Fighter Wing Design Example 2

M_∞ = 0.93, α_0=0.5°, 20% Increase in U_f,
Stress and Displacement Constraints

- 32,000. lbs tip load
- 17 in. z-disp allowable
- Von-Mises stress constraint

  $\sigma_t = \sigma_c$ = 60,000. psi

  σ_{xy} = 40, 000. psi

<u>Nonlinear</u>

- Flutter Only Design

  U_f = 14565.46 in/sec

  ω_f = 17.51 Hz

  designed weight = 426.91

(14.22% decrease from initial)

- Flutter, stress, and displacement Design

  4.8 hr YMP

  U_f = 14571.53 in/sec

  ω_f = 18.74 Hz

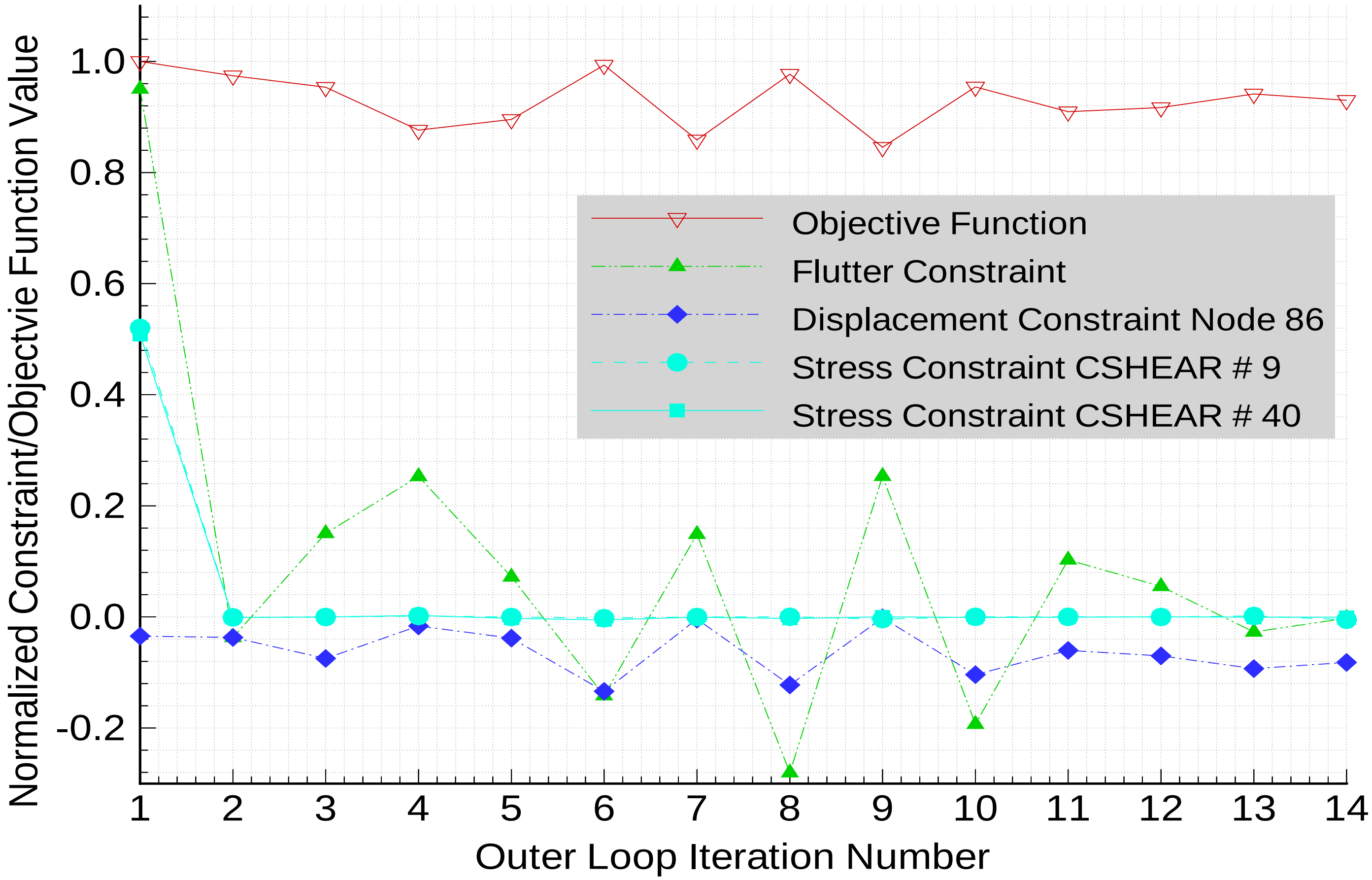
  designed weight = 462.91 lbs

  (7.0% decrease from initial)

Nonlinear Unsteady Aeroelastic Optimization

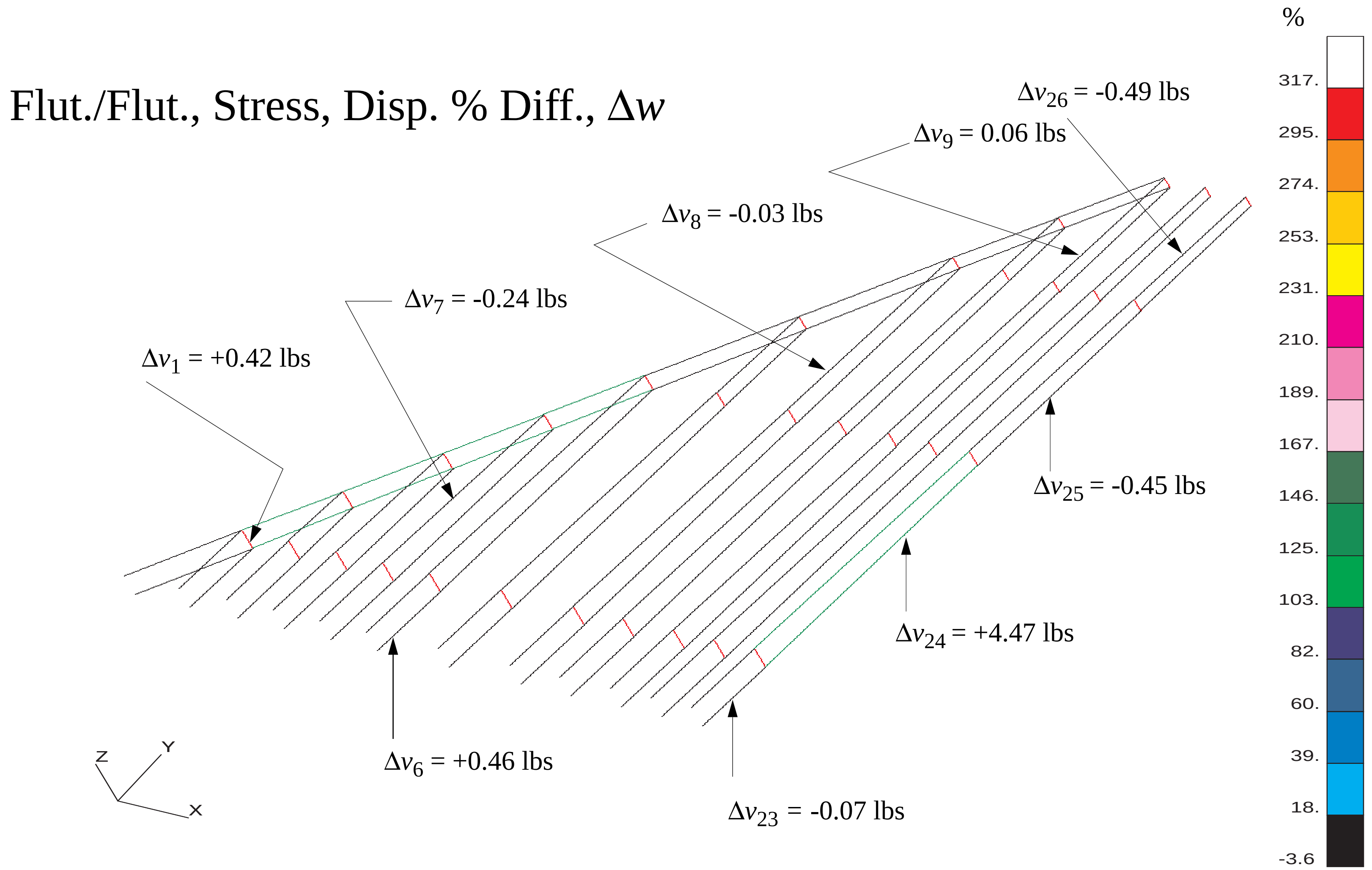
Fighter Wing Design Example 2

M_∞ = 0.93, α_0=0.5°, Flutter, Stress and Disp.



Fighter Wing Design Example 2

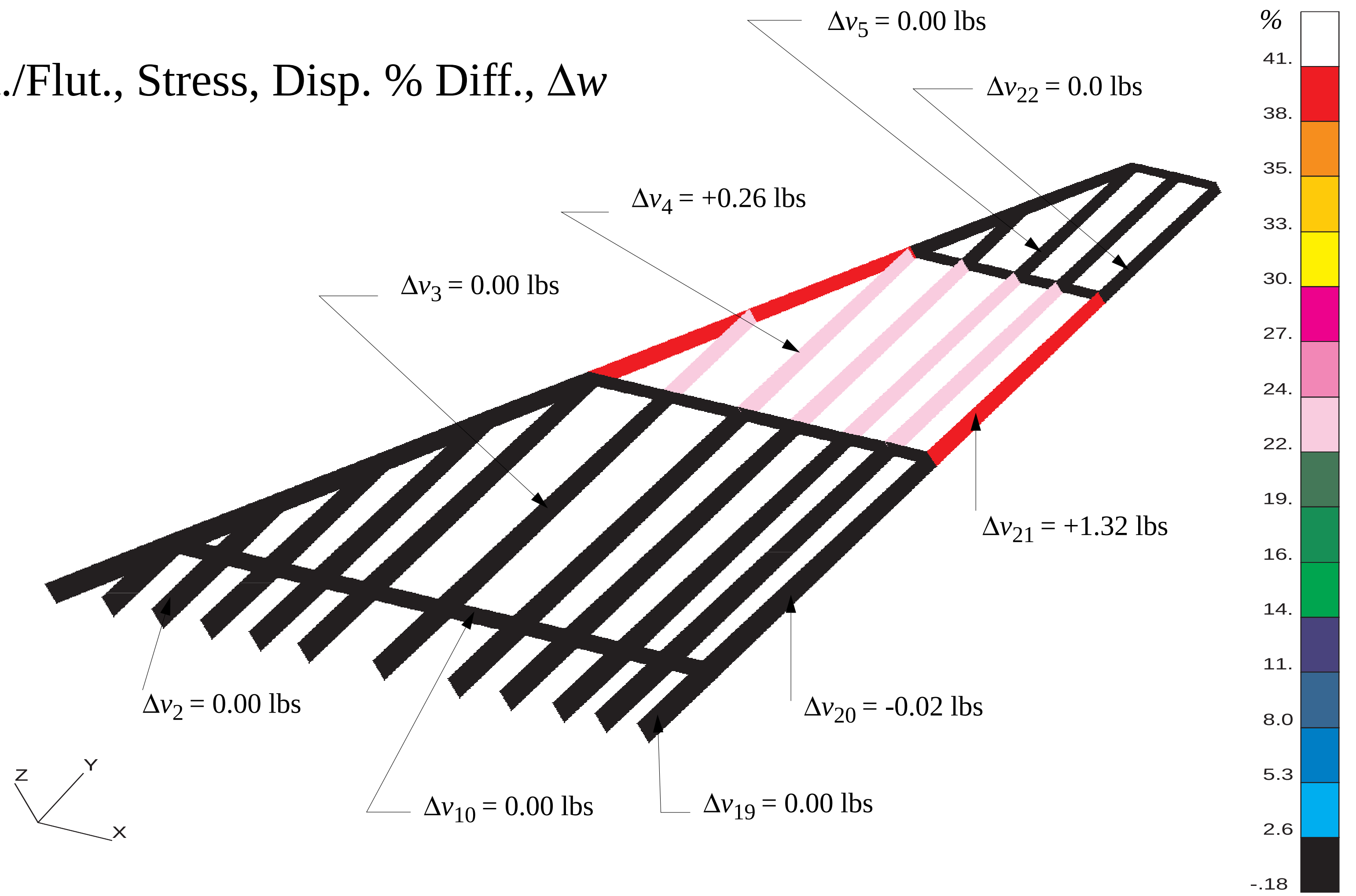
M_∞ = 0.93, α_0=0.5°, Flutter, Stress and Disp.



Fighter Wing Design Example 2

M_{∞} = 0.93, α_0=0.5°, Flutter, Stress and Disp.

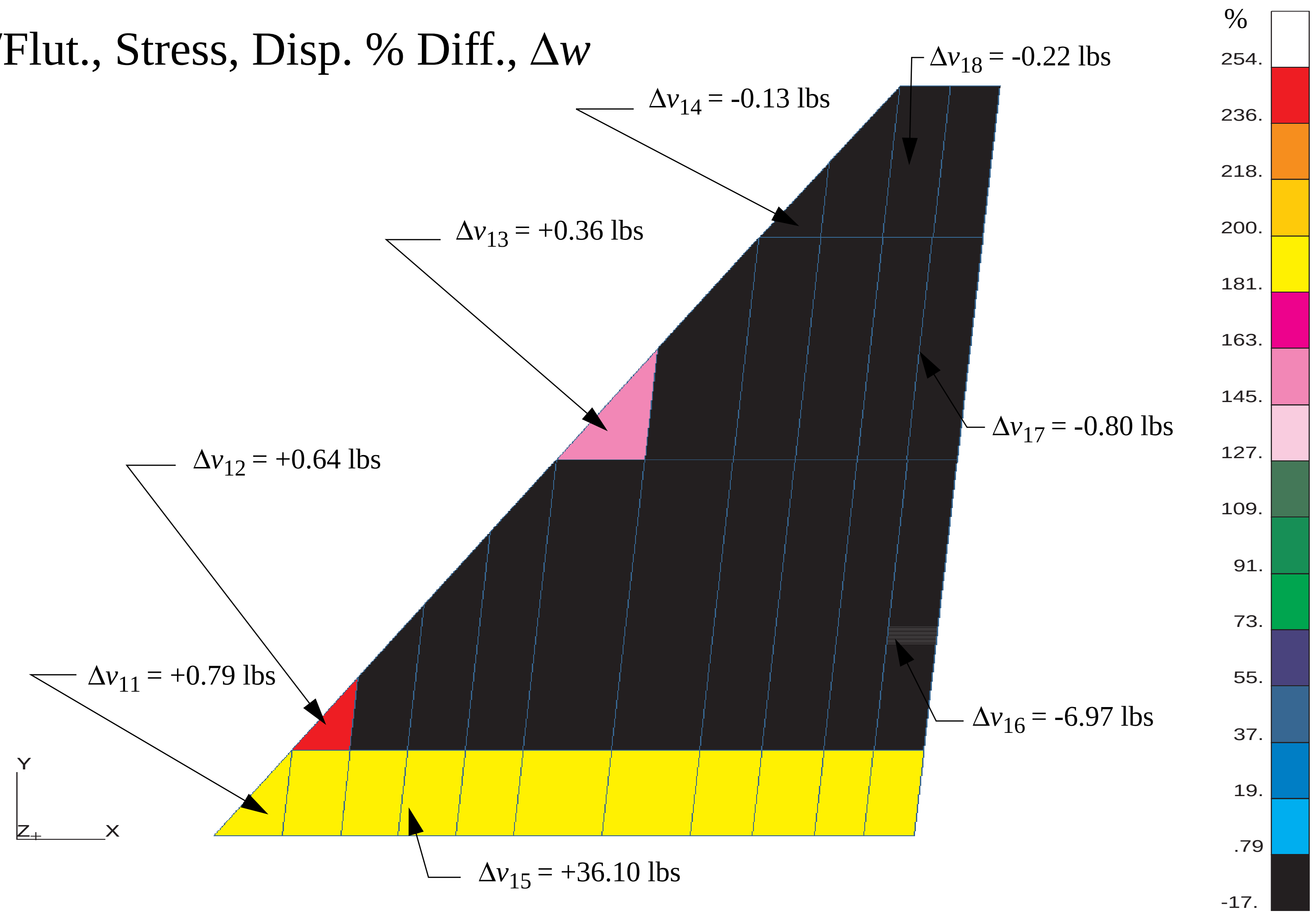
Flut./Flut., Stress, Disp. % Diff., Δw



Fighter Wing Design Example 2

M_∞ = 0.93, α_0=0.5°, Flutter, Stress and Disp.

Flut./Flut., Stress, Disp. % Diff., Δw



Concluding Remarks on IRM Flutter Design

- IRM computationally efficient transonic unsteady aeroelastic design method.
- Did not update unsteady aerodynamics every exact analysis.
- Found nonlinear term in sensitivity analysis negligible for cases tested (fully analytic sensitivities).
- Compared linear versus nonlinear designs for transonic regime (differ in both sizing and material distribution).
- IRM not restricted to TSD

Potential Research Areas in Nonlinear Unsteady Aeroelastic Design

- More efficient functional representation of unsteady aerodynamic forces in the Laplace domain. (ASE applications)
- Higher level CFD theory for mean flow solutions
- Include rigid body modes
- Further investigation of nonlinear term in damping sensitivities
- Alternate unsteady aerodynamic force approximations
- Investigate other nonlinear flow phenomena (tail buffet, LCO etc.)

Nonlinear Static Aeroelasticity For Design

Critical Issues/Requirements

- Requirements
  - Accurate maneuver loads and aeroelastic response predictions are required for structural design
  - Well established linear methods exist for subsonic and supersonic flight
  - Linear methods are efficient, but not accurate when applied to Transonic Flow Conditions
- Transonic Flow
  - Mixture of Subsonic and Supersonic Flow with Shocks at Interface
  - Flow Field Behavior is Highly Nonlinear across the Shock
  - Costly Partial Differential Equations must be Solved to Accurately Predict the Transonic Pressure Field

Objectives/Scope

- Develop an Efficient and Accurate Analysis Technique, for the MDO Environment, Capable of Determining the Aeroelastic Response of a Lifting Surface with an Articulated Control Surface in *Transonic Flow*

- Use the Technique to Predict the Rolling Performance and Static Aeroelastic Phenomena of a Lifting Surface in Transonic Flow Including Flow Nonlinearities and Aeroelastic Effects

Nonlinear Static Aeroelasticity For Design

Steady Aeroelastic Analysis

- Define Control Surface Effectiveness

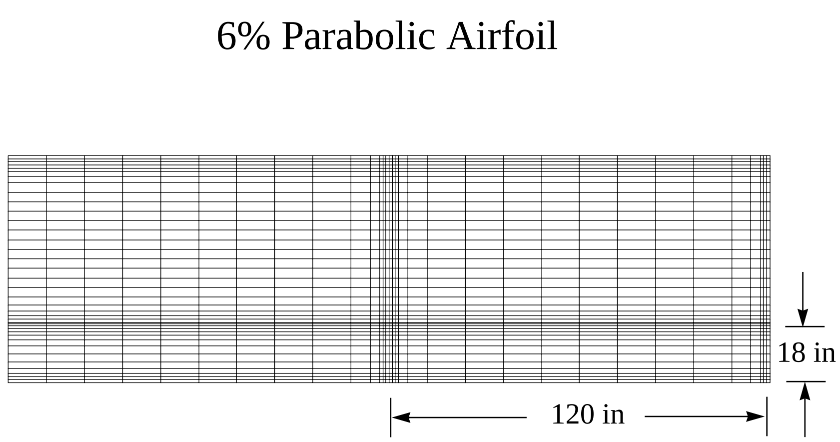
$$\varepsilon = \frac{C_{M_{\delta a_{flexible}}}}{C_{M_{\delta a_{rigid}}}}$$

- Control Surface Effectiveness

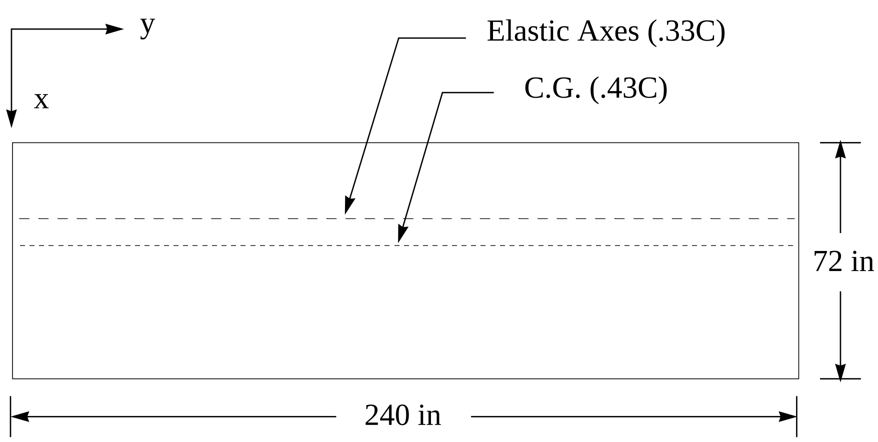
Indicates Ability of a Particular Control Surface to Generate a Rolling Moment

Control Surface Reversal Occurs when $\varepsilon = 0$

Rectangular Wing Example [15]



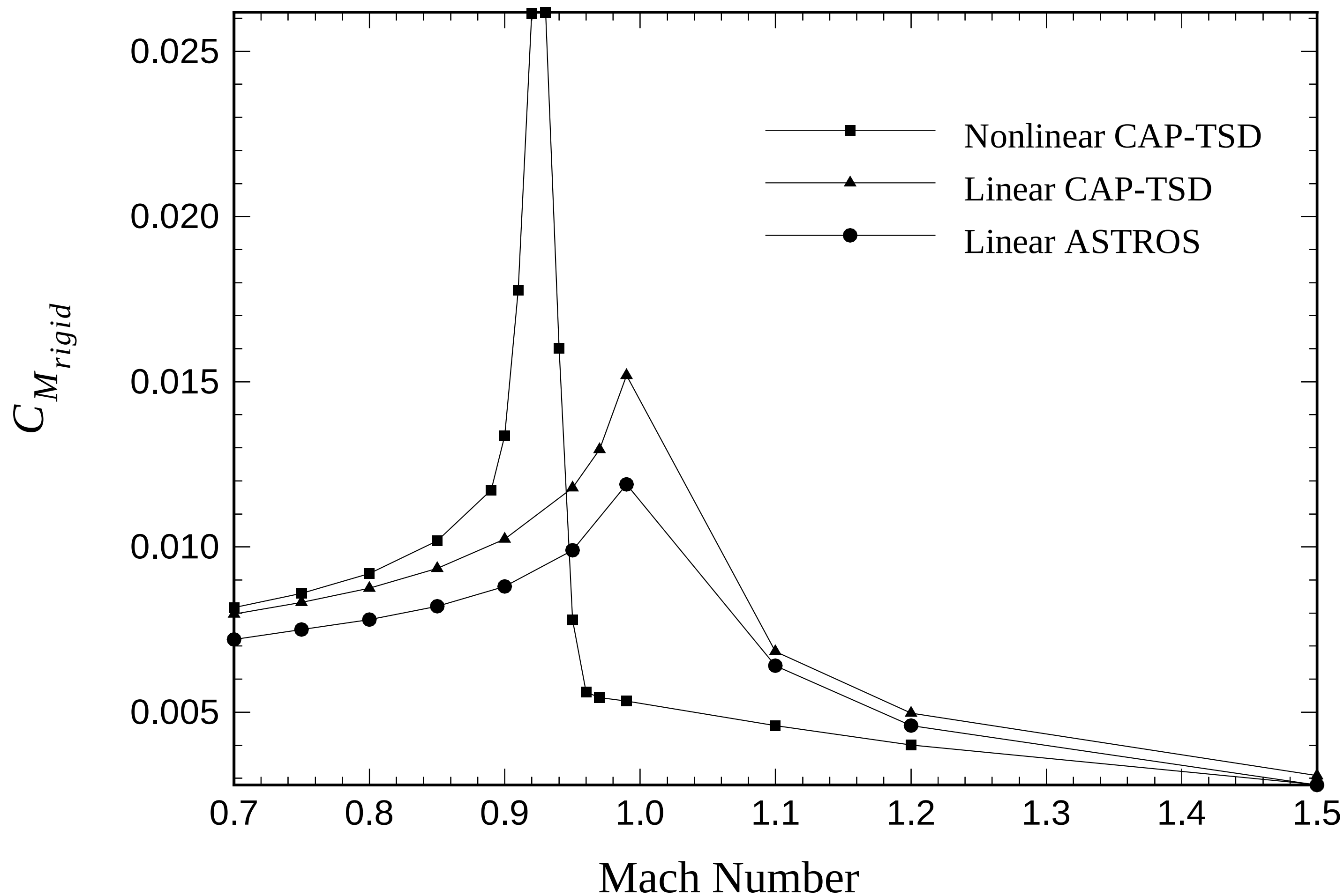
Aero Model and CAP-TSD Mesh



Structural Model

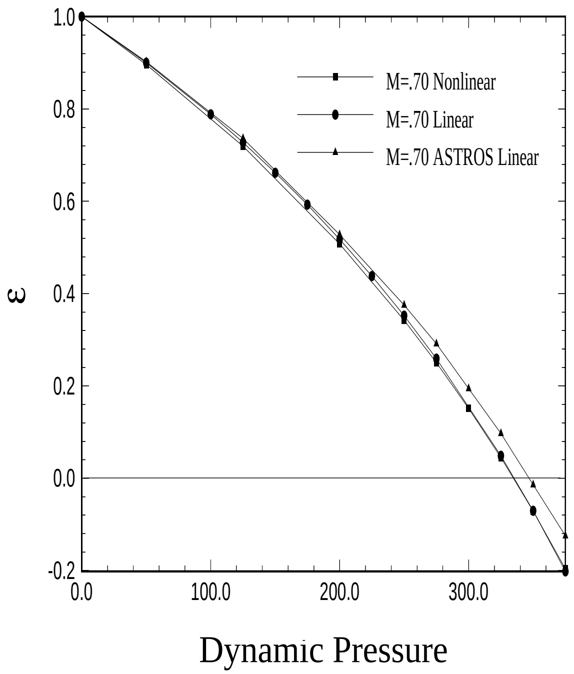
Rectangular Wing Example [15]

Rigid Rolling Moment vs. Mach Number

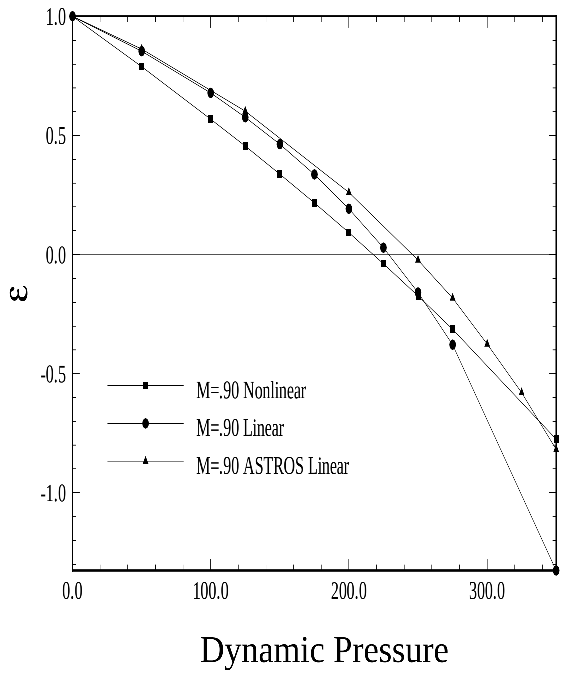


Rectangular Wing Example [15]

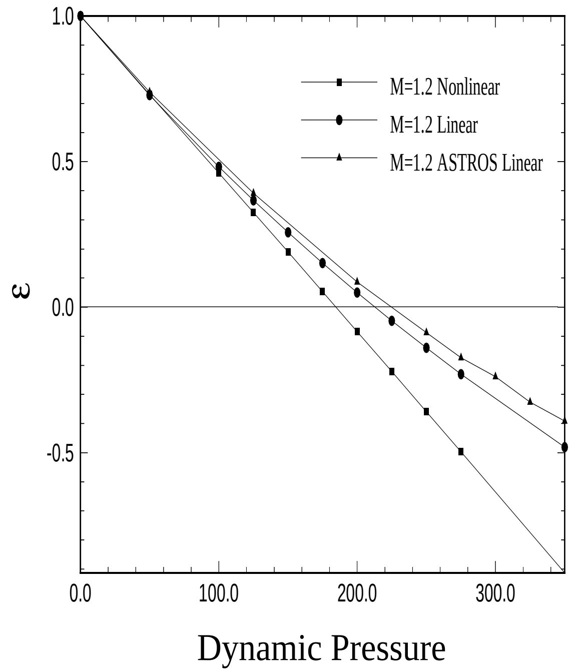
Control Surface Effectiveness



M=0.70



M=0.90

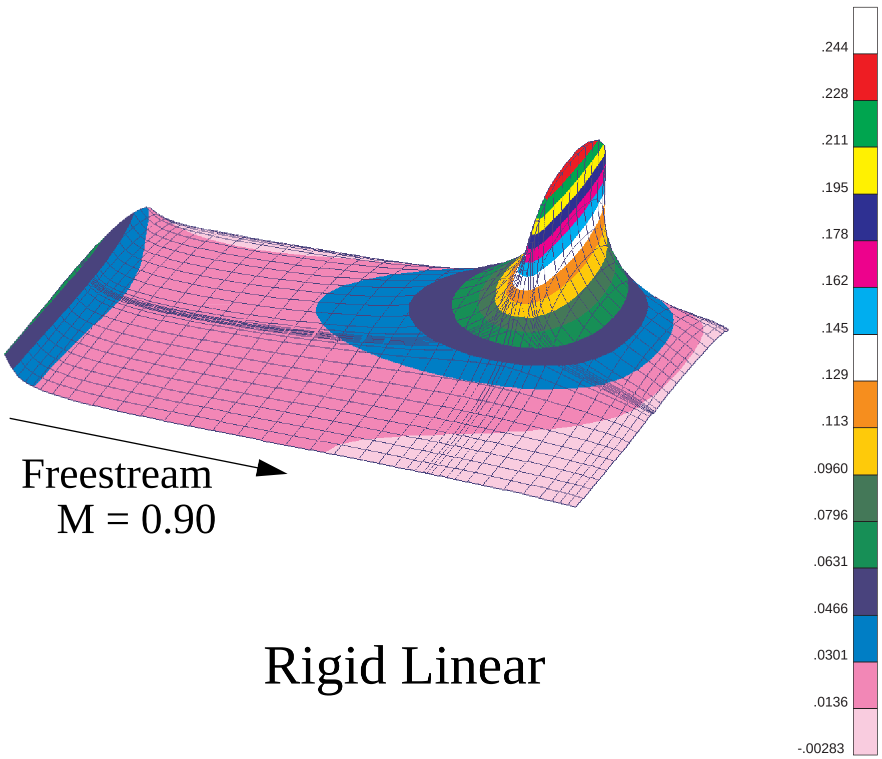


M=1.20

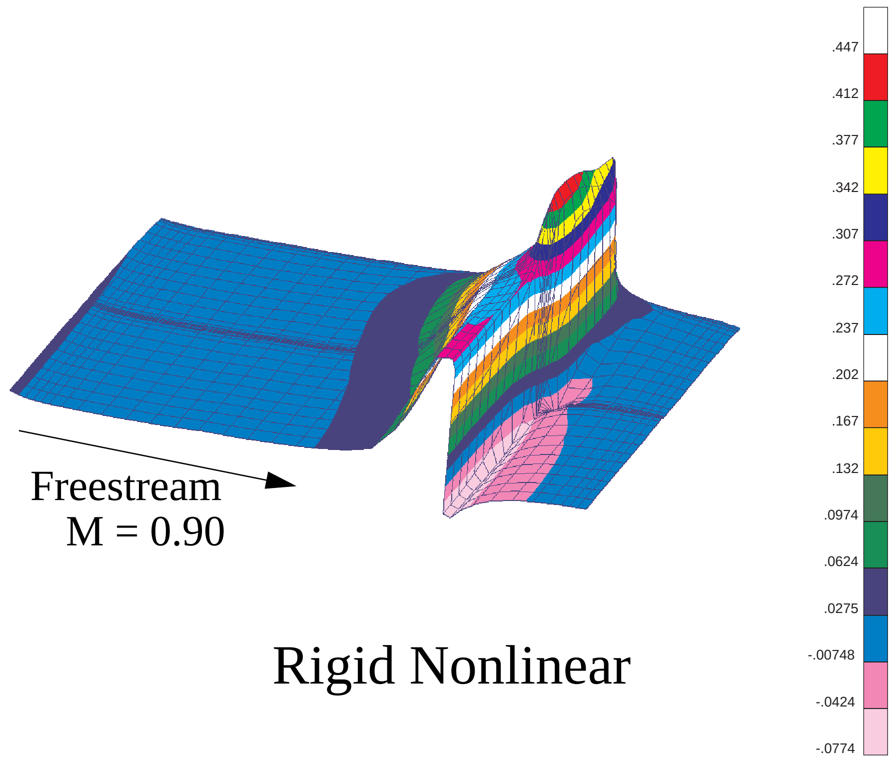
Nonlinear Static Aeroelasticity For Design

Rectangular Wing Example [15]

ΔC_p Distributions



Rigid Linear

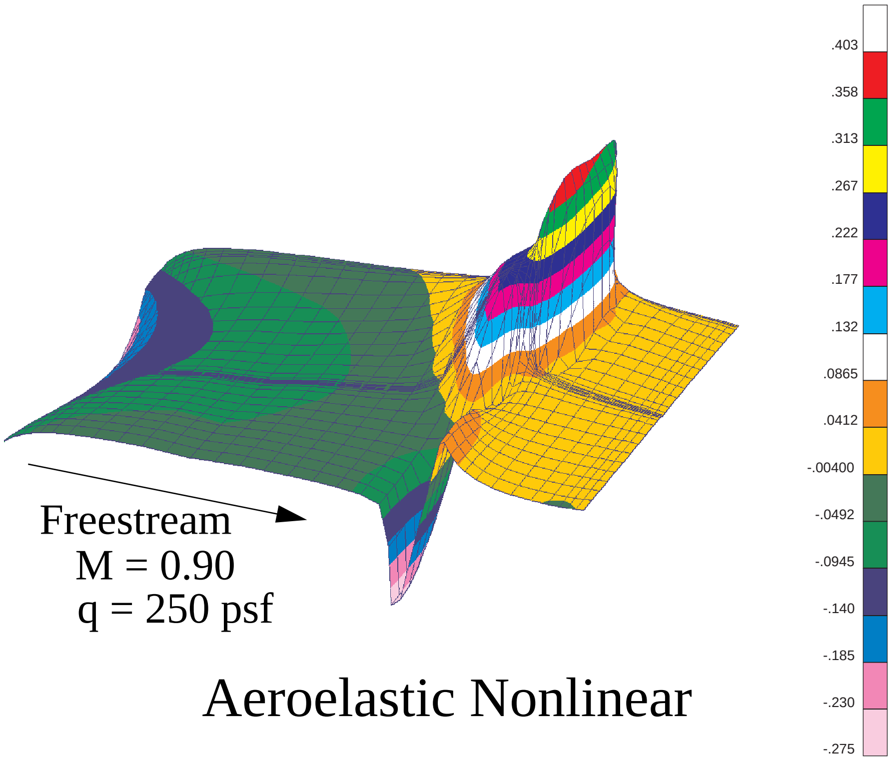


Rigid Nonlinear

Nonlinear Static Aeroelasticity For Design

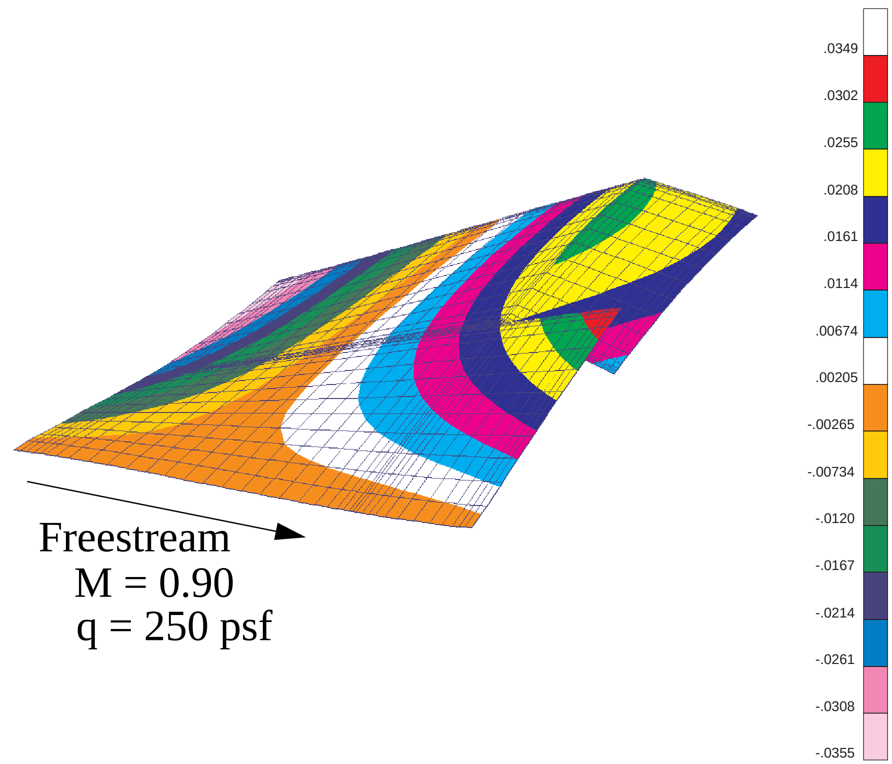
Rectangular Wing Example [15]

ΔC_p Distribution



Aeroelastic Nonlinear

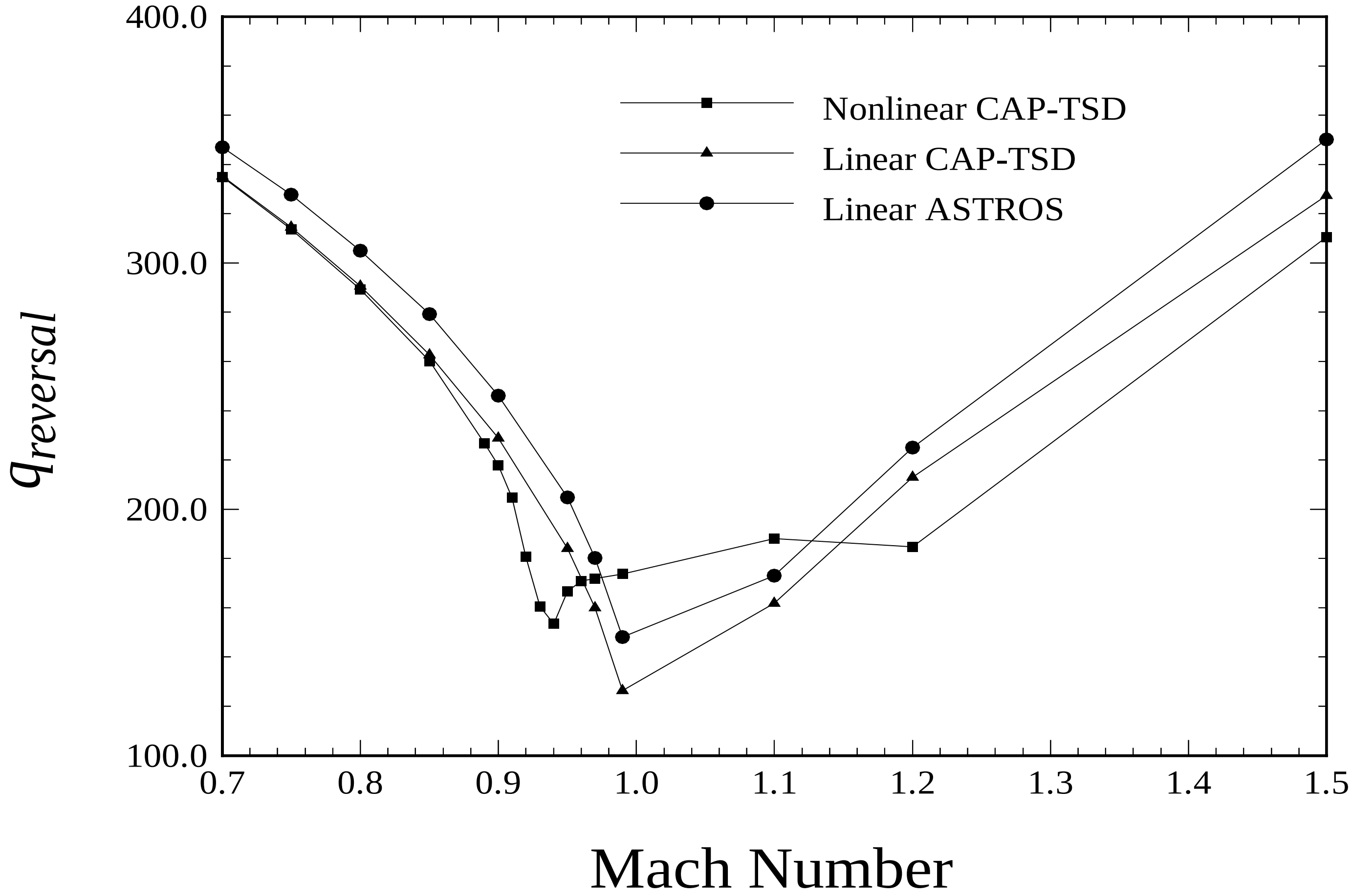
Aeroelastic Deformation



Nonlinear Static Aeroelasticity For Design

Rectangular Wing Example [15]

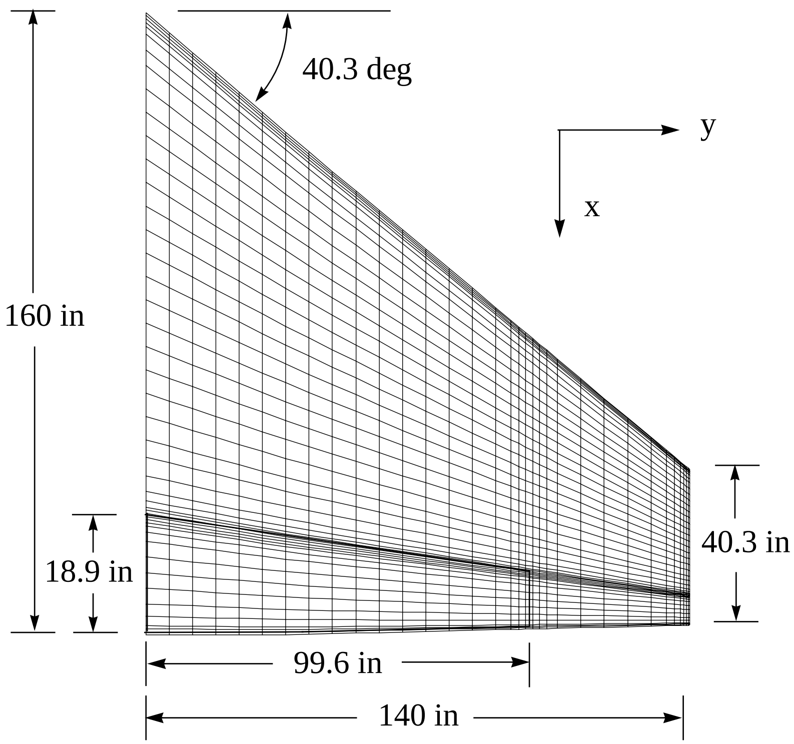
Reversal Dynamic Pressure



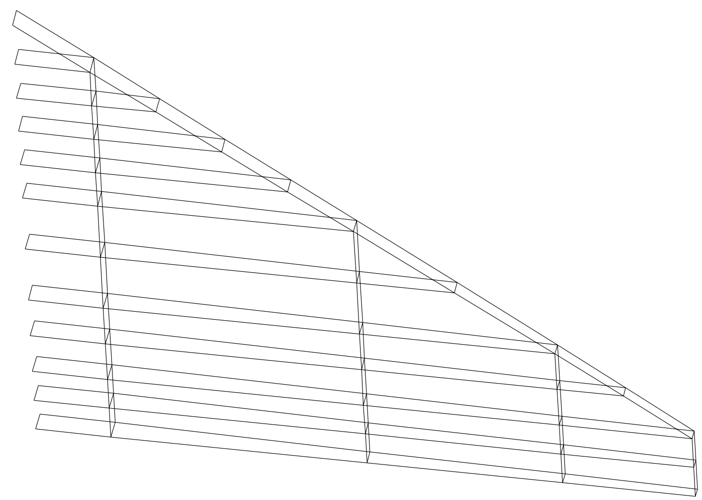
Nonlinear Static Aeroelasticity For Design

Fighter Wing Example [15]

Aero Model and CAP-TSD Mesh



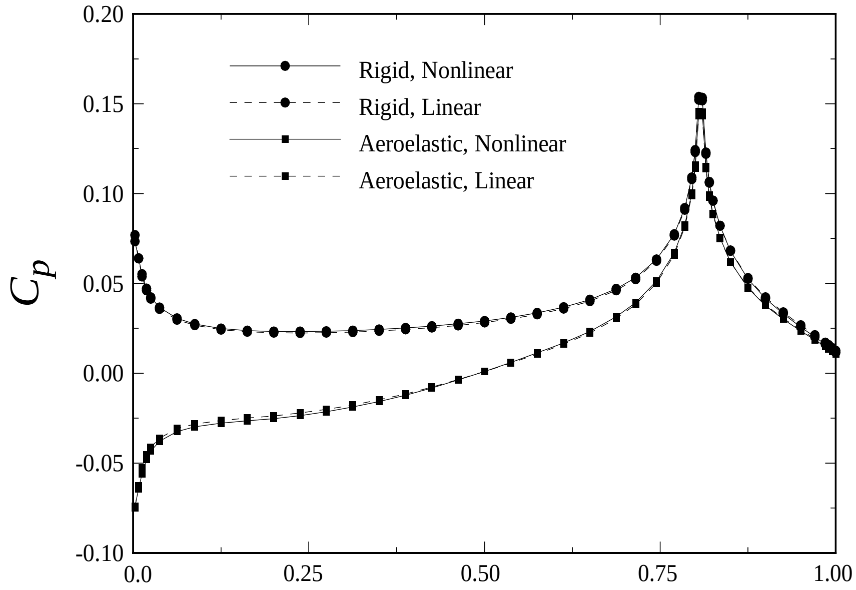
Structural Model



Nonlinear Static Aeroelasticity For Design

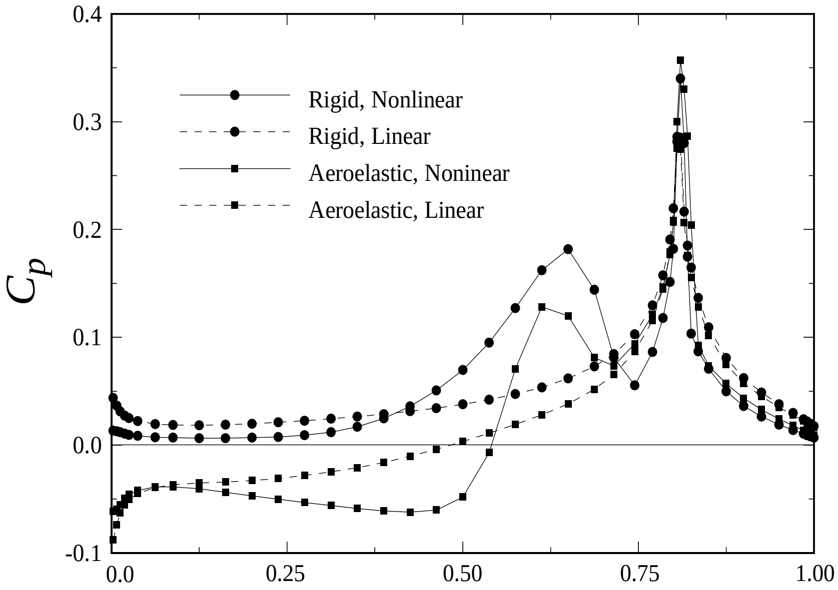
Fighter Wing Example [15]

Chordwise ΔC_p Distribution



x/c

M = 0.70



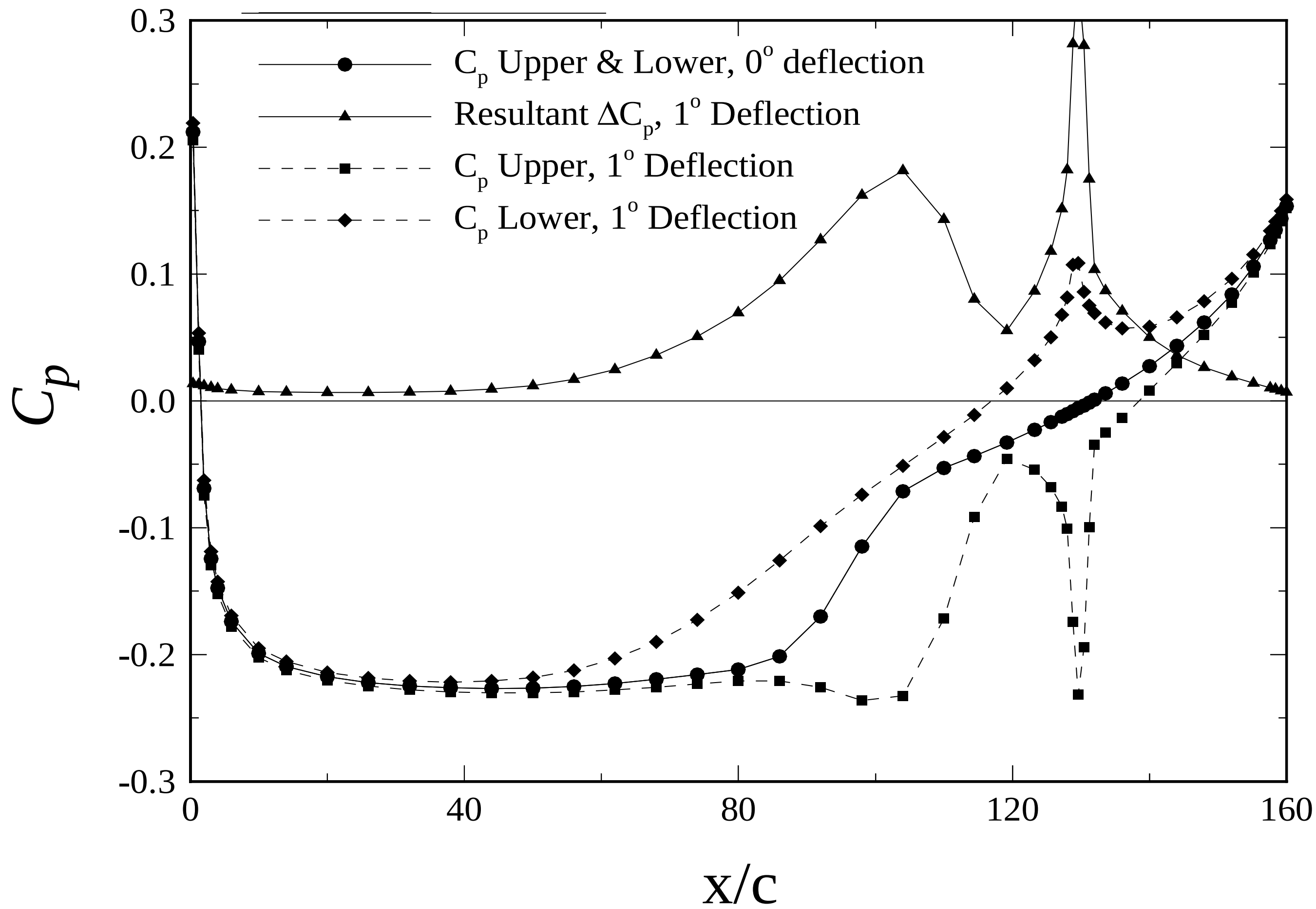
x/c

M = 0.94

Nonlinear Static Aeroelasticity For Design

Fighter Wing Example [15]

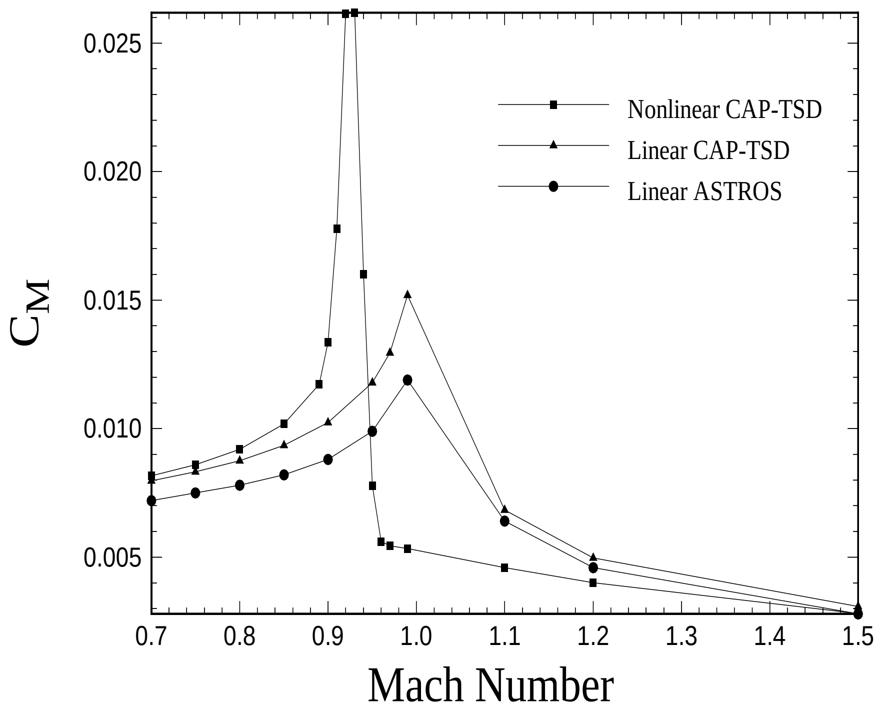
Chordwise C_p Distribution



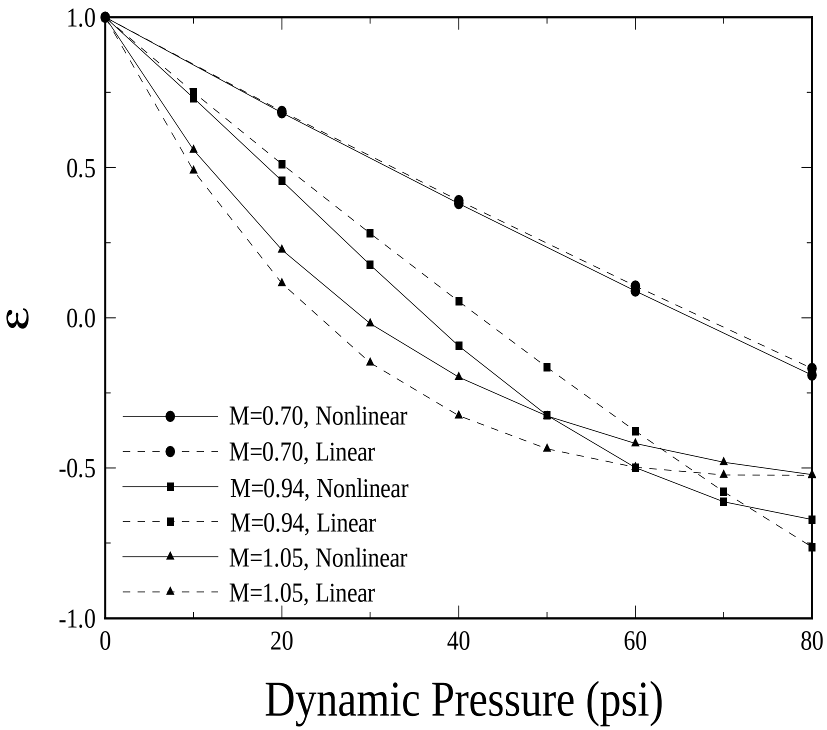
Nonlinear Static Aeroelasticity For Design

Fighter Wing Example [15]

Rigid Rolling Moment



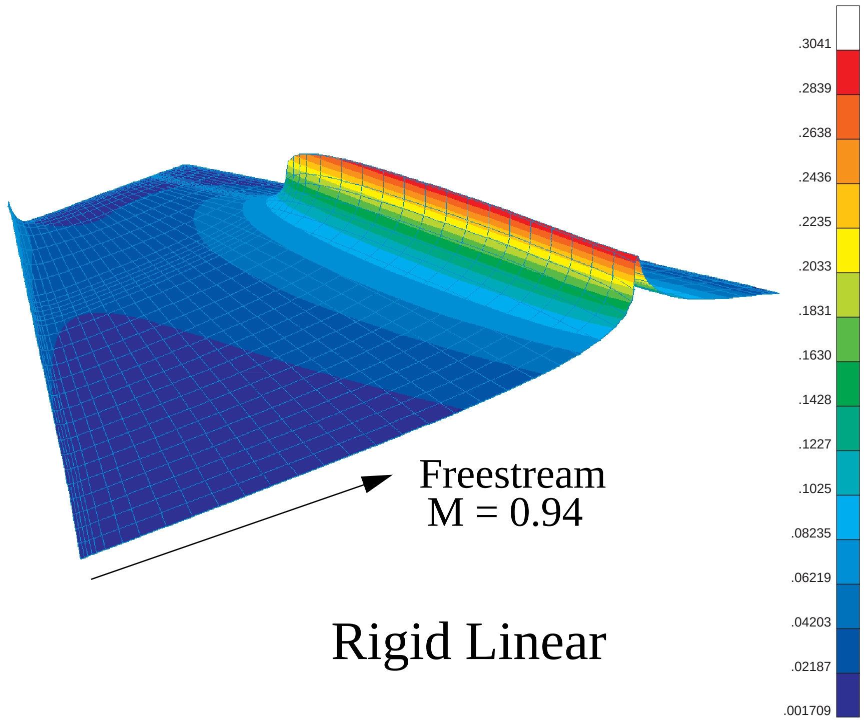
Control Surface Effectiveness



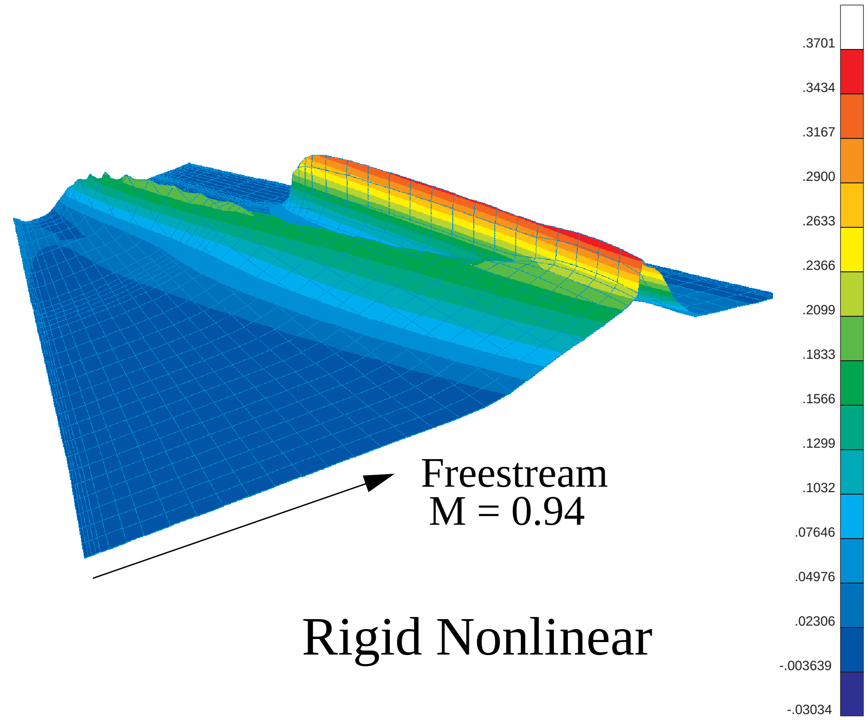
Nonlinear Static Aeroelasticity For Design

Fighter Wing Example [15]

ΔC_p Distributions



Rigid Linear

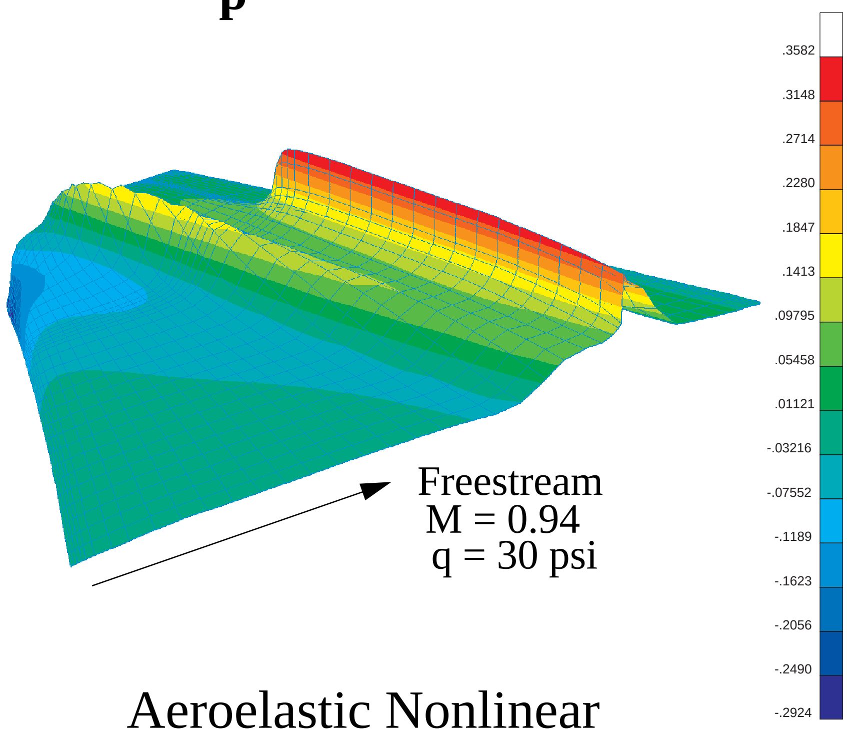


Rigid Nonlinear

Nonlinear Static Aeroelasticity For Design

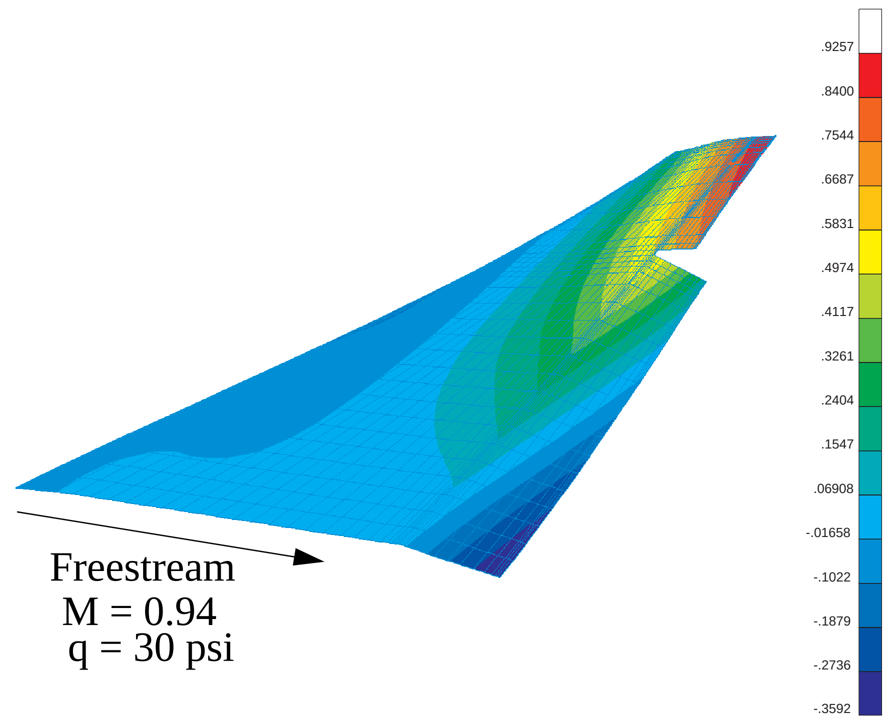
Fighter Wing Example [15]

ΔC_p Distribution



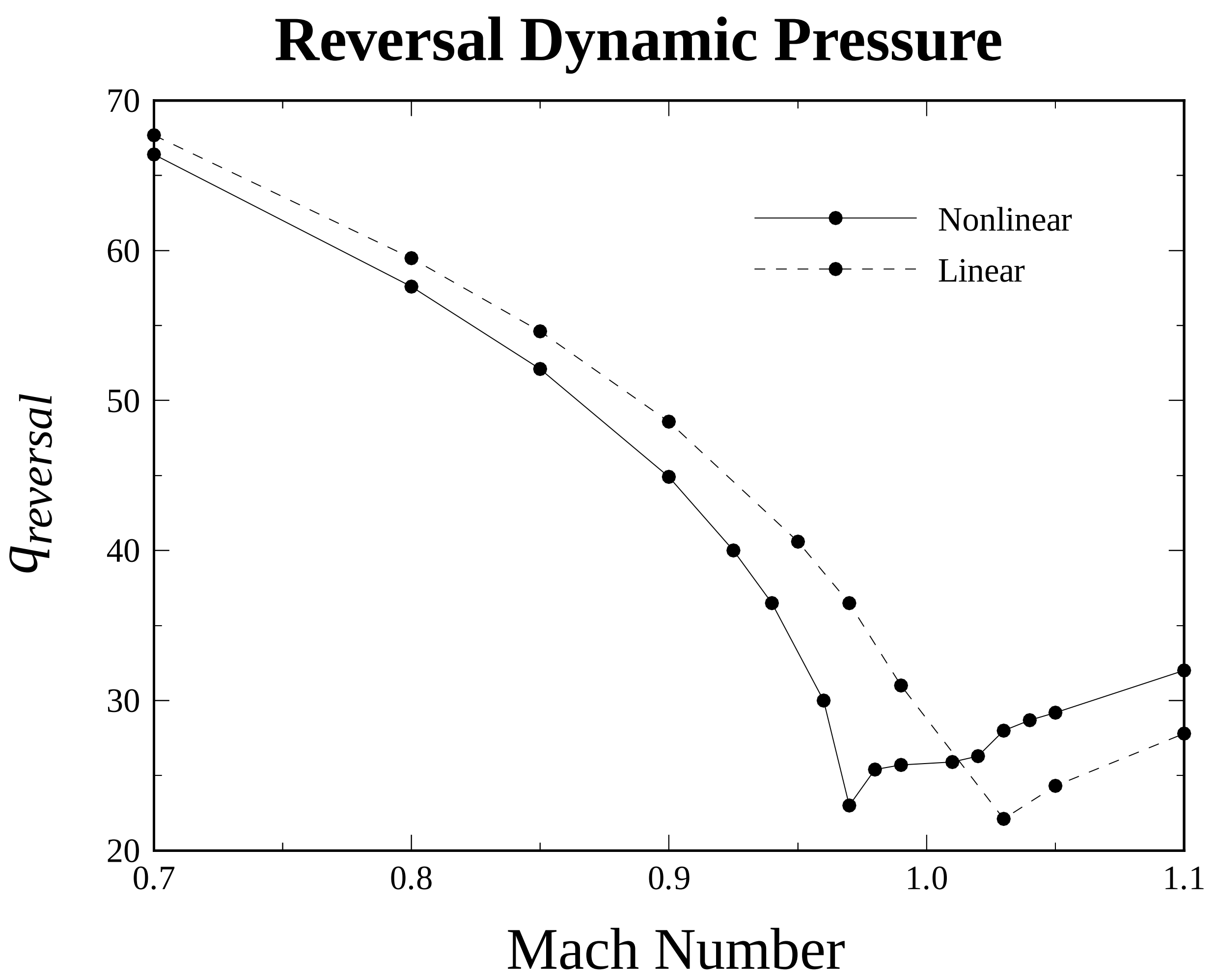
Aeroelastic Nonlinear

Aeroelastic Deformation



Nonlinear Static Aeroelasticity For Design

Fighter Wing Example [15]



Concluding Remarks Static Aeroelastic Analysis

- Research Indicates that Flow Nonlinearities Must Be Accounted for to Accurately Predict Steady Aeroelastic Behavior in the Transonic Regime
- Inclusion of Nonlinear Aerodynamics Significantly Affects Steady Aeroelastic Behavior in the Transonic Regime
  - Interaction between Shocks and Control Surface Deflection Results in a Pressure Rise in the Region of the Shocks
  - Increased Rigid Rolling Moments
  - Decreased Control Surface Effectiveness
  - Lower Reversal Dynamic Pressures

Nonlinear Static Aeroelasticity For Design

Research Topics for Nonlinear Static Aeroelastic Analysis

- Are Modal Coordinates Sufficient in Capturing Aeroelastic Response?
- Is Transonic Small-Disturbance Theory Sufficient?
  - Flow Rotationality
  - Viscous Effects
- Continue Development and Validation to Ensure Maturation into a Practiced Preliminary Design Methodology
  - Comparisons to Euler/Navier-Stokes, Experimental, and Flight Test Data
  - Integration into Preliminary Design Tools such as ASTROS
  - Application to Real Problems such as Active Aeroelastic Wing

CRD

References

1. Farhat, C., “Special Course on Parallel Computing in CFD,”AGARD-R807, October 1995.

2. Bendiksen, O. O., “Fluid-Structure Coupling Requirements for Time-Accurate Aeroelastic Simulations,” AD-Vol. 53-3, Fluid-Structure Interaction, Aeroelasticity, Flow Induced Vibration and Noise, Volume III ASME, 1997.

3. Romanowski, M.C., “Reduced Order Unsteady Aerodynamic and Aeroelastic Models Using Karhunen-Loeve Eigenmodes,” AIAA paper 96-3981-CP.

4. Lee-Rausch, E.M., Batina, J.T., “Calculation of AGARD Wing 445.6 Flutter Using Navier-Stokes Aerodynamics,” AIAA-93-3476-CP.

5. Silva, W.A., “Discrete-Time Linear and Nonlinear Aerodynamic Impulse Responses for Efficient CFD Analyses,” Ph.D. Dissertation, Department of Applied Science, The College of William and Mary in Virginia, 1997.

6. Ballhaus, W.F., and Goorjian, P.M., “Computation of Unsteady Transonic Flows by the Indicial Method”, AIAA Journal, Volume 16, No. 2, February 1978, pp. 117-124.

7. Kolonay, R.M., Yang, H.T.Y., “Unsteady Aeroelastic Optimization in the Transonic Regime,” Journal of Aircraft, Vol. 35, No. 1, pp 60-68, January-February 1998.

8. Kolonay, R.M., Yang, H.T.Y., “Static Aeroelastic Effects on a Transonic Indicial Response Wing Flutter Calculation,”, Journal of Aircraft, Vol. 35, No. 2, pp 339-340. March-April 1998.

9. Kolonay, R.M., Venkayya, V.B., Yang, H.T.Y., “Sensitivity Analysis for Transonic Unsteady Aeroelastic Constraints,” Journal of Aircraft Vol. 35, No. 4, pp 574-581, July-August 1998.

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References

10. Kolonay, R.M., “Unsteady Aeroelastic Optimization in the Transonic Regime”, Ph.D. dissertation Purdue University December 1996.

11. Borland C. J., “XTRAN3S-Transonic Steady and Unsteady Aerodynamics For Aeroelastic Applications,” AFWAL-TR-85-3124 Vol. 1, Jan. 1986.

12. Batina, J. T., “A Finite-Difference Approximate-Factorization Algorithm for Solution of the Unsteady Transonic Small-Disturbance Equation,” NASA Technical Paper 3129, Jan. 1992.

13. Rudisill S. C., Bhatia, G.K., “Optimization of Complex Structures to Satisfy Flutter Requirements,” AIAA Journal, Aug. 1971, pp. 1487-1491

14. Haftka, R. T. and Jr. Yates, C. E. “Repetitive Flutter Calculations in Structural Design,” Journal of Aircraft, Vol. 13, No. 7, 1976, pp. 454-461.

15. Andersen, G., Kolonay R., and Eastep, F., “Control Surface reversal in the Transonic Regime,” AIAA Paper 97-1385.