BSCW Computations Using KESTREL and AEROM

Walt Silva

Aeroelasticity Branch

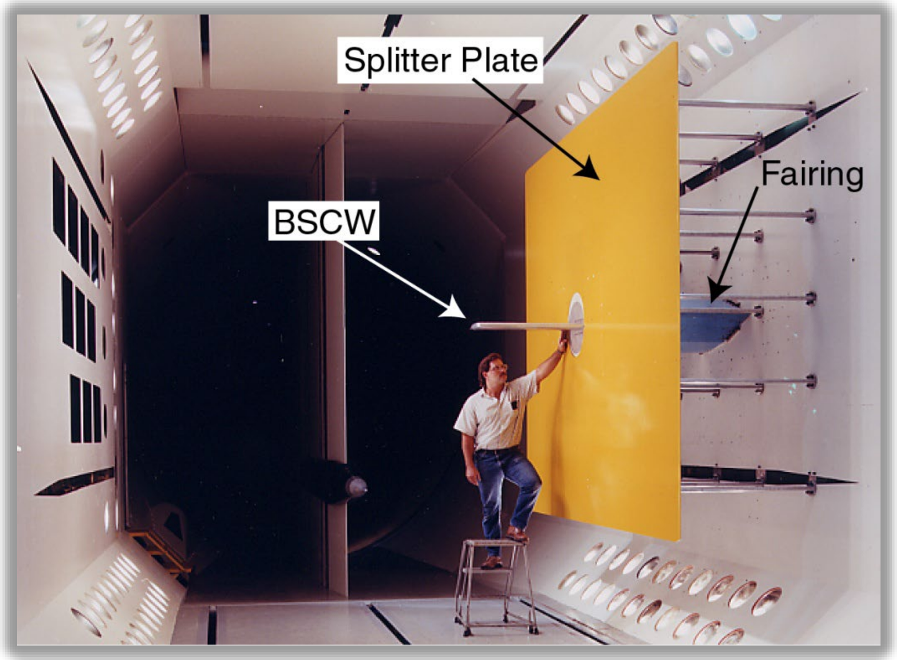
NASA Langley Research Center, Hampton, VA

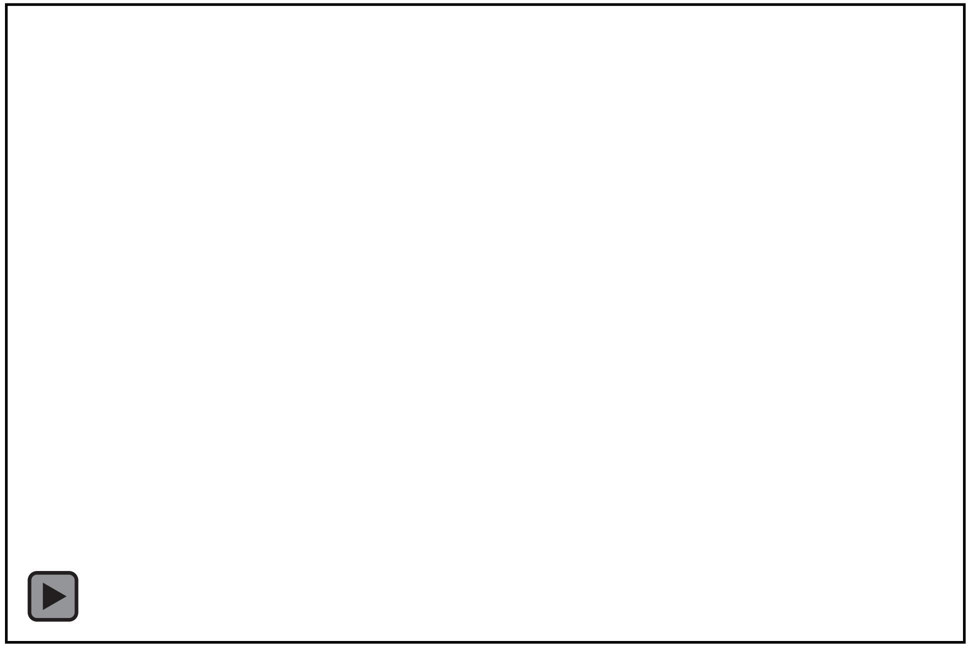
NASA/CREATE-AV Technical Interchange Meeting
May 21-22, 2024
NASA Langley Research Center | Hampton, VA

Outline

- **Benchmark SuperCritical Wing (BSCW), Aeroelastic Prediction Workshop (AePW)**
- **Background**
- **AEROM**
- **Results**
  - Alpha=0, 1, 3, and 5 degs (skip alpha=1 deg; similar to alpha=0 deg)
  - Amplitudes = 0.04, 0.01, 0.08, and 0.001 (modal)
  - Comparison of full solution GAFs vs ROM GAFs (error quantification)
  - Root locus
  - Comparison of full solution transients vs ROM transients (at a specified Q)

Benchmark Supercritical Wing (BSCW)

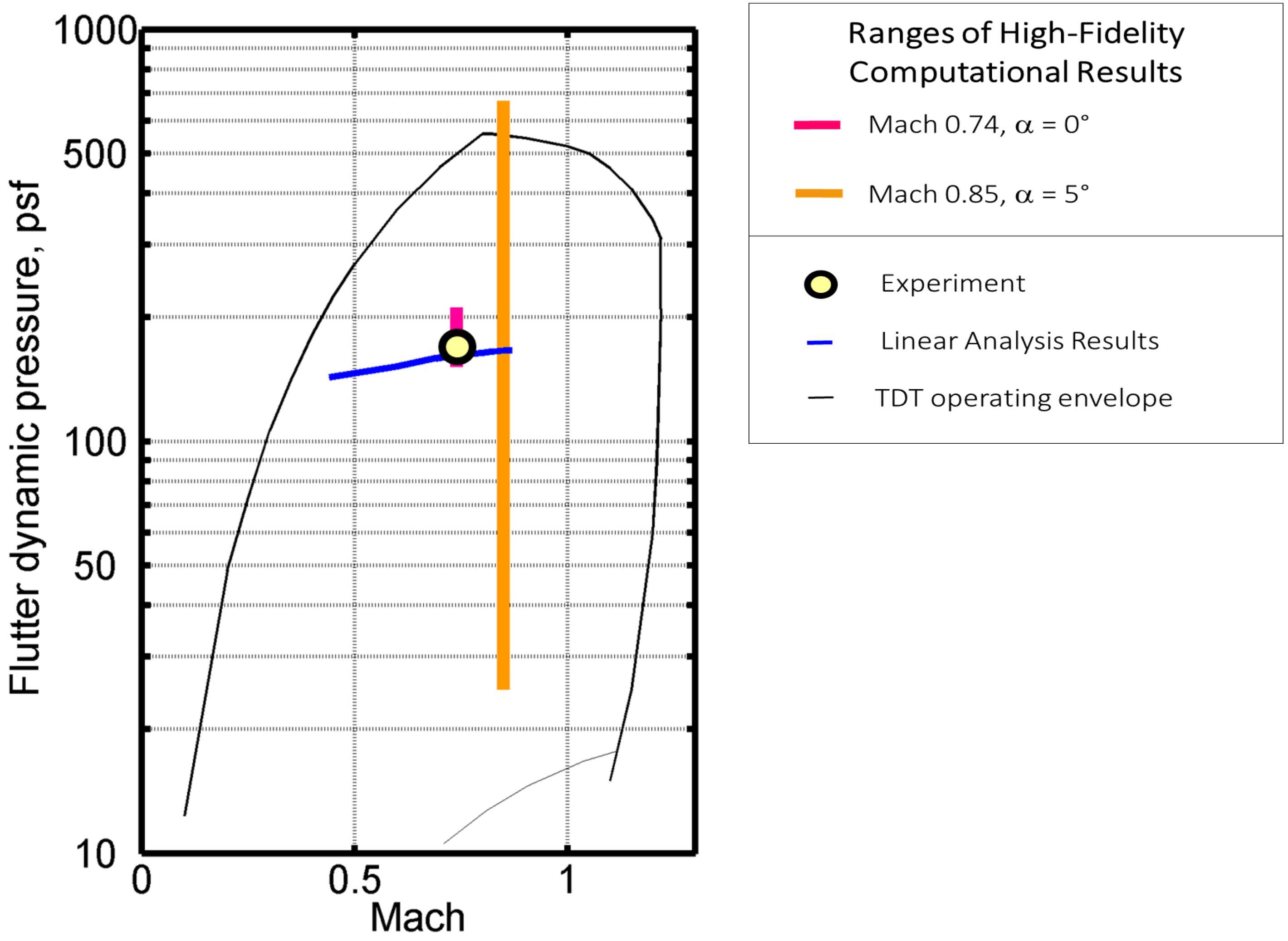




$M=0.85$, $Re_c=4.49$ million, test medium: R-134a, $\alpha = 5°$, $\theta = 1°$, freq 1 & 10 Hz

- Challenging test case, simple geometry, complex physics
- Strong shock with shock-induced separated flow
- Computational methods had difficulty producing converged solutions due to flow field complexity
- CFD solutions vary widely (static, aeroelastic solutions)

Aeroelastic Responses



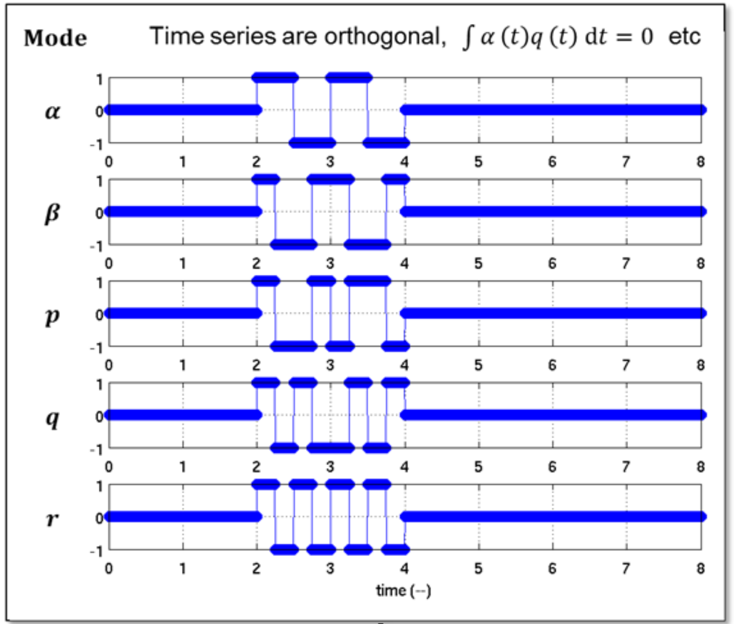
- At Mach 0.74, a = 0°
  - Small variation in computational results
  - Match the experimental results well
  - Match the linear results well
- At Mach 0.85, a = 5°
  - Significant variation in predictions
  - No experimental data for comparison

Background

- Application of KESTREL and KESTREL/AEROM to BSCW wing
- At M=0.74, alpha=0 deg, KESTREL, KESTREL/AEROM, FUN3D, and FUN3D/AEROM all compare nearly exactly with data
- At M=0.85, alpha=5 deg, large flow separation/unsteadiness; very challenging problem
- Large variance from one code to another at this condition; differences between KESTREL and FUN3D
- Goal of this analysis: evaluate application of AEROM using KESTREL at M=0.80 and alpha=0, 1, 3, and 5 deg (similar unsteadiness to M=0.85) using multiple amplitude excitations (Walsh functions)
- Follow-up with investigation of code-to-code comparisons
- ”Characterizing Aerodynamic Damping of a Supersonic Missile with CFD”, Shelton (AF), Martin (AF), Silva (NASA), SciTech 2018

System ID for MIMO Systems

Walsh Function Training Motion → **Aerodynamic Impulse Response**



Impulse Responses: $Y(k) = \begin{bmatrix} h_{N,\alpha}(k) & \cdots & h_{N,r}(k) \\ \vdots & \ddots & \vdots \\ h_{n,\alpha}(k) & \cdots & h_{n,r}(k) \end{bmatrix}$

with $Y(k) = \begin{cases} D & k = 0 \\ CA^{k-1}B & k \geq 1 \end{cases}$

State space model
$\dot{x} = Ax + Bu$
$y = Cx + Du$

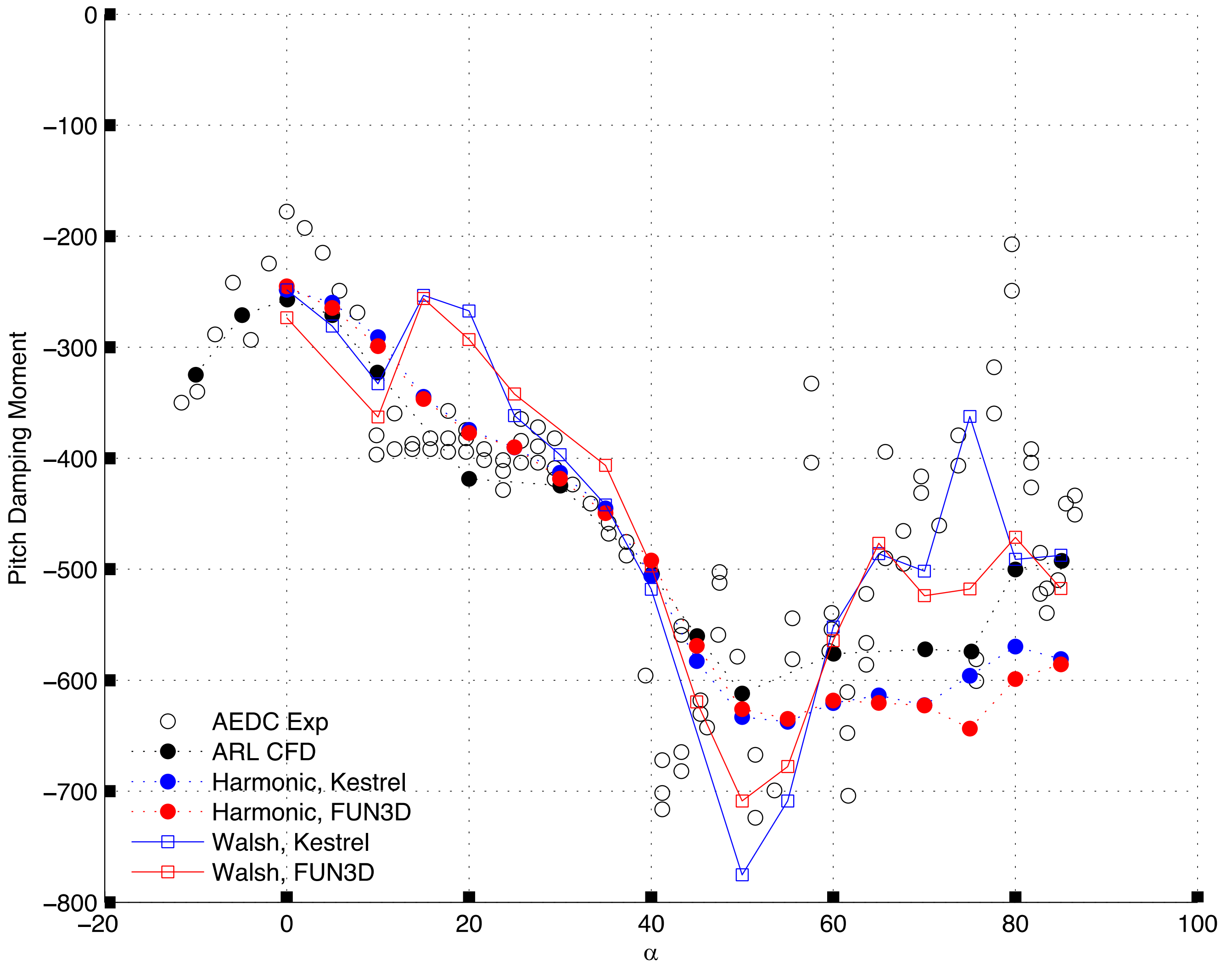
Input, $u(t) = (\alpha, \beta, p, q, r)$
Output, $y(t) = (C_A, C_S, C_N, C_l, C_m, C_n)$

System ID
- Observer/Kalman Identification
- Eigenvalue Realization Algorithm

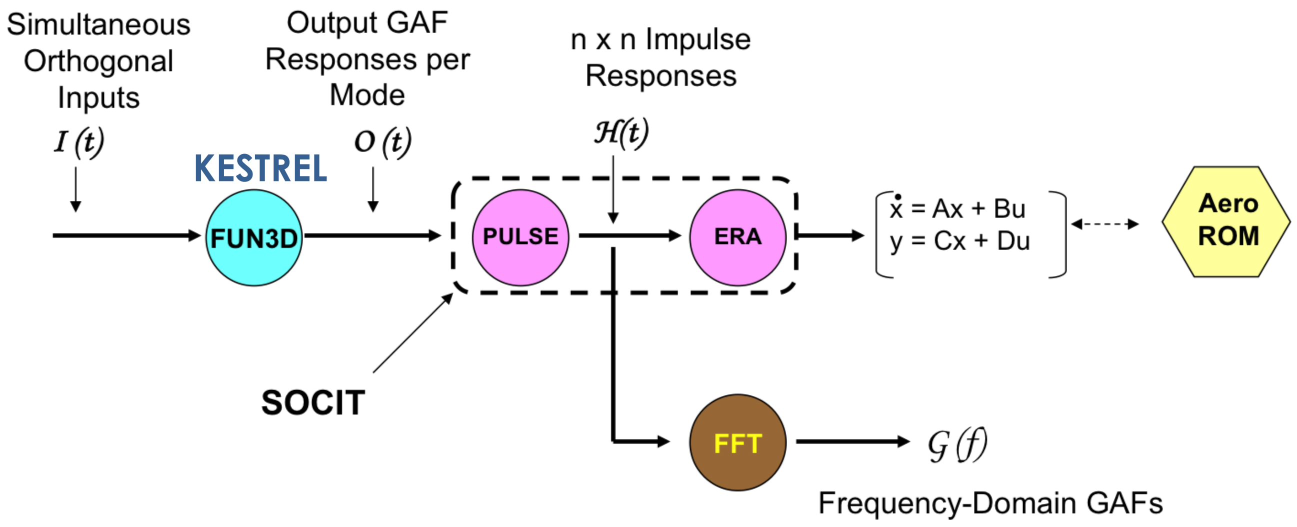
Computational Fluid Dynamics (Kestrel or FUN3D)

System/Observer/Controller Identification Toolbox (SOCIT)

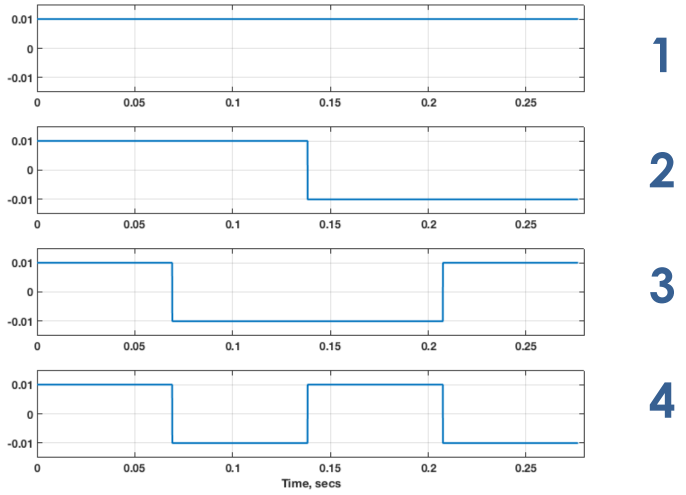
Pitch Moment Damping (Walsh vs Harmonic)



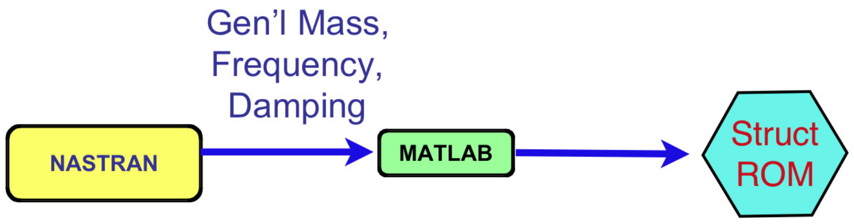
AEROM: Unsteady Aero State-Space ROM



Walsh Functions (modal)

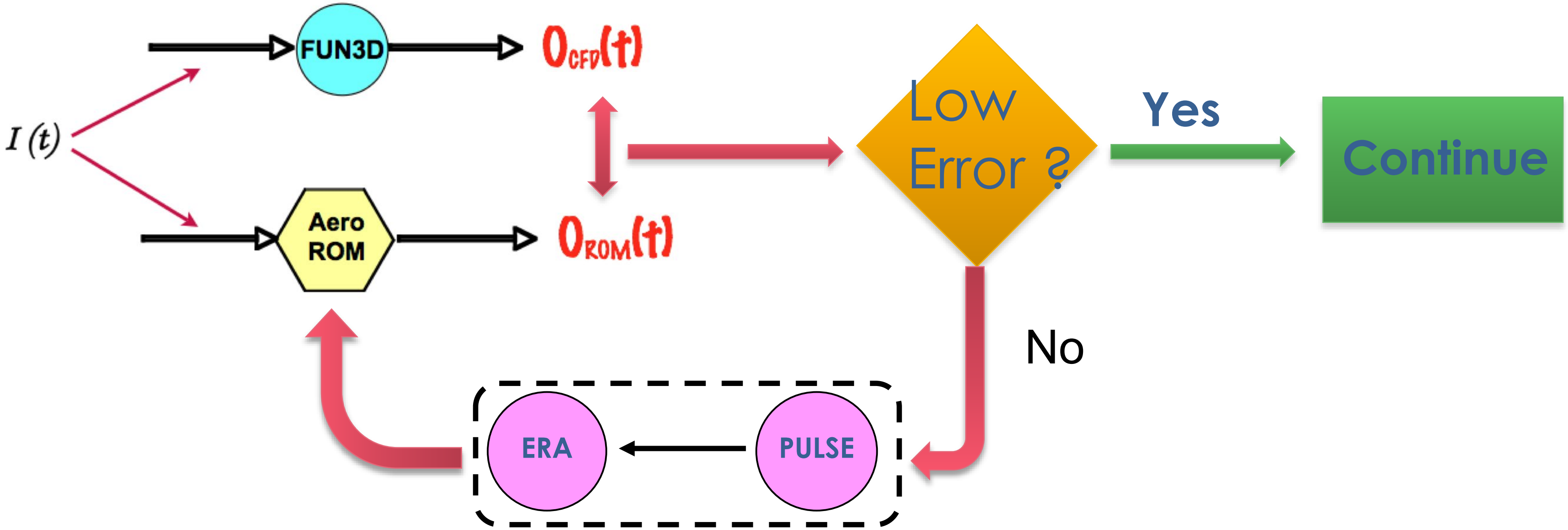


Structural state-space ROM



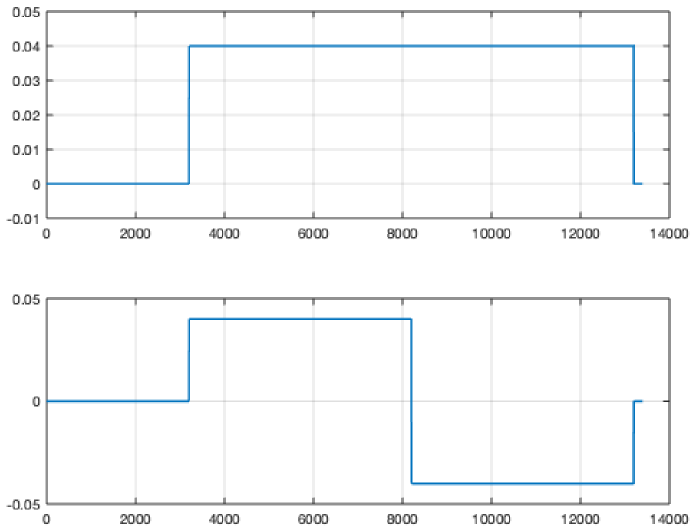
AEROM: Unsteady Aero State-Space ROM

Error Minimization (Unsteady Aero)



KESTREL/BSCW Application (Two Modes)

***.fmh file**

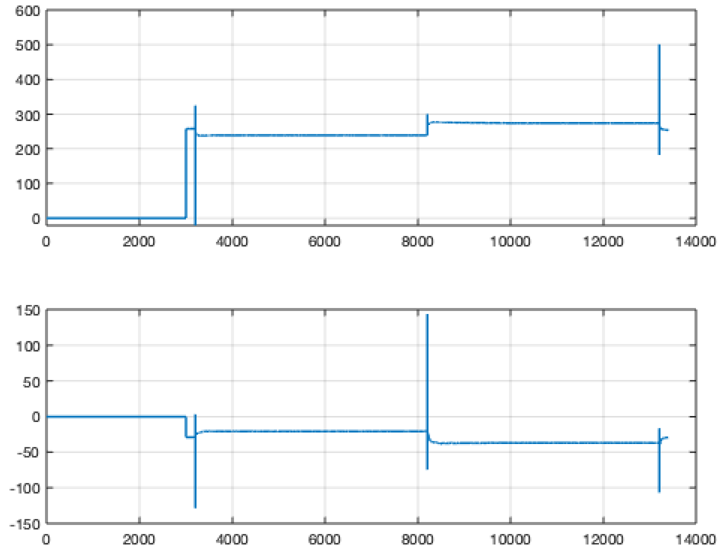


Two Walsh input functions

KESTREL

BSCW

***.modes file**



Two GAFs output functions

Walsh Functions Amplitudes, Alphas

Modal Amp/Alpha (deg)	0 (K)	1	3 (K)	5 (K)
0.04	M8A0a	M8A1a	M8A3a	M8A5a
0.01	M8A0b	M8A1b	M8A3b	M8A5b
0.08	M8A0c	M8A1c	M8A3c	M8A5c
0.001	M8A0d	M8A1d	M8A3d	M8A5d

K = comparison with full KESTREL solution available or underway; using 'Venkat' limiter

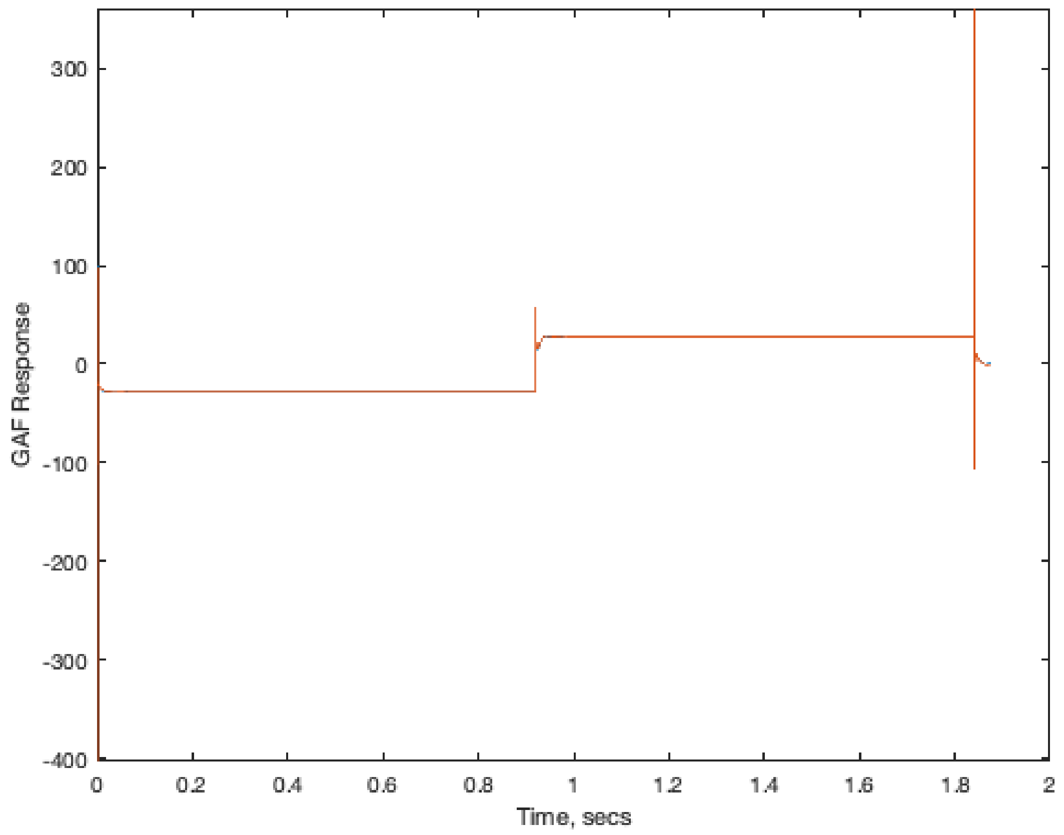
KESTREL Solutions: Alpha = 0 deg, Q = 100 psf, Initial Modal Velocity = 5
Alpha = 3 deg, Q = 100 psf, Initial Modal Velocity = 5
Alpha = 5 deg, Q = 50 psf, 130 psf, Initial Modal Velocity = 5

CPU Cost (NAS)
ROM solution: 10K steps, 240 cores, 9hrs 45min (set up, high alpha case; shorter duration for benign cases)
Full Solution per Q: 15K steps, 240 cores, 53 hrs 04min (~5.5 cycles)

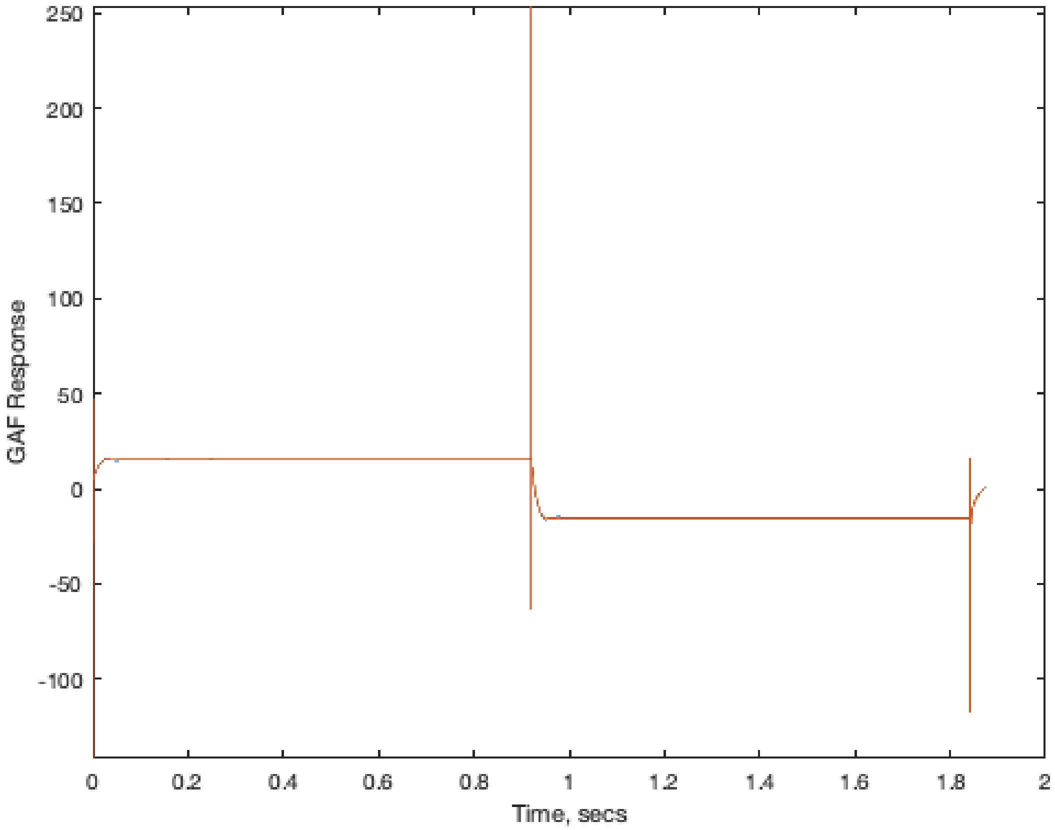
M8A0a – Comparison of ROM/KESTREL GAFs

a	.04
b	.01
c	.08
d	.001

GAF1 Output (ROM and KESTREL)

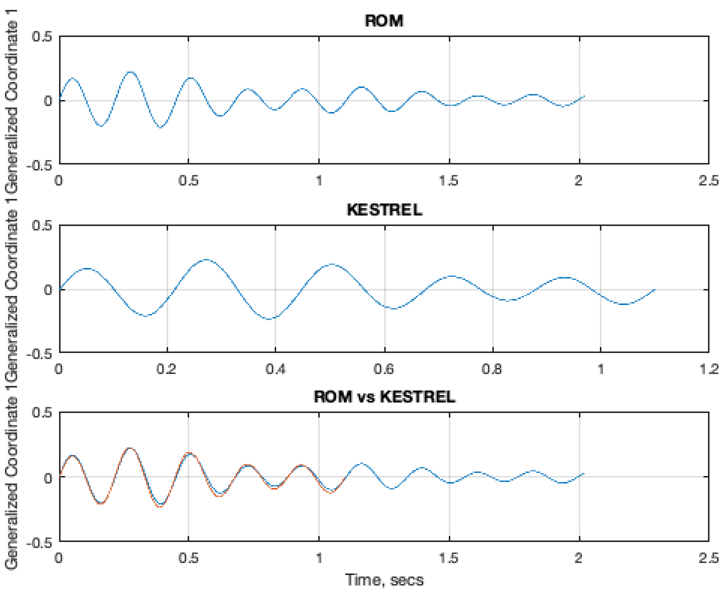


GAF2 Output (ROM and KESTREL)

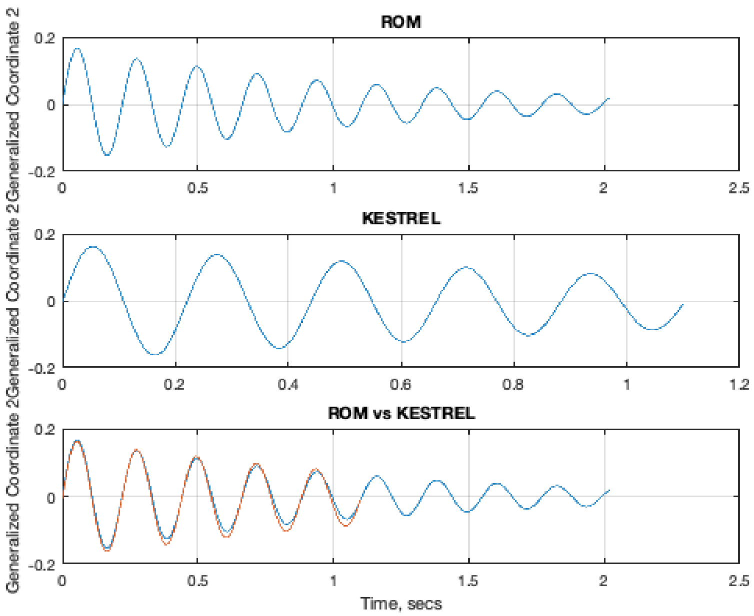


M8A0*i* – ROM/KESTREL Responses

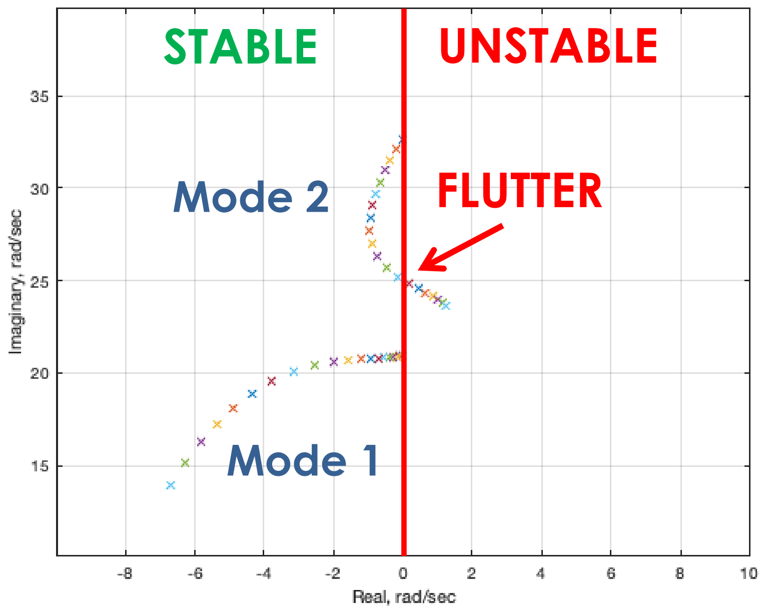
Mode 1 (Q=100 psf)



Mode 2 (Q=100 psf)



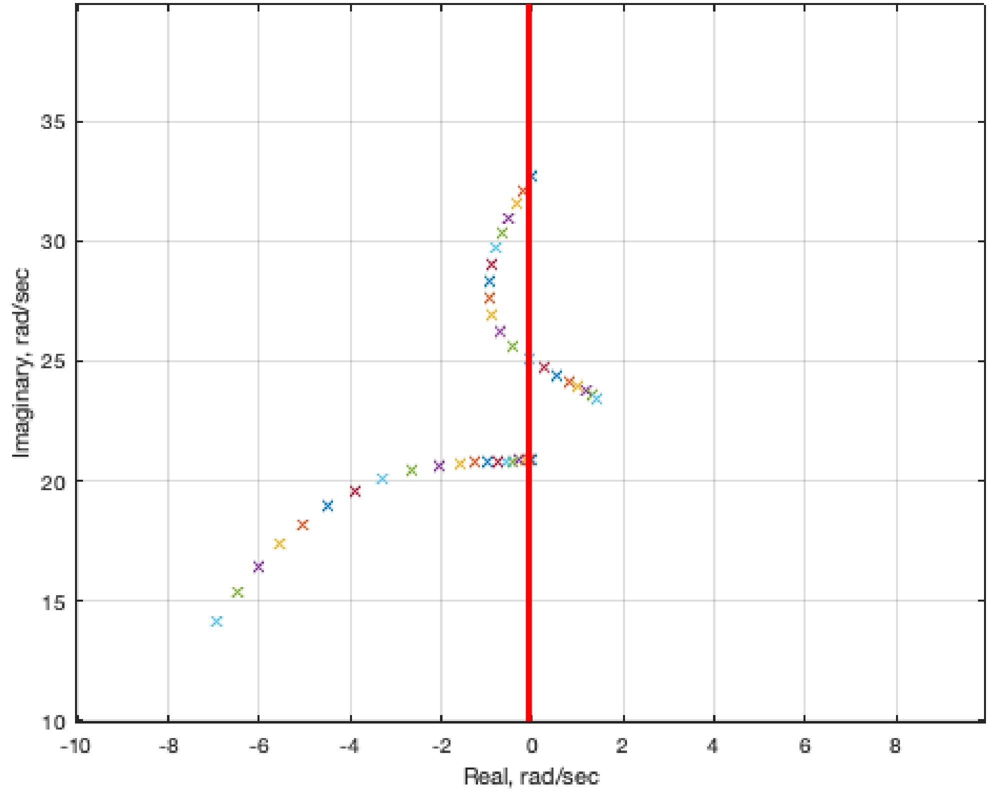
Aeroelastic Root Locus



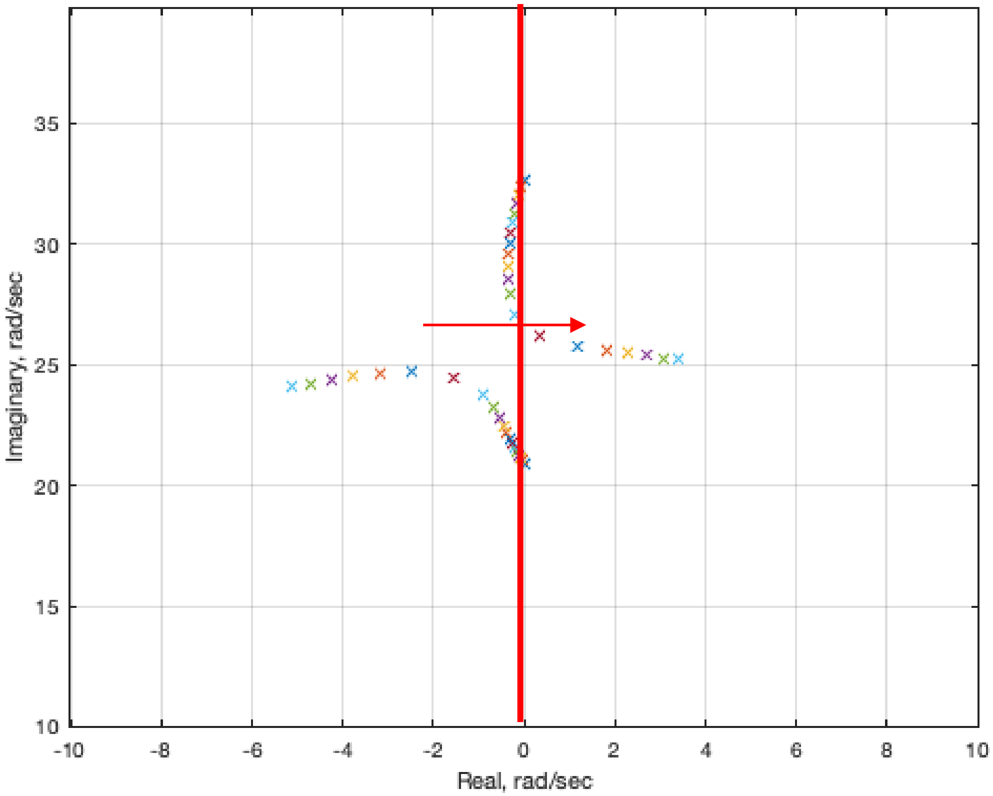
- At M=0.8, for alpha=0 and 1 degs, <u>all input amplitudes</u> yielded identical responses at all dynamic pressures, with identical aeroelastic root locus behaviors
- At M=0.8, for alpha=3 degs, started noticing <u>some input amplitude dependence</u> (larger amplitudes more accurate) with a slight change in aeroelastic root locus behaviors

M8A0*i*,M8A5*a*,*c* – ROM/KESTREL Responses

Alpha=0 deg, All input amplitudes



Alpha=5 deg, Larger input amplitudes



- At M=0.8, alpha=5 degs, obvious <u>input amplitude dependence </u>(larger amplitudes more accurate) with noticeable change in aeroelastic root locus behavior
- Proximity of Alpha=5 deg root locus to imaginary axis could be cause of significant sensitivity across various CFD codes