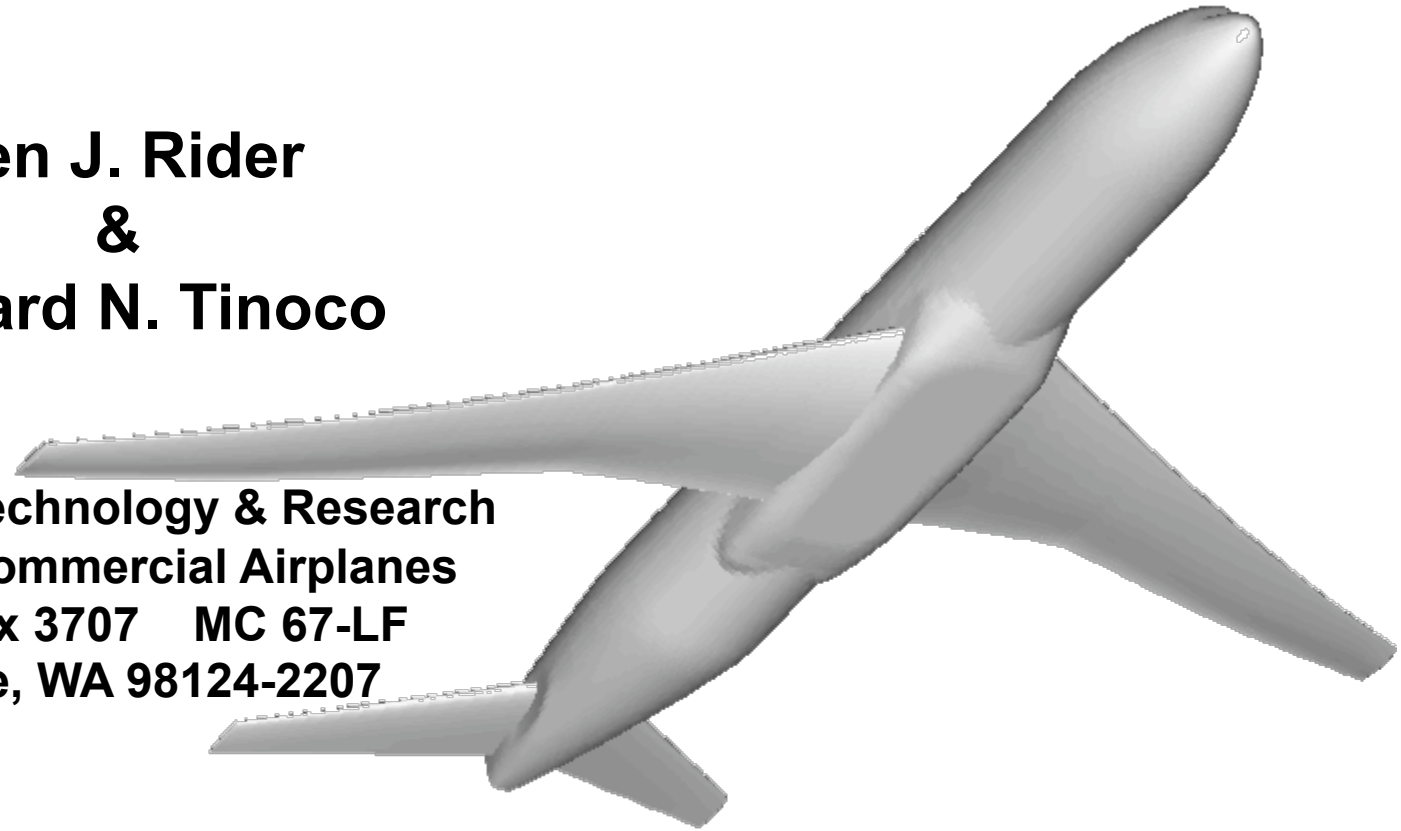
CFL3D Analysis of the NASA Common Research Model for the 4th Drag Prediction Workshop

Ben J. Rider
&
Edward N. Tinoco

Enabling Technology & Research
Boeing Commercial Airplanes
P.O. Box 3707 MC 67-LF
Seattle, WA 98124-2207



4th CFD Drag Prediction Workshop

San Antonio, Texas – June 2009

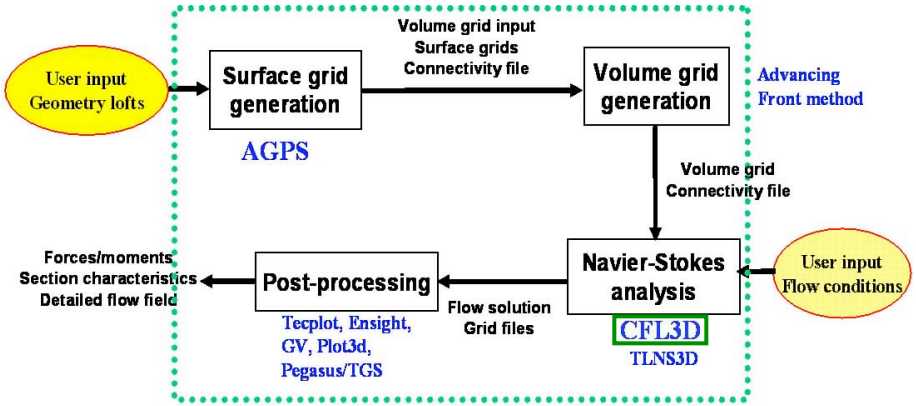
Objective

Investigate the use of a "Production Navier-Stokes Analysis System" for CFD Drag Prediction

-Major interest is in the prediction of drag and pitching moment increments

-Use "standard" processes as much as possible

Zeus/CFL3D



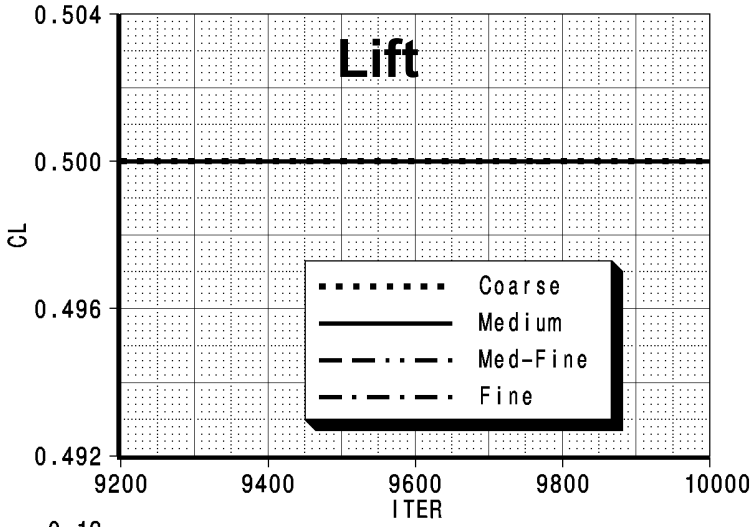
- CFL3D Developed at NASA Langley
- Finite volume, Upwind biased (Roe) and central difference for viscous terms
- Multigrid and mesh sequencing for acceleration
- Multiblock with 1-1 blocking, patched grid, and overlap-grid
- Numerous turbulence models
  - Spalart-Allmaras SA Model
  - Menter's k-ω SST Model
- Time accurate with dual-time stepping

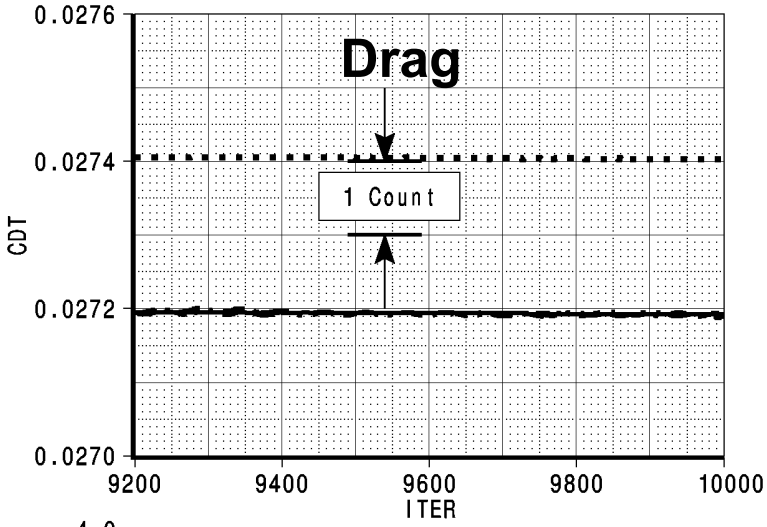
Acknowledgement

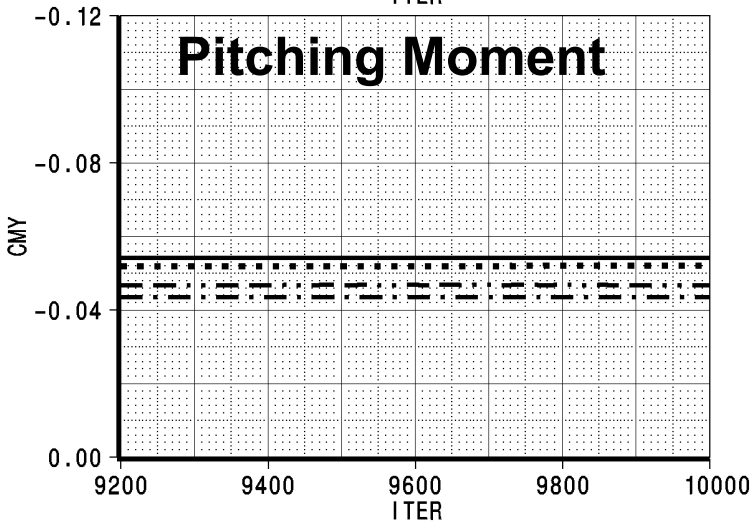
None of this work would have been possible without the considerable contributions of:
N. Jong Yu, Tsong-Jhy Kao, Margaret M. Curtin

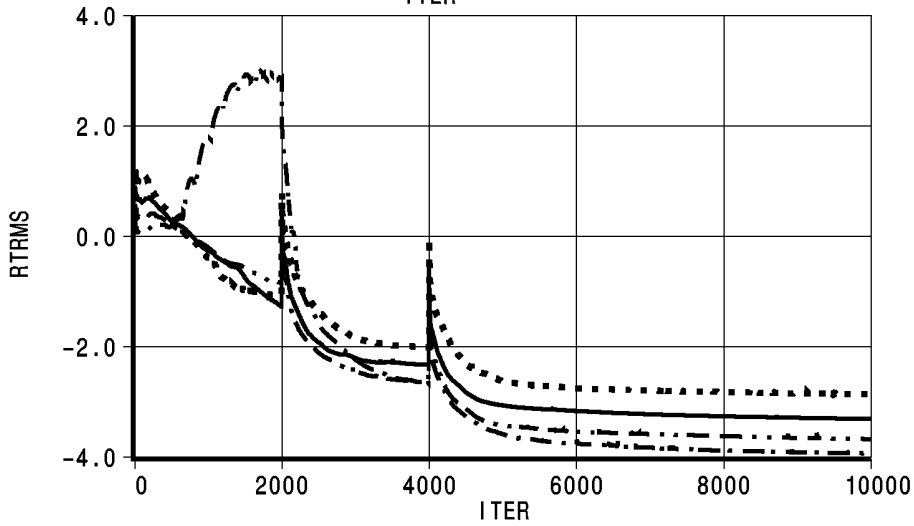
- **Case 1a: Grid Convergence Study**
  - Mach = 0.85, CL = 0.500 (±0.001)
  - Tail Incidence angle, iH= 0°
  - Coarse, Medium, Fine, Extra-Fine Grids (Extra-Fine optional)
  - Chord Reynolds Number: Re=5M

Case 1a: Grid Convergence Study – Thin-Layer / SST





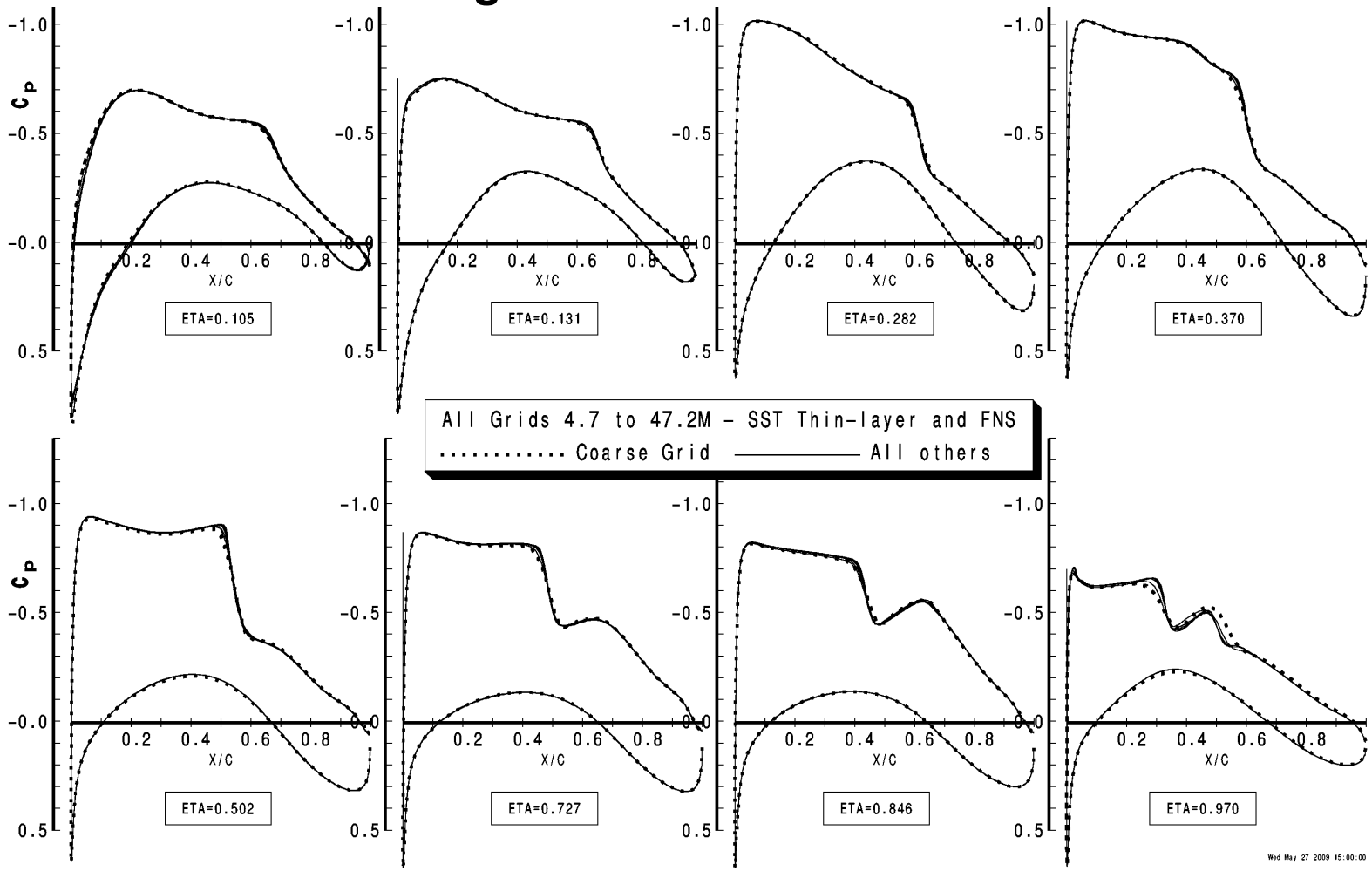




Rider

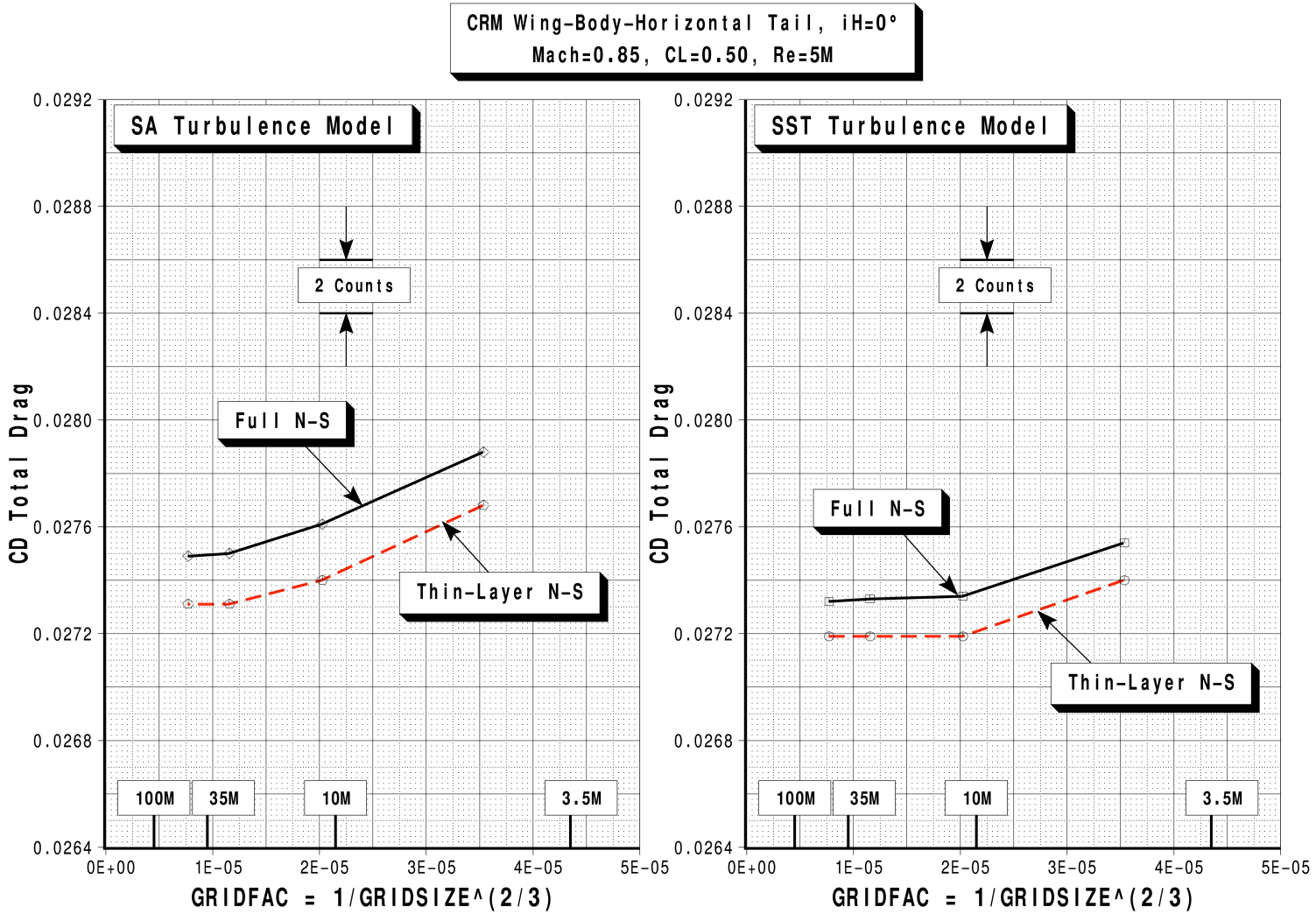
Case 1a: Grid Convergence Study – SST

Wing Pressure Distributions

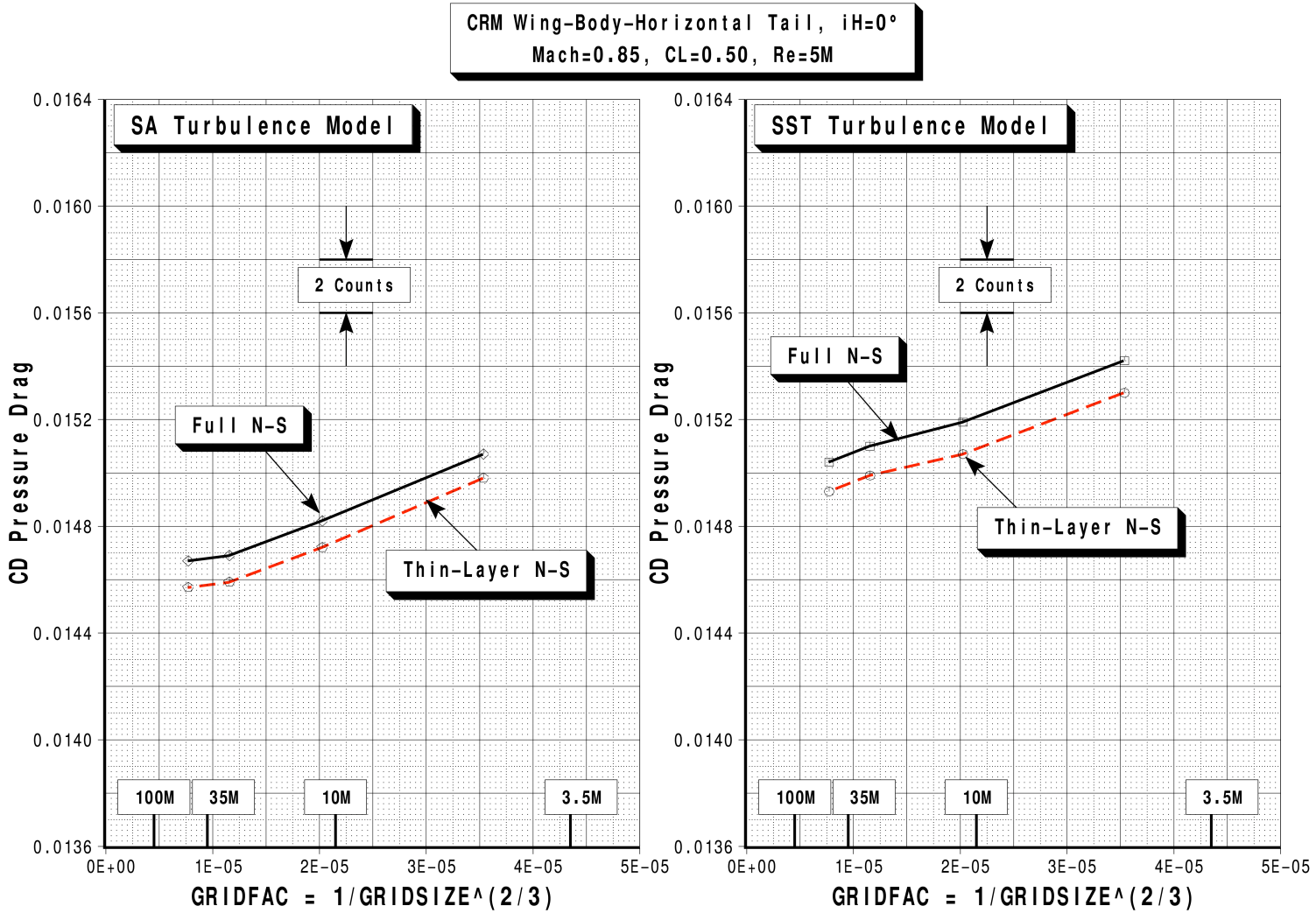


Rider

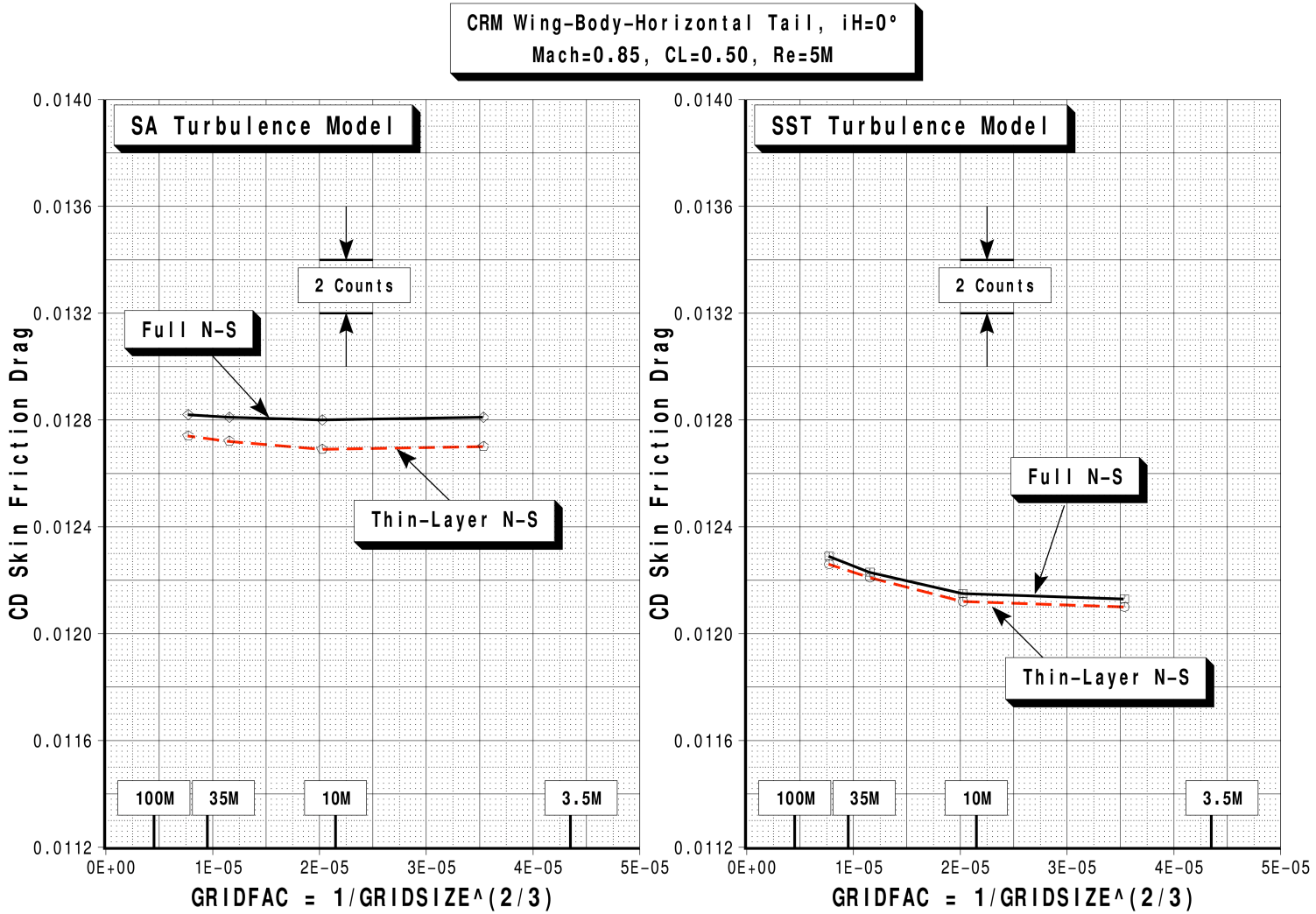
Case 1a: Total Drag Convergence



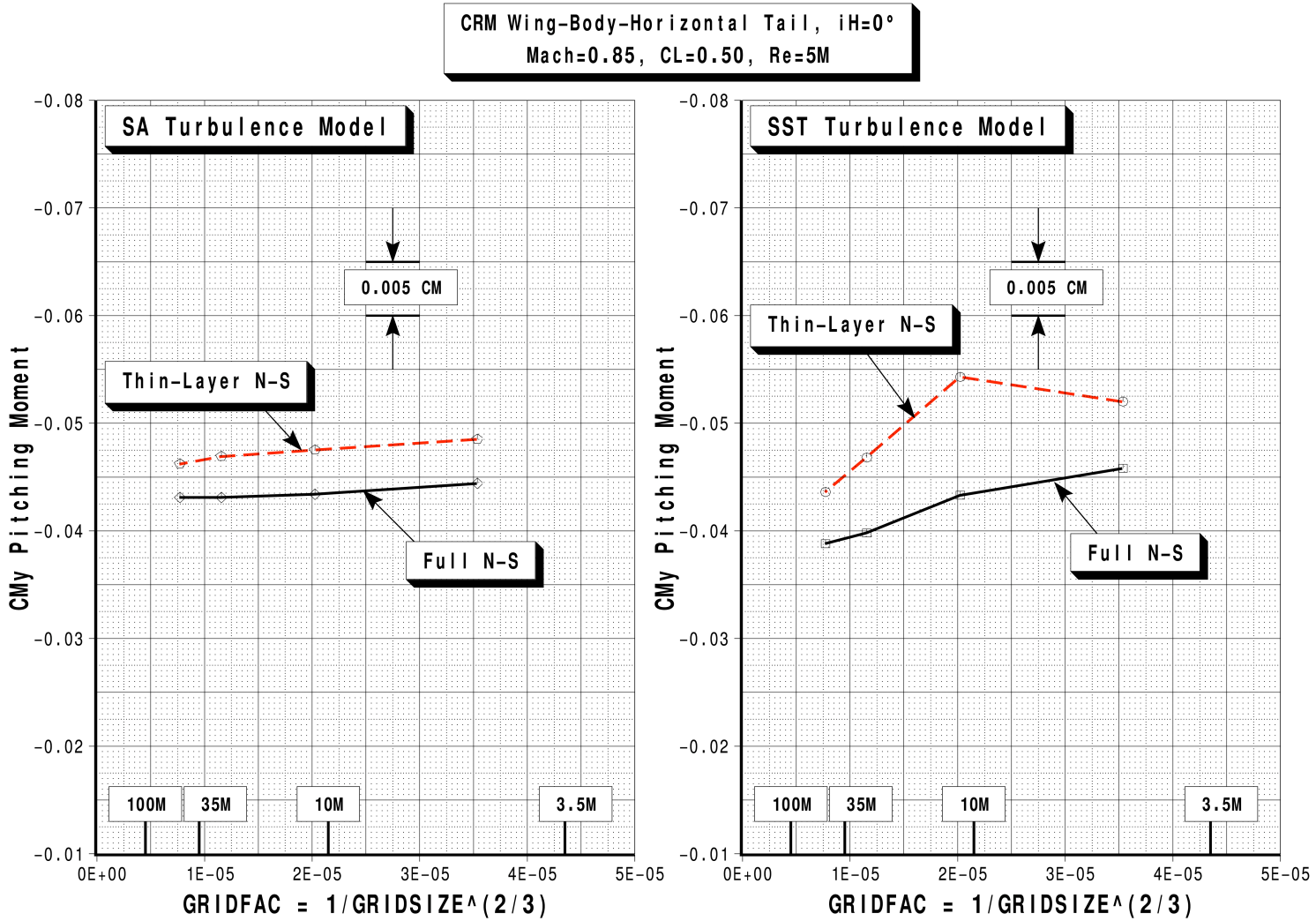
Case 1a: Pressure Drag Convergence



Case 1a: Skin Friction Drag Convergence

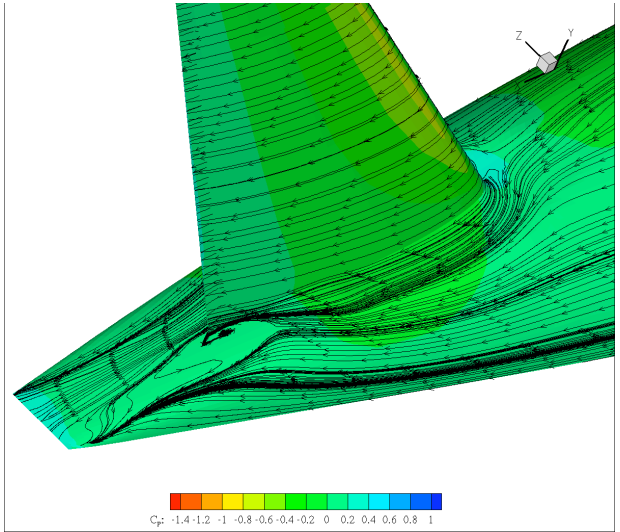


Case 1a: Pitching Moment Convergence

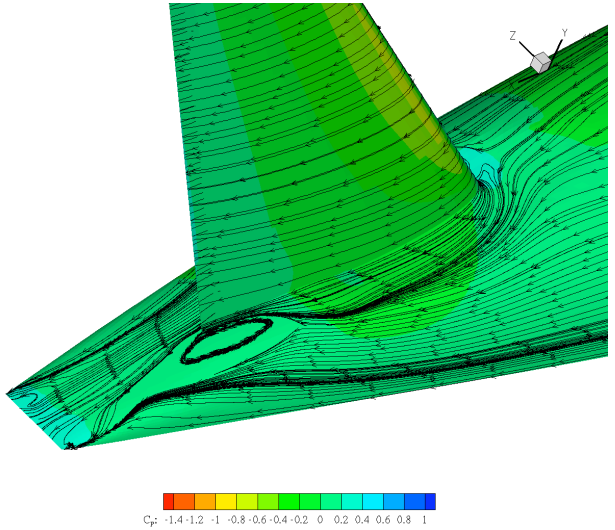


Case 1a: Grid Convergence Study – Thin-Layer NS / SST

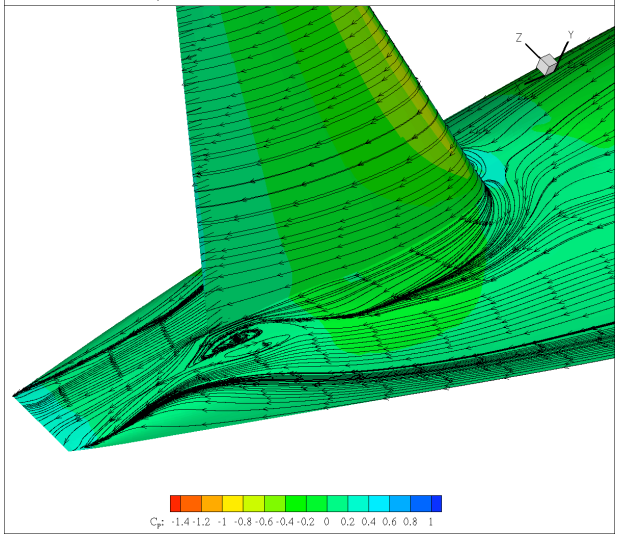
Coarse Grid



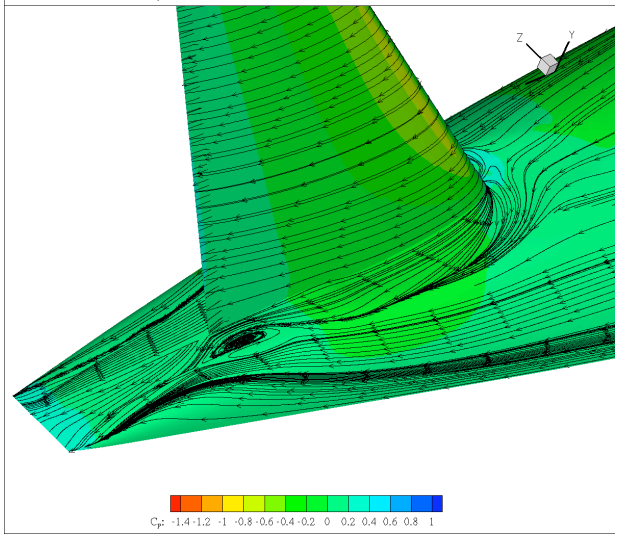
Medium Grid



Medium-Fine Grid



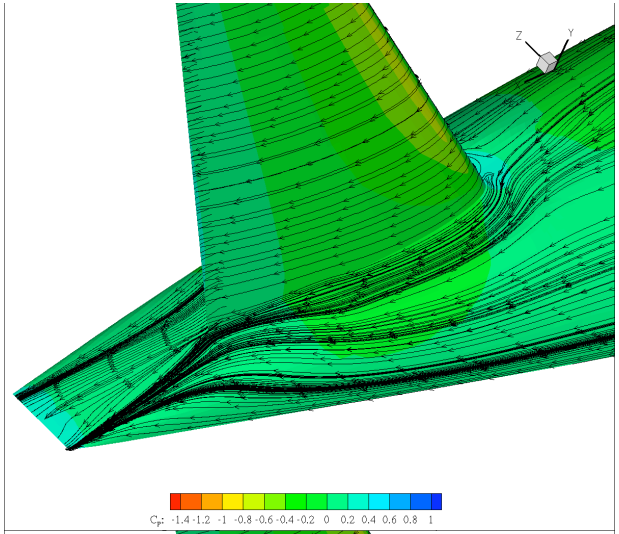
Fine Grid



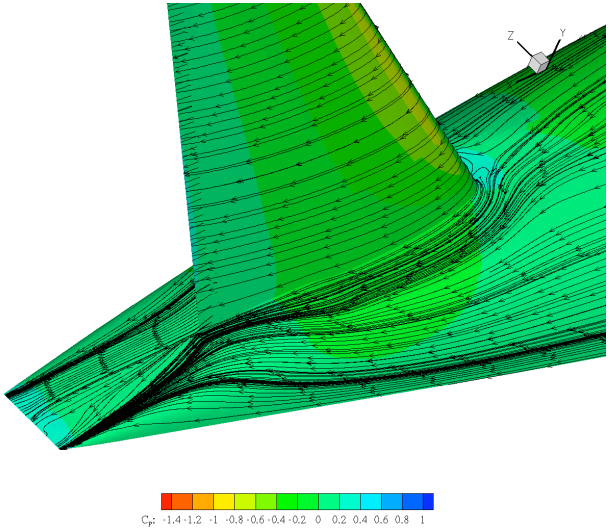
Rider

Case 1a: Grid Convergence Study – Thin-Layer NS / SA

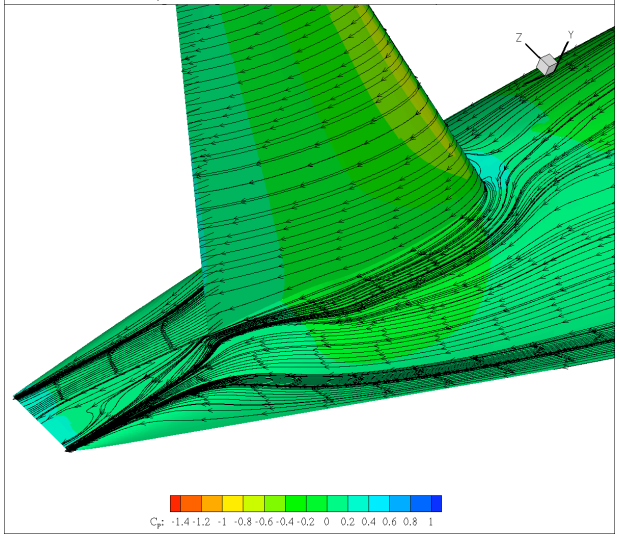
Coarse Grid



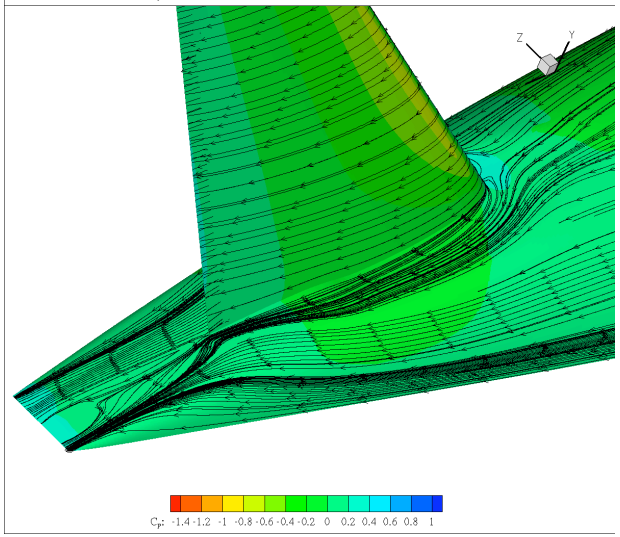
Medium Grid



Medium-Fine Grid



Fine Grid



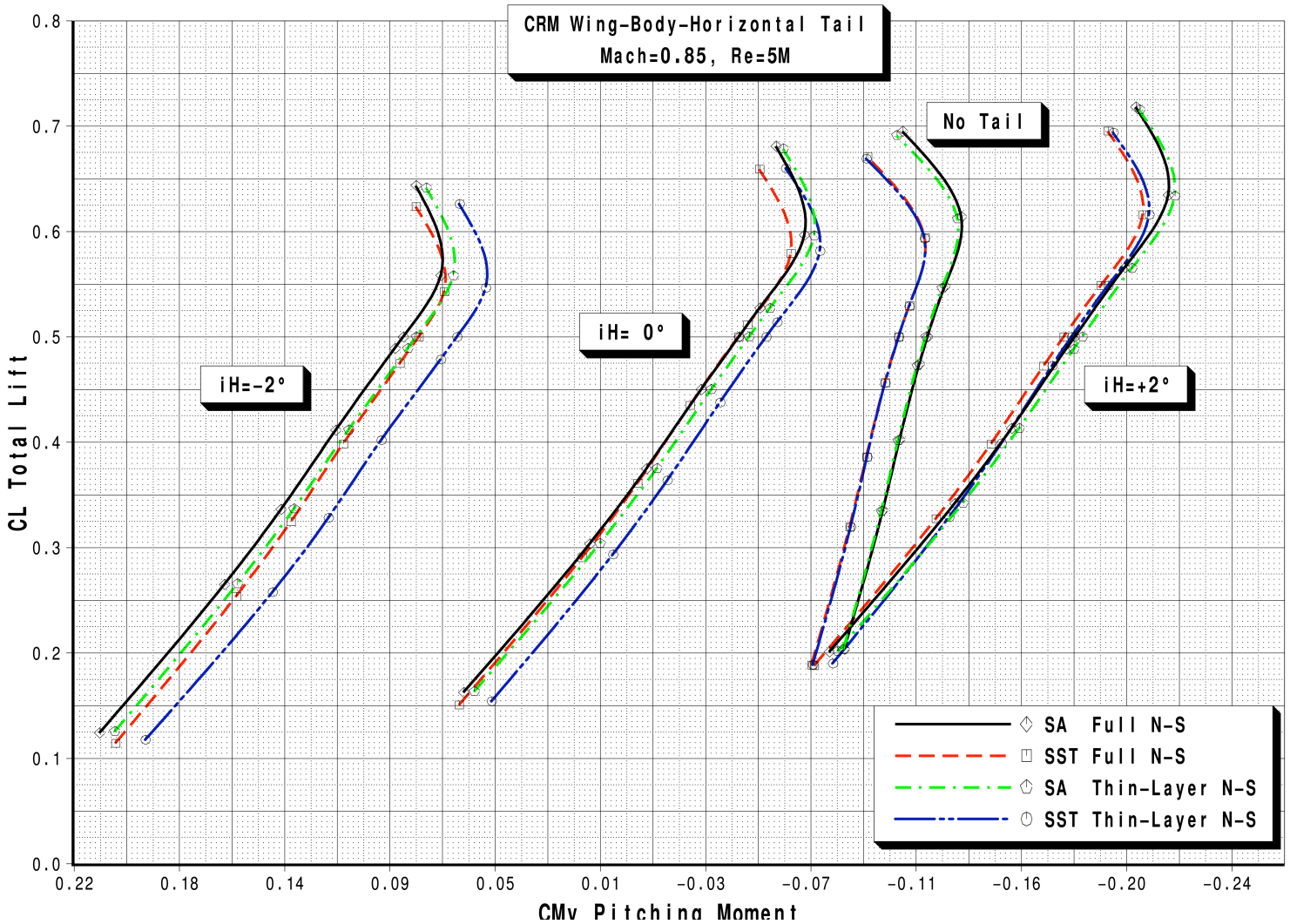
Rider

- **Case 1b: Downwash (Trim) 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
    - WB vs. WBH trimmed

4th CFD Drag Prediction Workshop

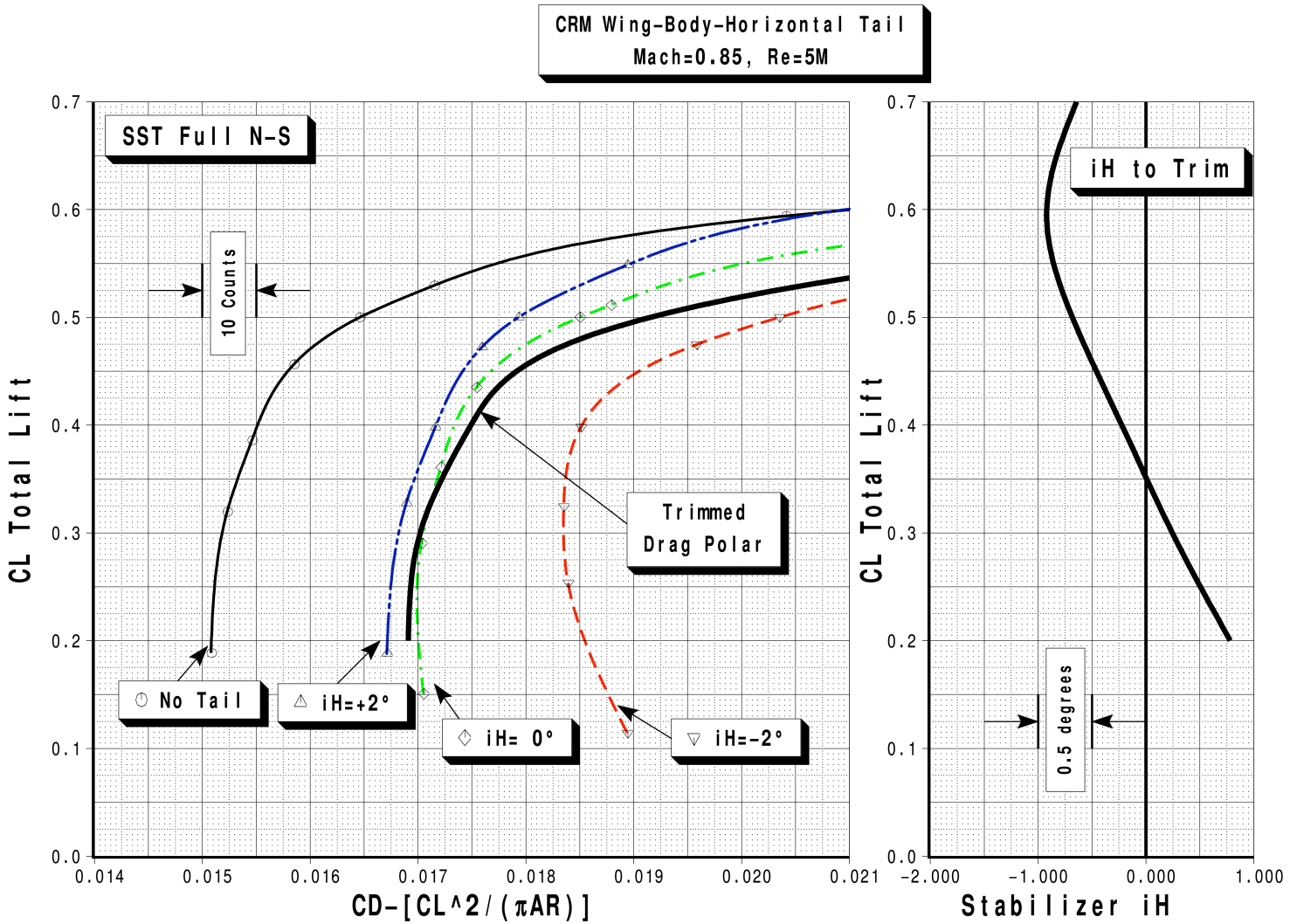
San Antonio, Texas – June 2009

Case 1b: Downwash (Trim) Study



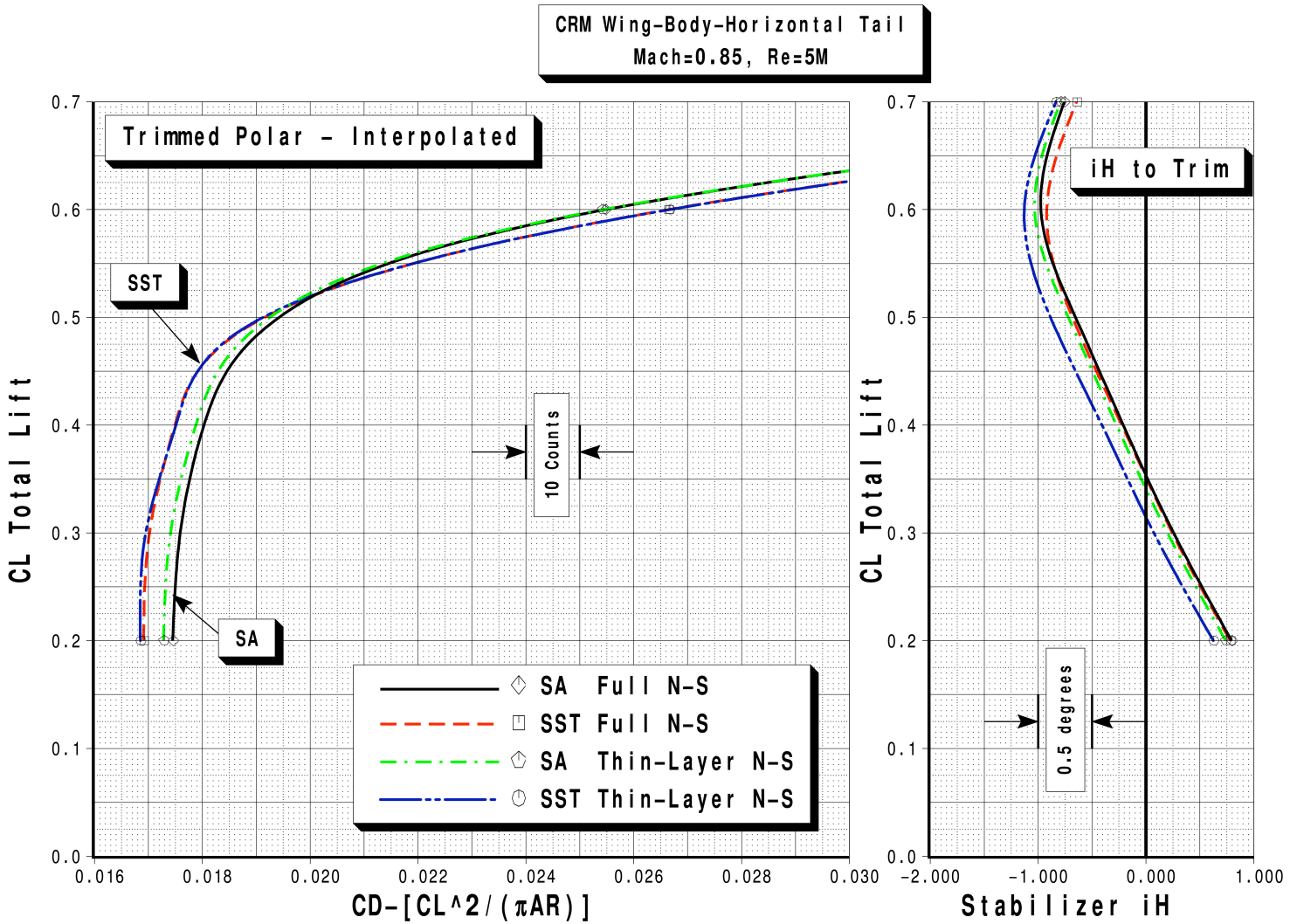
Rider

Case 1b: Downwash (Trim) Study

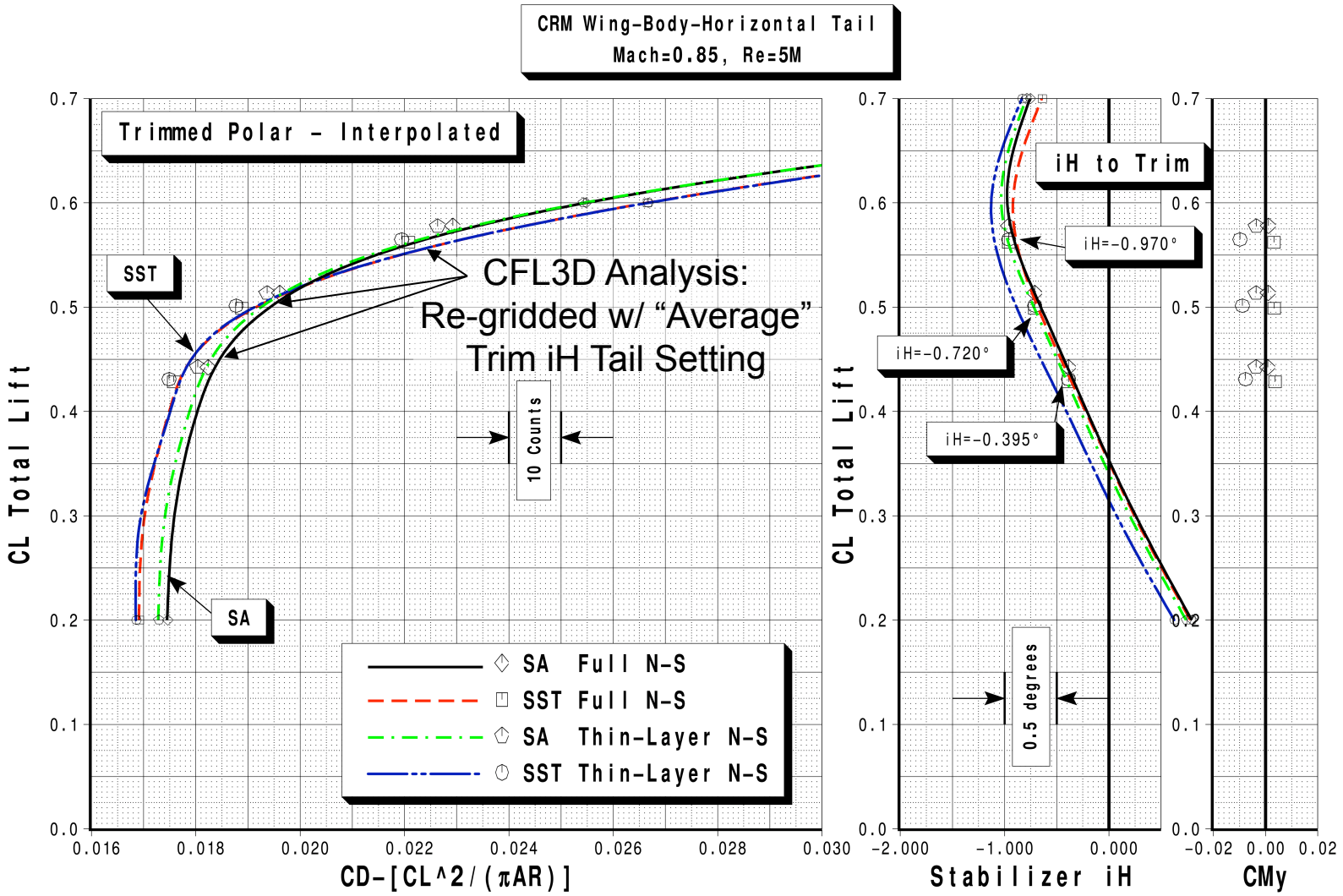


Rider

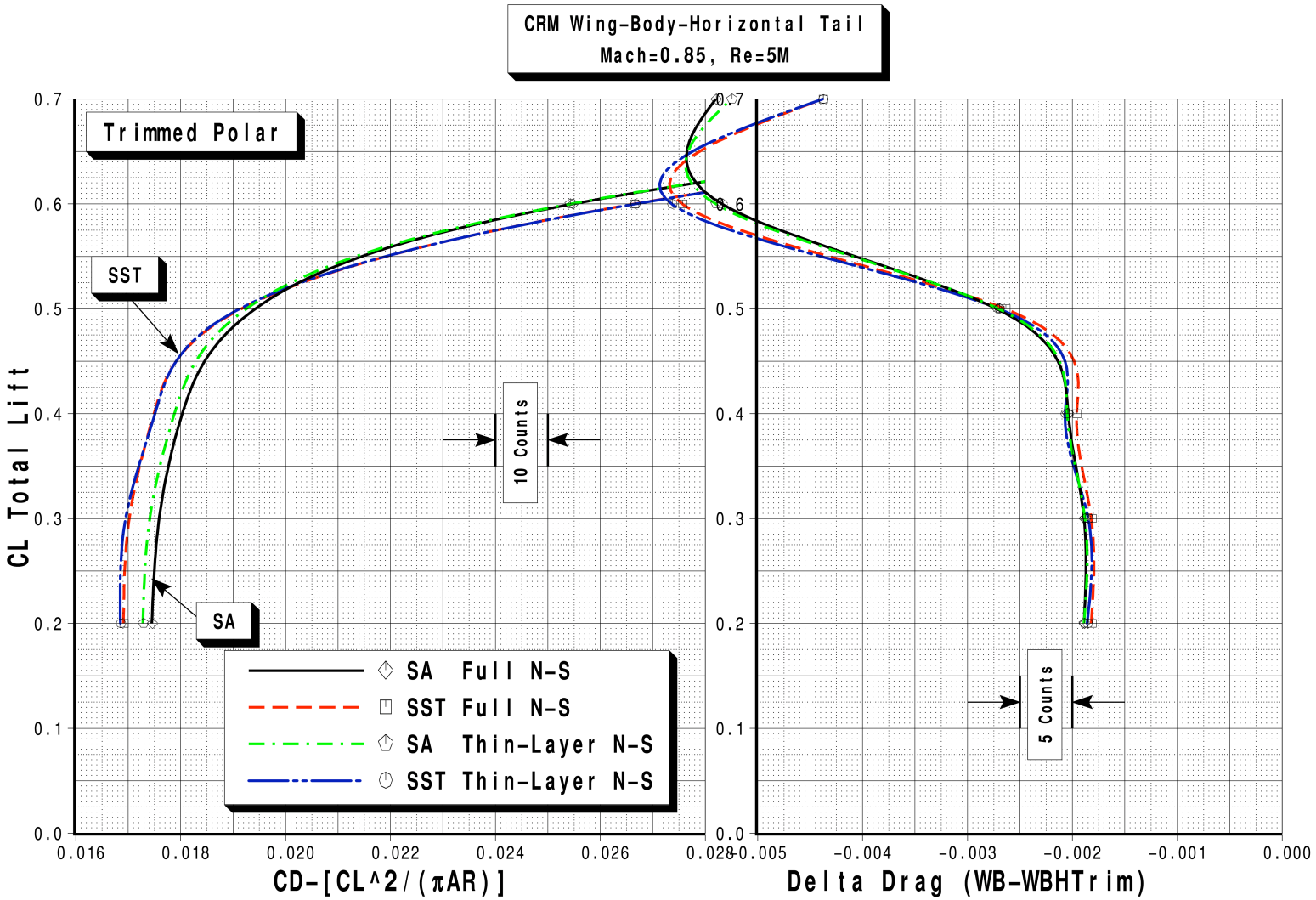
Case 1b: Downwash (Trim) Study



Case 1b: Downwash (Trim) Study



Case 1b: Downwash (Trim) Study

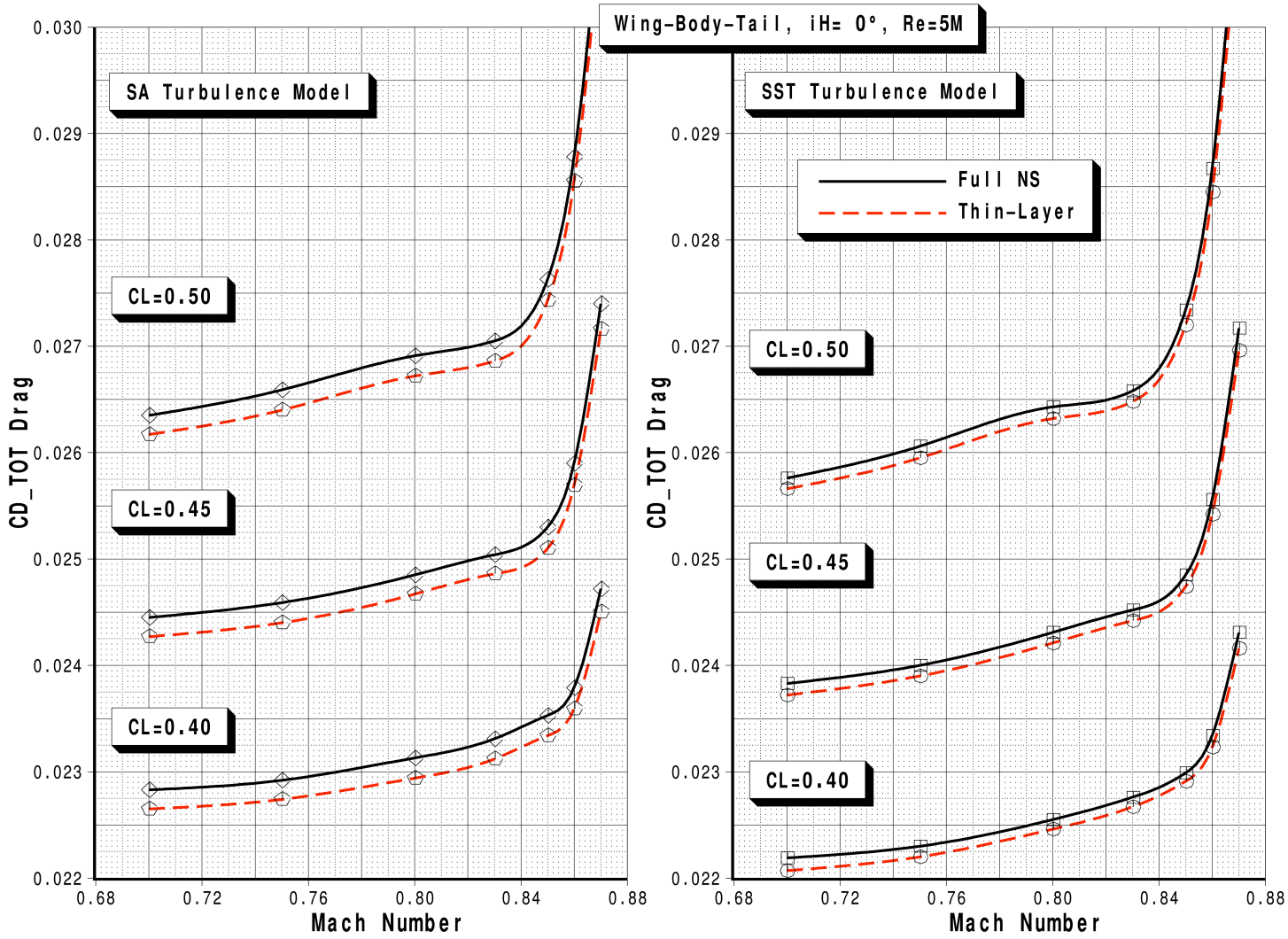


- **Case 2 (Optional) : Mach Sweep Study**
  - Drag Polars at:- Mach = 0.70, 0.75, 0.80, 0.83, 0.85, 0.86, 0.87
  - Drag Rise curves at CL = 0.400, 0.450, 0.500
    - (±0.001 or extracted from polars)
  - Untrimmed, Tail Incidence angle, iH = 0°
  - Medium grid
  - Chord Reynolds Number: Re=5M

4th CFD Drag Prediction Workshop

San Antonio, Texas – June 2009

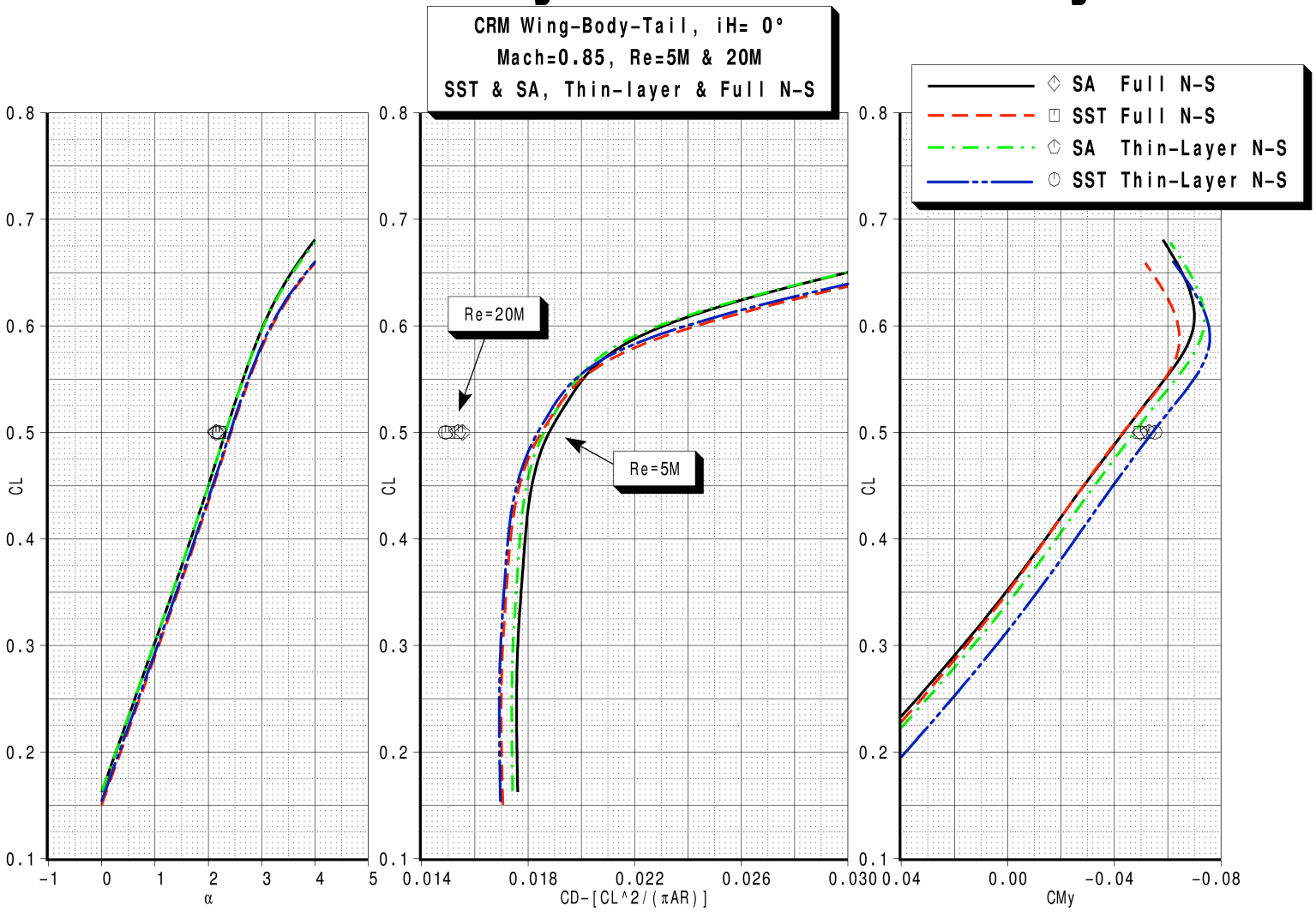
Case 2: Mach Sweep Study



Rider

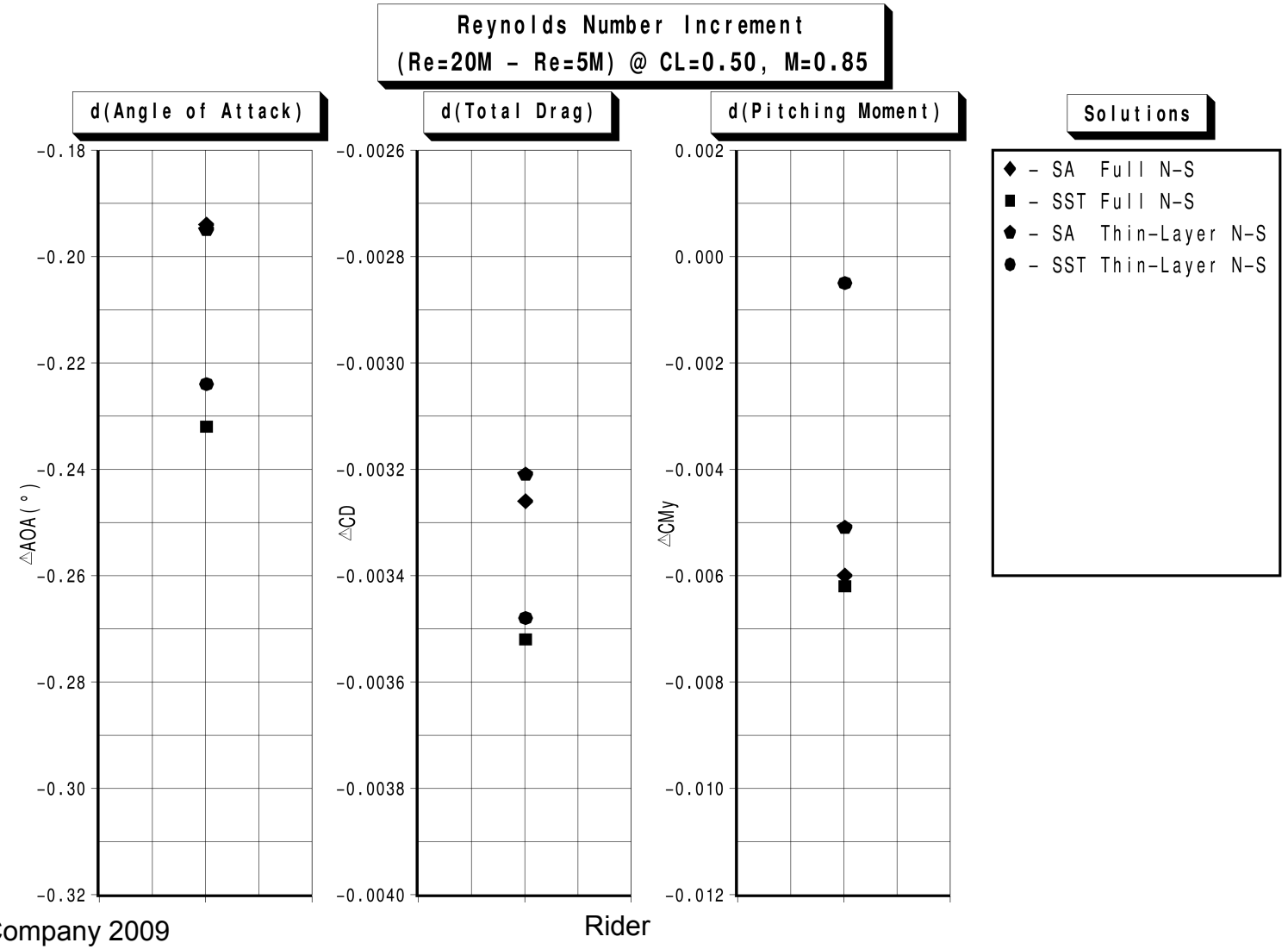
- **Case 3 (Optional) : Reynolds Number Study**
  - Mach = 0.85, CL = 0.500 (±0.001)
  - Tail Incidence angle, iH = 0°
  - Medium grid
  - Chord Reynolds Numbers: Re=5M and Re=20M

Case 3: Reynolds Number Study



Rider

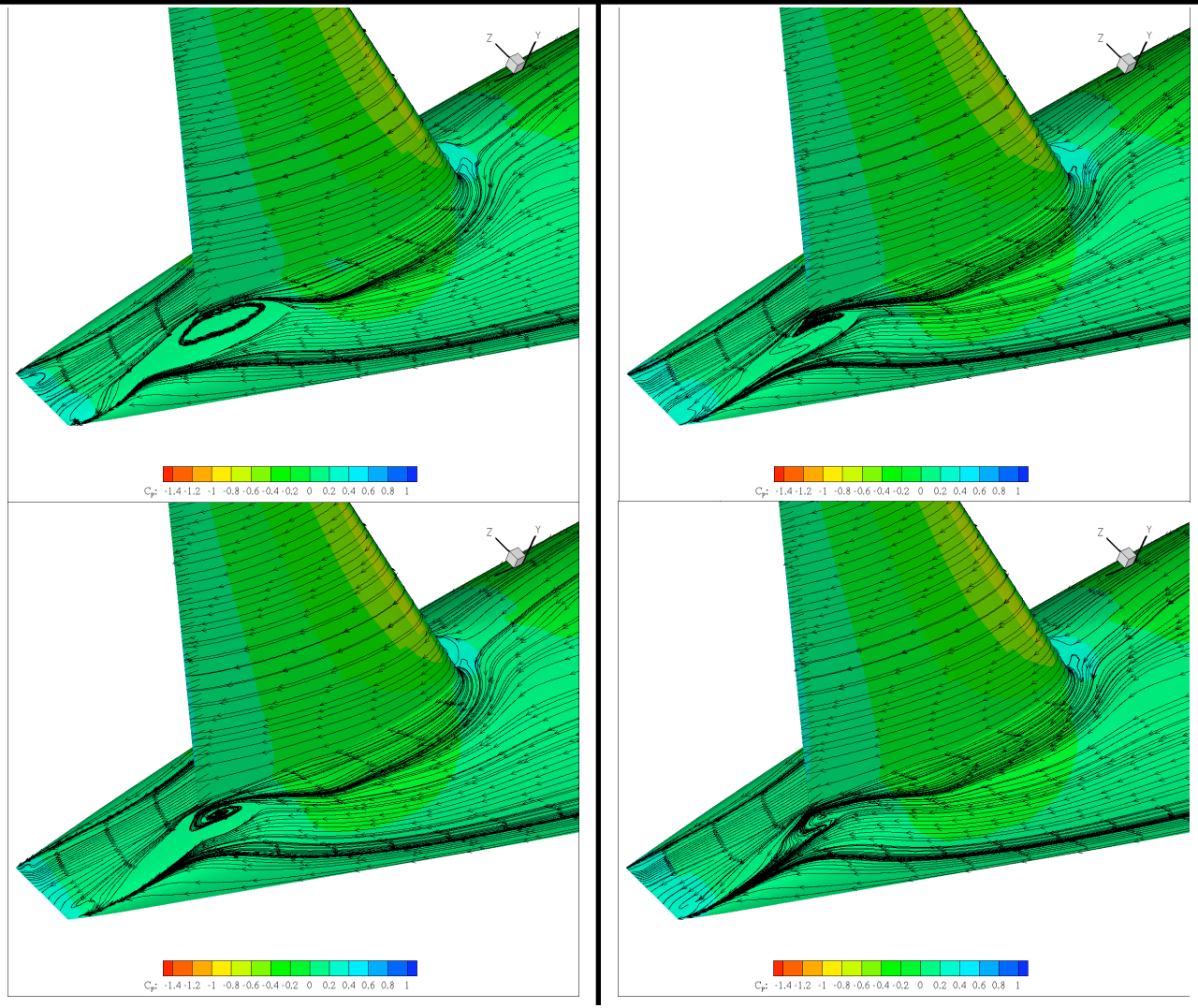
Case 3: Reynolds Number Study



4th CFD Drag Prediction Workshop

San Antonio, Texas – June 2009

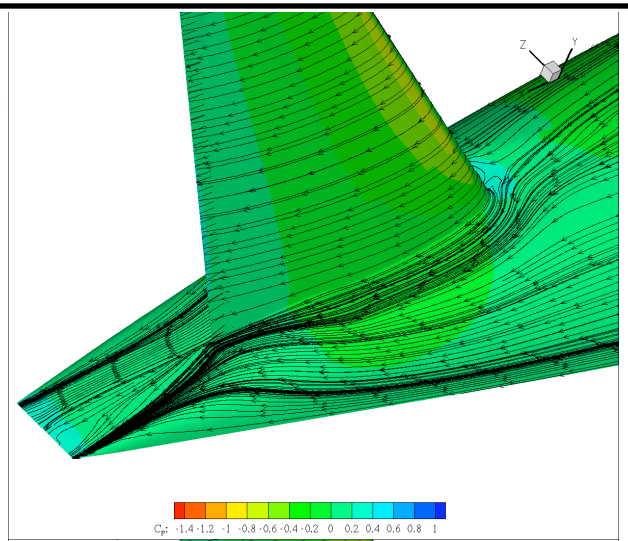
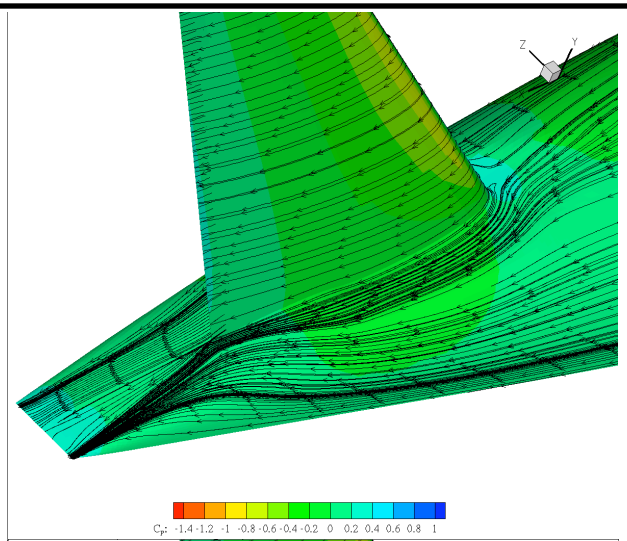
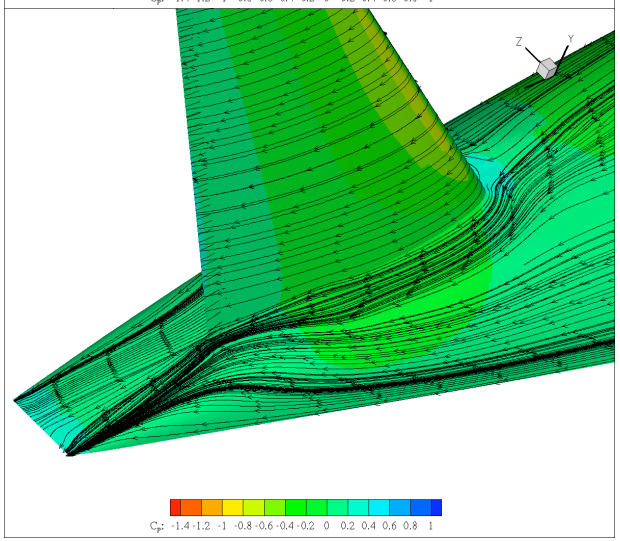
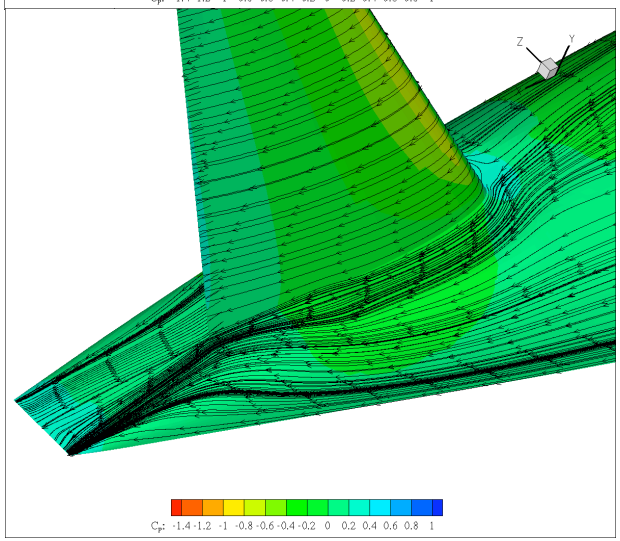
SST Turbulence Model, Re=5M	SST Turbulence Model, Re=20M
Thin-Layer	Thin-Layer
Full NS	Full NS



Rider

4th CFD Drag Prediction Workshop

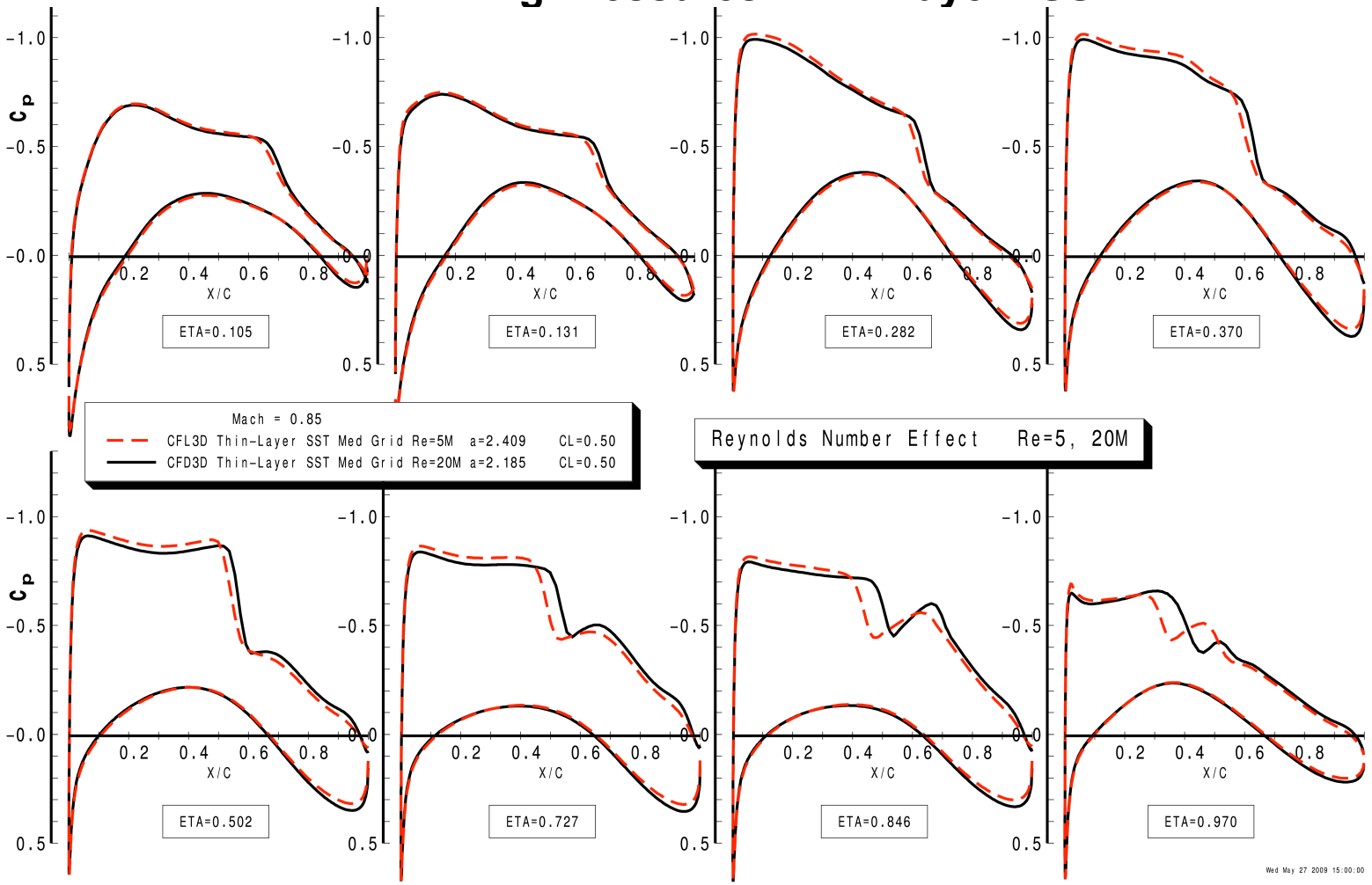
San Antonio, Texas – June 2009

	SA Turbulence Model, Re=5M	SA Turbulence Model, Re=20M
Thin-Layer		
Full NS		

Rider

Case 3: Reynolds Number Study

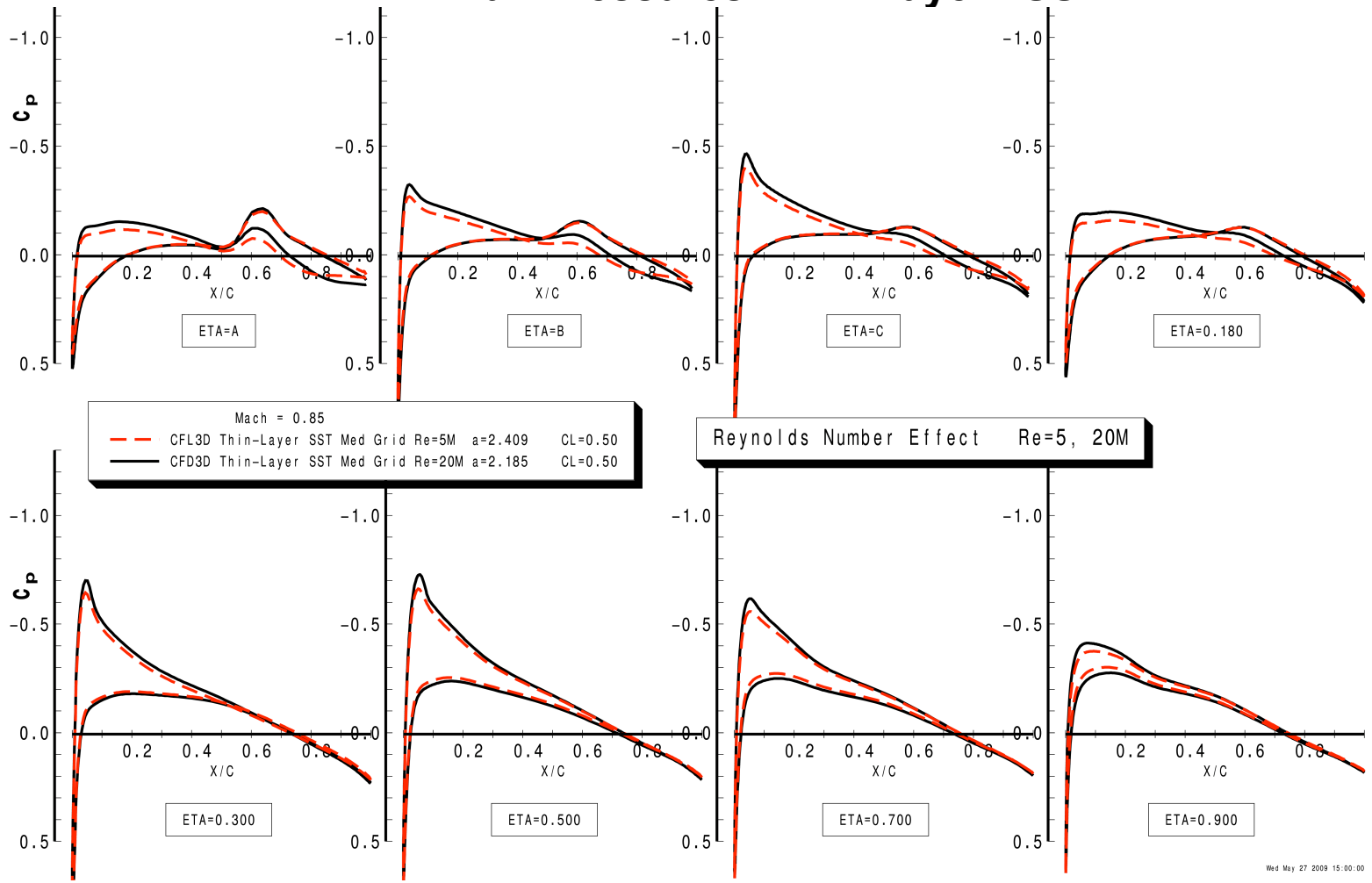
Wing Pressures: Thin-Layer / SST



Rider

Case 3: Reynolds Number Study

Tail Pressures: Thin-Layer / SST



Rider

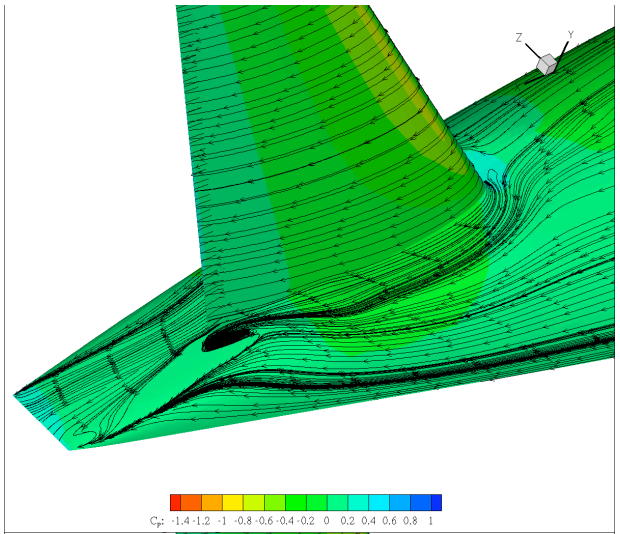
Concluding Remarks

- Zeus/CFL3D exhibited very good grid convergence characteristics for both SA and SST turbulence models.
  - Indicates a consistent family of grids
  - Acceptable solver convergence was achieved
- Pressure distributions essentially are invariant with grid
- Some variation of flow features due to turbulence model
  - Flow separation at tail side-of-body junction
- High degree of confidence in CFD results for similar configurations

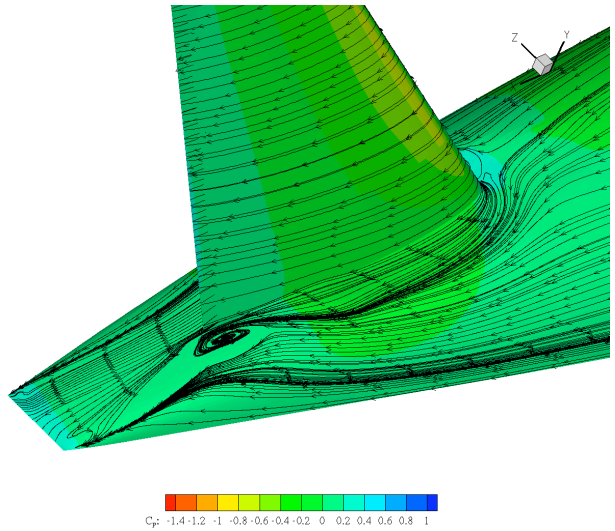
Q & A

Case 1a: Grid Convergence Study – Full NS / SST

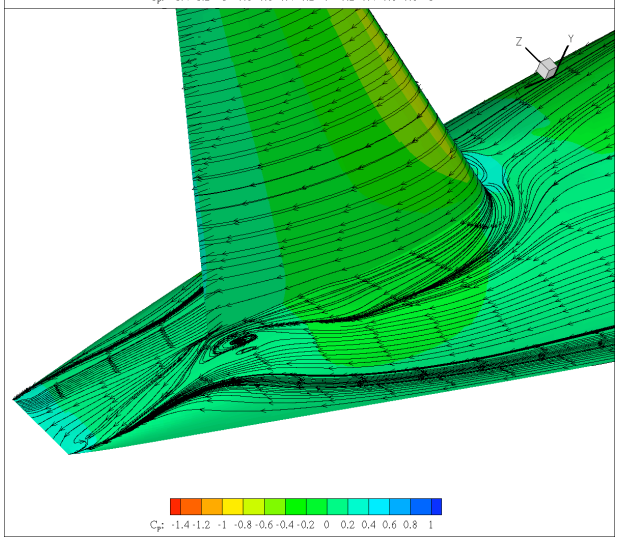
Coarse Grid



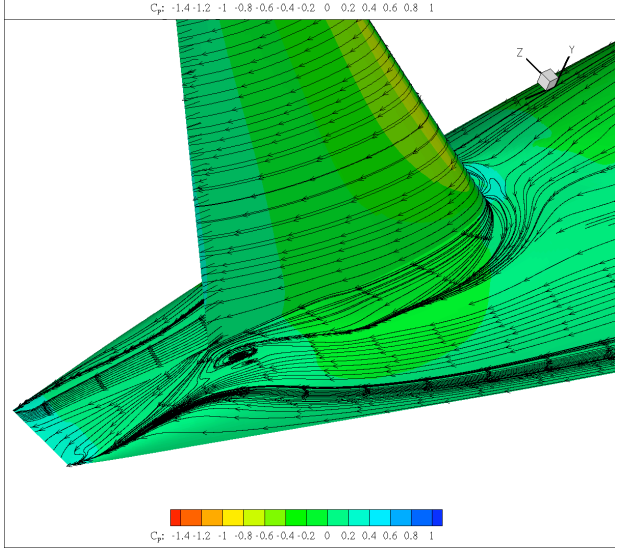
Medium Grid



Medium-Fine Grid



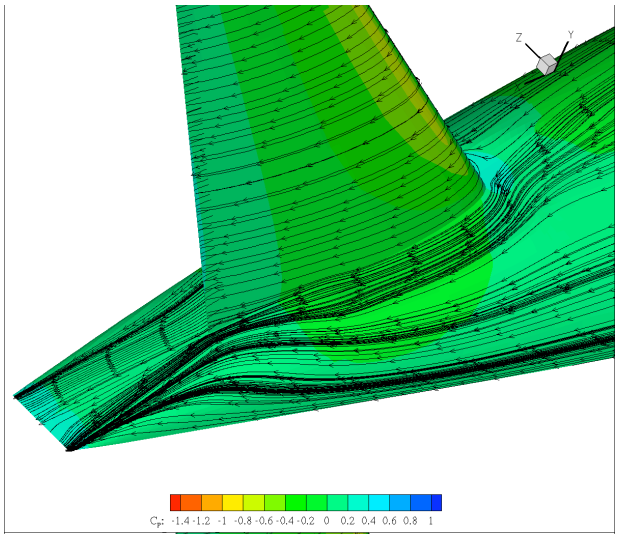
Fine Grid



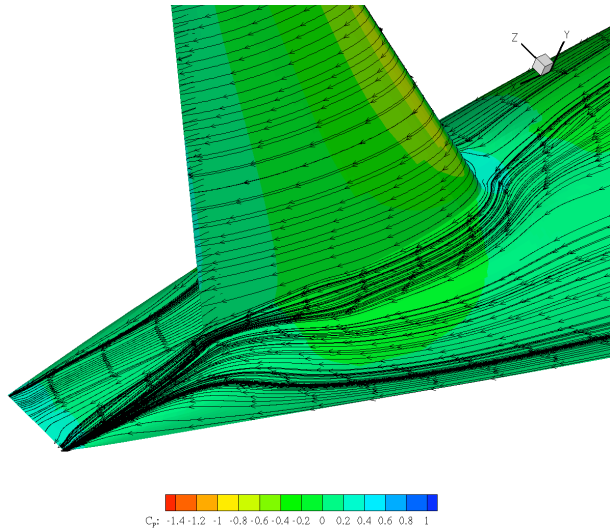
Rider

Case 1a: Grid Convergence Study – Full NS / SA

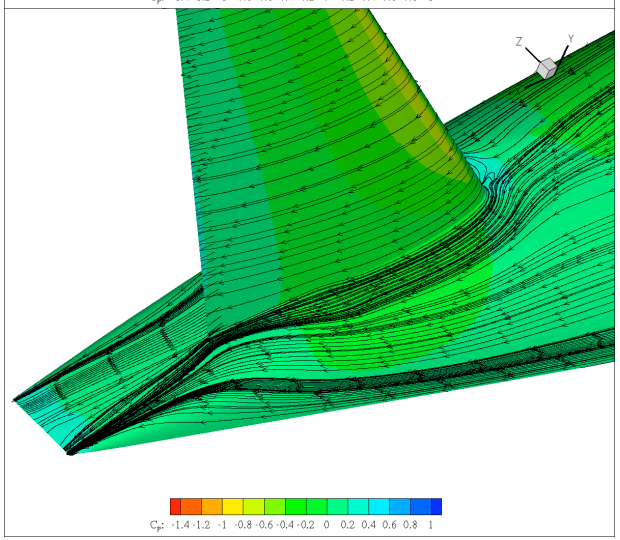
Coarse Grid



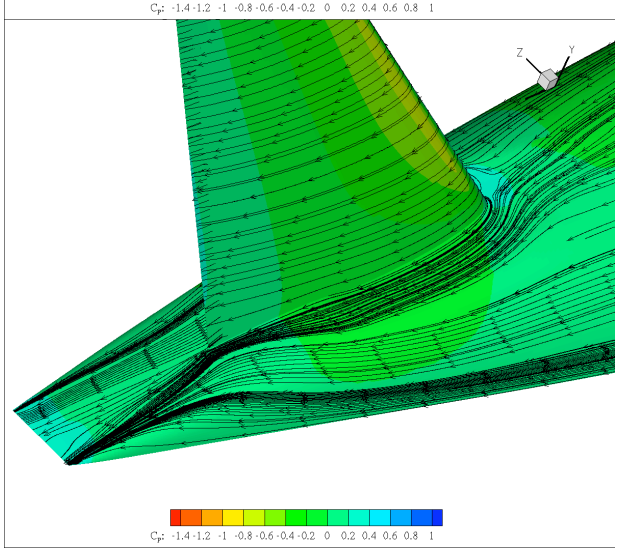
Medium Grid



Medium-Fine Grid



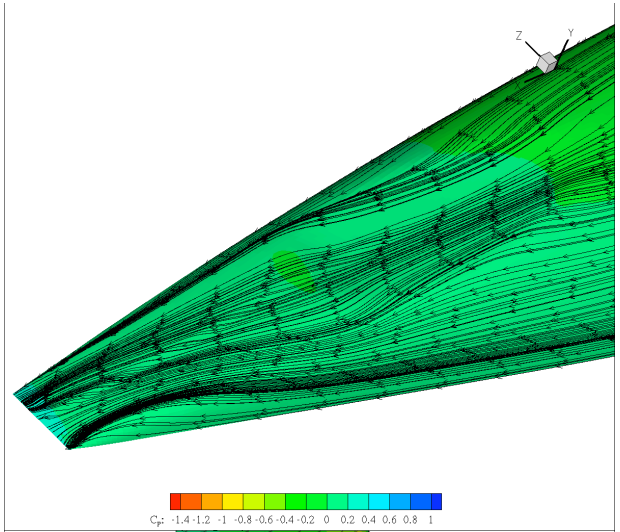
Fine Grid



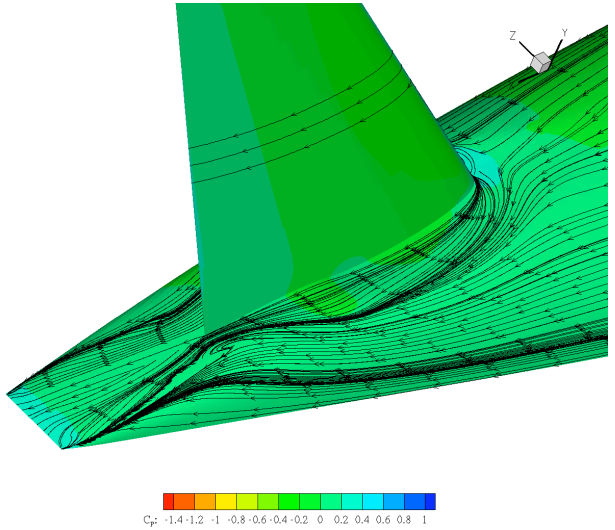
Rider

Case 1b: Downwash (Trim) Study – Full NS / SST (CL=0.5)

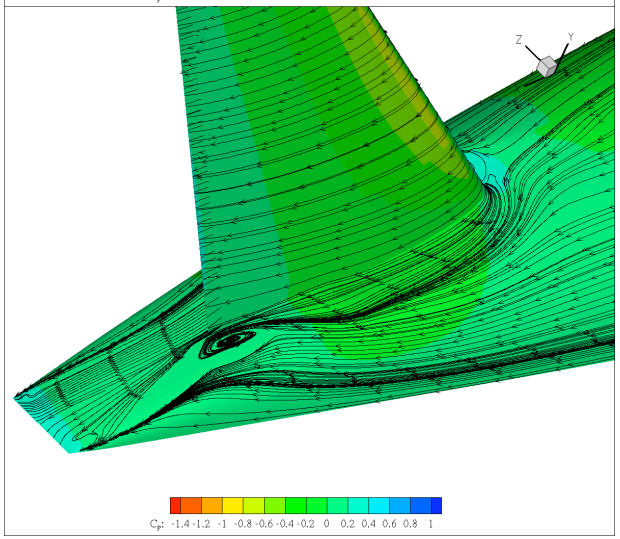
Tail Off



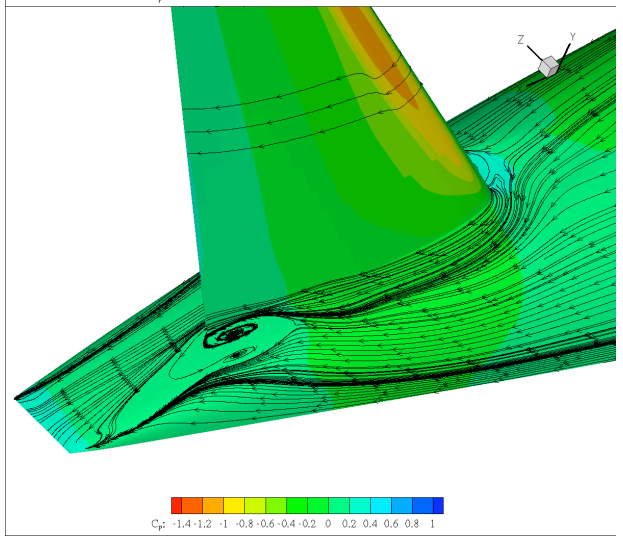
iH=+2°



iH= 0°



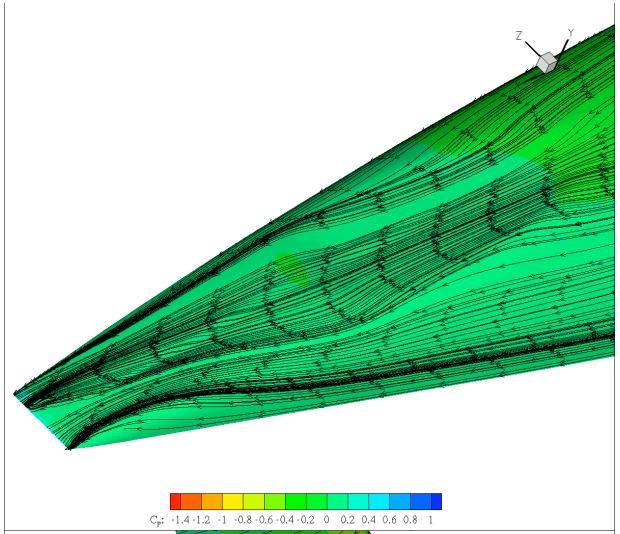
iH=-2°



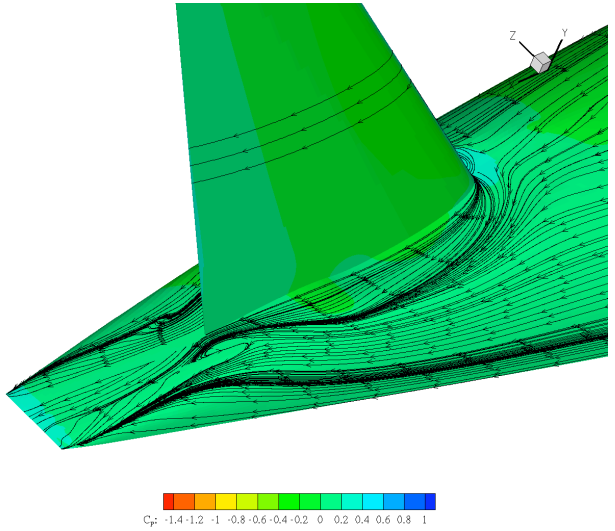
Rider

Case 1b: Downwash (Trim) Study – Thin-Layer / SST (CL=0.5)

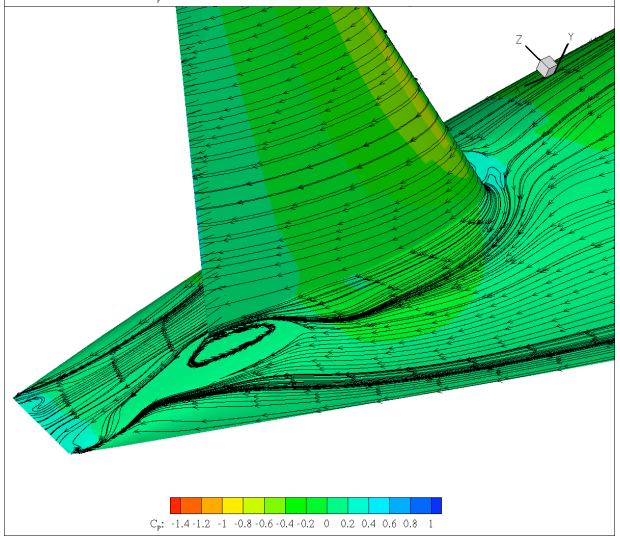
Tail Off



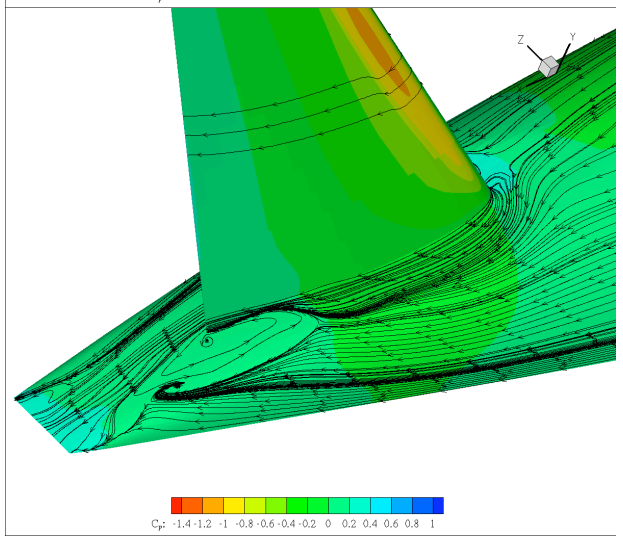
iH=+2°



iH= 0°



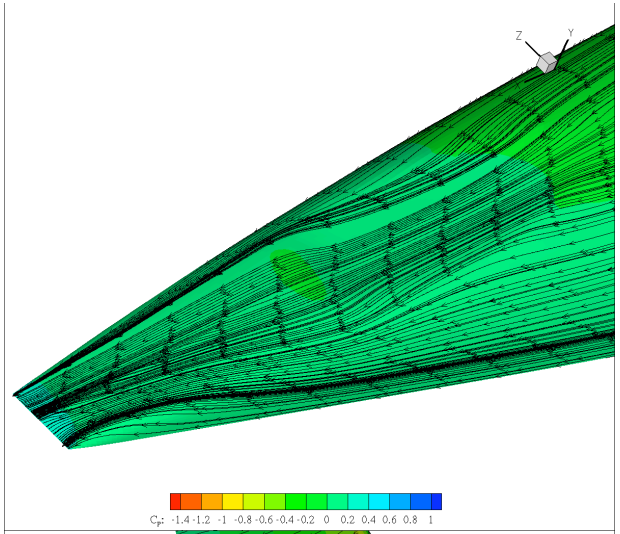
iH=-2°



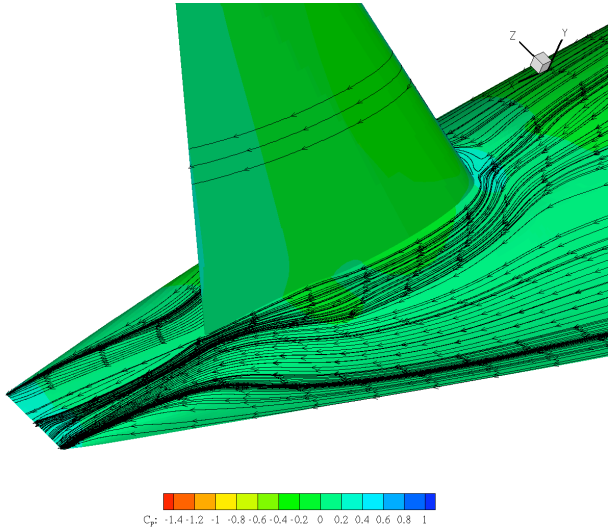
Rider

Case 1b: Downwash (Trim) Study – Full NS / SA (CL=0.5)

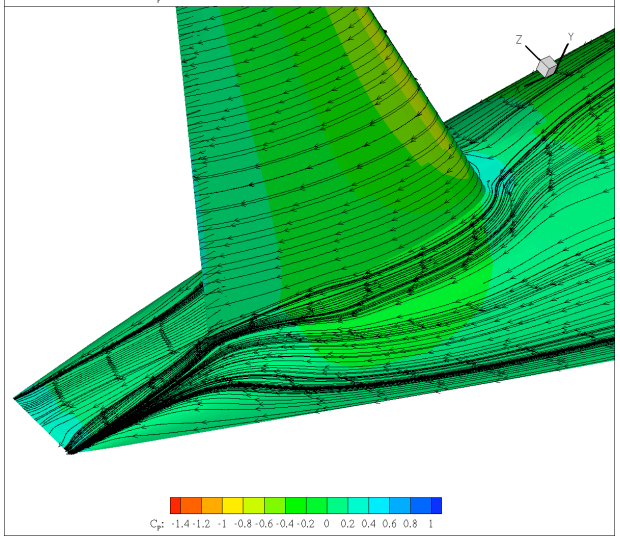
Tail Off



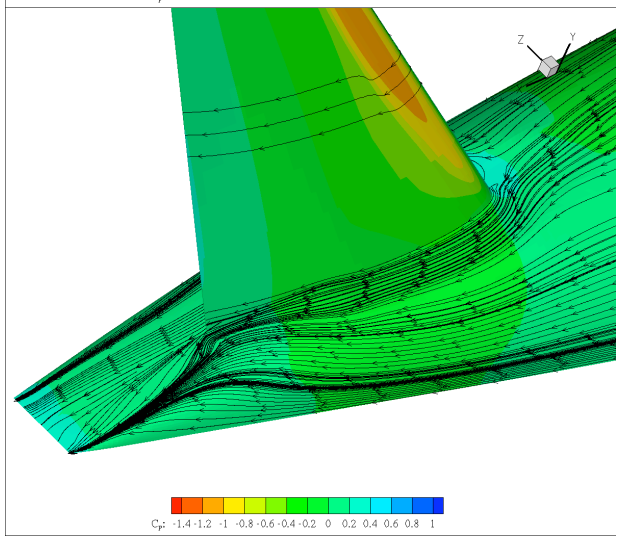
iH=+2°



iH= 0°



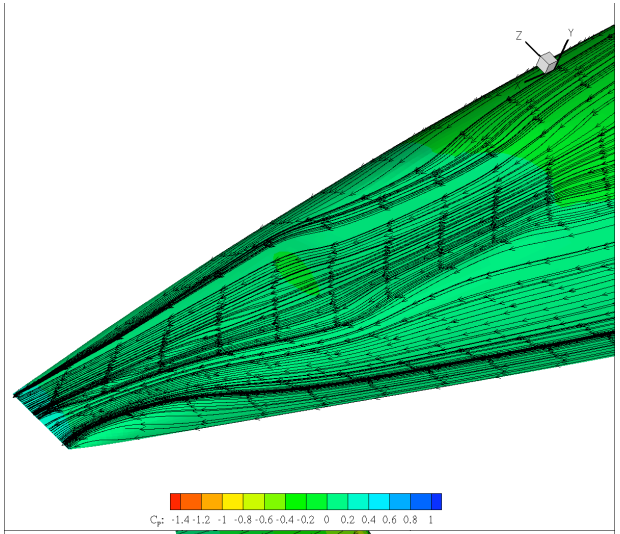
iH=-2°



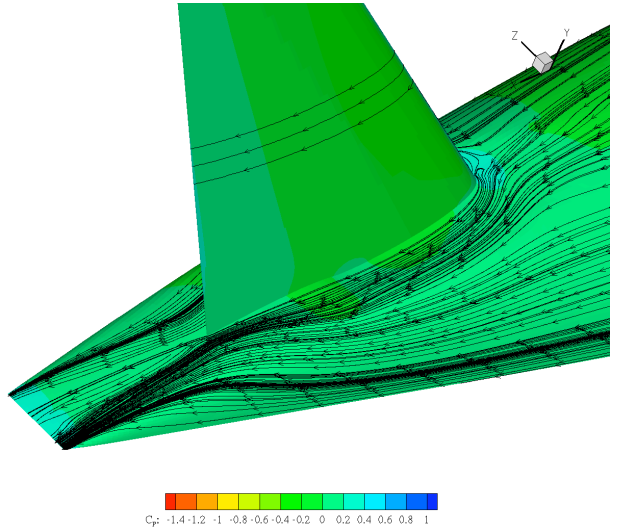
Rider

Case 1b: Downwash (Trim) Study – Thin-Layer / SA (CL=0.50)

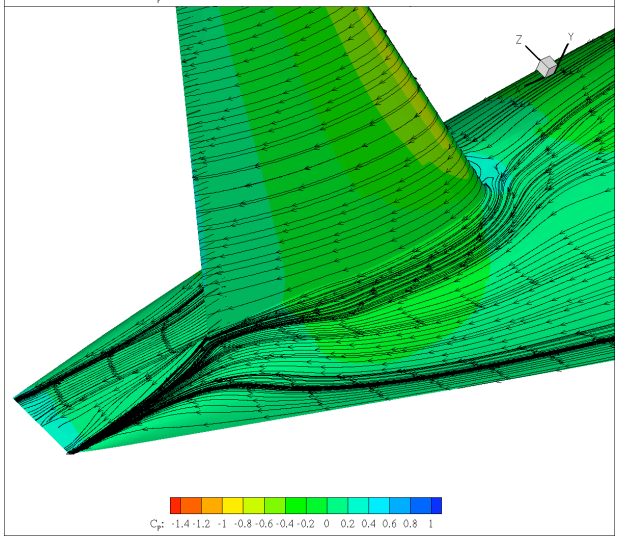
Tail Off



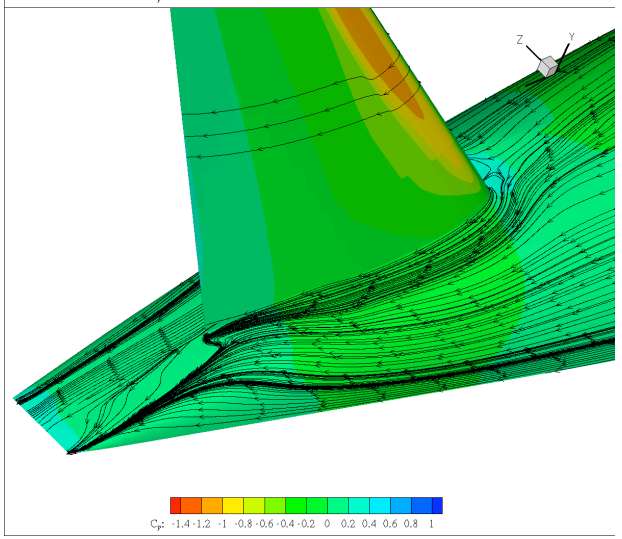
iH=+2°



iH= 0°



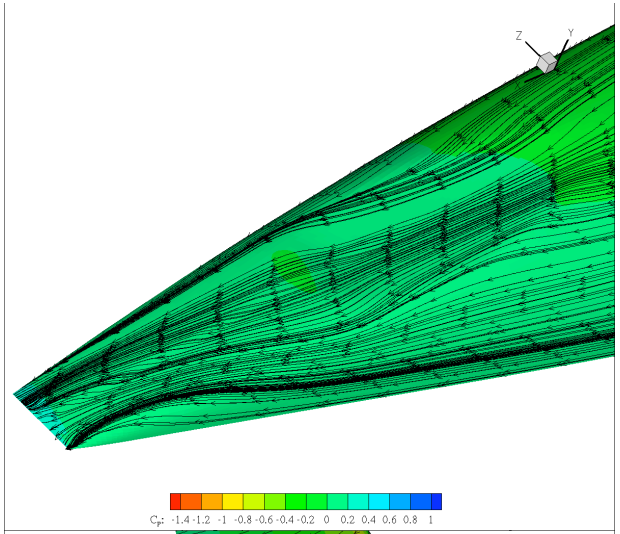
iH=-2°



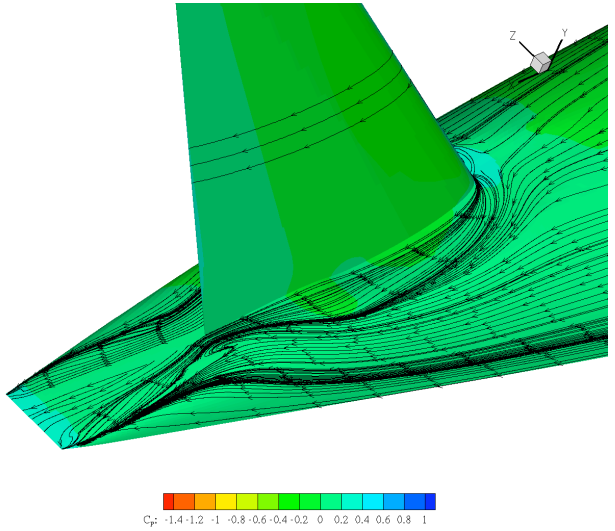
Rider

Case 1b: Downwash (Trim) Study – Full NS / SST (α=2.0°)

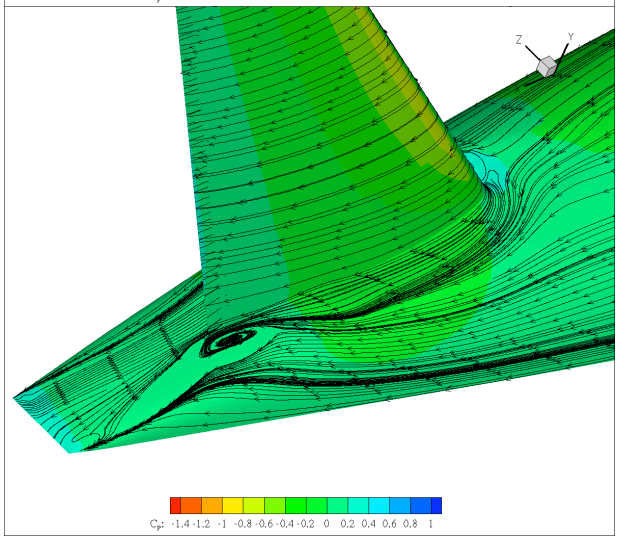
Tail Off



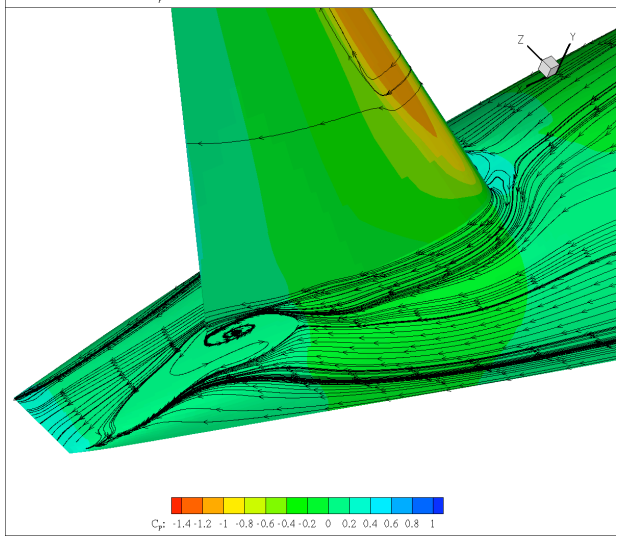
iH=+2°



iH= 0°



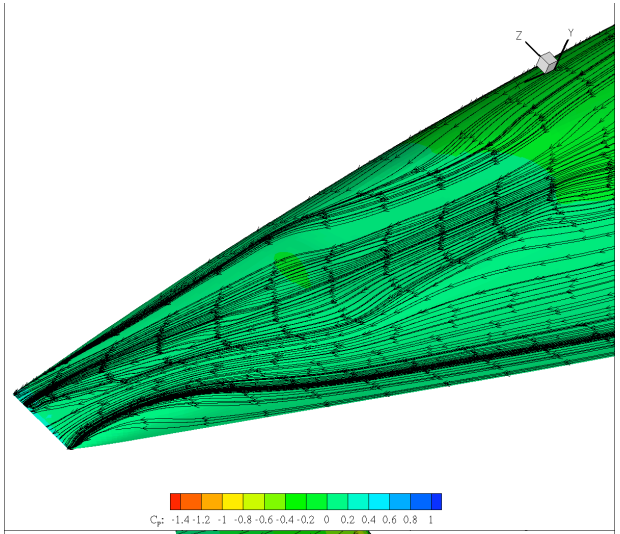
iH=-2°



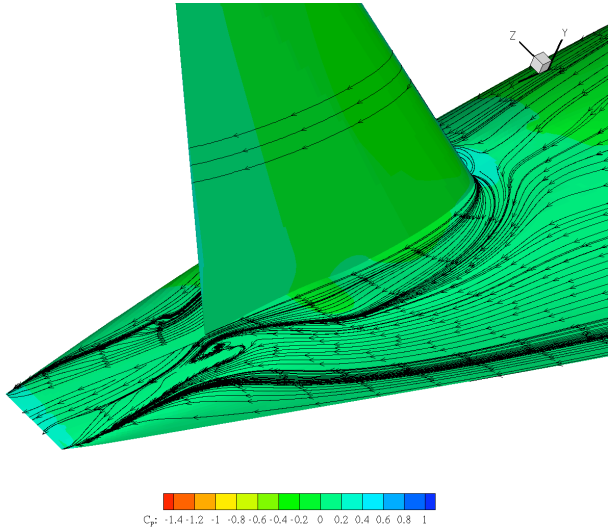
Rider

Case 1b: Downwash (Trim) Study – Thin-Layer / SST (α=2.0°)

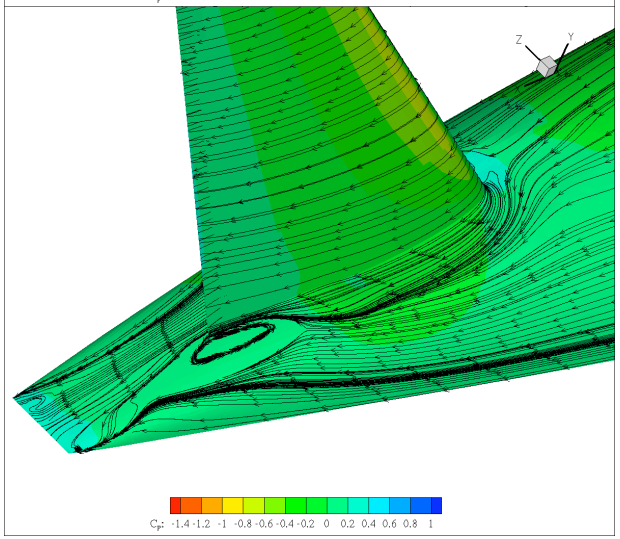
Tail Off



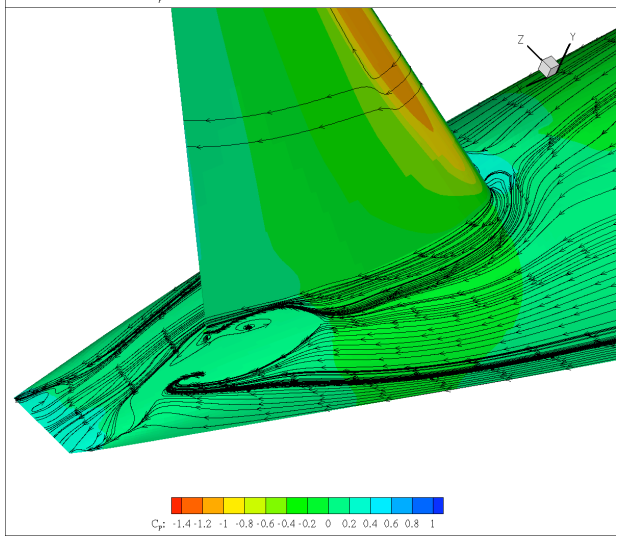
iH=+2°



iH= 0°



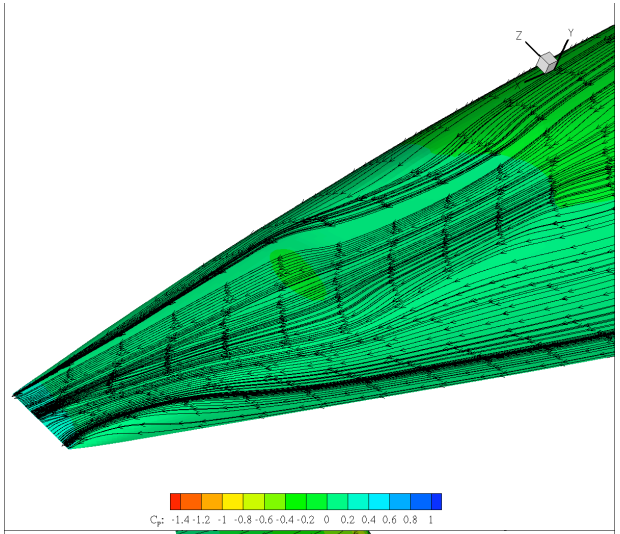
iH=-2°



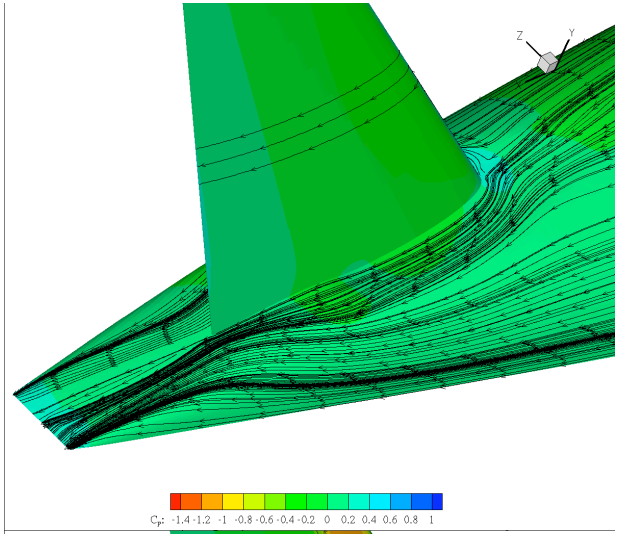
Rider

Case 1b: Downwash (Trim) Study – Full NS / SA (α=2.0°)

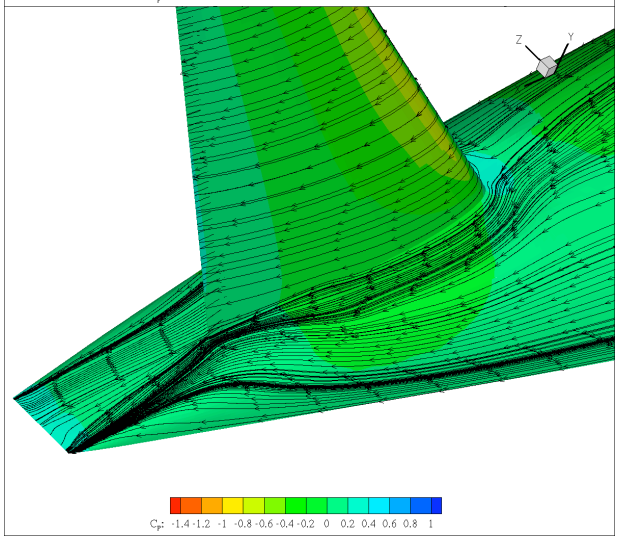
Tail Off



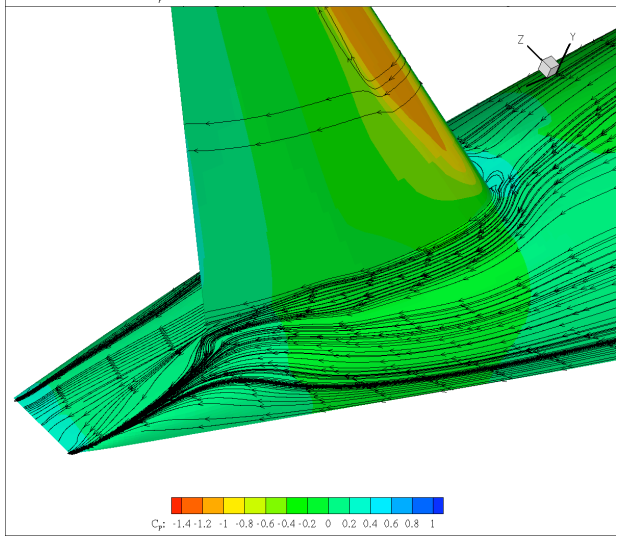
iH=+2°



iH= 0°



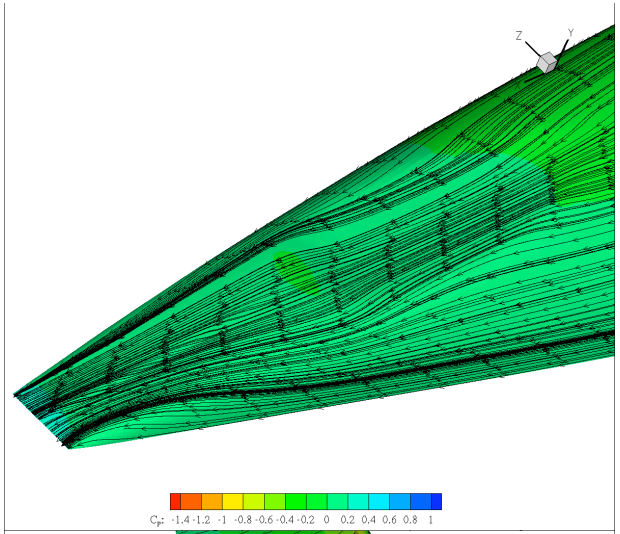
iH=-2°



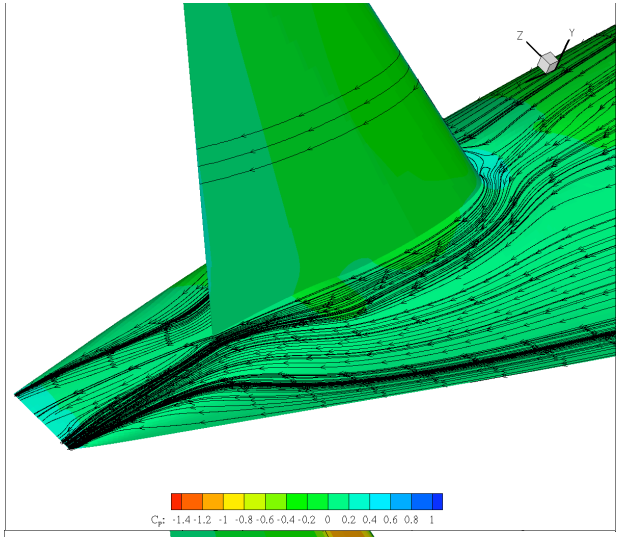
Rider

Case 1b: Downwash (Trim) Study – Thin-Layer / SA (α=2.0°)

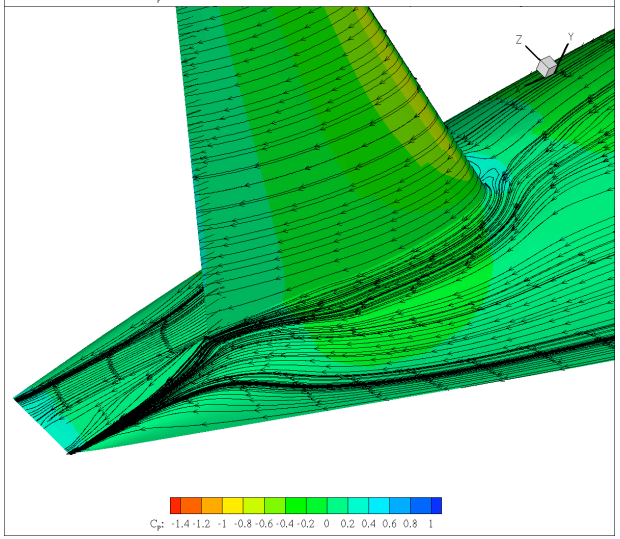
Tail Off



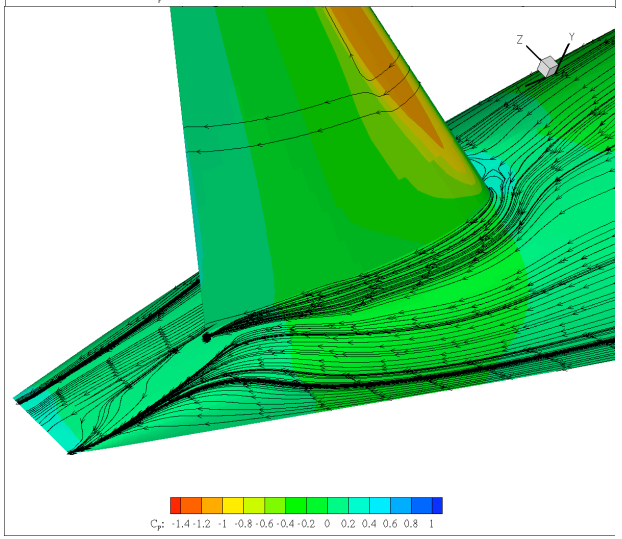
iH=+2°



iH= 0°



iH=-2°



Rider