Analysis of High-Speed Aerodynamics of a Swept Wing with Seamless Flaps (Invited)

Trong T. Bui[1]
NASA Armstrong Flight Research Center
Edwards, California 93523

[1]Aerospace Engineer, Aerodynamics and Propulsion Branch

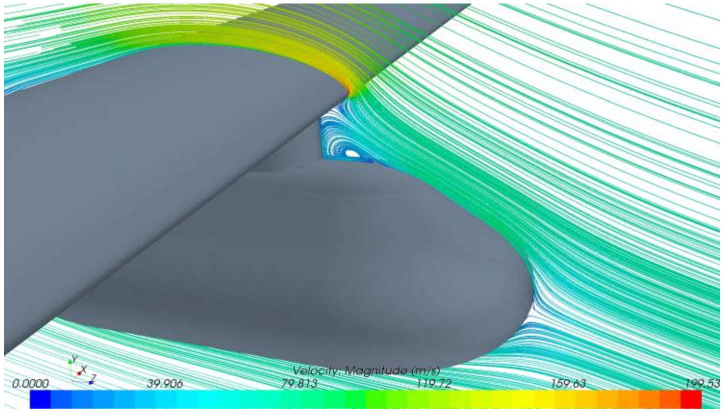
Presentation outline

- Synergy of CFD & flight at NASA Armstrong
- GIII Adaptive Compliant Trailing Edge (ACTE) wing description
- CFD Methodology:
  - CFD solver settings
  - CFD grid description
- High-Speed GIII Wing Flows Analysis Results:
  - Grid convergence study
  - Lift effects
  - Aircraft engine effects
  - Wing vortex generators effects
  - ACTE flap effects
- Conclusions

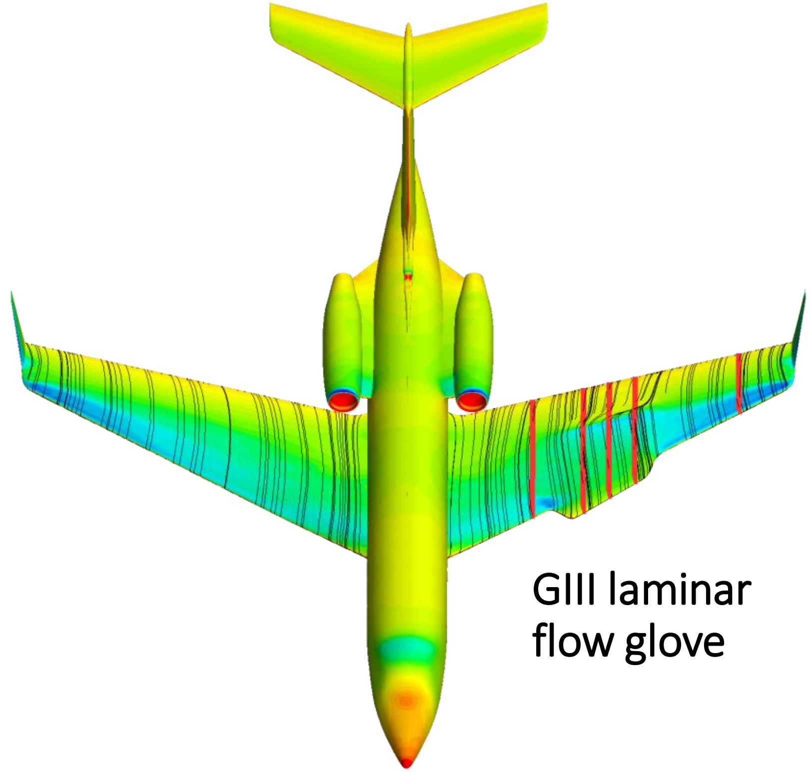
Synergy of CFD and flight at NASA Armstrong

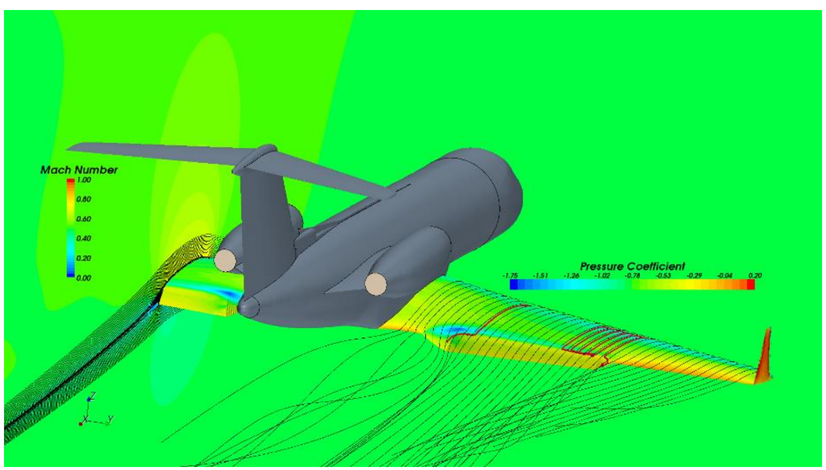
- Airworthiness and Flight Safety Reviews support:
  - Preliminary Design Reviews
  - Critical Design Reviews
  - Flight Readiness Reviews and Tech Briefs
  - Mishap investigations
  - New X-planes
  - Modified planes in existing inventory
  - Captive-carry flight experiments on flight testbeds
- New project advocacy support
- External collaborations with outside organizations: NASA, DoD, private companies
- CFD has been indispensable to us for:
  - Probing the unknowns before putting airplanes and crews in the air
  - Guiding the proposals, planning, and execution of our flight projects
  - Determining what went wrong
- In-house CFD expertise has been valuable

Examples



Ikhana UAV Pod


GIII laminar flow glove

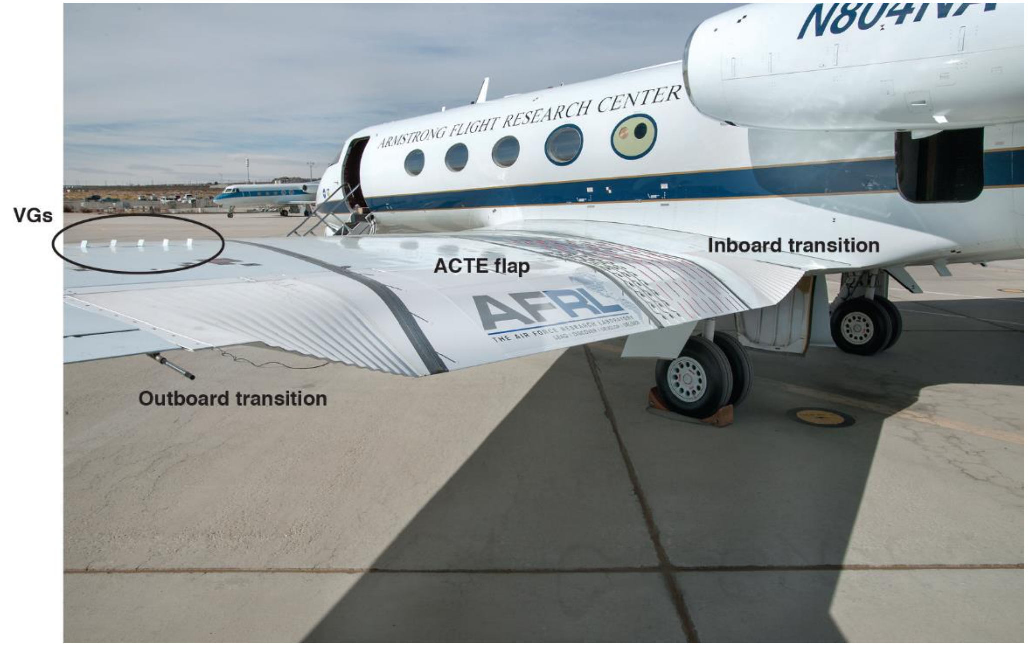


GIII ACTE


Generation Orbit inert test article

GIII ACTE wing description

- ACTE flap replaced the conventional GIII aircraft flap:
  - ~50% of the wing half-span
  - ~20% of the wing chord
- Inboard and outboard ACTE flap transition sections provided surface continuity when the ACTE flap was deflected
- One fixed ACTE flap position from take-off through landing
- The ground and flight wing spoilers were removed
- The 31 GIII wing vortex generators were retained

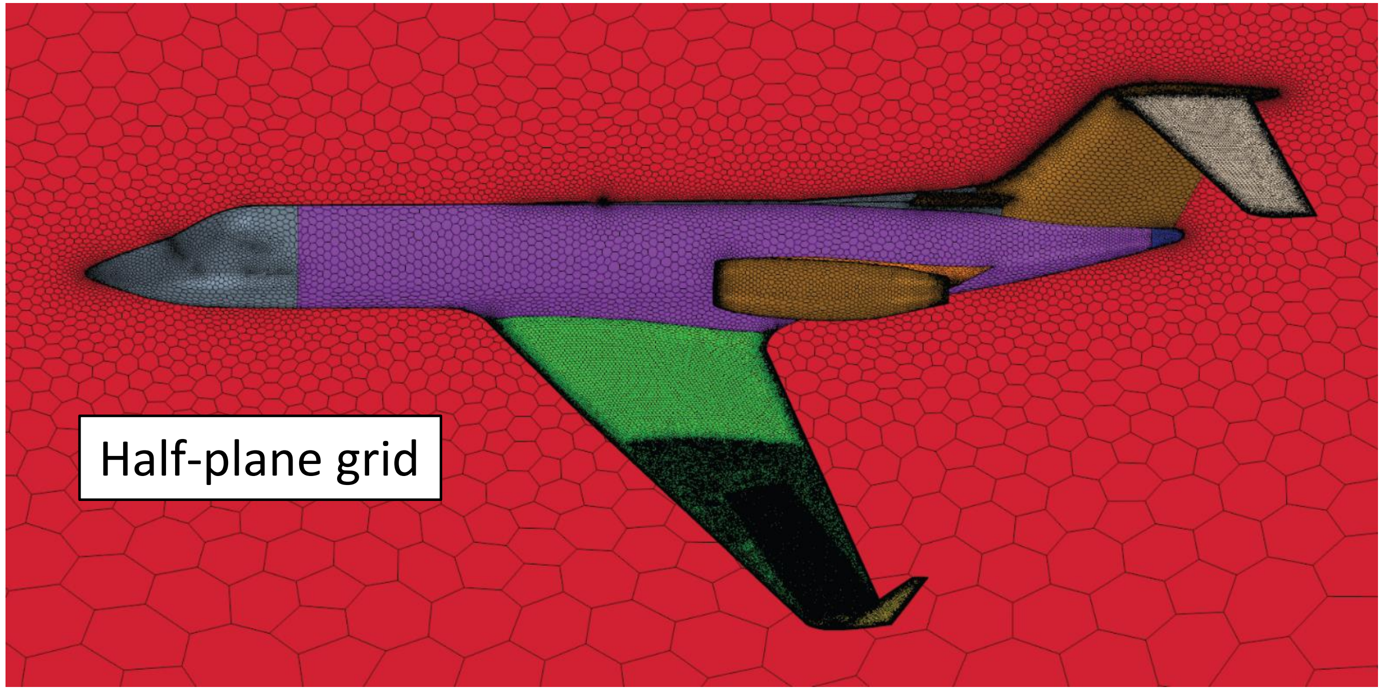


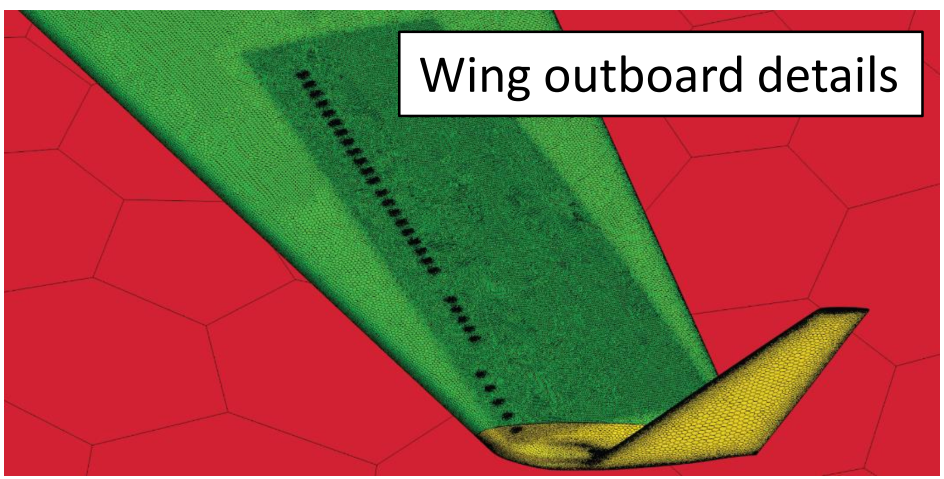
STAR-CCM+ CFD Methodology

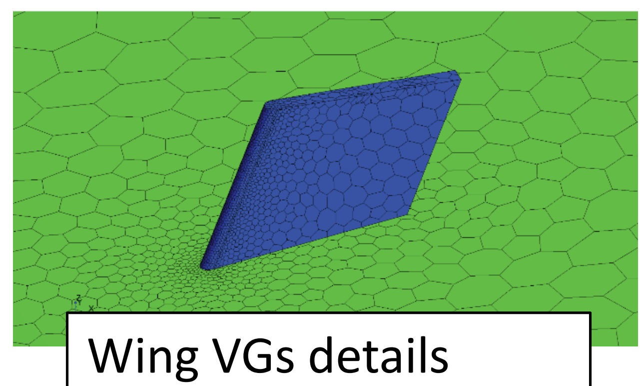
- Implicit, coupled steady, unstructured polygonal RANS CFD flow solver
- 2nd-order spatial discretization with Hybrid Gauss-LSQ reconstruction
- Roe FDS with Venkatakrishnan limiter
- Symmetry plane used for half-aircraft CFD simulations
- Half-airplane mesh sizes range from 13.3 to 41.9 million cells for the grid independence study – 41.9 million cells used for all subsequent CFD simulations
- SST (Menter's Shear Stress Transport) k-omega two-equation turbulence model
- All-y^+ wall treatment automatically uses wall function where appropriate
    - Typical near-wall y+ values around 1.0. Ranges from less than 1.0 at wing TE to ~8.0 at winglet LE
    - 19 (coarse), 25 (medium), and 31 (fine and finest) prism layers were used within a prism layer thickness of approximately 1.2 inches from the wall
- All surface and volume grid sizes were scaled as percentages of a single reference length which is then varied to obtain various grid sizes with the same overall grid topology

CFD Grid Description

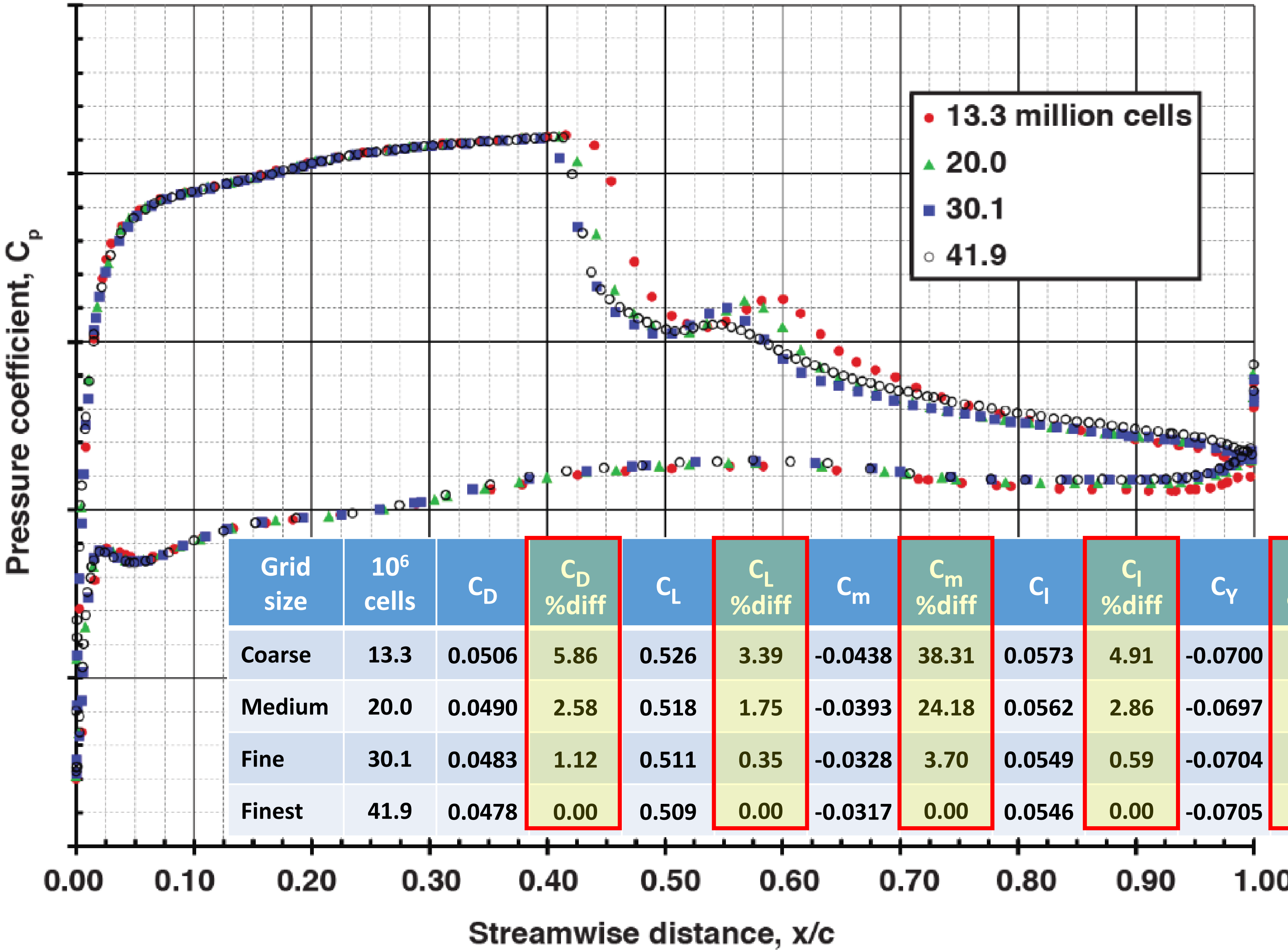
- Mach 0.85
- Hp = 40,000 ft
- C_L = 0.2 (low)
- C_L = 0.375 (mid)
- C_L = 0.5 (high)





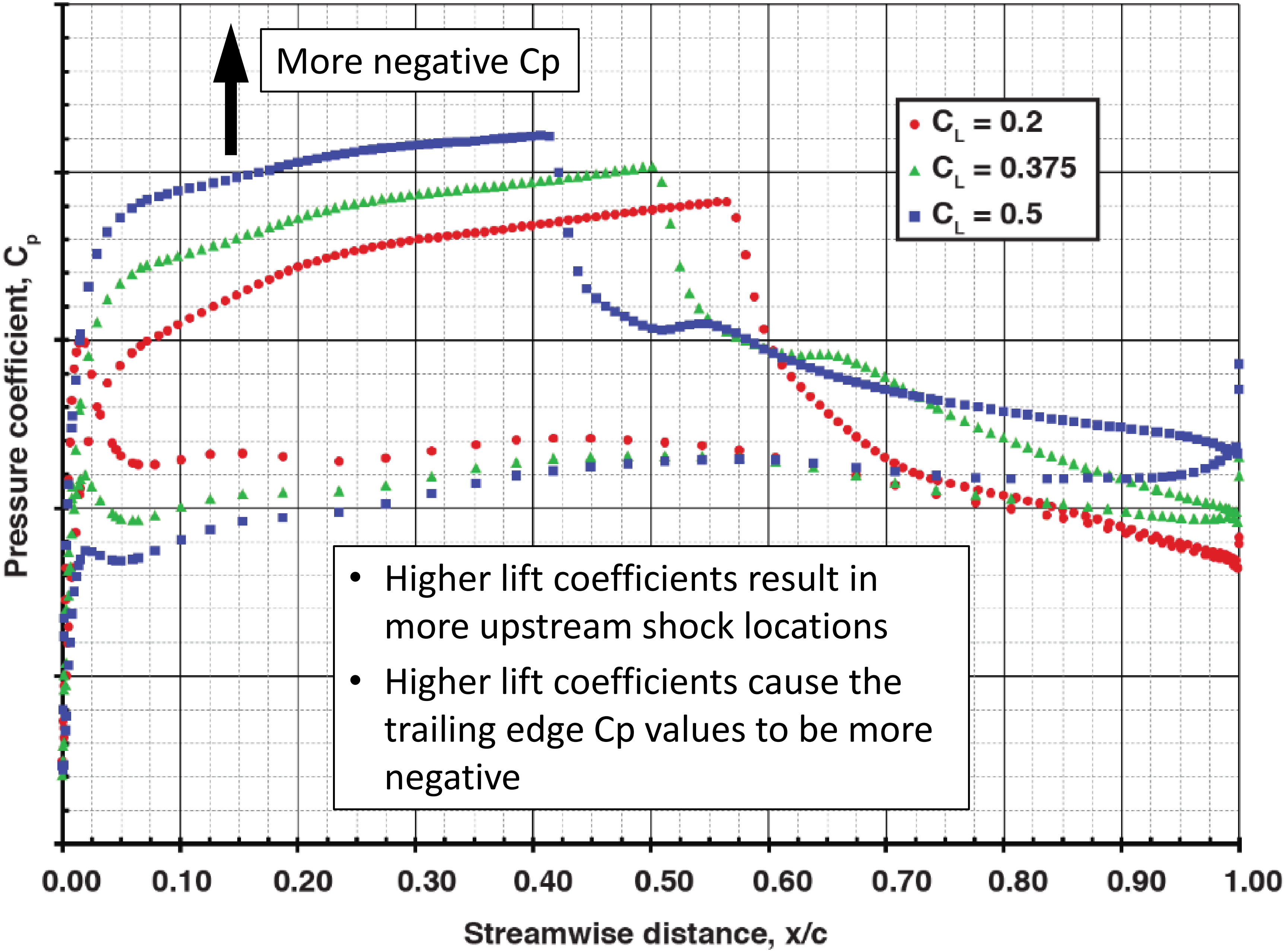


CFD Grid Convergence Results



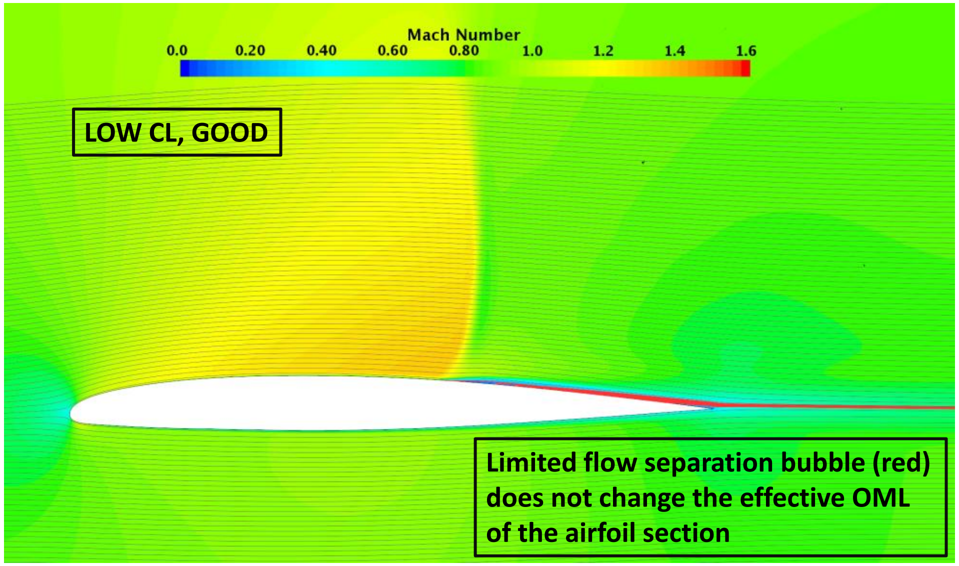
Grid size	10^6 cells	C_D	C_D %diff	C_L	C_L %diff	C_m	C_m %diff	C_l	C_l %diff	C_Y	C_Y %diff
Coarse	13.3	0.0506	5.86	0.526	3.39	-0.0438	38.31	0.0573	4.91	-0.0700	-0.72
Medium	20.0	0.0490	2.58	0.518	1.75	-0.0393	24.18	0.0562	2.86	-0.0697	-1.08
Fine	30.1	0.0483	1.12	0.511	0.35	-0.0328	3.70	0.0549	0.59	-0.0704	-0.04
Finest	41.9	0.0478	0.00	0.509	0.00	-0.0317	0.00	0.0546	0.00	-0.0705	0.00

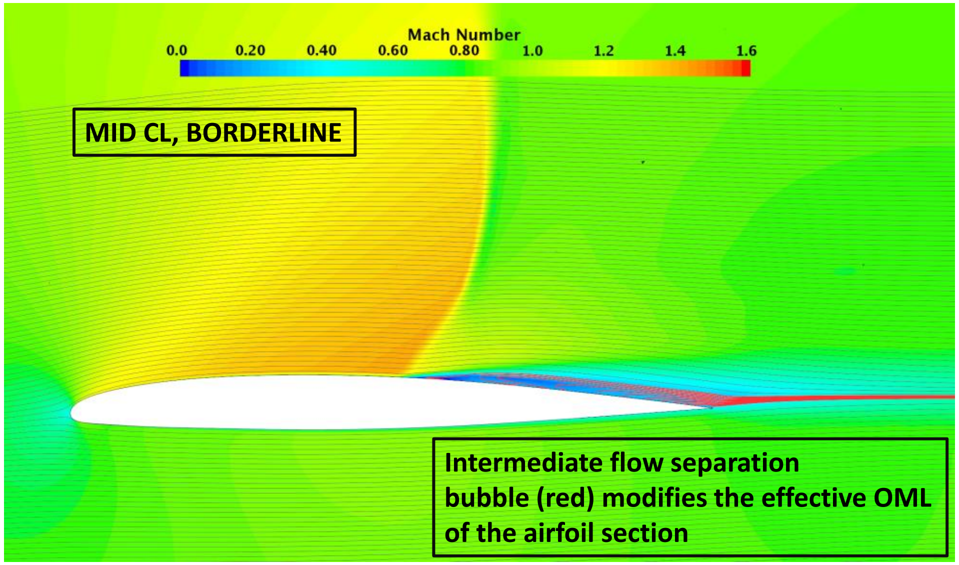
Lift Effects – Airfoil Cp Distribution



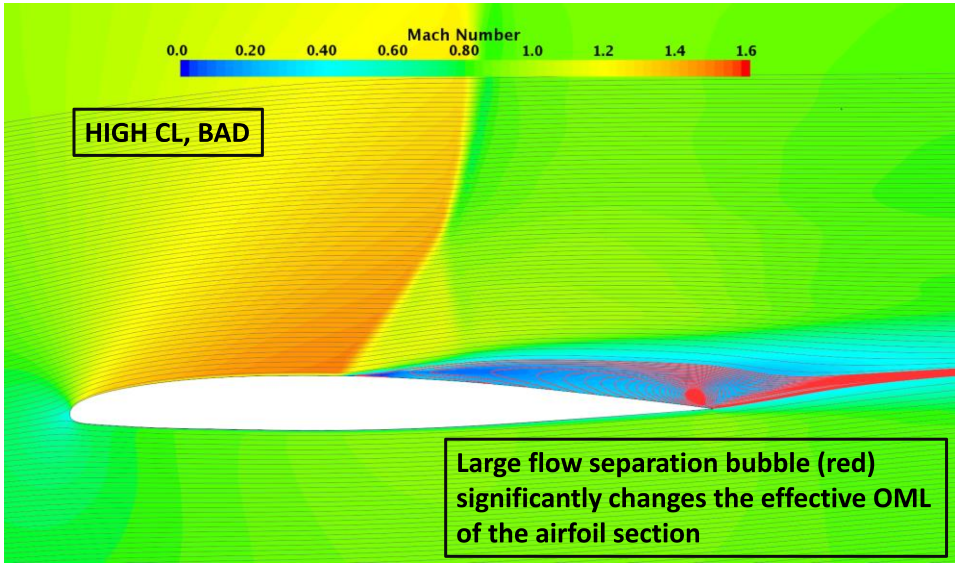
- Higher lift coefficients result in more upstream shock locations
- Higher lift coefficients cause the trailing edge Cp values to be more negative

Lift Effects – Mach Number Contours

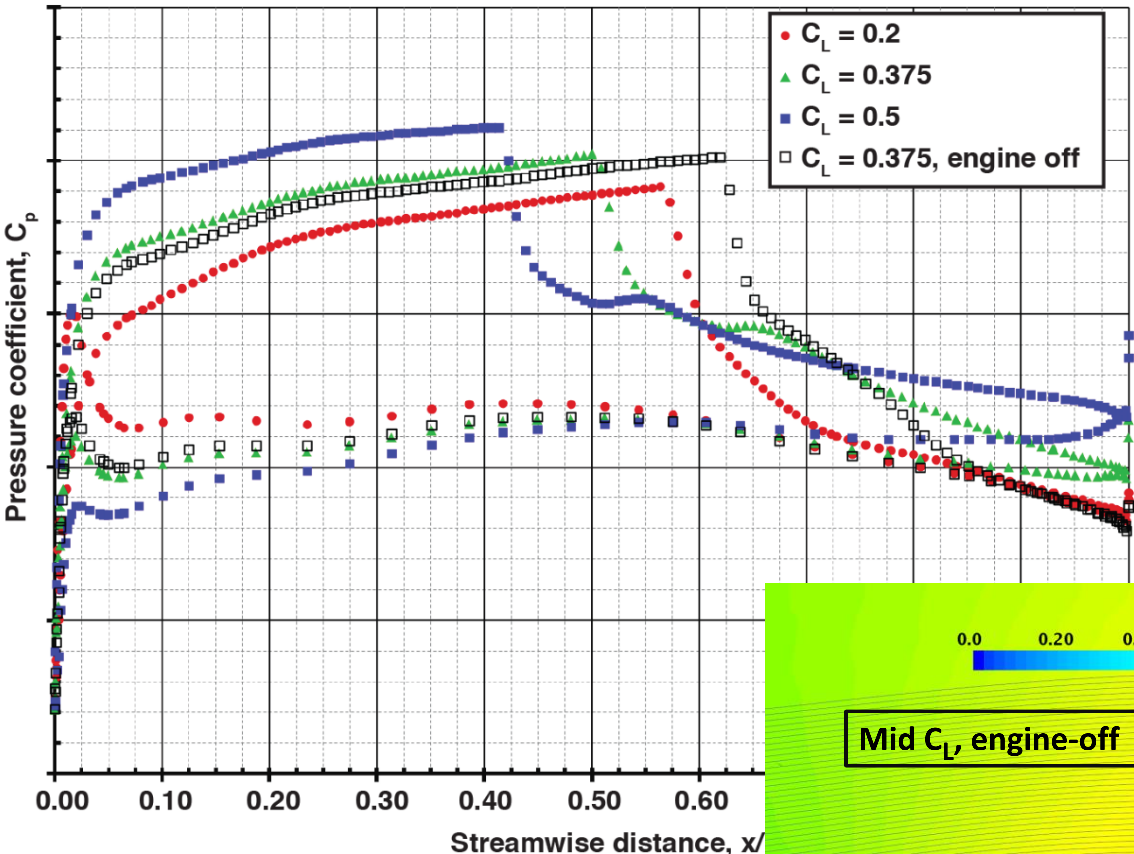


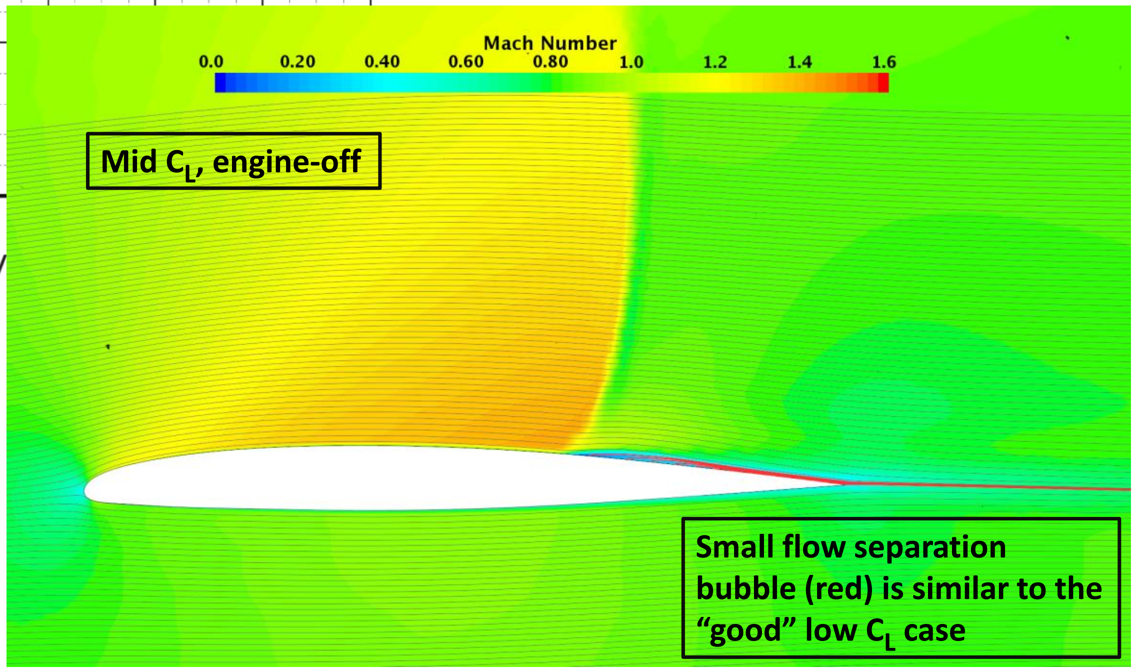


- Contour cuts were made at the same wing span station in the middle of the aileron
- Higher lift coefficients produce worse flows over the wing at high speeds
- Stronger shocks cause larger flow separation regions in the vicinity of the aircraft aileron



Aircraft Engine Effects

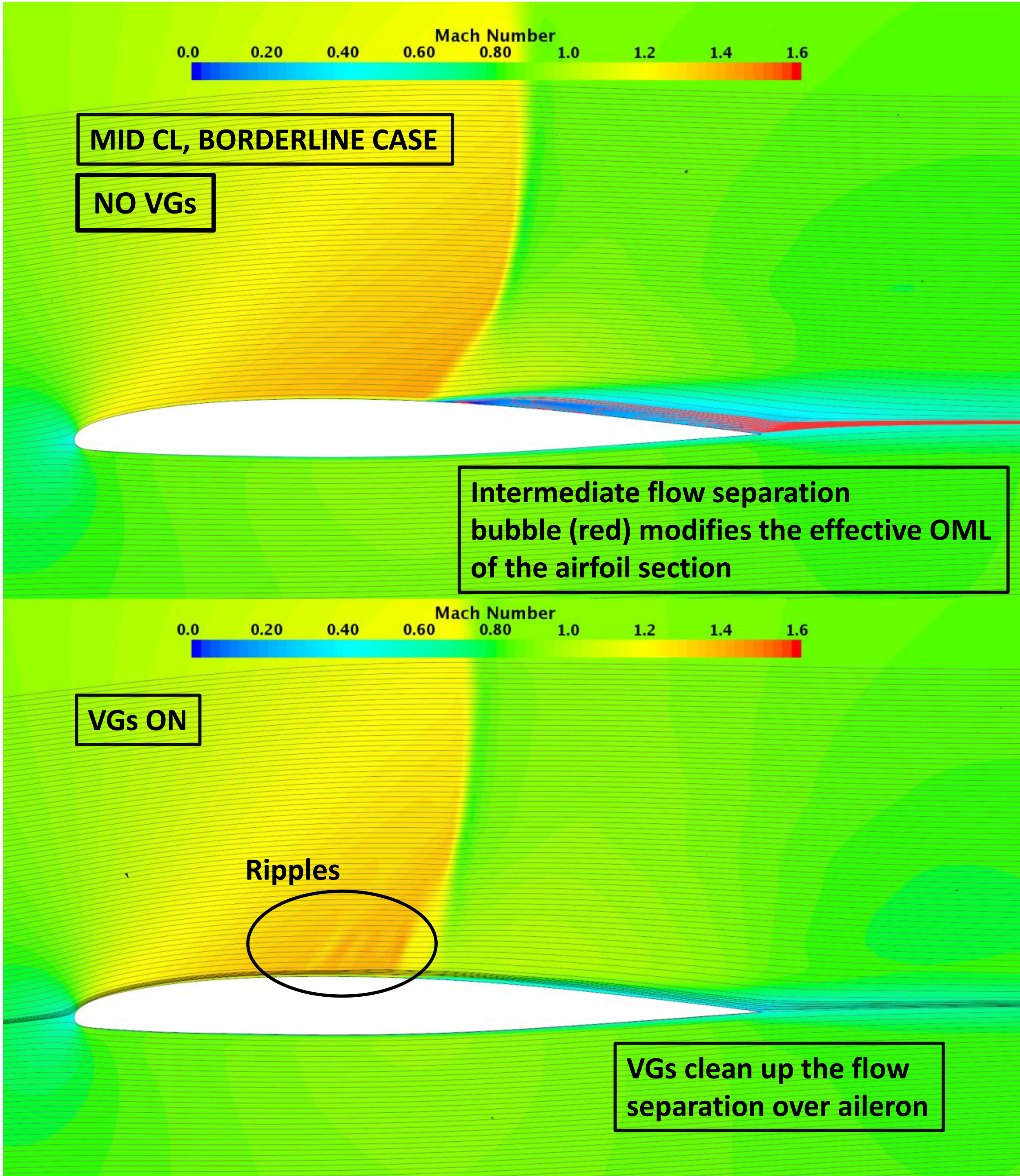




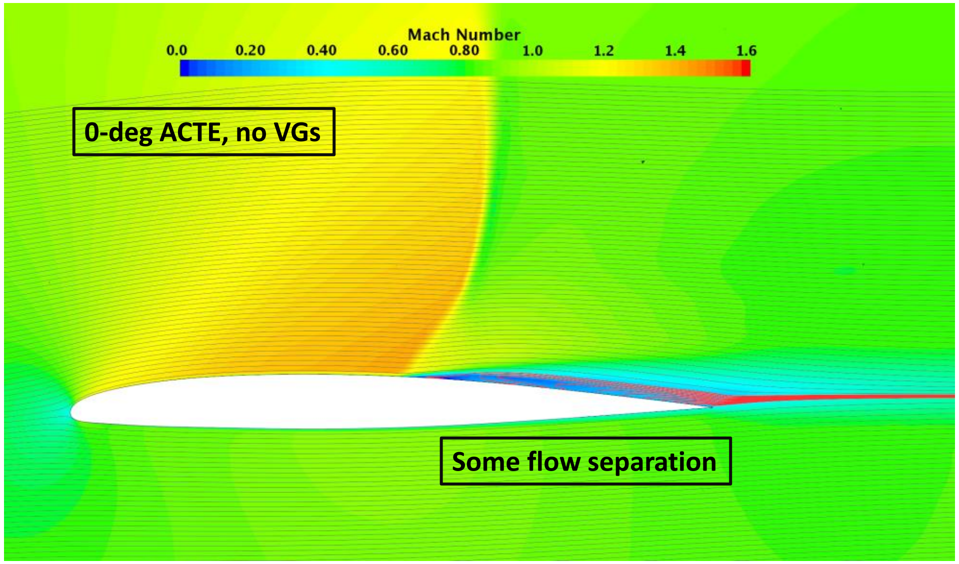
- Blocked engine (with no flow through engine) improves wing aerodynamics

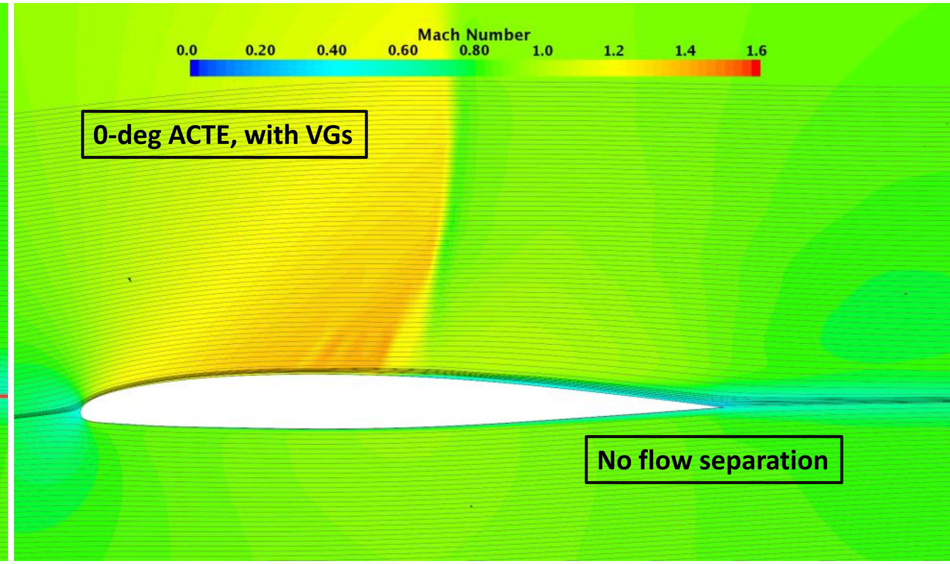
Wing Vortex Generators Effects

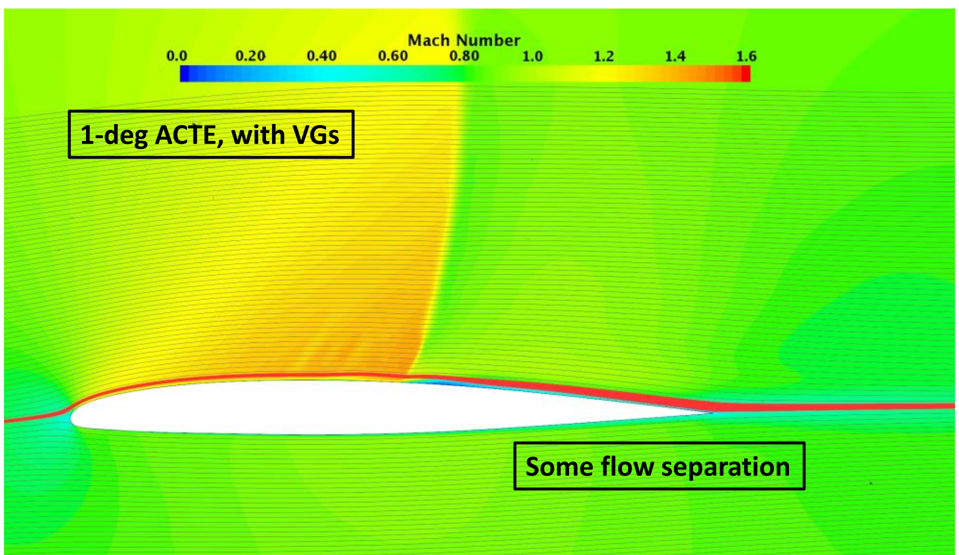
- Ripples in the Mach number contours caused by the VGs
- For the mid C_L case, the VGs completely remove the flow separation seen in the clean wing with no VGs
- VGs improve GIII wing aerodynamics at high speeds

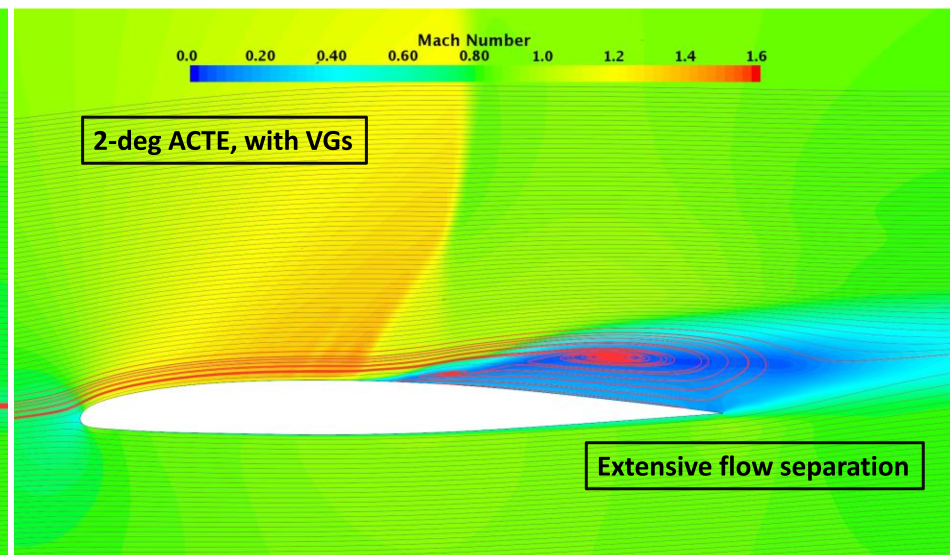


ACTE Flap Effects – Mid C_L









Conclusions

- CFD has made important contributions to the airworthiness and flight safety review process at NASA Armstrong
- The current analysis shows that the aerodynamics of the GIII wing at high speeds are complex
- Wing aerodynamics improve with lower C_L values, engine-off, VGs installed, and smaller ACTE flap deflections
- Inboard ACTE flap deflections affect aerodynamics in the wing outboard region in the vicinity of the aileron
- ACTE flap deflections as small as 1 deg negate the benefits of the VGs
- At 2 deg deflection the ACTE flap produces extensive flow separation in the vicinity of the aileron
    - This would likely result in unacceptable aircraft wing buffet and lateral aircraft control issues
- As the results of the current analysis the flight project flew the ACTE airplane only with the 0-deg ACTE flap deflection at high speeds