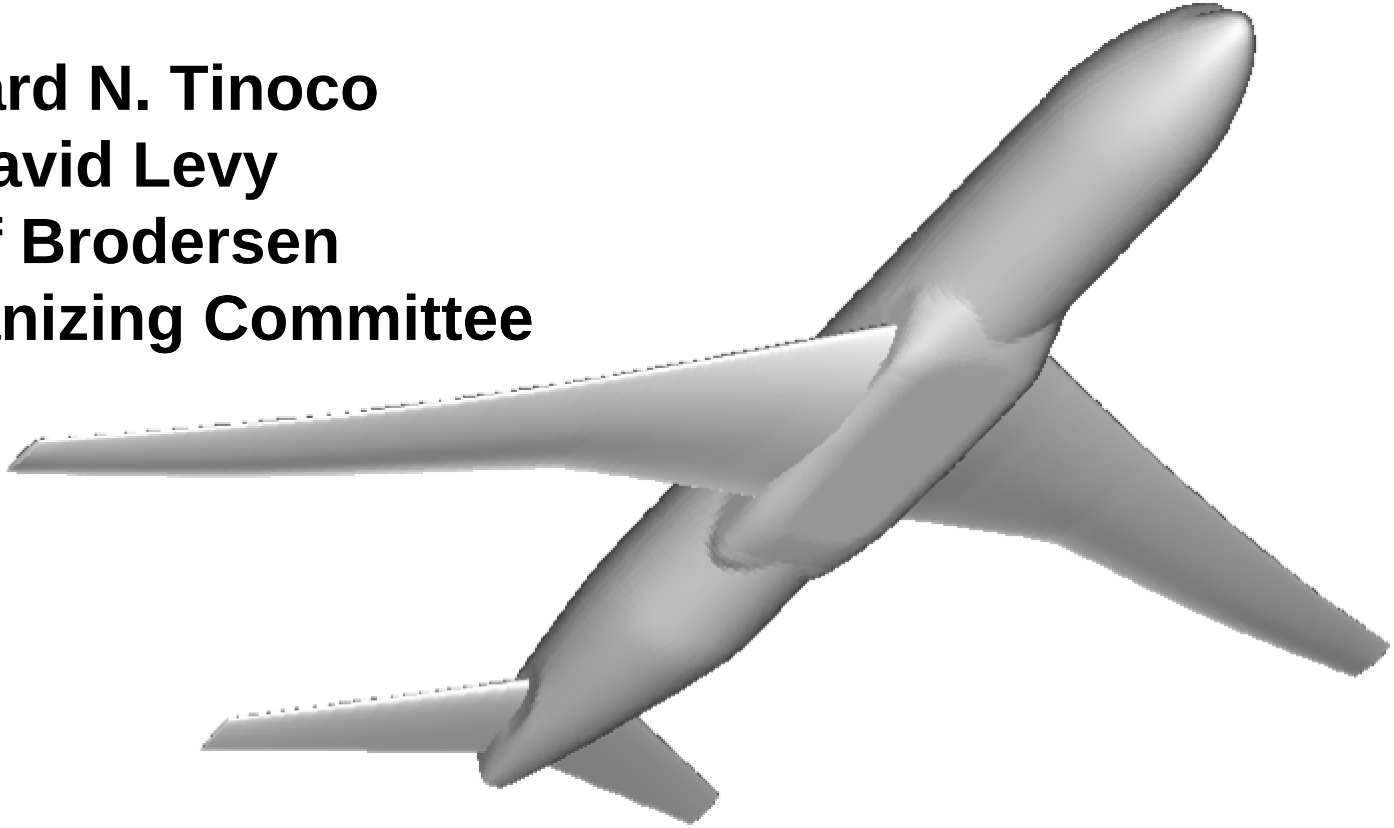
DPW-IV Summary of Participants Data

Edward N. Tinoco
David Levy
Olaf Brodersen
DPW Organizing Committee



Workshop Statistics

- 28 data entries from 17 organizations
  - 7 North America
  - 7 Europe
  - 3 Asia

- Grid types
  - 17 Unstructured
  - 11 Structured

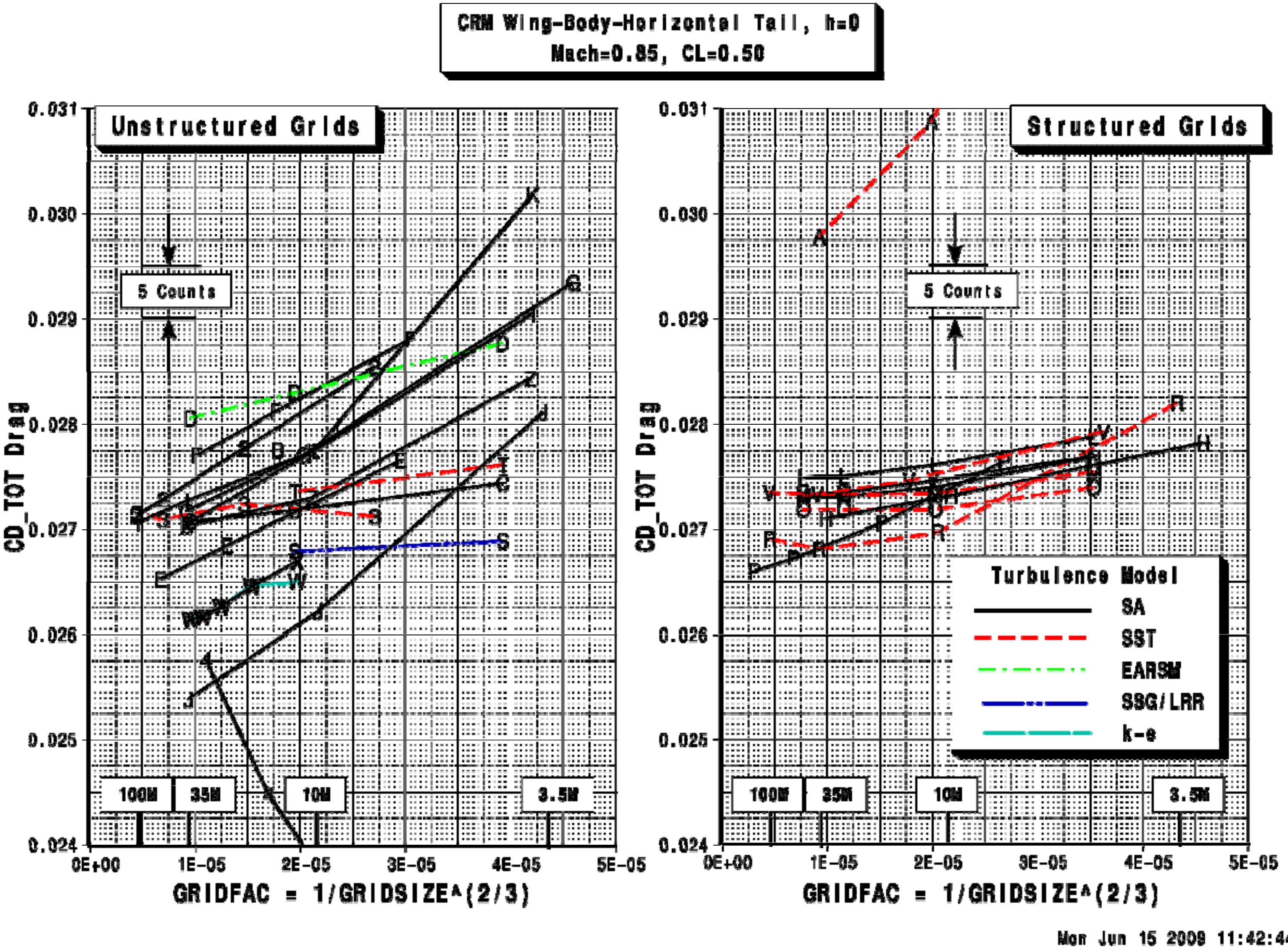
- Turbulence Models
  - 18 Spalart-Allmaras (all variations)
  - 7 Menter SST k-omega
  - 1 EARSM (Explicit Algebraic Reynolds Stress Model)
  - 1 SSG/LLR-omega (Reynolds Stress Model)
  - 1 Realizable k- epsilon

DPW4 Data Submittal Summary

Symbol Key	Legend Entry	Company	Code	Grid Type	Grid Generator	Turb Model
A	CFS_NSMB	CFS	NSMB	Multiblock/Structured	ICEM Hexa	SST k-w
B	DLR_TAU_Centaur	DLR	TAU	Unstr/Hybrid	Centaur	S-A
C	DLR_TAU_Solar_SAO	DLR	TAU	Unstr/Hybrid	Solar	S-A
D	FOI_Unstr	FOI	EDGE	Unstr/Hybrid	Solar	EARSM
E	IIS_HIFUN_Unstr	IIS	HIFUN	Unstr/Hybrid	Gambit/Tgrid	S-A
F	JAXA_TAS_hybrid	JAXA	TAS	Unstr/Hybrid	TAS_Mesh	S-A mod
G	JAXA_TAS_HEX	JAXA	TAS	Unstr Mostly Hex	HexaGrid	S-A
H	JAXA_UPACS	JAXA	UPACS	Multiblock/Structured	Gridgen	S-A mod
I	LARC_FUN3D	NASA LaRC	FUN3D	Unstr/Hybrid	VGRID/NASA	S-A
J	Cessna_NSU3D_Cessna	Cessna	NSU3D	Unstr/Hybrid	VGRID/Cessna	S-A
K	Cessna_NSU3D_NASA	Cessna	NSU3D	Unstr/Hybrid	VGRID/NASA	S-A
L	Boeing_CFL3D_FSA	Boeing Seattle	CFL3D	Multiblock/Structured	Zeus	S-A
M	Boeing_CFL3D_FSST	Boeing Seattle	CFL3D	Multiblock/Structured	Zeus	SST k-w
N	Boeing_CFL3D_TSA	Boeing Seattle	CFL3D	Multiblock/Structured	Zeus	S-A
O	Boeing_CFL3D_TSST	Boeing Seattle	CFL3D	Multiblock/Structured	Zeus	SST k-w
P	Boeing_OVERFLOW	Boeing HB	OVERFLOW	Overset	MADCAP/HYPGEN	S-A
R	ANSYS	ANSYS	Fleunt	Multiblock/Structured	ICEM Hexa	SST k-w
S	DLR_TAU_Solar_RSM	DLR	TAU	Unstr/Hybrid	Solar	SSG/LRR
T	DLR_TAU_Solar_SST	DLR	TAU	Unstr/Hybrid	Solar	SST k-w
U	ZeusNumerix_HLLC	ZeusNumerix	HLLC	Multiblock/Structured	GridZ	S-A
V	Airbus_elsA	Airbus	elsA	Multiblock/Structured	ICEM Hexa	SST k-w
W	Metacomp_CFD++_ke	Metacomp	CFD++	Unstr/Hybrid	MIME	k-epsilon
X	Metacomp_CFD++_SA	Metacomp	CFD++	Unstr/Hybrid	MIME	S-A
Y	ONERA	ONERA	elsA	Multiblock/Structured	Zeus	S-A
Z	UofWy_NSU3D_NASA	U Wyoming	NSU3D	Unstr/Hybrid	VGRID/NASA	S-A
2	Boeing_BCFD_SA	Boeing St. Louis	BCFD	Unstr/Hybrid	AFLR	S-A
3	Boeing_BCFD_SST	Boeing St. Louis	BCFD	Unstr/Hybrid	AFLR	SST k-w
4	Numeca	Numeca	Fine/Hexa	Unstr/Hex	Hexpress	S-A

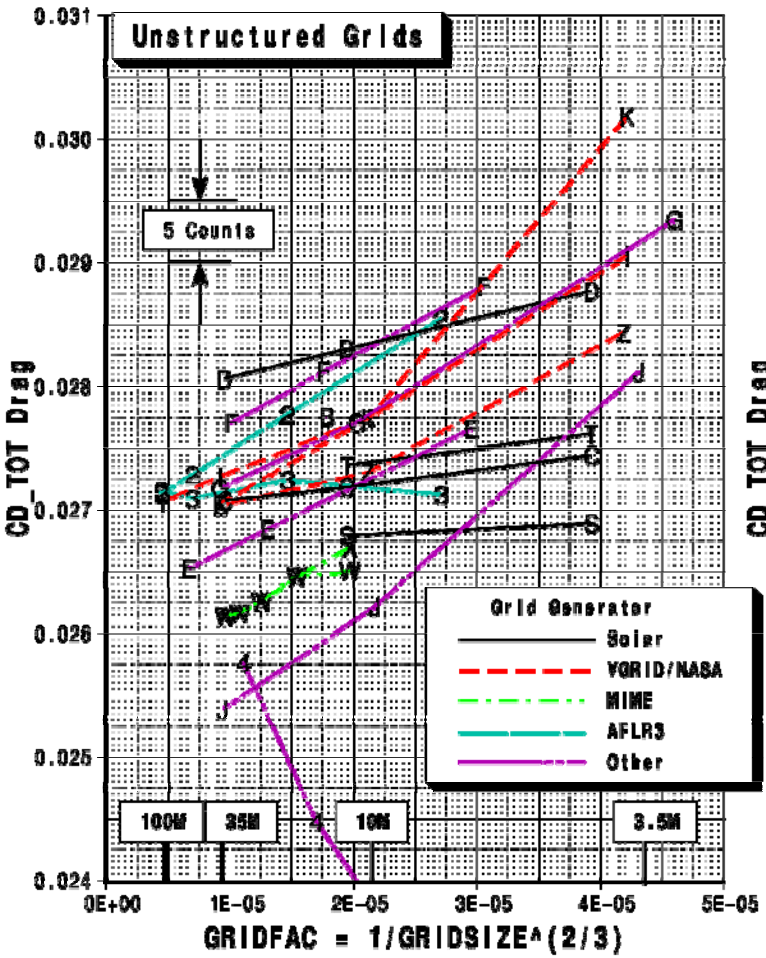
- **Case 1a: Grid Convergence Study**
  - Mach = 0.85, CL = 0.500 (±0.001)
  - Tail Incidence angle= 0°
  - Coarse, Medium, Fine, Extra-Fine Grids (Extra-Fine grid is optional)
  - Chord Reynolds Number: Re=5M

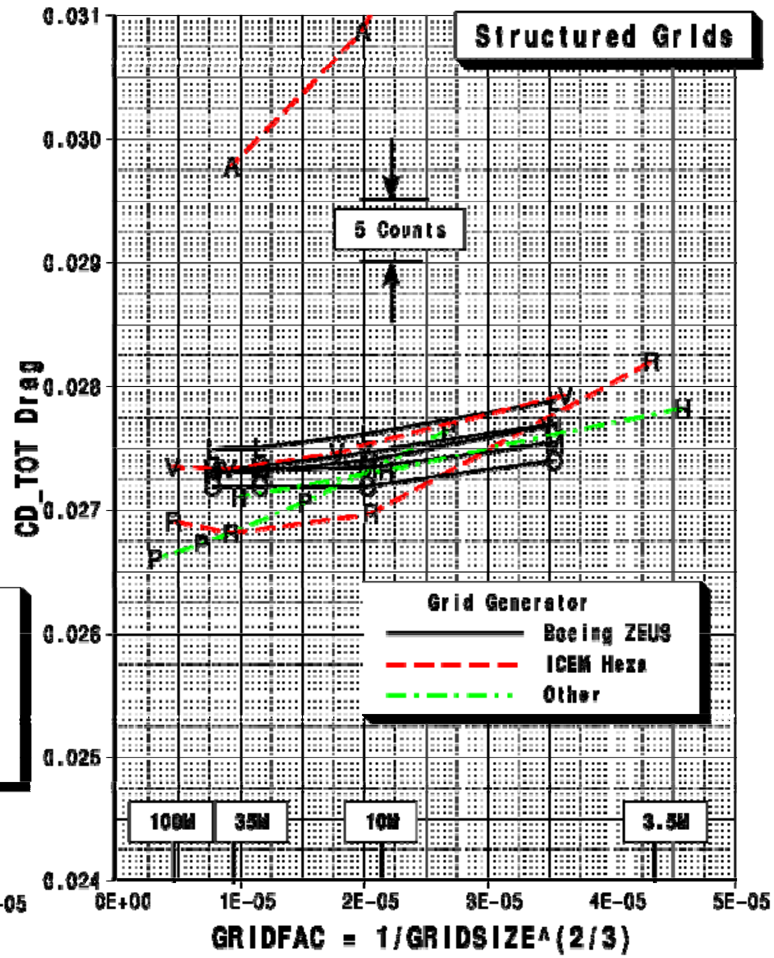
Total Drag - Grid Convergence – All Solutions



Total Drag - Grid Convergence – All Solutions

CRM Wing-Body-Horizontal Tail, h=0
Mach=0.85, CL=0.50





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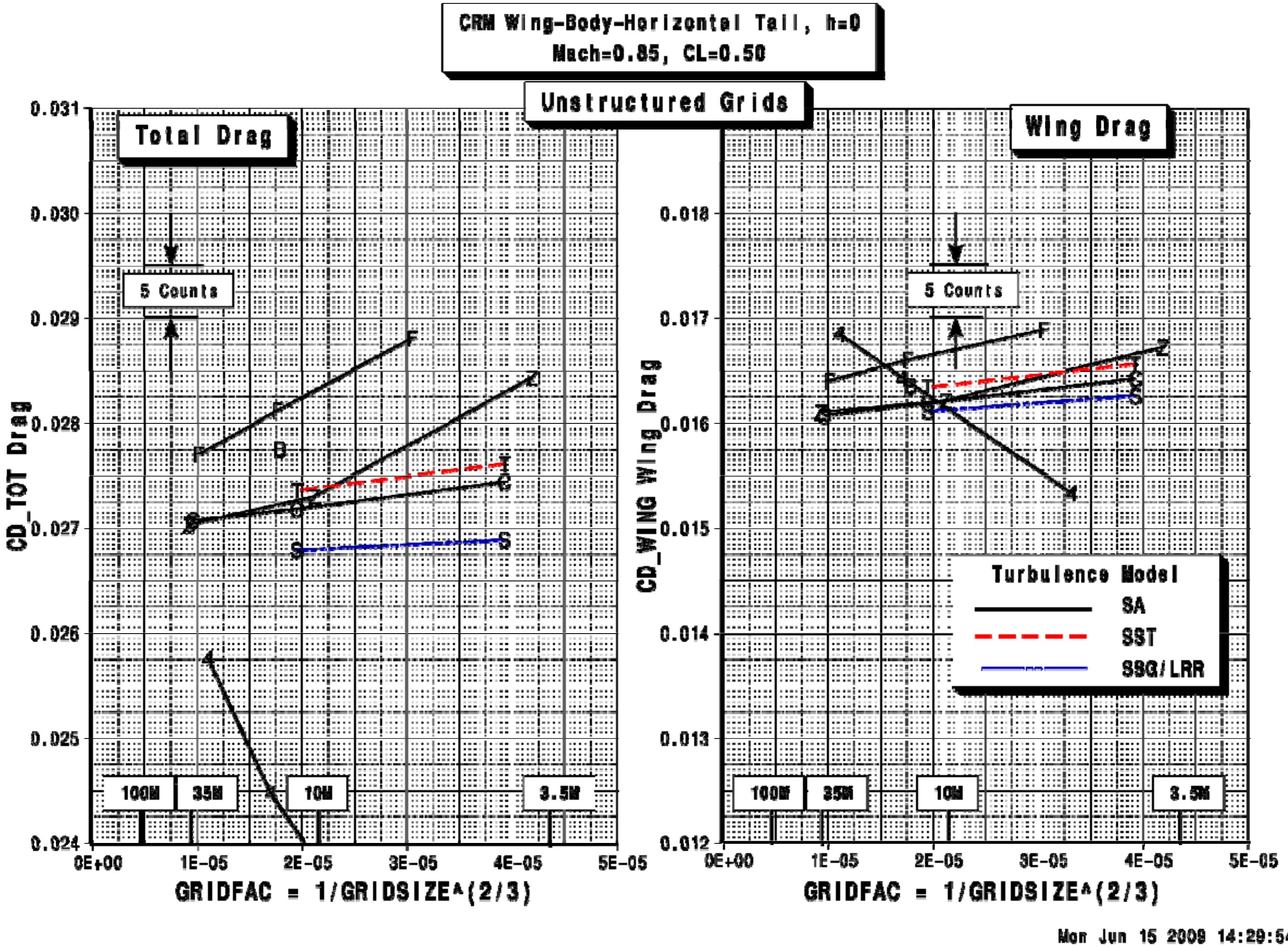
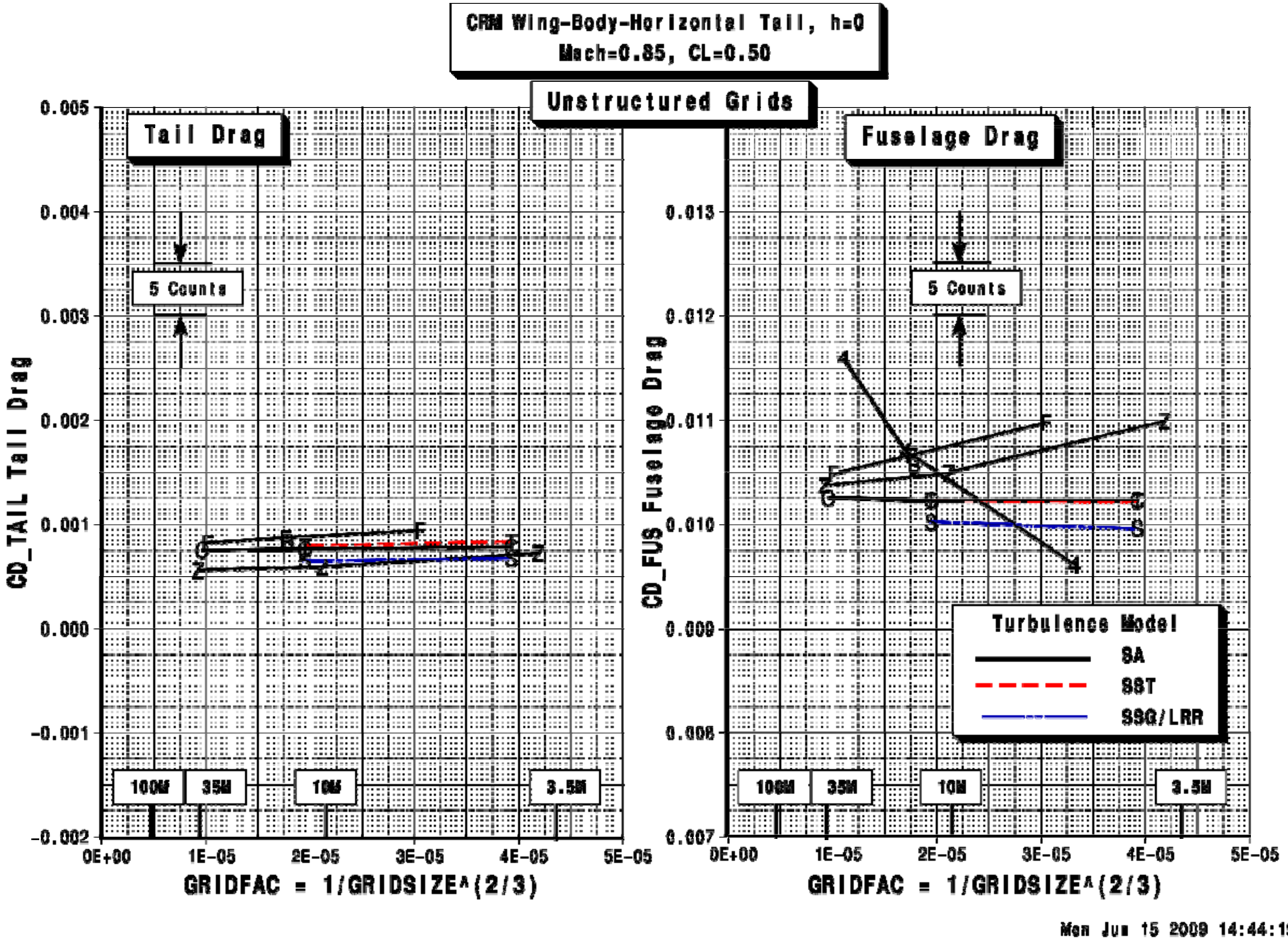
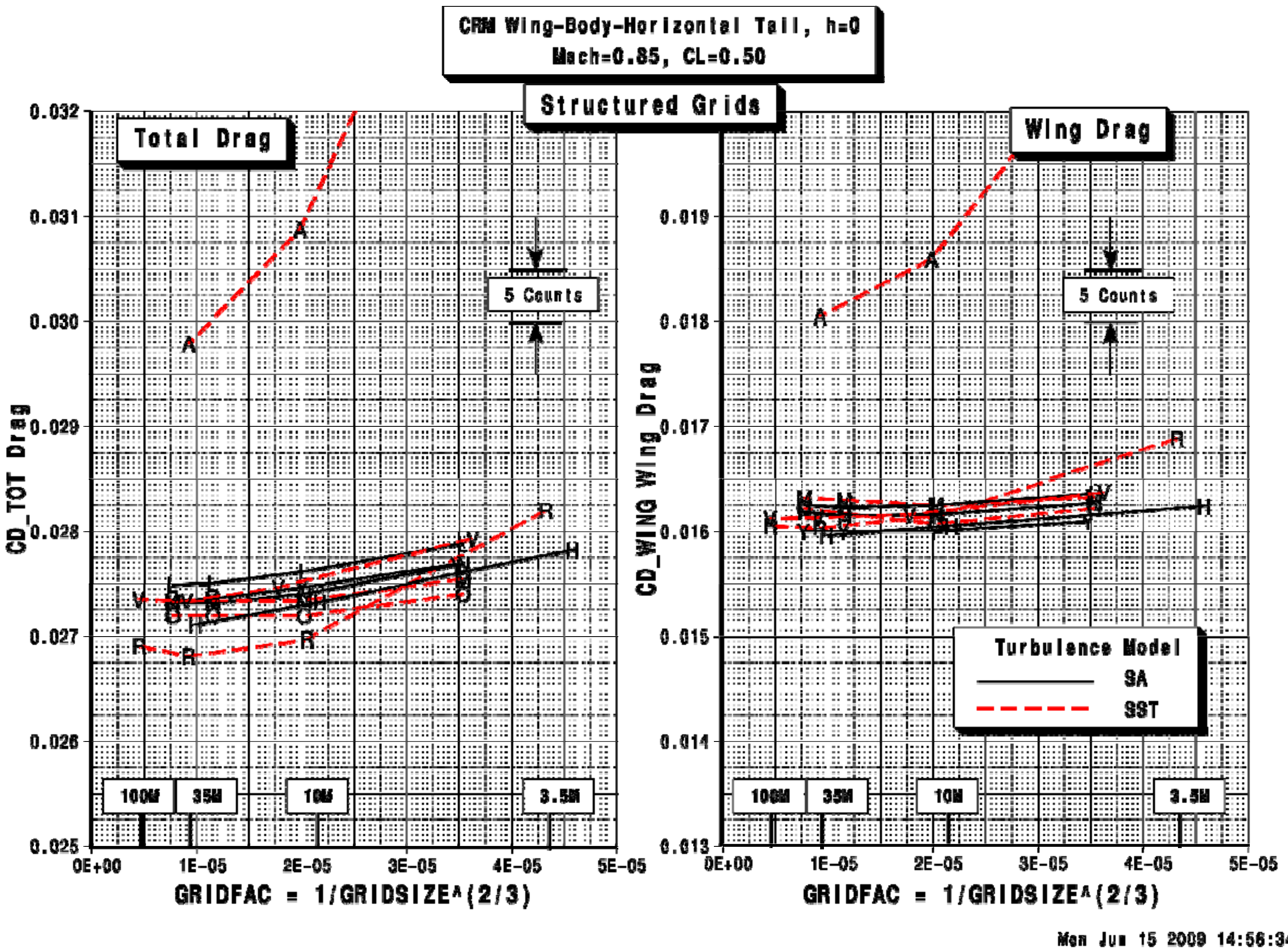
Drag Components - Grid Convergence – Unstructured Grids



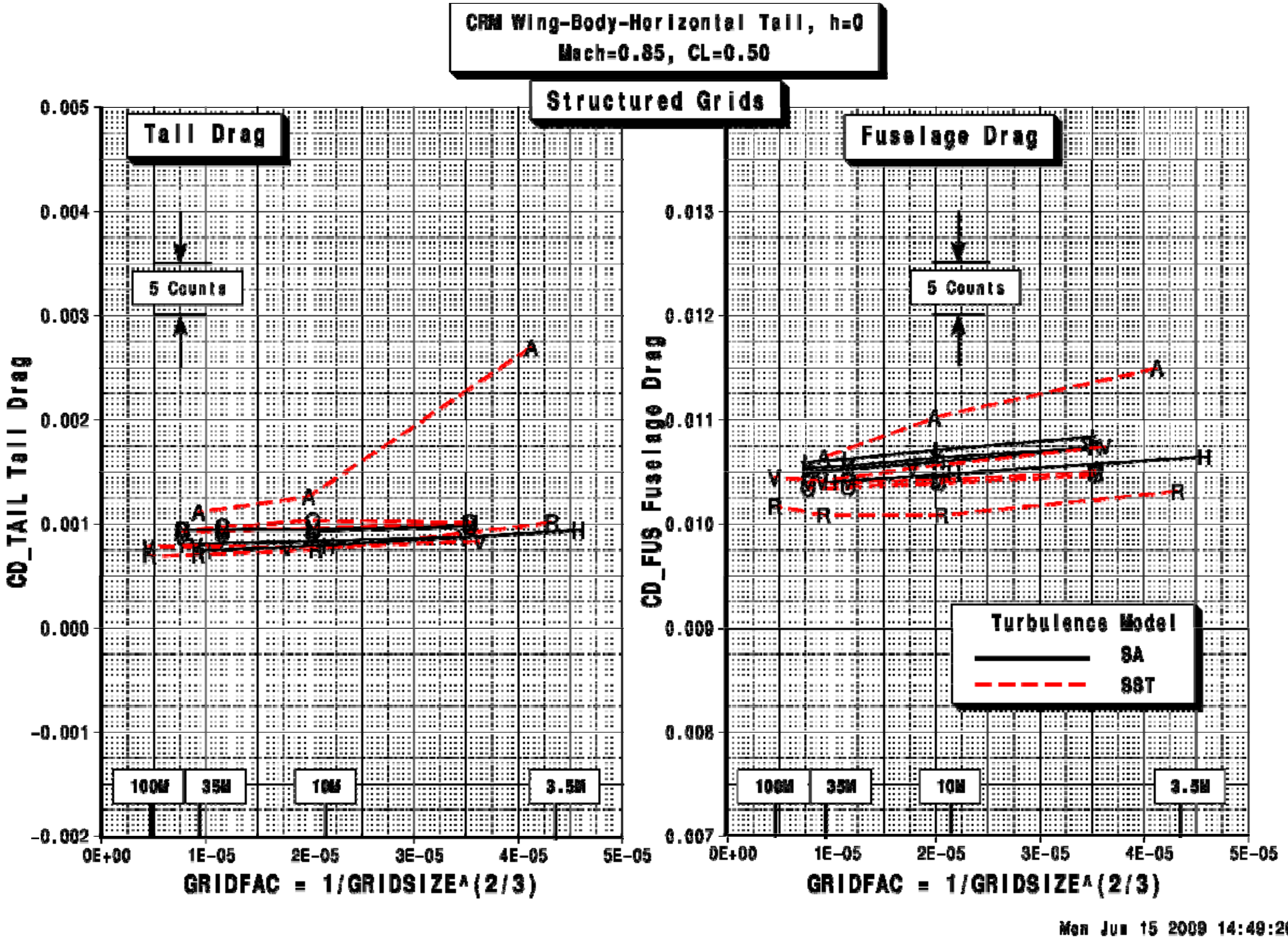
Drag Components - Grid Convergence – Unstructured Grids



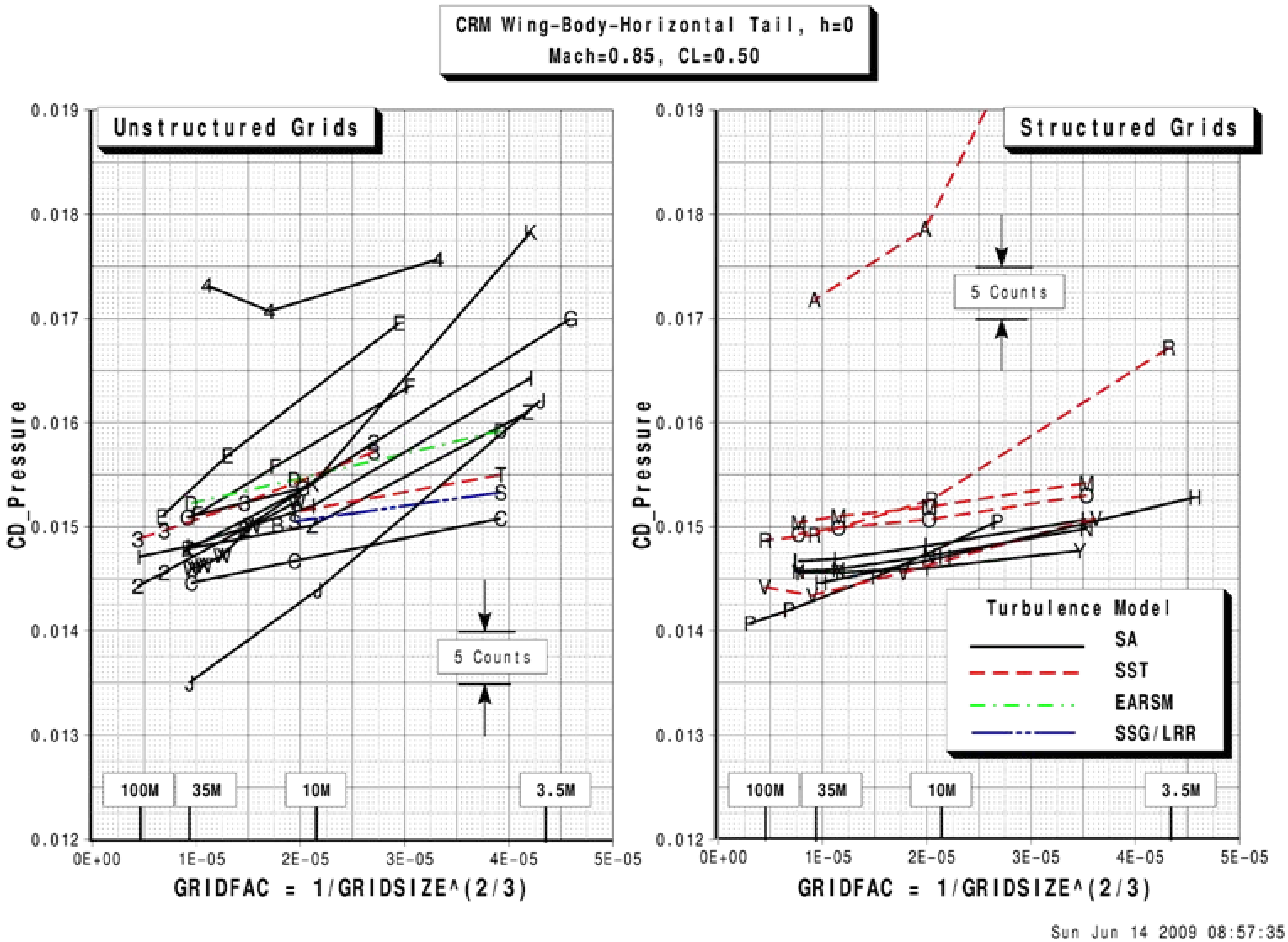
Drag Components - Grid Convergence – Structured Grids



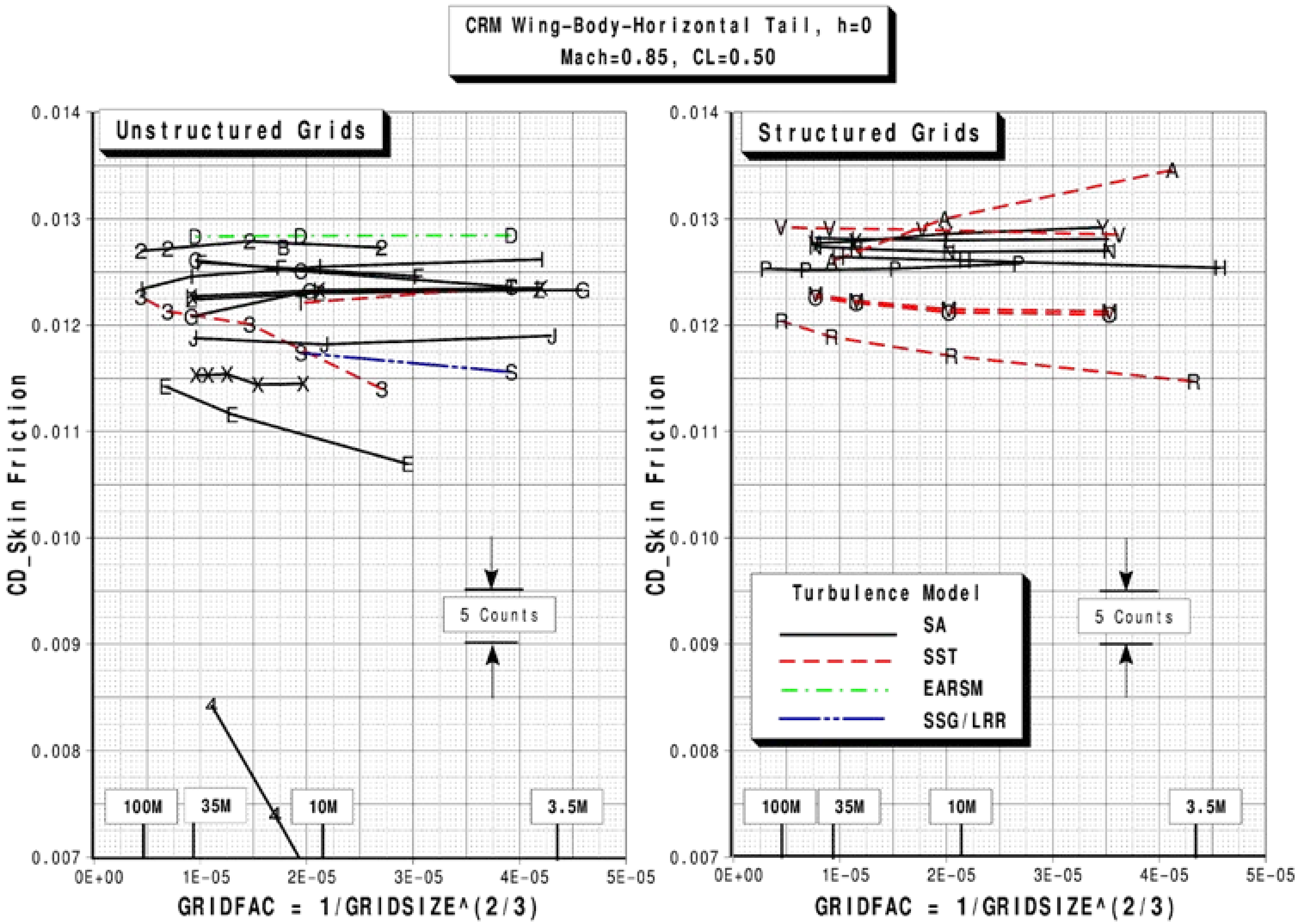
Drag Components - Grid Convergence – Structured Grids



Pressure Drag - Grid Convergence – All Solutions



Skin Friction Drag - Grid Convergence – All Solutions



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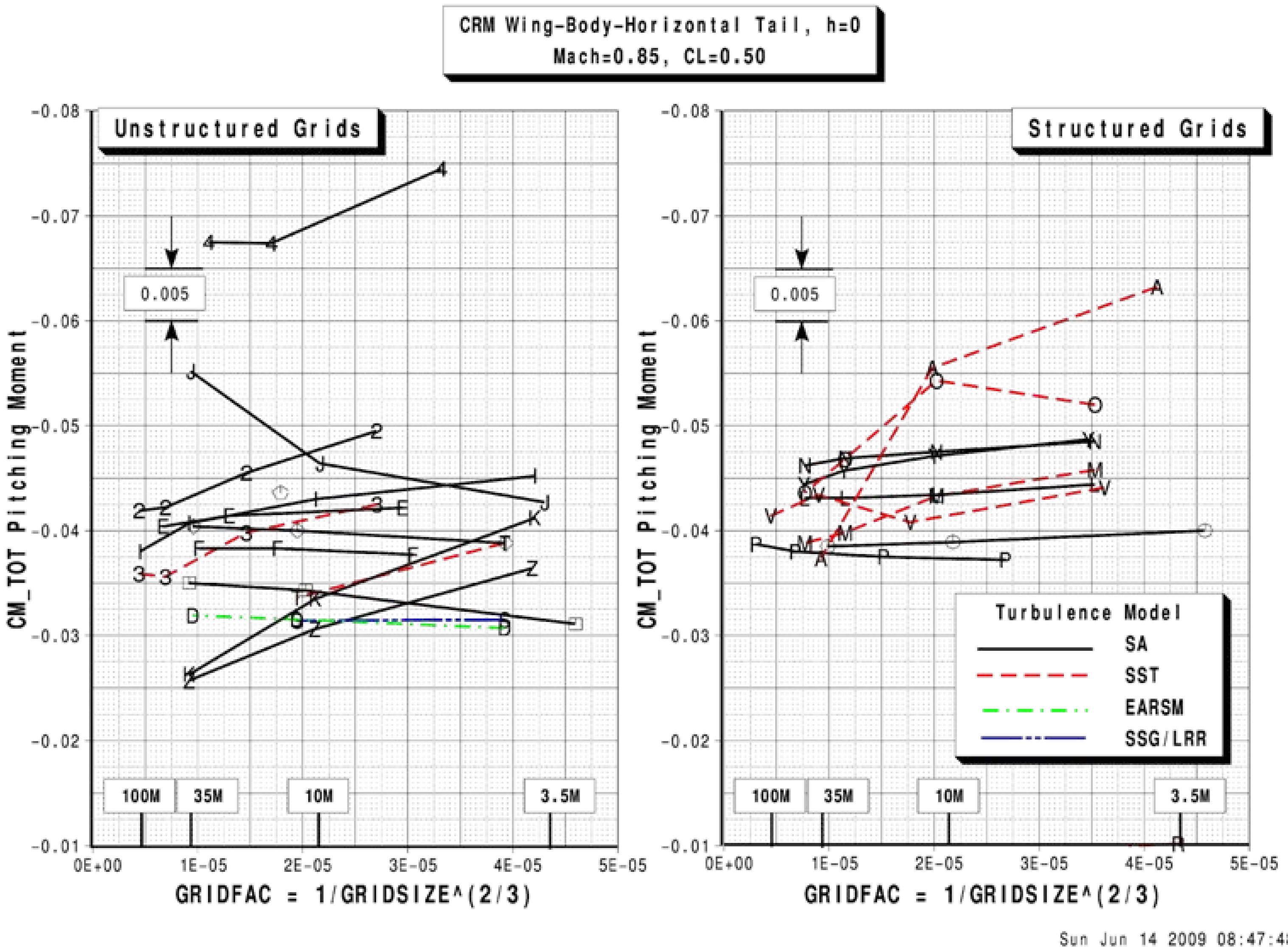
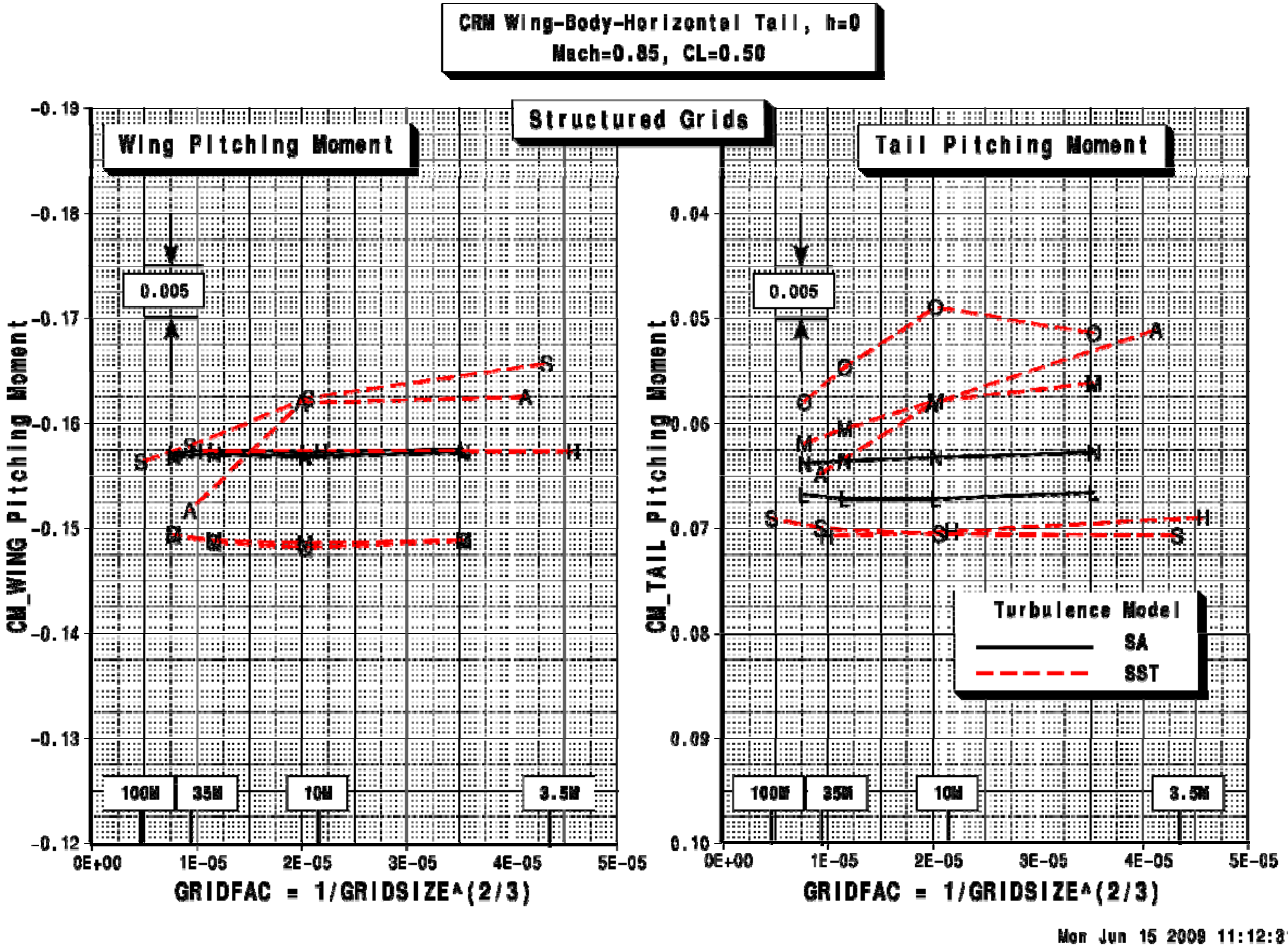
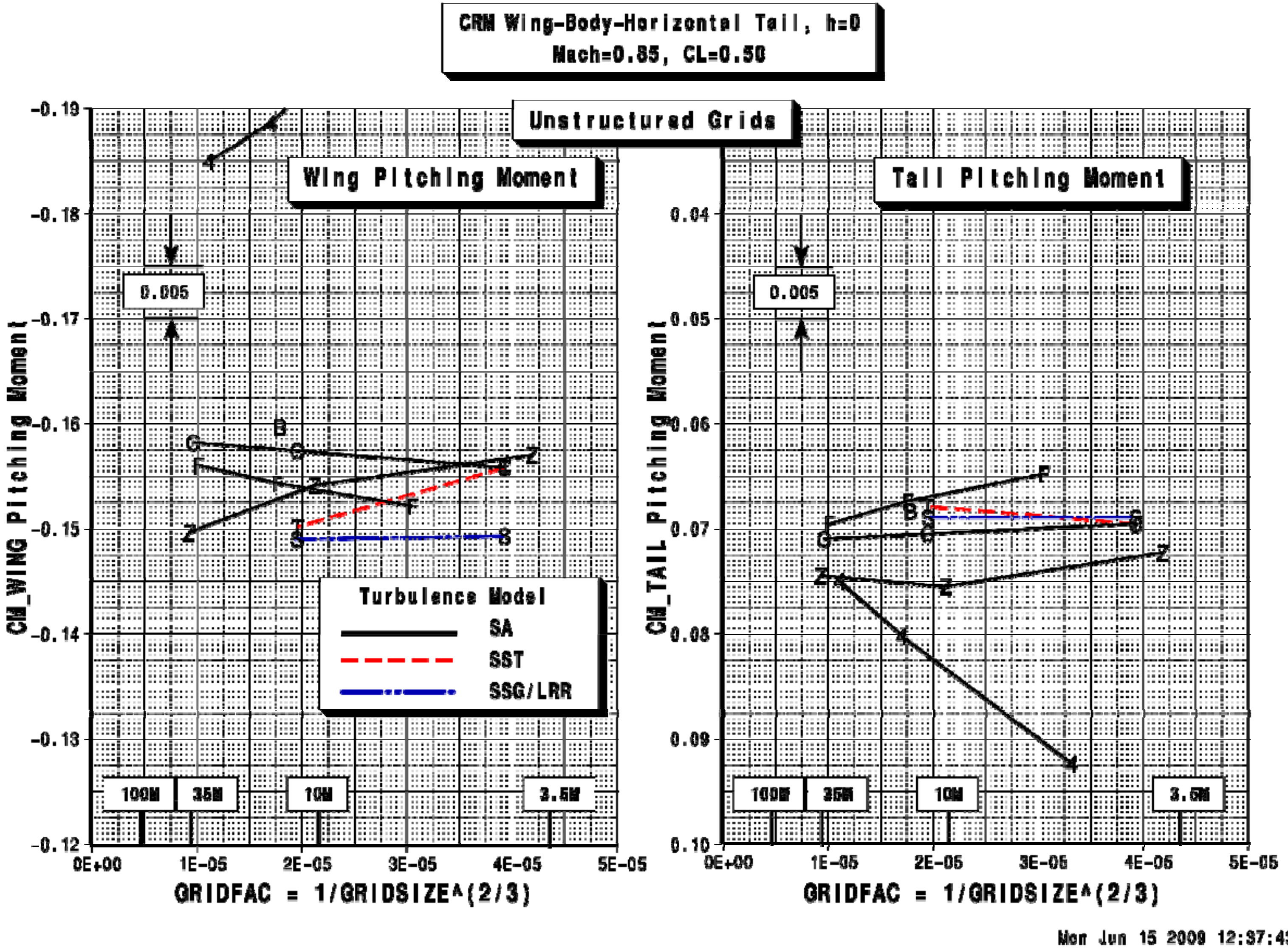
Pitching Moment - Grid Convergence – All Solutions



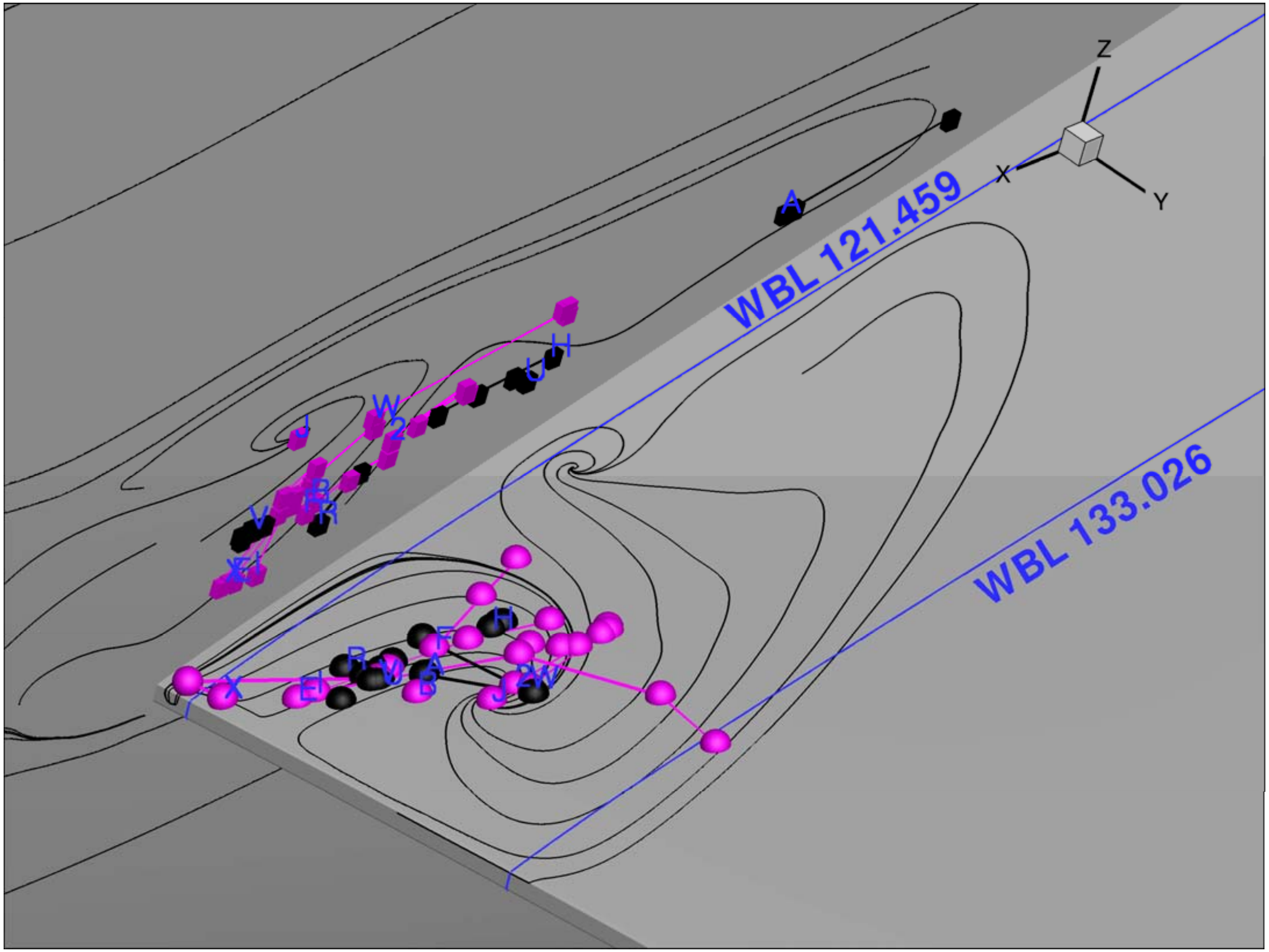
Pitching Moment Components - Grid Convergence – Structured Grids



Pitching Moment Components - Grid Convergence – Unstructured Grids

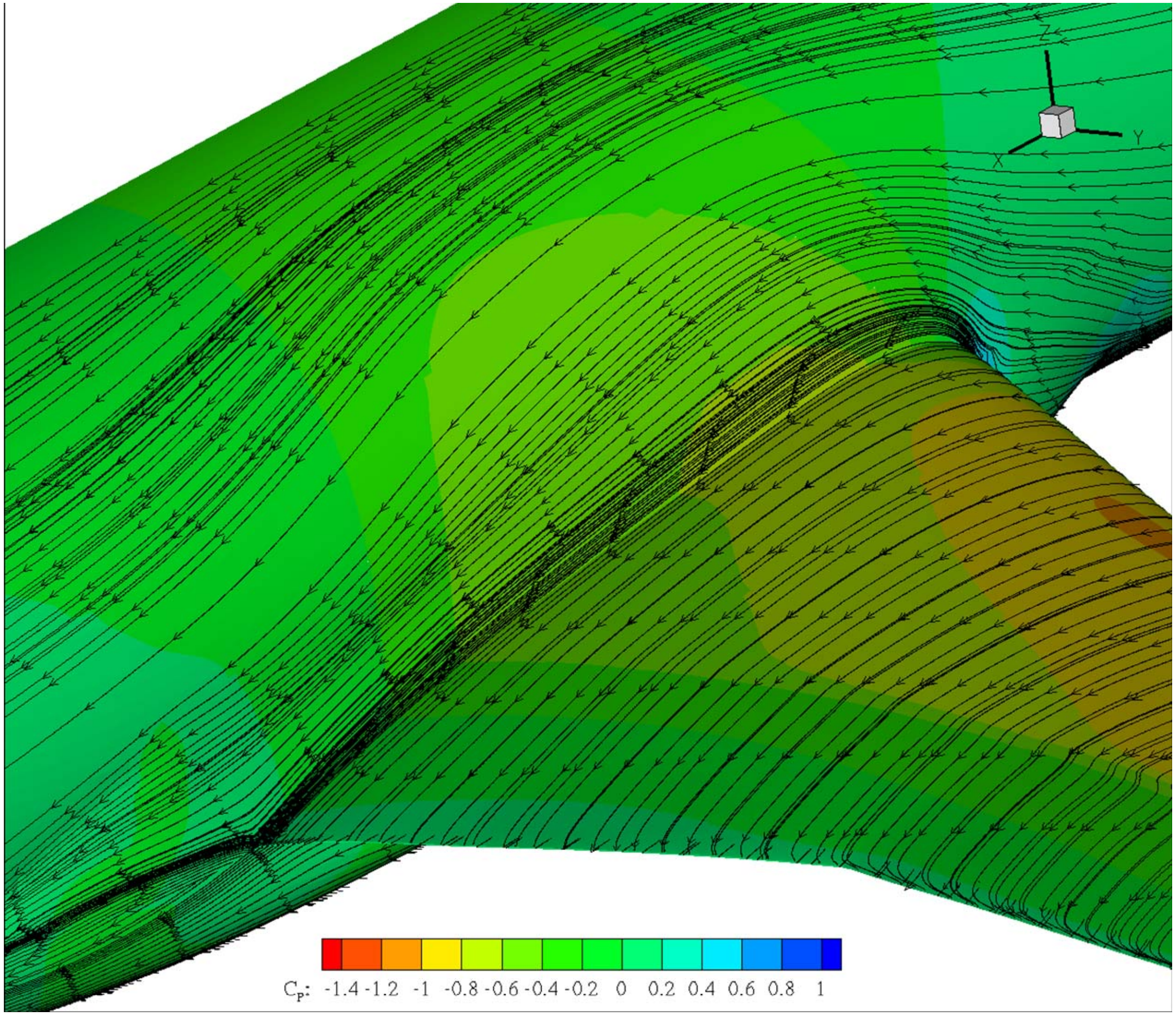


Side of Body Separation Reported



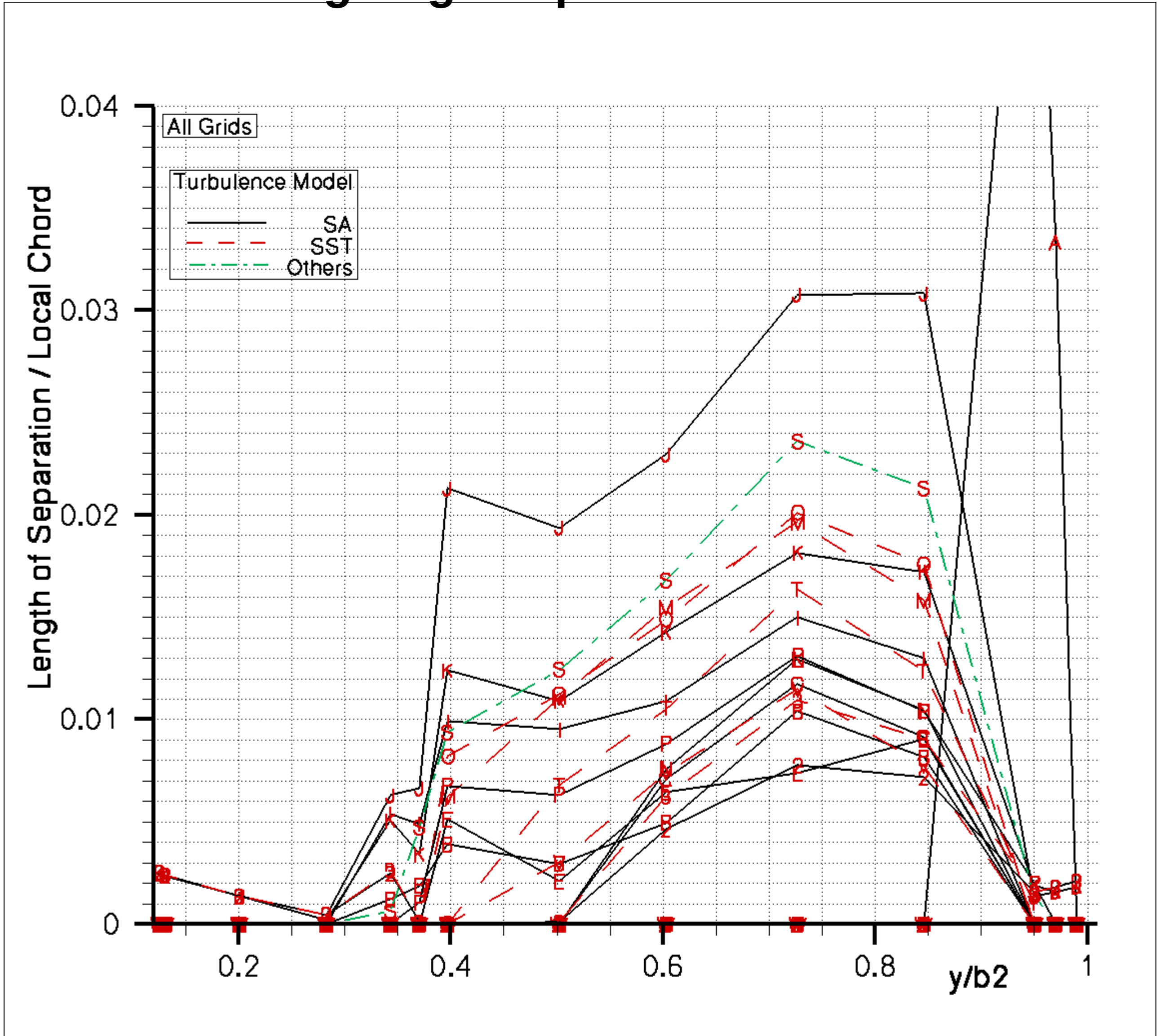
ID	Turb. Model
A	SST k-w
B	SA
E	SA
F	SA
H	SA
I	SA
J	SA
P	SA
R	SST k-w
U	SA
V	SST k-w
W	k-e
X	SA
2	SA
4	SA

Reported No Side of Body Separation

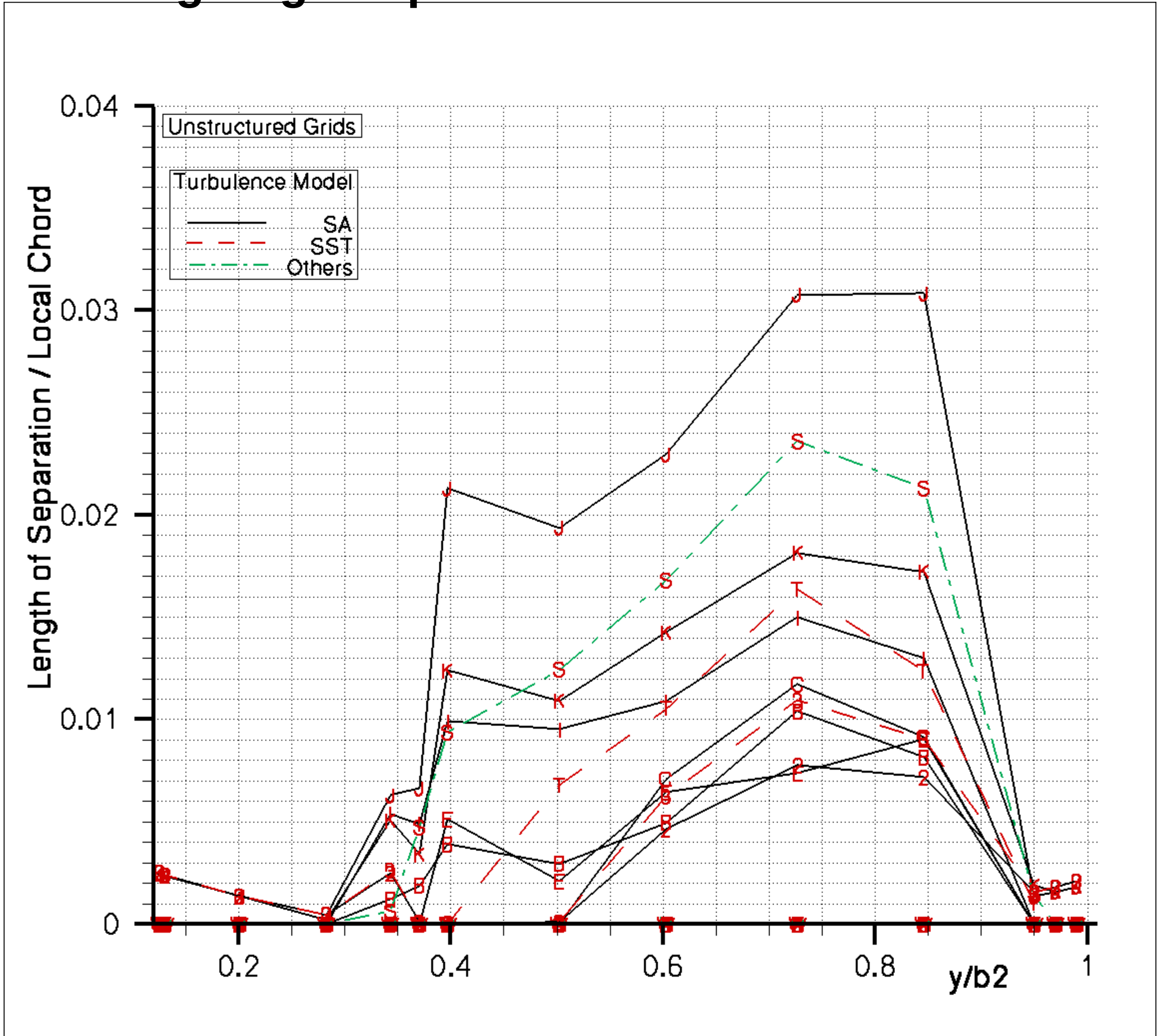


ID	Turb. Model
C	SA
L	SA
M	SST k-w
N	SA
O	SST k-w
S	SSG/LRR

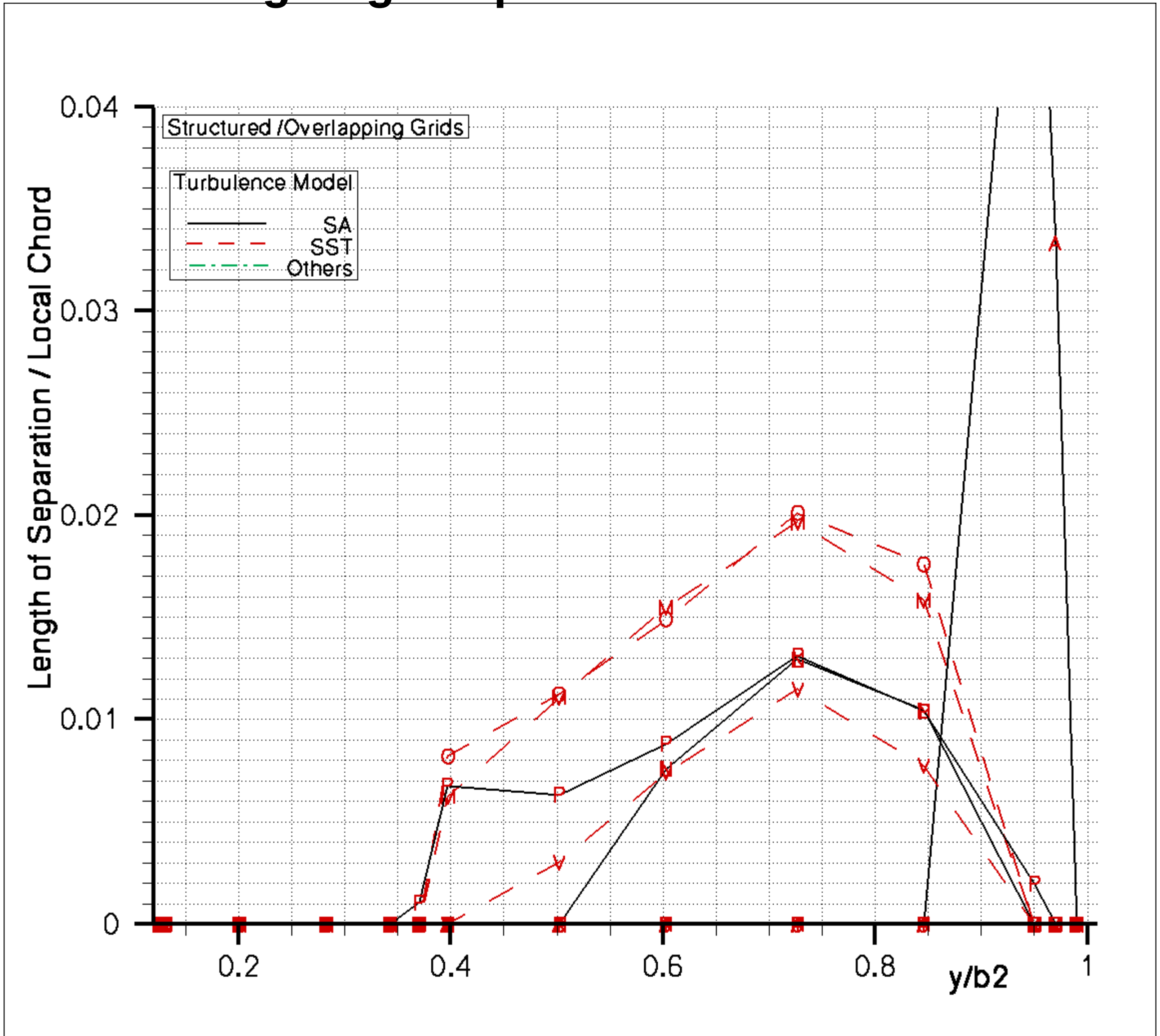
Trailing Edge Separation – All Grids



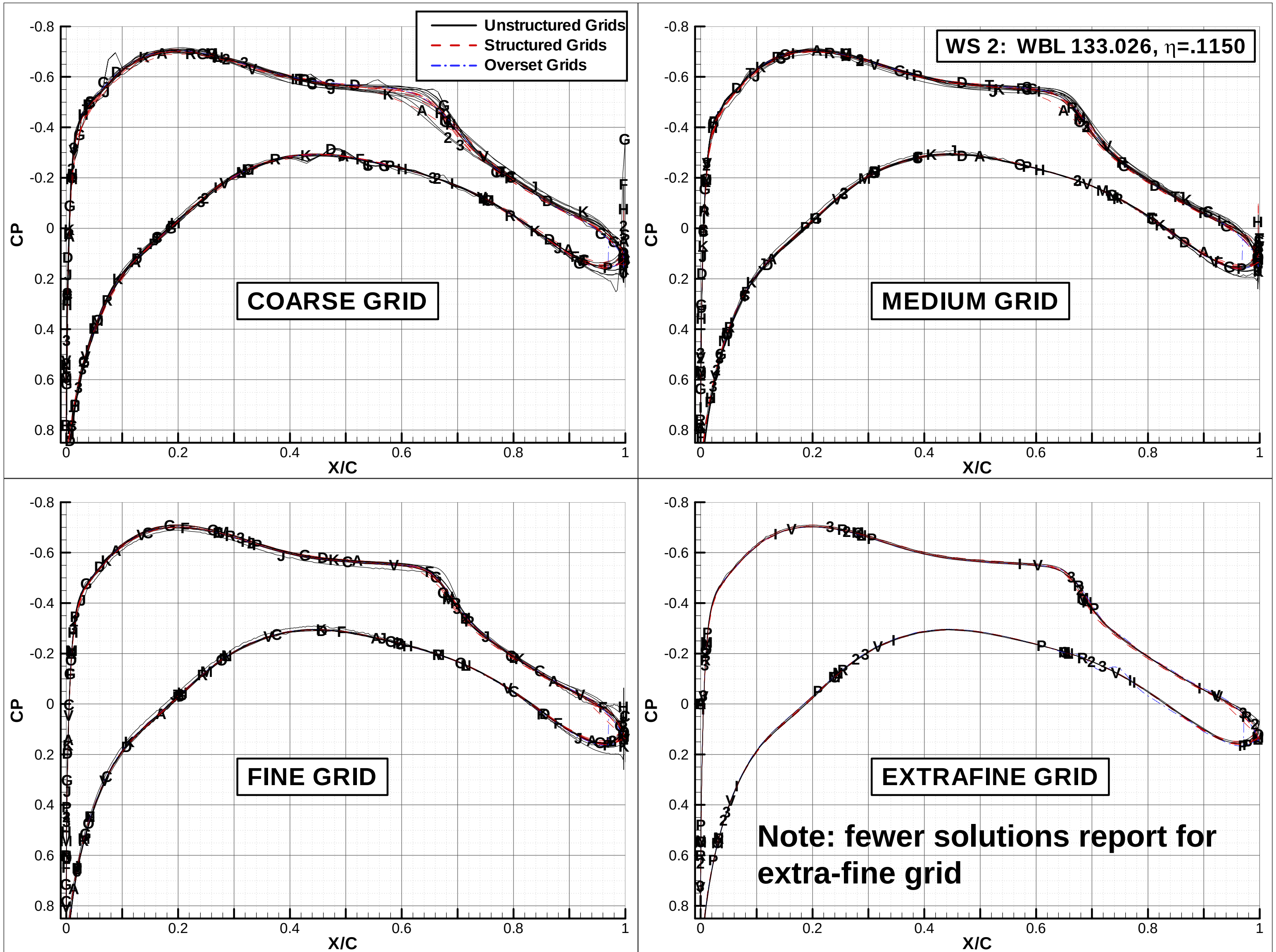
Trailing Edge Separation – Unstructured Grids



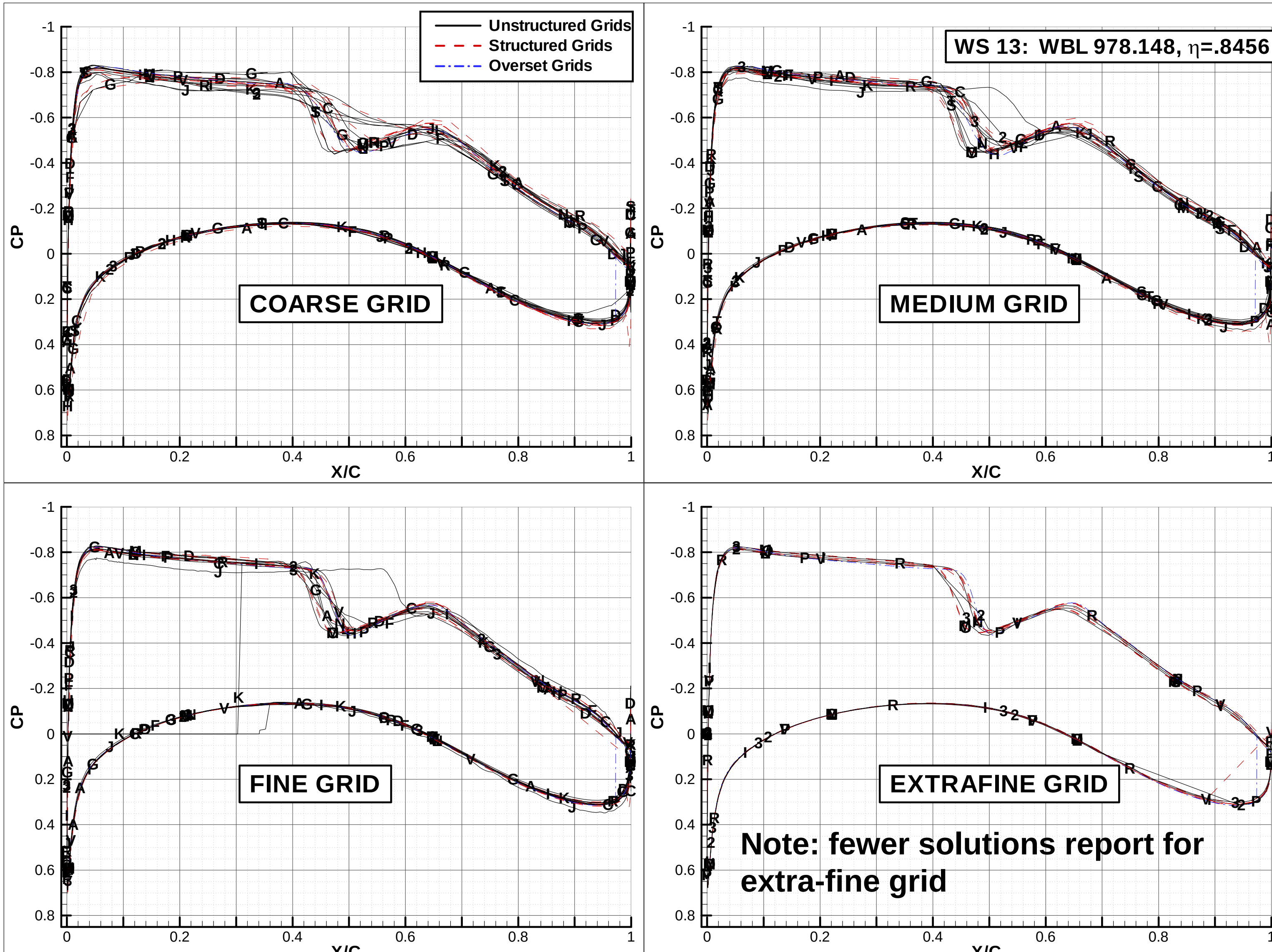
Trailing Edge Separation – Structured Grids



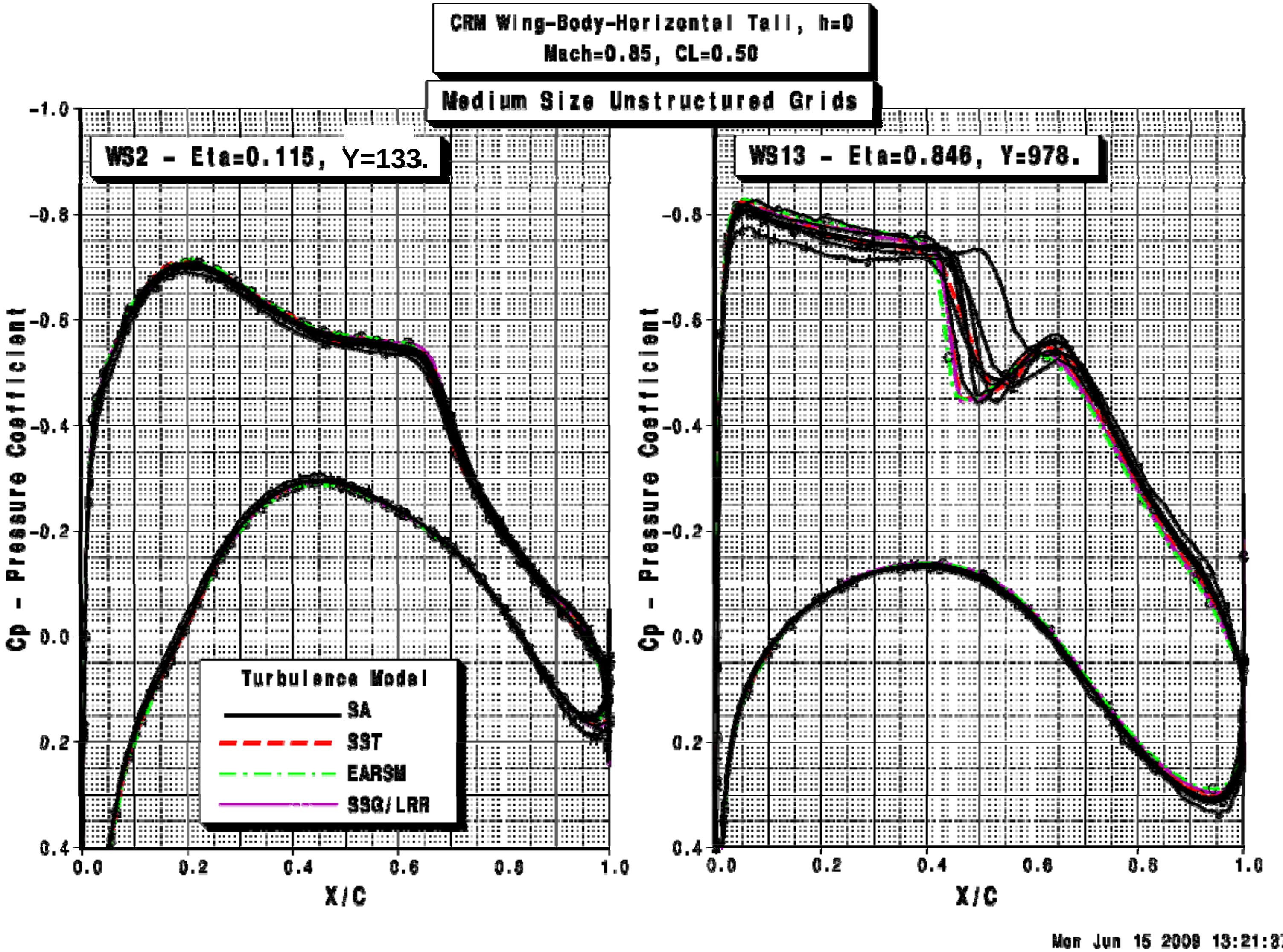
Wing Pressure Distribution – Grid Convergence – WS2: WBL 133



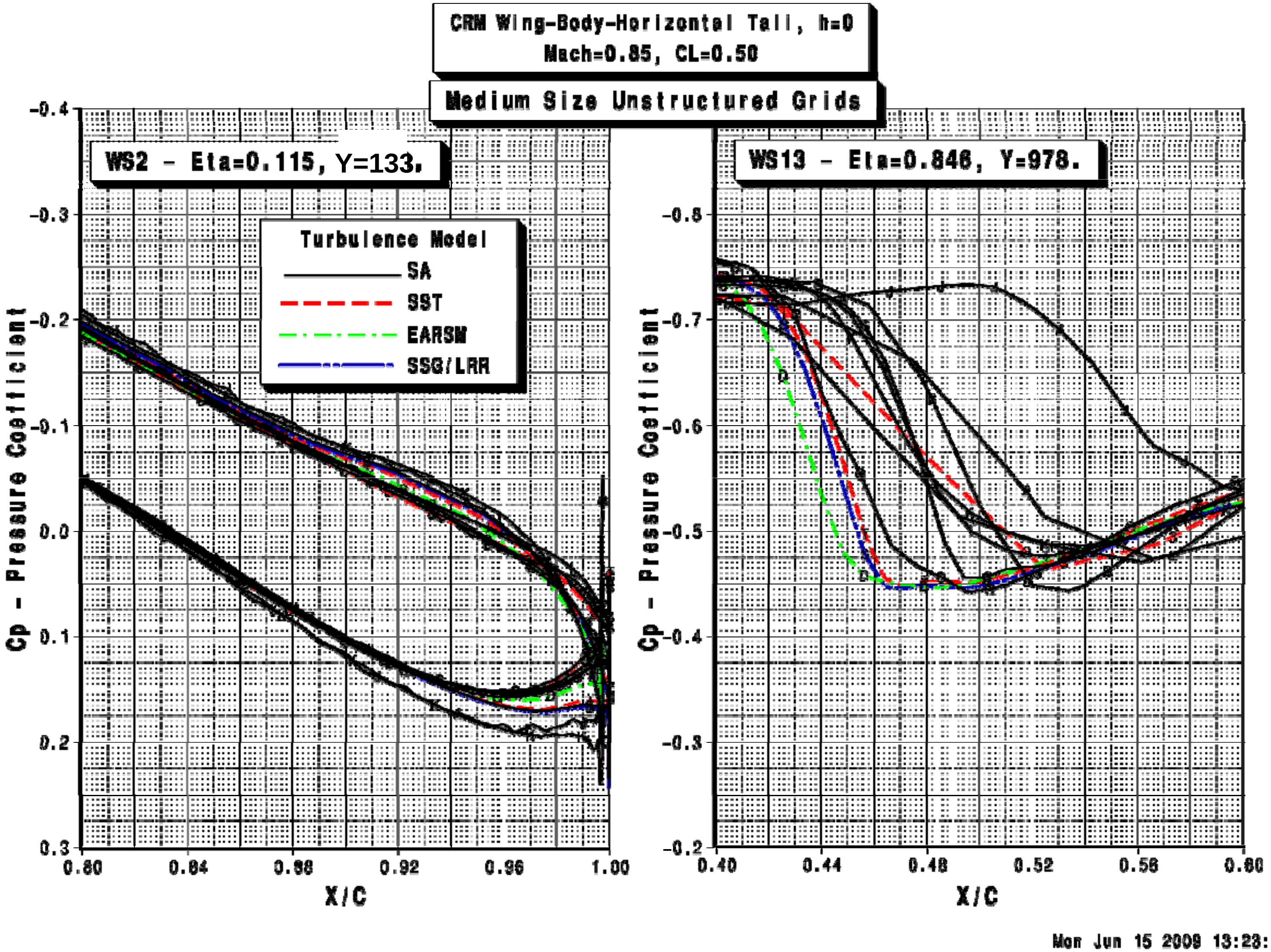
Wing Pressure Distribution – Grid Convergence – WS13: WBL 978



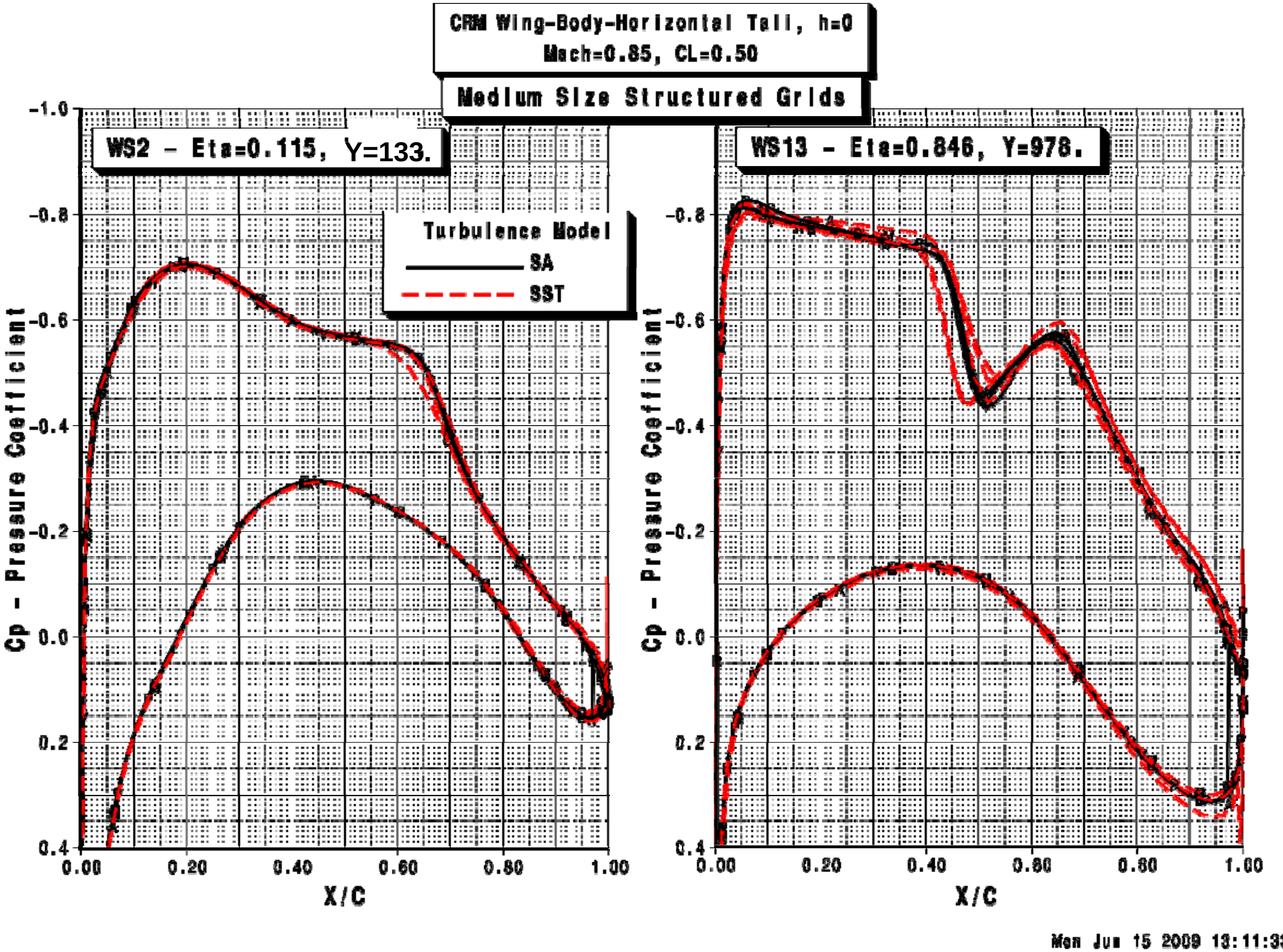
Wing Pressure Distribution – Medium Unstructured Grid



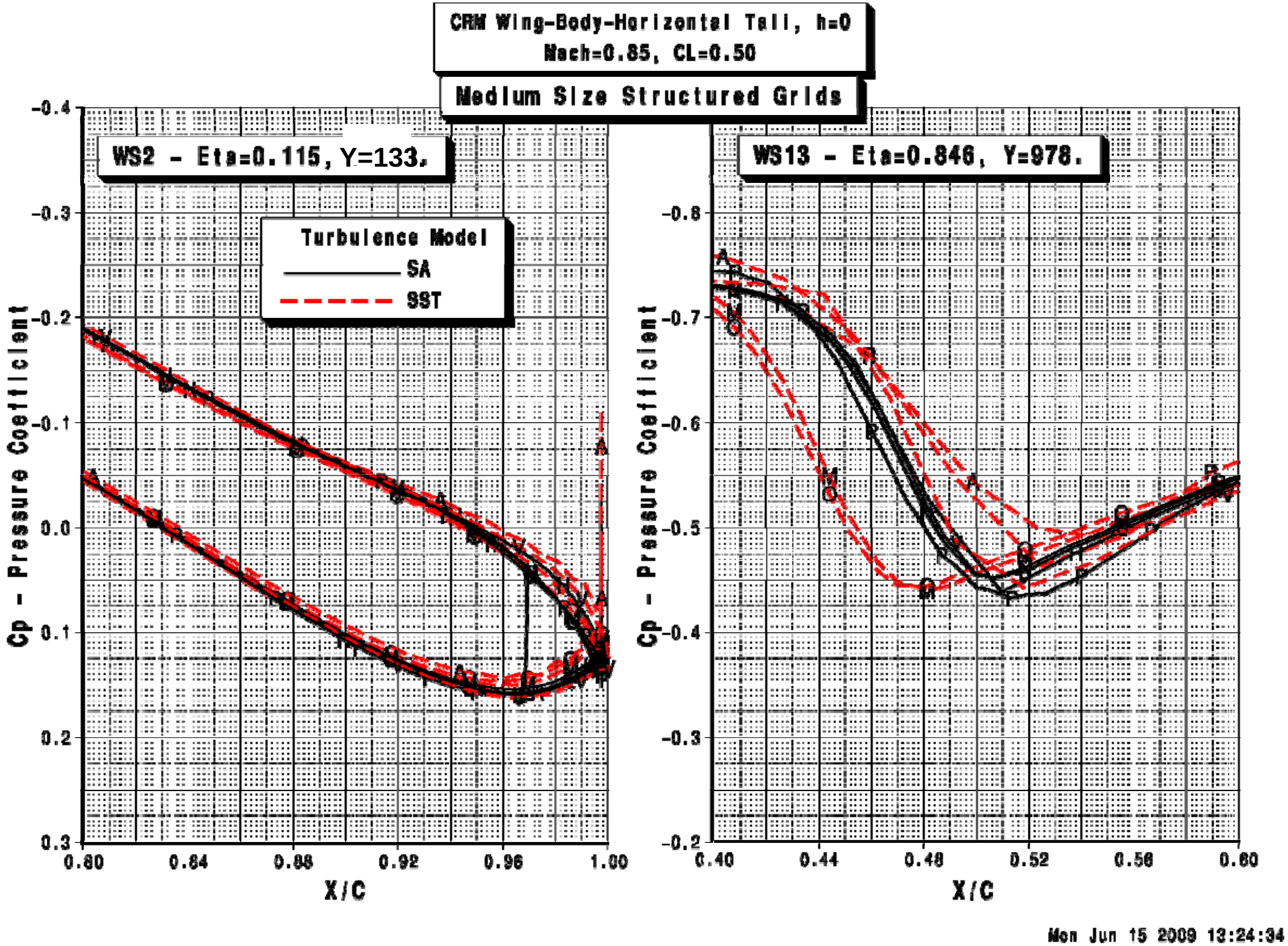
Wing Pressure Distribution – Medium Unstructured Grid



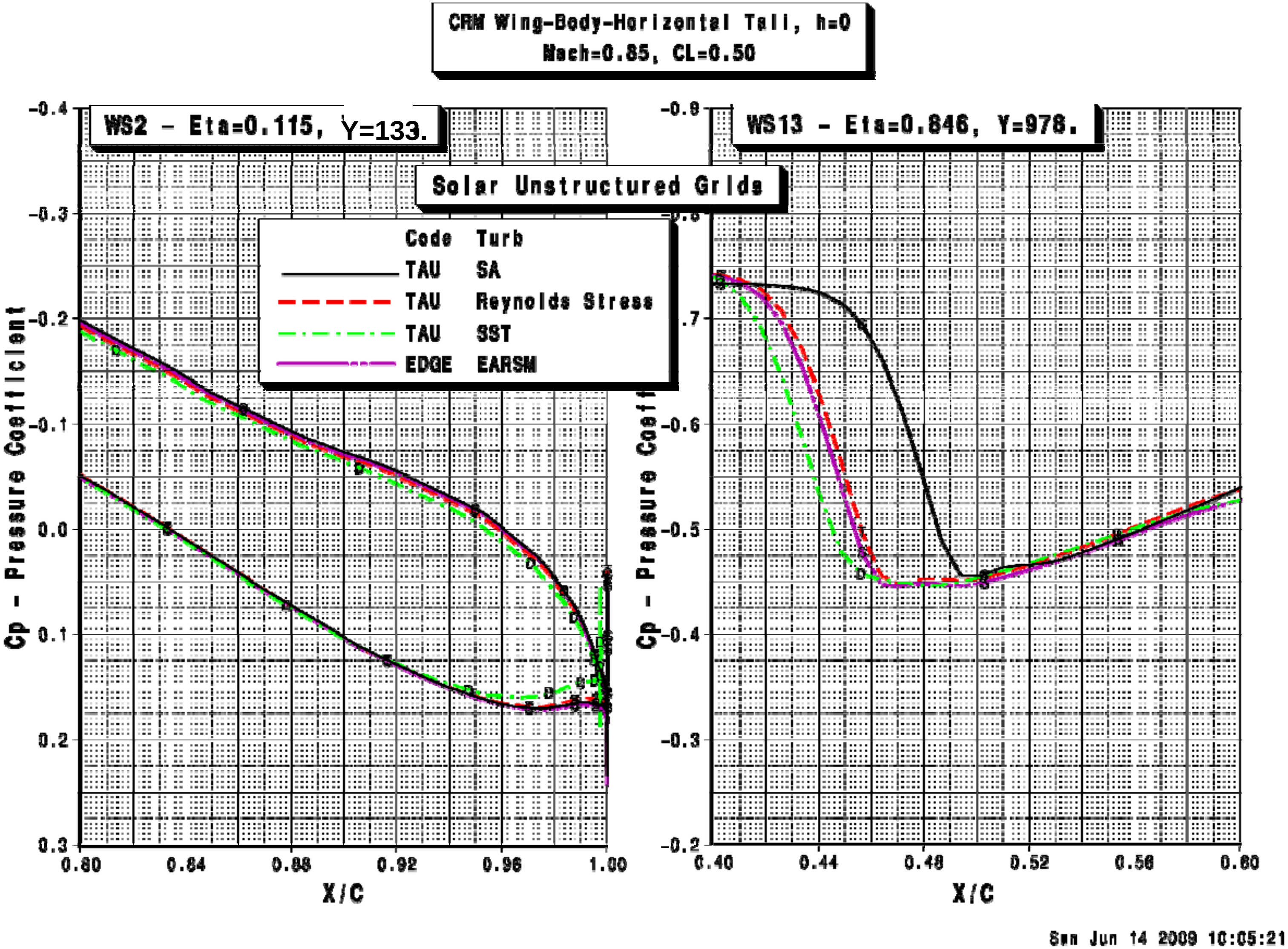
Wing Pressure Distribution – Medium Structured Grid



Wing Pressure Distribution – Medium Structured Grid

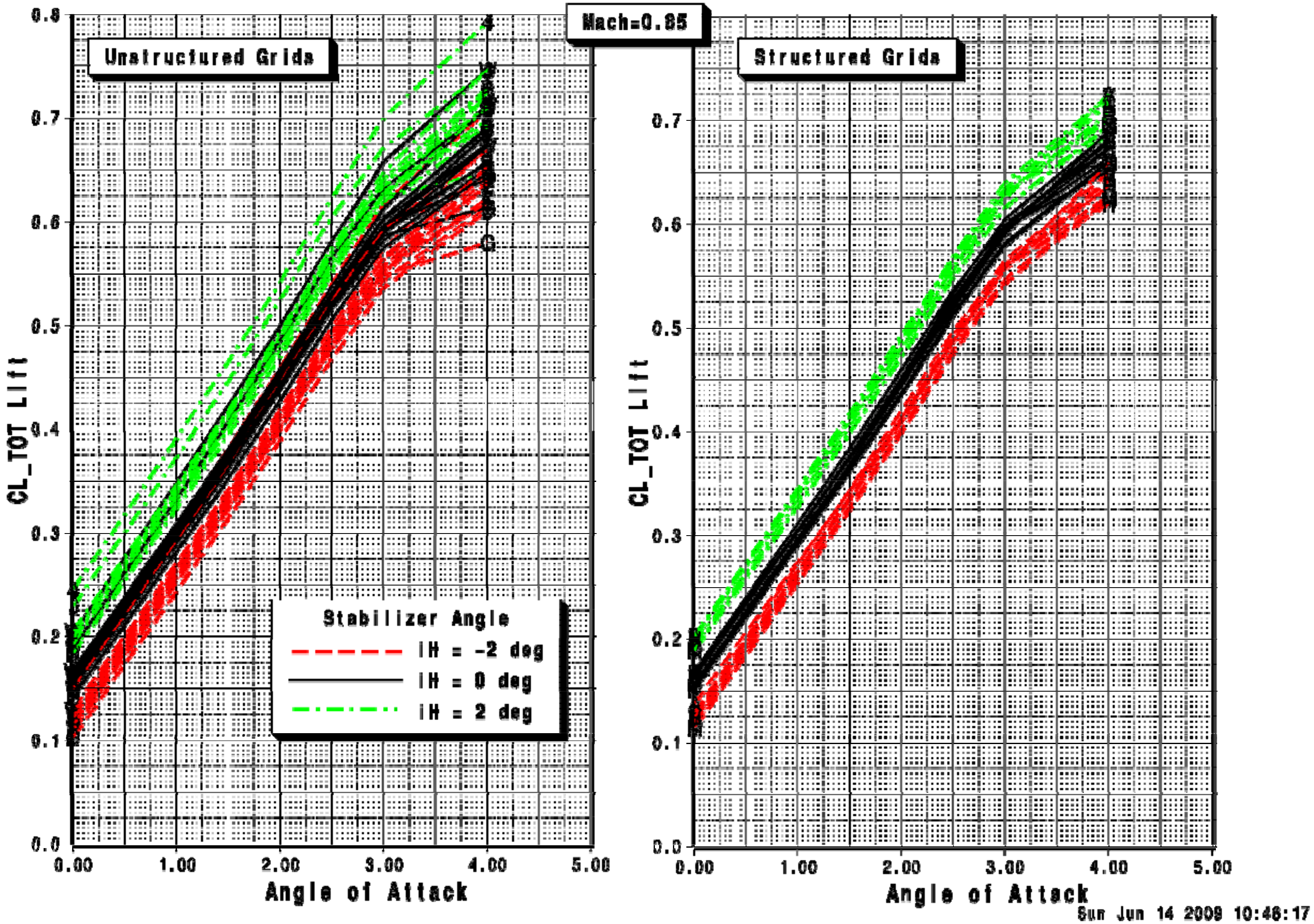


Wing Pressure Distribution – Solar Unstructured Grid

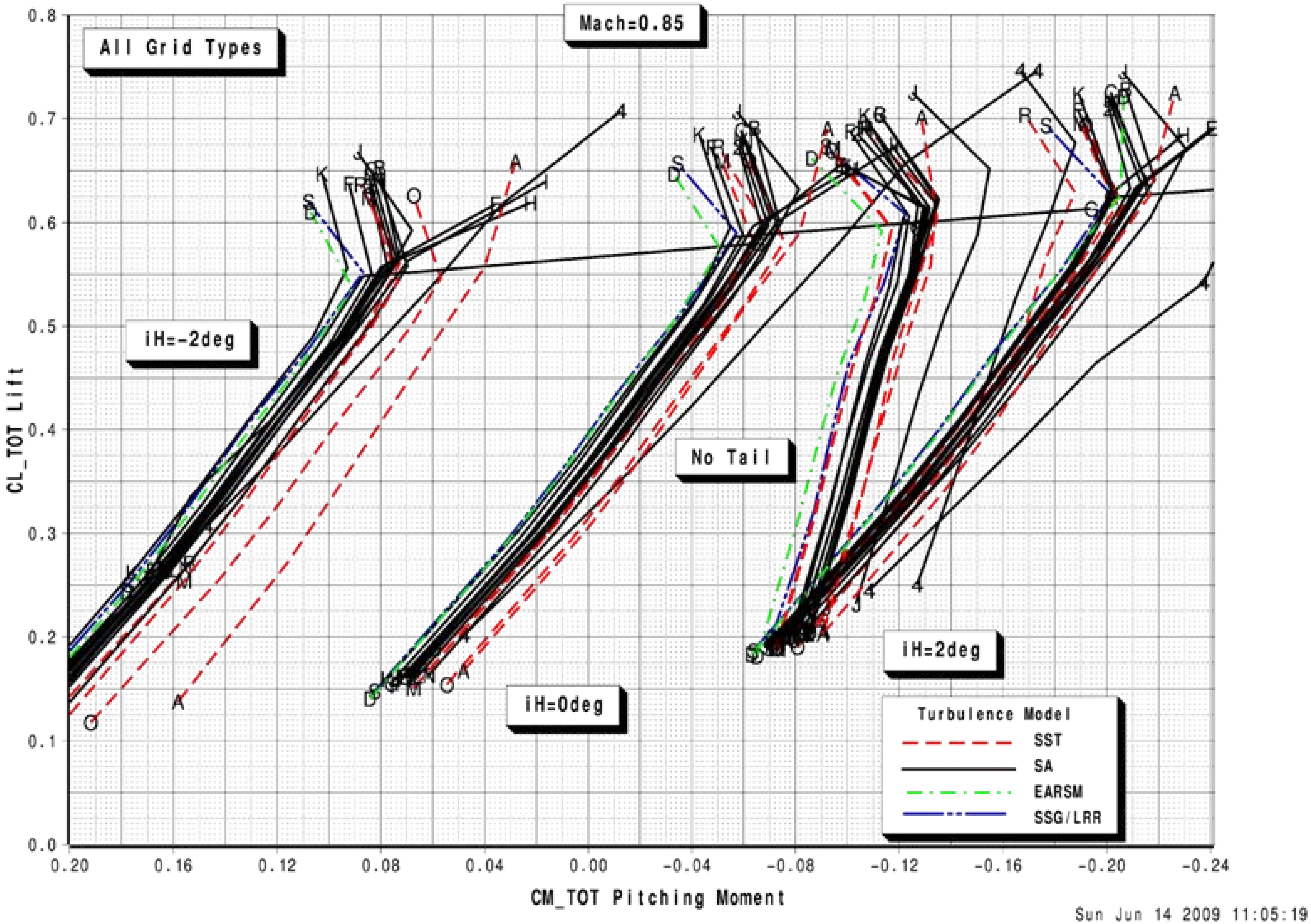


- **Case 1b: Downwash Study**
  - Mach = 0.85
  - Drag Polars for alpha = 0.0°, 1.0°, 1.5°, 2.0°, 2.5°, 3.0°, 4.0°
  - Tail Incidence angles iH = -2°, 0°, +2°, and Tail off
  - Medium grid
  - Chord Reynolds Number: Re=5M
  - Trimmed Drag Polar (CG at reference center) derived from polars at iH = -2°, 0°, +2°
  - Delta Drag Polar of tail off vs. tail on (i.e. WB vs. WBH trimmed)

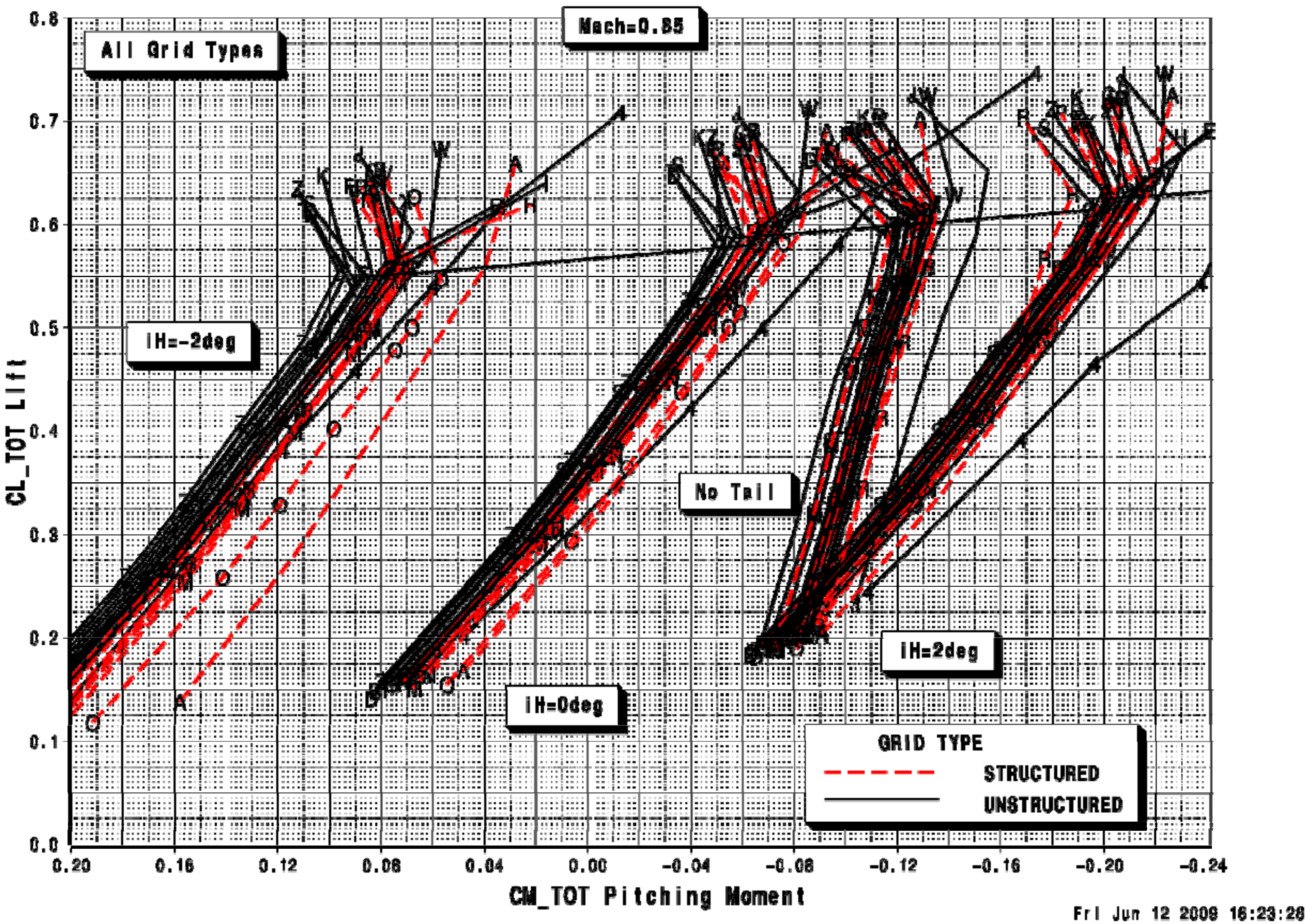
Lift vs. Angle of Attack – All Solutions – iH= -2, 0, 2 degrees



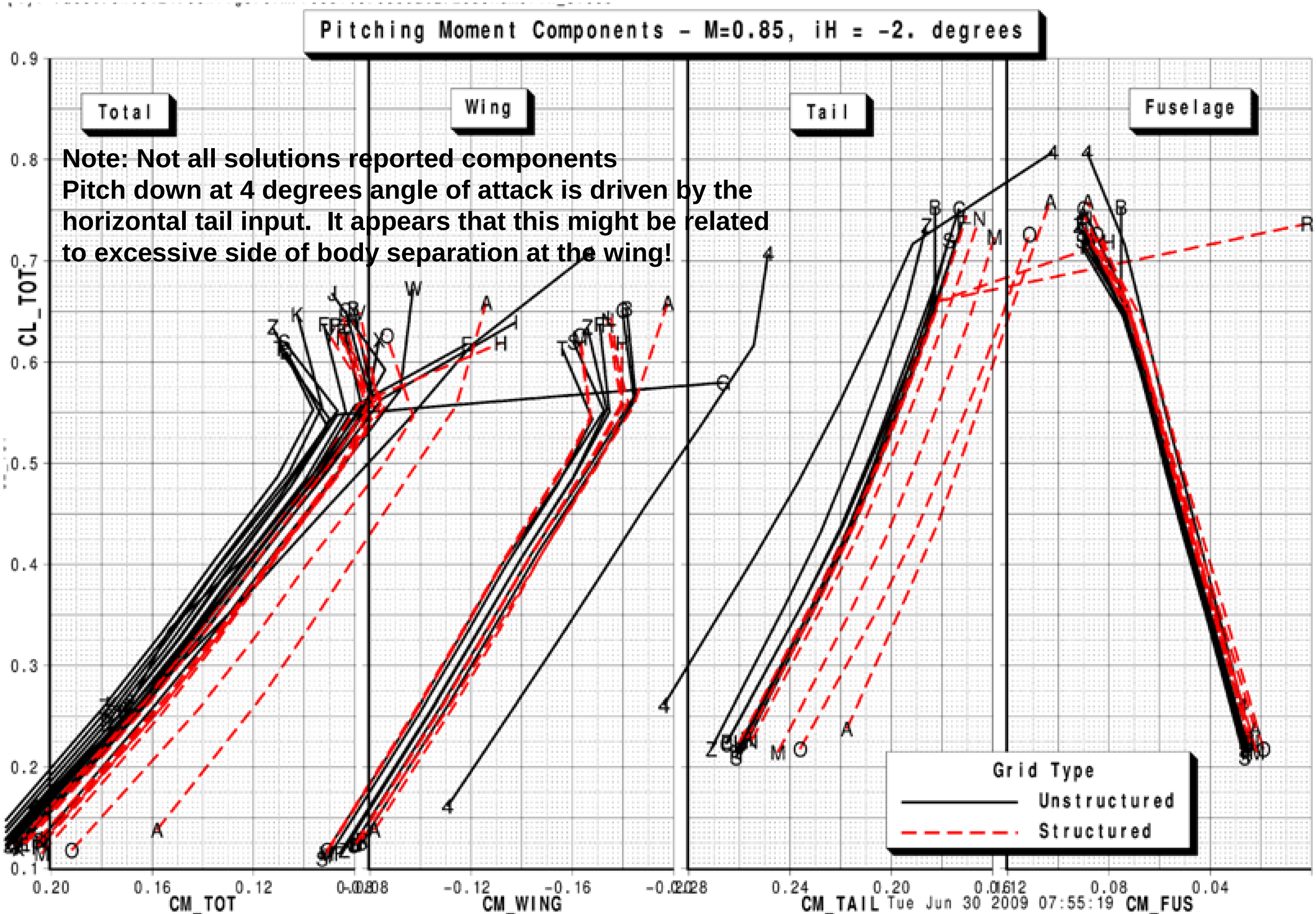
Lift vs. Pitching Moment – All Solutions – iH= -2, 0, 2 degrees



Lift vs. Pitching Moment – All Solutions – iH= -2, 0, 2 degrees

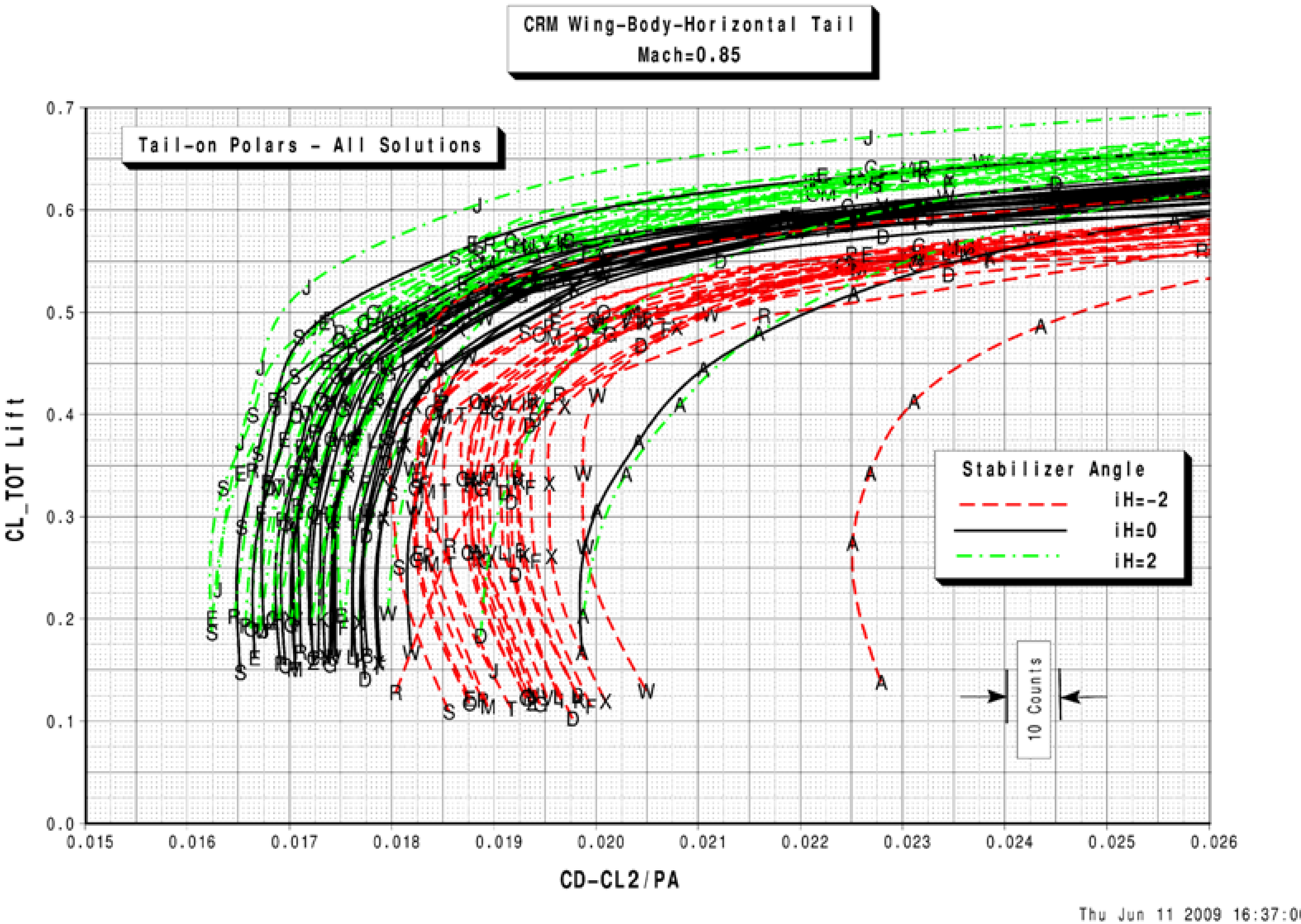


Lift vs. Pitching Moment Components – iH= -2 degrees

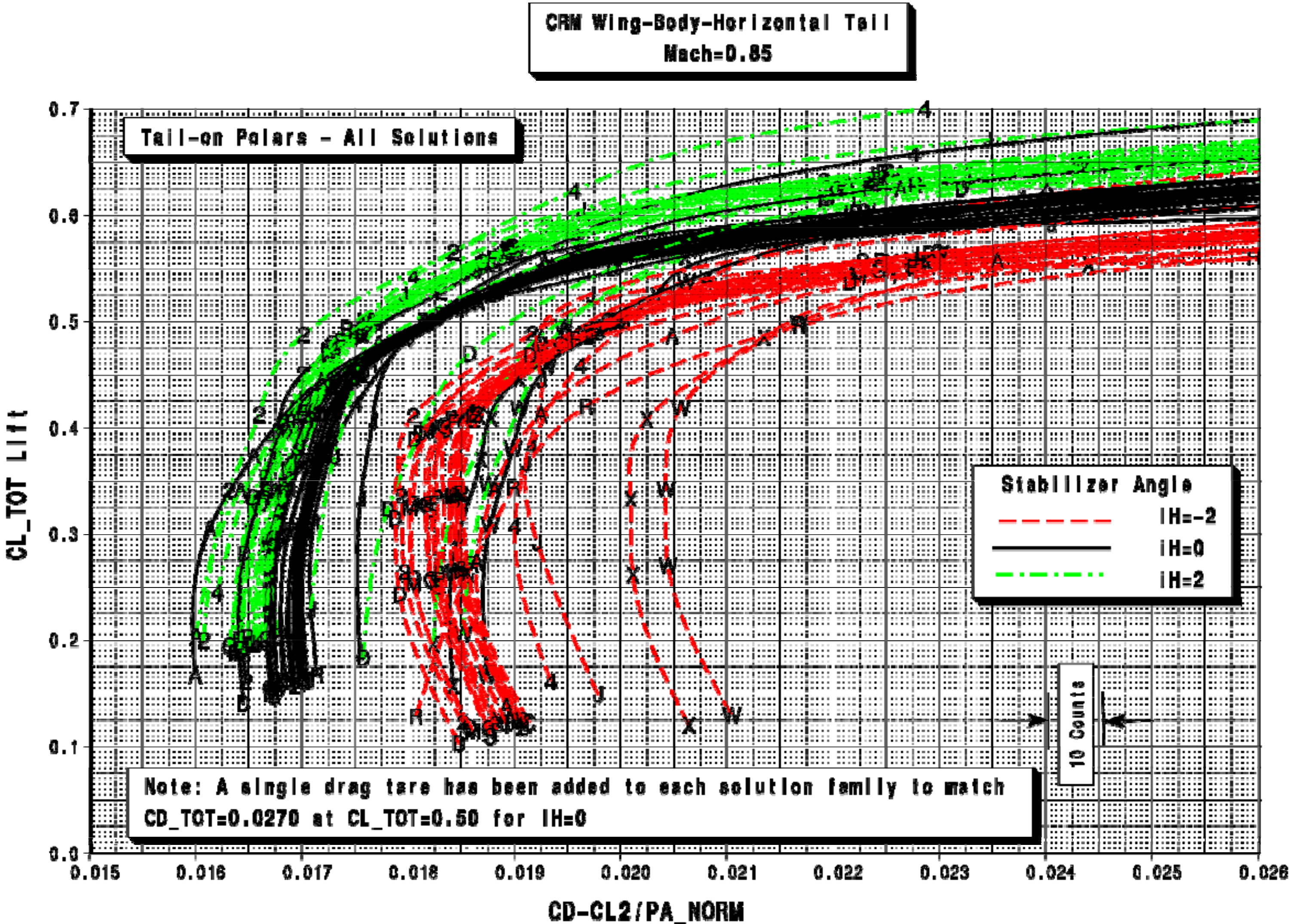


Note: Not all solutions reported components
Pitch down at 4 degrees angle of attack is driven by the horizontal tail input. It appears that this might be related to excessive side of body separation at the wing!

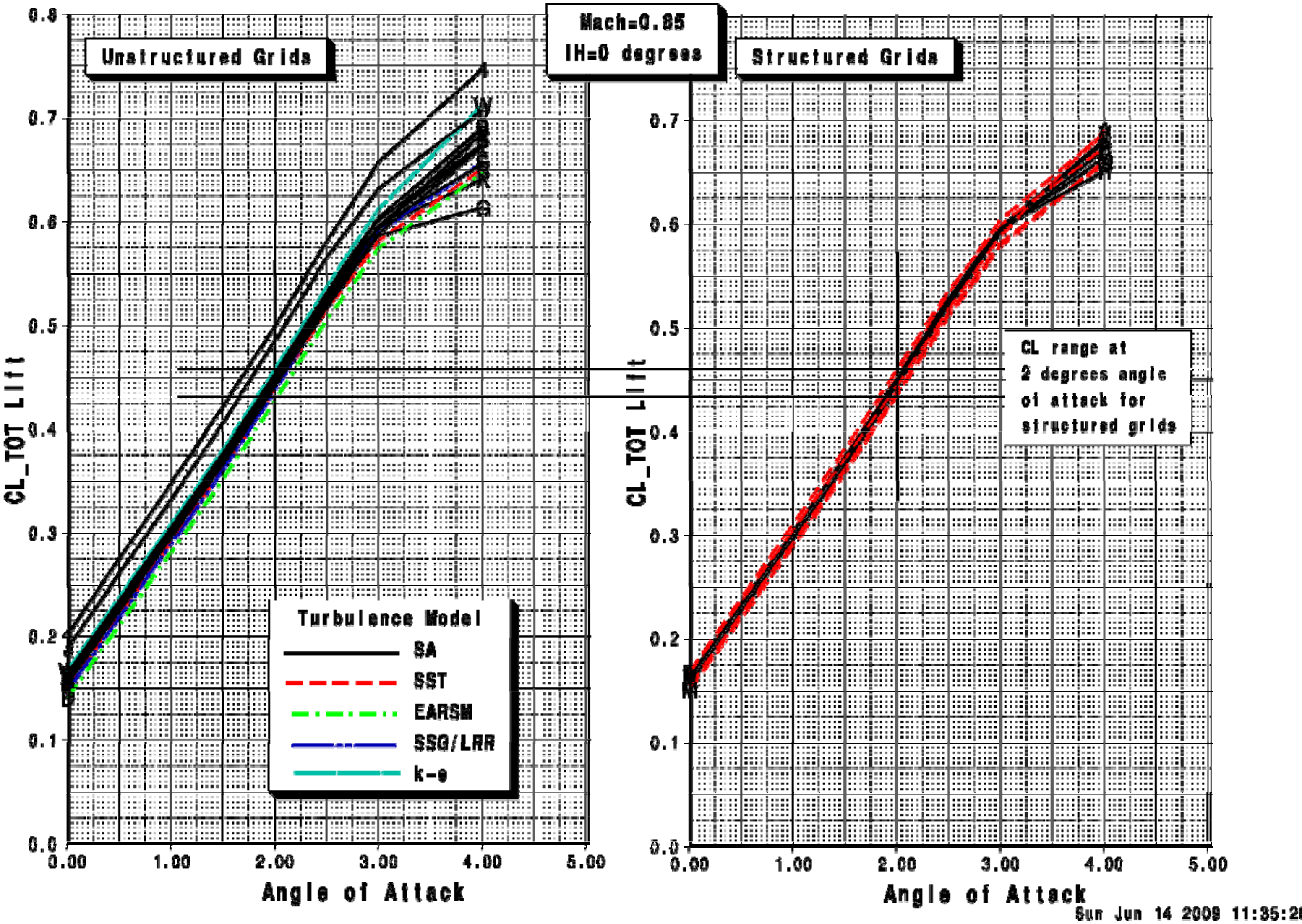
Lift vs. Drag – All Solutions – iH= -2, 0, 2 degrees



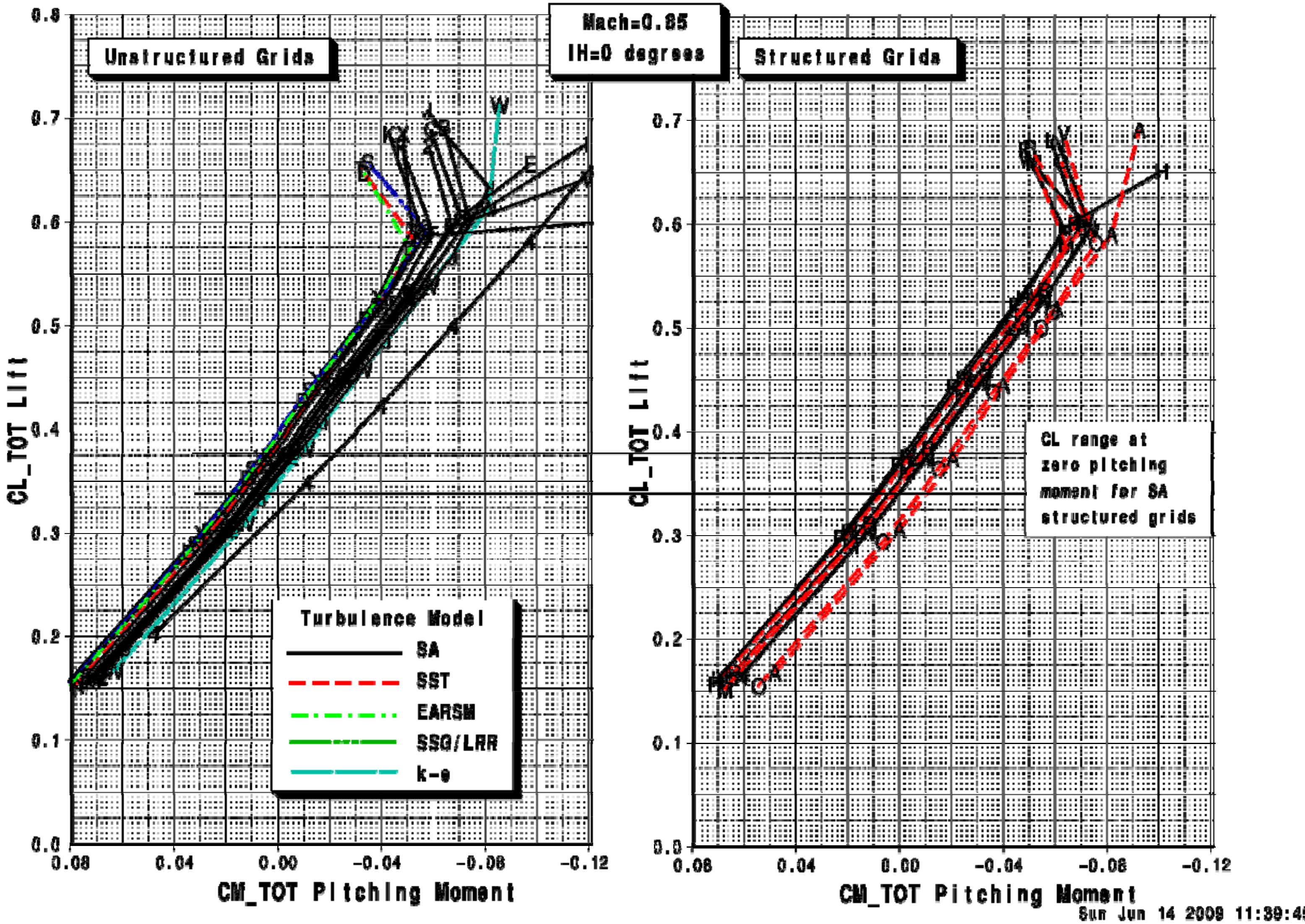
Lift vs. Drag – All Solutions – iH= -2, 0, 2 degrees



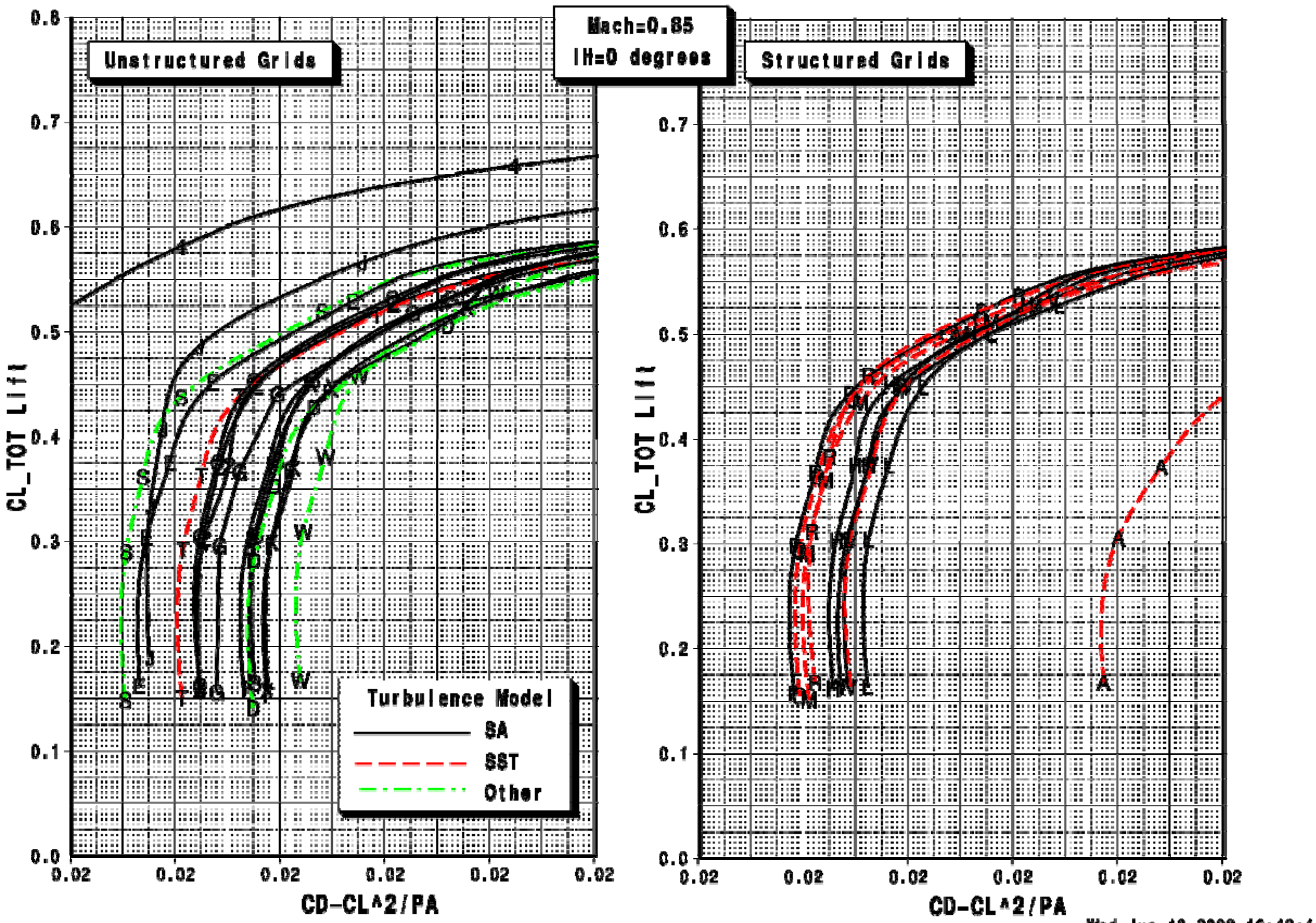
Lift vs. Drag – All Solutions – iH= 0. degrees



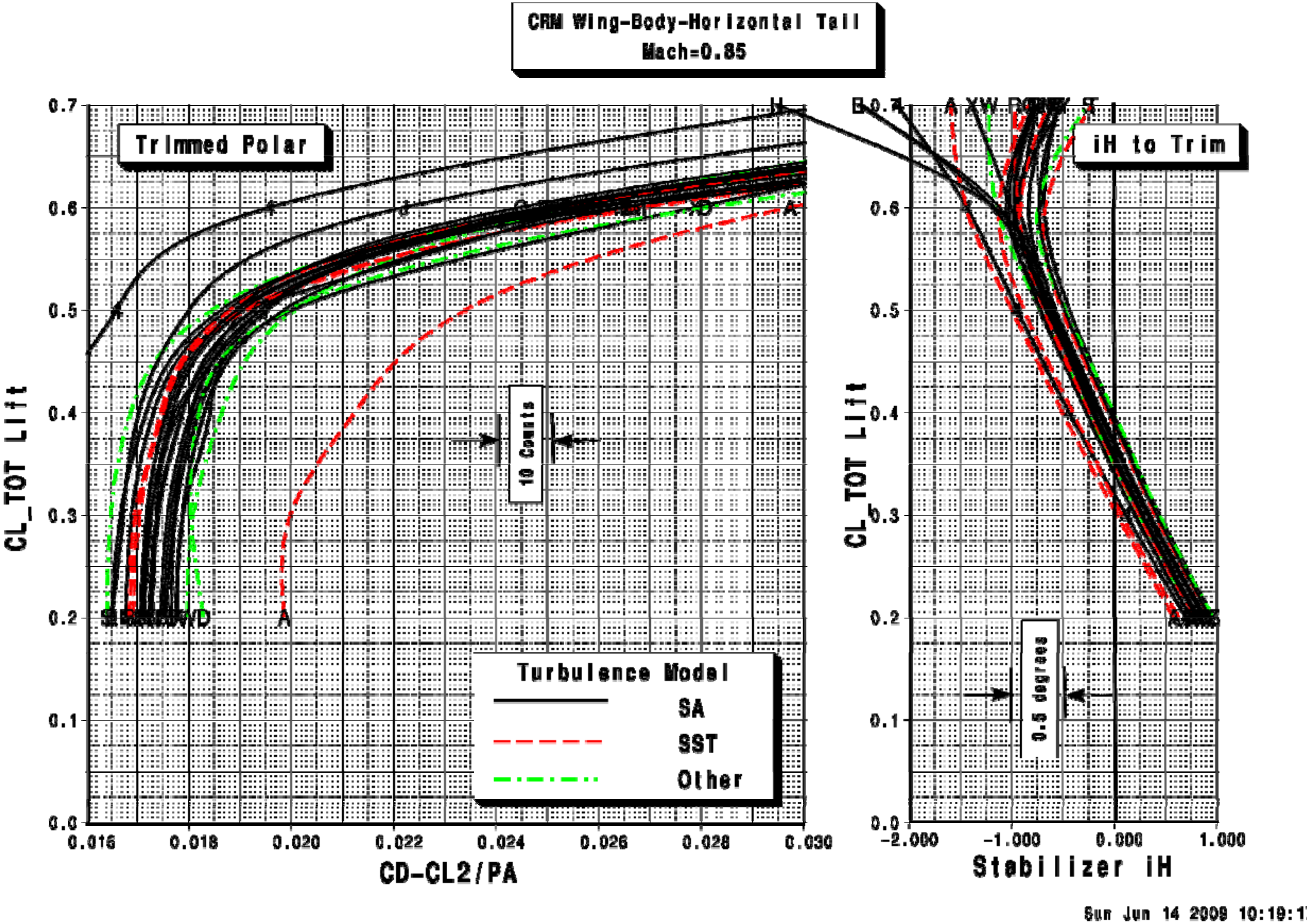
Lift vs. Pitching Moment – All Solutions – iH= 0. degrees



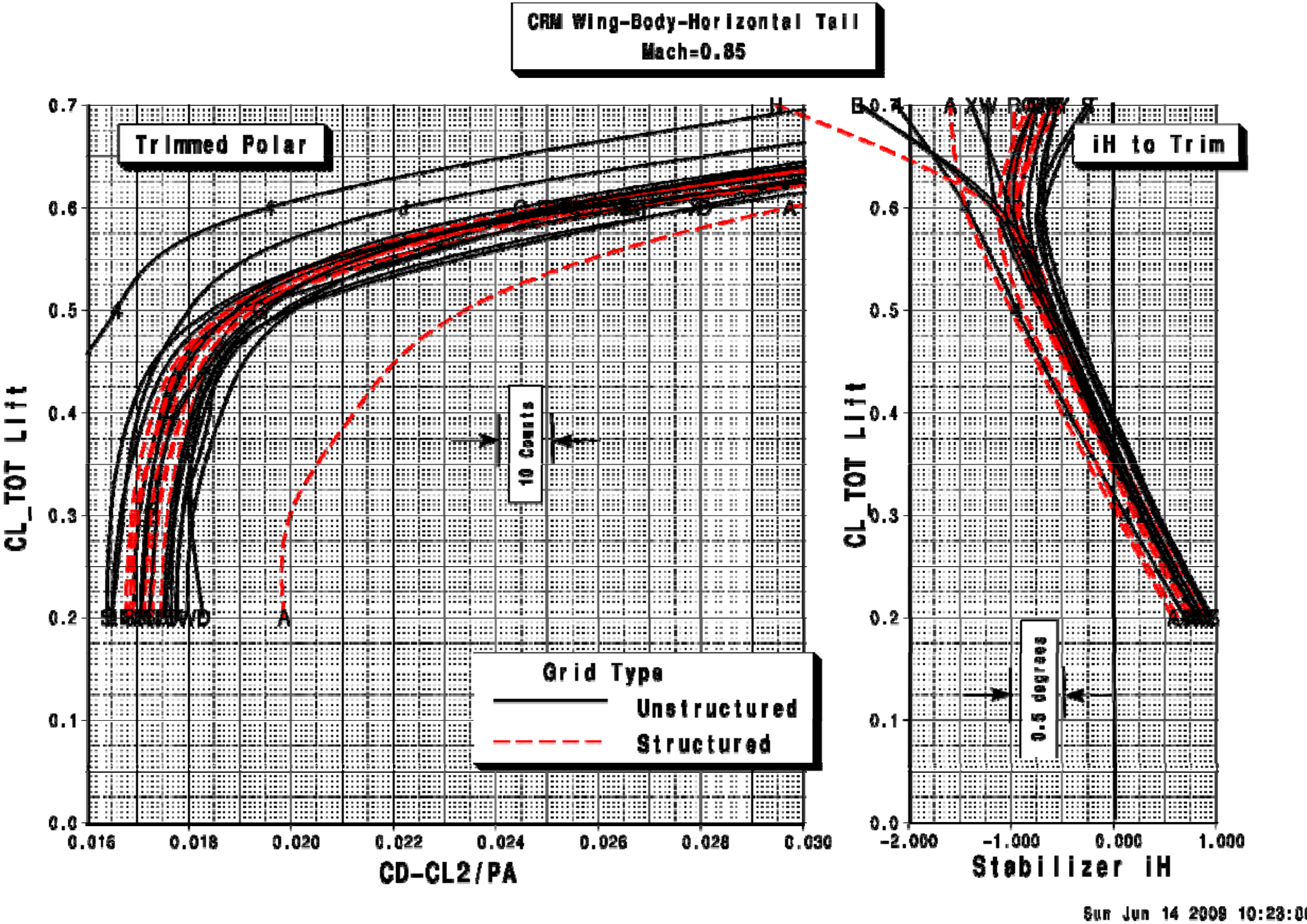
Lift vs. Drag – All Solutions – iH= 0. degrees



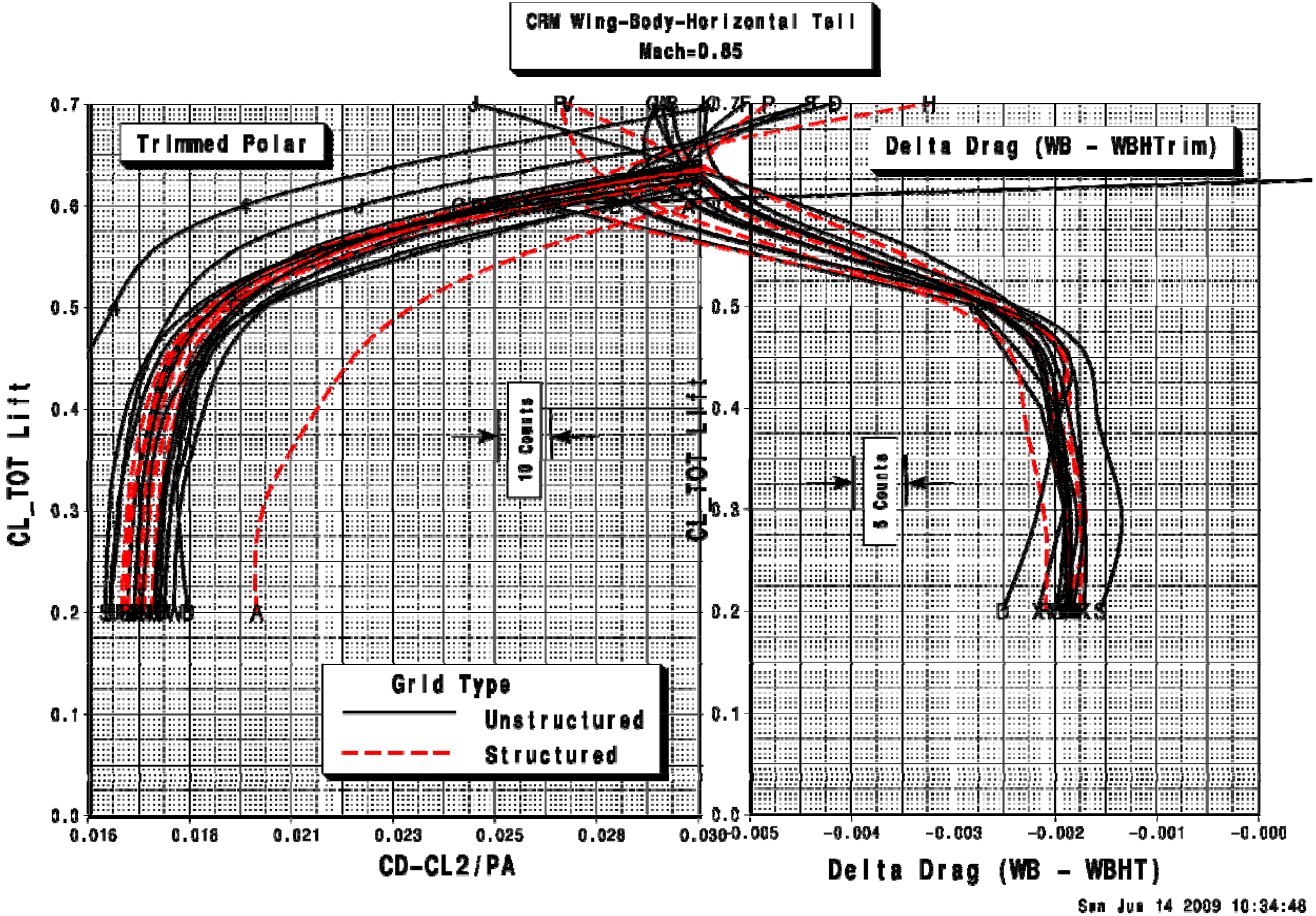
Drag and iH at Zero Pitching Moment – All Solutions



Drag and iH at Zero Pitching Moment – All Solutions

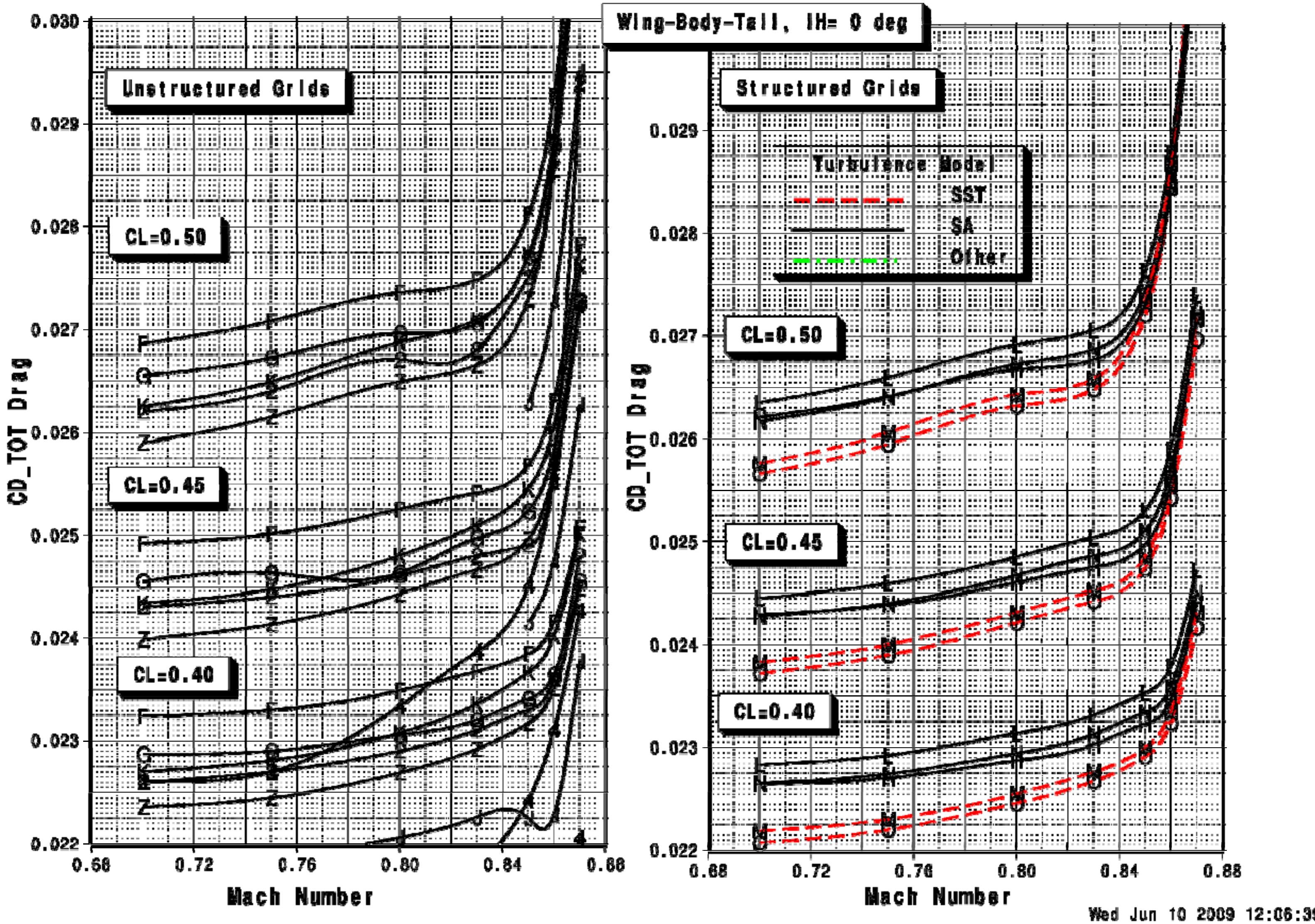


Trim Drag and Drag at Zero Pitching Moment – All Solutions



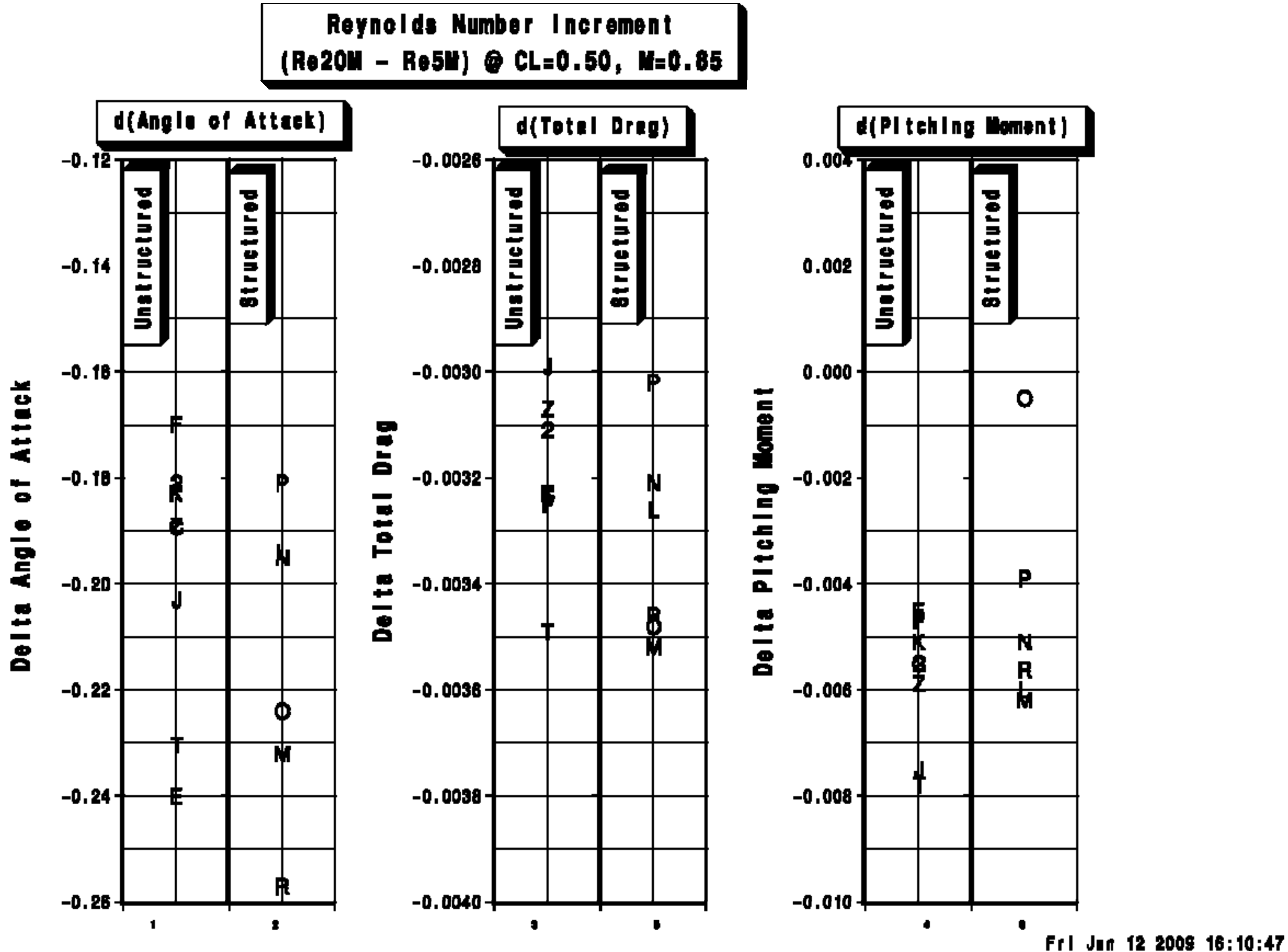
- **Case 2 (Optional) : Mach Sweep Study**
  - Drag Polars at:- Mach = 0.70, 0.75, 0.80, 0.83, 0.85, 0.86, 0.87
  - Drag Rise curves at CL = 0.400, 0.450, 0.500 (±0.001 or extracted from polars)
  - Untrimmed, Tail Incidence angle, iH = 0°
  - Medium grid
  - Chord Reynolds Number: Re=5M

Drag Rise – All Solutions

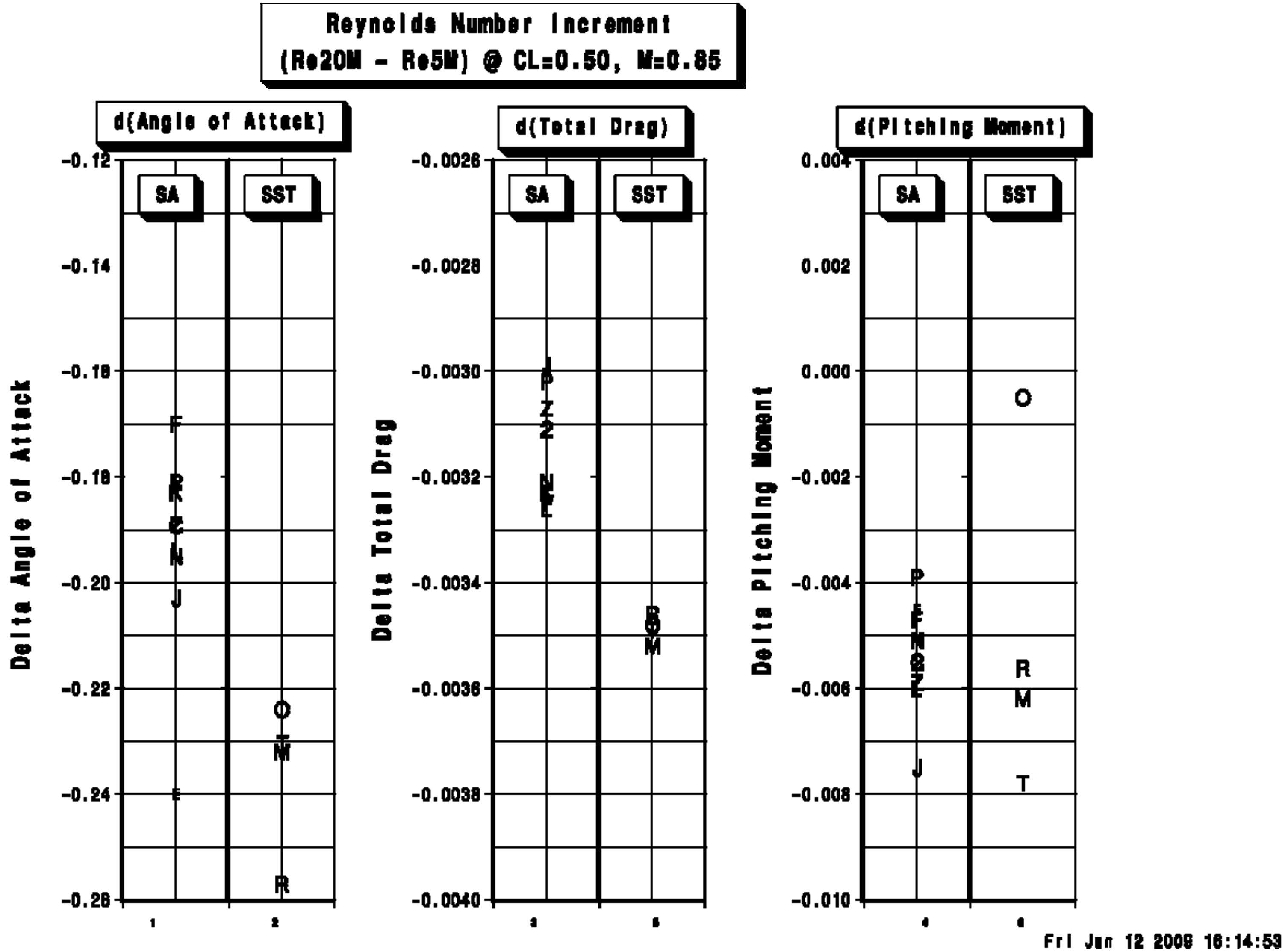


- **Case 3 (Optional) : Reynolds Number Study**
  - Mach = 0.85, CL = 0.500 (±0.001)
  - Tail Incidence angle iH = 0°
  - Medium grid
  - Chord Reynolds Numbers: Re=5M and Re=20M

Reynolds Number Increment – Grid Type



Reynolds Number Increment – Turbulence Model



Concluding Remarks

- Generally a successful effort in that a wide variety of submissions from different organizations with diverse codes and methods. Lots of data! Thanks to everyone for their efforts.
- More scatter from unstructured methods than from structured grid methods. Suspect this is more due to grid than to code.
- The number of unstructured codes that provided results within the span and accuracy of the structured grids have increased. Less outliers.
- Still a fair amount of scatter in the separation bubble, but the bubble itself is smaller on this configuration.
- A lot of scatter in the shock location at WS13 but tends to diminish with increasing grid size.
- Most of the codes predict similar drag and pitching moment levels for iH=0 and iH=+2, whereas there is a larger variation for iH=-2. Suspect tail-after body junction separation.
- Excessive nose down pitching moment at 4 degrees angle of attack reported for a few solutions. Suspect this is related to excessive side-of-body separation at this condition.

Concluding Remarks

- Less scatter seen for trim drag and iH to trim than seen for absolute levels of drag and pitching moment.
- Solutions at 4 degrees angle of attack showed a lot of scatter in pitching moment indicating very different separation patterns.
- MDD is pretty well captured by all the codes that submitted Case 2. Similar scatter levels as for Case 1b.
- Reynolds number increment predictions were very consistent. Correlated better with turbulence model than with grid type.
- As with previous DPW's, there are no clear trends for turbulence model. Clearly, SA and SST models dominate.

Recommendations for Proposed Testing of CRM

Issues raised by DPW4 CFD analysis suggest the need for certain (additional) wind tunnel testing.

- Current NTF plan is bare-bones.
- More tail angles at higher RN to get RN effect on tail and trim
- Repeat series at RN=20M & 5M and at Ames, RN=5M to better define drag levels.
- Pressure sensitive paint at NTF on wing and H. Tail
- Various flow measurement devices at NASA Ames – consider adding
  - UV or colored oil, especially for wing-body and tail-body juncture flow. (different tail angles and at high angle of attack)
  - Pressure sensitive paint on wing and tail.
- High angle of attack testing (3-6+ degrees by 0.25 deg.)
- Testing at ETW would provide useful comparisons between tunnels.

Next Steps?