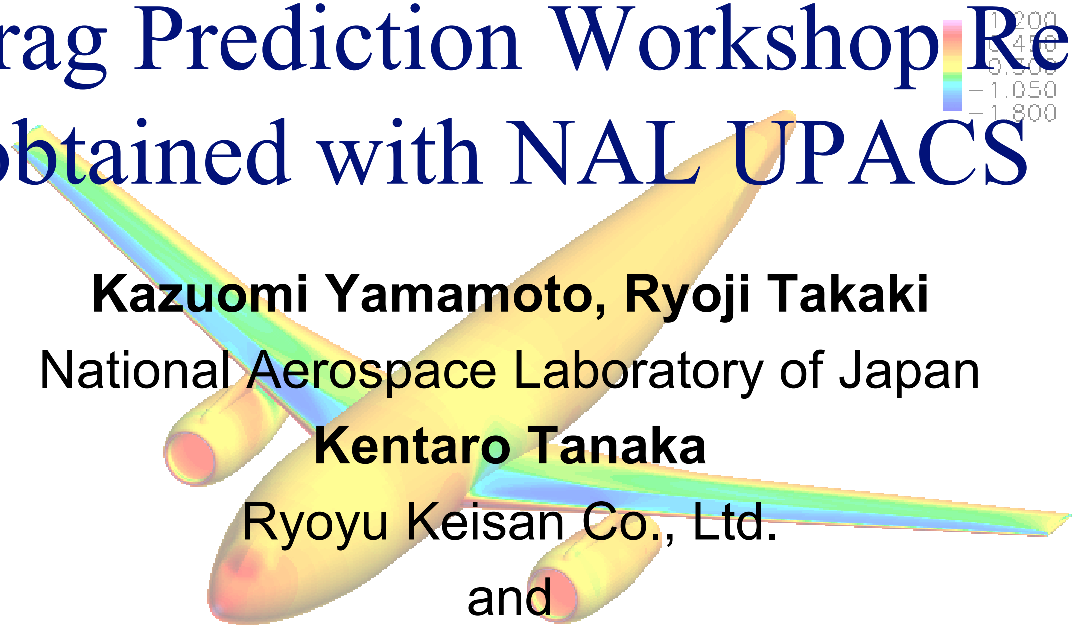
# 2nd Drag Prediction Workshop Results obtained with NAL UPACS

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Daiko Denshi Tsushin, Ltd.

AIAA 2nd CFD Drag Prediction Workshop
21-22 June, 2003

# Focus of presentation

**Drag prediction accuracy of UPACS**

- **Grid dependency**
  - **NAL grids** and the provided ICEM grids
- **Effect of transition**
- **Effect of thin-layer approximation**

# NAL UPACS code

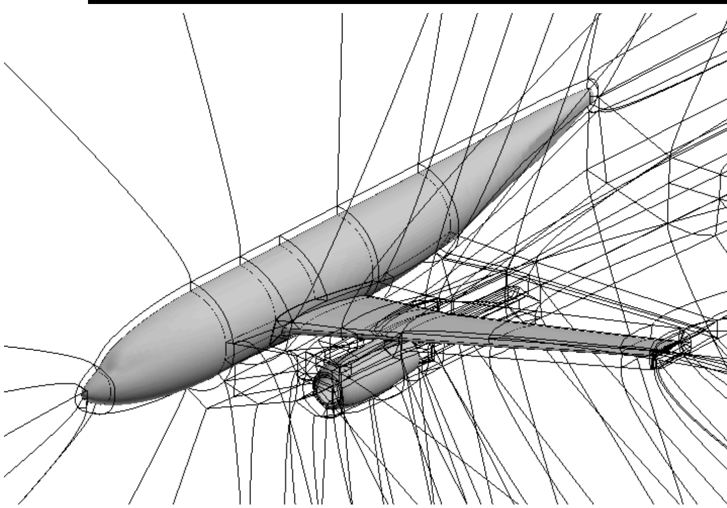
- Standard CFD code in NAL
  - Designed to be shared by researchers
- Flow solver of UPACS
  - Cell-centered finite-volume method
  - Multi-block structured grid
  - Roe's flux-difference splitting with MUSCL extrapolation
  - 2nd-order discretization of viscous terms
  - Matrix-free Gauss-Seidel implicit scheme
  - Spalart-Allmaras one-equation turbulence model
    - Transition is specified by a laminar mask where the production term is turned off.
  - Parallelized with MPI
- Fujitsu PrimePower HPC2500, SPARC64V(1.3GHz) x 1792
  - 16 - 32 hours / case for 14M (fine) grid with 99 cpu

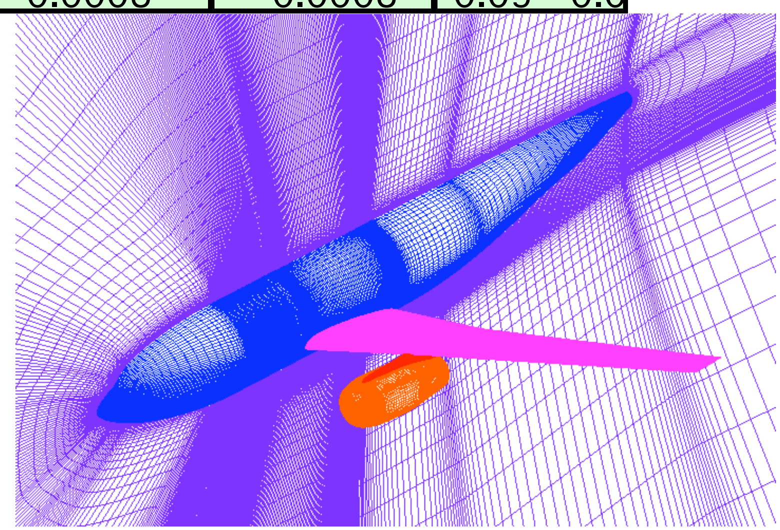
# Grids

- Generated by Gridgen
- Multi-block point-to-point matched

| Wing-Body | Grid size (million) | Stretching in B.L.. | Cell size [mm] | |
|---|---|---|---|---|
| | | | BL 1st-Cell Size | W-B corner |
| coarse | 1.2 | 1.44 | 0.0018 | 0.1 - 1.1 |
| fine | 8.7 | 1.2 | 0.0008 | 0.05 - 0.5 |
| finer | 9.0 | 1.2 | 0.0008 | 0.0008 |

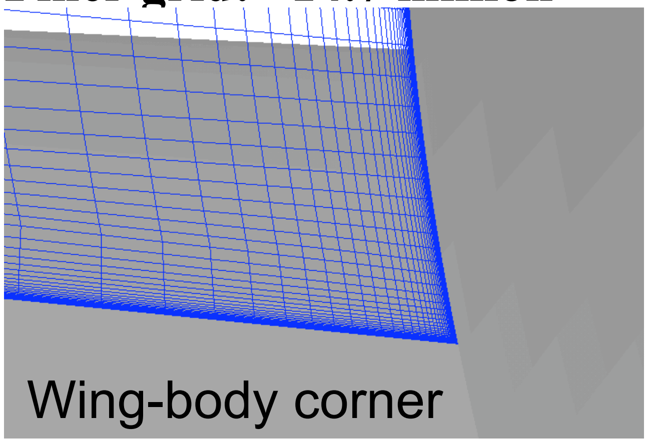
| Wing-Body-Nacelle-Pylon | Grid size (million) | Stretching in B.L.. | Cell size [mm] | | |
|---|---|---|---|---|---|
| | | | BL 1st-Cell Size | W-B corner | W-P corne |
| coarse | 1.9 | 1.44 | 0.0018 | 0.1 - 1.1 | 0.2 - 0.6 |
| fine | 13.7 | 1.2 | 0.0008 | 0.05 - 0.5 | 0.1 - 0.25 |
| finer | 14.7 | 1.2 | 0.0008 | 0.0008 | 0.05 - 0.0 |

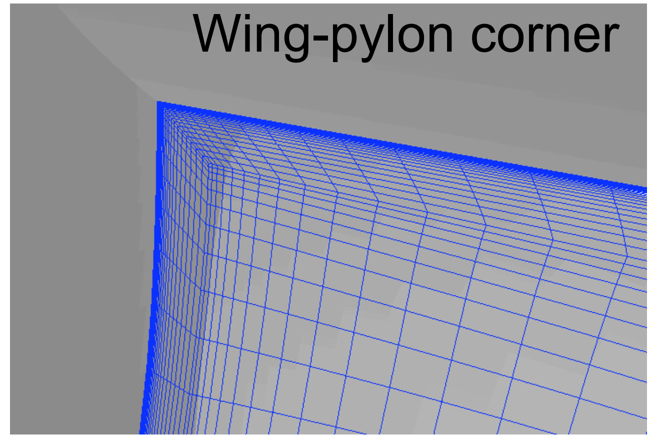




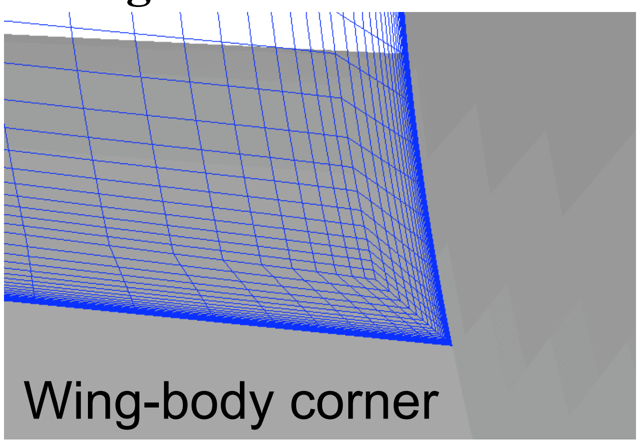
# Corner grid

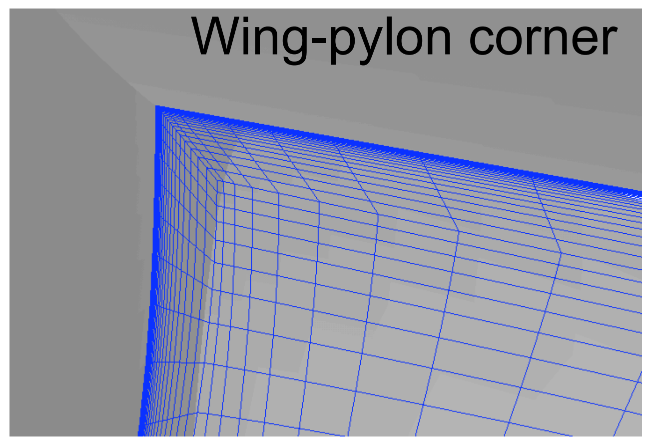
**Finer grid: 14.7 million**



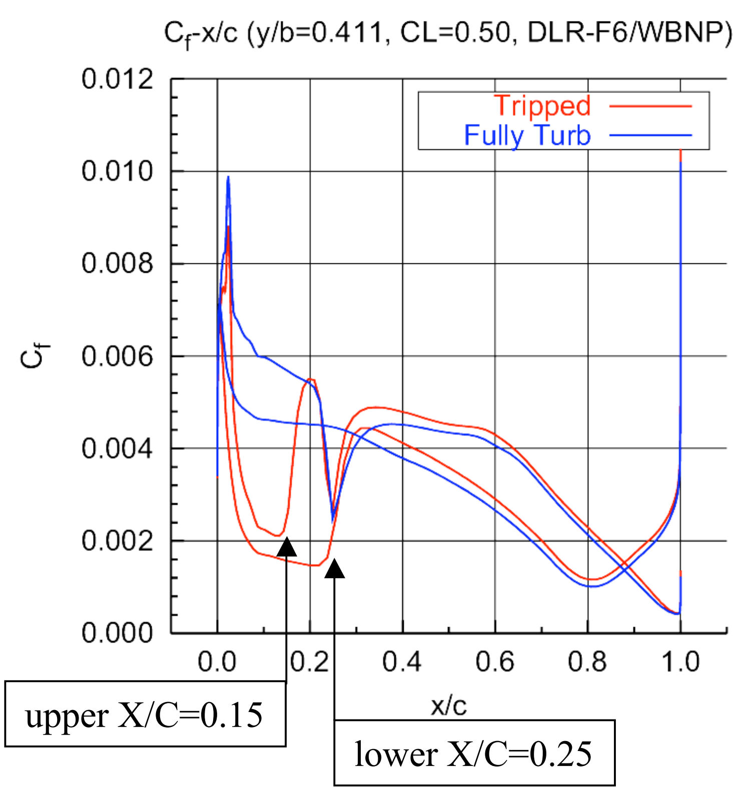



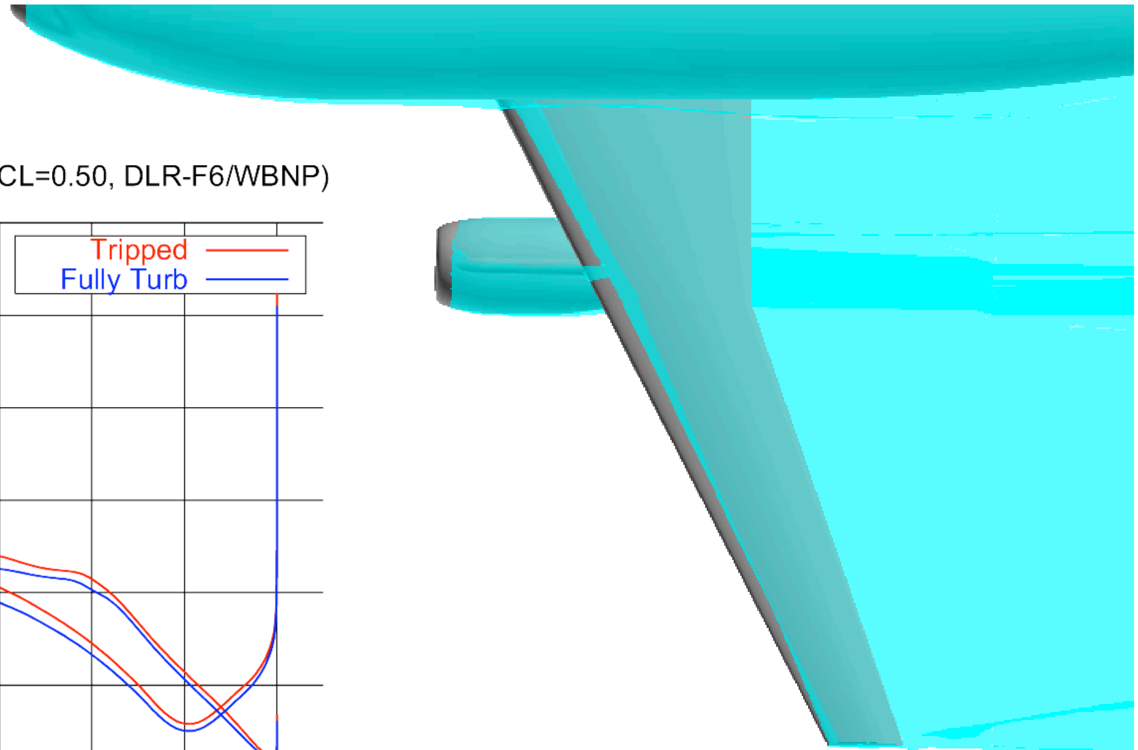

**Fine grid: 13.7 million**



# Transition location

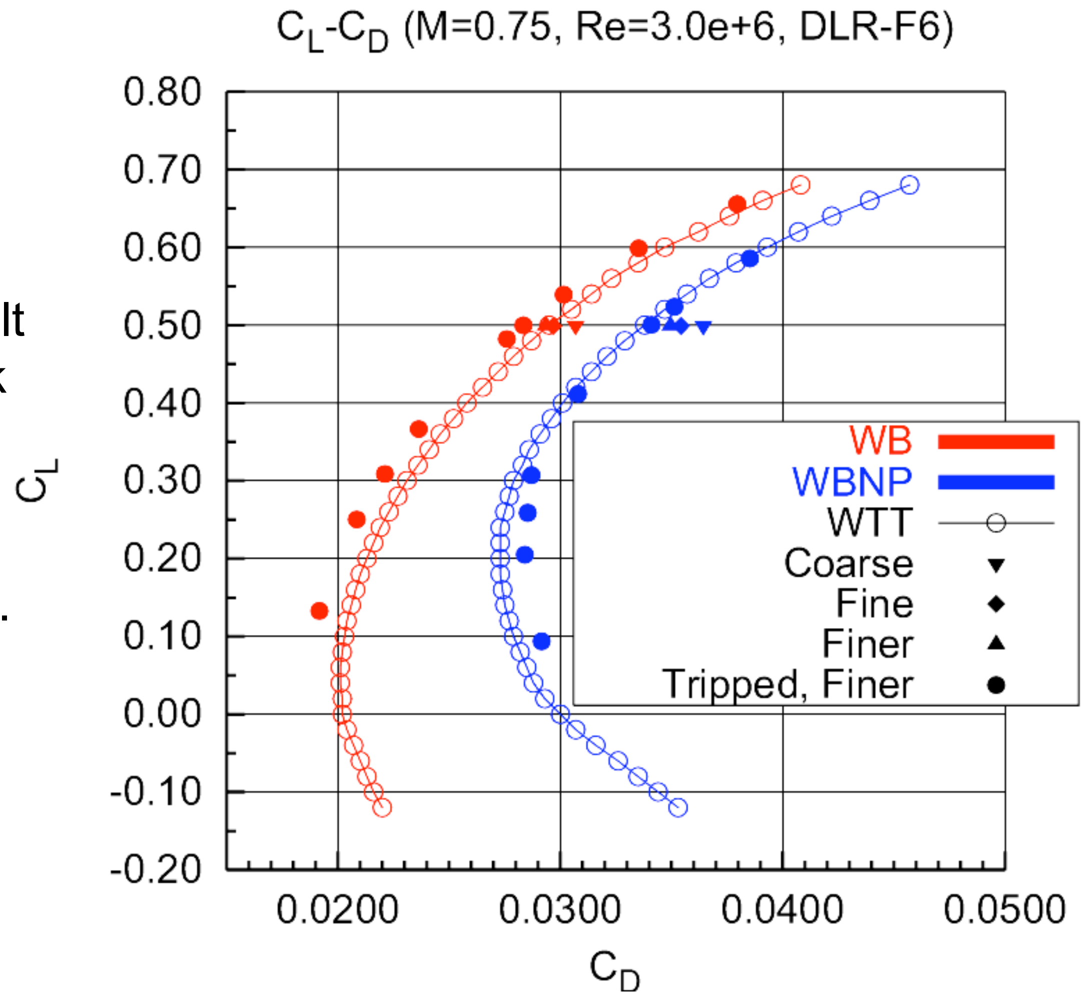


Isosurface of $\tilde{\nu}_t = 5$

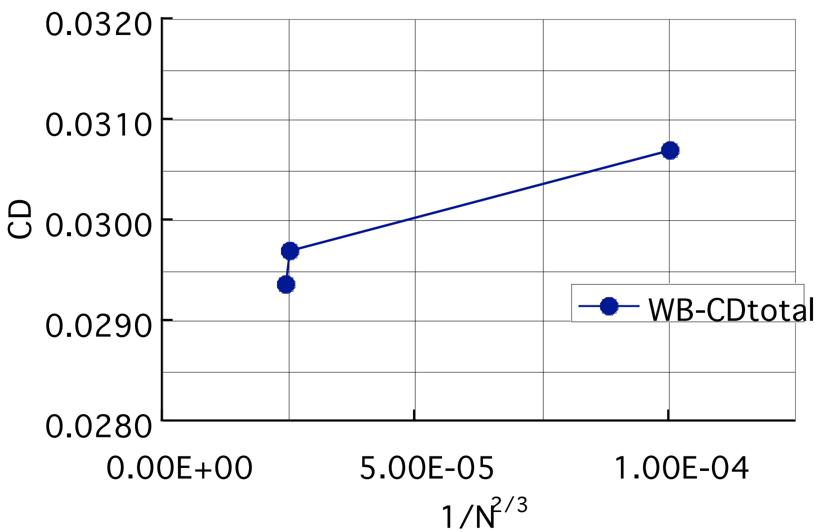
# $C_L$-$C_D$

- UPACS ⇔ Exp.
  - Within 15 counts difference
- Installation Drag
  - about 30 counts larger than experimental result at lower angle of attack
- Grid coarse _ fine
  - 10 counts of reduction
  - mostly due to pressure.
- Transition
  - 9 -10 counts reduction mostly due to friction.

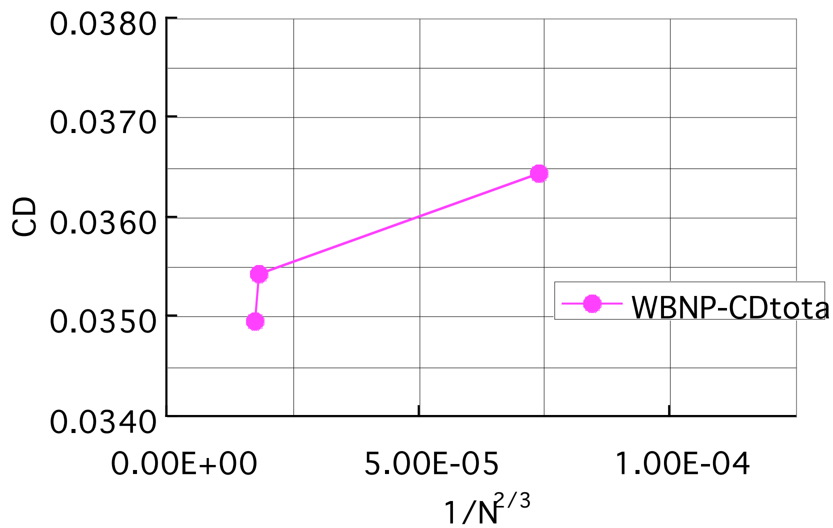


# Grid dependency

- Increasing the resolution at corners reduce the drag about 3 - 5 counts.



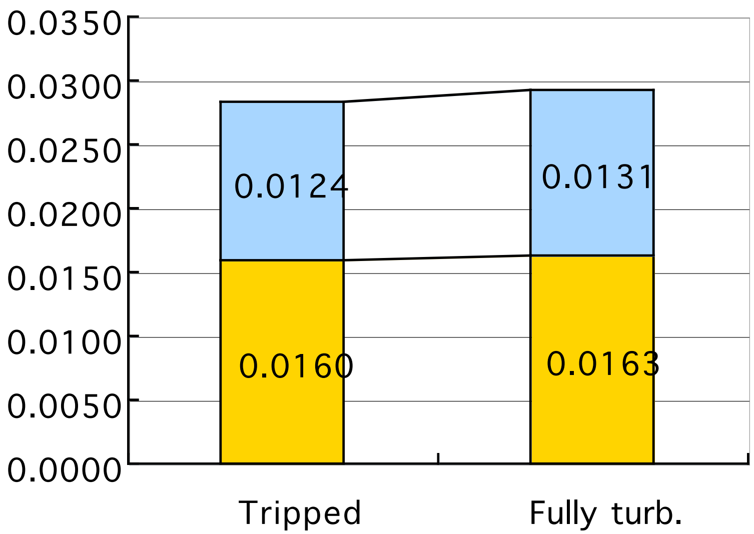

Wing-Body



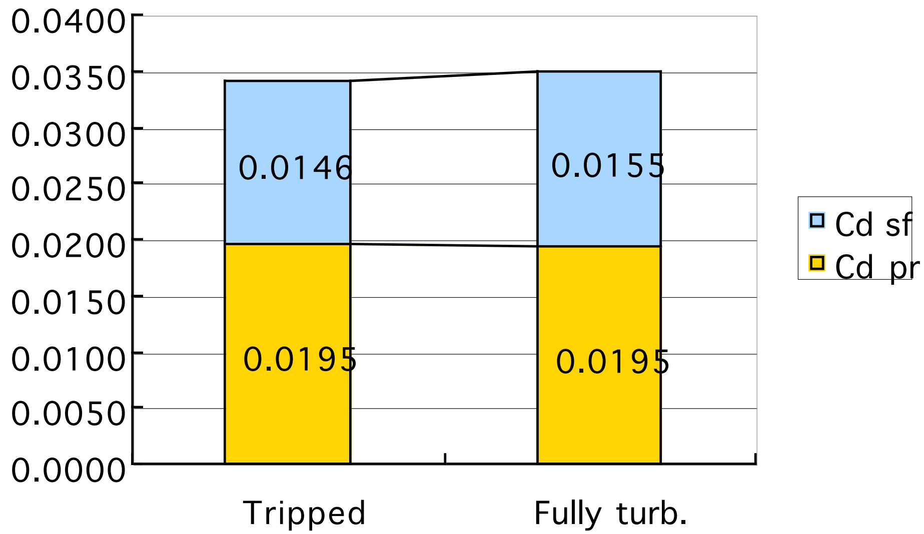

Wing-Body-Nacelle-Pylon

# Effect of transition on Cd

- M=0.75 Re=3.x10$^{6}$
- About 9 counts of reduction due to transition trip



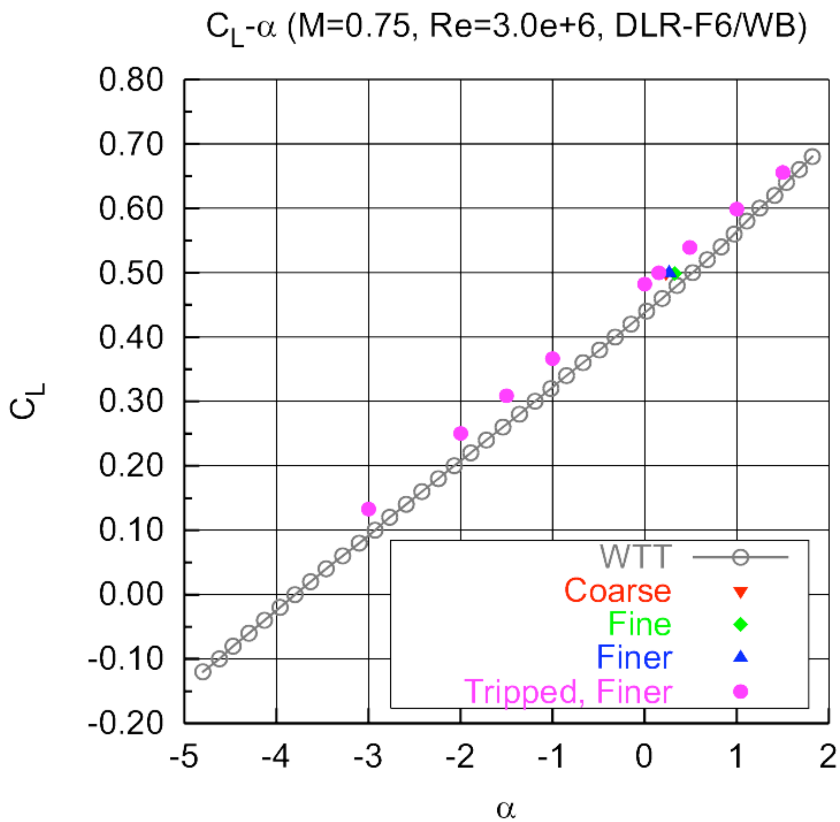

Wing-Body

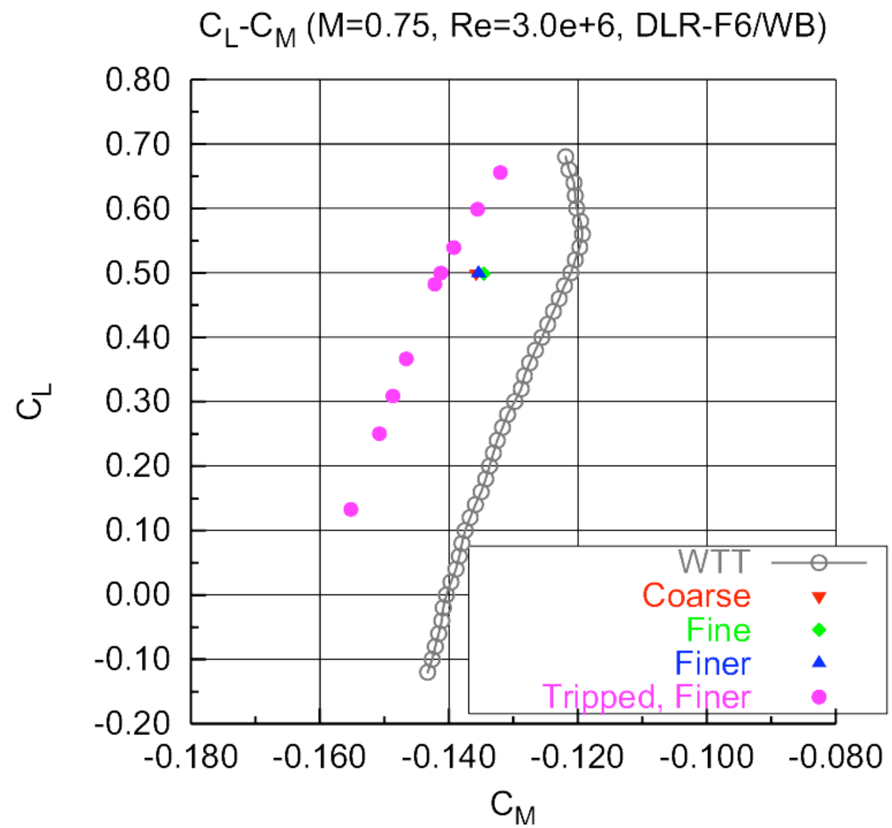



Wing-Body-Nacelle-Pylon

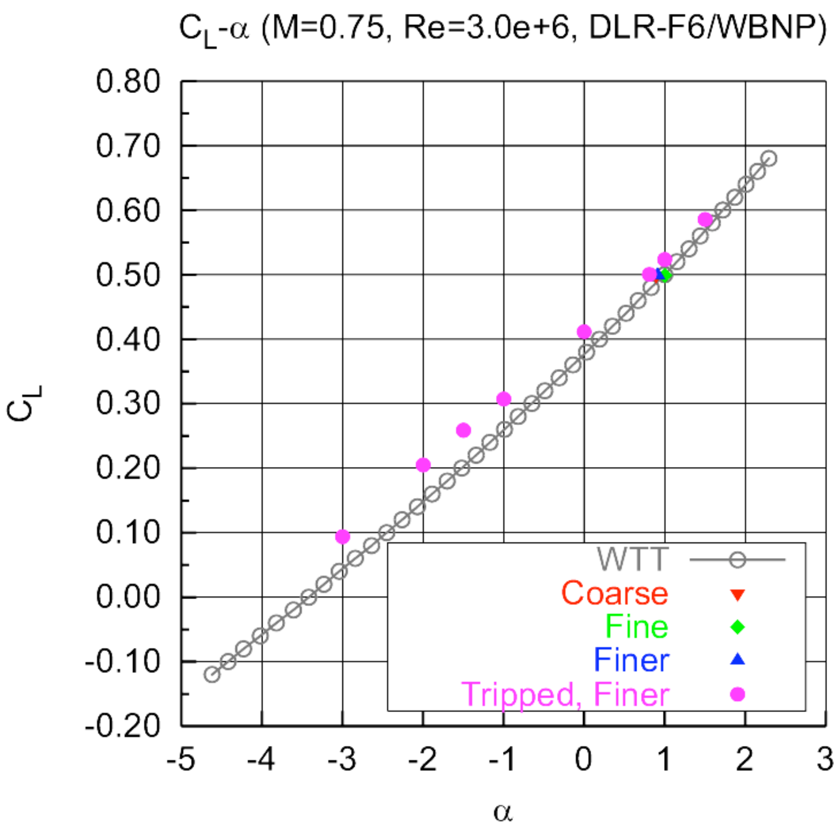
# $C_L$-_, $C_L$-$C_M$ (Wing-Body)

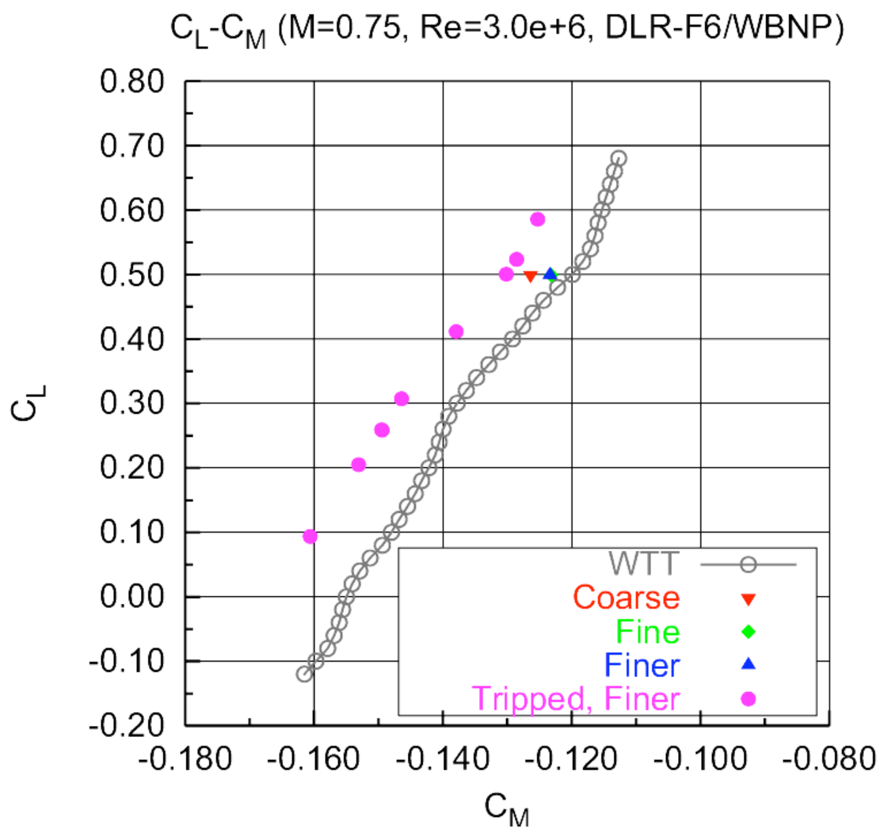
- $C_L$ is about 0.05 higher
- $C_M$ is 0.02 lower



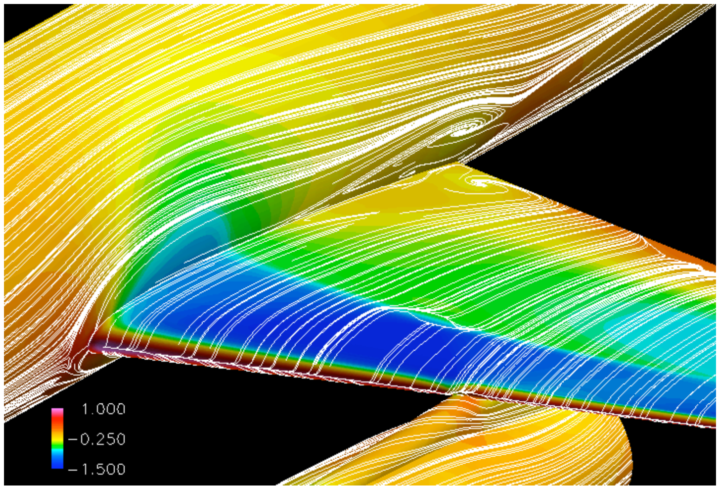
# $C_L$-_, $C_L$-$C_M$ (Wing-Body-Nacelle-Pylon)

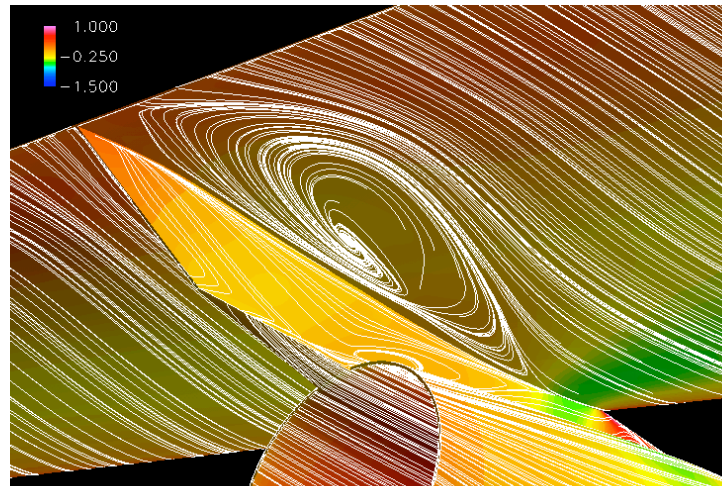


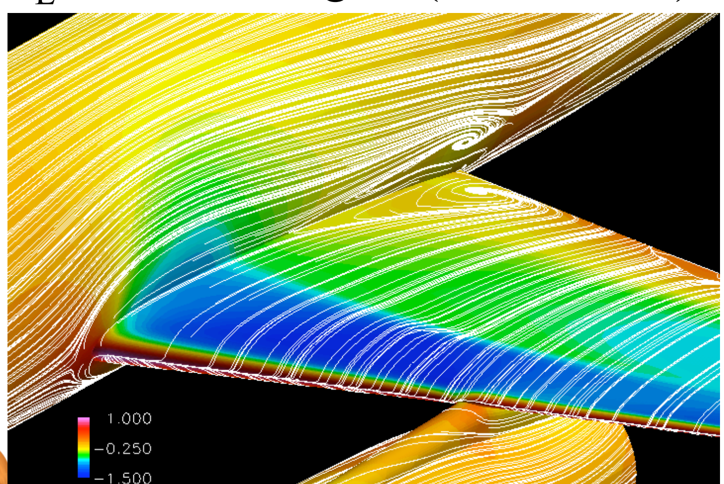
# Effect of grid size on the flow separation at corners

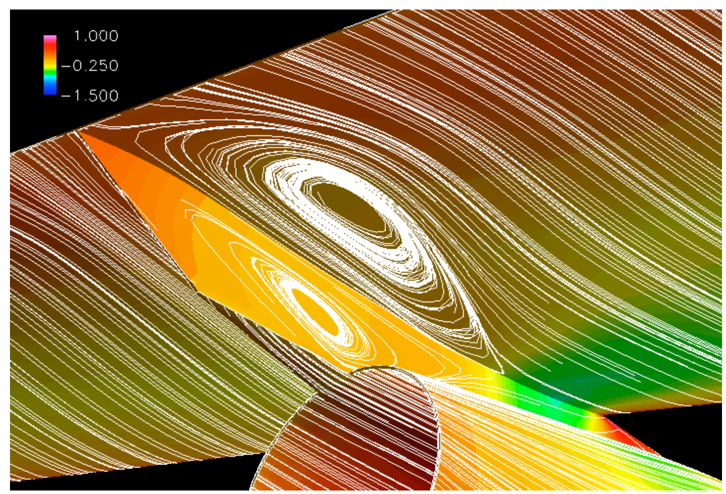
$C_L$=0.5 Finer grid (14.7 Million)



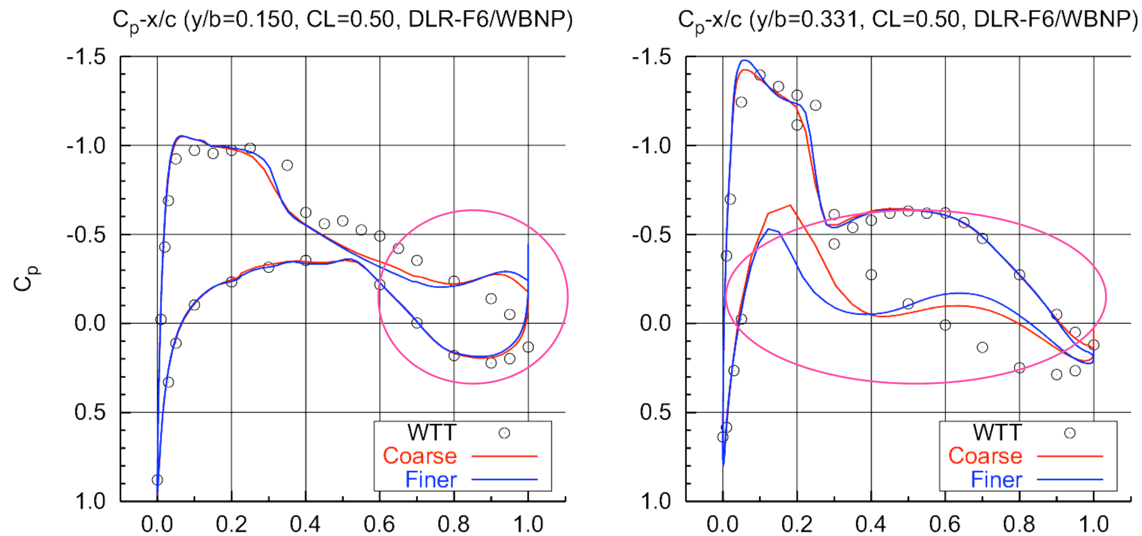

$C_L$=0.5 Coarse grid (1.9 Million)

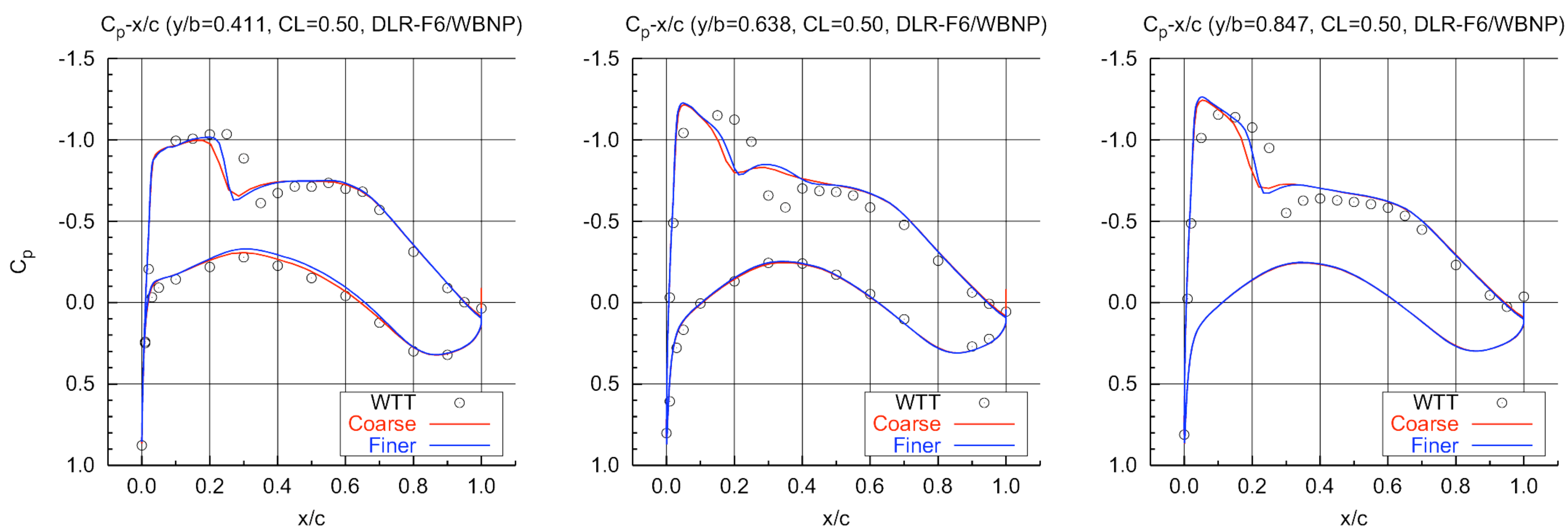


# Effect of grid size on Cp

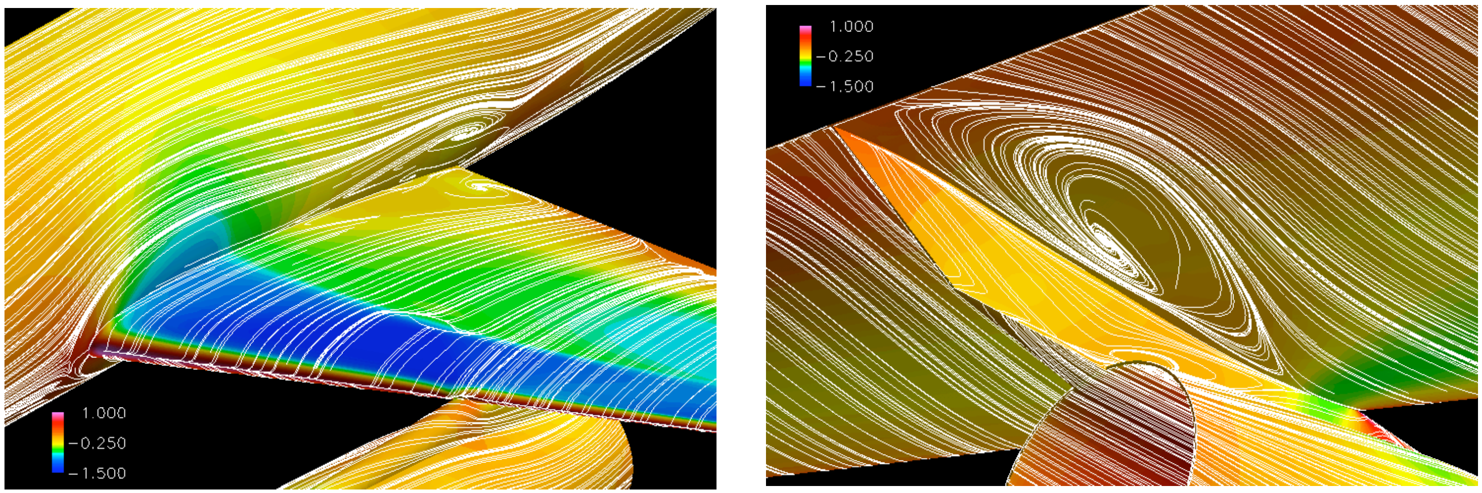
- Wing-Body-Nacelle-Pylon:
  M=0.75
  Re=3.x$10^6$
  $C_L$=0.5



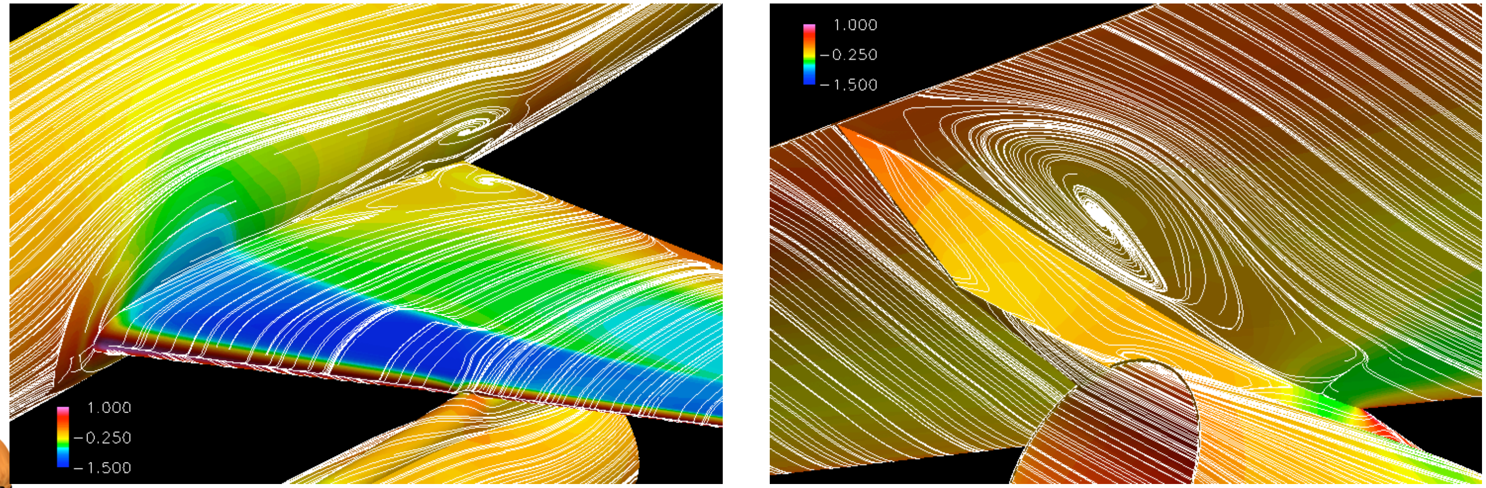



# Effect of transition on the flow separation at corners

$C_L$=0.5 (_= 0.91° )Fully turbulent

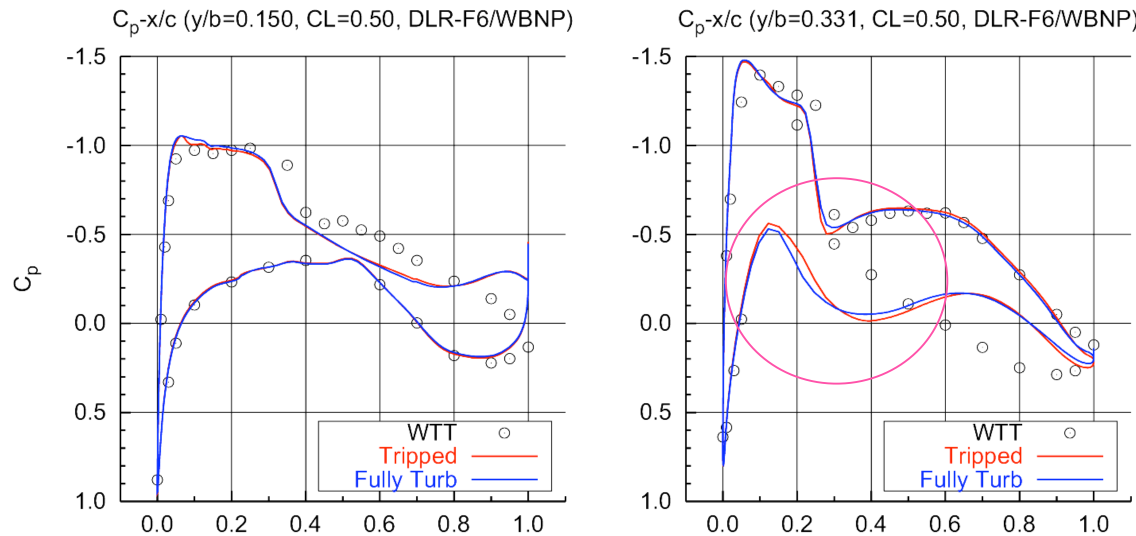


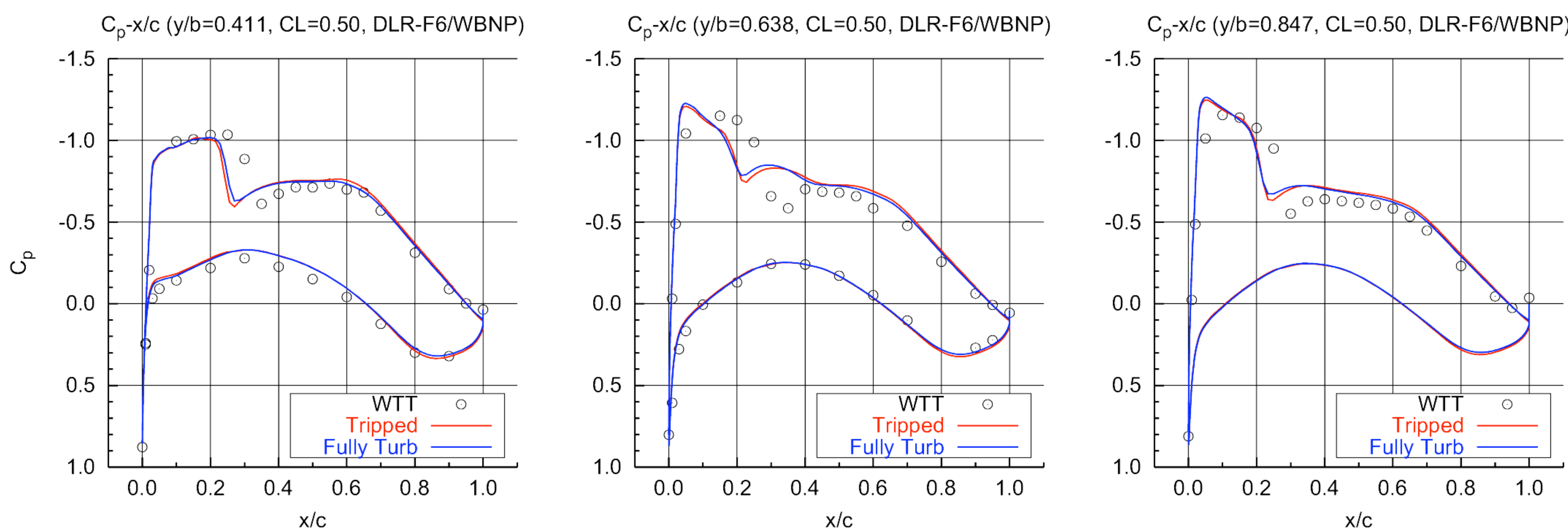

$C_L$=0.5 (_= 0.81° ) Transition



# Effect of transition on Cp

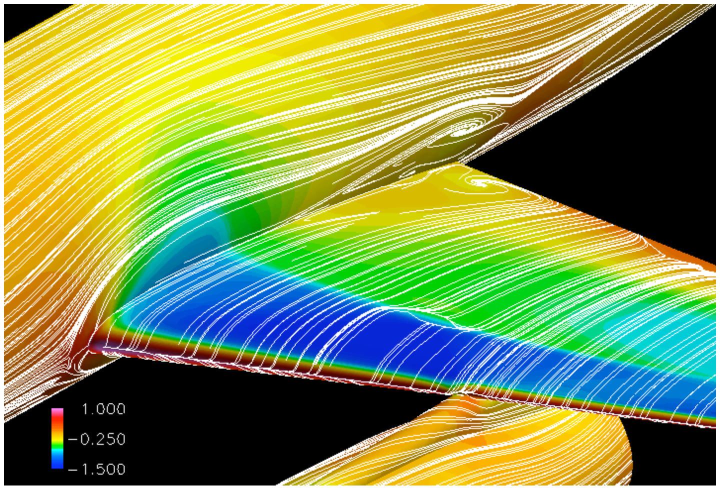
- Wing-Body-Nacelle-Pylon: M=0.75 $Re=3.x10^6$ $C_L=0.5$

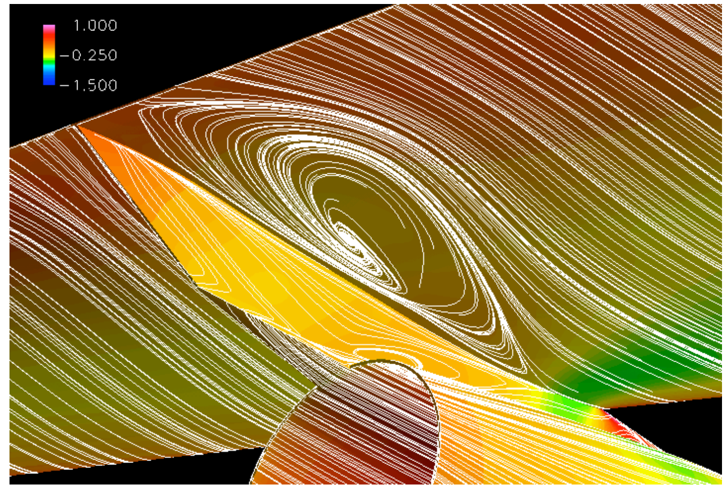


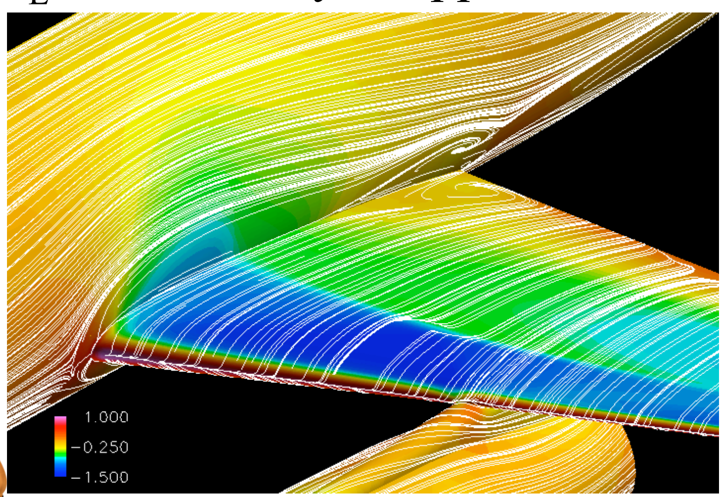
# Effect of thin-layer approximation on the flow separation at corners

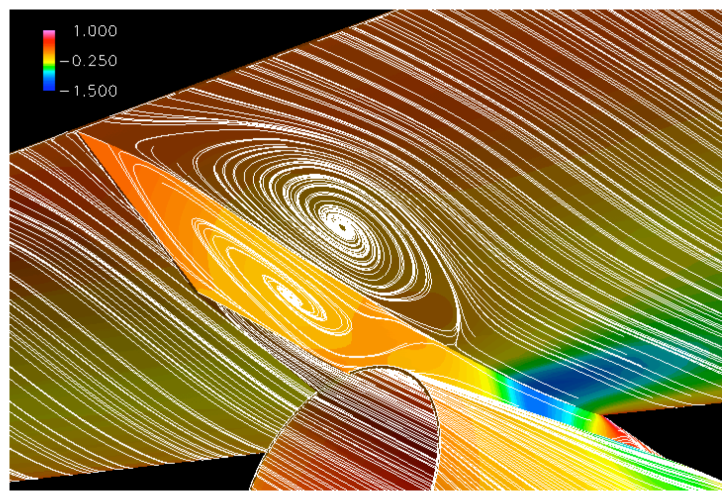
$C_L$=0.5 Full-NS



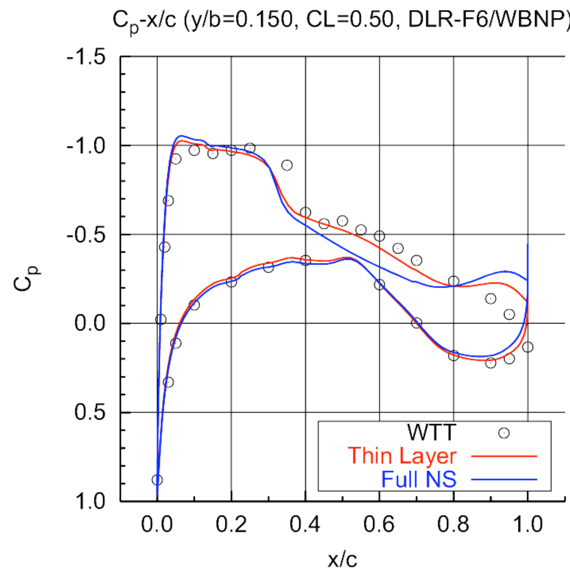

$C_L$=0.5 Thin-layer Approximation

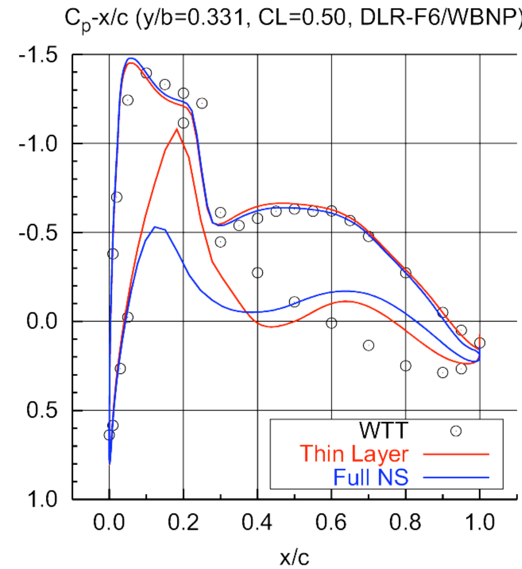


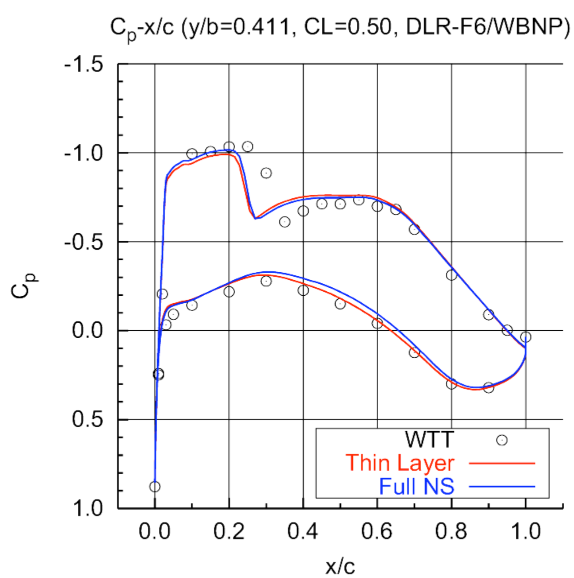



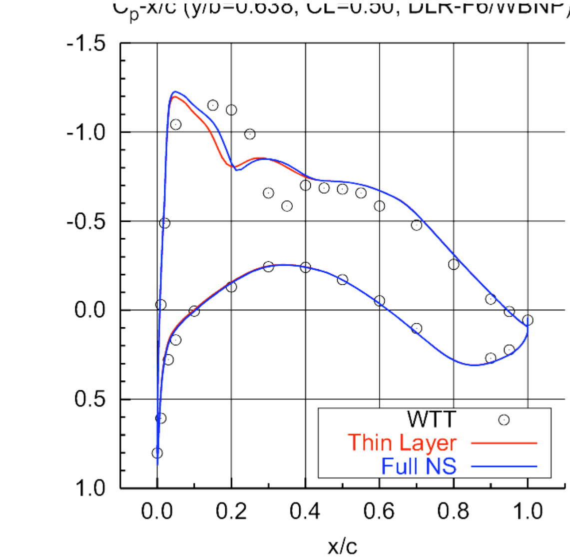
# Effect of thin-layer approximation on Cp

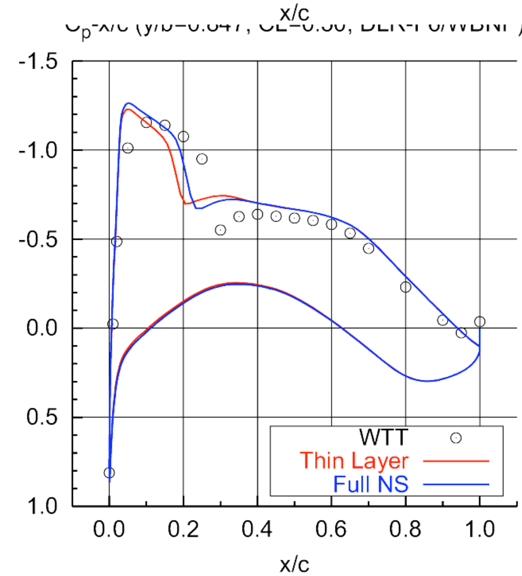
- Wing-Body-Nacelle-Pylon:
  M=0.75
  $Re=3.x10^6$
  $C_L=0.5$



# Summary

- Prediction of Aerodynamic characteristics
  - Deviation of predicted drag polar is 15 counts maximum.
  - Nacelle install drag is predicted larger at lower angle of attack.
  - Lift is shifted about 0.05 higher for both cases.
- Corner flow separation
  - Predicted size is much larger compared to experimental one.
  - Affects aerodynamic characteristics strongly.
- Effect of grid
  - Pressure drag is reduced by increasing the number of grid (The surface friction drag does not change much)
  - Grid resolution at the corners affect flow separation.
- Effect of transition
  - Drag is reduced about 10 counts in both cases mostly due to the friction decrease.
  - Less effect on wing surface pressure distribution.
- Effect of thin-layer approximation
  - Thin-layer approximation makes flow separation size smaller.

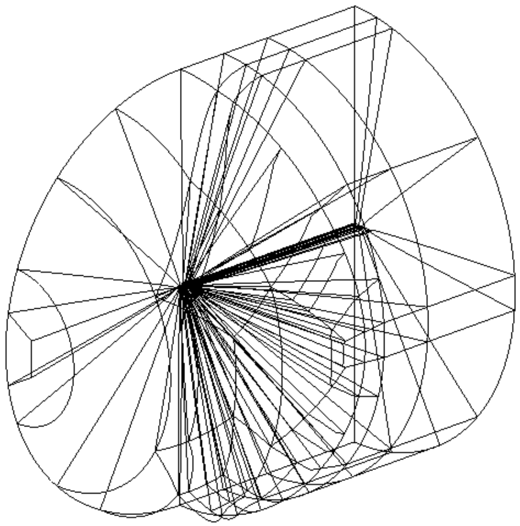
# Appendix

Snapshot of NAL Grid

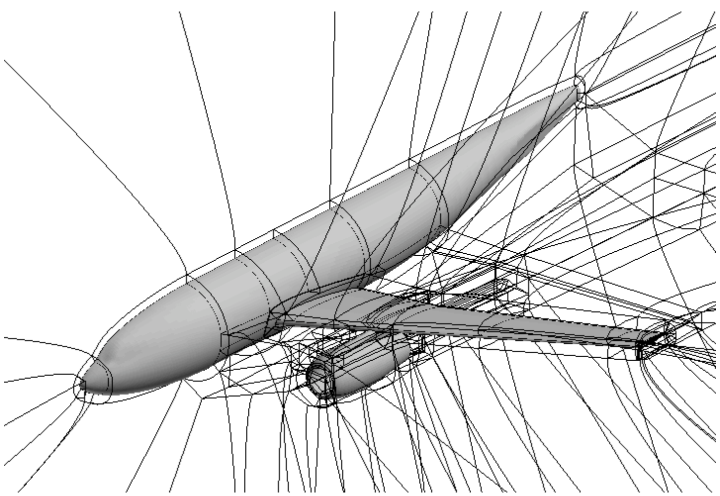
Other Cp distribution

Flow separation at lower _

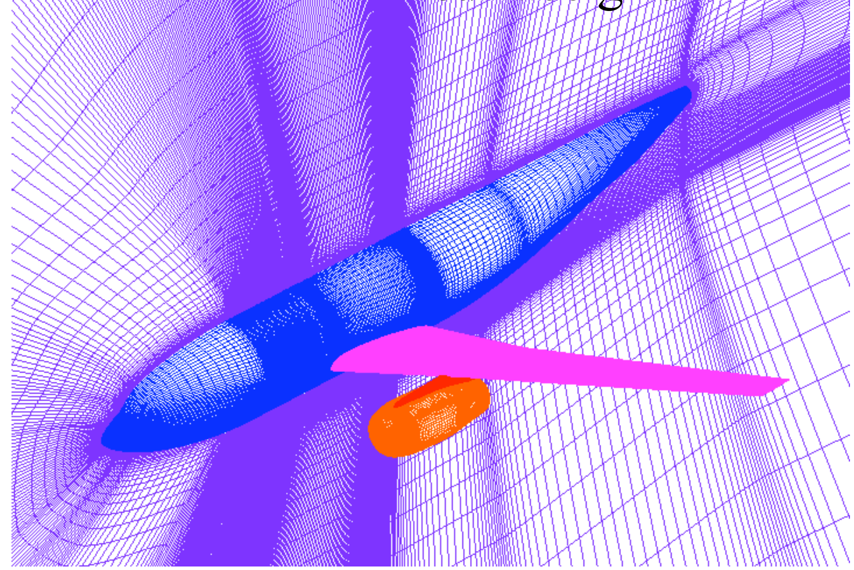
# NAL Grid



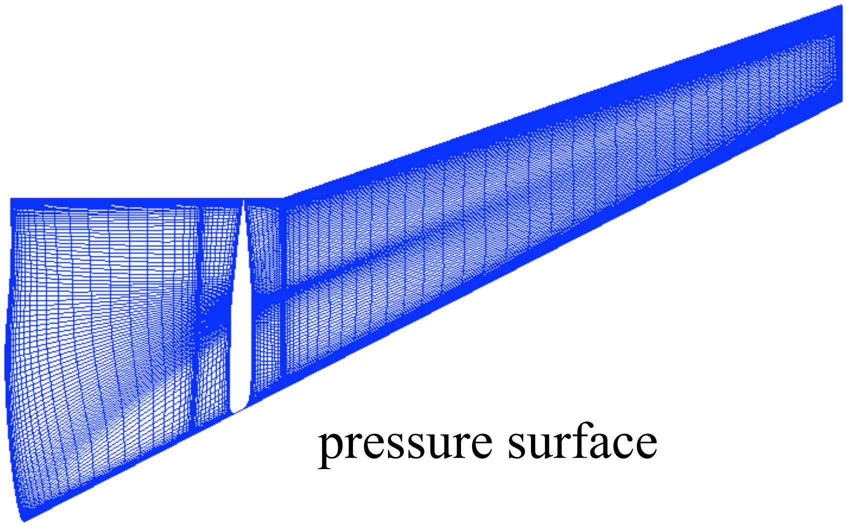
block wire-frame



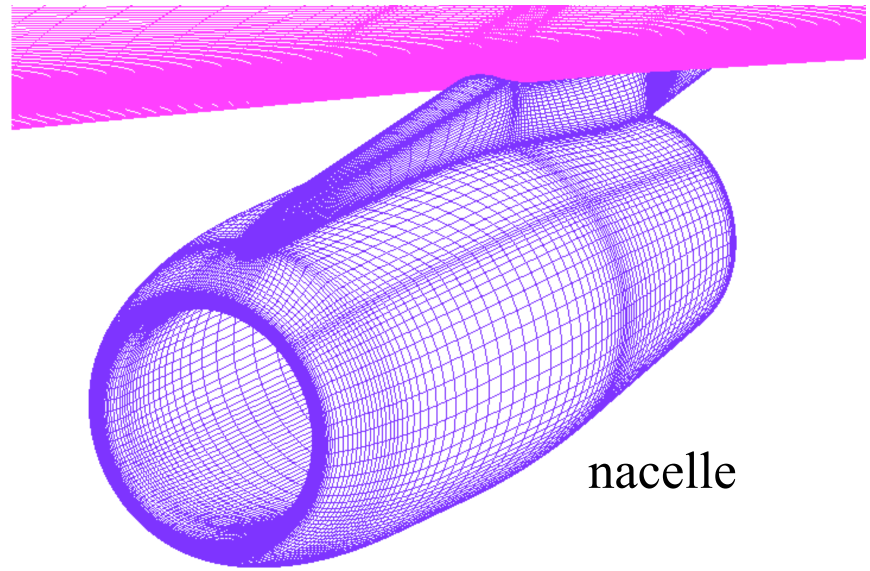
surface grid



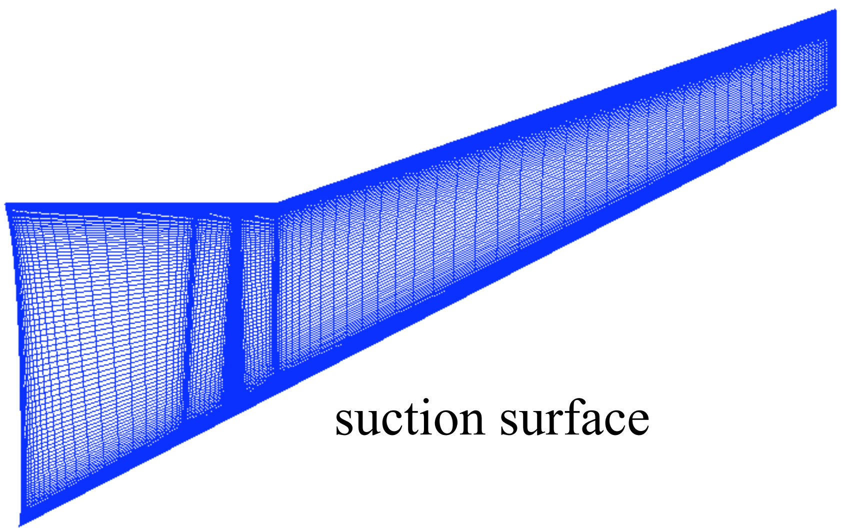
# Detail snapshots of NAL grid



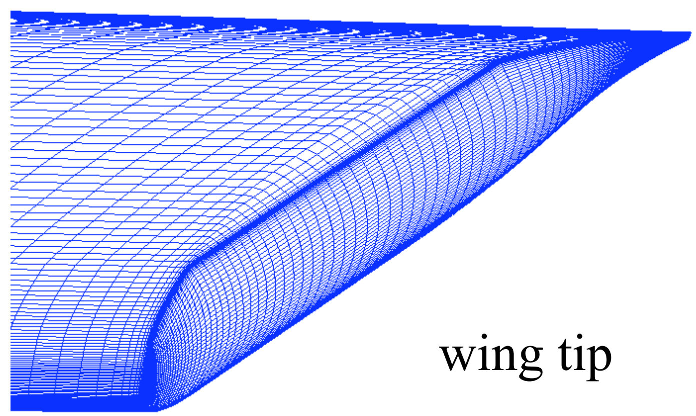
pressure surface



nacelle



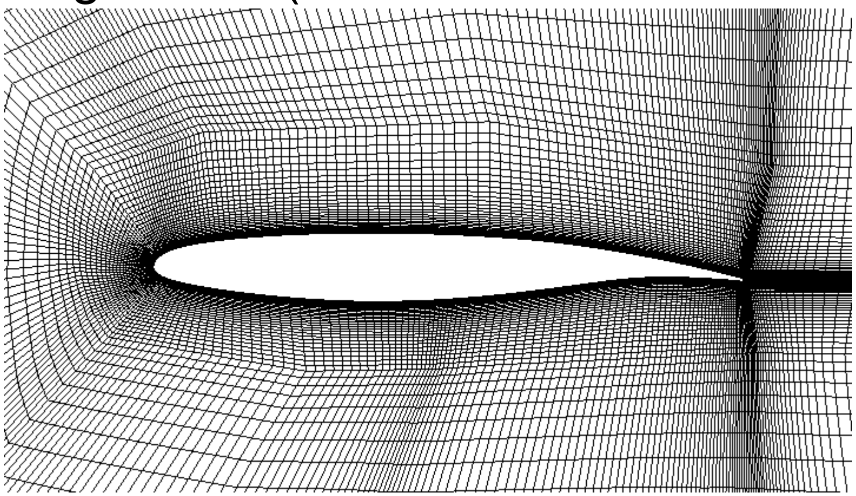
suction surface



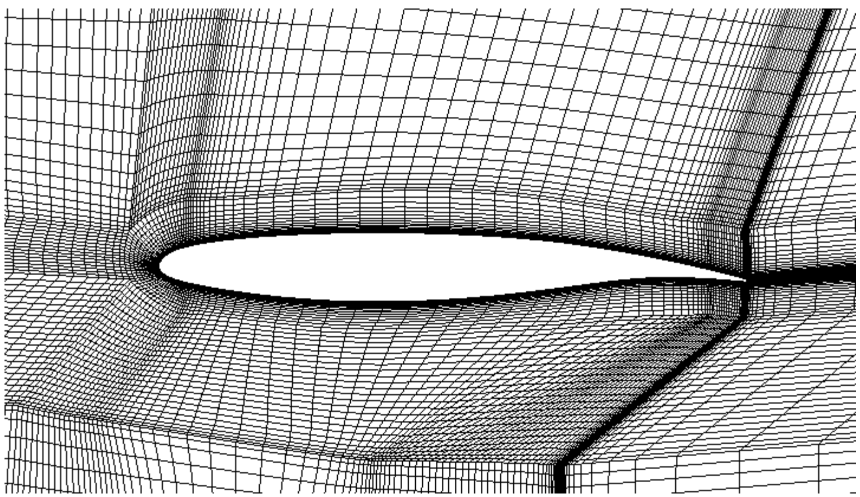
wing tip

# Grid comparison

- Wing section (_~50%) of WBNP grid
- Same grid size (Total cell size 13.5 million)



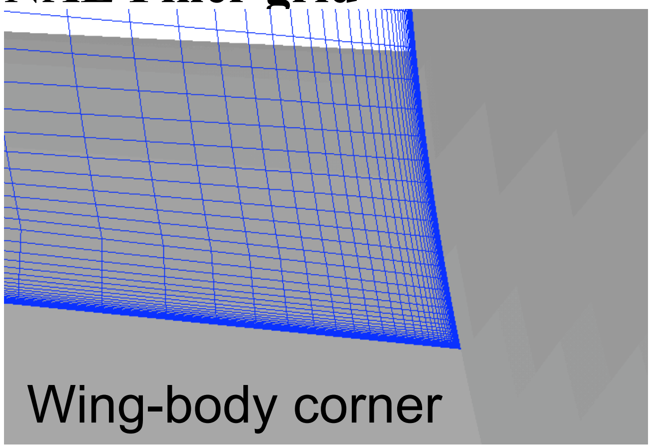
NAL

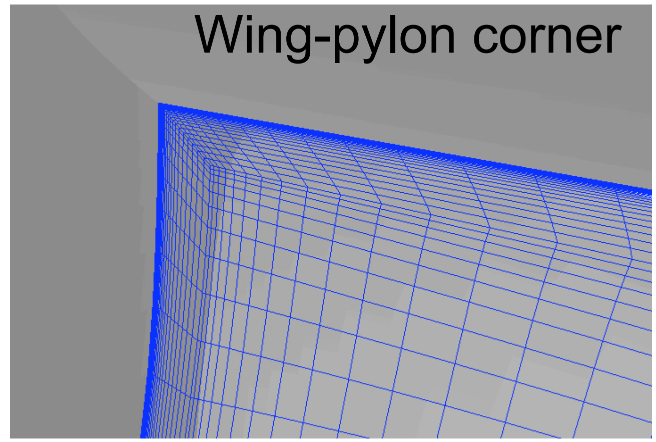


ICEM

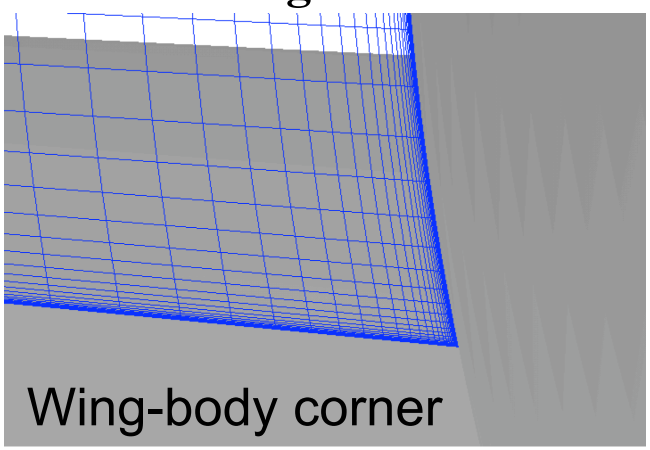
# Comparison of corner grid

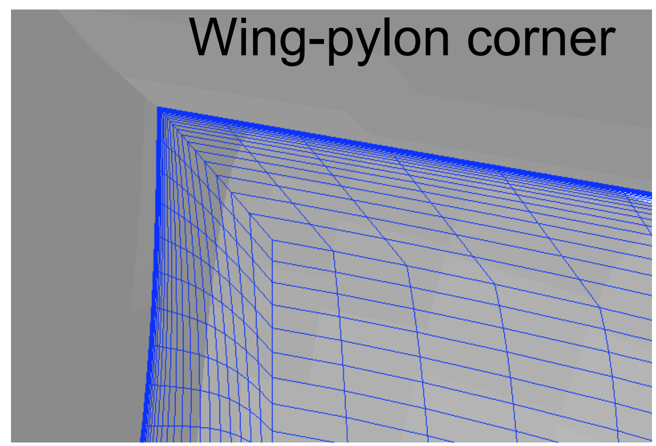
**NAL Finer grid**



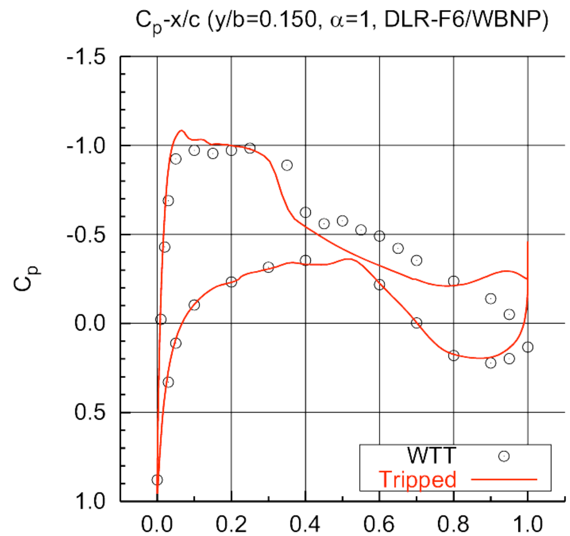

**ICEM Fine grid**

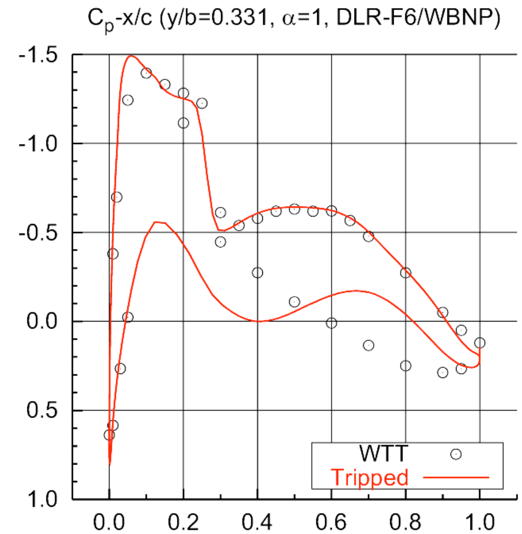


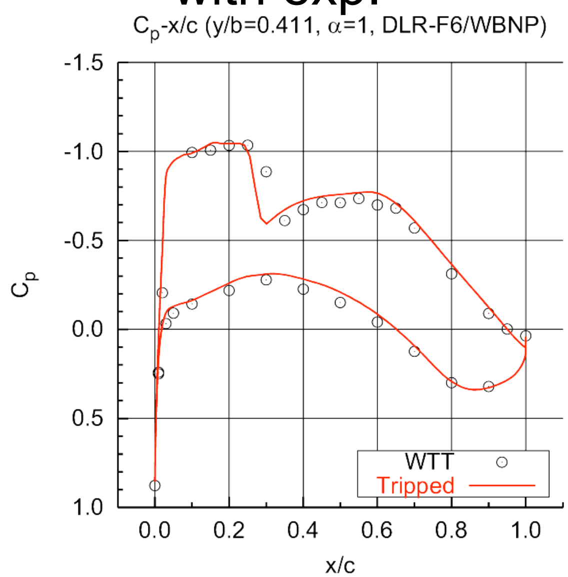



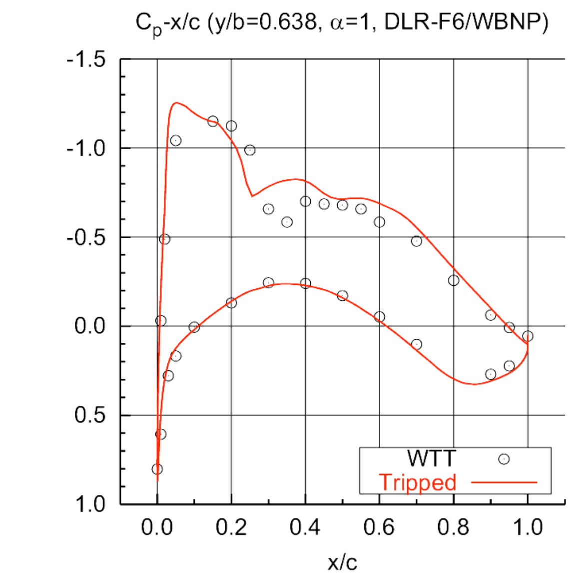
# $\alpha$ =1.0º case : Wing-Body-Nacelle-Pylon

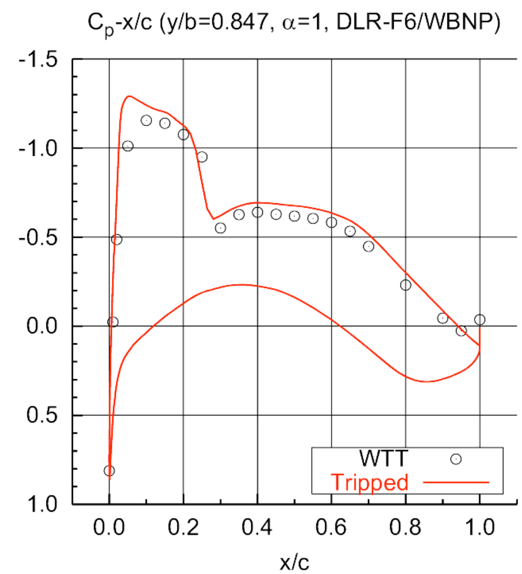
- Wing-Body-Nacelle-Pylon:
  M=0.75
  Re=3.x10$^6$
  _=1.0°
  CL=0.523
- Matching *better* with exp.



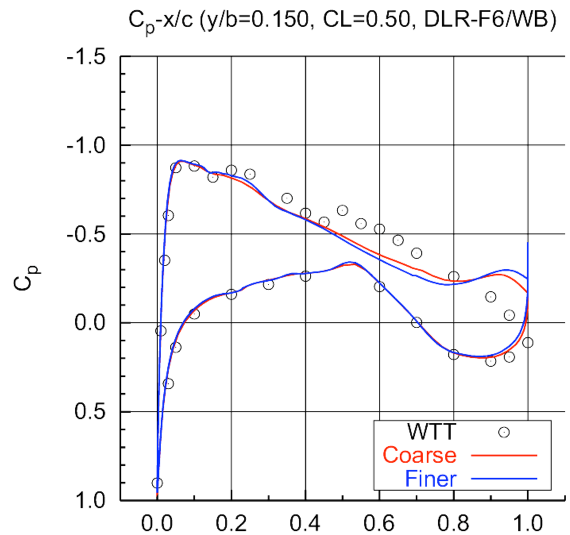



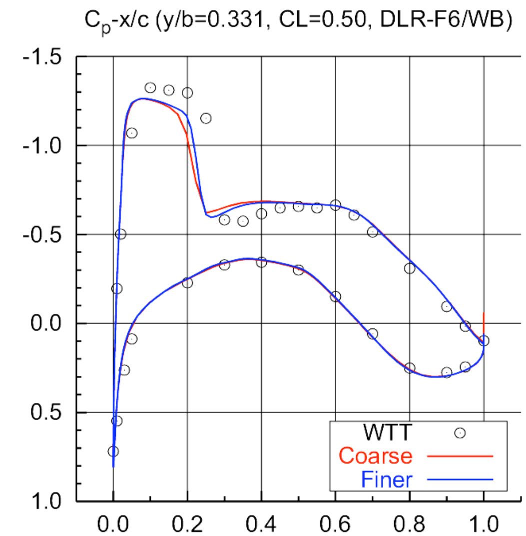



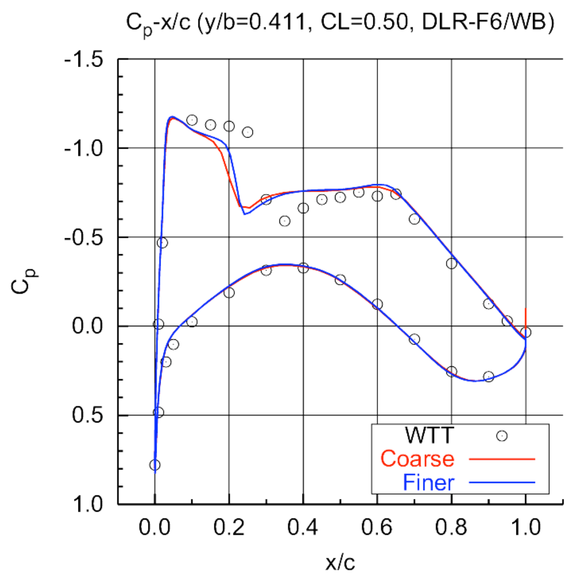



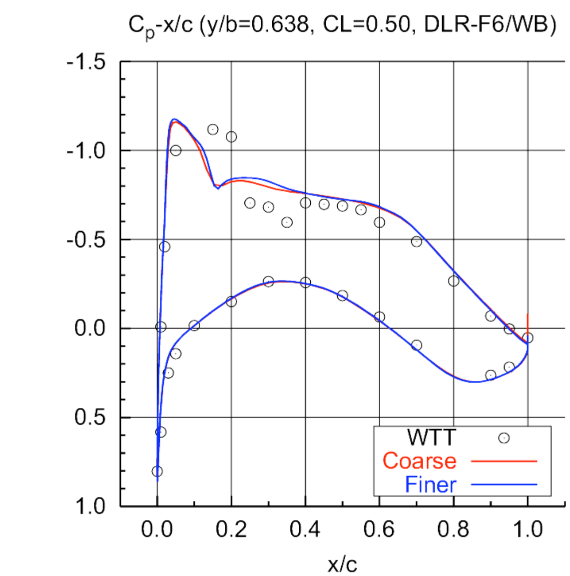
# Effect of grid on Cp: Wing-Body

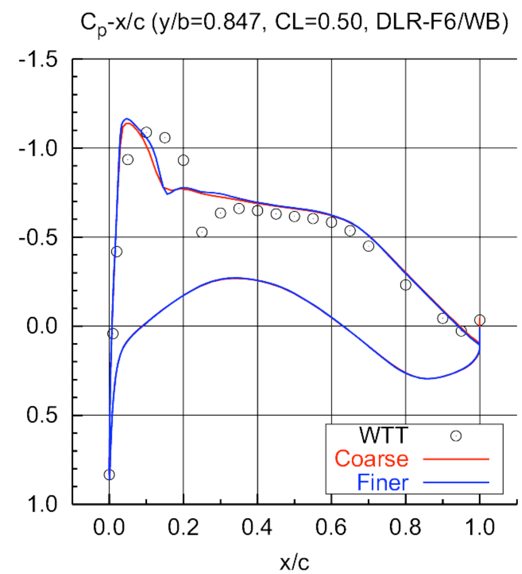
- Wing-Body:
  M=0.75
  $Re=3.x10^6$
  CL=0.5



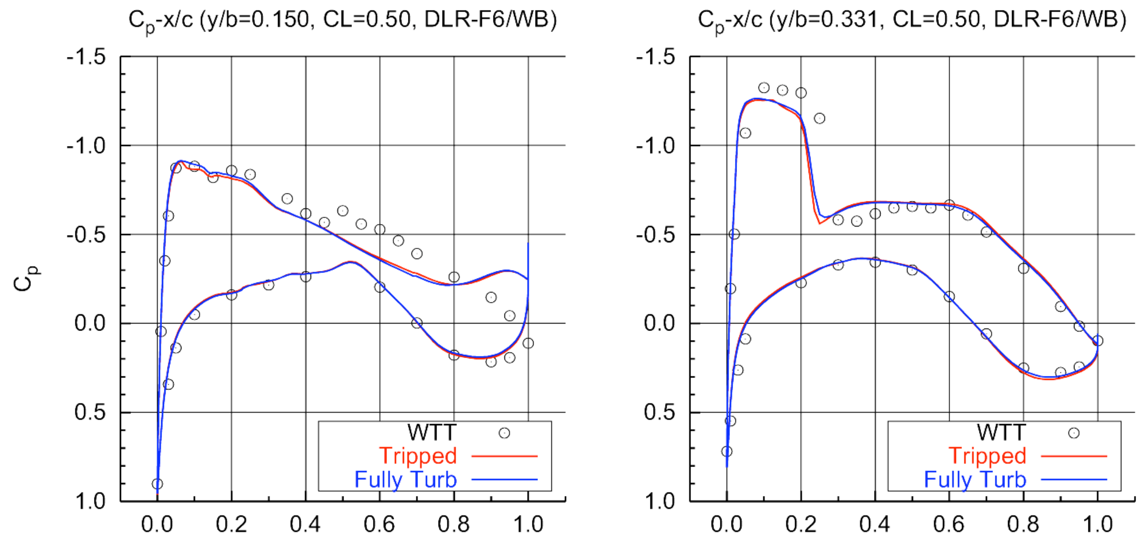



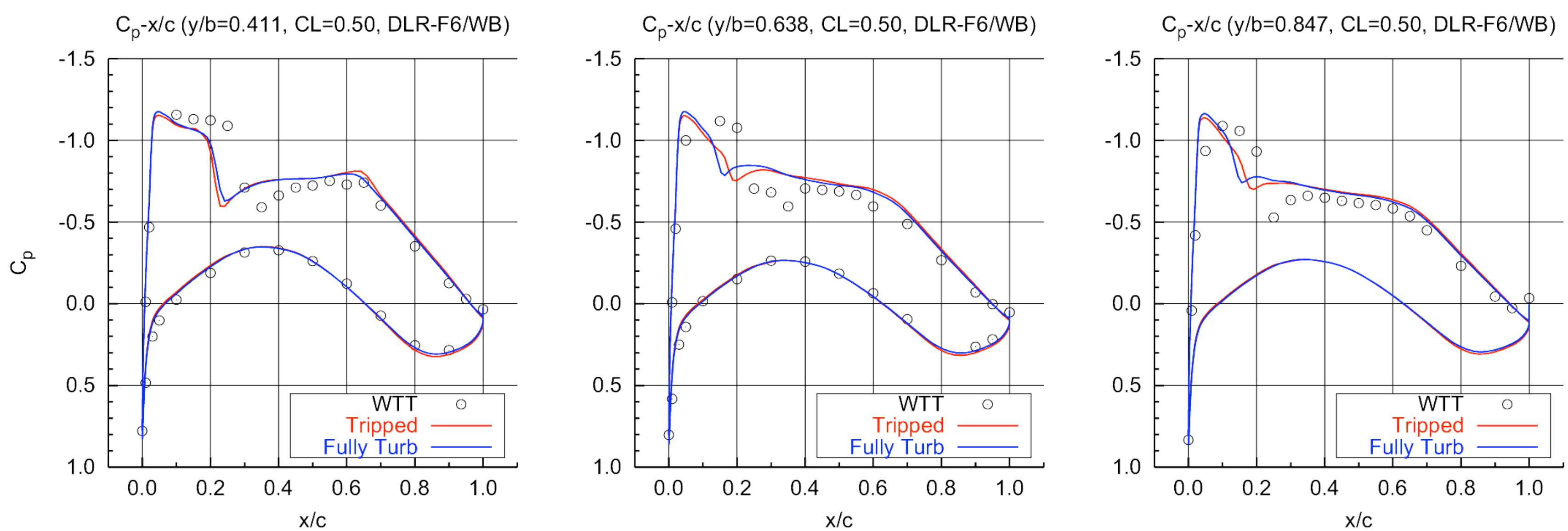



# Effect of transition on Cp: Wing-Body

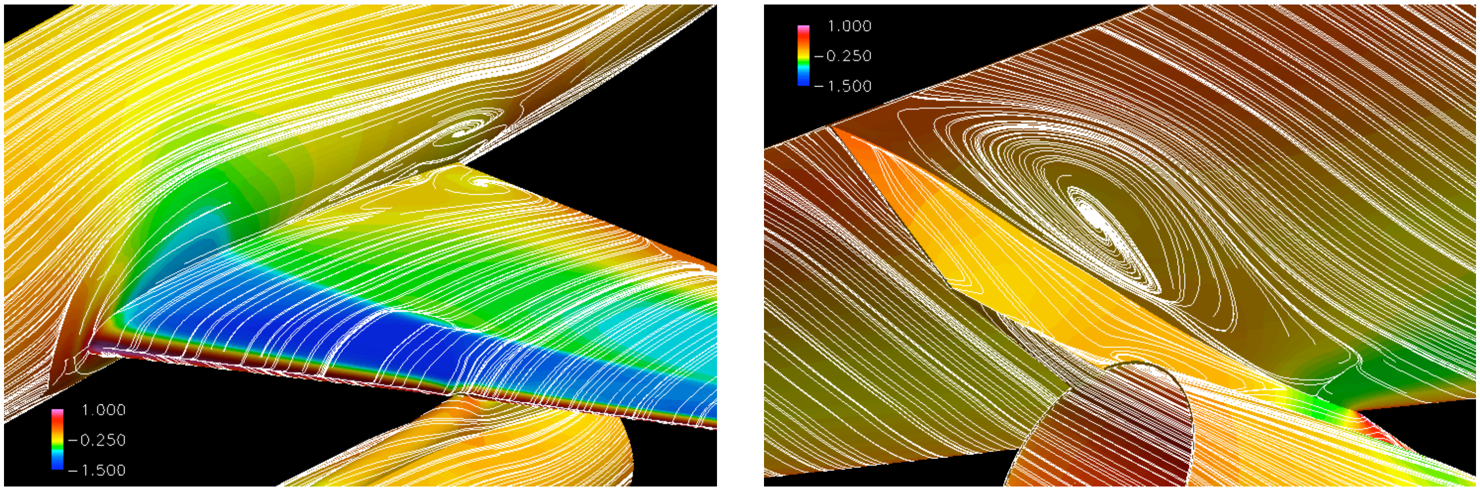
- Wing-Body:
  M=0.75
  Re=3.x10$^6$
  CL=0.5



# Flow separation at lower angle of attack

CL=0.5 (_= 0.81°) Transition




_= -2° Transition