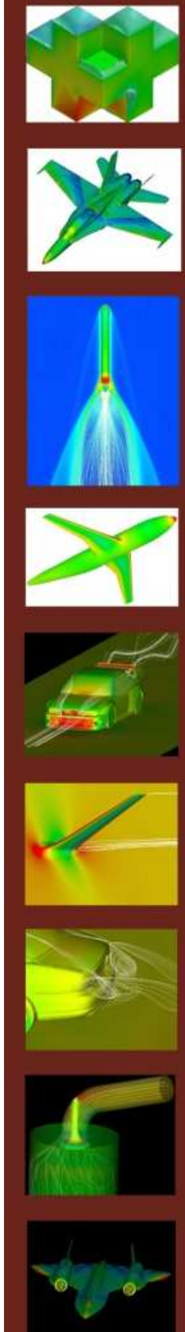

DPW-II
AIAA Orlando 2003
Metacomp Technologies



Drag Prediction Workshop II

PARTICIPANT INFORMATION

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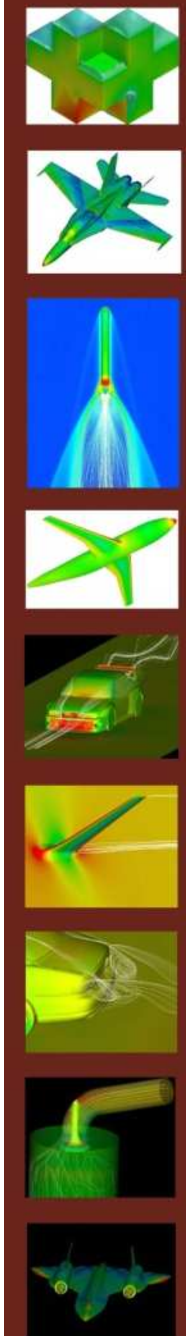
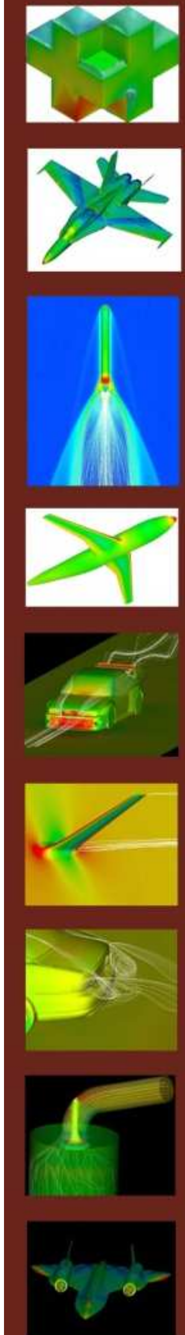


CFD++ Solver Information

- **Basic Algorithm: finite volume cell-based mixed-element unstructured**
- **Spatial Discretization: multi-dimensional TVD (inviscid terms), non-decoupling non-limited face polynomials (viscous terms)**
- **Time Integration: point implicit with multi-grid relaxation (for steady state)**
- **Turbulence Model used: wall-distance-free realizable k-ε**



Required Cases

CASE 1:

Hexahedral Mesh

Single Point Grid Sensitivity Study

M=0.75, Re=3 M, C_L=0.5

W+B+P+N (α=0.632 deg.):

- Coarse Mesh: 4.8 M
- Medium Mesh: 8.5 M
- Fine Mesh: 12.8 M

W+B (α=0.144 deg.):

- Coarse Mesh: 5.5 M
- Medium Mesh: 7.4 M
- Fine Mesh: 9.6 M

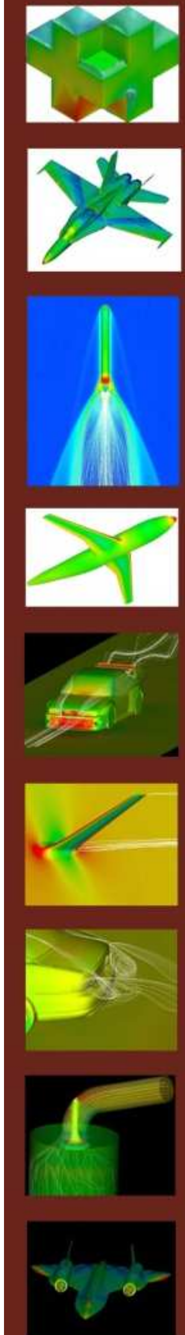
CASE 2:

Drag Polars (W+B & W+B+P+N)

- M=0.75, Re=3 M, α (deg.) = -3, -2, -1.5, -1, 0, 1, 1.5

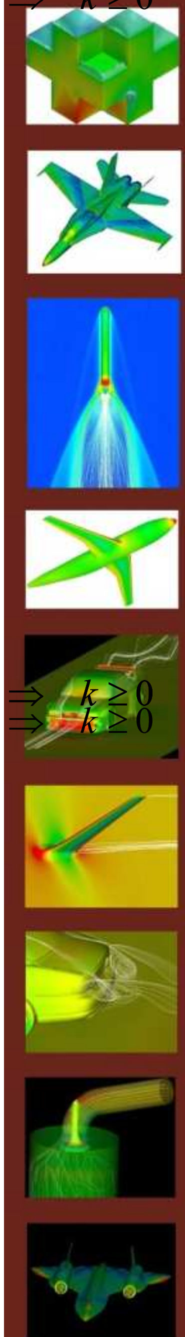
Mesh Information for Case 2:

- Field Cells: 7.4 M / 8.5 M (WB / WBPN)
- BL 1st Cell Size: 1.5-2.0E-6 m (y+<1, solve-to-wall)
- BL Growth Rate: 1.23–1.28
- BL Cells: ~20



Solution Information

- Computer Platform: PIV Xeon 2.4 GHz
- Number of Processors: 12
- Run Time CPU: 144–160 Hrs.
- Run Time Wall-Clock: 12-13 Hrs. (6-8 Hrs. for restarts)
- Memory Requirements: ~18 GB
- Forces converged in less than 400 time steps
- Inflow turbulence levels:
  - Turbulence intensity: T'= 0.002 (from AGARD-AR-303)
  - Turbulence length-scale: = 0.6 mm (assumed)
- Flow was allowed to transition naturally over the wing and fuselage.



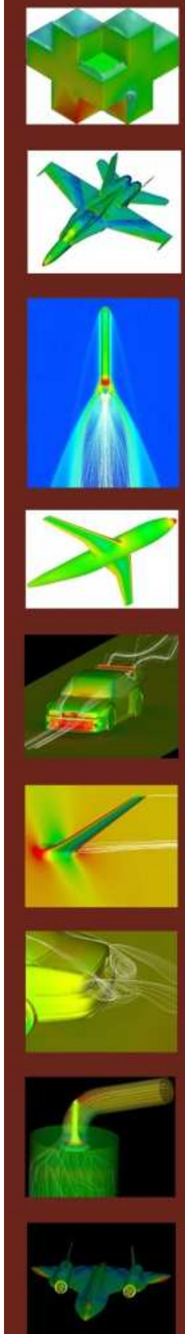
Solution Information

Realizable (to the hilt) k-ε closure

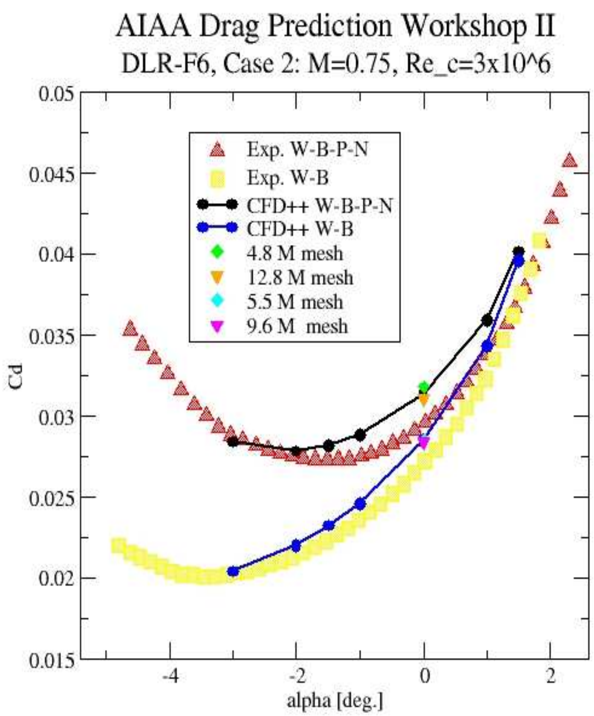
- **Positivity of Reynolds normal stresses:** → $\overline{u'_\alpha u'_\alpha} \geq 0, \quad \alpha = 1\ or\ 2\ or\ 3 \Rightarrow \quad k \geq 0$
- **Schwartz inequality:** → $\overline{u'_\alpha u'_\beta}^2 \leq \overline{u'_\alpha u'_\alpha} \bullet \overline{u'_\beta u'_\beta} \Rightarrow \nu_t \leq \frac{2k}{3|S|}$
- **Time- and velocity-scale realizability:** → $T_t \geq \sqrt{\nu/\varepsilon}, \quad V_t \geq (\nu\varepsilon)^{1/4}$
- **Topography-parameter-free formulation**

Sensitizing to non-equilibrium flow

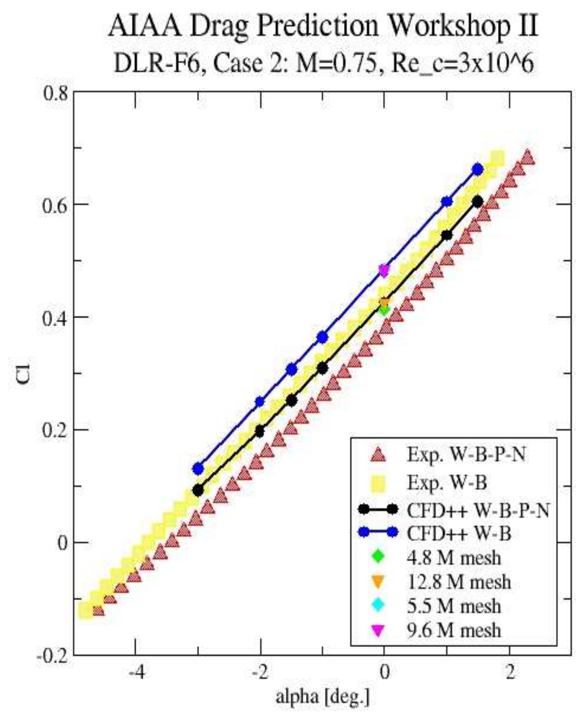
- **Extra source term in ε equation:** → $E : V_t\sqrt{\varepsilon T_t}\,\max\left\{\frac{\partial k}{\partial x_j}\frac{\partial(k/\varepsilon)}{\partial x_j},0\right\}$
- **Increases in non-equilibrium near-wall regions, thereby reducing eddy-viscosity. This improves prediction of backflows for example.**



Forces

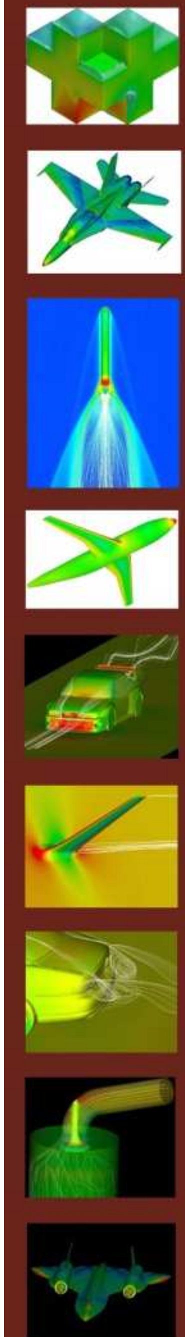


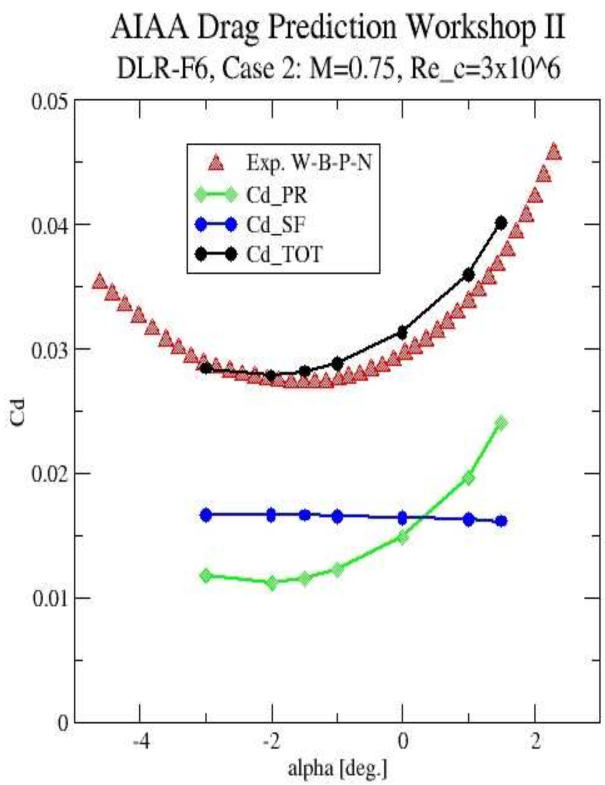
AIAA Drag Prediction Workshop II
DLR-F6, Case 2: M=0.75, Re_c=3x10^6
Cd
0.05
0.045
0.04
0.035
0.03
0.025
0.02
0.015
-4
-2
0
2
alpha [deg.]
Exp. W-B-P-N
Exp. W-B
CFD++ W-B-P-N
CFD++ W-B
4.8 M mesh
12.8 M mesh
5.5 M mesh
9.6 M mesh

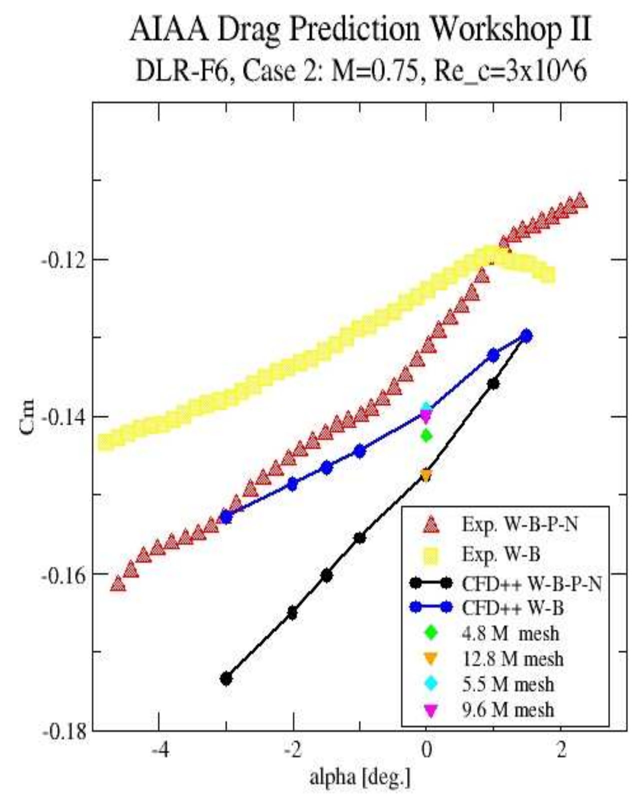


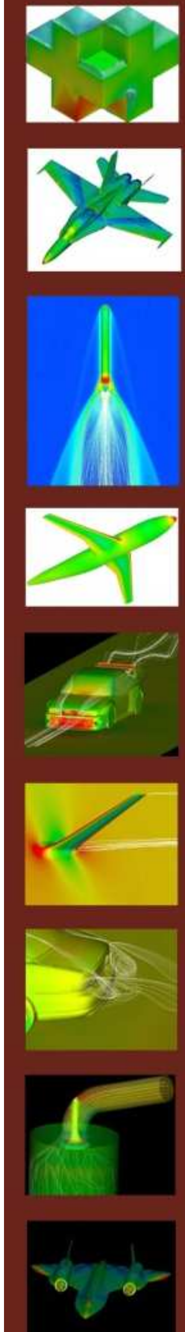
AIAA Drag Prediction Workshop II
DLR-F6, Case 2: M=0.75, Re_c=3x10^6
Cl
0.8
0.6
0.4
0.2
0
-0.2
-4
-2
0
2
alpha [deg.]
Exp. W-B-P-N
Exp. W-B
CFD++ W-B-P-N
CFD++ W-B
4.8 M mesh
12.8 M mesh
5.5 M mesh
9.6 M mesh

Forces

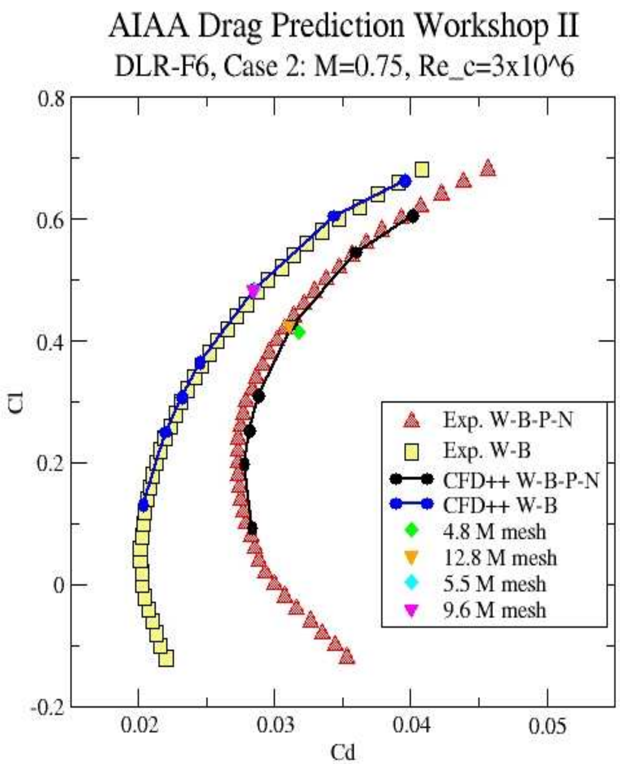



AIAA Drag Prediction Workshop II
DLR-F6, Case 2: M=0.75, Re_c=3x10^6
Exp. W-B-P-N
Cd_PR
Cd_SF
Cd_TOT
Cd
alpha [deg.]

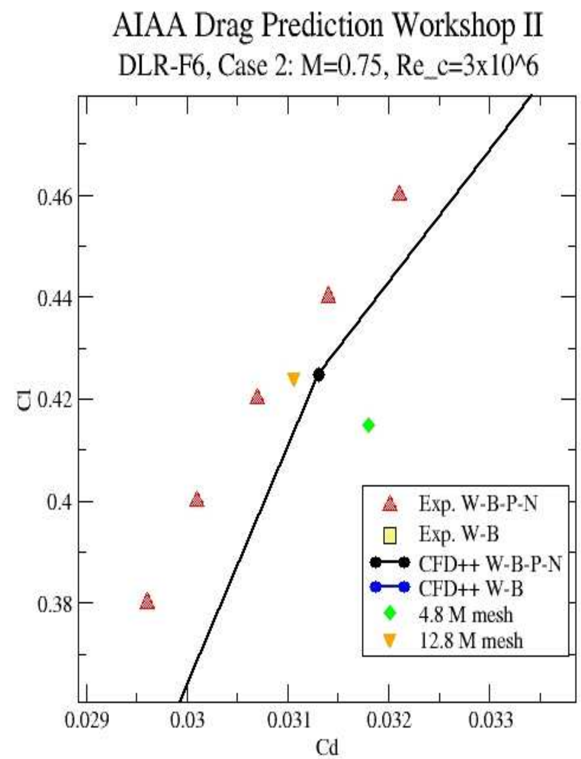

AIAA Drag Prediction Workshop II
DLR-F6, Case 2: M=0.75, Re_c=3x10^6
Exp. W-B-P-N
Exp. W-B
CFD++ W-B-P-N
CFD++ W-B
4.8 M mesh
12.8 M mesh
5.5 M mesh
9.6 M mesh
Cm
alpha [deg.]



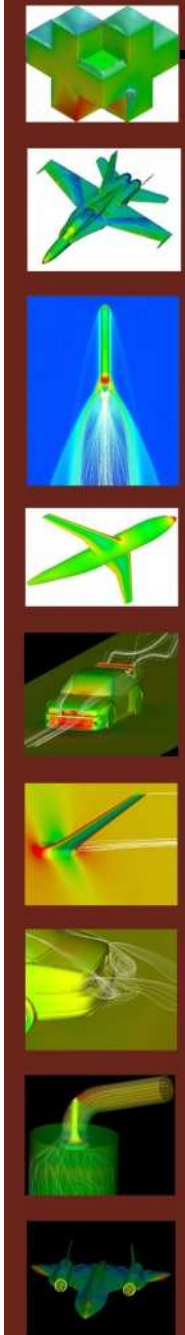
Forces



AIAA Drag Prediction Workshop II
DLR-F6, Case 2: M=0.75, Re_c=3x10^6
Cl
Cd
0.8
0.6
0.4
0.2
0
-0.2
0.02
0.03
0.04
0.05
Exp. W-B-P-N
Exp. W-B
CFD++ W-B-P-N
CFD++ W-B
4.8 M mesh
12.8 M mesh
5.5 M mesh
9.6 M mesh



AIAA Drag Prediction Workshop II
DLR-F6, Case 2: M=0.75, Re_c=3x10^6
Cl
Cd
0.46
0.44
0.42
0.4
0.38
0.029
0.03
0.031
0.032
0.033
Exp. W-B-P-N
Exp. W-B
CFD++ W-B-P-N
CFD++ W-B
4.8 M mesh
12.8 M mesh

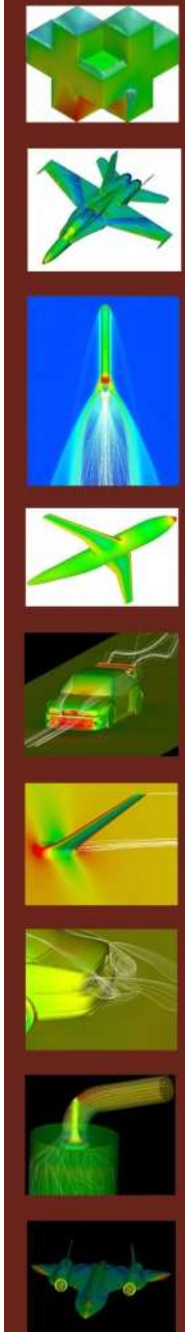


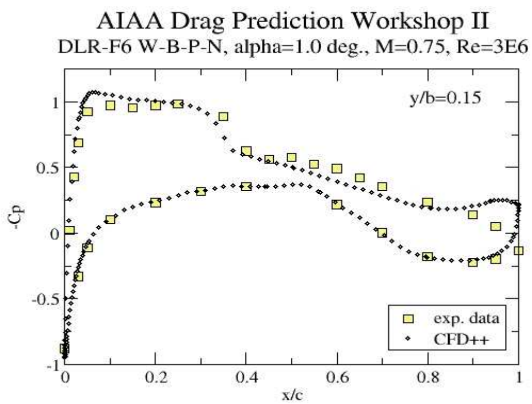
Total Drag Increment

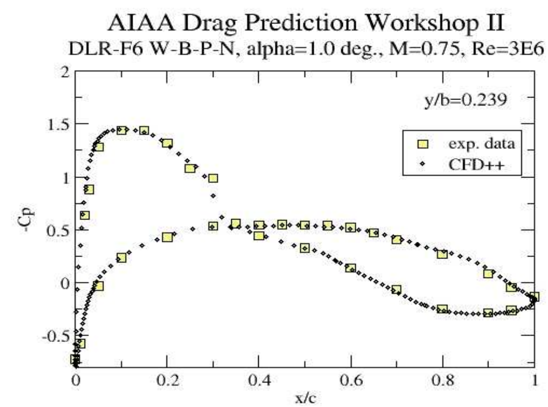
- W+B+P+N – W+B

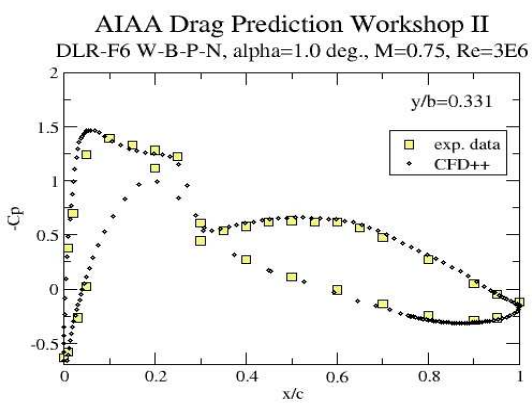
	Coarse	Medium	Fine	Exp.
$\Delta C_{D\,tot}$	0.0056	0.0049	0.0046	0.0043

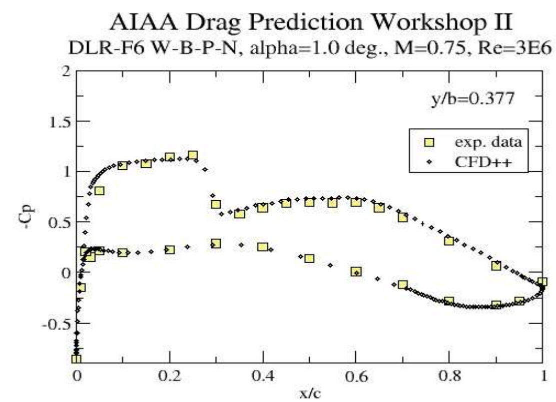
Cp Plots

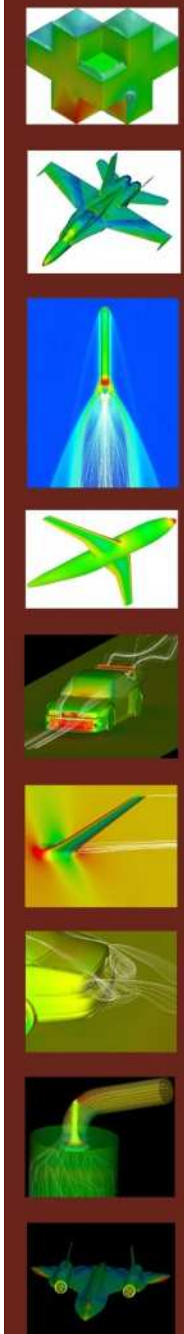



AIAA Drag Prediction Workshop II
DLR-F6 W-B-P-N, alpha=1.0 deg., M=0.75, Re=3E6
y/b=0.15
exp. data
CFD++
-Cp
x/c

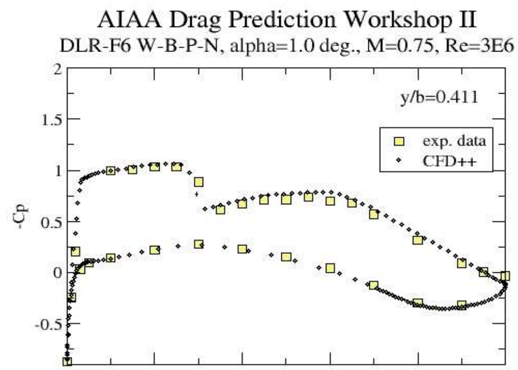

AIAA Drag Prediction Workshop II
DLR-F6 W-B-P-N, alpha=1.0 deg., M=0.75, Re=3E6
y/b=0.239
exp. data
CFD++
-Cp
x/c

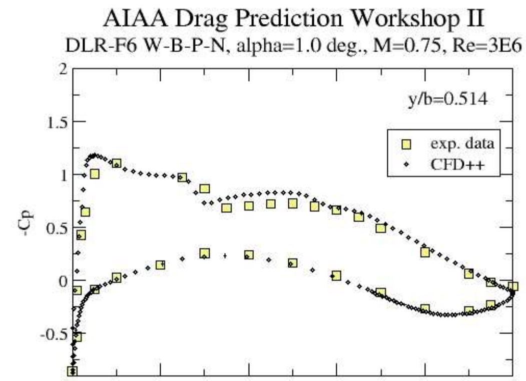

AIAA Drag Prediction Workshop II
DLR-F6 W-B-P-N, alpha=1.0 deg., M=0.75, Re=3E6
y/b=0.331
exp. data
CFD++
-Cp
x/c


AIAA Drag Prediction Workshop II
DLR-F6 W-B-P-N, alpha=1.0 deg., M=0.75, Re=3E6
y/b=0.377
exp. data
CFD++
-Cp
x/c



Cp Plots


AIAA Drag Prediction Workshop II
DLR-F6 W-B-P-N, alpha=1.0 deg., M=0.75, Re=3E6
y/b=0.411
exp. data
CFD++
-Cp


AIAA Drag Prediction Workshop II
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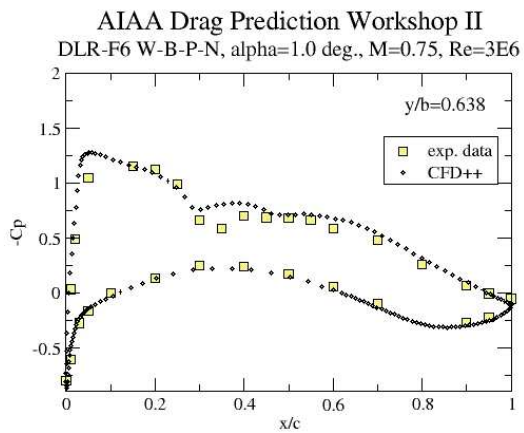
y/b=0.514
exp. data
CFD++
-Cp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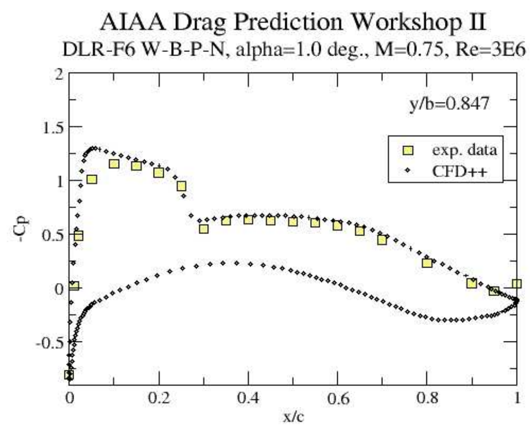
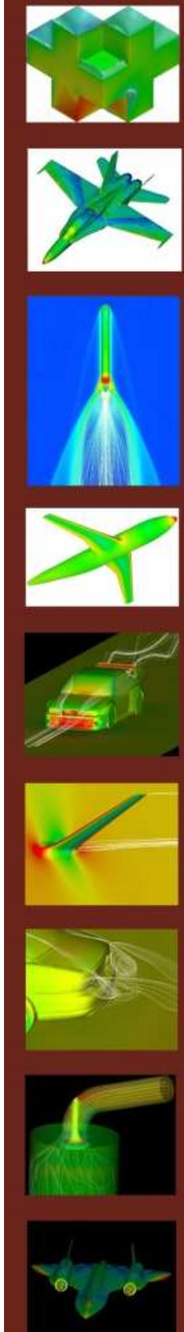
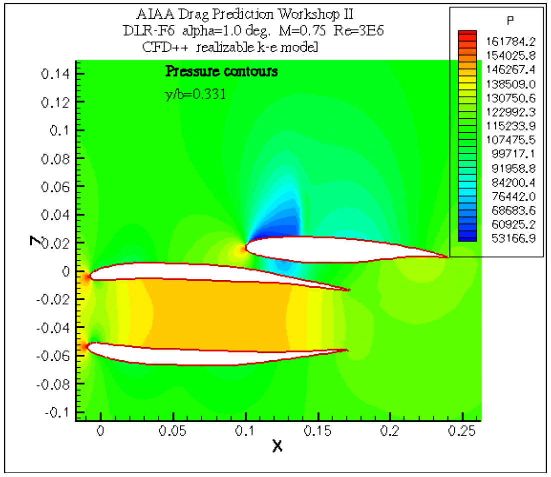
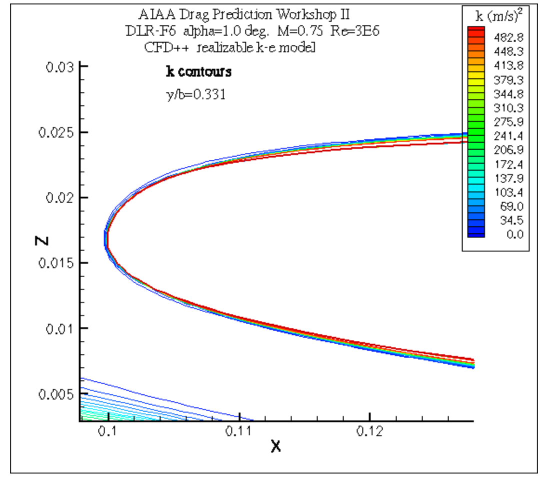
DLR-F6 W-B-P-N, alpha=1.0 deg., M=0.75, Re=3E6
y/b=0.638
exp. data
CFD++
-Cp
x/c

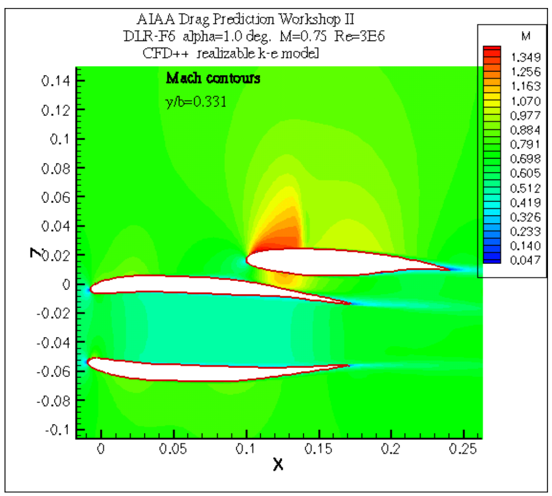

AIAA Drag Prediction Workshop II
DLR-F6 W-B-P-N, alpha=1.0 deg., M=0.75, Re=3E6
y/b=0.847
exp. data
CFD++
-Cp
x/c

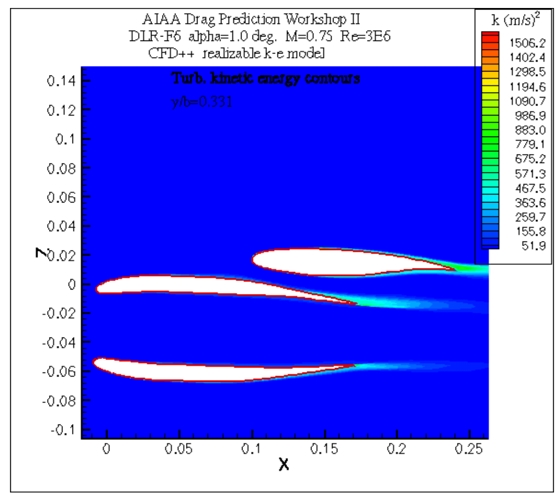


Contour Plots

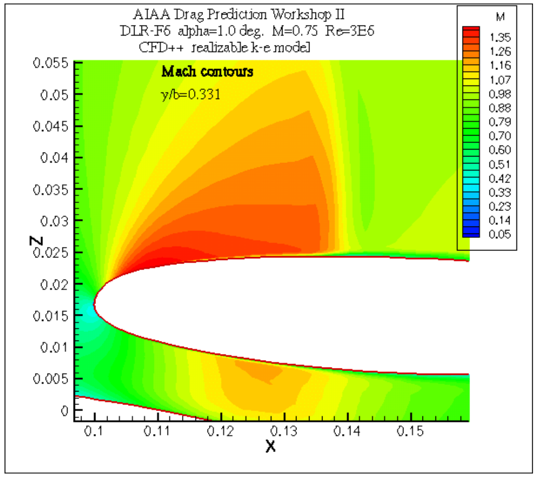


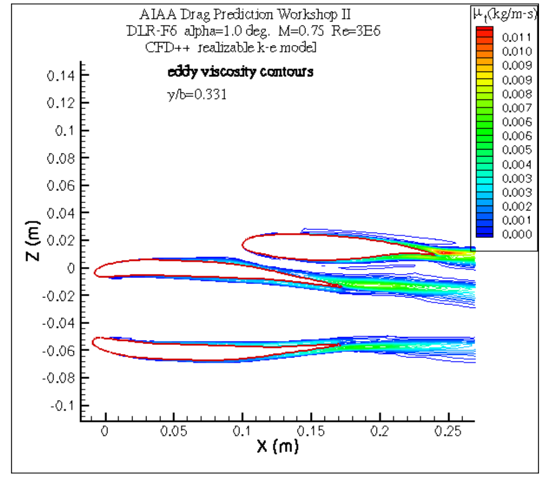


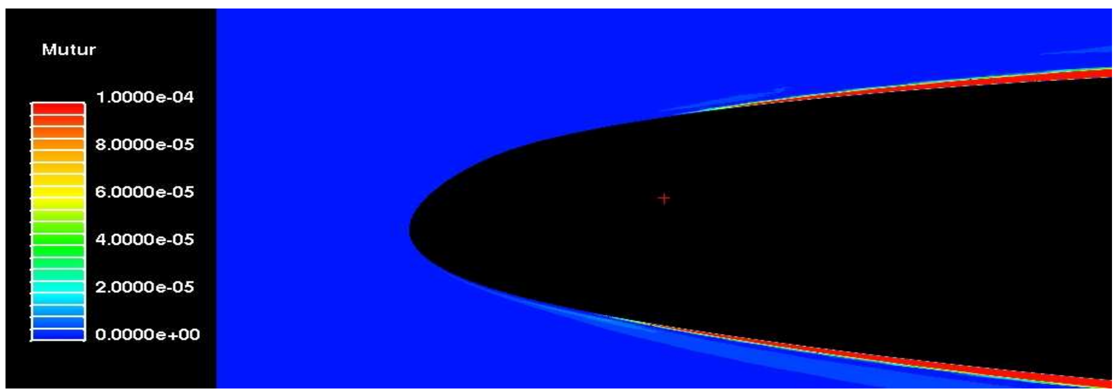




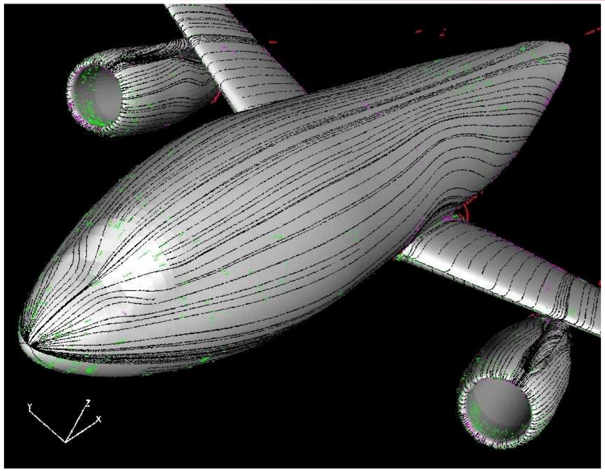
Contour Plots



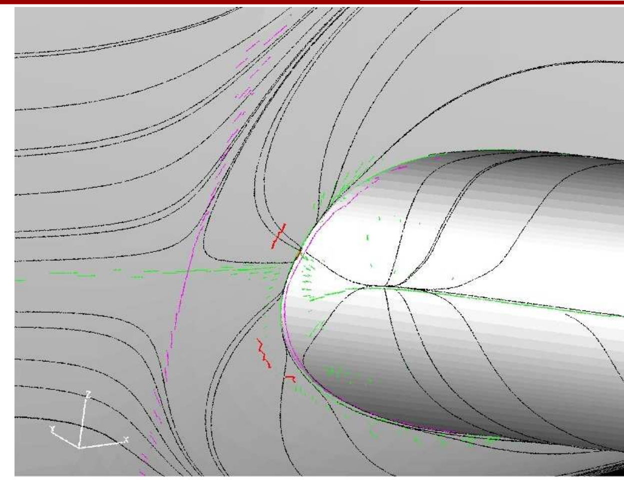


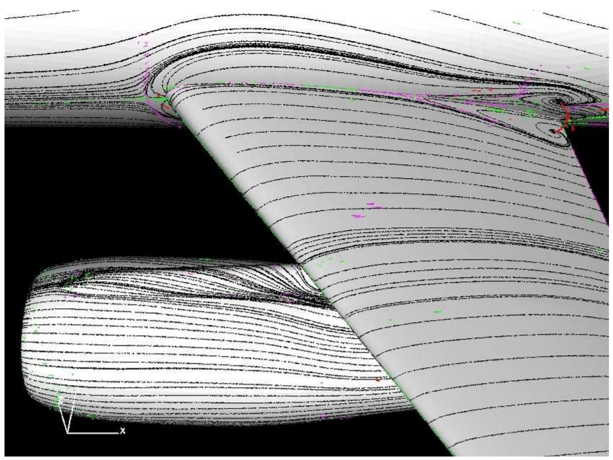


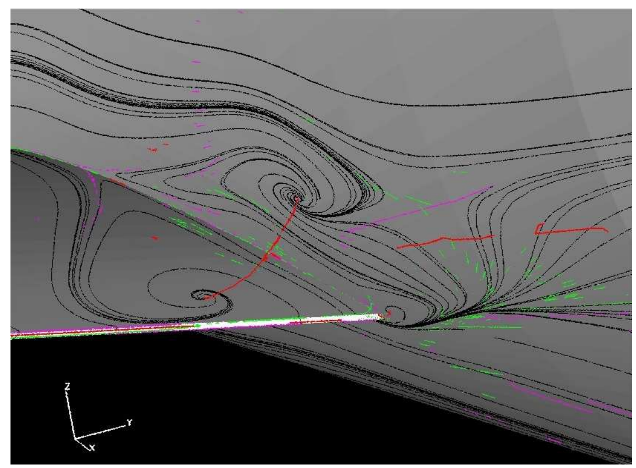
Separation bubble (courtesy: CEI)

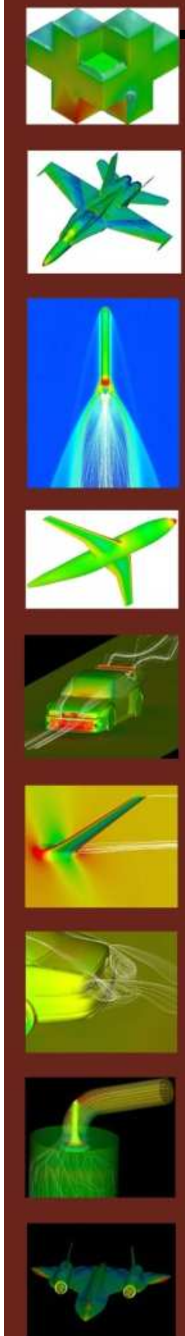


Courtesy: CEI

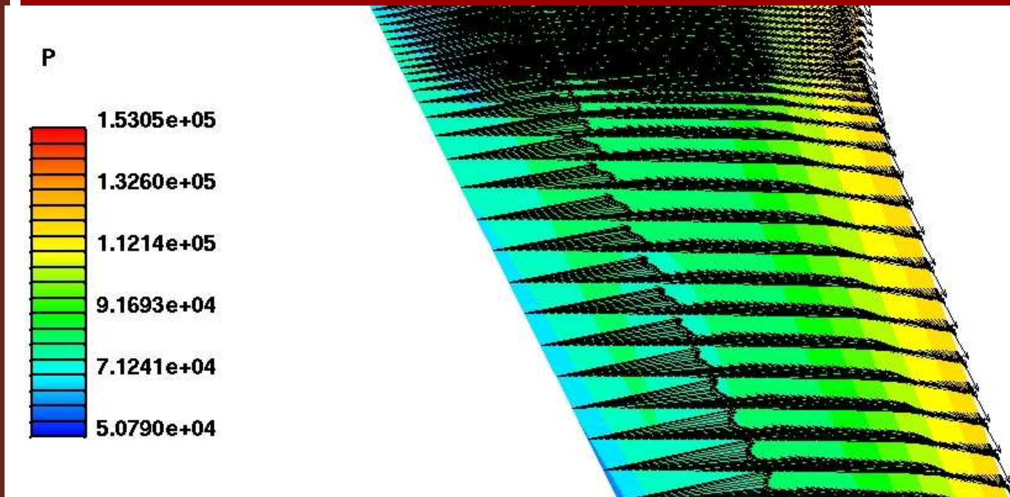


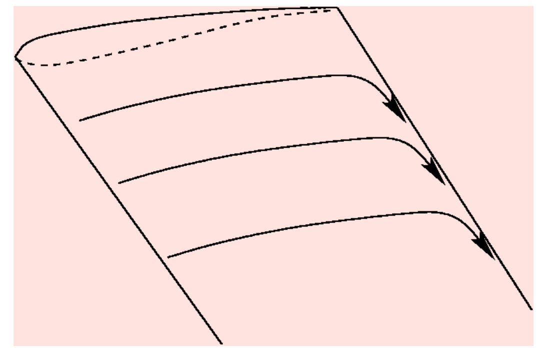


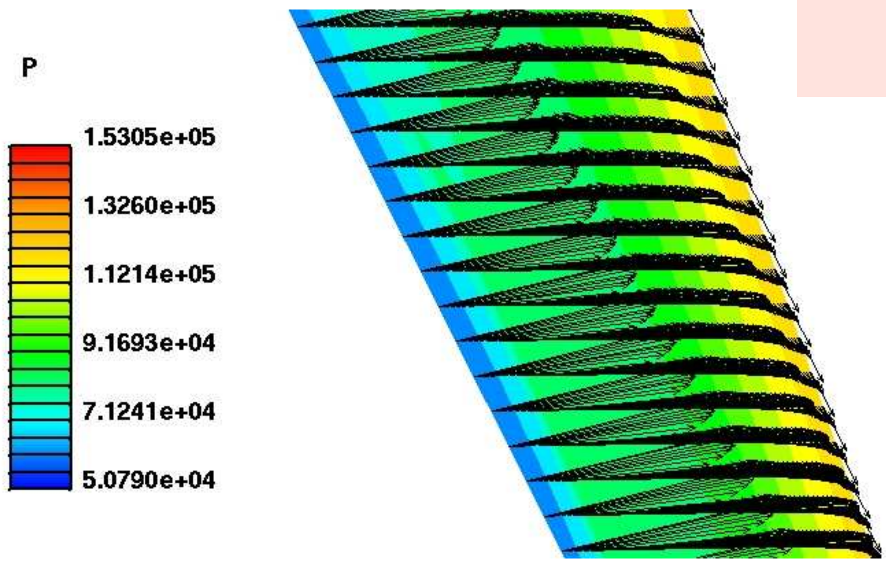




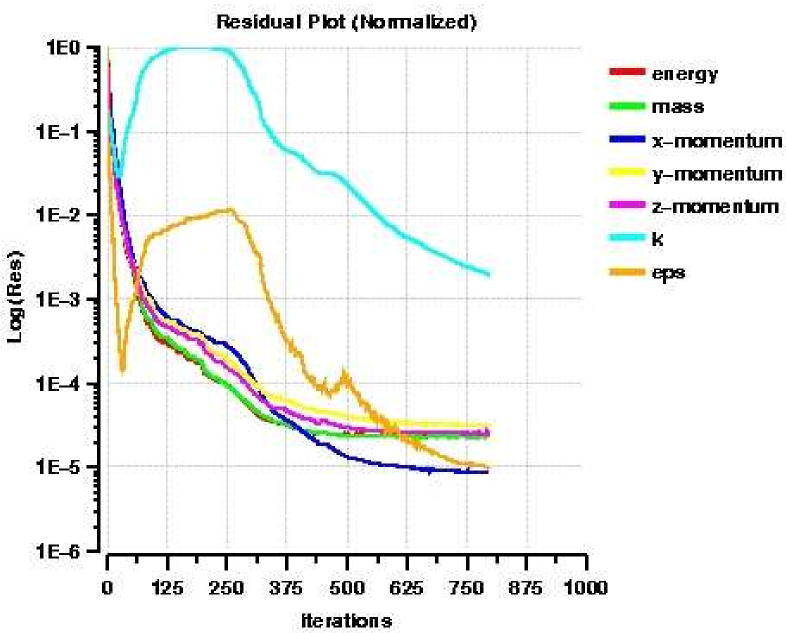
Trailing Edge Separation

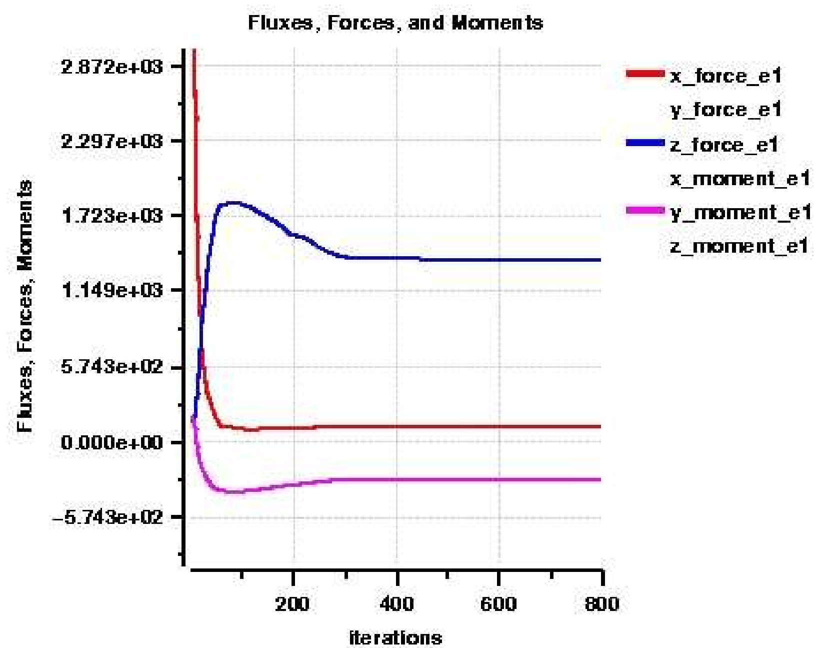


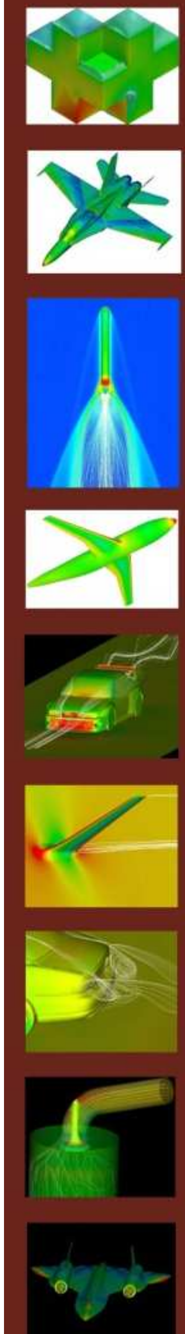




CFD++ Convergence

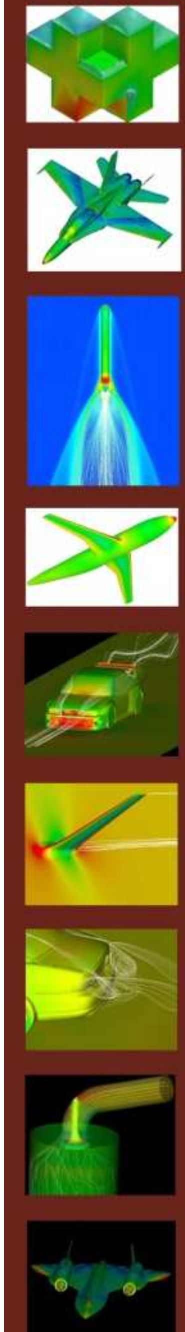






Conclusions

- **CFD++ took less than 400 steps to converge forces & moments**
- **Fully turbulent computations with natural transition at L.E. regions**
- **Excellent polar predictions for both configurations**
- **Max. Cd deviation measured from polars: 7 counts (WBPN), 5 counts (WB)**
- **Grid refinement led to improved results with CFD++**



Summary

Together these elements contribute to the overall effectiveness of CFD++