Applied Aerodynamics
Technical Committee

2nd AIAA CFD Drag Prediction Workshop

Data Summary and Comparison

Kelly Laflin

Overview

- Participant Summary
- Grid Convergence Study: Case 1
- Drag Polar: Case 2
- Tripped vs. Fully Turbulent: Case 3
- Drag Rise: Case 4
- Conclusions

Participant Summary

- 22 participants + many others (1st DPW: 18)

US 50%	Gov't 31%
Europe 29%	Industry 46%
Asia 21%	Academia 21%

- 20 codes, 30 data submittals

Grid Types	Turbulence Models
14 1-to-1 structured	16 Spalart-Allmaras
11 Unstructured	5 Menter's SST
5 Overset	3 k-□
	2 k-Wilcox, k-□, other

Participant Summary (cont.)

30 data submittals

- 16 complete sets for Case 1
- 30 *partial* data sets for Case 2
- 7 data sets for Case 3
- 3 data sets for Case 4

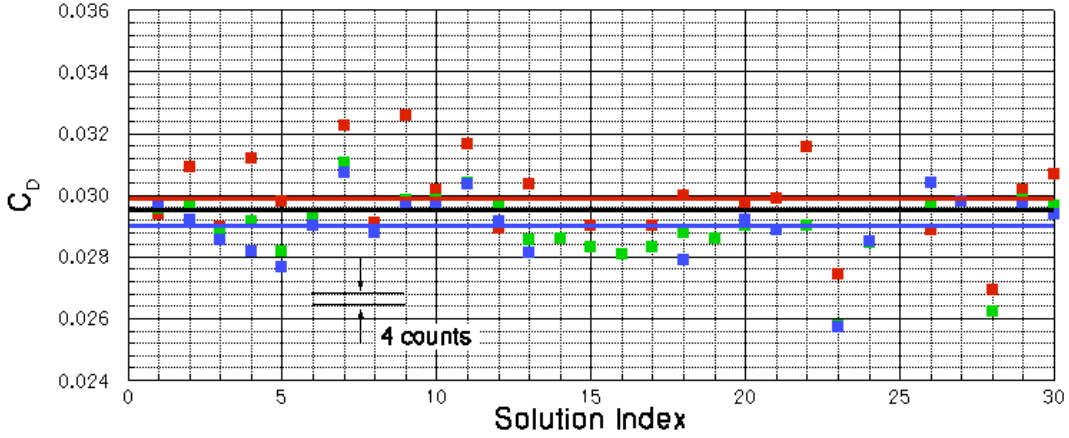
~ 480 Total Solutions Computed!

~ 1.25 years of CPU time!!!

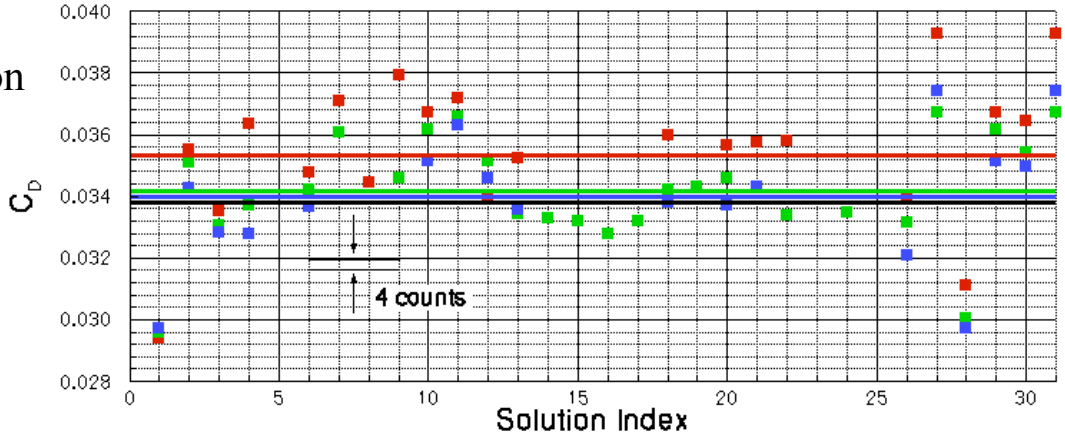
Single Point Grid Convergence Study

Mach = 0.75, Re = 3×10^6, $C_L = 0.500 \pm .001$

wing/body



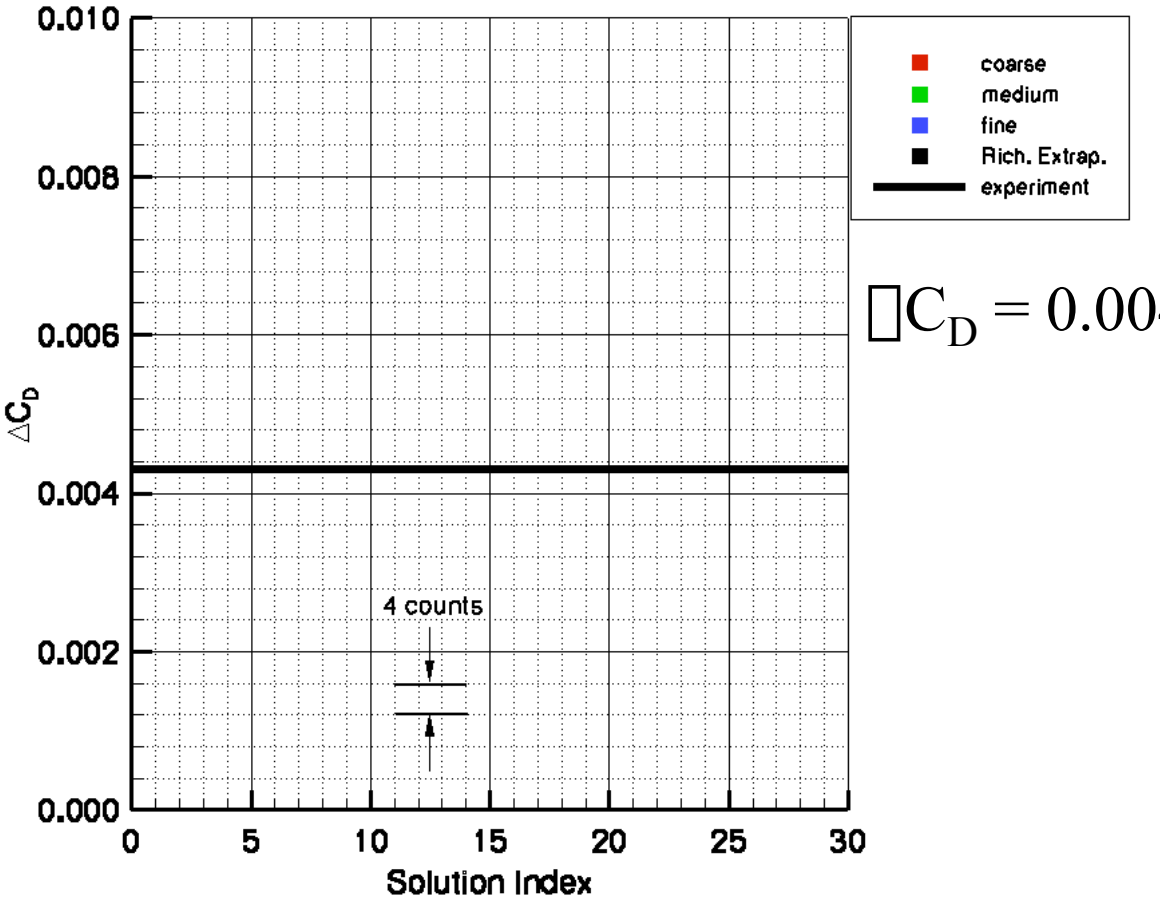
wing/body
+ nacelle/pylon



Grid Size
- coarse
- medium
- fine
- experiment
- ave. coarse
- ave. medium
- ave. fine

Case 1

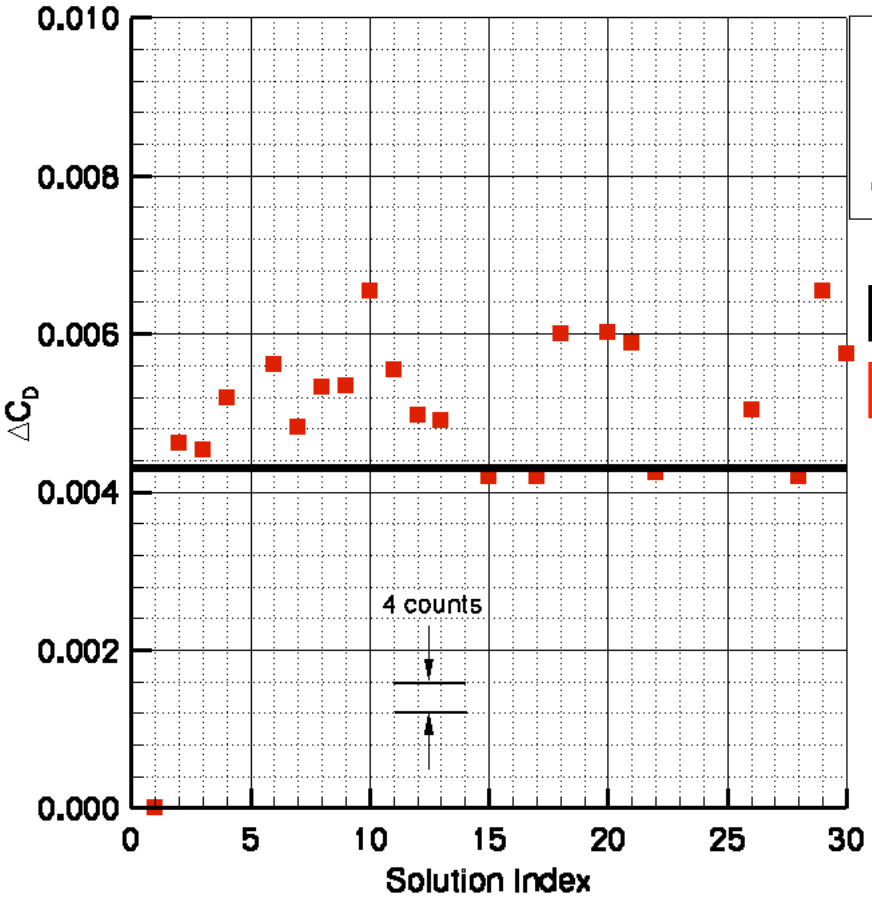
Experimental
Delta Drag



$\Delta C_D = 0.0043$

Case 1

Coarse Grid
Delta Drag

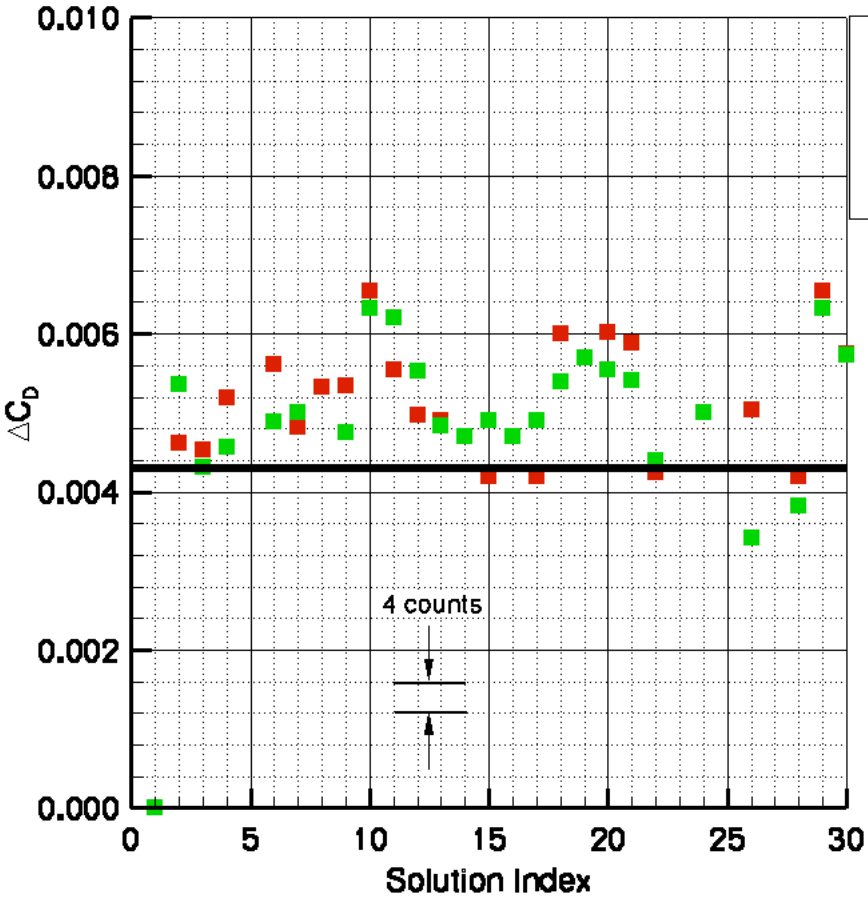


$\Delta C_D = 0.00433$

$\Delta C_D = 0.00538$

Case 1

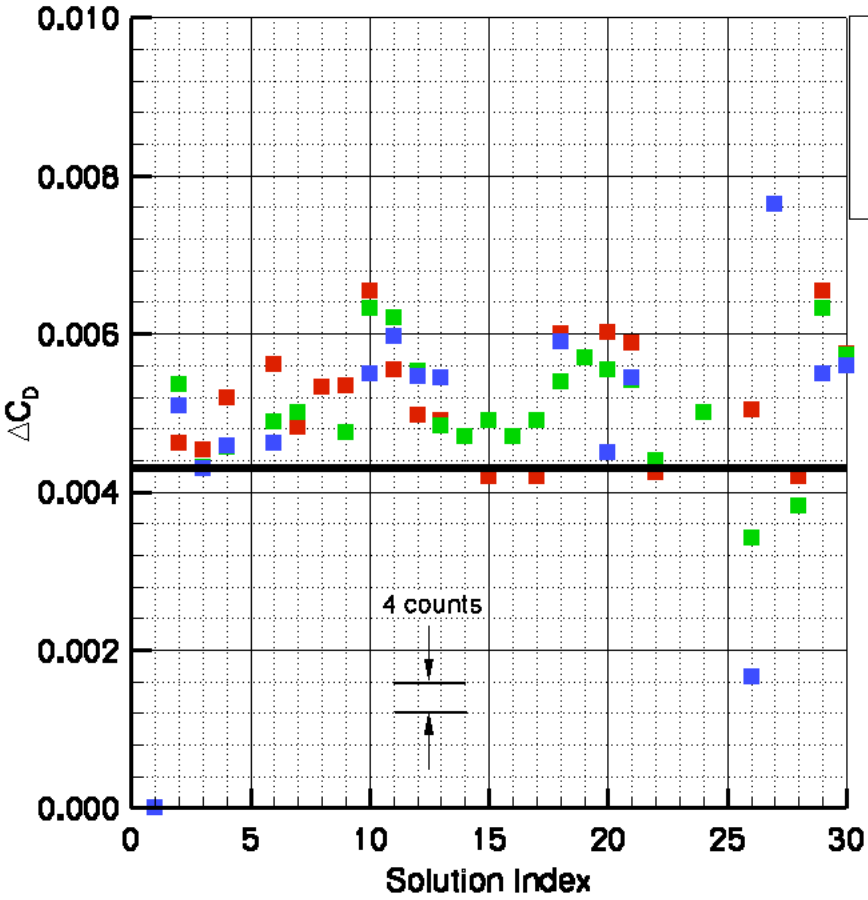
Medium Grid
Delta Drag



$\Delta C_D = 0.00433$
$\Delta C_D = 0.00538$
$\Delta C_D = 0.00515$

Case 1

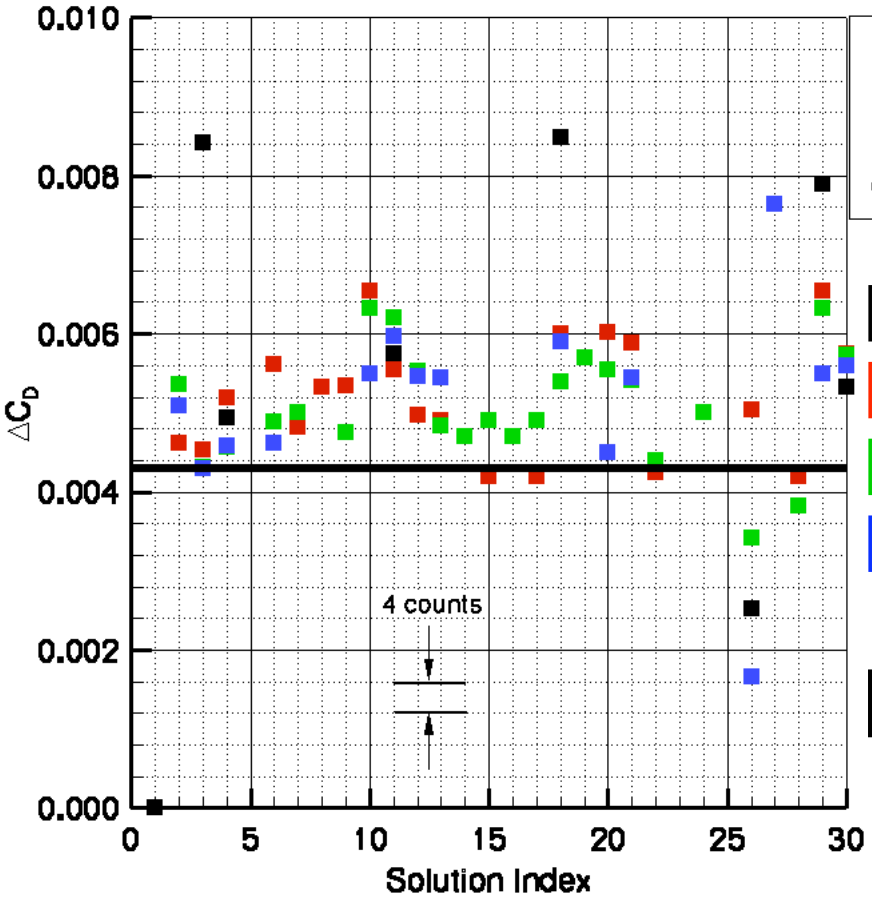
Fine Grid
Delta Drag



$\Delta C_D = 0.00433$
$\Delta C_D = 0.00538$
$\Delta C_D = 0.00515$
$\Delta C_D = 0.00513$

Case 1

Extrapolated
Delta Drag



$\Delta C_D = 0.00433$

$\Delta C_D = 0.00538$

$\Delta C_D = 0.00515$

$\Delta C_D = 0.00513$

$\Delta C_D = \underline{0.00619}$!?!

Case 1

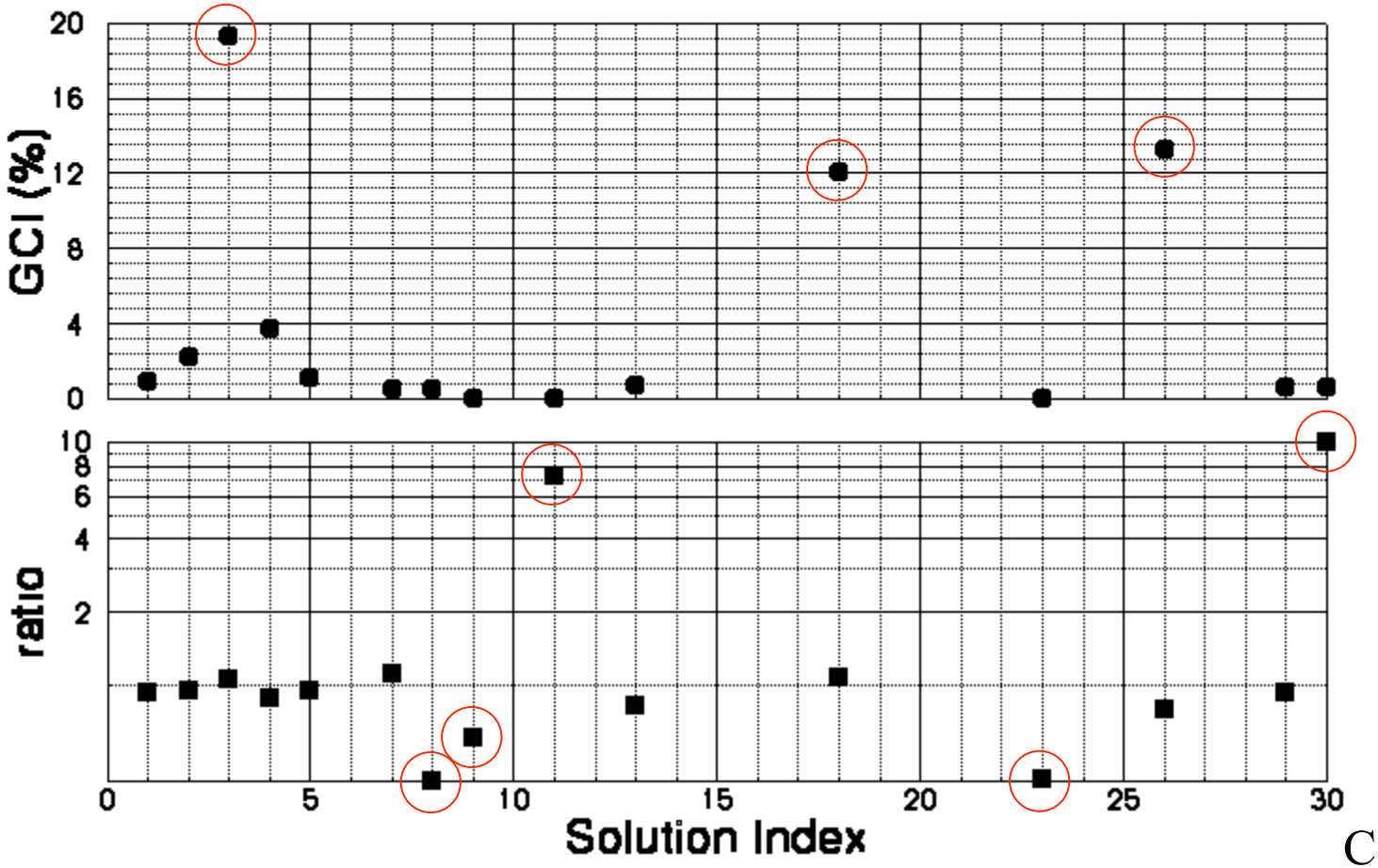
Why did Richardson Extrapolation fail?

Case 1

Cessna
A Textron Company

Richardson Extrapolation

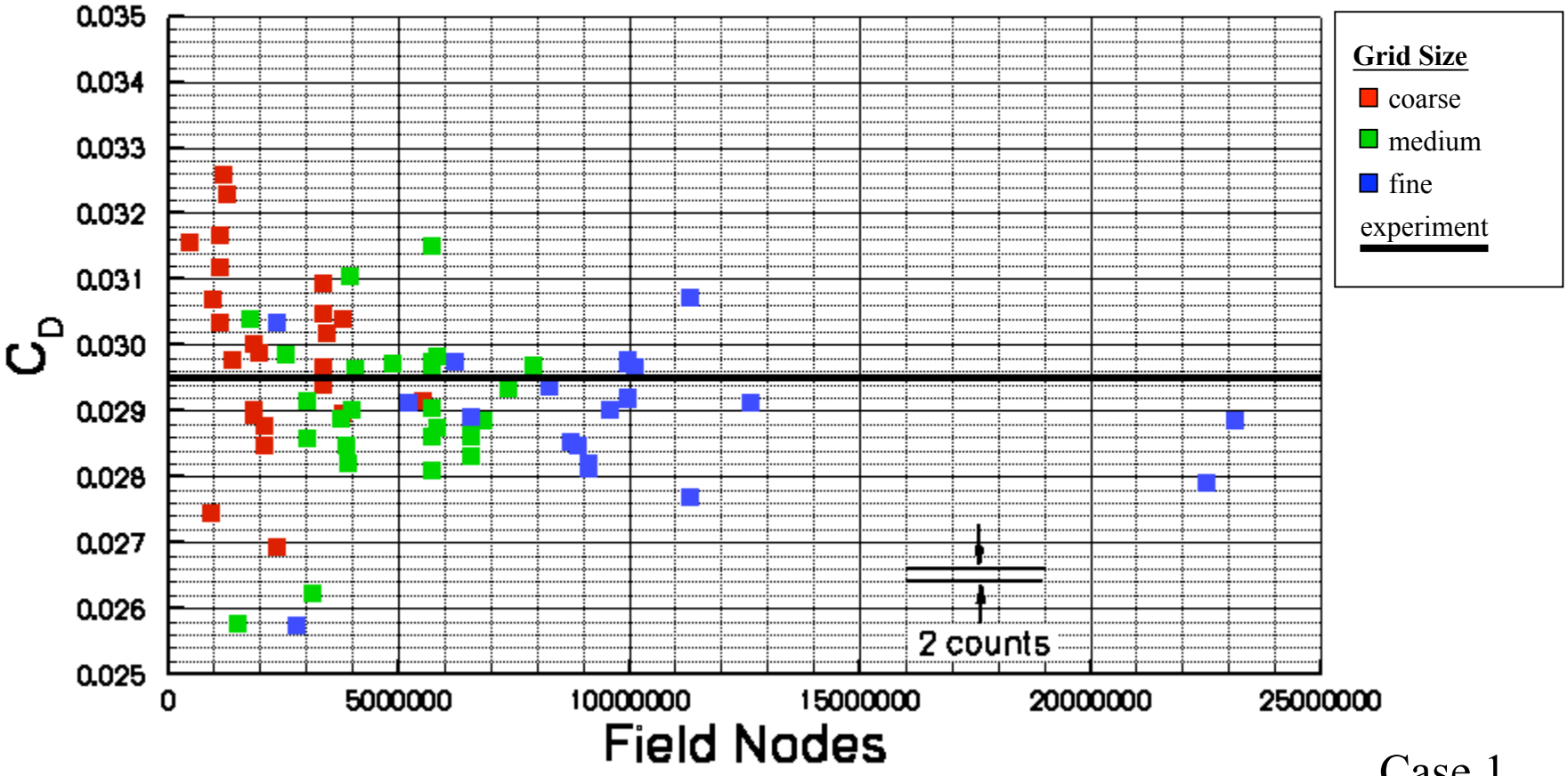
wing/body



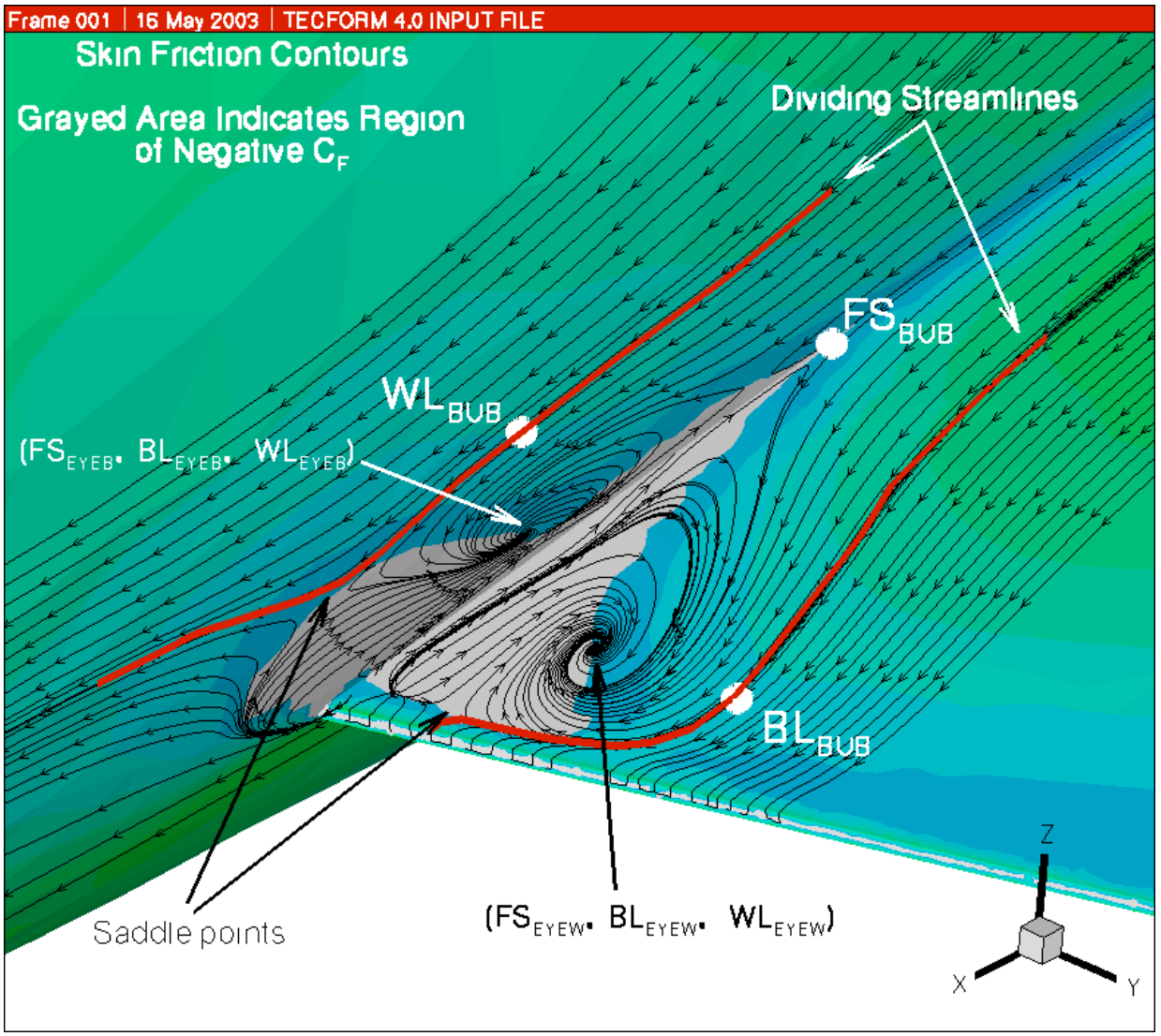
Case 1

Drag vs. Grid Size

wing/body

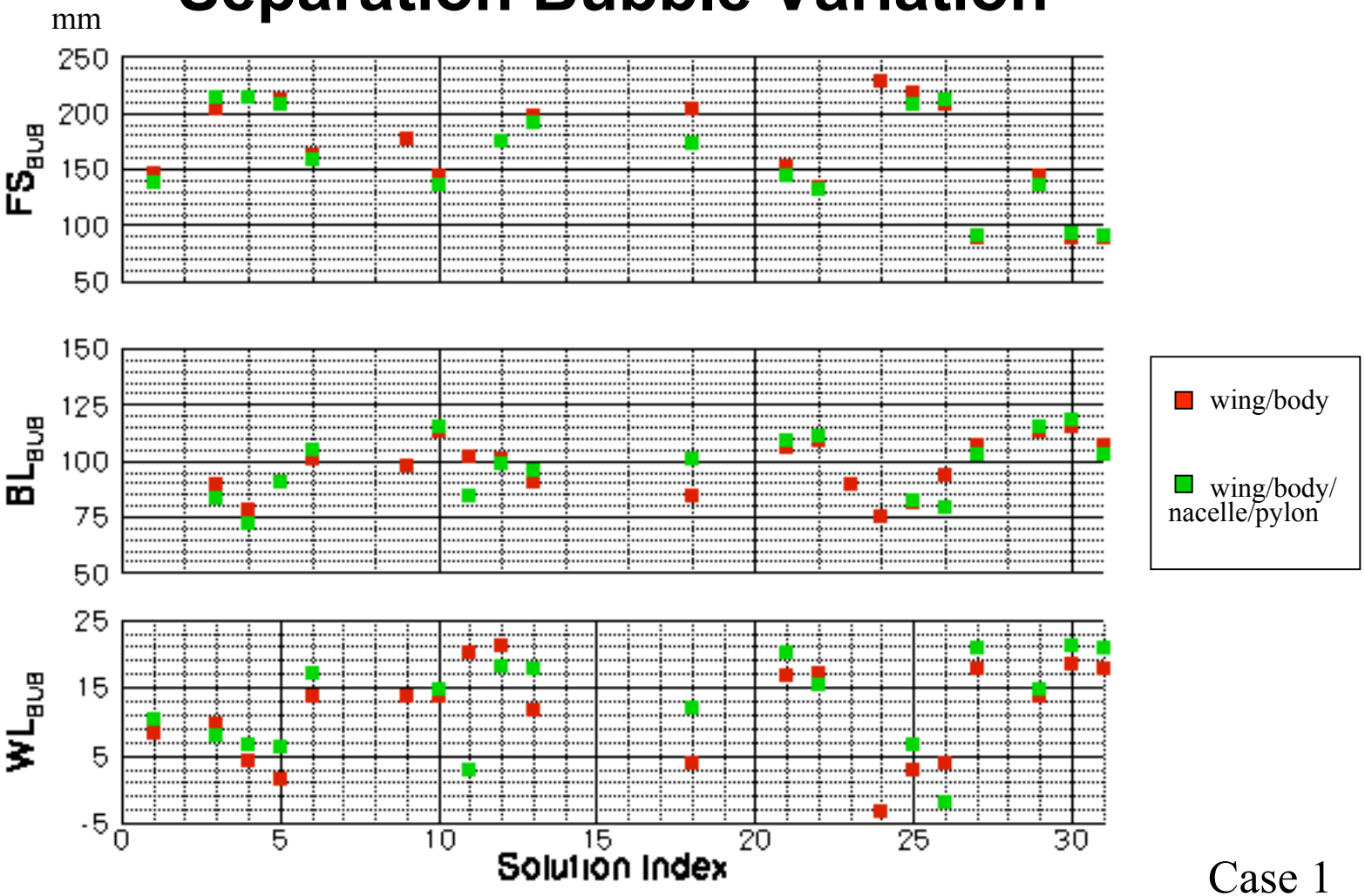


Case 1


Frame 001 | 16 May 2003 | TECFORM 4.0 INPUT FILE
Skin Friction Contours
Grayed Area Indicates Region of Negative C_F
Dividing Streamlines
FS_{BUB}
WL_{BUB}
$(FS_{EYEB}, BL_{EYEB}, WL_{EYEB})$
BL_{BUB}
Saddle points
$(FS_{EYEW}, BL_{EYEW}, WL_{EYEW})$
Z
X
Y

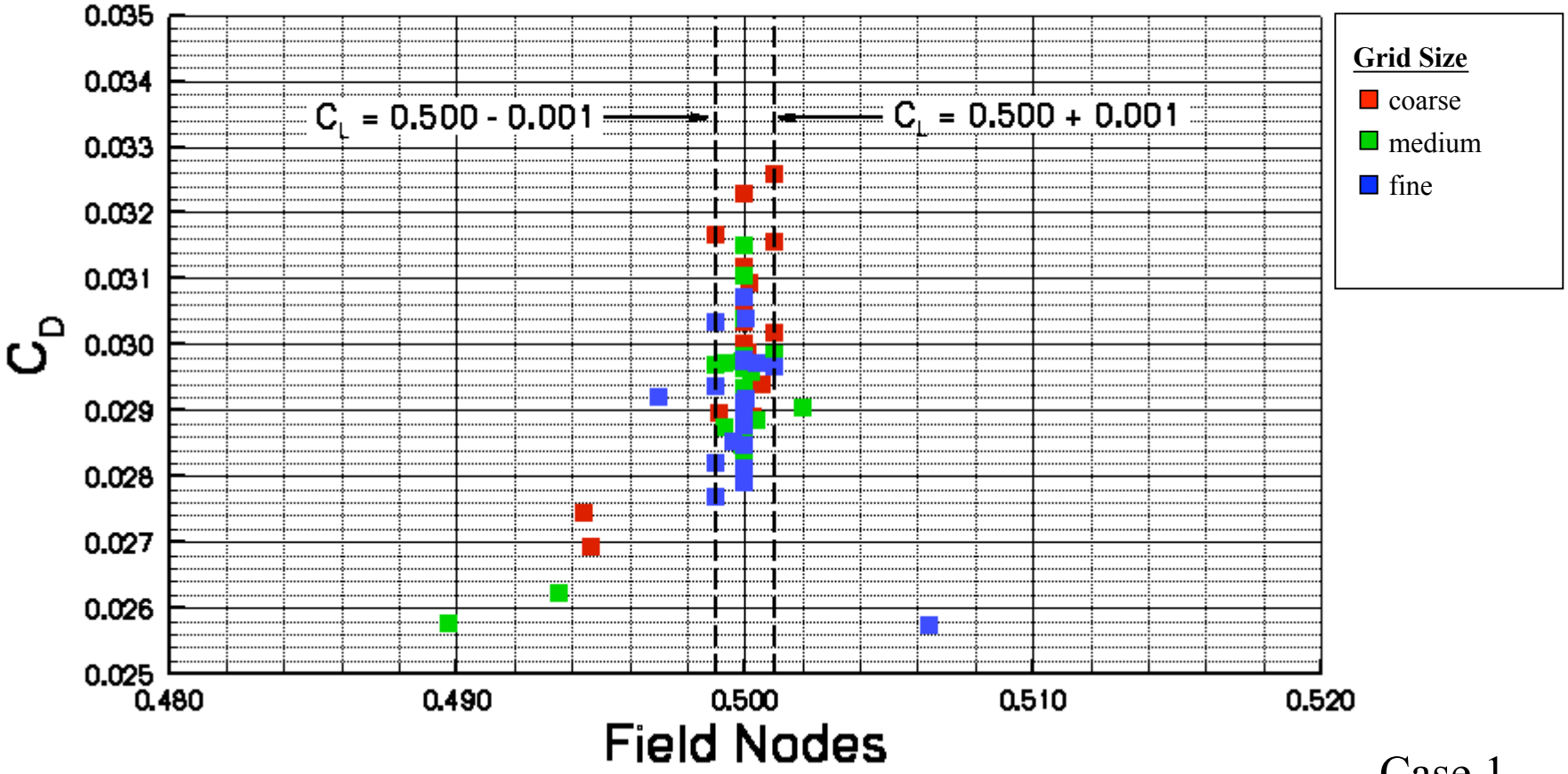
Case 1

Separation Bubble Variation



Case 1

C_L Tolerance
wing/body



Case 1

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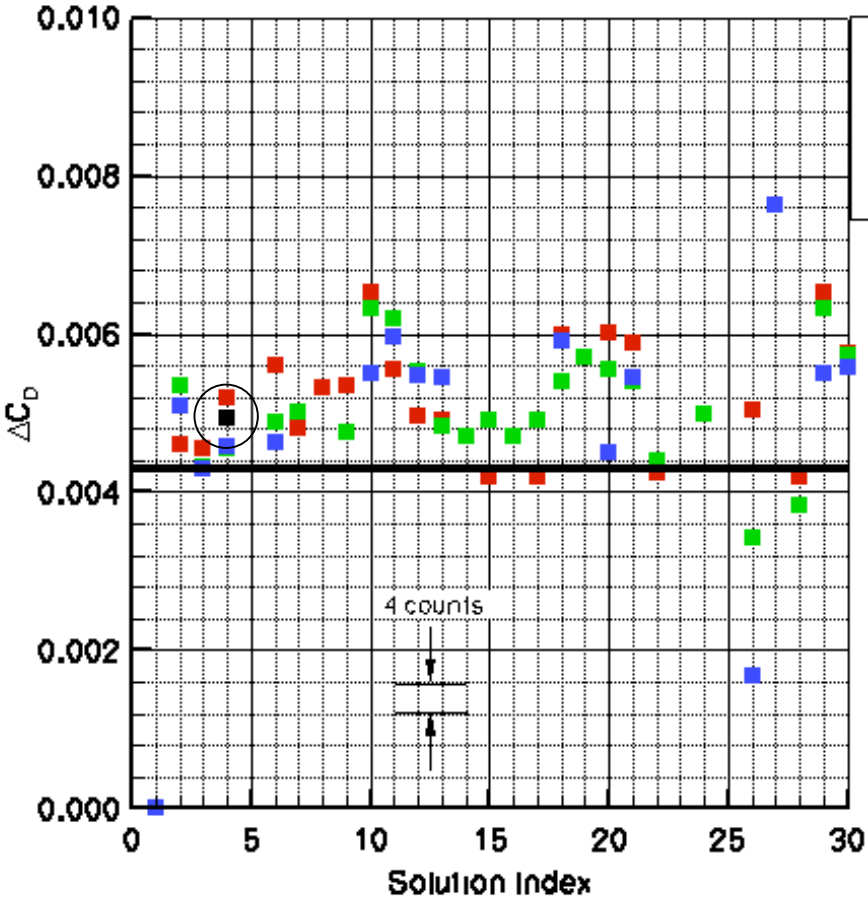
- Drag not converged
- C_L tolerance not met
- Low precision report of drag
- Participant reporting errors

Case 1

Extrapolated Delta Drag Revisited



$\Delta C_D = 0.00433$

$\Delta C_D = 0.00538$

$\Delta C_D = 0.00515$

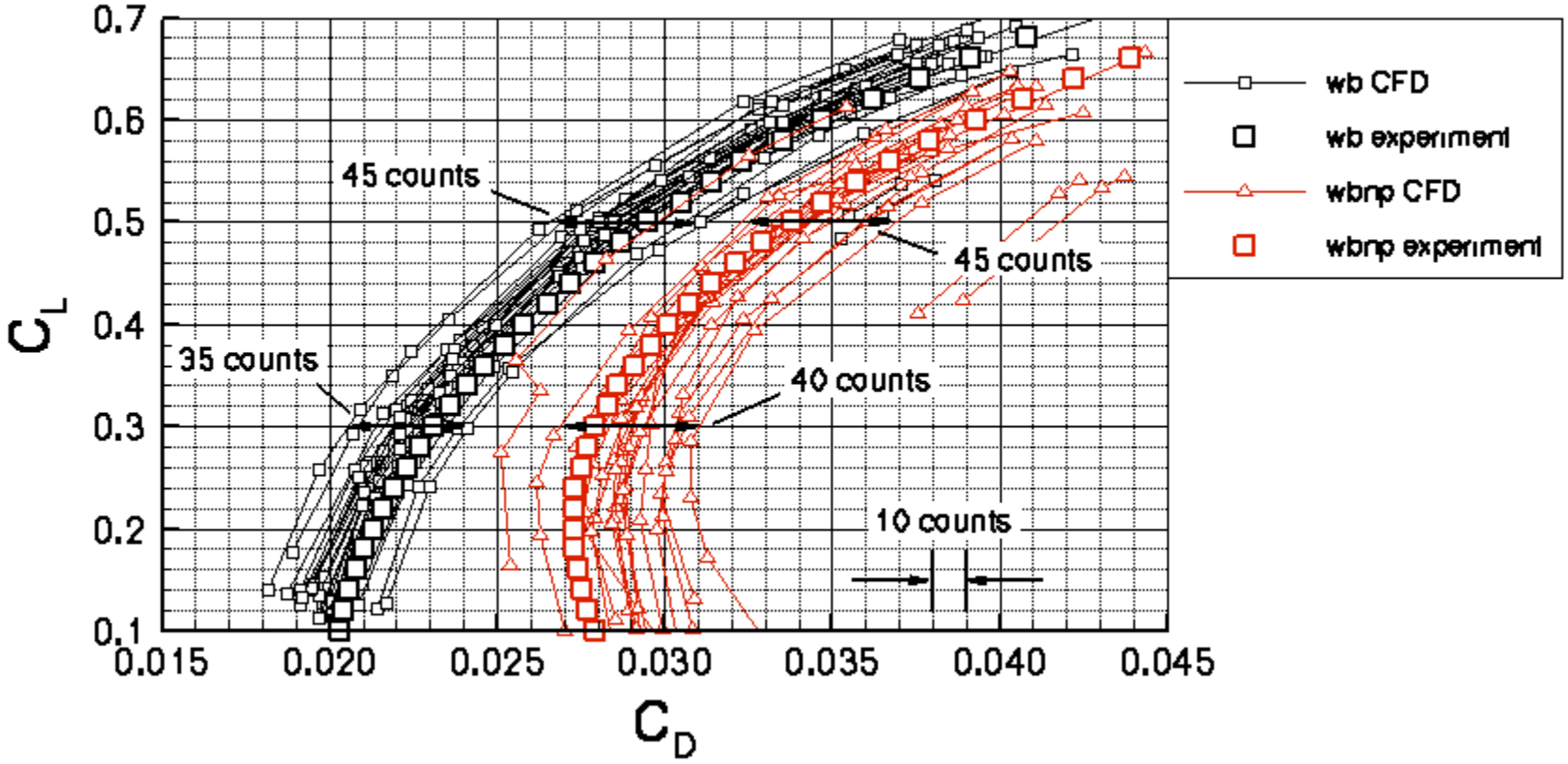
$\Delta C_D = 0.00513$

$\Delta C_D = 0.00494$

Case 1

Drag Polar

Mach = 0.75, Re = 3×10^6

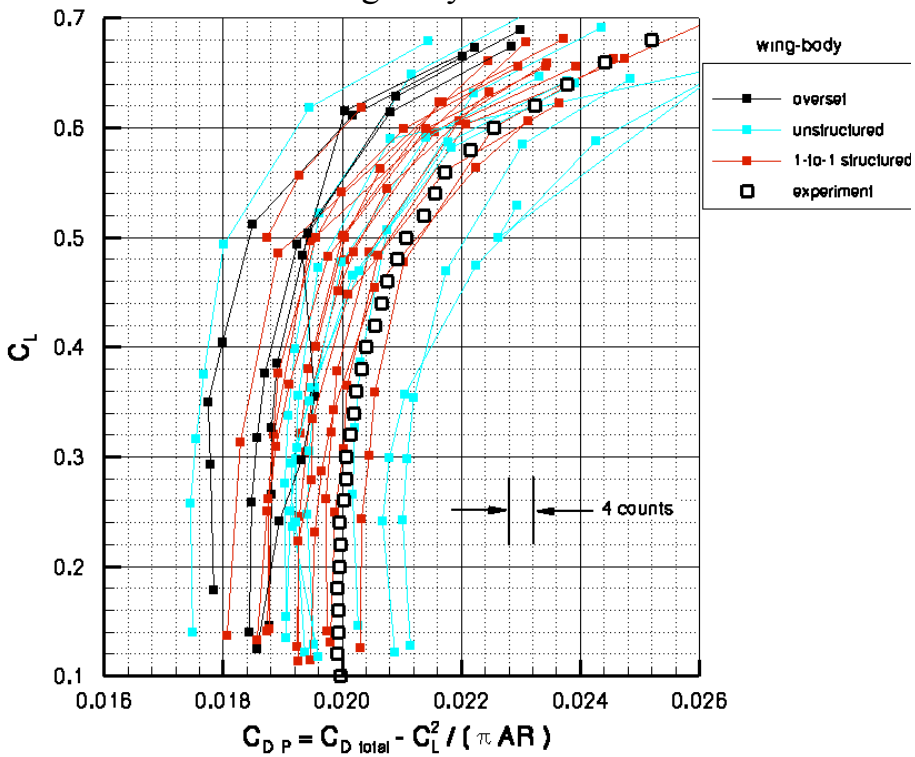


Case 2

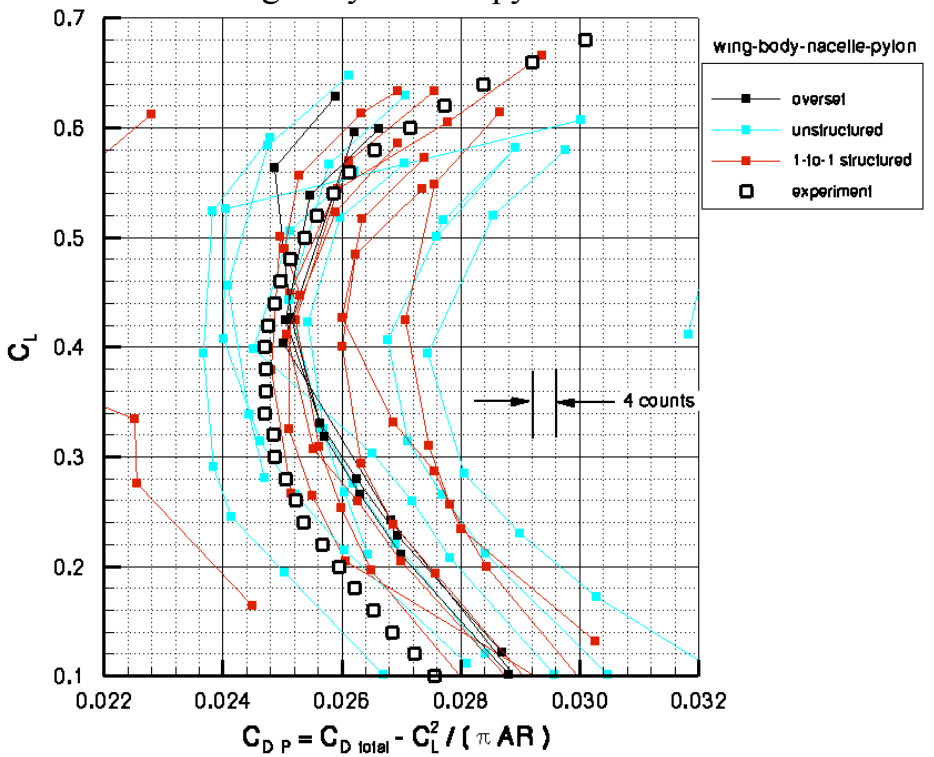
Grid Type

Idealized Profile Drag

wing/body



wing/body/nacelle/pylon

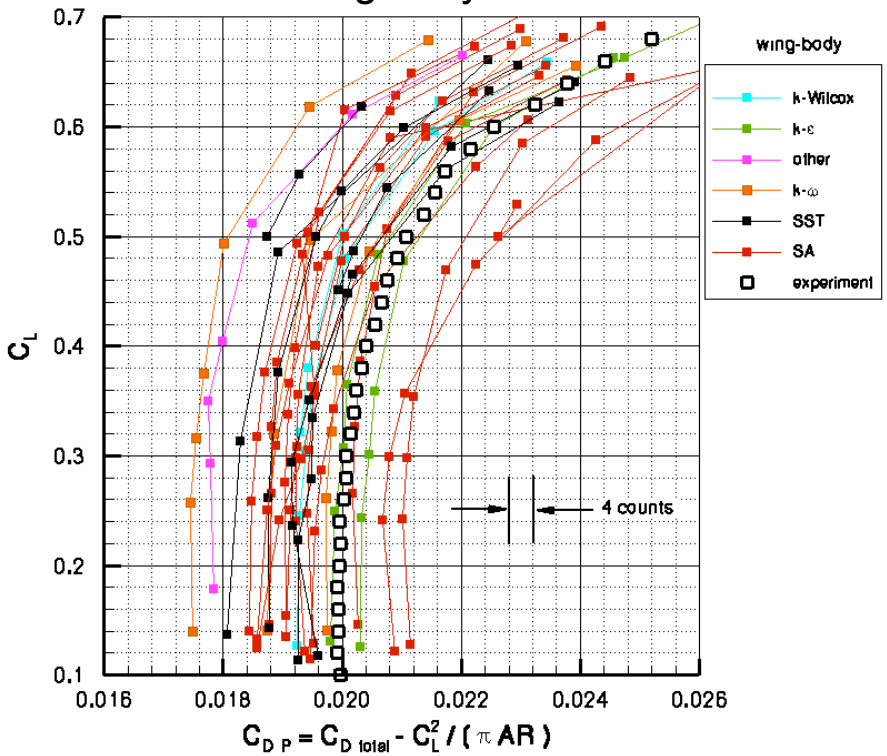


Case 2

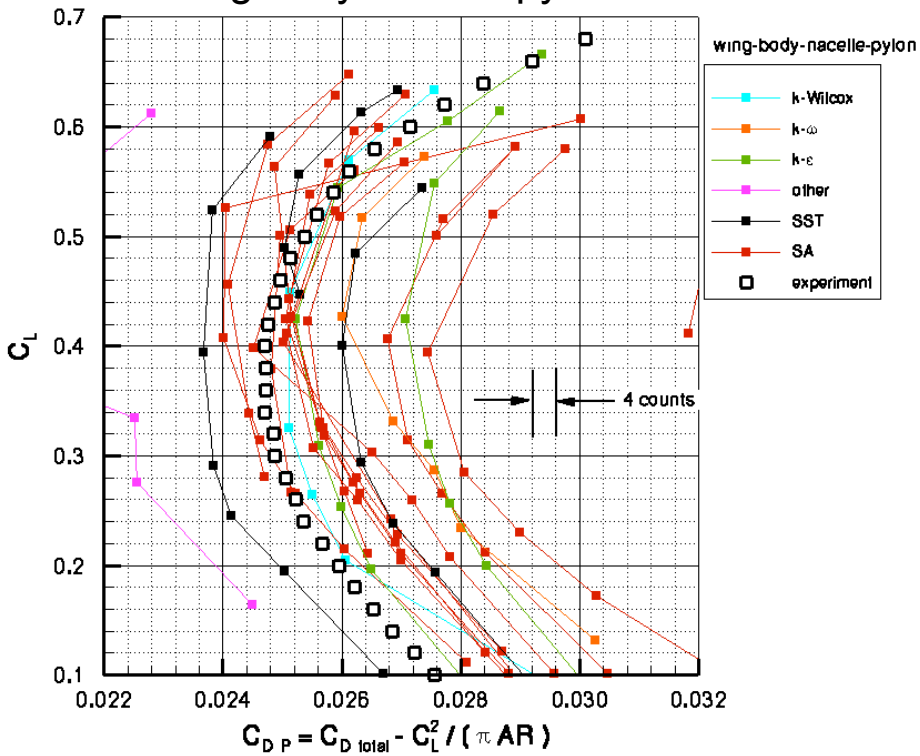
Turbulence Models

Idealized Profile Drag

wing/body



wing/body/nacelle/pylon

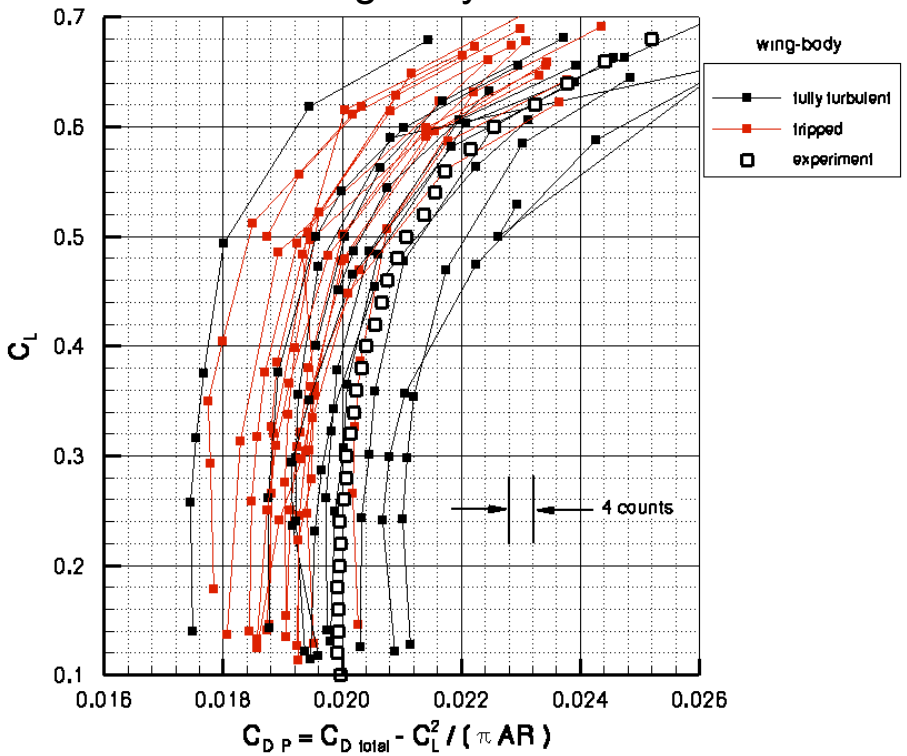


Case 2

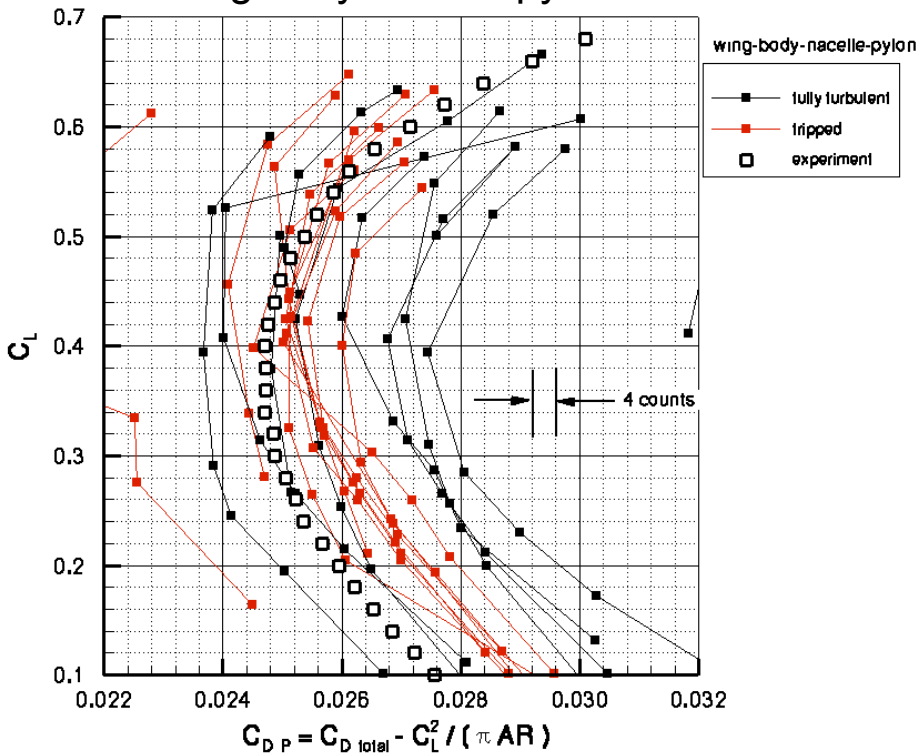
Tripped vs. Fully Turbulent

Idealized Profile Drag

wing/body



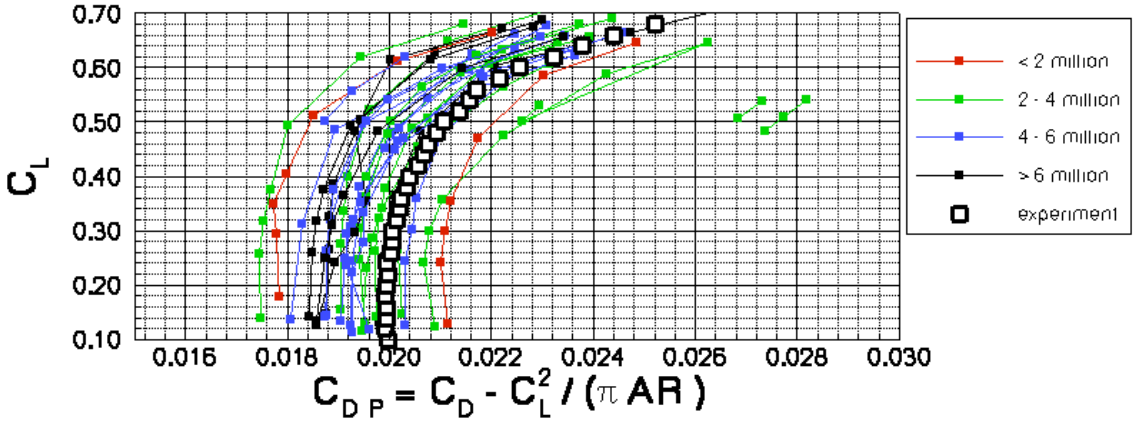
wing/body/nacelle/pylon

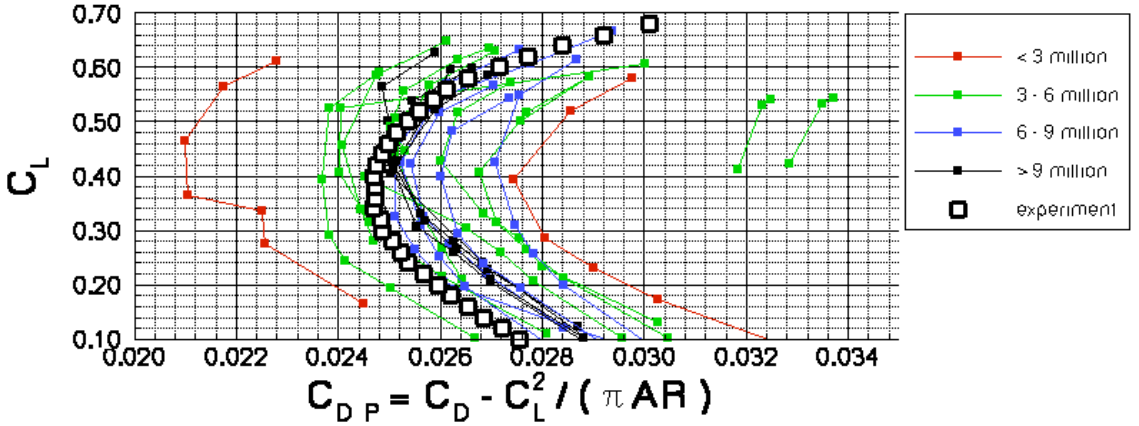


Case 2

Grid Size

Idealized Profile Drag

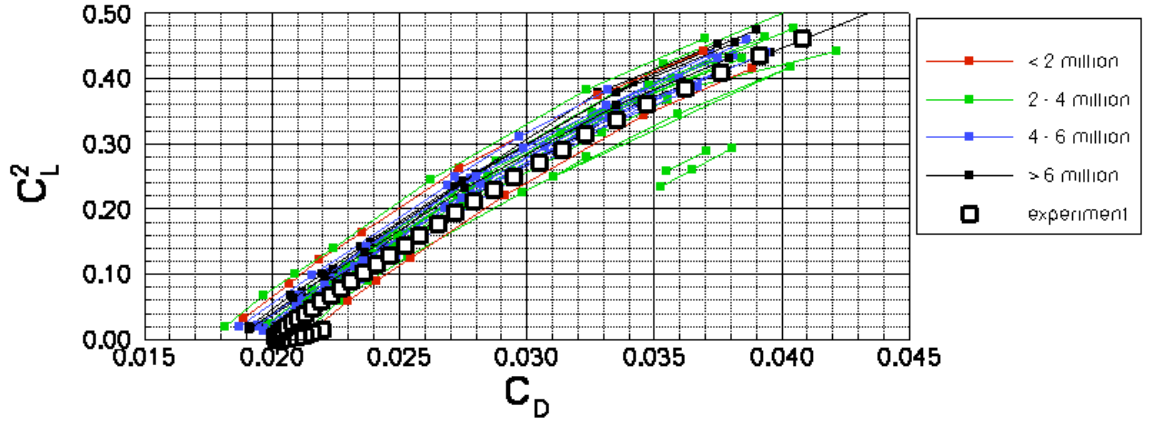


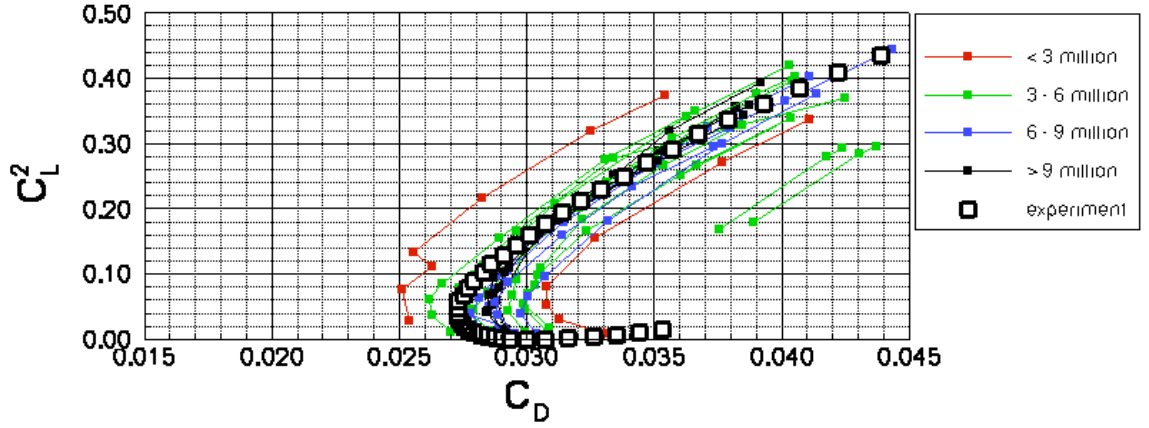


Case 2

Induced Drag

Grid Size

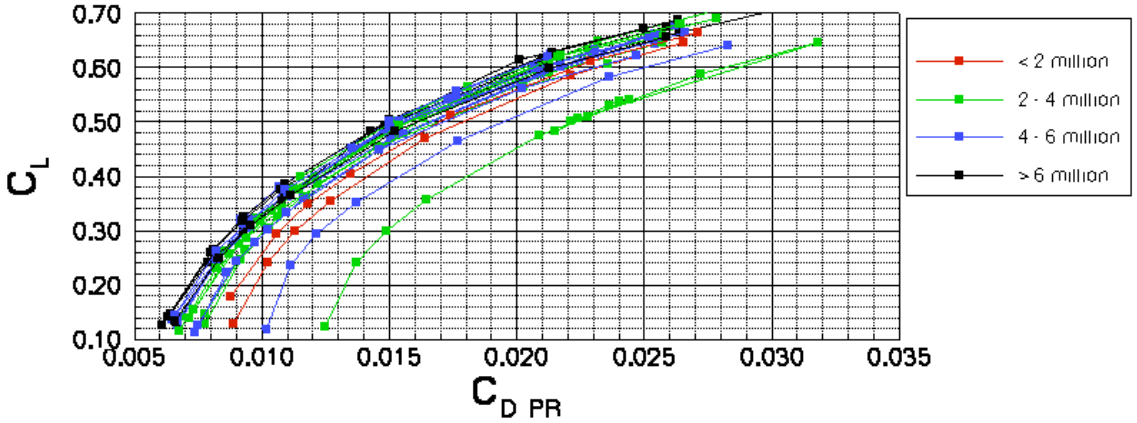


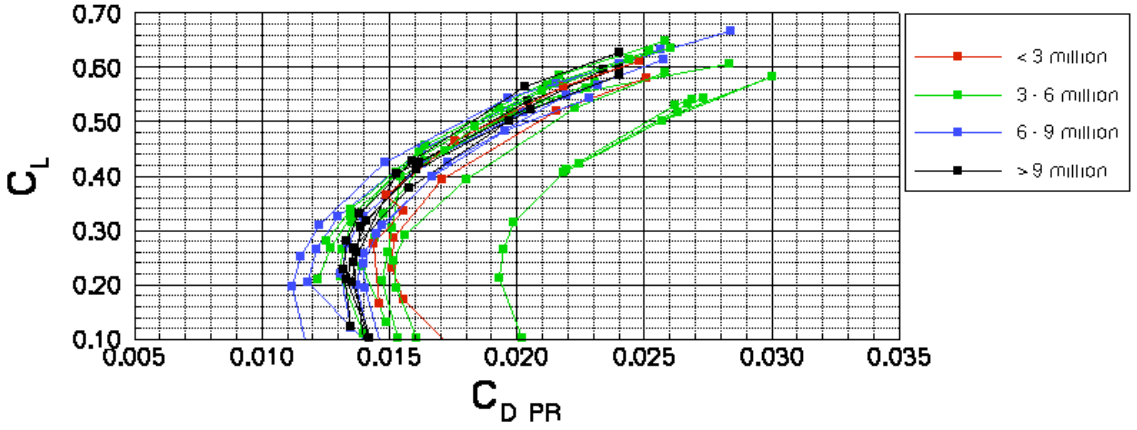


Case 2

Pressure Drag

Grid Size

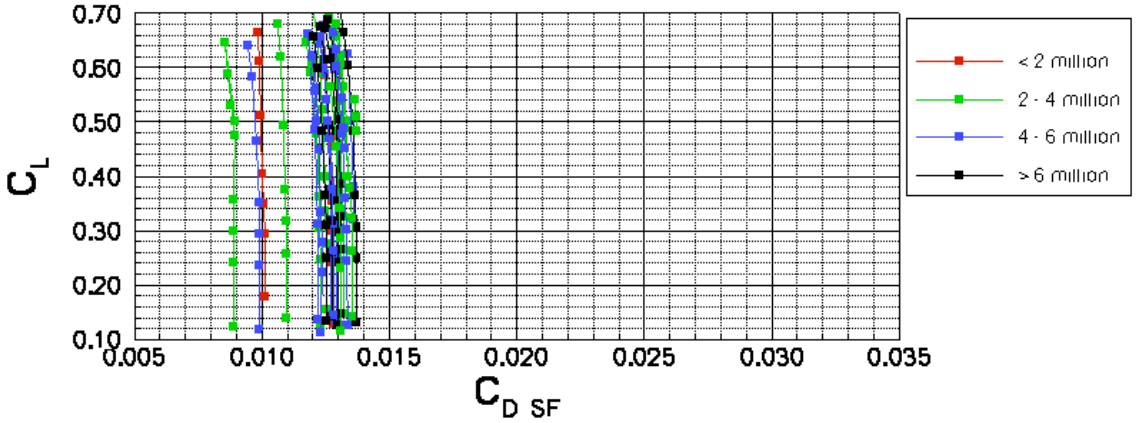


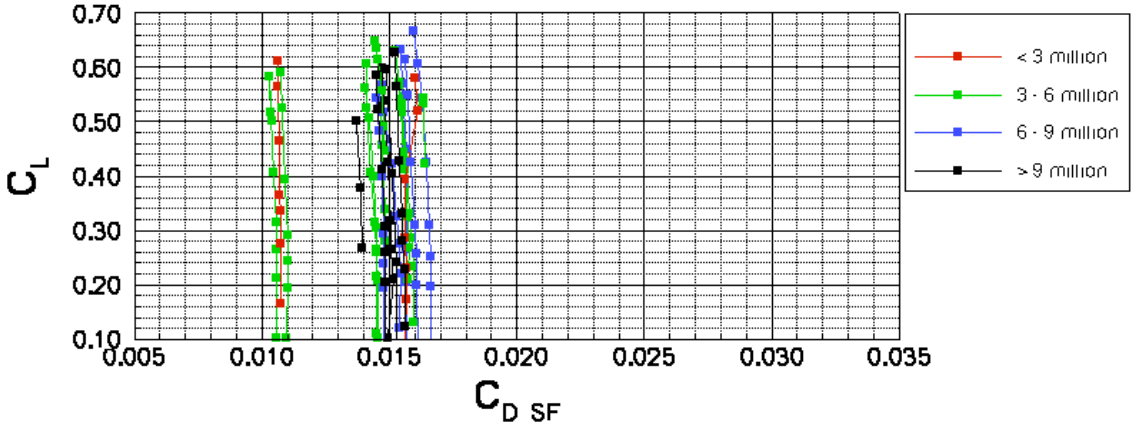


Case 2

Skin Friction Drag

Grid Size

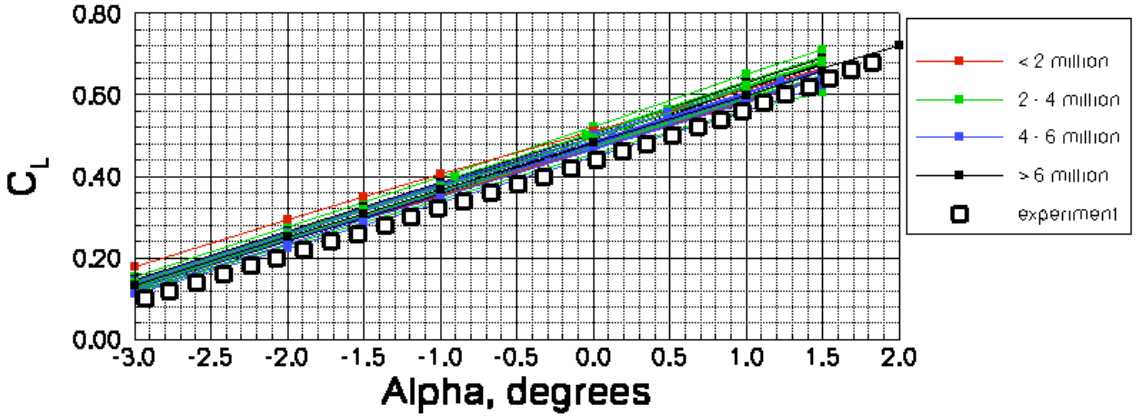


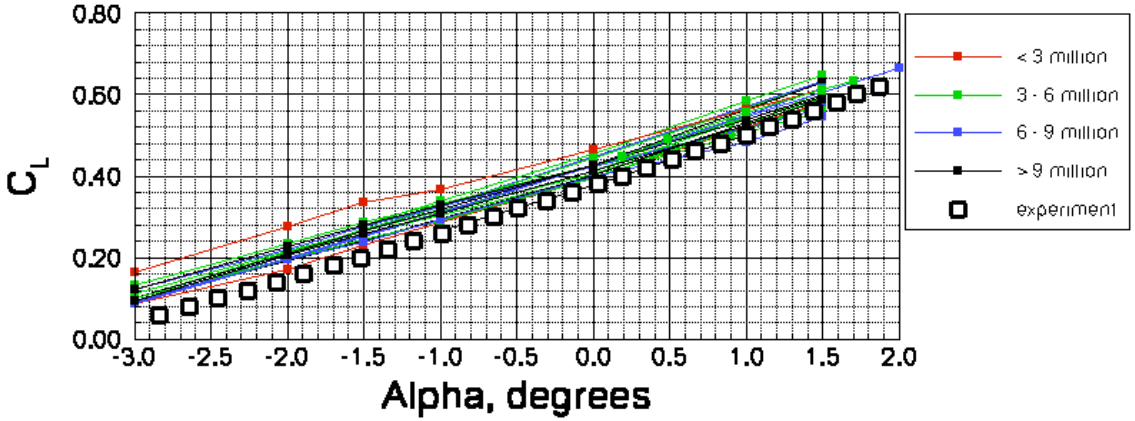


Case 2

Lift Curve

Grid Size

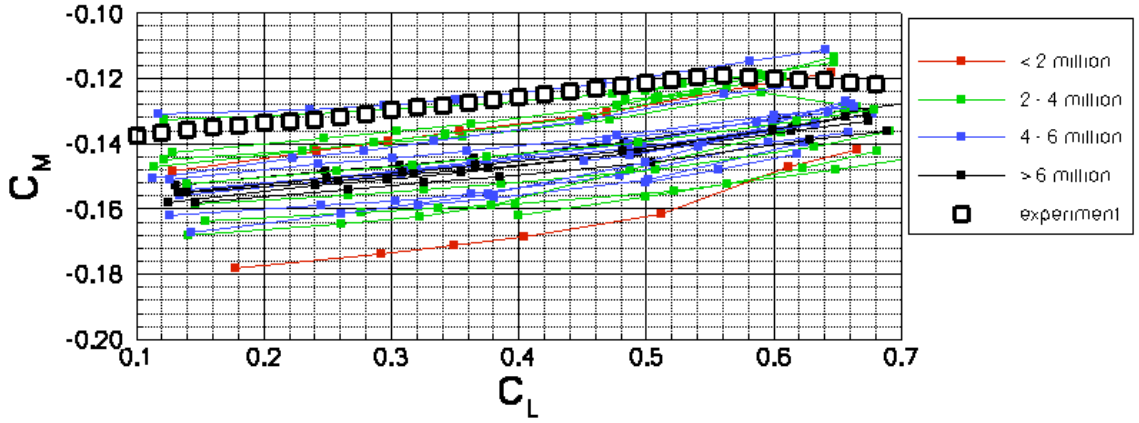


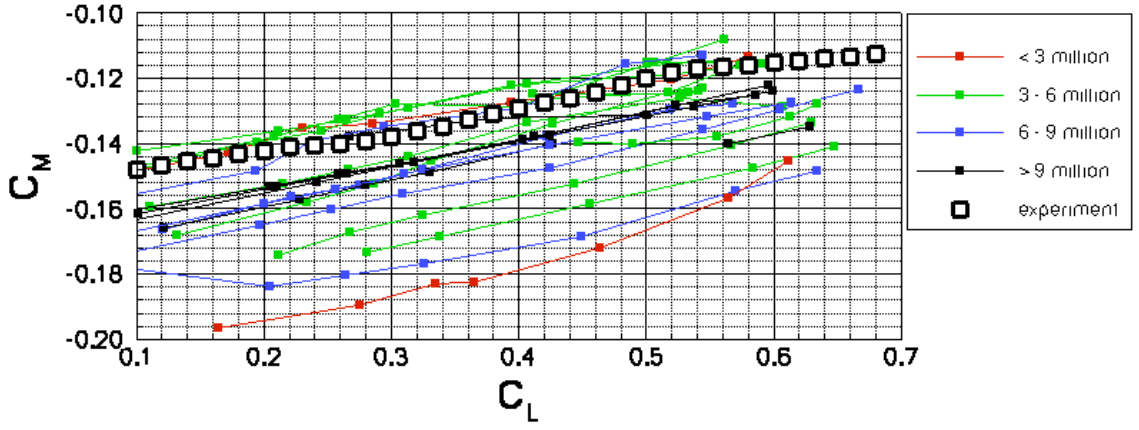


Case 2

Pitching Moment

Grid Size

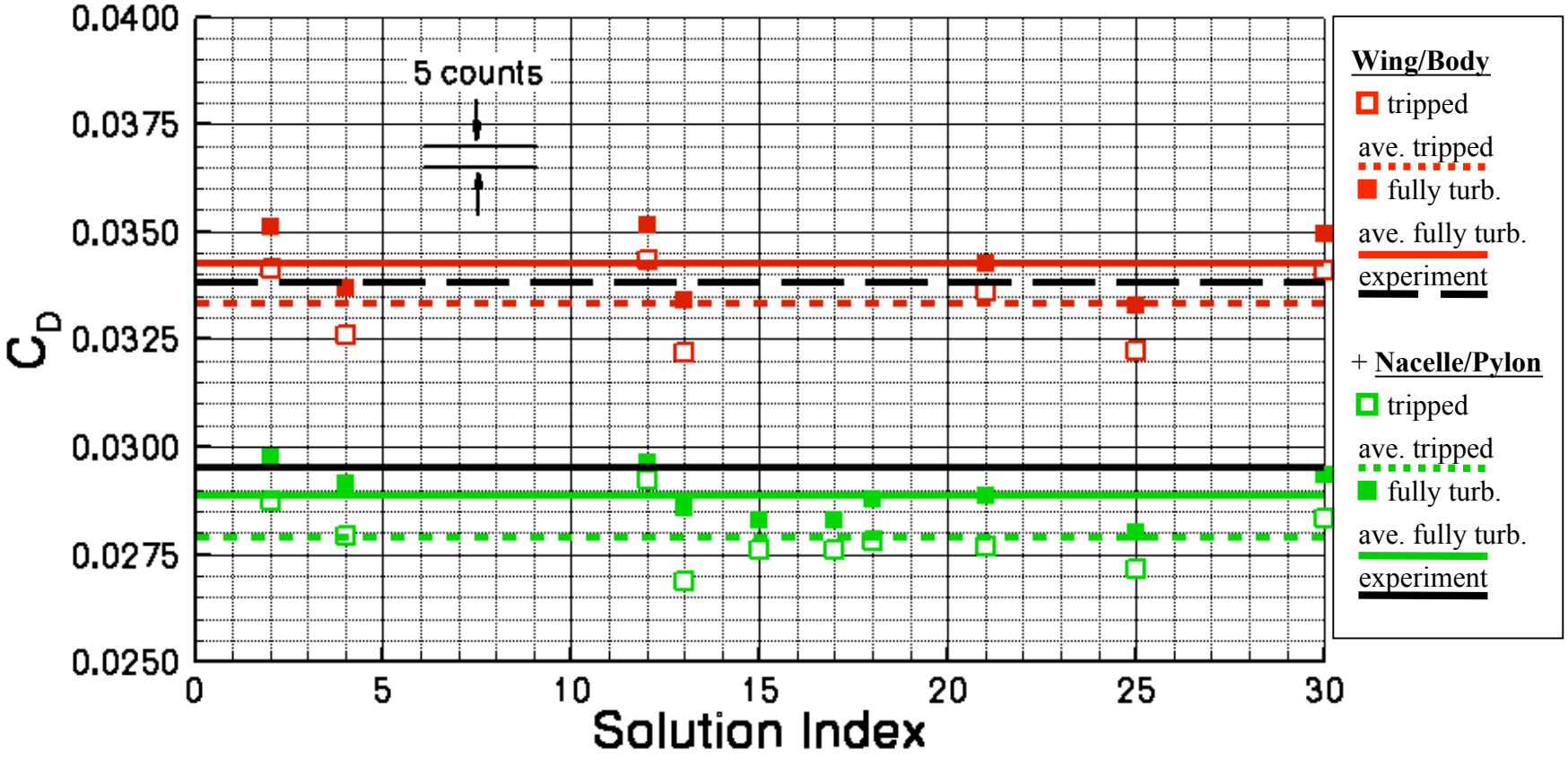




Case 2

Tripped vs. Fully Turbulent

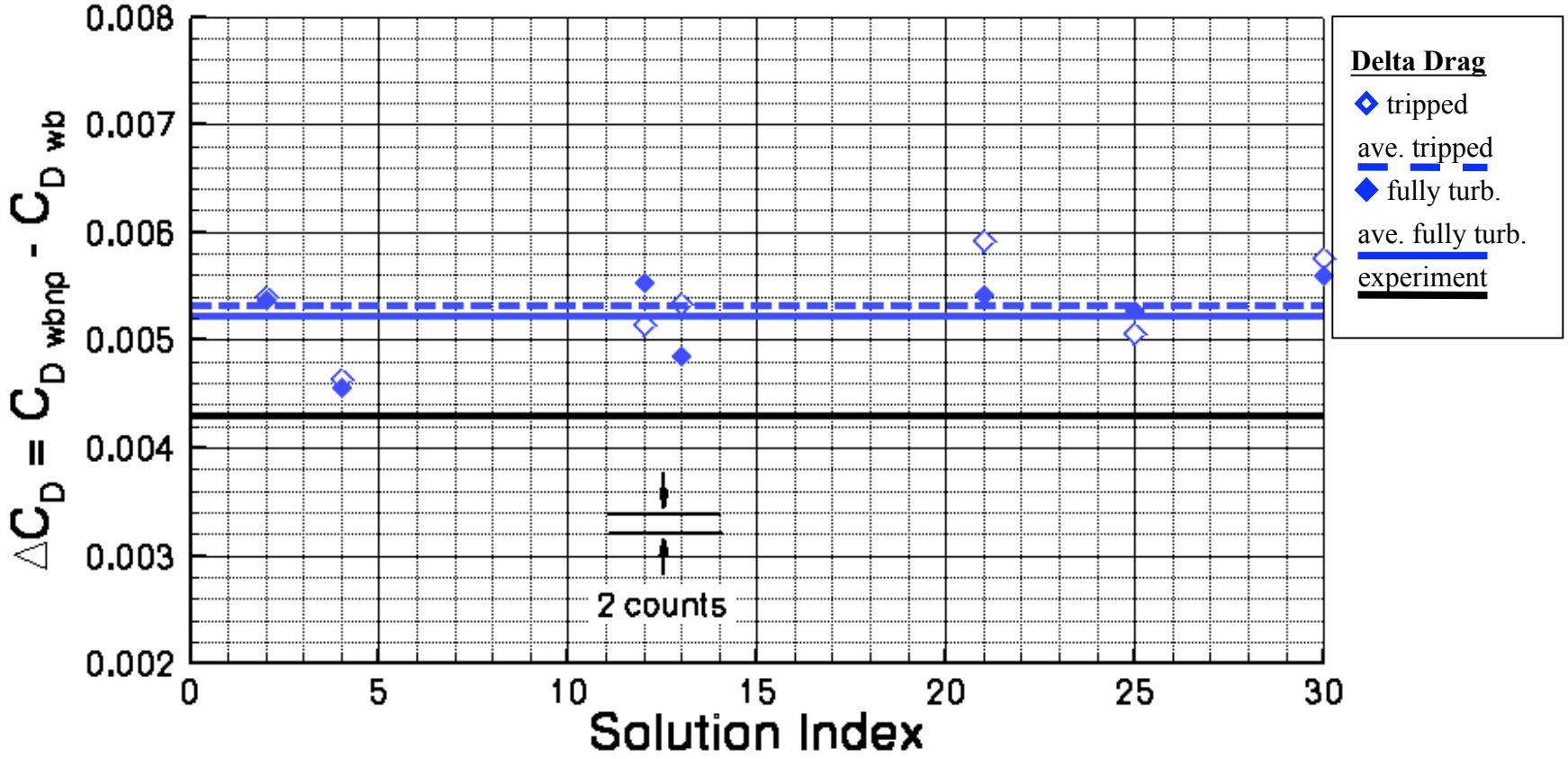
Mach = 0.75, Re = $3x10^6$, $C_L = 0.500 \pm .001$



Case 3

Tripped vs. Fully Turbulent

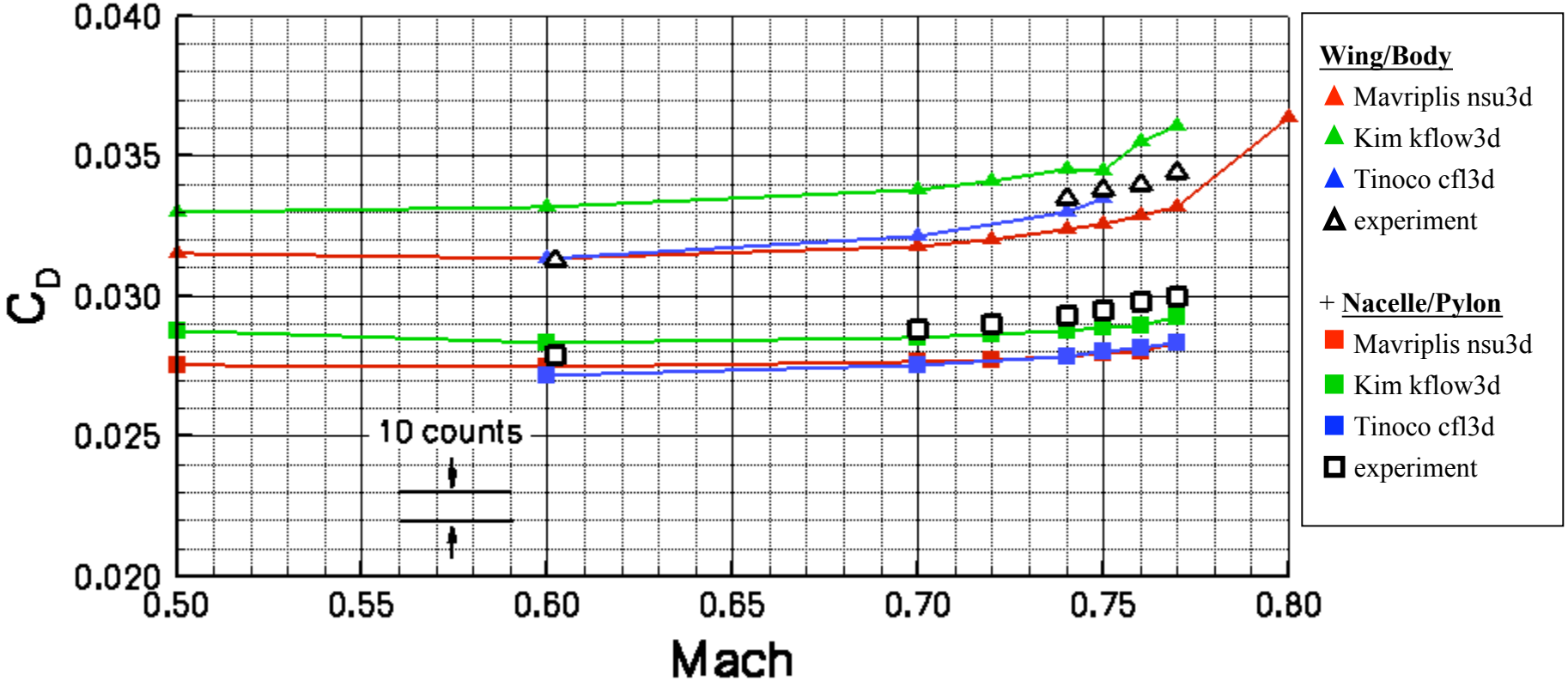
Delta Drag



Case 3

Drag Rise

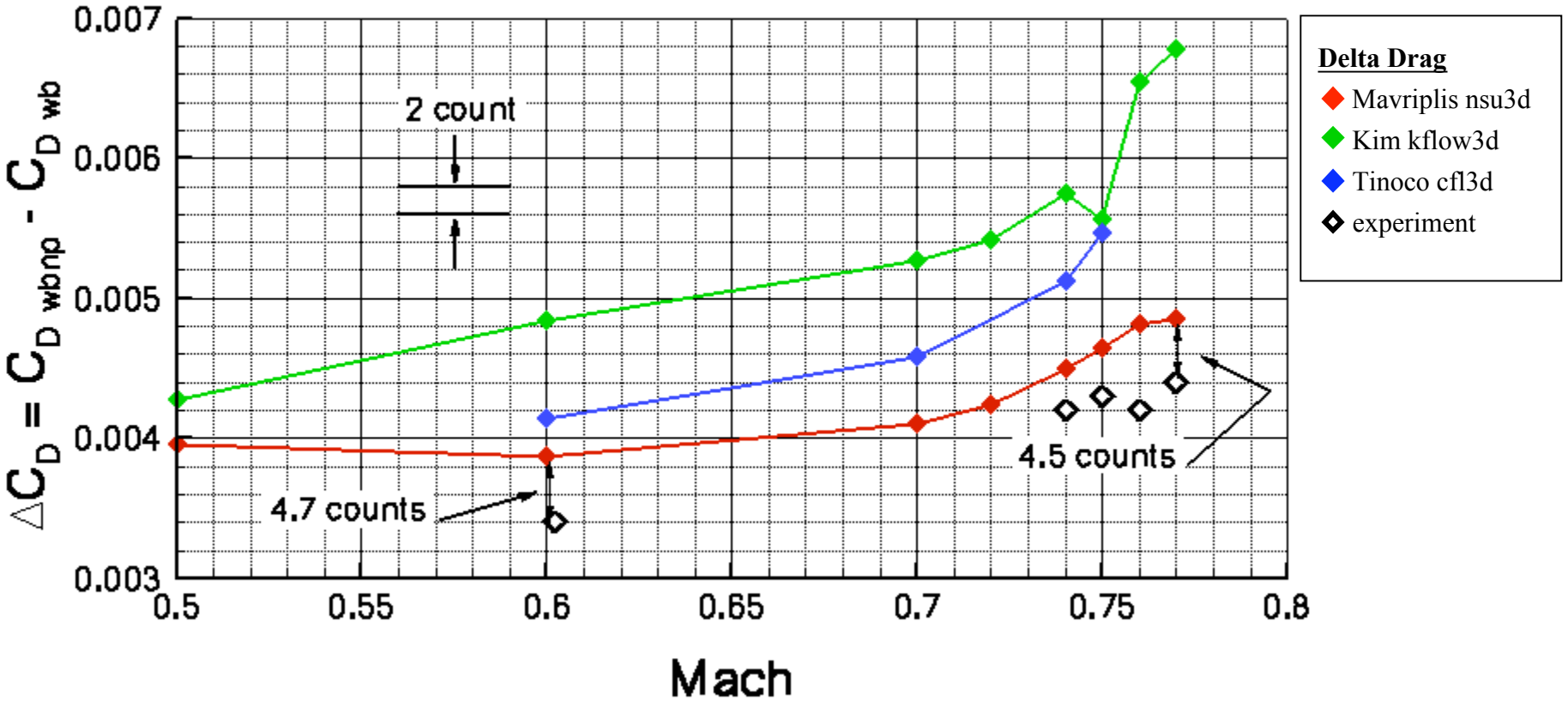
$Re = 3x10^6$, $C_L = 0.500 \pm .001$



Case 4

Drag Rise

Delta Drag



Case 4

Conclusions

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Conclusions

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- Fully turbulent calcs. okay for delta drag calculations.
- Grid resolution! Grid resolution! Grid resolution!
- More comprehensive summary at Reno 2004.

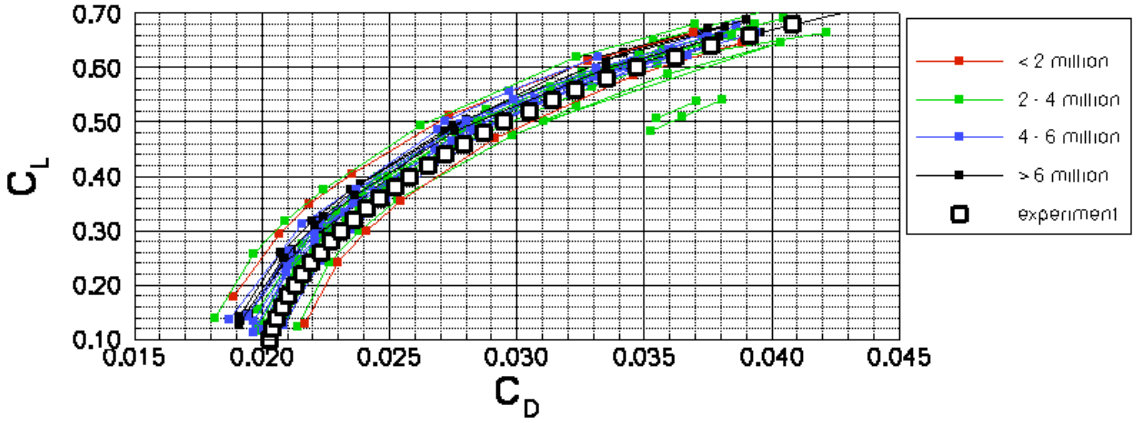
Requests

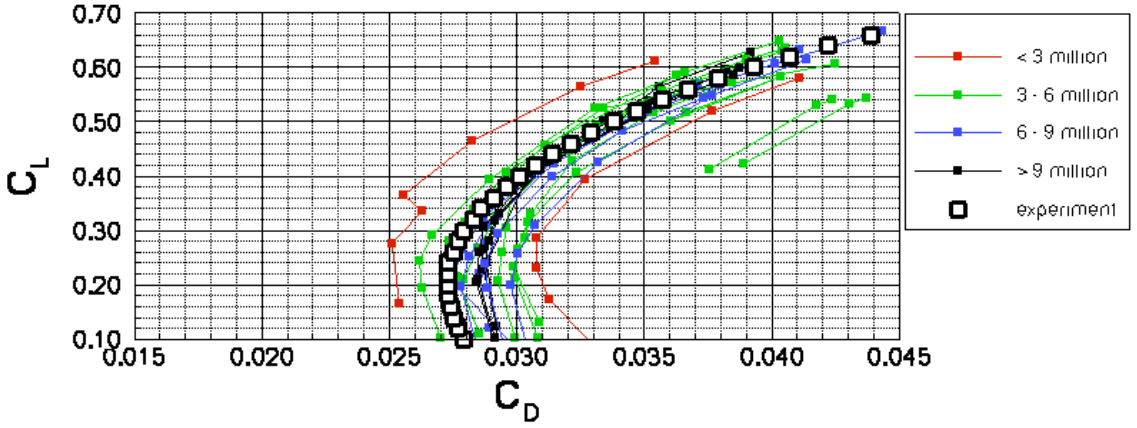
- Participants:
  - Complete/correct/recheck data and resubmit.
  - Report results to greater precision.
  - Indicate if code is node-based or cell-based.
  - Indicate if grid is supplied by DPW or otherwise.
- Need standard for reporting non- or slow-converging solutions. *Time ave. values, with max. delta reported?*

Thank You!

Drag Polar

Grid Size



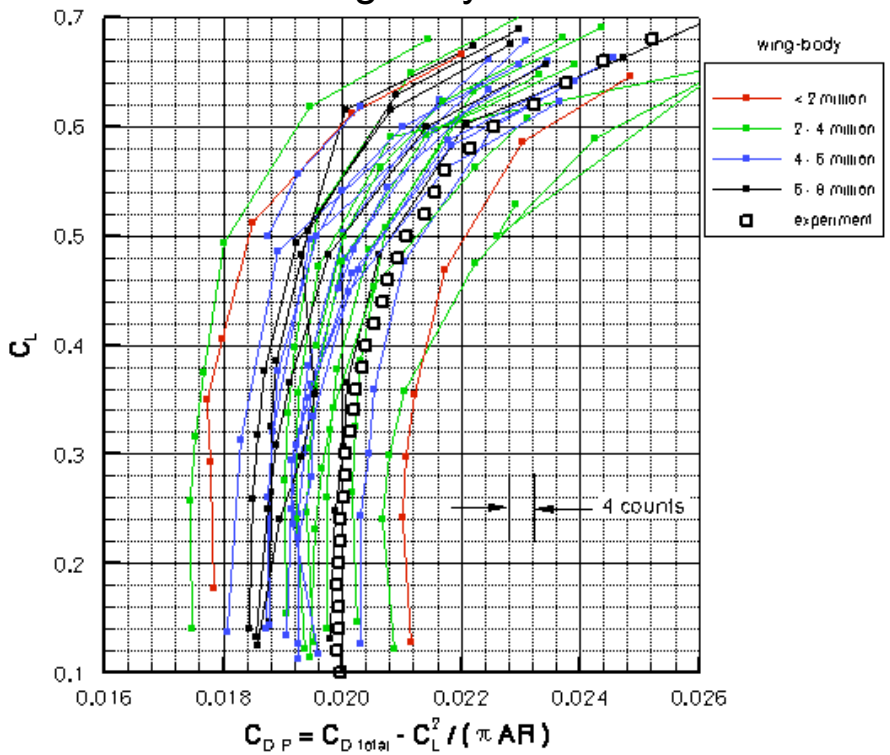


Case 2

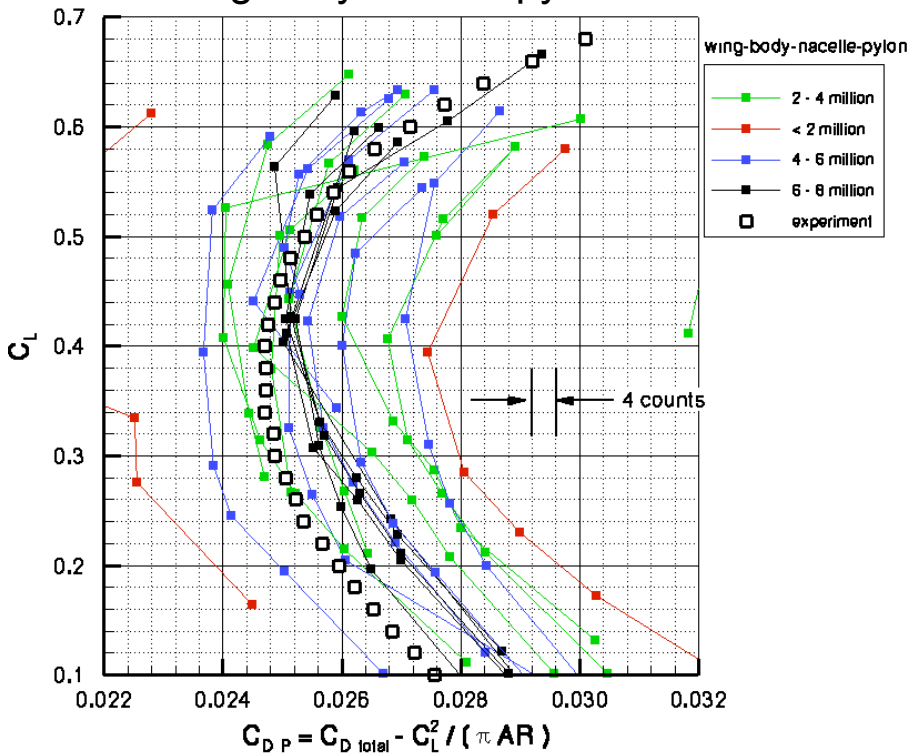
Grid Size

Mach = 0.75, Re = 3×10^6

wing/body



wing/body/nacelle/pylon



Case 2