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TECHNOLOGIES FOR THE NEXT GENERATION

Active flow control strategies using surface pressure measurements

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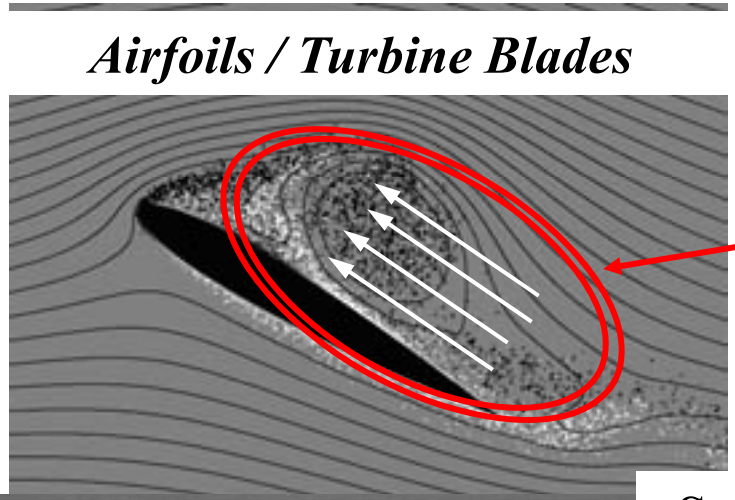
Outline of the presentation

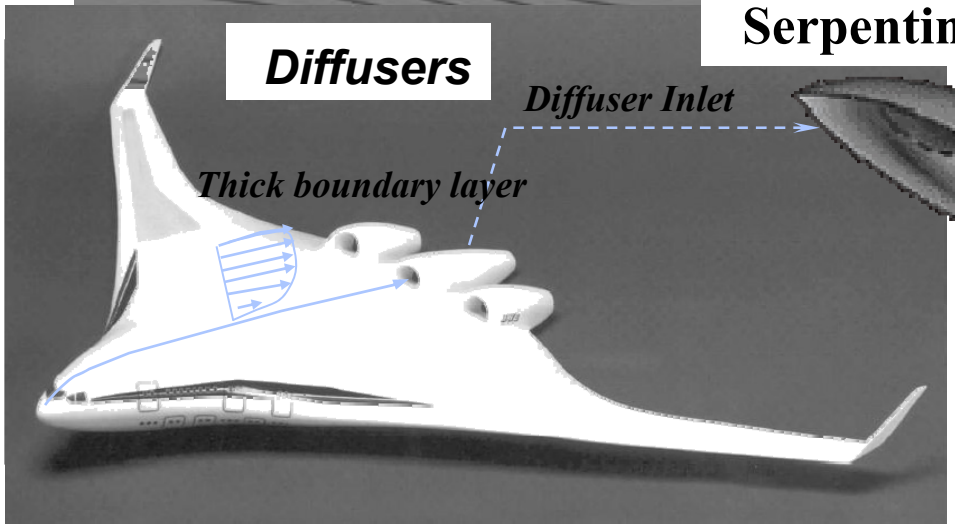
1. Motivation
2. Objectives of the present study
3. Results
4. Test case validation
5. Questions

Motivation – Separation Control and Flow Management

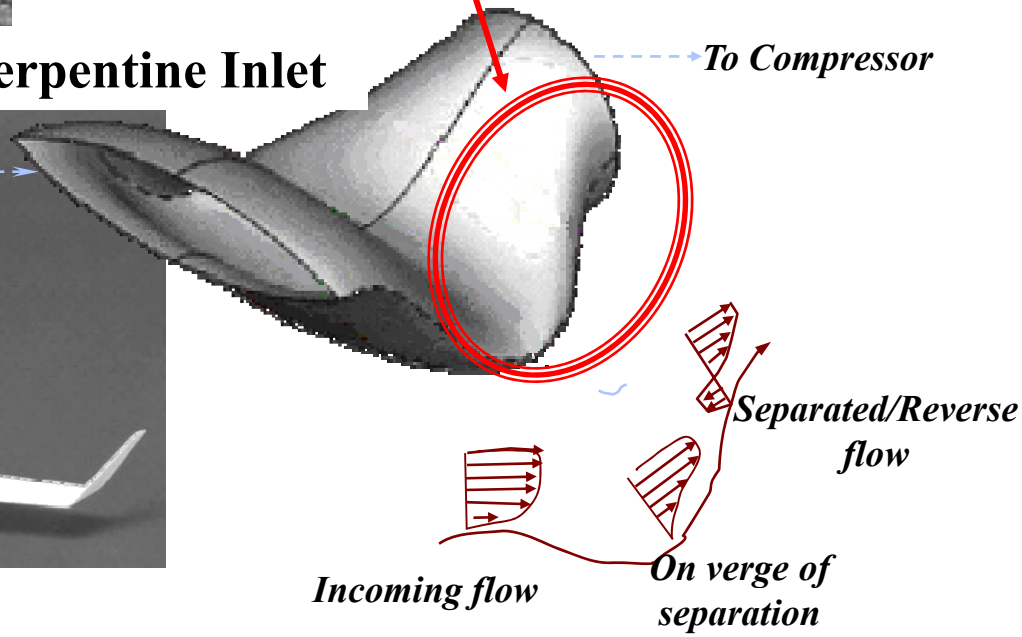


Airfoils / Turbine Blades

Problem Zone / Area of Interest



Blended Wing Body (BWB)



NEED for efficient control devices !!

Objectives of the Present Study

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Evaluate the efficacy of Microjets

- **Can we *eliminate/minimize* flow separation?**
- **Is the flow *unsteadiness* reduced?**

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- ***Guidelines for an active control***
  - ***Search* for an appropriate sensor.**
  - **Examine for means to develop a *flow model* for identifying the state of flow over the surface**
  - **Guidelines toward future development of a *Simple and Robust* control methodology.**

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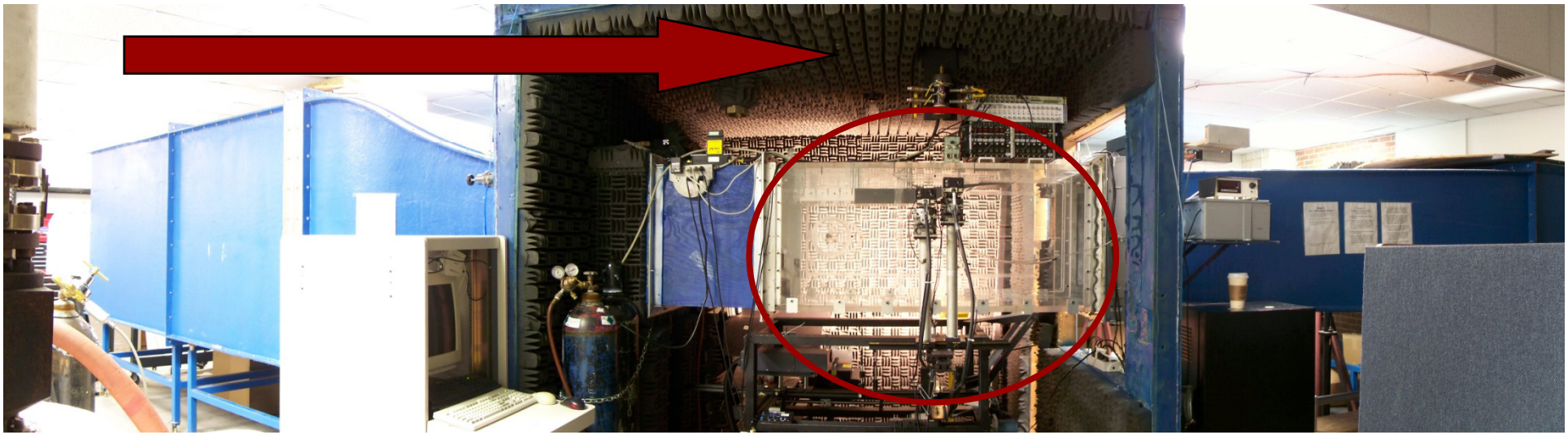
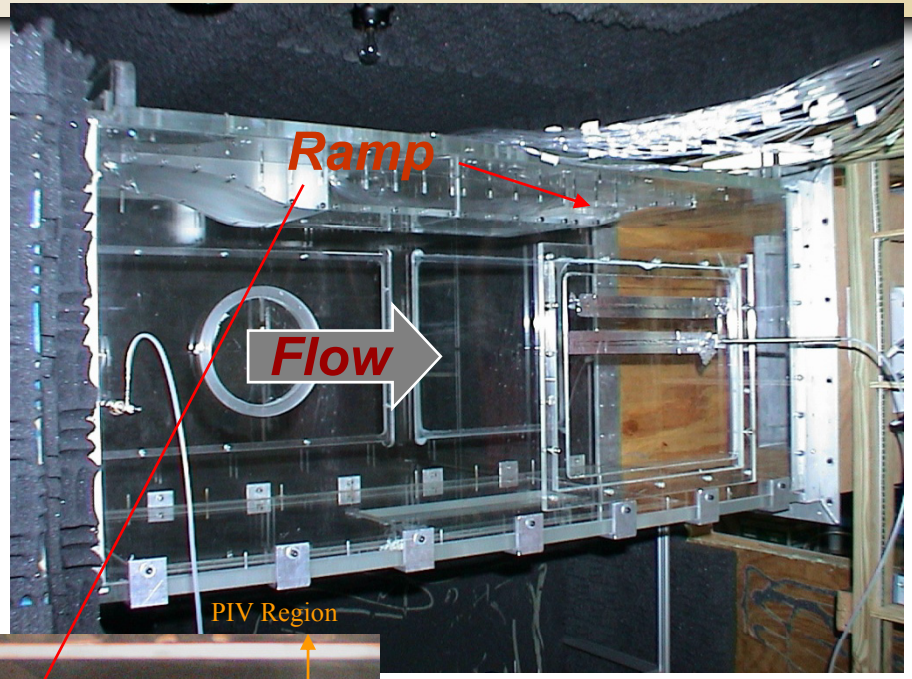
Test Facility - Subsonic Wind-tunnel

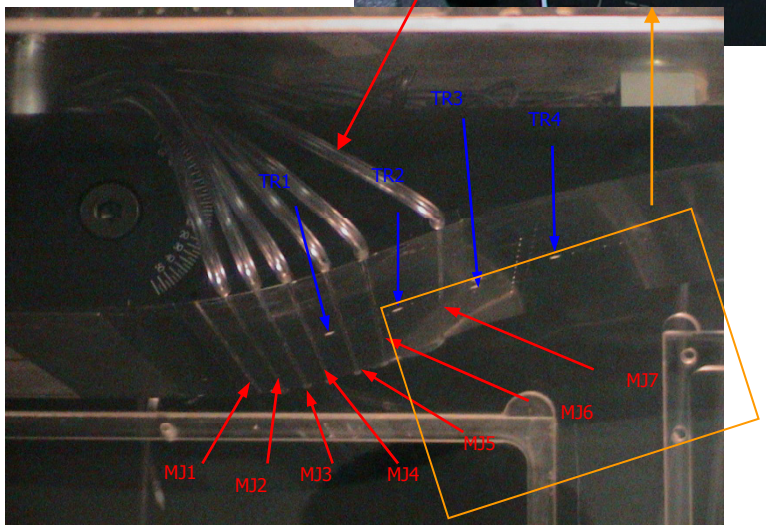


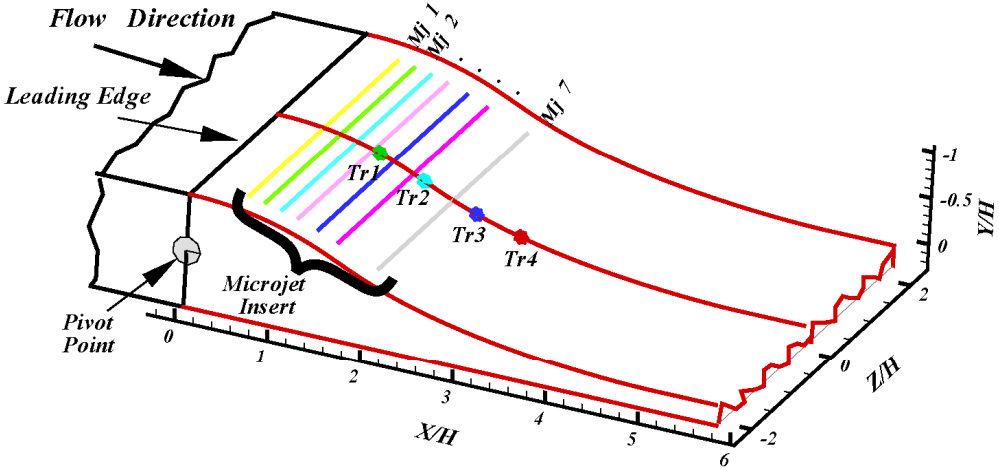
Wind Tunnel

- **Subsonic Closed-Loop Wind Tunnel**
- **Freestream Velocity: 10 – 65 m/s**
- **Test Section:**
  - **24” x 24” x 48”**
  - **Excellent Optical Accessibility**

Test Model - Details







Test Conditions

FLOW CONDITIONS

Freestream Velocity
10-65m/s

Angle of attack
0-10°

CONTROL PARAMETERS

Microjet Location
X/H=1.1 to 4.3

Microjet Angle
68-105°

Microjet Pressure
0 to 30 psig

Incoming B.L. turbulent: At U_∞= 40m/s, $Re_{L.E.}$=1.2 x 10^6

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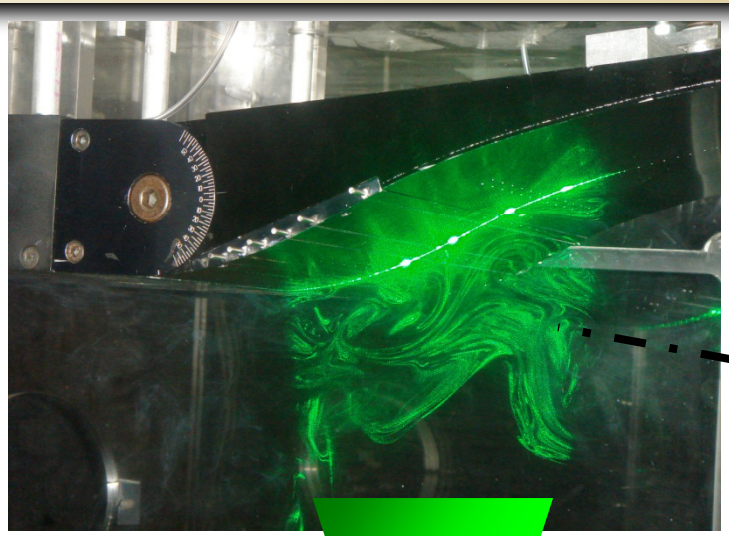
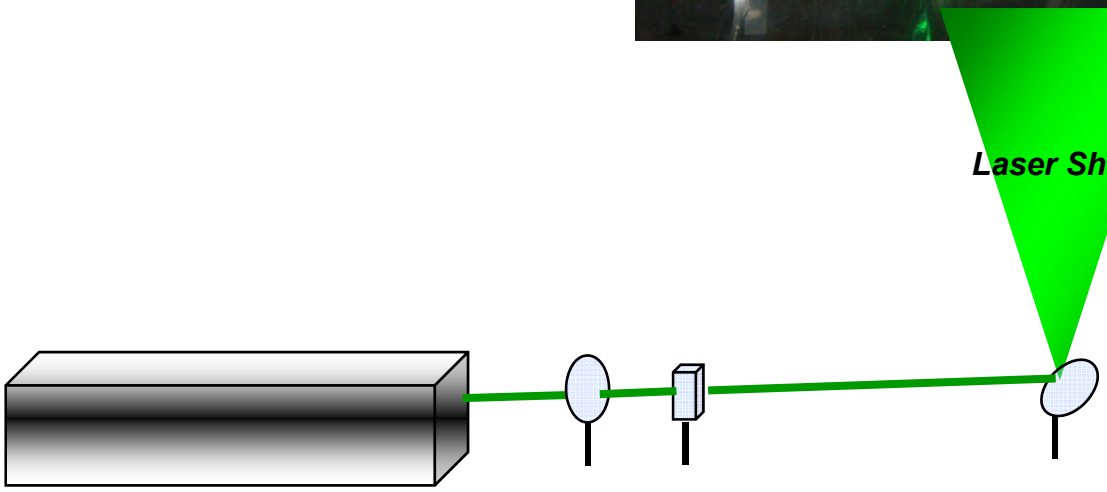
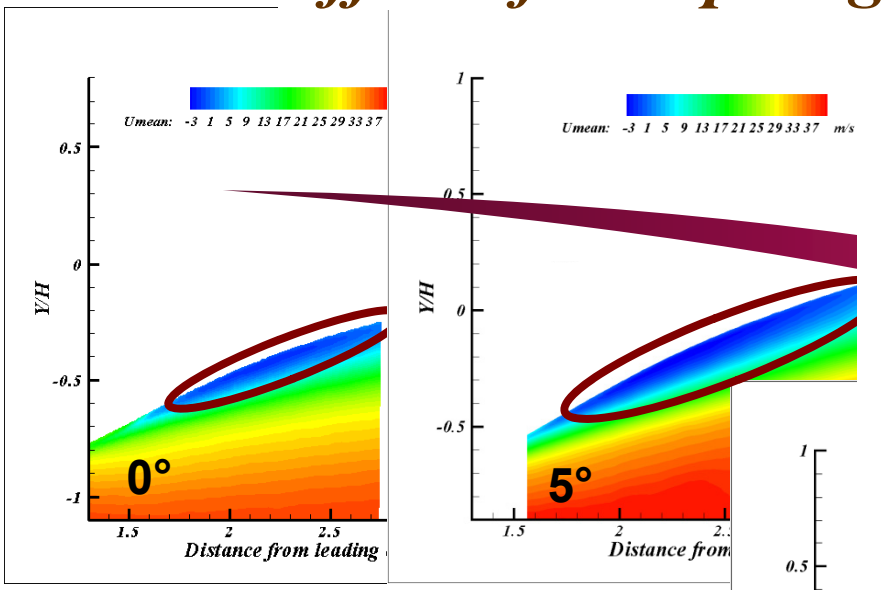
Particle Image Velocimetry (PIV)

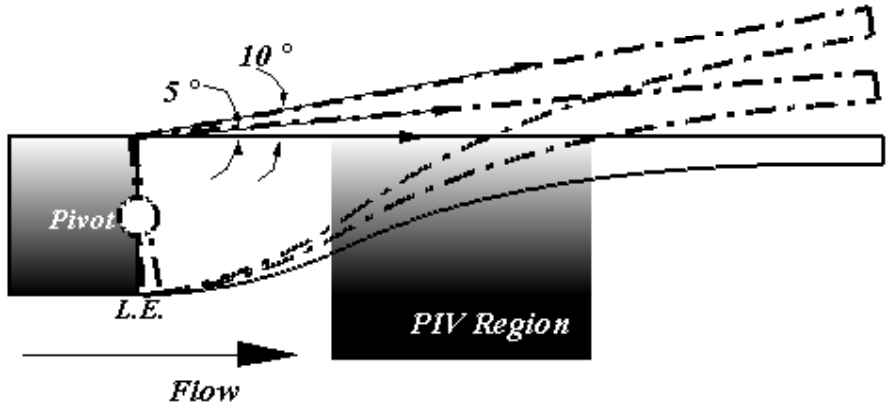


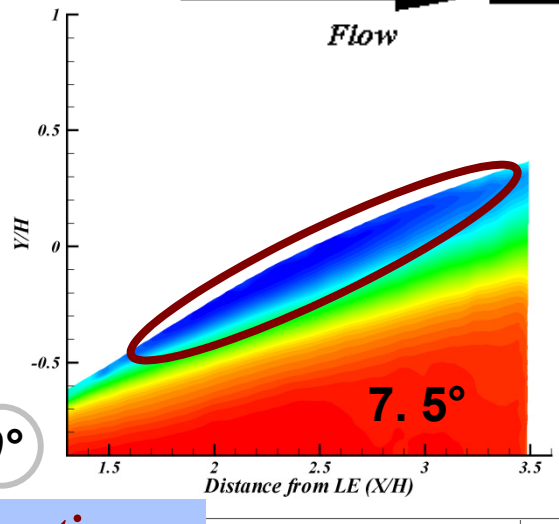


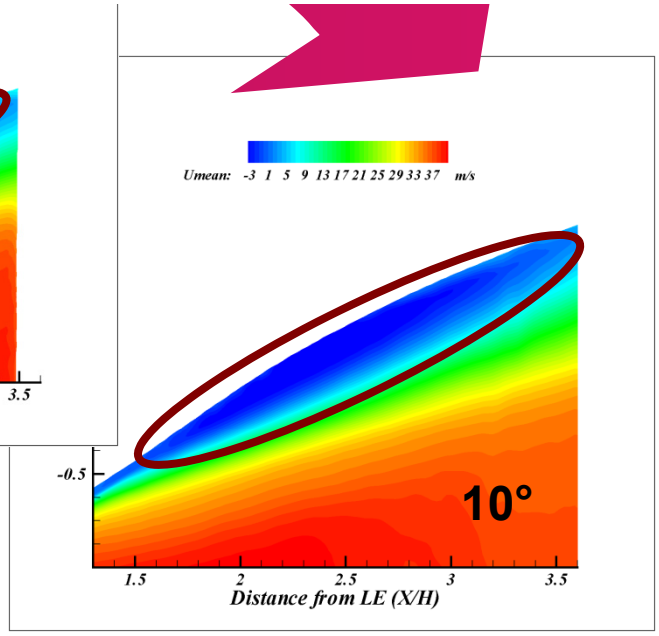
Flow Field Evolution with Ramp Angle

Effect of Ramp Angle, No Control, U_∞ = 40m/s









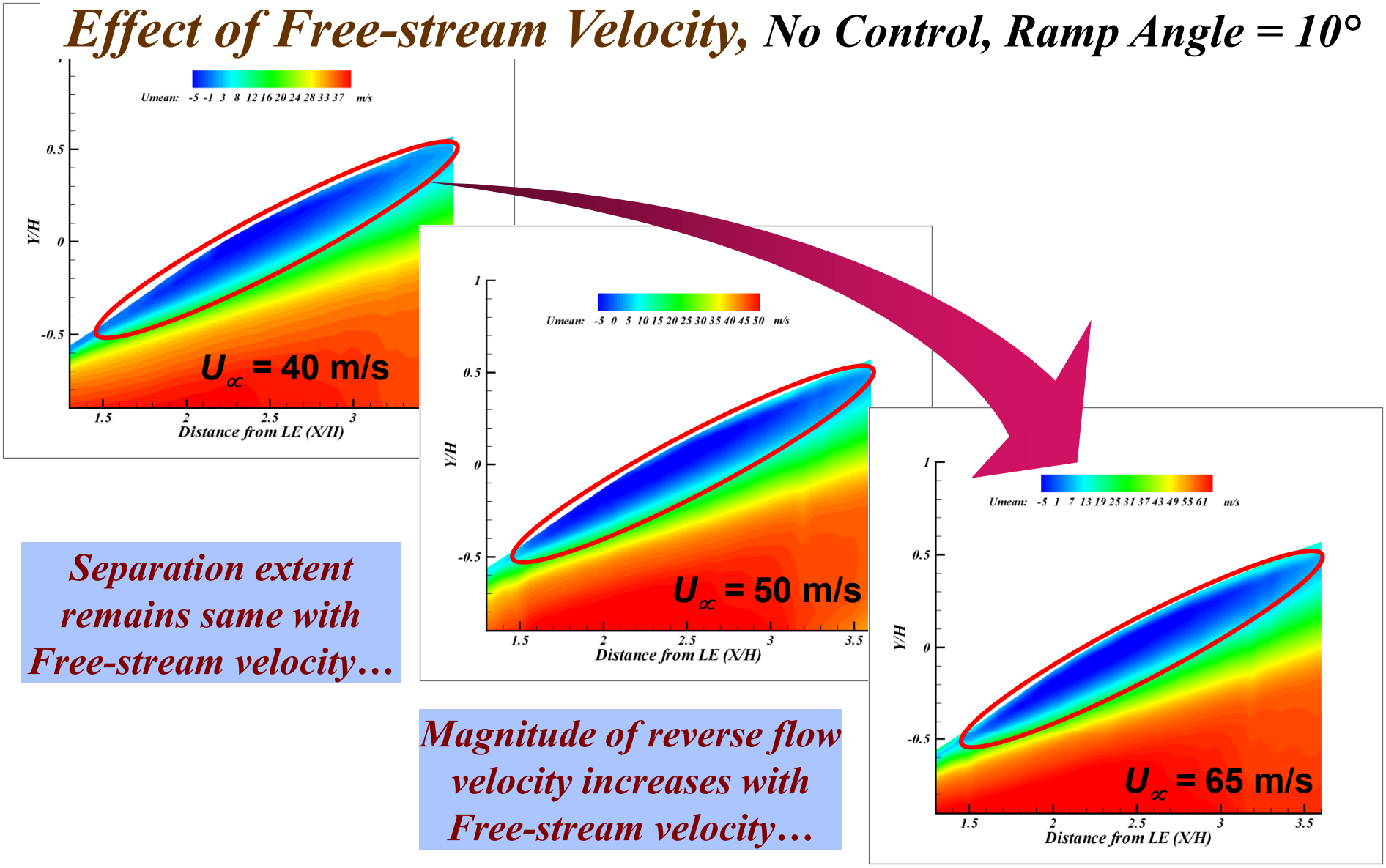
Separation region increases with increasing Angle of Attack…

ΔX ~ 1/3rd of Ramp length for 10°

Separation location moves upstream with increasing AOA…

Flow Field Evolution with Velocity

Effect of Free-stream Velocity, No Control, Ramp Angle = 10°

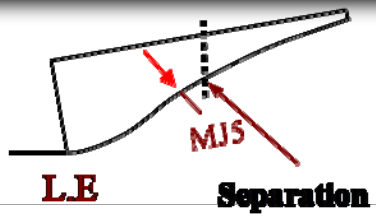


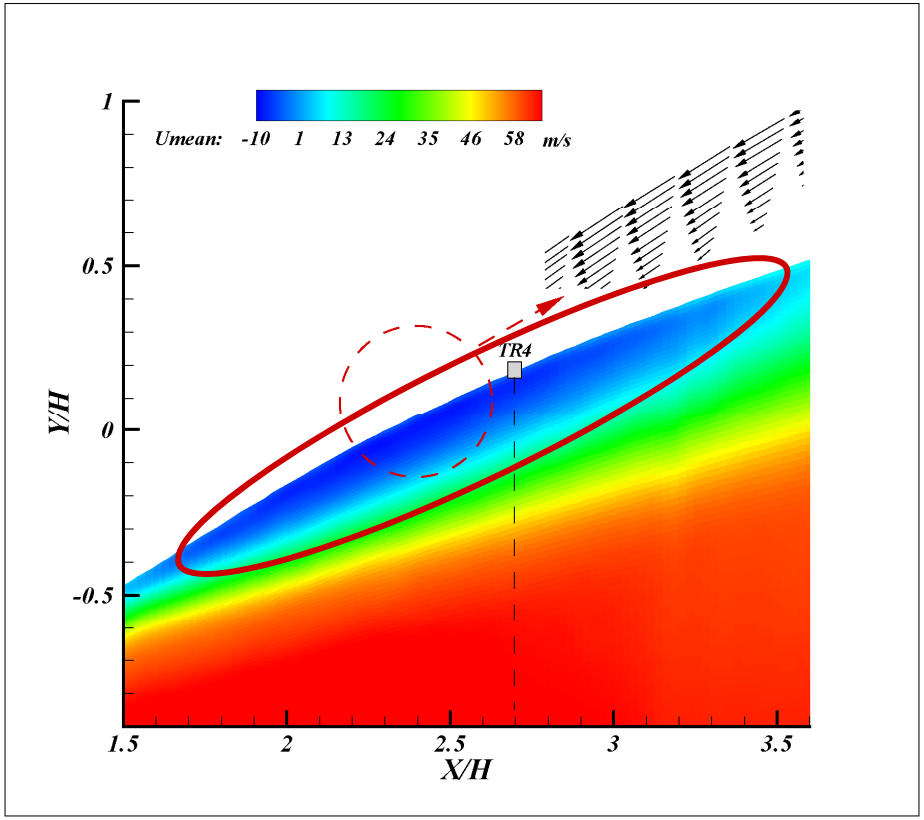
Separation extent remains same with Free-stream velocity…

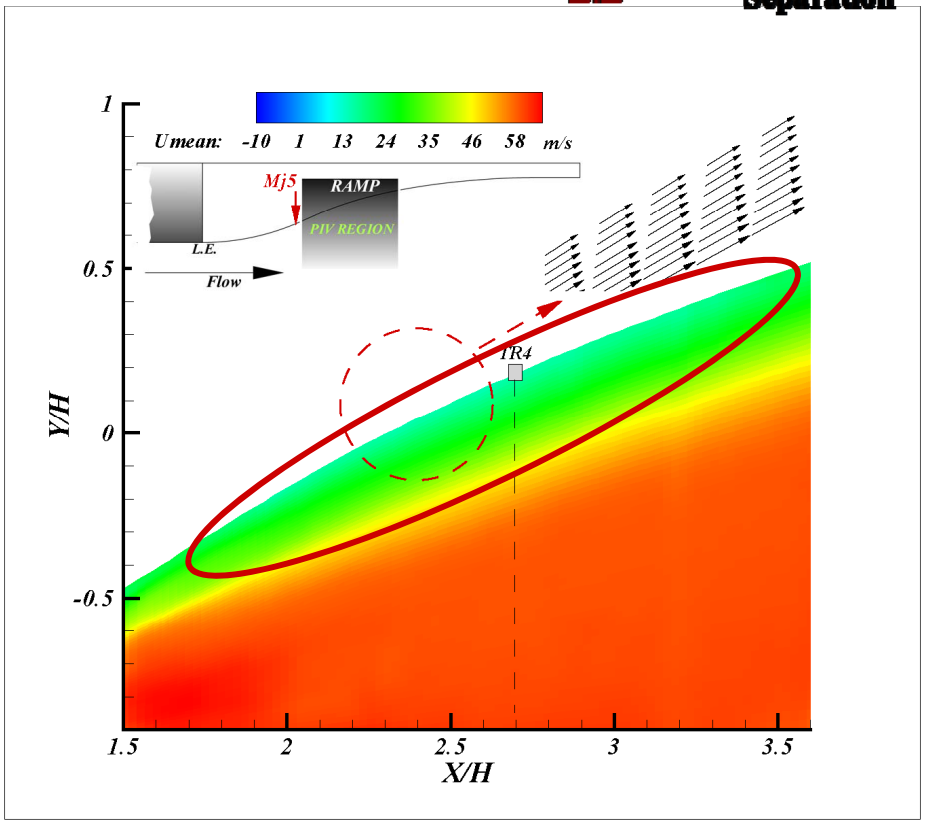
Magnitude of reverse flow velocity increases with Free-stream velocity…

Control Efficacy for the Largest Separation Case

Ramp Angle = 10° , U_∞= 65m/s





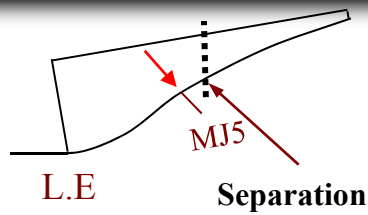


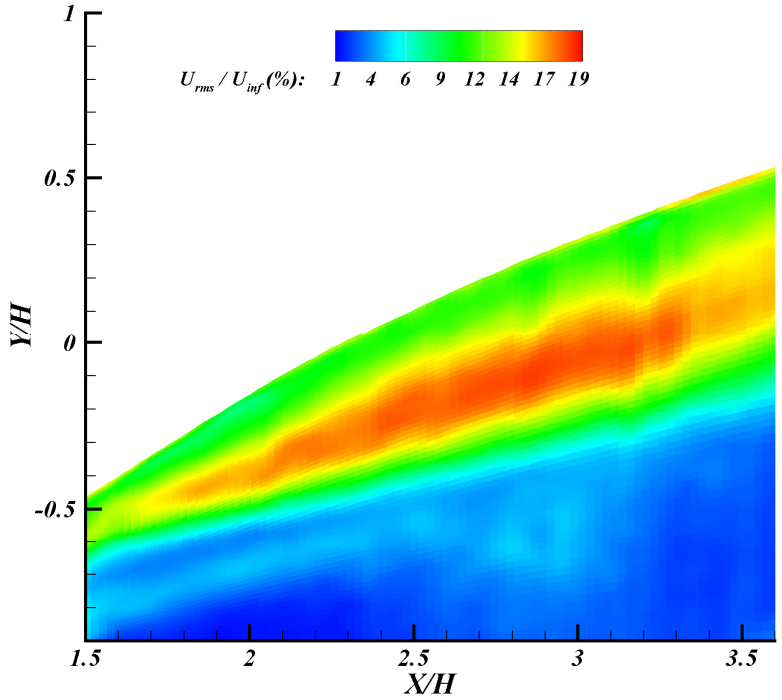
No Control

MJ5, 90° ,25psig

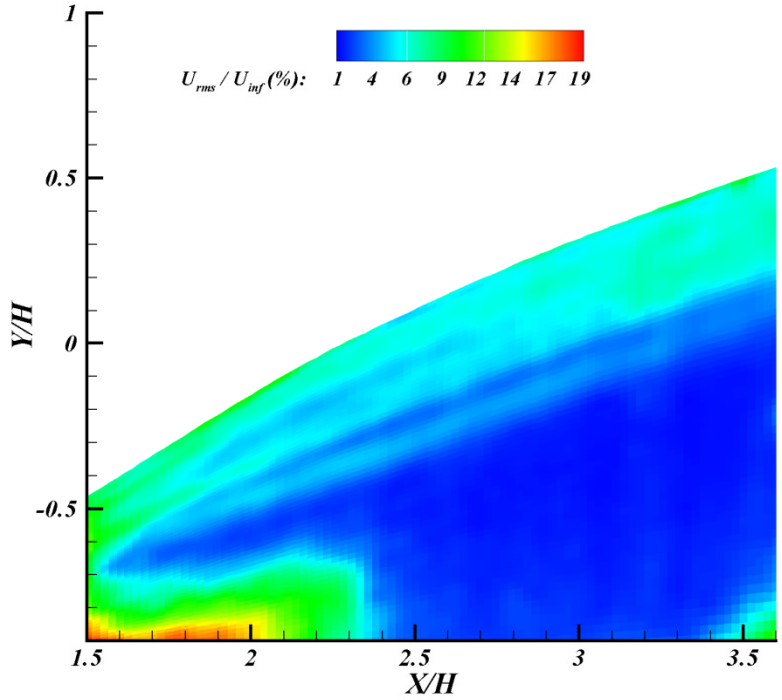
Unsteadiness – with and without control

Root Mean Square Velocity, U_{rms}
Ramp Angle = 10° , U_∞= 65m/s





No Control



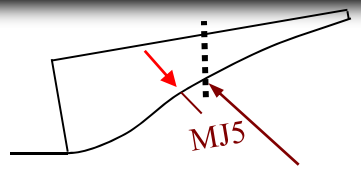
MJ5, 90°, 25 psig

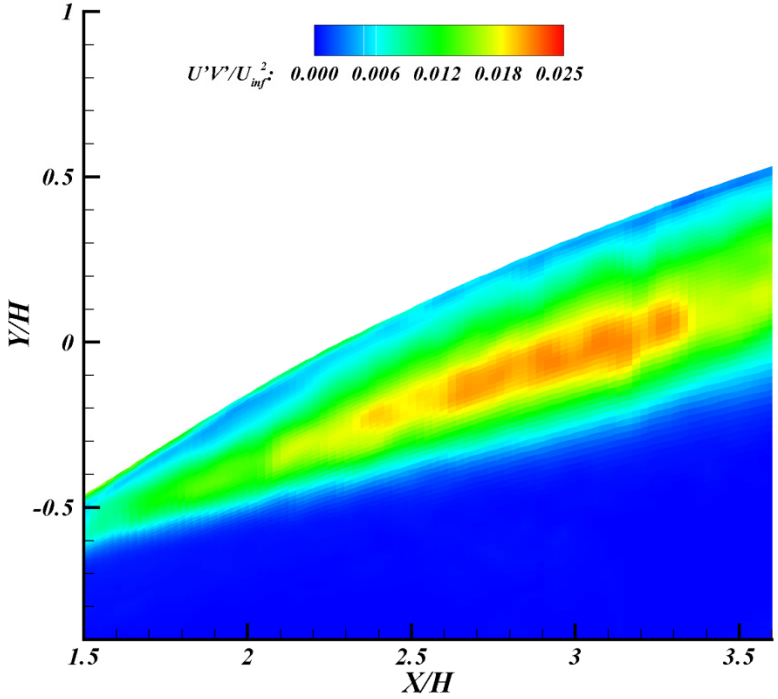
Peak unsteadiness reduced by 70%

Turbulent Shear Stress – with and without control

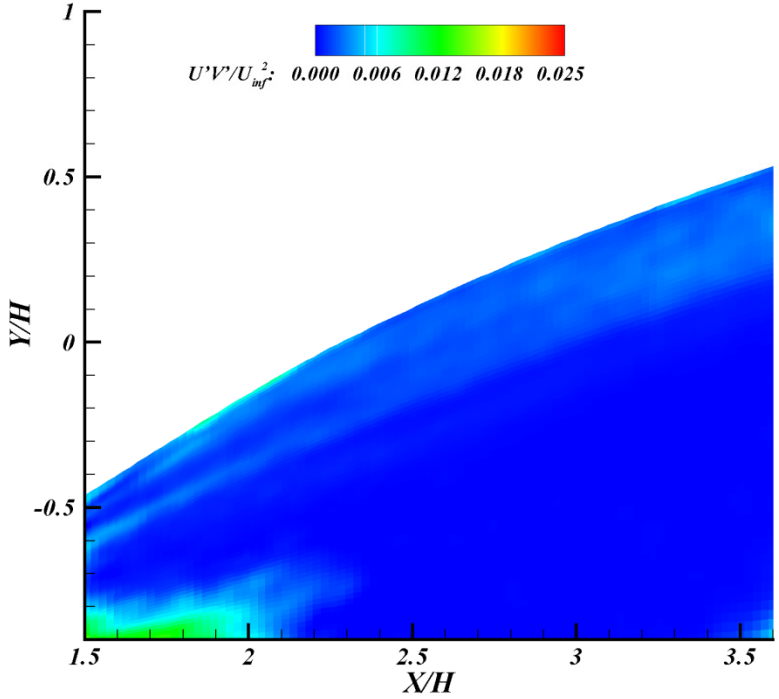
Turbulent Shear Stress, $U'V'$

Ramp Angle = 10° , U_∞ = 65m/s





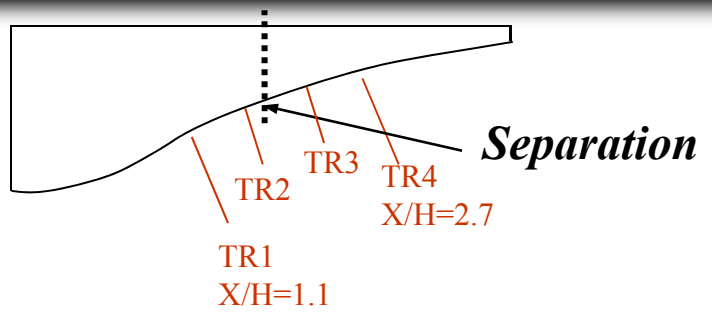
No Control

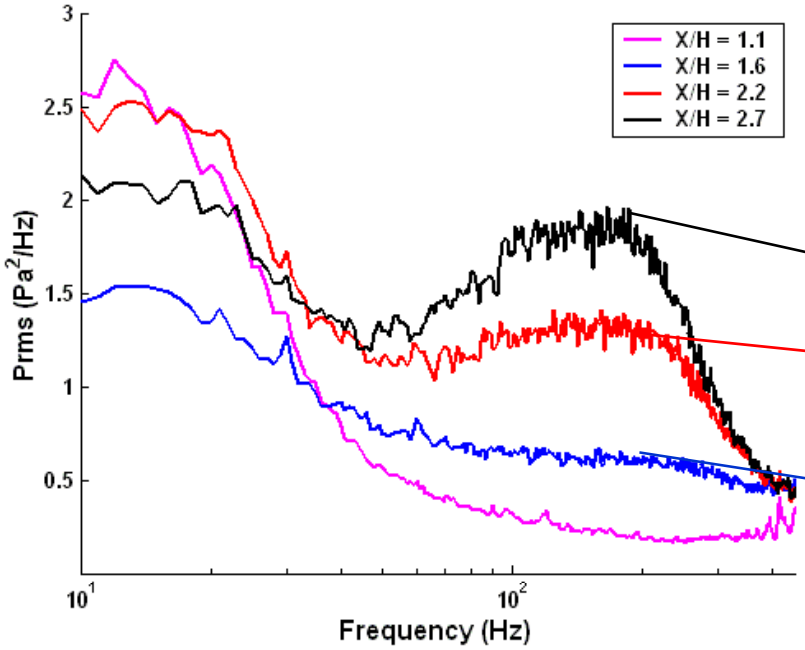


MJ5, 90°, 25 psig

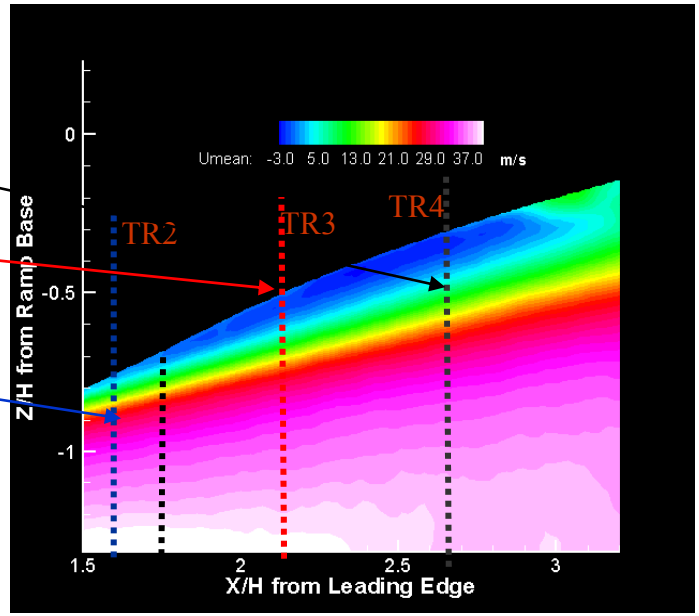
Unsteady Pressure, P´ in Flow-field

Ramp Angle = 5° , U_∞= 40m/s





Spatial Pressure spectra @ 40m/s



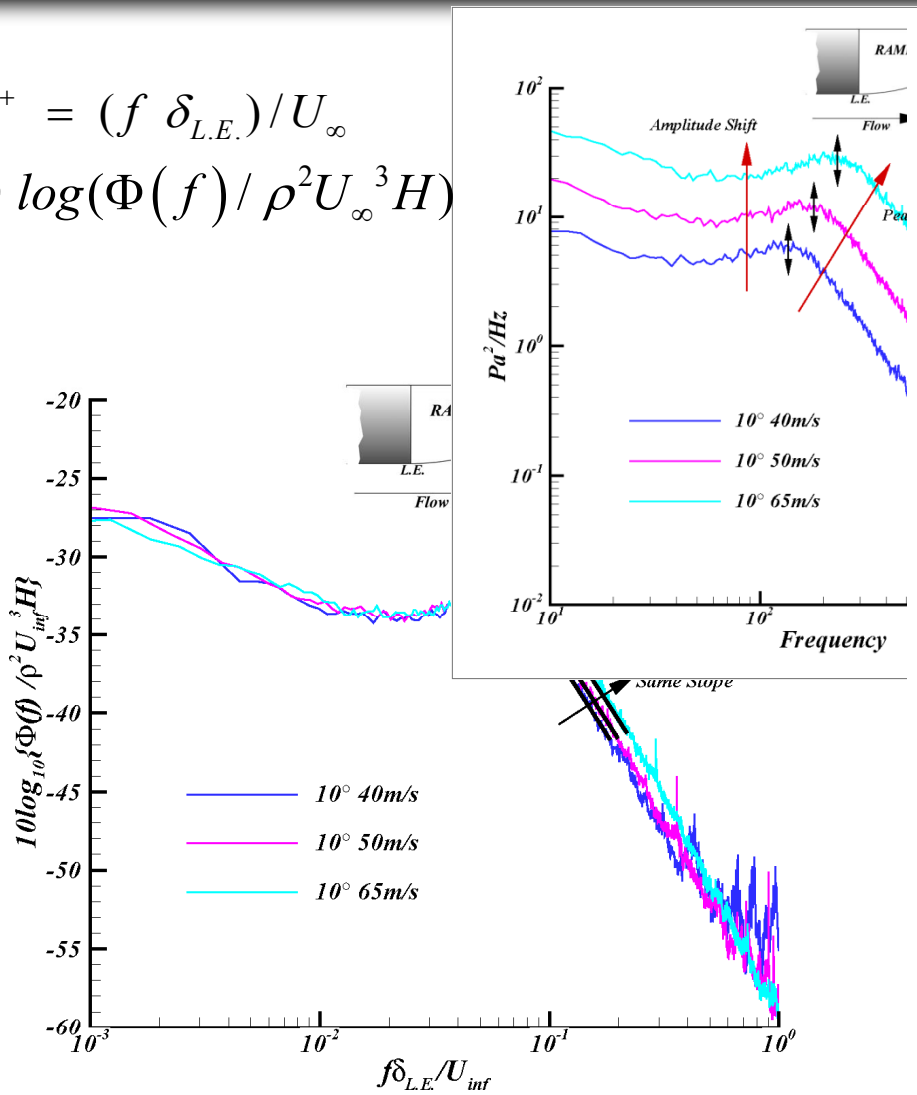
Corresponding Streamwise Locations

Substantial Increase in P_{RMS} across separation !!

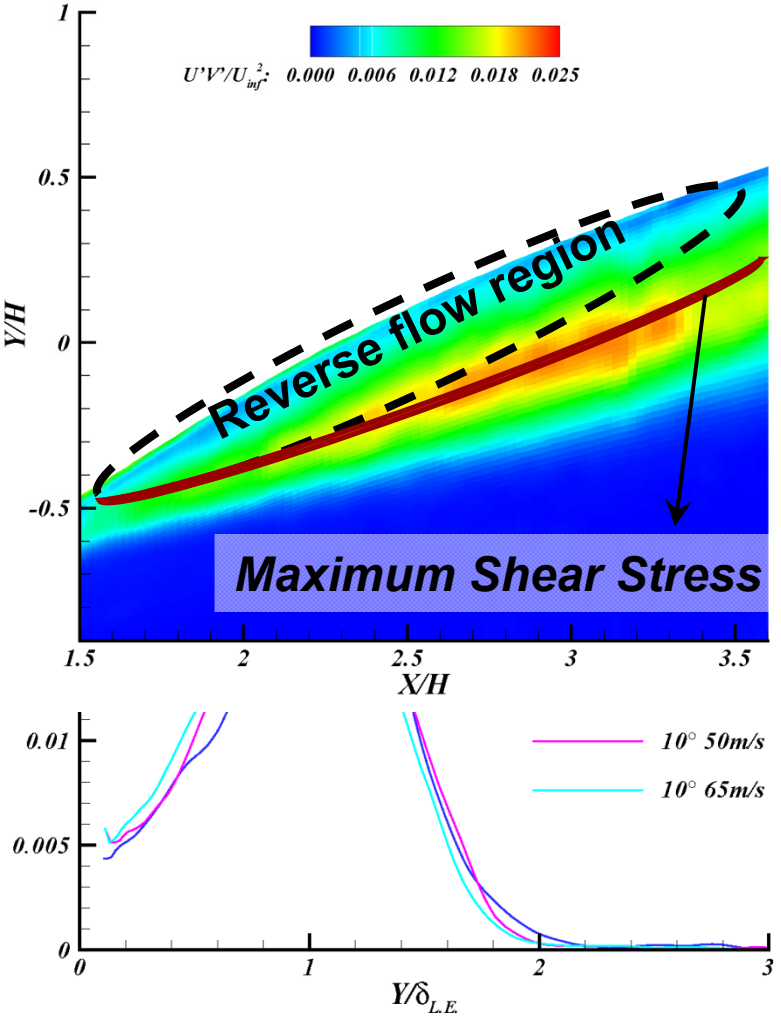
Effect of Freestream Velocity

$$f^{+} = (f\ \delta_{L.E.})/U_{\infty}$$

$$10\ log(\Phi(f)/\rho^{2}U_{\infty}{}^{3}H)$$



Non-dimensionalized Pressure Spectra

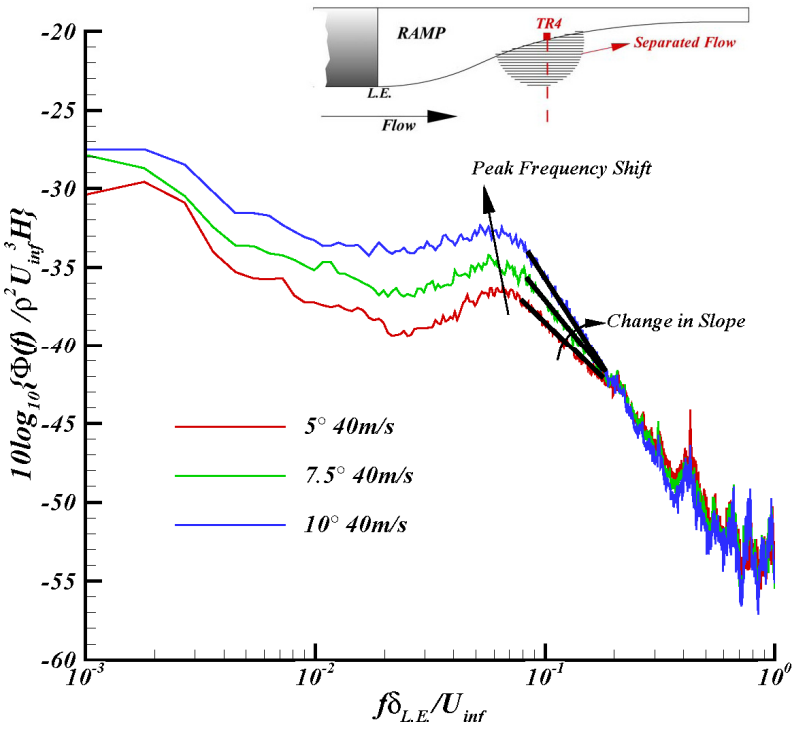


Non-dimensionalized shear stress

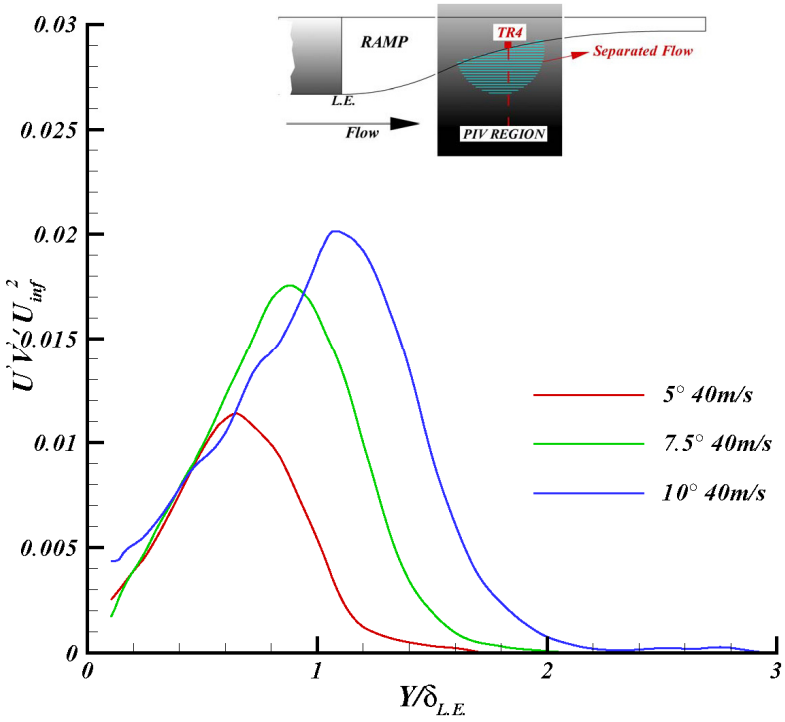
Dependence on Angle of Attack

Angle = 5°, 7.5°, 10°

U_∞ = 40 m/s



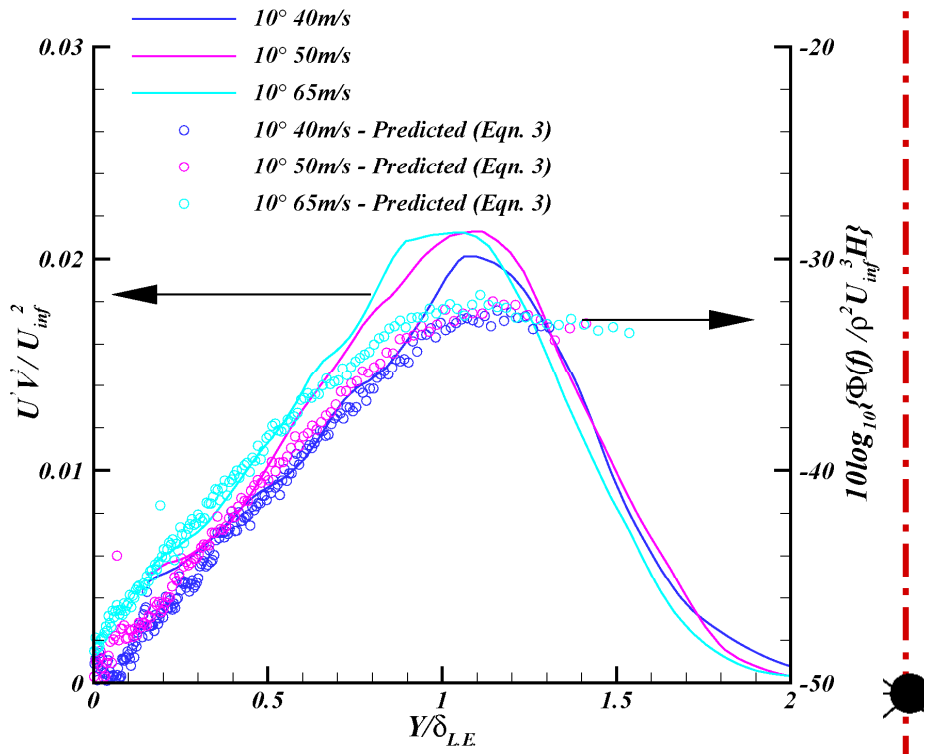
Non-dimensionalized Pressure Spectra



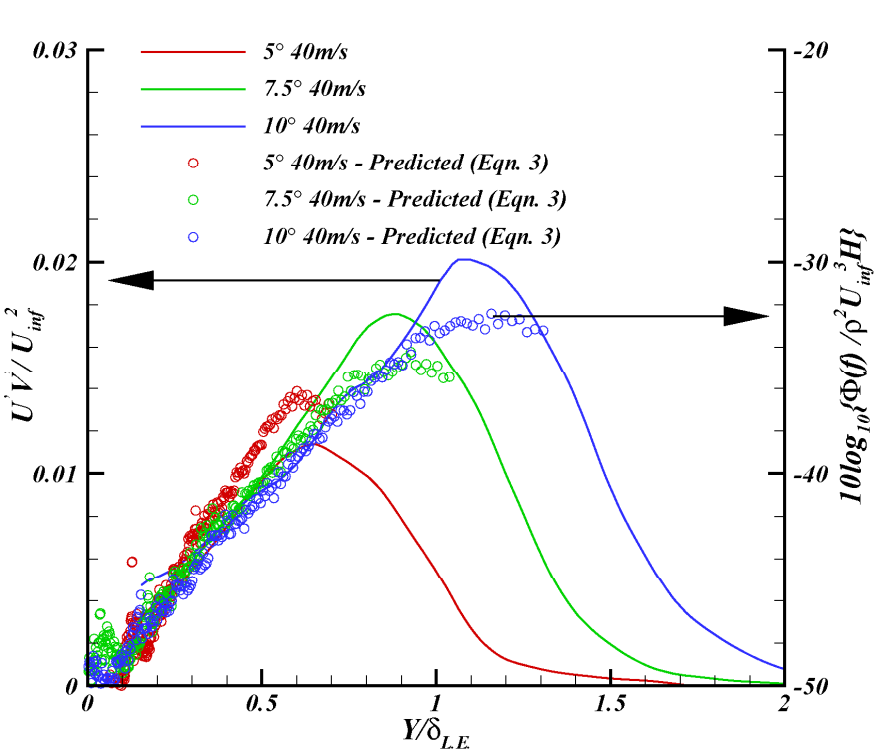
Non-dimensionalized shear stress

Developing a Sensor model

$$\frac{Y}{\delta_{L.E}} = \log(slope)\left[\log\left(\sqrt{\left(\frac{1}{f_c}\right)\times slope}\right)\right] + 0.25$$



Freestream Velocity variation



Angle of Attack dependence

A reasonably good estimate of the peak unsteadiness location can be obtained by unsteady surface pressure measurements

Virtual sensor

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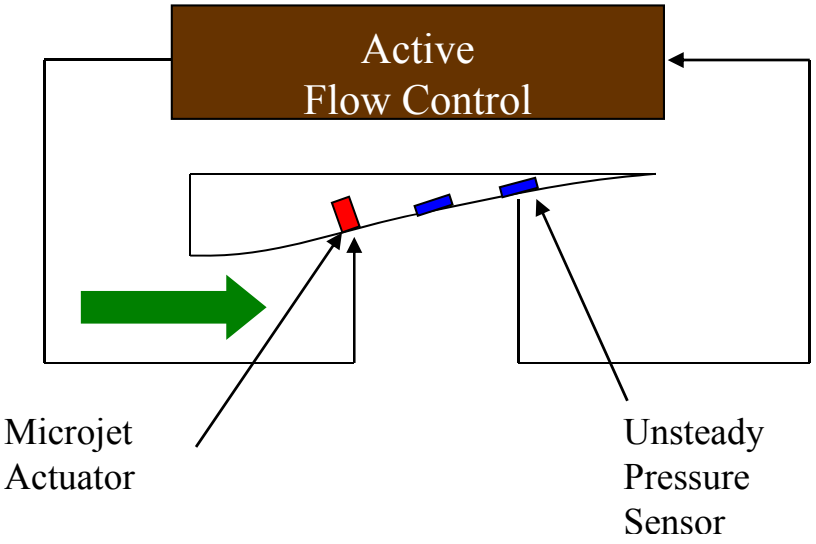
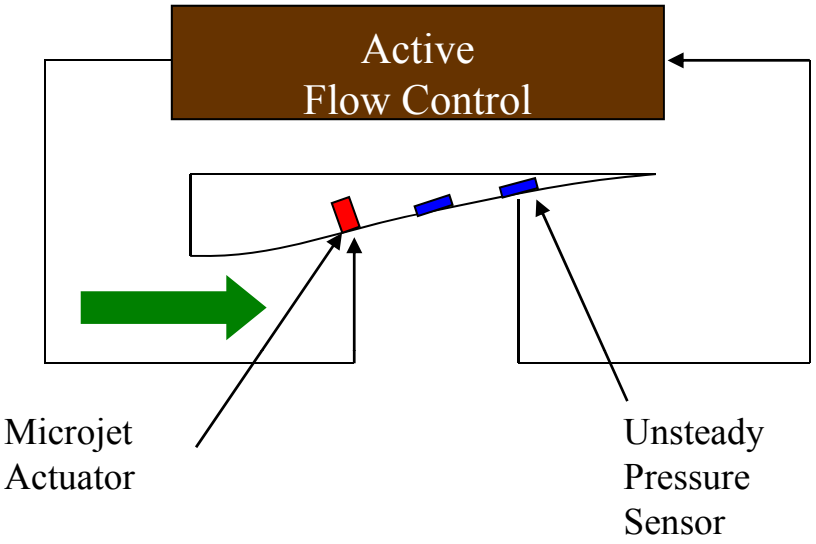
Advantages of the proposed 'Virtual Sensor'

- **Relatively *simple and fast estimations of flow conditions* above the surface => Faster ID of appropriate control parameters**
- ***Increased sensitivity* of the pressure measurements (Narrow frequency range to use)**
- **Control approach can be *'hard-wired'* or be *'software controlled'***
- **Provides a proportional *control knob***
  - **Can be used as part of an outer-loop for *'Overall System optimization'***



Proposed Control Schematic

Proposed Control Approach



Requirements

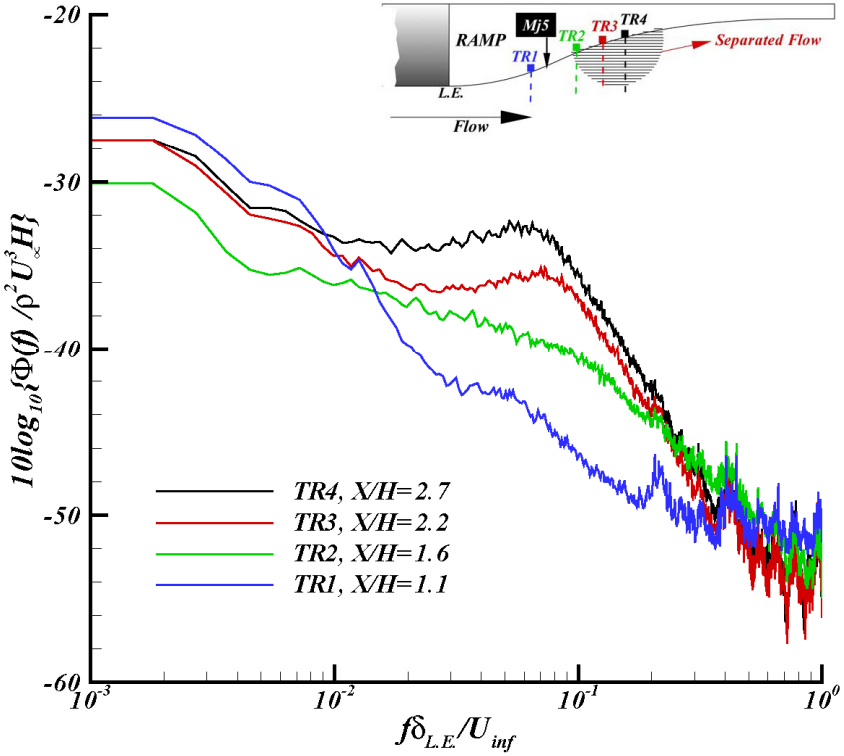
- Known *Geometry & Actuator Locations*
- *Jet trajectory* (based on C_μ)
- *Unsteady pressure measurements*

Steps for Control Approach

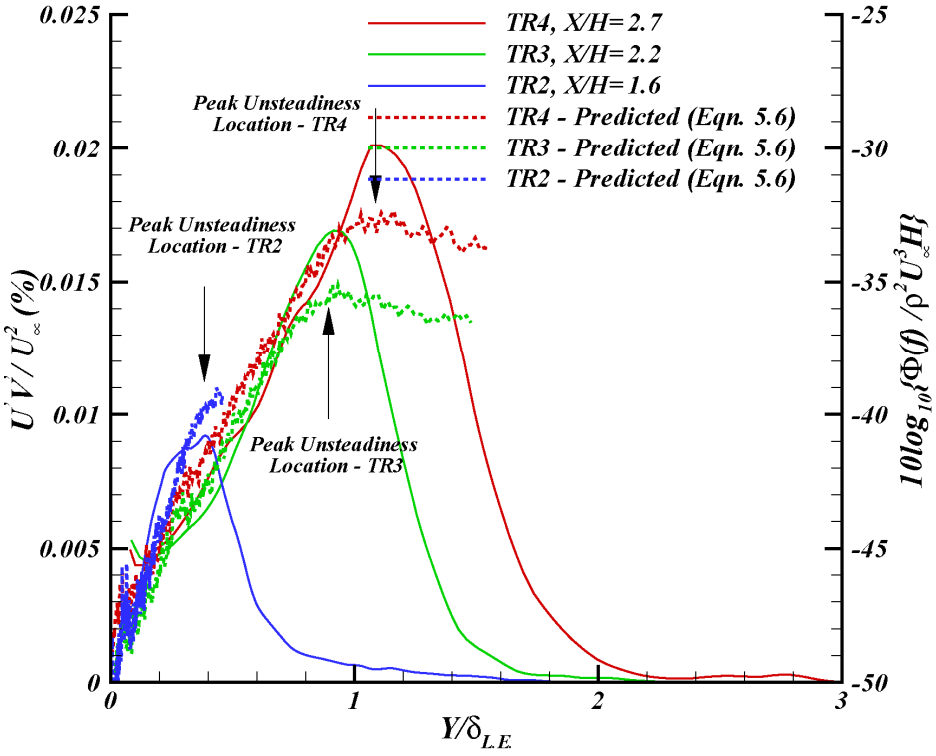
- Obtain P′(f)
- Transform to identify peak unsteadiness location (Y/δ to be affected)
- Use known geometry to identify the location of microjets available (X_i)
- Determination of C_μ based on X and Y for optimal effect.

Validation of the proposed model – Test Case

Ramp Angle = 10° , U_∞= 40m/s



Non-dimensionalized Pressure Spectra



Estimated shear stress profile

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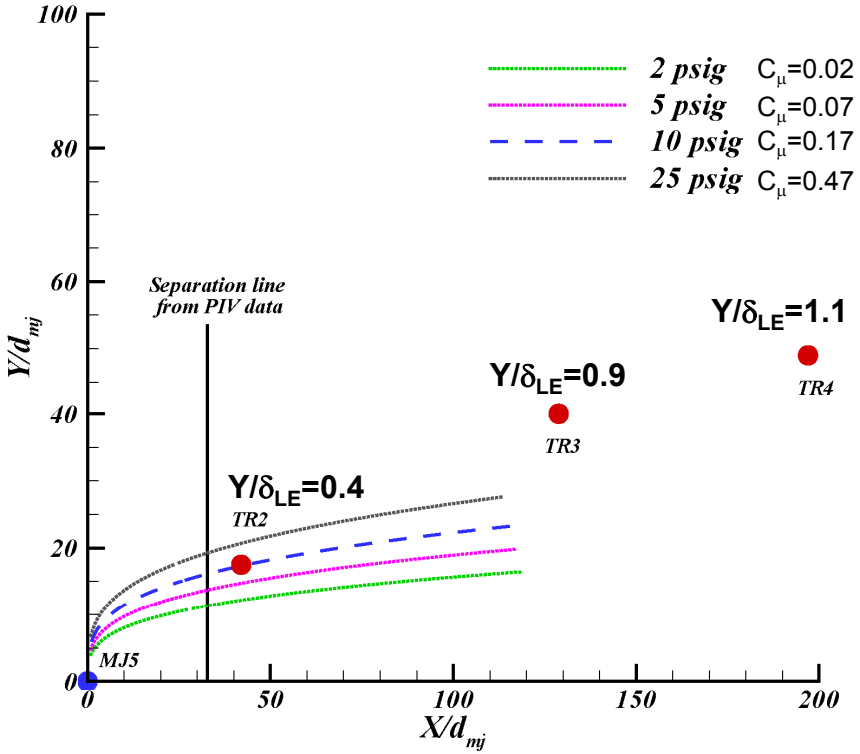
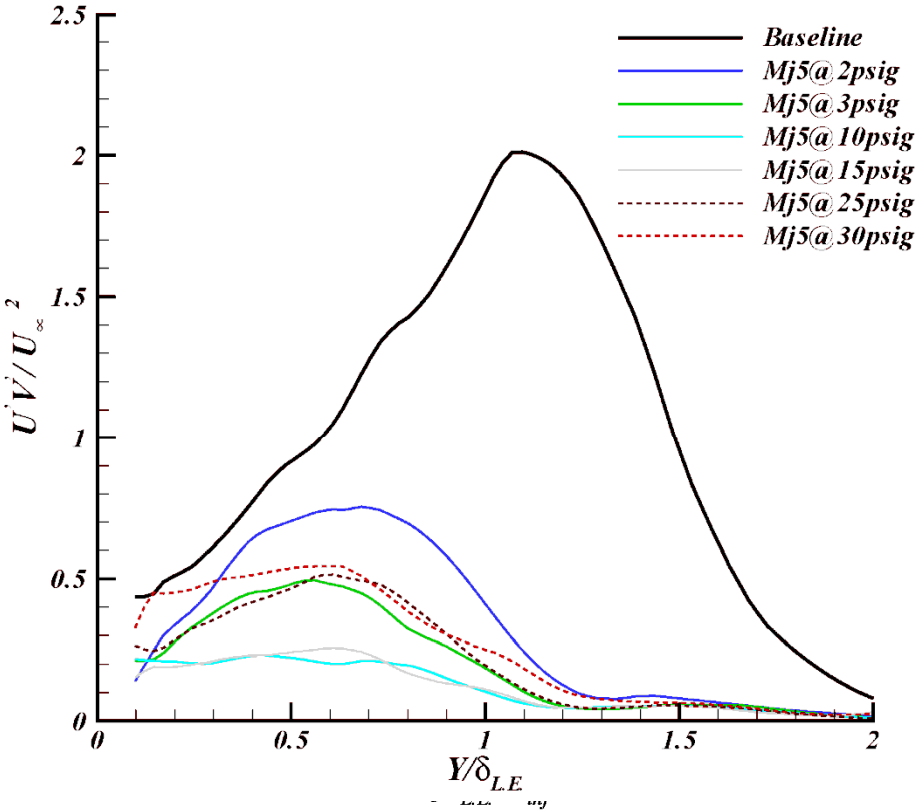
Control Strategy

Ramp Angle = 10° , U_∞= 40m/s; Microjet: MJ5, 90°



Location of Unsteadiness mapped with Microjet location and Jet Trajectory



Response on the flow-field

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Summary

Separation Control using Microjets

Effectiveness of Microjet Control

- Completely eliminated separation with very low mass flux
- More than 70% reduction in unsteadiness
- Makes flow nominally 2-dimensional

Use of Unsteady Surface Pressure for Active Flow Control

- Flow properties well reflected in the pressure spectra
- Relatively faster control schemes can be developed

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Questions ?

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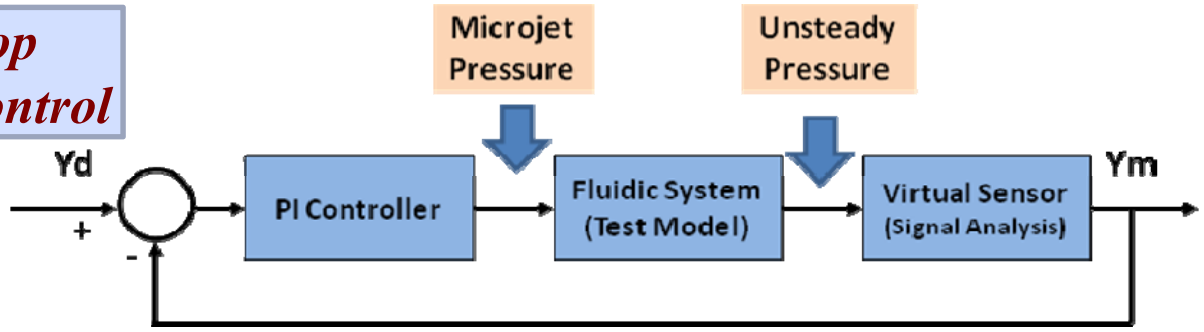
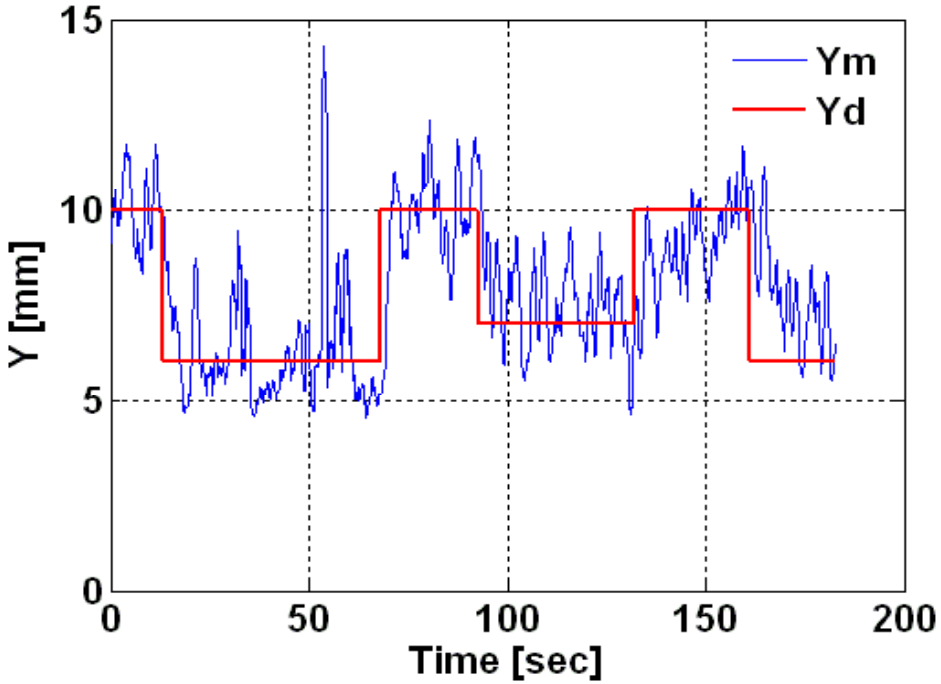
Closed Loop Tracking

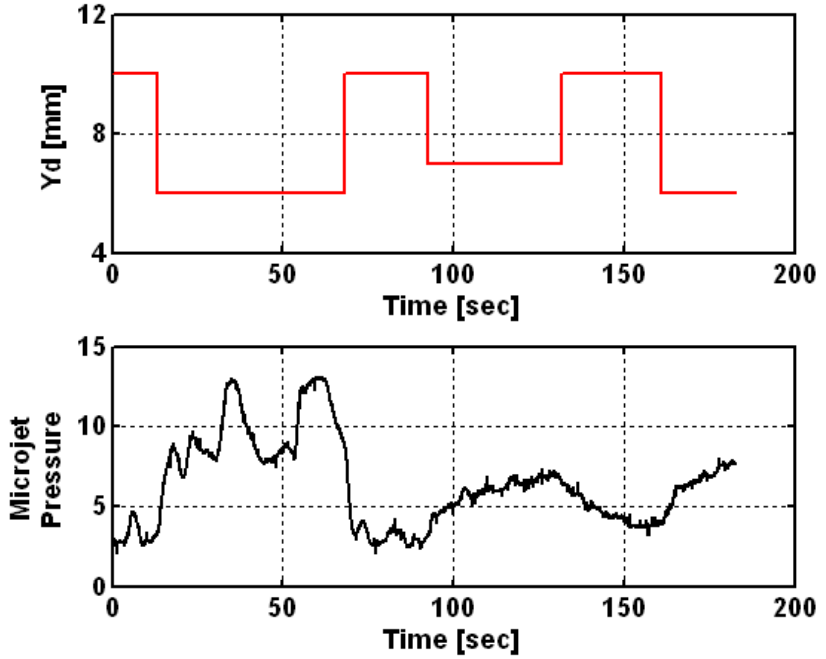
Collaborators: Oscar Y. Chuy, E. Collins

Closed Loop Separation Control





Tracking the degree of separation



Commanded Microjet pressure