AERODYNAMICS SYSTEM IDENTIFICATION

Charles R. O'Neill
School of Mechanical and Aerospace Engineering
Oklahoma State University

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Fluid Structure Interactions

A single unstable system can result from two normally well behaved and stable systems.

Two Critical Questions for the Design Engineer:

Will it break?
How can I control it?

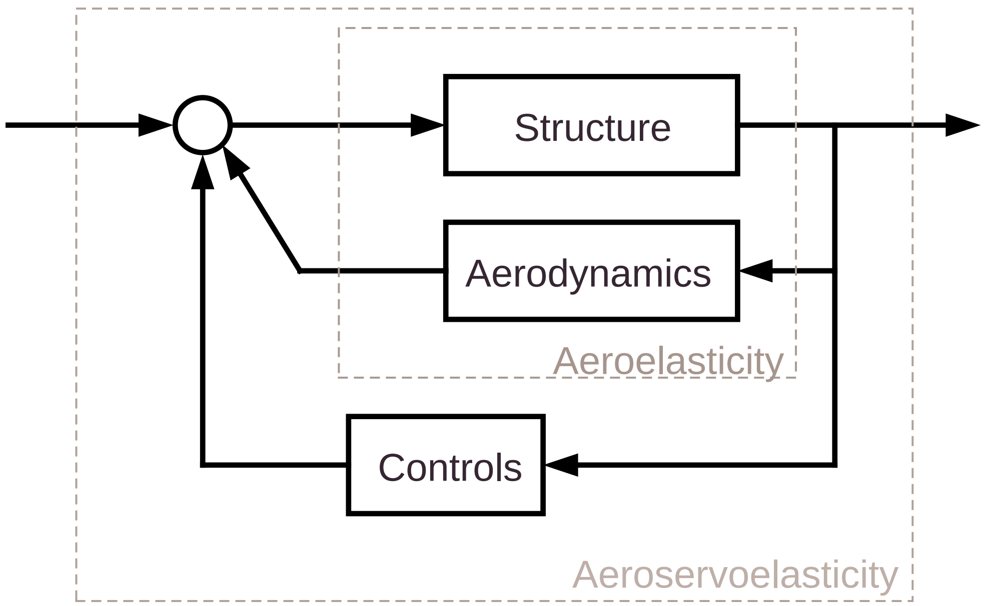
These questions reduce to one Fundamental Question:

How can I predict the system's response?

Aero Servo Elasticity

Combine:

- Aerodynamic Forces
- Structural Responses
- Control Algorithms

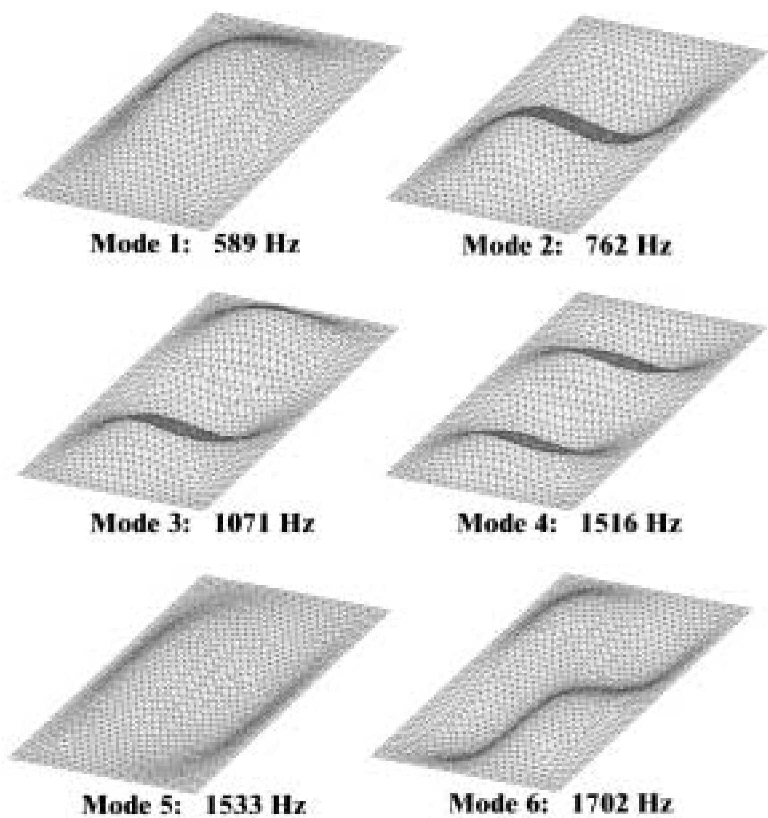


STRUCTURAL MODEL

Free Vibration with a forcing function

$$[M]\ddot{q} + [C]\dot{q} + [K]q = F$$

6 Mode Plate Example:



AERODYNAMICS MODEL

Conceptual Aerodynamics Function

$$f^{(n)} + \cdots + \ddot{f} + \dot{f} + f = c + x + \dot{x} + \ddot{x} + \cdots + x^{(n)}$$

Aerodynamics Model

An input/output relationship is needed.
One possible solution is an ARMA model.

$$f(k) = \sum_{i=1}^{na} [A_i] f(k-i) + \sum_{i=0}^{nb-1} [B_i] q(k-i)$$

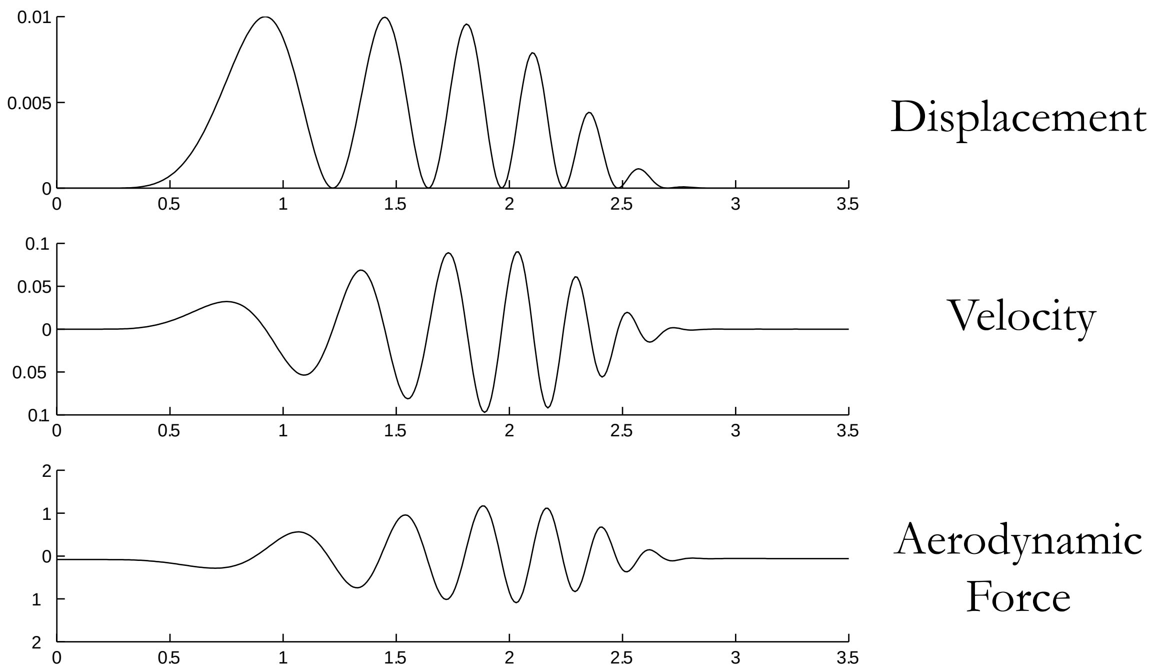
Internal Response — Describes how current forces depend on past forces.

Input Response — Describes how current forces depend on the input history.

TRAINING THE AERODYNAMICS MODEL

The training signal must excite the dominate aerodynamics while remaining within the limitations of discrete time.

Choose an analytic function with a linear frequency sweep and an envelope decay.



COMBINED AEROSTRUCTURE MODEL

Discrete time state space form

$$\begin{bmatrix} x_s(k+1) \\ x_a(k+1) \end{bmatrix} = \begin{bmatrix} G_s + q_\infty H_s D_a C_s & q_\infty H_s C_a \\ H_a C_s & G_a \end{bmatrix} \begin{bmatrix} x_s(k) \\ x_a(k) \end{bmatrix} + \begin{bmatrix} H_s \\ 0 \end{bmatrix} [f_I] + \begin{bmatrix} q_\infty H_s \\ 0 \end{bmatrix} [f_0]$$

$$q(k) = \begin{bmatrix} C_s & 0 \end{bmatrix} \begin{bmatrix} x_s(k) \\ x_a(k) \end{bmatrix}$$

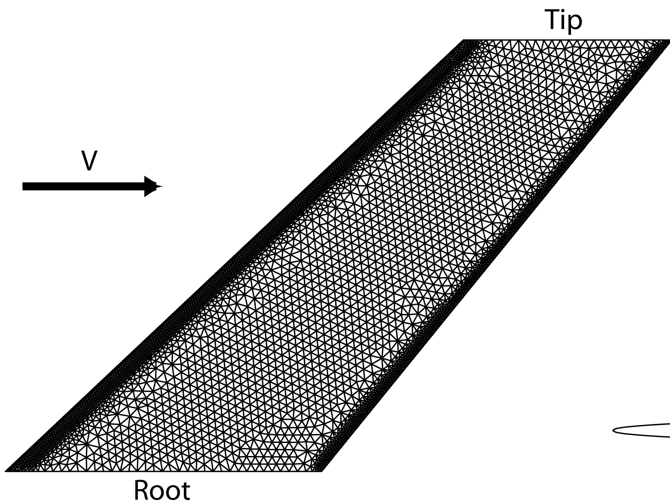
This coupled form is sufficient for determining free response characteristics.

OR

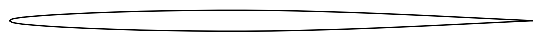
Retrieve the plant matrix from above and evaluate the eigenvalues.

$$\begin{bmatrix} G_s + q_\infty H_s D_a C_s & q_\infty H_s C_a \\ H_a C_s & G_a \end{bmatrix}$$

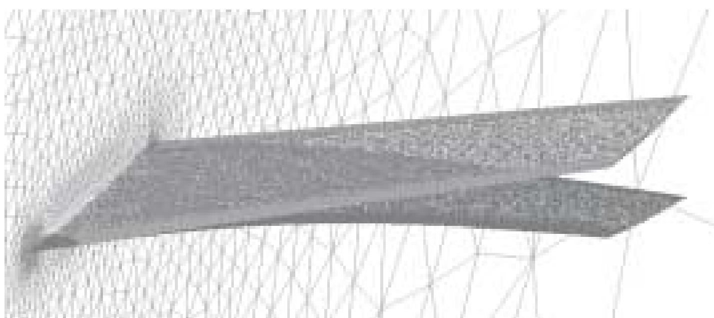
AGARD 445.6 TESTCASE



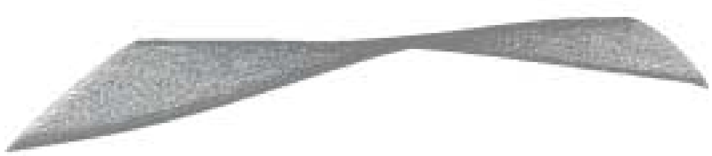
45 degree sweep
Aspect Ratio of 2
60% taper ratio
NACA 65A004



Two Mode Structural Model



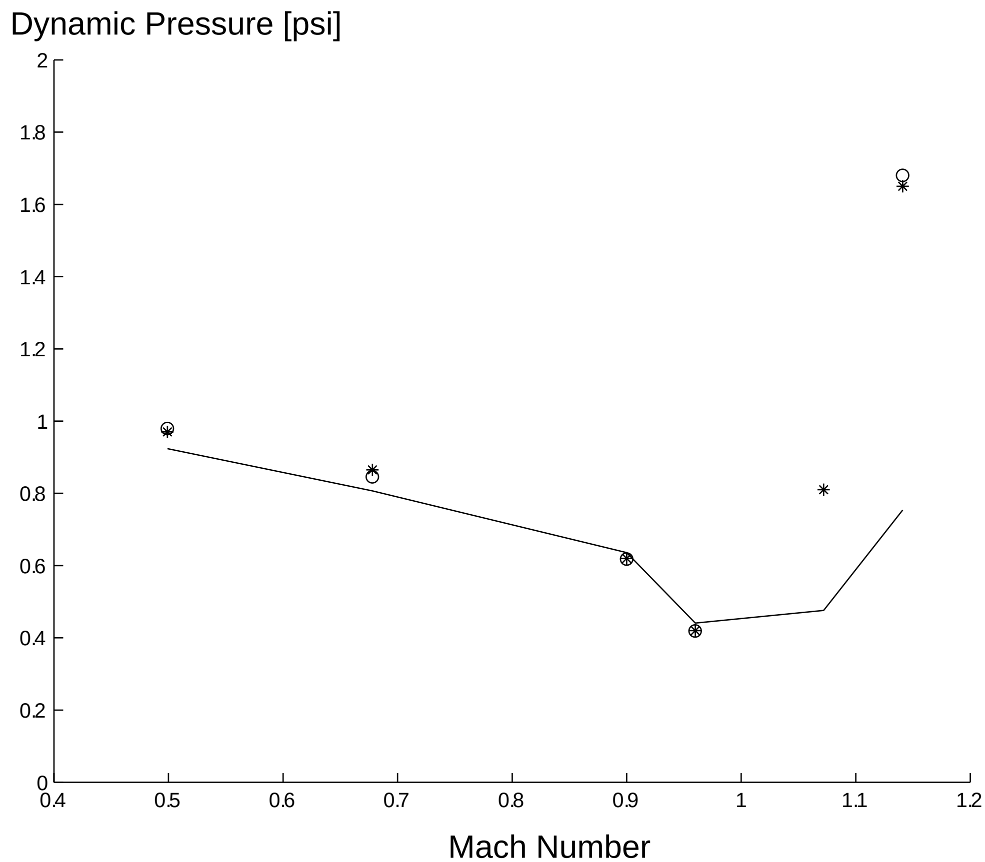
First Bending Mode
9.6 Hertz



First Torsional Mode
38.2 Hertz

STABILITY BOUNDARY

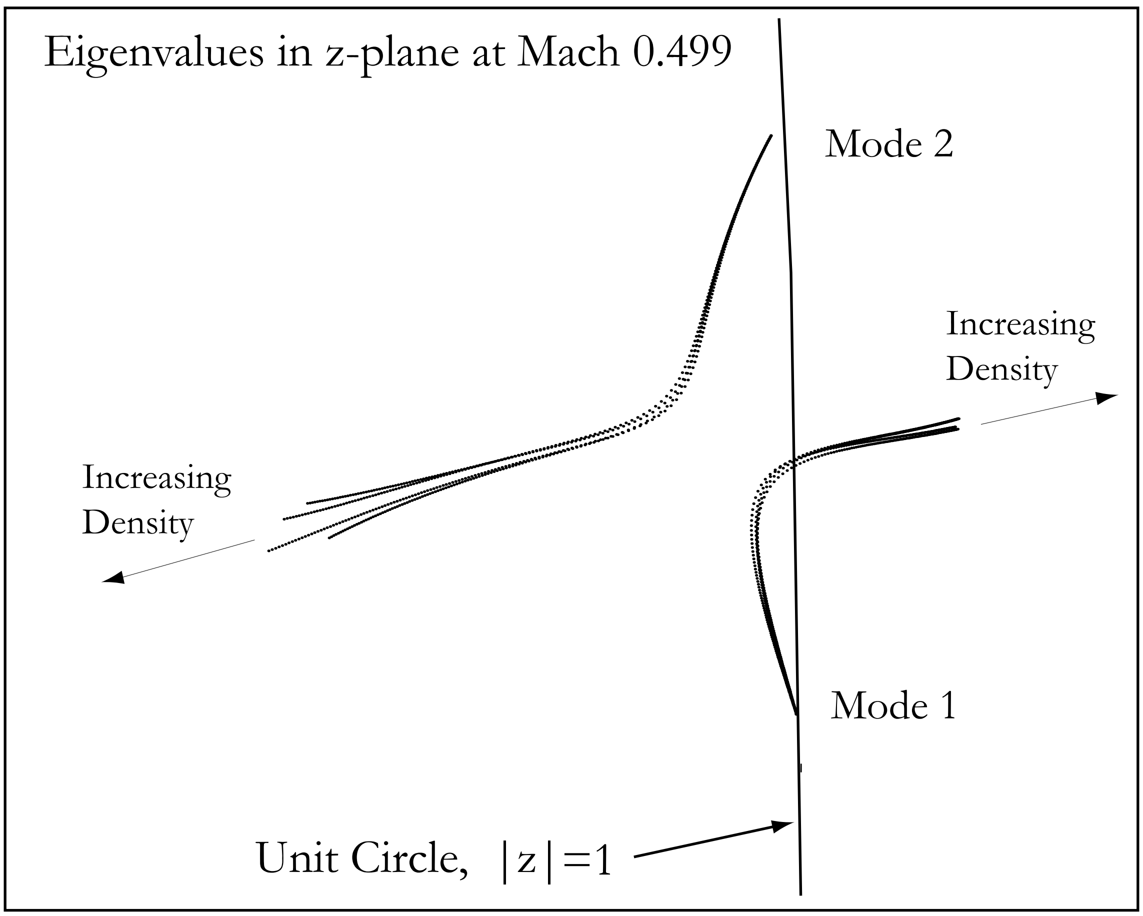
The stability boundary for the system model matches the CFD free response boundary.



SENSITIVITY STUDIES

Model Order Sensitivity

The eigenvalues corresponding to the first two structural modes are plotted for ARMA model orders: 1-5, 2-5, 5-10, 20-50

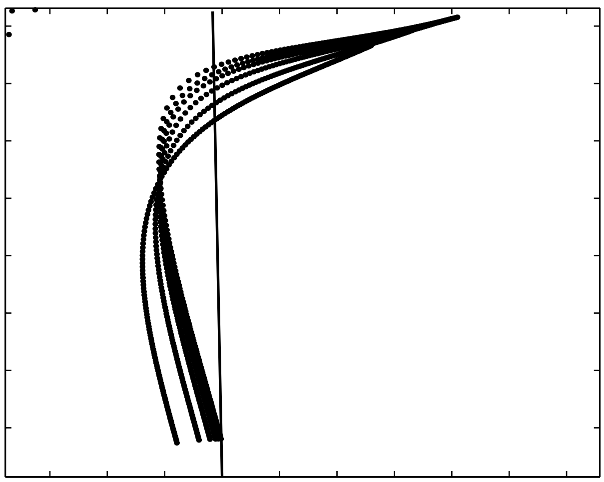


SENSITIVITY STUDIES

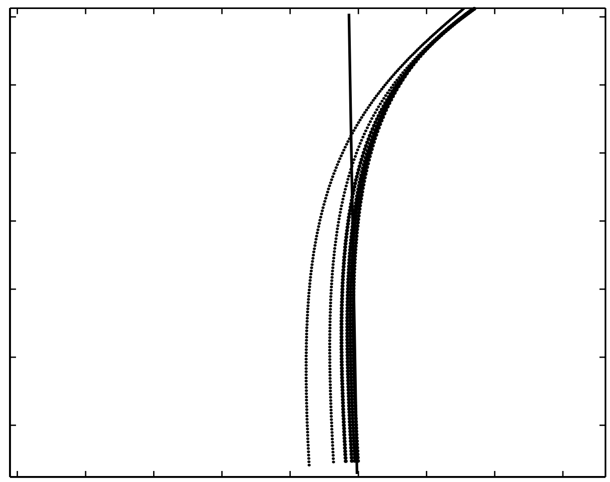
Structural Damping Sensitivity

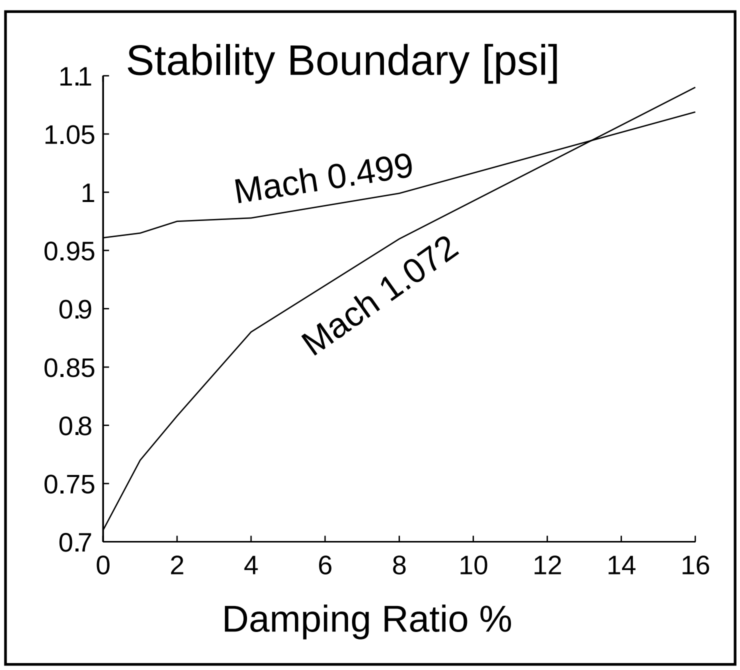
The eigenvalues corresponding to Mach 0.499 and Mach 1.072 are plotted for damping ratios of: ζ = 0% 1% 2% 4% 8% 16%

Mach 0.499



Mach 1.072



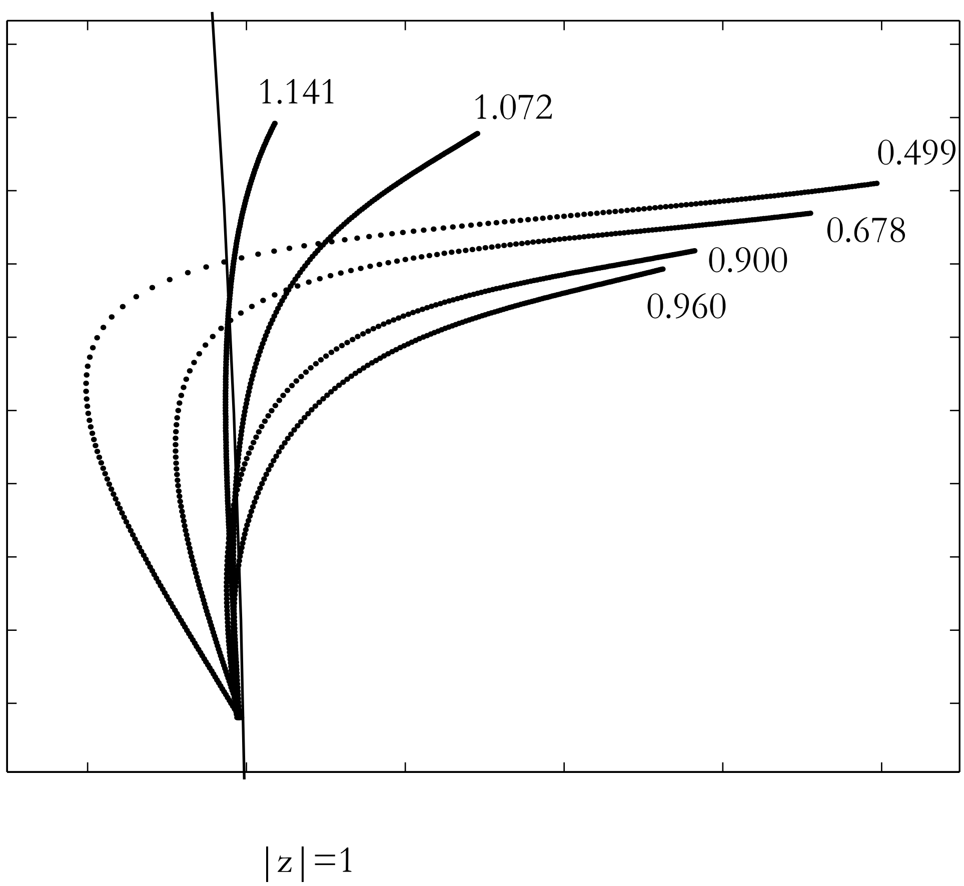


SENSITIVITY STUDIES

Mach Number Sensitivity:

Plotting the eigenvalues for a range of Mach numbers shows that aerodynamic damping in mode 1 causes the transonic stability boundary dip.

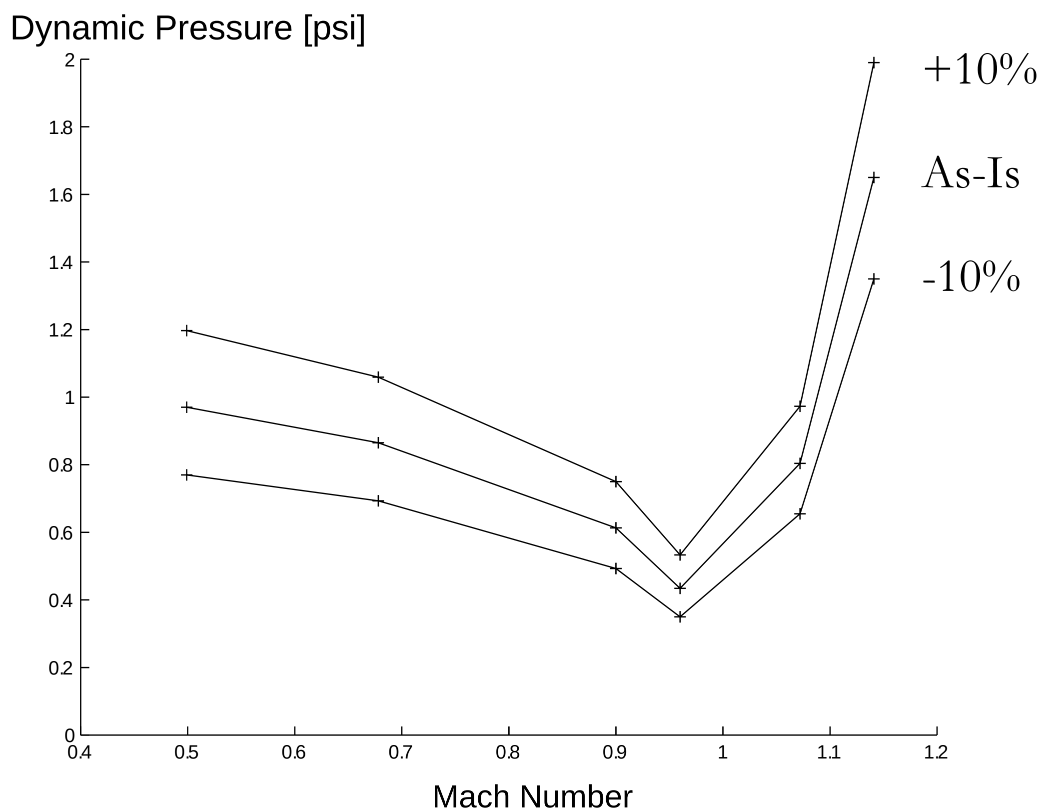
Density Sweep of Eigenvalues at each Mach #



SENSITIVITY STUDIES

Structural Sensitivity:

Change the free vibration frequencies by +10% and -10% and plot the stability boundary.



SUMMARY

Aerodynamics system identification offers
a practical solution to aeroservoelastic stability,
control and design.

System identification allows for comparisons
and discoveries that are not tractable in the
time domain.

System identification techniques offer powerful
tools to quantify and understand actual experimental
uncertainties.