A Flow Analysis of the NAL NEXST-1 using Hybrid Unstructured Grid System

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ABSTRACT

This paper provides CFD flow analysis results of the NAL NEXST-1 for the 3rd NAL SST CFD workshop. A hybrid unstructured grid system was employed for viscous aerodynamic analysis. Computations were conducted for both wind tunnel test condition and Flight Test condition. The CFD results showed very good correlation with wind tunnel test results.

Hybrid Grid System

The hybrid grid system used in this study consists of a large number of hexahedral and prism cells with a small number of pyramid and tetrahedron cells. Pyramid and tetrahedron cells are used as a link between hexahedral cells and prism cells. Surface grid consists of combination of quadrilaterals and triangles. Quadrilateral cell has a good property to obtain high resolution and high accuracy. Triangular cell is suitable for automatic surface mesh generation. In this study quadrilateral surface mesh is mainly used.

Grid Generation

The hybrid grid in this study is generated by PUFGG (Pile-Up Forming Grid Generator) from surface grid. PUFGG is an automatic volume grid generator. PUFGG generates the volume grid starting from a surface grid and piles up layers as shown in Fig. 1. Near the body surface, hexahedral and prism cells will be created from quadrilateral and triangular surface cells, respectively. In the off body region, grid cells are merged in order to reduce the number of grid cells. Grid generation time is about two hours for NEXST-1 configuration using PC (Pentium III 800MHz).

Flow Solver

An unstructured grid flow solver UG3, which is our in-house code, is used for flow analysis. UG3 is based on unstructured FVM (Finite Volume Method). Spatial discretization is made by MUSCL (Monotone Upwind Scheme for Conservation Laws). SHUS (Simple High-resolution Upwind Scheme)[2] is used to calculate the approximate Riemann fluxes. Time integration is performed by MFGS (Matrix Free Gauss-Seidel method).

The governing equations are the Thin layer approximated Navier-Stokes and the Euler equations for viscous and invscid analysis, respectively.

Typical calculation time for viscous analysis of wing-body configuration is about 8 hours using four nodes PC cluster (Athlon 1.2GHz x 4).

Calculation condition

1. Wind tunnel test (WTT) condition
   Mach=2.0, Unit Reynolds number $=27.5\times10^6$,
   Angle of attack (aoa)=-2°~6°, fully turbulent
2. Flight test (FT) condition
   Mach=2.0, Unit Reynolds number $=8.08\times10^6$,
   Angle of attack (aoa)=-2°~6°, modeled transition

Numerical Results

Calculated Lift, drag, and moment coefficients for wind tunnel condition are compared with WTT in Fig. 3. Lift vs. drag polar curve is show in Fig. 4. As shown in Fig.3 and 4, CFD results show very good agreement with WTT results.

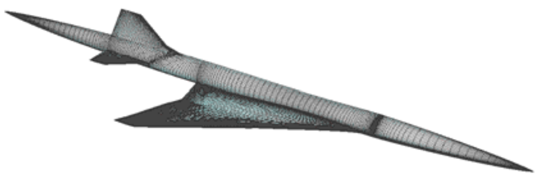
Figure 5 shows calculated three component force coefficients for FT condition. In FT condition, two kind of analysis were conducted. The first is a full turbulence analysis, and the second is a free transition analysis.

Pressure distributions were shown in figs. 6-9. While integrated forces showed very good agreement with WTT, small discrepancy is observed between CFD results and WTT results. Some negative pressure peak was not captures in particular case. Thus, It is not guaranteed that we will get good agreement between CFD and WTT for other case.

References

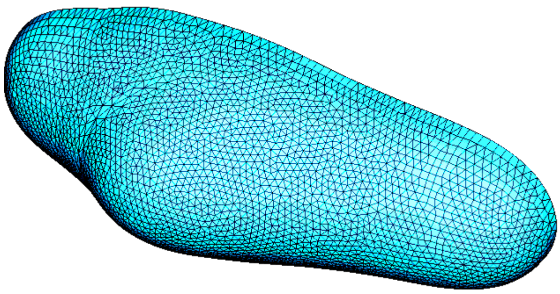
[1] Shima,E., Ochi,A., Nakamura,T., Saito,S., Iwamiya,T., Unstructured Grid CFD on Numerical Wind Tunnel, in Parallel Computational Fluid Dynamics, pp.475-482, North Holland, (1999)

[2] Shima,E. and Jounouchi,T.," Role of CFD in Aeronautical Engineering(No.14) -AUSM type Upwind Schemes-", Proceedings of the 14th NAL Symposium on Aircraft Computational Aerodynamics, pp.7-12

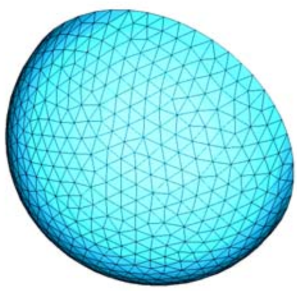


a) Surface grid

b) 40th layer



c) 60th layer



d) 95th layer (1/20 scale)
Fig.1 Growing volume grid.

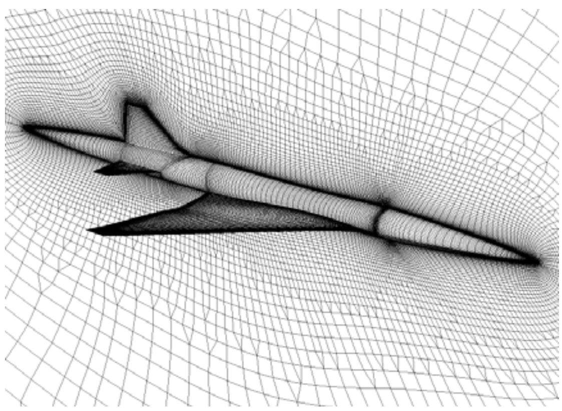


Fig.2 Surface and symmetry plane grid of NEXST-1

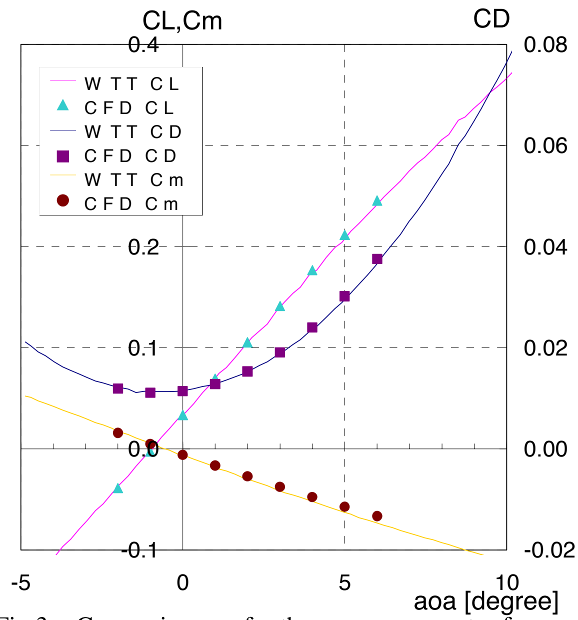


Fig.3 Comparison of three component force coefficients between CFD and WTT.

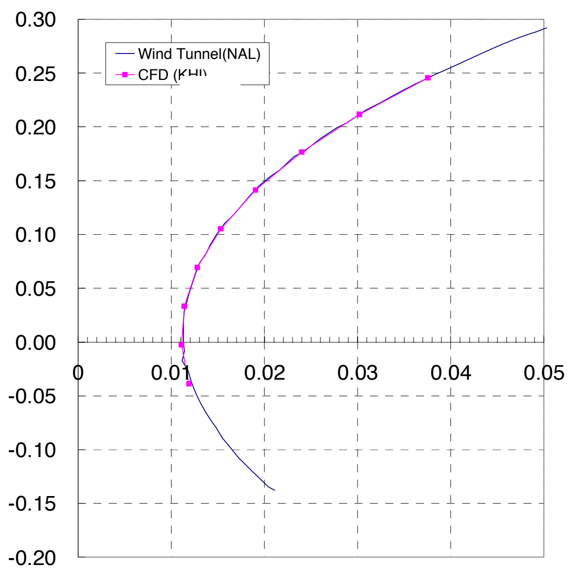


Fig.4 Comparison of lift vs. drag polar curve.

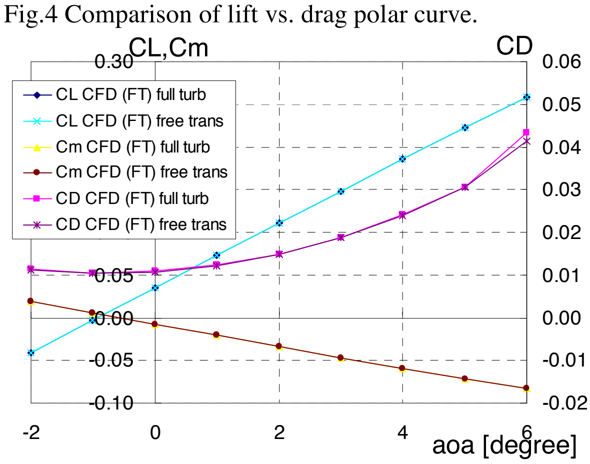
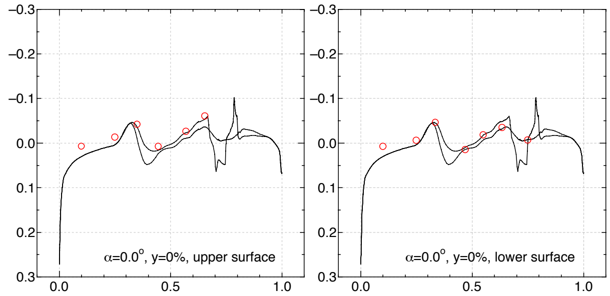
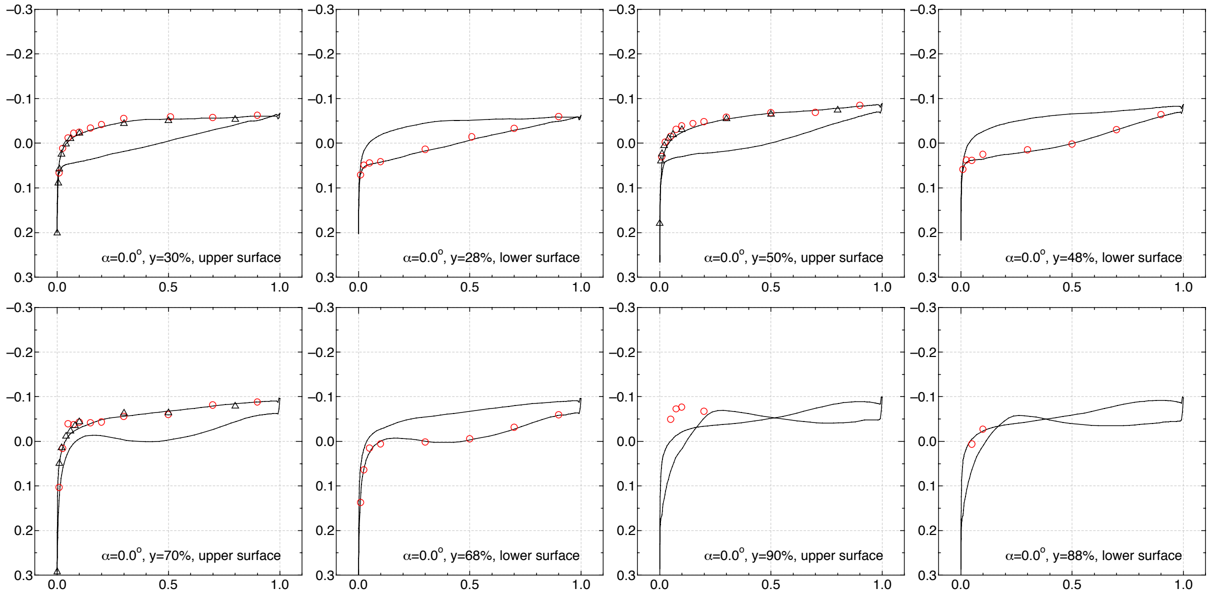


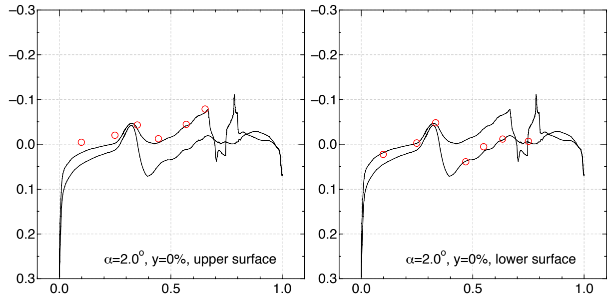
Fig.5 Calculated three component force coefficients for FT condition.



— CFD result
○ WTT result (8.5% scaled model)
△ WTT result (23% scaled model)

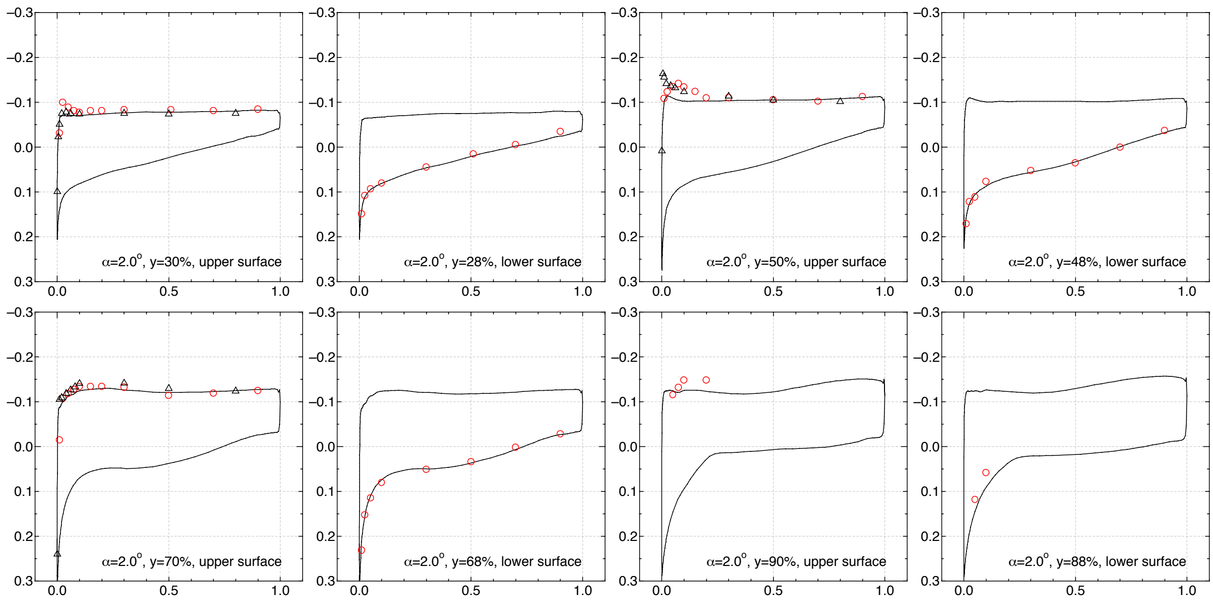
Fig. 6 Comparison of pressure coefficient (Cp) distributions between CFD and WTT (aoa=0.0deg)





— CFD result
○ WTT result (8.5% scaled model)
△ WTT result (23% scaled model)

Fig. 7 Comparison of pressure coefficient (Cp) distributions between CFD and WTT (aoa=2.0deg)



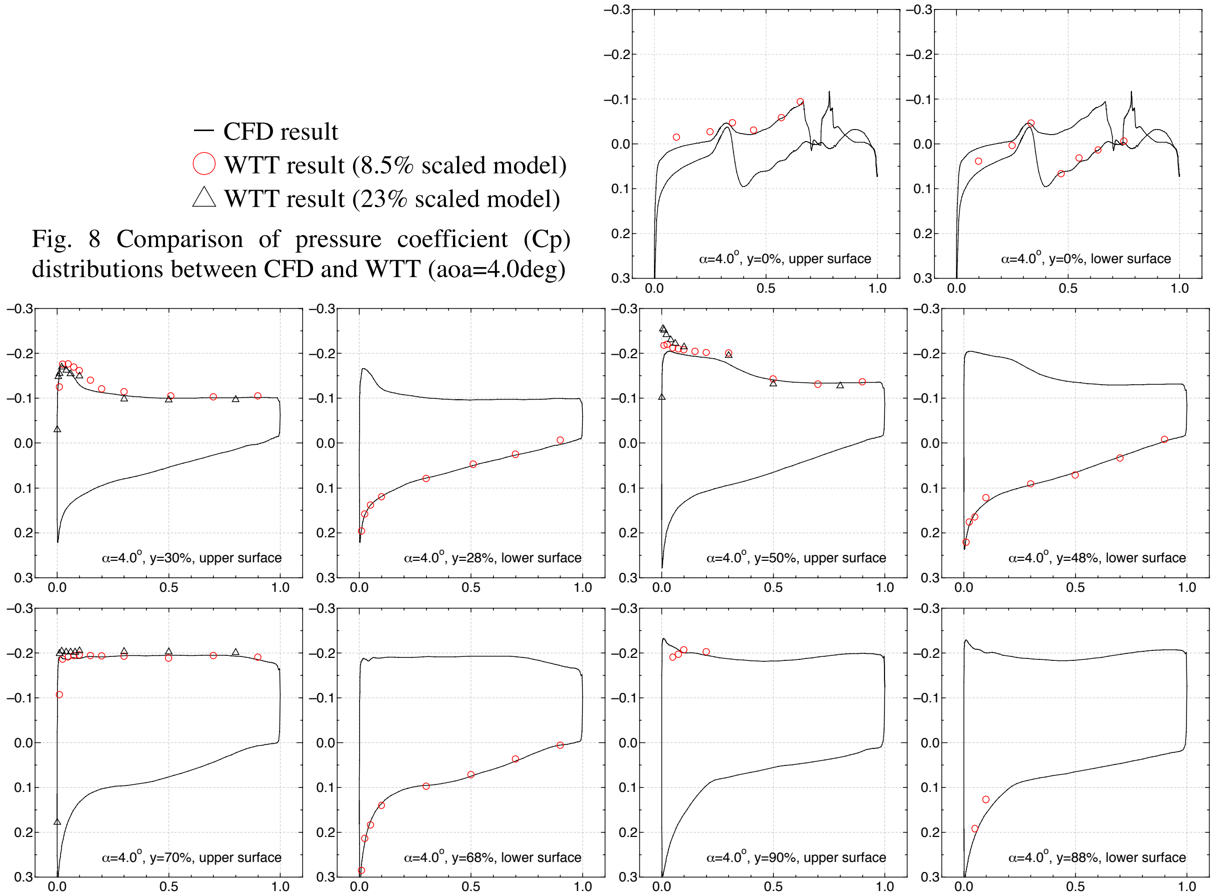


Fig. 8 Comparison of pressure coefficient (Cp) distributions between CFD and WTT (aoa=4.0deg)

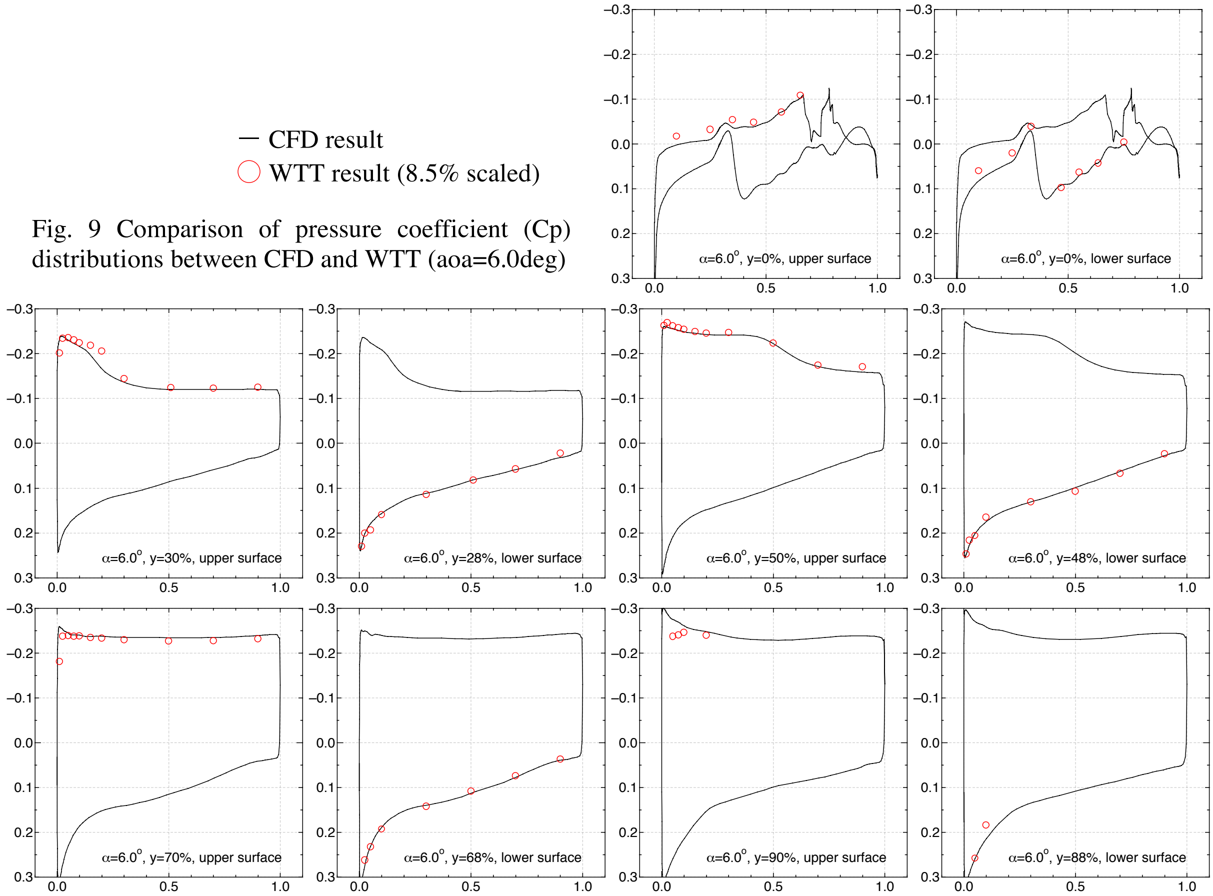


Fig. 9 Comparison of pressure coefficient (Cp) distributions between CFD and WTT (aoa=6.0deg)