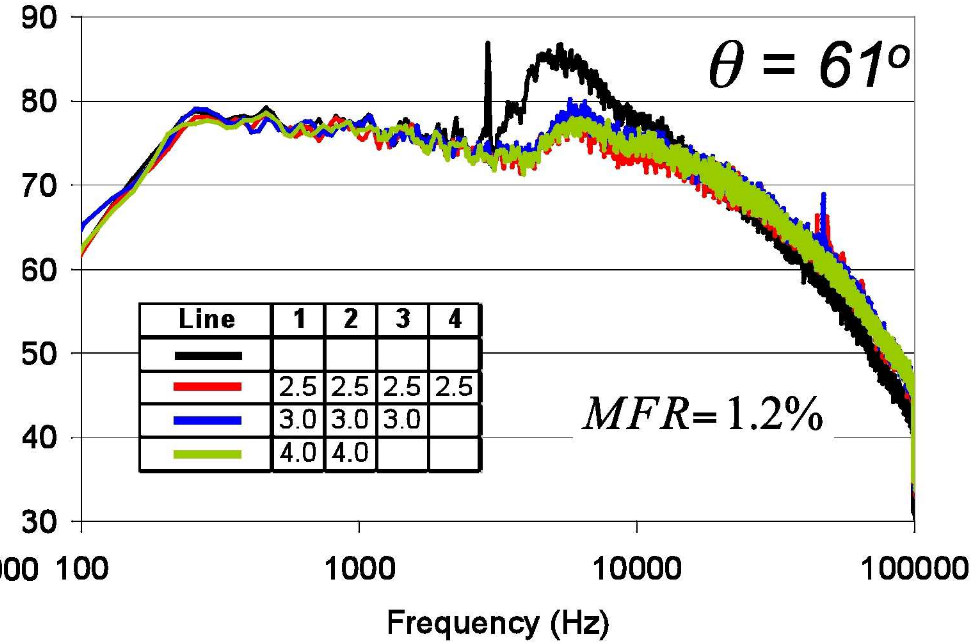
Injection near pylon reduces shock noise more than injection at other azimuthal locations

$NPR_c = 2.18$



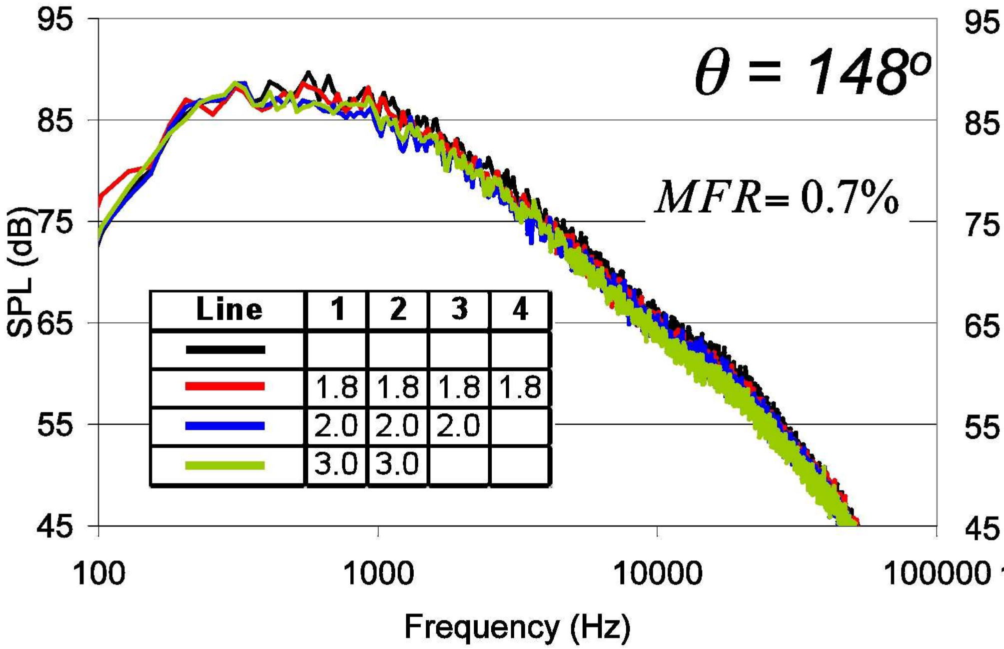
Equal Mass Injection

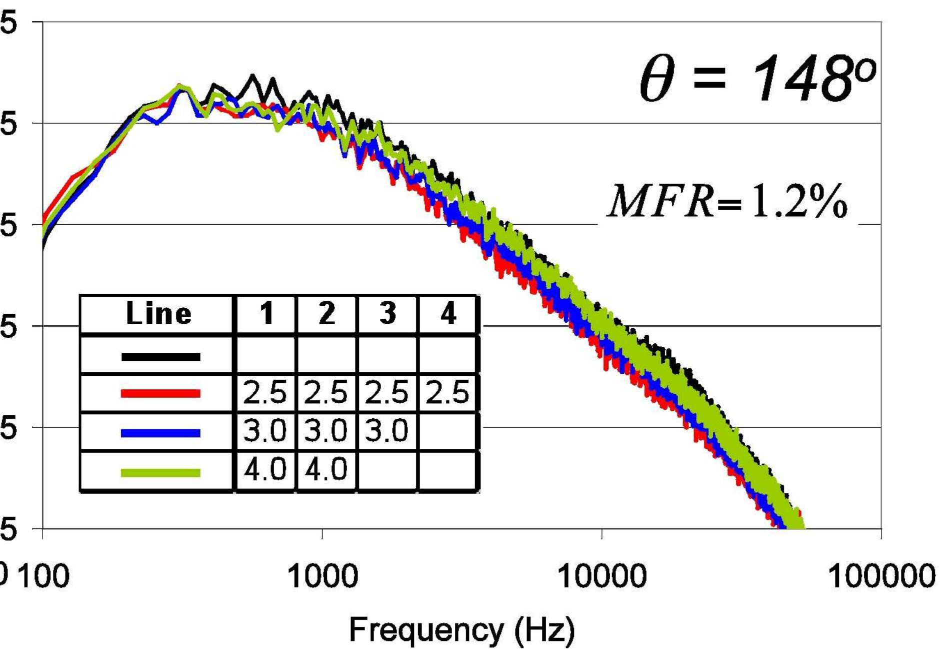




$NPR_c = 2.18$

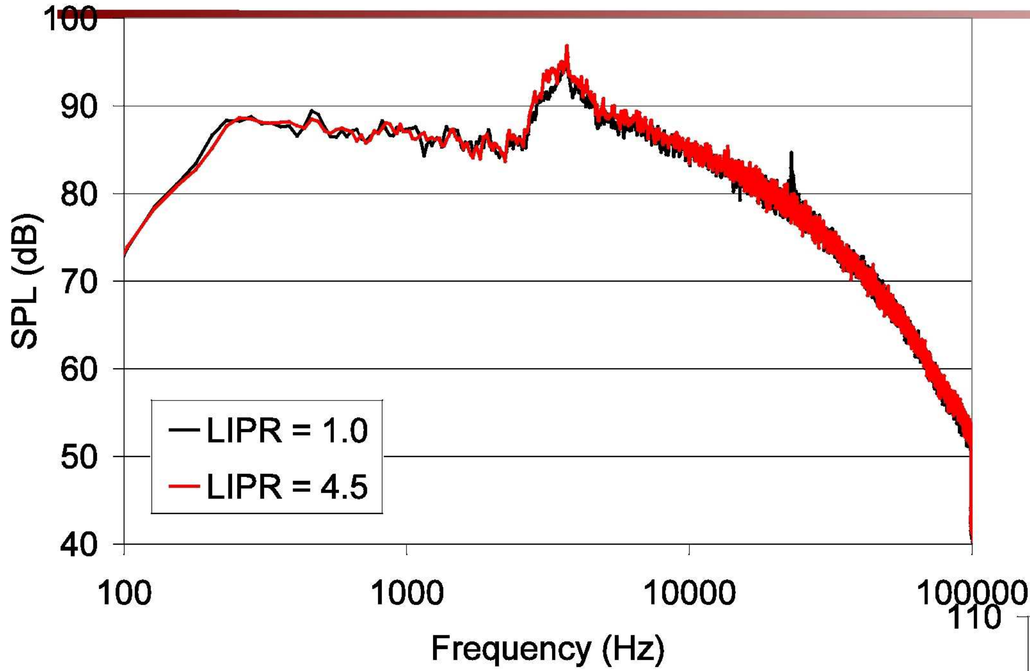
Equal Mass Injection





$NPR_c = 2.18$

Supersonic Fan, Transonic Core–Gen III

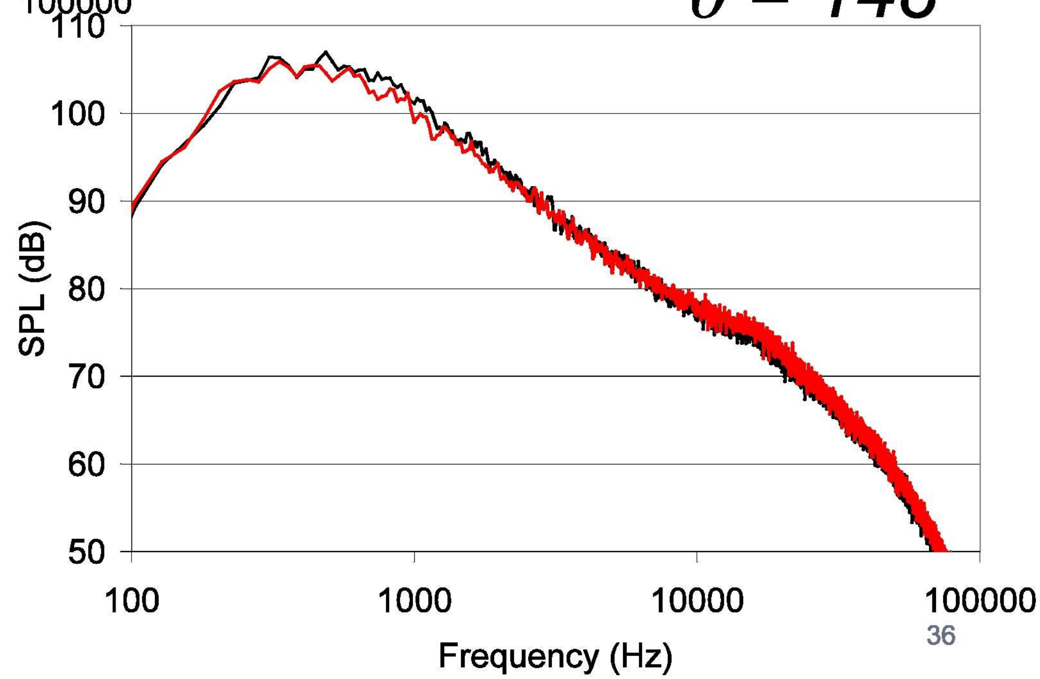


- No shock noise reduction
- Little mixing noise reduction

$\theta = 61^o$

$NPR_f = 2.36$
$NPR_c = 1.82$

$\theta = 148^o$

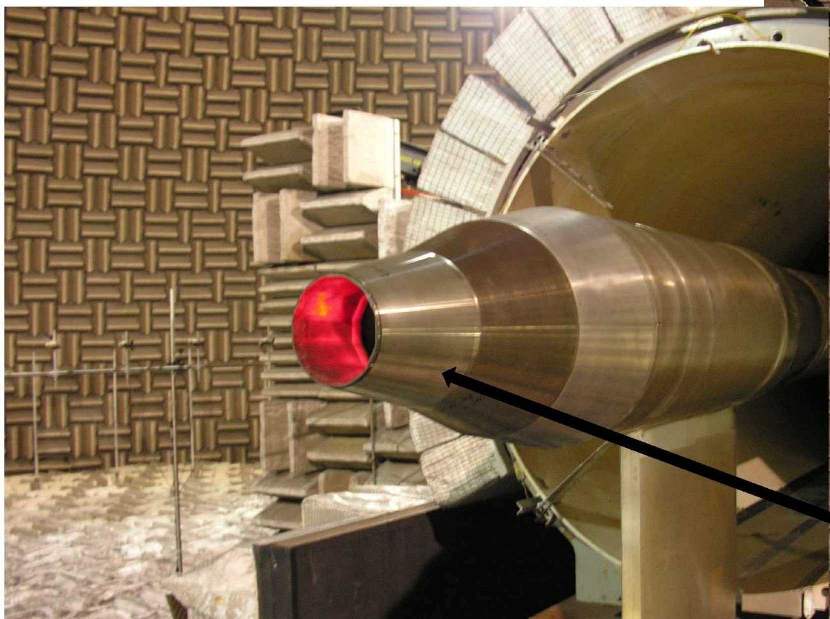


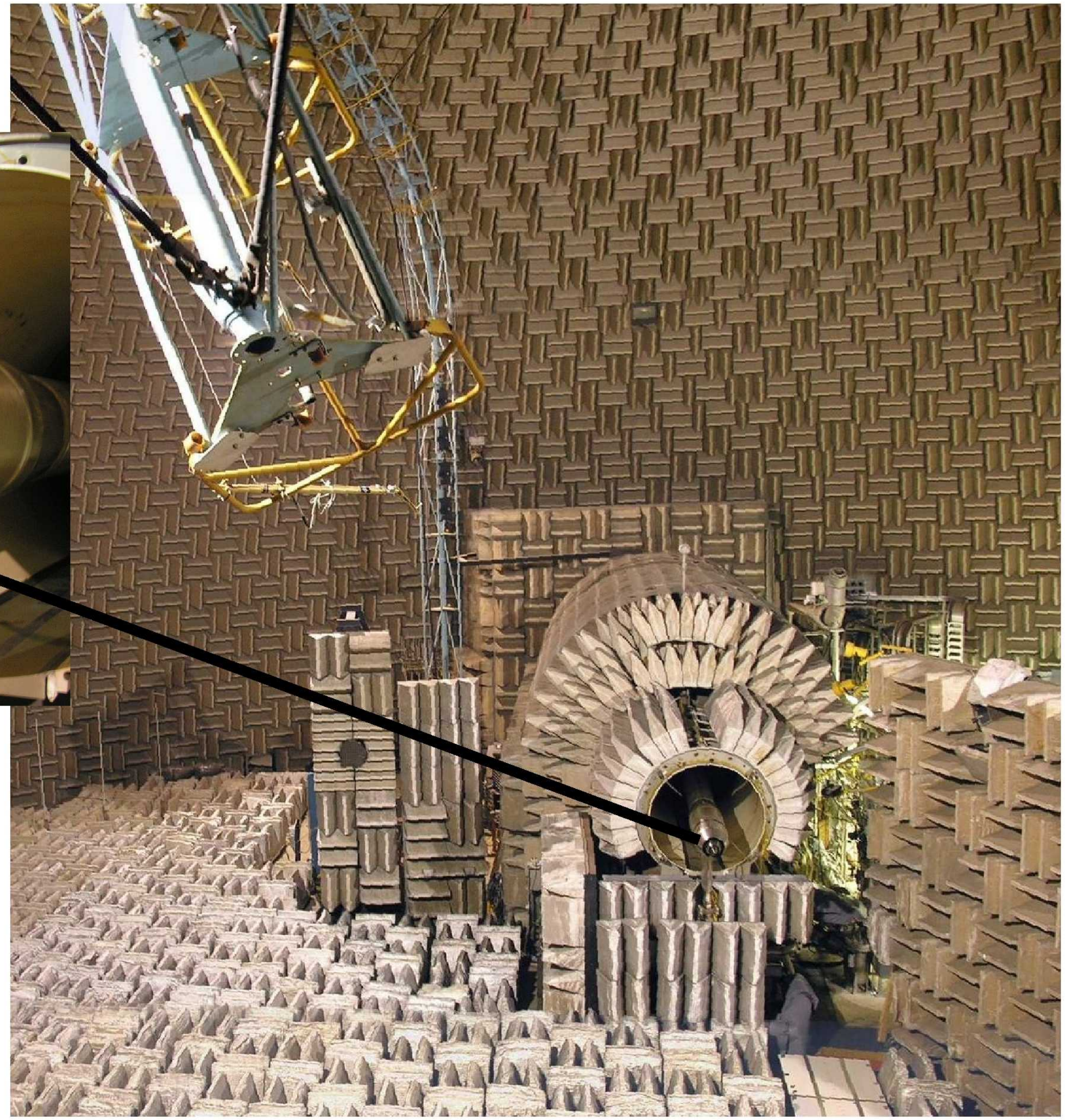
Overview

- Brief history of fluidic injection
  - Water and air
- NASA's acoustic measurements since 2002 on air injection
  - Subsonic dual-stream jets
    - Generation I nozzles
    - Generation II nozzles

  With Goodrich Aerostructures
  - Supersonic jets – Generation II and III
- NASA's flow-field measurements - 2009
- Concluding remarks

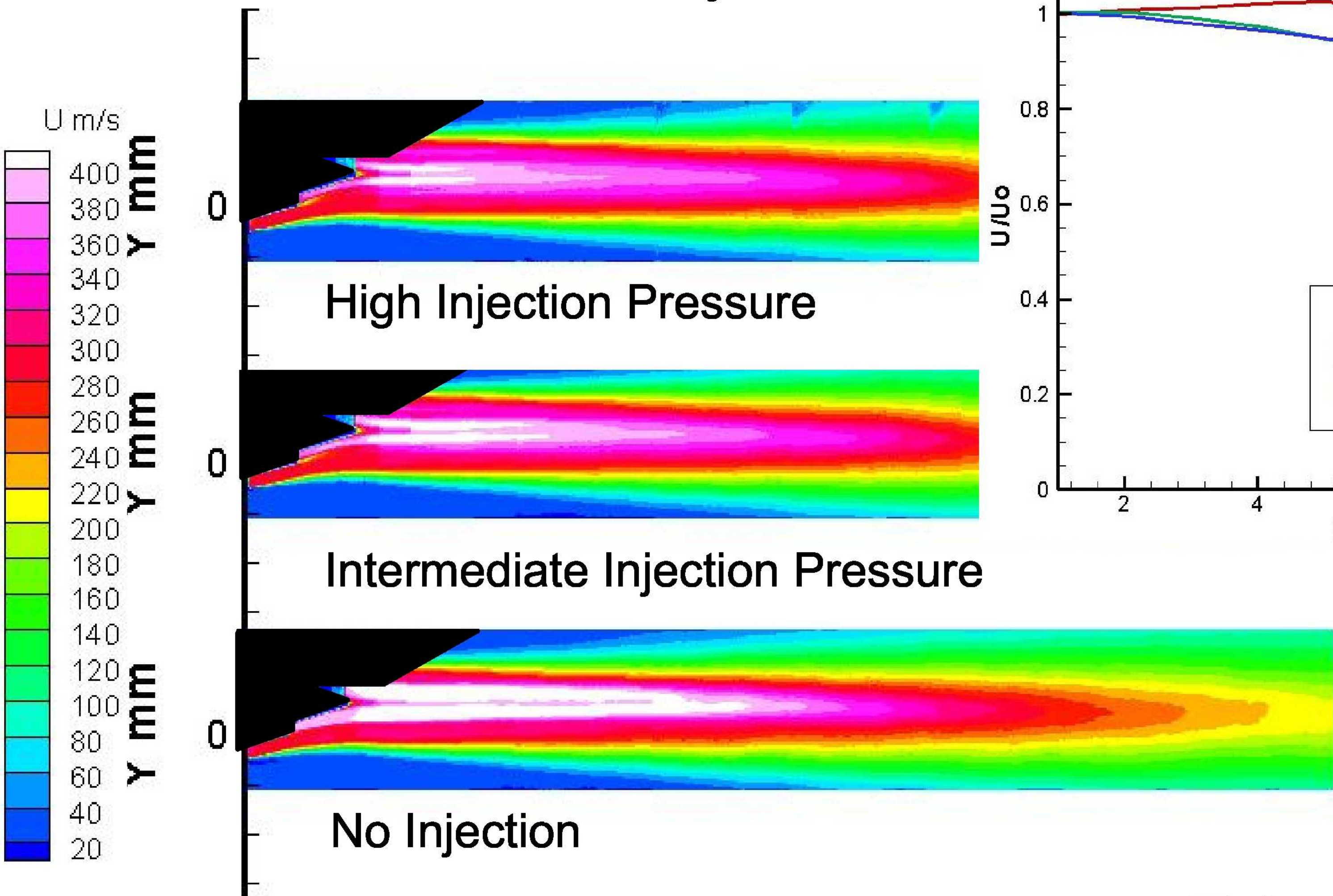
Aero-Acoustic Propulsion Laboratory
Glenn

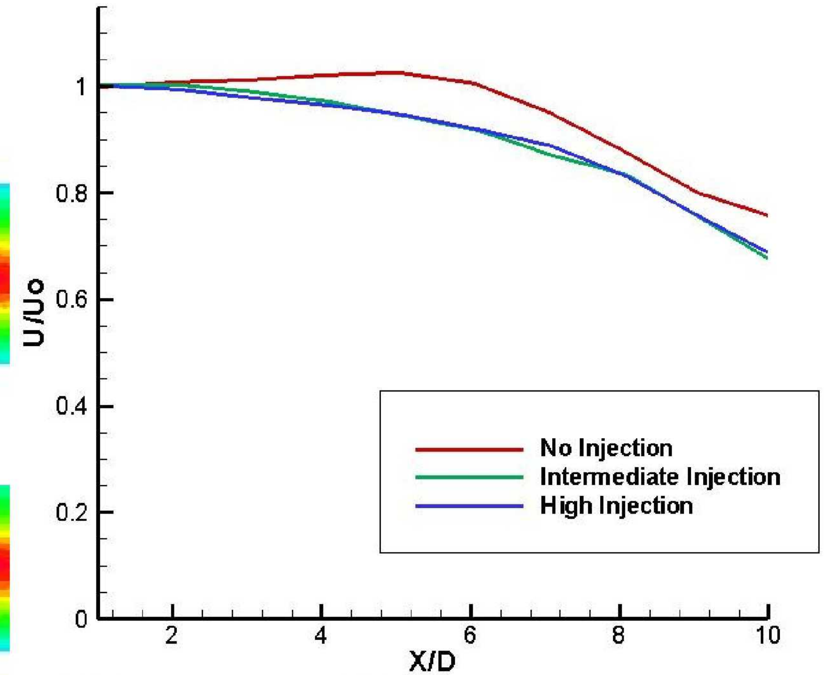




Subsonic Dual Stream – Gen II

Mean Velocity

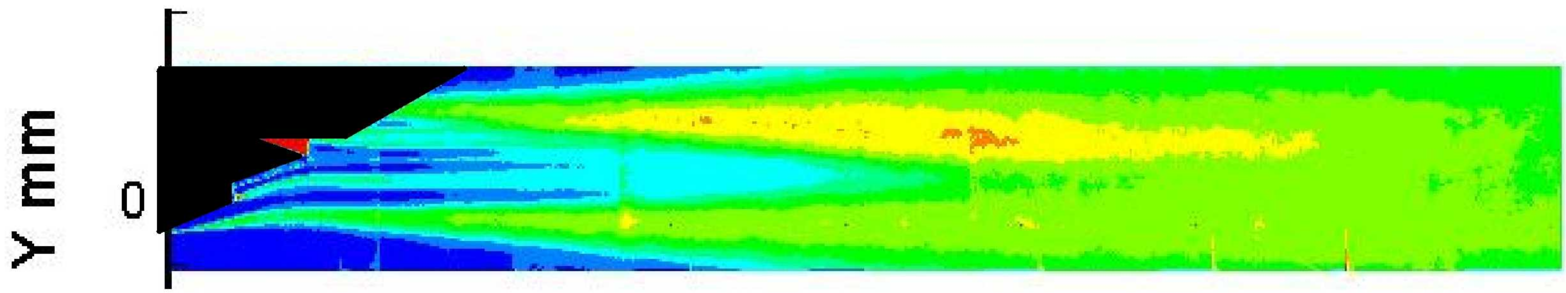




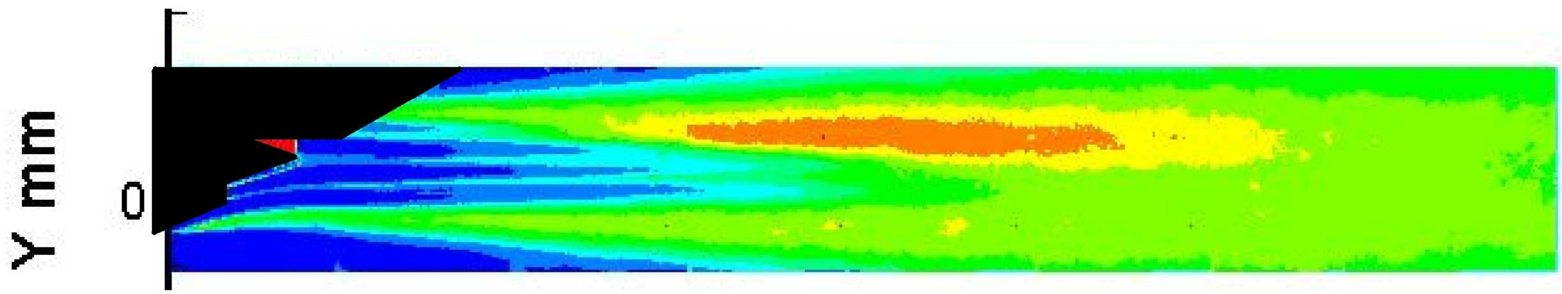
Takeoff

Subsonic Dual Stream – Gen II

Turbulence



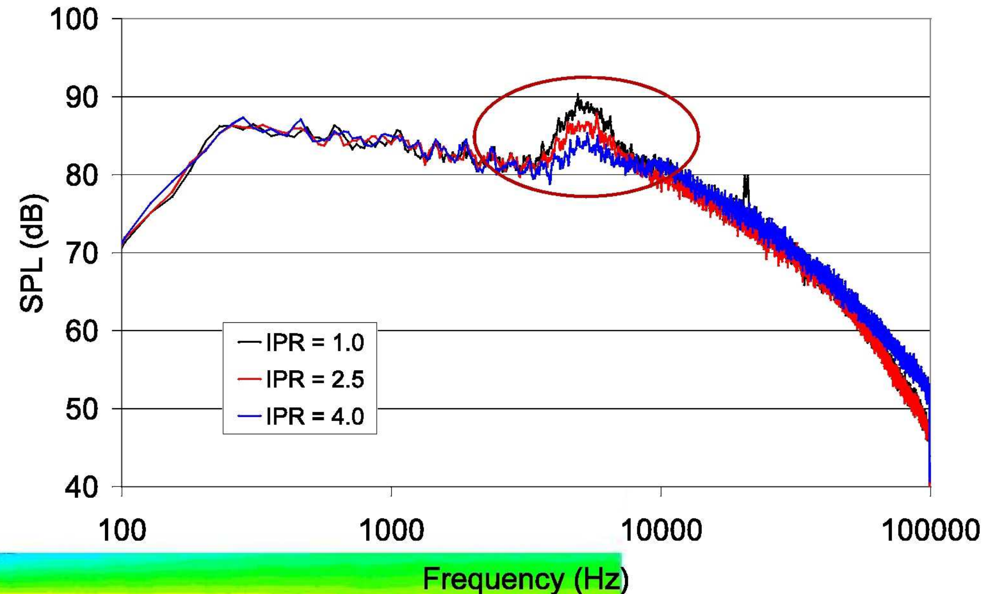
Intermediate Injection Pressure

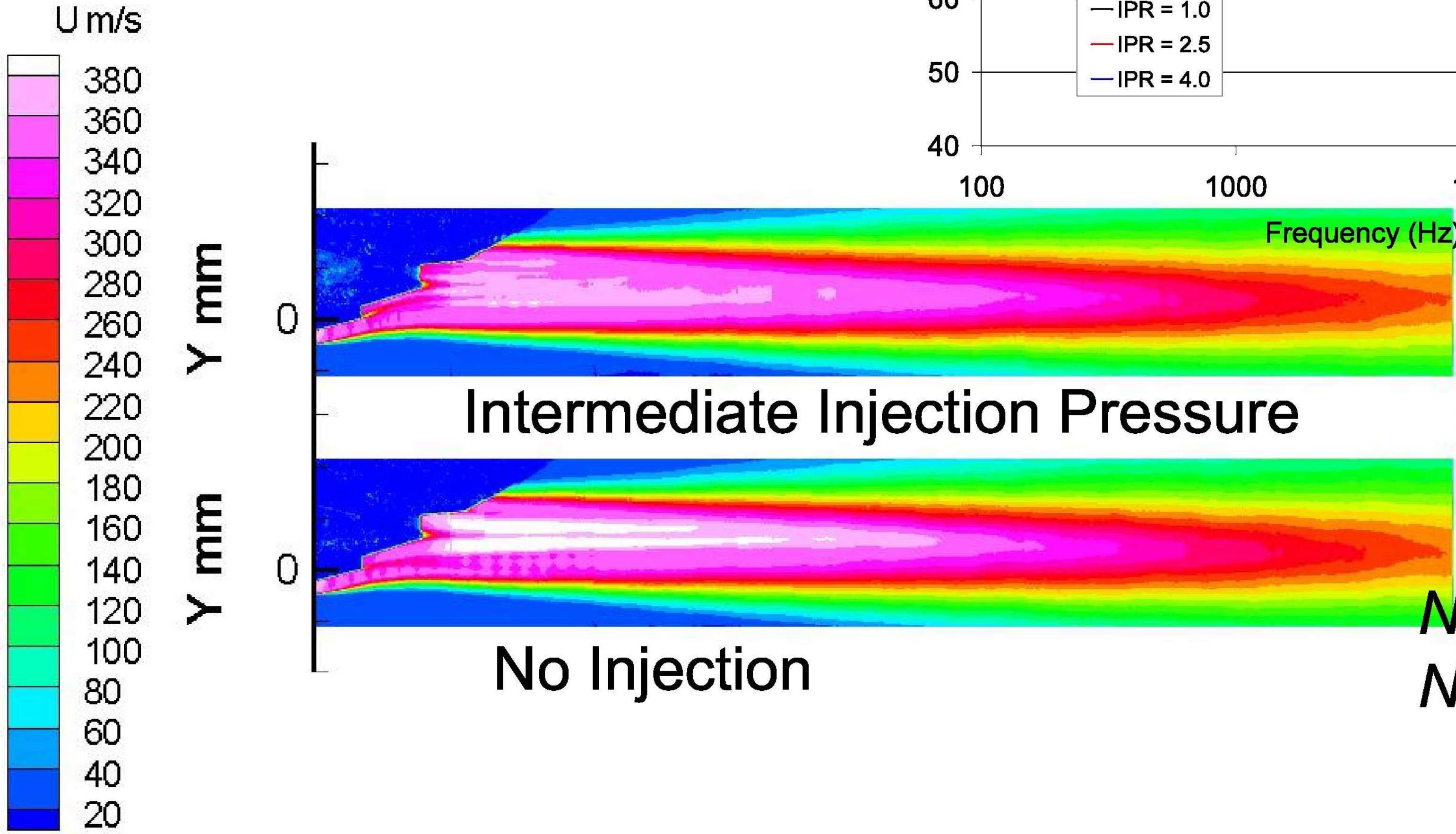


No Injection

Takeoff

Supersonic Fan, Transonic Core–Gen II





NPR_c = 1.61
NPR_f = 2.23
Hot Core

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Conclusions

- Noise reduction in subsonic dual-stream jets
  - Control injection angle and location
  - Control nozzle trailing edge thickness
- Noise reduction in single stream supersonic jets
  - Broadband shock noise controlled with moderate injection pressure
  - Higher pressures are required for mixing noise reduction
- Noise reduction in dual-stream supersonic jets
  - Limited reduction possible with core injection

NASA