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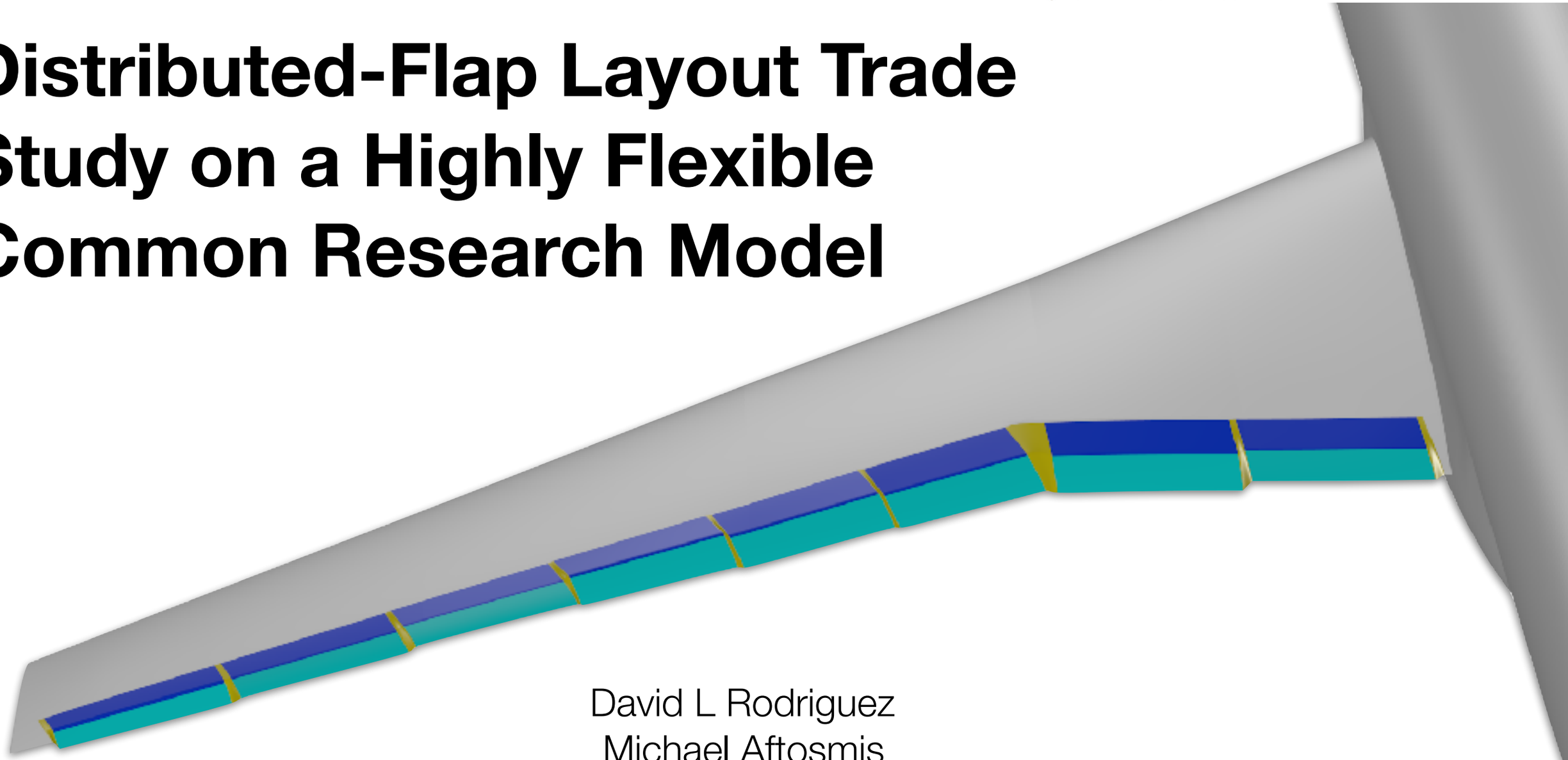
Distributed-Flap Layout Trade Study on a Highly Flexible Common Research Model



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June 27, 2018
Aviation Forum

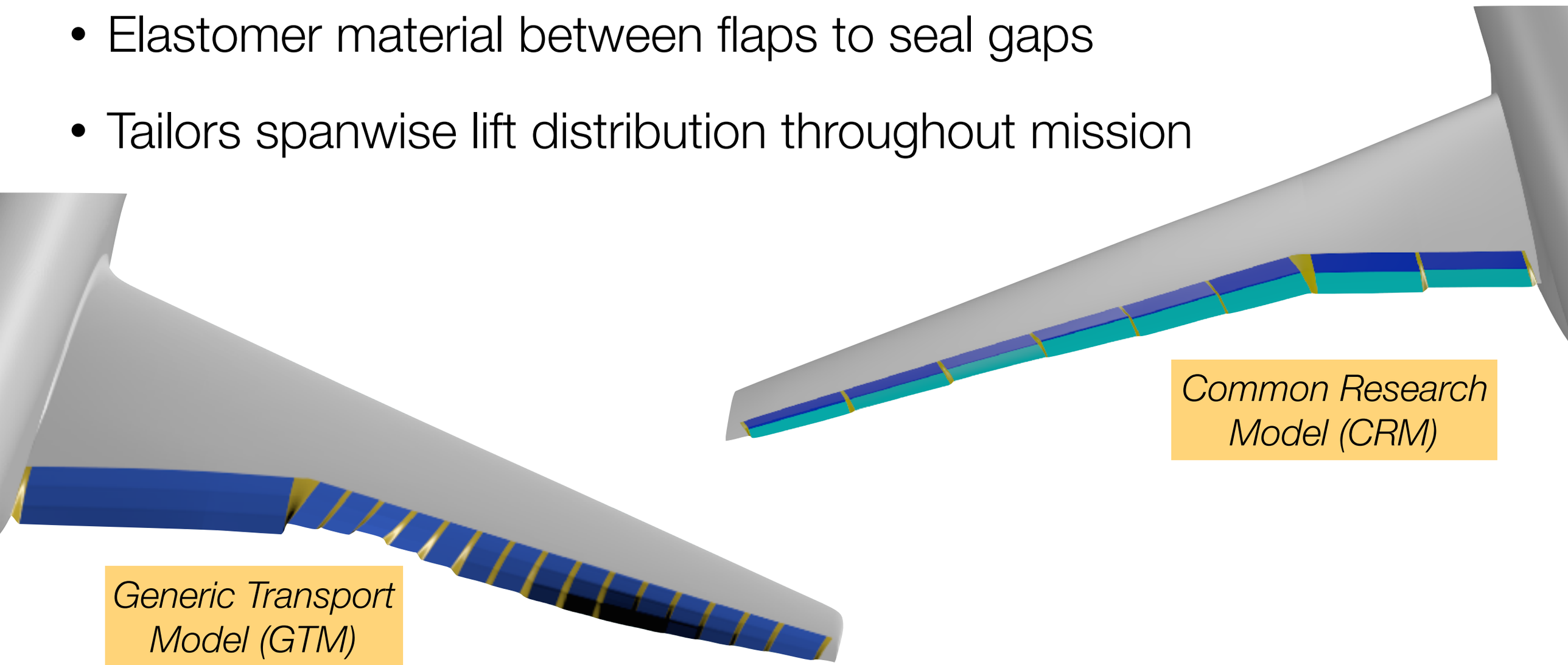
NASA Ames Research Center

Computational Aerosciences Branch

Advanced Supercomputing Division

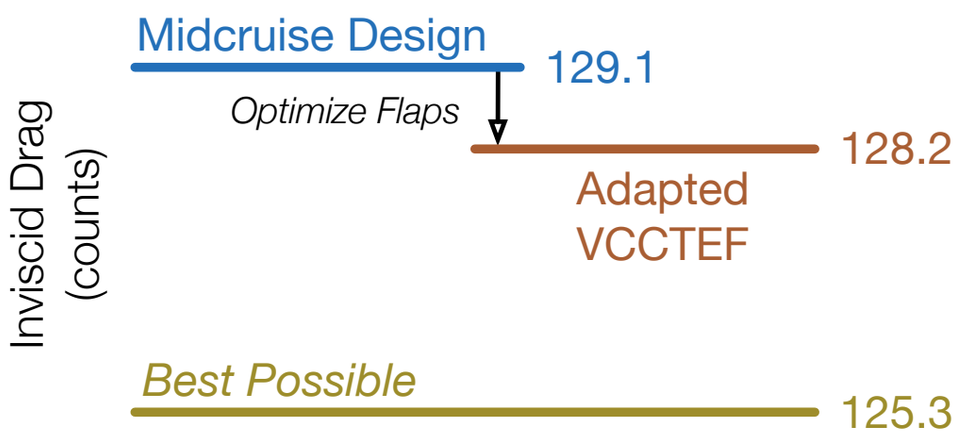
VCCTEF Concept

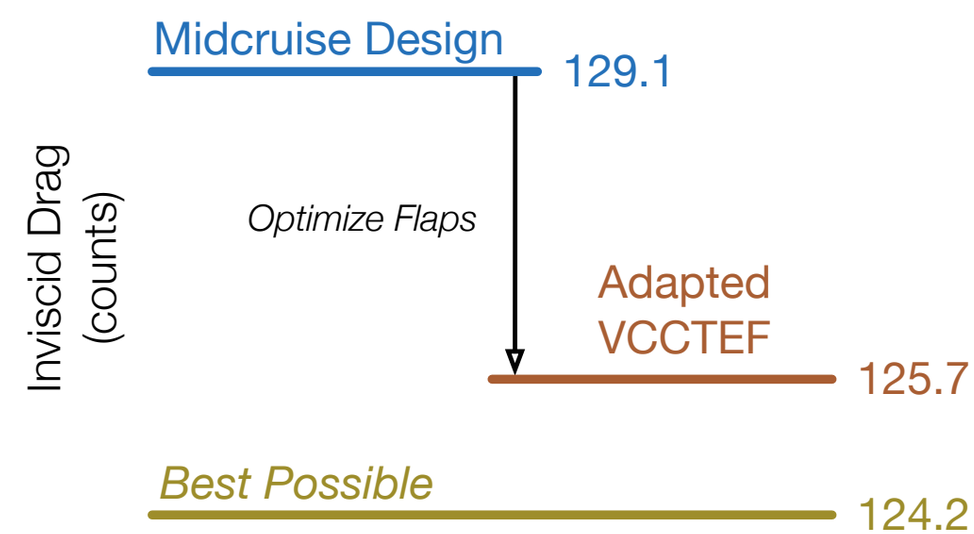
- **V**ariable **C**amber **C**ontinuous **T**railing **E**dge **F**laps
- Flaps distributed over most of the span of the wing
- Elastomer material between flaps to seal gaps
- Tailors spanwise lift distribution throughout mission

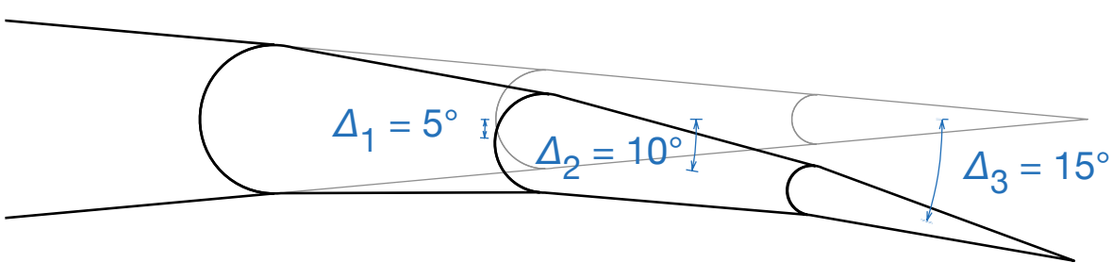


Motivation

- Early application of VCCTEF on GTM on overspeed case indicated wave drag could also be significantly reduced
- More effective if circular deflection relaxed



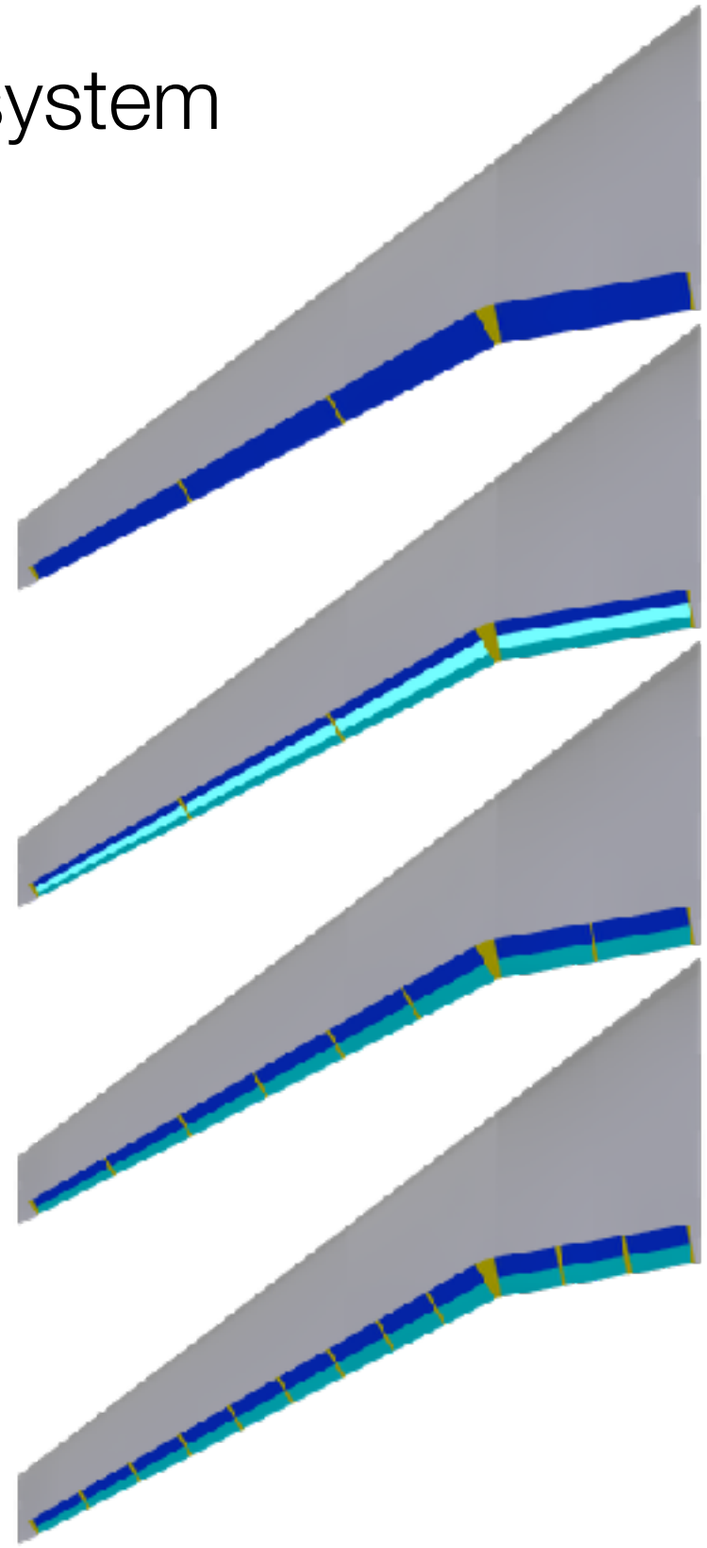




$\Delta_2 = 2\Delta_1, \Delta_3 = 3\Delta_1$

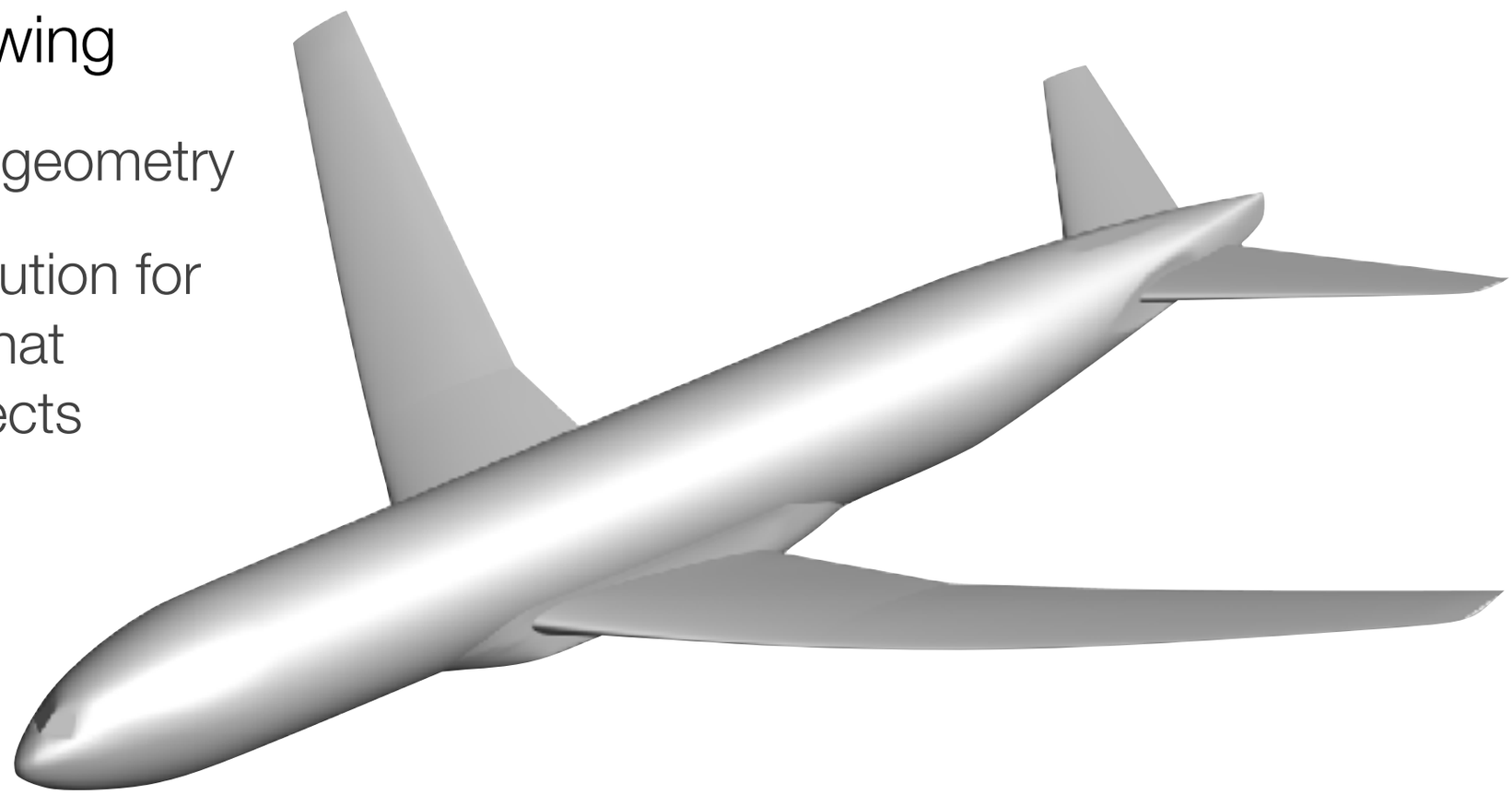
Goals and Methods

- Determine how complex a distributed flap system must be to be effective for overspeed drag reduction
  - how many spanwise flaps?
  - how many chordwise segments per flap?
- Flap layout trade study
  - Install various layouts with different number of spanwise flaps and chordwise segments
  - Optimize flap deflections on all layouts at overspeed condition
  - Examine results for trends

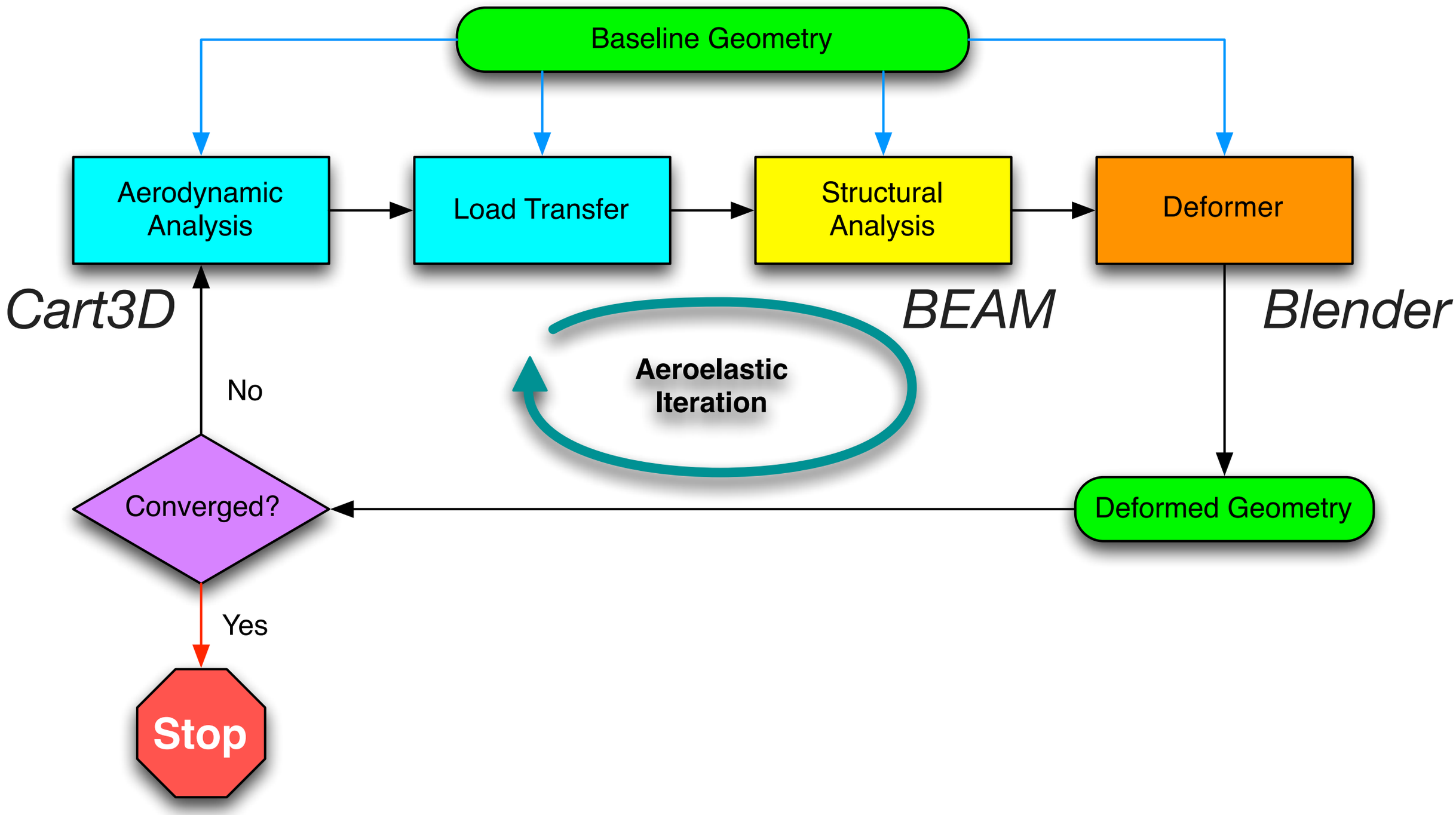


Platform for Trade Study

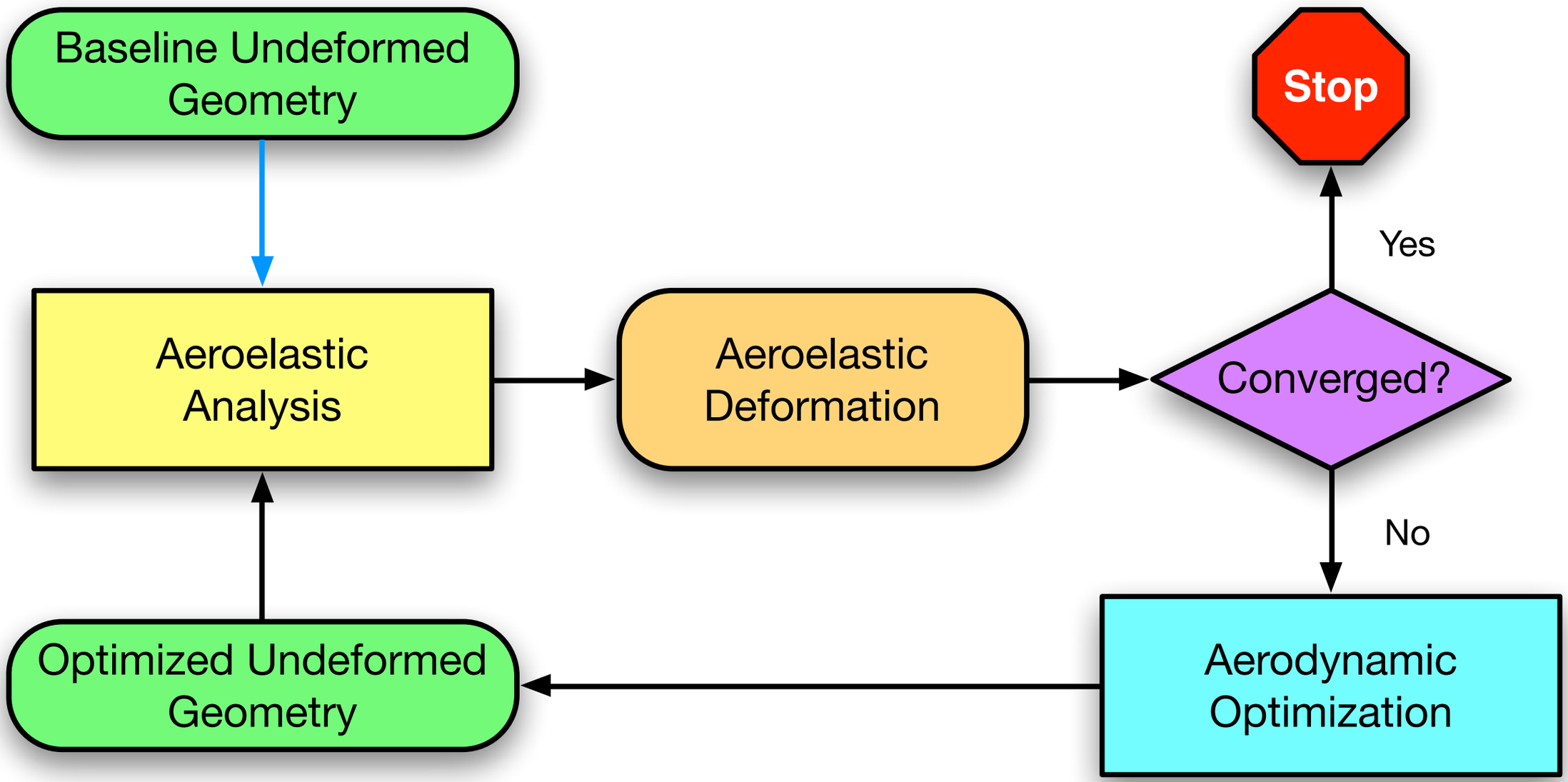
- Common Research Model (CRM) fuselage/wing/horizontal tail configuration)
- Assume composite wing
  - remove built in deformation from original CRM geometry
  - develop structural model that exhibits greater deformation (about twice original)
- Develop new baseline wing
  - start with original CRM geometry
  - re-optimize twist distribution for cruise using methods that address aeroelastic effects
    - minimize drag
    - constrain lift
    - maintain trim



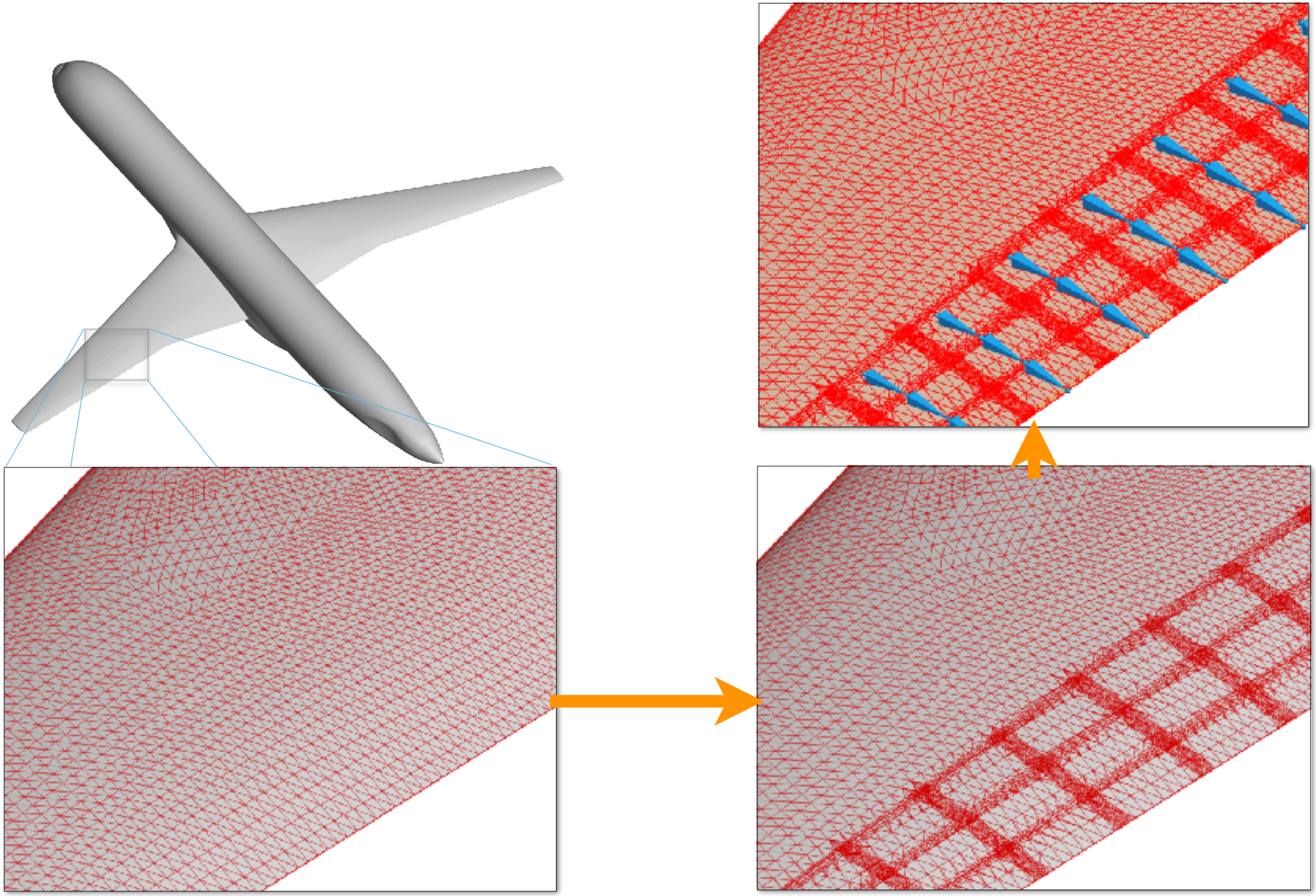
Static Aeroelastic Analysis Architecture



Aerodynamic Shape Optimization Architecture

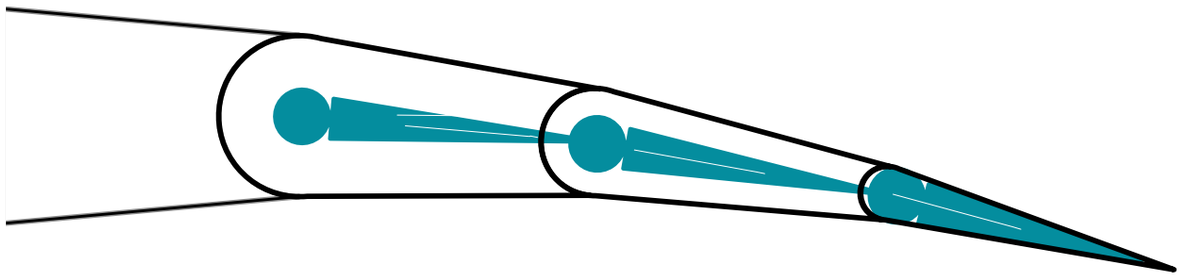


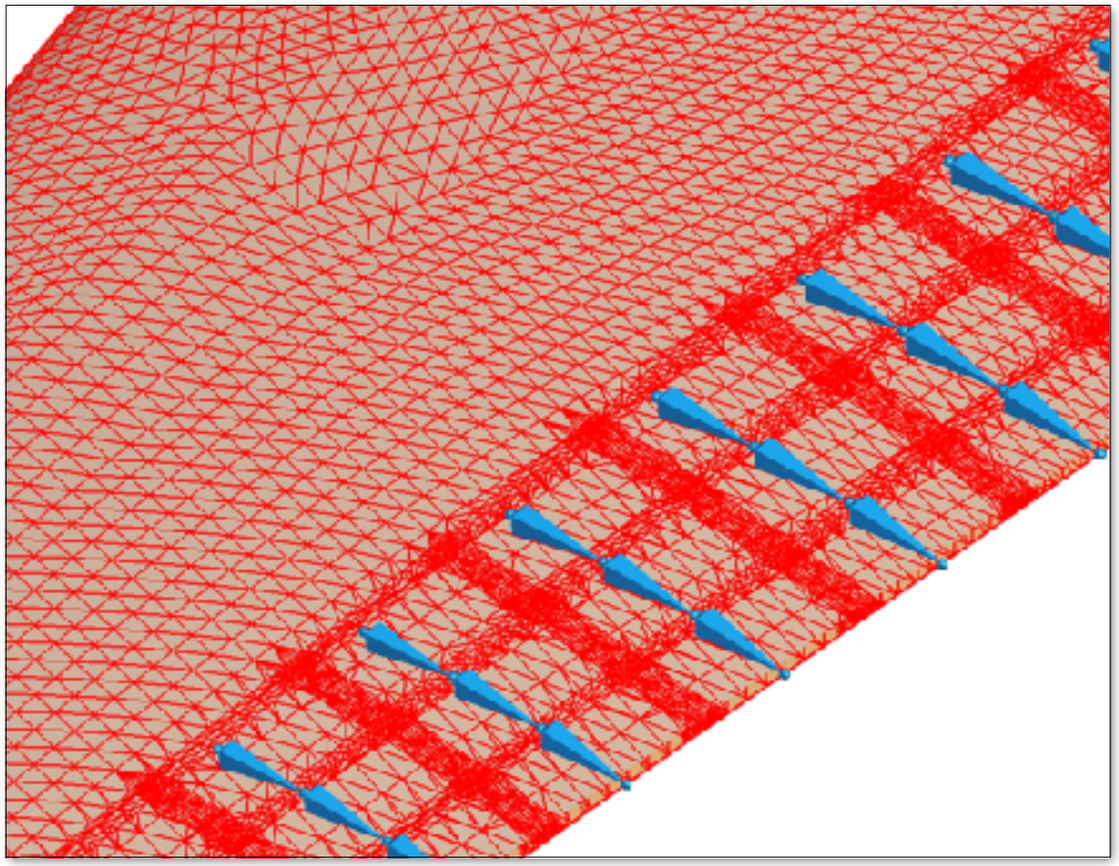
Modeling the VCCTEF

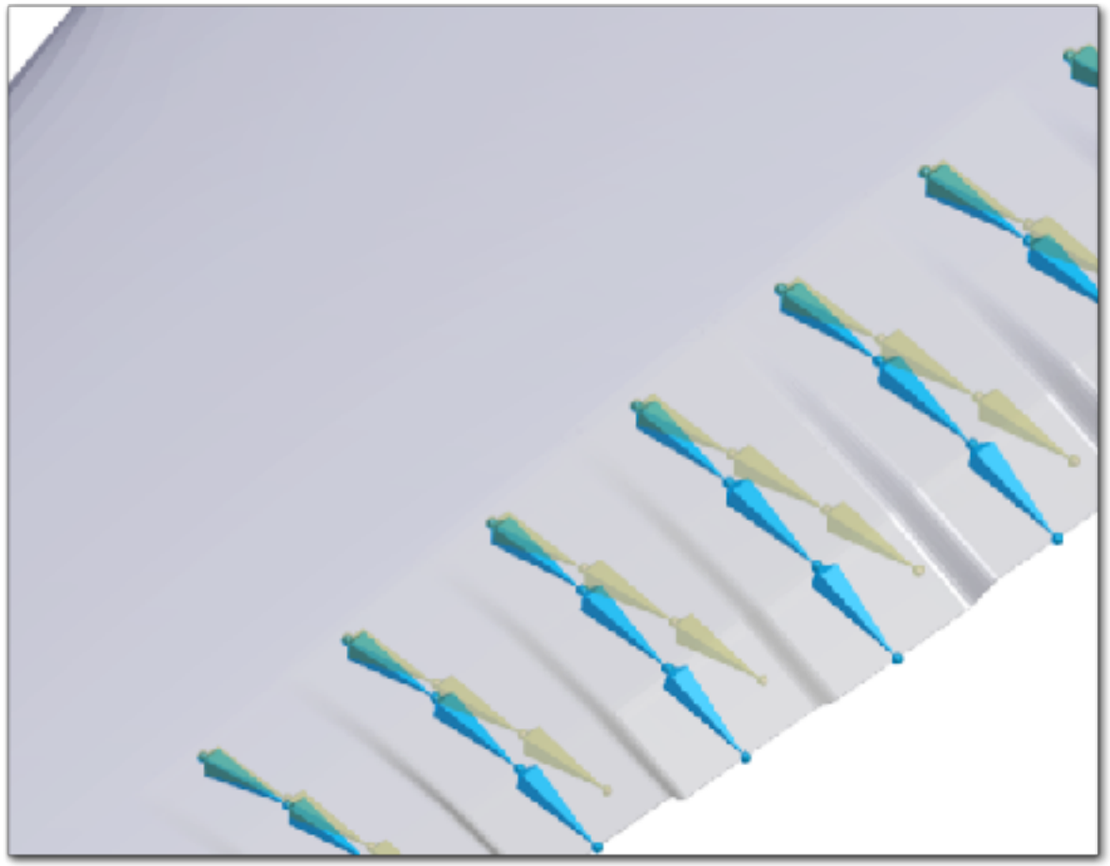


Modeling the VCCTEF

- Flap deflections controlled by Blender “armature” (analogous to a skeleton)
- Surface triangulation is bound to “bones”
- Bones can only rotate about hinge lines
- Sequential flaps bones linked to each other
- Blended transition between flaps to mimic elastomer material







Establishing a New Baseline CRM Design

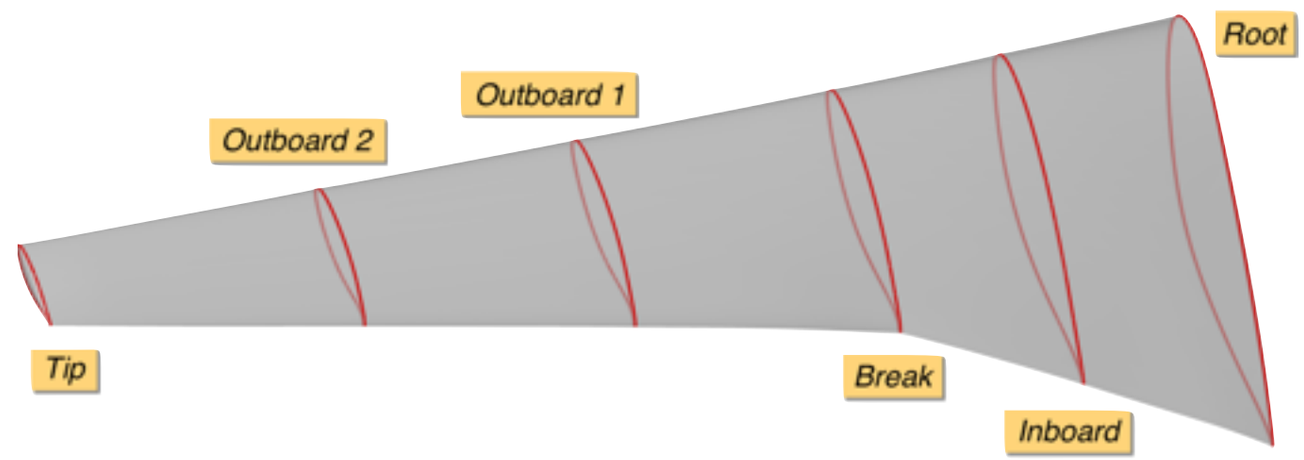
- CRM wing twist distribution re-optimized with more flexible structure
- Minimize drag (C_D) at cruise condition ($M_\infty = 0.85$)
  - maintain cruise lift ($C_L = 0.5$)
  - maintain longitudinal trim ($C_M = 0$)
  - cabin deck angle constraint ($\boldsymbol{\alpha}_{max} = 3°$)
- Design variables
  - section incidence at 6 spanwise stations (including root), while linearly vary change in incidence between stations
  - angle of attack (helps satisfy lift constraint)
  - tail incidence (helps satisfy trim)

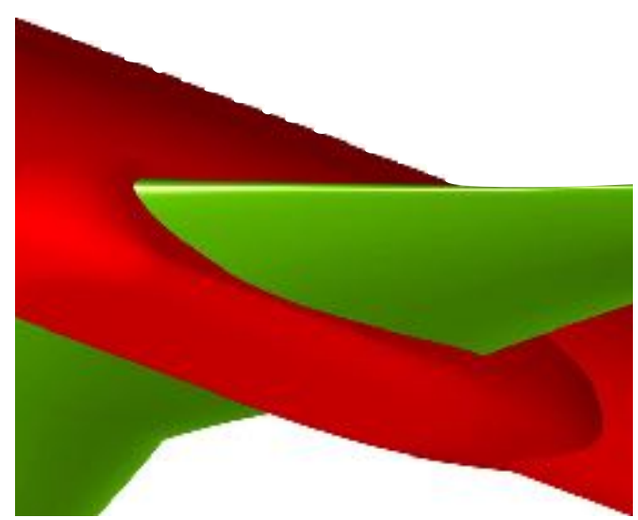
$$\text{minimize:} \quad C_D\,(\alpha, \boldsymbol{\theta}_w, i_t)$$

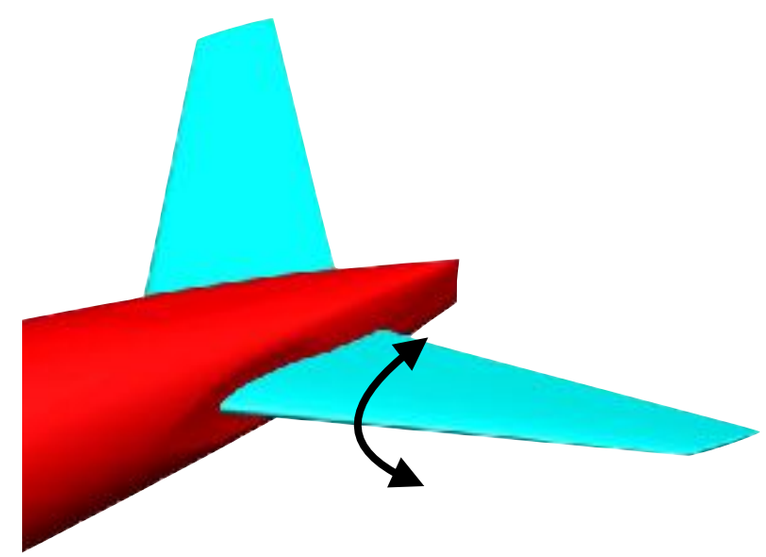
$$\text{subject to:} \quad C_L\,(\alpha, \boldsymbol{\theta}_w, i_t) = C_{L,cruise} = 0.5$$

$$C_M\,(\alpha, \boldsymbol{\theta}_w, i_t) = 0$$

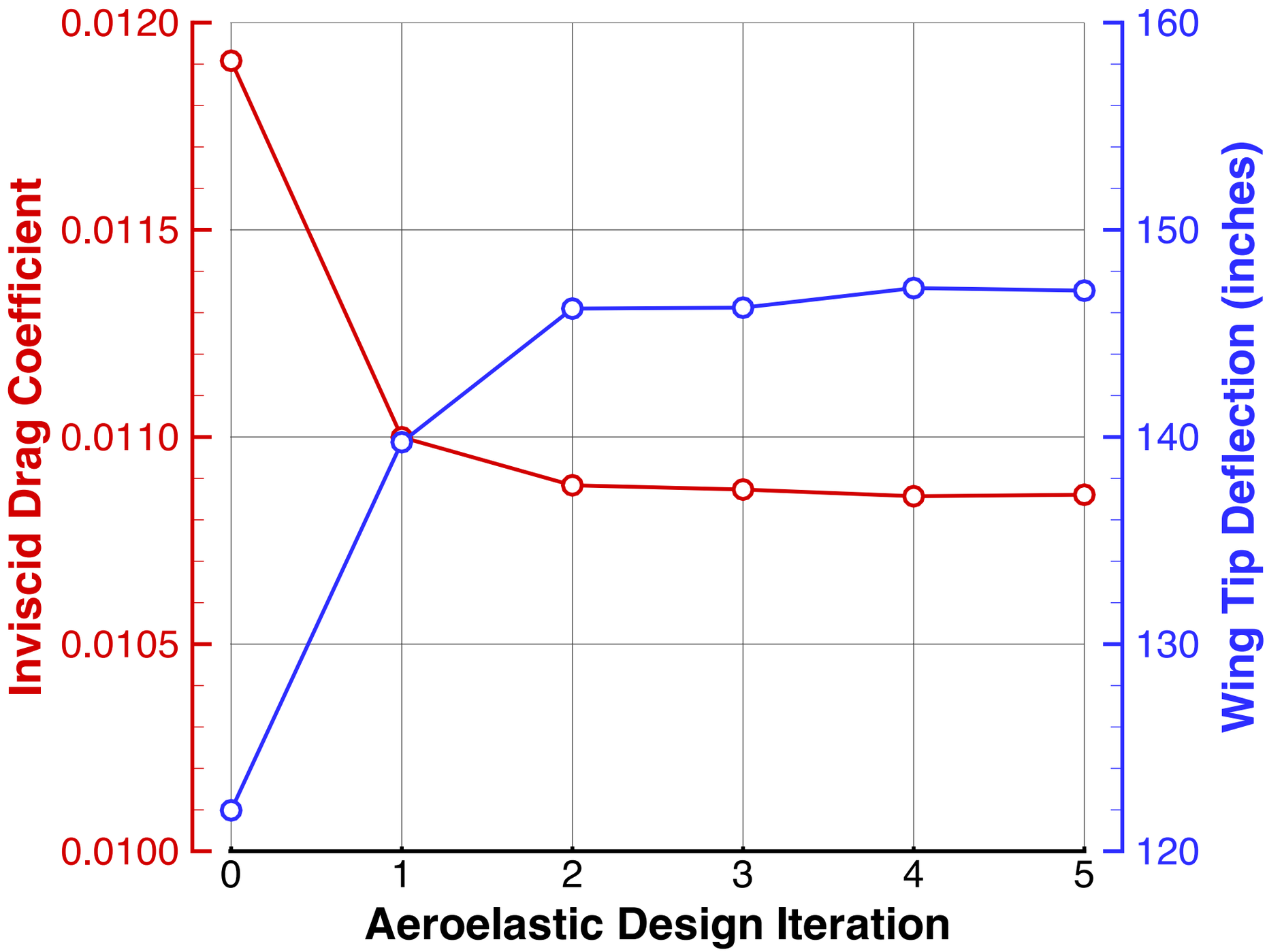
$$\alpha \leq \alpha_{max}$$



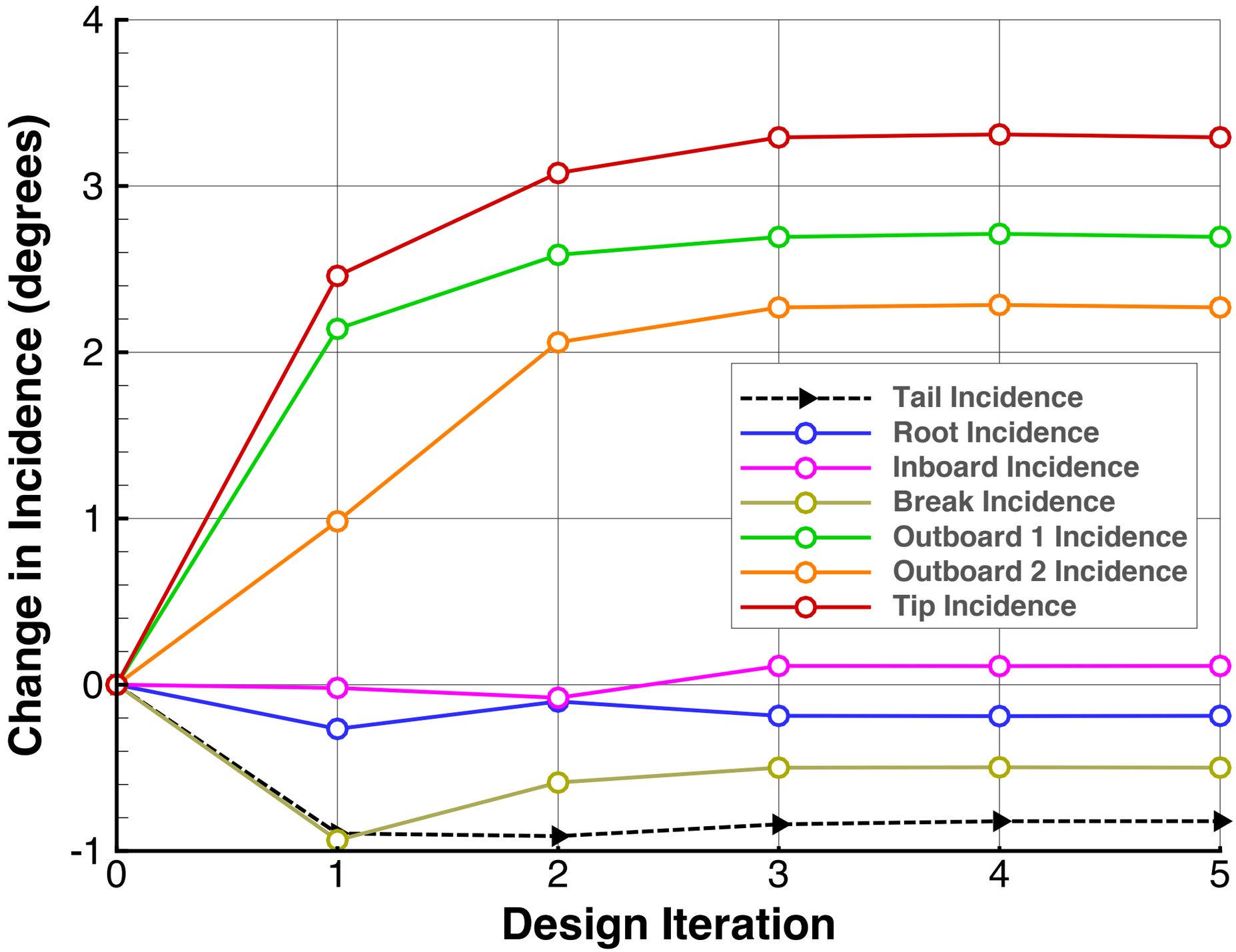




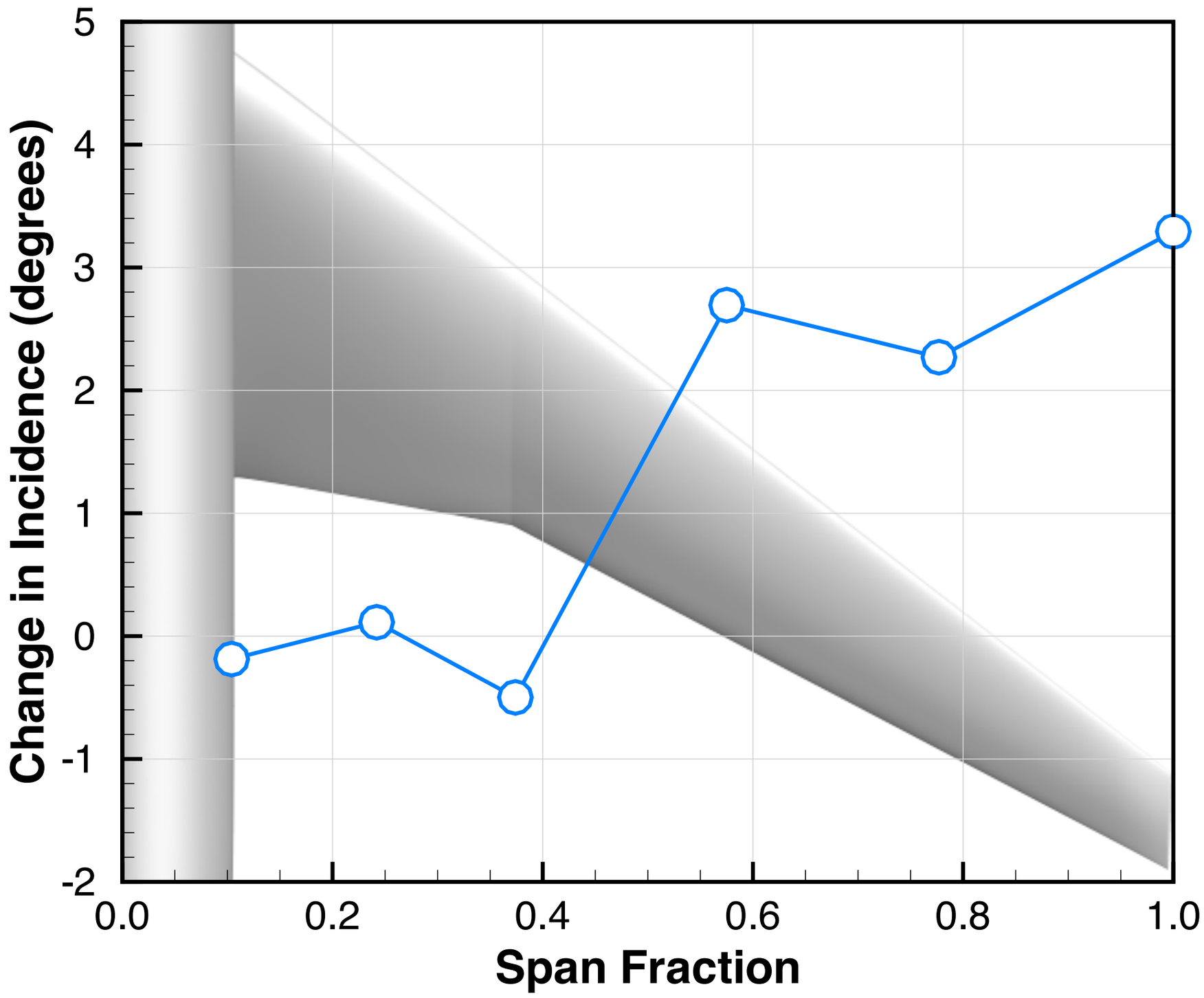
Convergence of Twist Optimization



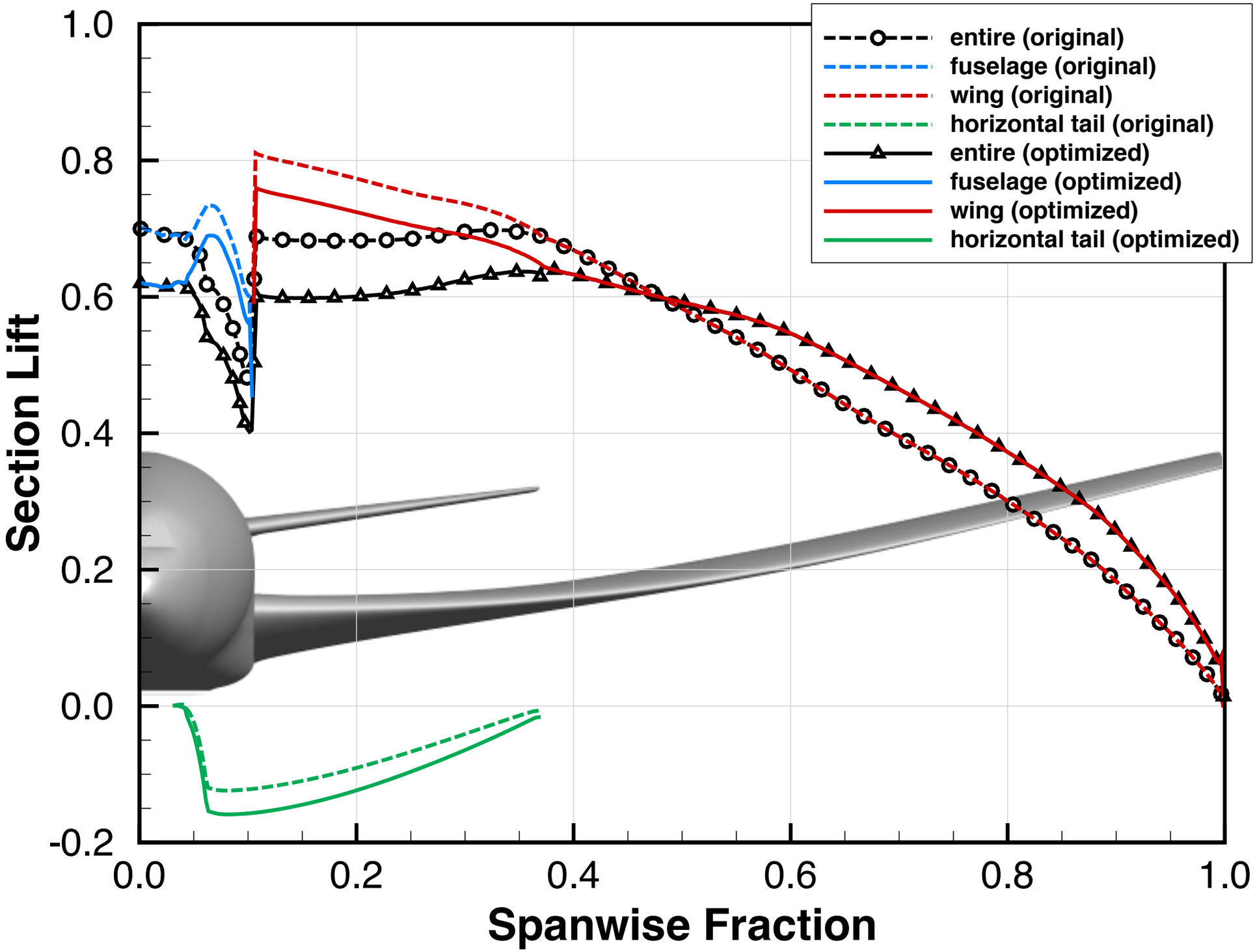
Convergence of Twist Optimization



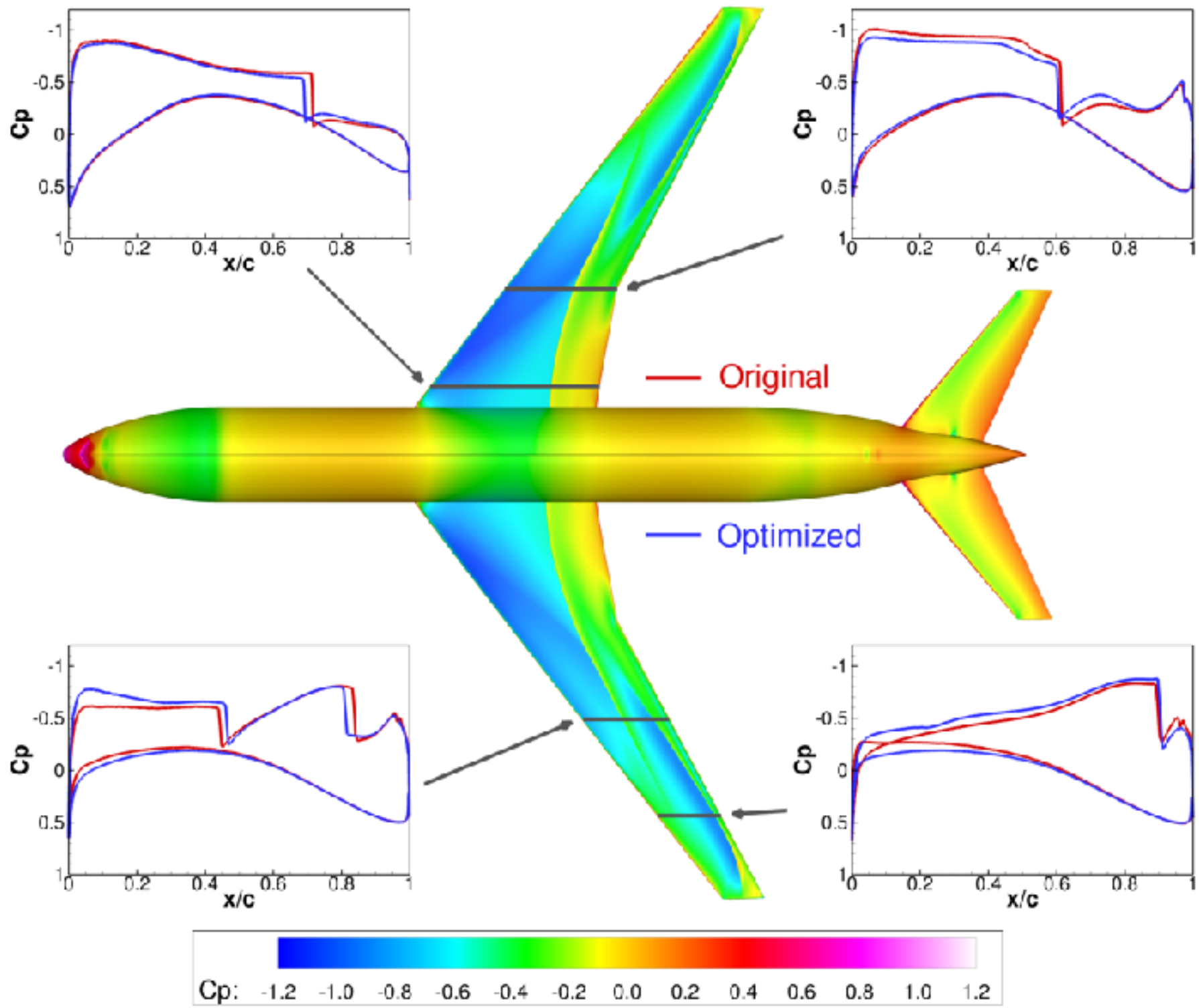
Optimized Twist Distribution



Optimized Spanwise Lift Distribution

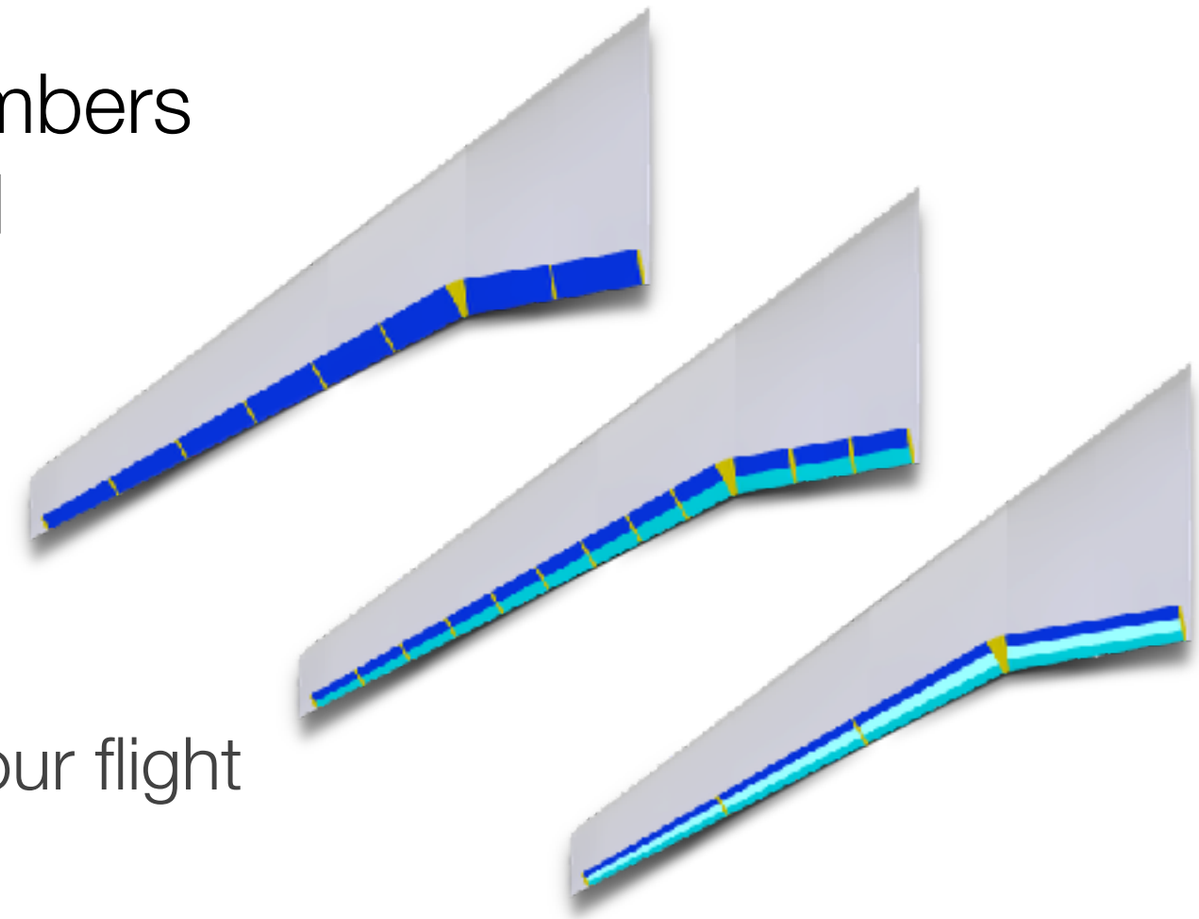


Surface Pressure Distribution



Flap Layout Trade Study

- Install systems with varying numbers of spanwise flaps (4, 8, 12) and chordwise segments (1, 2, 3)
- Increase cruise speed
  - $M_\infty = 0.85 \rightarrow M_\infty = 0.88$
  - would save 10 minutes on a 5 hour flight
- Optimize the flap deflections
  - minimize drag
  - maintain cruise lift
  - maintain trim



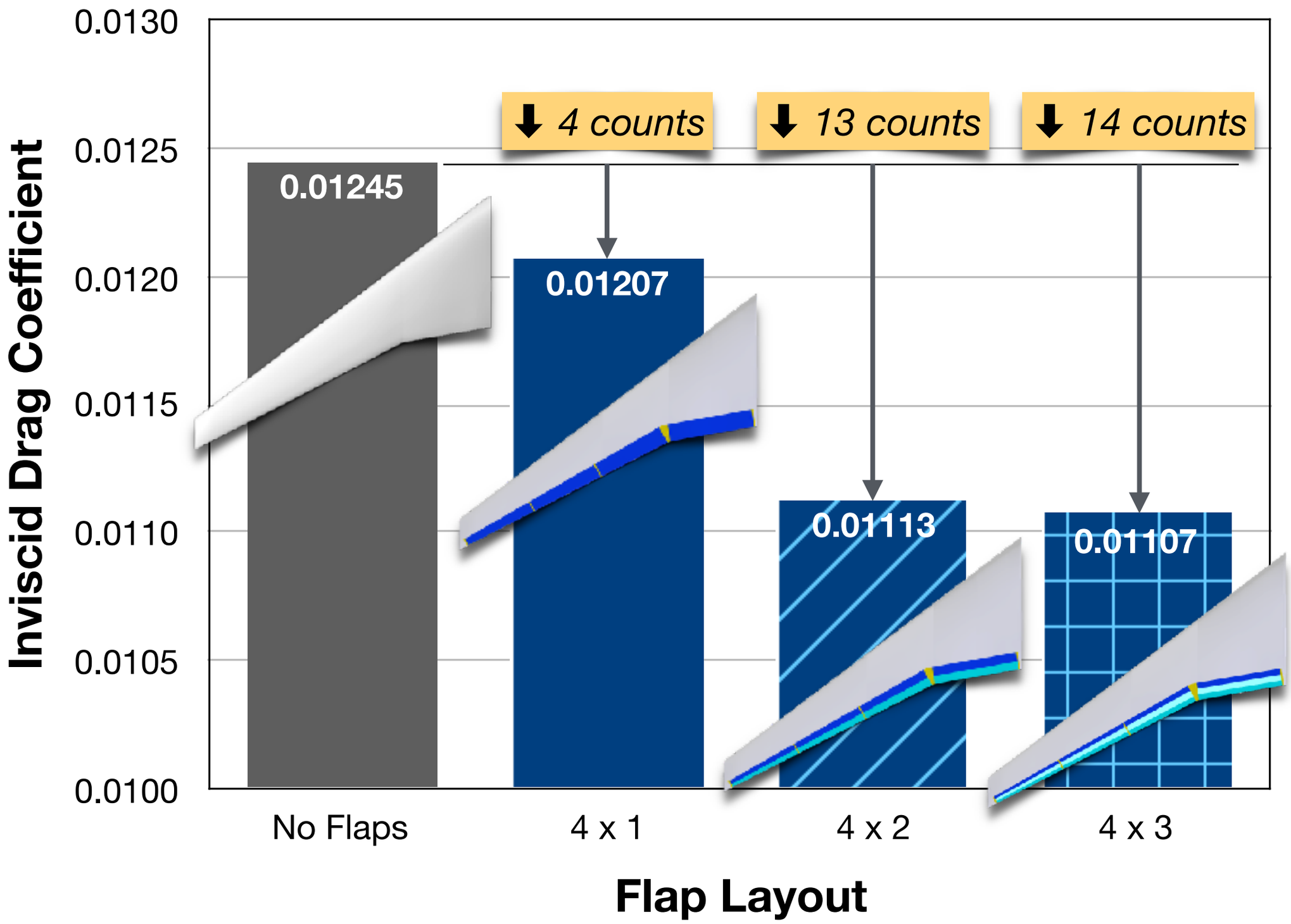
minimize: $C_D\,(\alpha, \Delta_{flaps}, i_t)$ @ $M_\infty = 0.88$

subject to: $C_L\,(\alpha, \Delta_{flaps}, i_t) = C_L = 0.4665$

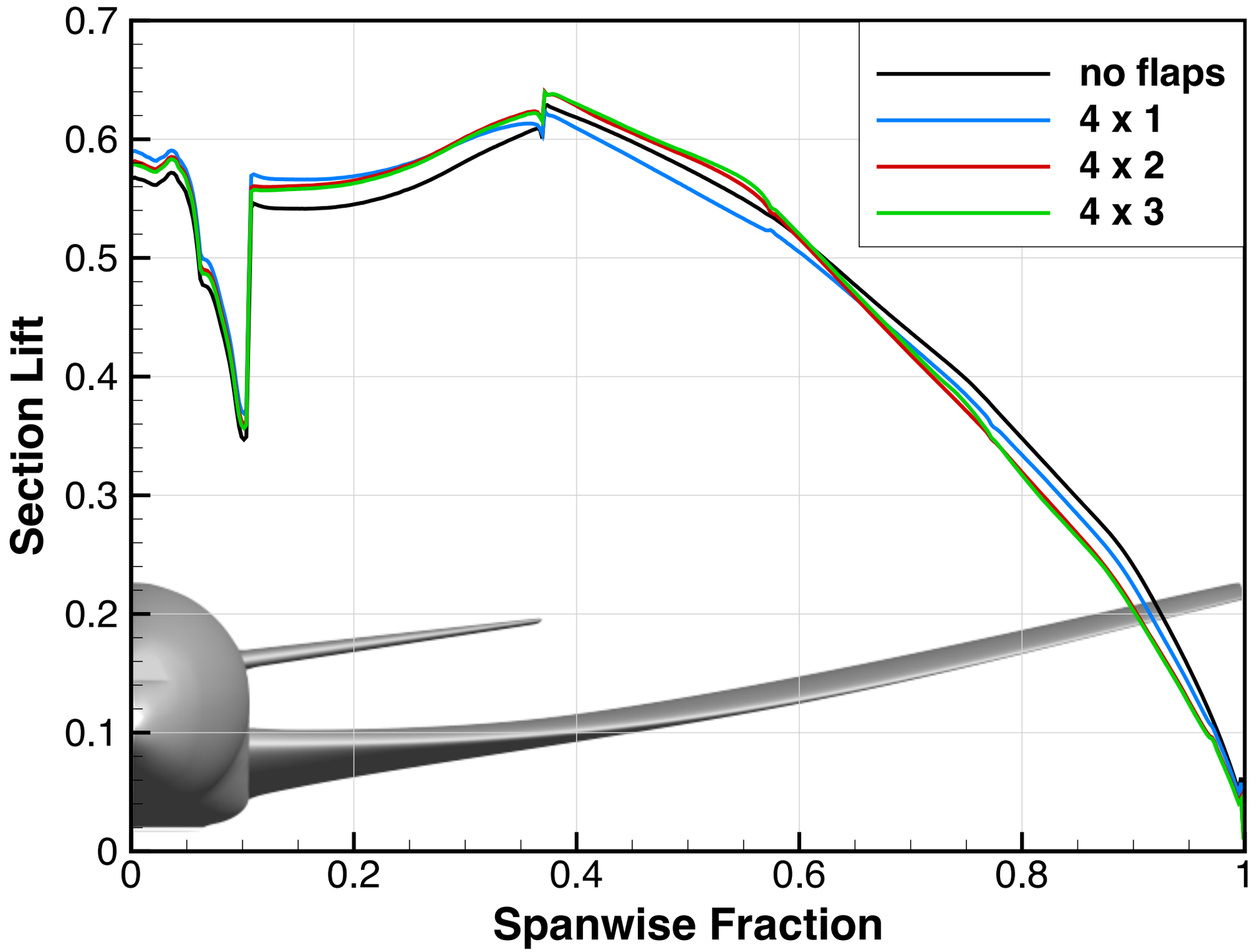
$C_M\,(\alpha, \Delta_{flaps}, i_t) = 0$

$\alpha \leq \alpha_{max} = 3°$

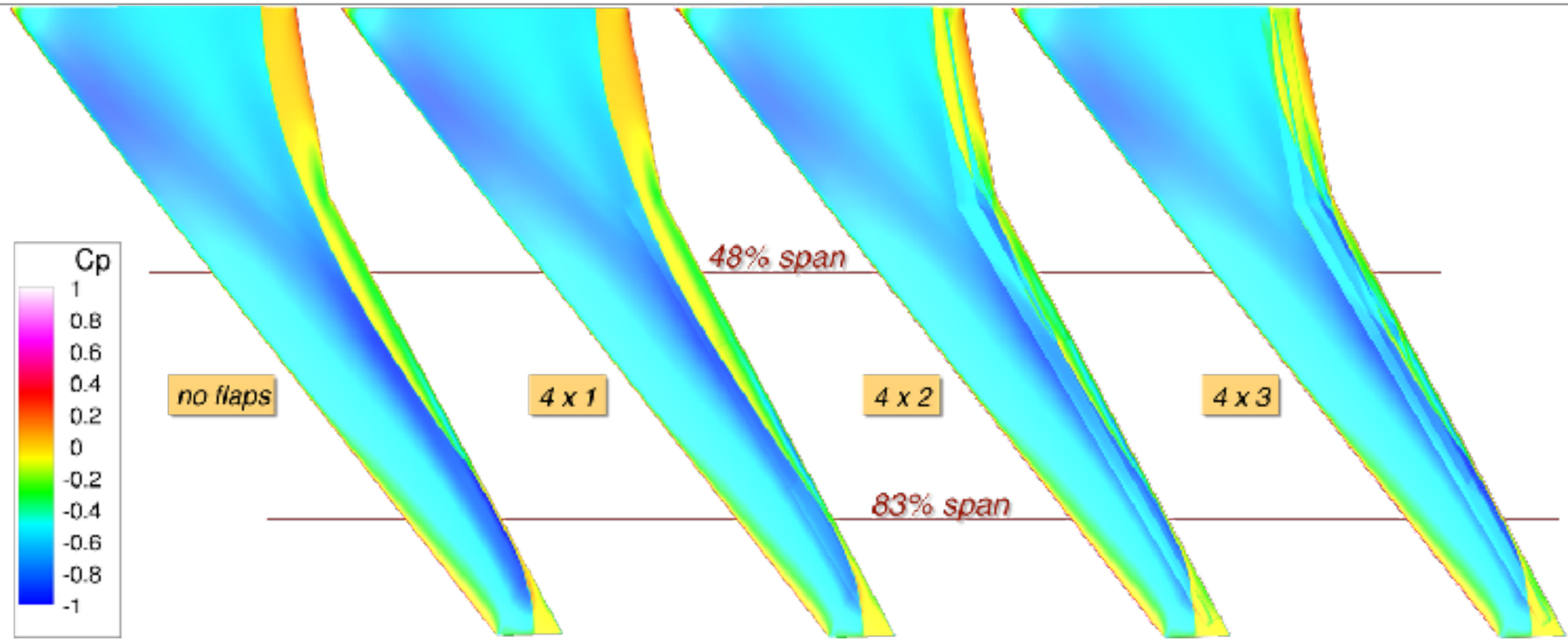
Performance of Optimized 4-Flap Layouts

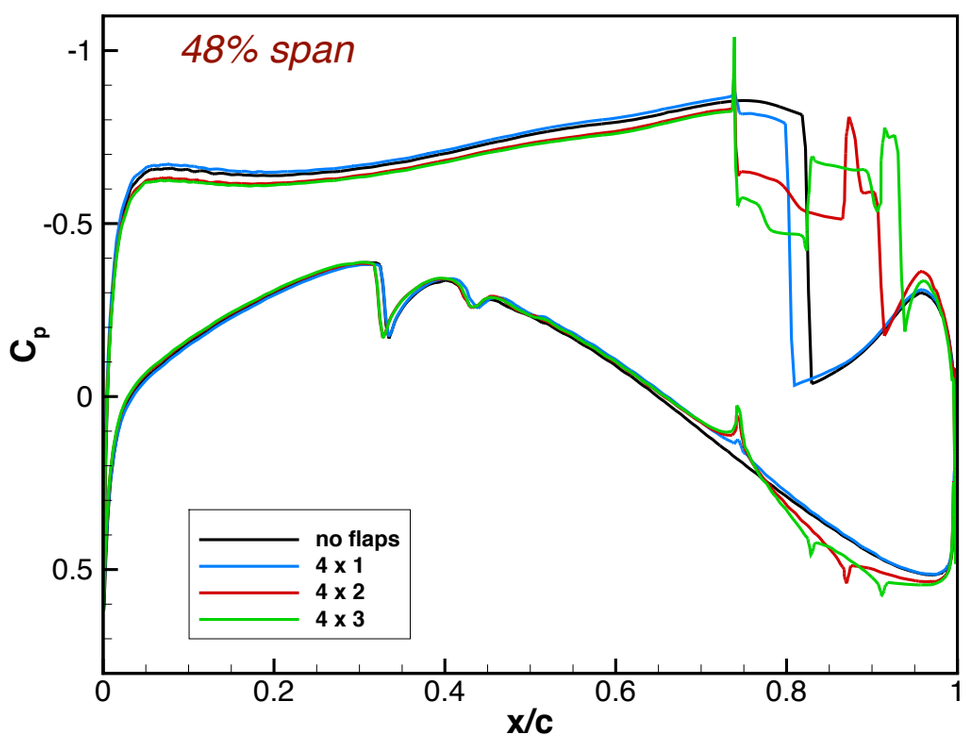


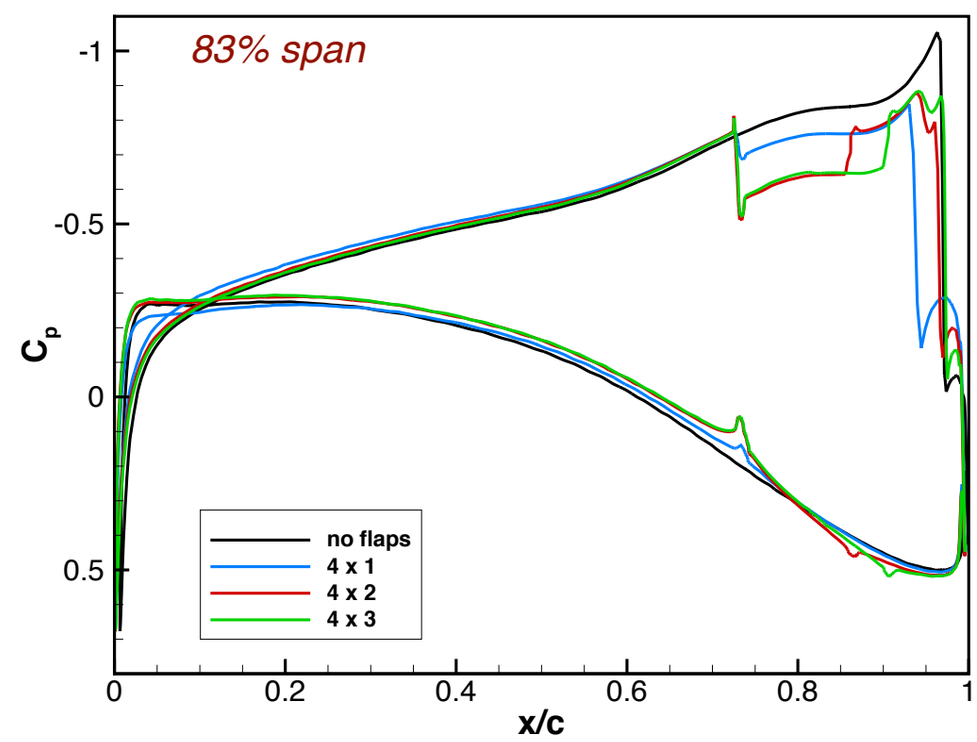
Lift Distribution on 4-Flap Systems



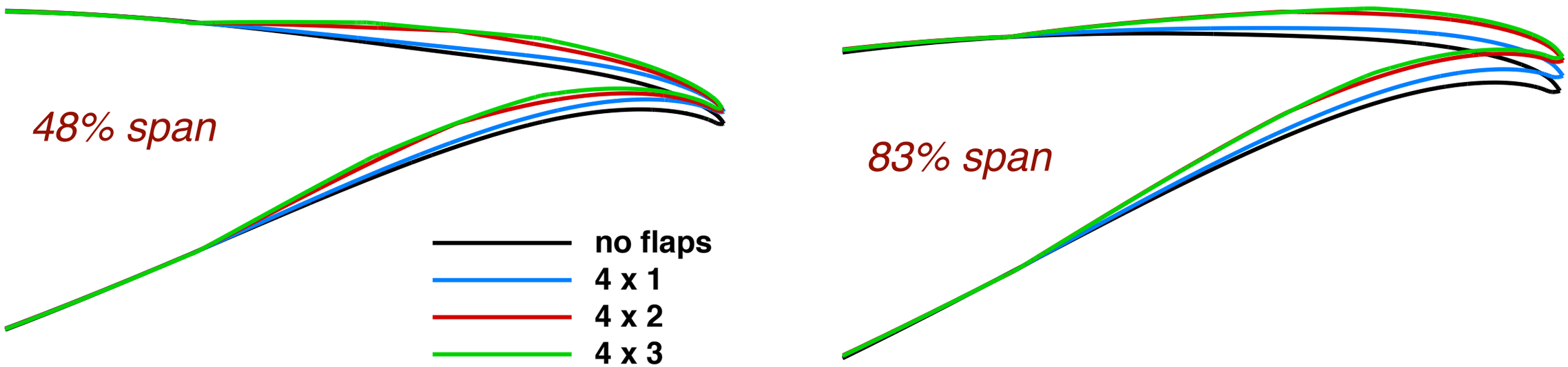
Pressure Distributions on 4-Flap Layouts







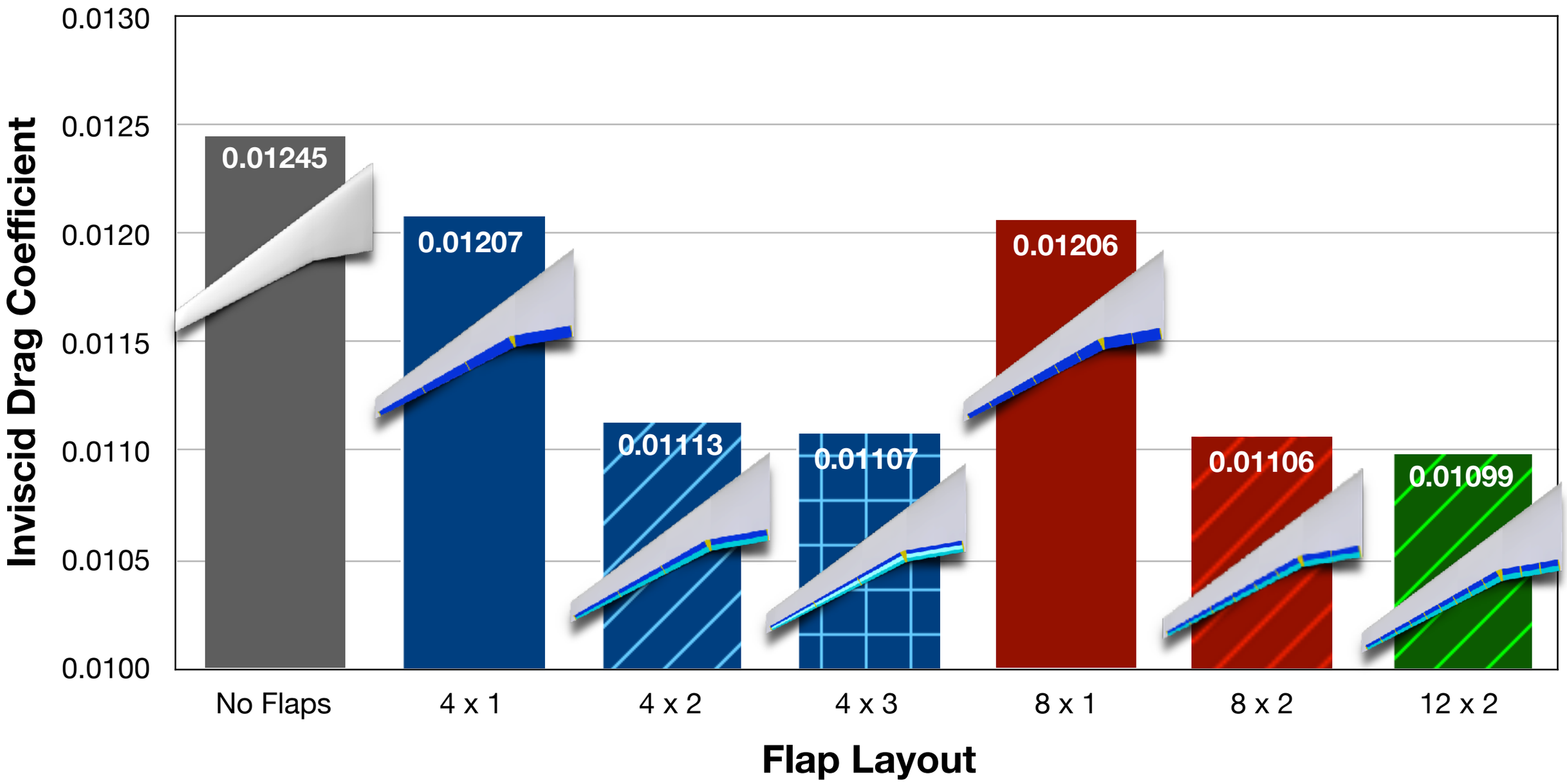
Optimized 4-Flap Geometry



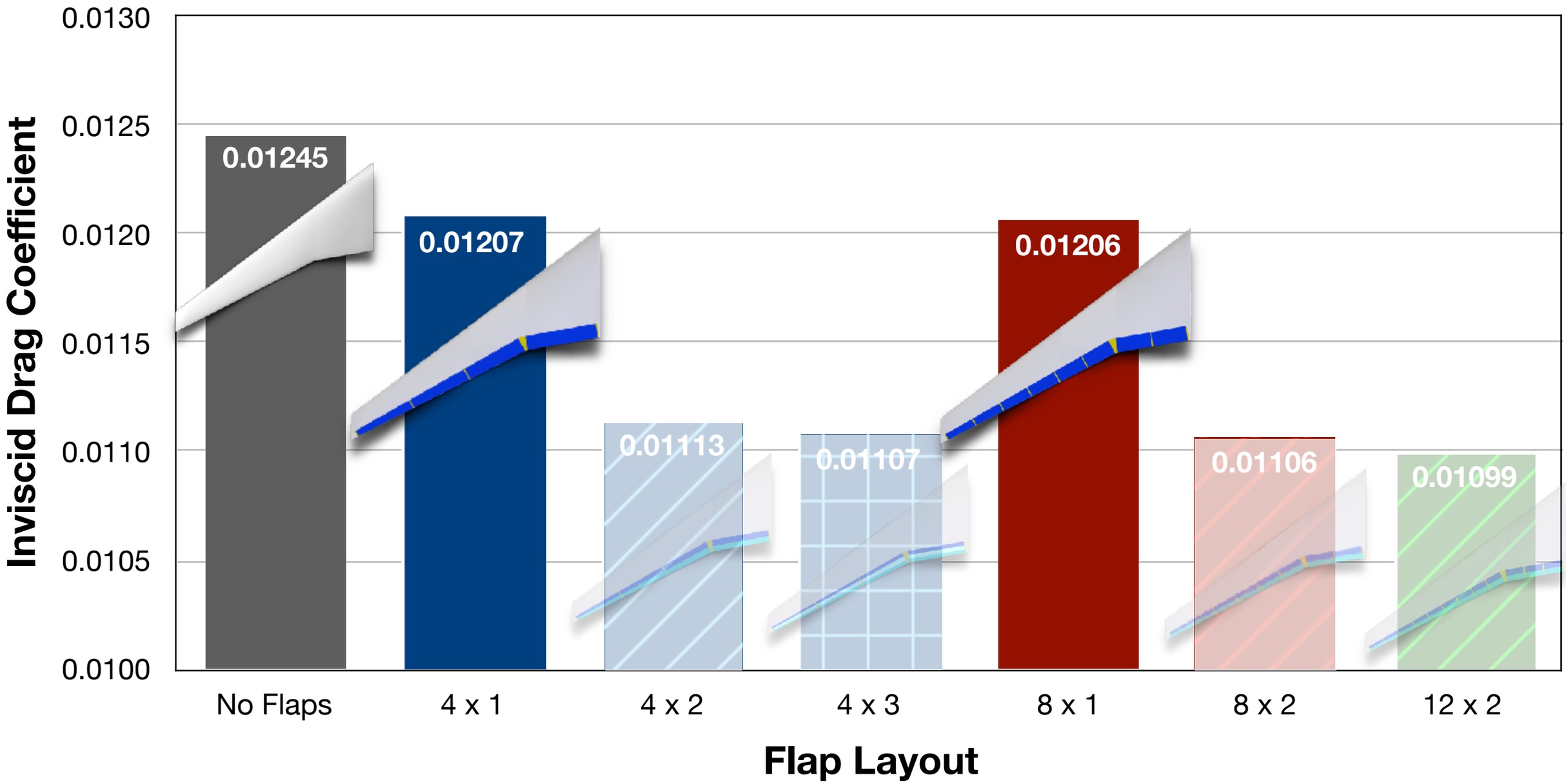
vertical scale is 4 times greater than horizontal for clarity

- 3-segment deflected flap profile very similar to 2-segment
- 1-segment deflected flap somewhere in between undeflected geometry and deflected 2-segment flap
- Deflecting flaps moves reflex backward (consistent with supercritical airfoil theory)

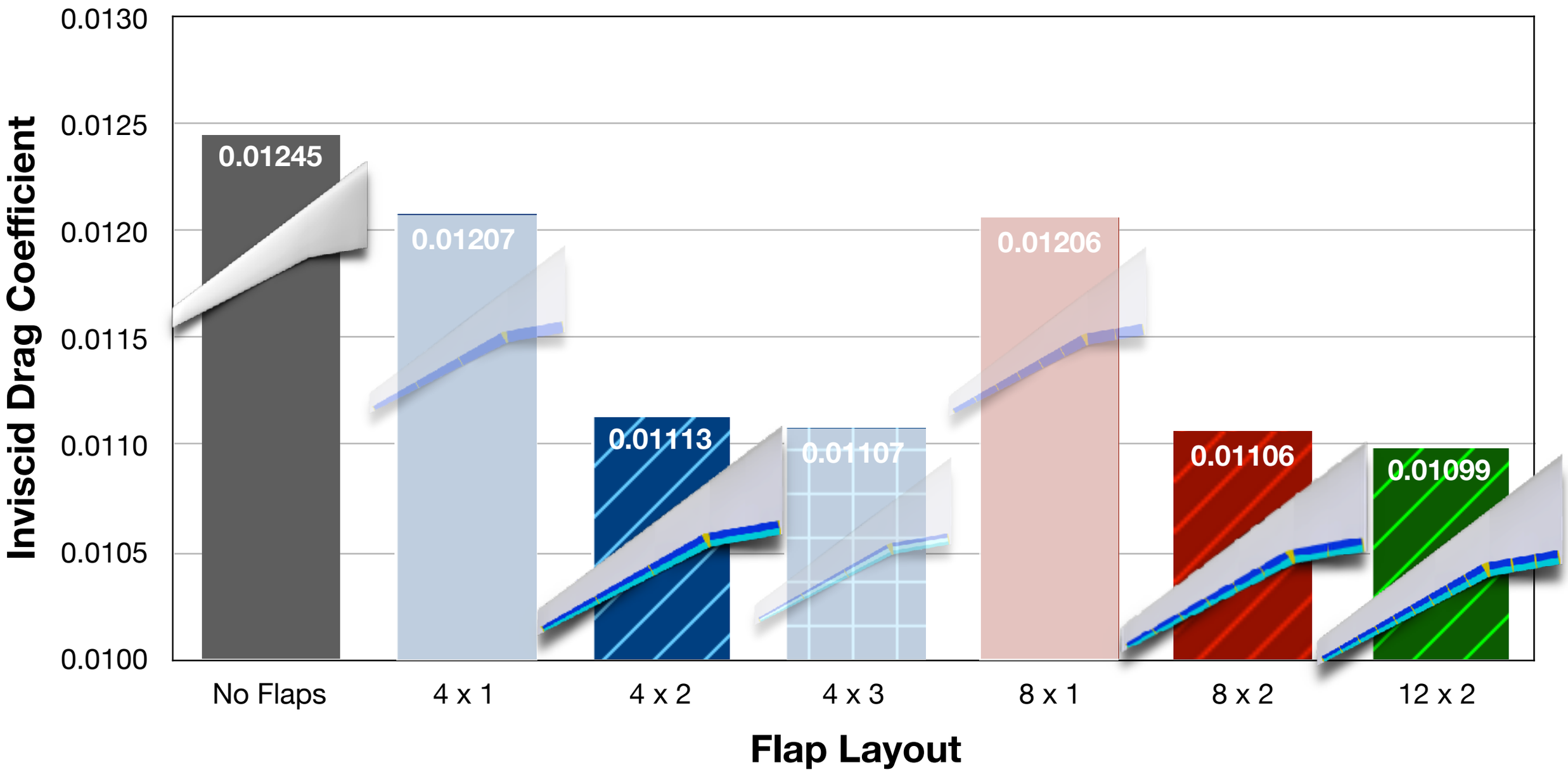
Performance of All Optimized Flap Layouts



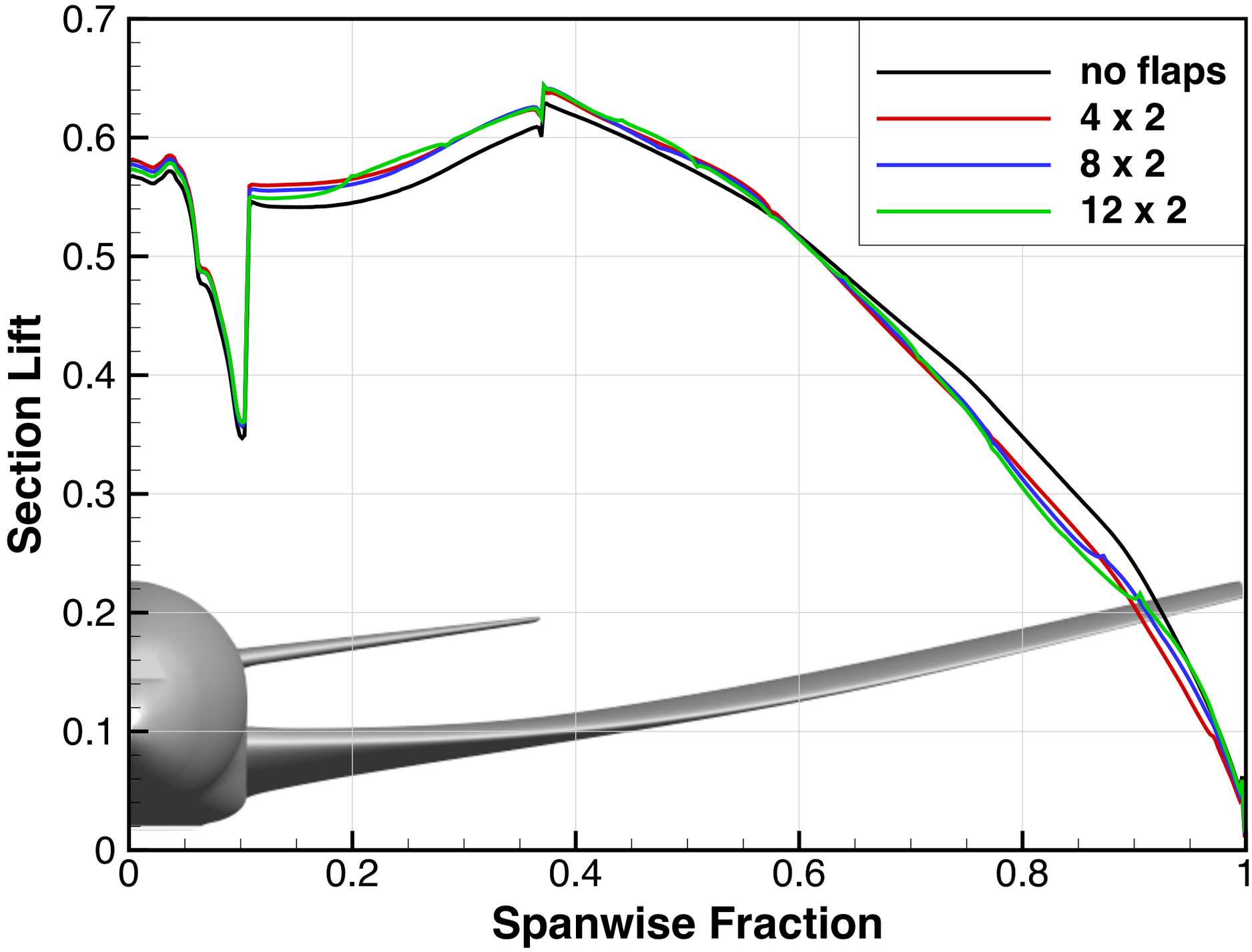
Performance of All Optimized Flap Layouts



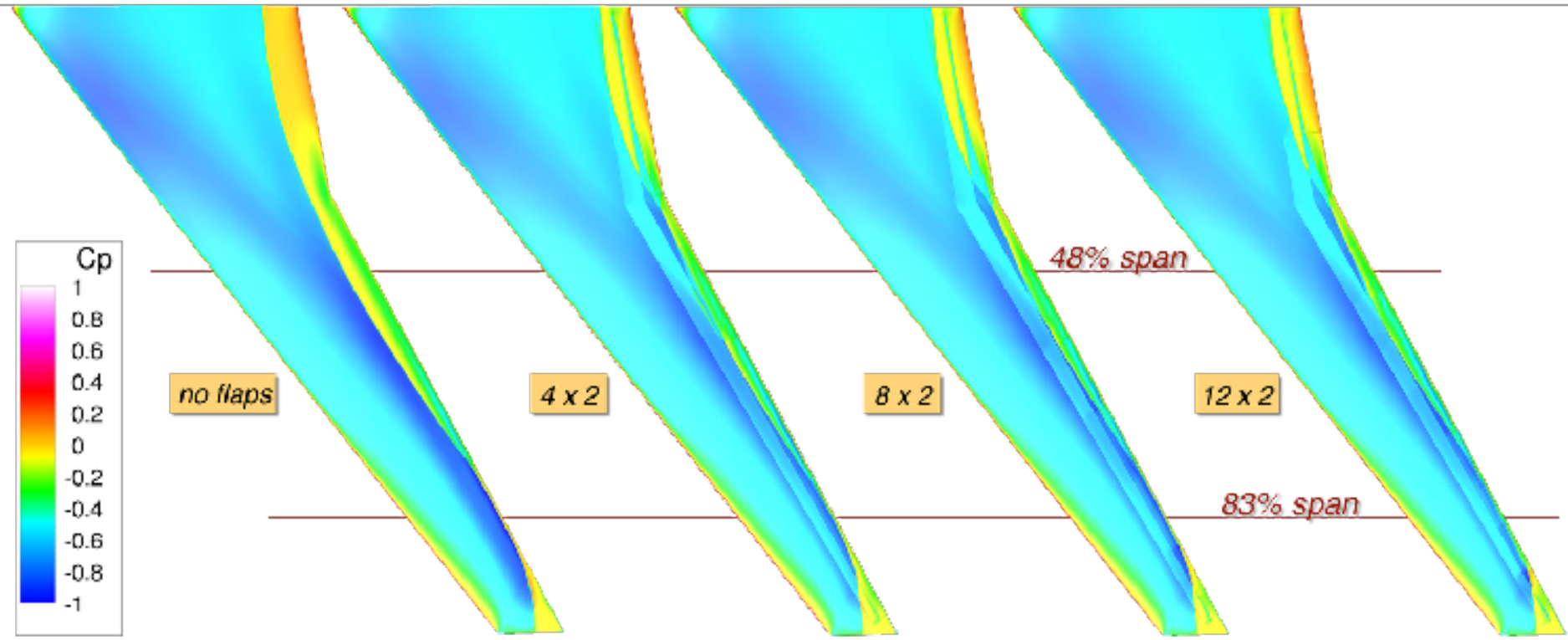
Performance of All Optimized Flap Layouts

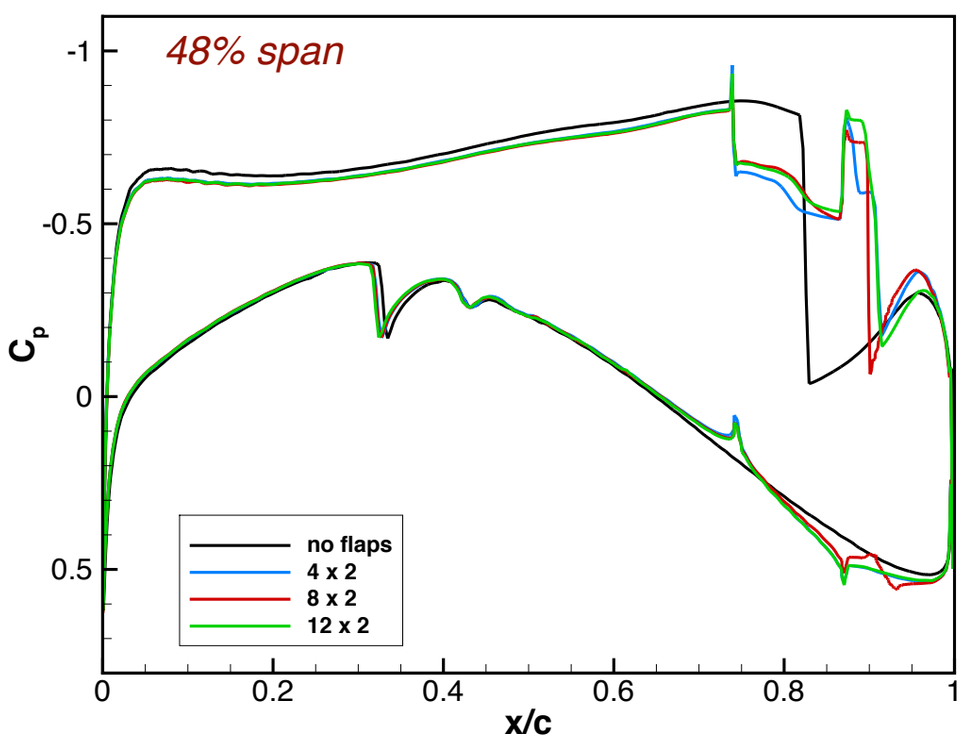


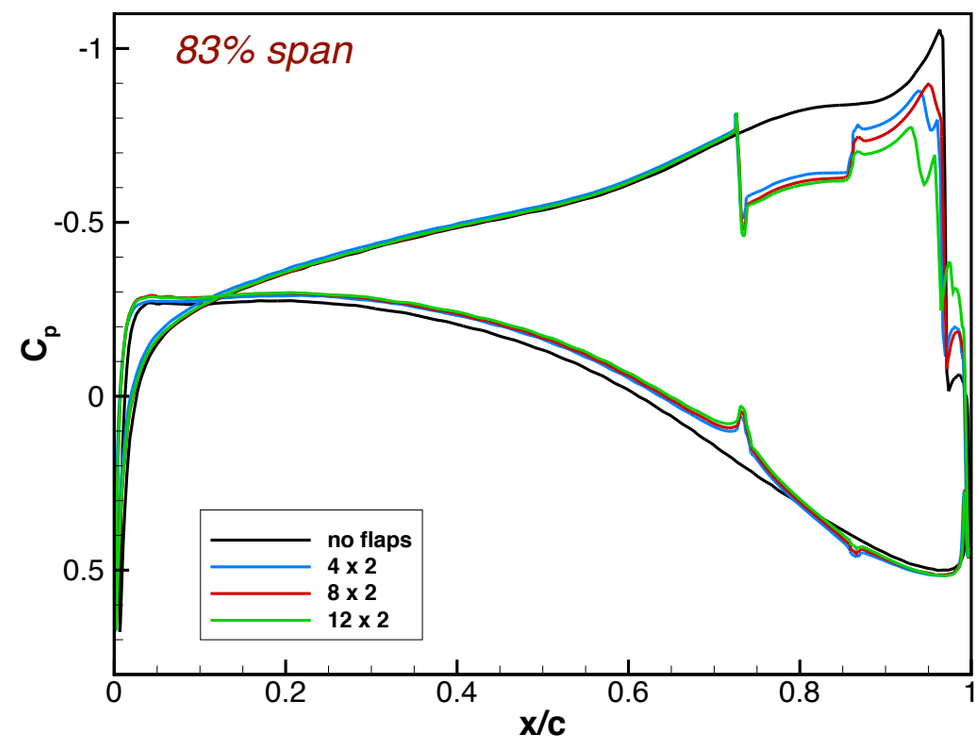
Spanwise Lift Distribution on 2-Segment Systems



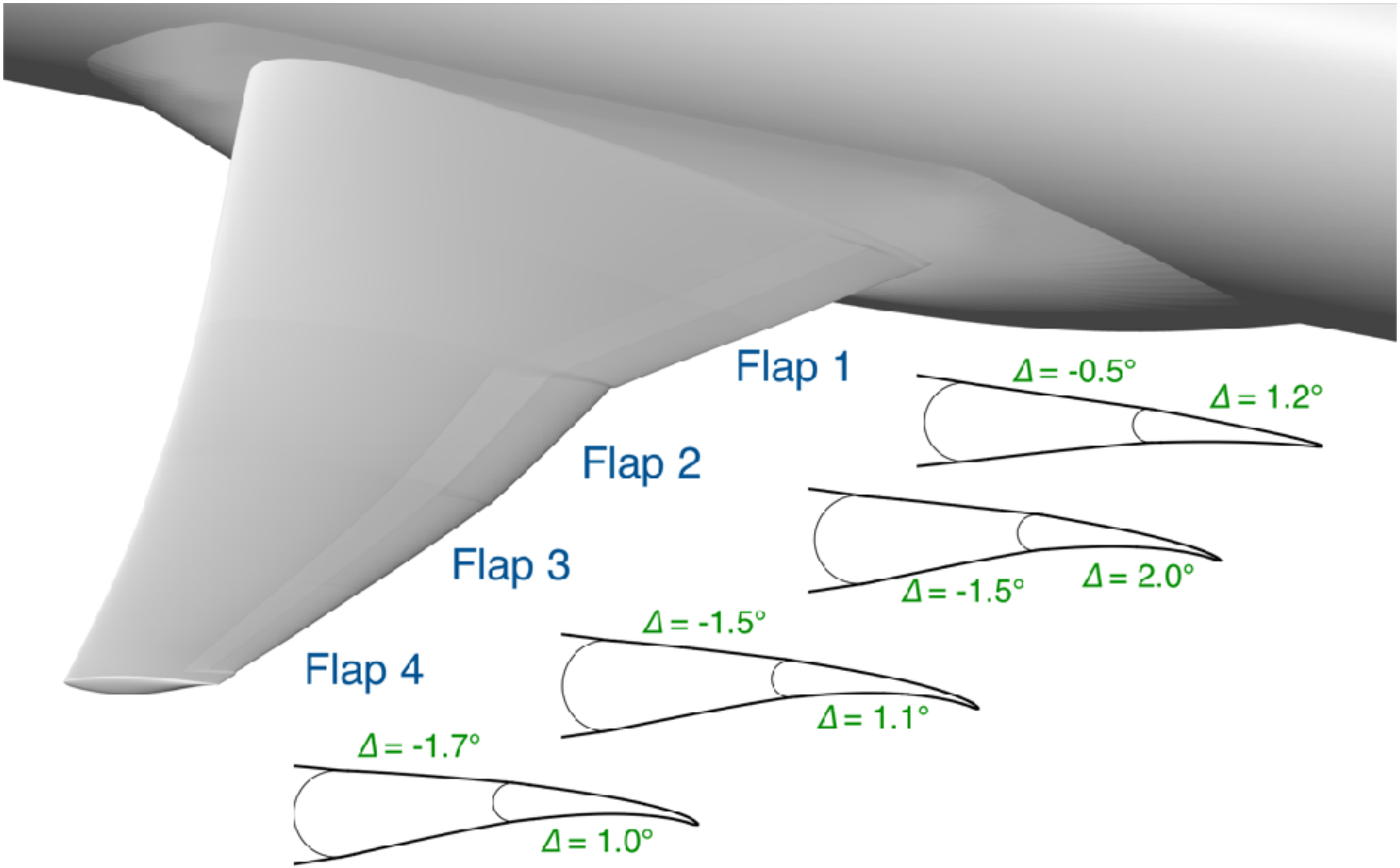
Pressure Distributions on 2-Segment Layouts







Optimized 4 x 2 Flap Layout Deflections



Conclusions and *Future Work*

- Flap layout trade study on highly flexible CRM conducted for overspeed off-design case
- 2-segment flaps found to be much more effective than 1-segment flaps, but 3-segment flaps provided only incremental improvement
- 4 spanwise flaps are almost as effective as 12, suggesting induced drag is either already near optimal or wave drag reduction dominates
- *Verification with viscous analysis*
- *Consider other off-design conditions (e.g. maneuver condition)*

Acknowledgements

- NASA Advanced Air Transport Technology Project provided partial funding for this work
- NASA Advanced Supercomputing (NAS) Center provided computing resources