AIAA

Embraer Contribution to DPW-8/AePW-4: Scatter WG Two-Dimensional Cases

Murilo C. Mestriner, Pedro de A. Secchi and Pedro A. G. Ciloni

Embraer

AIAA Aviation Forum, 21-25 July 2025

Scatter Case 1a

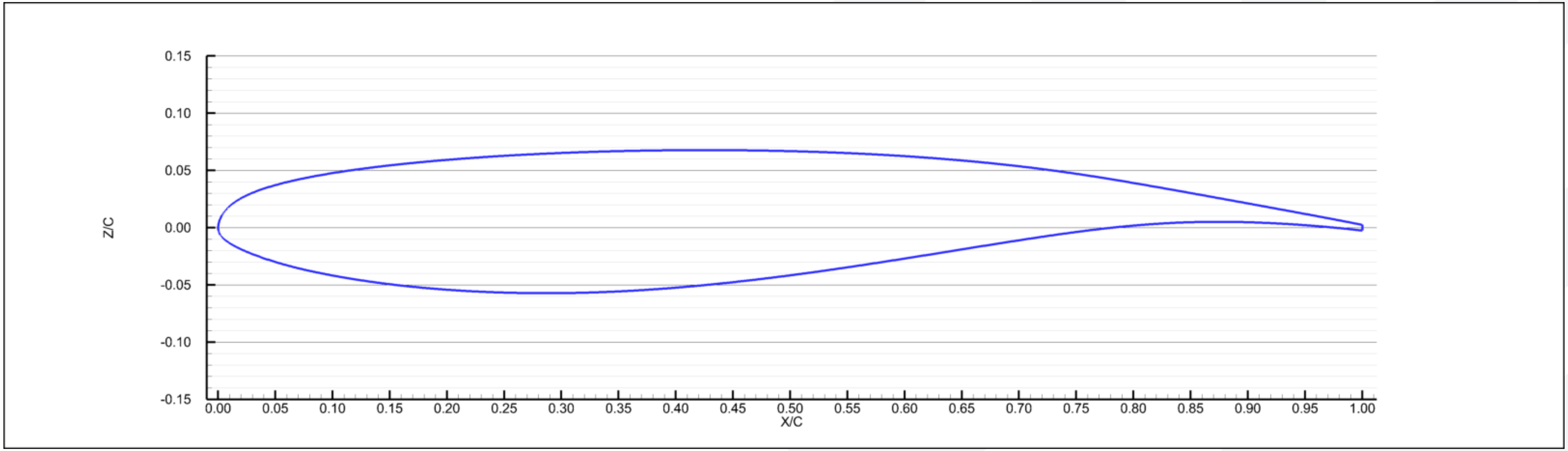
Methodology and Results

Scatter Case 1a

Geometry: ONERA OAT15A Airfoil

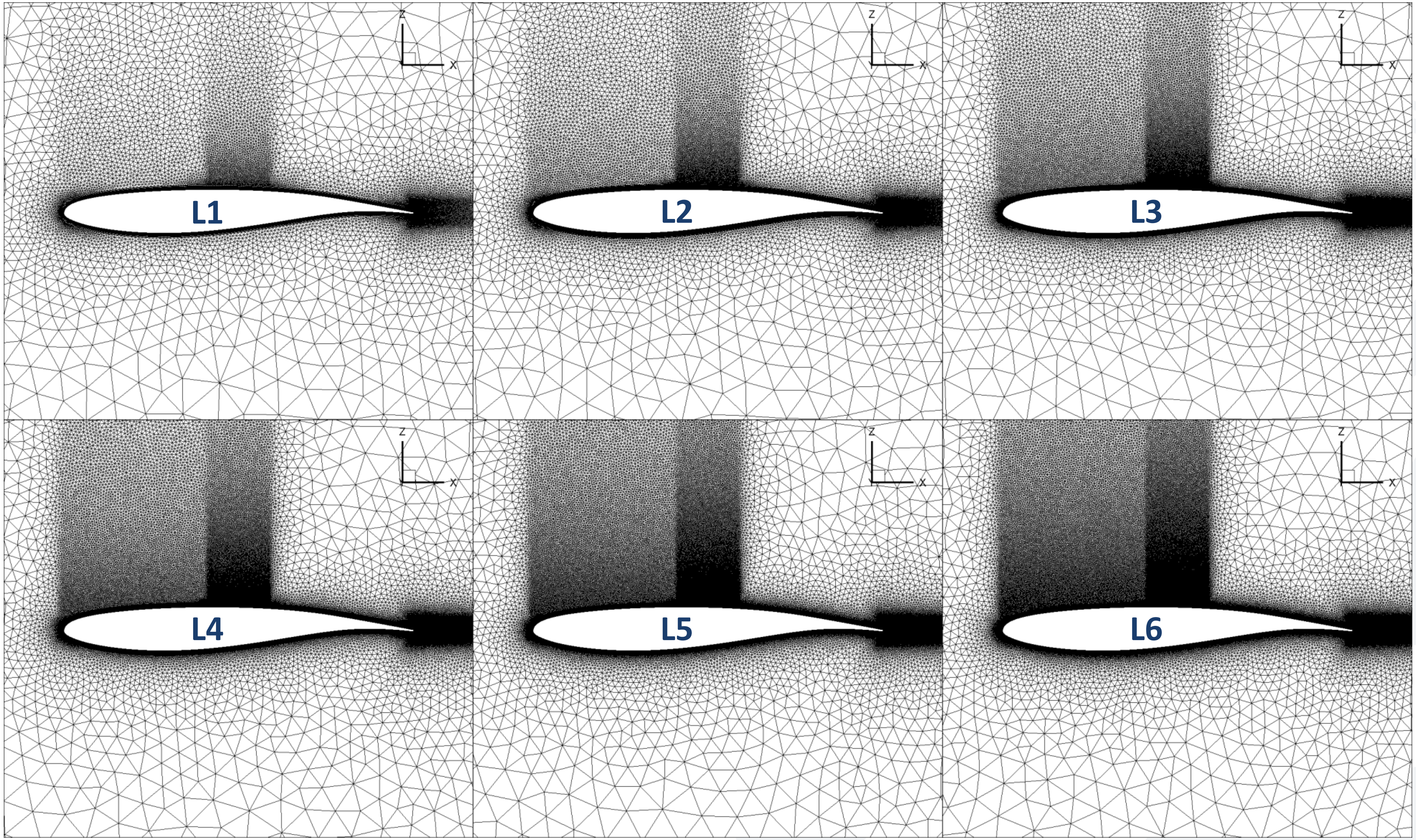
- Supercritical airfoil design, blunt trailing edge
- Extruded 2D geometry provided by Committee

Parameter	Value	Description
$c_{ref}\ [m]$	0.230	airfoil chord
$b_{ref}\ [m]$	0.023	extruded airfoil span
$S_{ref}\ [m^2]$	0.00529	extruded airfoil area
$X_{mom}\ [m]$	0.0575	moment reference X coord.



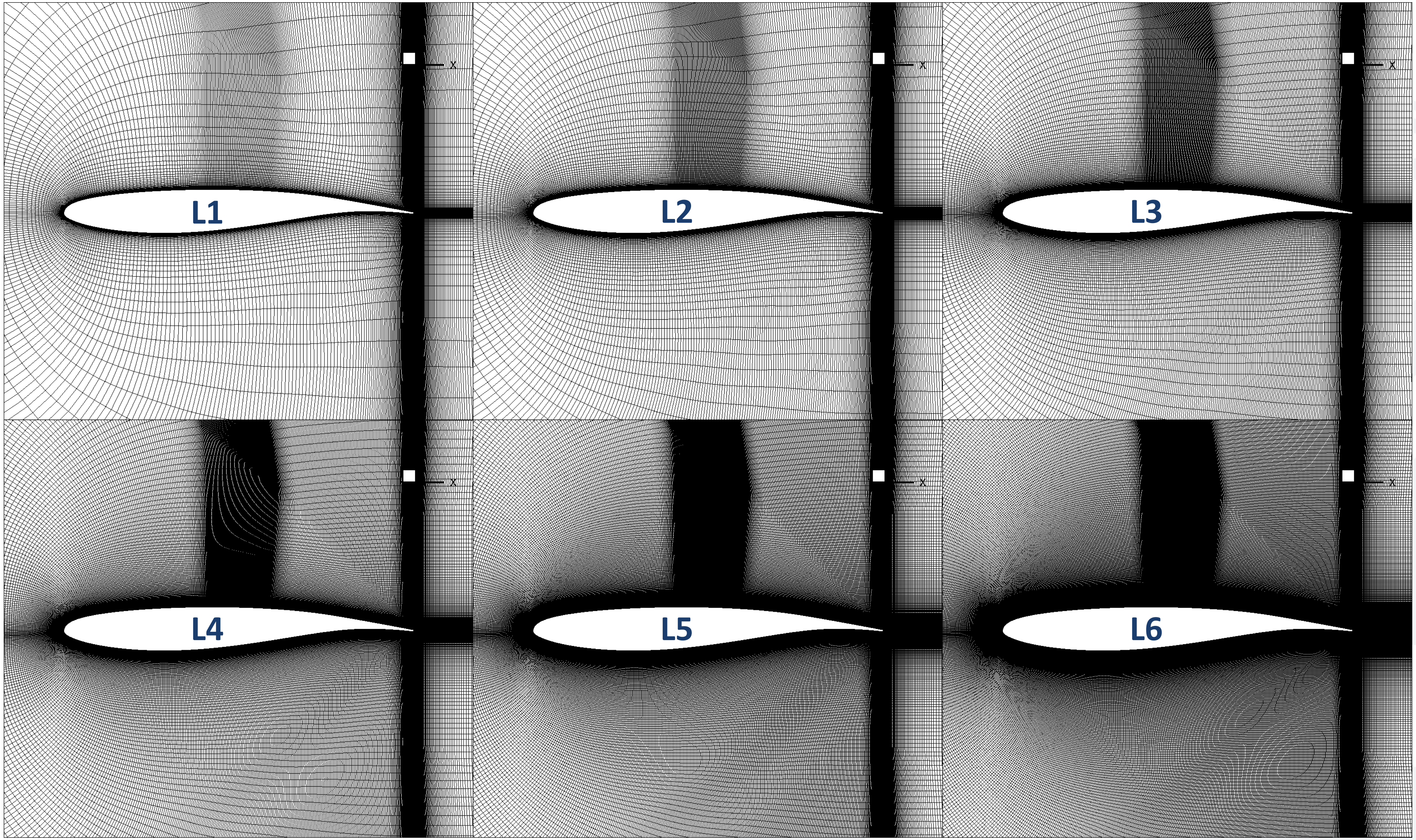
Scatter Case 1a

Grids: Cadence Unstructured Rev01



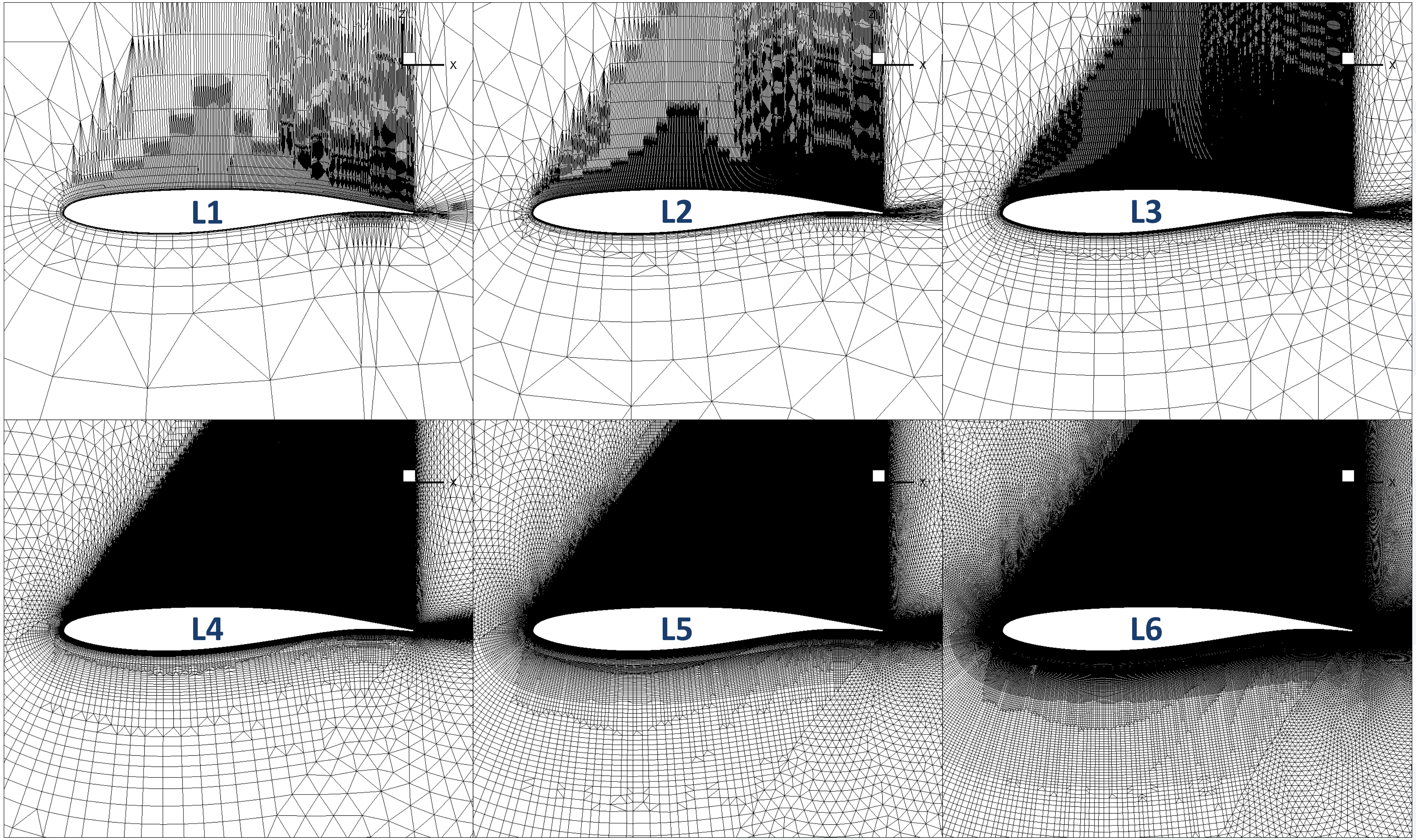
Scatter Case 1a

Grids: Cadence Structured Rev01



Scatter Case 1a

Grids: HeldenMesh Unstructured Rev01



Scatter Case 1a

Grids: Comparison

Rev01 Grids: farfield boundary at 100 chords

- Cadence Uns: refinement in trailing edge, wake and predicted shock locations
- Cadence Str: wider boundary layer refinement region
- HeldenMesh Uns: upper surface triangular refinement strategy
- No equivalence in cells/nodes count among grids

Grid Level	Cadence Unstructured		Cadence Structured		Helden Unstructured	
	Total Cells	Total Nodes	Total Cells	Total Nodes	Total Cells	Total Nodes
Level 1	47187	63480	151003	304176	10451	18336
Level 2	89616	122630	240554	483690	35830	63424
Level 3	150333	209778	378312	759654	134113	240390
Level 4	235491	337510	596792	1197134	528276	954006
Level 5	353725	522458	937027	1878216	2076273	3760558
Level 6	517448	790852	1471296	2947522	8208515	14926966

Scatter Case 1a

Solver: Case definition and solver setup

- Angle of attack warm sweep covering Scatter WG and Buffet WG requests
- Cost-effective industry-level solver setup (coefficient convergence thresholds)
- SA is the *French Vanilla SA* with *ft2* term

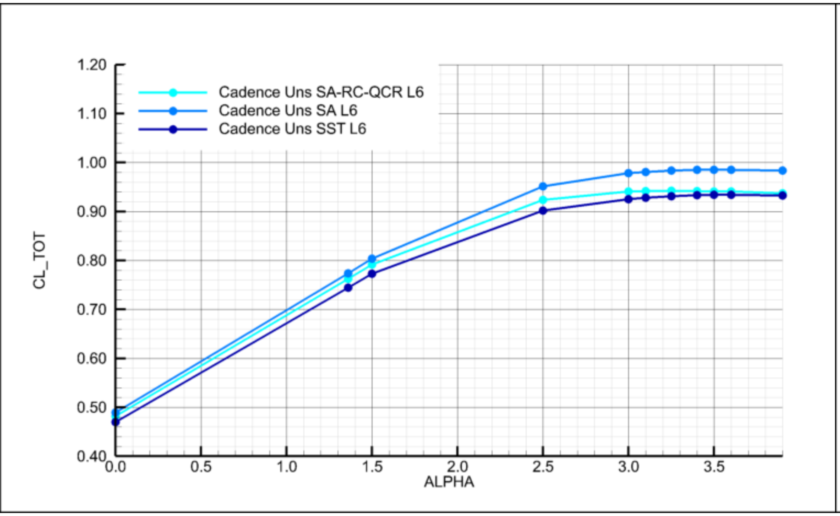
Case Definition	
Freestream conditions	M_∞=0.73 | Re_c=3mi | T_{static}=271K
Angle of attack	Warm sweep: 0.00°, 1.36°, 1.50°, 2.50°, 3.00°, 3.10°, 3.25°, 3.40°, 3.50°, 3.60°, 3.90°
Solver Setup	
General solver settings	CFD++ steady RANS | SA-RC-QCR, SA, SST turbulence models
Boundary conditions	Adiabatic viscous wall (airfoil) | symmetry (sidewalls) | characteristics-based (farfield)
Solver iterations	The minimum between 3000 iterations and coefficient convergence thresholds

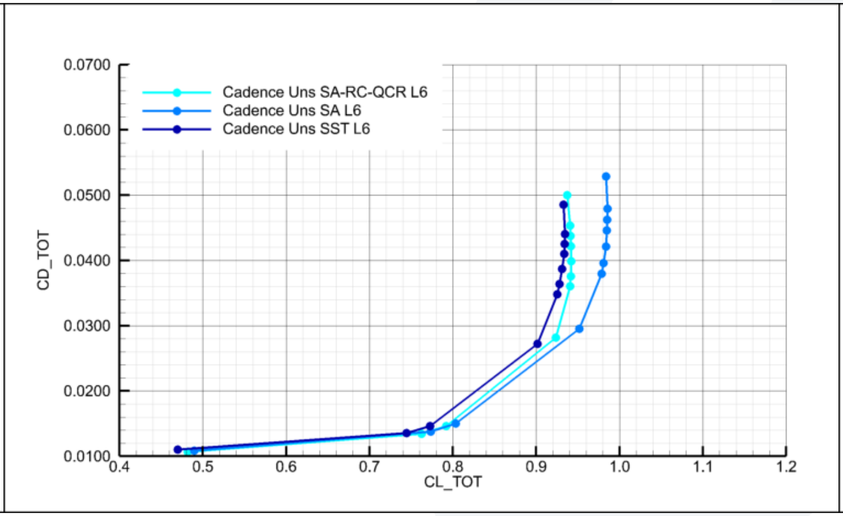
Scatter Case 1a

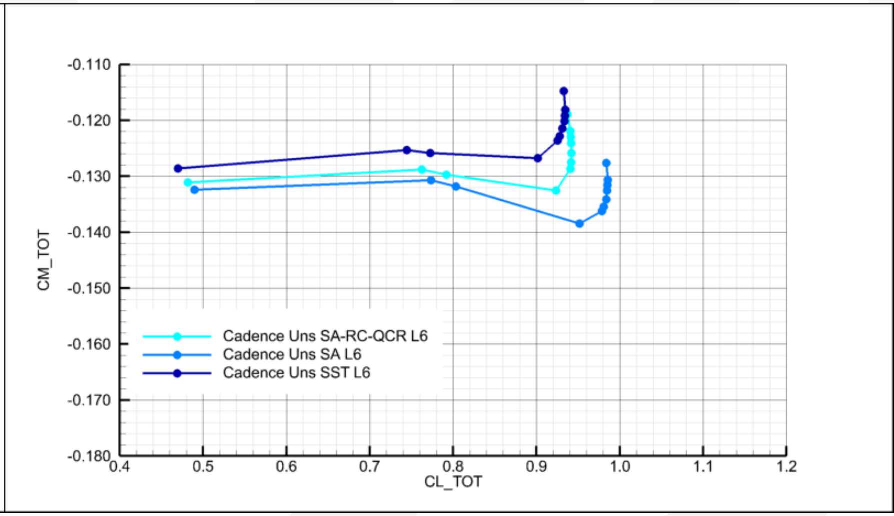
Results: Global Coefficients

Cadence Uns L6 in 3 different turbulence models

- SA-QCR-RC coefficients are between SA and SST results
- Scatter in lift curve from ΔC_L=0.03 (lower angles) to ΔC_L=0.06 (higher angles)





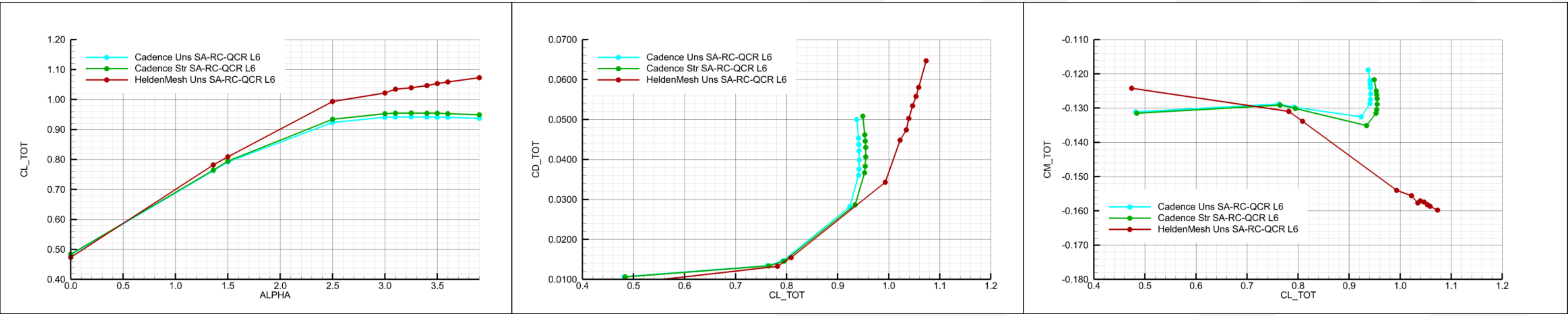


Scatter Case 1a

Results: Global Coefficients

SA-RC-QCR in 3 different grids

- Cadence Uns and Cadence Str with similar trends, HeldenMesh data as outliers
- Reduced scatter at α=1.36° and α=1.50°

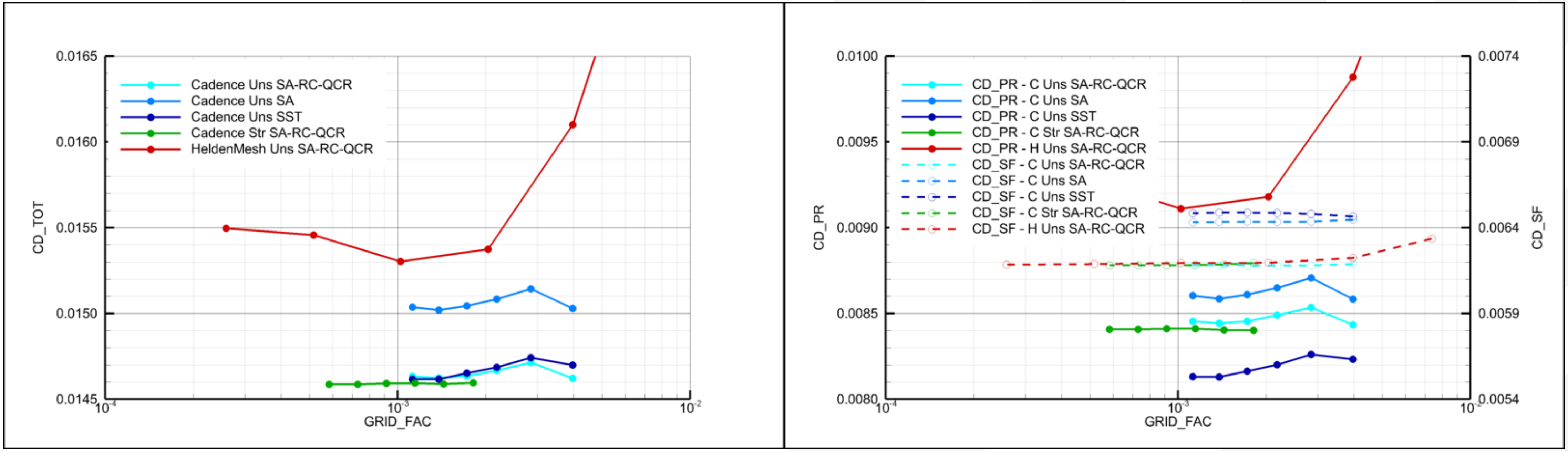


Scatter Case 1a

Results: Grid Convergence

Results at α=1.50°

- Turning on/off SA corrections has an impact of 4 drag counts for Cadence Uns
- Pressure and skin friction opposite offset between Cadence Uns SA-RC-QCR and Cadence Uns SST
- Consistency between Cadence Uns and Cadence Str results (both with SA-RC-SCR)

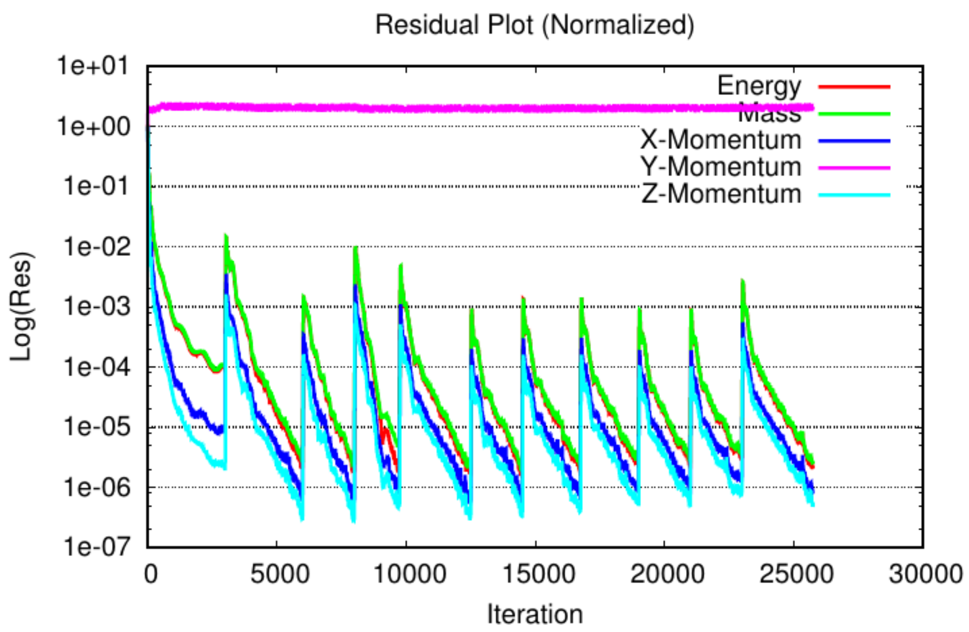


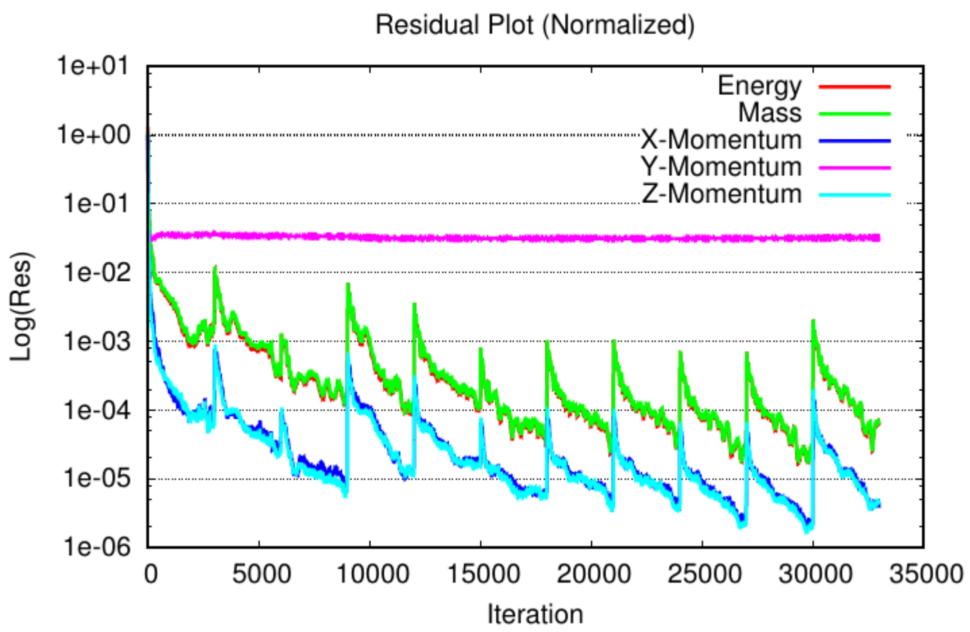
Scatter Case 1a

Results: Residuals Convergence

Warm sweep strategy limited to 3000 iterations per point

- All Cadence Uns/Str cases (left) with similar residuals trends and levels
- HeldenMesh grid calculations (right) one order of magnitude poorer





Scatter Case 1b

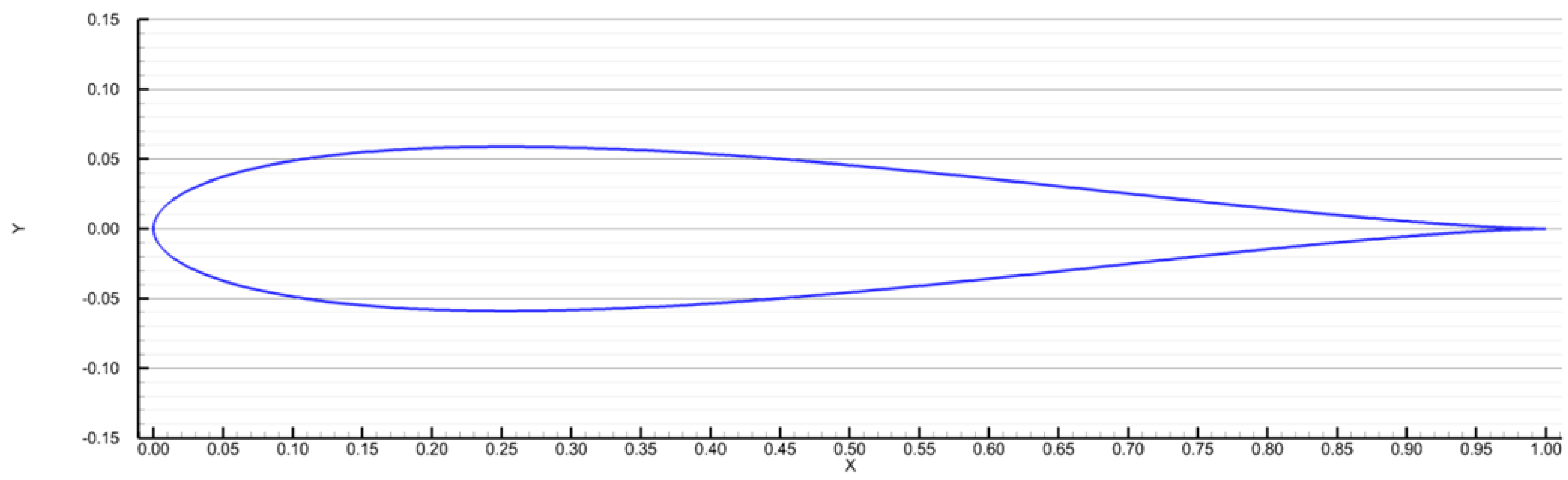
Methodology and Results

Scatter Case 1b

Geometry: Joukowski Airfoil

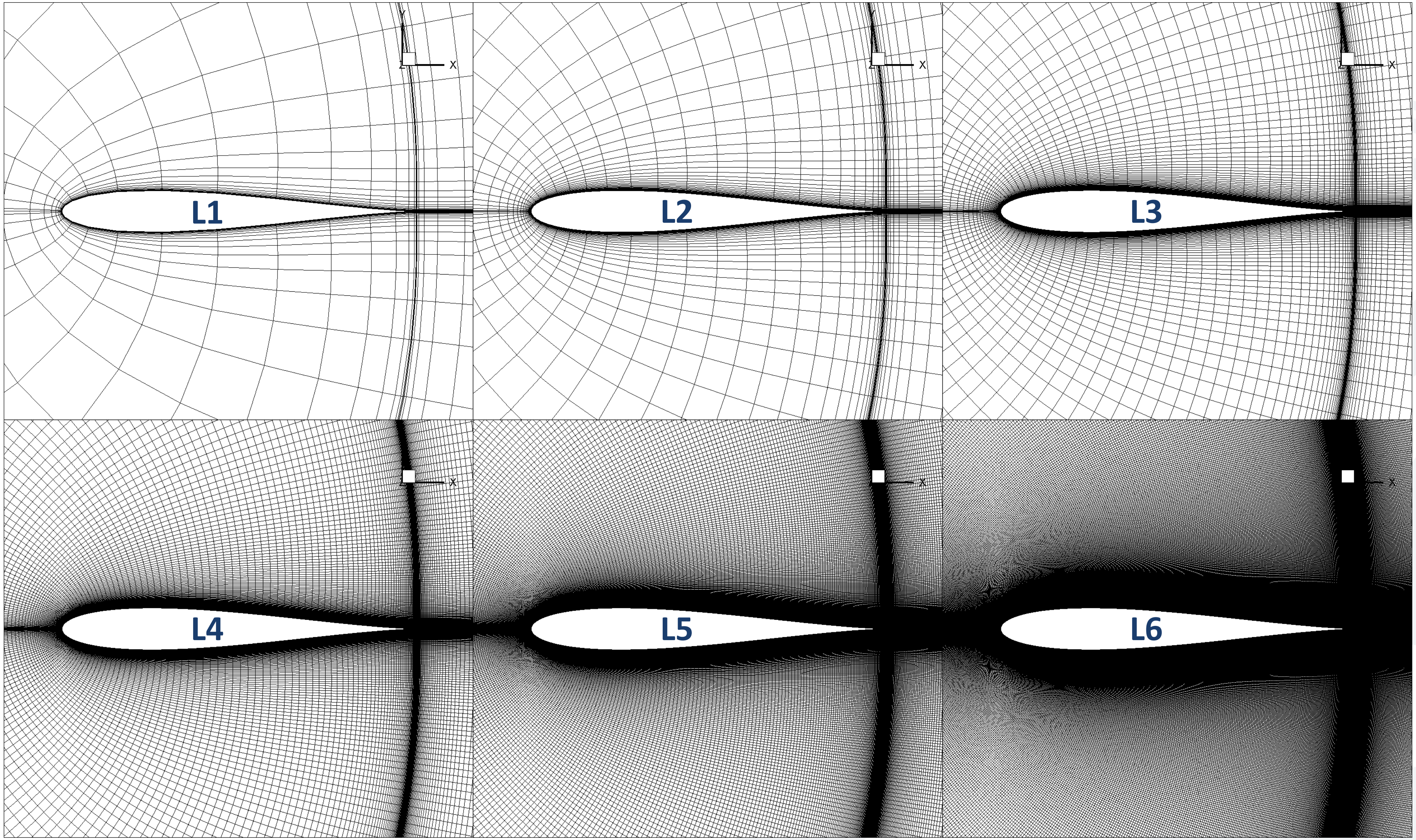
- 12% maximum thickness, sharp trailing edge
- Pure 2D geometry

Parameter	Value	Description
$c_{ref}\ [m]$	1.000	airfoil chord
$X_{mom}\ [m]$	0.250	moment reference X coord.



Scatter Case 1b

Grid: Classic Quad



Scatter Case 1b

Grid: Classic Quad

Python-scripts generated, farfield boundary at 1000 chords

- Choice between Classic or Challenge, Quad or Tri options
- Exact factor of 4 (2x2) from one level to the next one

Grid Level	Classic Quad	
	Total Cells	Total Nodes
Level 1	3072	3168
Level 2	12288	12480
Level 3	49152	49536
Level 4	196608	197376
Level 5	786432	787968
Level 6	3145728	3148800

Scatter Case 1b

Solver: Case definition and solver setup

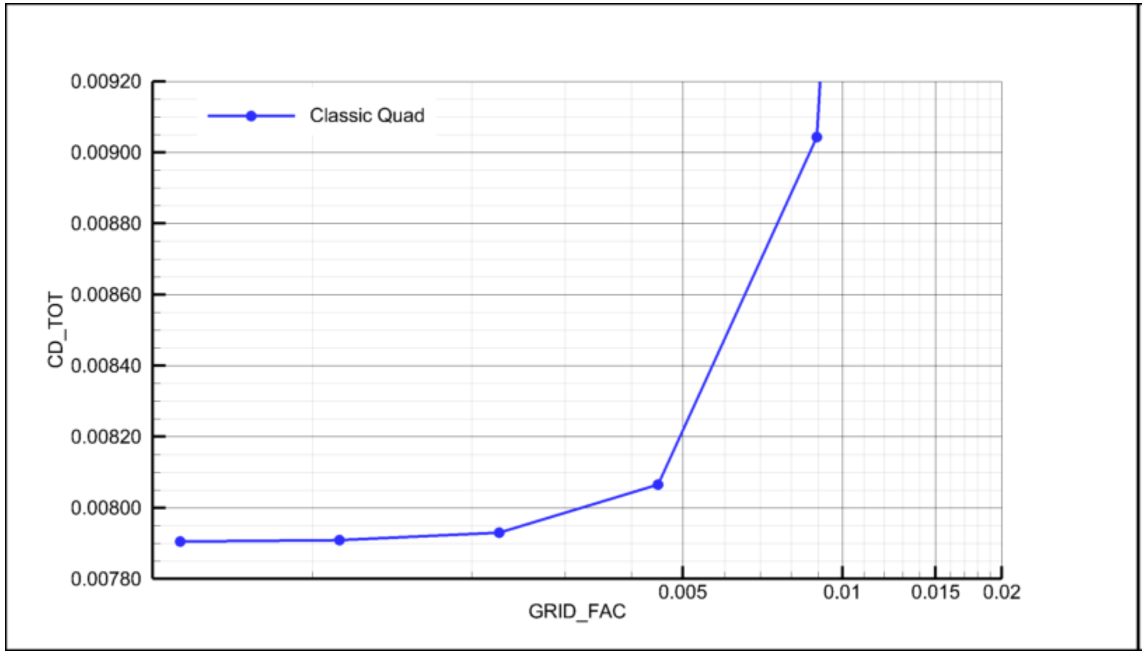
- Additional flow definition to fully describe the problem and reduce scatter
- Viscosity according to Sutherland's Law
- Residuals convergence to machine precision

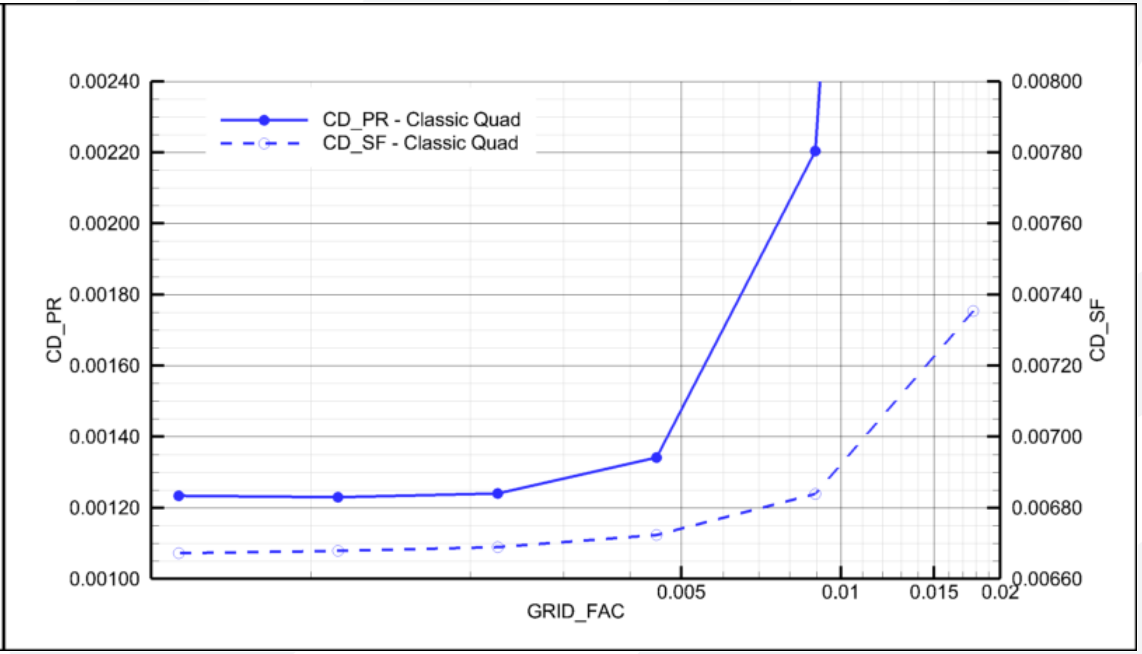
Case Definition	
Flow definition	M_∞=0.15 | Re_c=6mi | T_{static}=520R
Additional flow definition	Pr=0.72 | Pr_t=0.90 | γ=1.4 | Farfield χ=3
Angle of attack	Single point: **0.00°**
Solver Setup	
General solver settings	CFD++ steady RANS | **SA** turbulence model
Boundary conditions	Adiabatic viscous wall (airfoil) | characteristics-based (farfield)
Solver iterations	The minimum between **30000** iterations and residual L_2 norm close to machine zero ($\mathbf{10^{-10}}$)

Scatter Case 1b

Results: Grid Convergence

- Drag values lie within the 0.5 drag count band for levels 4-5-6 and within 0.1 drag count for 5-6
- Skin friction converges faster than pressure drag

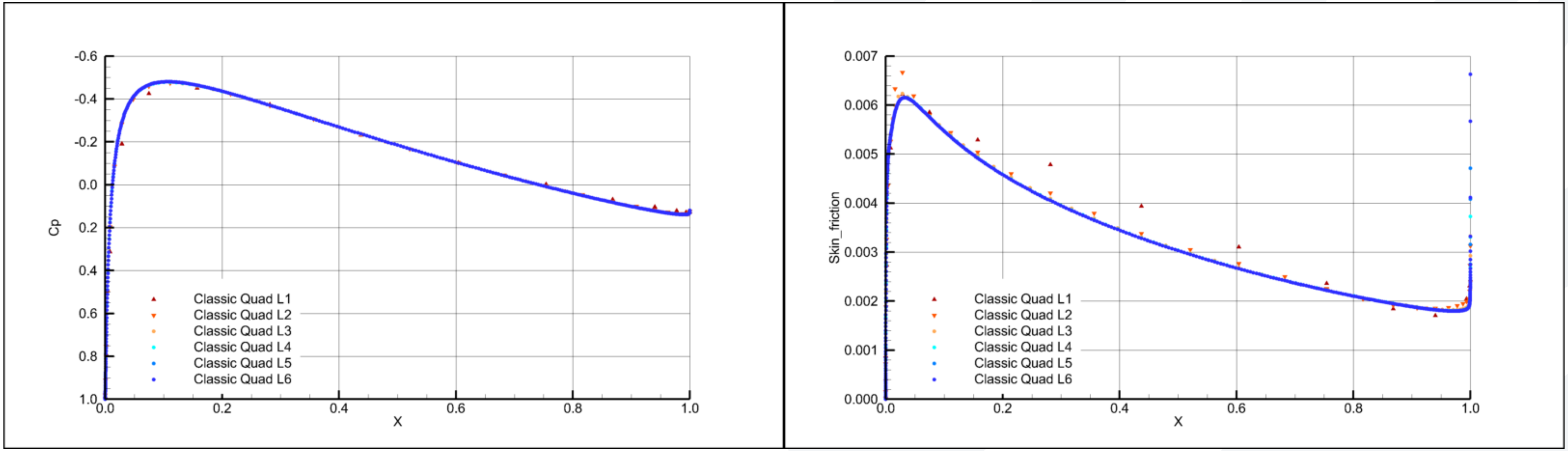




Scatter Case 1b

Results: Sectional Cuts

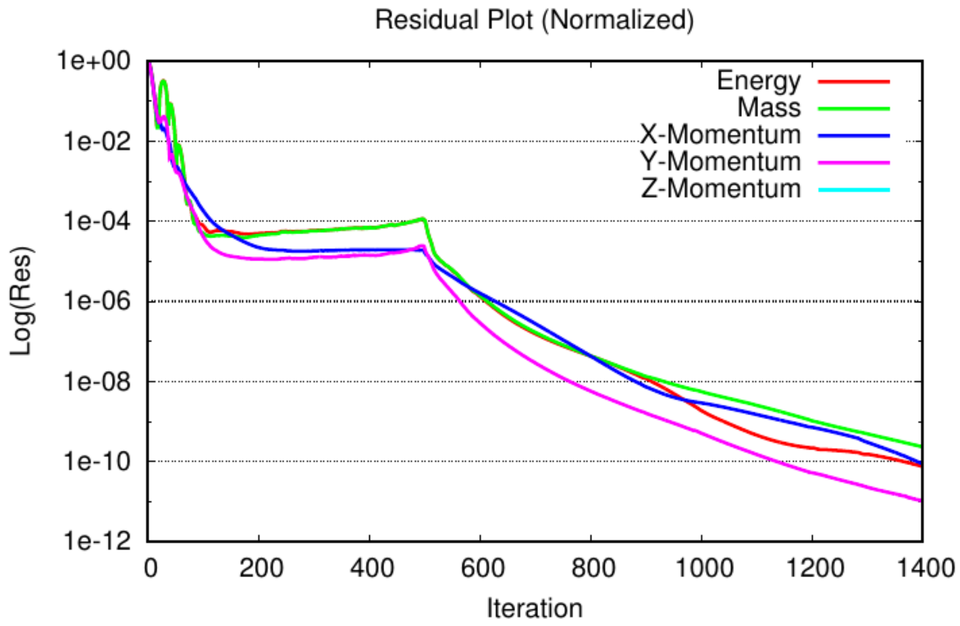
- Noticeable deviation in C_p levels only in level 1
- C_f distribution highlights differences until level 3

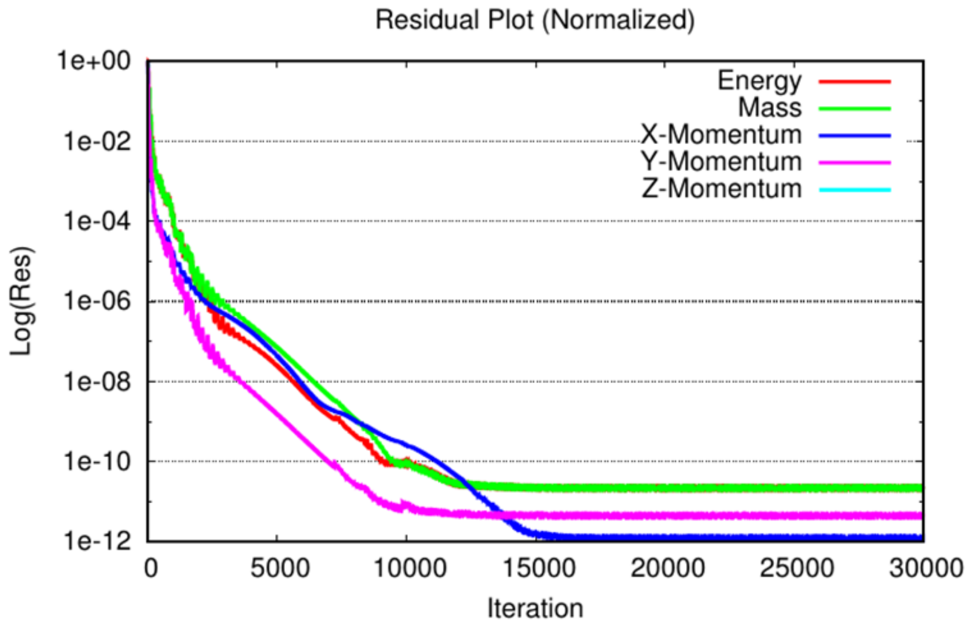


Scatter Case 1b

Results: Residuals Convergence

- Levels 2-3: reached residuals convergence threshold (left)
- Levels 1-4-5-6: reached number of iterations limit (right)



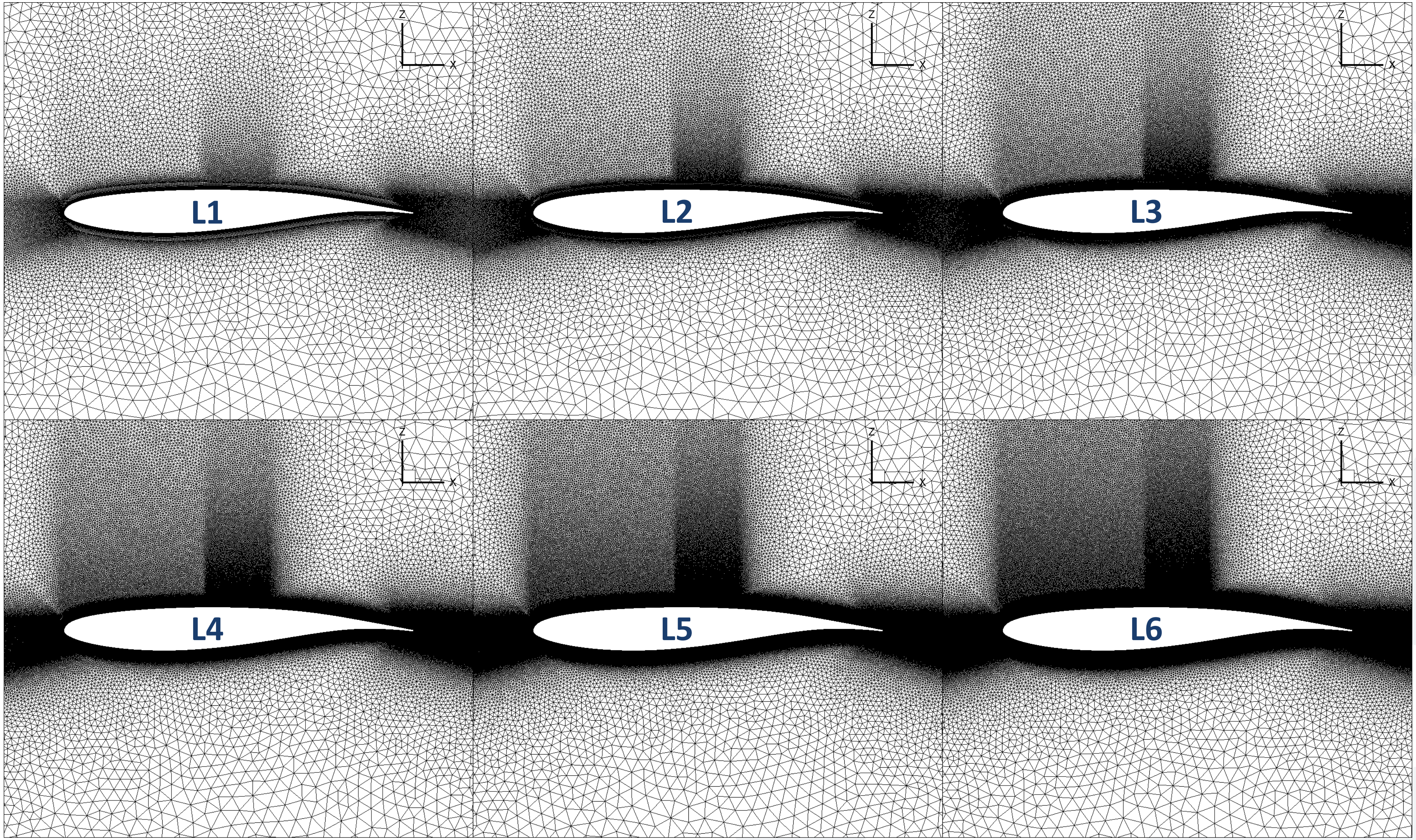


Scatter Case 1c

Methodology and Results

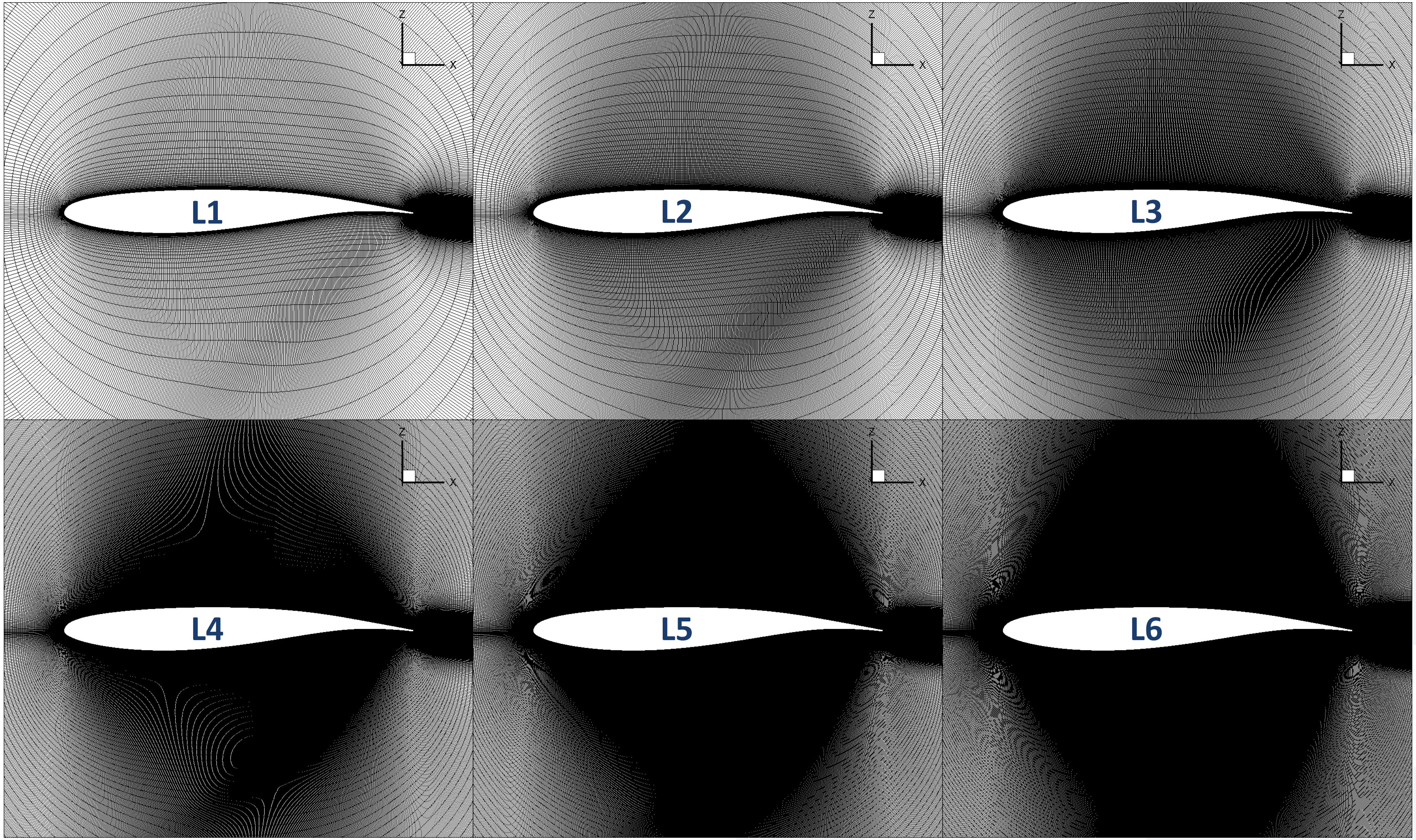
Scatter Case 1c

Grids: Cadence Unstructured Rev02



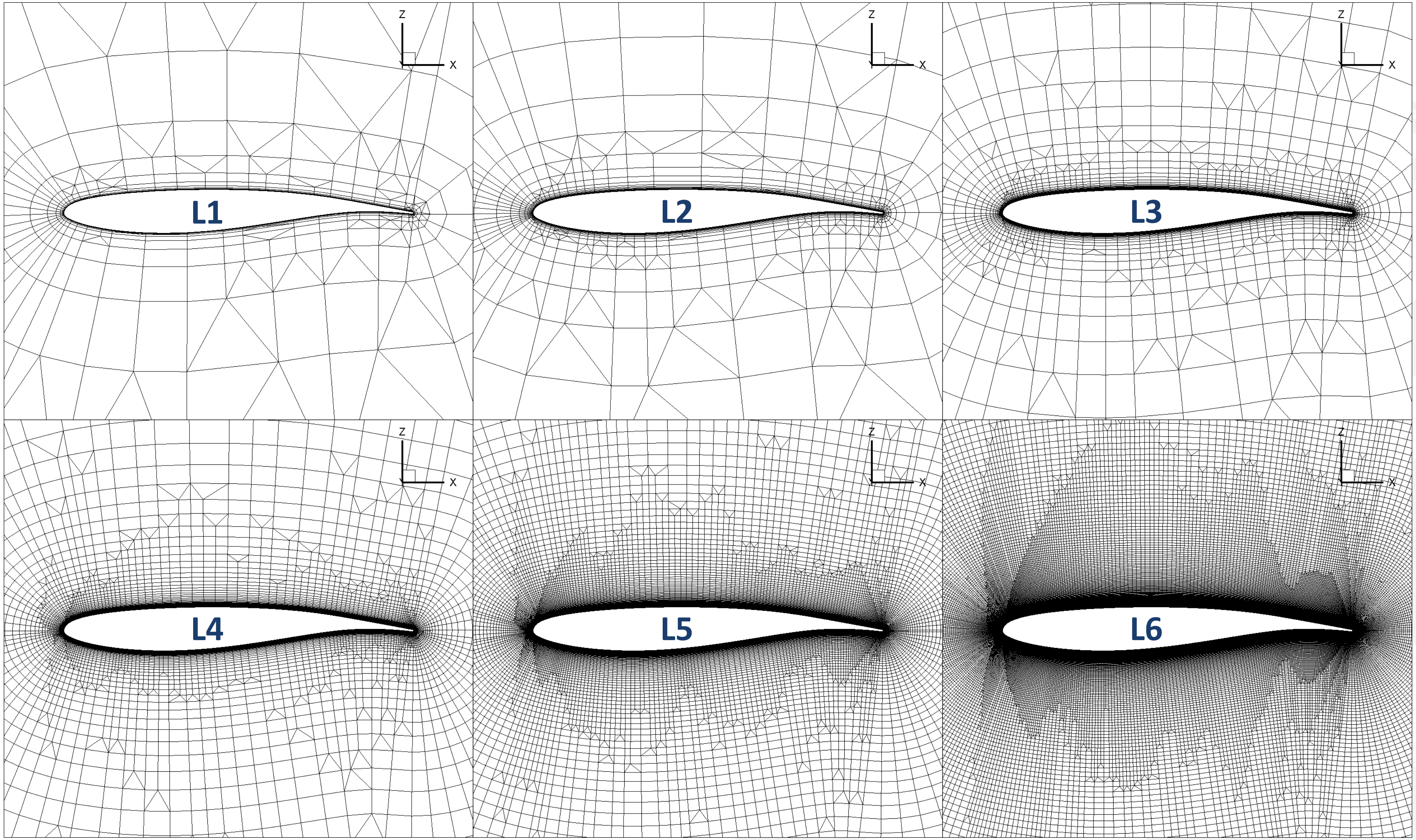
Scatter Case 1c

Grids: Cadence Structured Rev02



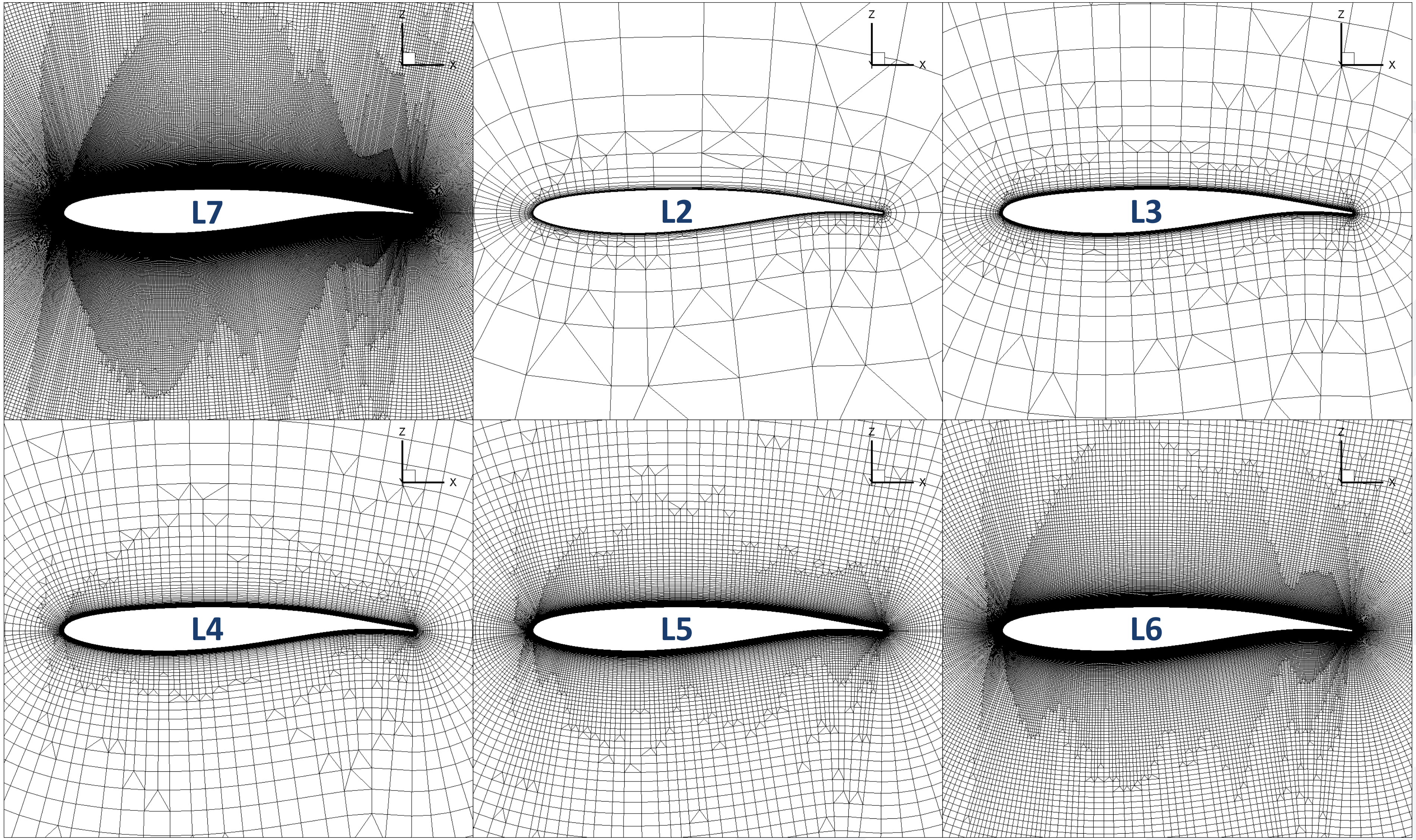
Scatter Case 1c

Grids: HeldenMesh Unstructured Rev02



Scatter Case 1c

Grids: HeldenMesh Unstructured Rev02



Scatter Case 1c

Grids: Comparison

Rev02 Grids: farfield boundary at 1000 chords

- In Cadence grids, Rev02 generally exhibits a significantly larger number of cells/nodes in relation to Rev01
- HeldenMesh grid presents the opposite behavior (L7-Rev02 is equivalent to L5-Rev01)
- Topological differences are also visible: Cadence Uns present a refinement region upstream the leading edge, Cadence Str/HeldenMesh are more uniformly refined than before

Grid Level	Cadence Unstructured		Cadence Structured		Helden Unstructured	
	Total Cells	Total Nodes	Total Cells	Total Nodes	Total Cells	Total Nodes
Level 1	131626	167848	133284	268866	1256	2340
Level 2	234629	311904	280662	564550	3352	6470
Level 3	379613	529370	535092	1074332	9847	19302
Level 4	584895	856406	969134	1943342	31887	63054
Level 5	879860	1355900	1691436	3388870	110856	220638
Level 6	1317314	2130350	2878720	5764360	437438	822060
Level 7	(N/A)	(N/A)	(N/A)	(N/A)	2085047	3952952

Scatter Case 1c

Solver: Case definition and solver setup

- Problem definition “best practices” of Case 1b applied to Case 1c
- Single angle of attack and only *French Vanilla SA* model

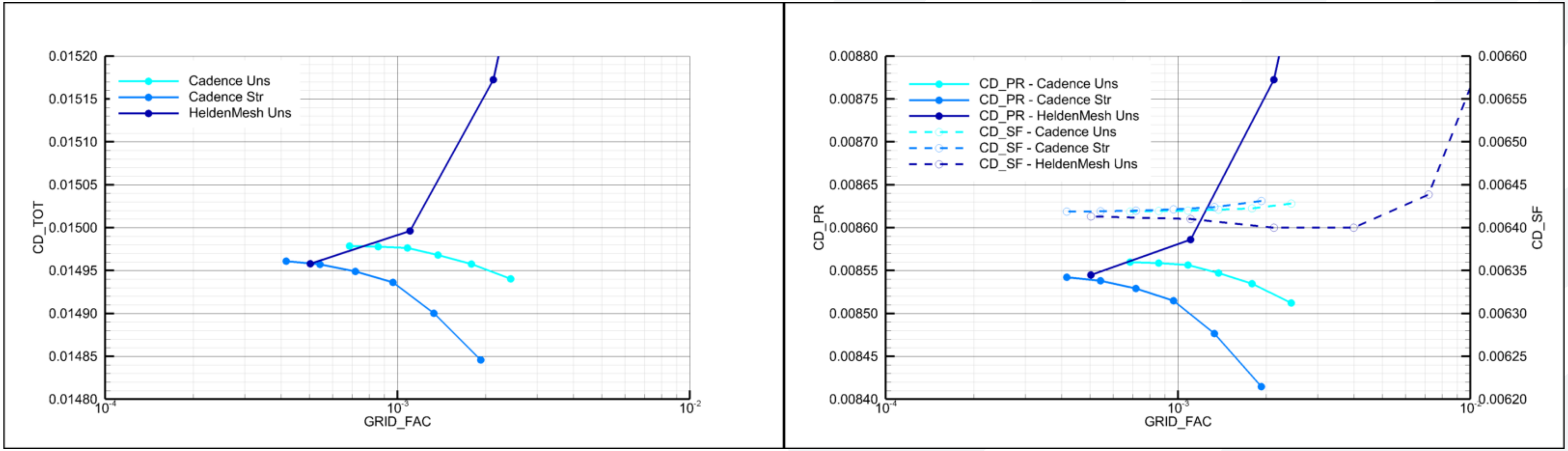
Case Definition	
Flow definition	M_∞=0.73 | Re_c=3mi | T_{static}=271K
Additional flow definition	Pr=0.72 | Pr_t=0.90 | γ=1.4 | Farfield χ=3
Angle of attack	Single point: **1.50°**
Solver Setup	
General solver settings	CFD++ steady RANS | **SA** turbulence model
Boundary conditions	Adiabatic viscous wall (airfoil) | symmetry (sidewalls) | characteristics-based (farfield)
Solver iterations	The minimum between **30000** iterations and residual L_2 norm close to machine zero ($\mathbf{10^{-10}}$)

Scatter Case 1c

Results: Grid Convergence

Results at α=1.50°

- Total C_D values lie within a 0.2 drag count range for the finest level of each family
- Pressure drag is responsible for most of the scatter, although much smaller is relation to Case 1a

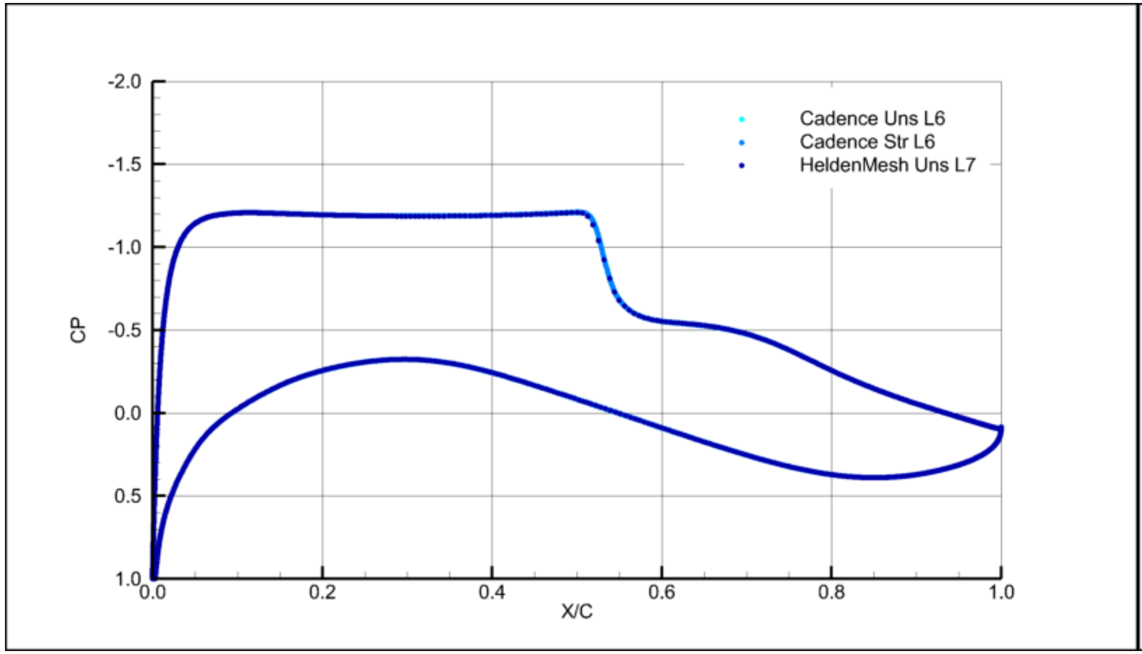


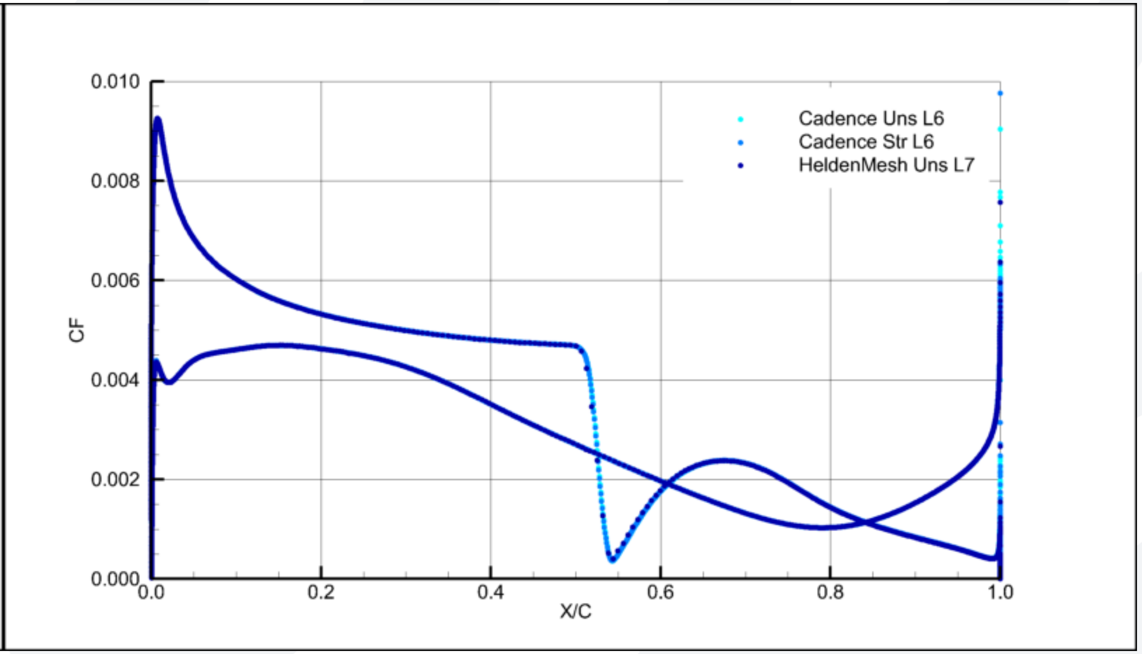
Scatter Case 1c

Results: Sectional Cuts

Most refined level of each family

- Excellent agreement in shock position and strength
- Skin friction distributions also similar





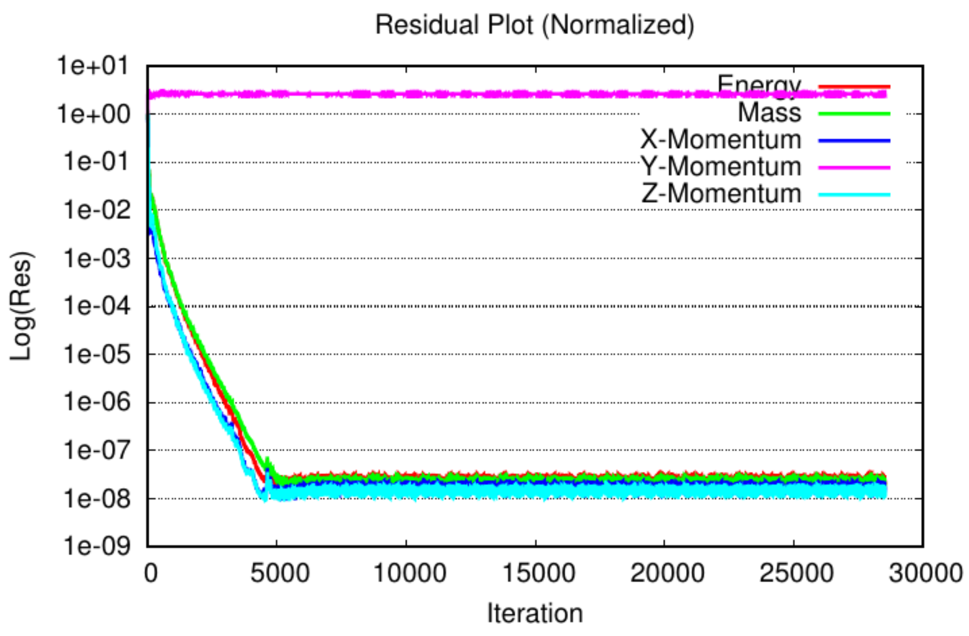
AIAA

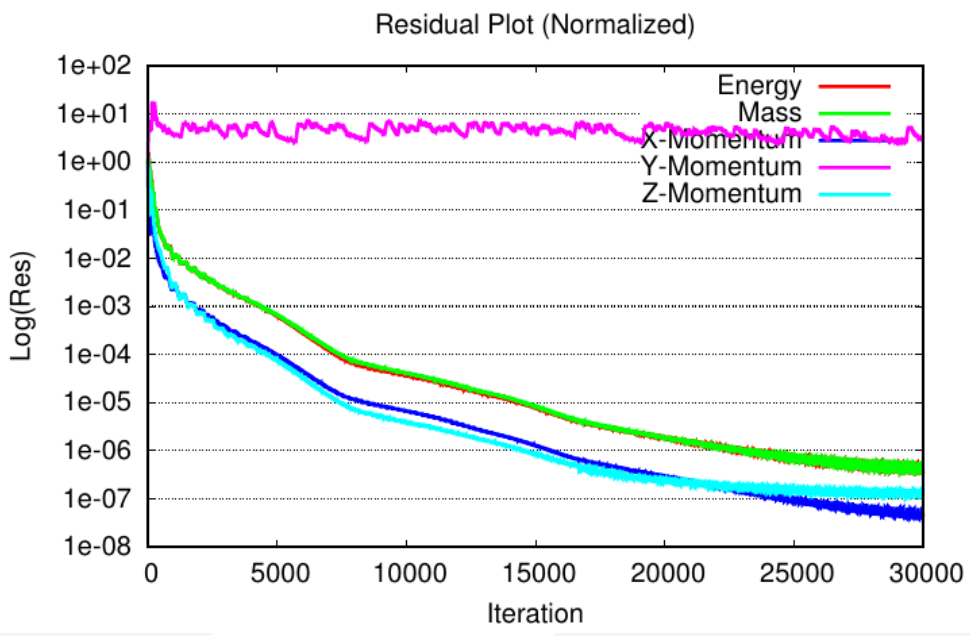
Scatter Case 1c

Results: Sectional Cuts

Most refined level of each family

- Cadance Uns/Str cases (left) with similar residuals trends and levels
- HeldenMesh calculations (right) one order of magnitude poorer
- Global coefficients convergence also checked and adequate for comparison





Conclusions

Conclusions

- Grid topology and quality play an important role in residuals convergence trends
- SA corrections (RC,QCR) may shift solutions in several drag counts even in a simple case
- A comprehensive problem definition tends to reduce sources of scatter

Thank You