Testing of High-Lift Common Research Model at Takeoff Configurations

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Background & Motivation

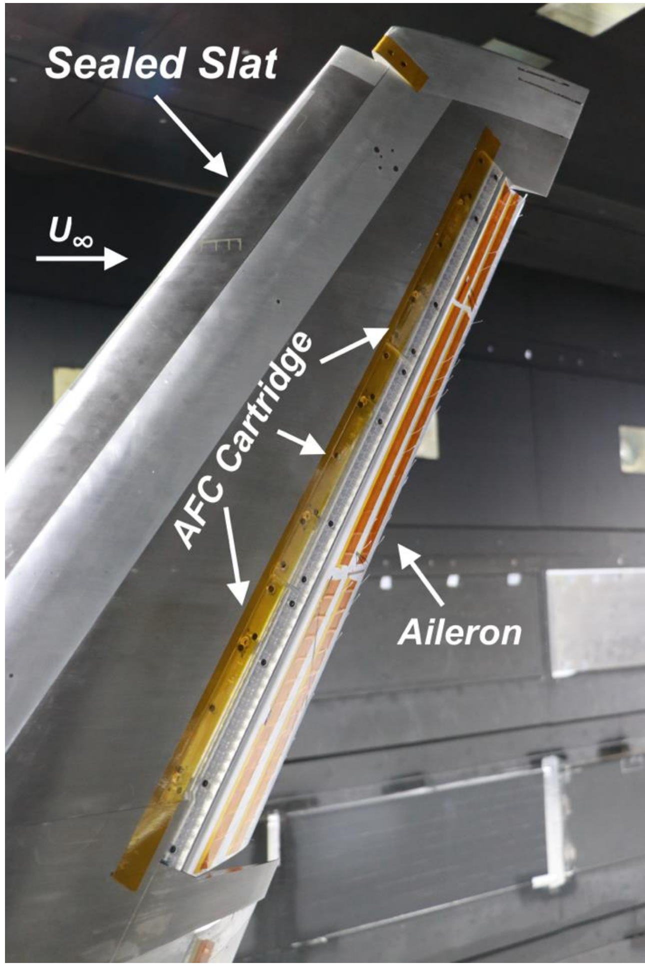
- The NASA AATT Project develops technologies for improved energy efficiency.
- 10% scale CRM-HL model was built/tested in 2018 to improve high-lift performance.
  - Replace Fowler flap mechanism with AFC-SHL systems to reduce cruise drag.
  - The CRM-HL model has been used in the CRM-HL ecosystem for CFD code validation.
- The test campaign was successful, but the required modifications were significant.
- A more practical approach could be the application of AFC concepts locally.
- Previous studies indicated 5% performance improvement with the localized AFC on the aileron.

Objective

- A wind tunnel test campaign was conducted to assess the performance improvement of localized AFC on the aileron of the CRM-HL model.

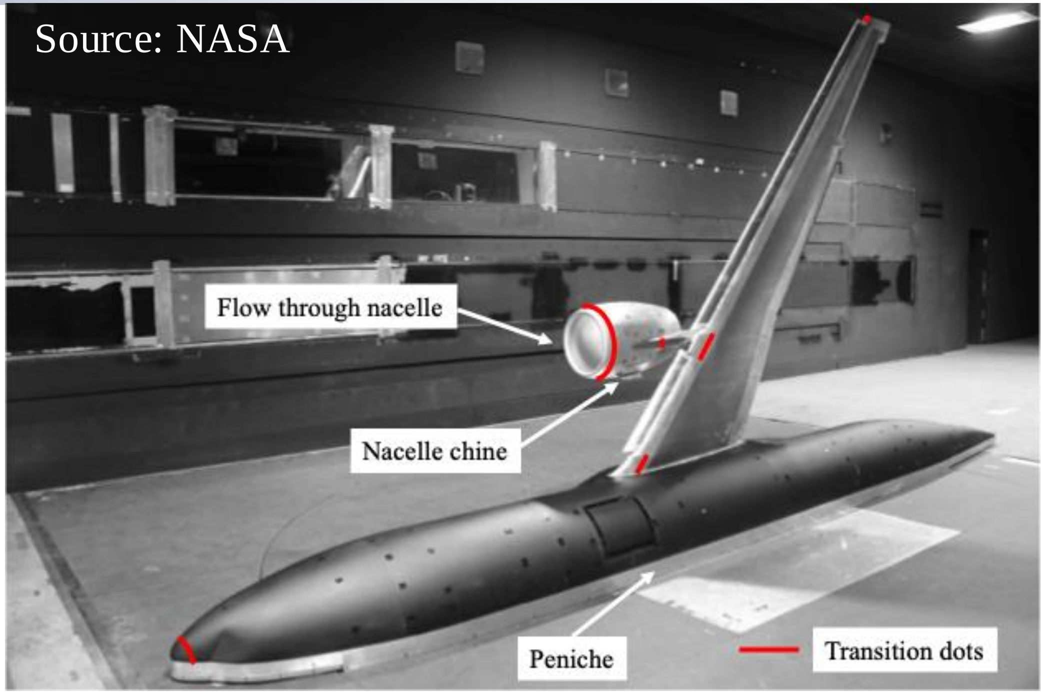
- A new outboard wing section with an adjustable aileron.
  - Different takeoff configurations.
  - AFC actuator integration.

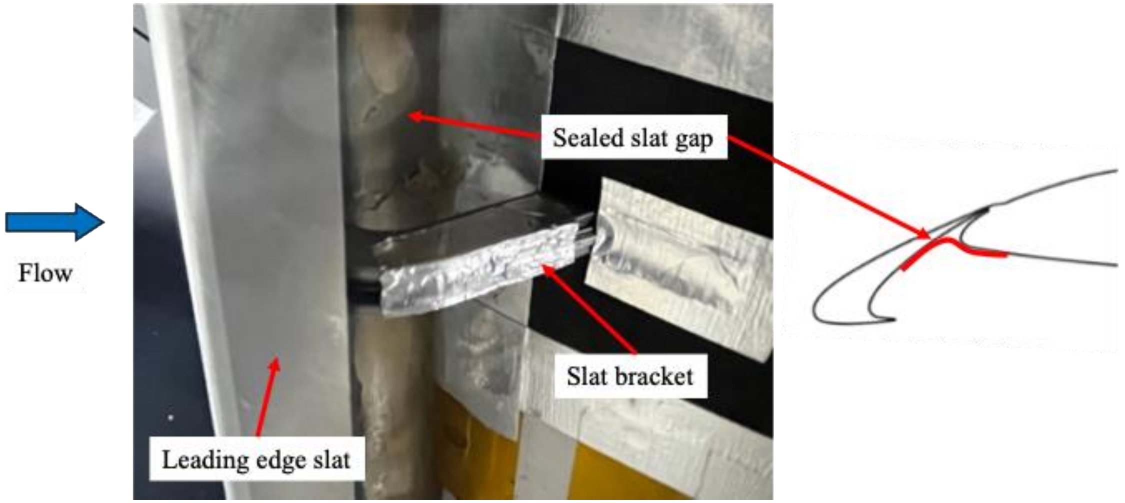
- Test the 10% scale CRM-HL model in 14x22.
  - – AFC results will be reported in a companion paper.
  - – Set a reference for the localized AFC research.
  - – Report the data relevant to the CRM-HL takeoff configurations.



Experimental Setup

- NASA Langley 14- by 22-Foot Subsonic Tunnel.
- 10% scale, semispan CRM-HL model.
  - Included wing, fuselage, leading edge strake, nacelle & chine, pylon, slats & brackets , flaps & fairings.
  - Aileron deflection of 0°, 7.5°, 16°, and 25°.
  - Transition trip dots at previously defined locations.
- Takeoff configuration.
  - $M_\infty = 0.2$, $Re_c = 3.0\text{x}10^6$.
  - 25° flaps and 22° slats with sealed slat gap.

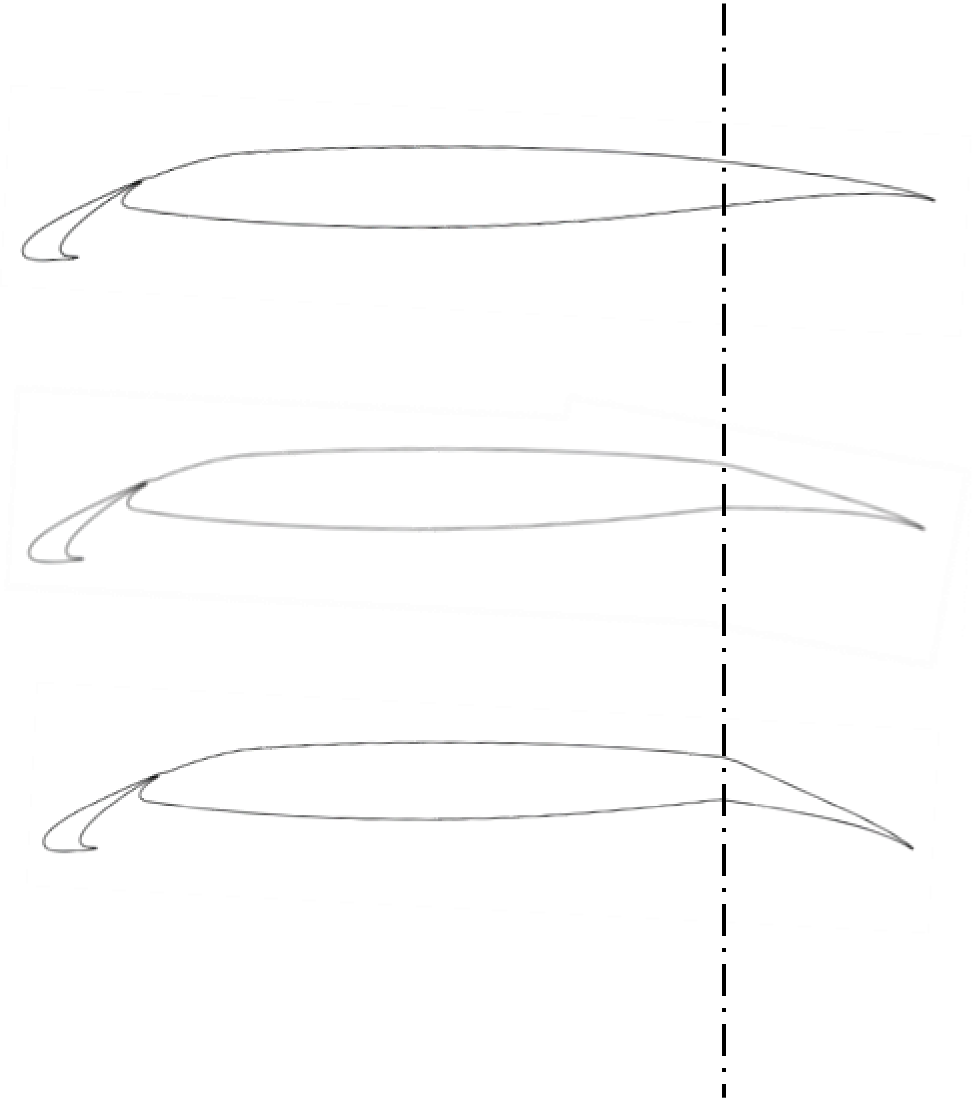




Source: NASA

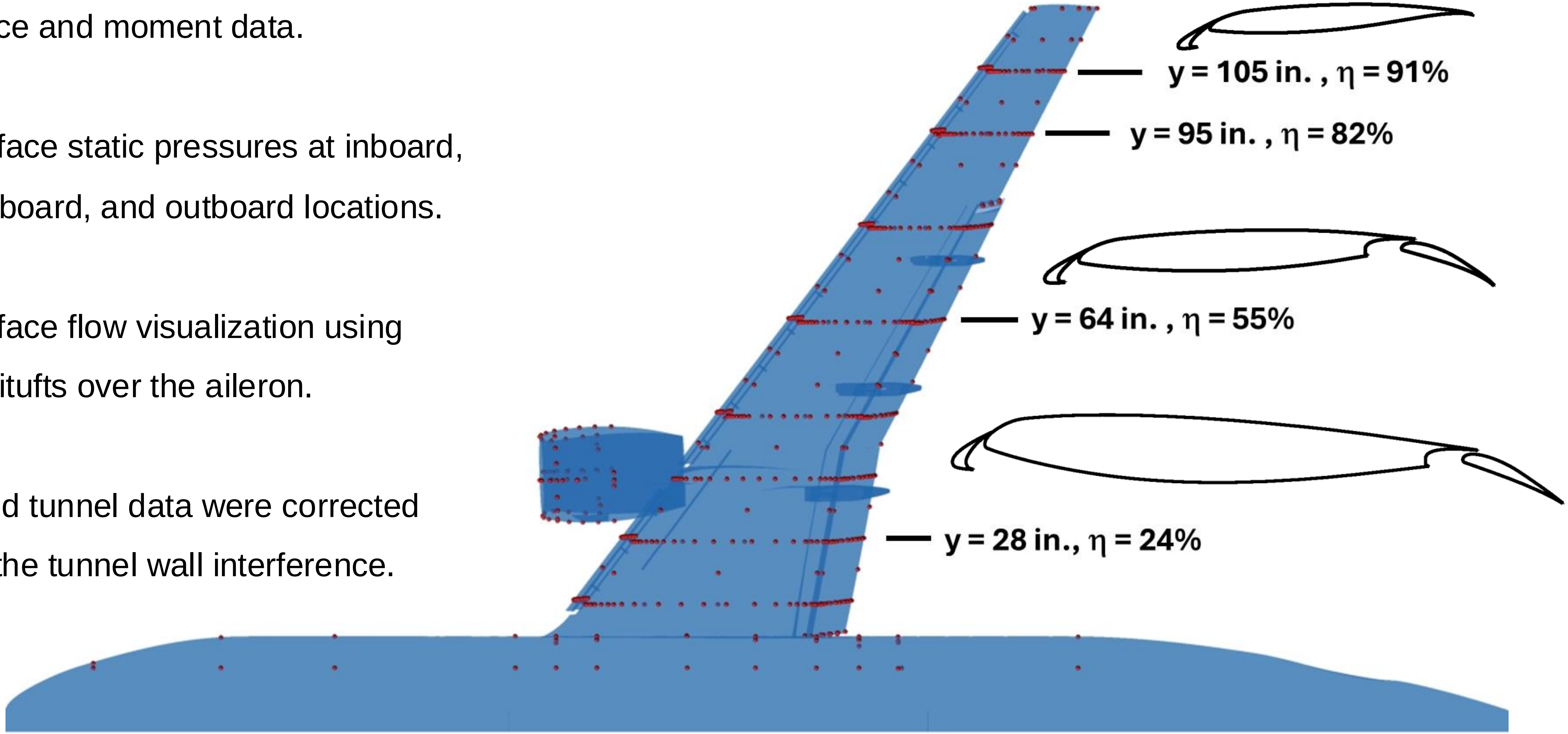
CRM-HL Takeoff Configurations

- Reference takeoff configuration was defined as:
  - 25° flaps and 22° slats with sealed slat gap.
  - Nondeflected ailerons (δ_a = 0°).
- Nominal takeoff configuration:
  - Airplanes benefit by deflecting the aileron during takeoff.
  - Nominal aileron deflection (δ_a = 7.5°).
- High-lift improved takeoff configuration:
  - Achieved by deflecting the aileron further.
  - δ_a = 16° and δ_a = 25°.
  - Intended to be used with AFC.



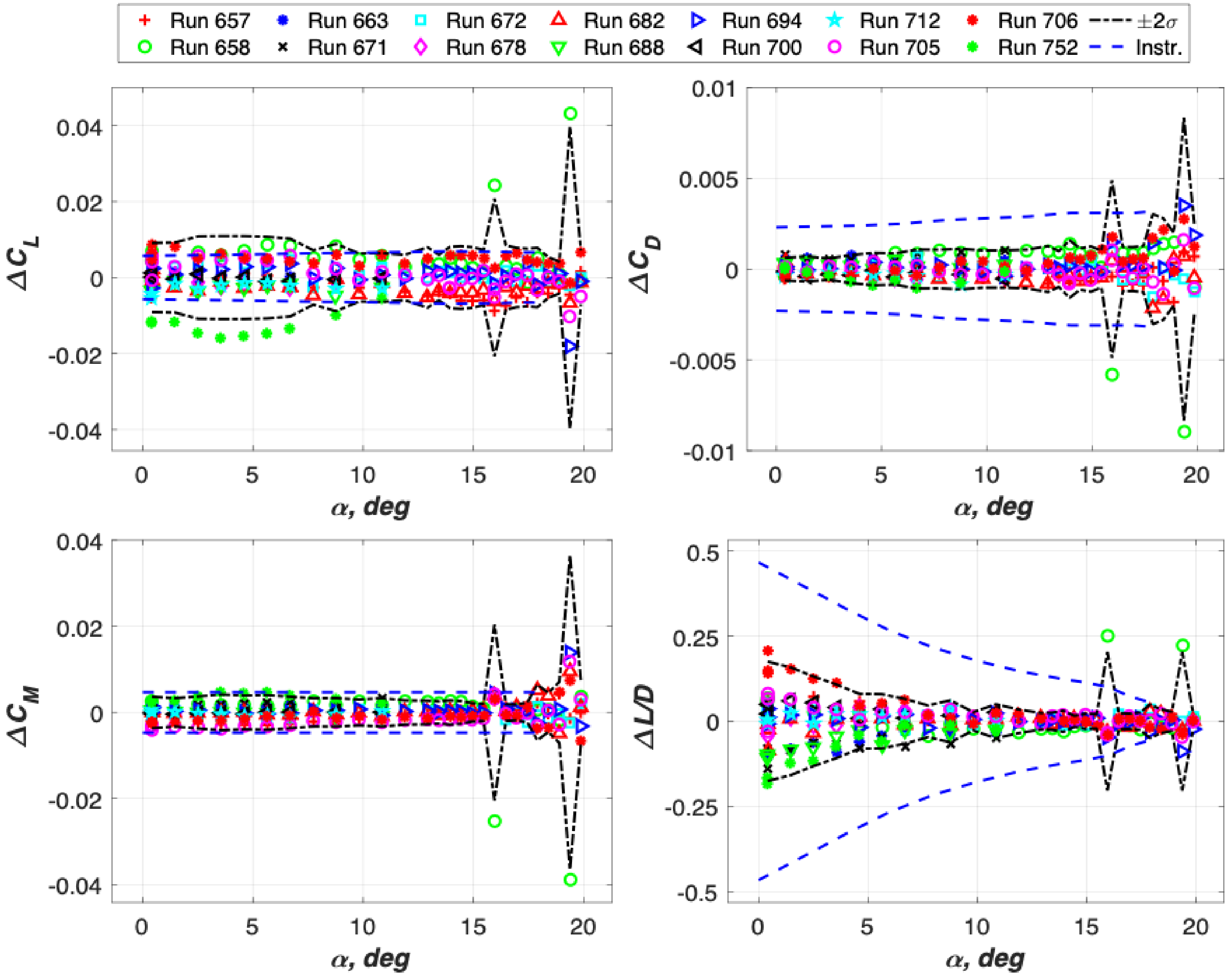
Wind Tunnel Measurements

- Force and moment data.
- Surface static pressures at inboard, midboard, and outboard locations.
- Surface flow visualization using minitufts over the aileron.
- Wind tunnel data were corrected for the tunnel wall interference.

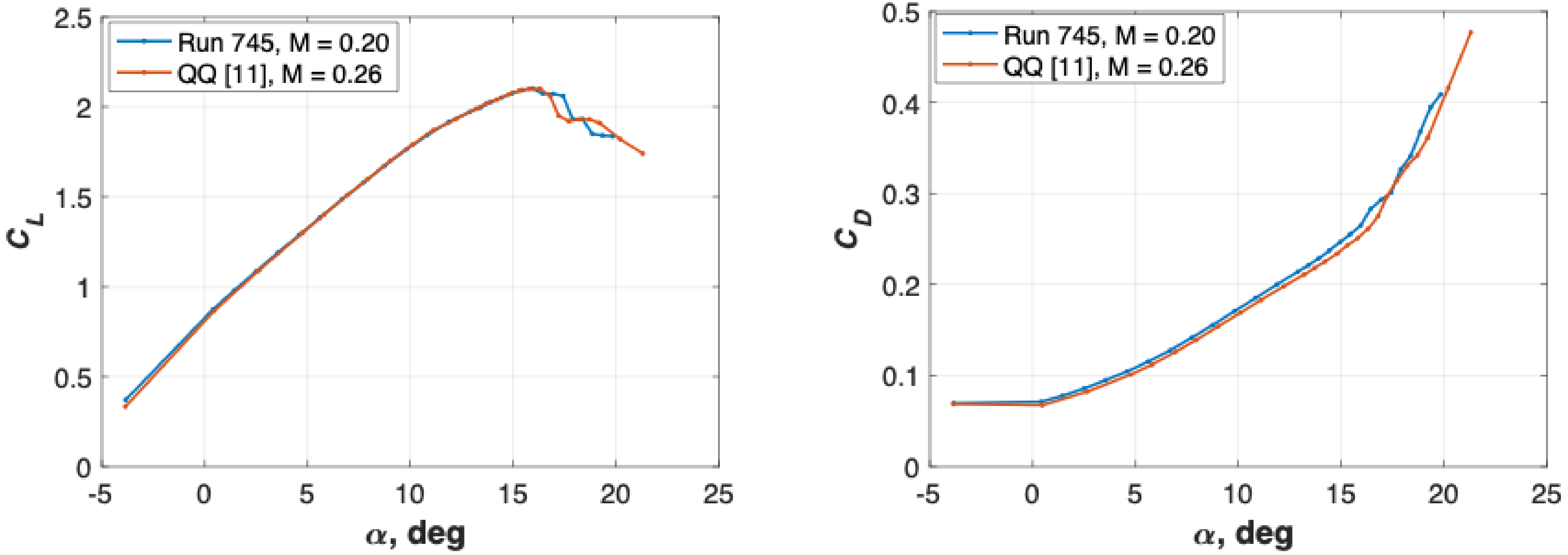


Measurement Repeatability

- Calculated residuals for the HL-improved takeoff configuration (M_∞ = 0.2, δ_a = 16°).
- Black dashed lines indicate ±2σ values.
- Blue dashed lines indicate the expected instrumentation uncertainty.
- These plots indicate that the variations in C_L, C_D, C_M, L/D are in general within the instrumentation uncertainty.



Comparison with the QinetiQ Test

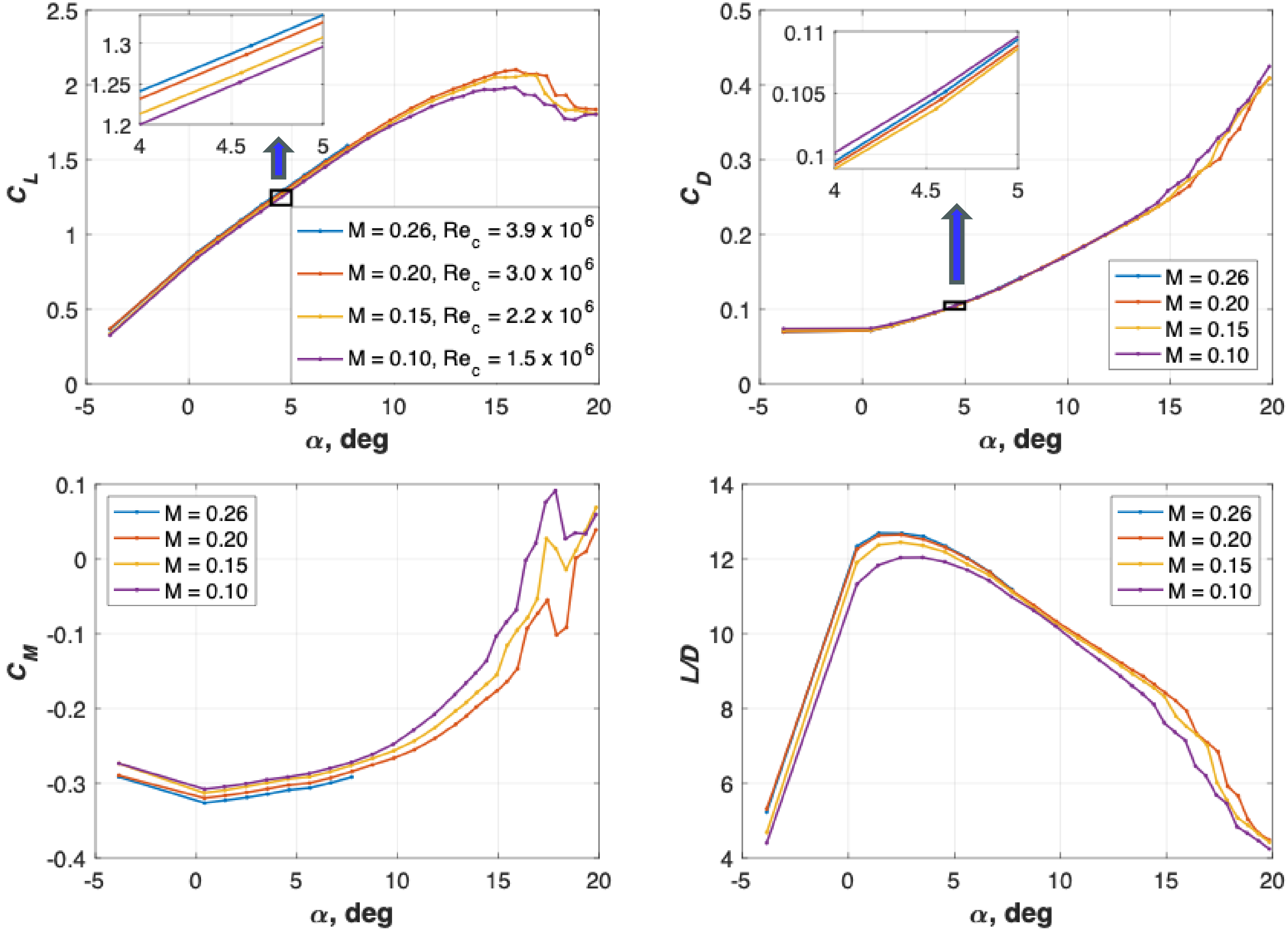


- The reference takeoff configuration was briefly tested in the QinetiQ 5m wind tunnel using the same model.
- The QinetiQ results are with the original nacelle cowl but without floor blowing system.
- The post stall lift curve experiences a sudden drop in lift, which was attributed to nacelle cowl flow separation.
- The current test produced slightly higher ($\Delta C_D \sim 0.005$) drag values.

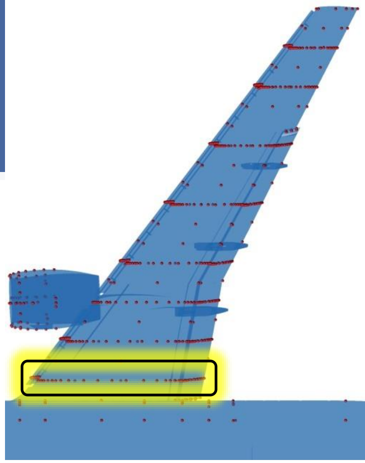
[11] Evans et al., 2020

The Effect of Reynolds Number

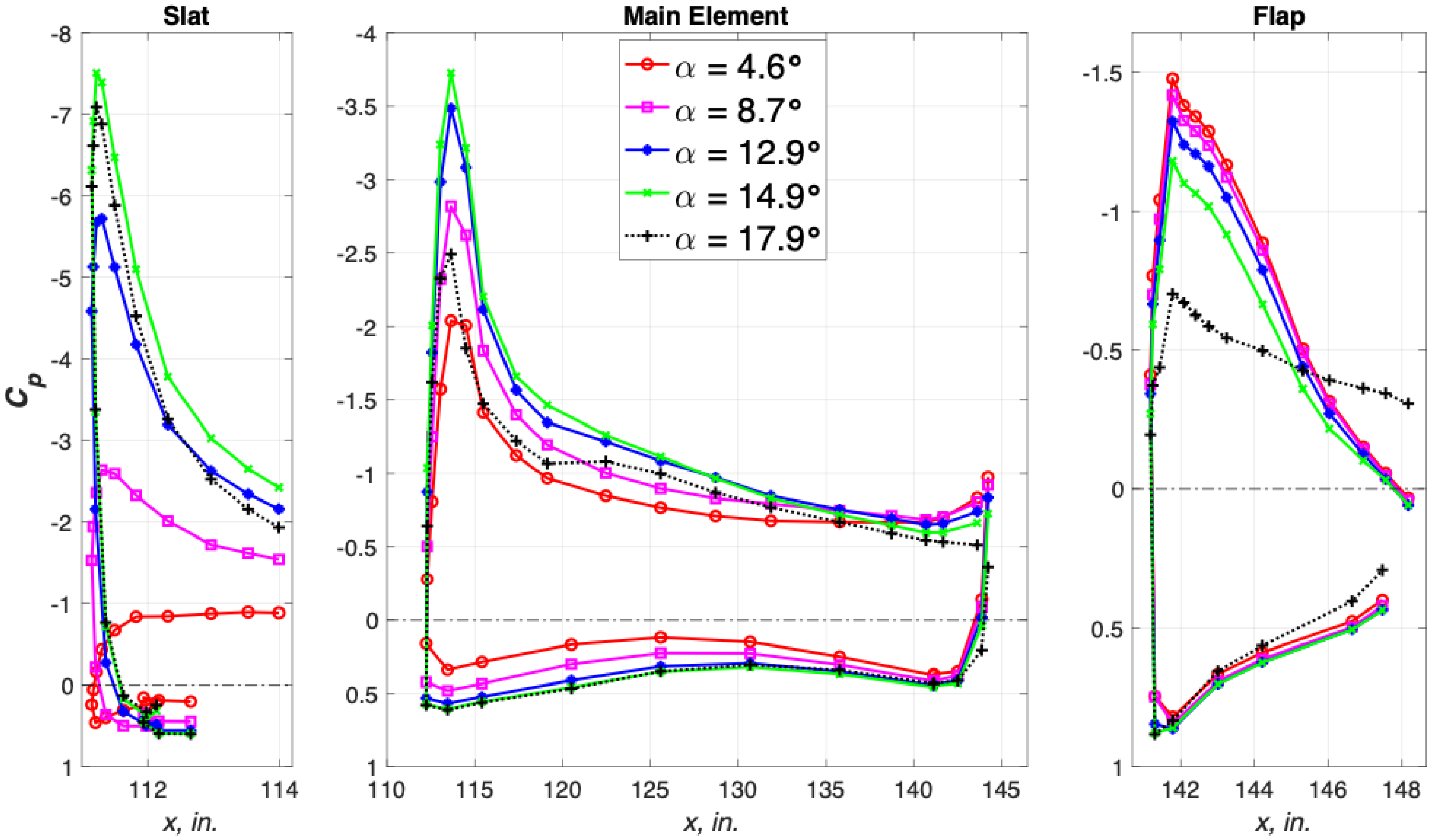
- $\delta_a = 0°$, $Re_c = 1.5\text{x}10^6 – 3.9\text{x}10^6$.
- Gradual improvement in C_L.
- C_{Lmax} values are 1.98, 2.06, 2.1.
- C_D values are close for $\alpha < 13°$.
- Negative (nose-down) C_M.
- A higher L/D peak near $\alpha = 2°$.
- $M = 0.2$ and $M = 0.26$ agree well.



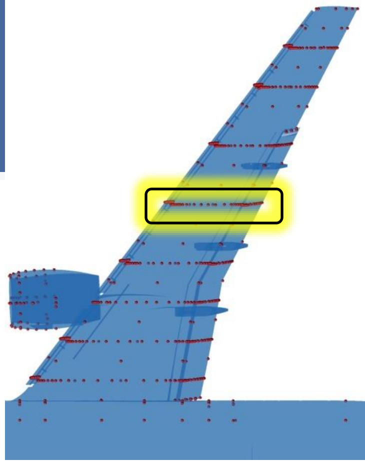
Reference Takeoff Configuration: Inboard Wing



- $M = 0.2$, $Re_c = 3\text{x}10^6$, $\delta_a = 0°$, $\eta = 24\%$.
- Higher suction pressures over the slat and main element as α increases until stall.
- Separated flow over the inboard wing for the poststall ($\alpha = 17.9°$).
- Suction pressures over the inboard flap decrease with increasing α.
- Flow over the inboard flap is attached except for $\alpha = 17.9°$.



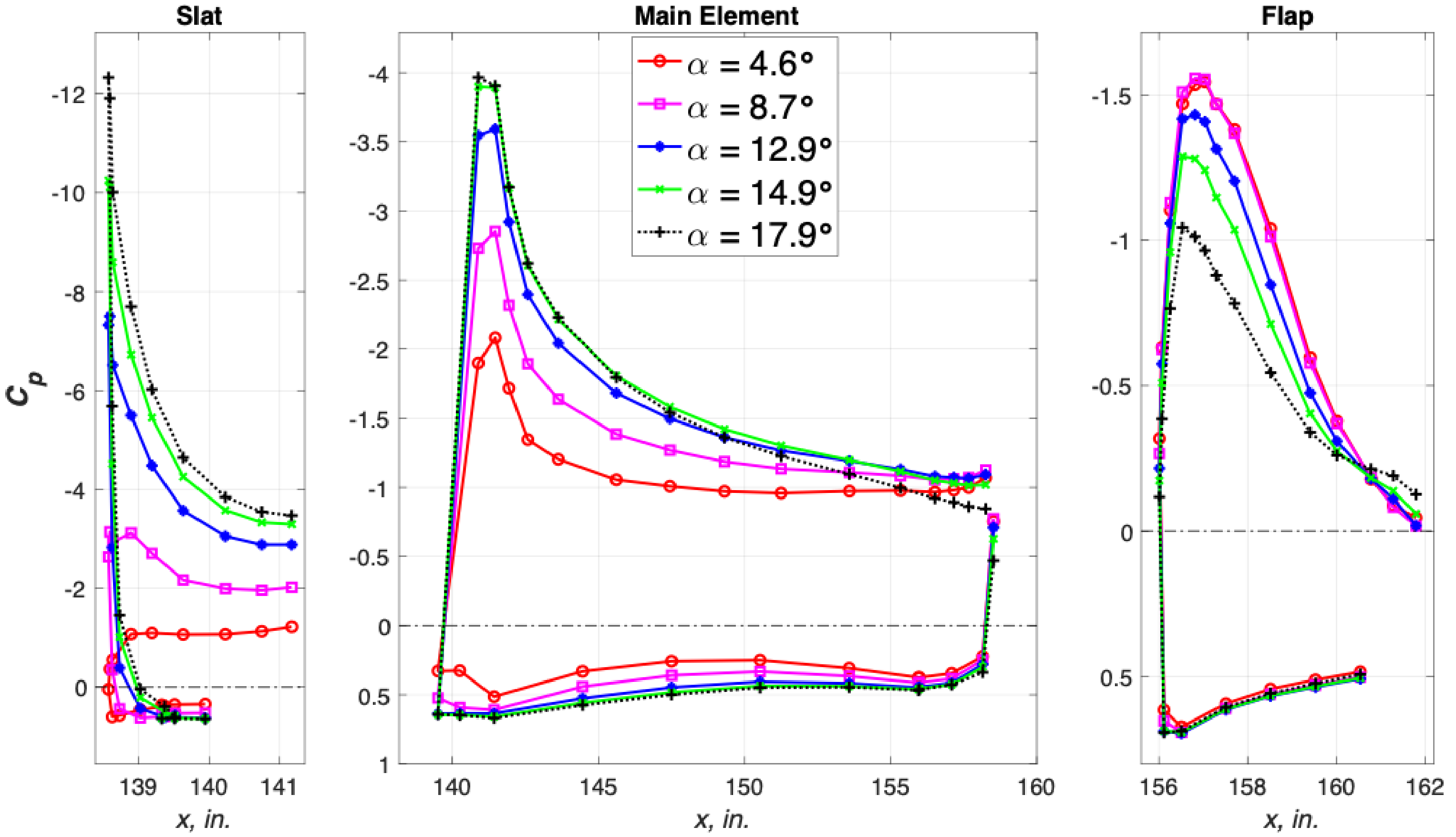
Reference Takeoff Configuration: Midboard Wing



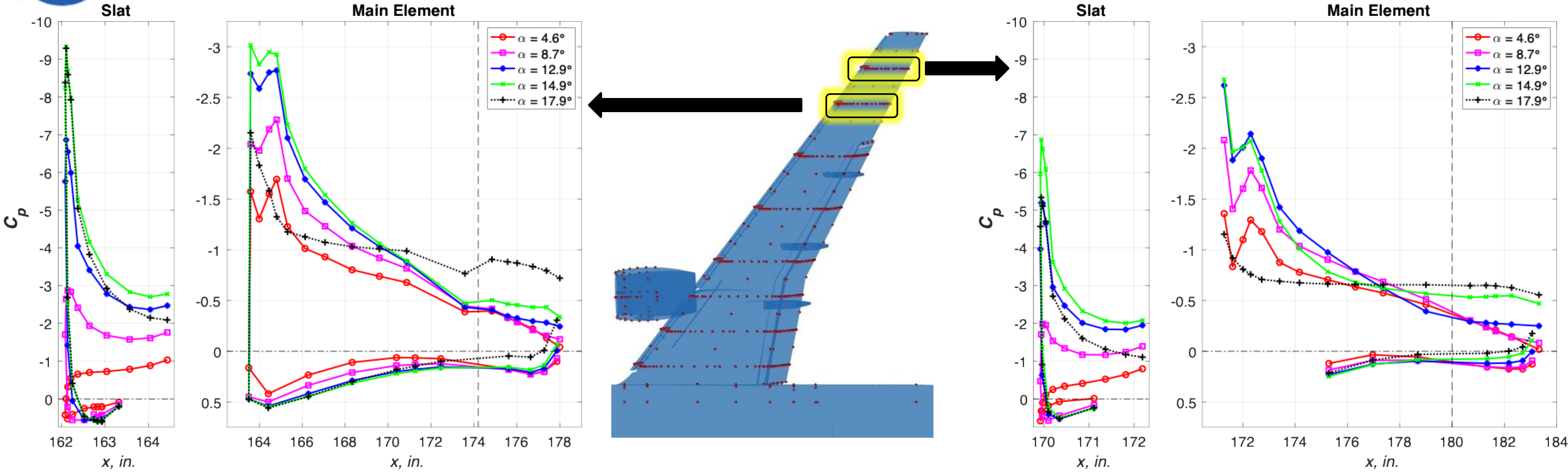
- $M = 0.2$, $Re_c = 3\text{x}10^6$, $\delta_a = 0°$, $\eta = 55\%$.

- A similar behavior for the midboard wing where larger α produced
  - higher suction pressures on the slat and the main element,
  - lower suction pressures on the flap.

- The pressure distribution indicates separated flow near the flap trailing edge for $\alpha = 17.9°$.



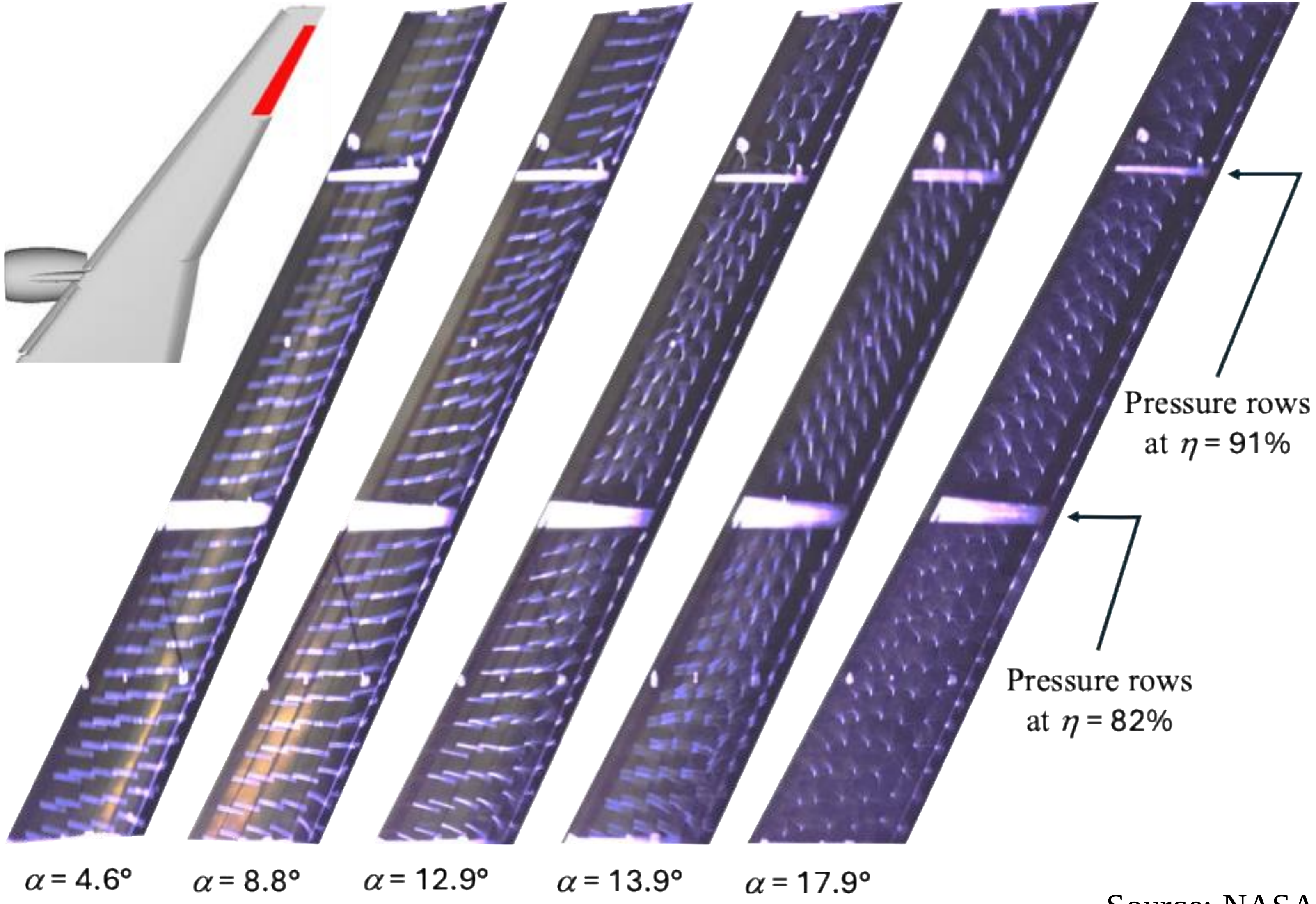
Reference Takeoff Configuration: Outboard Wing



- Increasing α results in higher suction pressures.
- The flow near the aileron trailing edge appears to be attached for $\alpha = 4.6°$.
- Entire main element is separated for $\alpha = 17.9°$.
- The flow over the main element separates earlier ($\alpha \leq 14.9°$) for the most outboard location.

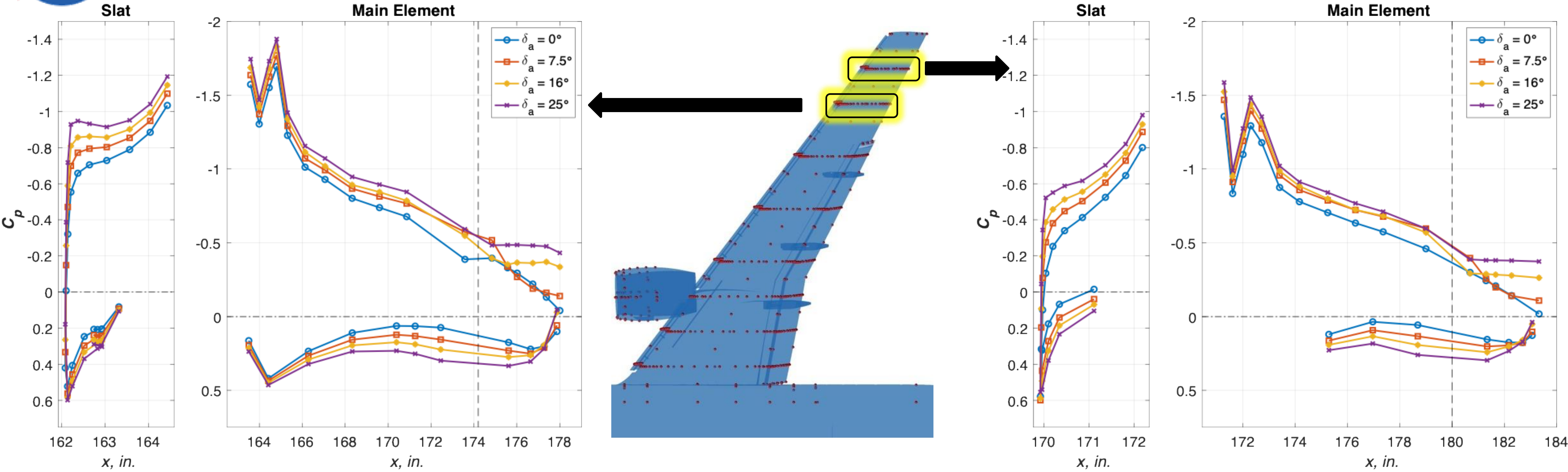
Reference Takeoff Configuration: Aileron Surface Flow Viz

- $M = 0.2$, $Re_c = 3\text{x}10^6$, $\delta_a = 0°$.
- Attached flow for $\alpha = 4.6°$.
- For $\alpha = 8.8°$, most of the flow over the aileron is still attached.
- Not enough tuft resolution to capture the TE flow separation shown in the C_p distribution.
- Flow separation moves upstream with α.
- The flow over the entire aileron is separated for $\alpha = 17.9°$.



Source: NASA

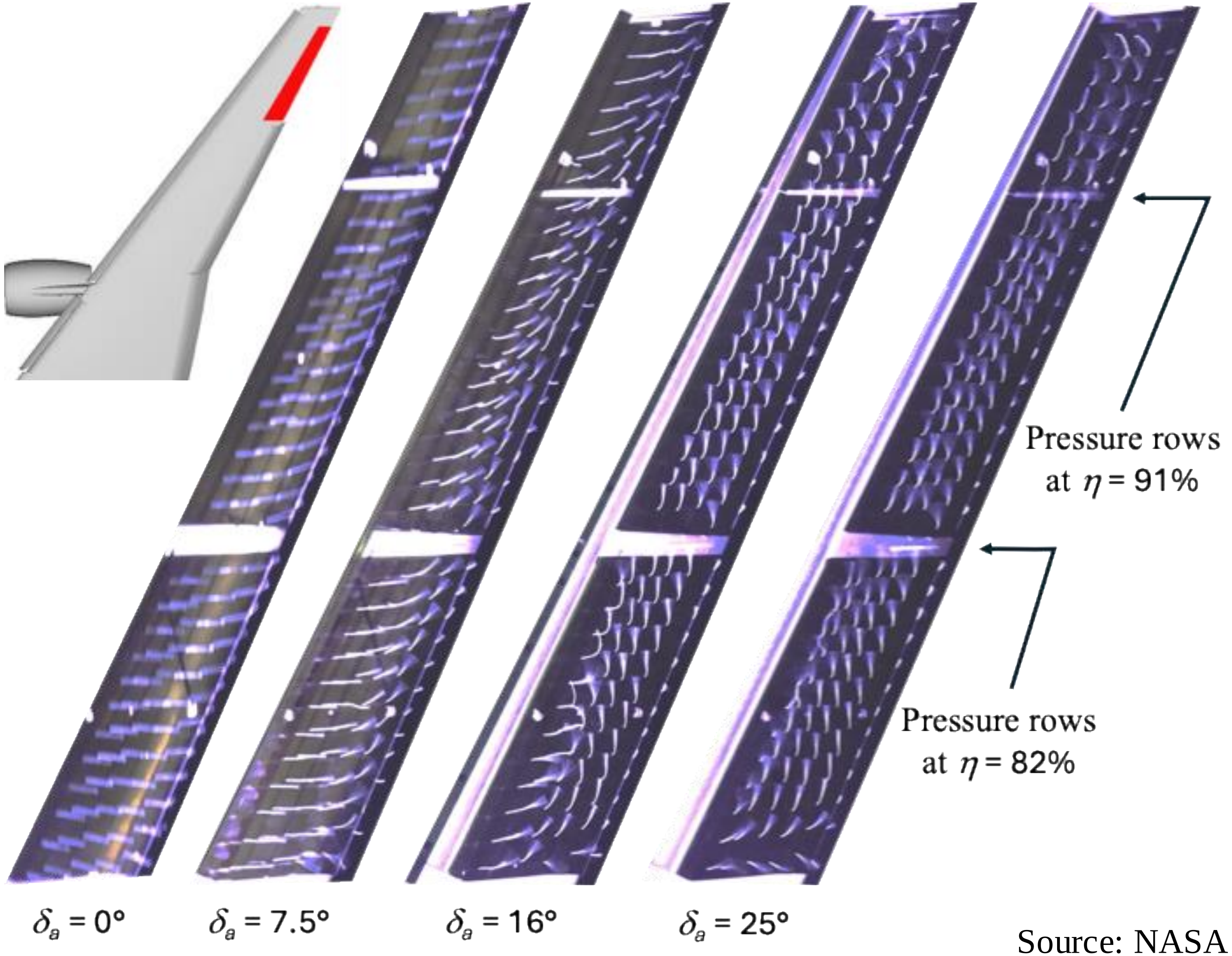
The Effect of Aileron Deflection on the Cp Distribution



- $M = 0.2$, $Re_c = 3 \times 10^6$, $\alpha = 4.6°$, $\eta = 82\%$ & 91%
- Increasing δ_a improves the pressure distribution both on the suction and pressure surfaces.
- Cp distributions indicate attached flow for $\delta_a = 0°$ for the two outboard locations.
- The flow separation moves upstream (i.e., getting larger) as δ_a increases.

Surface Flow Visualization for Different Aileron Deflections

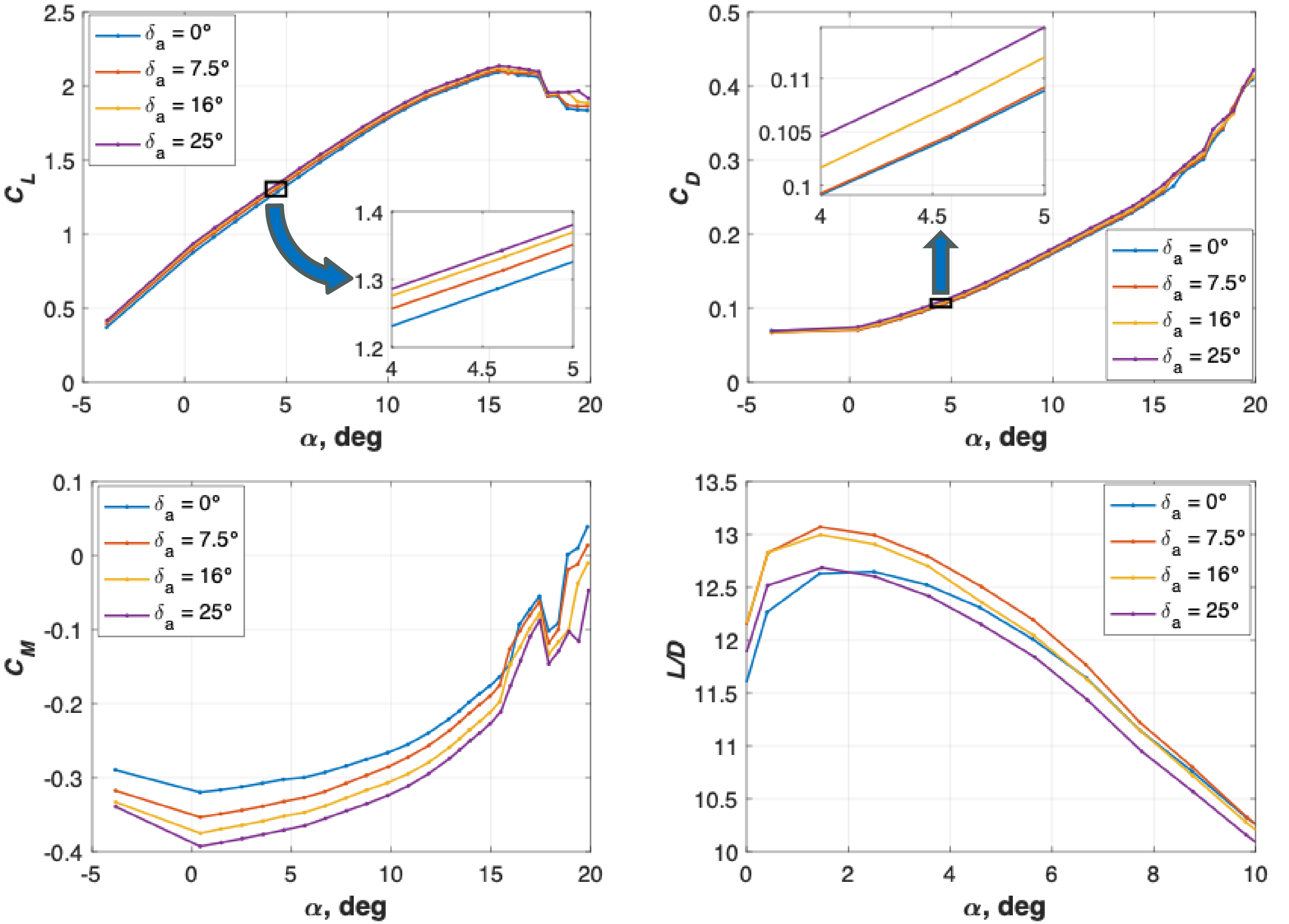
- $M = 0.2$, $Re_c = 3\text{x}10^6$, $\alpha = 4.6°$.
- Attached flow is maintained for δ_a = 0° at this angle of attack.
- A small separation bubble develops near the trailing edge of the aileron for δ_a = 7.5°.
- Deflecting the aileron further to 16° and 25° results in separated flow for the entire aileron surface.



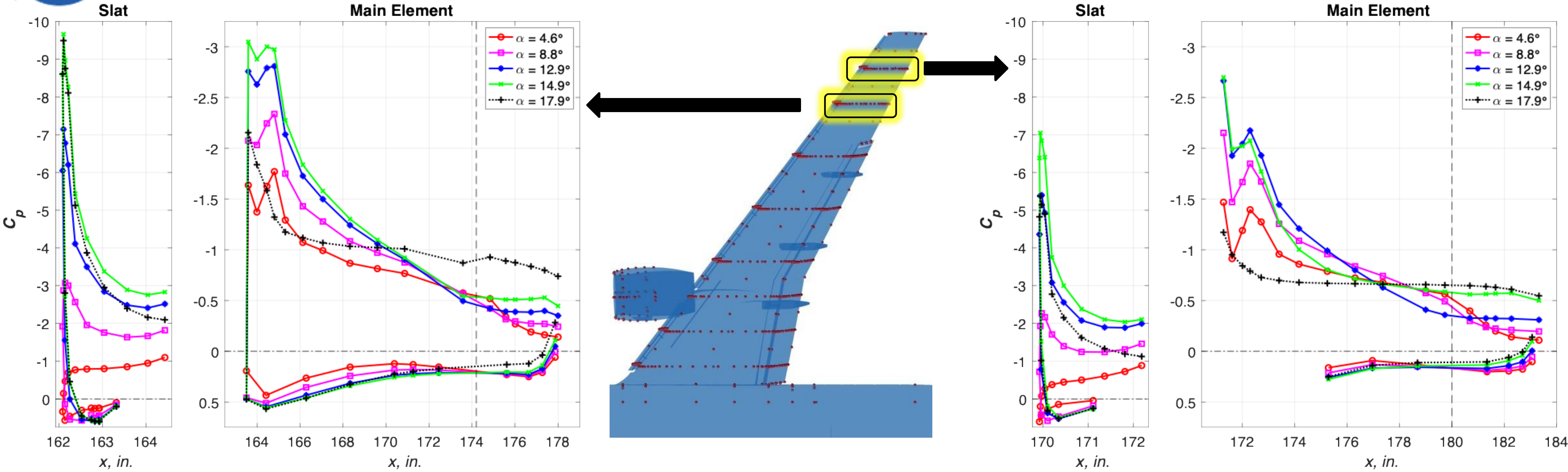
Source: NASA

The Effect of Aileron Deflection on the Aerodynamic Coefficients

- C_L increases with δ_a .
- The improvement is as much as ~0.06 at lower α and resulted in C_{Lmax} of 2.137 for δ_a = 25°.
- The flow separation over the aileron ($\delta_a \geq$ 7.5°) mainly affects C_D (50 drag counts).
- Nominal aileron deflection angle was chosen as 7.5° as it provided the largest L/D for a takeoff α.

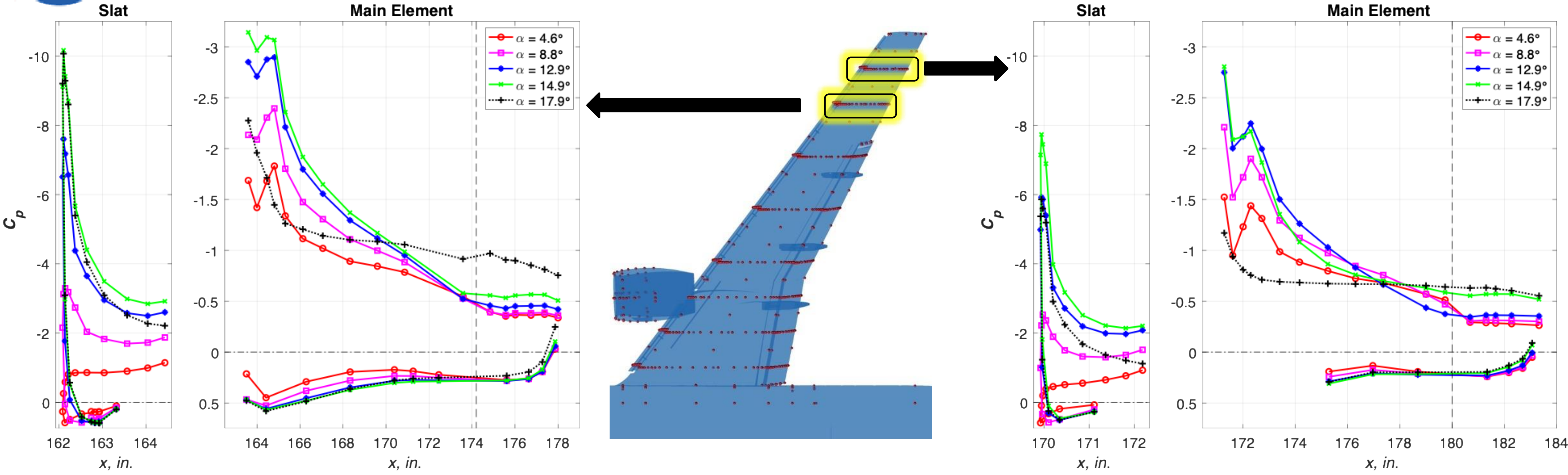


Outboard Wing: Nominal Takeoff Configuration ($\delta_a = 7.5°$)



- A small flow separation bubble at $\alpha = 4.6°$ (was attached flow for $\delta_a = 0°$).
- The trailing-edge flow separation moves upstream with α.
- Flow over the main element is mostly separated for poststall.
- Flow separated earlier ($\alpha \leq 14.9°$) for the most outboard location ($\eta = 91\%$).

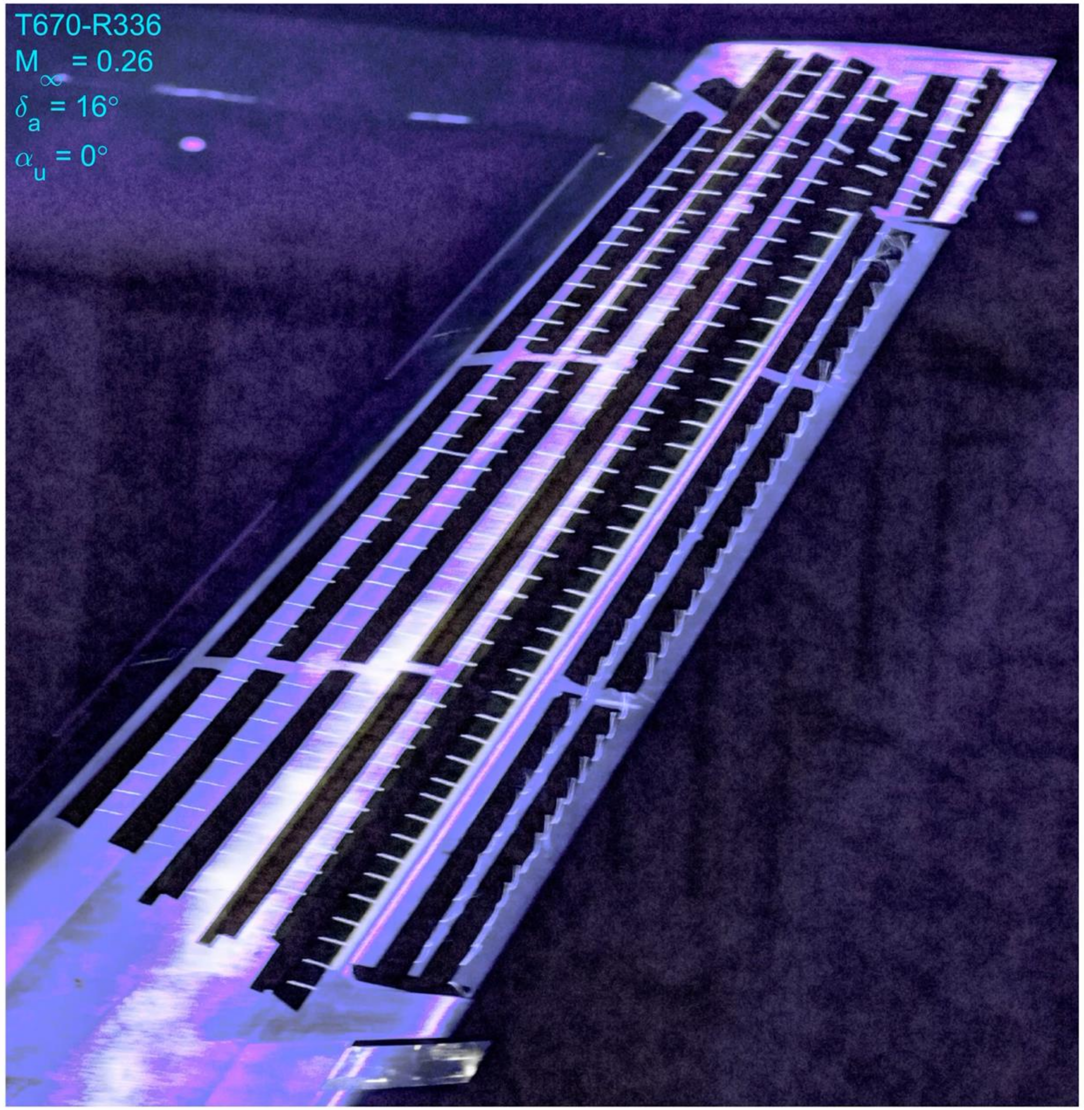
Outboard Wing: HL-Improved Takeoff Configuration ($\delta_a = 16°$)



- The C_p distributions indicate separated flow over the aileron for all angles of attack.
- Flow over the main element remains attached prior to stall for $\eta = 82\%$.
- Flow separated earlier ($\alpha \leq 14.9°$) for the most outboard location ($\eta = 91\%$).

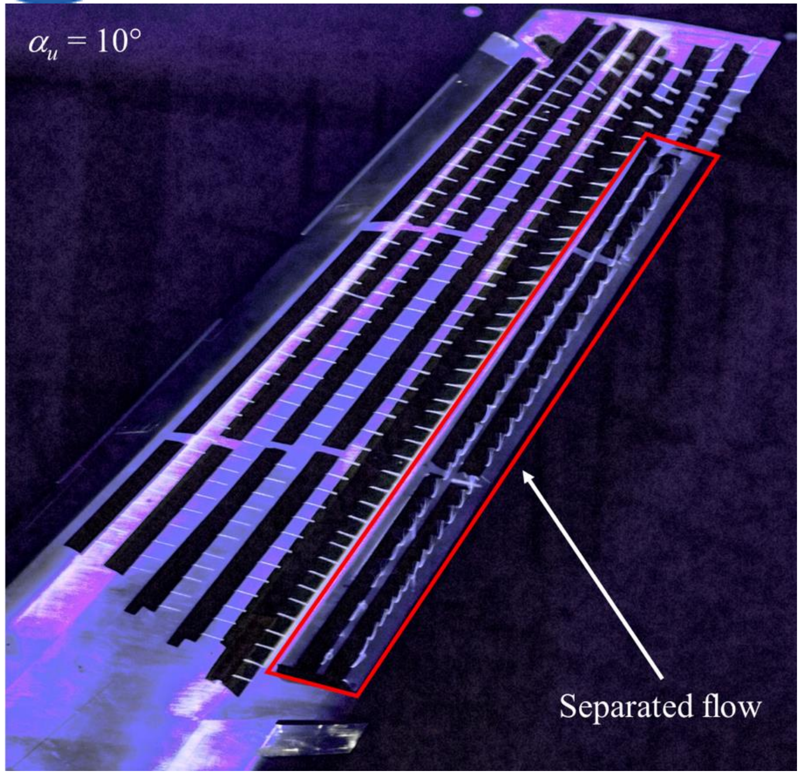
Surface Flow Visualization Over the Outboard Wing

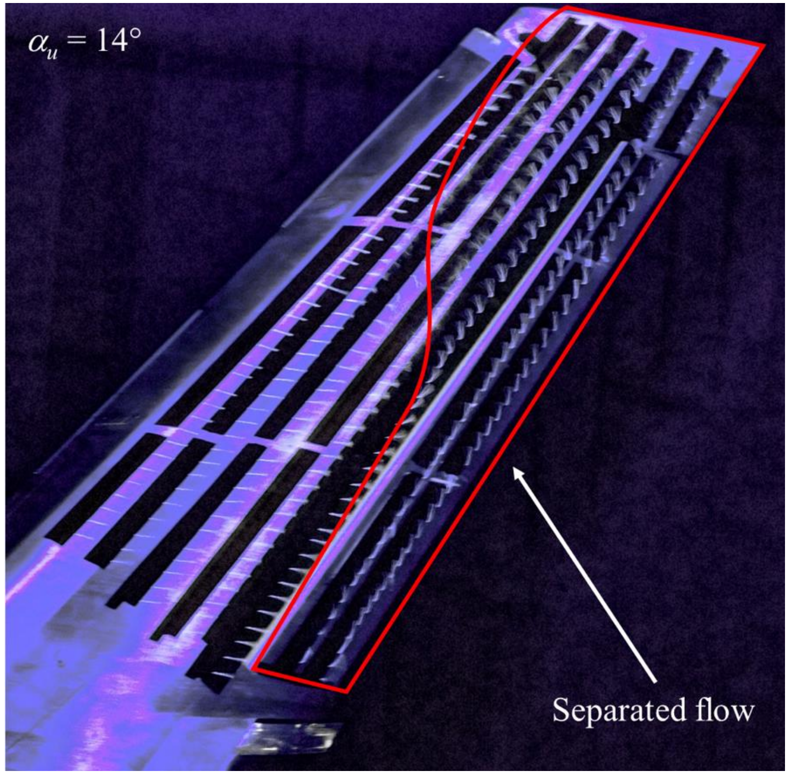
- $M_\infty = 0.26$, $Re_c = 3.9 \times 10^6$, $\delta_a = 16°$.
- Attached flow on the main element and separated flow on the aileron ($\alpha_u < 12°$).
- Flow separation is initiated near the outboard side of the aileron
- Stall progresses upstream as well as inboard as α_u increases.

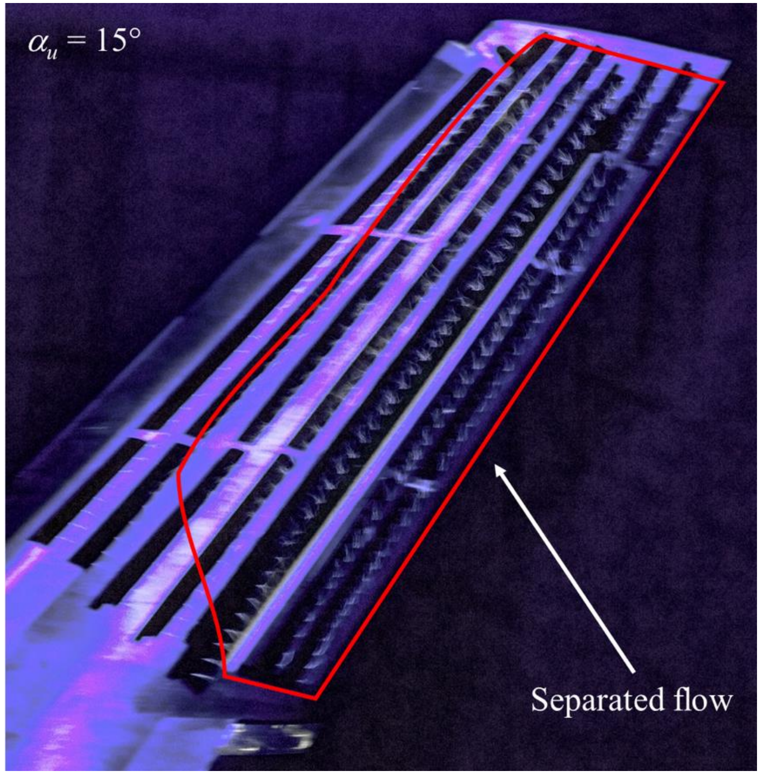


Source: NASA

The Stall Progress of CRM-HL Takeoff Configurations







- The stall is initiated over the most outboard wing.
- Gradually moves upstream and progresses inboard.

Source: NASA

Conclusion

- The 10% scale CRM-HL was tested in the NASA 14x22 at takeoff conditions.

- The objective was to improve the high-lift performance using localized AFC.
  - The assessment of AFC configurations and high-lift improvement results are reported in a companion paper.

- The current paper
  - reports the data relevant to the CRM-HL takeoff configurations
  - sets a reference case for the localized AFC applications.

- Three different takeoff configurations are documented.
  - The reference (δ_a = 0°), nominal (δ_a = 7.5°), and HL-improved (δ_a = 16° & δ_a = 25°) takeoff configurations.

- The results presented in this study could be used in the CRM-HL ecosystem as well as any high-lift research for takeoff configurations.

Acknowledgement

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- 14x22 Tunnel staff for their support.