Investigation of Turbulence Models for Multi-stage Launch Vehicle Analysis Including Base Flow

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ABSTRACT

The turbulent flow phenomenon around the multi-stage launch vehicle is investigated by applying various 2-equation turbulence models. Many researchers have investigated the motion of separated strap-ons in multi-stage launch vehicle numerically or experimentally.[1~7] However, almost all analyses seem to be insufficient for the description of turbulent flow characteristics around the detached bodies, which have high angle of attack. So, the present paper focuses on the exact prediction of trajectories of strap-ons by the turbulent flow analysis around the bodies including base region.

As for governing equations and numerical schemes, six degree-of-freedom rigid body equations of motion are integrated into the three-dimensional unsteady Navier-Stokes solution procedure to determine the dynamic motions of strap-ons. Chimera overset mesh technique[8] is applied to get the maximal efficiency for the relative motion of multiple bodies and each mesh is constructed as multi-block mesh for the representation of the after-body flow. For a spatial discretization, AUSMPW+(modified Advection Upstream Splitting Method Press-based Weight function)[9] has been applied. LU-SGS (Lower-Upper Symmetric Gauss-Seidel) scheme[10] is used as the implicit time integration method. For the temporal discretization of unsteady flowfield, dual time stepping is employed to obtain a second order accuracy. For an accurate prediction of base flow, 2-equation turbulence models are implemented to the flow solver. On the basis of k-ω SST turbulence model[11], different eddy viscosity definitions on strain rate based SST model and cubic model by Craft[12] are applied, as well as quadratic EASM(Explicit Algebraic Stress Model).

As the validation processes of Chimera overset mesh and turbulence models, developed flow solver is applied to the analyses of steady flowfield around Titan IV launch vehicle and a tandem-type two-stage launch vehicle experienced at NASA[13]. Finally, the complete analysis process is applied to the KSR-Ⅲ, a three-stage sounding rocket researched in Korea. From the analyses, the different flow features on various turbulence models are investigated and the motion of detached bodies with high angle of attack is accurately simulated.

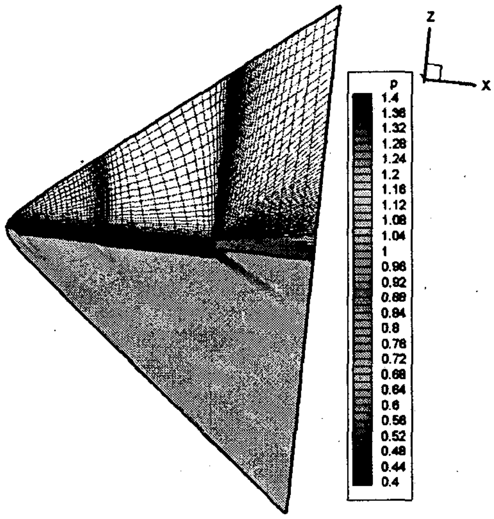

Fig. 1 A two-block mesh and pressure contour around a tandem-typed launch vehicle

Table 1 Aerodynamic Coefficients of a Two-stage Launch Vehicle

Ma \ Turbulence Model		EASM	Eddy Viscosity by Craft	k-ω SST	Inviscid Analysis	Experiment
1.6	C_A	0.51698	0.50356	0.59983	0.59983	0.50
	C_N	0.31941	0.31684	0.30706	0.30706	0.34
	C_M	1.91468	1.90876	1.84160	1.84160	1.85
2.0	C_A	0.46497	0.44658	0.52561	0.52561	0.44
	C_N	0.34965	0.35218	0.32814	0.32814	0.38
	C_M	2.0084	1.99241	1.91307	1.91307	2.05
2.36	C_A	0.42708	0.40703	0.46581	0.46581	0.42
	C_N	0.36730	0.37156	0.33794	0.33794	0.36
	C_M	2.02994	2.01901	1.94141	1.94141	2.10
2.86	C_A	0.39137	0.36933	0.39734	0.39734	0.38
	C_N	0.38538	0.40081	0.35706	0.35706	0.36
	C_M	2.05712	2.02488	1.95337	1.95337	2.10

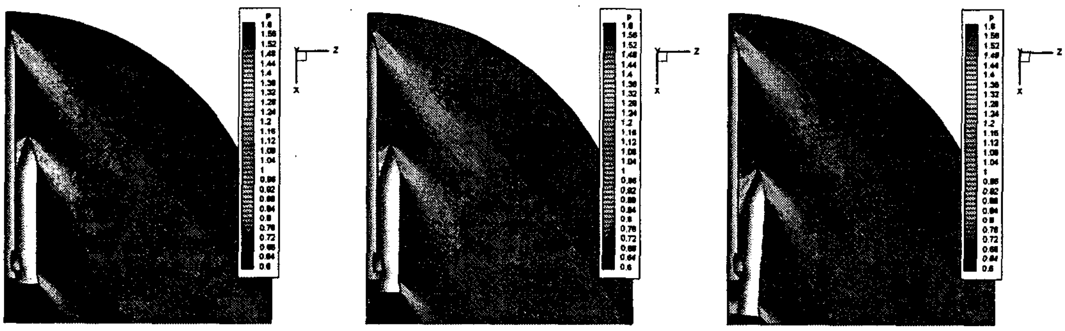

Fig. 2 The separation motion of strap-on booster at free separation case

(k-ω SST, From 0.00 to 0.20 seconds, time interval of 0.15 seconds)

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