Edge

3rd AIAA Drag Prediction Workshop

Drag Prediction for the DLR F6 model using the Edge solver

by

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General information

FOI

- Former FFA, Swedish Aeronautical Research Institute
- New research agency FOI formed in 2001
- Group with about 25 persons involved with CFD
- Support to Swedish industry with CFD tools and expertise
  - Saab consortium, Volvo Aero Corporation, …

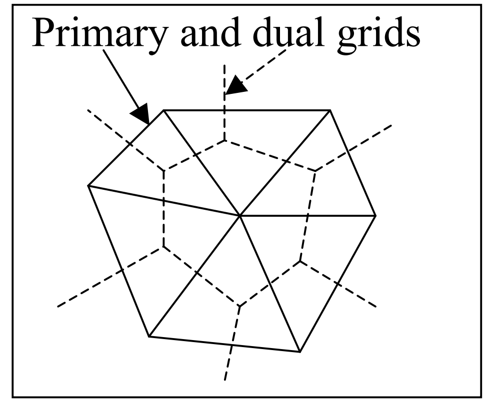
Edge

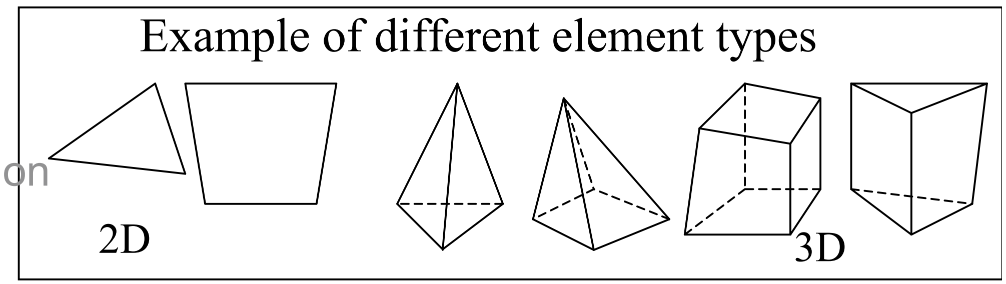
- CFD software for unstructured grids
- Distributed with source code to many collaborative partners
  - Swedish industries, European universities and research establishments
- Web site: http://www.edge.foi.se/

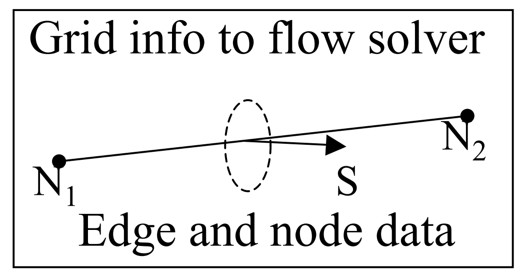
Edge solver

Edge – a Navier-Stokes solver for unstructured grids

- Solves the compressible NS equations
- RANS/RANS-LES/LES solver
- Node-centered/ finite-volume formulation
- Edge based formulation with dual grids
- Explicit Runge-Kutta time integration
- Agglomeration multigrid
- Parallel with MPI
- Dual time stepping for unsteady extension
- High temperature extension
- Low speed preconditioning
- Aeroelastic capability
- Grid adaptation
- Adjoint solver for shape optimization







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Computational information

- DLR F6 on ANSYS hybrid unstructured grids, with/without faring

	Wing body (WB)			Wing body fairing (FX2B)		
	Coarse	Medium	Fine	Coarse	Medium	Fine
# nodes	$3.05\text{x}10^6$	$8.04\text{x}10^6$	$18.1\text{x}10^6$	$3.16\text{x}10^6$	$8.27\text{x}10^6$	$20.5\text{x}10^6$
# boundary nodes	$75\text{x}10^3$	$168\text{x}10^3$	$329\text{x}10^3$	$79\ 10^3$	$179\text{x}10^3$	$375\text{x}10^3$
# prism layers	~31	~31	~31	~31	~31	~31
1st cell size (m)	$0.6\text{x}10^{-6}$	$0.4\text{x}10^{-6}$	$0.25\text{x}10^{-6}$	$0.6\text{x}10^{-6}$	$0.4\text{x}10^{-6}$	$0.25\text{x}10^{-6}$

Computational settings

- Hellsten k-ω EARSM for the turbulence (AIAA Journal, Vol. 43, 2005)
- 4 level W-cycles, full multigrid
- 3-stage Runge-Kutta scheme, CFL=1.25
- Central scheme with artificial dissipation ($\kappa^{(4)}$=3/200) for mean flow
- Thin-layer approximation
- 2nd order upwind scheme for turbulence equations
- Linux cluster used, up to 16 processors
  - Computing time 16*48 h for fine grid

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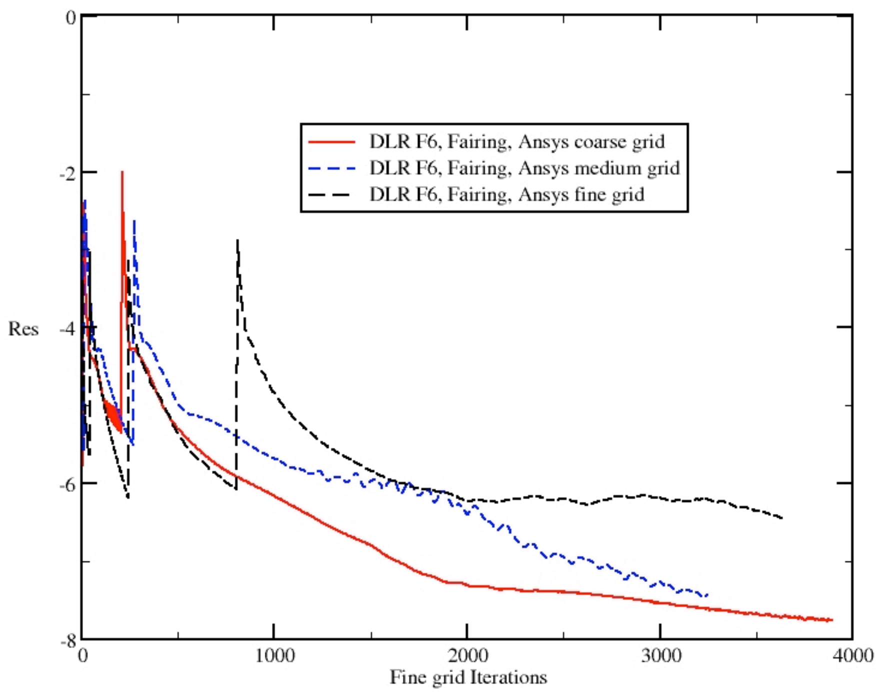
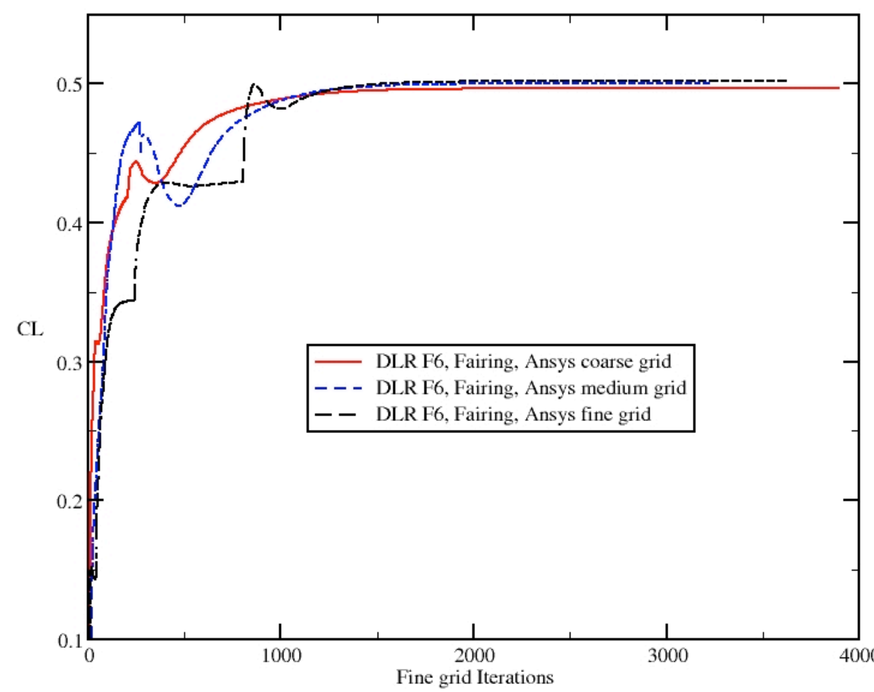
Convergence





- Convergence (density res. and lift) on WB fairing, Cl=0.5, coarse-medium-fine
- Convergence in 1500-2000 multigrid cycles
- Convergence obtained for all cases computed

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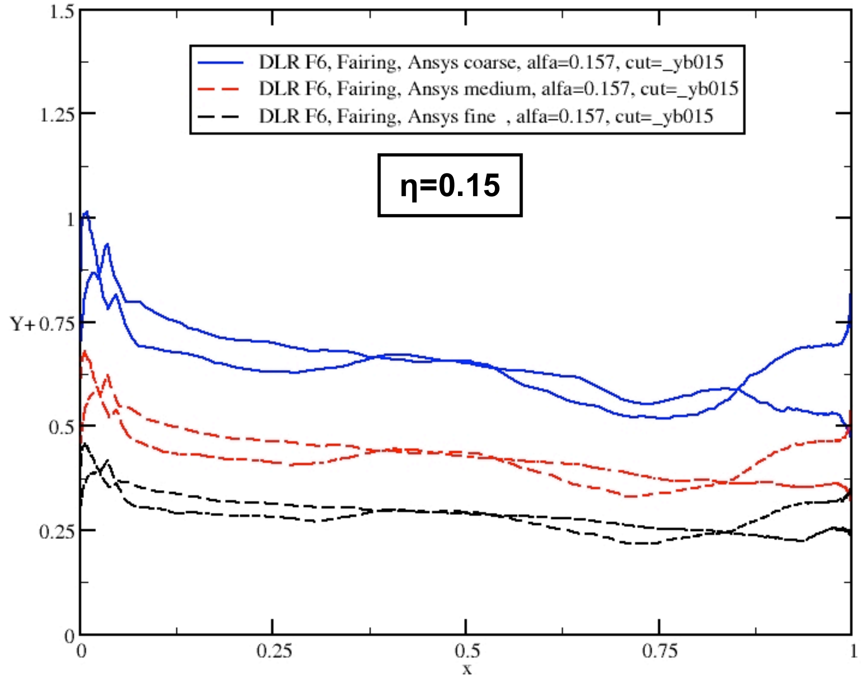
Y+ distribution

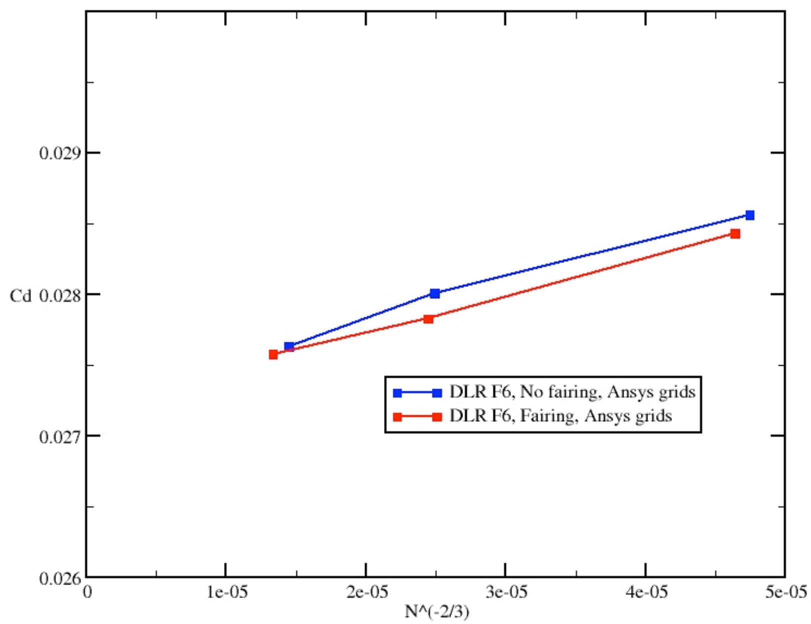


- **An example for the FX2B case (with fairing)**
- **Near wall Y+, Cl=0.5, coarse, medium, fine grids**
- **Wall-normal resolution unnecessarily fine**

Edge Grid convergence

- **Summary of forces and moments in grid convergence study**

	Wing body (WB)			Wing body fairing (FX2B)		
	Coarse	Medium	Fine	Coarse	Medium	Fine
Alpha	0.04	0.04	0.04	0.157	0.157	0.157
Cl	0.497	0.5006	0.5039	0.4968	0.5002	0.5021
Cd	0.02856	0.02800	0.02763	0.02843	0.02783	0.02757
ΔCd	+5.6 cts	0	-2.7 cts	+6.0 cts	0	-2.6 cts
Cm	-0.1325	-0.1366	-0.1474	-0.1268	-0.1301	-0.1315



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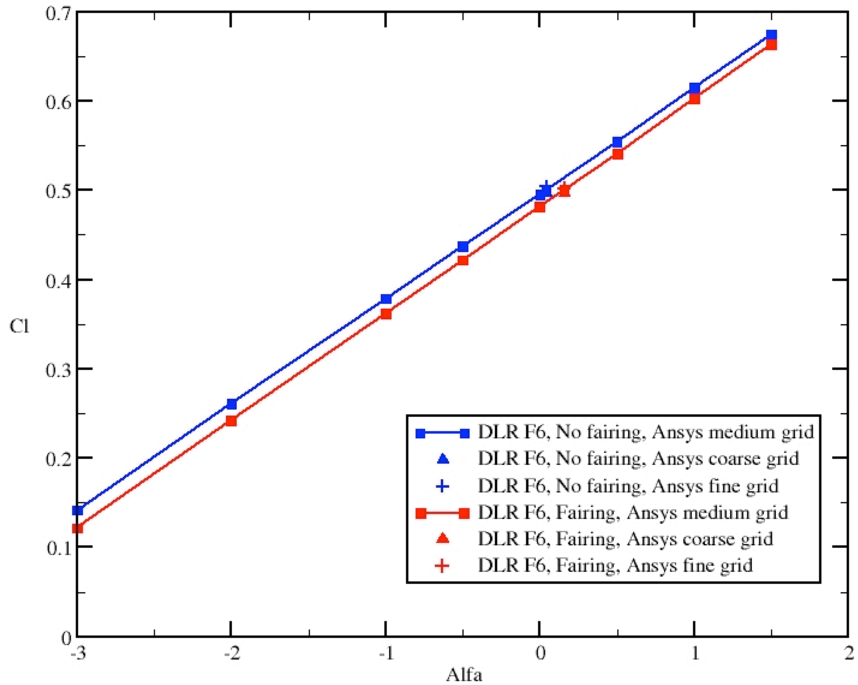
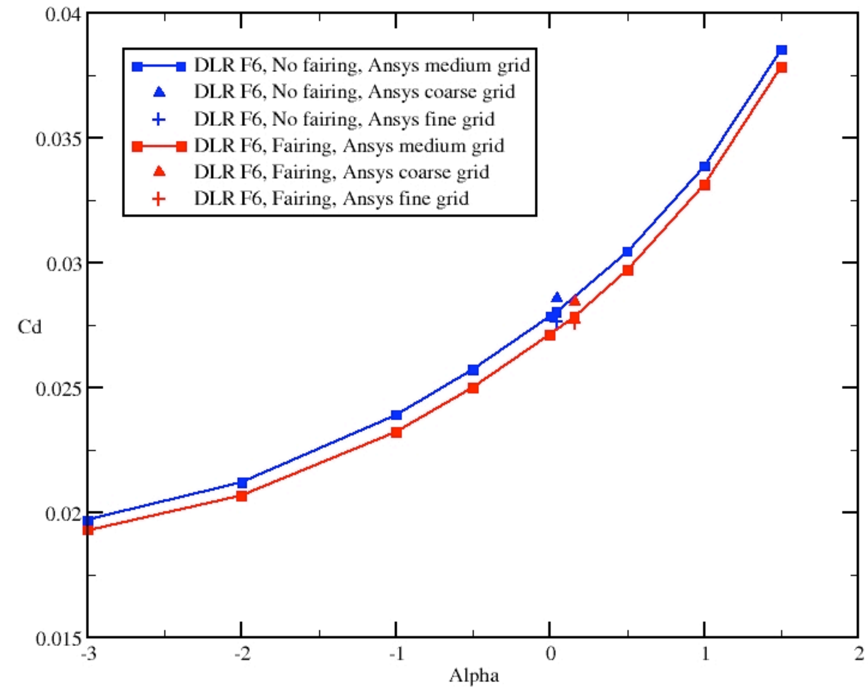
Lift and drag

- Angles of attack: α=-3º, - 2º, - 1º, -0.5, 0º, 0.5º, 1º, 1.5º
- Computations with ANSYS medium grids
- Coarse and fine grid results included at Cl=0.5

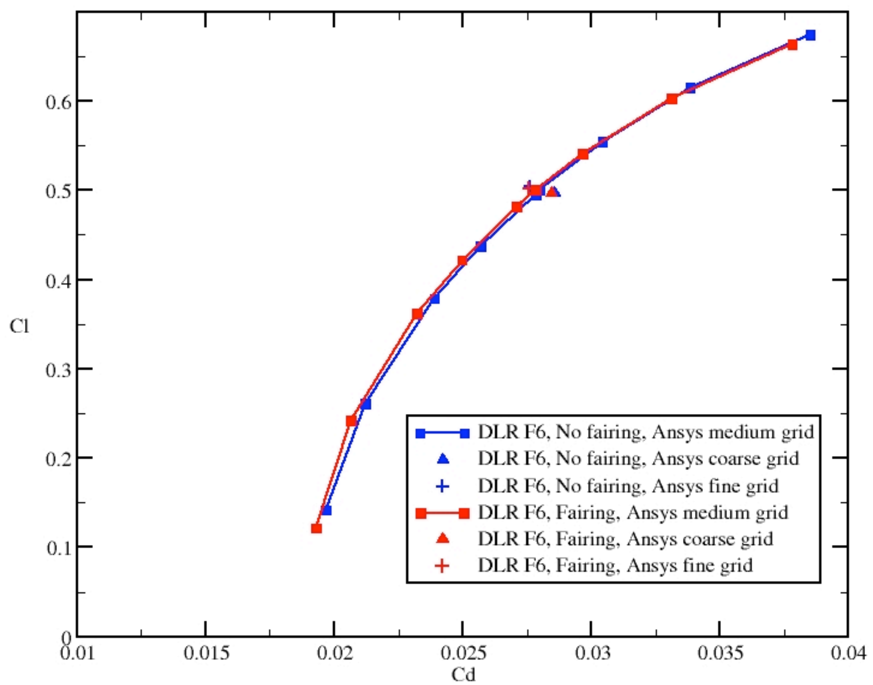


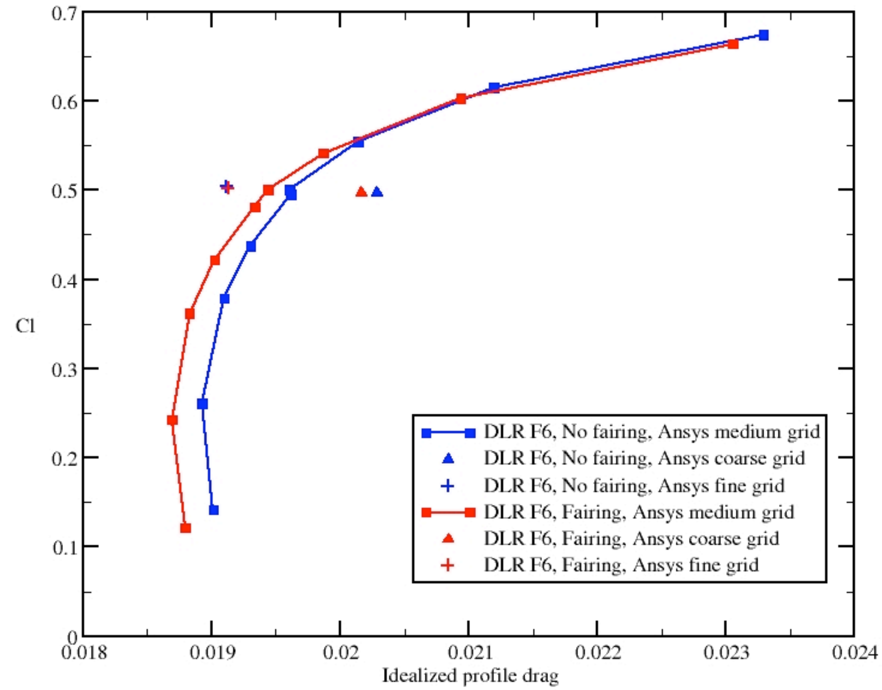


- Lift slightly higher without fairing, corresponding shift in a.o.a. of 0.09º-0.16º
- Small difference between coarse-medium-fine grid

Drag polar

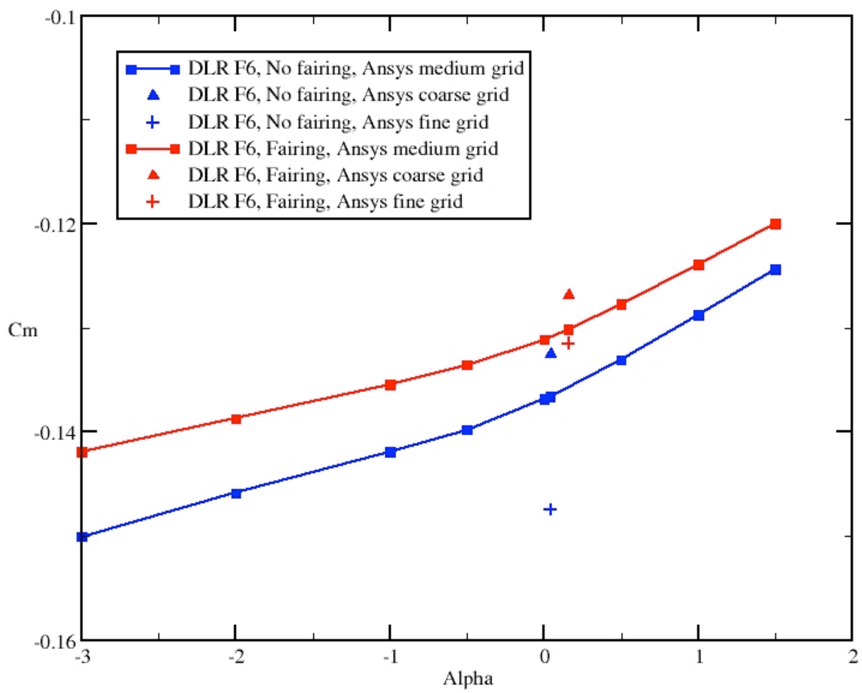
- Angles of attack: α=-3º, - 2º, - 1º, -0.5, 0º, 0.5º, 1º, 1.5º
- Computations with ANSYS medium grids
- Coarse and fine grid results included at Cl=0.5

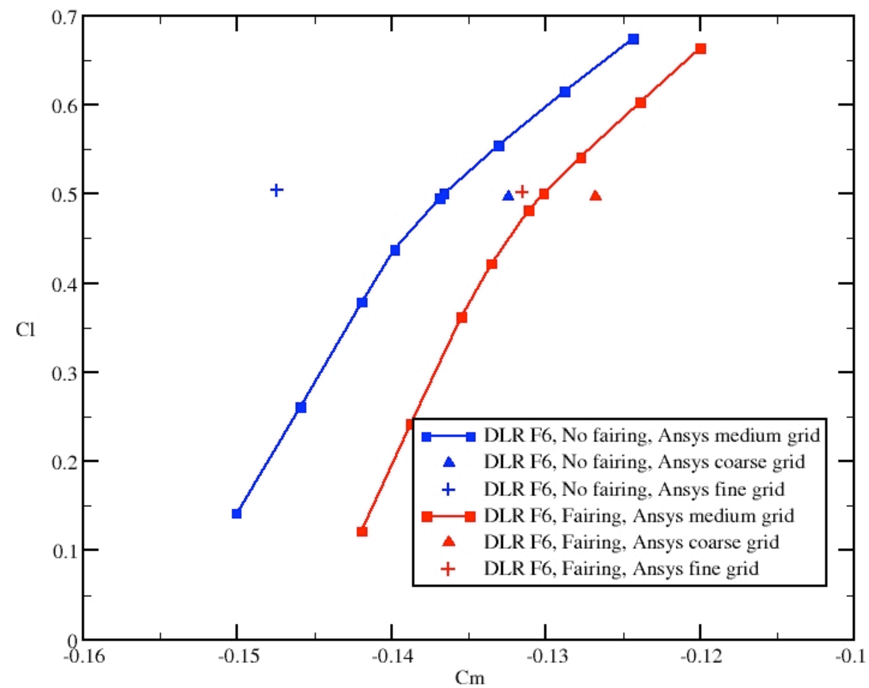




- Very similar polar with and without fairing
- Obvious difference in idealized profile drag for smaller Cl

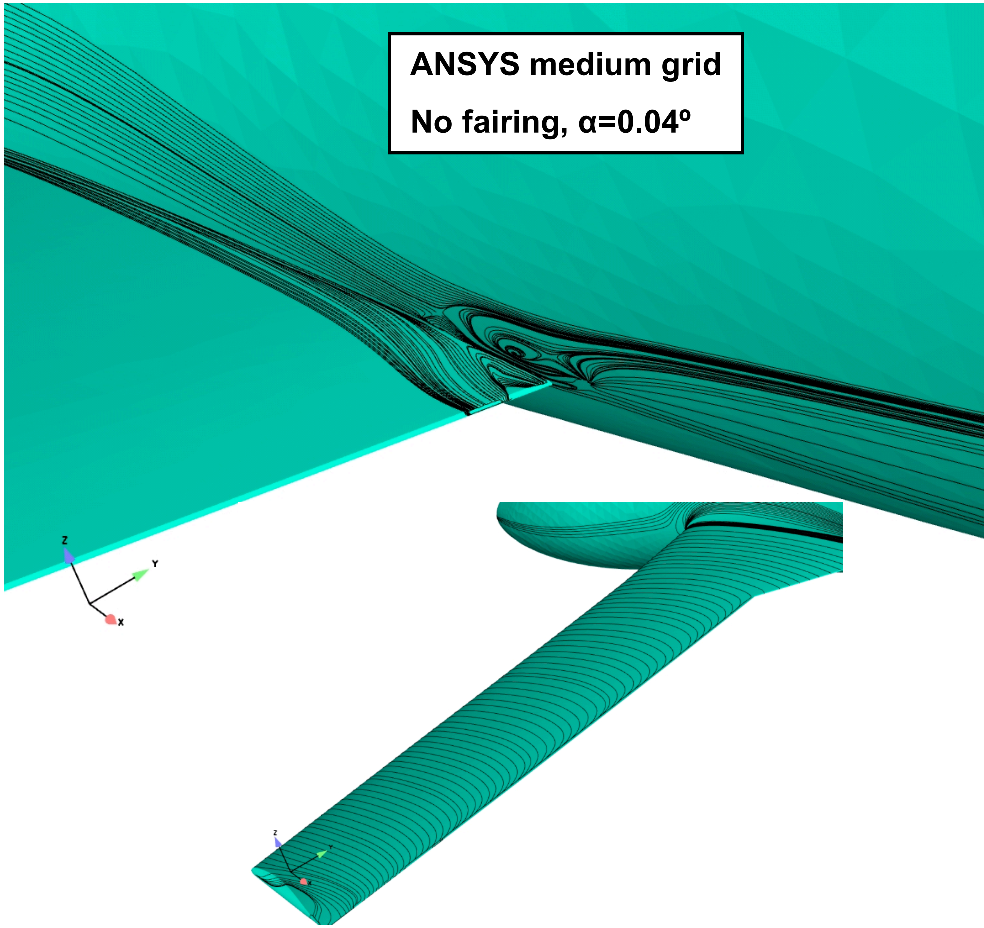
Pitching moment

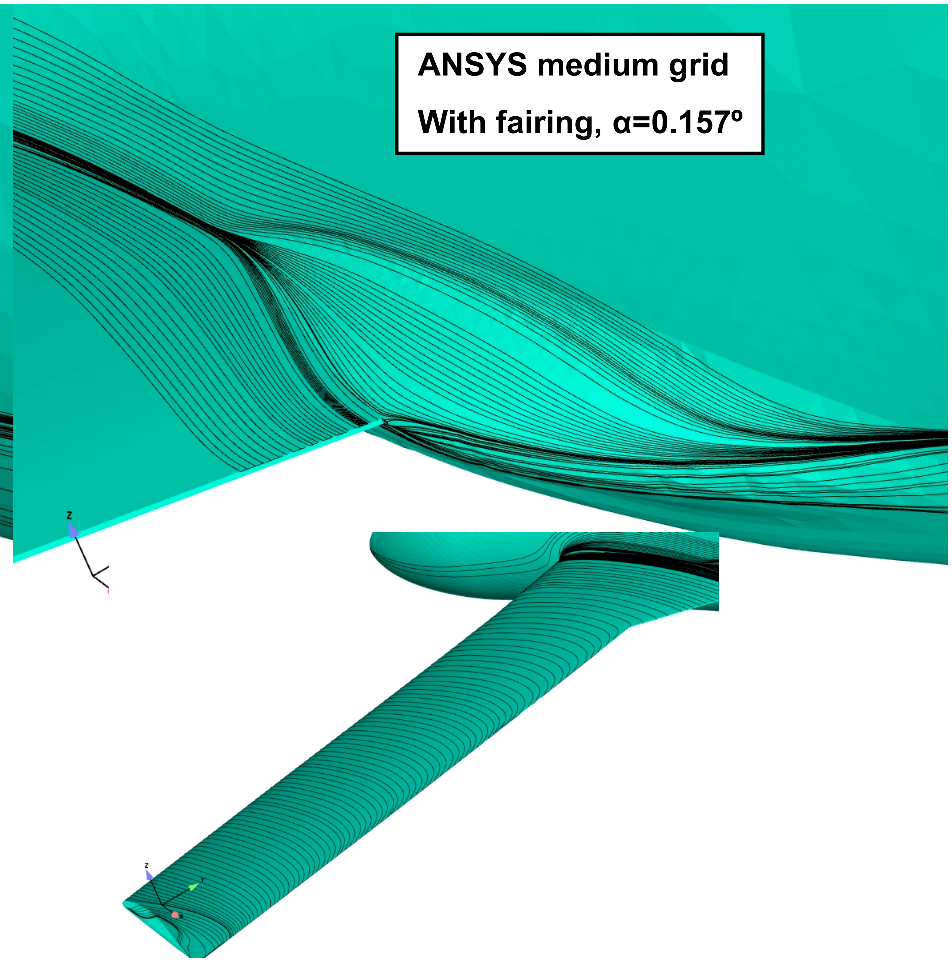




- Largest difference between grids in moment
- No fairing: Change in Cm increases as grid is refined
- With fairing: Change in Cm decreases as grid is refined

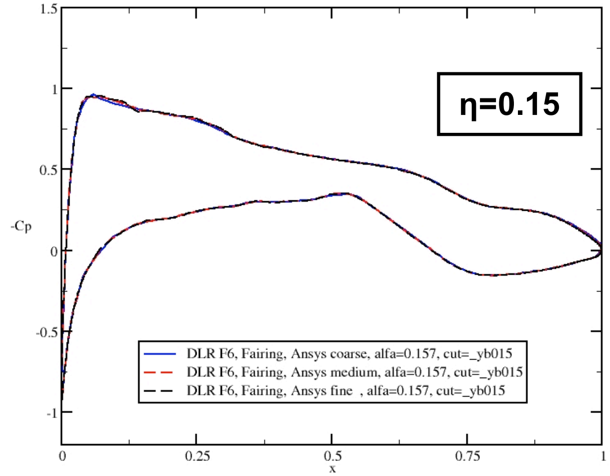
Surface friction lines, Cl=0.5

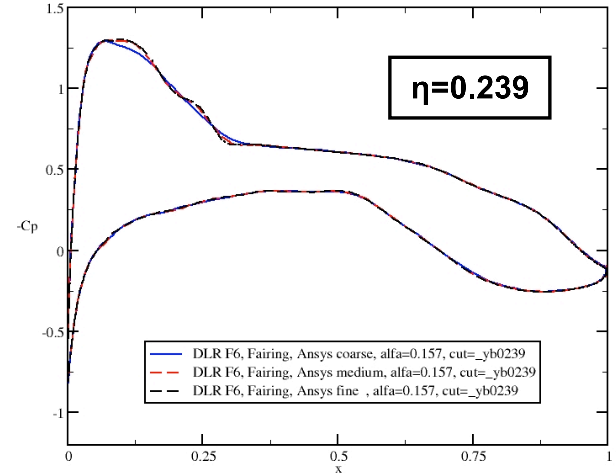


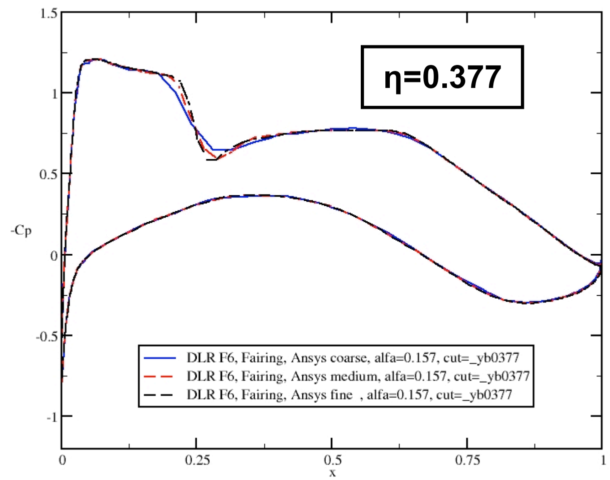


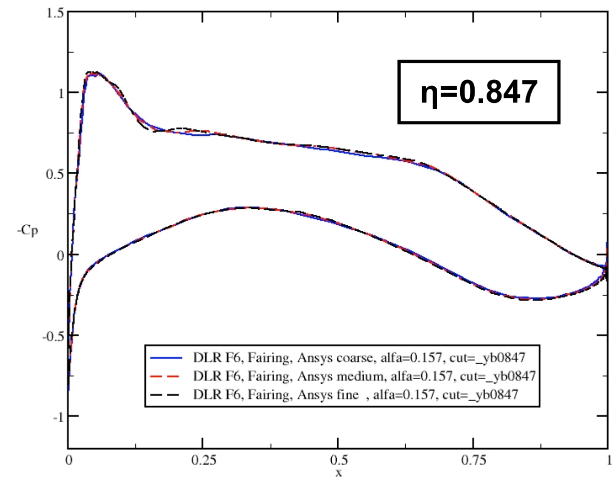
- Small separation bubble without fairing
- No bubble with faring
- No trailing edge separation

Pressure distributions



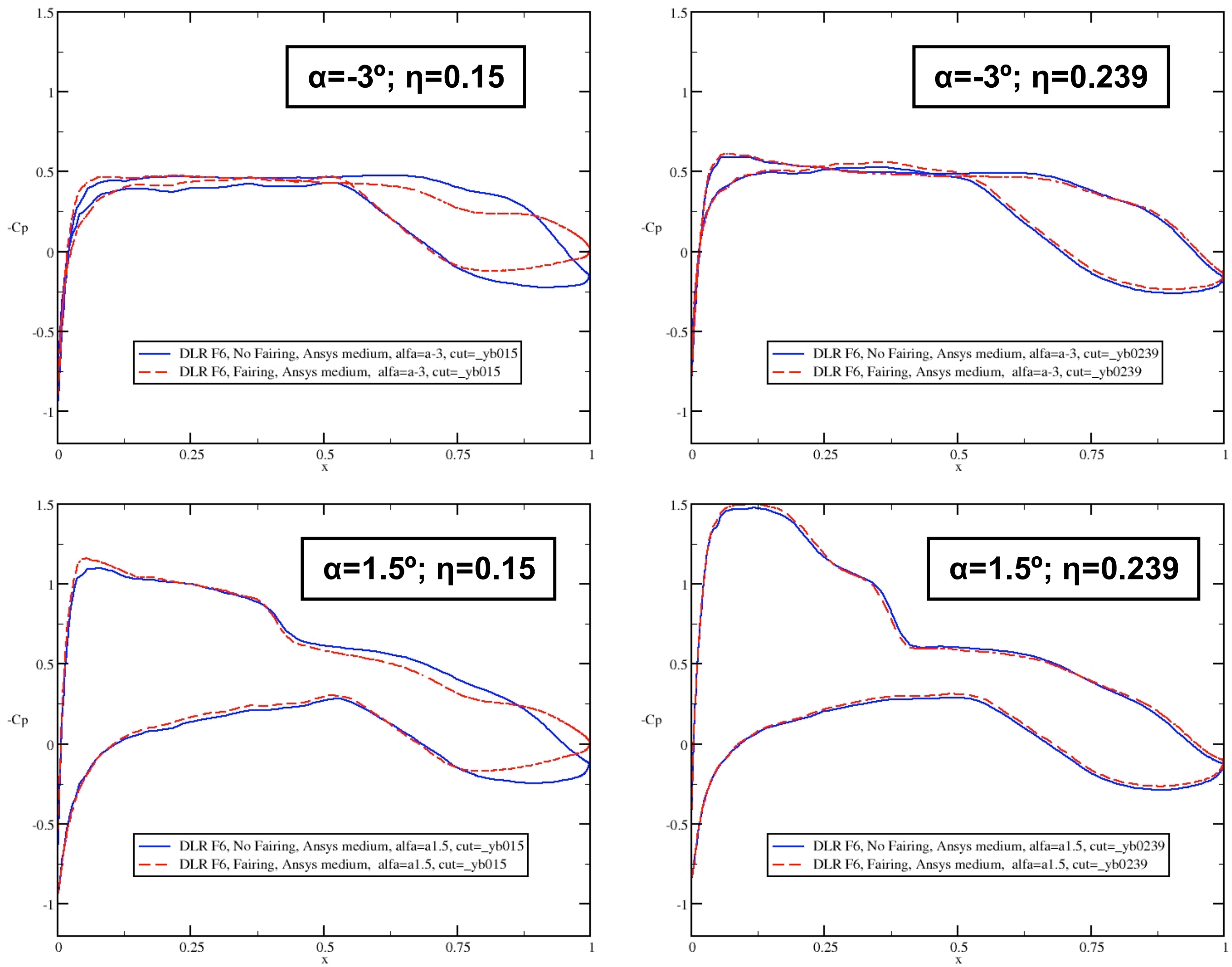






- **Cl=0.5, WB with fairing, Cp on coarse, medium, fine grids**
- **Very small differences**

Pressure distributions



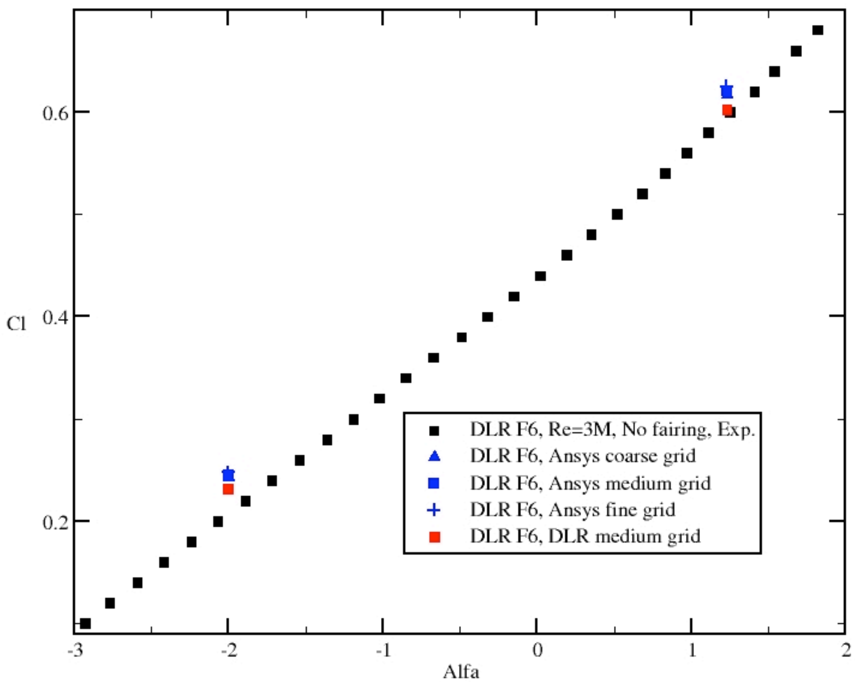
- Cp, with fairing/without fairing
- Differences near wing root
- Very small differences at larger span

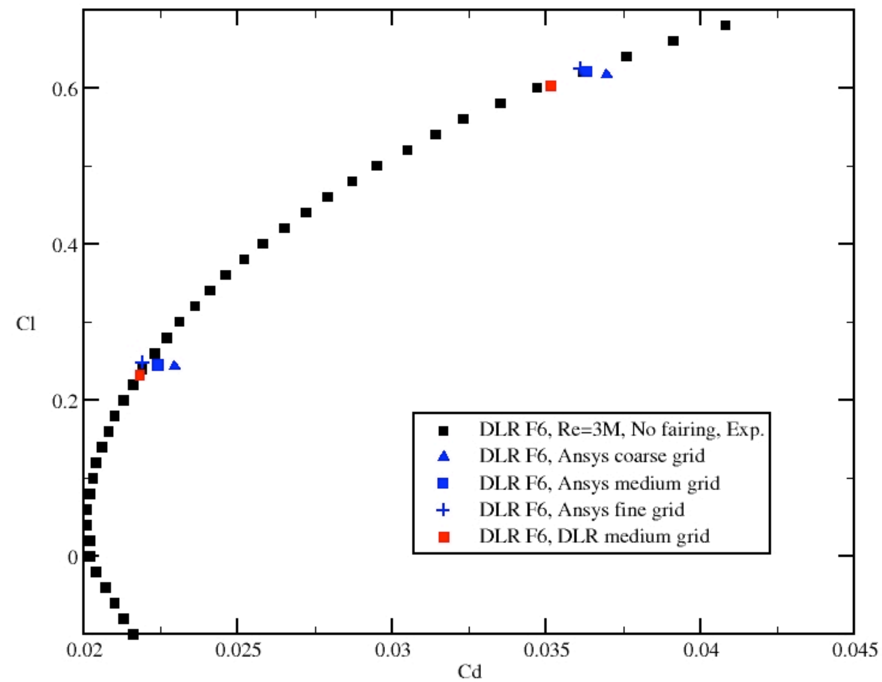
DPW2 computations

- Motivation
  - Establish quality of results by comparison to experiments
  - Investigate grid influence
- A few selected angles for the WB case from DPW2 recomputed
  - $Re=3x10^6$, α=- 2º, 1.23º
  - ANSYS coarse, medium, fine grids (no fairing)
- Computations on unstructured DPW2 medium grid from DLR

	ANSYS grids (WB)			DLR grid (WB)		
	Coarse	Medium	Fine	Coarse	Medium	Fine
# nodes	$3.05x10^6$	$8.04x10^6$	$18.1x10^6$		$3.16x10^6$	
# boundary nodes	$75x10^3$	$168x10^3$	$329x10^3$		$101x10^3$	
# prism layers	~31	~31	~31		~25	
1st cell size (m)	$0.6x10^{-6}$	$0.4x10^{-6}$	$0.25x10^{-6}$		$1x10^{-6}$	

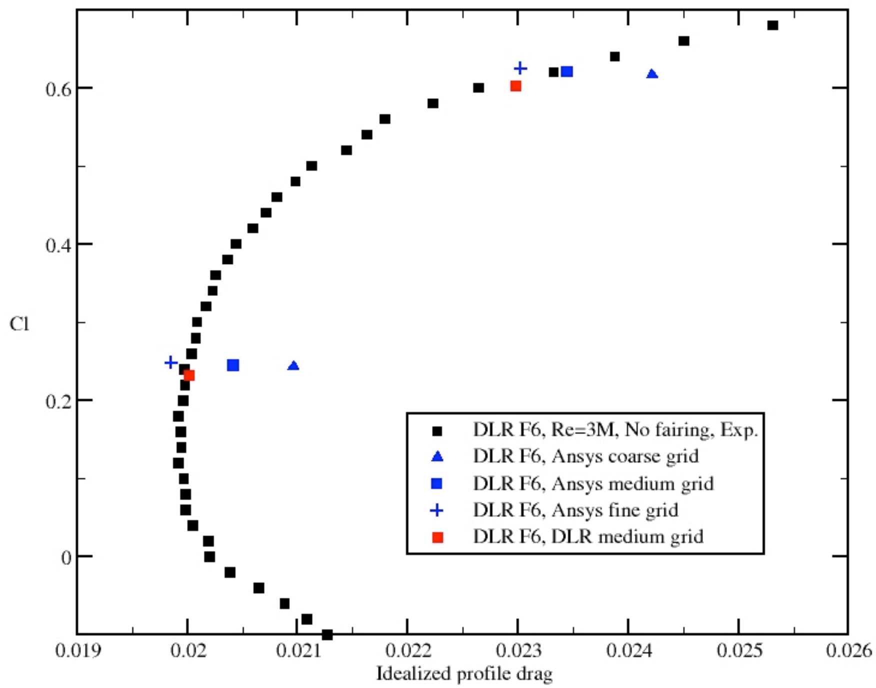
Forces, DPW2

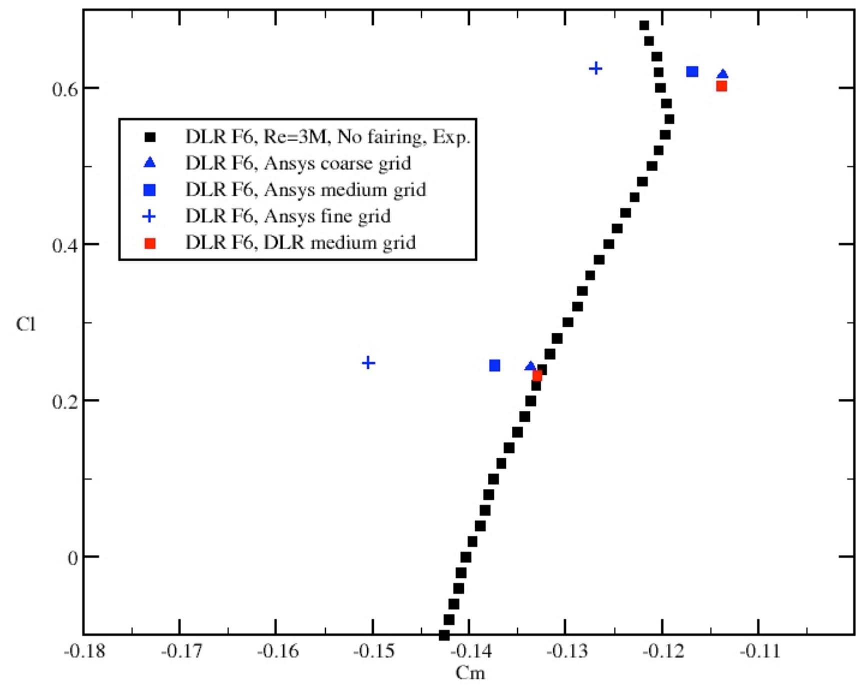




- Results on DLR grid closer to experiments
- With ANSYS grids, over-prediction in Cl corresponding to Δα~0.2º – 0.35º
- Excellent agreement Cl-Cd, with DLR grid and ANSYS fine grid

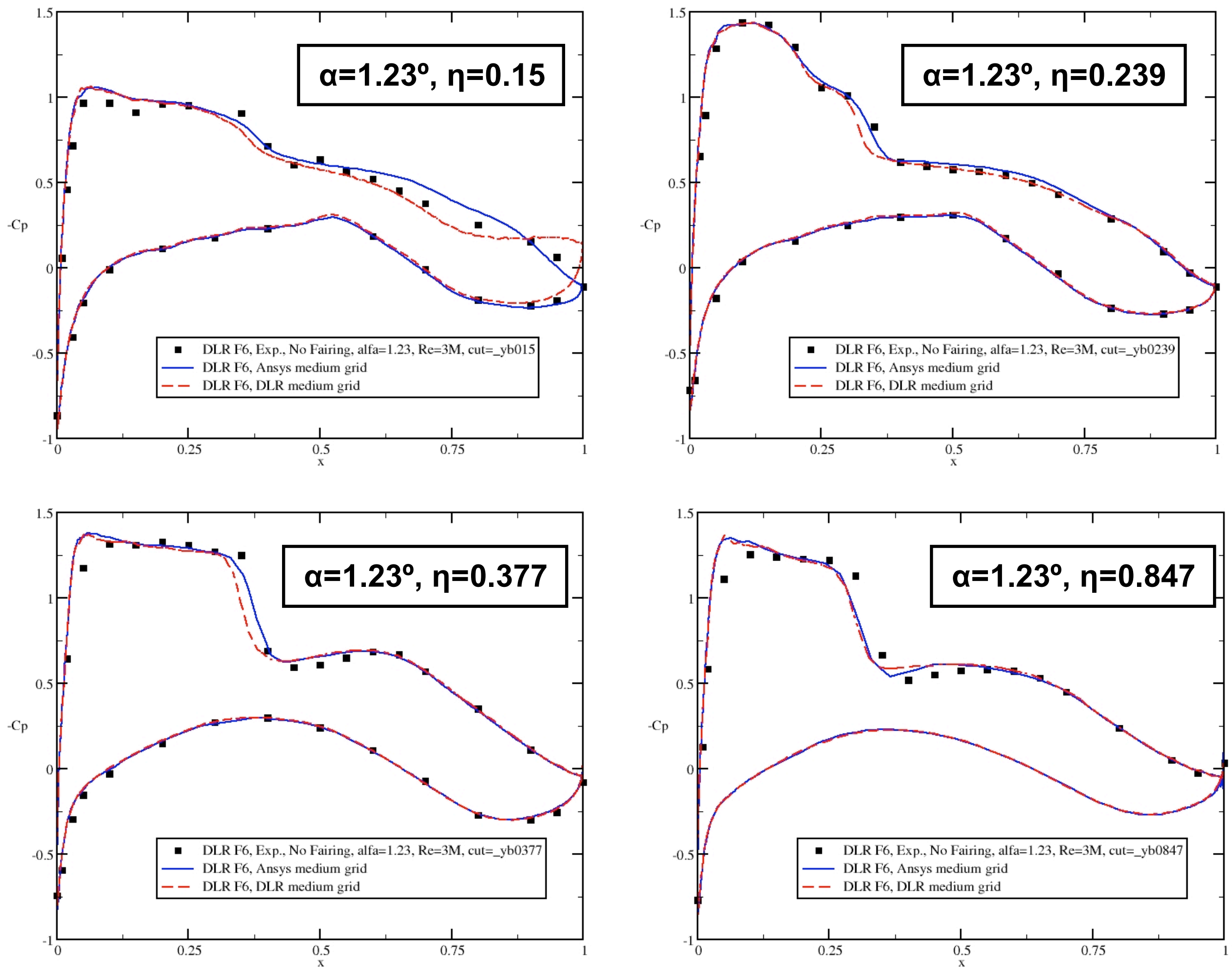
Forces and moments, DPW2





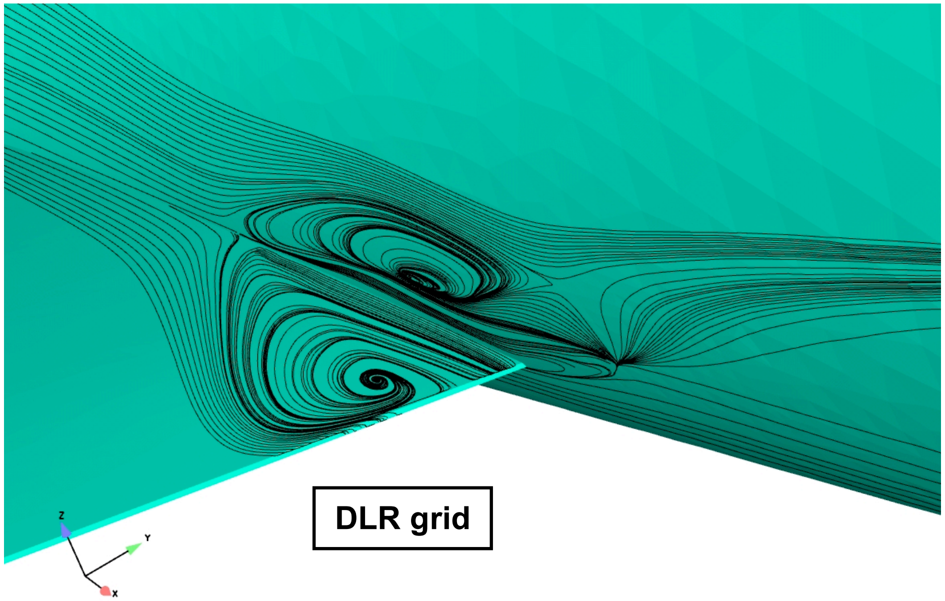
- **DLR medium grid produces results comparable to results with ANSYS fine grid**
- **Cm moves away from exp. with refined ANSYS grids but deviation smaller than other DPW2 results**

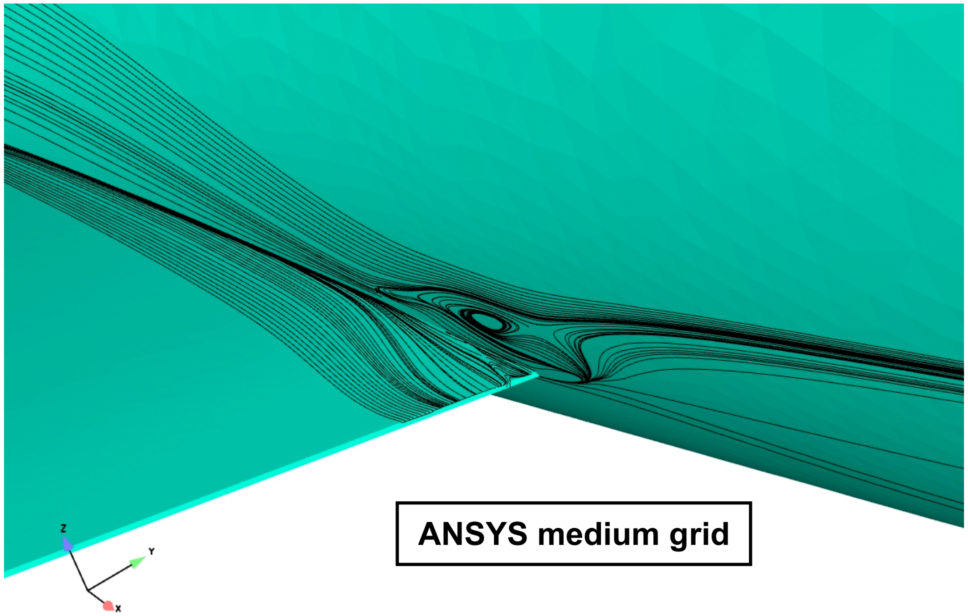
Pressure distributions, DPW2



- Separation bubble under predicted with ANSYS grid
- Shock better resolved with ANSYS grid

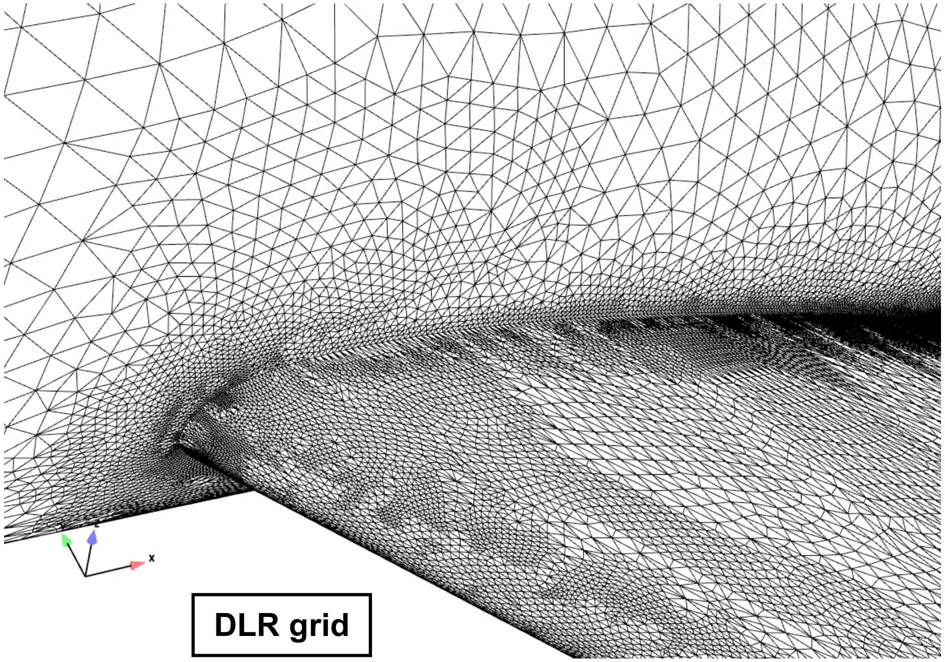
Surface friction lines, DPW2

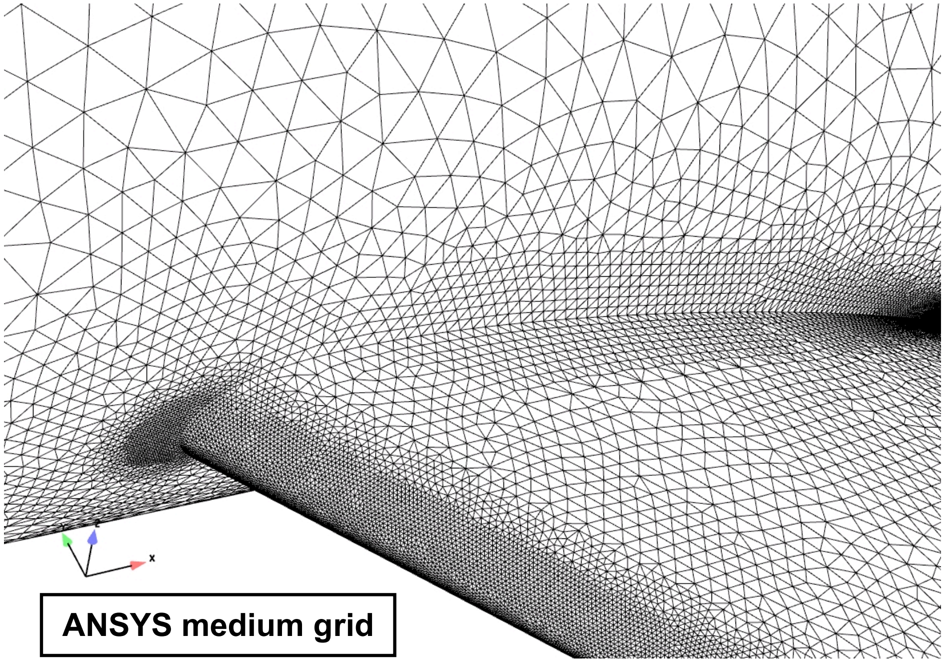




- Alpha 1.23º
- Large separation with DLR grid

Surface grids





- DLR grid: high resolution at junction, stretched triangles, adaptive
- ANSYS grid: high leading edge resolution, isotropic triangles

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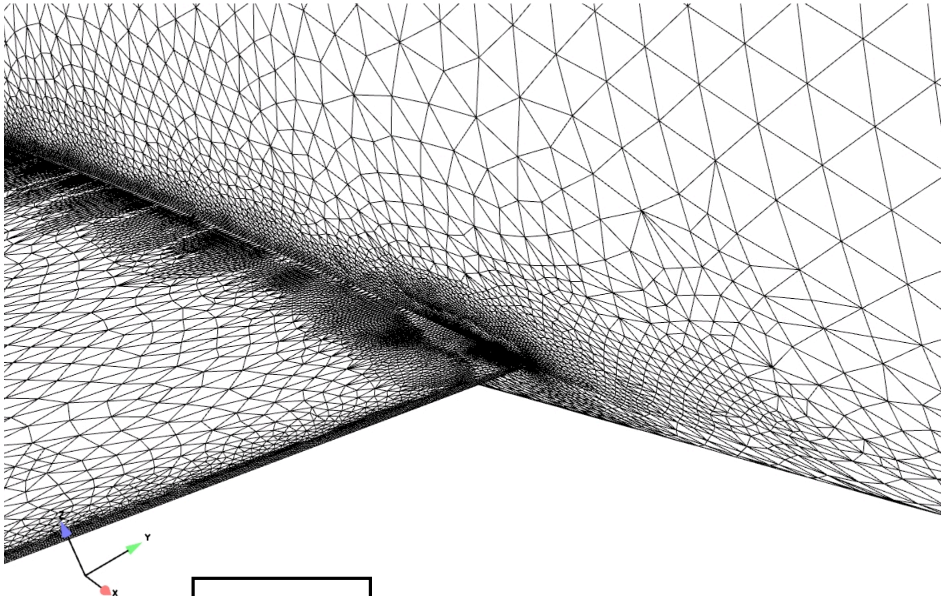
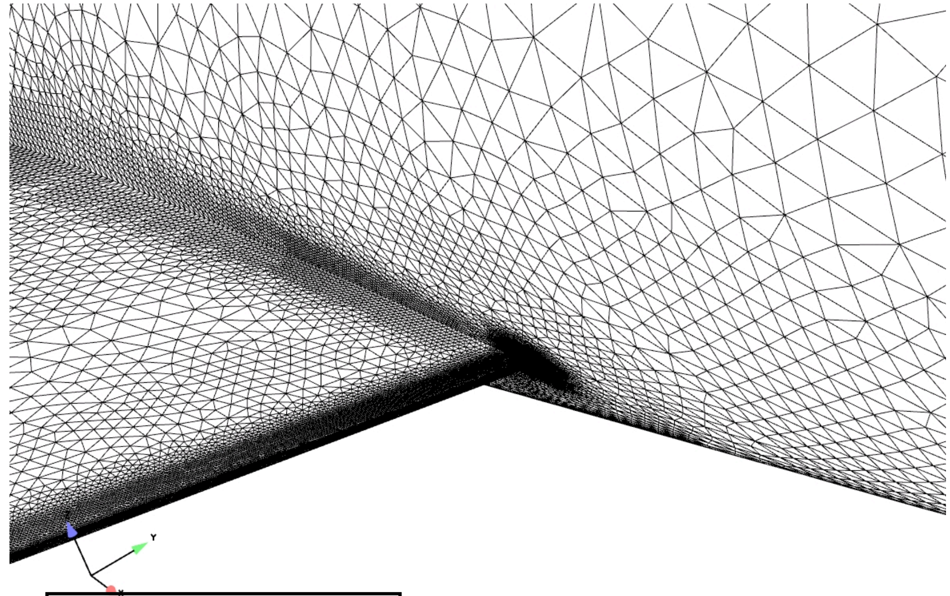
Surface grids



DLR grid



ANSYS medium grid

- DLR grid: high resolution at junction, stretched triangles, adaptive
- ANSYS grid: high leading edge resolution, isotropic triangles

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Summary

- Computations for Case 1 using ANSYS unstructured grids
- Solutions show small and asymptotic grid sensitivity
- No separation detected for the FX2B configuration
- Small separation bubble detected for the WB configuration
  - Smaller than with DLR grid from DPW2
  - Insufficient grid resolution in the wing body junction ?
- Additional calculations for the DPW2 case imply that the DPW3 results are reliable