Static Aeroelastic Predictions for the CRM using LAVA

Brandon M. Lowe*, Jeffrey A. Housman, Jared C. Duensing
Computational Aerosciences Branch
NASA Ames Research Center

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*Analytical Mechanics Associates

Static Aeroelastic Deformation Working Group

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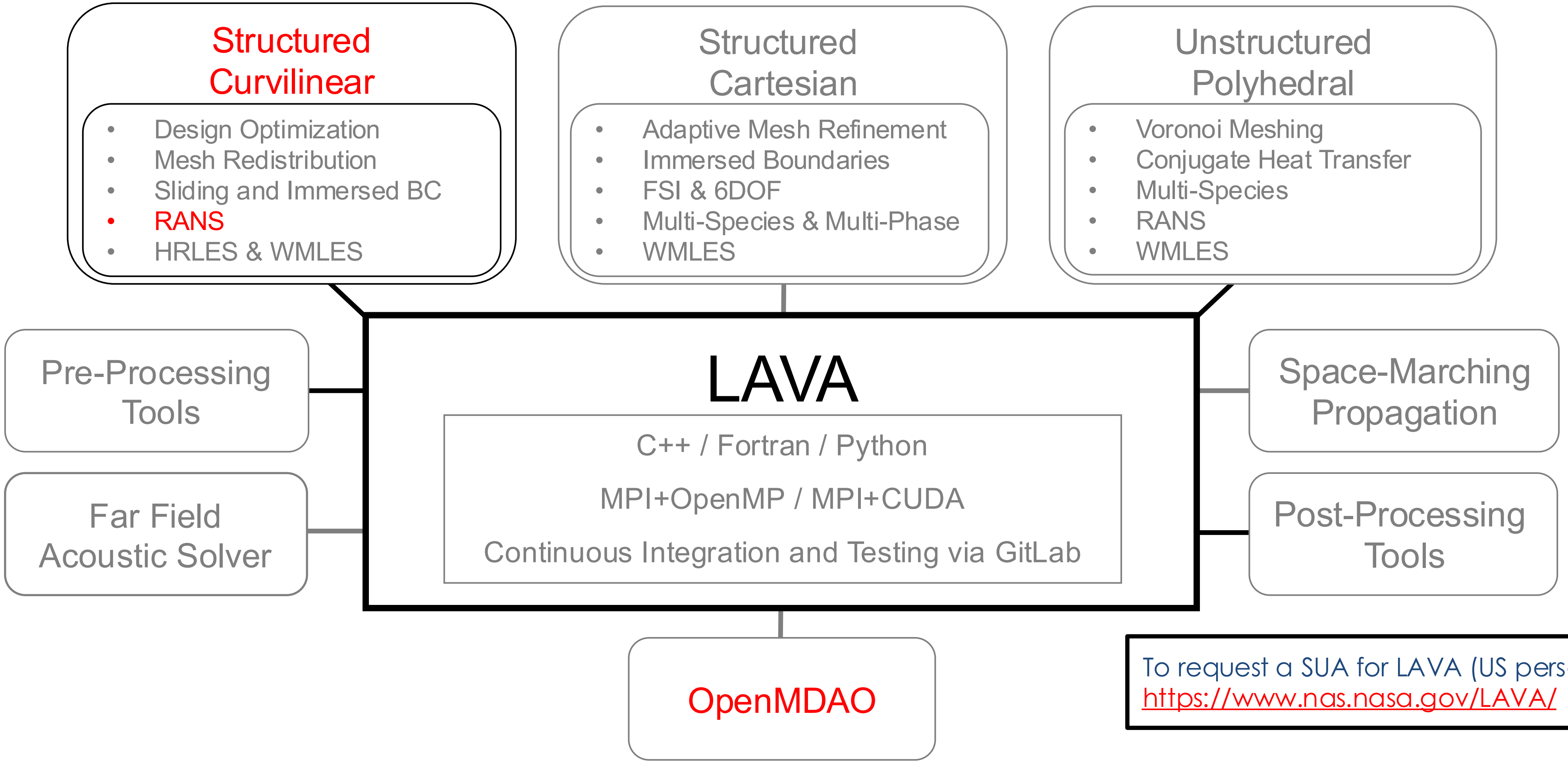
LAVA Framework

- Structured Overset / Multiblock
- Finite-difference formulation
- RANS equations + SAneg-RC-QCR2000
- 2nd order modified Roe scheme
- 3rd order left/right state reconstruction with a Koren slope limiter

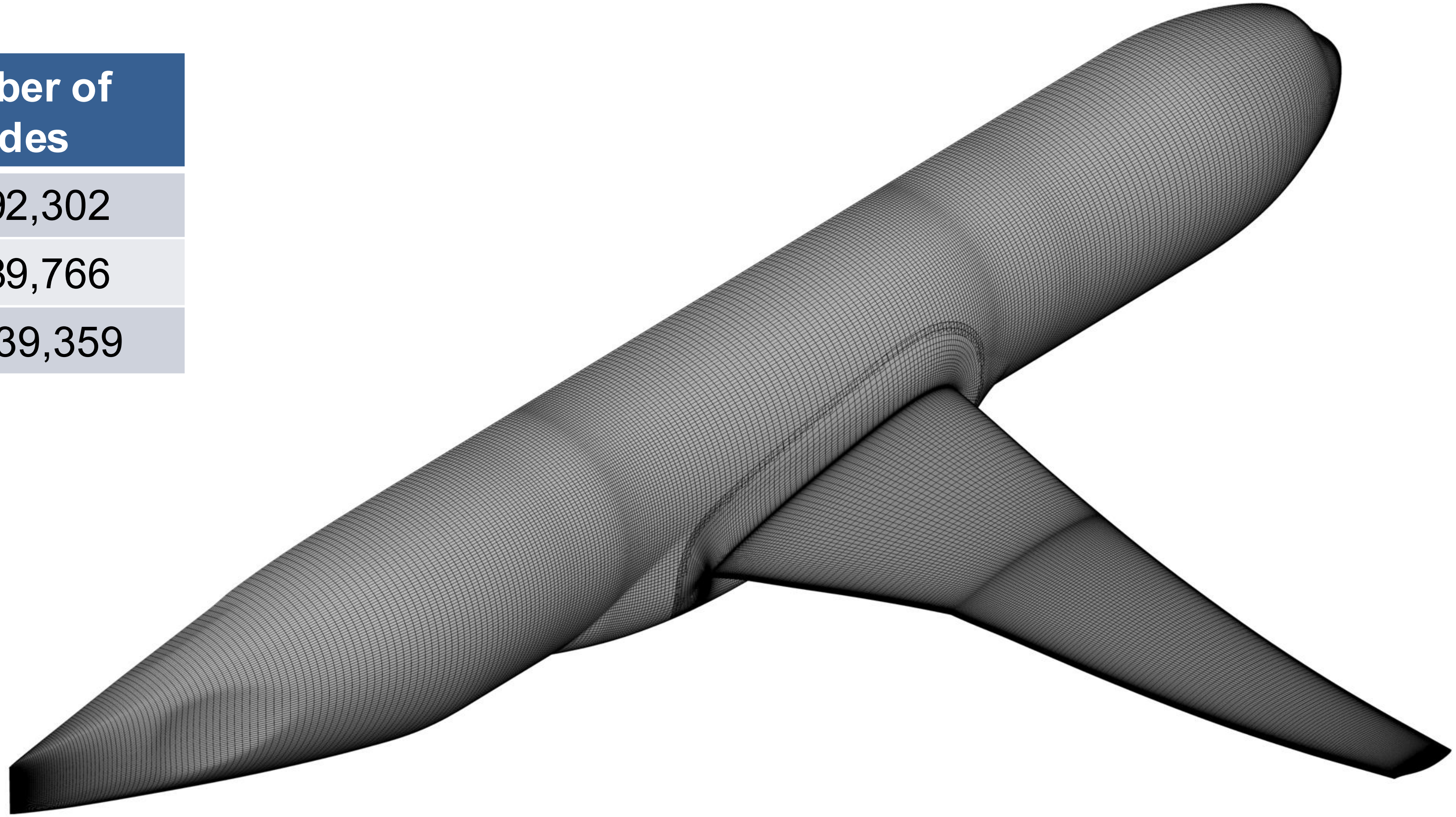


To request a SUA for LAVA (US persons only)
https://www.nas.nasa.gov/LAVA/

CFD Grids

In-house curvilinear overset/multiblock grids

Level	Refinement Factor	Number of Nodes
1	-	21,592,302
2	1.4	59,989,766
3	2	167,939,359



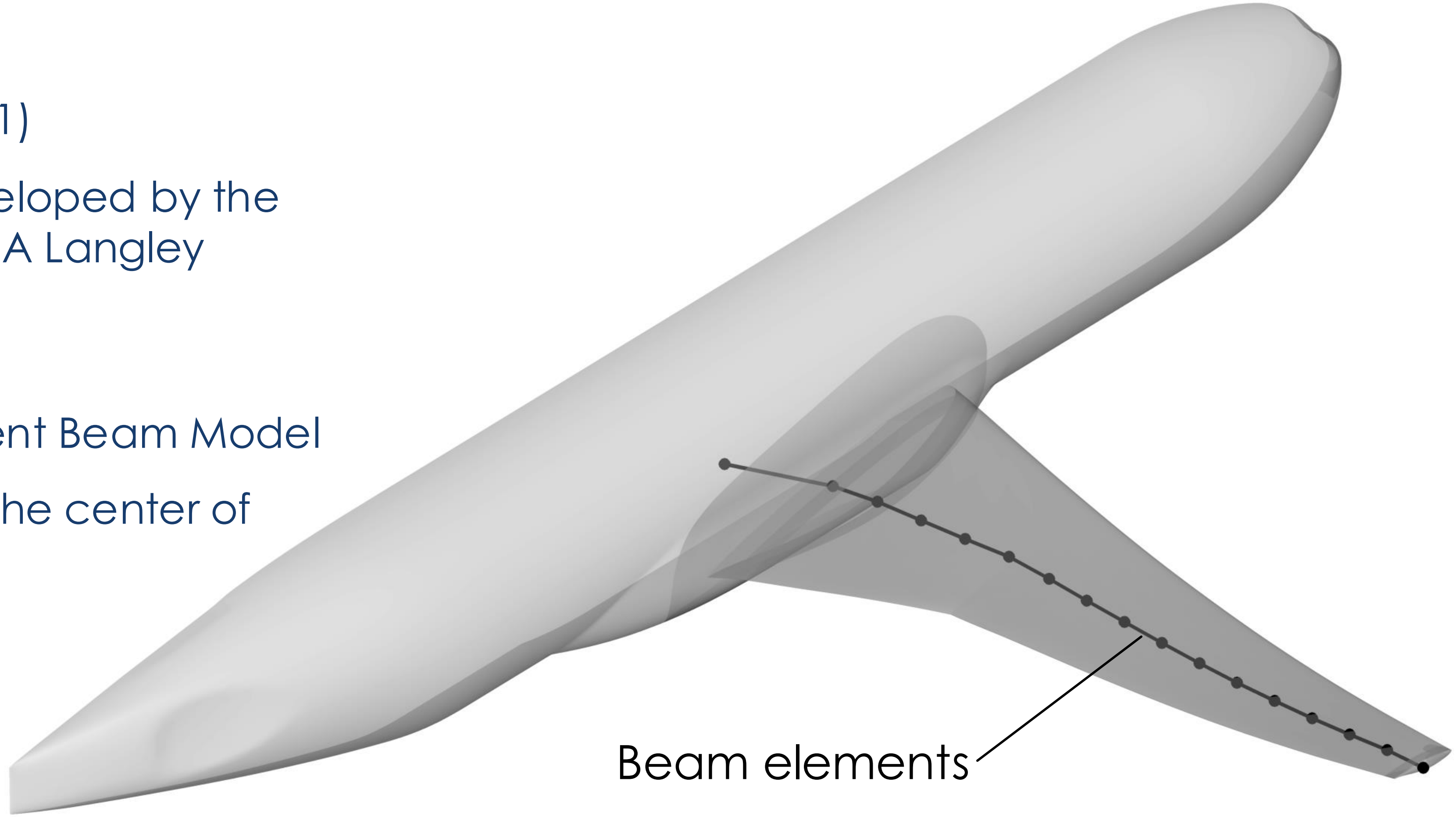
Structural Solver and Model

Structural Solver

- MSC NASTRAN v.2024.1
- Linear static analysis (SOL 101)
- NASTRAN MPhys Builder developed by the Aeroelasticity Branch at NASA Langley

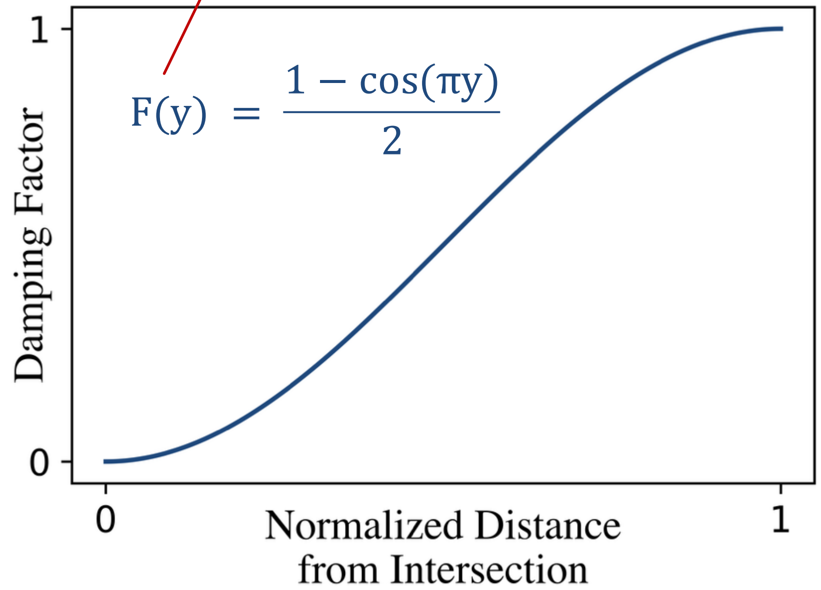
Structural Model

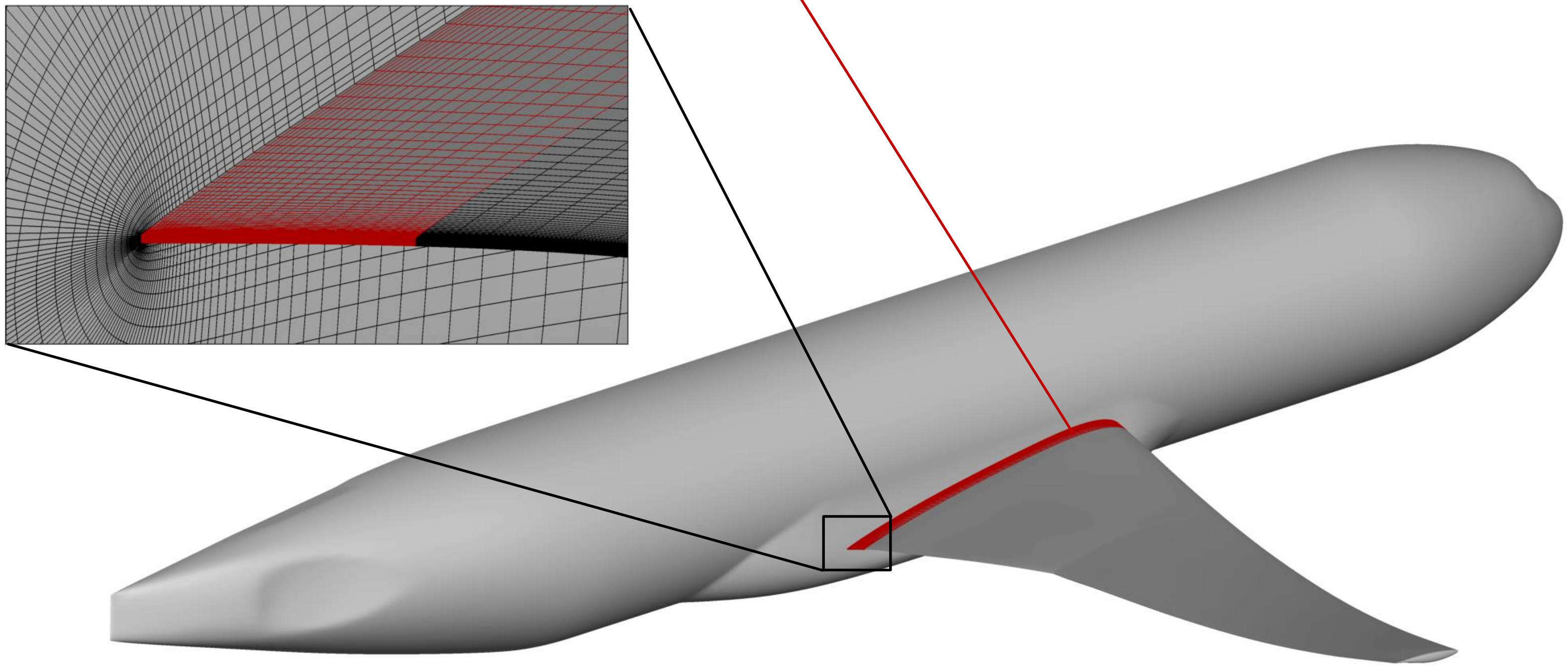
- Workshop-provided Equivalent Beam Model
- 16 beam elements through the center of the wing
- Converted to SI units for consistency with LAVA



Transfer Scheme & Intersection Damping

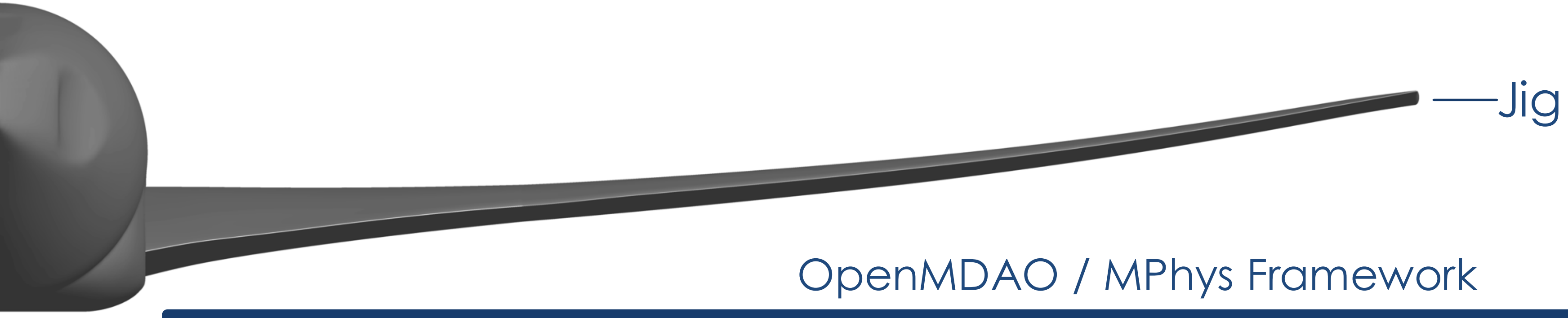
- FUNtoFEM's Matching-based Extrapolation of Loads and Displacements (MELD) scheme[1]
- Displacements limited to wing surface nodes
- Nodes on the wing-fuselage intersection were constrained not to move
- A displacement damping factor was applied to the set of nodes in a "buffer region" (2.3% span)





[1]Kiviaho and Kennedy, AIAA Journal, doi:10.2514/1.J057318

OpenMDAO/MPhys Coupling



OpenMDAO / MPhys Framework

LAVA Curvilinear
Flow Solver

Aero Forces →

FUNtoFEM MELD[1]
Load Transfer

Struct Forces →

MSC NASTRAN[2]
Structural Solver

← Struct Disp.

FUNtoFEM MELD[1]
Disp. Transfer

← Aero Disp.

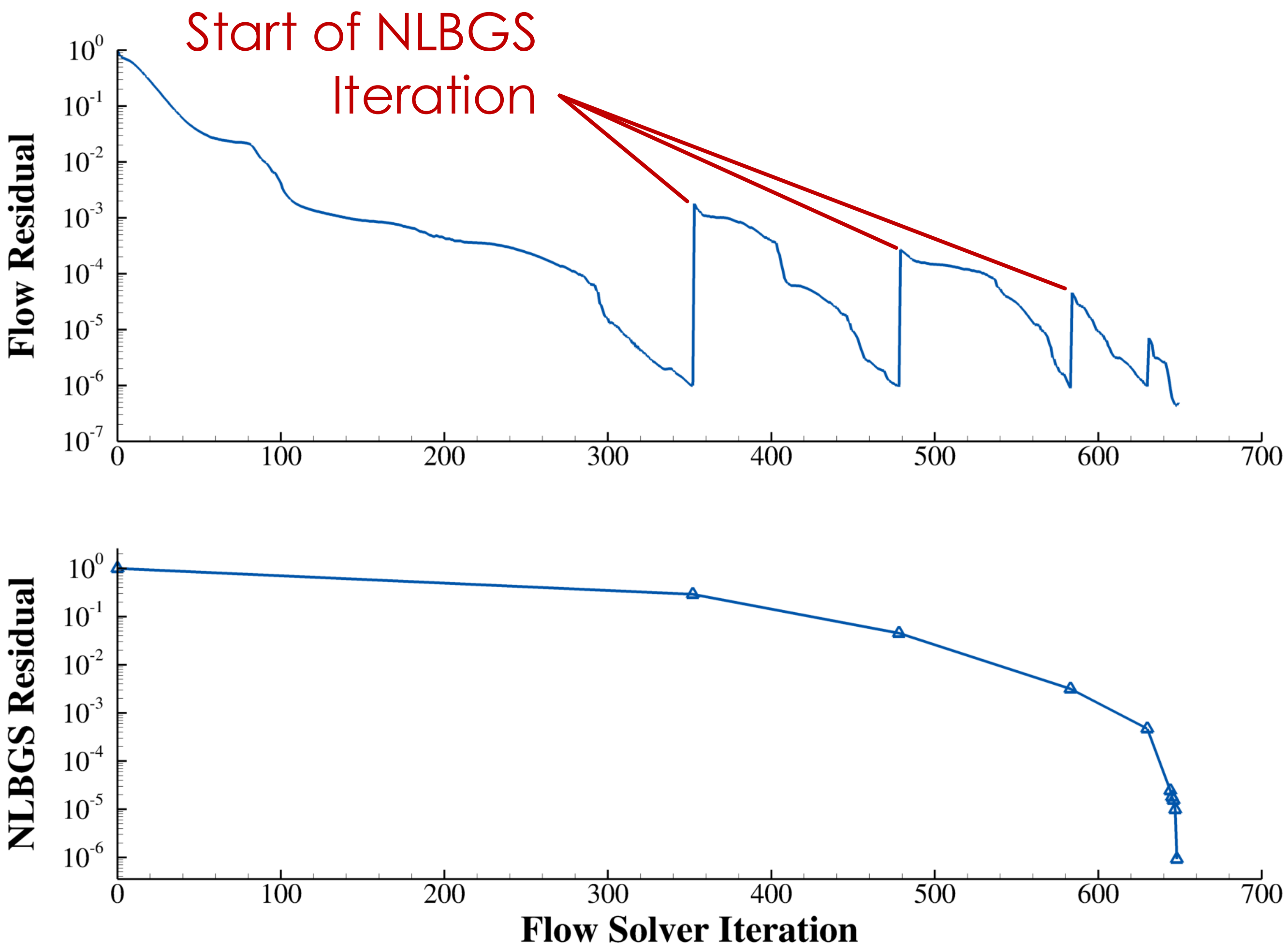
[1]FUNtoFEM MELD developed at Georgia Tech
[2]NASTRAN MPhys Builder developed at NASA Langley – Aeroelasticity Branch

Solver Convergence

Nonlinear Block Gauss Seidel (NLBGS) solver is run for 10 iterations at each angle of attack

At each NLBGS iteration:

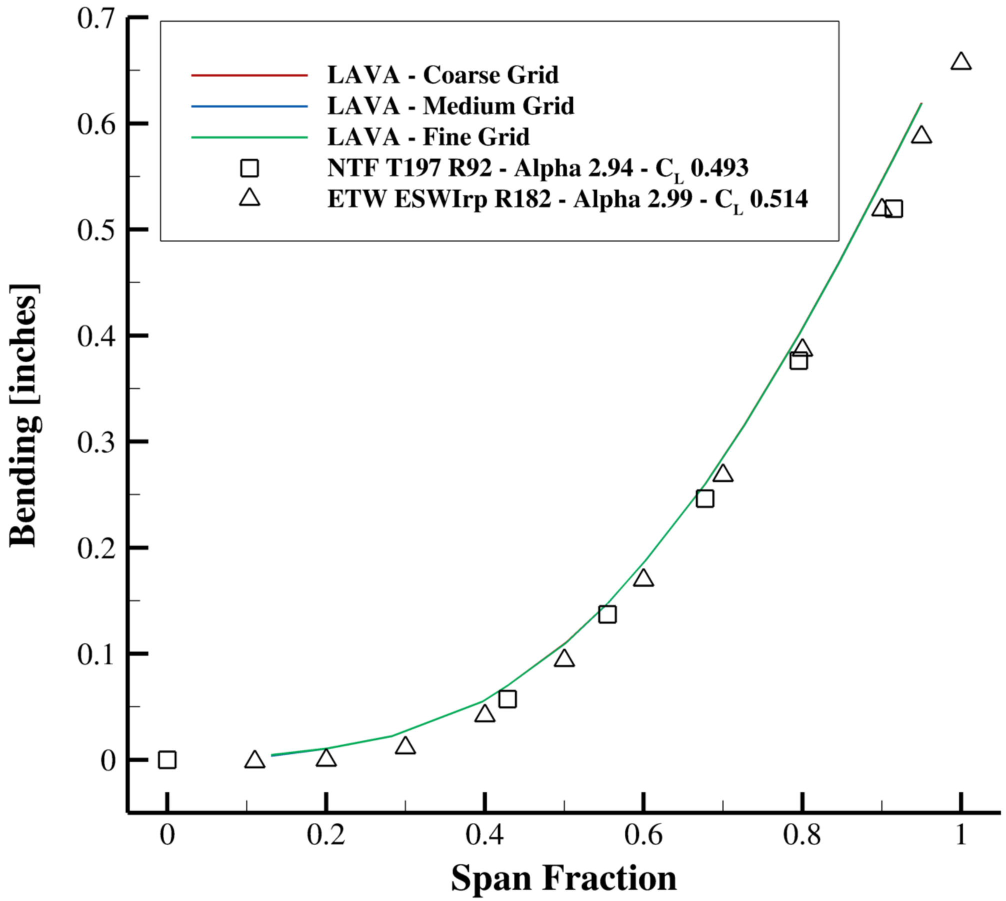
- Volume grid is deformed to conform to the displaced surface grid
- Flow solution is warm started from the previous iteration
- The norm of the RANS equations is converged 6 orders of magnitude relative to the freestream residual



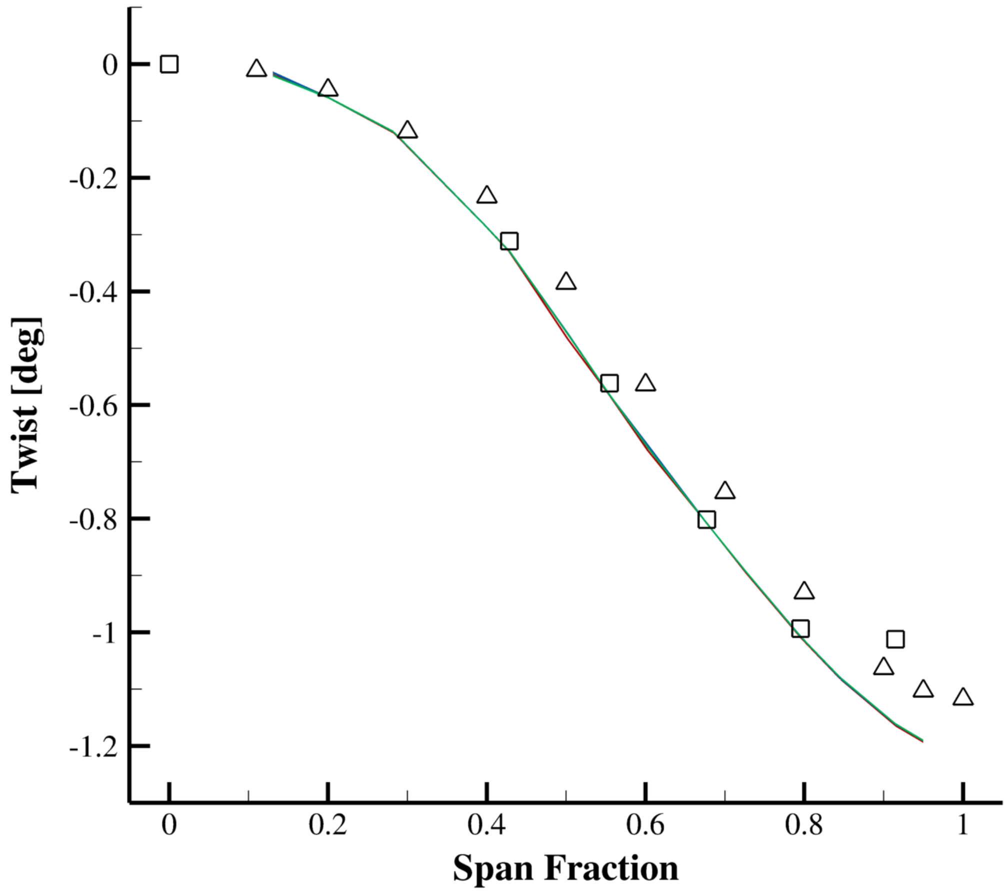
Test Case Results

Case 2a(E) (C_L=0.5) – Bending and Twist

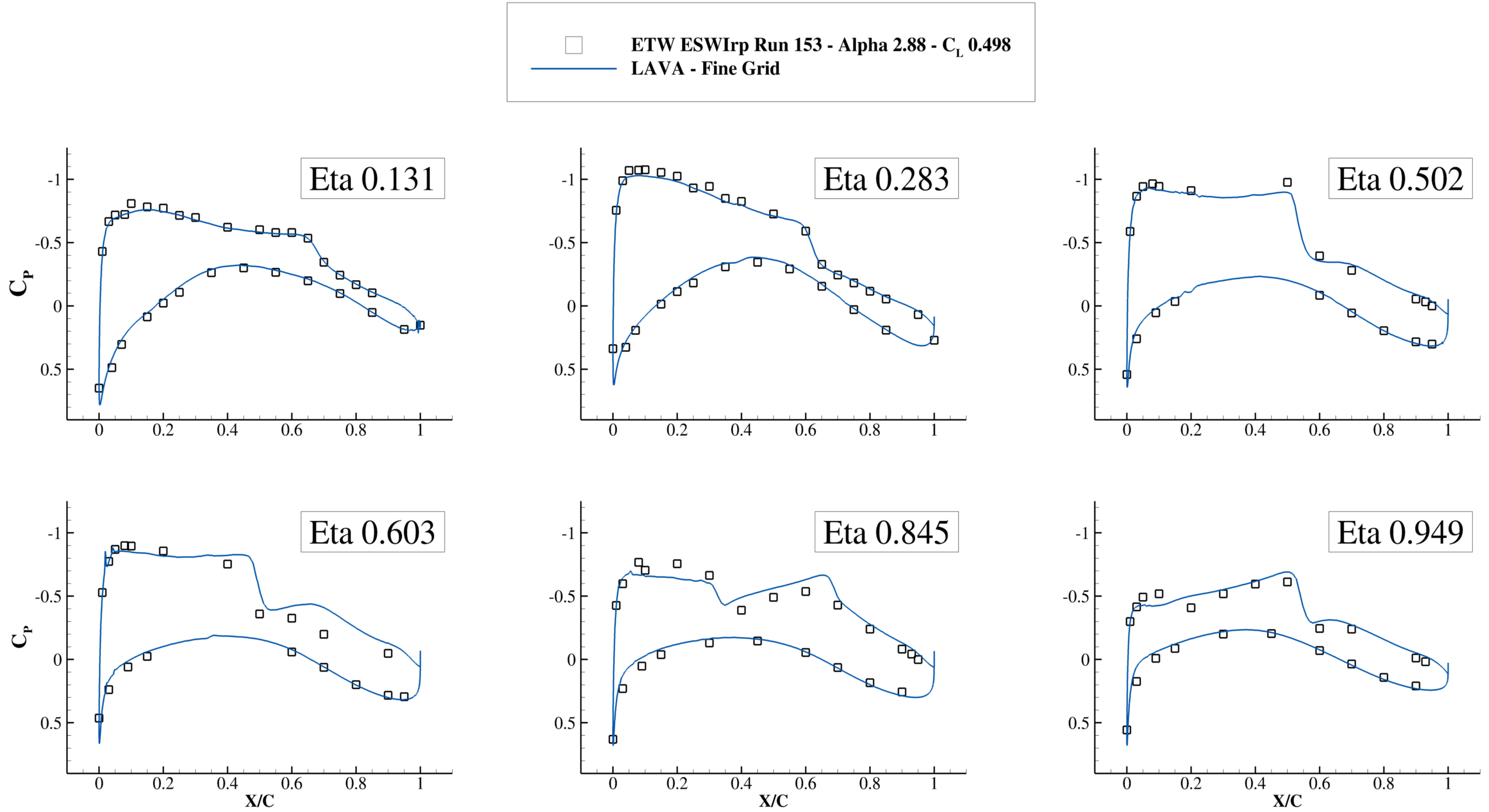
- Slight overprediction in bending along the wing
- Insensitive to grid refinement



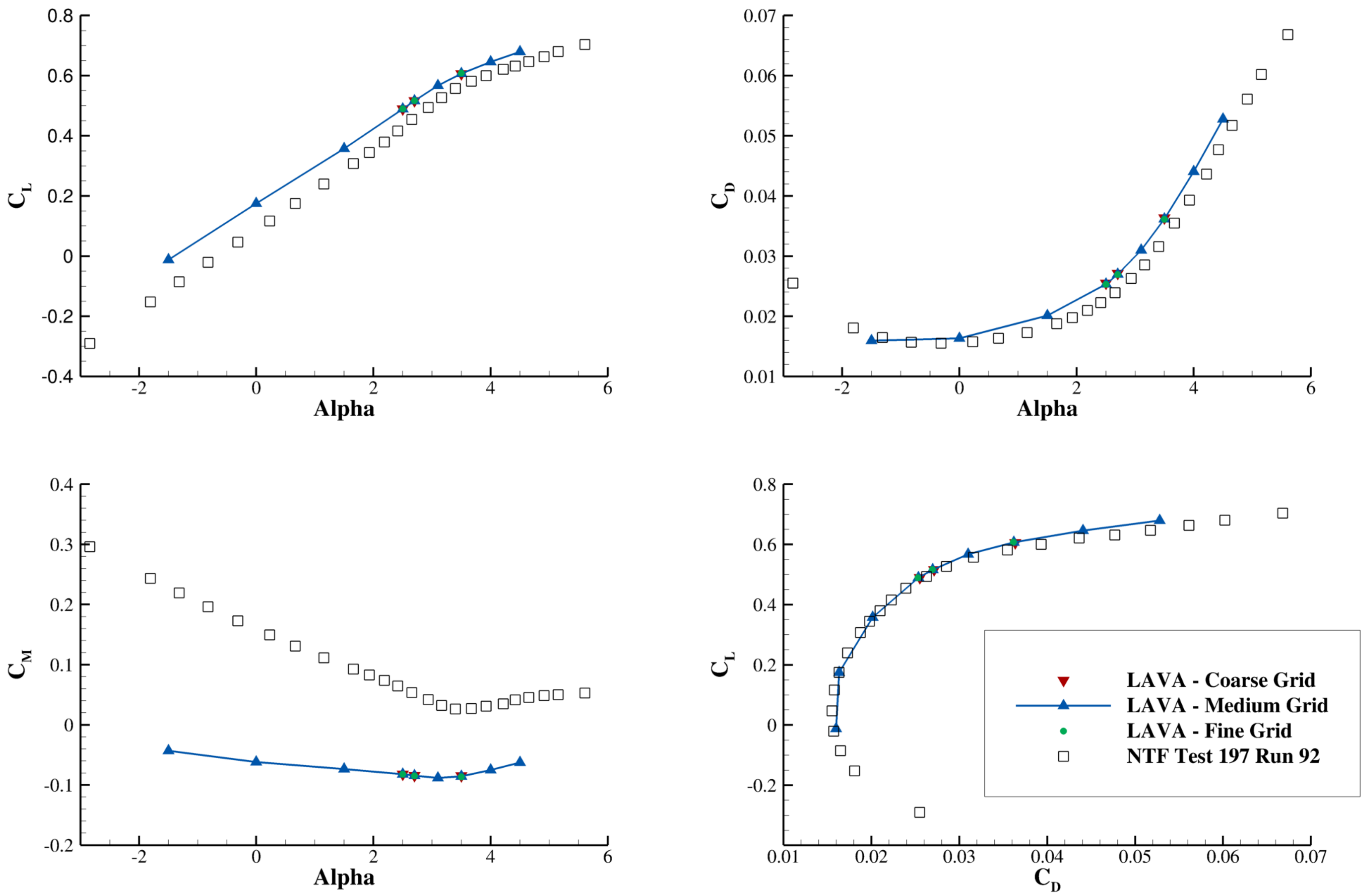
- Twist distribution matches well along the span
- Noticeable deviation near the tip of the wing
- Slightly increased grid sensitivities compared to bending



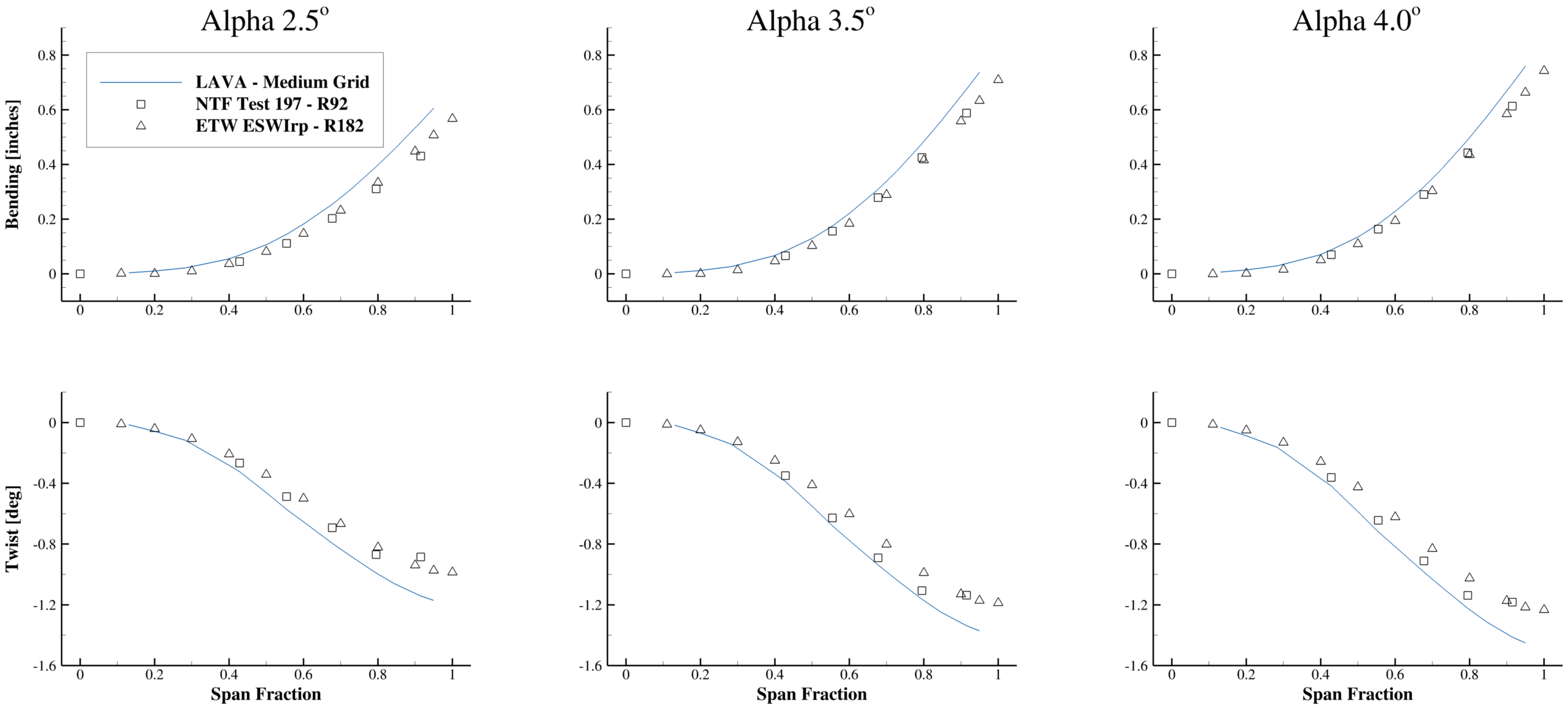
Case 2a(E) (C_L=0.5) – Pressure Cuts



Case 2b(E) (Polar) – Force and Moment Results



Case 2b(E) (Polar) – Bending and Twist



Summary and Future Work

Summary

- LAVA was coupled to MELD (force/disp. transfer) and NASTRAN (structural solver) using the OpenMDAO/MPhys framework
- Static aeroelastic analysis was successfully performed
- Results generally demonstrated an overprediction in wing bending and twist

Future Investigations / Open Questions

- Investigation of impact of tail and sting
- Impact of beam model vs the Tet4 half-span model
- Effects of half-span vs full-span model
- Impact from alternative transfer methods

Acknowledgements

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- Computational resources provided by the NASA High-End Computing (HEC) program through the NASA Advanced Supercomputing (NAS) facility at NASA Ames Research Center

- Drag Prediction Workshop committee members especially Bret Stanford

- Andrew Thelen and Kevin Jacobson of NASA Langley Research Center for providing the structural solver capabilities and support for this work

Thank You

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Extra Slides

Reference Conditions

For specified Temperature:

- Mach = 0.85
- Re = 5.0e+6
- Temperature = 322.04 K = 120.0 F

We obtain

- Dynamic Pressure = 78001 Pa = 1629 psf

(17.7% higher)

For specified dynamic pressure:

- Mach = 0.85
- Re = 5.0e+6
- Dynamic Pressure = 66266 Pa = 1384 psf

We obtain

- Temperature = 283.18 K = 50.0 F

Reference Condition Calculation

```
MUREF = (1.458E-6)*TREF**1.5/(TREF+110.4)

CREF = sqrt(GAMMA*RGAS*TREF)

UMAG = MACH*CREF

RHOREF = REYN*MUREF/(UMAG*LREF)

PREF = RHOREF*RGAS*TREF

NUREF = MUREF/RHOREF


QREF = 0.5*RHOREF*UMAG*UMAG
```

```
#Gas properties

GAMMA = 1.4

CP    = 1005.0  #J/Kg/K

RGAS  = CP*(GAMMA-1.0)/GAMMA
```

Transfer Scheme

Matching-based Extrapolation of Loads and Displacements (MELD) scheme[1]

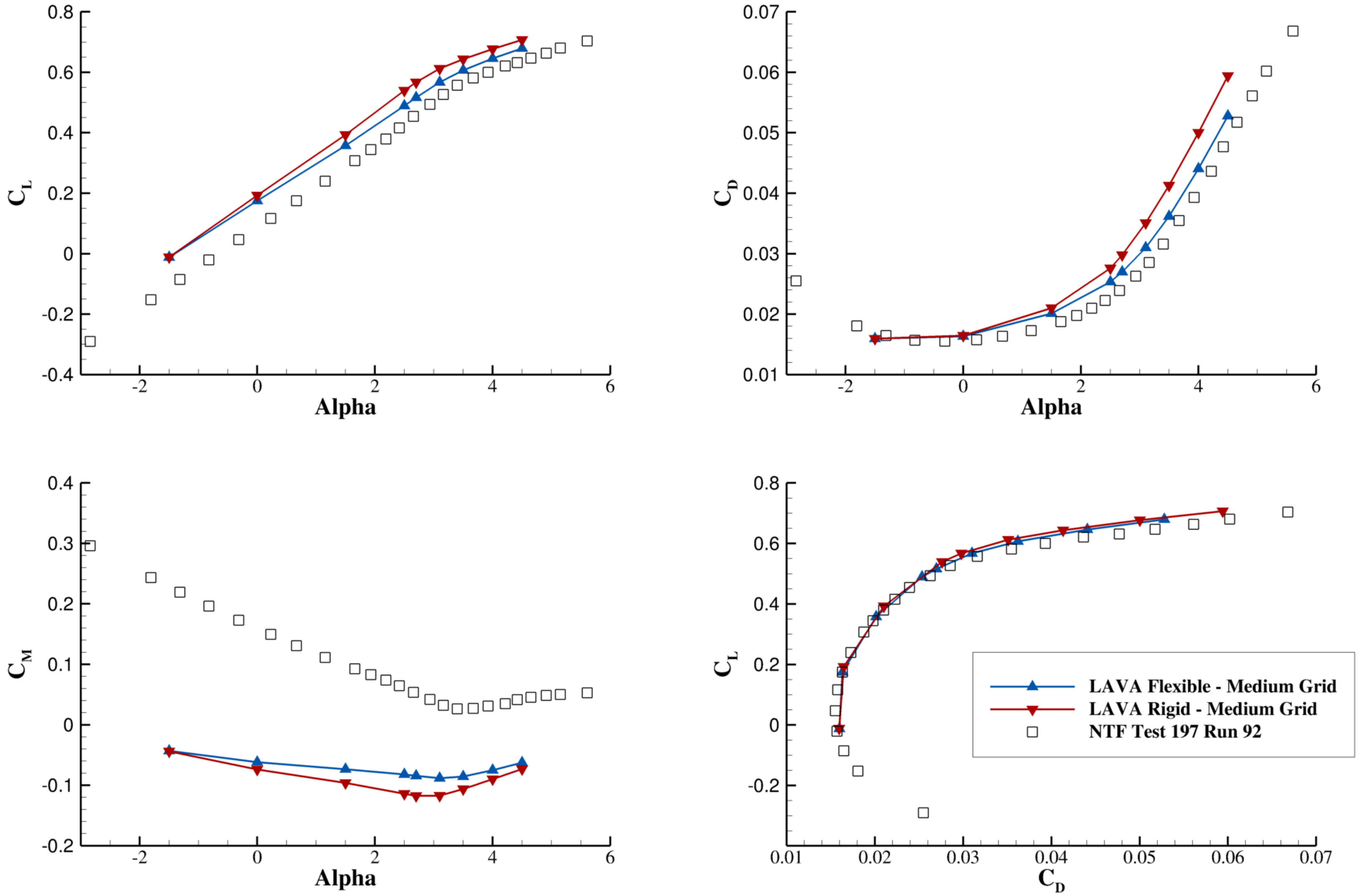
- Links each aerodynamic node to a set of nearest structural nodes
- Computes an optimal rigid rotation and translation from nearby structural node motions using a weighted least-squares formulation
- Weights are obtained from a distance-based Gaussian
- Ensures aerodynamic forces are consistently converted into equivalent structural loads via the virtual-work principle

Chosen Parameters

- Number of linked structural nodes per aerodynamic surface node : N = 10
- Gaussian decay parameter : $\beta = 0.5$

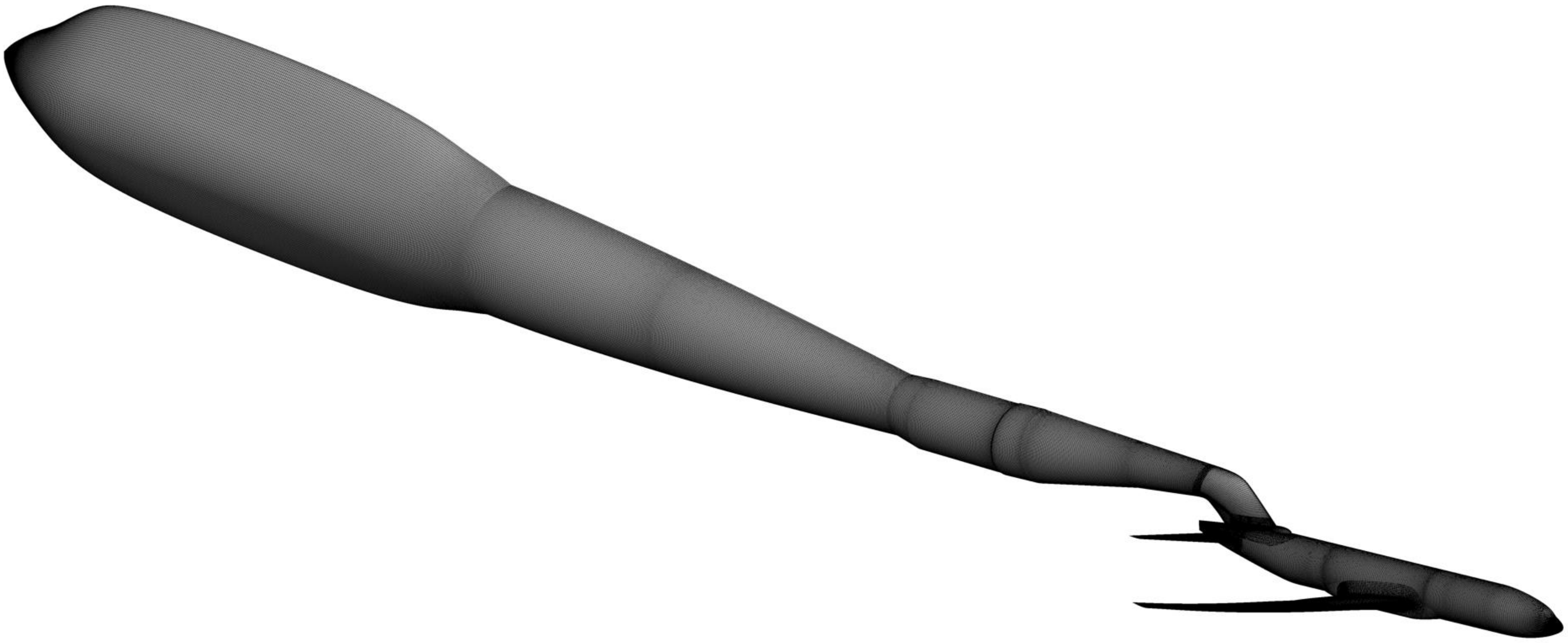
[1]Kiviaho and Kennedy, AIAA Journal, doi:10.2514/1.J057318

Case 2b(E) (Polar) – Comparison to Rigid Wing



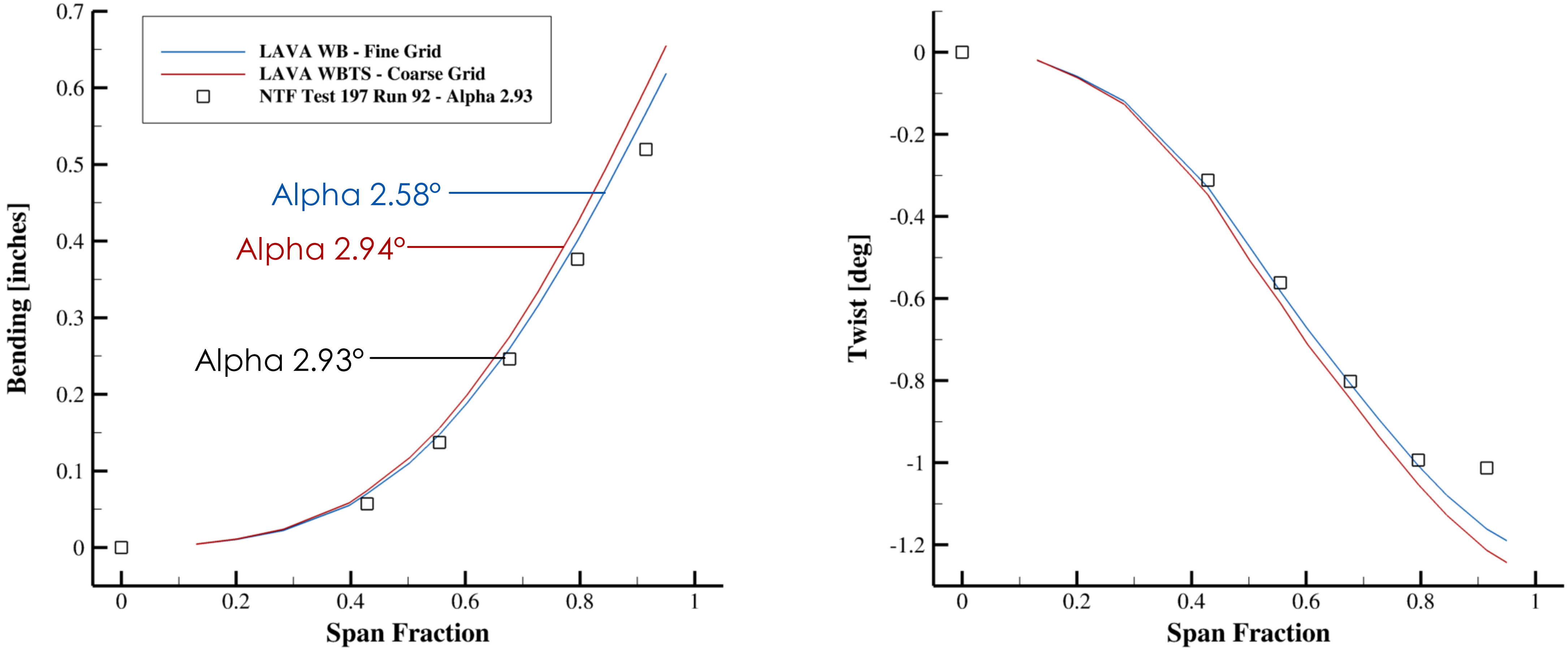
Wing-Body-Tail-Sting

A (very) preliminary investigation on the impact of the tail+sting on Case 2a(E)



Case 2a(E) (C_L=0.5) – Bending and Twist (WBTS)

- Inclusion of the tail+sting leads to slightly higher bending and twist
- Angle of attack better reflects wind tunnel conditions



Case 2a(E) (C_L=0.5) – Pressure Cuts (WBTS)