EVALUATION OF TRANSONIC FLOW ANALYSIS AROUND ONERA MODEL M5 CONFIGURATION USING CASPER-HYBRID UNSTRUCTURED NAVIER-STOKES CODE

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Abstract

A hybrid unstructured Navier-Stokes code with Spalart-Allamars one-equation turbulence model has been incorporated into a CFD-based design system of Japan Defense Agency, CASPER. For the code validation, we performed transonic flow computations around ONERA Model M5 configuration, which is a high Reynolds number transonic wind tunnel testing calibration model for the JDA 2m×2m trisonic wind tunnel in Higashi-Chitose. As the first step of the unification of CFD and EFD, the wind-tunnel testing data obtained here can be expected to be useful for improvement of CFD code reliability as well as evaluation of uncertainties arising from tunnel wall constraint, flow turbulence and so on. On wing surface pressure distributions, longitudinal forces and moment coefficients and boundary layer transition lines, the CASPER is quantitatively evaluated before implementation of higher Reynolds number CFD validation computations.

1 Introduction

Recently, a CFD (Computational Fluid Dynamics)-based design system becomes an increasingly powerful tool in conceptual process of aircraft design with a rapid progress of high performance computer engineering as well as numerical algorithm [1]. Taking account of the technical background, CASPER (Computational Aerodynamics System for Performance Evaluation and Research), has been developed by Technical Research and Development Institute of Japan Defense Agency [2].

A hybrid unstructured Navier-Stokes code with Spalart-Allamars one-equation turbulence model [3],[4] has been incorporated into the CASPER. For the validation, we performed transonic flow computations around an ONERA Model M5 configuration (see Fig.1), which is a high Reynolds number transonic wind tunnel calibration model for the JDA 2m×2m trisonic wind tunnel in Higashi-Chitose [5]. As the first step of the unification of CFD and EFD, the wind-tunnel testing data obtained here can be expected to be useful for improvement of CFD code reliability as well as evaluation of uncertainties arising from tunnel wall constraint, flow angularity, flow turbulence and so on.

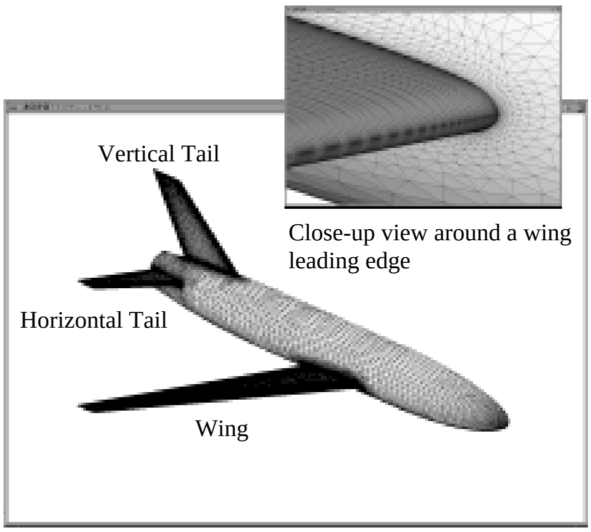


Fig.1 Surface unstructured grids of ONERA Model M5 configuration for computation of Re=60.0×10^6.

2 Numerical Results and Discussions

On pressure distributions, forces and moment coefficients and wing surface boundary layer transition lines, the present computed results obtained by CASPER-hybrid unstructured Navier-Stokes (henceforth N-S) code are quantitatively discussed with the Euler computed results [6] and the other N-S computed results [7],[8] and the wind-tunnel testing data [9],[10] before implementation of CFD validation in higher Reynolds number regions.

Figure 2 shows the front-above view of body surface pressure distributions at a freestream Mach number of 0.84, an angle of attack of -1.0 deg, and a Reynolds number of 60.0×10^6. This represents a transonic, high Reynolds number and viscous flow condition. Negative pressure region can be observed due to flow acceleration from the point of a fuselage. Also, negative pressure and compressible region can be also observed around the attached position of main wing. Above all, the location of shock wave moves forward a tip on the upper surface of main wing and as a result the λ-shaped triple shock wave is produced. In addition, because of the downwash effect of main wing, a compressible region can be seen on the upper surface of horizontal tail as well.

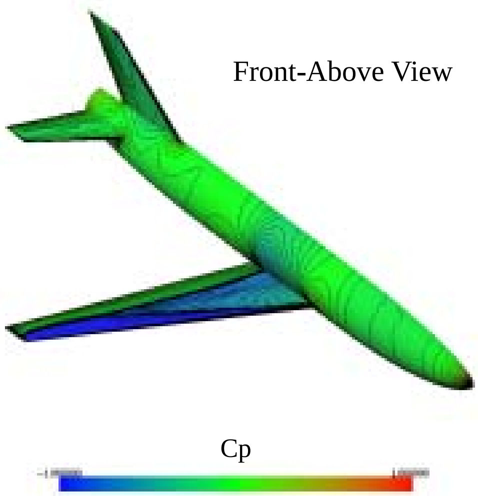
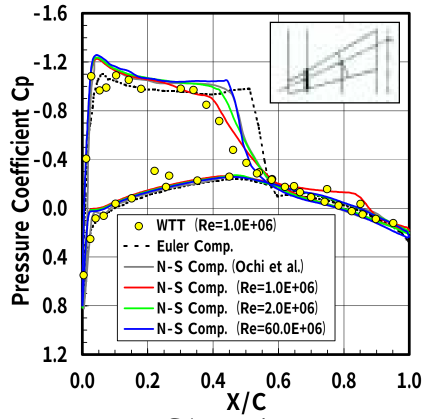
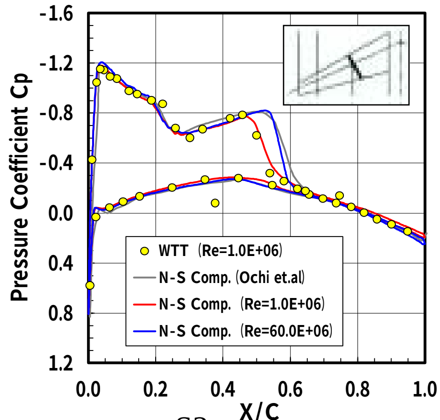


Fig.2 Computed pressure distribution at M_∞ =0.84, α =-1.0 deg, and Re=60.0×10^6.

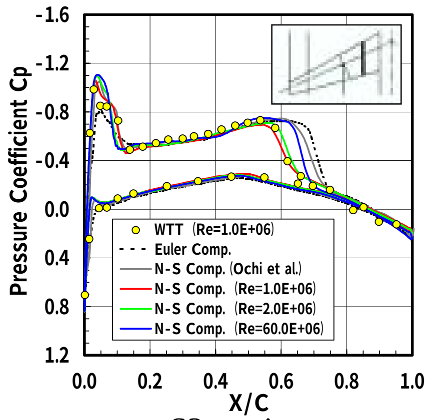
Figure 3 shows the comparisons of computed and experimental wing surface pressure coefficient distributions in S1, S2 and S3-sections at a freestream Mach number of 0.84, an angle of attack of -1.0 deg and Reynolds numbers of 1.0×10^6, 2.0×10^6 and 60.0×10^6, respectively.



S1-section



S2-section



S3-section

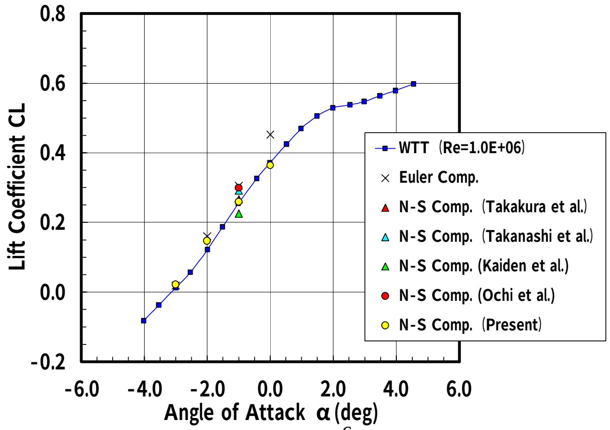
Fig.3 Comparison of wing surface pressure coefficient distributions at M_∞=0.84, α =-1.0 deg, and Re=1.0×10^6, 2.0×10^6 and 60.0×10^6.

As for the strength and the location of the combined and the double shock waves, which are one of the outstanding characteristics of main wing with a swept-back angle of 30.0 deg of the ONERA Model M5 configuration, the present N-S computed results show better agreement with the wind-tunnel testing data [9] than the unstructured N-S computed results by Ochi et al. [8] and the shock-boundary layer interaction can be accurately simulated. As for the location of trailing-edge shock wave, the computed result of a Reynolds number of 60.0 $\times 10^6$ is more aft than the computed results of a Reynolds number of 1.0×10^6 and the wind-tunnel testing data.

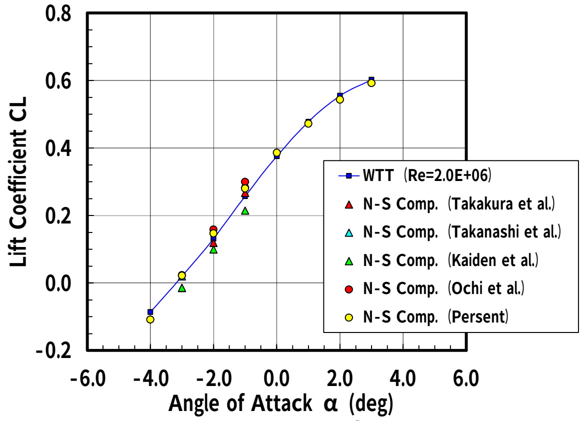
Table 1 Comparison of computed and experimental forces and moment coefficients.

	Reynolds Number Re ($\times 10^6$)	Angle of Attack α (deg)	Lift Coefficient CL			Drag Coefficient CD			Pitching Moment Coefficient CM		
				Diff. (cts)	ERR. (%)		Diff. (cts)	ERR. (%)		Diff. (cts)	ERR. (%)
WTT	1.0	-1.0	0.2591	—	—	0.0266	—	—	0.0586	—	—
	2.0	-3.0	0.0195	—	—	0.0198	—	—	0.0985	—	—
		-2.0	0.1307	—	—	0.0213	—	—	0.0786	—	—
		-1.0	0.2567	—	—	0.0269	—	—	0.0584	—	—
Euler Comp.	—	-1.0	0.3053	462	17.8	0.0299	33	12.4	0.1330	744	127.0
Unstructured N-S Comp. (Present)	1.0	-1.0	0.2599	8	0.3	0.0285	19	7.1	0.0779	193	32.9
	2.0	-3.0	0.0213	18	9.2	0.0206	8	4.0	0.1125	140	14.2
		-2.0	0.1468	161	12.3	0.0226	13	6.1	0.1002	216	27.5
		-1.0	0.2802	235	9.2	0.0286	17	6.3	0.0789	205	35.1
	60.0	-1.0	0.2923	—	—	0.0237	—	—	0.1095	—	—
Structured N-S Comp. (Takakura et al.)	1.0	-1.0	0.2668	77	3.0	0.0271	5	1.9	0.0802	216	36.9
	2.0	-3.0	-0.0154	349	178.9	0.0205	7	3.5	0.0985	0	0.0
		-2.0	0.1190	117	9.0	0.0215	2	0.9	0.0953	167	21.2
		-1.0	0.2666	99	3.9	0.0259	10	3.7	0.0841	257	44.0
	60.0	-1.0	0.2633	—	—	0.0258	—	—	0.0812	—	—
Structured N-S Comp. (Takanashi et al.)	1.0	-1.0	0.2908	317	12.2	0.0293	27	10.2	0.0831	245	41.8
	2.0	-3.0	0.0195	0	0.0	0.0205	7	3.5	0.1121	136	13.8
		-2.0	0.1560	253	19.4	0.0222	9	4.2	0.1006	220	28.0
		-1.0	0.2940	373	14.5	0.0286	17	6.3	0.0872	288	49.3
	60.0	-1.0	0.3067	—	—	0.0234	—	—	0.1044	—	—
Structured N-S Comp. (Kaiden et al.)	1.0	-1.0	0.2256	335	12.9	0.0323	57	21.4	0.0466	120	20.5
	2.0	-3.0	-0.0147	342	175.4	0.0243	45	22.7	0.0875	11	1.1
		-2.0	0.0990	317	24.3	0.0249	36	16.9	0.0697	89	11.3
		-1.0	0.2145	422	16.4	0.0286	17	6.3	0.0494	9	1.5
	60.0	-1.0	0.3200	—	—	0.0208	—	—	—	—	—
Unstructured N-S Comp. (Ochi et al.)	1.0	-1.0	0.2998	407	15.7	0.0290	24	9.0	0.1142	556	94.9
	2.0	-3.0	0.0230	35	17.9	0.0210	12	6.1	0.1414	429	43.6
		-2.0	0.1583	276	21.1	0.0230	17	8.0	0.1264	478	60.8
		-1.0	0.2991	424	16.5	0.0300	31	11.5	0.1103	519	88.9
	60.0	-1.0	0.3076	—	—	0.0254	—	—	0.1319	—	—

cf. Diff. ≡ | CFD − WTT |, ERR. ≡ | CFD − WTT | ／WTT × 100 (%), 1 ct = 0.0001.

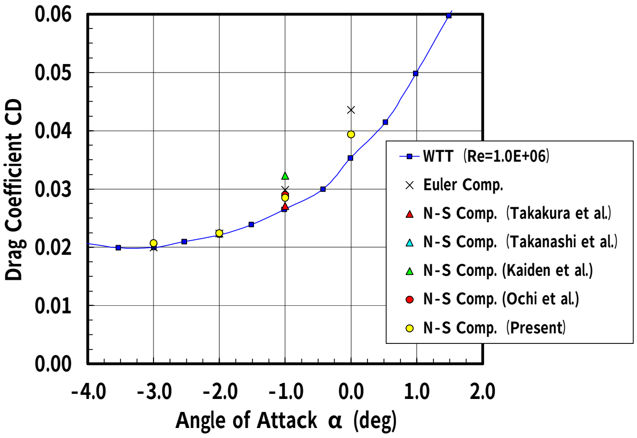


Re=1.0×10^6

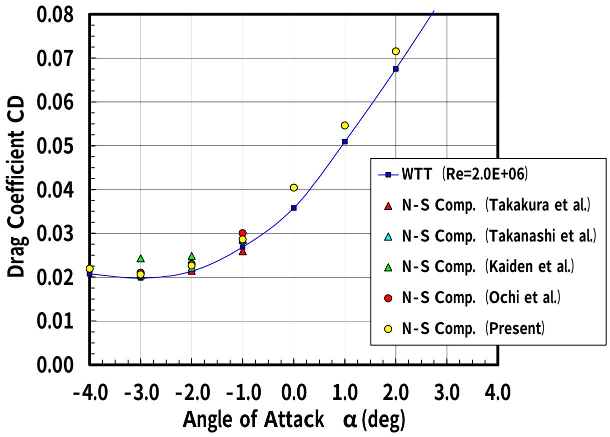


Re=2.0×10^6

Fig.4 Comparison of CL- α curves between computed and experimental results at M_∞=0.84, Re=1.0×10^6 and 2.0×10^6.

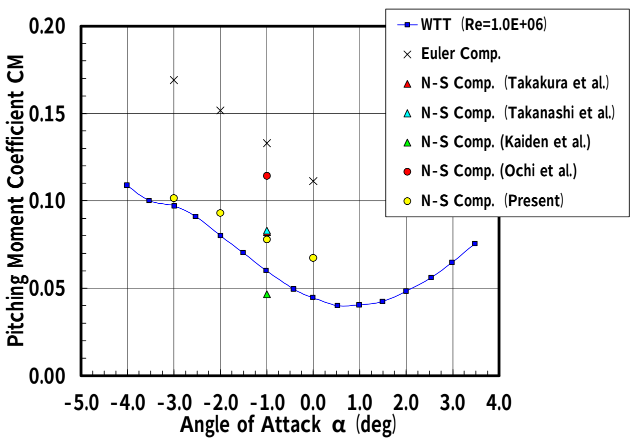


Re=1.0×10^6

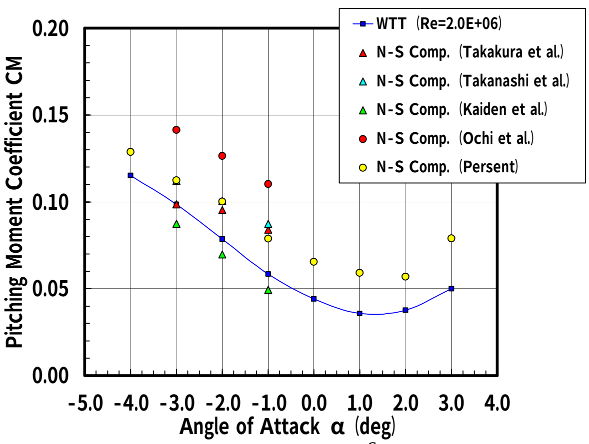


Re=2.0×10^6

Fig.5 Comparison of CD- α curves between computed and experimental results at M_∞=0.84, Re=1.0×10^6 and 2.0×10^6.



Re=1.0×10^6

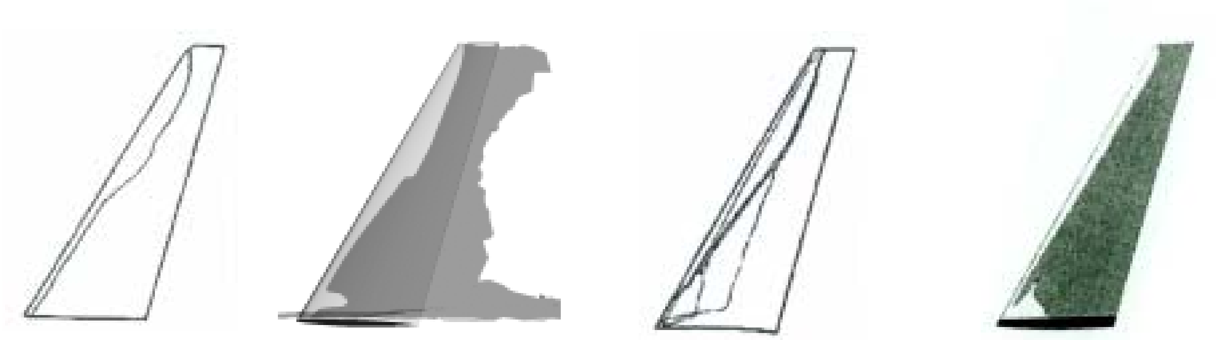


Re=2.0×10^6

Fig.6 Comparison of CM- α curves between computed and experimental results at M_∞=0.84, Re=1.0×10^6 and 2.0×10^6.

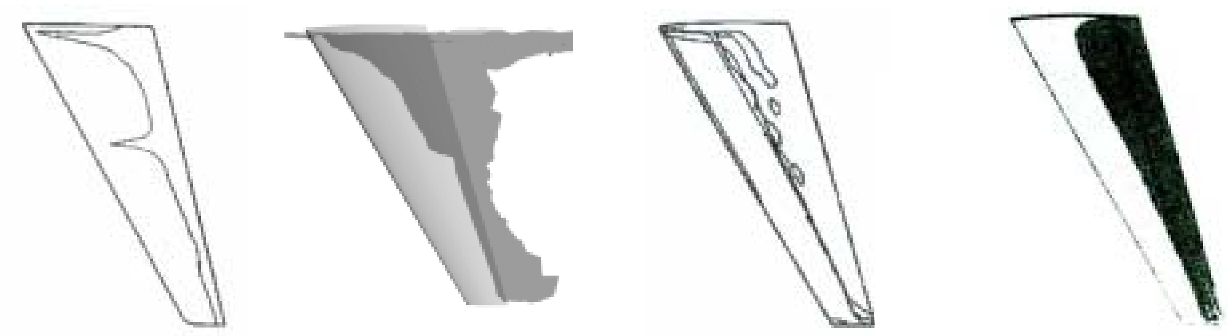
Subsequently, the present computed longitudinal forces and moment characteristics are compared quantitatively to the Euler computed results [6] and the other multi-blocked structured and unstructured N-S computed results [7],[8] and the wind-tunnel testing data [9],[10] at M_∞=0.84 and Re=1.0×10^6 and 2.0×10^6 (see Table 1). In Figures 4 to 6 the CL-, CD- and CM-α curves are illustrated respectively. As shown in Fig.5 the present drag prediction is remarkably improved by the following three strategies [11]: (1) high resolution of chord surface grids around each leading edge, (2) extension of Normalized Unstructured Mesh method [12] and (3) modification of transition parameters in Spalart-Allmaras turbulence model within their recommendation [4].

Moreover Figure 7 shows the CFD prediction of transition lines at Reynolds numbers of 1.0×10^6 and an angle of attack of -1.0 deg as compared to the other N-S computed results [7],[8] and the rough sketch of oil flow patterns obtained by the wind-tunnel tests [9]. Here, the computed transition lines are obtained visualizing the isosurface edge of specified turbulent viscosity value proposed as transition criteria in Baldwin-Lomax model [13]. The present computed results are better agreement with the wind-tunnel testing data than the other N-S computed results. In particular, the transition lines at the wing lower surface obtained by the other N-S computations are predicted a little to the upstream of the wind-tunnel testing data, but the present computed results are well simulated.



WTT [9] | Present | Structured N-S Comp. [7] | Unstructured N-S Comp. [8]

Wing Upper Surface



WTT [9] | Present | Structured N-S Comp. [7] | Unstructured N-S Comp. [8]

Wing Lower Surface

Fig.7 Comparison of boundary layer transition lines between computed and experimental results at M_∞=0.84, α=-1.0 deg, Re=1.0×10^6.

In the case of Reynolds numbers of 1.0×10^6 and 2.0×10^6, total number of the time iterations for the convergence was 150,000 with a CFL number of 5.0, which costs about 473 CPU hours on a single processor of the NEC SX-4/2C supercomputer. Also, in the case of Reynolds numbers of 60.0×10^6, total number of the time iterations for the convergence was 50,000 with a CFL number of 10.0, which costs about 116 CPU hours.

3 Conclusions

In this paper, transonic and high Reynolds number flows around the ONERA Model M5 configuration were computed by using the hybrid unstructured N-S code in CASPER. The present computed results were quantitatively compared with the other N-S computed results and the wind-tunnel testing data. These results lead us to the following conclusions:

(1) As is evident from the comparisons of wing surface pressure distributions on the strength and the location of shock waves, the shock-boundary layer interaction was well simulated.

(2) The longitudinal forces and moment prediction, drag, has shown to be of adequate accuracy.

(3) From the comparisons of boundary layer transition lines, the present CFD results show better agreement with wind-tunnel testing oil flow patterns than the other N-S computed results. Particularly, the present computed transition lines were greatly improved on the lower surface of wing.

References

[1] Jameson, A., “Re-Engineering the Design Process through Computation,” *Journal of Aircraft*, Vol.36, No.1, pp.36-50, 1999.

[2] OKI, Y., “Development and Evaluation of CFD-based Design System for Aircraft Design at TRDI-JDA,” *Journal of JSCFD*, (in Japanese), Vo.10, No.1, pp.25-40, 2002.

[3] Spalart, P.R., and Allmaras, S.R., “A One-Equation Turbulence Model for Aerodynamic Flows,” AIAA Paper 92-0439, 1992.

[4] Spalart, P.R., and Allmaras, S.R., “A One-Equation Turbulence Model for Aerodynamic Flows,” *Recherche Aerospatiale*, Vol.1, pp.5-21, 1994.

[5] Shibata, M., “Trisonic Wind Tunnel in Japan Defense Agency,” *Aeronautical and Space Sciences Japan*, Vol.48, No.557, 396-399, 2000.

[6] Sasaki, T., Sakata, T., Oki, Y., Shima, E., and Kaiden, T., “Numerical Analysis around ONERA Model M5 Configuration Using Solution Adaptive Unstructured Grid,” *Proceedings of the 1999 JSME Annual Meeting IV*, (in Japanese), pp.15-16, 1999.

[7] Nakamichi, J. “Compendium of Results Flow Analysis around ONERA Model M5 Configuration,” *Proceedings of the 12th NAL Symposium on Aircraft Computational Aerodynamics*, (in Japanese), NAL SP-20, pp.73-108, 1993.

[8] Ochi, A., and Shima, E., “Numerical Analysis of ONERA-M5Using Unstructured FVM Flow Solver,” *Proceedings of Aerospace Numerical Simulation Symposium 2002*, (in Japanese), NAL SP-53, pp.137-142, 2002.

[9] Staff of the Second Aerodynamics Division, “Results of the Test on ONERA Calibration Model M5 in NAL 2m×2m Transonic Wind Tunnel,” NAL TR-774T, 1983.

[10] Sawada, H., Suzuki, K., Nakamura, M., Suzuki, M., Komatsu, Y., and Koike, H., “Results of the Test on ONERA Calibration Model M5 in NAL 2m×2m Transonic Wind Tunnel,” (in Japanese), NAL TM-616, 1990.

[11] Oki, Y., Sakata, T., Uchiyama, N., and Kaiden, T., “Improvement of Drag Prediction for Transonic Transport Aircraft Configuration Using Hybrid Unstructured Navier-Stokes Solver,” *JSME International Journal*, Series B, Vol.45, No.4, pp.820-829, 2002.

[12] Shima, E., “An Unstructured Navier-Stokes Solver UG3,” *Proceedings of the 13th NAL Symposium on Aircraft Computational Aerodynamics*, (in Japanese), NAL SP-22, pp.25-30, 1994.

[13] Baldwin, B.S., and Lomax, H., “ Thin Layer Approximation and Algebraic Model for Separated Turbulent Flows,” AIAA Paper 78-0257, 1978.