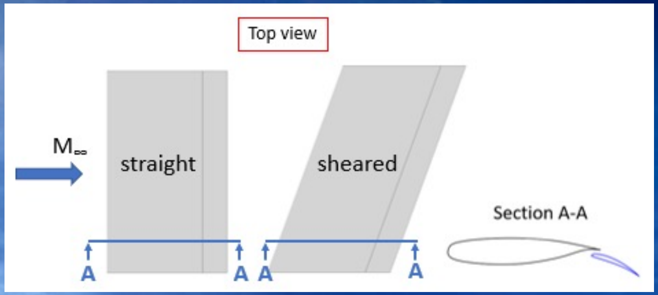
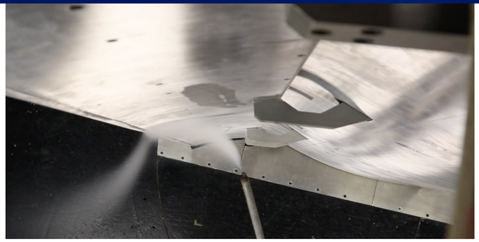
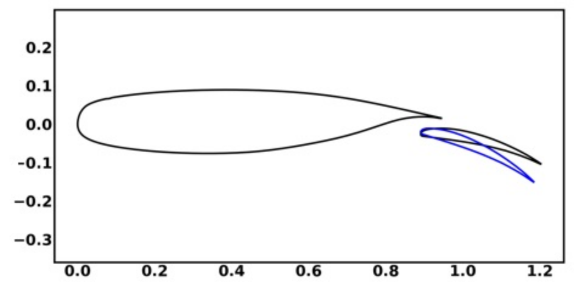
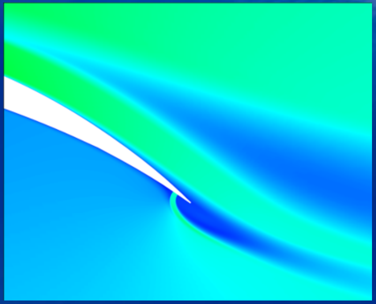
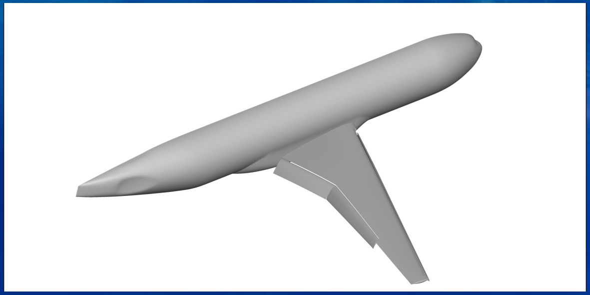




Source: Ed White et al., Texas A&M





# Surface-Normal Active Flow Control for High-Lift Systems

Sheida Hosseini*

C. P. van Dam**

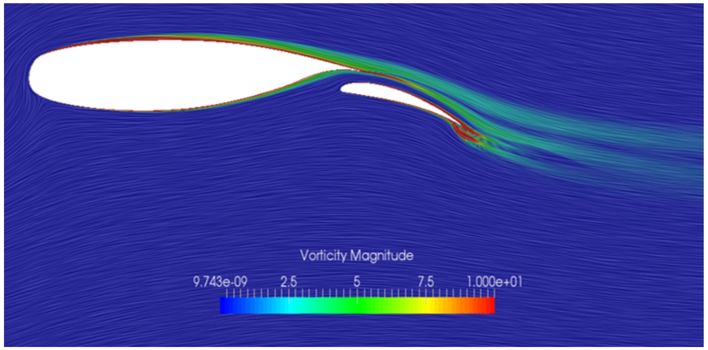
Shishir A. Pandya*

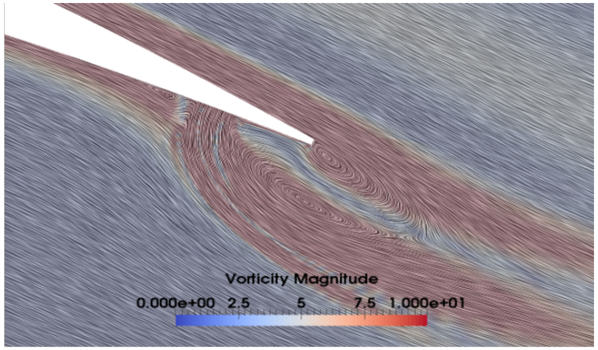
* NASA Ames Research Center

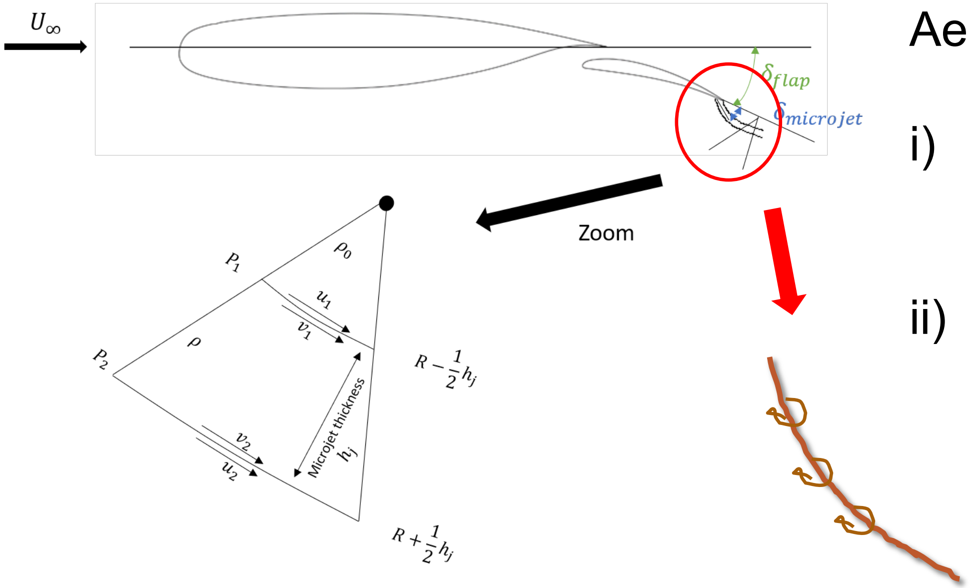
** University of California Davis

August 3 2021
AIAA Aviation Flow Control Forum

# Circulation Control Using Surface-Normal Jets



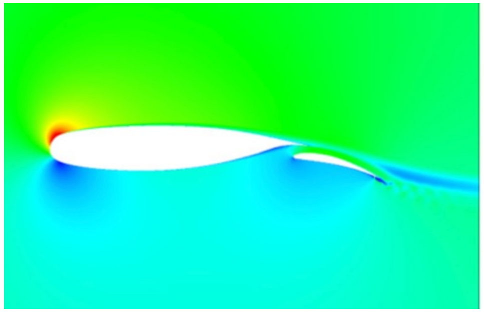

Aerodynamic forces are modified:

i) Reaction due to the vertical component of the microjet momentum force
ii) Due to the vertical component of the pressure on the airfoil surface which is modified by the asymmetry the microjet creates in the flow-field

# Motivation

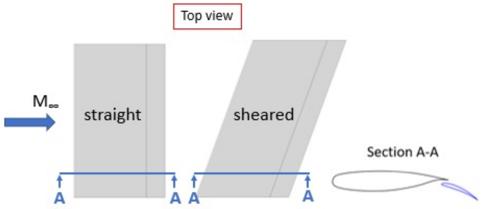
## Active Flow Control for high-lift systems

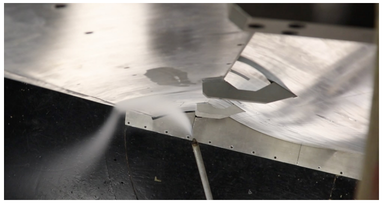
- $C_{L_{max}}$
- L/D
- Lift coefficient at an angle of attack dictated by the tail ground clearance angle



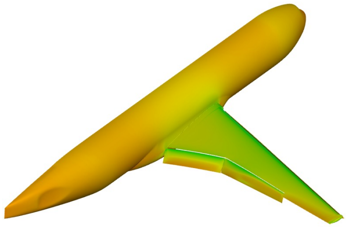
## Building block approach

- Start in 2D
  - CFD validation / computational sensitivities for the baseline
  - CFD microjet sensitives
- Extend the study to infinite wing configuration
- Validate 2D microjet trends experimentally
- Extend the study to a representative 3D configuration
- Validate 3D microjet trends experimentally



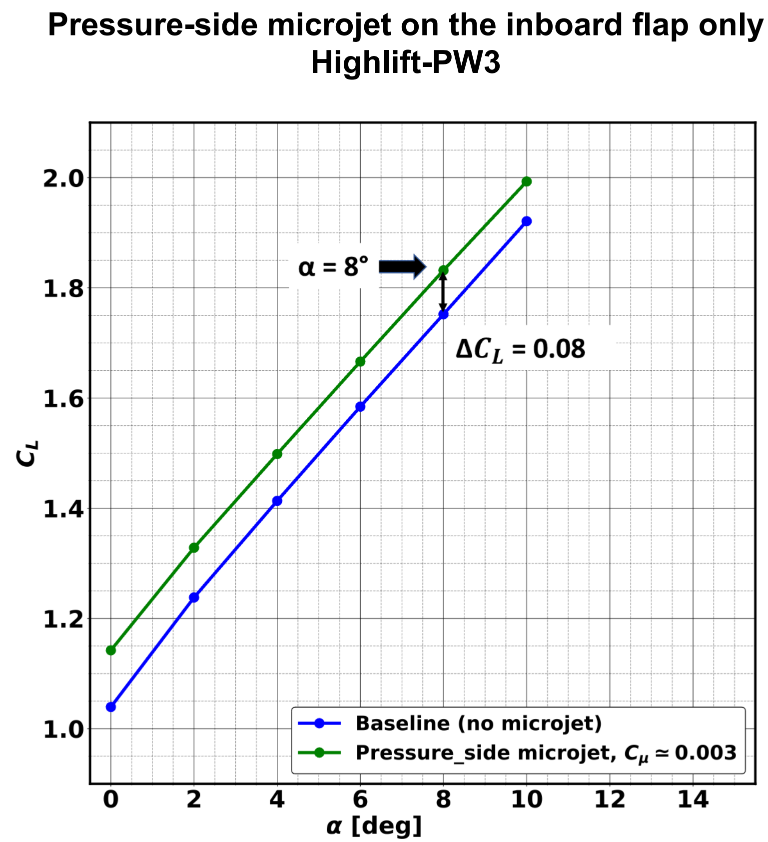



Source: Ed White et al., Texas A&M



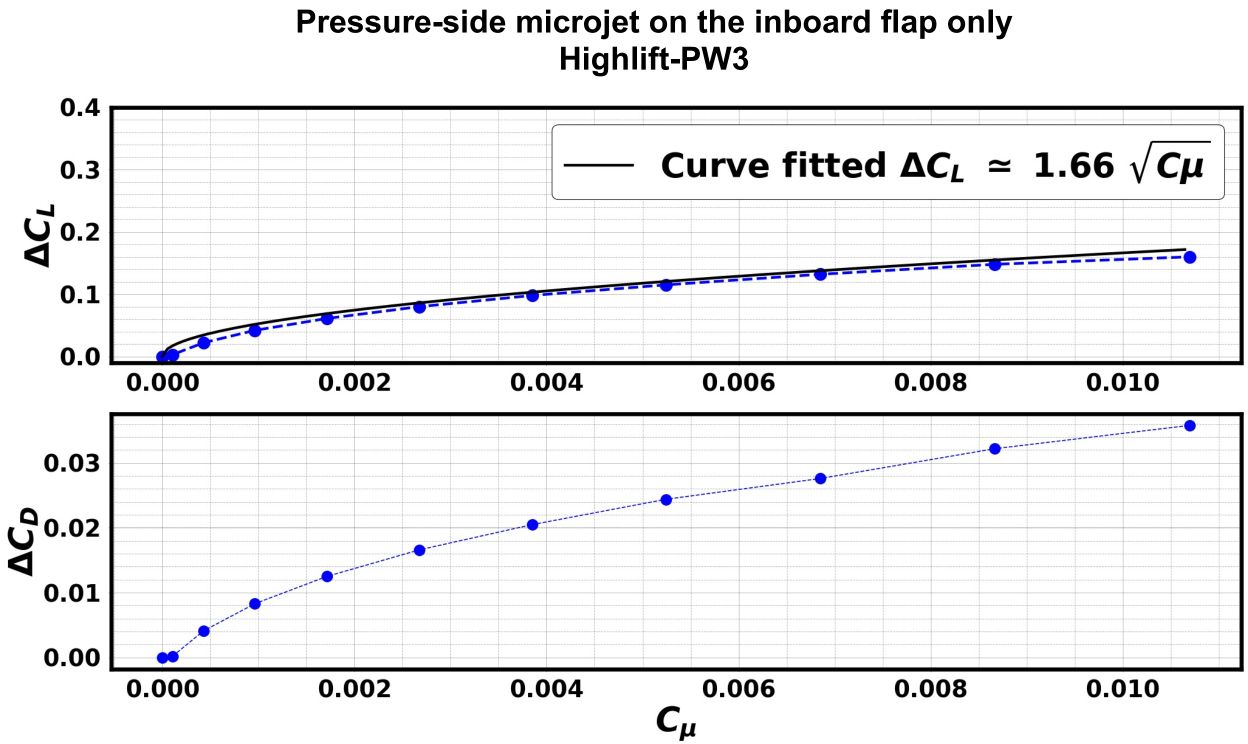
# Microjet Trends

- CFD studies has led to consistent trends regardless of geometry and flow conditions:
  - Modulation in lift curve



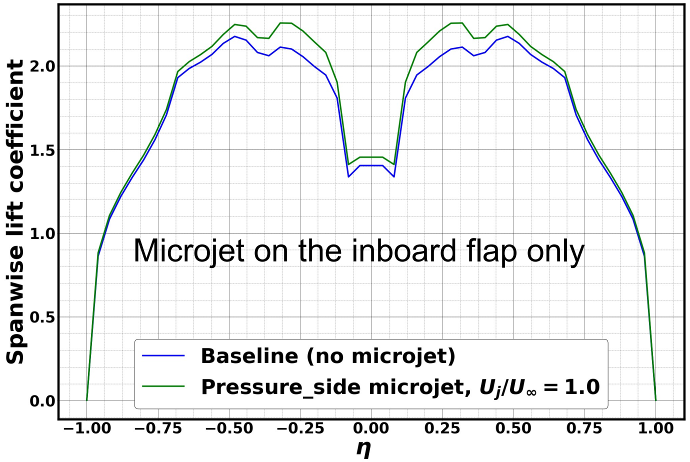
# Microjet Trends

- CFD studies has led to consistent trends regardless of geometry and flow conditions:
  - Modulation in lift curve
  - Lift enhancement in terms of $\Delta C_L \propto K\sqrt{C_\mu}$



# Microjet Trends

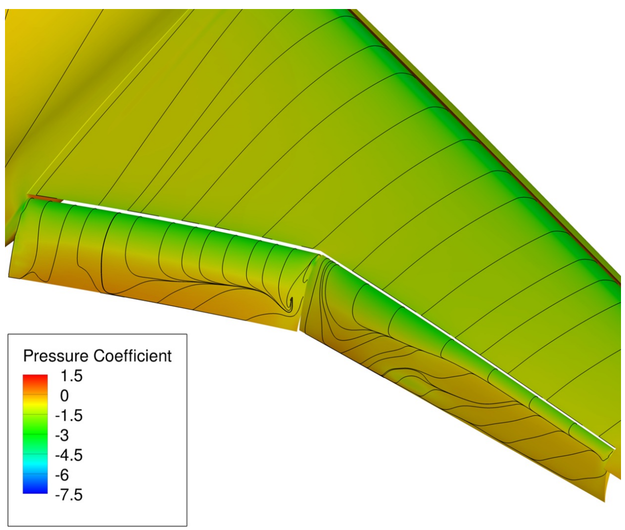
- CFD studies has led to consistent trends regardless of geometry and flow conditions:
  - Modulation in lift curve
  - Lift enhancement in terms of $\Delta C_L \propto K\sqrt{C_\mu}$
  - Pressure drag reduction (form drag)

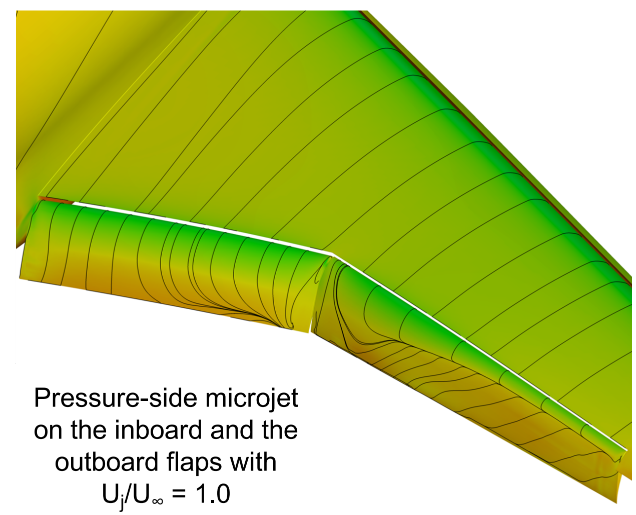



| Pressure integration | $C_{L_p}$ | $C_{D_p}$ | $C_{D_{p_{induced}}}$ | $C_{D_{p_{form}}}$ | $C_{D_{p_{induced}}}/C_{D_{total}}$ |
|---|---|---|---|---|---|
| Baseline (no microjet) | 1.752 | 0.1508 | 0.1197 | 0.0311 | ~0.71 |
| Pressure-side microjet on the inboard flap | 1.830 | 0.1656 | 0.1361 | 0.0295 | ~0.73 |
| $\Delta$ | 0.078 | 0.0148 | 0.0164 | -0.0016 | ~0.02 |

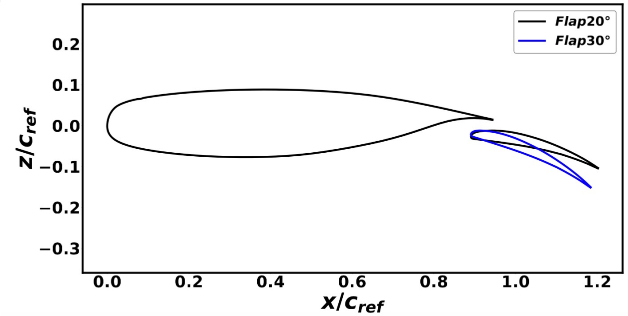
# Microjet Trends

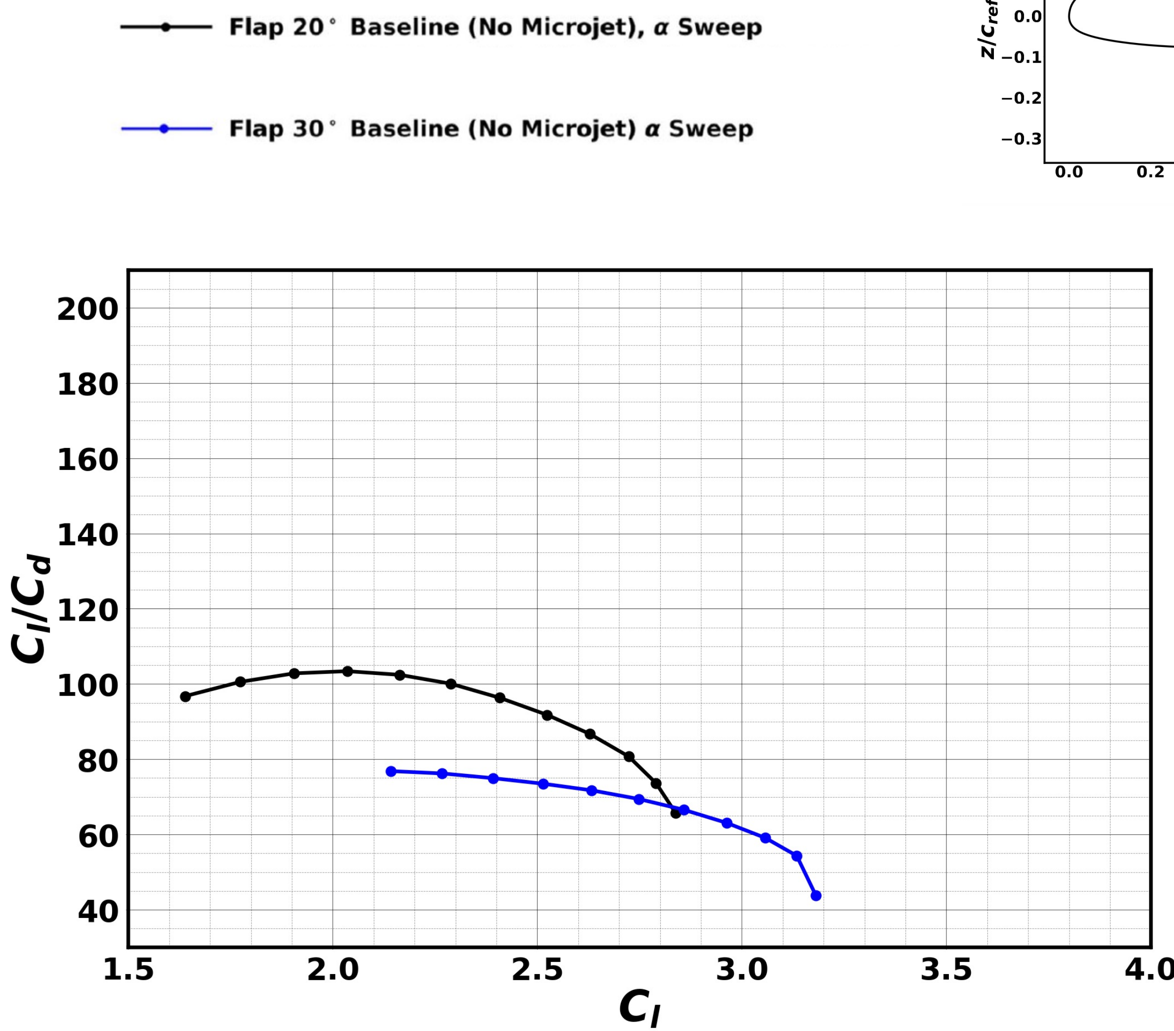
- CFD studies has led to consistent trends regardless of geometry and flow conditions:
  - Modulation in lift curve
  - Lift enhancement in terms of $\Delta C_L \propto K\sqrt{C_\mu}$
  - Pressure drag reduction (form drag)
  - Separation mitigation in the presence of moderate trailing edge flow separation



# Microjet vs. Flap Deflection Trade (2D)



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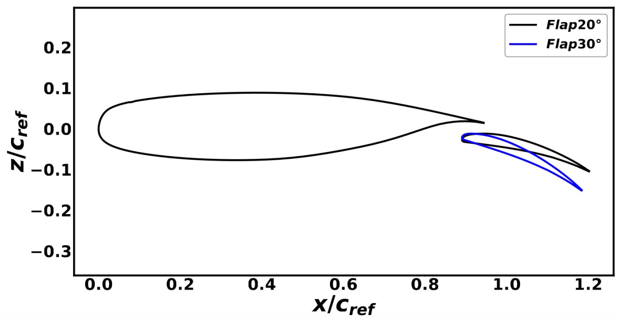
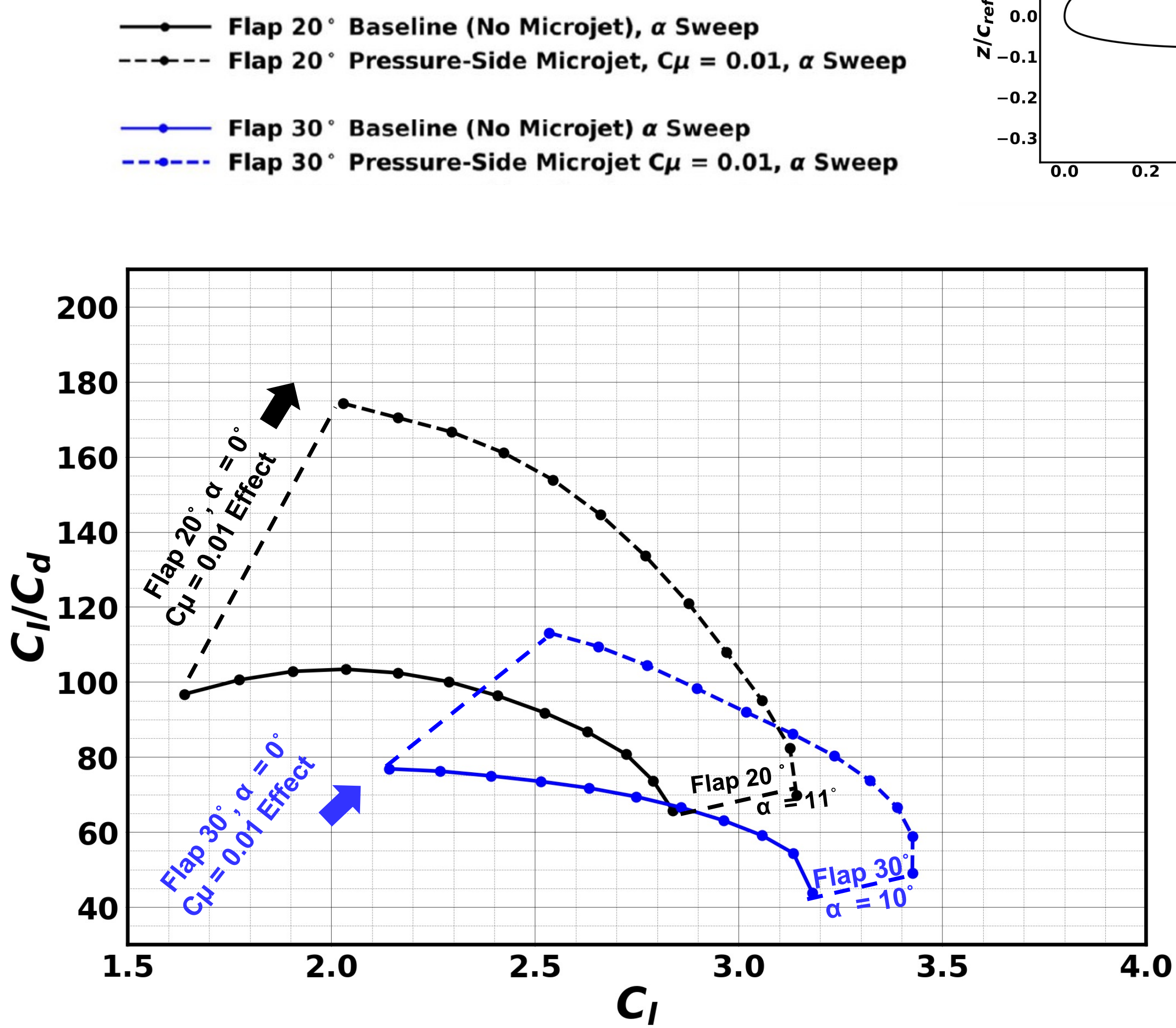
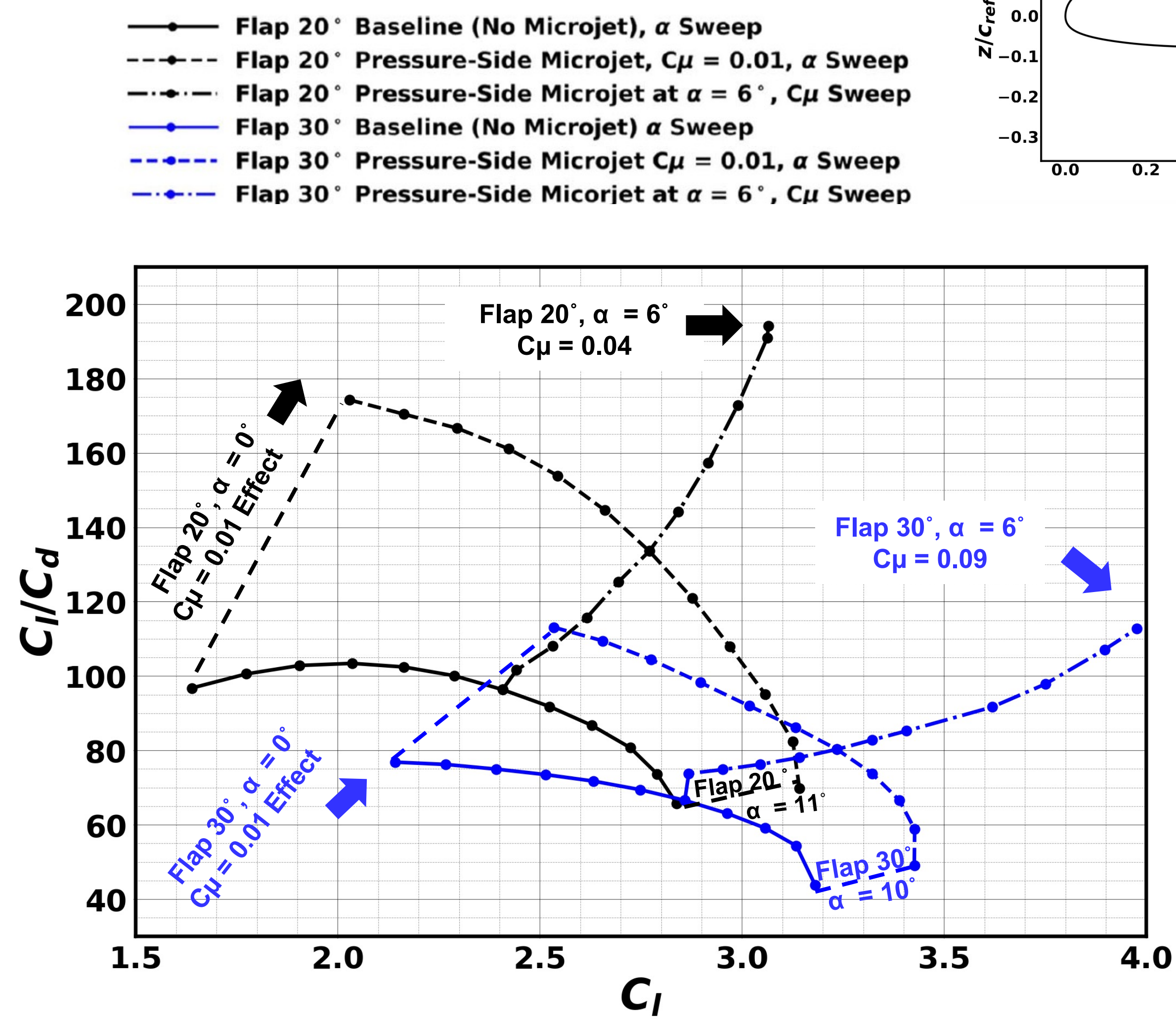
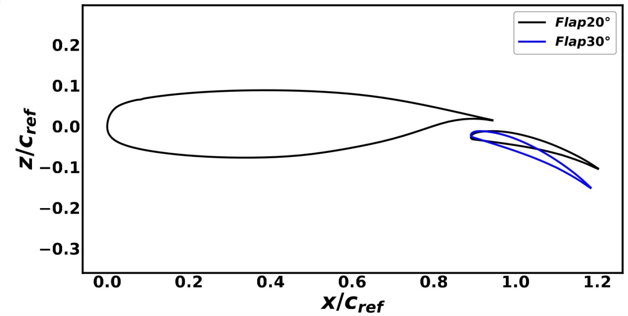


# Microjet vs. Flap Deflection Trade (2D)

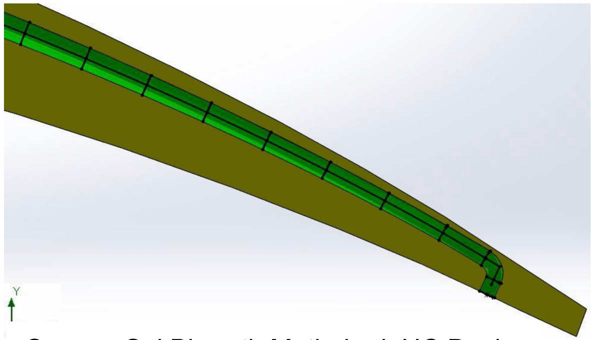


# Microjet Wind Tunnel Test, Spring 2021

- Two-element NLR7301 high-lift airfoil
- Flap 20 and Flap 30 configuration
- Reynolds number ≃ 2.0 million
- Mach number ≃ 0.10
- Microjet mass flow coefficient $C_q$ = 0 – 0.0078
- Microjet geometric width = 0.0025 $c_{ref}$
- Microjet cover 85% of model span

Source: Ed White et al., Texas A&M



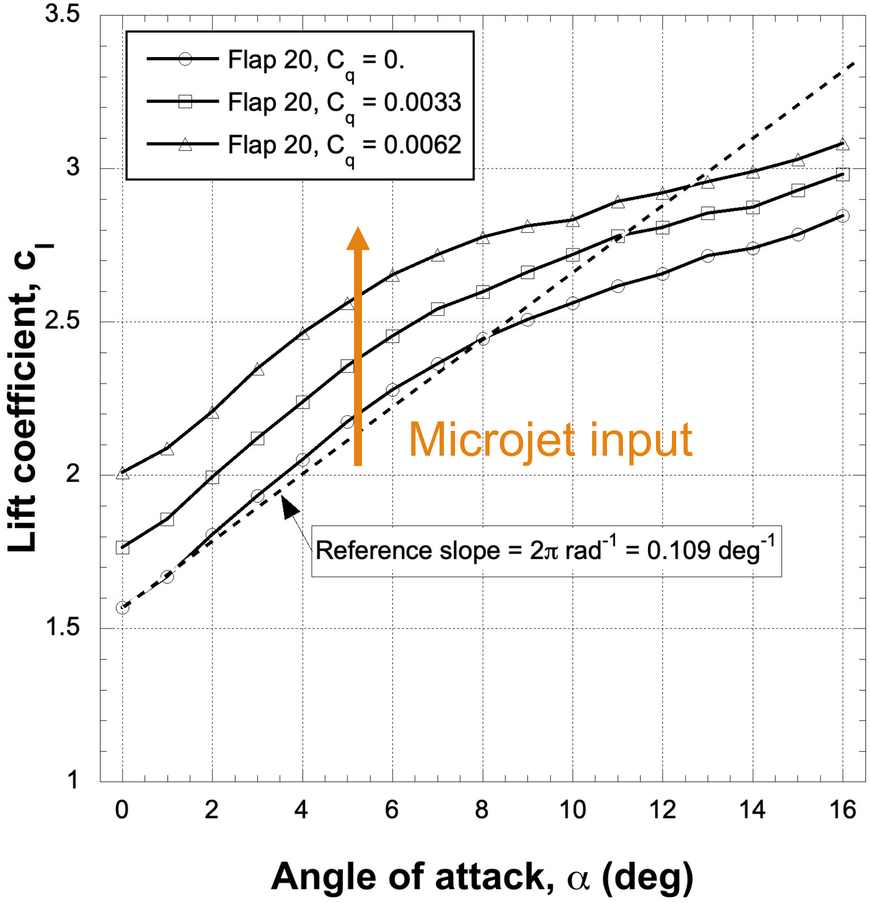
Source: Sai Bharath Mothukuri, UC Davis


Source: Ed White et al., Texas A&M

# Microjet Wind Tunnel Test, Spring 2021

- Focus of entries in Spring 2021 was on validation of model aerodynamic performance by comparing against benchmark test results for two-element NLR7301 and impact of microjet on lift.

- Measurement of microjet velocities to determine momentum coefficient $C_\mu$ and wake-based drag will be focus of Fall 2021 wind tunnel entry



# Summary

- Microjets have been proposed as a circulation control technology to enhance aerodynamic performance of multi-element high-lift systems.
  - Main focus on lift in linear regime
- Building block approach applied to research, develop and demonstrate this active flow control technology
  - ✓ 2D CFD validation/computational sensitivities for multi-element airfoils
  - ✓ 2D CFD microjet configuration studies
  - ✓ Infinite wing CFD (unswept & swept) to study impact of spanwise discontinuities on microjet effectiveness
  - Wind tunnel test of multi-element airfoil configuration studied in 2D
  - 3D CFD high-lift CRM
- Initial wind tunnel results are in general agreement with CFD
- Microjet technology has consistently shown to be effective in controlling lift

More information in recent publications:

- AIAA paper 2022-xxxx (Submitted for SciTech 2022)
- Journal of Aircraft paper DOI: 10.2514/1.C035986
- Journal of Aircraft paper DOI: 10.2514/1.C035248
- AIAA paper 2021-1192 (SciTech 2021)
- AIAA paper 2019-3498 (Aviation 2019)
- AIAA paper 2019-0590 (SciTech 2019)
- AIAA paper 2018-0559 (SciTech 2018)

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Thank You!