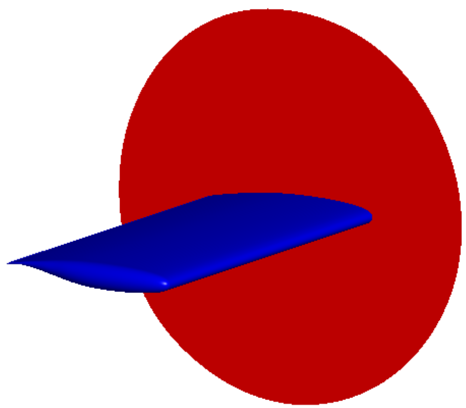
CFD Simulations for the 2nd Aeroelastic Prediction Workshop using EZAIR

Benchmark Supercritical Wing (BSCW)



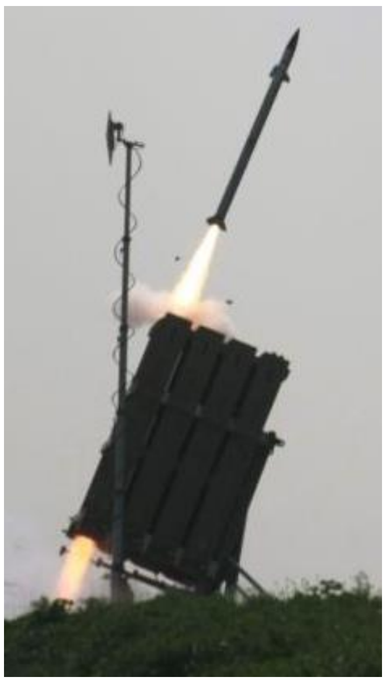
AIAA SciTech, January 2016, San-Diego CA

Dr. Tomer Rokita

Rafael, RD&E Division, Aerodynamics Department

Who are we?

- RAFAEL – Advanced Defense Systems
  - Develops and manufactures advanced defense systems for the IDF, as well as for foreign customers around the world.
  - Innovative solutions at the leading edge of global technology
    - Air superiority, space, underwater, naval, and ground systems



Iron Dome

SPICE

Python-5

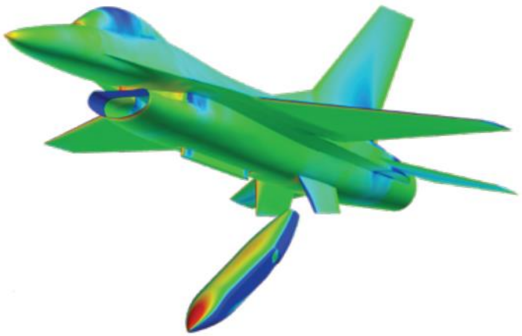
Flow Solver

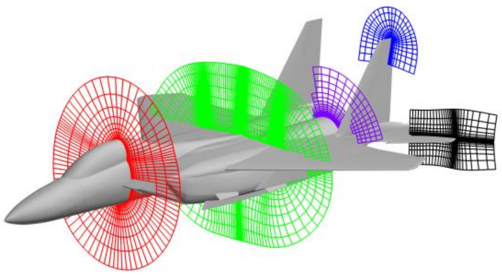
- EZAIR code
  - Developed by the Israeli CFD Center (***ISCFDC***)
  - 2nd generation code following the ***EZNSS*** code
  - Euler/Navier-Stokes finite volume solver
  - 3rd order (biased) spatial, 2nd order temporal
  - Chimera (overset) suite + 6-DOF motion suite
  - Aeroelastic suite (modal approach)
  - RANS + Hybrid RANS/LES turbulence mode
  - Fully parallel MPI/OpenMP

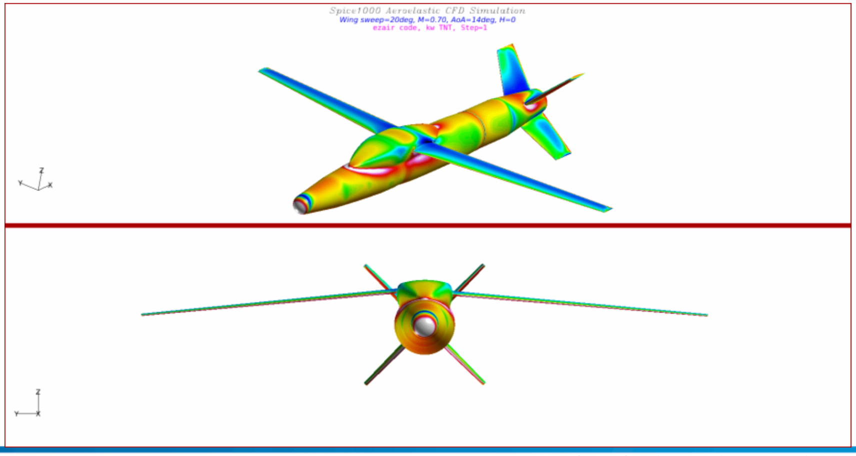
EZAIR

ISCFDC

Easy Air Flow Solver



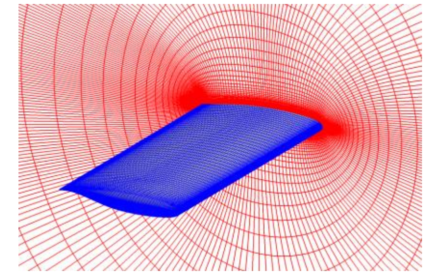




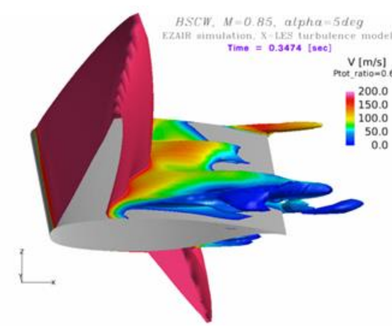
AePW2 Cases

	Case 1	Case 2	Case 3 (Optional)		
	✓	✓	✓	✓	
			A	B	C
Mach	0.70	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
Gas type	**R134-a gas**	**R12 gas**	**R134-a gas**		
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.

Computational Setup



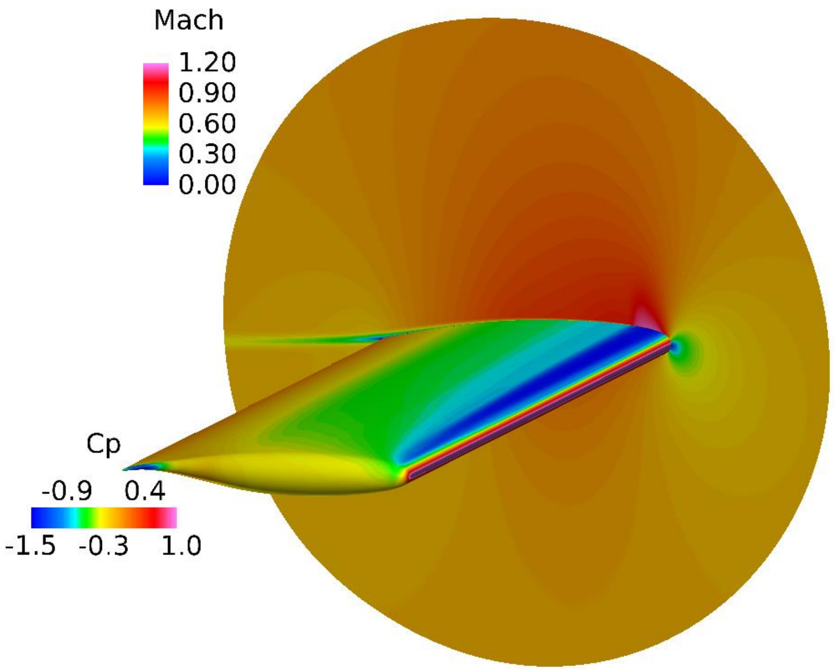
- Grid: single coarse grid (C-O topology, 1.7M)
- Flux construction: HLLC, vanalbada limiter
- Spatial order: Up-wind 3rd (biased) order
- Temporal order: 2nd order with dual-time stepping (basic time step used as 1ms, with 50 sub-iterations)
- Time marching:
  - Diagonally-dominant alternate direction implicit (DDADI)
  - Line Gauss-Seidel with B2 scheme (convergence issues)
- Turbulence model:
  - *RANS*: kω TNT (Kok, 2000)
  - ***Hybrid RANS/LES (DES)***: X-LES (Kok, 2004)

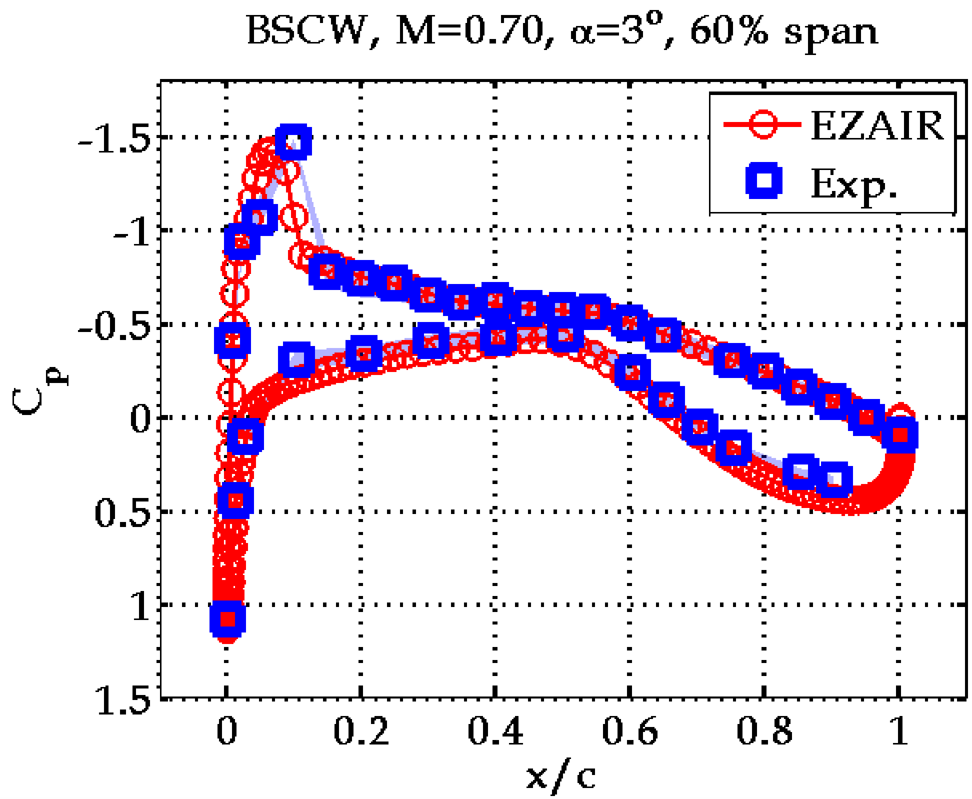


- Aeroelasticity: modal approach
  - ***Dynamic***: global time step coupling
  - ***Static*** (at flutter conditions): dynamic with high damping

Results – Case 1 (M=0.70, α=3°)

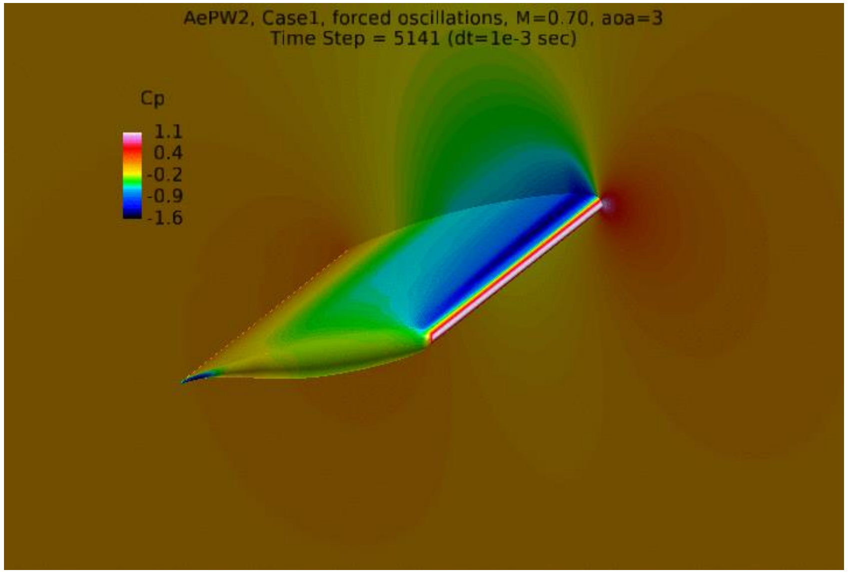
- Steady results:
  - "Straight-forward, simple" case
  - Linear regime: no shocks, limited trailing-edge flow separation
  - Good agreement with experimental results

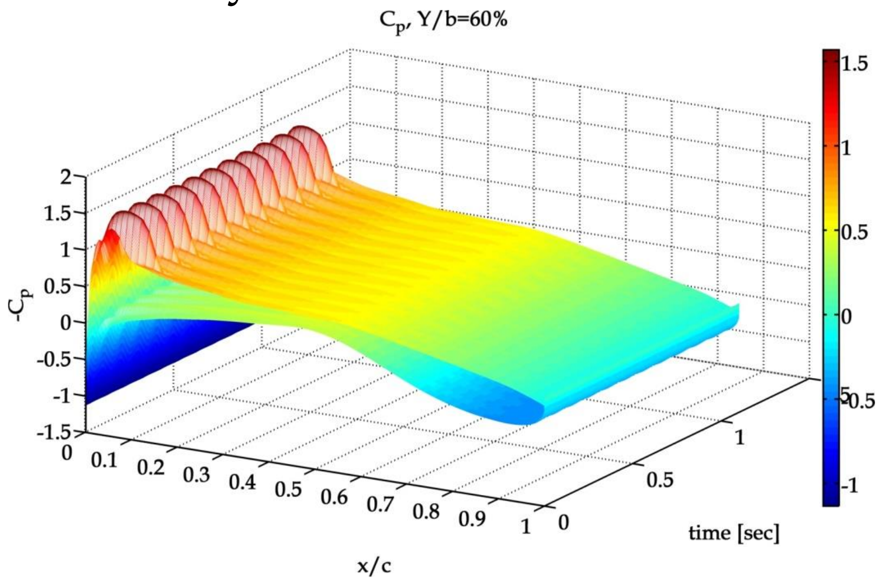




Results – Case 1 (M=0.70, α=3°)

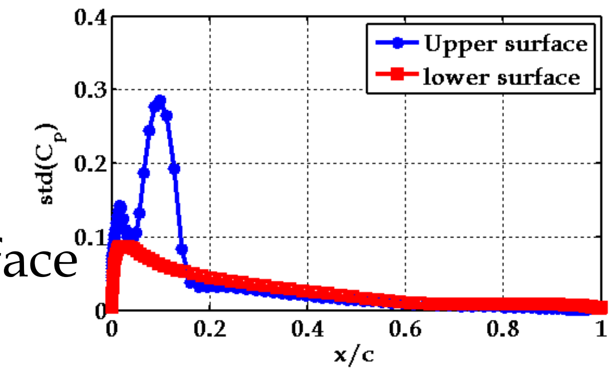
- Unsteady (forced oscillation) results:
  - Rigid-body prescribed motion (aeroelastic module is not activated)
  - Time step (1ms) corresponds to 100 steps per cycle (sensitivity checked for 200 step per cycle)
  - Dual-time stepping: 4 orders of magnitude convergence at each time step
  - Total time recorded: 1.2sec (12 oscillation cycles) for "complete" periodicity of the signal and statistical analysis

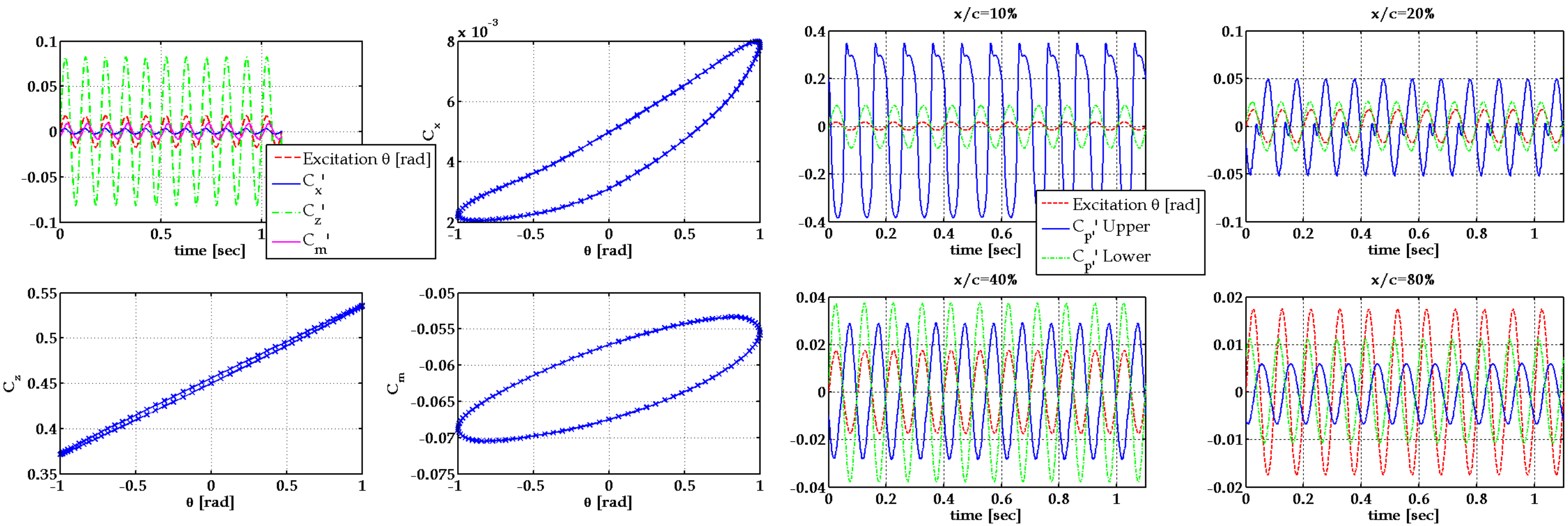




Results – Case 1 (M=0.70, α=3°)

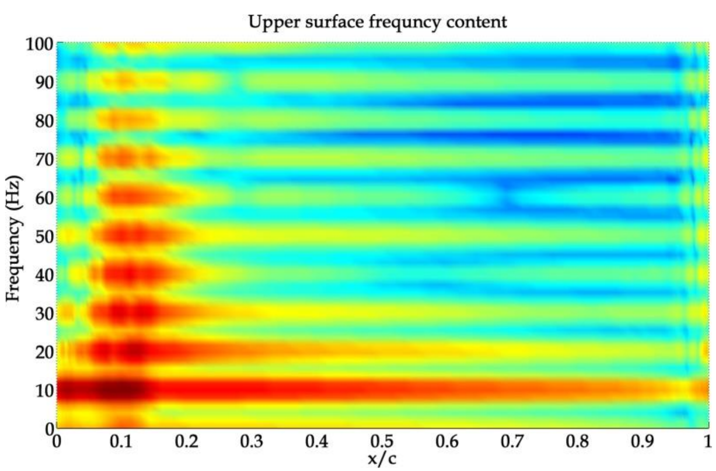
- Unsteady (forced oscillation) results:
  - Low frequency, almost quasi-steady (small time-lag in integral forces)
  - Large response concentrated at L.E. (expected)
  - Non-linear effect (shock) appears at upper surface
  - Response not only in the actuation frequency

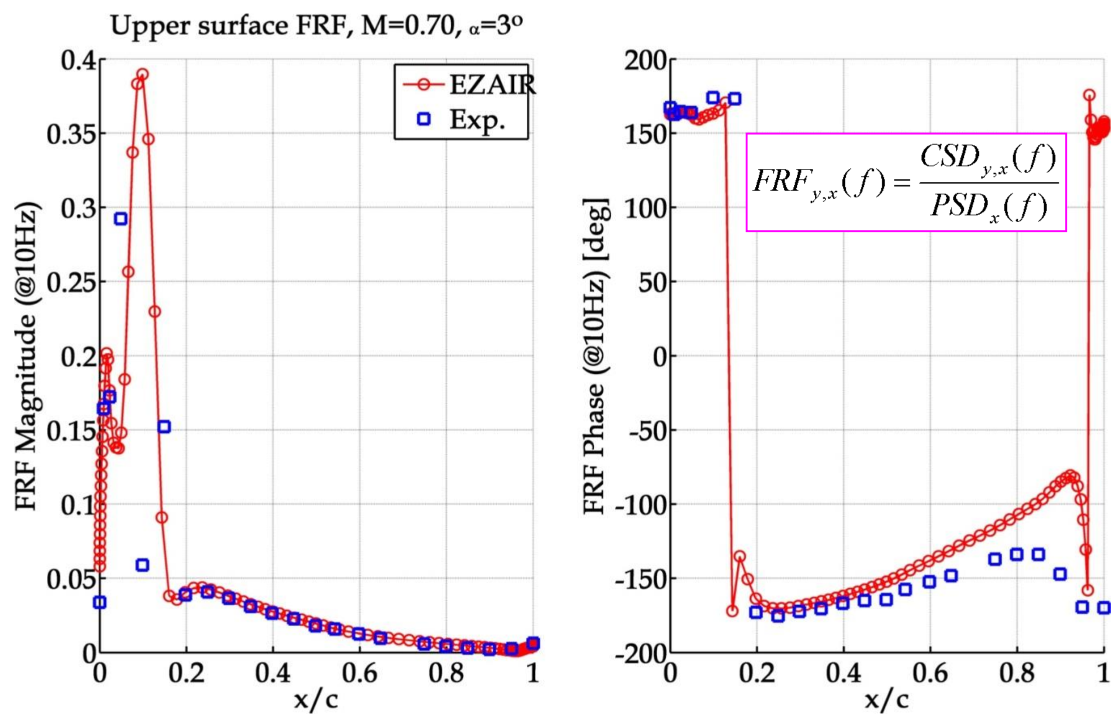




Results – Case 1 (M=0.70, α=3°)

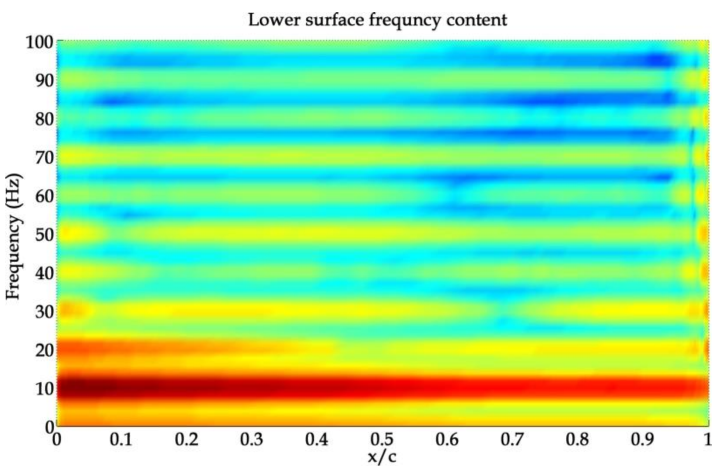
- Unsteady (forced oscillation) results:
  - Upper surface: main response at the actuation frequency, “folded” frequencies appear near shock location
  - Reasonable agreement with experimental results. Double-peak magnitude behavior corresponds to shock oscillation

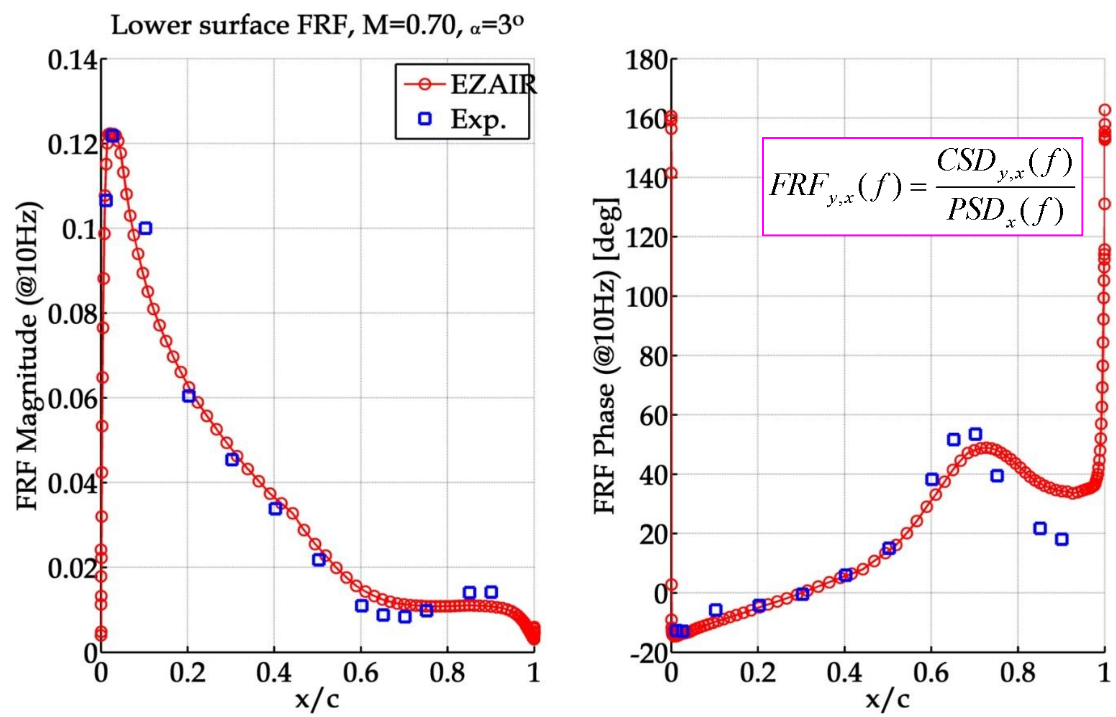




Results – Case 1 (M=0.70, α=3°)

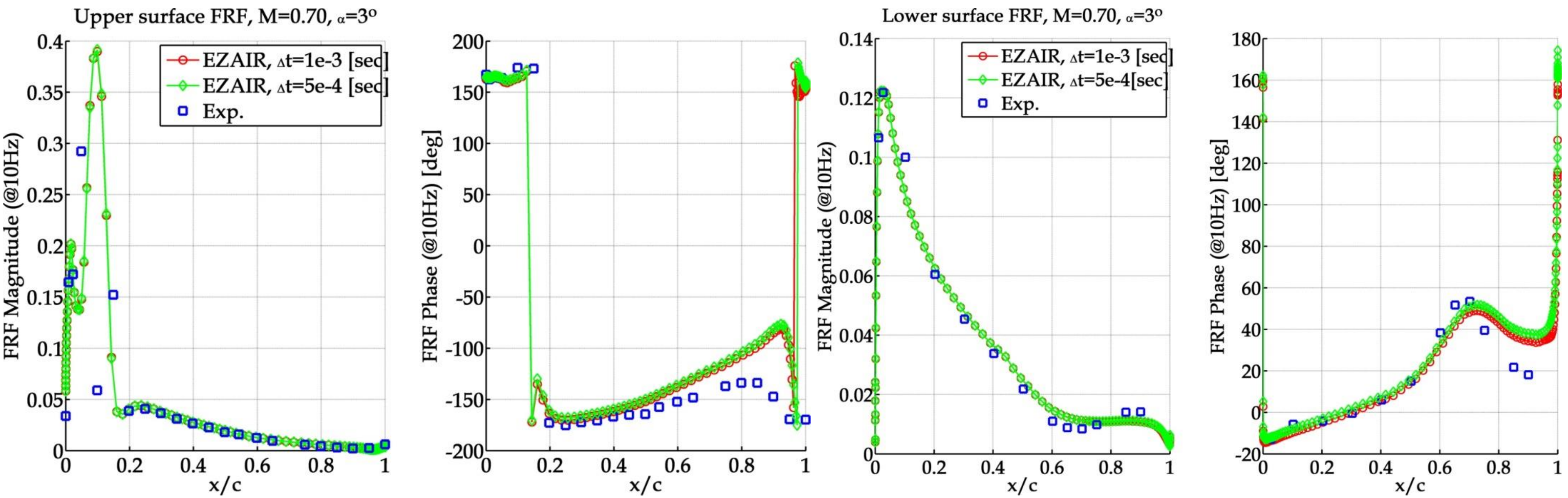
- Unsteady (forced oscillation) results:
  - Lower surface: “only” response at the actuation frequency (no shocks)
  - Good agreement with experimental results. Slight phase deviation near trailing-edge might be associated with T.E. separation





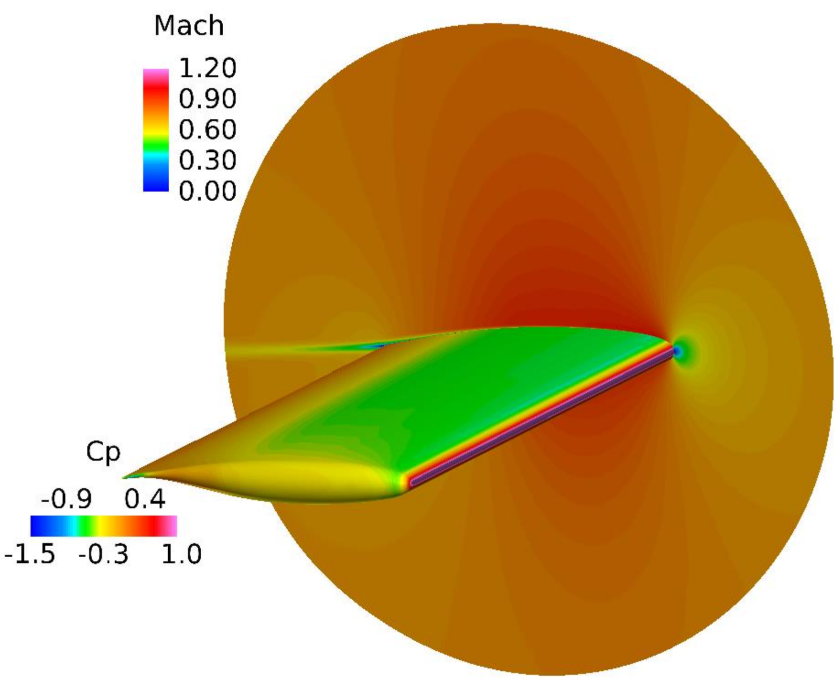
Results – Case 1 (M=0.70, α=3°)

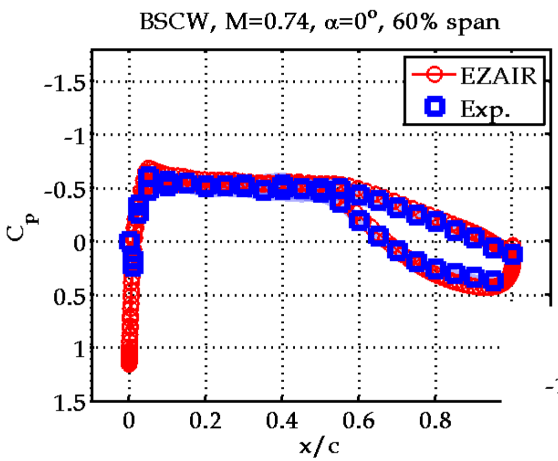
- Unsteady (forced oscillation) results:
  - Sum up of case 1: time-step sensitivity check showed convergence/independency

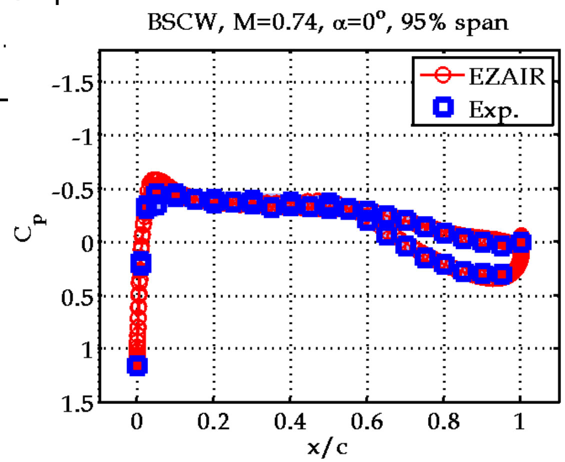


Results – Case 2 (M=0.74, α=0°)

- Steady results:
  - "Straight-forward, simple" case (low lift C_L≈0.2)
  - Linear regime: no shocks, limited trailing-edge flow separation
  - Good agreement with experimental results

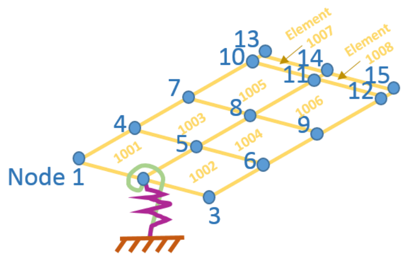


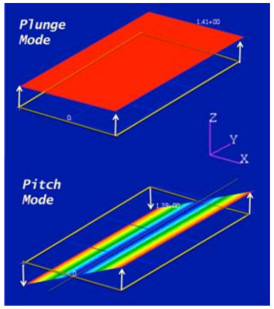


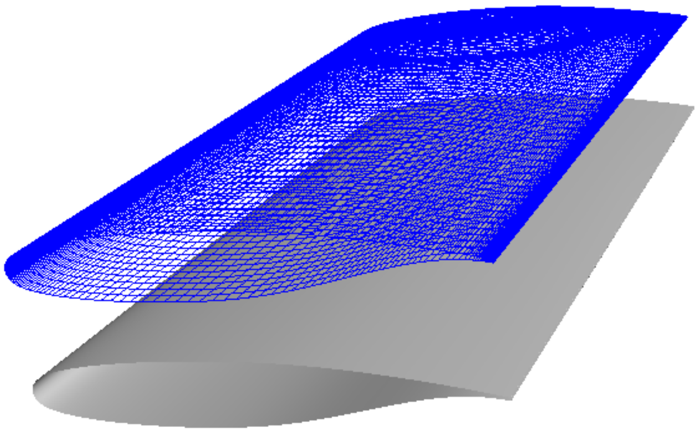


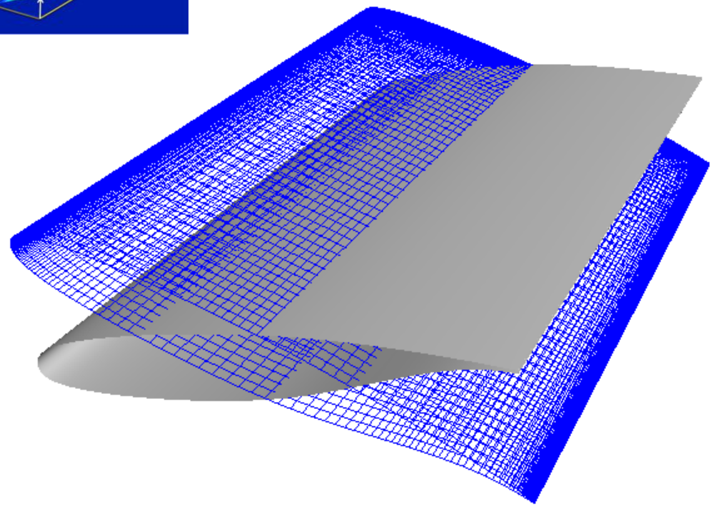
Results – Case 2 (M=0.74, α=0°)

- Flutter results: structural modes mapping
  - Used provided structural model (NASTRAN)







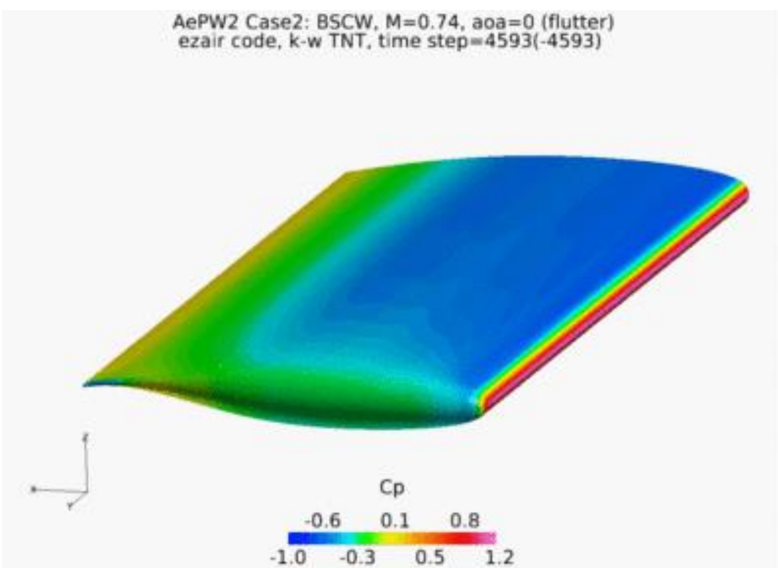


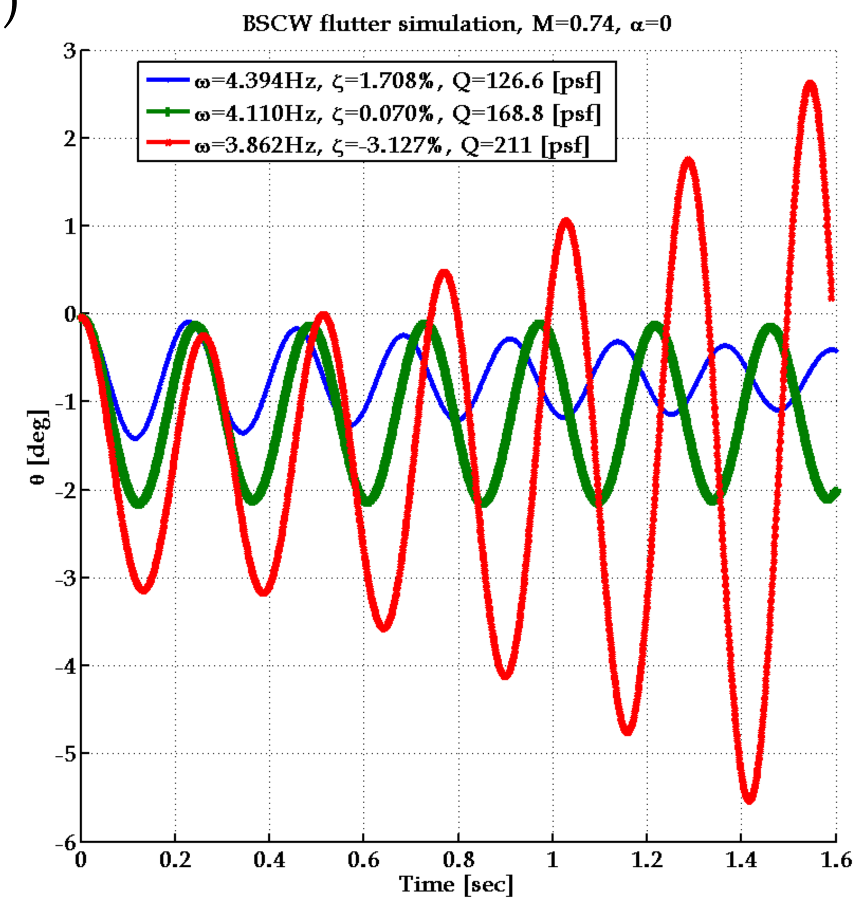
Heave mode, 3.32Hz

Pitch mode, 5.25Hz

Results – Case 2 (M=0.74, α=0°)

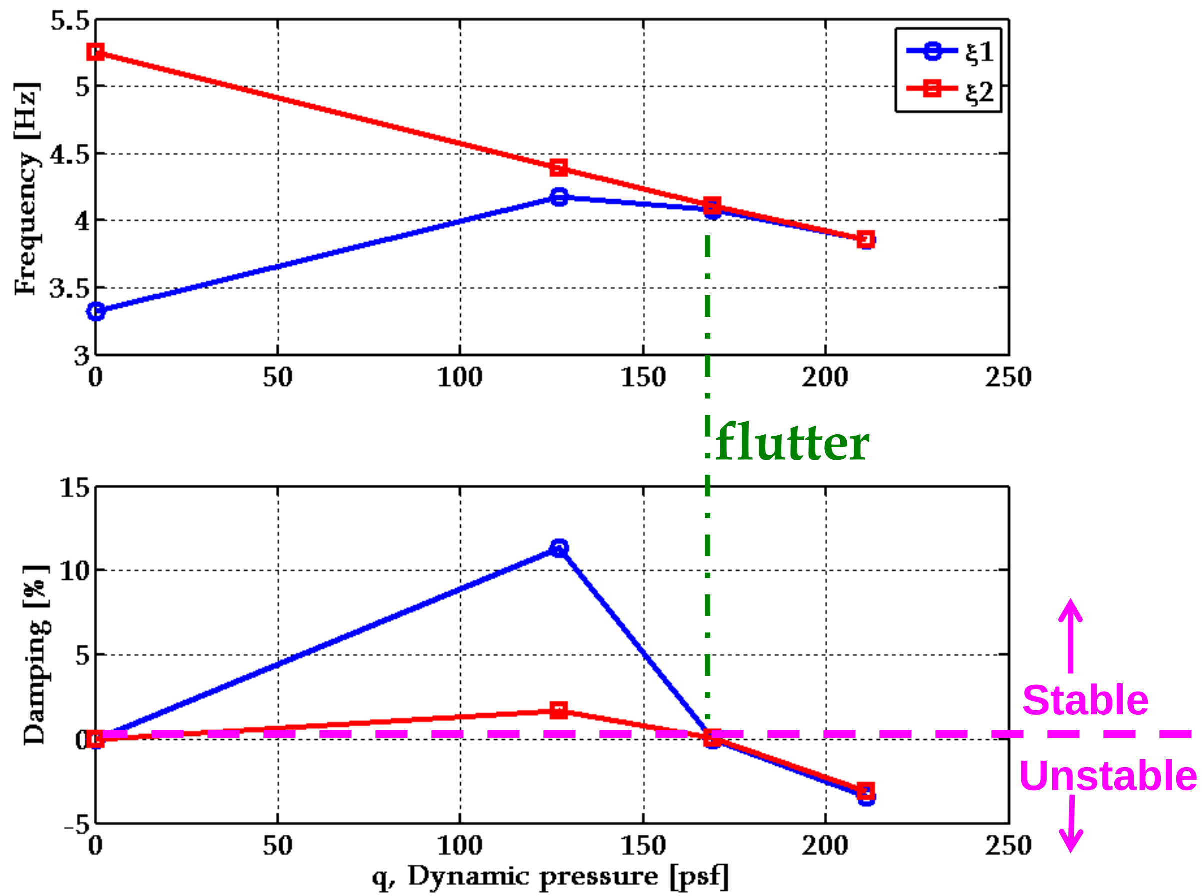
- Flutter results:
  - Three simulations ran: Exp. flutter dynamic pressure (168.8psf), -25% (pre-flutter), +25% (post-flutter)
  - Simulation I.C.: rigid solution
  - Recorded time: 1.6sec (dt=1ms)
  - Frequency and damping calculated based on pitch angle time history





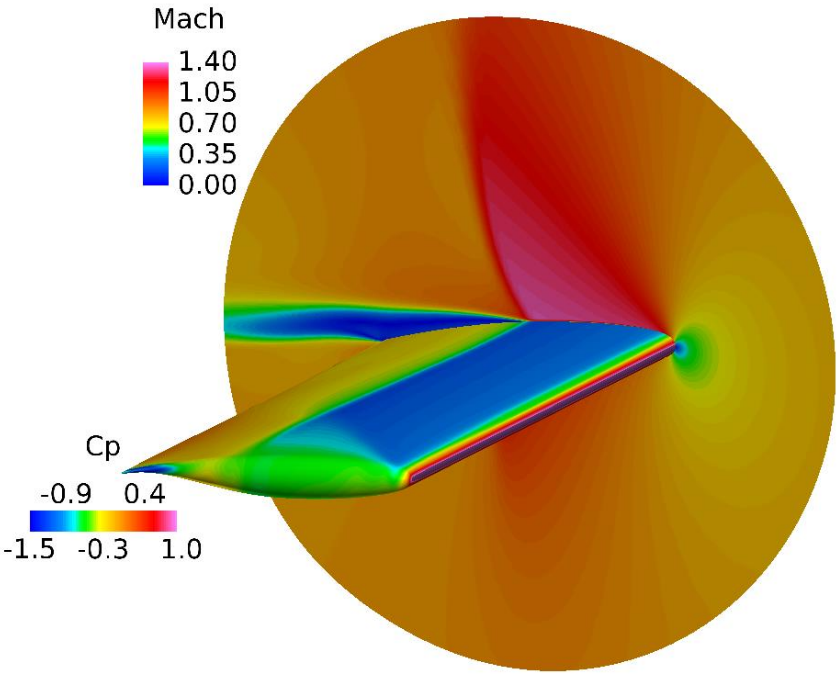
Results – Case 2 (M=0.74, α=0°)

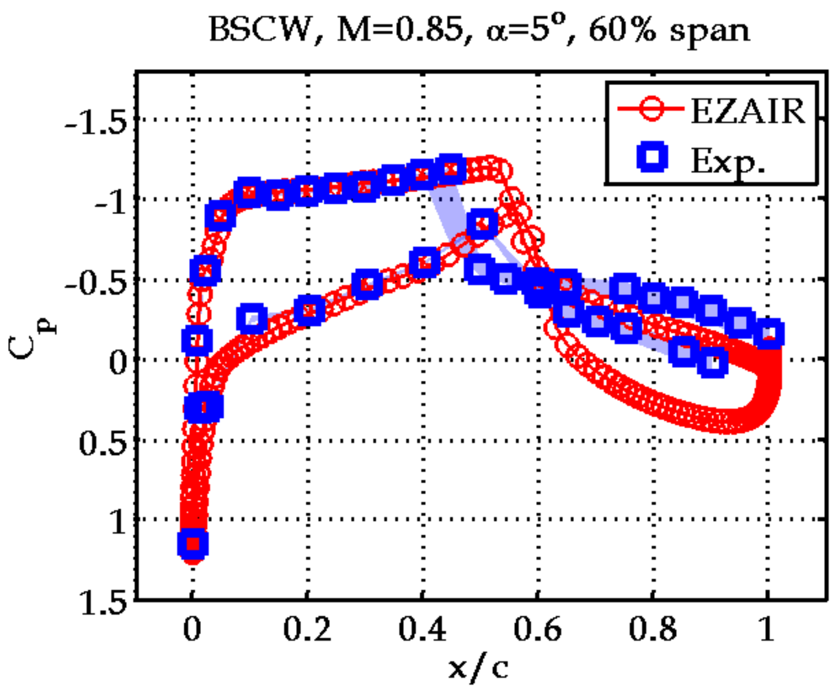
- Flutter results:
  – Frequency and damping calculation of each mode response (“V-g-ω”)



Results – Case 3 (M=0.85, α=5°)

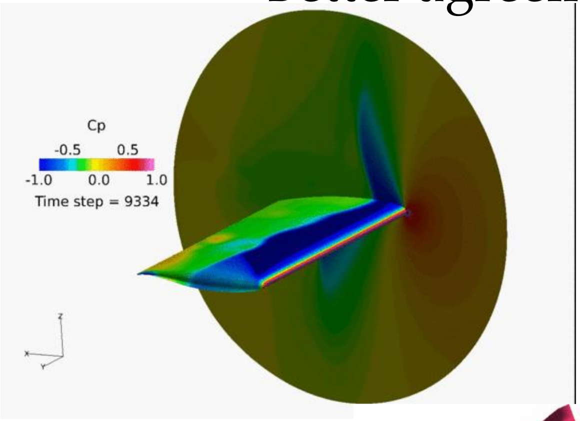
- Steady results:
  - Non-linear "complicated" case (shock induced flow separation)
  - RANS model, kω TNT: convergence issues, used robust LGS+B2 scheme to converge in steady state
  - Only fair agreement with experimental results; rear shock location

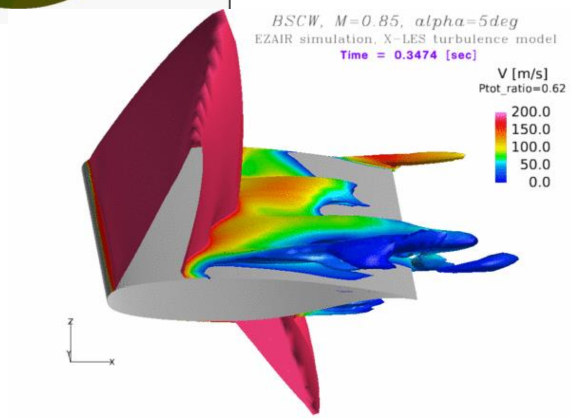


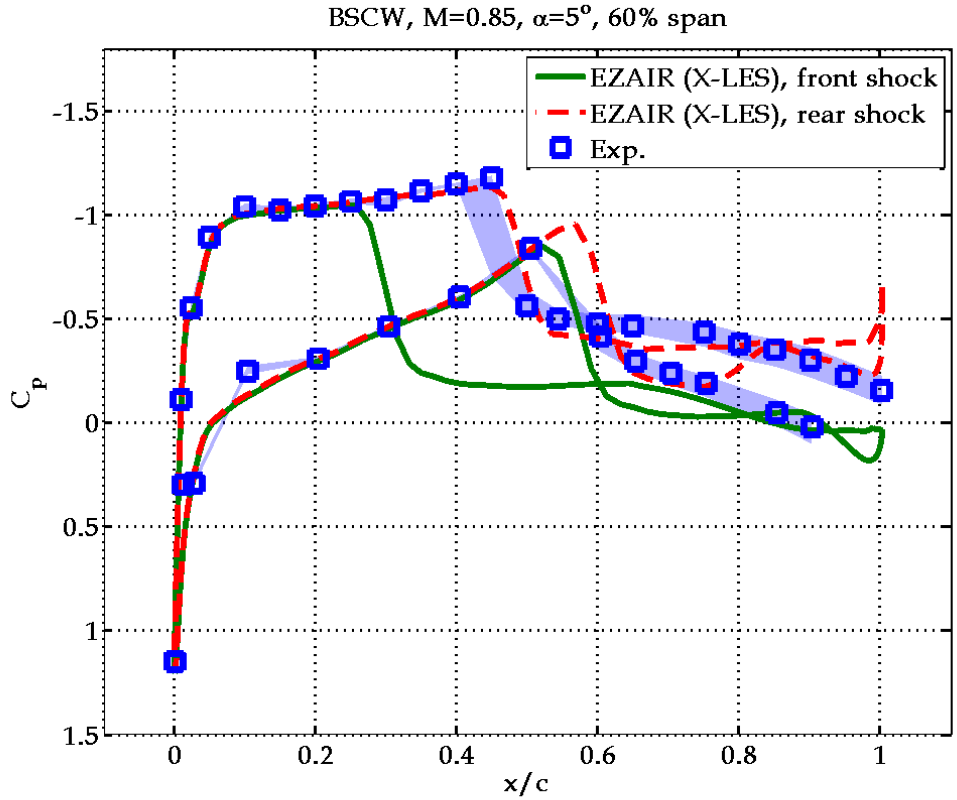


Results – Case 3 (M=0.85, α=5°)

- "Steady" results:
  - Hybrid RANS/LES (DES) model (X-LES): Shock-wave oscillation + spanwise structures (coarse grid is not suitable)
  - Better agreement to experimental results.



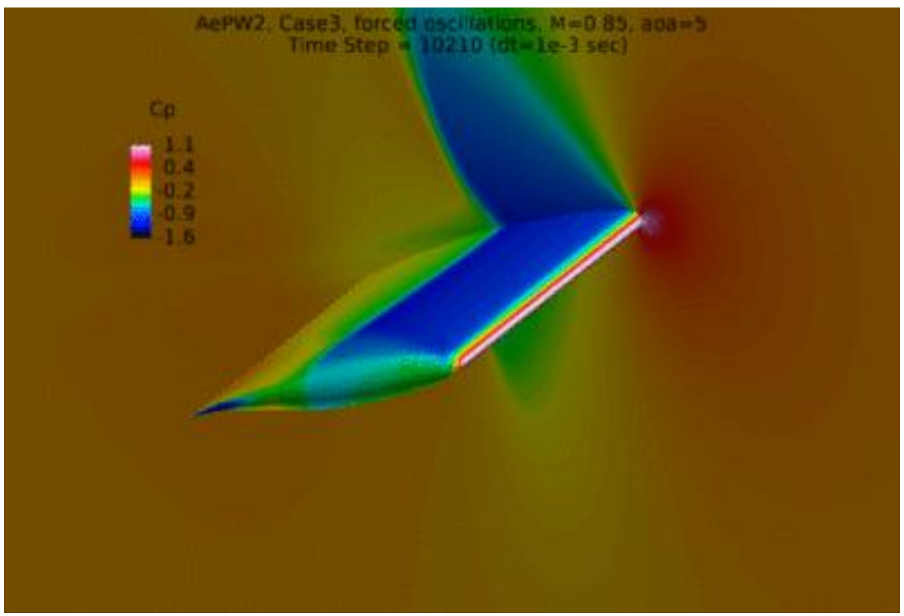




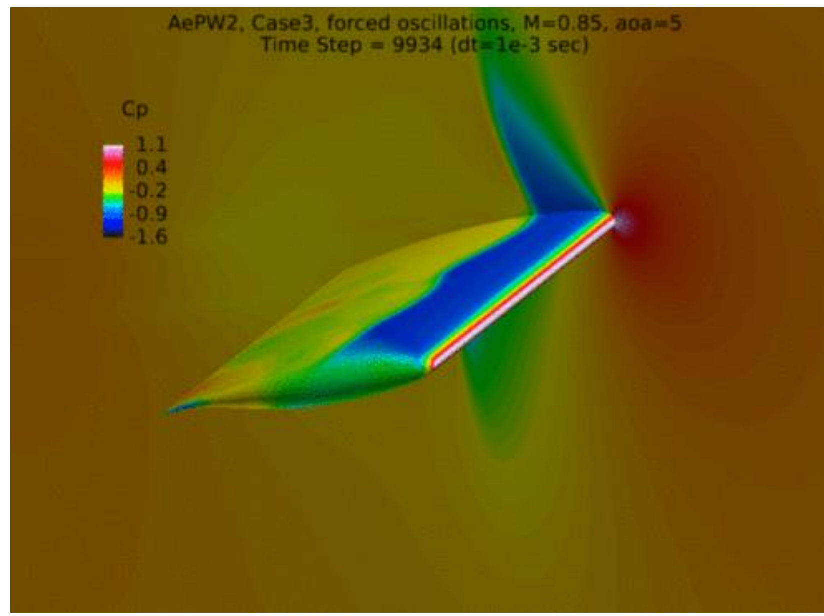
Results – Case 3 (M=0.85, α=5°)

- Unsteady (forced oscillation) results:
  - Shock wave frequency “locked” on actuation frequency
  - RANS results in a aft spanwise-uniform shock wave relative to DES (front, spanwise non-uniform)

kω (TNT)

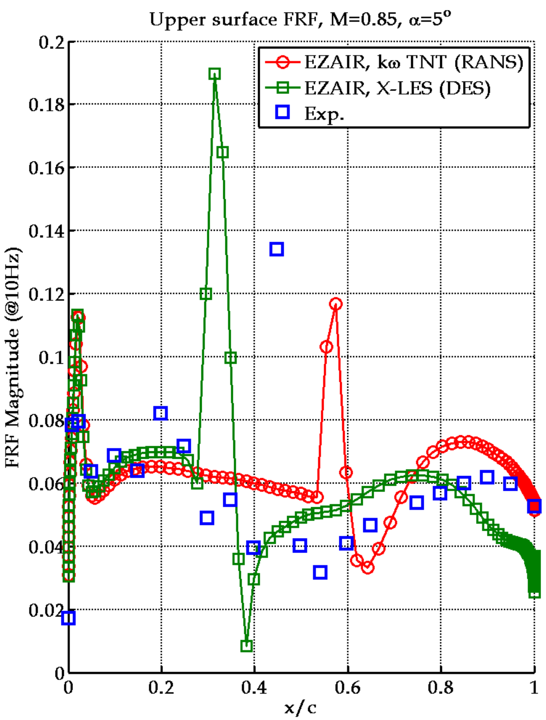


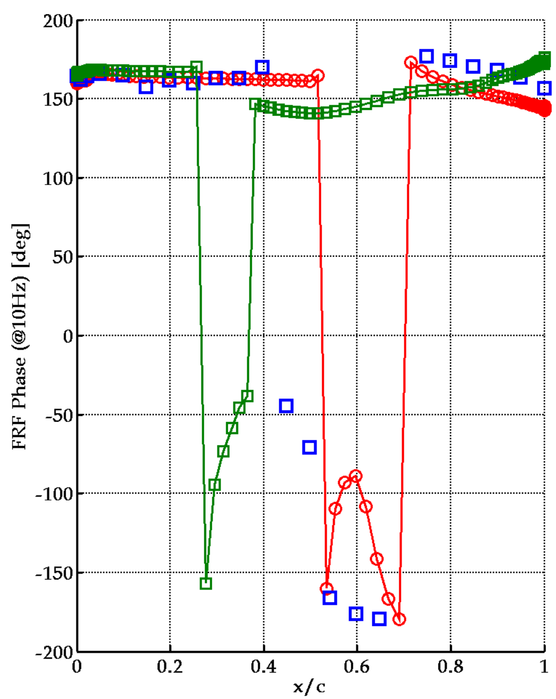
X-LES

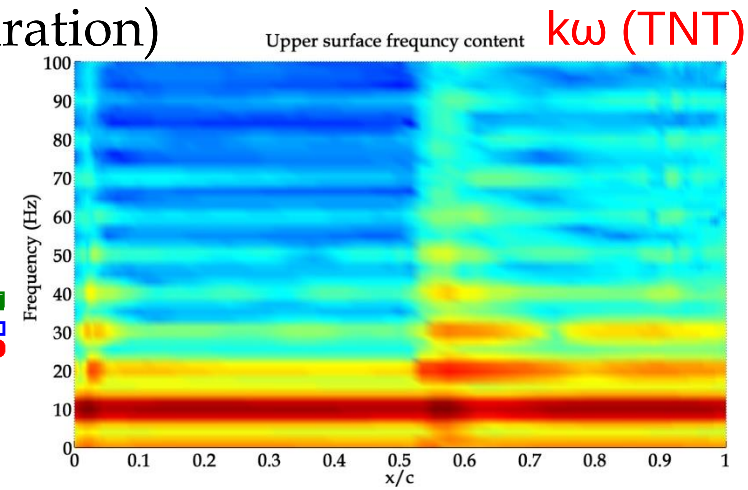


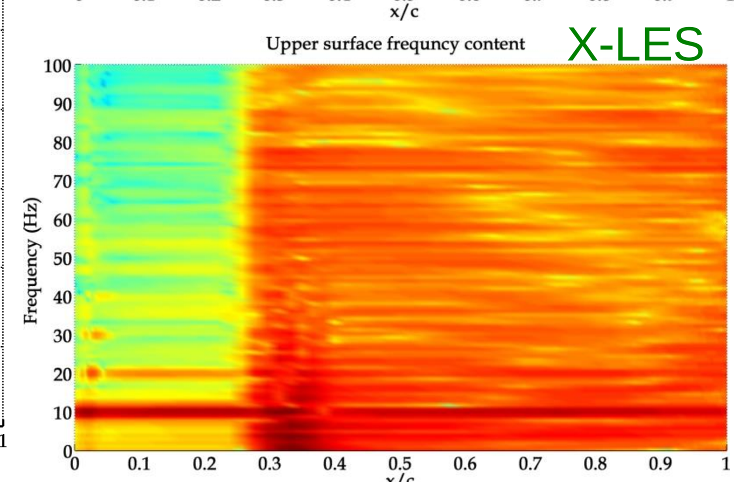
Results – Case 3 (M=0.85, α=5°)

- Unsteady (forced oscillation) results:
  - RANS: response mainly at actuation frequency
  - DES: turbulent spectrum after shock (separation)
  - Only fair agreement near shock, good agreement elsewhere



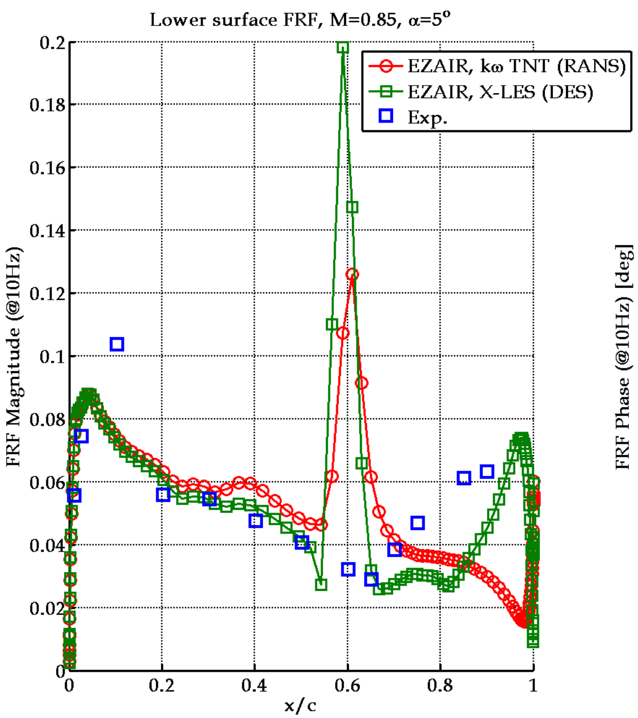


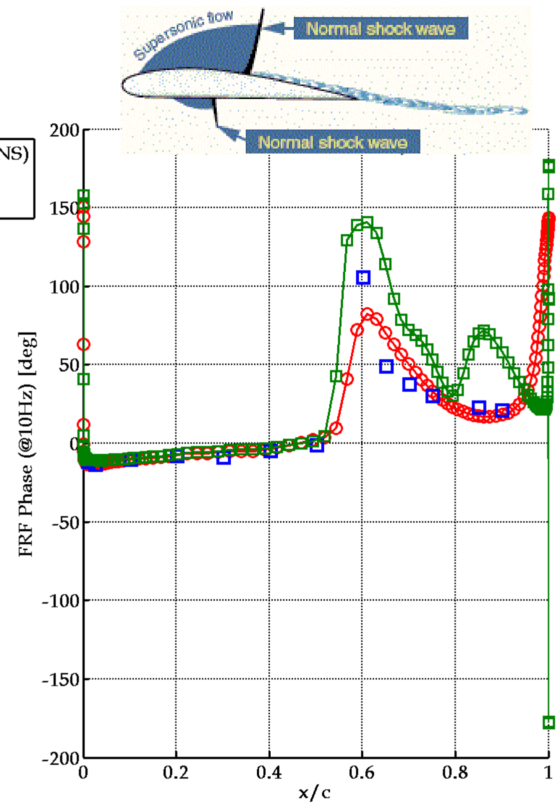


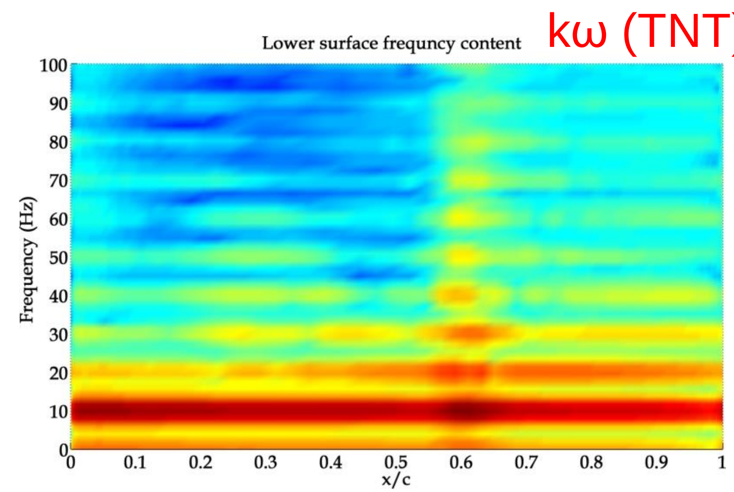


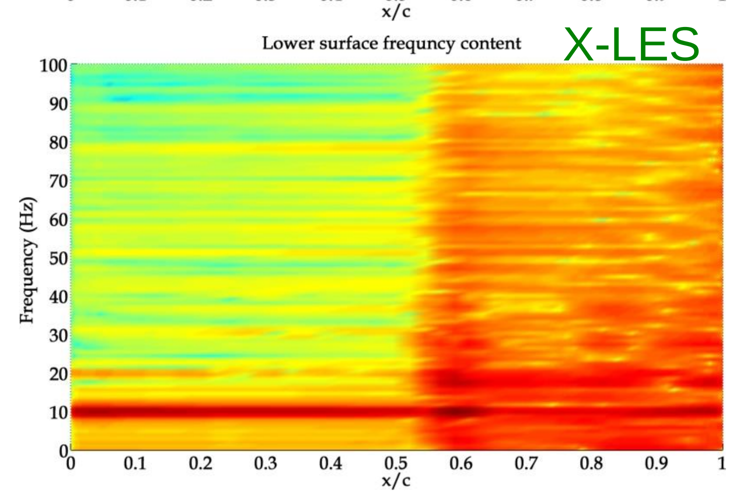
Results – Case 3 (M=0.85, α=5°)

- Unsteady (forced oscillation) results:
  - Better agreement for the lower surface
  - Shock oscillation is not apparent in the experimental magnitude FRF results









Conclusions

- ***EZAIR*** simulations results for the 2nd Aeroelastic Prediction Workshop (AePW2) were presented, for all three cases required

- Overall good agreement with experimental results:
  - "Exact" pressure distributions for the "simple" cases (1&2)
  - Accurate flutter dynamic pressure prediction (case 2)
  - Only fair agreement for the optional case 3 (DES capabilities were demonstrated for massive flow separation; however grid refinement is required for further investigation)

Thank you!

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