



4th Int. Workshop on High-Order CFD Methods, Crete Island, Greece, June 4th-5th, 2016

AR1 RANS of the Common Research Model Results of the DLR-PADGE code

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Test case AR1: CRM wing/body

Flow conditions (DPW-5, Case 1):

- ▶ Mach number: $M = 0.85$
- ▶ Target $C_L = 0.5 (\pm 0.001)$
- ▶ Reynolds number: 5×10^6 (based on reference chord $c_{\text{ref}} = 275.80$ inch)



CRM wing/body: initial grid

Additional information:

- ▶ Moment reference center at $(x, y, z)_{\text{ref}} = (1325.90, 468.75, 177.95)$ in [inch]
- ▶ Reference area (half model): $A_{\text{ref}} = 297360$ (inch)²
- ▶ Fully turbulent flow, no transition
- ▶ Steady-state RANS
- ▶ Free air farfield boundary, no modeling of support structures or wind tunnel walls

Test case AR1: CRM wing/body

Turbulent flow at $M = 0.85$, $Re = 5 \times 10^6$ with $C_L = 0.5 (\pm 0.001)$

Curved hexahedral mesh (cubic lines) from the workshop homepage

- crm_q3.msh with 79505 elements (initial mesh)

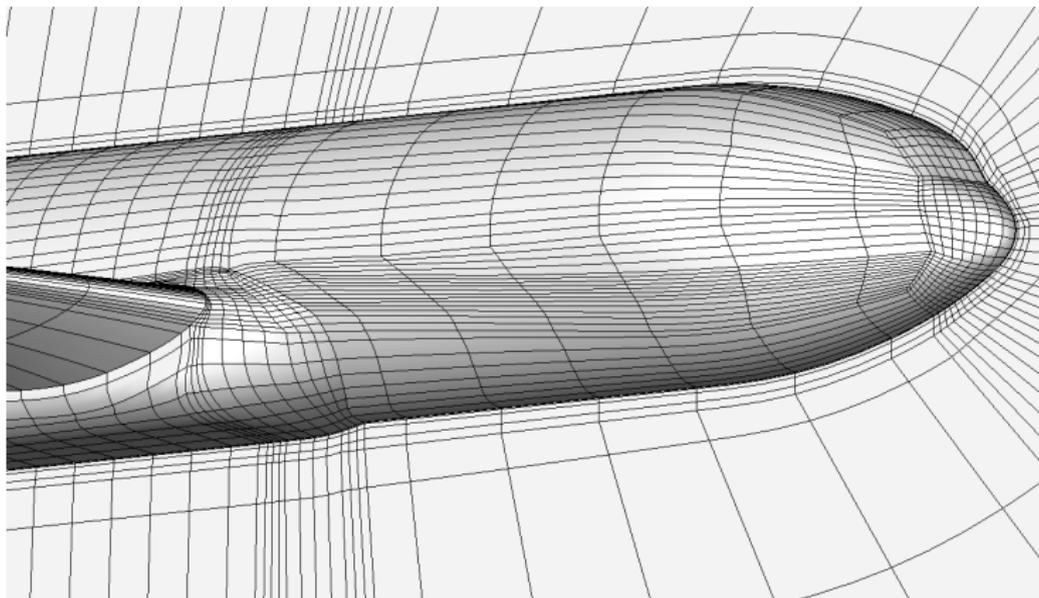


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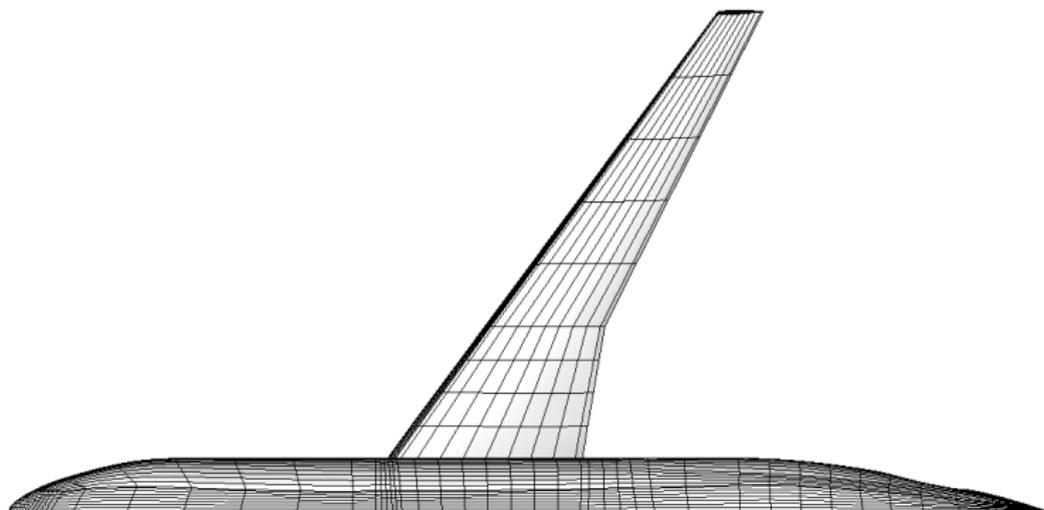


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Computational settings in the DLR-PADGE code

Discontinuous Galerkin discretization of the RANS and Wilcox $k-\omega$ equations

- ▶ Legendre polynomial basis functions of polynomial degree 1.
- ▶ Roe flux with Harten entropy fix (fix fraction=0.2)
- ▶ BR2 discretization of viscous terms
- ▶ Characteristic farfield and adiabatic wall boundary conditions

Flow solver:

- ▶ Backward Euler (fully implicit solver) with ILU preconditioned GMRes
- ▶ Damping of updates to ensure that pressure and density do not decrease more than 20% in each iteration step

Convergence criterion: Reduction of the (vector-) L^2 -norm of the residual vector to 10^{-12} relative to freestream conditions.

Main differences to the results shown on the last workshop:

- ▶ Target lift computation: α is kept constant once $TOL_{CL} = 0.001$ is reached. This tolerance is now reduced under mesh refinement.
- ▶ Adjoint solutions are solved more accurately: number of GMRes vectors and number of GMRes iteration steps doubled to 480 and 1920, respectively. ILU-per-process preconditioner replaced by line preconditioner.



Test case AR1: CRM wing/body

Turbulent flow at $M = 0.85$, $Re = 5 \times 10^6$ with $C_L = 0.5 (\pm 0.001)$

Residual-based mesh refinement

ref.step	DoFs/eqn	C_L	C_D	C_M	α	work units
initial	318020	0.5005	0.03428	-0.1180	2.179	19936
1	471184	0.5004	0.02963	-0.1076	2.244	42702
2	775068	0.5003	0.02872	-0.1026	2.296	85154
3	1314912	0.5001	0.02788	-0.1019	2.310	156206
4	2375948	0.5001	0.02728	-0.1005	2.326	331851
5	4492916	0.5000	0.02699	-0.0999	2.336	629813
6	8705556	0.5000	0.02650	-0.0996	2.341	1105033

Test case AR1: CRM wing/body

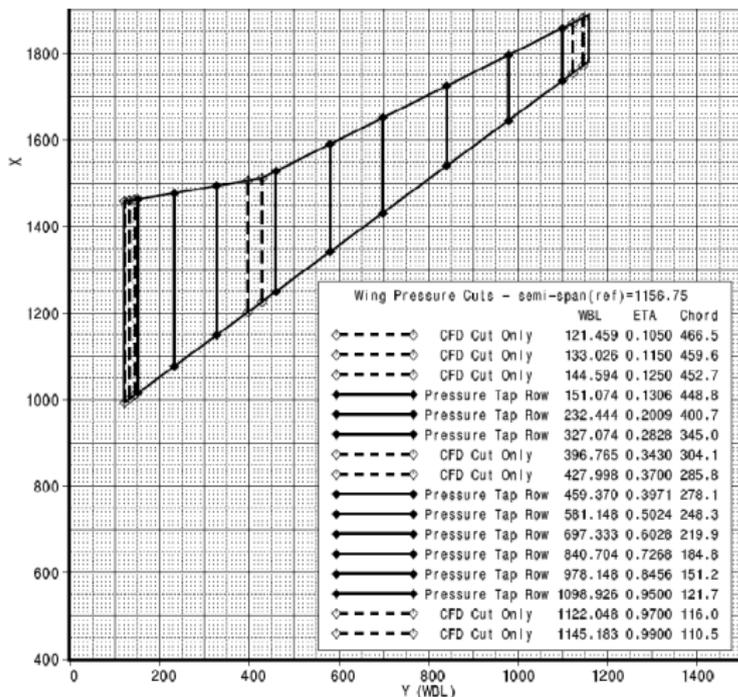
Turbulent flow at $M = 0.85$, $Re = 5 \times 10^6$ with $C_L = 0.5 (\pm 0.001)$

Adjoint-based mesh refinement for the lift coefficient

ref.step	DoFs/eqn	C_L	C_D	C_M	α	work units
initial	318020	0.5005	0.03428	-0.1180	2.179	19936
1	517120	0.5003	0.02781	-0.1080	2.251	63854
2	995104	0.5000	0.02561	-0.1014	2.315	128003
3	1953148	0.5000	0.02485	-0.1022	2.308	233742
4	3931028	0.5001	0.02472	-0.1033	2.297	453941
5	8138244	0.5001	0.02486	-0.1035	2.295	857034

work units include the flow as well as the adjoint solutions involved.

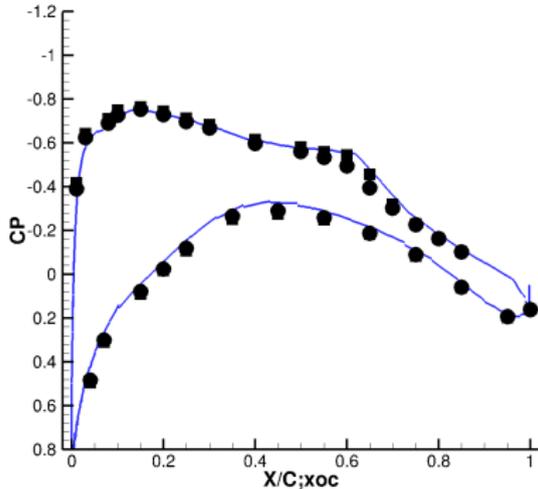
Test case AR1: CRM wing/body



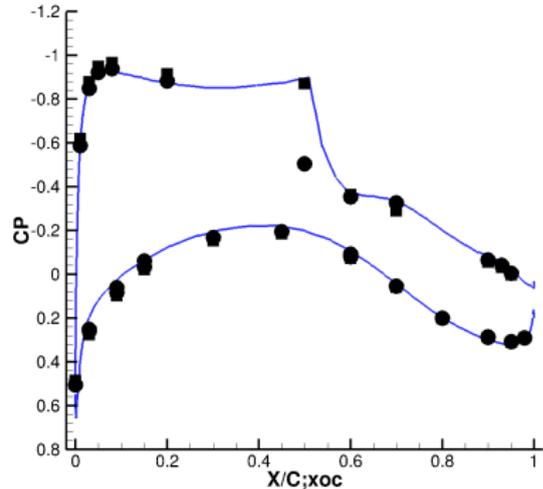
Following slides: c_p on
 wing section 04 $\eta = 0.1306$
 wing section 10 $\eta = 0.5024$

Test case AR1: CRM wing/body

Turbulent flow at $M = 0.85$, $Re = 5 \times 10^6$ with $C_L = 0.5$



wing section 04, $\eta = 0.1306$

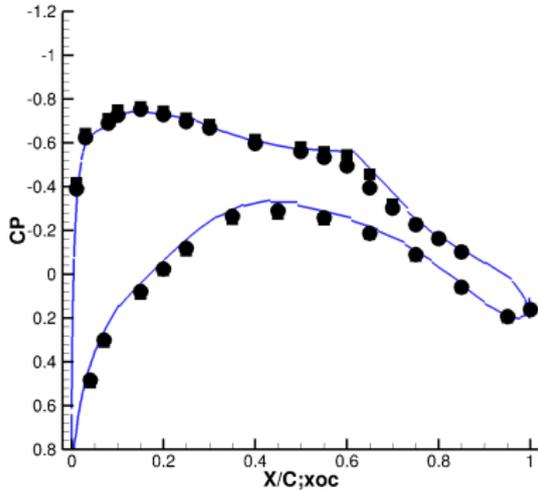


wing section 10, $\eta = 0.5024$

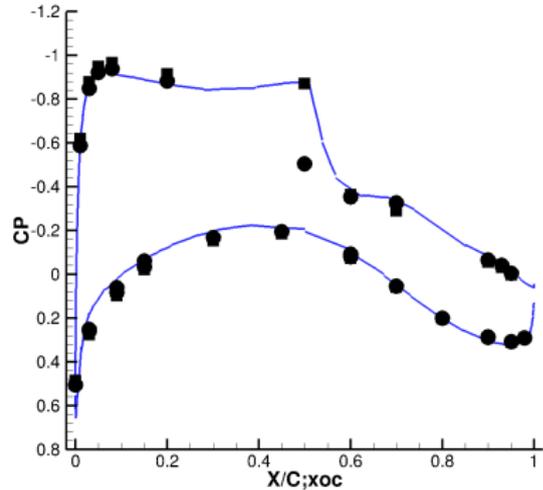
Solution for $\alpha = 2.341^\circ$ on 6 times residual-based refined mesh with 8.705.556 DoFs/eqn.

Test case AR1: CRM wing/body

Turbulent flow at $M = 0.85$, $Re = 5 \times 10^6$ with $C_L = 0.5$



wing section 04, $\eta = 0.1306$



wing section 10, $\eta = 0.5024$

Solution for $\alpha = 2.295^\circ$ on 5 times adjoint-based(C_L) refined mesh with 8.138.244 DoFs/eqn.

