Control of Compressible Dynamic Stall using Microjets

C. Shih, J. Beahn, and A. Krothapalli
Mechanical Engineering Department
Florida A & M University and Florida State University

M. Chandrasekhara
Naval Postgraduate School

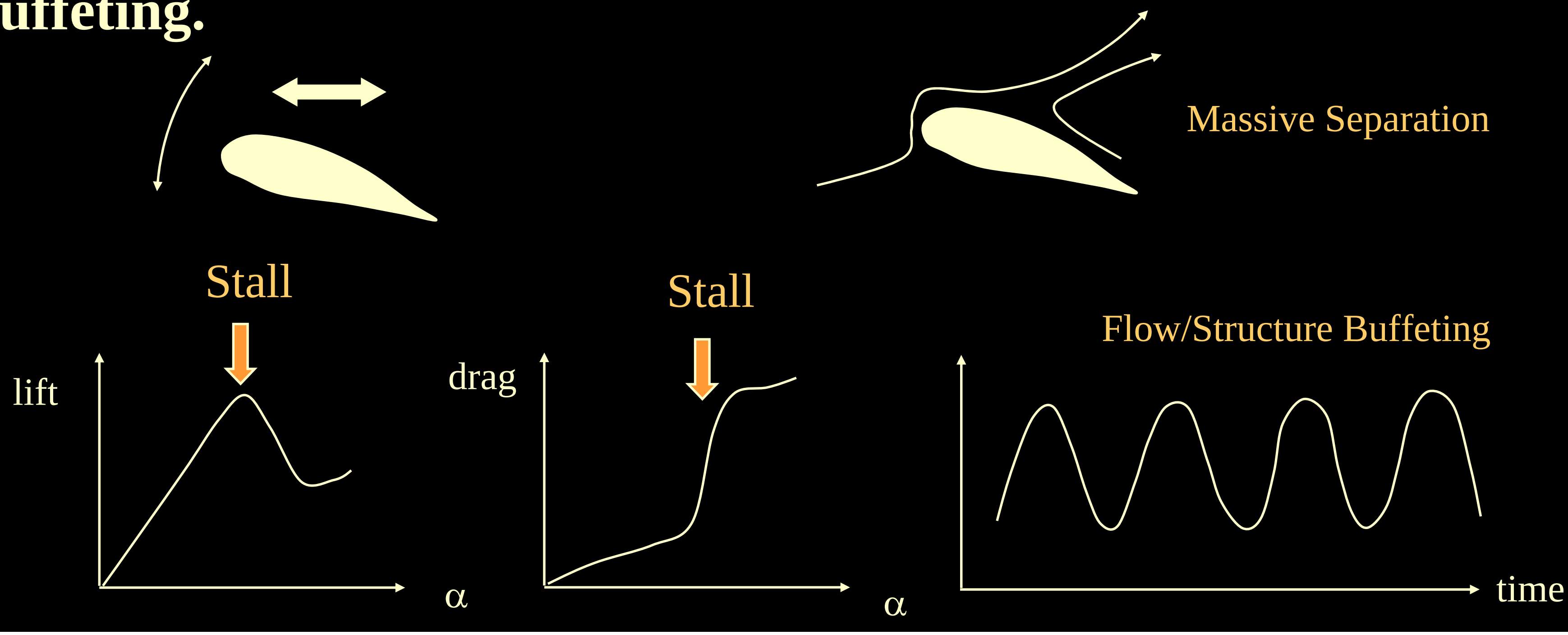
Supported by NASA Ames Research Center and Army Aeroflightdynamics Directorate, Rotorcraft Division

Outline

- Motivation
- Experimental Setup
  – Point Diffraction Interferometry (PDI)
- Dynamic Stall with and w/o Control
- Physical Mechanism/Control Strategy
- Conclusion

fmrl
fluid mechanics research laboratory

Dynamic stall: a flow phenomenon when wings and rotors experience sudden changes of their operating conditions (angle of attack, inflow conditions, etc). The flow response to these changes usually involves many adverse effects such as massive boundary flow separation, a loss of lift, drag surge, and buffeting.



Program Objectives

- Eliminate or minimize these adverse effects using microjets
- Devise control strategy to achieve the optimum efficacy

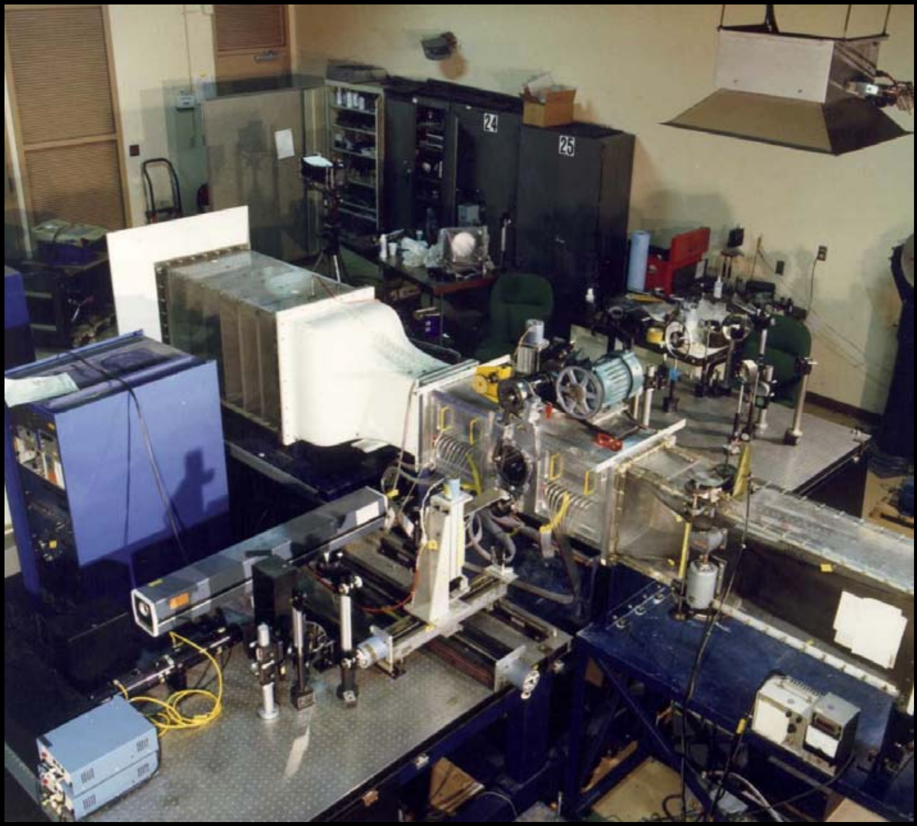
Previous control efforts

- Boundary layer blowing & suction, synthetic jets, pulsed vortex generator jets
- Nose modification
- Mechanical devices: vortex generators, flaps & slats

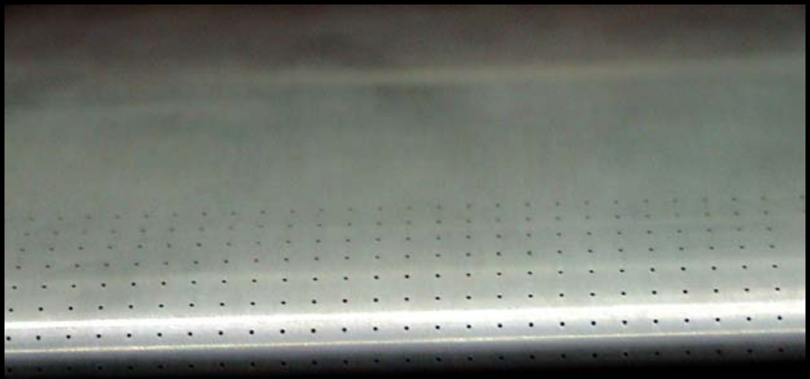
fmrl
fluid mechanics research laboratory

Experimental Setup

- NACA 0015 airfoil
- Blow-down wind tunnel
  - Operate at Mach 0.3-0.4
- Pitch rate: k=0.05 & 0.1, pitch angle: 5 to 25 deg.
- Reynold's number
  - $1.06 - 1.40 \times 10^6$
- Point Diffraction Interferometry (PDI)



Experimental Setup - Airfoil



Airfoil Leading Edge

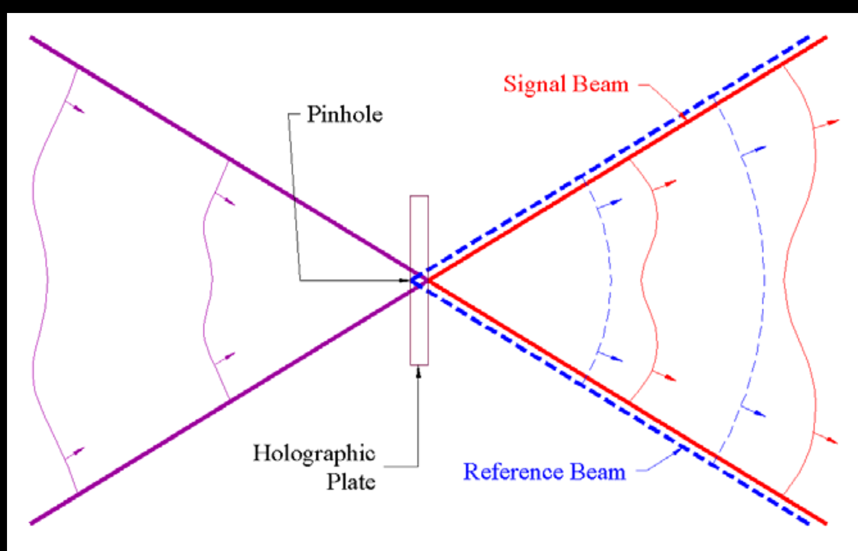
- 424 microjets (8 rows) on upper surface for 10% chord
  - 400 μm in diameter
  - Continuous blowing straight up
- Mass Flow Rate: 0.03 kg/s @ 22 psia Plenum pressure
- Blowing momentum ratio (C_μ): 0.01 to 0.02

Advantages of using the microjet control as compared to other existing control techniques

- Non-intrusive: no external mechanical device is required; provide no disturbance to the flow.
- Adaptive: can be turned on and off as needed.
- Easy to implement: mass bleeding flow is generally available in helicopters and airplanes.
- Simple and in-expensive: no complicated hydraulic/mechanical mechanisms are necessary.

PDI Technique

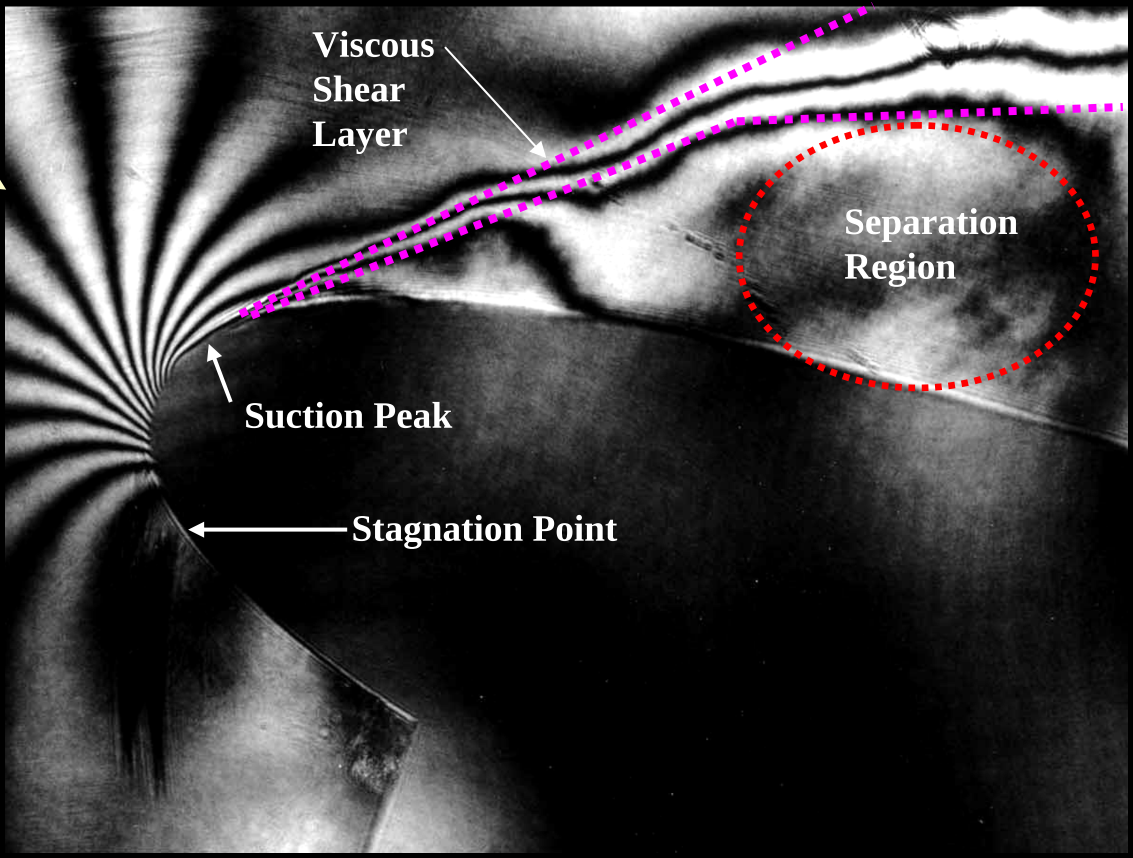
- Modified Z-shaped Schlieren system with coherent laser source
- Passing through flow field of interest, re-focus expanded laser column into spot through a semi-transparent holographic plate with a pinhole
  - Separates light source into Signal and Reference beams
  - “Cleans up” Reference beam through pinhole



fmrl
luid mechanics research laboratory

Interferogram Images

Bright and dark fringes



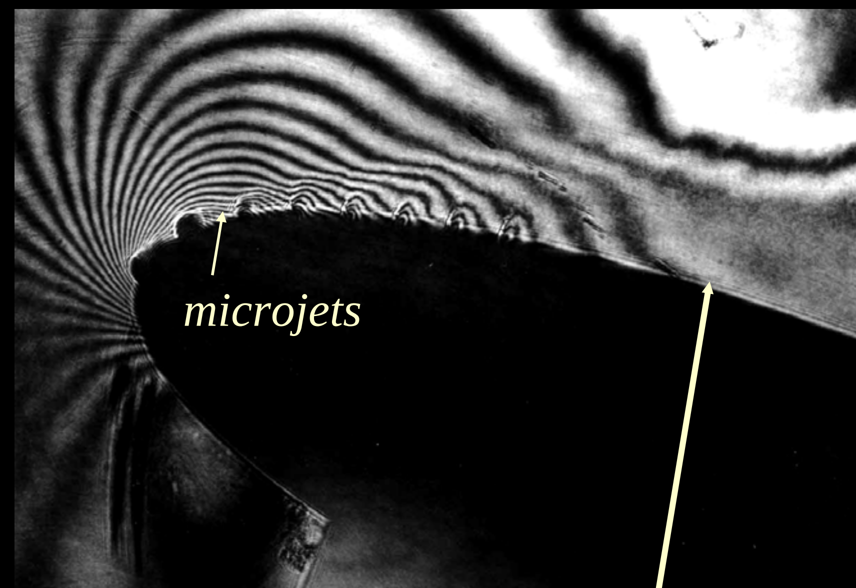
fmrl
fluid mechanics research laboratory

Typical Results

M=0.3, k=0.05, a=20 deg.

Massive Separation

No control



With control

Flow remains attached

• With control, the buffeting noise due to the wake shedding is drastically reduced.

fmrl

fluid mechanics research laboratory

Flow Sequence, M=0.3, k=0.05

No Control

α=11.5° upward α=15.9° upward α=19.9° upward

With Control

fmrl

fluid mechanics research laboratory

Flow Sequence, M=0.3, k=0.1

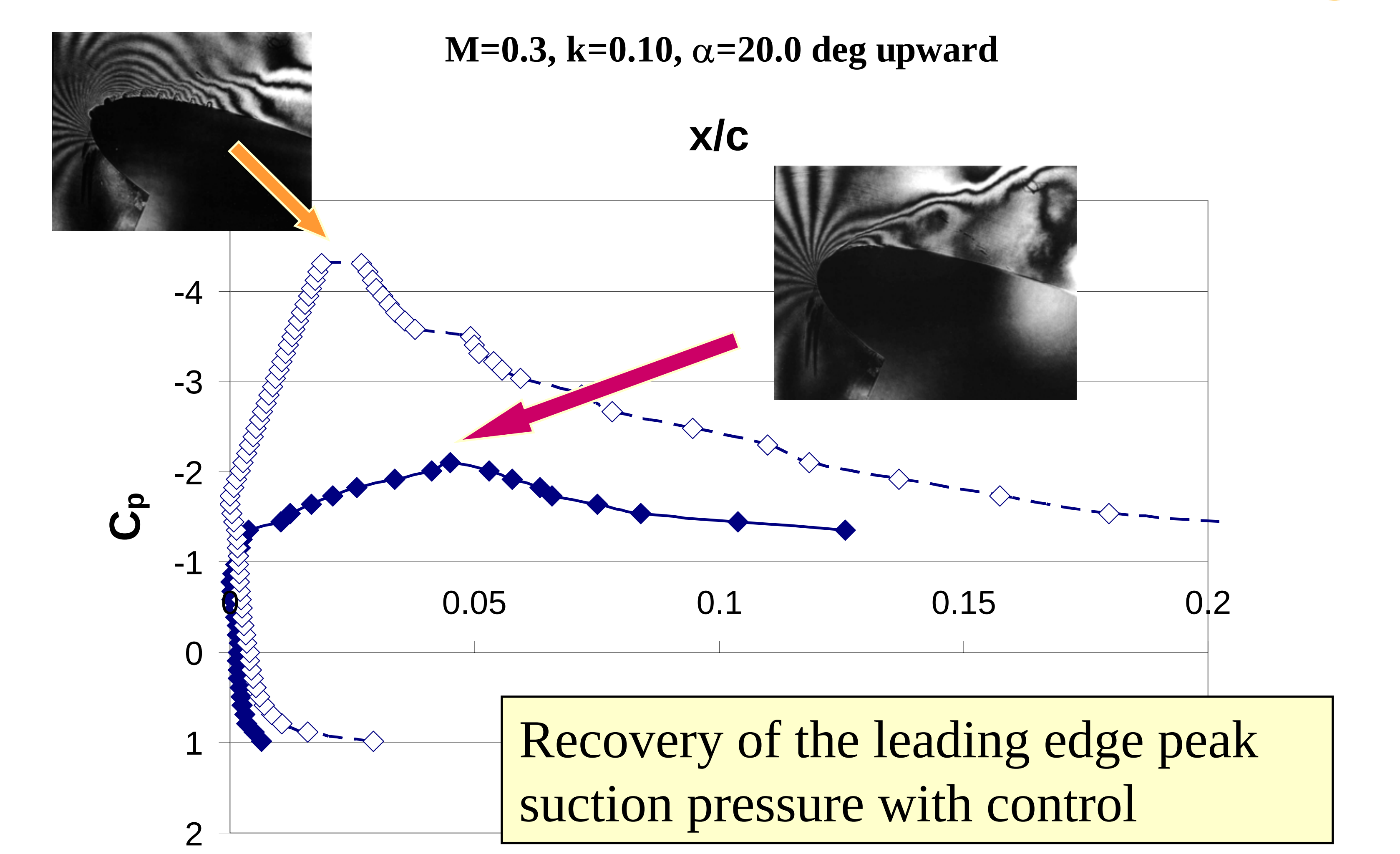
No Control

α=15.9° upward | α=18.0° upward | α=20.0° (apex)

With Control

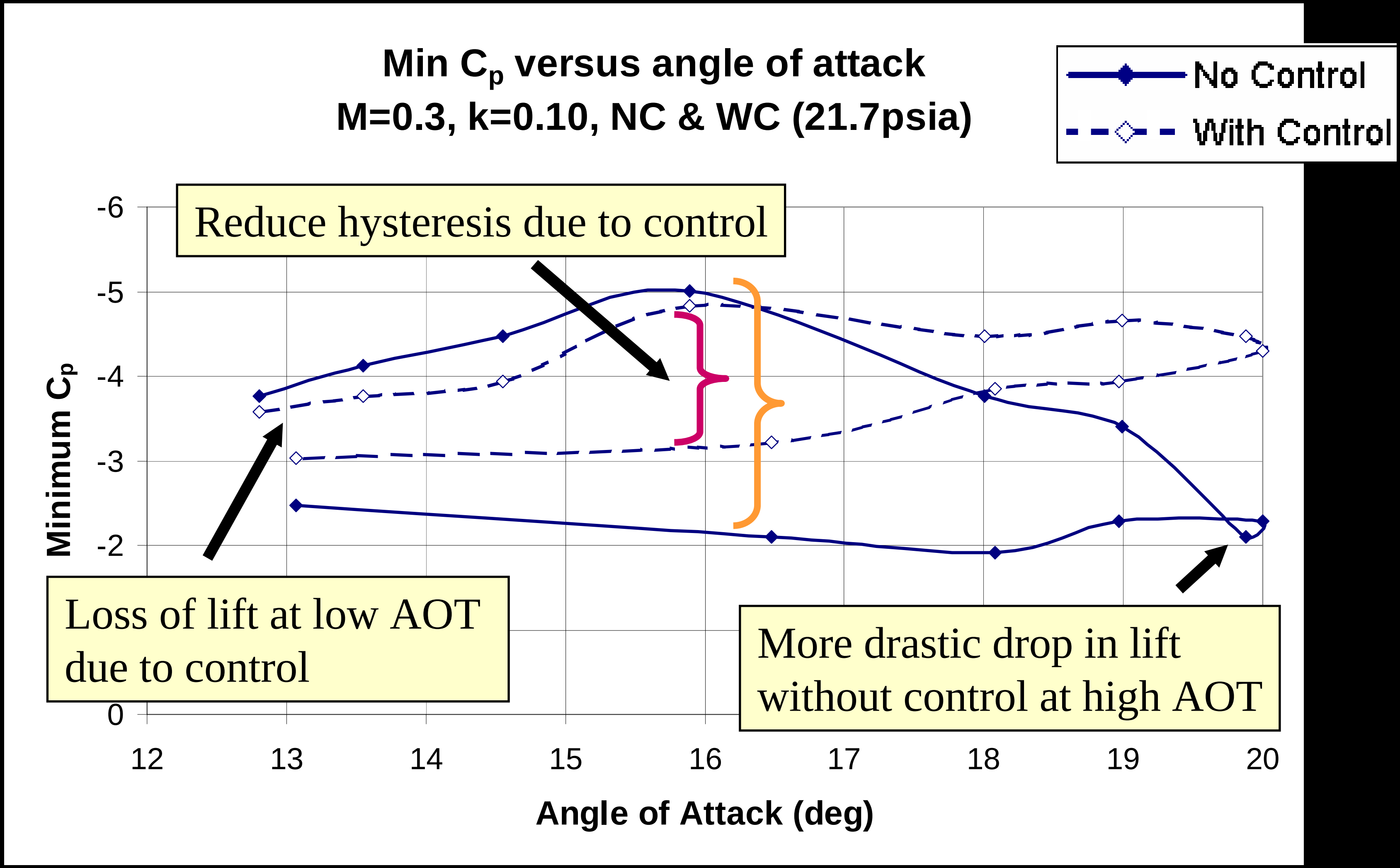
fmrl
fluid mechanics research laboratory

Surface Pressure Distribution
M=0.3, k=0.1, α=20 deg.



Recovery of the leading edge peak suction pressure with control

Peak Suction Pressure M=0.3, k=0.1



fmrl
fluid mechanics research laboratory

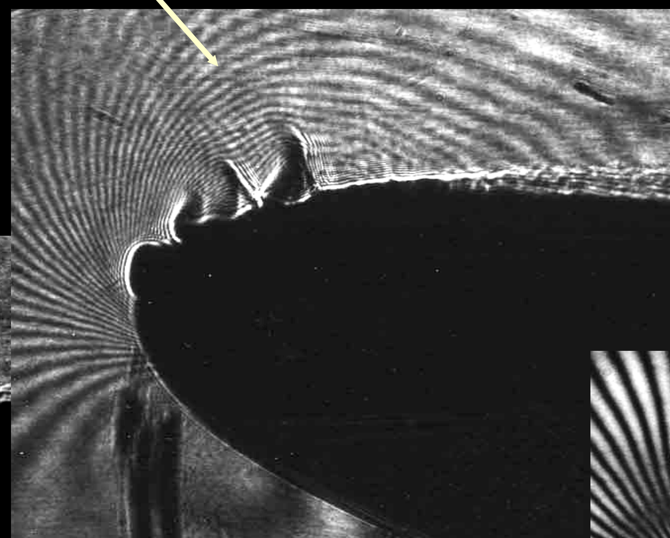
Shock-Induced Separation
M=0.4, k=0.05

Periodic λ shock structure

Thickening boundary layer

Triggering separation

α=10.4°



α=12.5°

α=14.5°

Effect of Microjet Control
M=0.4, k=0.05, α=20 deg.

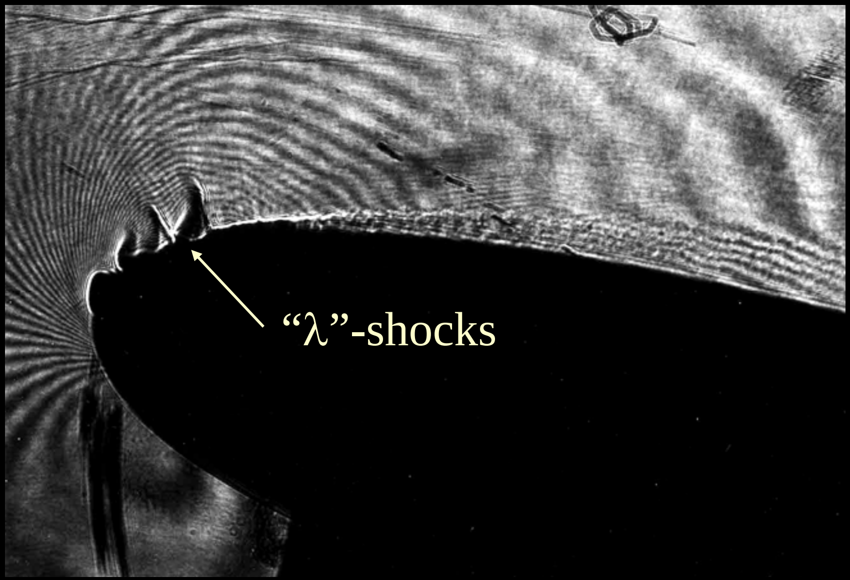
Release of dynamic stall vortex

No massive separation
No vortex

No Control

Microjet Control

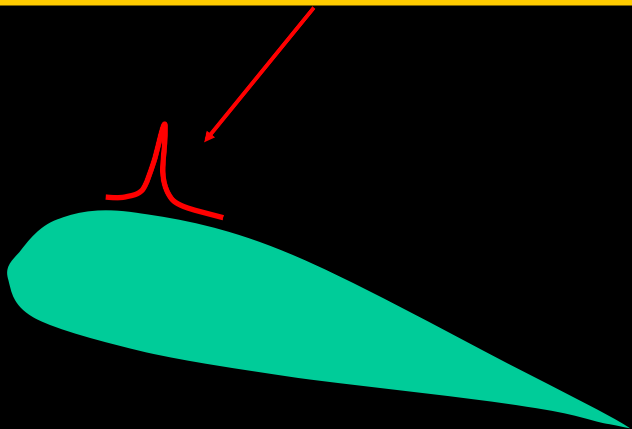
Shock Elimination
M=0.4, k=0.05

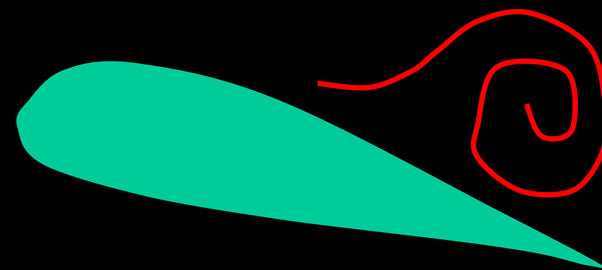


Physical Mechanism

Vorticity Accumulation and the Initiation of the Unsteady Separation Process (Van Dommelen & Shen) and/or Shock-Induced Separation ⇒ Explosive Vorticity Eruption

Leads to the Formation of a Dynamic Stall Vortex ⇒ Catastrophic Breakdown, Lift Loss, Drag Surge, Moment Stall





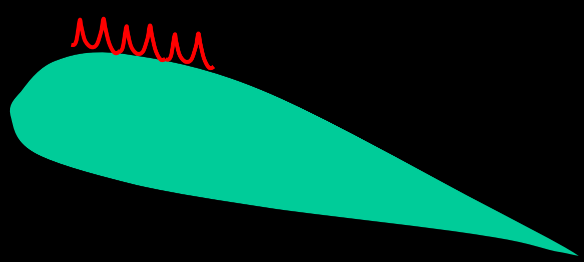
- Mismatch of time scales
- Vorticity accumulation due to an unbalanced vorticity generation, diffusion, and convection

Control Strategy

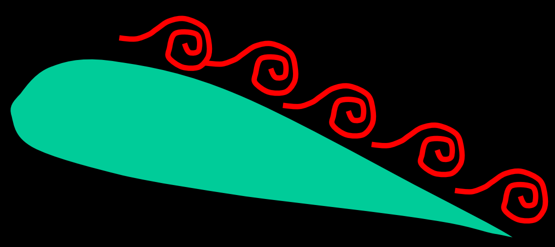
- **Tradition Schemes on Separation Control**
  - Relieve the adverse pressure gradient (nose modification..)
  - Re-energize the boundary layer (suction, blowing, vortex generators..)

- **Our Approach: Controlled Separation**
  - Eject vorticity away from the surface at a controllable manner using distributed microjets

Controlled, distributed ejection of surface vorticity ⇒ **redistribution** of the vorticity through ejection



Increase downstream convection of vorticity ⇒ No accumulation ⇒ More manageable breakdown process



fmrl
fluid mechanics research laboratory

Summary

- Dynamic stall has been significantly reduced or eliminated ⇒ improve aerodynamic performance

- Pressure recovery ⇒ an increase of lift

- Elimination of the shocks at the leading edge ⇒ alleviating the possibility of the shock-induced separation

- Suppression of the periodic shedding of the dynamic stall vortices ⇒ reduce buffeting noise and associated vibration

Future Work

• Obtain pressure distribution, lift, and drag measurements to quantify the effectiveness of control

• Reduce control mass flow rate: consider activation of control on an “as needed” basis

• Optimize flow control parameters: pressure, distribution pattern, jet angle, pulsating blowing

• Apply control to scaled-down helicopter rotor blades

Thank You