Aerodynamic Shape Optimization in the Conceptual and Preliminary Design Stages

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Quarterly Review
Ohio University
June 19, 2003

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Outline

- Aerodynamic Shape Optimization
- Present examples of use of design codes
  - Subsonic General Aviation Plane
  - Supersonic Business Jet
- Summary
- Work Plan

Motivation for Automatic Design

- Aerodynamic development typically “cut&try”
  - Slow (design time doing detailed design iterations)
  - Expensive
  - Relies on physical insight of designer for changes
- Automatic design to reduce time spent in detail design phase
  - Improved performance
  - Decreased costs

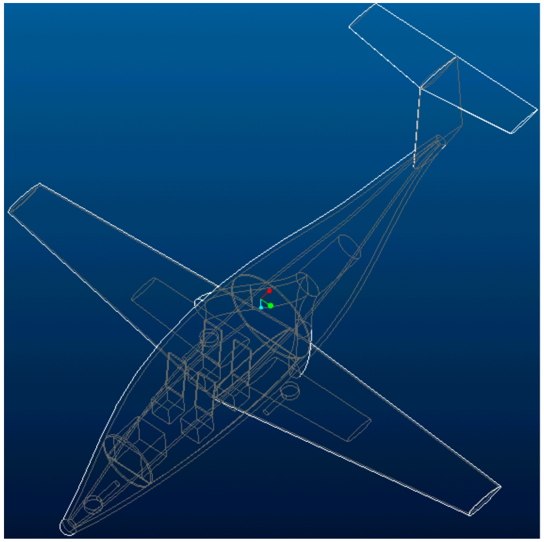
Aerodynamic Shape Optimization

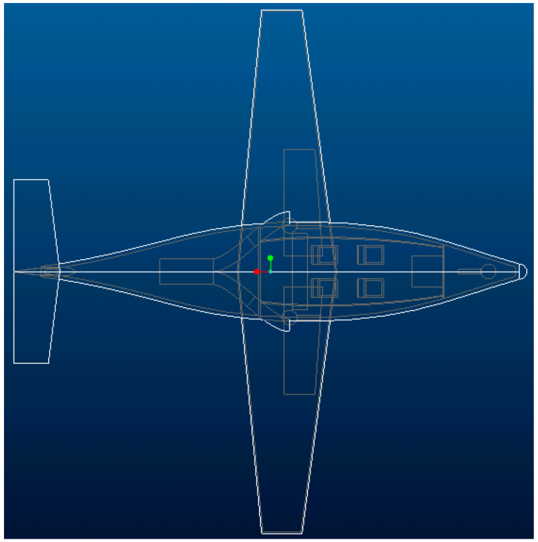
- Large number of design variables necessary for complete aircraft
- Control theory - gradient requires only the solution of an adjoint system
- Gradient calculation independent of the number of design variables

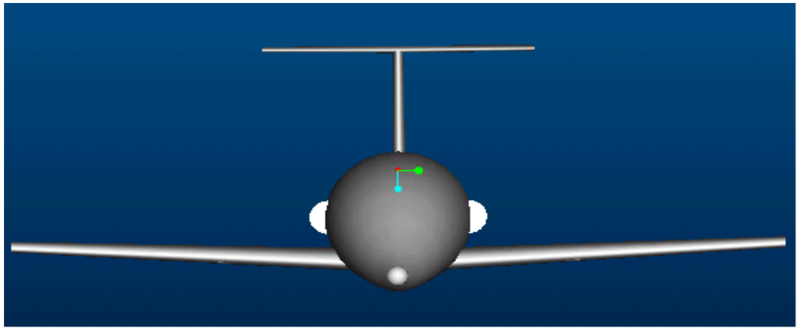
General Aviation Design Specifications

- Cruising Speed: Mach 0.5, 25,000 ft
- Range > 1000 nautical miles
- Takeoff Field Length < 2000 ft
- Stall Speed < 60 knots (sea level)
- Climb Rate > 2500 ft/min
- 4 Passengers + Luggage : 1050 pounds

Pro/E Layout







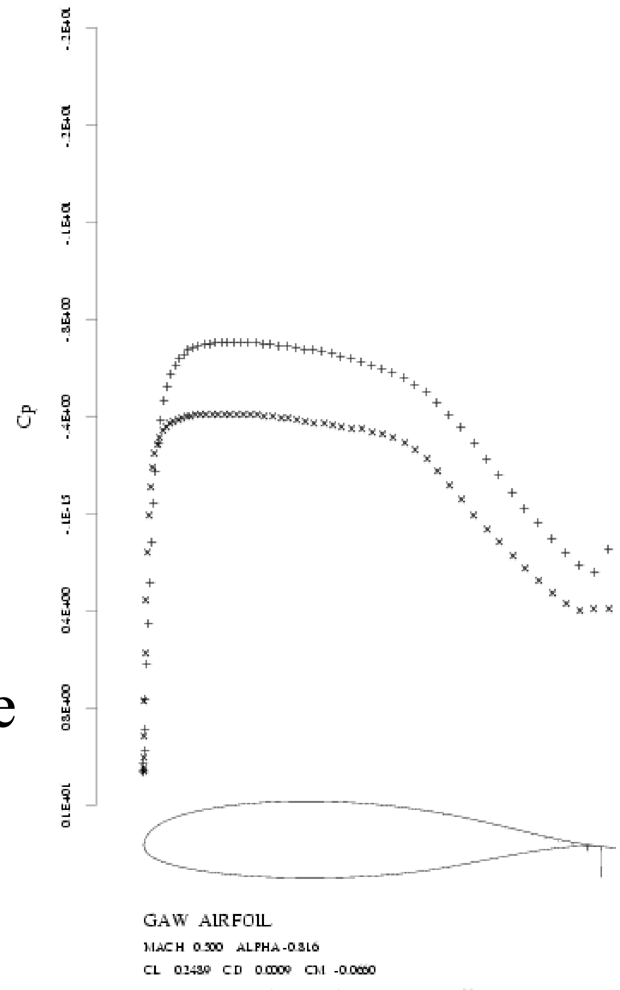
Reference: Neil McCann

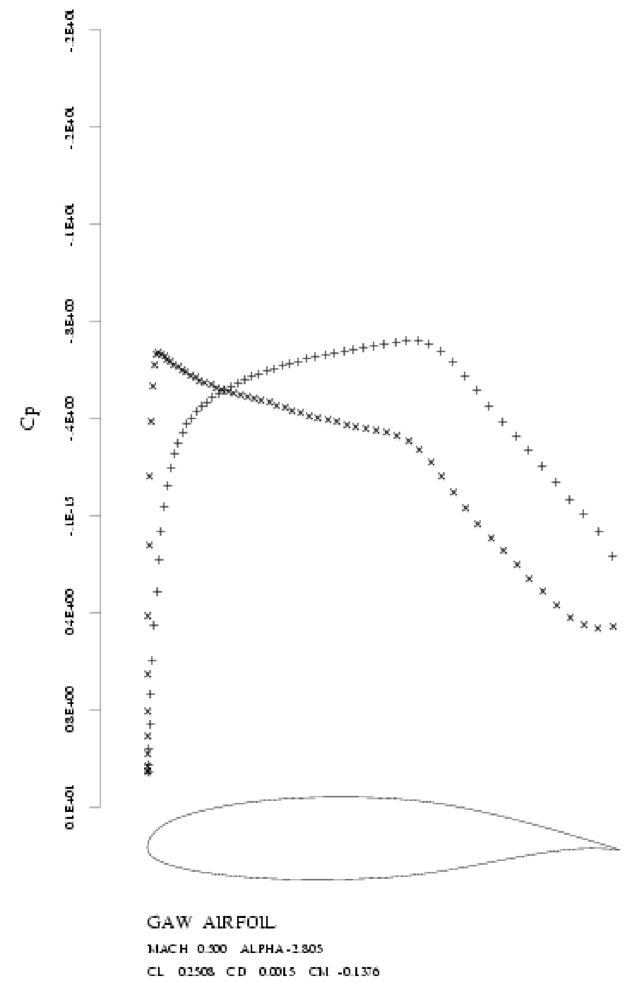
Aerodynamic Design Procedure

- 2D Section Design (SYN83)
  - Inviscid, automatic structured mesh
- 3D Clean Wing (SYN88)
  - Inviscid, automatic structured mesh
- 3D Wing/Body (SYN88)
- 3D Full Configuration (FLOPLANE)
  - Inviscid, unstructured mesh

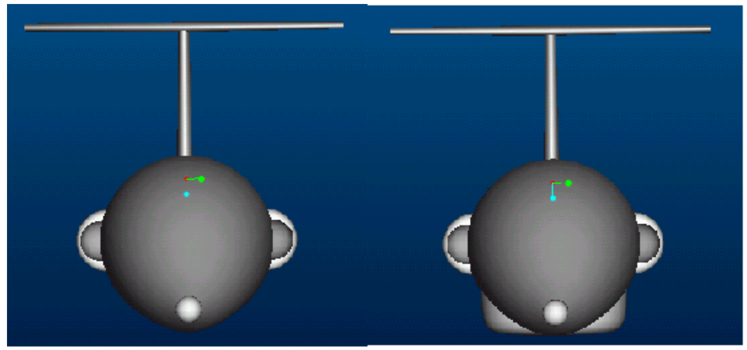
2D Section Results

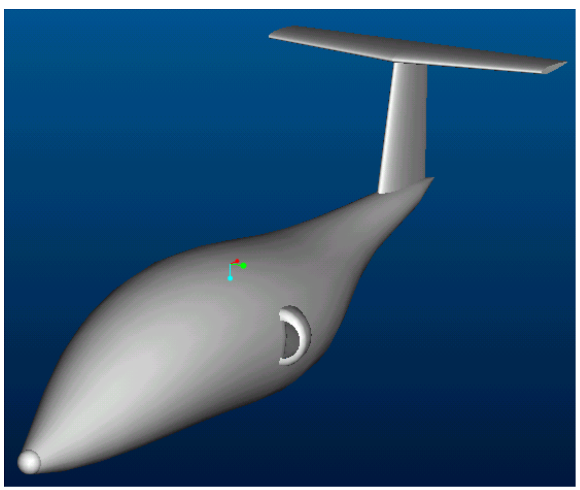
- Started with a GAW airfoil
- 40 design cycles
- Drag reduced from 15 counts to 9 counts
- <1 hour wall time

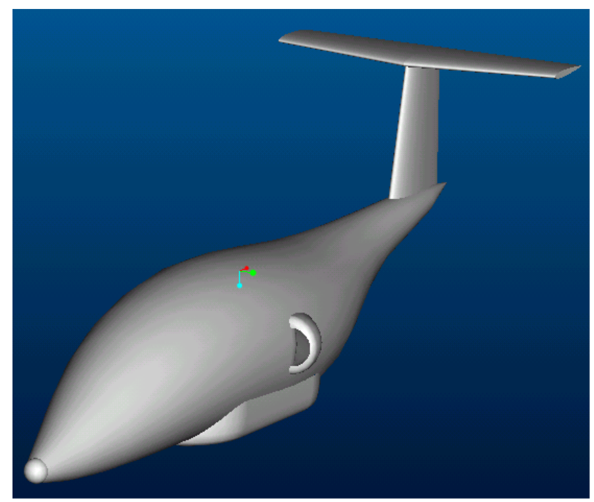




Fuselage Modification







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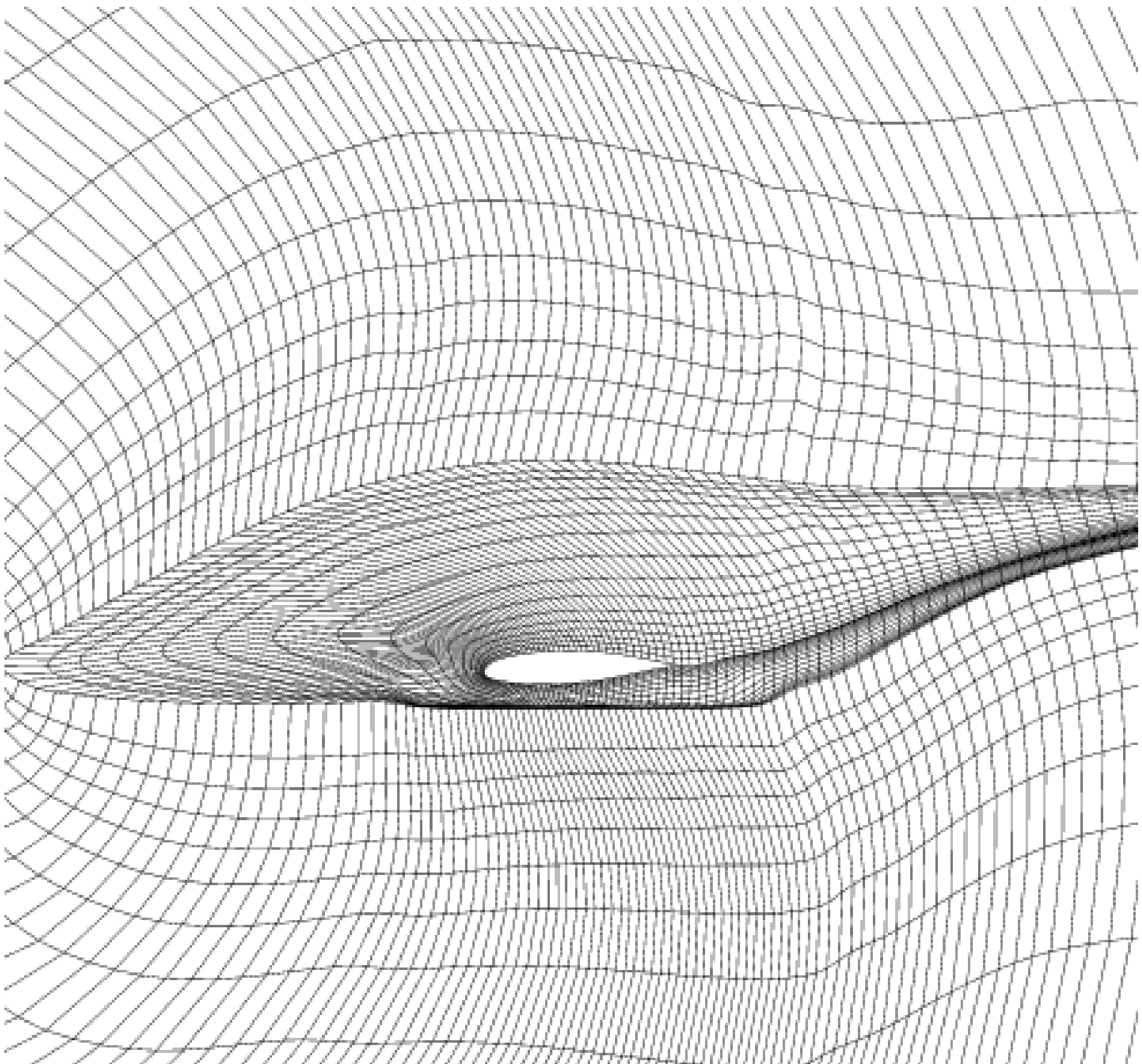
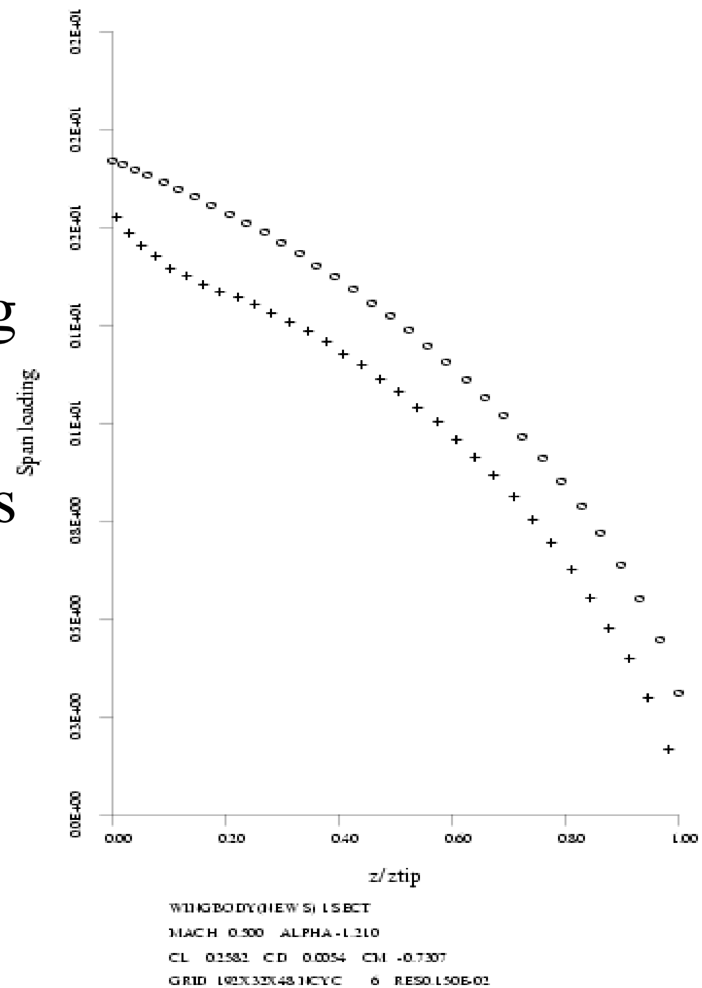
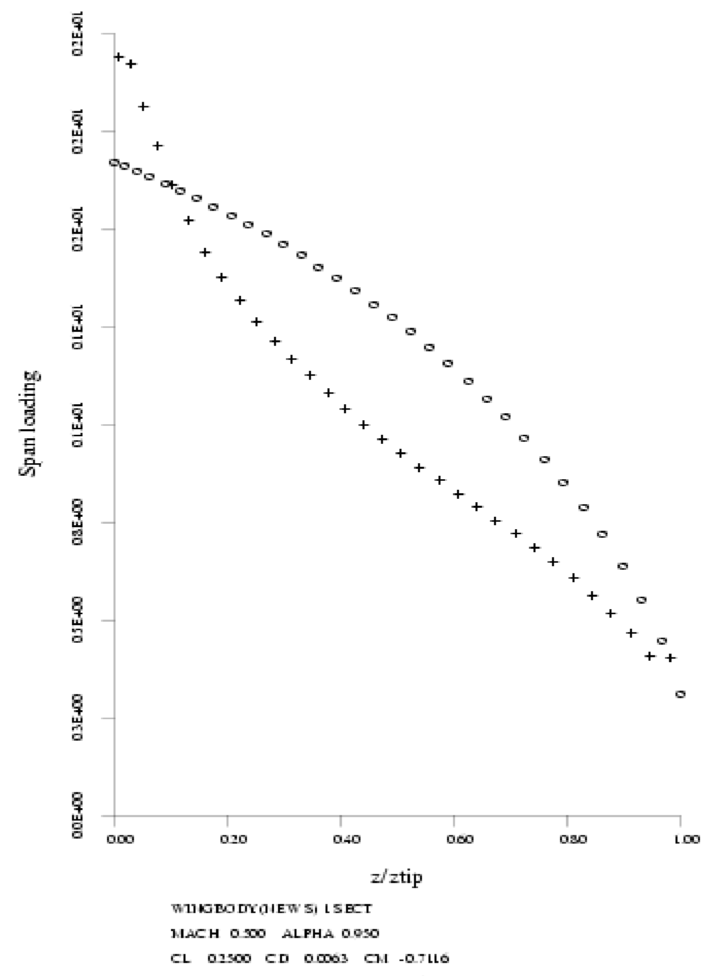
3D Wing/Body Mesh



3D Wing/Body Results

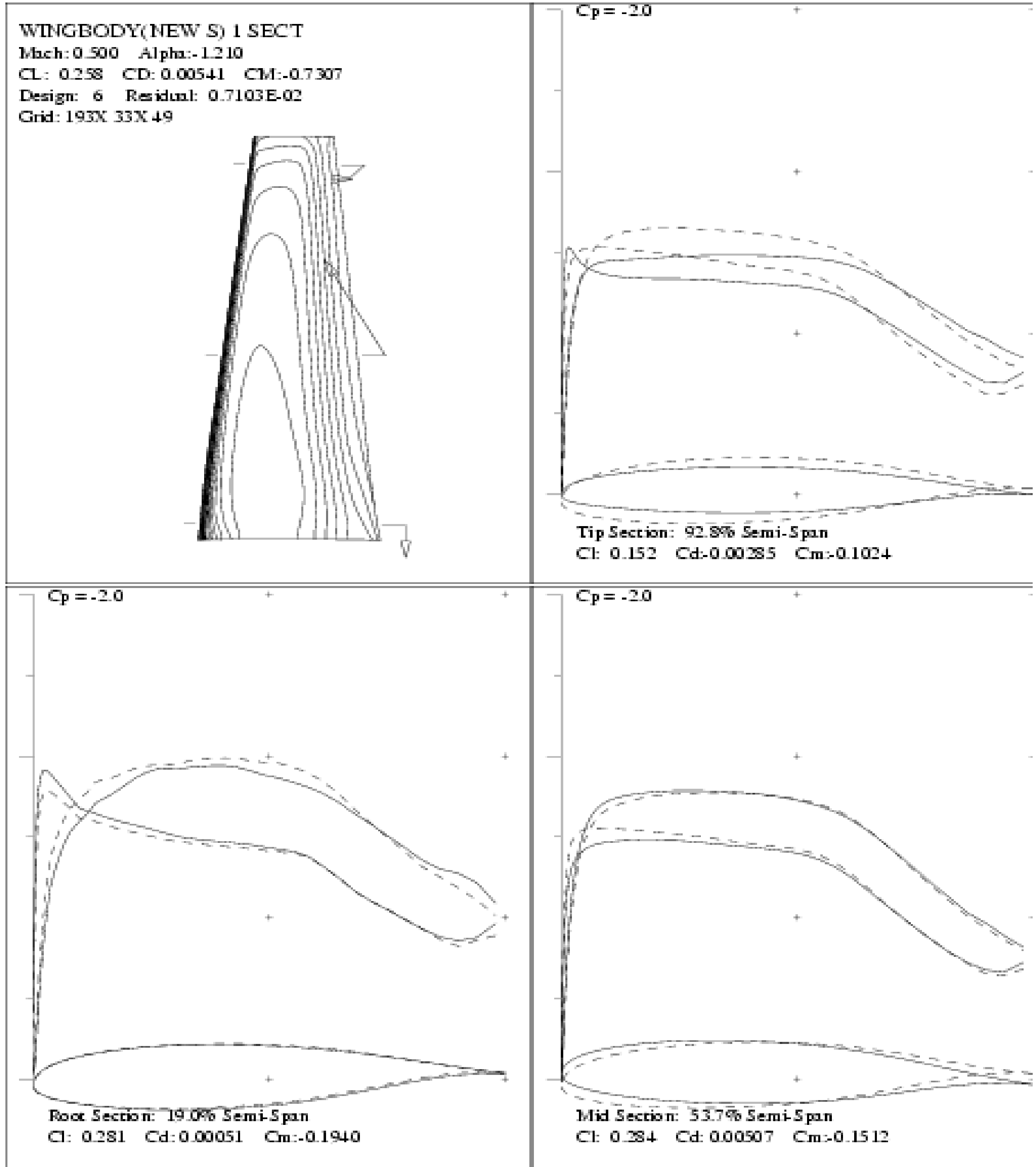
- •6 design cycles
- •Span loading corrected
- •Drag savings of 9 counts (54 total)
- •6 hour wall time





Planform & Sectional View of Wing/Body Design

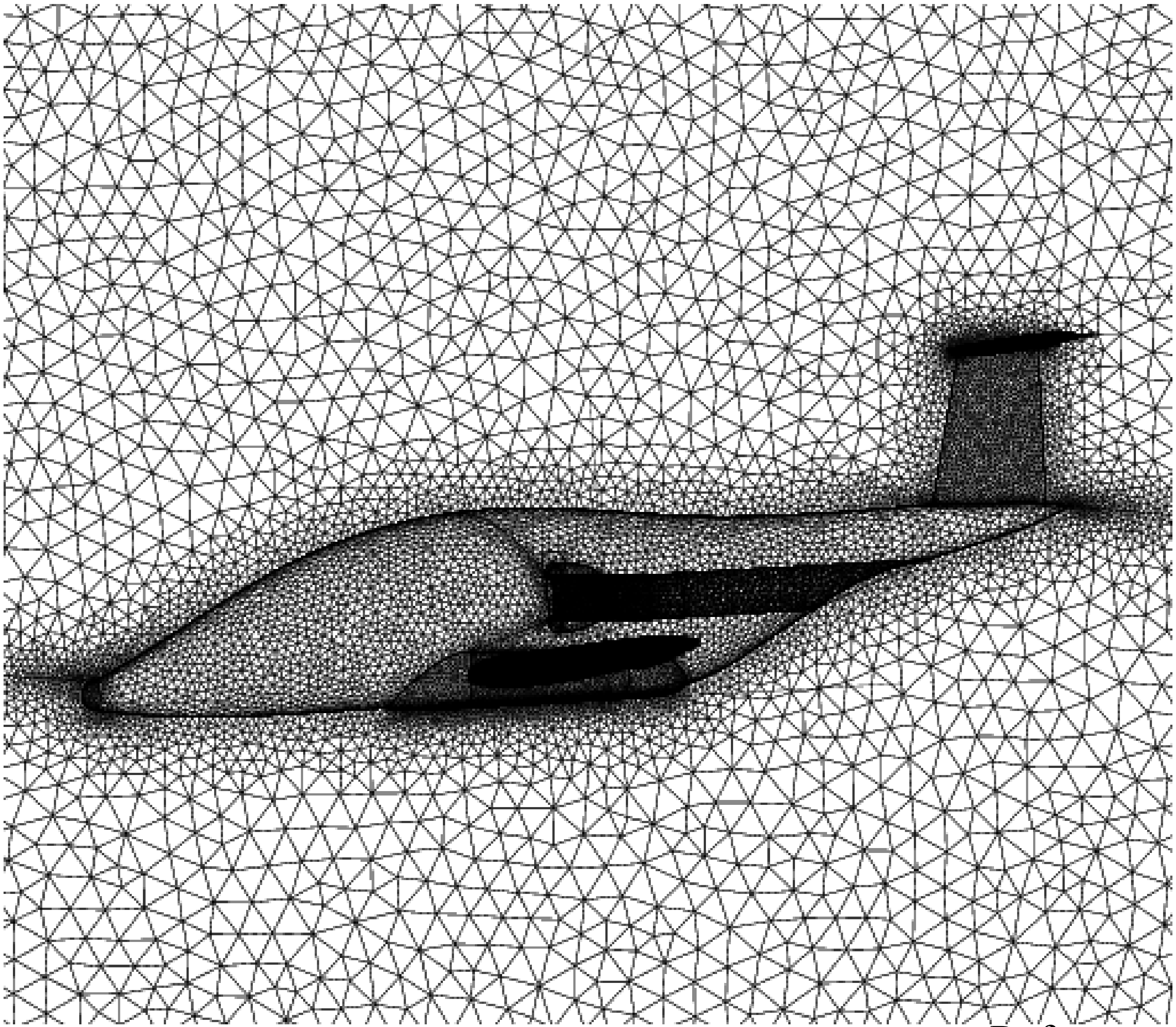
- 6 design cycles
- Tip sections thinned
- Root thickened



Full Configuration Analysis

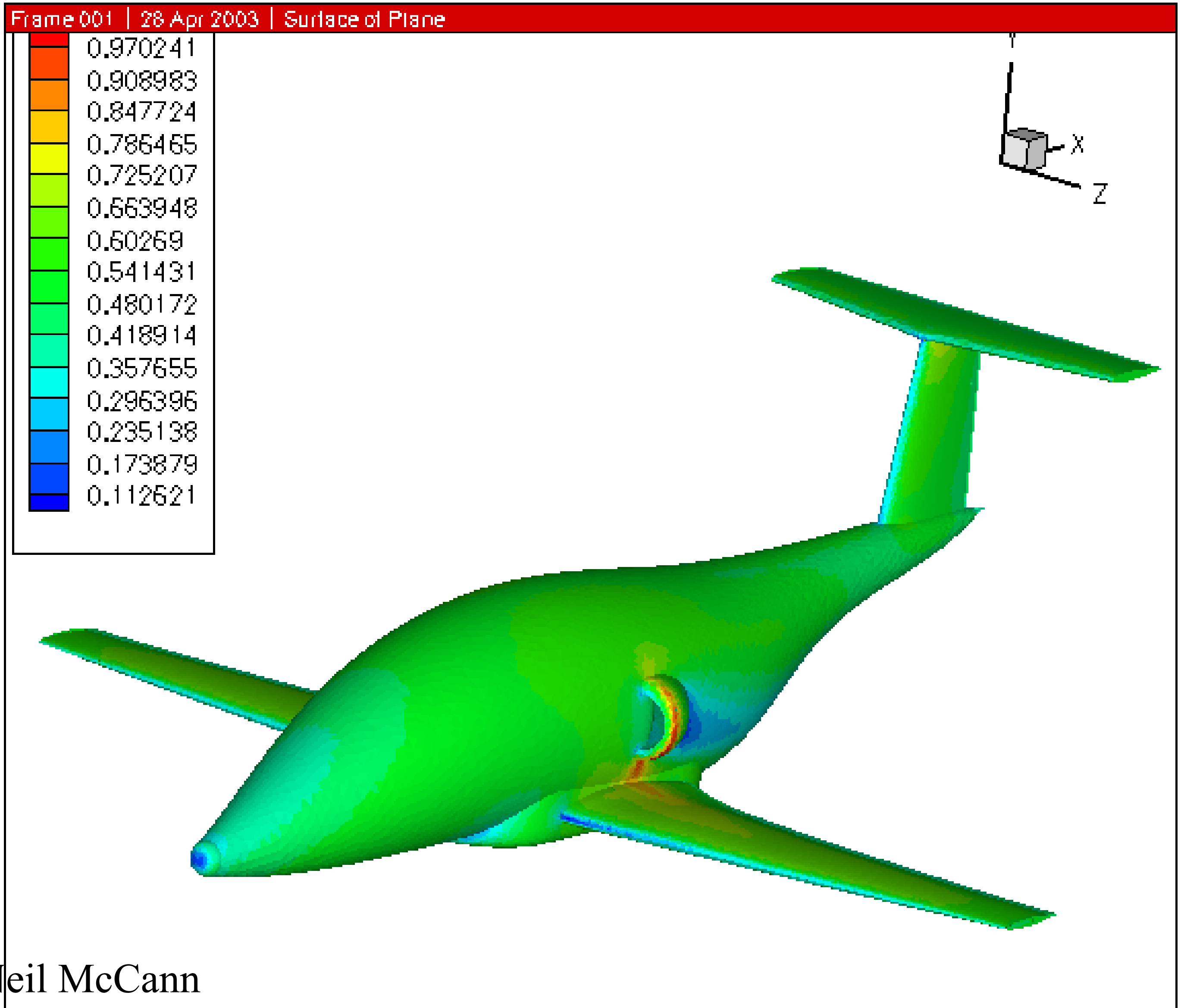
- FLOPLANE
  - Inviscid
  - Unstructured tetrahedral mesh
- Surface mesh created with Gridgen
- Volume mesh created with MESH3D
- Simulated flight at M = 0.5, 25,000 ft
- Half configuration
- 2.5 Hour wall time

Unstructured Surface Mesh



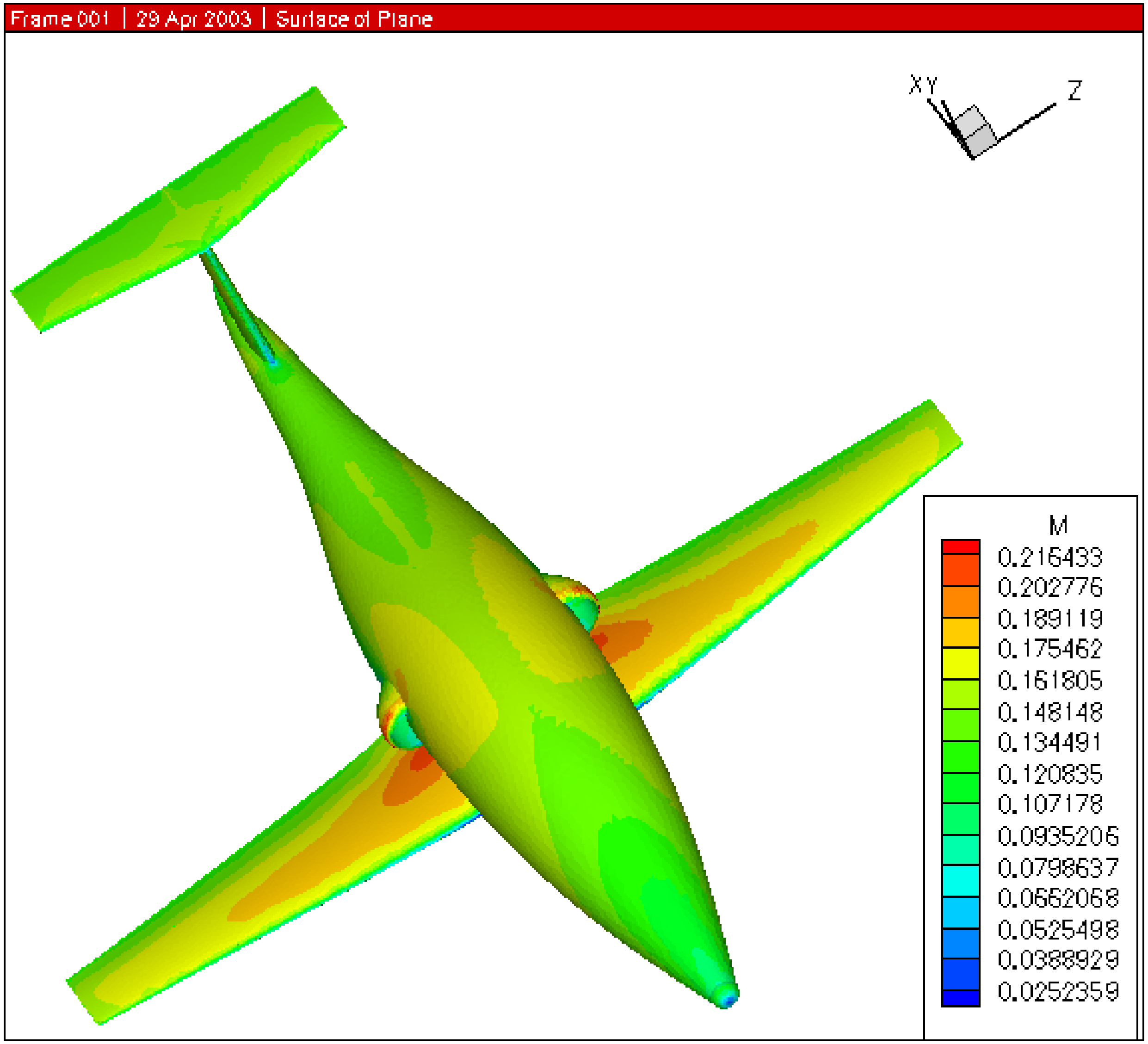
Reference: Neil McCann

Mach Contours, Cruise (M=0.5, aoa = 0 deg.)



Reference: Neil McCann

Mach Contours, s.l. (M=0.15, aoa = 0 deg.)



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Design Issues

- Drag prediction discrepancy
  - SYN88: 54 counts
  - FLOPLANE: 1080 counts
- Aerodynamic lessons
  - Significant lift from cambered fuselage
  - Wing/body interaction is highly important
- Geometry definition & meshing is bottleneck

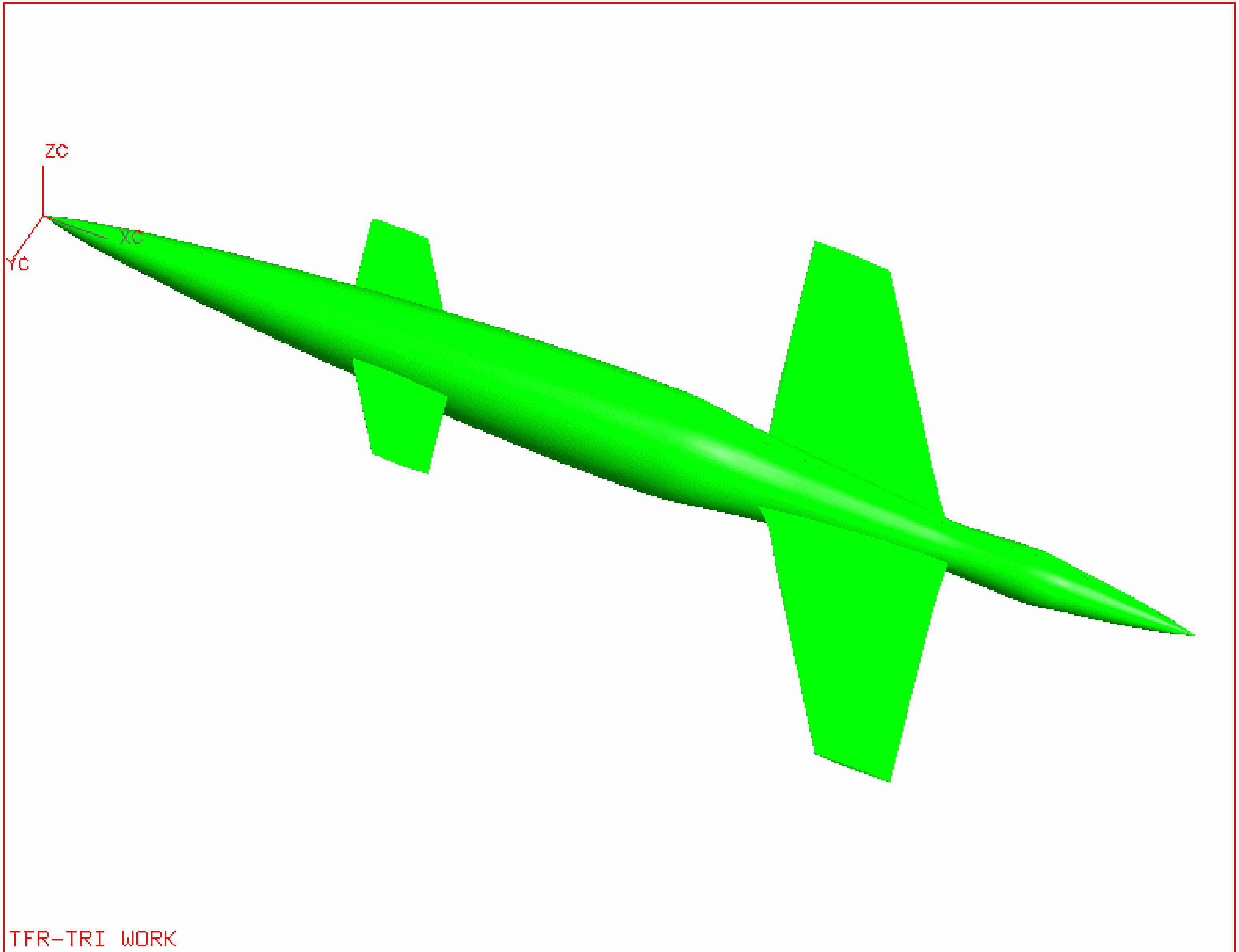
Quiet Supersonic Platform Design Objective

- Supersonic business jet
  - 20 passengers
  - Cruise speed: Mach 2.4
  - Cruise altitude: 60,000 ft
  - Range: 6,500 nautical miles
  - Maximum weight: 100,000 pounds

Conceptual Design Layout

- Symmetrical tapered wing canard configuration
  - Laminar boundary layer
    - Supersonic leading edge
    - Small root chord
    - Minimal cross-flow effects
      - Sweep
      - Twist

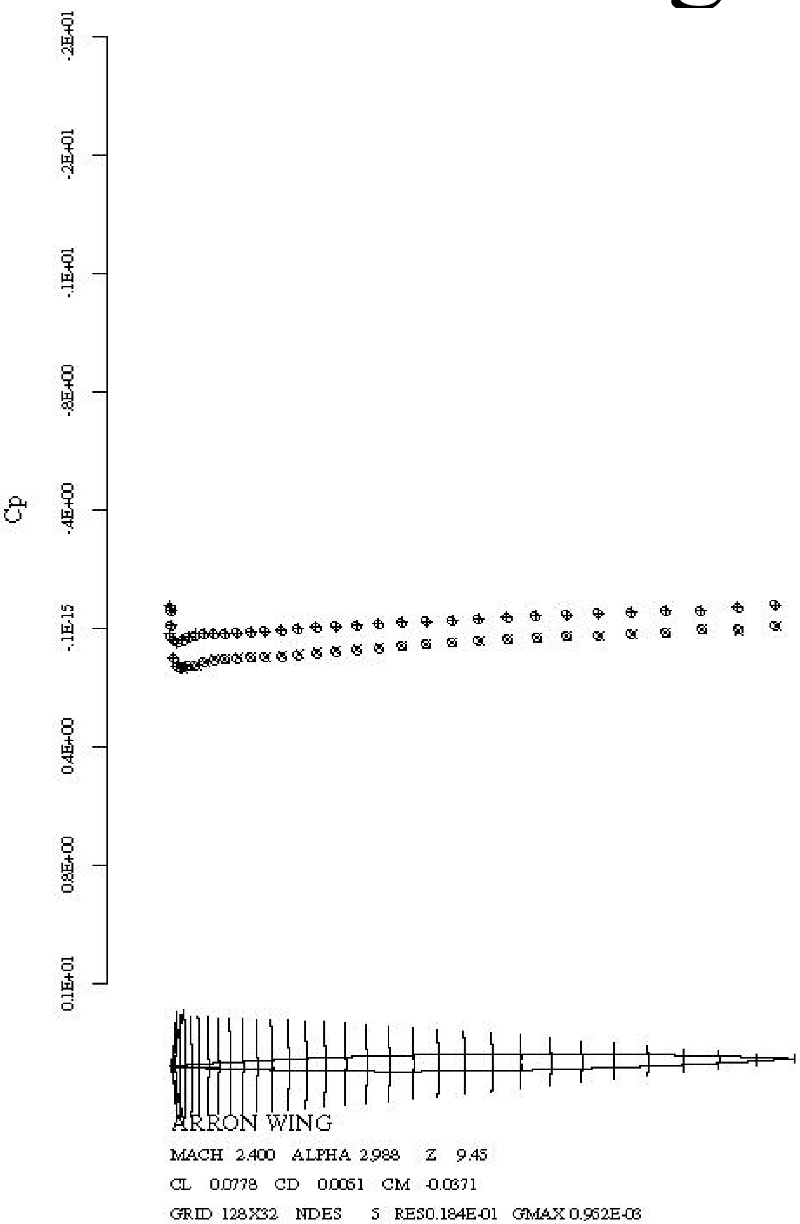
Pro/E QSP Wing/Body Model



QSP Main Wing Design

- Initial analysis: wing alone at cruise
- 3 planforms considered
  - Similar performance at cruise
  - Differences for transonic flight
    - Long span with constant 10° taper

Wing/Body Optimization



- 5 design cycles, single-point
- Mild pressure gradient
- Shape optimization thins wing

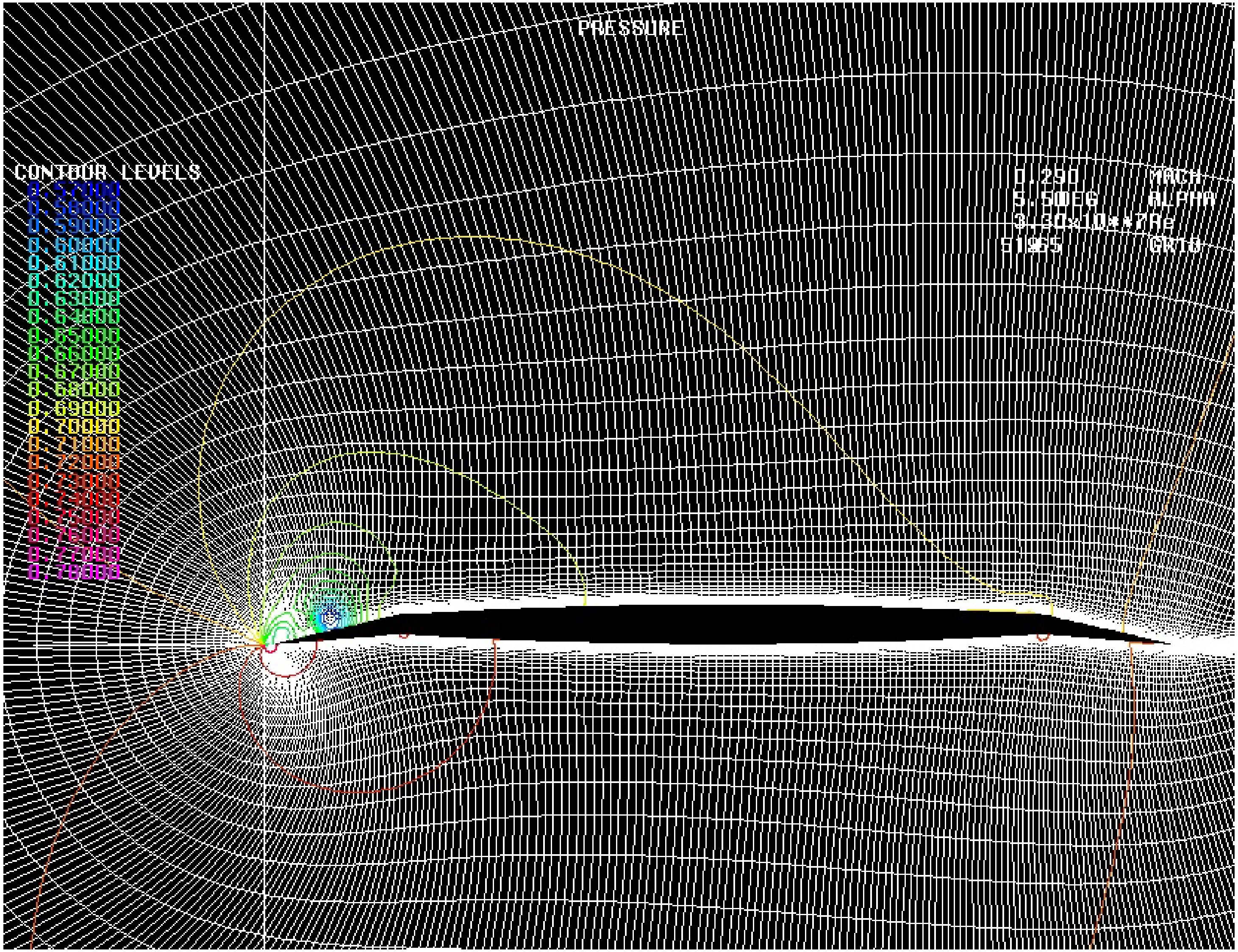
Aerodynamic Performance Estimates

	Cruise	M=0.9, 30,000 ft	M=0.5, 20,000 ft
Wing/Body CL	0.0943	0.1735	0.3633
Wing/Body Cdform	0.007	0.0028	0.0205
Wing/Body AOA	2.95	1.69	4.5
Total L/D	7.44	17.32	13.57

Weight = 350,000 N

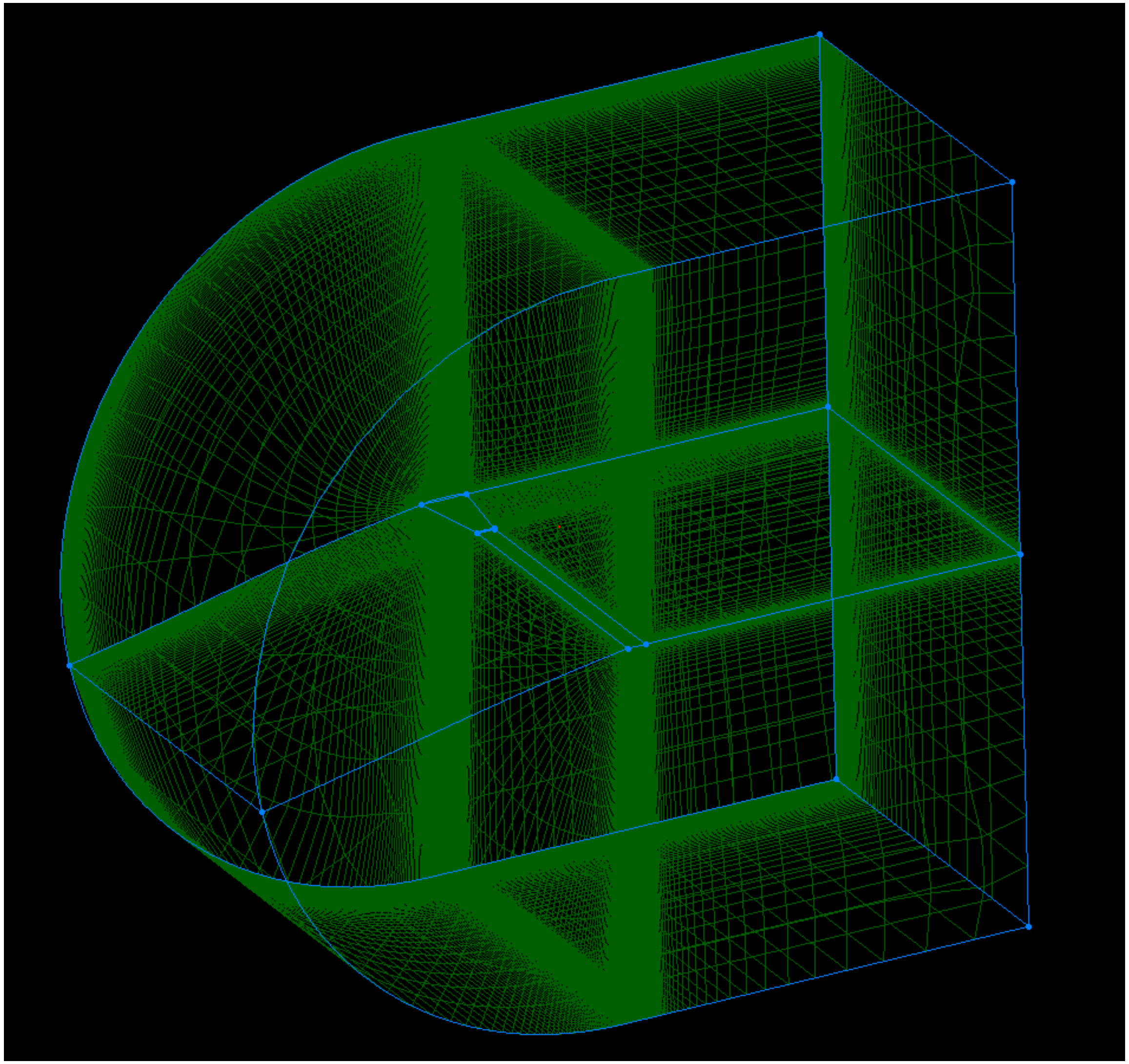
(Viscous drag calculated with flat plate boundary layer)

High-Lift 2D Section



High-Lift Wing

Gridgen C-mesh for SYN88



Concluding Remarks

- Useful design tool
  - allows more time for creativity
- Useful teaching tool
  - wing/body interaction
  - multipoint design demonstrates conflicting requirements of different modes of flight
- Need for fast and efficient mesh generation

  ↑Unstructured Meshes