



Assessment of the Unstructured Grid Software TetrUSS for Drag Prediction of the DLR-F6 Configuration

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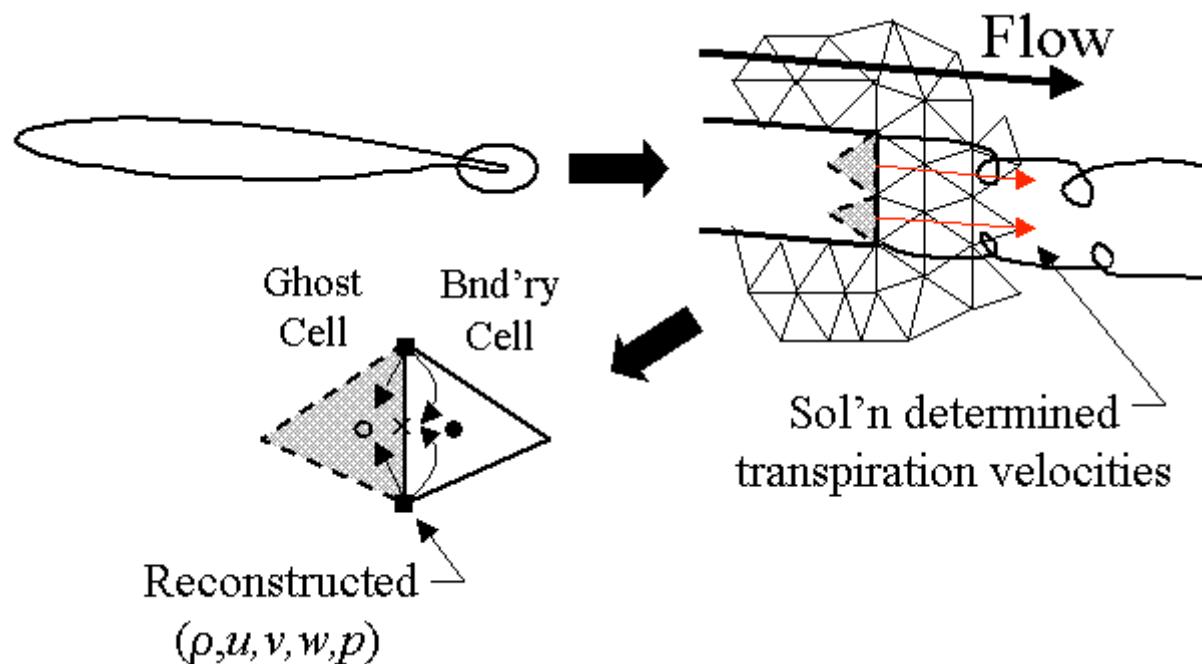
NASA Langley Research Center
Hampton, Virginia

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USM3Dns - Salient Features

- Tetrahedral cell-centered finite volume
 - Efficient analytic cell reconstruction scheme
- Euler and Navier-Stokes
 - Spalart-Allmaras turbulence model
 - DPW2 solutions computed with wall function
- Time Integration - Implicit GS and Explicit RK
- Roe's upwind FDS with flux limiting
- Standard and special boundary conditions
- Platforms
 - Clustered Linux PC, SGI, Mac OS/X
 - Cray vector processors

Special Wake BC



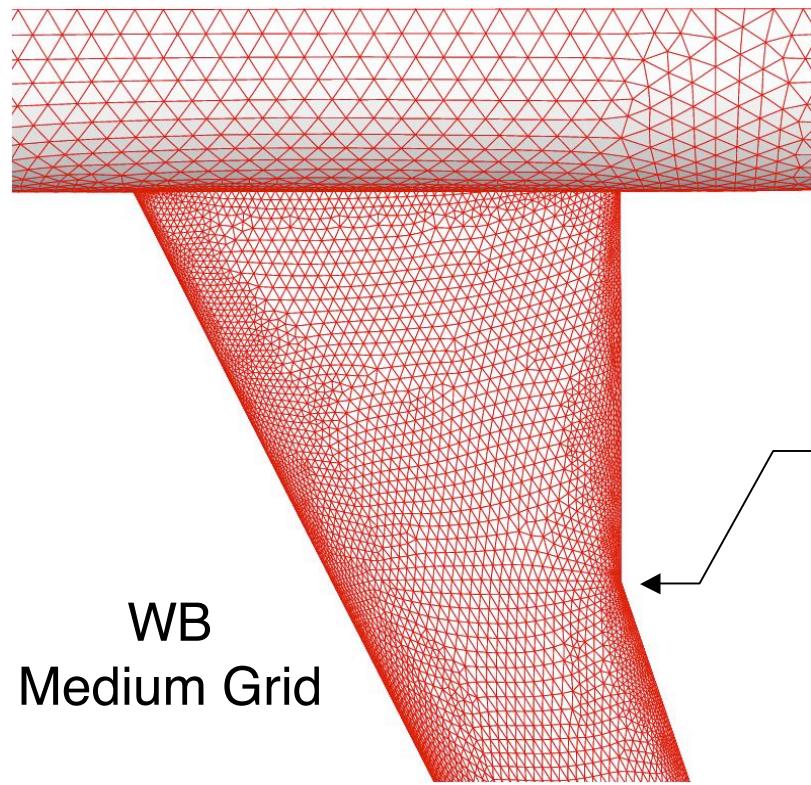
Tetrahedral Grids for DLR-F6 DPW2 Configuration

For Cell-Centered Codes with Wall Function

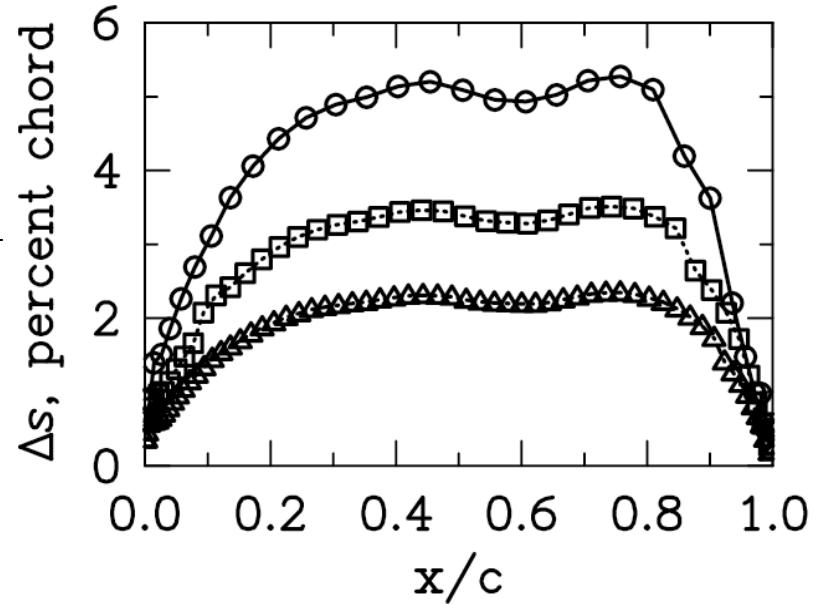
	WB	WBNP
Coarse Nominal $y^+_{node} = 52$ Avg. $\bar{n}_{n1} = 0.079$ Avg. $\bar{n}_{c1} = 0.020$	1,409,689 cells Avg. $y^+_{cell} = 13.1$	2,152,607 cells Avg. $y^+_{cell} = 12.9$
Medium Nominal $y^+_{node} = 36$ Avg. $\bar{n}_{n1} = 0.053$ Avg. $\bar{n}_{c1} = 0.013$	3,901,658 cells Avg. $y^+_{cell} = 8.9$	5,912,596 cells Avg. $y^+_{cell} = 8.7$
Fine Nominal $y^+_{node} = 24$ Avg. $\bar{n}_{n1} = 0.036$ Avg. $\bar{n}_{c1} = 0.009$	11,347,301 cells Avg. $y^+_{cell} = 5.9$	17,193,275 cells Did not run

Chordwise Spacing at WB Crank Station

DLRF6: Tetrahedral Cell-Centered Grids for USM3Dns

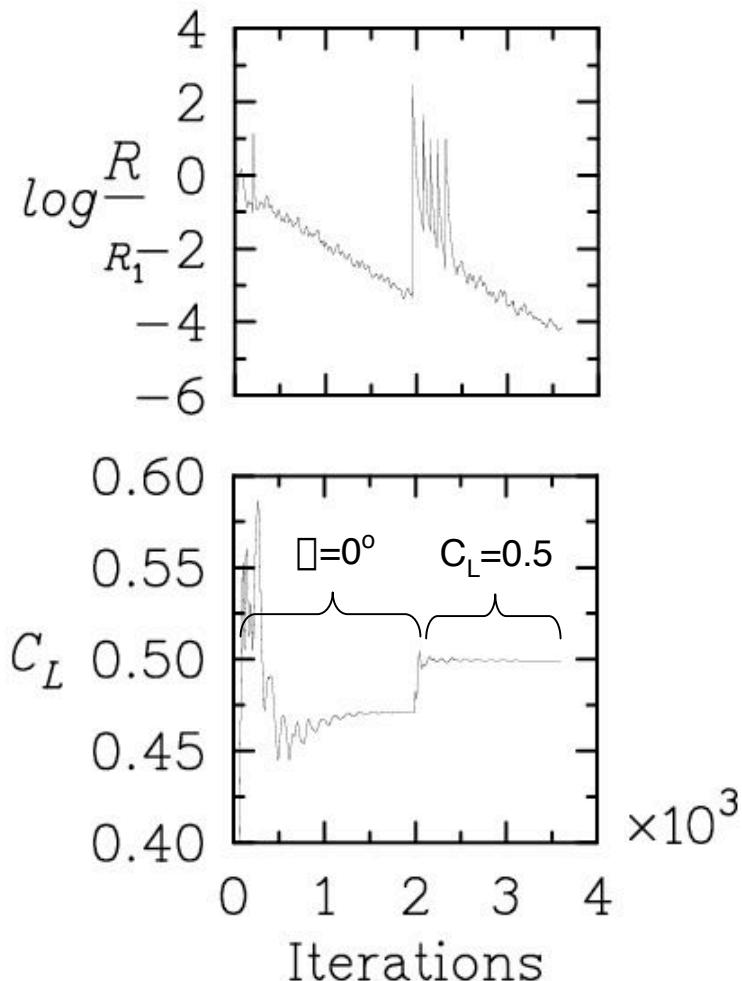


- Coarse (33 points)
- Medium (47 points)
- △··· Fine (68 points)



Typical USM3Dns Convergence for Case 1

DLR-F6 WB (Fine Grid: 11,347,301 cells)



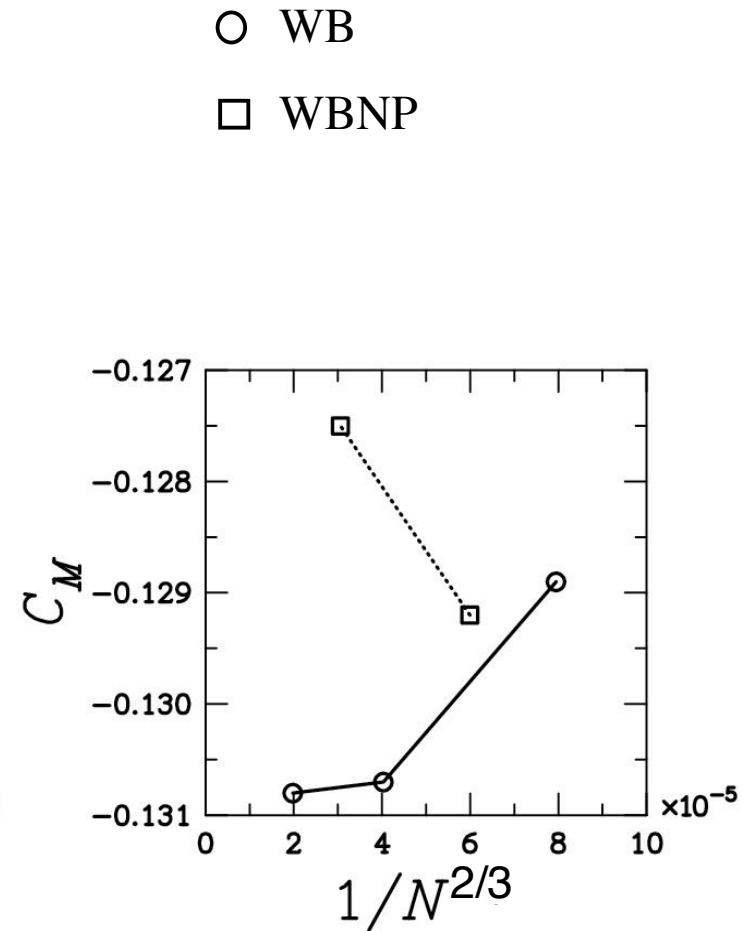
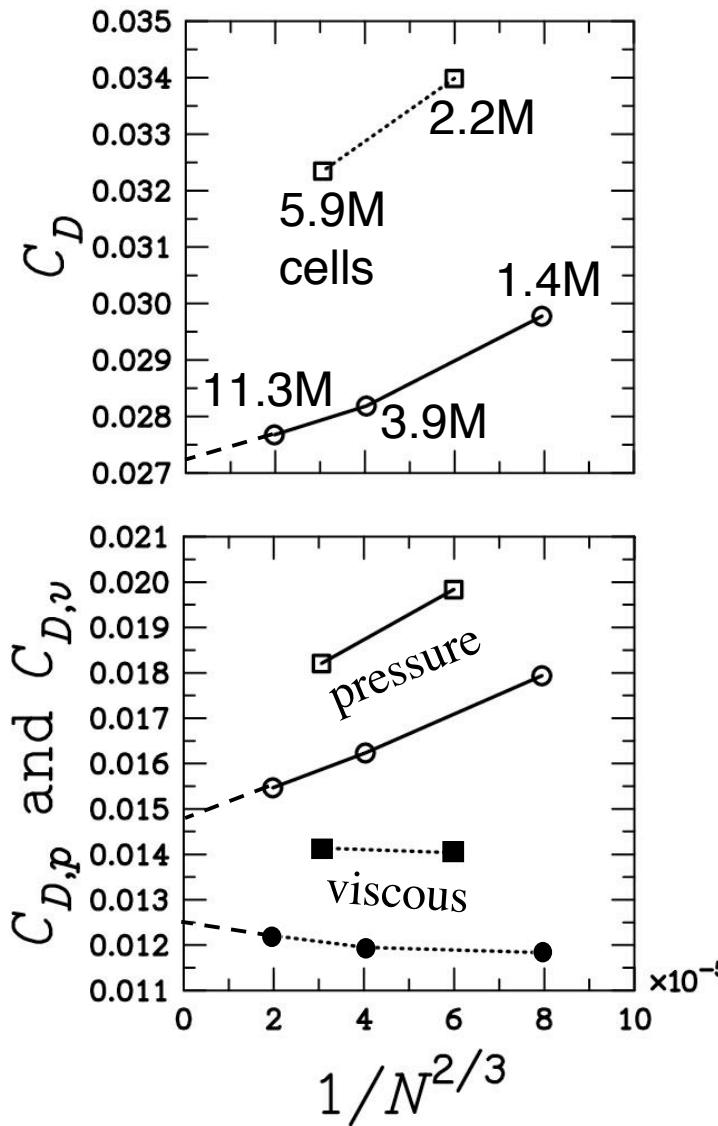
- NAS Origin 2000 – 64 processors
- 180 words/cell (8 bytes/word)
- 14.9 wallclock hours for $\alpha=0$ deg
- 12.4 wallclock hours for $C_L=0.500$
- Typical times for other grids
 - Medium: 5-6 hours on 48 procs
 - Coarse: 1-2 hours on 32 procs

3600 Iterations	
COEFFICIENTS AVERAGED OVER LAST 100 CYCLES	
CL_usm3d	= 0.499367 (+0.000011, -0.000019)
CD_usm3d	= 0.027679 (+0.000003, -0.000002)
CDV_usm3d	= 0.012213 (+0.000000, -0.000000)
CM_usm3d	= -0.130792 (+0.000010, -0.000017)
COEFFICIENTS AVERAGED OVER LAST 200 CYCLES	
CL_usm3d	= 0.499373 (+0.000034, -0.000025)
CD_usm3d	= 0.027679 (+0.000003, -0.000004)
CDV_usm3d	= 0.012213 (+0.000000, -0.000000)
CM_usm3d	= -0.130801 (+0.000019, -0.000018)

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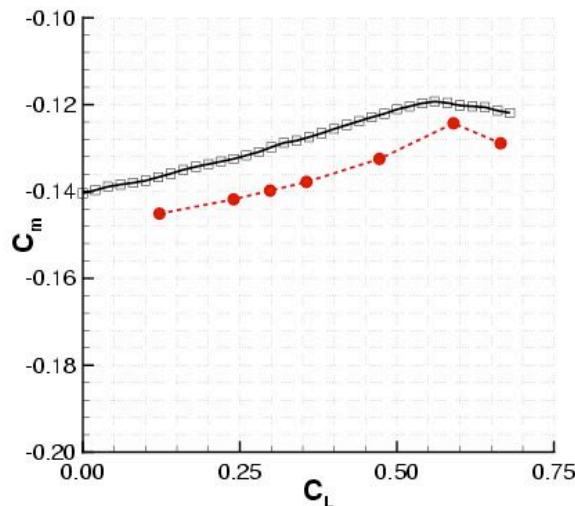
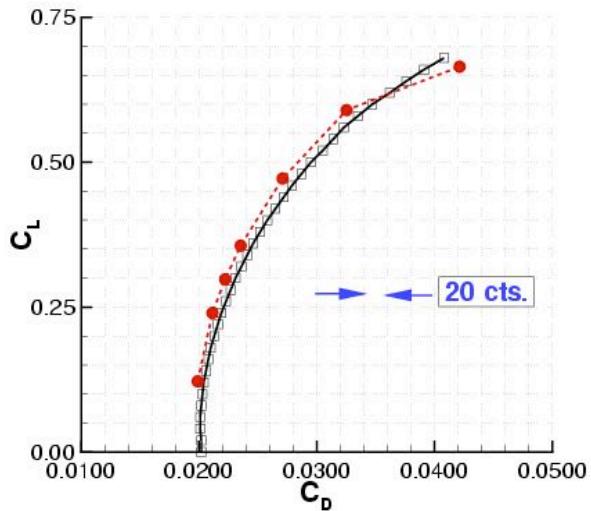
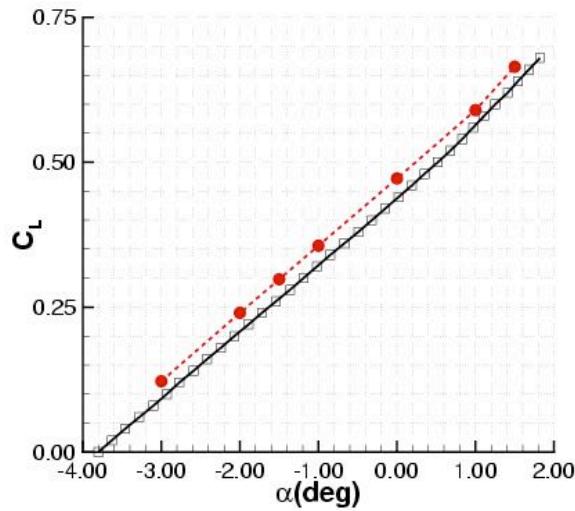
Grid Sensitivity on DLR-F6 – Case 1

$M_\infty=0.75$, $Re_{mac}=3.0\times 10^6$, $C_L=0.500$



Force and Moment Data on DLR-F6 WB – Cases 2

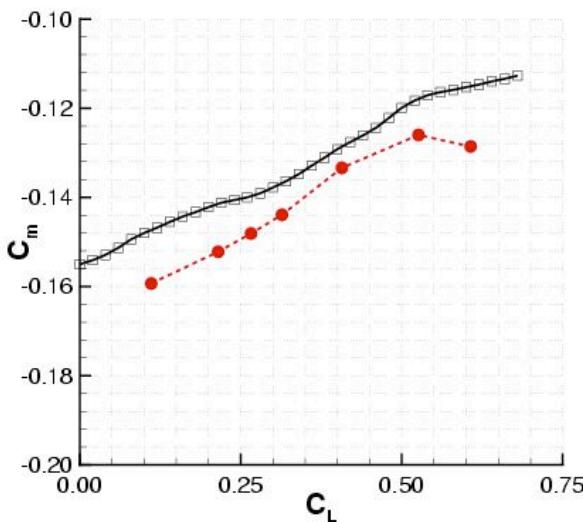
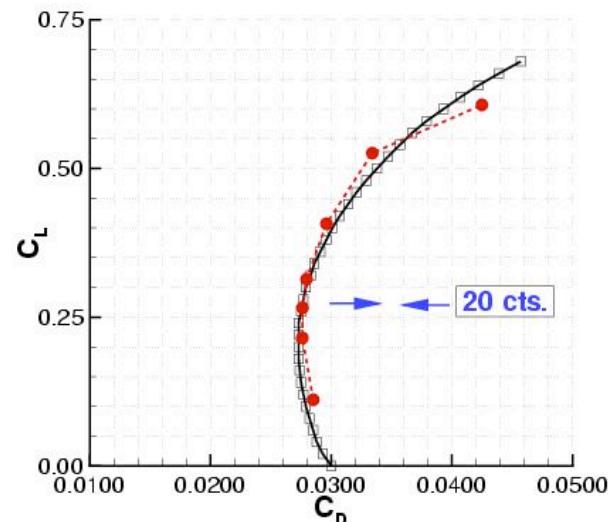
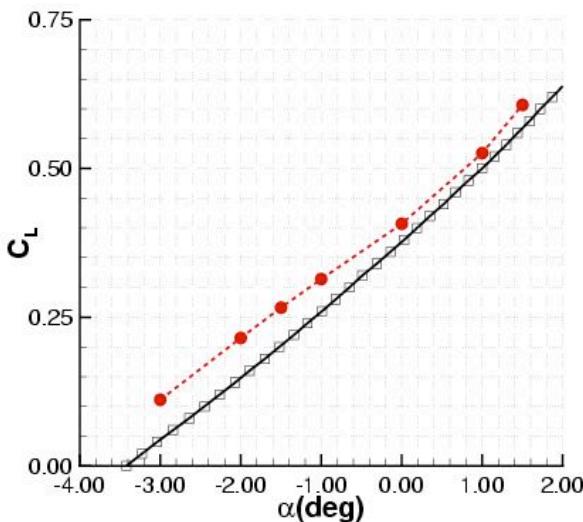
$M = 0.75, Re_{mac} = 3.0 \times 10^6$



Experiment (Lot 375)
USM3Dns

Force and Moment Data on DLR-F6 WBNP – Cases 2

$M = 0.75, Re_{mac} = 3.0 \times 10^6$



Experiment (Lot 175) USM3Dns

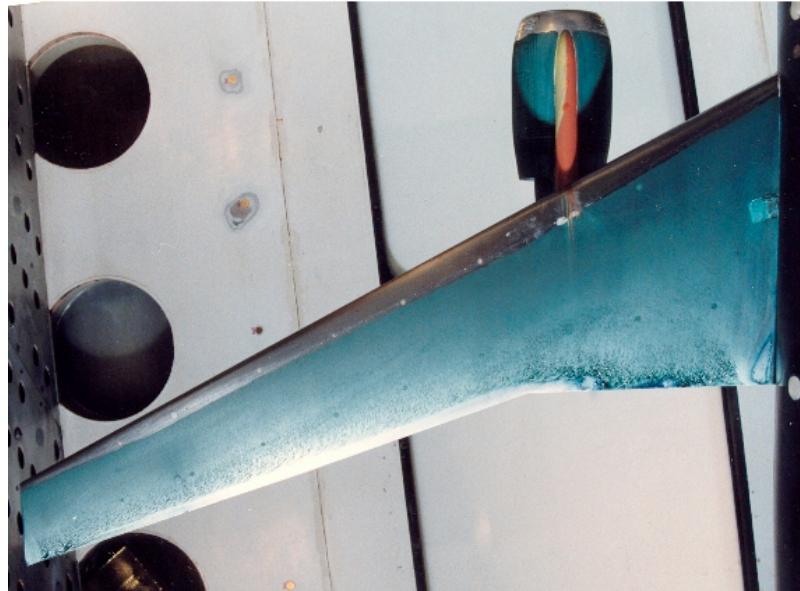
$\square C_D = 0.00410$ (Coarse)
 $= 0.00416$ (Medium)
 $= 0.0043$ (Expt)

where $\square C_D = (C_{D,WBNP} - C_{D,WB}) @ C_L = 0.500$

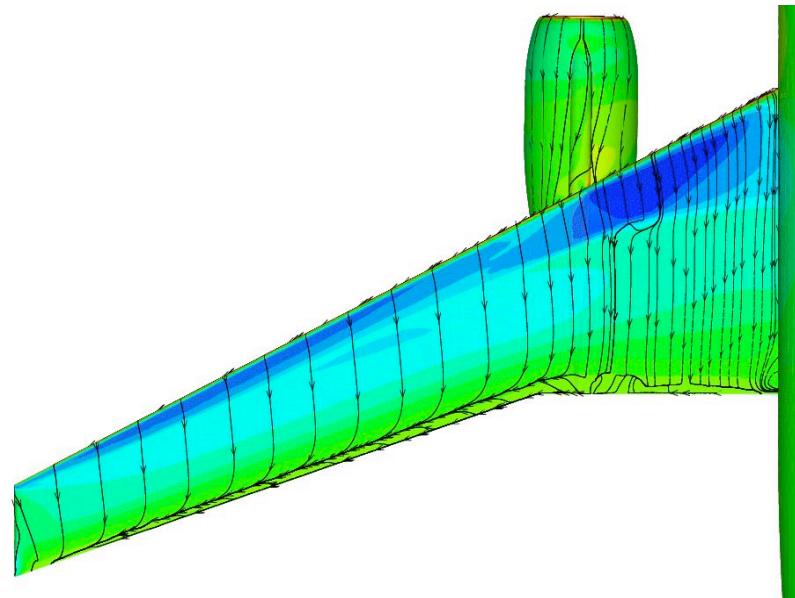
Comparison of Wing Flow Patterns

DLR-F6 WBNP: $M_\infty=0.75$, $Re_{mac}=3.0\times 10^6$, $C_L=0.500$

DLR Surface Oil Flow

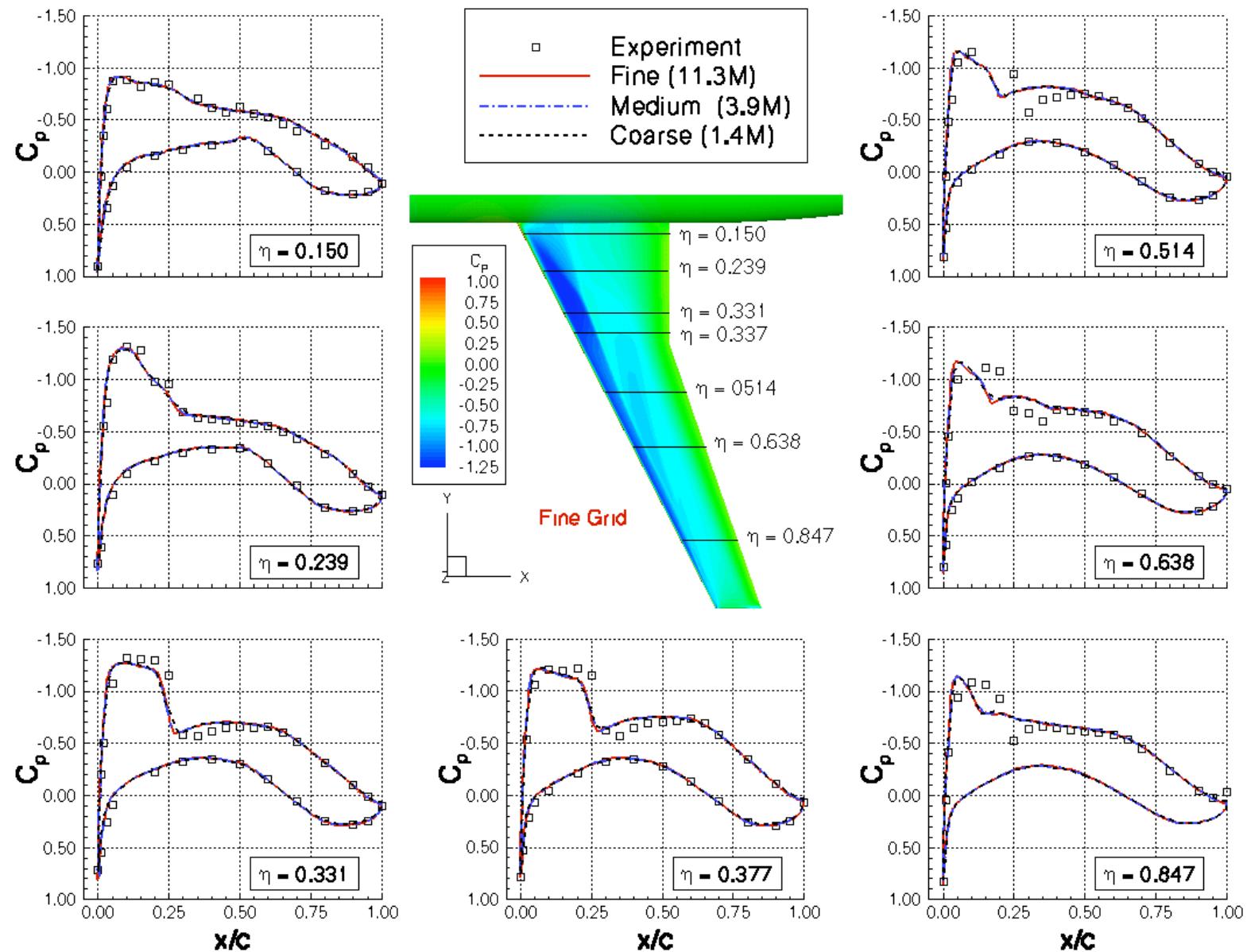


USM3Dns Fine Grid



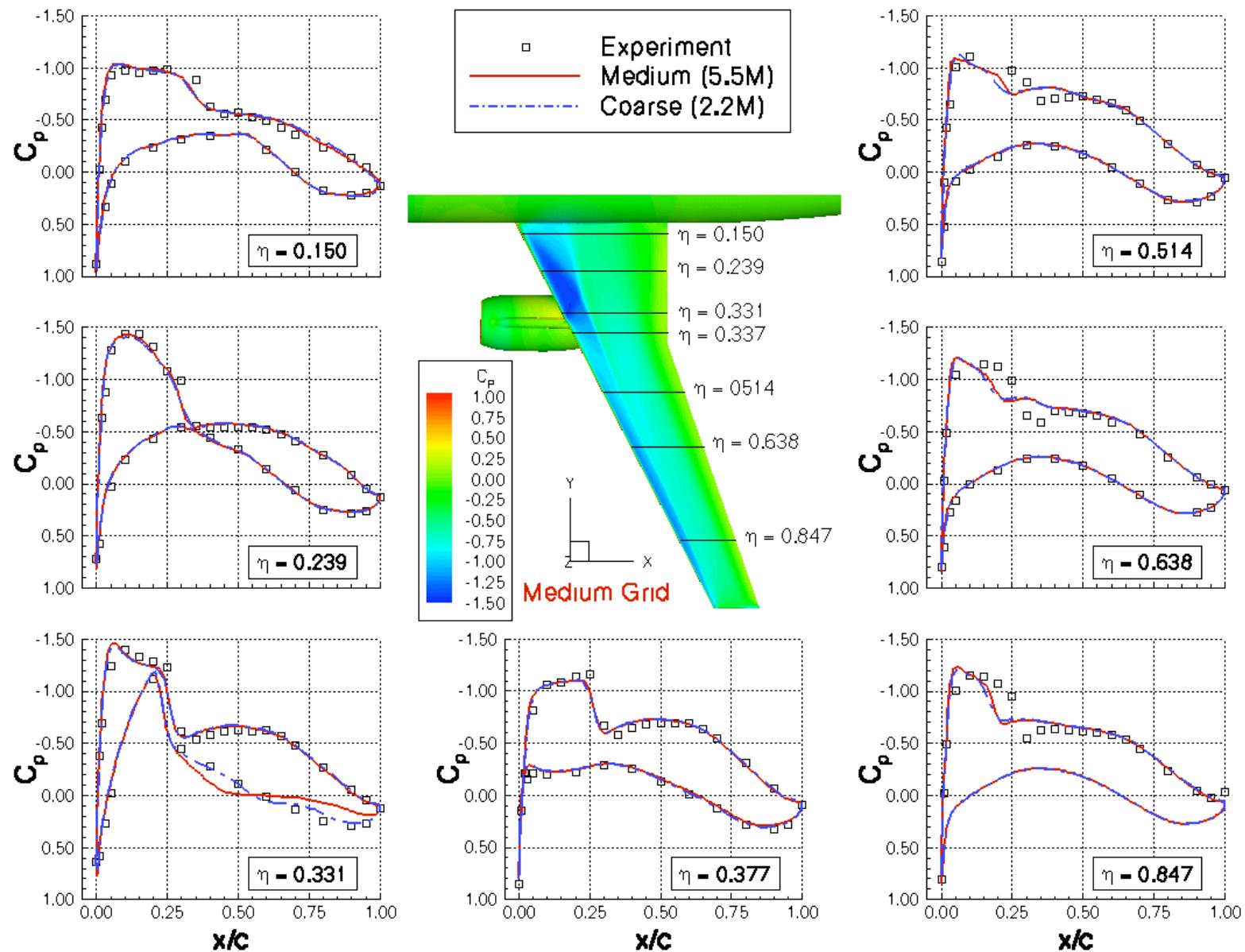
Wing Pressure Distributions

DPW2: DLR-F6 WB: $M_\infty=0.75$, $Re_{mac}=3.0\times 10^6$, $C_L=0.500$



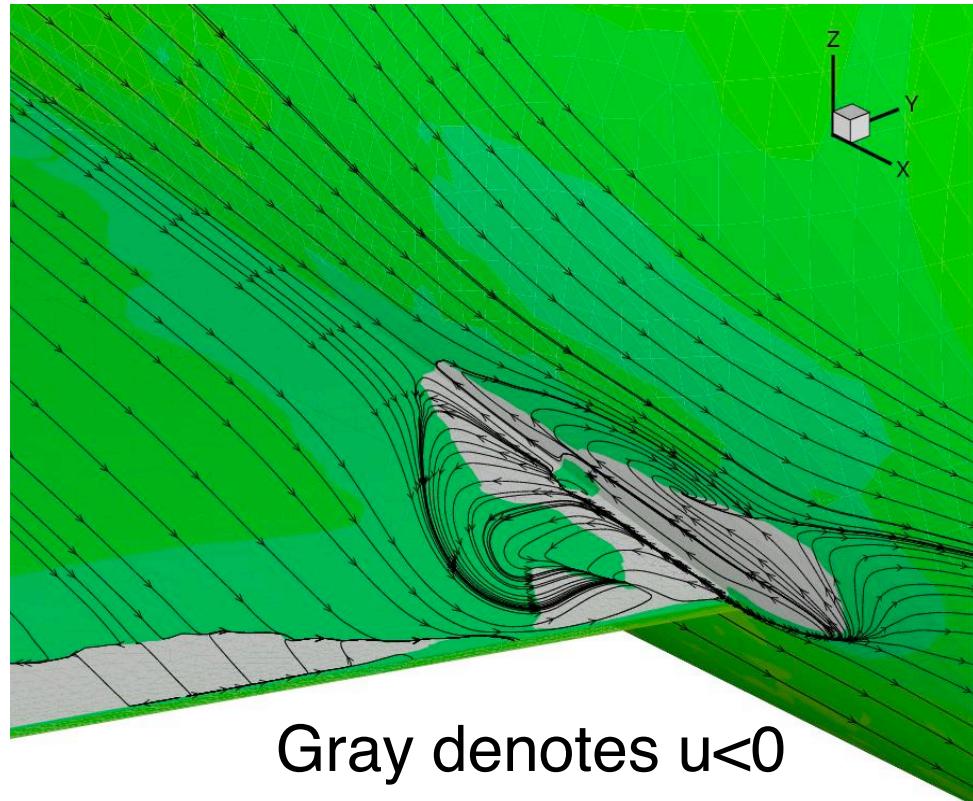
Wing Pressure Distributions

DPW2: DLR-F6 WBNP: $M_{\infty}=0.75$, $Re_{mac}=3.0\times 10^6$, $C_L=0.500$



Comparison of WB Juncture Separation

DLR-F6 WB Fine Grid: $M_\infty=0.75$, $Re_{mac}=3.0\times 10^6$, $C_L=0.500$

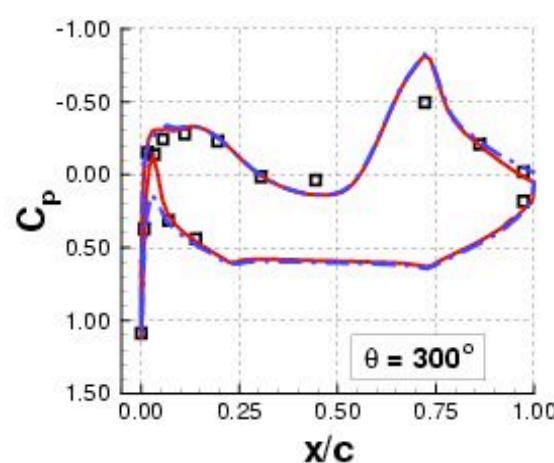


	BUB	EYE (W)	EYE (B)
FS	211.41	234.79	239.40
BL	-90.50	-74.14	-68.78
WL	1.36	-9.24	-2.67

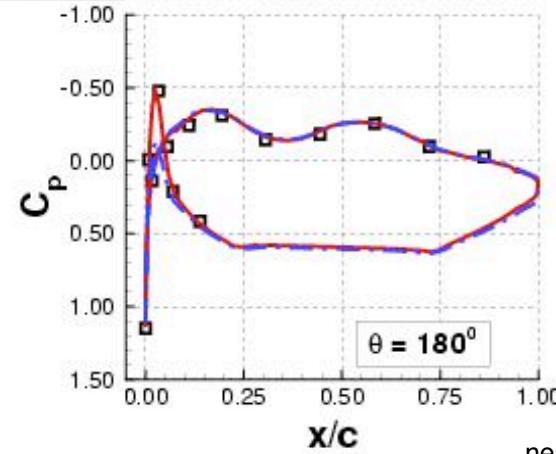
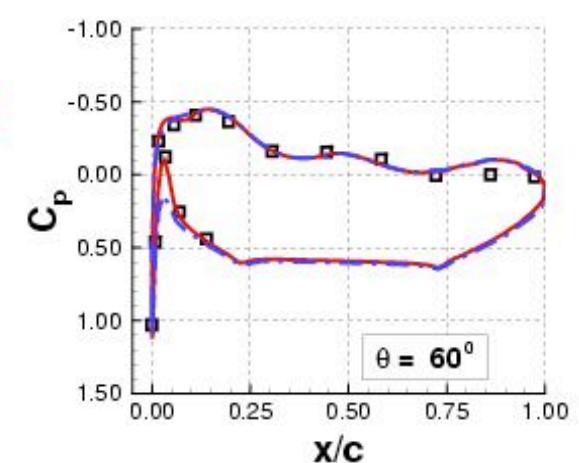
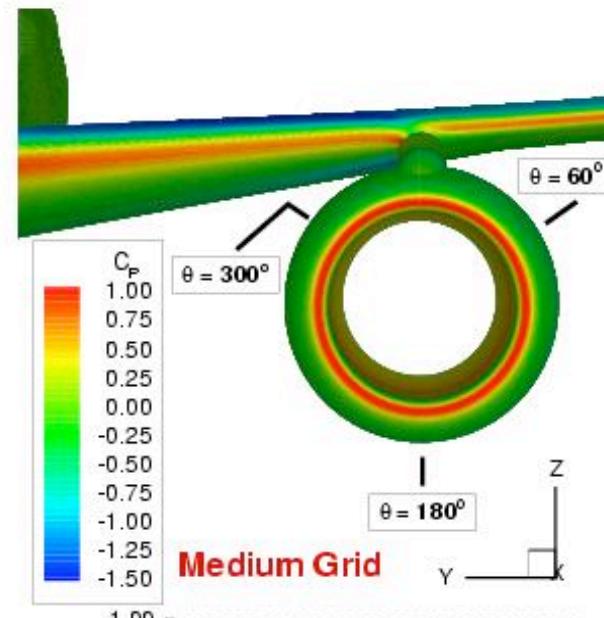
Dimensions in mm

Nacelle Pressure Distributions

DPW2: DLR-F6 WBNP: $M_\infty=0.75$, $Re_{mac}=3.0\times 10^6$, $C_L=0.500$



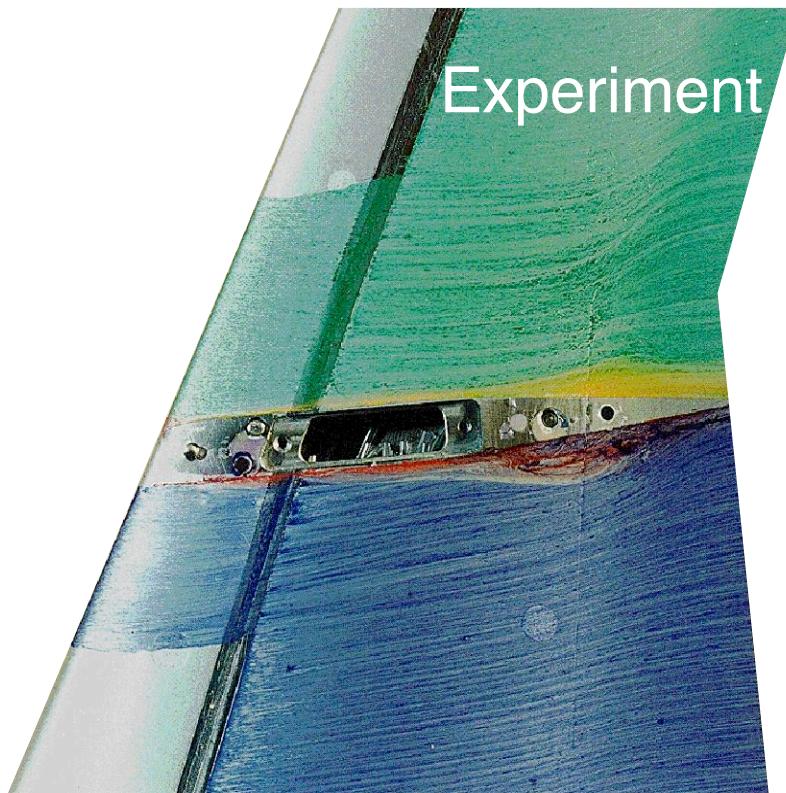
□ **Experiment**
— **Medium Grid**
- - - **Coarse Grid**



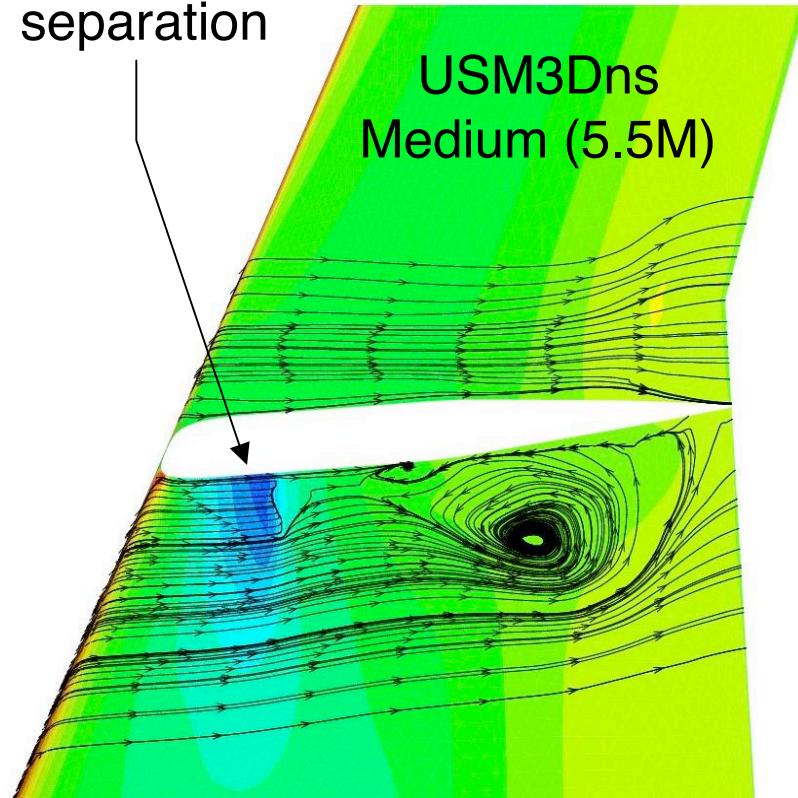
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Comparison of Inb'd Pylon Separation

DPW2: DLR-F6 WBNP: $M_\infty=0.75$, $Re_{mac}=3.0\times 10^6$, $C_L=0.500$



Shock-induced
separation



Supplemental slides

DLR-F6 Unstructured WB grids for Cell-Based Solvers

Grid Generation by VGRIDns

$$\Delta n_j = \Delta n_1 (1+a(1+b)^{j-1})^{j-1}$$

Grid statistics:	Coarse	Medium	Fine
• Tetrahedral cells:	1,409,689	3,901,658	11,347,301
• Total grid nodes	246,020	675,946	1,954,524
• Total Bndry triangles	33,408	66,022	135,482
• Triangles on no-slip surfaces	24,638	49,919	104,180
• Tet cells in viscous layer	524,213	1,051,794	2,017,809
• Nodes in the viscous layers:	103,973	208,210	404,276
• T.E. patches	2	2	2

Grid spacings:	Coarse	Medium	Fine
% chordwise spacing at LE	0.90	0.60	0.35
% chordwise spacing at TE	0.494	0.29	0.185
Avg <u>cell</u> y^+ Avg <u>node</u> y^+ (sized for wall function)	13 52	9 36	6 24
Nominal BL cells	16	18	20
Init ‘viscous’ wall spacing (Δn_1)	0.0855	0.057	0.038
Geometric stretching rates a and b	0.456, 0.07	0.456, 0.07	0.456, 0.07
Outer boundary box	106 c_{ref}	106 c_{ref}	106 c_{ref}

Grids generated by Jonathon Nehrbass, intern in the Configuration Aerodynamics Branch, NASA LaRC under direction of Neal Frink

DLR-F6 Unstructured WB grids for Node-Based Solvers

Grid Generation by VGRIDns

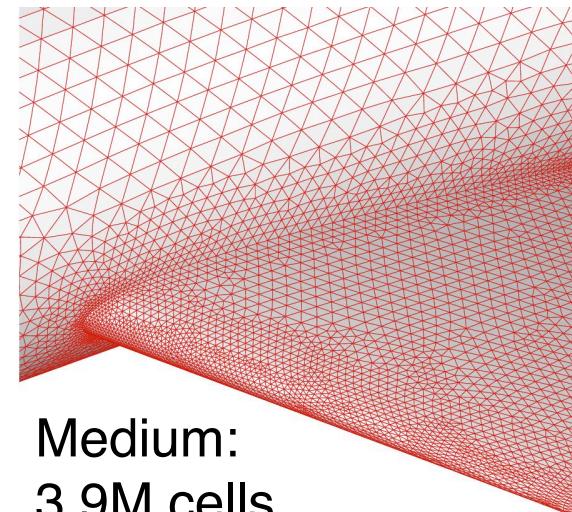
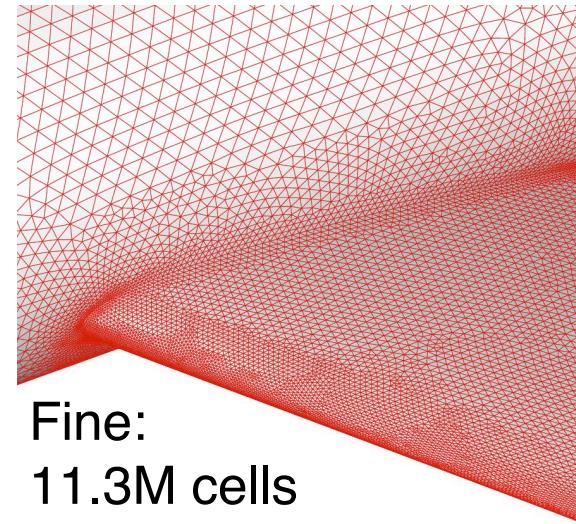
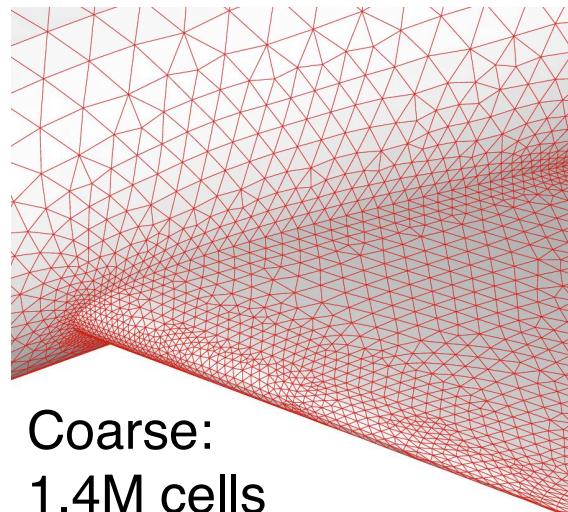
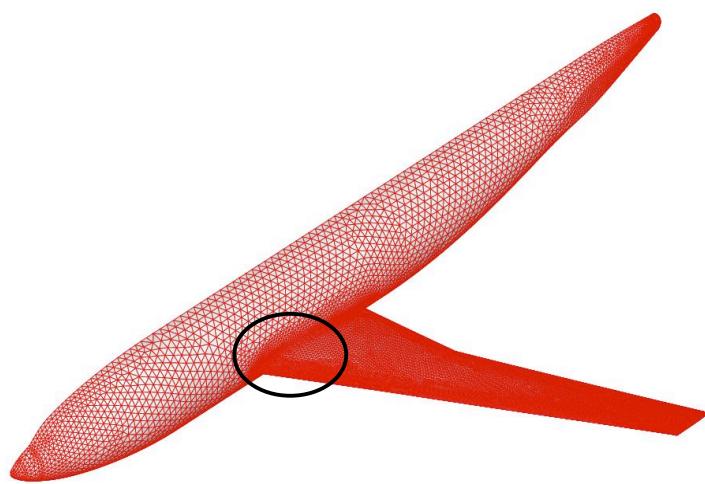
Grid statistics:	Coarse	Medium	Fine
Total grid nodes	1,121,301	3,010,307	9,133,352
Tetrahedral cells:	6,558,758	17,635,283	53,653,279
Nodes on no-slip boundaries	25,104	55,069	118,903
Nodes in viscous layers:	674,338	1,462,475	3,975,437
Tet cells in viscous layer	3,826,019	8,313,126	22,866,866
T.E. patches	2	4	6

$$\square n_j = \square n_1 (1+a(1+b)^{j-1})^{j-1}$$

Grid spacings:	Coarse	Medium	Fine
Nominal BL nodes	26	26	33
Init 'viscous' wall spacing ($\square n_1$)	0.00144	0.001	0.000695
Geometric stretching rates a and b	0.2, 0.02	0.2, 0.02	0.13, 0.02
Outer boundary box	106 c_{ref}	106 c_{ref}	106 c_{ref}

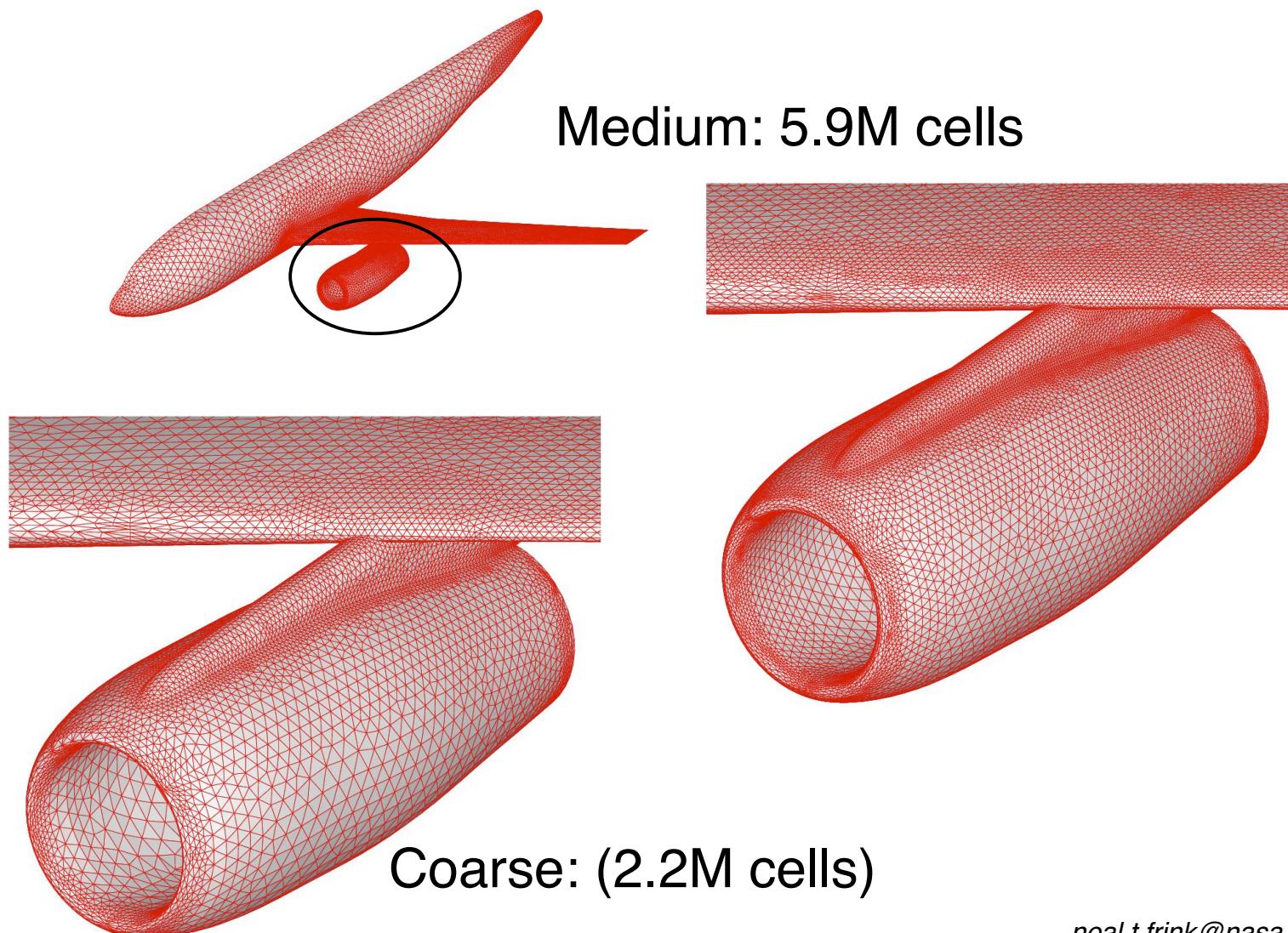
Grids generated by Beth Lee-Rausch, Computational Modeling & Simulation Branch, NASA LaRC

DLR-F6 WB Tetrahedral Viscous Grids for Cell-Centered Solvers



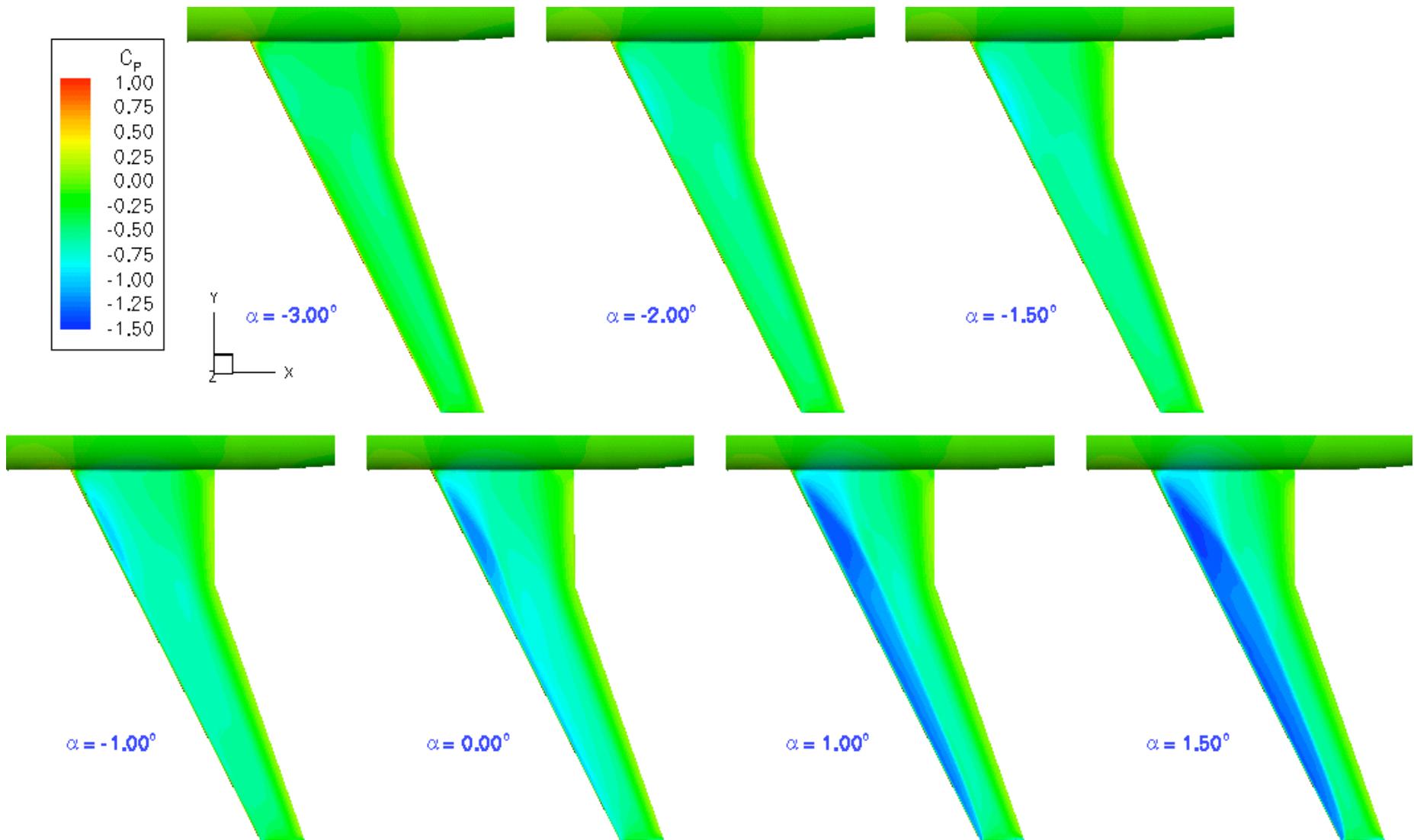
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DLR-F6 WBNP Tetrahedral Viscous Grids for Cell-Centered Solvers



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Case2: WB angle-of-attack sweep



Case2: WBNP angle-of-attack sweep

