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# A STUDY ON THE PREDICTION OF THE BASE FLOW CHARACTERISTICS OF A LAUNCH VEHICLE USING CFD

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## ABSTRACT

Numerical simulations are made to predict the axial force coefficients of a two-stage launch vehicle, and the results are compared with those by wind tunnel tests. It is found that the forebody axial force is not affected by whether the base of the body is modeled or not. Modeling the sting support used in wind tunnel tests reduced the base axial force compared to the results without it. The present calculation shows that the forebody axial forces are underestimated while the base axial forces are overestimated. The total axial force, therefore, compares with the experimental data with better accuracy by cancelling out the errors of opposite signs. Modeling of the sting support in numerical simulations is found to be necessary to get a better agreement with the experiments for both base and overall axial force coefficients.

*Keywords*: launch vehicle, axial force coefficient, base flow, CFD, wind tunnel test, sting support

## 1. INTRODUCTION

An accurate prediction of the axial force coefficients is required in a launch vehicle development to get a better estimation of the vehicle performance. Empirical and analytical methods and wind tunnel tests have been used to predict the aerodynamic characteristics of a launch vehicle. But the recent advancements in CFD solution techniques and computer technologies enabled the use of CFD as an efficient and accurate design tool. In this paper, presented are various aspects of axial force coefficient prediction using CFD with the focus placed on determining the effect of wake in the base region. Also presented is the effect of the sting which is used to support the test model in the wind tunnel tests, and the results are compared with the test data.

## 2. PREDICTION METHOD

The in-house CFD code of KARI is used to solve the flow around a launch vehicle which solves the Reynolds-Averaged Navier-Stokes equations. A diagonalized three factored implicit scheme is used for time integration, and 4-th order central difference with artificial dissipation (Pulliam 1985) is used for spatial discretization. The Spalart-Allmaras turbulence model is used to predict the

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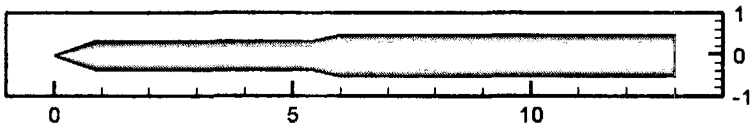



Figure 1. Configuration of a two-stage launch vehicle.

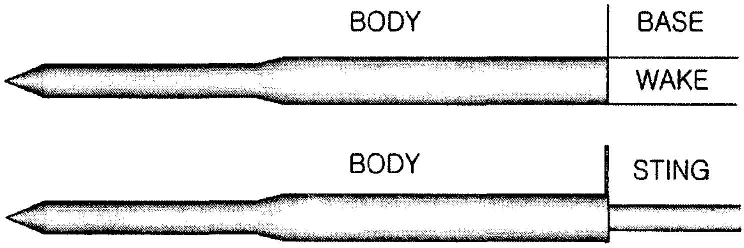



Figure 2. Computational zones around a two-stage launch vehicle.

turbulent viscosity. The overset grid method (Steger, Dougherty, & Benek 1983) is implemented to facilitate the mesh generation for complex geometries.

## 3. MODEL GEOMETRY

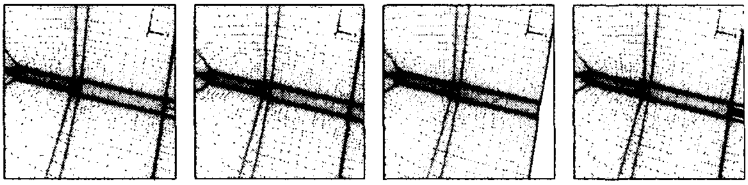
The model geometry of a two-stage launch vehicle used in the experiment and in this numerical study is shown in the Figure 1. Wind tunnel experiments were performed at both a subsonic and a supersonic wind tunnel separately (Kelly & Ross 1964, Samuels & Blackwell 1966). This simple model without any aerodynamic supplement devices such as fin, roll thruster/vane has an aspect ratio of approximately 13, a nose cone angle of 22.5°, a flare angle of 15°.

## 4. NUMERICAL RESULTS

The maximum angle of attack encountered during flight for a launch vehicle is generally set to about 5 degrees in mission definition. Thus, numerical analysis is performed for an angle of attack of 6°, Mach numbers ranging from 0.4 to 2.86 and Reynolds number of $10^6$.

The flow field around a two-stage launch vehicle is divided into four zones called BODY, BASE, WAKE, STING respectively as shown in Figure 2 and then the base flow characteristics are predicted for the four cases, Case 1: BODY+BASE+WAKE (Figure 3 (a)), Case 2: BODY+BASE (Figure 3 (b)), Case 3: BODY only (Figure 3 (c)), and Case 4: BODY+STING (Figure 3 (d)).

Figure 4 shows the change of the forebody axial force coefficient as Mach number varies. This result shows that the forebody axial force is not affected by whether the base of the body is modeled or not. The axial force coefficient for the base region, however, varies remarkably depending on the way of the base region modeling as shown in Figure 5. Case 4 in which the sting support of the wind tunnel test is modeled predicts the base axial force very well. It should be noted that the axial force



(a) Case 1 (b) Case 2 (c) Case 3 (d) Case 4

Figure 3. Grid systems around a two-stage launch vehicle.

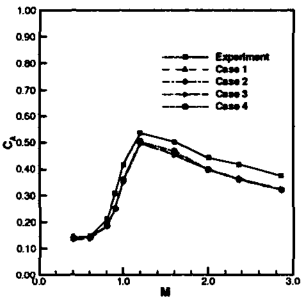



Figure 4. Mach number vs. forebody axial force coefficient.

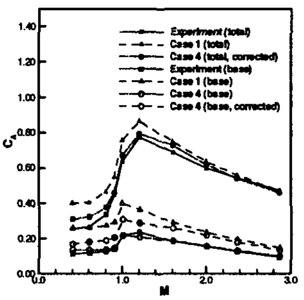



Figure 5. Mach number vs. base and total axial force coefficient.

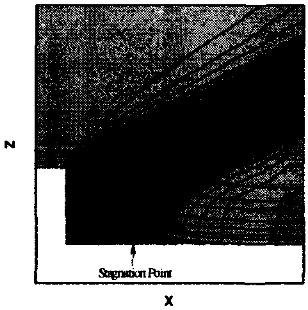



Figure 6. Streamline pattern around the base (M=2.86, axisymmetric).

coefficients of wind tunnel tests are measured for entire base area including the region occupied by the sting support. When the base area correction is made to the results of case 4, the base axial force coefficients are slightly over-predicted for all Mach numbers. Even with this discrepancy, case 4 shows better agreement with the test data than case 1 without modeling the sting support. The forebody axial forces are underestimated while the base axial forces are overestimated for all Mach numbers. Thus, the total axial force is in better agreement with the test data by cancelling out the discrepancies of opposite signs as shown in Figure 5. Figure 6 shows the flow field around the base region, and the complex flow features such as expansion wave, flow separation and reattachment are well simulated.

## 5. CONCLUSIONS

Numerical simulations to predict the axial force coefficients of a two stage launch vehicle are performed and the results are compared with those of wind tunnel tests for both subsonic and supersonic flows. The forebody axial force is not affected by whether the base of the body is modeled or not. It is also found that modeling of sting support is necessary to get better agreement with the wind tunnel test data. The forebody axial forces are underestimated and the base axial forces are overestimated for all Mach numbers simulated, and the total axial forces are in better agreement by cancelling out the discrepancies of opposite signs.

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