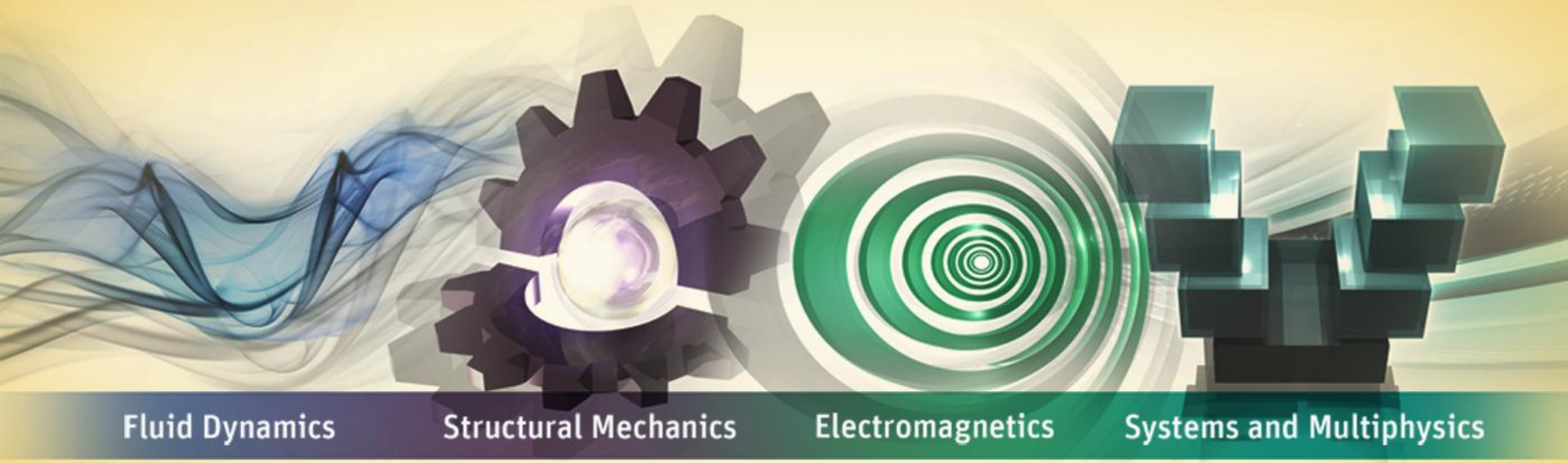
ANSYS

Realize Your Product Promise™

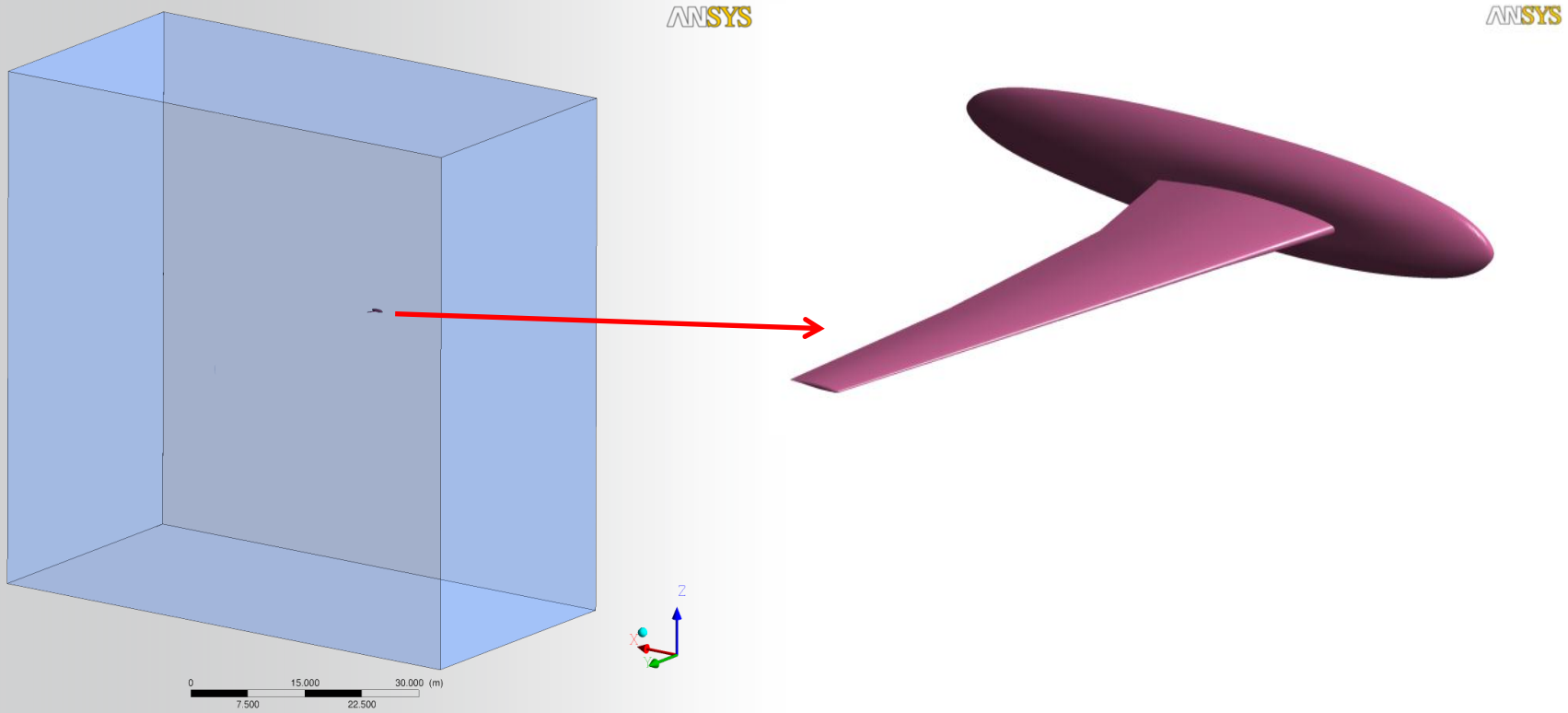
HIRENASD



Thorsten Hansen
ANSYS Germany GmbH

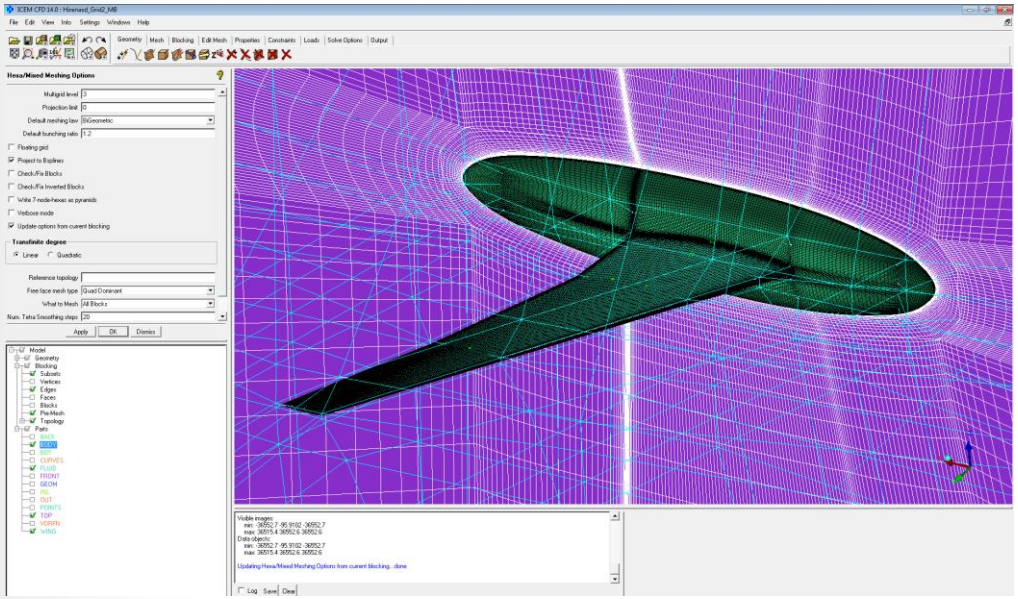
Computational Domain

- $Cref_{mean}$ = 0.3445 m
- 100 * Cref in all directions



Grid Information

- ANSYS ICEM CFD 14
- Hexahedral elements
- Scalable grids
  - Consistent mesh quality upon grid refinement
- Multigrid
  - levels = 3

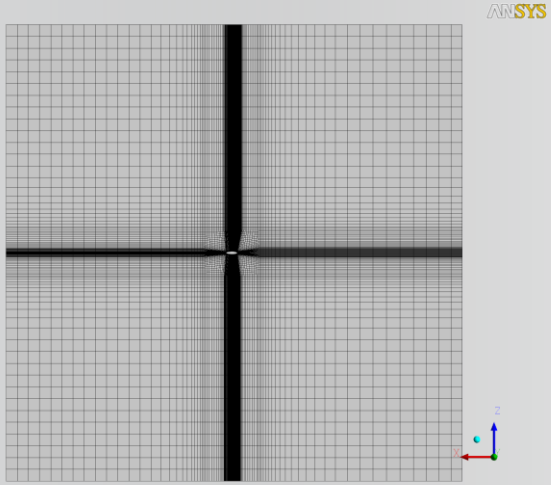


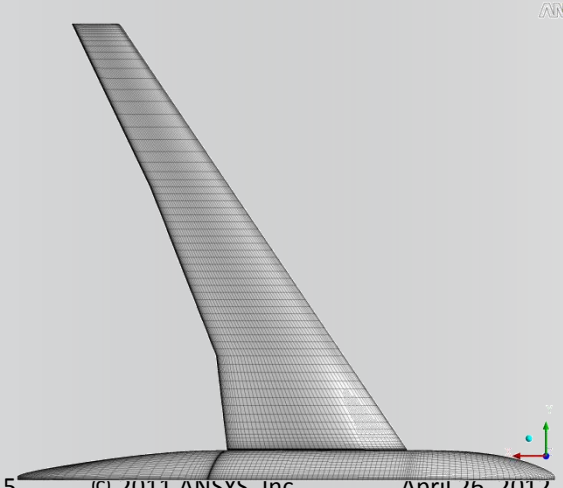
Grid Information

	Grid 1	Grid 2	Grid 3
Number of nodes	3,158,849	10,025,769	28,458,329
Number of elements	3,088,384	9,872,384	28,149,248
Minimum grid angle	23.3°	24.17°	24.33°
Maximum aspect ratio	149,529	125,250	134,515
First grid node @ Wall, m	4.4e-07 m (y^+=0.58)	2.94e-07 m (y^+=0.41)	1.96e-07 m (y^+~4/9)

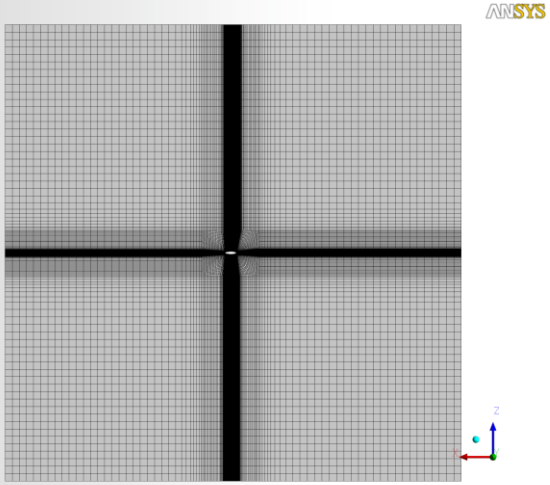
Grid Information

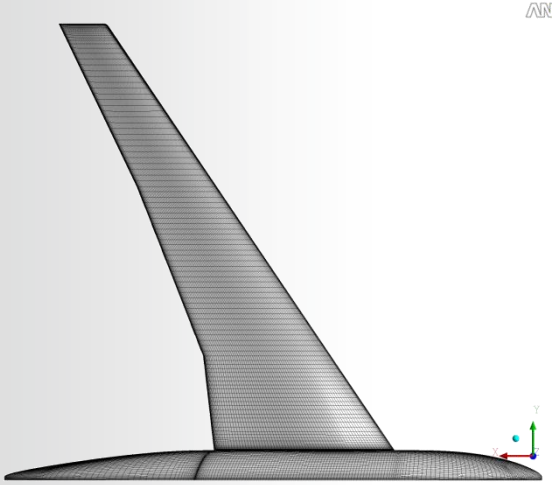
Grid 1



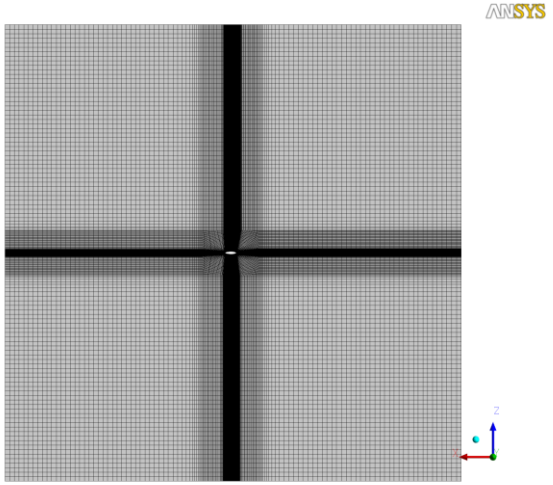


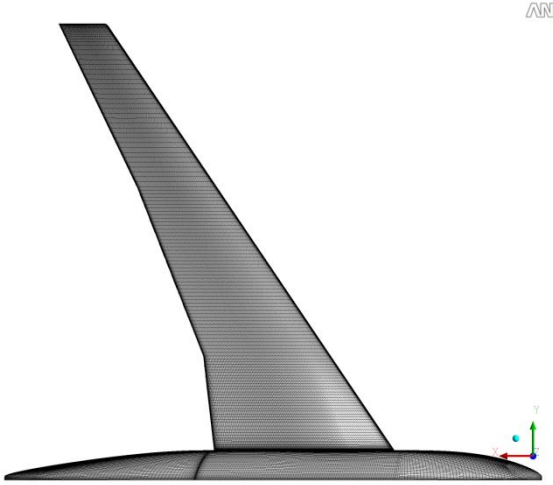
Grid 2





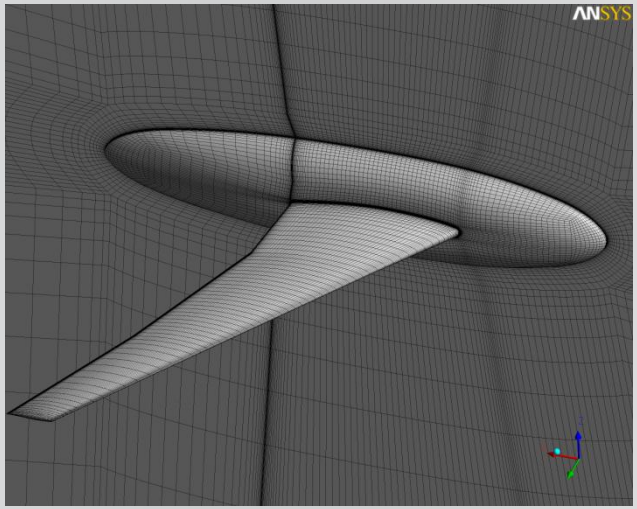
Grid 3

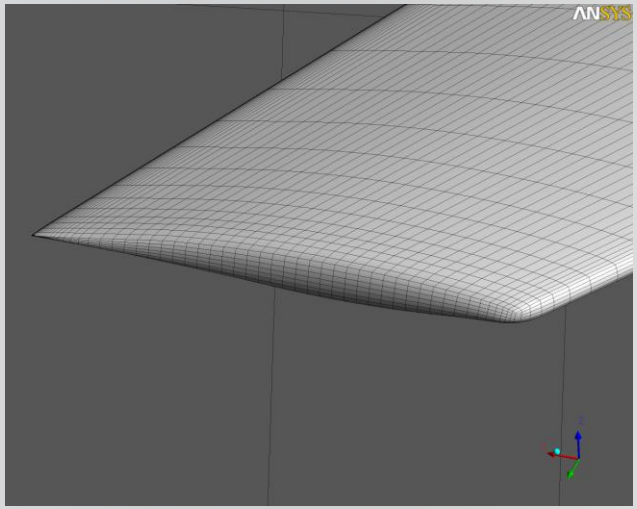




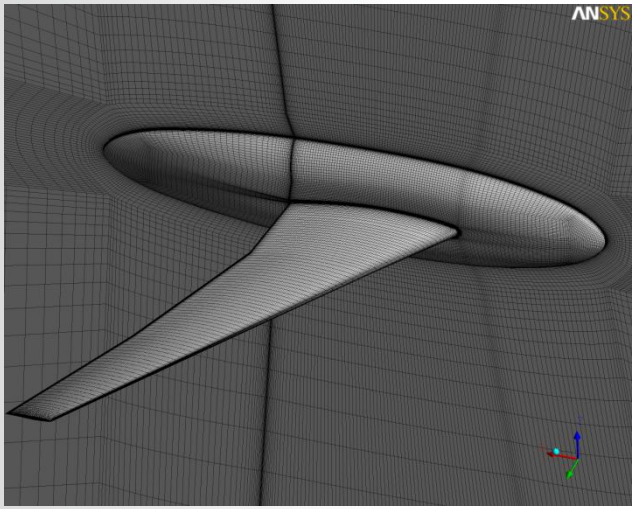
Grid Information

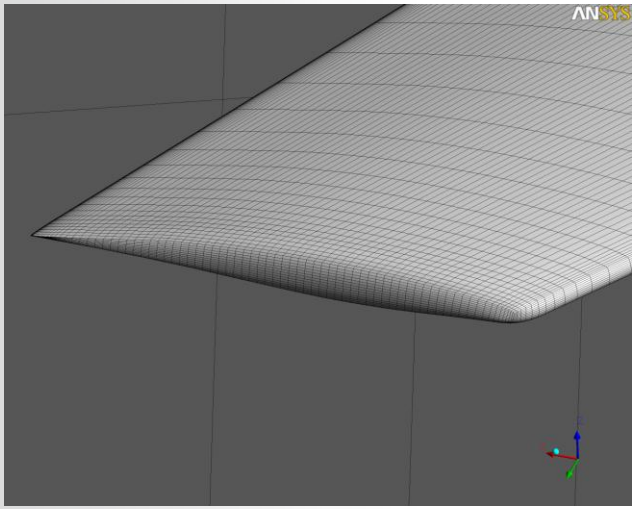
Grid 1



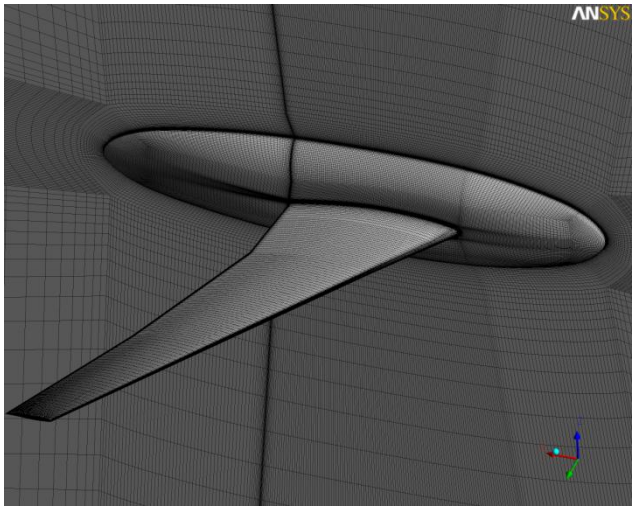


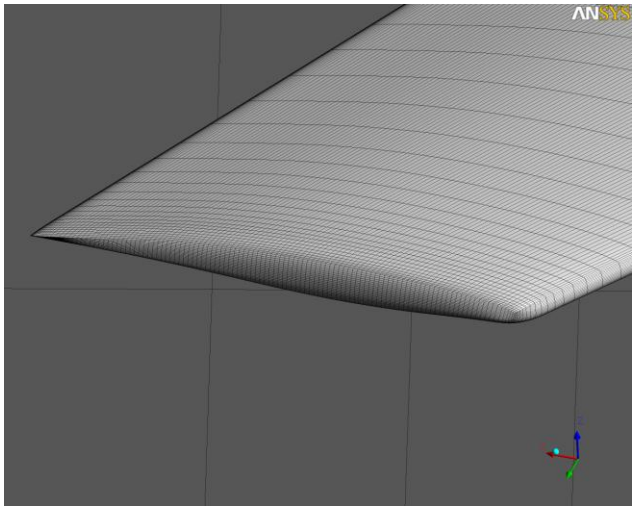
Grid 2





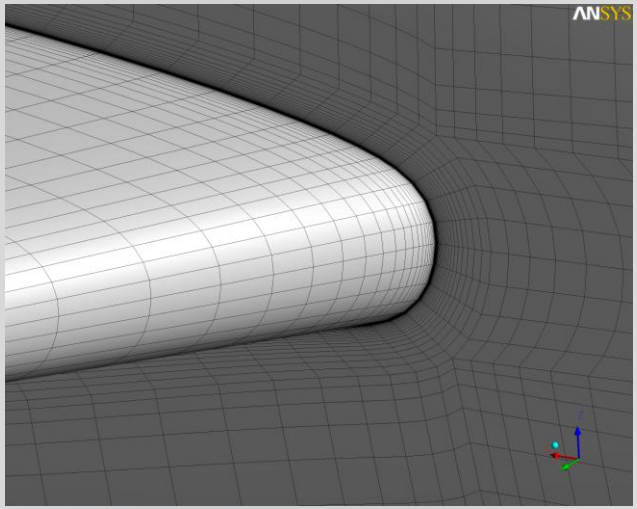
Grid 3

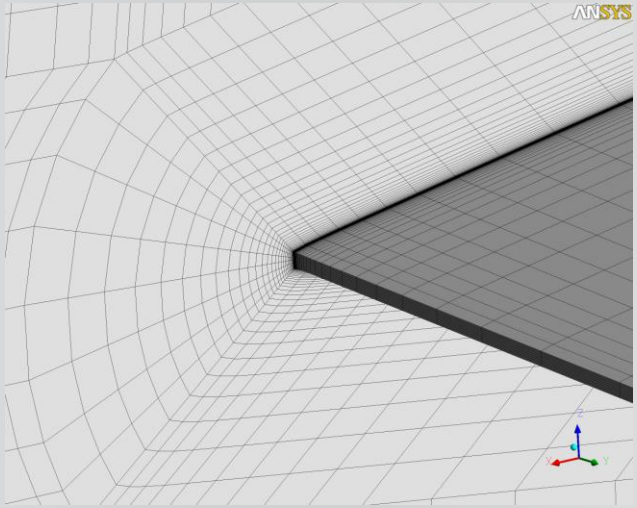




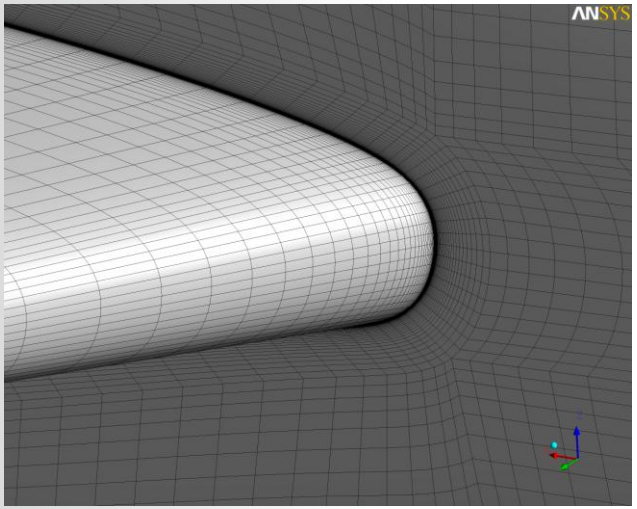
Grid Information

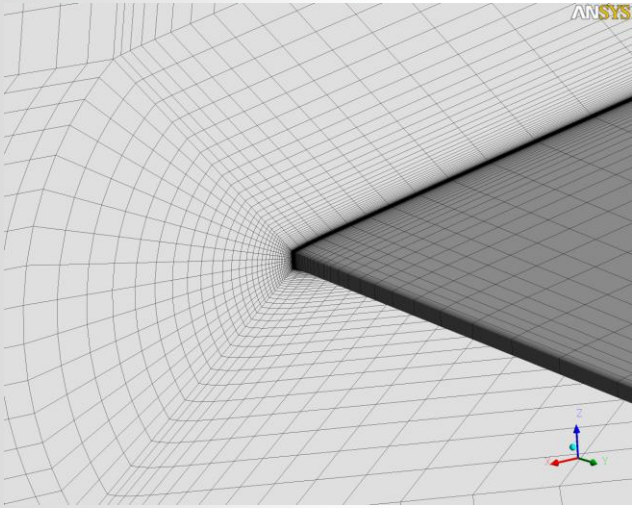
Grid 1



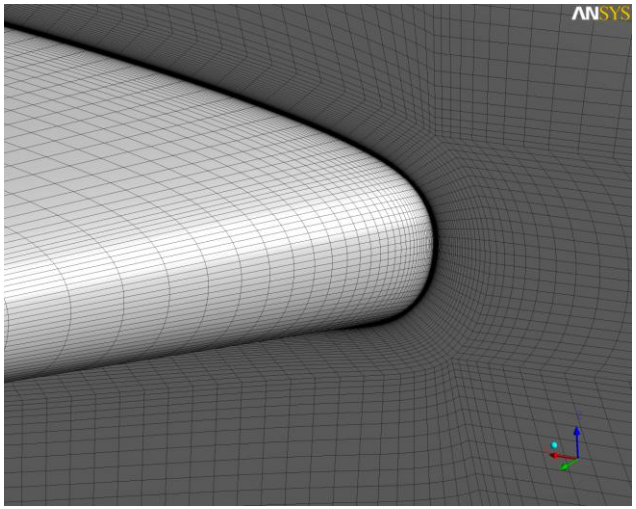


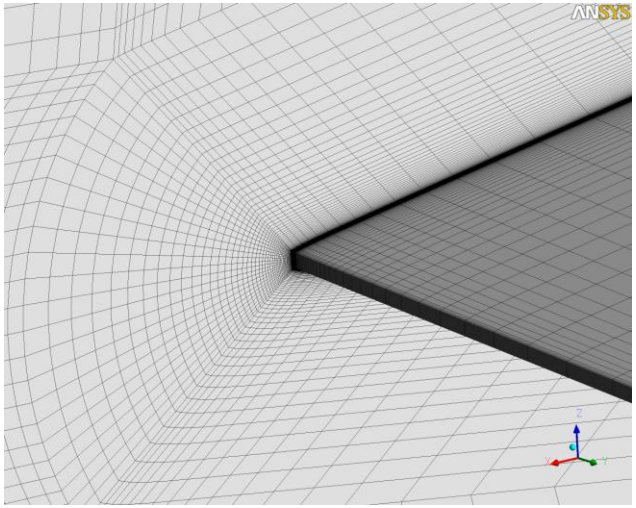
Grid 2





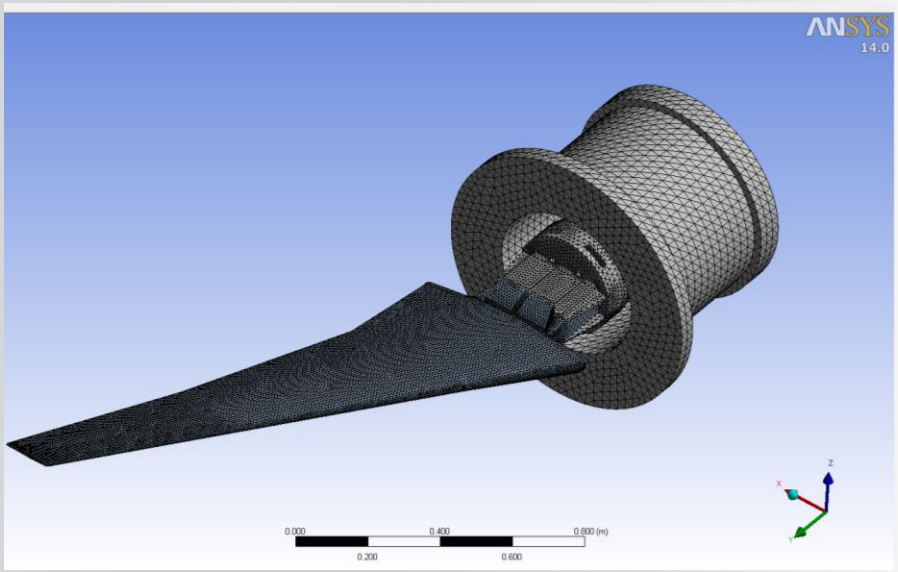
Grid 3





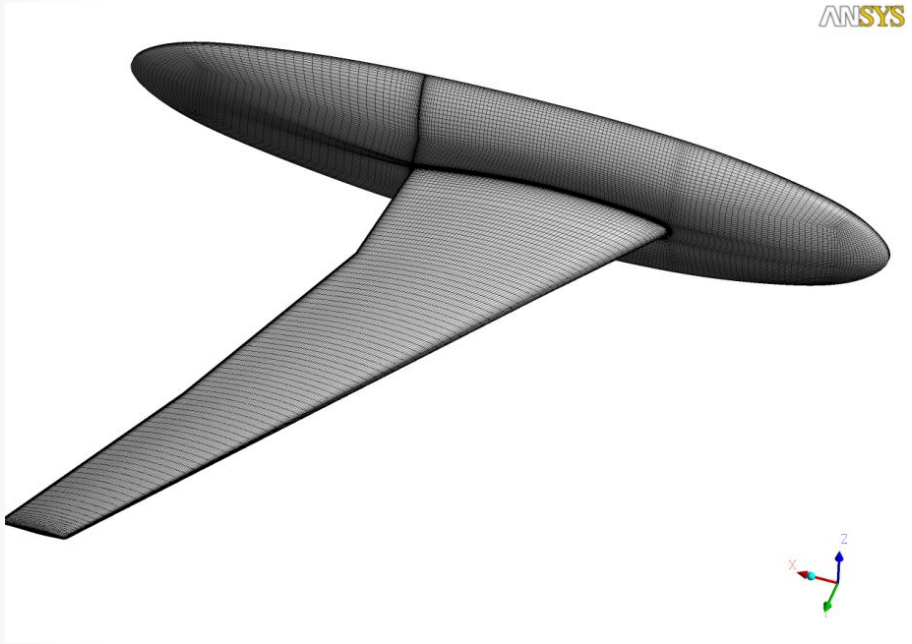
Grid Information

FEM Grid

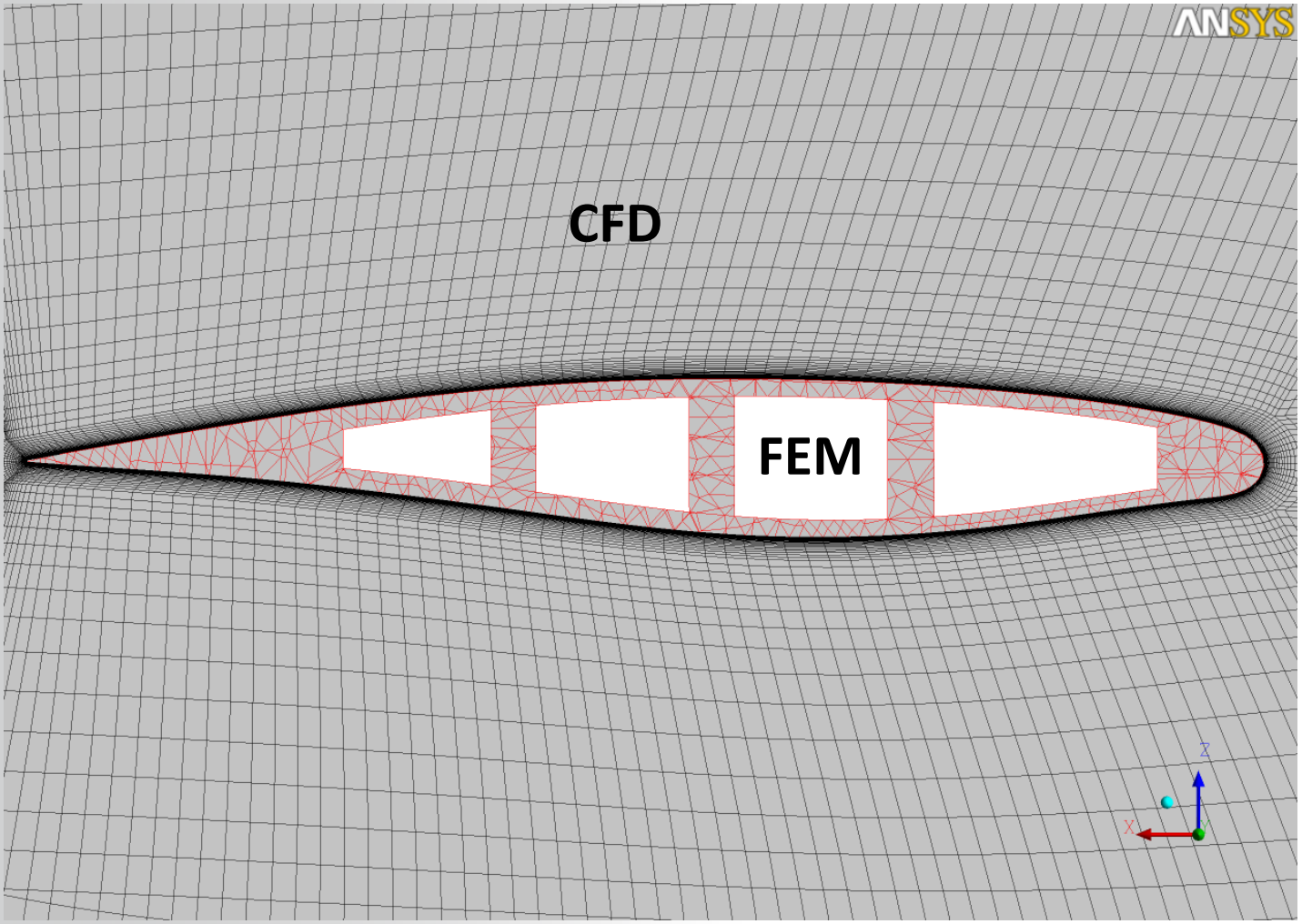


Downloaded from the AePW website

CFD Grid

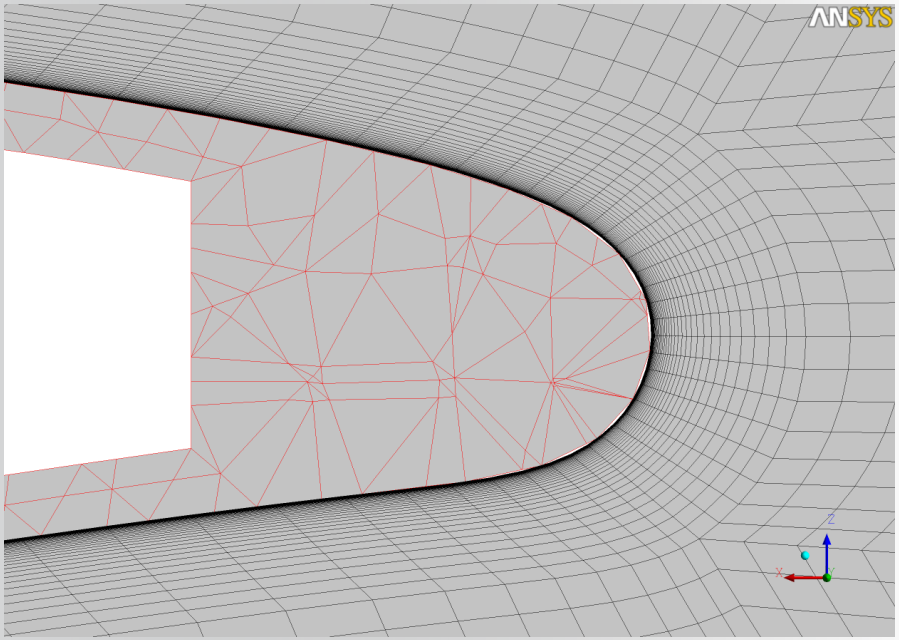


Grid Plane @ Eta = 0.145

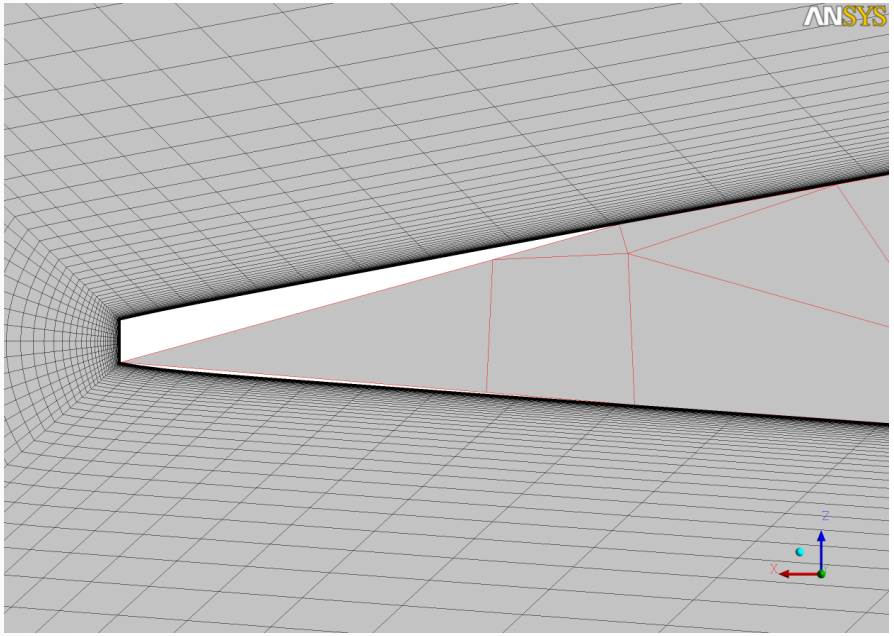


Grid Plane @ Eta = 0.145

Leading Edge

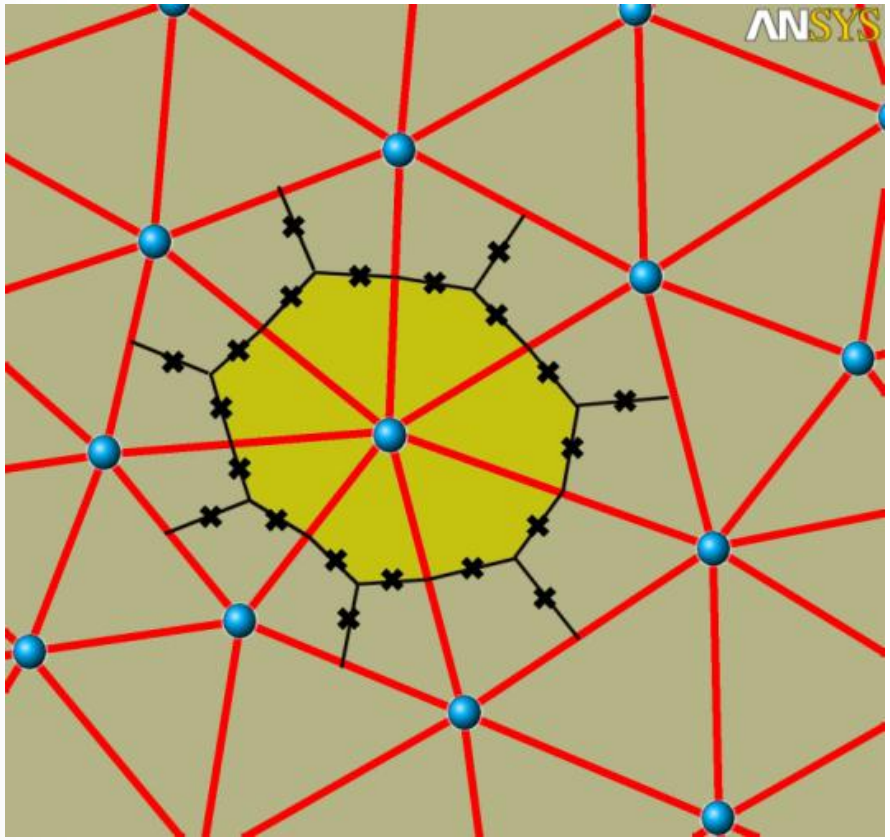


Trailing Edge



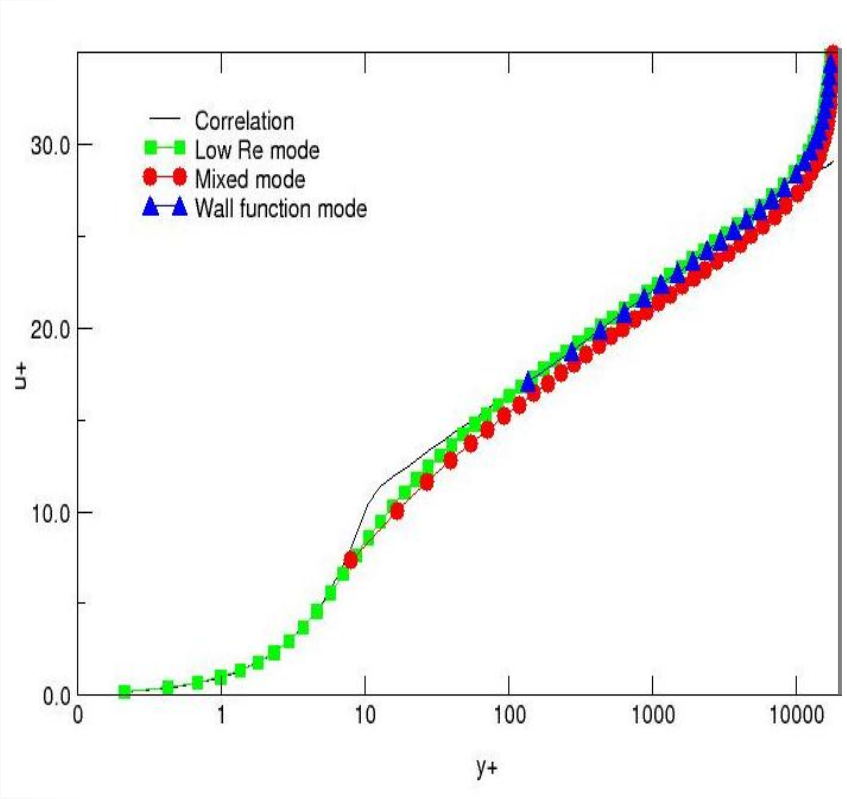
Numerical Method

- ANSYS CFX 14
- Coupled (U,V,W,P) solver
  - Pressure based
- Convective discretization
  - High-resolution scheme
- Algebraic multigrid
- Vertex centred



Mathematical Model

- **Ensemble-averaged mass, momentum and energy conservation equations**
- **Turbulence model**
  - **SST (Menter, 1994)**
- **Automatic choice of linear/logarithmic near wall profiles**

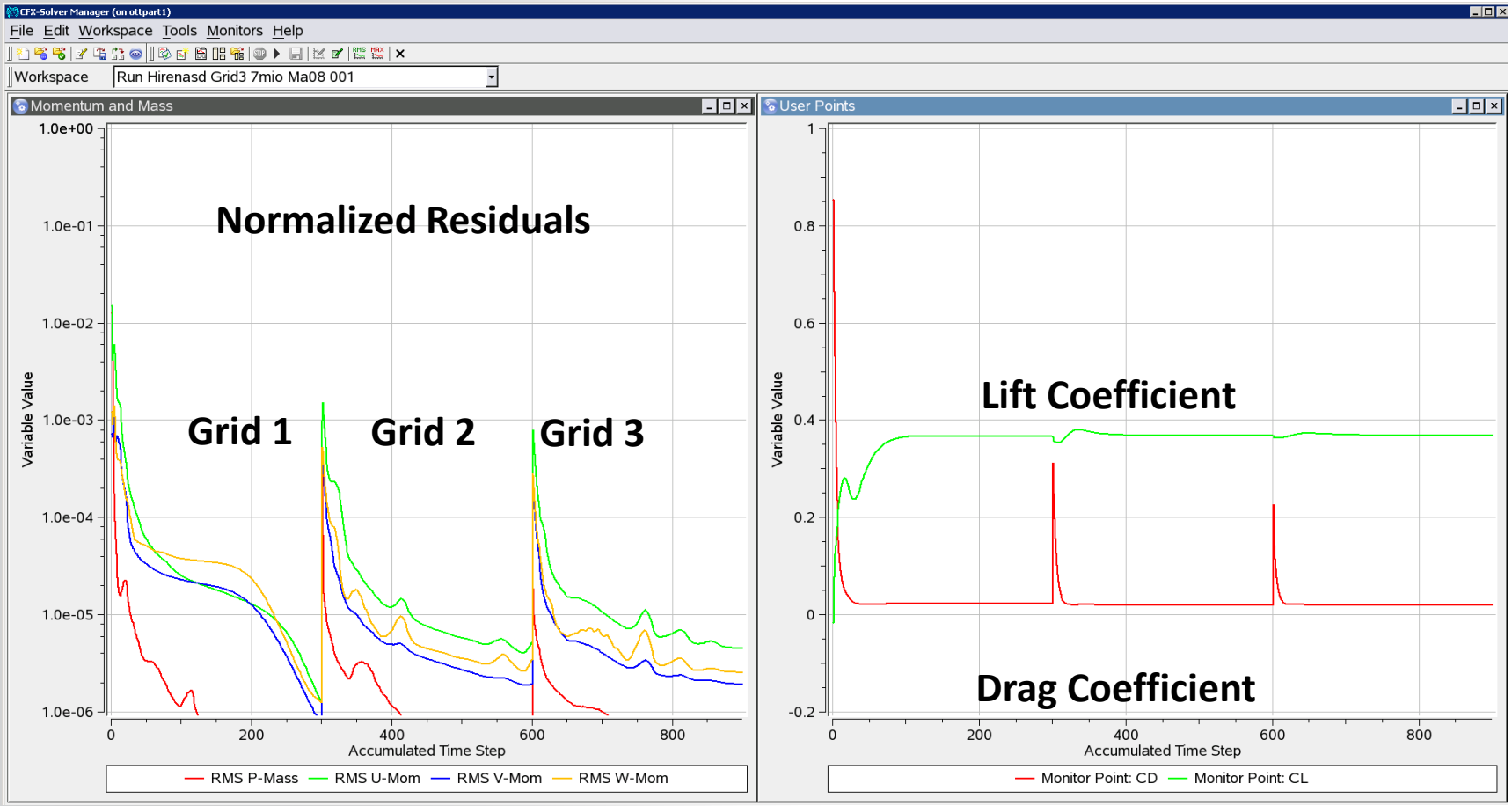


Automatic Wall Treatment

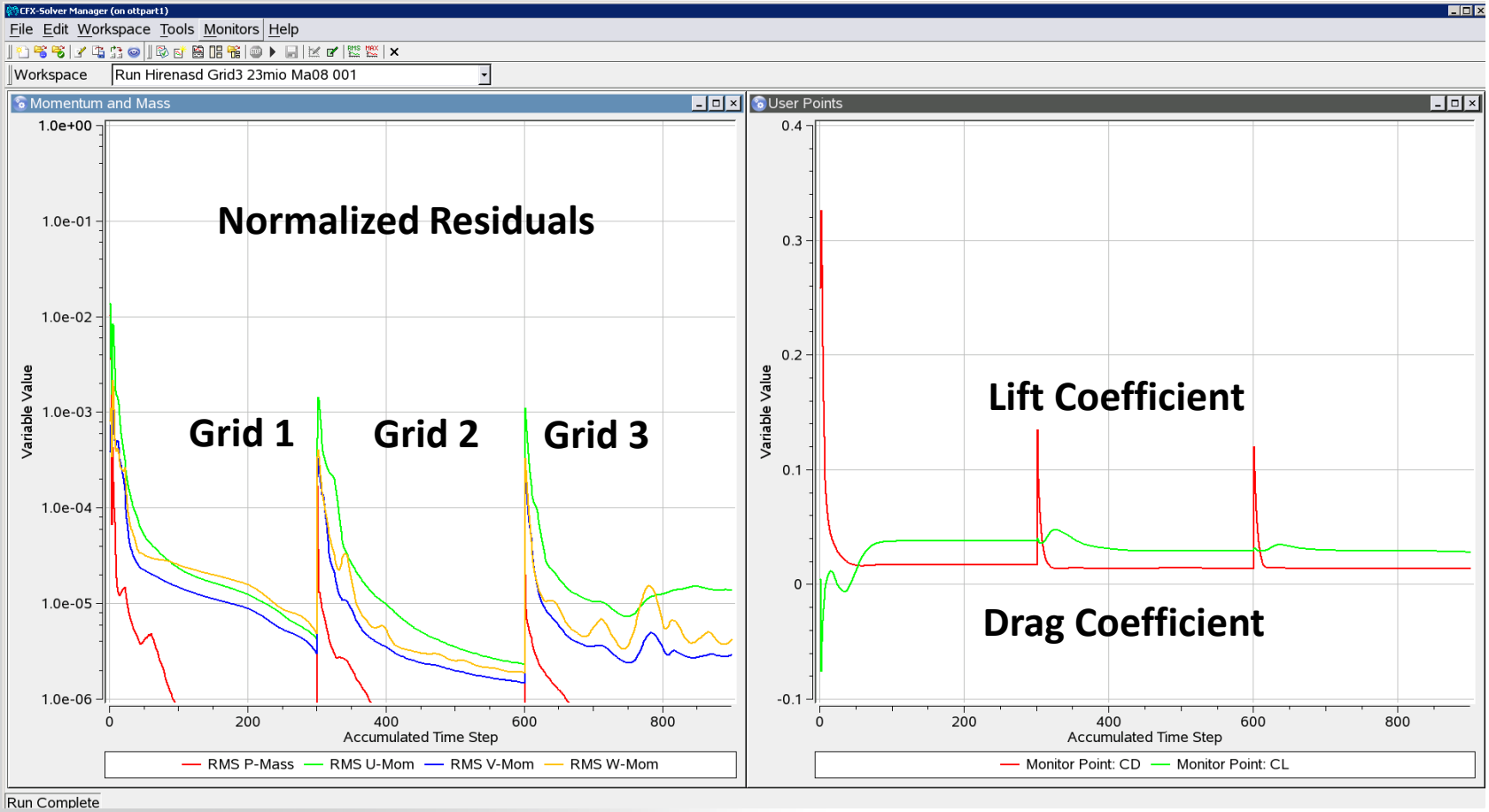
Solver Information

	# of CPUs	Total Wall Clock Time, h	Memory, GByte
Grid 1	12	3 h 19 min	8.05
Grid 2	36	3 h 11 min	25.58
Grid 3	96	4 h 2 min	72.06

CFX Solver Information, ETW 132

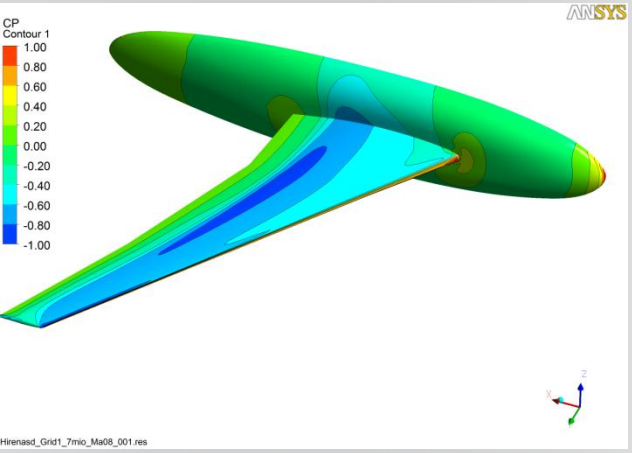


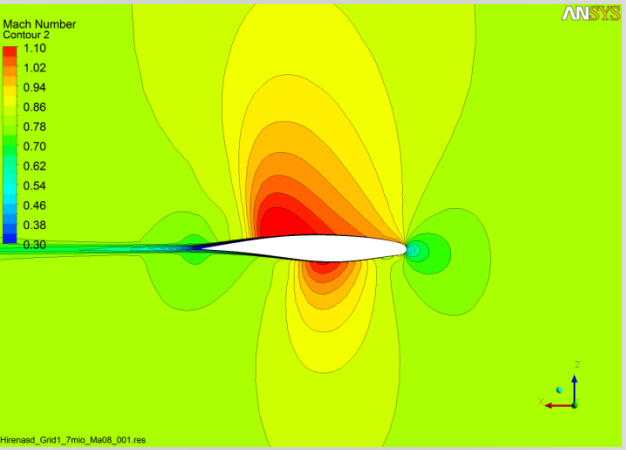
CFX Solver Information, ETW 250



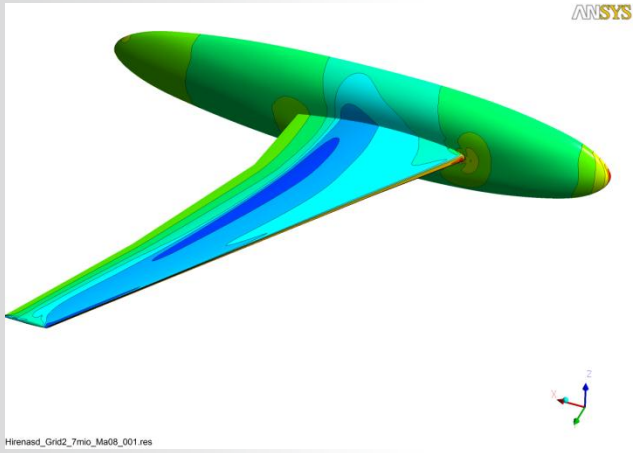
CP & Ma, Re = 7 mio, Ma = 0.8, α = 1.5°

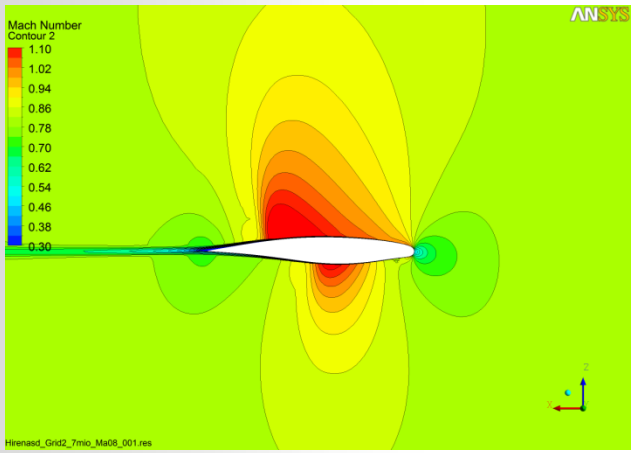
Grid 1



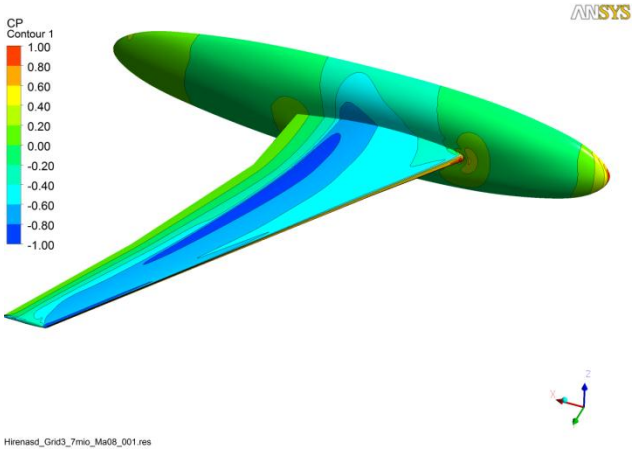


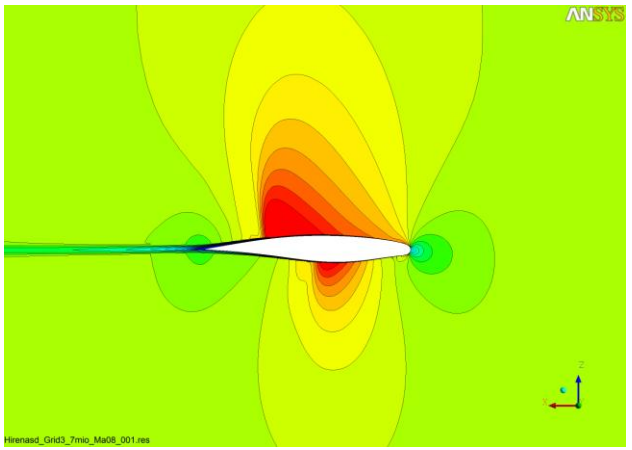
Grid 2





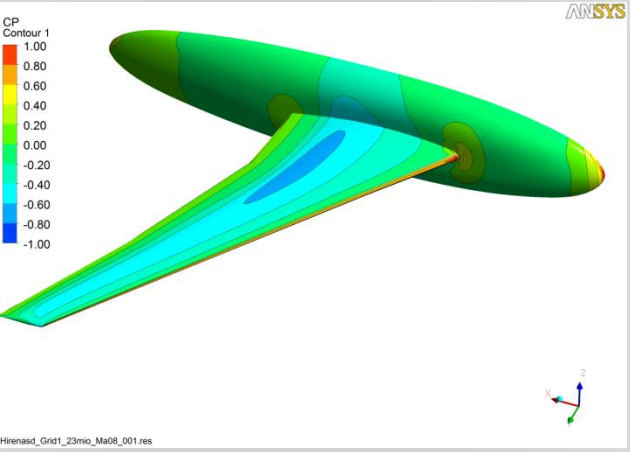
Grid 3

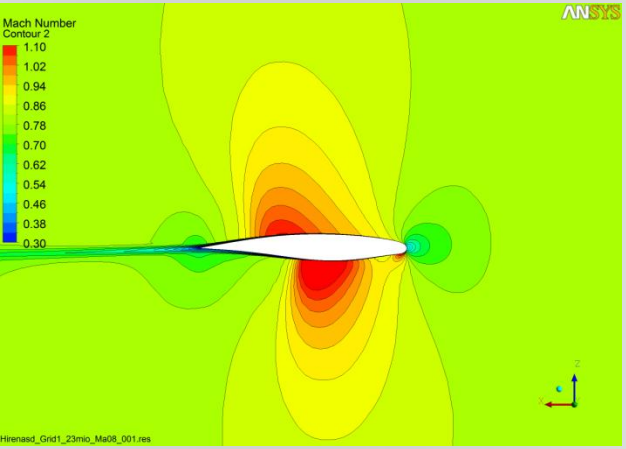




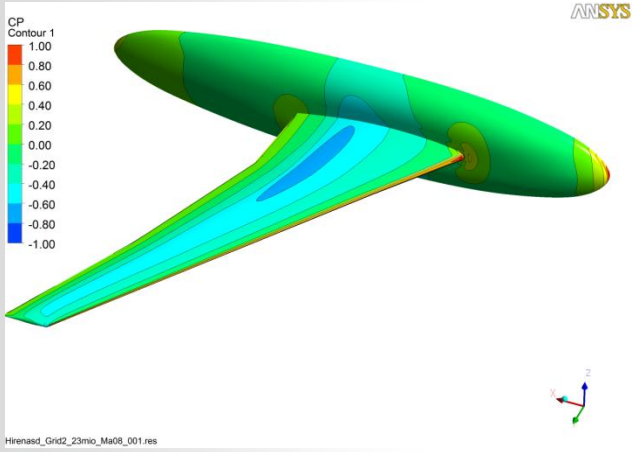
CP, Re = 23.5 mio, Ma = 0.8 α = -1.34°

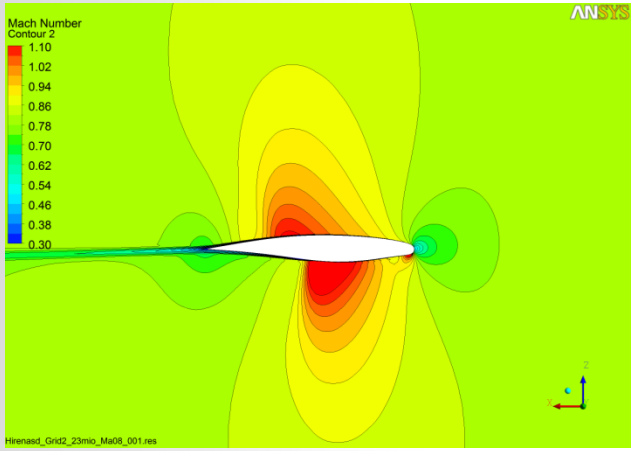
Grid 1



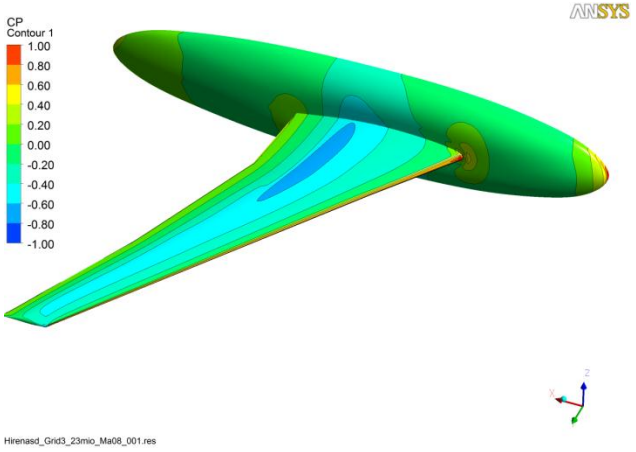


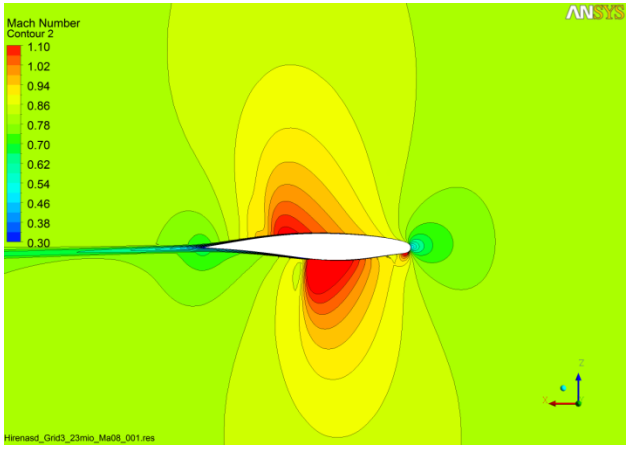
Grid 2





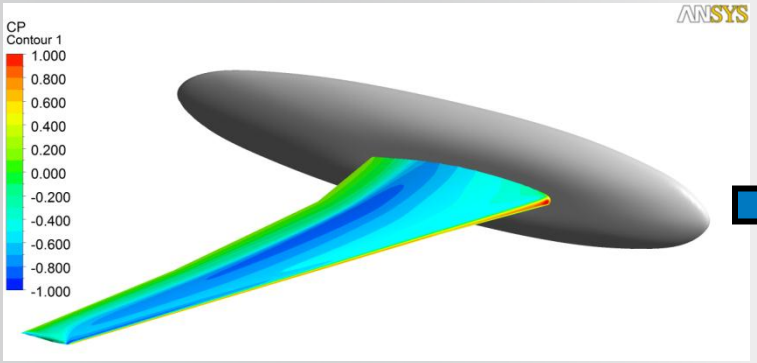
Grid 3



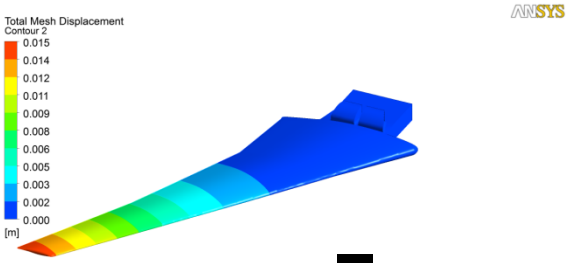


ANSYS Solver Coupling

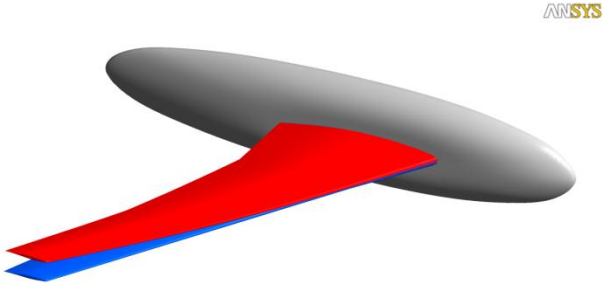
Solve CFD undeformed grid



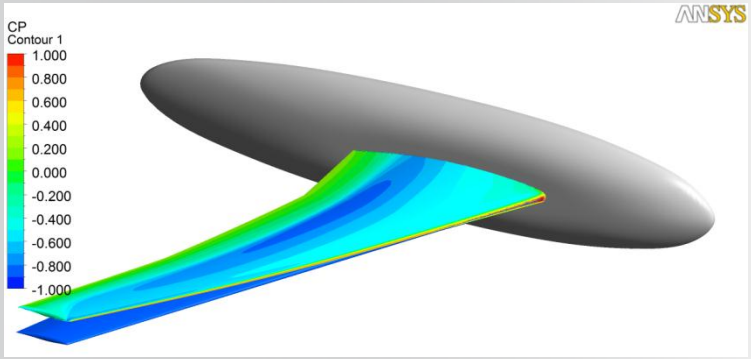
Transfer CFD loads to FEA and solve structural deformation



Transfer deformation to FEA and solve mesh deformation

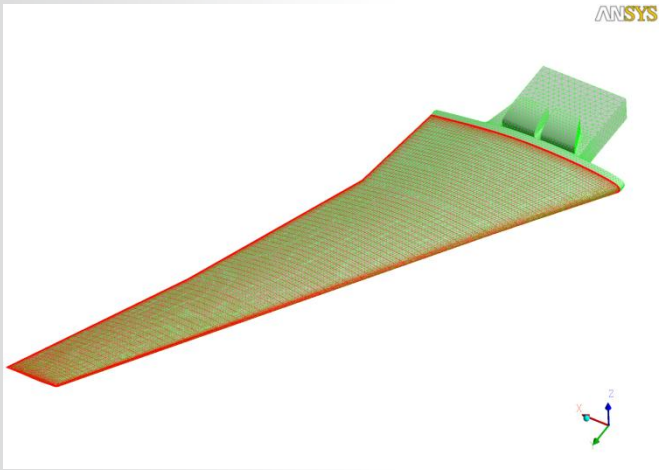


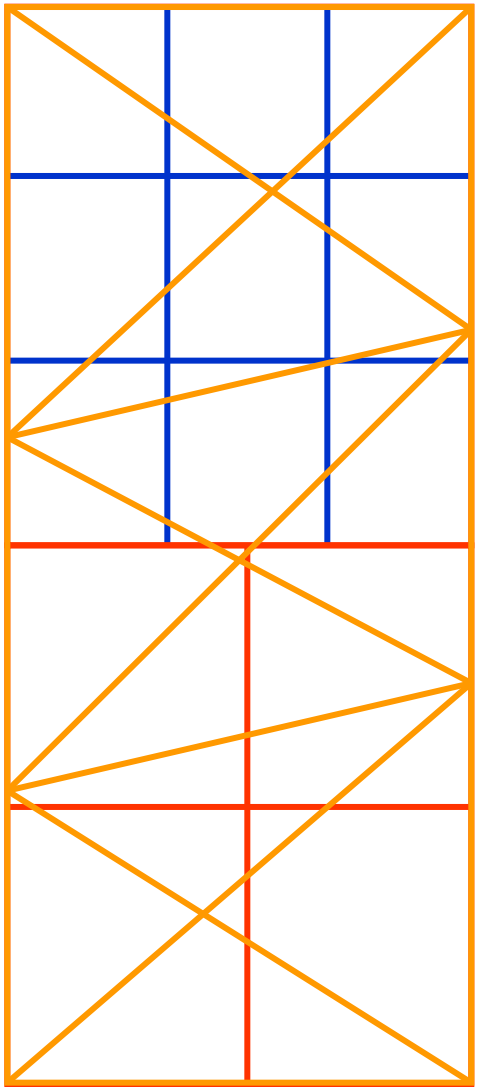
Solve CFD deformed grid



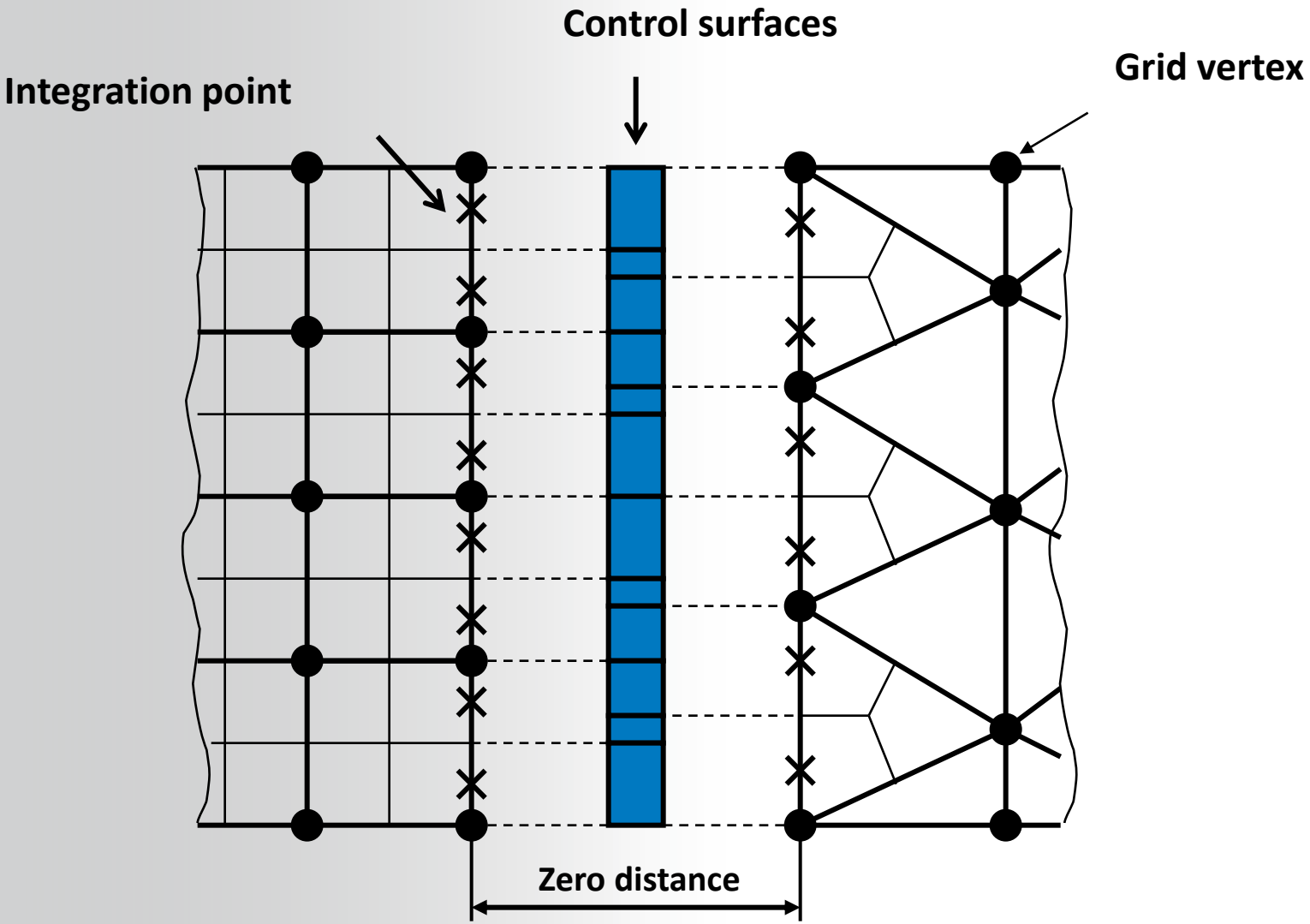
Load Transfer Algorithms

- Different grids on CFD & FEM side
  - Topology
  - Grid width
- Load transfer
  - Search
  - Interpolation
- Interpolation algorithms
  - Profile preserving or
  - Globally conservative
  - Profile preserving & conservative → GGI technology

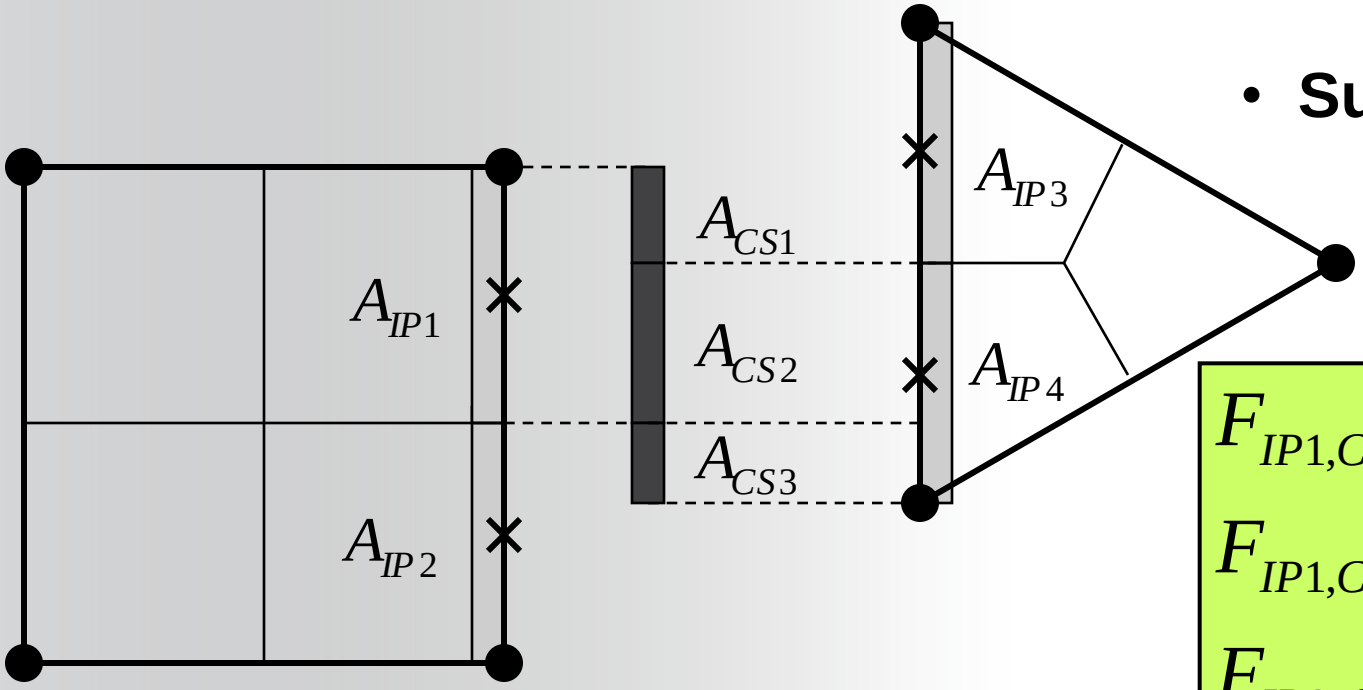




Generalised Grid Interface



Generalised Grid Interface

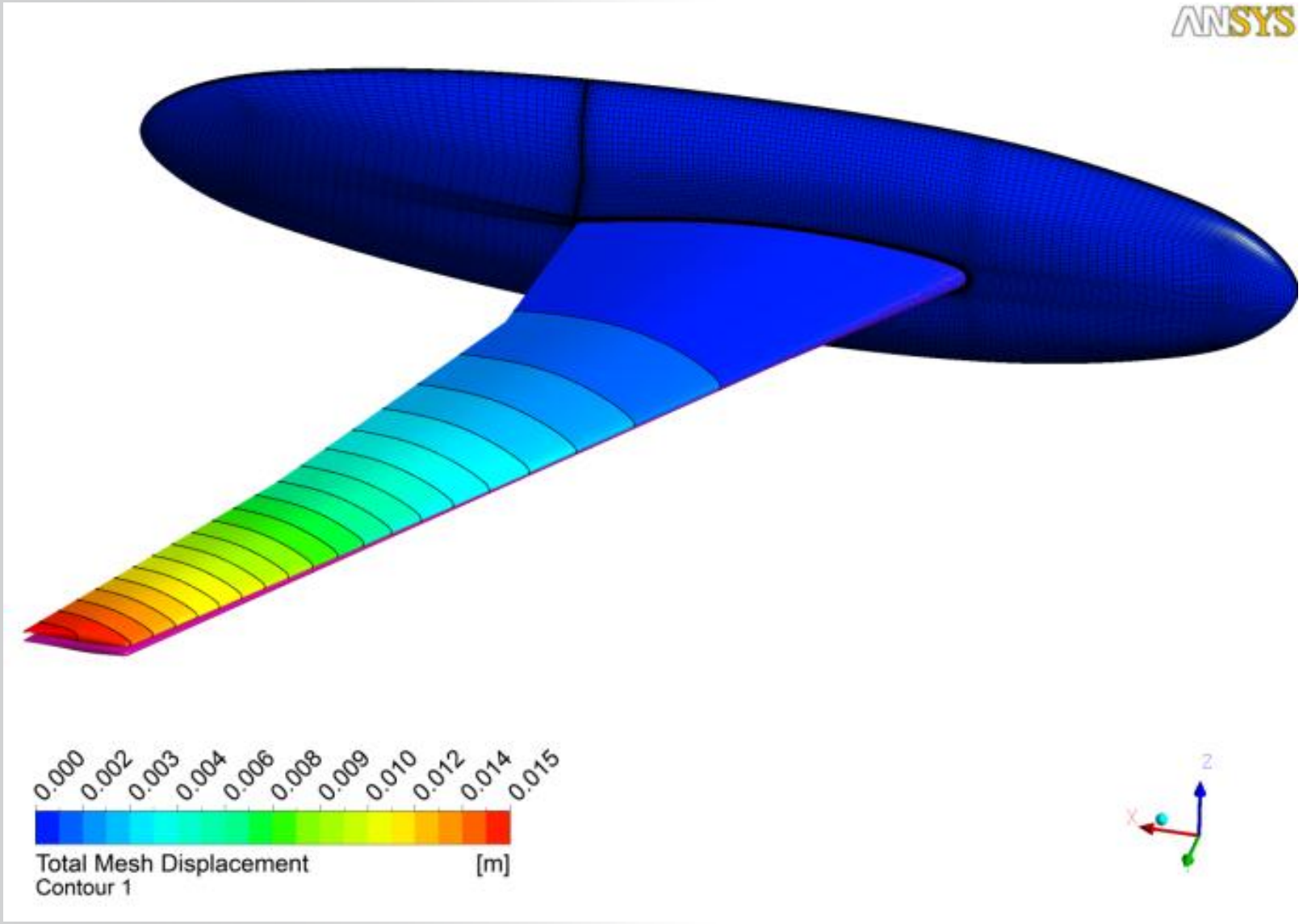


- **Surface fractions**

$$A_{IP1} \cap A_{IP3} = A_{CS1}$$
$$A_{IP1} \cap A_{IP4} = A_{CS2}$$
$$A_{IP2} \cap A_{IP4} = A_{CS3}$$

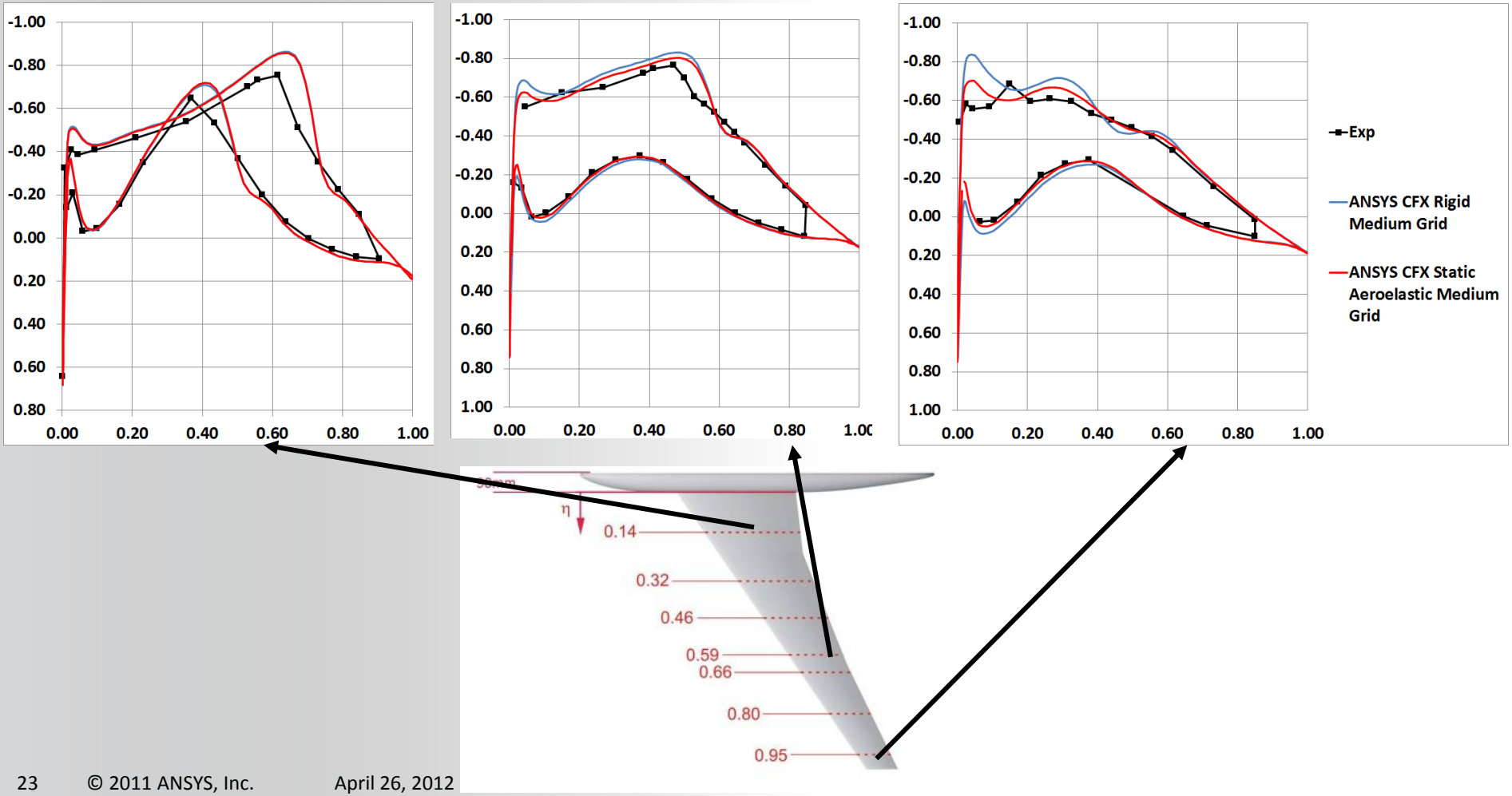
$$F_{IP1,CS1} = A_{CS1} / A_{IP1}$$
$$F_{IP1,CS2} = A_{CS2} / A_{IP1}$$
$$F_{IP2,CS3} = A_{CS3} / A_{IP2}$$
$$F_{IP3,CS1} = A_{CS1} / A_{IP3}$$
$$F_{IP4,CS2} = A_{CS2} / A_{IP4}$$
$$F_{IP4,CS3} = A_{CS3} / A_{IP4}$$

Total Deformation @ CFX



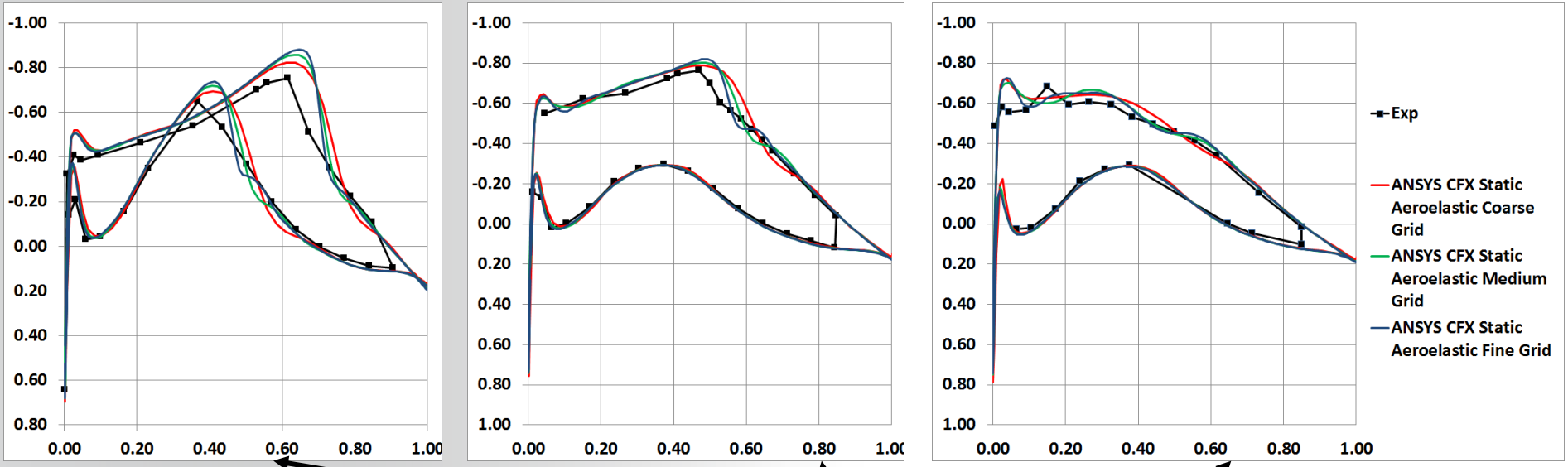
Grid 2: Static Aeroelastic Equilibrium

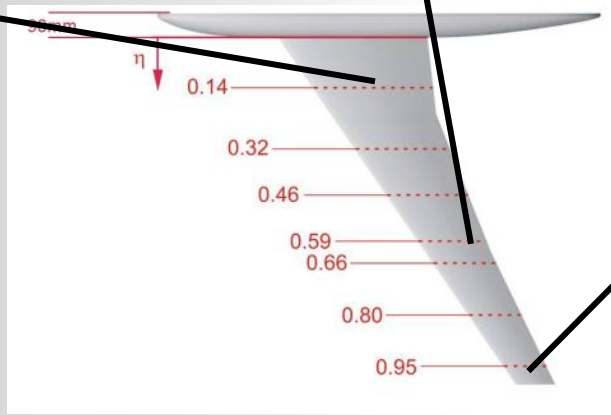
Re = 7 mio, Ma = 0.8, a = 1.5°



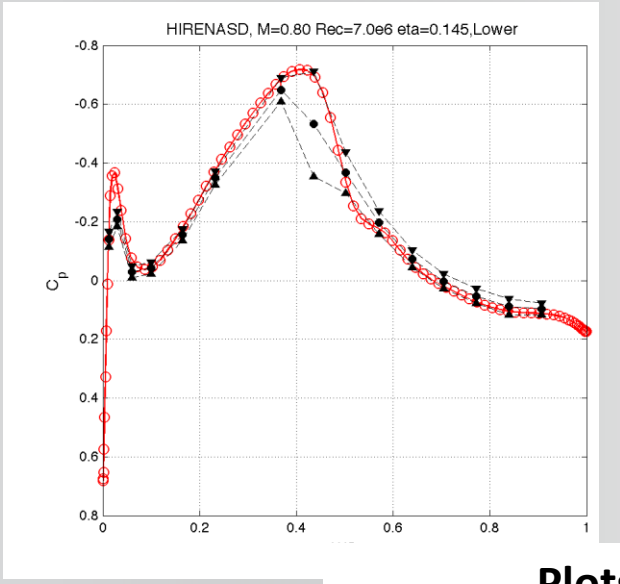
Discretization Error

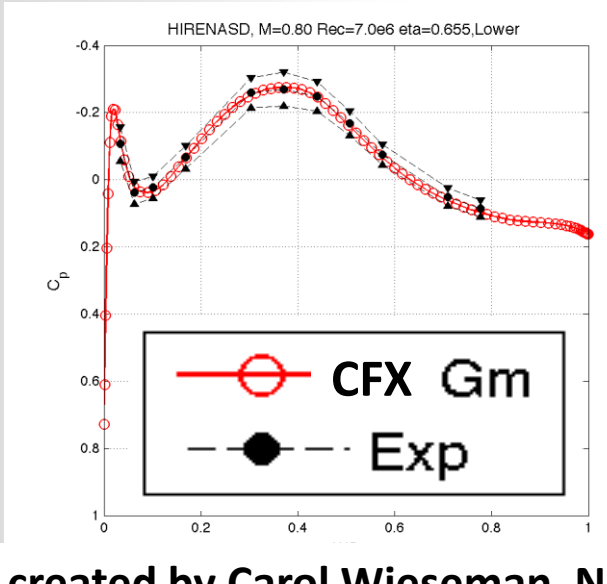
Re = 7 mio, Ma = 0.8, a = 1.5°

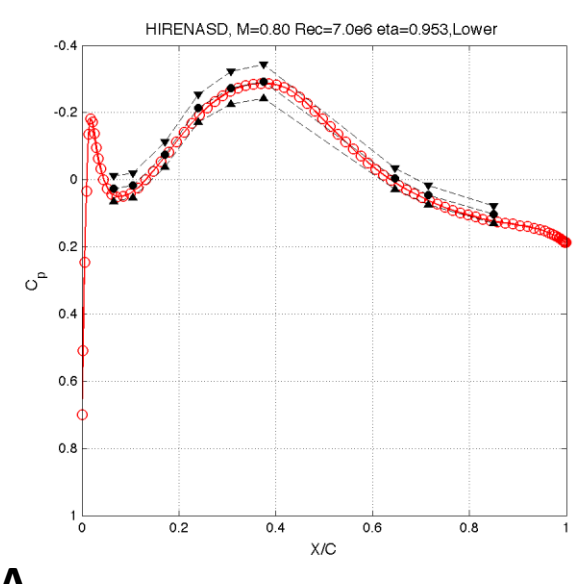




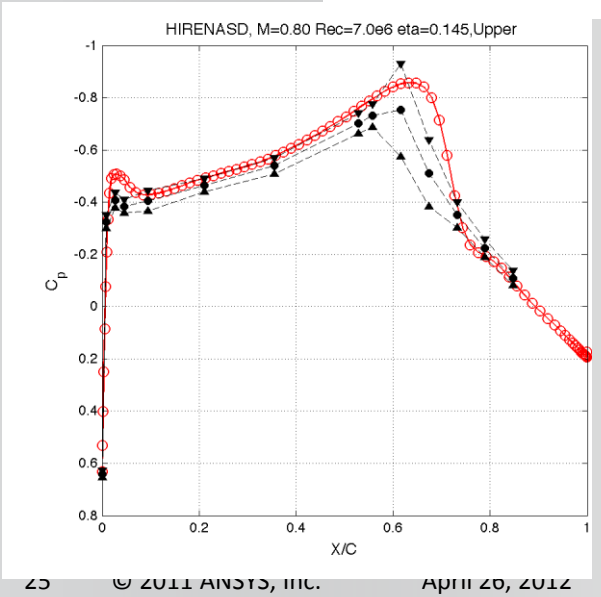
Re = 7 mio, Ma = 0.8, a = 1.5°

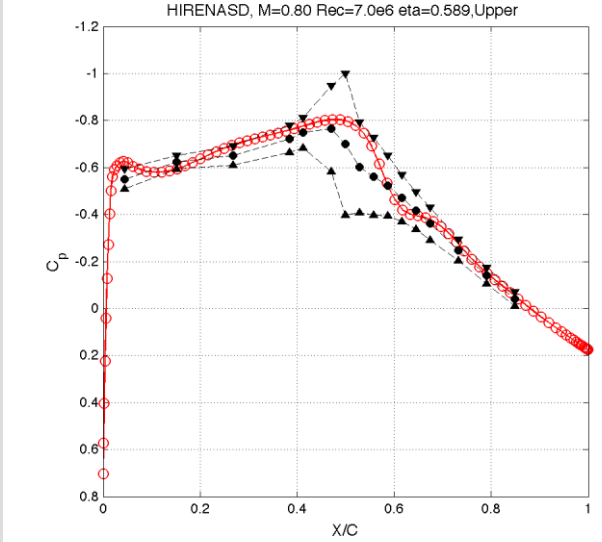


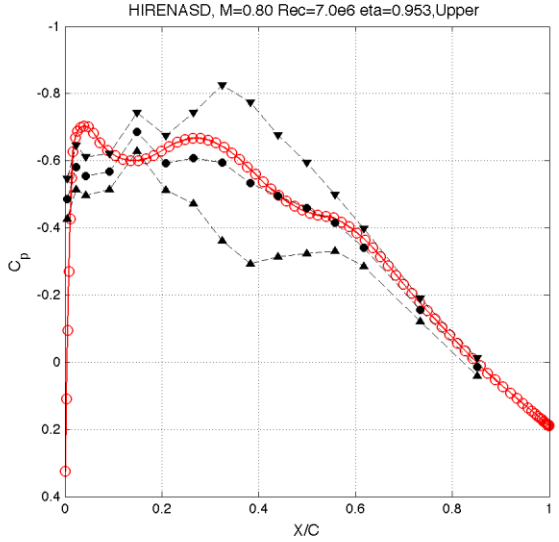




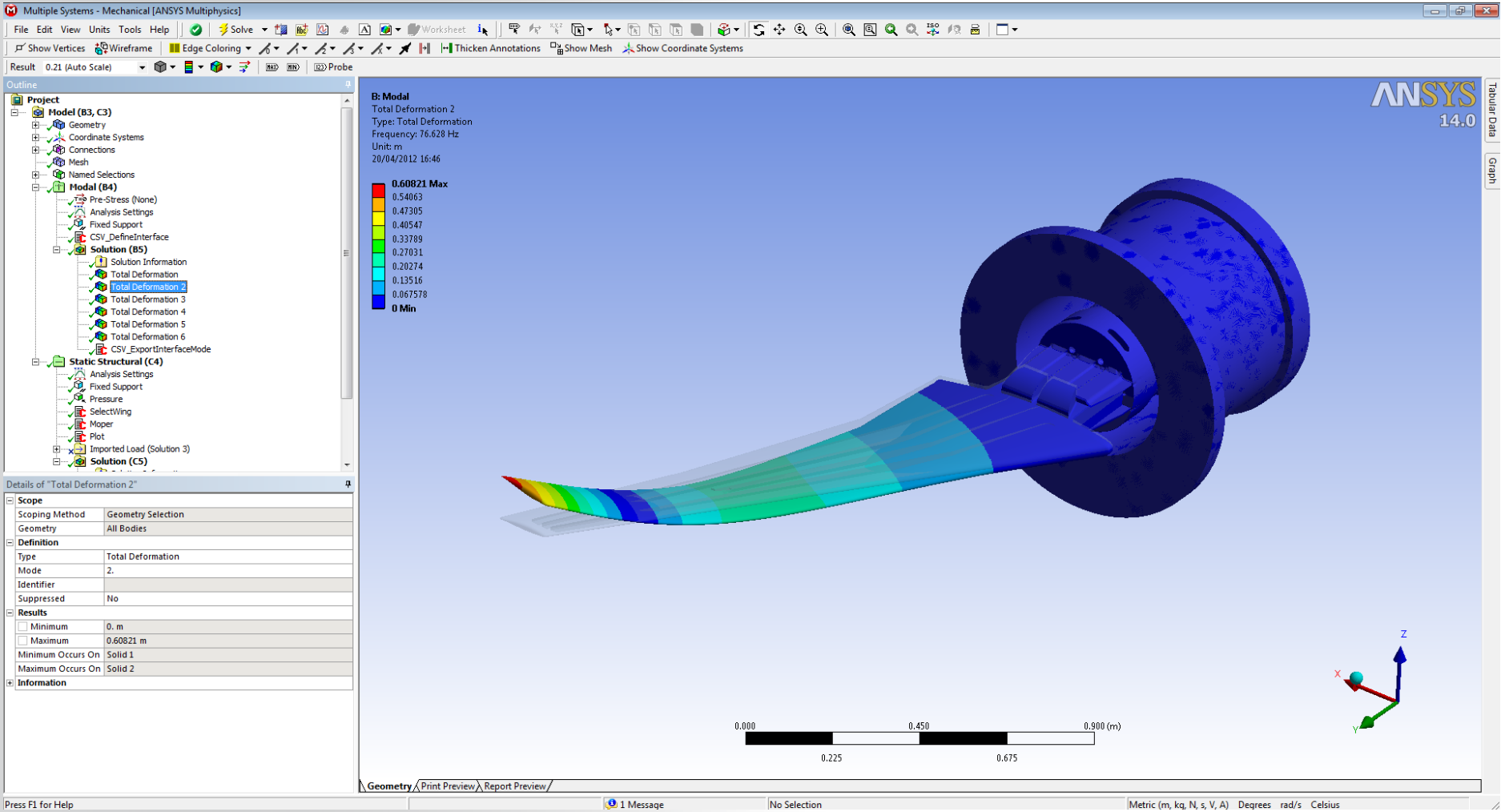
Plots created by Carol Wieseman, NASA





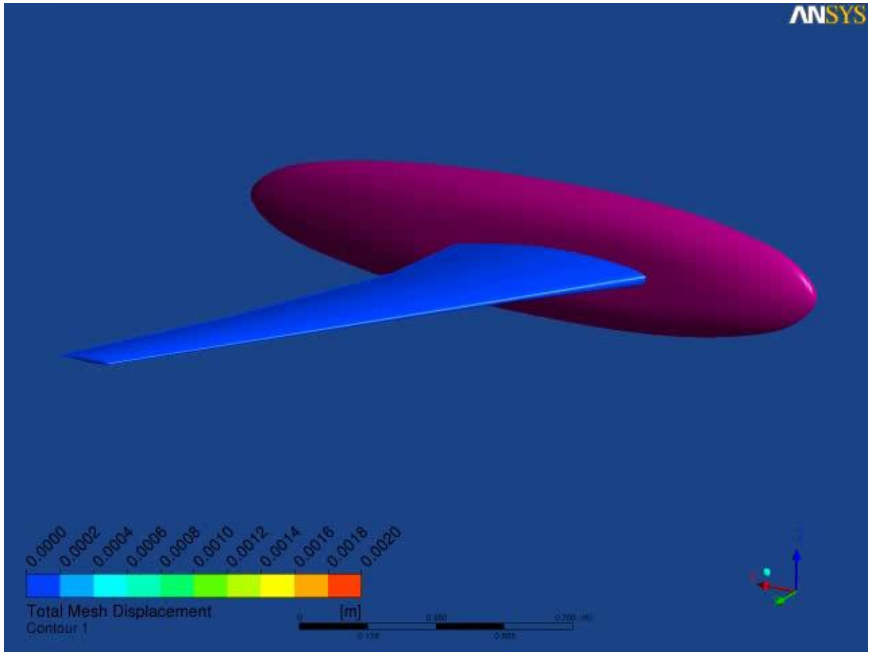


ANSYS Modal Analysis, 2nd Bending



Unsteady-State Calculation

- Oscillations for the 2nd bending mode
- Mesh displacement
  - Harmonic wing motion
  - A*sin(omega*t)
- Initial condition
  - Converged steady-state solution
- Monitor frequencies
- FFT



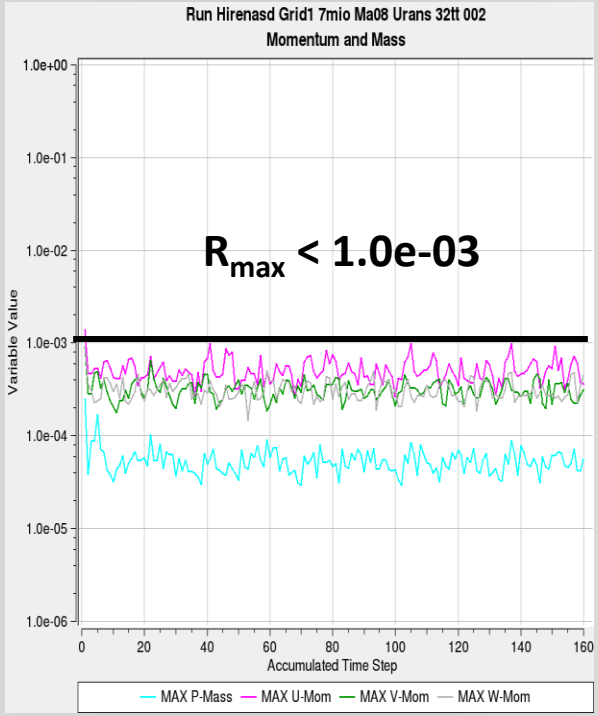
Numerical Information

- Transient scheme
  - Second order backward Euler
- Convective discretization
  - High Resolution
- Initial condition
  - Steady-state solution

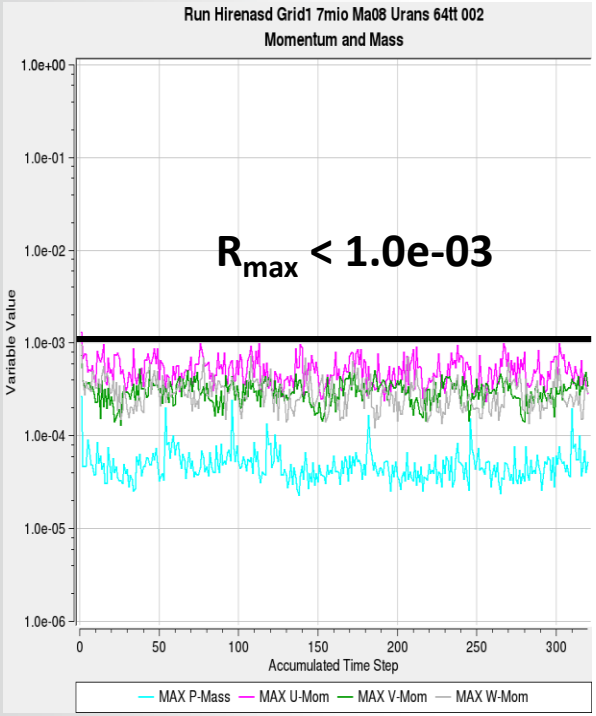
- Time steps per period
  - Run1: 32 > 3.125 ms
  - Run2: 64 > 1.562 ms
  - Run3: 128 > 0.781 ms
- Total time = 5 * period
  - 32 * 5 = 160 iterations
  - 64 * 5 = 320 iterations
  - 128*5 = 640 iterations

CFX Solver, Grid 1, MAX Residuals

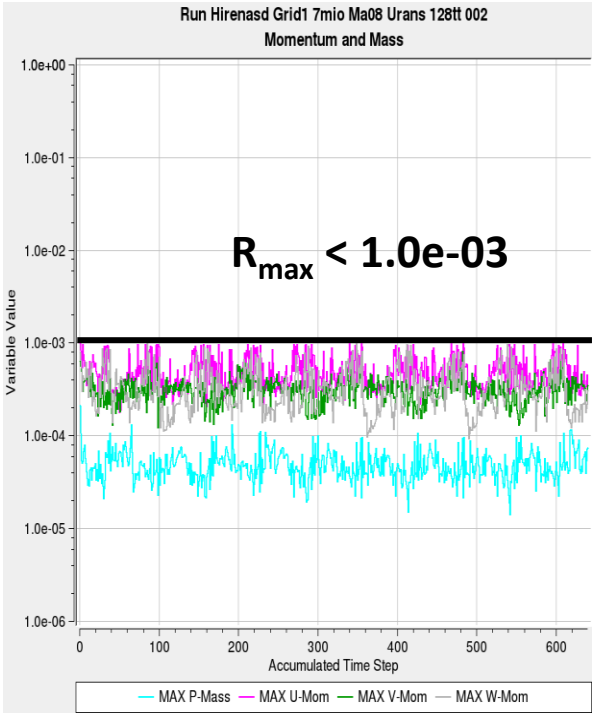
Timestep = Period/32



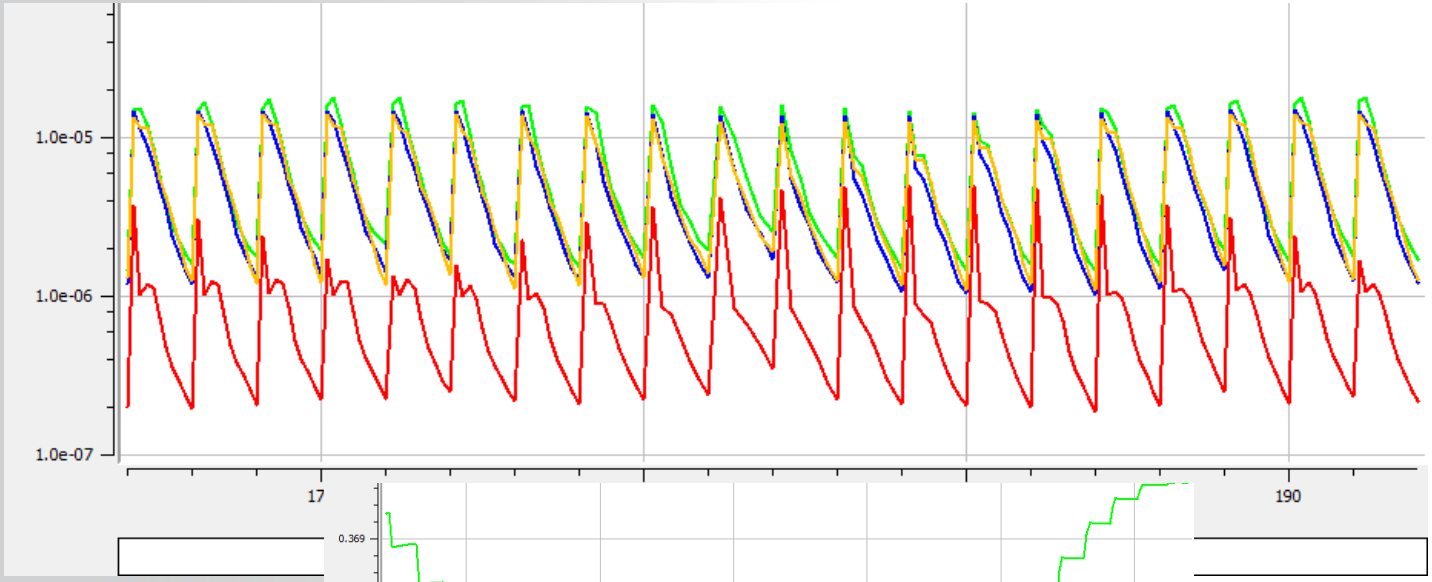
Timestep = Period/64

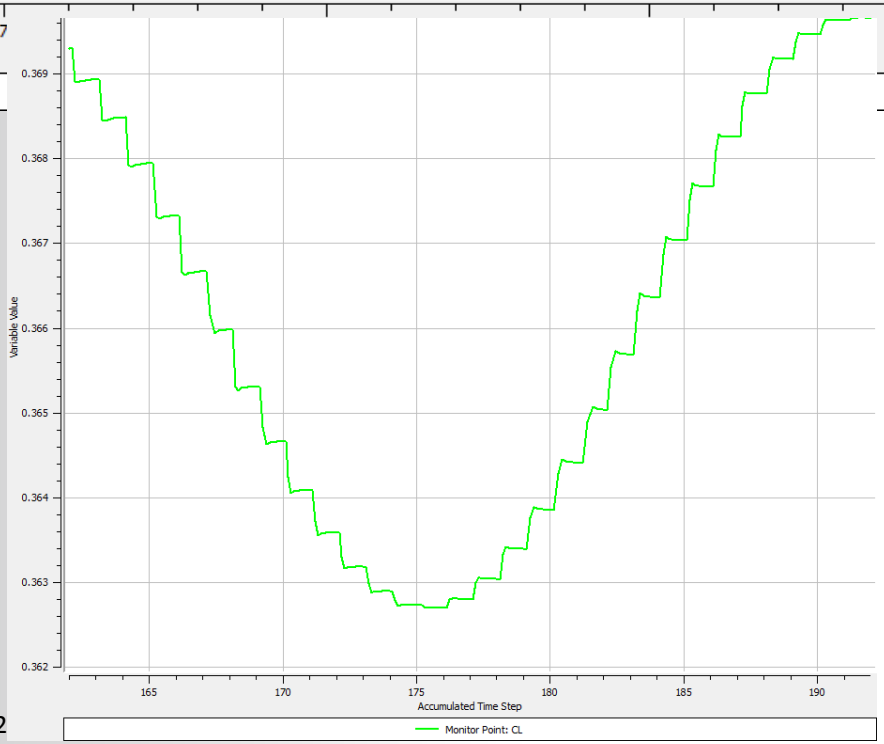


Timestep = Period/128

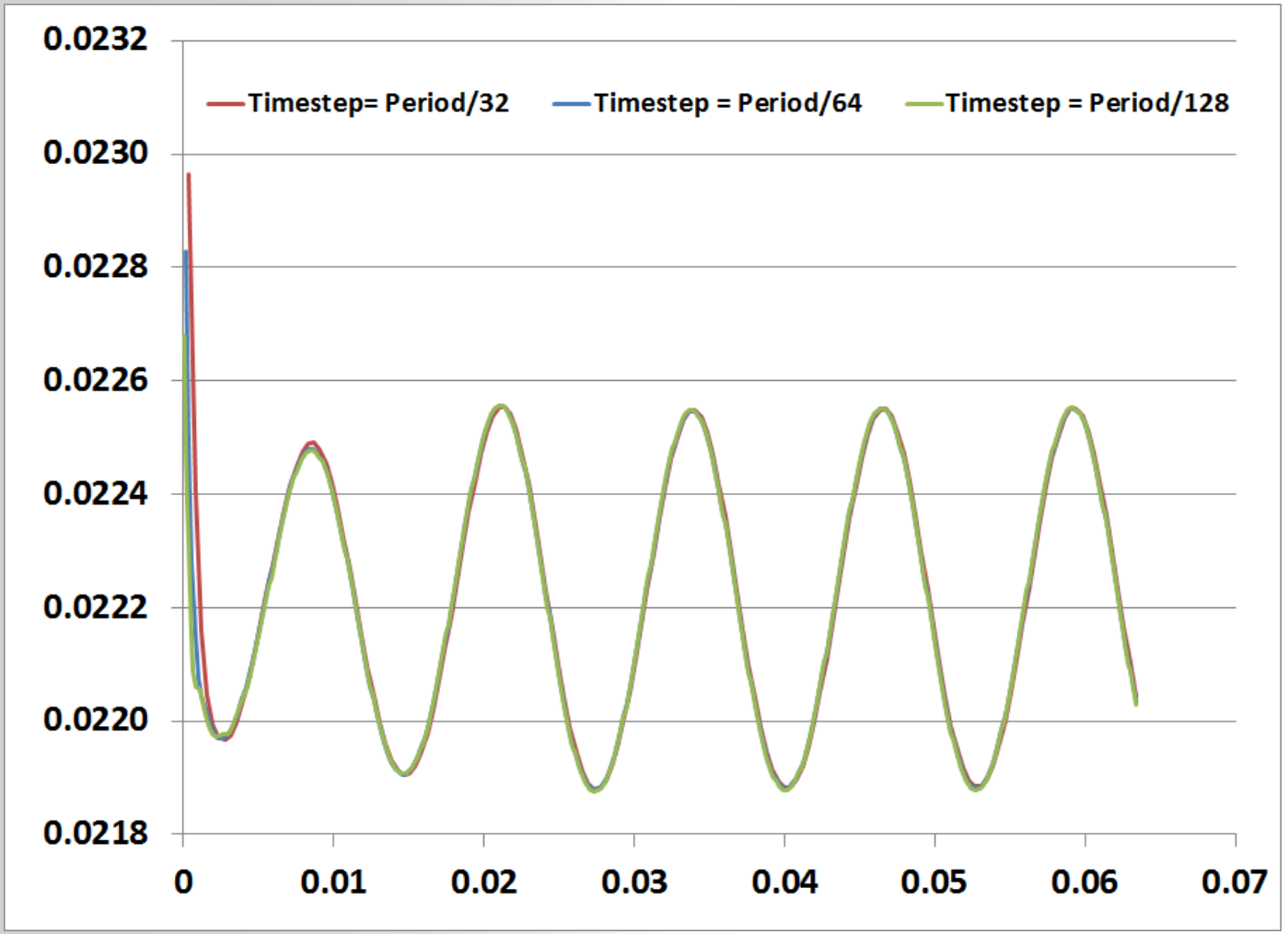


RMS Residuals & CL





Temporal Error



Frequency Response Function

- **Fourier Series is written in form of sines and cosines**

$$x(t) = a_0 + \sum_{n=1}^{\infty} a_n \cos(n\omega_0 t) + b_n \sin(nw_0 t)$$

- **where for n > 0:**

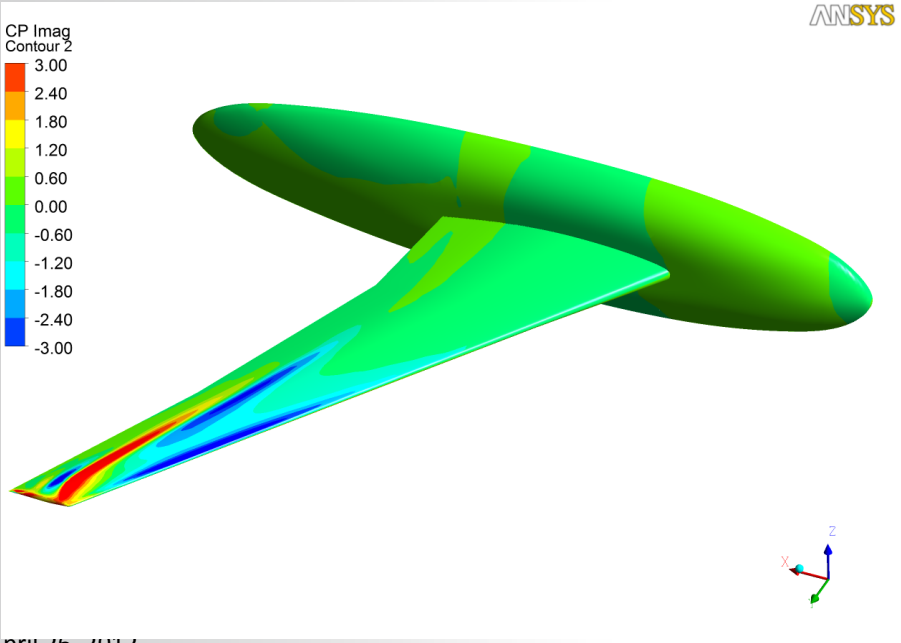
$$a_n = \frac{2}{T}\int_{t_0}^{t_0+T} x(t)\cos(nw_0 t)dt,\ b_n \frac{2}{T}\int_{t_0}^{t_0+T} x(t)\sin(nw_0 t)dt$$

- **and where**

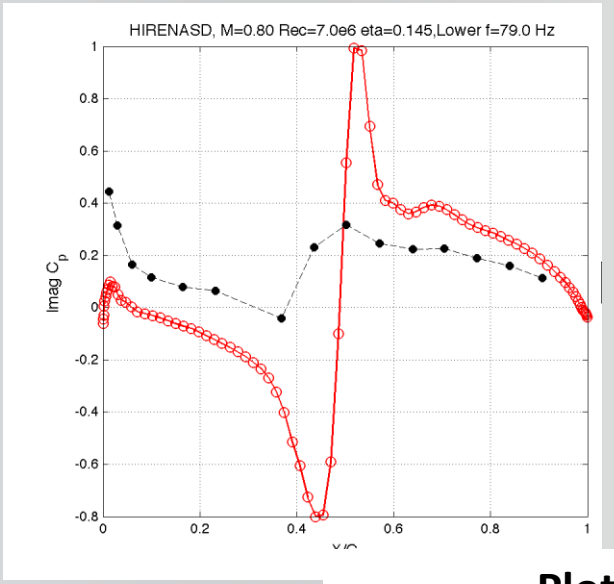
$$\omega_0 = \frac{2\pi}{T},\quad a_0 = \frac{1}{T}\int_{t_0}^{t_0+T} x(t)dt$$

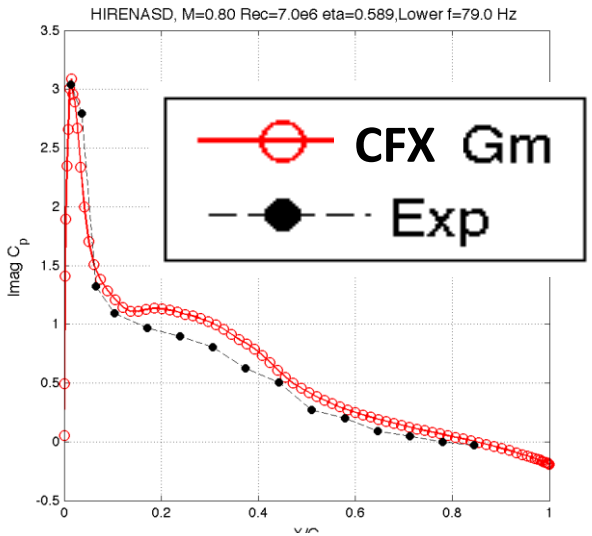
Frequency Response Function

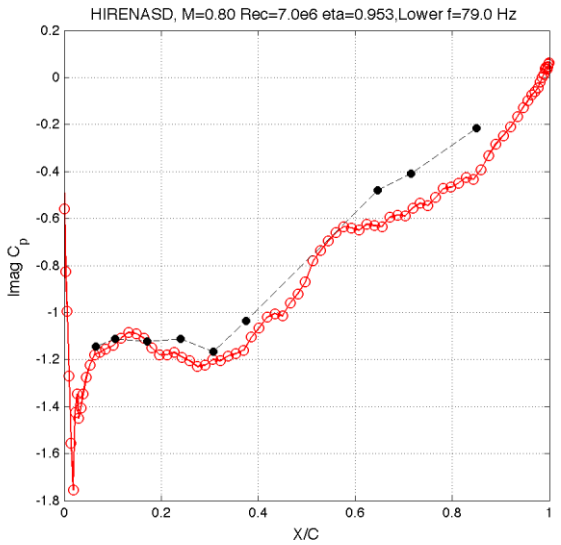
- Fourier coefficients calculated in CFD solver
- Additional Variable @ ANSYS CFX
  - CP Real, CP Imag
  - Magnitude = sqrt(CP Real^2+CP Imag^2)
  - Phase = atan2(CP Imag/CP Real)



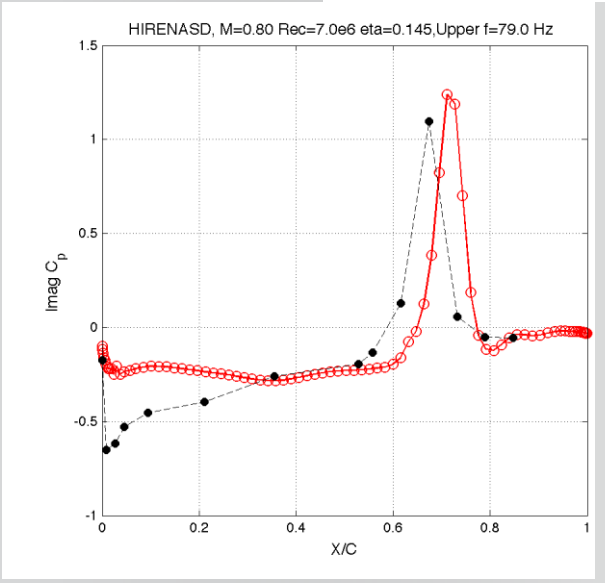
Imag Cp: Re = 7 mio, Ma = 0.8, α = 1.5°

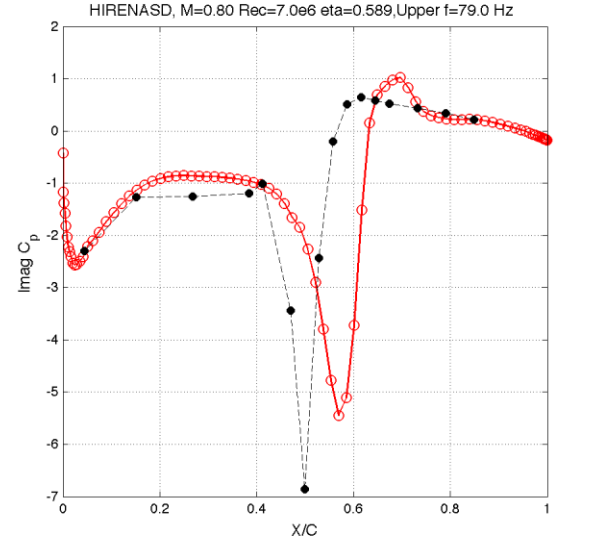


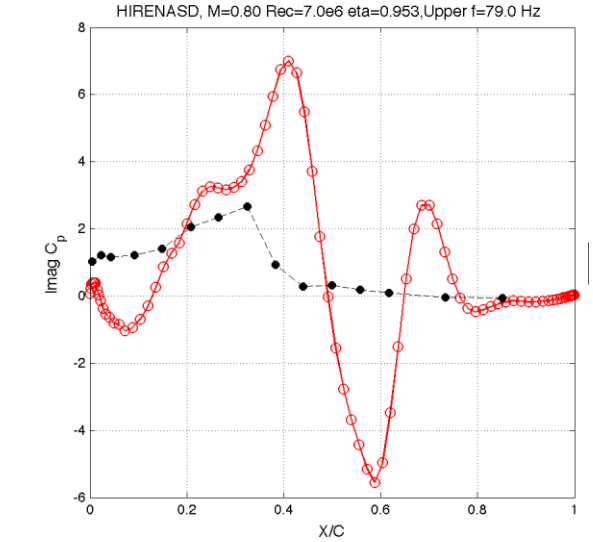




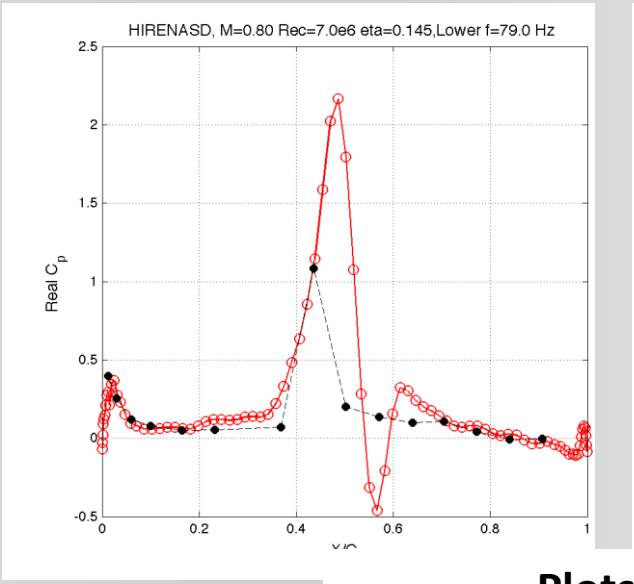
Plots created by Carol Wieseman, NASA

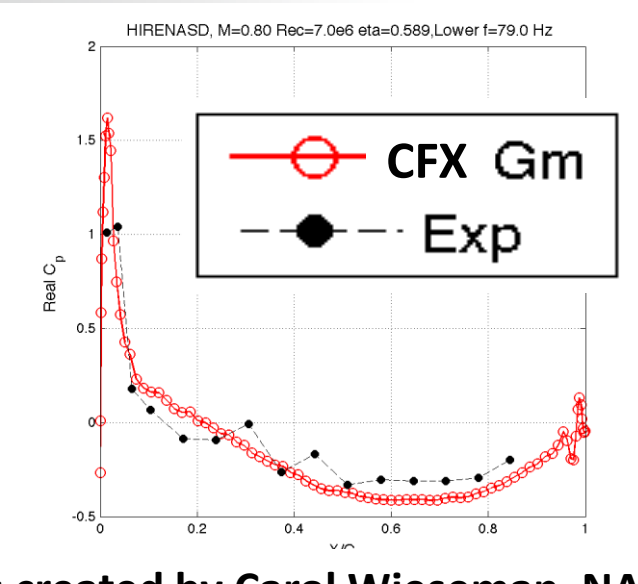


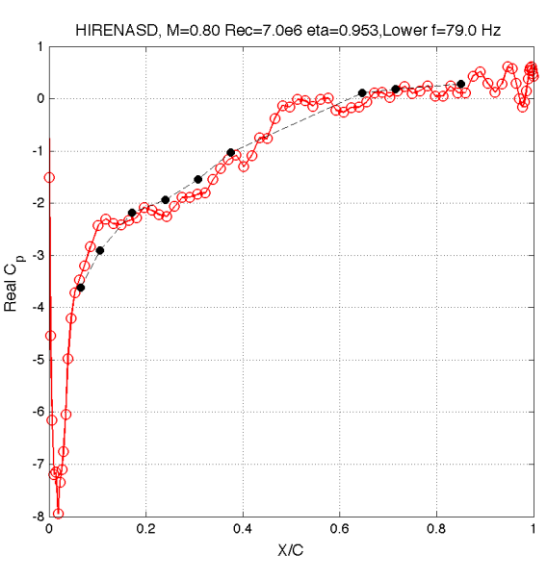




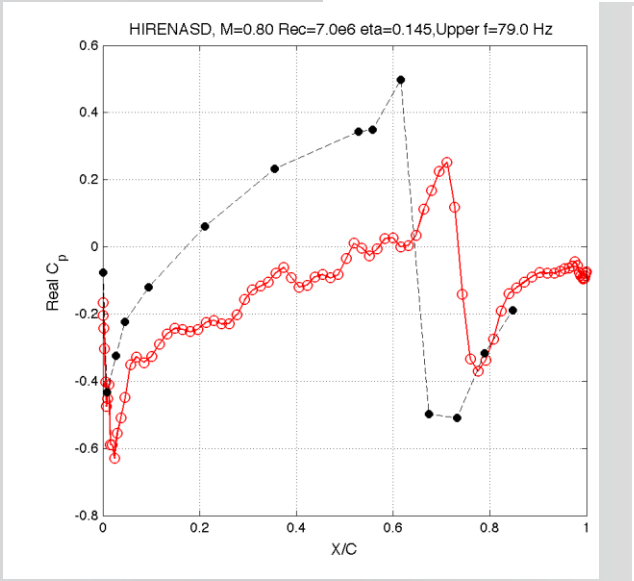
Real Cp: Re = 7 mio, Ma = 0.8, α = 1.5°

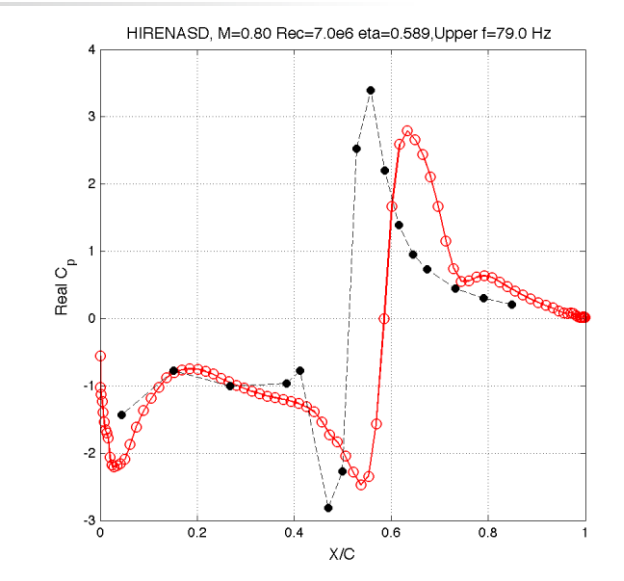


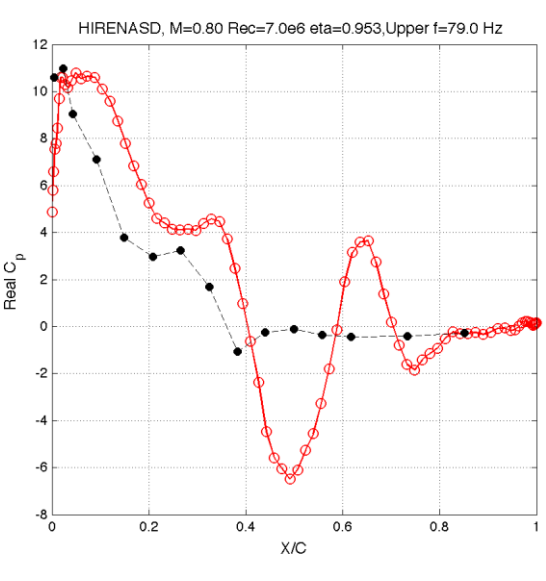




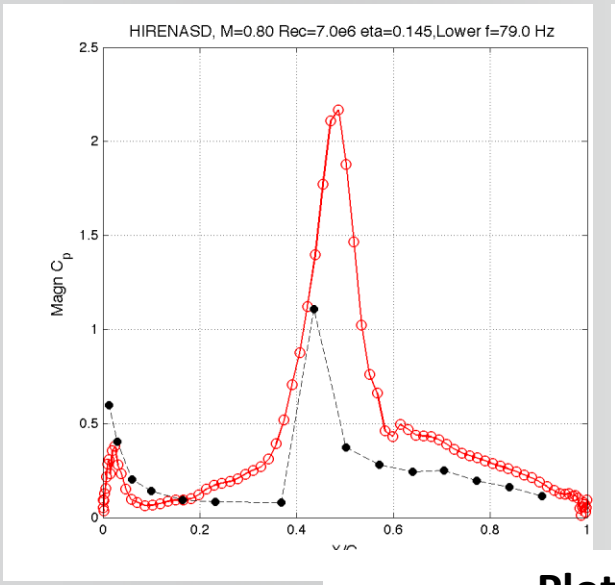
Plots created by Carol Wieseman, NASA

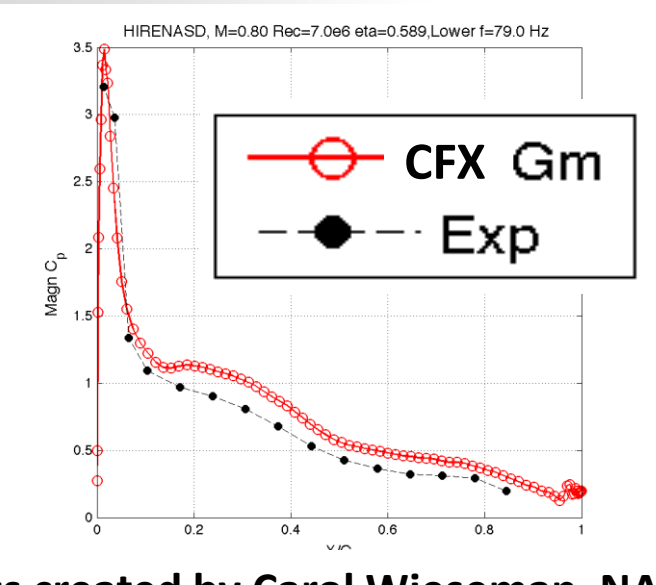


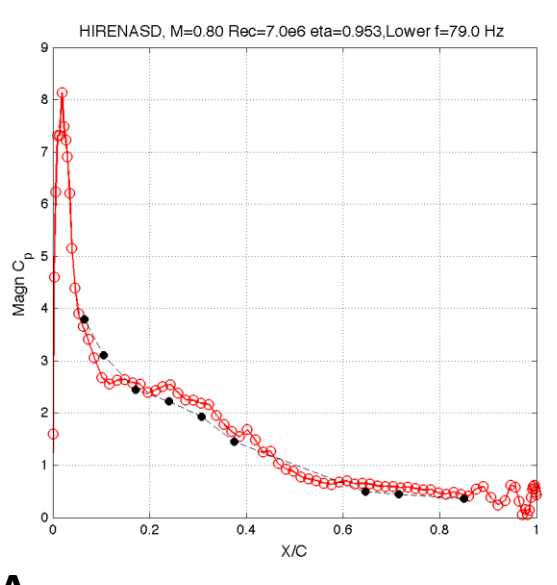




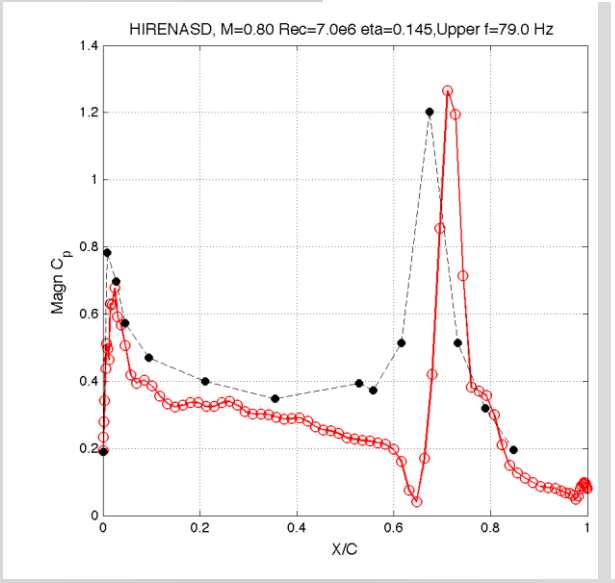
Magnitude: Re = 7 mio, Ma = 0.8, α = 1.5°

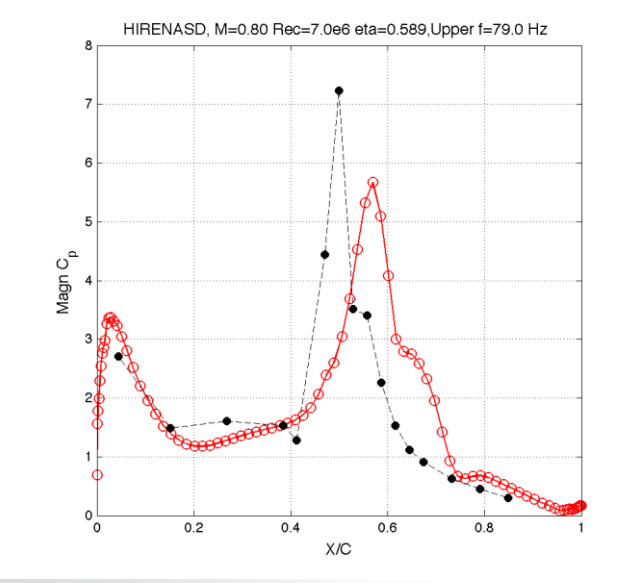


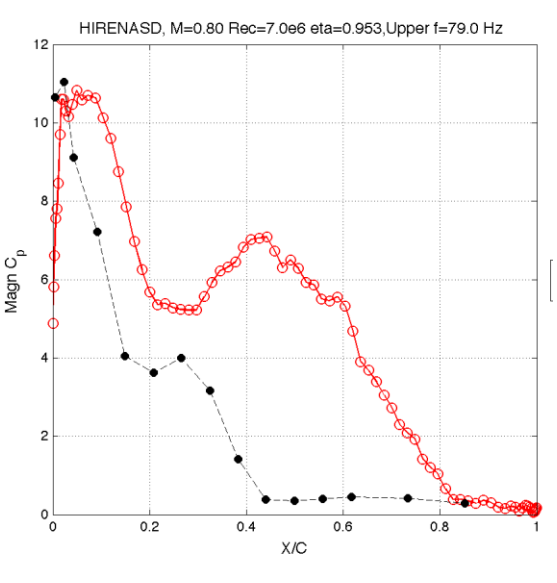




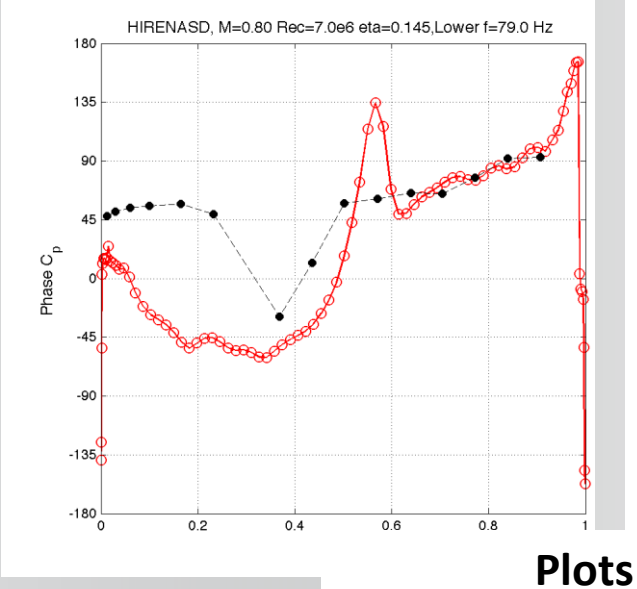
Plots created by Carol Wieseman, NASA

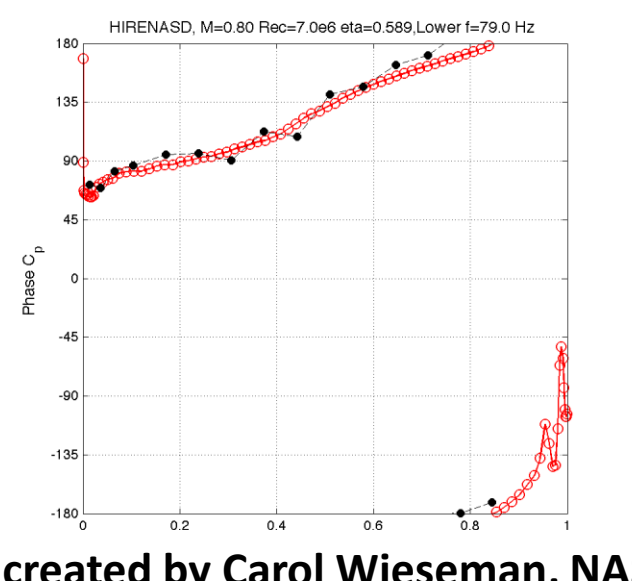


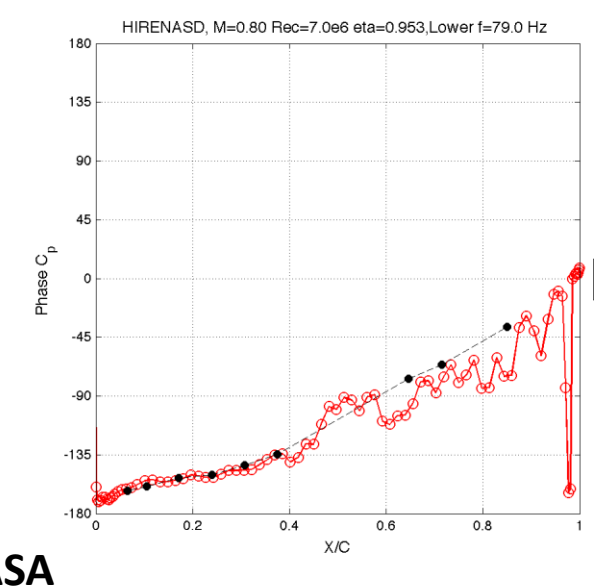




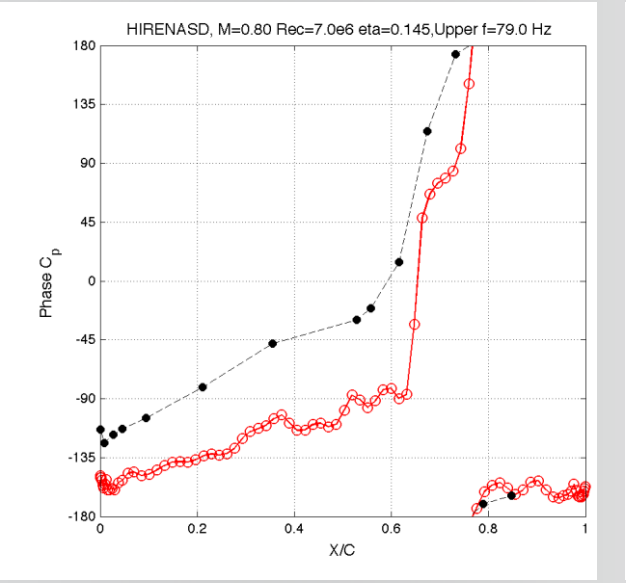
Phase: Re = 7 mio, Ma = 0.8, a = 1.5°

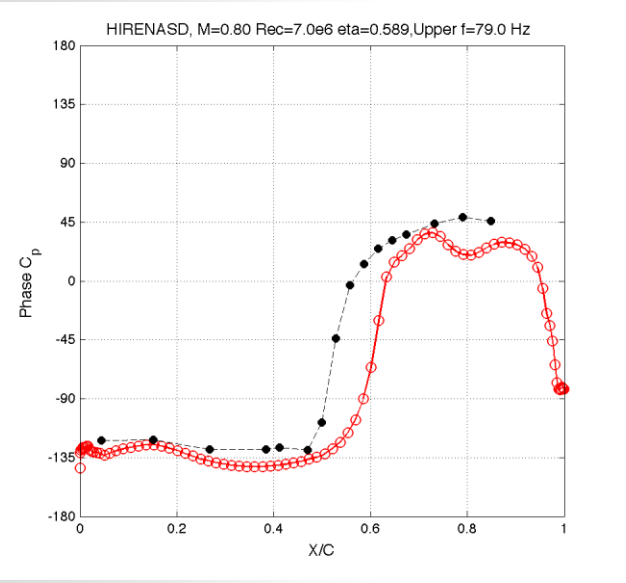


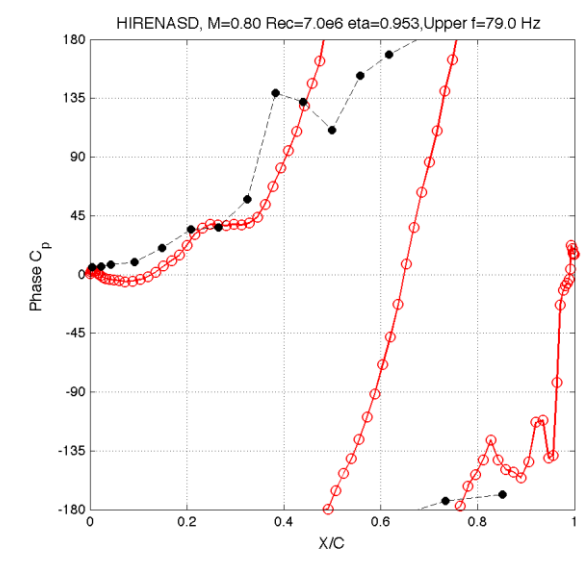




Plots created by Carol Wieseman, NASA



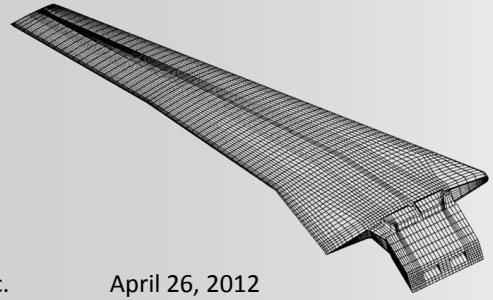




Summary & Outlook

- **ANSYS CFD calculation of a HIRENASD aeroelasticity case**
- **Detailed quality assurance of numerical errors**
  - **Iteration error**
  - **Discretization error (Spatial and temporal)**

- **Full Wind Tunnel model**
- **FEM Hex-mesh with real TE**
- **Dynamic coupling with ANSYS**



Courtesy of RWTH Aachen