3rd Int. Workshop on High-Order CFD Methods, Kissimmee, Florida, Jan 3-4, 2015

Results for the C3.5 test case with the DLR-PADGE code

Ralf Hartmann

Institute of Aerodynamics and Flow Technology
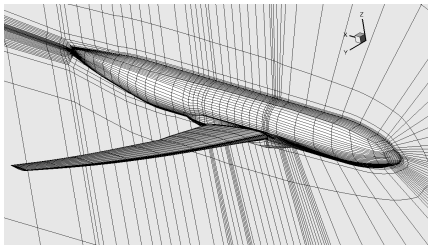German Aerospace Center

4. Jan. 2015 (Updated: 31st March 2015)

Deutsches Zentrum
für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

Results for the C3.5 test case with the DLR-PADGE code   1 / 11
Ralf Hartmann

Test case C3.5: 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 $c_{\mathrm{ref}} = 275.80$ inch)

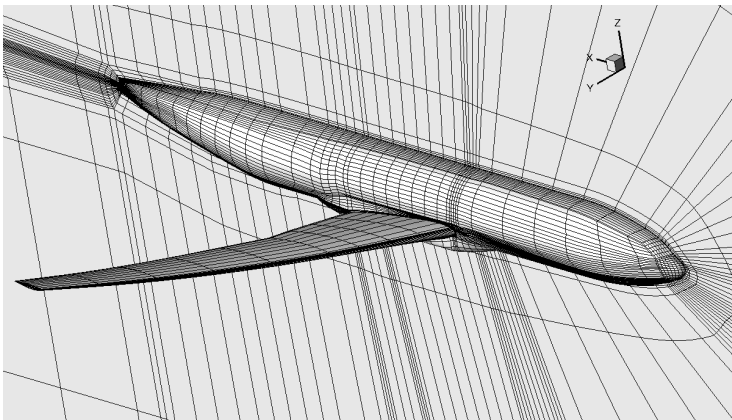CRM wing/body: initial grid

Additional information:

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

Deutsches Zentrum
für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

Results for the C3.5 test case with the DLR-PADGE code   2 / 11
Ralf Hartmann

Test case C3.5: CRM wing/body

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

Curved hexahedral mesh (cubic lines) from the workshop homepage

- crm_q3.msh with 79505 elements (initial mesh)

Deutsches Zentrum
für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

Results for the C3.5 test case with the DLR-PADGE code   3 / 11
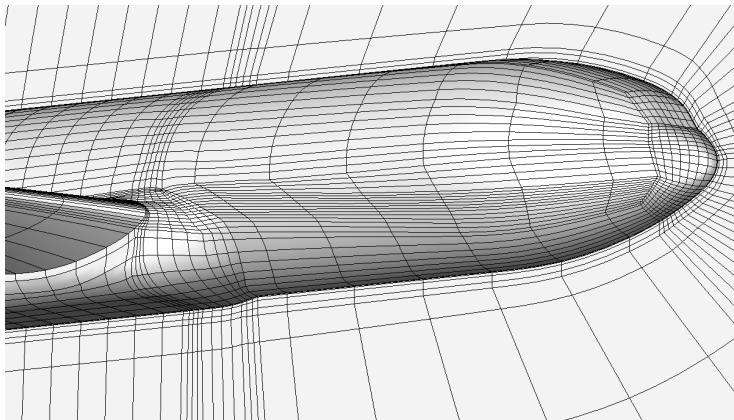Ralf Hartmann

Test case C3.5: CRM wing/body
Turbulent flow at $M = 0.85$, $Re = 5 \times 10^6$ with $C_L = 0.5$

Curved hexahedral mesh (cubic lines) from the workshop homepage
- crm_q3.msh with 79505 elements (initial mesh)

Deutsches Zentrum
für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

Results for the C3.5 test case with the DLR-PADGE code   4 / 11
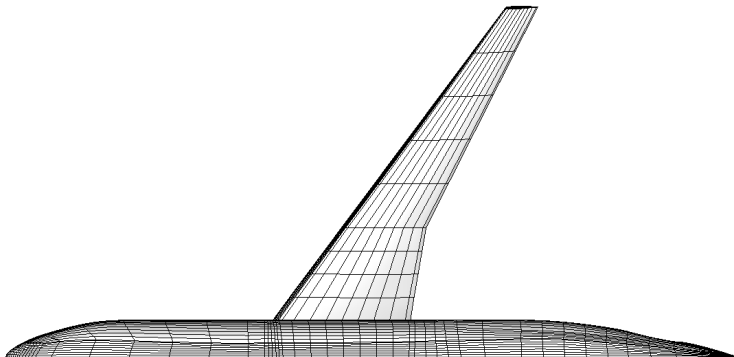Ralf Hartmann

Test case C3.5: CRM wing/body

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

Curved hexahedral mesh (cubic lines) from the workshop homepage

- ▶ crm_q3.msh with 79505 elements (initial mesh)

Deutsches Zentrum
DLR für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

Results for the C3.5 test case with the DLR-PADGE code   5 / 11
Ralf Hartmann

Test case C3.5: CRM wing/body

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

Methods in the DLR-PADGE code used for this test case

Discontinuous Galerkin discretization of the RANS and Wilcox k-ω 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 boundary conditions
- ► Adiabatic wall boundary condition

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

Deutsches Zentrum
für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

Test case C3.5: 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

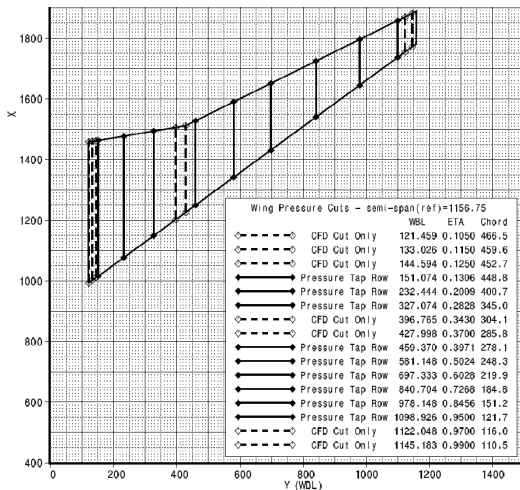| ref.step	DoFs/eqn	C_L	C_D	C_M	α	work units
initial	318020	0.5005	0.03428	-0.1180	2.179	19936
1	471184	0.5004	0.02963	-0.1076	2.244	42702
2	775068	0.5003	0.02872	-0.1026	2.296	85154
3	1314912	0.5001	0.02788	-0.1019	2.310	156206
4	2375948	0.5001	0.02728	-0.1005	2.326	331851
5	4492916	0.5000	0.02699	-0.0999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

Test case C3.5: 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.

Deutsches Zentrum
DLR für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

Results for the C3.5 test case with the DLR-PADGE code   8 / 11
Ralf Hartmann

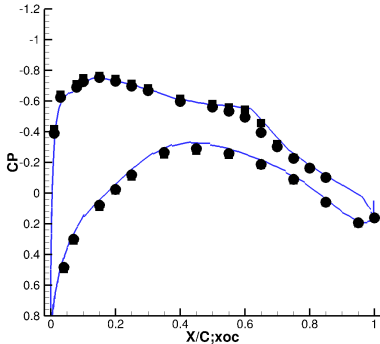**Test case C3.5: CRM wing/body**

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

Deutsches Zentrum
für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

Results for the C3.5 test case with the DLR-PADGE code   9 / 11
Ralf Hartmann

Test case C3.5: CRM wing/body

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

wing section 04, $\eta = 0.1306$
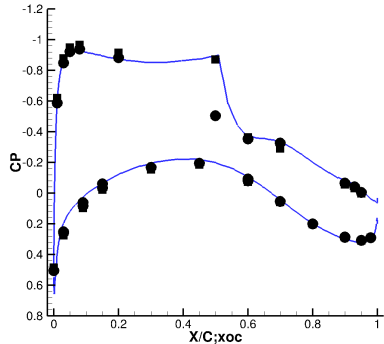
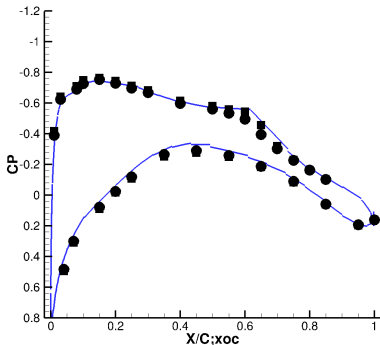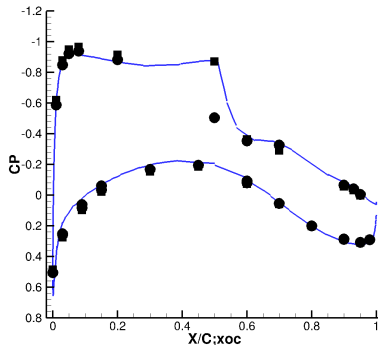wing section 10, $\eta = 0.5024$

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

Deutsches Zentrum
für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

Test case C3.5: 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 $\alpha = 2.295°$ on 5 times adjoint-based(C_L) refined mesh with 8.138.244 DoFs/eqn.