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Adaptive Flow Control Of Supersonic Impinging Jets

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Background

- **The feedback loop leading to self-sustained flow oscillations and high amplitude acoustic tones occurs in a number of flows**
  - ***Impinging Tones*, *Jet screech, Edge Tones***

- **Leads to a number of performance diminishing effects.**
  - ***Increased Noise, Sonic Fatigue and Ground Effects*** **(STOVL Aircraft)**

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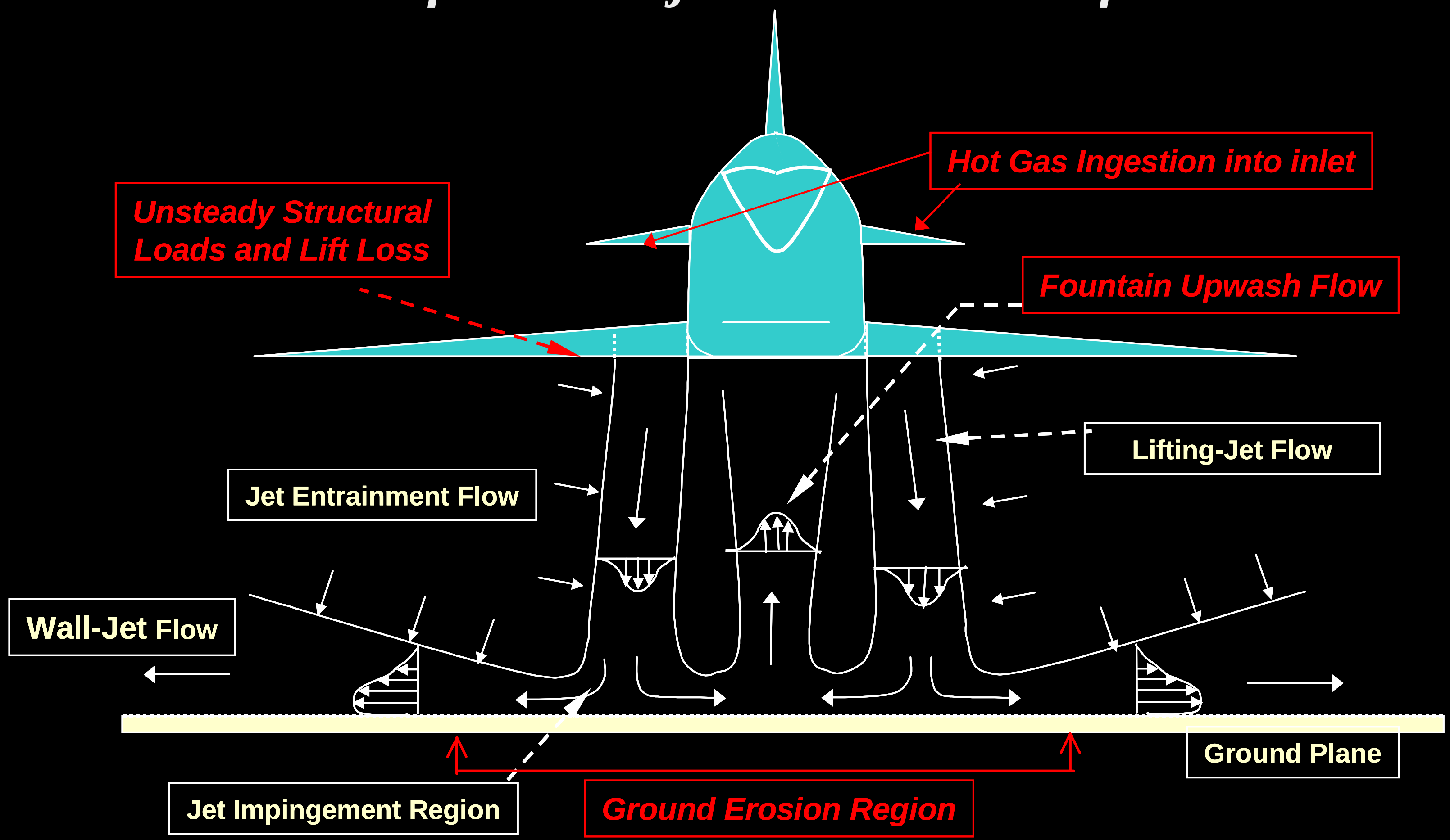
Motivation

Flow schematic for a twin jet STOVL aircraft in hover



Goal

- **To actively and efficiently control the jet behavior by disrupting the feedback loop.**
    - **Reduce: Tones, OASPL and other related adverse effects**

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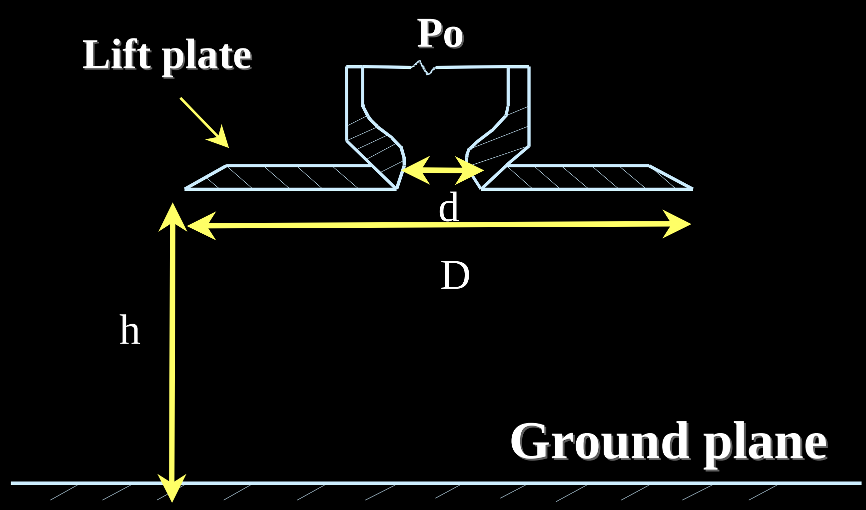
Experimental Details



Parametric Space

NPR (Po/Pa)	=	3.7 & 5.0
h/d	=	2.0 - free
Nozzle	=	Mach 1 & 1.5
Microjet Press.	=	80 - 120 psi

DIAGNOSTICS

- Unsteady Pressures
  - Ground & Lift Planes
- Acoustic
- Flow visualization
  - Shadowgraph
  - Planar Laser Scattering (PLS)
- Mean Pressures
  - Ground & Lift Planes
- PIV

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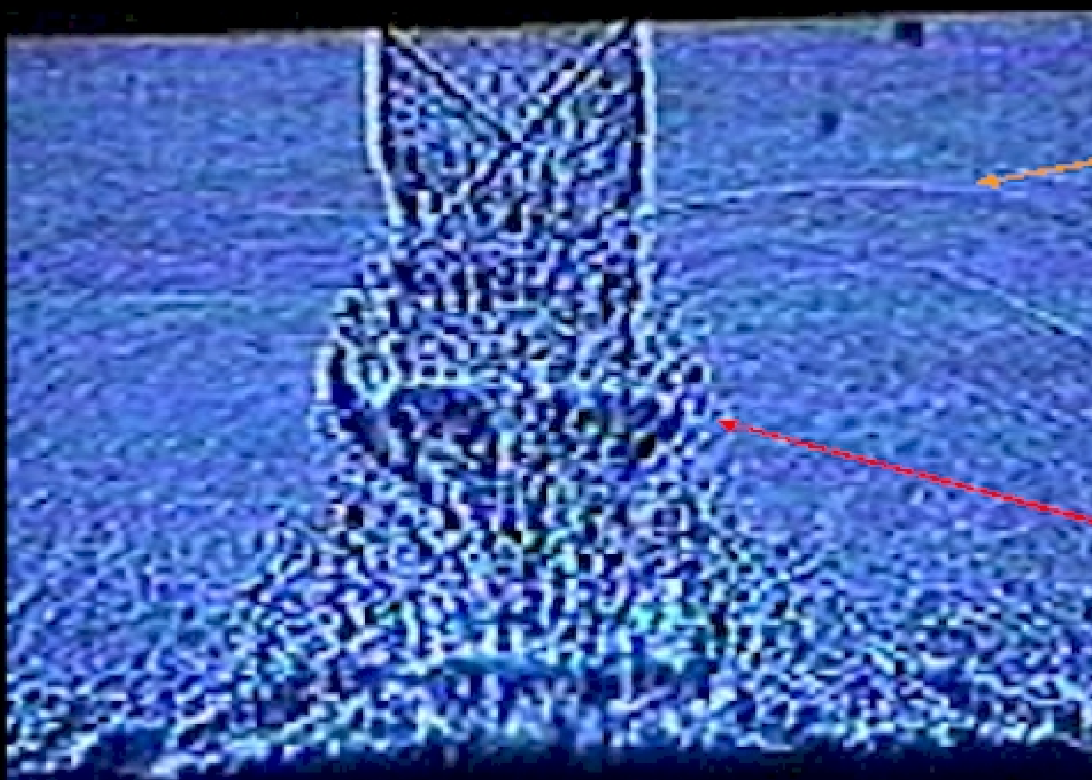
Test Model and Facility

Lift plate

Ground plate

Instantaneous Shadowgraphs
Uncontrolled Jet



Upstream-propagating acoustic waves

Downstream-travelling instability structure

NPR=3.7, h/d=4, No Control

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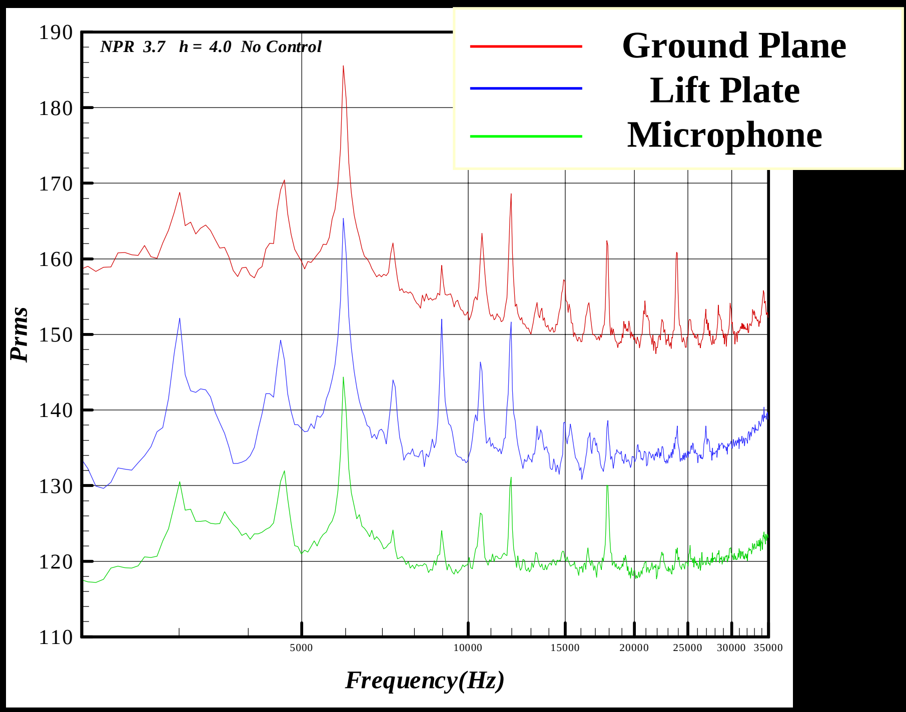
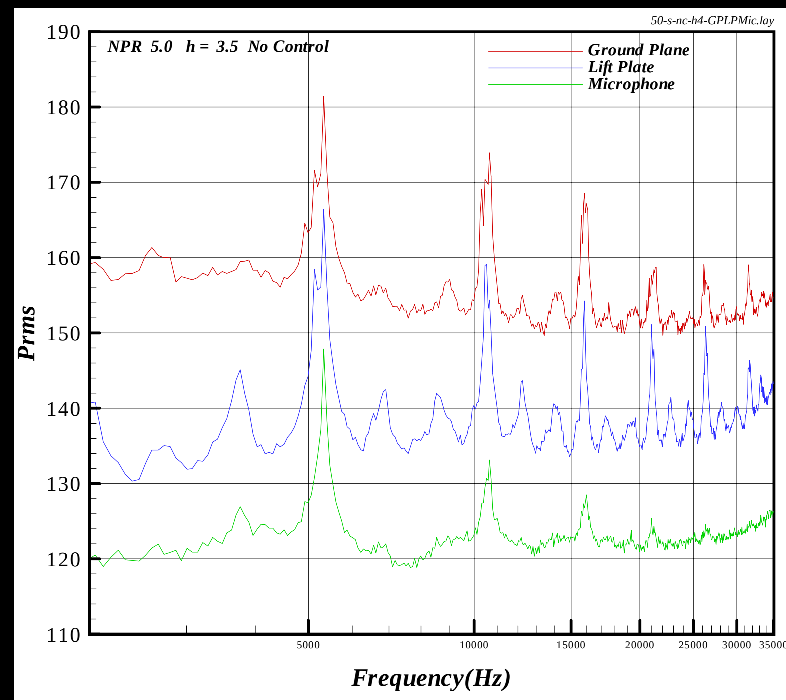
Experimental Results
Unsteady Pressure Spectra



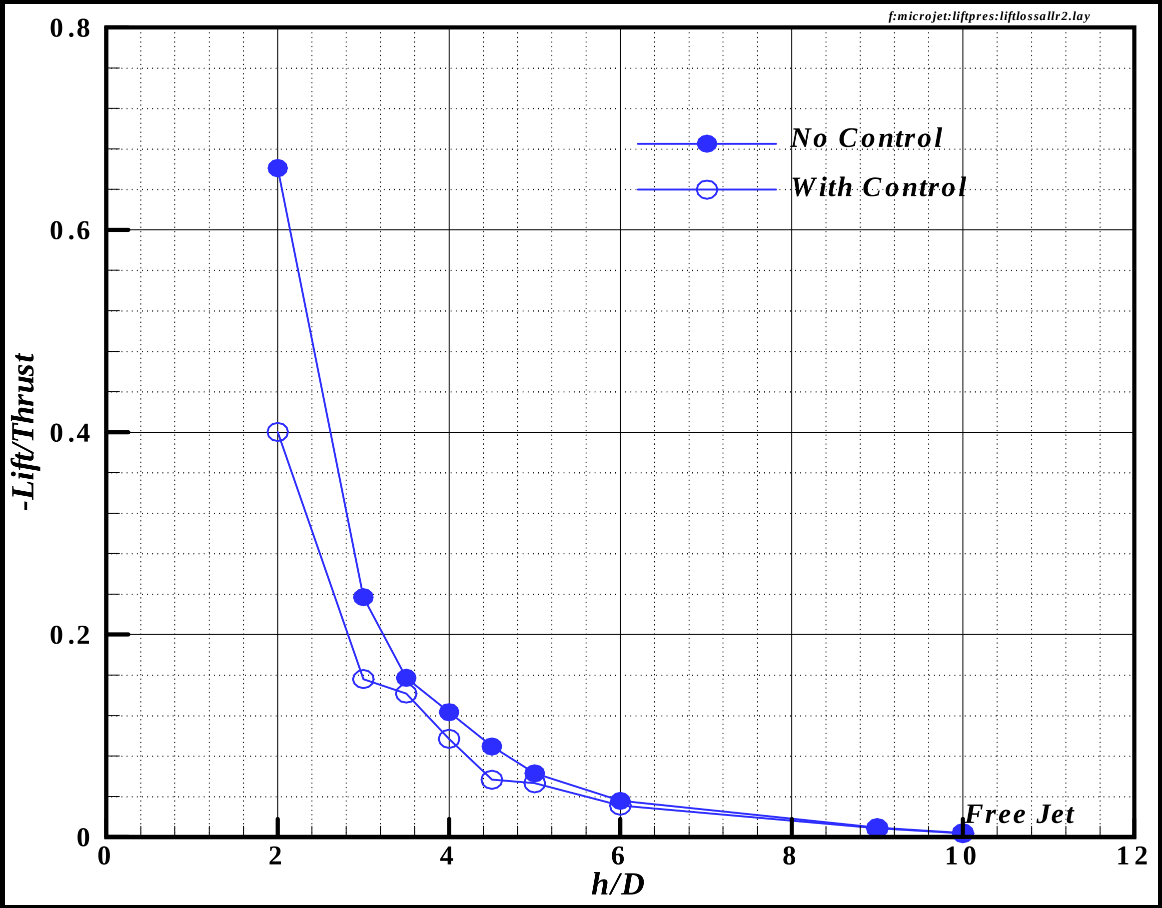


NPR = 3.7 h/d=4.0 No Control **NPR = 5.0 h/d=3.5 No Control**

Unsteady Pressure Loads:
Ground Plane ~ 185-195 dB
Lift Plate ~ 165-175 dB

Lift Loss

NPR = 3.7



Prior Attempts at Feedback Control

- **Karamcheti et al. (1969) : Edge tone suppression using baffles/plates**
- **Sheplak & Spina (1994): Impinging tone suppression via coflow**
- **Shih et al. (1999): Screech tone suppression using counterflow**
- **Elavarasan et al. (1999): Impinging tone suppression via baffles**

Present Approach

- **Use supersonic microjets to disrupt the coherent flow-acoustic coupling.**
  - **High momentum, small, low mass flow, relatively simple, can be actively manipulated to provide on-demand control.**

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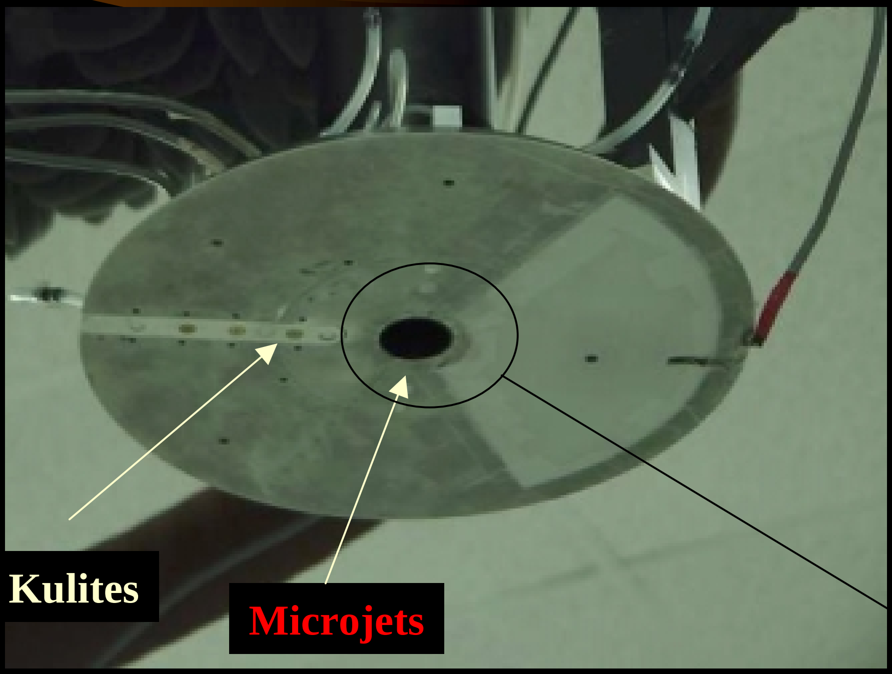
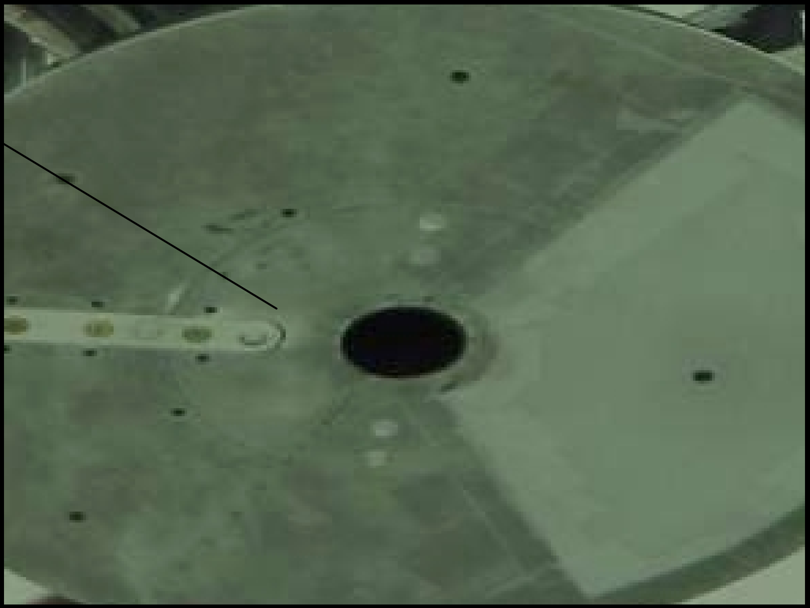
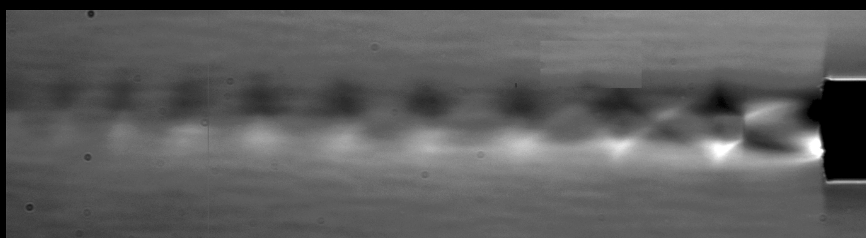
Test Model with Microjets

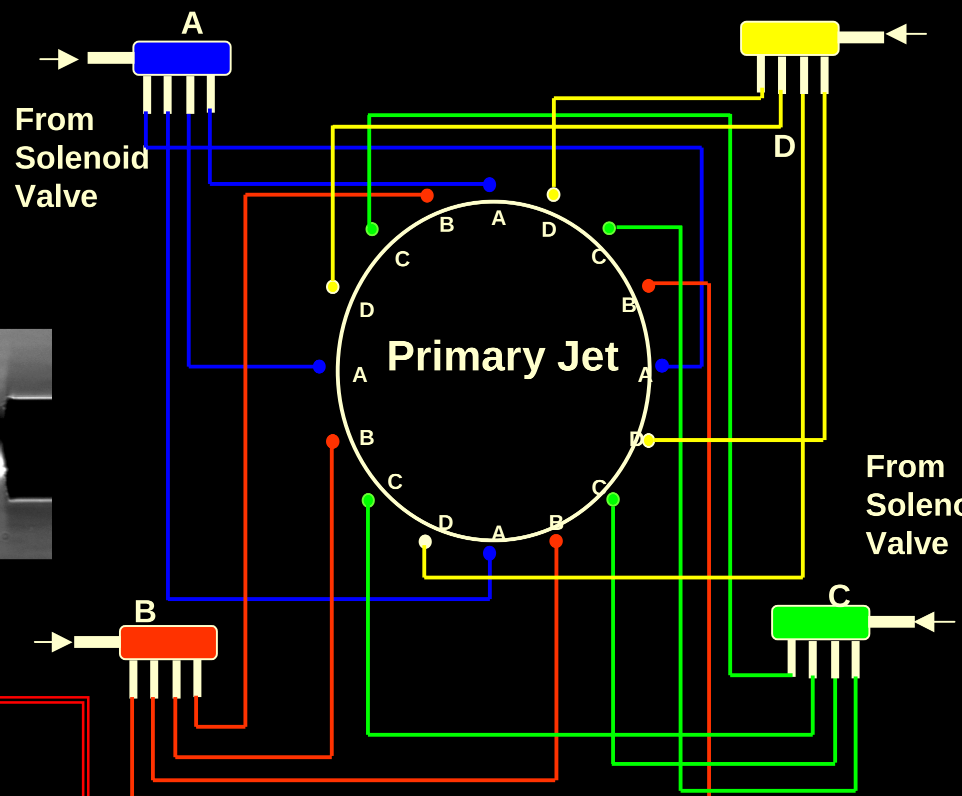




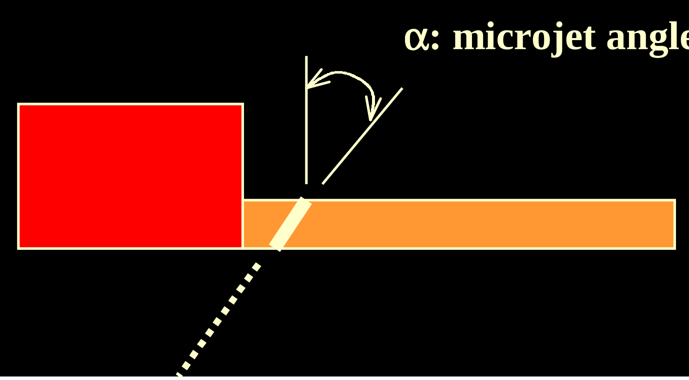
Micro Jet Details

400 μm Jet





- Microjet diameter – 400 μm
- Operating pressure – 80- 120 psi
- Mass flow (total) ~ 0.4% – 0.7 % of main jet
- Operating gas – Nitrogen/Air
- Microjet inclination angle (α) ~20^0 or 90^0



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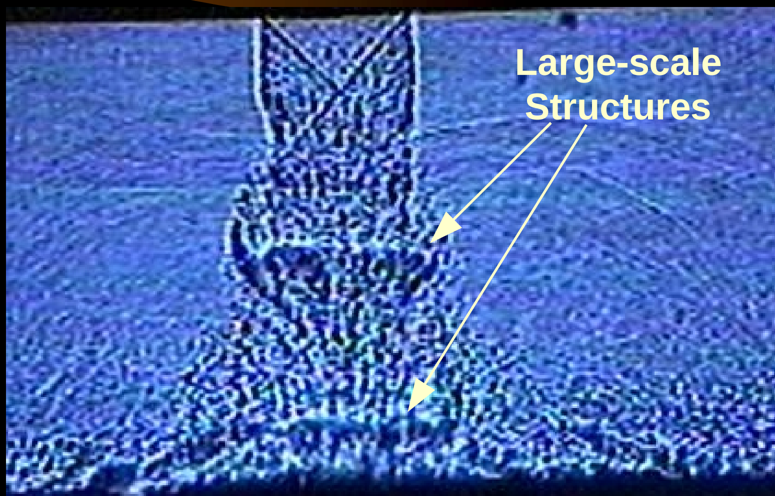
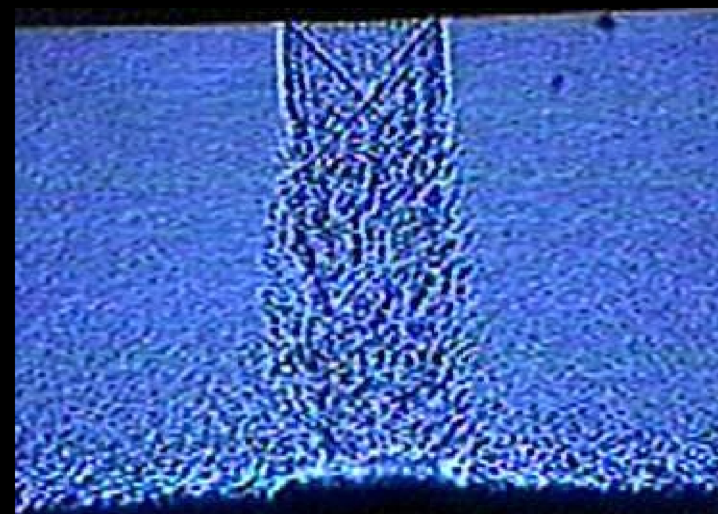
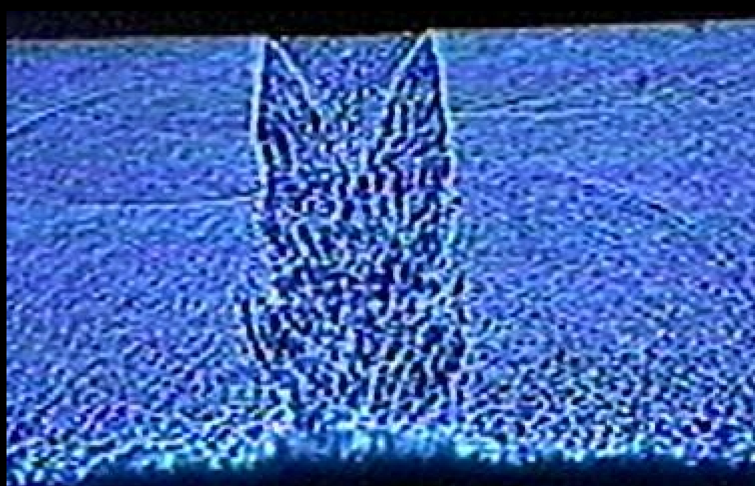
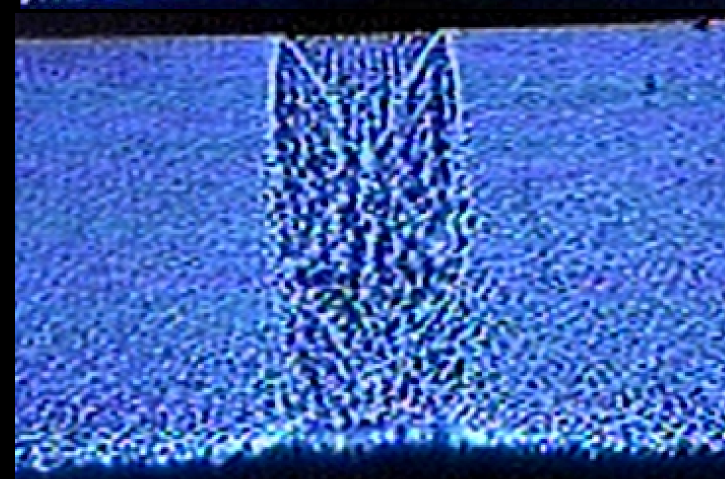
Impinging Jet With and Without Control





NPR 3.7 h/d=4.0





NPR 5.0 h/d=3.5

With Control

No Control

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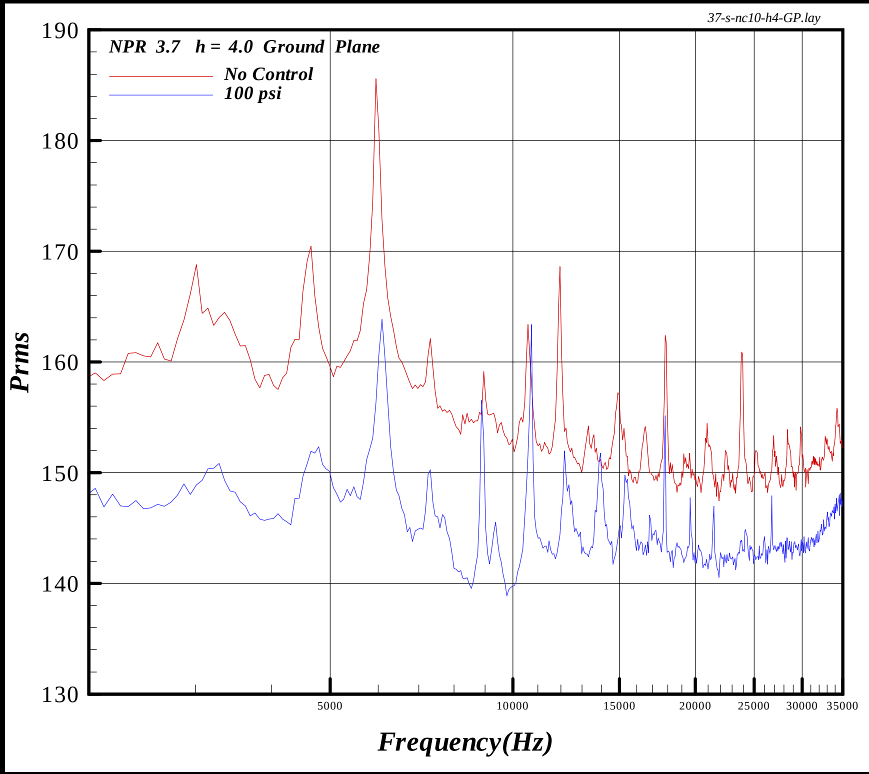
Effect of Microjet Control Noise and Pressure Spectra

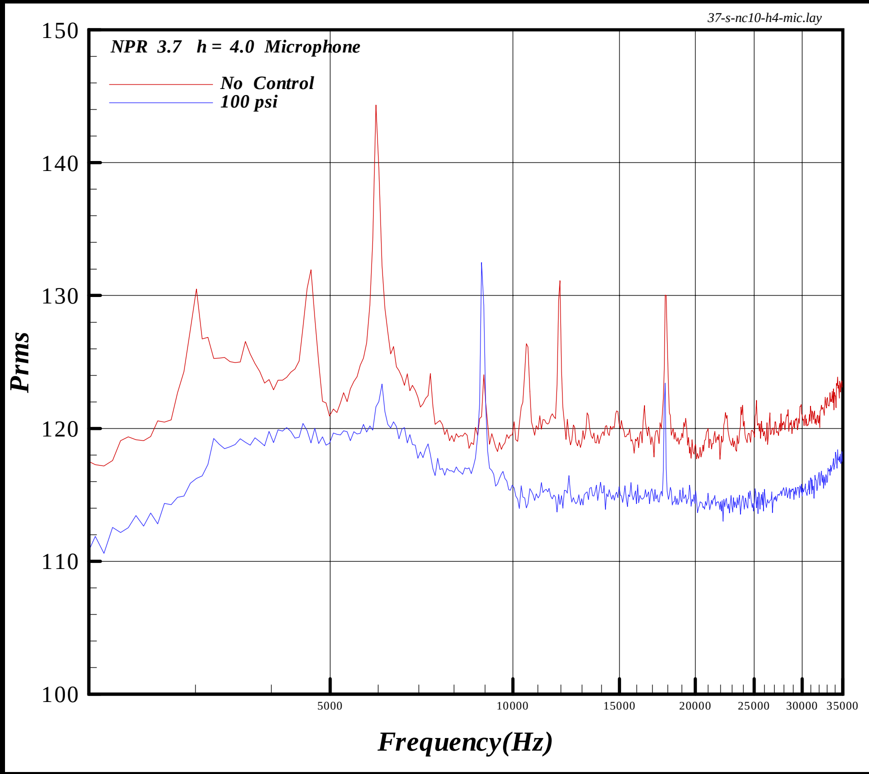
NPR 3.7, h/d=4.0

(20°, 100 psi, 16 microjets)

Ground Plane



Lift Plate

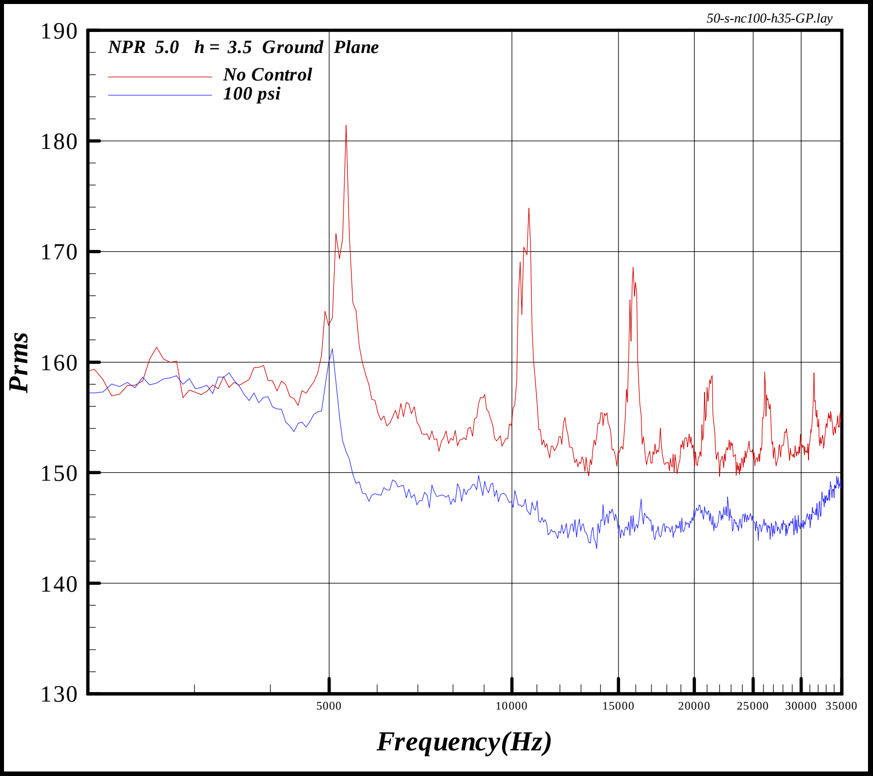


Effect of Microjet Control Noise and Pressure Spectra

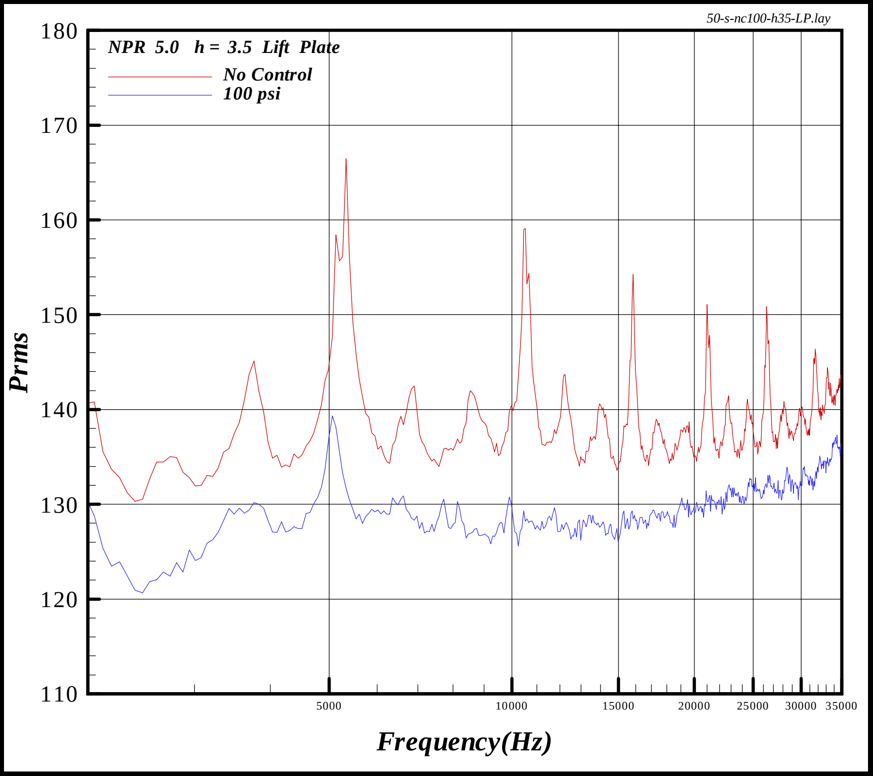
NPR 5.0, h/d=3.5

(20°, 100 psi, 16 microjets)

Ground Plane



Lift Plate



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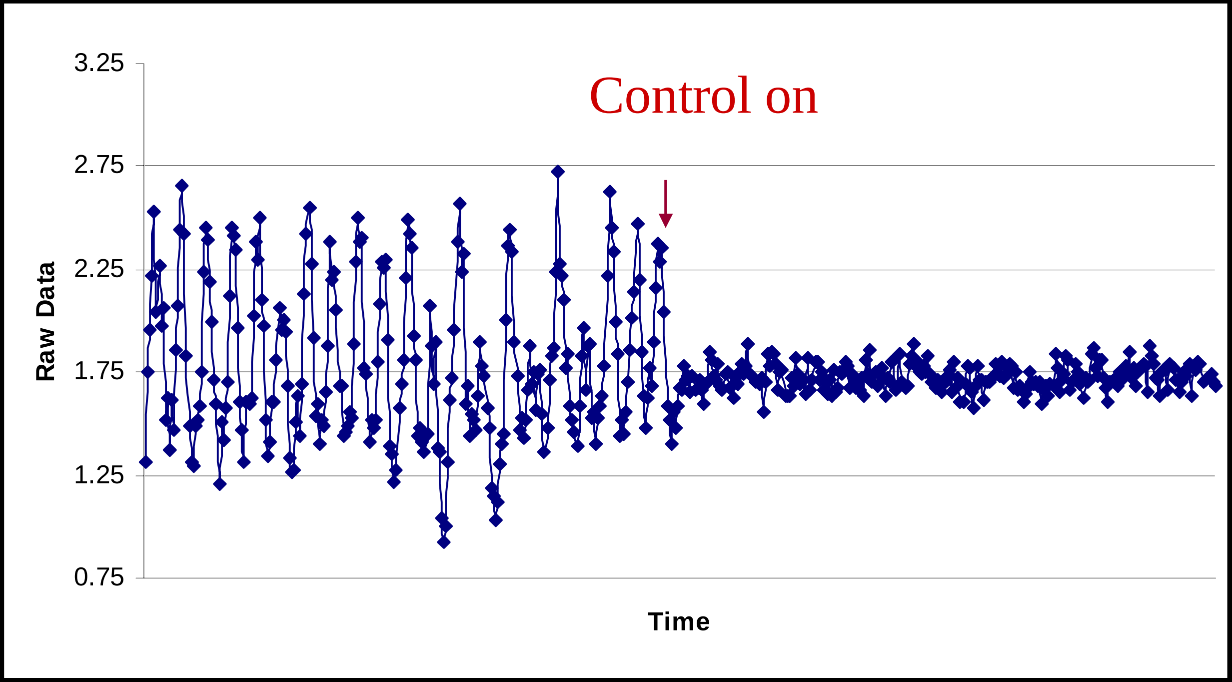
Effect of Microjet Control

NPR 3.7, h/d=3.5



Ground Plate

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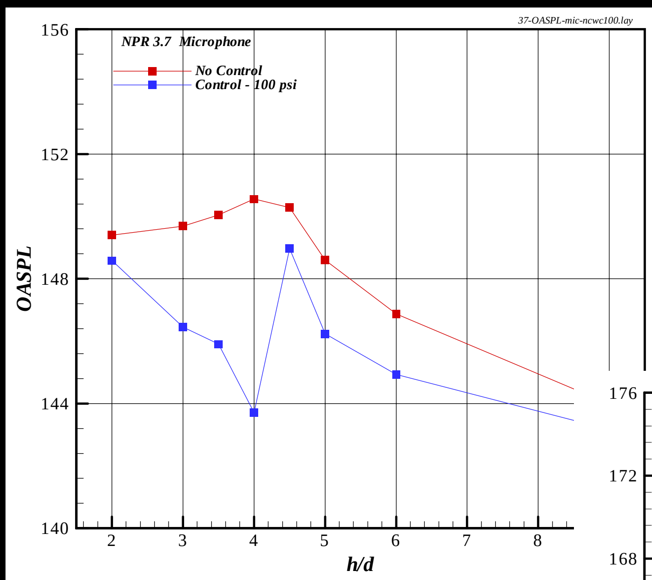
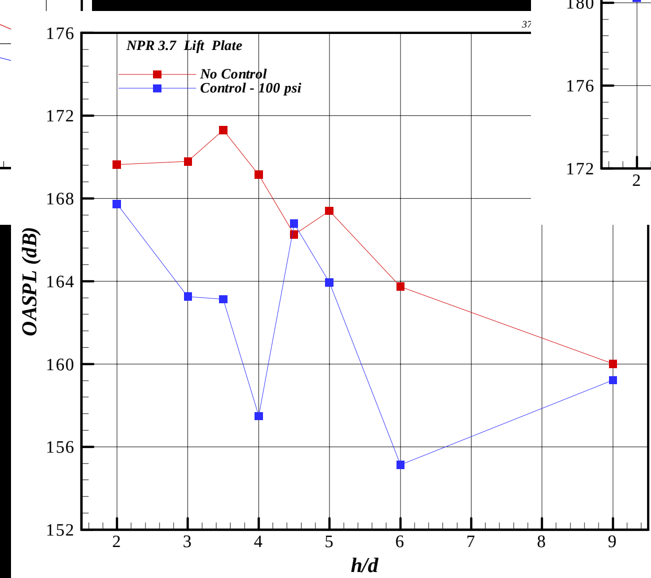
Effect of Microjet Control
OASPL For Different h/d

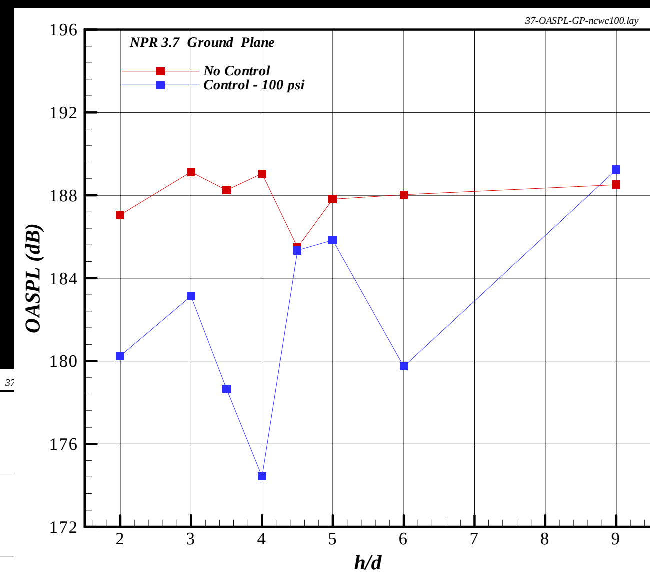
NPR 3.7



Microphone



Lift Plate



Ground Plane

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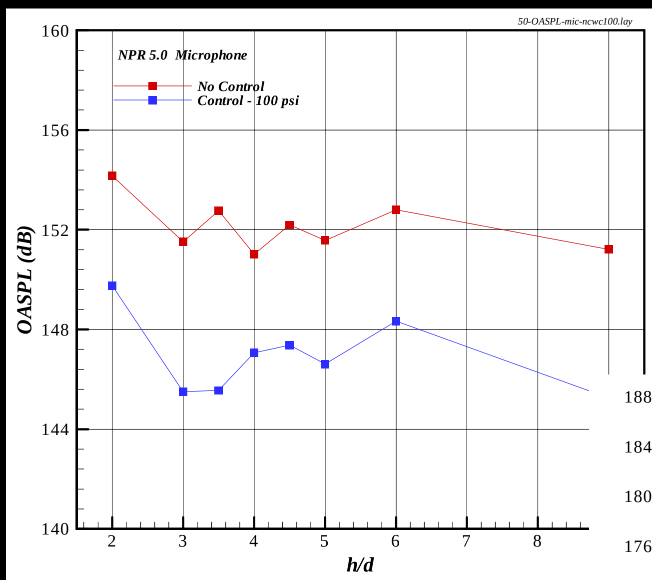
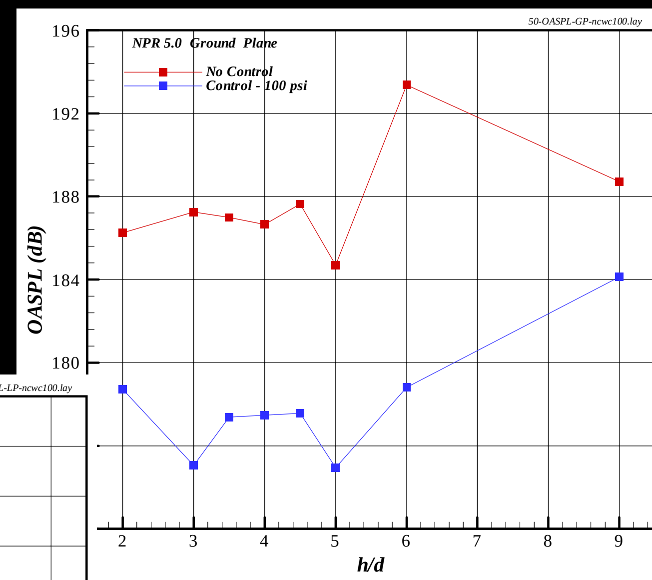
Effect of Microjet Control
OASPL For Different h/d

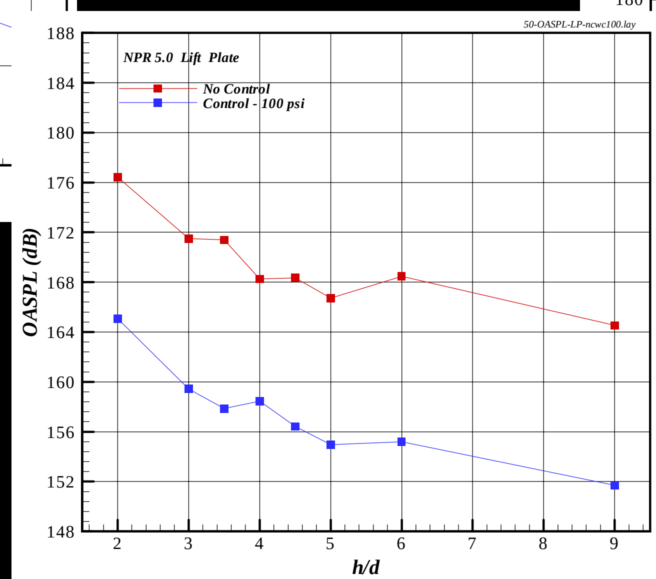
NPR 5.0



Microphone



Ground Plane



Lift Plate

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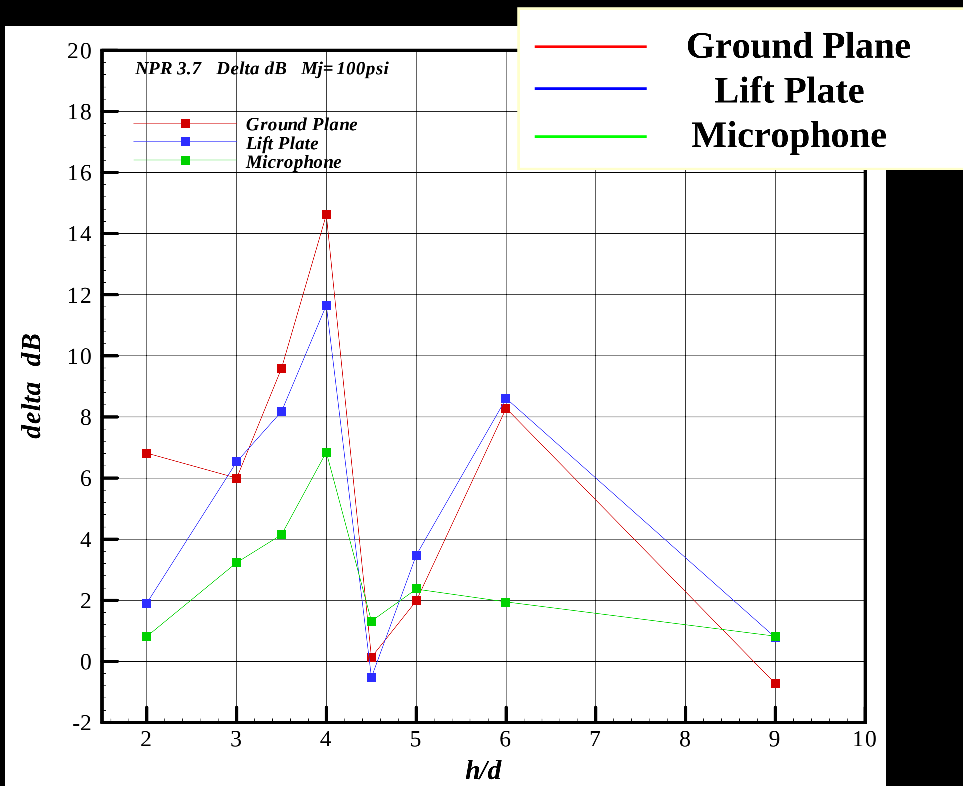
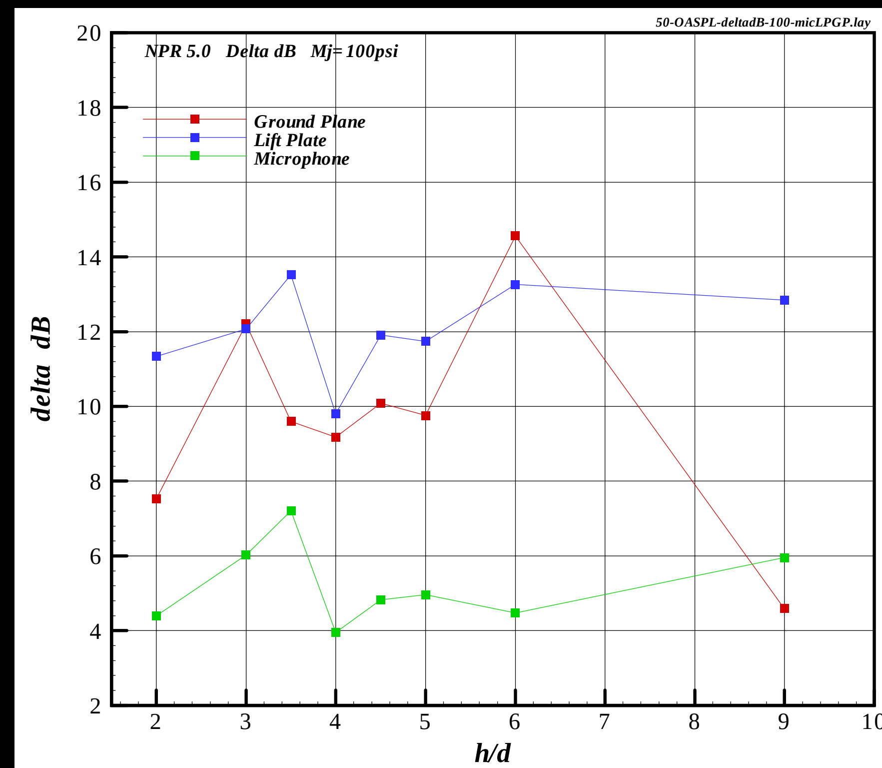
OASPL reduction



NPR 3.7



NPR 5.0

20°, 100 psi, 16 microjets

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Paramteric Effects on Suppression Efficiency

- **Microjet Pressure**
- **Microjet Angle**
- **Micro-Tabs vs Microjets**
- **Microjet Distribution/Spacing**
- **Microjet Size/Number**

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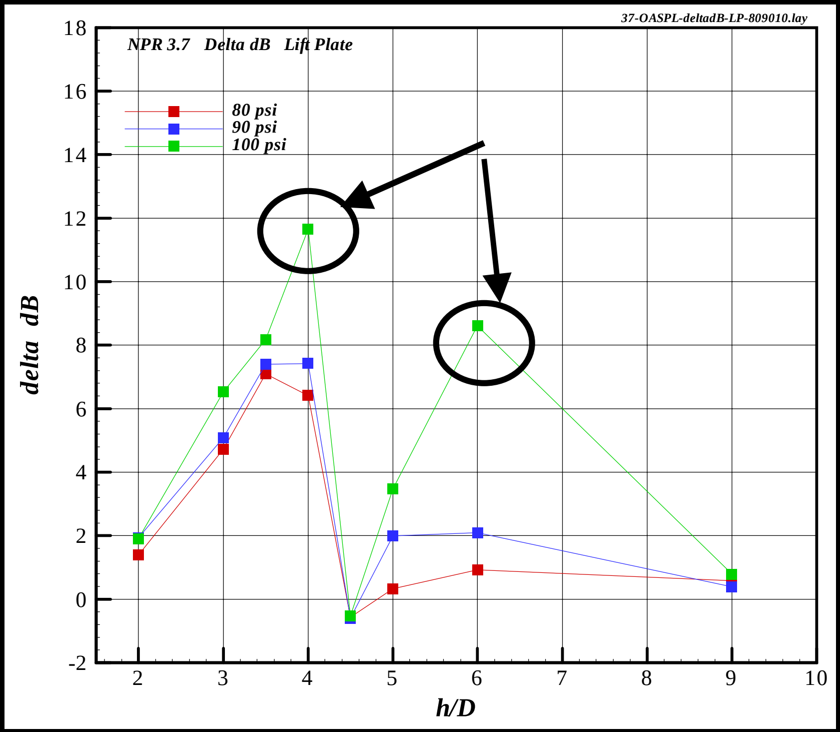
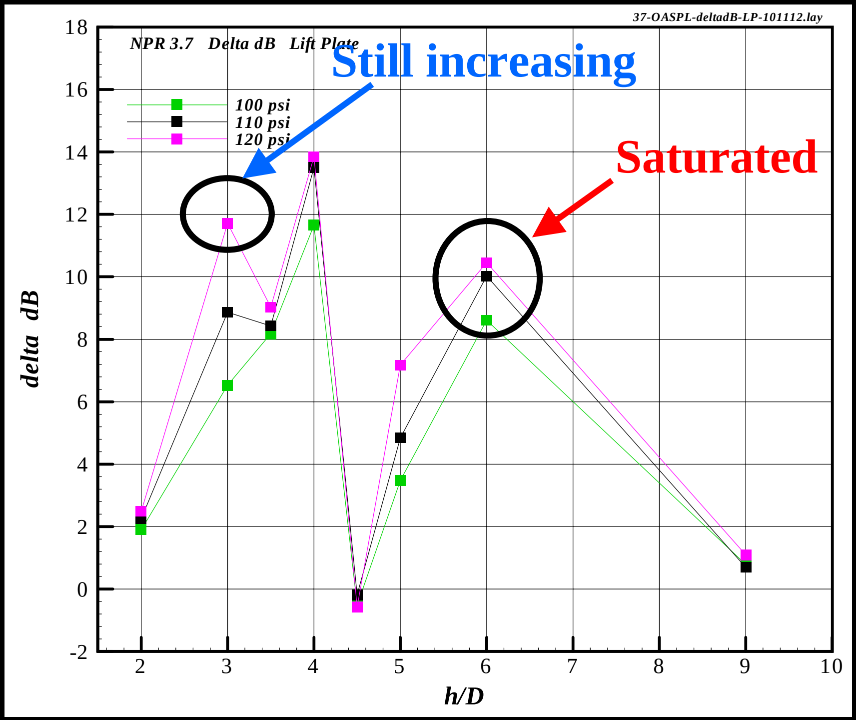
Effect of Microjet Pressure

NPR = 3.7, *16 microjets*



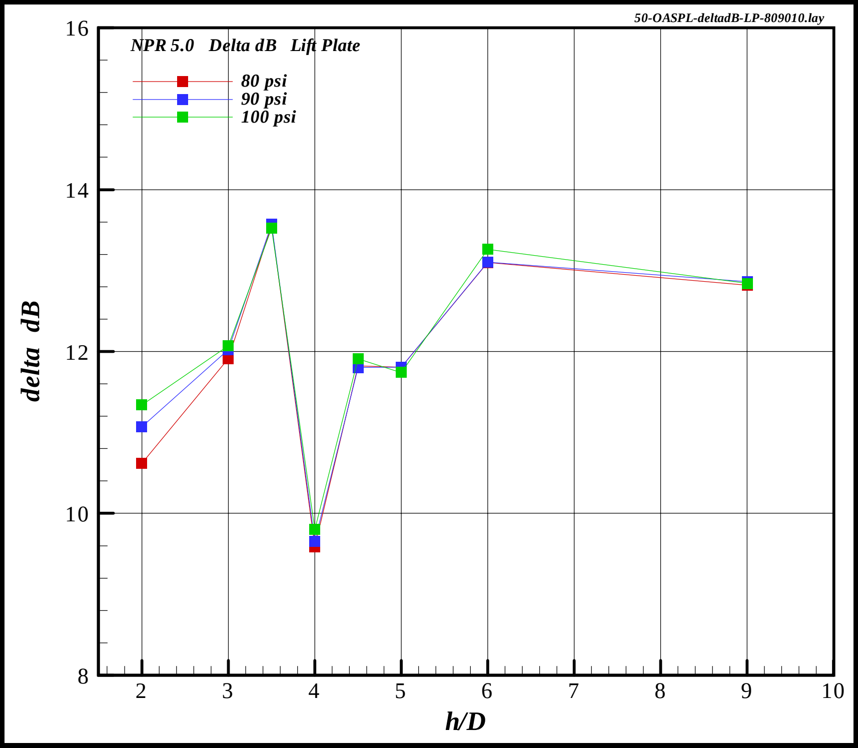


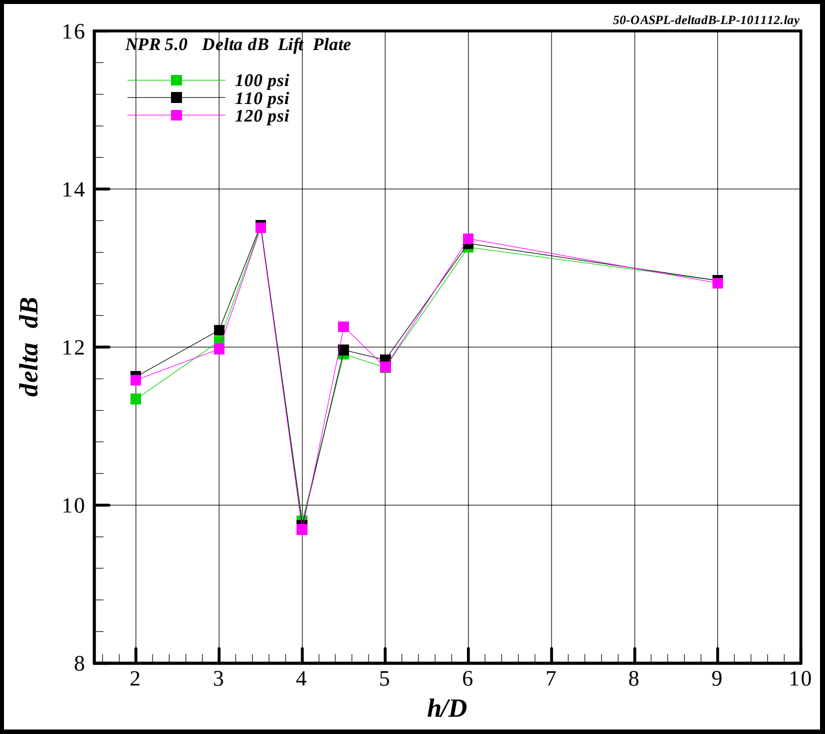
Systematic increase in OASPL reduction up to 100 psi

- Beyond 100 psi, the gains are smaller

Effect of Microjet Pressure

NPR = 5, *16 microjets*





- As NPR increases:
  - Overall reductions are higher
  - Less sensitive to microjet pressure.

Effect of Microjet Angle

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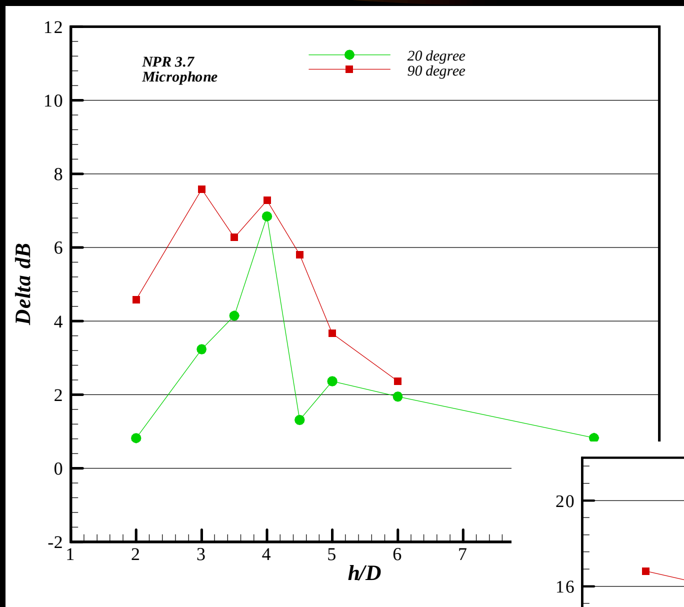
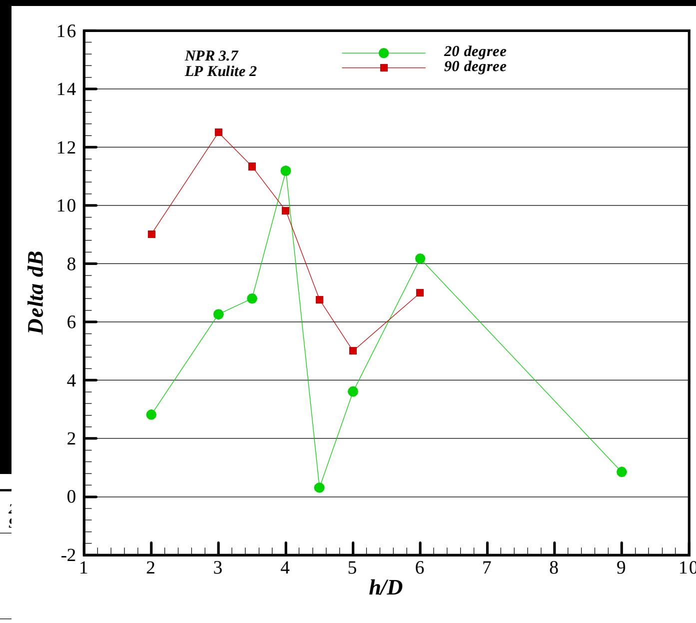
20° vs. 90 °

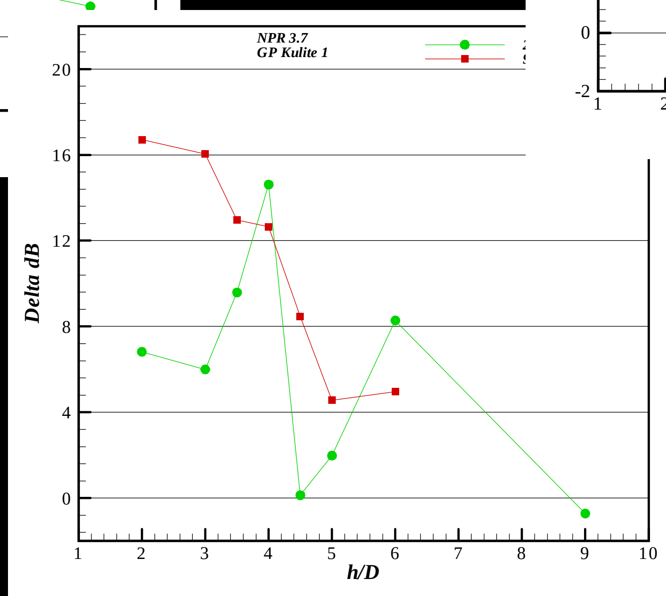
NPR = 3.7



Microphone



Lift Plate



Ground Plane

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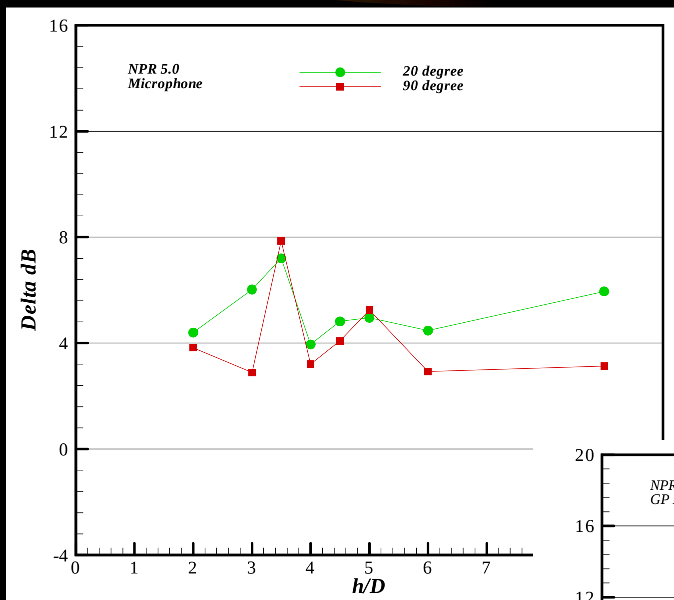
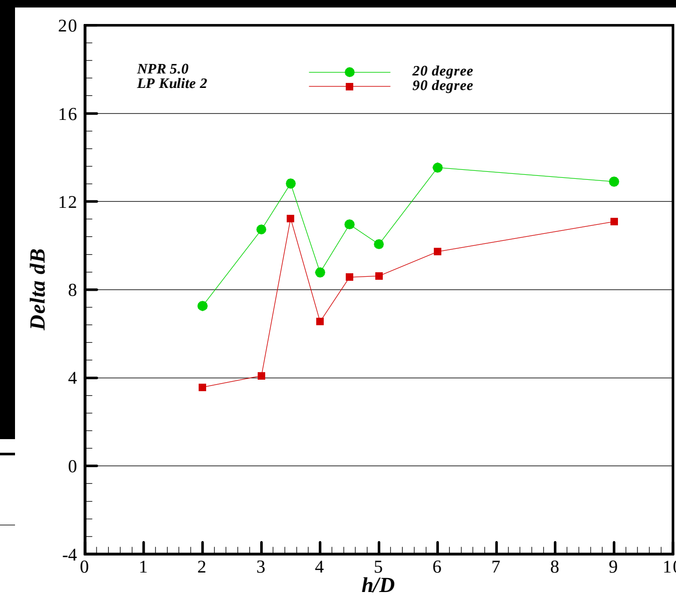
Effect of Microjet Angle

20° vs. 90 °

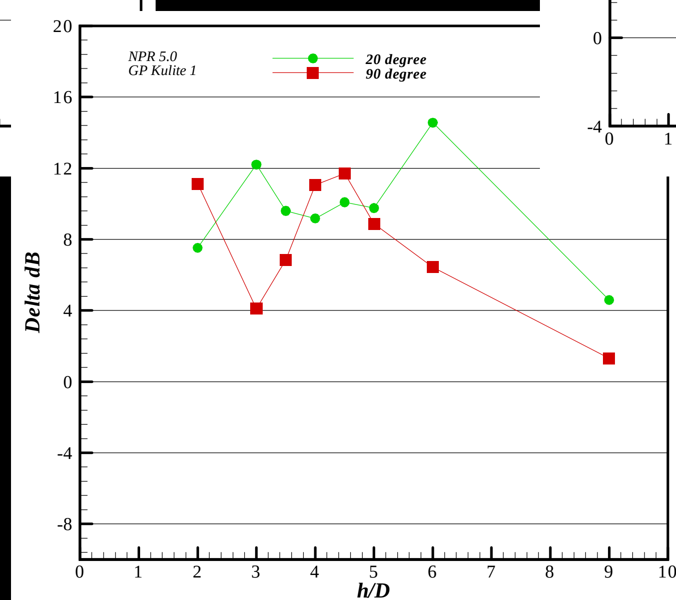
NPR = 5



Microphone

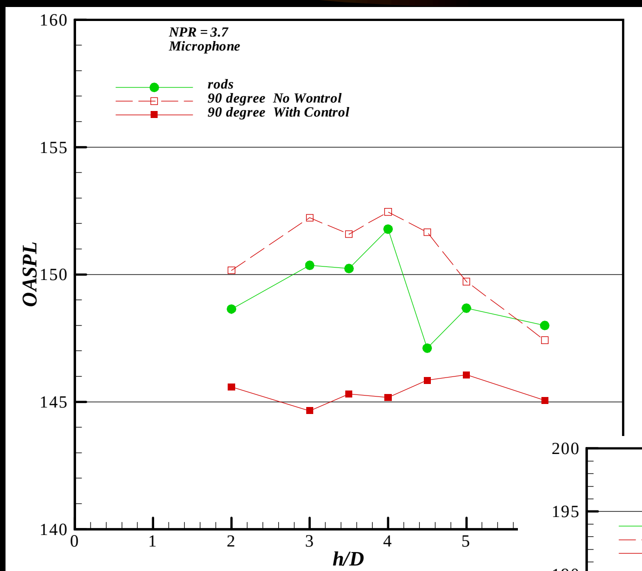


Lift Plate



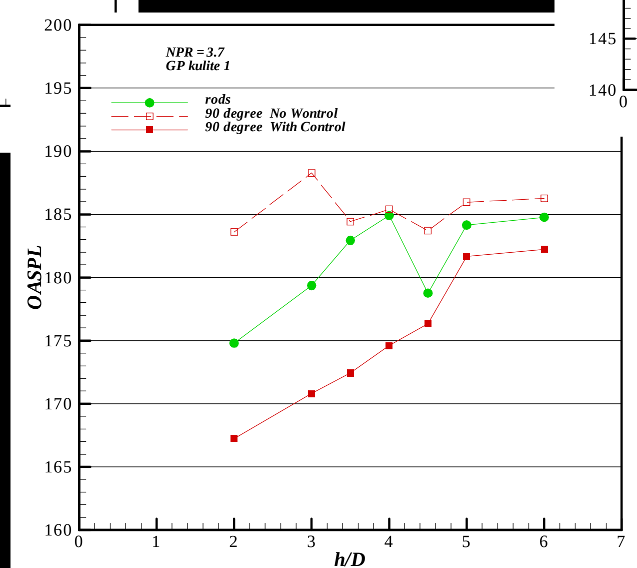
Ground Plane

90° Tabs vs. 90 ° Microjets

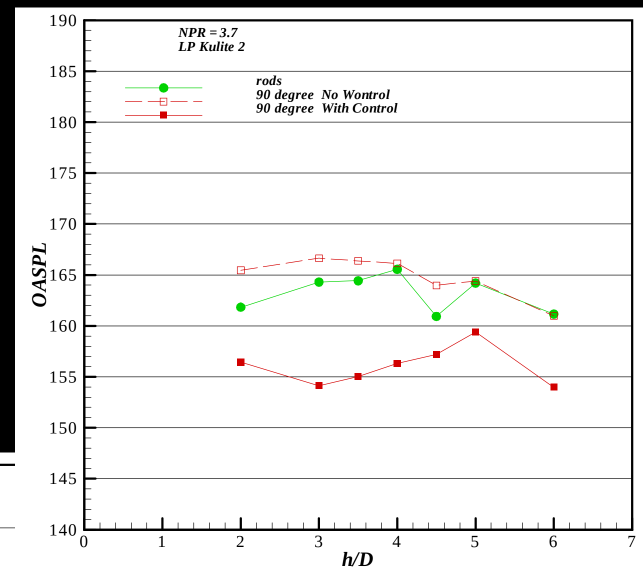


Microphone

NPR = 3.7

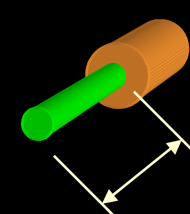


Ground Plane



Lift Plate

Micro-tabs



400 µm dia.
2.5 mm length

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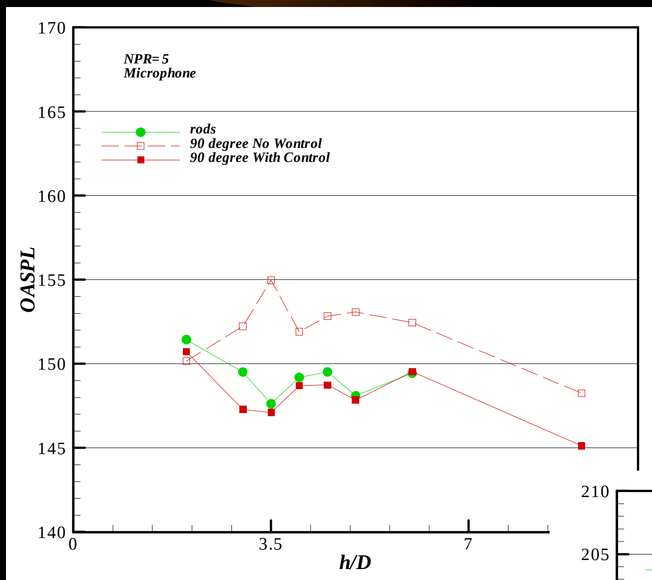
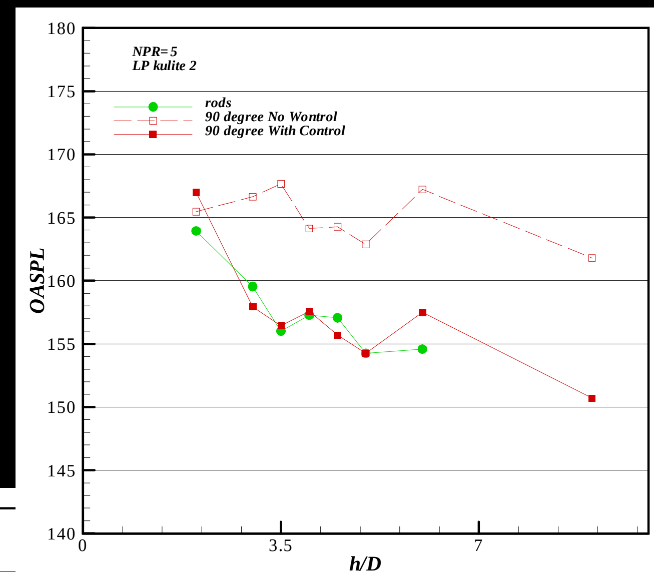
90° Tabs vs. 90 ° Microjets

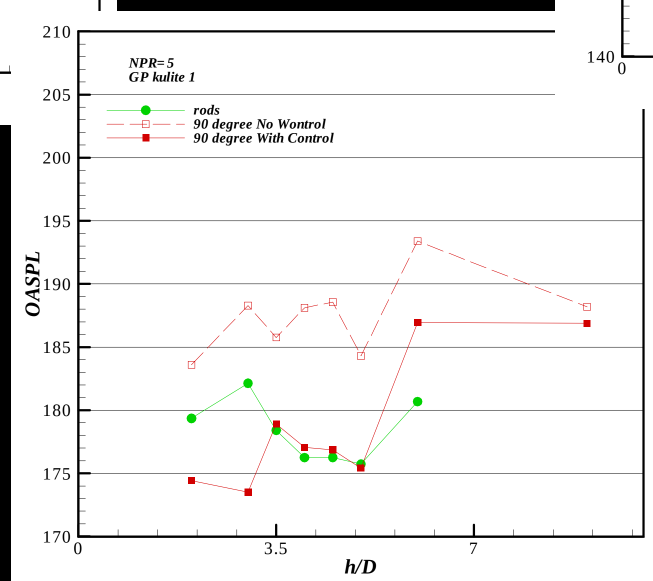


Microphone

NPR = 5



Lift Plate



Ground Plane

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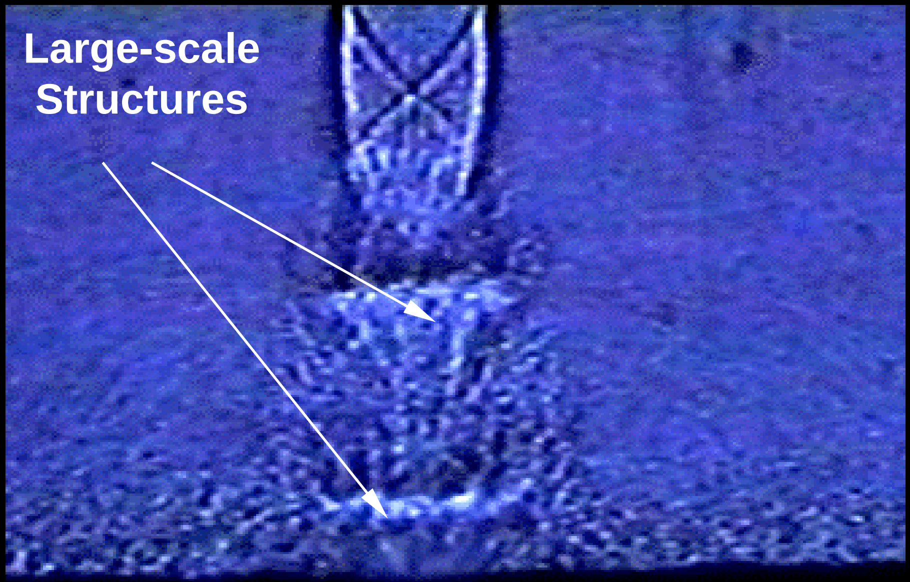
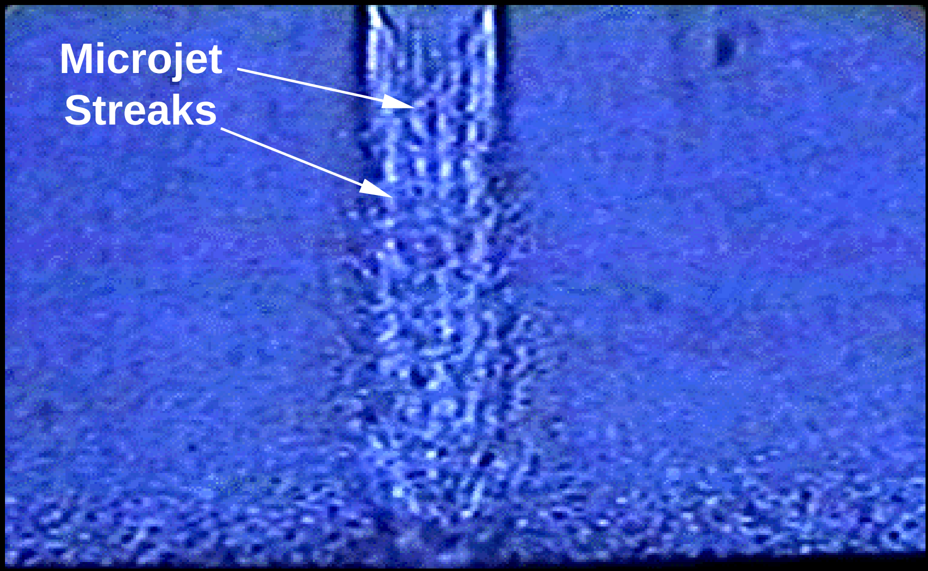
Phase-Averaged Shadowgraphs
M = 1.5 nozzle, NPR = 3.7



No Control

With Control



Cross flow visualization, PLS Images, Instantaneous

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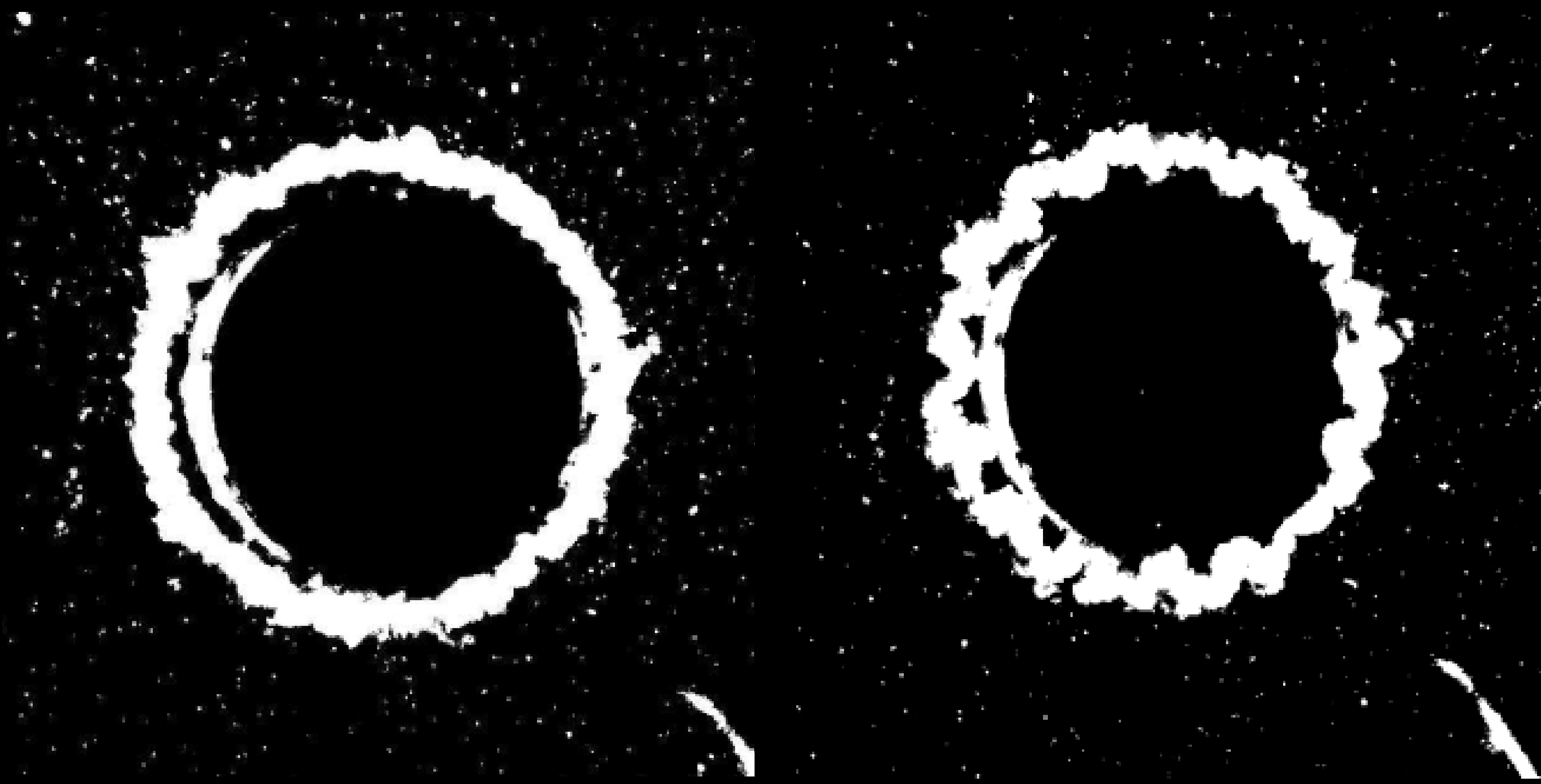
NPR=5 h/D=4

No Control

With Control

PLS Images, Averaged

NPR=5 h/D=4



No Control

With Control

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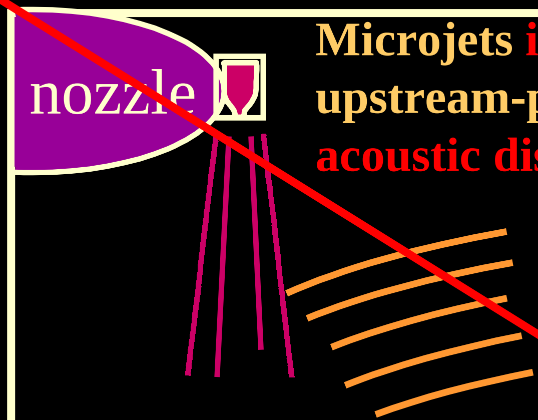
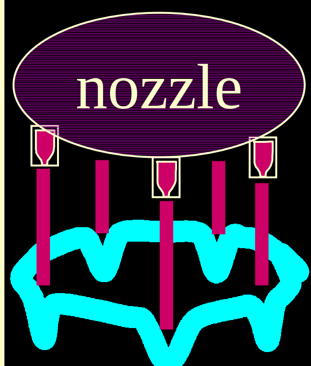
Resonance Disruption and Noise Reduction Mechanism ?

Microjets thicken the nozzle shear layer, decreasing its receptivity to acoustic disturbances.



Microjets intercept the upstream-propagating acoustic disturbances.



Microjets disrupt the axisymmetric coherent coupling between the instability & acoustic waves.

- **Microjets introduce significant streamwise vorticity which efficiently extracts energy from large scale disturbances.**
- **Vortex tilting and stretching**

SUMMARY

- **Control/disruption of feedback using supersonic microjets enhanced performance**
- **Microjet control eliminated or significantly attenuated**
  - **Large-scale structures & acoustic waves (tones)**
- **Unsteady loads on nearby surfaces reduced for ideally expanded and under-expanded jets**
- **Performance gains not uniform over the entire operating range.**
  - **Need for adaptive microjet control.**
  - **Number of microjets, azimuthal distribution, pressure, orientation and pulsed actuation are possible control inputs for adaptive control**
- **Microjet control mechanism appears to be different than passive tabs.**