Aerodynamic Evaluation of the D8 "Double-Bubble" Aircraft Nacelle Design

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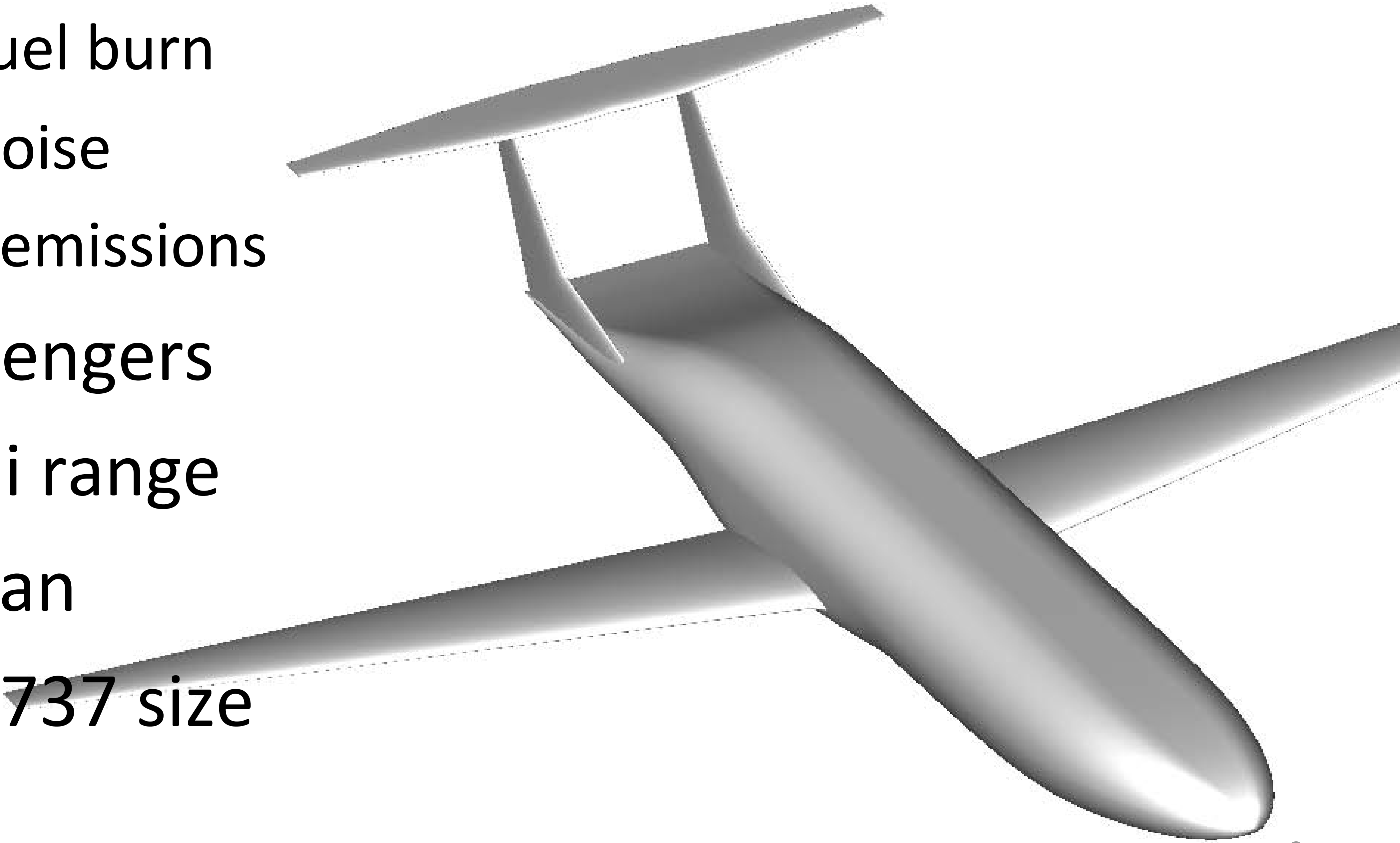
Outline

- The D8
  - Concept
  - Goals
- Modeling and Mesh Topology
  - Use Cart3D inviscid mesh adaptation to guide overset viscous mesh
  - O-mesh with wake boxes
  - Mesh sensitivity
- Clean Configuration
  - Comparison with experiment
  - Independent verification of D8 concepts
- Podded Nacelle
  - Geometry
  - Results

MIT D8 “Double-Bubble” Aircraft

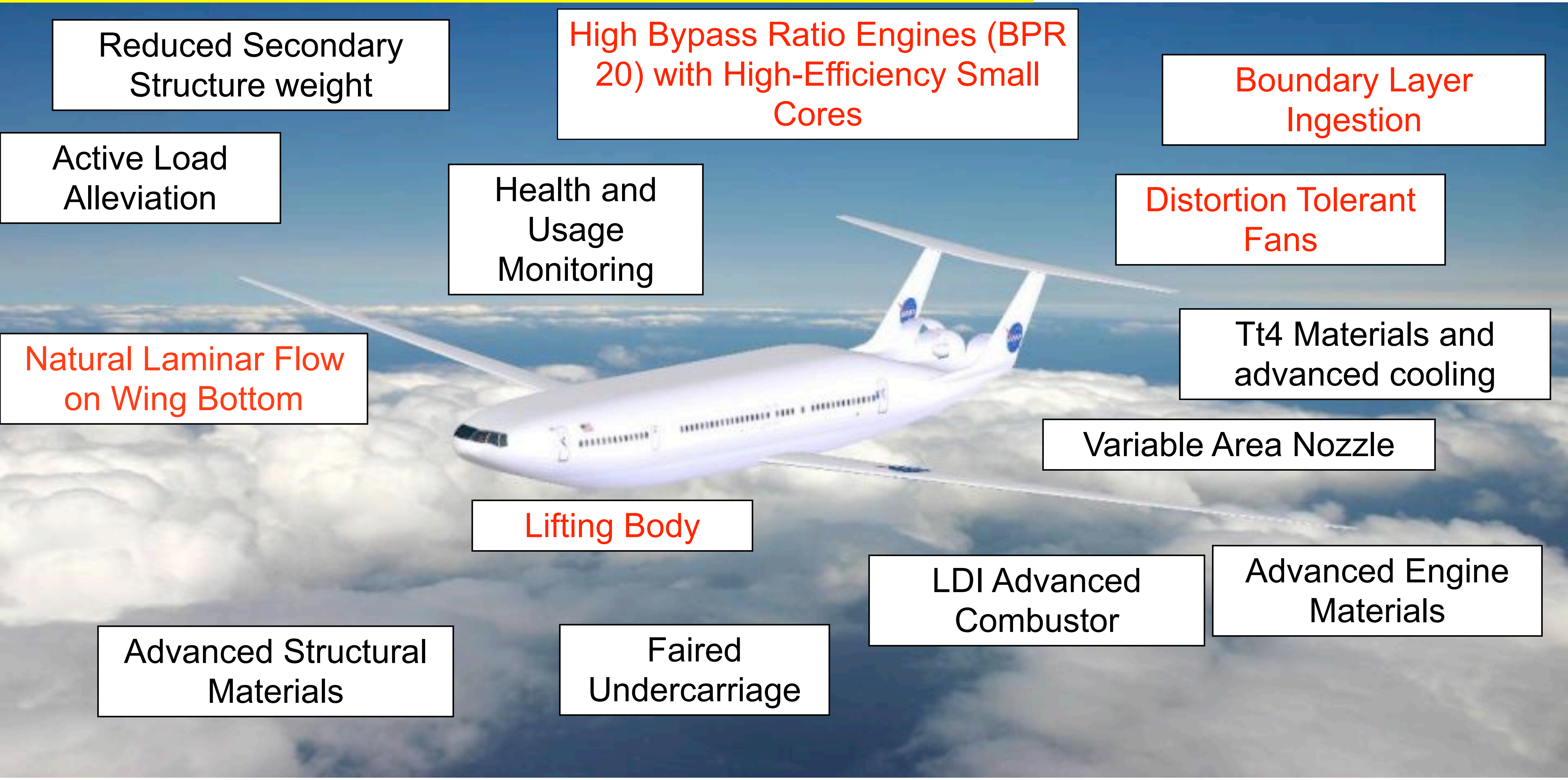
- MIT team concept of N+3 advanced vehicle configuration
  - –Lower fuel burn
  - –Lower noise
  - –Reduce emissions
- 180 passengers
- 3000 nmi range
- 118 ft span
- ~Boeing 737 size



MIT/Pratt & Whitney/Aurora D Series

Airframe & Propulsion Technology Overview

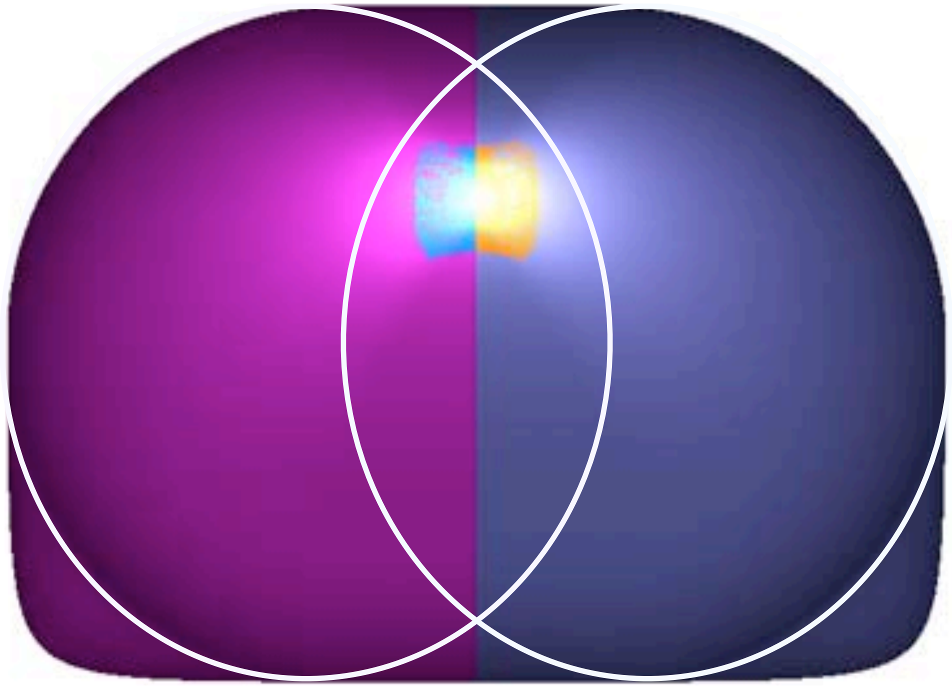
Novel configuration plus suite of airframe and propulsion technologies, and operations modifications



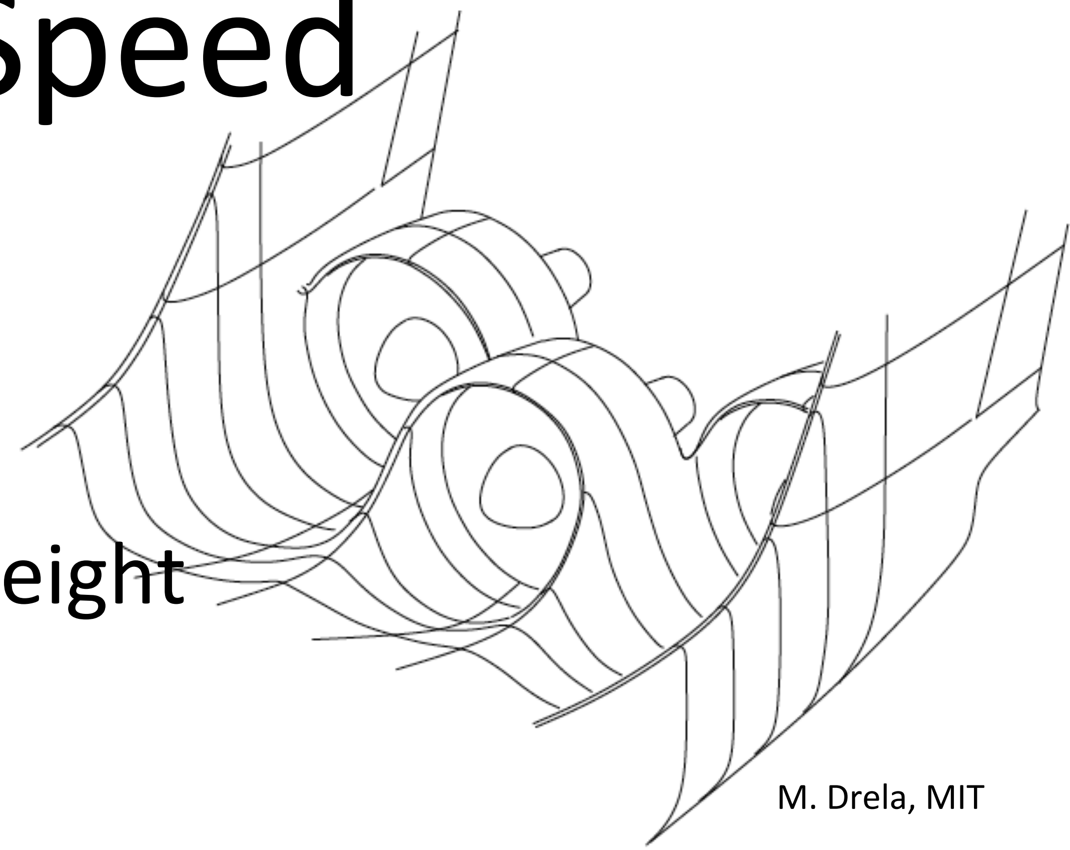
Massachusetts Institute of Technology   Aurora Flight Sciences   Pratt & Whitney A United Technologies Company

Fuselage Advantages

- “Double-bubble” fuselage provides more lift
  - Gives partial span-wise loading / smaller wing
- Shorter cabin (wider body)
  - Results in lighter landing gear support structure
- Provides a nose-up pitching moment
  - Shrinks horizontal tail
  - Lighter horizontal tail



Lower Cruise Speed



M. Drela, MIT

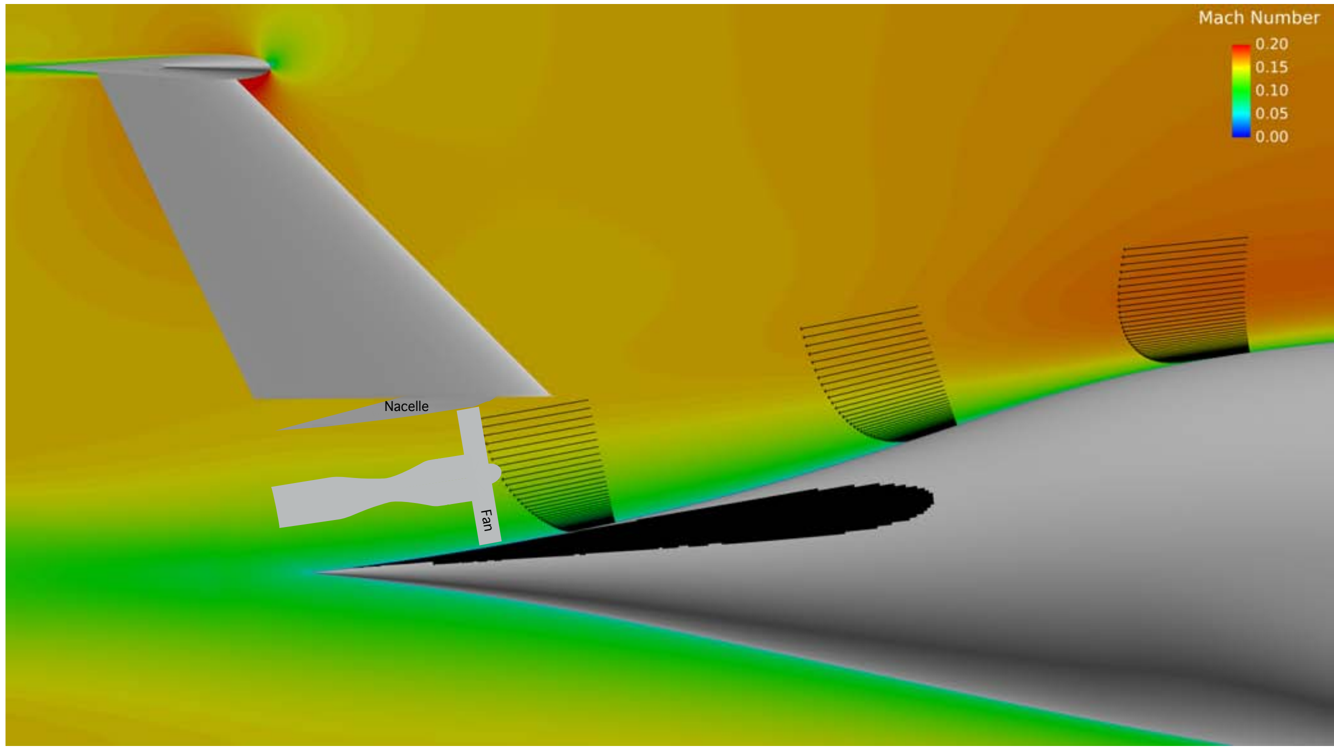
- M=0.72
  - Lower sweep wing
    - Reduced structural load => Lower weight
    - Increased CL
    - Can eliminate high-lift devices
  - Proper speed at engine fan face (M=0.6)
    - Reduces nacelle, inlet size
- Reduced nacelle drag
  - Nacelles embedded in the π-tail and fuselage
  - Reduced size, weight

Embedded Rear-Mounted Engines

- Boundary Layer Ingesting (BLI) engines for propulsive efficiency

Fans like flow at ~ M=0.6

  - Thicker boundary layer in the rear
  - Designed for M=0.6 flow around engine inlet area
  - Distortion tolerant fan
  - High bypass ratio (~20)
- Lower engine-out yaw
  - Reduced vertical tail size
- Noise shield



Wind Tunnel Tests

The Mach and Re don't match the flight, but the BLI effect is not expected to be very different

- Wright brothers wind tunnel at MIT
  - Low speed (100 and 120 mph) ≈ M=0.15
  - Clean configuration: α=0, 1.9, 4.4, 6.6, 8.8, 11, 13.3
  - $Re_c \approx 0.5$ Million
  - 1:20 scale model
    - Tests complete
  - 1:11 scale model
    - Being constructed
    - w/, w/o empennage
    - Podded nacelle
    - Blended nacelle

A. Uranga, MIT

Goals of This Work

- Independent assessment of the D8 design assumptions
  - Is the “double-bubble” fuselage advantageous?
    - Does it provide lift in the range of 10 to 20%?
    - Does it provide a nose-up pitching moment?
  - Boundary Layer Ingestion (BLI)
    - Quantify flow diffusion from fuselage geometry resulting in lower speed at the fan face
- Validate Overflow against the wind tunnel tests
  - Use best practices for nacelle assessment
- Assess nacelle performance using Overflow
  - Clean vs. Podded vs. Embedded

Simulations

- 120 mph (M=0.16)
- Alpha sweep: -2° to 14° in 2° increments
  - Half-body cases (symmetry assumed)
- Steady, turbulent flow
- Clean configuration
  - in Free-air
  - w/ WT
  - w/ WT+mount/fairing
- Podded
- Embedded (geometry, mesh generation in progress)

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  - Mesh sensitivity
- Clean Configuration
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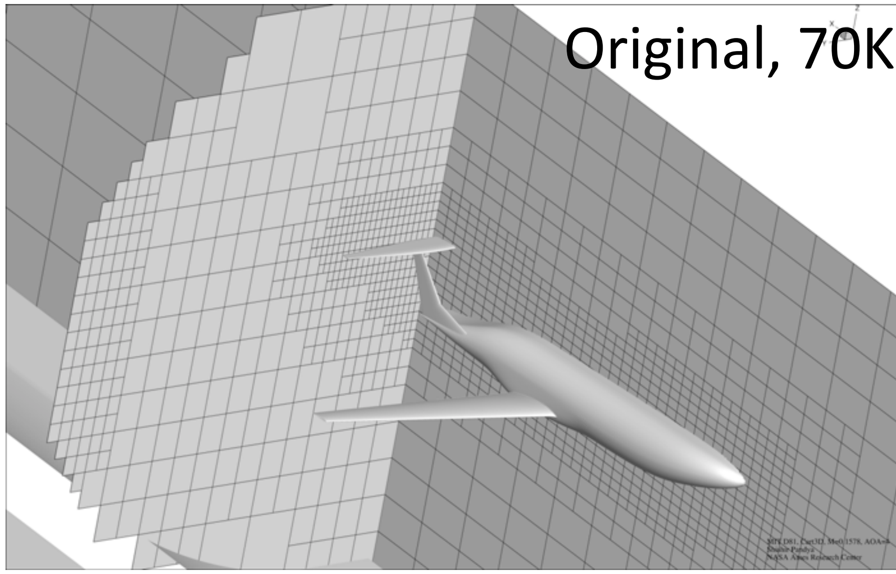
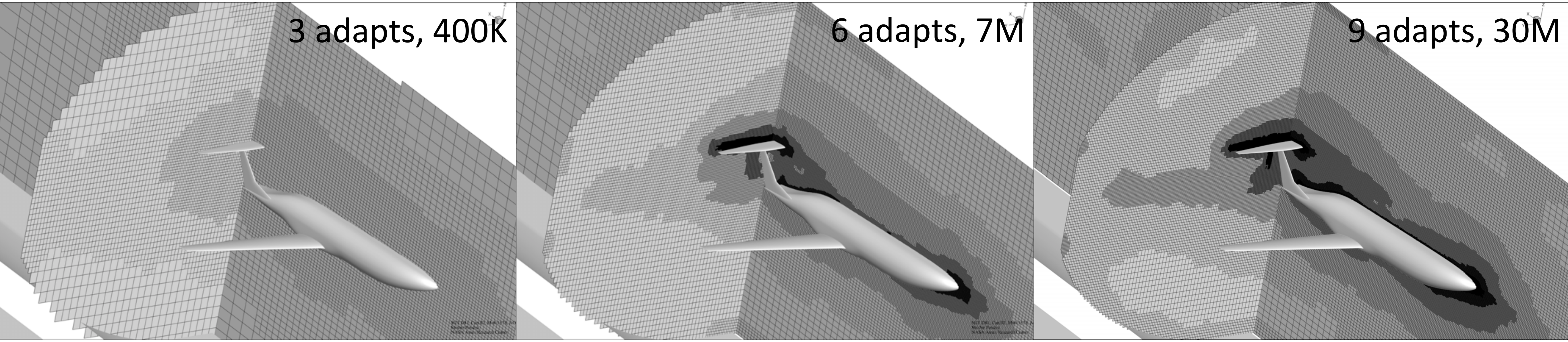
Cart3D/Aero Solution Adaptive Mesh

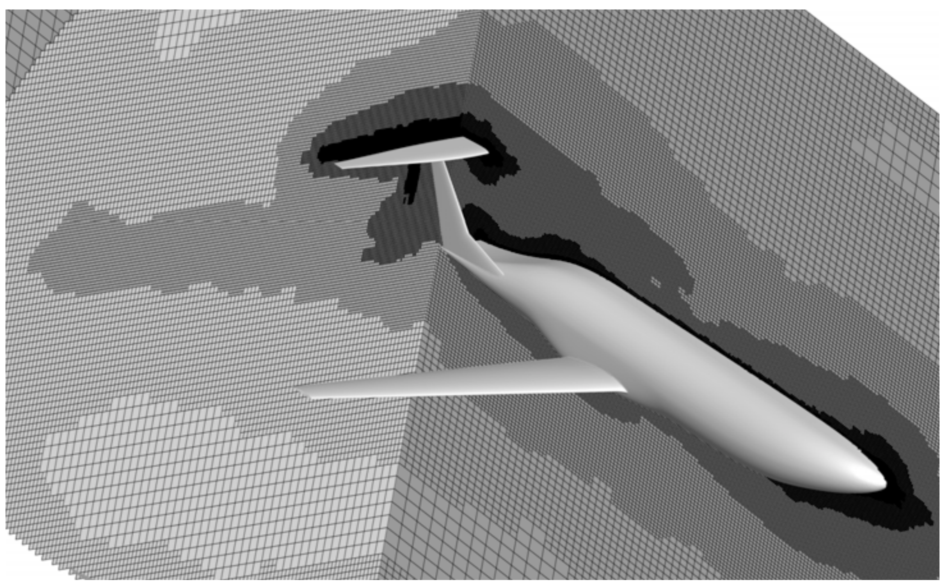


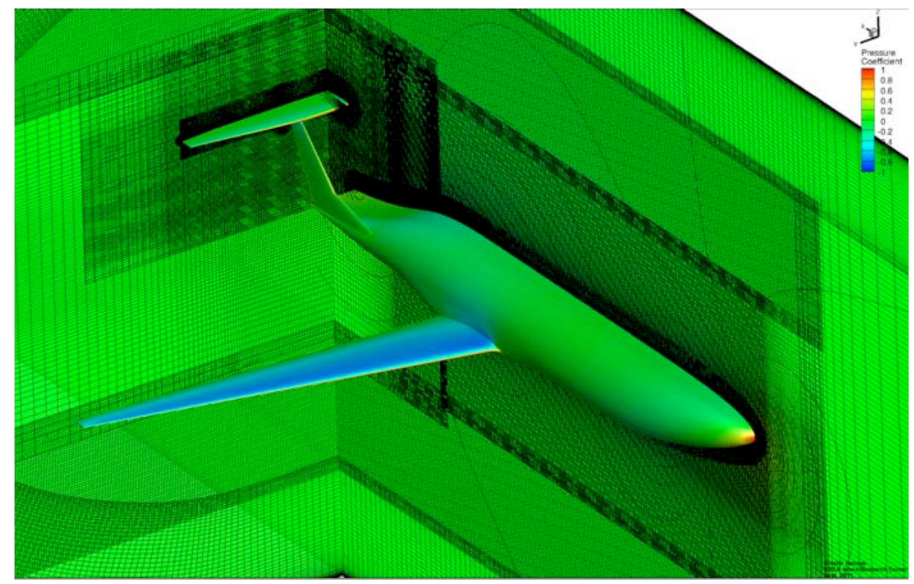
- Component based inviscid solver
  - –Automated mesh generation, complex geometries
- Adjoint-based adaptive mesh refinement used
  - –Takes place of a lot of user time and expertise



Overflow

- Overset mesh generation follows
  - Overset best practices
  - Guidance from Cart3D adaptive refinement

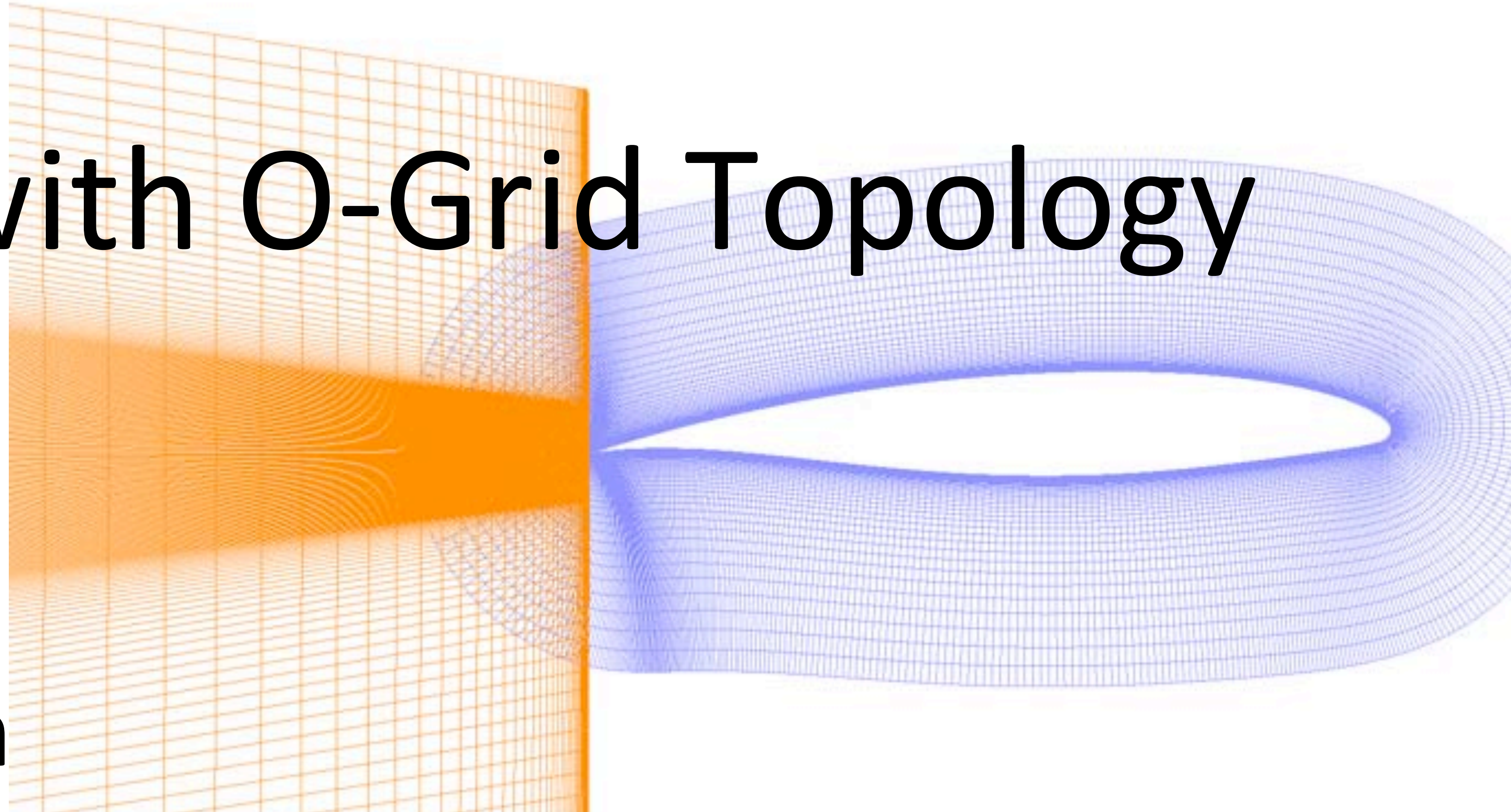


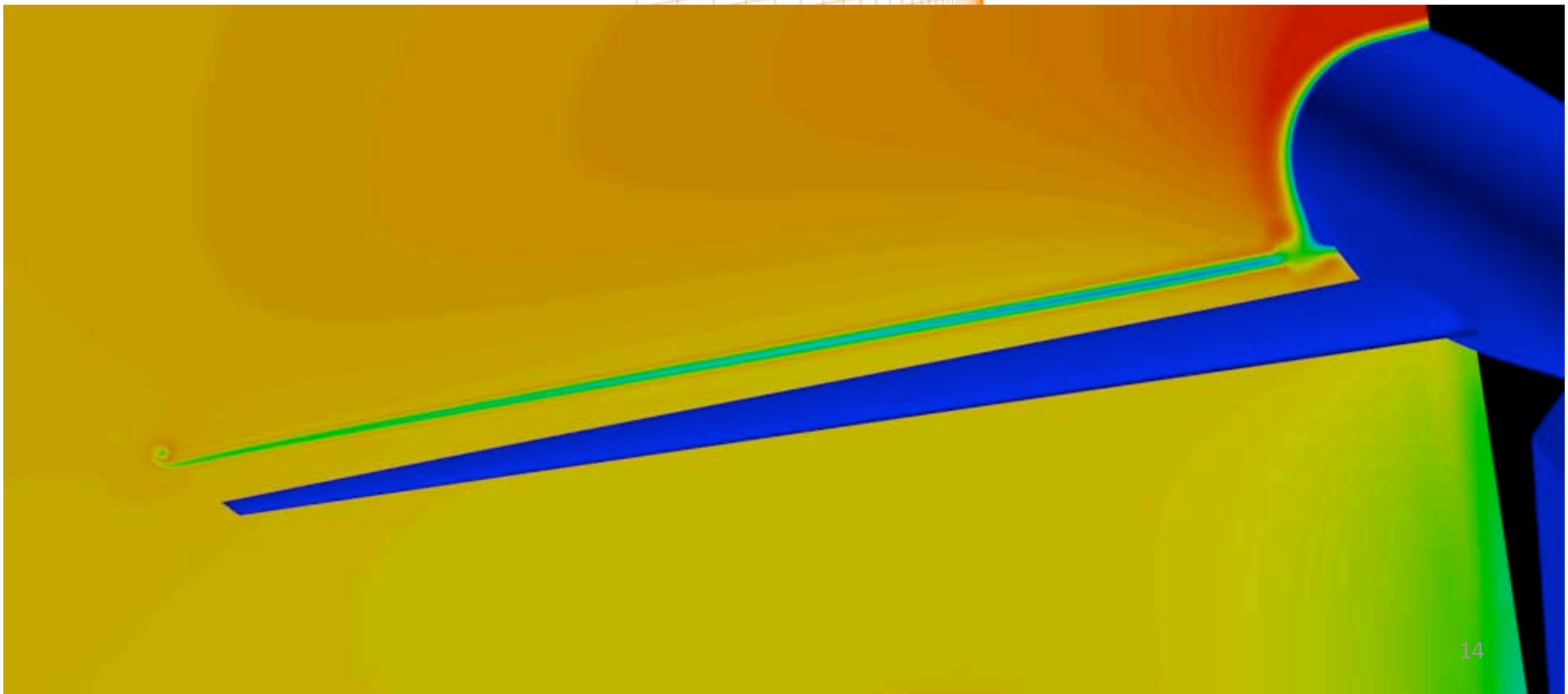


- Finite difference
  - Beam-Warming (approximate factorization/central difference)
  - Scalar dissipation
- Turbulence model (SA, SST) with target $y^+ \approx 1$

Wake Grid with O-Grid Topology

- Eliminate C- mesh
- Wake capture
- Tip vortex resolution





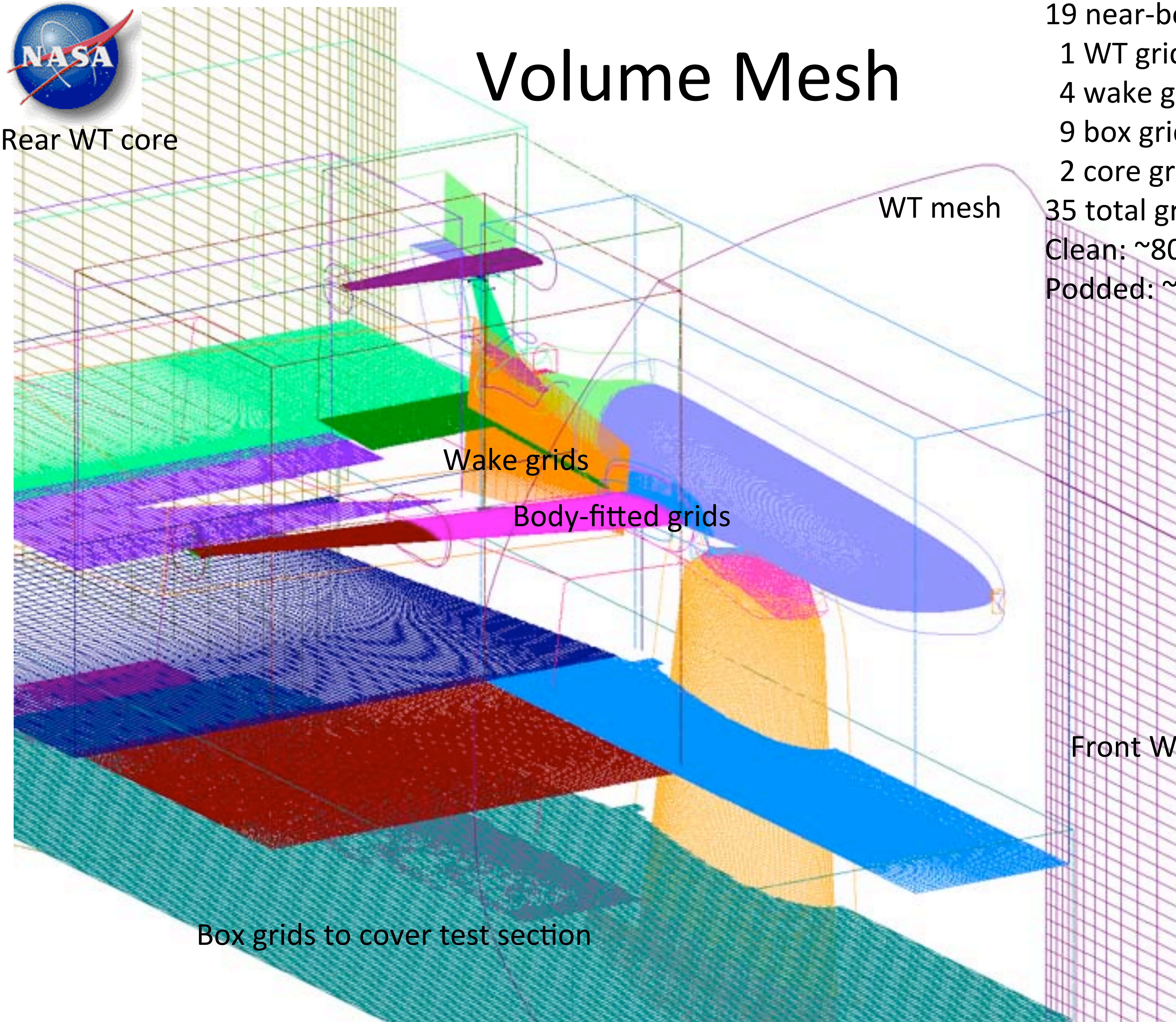
Volume Mesh

19 near-body grids
- 1 WT grid
- 4 wake grids
- 9 box grids
- 2 core grids

35 total grids

Clean: ~80 Million Pts.

Podded: ~87 Million Pts.

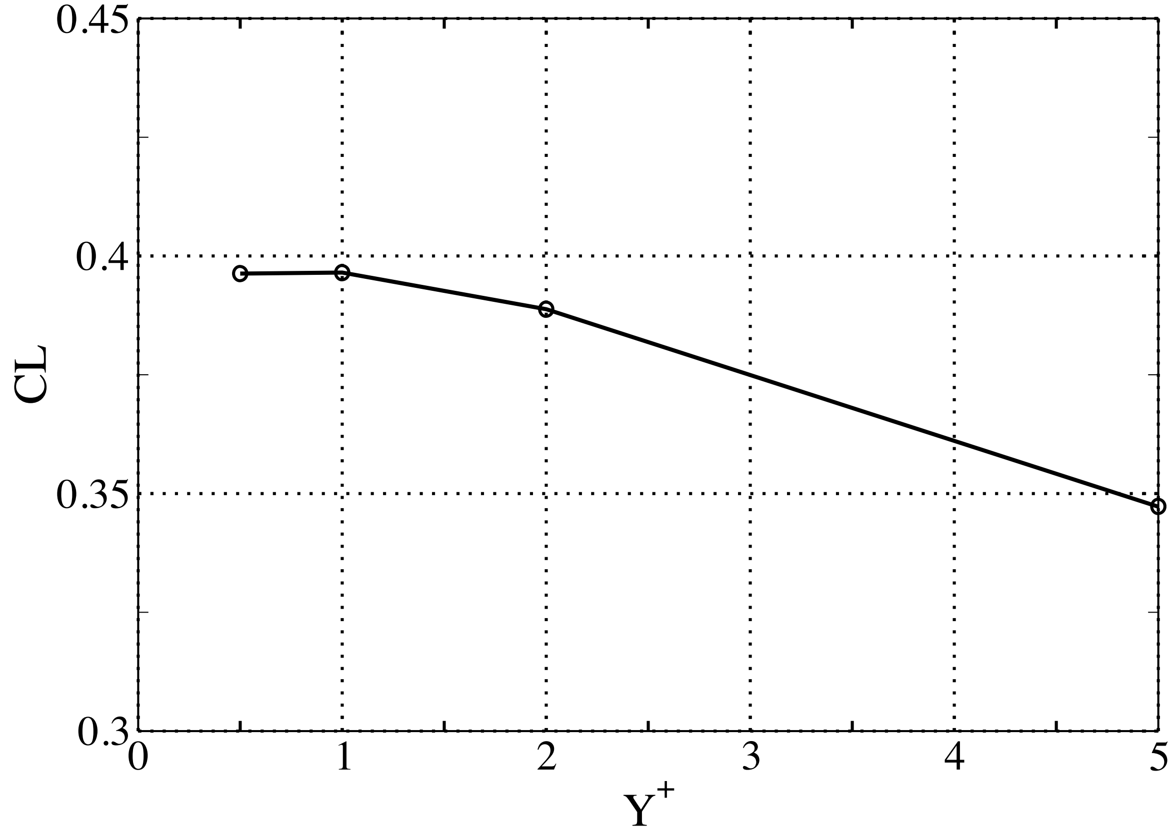


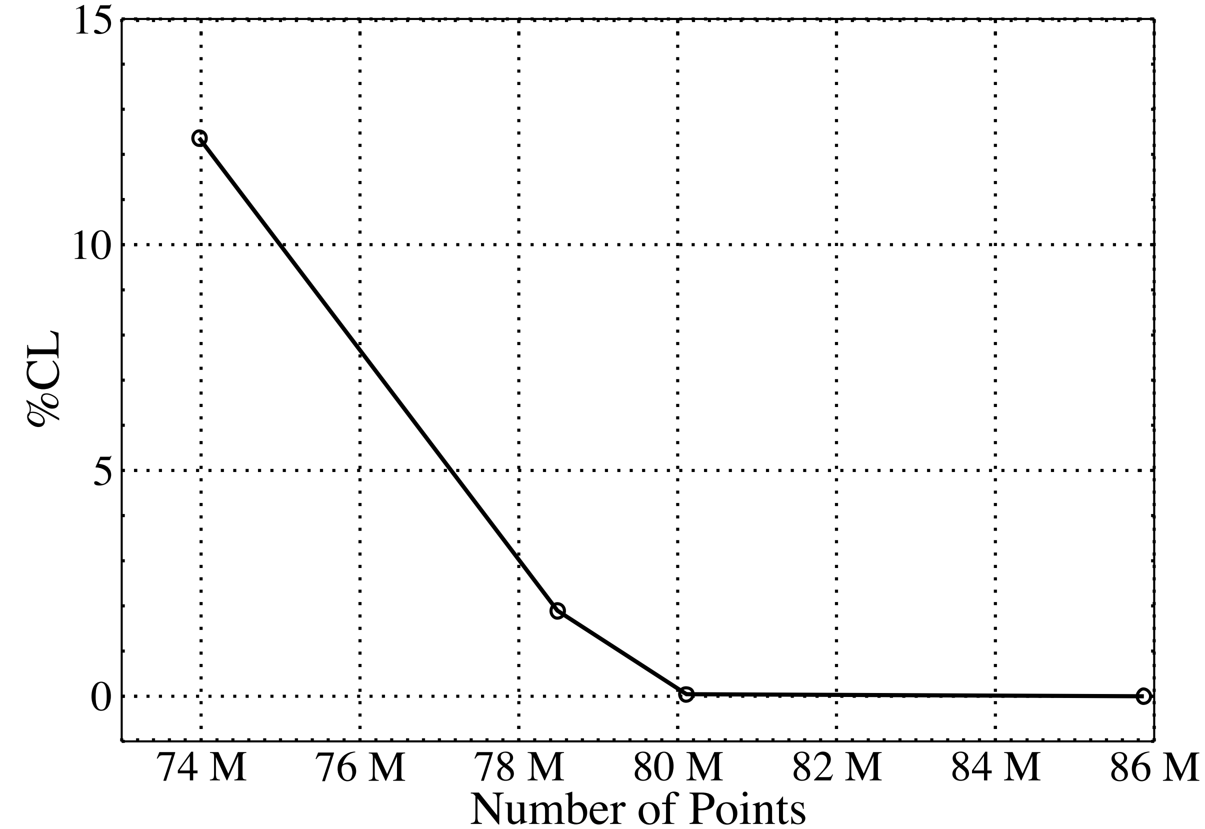
Mesh Sensitivity

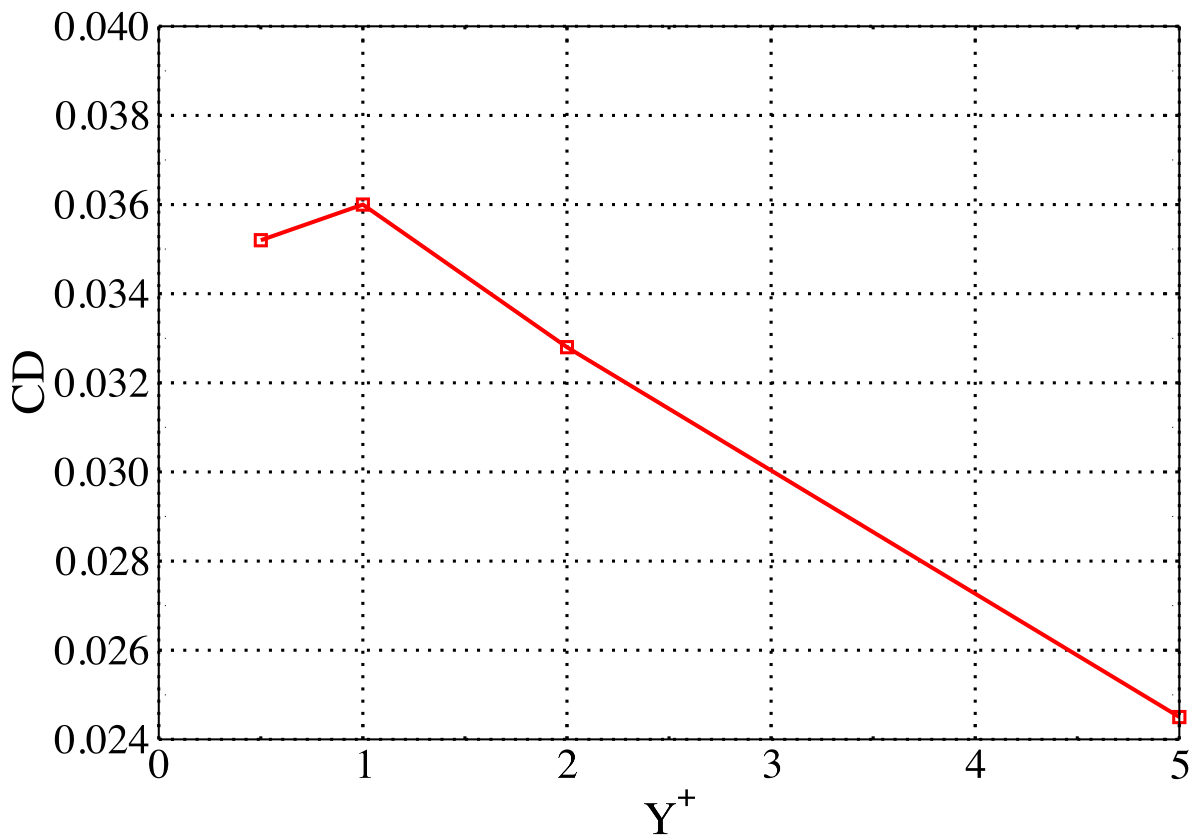
- Test each parameter independently
  - –Wall spacing (y^+)
  - –Near-wall stretching ratio
  - –Surface spacing
    - LE, TE, ...
  - –Off-body spacing
- Study done at α=0°
  - –SA turb. model

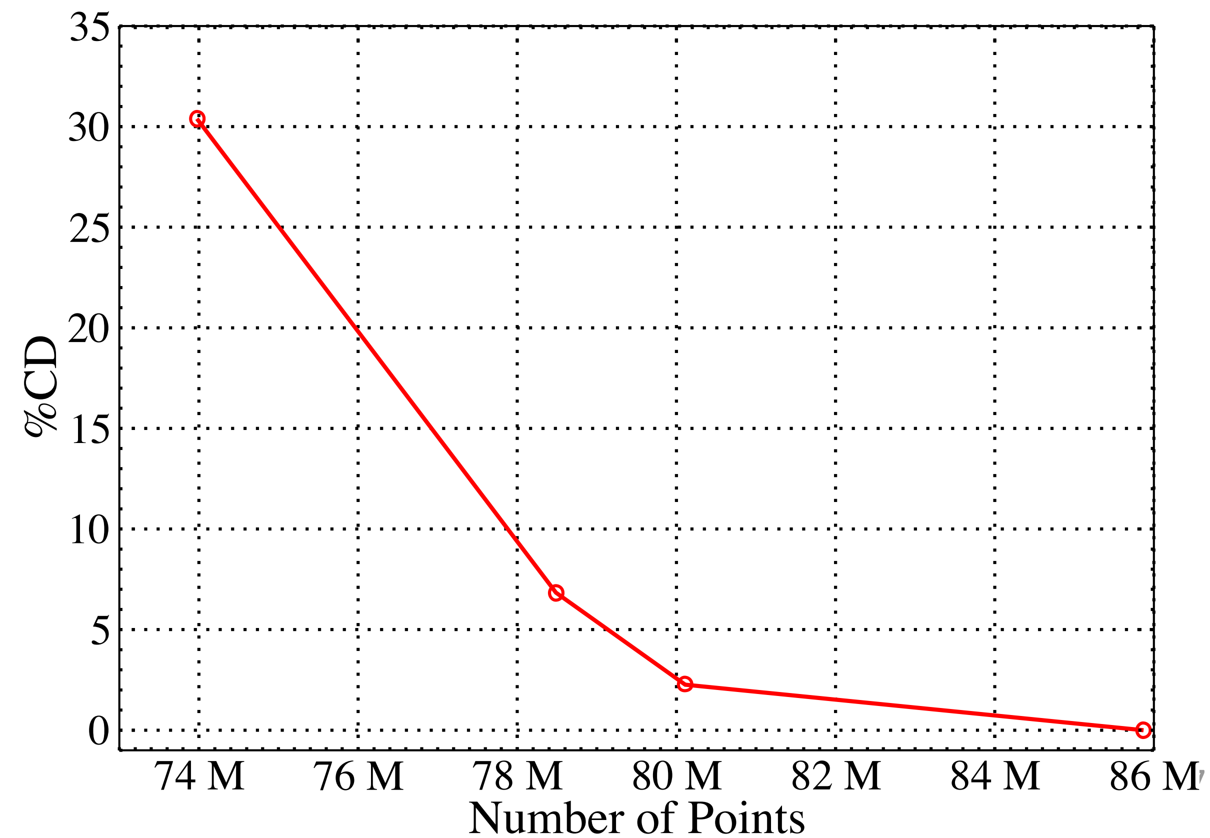
CL, CD Sensitivity to y^+

D8 with WT walls and Strut, M=0.16, α=0   SR=1.15, DS_s=1, DS_o=0.15



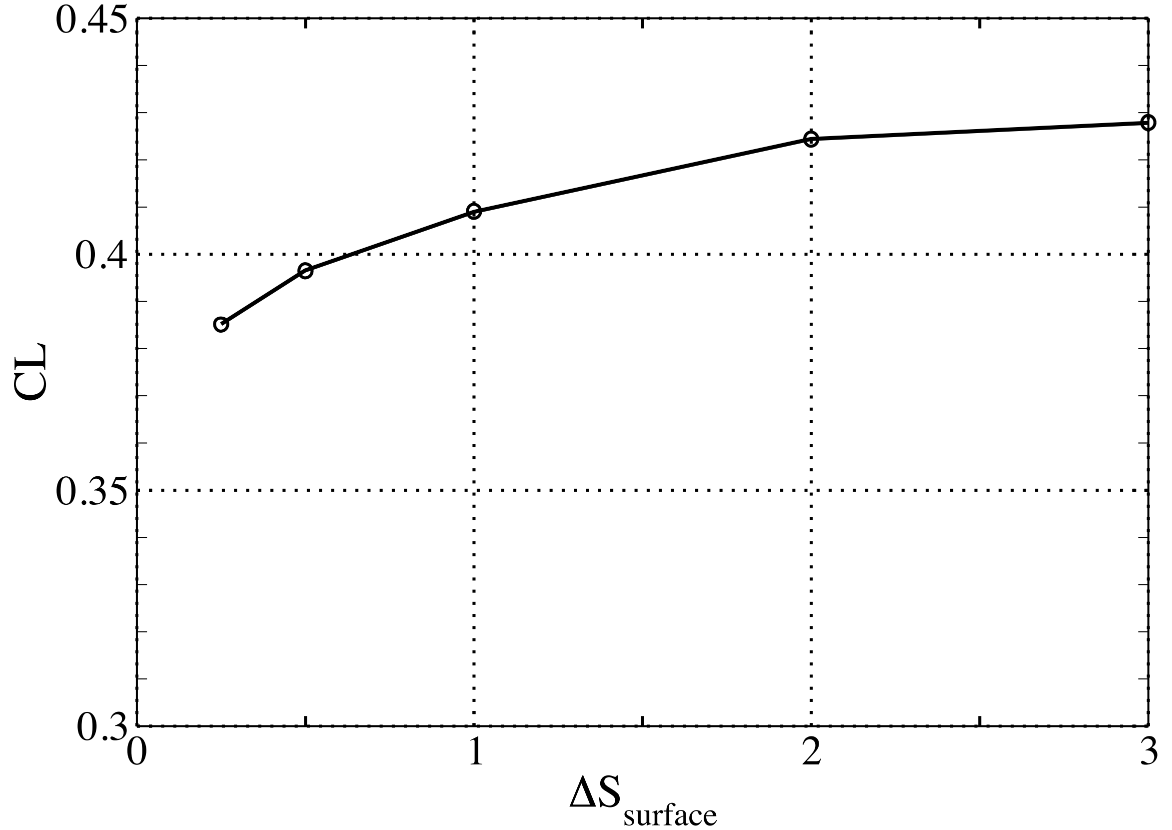


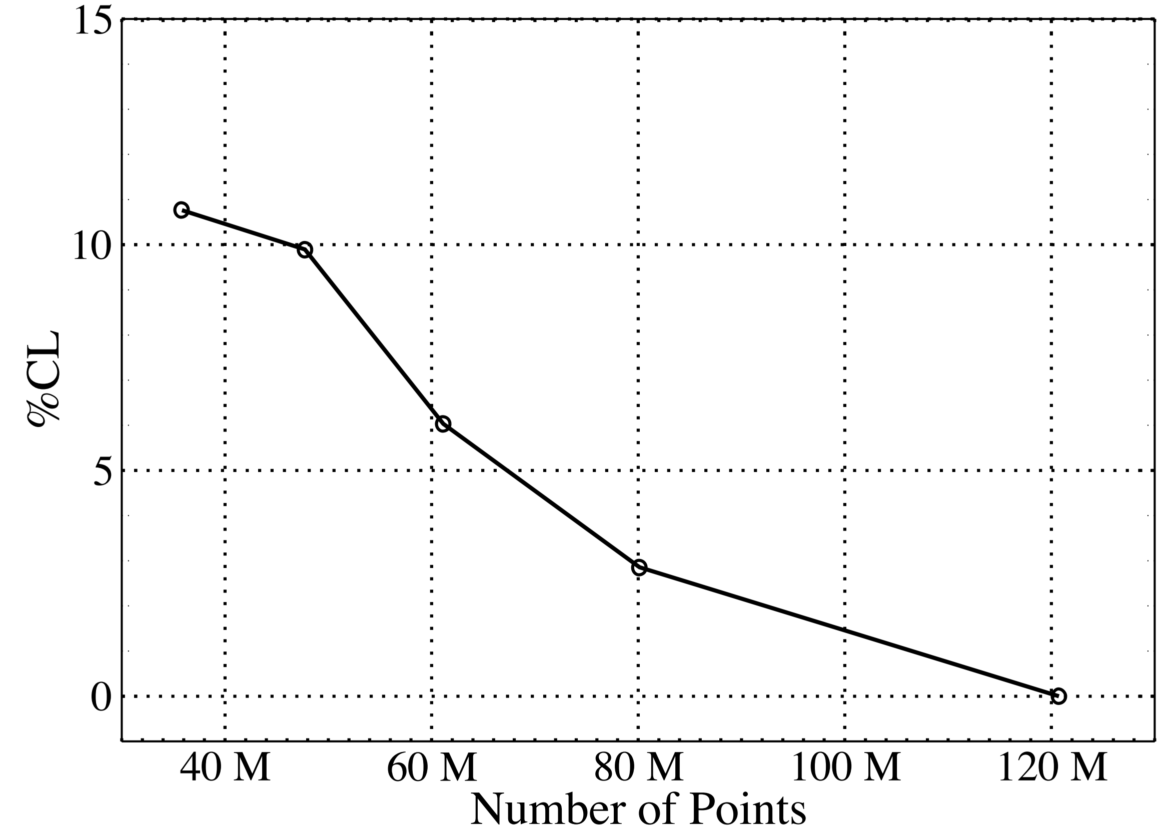


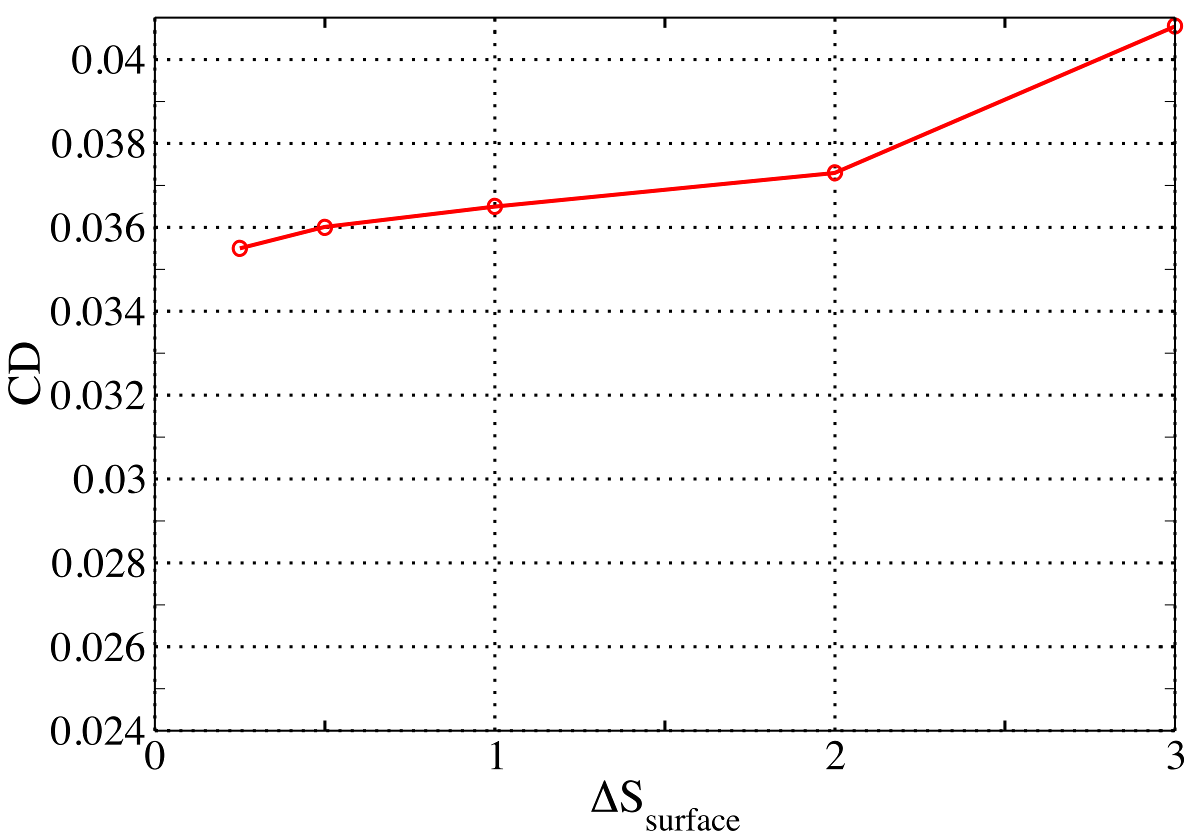


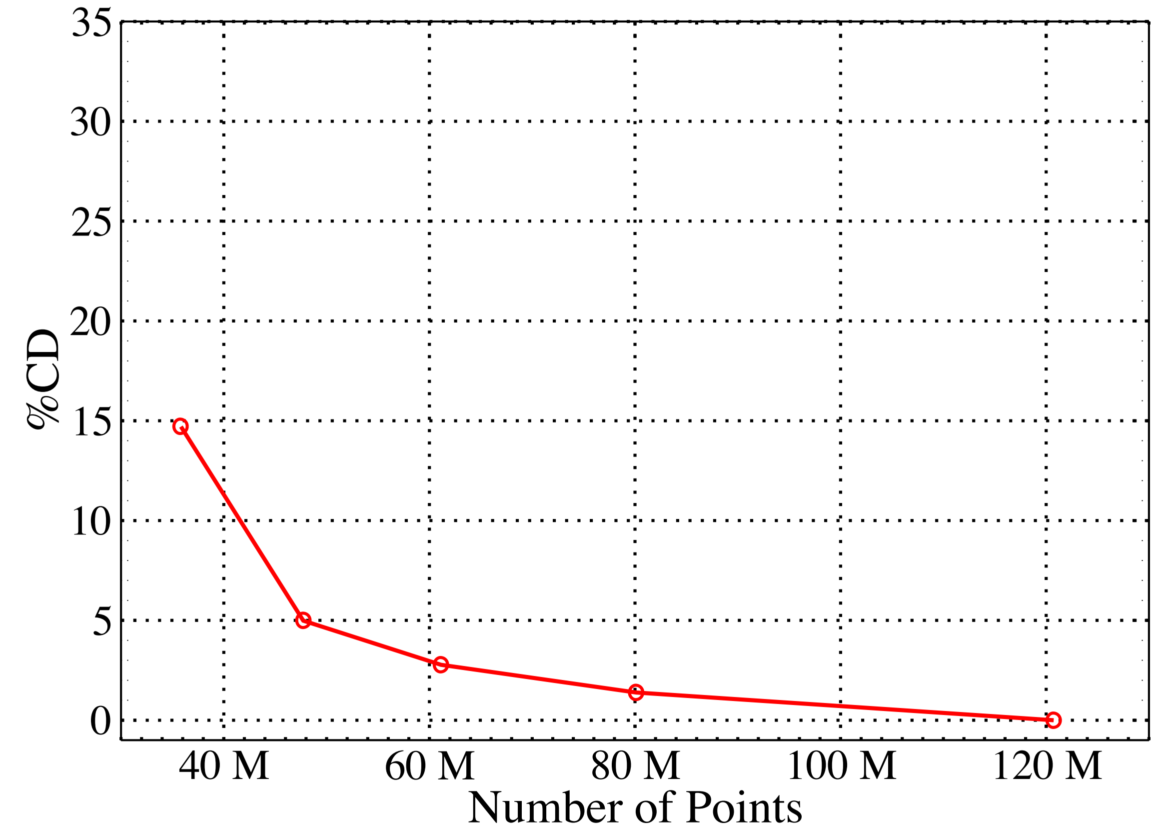
CL, CD Sensitivity to Surface Spacing

D8 with WT walls and Strut, M=0.16, α=0 y^+=1, SR=1.15, DS_o=0.15



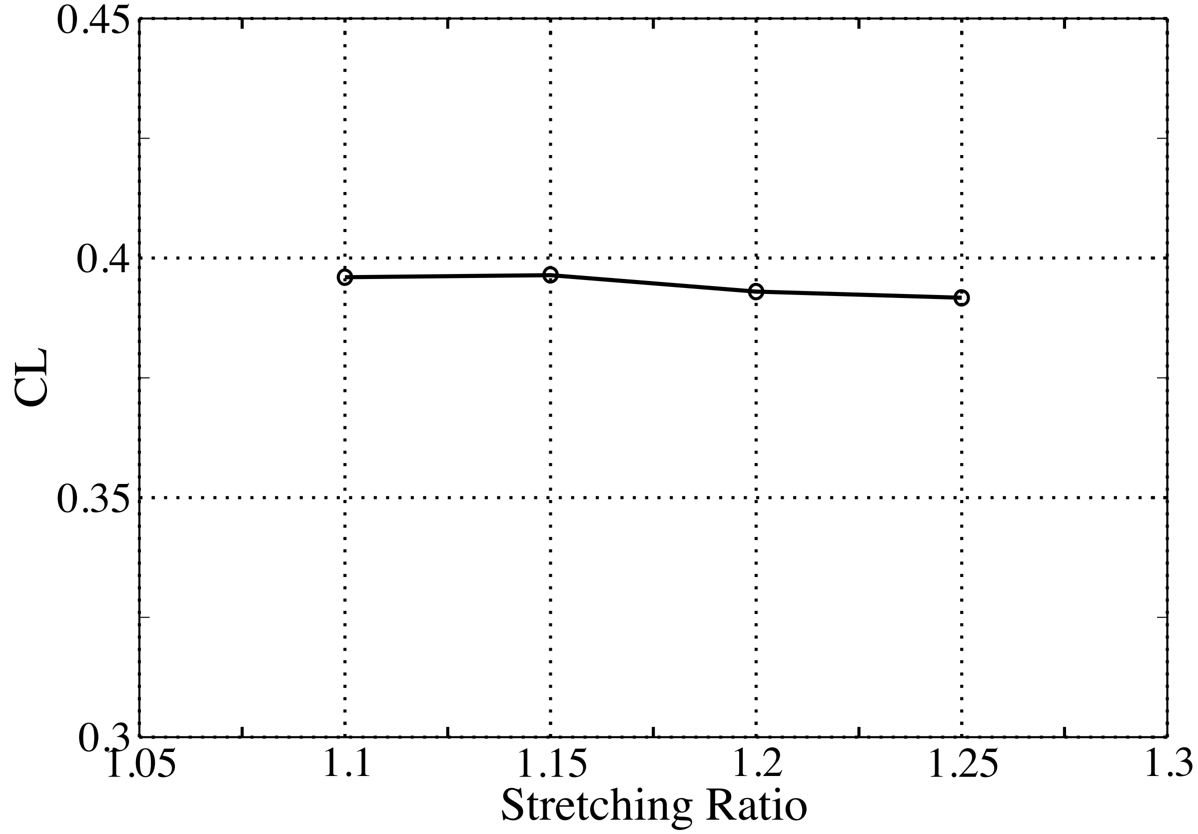


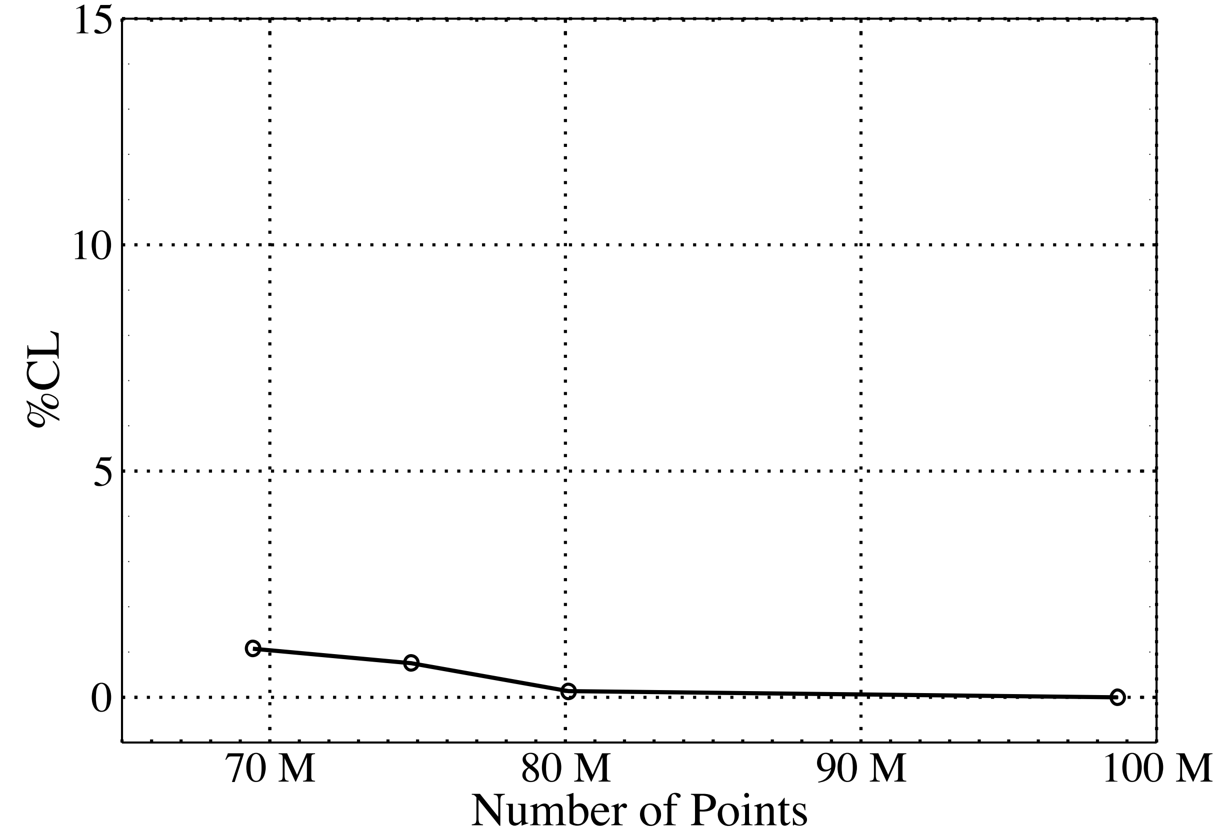


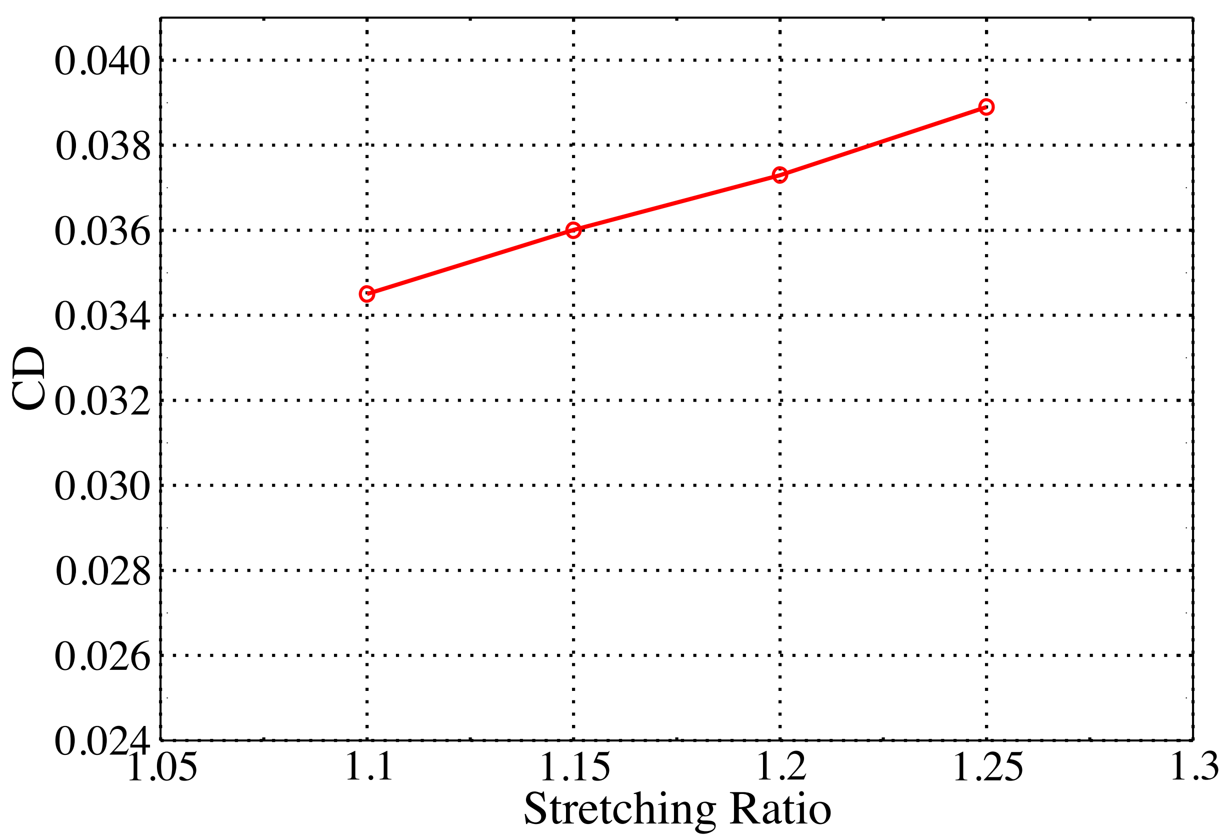


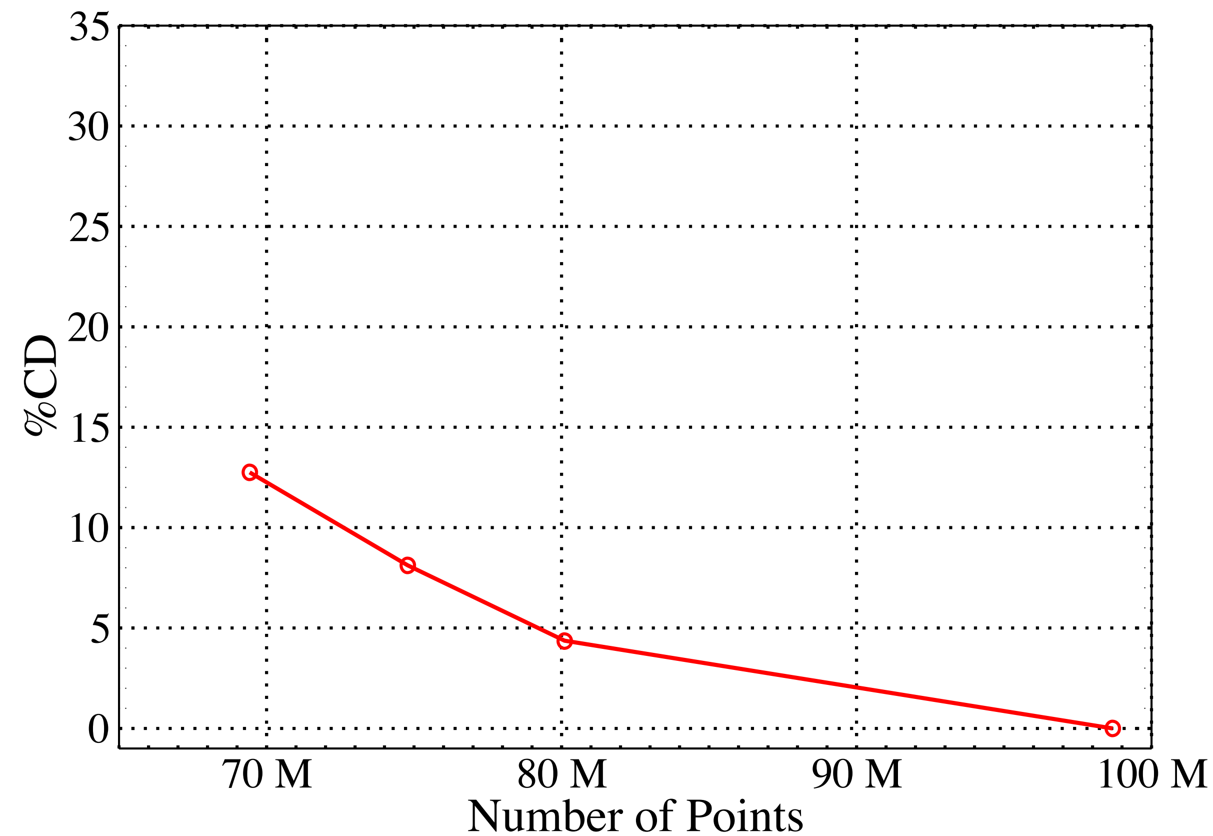
CL, CD Sensitivity to Stretching Ratio

D8 with WT walls and Strut, M=0.16, α=0 $y^+=1$, $DS_s=1$, $DS_o=0.15$



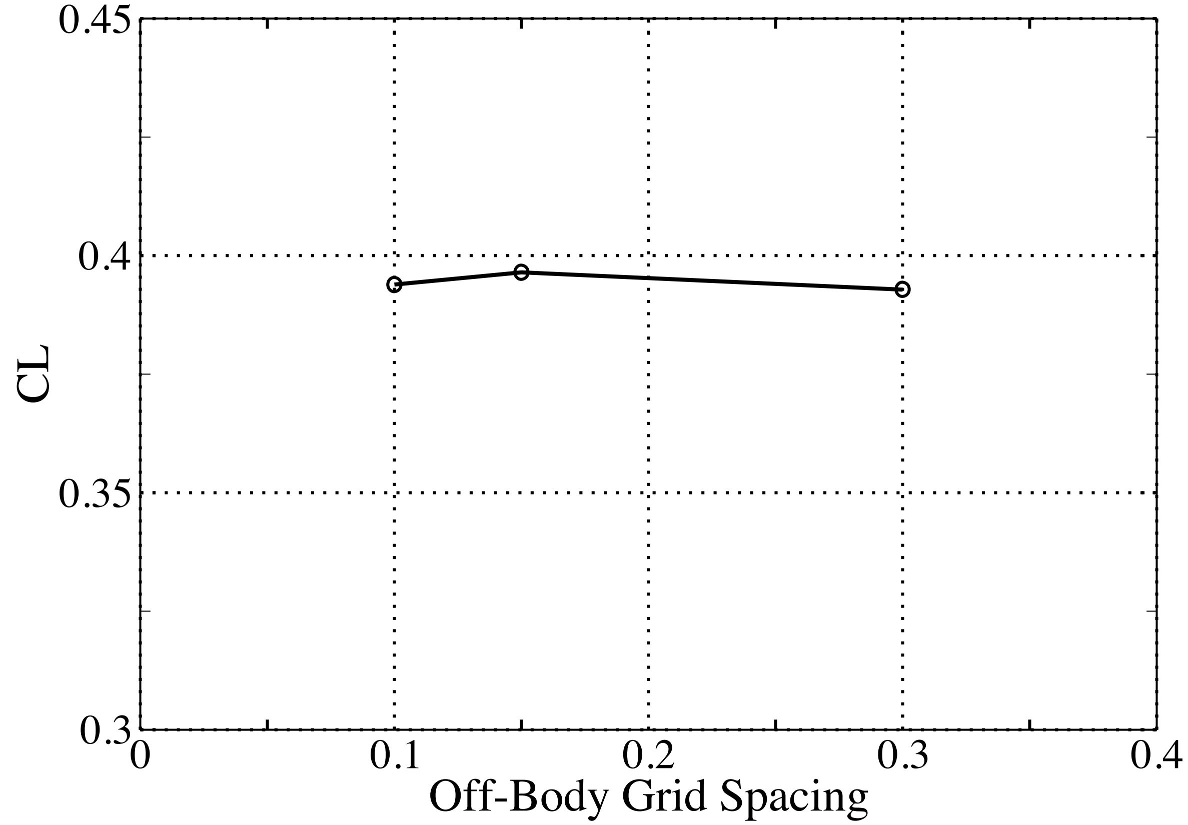


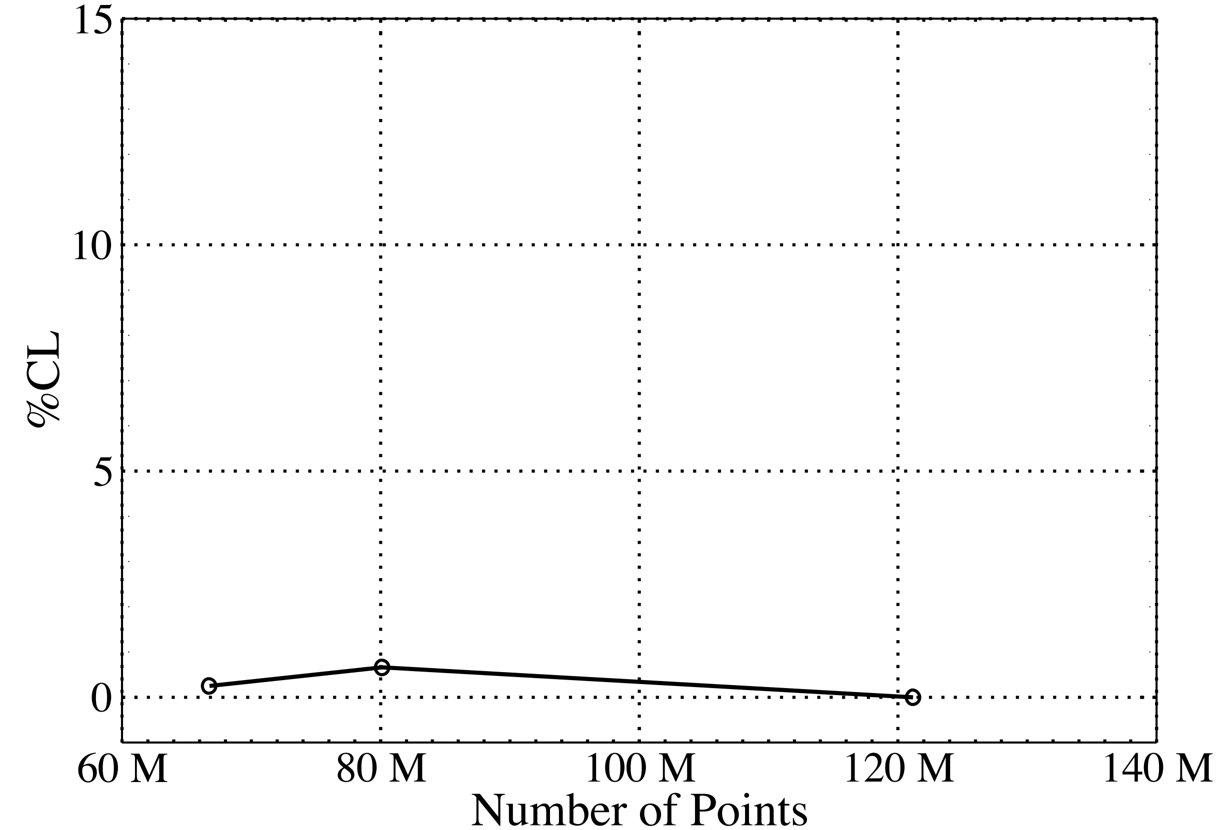


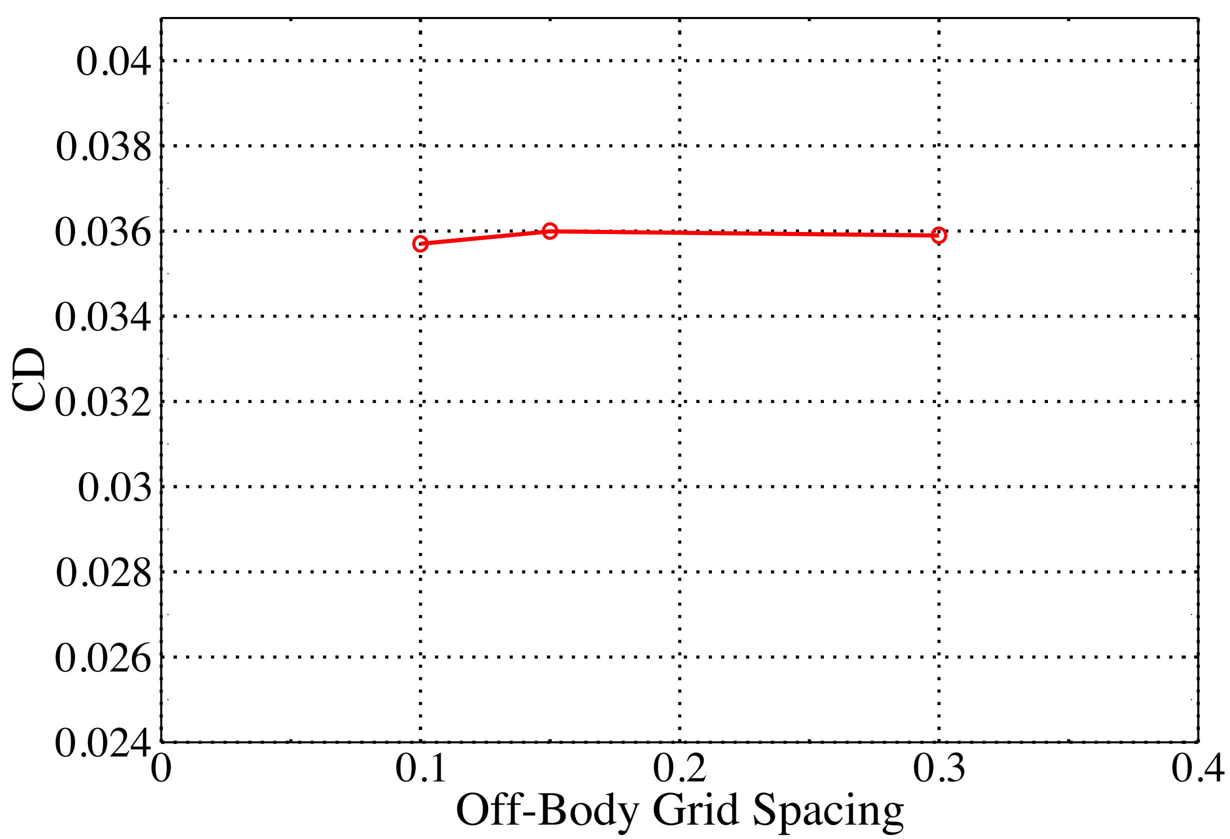


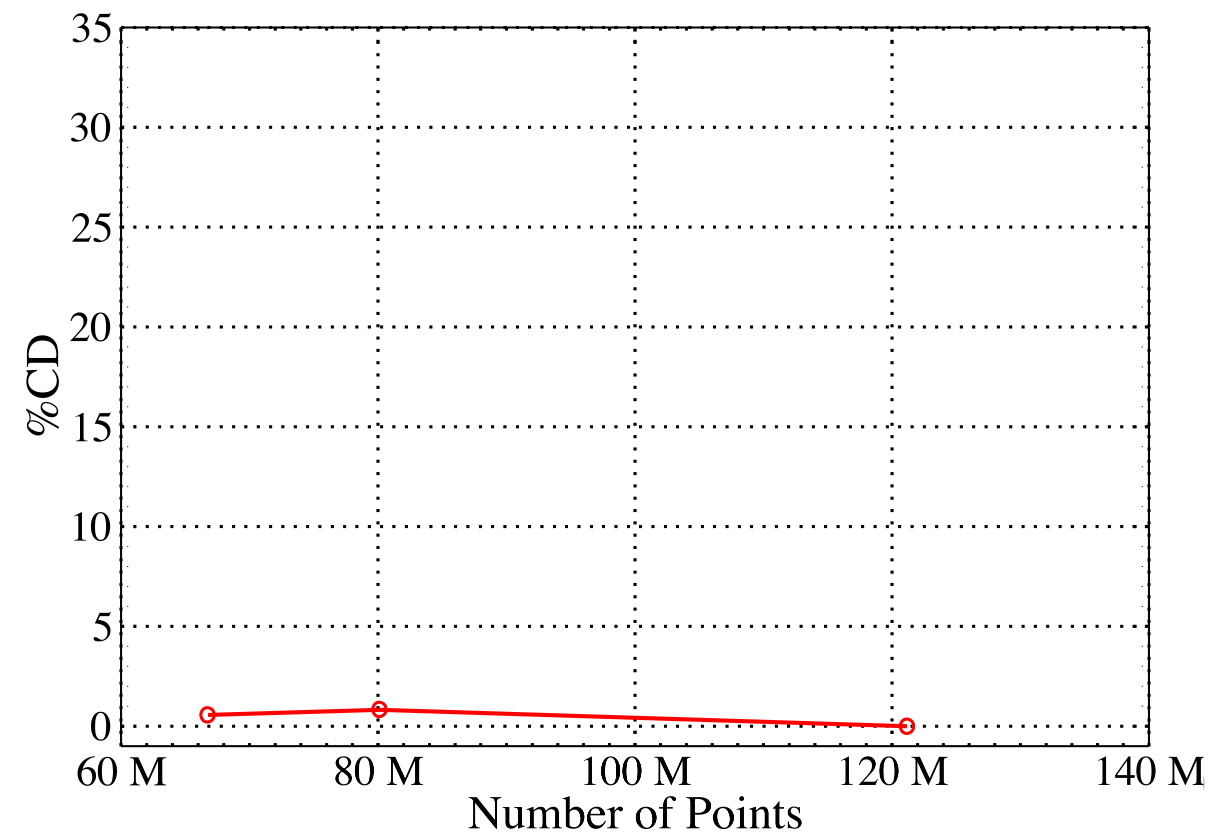
CL, CD Sensitivity to Off-Body Spacing

D8 with WT walls and Strut, M=0.16, α=0 y^+=1, SR=1.15, DS_s=1









Production Mesh

- Tested each parameter independently (α=0°, SA)
  - Wall-normal spacing (tested 0.5 to 5)
    - 0.00016 => $y^+ \approx 1$
  - Stretching ratio (tested 1.1 to 1.25)
    - 1.15
  - Surface spacing (tested LE spacing of 0.025 to 0.3%)
    - LE spacing ≈ 0.006 (0.1% chord)
    - TE spacing ≈ 0.003 (0.05% chord)
    - Inboard airfoil covered by ~550 points
    - Outboard airfoil covered by ~300 points
  - Off-body spacing (tested 0.1 to 0.3)
    - 0.15

Solution Consistency, Sensitivity

- Pegasus vs. Xrays vs. c3Lib
  - lift varies 2.9%, drag varies 1.1%
- AF vs. Diagonal vs. Roe vs. HLLC
  - lift varies 3%, drag varies 1.4%
- Low-Mach pre-conditioner
  - No change in lift and drag
- Unsteady algorithm
  - Flow remained steady with minor change in lift and drag
- Various WT Inlet/Exit Boundary Conditions
  - Minor variations in integrated forces

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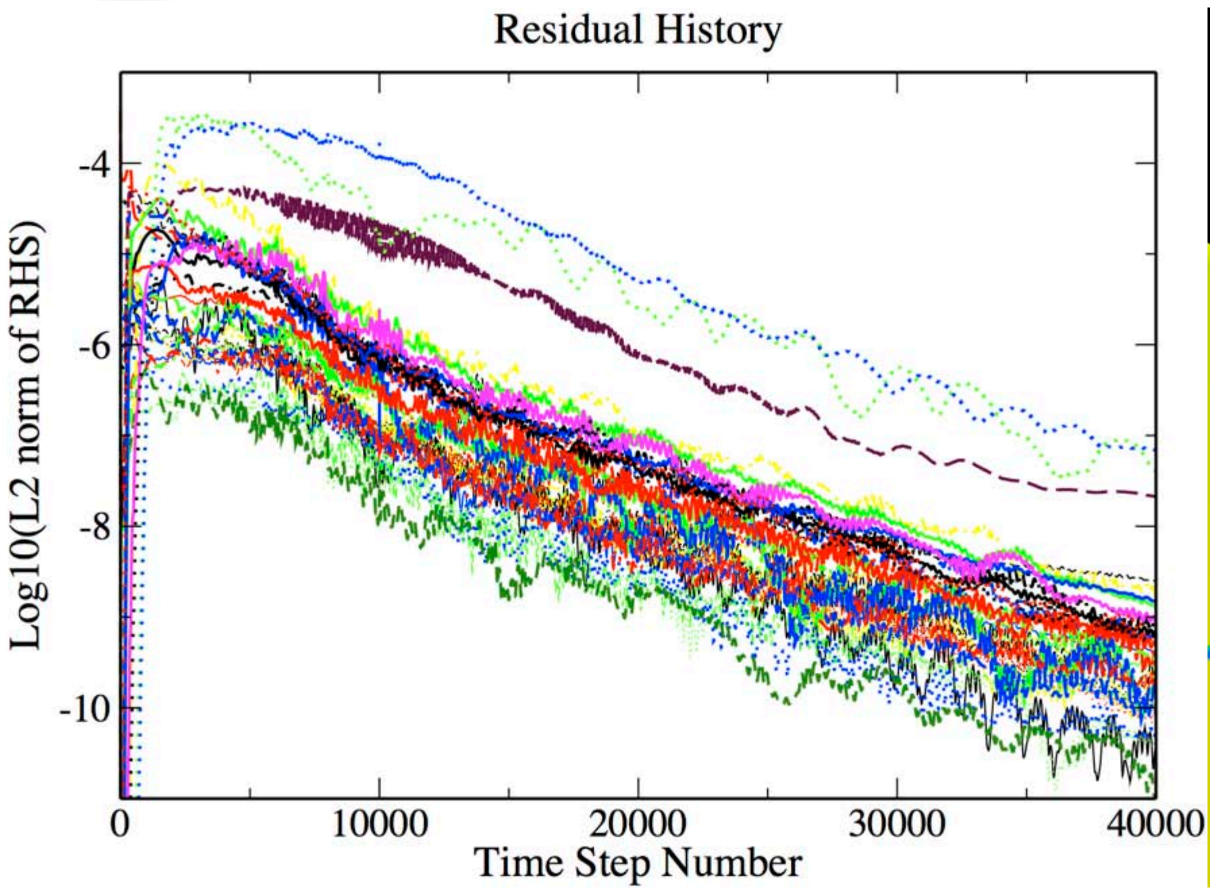
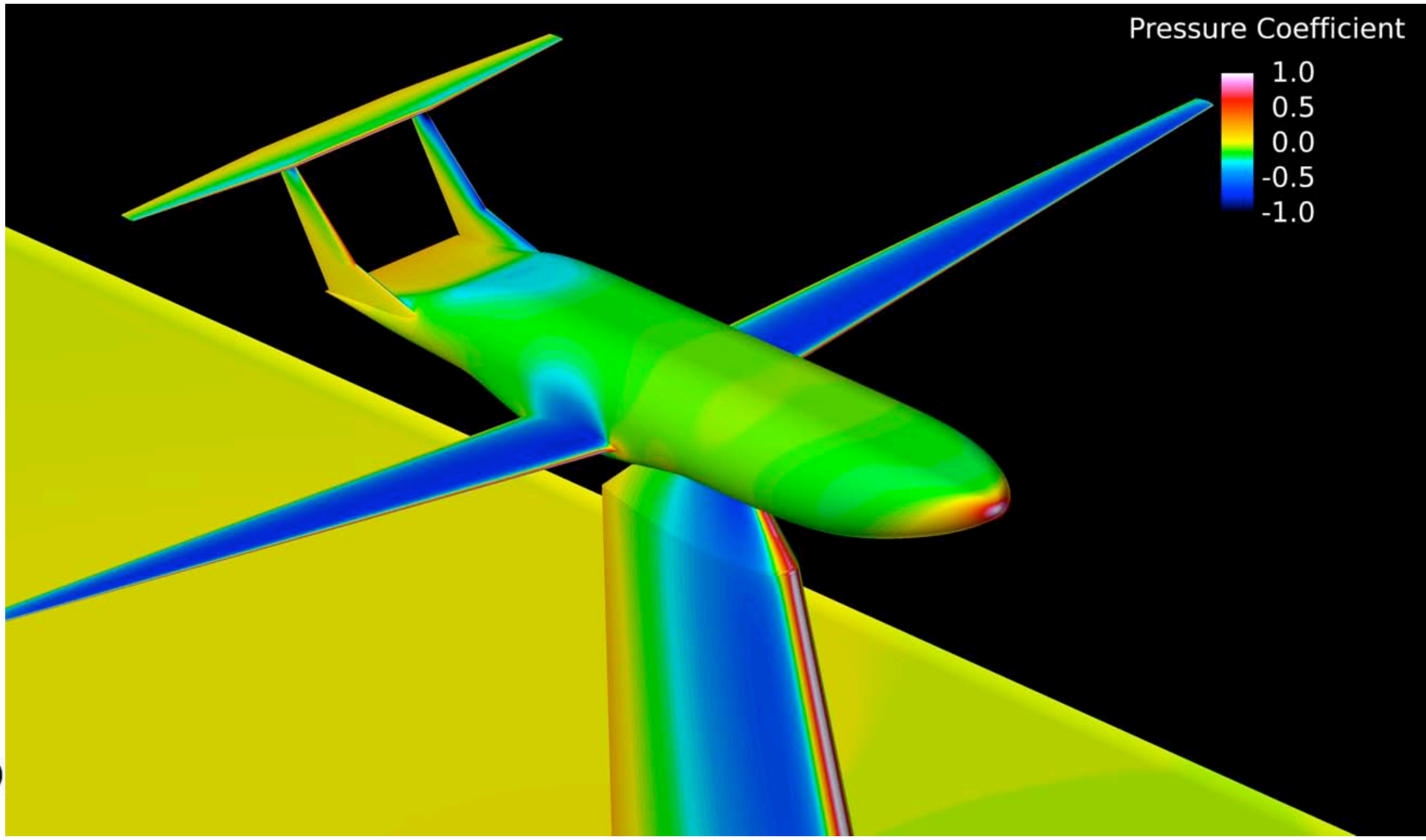
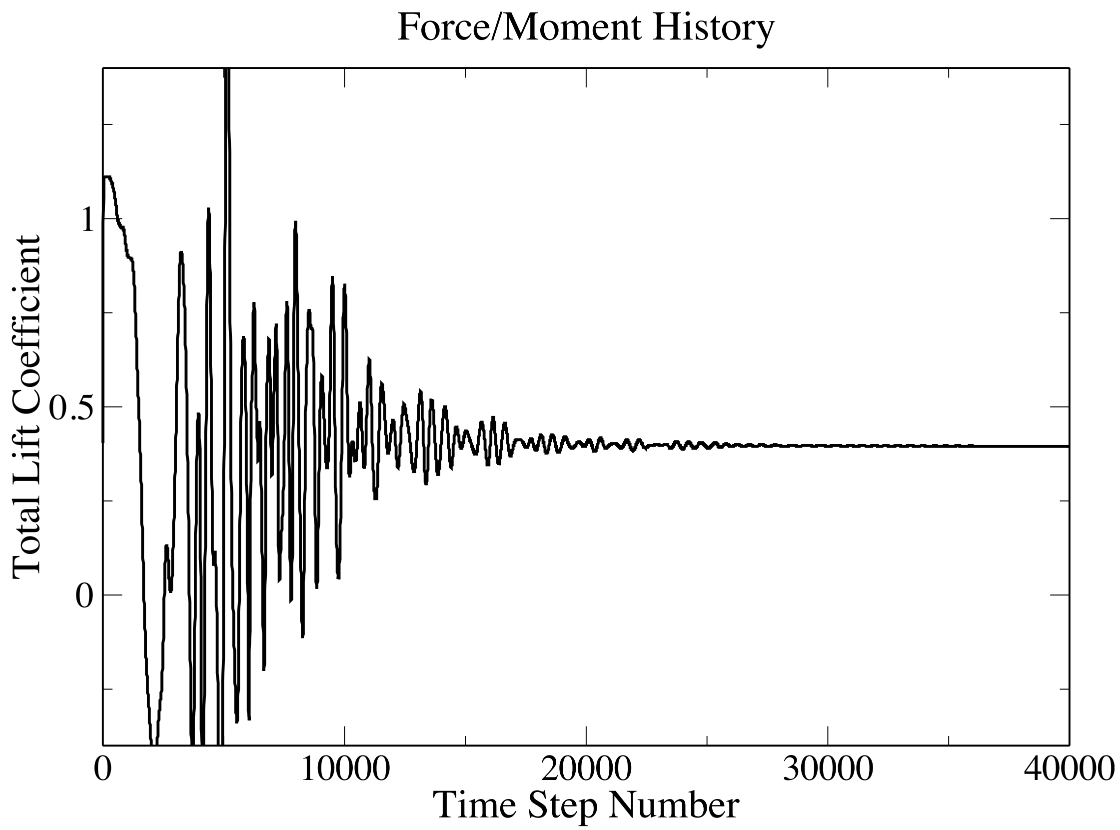
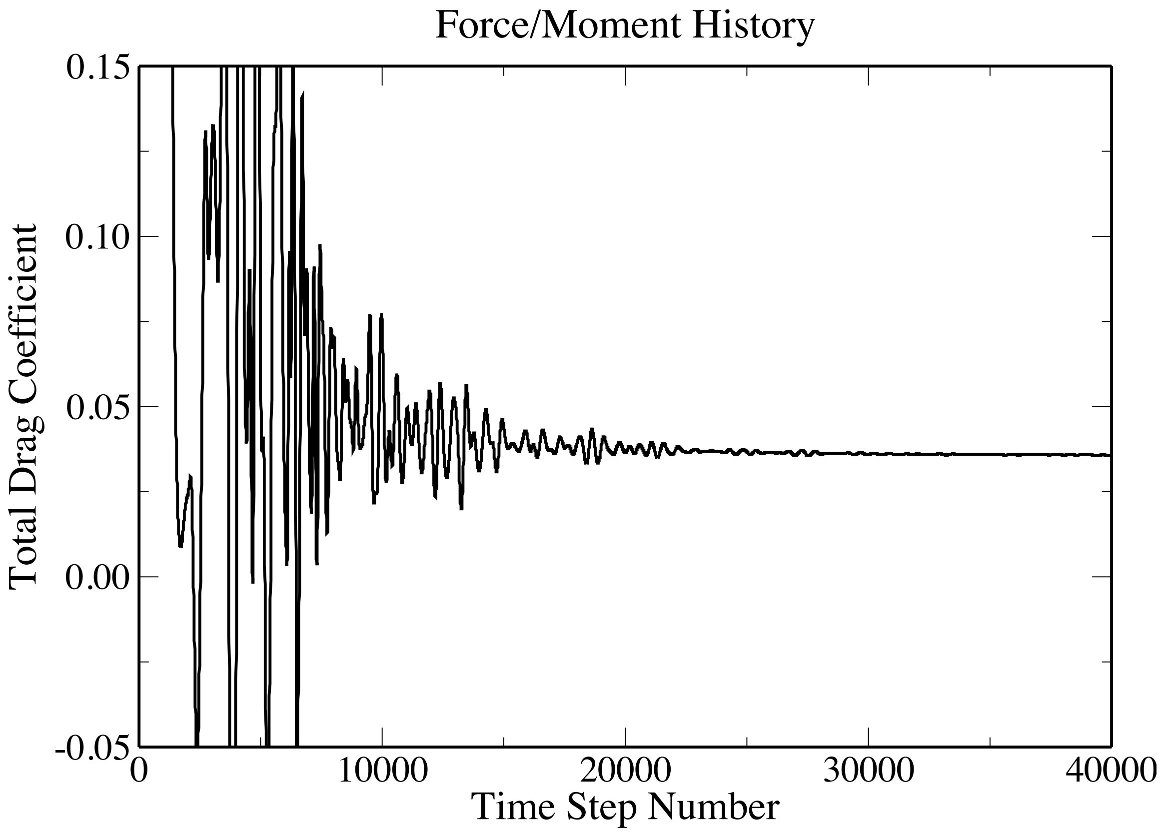
Convergence and Solution

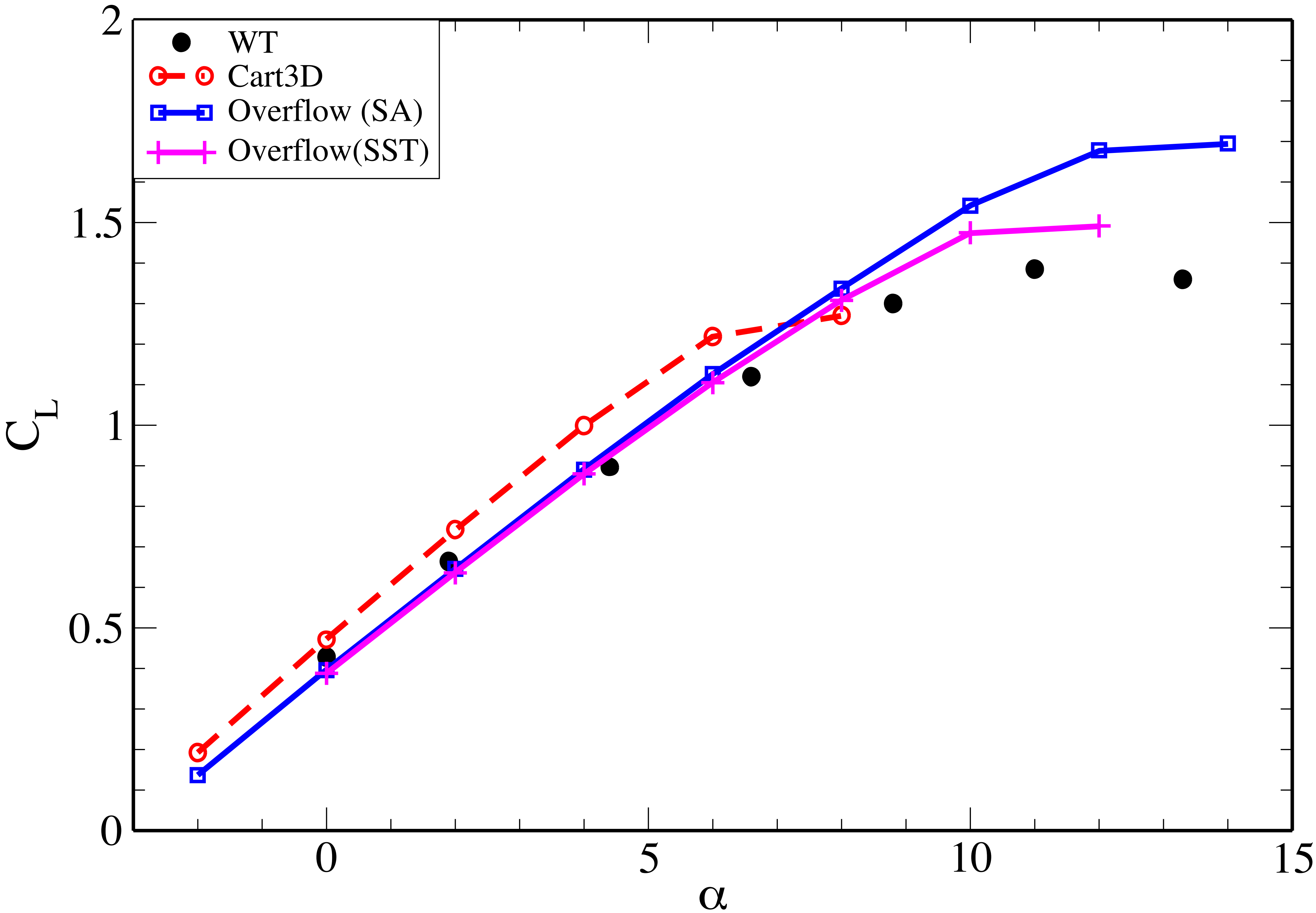




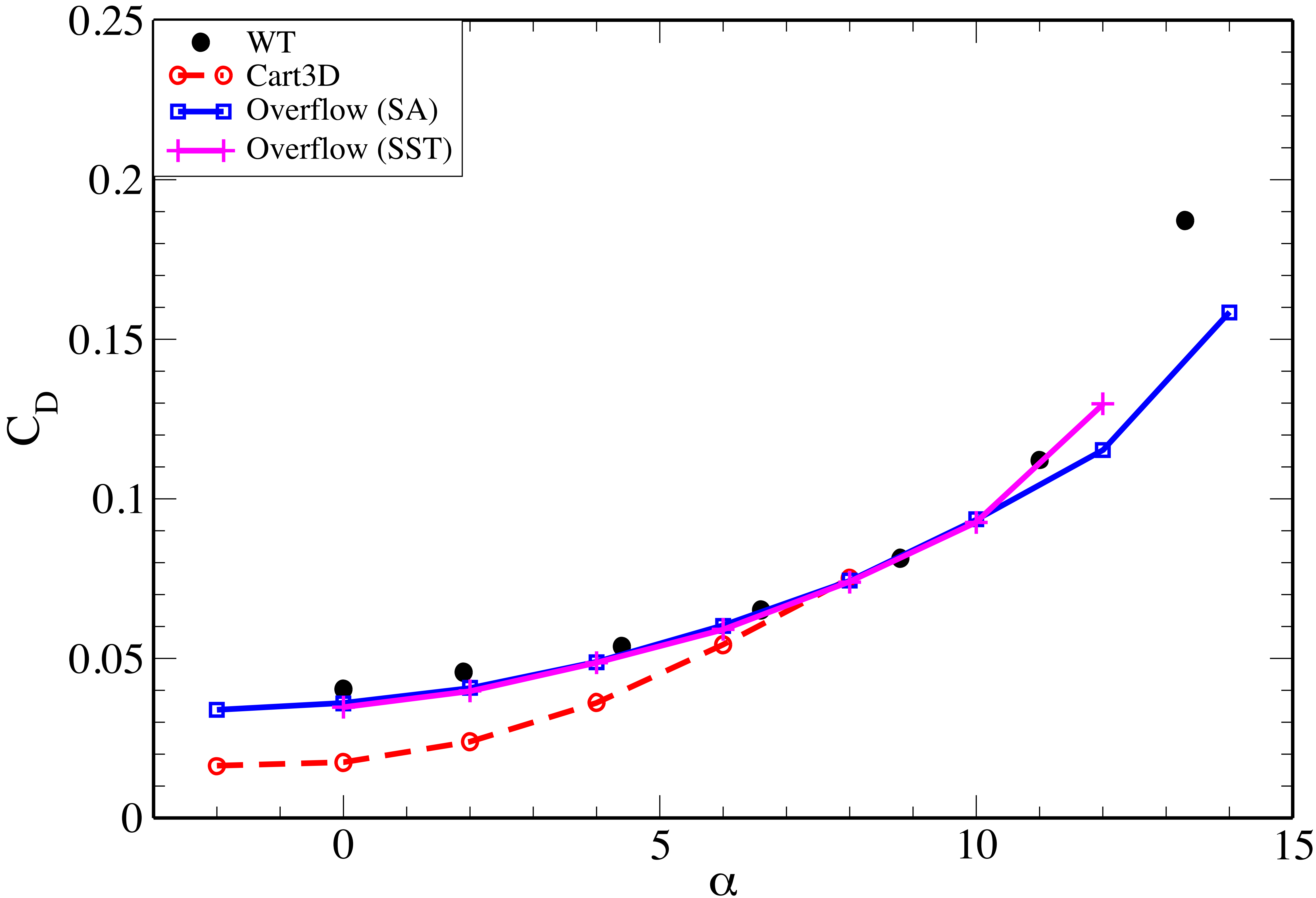




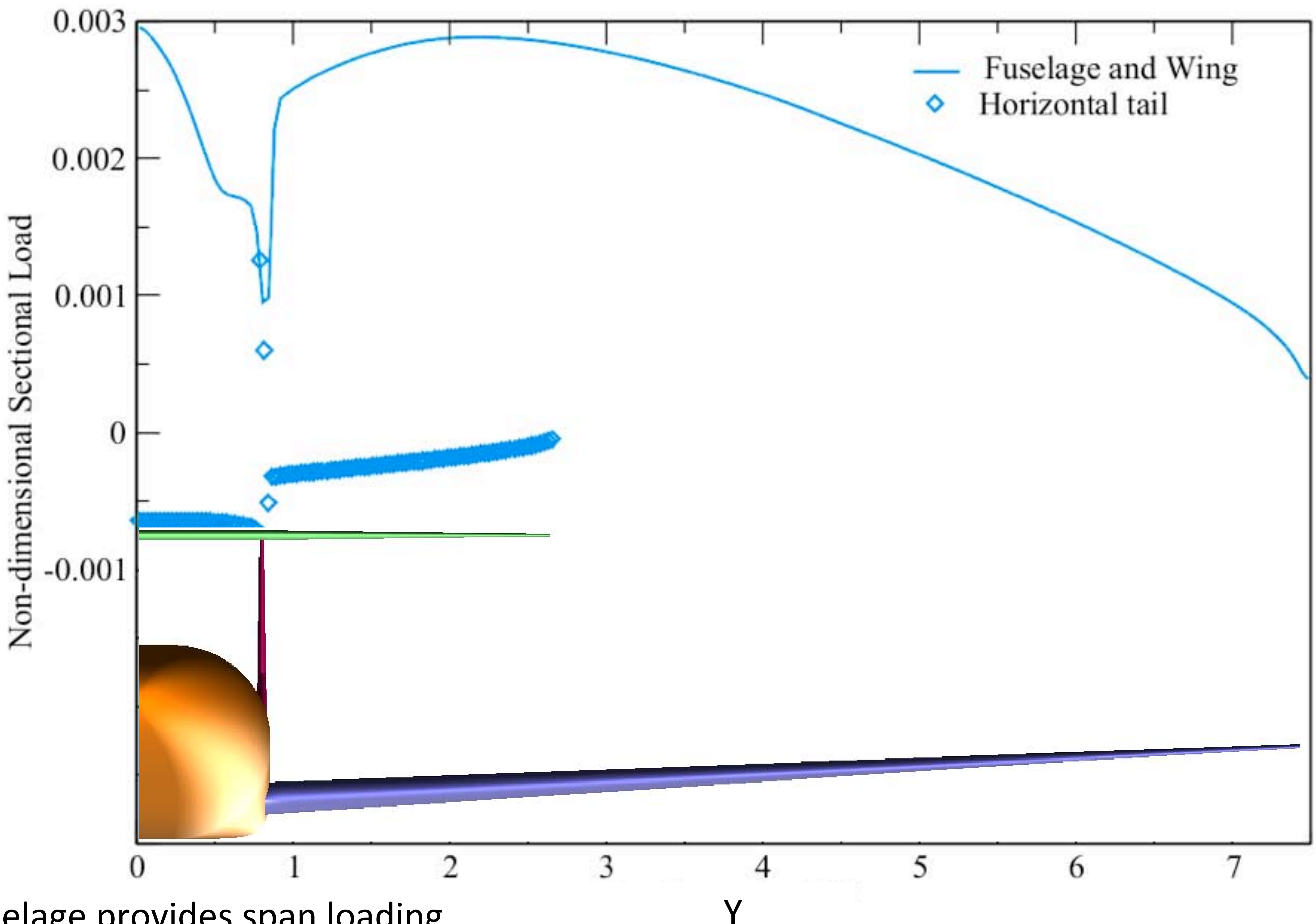
C_L Comparison



C_D Comparison

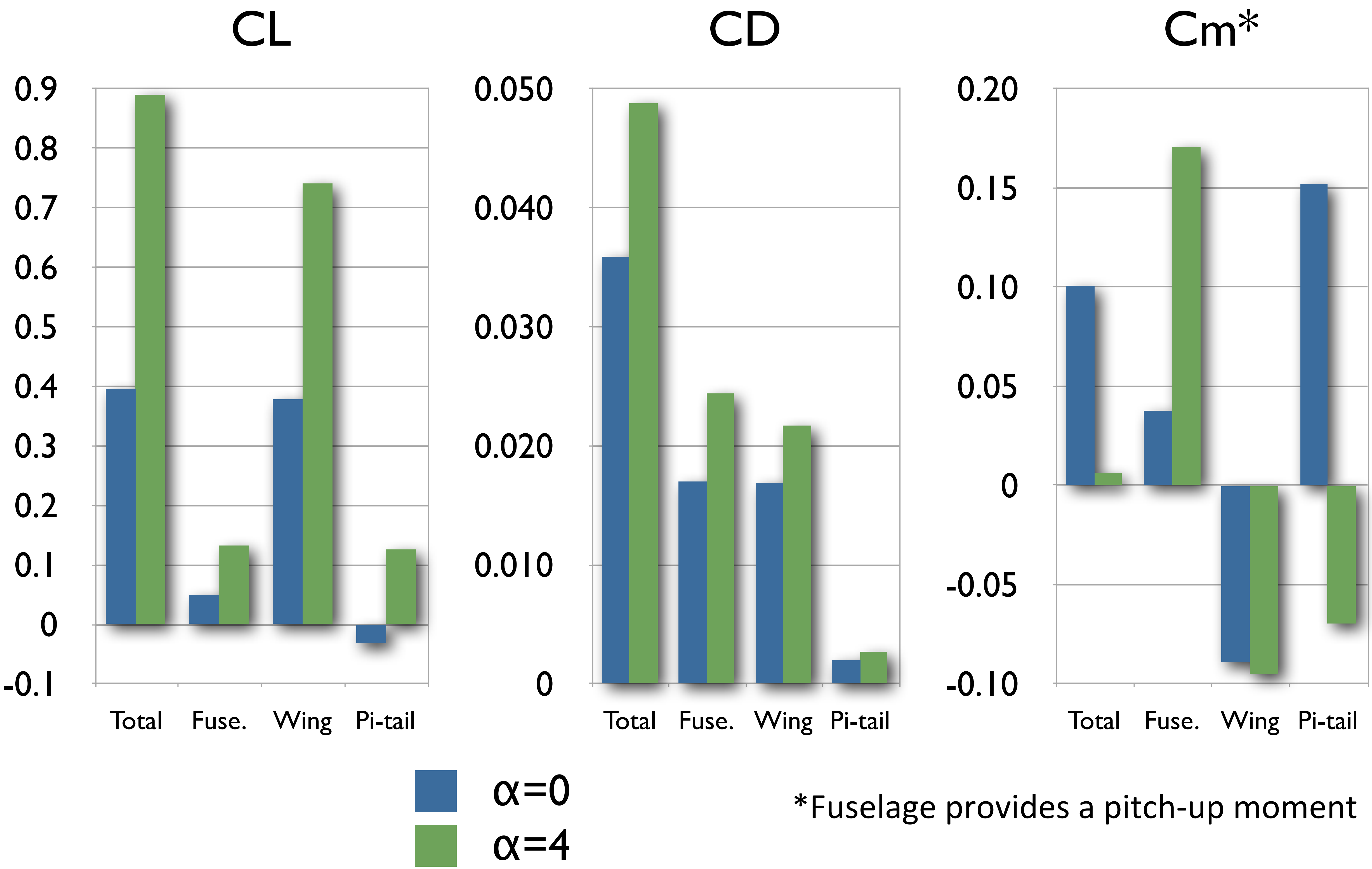


Span-wise Loading



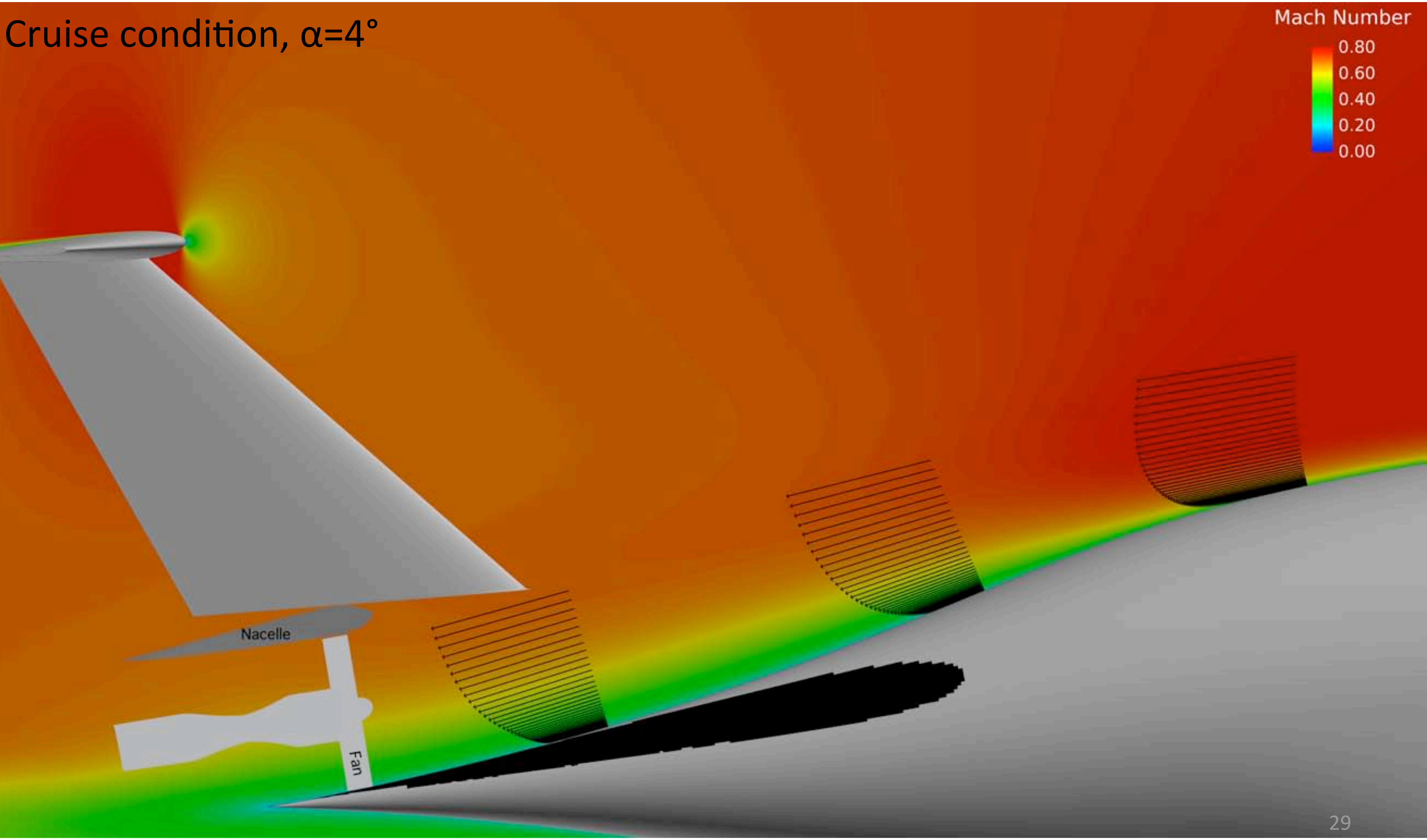
Fuselage provides span loading
Pi-tail has minimum negative loading

Component-wise Break-down



*Fuselage provides a pitch-up moment

Boundary Layer Ingestion



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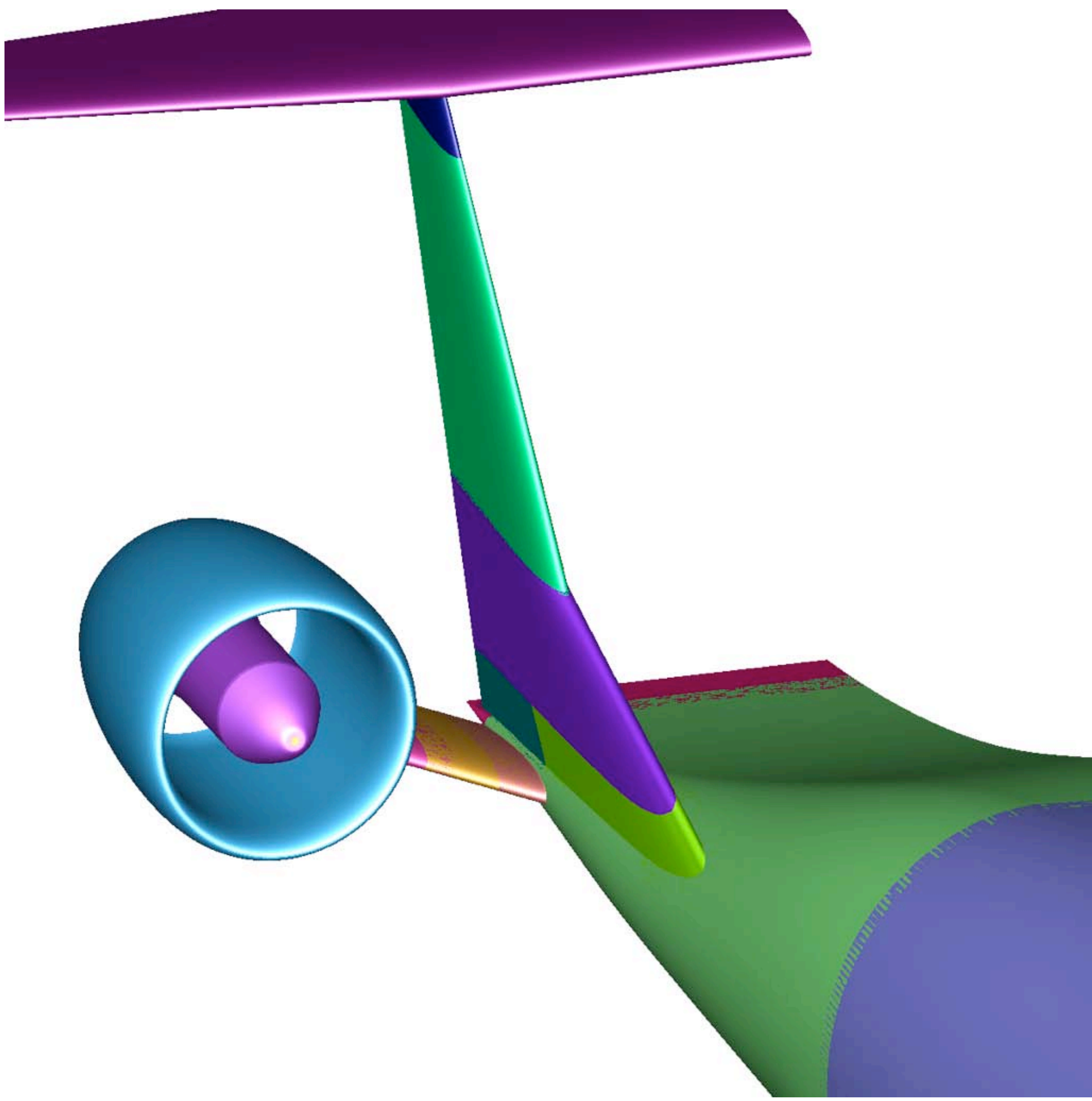
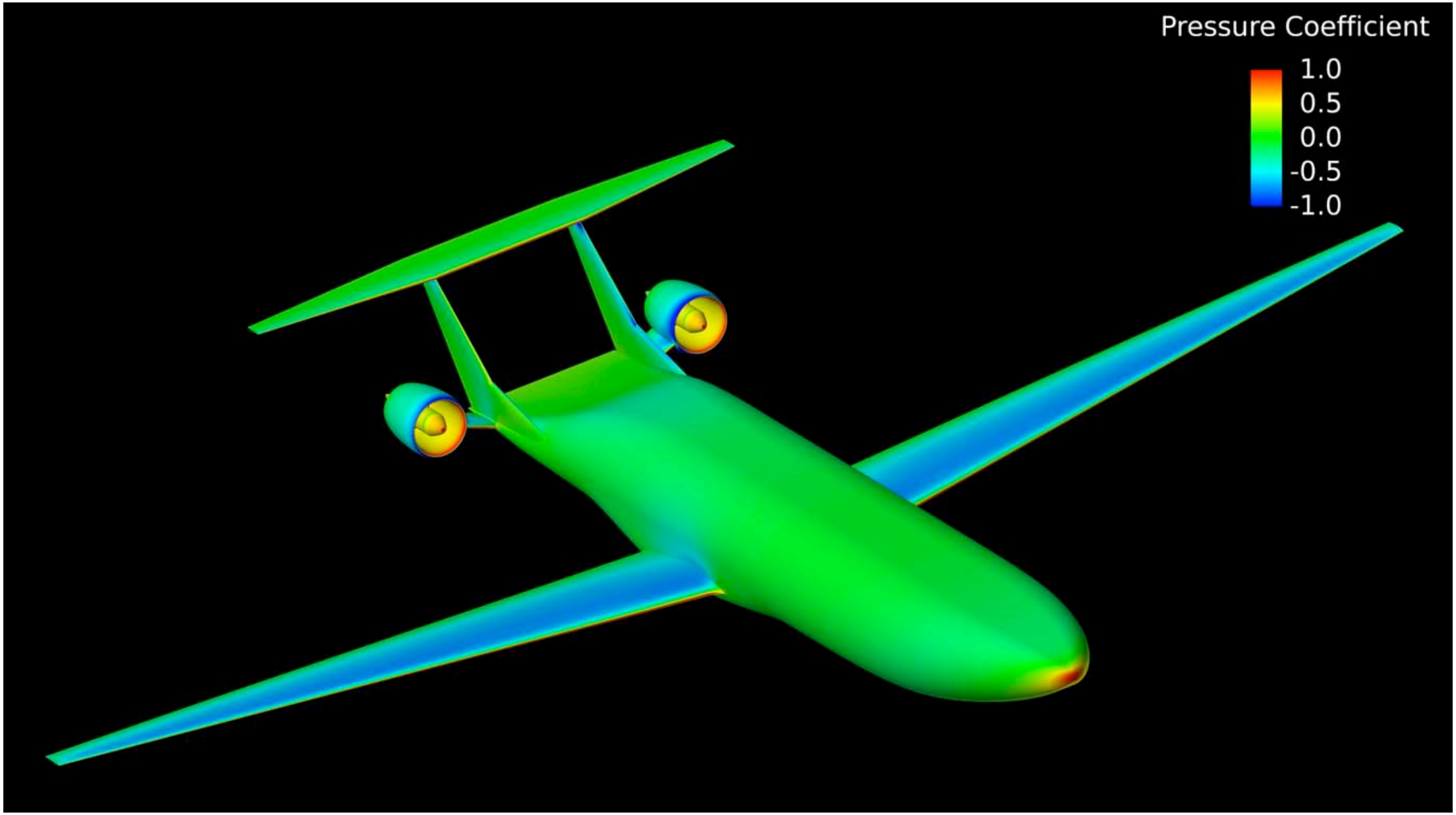
Podded Nacelle

- In free-stream
  - Under-wing
  - Between π-tail
  - Side-mount
- Nacelle/Hub/Pylon
  - 7 additional grids
    - One for each component
    - Two collar grids
      - Fuselage/pylon, nacelle/pylon
    - Two caps for the hub
      - nose, base

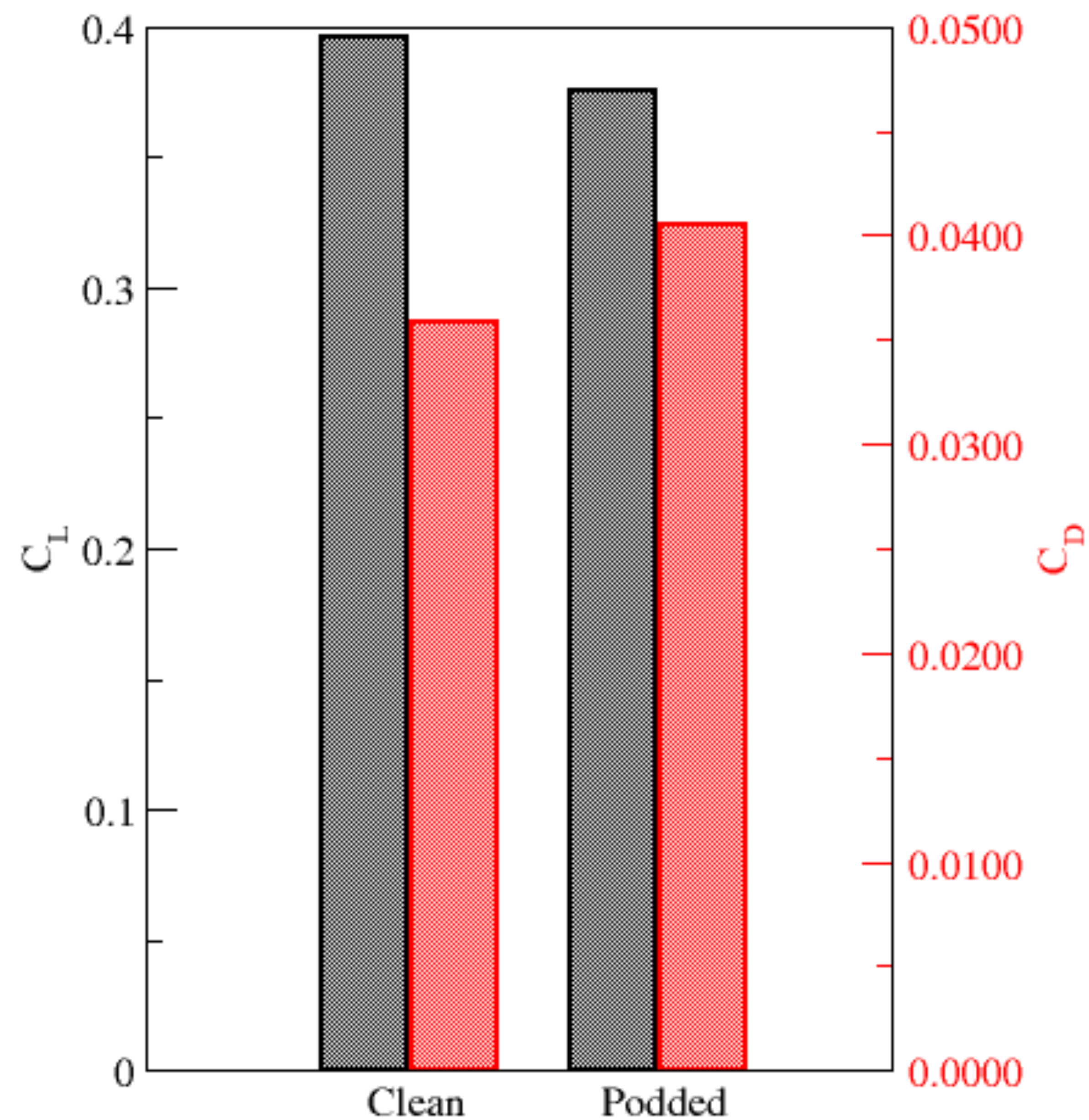


Podded Nacelle



Podded Nacelle

- Flow-through nacelle
- CL, CD increments w/rt clean configuration
  - –Lower CL
  - –Higher CD
- Compare w/ embedded
- Engine model



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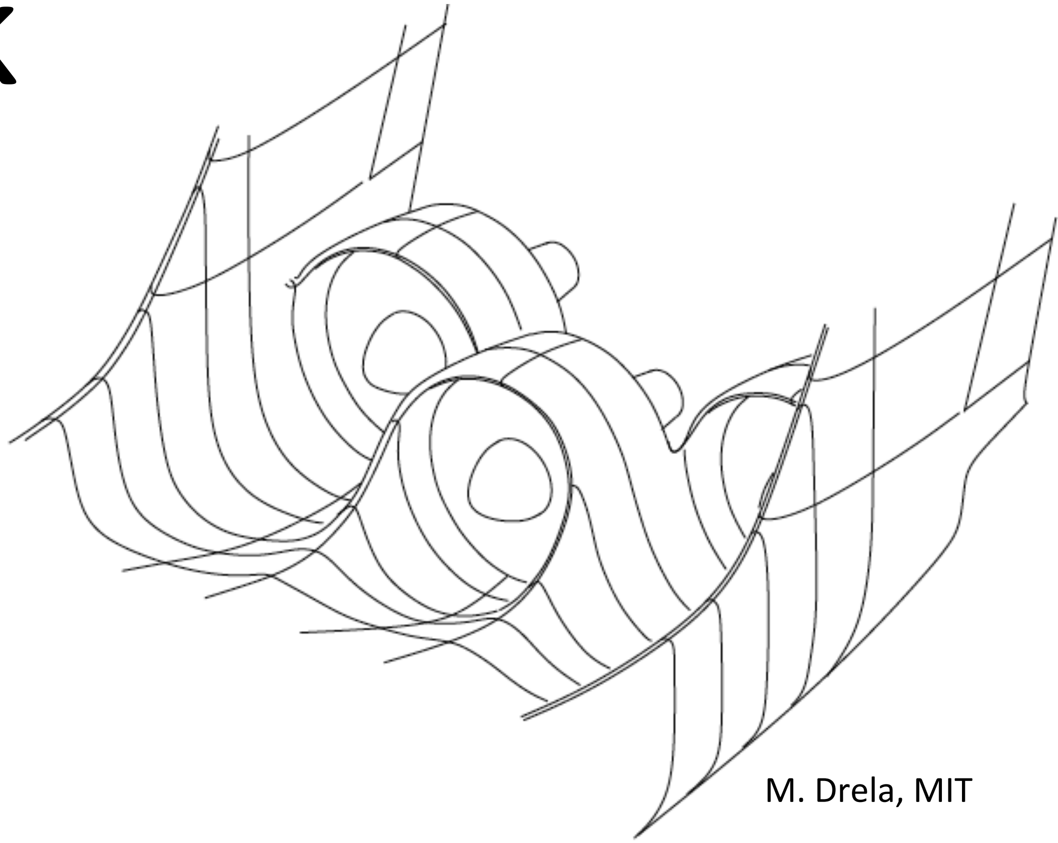
Conclusions

- CFD predictions validate basic ideas behind D8
  - –Fuselage carries ~15% of the lift at cruise
  - –Fuselage provides a positive pitching moment at cruise
  - –Rear of the fuselage acts as diffuser
- CL, CD compare well to the experiment
  - –Better agreement with SST
- Podded: Results in increased drag, reduced lift as expected

Future Work

- Placement of Podded Nacelles
- Blended Nacelles
  - –Original configuration
    - Three-engine
  - –Present concept
    - Two-engine
  - –Geometry, mesh, CL, CD increments
    - CGT
    - Blender Sub-D surfaces for C-2 continuity?
- Fan model (pressure disk, rotating blades?)



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