OVERFLOW Drag Prediction for the DLR-F6 Wing-Body Transport Configuration

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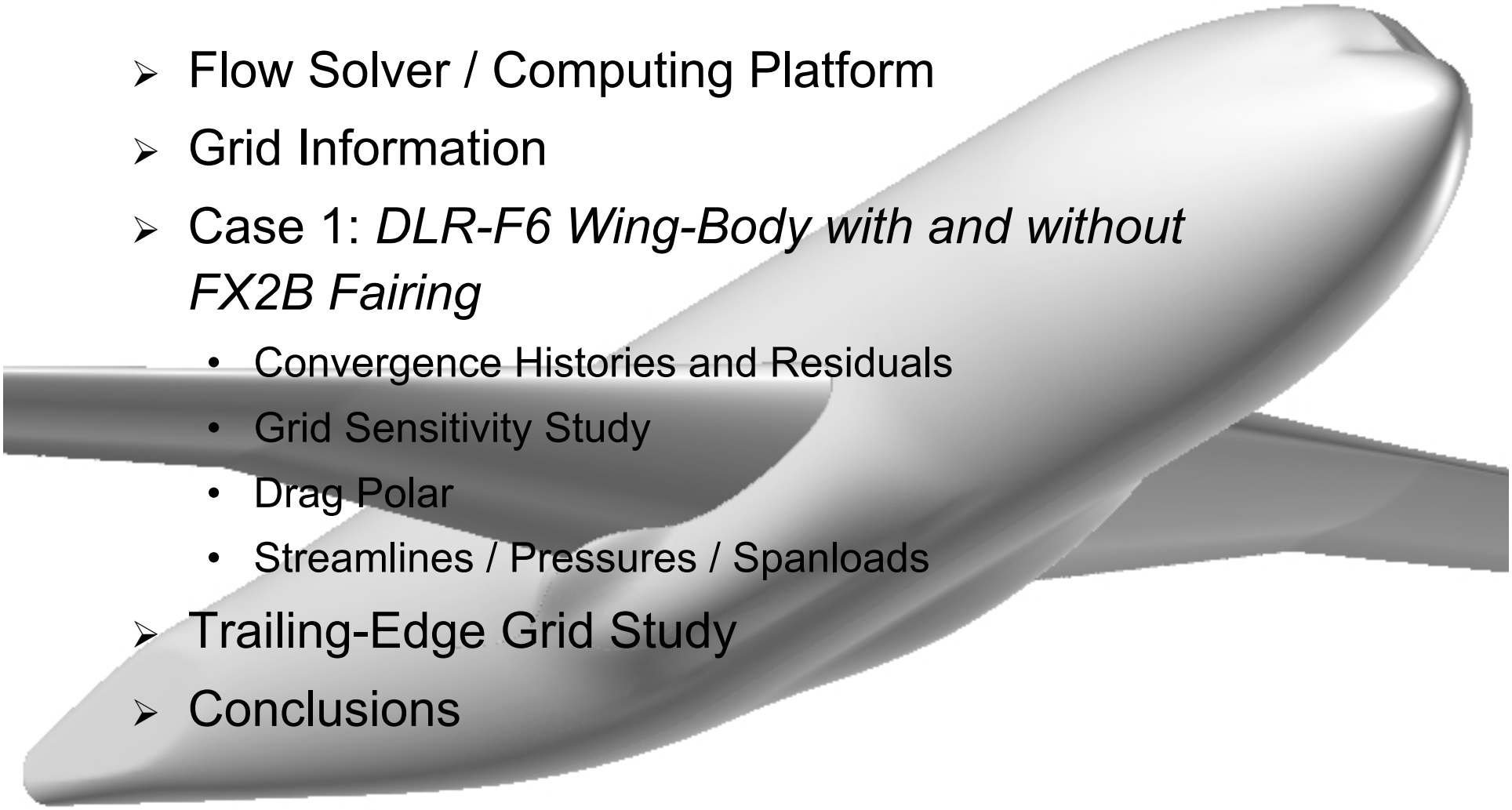
DLR-F6 Wing-Body
Outline



- Flow Solver / Computing Platform
- Grid Information
- Case 1: *DLR-F6 Wing-Body with and without FX2B Fairing*
  - Convergence Histories and Residuals
  - Grid Sensitivity Study
  - Drag Polar
  - Streamlines / Pressures / Spanloads
- Trailing-Edge Grid Study
- Conclusions

DLR-F6 Wing-Body
Flow Solver / Computing Platform

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OVERFLOW MPI Version 2.0z

- Setup was consistent with DPW2
- Spalart-Allmaras turbulence model
- Roe upwind scheme
- Viscous terms computed in all three directions (full N-S)

Parallel Processing Done on a PC Cluster

- Linux operating system
- 906 Opteron dual CPU nodes with 4 GB of memory each
- F6 wing-body medium grid run on 8 processors (4 nodes)
  - 3.2 hours per 1000 fine grid iterations
  - Full convergence reached after 4000 fine grid iterations
  - Roughly 13 hours of wall clock time needed per case for the medium grid

DLR-F6 Wing-Body
Grid Information

- The F6 and FX2B grid systems consisted of 12 zones.
- The medium grid is typical for drag-quality design studies.

F6

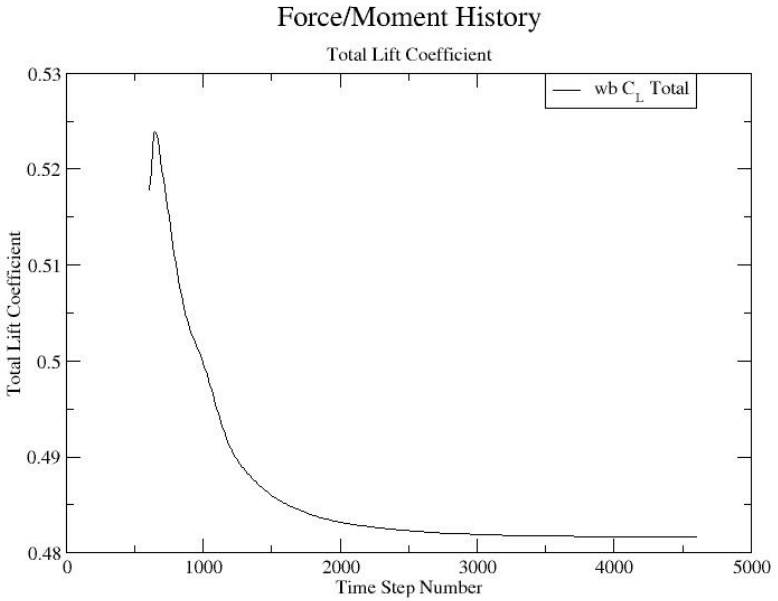
Grid	Points	1st Cell Size	y^+	Constant Cells	Growth Rate
Coarse	2,387,918	.00055 mm	.90	2	1.29
Medium	7,985,236	.00038 mm	.62	3	1.19
Fine	26,892,352	.00025 mm	.41	4	1.12

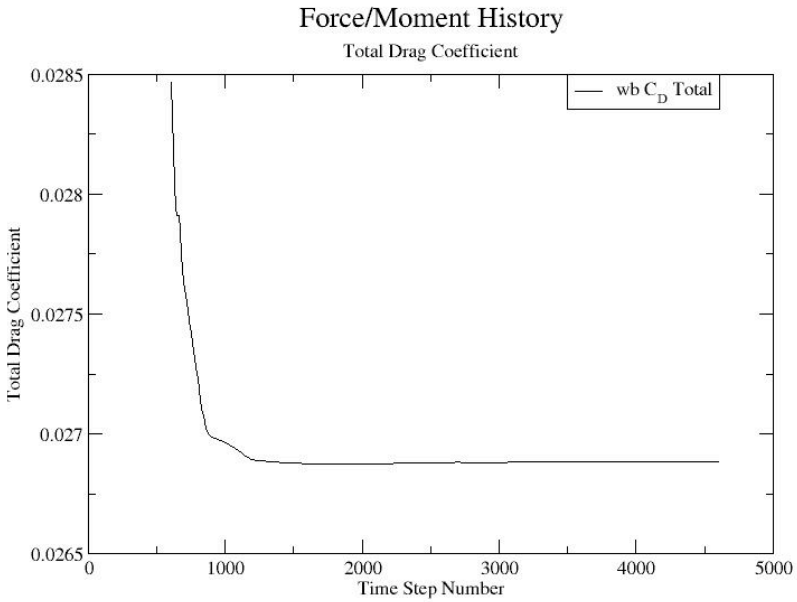
F6 with FX2B

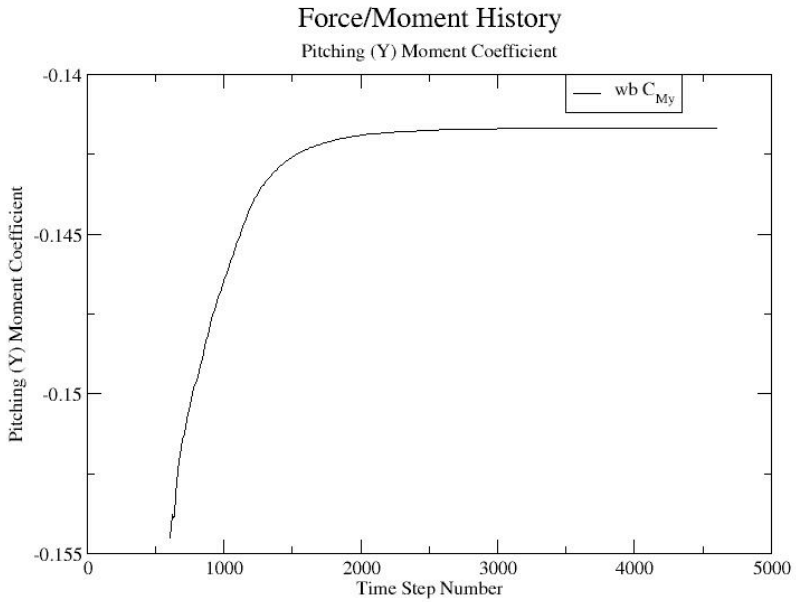
Grid	Points	1st Cell Size	y^+	Constant Cells	Growth Rate
Coarse	2,395,170	.00055 mm	.90	2	1.29
Medium	8,020,348	.00038 mm	.62	3	1.19
Fine	26,969,192	.00025 mm	.41	4	1.12

DLR-F6 Wing-Body
Convergence Histories

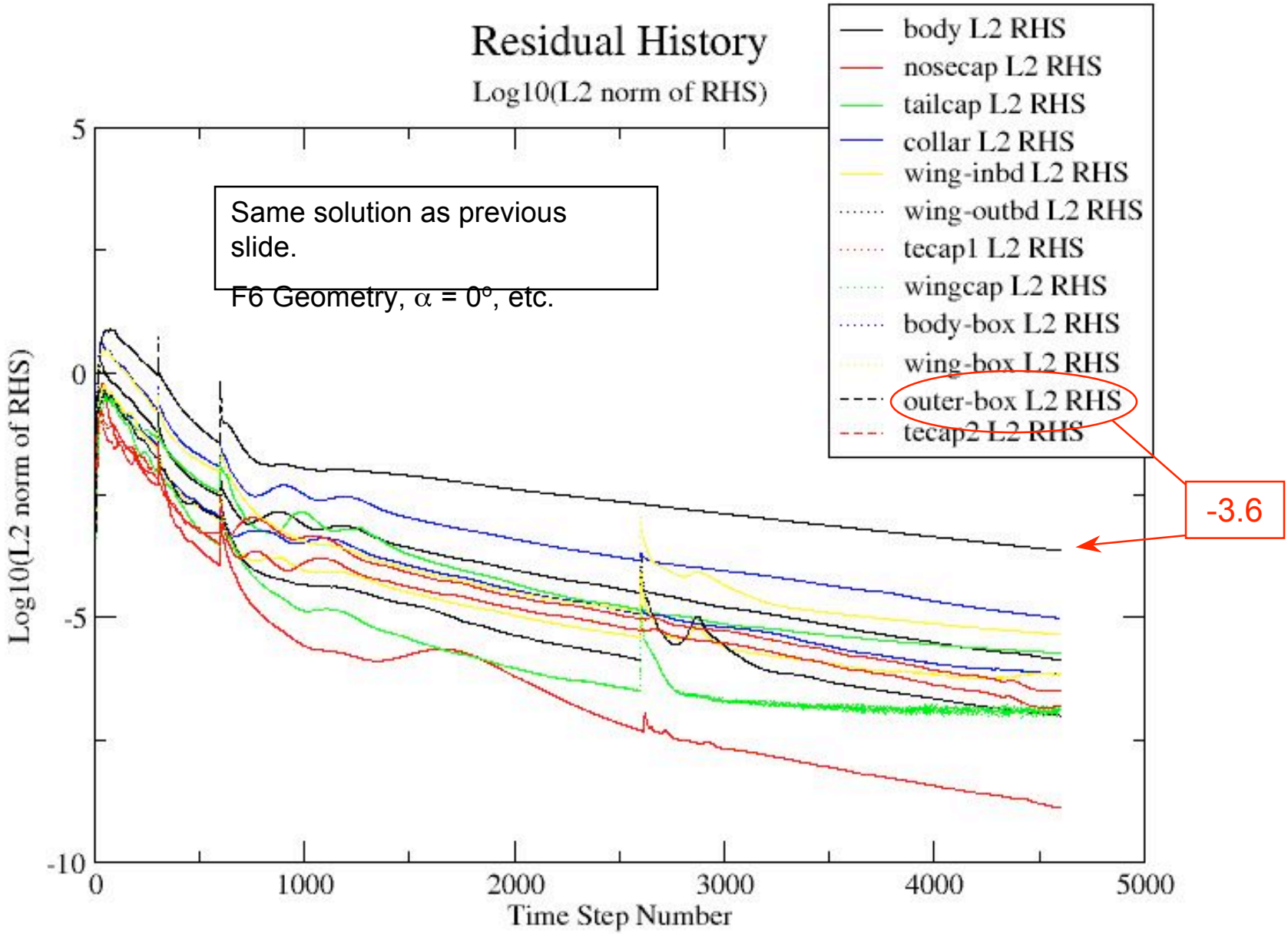
- F6 geometry
- Fully turbulent
- Reynolds Number = 5 million
- Mach = 0.75
- $\alpha = 0^o$
- Medium grid
- These flat-line convergence histories are representative of the coarse/fine grid as well as FX2B solutions at the above condition.







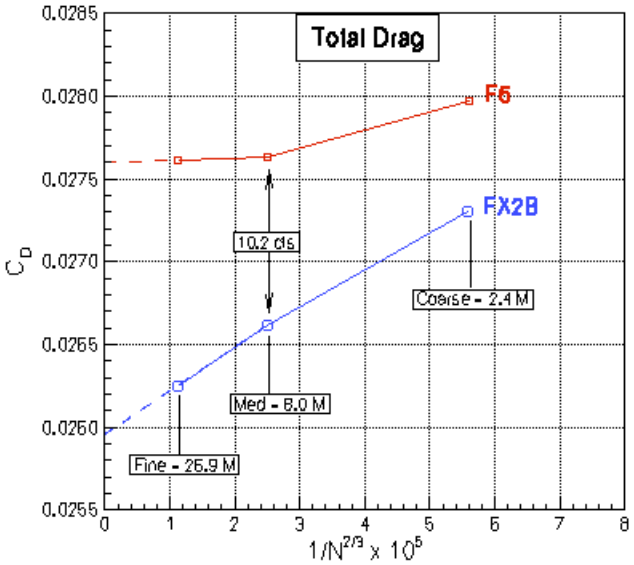
DLR-F6 Wing-Body
Residuals

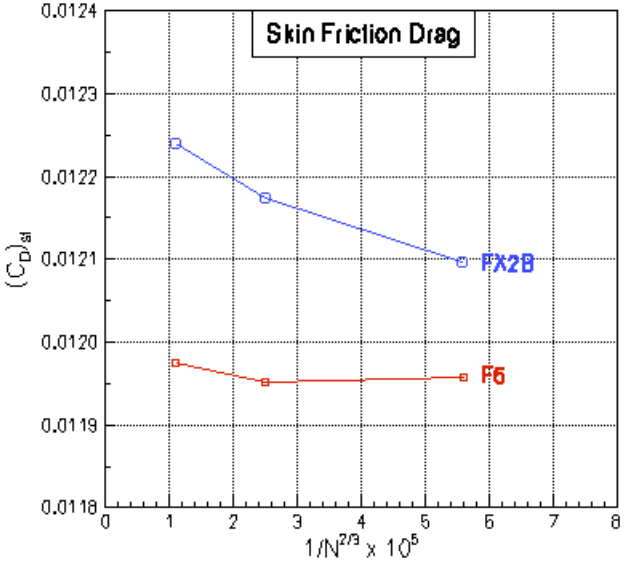


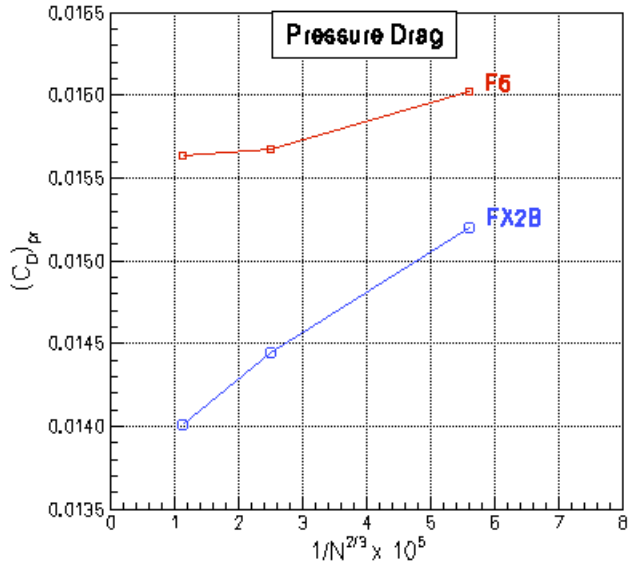
DLR-F6 Wing-Body
Grid Sensitivity Study

Wing-Body OVERFLOW Results

Mach = 0.75, R_N = 5.0 million, C_L = 0.5, Fully Turbulent





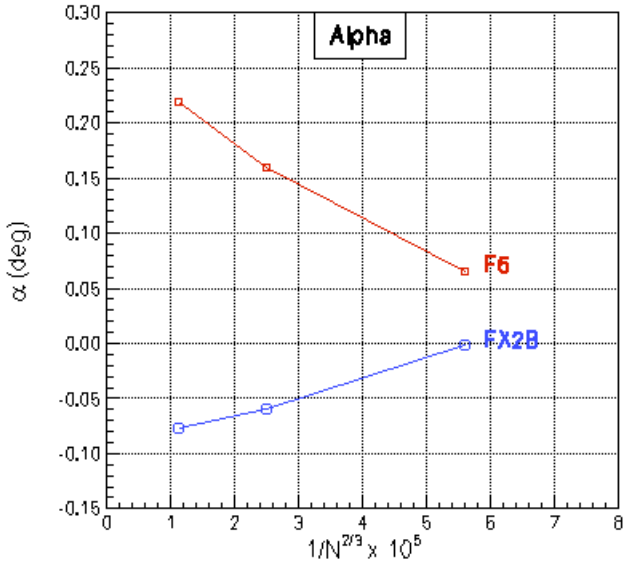


- Dashed lines are linear extrapolation of medium and fine data.
- The total drag increment (FX2B – F6) has a large variation with grid refinement.
  - $(\Delta C_D)_{coarse}$ = -6.7 counts
  - $(\Delta C_D)_{medium}$ = -10.2 counts
  - $(\Delta C_D)_{fine}$ = -13.6 counts
  - $(\Delta C_D)_{extrap}$ = -16.4 counts

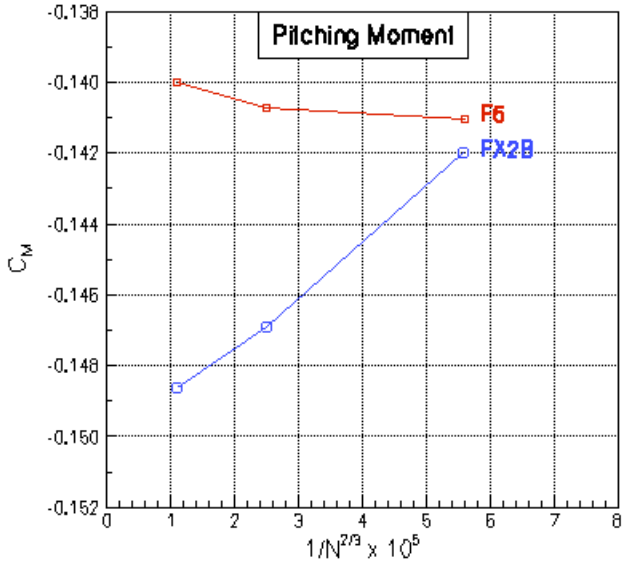
DLR-F6 Wing-Body
Grid Sensitivity Study (cont.)

Wing-Body OVERFLOW Results

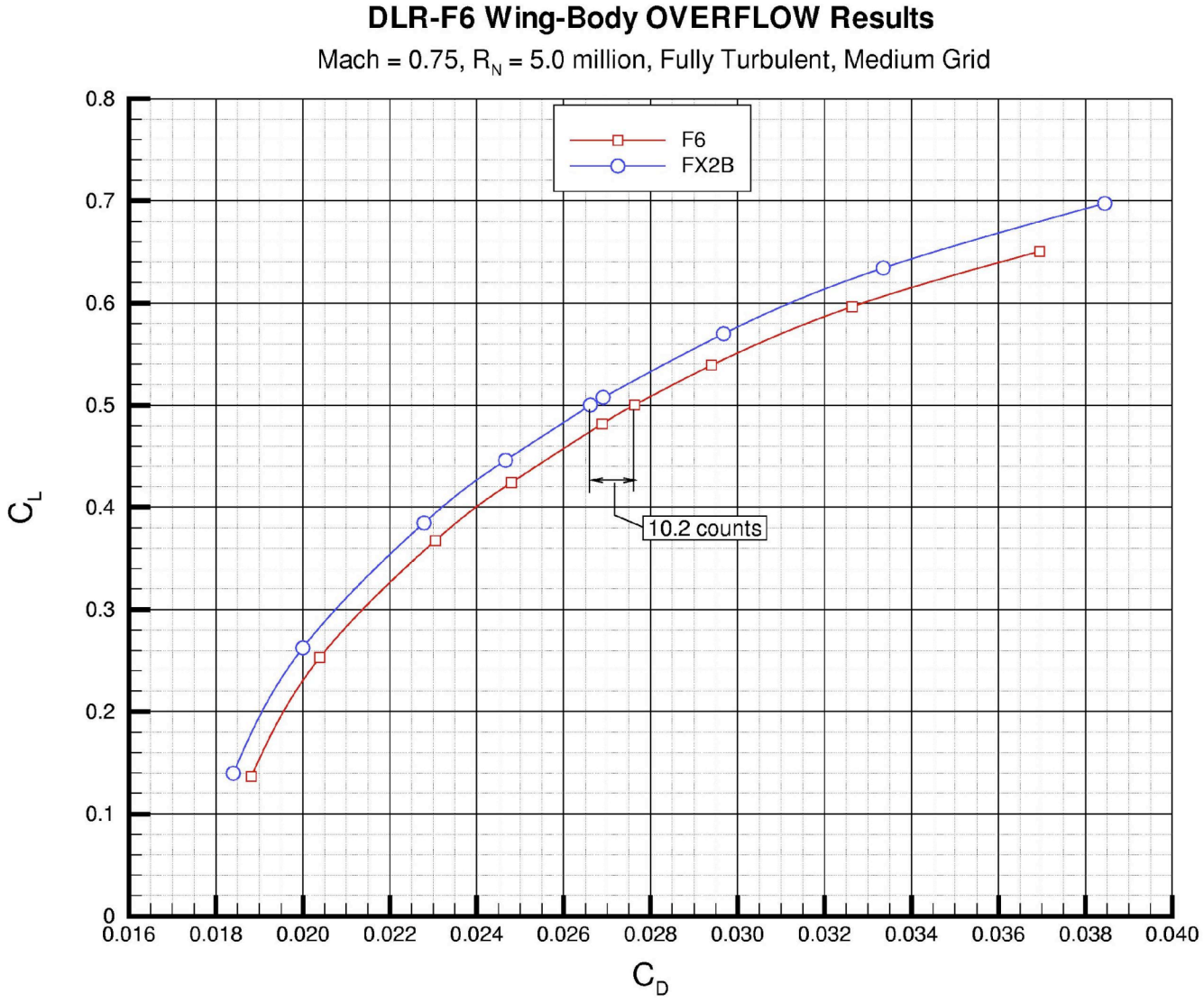
Mach = 0.75, R_N = 5.0 million, C_L = 0.5, Fully Turbulent



- As with drag, alpha and C_M increments grow with grid convergence.
- Based on these two plots, it's difficult to say one config is closer to asymptotic convergence than the other.

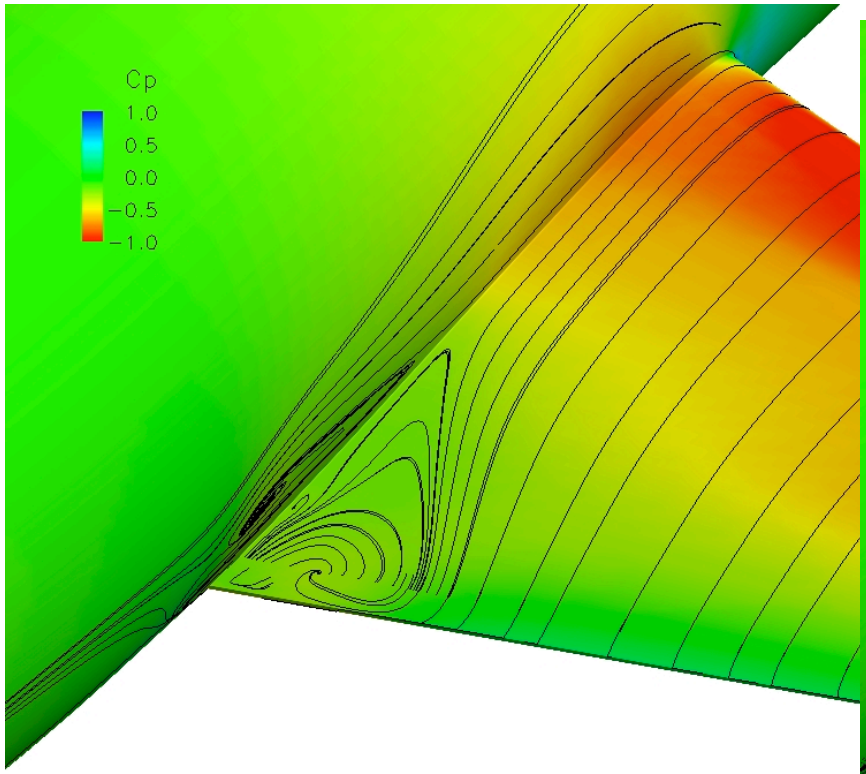


DLR-F6 Wing-Body
Drag Polar

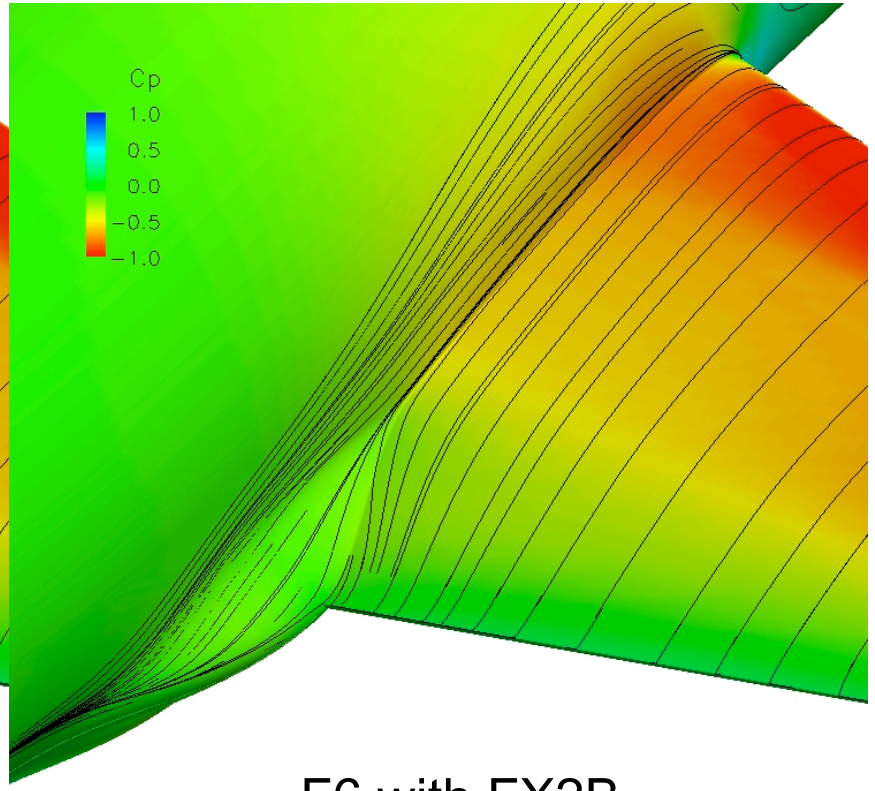


DLR-F6 Wing-Body
Surface Streamlines – Side of Body Flow

Medium Grid, Mach = 0.75, C_L = 0.50, R_N = 5.0 million, Fully Turbulent



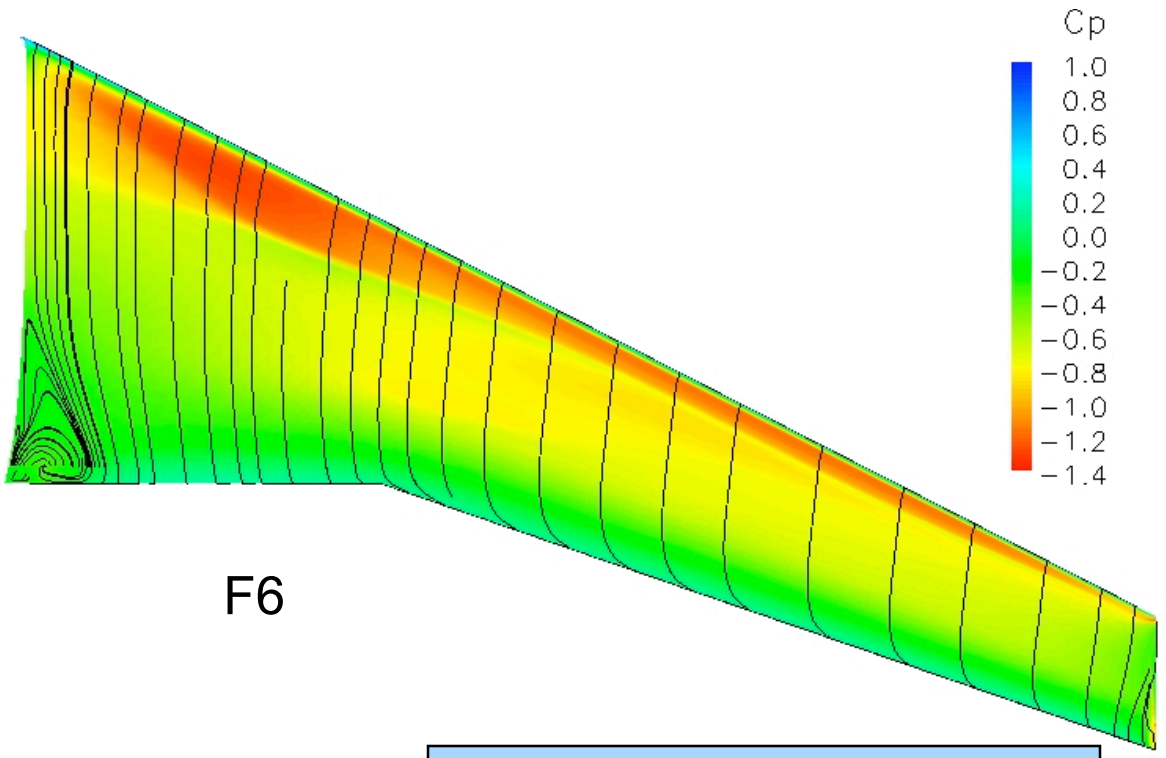
F6



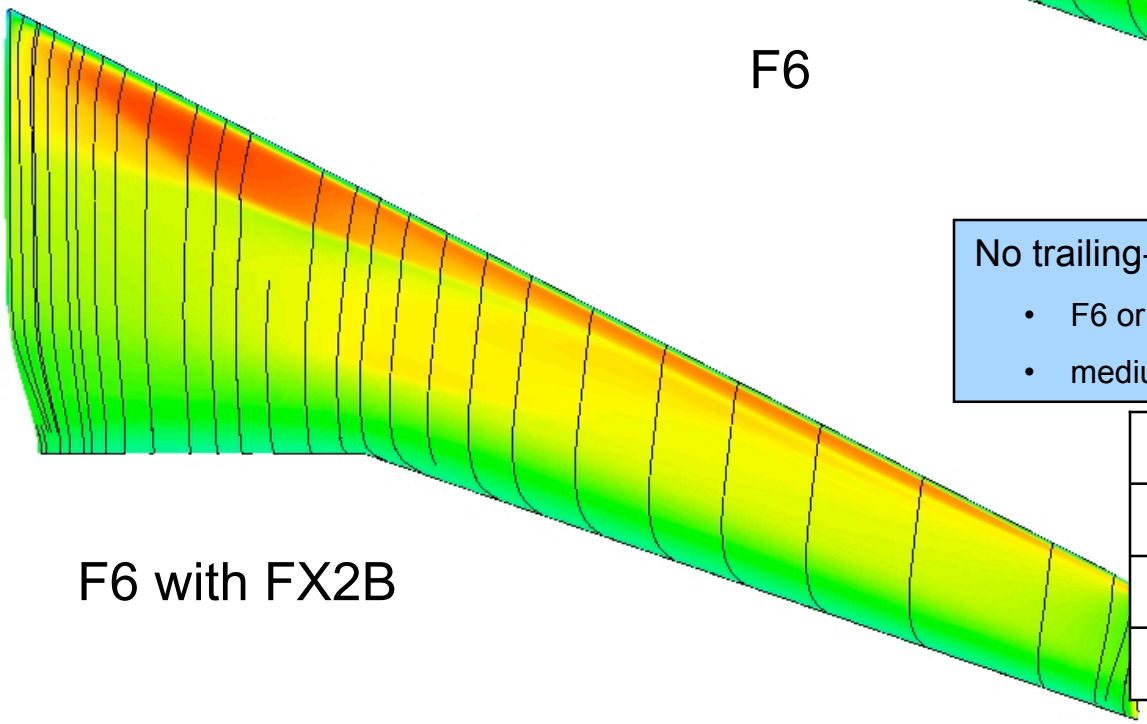
F6 with FX2B

DLR-F6 Wing-Body
Surface Streamlines

- Medium Grid
- Mach = 0.75
- C_L = 0.50
- R_N = 5.0 million
- Fully Turbulent
- Spalart-Allmaras (SA)



F6



F6 with FX2B

No trailing-edge separation seen on:

- F6 or FX2B configurations
- medium or fine grids

F6 Medium Grid TE Separation			
RN	SA	SST	BB
3 mil	yes	n/a	yes
5 mil	no	no	yes

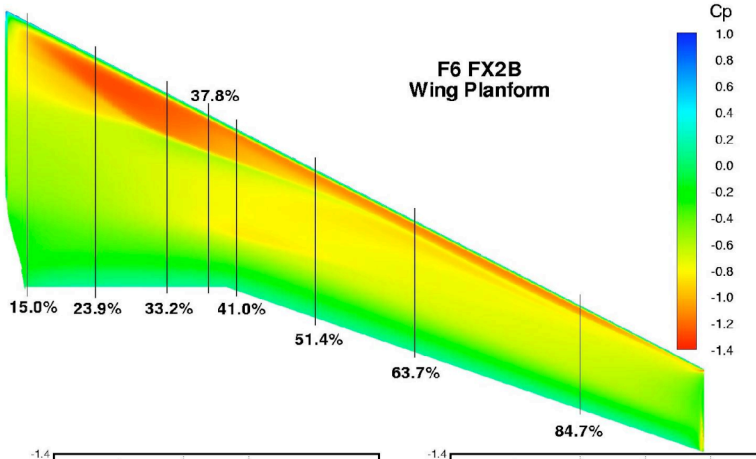
DLR-F6 Wing-Body
Wing Pressure Comparison

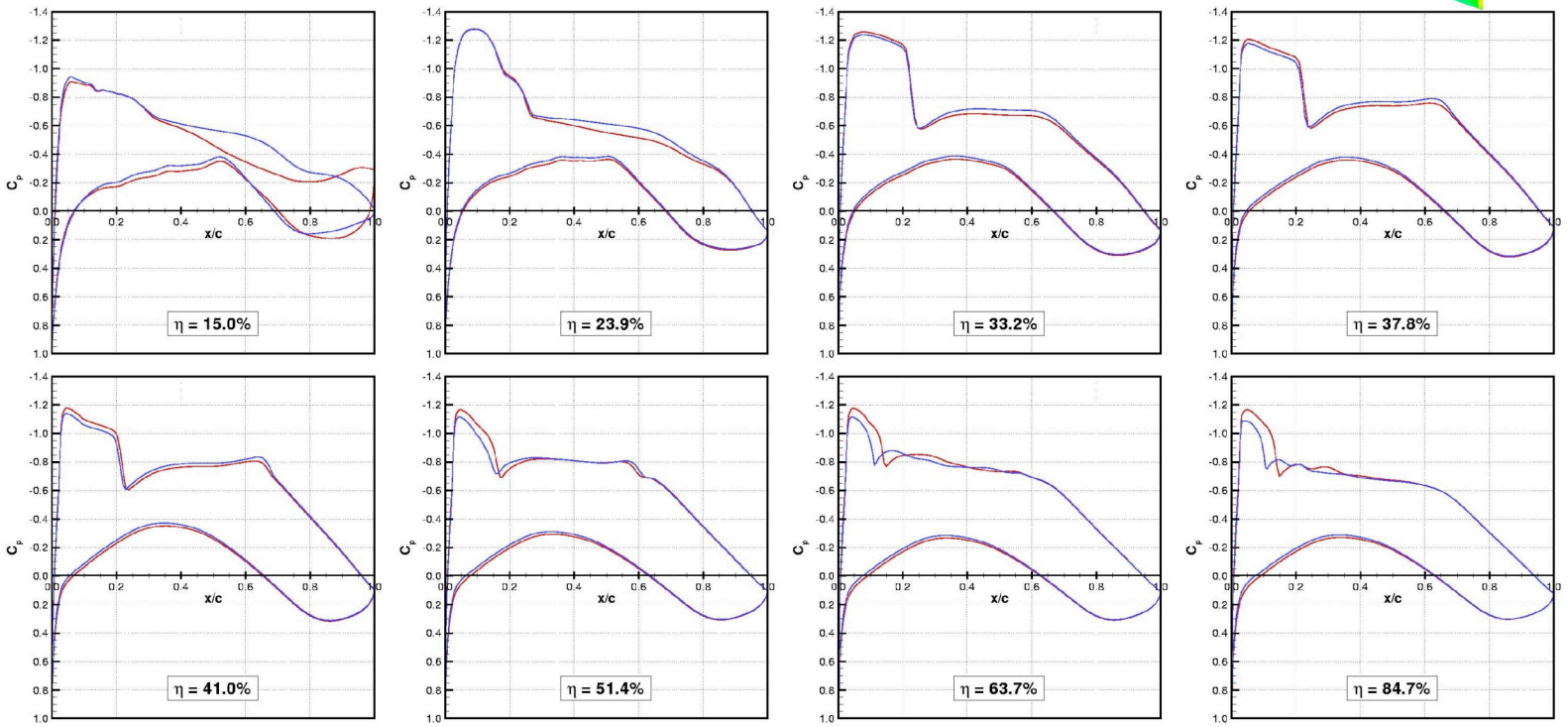
F6 Wing/Body Pressure Comparison
Fine Grid Fully Turbulent OVERFLOW Solutions

Mach = 0.75, R_N = 5.0 million

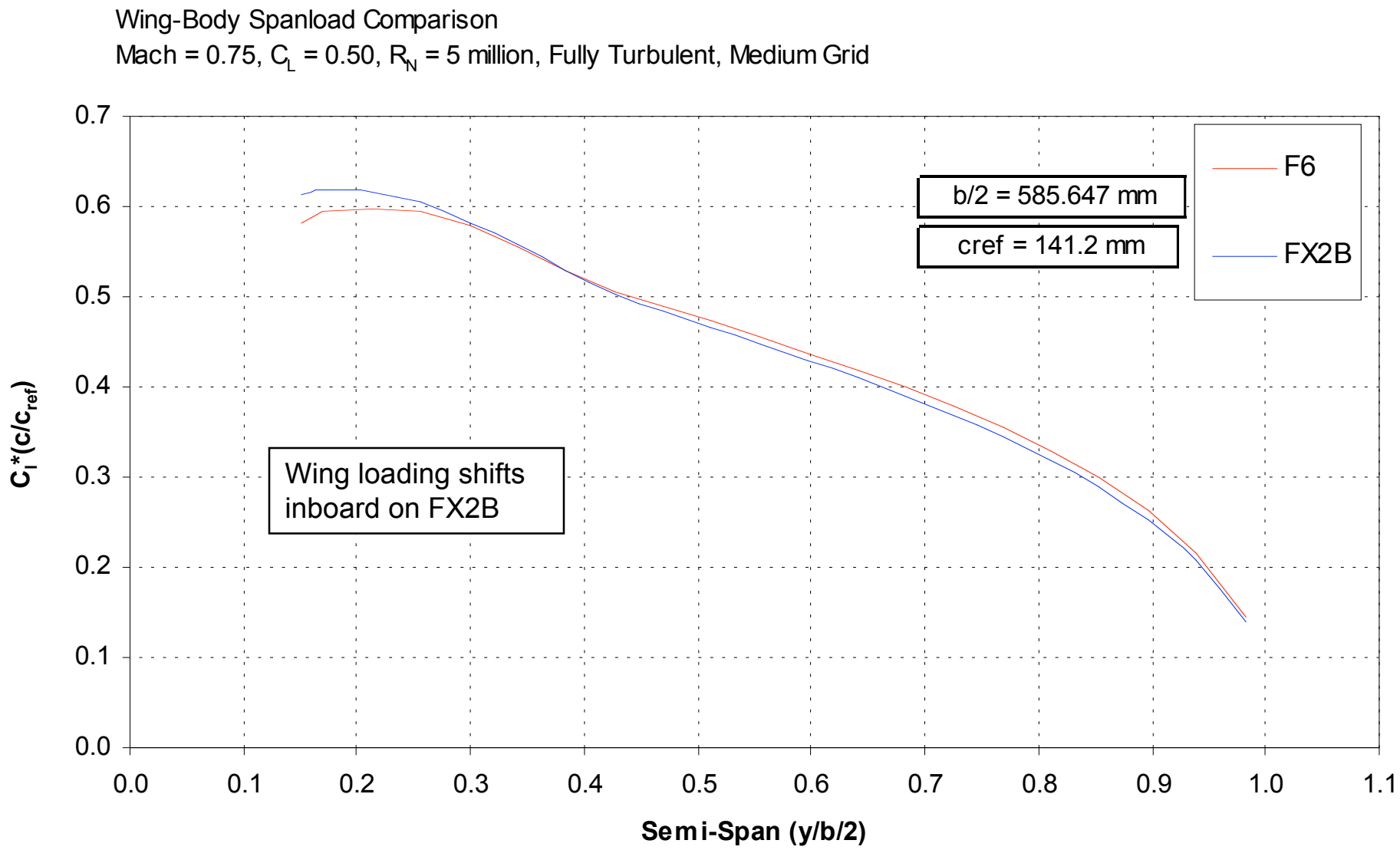
F6, OVERFLOW, Fine Grid, SA-Upwind
$\alpha = 0.219°$, $C_L = 0.4998$, $C_D = 0.02761$, $C_M = -0.1400$

F6 FX2B, OVERFLOW, Fine Grid, SA-Upwind
$\alpha = -0.077°$, $C_L = 0.5000$, $C_D = 0.02625$, $C_M = -0.1486$

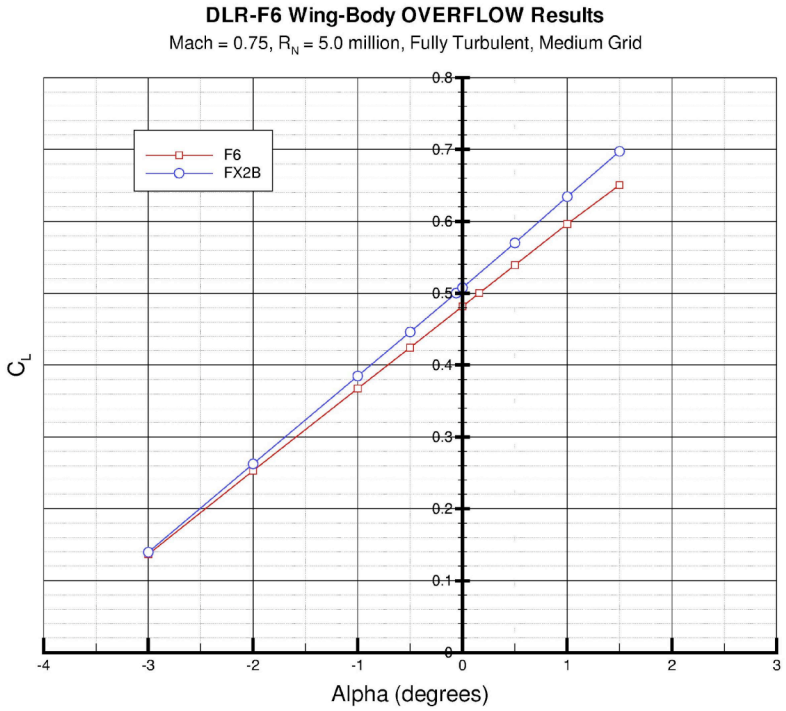


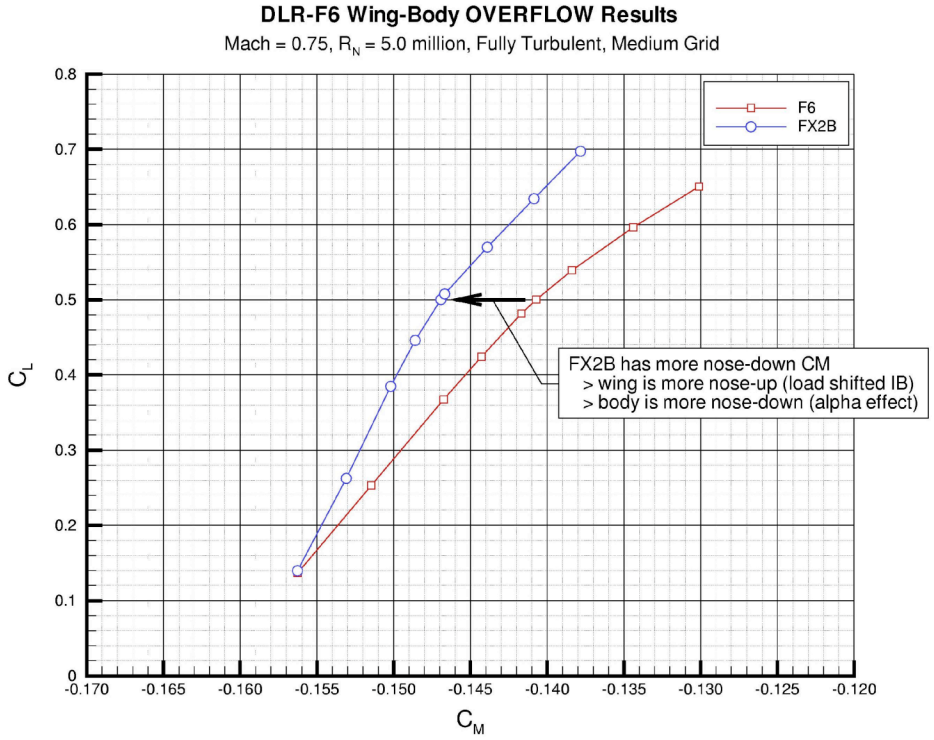


DLR-F6 Wing-Body
Spanload Comparison



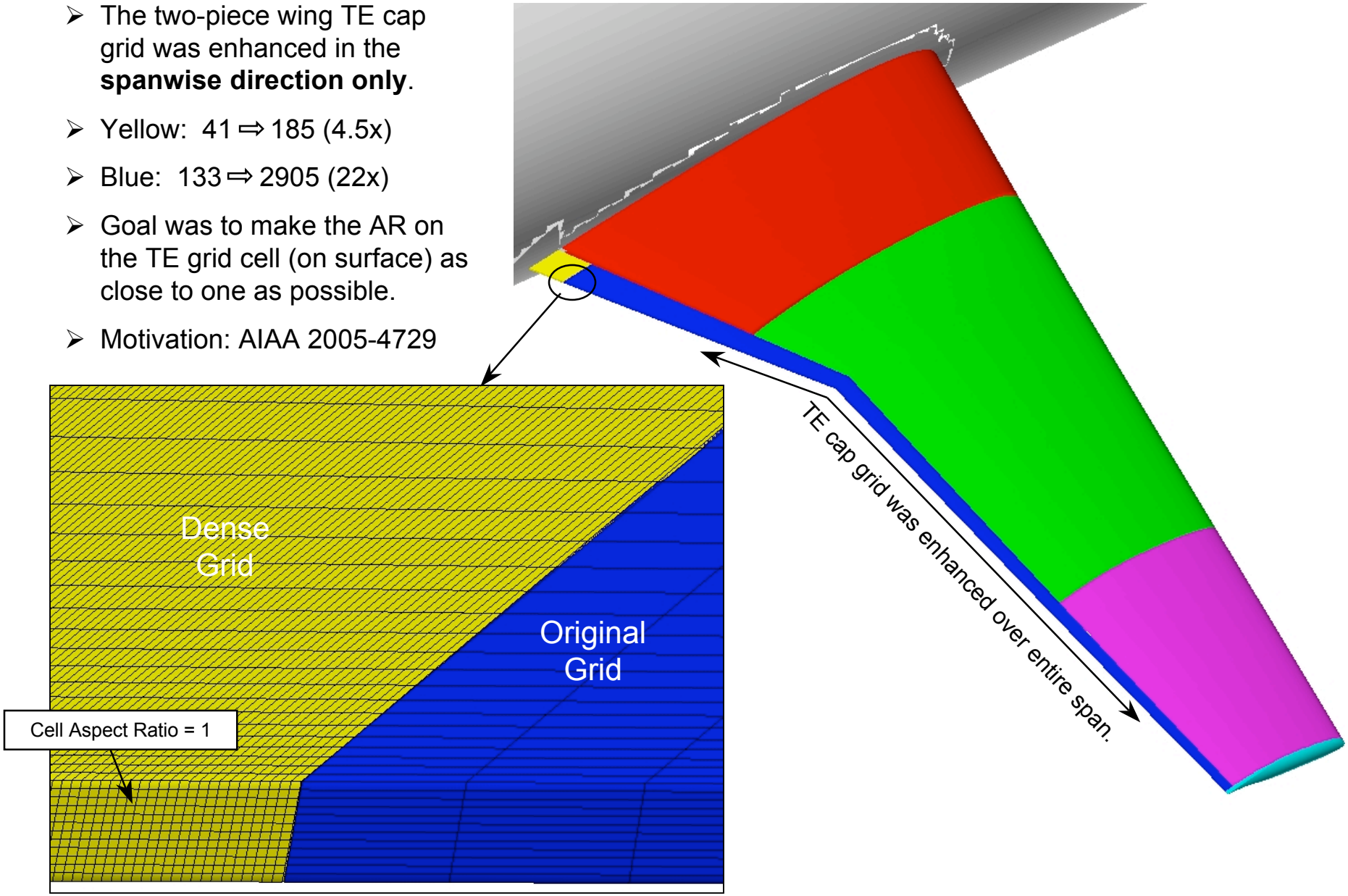
DLR-F6 Wing-Body
C_L and C_M Curves





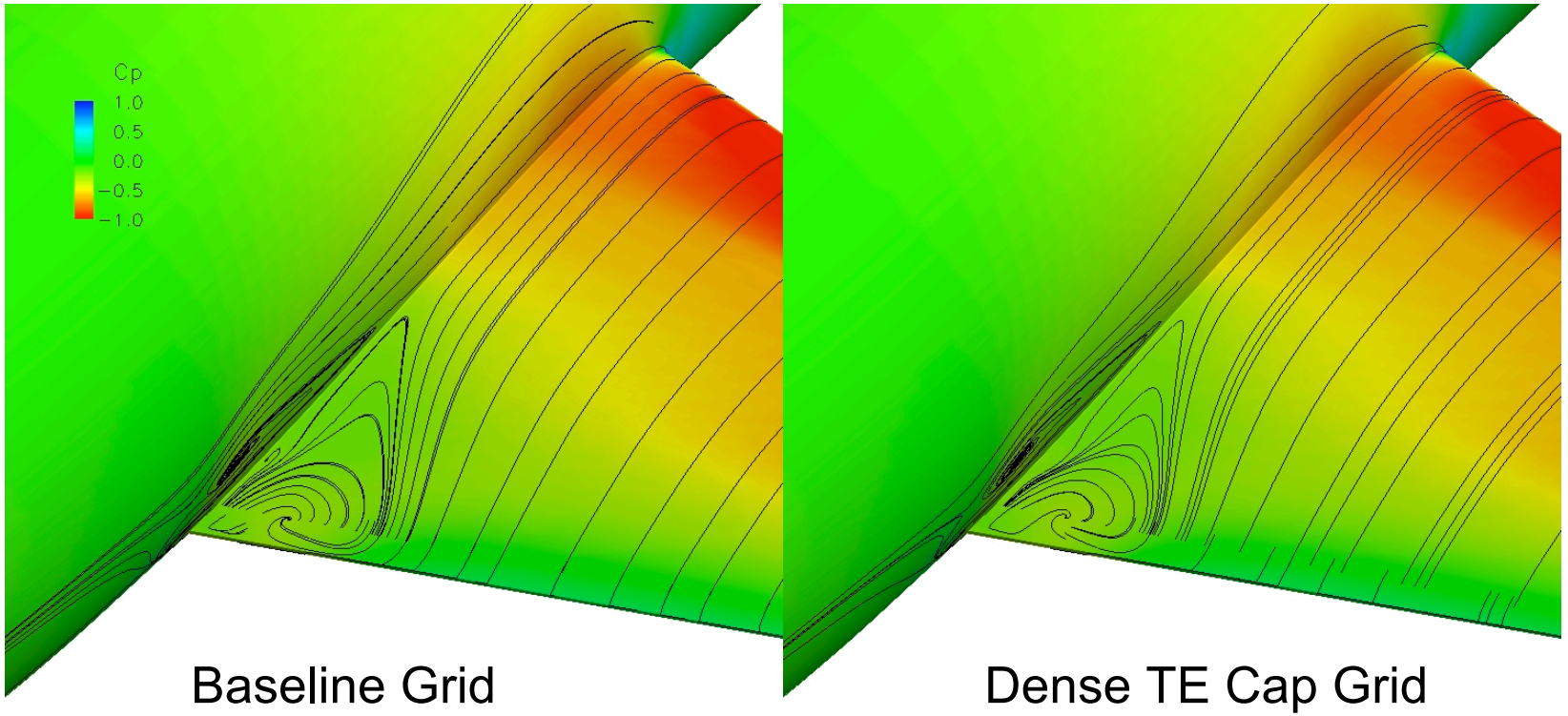
DLR-F6 Wing-Body
F6 Dense Trailing-Edge Cap Grid

- The two-piece wing TE cap grid was enhanced in the **spanwise direction only**.
- Yellow: 41 ⇨ 185 (4.5x)
- Blue: 133 ⇨ 2905 (22x)
- Goal was to make the AR on the TE grid cell (on surface) as close to one as possible.
- Motivation: AIAA 2005-4729



DLR-F6 Wing-Body
F6 Dense Trailing-Edge Cap Grid (cont.)

Medium Grid, Mach = 0.75, C_L = 0.50, R_N = 5.0 million, Fully Turbulent



Baseline Grid

Dense TE Cap Grid

- Total drag for the dense TE cap grid solution increased by 0.4 counts at C_L = 0.5
- At the same α, C_L increased by .004 (C_L decreased in AIAA 2005-4729)
- Surface streamlines indicate:
  - No significant change to side-of-body separation
  - No TE separation in either solution (outboard of side-of-body separation)

DLR-F6 Wing-Body
Conclusions

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Convergence Histories

- C_L converged to 0.5 +/- 0.0002
- No C_L or C_D fluctuation
  - Lift varied by less than 0.00001 over last 100 iterations
  - Drag varied by less than 0.000001 over last 100 iterations
- Residuals reduced ~4 orders of magnitude

Grid Convergence Study

- Not sure if asymptotic convergence was achieved on baseline
  - Characterized with side-of-body separation bubble
- Probably achieved asymptotic convergence on FX2B
  - Characterized with predominately attached flows
- Extra-fine grid may be required to eliminate uncertainty
  - Possible follow-on study

Drag Increments (FX2B – F6)

- Medium grid = -10.2 counts
- Extrapolated = -16.4 counts
- Increments tainted by baseline calculations