Estimating the Pitch Damping Coefficient of A Fin Stabilized Rocket using Particle Based CFD

Chatrat Koomphati
Aeronautical Engineering Division
Defence Technology Institute
Pakkret, Nonthaburi, Thailand
chatrat.k@dti.or.th

***Abstract*—Computational fluid dynamics (CFD) is common used to analyze rocket aerodynamics but their application on pitch damping estimation is still limited. This limitation is partly due to the fact that most CFD tools available on market employ a conventional Eulerian mesh-based method. To simulate a transient pitching motion of a rocket, it requires dynamic mesh or other special techniques. With recent introduction of Lagrangian particle-based CFD tools, it has become more convenience to apply CFD to simulate the transient pitching motion of a rocket. This paper investigates the application of a Lagrangian particle-based CFD to estimate the pitch damping coefficient of a fin stabilized rocket (Hydra 70 MK66/M151). The pitching response from 10 degree initial angle of attack was simulated for Mach 0.6 to 2.48 using XFlow, which is a particle-based CFD software. Simulation results were compared to the available wind tunnel test data to evaluate the accuracy. The results showed a good correlation between the simulation results and test data at high Mach number.**

Keywords—Pitch damping coefficient; Lattice Boltzmann method; Computational fluid dynamics; Hydra MK66/M151.

I. INTRODUCTION

Pitch damping coefficient is an aerodynamic parameter that indicates dynamic stability of a rocket. The coefficient represents the change in pitching moment at different pitch rate q and rate of angle of attack $\dot{\alpha}$. This aerodynamic parameter can be estimated by several methods such as wind tunnel testing, flight testing, empirical calculation, and computation fluid dynamics (CFD) simulation. Each method has its own advantage and disadvantage. Well controlled flight tests or wind tunnel tests can provide accurate results but are quite expensive. On the other hand, the empirical calculations can be carried out quickly but are less accurate in most cases. In addition, CFD simulation is arguably more accurate than the empirical calculations and less expensive than those experimental methods. But it requires some techniques to apply CFD simulation to estimate the pitch damping coefficient.

Finite volume method (FVM) can be employed in conventional CFD simulation for estimating the pitch damping coefficient of a rocket. FVM is an Eulerian method that focuses on the fluid motion at specific locations in the space as time passes. This method is suitable for flow simulation in which the fluid domain (i.e., the location where the flow computation is needed) doesn't change. However, to estimate the pitch damping coefficient, the motion of the rocket must move accordingly to the motion of fluid flow and vice versa (i.e., the transient movement of rocket effects the flow field). The FVM presents some difficulty problem since the computation boundary has to be adapted as the rocket moves. On the other hands, the Lagrangian method discretizes the flow field into fluid particles and focuses on calculating the motion of each individual particle as it moves through the computation domain. The particle based method is then suitable for the moving boundary problems since it does not require mesh adaptation.

In this paper, the application of particle-based CFD simulation to estimate rocket pitch damping coefficient is investigated. The Hydra 70 rocket, which consists of MK66 motor and M151 warhead, was selected as a case study. Fig. 1 presents the rocket model. The simulation was performed in XFlow 2015, which is a particle based CFD software. XFlow utilizes Lattice Boltzmann method for flow field calculation and also features the rigid body motion simulation. The rocket was constrained in the fluid domain to allow pure pitching simple harmonic motion as illustrated in Fig. 2. The center of rotation of the rocket was specified at the center of gravity of the rocket. The motion of the rocket were simulated at Mach number of 0.6 to 2.48. The motion data obtained through the flow time were used to compute the pitch damping coefficient.

In the following sections, the concept of flow simulation using Lattice Boltzmann method, the estimation technique for the pitch damping coefficient, and the flow simulation setting of XFlow 2015 are briefly described. Simulated pitch responses of the rocket at different Mach numbers are presented. Then the pitch damping coefficients are computed for each Mach number and are compared to the available wind tunnel test data. The results are compared and discussed. Finally, the conclusion is presented.

Fig. 1. Hydra MK66/M151 model in XFlow