21-22. Jun. 2003 AIAA Drag Prediction Workshop II, Orlando, FL

AIAA Drag Prediction Workshop II

KHI Results with Hybrid Unstructured Grid

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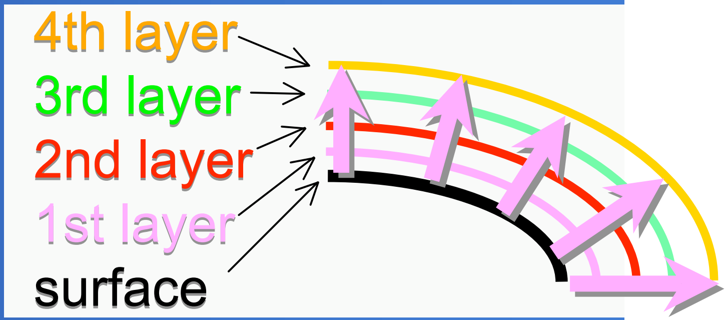
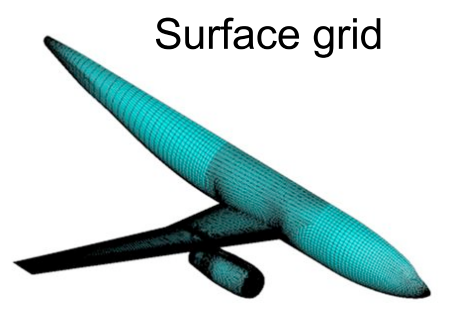
Outline

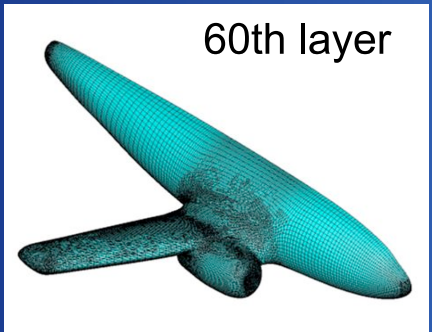
- Grid system
- Numerical method
- Computed cases
- Results
  - Wing-Body (WB) configuration
  - Wing-Body-Nacelle-Pylon (WBNP) configuration
- Summary

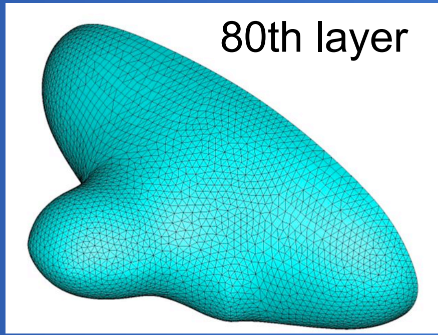
Grid generation process

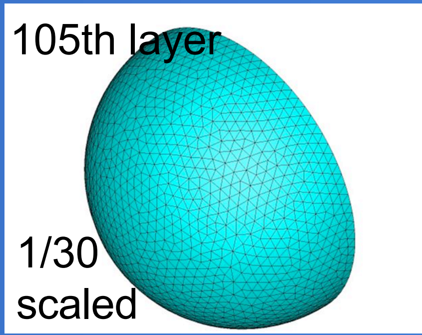
- Hybrid unstructured volume grid
- CFD volume mesh is generated by KHI original code
  PUFGG (Pile-Up Forming Grid Generator)
- Piles up layers from surface mesh
- Applicable both viscous and inviscid flow
- For surface mesh, triangle, quadrilateral, or mixed cells can be used
- 1 hour to generate viscous mesh for WBNP



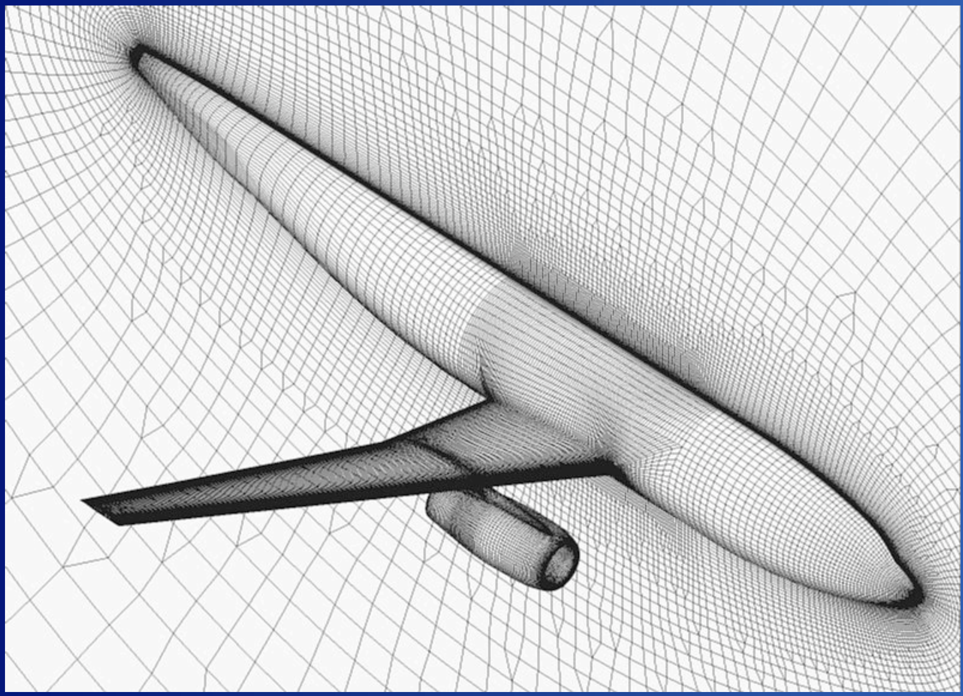


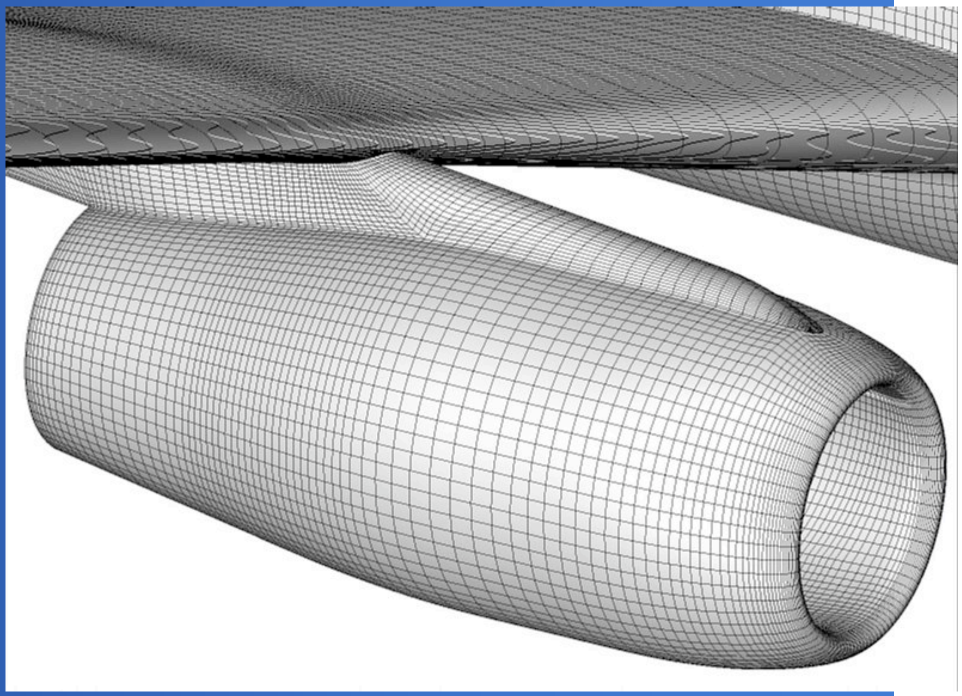






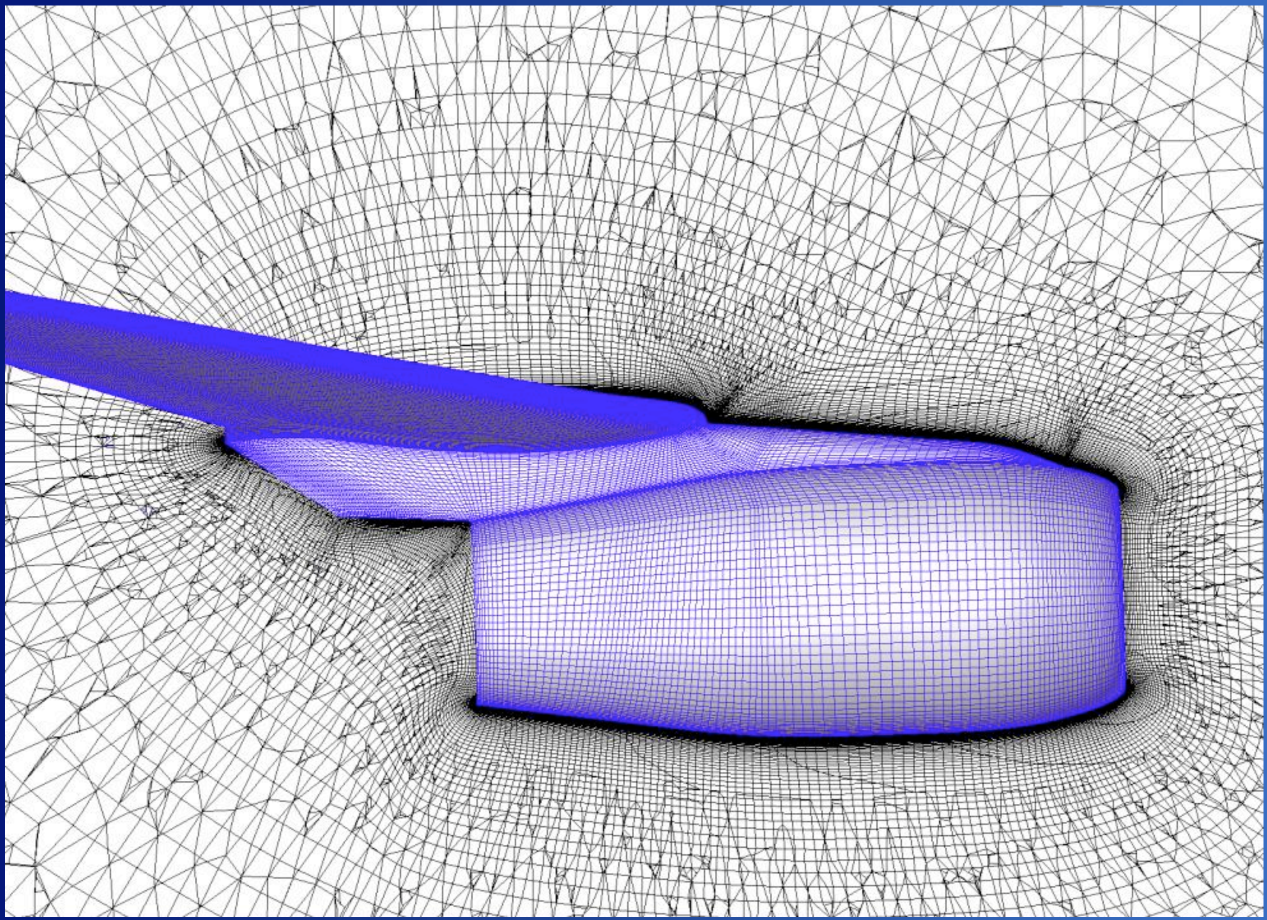
Surface Grid





- Medium density grid
- Surface mesh consists of 98% quadrilateral cells and 2% triangle cells
- Volume mesh consists of 78% hex, 16% prism, 3% pyramid, and 3% tetra cells

Cross section at nacelle

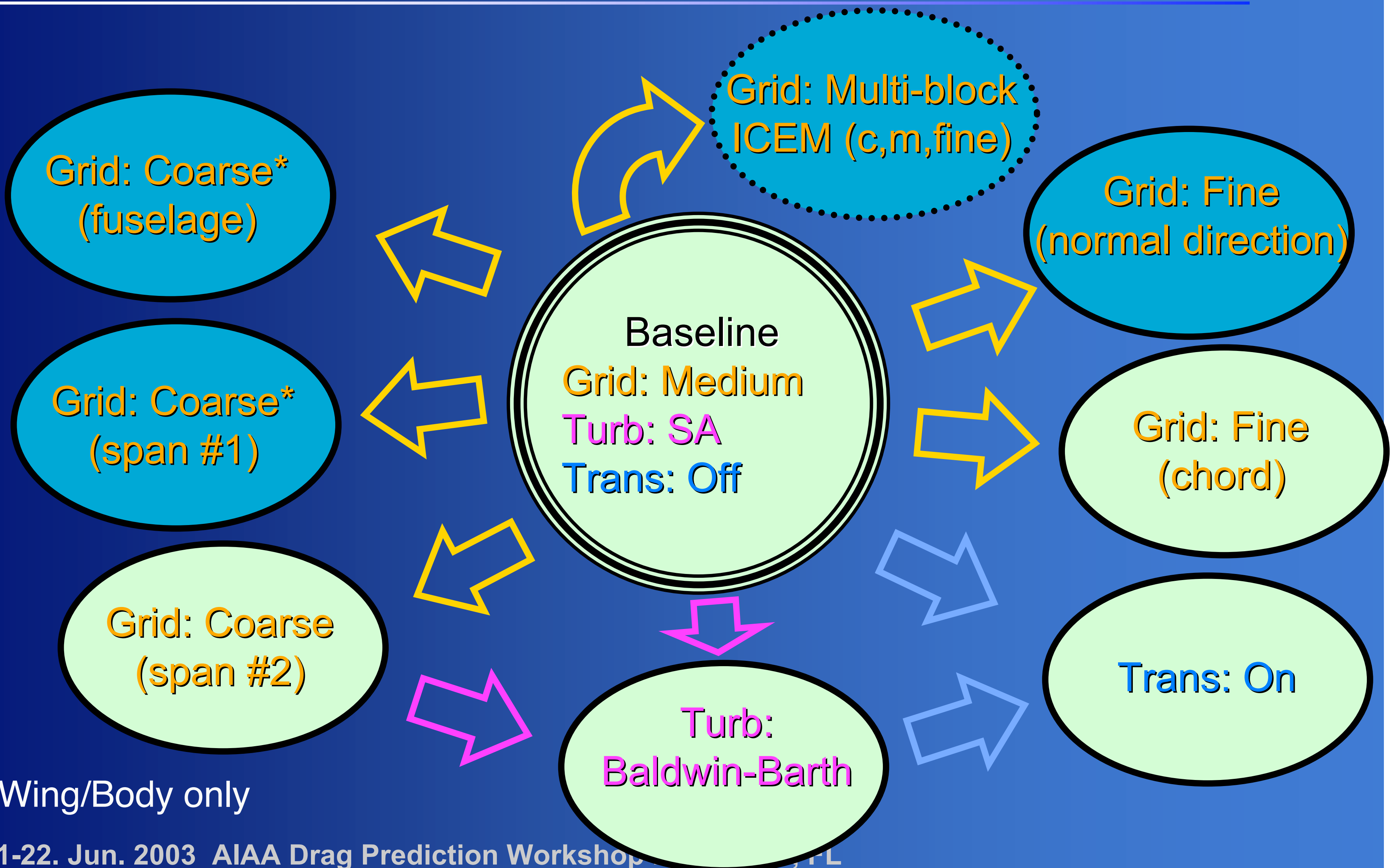


- Medium grid
- Black lines are cut volume grid lines at center of nacelle.
- Blue lines show surface mesh.
- Grid cells near body surface are similar to structured grid cells, because grid cells this region consist of hex cells.
- Far field grid keeps ordered structure, because grid cells mainly consist of prism cells.

Numerical Method UG3

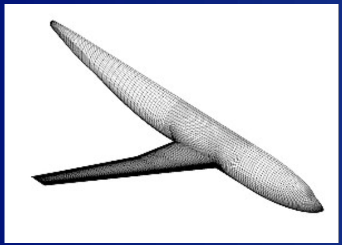
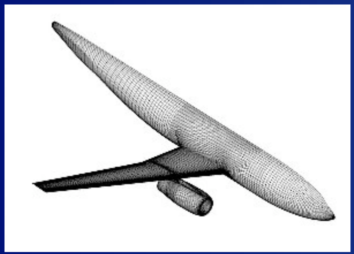
- Governing equations : Thin layer RANS equations
- Grid system: Hybrid unstructured grid
- Numerical scheme: Cell centered finite volume method
  - Spatial discritization : MUSCL+SHUS
  - Time integration : MFGS Implicit scheme
  - Turbulence modeling : Spalart-Allmaras (SA) model
Baldwin-Barth (BB) model

Computed Cases



*:Wing/Body only

Grid size

	Grid size	Surface cells	Volume points	Volume cells
 Wing/Body	Coarse	22k	1.6M	1.8M
	Medium	57k	3.6M	4.1M
	Fine	73k	4.7M	7.5M
 Wing/Body/ Nacelle/Pylon	Coarse	49k	2.8M	3.3M
	Medium	105k	5.9M	6.7M
	Fine	160k	8.6M	9.5M

Comparison of CL,CD,CM between SA and BB turbulence model for Wing-Body configuration

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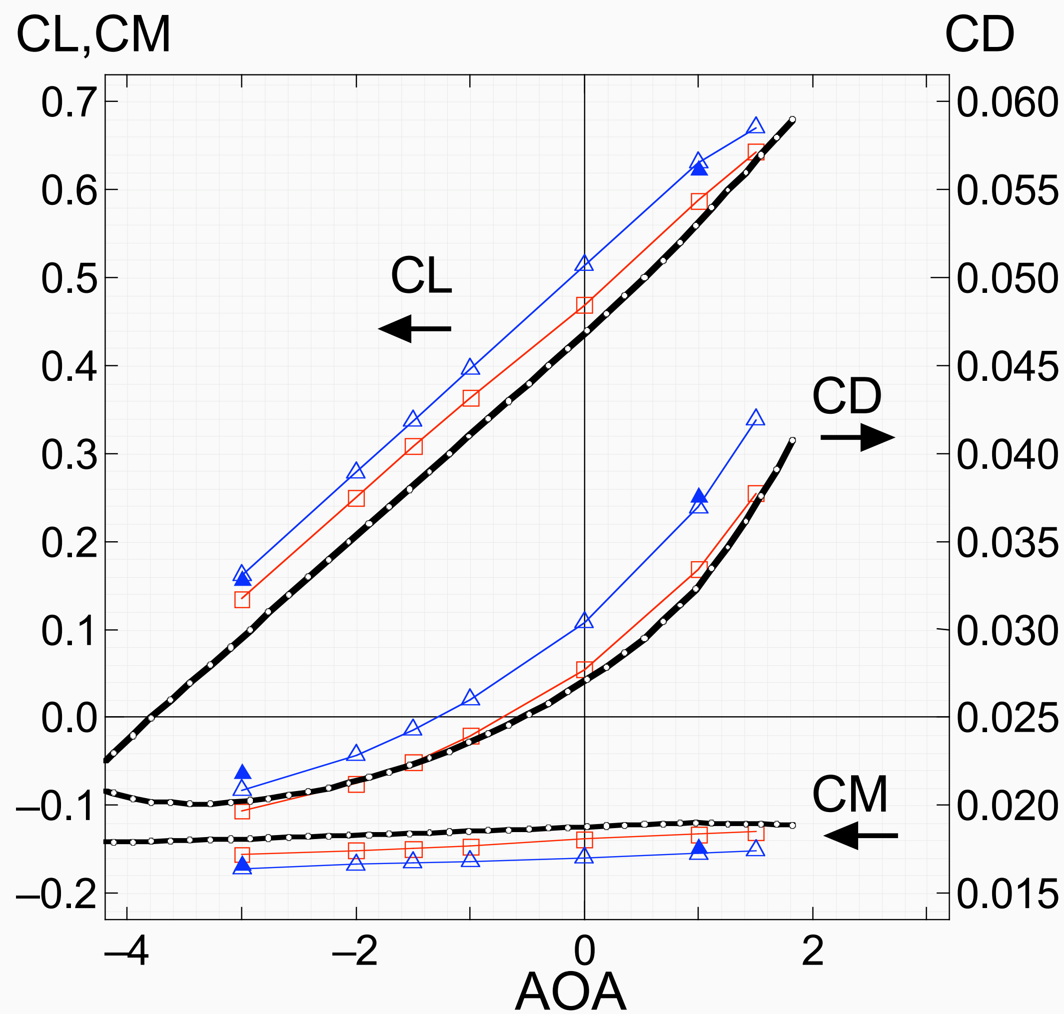

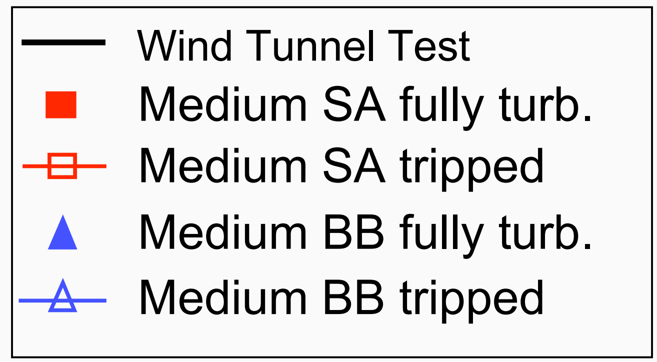

Calculation condition: Wing-Body, M=0.75

- Spalart-Allmaras (SA) turbulence model shows closer value to WTT, while Baldwin-Barth (BB) model shows large alpha shift.
- CL□ slope computed by BB model is in good agreement with WTT result
- CL□ slope computed by SA model is slightly smaller value than WTT result.
- Transition effect:
  - Increase CL by approx. +0.02
  - Decrease CD by approx. 4 drag counts.
  - CL□ slope is nearly same

Surface mesh effect on separation vortex for Wing-Body configuration

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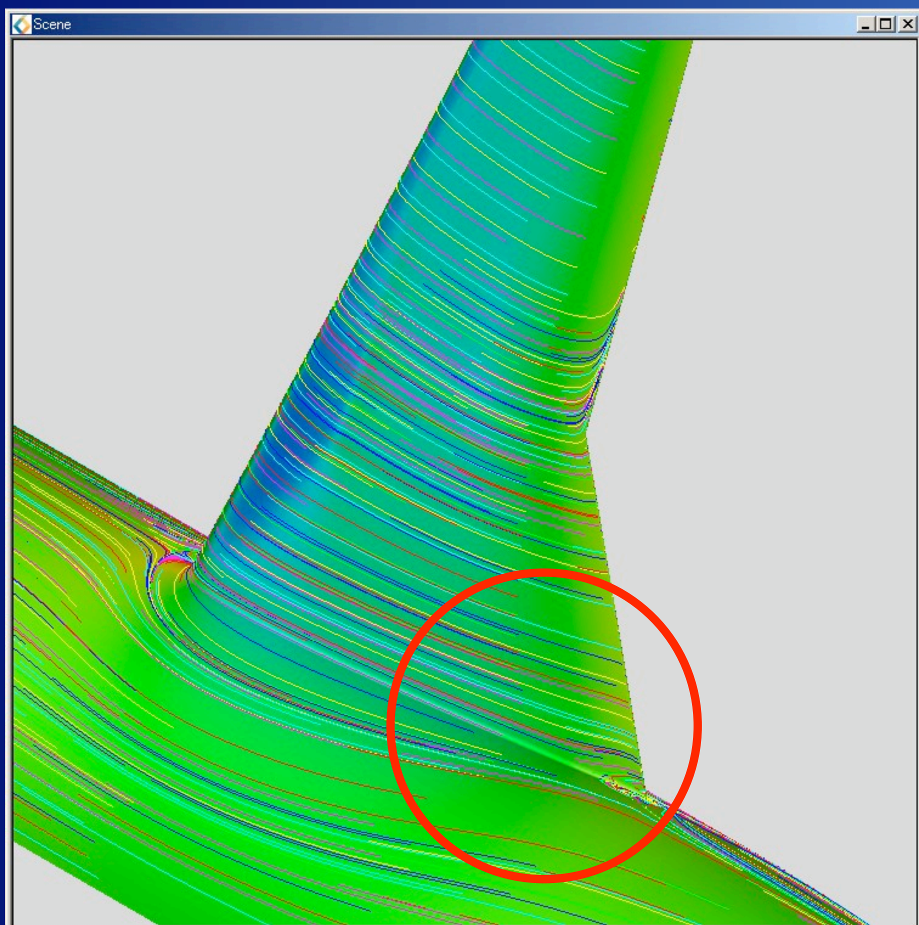
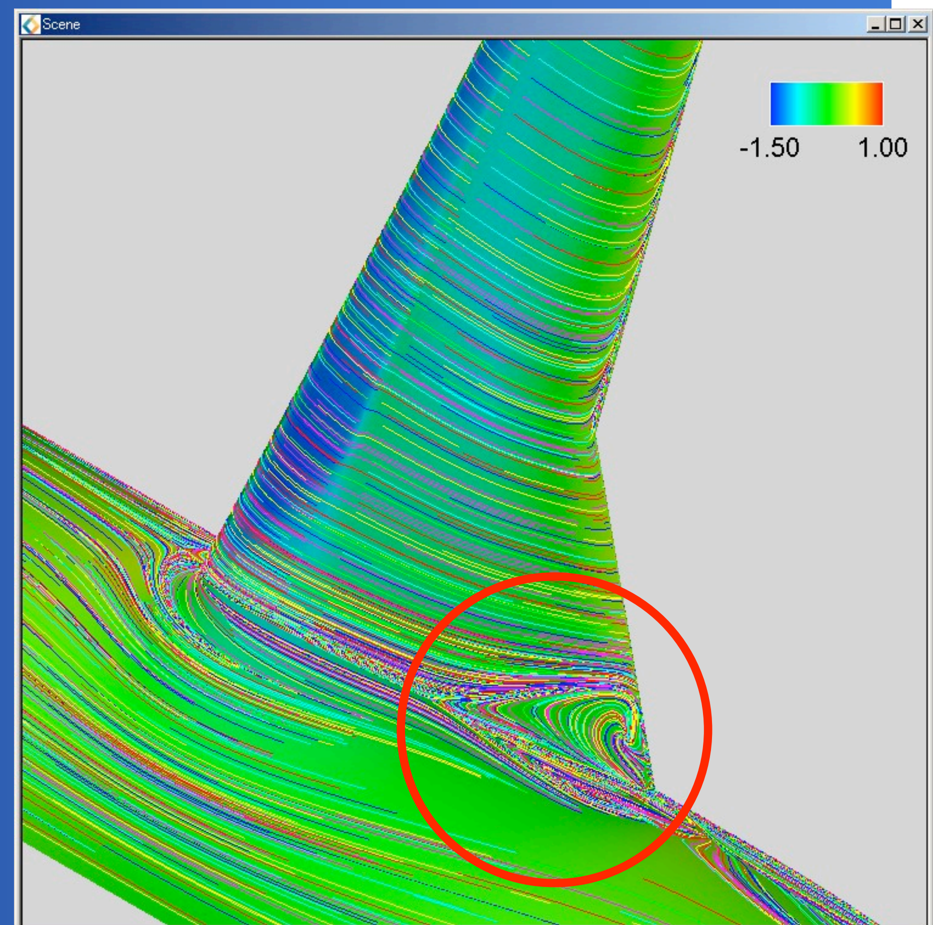
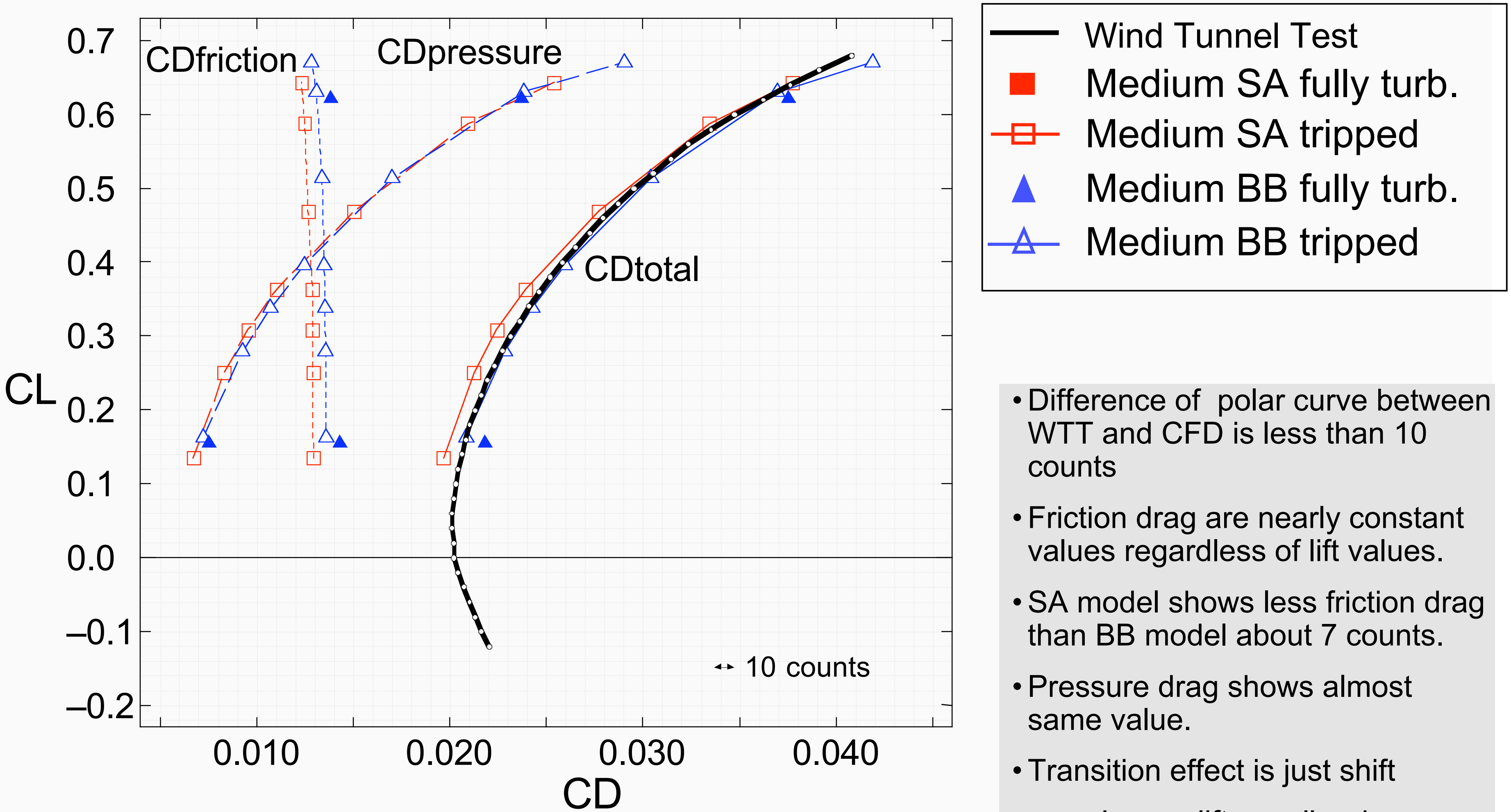
Coarse



Medium



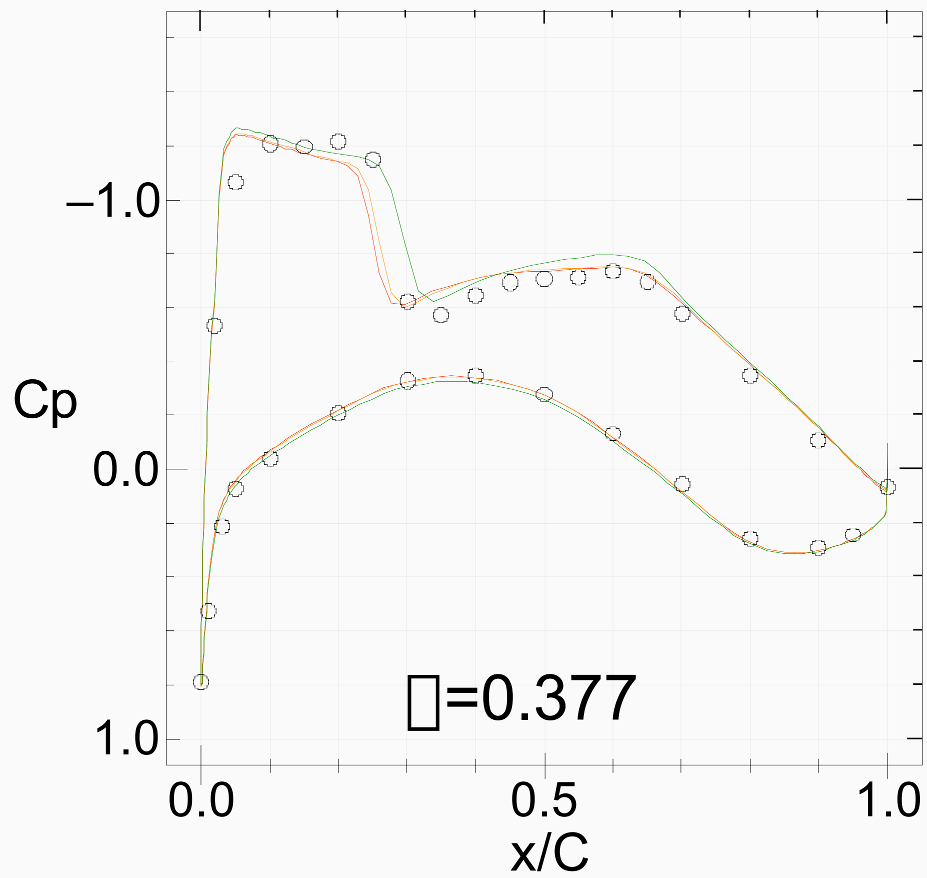
Comparison of polar, CDf, and CDp between SA and BB turbulence model for Wing-Body configuration



Calculation condition: Wing-Body, M=0.75

- Difference of polar curve between WTT and CFD is less than 10 counts
- Friction drag are nearly constant values regardless of lift values.
- SA model shows less friction drag than BB model about 7 counts.
- Pressure drag shows almost same value.
- Transition effect is just shift
  - Larger lift, smaller drag

Difference of span-wise grid density



--- 100x67 chord(one side) x span

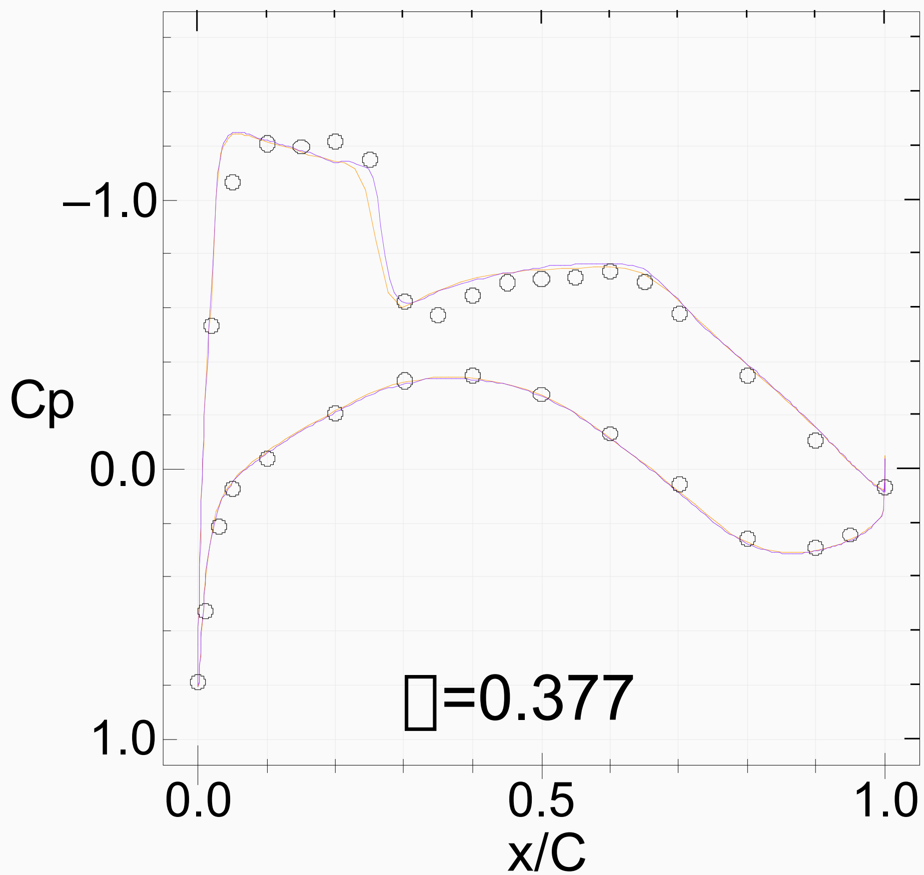
--- 100x93

--- 200x121

- Shock location moves forward with increase of span-wise direction grid points.
- Shock location shift looks like converged at 121 points.
- 67 points grid results seems to be good results, however if transition is not applied in this calculation.

Calculation condition: Wing-Body, M=0.75, AOA=0.49, SA model, **fully turbulent**

Difference of Chord-wise grid density



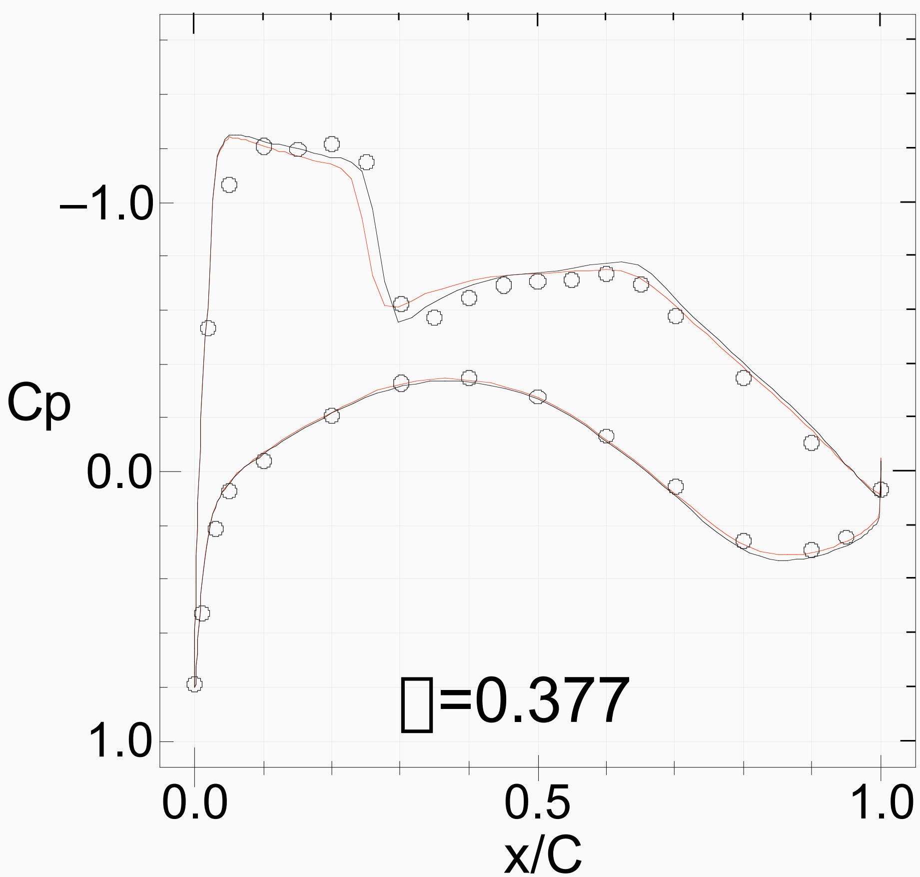
--- 100x93 chord(one side) x span

--- 200x88

- Difference between two grid is small
- Shock is slightly steep in fine grid results.

Calculation condition: Wing-Body, M=0.75, AOA=0.49, SA model, fully turbulent

Transition effect



--- 100x121

--- 100x121 (with transition)

- Transition effect:
  - Shock location moves backward
  - Shock intensity becomes strong
    - Wave drag estimation should be affected.

Calculation condition: Wing-Body, M=0.75, AOA=0.49, SA model

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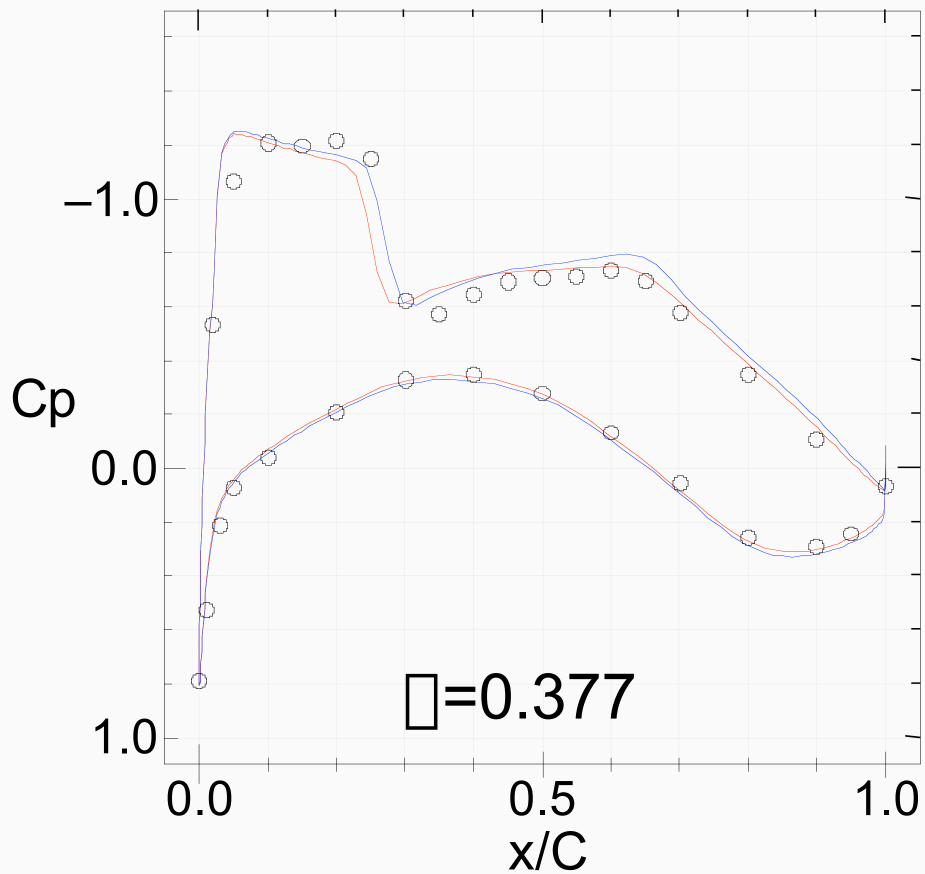
Difference of turbulence model



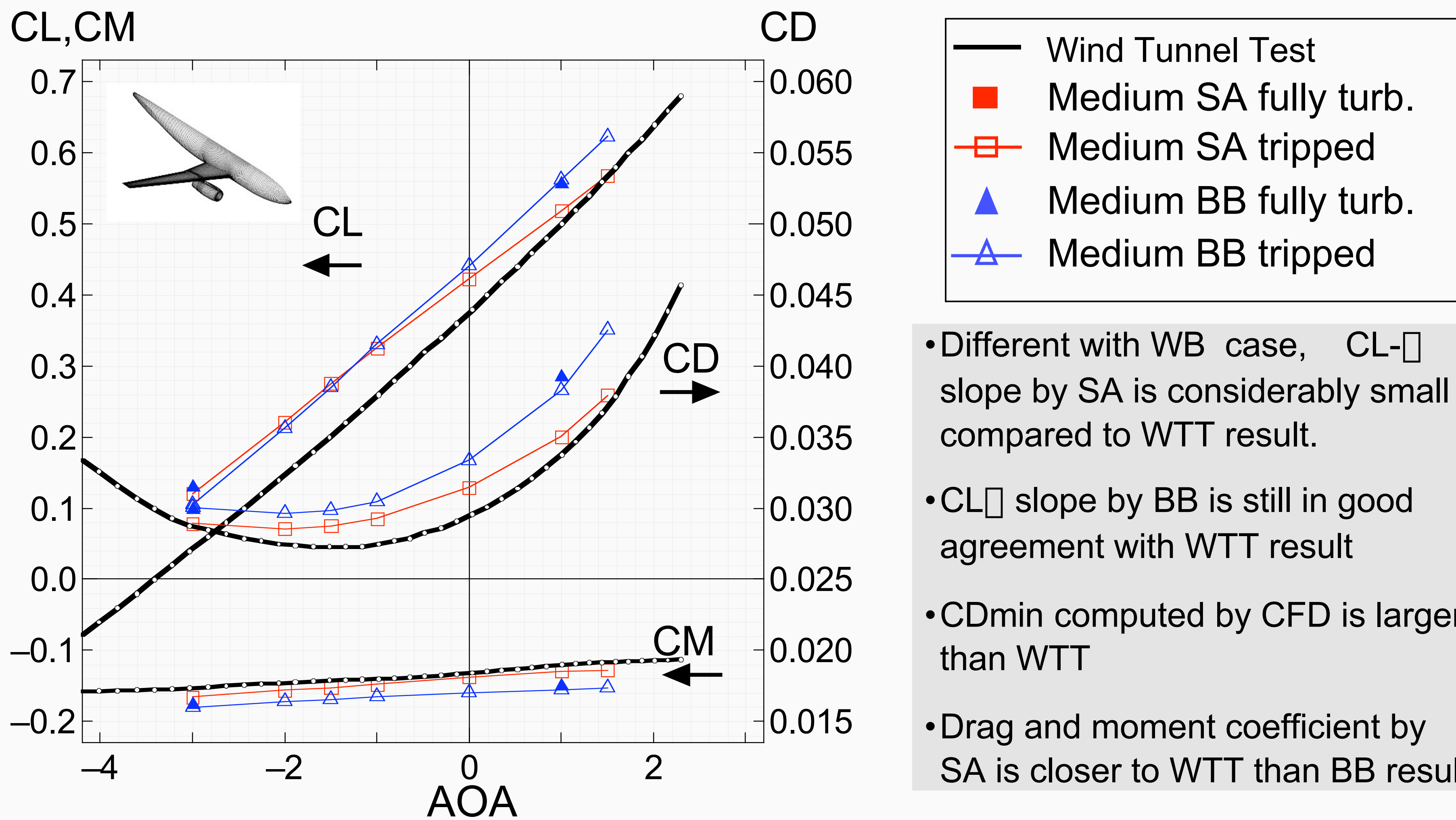
--- 100x121 (SA fully turbulent)

--- 100x121 (BB fully turbulent)

- SA shows forward shock location.
- BB shows larger lift.

Calculation condition: Wing-Body, M=0.75, AOA=0.49, fully turbulent

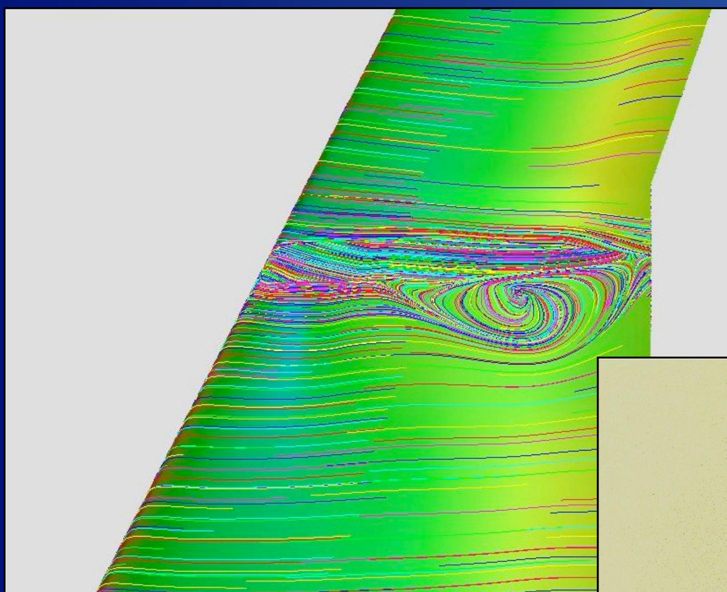
Comparison of CL,CD,CM between SA and BB turbulence model for Wing-Body-Nacelle-Pylon



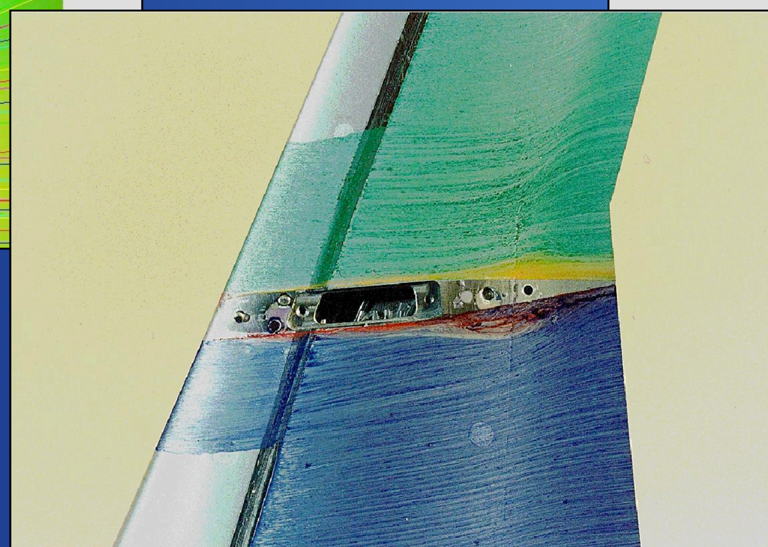
Calculation condition: Wing-Body-Nacelle-Pylon, M=0.75

- Different with WB case, CL-□ slope by SA is considerably small compared to WTT result.
- CL□ slope by BB is still in good agreement with WTT result
- CDmin computed by CFD is larger than WTT
- Drag and moment coefficient by SA is closer to WTT than BB result

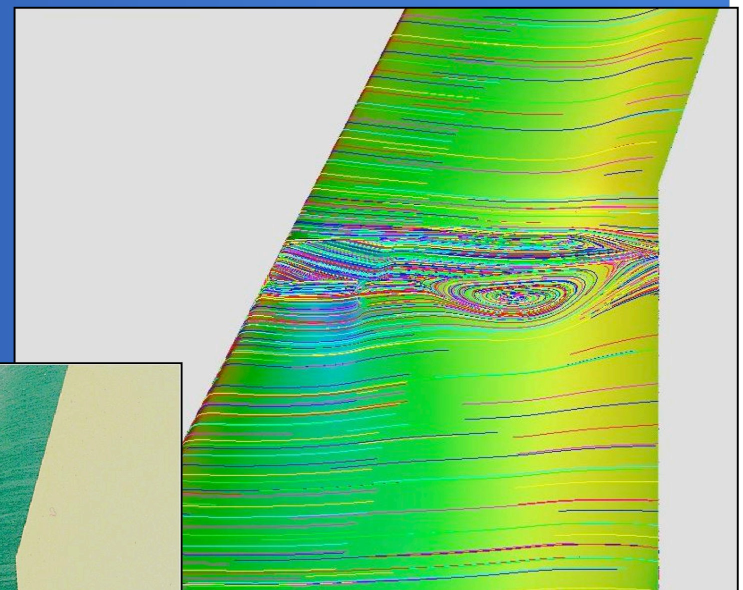
Comparison of separation bubble size



SA model



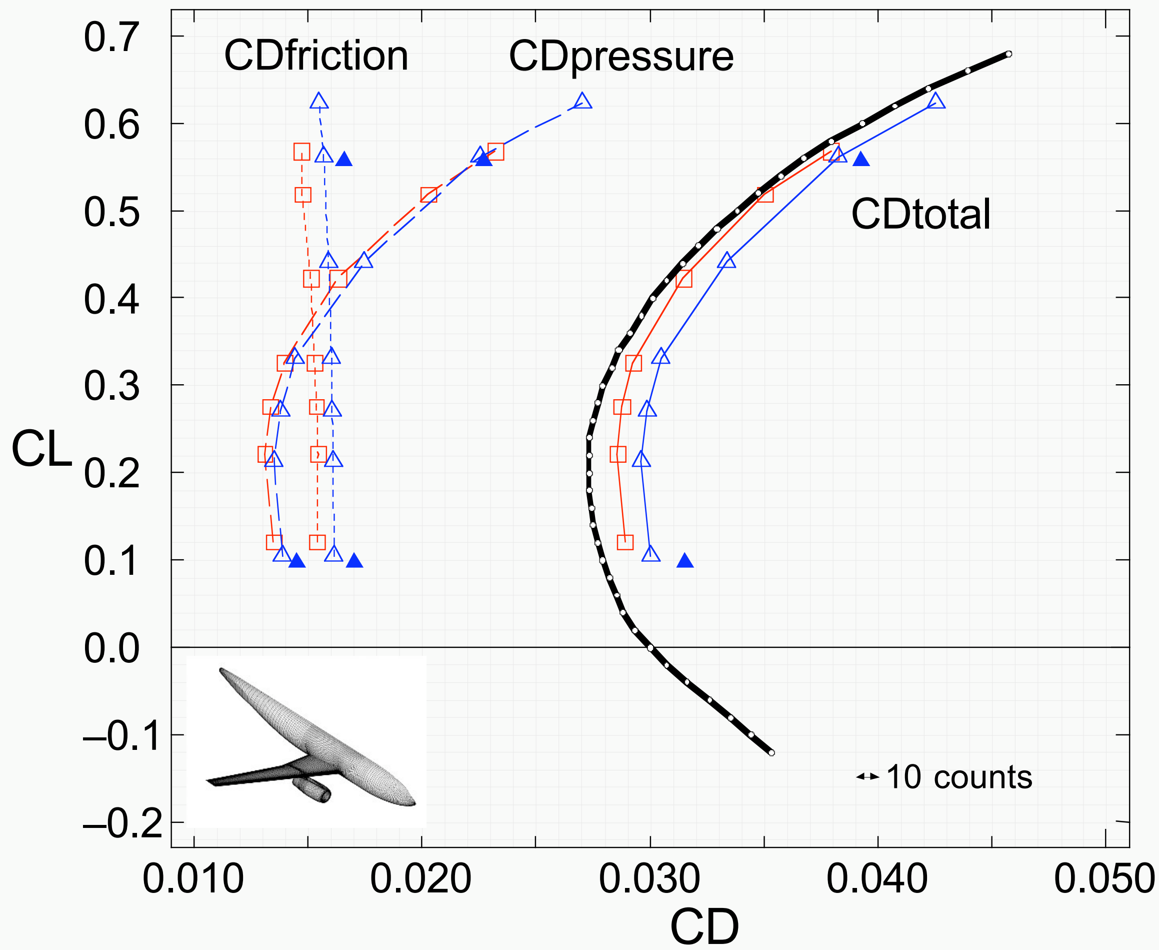
Wind Tunnel Test



BB model

Calculation condition: Wing-Body-Nacelle-Pylon, M=0.75, □=1.0

Comparison of polar, CDf, and CDp between SA and BB turbulence model for Wing-Body configuration



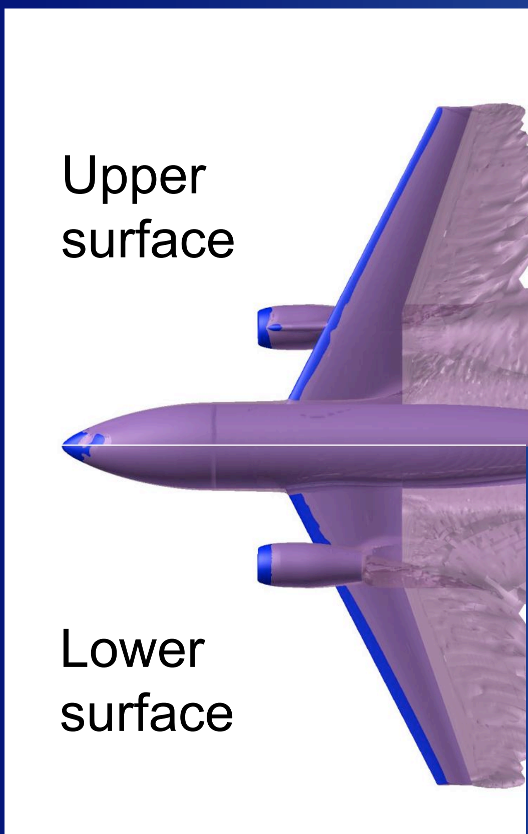
Calculation condition: Wing-Body-Nacelle-Pylon, M=0.75

- Difference of polar curve between WTT and CFD is larger than Wing-Body case.
- Cdmin is not well predicted.
- Polar curve by CFD is opened compared to WTT.
- Pressure drag differ up to 5 drag counts around CDmin
- SA model shows less friction drag than BB model about 8 to 10 counts.
- Transition effect is just shift
    - Larger lift, smaller drag

Transition

Transition location

$\square_T / \square$ = 10 Iso-surface visualization



WING/BODY

	AOA	CL	CDtotal	CDp	CDf	CM
FULLY TURBULENT	0.292	0.500	0.0296	0.0164	0.0132	-0.135
TRIPPED	0.263	0.500	0.0292	0.0166	0.0126	-0.137
?	-0.029	0.000	-0.0004	0.0002	-0.0006	-0.002

WING/BODY/NACELLE/PYLON

	AOA	CL	CDtotal	CDp	CDf	CM
FULLY TURBULENT	0.975	0.500	0.0352	0.0196	0.0159	-0.125
TRIPPED	0.809	0.500	0.0343	0.0195	0.0148	-0.131
?	-0.166	0.000	-0.0008	-0.0001	-0.0011	-0.006

Summary

Wing-Body.

- Spalart-Allmaras (SA) turbulence model is closer to WTT, while Baldwin-Barth (BB) model shows large alpha shift.
- CL slope overall agreement is good.
- Drag polar is in good agreement.
- Coarse grid could not capture separation bubble at wing-body junction. However medium and fine grid over estimated separation bubble.

Wing-Body-Nacelle-Pylon.

- CL slope by SA model is considerably small.
- (Coarse grid SA showed better CL slope)
- Cdmin was not well predicted differences are 20counts(SA) and 30counts(BB). Polar curve is slightly opened.
- SA model showed larger separation bubble at pylon inboard than BB model.

Summary cont'd

Directional grid density.

- If span-wise grid is increased, shock location moves forward. Lift is decreased.
- If chord-wise grid is increased, shock location is almost same. Lift is a little increased.
- (If normal direction grid to the surface is increased, lift is a little increased. However cp distribution is hardly changed.).

Transition effect.

- Just shift.
  - CDf = -4counts(WB), -9counts(WBNP)

END

Thank you for your attention

- Wall clock time 1day for medium WBNP using 8PCUs PC cluster(P4 2.8GHz).
- Convergence criteria
  Max(□CL, □CD, □CM) < 5×10^{-7}/step

Case#1 Grid convergence

Wing-Body Configuration

	Grid	cells	AoA	CL	CD	CM	CDp	CDf
WTT			0.52	0.5000	0.0295	-0.1211	--	--
PUFGG	Coarse	1.8M	-0.15	0.5003	0.0289	-0.1619	0.0156	0.0133
PUFGG	medium	4.1M	0.29	0.4999	0.0296	-0.1449	0.0164	0.0132
PUFGG	fine	7.5M	0.27	0.5247	0.0292	-0.1355	0.0162	0.0130
ICEM	coarse	3.4M	0.33	0.4995	0.0289	-0.1392	0.0158	0.0131
ICEM	medium	5.7M	0.27	0.5004	0.0284	-0.1427	0.0154	0.0130
ICEM	fine	10.0M	0.26	0.5001	0.0282	-0.1436	0.0151	0.0130

Case#1 Grid convergence

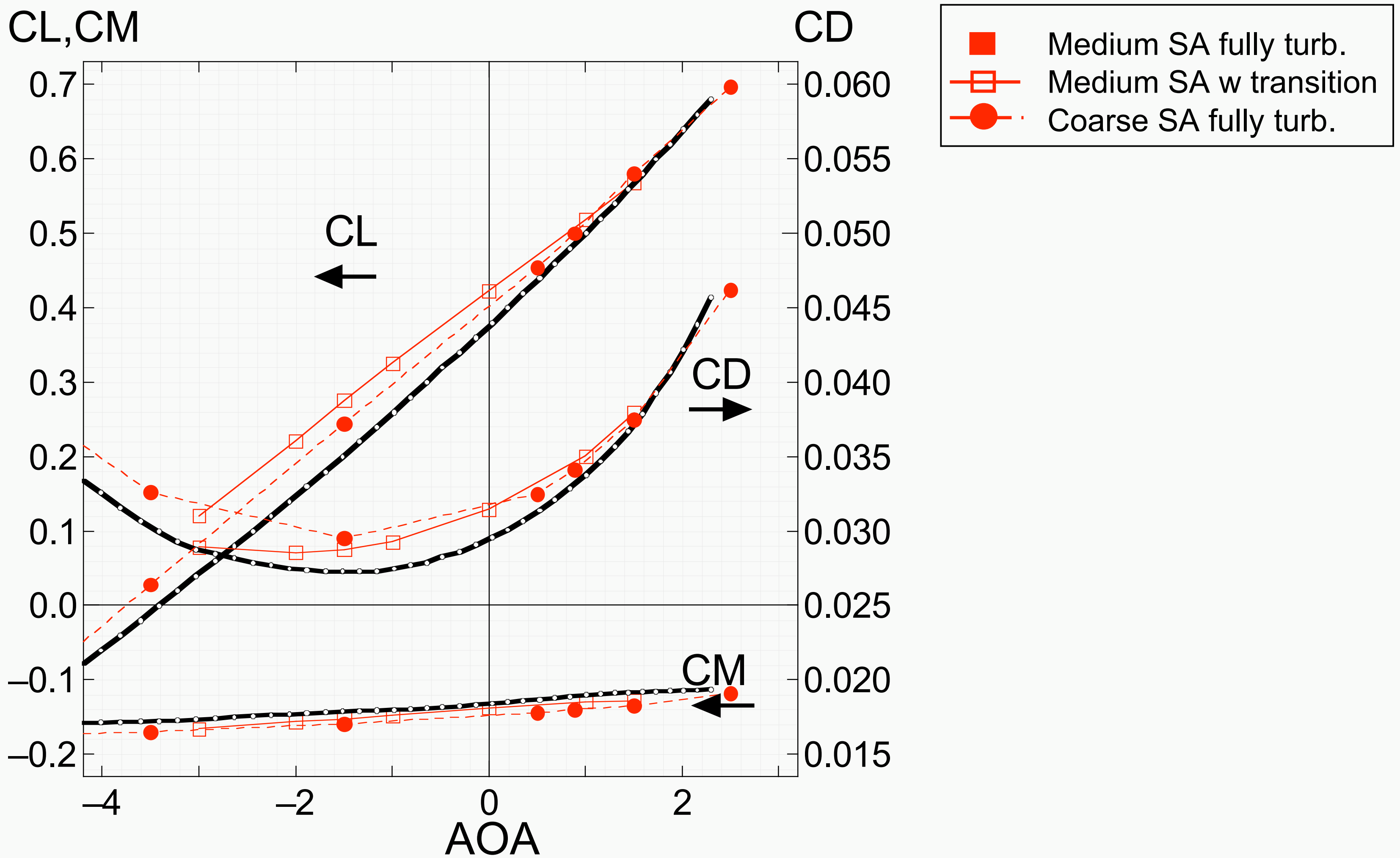
Wing-Body-Nacelle-Pylon Configuration

	Grid	cells	AoA	CL	CD	CM	CDp	CDf
WTT			1	0.5000	0.0338	-0.1199	--	--
PUFGG	Coarse	3.3M	0.61	0.4994	0.0358	-0.1505	0.0201	0.0157
PUFGG	medium	6.7M						
PUFGG	fine	9.5M						
ICEM	coarse	4.8M	0.89	0.5005	0.0341	-0.1374	0.0184	0.0156
ICEM	medium	8.3M	0.86	0.5003	0.0336	-0.1400	0.0180	0.0156
ICEM	fine	13.5M						

Summary cont'd

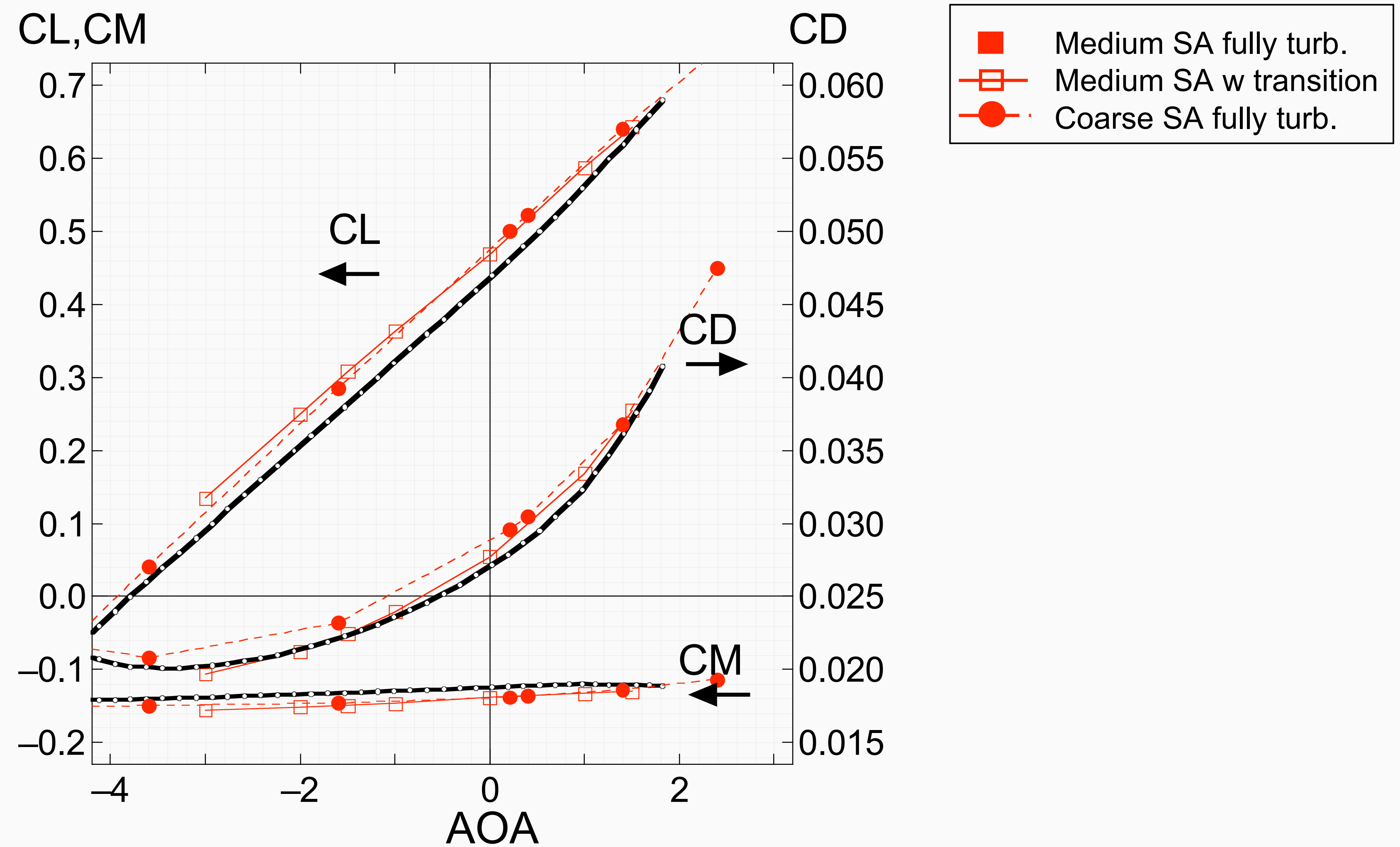
- Grid density affects separation bubble size at wing-body junction. Consequently, lift is considerably changed.
  - For worst case ΔCL=0.06, as AOA Δa=0.5
- Spurious drag is reduced with increasing grid density
  - Corase(2M) grid; CDspurious=10counts(WB),17counts(WBNP)
  - Fine(8M) grid;   CDspurious= 5counts(WB), 8counts(WBNP)
- Transition effect is simple.
  - ΔCL = +0.01 to +0.02
  - ΔCLa is about +1% (for SA,BB, KHI grid, ICEM grid)
  - ΔCD = -4counts(WB), -9counts(WBNP)
  - ΔCDf = -4counts(WB), -10counts(WBNP)
  - Shock location moves backward. Shock becomes strong.

Comparison of CL,CD,CM between medium and fine grid for Wing-Body-Nacelle-Pylon using SA model



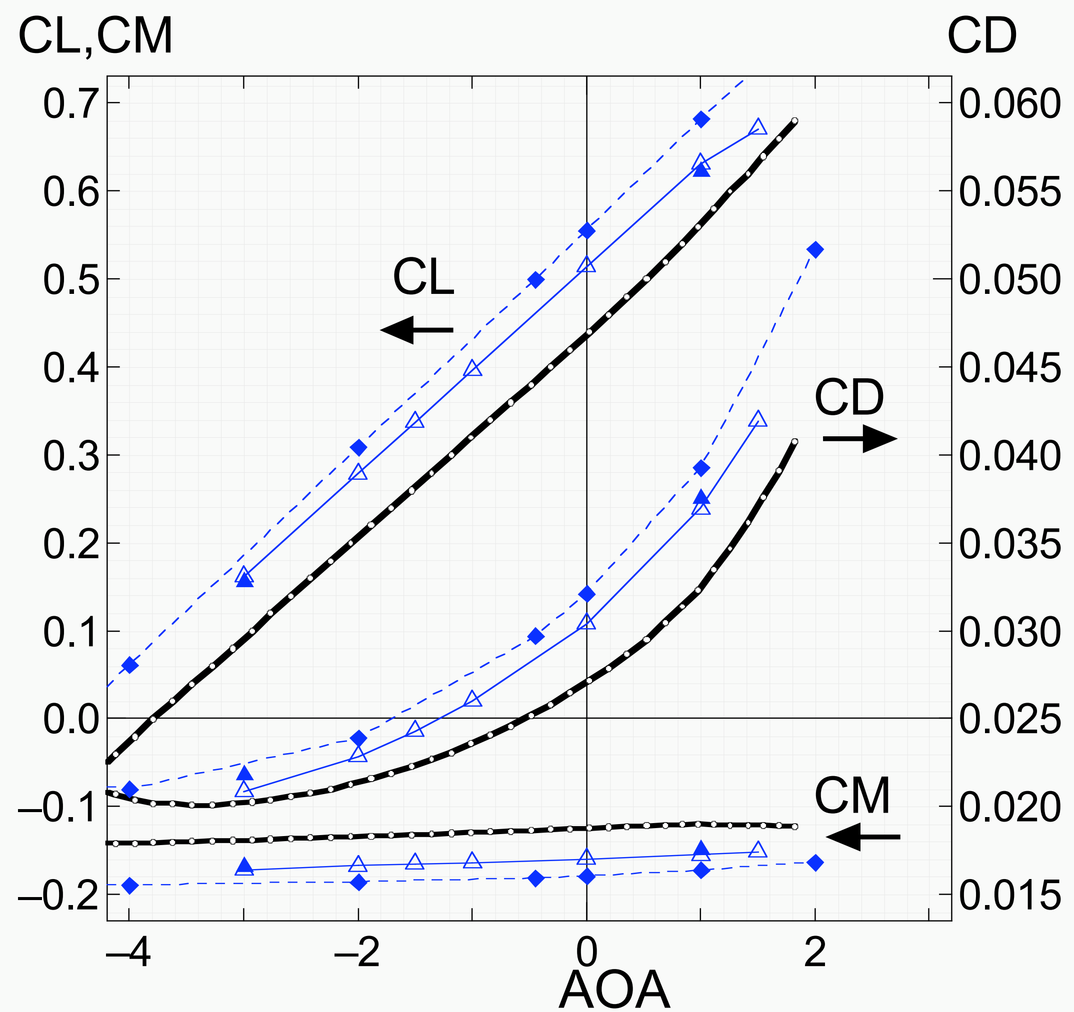
Calculation condition: Wing-Body-Nacelle-Pylon, M=0.75

Comparison of CL,CD,CM between medium and fine grid for Wing-Body config. using SA model



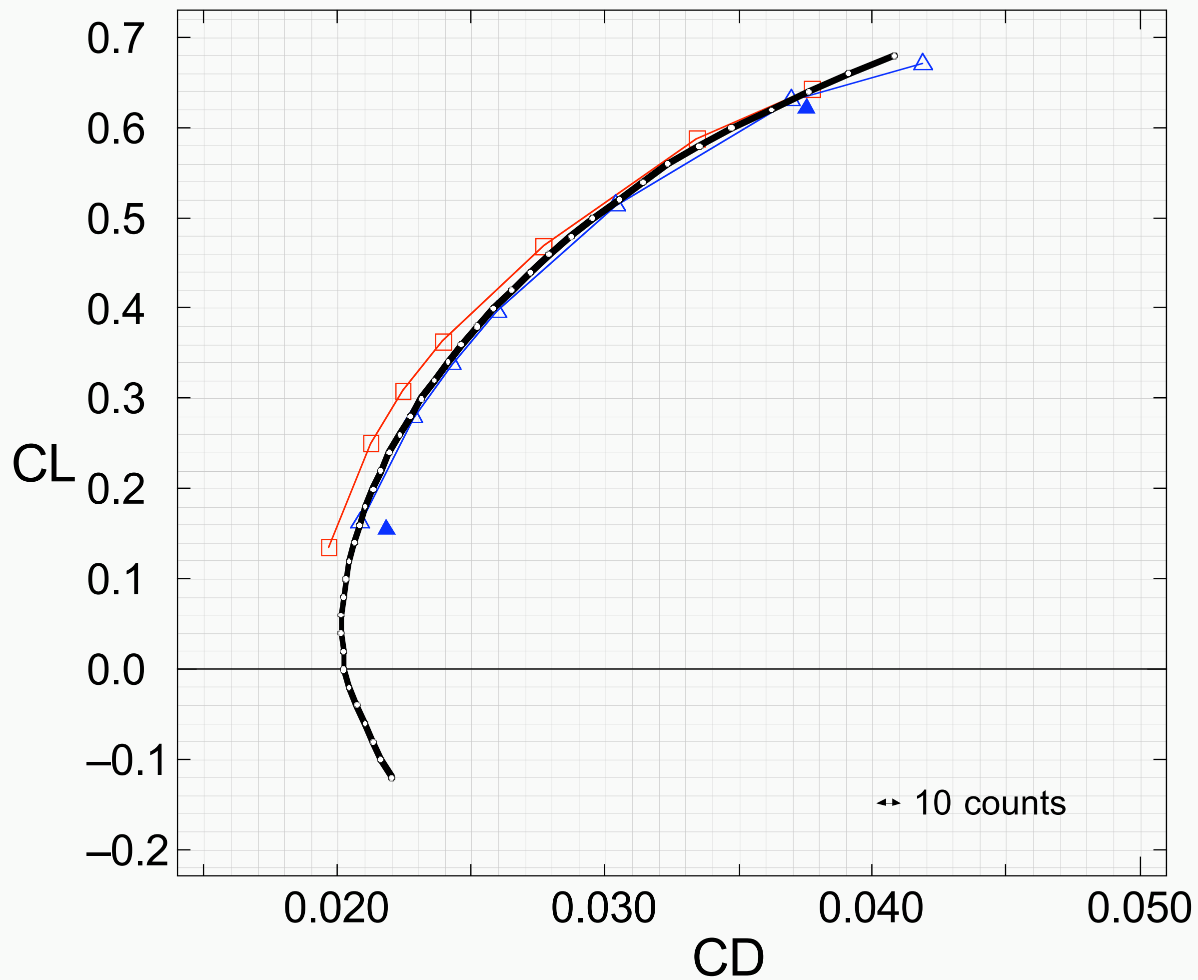
Calculation condition: Wing-Body, M=0.75

Comparison of CL,CD,CM between medium and fine grid for Wing-Body config. using BB model



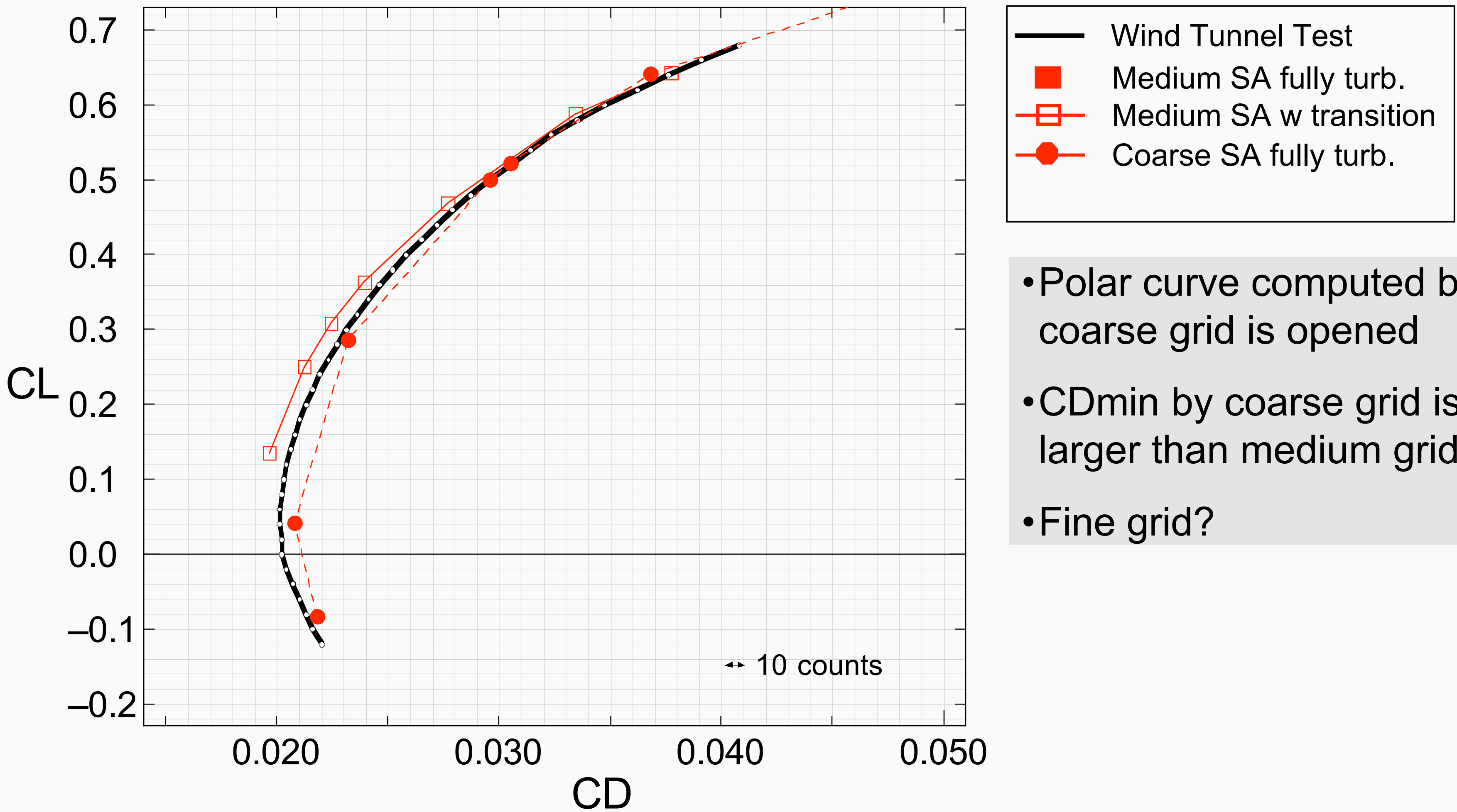
Calculation condition: Wing-Body, M=0.75

Comparison of polar curve between SA and BB turbulence model for Wing-Body configuration



Calculation condition: Wing-Body, M=0.75

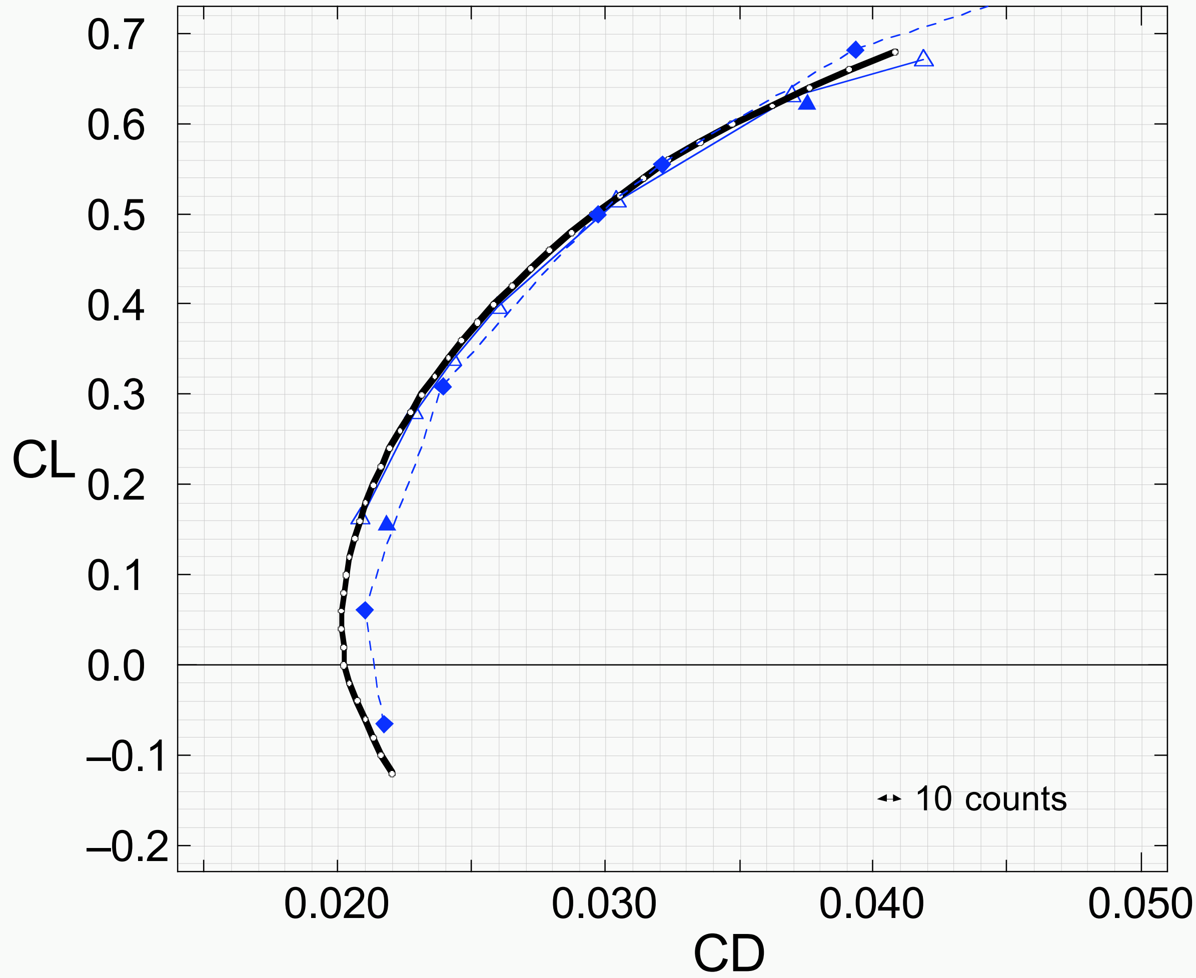
Comparison of polar curve between medium and fine grid for Wing-Body config. using SA model



- Polar curve computed by coarse grid is opened
- CDmin by coarse grid is larger than medium grid
- Fine grid?

Calculation condition: Wing-Body, M=0.75

Comparison of polar curve between medium and fine grid for Wing-Body config. using BB model



Fully turbulentとTransに注意

格子が粗いほうがポーラーが開いていることに注意

Calculation condition: Wing-Body, M=0.75

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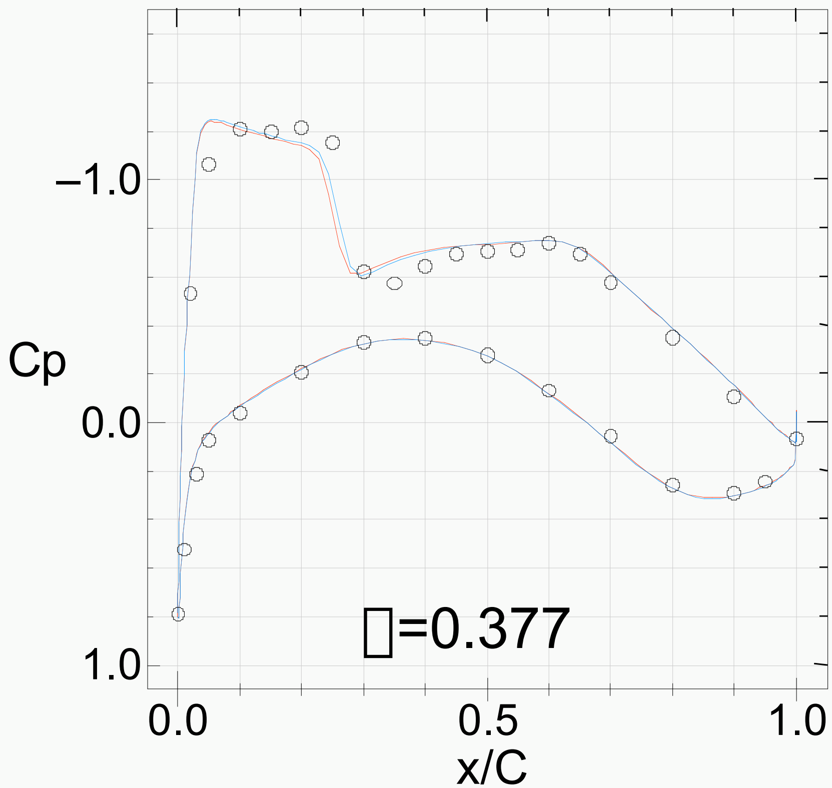
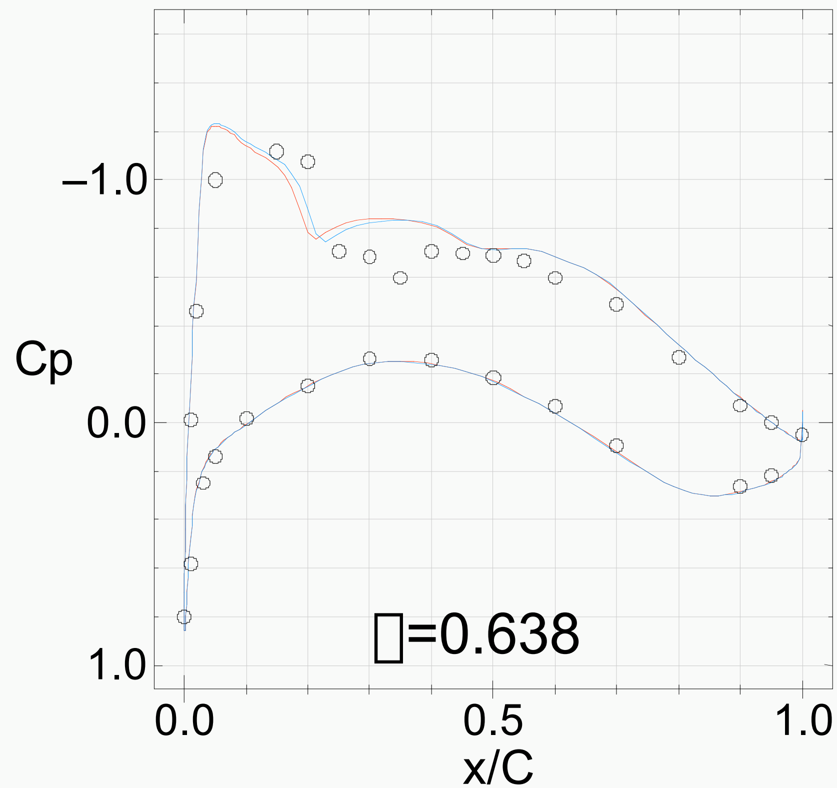
Normal to body surface direction grid density effect on Cp distributions for Wing-Body configuration

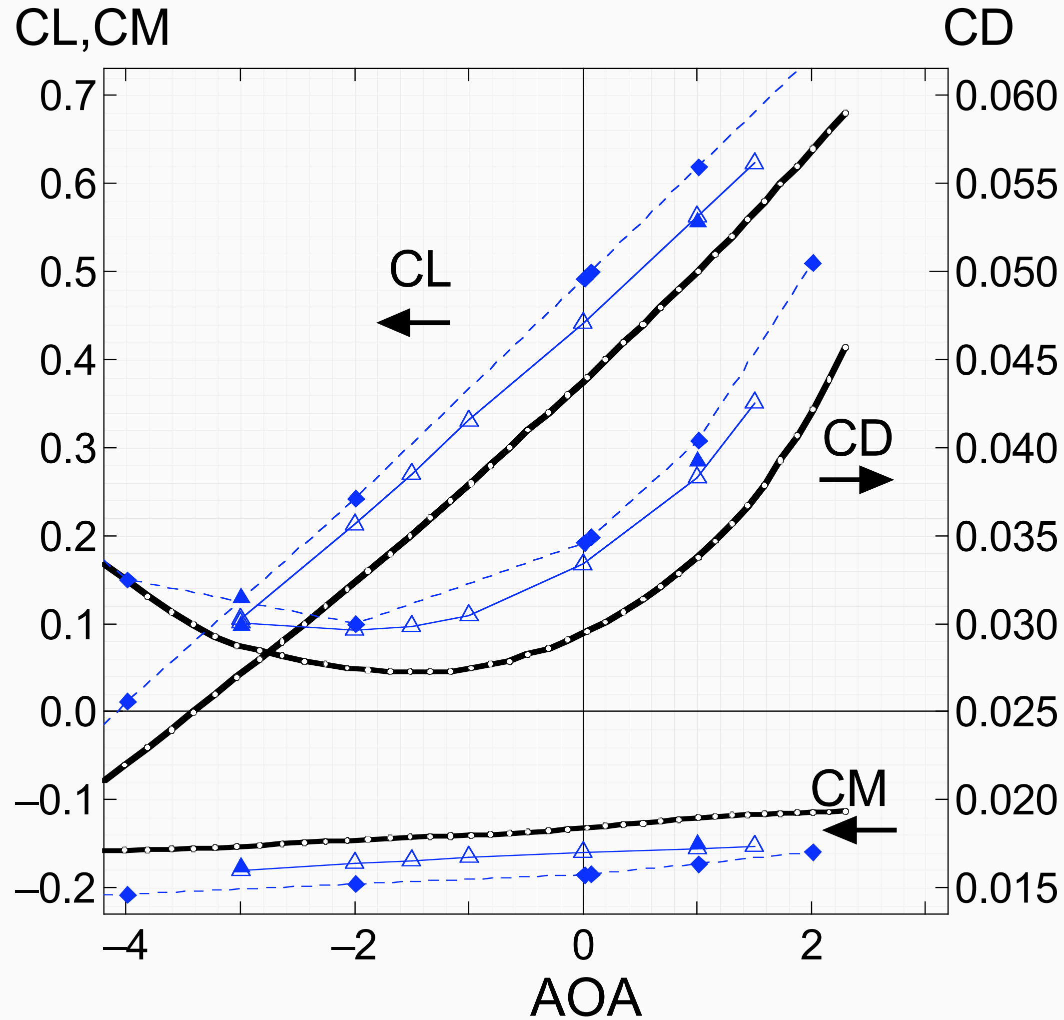
O WTT — 100x121 – 100x121 (normal direc. fine)(chord x span)





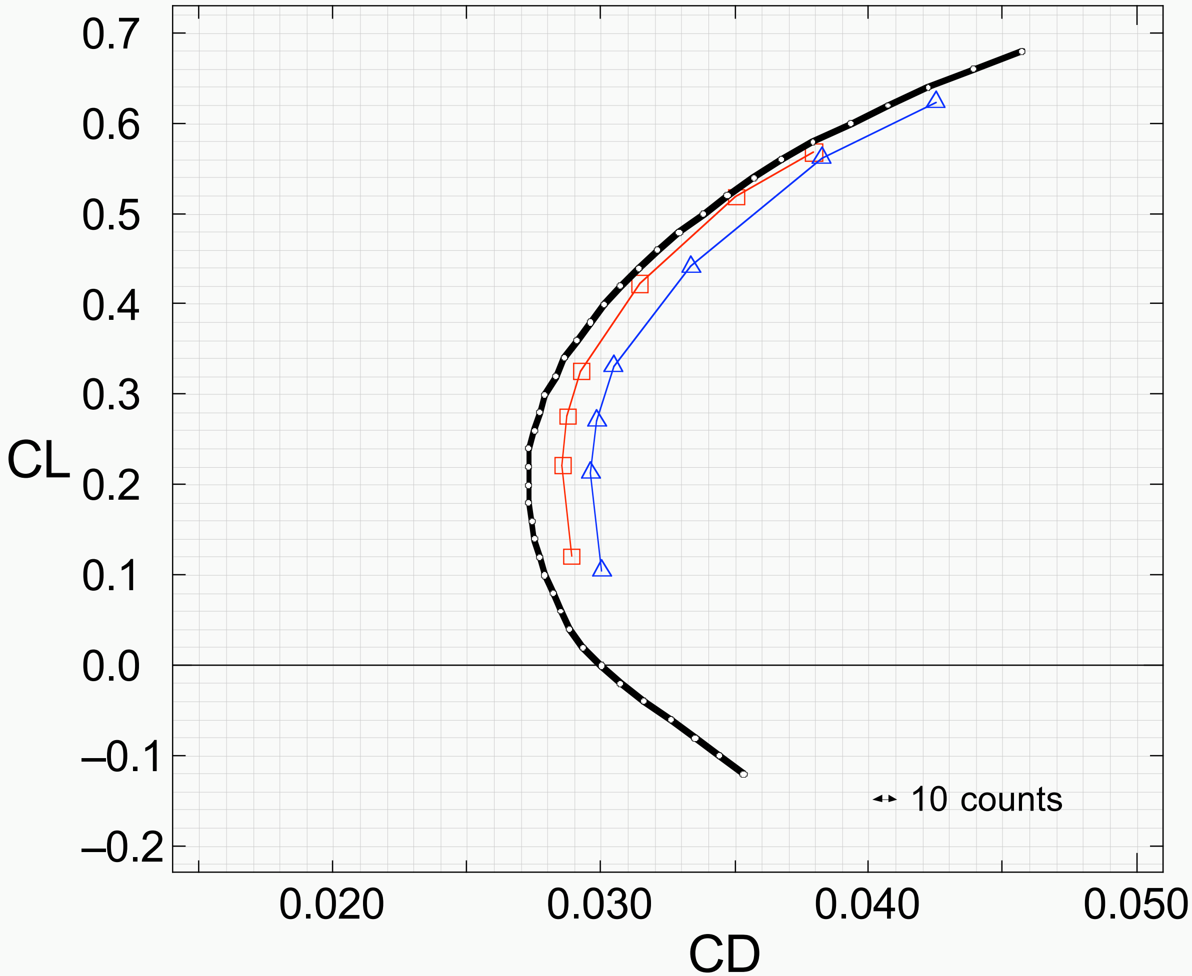
Calculation condition: Wing-Body, M=0.75, AOA=0.49, SA model, fully turbulent

Comparison of CL,CD,CM between medium and fine grid for Wing-Body-Nacelle-Pylon using BB model



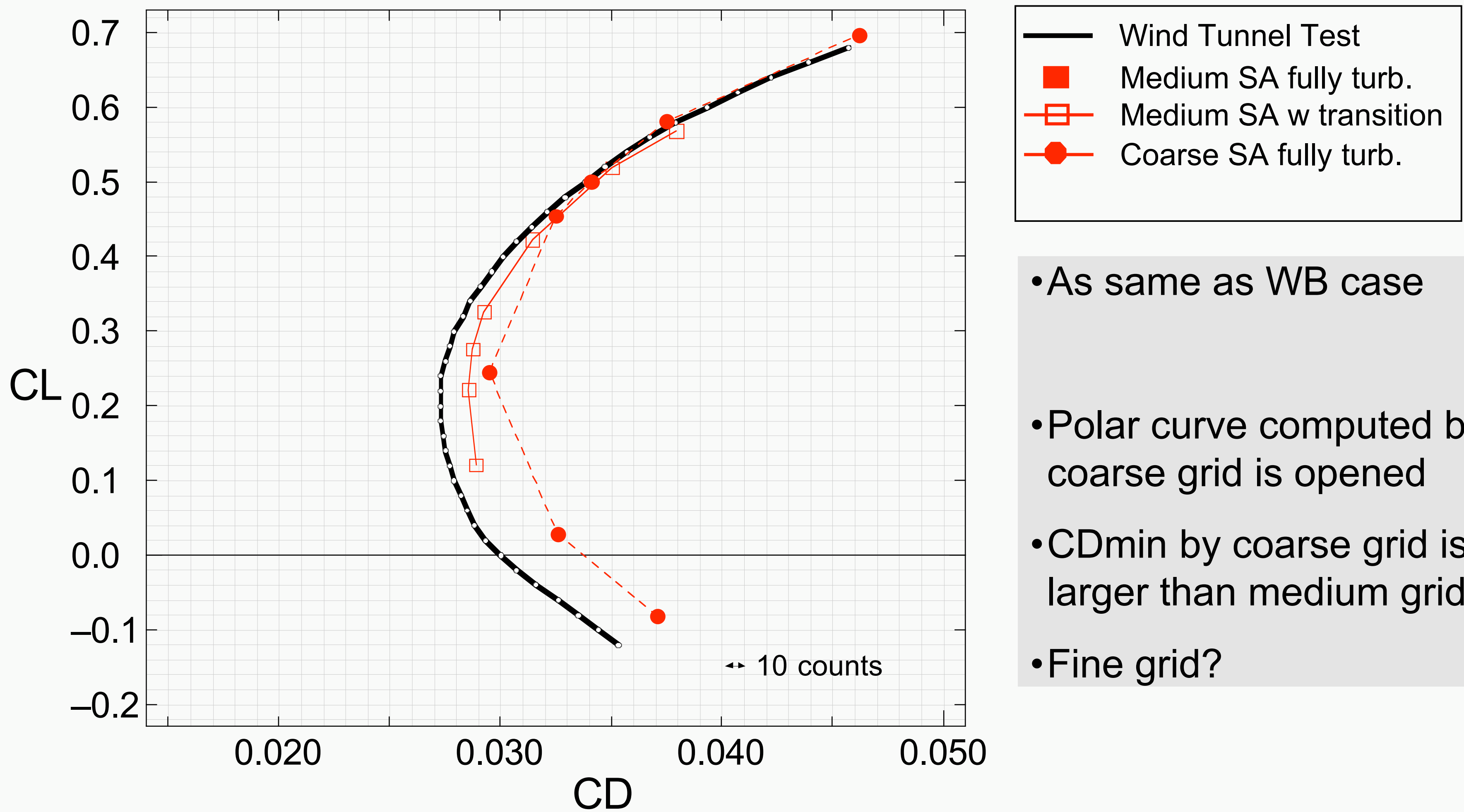
Calculation condition: Wing-Body-Nacelle-Pylon, M=0.75

WBNP



Calculation condition: Wing-Body-Nacelle-Pylon, M=0.75

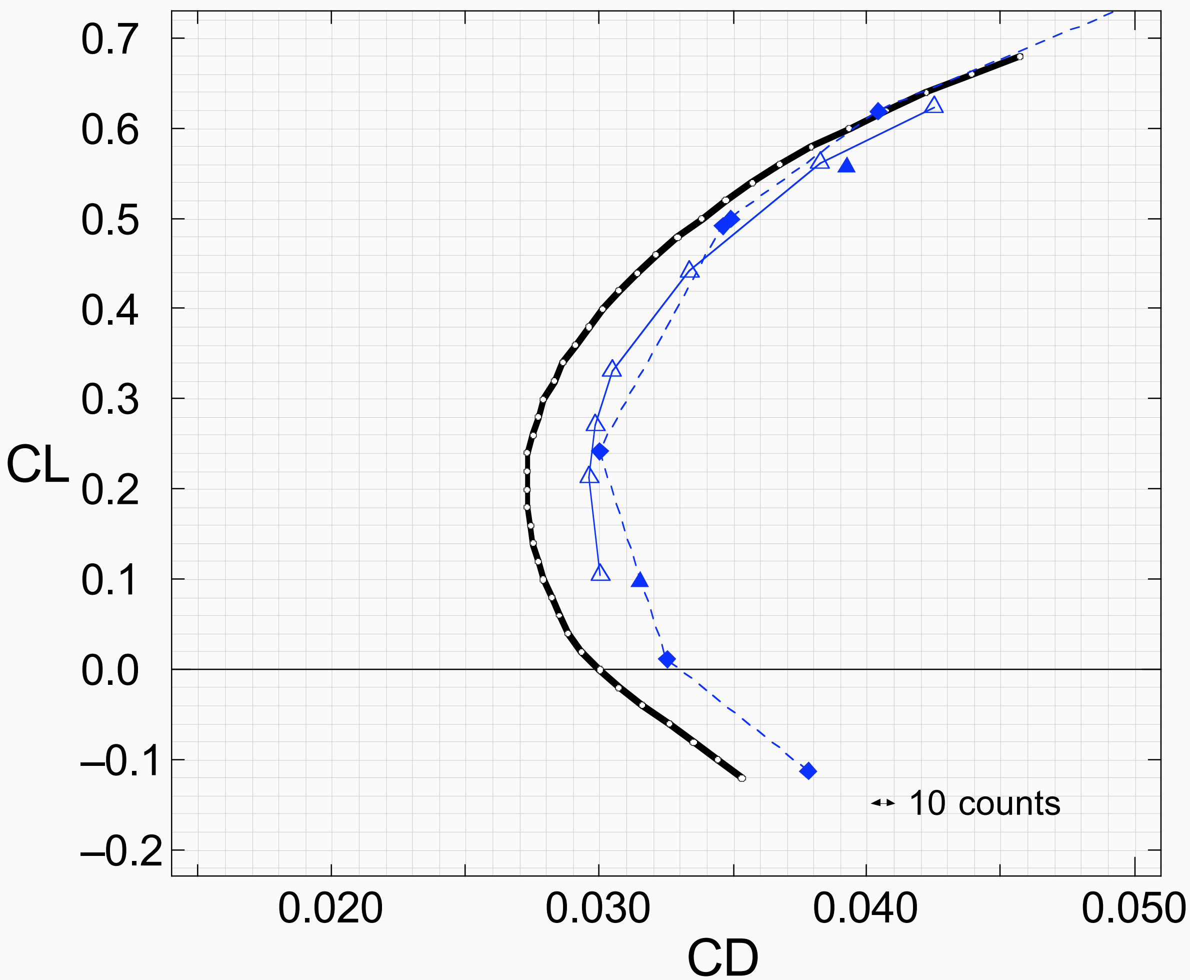
WBNP



- As same as WB case
- Polar curve computed by coarse grid is opened
- CDmin by coarse grid is larger than medium grid
- Fine grid?

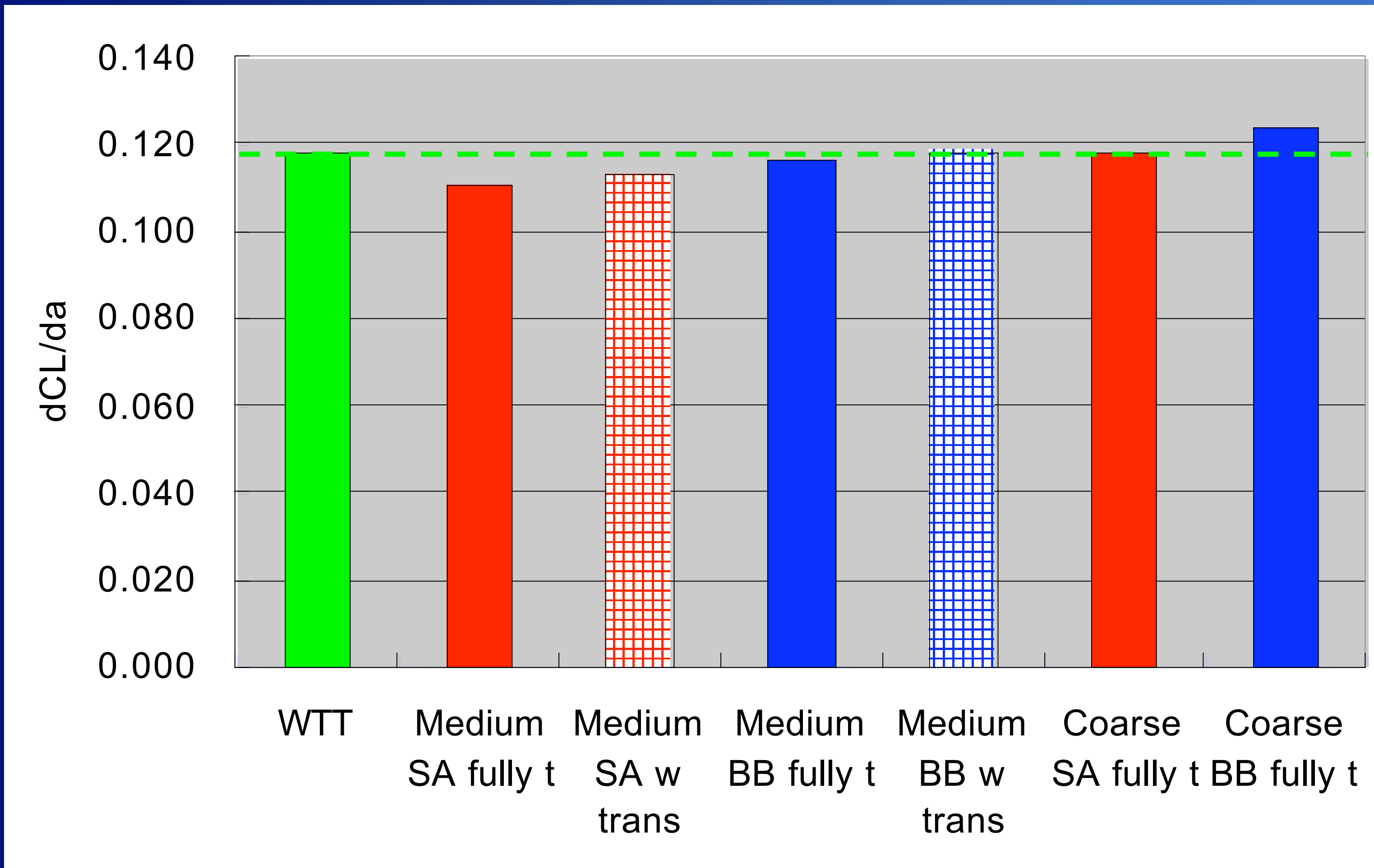
Calculation condition: Wing-Body-Nacelle-Pylon, M=0.75

WBNP

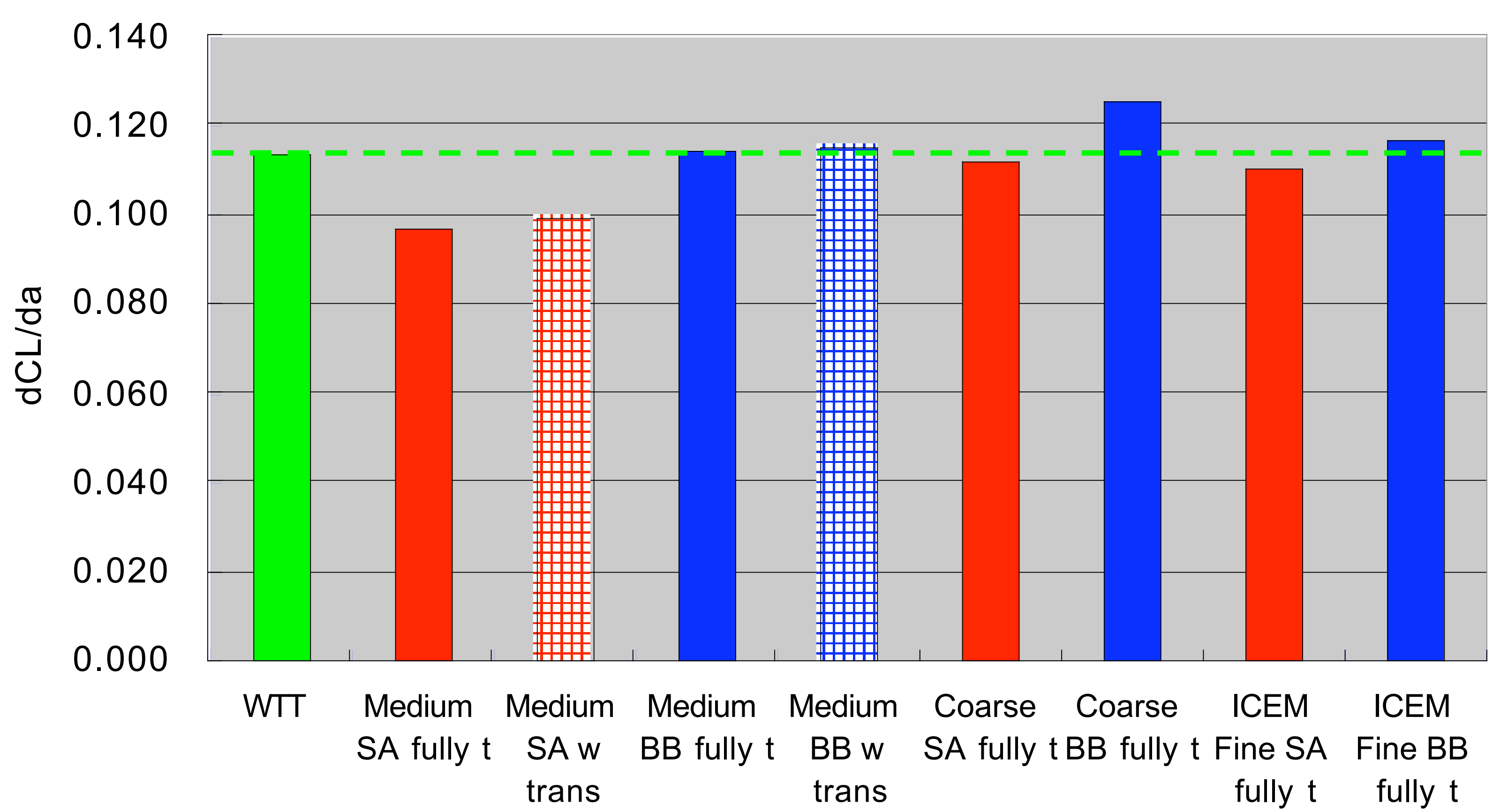


Calculation condition: Wing-Body-Nacelle-Pylon, M=0.75

WB CL (-3to1degs)



WBNP


0.140
0.120
0.100
0.080
0.060
0.040
0.020
0.000
dCL/da
WTT
Medium SA fully t
Medium SA w trans
Medium BB fully t
Medium BB w trans
Coarse SA fully t
Coarse BB fully t
ICEM Fine SA fully t
ICEM Fine BB fully t

Assessed items

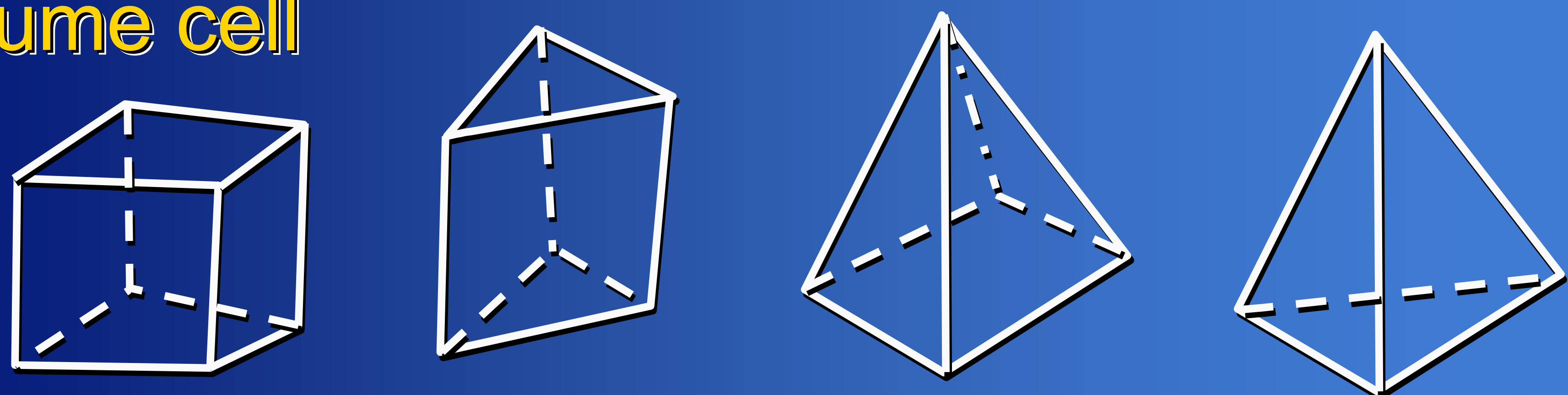
- CL,CD,CM
- CL α
- Drag polar
- CDpressrue, CDfriction
- Cp distribution
- Span load distribution
- Oil flow visualization
- Transition point

Grid cell elements

Surface cell

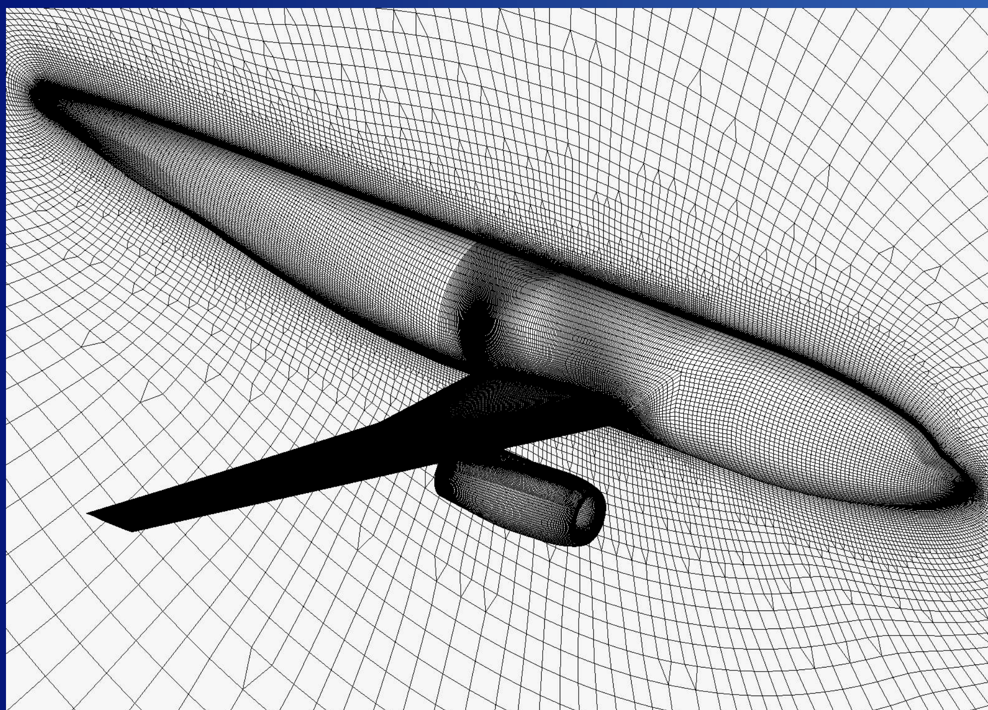
Quadrilateral Triangle

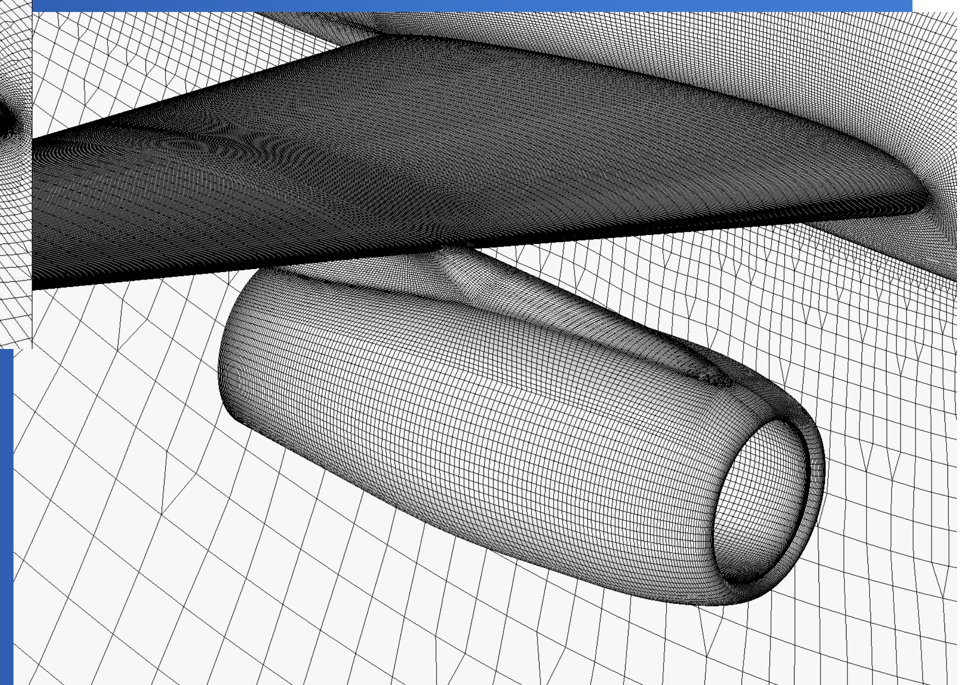
Volume cell



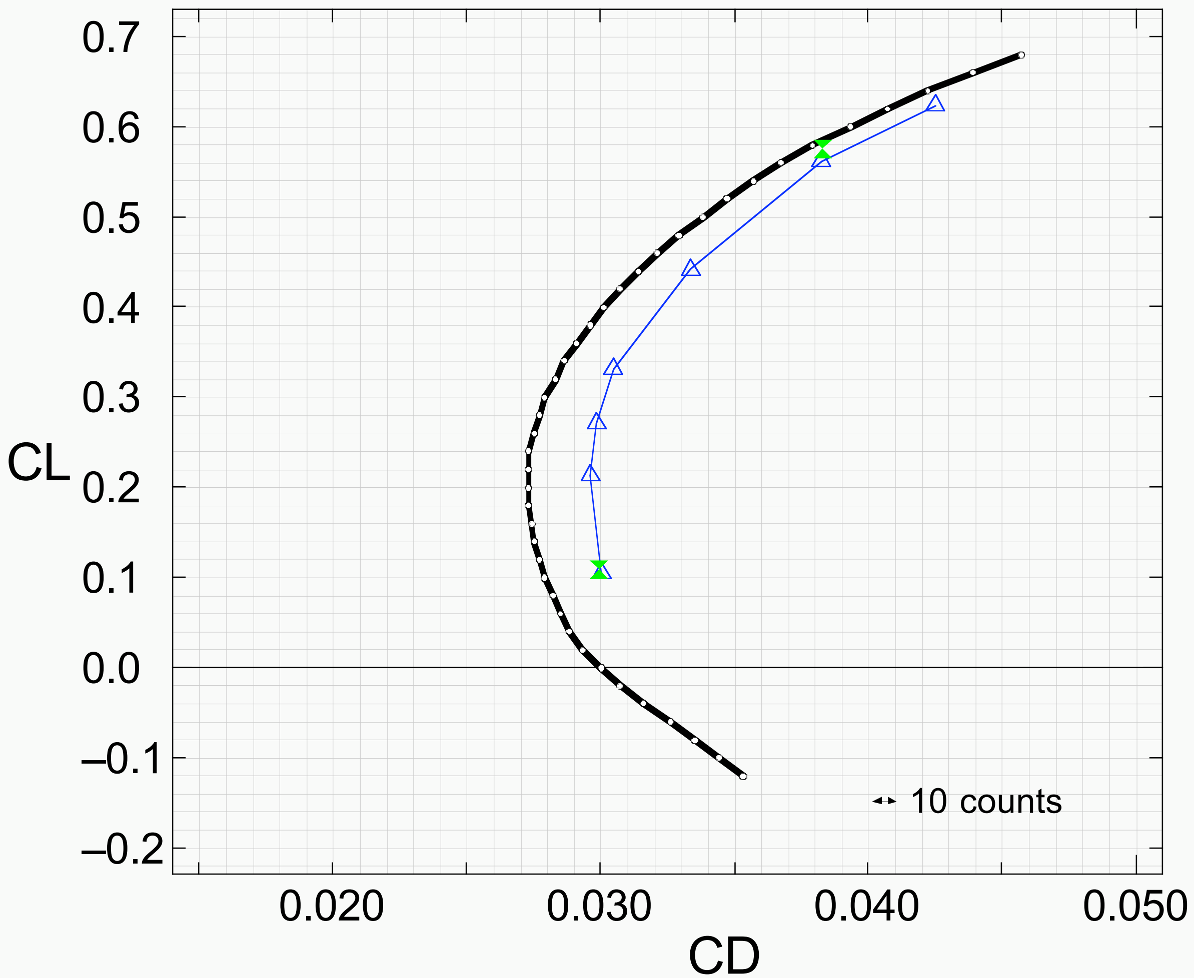
Hexahedron Prism Pyramid Tetrahedron

Fine Grid



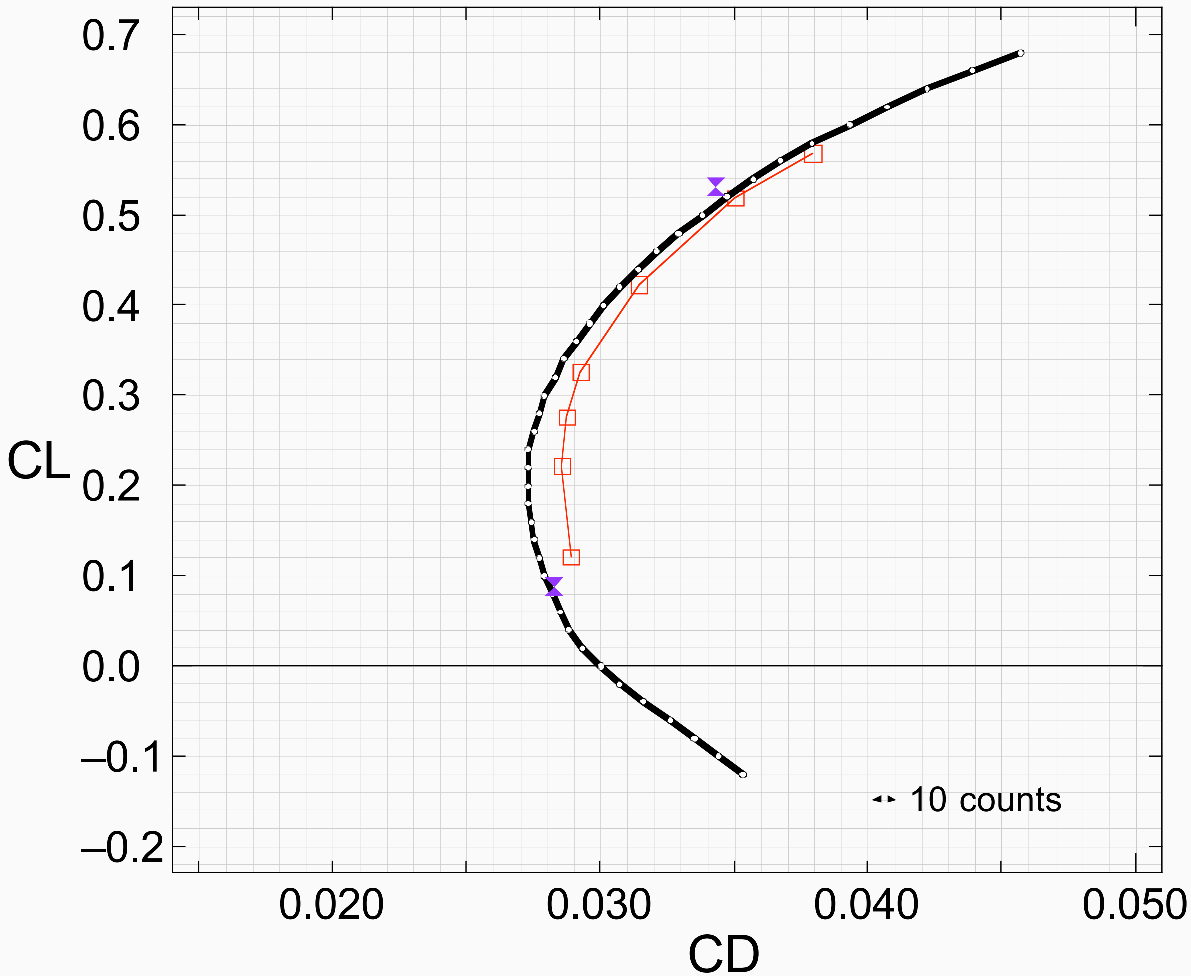


WBNP

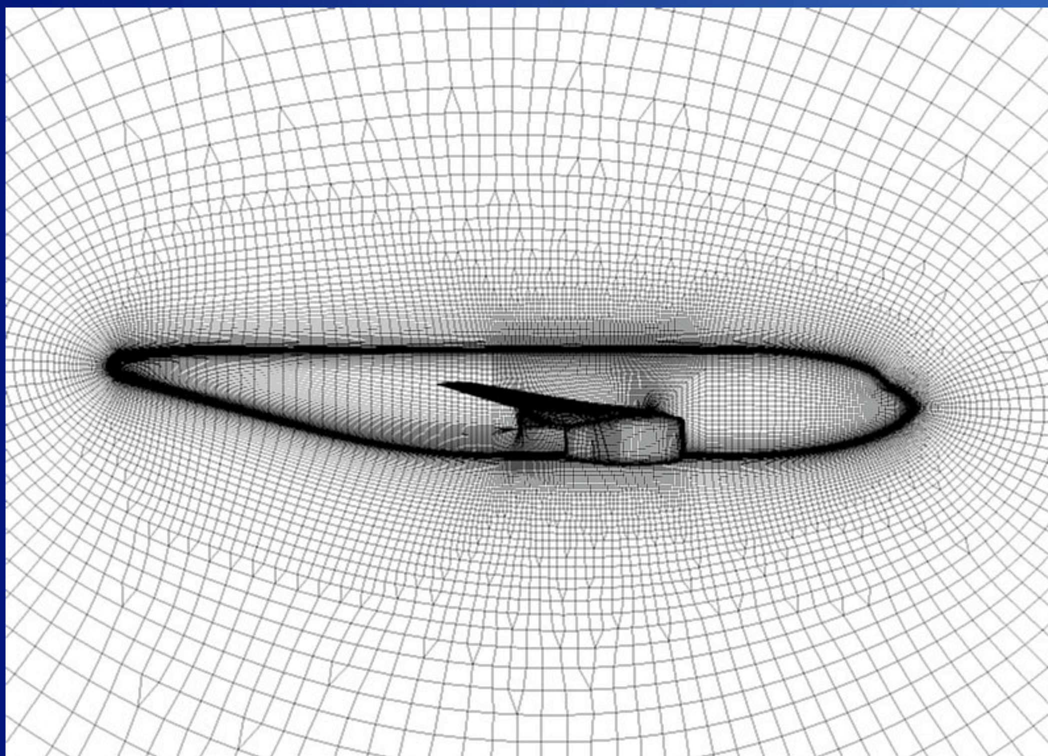


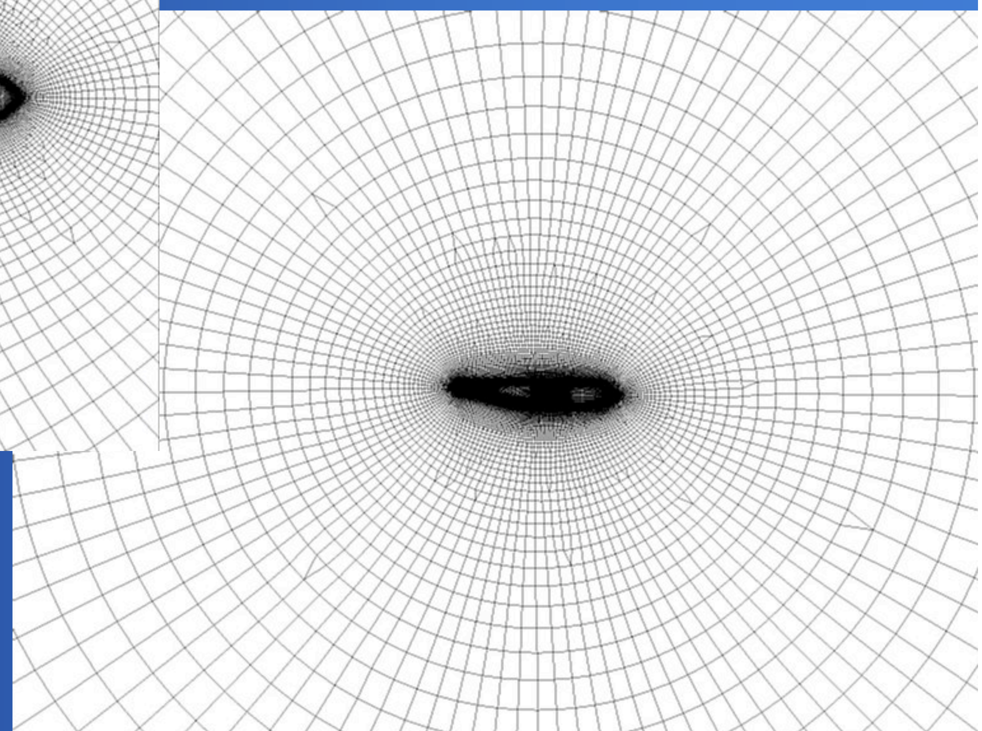
Calculation condition: Wing-Body-Nacelle-Pylon, M=0.75

WBNP

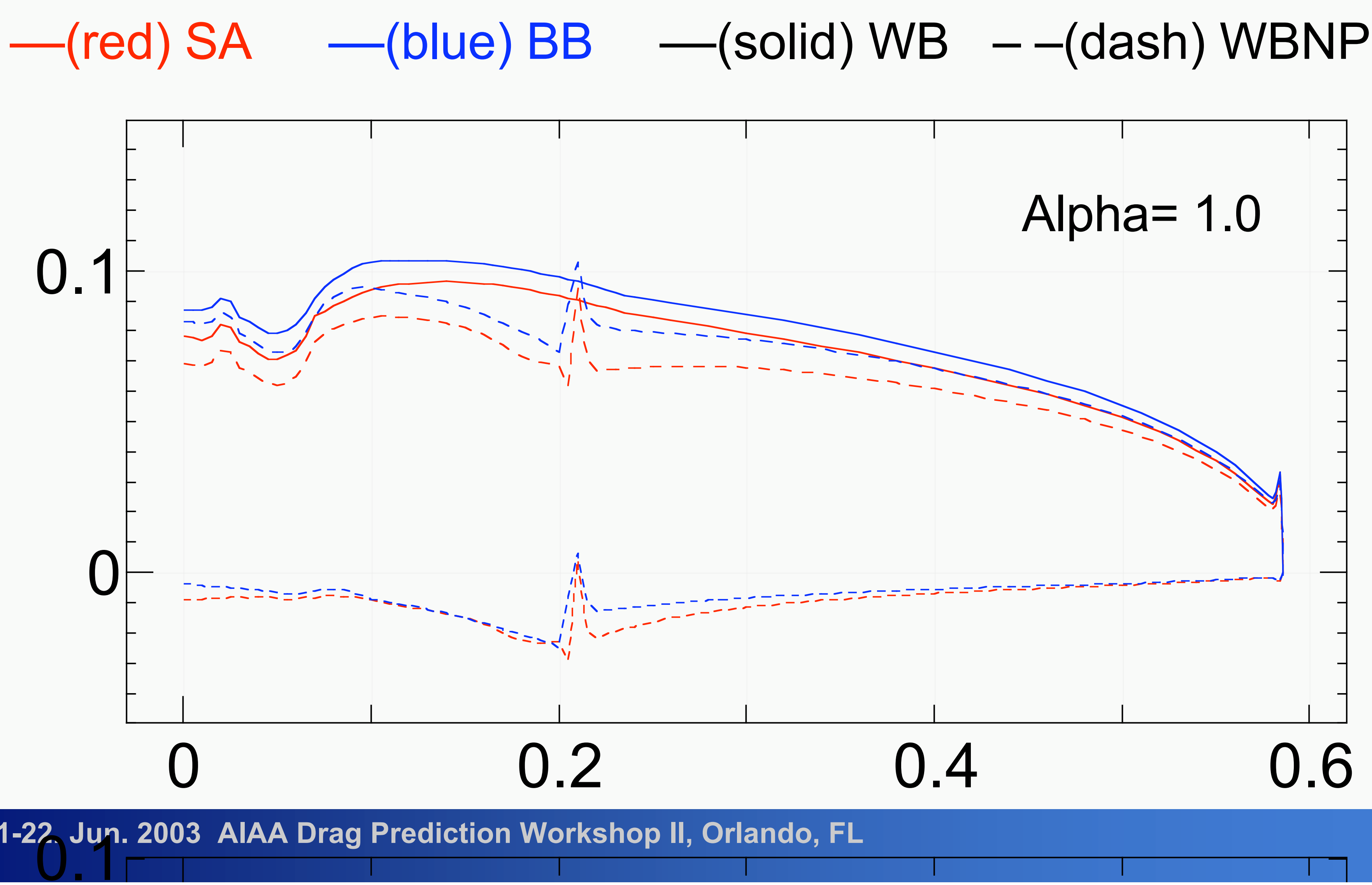


Calculation condition: Wing-Body-Nacelle-Pylon, M=0.75





Span load distributions



Kawasaki

Comparison of Cp distributions nacelle surface

O WTT – CFD(Fine)