



Assessment of Surface-Normal Active Flow Control for Lift Enhancement on the High-Lift Common Research Model

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Experiment and Computation III

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Motivation

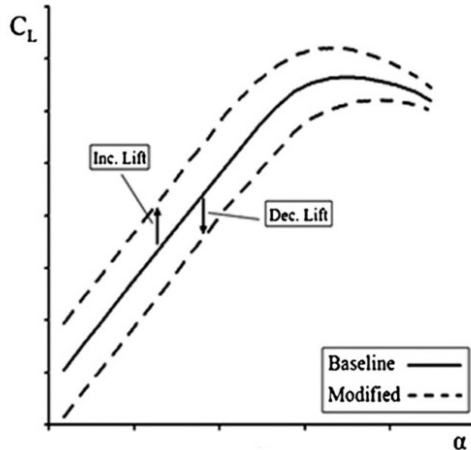
- Wing design for a wide range of airplane weights, fuselage lengths, airspeeds, and altitudes is challenging
- High-lift systems generate higher lift to allow for reduced airspeed for shorter take-off and landing distances
- High-lift systems are important to ensure commonality among airplane family members with widely varying fuselage lengths
- Longer fuselage lengths increases risk of tail strike
- Tail ground clearance angle imposes a limitation on AOA
- Limited AOA limits flap capability to generate required lift at take-off or landing
 - Landing gear height must increase or flaps must be redesigned
- $\Delta C_L \cong 0.10^*$ allows for 1400lb weight saving related to 14 in. landing gear height

* P. Meredith, "Viscous Phenomena Affecting High-Lift Systems and Suggestions for Future CFD Development. High-Lift System Aerodynamics," AGARD CP 515, pp. 19(1)–19(8), 1993.

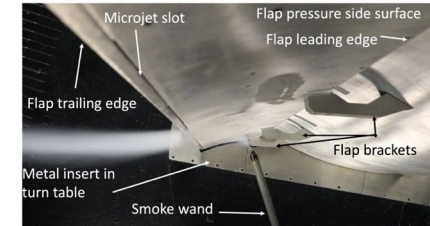
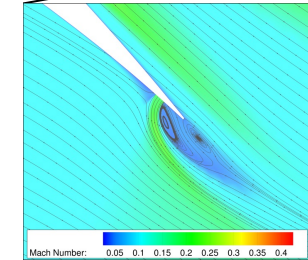
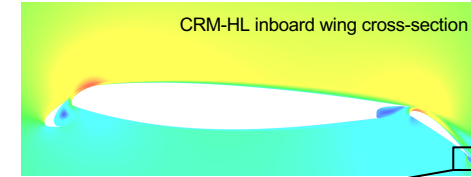


Motivation

- Assess the potential of surface-normal pneumatic AFC, microjets, for enhancing performance of wing in high-lift configuration in the linear regime of the lift curve
- Computational and experimental building-block approach to assess microjet enabled lift control at a range of flow conditions



- Journal of Aircraft paper DOI: 10.2514/1.C036864
- Journal of Aircraft paper DOI:10.2514/1.C035986
- Journal of Aircraft paper DOI: 10.2514/1.C035248
- AIAA paper 2022-2535 (SciTech 2022)
- AIAA paper 2021-1192 (SciTech 2021)
- AIAA paper 2019-3498 (Aviation 2019)
- AIAA paper 2019-0590 (SciTech 2019)
- AIAA paper 2018-0559 (SciTech 2018)



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

Research Tasks and Goals

- Use OVERFLOW Reynolds-Averaged Navier-Stokes (RANS) methods to investigate sensitivity of flap flow features to Reynolds number on the High Lift Common Research Model (HiLiftPW-3) through
 - CFD vs. experiment* validation study at a wind tunnel Reynolds number ($Re_{MAC} = 3.26M$)
 - CFD study at a flight Reynolds number ($Re_{MAC} = 24.6M$)
- Use OVERFLOW RANS methods to investigate the sensitivity of microjet effectiveness to Reynolds number on the CRM-HL addressing microjet trends on
 - Lift
 - Oswald efficiency
 - Trim Drag

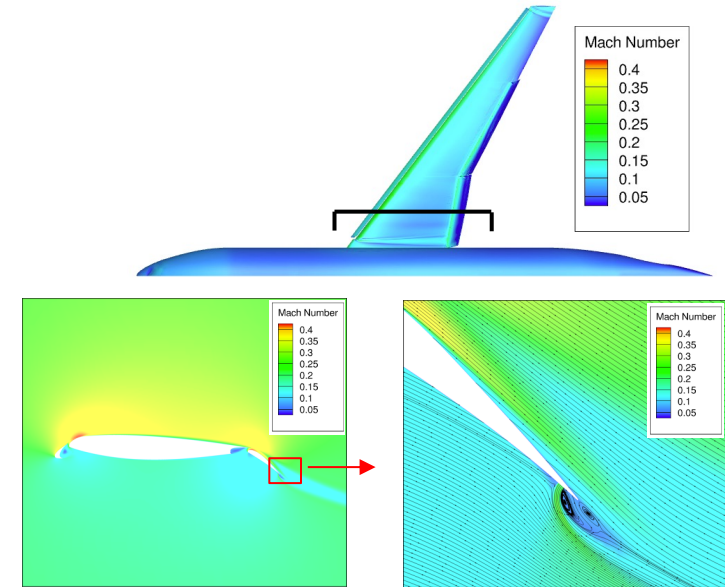
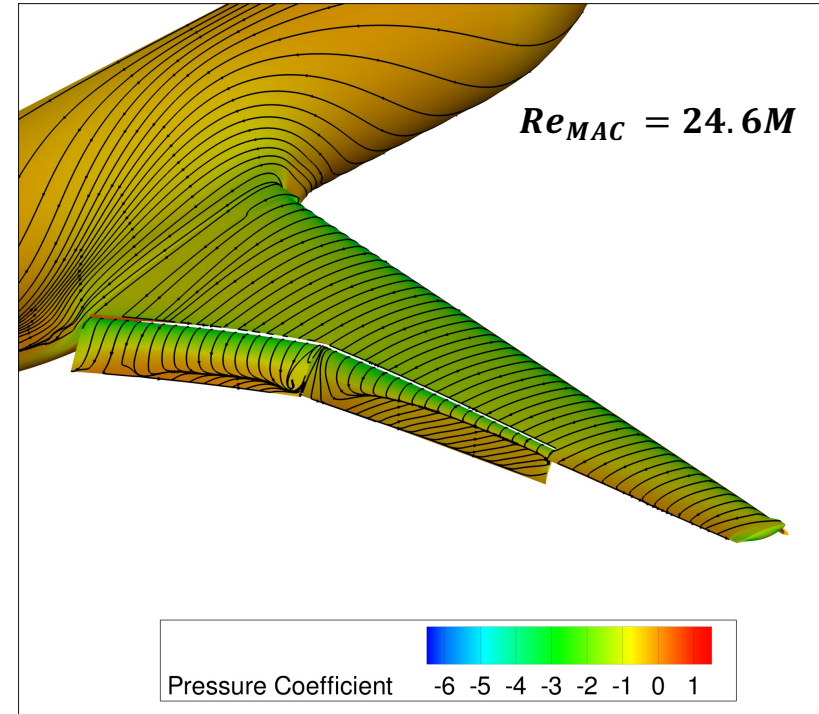
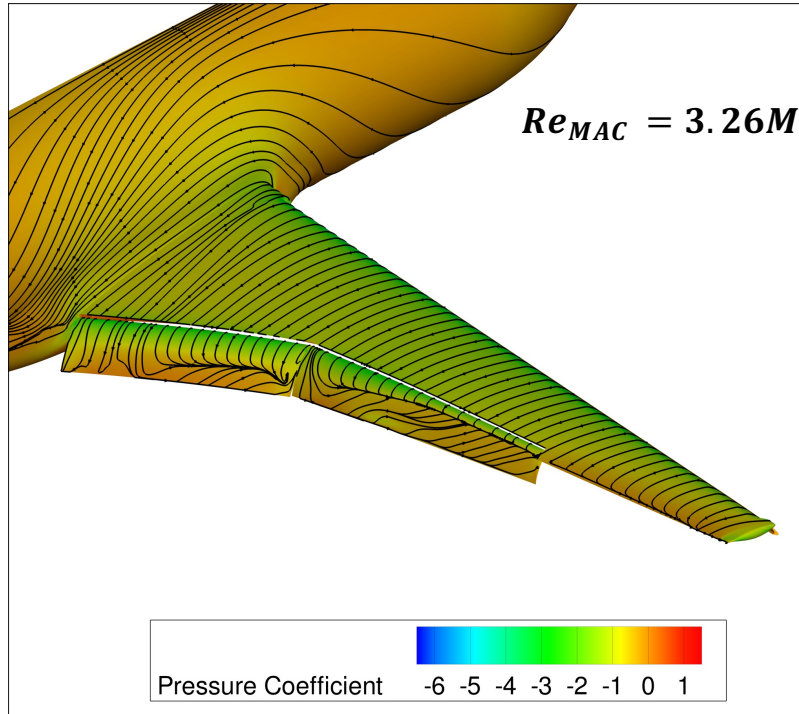


Illustration of microjet implantation on the HiLiftPW-3 inboard flap

*Lin, J. C., Melton, L. P., Hannon, J. A., Andino, M. Y., Koklu, M., Paschal, K. B., and Vatsa, V. N., "Testing of High-Lift Common Research Model with Integrated Active Flow Control," *Journal of Aircraft*, Vol. 57, No. 6, 2020, pp. 1121–1133

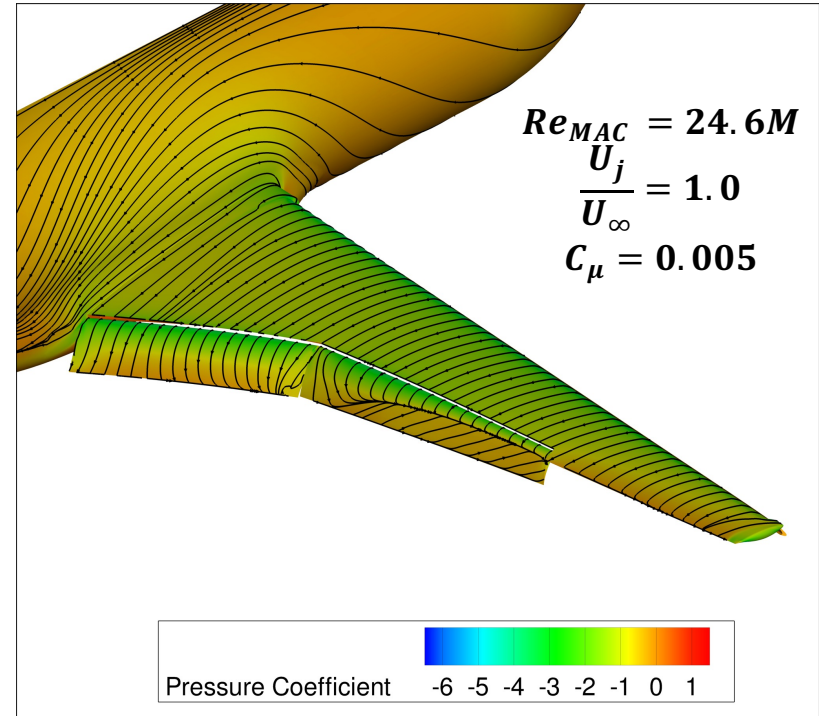
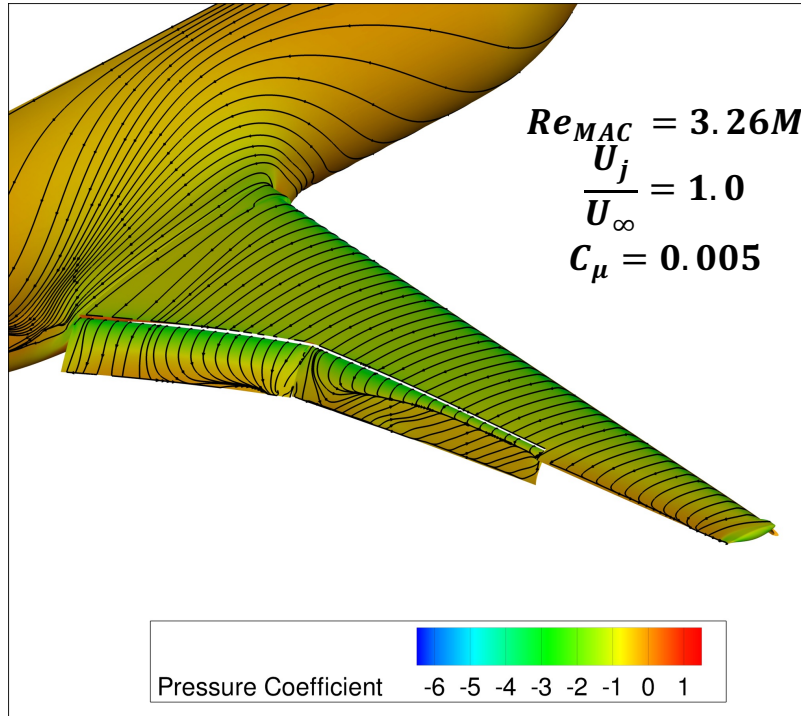
High-Lift CRM Sensitivity to Reynolds Number

$\alpha = 8^\circ$ and $M_\infty = 0.2$



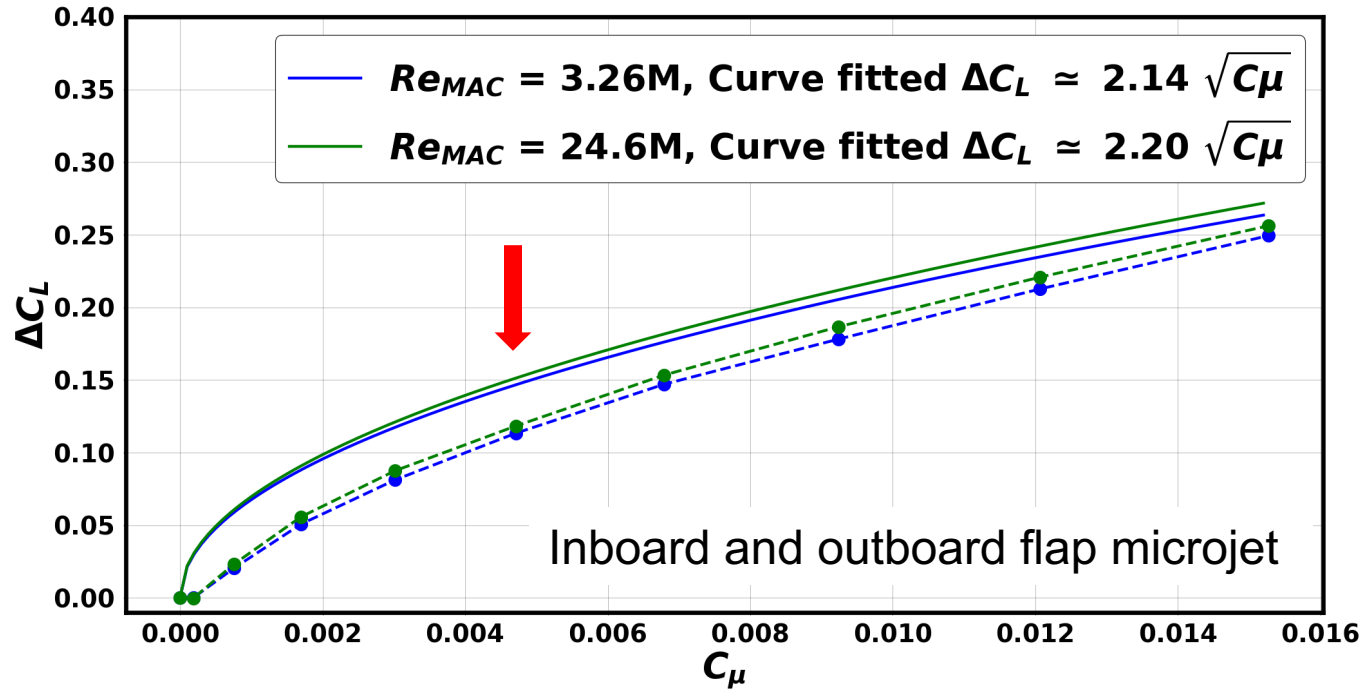
Microjet Sensitivity to Reynolds Number

$\alpha = 8^\circ$ and $M_\infty = 0.2$



Microjet Sensitivity to Reynolds Number – Lift

$\alpha = 8^\circ$ and $M_\infty = 0.2$



Dashed lines represent the computational results, while the solid lines represent the trends fit by $k\sqrt{C_\mu}$



Microjet Sensitivity to Reynolds Number – Lift

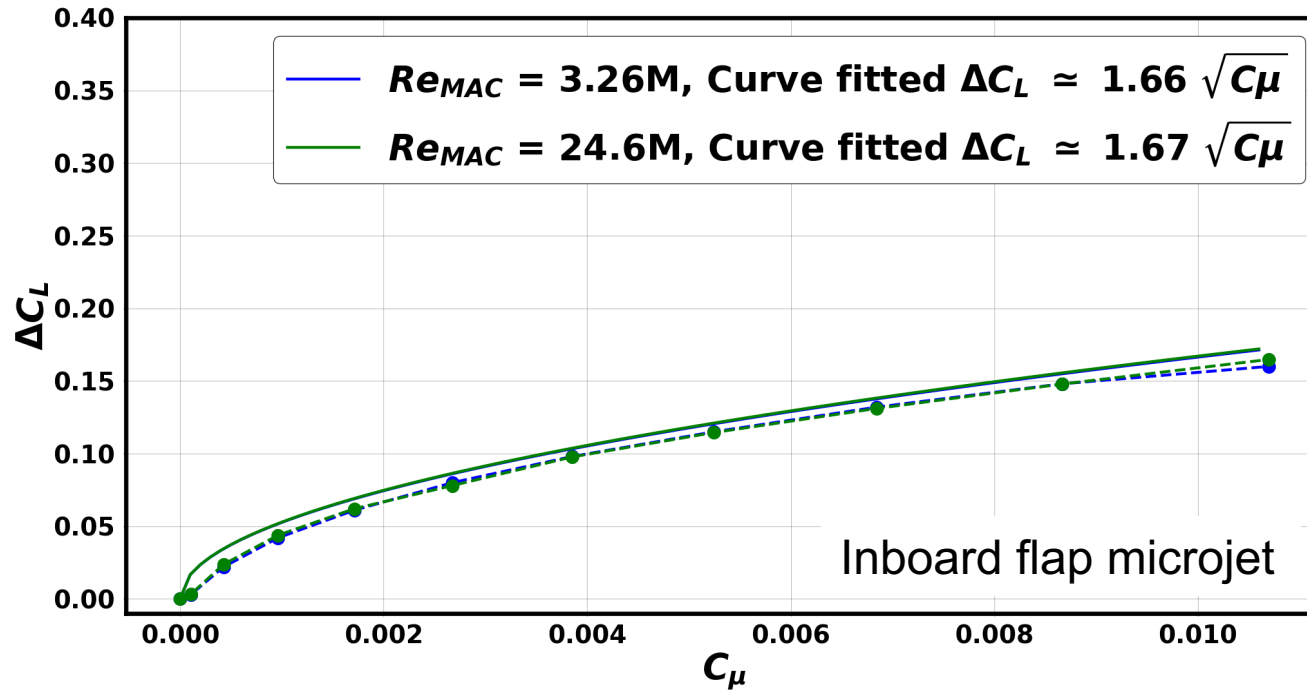
$$\alpha = 8^\circ, M_\infty = 0.2, C_\mu = 0.005$$

Reynolds number	Baseline C_L	Baseline C_D	+Microjet C_L	+Microjet C_D	ΔC_L
$Re_{MAC} = 3.26 \times 10^6$	1.752	0.1698	1.866	0.1903	0.114
$Re_{MAC} = 24.6 \times 10^6$	1.815	0.1706	1.935	0.1927	0.120

Reynolds number	Baseline C_L	+Microjet C_L	Inboard Microjet ΔC_L	Outboard Microjet ΔC_L
$Re_{MAC} = 3.26 \times 10^6$	1.752	1.866	0.079	0.035
$Re_{MAC} = 24.6 \times 10^6$	1.815	1.935	0.079	0.041

Microjet Sensitivity to Reynolds Number – Lift

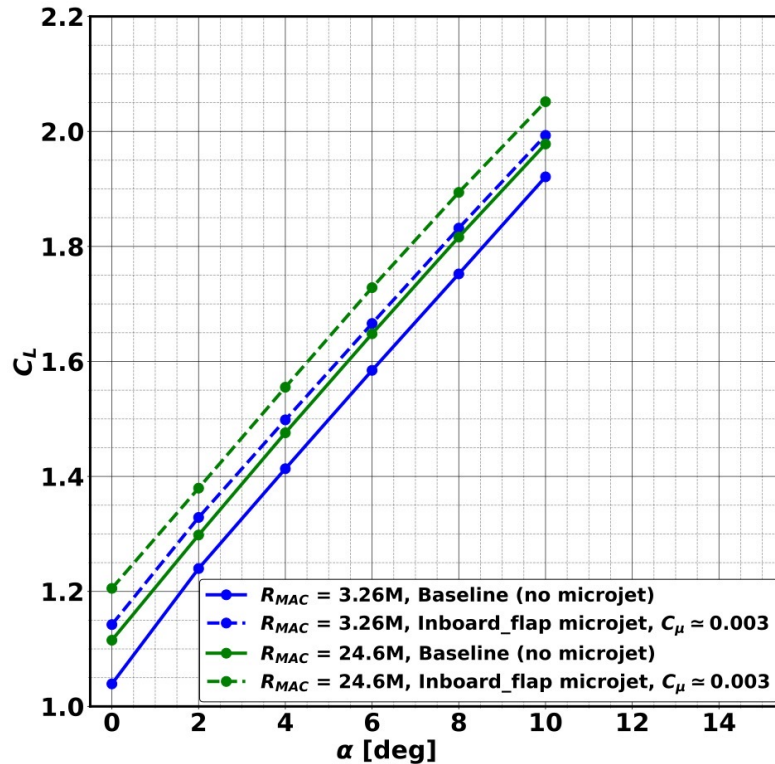
$\alpha = 8^\circ$ and $M_\infty = 0.2$



Dashed lines represent the computational results, while the solid lines represent the trends fit by $k\sqrt{C_\mu}$

Microjet Sensitivity to Reynolds Number – Lift

Inboard flap microjet $\frac{U_j}{U_\infty} = 1.0$ and $C_\mu = 0.003$



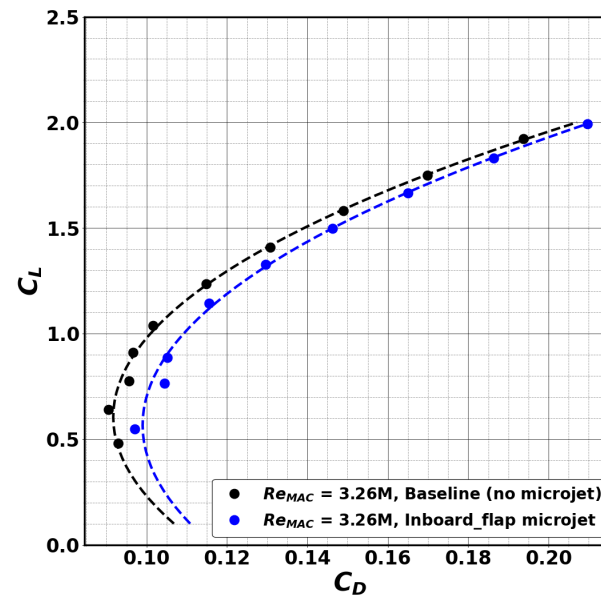
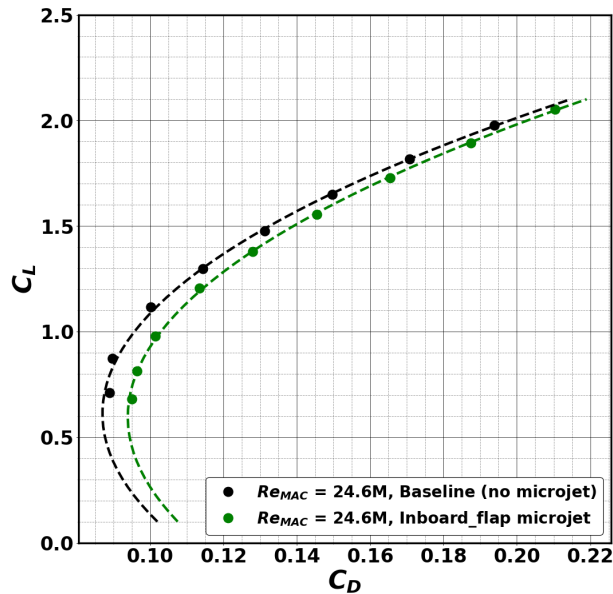
Microjet-induced $\Delta C_L = 0.08$
 $\Delta C_L = 0.10 \Delta C_L \propto 14$ in $h_{landing\ gear}$
 $\propto 1400$ lb (approx. 7 passengers)*

*P. Meredith, "Viscous Phenomena Affecting High-Lift Systems and Suggestions for Future CFD Development. High-Lift System Aerodynamics," AGARD CP 515, pp. 19(1)–19(8), 1993.

Microjet Sensitivity to Reynolds Number – Oswald Efficiency

Inboard flap microjet $\frac{U_j}{U_\infty} = 1.0$ and $C_\mu = 0.003$

$$C_D = C_{D_{min}} + \frac{(C_L - C_{L_{min}})^2}{\pi e A R} = (C_{D_{min}} + \frac{C_{L_{min}}^2}{\pi e A R}) + (\frac{-2C_{L_{min}}}{\pi e A R})C_L + (\frac{1}{\pi e A R})C_L^2$$





Microjet Sensitivity to Reynolds Number – Oswald Efficiency

Inboard flap microjet $\frac{U_j}{U_\infty} = 1.0$ and $C_\mu = 0.003$

	C_L	C_D	C_L/C_D	$\Delta(C_L/C_D)$	e	Δe
$Re_{MAC} = 24.6 \times 10^6$						
Baseline	1.815	0.1706	10.64	-	61.5%	-
Inboard-flap microjet	1.894	0.1874	10.11	-0.53	64.0%	+2.5%
$Re_{MAC} = 3.26 \times 10^6$						
Baseline	1.752	0.1698	10.32	-	59.7%	-
Inboard-flap microjet	1.832	0.1864	9.82	-0.50	65.1%	+5.4%

Microjet implemented for lift enhancement
increases wing efficiency

Microjet Sensitivity to Reynolds Number – Trim Drag

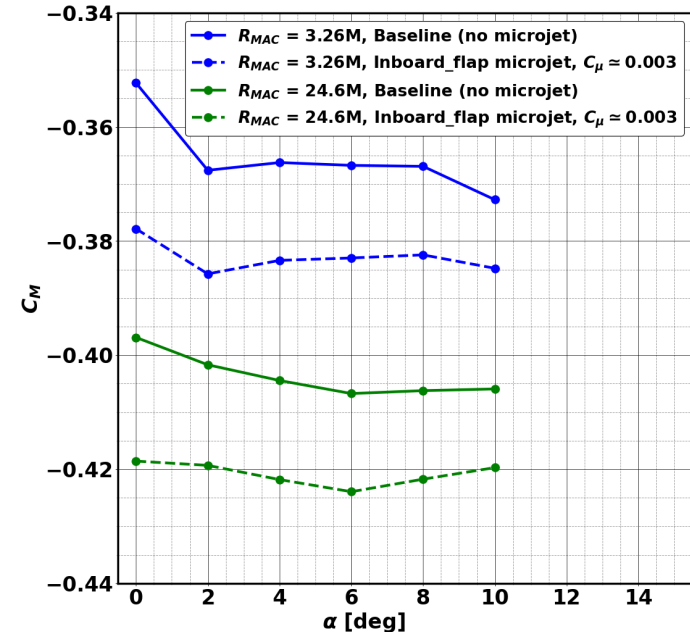
- Lift coefficients required by the horizontal tail to offset the pitching moment effects are supplied to the drag polars for trim drag estimates

Inboard flap microjet $\frac{U_j}{U_\infty} = 1.0$ and $C_\mu = 0.003$

$$C_{L_{trim}} = C_{L_{tailoff}} + C_{M_{tailoff}} \frac{MAC}{\cos(\alpha)(X_{tail-MAC} - X_{cg}) + \sin(\alpha)(Z_{tail-MAC} - Z_{cg})}$$

$\alpha = 8.0^\circ$ and $M = 0.2$	$C_{D_{pre-trim}}$	$C_{D_{trim}}$	$C_{D_{total}}$	$\Delta C_{D_{trim}}$
$Re_{MAC} = 24.6 \times 10^6$				
Baseline	0.1706	0.0173	0.1879	-
Inboard-flap microjet	0.1874	0.0186	0.2060	0.0013
$Re_{MAC} = 3.26 \times 10^6$				
Baseline	0.1698	0.0153	0.1851	-
Inboard-flap microjet	0.1864	0.0161	0.2025	0.0008

Microjet implemented for lift enhancement increases trim drag by ~ 0.5% total drag



Summary



- Demonstrated that microjets have the potential to enhance high-lift performance across Reynolds numbers of 3.26M and 24.6M
- Trailing edge flow separation on the baseline configuration showed high sensitivity to Reynolds number
 - At the flight Reynolds number, the onset of TE flow separation was shown to shift downstream resulting in less flow separation compared to at the WT Reynolds number
 - Outboard flap microjet lift enhancement was improved by 17% at the flight Reynolds number
 - Inboard and outboard flap microjet lift enhancement was improved by 5% at the flight Reynolds number
- Computational investigations of AFC at appropriate flight conditions in addition to commonly used wind tunnel conditions are encouraged to obtain representative results
- Inboard flap microjet for lift enhancement was shown to increase Oswald efficiency by 2.5-5.4%
- Microjet impact on trim drag was shown to increase ~ 0.5% total drag

Acknowledgements



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