The NASA CST-ASE Project: Status Review

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NASA ASE Summit
NASA Ames Research Center
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Outline

- Introduction to NASA's High Speed ASE Project
- Lockheed-Martin N+2 Configuration
- Definition and Status of Tasks
  - Finite Element Model (FEM) Updates, Parametric Studies
  - Normal Modes Analysis
  - Steady CFD-Based Results
  - Linear Aeroelastic Analyses
  - CFD-Based Static Aeroelastic and Sonic Boom Results
  - ROM Results
- Concluding Remarks

Introduction: NASA High Speed Project

Develop and Validate Tools, Technologies and Concepts to Overcome the Barriers to Practical High Speed Vehicles

Project Focus FY 13-17

Development of tools and integrated concepts that will enable demonstration of overland supersonic flight with acceptable sonic boom

Renamed: Commercial Supersonic Transports (CST)

Scope

- Civil Supersonic Aircraft: business class to supersonic airliners

Introduction: CST ASE Project

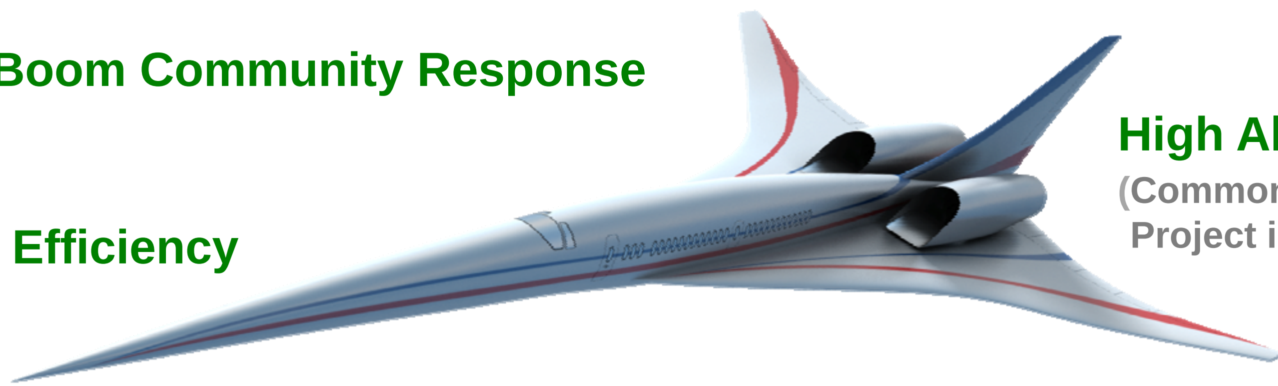
CST Project Builds on the Success of Supersonics

Research Themes Focus on Low Boom Flight Demonstration Readiness

Integrated Design Solutions

Airport Community Noise

Sonic Boom Community Response



High Altitude Emissions

(Common content moved to AS Project in FY13)

Cruise Efficiency

Aeroservoelasticity (ASE)

Flight Systems

Scramjet Propulsion

(Moved from Hypersonics in FY 13)

CST – ASE Team

- LaRC
  - Pawel Chwalowski (FUN3D)
  - James Florance (FEM, APSE)
  - Christie Funk (Gust Loads)
  - Mark Sanetrik (FUN3D)
  - Walt Silva (Tech Lead, FUN3D, CFD-ROM)
  - Carol Wieseman (ISAC)
  - David Christhilf, Contractor (APSE)
  - Jiyoung Hur, Contractor (CFL3D-ASE)
- GRC
  - George Kopasakis (APSE)
  - Joe Connolly (APSE)
  - David Friedlander (APSE)
  - Jonathan Seidel (APSE)
  - Jeff Chin (APSE)
  - Noulie Theofylaktos (APSE)
  - Xiao Yen-Wang (APSE)
- AFRC
  - Chan-Gi Pak (MDAO)
  - Paul Yoo (CFL3D)

Lockheed-Martin N+2 Configuration

Length: 244 ft.
Span: 83 ft. 10 in.
Weight: 320,000 lbs (TOGW)
Cruise: M=1.7
Payload: 80 pax
Range: > 5000 nm

Definition of Tasks

- **CFD & ROM (LaRC, AFRC)**
  - Lockheed-Martin N+2 configuration Finite Element Model (FEM)
  - CFL3D, FUN3D grid development for N+2 configuration
  - AE analyses (linear, CFL3D, FUN3D)
    - Impact on Boom
    - Rigid-body (RB) modes
  - CFL3D, FUN3D Reduced Order Model (ROM) development
- **AeroPropulsoServoElasticity (LaRC, GRC)**
  - Dynamic engine modeling and control
  - APSE detailed model development
- **ASE & Active Controls (LaRC, AFRC)**
  - Linear ASE models
  - ASE optimization (MDAO)
  - ROM ASE models
  - Control law design & evaluation (CFL3D-ASE, FUN3D-ASE)

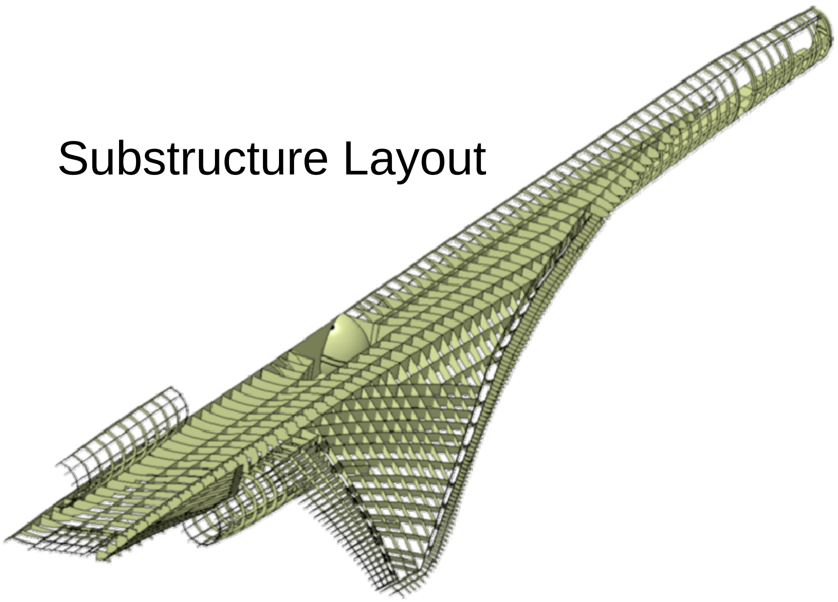
Definition of Tasks (cont'd)

- **Links to other Projects/Tasks**
  - Sonic Boom Prediction/Propagation
  - AE/ASE/MDAO (High Speed, Fixed Wing, Aerosciences)

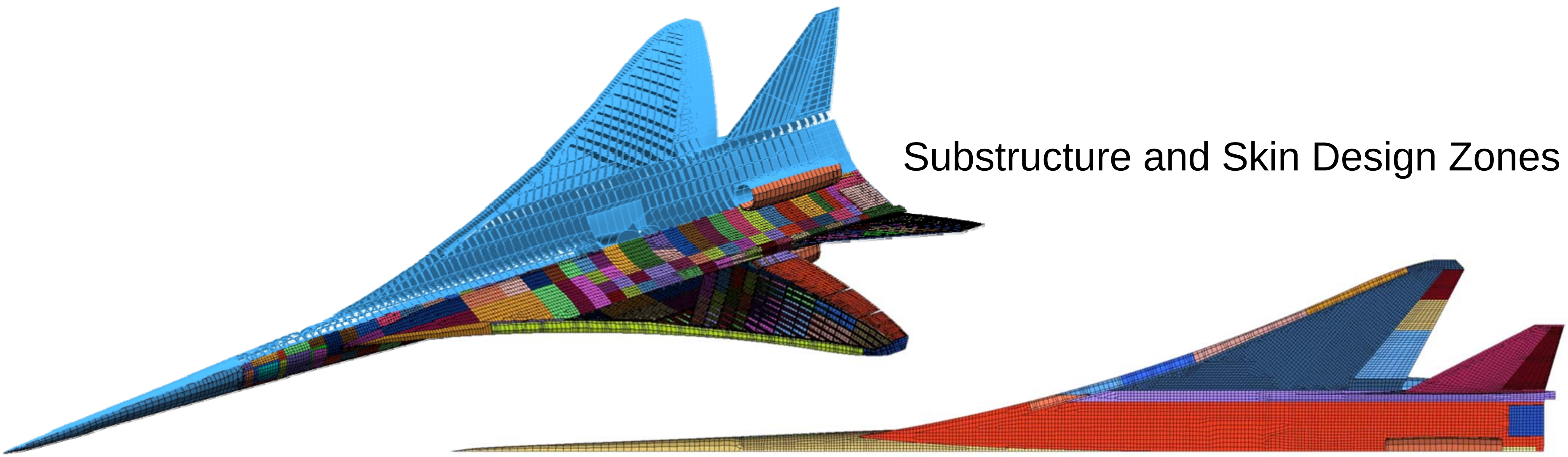
CFD & ROM:
LM Finite Element Model (FEM)
COMPLETED

Lockheed-Martin N+2 FEM Development

Substructure Layout



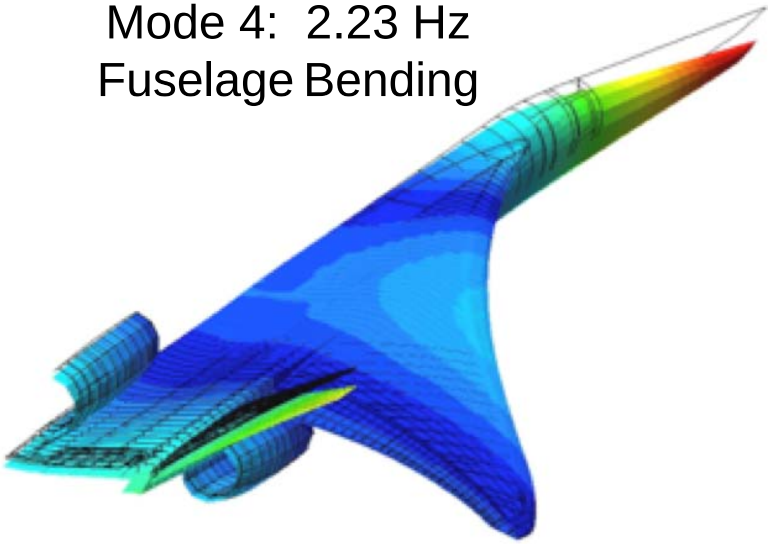
- Realistic global stiffness, mass distribution to enable AE analyses
- Optimized using multiple load cases (landing, maneuver, gust)
- Graphite/BMI unidirectional tape with honeycomb core
- 28,548 grid points



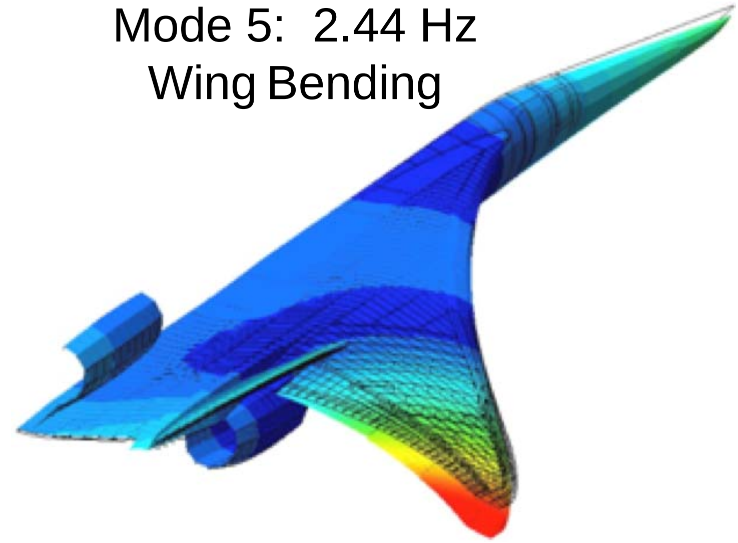
Substructure and Skin Design Zones

N+2 Structural FEM Flexible Modes for FEM017

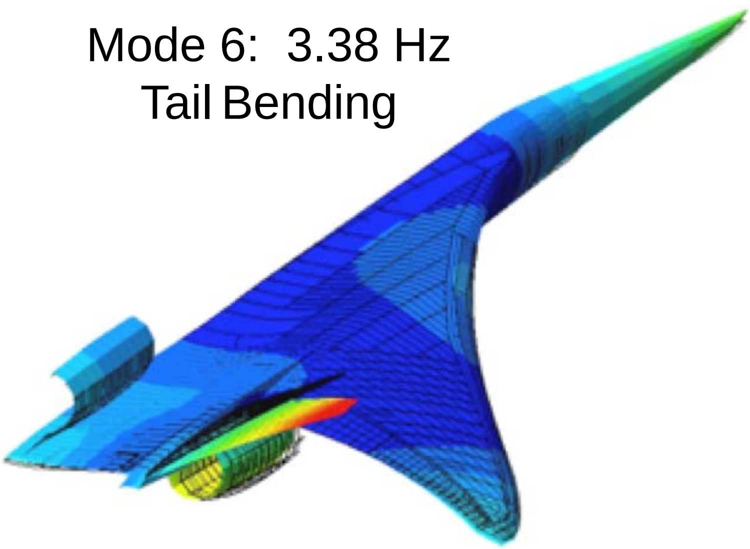
Mode 4: 2.23 Hz
Fuselage Bending



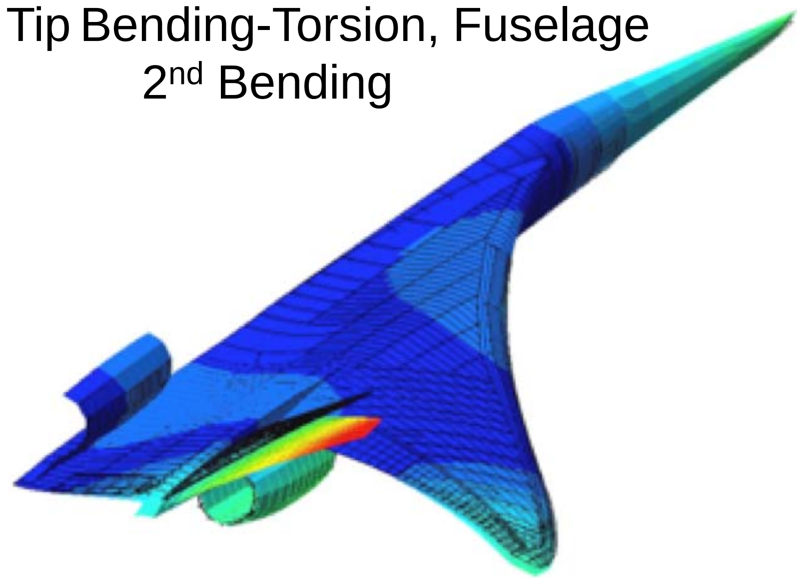
Mode 5: 2.44 Hz
Wing Bending



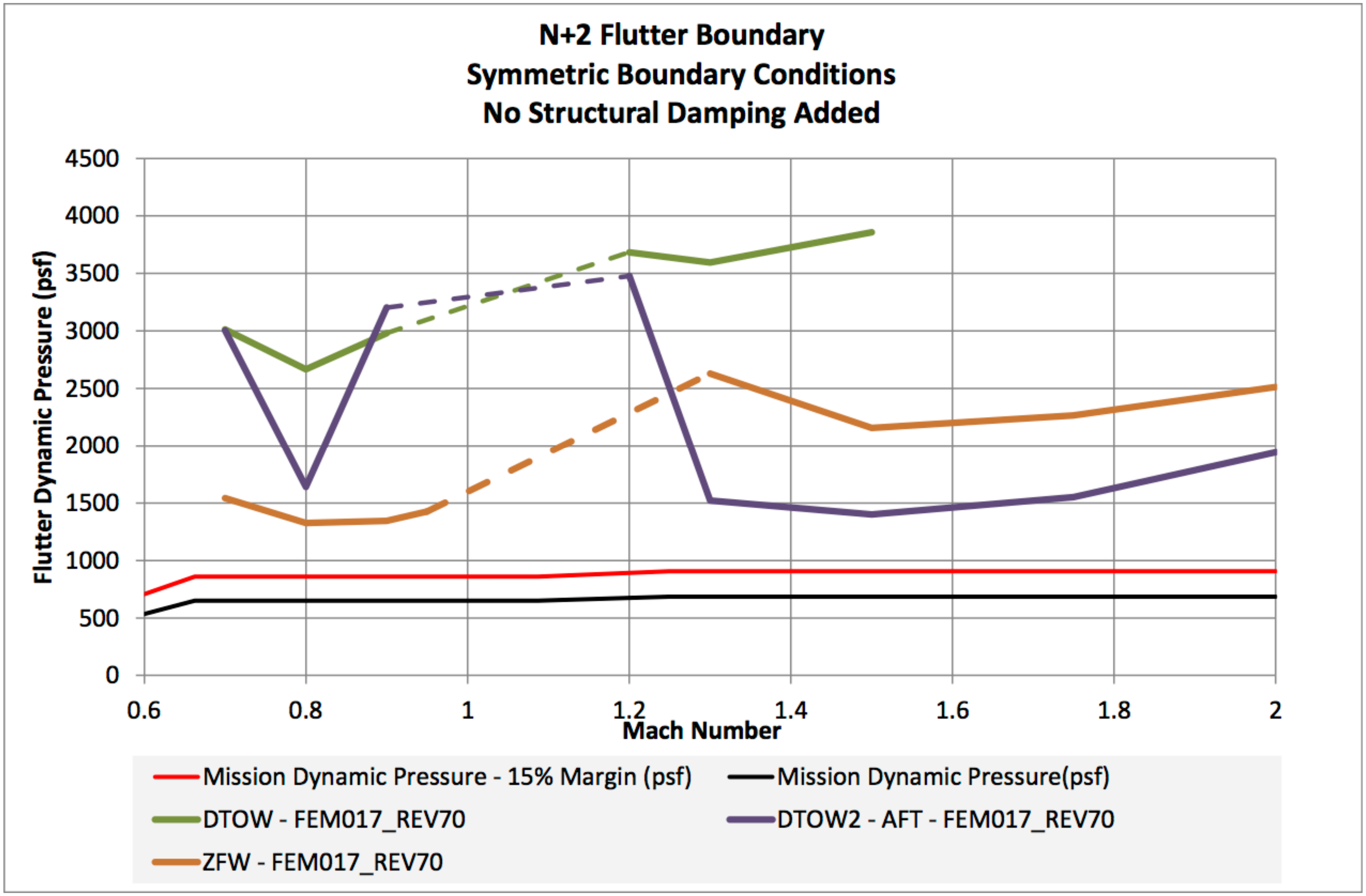
Mode 6: 3.38 Hz
Tail Bending



Mode 7: 3.67 Hz
Wing Tip Bending-Torsion, Fuselage
2nd Bending



Linear Flutter Analysis of FEM017 Model



Conclusions

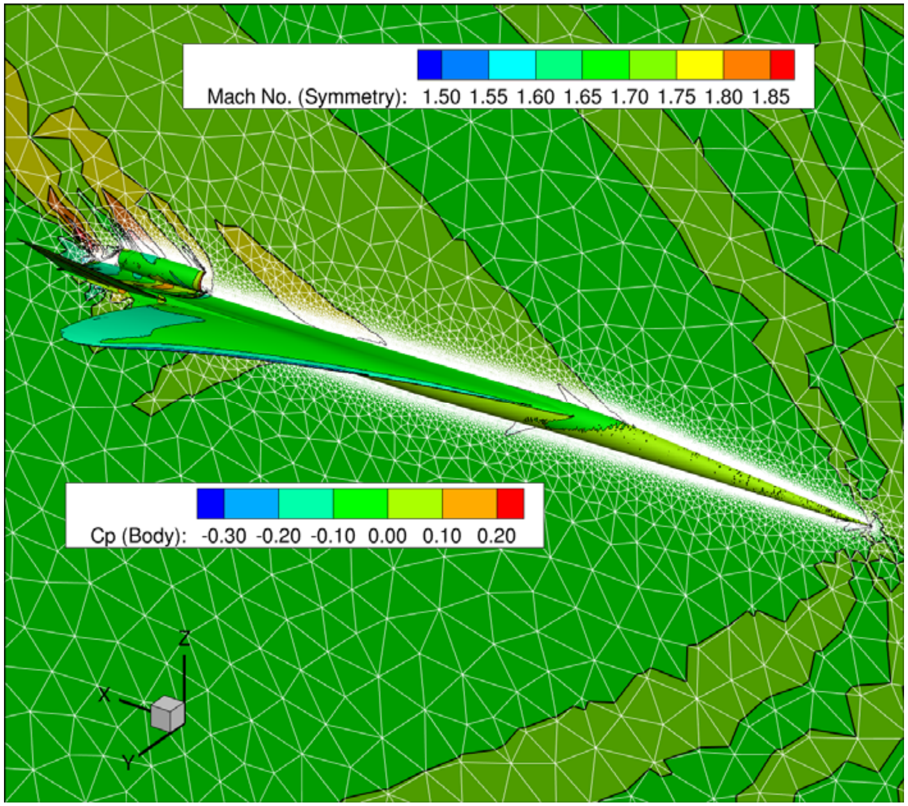
- Initial open-loop flutter analysis of N+2 configuration has not revealed show-stopping aeroelastic issues
  - Minimum flutter dynamic pressure meets margin
- Constraining deformation of tail stiffens tail and aft-deck and significantly increases flutter speed (adds 1731 lb of airframe weight or 2% of vehicle structural weight)
- Additional analysis is needed in the transonic regime with a more suitable aero method (e.g., Euler, TSD, Navier-Stokes)
- Considering that primary flutter mechanism involves aft-deck bending further ASE analysis should be performed with pitch controller in the loop.
  - If body flap is primary pitch controller, how will that interact with flutter mode ? Could it potentially excite it ?
- Sensitivity of flutter speed to engine mass
- FINAL REPORT PROVIDED

- **This concludes LM FEM task.**

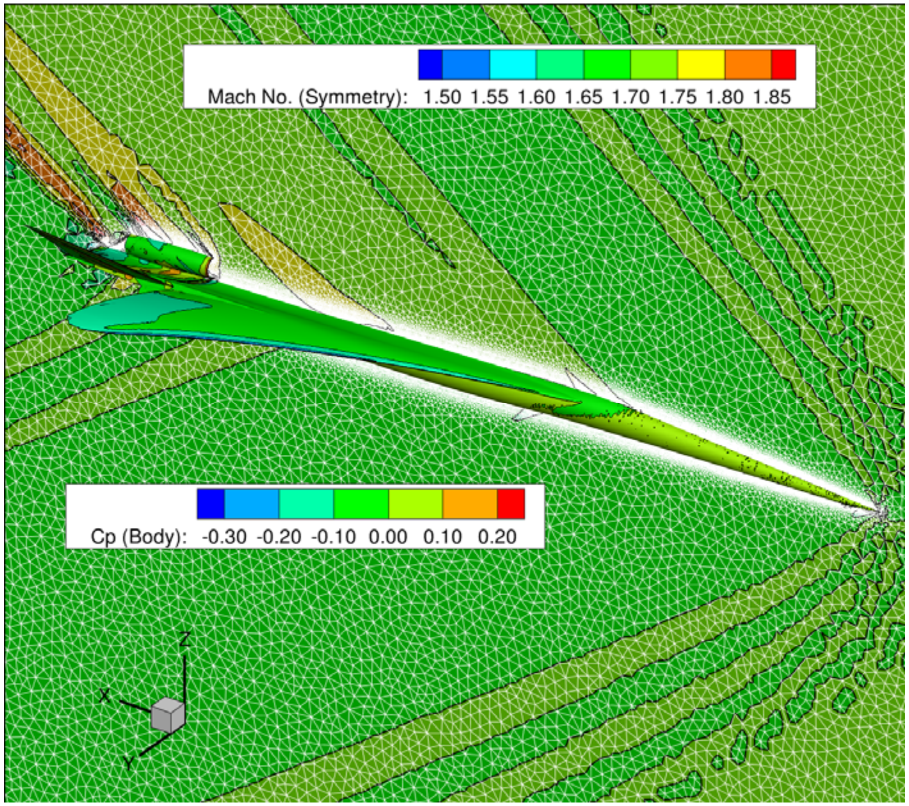
CFD & ROM:
Progress Report

Pressure and Mach Contours

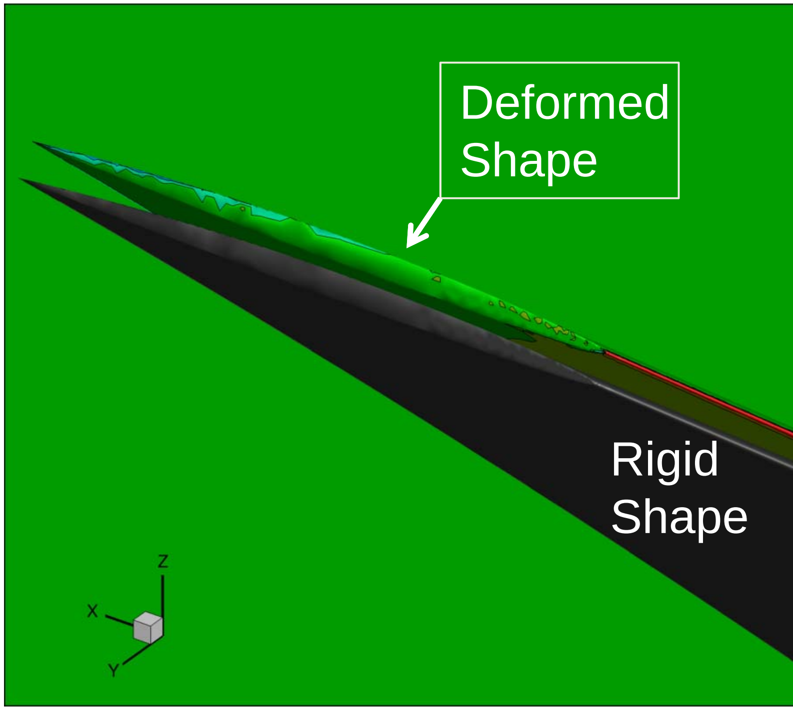
Inviscid, Mach = 1.70, α = 2.1 degrees



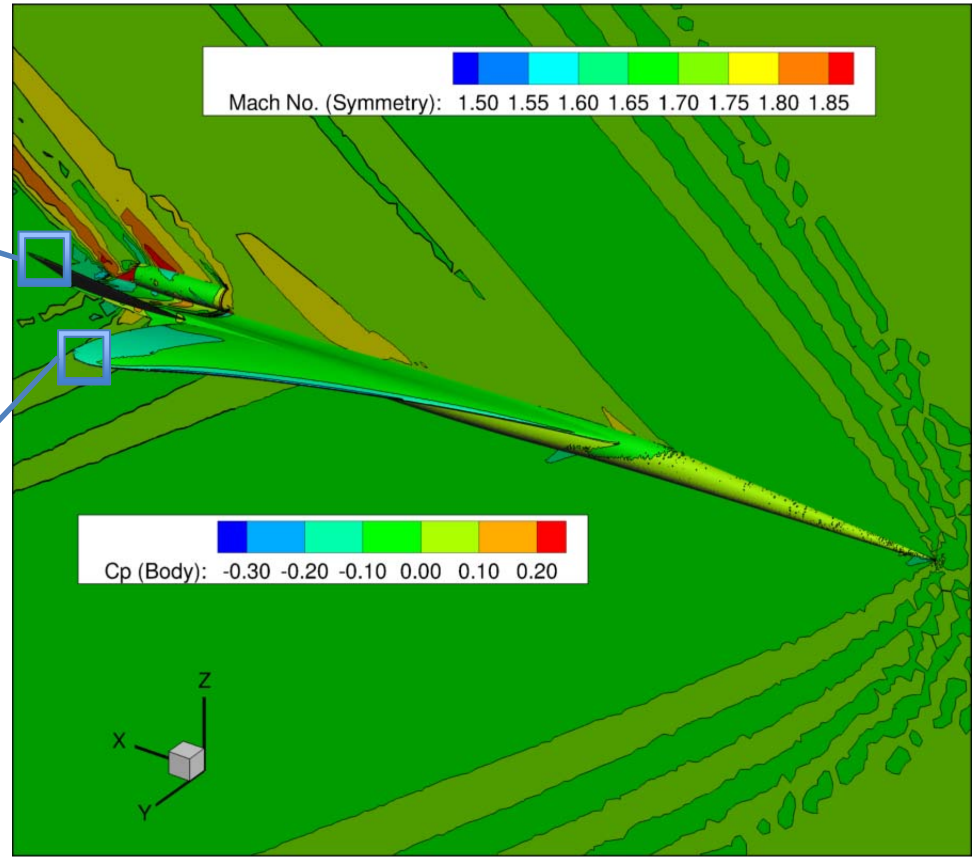
Coarse volume grid
C_l = 0.20199, C_d = 0.01352

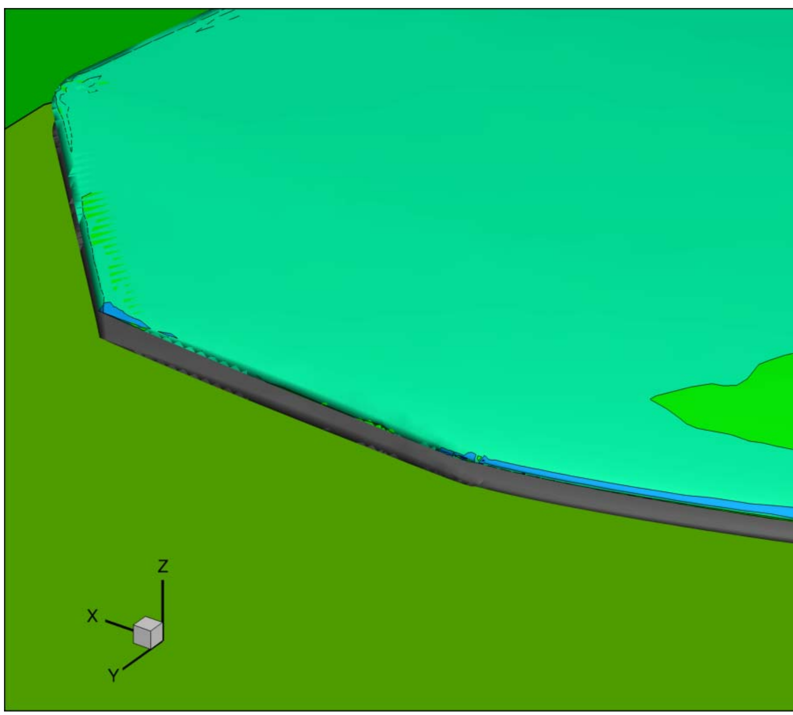


Fine volume grid
C_l = 0.20198, C_d = 0.01351



V = 19,748.75 in/sec
q = 3.403 psi
Mach = 1.7, AOA=2.1



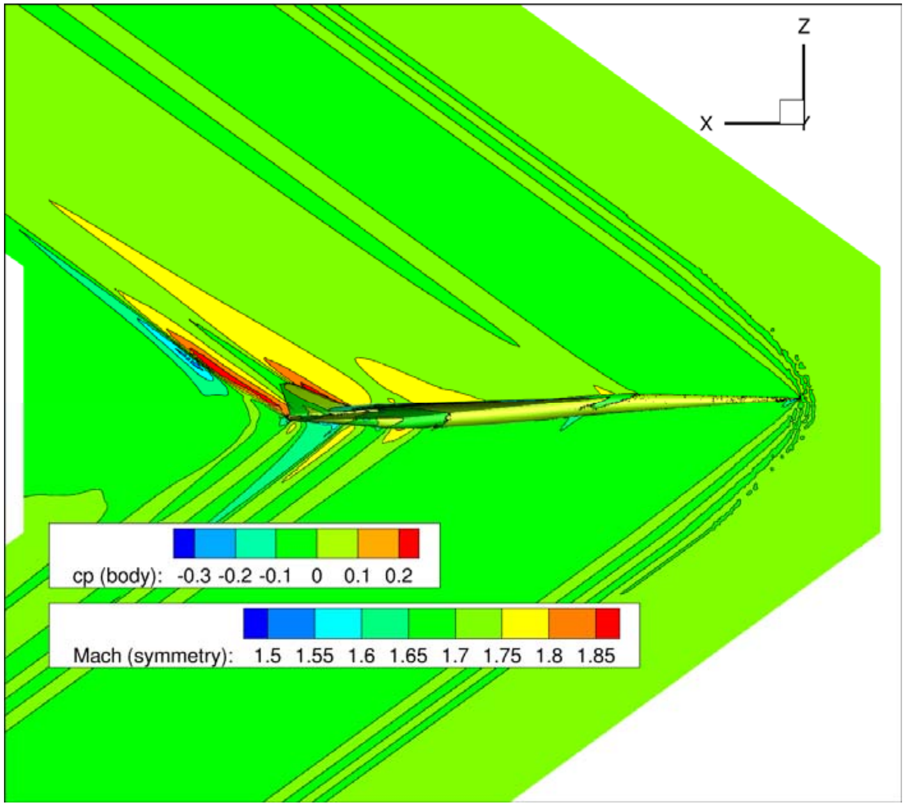


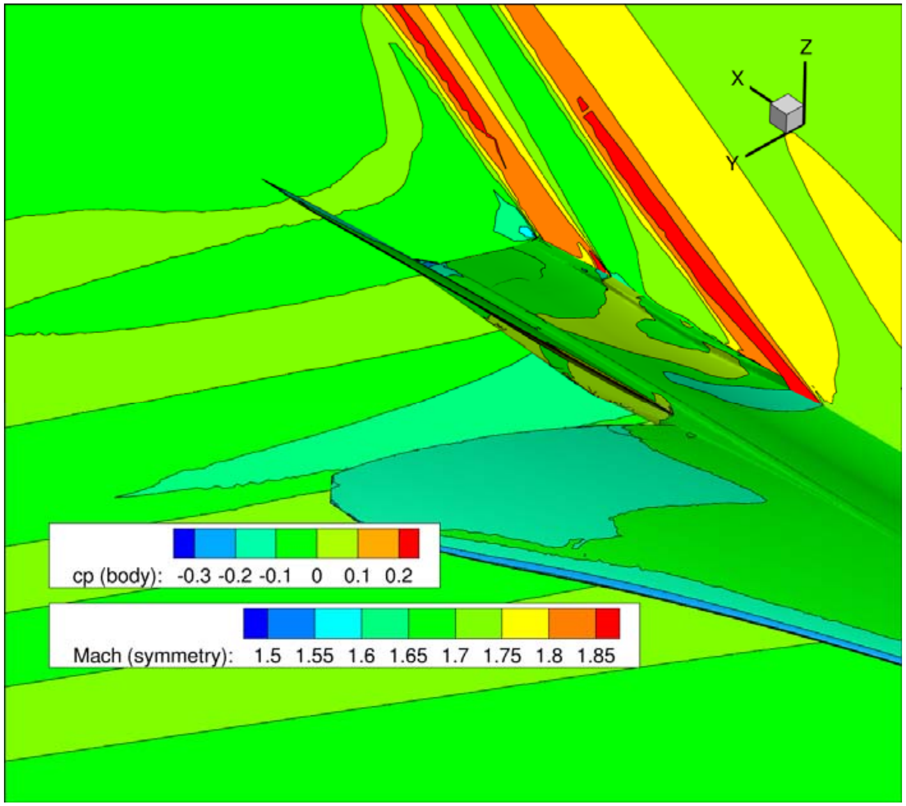
Fun3D Static Aeroelastic Solution:

- 25 flexible modes used
- ~6.5” computed deflections at wing and tail tips
- Euler solution

Pressure and Mach Contours

Undeformed, Inviscid, Mach = 1.70, α = 2.25 degrees



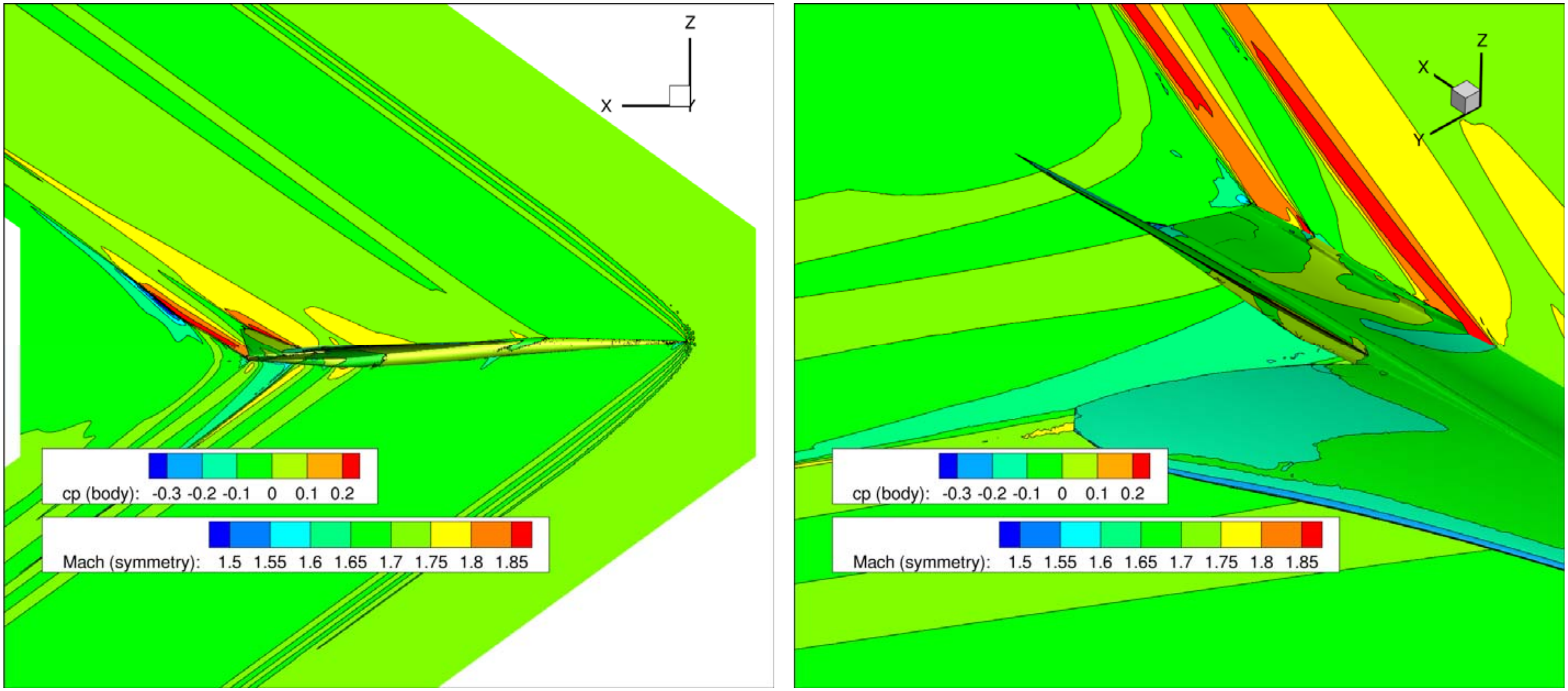


Coarse grid (5.4 million grid points)

C_l = 0.143427, C_d = 0.009253, C_m = -5.6745

Pressure and Mach Contours

Undeformed, Inviscid, Mach = 1.70, α = 2.25 degrees

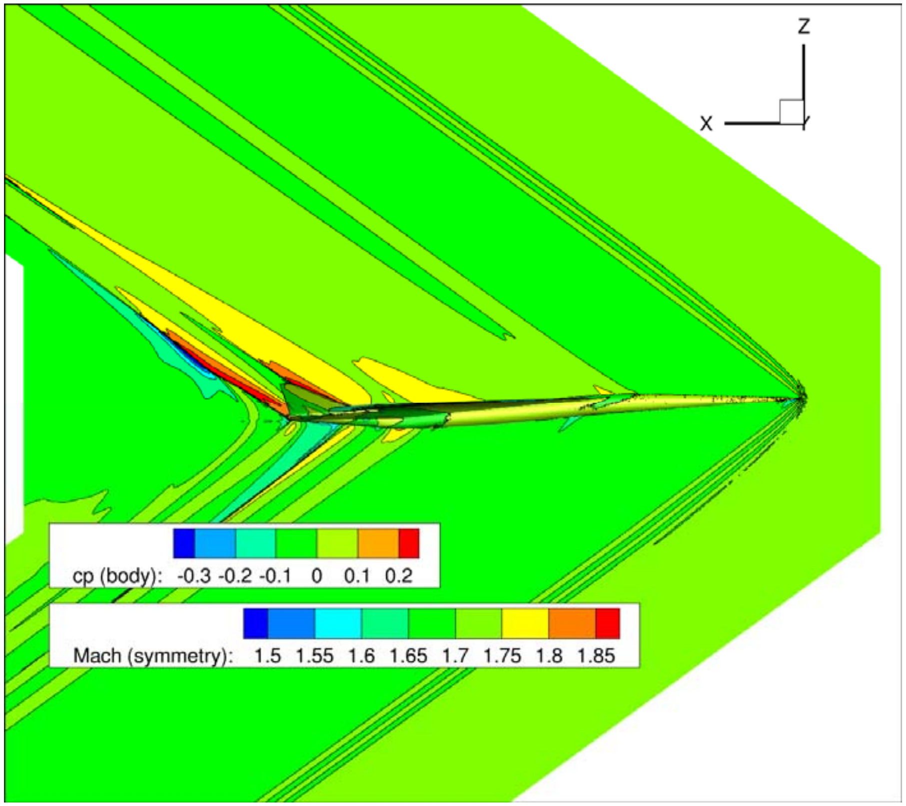


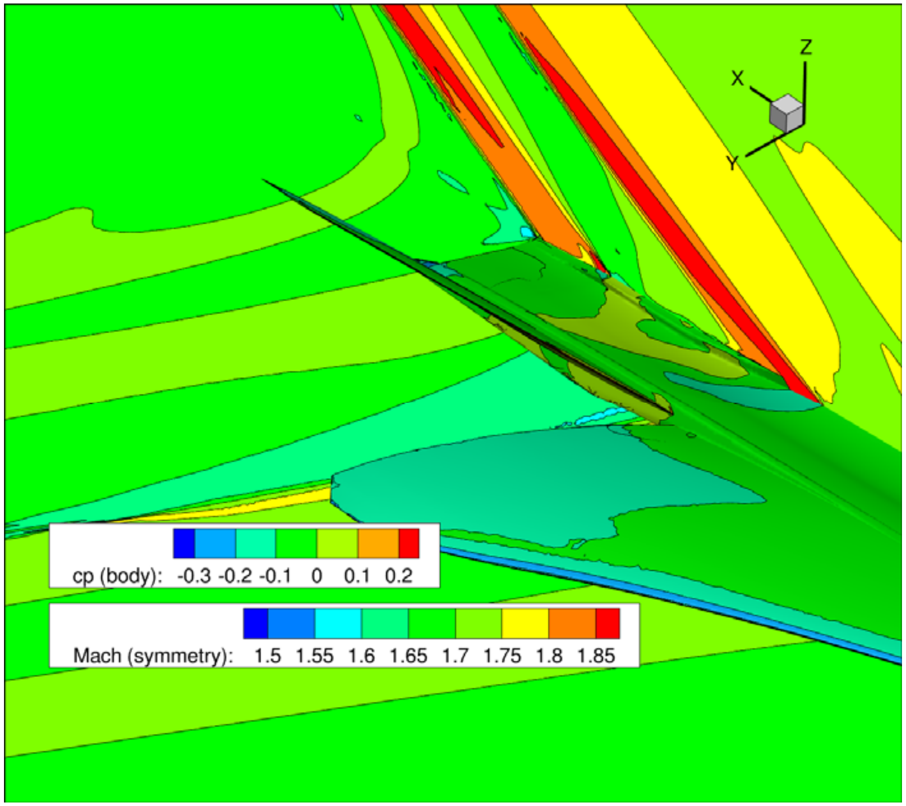
Medium grid (17.5 million grid points)

C_l = 0.143431, C_d = 0.009251, C_m = -5.6712

Pressure and Mach Contours

Undeformed, Inviscid, Mach = 1.70, α = 2.25 degrees

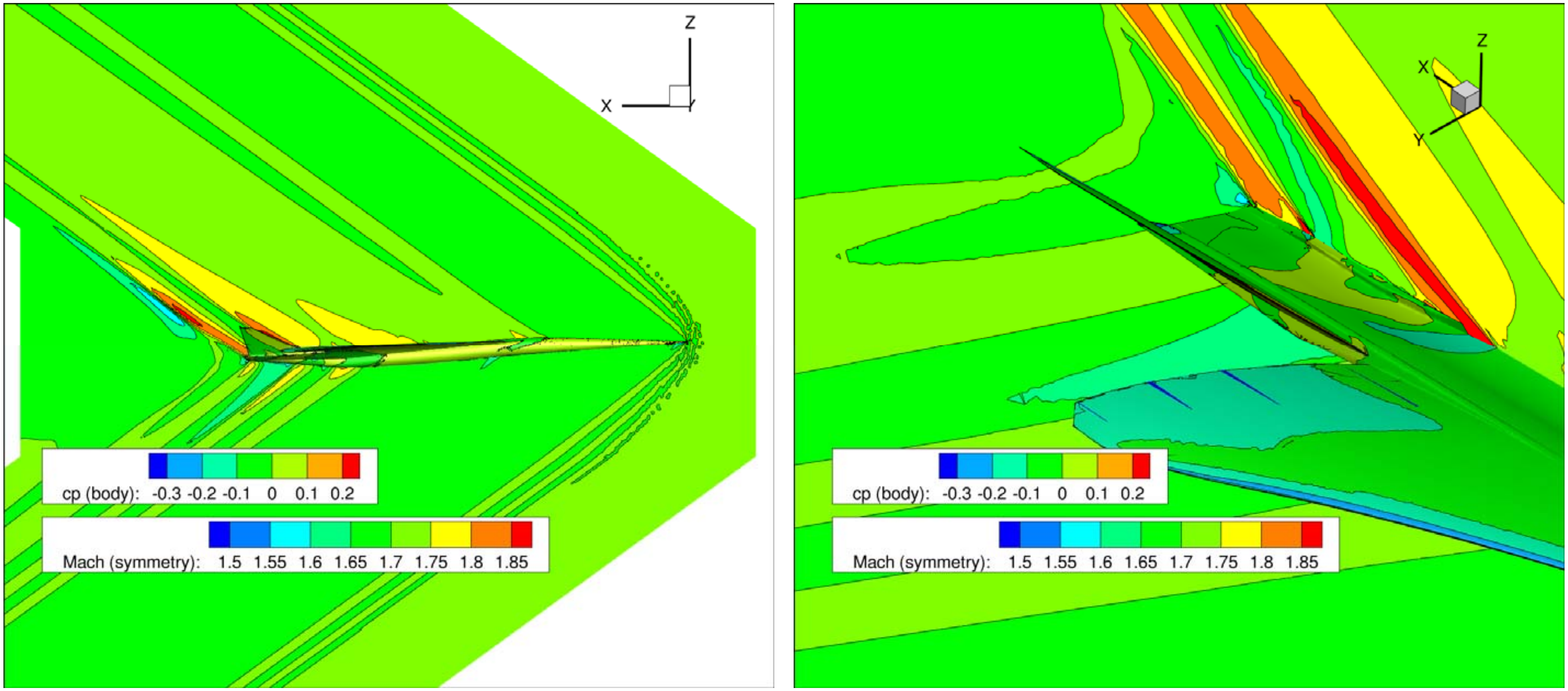




Fine grid (57.5 million grid points)
C_l = 0.143421, C_d = 0.009251, C_m = -5.6654

Pressure and Mach Contours

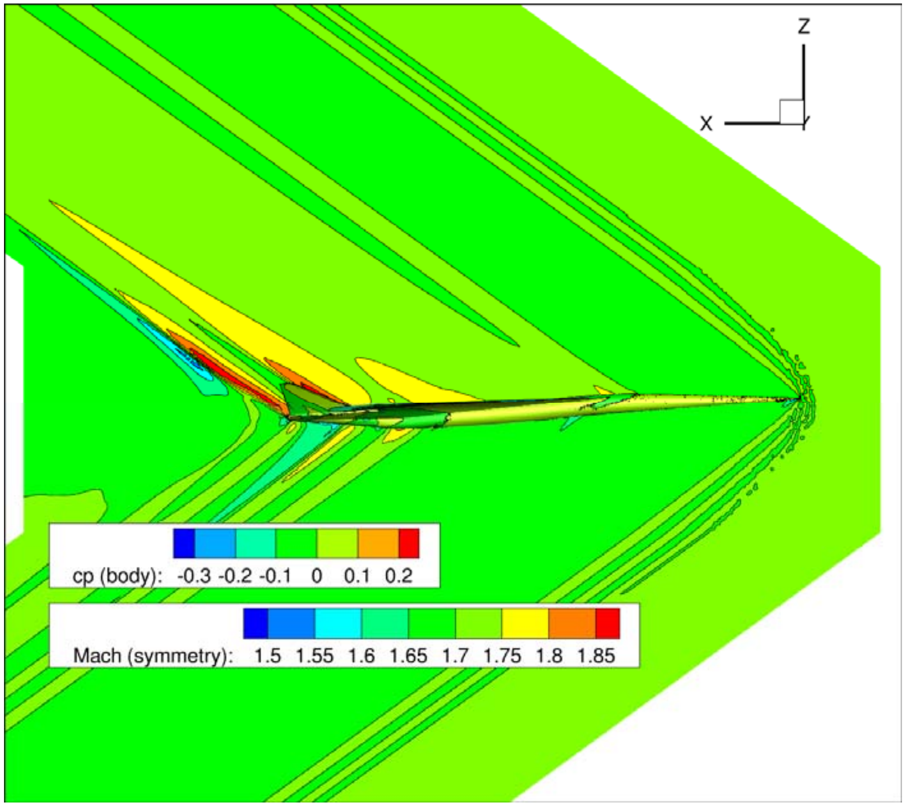
Deformed, Inviscid, Mach = 1.70, α = 2.25 degrees

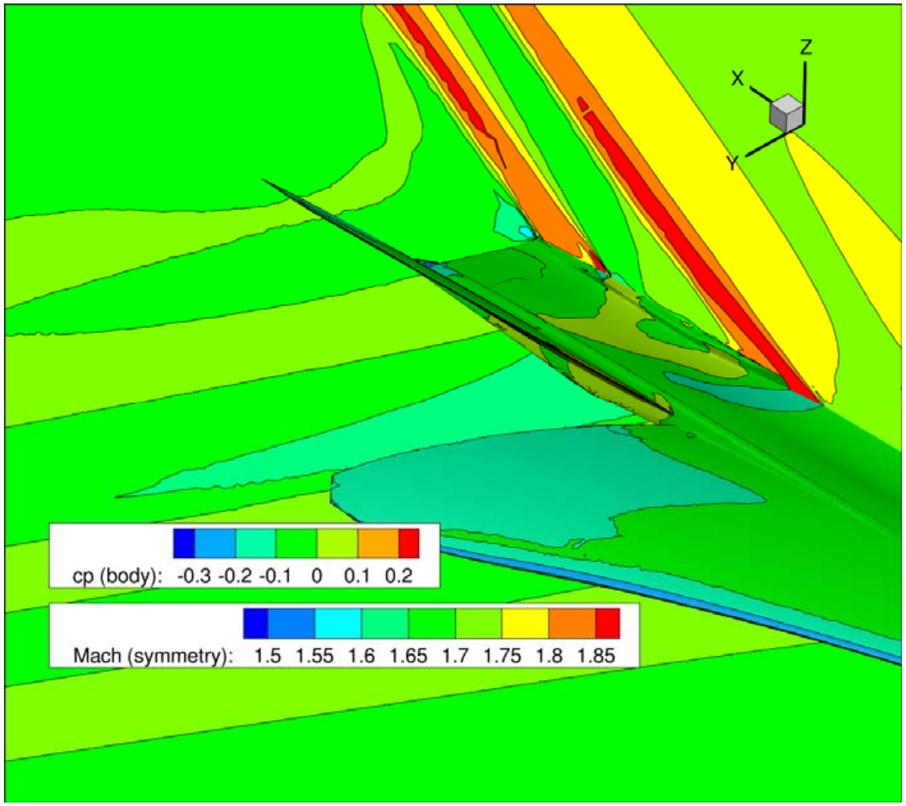


Coarse grid (5.4 million grid points)
C_l = 0.134223, C_d = 0.008578, C_m = 0.27254

Pressure and Mach Contours

Undeformed, Inviscid, Mach = 1.70, α = 2.25 degrees

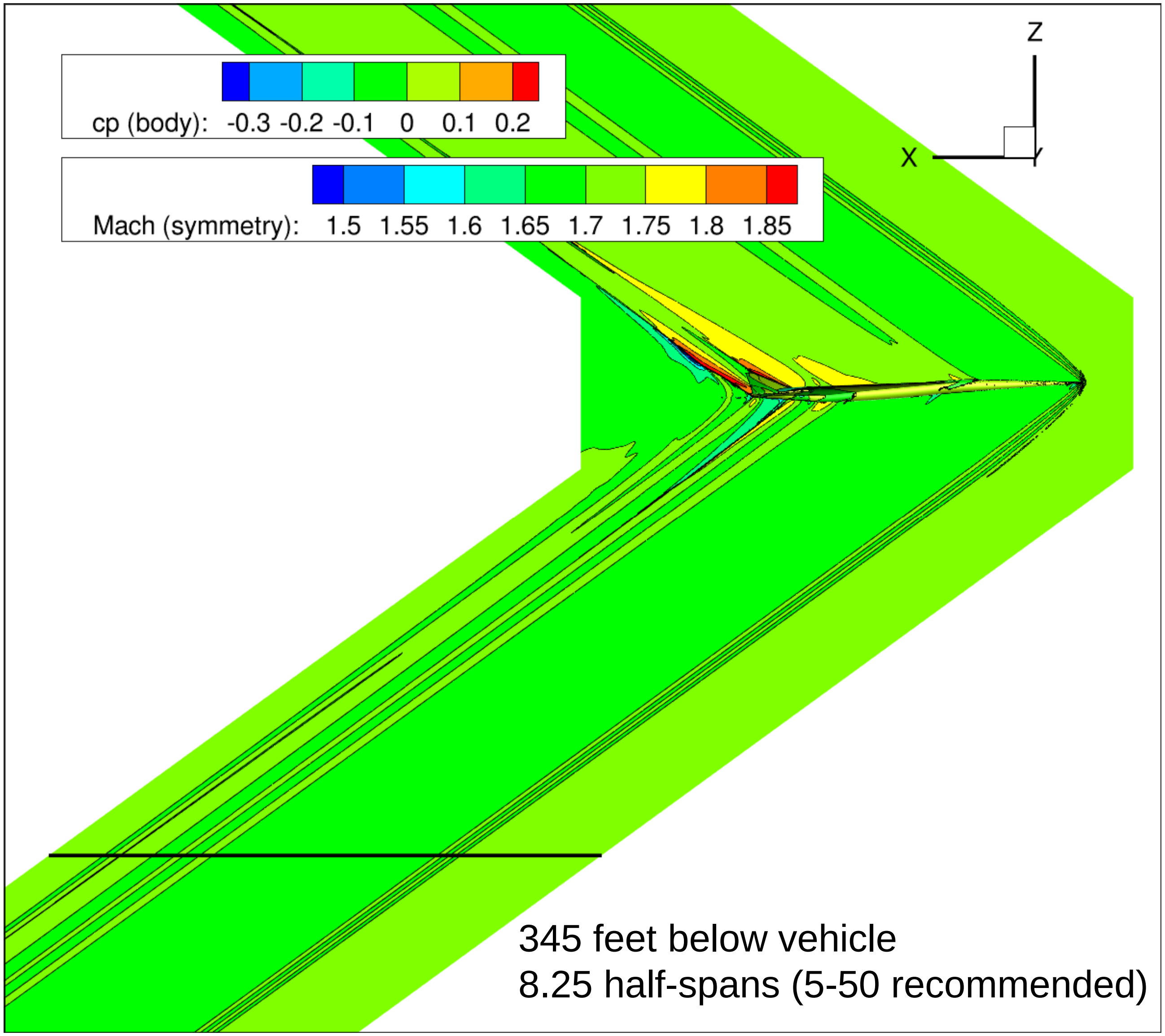




Coarse grid (5.4 million grid points)
C_l = 0.143427, C_d = 0.009253, C_m = -5.6745

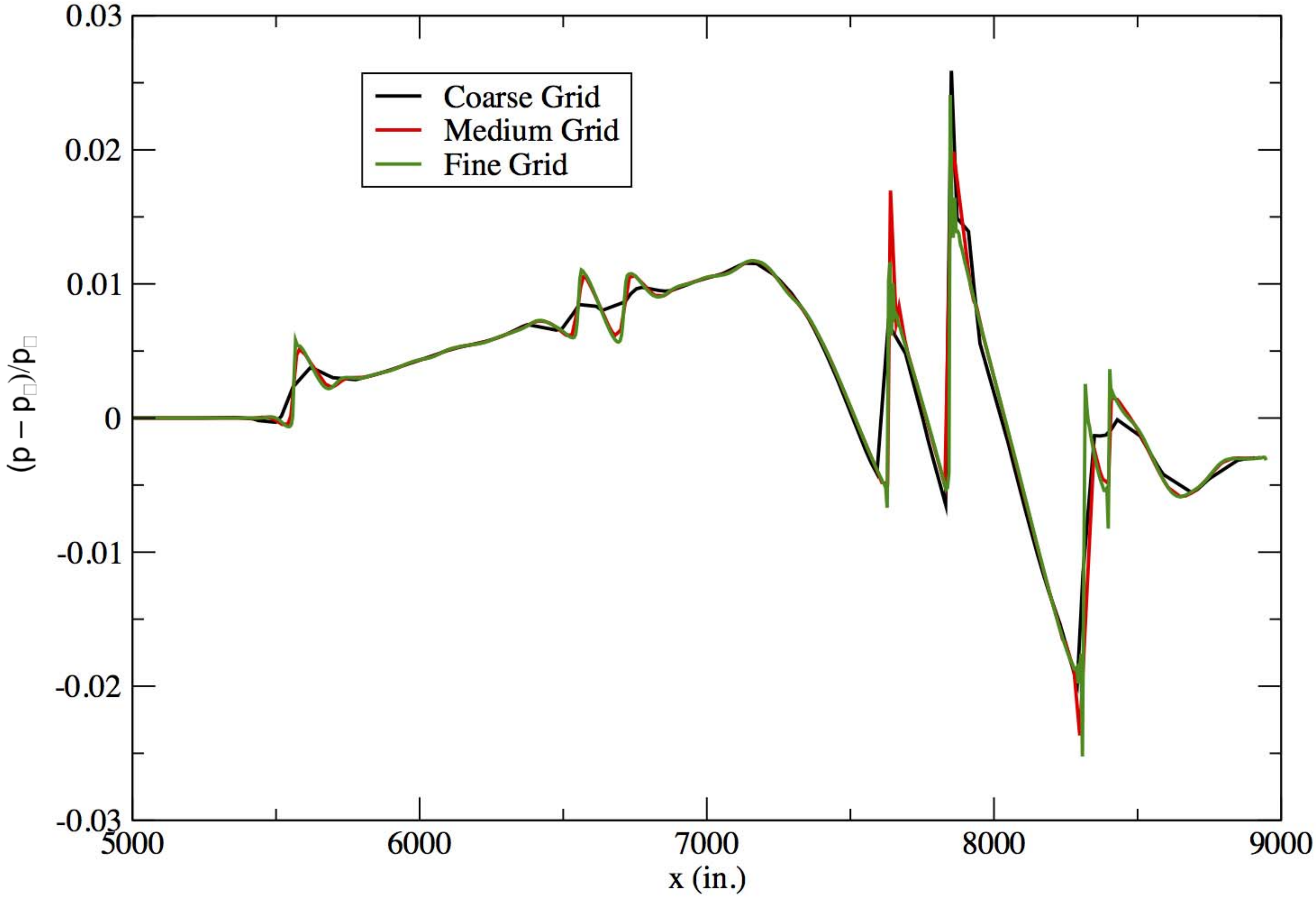
Location of Near-Field Pressure Extraction

Undeformed, Inviscid, Mach = 1.70, α = 2.25 degrees



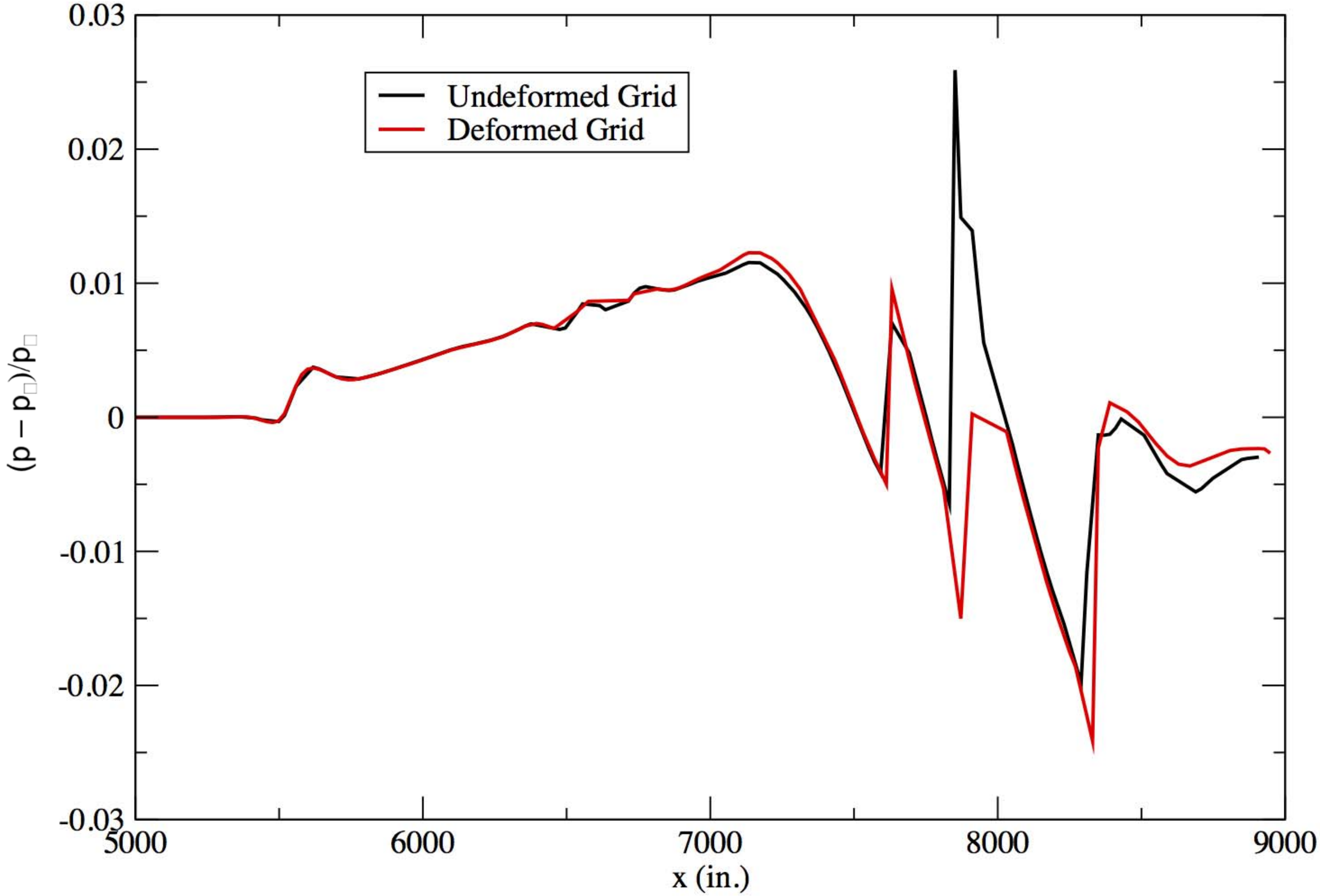
Near-Field Pressure Distribution

Undeformed, Inviscid, Mach = 1.70, α = 2.25 degrees



Near-Field Pressure Distribution

Coarse Grid, Inviscid, Mach = 1.70, α = 2.25 degrees



N+2 ROM Aeroelastic Analysis
Preliminary Results

Inviscid ROM vs. Full FUN3D Solutions

First 10 Symmetric Modes

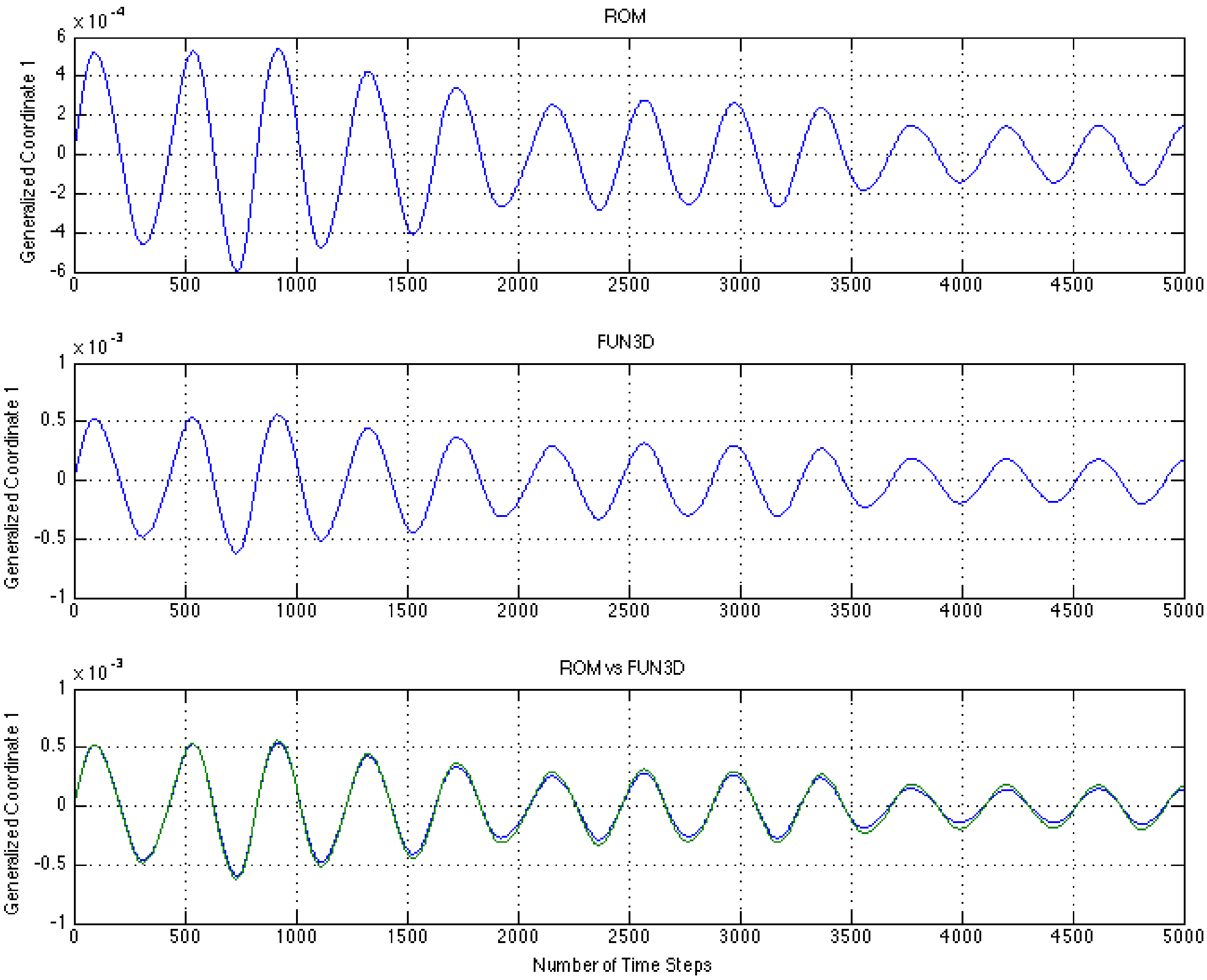
100 steps/cycle of 10^{th} mode

M=1.7

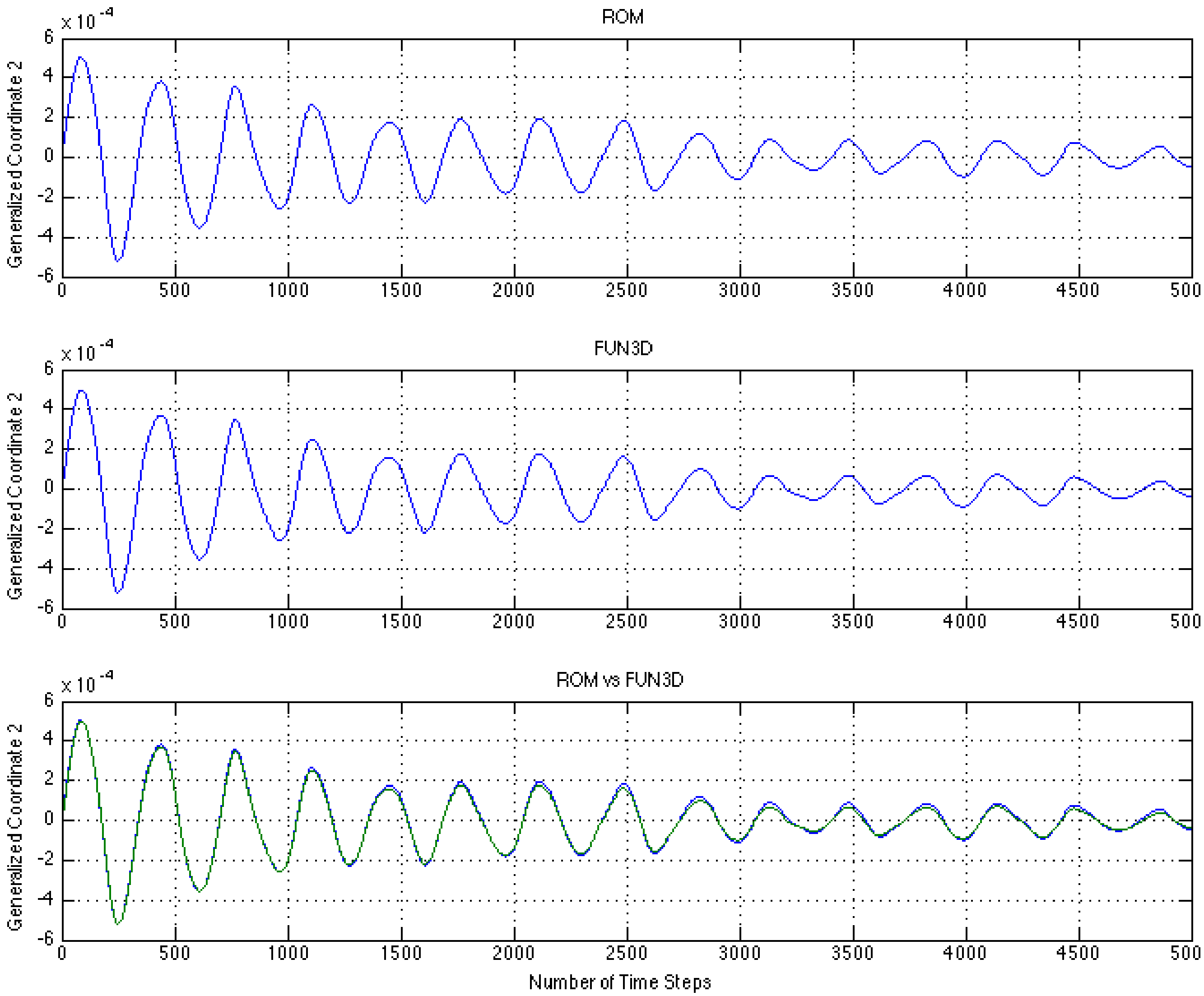
Background

- Performing full FUN3D AE solutions and ROM solutions at M=1.7, various Qs
- Need a full AE solution for each Q; need only one ROM solution for all Qs
- Need to verify accuracy of ROM by comparing with full solutions at a subset of Qs (min, max, in between values)
- ROM solution computed in 3 hrs (2400 time steps)
- Full AE solution requires 2 solutions/Q: static AE, 10 hrs (1000 time steps) + dynamic AE, 18 hrs (6000 time steps); some optimization possible to improve times
- Results presented include comparison of modal responses (time, frequency) and root locus generated from ROM

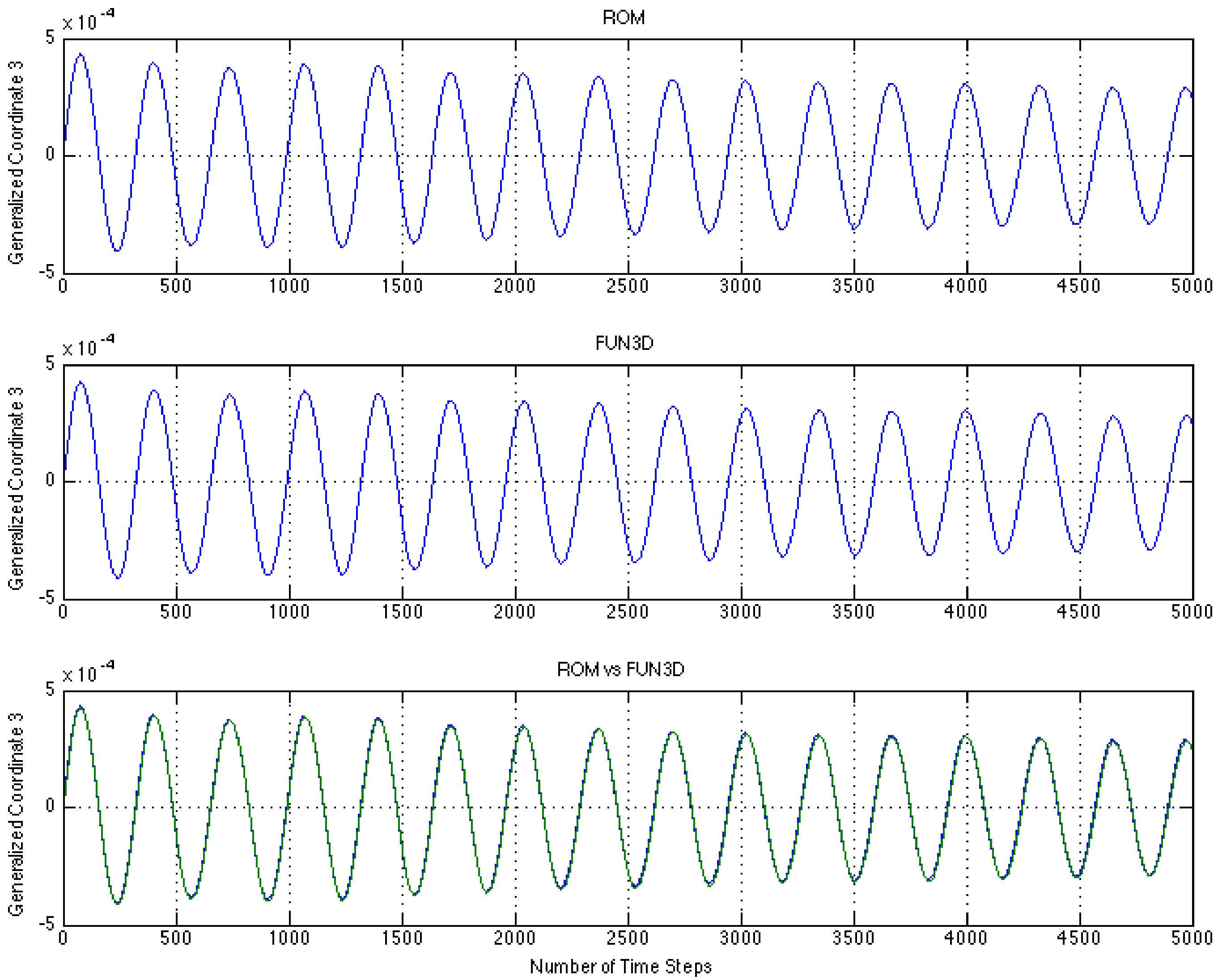
Time Domain: Mode 1, Q=2.419 psi



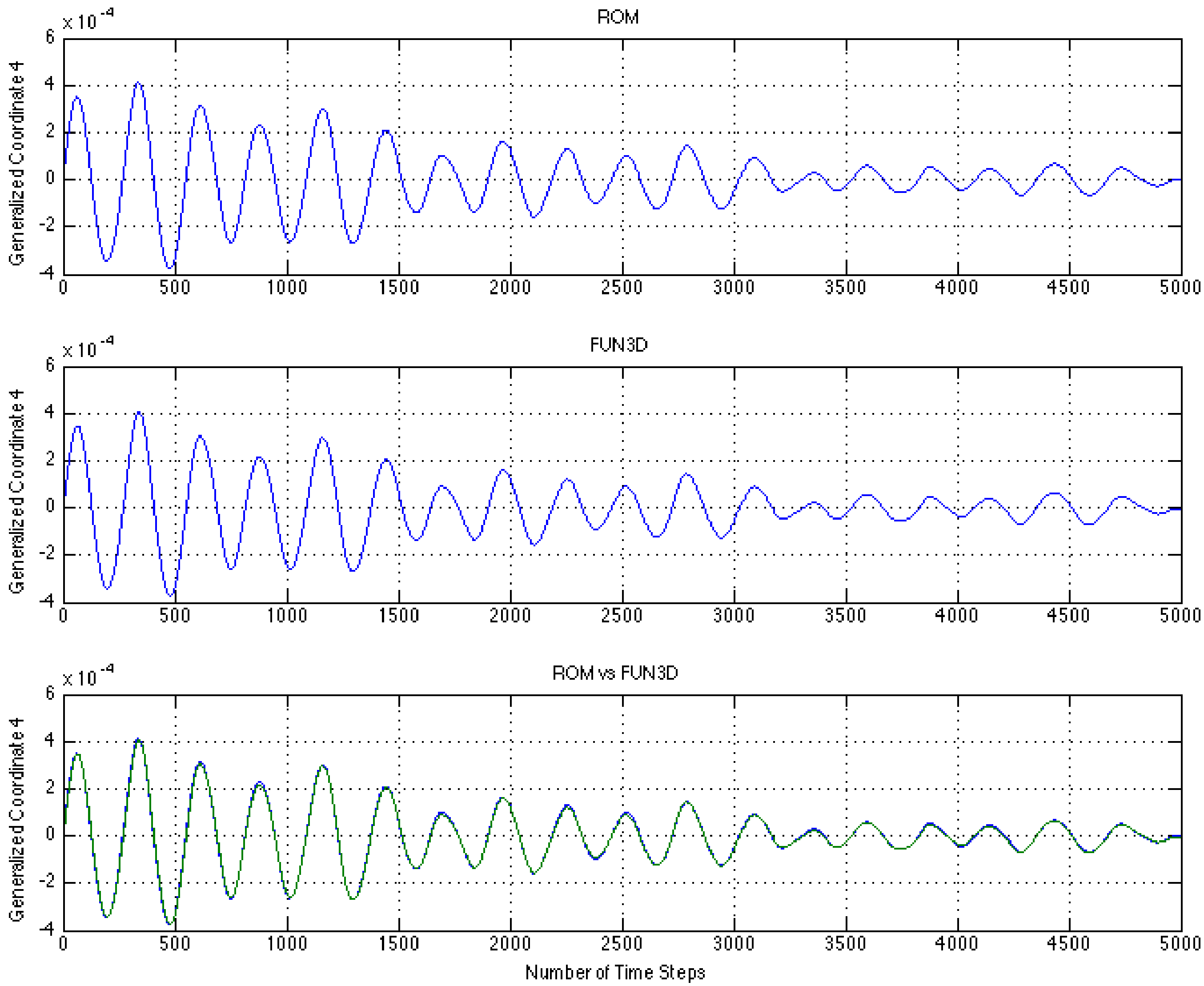
Time Domain: Mode 2, Q=2.419 psi



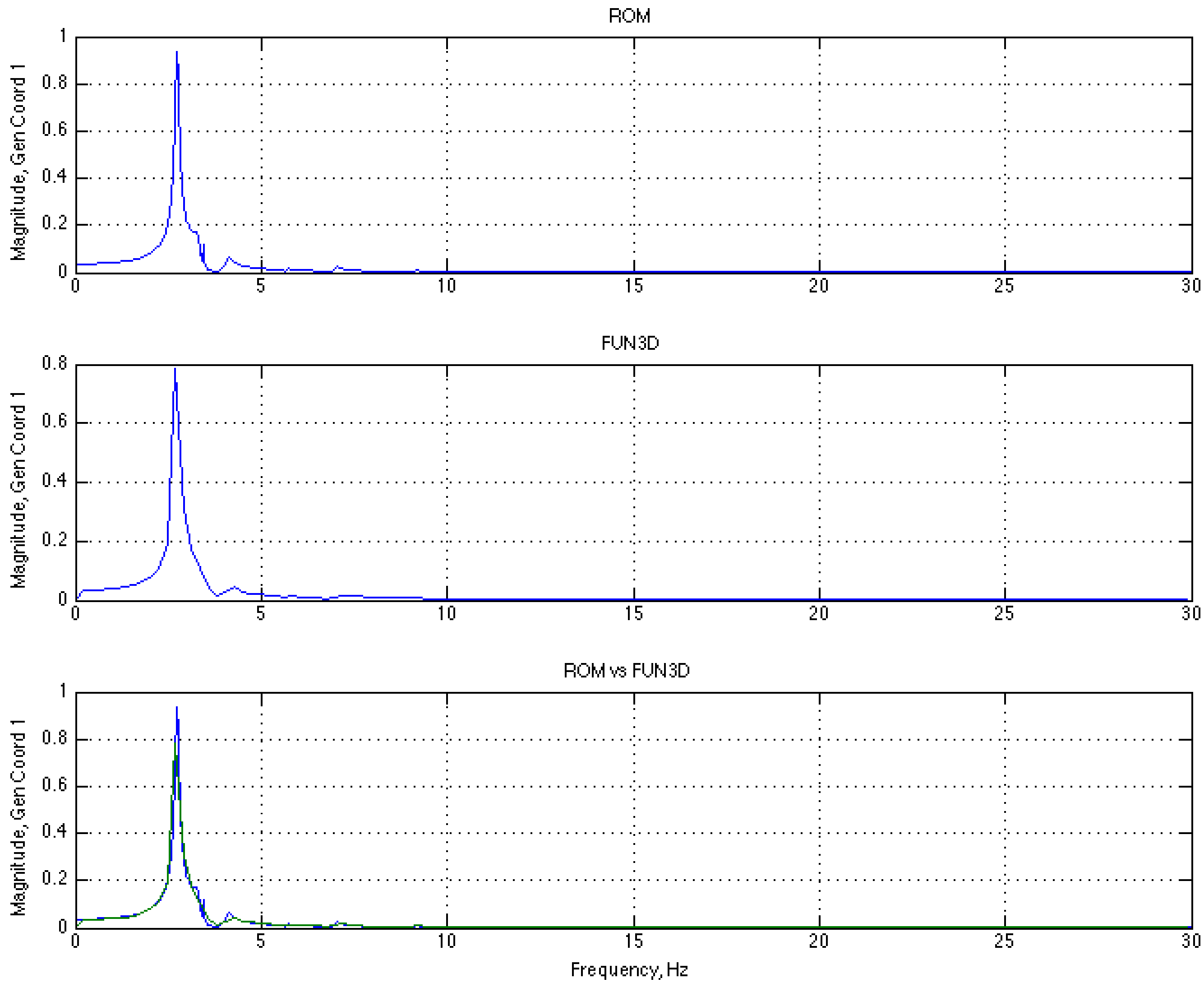
Time Domain: Mode 3, Q=2.419 psi



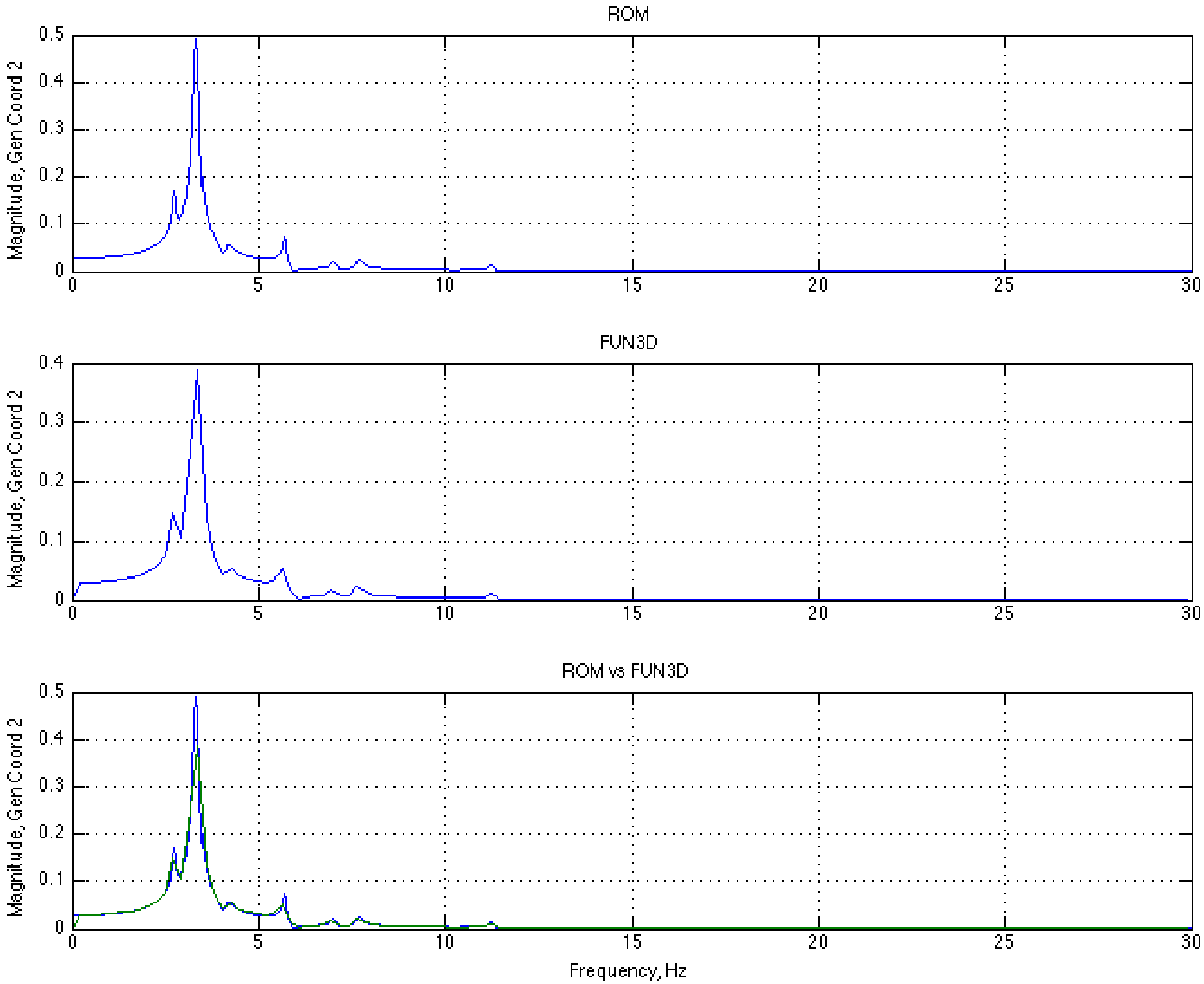
Time Domain: Mode 4, Q=2.419 psi



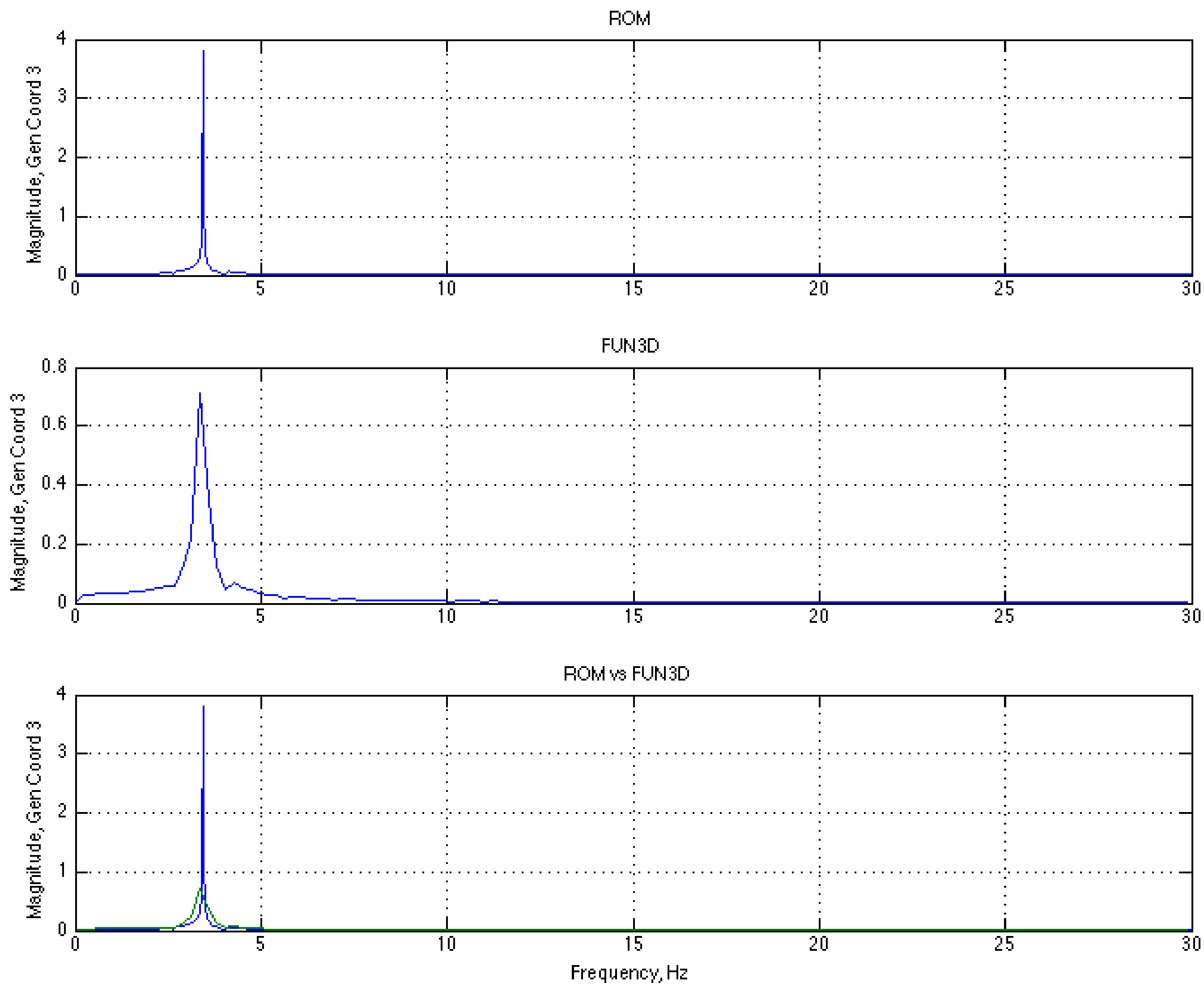
Frequency Domain: Mode 1, Q=2.419 psi



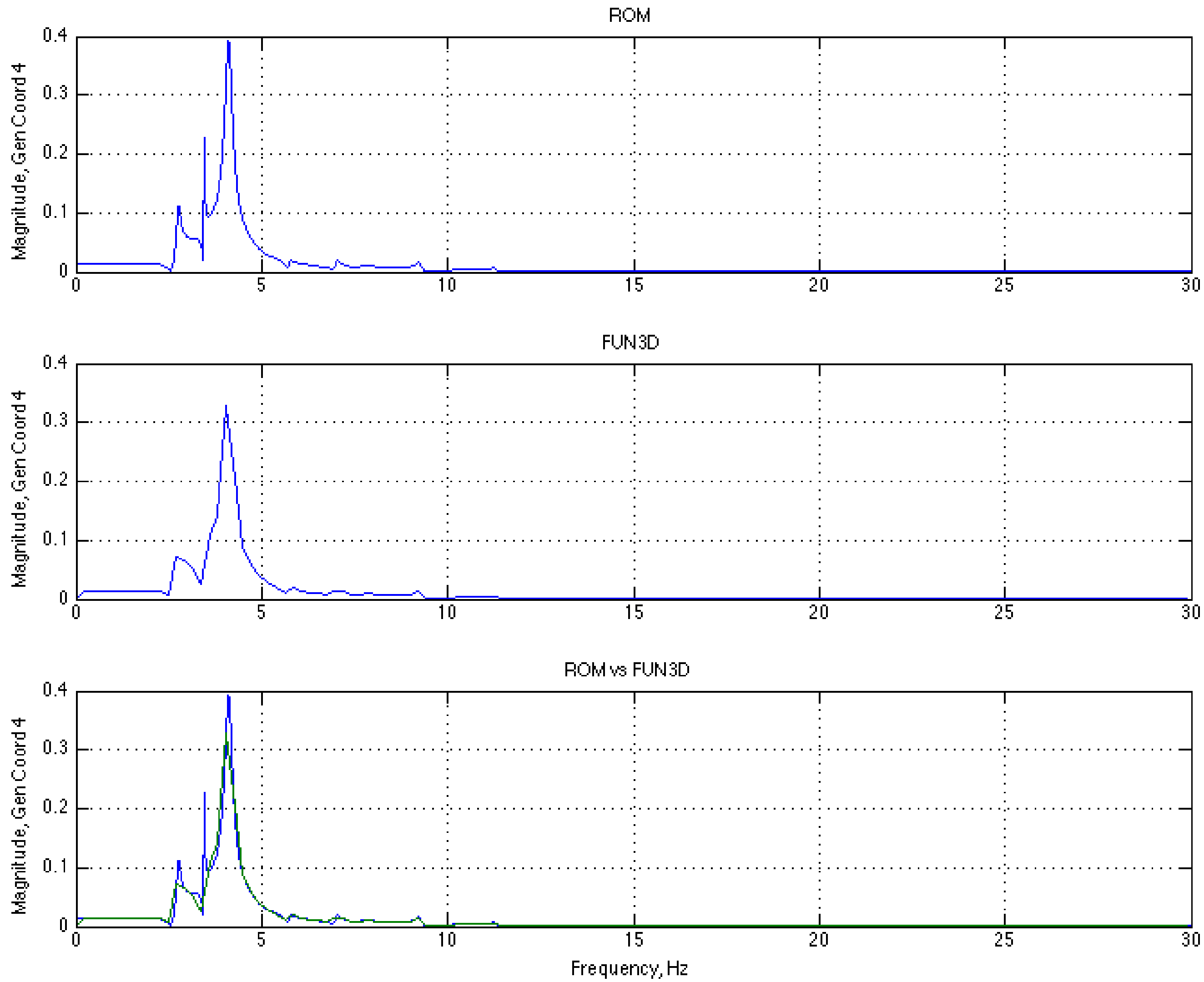
Frequency Domain: Mode 2, Q=2.419 psi



Frequency Domain: Mode 3, Q=2.419 psi



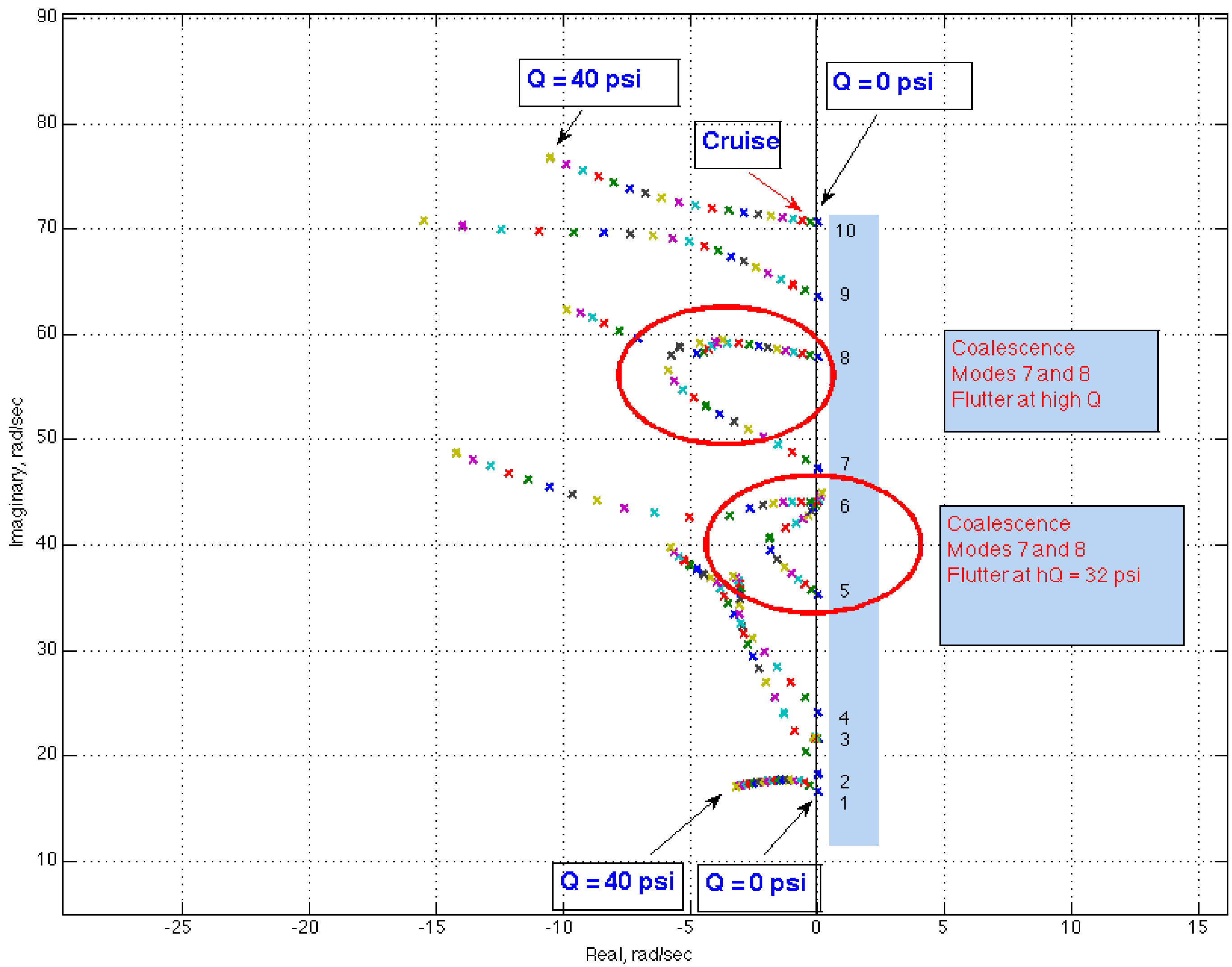
Frequency Domain: Mode 4, Q=2.419 psi



Root Locus, M=1.7

- Using ROM, can generate root locus plot of aeroelastic response for a range of Qs
- Root migrations show AE behavior, couplings
- If a root locus was to be generated from full AE solutions, would need to compute full solutions at each Q (each symbol in root locus)
- Root locus plot generated from ROM in seconds
- FUN3D results at higher Qs not possible due to grid deformation issues

ROM Root Locus Plot, M=1.7



Next Steps

- Generate additional FULL solutions at different Qs to compare with ROM solution and root locus plot
- Perform same analyses at different Mach numbers, special attention to high subsonic/low supersonic Mach numbers
- Perform same analyses using different time steps (400 steps/cycle, etc.)
- Perform same analyses for configurations with engines and for viscous solutions
- Evaluate different vehicle weight conditions

AeroPropulsoServoElasticity (APSE)

George Kopasakis (GRC)

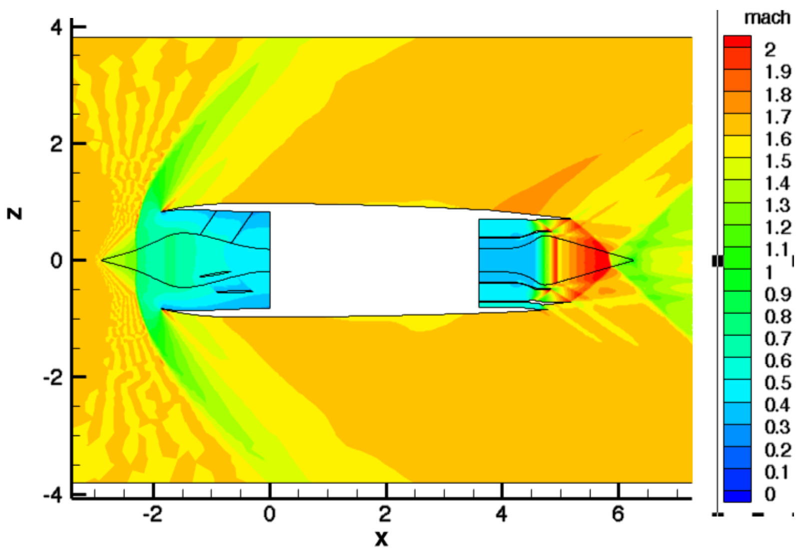
Updated APSE Simulation Testbed

Started new effort to develop an APSE FUN3D test-bed simulation:

-- This simulation will incorporate propulsion system inlets and nozzles as part of the structure, while the VCE model will be the same but brought to the FUN3D platform as a library component.

-- This model will also function as the truth model for the existing APSE model concept.

-- Proof of concept model developed successfully in FUN3D w/ GE inlet-nozzle geometries w/ simple steady state conservation engine model w/ uniform freestream flow conditions



ASE & Active Controls:
ASE model development, Gust loads

ASE & Active Controls

- Application of CFL3D-ASE
- Reviving ISAC (Interaction of Structures, Aerodynamics, and Control)
  - "Bread-n-Butter" system of linear programs for AE/ASE
  - Written in archaic Fortran and was executable only on an old SGI machine
  - Updating/modernizing coding so it can run on any architecture (laptop)
  - Converting plotting over to MATLAB (replacing archaic plotting routines)
  - Structural splining and unsteady aero up and running
  - Working on flutter computation and ASE modules
  - DONE
- Gust loads analyses (including rigid body modes, trim)
- Design of an ASE-tailored vehicle based on the LM N+2 FEM (MDAO)

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