

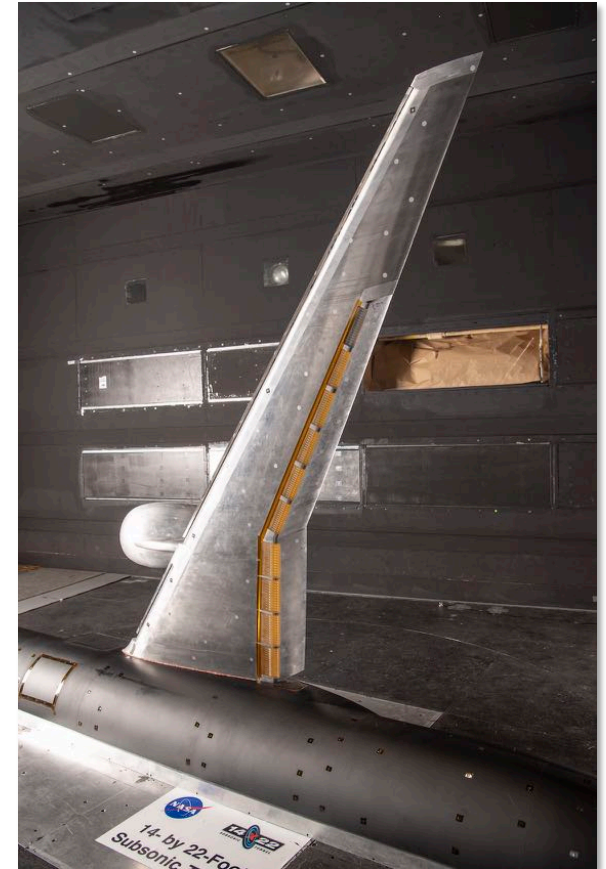
Active Flow Control on the High-Lift Common Research Model



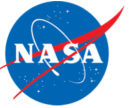
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NASA Langley Research Center

AVTech 2019
Advanced Aerodynamic Session
September 10-12, 2019



Outline



- Background/Motivation
- Approach
- Model Description
- CRM-HL vs CRM-SHL
- AFC Results
- Concluding Remarks

Motivation

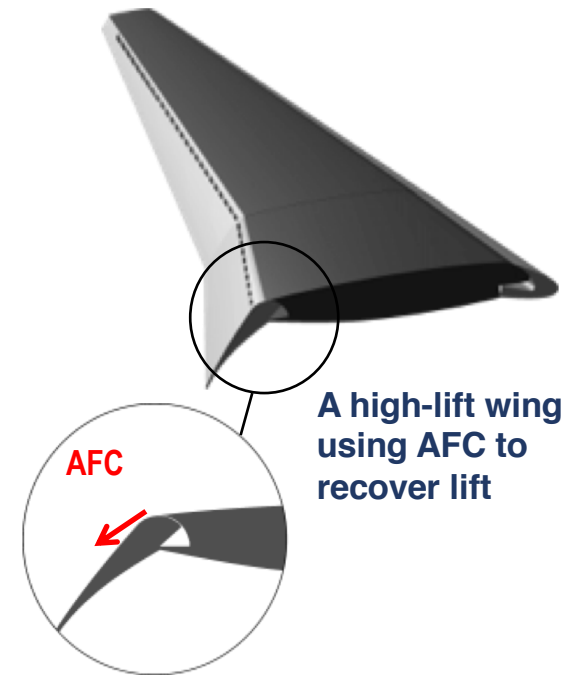


Conventional High-Lift



Fairings for flap mechanism increase cruise drag

AFC-enabled Simplified High-Lift



Hartwich et al. NASA/CR 2016-219170

3.3 count cruise drag reduction and 2.25% fuel savings motivate research

Approach

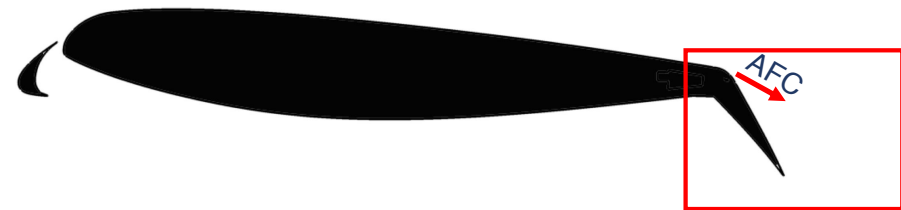


- Fabricate a relevant high-lift model that can be configured with either a single-element Fowler flap or an AFC-enabled simple-hinged flap.
- Integrate efficient AFC actuation systems capable of recovering the lift of the conventional high-lift system.
- Perform a wind tunnel test to compare the performance of the high-lift systems.

Single-element Fowler flap



AFC-enabled simple-hinged flap



High-Lift Version of Common Research Model (CRM-HL): Landing Configuration



Single-element Fowler Flap



10% scale model
Lacy and Scafani geometry
AIAA Paper 2016-0308



CRM-HL landing configuration: $\delta_{slat}=30^\circ$, Fowler $\delta_{flap}=37^\circ$

High-Lift Version of Common Research Model (CRM-HL): Landing Configurations

Single-element Fowler Flap



10% scale model
Lacy and Scafani geometry
AIAA Paper 2016-0308

Simplified high-lift version of the
CRM-HL (CRM-SHL-AFC)

Model tested in NASA Langley
14- by 22-Foot Subsonic Tunnel

AFC-enabled Simple-hinged Flap



CRM-HL landing configuration: $\delta_{slat}=30^\circ$, Fowler $\delta_{flap}=37^\circ$ & SHL $\delta_{flap}=50^\circ/55^\circ$

High-Lift Version of Common Research Model (CRM-HL)



- **Wind tunnel model scale:** 10%-Scale
- **Semispan:** 115.675 inches (9.64 feet)
- **Mean aerodynamic chord:** 27.58 inches
- **Aspect Ratio:** 9
- **Fuselage length:** 247.08 inches (20.59 feet)
- **Penicne:** 3.5 inches
- **Number of slat brackets:** 15
- **Number of flap brackets:** 1 internal and 3 external flap brackets

Nominal Landing Configuration

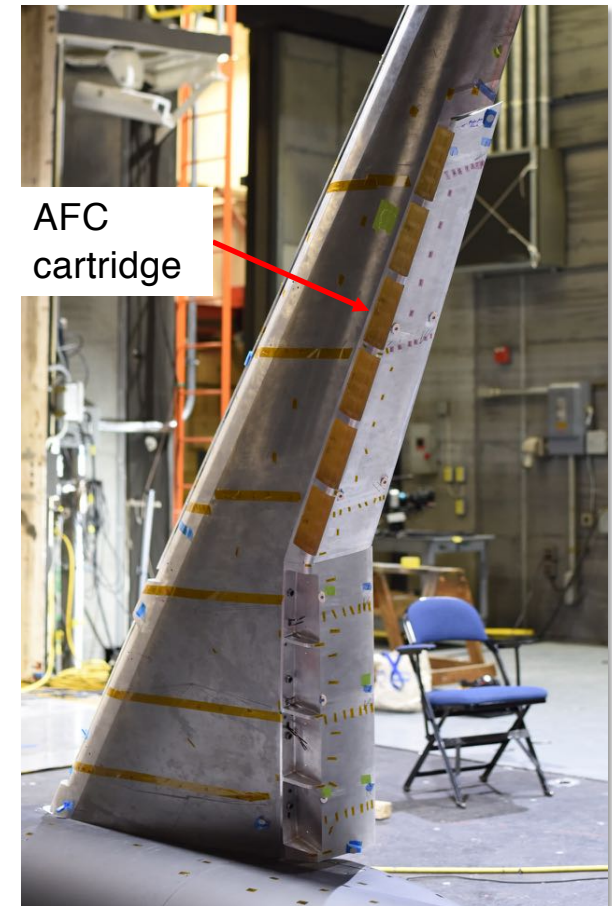


CRM-HL landing configuration: $\delta_{slat}=30^\circ$, $\delta_{flap}=37^\circ$

Simplified High-Lift Version of CRM-HL (CRM-SHL-AFC)



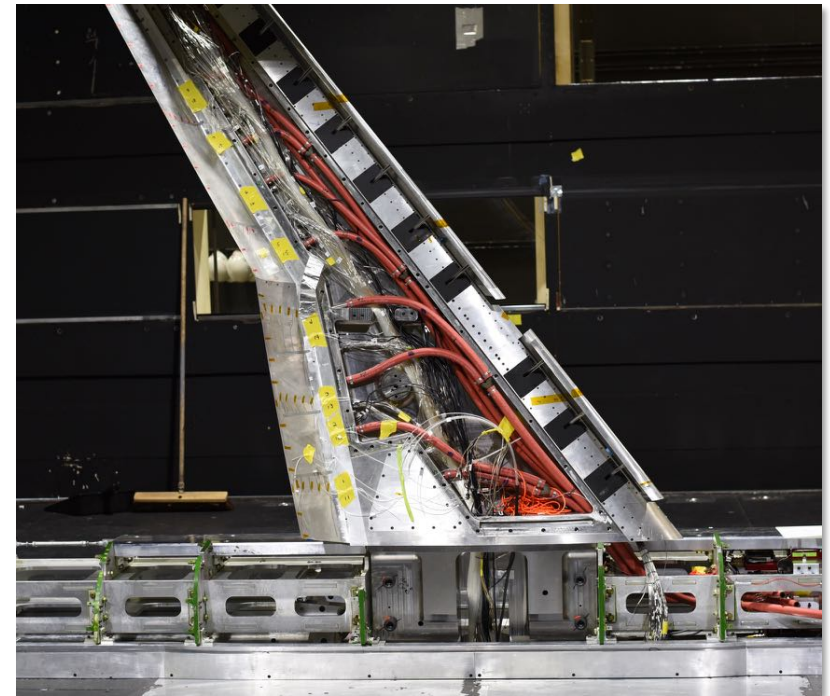
- $\delta_{\text{flap, inboard}}=50^\circ$, $\delta_{\text{flap, outboard}}=55^\circ$
- 10 AFC actuator cartridge locations
- Internal pneumatic supply lines
- 5 electronic valves
- 1 thermal mass flowmeter
- Pressure & temperature sensors in each cartridge
- Candidate actuators
 - Double Rows Sweeping Jets (DRSWJ)
 - Alternating Pulsed Jets (APJ)
 - High Efficiency Low Power (HELP)



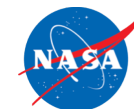
Simplified High-Lift Version of CRM-HL (CRM-SHL-AFC)



- 14- by 22-Foot Subsonic Tunnel capable of delivering air at 4000 psia and 30 lbm/sec
- Custom air delivery system used to supply CRM-SHL-AFC
- Input air supply lines and manifold rated for 200 psia
- Each valve controlled 2 actuator cartridges
- Manifold with valves located in model fuselage
- **Nozzle Pressure Ratio (NPR) range: 1 to 3**
- **Maximum mass flow rate: $\cong 1.0$ lbm/sec**



Sweeping Jet (SWJ) Actuator Cartridge Example

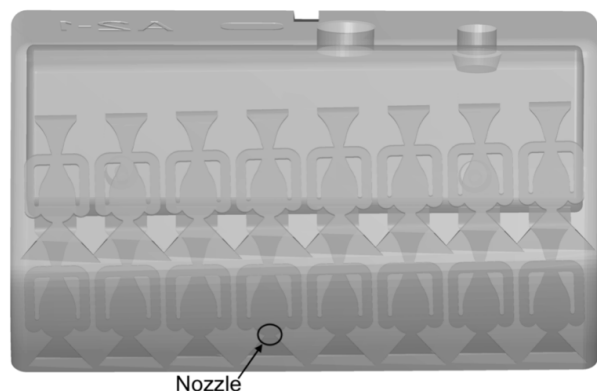


DRSWJ Cartridge 1

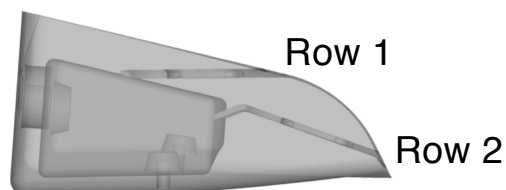
Melton et al. (<https://doi.org/10.2514/6.2019-3726>)

Oscillating jet, no moving parts

Top view



Cartridge 1
Side view



Actuator location	Nozzle Width (inches)	Nozzle Height (inches)	Nozzle spacing (inches)	Actuators /cartridge
Inboard	0.120	0.060	0.9	8/row
Outboard	0.080	0.050	0.75	10/row

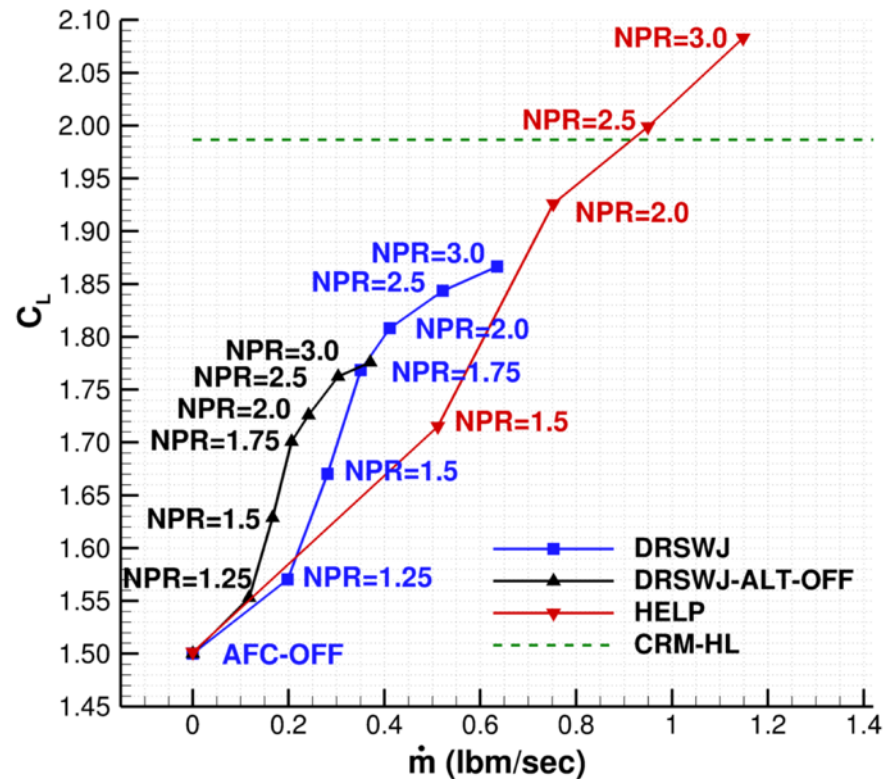
SWJ candidate actuator because of success on other configurations

CRM-SHL-AFC Pre-test CFD Lift Predictions



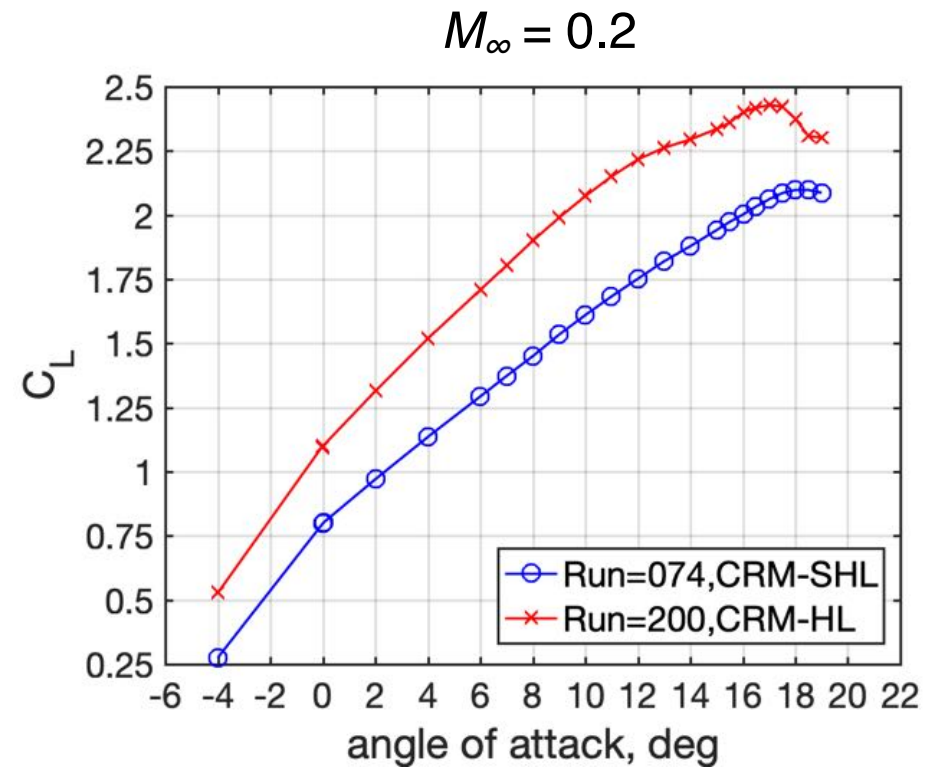
Vasta et al. (<https://doi.org/10.2514/6.2019-3724>)

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



Pre-test simulations HELP actuators meet target, DRSWJ actuators increase lift

Comparison of CRM-HL and CRM-SHL (AFC off)



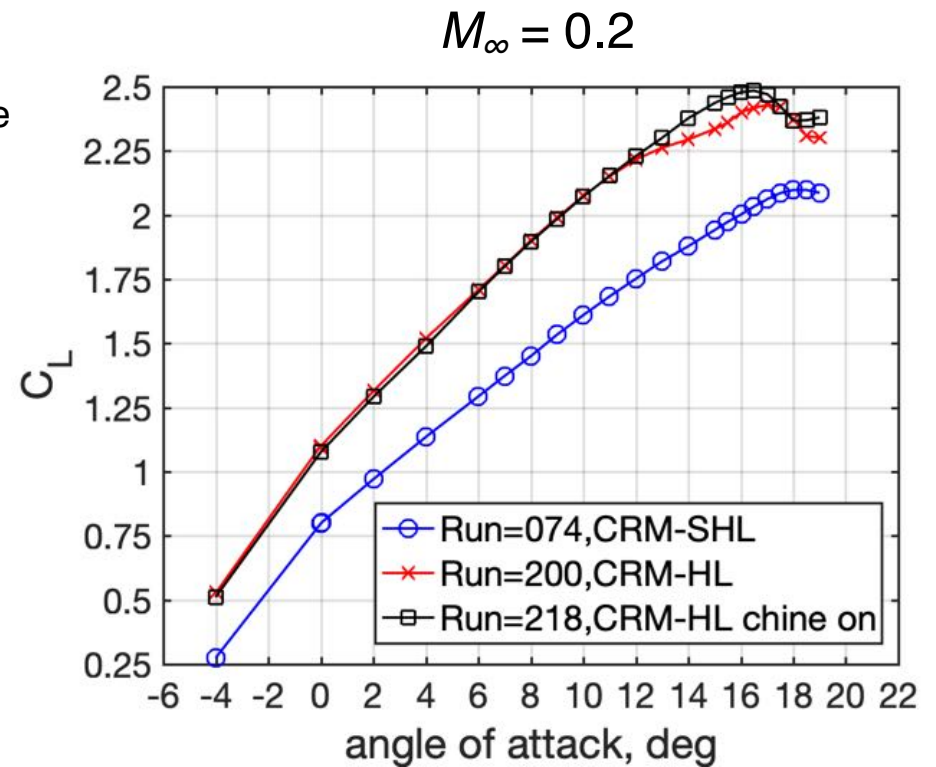
Comparison of CRM-HL and CRM-SHL (AFC off)



Lift degradation corrected with installation of nacelle chine



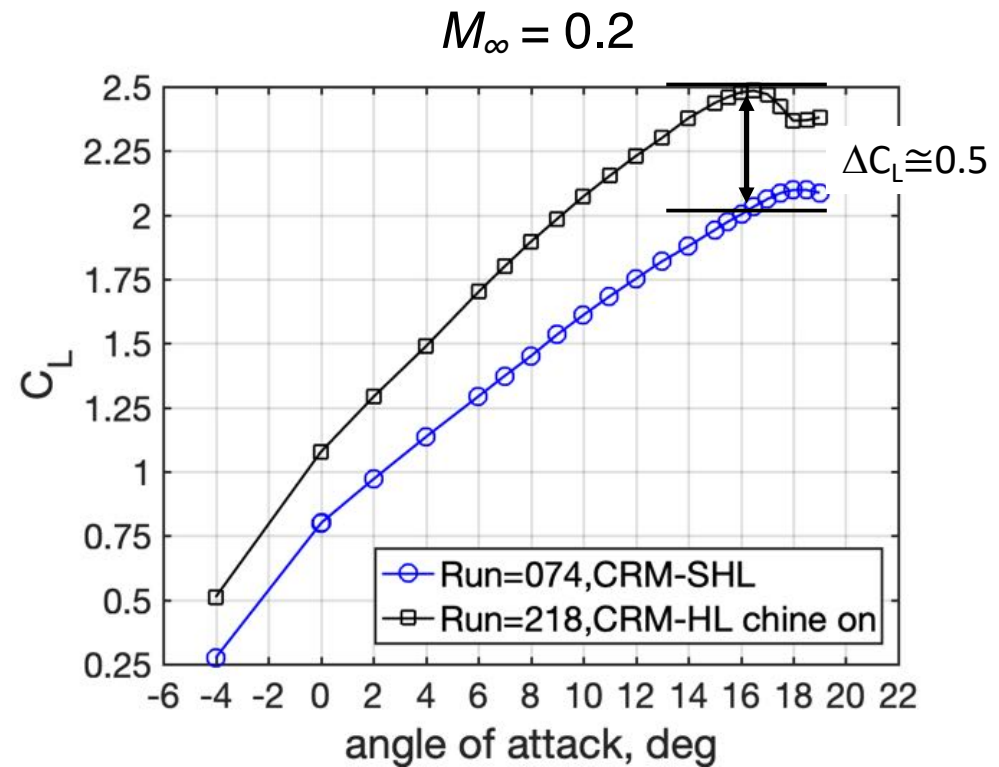
Koklu et al. (<https://doi.org/10.2514/6.2019-3727>)



Comparison of CRM-HL and CRM-SHL (AFC off)



CRM-HL with nacelle chine is reference configuration



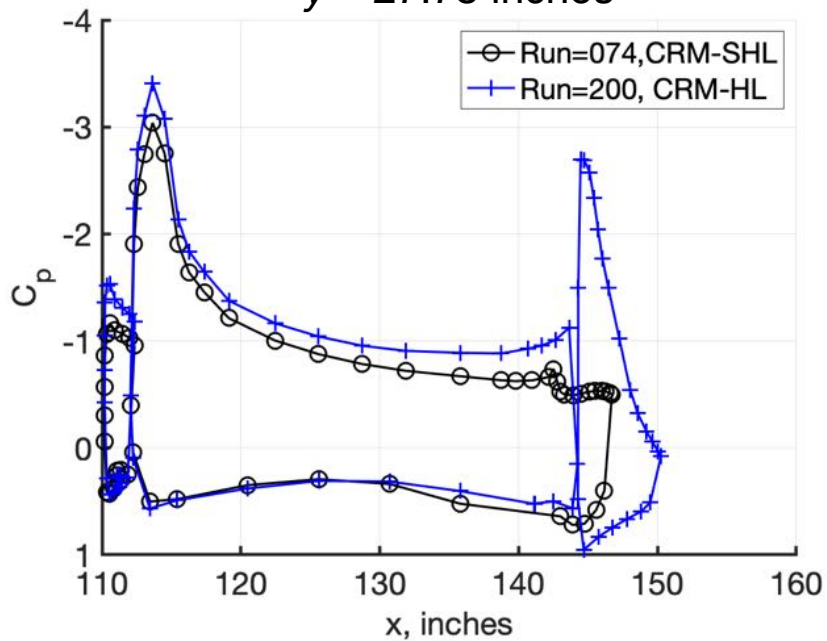
Comparison of CRM-HL with nacelle chine to CRM-SHL provides C_L target

Comparison of CRM-HL and CRM-SHL (AFC off) C_p Distributions

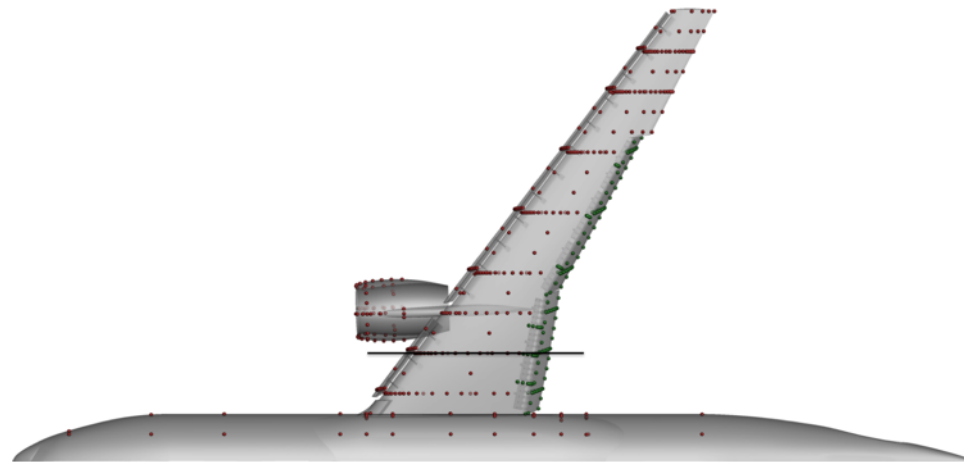


$M_\infty = 0.2$, $\alpha = 8^\circ$

$y = 27.75$ inches



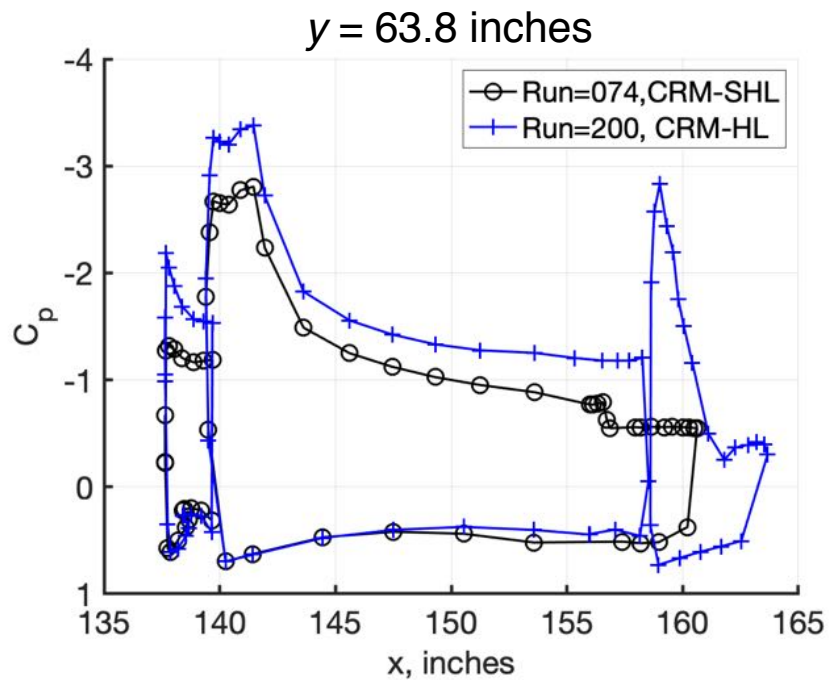
Midspan inboard flap



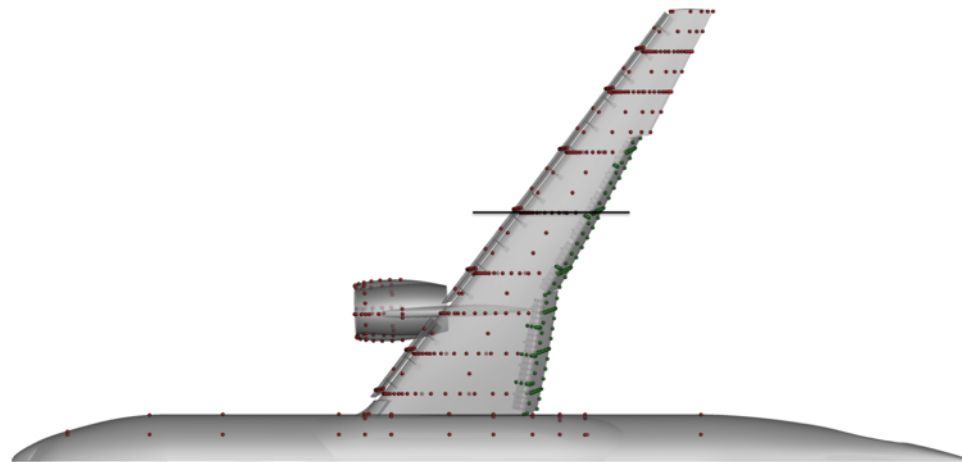
Comparison of CRM-HL and CRM-SHL (AFC off) C_p Distributions



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



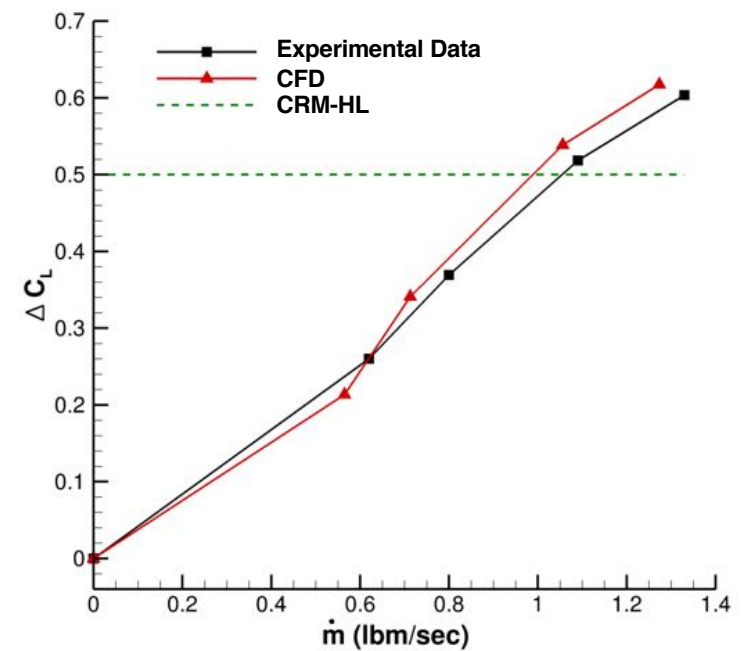
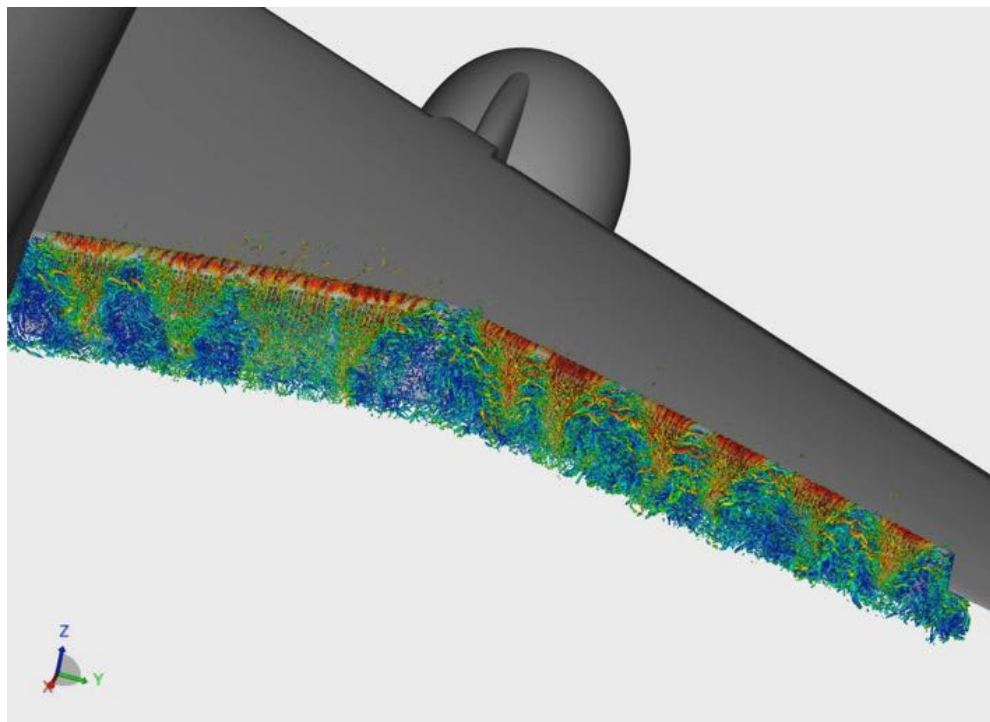
Midspan outboard flap



AFC Results



Results of CFD simulations on CRM-SHL-AFC with HELP actuators

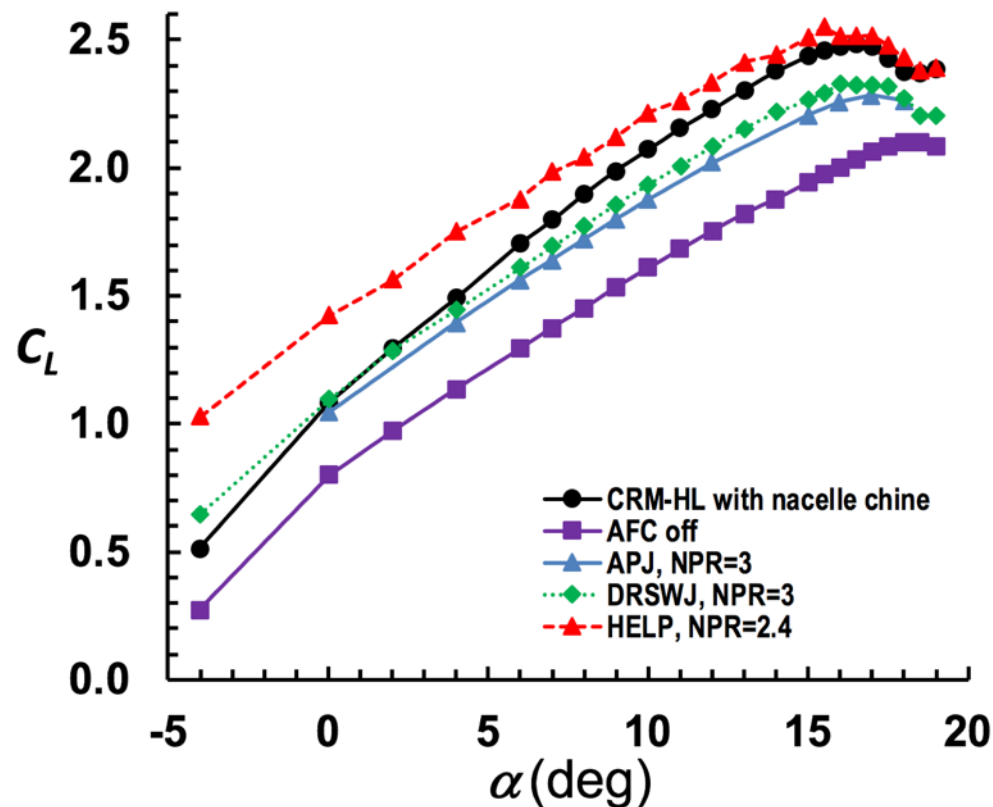


Vatsa et al. (<https://doi.org/10.2514/6.2019-3724>)

CRM-SHL-AFC Lift Performance Summary



Lin et al. (<https://doi.org/10.2514/6.2019-3723>)

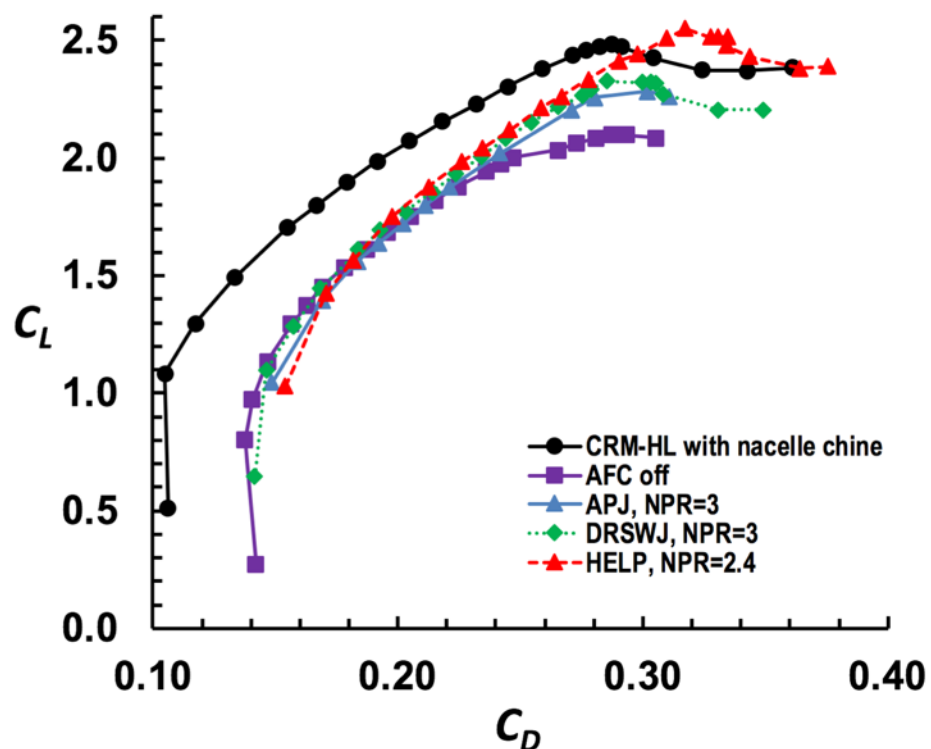


Uncertainty in C_L is within ± 0.01
(based on balance accuracy, α and q_∞)

All data presented herein are
without wall corrections

CRM-SHL with HELP actuation exceeds lift of CRM-HL

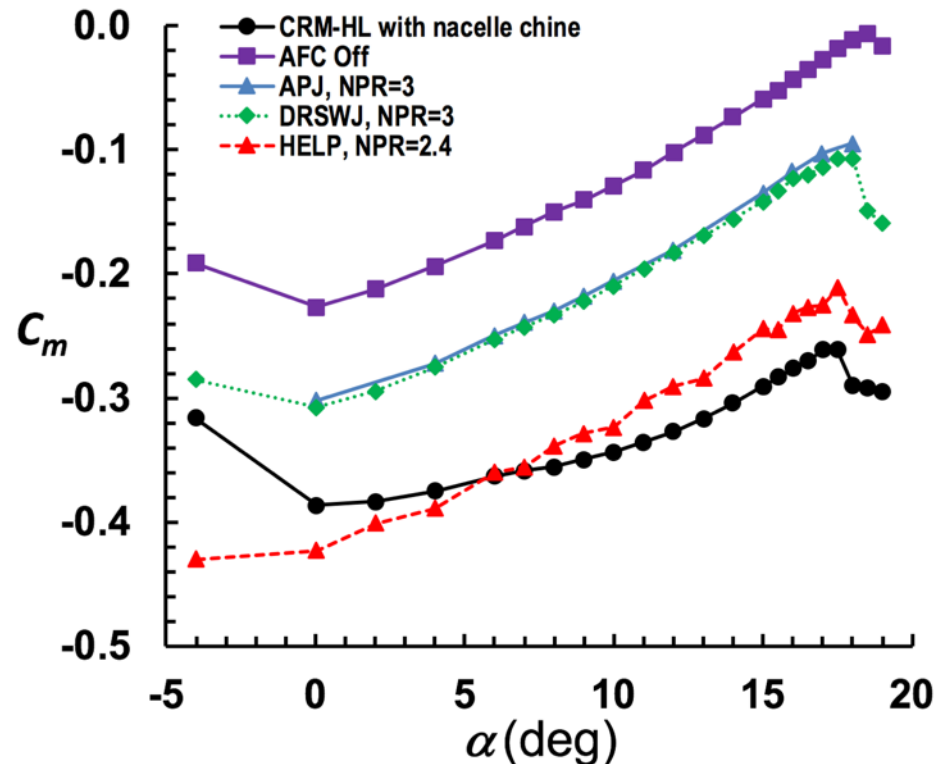
Drag Polar Comparison between CRM-SHL-AFC and CRM-HL ($M_\infty = 0.2$)



Uncertainty in C_D is ± 0.0030 to ± 0.0040 (based on balance accuracy, α and q_∞).

- Higher flap deflection ($50^\circ/55^\circ$) of CRM-SHL-AFC produced higher drag than CRM-HL (37° deflection).
- HELP actuation produced the highest induced drag (drag due to lift) at higher α .

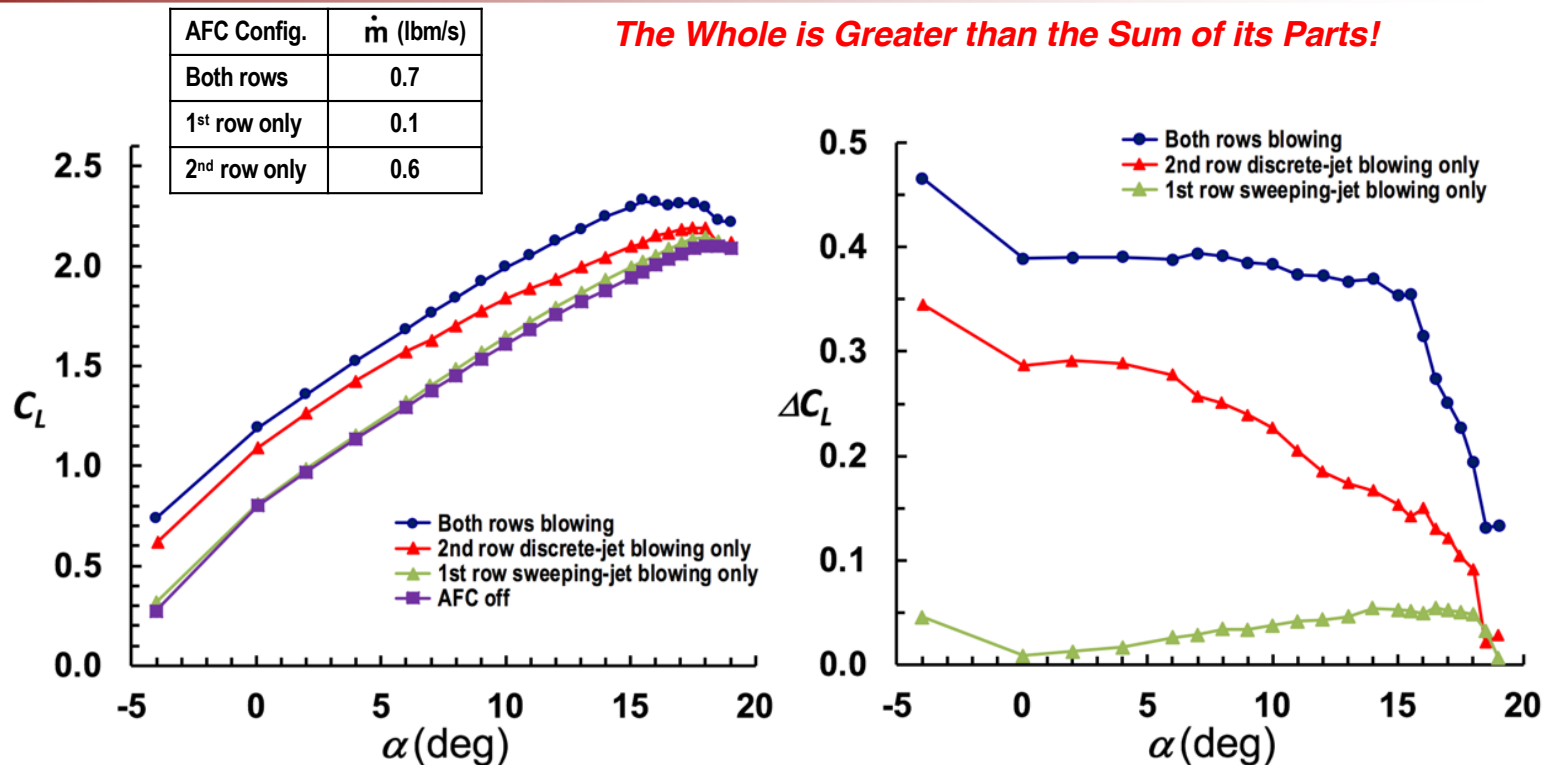
Pitching Moment Comparison between CRM-SHL-AFC and CRM-HL ($M_\infty = 0.2$)



Uncertainty in C_m is
 ± 0.0030 to ± 0.0035
(based on balance
accuracy, α and q_∞)

- Nose-down pitching (negative C_m) for all cases examined is consistent with typical high-lift wings.
- CRM-SHL-AFC without AFC has the least nose-down pitching moment, while CRM-HL at higher α has the most.
- HELP actuation produced about the same level of C_m as the conventional Fowler flap.

Synergetic Benefit of HELP Actuation between 1st and 2nd Rows (NPR = 1.5, $M_\infty = 0.2$)



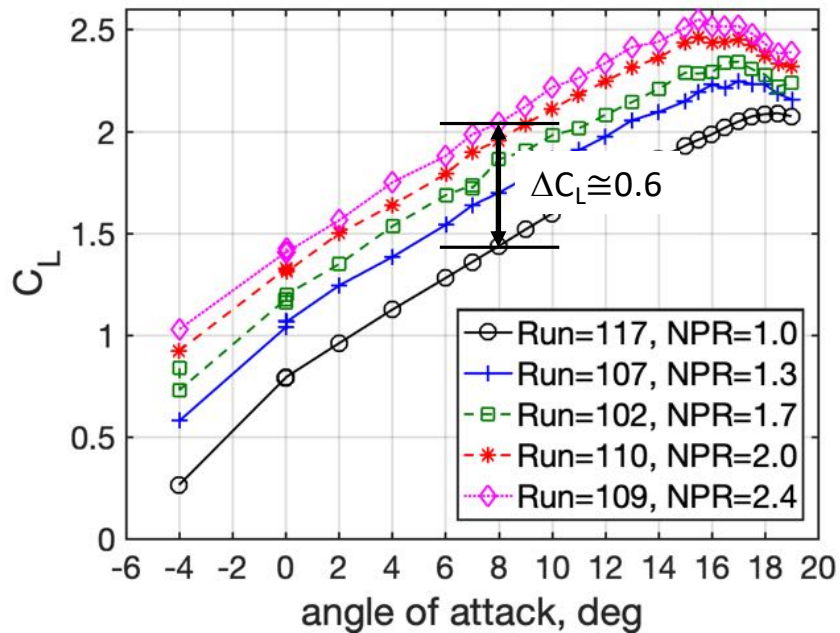
- Synergetic benefit of allowing the two rows actuating together to produce a lift that is greater than the sum of each row actuating individually is clearly illustrated — also confirmed by mass flow data.
- Synergy more pronounced at higher α where the adverse pressure gradient is stronger.
- Row 1 sweeping jets provided a “Coanda effect boost” to the Row 2 discrete jets.

Effect of NPR on C_L

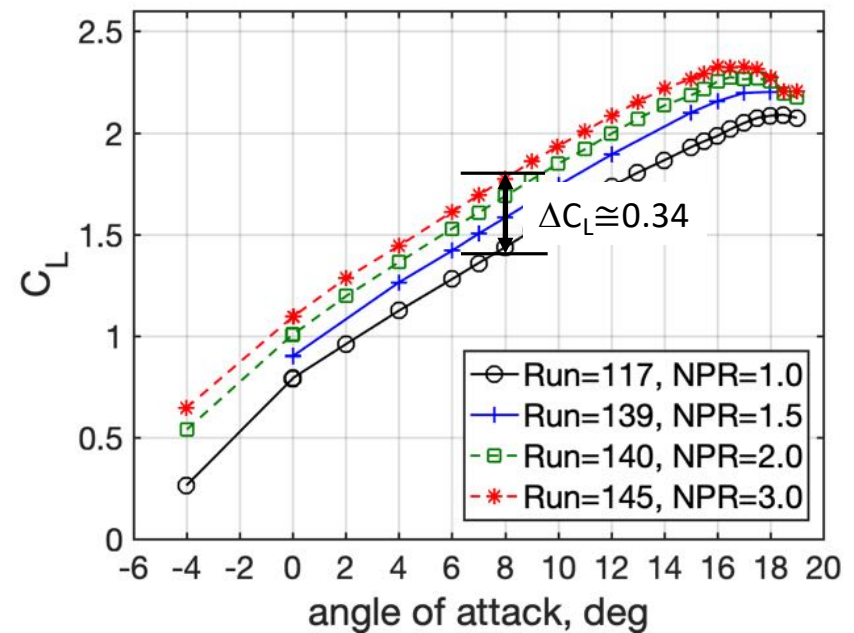


$M_\infty = 0.2$

HELP Actuators



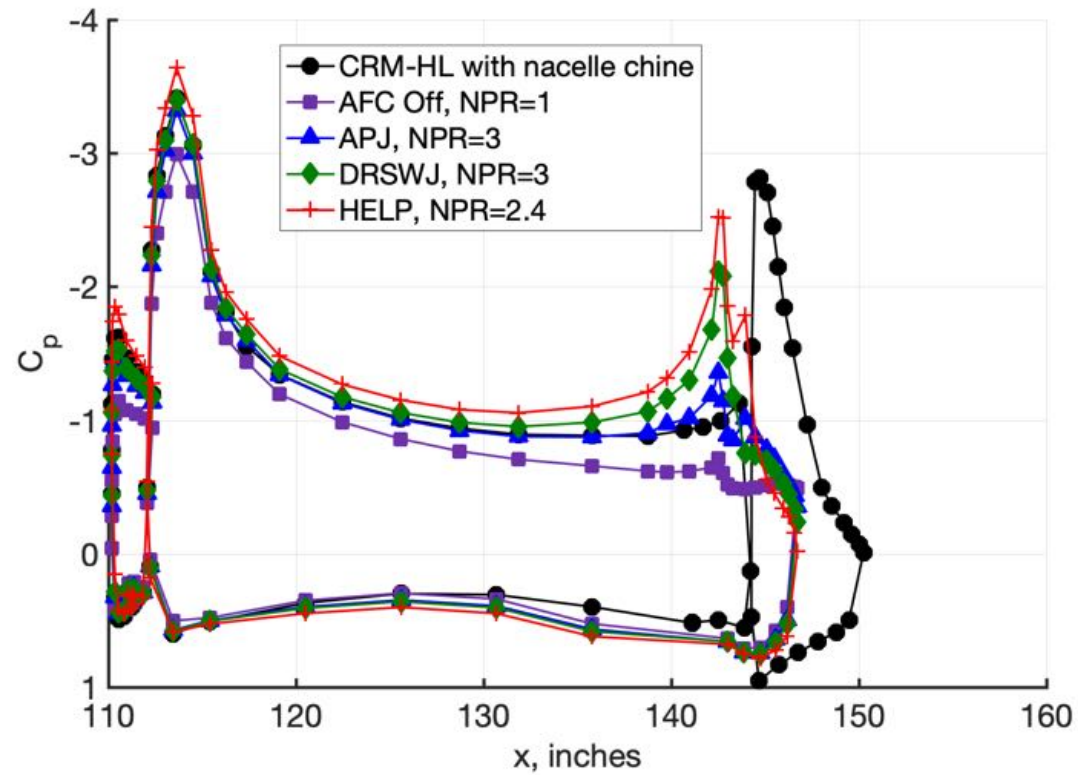
DRSWJ Actuators



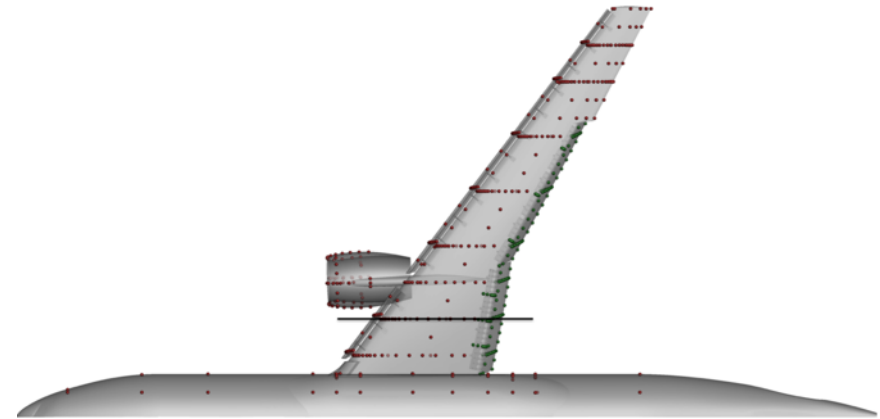
C_L increases as NPR increases over α range

Comparison of CRM-HL and CRM-SHL-AFC C_p Distributions

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

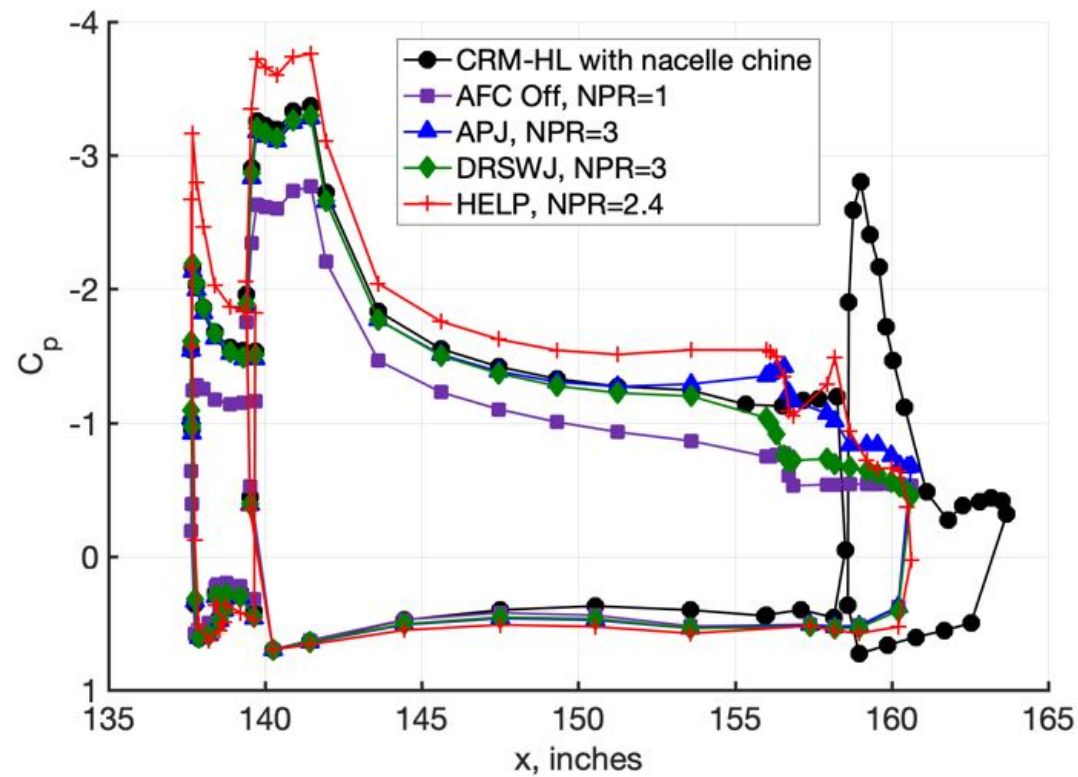


$y = 27.75$ inches

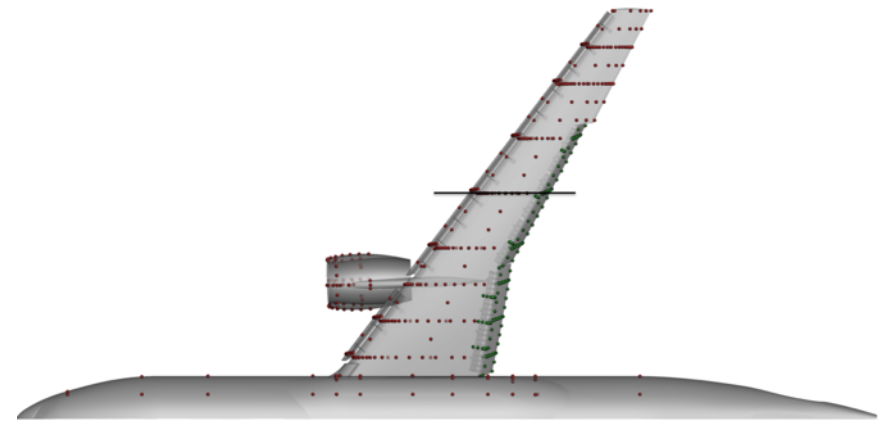


Comparison of CRM-HL and CRM-SHL-AFC C_p Distributions

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

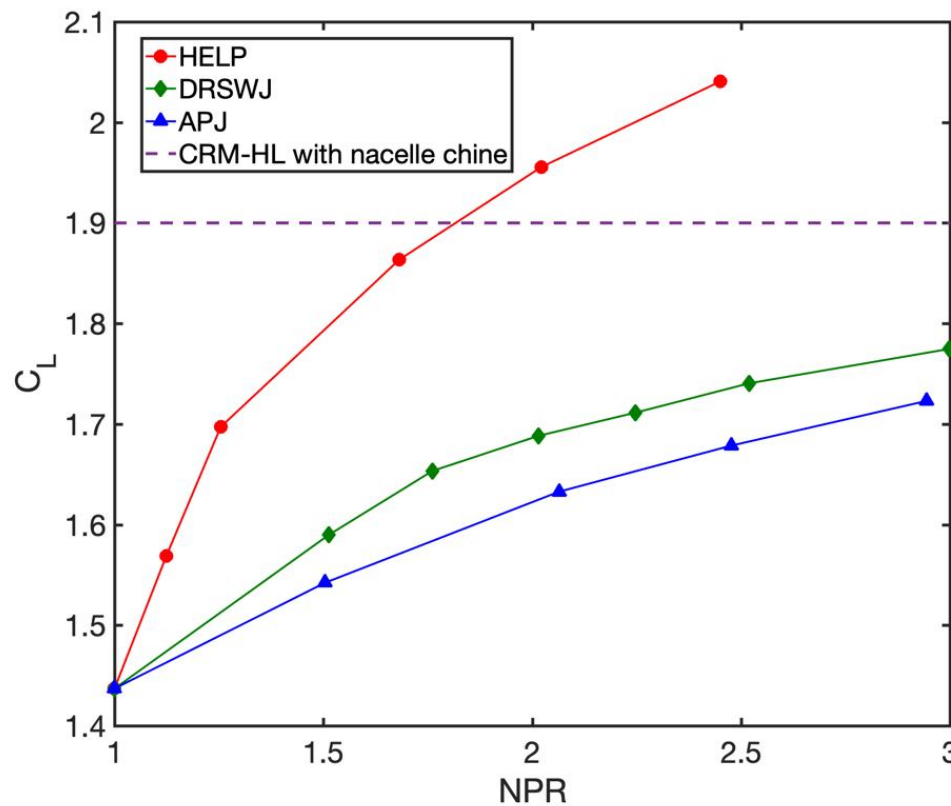


y = 63.8 inches



C_L versus NPR Comparison between AFC Actuators

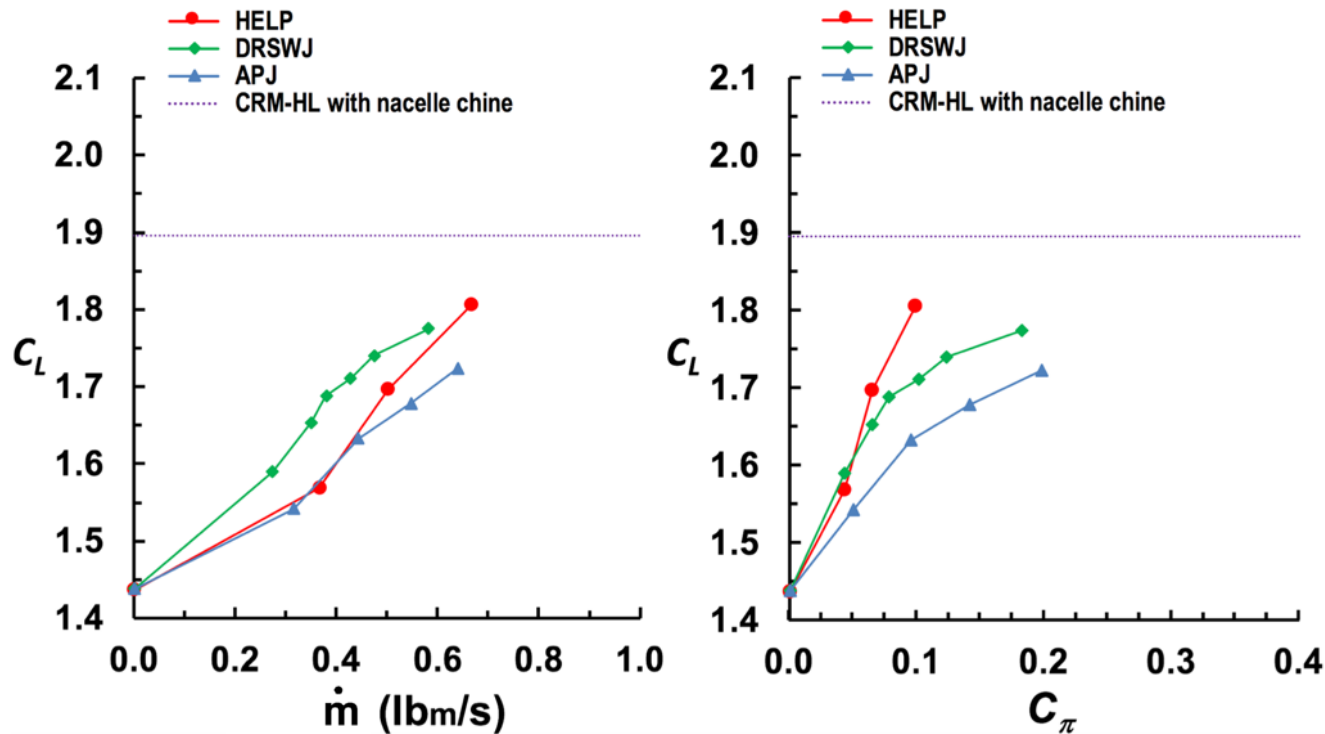
$$\alpha = 8^\circ, M_\infty = 0.2$$



Nozzle Pressure Ratio
 $\text{NPR} = P_{\text{cavity}}/P_\infty$

- HELP actuators are most efficient and effective in lift enhancement based on NPR
- $\text{NPR} \geq \sim 1.8$ at $\alpha = 8^\circ$ needed to reach the C_L goal.

C_L versus $\dot{m}$ and C_π Comparison between AFC Actuators $(\alpha = 8^\circ, M_\infty = 0.2)$



- Power coefficient, $C_\pi = (\dot{m} \cdot P_a) / (\rho_\infty \cdot S \cdot U_\infty \cdot q_\infty)$, is a more inclusive parameter.
- DRSWJ actuators are more efficient based on mass flow rate.
- HELP actuators are more efficient based on C_π .
- $\dot{m} \approx 0.8$ lbm/s ($C_Q = 0.0023$, $C_\mu = 0.02$) and $C_\pi \geq \sim 0.15$ are needed to reach C_L goals at $\alpha = 8^\circ$. 26

Summary



- Synergistic benefit of High Efficiency Low Power (HELP) actuation used on AFC-enabled simple-hinged flap and exceeded performance of CRM-HL in nominal landing configuration.
- The Double Rows Sweeping Jets (DRSWJ) actuators and the Alternating Pulsed Jets (APJ) actuators were also effective at increasing lift.
- The AFC-induced lift increment maintained for the entire lift curve for all actuation concepts studied.
- CFD simulations guided actuator selection and contributed to the success of the wind tunnel test campaign.

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 - **CRM-HL consultation:** *Doug Lacy* of Boeing Commercial Airplanes.

Presentation References



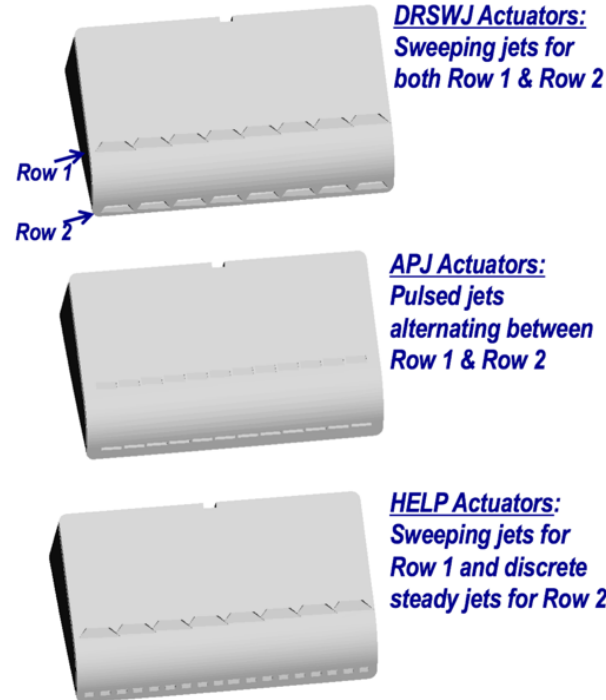
AIAA Paper 2019-3723 (<https://doi.org/10.2514/6.2019-3723>),
“Wind Tunnel Testing of Active Flow Control on the High-Lift Common Research Model,”
by Lin et al.

AIAA Paper 2019-3724 (<https://doi.org/10.2514/6.2019-3724>),
“Comparative Study of Active Flow Control Strategies for Lift Enhancement of a Simplified High-Lift CRM
Configuration,”
by Vatsa et al.

AIAA Paper 2019-3726 (<https://doi.org/10.2514/6.2019-3726>),
“Sweeping Jet Flow Control on the Simplified High-Lift Version of the Common Research Model,”
by Melton, et al.

AIAA Paper 2019-3727 (<https://doi.org/10.2514/6.2019-3727>),
“Surface Flow Visualization of the High-Lift Common Research Model,”
by Koklu, et al.

CRM-SHL-AFC with Interchangeable AFC Cartridges



Investigate 3 types of actuators to overcome strong adverse pressure gradient

- **Double-Rows Sweeping Jets (DRSWJ) actuators**
- **Alternating Pulsed Jets (APJ) actuators**
- **High Efficiency Low Power (HELP) actuators**