Plans for an Aeroelastic Prediction Workshop -Discussion Session

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https://c3.ndc.nasa.gov/dashlink/projects/47/

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Paris

Some Topics for discussion

- Selection rationale
- Flow / aeroelastic phenomena of interest
  - Potential other data sets
  - Future AePW
- Computational resource requirements
- Anticipated end product of AePW
- Preliminary test case results & lessons learned
- Analyst data resources available

Case 1 Selection Rationale
Rectangular Supercritical Wing (RSW)

- Cases chosen to focus on the steady and unsteady aerodynamic solutions and their variation.
- Mach 0.825 generates transonic conditions with a terminating shock; highest Mach number with forced transition
- Steady Data: Two static angles of attack chosen
  - $\alpha = 2.0^\circ$ generates a moderate-strength shock with some potential for shock-separated flow; corresponding forced oscillation data exists.
  - $\alpha = 4.0^\circ$ generates strong shock with greater potential for shock-separated flow .
- Unsteady Data: Two forced oscillation frequencies chosen to evaluate methods abilities to distinguish frequency effects.
  - Non-zero mean AoA introduces a wing loading bias for which code-to-code comparisons can be accomplished.

Case 2 Selection Rationale
Benchmark Supercritical Wing (BSCW)

- Highly nonlinear aerodynamic phenomena.
  - Known shock-separated transient flow.
  - Relatively obscure data that serves as a virtually blind test case for the methods.
- Better data detail and insight than for RSW.
  - Statistical and time-history data are available for comparison.
  - Good possibilities for retesting for future workshops.

Case 3 Selection Rationale HIRENASD Wing

- Aircraft-representative geometry, rather than "unit problem"
- Initial test for fully coupled aeroelastic analysis.
- Steady cases demonstrate prediction capabilities for static aeroelastic problems.
- Dynamic cases demonstrate structural dynamics coupling with unsteady aerodynamics techniques.
  - Relatively weak aeroelastic coupling make it a good entry-level aeroelastic test case.

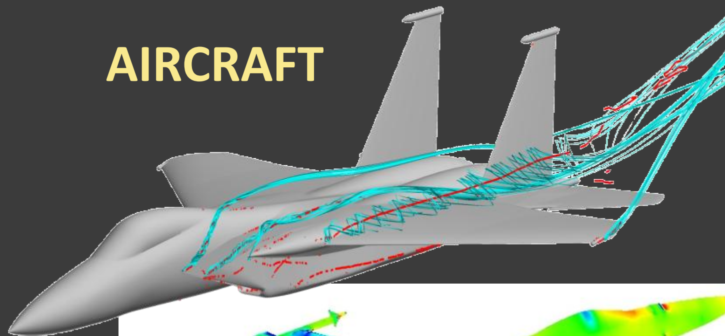
Technical challenges

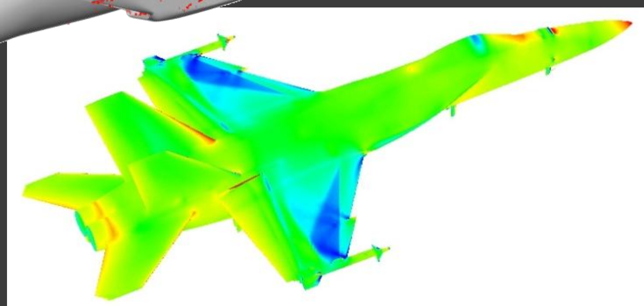
We need the equivalent slide for AePW:
<u>Flow phenomena:</u>
Transonic flow: terminal shock strength varying
Attached flow
Shock-Separated flow
Shock-boundary layer interaction
Buffeting flow
Vortical flow
<u>Aeroelastic challenges:</u>

Aerodynamic Viewpoint

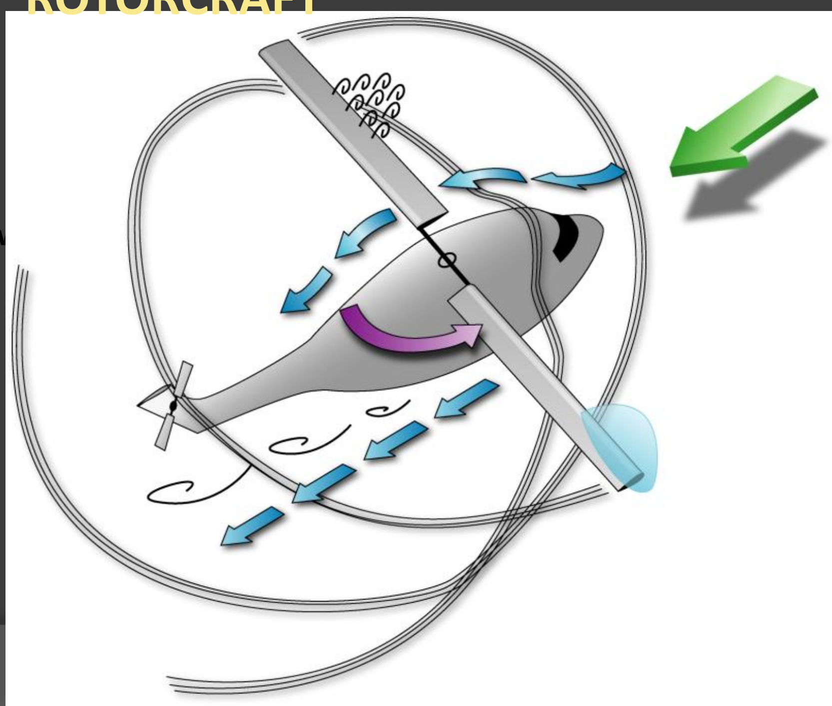
- Nonlinear Aeroelastic Issues of interest:
- Characterized by nonlinear flow phenomenon:
  - Transient and oscillating shocks, separated flow, vortex impingement and bursting.
  - Complex interactions of above.
  - Buffet, Limit Cycle Oscillations.
  - Pushing into aeroacoustic response, aero-control, and aero-propulsion interactions.
- Prediction challenges:
  - Resolution of fine flow details (accuracy and modeling)
  - Large models/grids and long computation times.
  - Numerical dissipation (algorithms)

AIRCRAFT

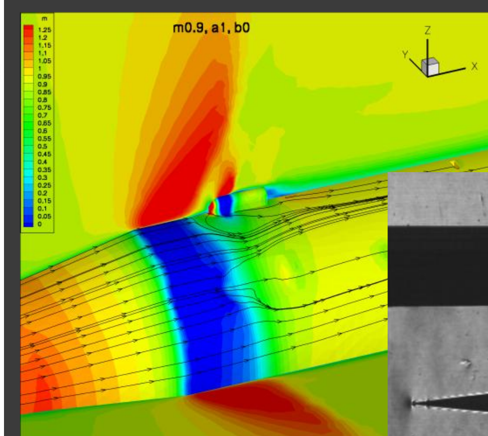


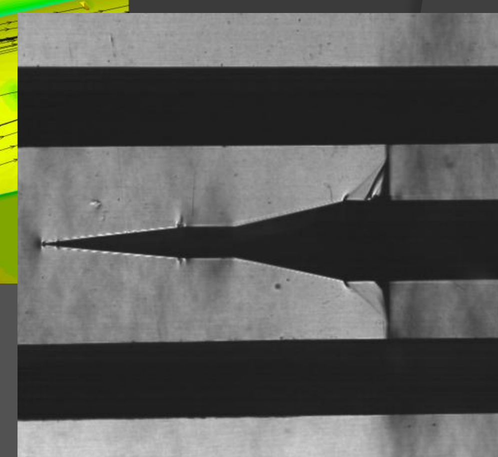


ROTORCRAFT



LAUNCH VEHICLES





Aeroelastic Viewpoint

Aeroelastic Issues of interest

- Characterized by nonlinear flow & structural phenomenon:
  - Transient and oscillating shocks, separated flow, vortex impingement and bursting
  - Nonlinear structural stiffness and damping
  - Complex interactions of above.
- Prediction challenges:
  - Scientifically identifying the sources of discrepancies between the experimental data and the computational results
  - Scientifically identifying dominant nonlinearities
  - Develop models that greatly reduce computational time with no essential loss in accuracy
  - Enable finer solution resolution and direct Navier Stokes computations without empirical turbulence models

AePW Workshop Timing Evaluation

- Considerations:
  - Computer variations
    - Benchmark computer using TauBench (see http://www.public.iastate.edu/~zjw/hiocfd/Guideline.html)
    - Could also be used to combine components run on different machines (i.e. structural solver vs CFD)
  - Simulation duration may vary from one contribution to another
    - Normalize to a standard duration (1sec)
    - Not always representative for multiple problems because of different structural/fluid frequencies, but would provide a baseline for a particular problem
- Cost Metric = (CPU-time for simulation)/(TauBench)/(simulation time)

- Grid/time step size impacts accuracy and timing. Migrate toward plot of "cost" vs "accuracy metric" to reflect balance. Not sure what "accuracy metric" should be. May depend on if grids are supplied and time step specified.

TauBench

- The scalable Benchmark TauBench is a pseudo benchmark.
- Emulates the run-time behavior of the Tau Flow Solver with respect to memory footprint and floating point performance.
- In order to accomplish this, a run time profile of the TAU FLOW SOLVER was generated.
- After analyzing the profile, the actual loop structure of the most cpu consuming kernels was duplicated.
- TAUBENCH can predict the performance of the flow-solver not only with respect to machine properties like memory bandwidth or cache latencies, but also with respect to the quality of compilers.

Anticipated End Products of AePW1: The questions we are asking

- For the "relatively simple cases" under consideration:
  - How good are our methods?
  - What are the major sources of the uncertainties/ errors/ variations?
  - Do we need to improve upon this?
  - Can we improve upon this?
- What are the next building blocks that should be considered?

Anticipated End Products of AePW1

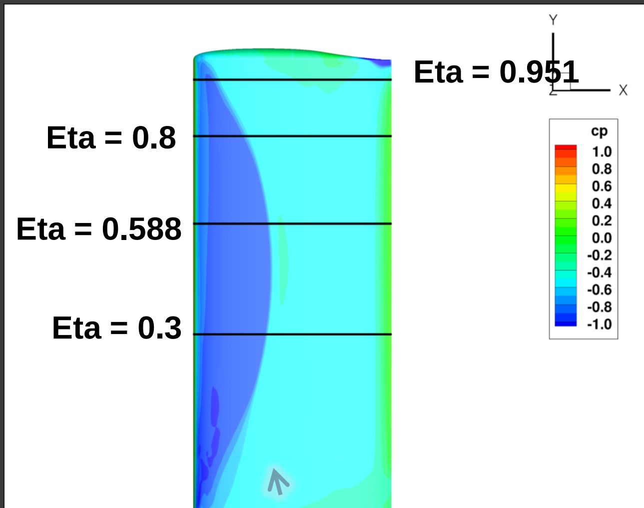
- Update to the state-of-the-art assessment of computational aeroelasticity
- Assessment of data sets used

- Identification of desirable characteristics of a good validation experimental data set
- Identification of a good validation computational exercise for aeroelastic solutions
- Address the path forward
  - Next test cases
  - Future experiments
  - Methods improvements

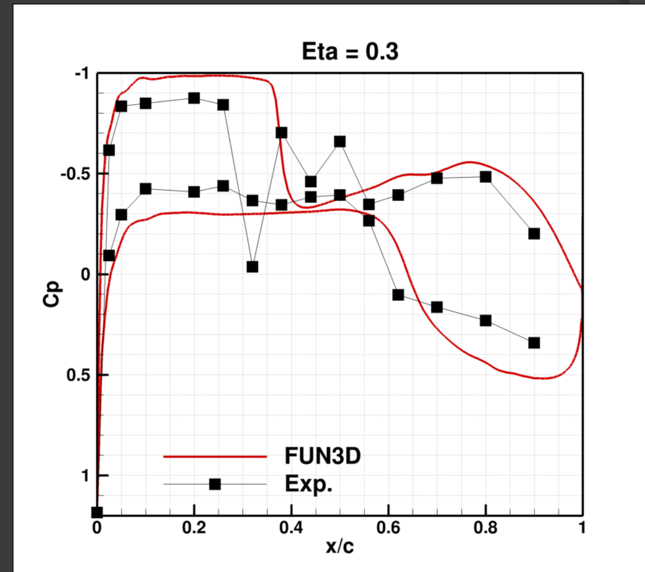
Preliminary test case results & lessons learned

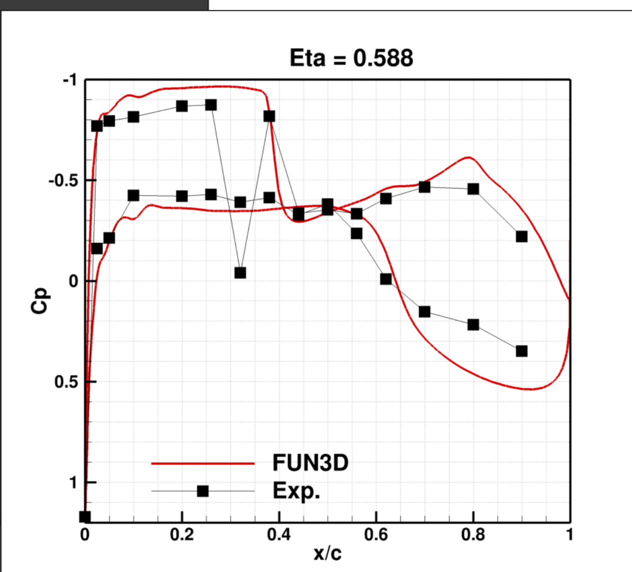
Preliminary RSW Analysis Update
Mach = 0.825, AoA = 2deg, FUN3D vs. Steady Experimental Data

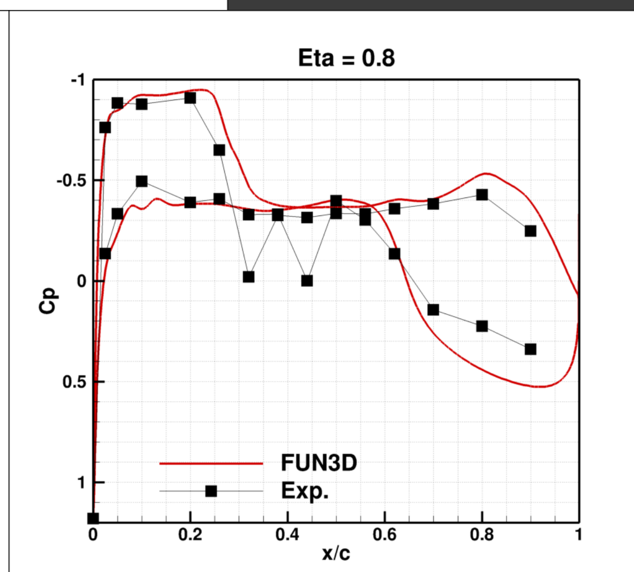
No splitter plate!
And viscous tunnel wall!
Model D

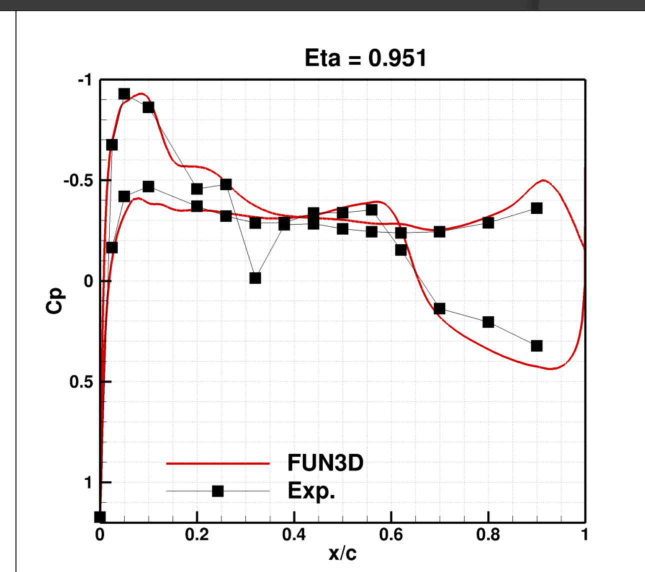


Tunnel Wall: Viscous









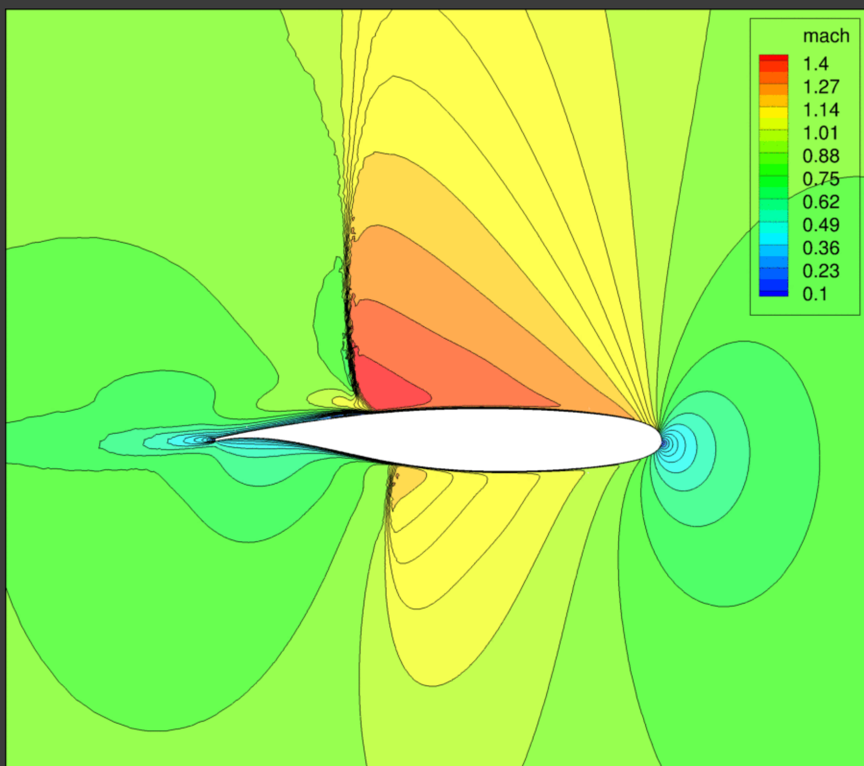
Preliminary BSCW Analysis Update

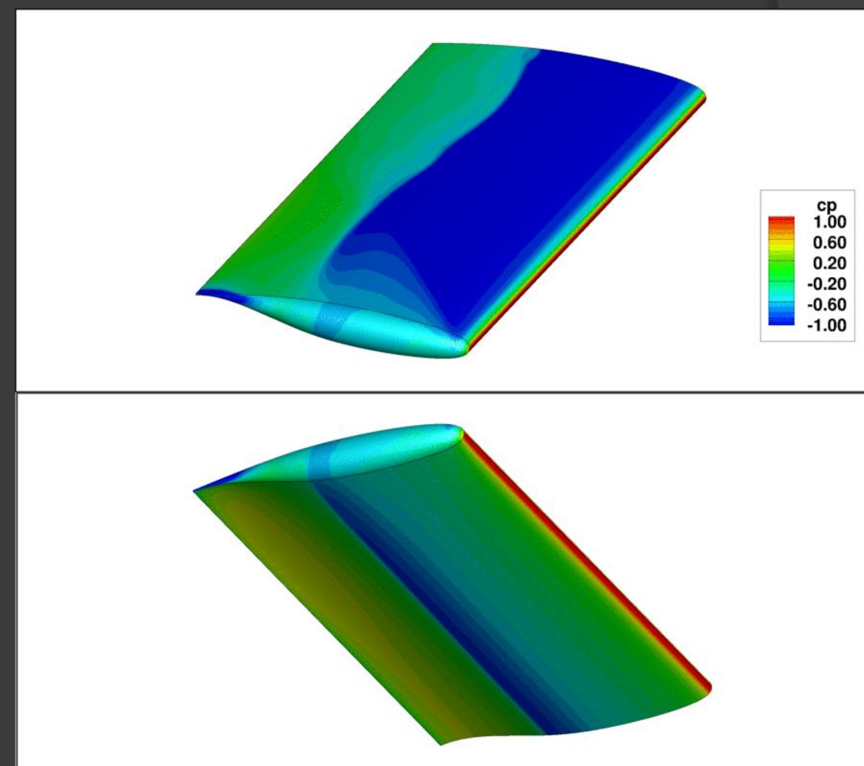
Unsteady Analysis

Mach = 0.85, AoA = 5deg, f = 10Hz, A = 1deg

T = 1/10 sec split into 128 time steps and run for 512 steps with 25 subiterations,

For animation data was collected at each time step

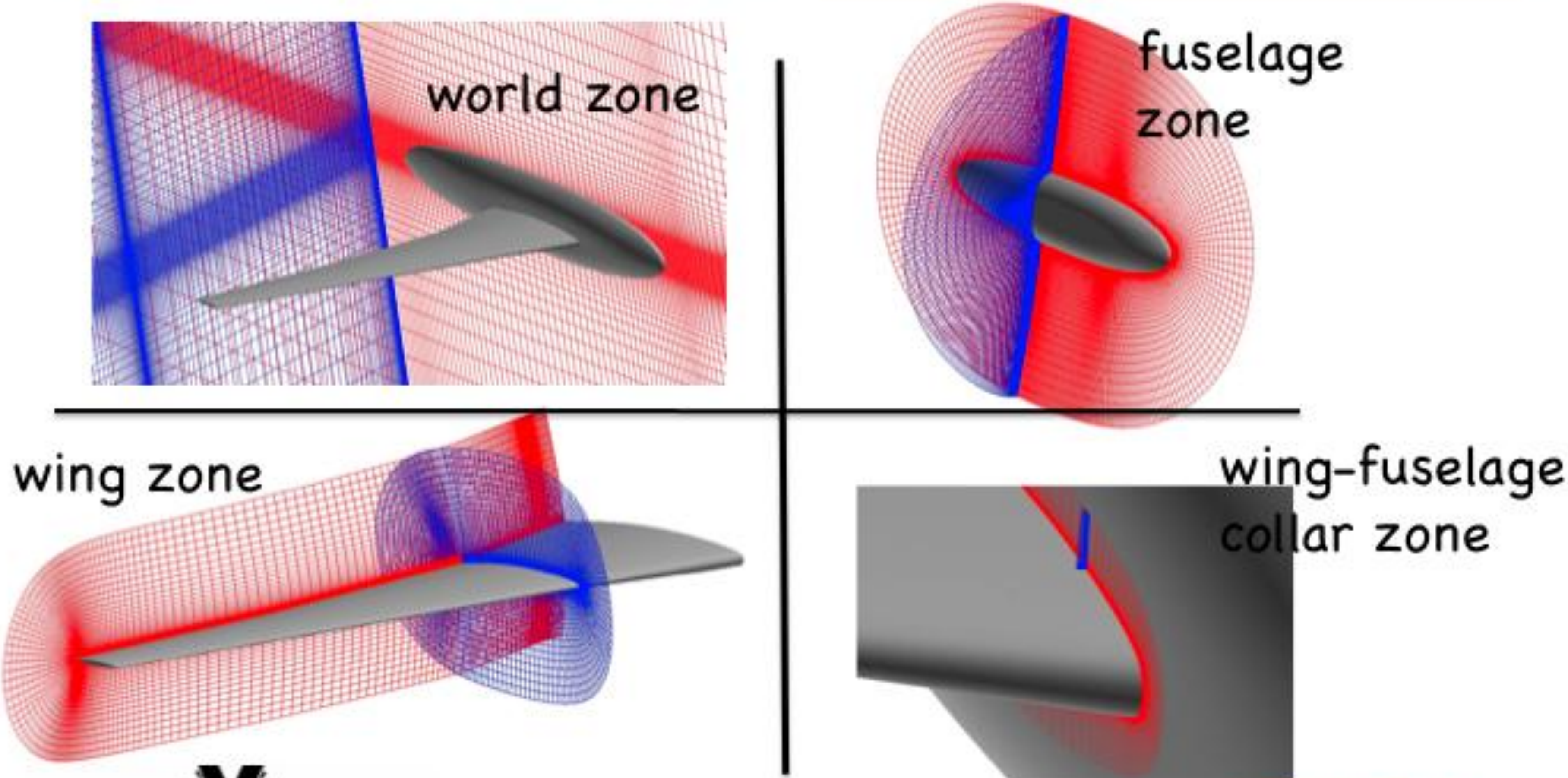




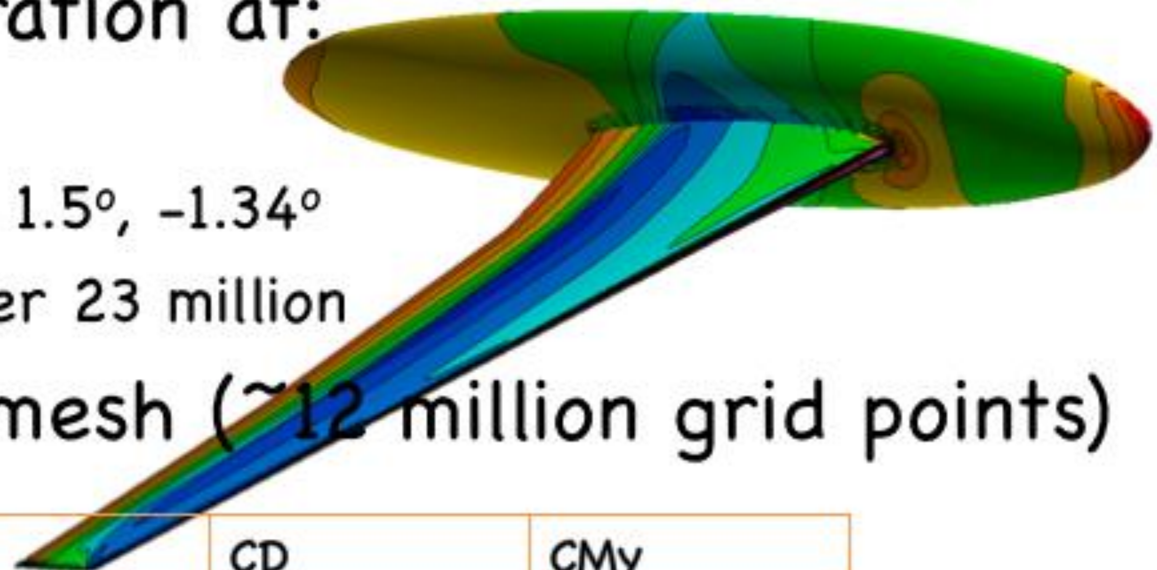
HIRENASD Wing Analysis

- EZNSS (Elastic Zonal Navier-Stokes Solver) CFD Code by the Israeli CFD Center
  - Chimera overset grid
  - SA & k-ω TNT/SST turbulence models.
  - HLLC 3rd order MUSCL Scheme.
  - Full viscous scheme.
  - 1st/2nd order in time.

Medium-Size Mesh



Flow Analysis

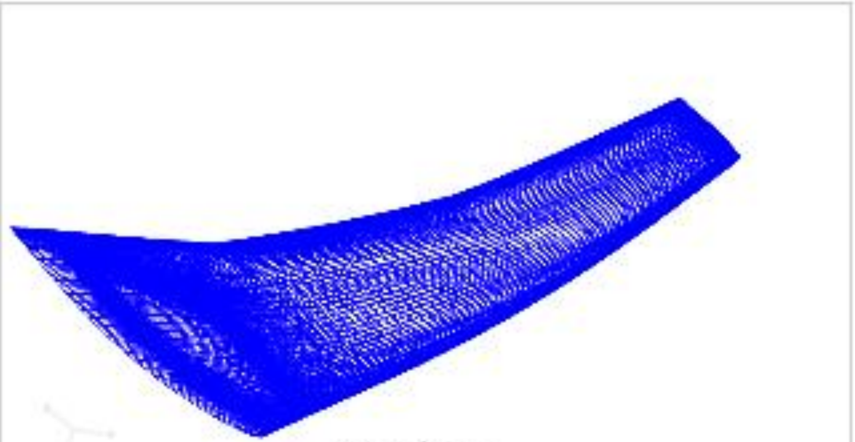


- Rigid Configuration at:
  - Mach 0.8
  - angle of attack 1.5°, -1.34°
  - Reynolds number 23 million
- Medium-size mesh (~12 million grid points)

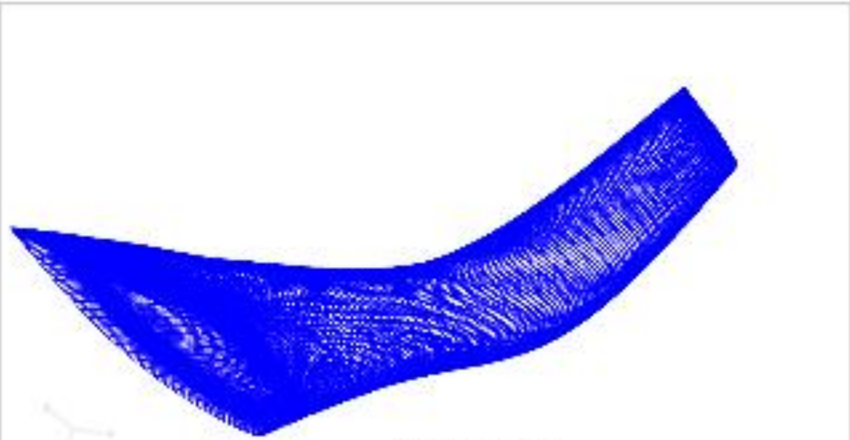
AoA (deg)	CL	CD	CMy
1.5	0.34918	0.01397	-0.54943
-1.34	-0.00205	0.00506	-0.00827

Mode Spline

Structural modes were mapped from finite-element grid to the CFD surface grid



Mode 1

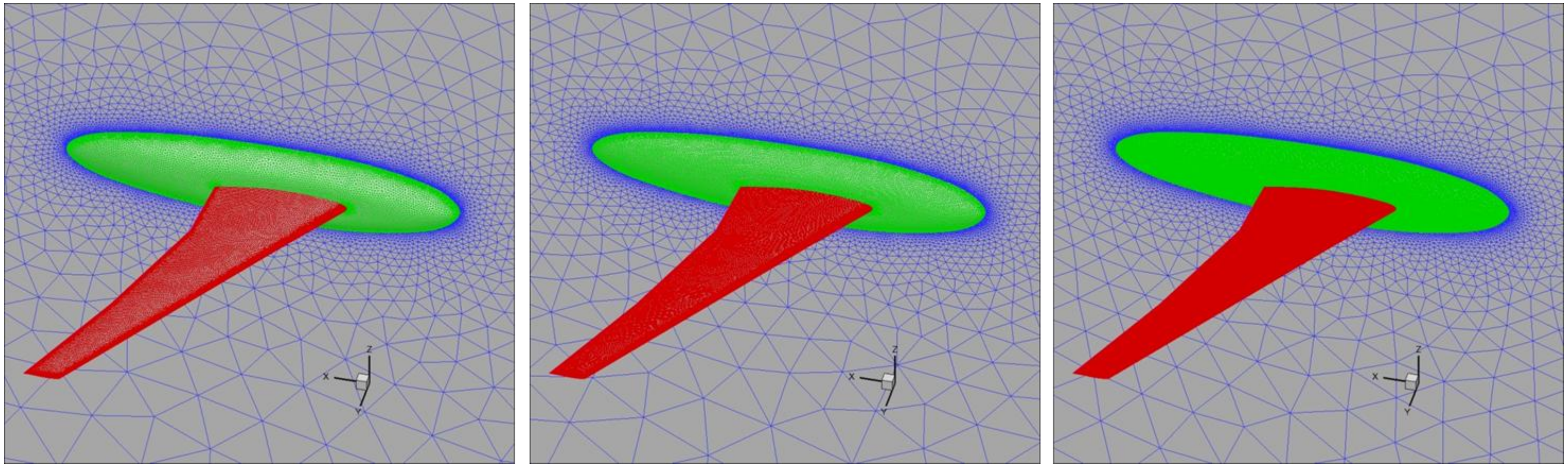


Mode 2

Challenges

- Create and analyze coarse and fine meshes
- Perform aeroelastic analyses

Gridding progress of unstructured HIRENASD meshes



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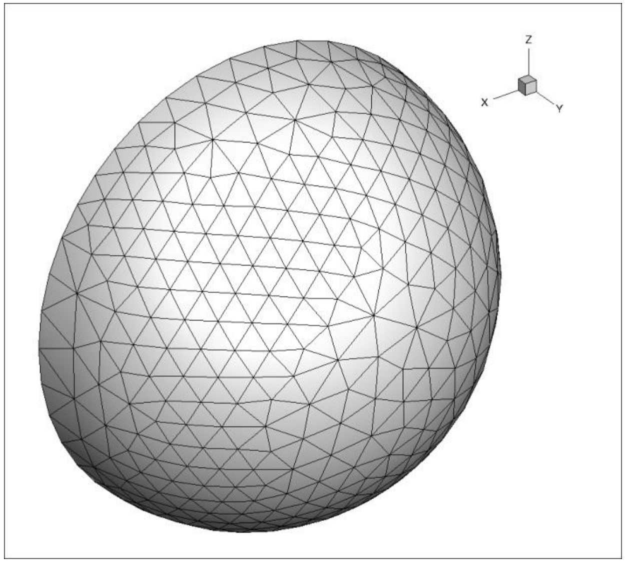
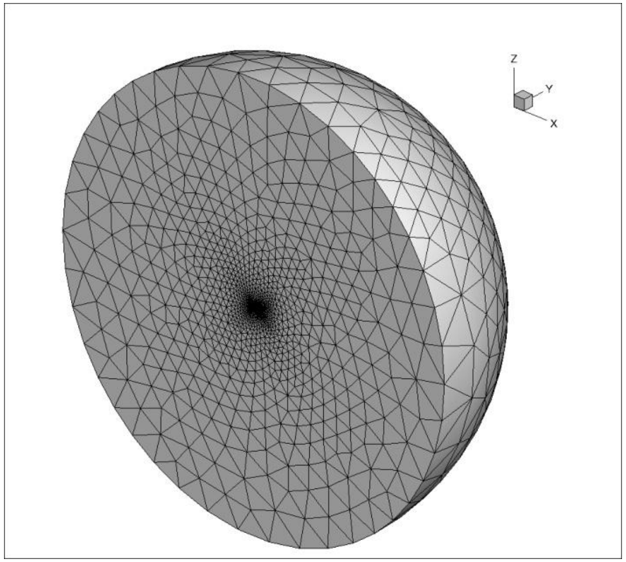
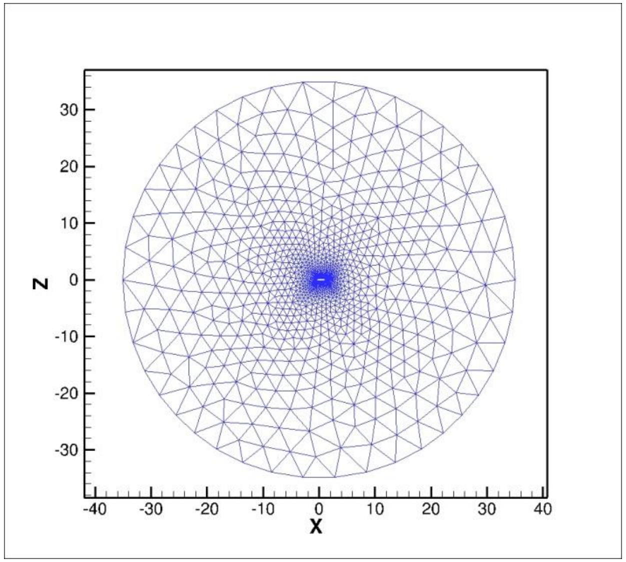
in der Helmholtz-Gemeinschaft

Overview of the coarse, medium, and fine unstructured HIRENASD meshes

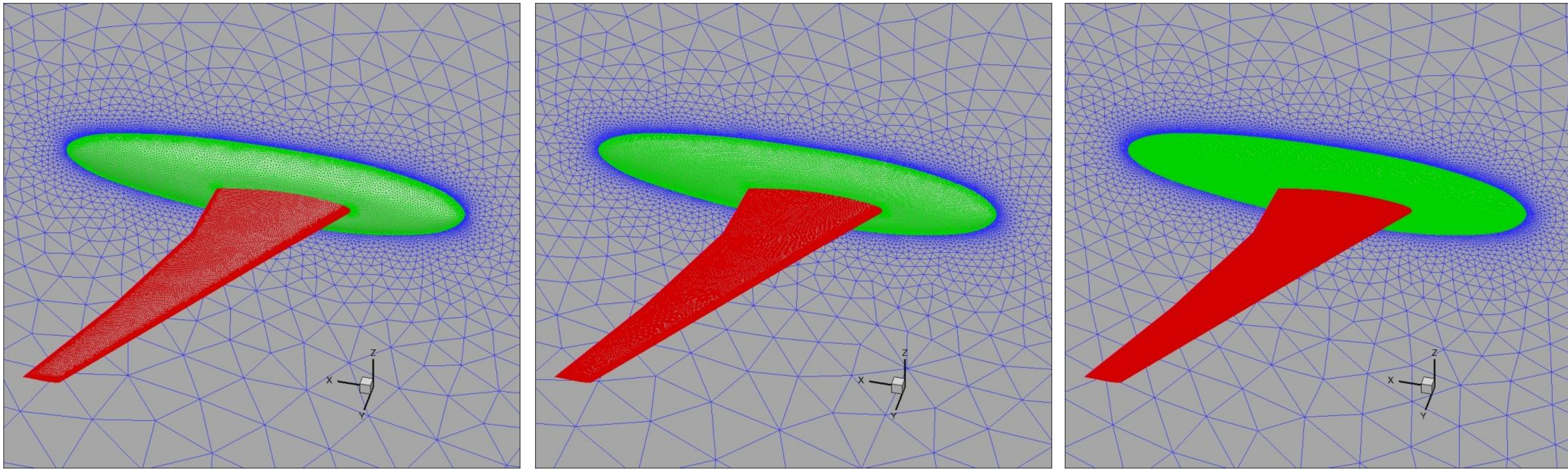






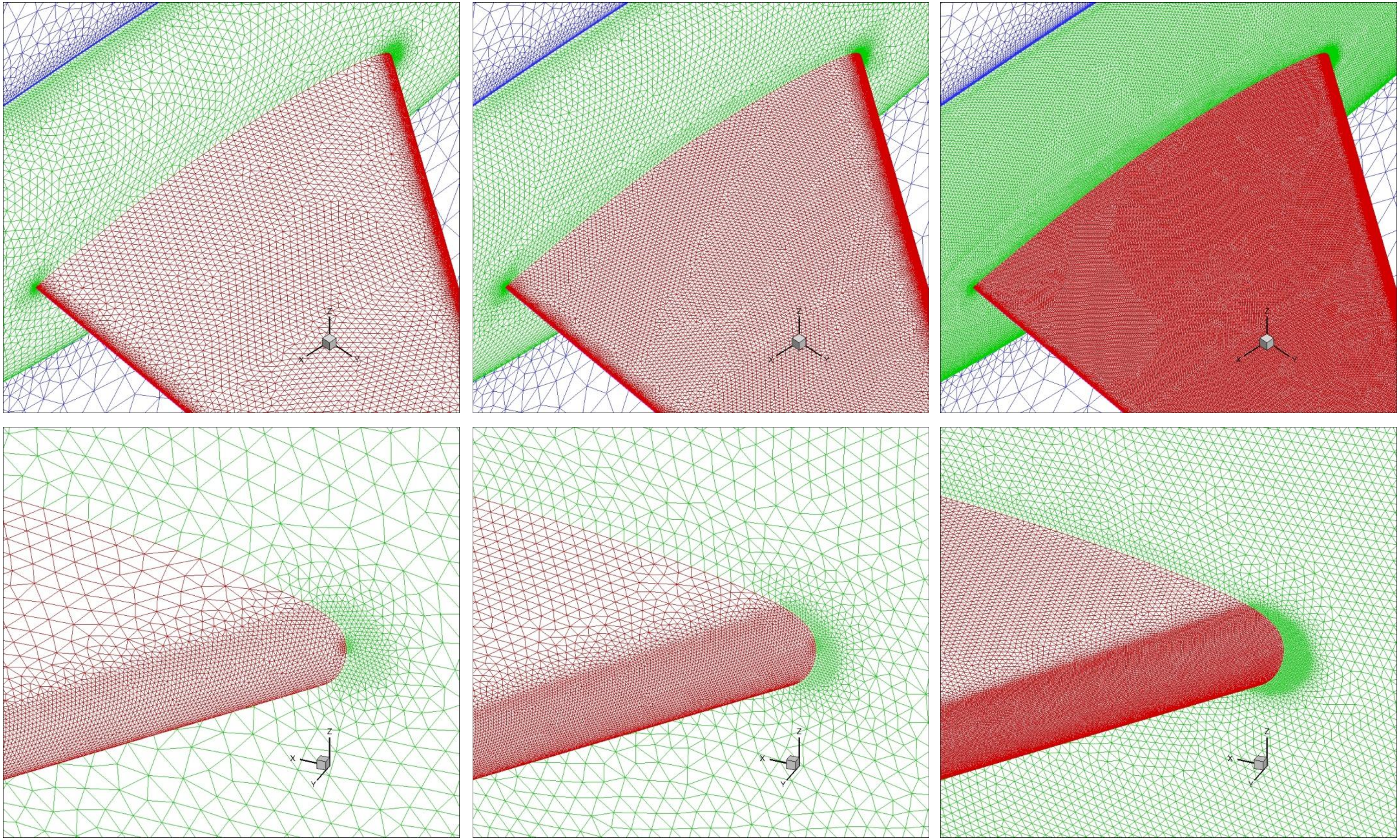
- **Semispherical farfield shape**
- **Radius ca. 100c_{ref} (100 x 0.3445m)**

Overview of the coarse, medium, and fine unstructured HIRENASD meshes



- **Coarse:**
  - **5676008 Total Nodes**
  - **14378129 Total Elements**
  - **Boundary layer cells:**
    - **34 prism layers**
    - **Stretching factor 1.28**
- **Medium:**
  - **16052763 Total Nodes**
  - **38871412 Total Elements**
  - **Boundary layer cells:**
    - **40 prism layers**
    - **Stretching factor 1.25**
- **Fine:**
  - **46393528 Total Nodes**
  - **104678223 Total Elements**
  - **Boundary layer cells:**
    - **45 prism layers**
    - **Stretching factor 1.23**

Overview of the coarse, medium, and fine unstructured HIRENASD meshes



- **Estimation of the turbulent boundary layer height (cf. e.g. Anderson):**

$$\delta_{te} = \frac{0.371 \; * \; chord}{Re^{0.2}}$$

- **Worst case: Re = 7 million**

$$\delta_{te} = \frac{0.371 \; * 0.3445m}{7000000^{0.2}} \approx \mathbf{0.00546m}$$

- **Entire boundary layer should be included in prism layer due to high dissipation of tetrahedra cells**
- **Therefore the coarse mesh needs a comparatively high stretching ratio (1.28) to avoid large mesh size**

Preliminary Results of the HIRENASD configuration obtained by TAU using the coarse and the medium mesh

- Thermodynamic conditions and integral values for test case 1:
  - Ma = 0.8, Re = 23.5million, AoA = -1.34°
  - No fluid-structure coupling!

Gas constant (NITROGEN)	**296.8**	**J/kg*K**
Reynolds number	**23483300**	**-**
Prandtl number	**0.72**	**-**
Sutherland constant	**111**	**K**
Sutherland reference viscosity	**1.766e-05**	**Pa*s**
Sutherland reference temperature	**300.55**	**K**
Reference density	**3.628**	**kg/m³**
Reference temperature	**182.776**	**K**
Reference pressure	**196816.890**	**Pa**
Reference Mach number	**0.8**	**-**
Reference velocity:	**220.440**	**m/s**

	Coarse grid 5.7 million nodes	**Medium grid 16 million nodes**
C_L	**0.033519**	**0.033239**
C_D	**0.009154**	**0.009181**
C_{mx}	**0.027913**	**0.027526**
C_{my}	**-0.042686**	**-0.042472**
C_{mz}	**0.00427**	**0.004355**
Reference point for moment: (0., 0., 0.) All values without fuselage		

Preliminary Results of the HIRENASD configuration obtained by TAU using the coarse and the medium mesh

- Thermodynamic conditions and integral values for test case 2:
  - Ma = 0.8, Re = 7 million, AoA = 1.495°
  - No fluid-structure coupling!

Gas constant (NITROGEN)	**296.8**	**J/kg*K**
Reynolds number	**7001020**	**-**
Prandtl number	**0.72**	**-**
Sutherland constant	**111**	**K**
Sutherland reference viscosity	**1.766e-05**	**Pa*s**
Sutherland reference temperature	**300.55**	**K**
Reference density	**1.2001**	**kg/m³**
Reference temperature	**248.2252**	**K**
Reference pressure	**88460.72**	**Pa**
Reference Mach number	**0.8003**	**-**
Reference velocity:	**257.0229**	**m/s**

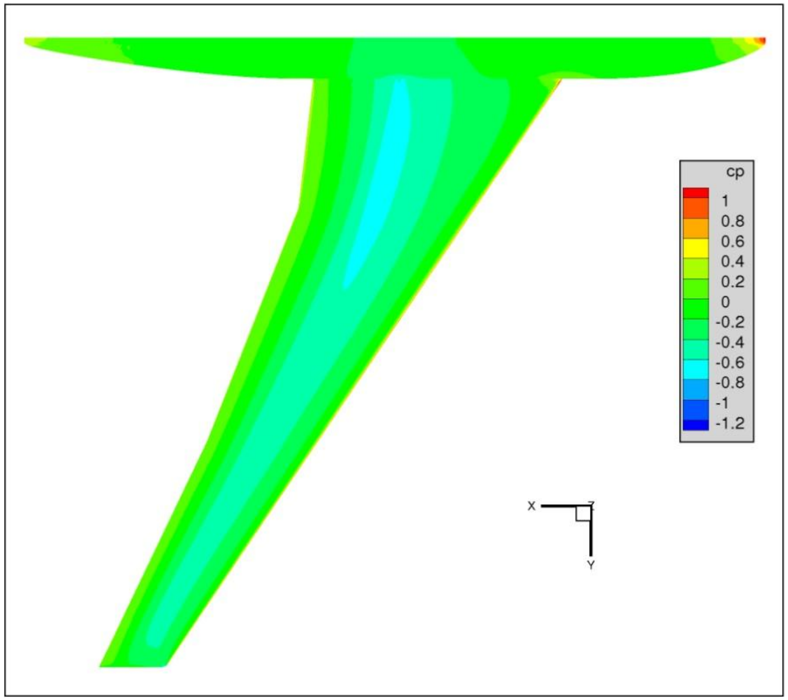
	Coarse grid 5.7million nodes	**Medium grid 16 million nodes**
C_L	**0.356374**	**0.358478**
C_D	**0.014483**	**0.014516**
C_{mx}	**0.206806**	**0.207625**
C_{my}	**-0.192529**	**-0.193579**
C_{mz}	**0.010895**	**0.011135**

Reference point for moment: (0., 0., 0.)
All values without fuselage

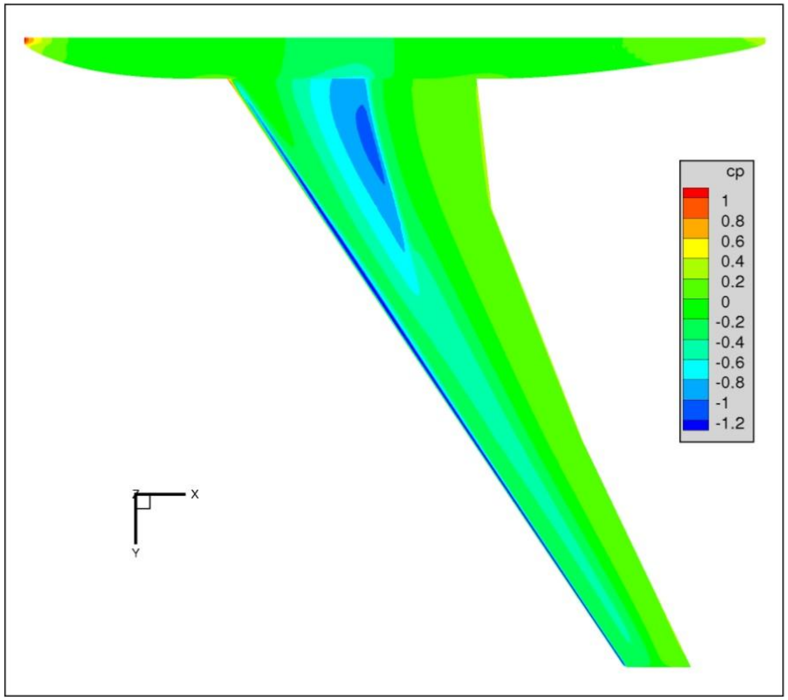
Preliminary Results of the HIRENASD configuration obtained by TAU using the coarse and the medium mesh

- Test case 1: cp at pressure sensor cuts (Ma = 0.8, Re = 23.5million, AoA = -1.34°)

Suction side

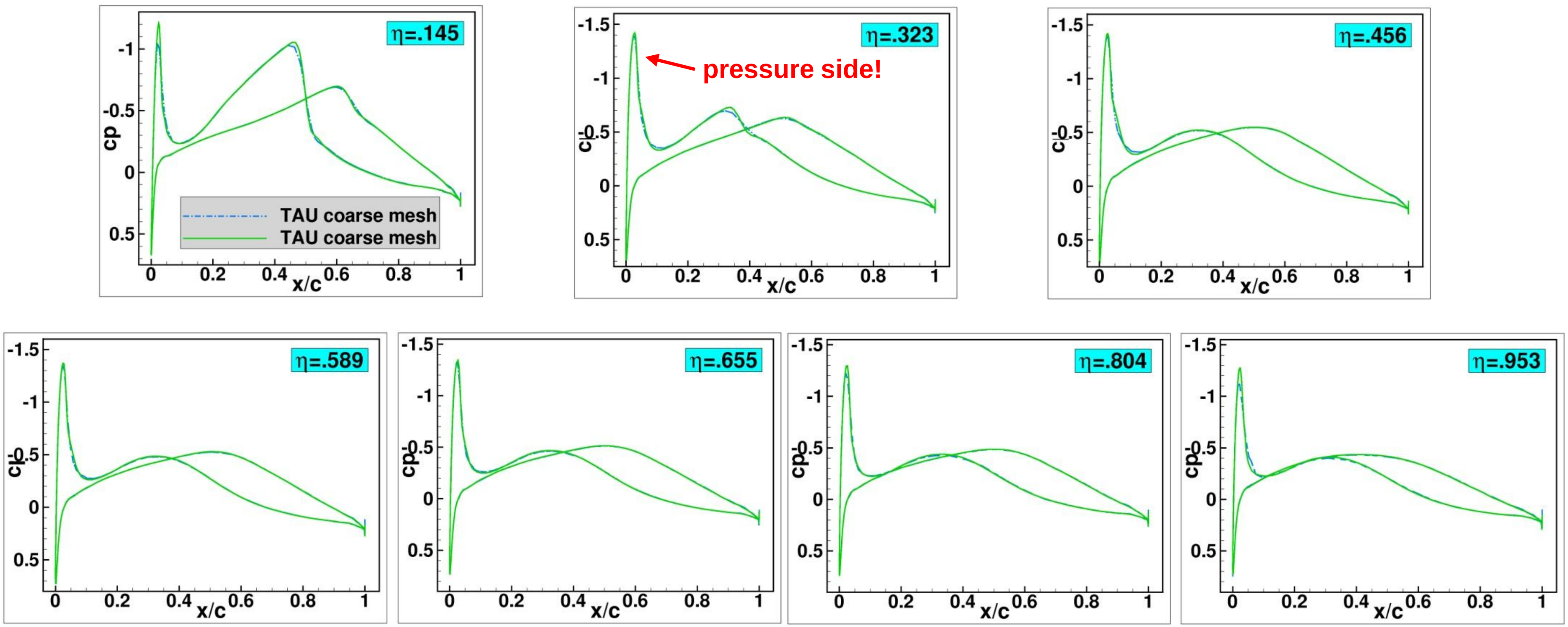


Pressure side



Preliminary Results of the HIRENASD configuration obtained by TAU using the coarse and the medium mesh

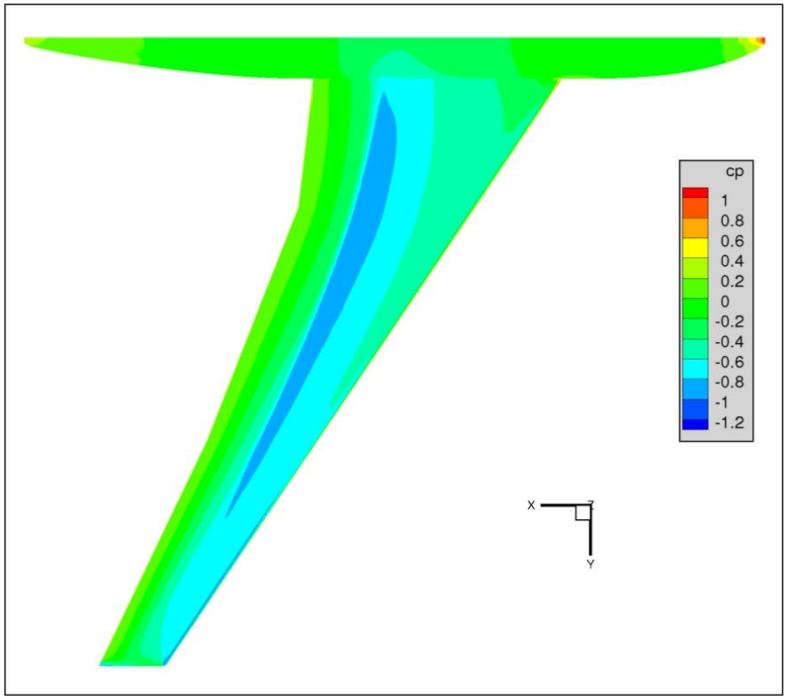
- Test case 1: cp at pressure sensor cuts (Ma = 0.8, Re = 23.5million, AoA = -1.34°)



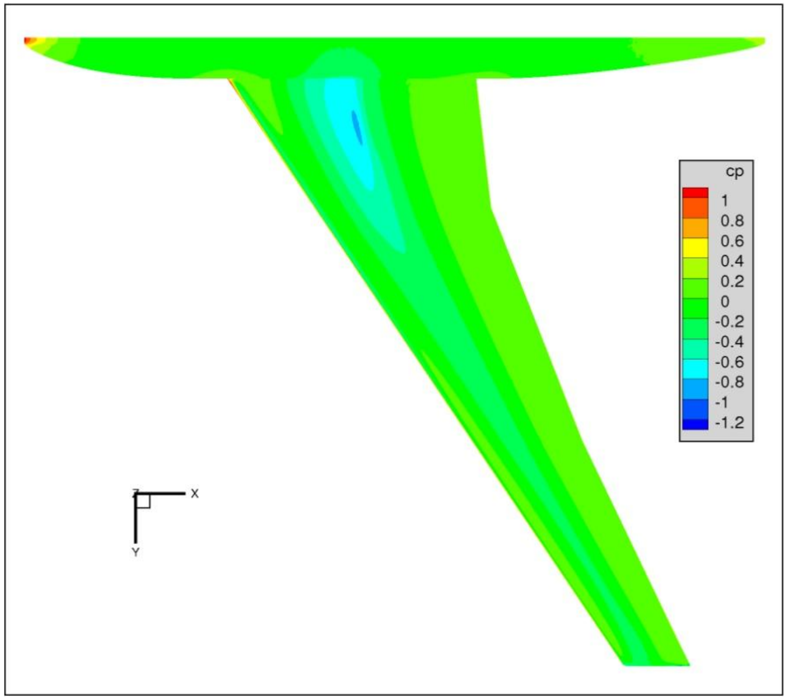
Preliminary Results of the HIRENASD configuration obtained by TAU using the coarse and the medium mesh

- Test case 2: cp at pressure sensor cuts (Ma = 0.8, Re = 7million, AoA = 1.5°)

Suction side

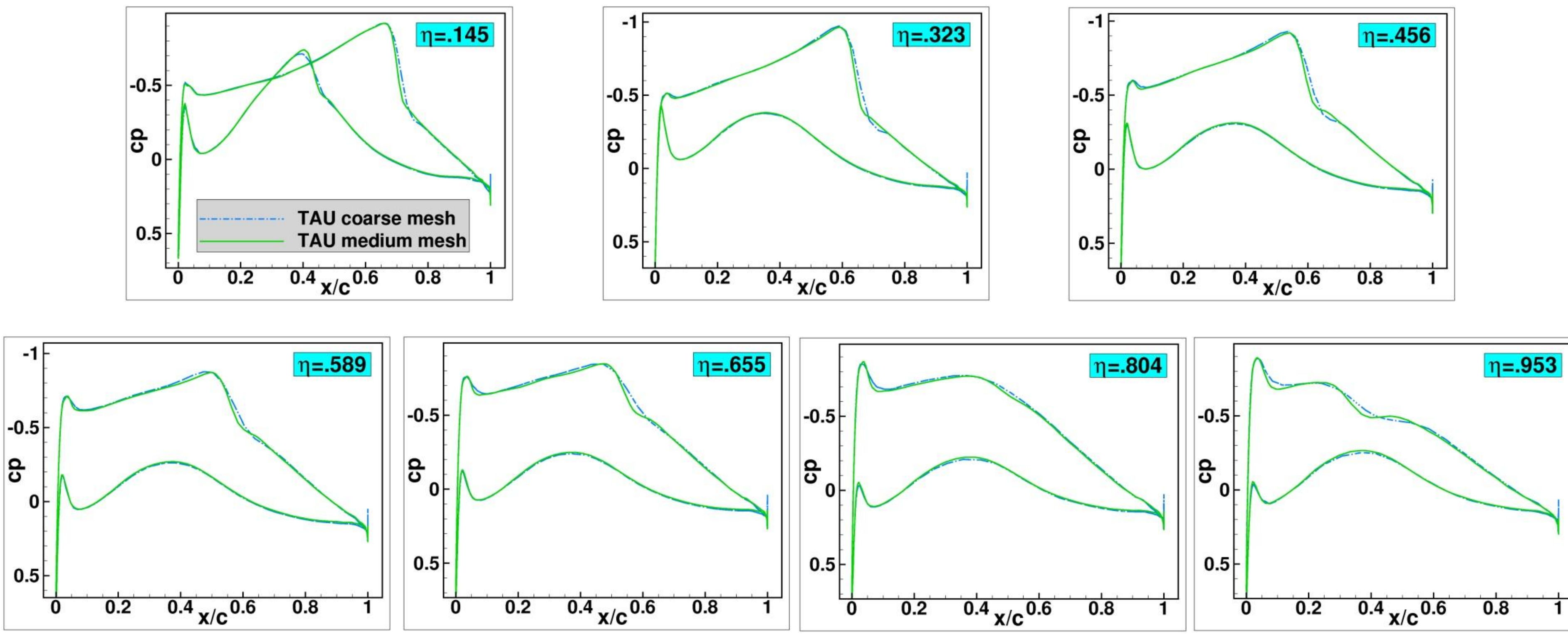


Pressure side



Preliminary Results of the HIRENASD configuration obtained by TAU using the coarse and the medium mesh

- Test case 2: cp at pressure sensor cuts (Ma = 0.8, Re = 7million, AoA = 1.5°)



Aeroelastic Prediction Workshop Grid Guidelines Committee

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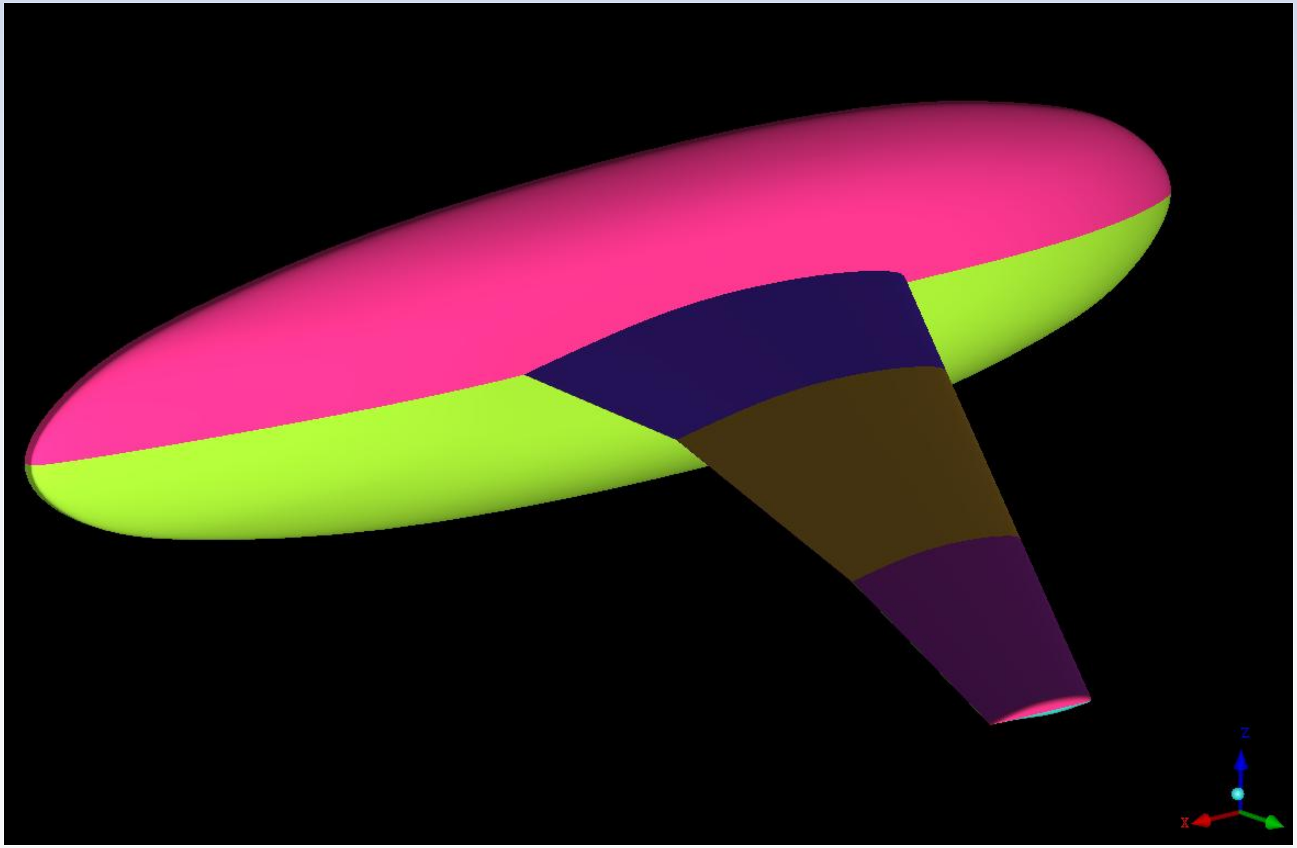
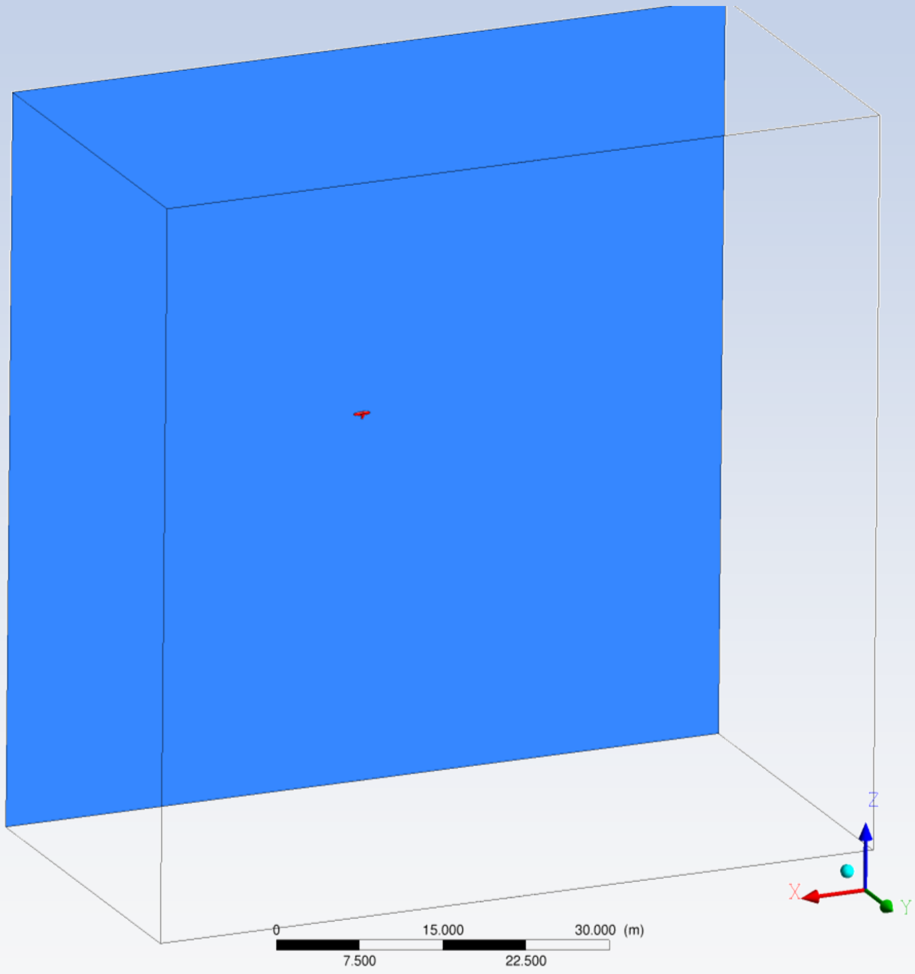
HIRENASD Geometry

- https://c3.ndc.nasa.gov/dashlink/resources/354/hirenasd_AePW_DLR.igs.gz
- IGES-format, Units in mm

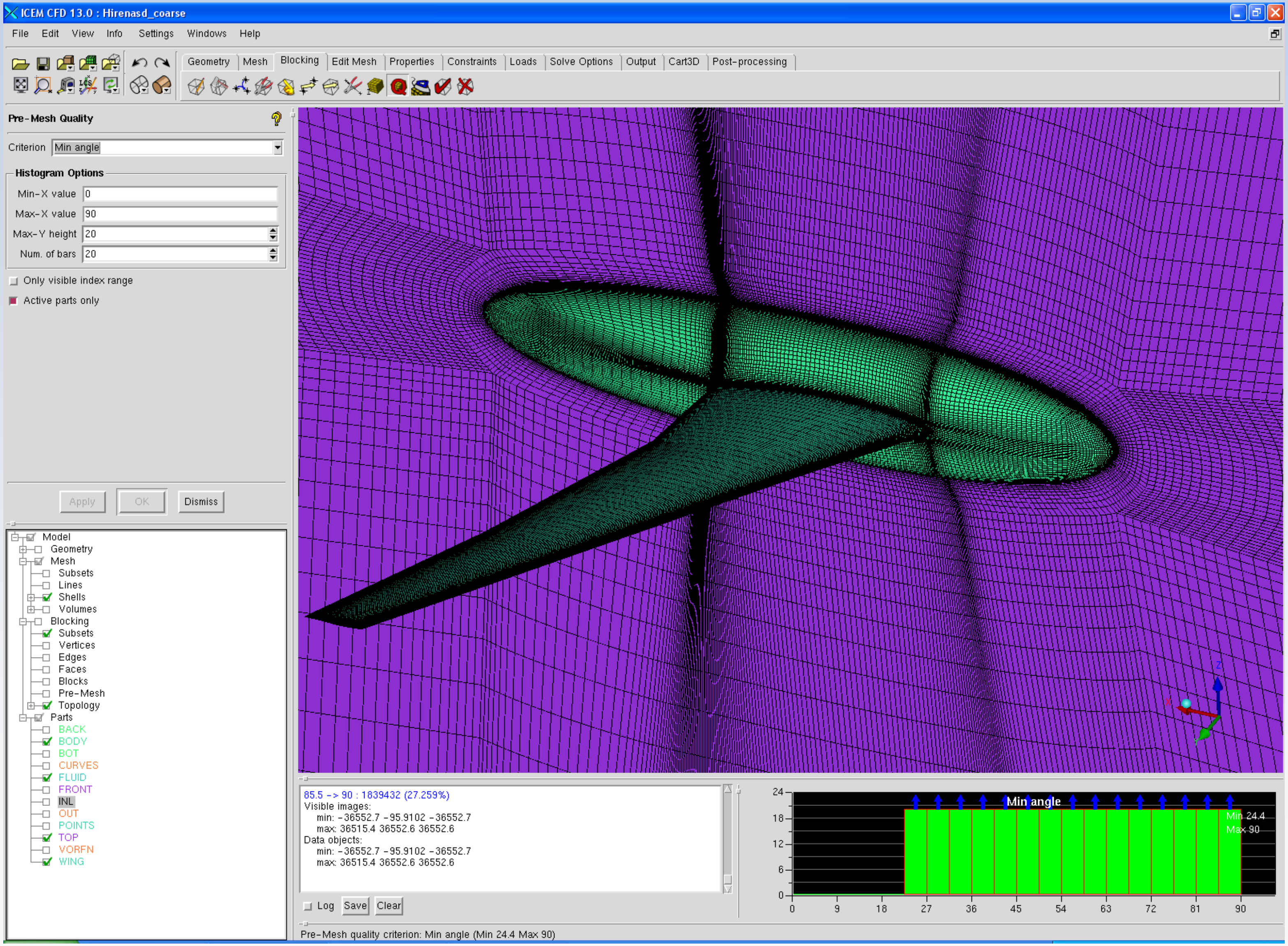


Computational Domain

- Chord length
  - C_{ref}= 0.3445 m
- Domain
  - ~100 * Cref in all directions



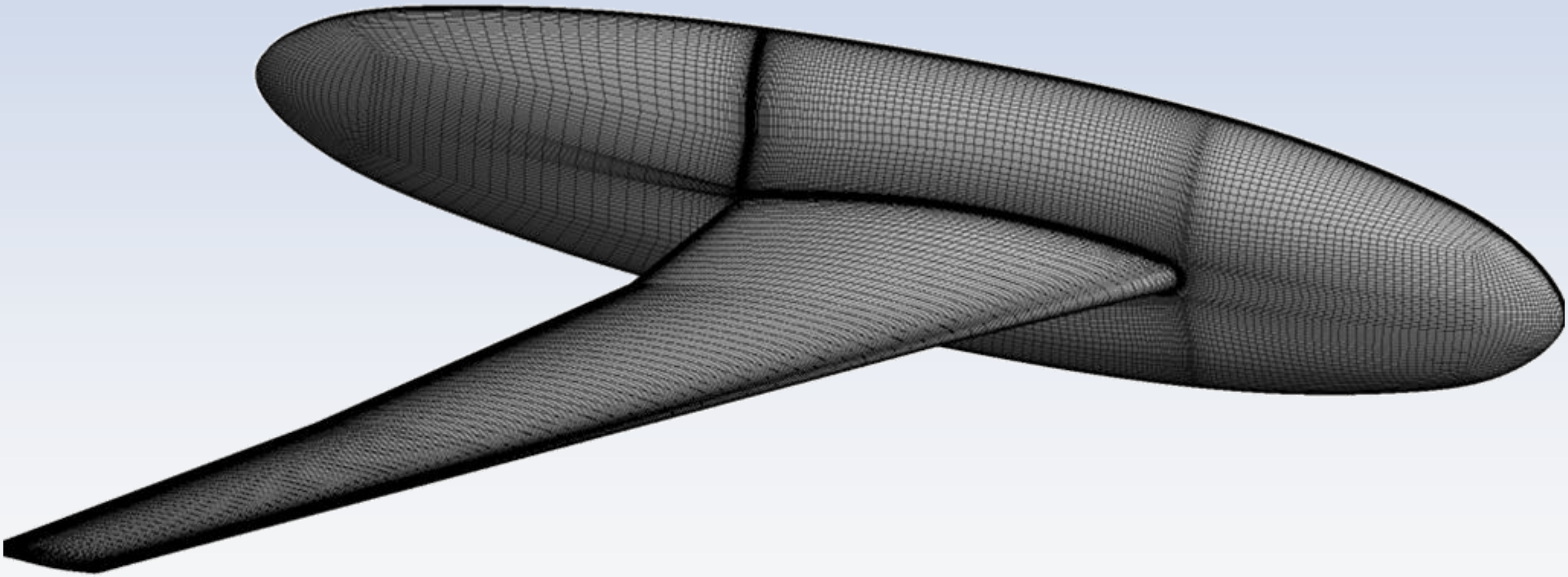
Structured Hexahedral Grid



Grid Information

	Grid 1	Grid 2	Grid 3
Number of nodes	6,878,220		
Number of elements	6,747,910		
Minimum grid angle	24°		
Maximum aspect ratio	67,948		
First grid node @ Wall, mm	0.000441 (y^+~1)		

Grid Information



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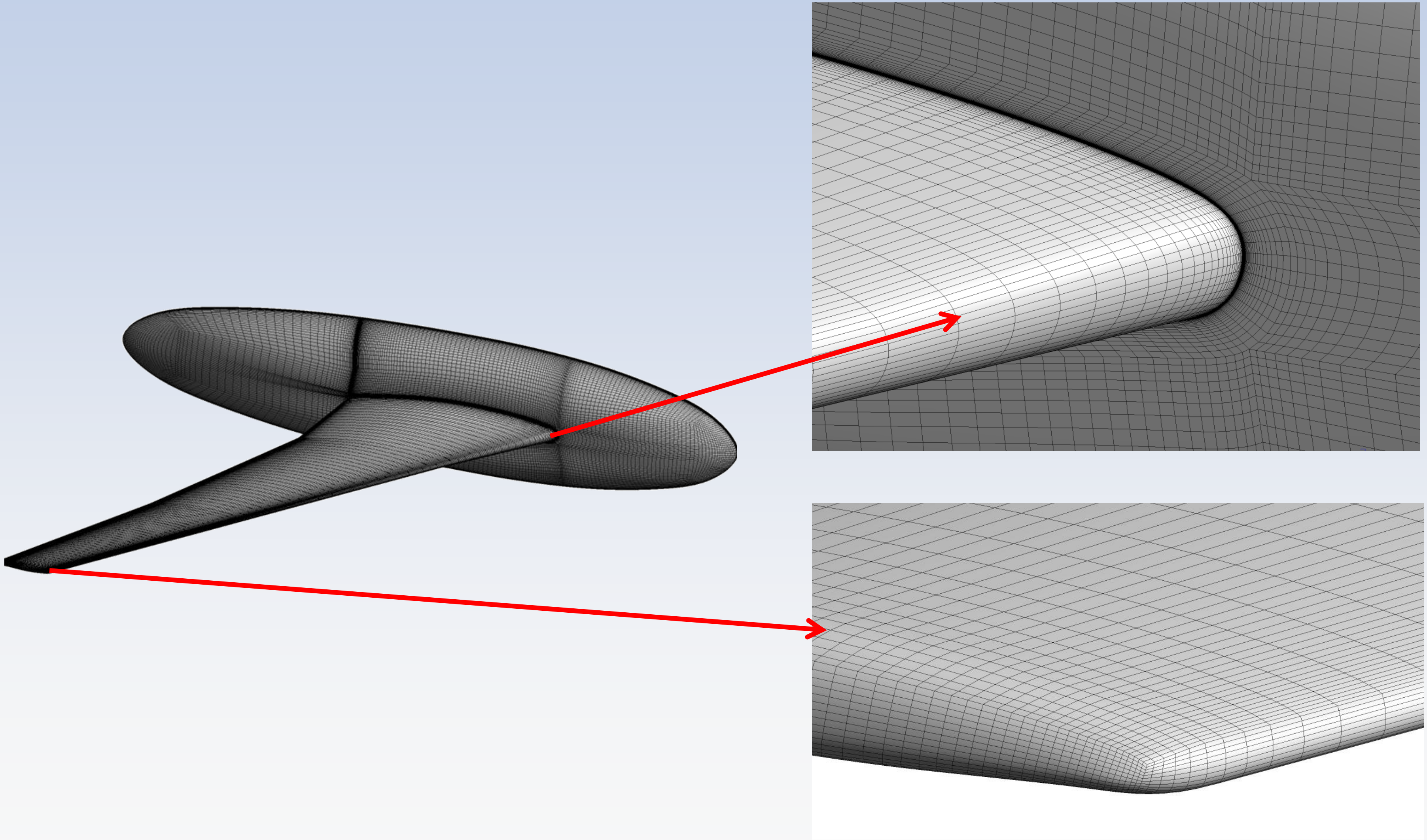

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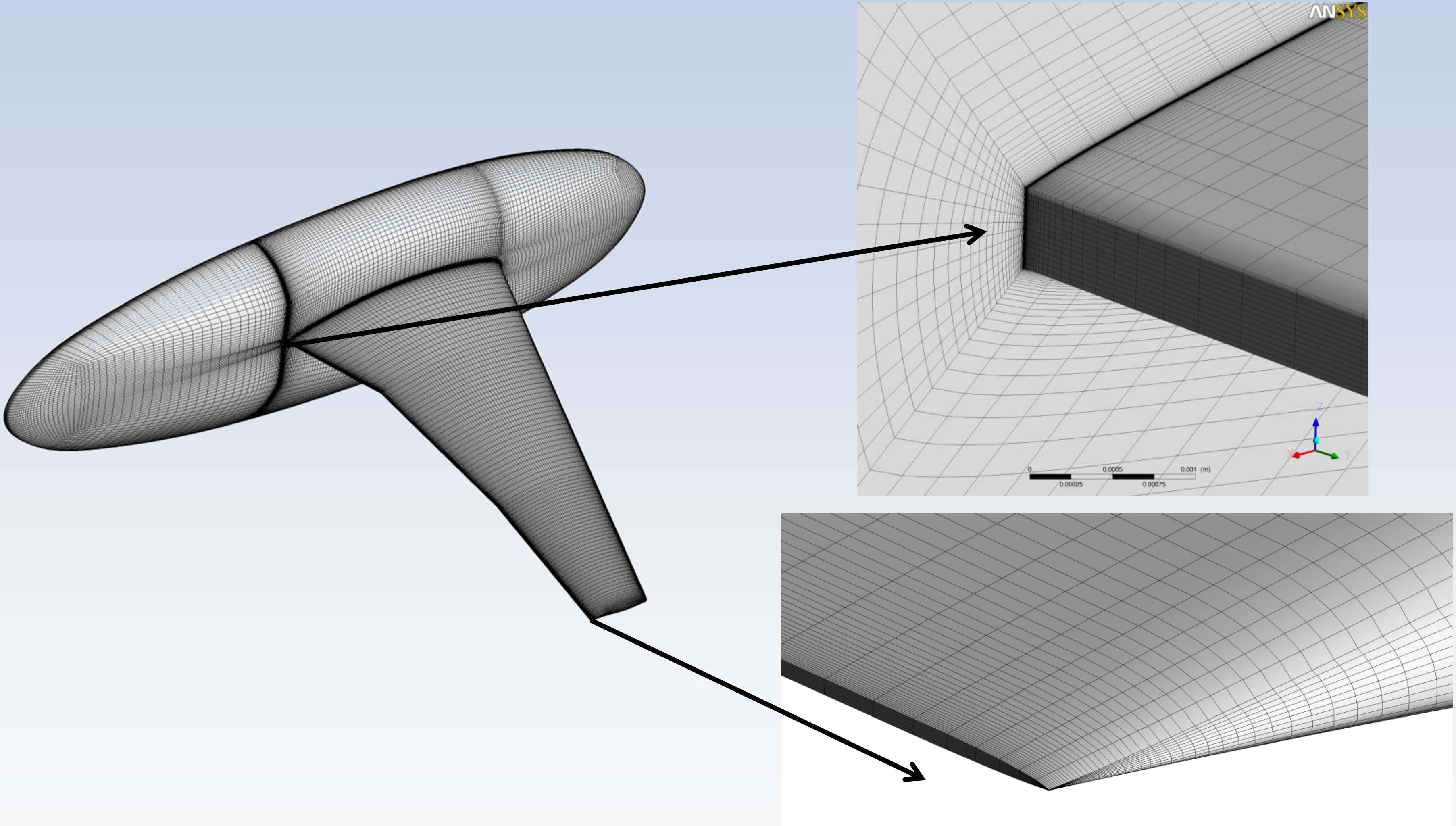

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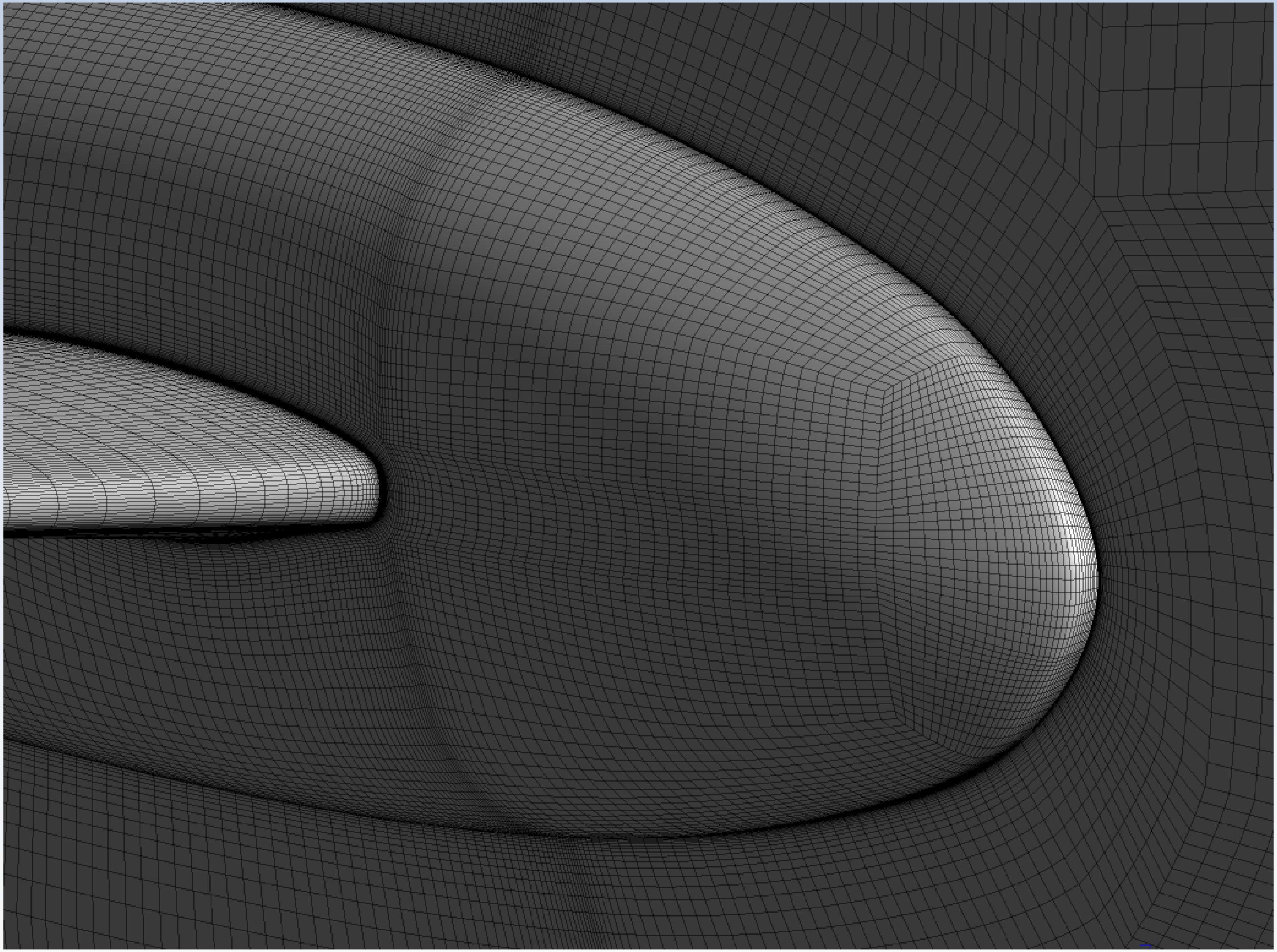

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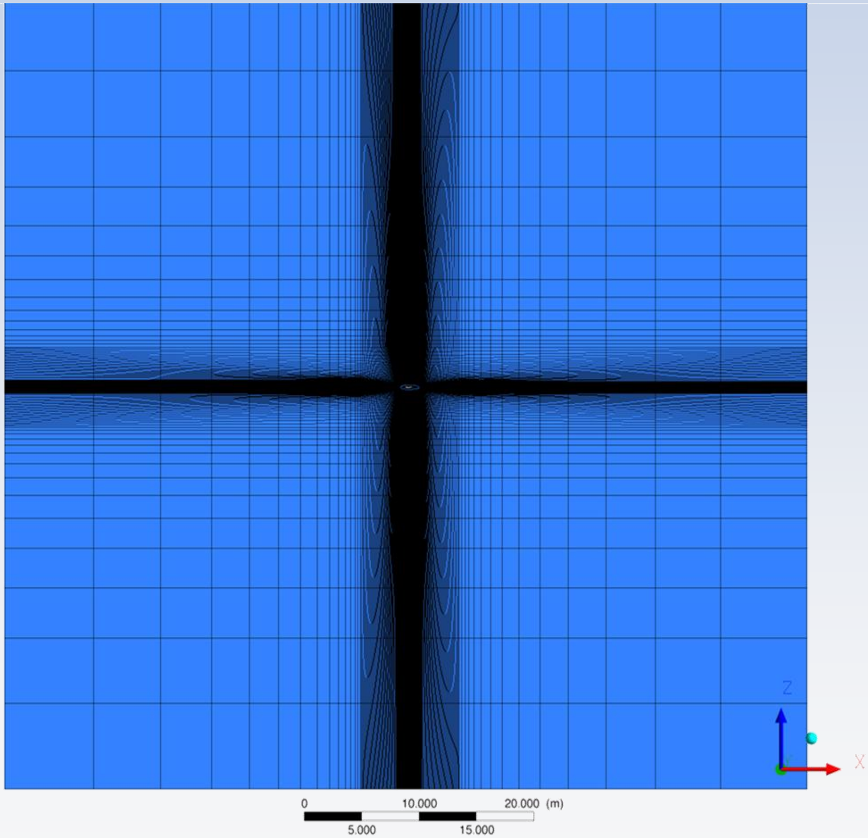
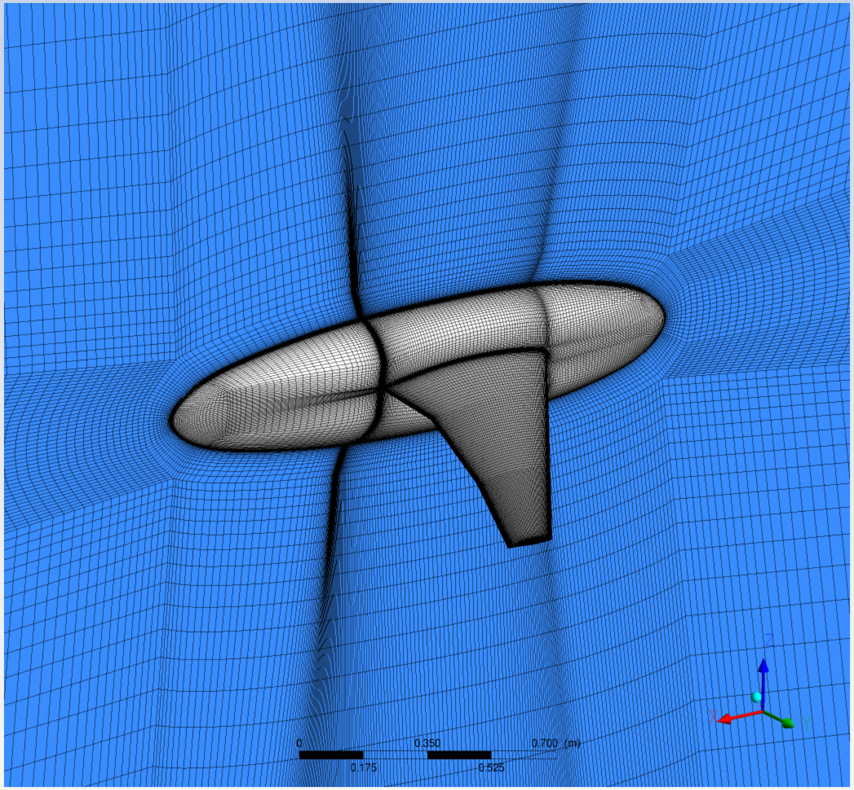
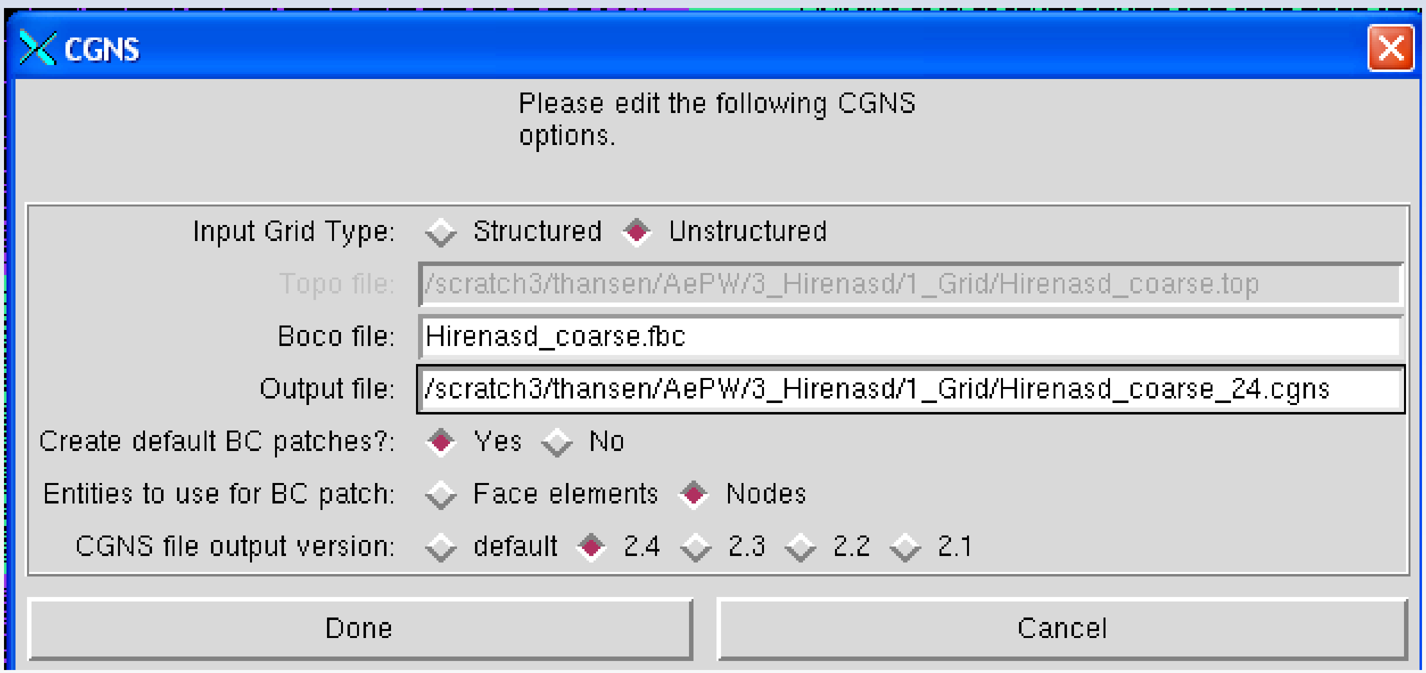




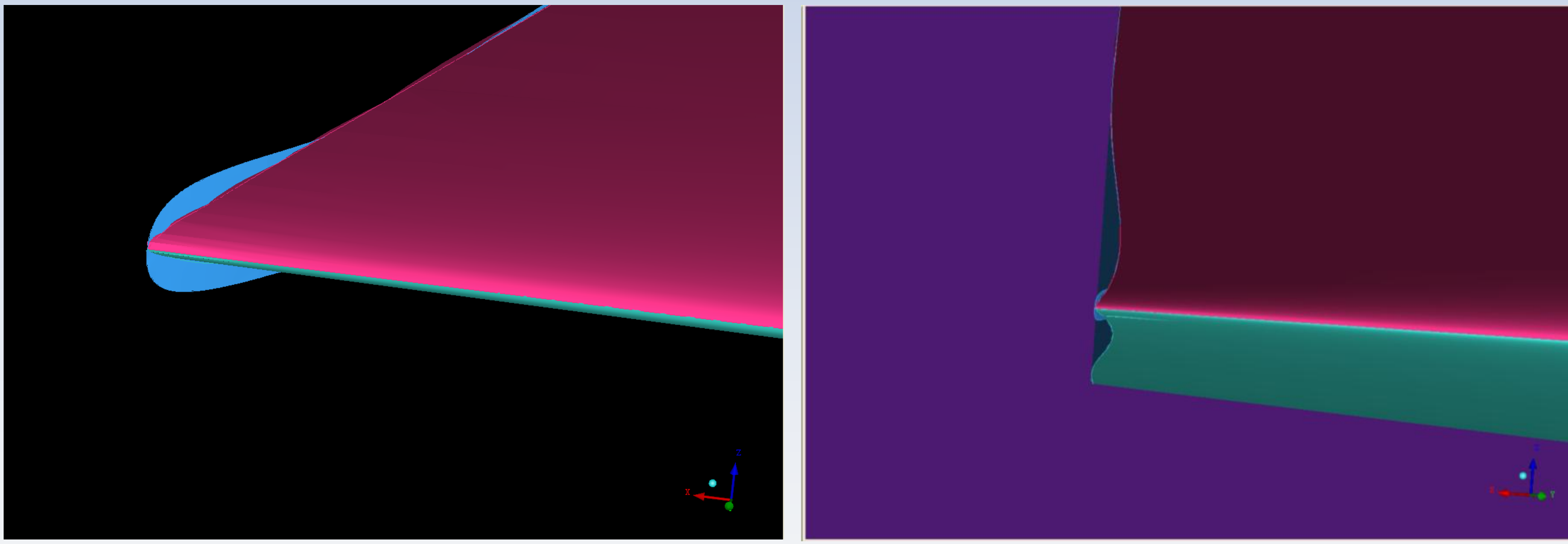
Grid Information

- Output format:
  - Unstructured CGNS
  - Units in m!
  - Double precision format



HIRENASD Geometry

- Surfaces @ Trailing edge!



Status FOI

Mats Dalenbring and Adam Jirasek

First NS analysis

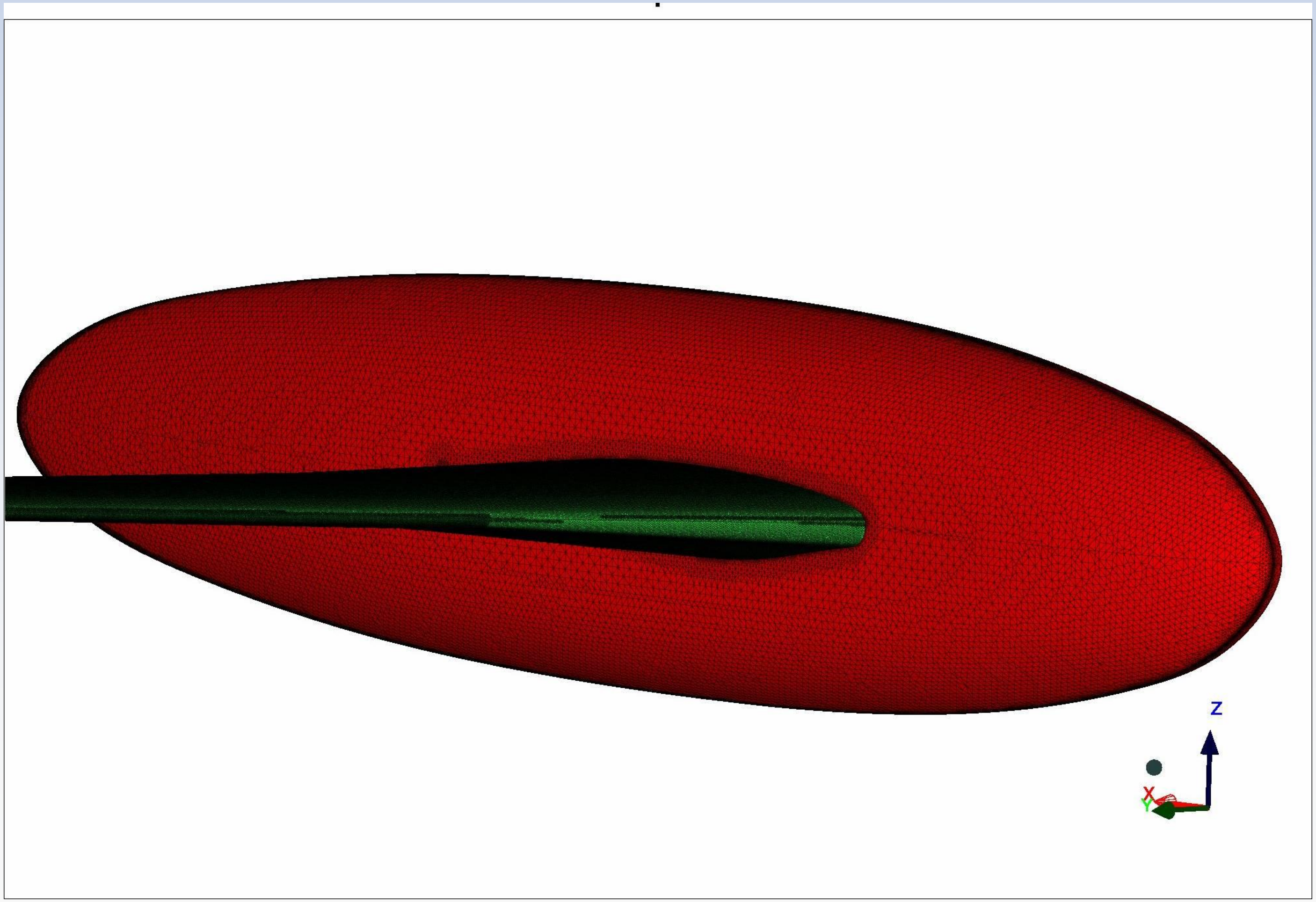
- DLR coarse unstructured mesh
  - M=0.8, a=1.5, ref data as provided by Markus and Pawel
  - Edge code (steady RANS, mltigrid, line implicit)
    - SA model
    - EARSM model

	SA	EARSM
C_L	0.35580325	0.355901772
C_D	0.013656779	0.013072134
C_M	-0.556598453	-0.556491164

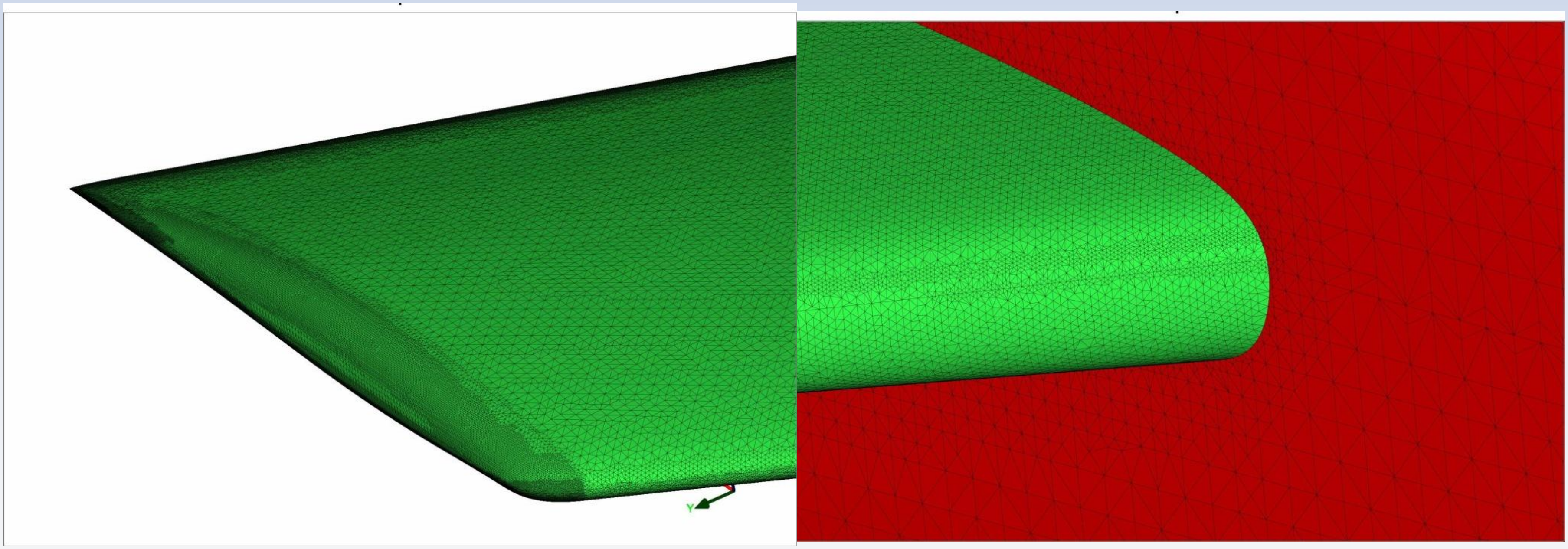
Mesh generation

- IcemCFD + TRITET
  - IcemCFD – baseline inviscid mesh, used as a “background” mesh for TRITET

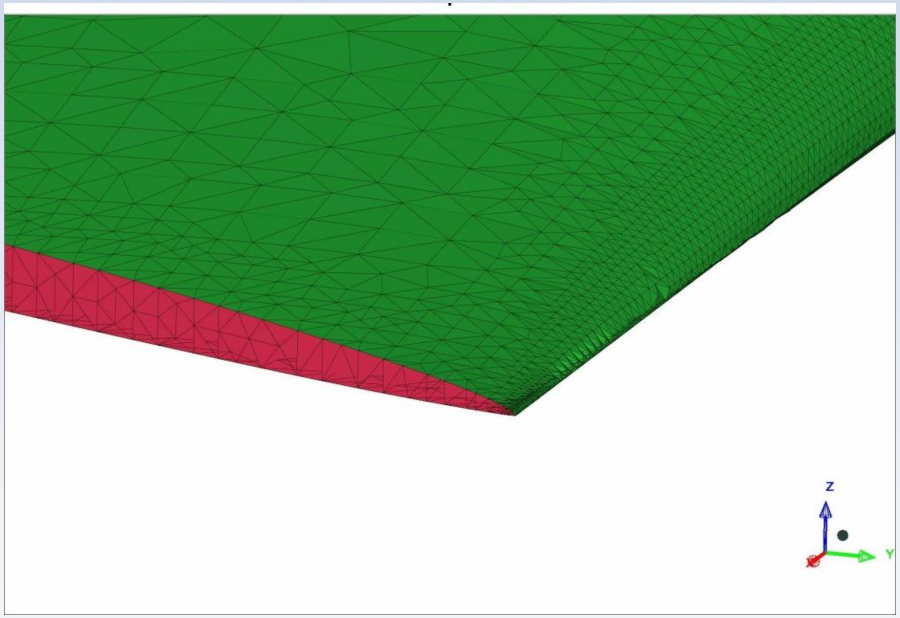
First mesh

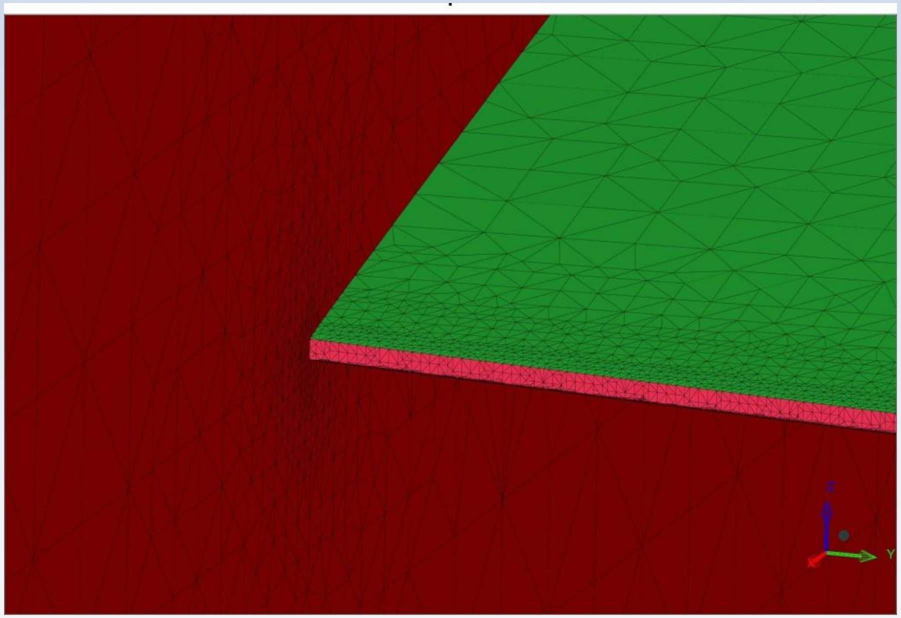


First mesh – details of trailing edge



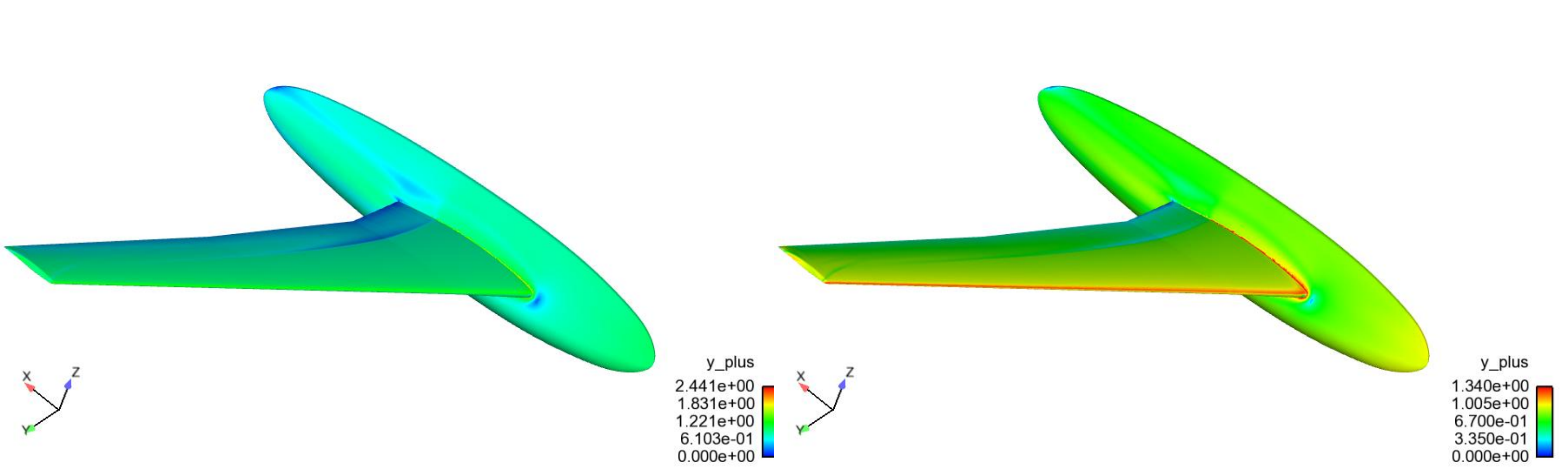
First mesh – details of trailing edge





First mesh

- Maximum y+ around 2.44 – wing-fuselage intersection
  - Y+ on LE larger then 1 too (y_1 = 0.0004mm)

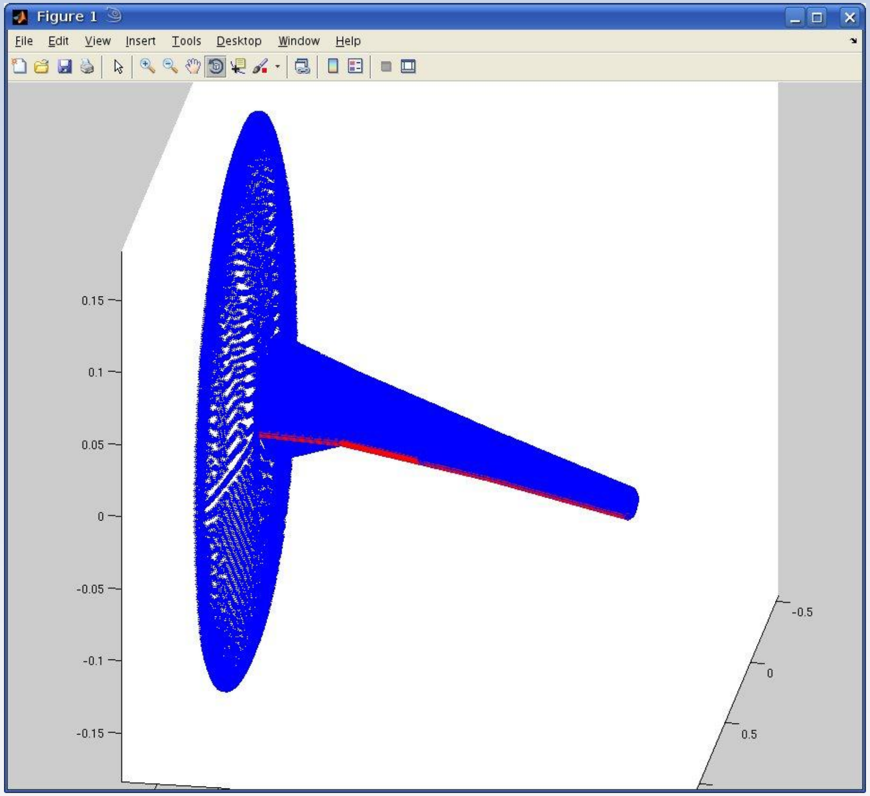


Next mesh

- Better resolution of TE, approx 6 points, can be more
- Improved resolution of LE
- Improved intersection between wing and wing-tip mesh

Interpolated Mode Shapes onto the CFD Mesh

- The number of nodes for the coupling surface, Panels 1-14, sum up to 141496 (Export from CGNS to Edge format)
- The modes from DLR interpolated (NASA) onto the surface mesh sum up to 159841 nodes?



Summary of preliminary results, Re = 23.5M, Mach = 0.8

AoA (deg)	CL	CD	CMy
1.5	0.34918	0.01397	-0.54943
-1.34	-0.00205	0.00506	-0.00827

Medium Overset Grid

AOA	1.5 deg	SA	EARSM
	C_L	0.35580	0.35590
	C_D	0.01366	0.01307
	C_M	-0.55660	-0.55649

Coarse unstructured grid
Centaur, Edge software

AoA = -1.34deg	Coarse grid 5.7 million nodes	Medium grid 16 million nodes
C_L	0.033519	0.033239
C_D	0.009154	0.009181
C_{mx}	0.027913	0.027526
C_{my}	-0.042686	-0.042472
C_{mz}	0.00427	0.004355

Reference point for moment: (0., 0., 0.)
All values without fuselage

AoA = 1.5deg	Coarse grid 5.7 million nodes	Medium grid 16 million nodes
C_L	**0.368418**	**0.371262**
C_D	**0.013735**	**0.013859**
C_{mx}	**0.213967**	**0.215119**
C_{my}	**-0.199340**	**-0.200775**
C_{mz}	**0.011759**	**0.011955**

Reference point for moment: (0., 0., 0.)
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All values without fuselage

Series	Transition	ReC M>=0.8 [Mio]	Tt M=0.8 [K]	Pt M=0.8 [kPa]	q/E M=0.8 [Mio]	Excitation	Nominal Excitation Frequency (HS=Ma0.8) [Hz]	Nominal Alpha M=0.8 [Deg]	Wind-off Excitation Trials [%] 20	40	50	60	20, 40	40, 60	44, 66	80	Mach Number 0.20	0.70	0.75	0.80	0.83	0.85	0.88
0	ON	2.08	276	125	-	ON (1 Power Level)	26.04	-2.00		94		83					100, 102, 103						
		(M=0.2)				ON (1 Power Level)	26.2	-2.00	80, 81	82													
						ON (1 Power Level)	71	-2.00	84														
						ON (1 Power Level)	78	-2.00	85, 86	87, 95		88					104, 105, 106, 107						
						ON (1 Power Level)	263	-2.00	89, 90	91,92, 96,97		93					108, 109, 110, 111						
1	ON	7.0	279	136	0.22	OFF	-	-2.9 to +4.2									128	129	131	132	133	134	135
						ON (2 Power Levels)	26.92	-1.27										138	140	142	146	148	150
						ON (2 Power Levels)	26.92	1.50										139	141	143	147	149	153
						ON (2 Power Levels)	78.9	-1.27										154	156	158	160	162, 163	165
						ON (2 Power Levels)	78.9	1.50										155	157	159	161	164	166
						ON (2 Power Levels)	265.8	-1.27										169	171	173	175	177	179
						ON (2 Power Levels)	265.8	1.50										170	172	174	176	178	180
[illegible]	ON	10.0	295	210	0.34	OFF	-	-2.9 to +4.2										183	186	187	188	189	[illegible]
3	[illegible]	14.0	297	296	0.48	OFF	-	-2.9 to +3.2										194	195	196			
						ON (1 Power Level)	26.04	-2.00	207, 213	208, 214													
						ON (1 Power Level)	26.2	-2.00	209														
						[illegible]	78	-2.00	215	210, 216													
						ON (1 Power Level)	[illegible]	[illegible]	[illegible]	[illegible]													
4	OFF	7.0	279	136	0.22	ON (2 Power Levels)	26.04	-2.00					226	227									
						ON (2 Power Levels)	78	-2.00					228	229									
						ON (2 Power Levels)	263	-2.00					230	231									
						OFF	-	-2.9 to +4.2											234	235			
						OFF	-	-0.03											236	237			
5	OFF	23.5	205	302	0.48	ON (2 Power Levels)	26.04	-2.00							242								
						ON (2 Power Levels)	78	-2.00							243								
						ON (2 Power Levels)	263	-2.00							244								
						OFF	-	-2.0 to +3.0										248	249	250	251	252	253
						ON (2 Power Levels)	28.4	-1.34										256	258	260	262	264	266
						ON (2 Power Levels)	28.4	1.50										257	259	261	263	265	267
7	OFF	35.0	124	218	0.34	ON (1 Power Level)	26.5	-2.00		368													
						ON (1 Power Level)	80.0	-2.00		369													
						ON (1 Power Level)	262.0	-2.00		370													
						OFF	-	-2.9 to +4.2										360	361	362	363	364	365
						ON (1 Power Level)	29.3	-1.33											373	374	375	376	
						ON (1 Power Level)	82.0	-1.33											377	378	379	380	
						ON (1 Power Level)	272.4	-1.33											383	384	385	386	387
						2 x ON (1 Power Level)	272.4	-1.33											388	389		390	
8	OFF	50.0	123	308	0.48	ON (1 Power Level)	26.5	-2.00		400													
						ON (1 Power Level)	80.5	-2.00		401													
						ON (1 Power Level)	273.8	-2.00		403													
						OFF	-	-2.9 to +3.2											393	394	395,396	397	
						ON (1 Power Level)	269	-1.33											406	407	408	409	
						ON (1 Power Level)	OFF	-1.33											412	413	414	415	
9	OFF	73.0	122	449	0.70	ON (1 Power Level)	26.0	-2.00			431												
						ON (1 Power Level)	81.5	-2.00				432											
						ON (1 Power Level)	272.0	-2.00								433							
						OFF	-	-2.9 to +2.2											419	420	421	422	
						2 x ON (1 Power Level)	271.4	-1.32											425	426	427	428	
10	OFF	23.5	162	216	0.34	ON (1 Power Level)	26.4	-2.00			451												
						ON (1 Power Level)	81.3	-2.00				452											
						ON (1 Power Level)	270.9	-2.00								453							
						OFF	-	-2.9 to +4.2										442,443	444	445	446	447	448
						ON (1 Power Level)	29.4	-1.33											456	457	460	461	
						ON (1 Power Level)	29.4	2.50												459		462	
						ON (1 Power Level)	81.4	-1.33											463	464	465	466	
						ON (1 Power Level)	269.0	-1.33											469	470	471	472	
						2 x ON (1 Power Level)	269.0	-1.33											473	474	476	477	
						2 x ON (1 Power Level)	269.0	2.50												475		478	
11	OFF	23.5	205	302	0.48	ON (1 Power Level)	26.25	-2.00			485												
						ON (1 Power Level)	80.25	-2.00				486											
						ON (1 Power Level)	269.9	-2.00								487							
						OFF	-	-2.9 to +3.2												482			
						OFF	-	-1.34											490	491	493	494	
						2 x ON (1 Power Level)	269.2	-1.34											495	496	499	500	
12	OFF	7.0	279	136	0.22	ON (1 Power Level)	26.2	-2.00		507													
						ON (1 Power Level)	79	-2.00		508													
						ON (1 Power Level)	266.8	-2.00		509													
						OFF	-	-0.9 to +8.0											504				

ReC M>=0.8 [Mio]	Tt M=0.8 [K]	Pt M=0.8 [kPa]	q/E M=0.8 [Mio]	Excitation	Nominal Excitation Frequency (HS=Ma0.8) [Hz]	Nominal Alpha M=0.8 [Deg]	Wind-off Excitation Trials [%] 20	40	50	60	20, 40	40, 60	44, 66	80	Mach Number 0.20	0.70	0.75	0.80	0.83	0.85
2.08	276	125	-	ON (1 Power Level)	26.04	-2.00		94		83					100, 102, 103					
(M=0.2)				ON (1 Power Level)	26.2	-2.00	80, 81	82												
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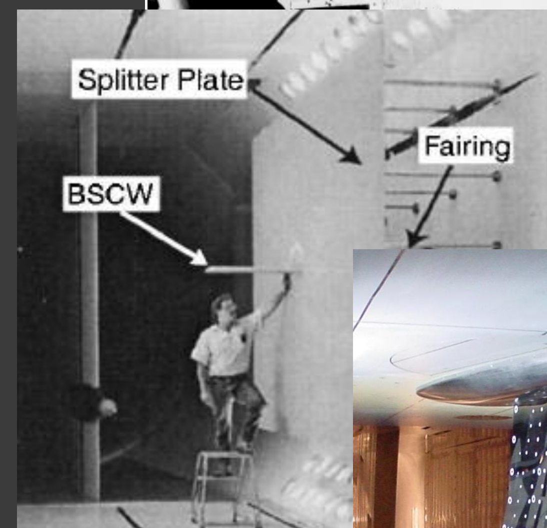
				ON (1 Power Level)	78	-2.00	85, 86	87, 95		88					104, 105, 106, 107					
				ON (1 Power Level)	263	-2.00	89, 90	91,92, 96,97		93					108, 109, 110, 111					
7.0	279	136	0.22	OFF	-	-2.9 to +4.2									128	129	131	132	133	134
				ON (2 Power Levels)	26.92	-1.27										138	140	142	146	148
				ON (2 Power Levels)	26.92	1.50										139	141	143	147	149
				ON (2 Power Levels)	78.9	-1.27										154	156	158	160	162, 163
				ON (2 Power Levels)	78.9	1.50										155	157	159	161	164
				ON (2 Power Levels)	265.8	-1.27										169	171	173	175	177
				ON (2 Power Levels)	265.8	1.50										170	172	174	176	178

Analyst Data Resources Available

- Configurations in detail
  - Model description
  - Test/analysis conditions
  - Known deficiencies
  - Instrumentation
  - Coordinate system definition
  - Excitation for oscillatory cases
  - Structural dynamic information
  - Reference quantities
- Grids
- Structural dynamic model- HIRENASD
- Preliminary analysis results
- Experimental comparison data (except for semi-blind case)

Configurations Selected

- Rectangular Supercritical Wing
- Benchmark Supercritical Wing
- HIRENASD



AePW Dataset Selection

1. Rectangular SuperCritical Wing:
   a) Steady Cases
      i. $M = 0.825$, $\alpha = 2^\circ$ (RTO Case 6E23, TDT pt. 626)
      ii. $M = 0.825$, $\alpha = 4^\circ$ (RTO Case 6E24, TDT pt. 624)

   b) Dynamic Cases
      i. $M = 0.825$, $\alpha = 2^\circ$, $\theta = 1.0^\circ$, $f = 10$ Hz. (RTO Case 6E54, TDT pt. 632)
      ii. $M = 0.825$, $\alpha = 2^\circ$, $\theta = 1.0^\circ$, $f = 20$ Hz. (RTO Case 6E56, TDT pt. 634)

2. Benchmark Supercritical Wing (Semi-Blind)
   a) Steady Case
      i. $M = 0.85$, $\alpha = 5^\circ$
   b) Dynamic Cases
      i. $M = 0.85$, $\alpha = 5^\circ$, $\theta = 1^\circ$, $f = 1$ Hz
      ii. $M = 0.85$, $\alpha = 5^\circ$, $\theta = 1^\circ$, $f = 10$ Hz

3. HIRENASD
   a) Steady (Static Aeroelastic) Cases
      i. Mach 0.80, Re = 7.0 million, $\alpha = 1.5^\circ$, static aeroelastic, (exp. 132).
      ii. Mach 0.80, Re = 23.5 million, $\alpha = -1.34^\circ$, static aeroelastic, (exp. 250).

   b) Dynamic Cases: forced oscillation at 2^{nd} Bending mode frequency
      i. Mach 0.80, Re = 7.0 million, $\alpha = 1.5^\circ$, (exp. 159).
      ii. Mach 0.80, Re = 23.5 million, $\alpha = -1.34^\circ$, (exp. 271).

Gridding Guidelines for 1st AePW (AePW1)

For the current workshop, a sequence of coarse, medium and fine grids are required for each configuration and the guidelines can be summarized as follows:

1. RSW initial spacing normal to all viscous walls (Re = 4M based on C_{ref} = 24")
   a. Coarse: $y^+ \sim 1.0$, dy = 0.000158"
   b. Medium: $y^+ \sim 2/3$, dy = 0.000105"
   c. Fine: $y^+ \sim 4/9$, dy = 0.000070"

2. BSCW initial spacing normal to all walls (Re = 4.5M based on C_{ref} = 16")
   a. Coarse: $y^+ \sim 1.0$, dy = 0.000094"
   b. Medium: $y^+ \sim 2/3$, dy = 0.000063"
   c. Fine: $y^+ \sim 4/9$, dy = 0.000042"

3. HIRENASD wing initial spacing normal to all walls (Re = 23.5M based on C_{ref} = 0.3445 meter) Note: Same grids to be used for Re = 7M and Re = 23.5M cases.
   a. Coarse: $y^+ \sim 1.0$, dy = 4.40961e-7 meter
   b. Medium: $y^+ \sim 2/3$, dy = 2.93973e-7 meter
   c. Fine: $y^+ \sim 4/9$, dy = 1.95982e-7 meter

4. Normal growth rate for cells in boundary layer region < 1.25
5. Structured grids will have at least 2 cell layers of constant spacing normal to viscous walls.
6. Farfield will be located at ~100 c_{ref} for all grids.
7. Local spacings on medium grid:
   a. Chordwise spacing for wing leading and trailing edges ~0.1% local chord
   b. Wing spanwise spacing at root and at tip ~0.1% local semispan
   c. Cell size near fuselage nose and aftbody ~2% c_{ref}
8. Wing trailing edge: minimum 4, 6 and 9 cells for coarse, medium and fine grids, respectively.
9. Grid family:
   a. Medium mesh representative of current engineering practice
   b. Maintain a parametric family of uniformly refined grids in sequence
   c. Grid size to grow ~3X for each level of refinement [Structured 1.5X in I,J,K directions]
   d. Give consideration to multigridable dimensions on structured meshes
   e. Sample sizes: Coarse: 3M, Medium: 10M, Fine 30M

dy refers to the normal spacing of the first cell at the viscous wall. Special effort is required to ensure that sequences of coarse, medium and fine meshes constitute a consistent "family" of grids suitable for a grid convergence study. This entails the preservation of mesh topology, stretching factors, and local variations in resolution as much as possible between grids of the same sequence. The mesh spacing specifications given for the medium grid are to be scaled appropriately for the coarse and fine grids. The given grid sizes are only estimates based on the objective that the medium grid should be representative of current engineering practice enabling a solution on mid-range computational hardware in reasonable turnaround time (i.e. considerably less than 24 hours). For unstructured grids designed for vertex-based solvers, the spacing refers to inter-nodal spacing and the resulting grid sizes are expected to be similar to the structured grid sizes. For unstructured grids for cell-centered solvers, the spacing refers to spacing between cell centers (or surface face centers), which corresponds approximately to a factor of 2 reduction in the overall number of surface points compared to the nodal solver case, for a triangular surface grid. For tetrahedral cell-centered solver mesh, the total number of grid points will be approximately 1/3 of the node based solver mesh.

Summary of AePW Grids

Configuration	GRID TYPE																							
	Unstructured												Structured			Overset		
	Node Based						Cell Centered						Hex Multiblock					
	Mixed			Tetrahedra			Mixed			Tetrahedra								
	C	M	F	C	M	F	C	M	F	C	M	F	C	M	F	C	M	F
RSW	√	√	√	√	√	√	○	○	○				√					
BSCW	⊙	⊙	⊙				○	○	○				○	○	○			
HIRENASD	√	√	√				○	○	○				√			√		

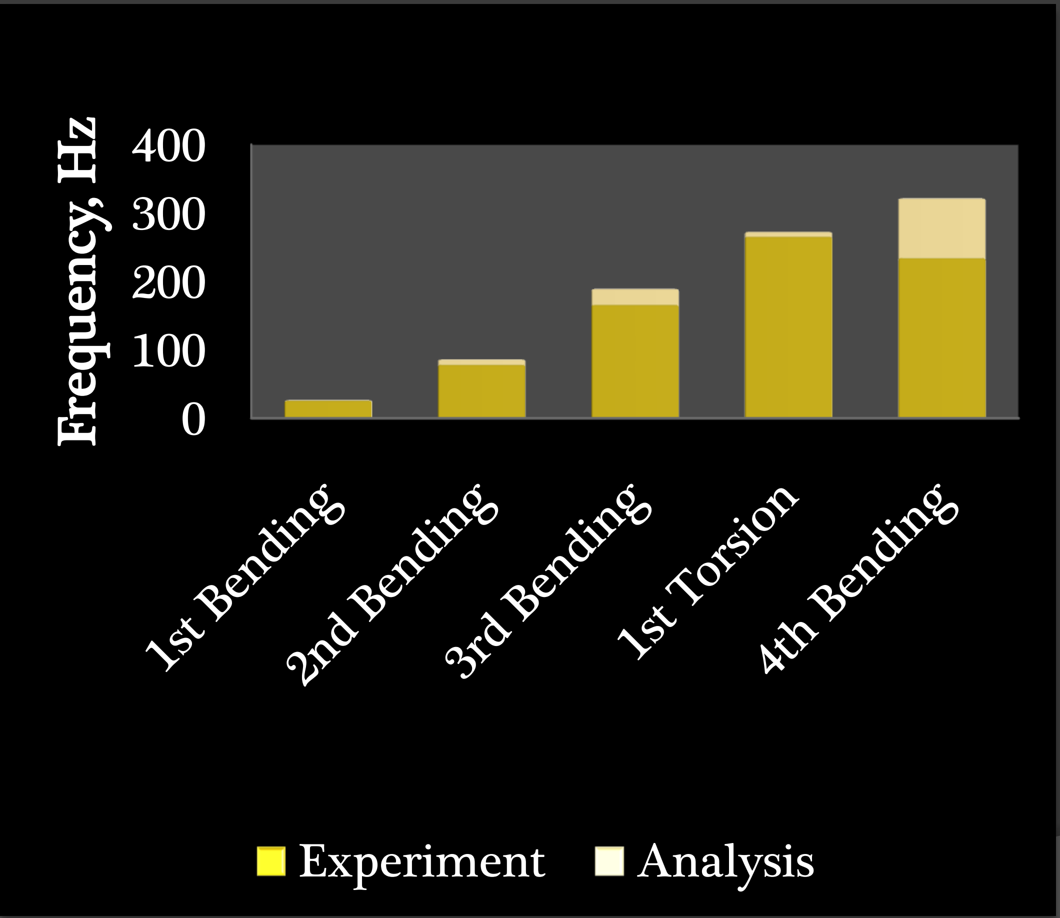
√ = Complete

⊙ = In process

○ = Desired

Plan of action for structural dynamic model

- Use analytical mode shapes
- Use experimental frequencies for
  1st 4 Bending modes & 1st Torsion
- Use analytical frequencies for additional 5 modes



Mode #	Description	Analytical Frequency (Hz)	Experimental Frequency (Hz)
1	1st Bending	26.54	26
2	2nd Bending	86.02	78.6
3	1st Fore-Aft	156.94	
4	3rd Bending	189.31	166.2
5	1st Torsion	272.86	265.8
6	4th Bending	321.77	234.6
7	2nd Fore-Aft	422.98	
8	2nd Torsion	450.51	
9	5th Bending	496.68	
10	3rd Torsion	622.41	

Analysis Condition Parameters

Parameters		Units		Configuration			
		English	SI	RSW (English units)	BSCW (English units)	HIRENASD (SI units)	HIRENASD (SI units)
Mach number	M			0.826	0.848	0.8003	0.8
Reynolds number (based on ref chord)	Re_c			4.01E+06	4.49E+06	7001020	23483300
Dynamic pressure	q	psf		108.65	204.20		
Velocity	V	ft/s	m/s	413.73	468.98	257.02	220.44
Speed of sound	a	ft/s		501.18	552.93		
Static temperature	Tstat	deg F	Deg K	37.12	87.91	248.2	182.776
Density		slug/ft^3	kg/m^3	0.001270	0.001857	1.2001	3.628
Ratio of specific heats				1.132	1.116		
Dynamic viscosity		slug/ft-s		2.620E-07	2.590E-07		
Prandtl number	Pr			0.78	0.67	0.72	0.72
Test medium				R-12	R-134a	Nitrogen	Nitrogen
Total pressure	H	psf		410.48	757.31		
Static pressure	P	psf	Pa	280.76	512.12	88460.7	196816.89
Purity	X	%			95		
Total temperature	T	deg F		60.00	109.59		

Reference quantities

		RSW	BSCW	HIRENASD
Reference chord	c_{ref}	24 inches	16 inches	0.3445 m
Model span	b	48 inches	32 inches	1.28571 m
Area	A	1152 in^2	512 in^2	0.3926 m^2
Moment reference point, relative to axis system defns	x	11.04 inches	4.8 inches	0.252 m
	y	0	0	-0.610 m
	z	0	0	0
Transfer function reference quantity		Pitch angle	Pitch angle	Vertical displacement (at x=1.24521m, y=0.87303m)

Comparison Data Matrix

CONFIGURATION	REQUIRED CALCULATIONS		
	GRID CONVERGENCE STUDIES	STEADY CALCULATIONS	DYNAMIC CALCULATIONS
Steady-Rigid Cases (RSW, BSCW)	C_L, C_D, C_M vs. N-2/3	• Mean Cp vs. x/c • Means of C_L, C_D, C_M	
Static-Aeroelastic Cases (HIRENASD)	C_L, C_D, C_M vs. $N^{-2/3}$	• Mean C_p vs. x/c • Vertical displacement vs. x/c • Twist angle vs. x/c • Means of C_L, C_D, C_M	
Forced Oscillation Cases (all configurations)	TBD		• Magnitude and Phase of C_p vs. x/c at span stations corresponding to transducer locations • Magnitude and Phase of C_L, C_D, C_M at excitation frequency • Time history of Cp at each span station for 3 pressure transducer locations

An ascii template will be provided for submission of data

Workshop participant submittals

- No formal AIAA papers
- Presentation & data submission only
- Requires 1 page letter of intent or abstract

MRL and USF Contribution to AePW - 1

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Soar N. Air†
University of Southern Flight, Mail Code 98765, Lofty Heights, TX 00000
email: s.n.air@usf.edu, (888) 888-8888

We intend to participate in the AePW-1, to be held April 21-22 2012 in Honolulu, HI. We plan to perform the following sets of computations:

1. Configuration 1 – RSW , Steady Case, i. M=.825, α=2 deg
   - Code: RANS-CFD-3D
   - Grid: Str-OnetoOne-C-v1 (supplied by AePW-1 committee)
   - Turbulence model: Menter SST
2. Configuration 1 – RSW , Unsteady Case, i. M=.825, α=2 deg, 10 Hz
   Same as above
3. Configuration 2 – BSCW, Steady case, M=.85, α=5 deg, 10 Hz
   Same as above
4. Configuration 2 – BSCW, Unteady case, M=.85, α=5 deg, 20 Hz
   Same as above
5. Configuration 3 - HIRENASD Configuration, steady, M=.8, Re=7 million, α =1.5 deg
   - Code: RANS-CFD-3DAe
   - Grid: Str-OnetoOne-C-v1 (supplied by AePW-1 committee)
   - Turbulence model: S-A

We plan to submit our results electronically by the March 20, 2012 deadline to the AePW-1 committee.

RANS-CFD-3DAe is a Reynolds-averaged Navier-Stokes code developed by Et et al.,[1] widely used at the Multielement Research Lab. It is specifically formulated to work on three-element wing configurations. It uses point-matched grids, and is an upwind finite-volume structured code.
LES-CFD-3D is a large-eddy simulation code developed at the University of Southern Flight.[2] It employs 6th order central differencing in space and 3rd order temporal differencing, along with 9th order explicit filtering.

References

1 Et, H., Cet, P., and Era L., "Description of RANS-CFD-3D," Journal of Codes, Vol. 6, No. 5, 1994, pp. 5–21.
2 Author, A. and Author B., "Description of LES-CFD-3D," Journal of Lengthy Papers, Vol. 9, No. 2, 2008, pp. 22–1021.

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† Professor and Chair, Dept. of Aeronautical Engineering.

Information follows for reference during the panel discussion

RSW

Rectangular Supercritical Wing (RSW)

- Simple, rectangular wing
- Static and forced oscillation pitching motion about the 46% chord
- Treated here as rigid

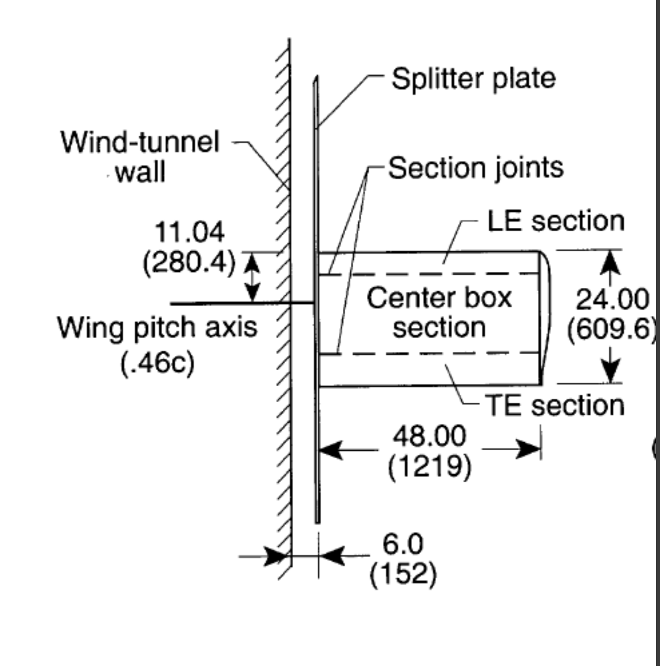
<u>Known deficiencies:</u>

- Splitter plate deficiencies
  - Small size
  - Located in the tunnel wall boundary layer
    - 6” off of the wall
    - Estimated boundary layer thickness: 12”
- Tunnel wall slots open

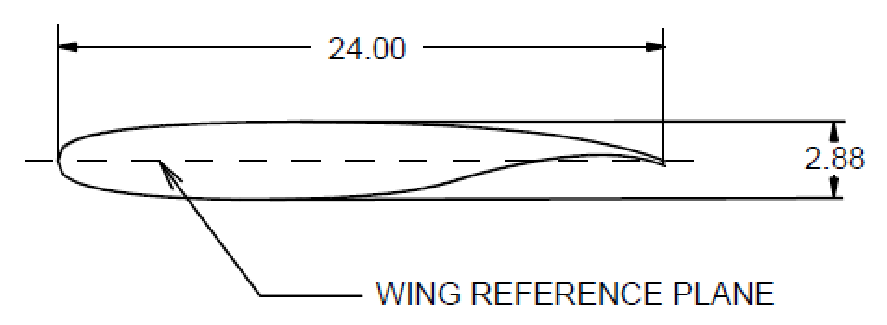
M=0.825, Re_c=4.0 million, test medium: R-12

a) Steady Cases
   i. $\alpha = 2°$
   ii. $\alpha = 4°$
b) Dynamic Cases
   i. $\alpha = 2°$, $\theta = 1.0°$, f = 10 Hz
   ii. $\alpha = 2°$, $\theta = 1.0°$, f = 20 Hz

RSW Model Layout and Airfoil



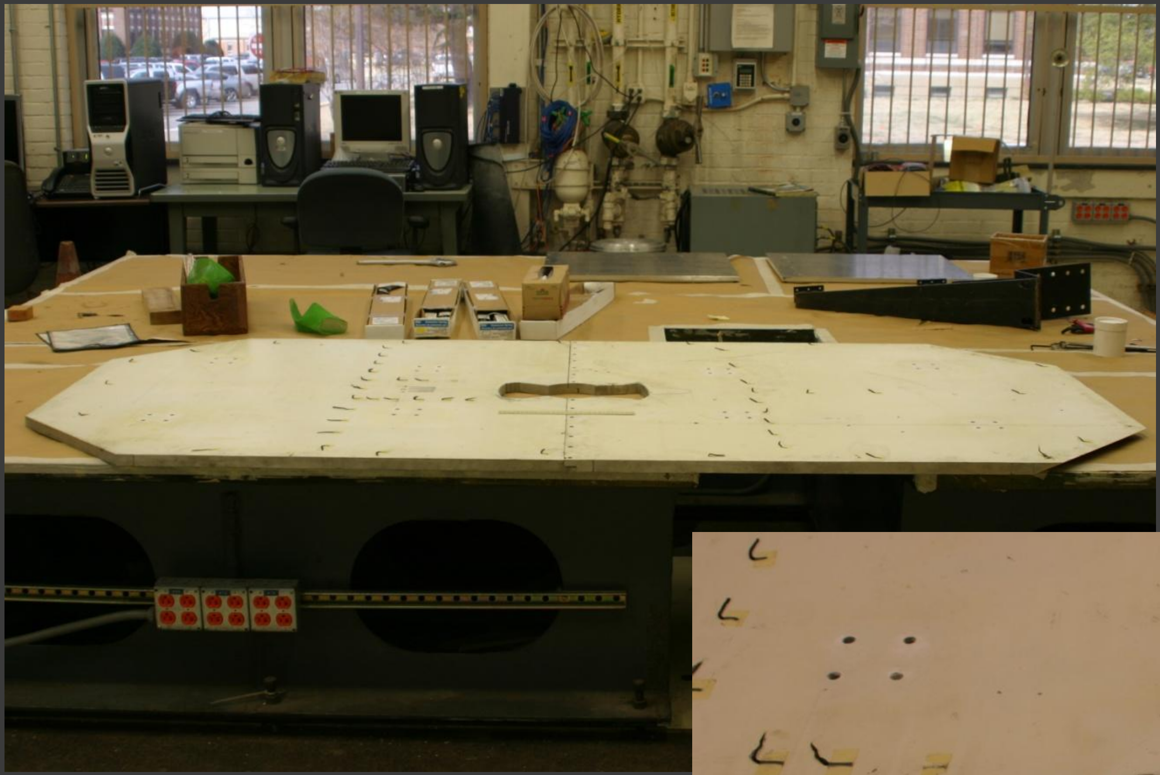
Shown as mounted in the wind tunnel
Oscillated in pitch about the 46% chord
All units in inches



12% thick supercritical airfoil

Experimental data acquired in R-12 @ Re_c = 4 million, Mach=0.825

RSW Model Layout and Airfoil



Known deficiencies:

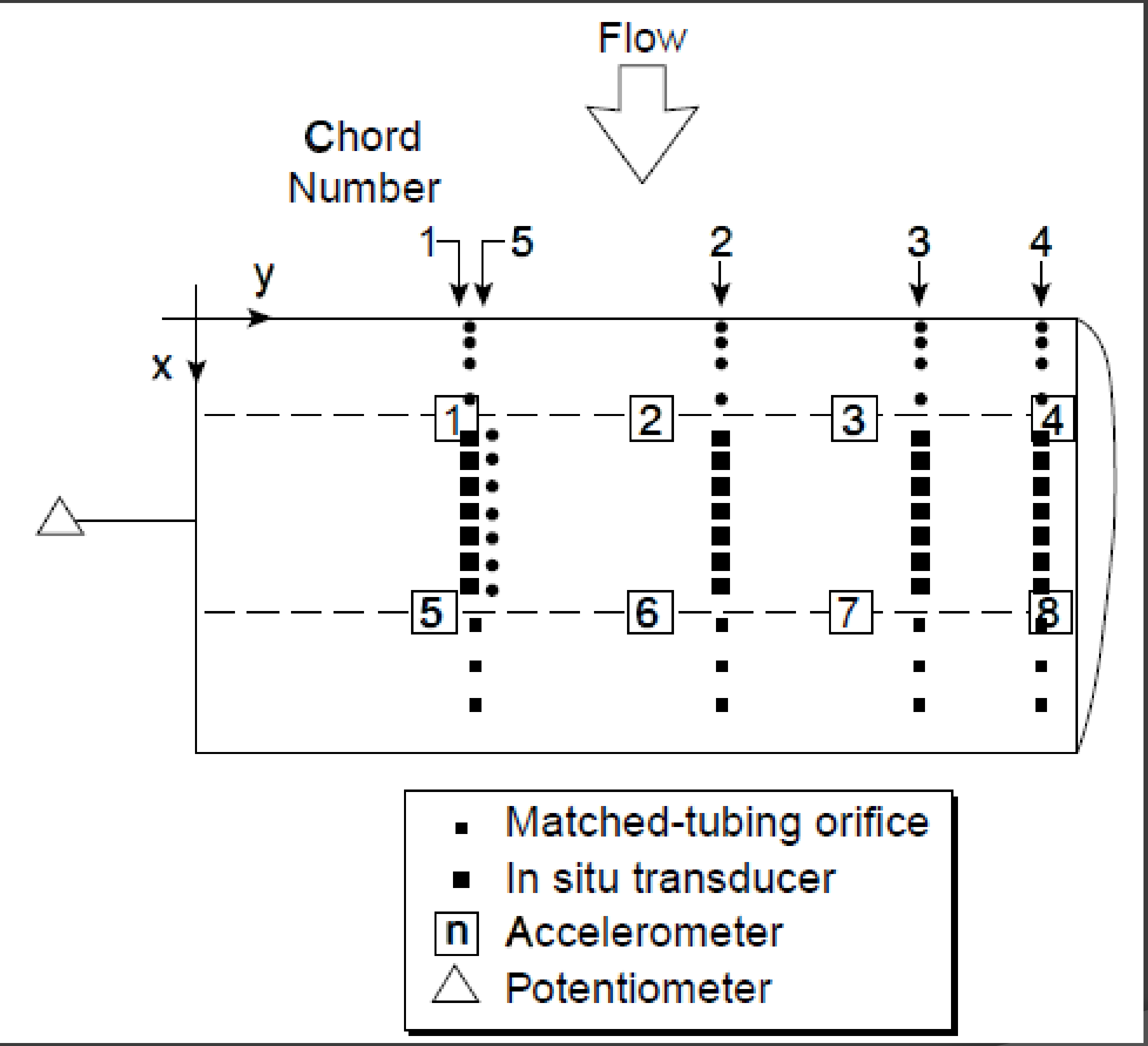
Splitter plate deficiencies

- Small size
- Located in the tunnel wall boundary layer
  - 6" off of the wall
  - Estimated boundary layer thickness: 12"

RSW Data

- Only data with fixed BL trip (6% chord) considered due to transition effects.
- Mach 0.825 is target Mach number since it is off-design for the airfoil and exhibits transonic nonlinearity.
  - Steady case 1a matches mean AOA for dynamic cases
  - Steady case 1b is most extreme Mach/AOA combination available (static stress case)
  - Two dynamic cases chosen to demonstrate ability of methods to properly capture frequency effects.
- All data acquired in R-12 @ $Re_c = 4$ million
- 4 chords of data each with a total of 29 pressure measurements (14Upper, 14 Lower)
  - 30.9, 58.8, 80.9, and 95.1 percent span.
  - Static data: Mean Cp
  - Forced Oscillation Data: Real and Imaginary Cp/Θ.

RSW: Coordinate system, Instrumentation



Unsteady Pressure Measurements

4 chords

(30.9, 58.8, 80.9, and 95.1 % span)

29 pressure per chord

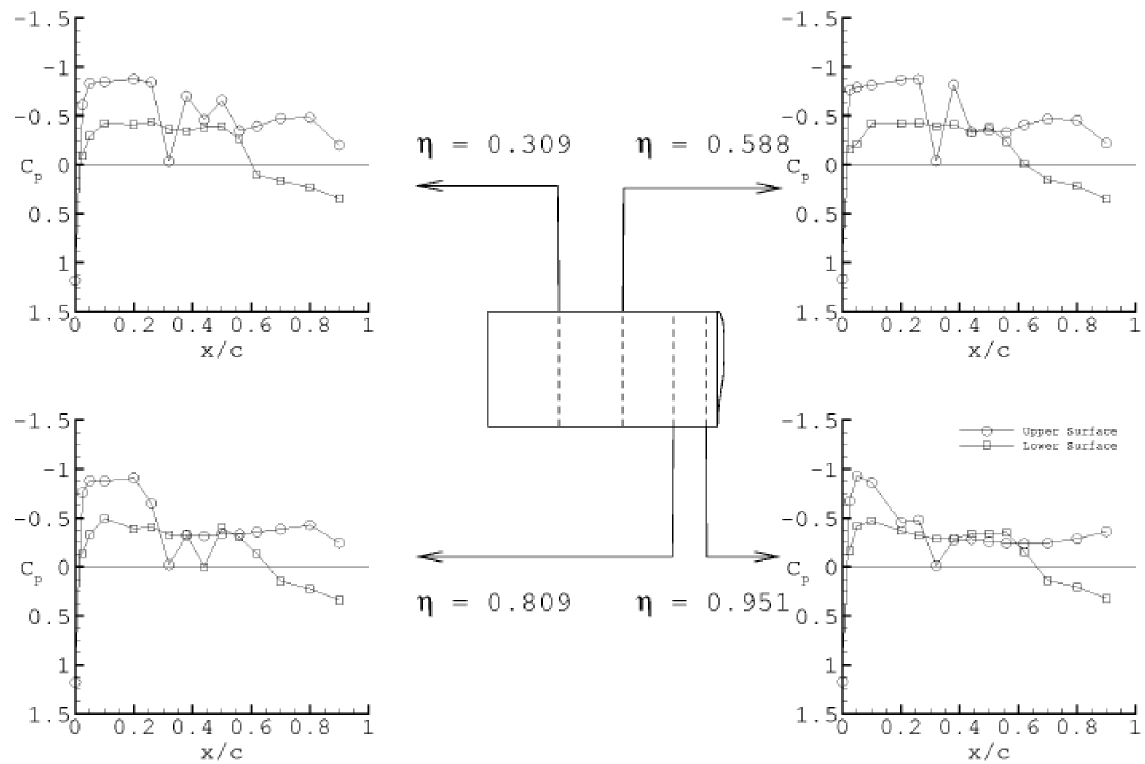
(14Upper, 14 Lower)

Case 1a

Point Number = 626 Mach Number = 0.825 Alphao = 2.00, deg.

q	H	V	Rn	gamma	Cp*
108.5	410.1	413.4	.401E+07	1.132	-0.409

	y/s =0.309		y/s =0.588		y/s =0.809		y/s =0.951	
x/c	Cpu	Cpl	Cpu	Cpl	Cpu	Cpl	Cpu	Cpl
.000	1.184		1.171		1.180		1.173	
.025	-0.616	-0.092	-0.768	-0.160	-0.761	-0.136	-0.675	-0.165
.050	-0.834	-0.295	-0.793	-0.213	-0.883	-0.333	-0.928	-0.419
.100	-0.849	-0.424	-0.814	-0.424	-0.877	-0.494	-0.862	-0.468
.200	-0.875	-0.409	-0.868	-0.420	-0.908	-0.389	-0.456	-0.370
.260	-0.841	-0.438	-0.873	-0.429	-0.649	-0.407	-0.479	-0.321
.320	-0.036	-0.365	-0.040	-0.391	-0.020	-0.329	-0.014	-0.287
.380	-0.703	-0.344	-0.817	-0.413	-0.325	-0.331	-0.278	-0.289
.440	-0.460	-0.384	-0.336	-0.327	-0.314	-0.001	-0.283	-0.337
.500	-0.659	-0.393	-0.353	-0.381	-0.335	-0.398	-0.258	-0.338
.560	-0.347	-0.265	-0.333	-0.236	-0.332	-0.302	-0.244	-0.352
.620	-0.393	0.103	-0.409	-0.009	-0.358	-0.134	-0.238	-0.153
.700	-0.476	0.164	-0.466	0.153	-0.382	0.144	-0.244	0.138
.800	-0.483	0.231	-0.456	0.218	-0.428	0.225	-0.288	0.204
.900	-0.201	0.342	-0.220	0.349	-0.248	0.339	-0.361	0.322

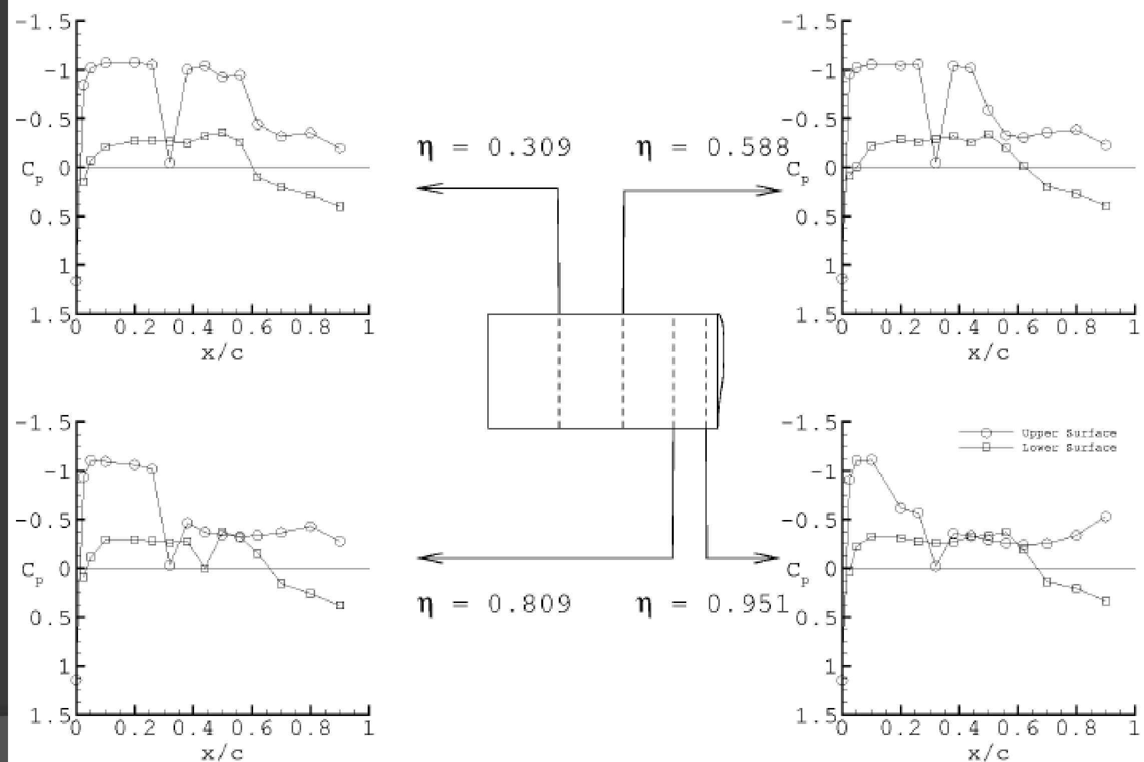


Case 1b

Point Number = 624   Mach Number = 0.826   Alphao = 4.01, deg.

q	H	V	Rn	gamma	Cp*
108.5	409.8	413.7	.401E+07	1.132	-0.406

	y/s =0.309		y/s =0.588		y/s =0.809		y/s =0.951	
x/c	Cpu	Cpl	Cpu	Cpl	Cpu	Cpl	Cpu	Cpl
.000	1.164		1.139		1.146		1.150	
.025	-0.841	0.144	-0.956	0.088	-0.934	0.092	-0.904	0.028
.050	-1.024	-0.073	-1.028	-0.005	-1.108	-0.115	-1.108	-0.227
.100	-1.072	-0.213	-1.057	-0.223	-1.096	-0.290	-1.115	-0.327
.200	-1.078	-0.274	-1.046	-0.289	-1.065	-0.290	-0.620	-0.312
.260	-1.054	-0.277	-1.060	-0.260	-1.019	-0.277	-0.568	-0.272
.320	-0.048	-0.268	-0.048	-0.293	-0.034	-0.262	-0.020	-0.260
.380	-1.005	-0.250	-1.044	-0.320	-0.463	-0.274	-0.356	-0.266
.440	-1.045	-0.323	-1.021	-0.256	-0.368	-0.001	-0.333	-0.326
.500	-0.925	-0.354	-0.590	-0.342	-0.343	-0.374	-0.286	-0.335
.560	-0.950	-0.263	-0.331	-0.201	-0.323	-0.318	-0.258	-0.369
.620	-0.442	0.101	-0.308	-0.013	-0.336	-0.157	-0.241	-0.189
.700	-0.317	0.200	-0.358	0.191	-0.365	0.156	-0.251	0.138
.800	-0.351	0.284	-0.384	0.268	-0.428	0.260	-0.337	0.205
.900	-0.199	0.400	-0.233	0.393	-0.277	0.379	-0.528	0.334



Case 2a

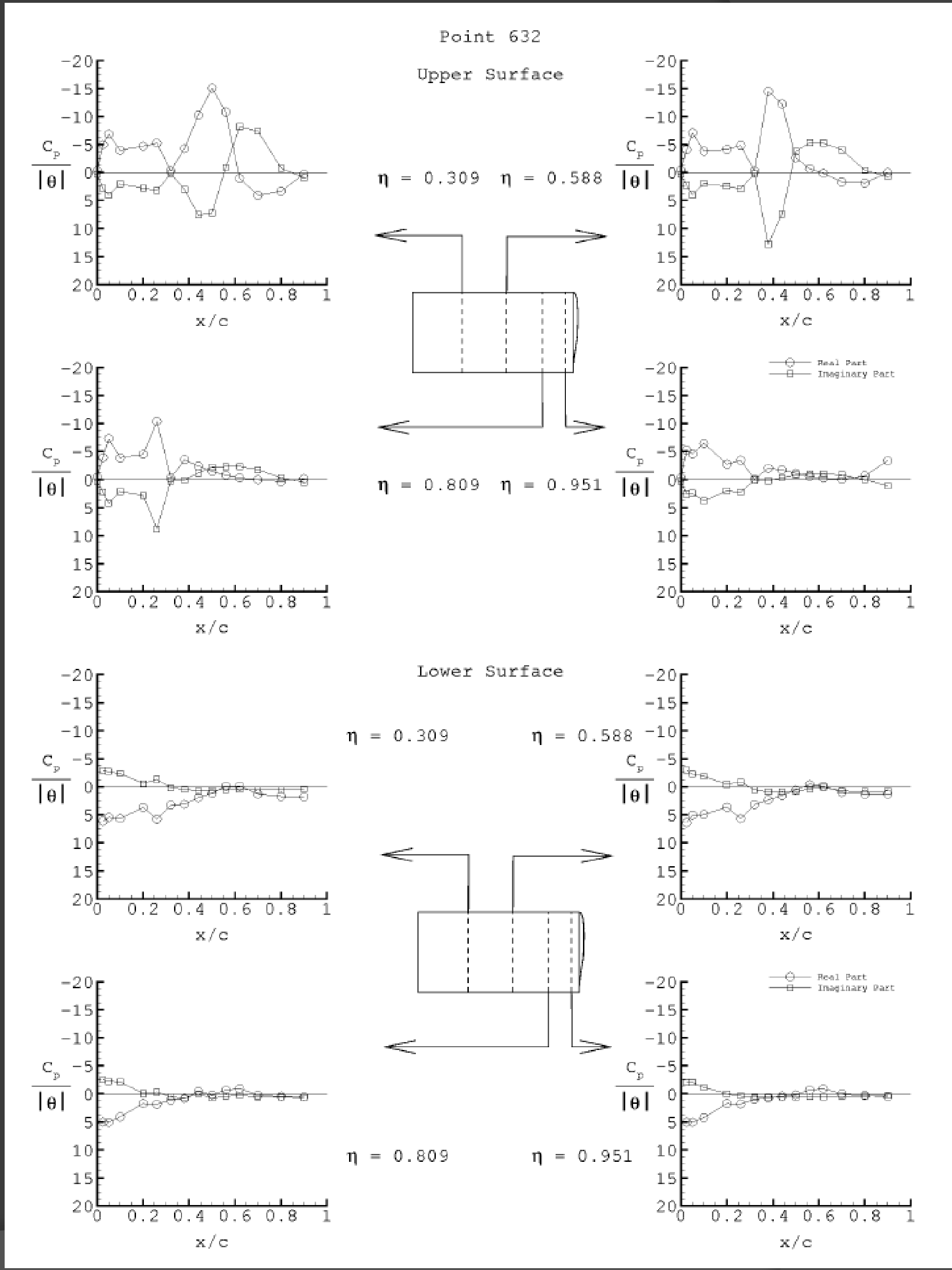
Point Number = 632 Mach Number = 0.825 Alphao = 1.98, deg.

q,psf	H,psf	V,fps	Rn	gamma	freq,Hz	k	theta,deg
108.7	410.9	413.7	.401E+07	1.132	10.03	0.152	1.014

	y/s = 0.309				y/s = 0.588			
x/c	ReCpu/t	ImCpu/t	ReCpl/t	ImCpl/t	ReCpu/t	ImCpu/t	ReCpl/t	ImCpl/t
.000	-0.315	0.324			-0.424	0.374		
.025	-4.957	2.828	6.145	-2.866	-4.078	2.317	6.412	-2.963
.050	-6.858	4.056	5.476	-2.694	-7.082	4.007	5.059	-2.252
.100	-3.974	2.033	5.694	-2.347	-3.826	1.950	4.975	-1.860
.200	-4.708	2.806	3.684	-0.577	-4.134	2.445	3.648	-0.429
.260	-5.251	3.218	5.786	-1.314	-4.838	2.919	5.702	-0.842
.320	-0.277	0.196	3.272	0.194	-0.269	0.206	3.176	0.537
.380	-4.289	3.037	3.133	0.446	-14.473	12.805	2.371	0.920
.440	-10.220	7.562	1.948	0.759	-12.228	7.406	1.560	0.915
.500	-15.071	7.253	1.172	0.682	-2.619	-3.754	0.566	0.912
.560	-10.809	-0.927	-0.083	0.502	-0.710	-5.321	-0.404	0.395
.620	1.063	-8.181	-0.111	0.496	0.138	-5.253	-0.095	0.140
.700	4.069	-7.371	1.297	0.559	1.694	-4.069	0.991	0.750
.800	3.353	-0.799	1.725	0.541	1.879	-0.399	1.340	0.841
.900	0.303	0.911	1.822	0.397	0.003	0.735	1.324	0.758

	y/s = 0.809				y/s = 0.951			
x/c	ReCpu/t	ImCpu/t	ReCpl/t	ImCpl/t	ReCpu/t	ImCpu/t	ReCpl/t	ImCpl/t
.000	-0.459	0.329			-0.311	0.245		
.025	-3.938	2.219	5.071	-2.509	-5.264	2.613	5.078	-2.062
.050	-7.291	4.210	5.096	-2.226	-4.581	2.457	5.085	-2.044
.100	-3.881	2.089	4.128	-2.157	-6.482	3.803	4.251	-1.163
.200	-4.509	2.807	1.751	-0.054	-2.760	1.969	1.752	0.015
.260	-10.386	8.808	1.861	-0.310	-3.463	2.241	1.827	0.375
.320	-0.277	0.195	1.134	0.535	-0.107	0.036	0.994	0.648
.380	-3.559	0.062	0.846	0.777	-2.025	0.191	0.758	0.590
.440	-2.438	-1.189	-0.448	0.000	-1.716	-0.349	0.420	0.602
.500	-1.470	-2.212	0.199	0.803	-1.133	-0.844	0.185	0.593
.560	-0.807	-2.292	-0.646	0.439	-0.609	-1.018	-0.688	0.495
.620	-0.318	-2.352	-0.961	0.277	-0.278	-1.037	-0.905	0.577
.700	0.028	-1.751	0.292	0.560	-0.053	-0.846	0.029	0.451
.800	0.380	-0.338	0.435	0.585	-0.678	-0.015	0.283	0.423
.900	-0.195	0.470	0.530	0.709	-3.380	1.118	0.549	0.292

Case 2a (Cont'd)



Case 2b

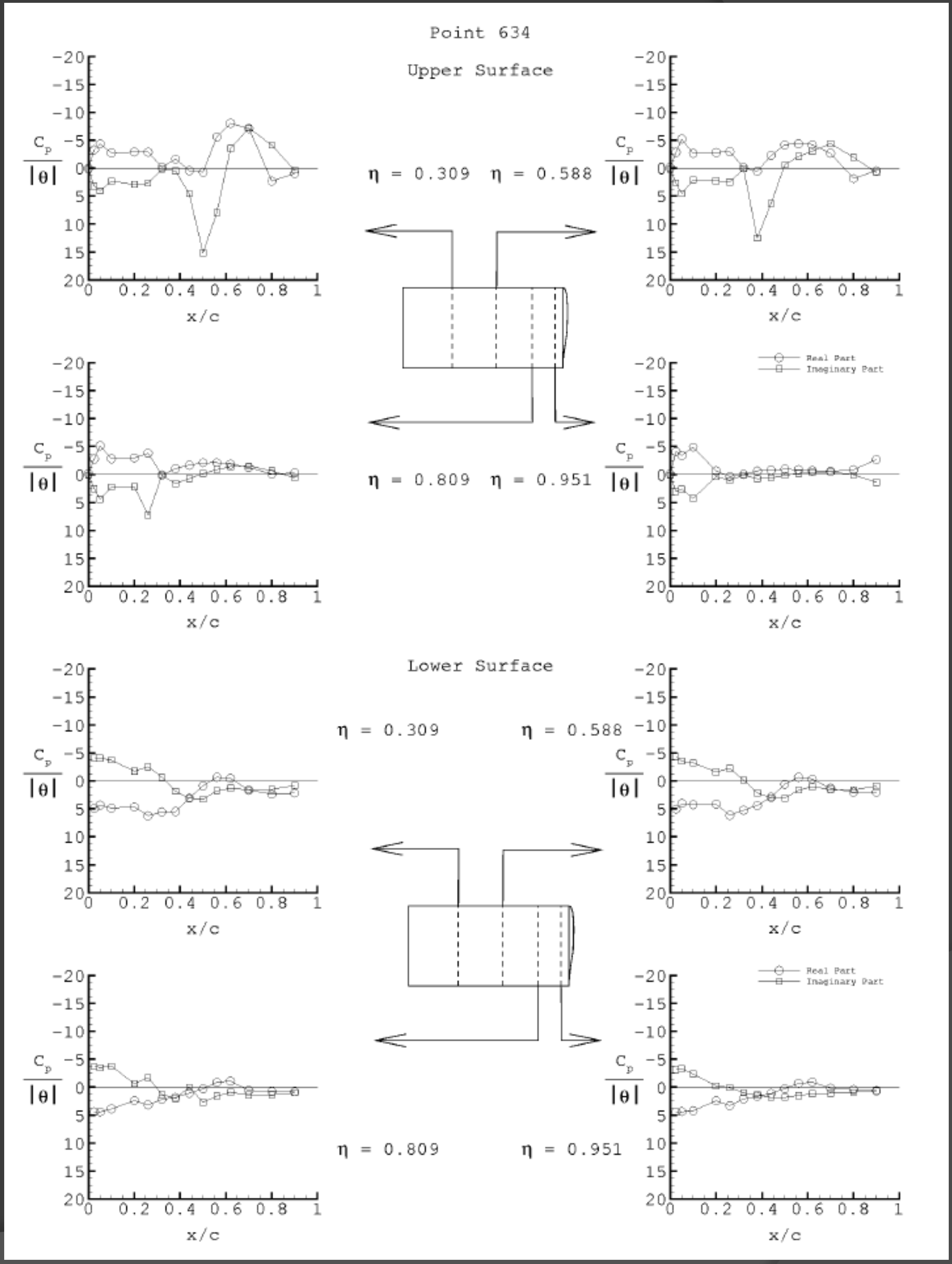
Point Number = 634 Mach Number = 0.826 Alphao = 1.98, deg.

q,psf	H,psf	V,fps	Rn	gamma	freq,Hz	k	theta,deg
108.9	411.1	414.1	.401E+07	1.132	20.09	0.305	1.005

	y/s = 0.309				y/s = 0.588			
x/c	ReCpu/t	ImCpu/t	ReCpl/t	ImCpl/t	ReCpu/t	ImCpu/t	ReCpl/t	ImCpl/t
.000	0.030	0.168			-0.135	0.184		
.025	-3.311	3.219	4.942	-4.132	-2.849	2.629	5.057	-4.350
.050	-4.336	4.044	4.336	-4.044	-5.198	4.535	4.038	-3.523
.100	-2.735	2.328	4.891	-3.740	-2.632	2.094	4.269	-3.240
.200	-2.903	2.903	4.658	-1.705	-2.807	2.241	4.154	-1.586
.260	-2.872	2.688	6.246	-2.498	-2.970	2.492	6.165	-2.232
.320	-0.137	0.182	5.548	-0.662	-0.108	0.133	5.243	-0.137
.380	-1.639	0.489	5.511	1.855	0.545	12.473	4.399	2.165
.440	0.435	4.597	3.099	3.109	-2.268	6.334	2.936	3.030
.500	0.714	15.148	0.862	3.310	-4.179	-0.580	0.593	3.079
.560	-5.578	7.996	-0.628	1.773	-4.363	-2.109	-0.616	1.656
.620	-8.027	-3.557	-0.450	1.292	-4.218	-3.020	-0.320	1.035
.700	-7.085	-7.185	1.660	1.564	-2.643	-4.398	1.333	1.561
.800	2.308	-4.131	2.407	1.527	1.844	-1.944	2.013	1.590
.900	0.951	0.384	2.191	0.815	0.457	0.789	2.015	0.940

	y/s = 0.809				y/s = 0.951			
x/c	ReCpu/t	ImCpu/t	ReCpl/t	ImCpl/t	ReCpu/t	ImCpu/t	ReCpl/t	ImCpl/t
.000	-0.170	0.152			-0.127	0.114		
.025	-2.796	2.518	4.404	-3.717	-4.114	3.066	4.415	-3.137
.050	-5.136	4.433	4.428	-3.485	-3.406	2.585	4.371	-3.294
.100	-2.823	2.221	3.895	-3.798	-4.890	4.281	4.226	-2.372
.200	-2.983	2.199	2.406	-0.626	-0.634	0.384	2.439	-0.248
.260	-3.816	7.269	3.175	-1.718	0.351	1.025	3.306	0.069
.320	0.089	0.146	2.175	1.337	-0.028	0.050	2.101	1.025
.380	-1.053	1.627	1.817	2.018	-0.629	0.737	1.645	1.410
.440	-1.673	0.727	1.064	0.000	-0.768	0.591	1.099	1.800
.500	-2.103	-0.162	0.289	2.702	-0.954	0.170	0.276	1.803
.560	-2.114	-0.854	-0.854	1.611	-0.884	-0.224	-0.680	1.507
.620	-1.859	-1.416	-1.084	0.894	-0.692	-0.398	-0.913	1.168
.700	-1.248	-1.557	0.599	1.425	-0.538	-0.509	0.164	1.071
.800	-0.107	-0.676	0.773	1.387	-0.854	0.045	0.432	0.931
.900	-0.317	0.606	0.804	1.051	-2.675	1.405	0.675	0.614

Case 2b (Cont'd)



Questions

- Influence of splitter plate
- Influence of tunnel wall
- Influence of structural dynamics

RSW Structural dynamics

- Assumed rigid
- Oscillated at frequencies separated from structural dynamic / aeroelastic modes
- 1^{st} bending mode: 34.8 Hz

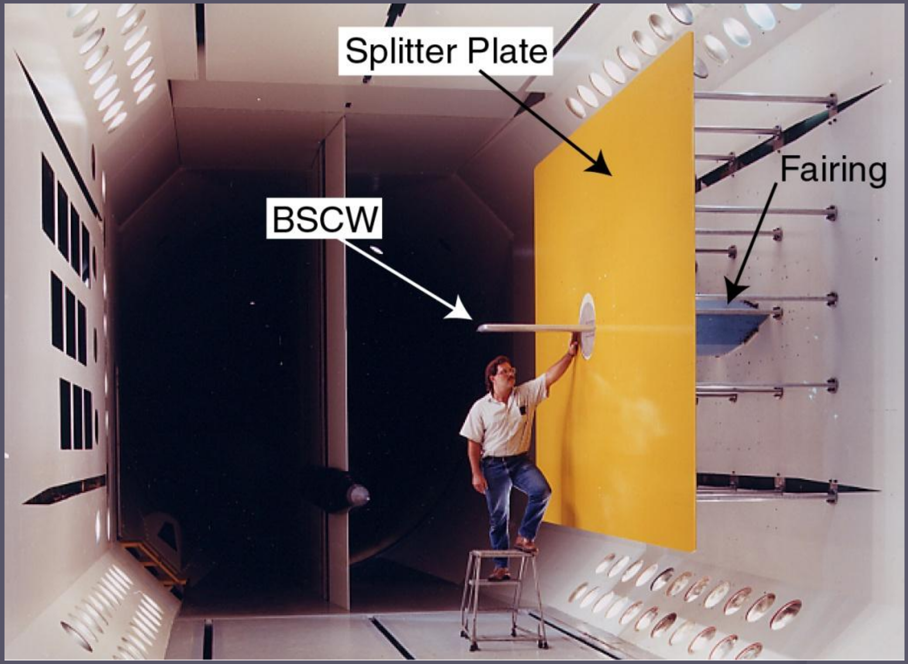
BSCW

Benchmark Supercritical Wing (BSCW)

- Simple, rectangular wing
- Data acquired under mixed attached/separated flow conditions

Known deficiencies:

- Limited number of pressure transducers in experimental data
- Limited number of discrete frequencies of oscillation
- Mach number is at edge of acceptable range for quality pressure data with splitter plate



M=0.85, Re_c=4.49 million, test medium: R-134a

a) **Steady Case**
   i. **α = 5°**

b) **Dynamic Cases**
   i. **α = 5°, θ = 1°, f = 1 Hz**
   ii. **α = 5°, θ = 1°, f = 10 Hz**

BSCW Geometry and Test Configuration

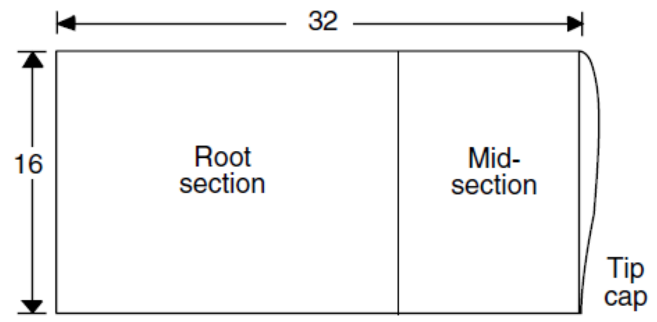
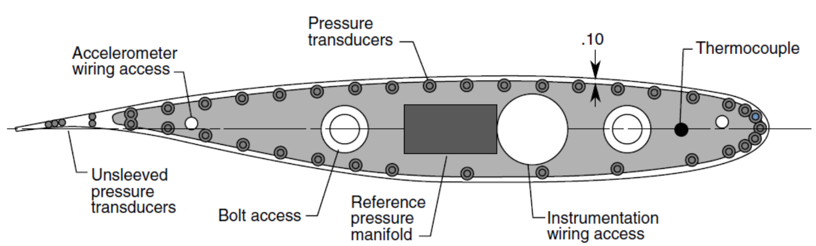


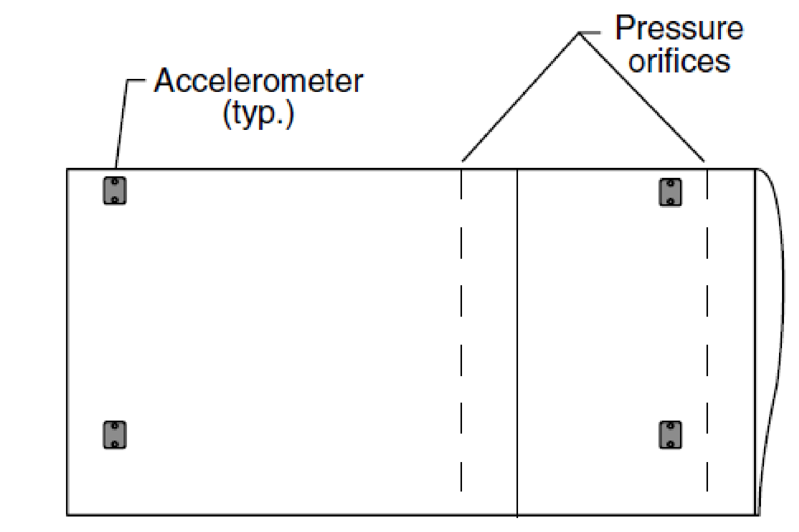
Figure 1. Planform of model. Dimensions are in inches.

Figure 2. NASA SC(2)-0414 airfoil.



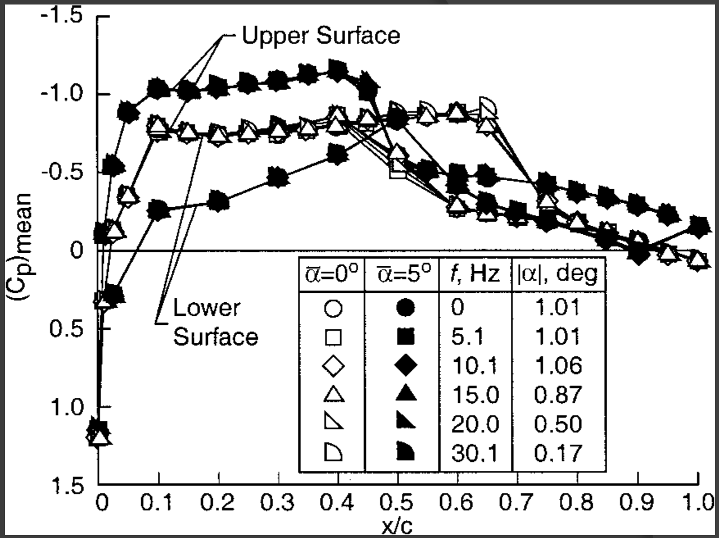
Unsteady Pressure Measurements

1 chord at 60% span



Experimental data acquired in R-134a @ q = 200 psf, Re_c = 4.49 million, Mach=0.85

BSCW Data

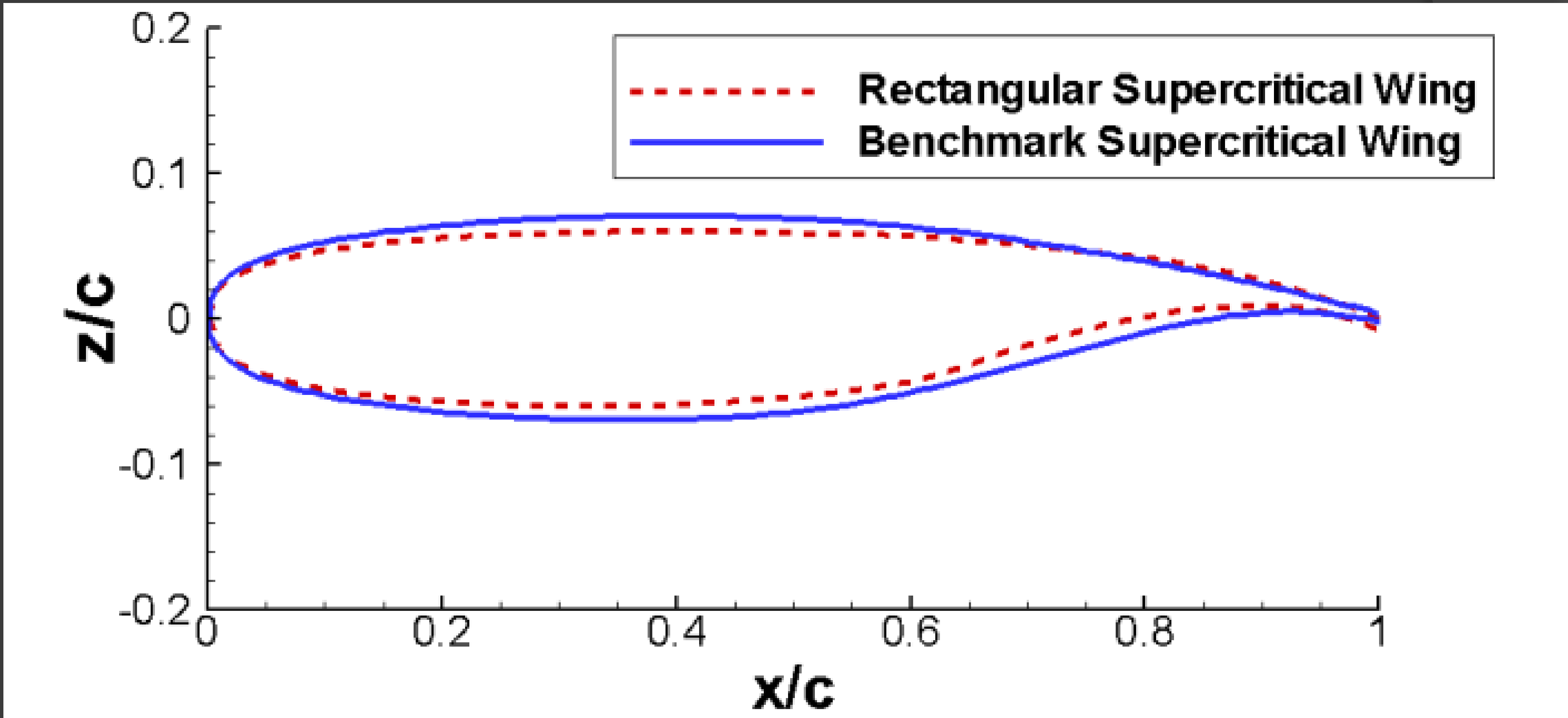


- Fixed transition @ 7.5% chord.
- 1 chord of data with a total of 40 in-situ unsteady pressure measurements (20 Upper, 20 Lower)
  - 60 percent span.
  - Static data: Mean Cp
  - Forced Oscillation Data: Mean Cp, Real and Imaginary Cp/Theta, CP time histories.

BSCW Structural Properties

- Designed as a rigid wing on a rigid mounting system.
  - Mounting system oscillates wing in pitch about 0.30 chord.
- Structural frequencies of installed wing and mounting system:
  - 24.1 Hz spanwise (Wing flapping)
  - 27.0 Hz in-plane.
  - 79.9 Hz torsion

Airfoil Comparisons



HIRENASD

HIRENASD
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HIRENASD

- 3-D aeroelastic wing with generic fuselage model
- Steady and forced (structural resonance) oscillation testing
- Data:
  - Balance forces for integrated load comparisons,
  - Mean and fluctuating pressure data
  - Surface deformation data from optical and strain measurements during testing
- Known deficiencies:
  - Limited deflection data
  - Only excited at natural frequencies

M = 0.80, test medium: nitrogen

a) Steady (Static Aeroelastic) Cases
   i. Re = 7.0 million, $\alpha = 1.5^\circ$
   ii. Re = 23.5 million, $\alpha = -1.34^\circ$

b) Dynamic Cases: forced oscillation at 2^{nd} Bending mode frequency
   i. Re = 7.0 million, $\alpha = 1.5^\circ$
   ii. Re = 23.5 million, $\alpha = -1.34^\circ$

HIRENASD Project Partners

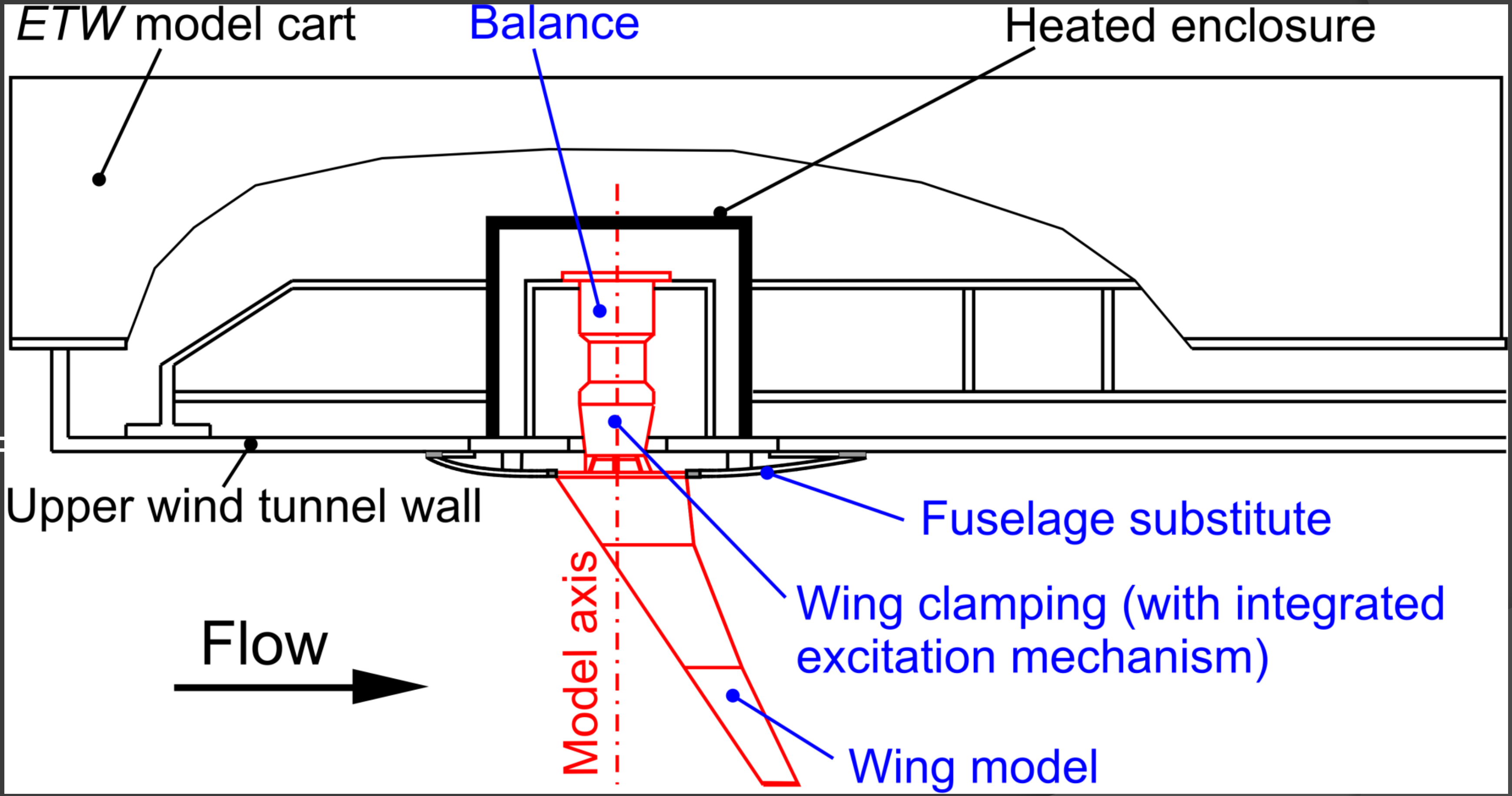
Aachen University:

- Department of Mechanics
- Institute for Lightweight Structures
- Institute for Geometry and Applied Mathematics
- Shock Wave Laboratory

Thanks to ...

- German Research Foundation (*DFG*) for funding *HIRENASD*
- *Airbus Industry* for supporting the balance for dynamic force measurement
- *DLR* for advice concerning data acquisition and providing AMIS II
- *ETW* for providing windtunnel adaptations, for e.g. dynamic force measurement, and continuous advice during preparation of model and measuring equipment

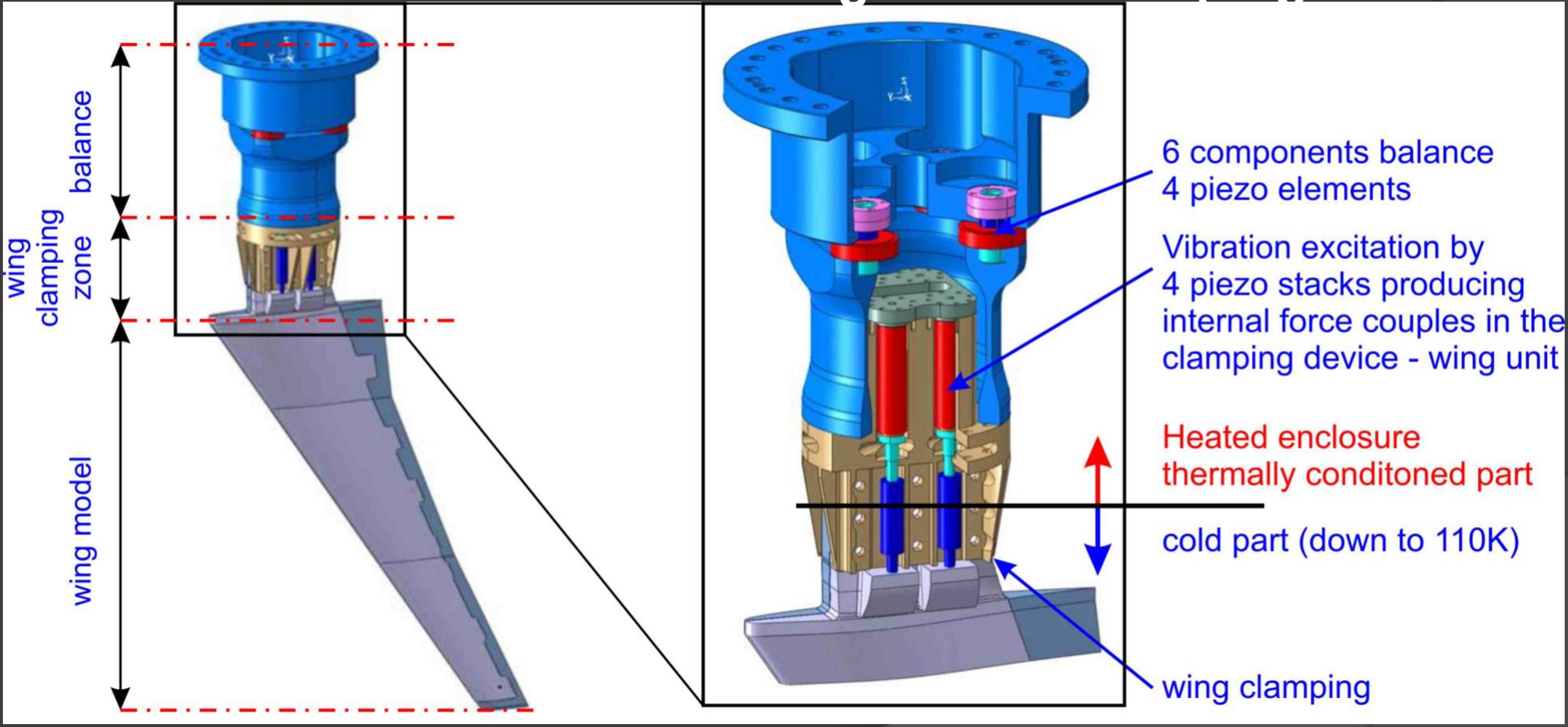
Windtunnel Model and Assembly



Wind Tunnel Balance and Vibration Excitation Mech.

- No access to wind tunnel test section during tests
- Due to thermal insulation, space for excitation mechani

→ Excitation mechanism integrated in clamping unit



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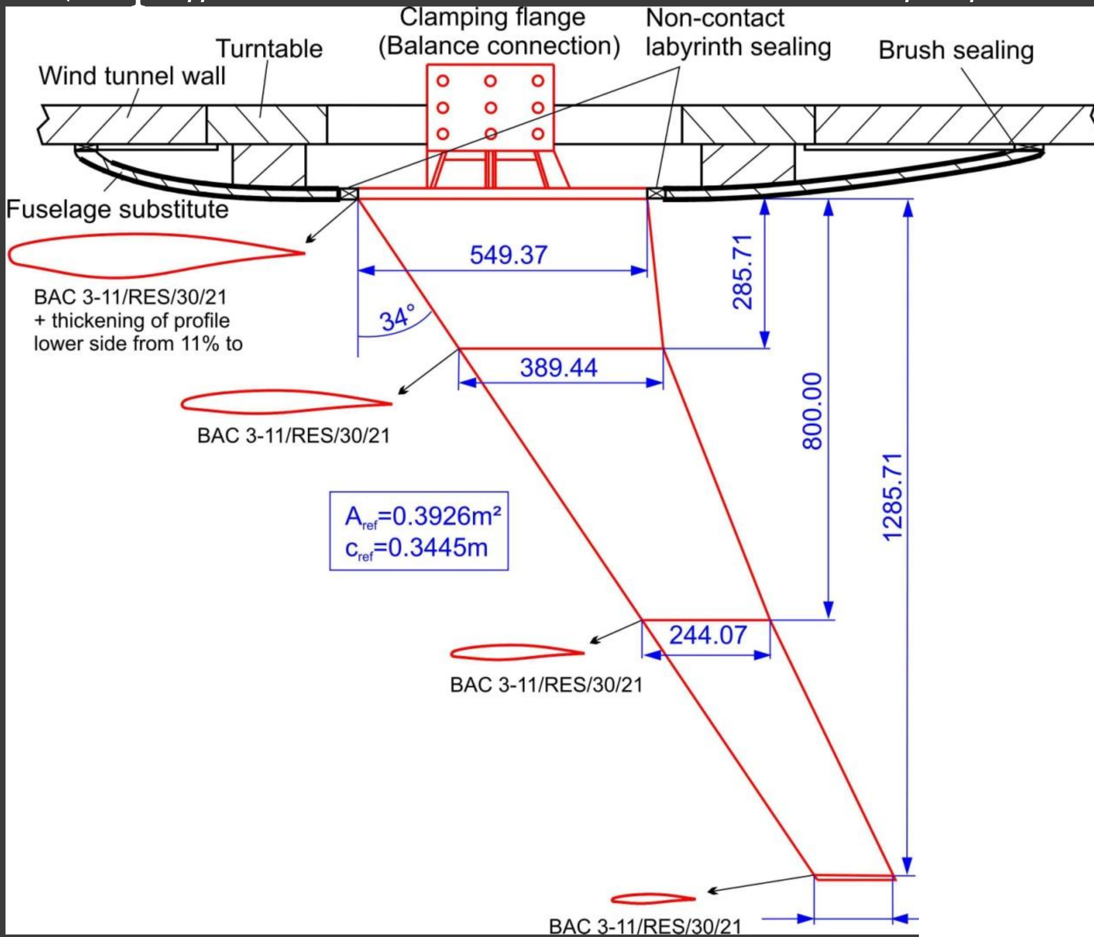
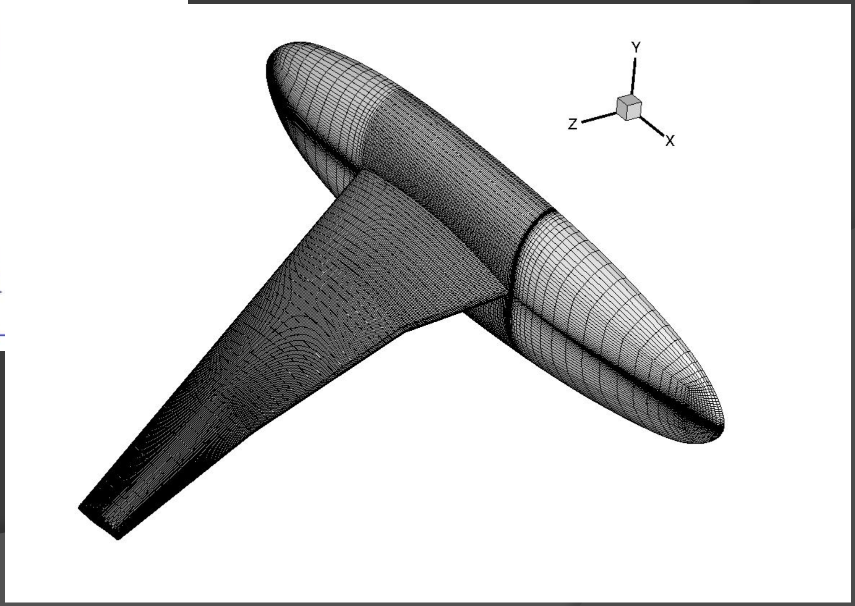
HIRENASD Geometry

(https://heinrich.lufmech.rwth-aachen.de/en/windtunnel-assembly)





Mach 0.80, Re = 7.0 million and Re = 23.5 million

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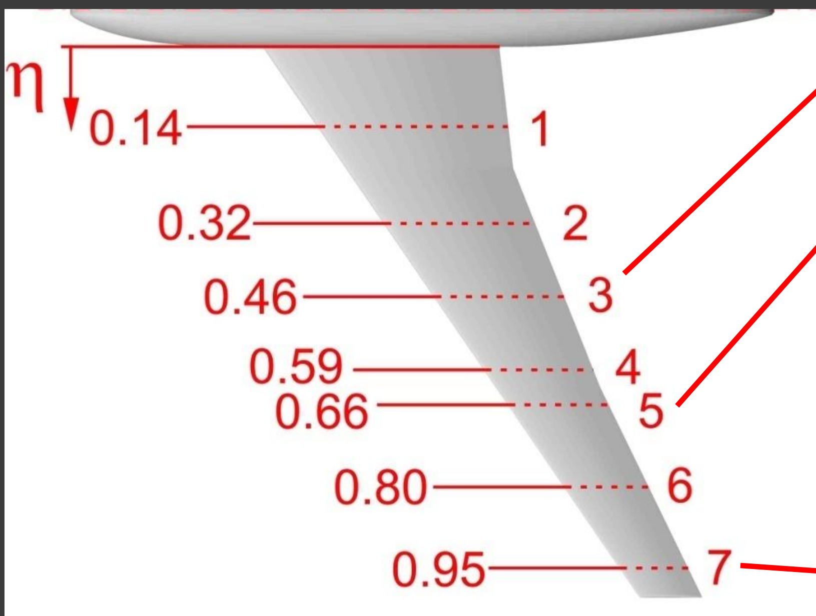
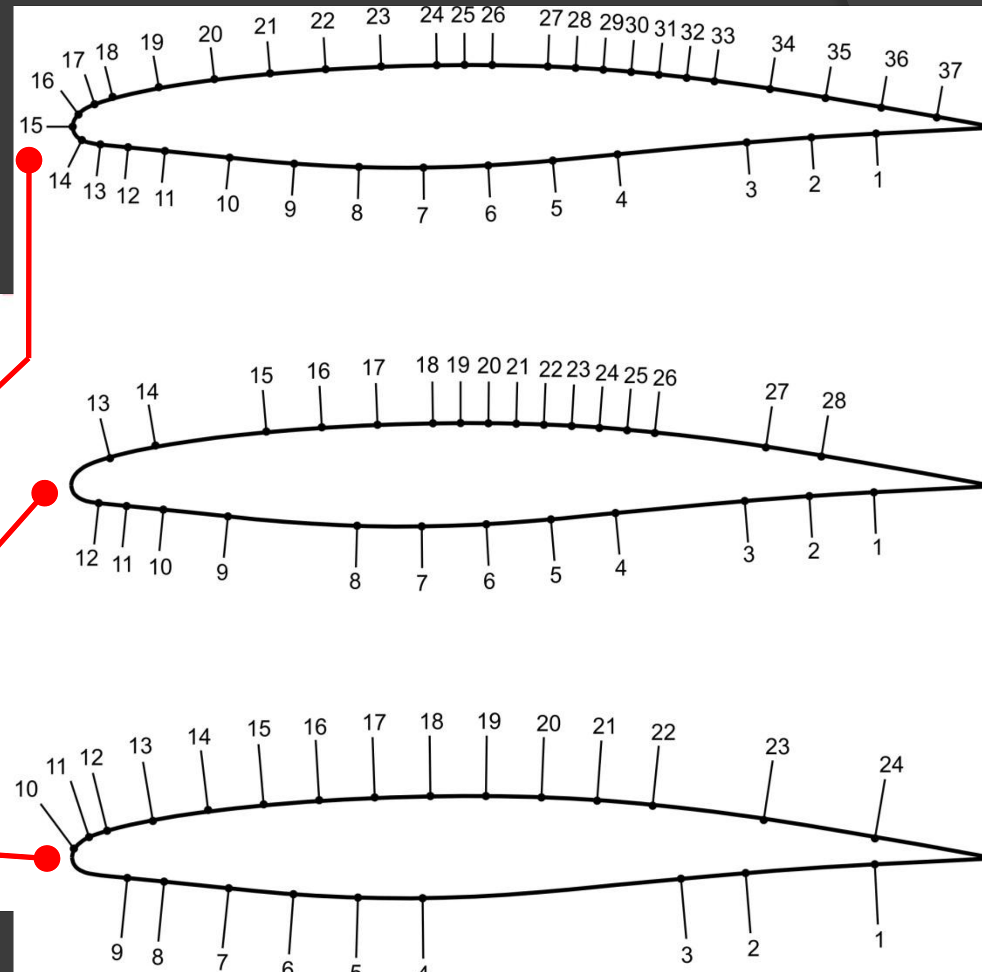
Measuring Equipment for Pressure

Pressure Sensors:
259 unsteady pressure sensors distributed at 7 span stations



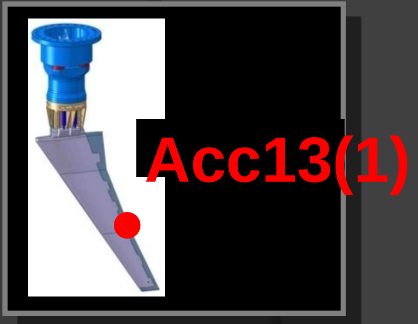


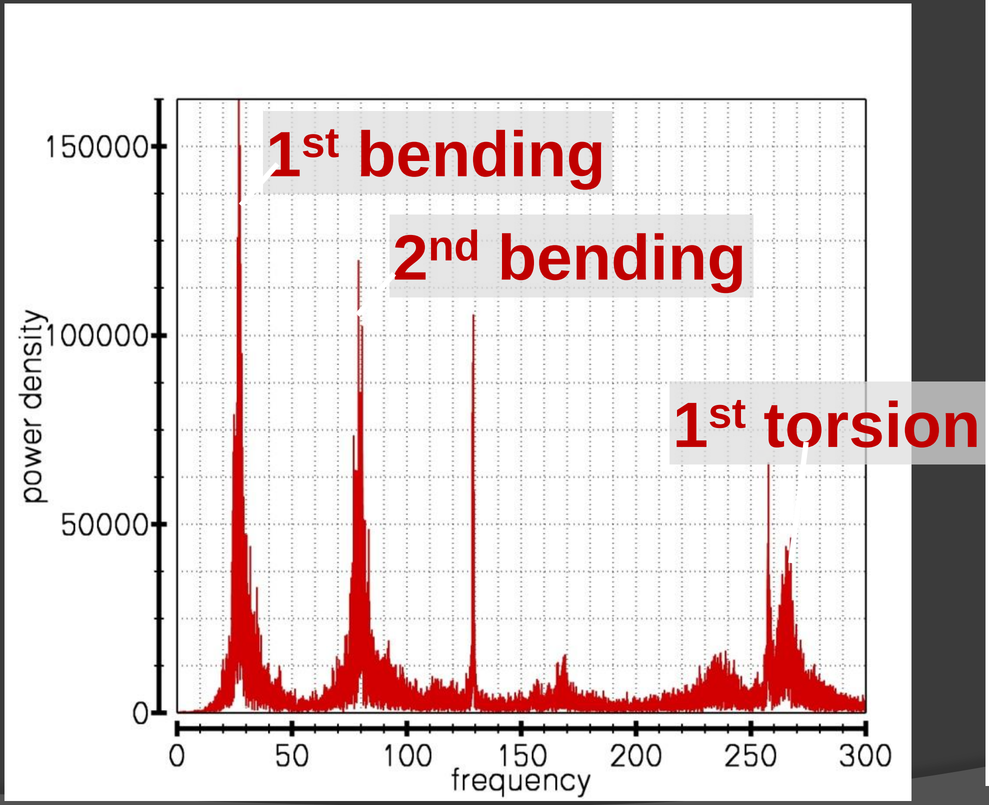
HIRENASD Structural Dynamics

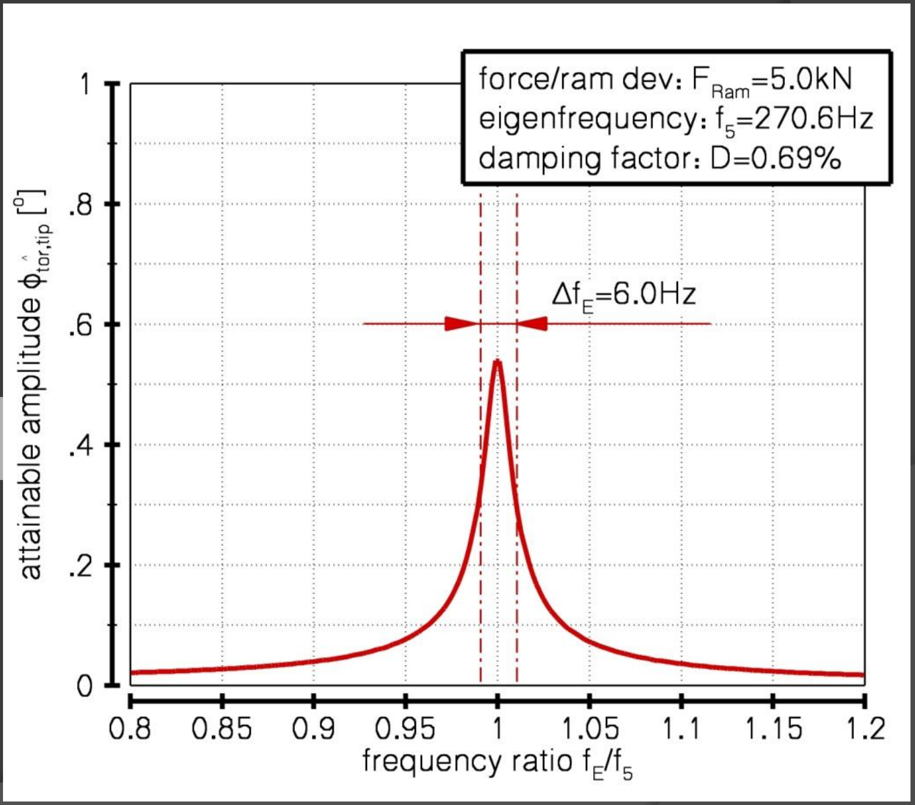
Excitation Frequencies from Raw Data of Static Tests

Determination of resonance frequency:

- Maximum effectiveness of excitation mechanism at resonance frequency
- Resonance frequency depending on flow conditions
- Determination of frequencies during steady wind tunnel tests from power spectra

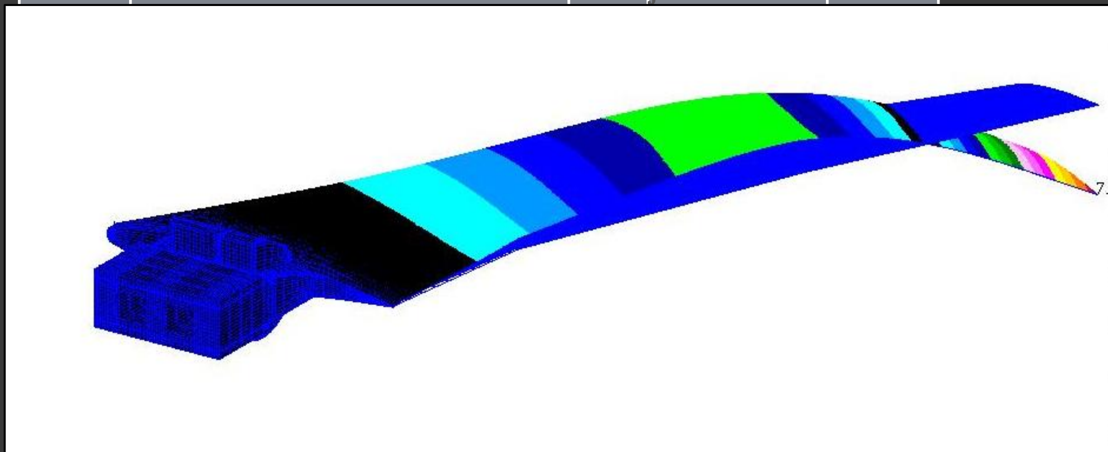


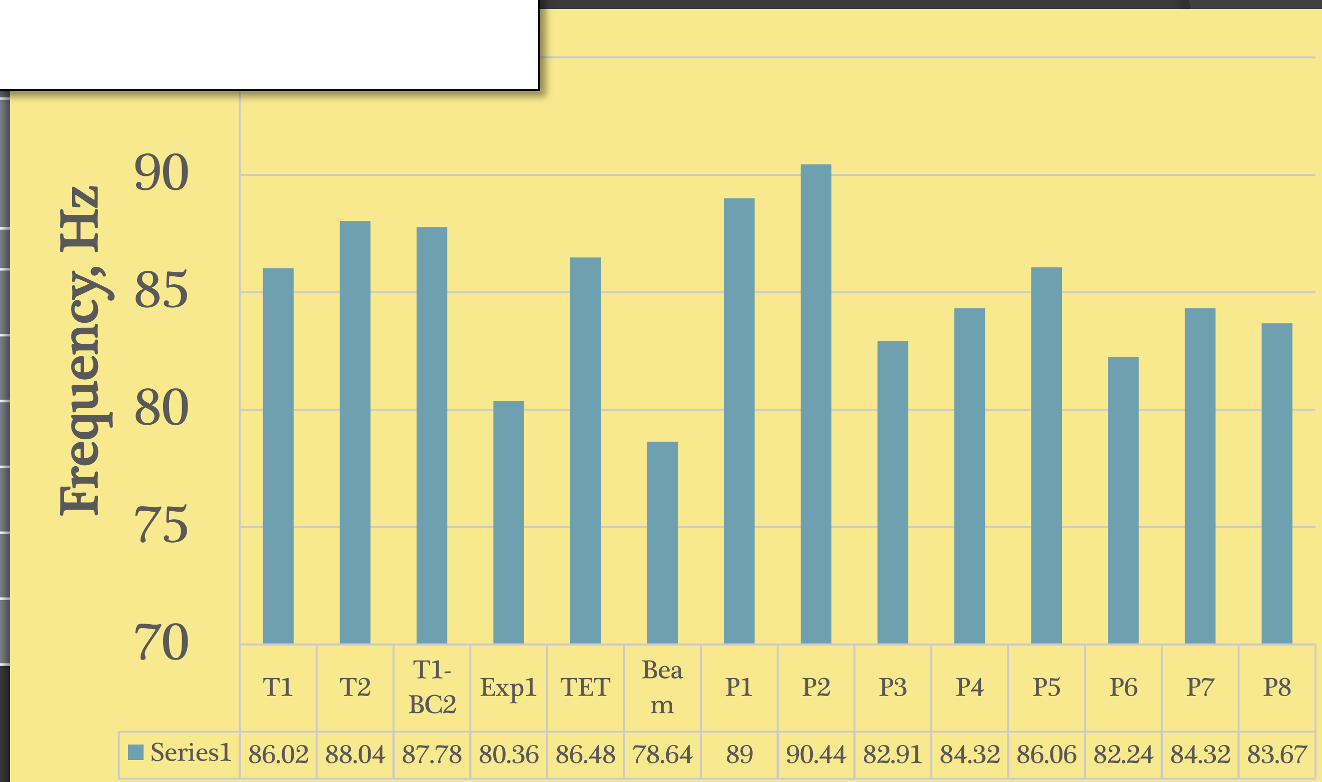




HIRENASD 2nd Bending Mode Variation among Analyses

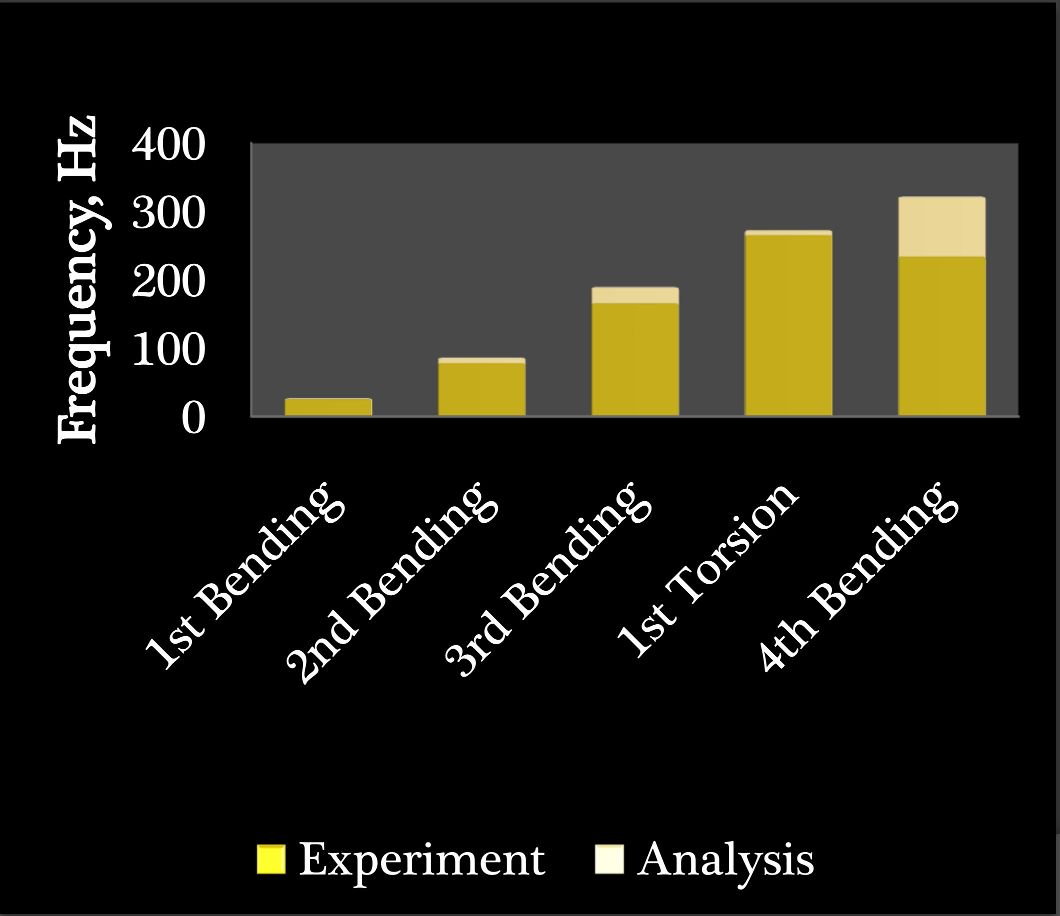
Case Label	Description	Temp (K)	Boundary condition	Mode 2
			constrained just at end of	
P1	Unstr. FEM TET10 IFASD 2009-130 fig 7			
P2	Beam A IFASD 2009-130 Fig 7			
P3	TET10 IFASD 2009-130 (revised beam at root) Fig 8			
P4	Beam A IFASD 2009-130 (revised beam at root) Fig 8			
P5	Beam A IFASD 2009-130 (revised beam at root) Fig 8			
P6	Tet 10 IFASD 2009-130 Fig 10 - att. to ETW model art adaptor			
P7	Beam B IFASD 2009-130 Fig 10 - att. to ETW model art adaptor			
P8	Beam C IFASD 2009-130 Fig 10 - att. to ETW model art adaptor			





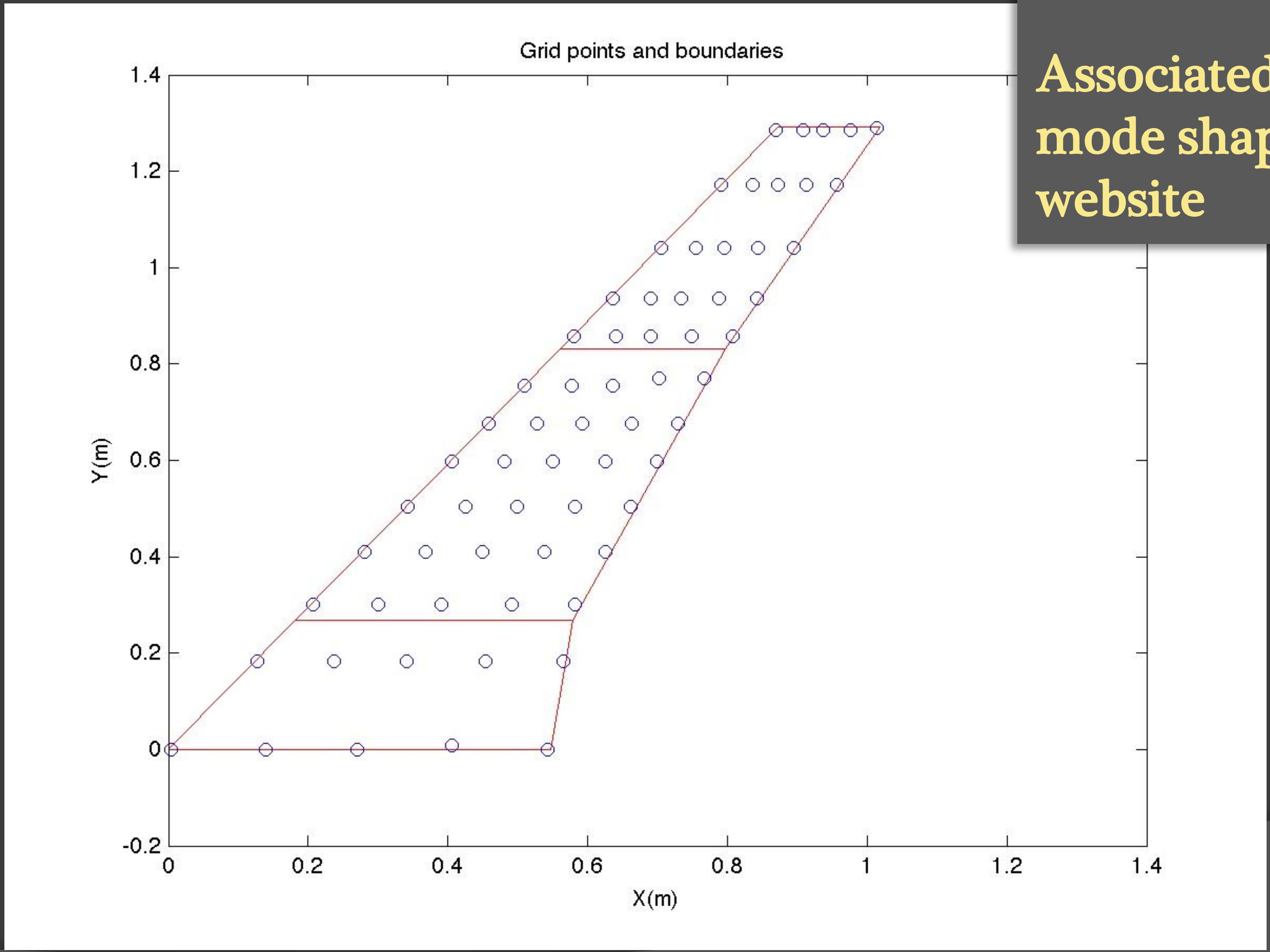
Plan of action for structural dynamic model

- Use analytical mode shapes
- Use experimental frequencies for
  1st 4 Bending modes & 1st Torsion
- Use analytical frequencies for additional 5 modes



Mode #	Description	Analytical Frequency (Hz)	Experimental Frequency (Hz)
1	1st Bending	26.54	26
2	2nd Bending	86.02	78.6
3	1st Fore-Aft	156.94	
4	3rd Bending	189.31	166.2
5	1st Torsion	272.86	265.8
6	4th Bending	321.77	234.6
7	2nd Fore-Aft	422.98	
8	2nd Torsion	450.51	
9	5th Bending	496.68	
10	3rd Torsion	622.41	

Reduced node set available for modal splining



Flat Plate with 65 nodes

Associated grid points and 1st 10 mode shapes are on AePW website

Follow on plan_version 1

- Generate NASTRAN beam model to match Aachen Timoshenko beam model that has been tuned to the experimental frequencies
- Update hexahedral-based FEM to incorporate instrumentation weight and balance boundary condition
- Assess goodness of updated FEM relative to experimental data
- Provide updated modes and frequencies for participant consideration as extended test case

Follow on plan_version 2 July 2, 2011 (following meeting at RTA)

- Document and distribute for consideration and information:
  - Experimental data sets pertinent to the structural dynamic of the HIRENASD (for example Ground vibration test data? Stiffness test data?)
    - That we have in hand
    - That could possibly be made available
  - Analytical and computational models of the structural dynamics (i.e. FEMs and beams)
    - That we have in hand
    - That could possibly be made available
- Telecon July 15, 1430 GMT to discuss status and develop plan going forward for the structural dynamics representation

GRIDS

Gridding Guidelines for 1st AePW (AePW1)

For the current workshop, a sequence of coarse, medium and fine grids are required for each configuration and the guidelines can be summarized as follows:

1. RSW initial spacing normal to all viscous walls (Re = 4M based on C_{ref} = 24")
   a. Coarse: $y^+ \sim 1.0$, dy = 0.000158"
   b. Medium: $y^+ \sim 2/3$, dy = 0.000105"
   c. Fine: $y^+ \sim 4/9$, dy = 0.000070"

2. BSCW initial spacing normal to all walls (Re = 4.5M based on C_{ref} = 16")
   a. Coarse: $y^+ \sim 1.0$, dy = 0.000094"
   b. Medium: $y^+ \sim 2/3$, dy = 0.000063"
   c. Fine: $y^+ \sim 4/9$, dy = 0.000042"

3. HIRENASD wing initial spacing normal to all walls (Re = 23.5M based on C_{ref} = 0.3445 meter) Note: Same grids to be used for Re = 7M and Re = 23.5M cases.
   a. Coarse: $y^+ \sim 1.0$, dy = 4.40961e-7 meter
   b. Medium: $y^+ \sim 2/3$, dy = 2.93973e-7 meter
   c. Fine: $y^+ \sim 4/9$, dy = 1.95982e-7 meter

4. Normal growth rate for cells in boundary layer region < 1.25
5. Structured grids will have at least 2 cell layers of constant spacing normal to viscous walls.
6. Farfield will be located at ~100 c_{ref} for all grids.
7. Local spacings on medium grid:
   a. Chordwise spacing for wing leading and trailing edges ~0.1% local chord
   b. Wing spanwise spacing at root and at tip ~0.1% local semispan
   c. Cell size near fuselage nose and aftbody ~2% c_{ref}
8. Wing trailing edge: minimum 4, 6 and 9 cells for coarse, medium and fine grids, respectively.
9. Grid family:
   a. Medium mesh representative of current engineering practice
   b. Maintain a parametric family of uniformly refined grids in sequence
   c. Grid size to grow ~3X for each level of refinement [Structured 1.5X in I,J,K directions]
   d. Give consideration to multigridable dimensions on structured meshes
   e. Sample sizes: Coarse: 3M, Medium: 10M, Fine 30M

dy refers to the normal spacing of the first cell at the viscous wall. Special effort is required to ensure that sequences of coarse, medium and fine meshes constitute a consistent "family" of grids suitable for a grid convergence study. This entails the preservation of mesh topology, stretching factors, and local variations in resolution as much as possible between grids of the same sequence. The mesh spacing specifications given for the medium grid are to be scaled appropriately for the coarse and fine grids. The given grid sizes are only estimates based on the objective that the medium grid should be representative of current engineering practice enabling a solution on mid-range computational hardware in reasonable turnaround time (i.e. considerably less than 24 hours). For unstructured grids designed for vertex-based solvers, the spacing refers to inter-nodal spacing and the resulting grid sizes are expected to be similar to the structured grid sizes. For unstructured grids for cell-centered solvers, the spacing refers to spacing between cell centers (or surface face centers), which corresponds approximately to a factor of 2 reduction in the overall number of surface points compared to the nodal solver case, for a triangular surface grid. For tetrahedral cell-centered solver mesh, the total number of grid points will be approximately 1/3 of the node based solver mesh.

Summary of AePW Grids

	GRID TYPE																	
Configuration	Unstructured												Structured			Overset		
	Node Based						Cell Centered						Hex Multiblock					
	Mixed			Tetrahedra			Mixed			Tetrahedra								
	C	M	F	C	M	F	C	M	F	C	M	F	C	M	F	C	M	F
RSW	√	√	√	√	√	√	○	○	○				√					
BSCW	⊙	⊙	⊙				○	○	○				○	○	○			
HIRENASD	√	√	√				○	○	○				√			√		

√ = Complete

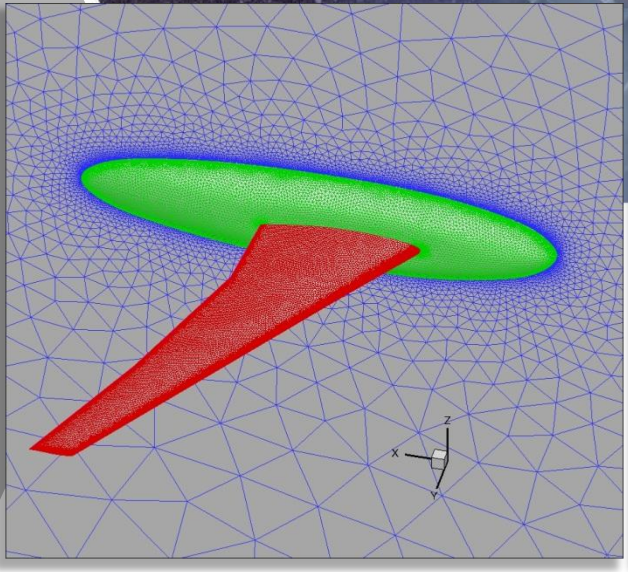
⊙ = In process

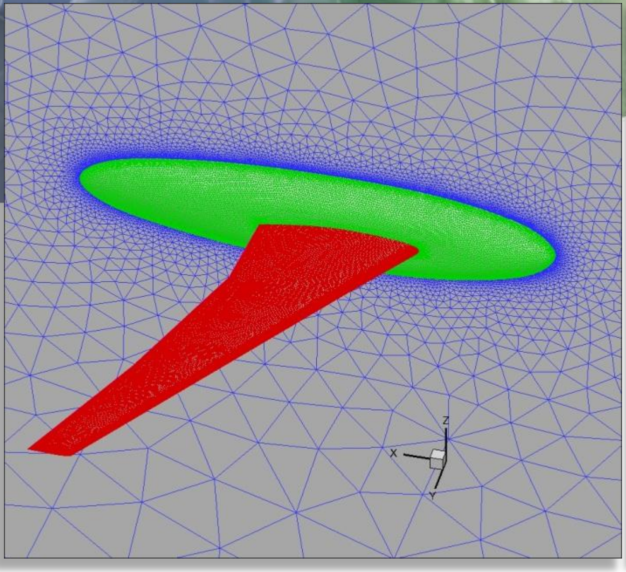
○ = Desired

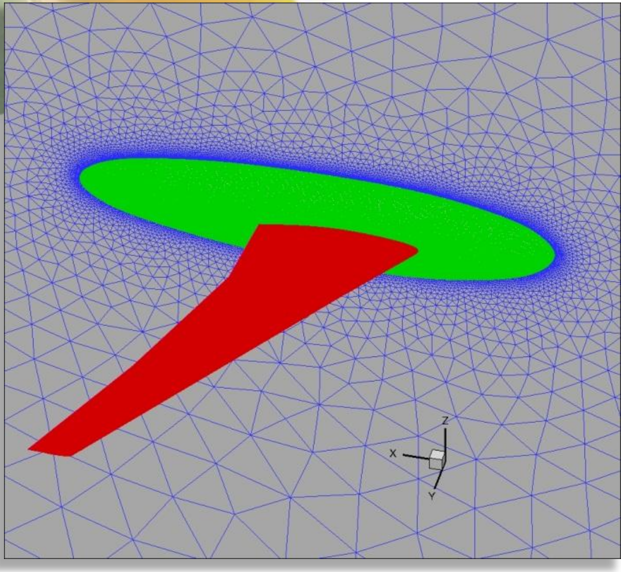
RSW grids from Eric

BSCW grids from Marilyn

Overview of the coarse, medium, and fine unstructured HIRENASD meshes







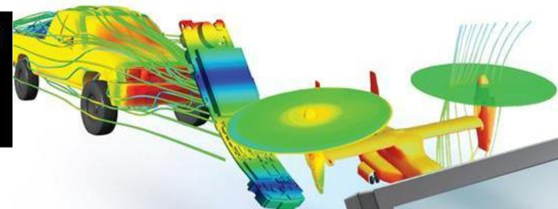
- **Coarse:**
  - **5676008 Total Nodes**
  - **14378129 Total Elements**
  - **Boundary layer cells:**
    - **34 prism layers**
    - **Stretching factor 1.28**
- **Medium:**
  - **16052763 Total Nodes**
  - **38871412 Total Elements**
  - **Boundary layer cells:**
    - **40 prism layers**
    - **Stretching factor 1.25**
- **Fine:**
  - **46393528 Total Nodes**
  - **104678223 Total Elements**
  - **Boundary layer cells:**
    - **45 prism layers**
    - **Stretching factor 1.23**

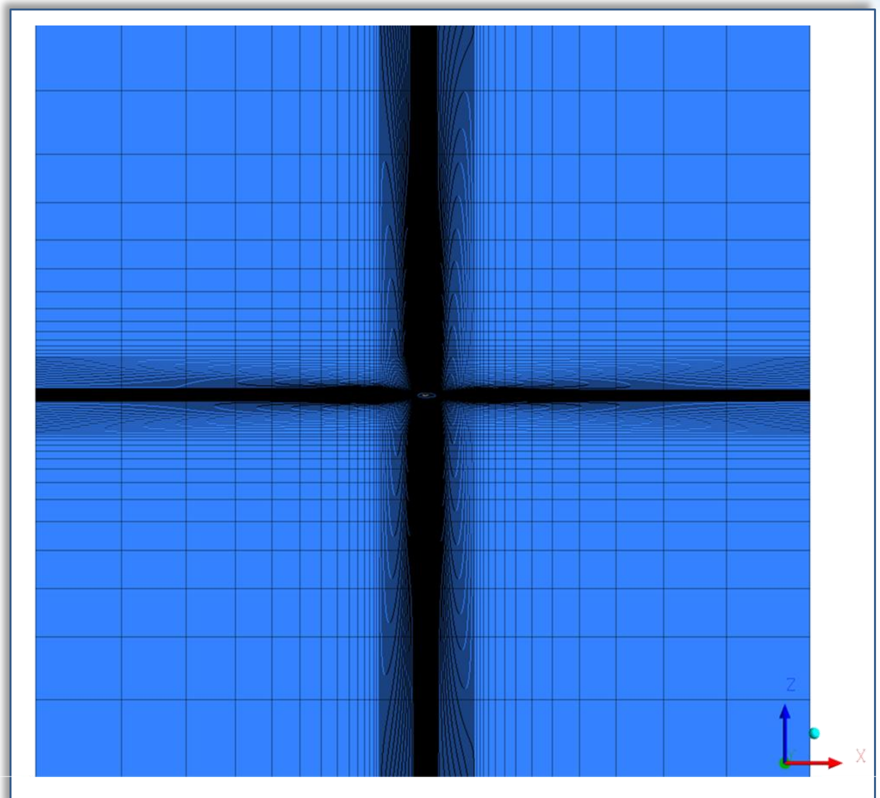
Aeroelastic Prediction Workshop Structured Grids

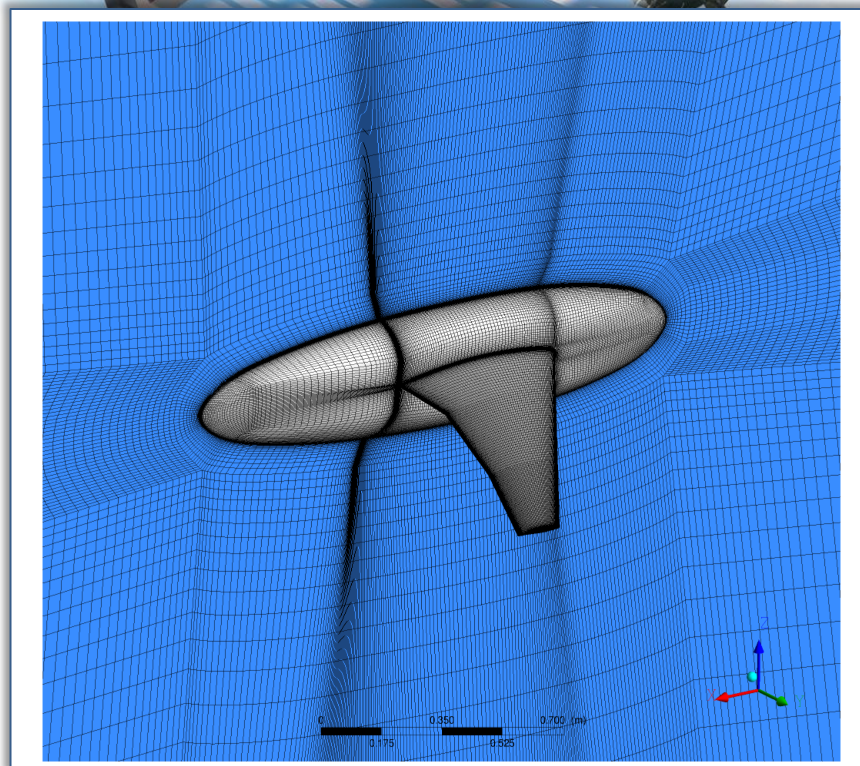
Thorsten Hansen

ANSYS Germany

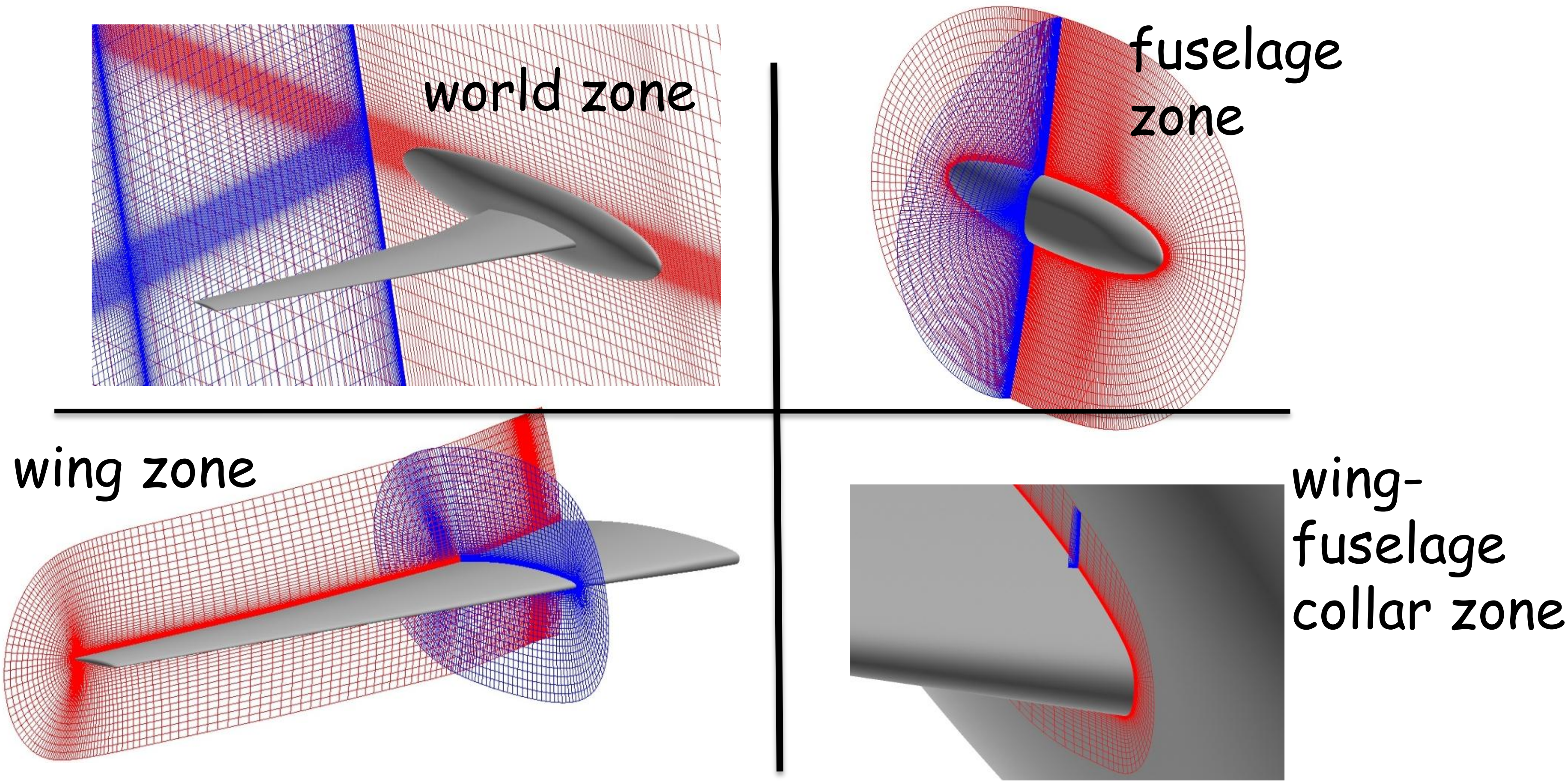
thorsten.hansen@ansys.com







HIRENASD Overset Mesh with Chimera (Medium-Size Mesh)



Analysis Condition Parameters

Parameters		Units		Configuration			
		English	SI	RSW* (English units)	BSCW (English units)	HIRENASD (SI units)	HIRENASD (SI units)
Mach number	M			0.826	0.848		
Reynolds number (based on ref chord)	Re_c			4.01E+06	4.49E+06		
Dynamic pressure	q	psf		108.65	204.20		
Velocity	V	ft/s		413.73	468.98		
Speed of sound	a	ft/s		501.18	552.93		
Static temperature	Tstat	deg F		37.12	87.91		
Density	ρ	slug/ft^3		0.001270	0.001857		
Ratio of specific heats	γ			1.132	1.116		
Dynamic viscosity	μ	slug/ft-s		2.620E-07	2.590E-07		
Prandtl number	Pr			0.78	0.67		
Test medium				R-12	R-134a	Nitrogen	Nitrogen
Total pressure	H	psf		410.48	757.31		
Static pressure	P	psf		280.76	512.12		
Purity	X	%			95		
Total temperature	T	deg F		60.00	109.59		

AePW Website Info

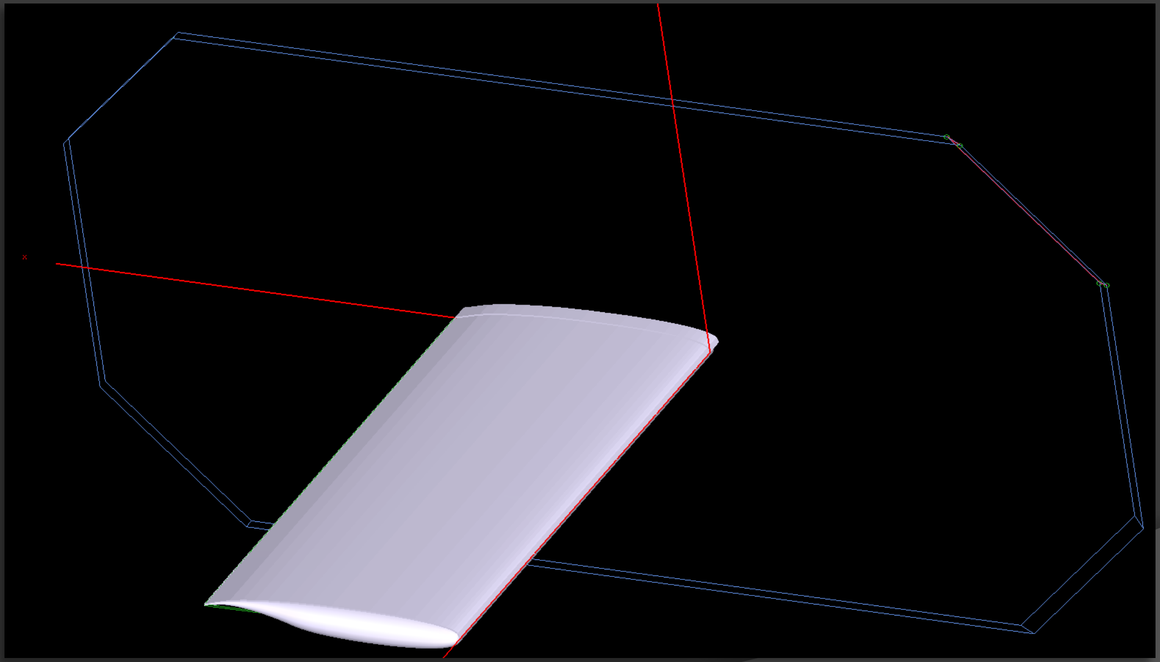
- https://c3.ndc.nasa.gov/dashlink/projects/47/

- Content is viewable by the world
- Website contributions limited to members
- Membership by request or commitment to the workshop

Send email to : AeroelasticPW@gmail.com

Geometry (.iges) files

- NASA is responsible for preparing IGES files
  - Measured geometry used for all configurations
  - RSW and BSCW IGES files generated with and without splitter plates
  - HIRENASD with blunt trailing edge



Progress: Gridding

- Gridding guidelines and rules from Drag Prediction Workshop and High Lift Prediction Workshop will be adopted as the initial guidelines for AePW.
- Unstructured and structured grids will be constructed and made available to the participants.
- Grid generation by volunteers from 5 organizations

	RSW	BSCW	HIRENASD
Structured			
Unstructured			
Overset			

- Initial analyses prior to IFASD will be conducted using new grid family:
  - RSW and BSCW (NASA)
  - HIRENASD (FOI Sweden)

AePW-1 Tentative Agenda

- Workshop Overview
- Geometry, grid & structural model overview
- Experimental Data summary
- Computational Results by each analysis team
- Summarized Results with comparison to experiment
- Open forums
- Lessons learned
- Planning for reanalysis & publication
- Initial discussions on workshop path forward

Workshop participant submittals

- No formal AIAA papers
- Presentation & data submission only
- Requires 1 page letter of intent or abstract

MRL and USF Contribution to AePW - 1

N. N. Thusiast_

Multielement Research Lab, Mail Stop 000, Happy Forks, VA 00000

email: m.n.thusiast@mrl.gov, (777) 777-7777

Soar N. Air†

University of Southern Flight, Mail Code 98765, Lofty Heights, TX 00000

email: s.n.air@usf.edu, (888) 888-8888

We intend to participate in the AePW-1, to be held April 21-22 2012 in Honolulu, HI. We plan to perform the following sets of computations:

1. Configuration 1 – RSW , Steady Case, i. M=.825, α=2 deg
   - Code: RANS-CFD-3D
   - Grid: Str-OnetoOne-C-v1 (supplied by AePW-1 committee)
   - Turbulence model: Menter SST
2. Configuration 1 – RSW , Unsteady Case, i. M=.825, α=2 deg, 10 Hz
   Same as above
3. Configuration 2 – BSCW, Steady case, M=.85, α=5 deg, 10 Hz
   Same as above
4. Configuration 2 – BSCW, Unteady case, M=.85, α=5 deg, 20 Hz
   Same as above
5. Configuration 3 - HIRENASD Configuration, steady, M=.8, Re=7 million, α =1.5 deg
   - Code: RANS-CFD-3DAe
   - Grid: Str-OnetoOne-C-v1 (supplied by AePW-1 committee)
   - Turbulence model: S-A

We plan to submit our results electronically by the March 20, 2012 deadline to the AePW-1 committee.

RANS-CFD-3DAe is a Reynolds-averaged Navier-Stokes code developed by Et et al.,[1] widely used at the Multielement Research Lab. It is specifically formulated to work on three-element wing configurations. It uses point-matched grids, and is an upwind finite-volume structured code.

LES-CFD-3D is a large-eddy simulation code developed at the University of Southern Flight.[2] It employs 6th order central differencing in space and 3rd order temporal differencing, along with 9th order explicit filtering.

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2 Author, A. and Author B., "Description of LES-CFD-3D," Journal of Lengthy Papers, Vol. 9, No. 2, 2008, pp. 22–1021.

_ Corresponding Author. Senior Research Scientist, High Lift Branch.

† Professor and Chair, Dept. of Aeronautical Engineering.

Invitation to patticipate

AePW email distribution list is being generated now

Go to

https://c3.ndc.nasa.gov/dashlink/projects/47/

To sign up for

Email distribution list → Click Join Distribution List

Workshop participation → Click Participate in AePW

AeroelasticPW@gmail

Participant Information Sources

- Organizing committee website:
  - https://c3.ndc.nasa.gov/dashlink/projects/39/
- Workshop website, open for public viewing, member postings:
  - https://c3.ndc.nasa.gov/dashlink/projects/47/
- Links to:
  - HIRENASD website (German and English languages)
    - http://www.lufmech.rwth-aachen.de/HIRENASD/
    - https://heinrich.lufmech.rwth-aachen.de/index.php?lang=en&pg=home
  - NASA White Paper reviewing experimental data sets
    - http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20100016316_2010017232.pdf
  - 2011 International Forum on Aeroelasticity & Structural Dynamics
    - http://www.ifasd2011.com/
  - Fun3D
    - http://fun3d.larc.nasa.gov/
  - Drag and High-Lift Prediction Workshops
    - http://aaac.larc.nasa.gov/tsab/cfdlarc/aiaa-dpw/
    - http://hiliftpw.larc.nasa.gov/

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Data comparisons & processing

Comparison Data Matrix

CONFIGURATION	REQUIRED CALCULATIONS		
	GRID CONVERGENCE STUDIES	STEADY CALCULATIONS	DYNAMIC CALCULATIONS
Steady-Rigid Cases (RSW, BSCW)	C_L, C_D, C_M vs. N-2/3	• Mean Cp vs. x/c • Means of C_L, C_D, C_M	
Static-Aeroelastic Cases (HIRENASD)	C_L, C_D, C_M vs. $N^{-2/3}$	• Mean C_p vs. x/c • Vertical displacement vs. x/c • Twist angle vs. x/c • Means of C_L, C_D, C_M	
Forced Oscillation Cases (all configurations)	TBD		• Magnitude and Phase of C_p vs. x/c at span stations corresponding to transducer locations • Magnitude and Phase of C_L, C_D, C_M at excitation frequency • Time history of Cp at each span station for 3 pressure transducer locations

An ascii template will be provided for submission of data

Ascii file specification

Wieseman Euler CFD solution Wing 1 case 1					*Description: include software name, persons name, company*
M	0.8				*Mach*
Q	100	psf			*Dynamic pressure (options: psf or Pa)*
aoa		degrees			*angle of attack*
rn	1.0E+10	ND			*Reynolds number (based on reference chord)*
oscfreq	999	HZ			*oscillation frequency (if static case set to 999)*
Tstatic	999	degK			*Static temperature (options: degK or degR)*
Pstatic	999	Pa			*Static pressure*
Ttotal	999	degK			*Total temperature*
Ptotal	999	Pa			*Total pressure*
Pr	999				*Prandtl*
gamma	1.4				*gamma*
rho	999	kg/m^3			*density (options: kg/m^3 or slugs/ft^3)*
vel	100	m/sec			*velocity (options: m/sec or ft/sec)*
-- Aerodynamic Modeling					
Turbulence Model	SST				*text string*
Flux Construction	ROE				*text string*
Flux Limiter	MINMOD				*text string*
Solver Method	RANS				*options: RANS, URANS, LES, Euler, Doublet Lattice, ….*
-- processing parameters					
ncycles	999				*only for dynamic*
ntpercycle	999				*only for dynamic*
ntimesteps	10000				*only for dynamic*
CPUtime		sec			
comment					*can include comment on convergence if desired*
-- post processing information					*For static and dynamic variables will be different*
initialtimestep	10	sec			*initial timestep for processing*
finaltimestep	400	sec			
ncyclesprocessed	5				*=(final-initial)*ntpercycle*
-- grid information					*if experimental data - this section will not exist*
gridname	Carols grid				*if grid provided*
gridtype	structured				*options: structured, unstructured,overset, hybrid, adaptive*
elementtype	mixed element				*options: mixed element, fully tetrahedral or other*
gridresolution	coarse				
gridsolver	node				*options: node, cell*
gridsize	1000000				*N - number of nodes or cells depending on the gridsolver*
AePW Provided Gr	N				*options: Y, N or Yes or No, or if No - can omit from file*
-- Loads Data					*If experimental - whole block of data may not exist*
CL	1				*If static - results only in 2 columns*
CM	2				*If dynamic -2nd column = real, 3rd column = imaginary*
CD	3				
-- Pressure Data					
-- x/c	**eta**	**CP**	**Flag**		***if unsteady data will be x/c, eta, Cpreal, Cpimag, Flag for whe***

Summary of entries

	001	002	003.01	003.02	003.03	004	005.01	005.02	006	007	008.01	008.02	008.03	009	010	011	012.01	012.02	013.01	013.02	013.03	014.01	014.02	014.03	014.04	014.05	015	016	017.01	017.02	017.03	017.04	017.05	018	019	020.01	020.02	021.01	021.02
Code	CFX	CFD++	OVER	OVER	OVER	HIFUN	FUN3D	NSU3D	FUN3D	TAU	TAU	TAU	TAU	POWER	EDGE	NSU3D	TAS	UPACS	CFD++	CFD++	CFD++	OVER	OVER	OVER	OVER	OVER	USM3D	FUN3D	FUN3D	CFL3D	CFL3D	CFL3D	CFL3D	ELSA	NSMB	USM3D	USM3D	NSU3D	NSU3D
Type	N	C	N	N	N	C	N	N	N	N	N	N	N	B	N	N	N	C	C	C	C	N	N	N	N	N	C	N	N	C	C	C	C	C	C	C	C	N	N
Grid	UX 9	UH 13	SX 3	SX 3	SX 3	UH 14	UH 6	UH 6	UT 5	UH 8	UH 7	UH 7	UH 7	CB 16	UH 8	UT 12	UH 15	SX 11	UT 5	UT 5	UX 9	SX 3	SX 3	SX 3	SX 3	SX 3	UT 4	UT 5	UH 6	SX 1	SX 1	SX 2	SX 1	SX 1	SX 10	UT 4	UT 4	UH 6	UH 6
Turb	SST*	KE*	SA*	SA*	SA*	SA	SA	SA	SA	SA	SA	SST	RSM	VLES	SA	SA	SA*	SA*	SA	KE*	KE*	SA*	SA*	SA*	SST	SA	SA	SA	SA	SST	SA	SST	SA	SA	SST	KO	KO*	SA	SST
Notes	Trans-ition, limited config 8		Bracket	brckets off on bracket-like grid	Config 8 grid study			Thin, no F	No polars	Bracket	No config 8, no F	No config 8, no F	No config 8, no F	Trans-ition, polars on F, Bracket	Thin, Bracket	Thin	Bracket		Used node-center grids	Used node-center grids		Bracket	HLLC, limited config 8	Central, no grid study, no config 8	No config 8, Bracket	Only 1 condition run				Thin	Thin	Thin				No F		Thin	Thin, no grid study

N=node-centered
C=cell-centered
B=Boltzmann

SX=Structured
UX=Unstructured hex
UT=Unstructured tet
UH=Unstructured hybrid
CB=Cartesian based

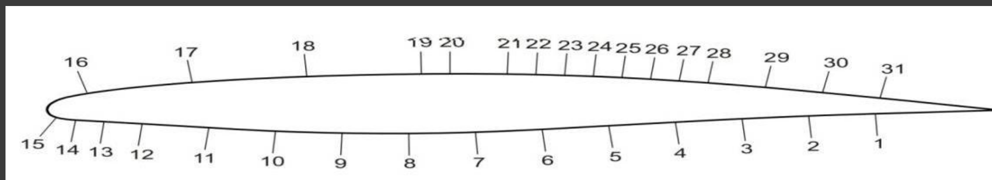
1=Str point-matched A
2=Str point-matched B
3=Str overset A
4=Unstr tet cell-center A
5=Unstr tet node-center A
6=Unstr hybrid (merged from 5)
7=Unstr hybrid node-center A
8=Unstr hybrid node-center B
9=Unst hex (from 1)

SA=Spalart-Allmaras
SST=Menter Shear Stress Transport
KE=K-Epsilon
RSM=Reynolds Stress Model
KO=Wilcox K-Omega
VLES=Very Large Eddy Simulation
* = modified in some way

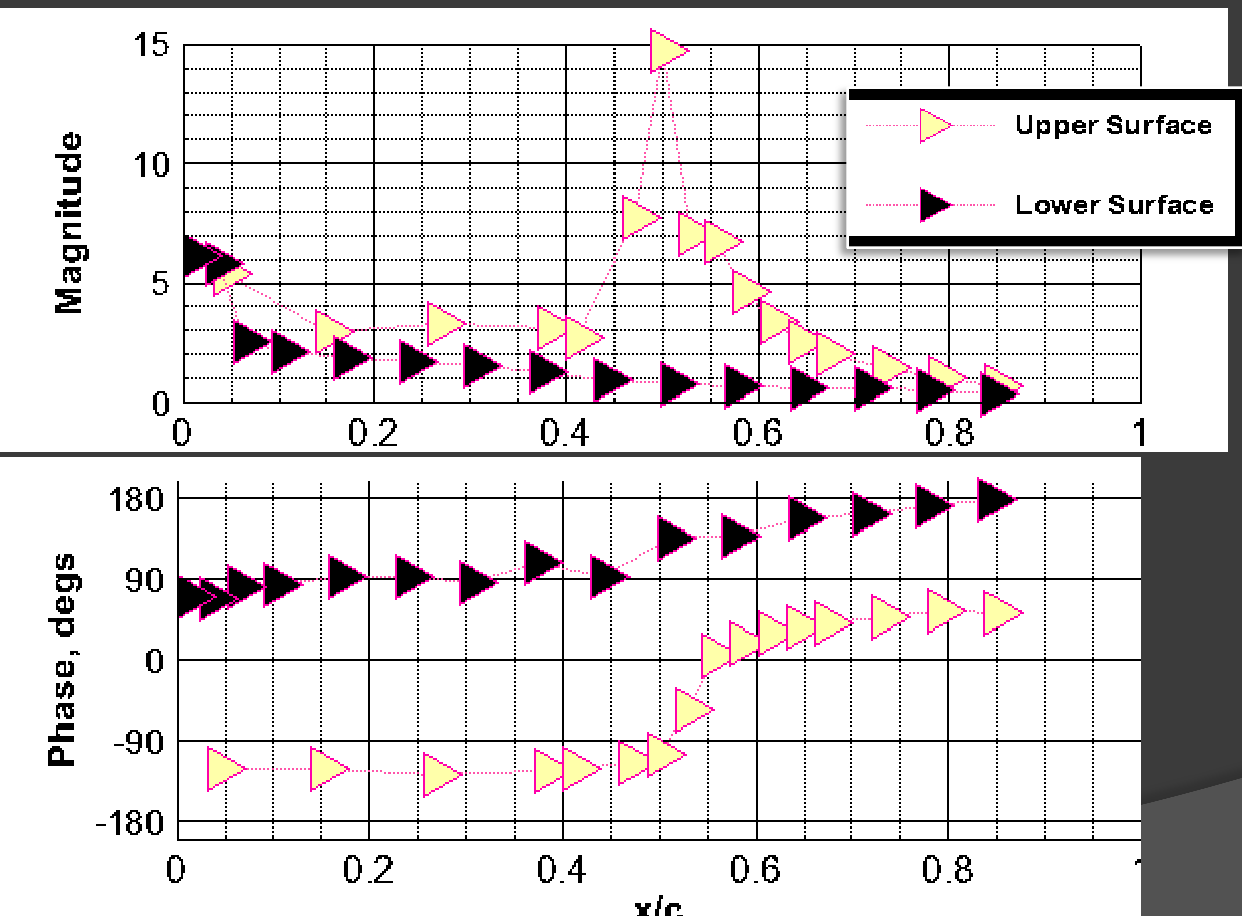
Data processing slide goes here

Static data example

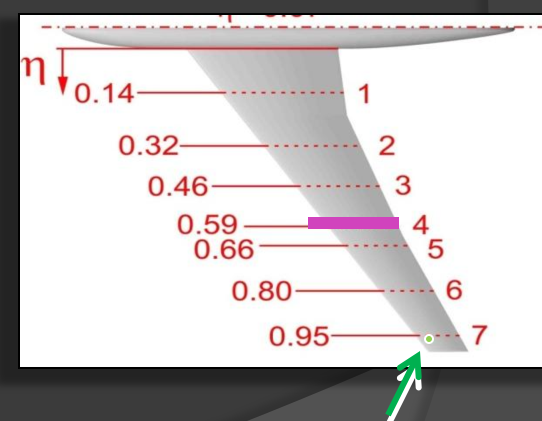
HIRENASD Frequency Responses at 2nd Bending Mode Frequency (78.9 Hz)



Cp(x)/displacement



Pressure coefficients at span station 4 due to displacement at location (15,1)



Reference quantity: Displacement at location (15,1)

Data comparisons, a beginning

- Code-to-code comparisons:
  - Start with DPW and HiLift Methods
    - Statistics of the process
      - Define variation
      - Define means
      - Determination of outlier data sets
      - Coefficients of variation
  - Comparison methods relative to experimental data undetermined

DPW & HiLift Statistical analyses

- Focused on the code-to-code comparisons
- Treated the computations of a test case as a collective
- Used N-version testing in a statistical framework

A population mean estimate, $\hat{\mu}$, was estimated using the sample MEDIAN
(The median is thought to provide a robust estimate when outliers are present)

A population standard deviation estimate, $\hat{\sigma}$,is calculated employing the sample mean, $\bar{x}$

$$\hat{\sigma} = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2}$$

Scatter limits are calculated employing these estimates and a coverage factor, K, estimated for a uniform distribution ($K = \sqrt{3}$)

$$Limit = \hat{\mu} \pm K\hat{\sigma}$$

Coefficient of variation estimates, $\widehat{C}_v$, were used to compare the variation of populations with different means. Employed to compare workshop-to-workshop and among different grid resolutions and among grid types (e.g. str, unstr)

$$\widehat{C}_v = \frac{\widehat{\sigma}}{\widehat{\mu}}$$

DPW & HiLift Statistical analyses

- Focused on the code-to-code comparisons
- Treated the computations of a test case as a collective
- Used N-version testing in a statistical framework

A population mean estimate, , was estimated using the sample MEDIAN

OUTLIERS are identified as those submitted results that lie outside of the scatter limits

They identify potential significant CFD differences

The outlier data sets should be investigated to determine why that analysis result is an outlier

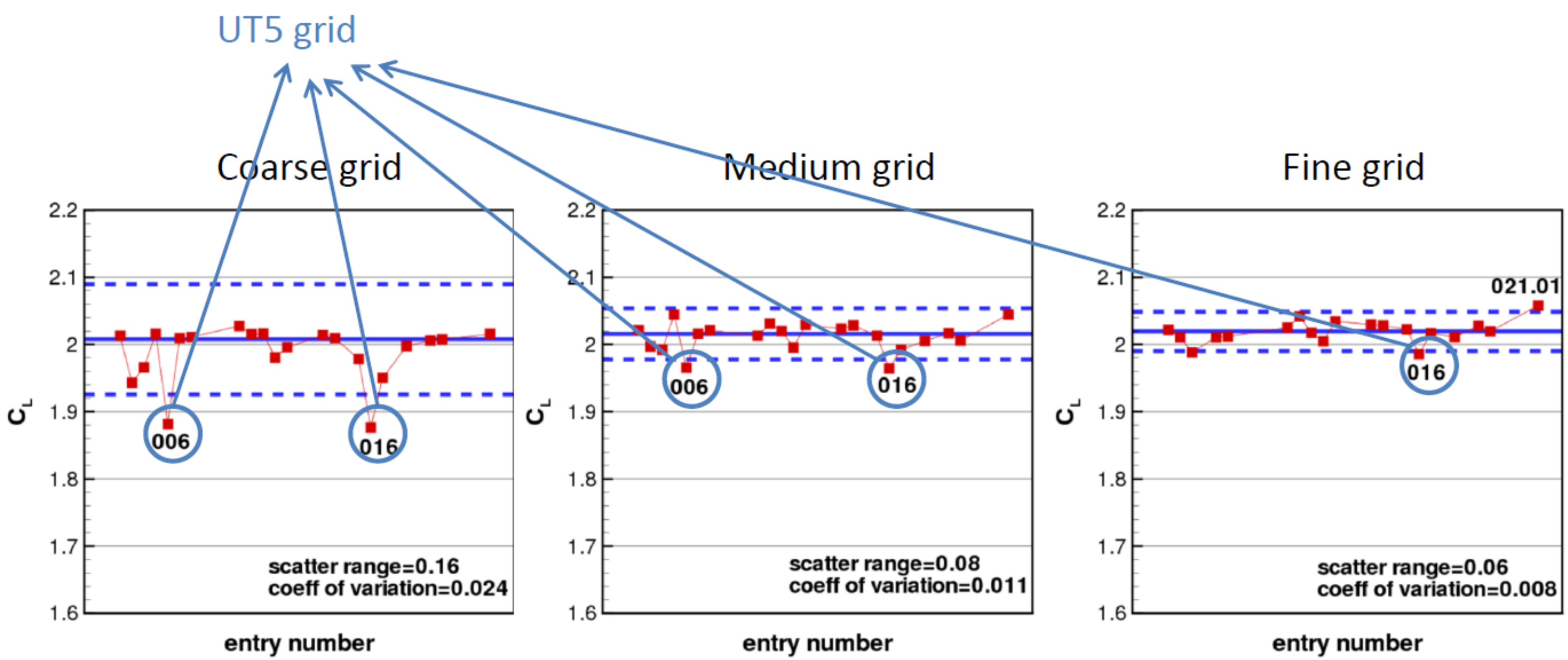
Scatter limits are calculated employing these estimates and a coverage factor, K, estimated for a uniform distribution ($K = \sqrt{3}$)

$$Limit = \hat{\mu} \pm K\hat{\sigma}$$

Coefficient of variation estimates, , were used to compare the variation of populations with different means. Employed to compare workshop-to-workshop and among different grid resolutions and among grid types (e.g. str, unstr)

SA entries, alpha=13°

Lift Coefficient



-Range of scatter limits and coefficient of variation decreased as grid was refined

-Smaller variation (on M & F) for SA alone

-Similar story for C_D and C_M

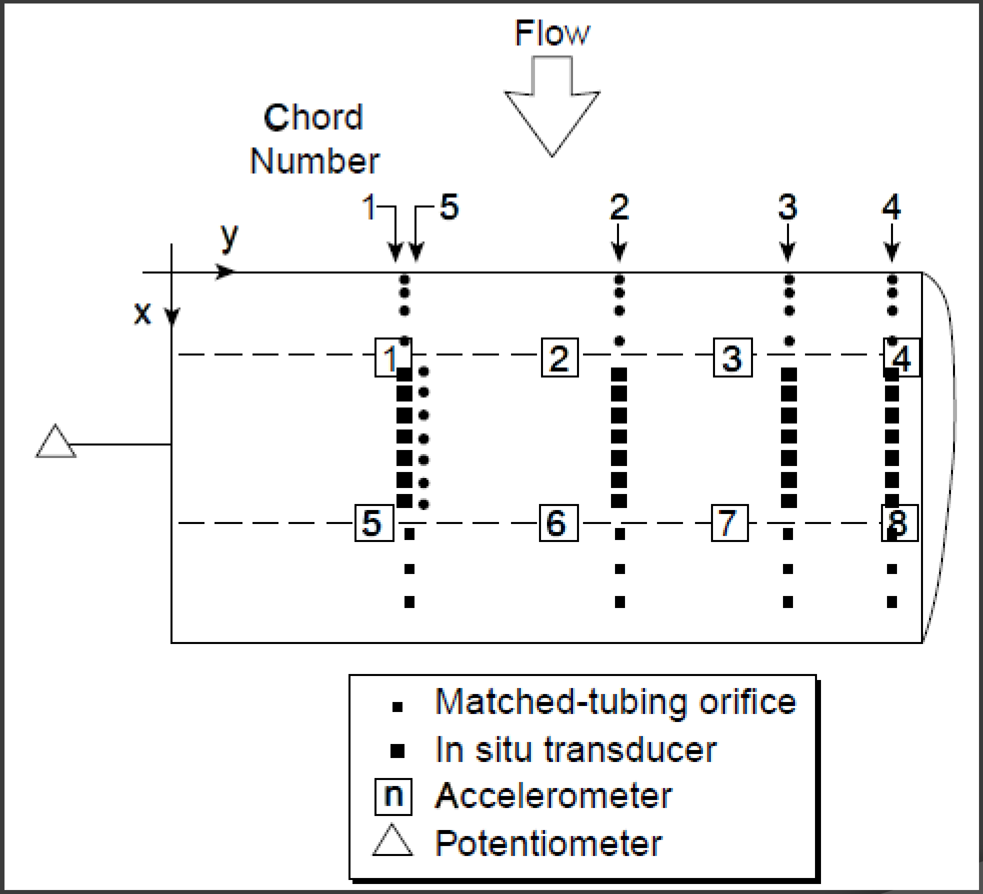
Ref: Rumsey, Long, Stuever, and Wayman HiLift Prediction Workshop

Configuration reference information

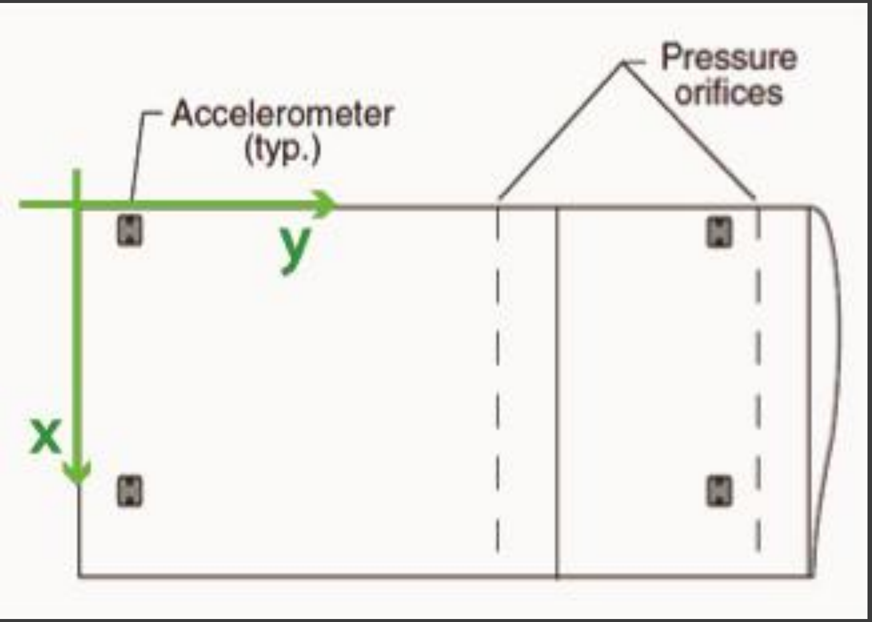
Reference quantities

		RSW	BSCW	HIRENASD
Reference chord	c_{ref}	24 inches	16 inches	0.3445 m
Model span	b	48 inches	32 inches	1.28571 m
Area	A	1152 in^2	512 in^2	0.3926 m^2
Dynamic pressure	q	108.9 psf	200 psf	40.055 kPa (pt 159,132) 88.697 kPa (pt 271,250)
Moment reference point, relative to axis system shown in Figs 2, 5 and 9		11.04 inches	4.8 inches	0.252 m
		0	0	-0.610 m
		0	0	0
Transfer function reference quantity		Pitch angle	Pitch angle	Vertical displacement (at x=1.24521m, y=0.87303m)

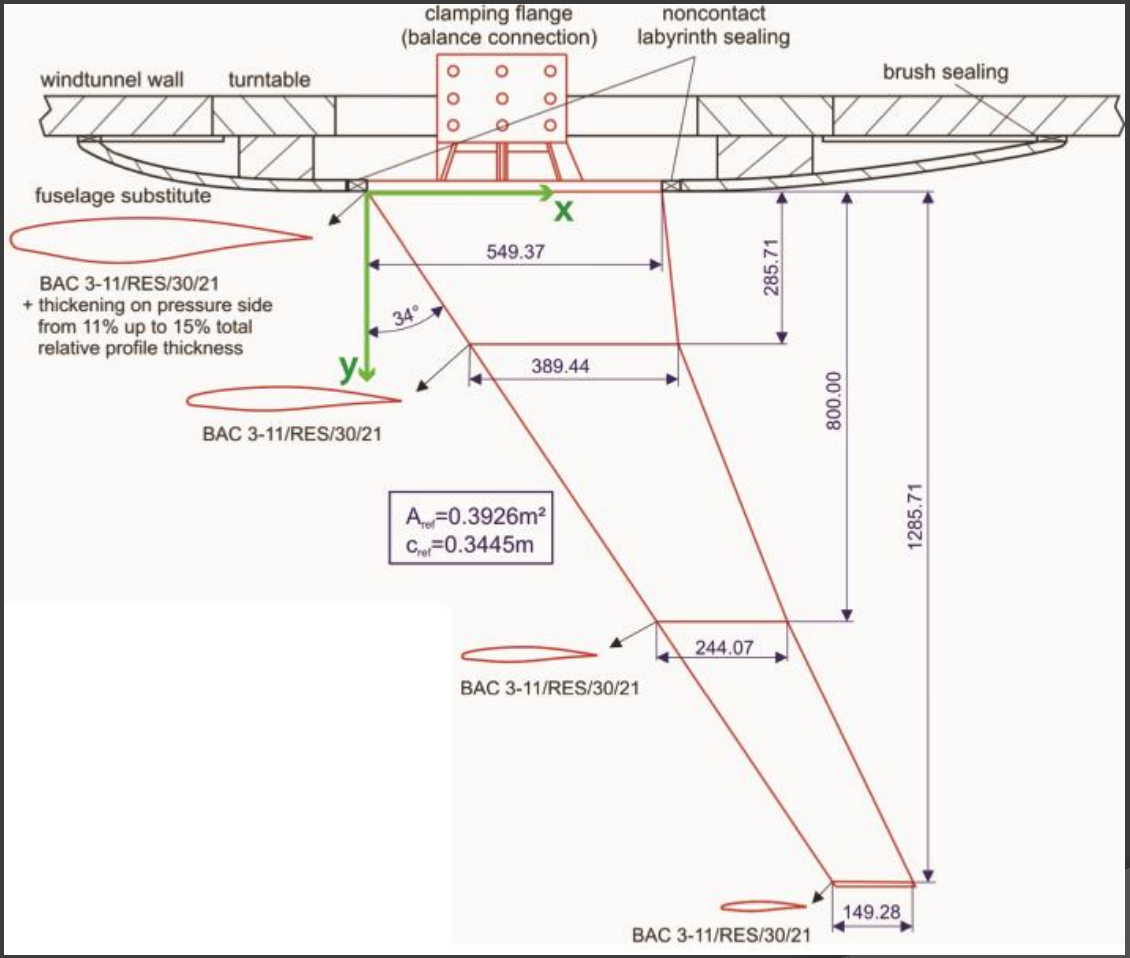
Coordinate System, Reference Point (RSW)



Coordinate System, Reference Point (BSCW)



Coordinate System, Reference Point (HIRENASD)



Preliminary Analysis Results

Preliminary Analysis Progress & Results

- RSW: NASA- Pawel Chwalowski
- BSCW: NASA- Pawel Chwalowski
- HIRENASD: Technion & ISCFDC- Daniella Raveh, Yair Moryossef
- HIRENASD: FOI- Mats Dalenbring
- HIRENASD: DLR- Markus Ritter

Preliminary RSW Analysis Update

• Marilyn Smith generated unstructured grids (node based, mixed elements and tets only) using SolidMesh (coarse, medium, fine grid resolution). Thanks!

• Thorsten Hansen, Ansys Germany, generated structured hexahedral grid (coarse grid). Thanks!

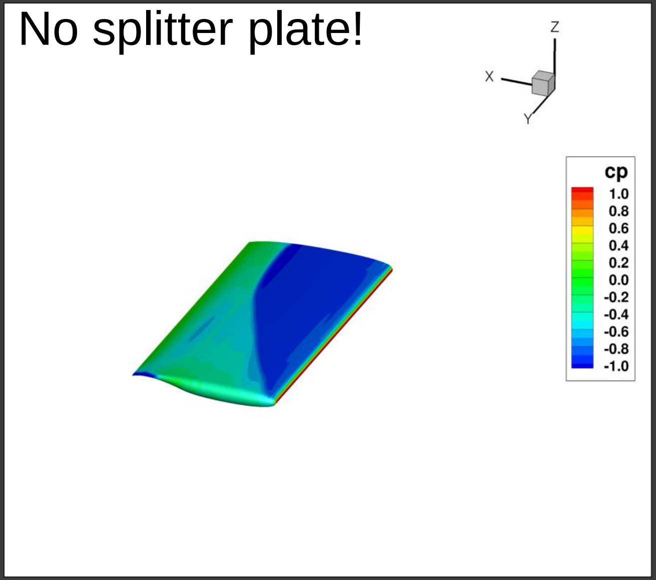
• Pawel Chwalowski generated unstructured mixed elements grids with and without splitter plate and tunnel wall using VGRID.

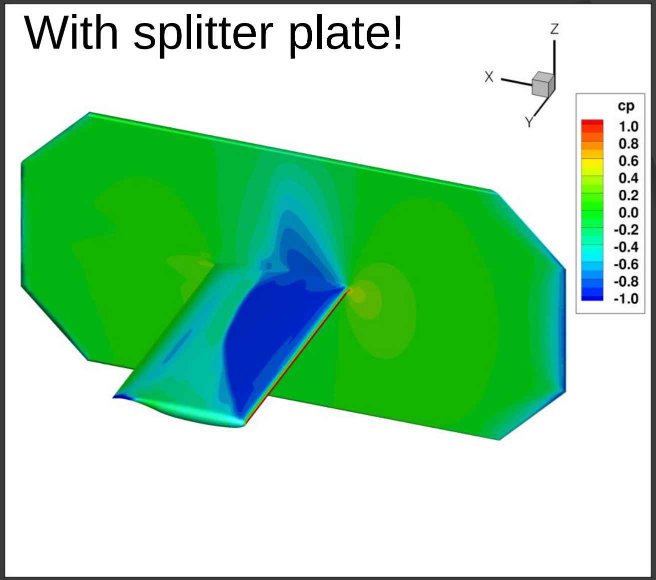
• Steady and Unsteady runs are completed on a medium grid. Data needs to be post-processed!

Preliminary RSW Analysis Update

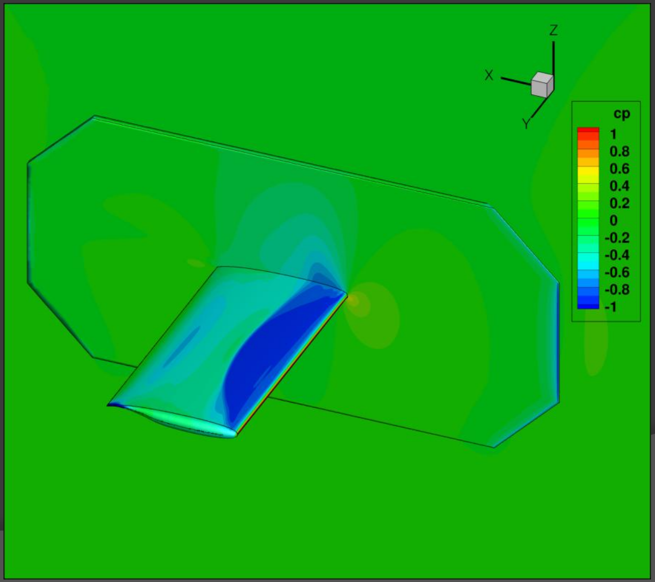
Mach = 0.825, AoA = 2deg

As proposed for AePW:

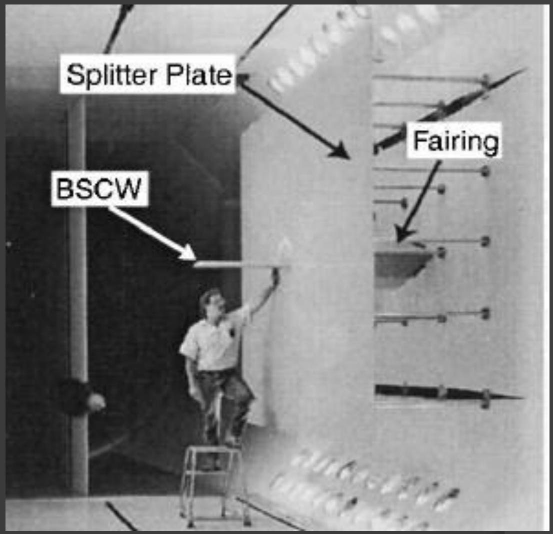




With splitter plate!
And viscous tunnel wall!



Preliminary BSCW Analysis Update



- Eric Blades generated unstructured grid (node based, mixed elements) using SolidMesh (medium resolution grid). Thanks!

- Pawel Chwalowski generated unstructured mixed elements grids using VGRID (medium resolution grid).

- First analysis attempt identified a discontinuity on the leading edge of the wing.

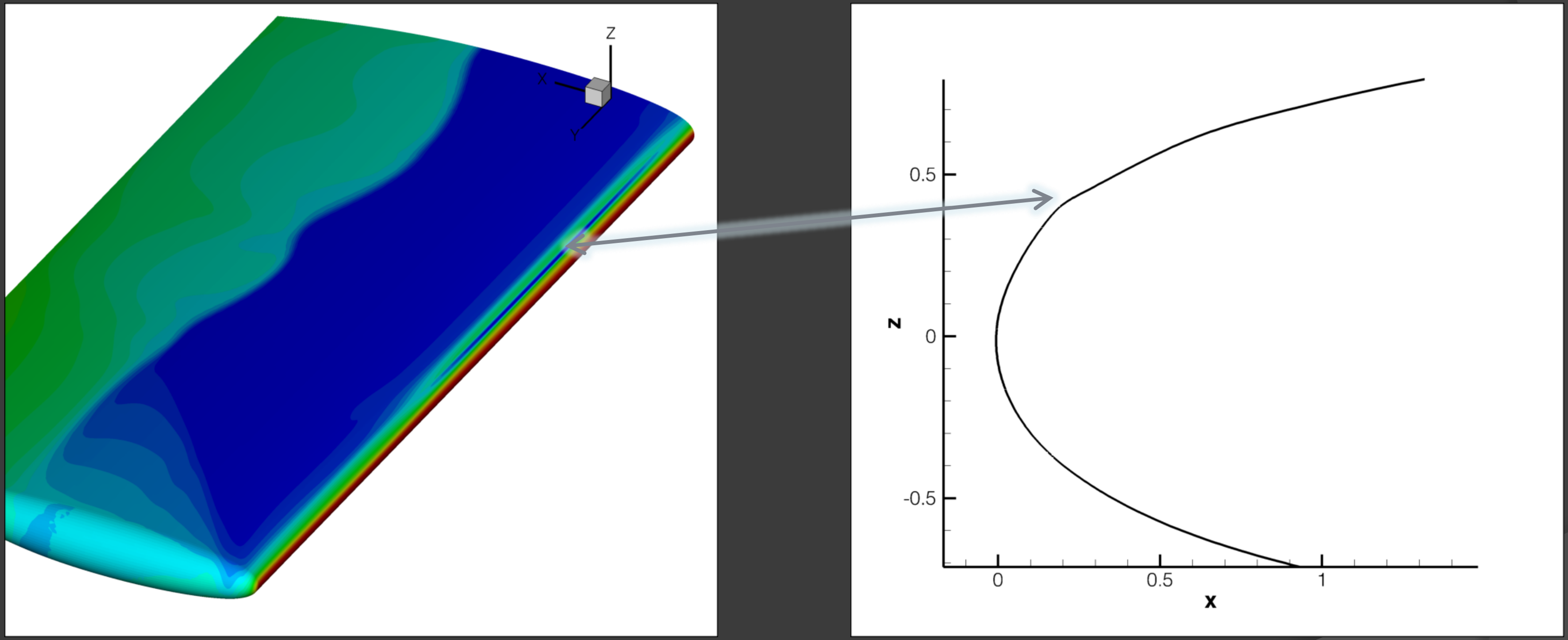
- Iges file needed to be corrected and new grids constructed.

- The effect of the splitter plate has not been investigated.

Preliminary BSCW Analysis Update

discontinuity on the leading edge

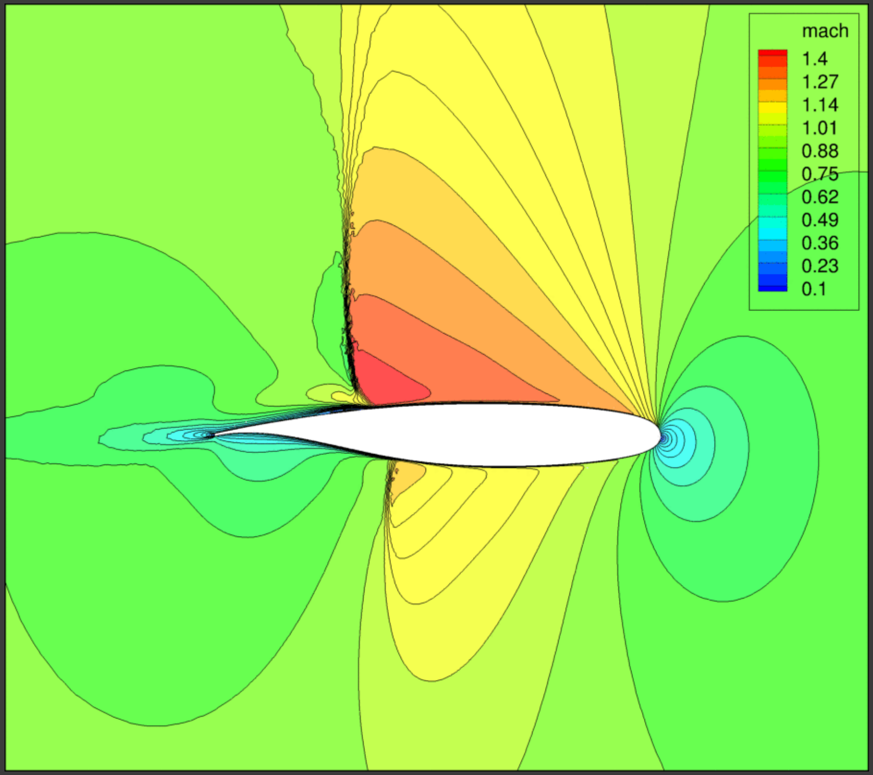
Mach = 0.85, AoA = 5deg

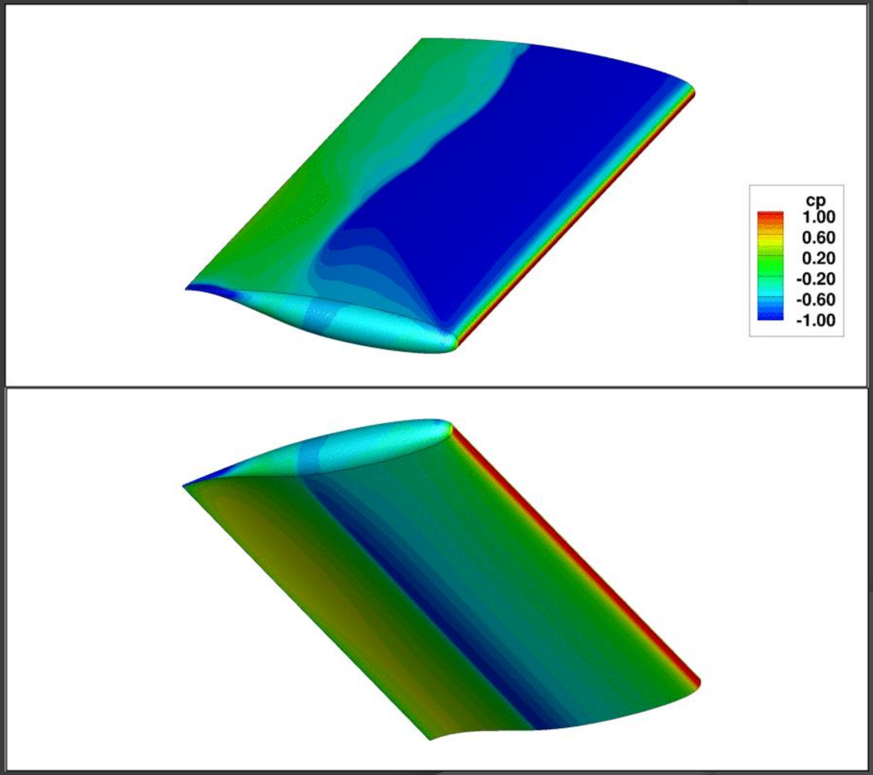


Preliminary BSCW Analysis Update

Unsteady Analysis

Mach = 0.85, AoA = 5deg, f = 10Hz, A = 1deg



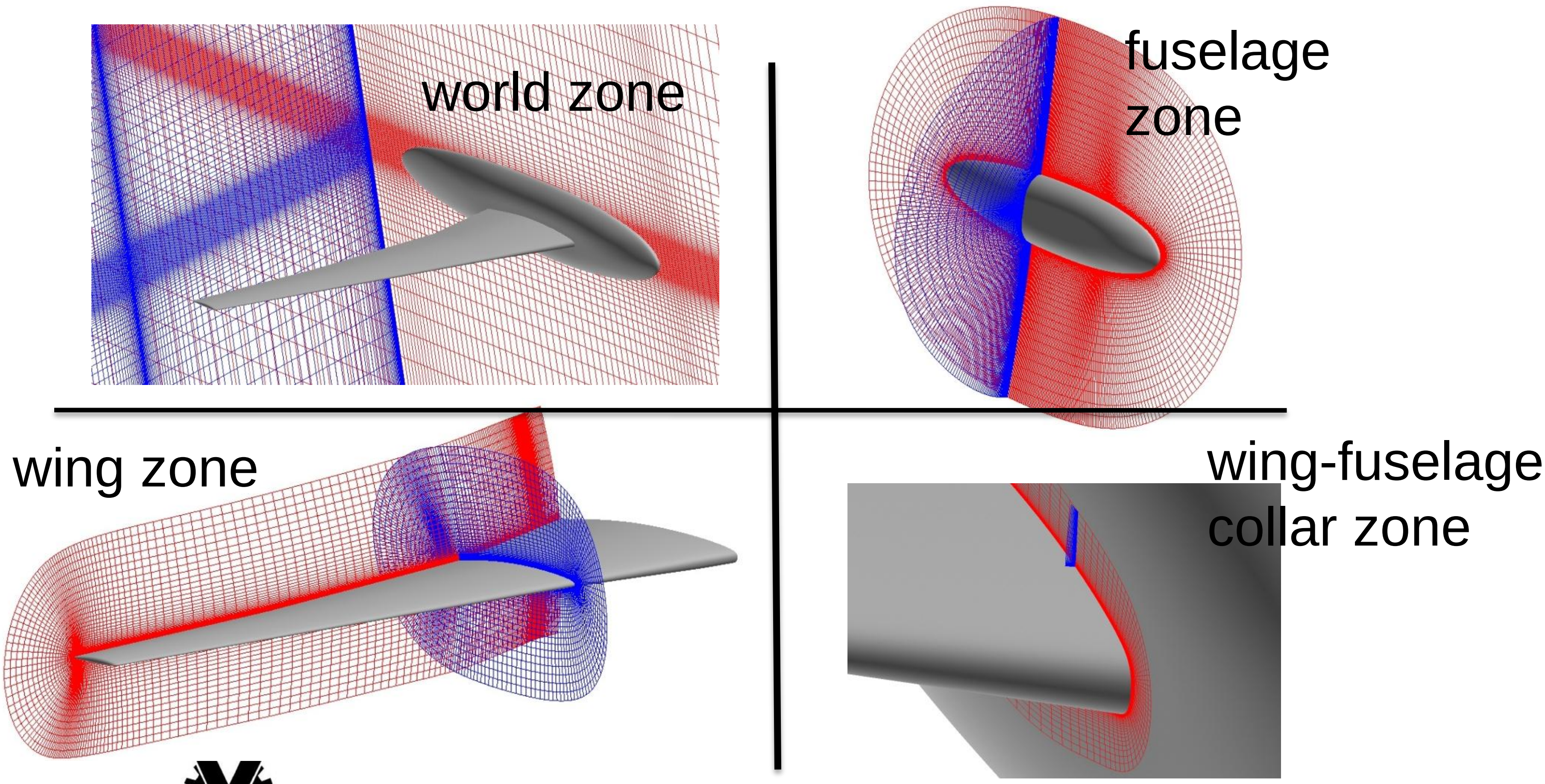


- HIRENASD:
- Steady state rigid body coefficients only available for preliminary results

HIRENASD Wing Analysis

- EZNSS (Elastic Zonal Navier-Stokes Solver) CFD Code by the Israeli CFD Center
  - Chimera overset grid
  - SA & k-ω TNT/SST turbulence models.
  - HLLC 3^{rd} order MUSCL Scheme.
  - Full viscous scheme.
  - $1^{st}/2^{nd}$ order in time.

Medium-Size Mesh



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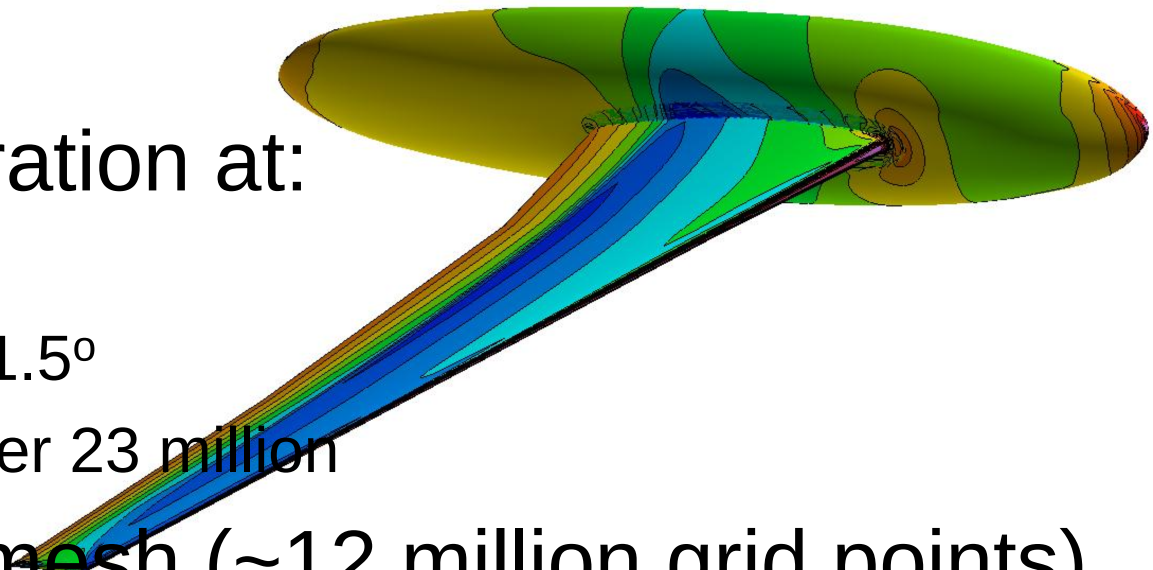
ISCFDC

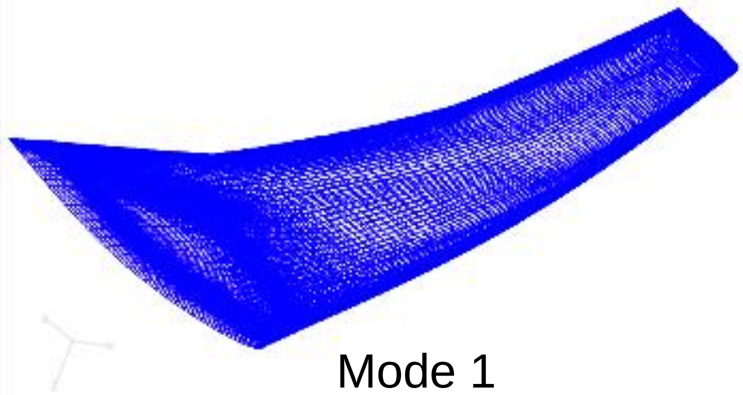
Flow Analysis



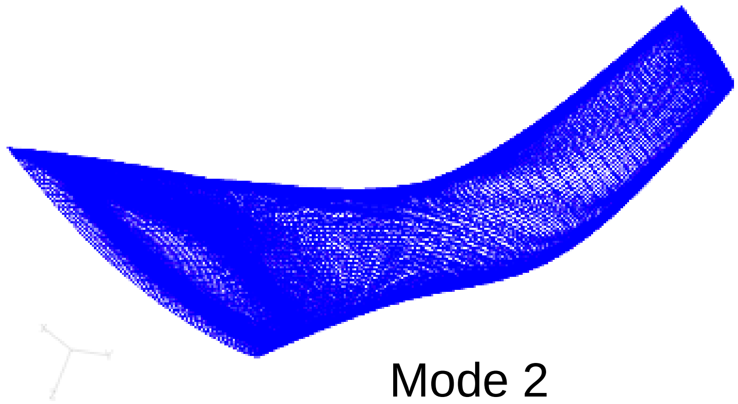
- Rigid Configuration at:
  - Mach 0.8
  - angle of attack 1.5^o
  - Reynolds number 23 million
- Medium-size mesh (~12 million grid points)
- CL=0.3492 ; CD=0.0139 ; Cmy=-0.1893

Mode Spline

Structural modes were mapped from finite-element grid to the CFD surface grid



Mode 1



Mode 2

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ISCFDC

Challenges

- Create and analyze coarse and fine meshes
- Perform aeroelastic analyses

Presentation

Plans for an Aeroelastic Prediction Workshop

Jennifer Heeg, Josef Ballmann, Kumar Bhatia, Eric Blades, Alexander Boucke, Pawel Chwalowski, Guido Dietz, Earl Dowell, Jennifer Florance, Thorsten Hansen, Mori Mani, Dimitri Mavriplis, Boyd Perry, Markus Ritter, David Schuster, Marilyn Smith, Paul Taylor, Brent Whiting, and Carol Wieseman

AeroelasticPW@gmail.com

https://c3.ndc.nasa.gov/dashlink/projects/47/

15th International Forum on Aeroelasticity & Structural Dynamics
June 26-30, 2011
Paris

Organizing Committee Roster

Name	Affiliation
Bhatia, Kumar	Boeing Commercial Aircraft
Ballmann, Josef	Aachen University
Blades, Eric	ATA Engineering, Inc.
Boucke, Alexander	Aachen University
Chwalowski, Pawel	NASA
Dietz, Guido	European Transonic Windtunnel (ETW)
Dowell, Earl	Duke University
Florance, Jennifer	NASA
Hansen, Thorsten	ANSYS Germany GmbH
Mani, Mori	Boeing Research & Technology
Mavriplis, Dimitri	University of Wyoming
Perry, Boyd	NASA
Ritter, Markus	Deutsches Zentrum für Luft- und Raumfahrt (DLR)
Schuster, David	NASA
Smith, Marilyn	Georgia Institute of Technology
Taylor, Paul	Gulfstream Aerospace
Whiting, Brent	Boeing Research & Technology
Wieseman, Carol	NASA

Acknowledgments

Funding of NASA participation,
geometry generation & workshop organization
NASA Subsonic Fixed Wing Program

Funding of Workshop organization
NASA Engineering & Safety Center

HIRENASD Research Project
Aachen University

HIRENASD Project Funding
German Research Foundation (DFG)

Grid Generation
Ansys, ATA, Georgia Tech, Technion University, ISCFDC, NASA

OUTLINE

- Overview
- Configurations
  - RSW
  - BSCW
  - HIRENASD
- Participation

Objectives of AePW

Assess state-of-the-art Computational Aeroelasticity(CAe) methods as practical tools for the prediction of static and dynamic aeroelastic phenomena and responses on relevant geometries

- Perform comparative computational studies on selected test cases
- Identify errors & uncertainties in computational aeroelastic methods
- Identify gaps in existing aeroelastic databases
- Provide roadmap of path forward
  - Additional existing data sets?
  - New experimental data sets?
  - Analytical methods developments?

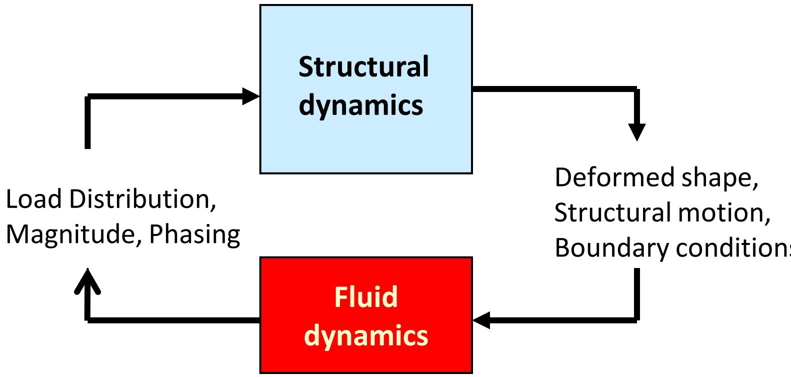
Guiding Principles

- Provide an **impartial** international **forum** for evaluating the **effectiveness of CAe methods**
- Promote **balanced participation** across academia, government labs, and industry
- Use common **public-domain** subject geometries, simple enough to permit **high-fidelity computations**
- **Provide** baseline **grids** and baseline **structural models** to encourage participation and help reduce variability of CAe results
- **Openly discuss** and identify areas needing **additional research** and development
- Conduct uncertainty quantification analyses of CAe results to **establish confidence levels in predictions**
- Schedule **open-forum sessions** to further engage interaction among all interested parties
- Maintain a **public-domain-accessible database** of geometries, grids, and results
- **Document** workshop findings; **disseminate** this information through publications and presentations

Building block approach to validation

Utilizing the classical considerations in aeroelasticity

- Fluid dynamics
- Structural dynamics
- Fluid/structure coupling



Validation Objective of 1st Workshop

Unsteady aerodynamic pressures due to forced modal oscillations

Future Workshops

- Directed by results of this workshop
- Directed by big-picture assessment of needs & interests

1st AePW to be held weekend before next year's AIAA SDM conference April 21-22, 2012

- Presentations by workshop participants
- No formal AIAA papers
- Prior commitment & data submission required for presentation
- Attendance & forum discussions open to all (separate registration from SDM conference)

Aeroelastic Prediction Workshop Schedule

- Identified organizing committee: Dec 1, 2010
- Data Release & Workshop Kickoff: IFASD 2011, Paris
- 10 months to perform computations
- Workshop: April 2012

Activity	FY10	FY11	FY12	FY13
Form organizing committee				
Workshop kick-off			Kickoff at IFASD	
Config, grids, etc. available on-line				
Perform analysis of selected config.				
Conduct 1st Aeroelastic Prediction Workshop				Workshop at 2012 SDM
Update / improve CFD results / code(s)				
Perform comparisons, Statistical analyses				
Present conference papers				
Formulate AePW 2				

FY= USGovt Fiscal Year, Oct-Oct (e.g. FY12 – Oct 2011-Oct 2012)

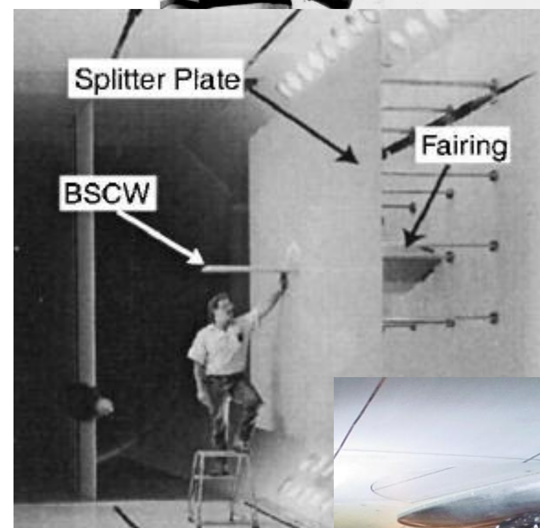
OUTLINE

- Overview
- Configurations
  - RSW
  - BSCW
  - HIRENASD
- Participation

Configurations Selected

- Rectangular Supercritical Wing

- Benchmark Supercritical Wing



- High Reynolds number Aero-Structural Dynamics Model

Rectangular Supercritical Wing (RSW)

- Simple, rectangular wing
- Static and forced oscillation pitching motion

Known deficiencies:

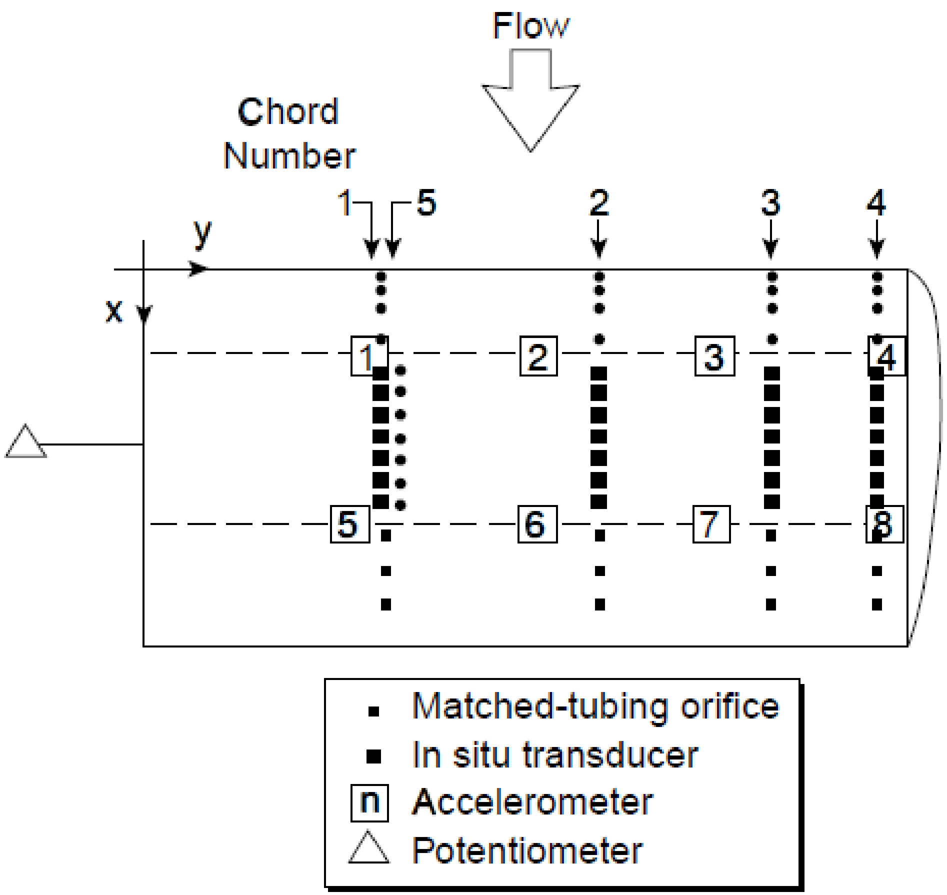
- Splitter plate deficiencies
  - Small size
  - Located in the tunnel wall boundary layer (6 " off of the wall)
- Tunnel wall slots open

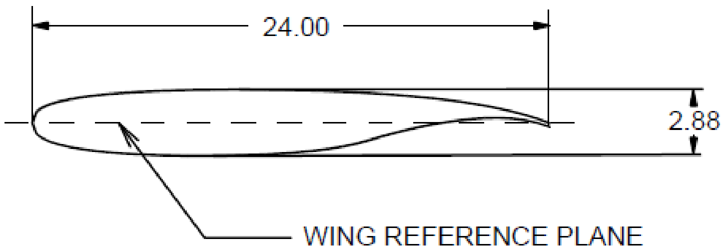
M=0.825, Re_c=4.0 million, test medium: R-12

a) Steady Cases
   i. $\alpha = 2°$
   ii. $\alpha = 4°$

b) Dynamic Cases: $\alpha = 2°$, $\theta = 1.0°$
   i. f = 10 Hz
   ii. f = 20 Hz

RSW Model Layout and Airfoil

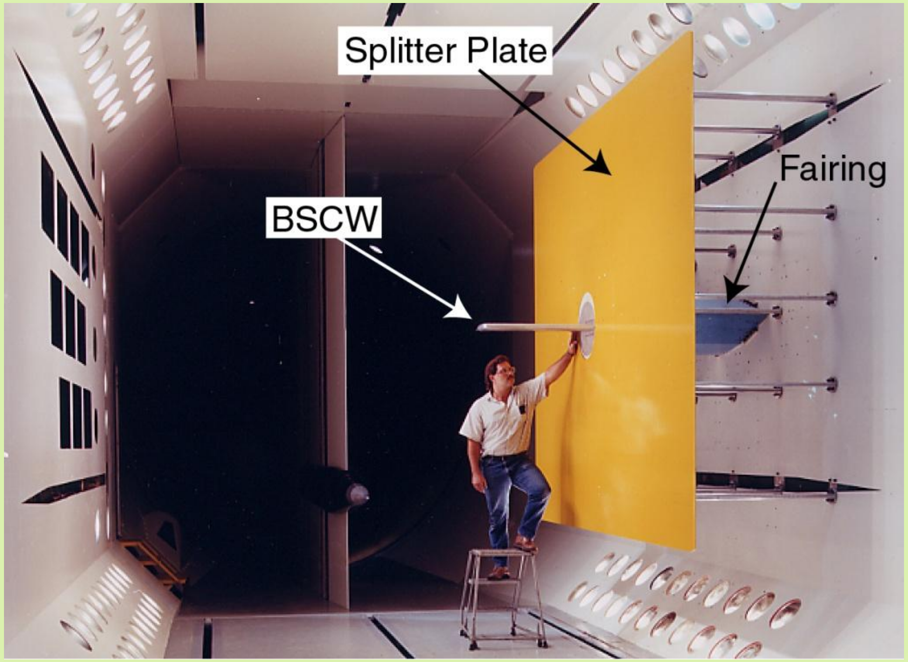




Experimental data acquired in R-12 @ Re_c = 4 million, Mach=0.825

Benchmark Supercritical Wing (BSCW)

- Simple, rectangular wing
- Data acquired under mixed attached/separated flow conditions



Known deficiencies:

- Limited number of pressure transducers in experimental data
- Limited number of discrete frequencies of oscillation
- Mach number is at edge of acceptable range for quality pressure data with splitter plate

M=0.85, Re_c=4.49 million, test medium: R-134a

a) Steady Case
   i. $\alpha = 5°$
b) Dynamic Cases
   i. $\alpha = 5°, \theta = 1°, f = 1$ Hz
   ii. $\alpha = 5°, \theta = 1°, f = 10$ Hz

BSCW Geometry and Test Configuration

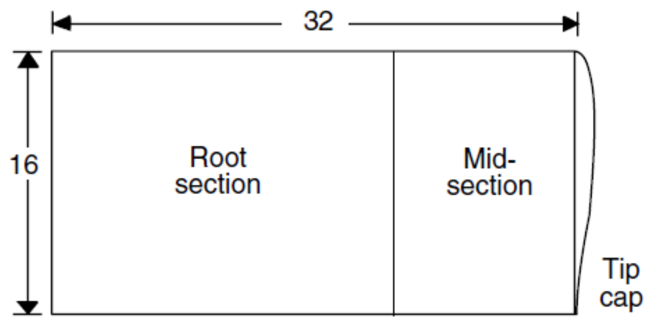
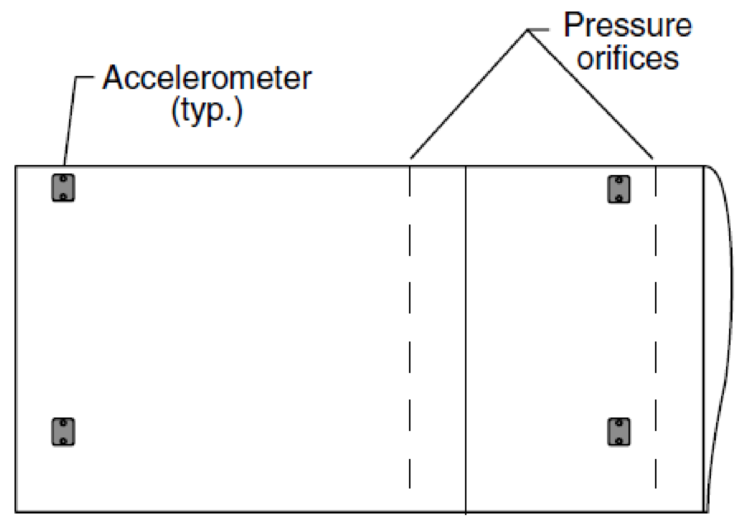
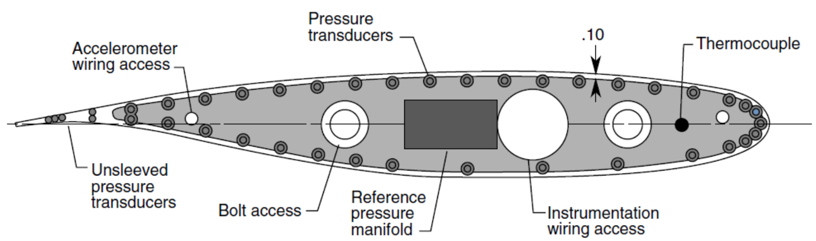


Figure 1. Planform of model. Dimensions are in inches.

Figure 2. NASA SC(2)-0414 airfoil.





Experimental data acquired in R-134a @ q = 200 psf, Re_c = 4.49 million, Mach=0.85

HIRENASD
funded by DFG

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HIRENASD

- 3-D aeroelastic wing with generic fuselage model
- Steady and forced (structural resonance) oscillation testing
- Data:
  - Balance forces for integrated load comparisons,
  - Mean and fluctuating pressure data
  - Surface deformation data from optical and strain measurements during testing
- Known deficiencies:
  - Limited deflection data
  - Only excited at natural frequencies

M = 0.80, test medium: nitrogen

a) Steady (Static Aeroelastic) Cases
   i. Re = 7.0 million, α = 1.5°
   ii. Re = 23.5 million, α = -1.34°

b) Dynamic Cases: forced oscillation at 2nd Bending mode frequency
   i. Re = 7.0 million, α = 1.5°
   ii. Re = 23.5 million, α = -1.34°

HIRENASD
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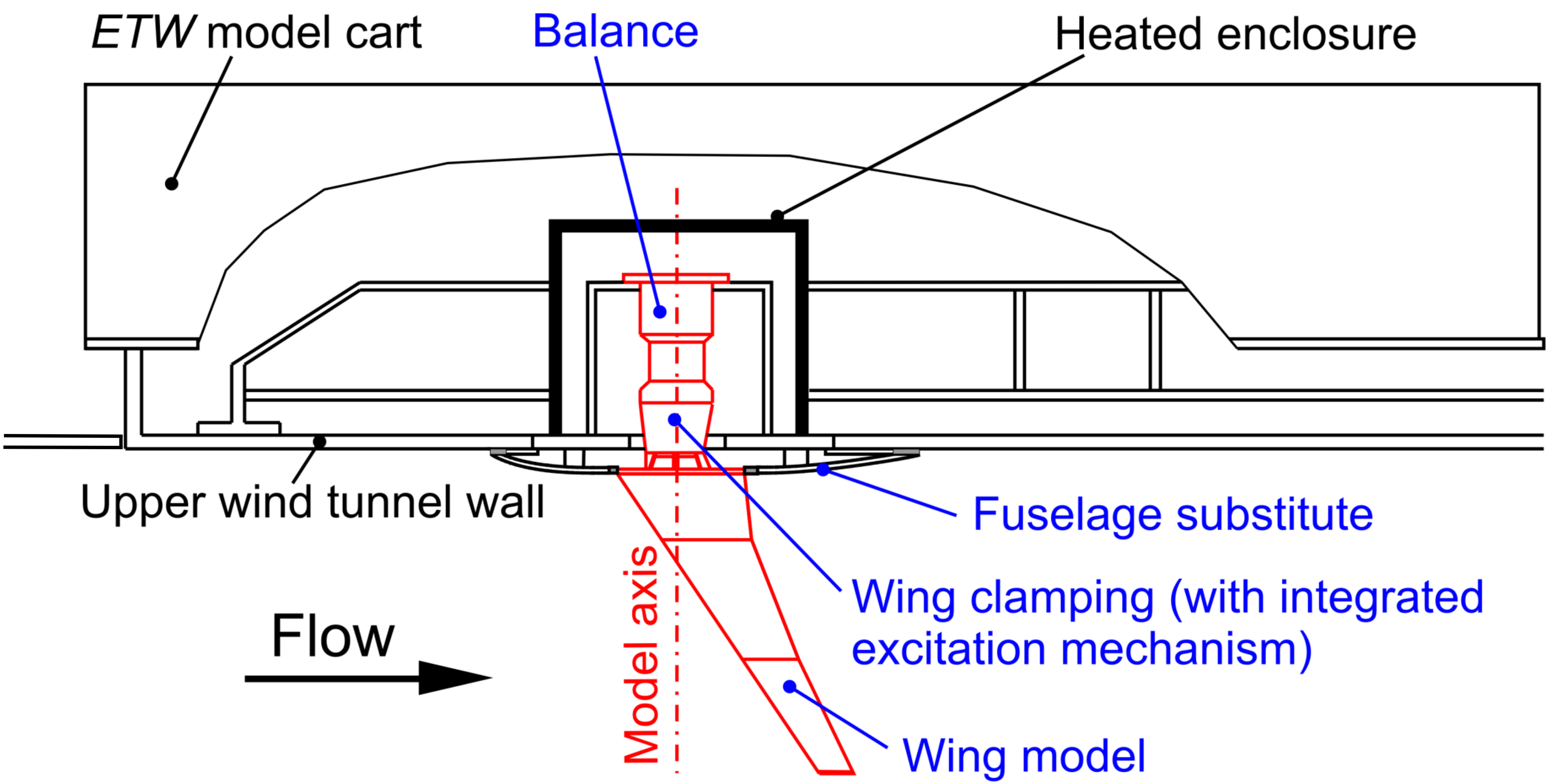
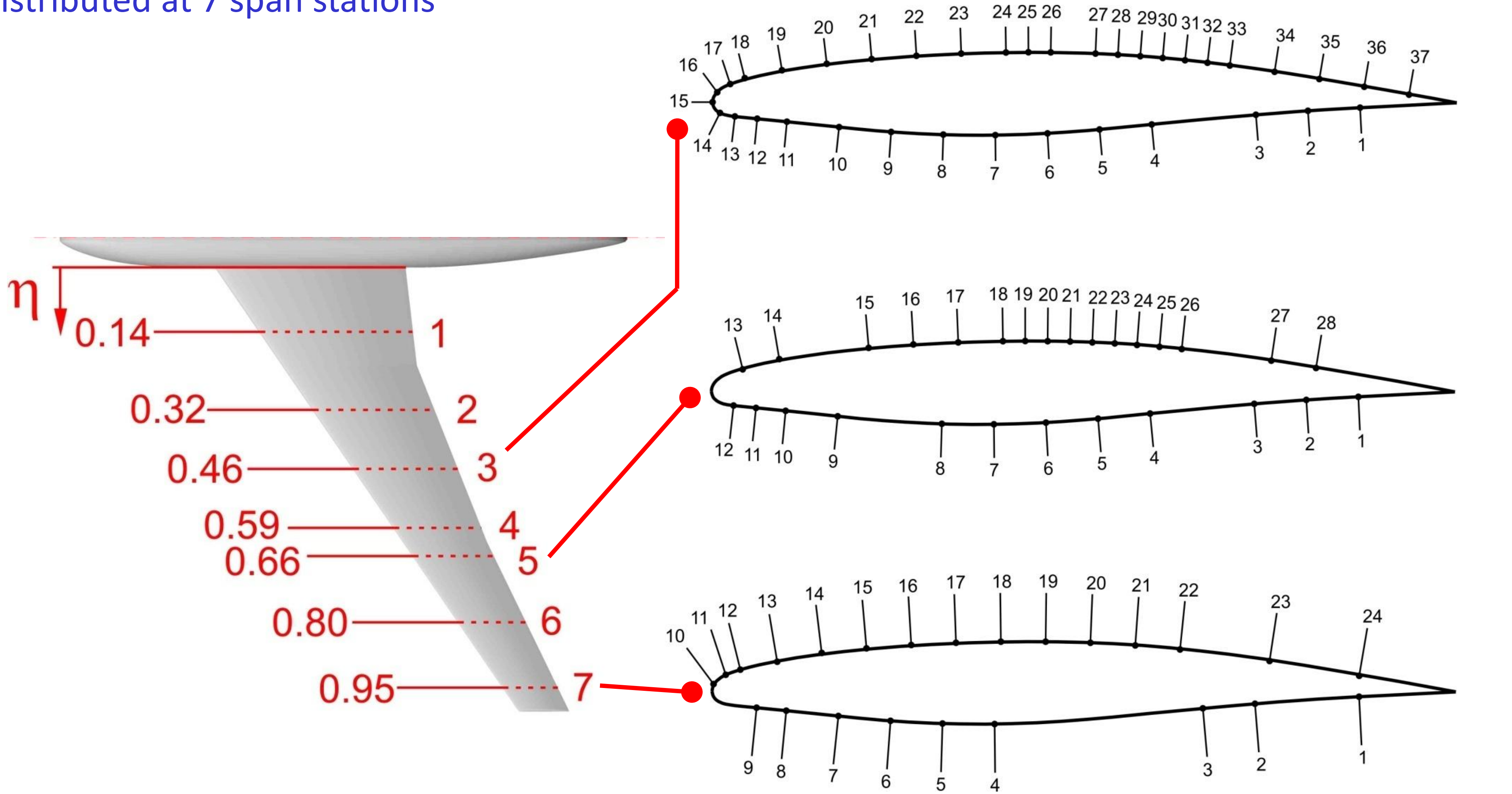


HIRENASD
funded by DFG

RWTH AACHEN UNIVERSITY

Pressure Sensors:

259 unsteady pressure sensors distributed at 7 span stations



AePW Dataset Selection

- Rectangular Supercritical Wing: (M=0.825, Re_c=4.0 million, test medium: R-12)
  - Steady Cases
    - $\alpha = 2°$
    - $\alpha = 4°$
  - Dynamic Cases: forced pitching oscillation ($\alpha = 2°$, $\theta = 1.0°$)
    - f = 10 Hz.
    - f = 20 Hz.

- Benchmark SuperCritical Wing (Semi-Blind) (M=0.85, Re_c=4.49 million, test medium: R-134a)
  - Steady Case
    - $\alpha = 5°$
  - Dynamic Cases: forced pitching oscillation ($\alpha = 5°$, $\theta = 1°$)
    - f = 1 Hz
    - f = 10 Hz

- HIRENASD (M = 0.80, test medium: nitrogen)
  - Steady Cases
    - Re_c = 7.0 million, $\alpha = 1.5°$, static aeroelastic
    - Re_c = 23.5 million, $\alpha = -1.34°$, static aeroelastic
  - Dynamic Cases: forced oscillation at 2^{nd} Bending mode frequency
    - Re_c = 7.0 million, $\alpha = 1.5°$, f= 78.9 Hz
    - Re_c = 23.5 million, $\alpha = -1.34°$, f=80.3 Hz

OUTLINE

- Overview
- Configurations
  - RSW
  - BSCW
  - HIRENASD
- Participation
  - Invitation to participate
  - Data provided to participants
  - Data expected from participants

Invitation to participate

Go to

https://c3.ndc.nasa.gov/dashlink/projects/47/

To sign up for

Email distribution list → Click

Workshop participation → Click

Join Distribution List

Participate in AePW

AePW email address:

AeroelasticPW@gmail.com

Participant Information Sources

- Workshop website: with downloads of grids, geometry, structural model, etc
  - https://c3.ndc.nasa.gov/dashlink/projects/47/
- Links to:
  - HIRENASD website (German and English languages)
    - http://www.lufmech.rwth-aachen.de/HIRENASD/
    - https://heinrich.lufmech.rwth-aachen.de/index.php?lang=en&pg=home
  - Drag and High-Lift Prediction Workshops
    - http://aaac.larc.nasa.gov/tsab/cfdlarc/aiaa-dpw/
    - http://hiliftpw.larc.nasa.gov/

Summary of AePW Grids

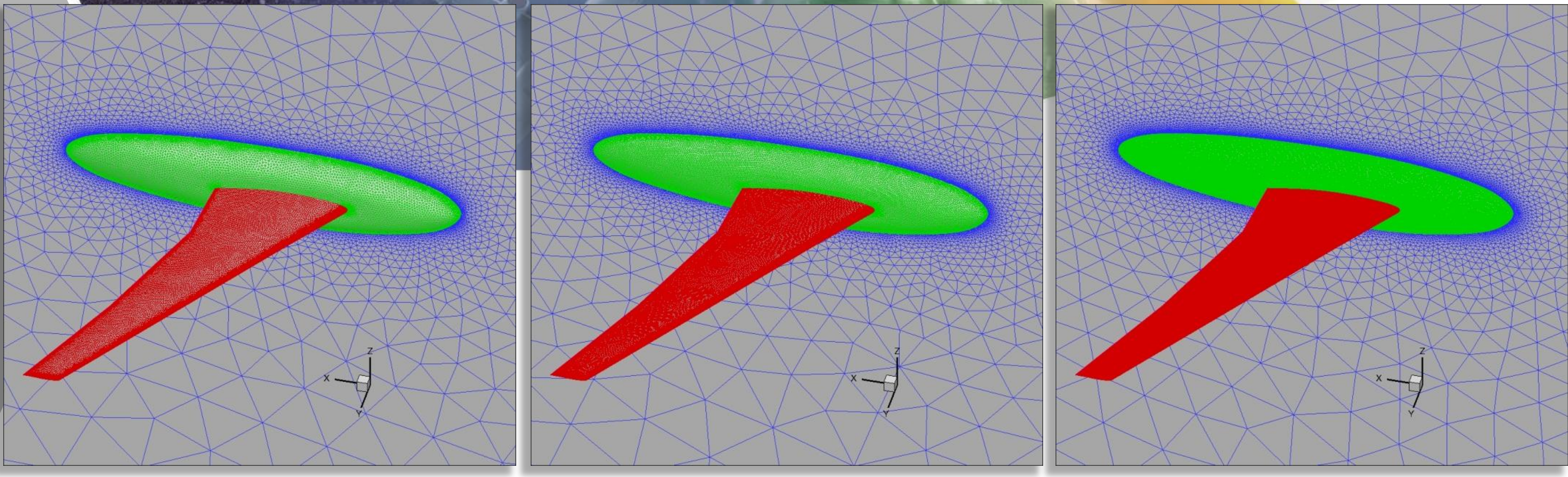
Configuration	GRID TYPE																				
	Unstructured												Structured			Overset		
	Node Based						Cell Centered						Hex Multiblock					
	Mixed			Tetrahedra			Mixed			Tetrahedra								
	C	M	F	C	M	F	C	M	F	C	M	F	C	M	F	C	M	F
RSW	√	√	√	√	√	√	○	○	○				√					
BSCW	⊙	⊙	⊙				○	○	○				○	○	○			
HIRENASD	√	√	√				○	○	○				√			√		

√ = Complete

⊙ = In process

○ = Desired

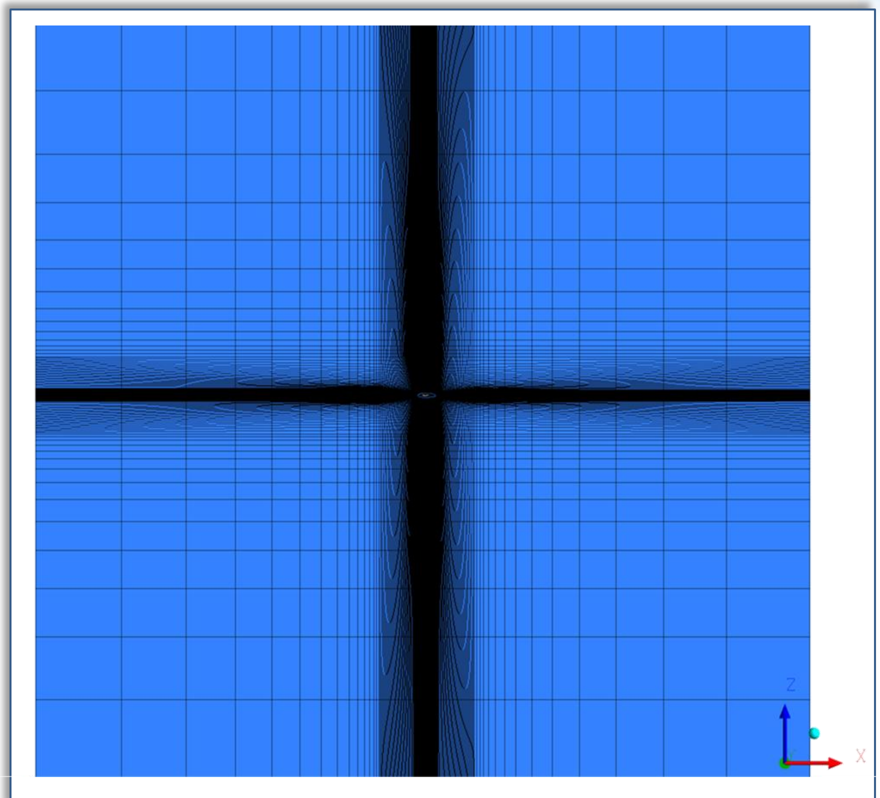
Overview of the coarse, medium, and fine unstructured HIRENASD meshes

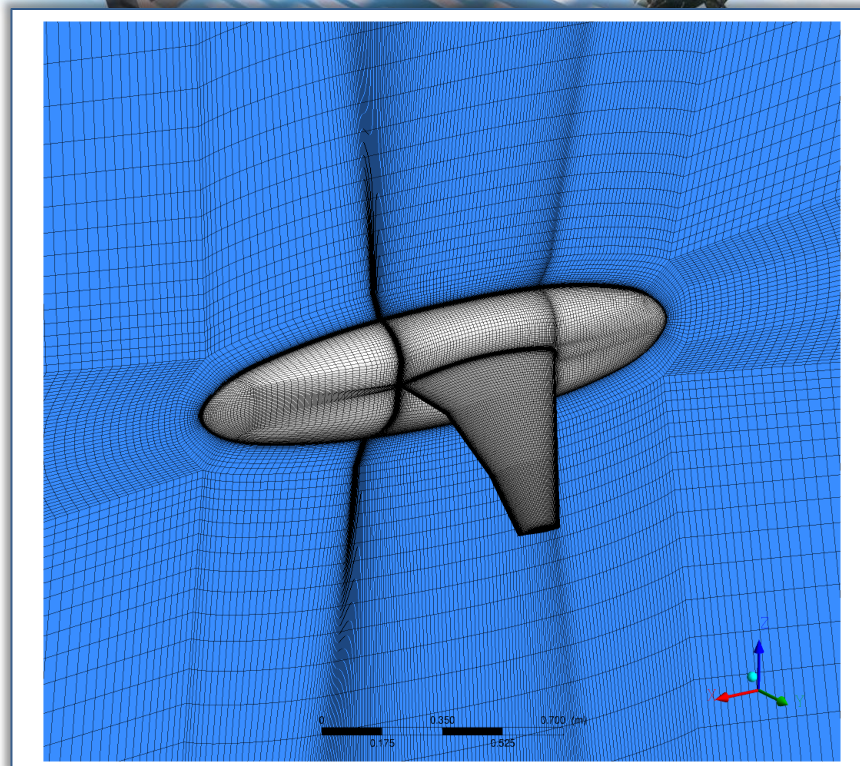


- **Coarse:**
  - **5676008 Total Nodes**
  - **14378129 Total Elements**
  - **Boundary layer cells:**
    - **34 prism layers**
    - **Stretching factor 1.28**
- **Medium:**
  - **16052763 Total Nodes**
  - **38871412 Total Elements**
  - **Boundary layer cells:**
    - **40 prism layers**
    - **Stretching factor 1.25**
- **Fine:**
  - **46393528 Total Nodes**
  - **104678223 Total Elements**
  - **Boundary layer cells:**
    - **45 prism layers**
    - **Stretching factor 1.23**

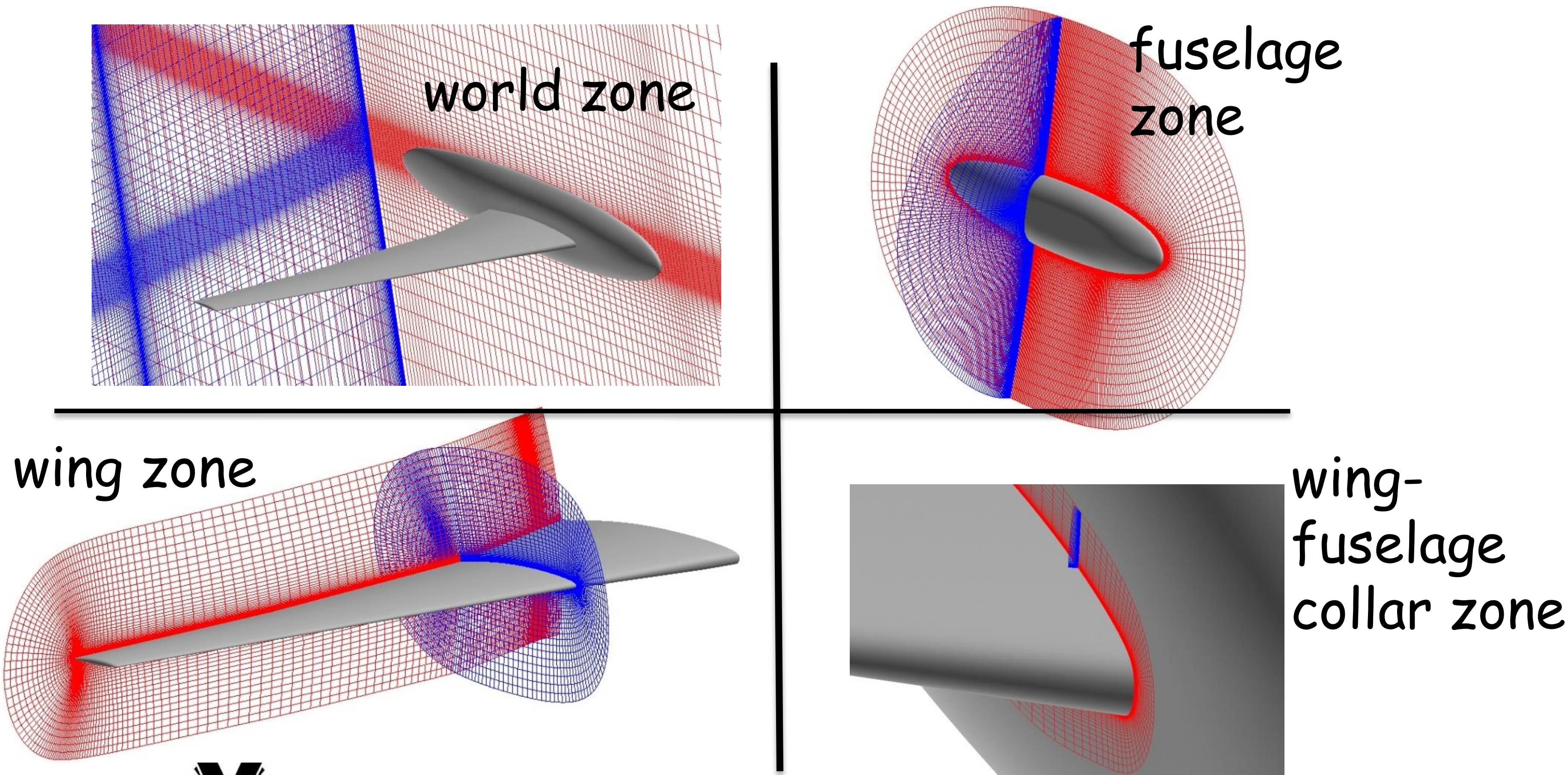
Aeroelastic Prediction Workshop Structured Grids

Thorsten Hansen
ANSYS Germany
thorsten.hansen@ansys.com





HIRENASD Overset Mesh with Chimera (Medium-Size Mesh)



Technion - Israel Institute of Technology
הטכניון – מכון טכנולוגי לישראל

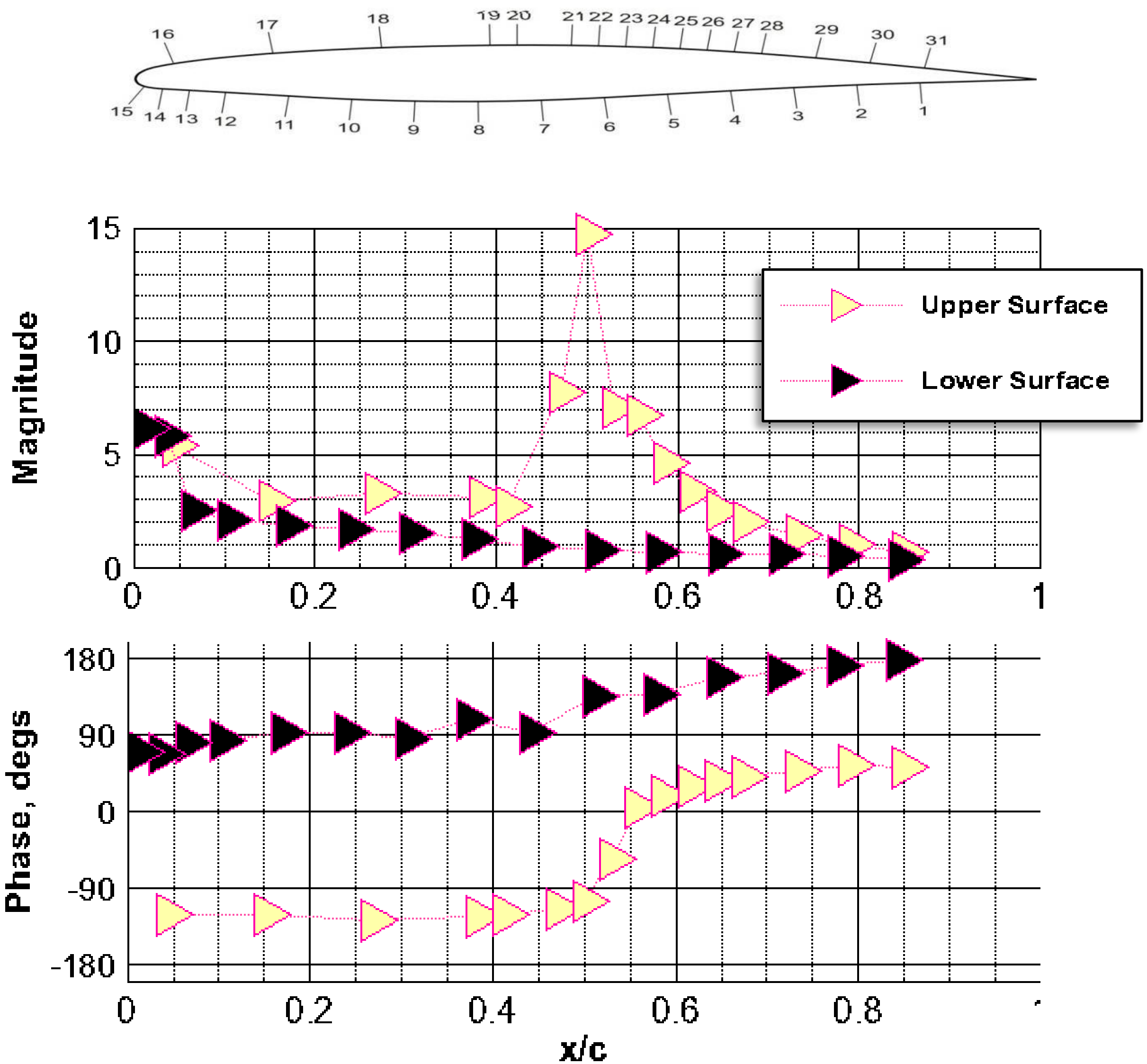
ISCFDC

Comparison Data Matrix

CONFIGURATION	REQUIRED CALCULATIONS		
	GRID CONVERGENCE STUDIES	STEADY CALCULATIONS	DYNAMIC CALCULATIONS
Steady-Rigid Cases (RSW, BSCW)	C_L, C_D, C_M vs. N-2/3	• Mean Cp vs. x/c • Means of C_L, C_D, C_M	
Static-Aeroelastic Cases (HIRENASD)	C_L, C_D, C_M vs. $N^{-2/3}$	• Mean C_p vs. x/c • Vertical displacement vs. x/c • Twist angle vs. x/c • Means of C_L, C_D, C_M	
Forced Oscillation Cases (all configurations)	TBD		• Magnitude and Phase of C_p vs. x/c at span stations corresponding to transducer locations • Magnitude and Phase of C_L, C_D, C_M at excitation frequency • Time history of Cp at each span station for 3 pressure transducer locations

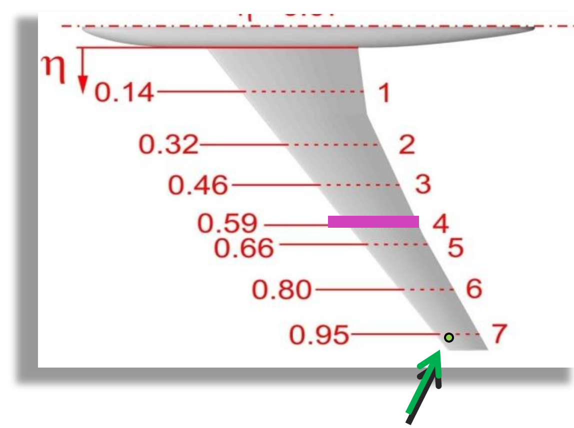
An ascii template will be provided for submission of data

HIRENASD Frequency Responses at 2nd Bending Mode Frequency (78.9 Hz)



Cp(x)/displacement

Pressure coefficients at span station 4 due to displacement at location (15,1)



Reference quantity: Displacement at location (15,1)

We are actively seeking participation from the technical community

We look forward to working with you to better define and advance the state of the art in computational aeroelasticity

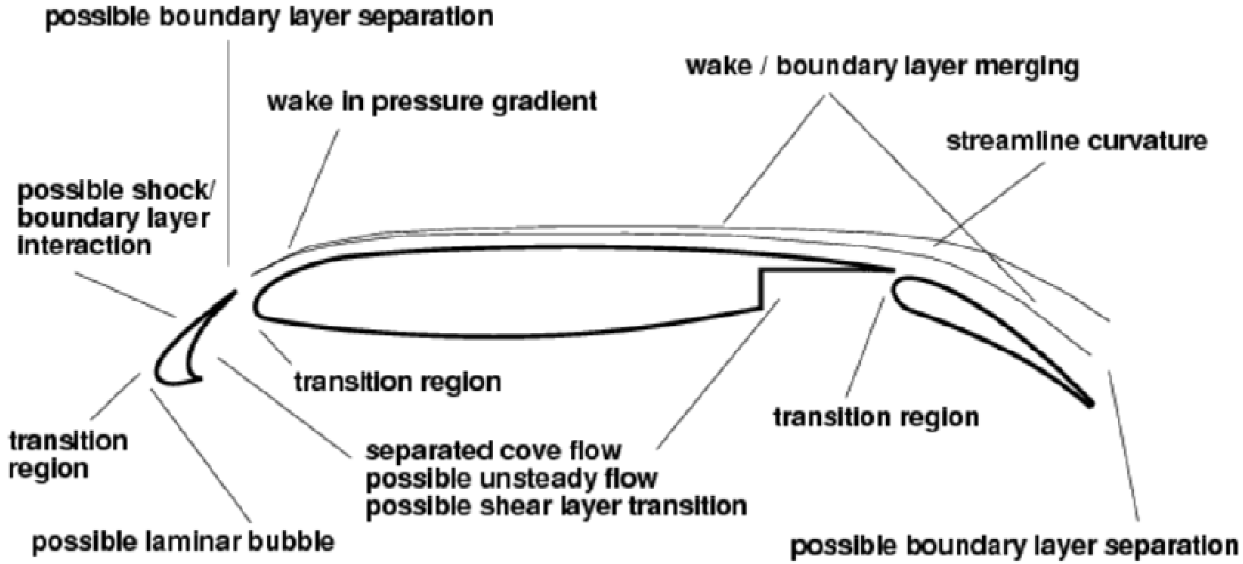
Big picture stuff that I'm working on…

Flow field challenges

Jen- we need the equivalent
Slide for AePW:
Flow phenomena:
Transonic flow: terminal shock strength varying
Attached flow
Shock-Separated flow
Shock-boundary layer interaction
Buffeting flow
Vortical flow

- Wakes in pressure gradients
- Wake/boundary layer merging
- Steamline curvature
- Separated flow
- Possible unsteady flow
- Wing-tip vortical flow
- Laminar/turbulent transition

- Prediction of high-lift flows is challenging



Rumsey, Long, Stuever, and Wayma

CFD Flow modeling progress: 1992 Assessment

Transonic Small Disturbance
Full Potential Equation

Euler Equations

Thin Layer Navier Stokes
Full Navier Stokes

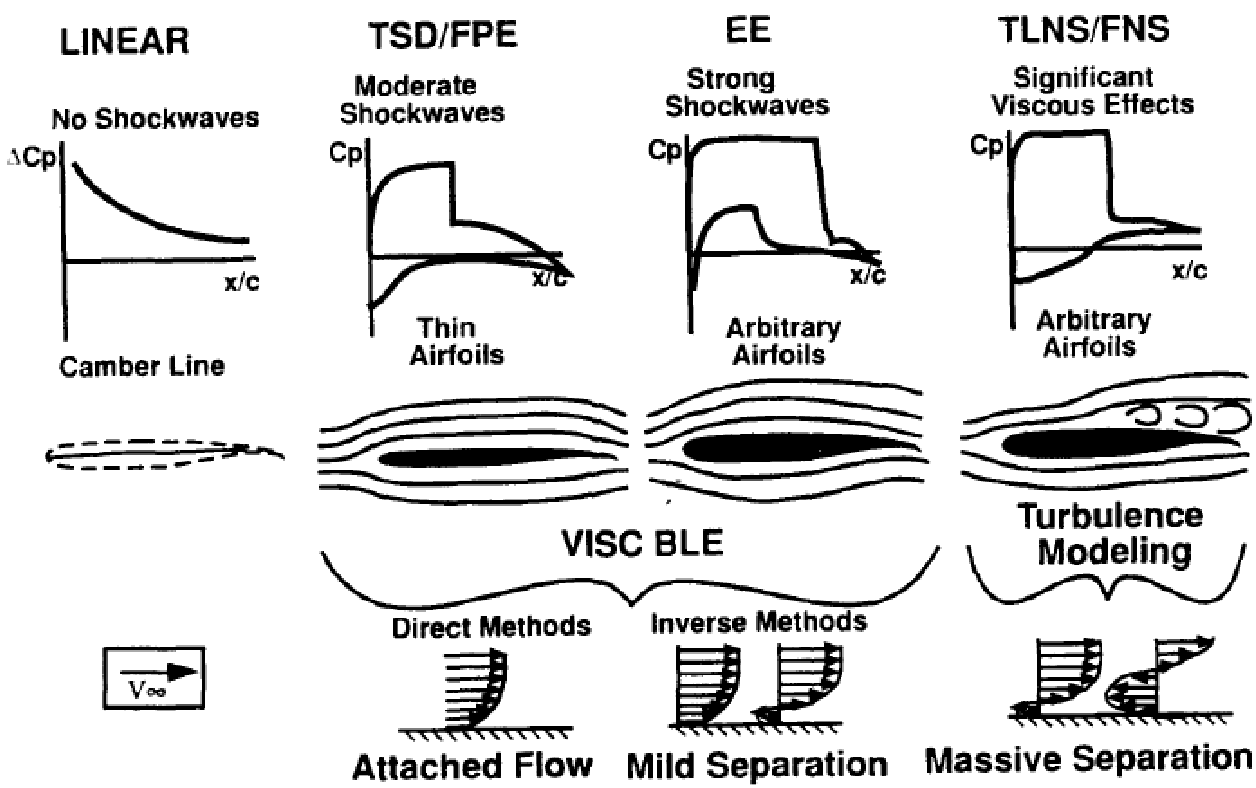


Figure 1. CFD Flow Modeling Levels

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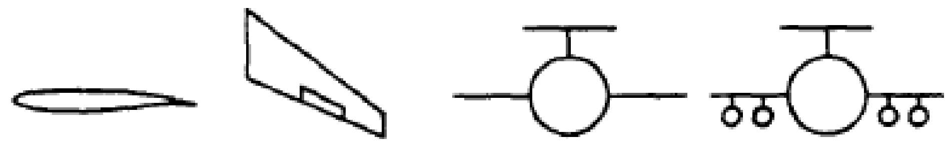
Transonic Unsteady Aerodynamics and Aeroelasticity

TECHNICAL EVALUATION REPORT ON 1991
SPECIALISTS'MEETING ON "TRANSONIC UNSTEADY AERODYNAMICS AND AEROELASTICITY"

by
John W. Edwards
Unsteady Aerodynamics Branch
NASA Langley Research Center
Hampton, Virginia 23665 USA

1992 Assessment contd
Configuration complexity



TSD	✓	✓	✓	
FPE	✓	✓	?	
EE	✓	✓	?	
TSD/FPE/EE-VISC	✓	?		
NS	✓			

Figure 2. Configuration Modeling Capability for Aeroelastic Analysis

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Transonic Unsteady Aerodynamics and Aeroelasticity

March 1992

TECHNICAL EVALUATION REPORT ON 1991 SPECIALISTS' MEETING ON "TRANSONIC UNSTEADY AERODYNAMICS AND AEROELASTICITY"

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NASA Langley Research Center
Hampton, Virginia 23665 USA

2008 Assessment

- Classification of problem areas delineated by fluid/structure dynamic complexity
  - Aerodynamic characteristics
    - Attached / separated flow
    - Vortical flow
    - Shock wave dominated separation
    - Shock-boundary layer interaction
  - Structural characteristics
    - Linear
    - Nonlinear
      - Large amplitude geometric nonlinearities
      - Material nonlinearities
    - Transient or morphing
- CA Analysis Validation
  - Methods should be demonstrated to have acceptable accuracy for classification levels for which they can be recommended. Accomplish through systematic computations. Test cases selected from available data bases and published results compared at organized meetings
- Uncertainty in Aeroelastic model testing
  - Facility variability
  - Test medium effects

2008 Assessment contd
Perceived Deficiencies

- Naturally unsteady flows
- Separated flows & separation onset flows: nonlinearity of the separation often triggers unsteadiness in the flow
- "Convective and diffusive nature of the flow" may not be captured by the algorithms currently implemented; the approach of adapting steady flow methods to unsteady flow analysis may be fundamentally flawed
- Steady flow algorithms are optimized to converge to a steady state without adversely affecting the mean flow prediction. Thus, these algorithms quickly dmap transient oscillations, whether numerical or physical
- Forced oscillations involve continuous influx of perturbations. Thus, this may not be the best approach to validation of critical fluid dynamic characteristics

2008 Assessment contd

- Forced oscillation problems:
  - Result in bounded periodic amplitude and frequency responses that can be used to quantitatively evaluate the methods
  - Thus, logical V&V candidates

History of Computational Aeroelasticity

- Strip Theory & Typical sections
- Panel Methods
- TSD
- Euler methods
- Viscous effects
- Thin layer Navier Stokes
- Navier Stokes- RANS

- Close-coupled analyses
- Navier Stokes- LES, DES

A nice way to track progress in Computational AE might be a timeline of AGARD 445.6 analyses