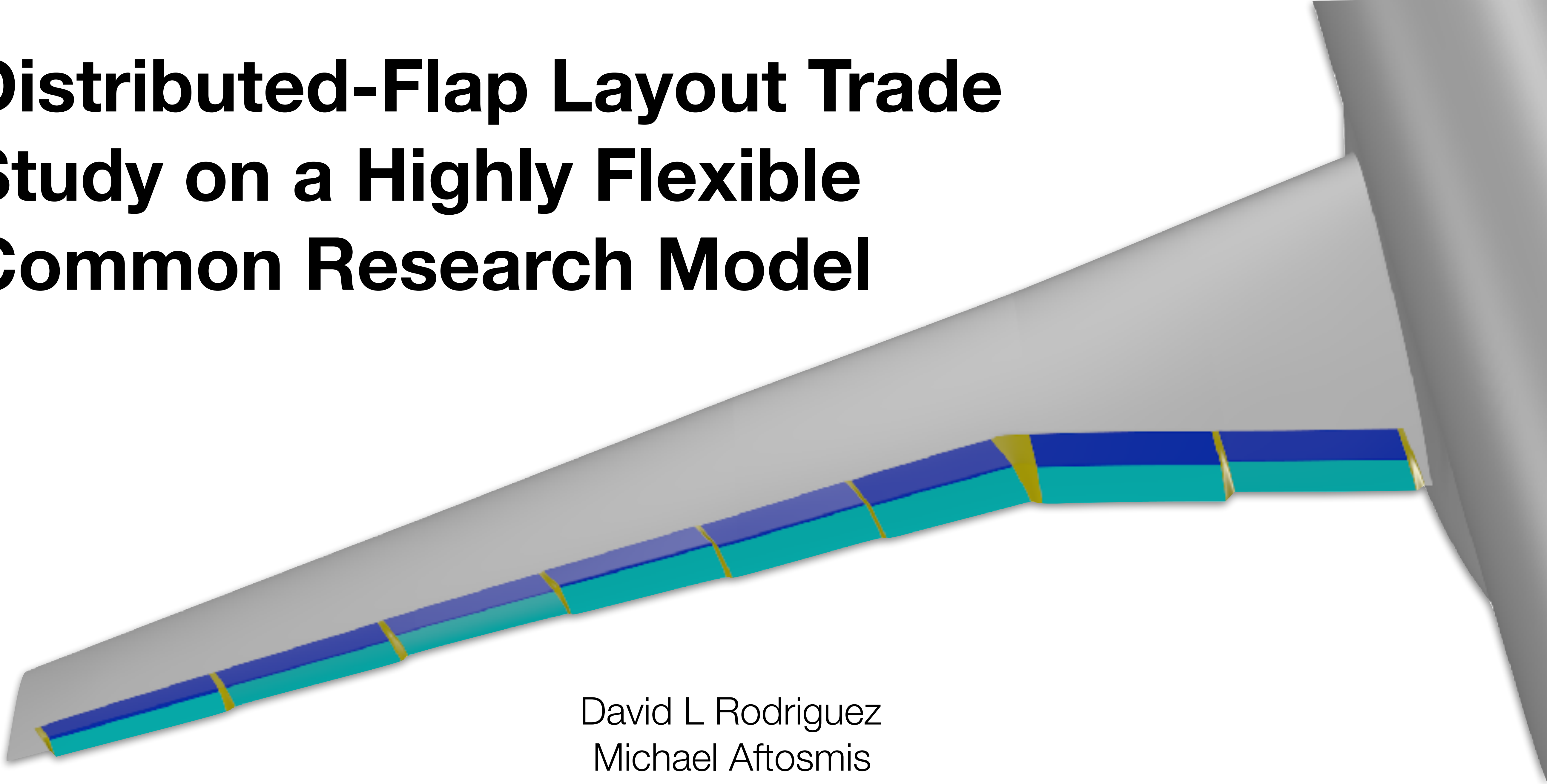
Distributed-Flap Layout Trade Study on a Highly Flexible Common Research Model



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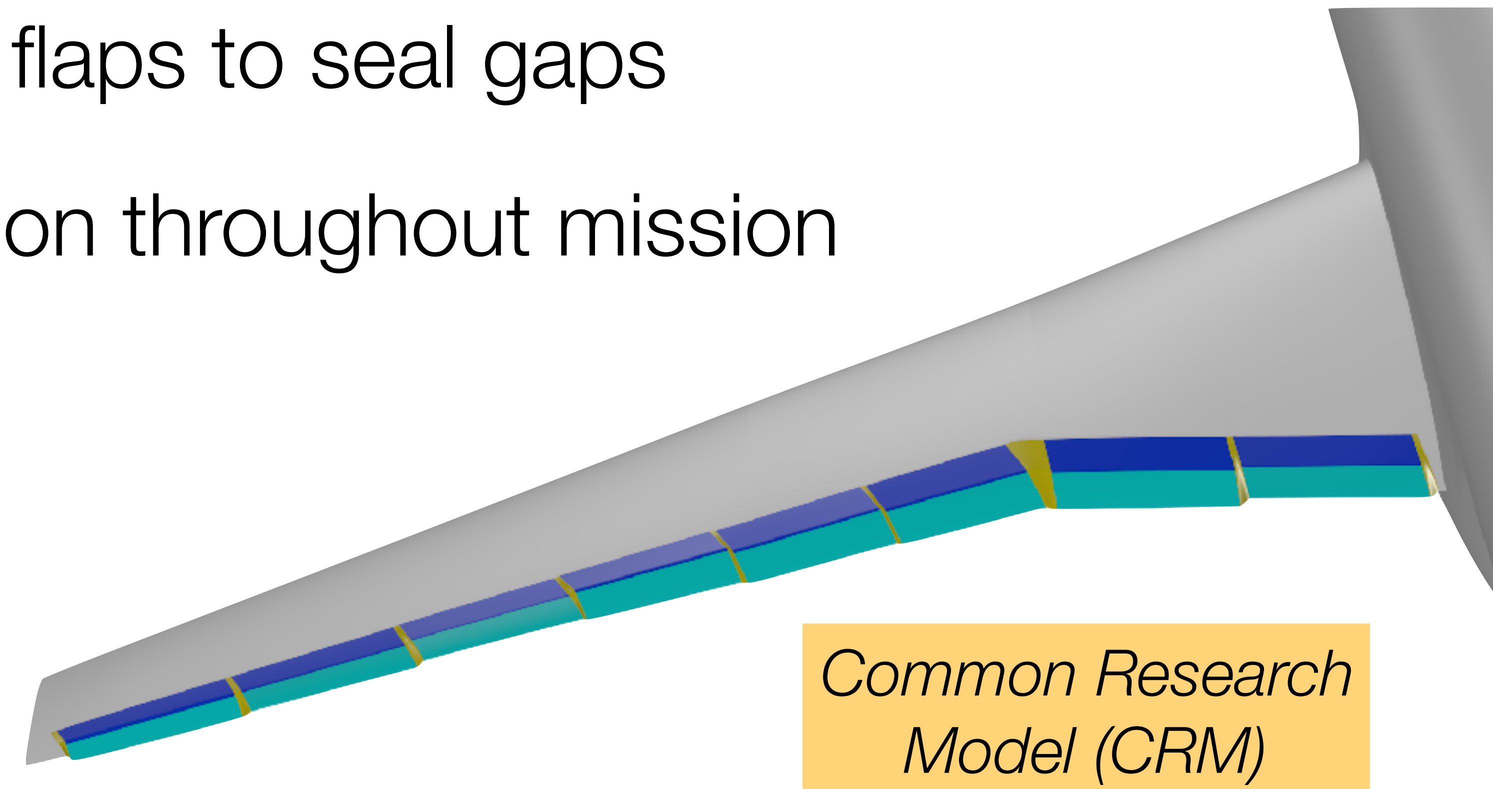
Computational Aerosciences Branch

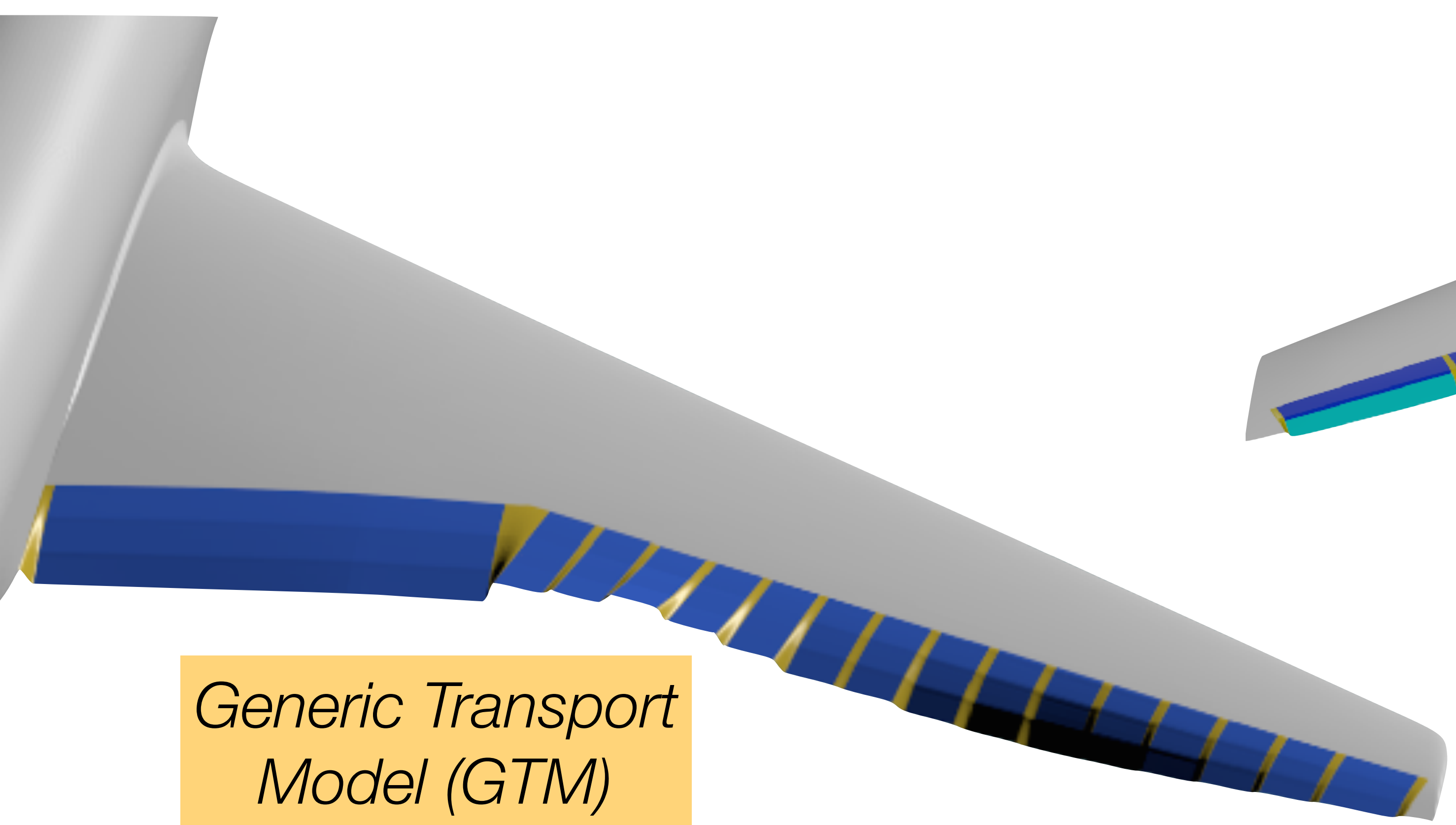
Advanced Supercomputing Division

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



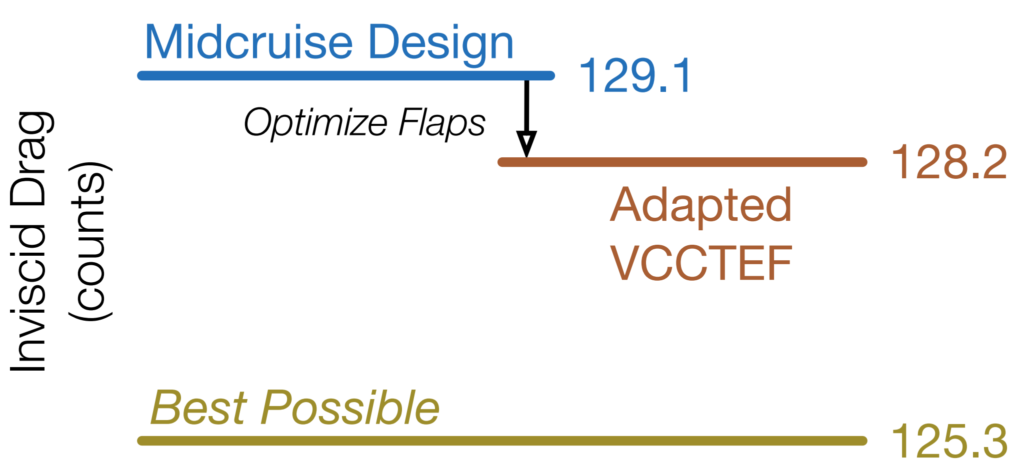
Common Research Model (CRM)

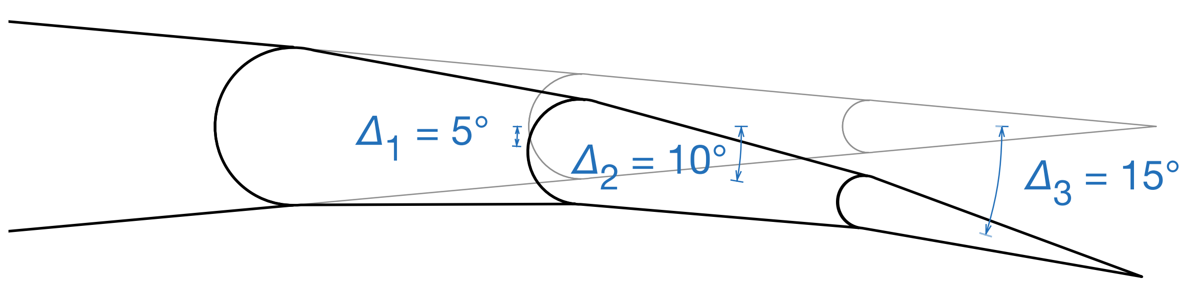


Generic Transport Model (GTM)

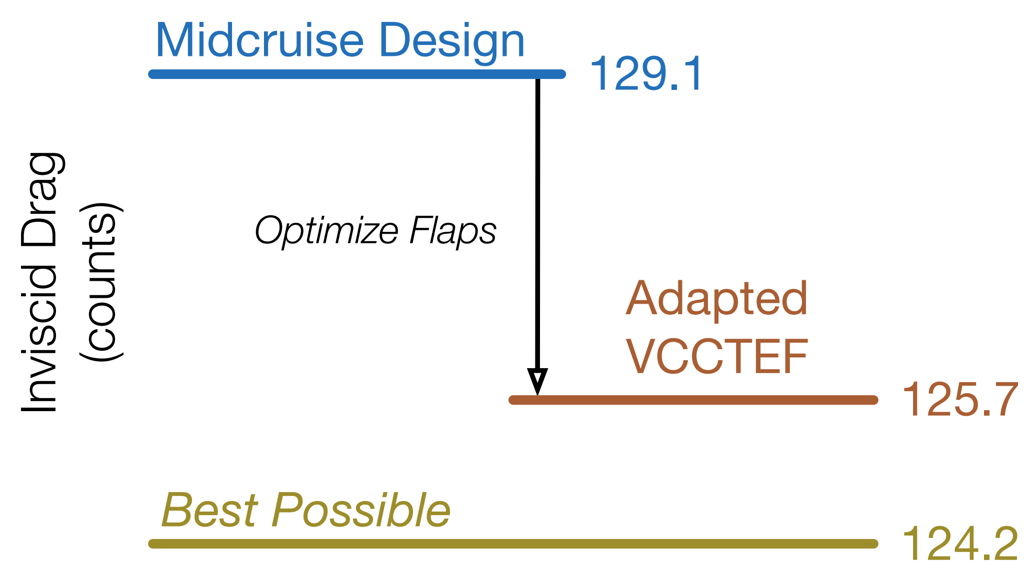
Motivation

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



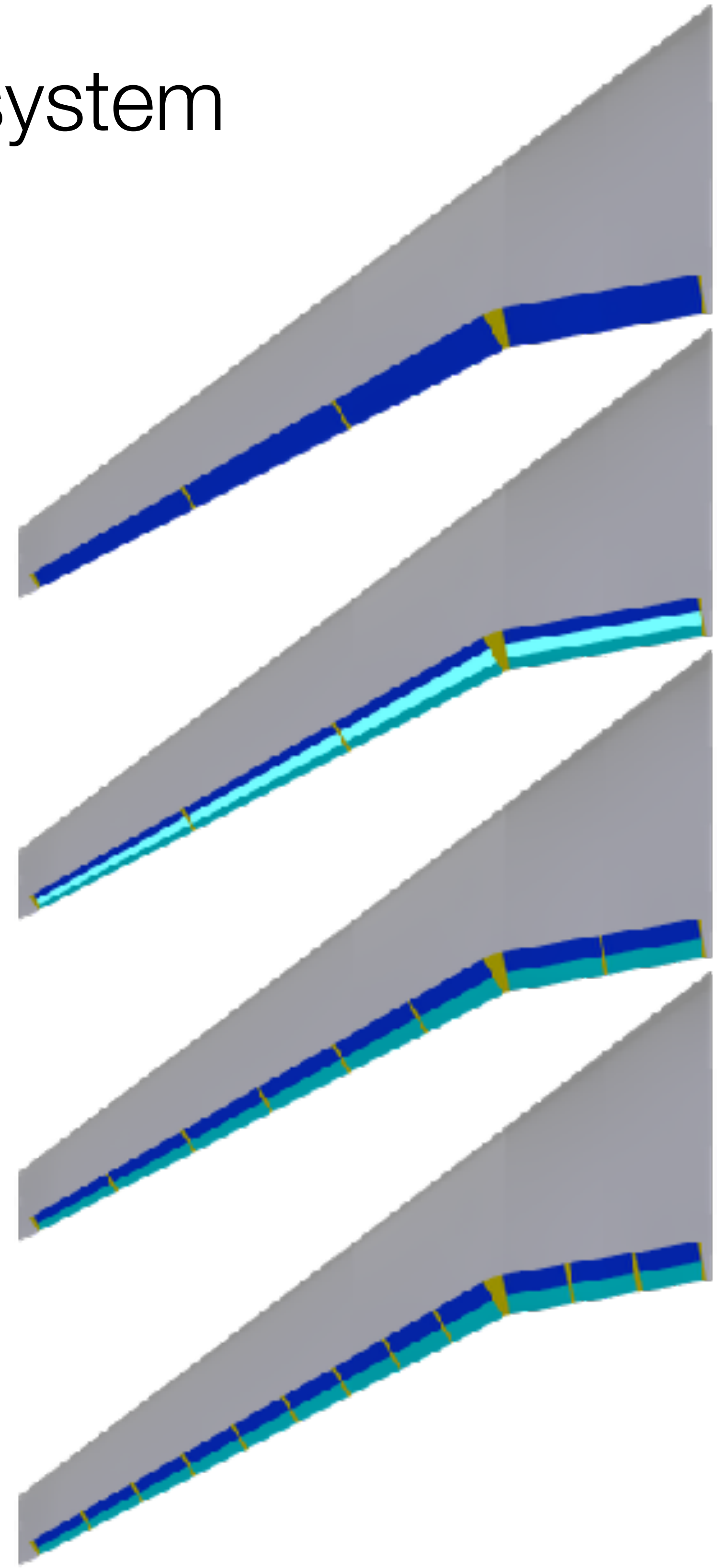


$\Delta_2 = 2\Delta_1$, $\Delta_3 = 3\Delta_1$



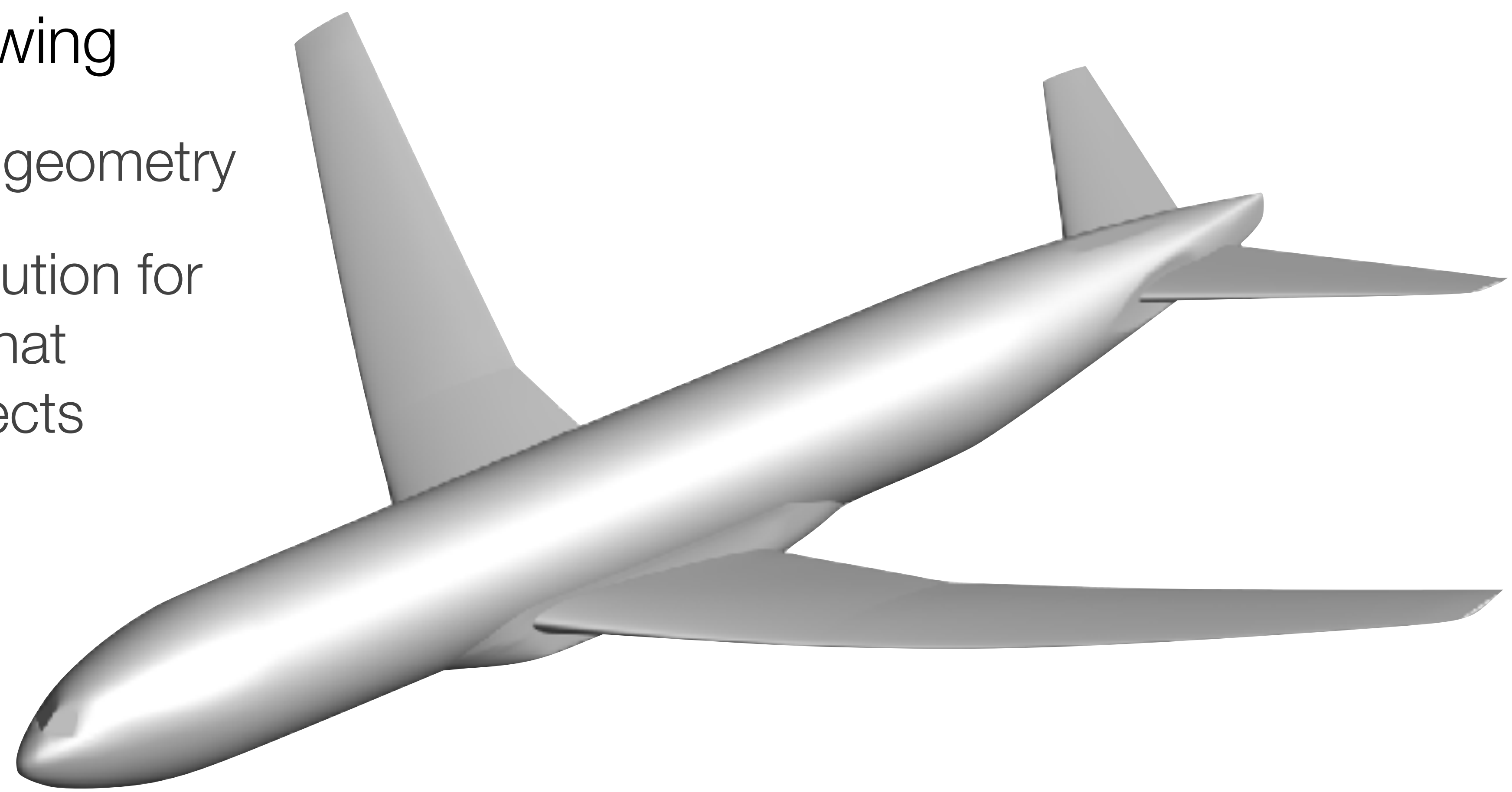
Goals and Methods

- 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

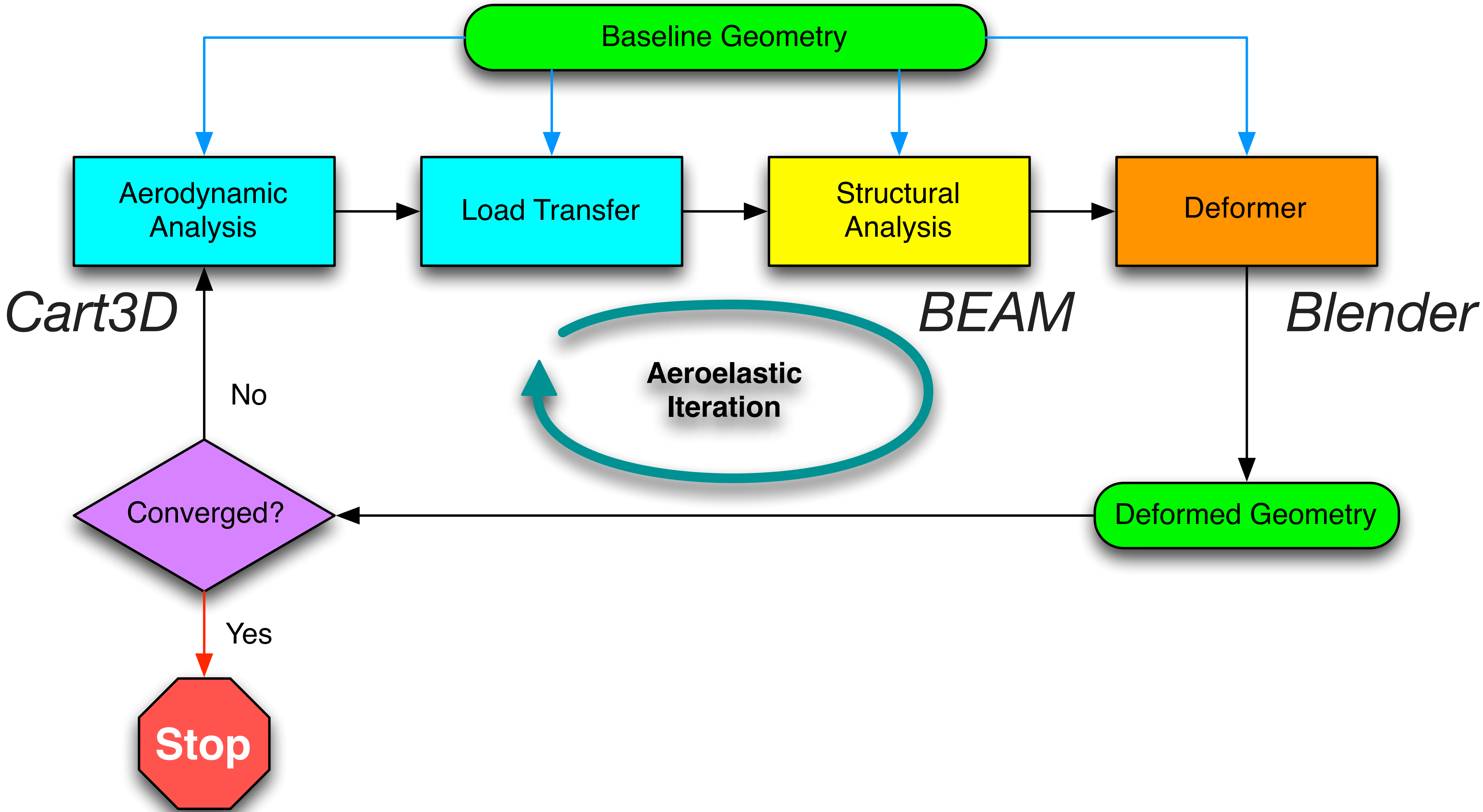


Platform for Trade Study

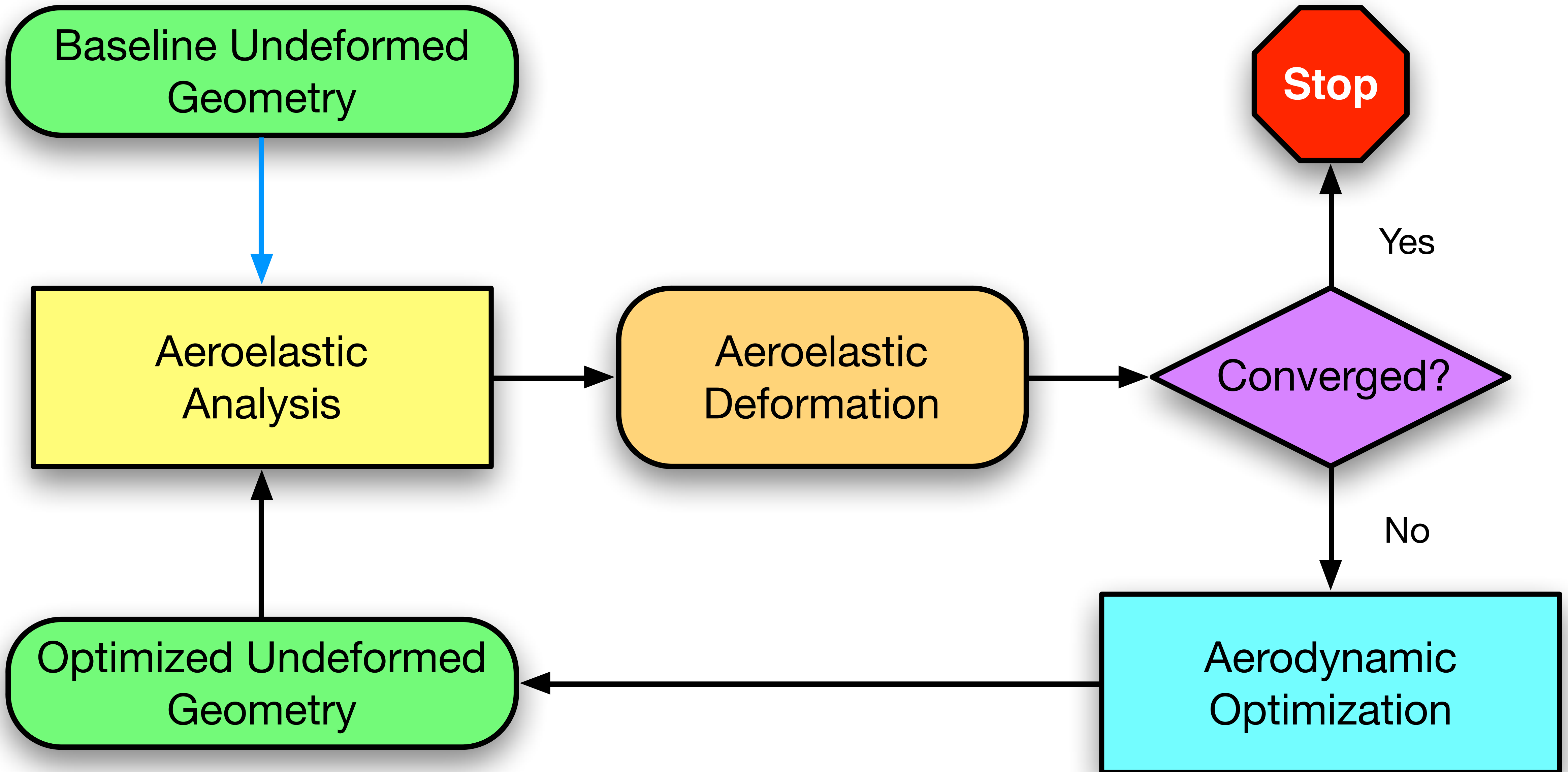
- Common Research Model (CRM) fuselage/wing/horizontal tail configuration)
- Assume composite wing
  - remove built in deformation from original CRM geometry
  - develop structural model that exhibits greater deformation (about twice original)
- Develop new baseline wing
  - start with original CRM geometry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



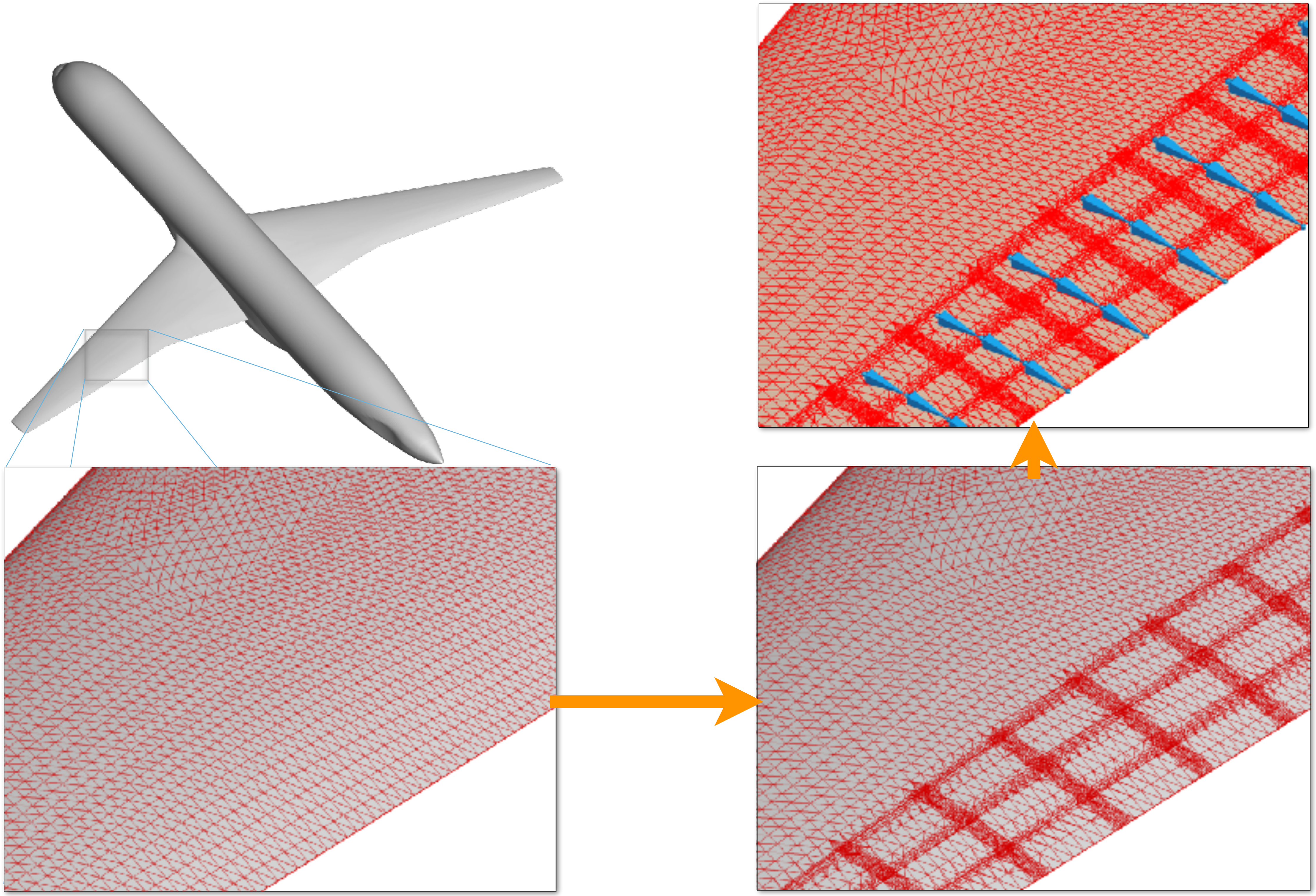
Static Aeroelastic Analysis Architecture



Aerodynamic Shape Optimization Architecture

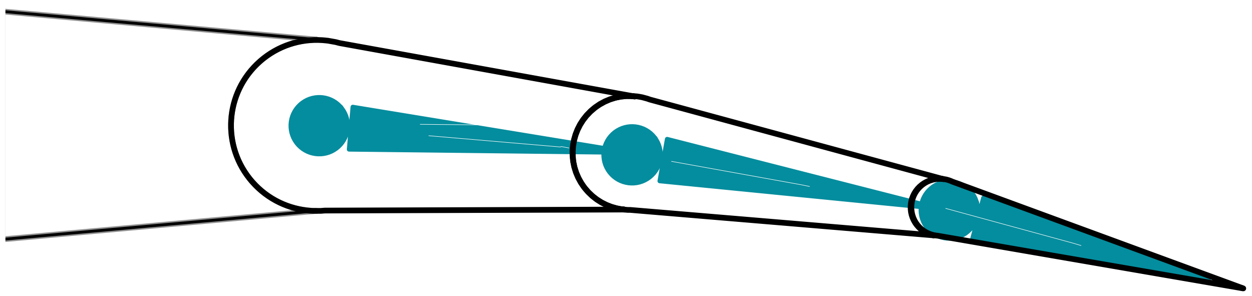


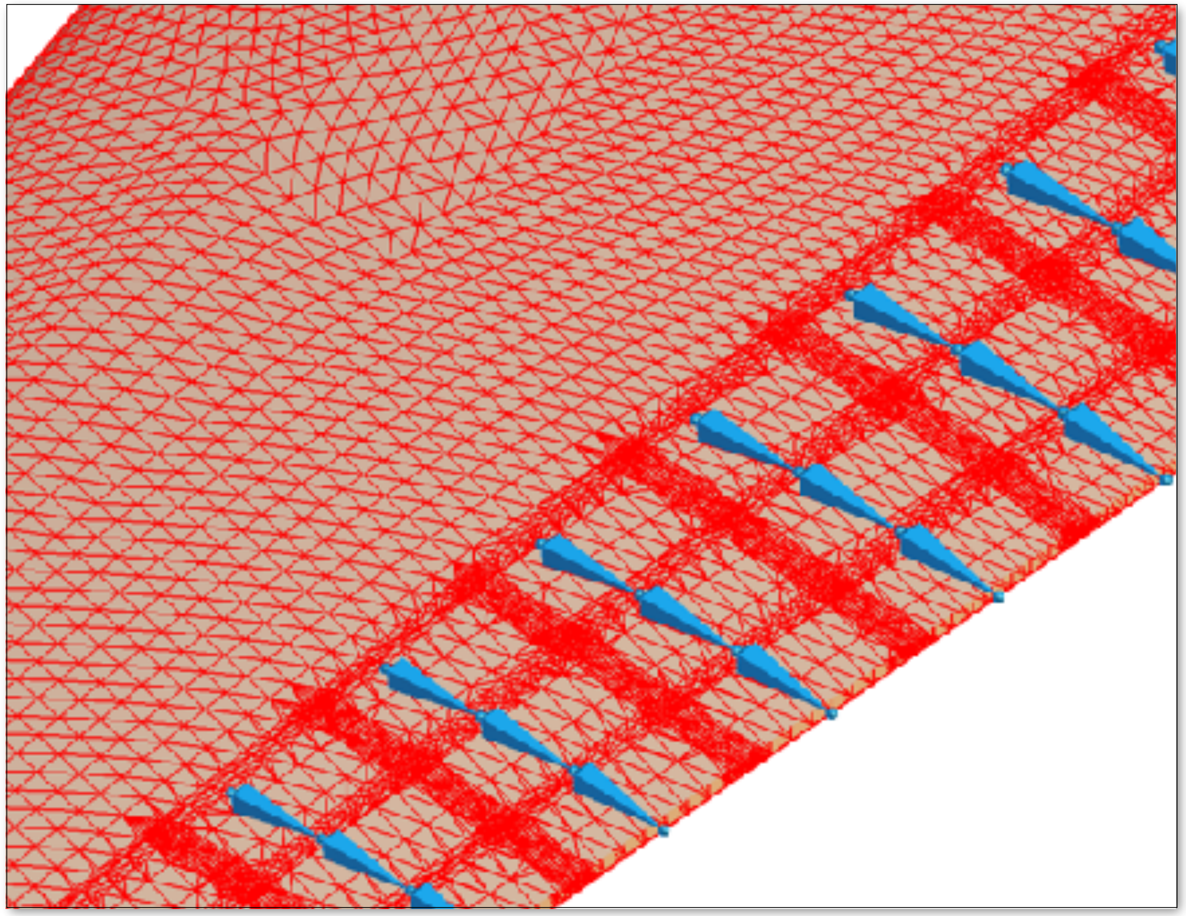
Modeling the VCCTEF

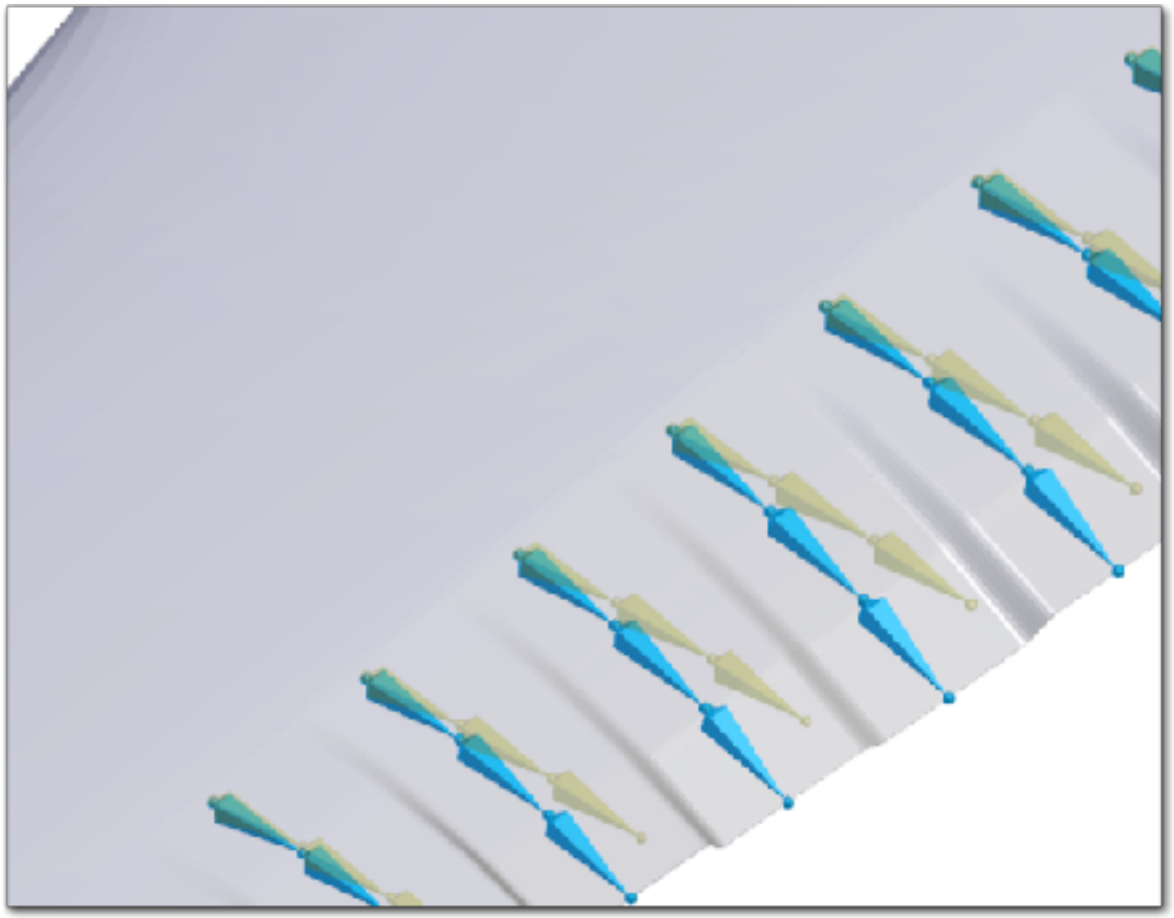


Modeling the VCCTEF

- 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

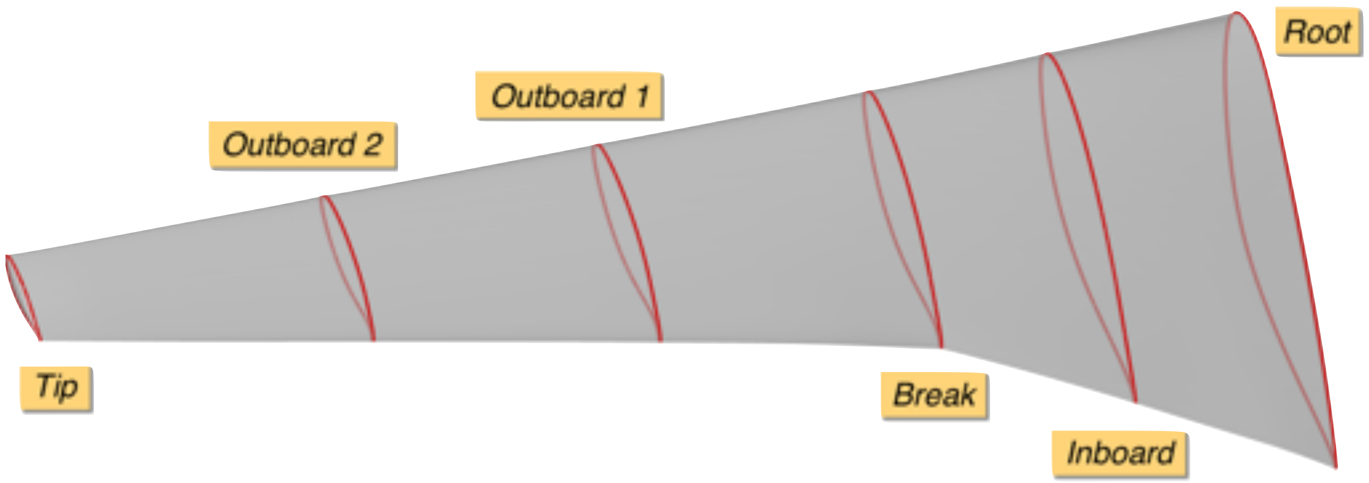
- CRM wing twist distribution re-optimized with more flexible structure
- Minimize drag (C_D) at cruise condition ($M_\infty = 0.85$)
  - maintain cruise lift ($C_L = 0.5$)
  - maintain longitudinal trim ($C_M = 0$)
  - cabin deck angle constraint ($\boldsymbol{\alpha}_{max} = 3°$)
- Design variables
  - 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)

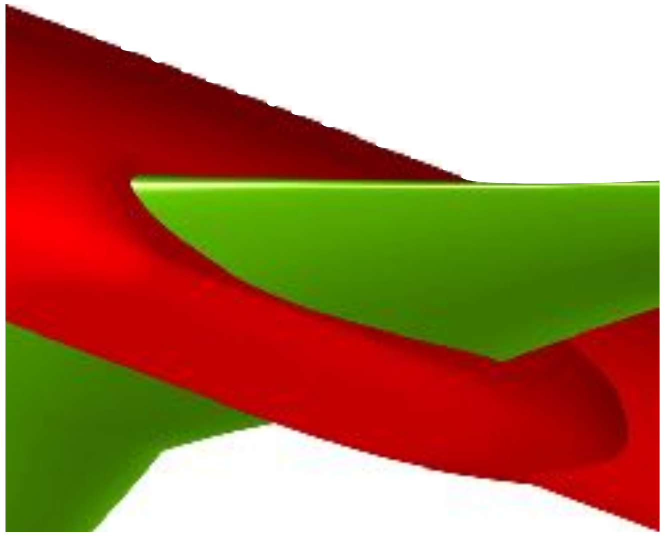
minimize: $C_D\,(\alpha, \boldsymbol{\theta}_w, i_t)$

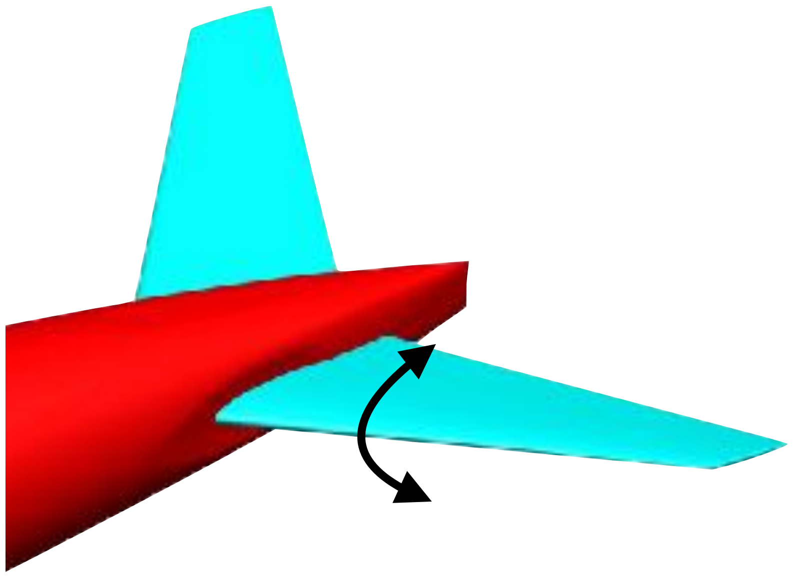
subject to: $C_L\,(\alpha, \boldsymbol{\theta}_w, i_t) = C_{L,cruise} = 0.5$

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

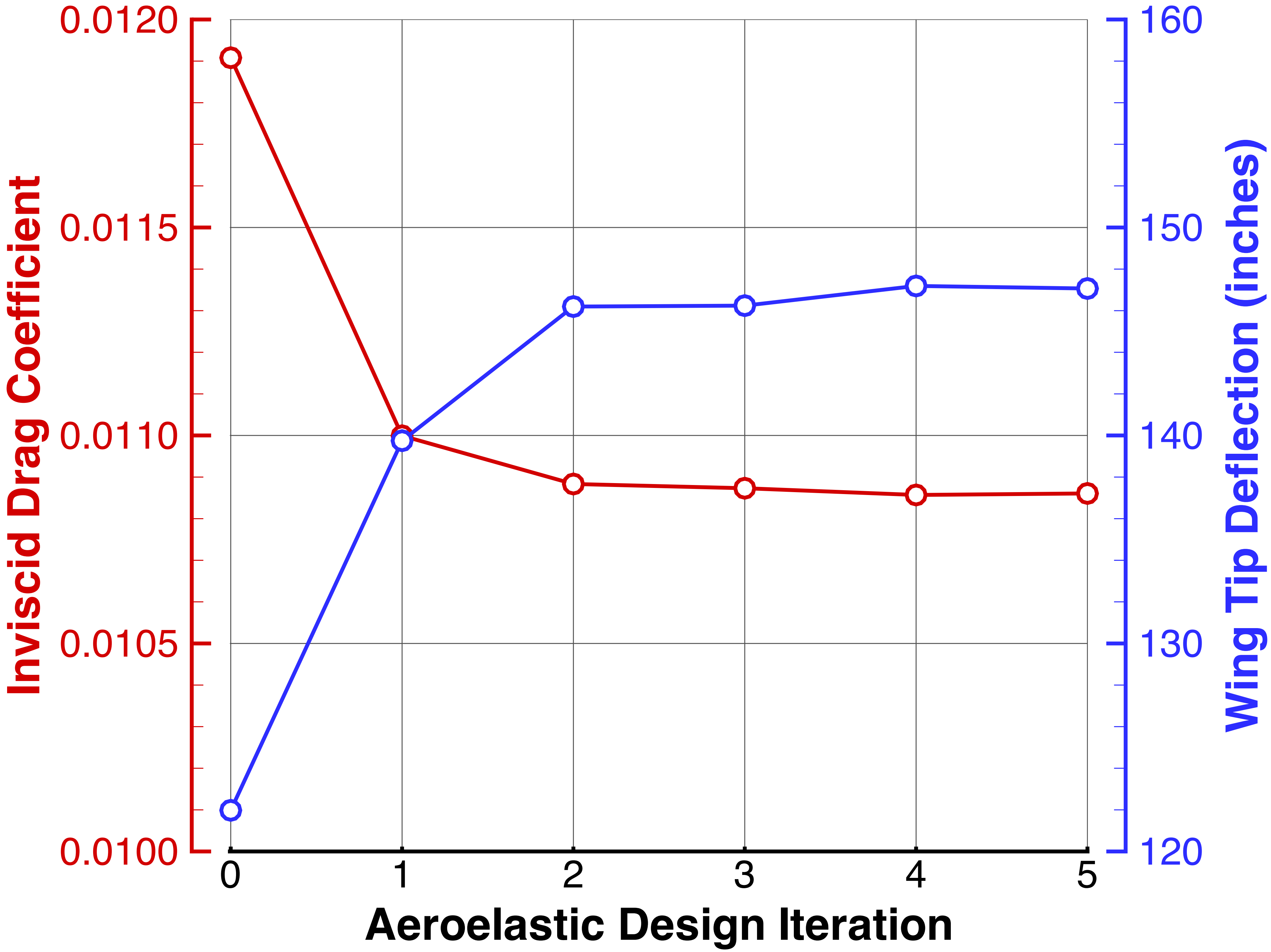
$\alpha \leq \alpha_{max}$



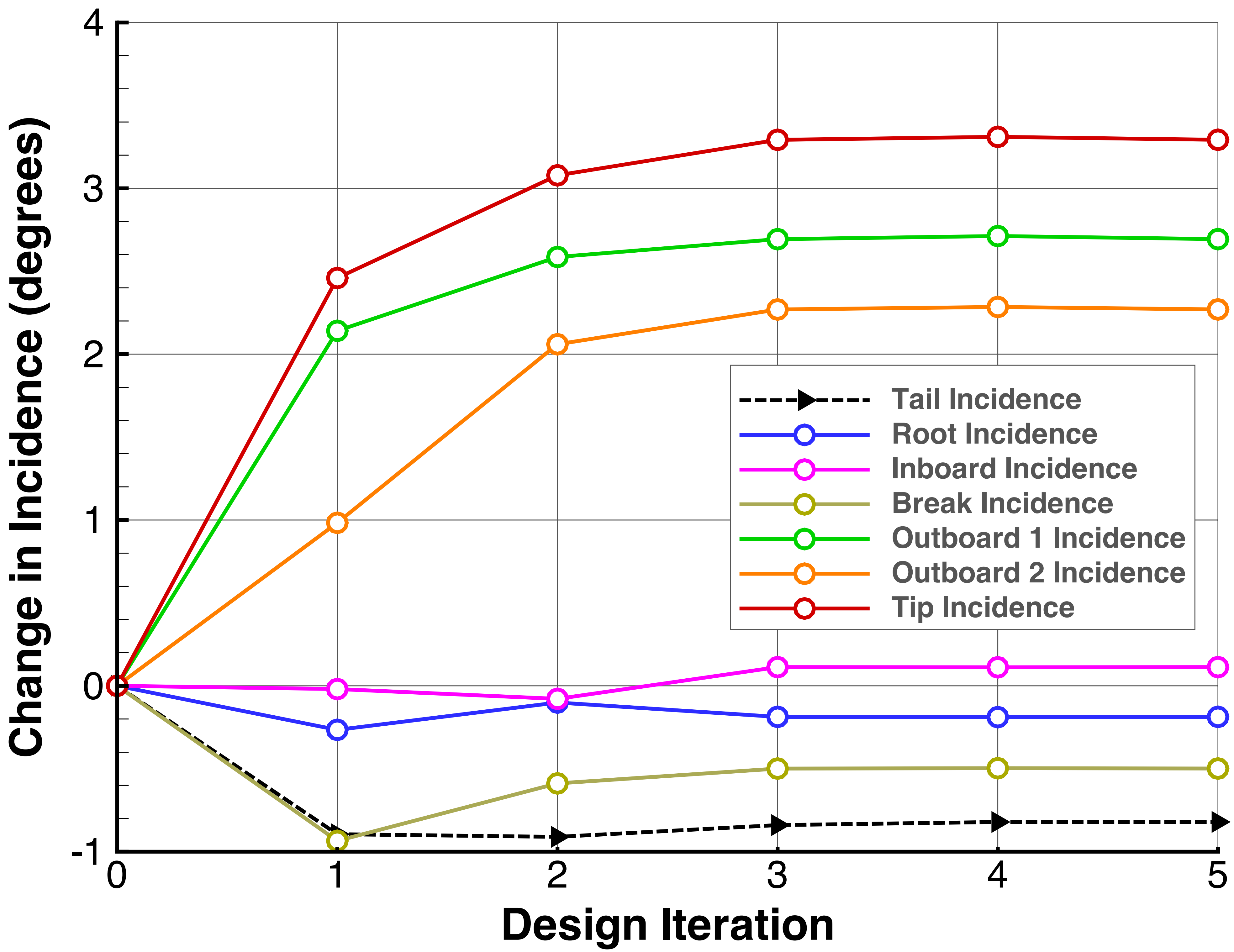




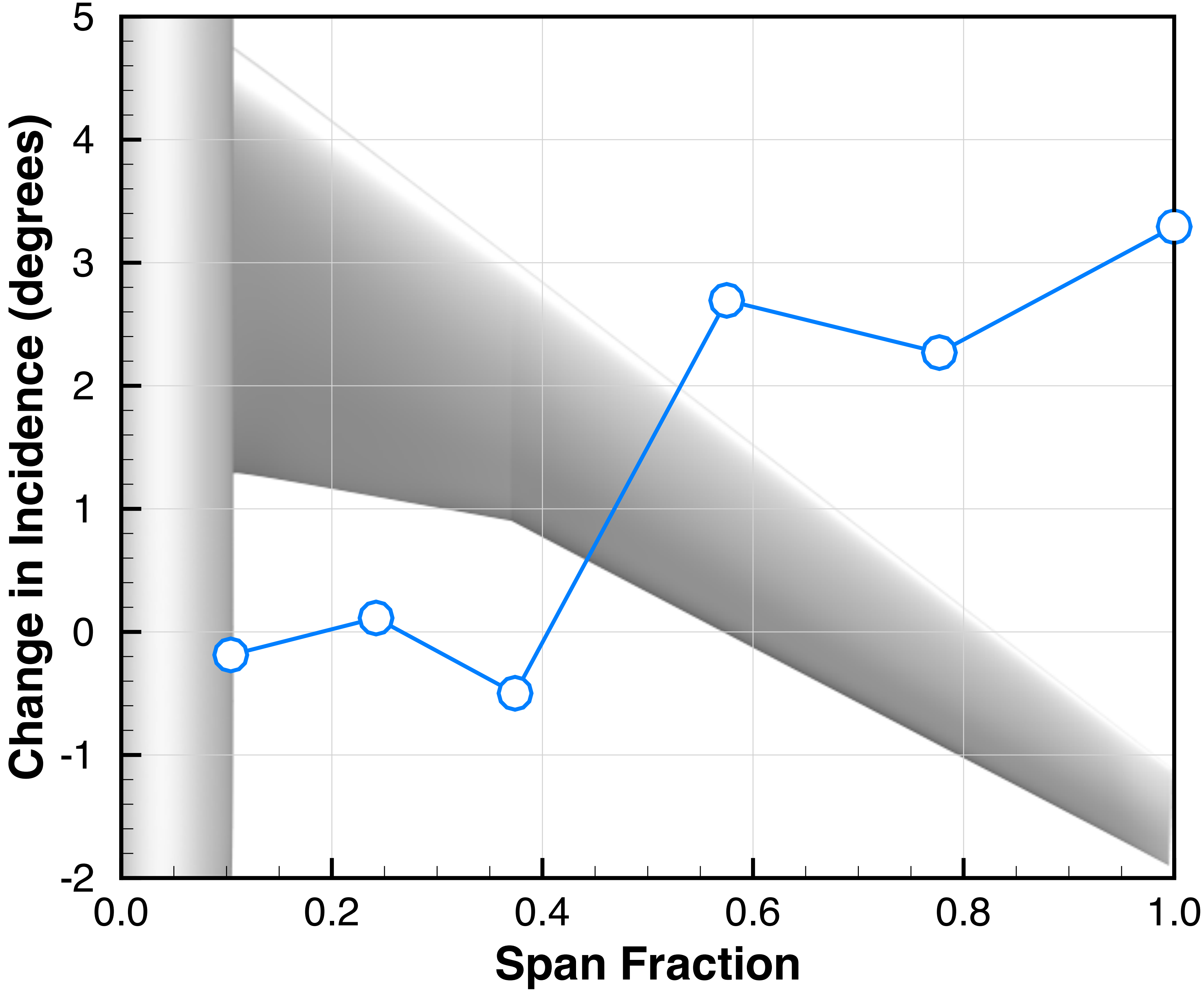
Convergence of Twist Optimization



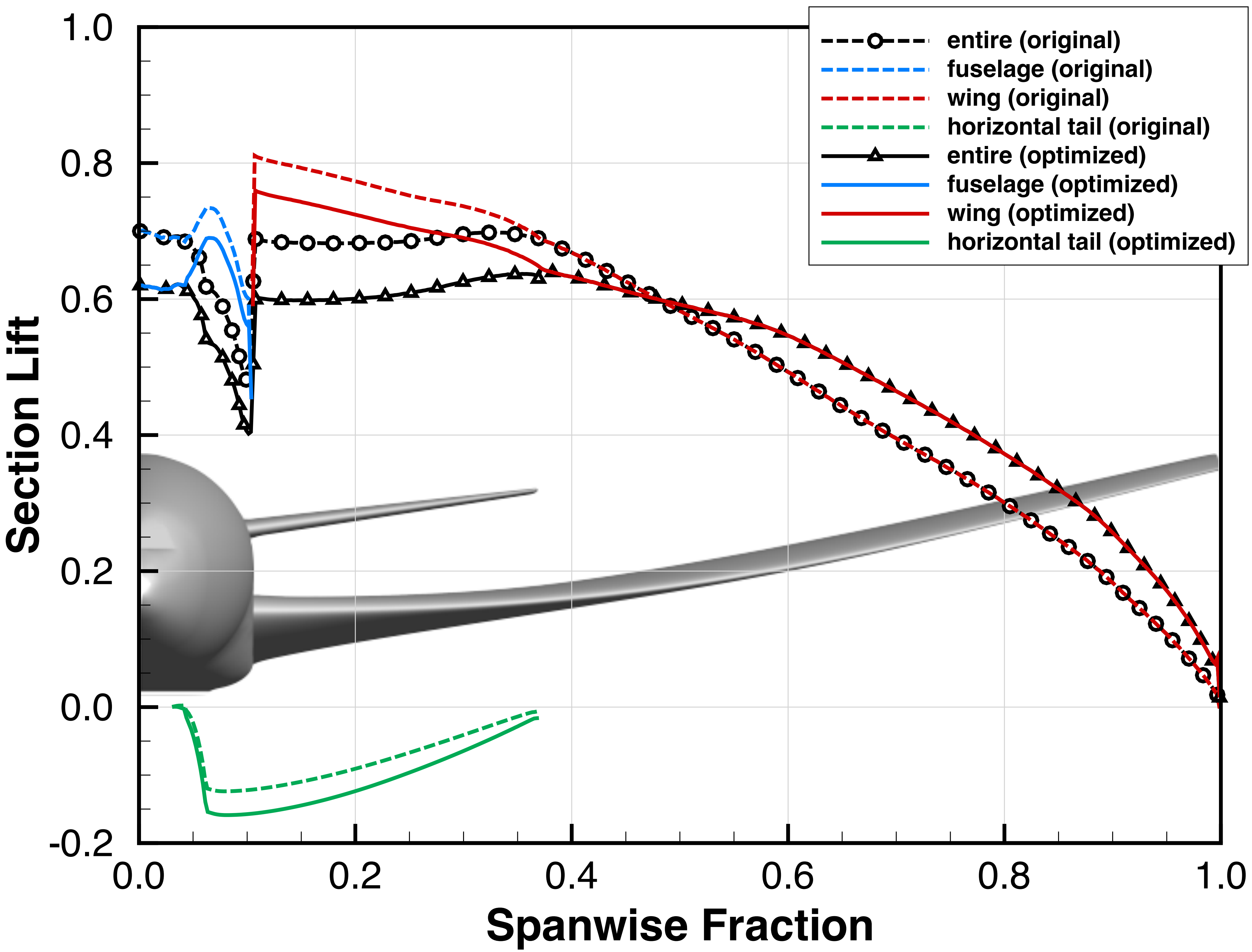
Convergence of Twist Optimization



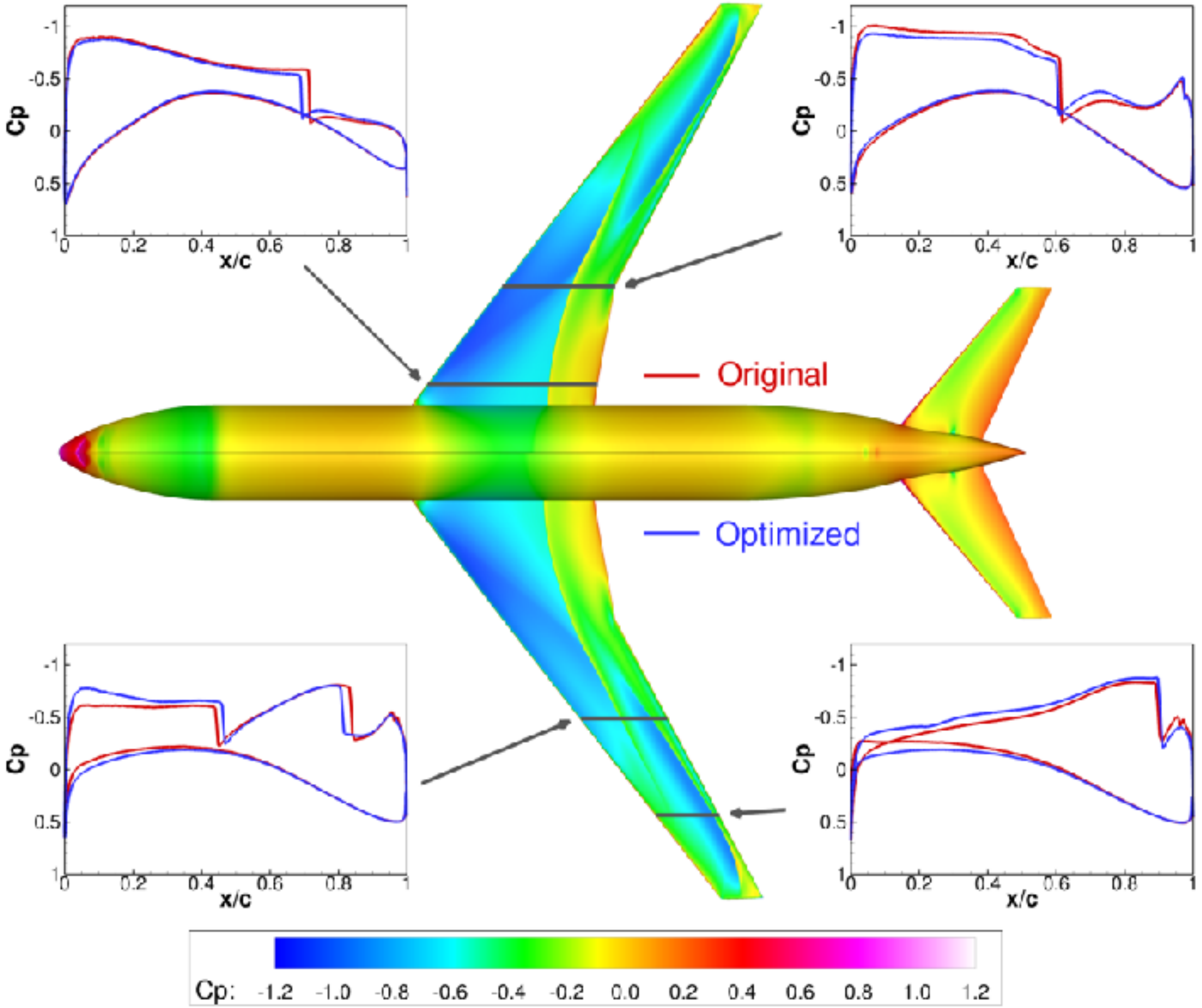
Optimized Twist Distribution



Optimized Spanwise Lift Distribution

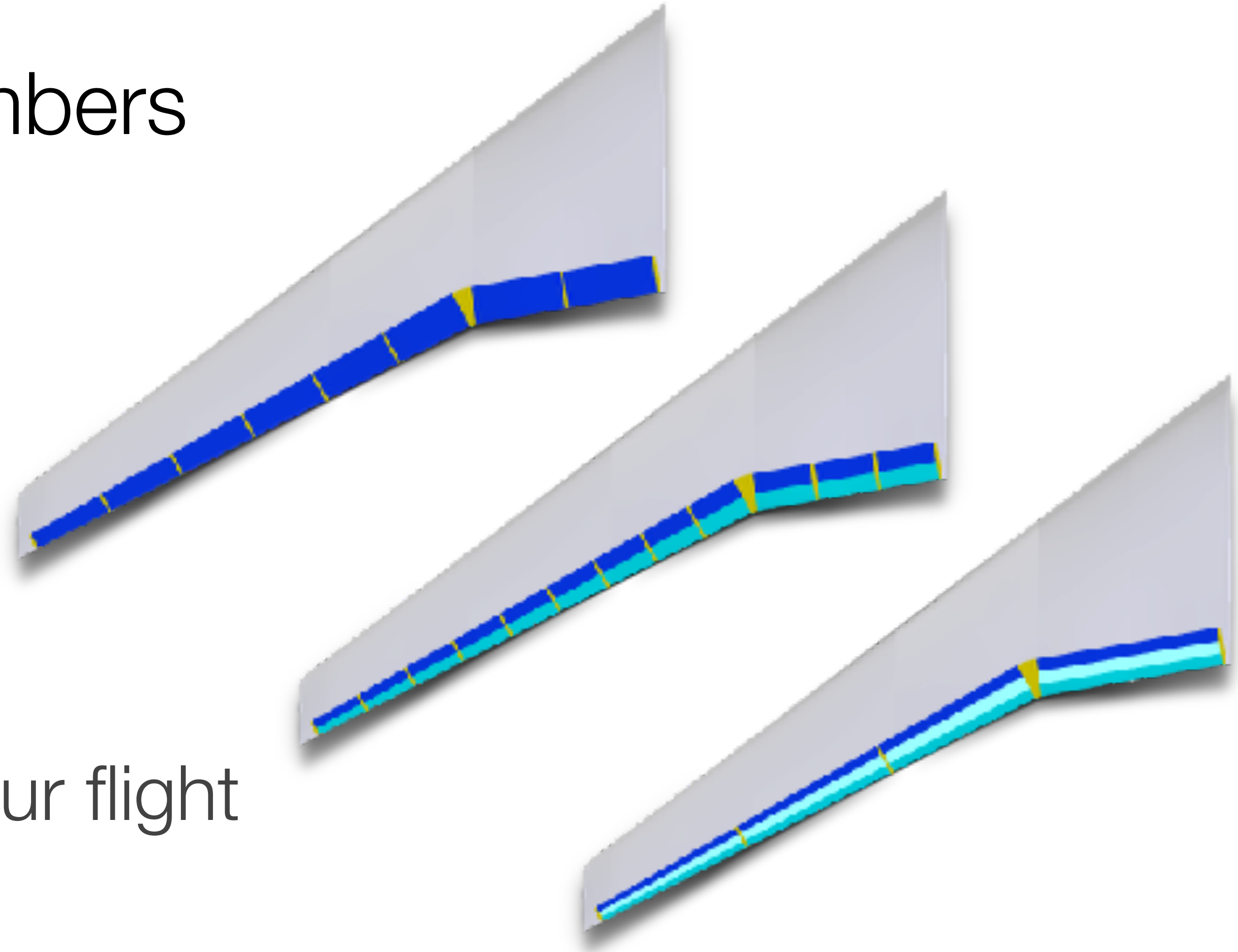


Surface Pressure Distribution



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



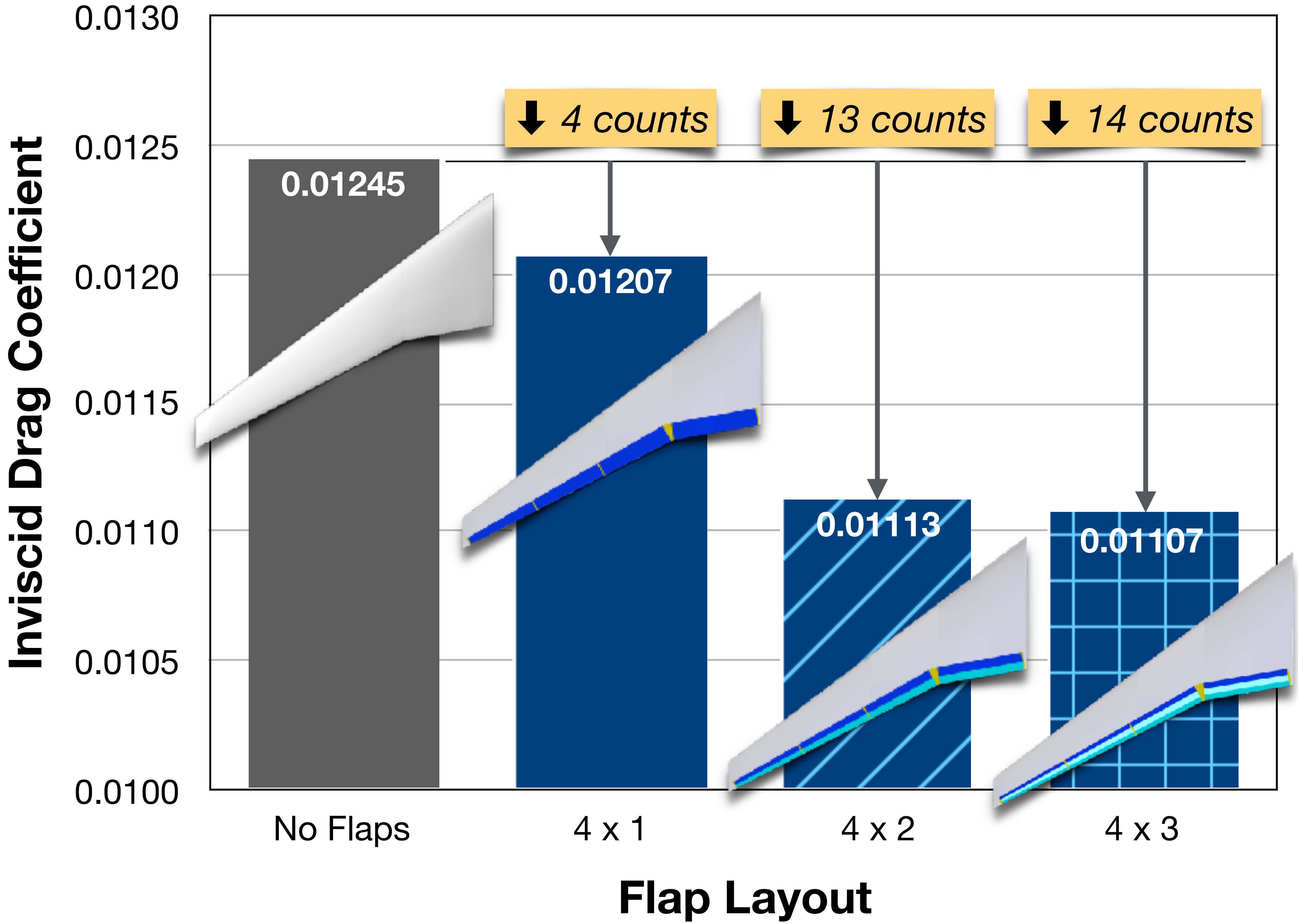
minimize: $C_D\,(\alpha, \Delta_{flaps}, i_t)$ @ $M_\infty = 0.88$

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

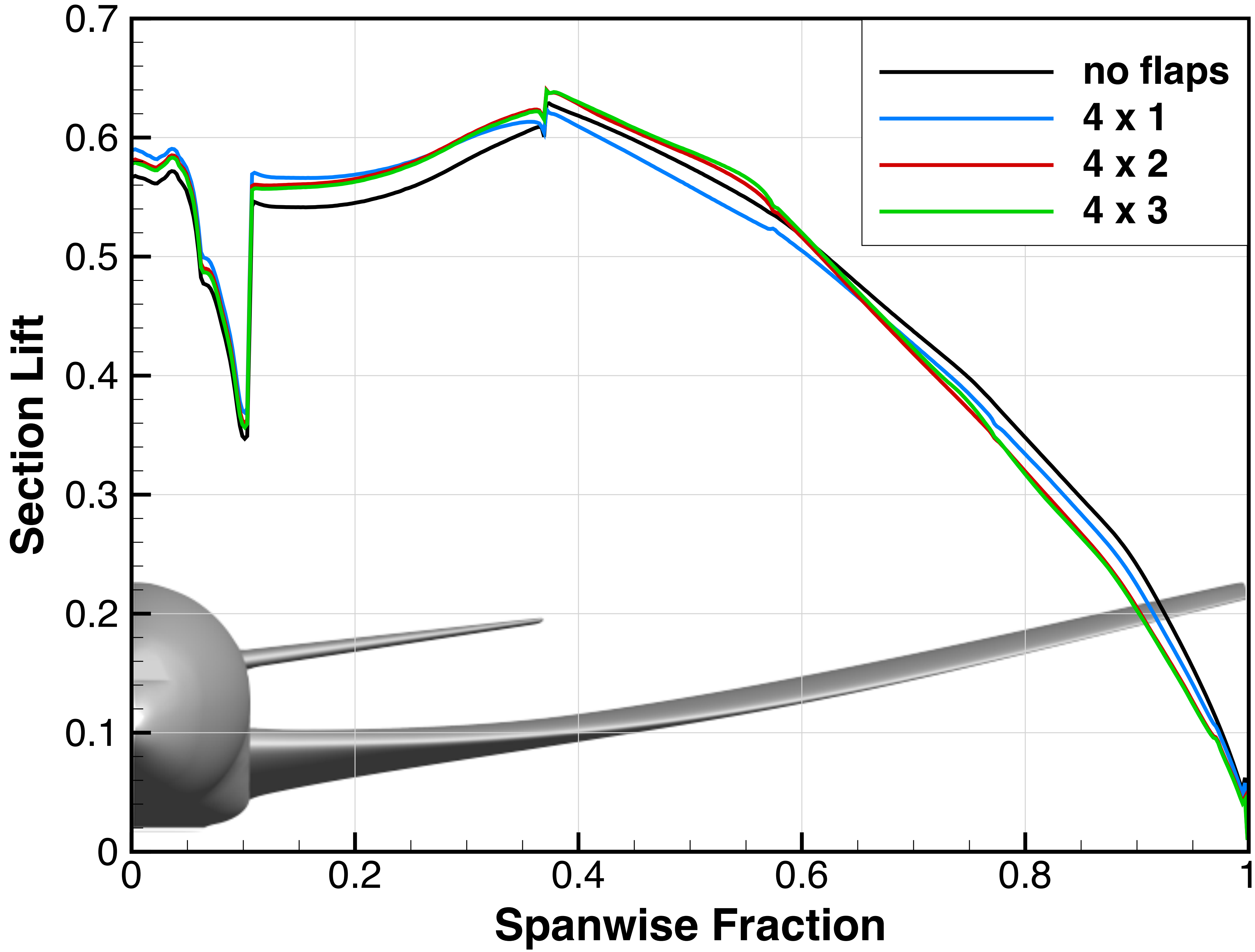
$C_M\,(\alpha, \Delta_{flaps}, i_t) = 0$

$\alpha \leq \alpha_{max} = 3°$

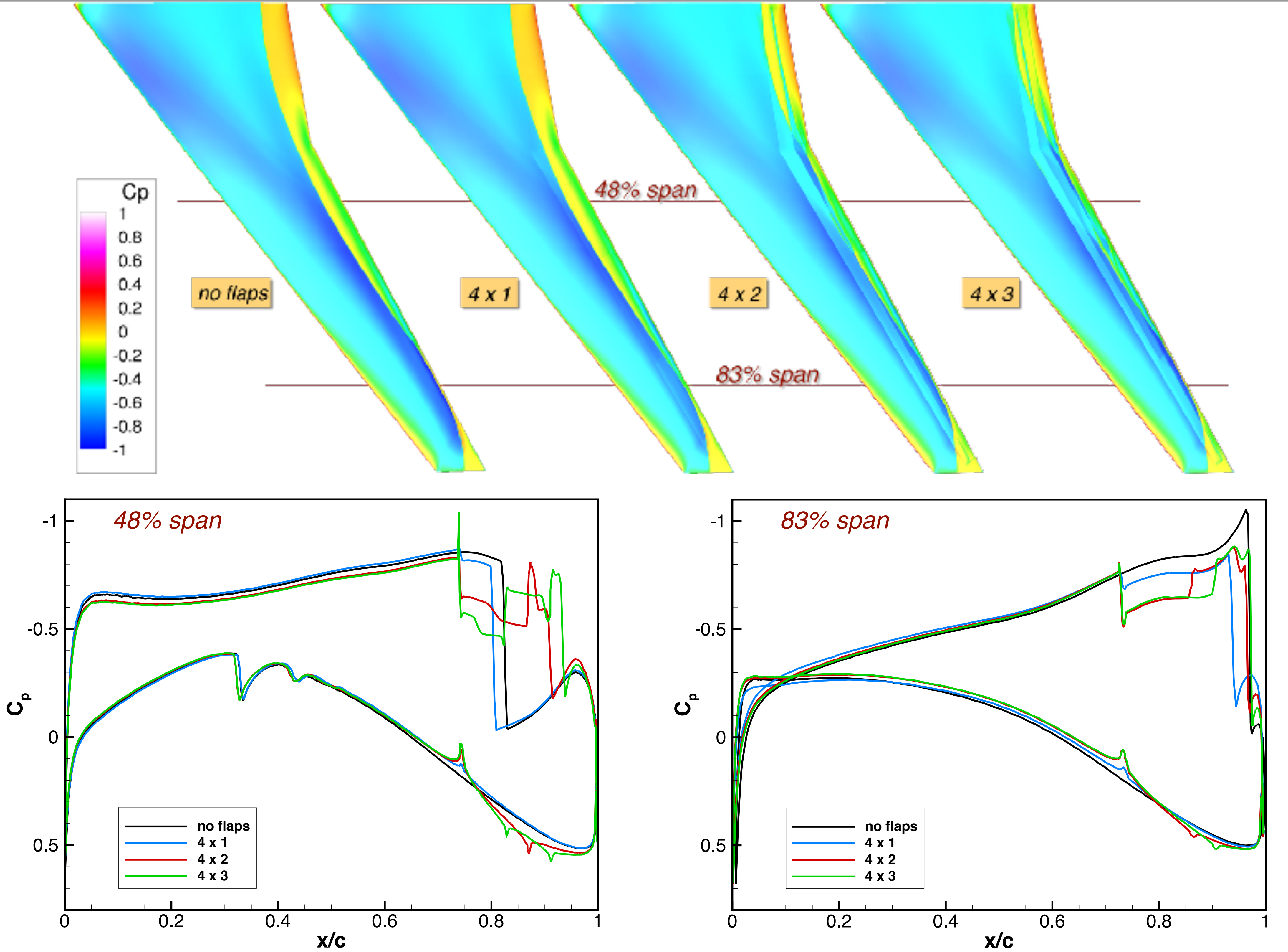
Performance of Optimized 4-Flap Layouts



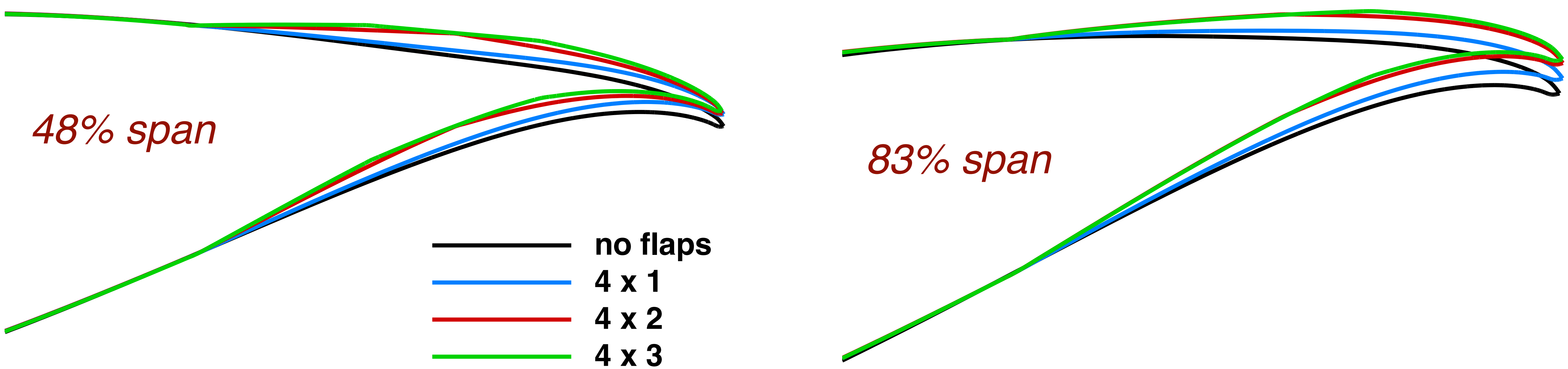
Lift Distribution on 4-Flap Systems



Pressure Distributions on 4-Flap Layouts



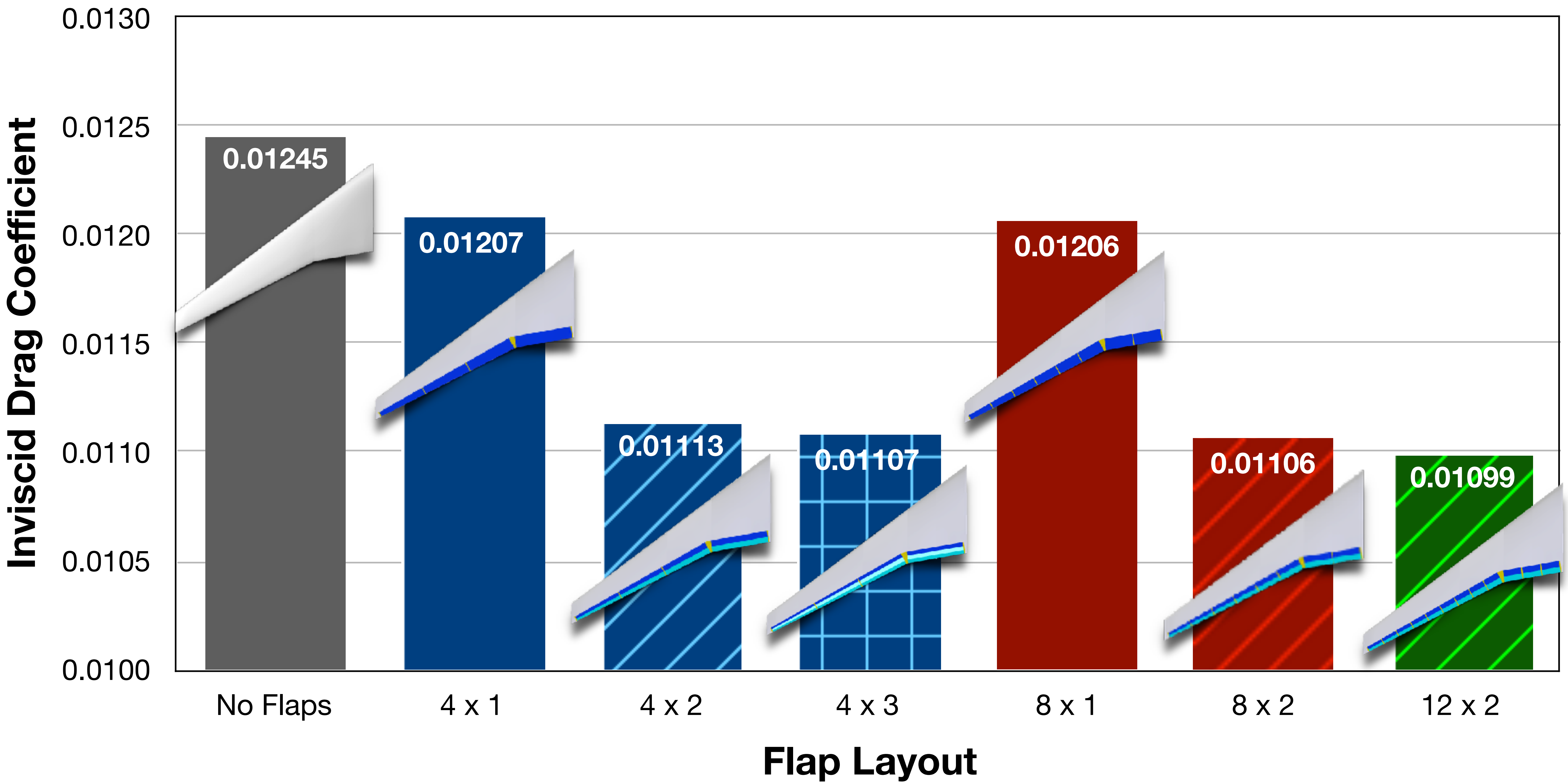
Optimized 4-Flap Geometry



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



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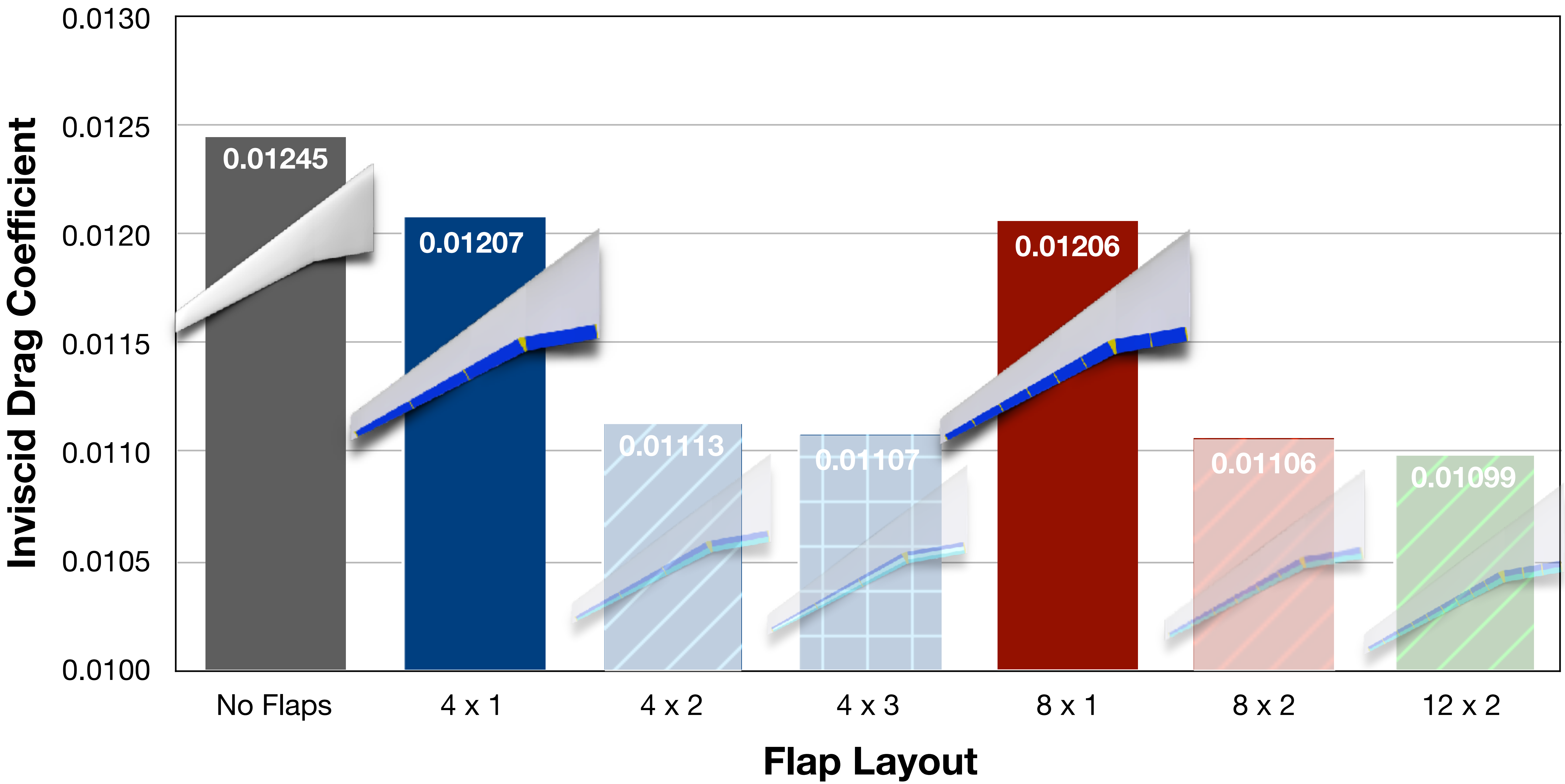
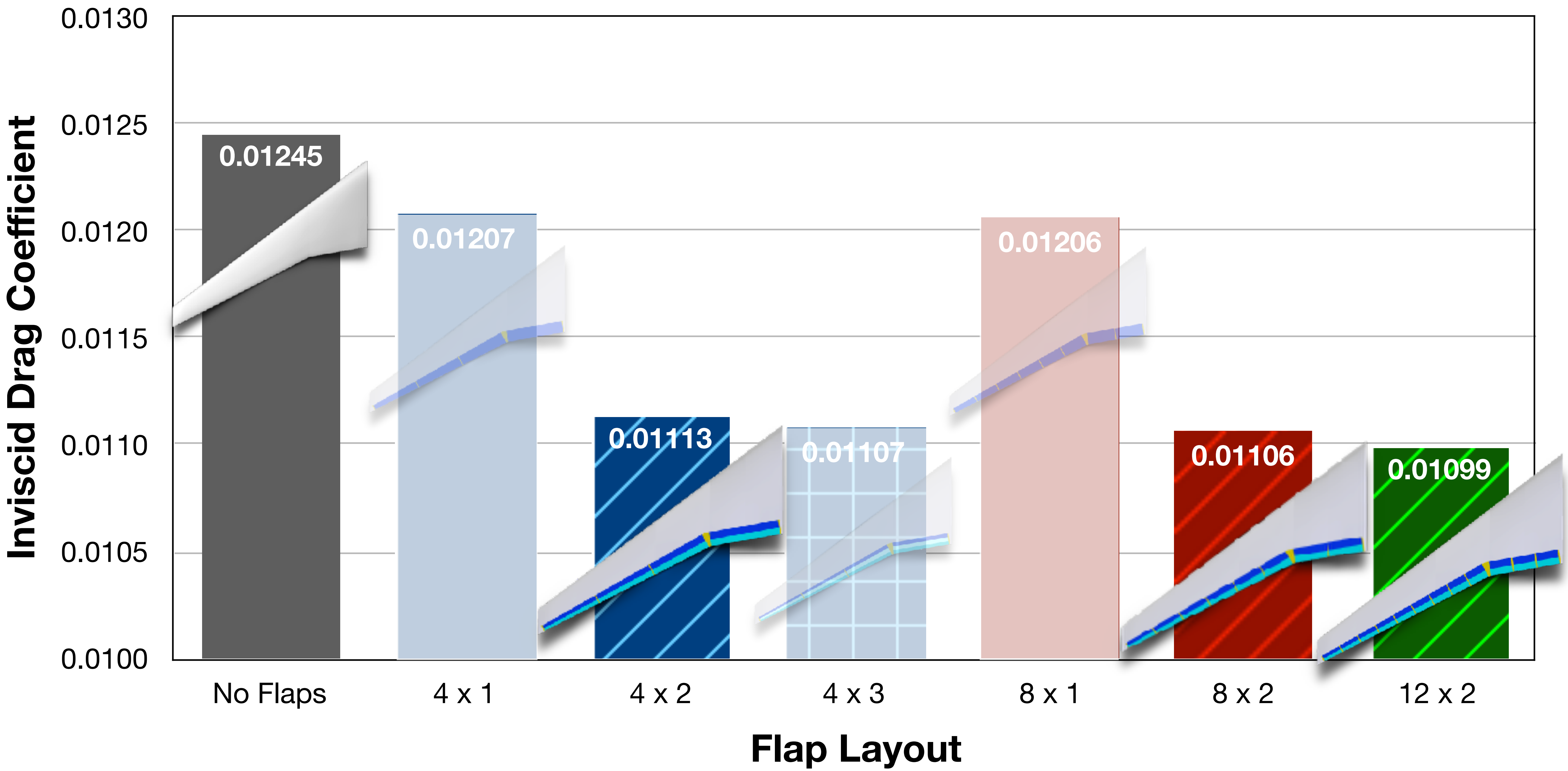
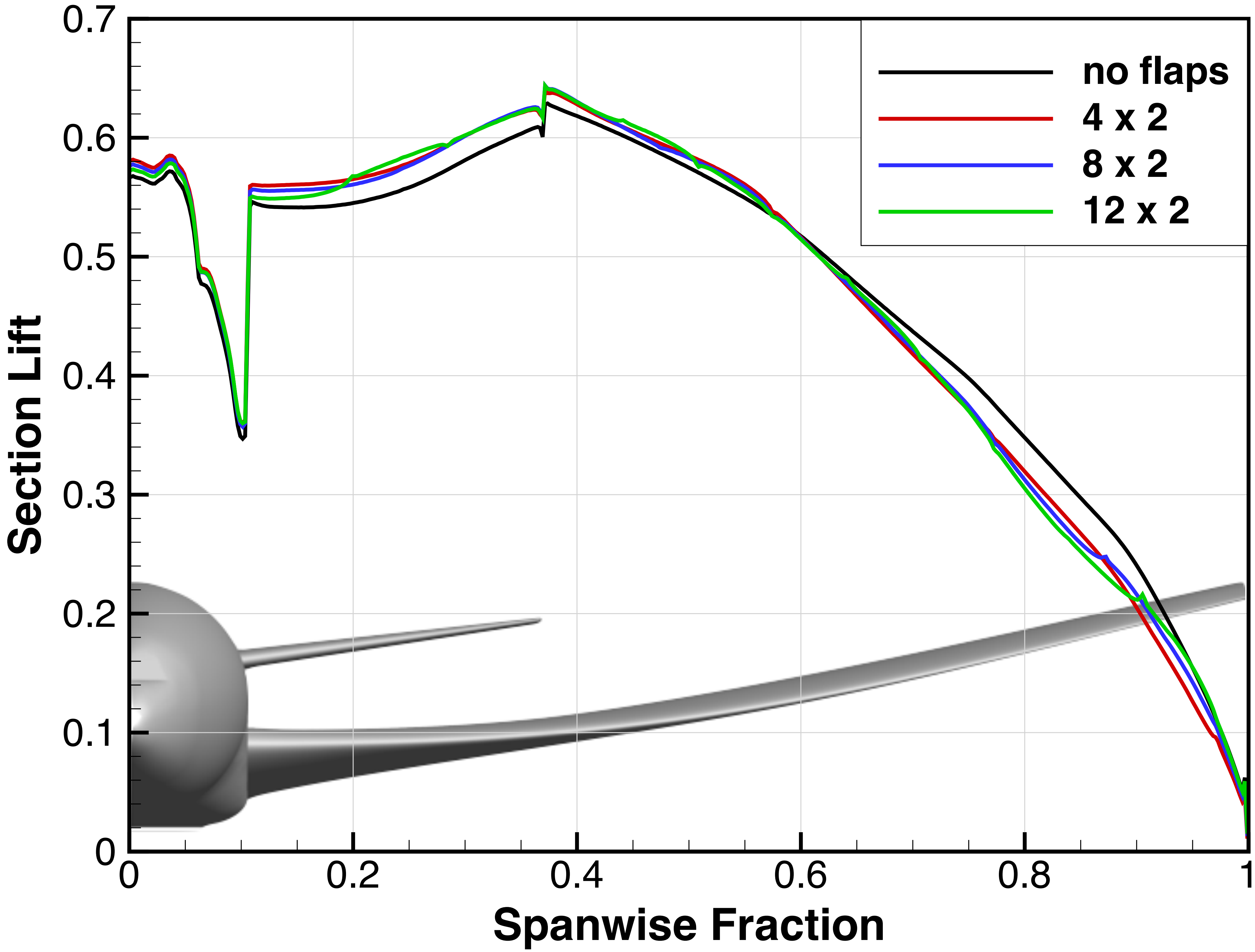


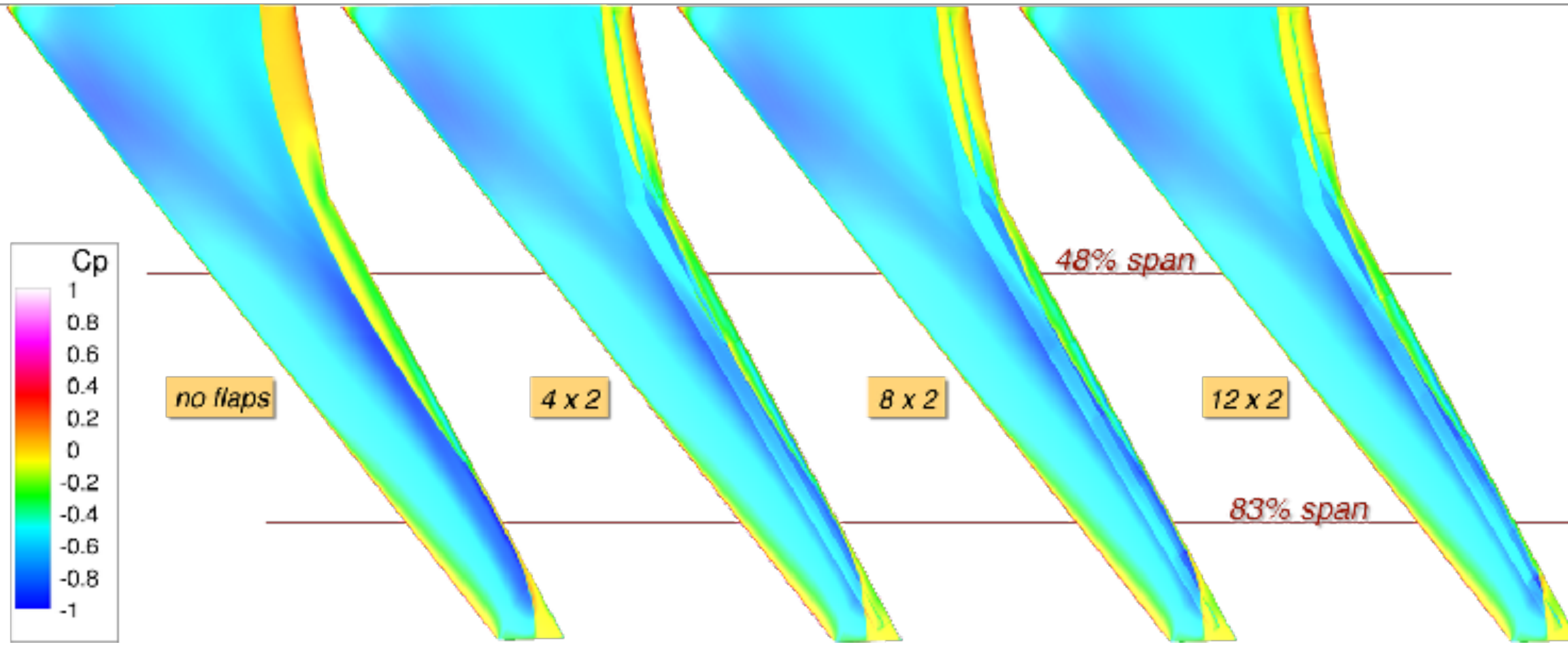
Performance of All Optimized Flap Layouts

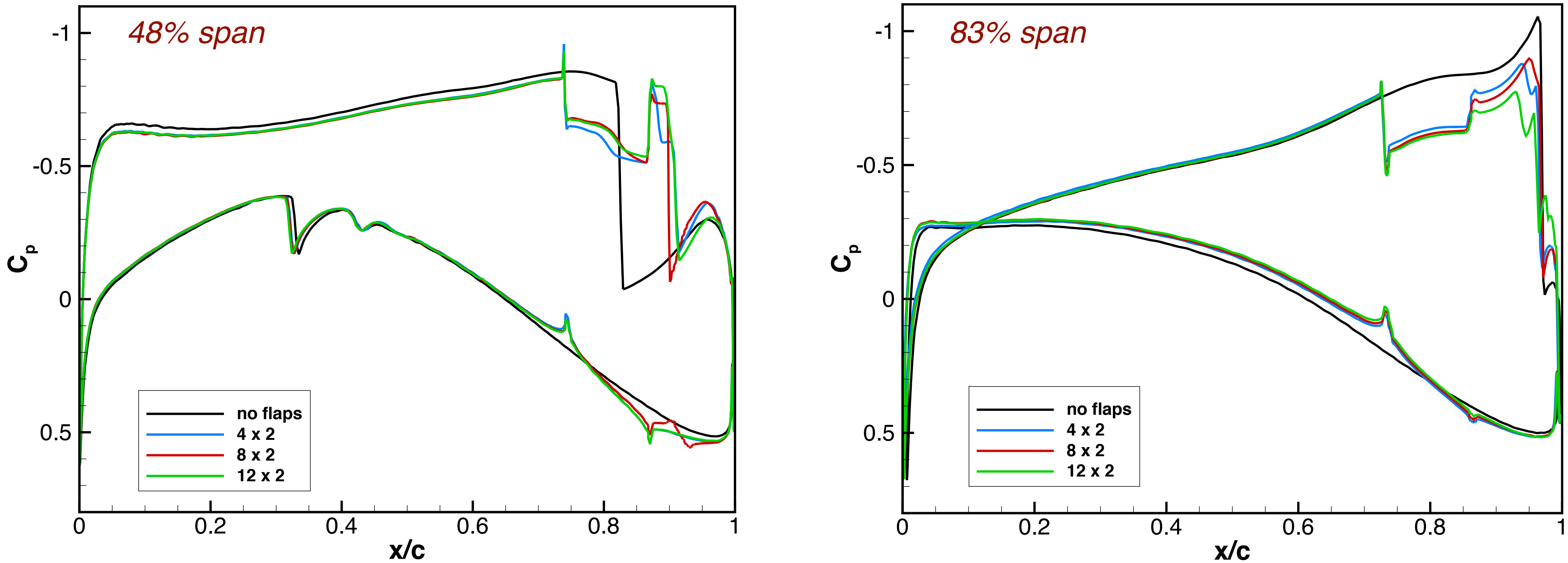


Spanwise Lift Distribution on 2-Segment Systems

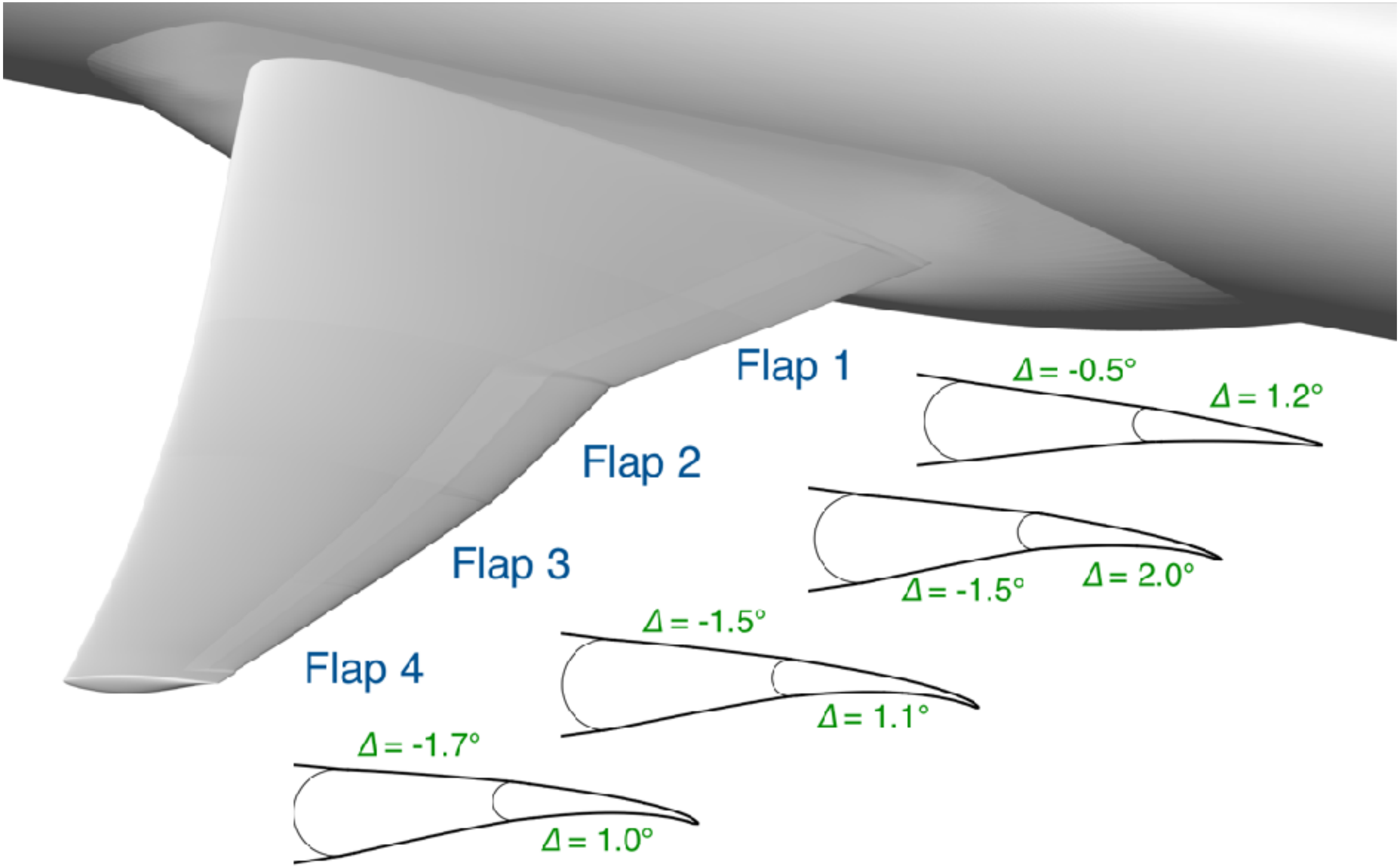


Pressure Distributions on 2-Segment Layouts





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

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- NASA Advanced Supercomputing (NAS) Center provided computing resources