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The Role of Streamwise Vorticity in the Control of Supersonic Impinging Jets

F. S. Alvi, H. Lou, and C. Shih

Department of Mechanical Engineering

Florida A & M University and Florida State University

4TH ASME_JSME Joint Fluids Engineering Conference
Honolulu, Hawaii, USA, July 6-11, 2003

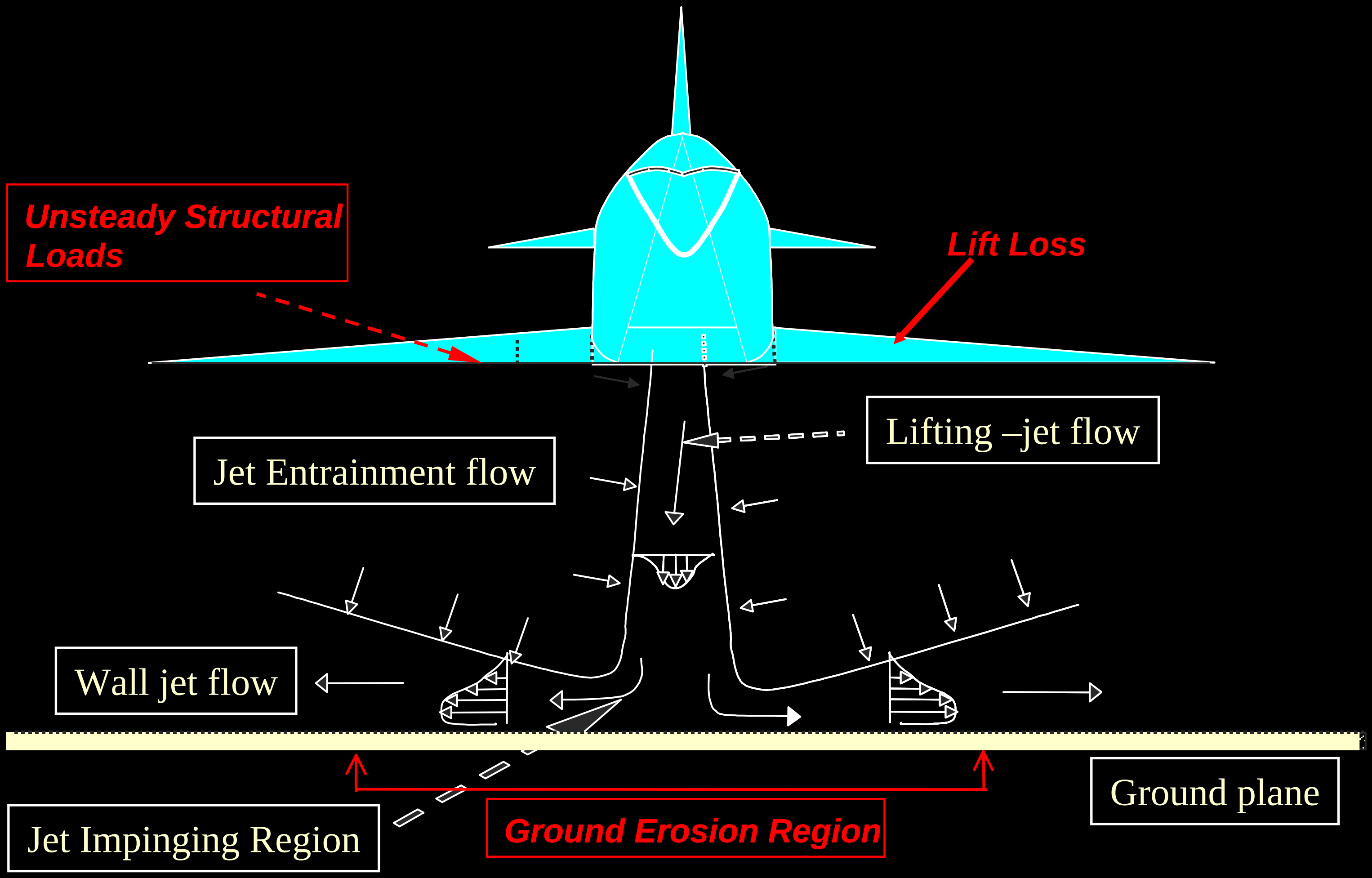
Research sponsored by AFOSR

Outline

- Motivation
- Feedback Loop Control
- Global Velocity and Vorticity Fields
- Role of Streamwise Vorticity
- Summary

Motivation

Flow schematic of a STOVL aircraft in hover



Unsteady Structural Loads

Lift Loss

Lifting –jet flow

Jet Entrainment flow

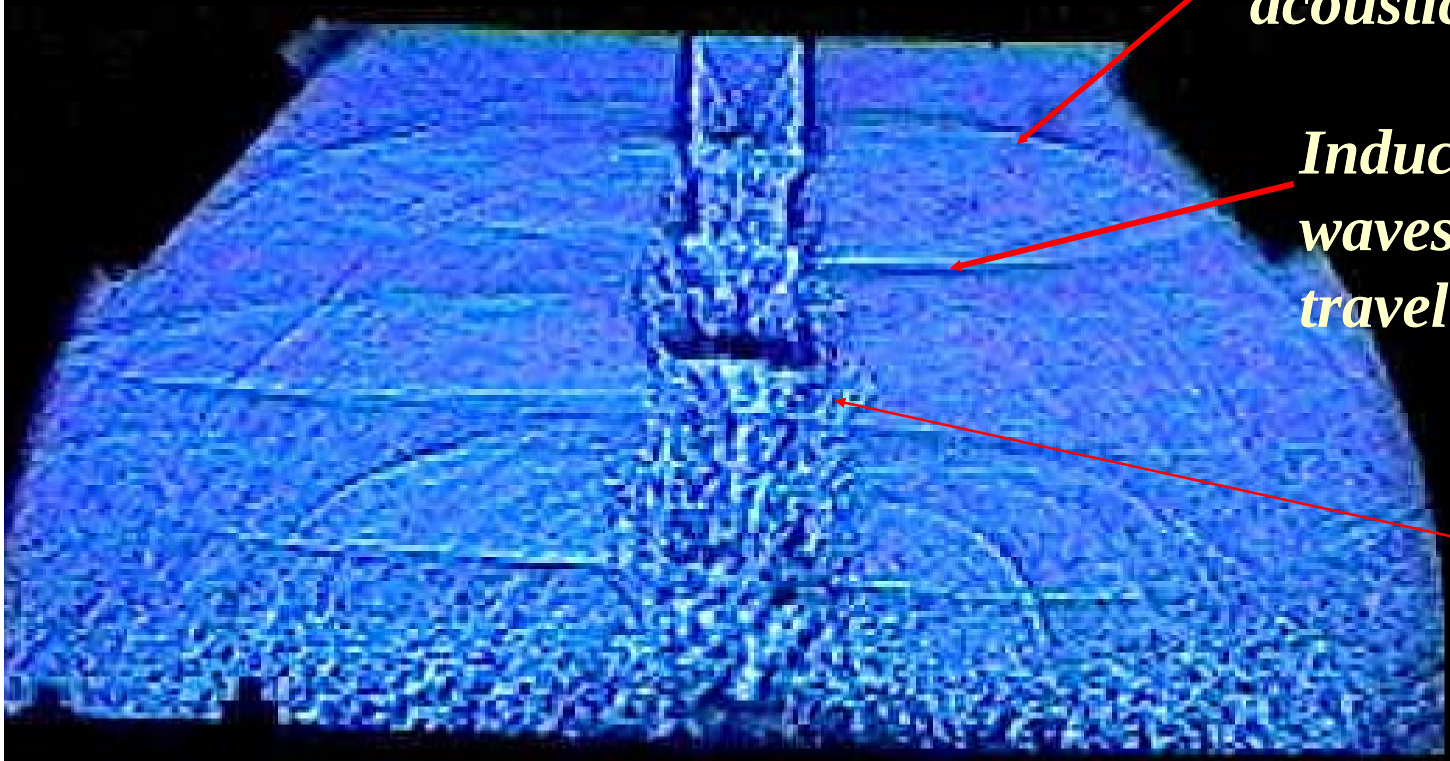
Wall jet flow

Ground plane

Jet Impinging Region

Ground Erosion Region

Feedback loop



Upstream propagating acoustic waves

Induced acoustic waves by downstream-traveling structures

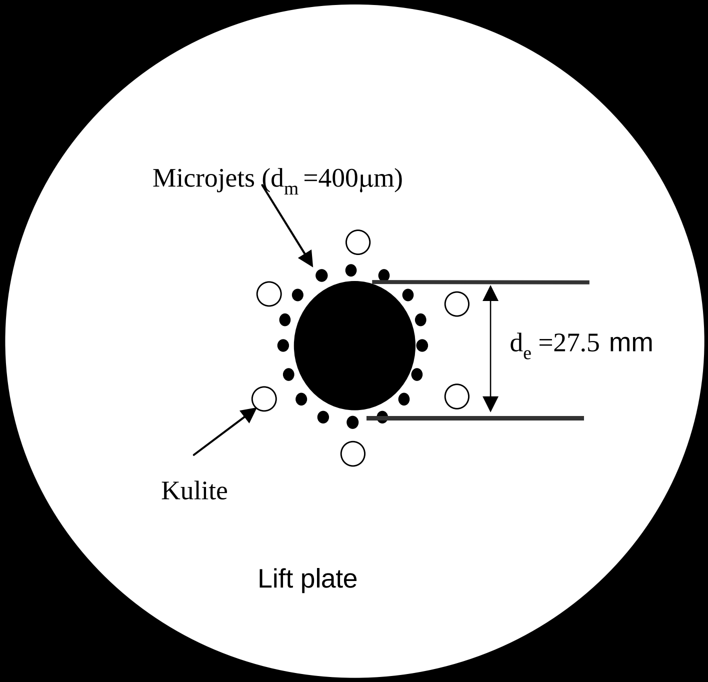
Larger Scale Structures

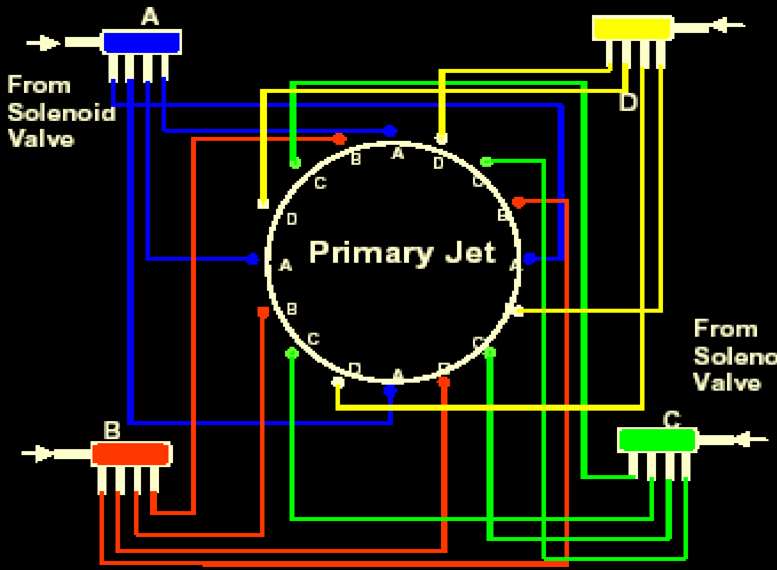
Jet impingement

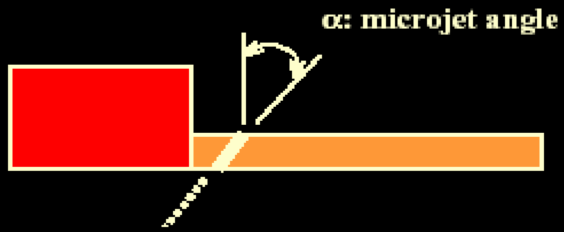
Goal

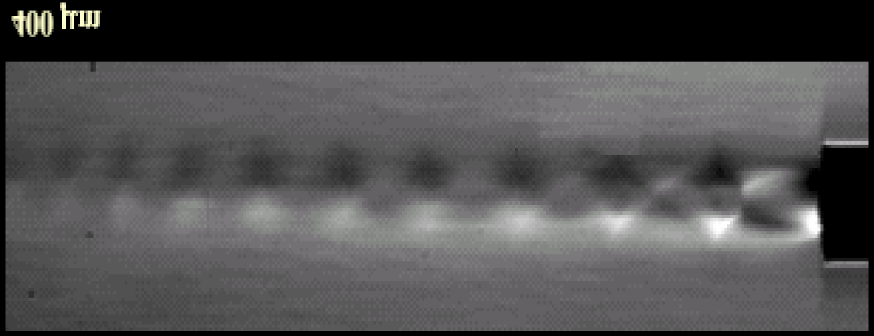
- **To actively and efficiently control the jet behavior by disrupting the feedback loop**
  - ➢ Reduce tones, OASPL and other related adverse effects

Present control approach









- Microjet angle- 90 deg.
- Microjet pressure-100 psia
- Microjet diameter- 400μm

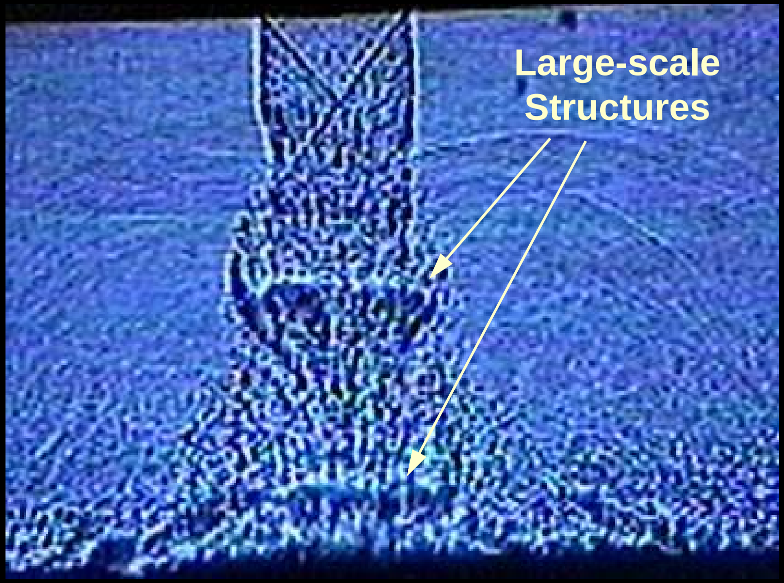
Facility and Test Mode

Lift Plate

Ground Plane

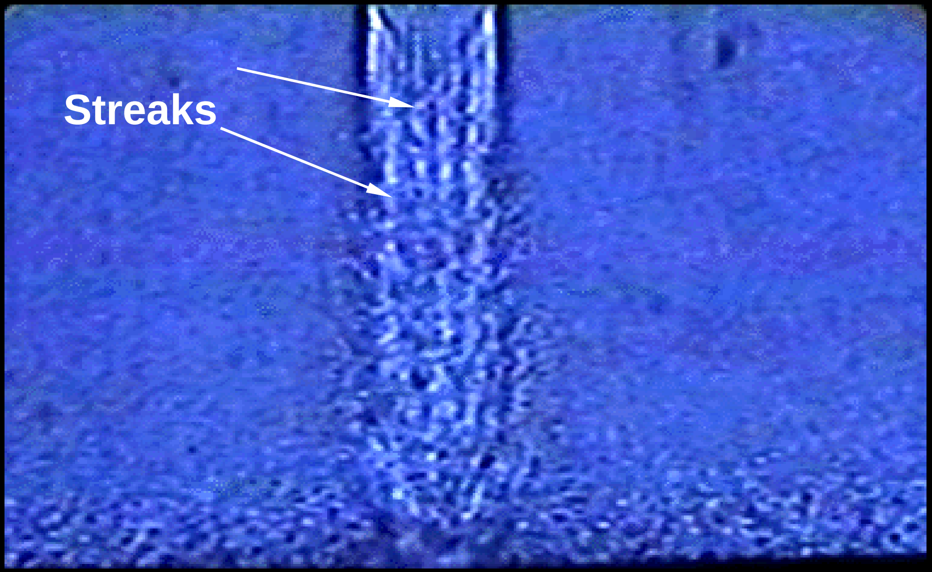
Effect of Microjet Control

Shadowgraphs NPR = 3.7, h/d = 4

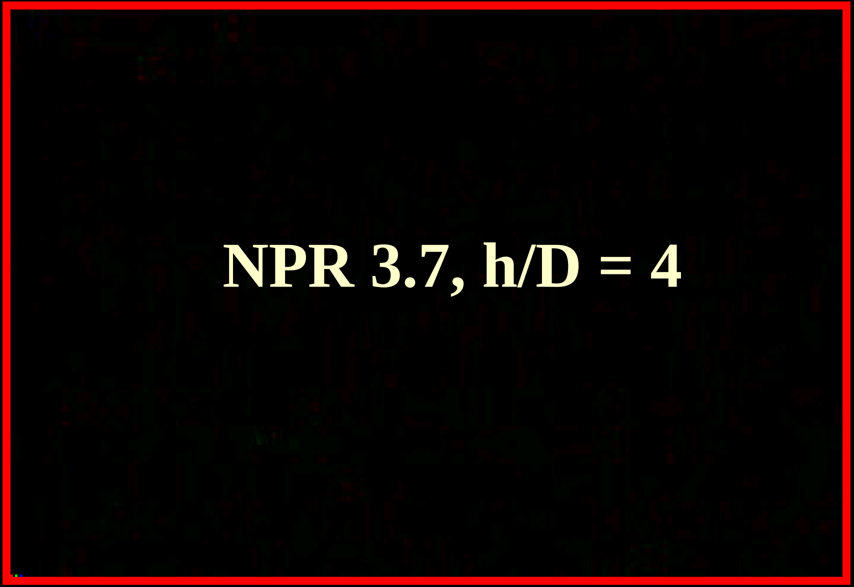


No Control

With Control



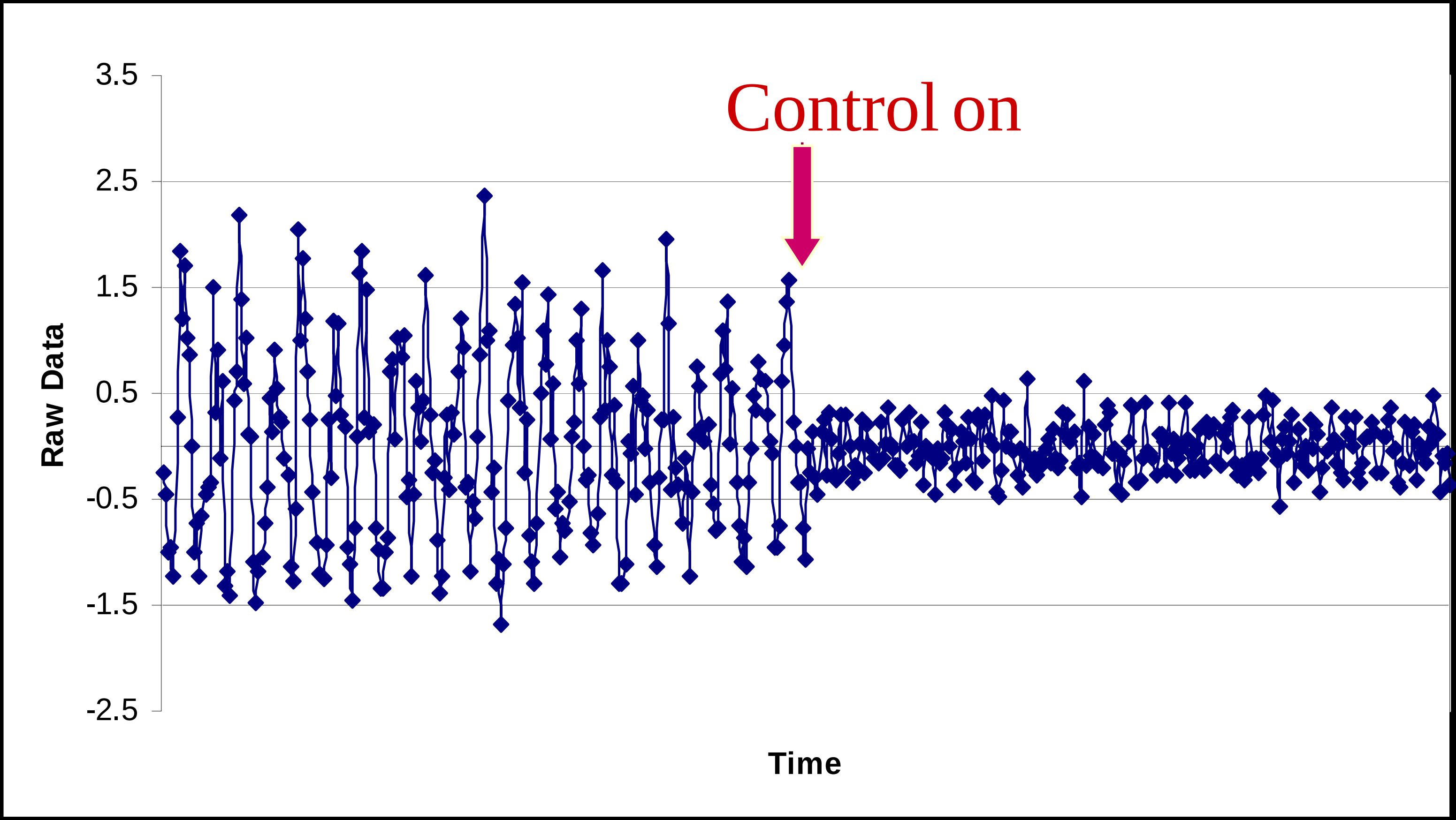
Effect of Microjet Control



NPR 3.7, h/D = 4

Effect of Microjet Control

NPR 3.7, h/d=4

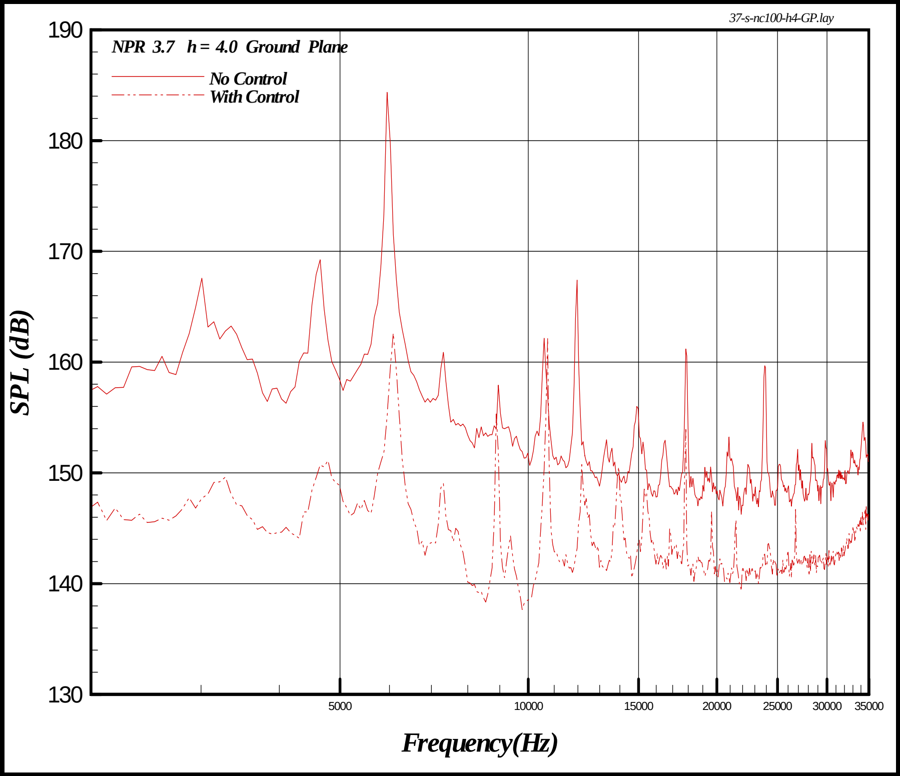


Effect of Microjet ControlPressure Spectra

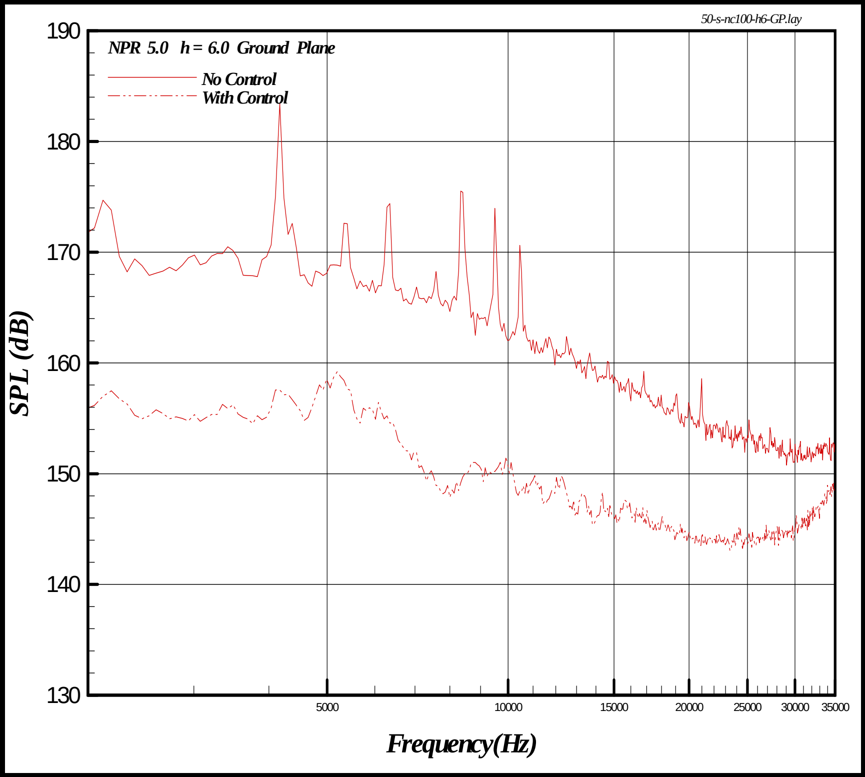
— No control

- - - - With Control

Ground Plate



NPR 3.7

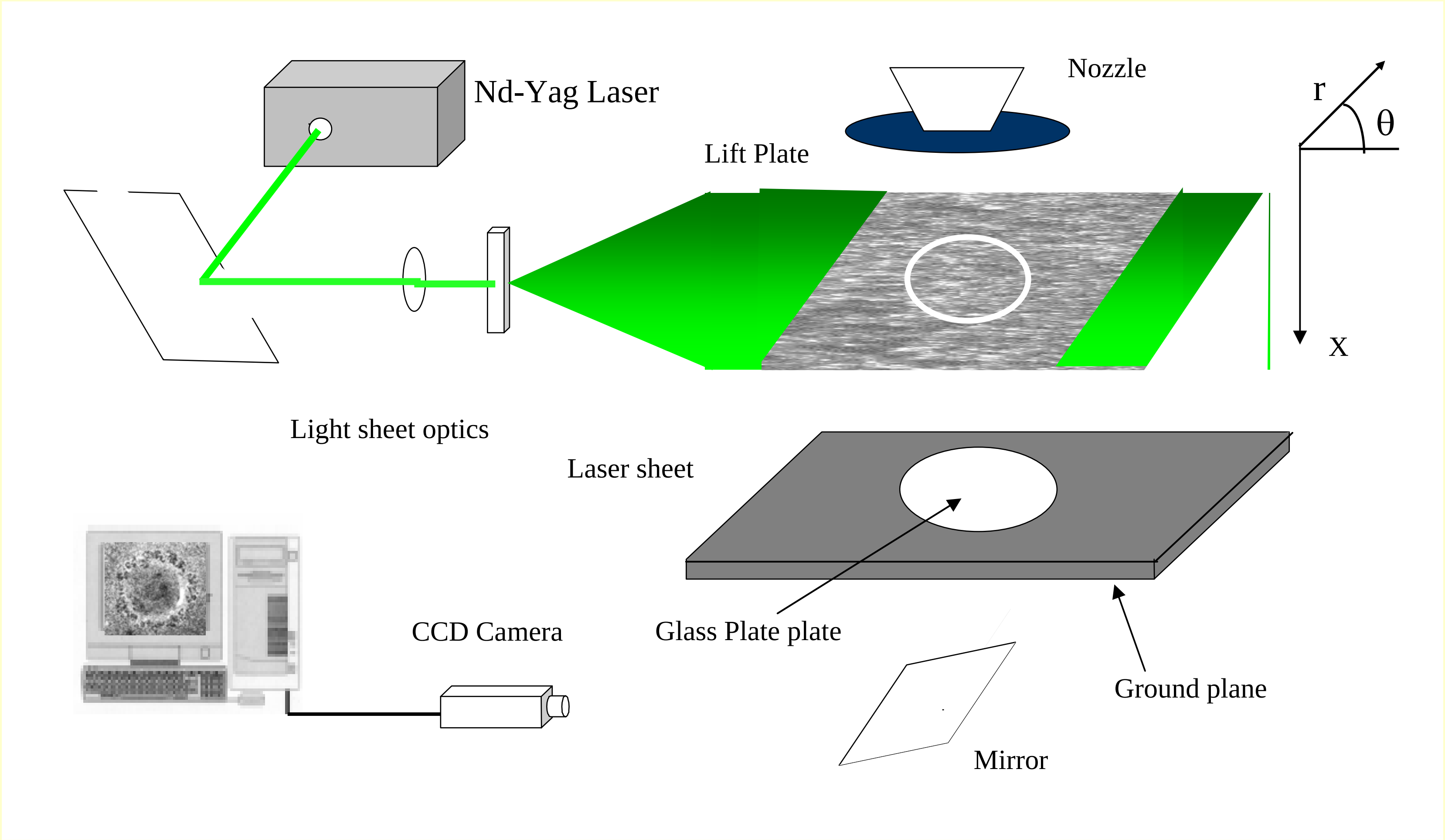


NPR 5

General Observation

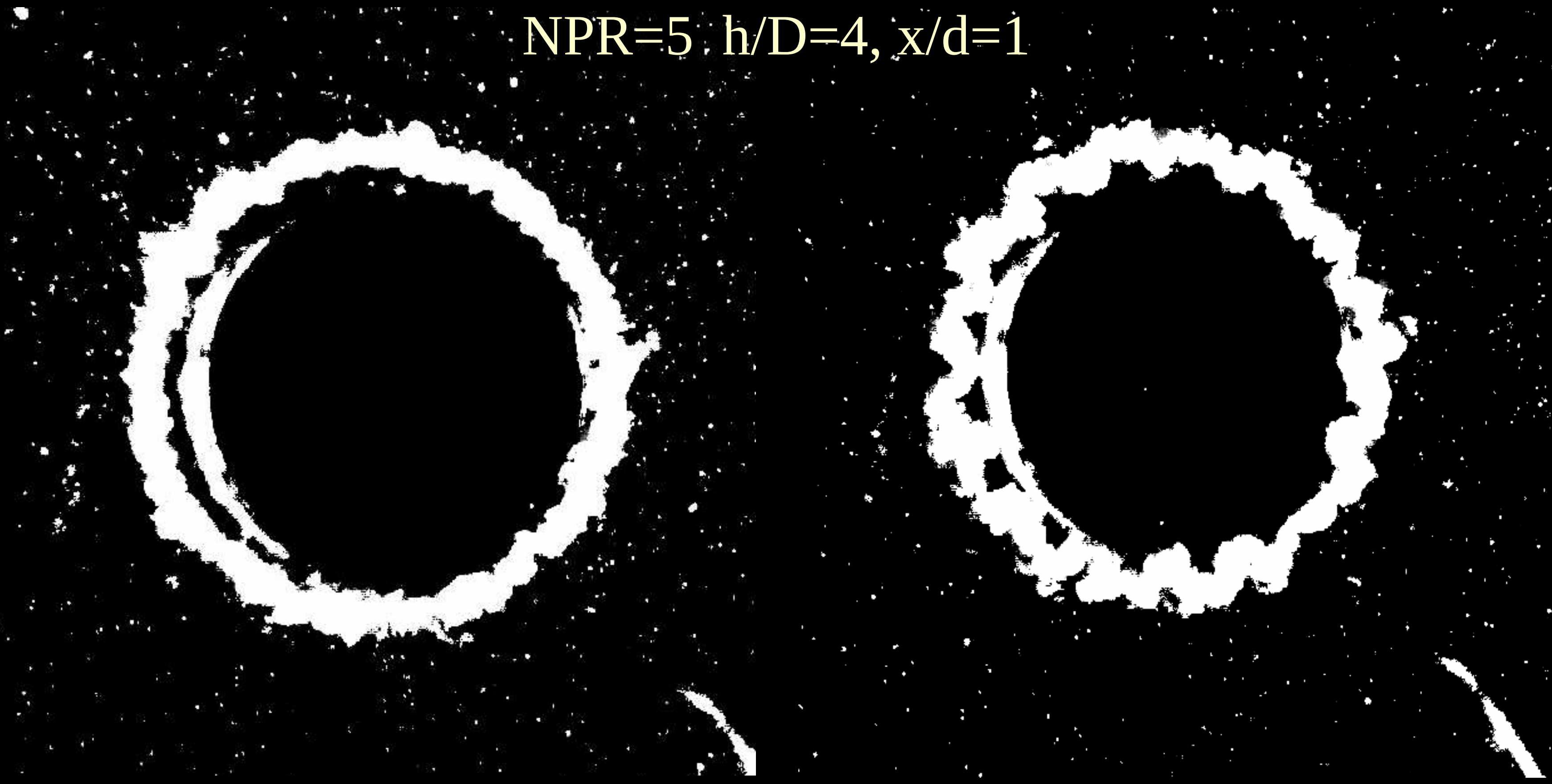
- Effective screen tone elimination, peak SPL reduction up to 26 dB (95% reduction)
- Suppression of the large scale structures
- OASPL reduction up to 14 dB (80% reduction) in selected cases (broadband noise reduction)
- Appearance of streak-like structures in shear layer – emergence of streamwise vorticity

Cross Section PIV Setup



PLS Images, Averaged

NPR=5 h/D=4, x/d=1



No Control

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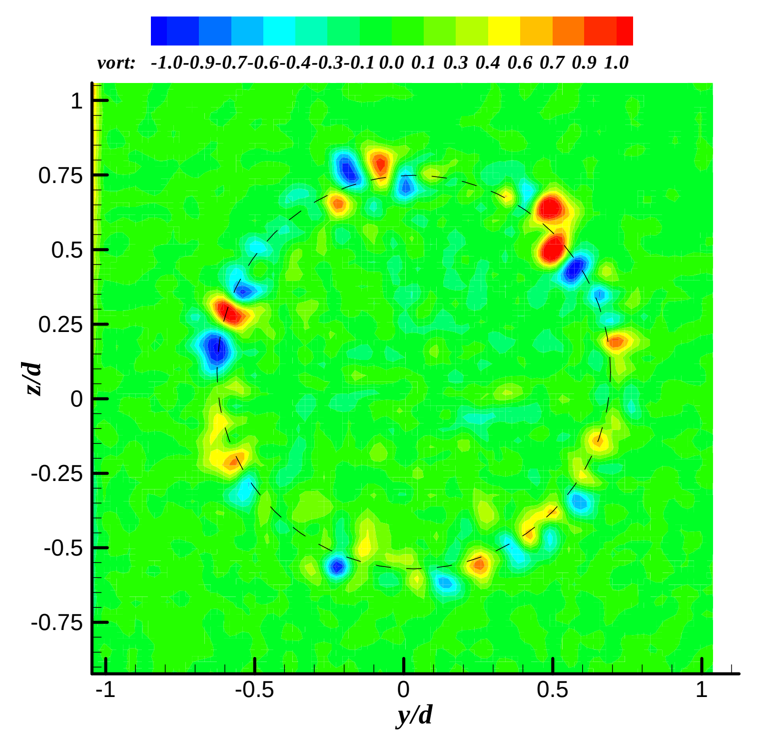
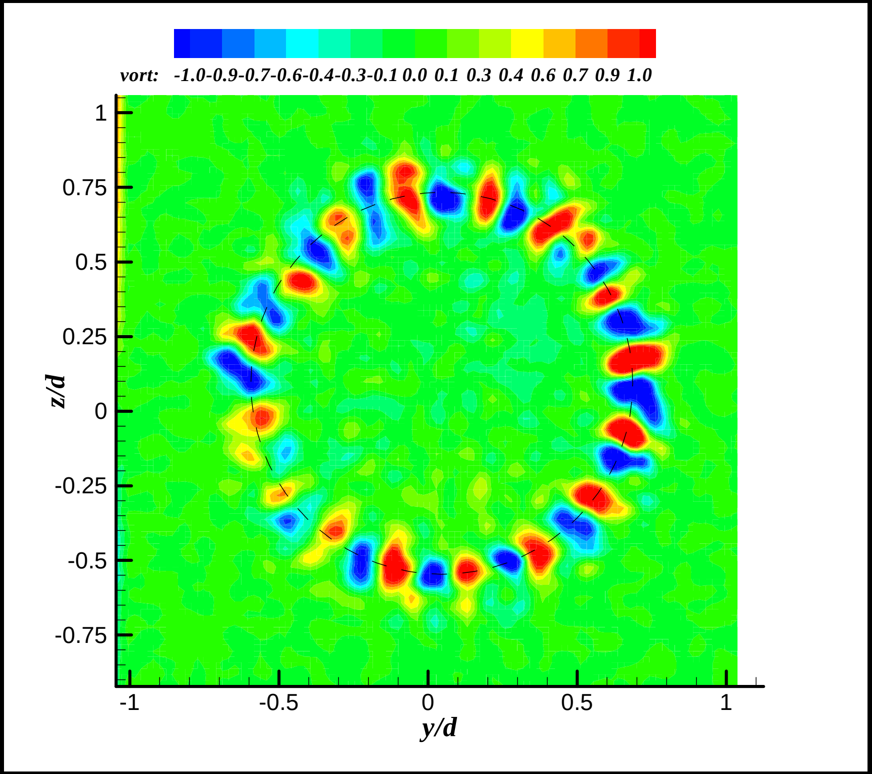
Ensemble-averaged streamwise voriticity field

NPR=5, h/d=4, x/d=1, 90 deg. microjet



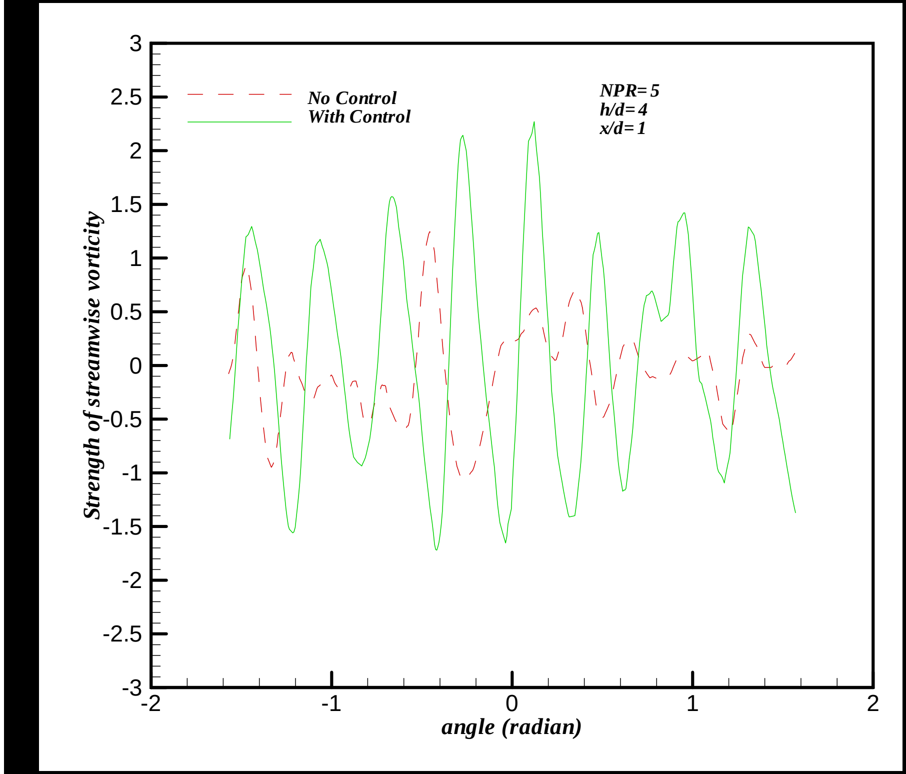
No Control



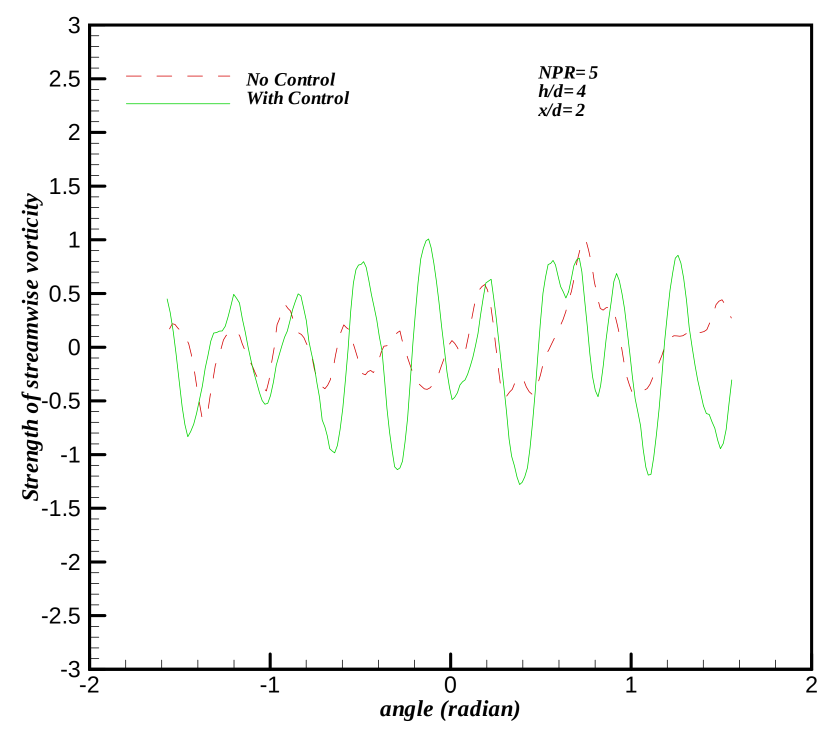
With Control

Streamwise vorticity distribution vs. azimuthal angle

NPR=5, h/d=4, 90 deg. microjet



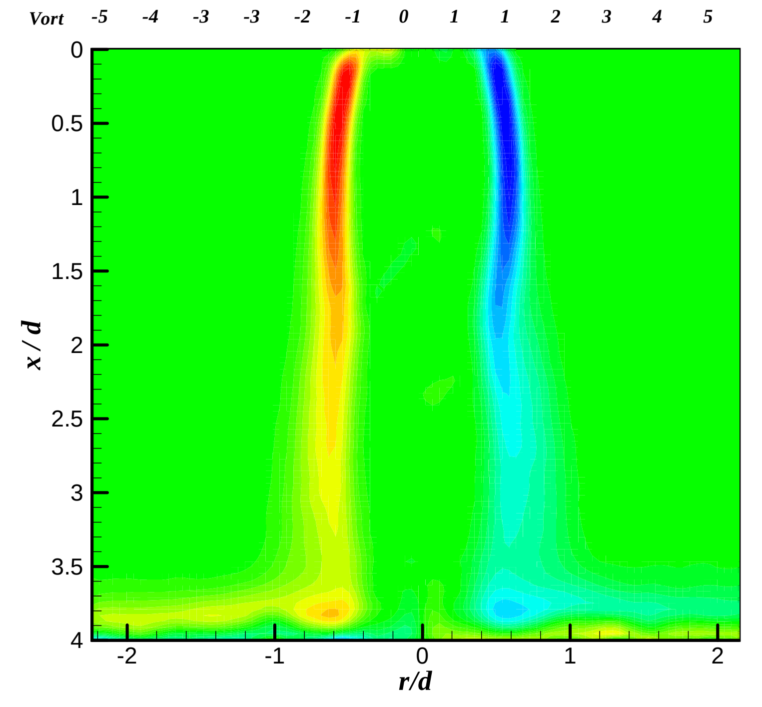
x/d=1



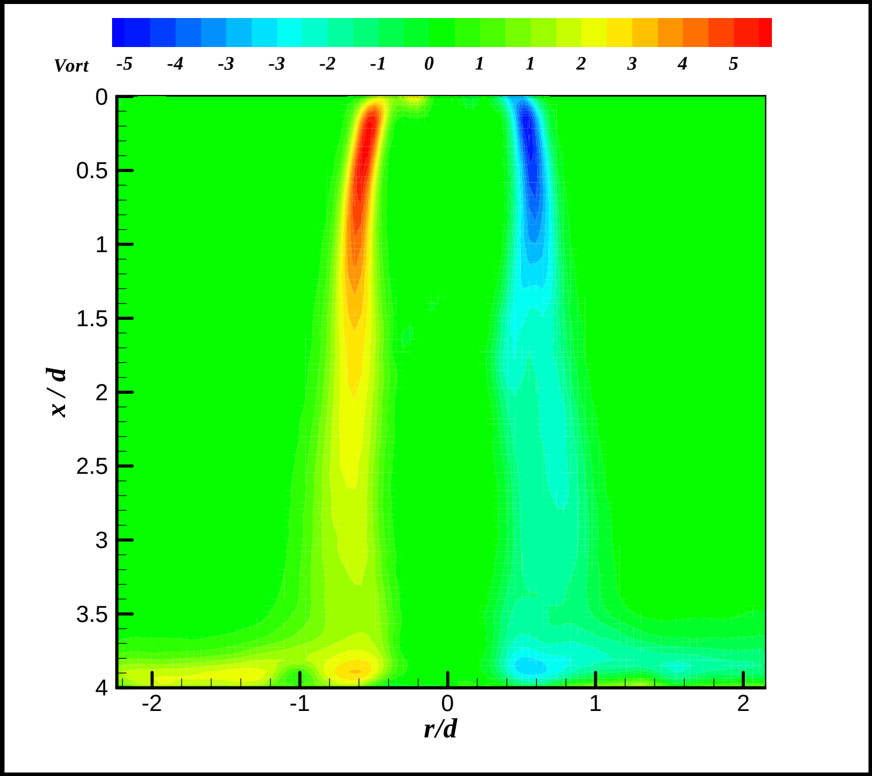
x/d=2

Mean vorticity distribution in the central plane

NPR=5, h/d=4, 90 deg. microjet.

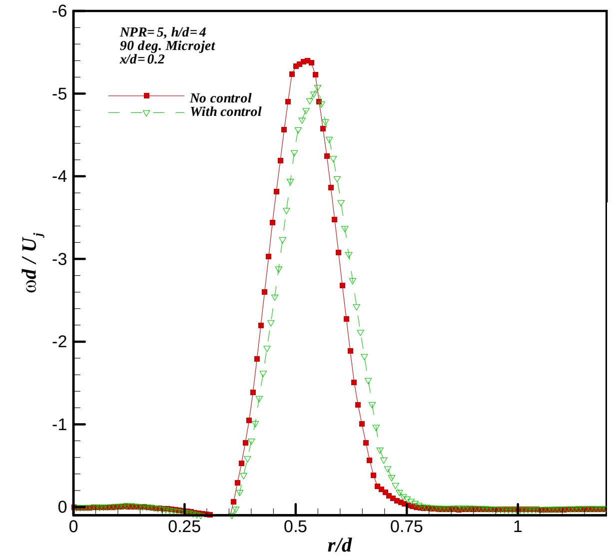


No control

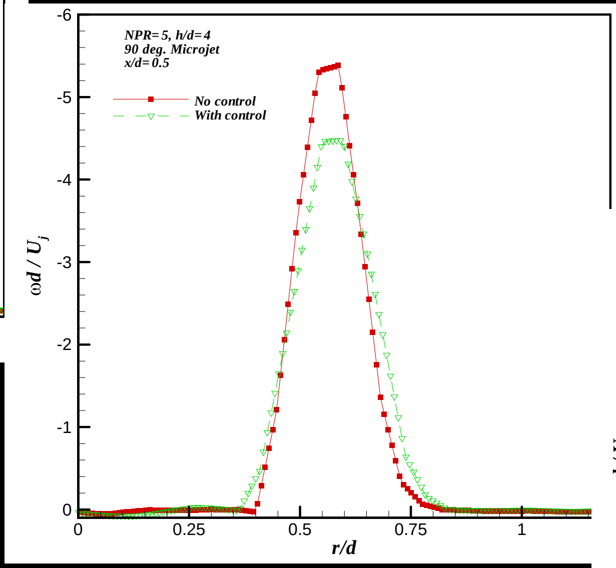


With control

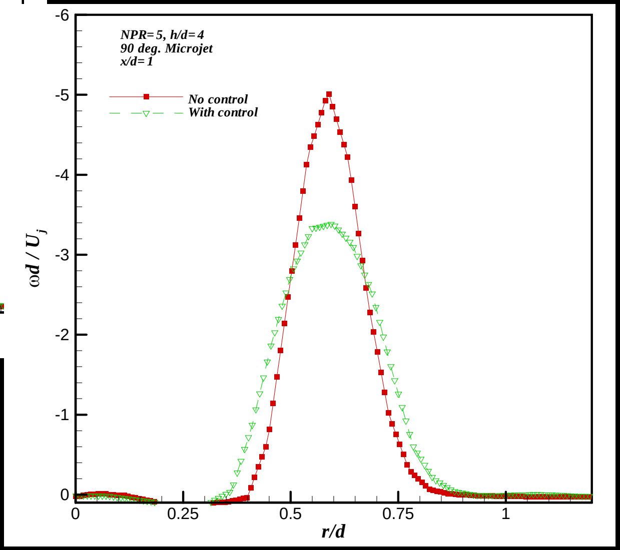
Streamwise Development of Vorticity Distribution, NPR=5, h/d=4



x/d=0.2



x/d=0.5



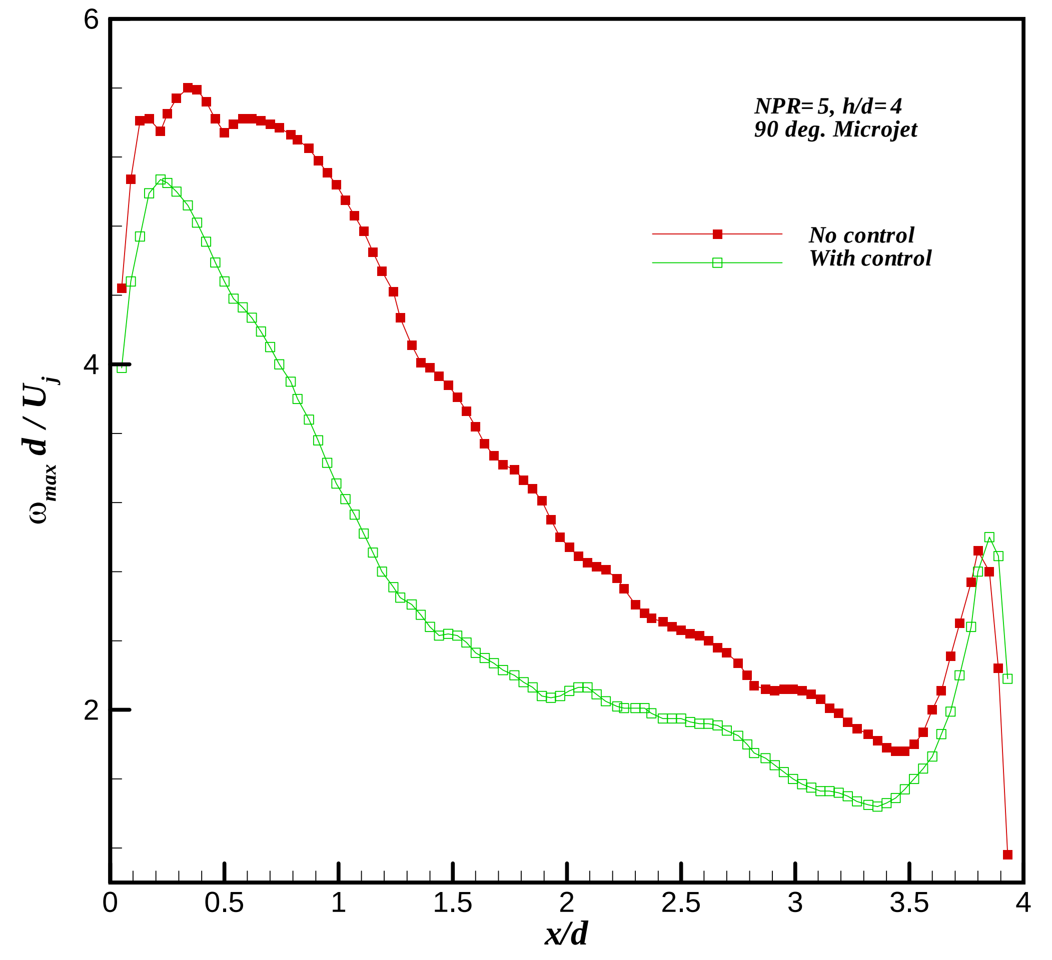
x/d=1

━━ No Control

- - - With Control

Streamwise Variation of Peak Vorticity

NPR=5, h/d=4



Effect of Control on the Vorticity Distribution

- Emergence of strong streamwise vortical structures
  - Organized counter-rotating vortex pairs
- Weakening of the primary azimuthal vorticity
  - Decrease peak vorticity and increase shear layer thickness

➡ Vorticity redistribution

Streamwise Vorticity Formation Mechanism

Vorticity Transportation Equation:

$$\frac{D\vec{\varpi}}{Dt} = \vec{\varpi}\cdot\nabla\vec{U} - \nabla\frac{1}{\rho}\times\nabla P + Stress\ \ \text{term} + \upsilon\nabla^{2}\vec{\varpi}$$

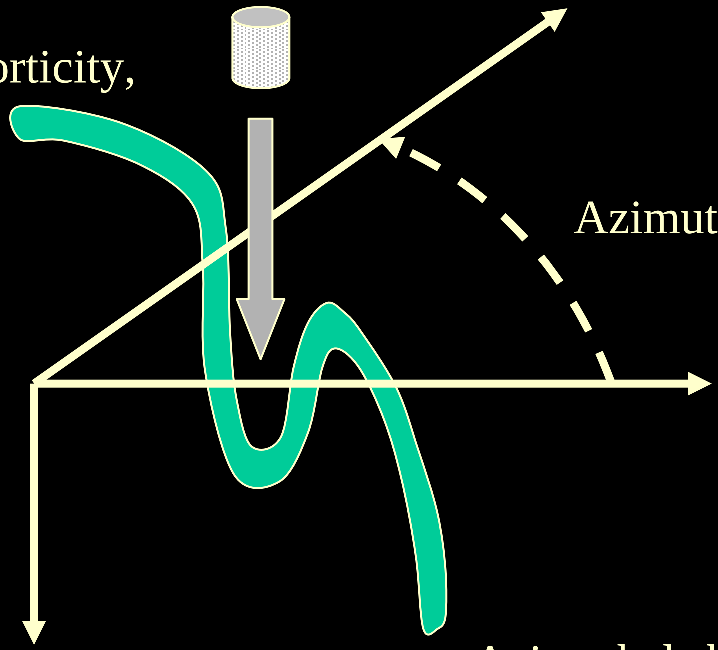
the streamwise vorticity component

$$\frac{D\varpi_x}{Dt} = \varpi_x\frac{\partial U_x}{\partial x} + \varpi_r\frac{\partial U_x}{\partial r} + \varpi_\theta\left(\frac{1}{r}\frac{\partial U_x}{\partial \theta}\right)$$

Stretching

Tilting

Generation of Streamwise Vorticity Due to the Tilting of Azimuthal Vorticity by the Microjet Blowing



Microjet blowing

Generation of Streamwise vorticity,

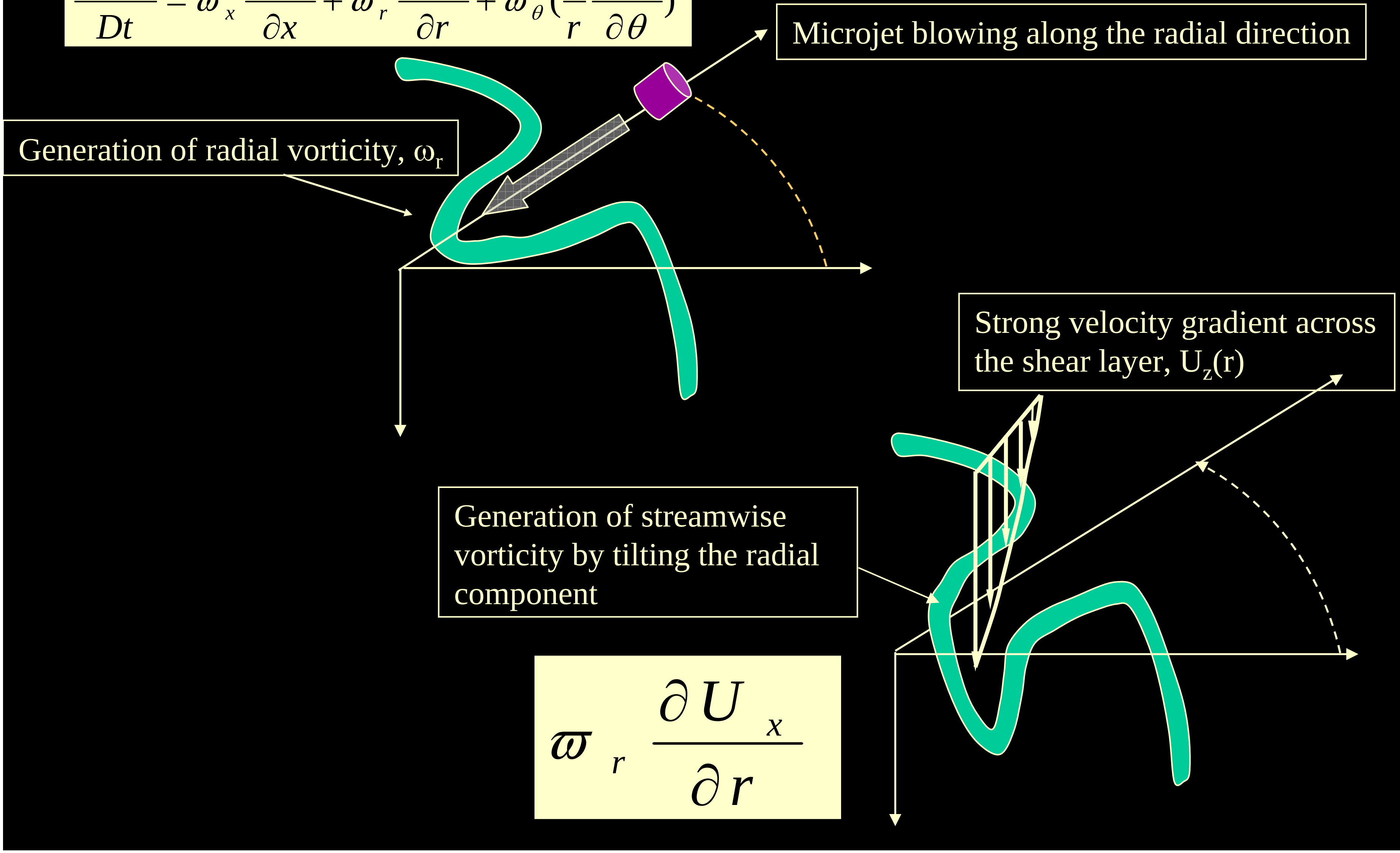
Azimuthal direction

$$\varpi_\theta \frac{\partial U_x}{r\partial\theta}$$

Azimuthal shear layer vorticity line, ω_θ

Streamwise direction

$$\frac{D\varpi_x}{Dt} = \varpi_x \frac{\partial U_x}{\partial x} + \varpi_r \frac{\partial U_x}{\partial r} + \varpi_\theta \left(\frac{1}{r}\frac{\partial U_x}{\partial \theta}\right)$$



Microjet blowing along the radial direction

Generation of radial vorticity, ω_r

Strong velocity gradient across the shear layer, $U_z(r)$

Generation of streamwise vorticity by tilting the radial component

$$\varpi_r \frac{\partial U_x}{\partial r}$$

Summary

- Supersonic microjets are very effective in reducing flow unsteadiness in supersonic impinging jets
- The velocity/vorticity field data clearly reveal the appearance of well-organized, strong, streamwise vortices with the activation of microjets
- This stronger streamwise vorticity appears to primarily come from the existing primary shear layer vorticity through:
  - ➢ Titling and Stretching