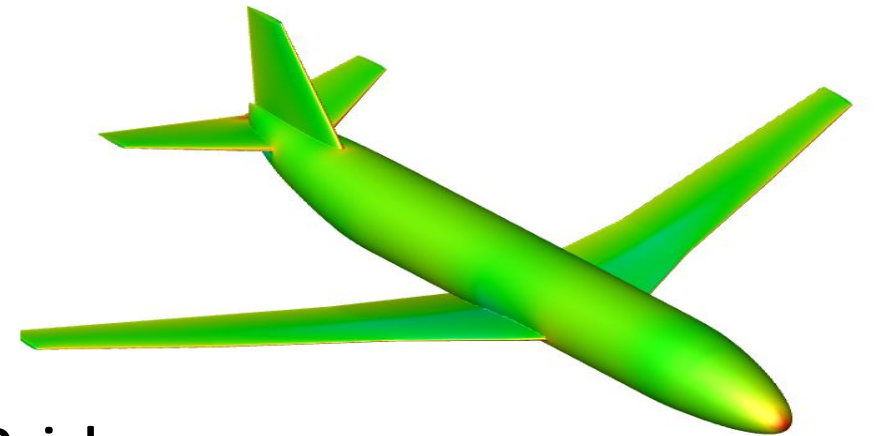
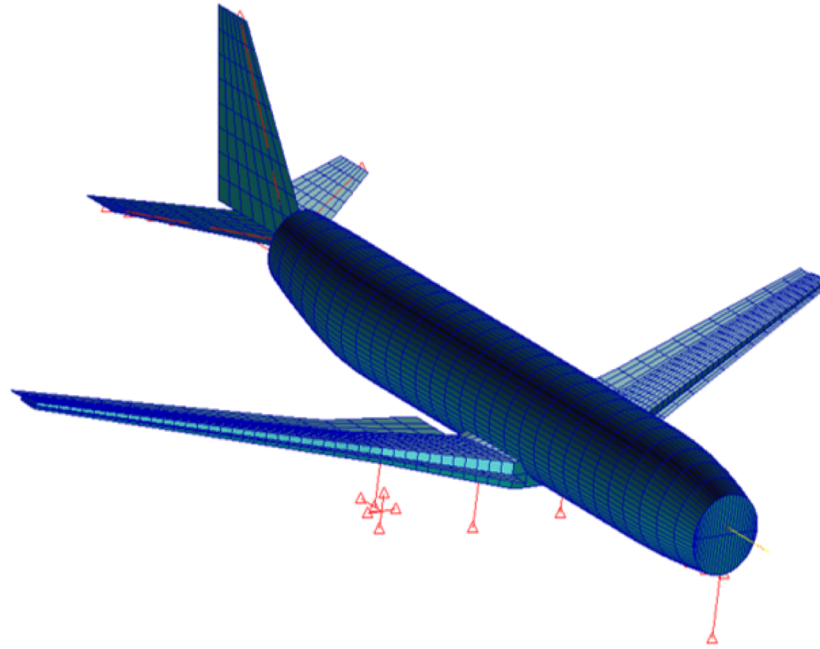
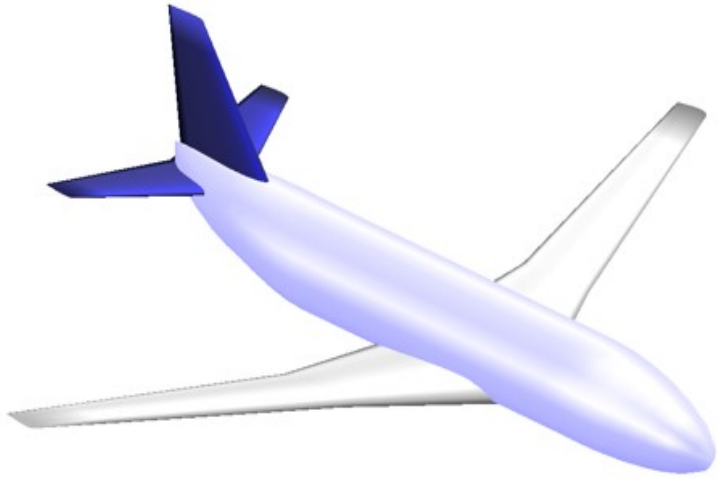


Investigation of Aerodynamic-Matching Sensitivities using HCDstruct



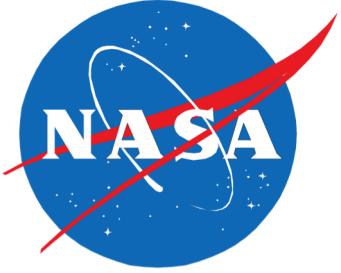
Roger Simon

Dr. Jesse Quinlan

**Aeronautics Systems Analysis Branch
Systems Analysis and Concepts Directorate**

NASA Langley Research Center

July 24, 2019



About Me

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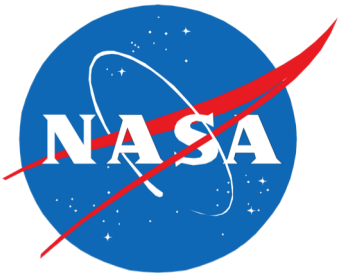
Vehicle Model
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Summary

Future Work

- College: Texas A&M University
- Program: Master of Science in Aerospace Engineering
- Research Background:
 - Experimental Aerodynamics
 - Boundary-layer theory
 - Water-droplet dynamics
- Hobbies:
 - Playing the piano
 - Working out
 - Traveling
 - Watching movies
 - Reading





What is HCDstruct?

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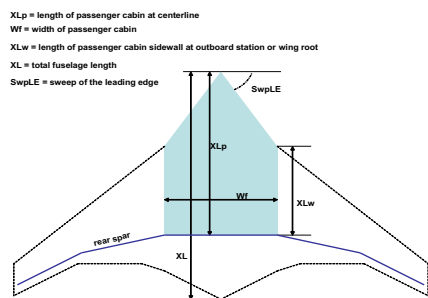
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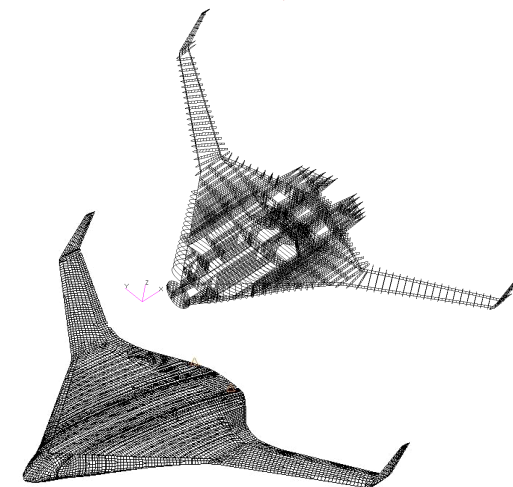
An analysis gap existed between FLOPS based HWB primary structural weight calculations and more detailed point design analyses, where a higher-fidelity, finite-element-based weight estimation tool for conceptual design environments was needed...

Low-fidelity/cost

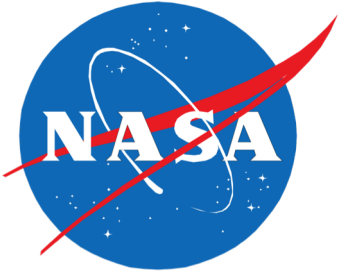
High-fidelity/cost



FLOPS
(Regression-based)



Boeing
(Detailed FEM)



What is HCDstruct?

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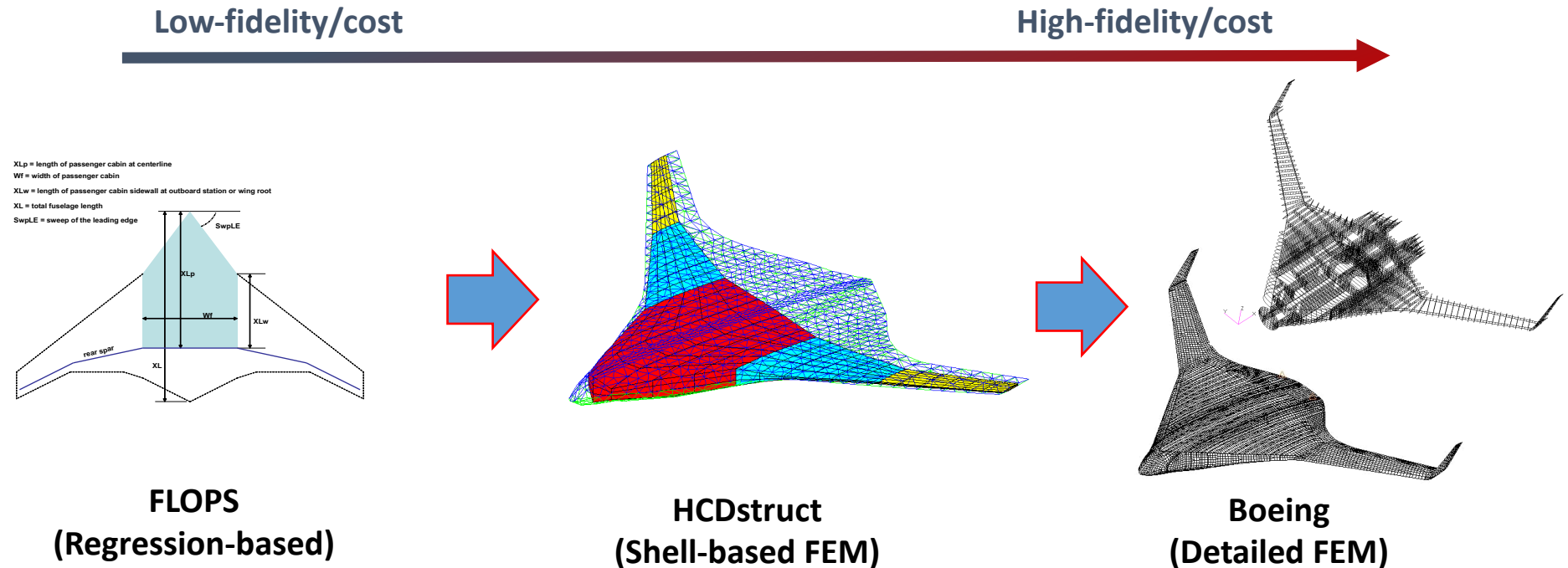
CFD Study

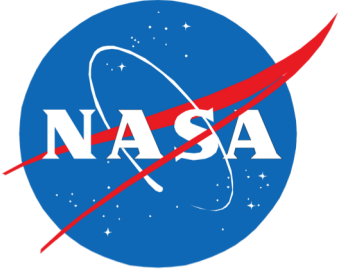
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An analysis gap existed between FLOPS based HWB primary structural weight calculations and more detailed point design analyses, where a higher-fidelity, finite-element-based weight estimation tool for conceptual design environments was needed...





Why an extension for aero-modeling?

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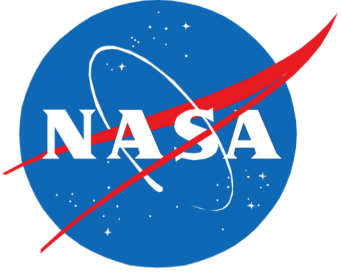
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- Doublet-lattice method (DLM) is baseline
- DLM **generally reasonable** for subsonic aerodynamics
- DLM **not reasonable** for transonic and complex flowfields
 - Flow separation, high lift, complex geometry, shocks, etc.

Modeling transonic flowfields and complex geometries requires the extension of DLM for proper modeling of transonic flutter (e.g. capturing the transonic dip)



What are the objectives of this study?

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Primary Objective:

Investigate the sensitivity of the aerodynamic matching methodology relative to changes in flight conditions and model parameters

... to be achieved through...

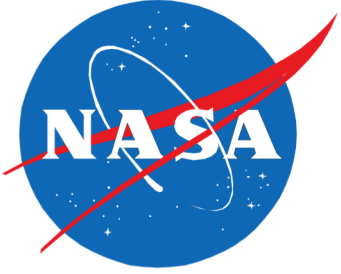
1. *aeroMatch*

[ECFT]...[Methodology]...[Framework Development]

2. *aeroMatch* Sensitivity Study

[Vehicle Model]...[CFD Study]...[W_{kk} Sensitivity]

3. Summary and Future Work



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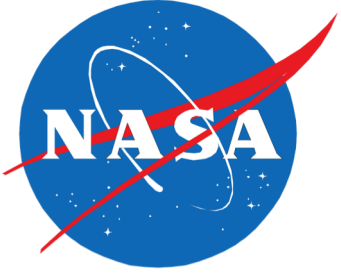
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aeroMatch:

An aerodynamic matching utility for HCDstruct



Enhanced Correction Factor Technique (ECFT)

- DLM modeling in Nastran is widely-used
- The Enhanced Correction Factor Technique (ECFT) was developed at Raytheon Aircraft Company in 1999*
 - Expands the earlier, diagonalized correction methodology of Giesing, et al. to a full correction factor matrix
 - Specifies a pre-multiplier matrix for use with the aerodynamic influence coefficients (A_{jj}) matrix on the k-set in Nastran:

$$P_k = W_{kk} S_{kj} f_j = q W_{kk} S_{kj} A_{jj} w_j$$

Forces/Moments

Correction Matrix (k-set)

Integration Matrix (j- to k-set)

Pressures

Dynamic Pressure

Aerodynamic Influence Coefficients

Downwash

*Jadic, I., Dayton, H., and Jagannath, G., "An Enhanced Correction Factor Technique for Aerodynamic Influence Coefficient Methods," MSC Aerospace User's Conference, 1999.

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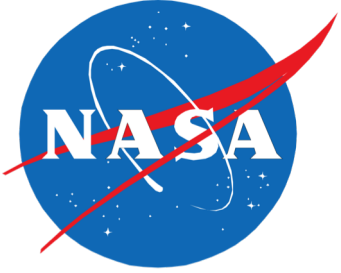
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Enhanced Correction Factor Technique (ECFT)

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The ECFT can be generally defined as:

1. Define the downwash modes matrix W
2. Compute original forces due to downwash modes as:

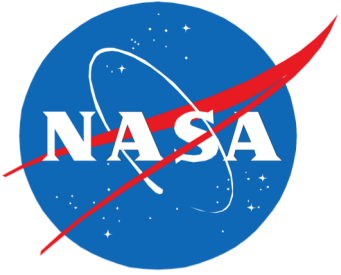
$$F_0 = A_{jj} * W$$

3. Compute a constraint force matrix, F_1 , by replacing selected modal force vectors with experimental or CFD aerodynamic force data
4. Computing a complete correction factor matrix C_F by noting the relation:

$$F_1 = C_F A_{jj} W = C_F F_0$$

From which it follows:

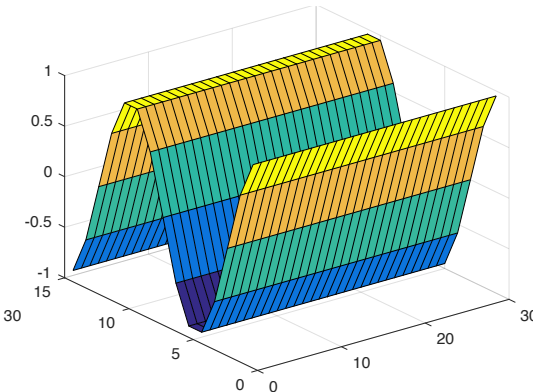
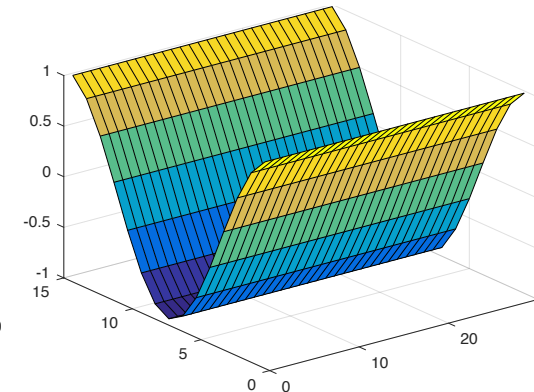
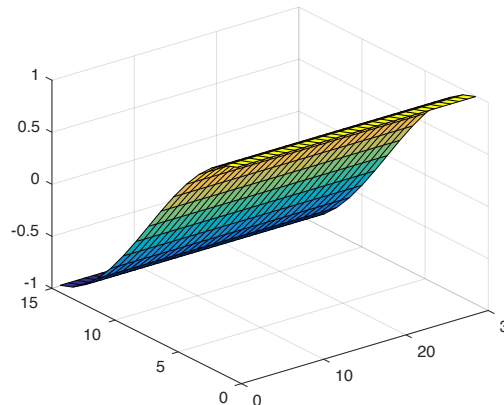
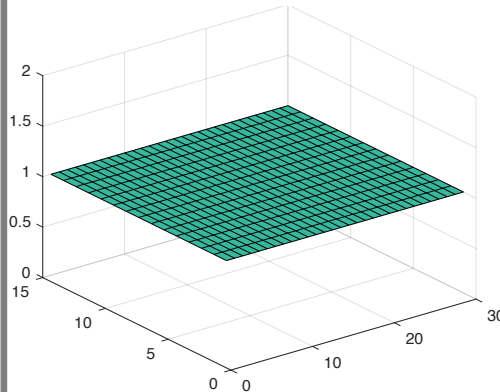
$$C_F = F_1 F_0^{-1} \equiv W_{jj}$$



Enhanced Correction Factor Technique (ECFT)

ECFT is based on a modal decomposition of the aerodynamic downwash by forming a base matrix, which is composed of harmonic aerodynamic downwash vectors

$$W(g_{chord}, g_{span}, m_{chord}, m_{span}) = \cos\left(\frac{(2g_{chord} - 1)(m_{chord} - 1)\pi}{2l}\right) \cos\left(\frac{(2g_{span} - 1)(m_{span} - 1)\pi}{2m}\right)$$



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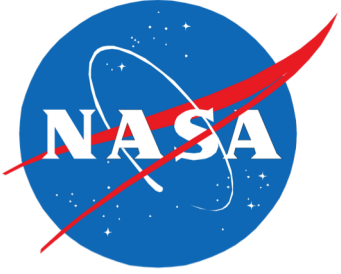
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aeroMatch ECFT Methodology

While the ECFT is devised to operate on the j-set (i.e. on aerodynamic pressures), the method can be extended to operate on the k-set (i.e. on force and moments)

Within Nastran, the S_{kj} integration matrix is used to integrate the j-set aerodynamic pressure to the k-set force-moment data according to:

$$P_k = W_{kk} S_{kj} f_j = q W_{kk} S_{kj} A_{jj}^{-1} w_j$$

Or

$$P_k = S_{kj} W_{jj} f_j = q S_{kj} W_{jj} A_{jj}^{-1} w_j$$

From which it follows that:

$$W_{kk} S_{kj} = S_{kj} W_{jj}$$

However, noting that:

$size(W_{kk}) = [2l, 2l]$, $size(S_{kj}) = [2l, l]$, and $size(W_{jj}) = [l, l]$,
 $W_{kk} S_{kj} = S_{kj} W_{jj}$ is an indeterminate system; the method prescribed in Moreno, et al.* is
used to compute the corresponding W_{kk}

*Moreno, R., Fedime, K., Nariseti, R., and Taylor, P.F., "A Modification to the Enhanced Correction Factor Technique to Correlate with Experimental Data," AIAA 2015-1421.

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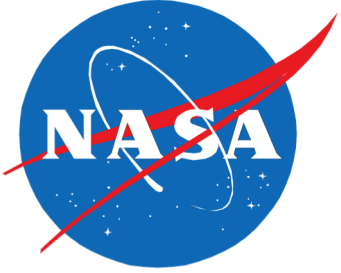
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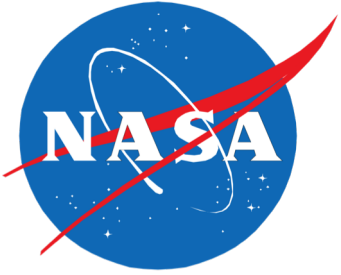
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- The modified ECFT is implemented for use with HCDstruct 2.1.0+ and is implemented as the *aeroMatch* function in the executive control deck
- *aeroMatch* calculates the ΔC_p corresponding to the CAERO1 panel center location, which is then used to build the force constraint matrix, F_1
- Application of *aeroMatch* relies on a Tecplot formatted triangulated surface solution file containing x, y, z, C_p data
- Cart3D was used in development of *aeroMatch*; however, the only requirement on the aerodynamic data input for computing F_1 is that it is a Tecplot-formatted, triangulated surface solution file



Framework Development

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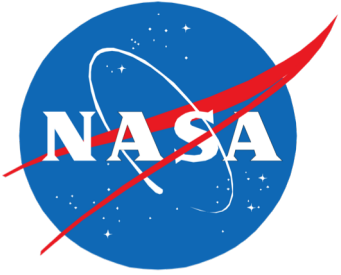
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- Ultimately, we want to be capable of performing sweeps on flight condition ($M = 0.1 - 0.9$ and $\alpha = 0^\circ - 10^\circ$, nominally) while also linking to OpenVSP to permit for design parameter sweeps, too
- For this study, we focused on building the framework using shell scripts to develop the database of solutions necessary to perform the sensitivity analysis
- We demonstrated this framework for a relatively coarse sweep ($M = 0.4 - 0.95$ and $\alpha = 0^\circ - 8^\circ$) and took a preliminary look at potential sensitivities of W_{kk} w.r.t. Mach number and angle of attack



Process Automation Framework

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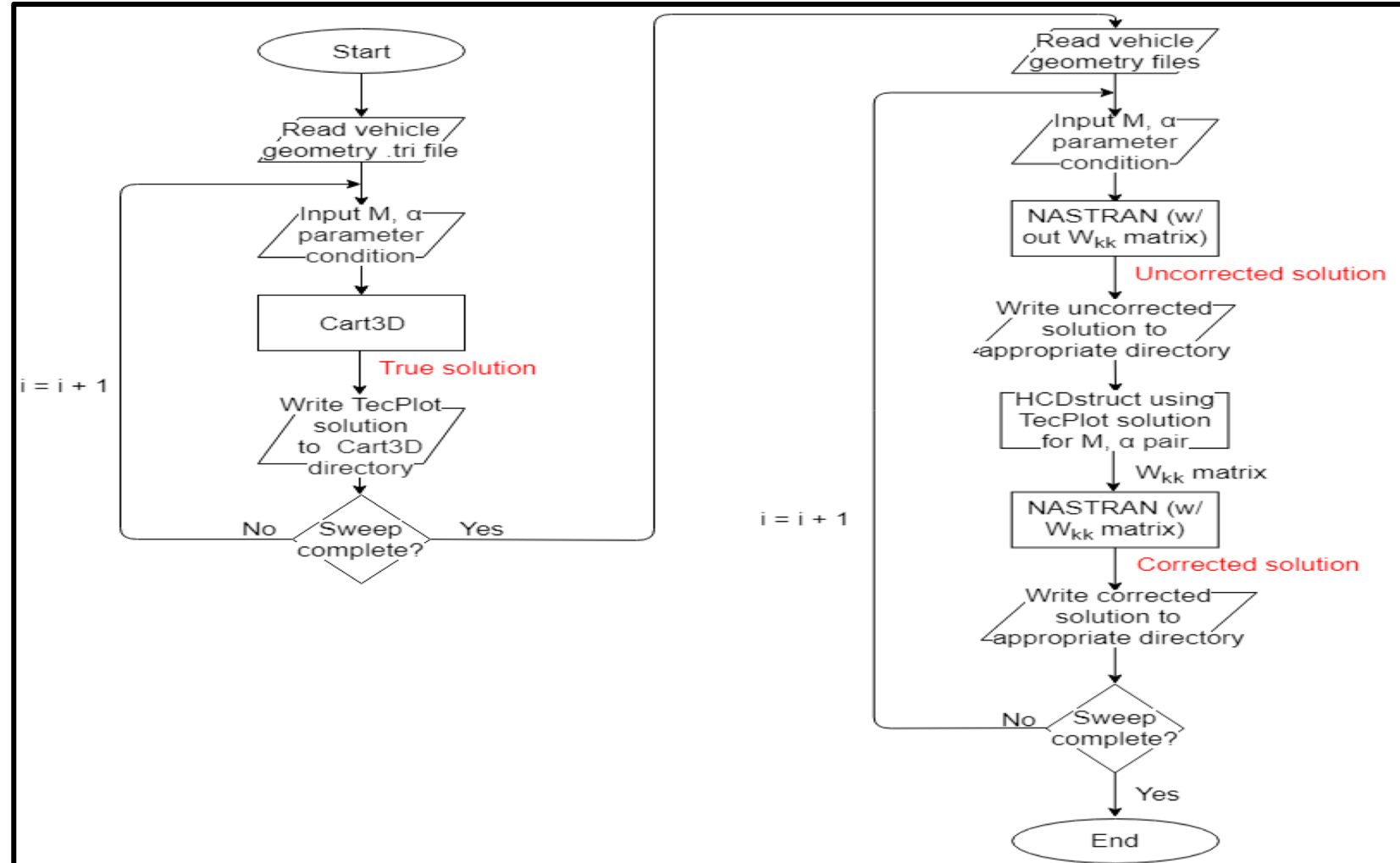
Vehicle Model

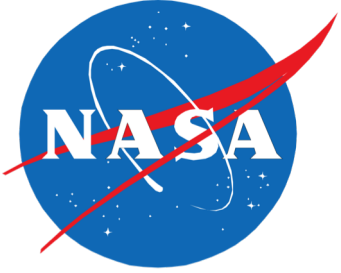
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Vehicle Model: Boeing 737-200

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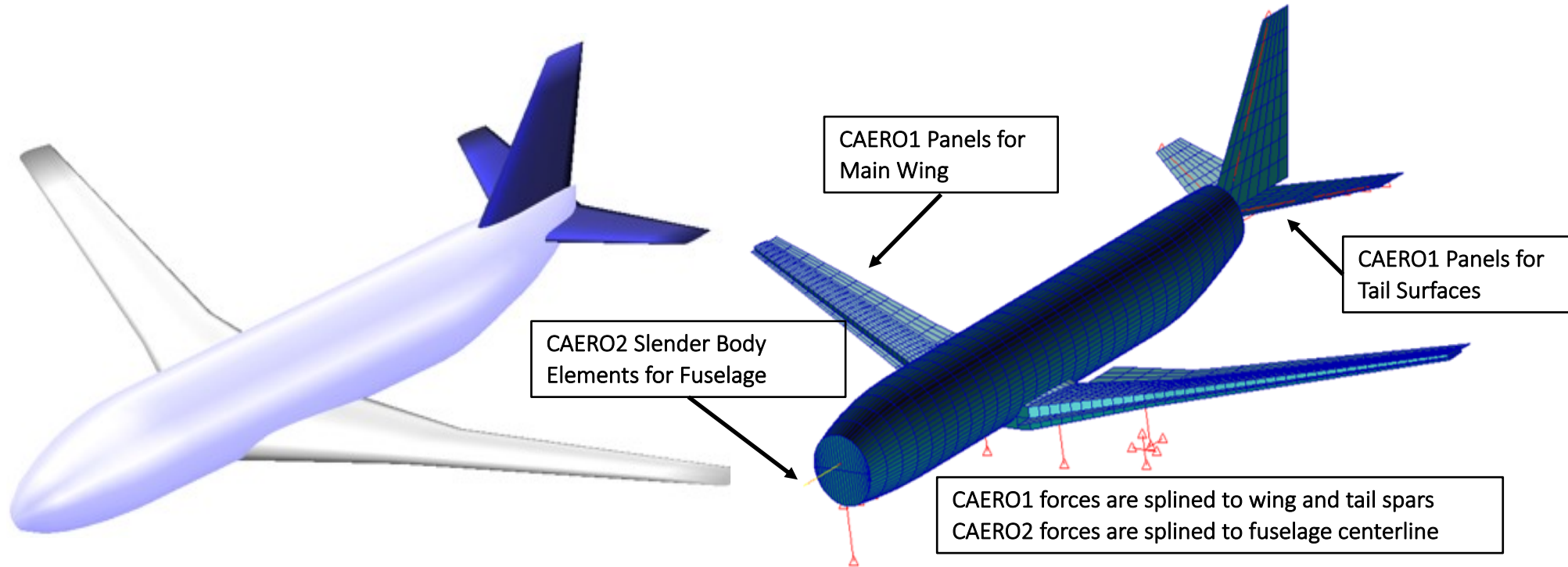
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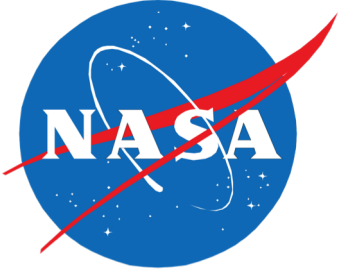
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OpenVSP Model

Aeroelastic FE Model



CFD Configuration

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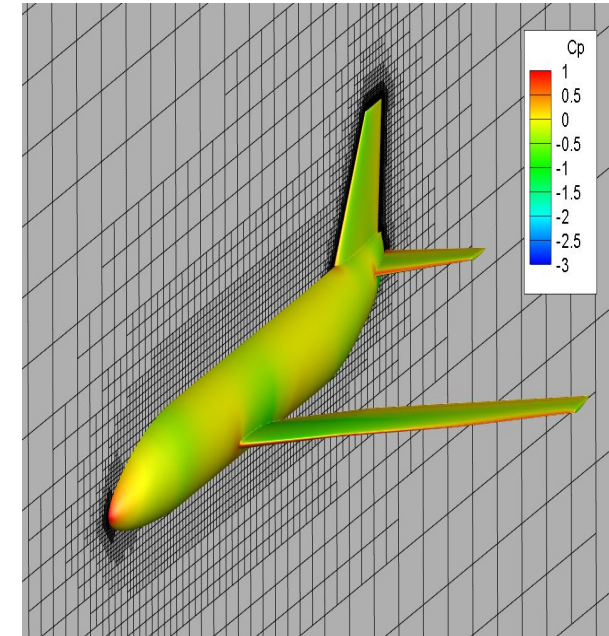
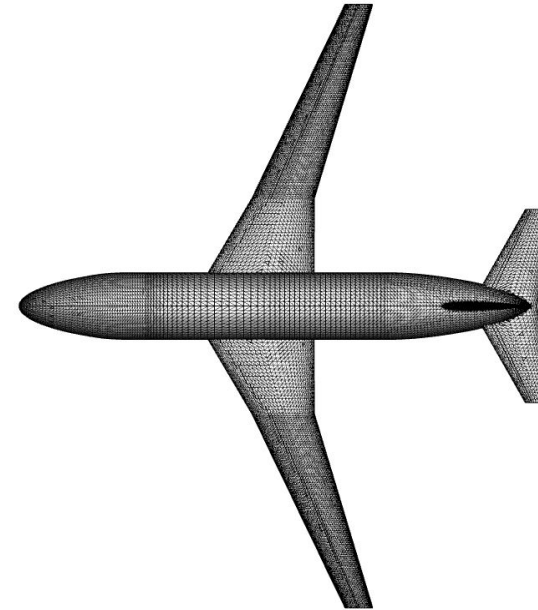
Future Work

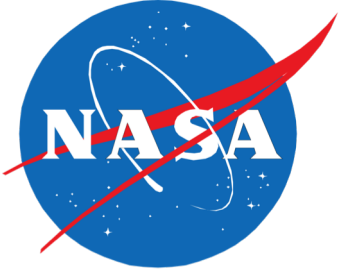
Mesh Details:

- 3.5 million cells
- Mesh convergence study on different levels of refinements
- Assumed NACA 6300 supercritical airfoils
- Chord and twist distribution based on published figures

Solver Details:

- Inviscid/Euler (Cart3D)
- AOA = $[0^\circ, 2^\circ, 4^\circ, 6^\circ, 8^\circ]$
- $M = [0.4, 0.5, 0.6, 0.65, 0.7, 0.75, 0.8, 0.85, 0.9, 0.95]$
- CFL = 1.0
- Van Leer flux limiter
- Five-stage RK integration





Mesh Convergence Study

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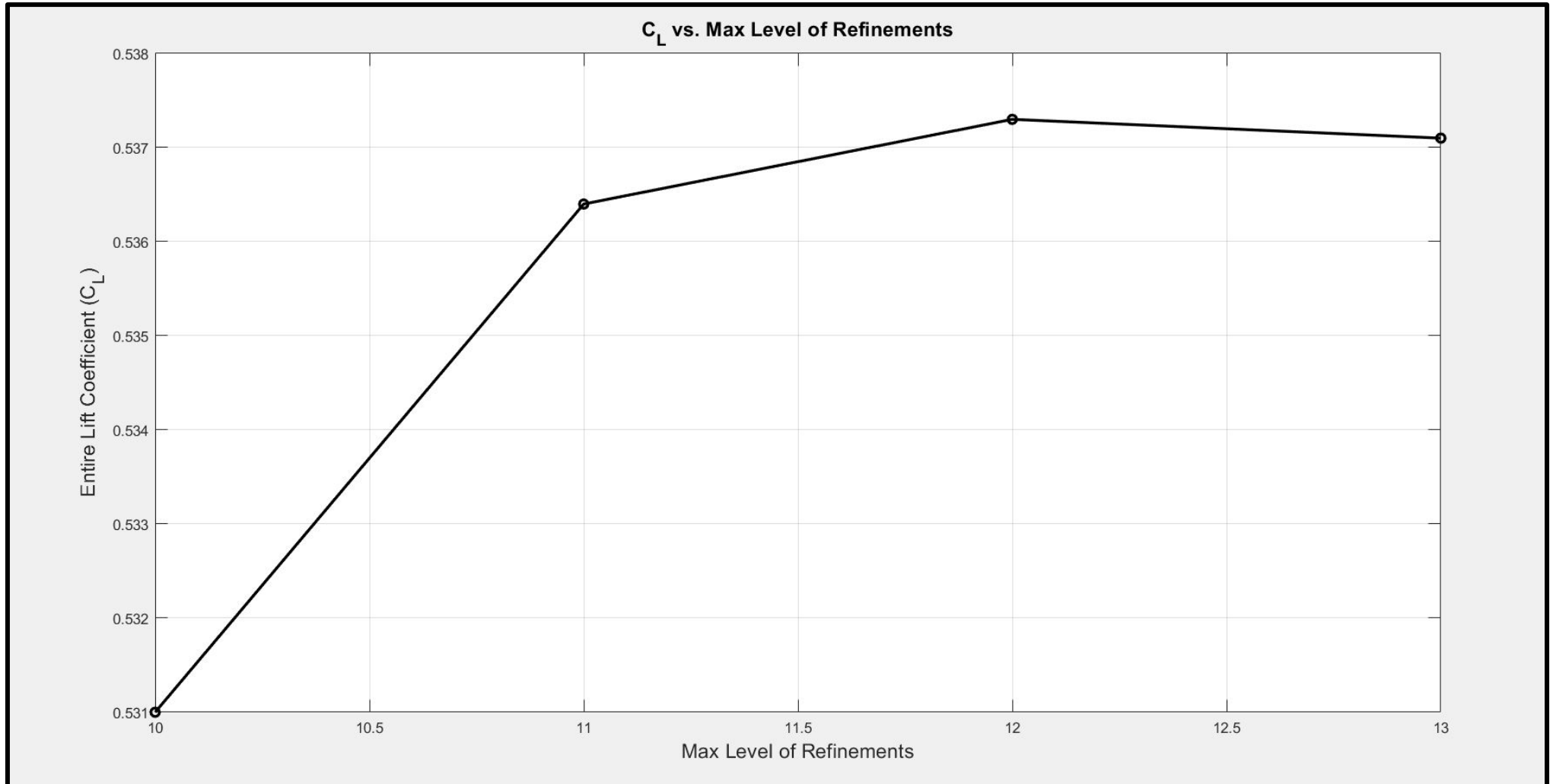
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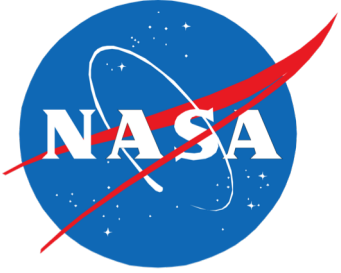
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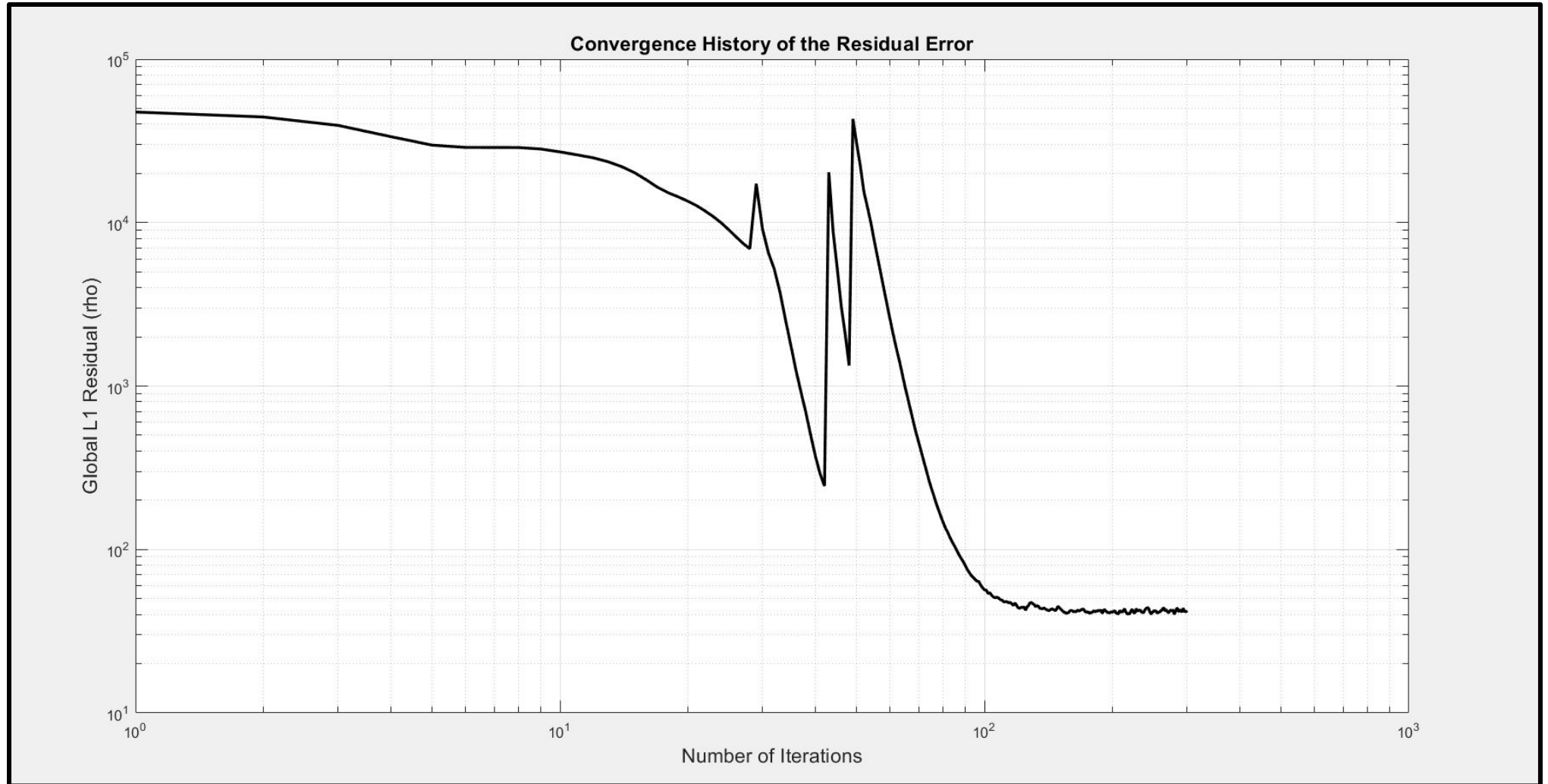
Vehicle Model

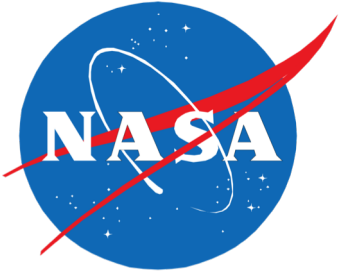
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Results: Uncorrected, Corrected, CFD curves

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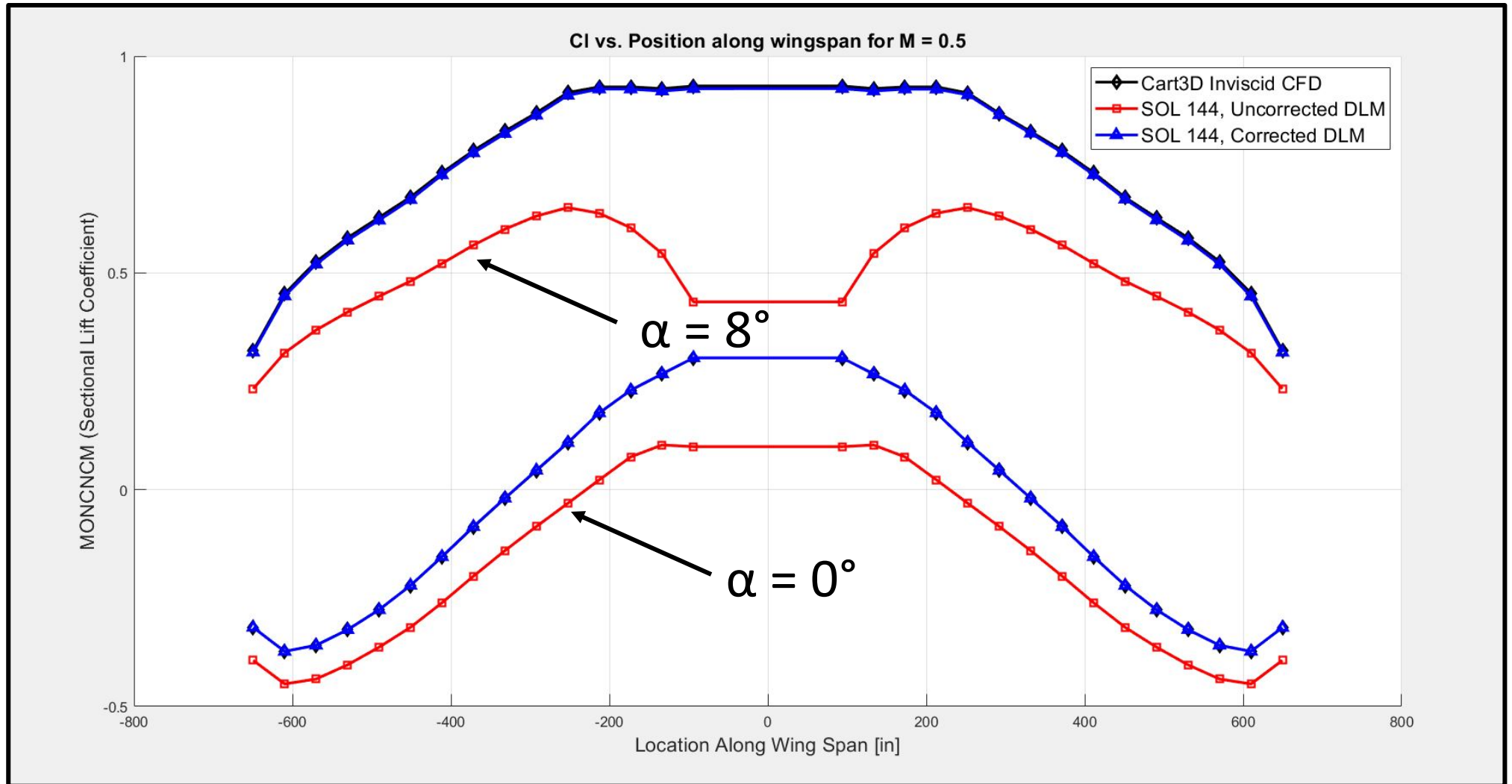
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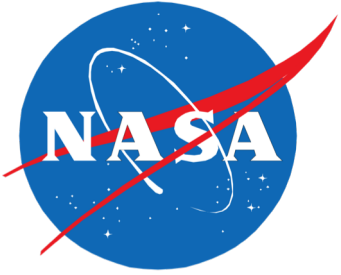
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Results: Corrected Curves for variable $W_{kk}(M, \alpha)$

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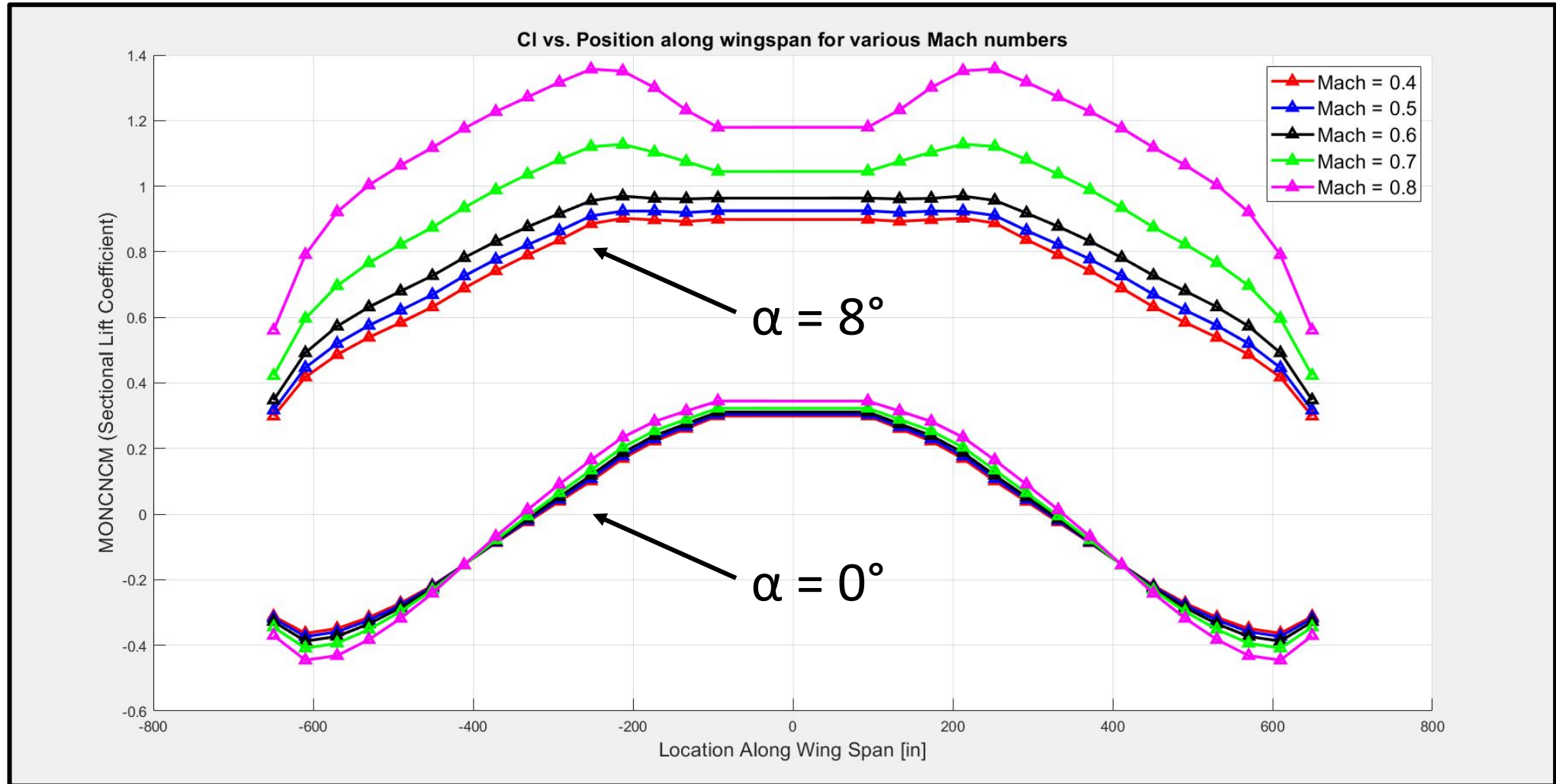
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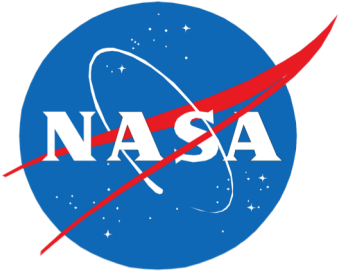
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Results: Corrected Curves for Fixed $W_{kk}(M=0.5, \alpha=0^\circ)$

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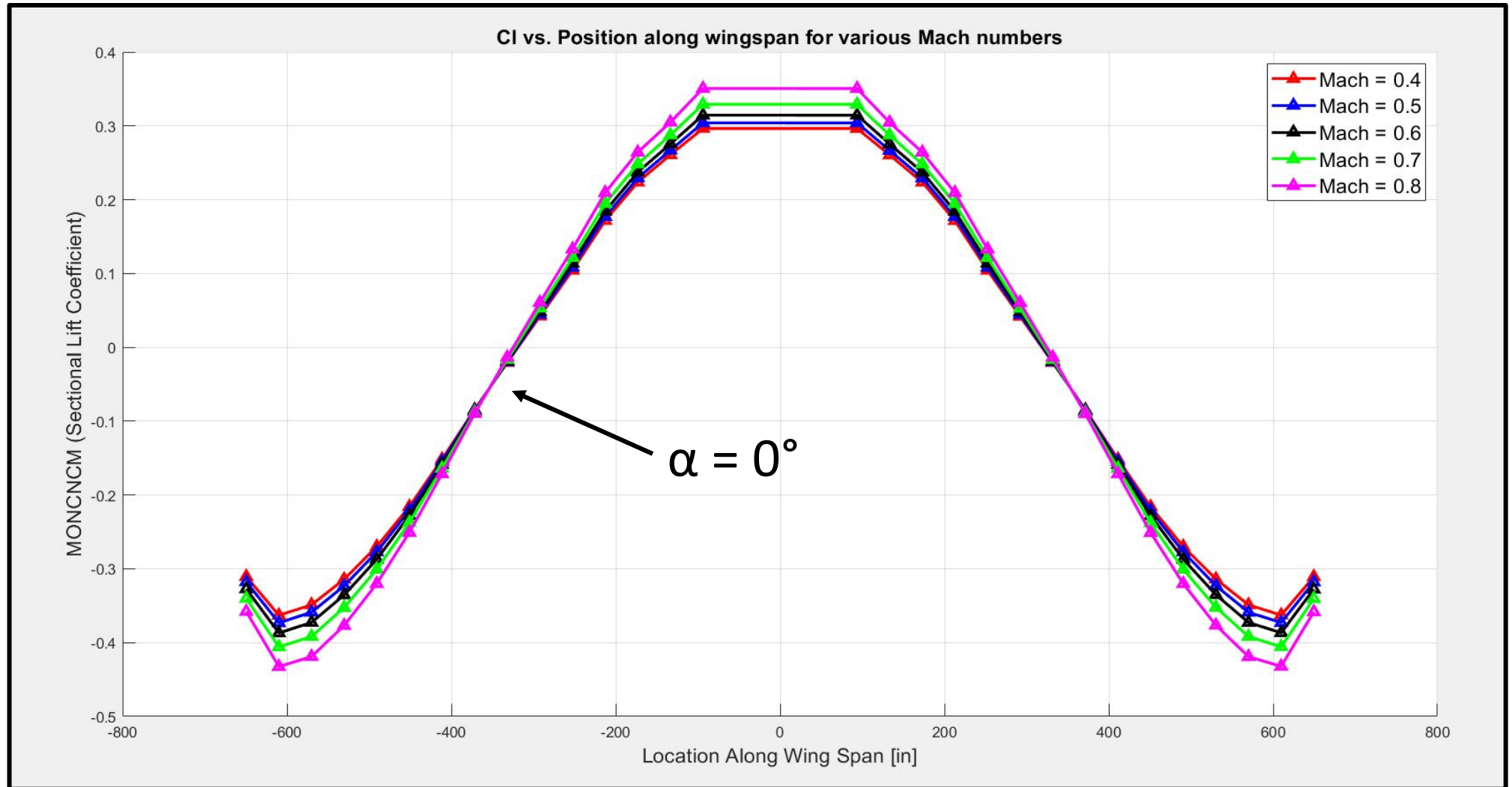
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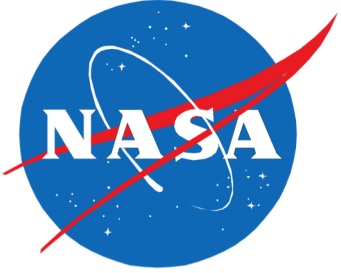
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CI % Error

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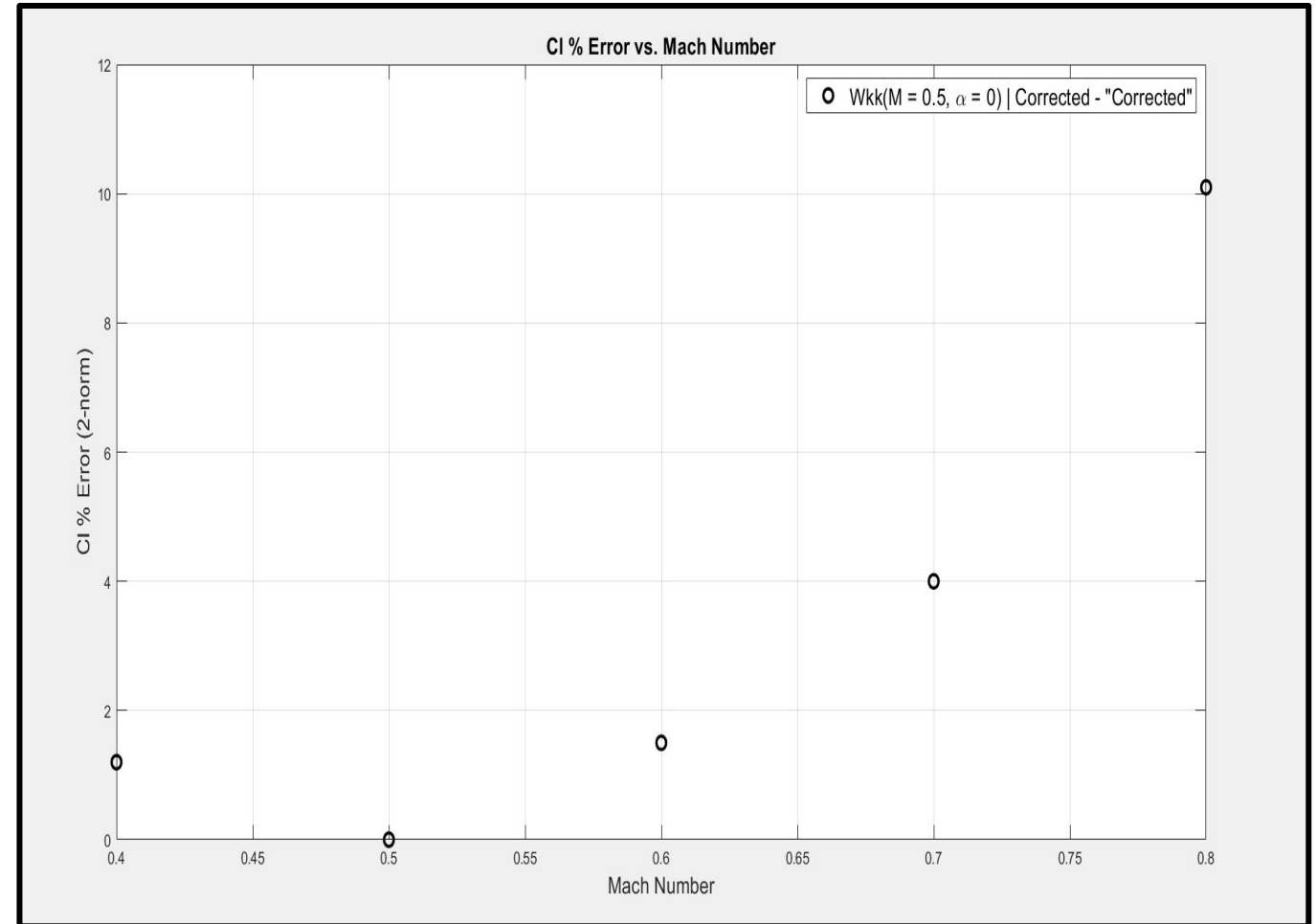
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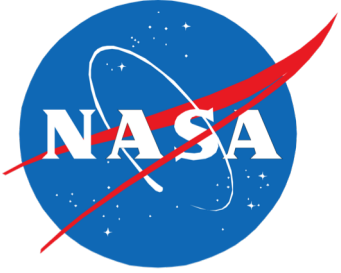
W_{kk} Sensitivity

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- As we expected, the associated CI error increases as Mach number increases for a fixed W_{kk}
- For this example, using $W_{kk}(M=0.5)$ results in less than 2% error for $\pm \Delta M \approx 0.1$
- We expect that the applicability of a given W_{kk} at varying flight condition will decrease with increasing M





CI % Error

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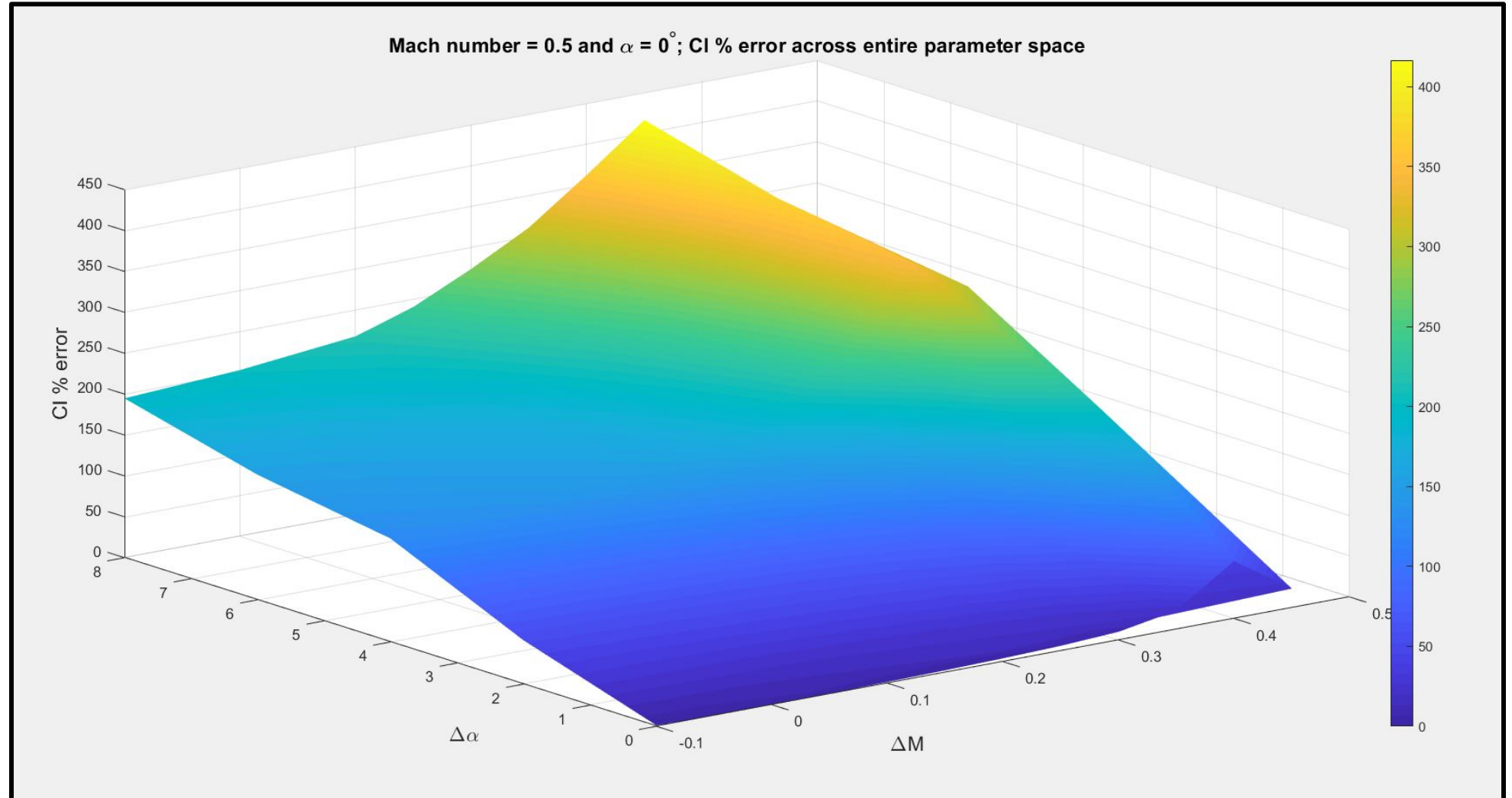
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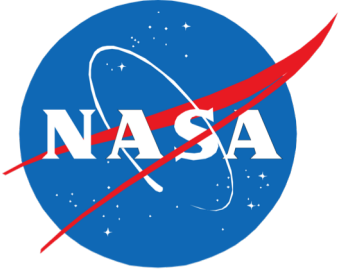
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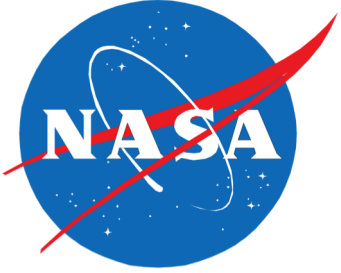
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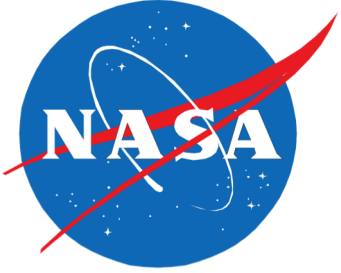
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- HCDstruct 2.1.0+ is an aerodynamic-matching utility, dubbed *aeroMatch*, based on a modified version of the ECFT
- CFD analysis using Cart3D was used to establish correction data
- Shell script was created to automate entire process
- Mesh convergence study was performed in order to find a sufficient volume mesh
- A preliminary sensitivity analysis of W_{kk} with respect to Mach and alpha was performed



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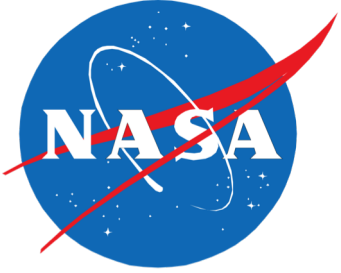
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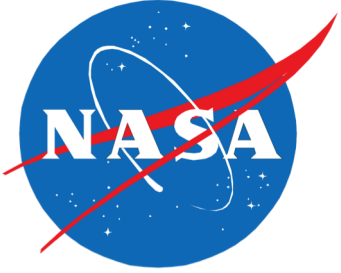
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- Perform a full sweep of Mach number and alpha for the Boeing 737-200 at increased resolution
- Change flight parameters such as wing sweep, dihedral, etc.
- Publish conference paper once sensitivity study is complete



Acknowledgements

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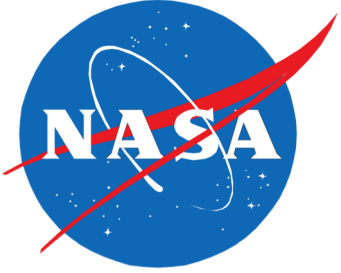
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- Special thanks goes to Dr. Jesse Quinlan for helpful guidance and words of encouragement during the duration of this internship
- This internship was sponsored by ASAB and SACD, and support for HCDstruct development was provided by NASA's Advanced Air Transport Technology (AATT) and Transformational Tools & Technologies (TTT) projects



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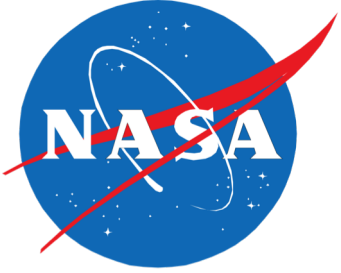
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Variable and fixed $W_{kk}(M=0.8, \alpha=8^\circ)$

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