

# Microjet Angle Sensitivity for Active Flow Control on Multi-Element High-Lift Systems

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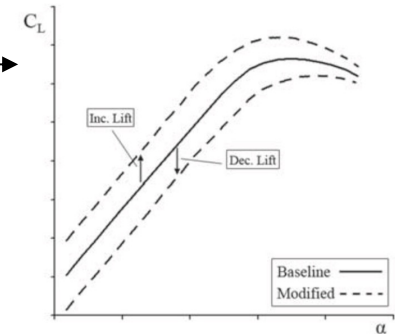
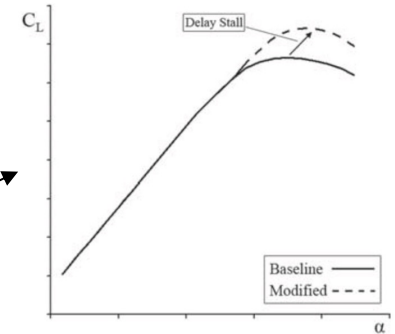
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# Motivation

- High-lift systems dictate many aspects of airplane design as they determine limits such as aircraft payload, angle of attack, and lift-to-drag ratio.
- Active flow control methods can be used to improve the performance of high-lift systems within the constraints of an existing wing design.
  - Separation mitigation (tangent-blowing jets).
  - Aerodynamic load control (normal-blowing microjets).
- One of the key microjet parameters which hasn't been looked at yet is jet angle: developed appropriate BC strategy.
- Compare normal and tangent-blowing jets.
- Two high-lift system geometries are considered:
  - The NLR7301 two-element airfoil.
  - The Common Research Model in High Lift configuration (CRM-HL).



Johnson, S. J., Baker, J. P., van Dam, C. P., and Berg, D., "An overview of active load control techniques for wind turbines with an emphasis on microtab" *Wind Energy*, Vol. 13, 2010, pp. 239–253.

# Angled Microjets

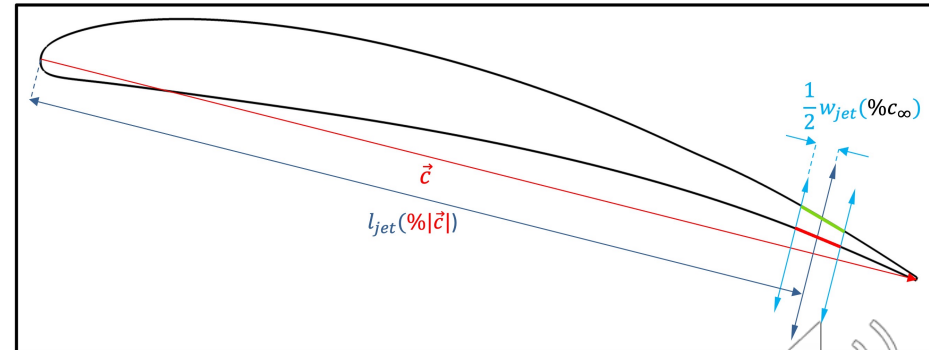
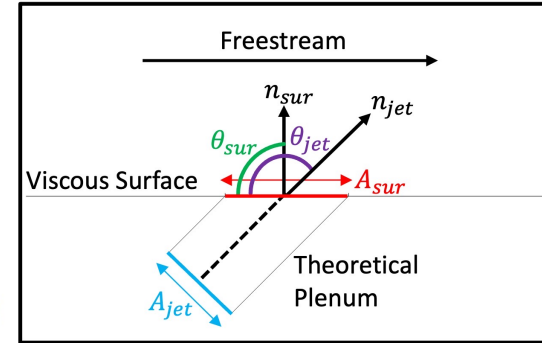
- Jet momentum strength characterized by  $C_{\mu}$ .
- Can treat mass parameter as  $\rho$  or  $\dot{m}$ .
- Two of three jet parameters must be provided ( $C_{\mu}$ ,  $\rho$  or  $\dot{m}$ ,  $\vec{U}$ ).
- Area of jet must be projected from the surface to a theoretical plenum plane.
- Normal blowing assumed  $\rho_{jet} = \rho_{\infty}$  and  $n_{jet} = n_{sur}$ .
- Jet surfaces are automatically constructed on airfoils by intersecting it with vectors normal to chord vector.

$$C_{\mu,jet} = \frac{2\rho_{jet}A_{jet}U_{jet}^2}{\rho_{\infty}A_{\infty}U_{\infty}^2}$$

$$C_{\mu,jet} = \frac{2 * \dot{m}_{jet} * U_{jet}}{\dot{m}_{\infty} * U_{\infty}}$$

$$\dot{m}_{jet} = \rho_{jet} * A_{jet} * U_{jet}$$

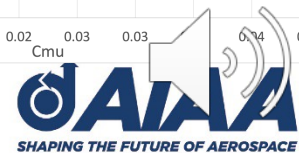
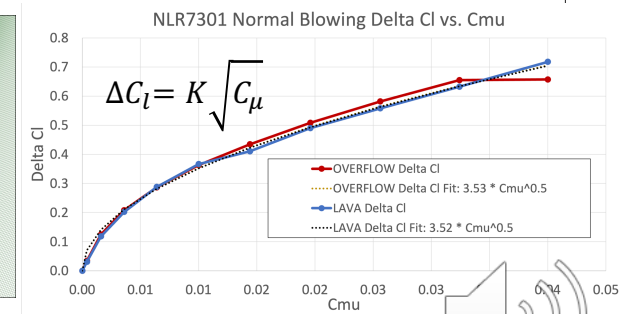
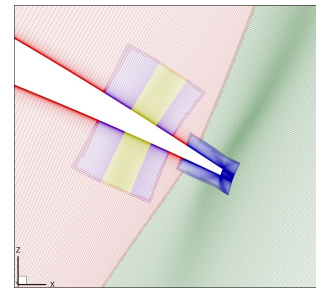
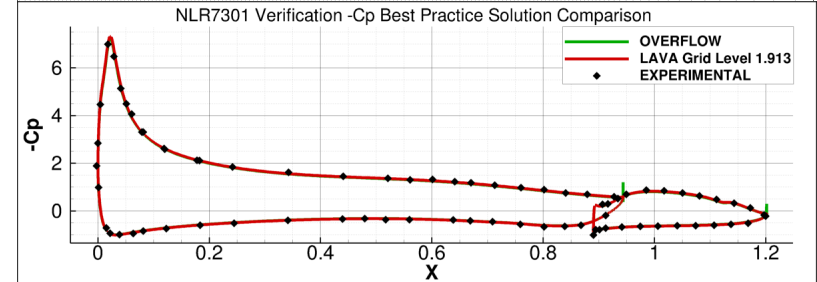
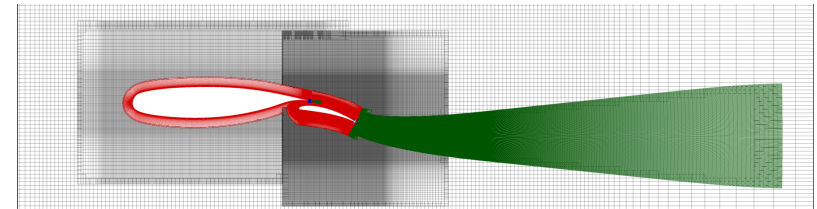
$$A_{jet} = A_{sur} * (n_{sur} \cdot n_{jet})$$



# NLR7301 Geometry Best Practices



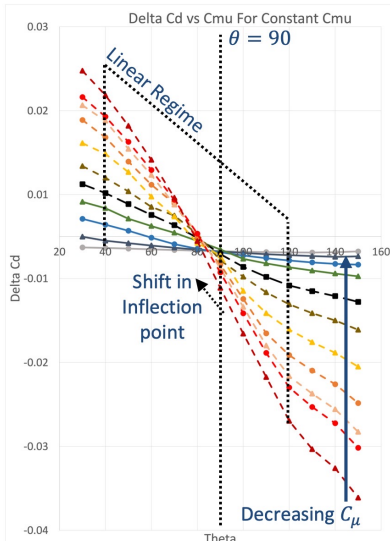
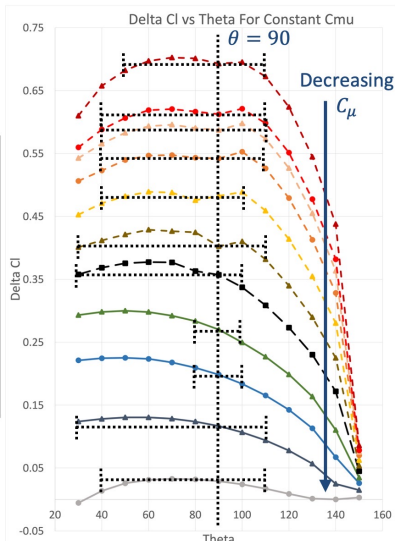
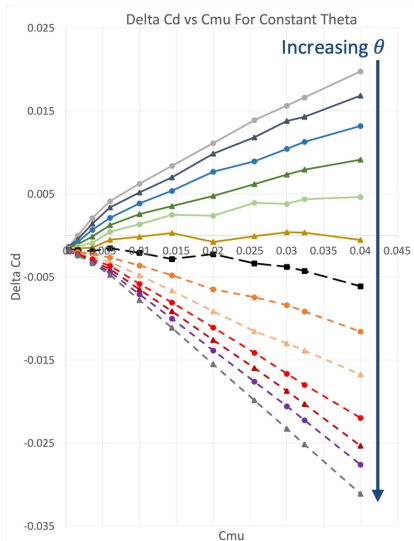
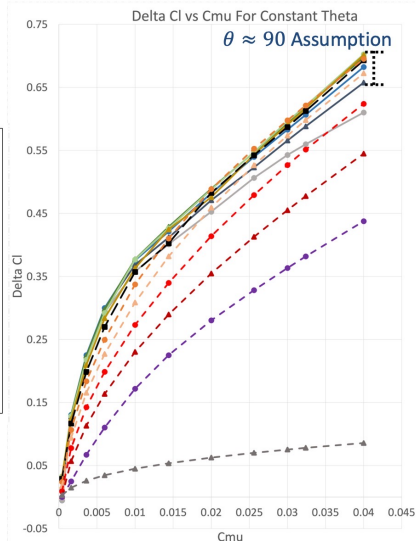
- Curvilinear overset grid system consisting of 0.825 Million computational nodes.
  - 20° flap deflection.
  - Jets inserted at 95.0% $c_{flap}$ .
- LAVA solver settings:
  - 3<sup>rd</sup> order upwind modified Roe scheme, Koren limiter.
  - Node-centered differencing for fluxes.
  - Spalart Allmaras with rotational and quadratic constitutive relation corrections.
- Run by successively restarting URANS with smaller timesteps.
  - Mach=0.185,  $Re=2.51$  millions/ $c_\infty$ .
- Refinement study.
- Experimental and Code to Code Validation.
  - Jets off.
- 4 ➤ Normal blowing assumption.



# NLR7301 Angle Vs. Strength Study



- Pressure-side jet strength  $C_{\mu} \in [0.0004, 0.04]$  (corresponds to  $\frac{U}{U_{\infty}} \in [0.2, 2]$  in steps of 0.2).
- Pressure-side jet angle  $\theta \in [30, 150]$  in steps of 10 (30 degrees from up and downstream surface).



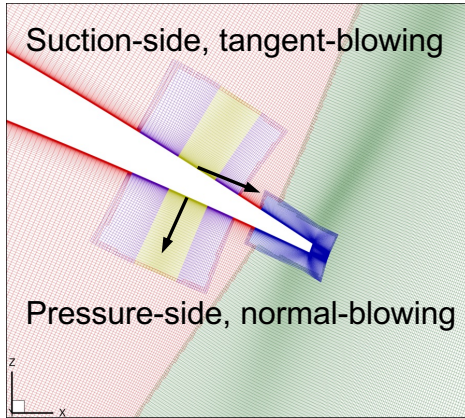
Constant Jet Angle

$\Delta C_l$  normal-blowing assumption holds for  $40 \lesssim \theta \lesssim 110$

Constant Jet Strength

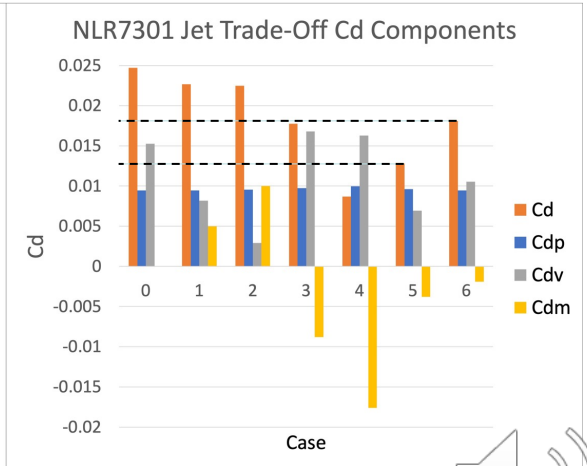
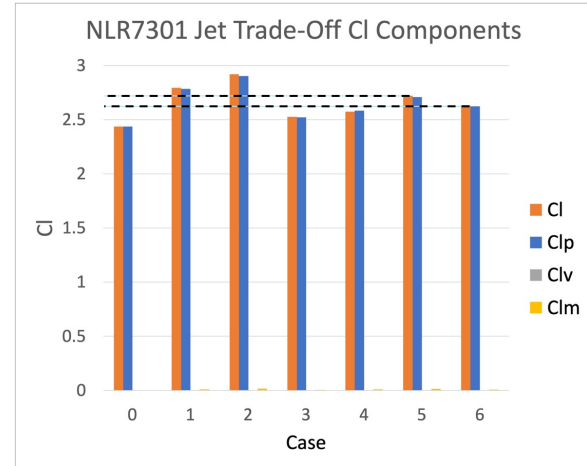


# NLR7301 Tradeoff Study



Case ID	0	1	2	3	4	5	6
$\theta_{jet,nrm}$	Off	90	90	Off	Off	90	90
$\theta_{jet,tan}$	Off	Off	Off	170	170	170	170
$C_{\mu,jet}$	0.0	0.01	0.02	0.01	0.02	0.01	0.005
$\frac{\dot{m}_{jet}}{\dot{m}_{\infty}}$	0.0	0.005173	0.007315	0.005173	0.007315	0.005173	0.003662

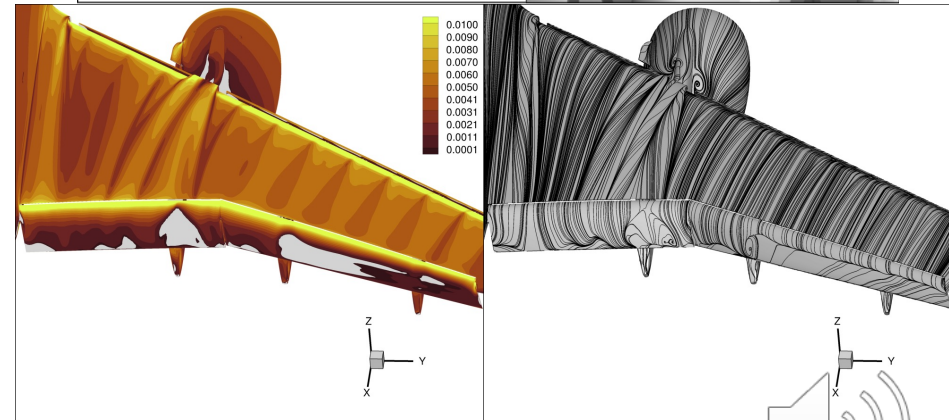
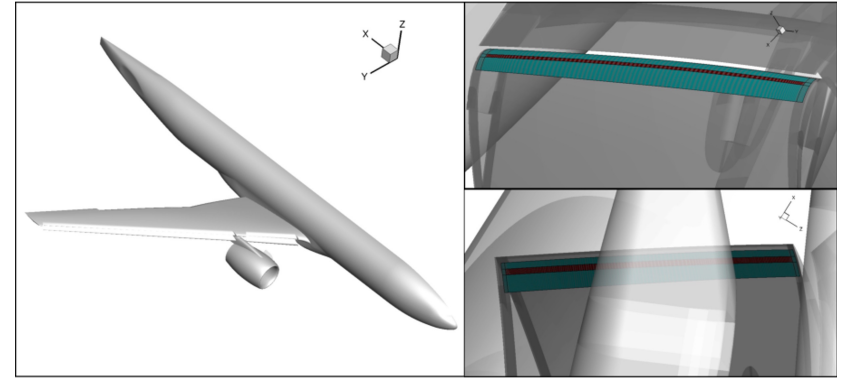
- Case set 1-3-5:
  - Tandem jets same strength.
- Case set 1-3-6 and 2-4-5:
  - Tandem jets half strength.
- All cases increase lift.
- **Normal blowing is more effective for lift enhancement.**



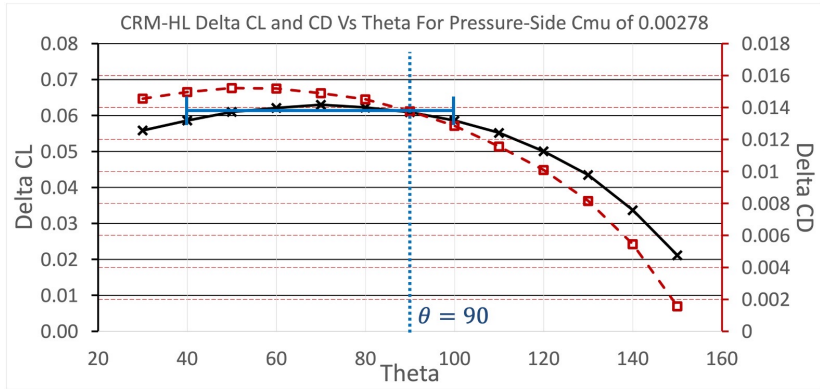
# CRM-HL Geometry Best Practices



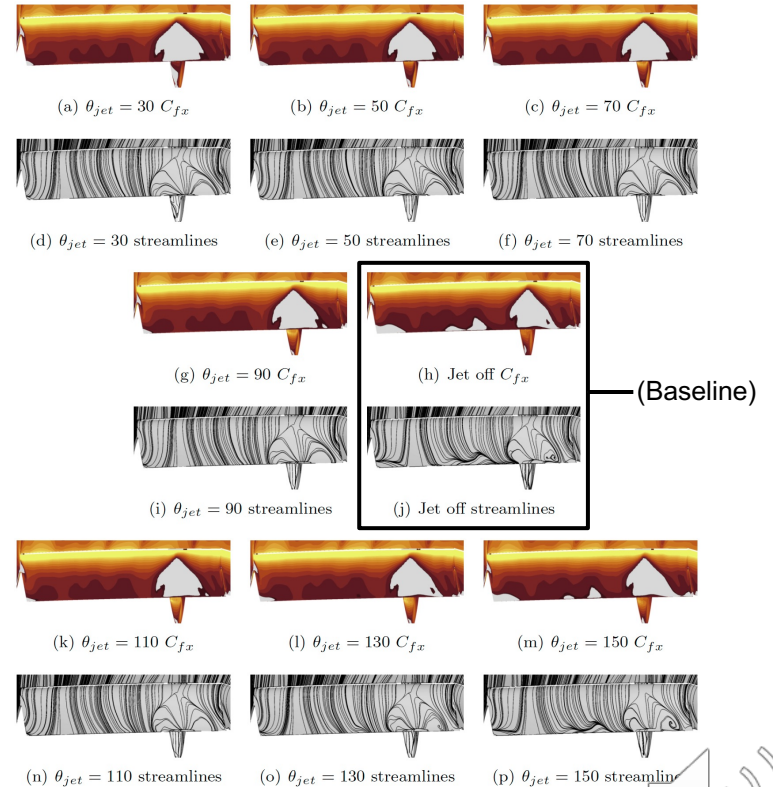
- LAVA Curvilinear overset grid system used for the 4<sup>th</sup> High Lift Prediction Workshop.
  - Inboard flap deflected by 40 degrees.
  - Outboard flap deflected by 37 degrees.
- LAVA solver settings:
  - 3<sup>rd</sup> order upwind modified Roe scheme, Koren limiter.
  - Node-centered differencing for fluxes.
  - Spalart Allmaras.
- Run with RANS.
  - Mach=0.2,  $Re=5.49$  millions/MAC.
- Solution with jets-off matches workshop results.
- Microjets placed onto inboard flap:
  - Pressure jet inserted at  $95.0\%c_{flap}$ .
  - Suction jet inserted at  $4.75\%c_{flap}$ .



# CRM-HL Angle Sweep Study

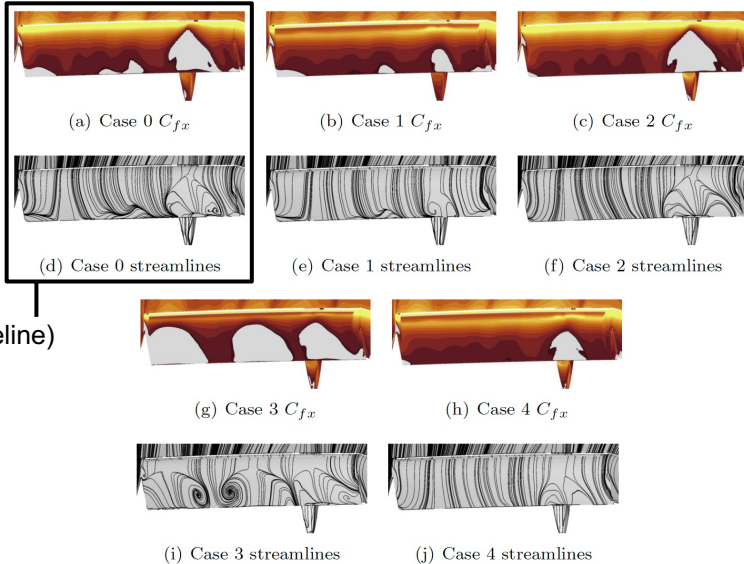


- Momentum term no longer relevant for drag – similar trend to lift.
- Similar tolerance in angle for normal blowing assumption as seen for the NLR7301.
- Effect of pressure jet on inboard flap separation pattern insensitive to jet angle.

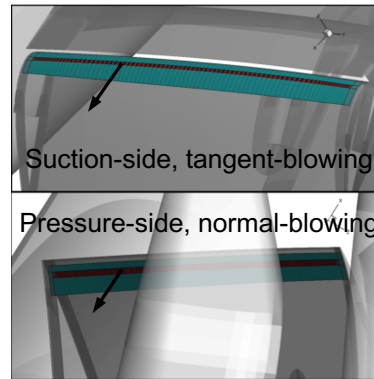
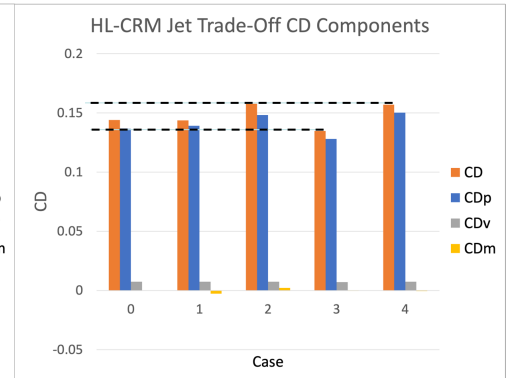
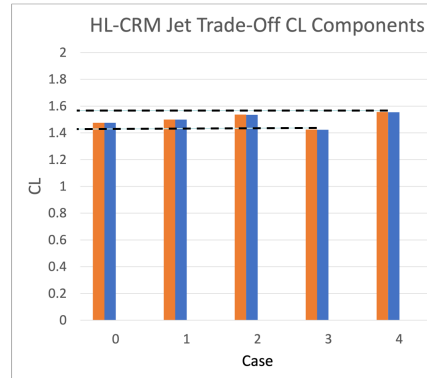


# CRM-HL Tradeoff Study

Case ID	0	1	2	3	4
$\theta_{jet,nrm}$	Off	Off	90	90	90
$\theta_{jet,tan}$	Off	170	Off	170	170
$C_{\mu,jet}$	0.0	0.00278	0.00278	0.00139	0.00278
$\frac{\dot{m}_{jet}}{\dot{m}_{\infty}}$	0.0	0.001390	0.001390	0.000983	0.001390



(Baseline)



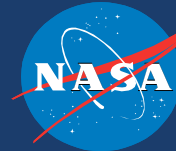
- Case set 1-2-3:
  - Tandem jets half strength.
  - Decreases both lift and drag.
- Case set 1-2-4:
  - Tandem jets full strength.
  - Increases both lift and drag.
- **Normal blowing is more effective for lift enhancement.**

# Conclusions



- The effect of ‘normal-blowing’ lift enhancement held for jet angles  $40 \lesssim \theta \lesssim 100$ , indicating some available leeway in plenum design.
- Changes in drag were significantly influenced by jet momentum in 2D, but not in 3D.
- When comparing the effects of suction-side tangent-blowing jets and pressure-side normal-blowing jets:
  - Normal-blowing is a more effective lift enhancement method than tangent blowing for a given jet strength for the configurations considered in this work.
  - Lift increased for all 2D NLR7301 cases.
  - For the weakly-blowing tandem 3D CRM-HL case, the half-strength suction jet is too weak and creates extremely detrimental blockage/mixing.

# Acknowledgments



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