



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

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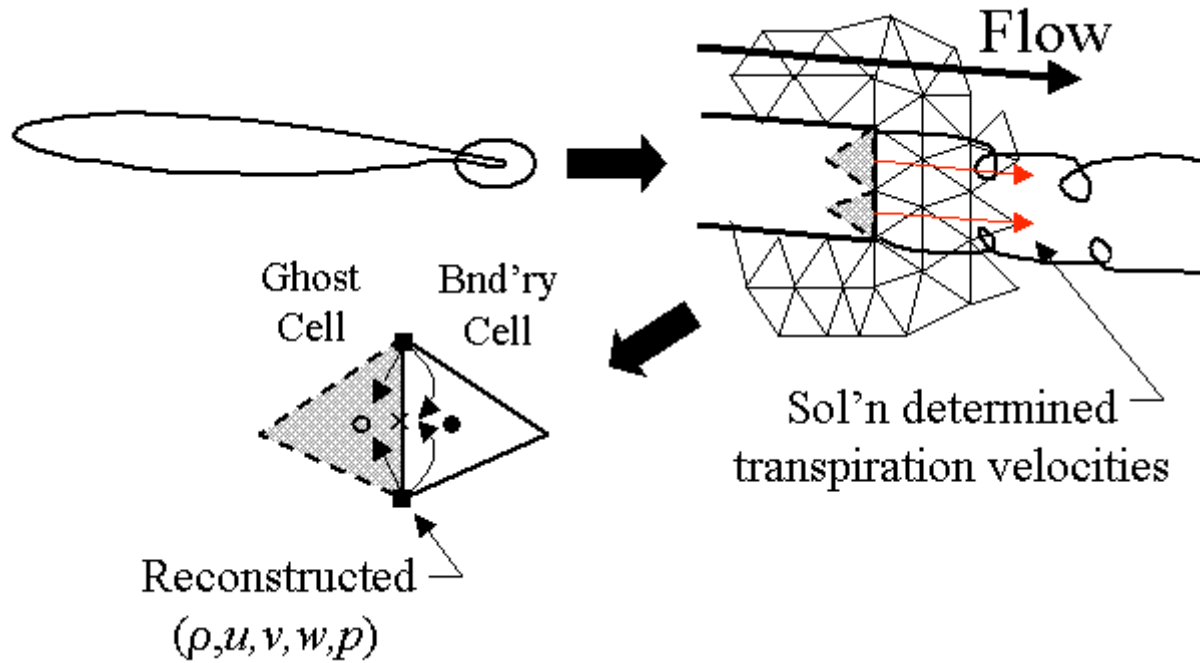
Orlando, Florida

21,22 June, 2003

# 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



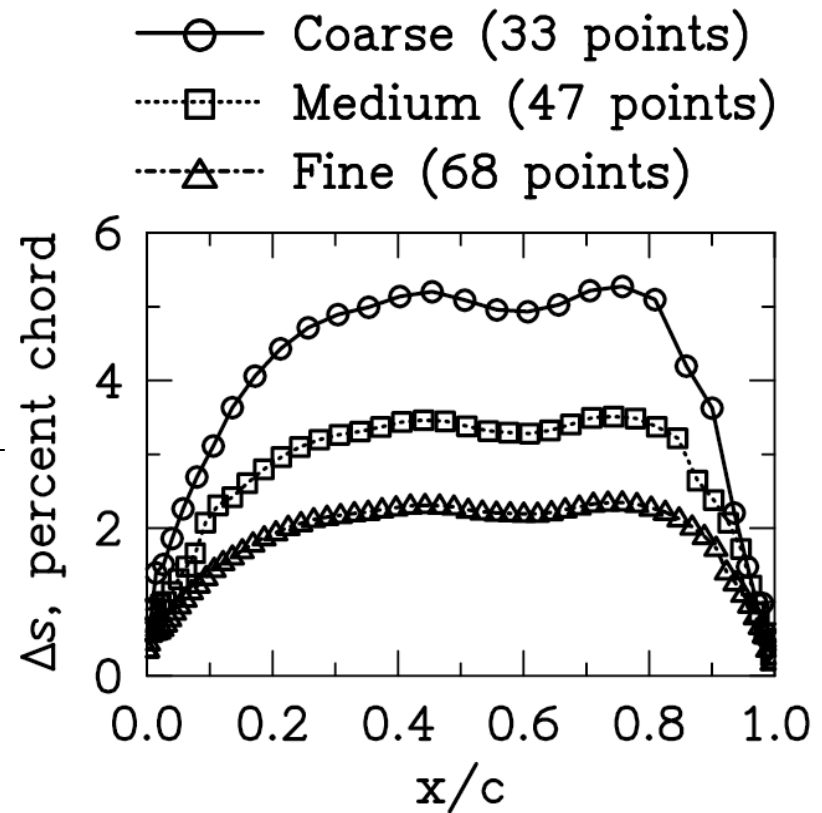
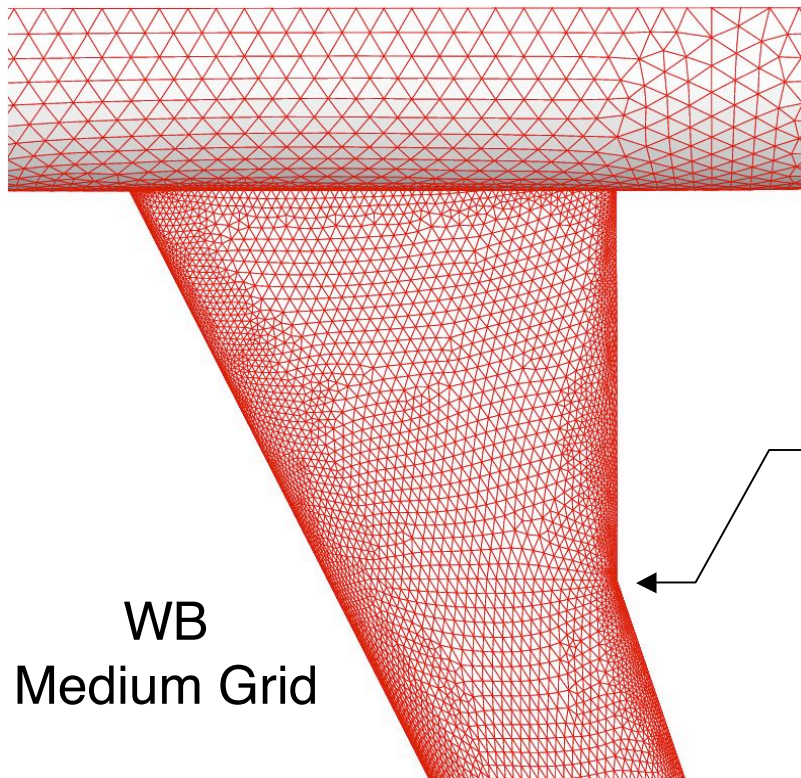
# Tetrahedral Grids for DLR-F6 DPW2 Configuration

## For Cell-Centered Codes with Wall Function

	WB	WBNP
<p style="text-align: center;"><b>Coarse</b></p> <p>Nominal <math>y^+_{node} = 52</math>            Avg. <math>\Delta n_{n1} = 0.079</math>            Avg. <math>\Delta n_{c1} = 0.020</math></p>	<p style="text-align: center;"><b>1,409,689 cells</b></p> <p>Avg. <math>y^+_{cell} = 13.1</math></p>	<p style="text-align: center;"><b>2,152,607 cells</b></p> <p>Avg. <math>y^+_{cell} = 12.9</math></p>
<p style="text-align: center;"><b>Medium</b></p> <p>Nominal <math>y^+_{node} = 36</math>            Avg. <math>\Delta n_{n1} = 0.053</math>            Avg. <math>\Delta n_{c1} = 0.013</math></p>	<p style="text-align: center;"><b>3,901,658 cells</b></p> <p>Avg. <math>y^+_{cell} = 8.9</math></p>	<p style="text-align: center;"><b>5,912,596 cells</b></p> <p>Avg. <math>y^+_{cell} = 8.7</math></p>
<p style="text-align: center;"><b>Fine</b></p> <p>Nominal <math>y^+_{node} = 24</math>            Avg. <math>\Delta n_{n1} = 0.036</math>            Avg. <math>\Delta n_{c1} = 0.009</math></p>	<p style="text-align: center;"><b>11,347,301 cells</b></p> <p>Avg. <math>y^+_{cell} = 5.9</math></p>	<p style="text-align: center;"><b>17,193,275 cells</b></p> <p style="text-align: center;">Did not run</p>

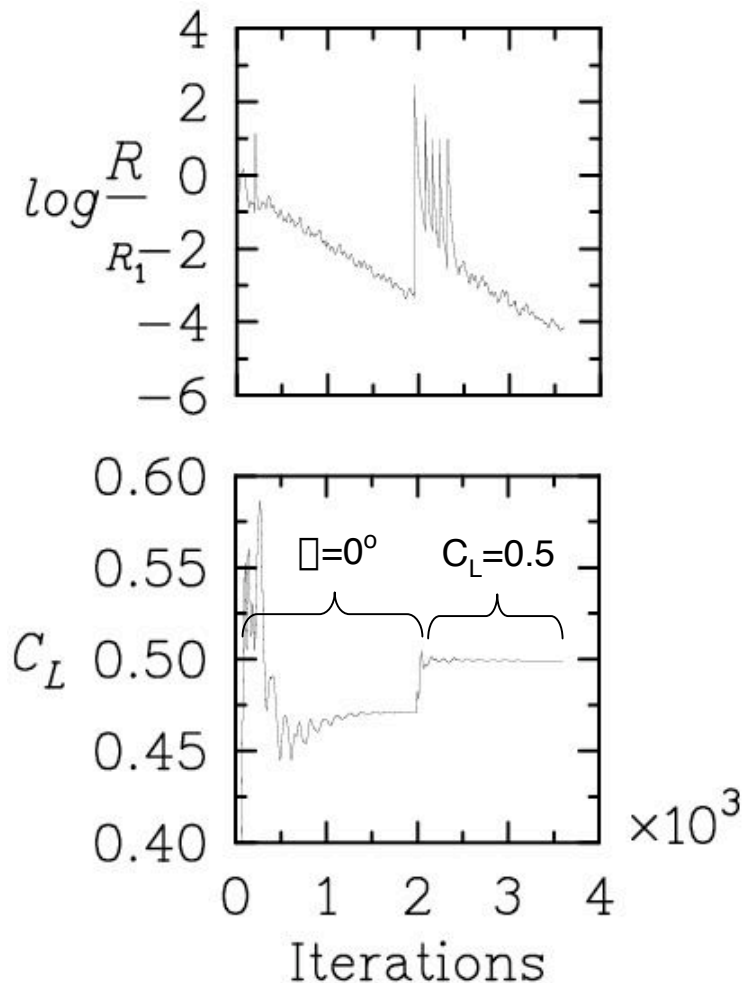
# Chordwise Spacing at WB Crank Station

DLRF6: Tetrahedral Cell-Centered Grids for USM3Dns



# Typical USM3Dns Convergence for Case 1

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

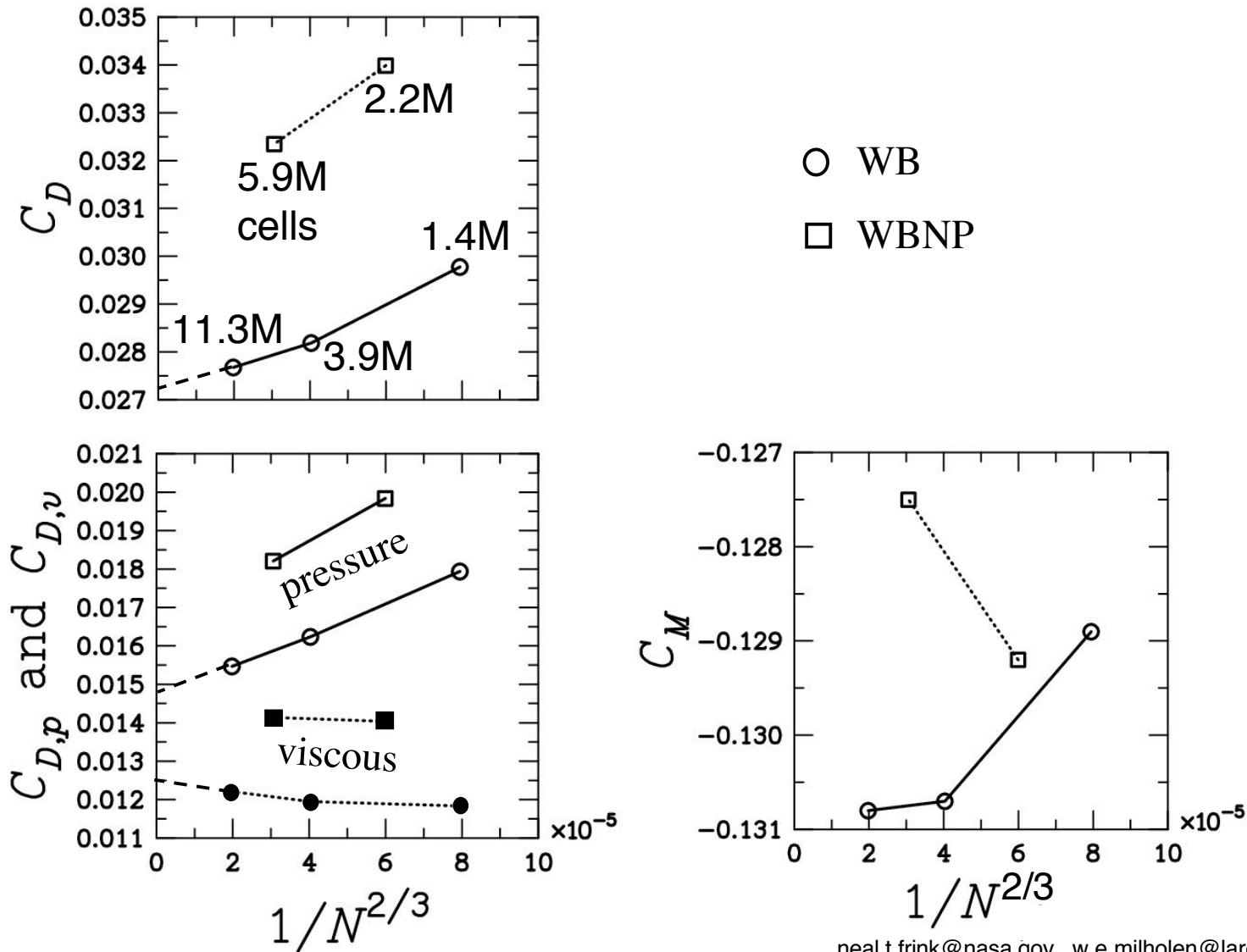


- NAS Origin 2000 – 64 processors
- 180 words/cell (8 bytes/word)
- 14.9 wallclock hours for  $\alpha = 0$  deg
- 12.4 wallclock hours for  $C_L = 0.500$
- Typical times for other grids
  - Medium: 5-6 hours on 48 procs
  - Coarse: 1-2 hours on 32 procs

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)

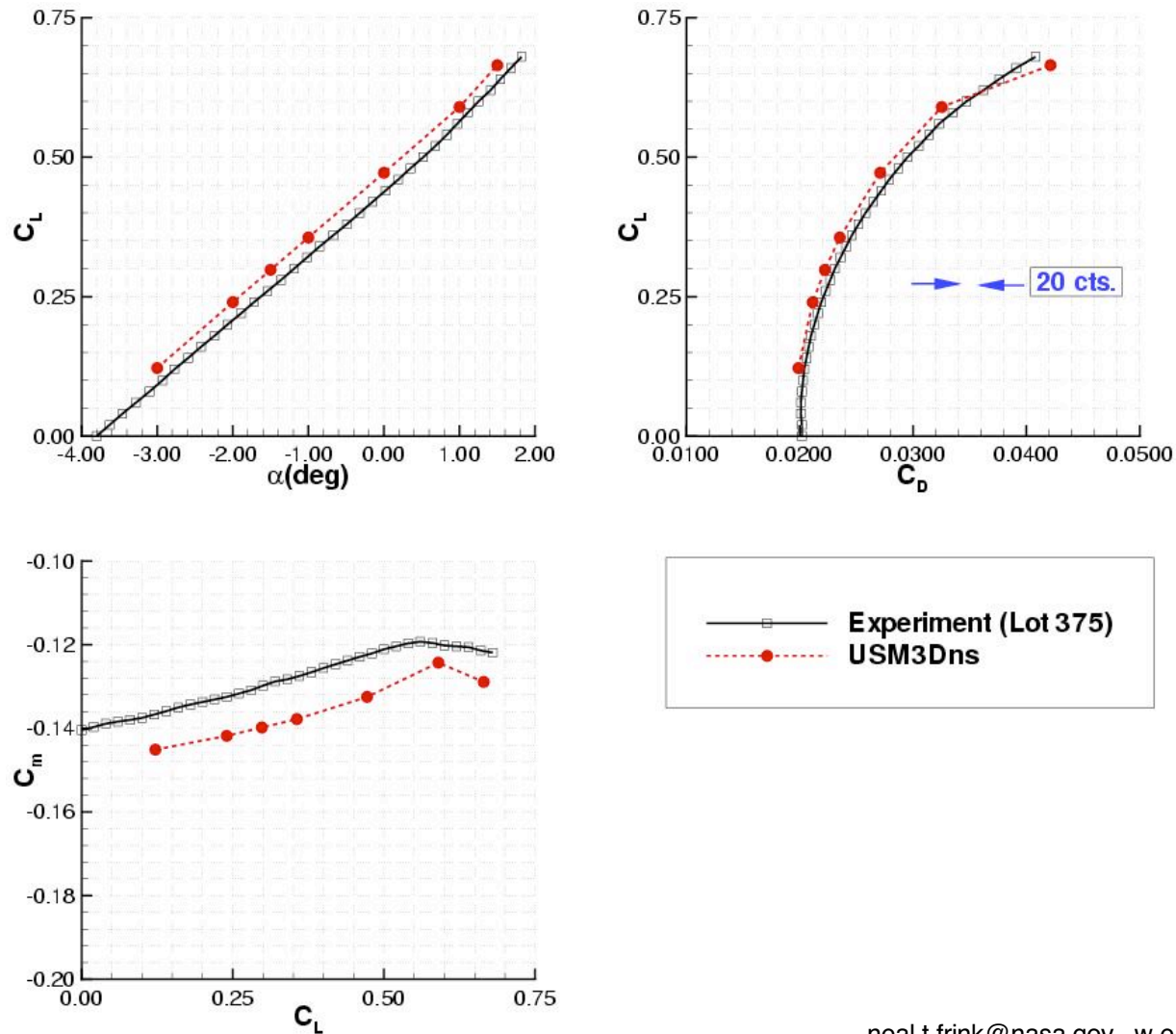
# Grid Sensitivity on DLR-F6 – Case 1

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



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

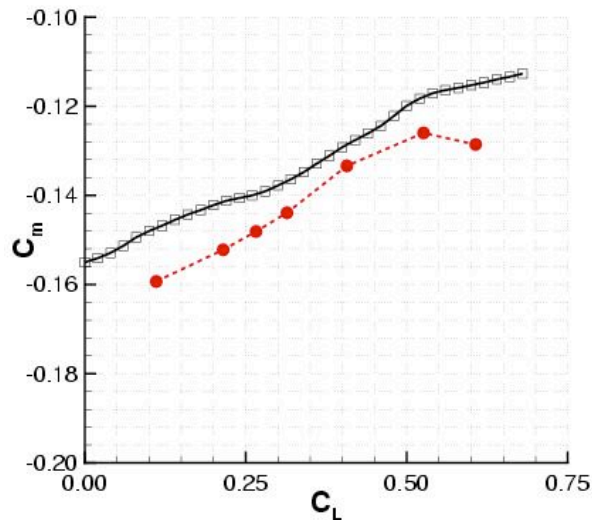
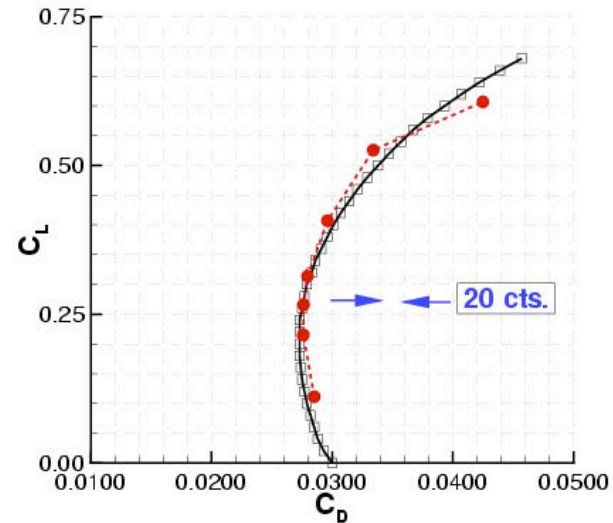
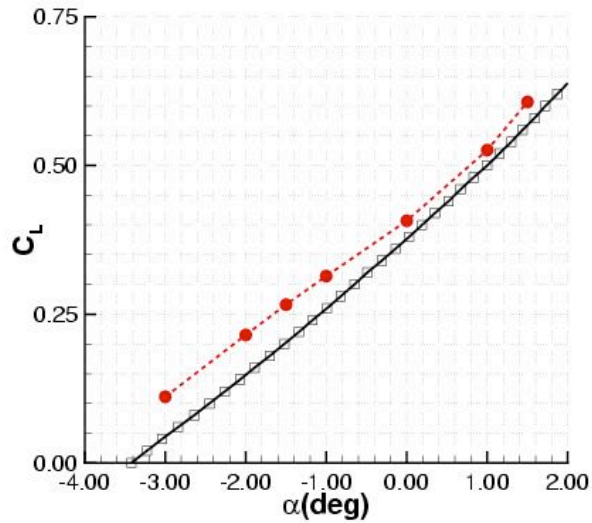
$M = 0.75$ ,  $Re_{mac} = 3.0 \times 10^6$





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

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



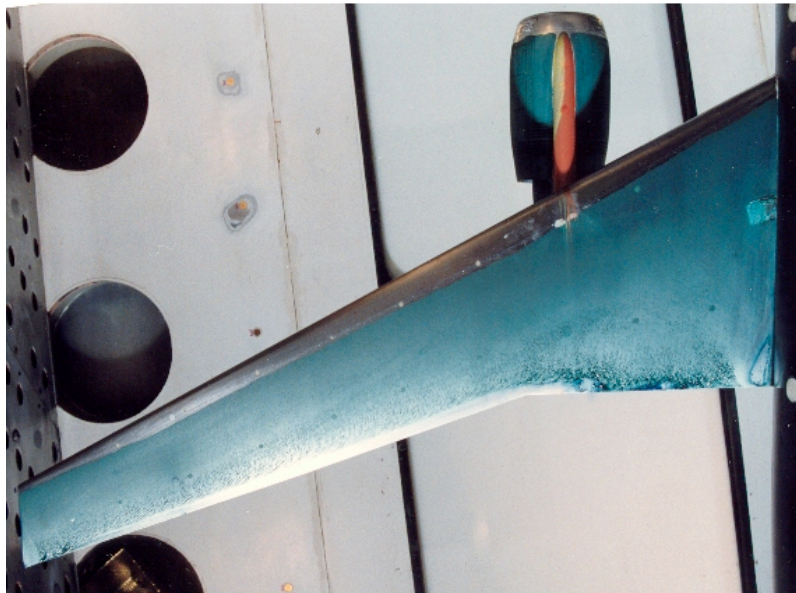
$\Delta C_D = 0.00410$  (Coarse)  
 $= 0.00416$  (Medium)  
 $= 0.0043$  (Expt)

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

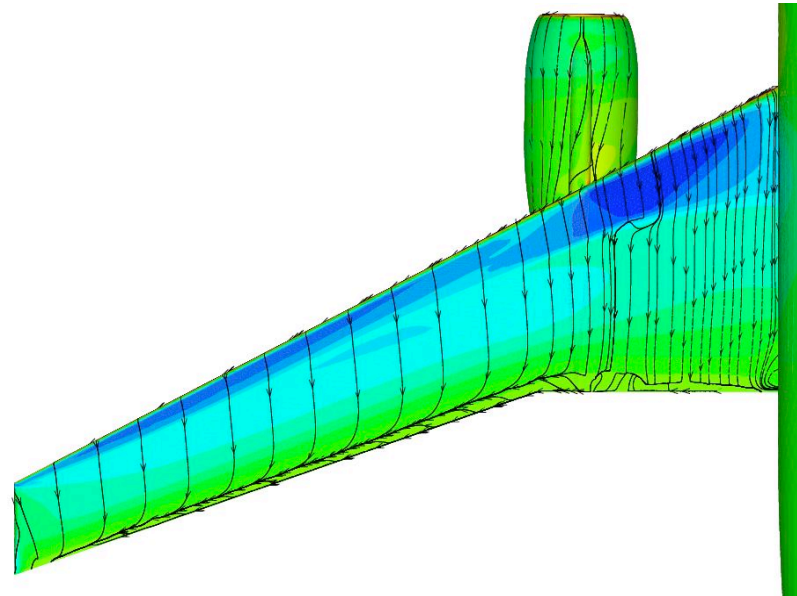
# Comparison of Wing Flow Patterns

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

DLR Surface Oil Flow

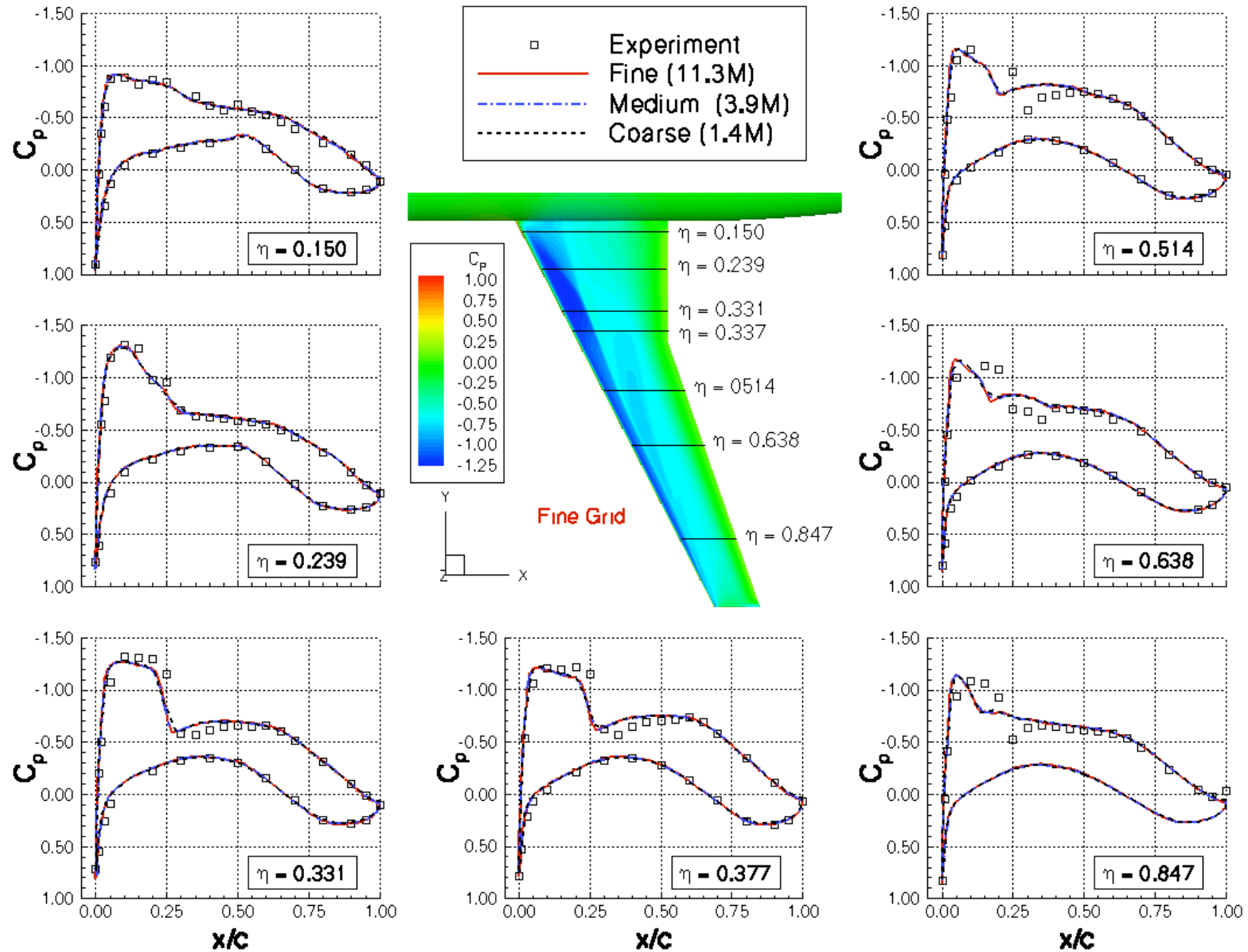


USM3Dns Fine Grid



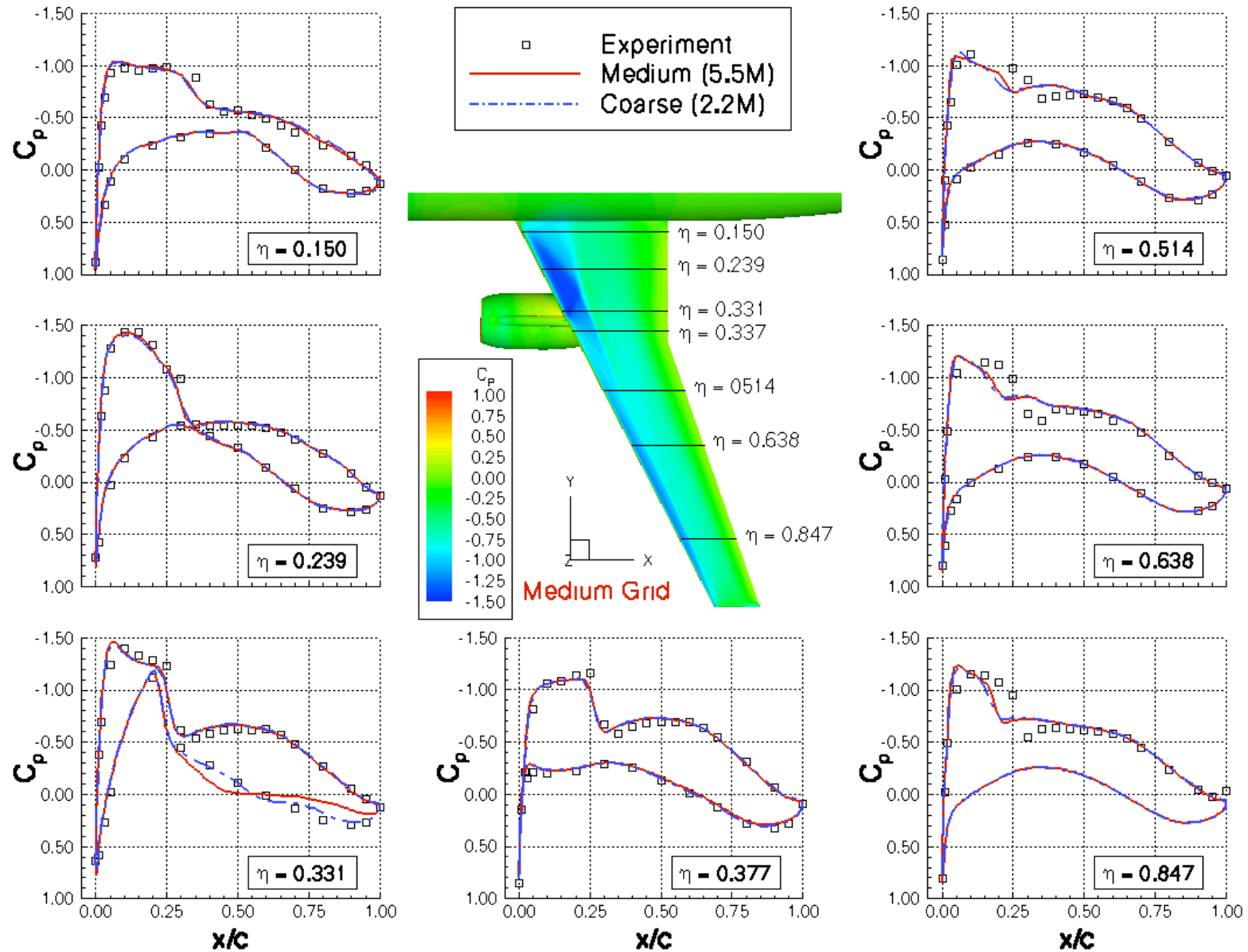
# Wing Pressure Distributions

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



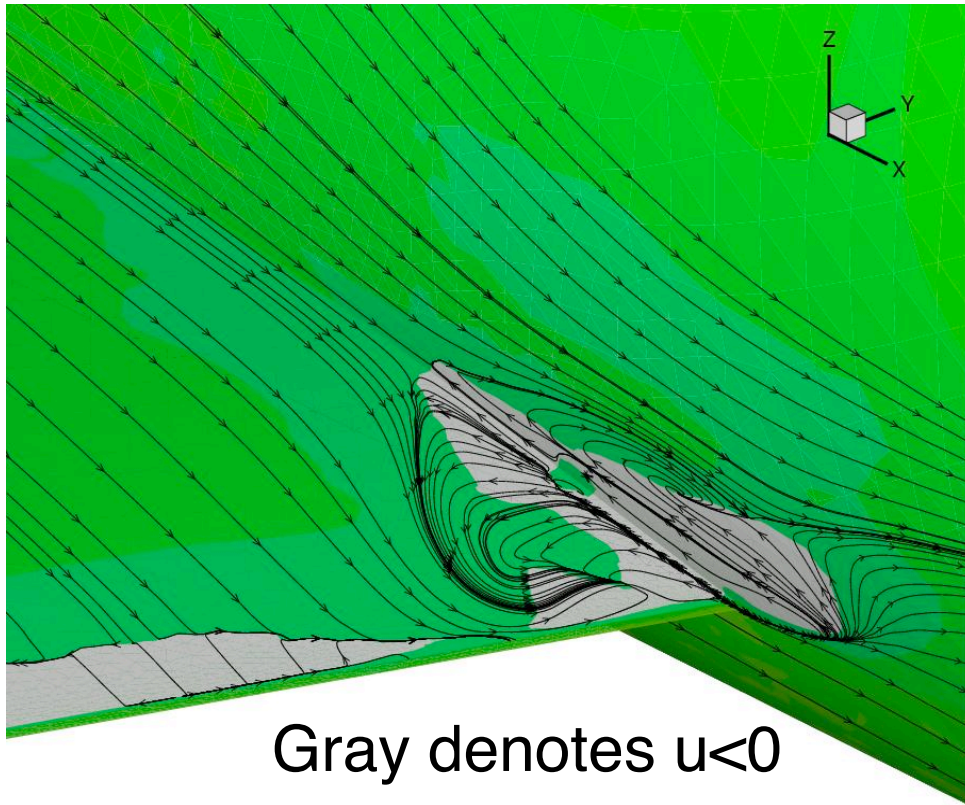
# Wing Pressure Distributions

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

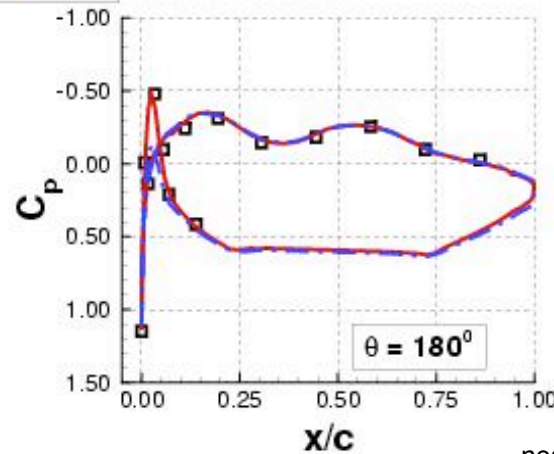
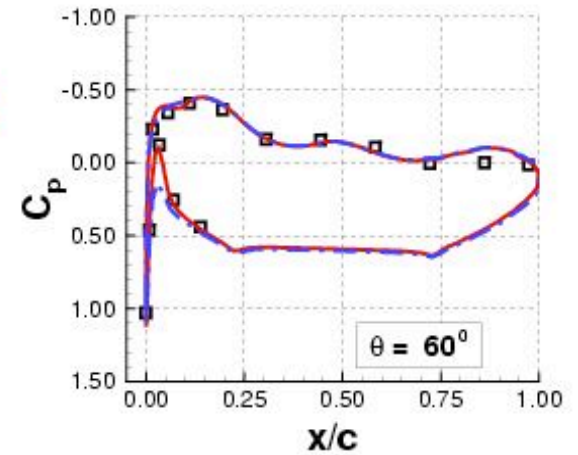
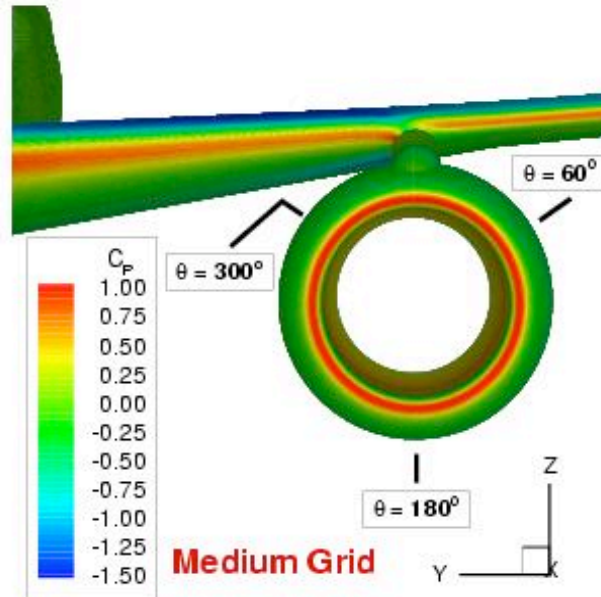
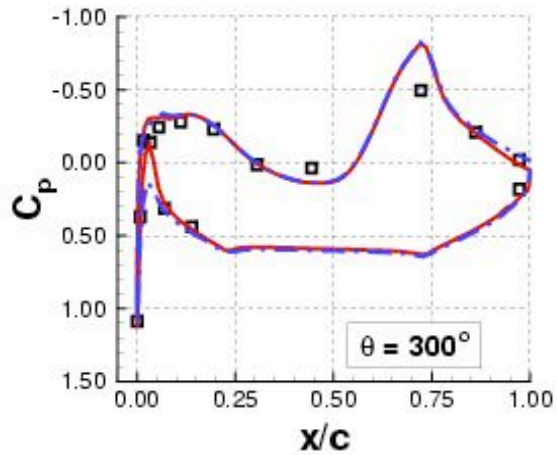


	BUB	EYE (W)	EYE (B)
FS	211.41	234.79	239.40
BL	-90.50	-74.14	-68.78
WL	1.36	-9.24	-2.67

Dimensions in mm

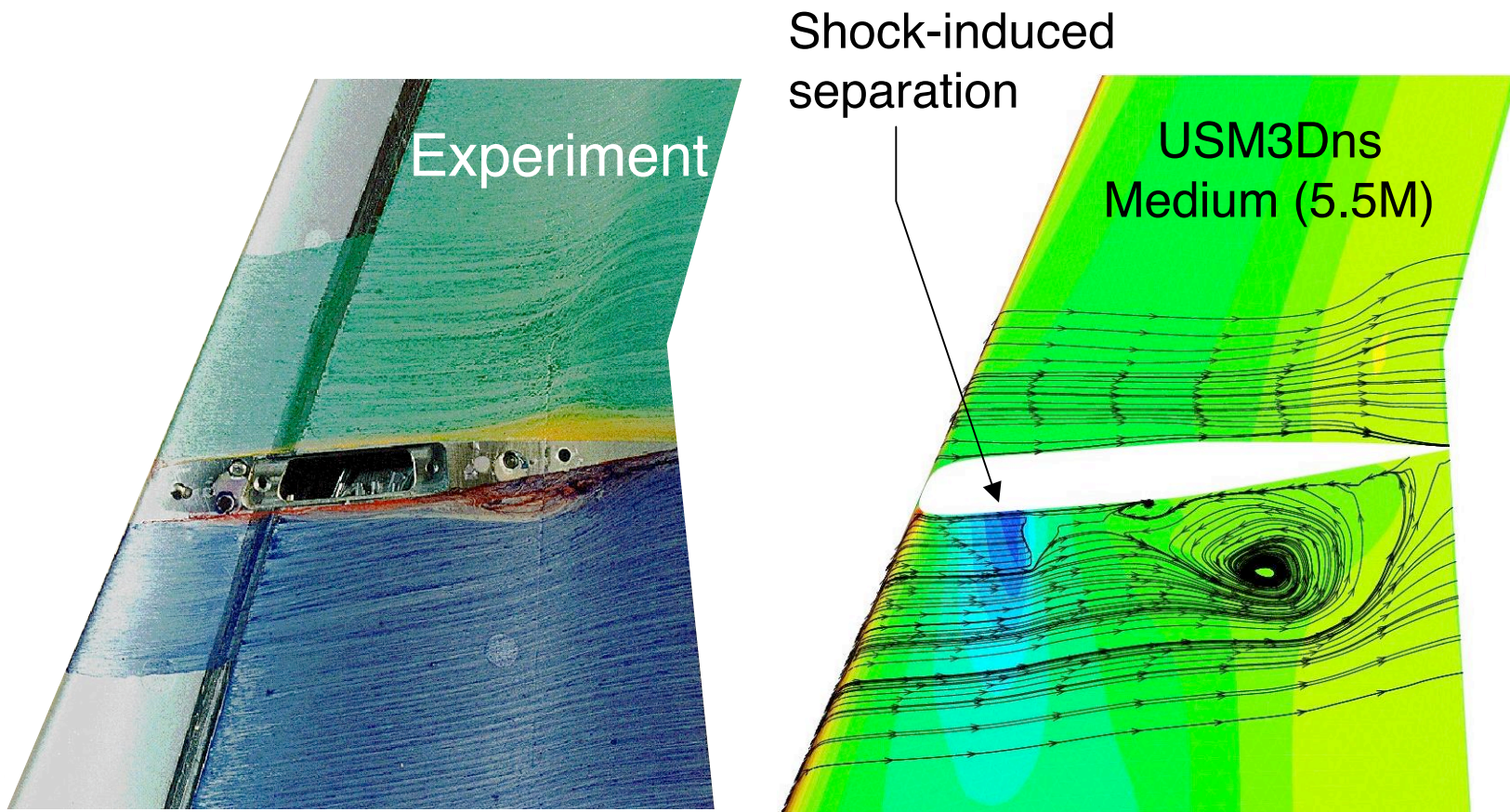
# Nacelle Pressure Distributions

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



# Comparison of Inb'd Pylon Separation

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



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
<b>Avg cell <math>y^+</math></b> Avg node $y^+$ <i>(sized for wall function)</i>	13 52	9 36	6 24
Nominal BL cells	16	18	20
Init 'viscous' wall spacing ( $\Delta n_1$ )	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

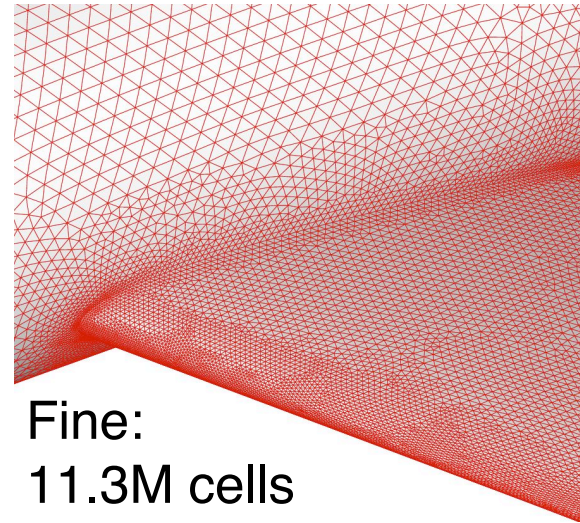
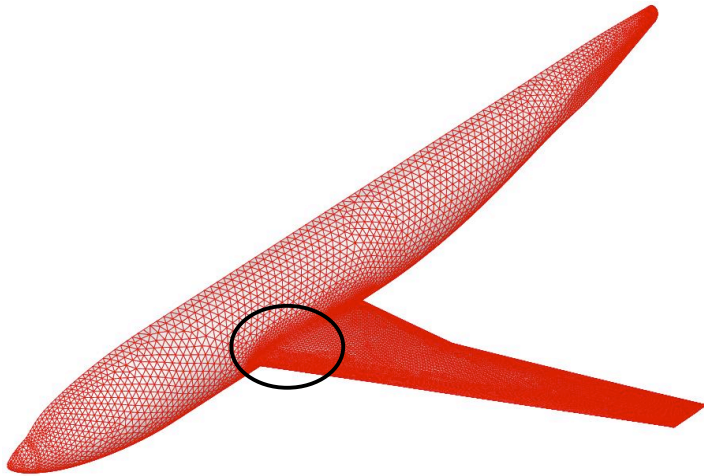
$$\Delta n_j = \Delta n_1 (1+a(1+b)^{j-1})^{j-1}$$

<b>Grid statistics:</b>	<b>Coarse</b>	<b>Medium</b>	<b>Fine</b>
Total grid nodes	1,121,301	3,010,307	9,133,352
Tetrahedral cells:	6,558,758	17,635,283	53,653,279
<b>Nodes</b> on no-slip boundaries	25,104	55,069	118,903
<b>Nodes</b> 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

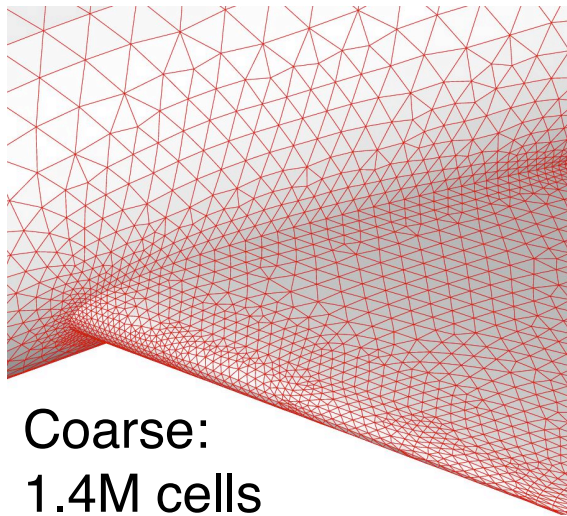
<b>Grid spacings:</b>	<b>Coarse</b>	<b>Medium</b>	<b>Fine</b>
Nominal BL nodes	26	26	33
Init 'viscous' wall spacing ( $\Delta n_1$ )	0.00144	0.001	0.000695
Geometric stretching rates <i>a</i> and <i>b</i>	0.2, 0.02	0.2, 0.02	0.13, 0.02
Outer boundary box	106 $c_{ref}$	106 $c_{ref}$	106 $c_{ref}$

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

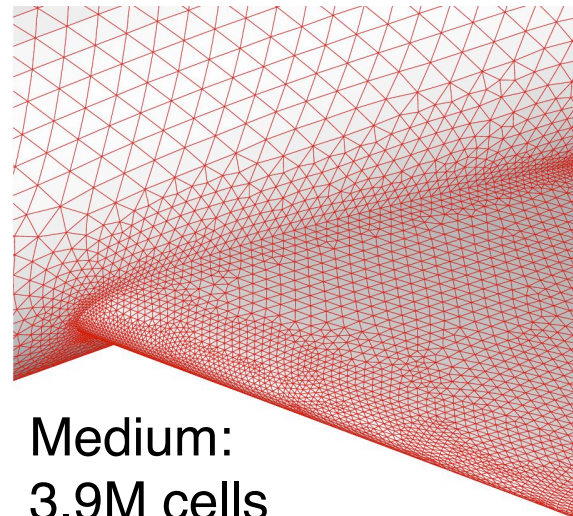
# DLR-F6 WB Tetrahedral Viscous Grids for Cell-Centered Solvers



Fine:  
11.3M cells

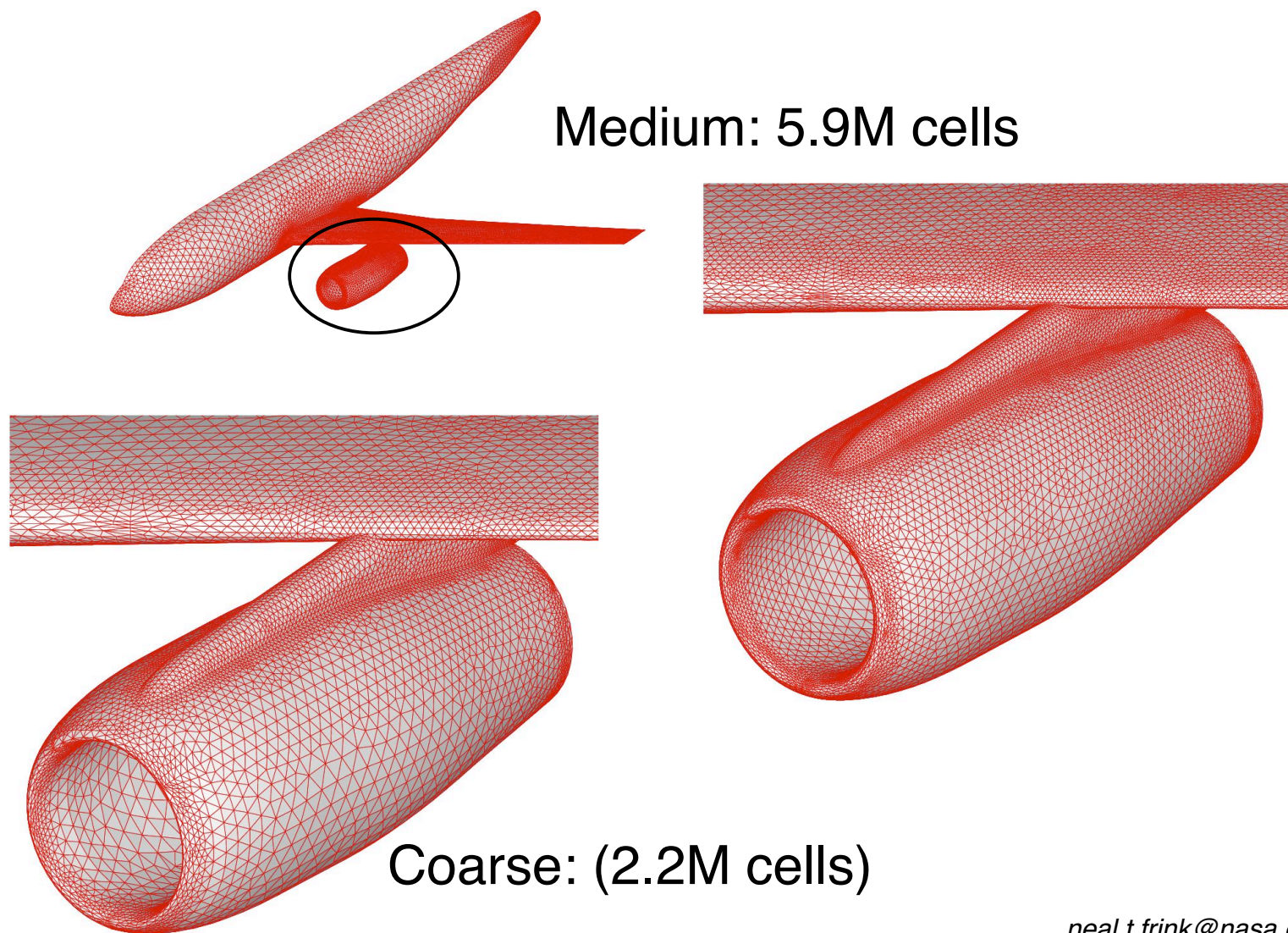


Coarse:  
1.4M cells

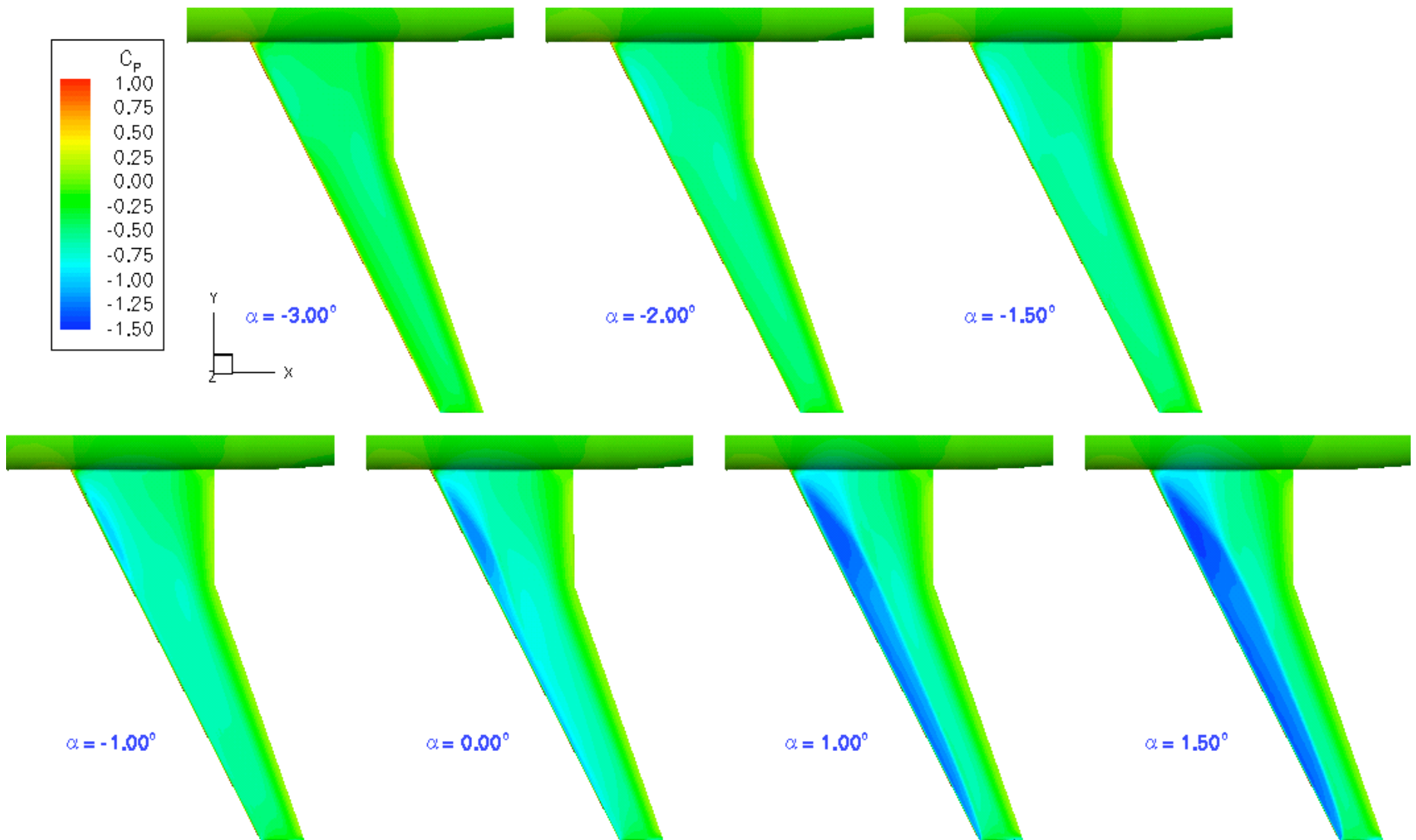


Medium:  
3.9M cells

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



## Case2: WB angle-of-attack sweep



## Case2: WBPN angle-of-attack sweep

