AePW-2 Website: https://AePW2.larc.nasa.gov

2nd AIAA Aeroelastic Prediction Workshop: Plans & an Interesting Technical Issue

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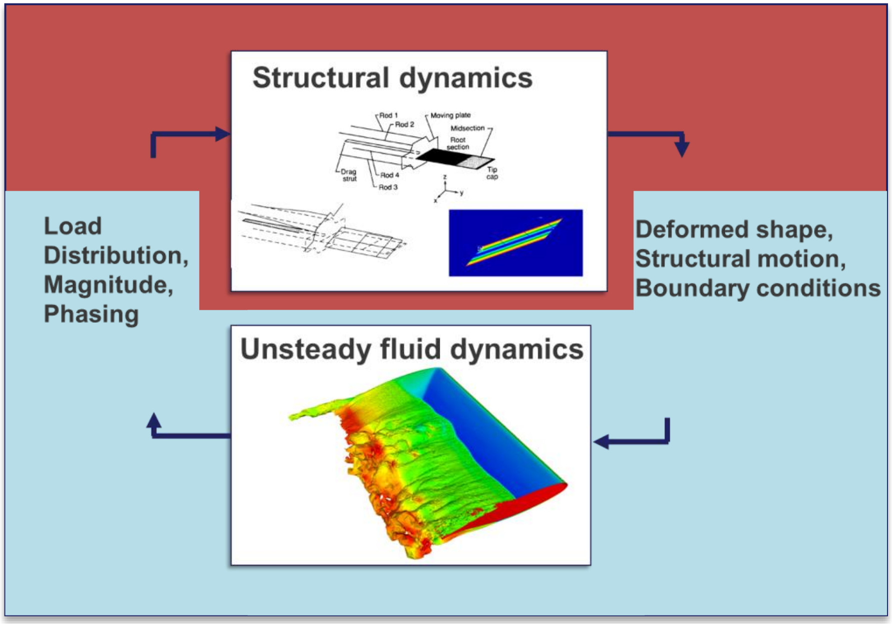
AePW building block approach to validation

Utilizing the classical considerations in aeroelasticity

- **Fluid dynamics**
- **Structural dynamics**
- **Fluid/structure coupling**



AePW-1: Focused on Unsteady fluid dynamics

AePW-2: Extend focus to coupled aeroelastic simulations

You are invited to participate in AePW-2

Extend focus to coupled aeroelastic simulations

	Case 1	Case 2	Optional Case 3		
			A	B	C
Mach	0.7	0.74	0.85	0.85	0.85
Angle of attack	3	0	5	5	5
Dynamic Data Type	Forced Oscillation	Flutter	Unforced Unsteady	Forced Oscillation	Flutter
Notes:	• Attached flow solution • Oscillating Turn Table (OTT) exp data	• Unknown flow state • Pitch and Plunge Apparatus (PAPA) exp data	• Separated flow effects • Oscillating Turn Table (OTT) experimental data	• Separated flow effects • Oscillating Turn Table (OTT) experimental data	• Separated flow effects on aeroelastic solution • No experimental data for comparison

AePW-1: Applying the Lessons Learned

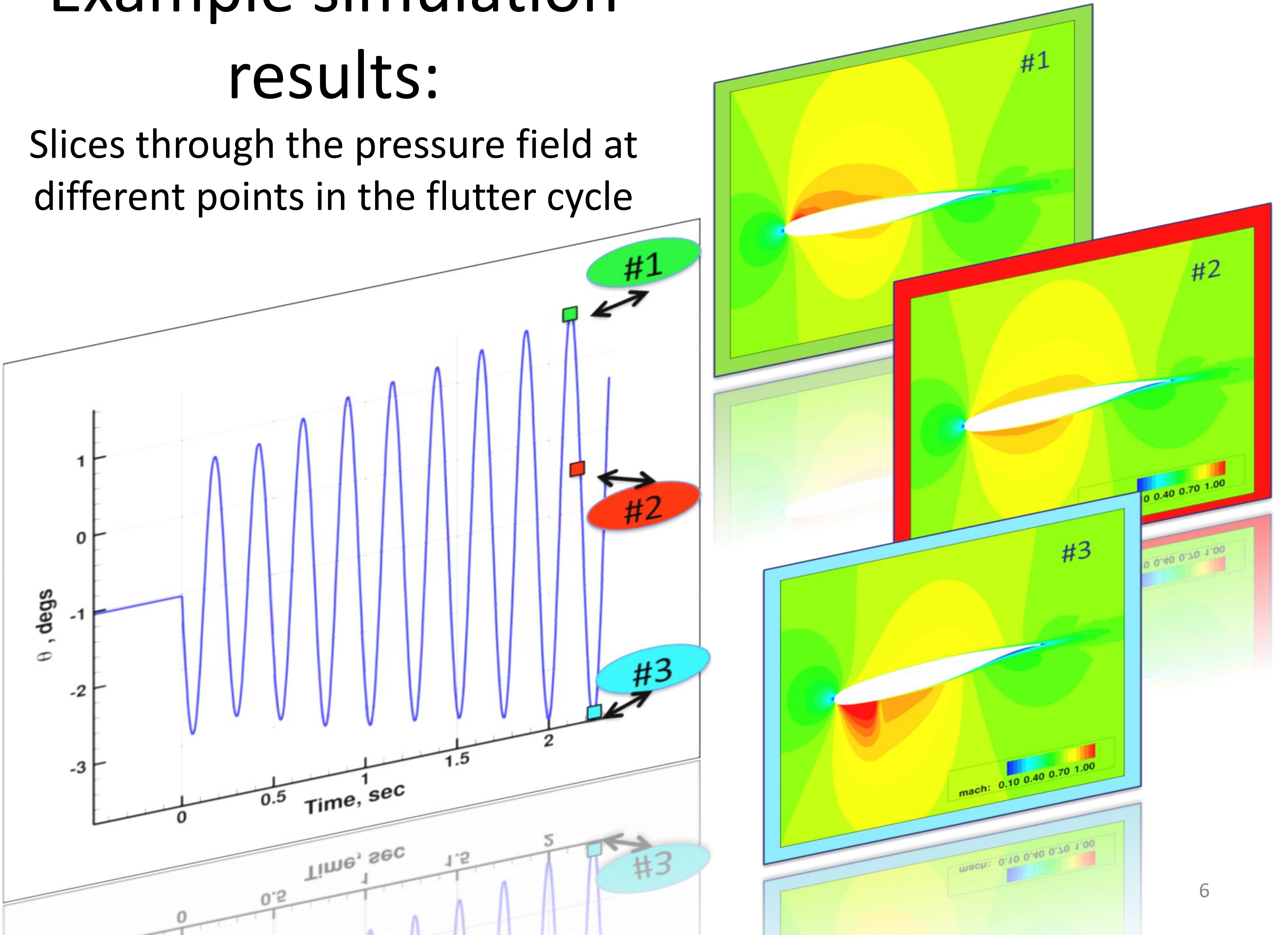
- One configuration only
- Benchmarking case: including a case that we have confidence can be "well-predicted"
- Comparison metrics:
  - Unsteady quantities for all cases
  - Integrated sectional forces and moments
  - Critical damping ratios and frequencies
  - Extended statistics: mean, std, mode, max, min
- Time histories from solutions requested because
  - nothing is steady
  - single person, single method of post-processing matters
  - there's always more to see- nonlinearities, off-nominal frequency content
- Results requested at more finely spaced points than experimental data
- Common grids suggested for analyses
- Various fidelity aerodynamic contributions encouraged
- Discussion telecons for analysis teams

Overview of requested submittal data sets

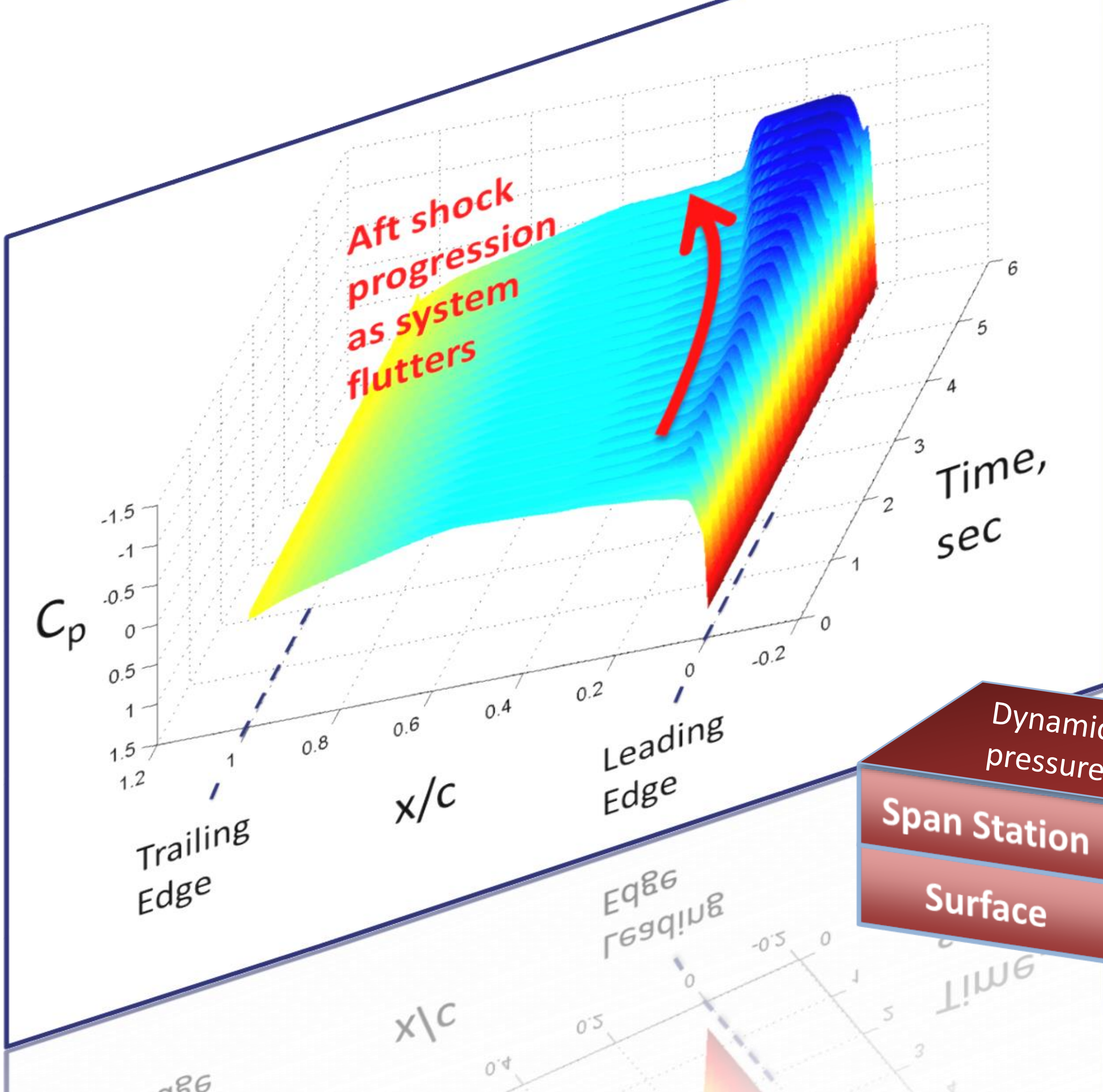
- Steady rigid pressure coefficient distributions: statistics of the results
- Time histories
  - Angle of attack
  - Leading and trailing edge displacements
  - Pressure coefficients
  - Lift & pitching moment coefficients
  - Sectional lift & pitching moment coefficients
- Frequency response functions: C_p/θ
  - At forced oscillation or flutter frequency
  - Across 0-100 Hz
- Static aeroelastic pressure coefficient distributions: statistics of the results
- Flutter bounds

Example simulation results:

Slices through the pressure field at different points in the flutter cycle



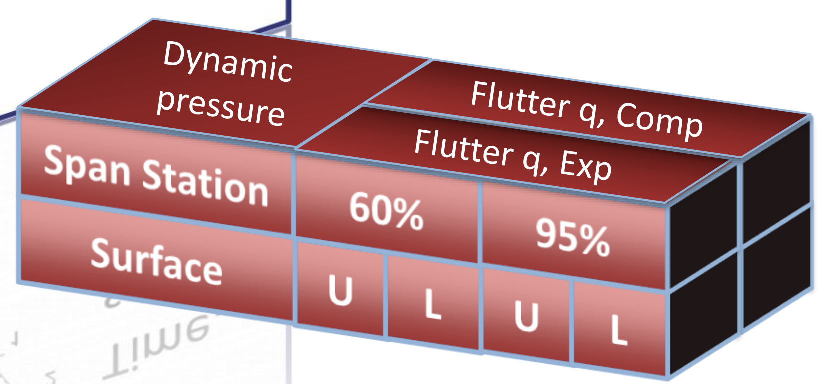
Cp vs time and x/c



The results shown here are at 60% span for the upper surface at the dynamic pressure of the experimental data set (168.8 psf)

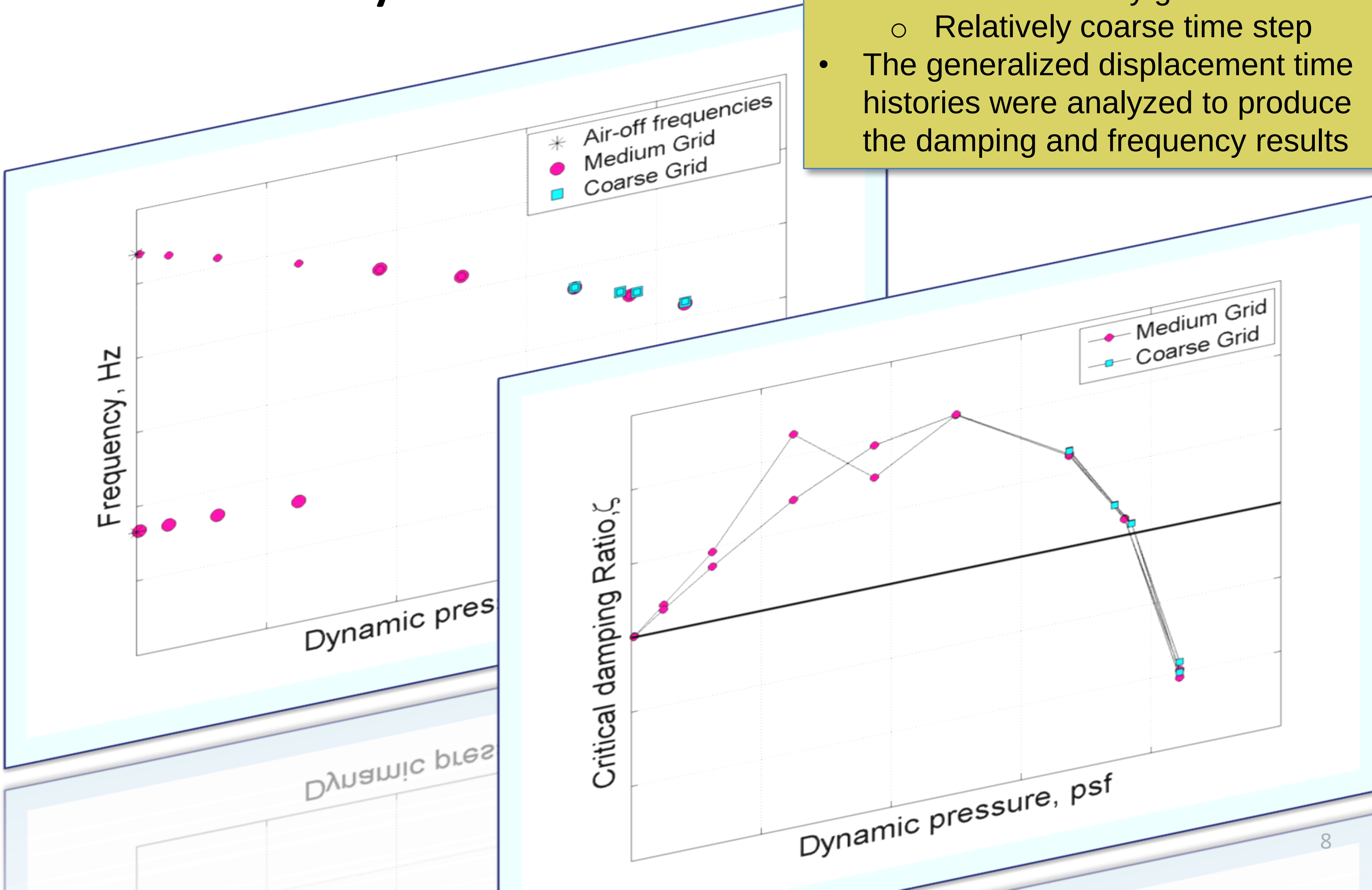
Data sets are requested at

- 60% and 95% span
- Upper & lower surfaces
- Experimental flutter condition (168.8 psf) & Computational flutter condition as determined by each analysis team



Example Flutter summary results

- These example results were calculated using
  - URANS + SA
  - Medium fidelity grid
  - Relatively coarse time step
- The generalized displacement time histories were analyzed to produce the damping and frequency results



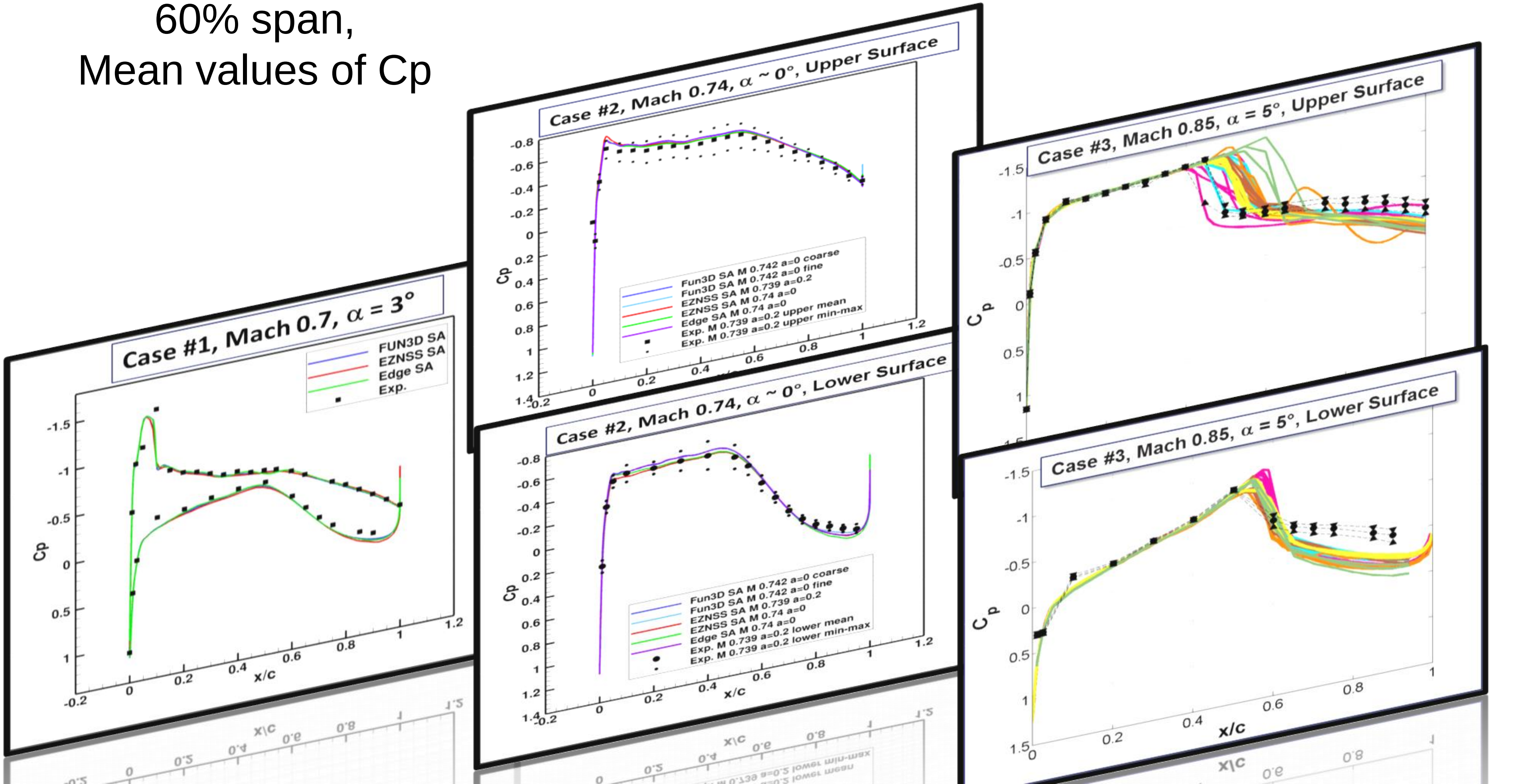
Steady rigid pressure distributions

Case comparisons
60% span,
Mean values of Cp

For the primary forced oscillation case, Case #1, disagreements with experimental data limited to the peak of the upper surface shock.

For the primary flutter case, Case #2, shows a well-matched rigid pressure distribution without much variation among the computational results.

The complexity of the Case #3 is indicated by the variation among the computational results & difference from the experimental data →Shock location, shock strength, aft loading especially on lower surface.



Temporal parameter influences on aeroelastic stability results

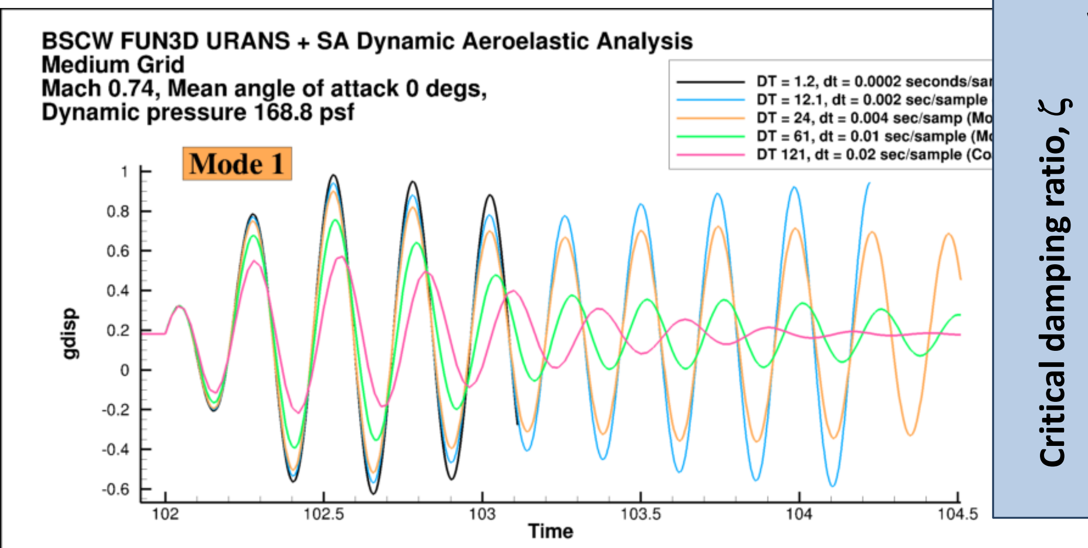
FUN3D analysis (URANS + SA)

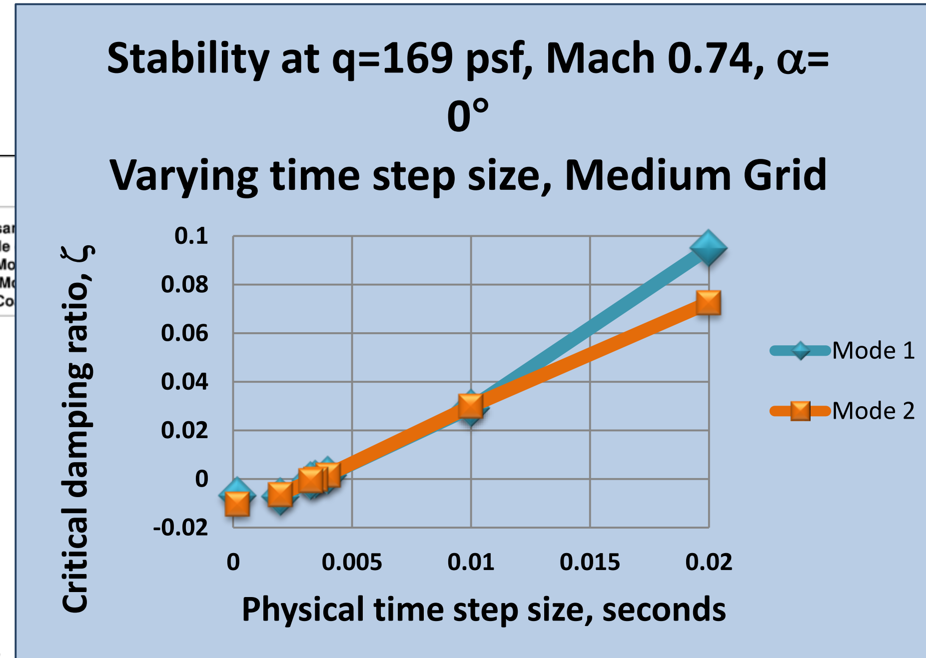
	Case 1	Case 2	Optional Case 3		
			A	B	C
Mach	0.7	0.742	0.85	.85	.85
Angle of attack	3°	-0°	5°	5°	5°
Dynamic Data Type	Forced oscillation	Flutter	Unforced Unsteady	Forced Oscillation	Flutter
Notes:	• Attached flow solution. • Oscillating Turn Table (OTT) experimental data. • R-134a	• Pitch and Plunge Apparatus (PAPA) experimental data. • R-12	• Separated flow effects. • Oscillating Turn Table (OTT) experimental data. • R-134a	• Separated flow effects. • Repeat of AePW-1 • Oscillating Turn Table (OTT) experimental data. • R-134a	• No experimental data for comparison. • Separated flow effects on aeroelastic solution. • R-134a

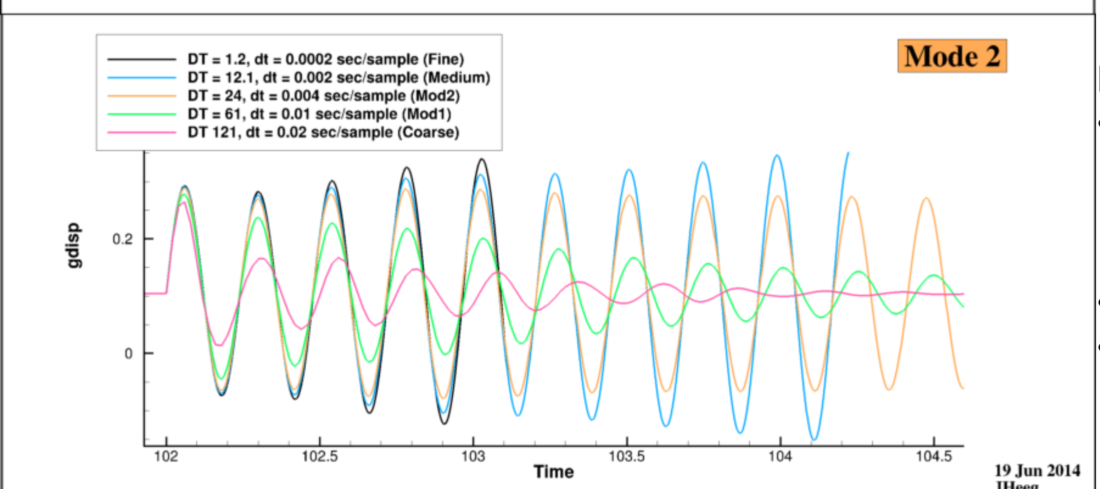
Summary of temporal parameters for different solutions

	Summary of temporal properties		
directory	**DT**	**dt**	**sample/4Hzcycle**
	(nondim)	**(sec/sample)**	
coarseDT	121.876	0.02	12.500
mod1DT	60.93801	0.01	25.000
mod2DT	24.3752	0.004	62.500
mod4DT	21.2	0.003478946	71.861
mod3DT	20	0.003282024	76.173
DT15	15.2345	0.0025	100.000
medDT	12.1876	0.002	125.000
DT7	7.61725	0.00125	200.000
DT6	6.093801	0.001	250.000
DT3	3.0469	0.0005	500.000
fineDT	1.21876	0.0002	1250.000
xfineDT	0.121876	0.00002	12500.000

Varying time step size at q = 168.8 psf; 25 subiterations per global time step





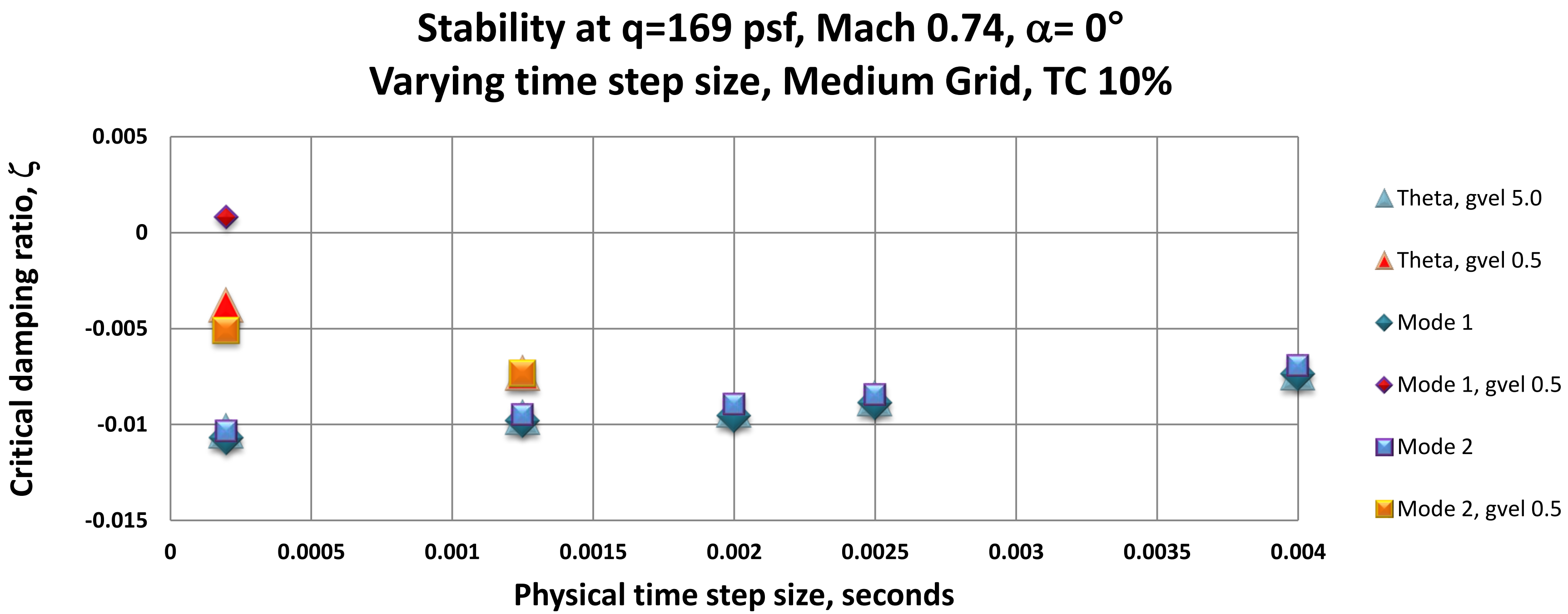


For constant number of subiterations, 25:

- Simulation shows stable results for DT >= 24 (refinement later showed That the neutrally stable DT at this dynamic pressure is 21.2?)
- Smaller time steps show unstable behavior.
- Larger time steps show stable behavior.

Varying time step size at q = 168.8 psf;

Temporal error convergence 10%, 1000 subiterations maximum per global time step



For temporal error convergence of 10%, with
gvel0 = 5.0 on both modes:

- Simulation shows unstable system for all cases

gvel0 = 0.5 on both modes:

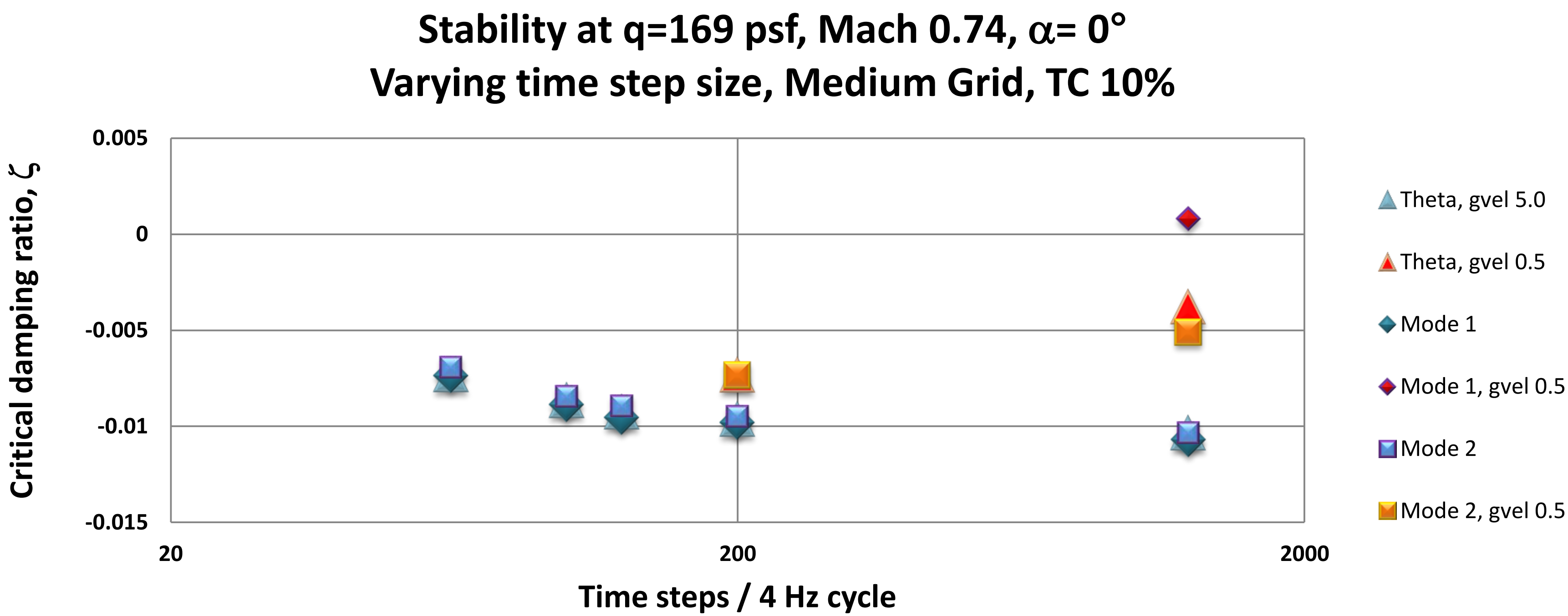
- Simulation shows stable Mode 1 behavior at smallest time step (more iterations running to see if this changes)

- Smaller time step = more unstable
- Higher value of initial kick = more unstable

Jen, remember that you are
Assuming that there are 2 eigenvalues,
One stable and one unstable.
The fine grid result with gvel = 0.5 may just
Be indicating this other root.
Need to combine the gvel results and then
analyze the resulting signal for 2 modes.

Varying time step size at q = 168.8 psf;

Temporal error convergence 10%,
1000 subiterations maximum per global time step



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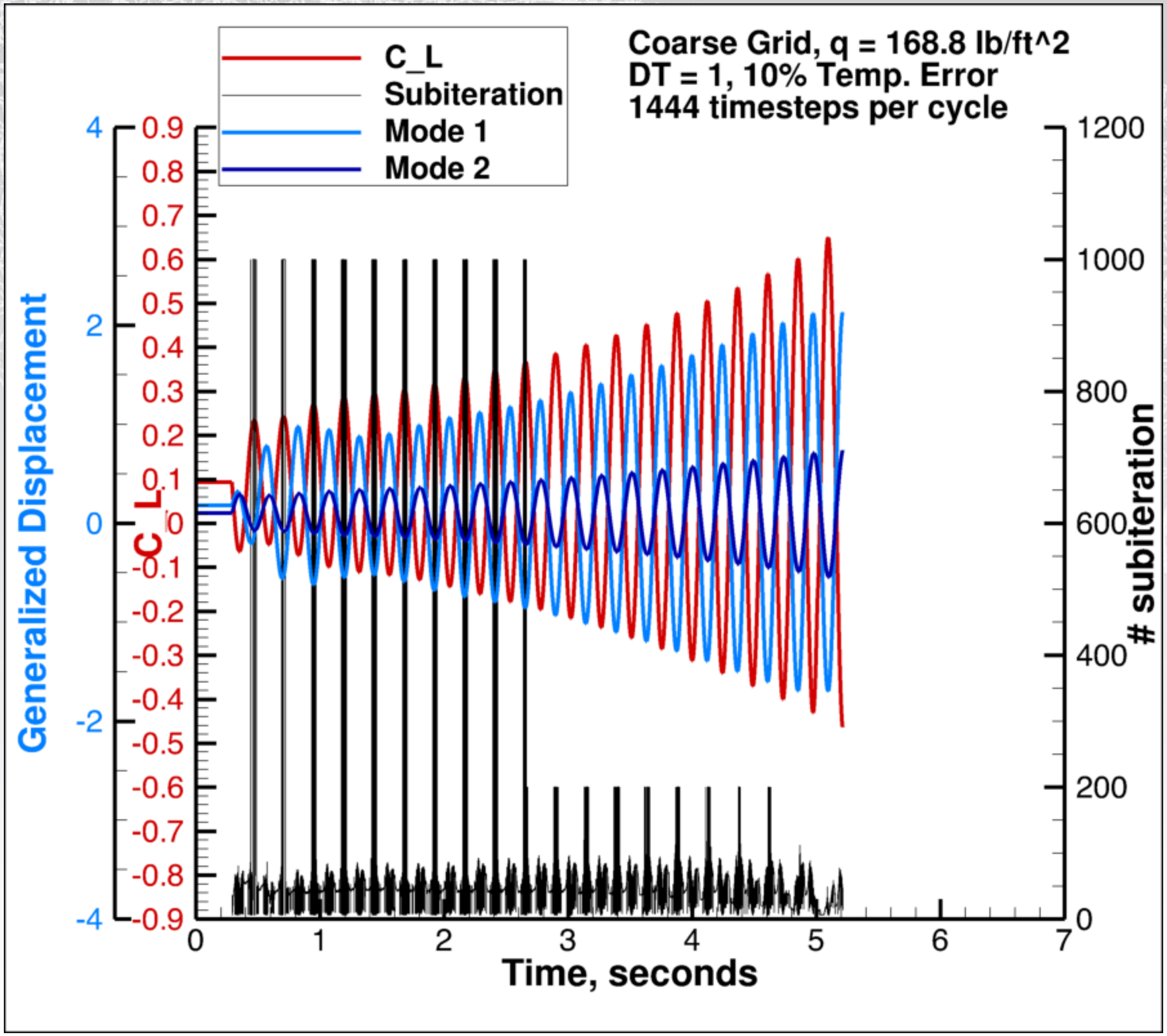
- Smaller time step = more unstable
- Higher value of initial kick = more unstable

SAME INFORMATION AS ON PREVIOUS SLIDE, but showing Horizontal axis as Time steps/4 Hz cycle

The following 4 slides are from Pawel and show the results for Coarse, Medium and Fine grids for DT = 1, with 10% temporal error convergence and 1444 as the maximum number of subiterations

Current FUN3D results: spatial and temporal convergence AePW-2 Case#2 Flutter results



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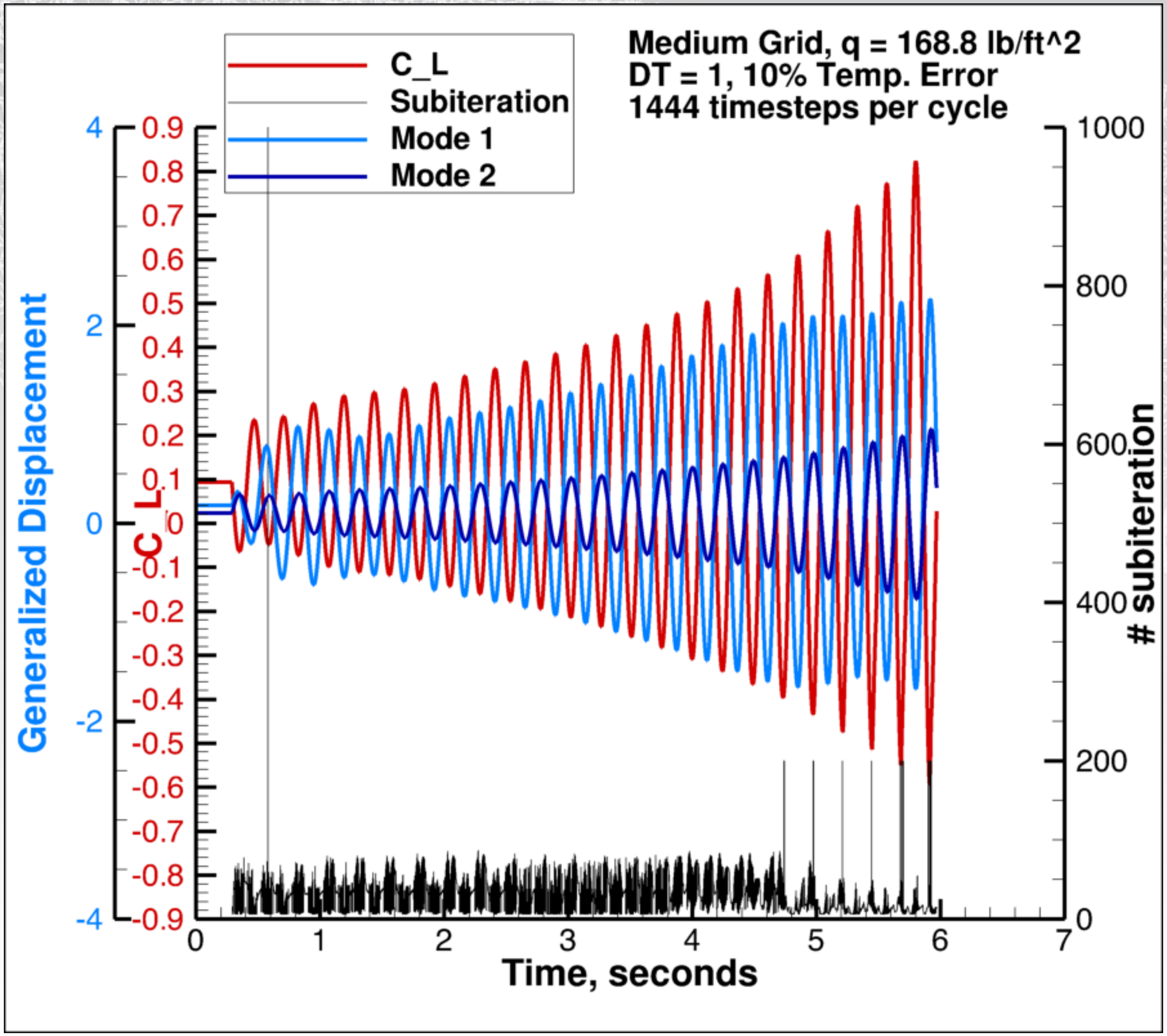
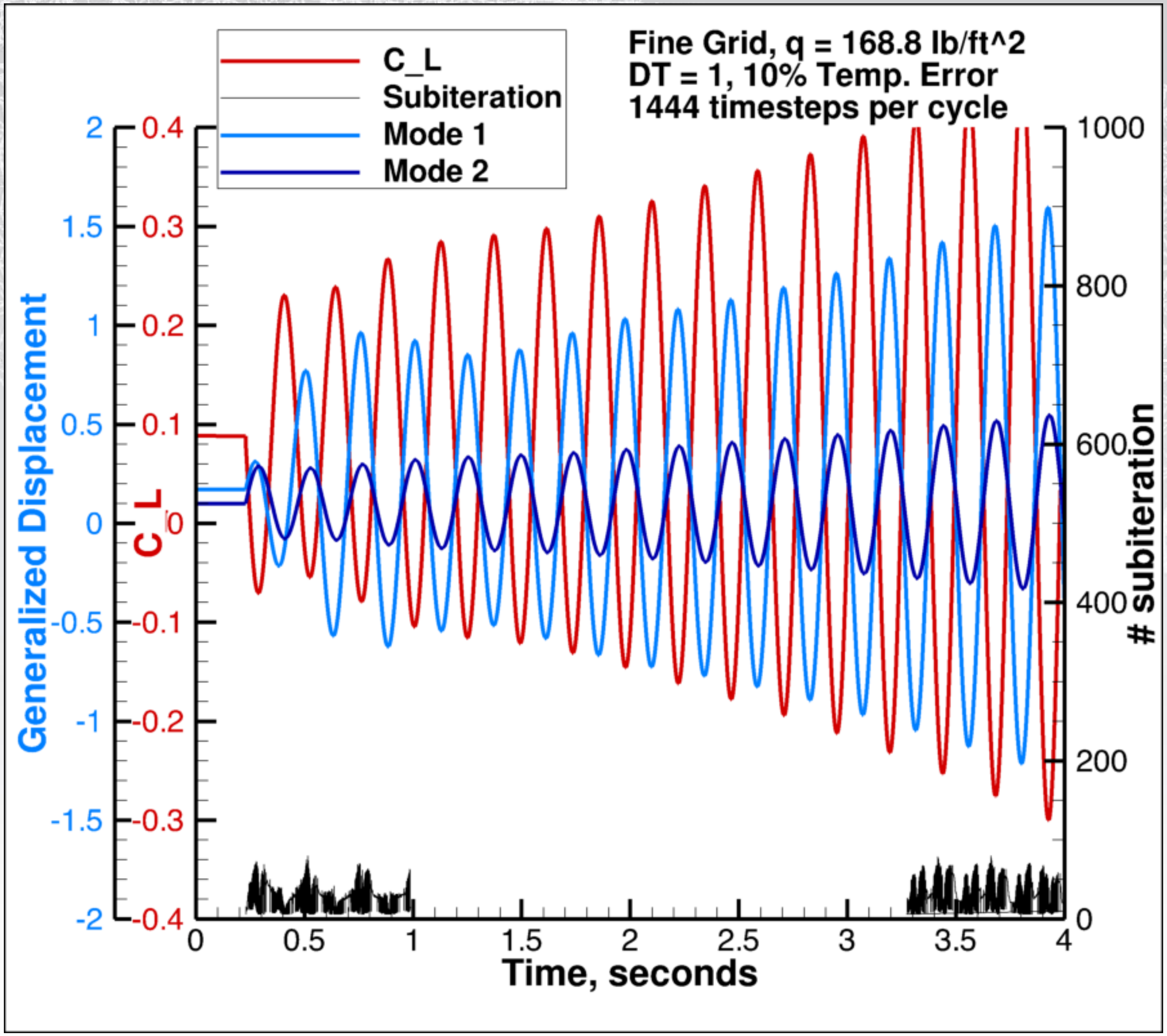
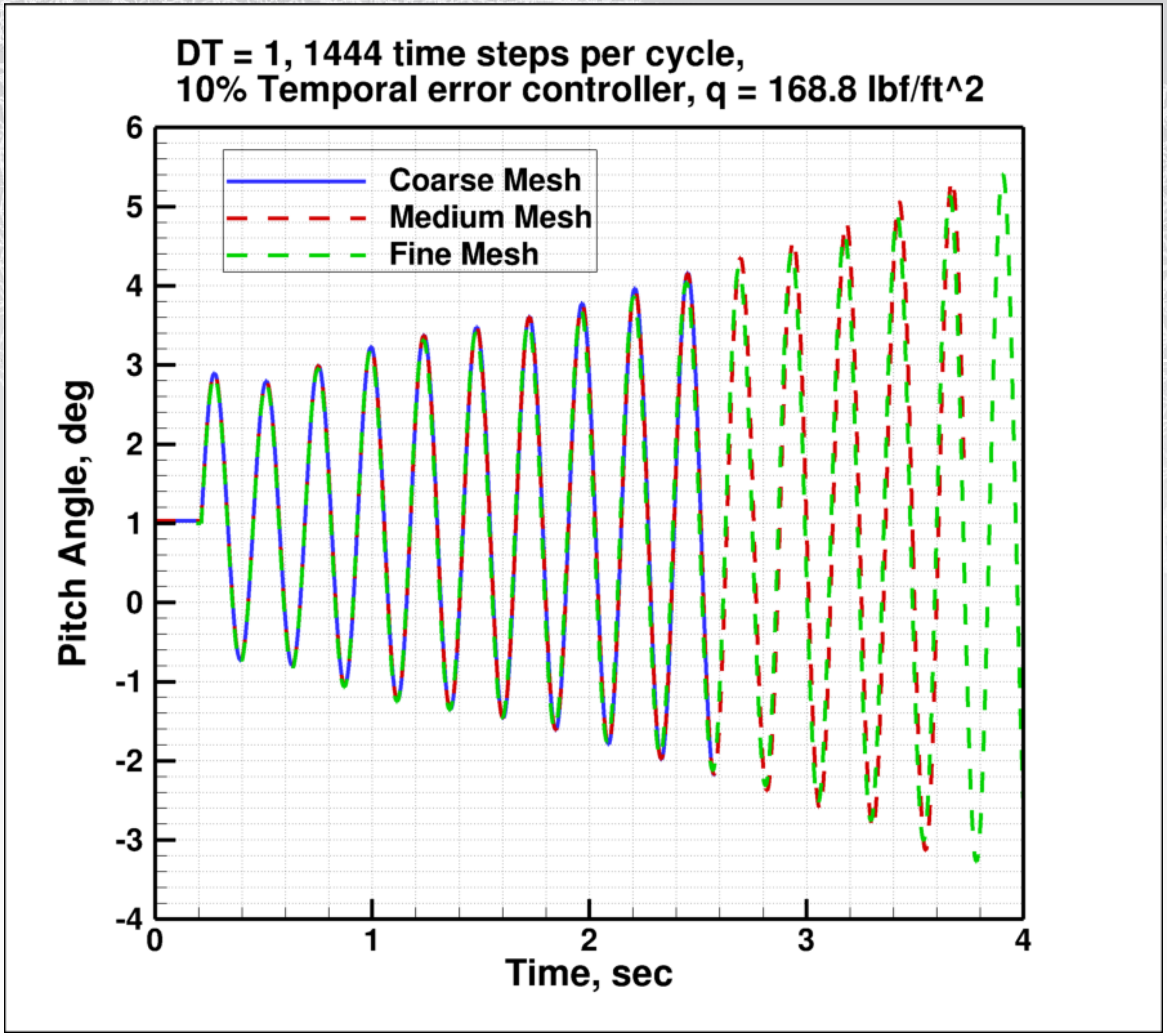


Current FUN3D results: spatial and temporal convergence AePW-2 Case#2 Flutter results



Current FUN3D results: spatial and temporal convergence AePW-2 Case#2 Flutter results

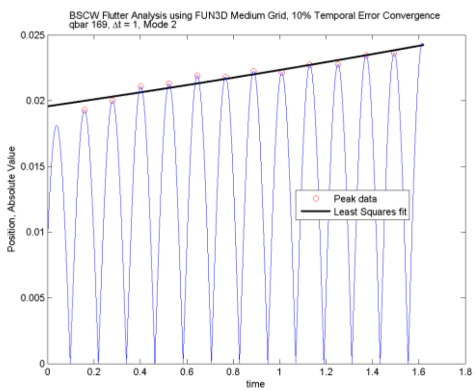


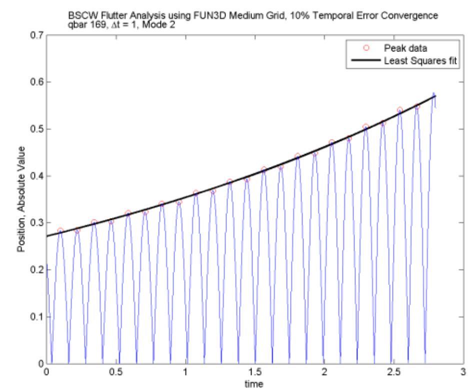
Varying time step size at q = 168.8 psf;

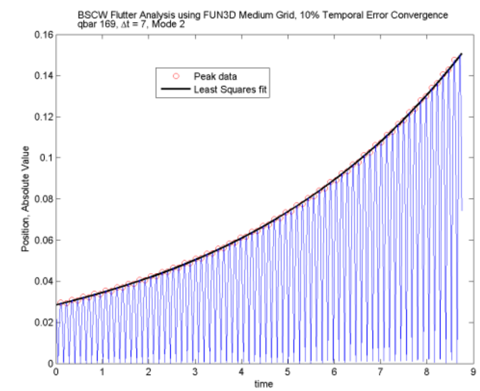
Temporal error convergence 10%,
1000 subiterations maximum per global time step

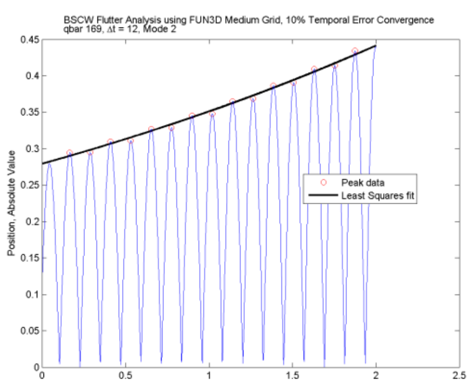
Damping values were calculated using the generalized displacements associated With the two aeroelastic modes, treating each as if they contained only A single mode. Near neutral stability, this isn’t a bad assumption.

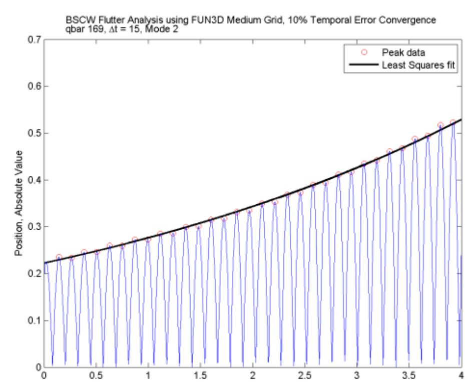
How good are the fits that are used in the damping calculations?
The following plots show this for the Mode 2 data sets.

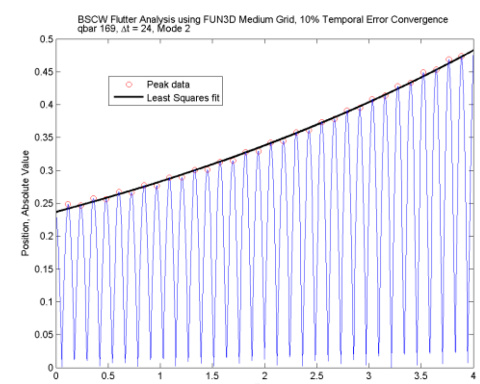




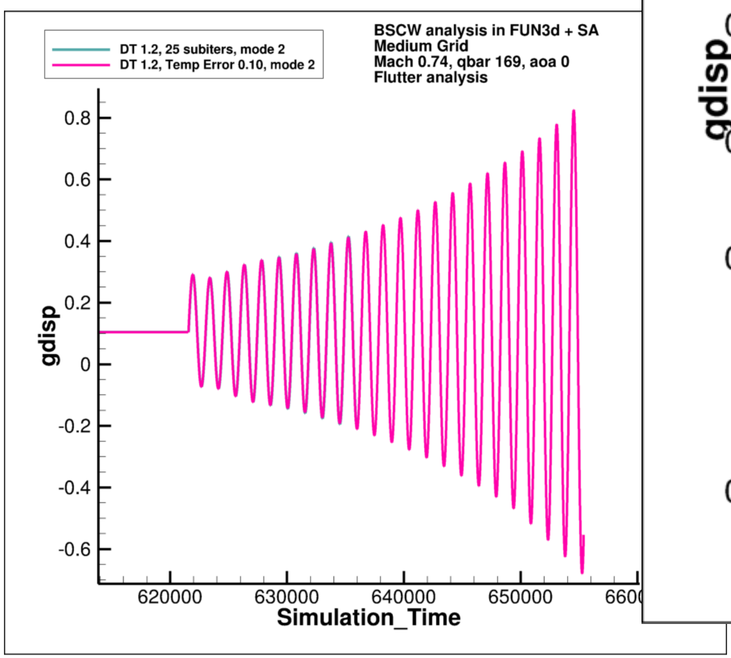


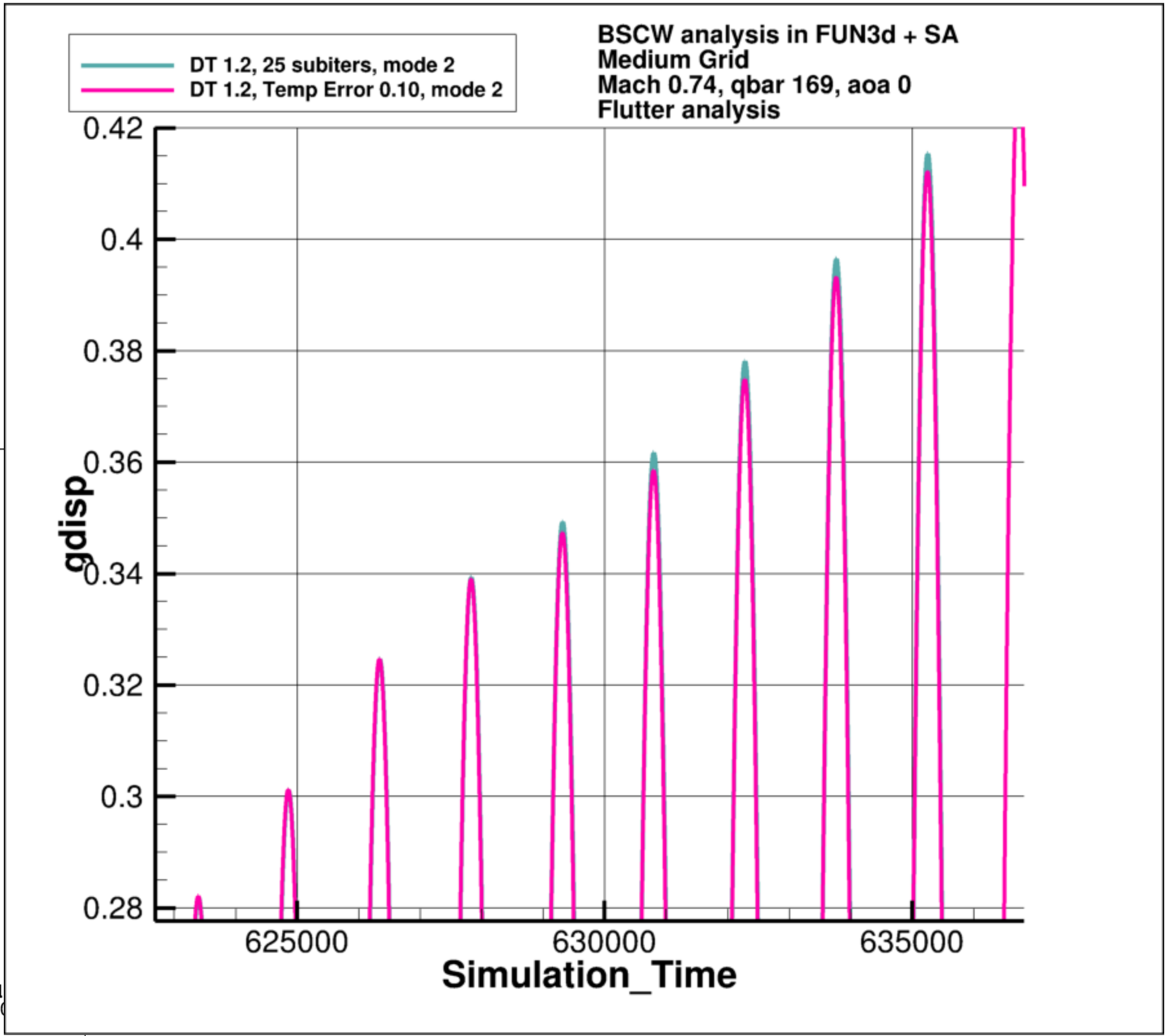




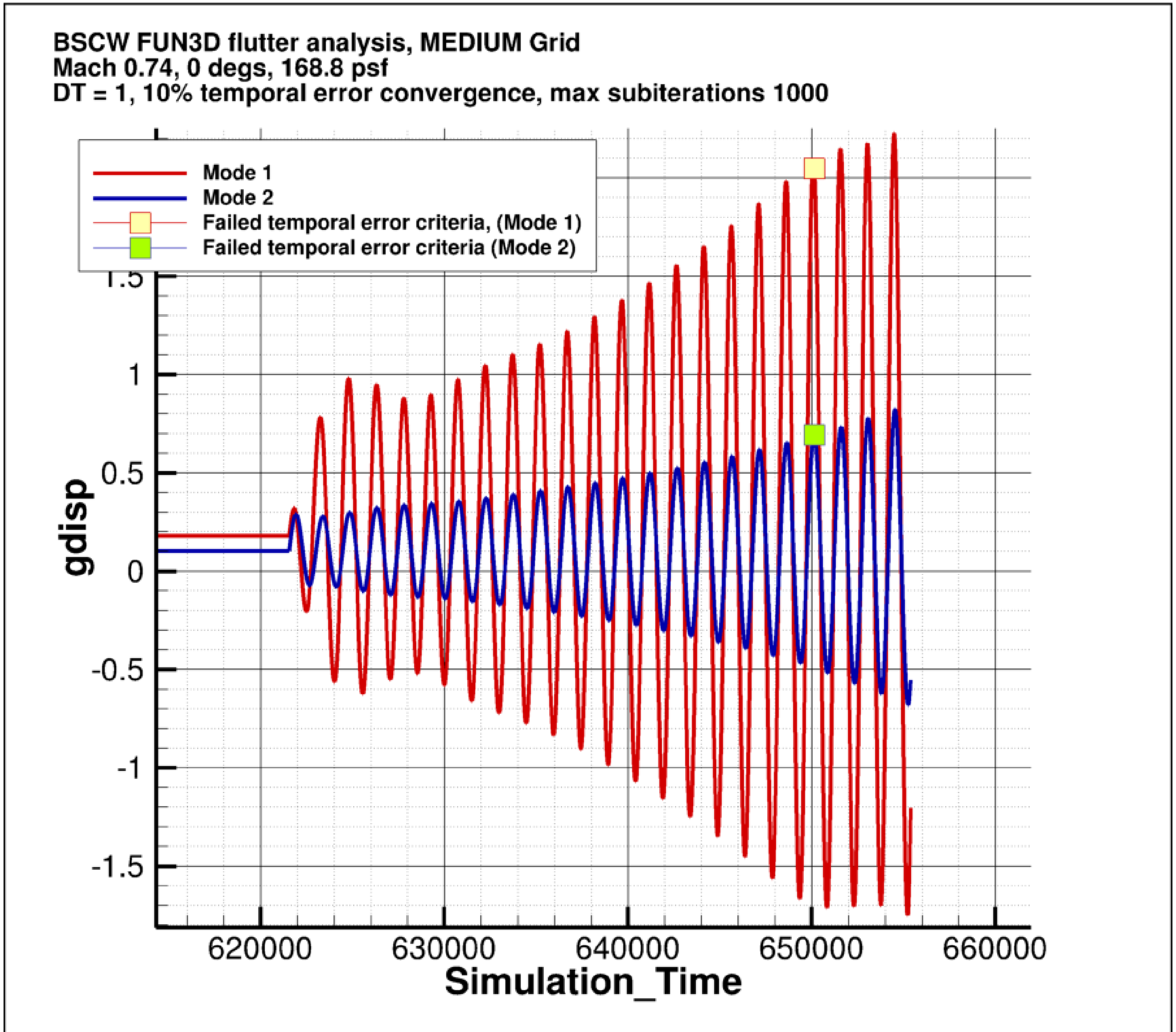


Q 169, DT 1.2, comparison of temporal error convergence & fixed number (25) subiterations

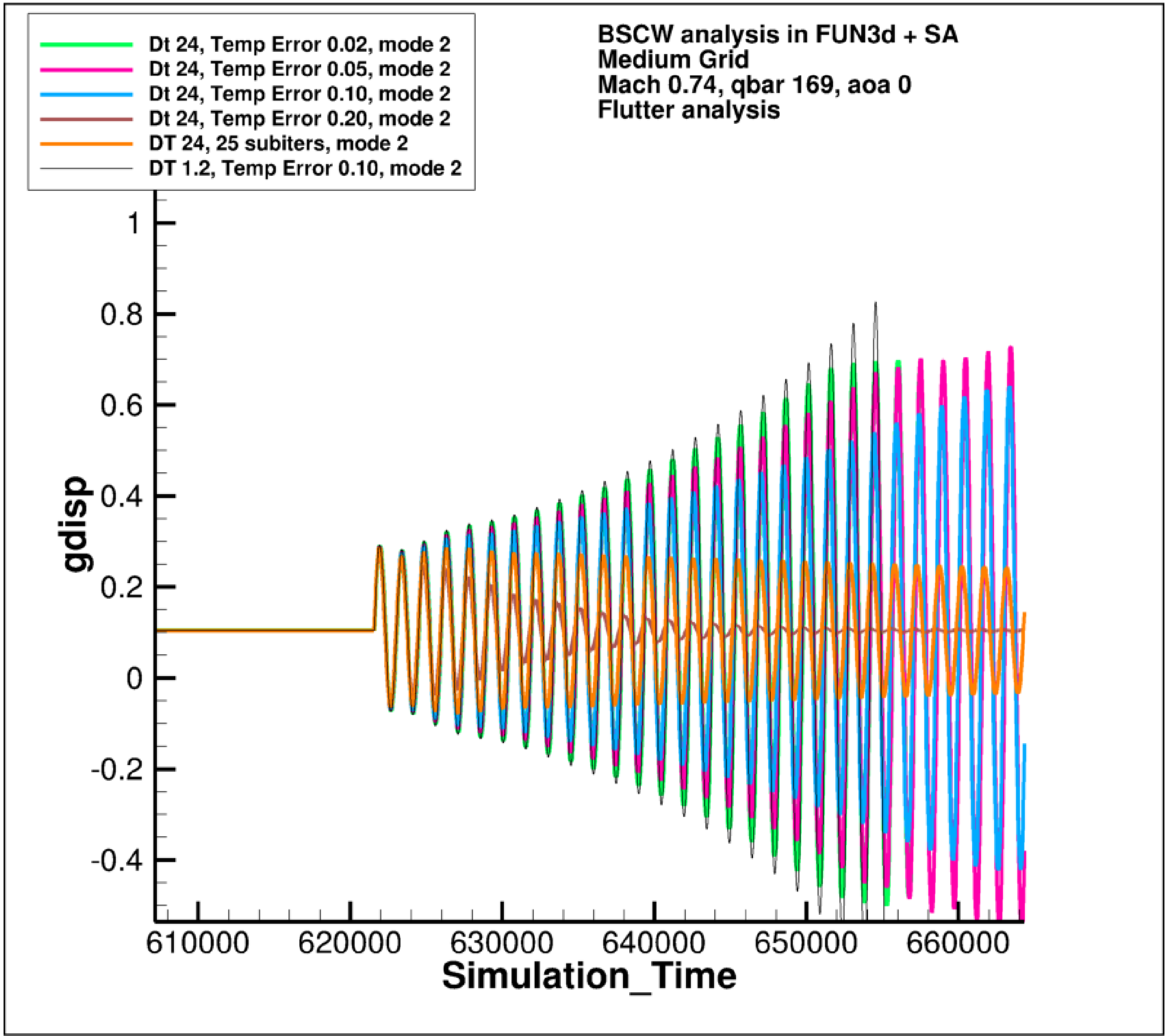




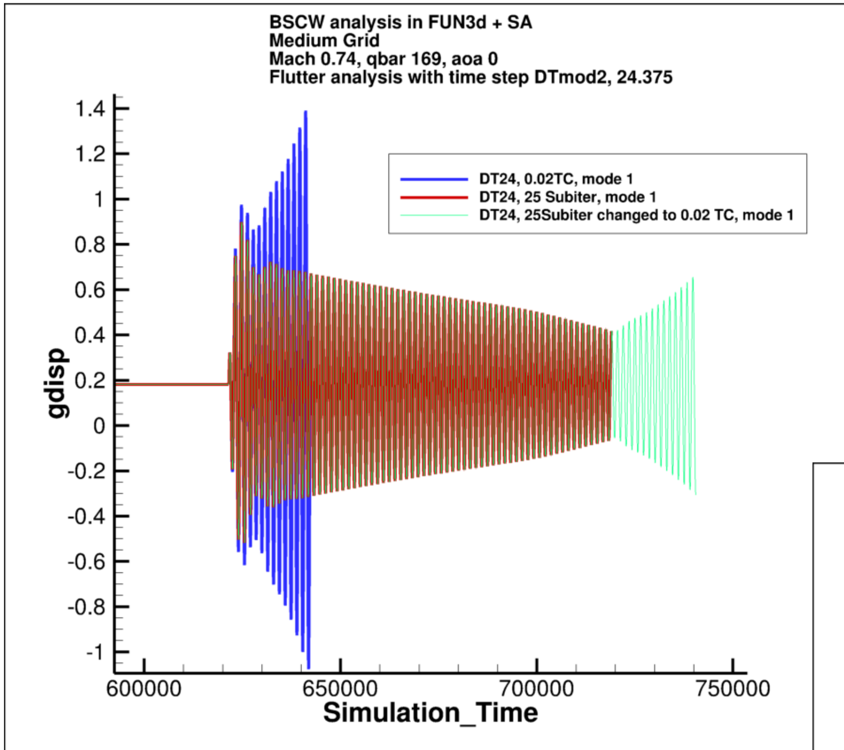
q = 168.8, DT = 1.2, Temporal Error Convergence Criteria 10%, Maximum # of subiterations: 1000

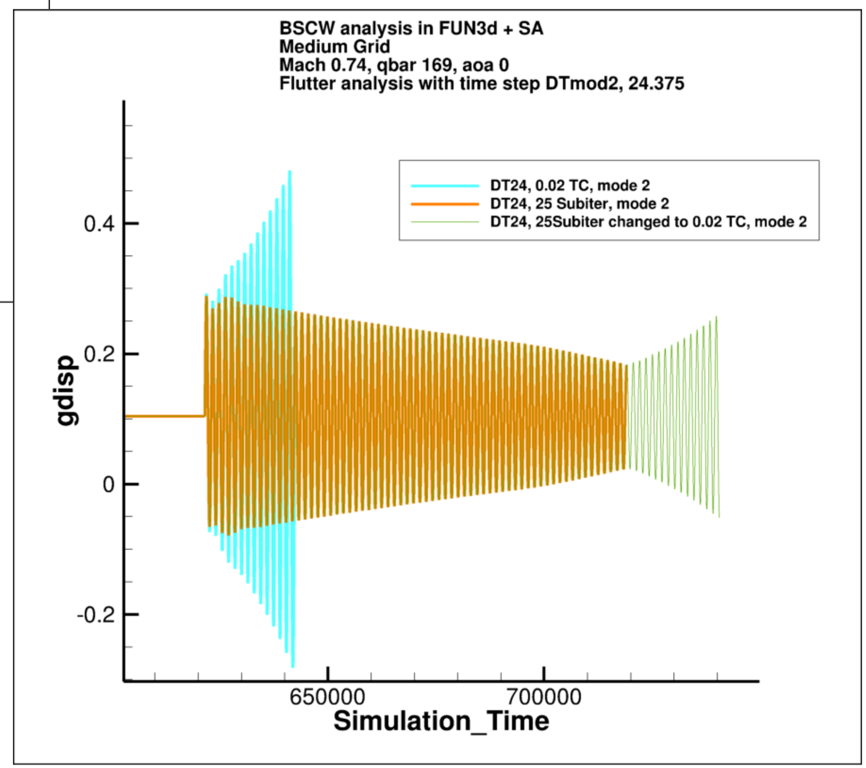


Q 168.8 psf, DT 24 comparison with DT=1 10% temporal error convergence

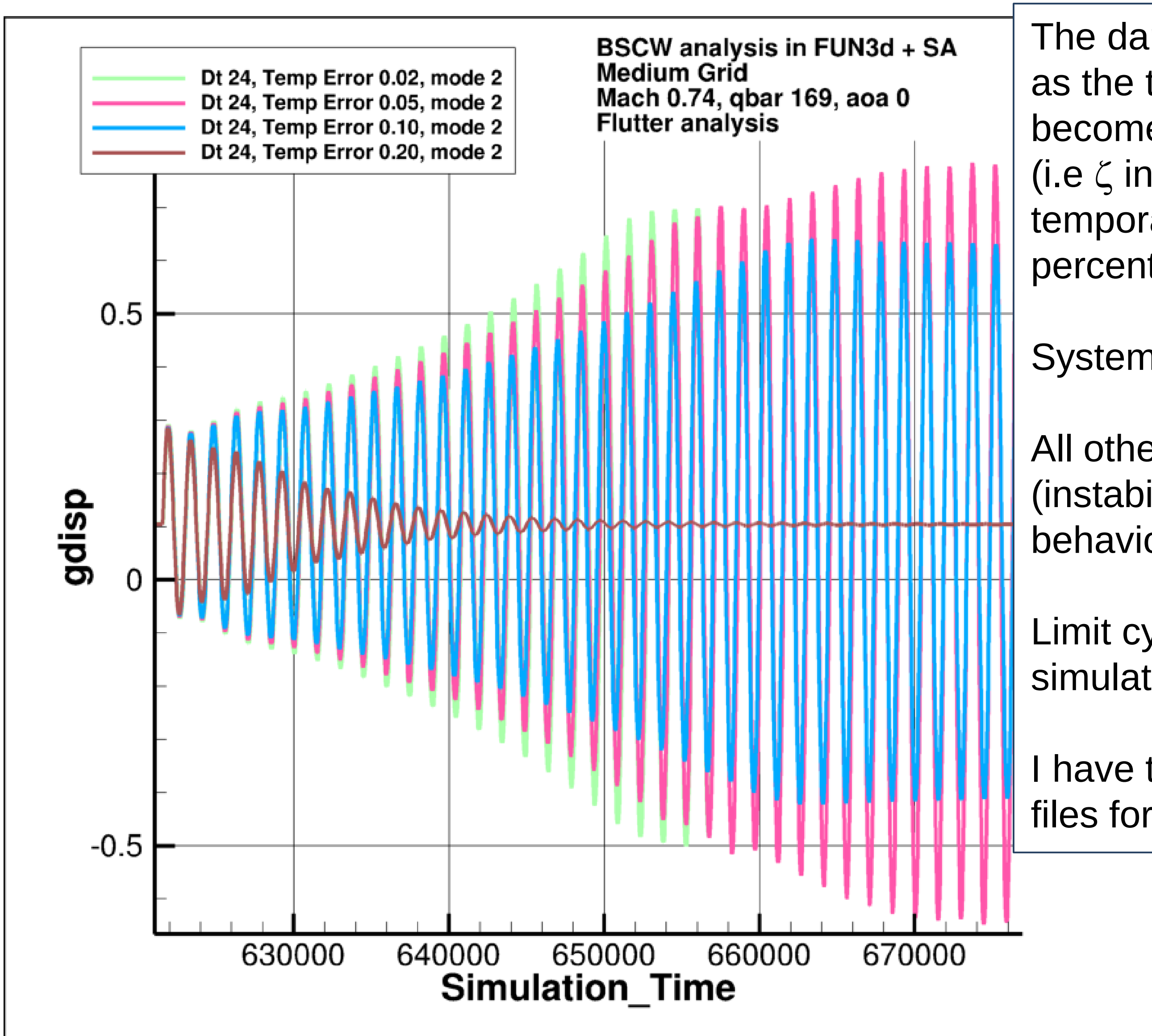


Changing the subiteration criteria after stability behavior is established





Varying temporal error convergence criteria



The damping increases
as the temporal error criteria
becomes less stringent.
(i.e ζ increases with increasing
temporal error convergence
percentage)

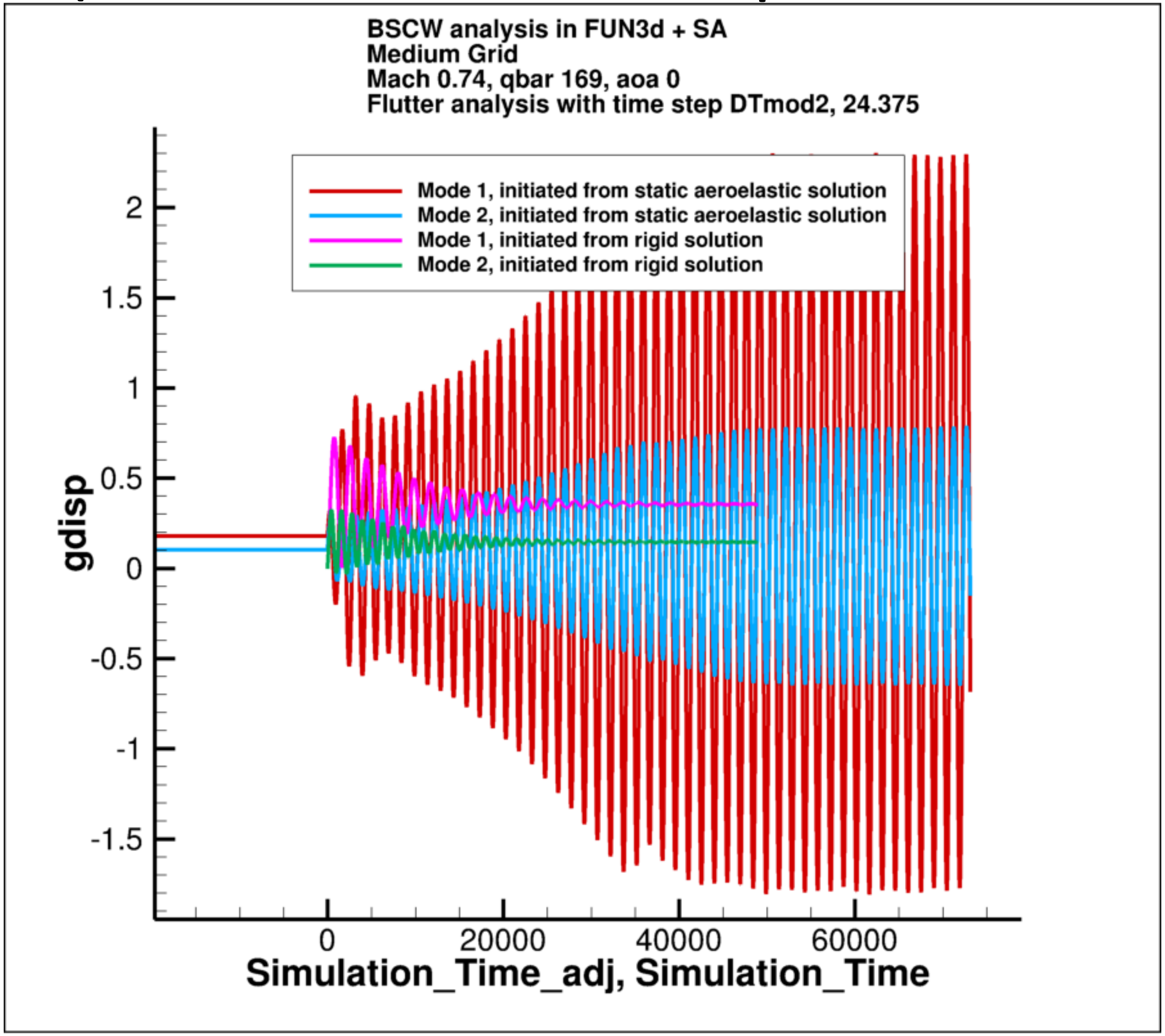
System is stable for 20% TEC

All other solutions show flutter
(instability) and then limit cycle
behavior.

Limit cycle onset occurs at different
simulation time for each case.

I have the subhist and fun3d.out
files for the 2% and 5% TC cases.

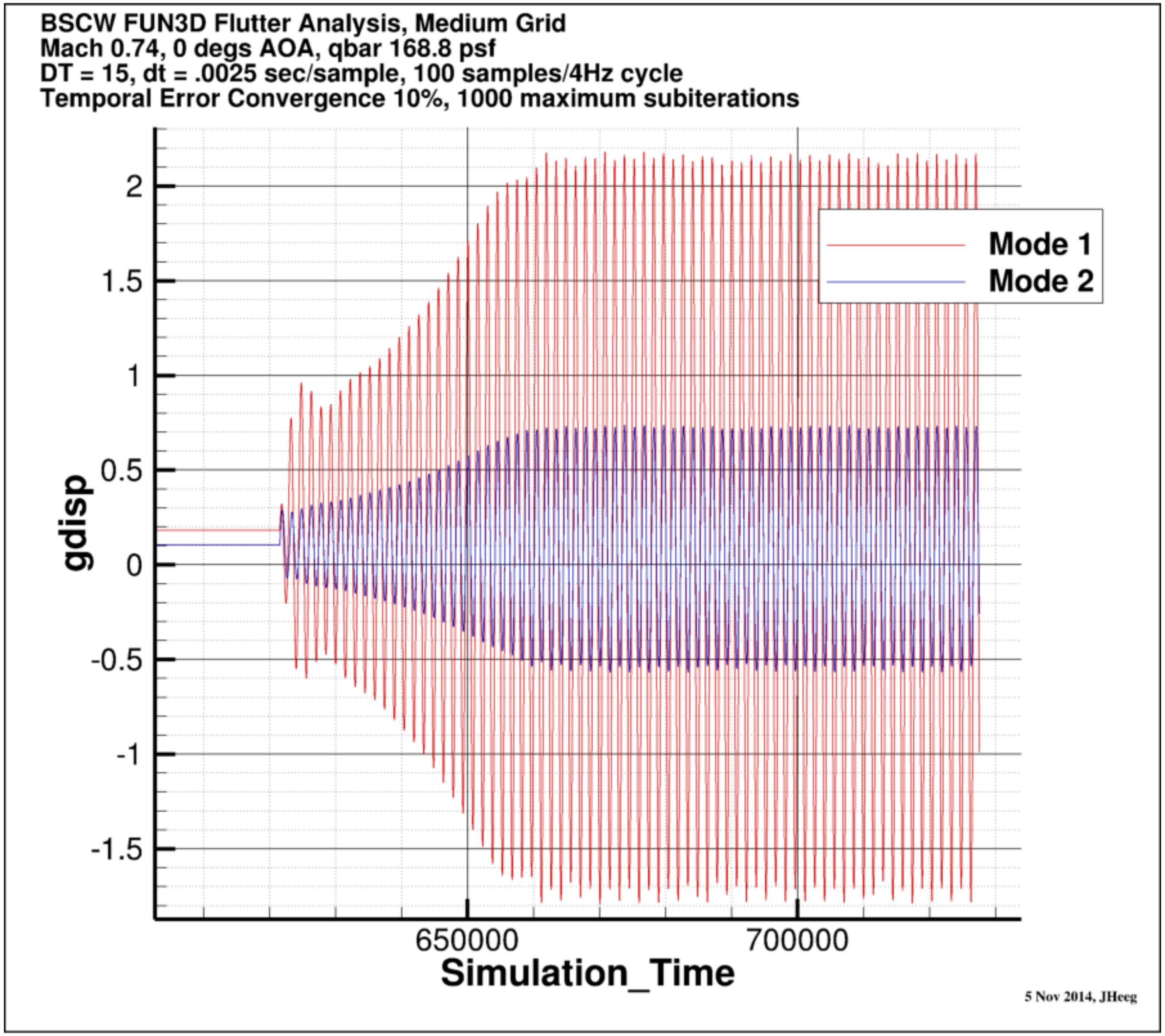
Flutter solution starting from rigid solution vs static aeroelastic solution (DT = 24.375, 5% temporal error convergence)



Solution initiated from The rigid solution shows table behavior.

Solution from static aeroelastic solution shows unstable behavior and then limit cycle oscillation

Physical LCO prediction?
Q 169, DT 15, TC 10%



Initial velocity kick (gvel0) variations

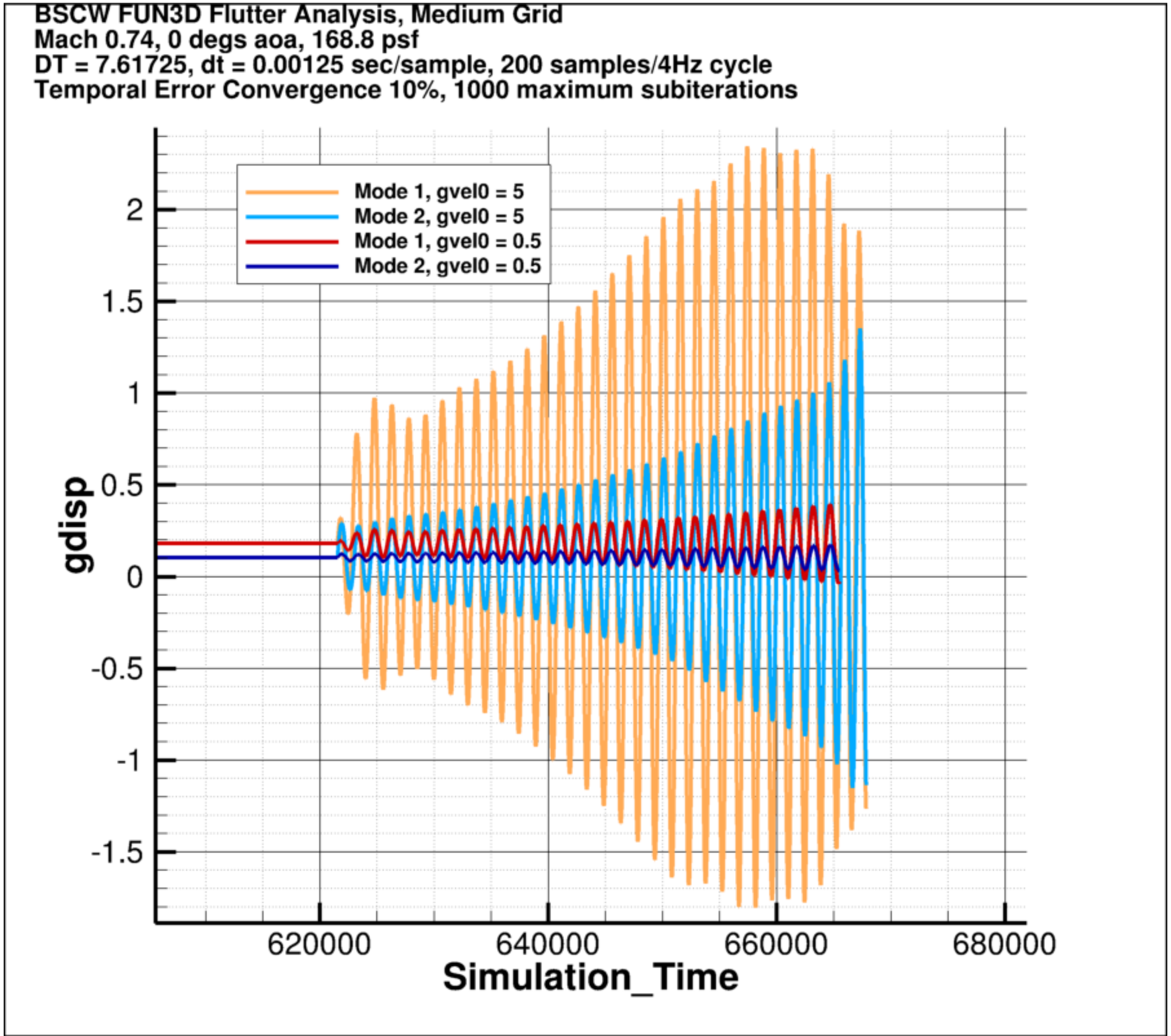
For case 1250 time steps/cycle (DT = 1.2), Medium grid, 10% temporal error convergence, qbar = 168.8 psf

- Currently running 0.5, 2.75 & 10.0

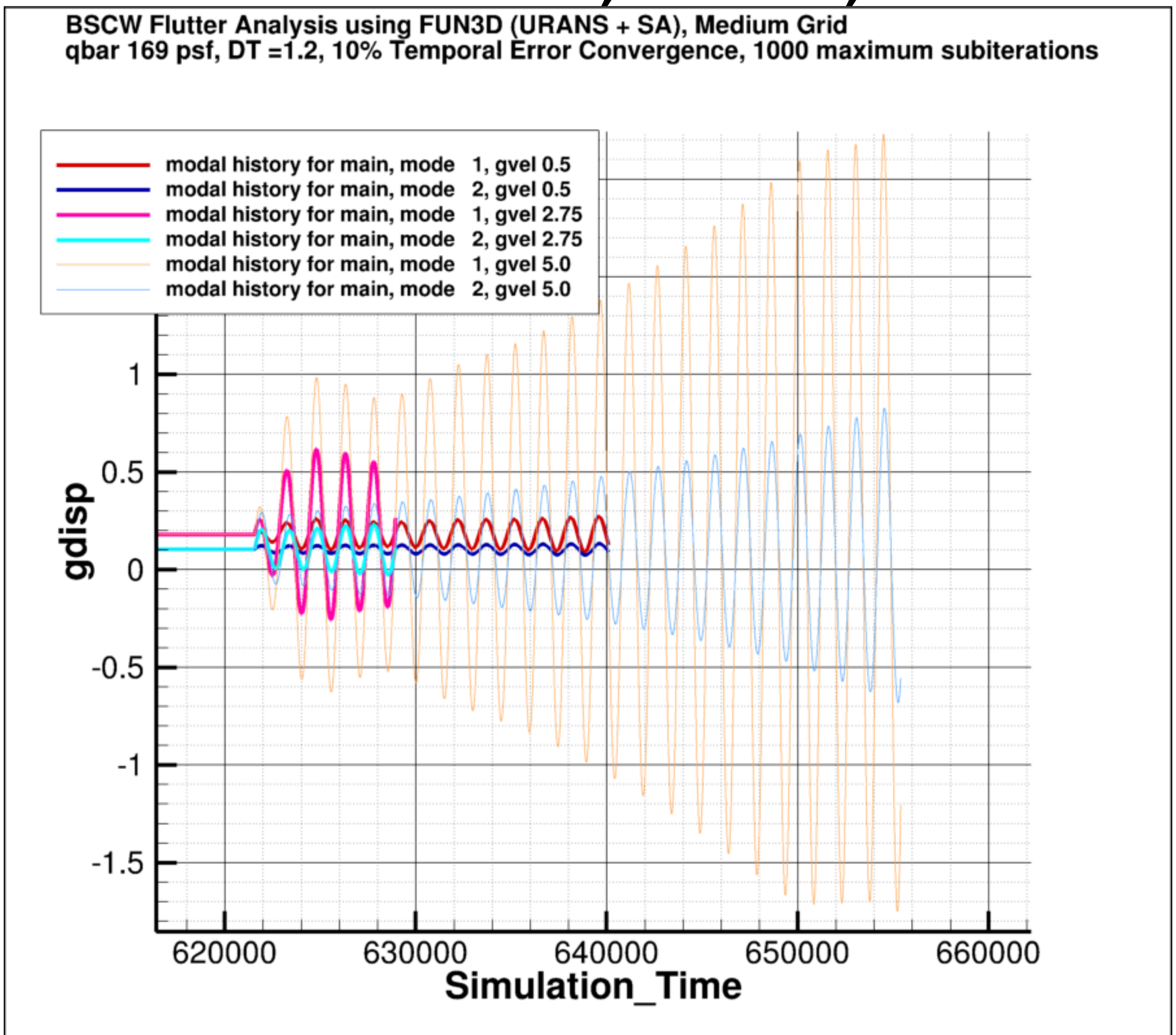
For case ~ 200 times steps/cycle (DT = 7), Medium grid, 10% temporal error convergence, qbar = 168.8 psf

- Ran gvel0 = 5.0 & gvel0 = 0.5

Velocity kick influence
Q = 168.8, DT = 7
TC 10%



Velocity kick influence
Q = 168.8, DT = 1.2, TC 10%
Partial results, Dec 8, 2014

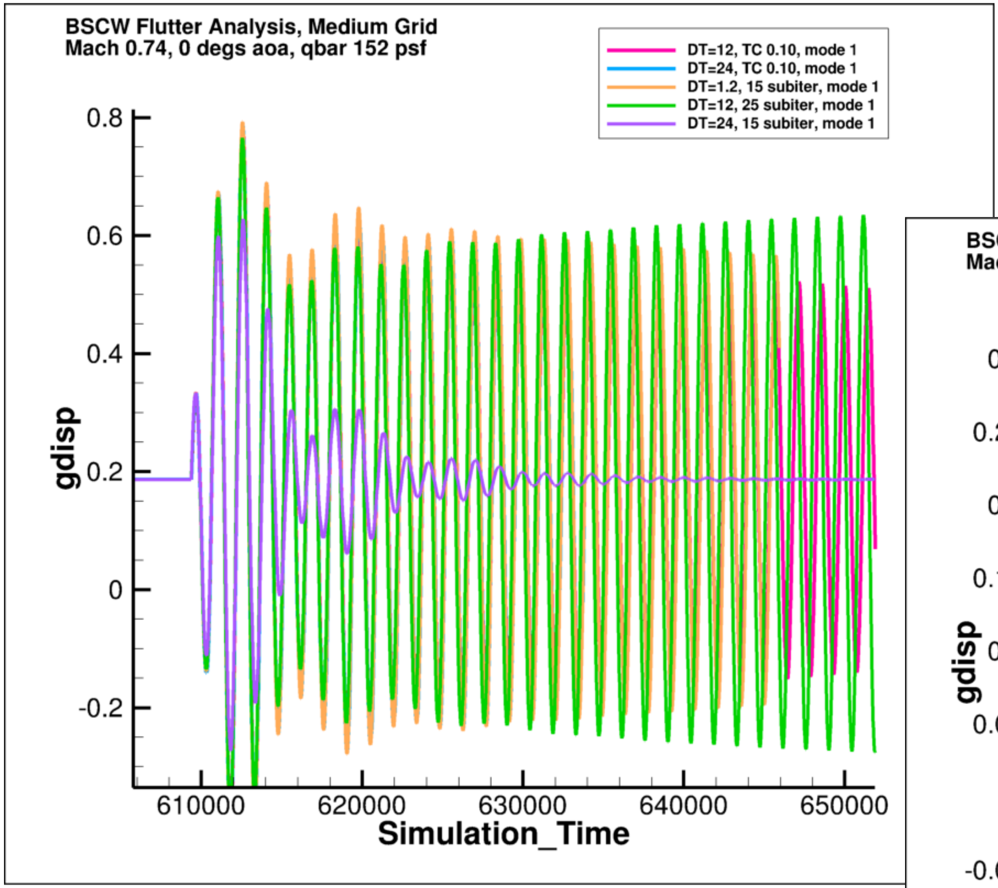


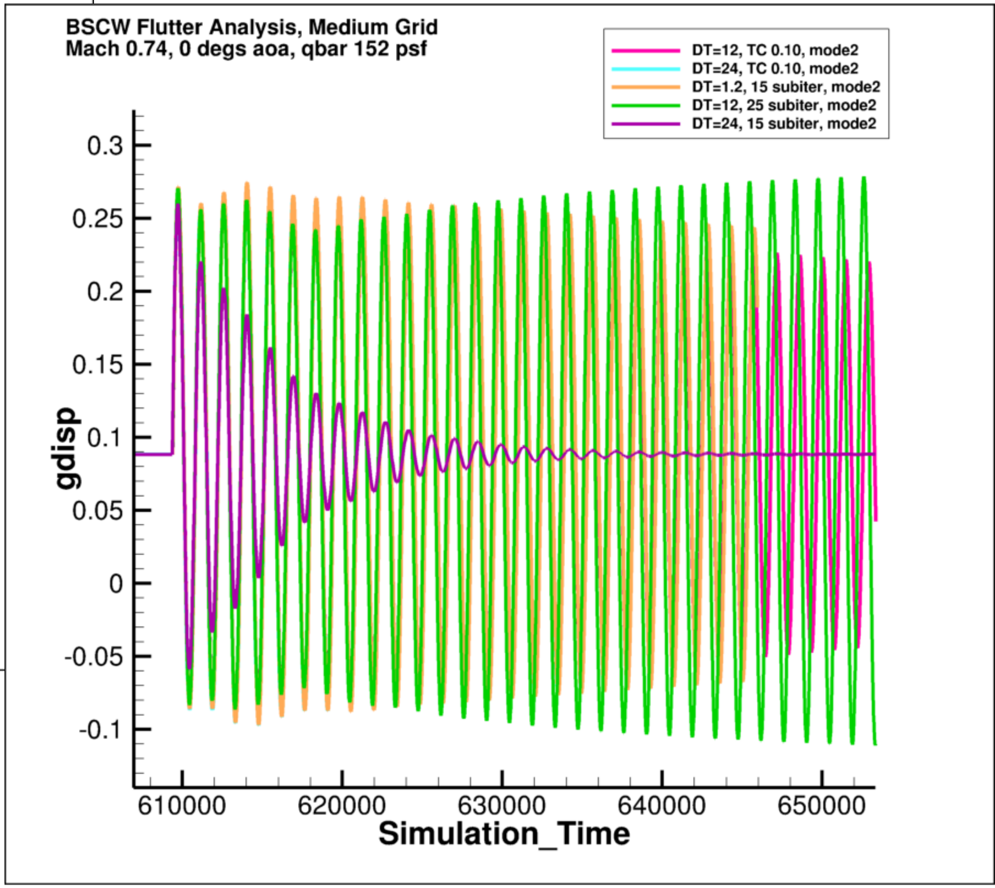
Dec 8, 2014

Thoughts regarding LCO results

- If these are physical LCO results, then regardless of the gvel, the results should go to the same magnitude?
- That is, if they do not encounter some violation or explosion due to numeric
- Hmmm. Should they? Or, if it's physical, shouldn't the size of the velocity perturbation influence the results? Basins of attraction and all that?

152 psf,
Varying DT and subiteration convergence specification





135 psf,
Varying DT and subiteration convergence specification