

Replacing the Aileron of the High-Lift Common Research Model with Trailing-Edge Coanda Actuators

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Background and Motivation

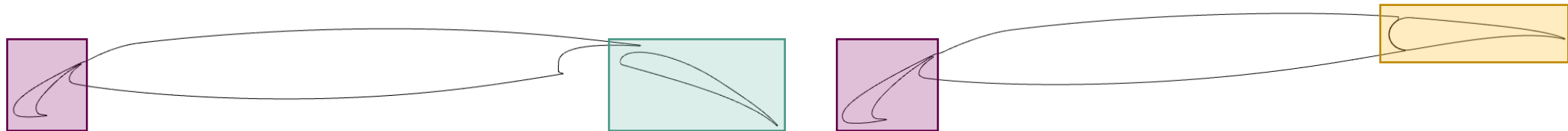
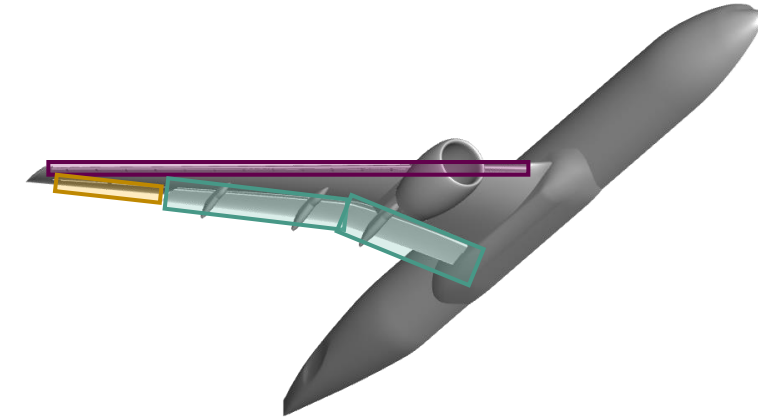


High-Lift Common Research Model (CRM-HL)

Focused on the CRM-HL in the takeoff configuration (10% scale model)

$$M = 0.20; \quad Re_c = 3e6; \quad \alpha = 4.6^\circ$$

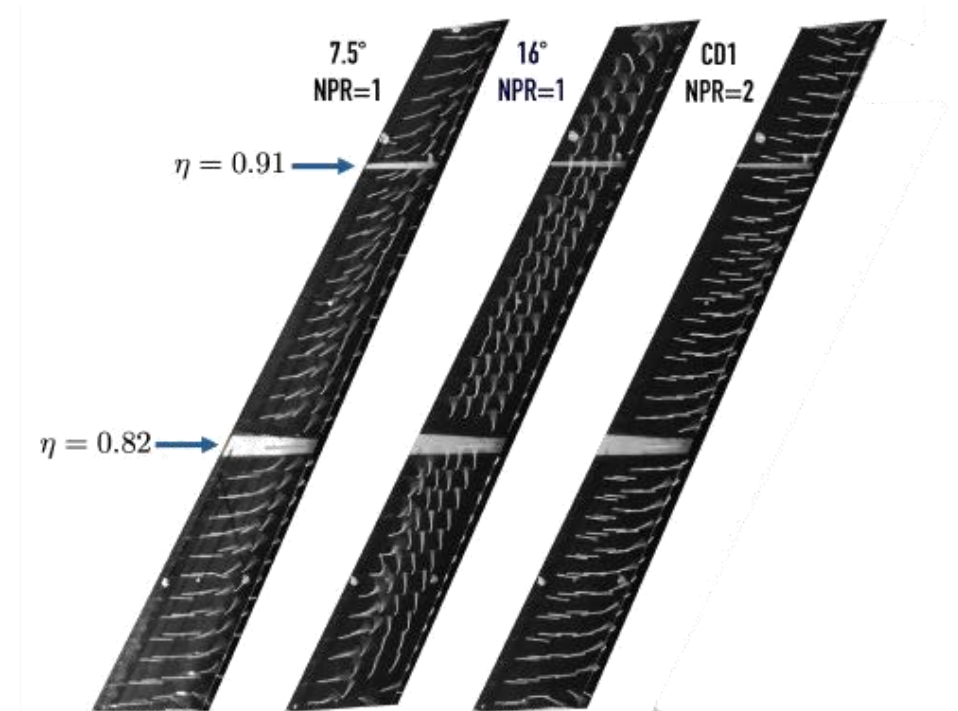
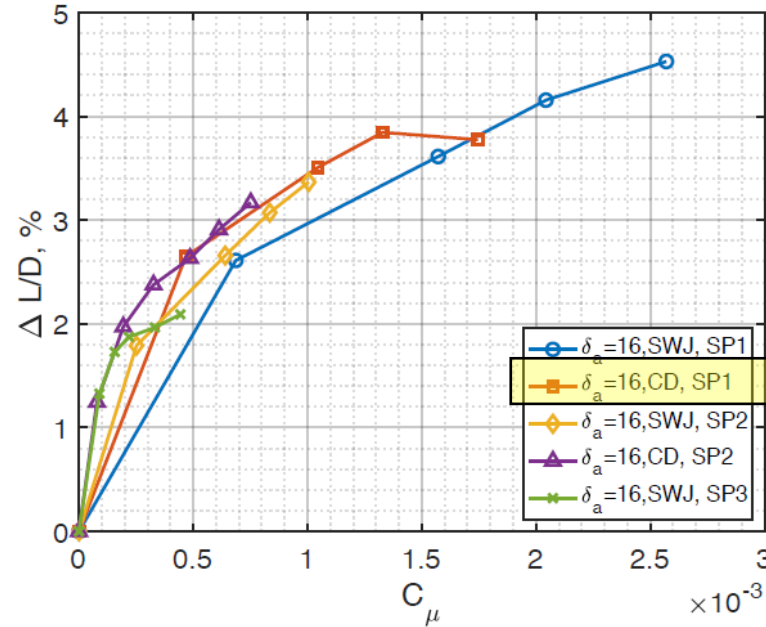
- Model components:
 - Semispan model of wing, fuselage, nacelle, and pylon
- High lift devices:
 - Inboard **slat**, outboard **slat**, inboard **flap**, outboard **flap**, and **aileron**
 - For takeoff, slats at 22° , flaps at 25° , aileron at 0° , 7.5° , 16° , or 25°
- Support devices:
 - 15 brackets to hold slat in place, trailing edge of slat sealed to main element (no bracket wakes)
 - 3 brackets to position the fowler flaps and fairings to aerodynamically conceal the brackets
 - 3 brackets to hold the aileron in position



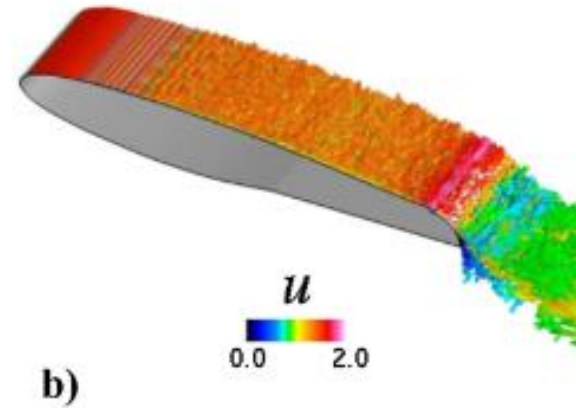
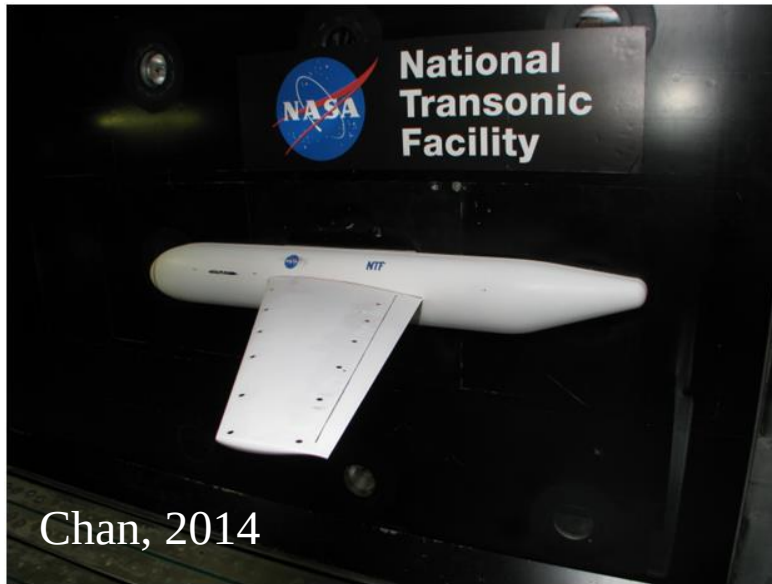
Active Flow Control Enhanced Aileron

Andino et al., Koklu et al., Melton et al., Shmilovich et al., Vijgen et al.

- Blew air through steady jets and sweeping jets over highly deflected aileron ($\delta_a = 16^\circ$)
- Produced $\sim 4\%$ increase in takeoff L/D vs. nominal takeoff aileron ($\delta_a = 7.5^\circ$)
 - Just 1% improvement in L/D $\rightarrow$ +2800 lbs. GTOW or +150nm range (Garner et al., 1991)



Trailing-edge circulation control in literature



Simon, 2024
D90-v2 tailless delta wing
Circulation control as a control surface

Englar, 1979
Circulation control modification on
A-6 Intruder

Frith, 2003
Delta Wing with trailing edge
circulation control

Objectives for Current Study

1. Design circulation control AFC segment to replace the CRM-HL aileron
2. Evaluate performance of AFC at takeoff conditions

Goals:

- Recreate the takeoff L/D benefit of the AFC-aileron
- Report the drag increase due to integration
- Minimize mass flow requirement

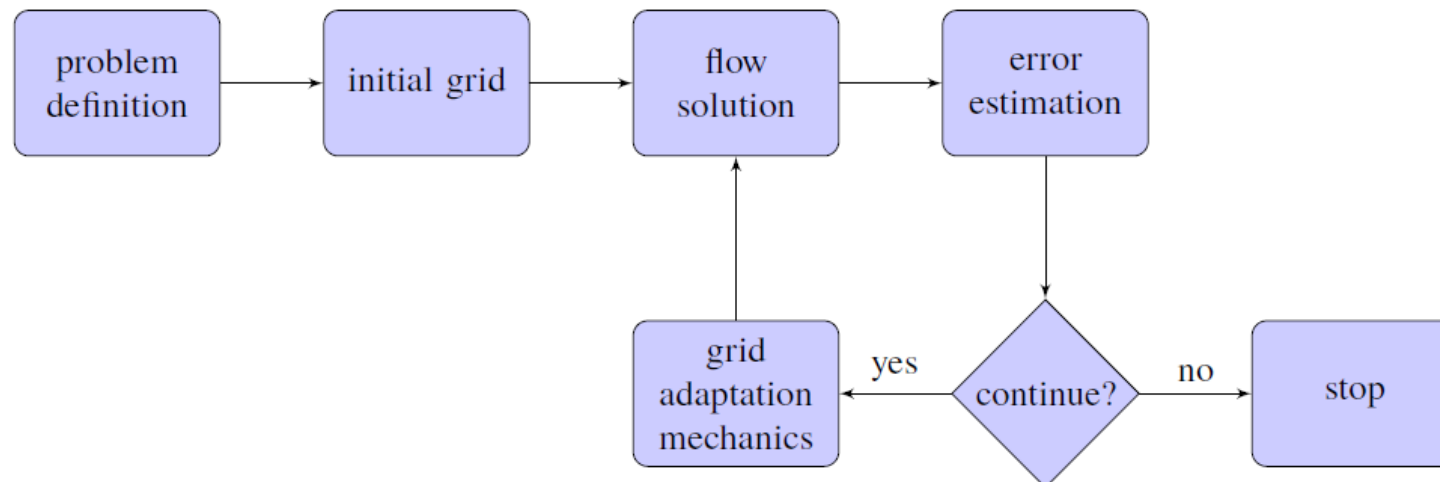
Methods



Computational Methods

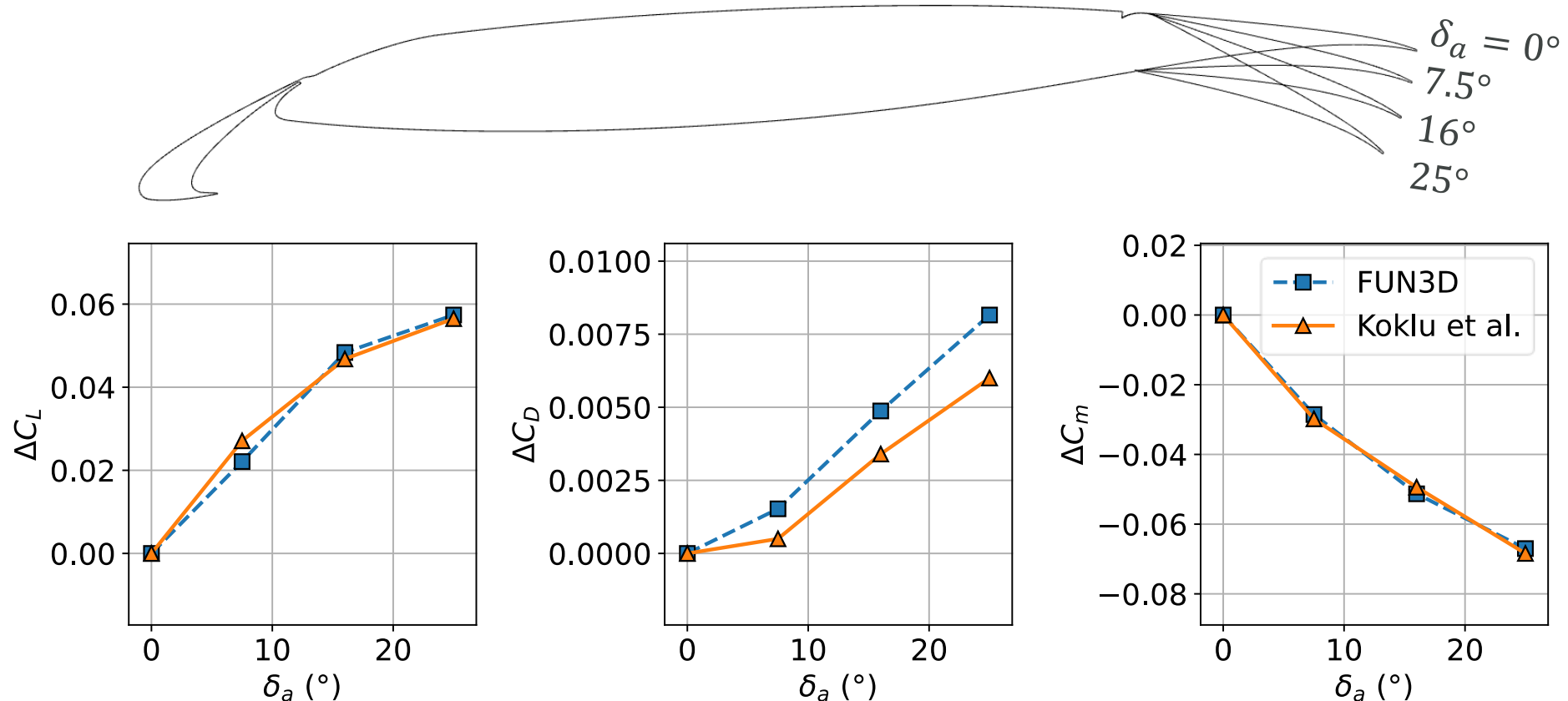
Computational Fluid Dynamics Simulations

- RANS simulations in FUN3D (FV)
 - Geometry-linked adaptive mesh refinement, aka Sketch-to-Solution
 - Meshes adapted from gradients in Mach number, up to 1 billion cells
 - Turbulence modeled with SA-neg-RC
 - HANIM for adaptive CFL controller, preconditioner, realizability checks, and GCR method
- Computed on NASA's Advanced Supercomputing (NAS) Division hardware



Aileron Deflection Study – CFD Validation

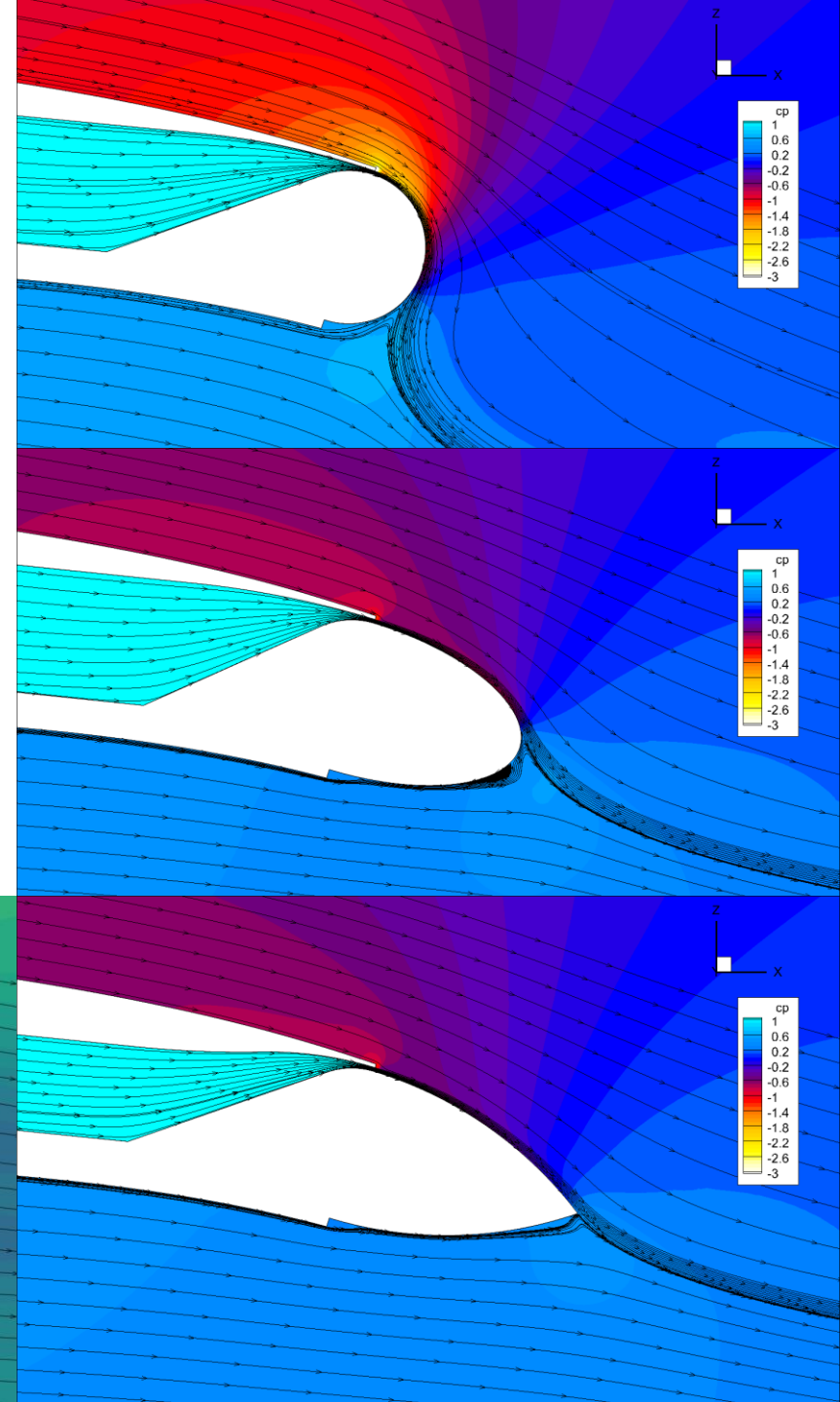
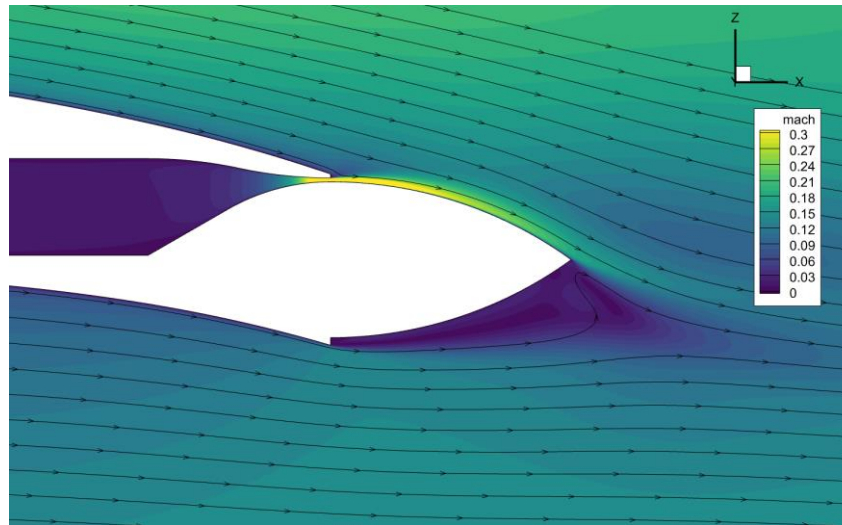
- Compare simulations of aileron deflections to experimental data.
 - Consistent with takeaways from HLPW4,5
- Defines threshold for takeoff configuration performance from AFC



2D Coanda Actuator Design

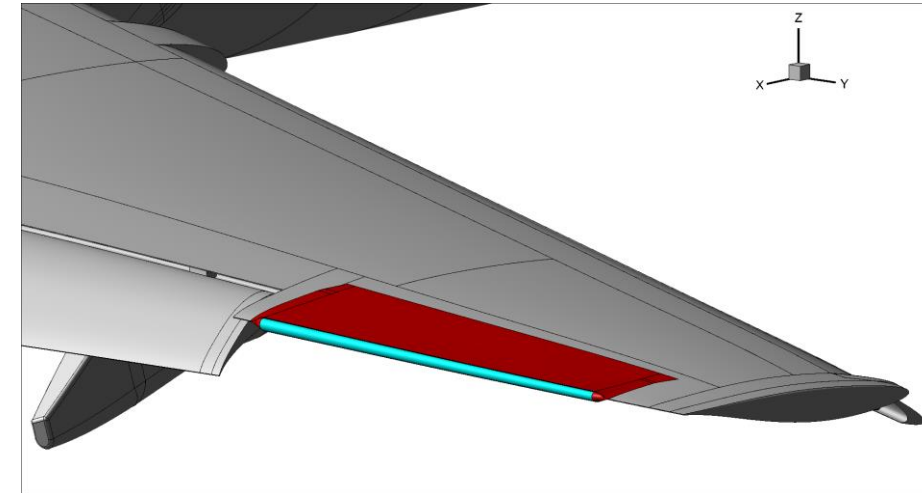
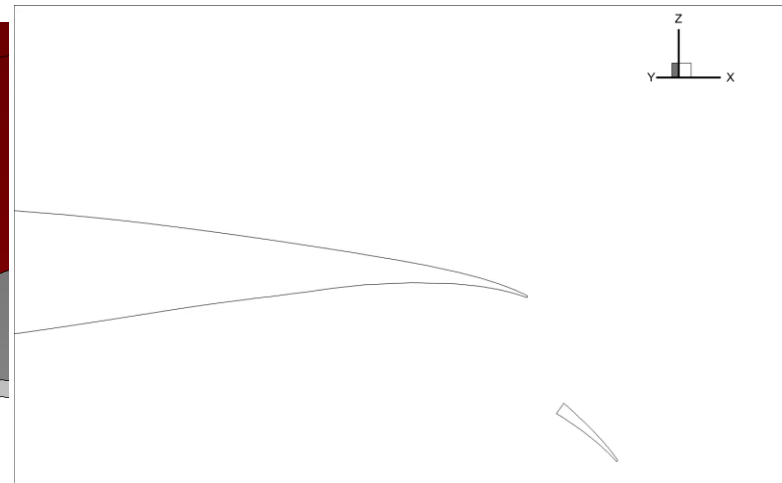
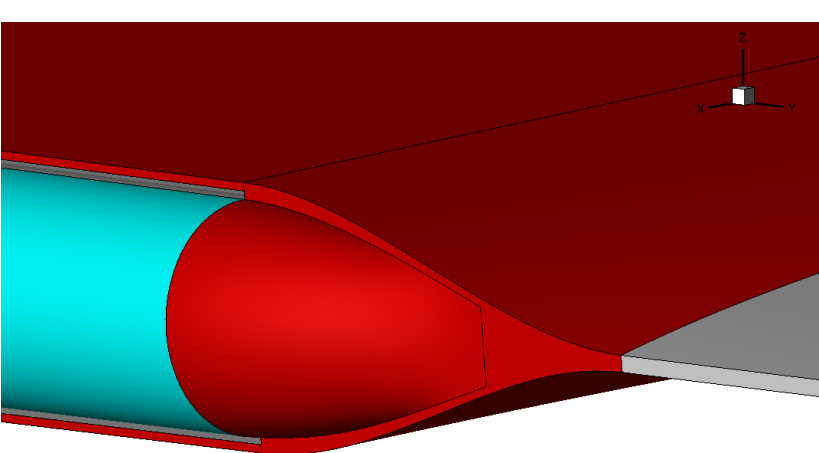
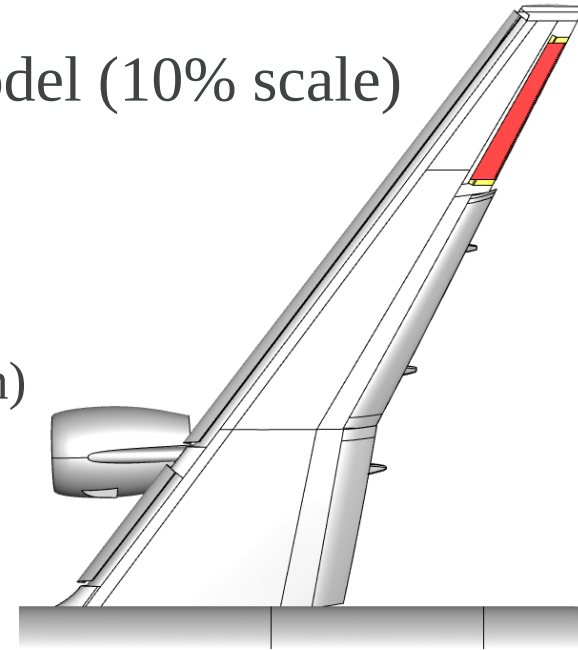
Coanda Actuator Variable	Range tested
Actuator placement as x/c	0.90, 0.95, 1.0
Surface shape (Aspect Ratio)	Circular (1), Elliptical (2.3), Biconvex (3.1)
Blowing direction	Chord-aligned, camber-aligned
Slot height as h/r	0.010 to 0.075
Coanda radius as r/c	0.0076 to 0.039
NPR	1.0 to 1.5

More details in conference paper



Implementation on CRM-HL semispan

- Contained entirely within aileron cutout section of CRM-HL WT model (10% scale)
- Contoured transition between regular TE and Coanda TE
 - Radius varies with span ($r/c = 0.014$)
 - Blowing aligned trailing-edge-normal
 - Slot height and lip height held constant at $h = 0.010''$ (h/r increasing with span)
 - Contraction ratio $>10\times$ for supply plenums
 - Upper and lower slots have independent control



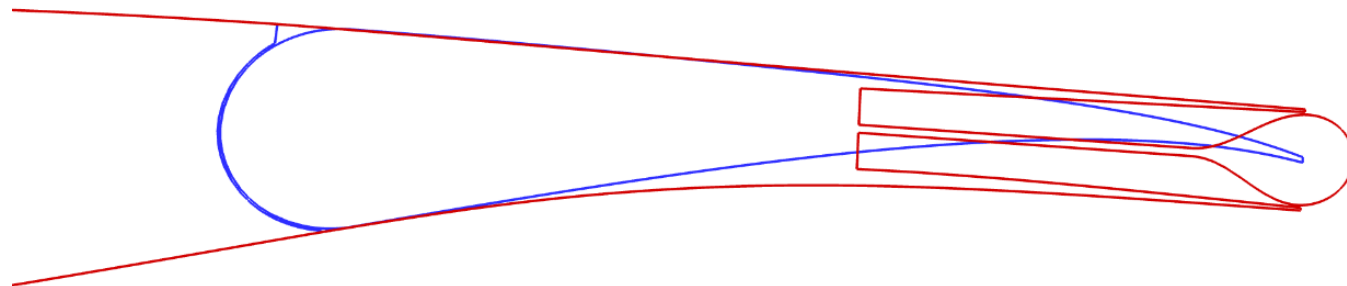
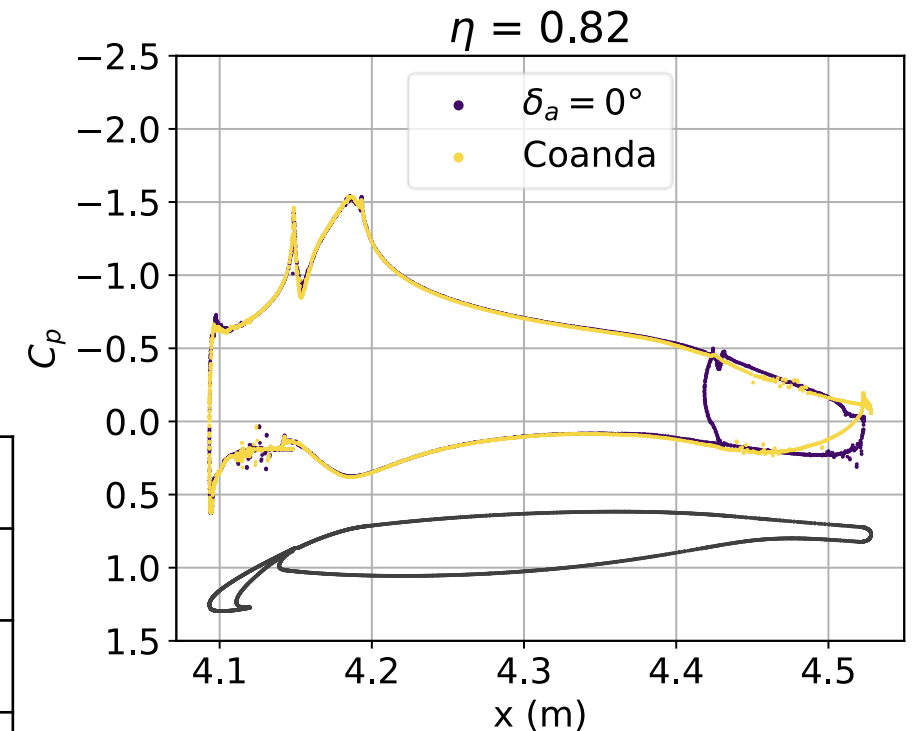
Results



Installation Impact

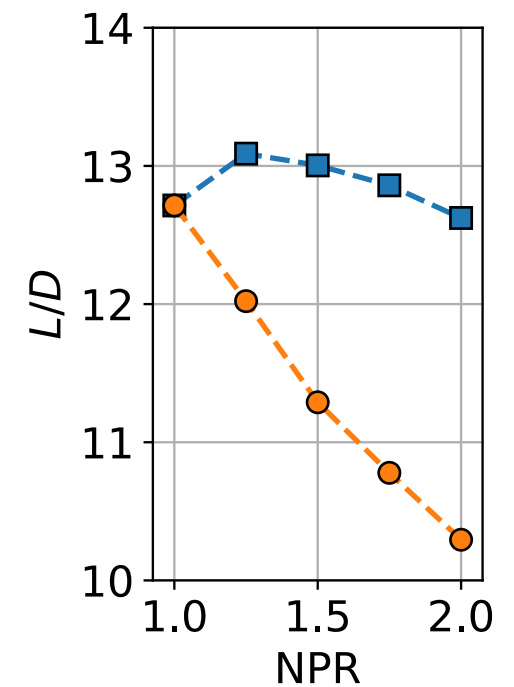
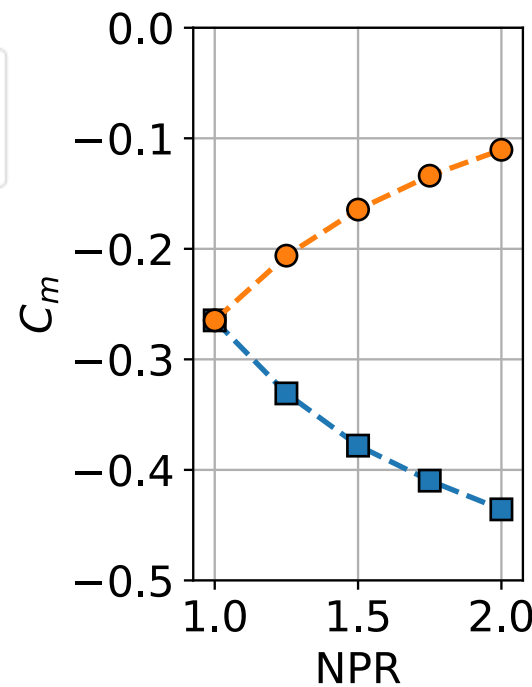
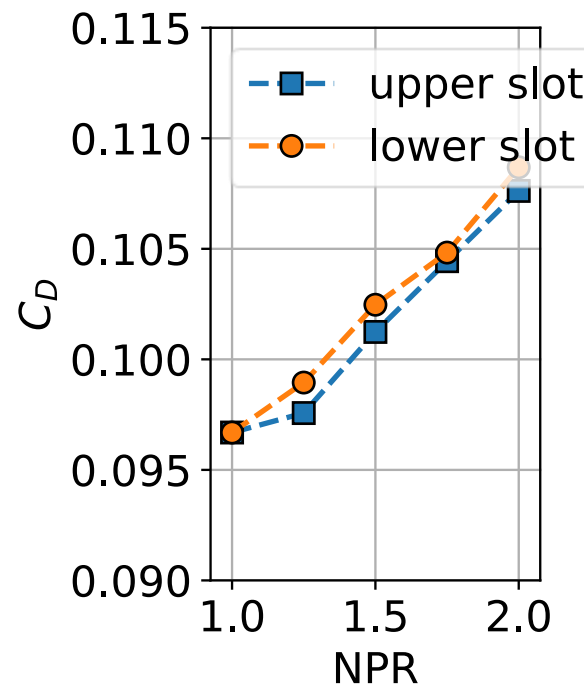
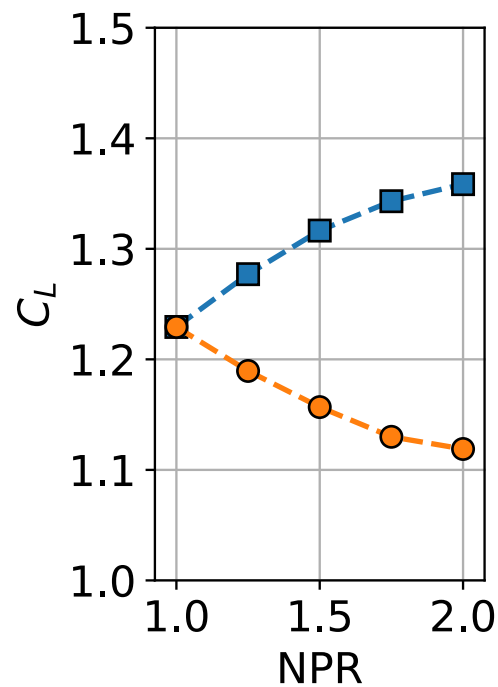
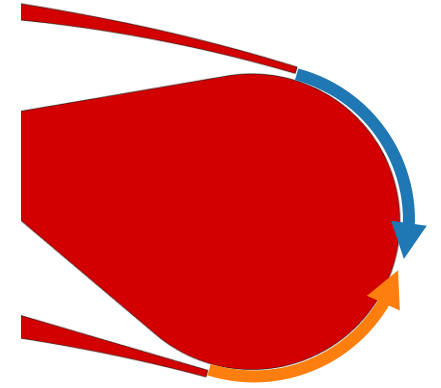
- C_D increases by 12 counts at takeoff
- AFC must provide increment expected for nominal takeoff configuration

	C_L	C_D	C_M	L/D
$\delta_a = 0^\circ$	1.224	0.0955	-0.265	12.81
$\delta_a = 7.5^\circ$	1.246	0.0971	-0.294	12.84
Coanda, baseline	1.229	0.0967	-0.265	12.71



Performance at nominal takeoff angle of attack

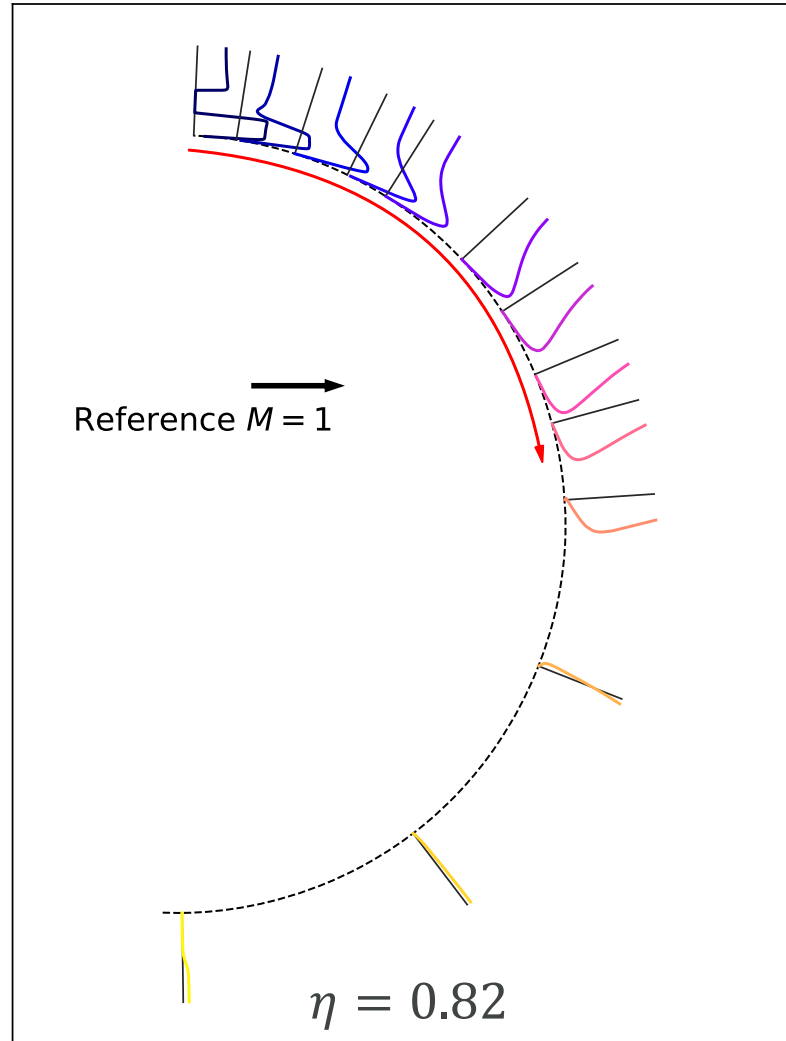
- Lift increase up to 10.5% at NPR = 2.0
- 1.9% increase in L/D at NPR = 1.25
- Symmetric decrements with lower slot blowing



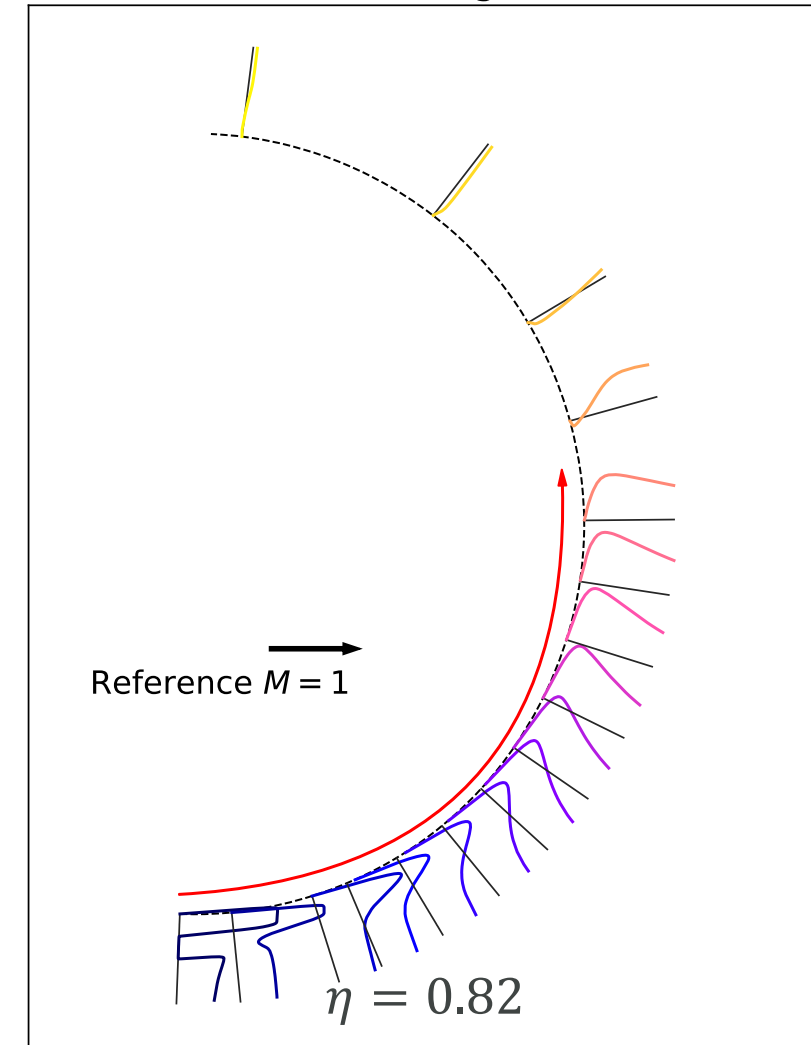
Performance at nominal takeoff angle of attack

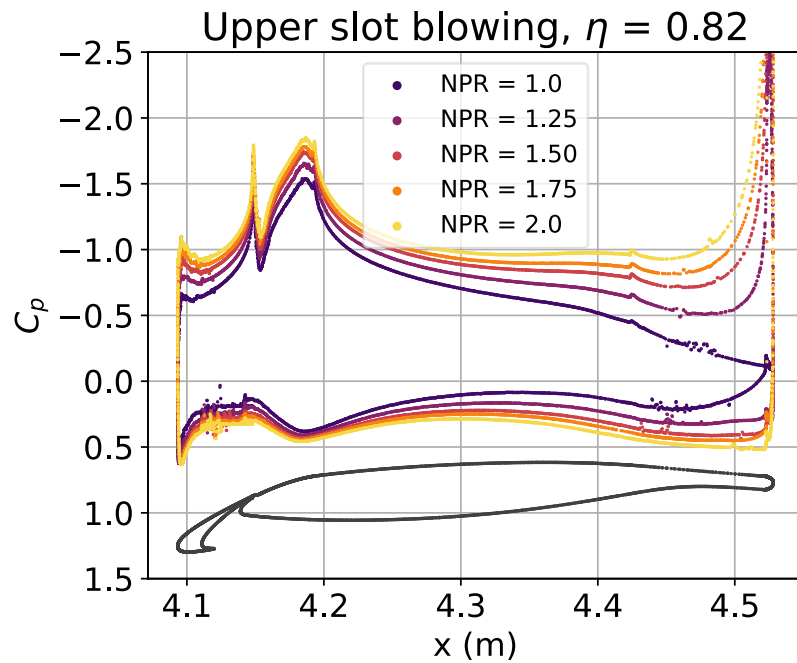
- Wrapping effective around Coanda surface
 - up to 105°
- Imposing circulation on wing section

Upper Slot Blowing, NPR = 1.5

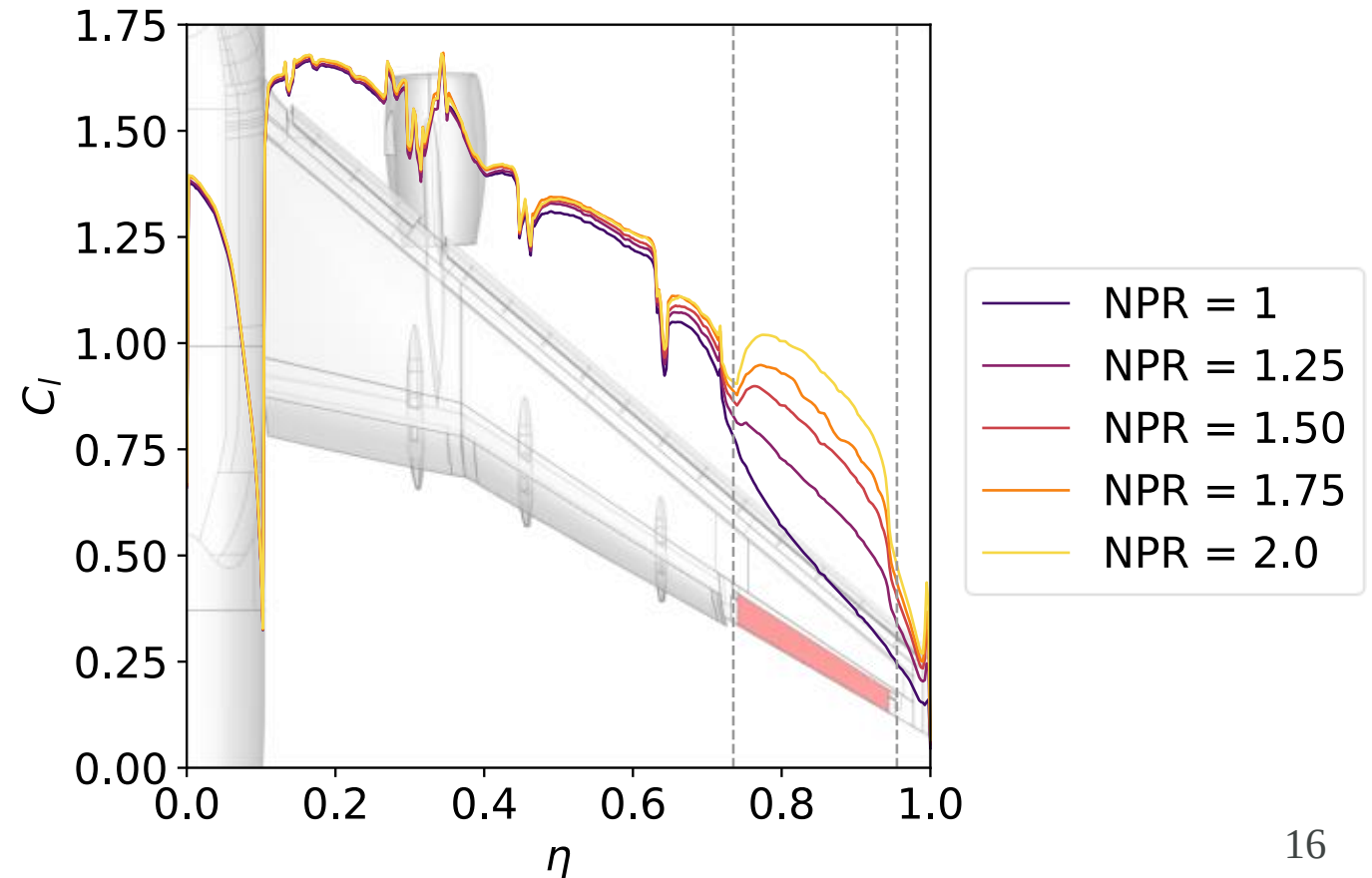
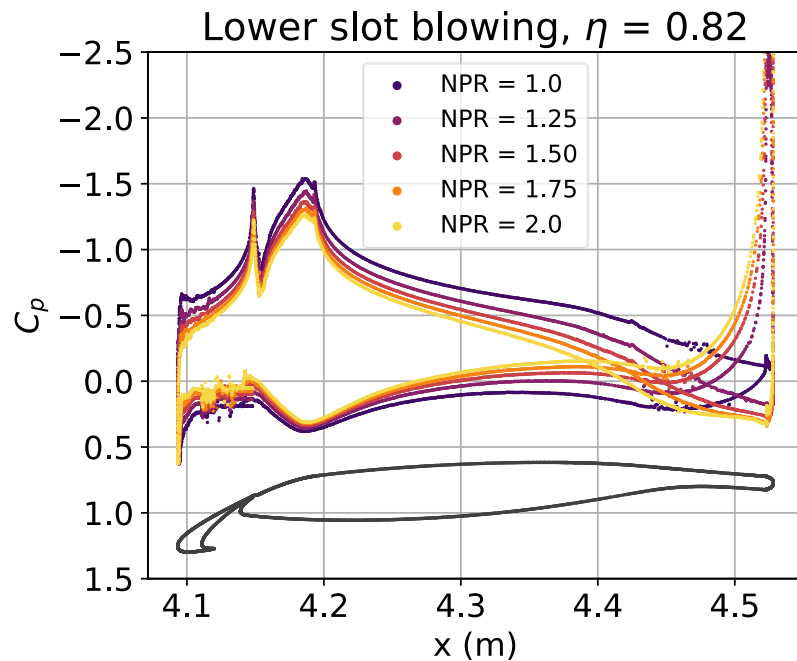


Lower Slot Blowing, NPR = 2.0



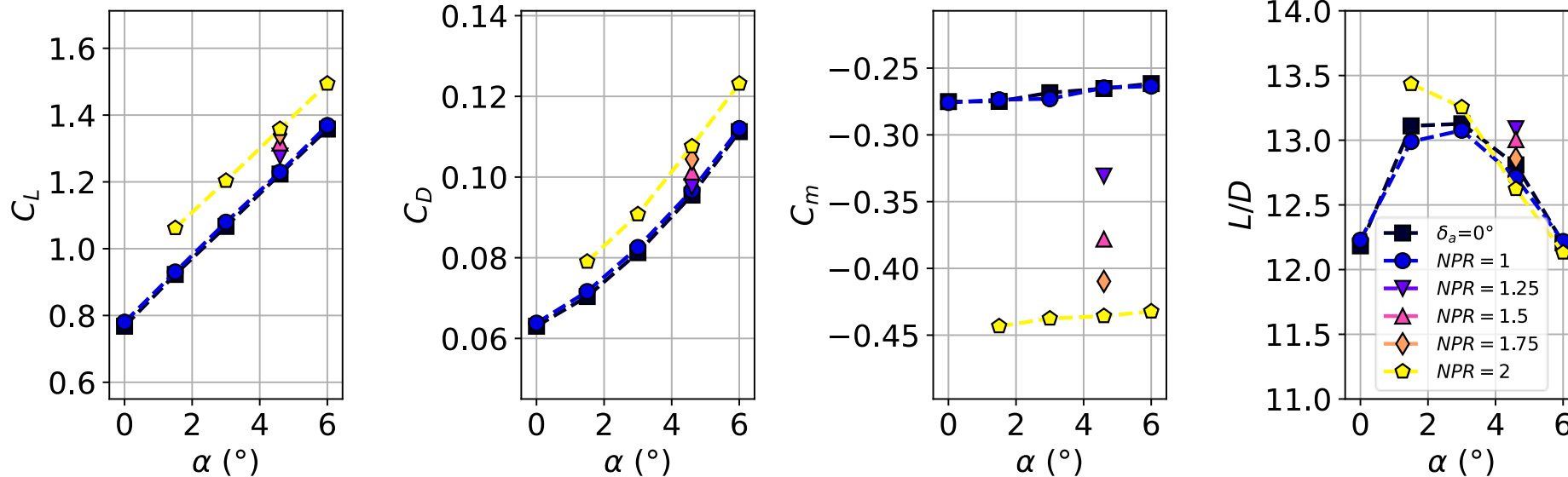


- Change in circulation reflected in surface pressure distributions
- Large lift increments over aileron section
- Smaller lift benefits outside of aileron section



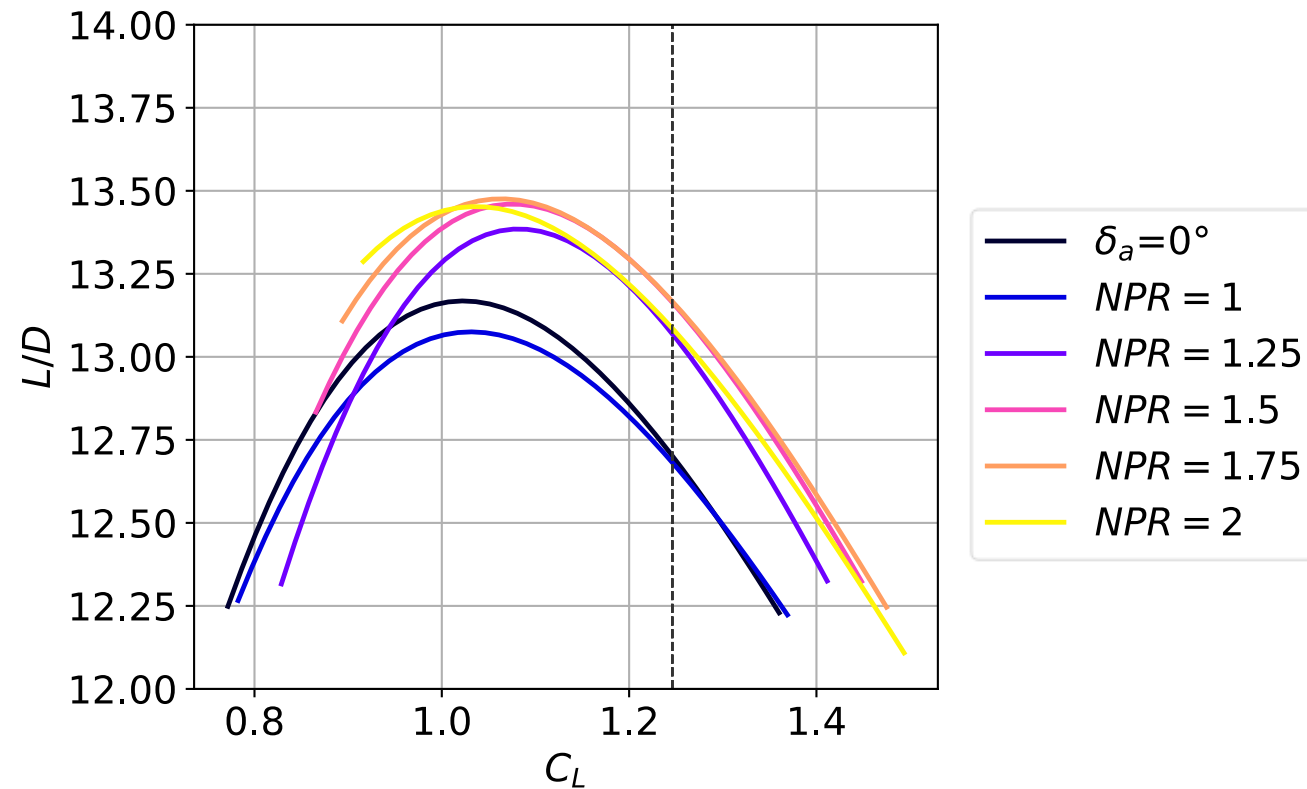
Performance at nominal takeoff lift coefficient

- Compare at constant C_L to differentiate L/D changes from drag due to lift
- Simulate baseline and $\text{NPR} = 2$ at a range of angles of attack
- Interpolate solutions to other NPRs
 - On basis of C_μ and NPR



Comparing L/D at constant C_L

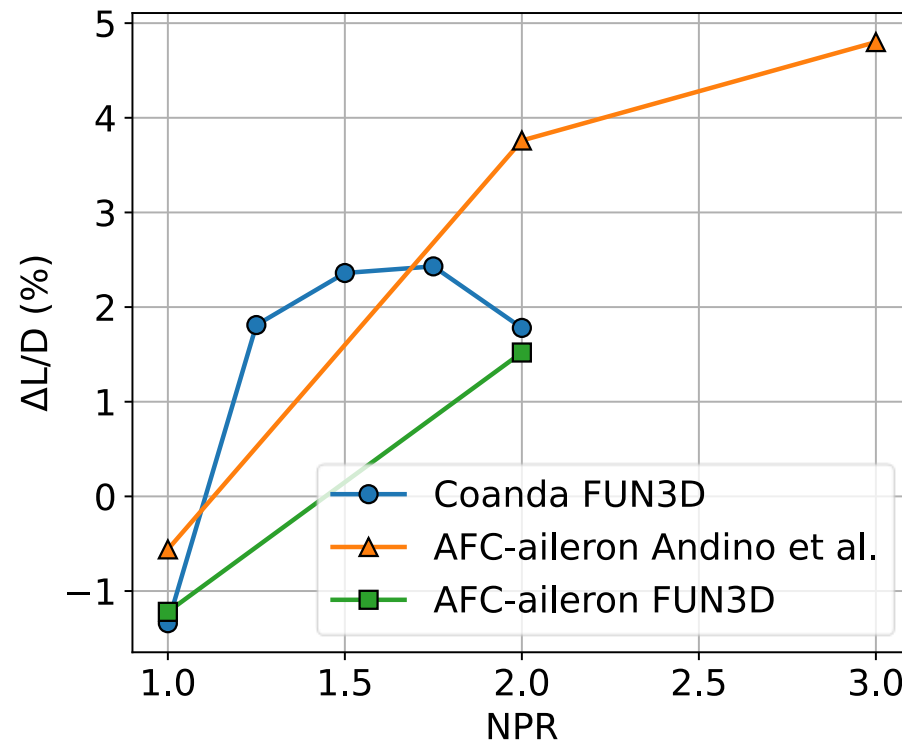
- From simulations and interpolated data, can produce:



- L/D increases with Coanda AFC, C_L of max L/D increases

Comparison to AFC-aileron

- Net 2.5% increase in takeoff L/D
- Current simulations for AFC-aileron = 1.5% increase in takeoff L/D
 - Shmilovich et al. simulated higher benefit for AFC-aileron
- Experiments = $\sim 5\%$ increase in takeoff L/D at constant C_L



Summary and Conclusions

- Coanda actuators designed for CRM-HL at takeoff conditions
- Installed onto CRM-HL for only 12 counts increase in drag
- Increased C_L up to 10% at constant angle of attack
- Discretizing slot substantially reduced aerodynamic benefit
- Increased takeoff L/D by 2.5% with no moving parts

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 - GEOLAB team at NASA LaRC
- NASA Advanced Supercomputing Division

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QUESTIONS

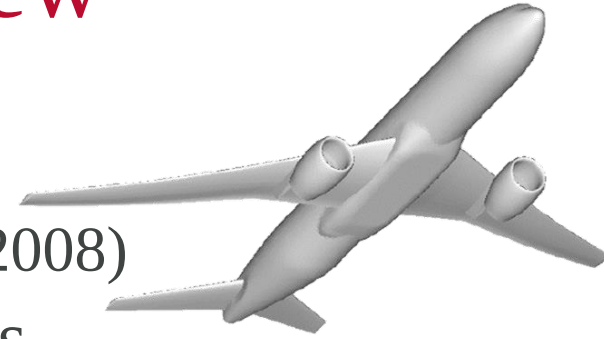


Backup Slides



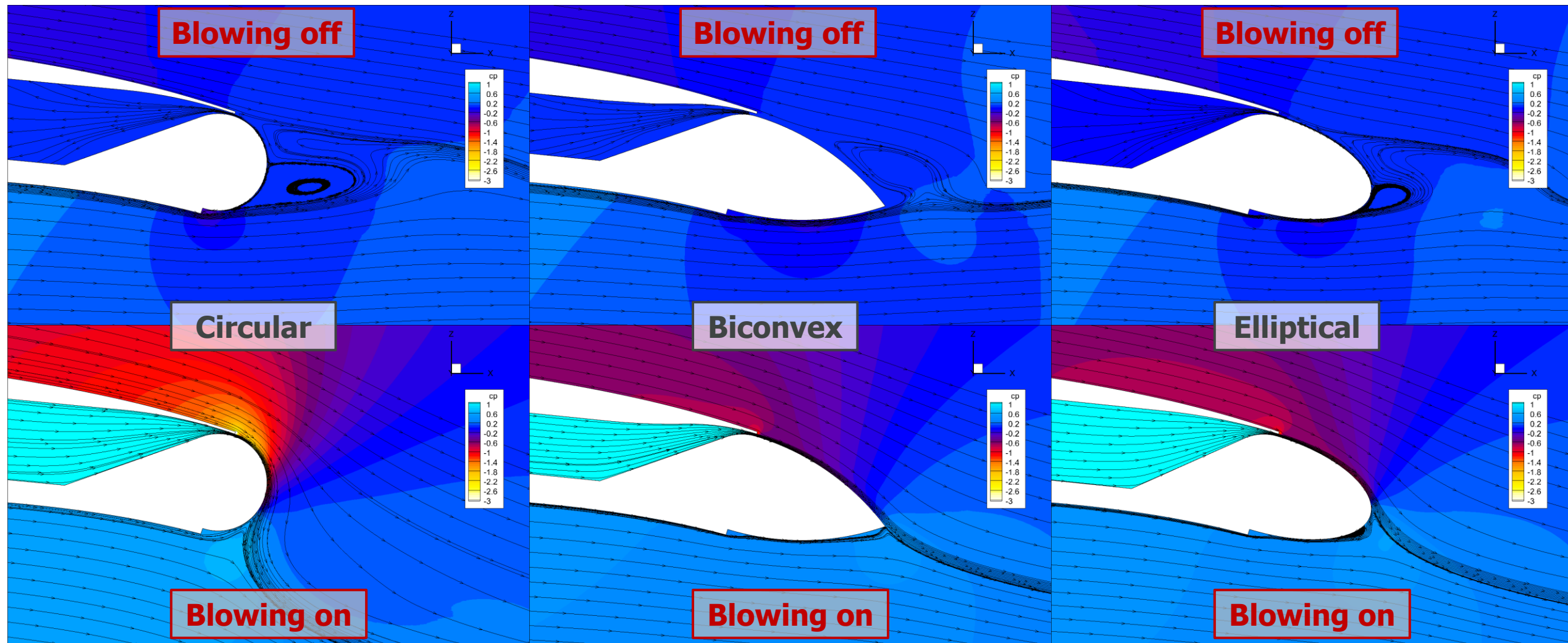
Common Research Model (CRM) Overview

- Nonproprietary commercial transport model
 - Designed by Boeing and NASA teams in 2008 (Vassberg et al., 2008)
- Serves as research testbed to connect CFD and experiments
 - Primary model used for AIAA prediction workshops: High Lift, Drag, etc.
 - Tested many facilities such as 14x22, NTF, IRT, QinetiQ, JAXA, and more!
- Many different modifications to CRM for focused aerospace disciplines
 - High-Speed CRM
 - High-Lift CRM (CRM-HL)
 - Natural Laminar Flow CRM (CRM-NLF)
 - Can include nacelle, pylon, horizontal tail, vertical tail, landing gear, etc.
 - Can position control surfaces for takeoff, landing, other
 - Wing deflections at cruise recorded for CFD comparisons



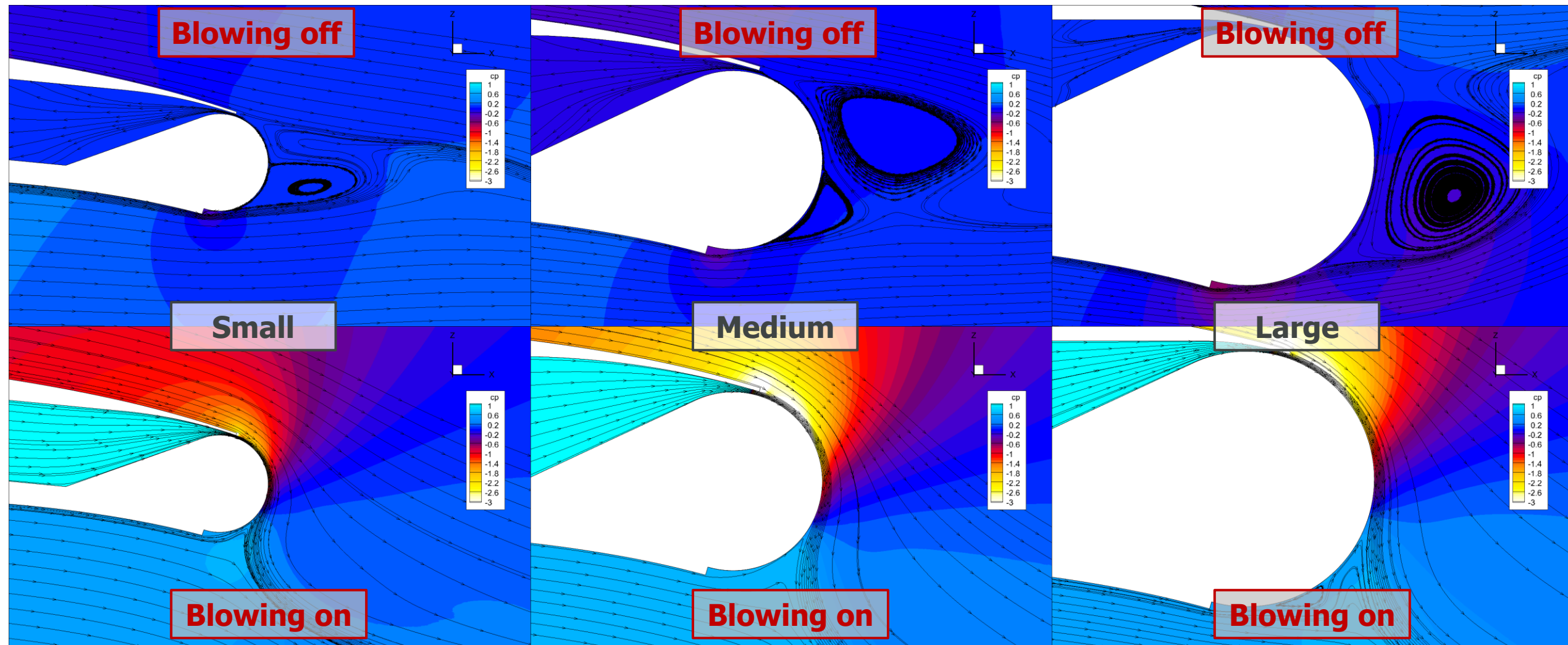
2D simulations of CRM-HL airfoil

Evaluate lift performance of different Coanda surface shapes



2D simulations of CRM-HL airfoil

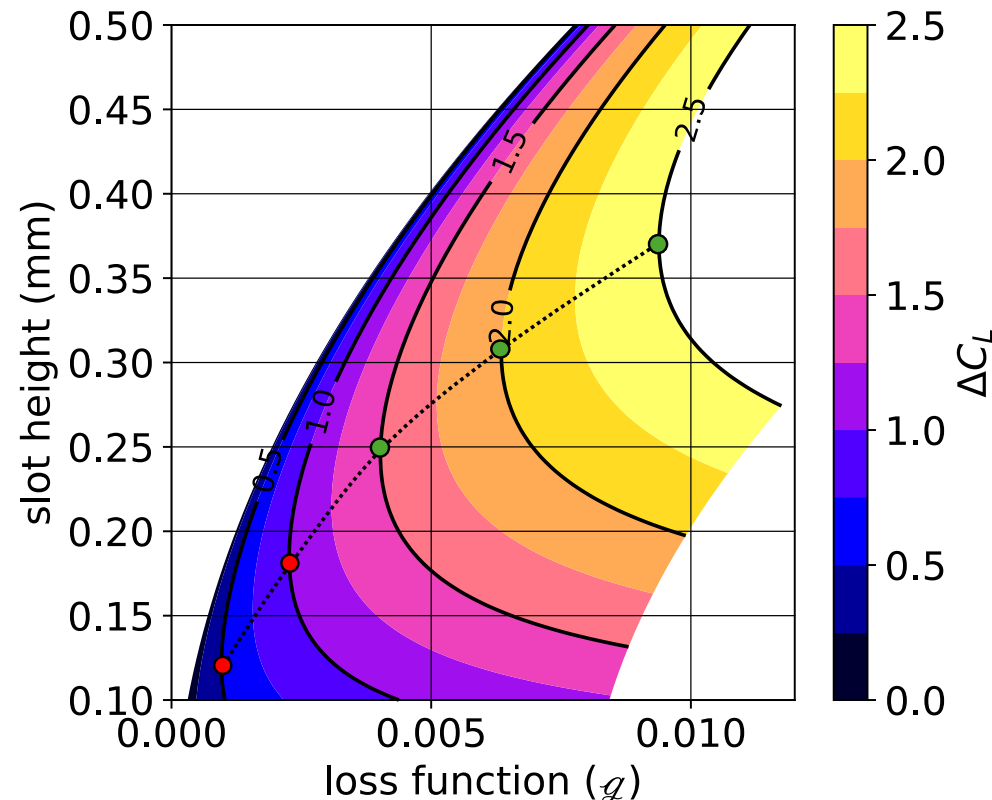
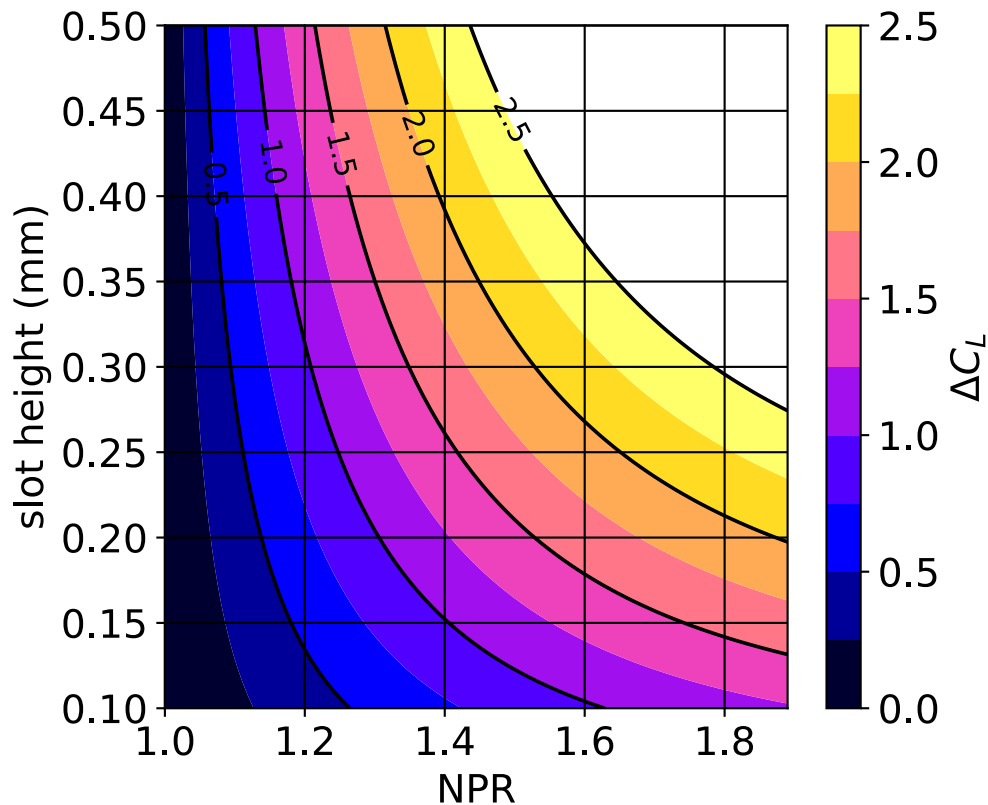
Variation in Coanda surface radii



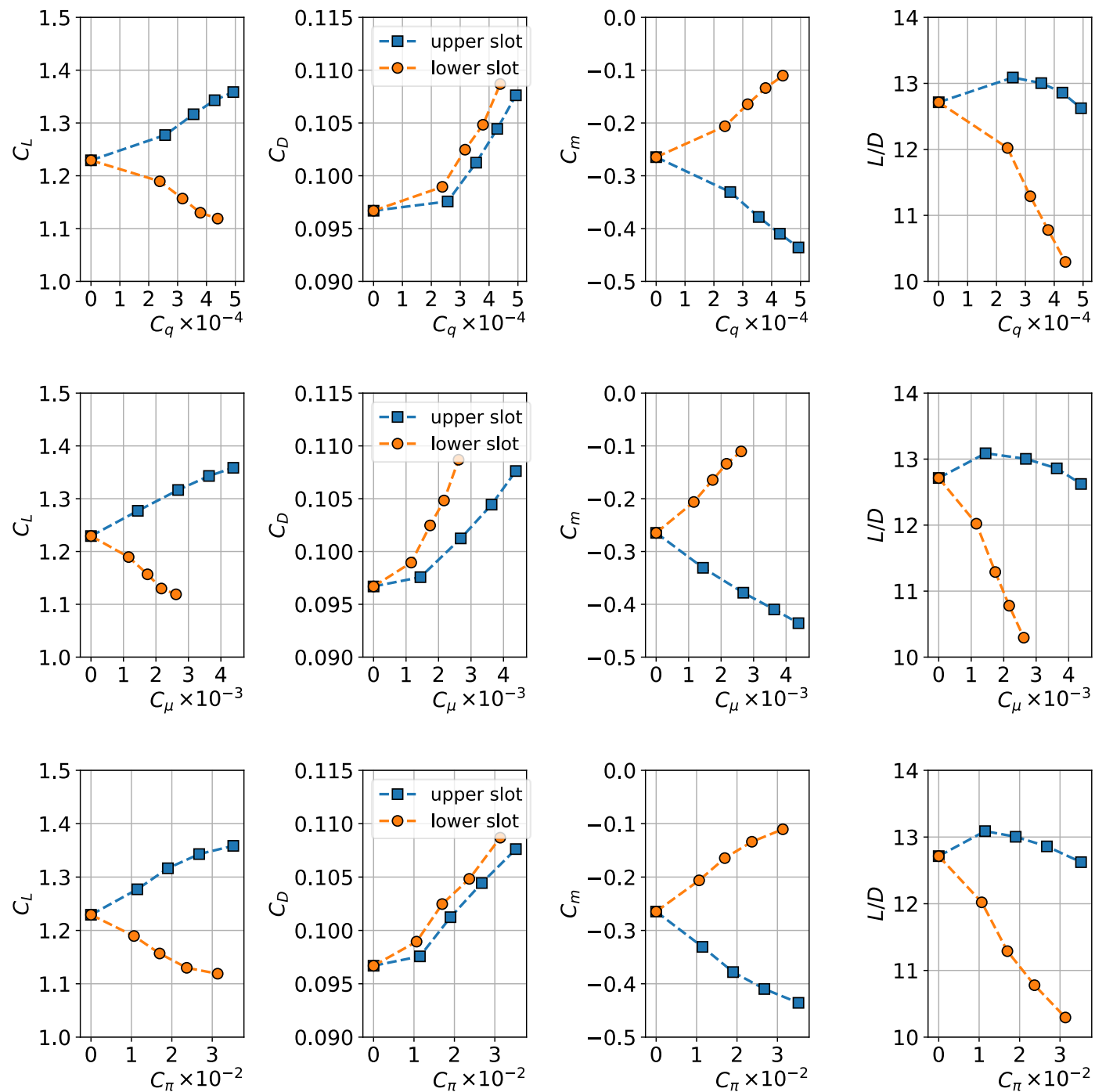
Coanda down selection procedure

- Assembled all tests into performance map of ΔC_L
- Applied cost function accounting for pressure, massflow, and momentum:

$$\mathcal{g}(\text{NPR}, h) = (0.1 * (\text{NPR} - 1))^2 + \left(\frac{h}{r}\right)^2 + \left(C_\mu(h, \text{NPR})\right)^2$$



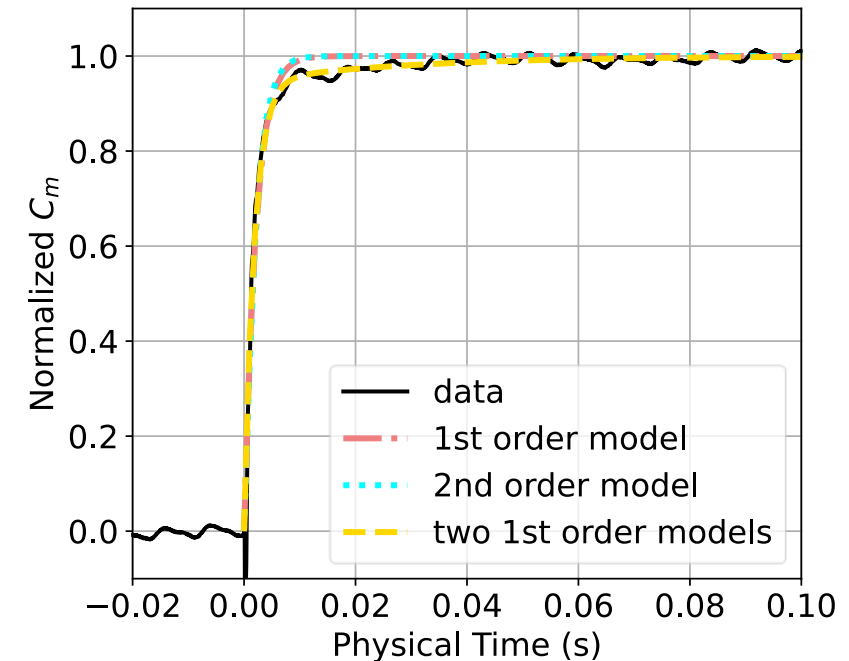
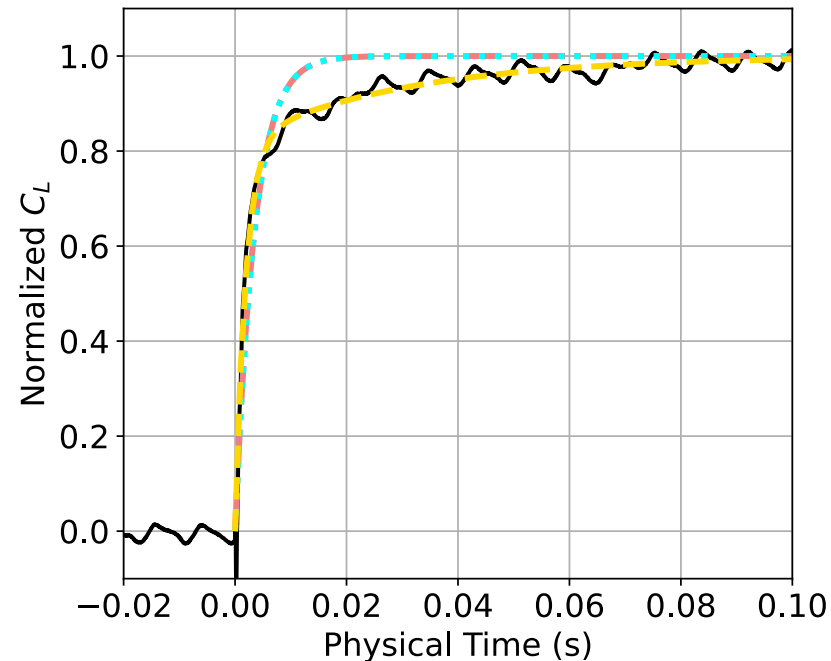
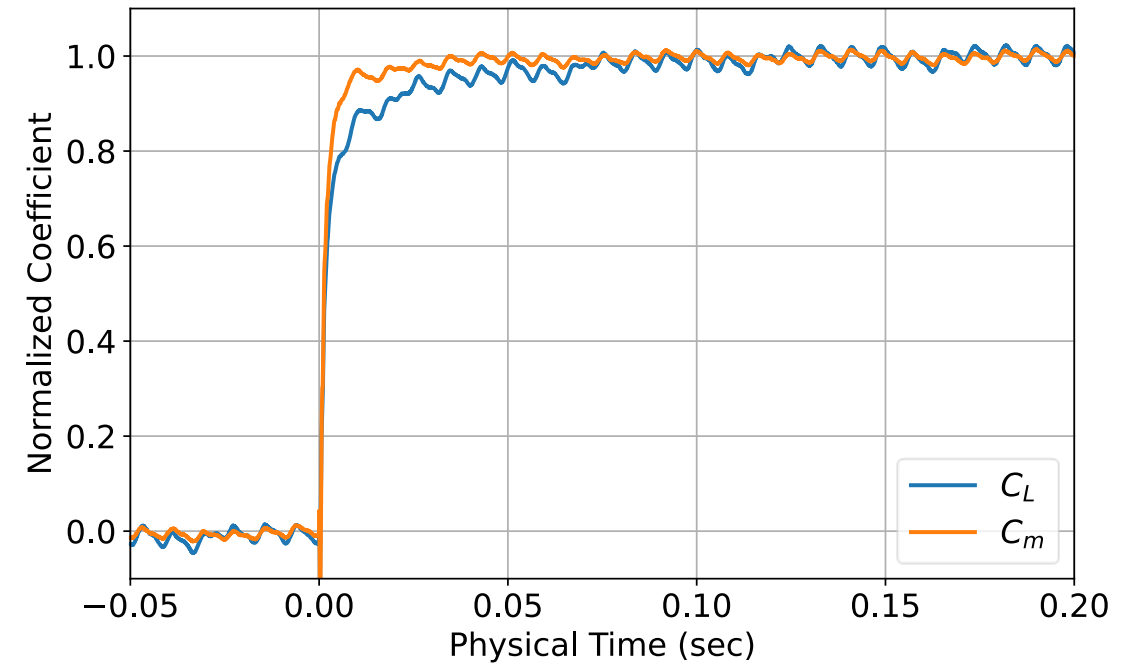
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Time response to actuation

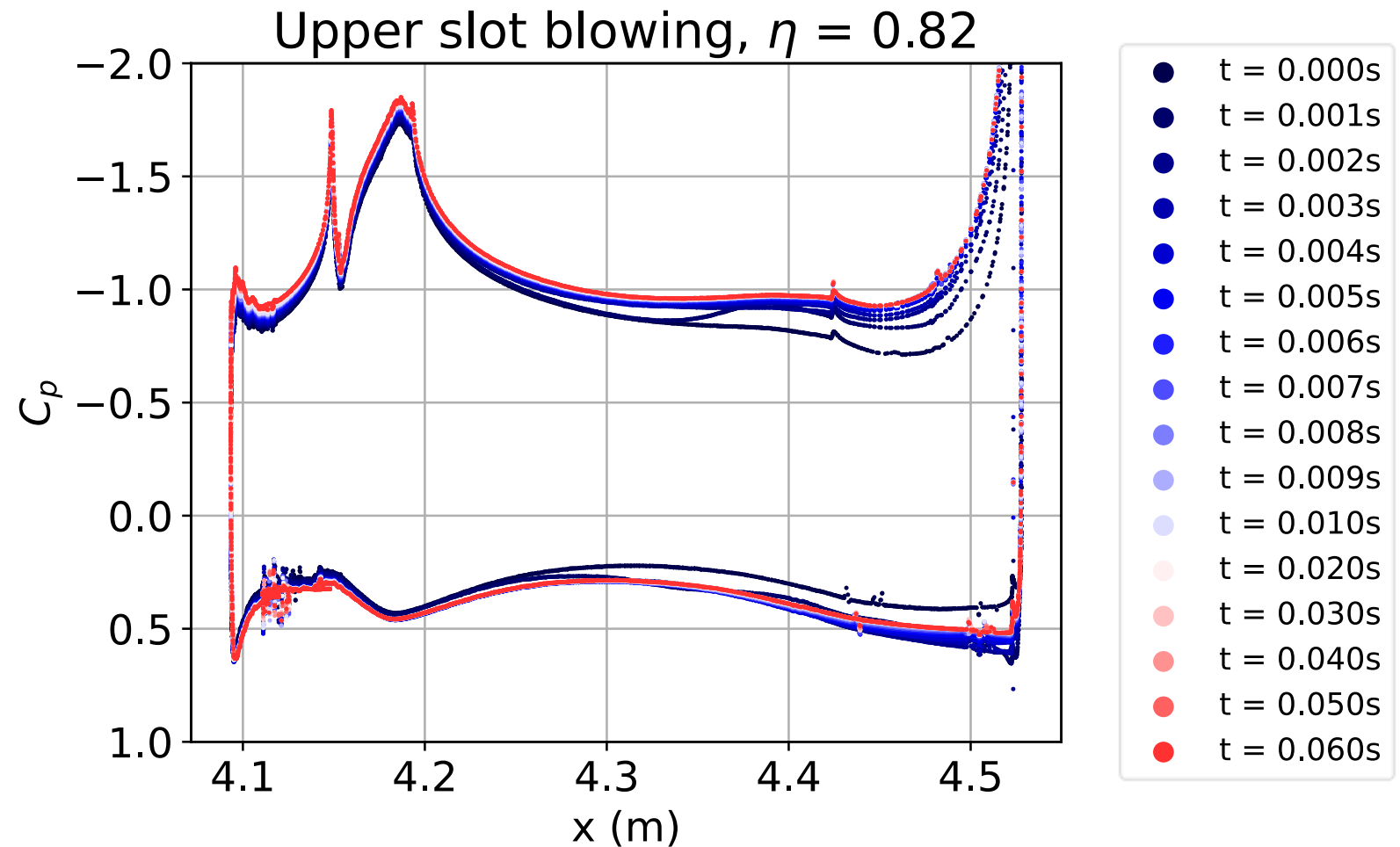
$$y(t) = 1 - \left[(1 - w) * e^{-\frac{t}{\tau_1}} + w * e^{-\frac{t}{\tau_2}} \right]$$

	C_L	C_m
τ_1	0.00118s	0.00183s
τ_2	0.0303s	0.0284s
w	0.181	0.0547



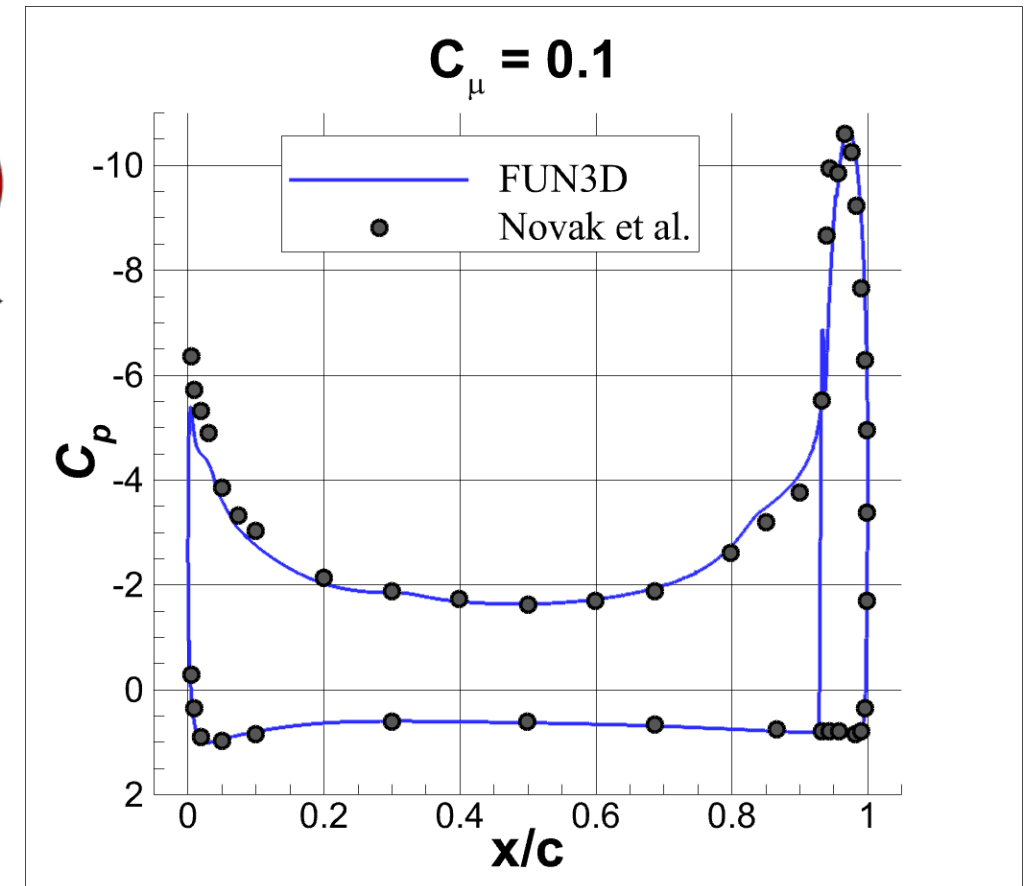
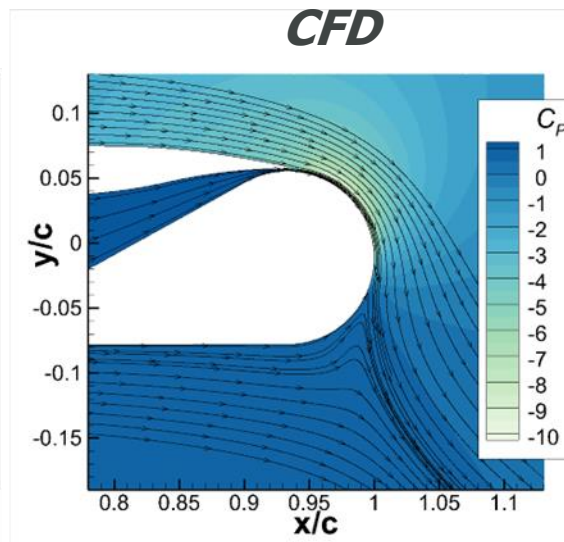
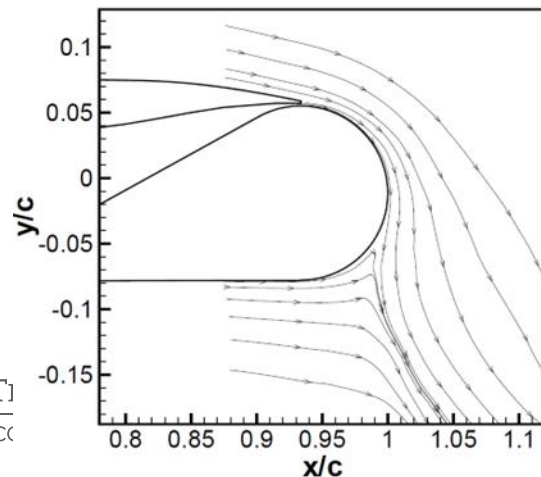
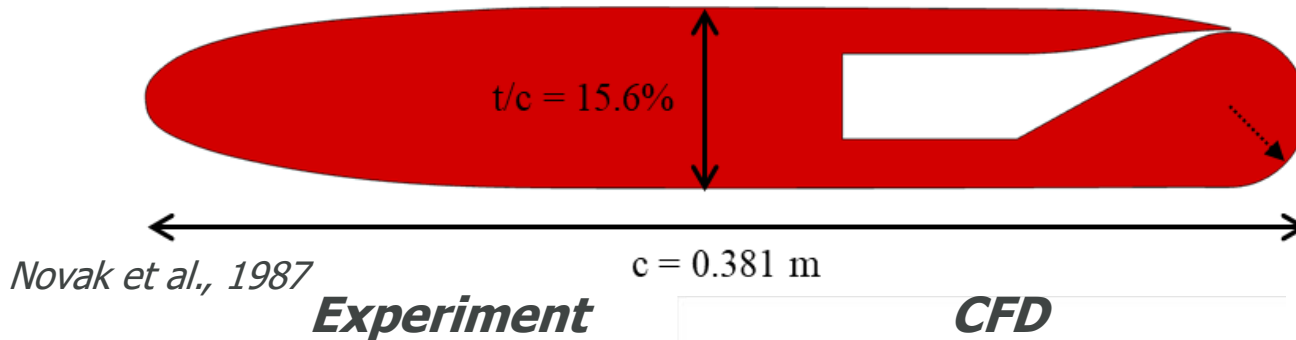
Time response to actuation

- Time response



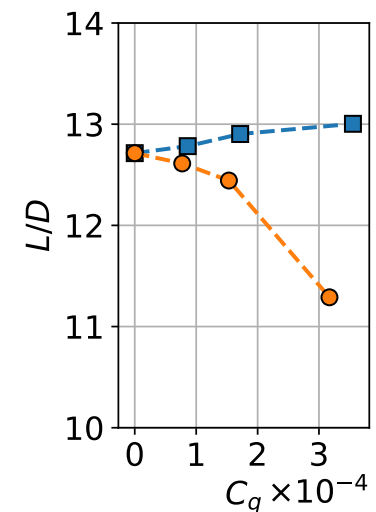
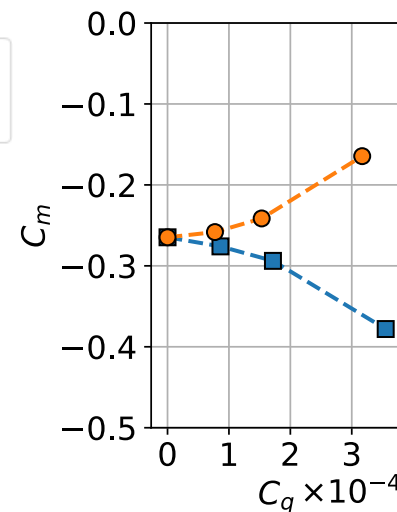
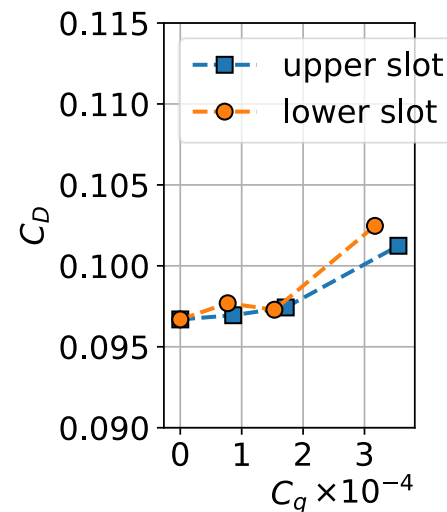
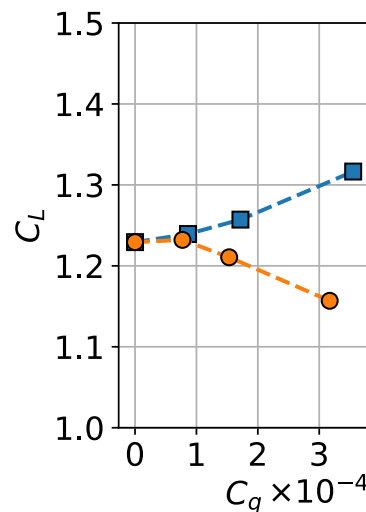
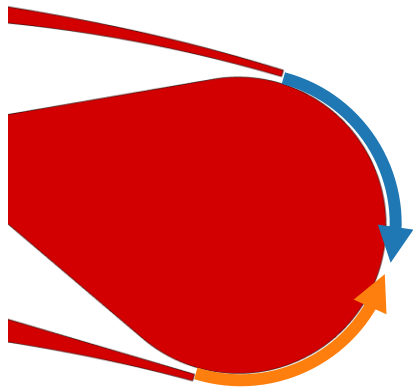
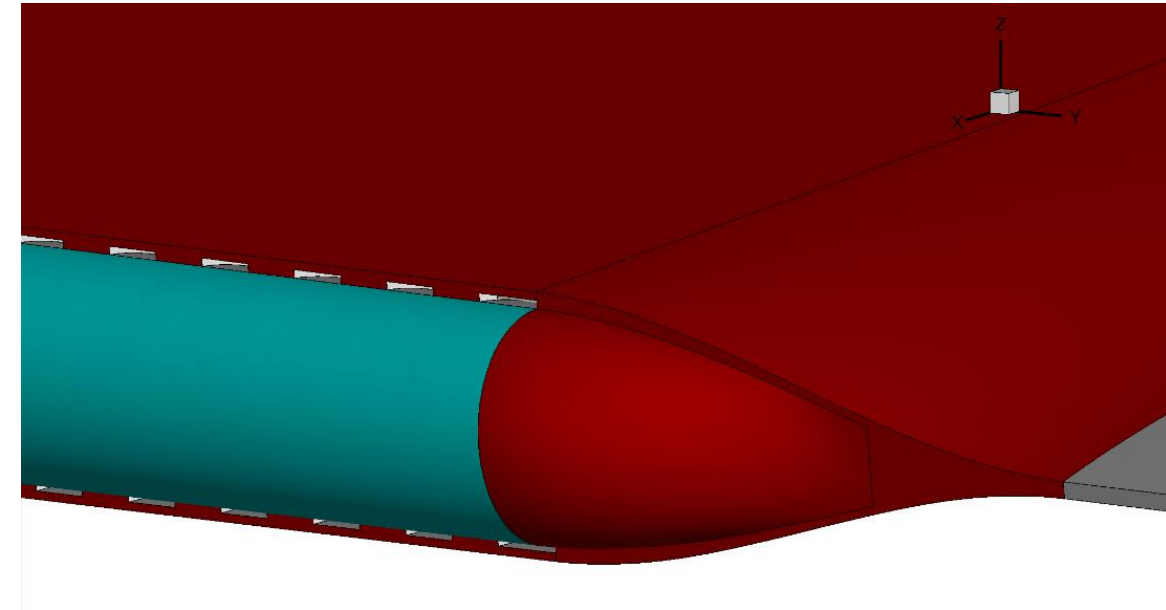
Circulation Control – CFD Validation

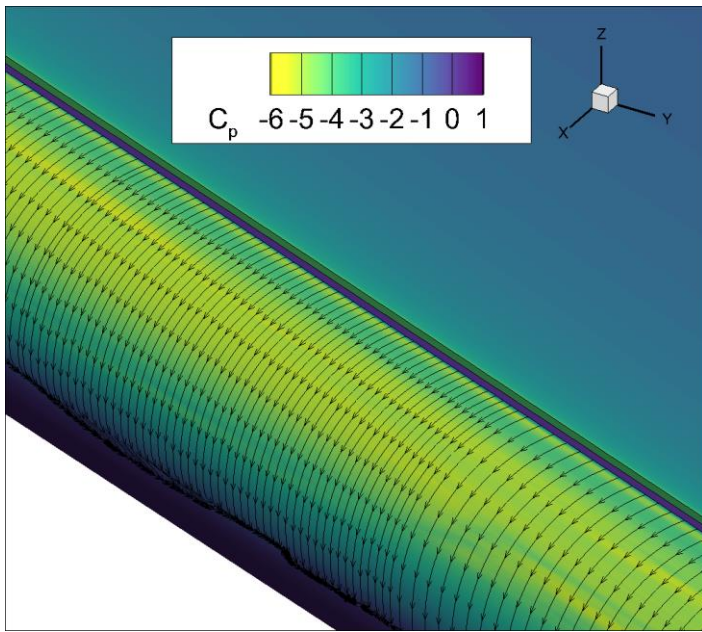
- Stagnation points on airfoil modified with trailing edge blowing and the Coanda effect:
 - Coanda effect: the tendency of a free jet to stay attached to a surface and entrain surrounding fluid
- Dubbed them “Circulation Control Actuators” or “Trailing-edge Coanda Actuators”



Reducing mass flow requirements

- Divide slot into discrete actuators
 - 25.4% of total slot area
 - 50.3% of total slot area
- Tested at NPR = 1.5
- Aero benefits substantially reduced





- Full slot stays attached to Coanda surface
 - Separates in spanwise uniform “sheet”
- Discrete actuators separate as stall cells
 - Edge effects are significant, 3-dimensionality produces losses

