LONGITUDINAL AERODYNAMIC MODELING OF THE ADAPTIVE COMPLIANT TRAILING EDGE FLAPS ON A GIII AIRPLANE AND COMPARISONS TO FLIGHT DATA

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Outline

- Introduction/Background
- Project description
- Aerodynamic modeling approach
- Results
- Conclusion

Purpose of this presentation:

- Discuss ACTE aerodynamic modeling efforts and provide comparisons of predictions to flight results for lift and pitching moment increments.

Introduction / Background

- Adaptive Compliant Trailing Edge (ACTE) flaps
  - Gapless flaps that deflect by bending
  - Potential noise reduction, weight savings, and improved aerodynamic efficiency with respect to traditional flaps
  - Flight tested at NASA Armstrong Flight Research Center

- NASA's Environmentally Responsible Aircraft (ERA) project, partnered with U.S. Air Force Research Laboratory

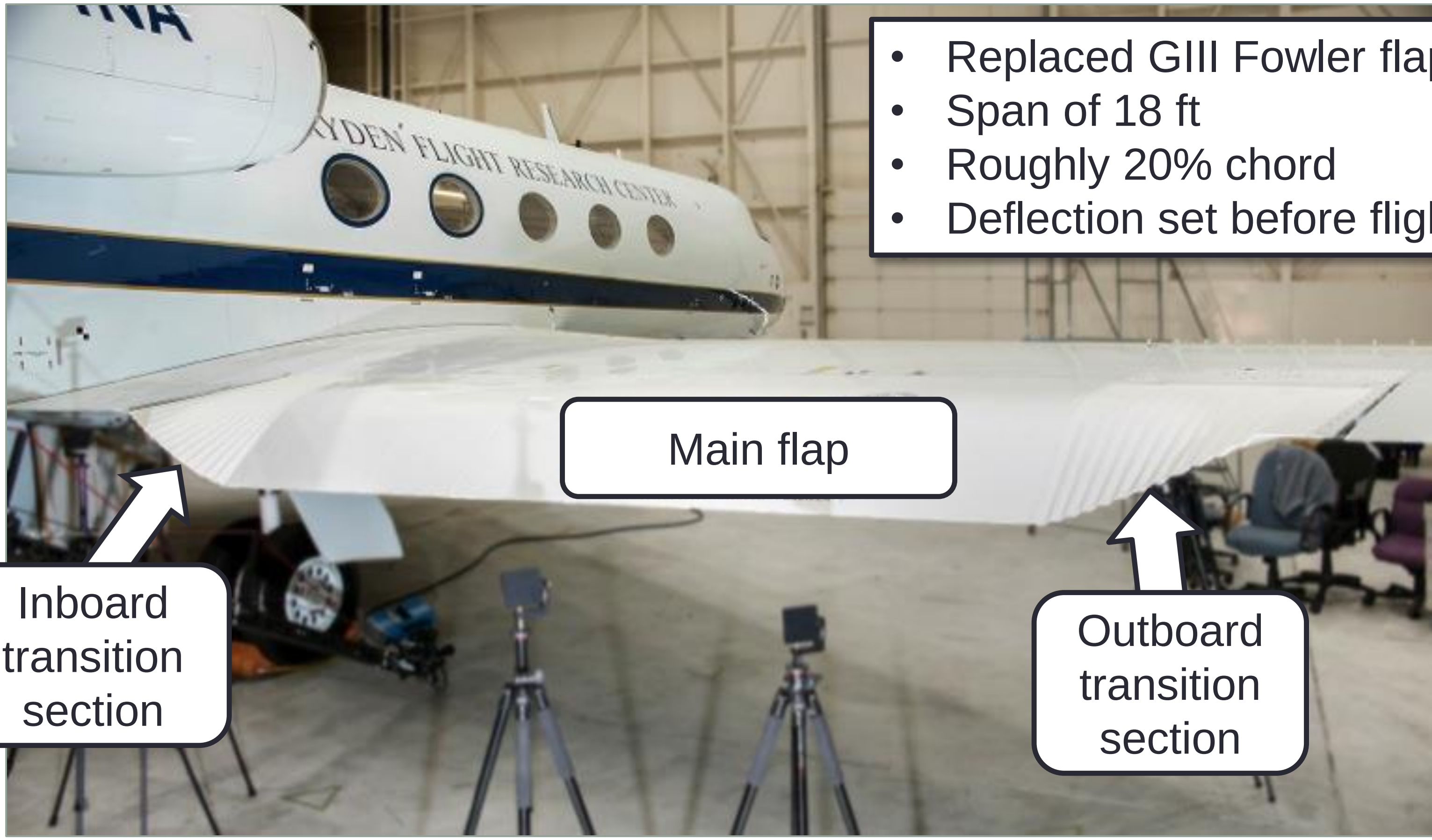
Test Airplane

Gulfstream GIII modified for flight research:

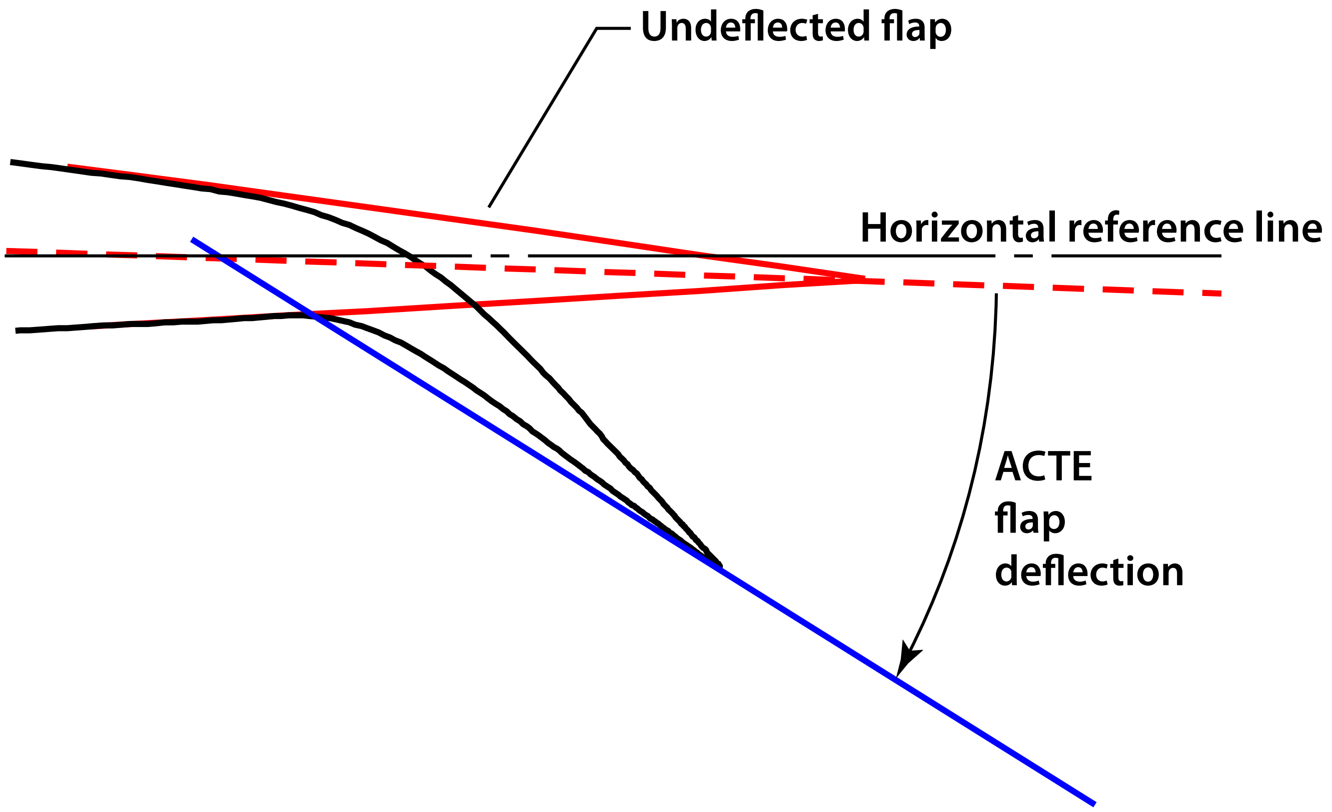
- Flow angle vanes added to the nose
- Embedded GPS/INS (EGI) for rates, accels, Euler angles
- Control surface position measurements
- Pressure measurements and tufts
- Structural measurements

ACTE Flaps

- Replaced GIII Fowler flaps
- Span of 18 ft
- Roughly 20% chord
- Deflection set before flight



ACTE Flap Deflection Definition



ACTE Aerodynamic Modeling

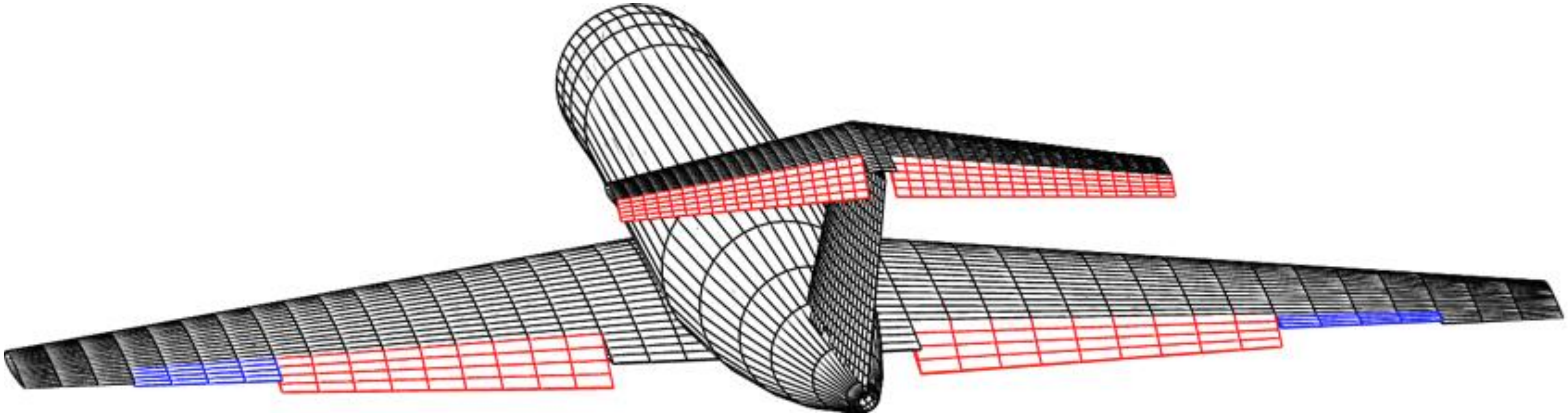
- Purposes of aerodynamic model
  - Add to 6-DOF GIII simulation for pilot training
  - Safety of flight and design reviews
  - Charts for control room
- Approach
  - Stage the work so that intermediate models could be generated to support project milestones
  - Use lower-order methods for initial models, while more complex analyses are being performed
  - Update models with sets of data from the more complex tools when complete

Terms of Interest

- ACTE aerodynamic model consisted of many terms
  - ΔC_L, ΔC_m, ΔC_D, as well as β derivative increments
  - Asymmetric flap deflection effects
  - Missing transition section effects
- For flight comparisons:
  - Focus on lift and pitching moment coefficient increments (ΔC_L and ΔC_m)
  - Could not get ΔC_D (no thrust measurements for calculating C_D)
  - Lateral-directional (β derivative) changes were small and scatter was large

Modeling Tools: Digital Datcom

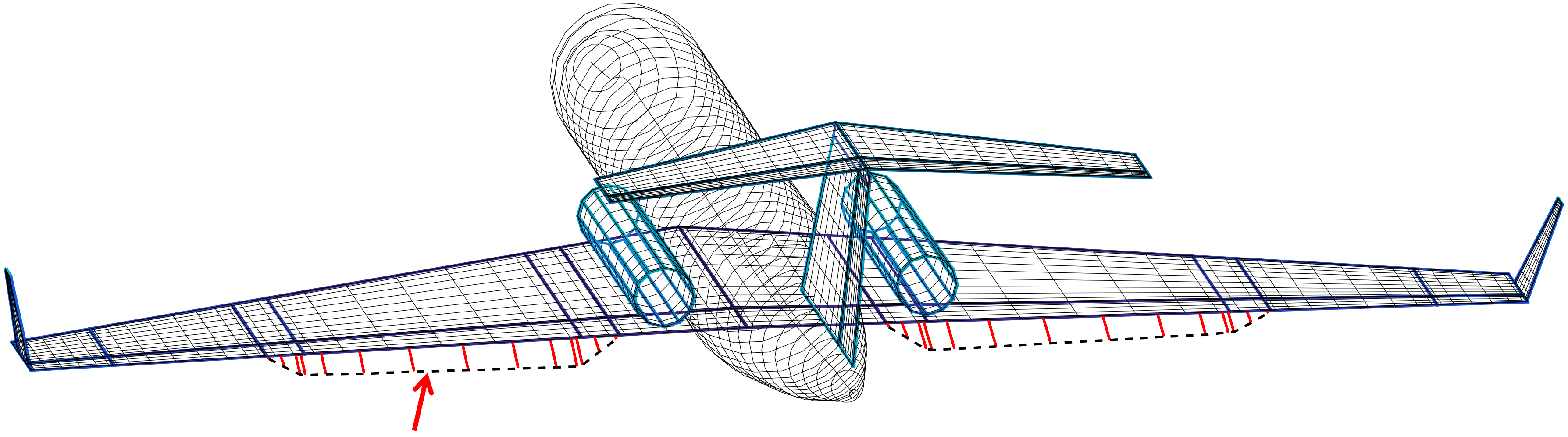
- Digital Datcom
  - Software version of USAF Datcom report
  - ACTE flaps modeled as plain flaps with transition sections included as part of flap area
  - Flap calculations do not involve the rest of the airplane



Graphical representation of full-GIII Datcom setup (Datcom does not use meshes)

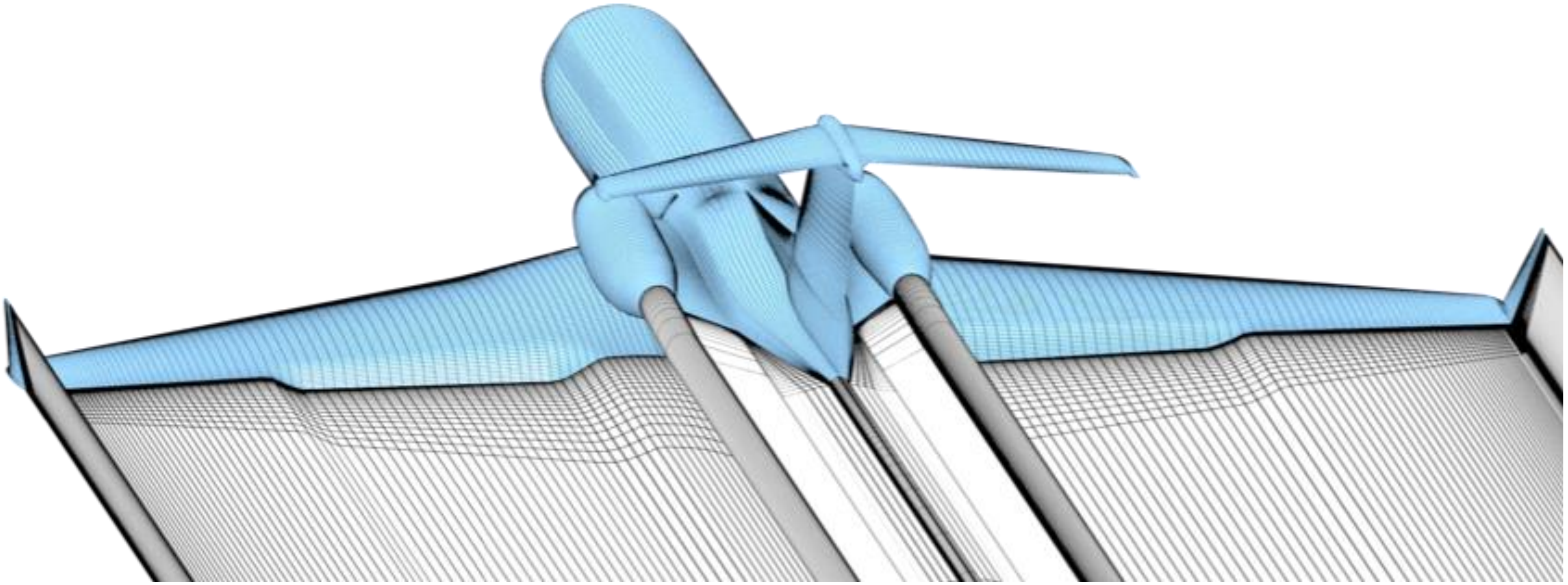
Modeling Tools: AVL

- Athena Vortex Lattice (AVL)
  - Applicability limited to small angles of attack and small flap deflections
  - Compressibility effects through Prandtl-Glauert transformation



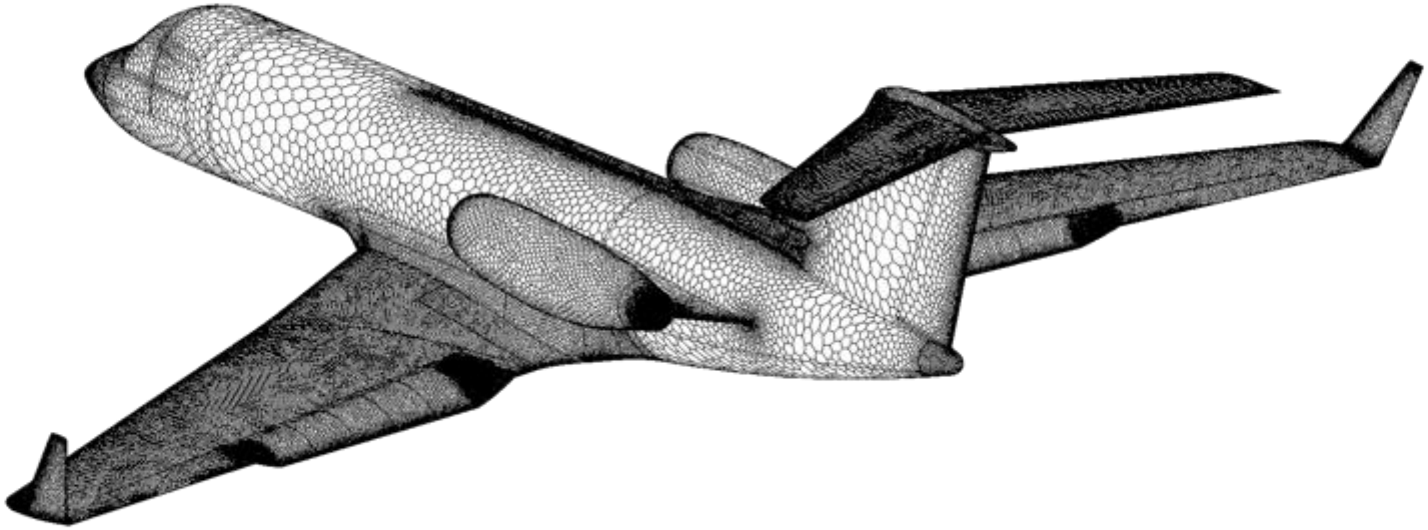
Modeling Tools: TRANAIR

- TRANAIR
  - Full potential flow solver – generally want attached flow
  - Requires surface and wake grids



Modeling Tools: STAR-CCM+

- STAR-CCM+
  - Unstructured, Navier-Stokes
  - SST k-omega turbulence model
  - Around 35 million finite volume cells



Flight ΔC_L & ΔC_m Calculation

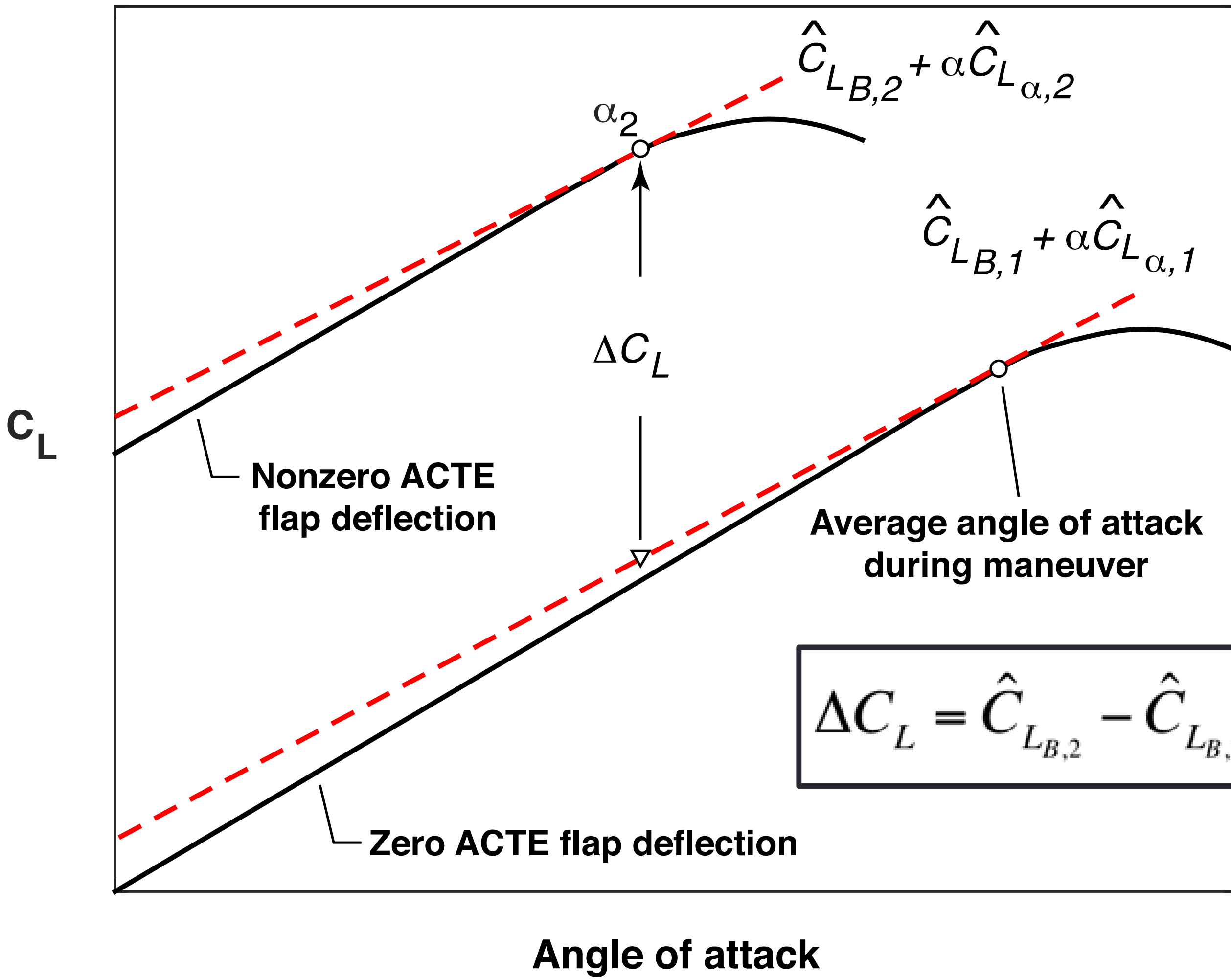
- Use parameter estimation results
  - Makes it possible to remove effects of differences in trim angle of attack and elevator position

$$C_L = C_{L_B} + C_{L_\alpha}\alpha + C_{L_q}\frac{q\bar{c}}{2V_\infty} + C_{L_{de}}de$$

$$\Delta C_L = \hat{C}_{L_{B,2}} - \hat{C}_{L_{B,1}} + \alpha_2\left(\hat{C}_{L_{\alpha,2}} - \hat{C}_{L_{\alpha,1}}\right)$$

(Same setup was used for ΔC_m)

Definition of ΔC_L



$$\Delta C_L = \hat{C}_{L_{B,2}} - \hat{C}_{L_{B,1}} + \alpha_2\left(\hat{C}_{L_{\alpha,2}} - \hat{C}_{L_{\alpha,1}}\right)$$

Flight Results Confidence Regions

- Uncertainties are based on estimated parameter standard errors or Cramér-Rao bounds, corrected for colored residuals
- Estimates for individual maneuvers are combined into a weighted mean and a weighted standard error
- Overall uncertainty for the estimated increments:

$$U^2 \approx \hat{\sigma}^2_{C_{L_{B,2}}} + \hat{\sigma}^2_{C_{L_{B,1}}} + \left(\alpha_2 \hat{\sigma}_{C_{L_{\alpha,2}}}\right)^2 + \left(\alpha_2 \hat{\sigma}_{C_{L_{\alpha,1}}}\right)^2$$

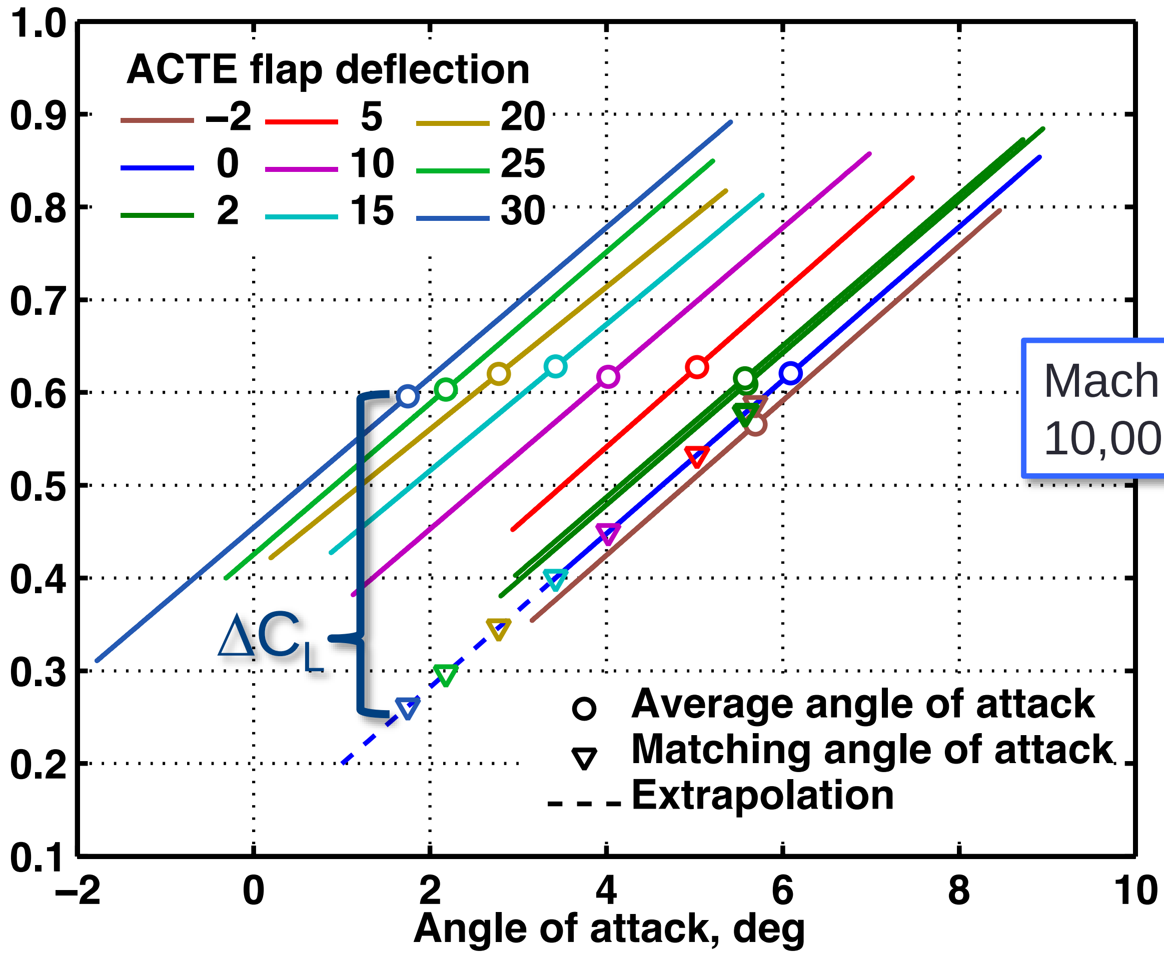
- Confidence regions for plots are based on 2*U about the weighted means of the parameter estimates

Flight Summary

- ACTE flight test series spanned 23 flights
- Parameter estimation info:
  - 153 test points
  - Used 2-1-1 maneuvers, equation error and output error techniques
  - Some unreconciled differences between the two parameter estimation techniques, mostly at ends of Mach range
    - For deflections of 10 deg and greater, ΔC_L differences were 6% or less and ΔC_m differences were less than 10%
    - Results to be shown here are from output error

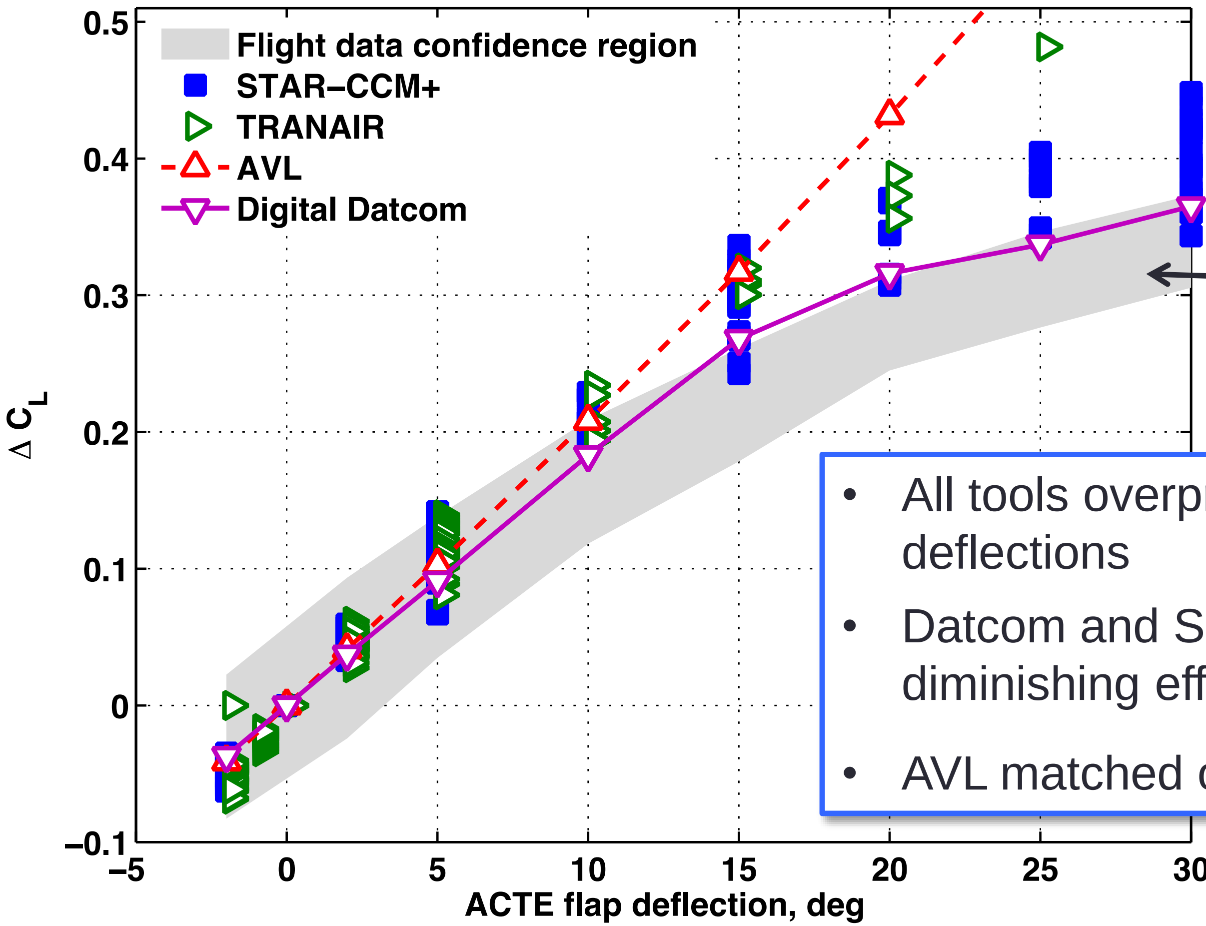
Estimated Linear C_L Models

$$\hat{C}_{L_B} + \alpha \hat{C}_{L_\alpha}$$



Mach 0.3
10,000 ft MSL

ΔC_L vs. ACTE Flap Deflection

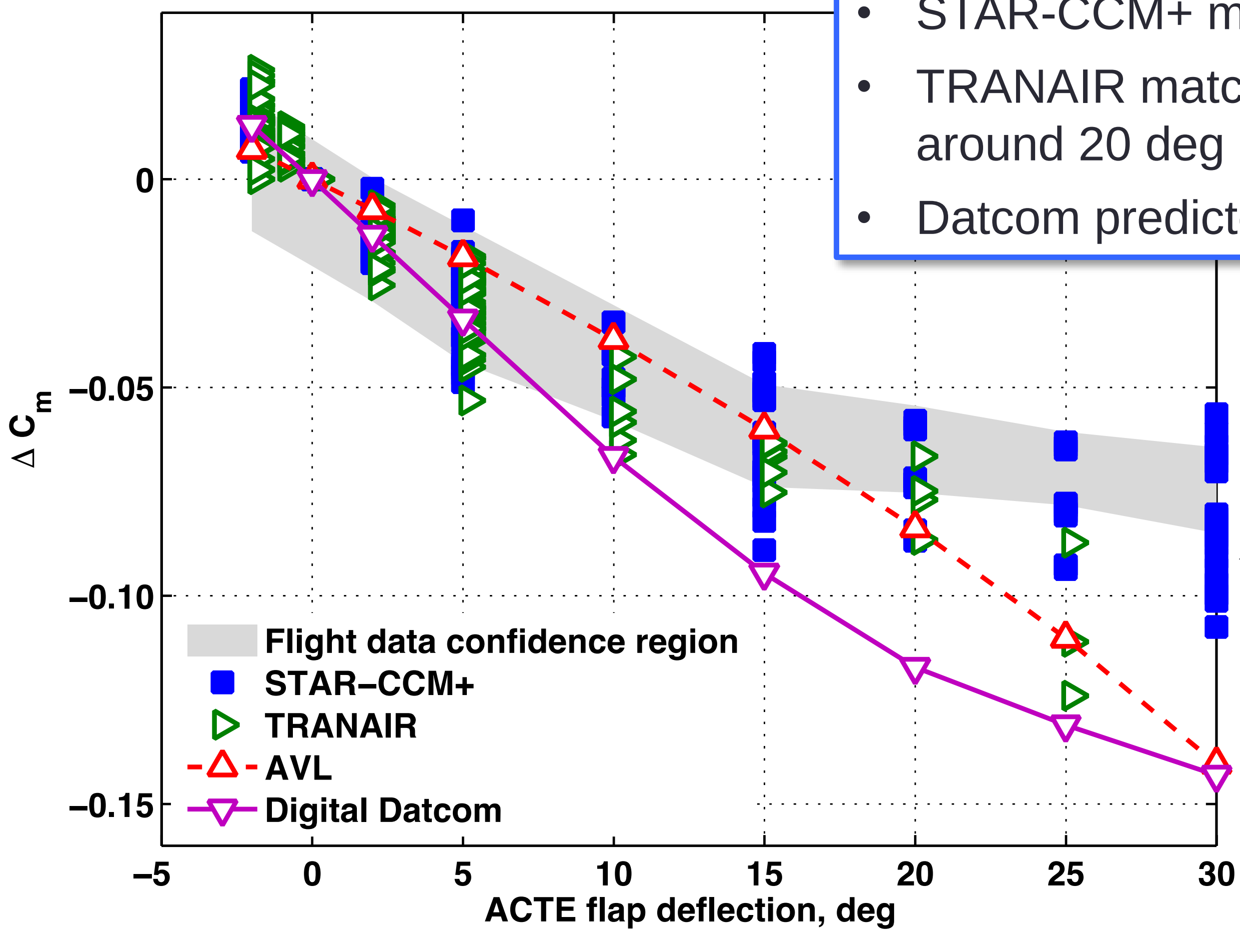


CFD results include different altitudes and AOA

*Confidence region is based on 2*U for flight results…*

- All tools overpredicted ΔC_L at high deflections
- Datcom and STAR-CCM+ predicted diminishing effectiveness
- AVL matched others through 10 deg

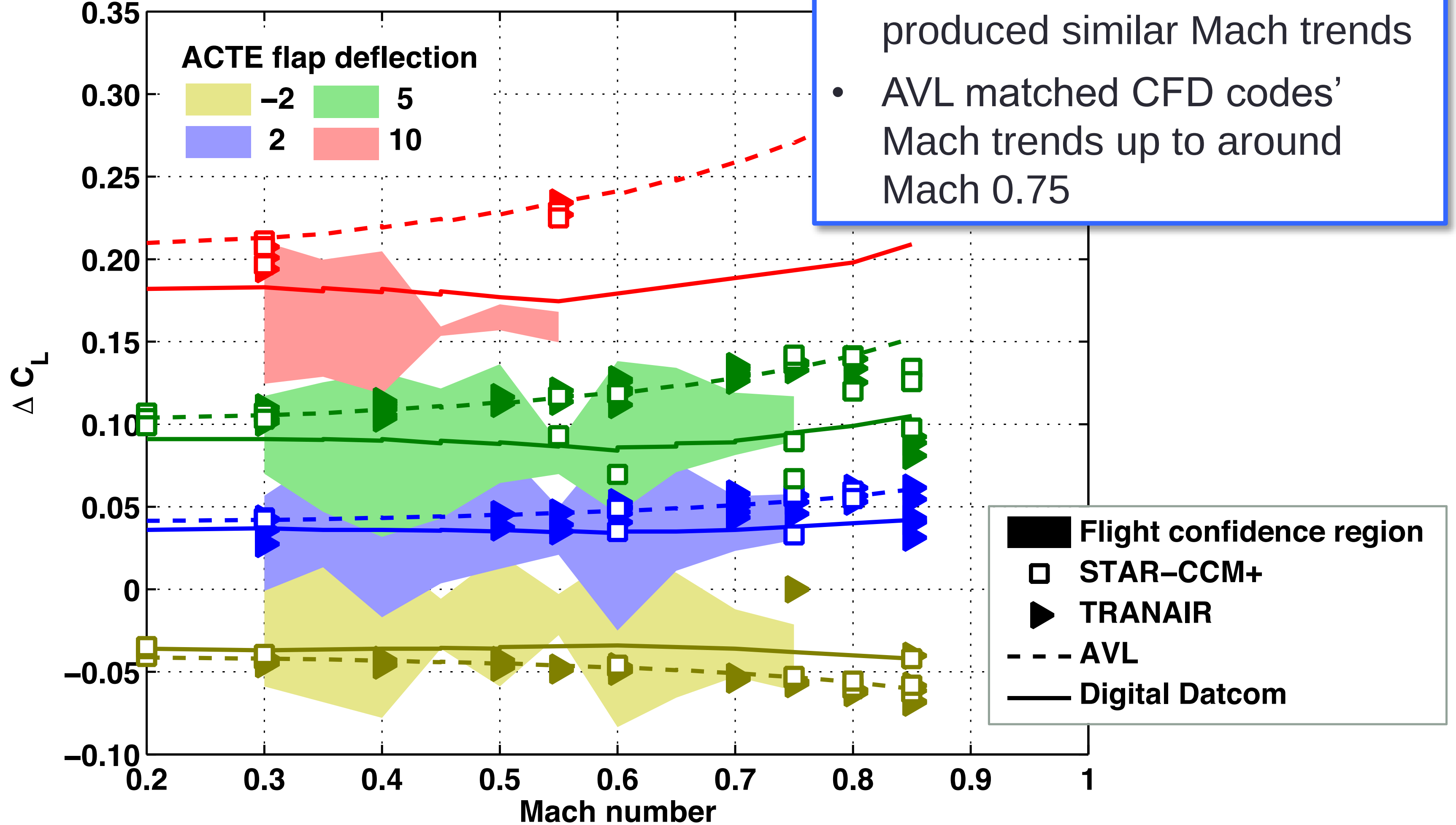
ΔC_m vs. ACTE Flap Deflection



- STAR-CCM+ matched trend
- TRANAIR matched trend up to around 20 deg
- Datcom predicted a steeper slope

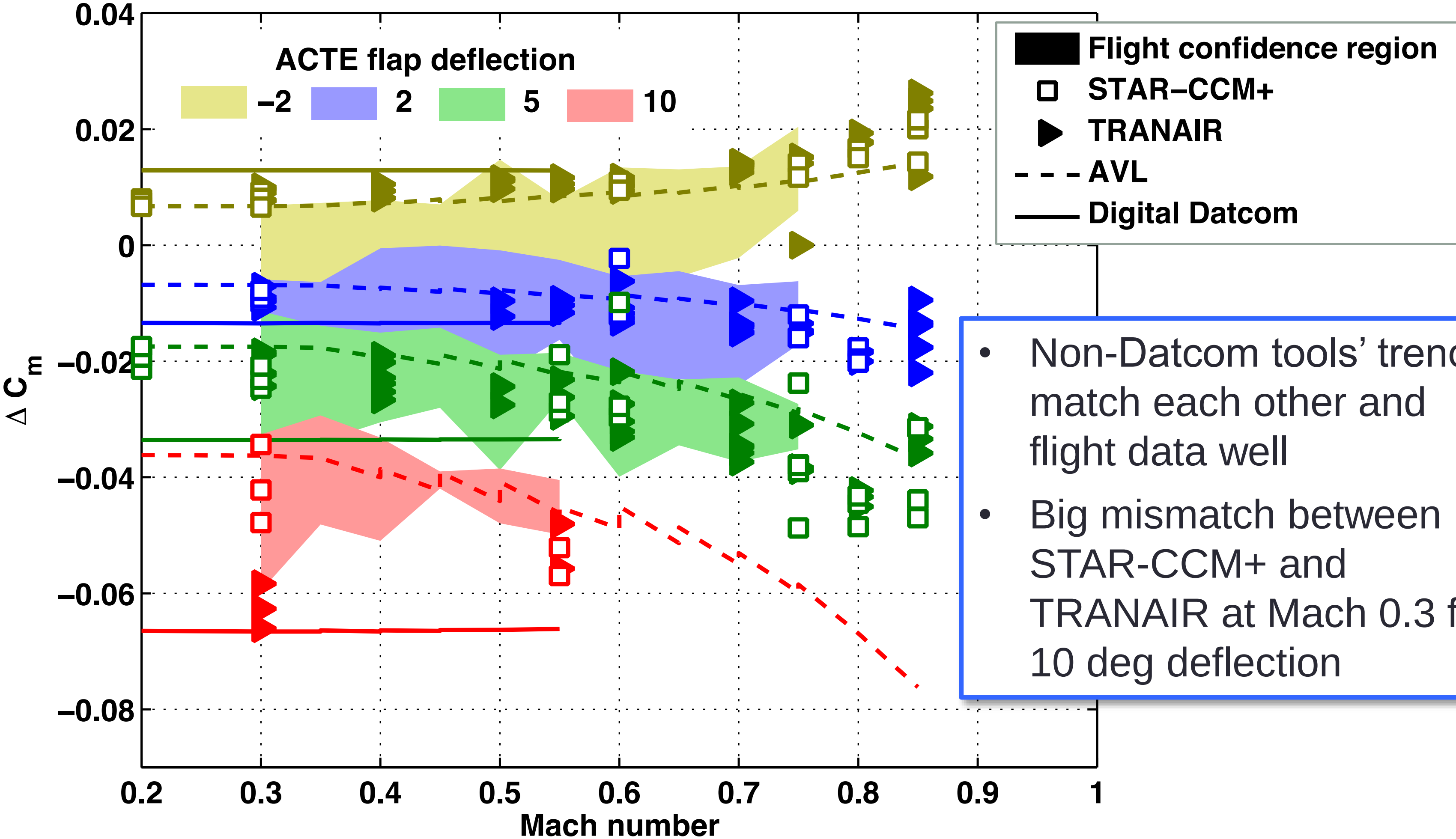
CFD results include different altitudes and angles of attack

ΔC_L vs. Mach Number



- STAR-CCM+ and TRANAIR produced similar Mach trends
- AVL matched CFD codes' Mach trends up to around Mach 0.75

ΔC$_m$ vs. Mach Number



- Non-Datcom tools' trends match each other and flight data well
- Big mismatch between STAR-CCM+ and TRANAIR at Mach 0.3 for 10 deg deflection

Summary of Results

- Digital Datcom
  - Good for ΔC_L; not as good for ΔC_m and Mach trends
  - Program may be buggy
  - In hindsight, would be better off using regular Datcom for this problem
- AVL
  - Matched CFD codes well up through 10 deg of flap deflection
  - Matched CFD codes' Mach number trends very well
- TRANAIR
  - Comparable results to Navier-Stokes up to around 20 deg of flap deflection
- STAR-CCM+
  - Didn't get ΔC_L completely correct, but is still probably trusted more than other tools

Concluding Remarks

- Parameter estimation approach to computing ΔC_L and ΔC_m worked well, uncertainties may be inadequate
- All tools overpredicted ΔC_L due to flaps at high deflection angles and the quality of ΔC_m results varied
- Lower-order prediction tools produced reasonable results for small flap deflections
- Results suggest the simpler tools were adequate for modeling ACTE flaps for certain speeds and deflections
  - Navier-Stokes solutions could be targeted to cases where the other tools are not appropriate
  - The results validate the approach used for creating the ACTE aerodynamic model