The Prediction of the Dynamic Derivatives for the Separated Payload Fairing Halves of a Launch Vehicle in Free Falling

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ABSTRACT

The dynamic derivatives for the separated Near/Far PLF(Payload Fairing) halves in free falling are needed to predict the accurate dispersed range of the impact point. A number of approach methods are applied to obtain the dynamic damping parameters. The methods to predict the dynamic derivatives consist of the wind tunnel test, using the empirical data base and the CFD analysis. The wind tunnel test for the PLF halves in free falling is so much time and cost consuming. The prediction approach using the empirical data base is the simplest but there are no data base for the PLF halves. In this paper, predicted are the dynamic damping parameters for the configuration of the three dimensional PLF halves using the most complicated approach, CFD analysis even though it spends a lot of time since the configuration of the PLF halves is so unique and the range of the angle-of-attack and the side slip angle are highly wide.

Obtained are the dynamic derivatives with a CFD code implementing the forced harmonic oscillation of a grid system. The unsteady Euler equation as a governing equation is applied to predict more economically the aerodynamic characteristics neglecting the viscous effects even though using Navier-Stokes equation is more precise approach. The CFD code to apply the oscillation of the grid system is presented from Computational Aerodynamics & Design Optimization Lab., KAIST(Korea Advanced Institute of Science and Technology).[1] A simple equation to simulate the forced harmonic oscillation is as below.

$$\theta = \theta_0 + \theta_1 \sin(2M_\infty kt)$$

where θ_0 is the initial angular displacement, θ_1 is the amplitude of the oscillation, M_∞ is the free stream Mach number, k is the reduced frequency and t is the nondimensional time.

It is assumed that the rotation center for the oscillation motion is the center of gravity. θ means the angular displacement containing the effect of the roll rate only for the oscillation with respect to the x-axis. θ, however, includes the effect of both the pitch rate and the variation of the angle-of-attack for the oscillation with respect to the y-axis and θ also contains the effect of both the yaw rate and the variation of the side slip angle for the oscillation with respect to the z-axis. It is also assumed that the dynamic derivatives are constant during the oscillatory motion. In this paper, θ_1 is 0.25 deg since the amplitude of oscillation is small in order that the dynamic derivatives are constant during the oscillatory motion and k is arbitrary value 0.1 because the dynamic derivatives are not highly dependent on the variation of the damping frequency. θ_0 is 0 deg since the harmonic motion starts at the initial position. The dynamic damping coefficients are obtained integrating the moment coefficients for a period for the forced harmonic oscillation as below. [2]

$$Dynamic\ Derivative = \frac{2M_{\infty}}{\pi\theta_0}\int_0^T C_m \cos(2M_{\infty}kt)dt$$

The configurations of the Near and Far PLF are quite different from each other. The Far PLF has more complex geometry consisting of spherical nose, cone and cylindrical part, and the Near PLF doesn't have a spherical nose.(Fig. 1) And it is assumed that the thickness of the PLF halves is uniformly 0.2 m. In this research, the dynamic derivatives of PLF halves are presented for Mach number ranging from 0.6 to 2.0 and angle-of-attack ranging from -180 deg. to 180 deg., side slip angle ranging from -90 deg. to 90 deg. The reference length and area are the diameter 2.0 m and the area of base π m^2, respectively. The aerodynamic moments are calculated about the c.g point of the PLF halves. Fig. 1 shows the configurations of PLF halves and the reference axis system.

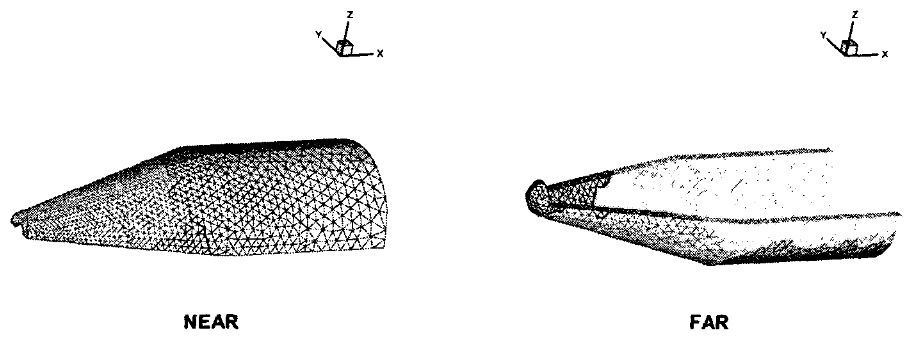

Fig. 1 The configurations and reference grid system of the Near and Far PLF Halves

In the CFD code, the forced harmonic oscillation of the PLF halves is simulated. And the dynamic derivatives are predicted separately using the aerodynamic moment coefficients. Validated below for the simple basic finner is, therefore, the numerical method to predict the dynamic derivatives.[2]

Table 1. The validation for the configuration of the basic finner

M=1.1, k=0.05	Pitching-damping moment coefficient ($C_{M_q} + C_{M_{\dot{\alpha}}}$)	Roll-damping moment coefficient (C_{L_p})
Ref. CFD result [2]	-399	-20.5
Present	-378.360	-25.996

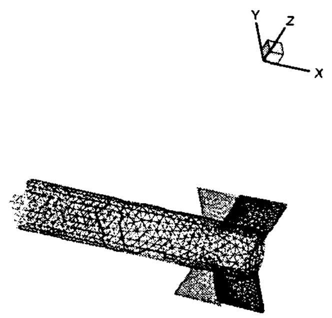

Fig. 2 The configuration of the basic finner

The dynamic derivatives for the Near half which has simpler configuration are firstly predicted. And then those of the Far half are obtained. The flow characteristics of the Far PLF are different from static coefficients of the Near PLF due to the existence of the spherical nose. The six components of the aerodynamic static coefficients, however, are similar to each other.[3] Thus, the dynamic derivatives are also similar each other since the dynamic derivatives are obtained integrating the aerodynamic moment coefficients. Fig. 3 shows the comparison of the dynamic derivatives between the Near PLF and the Far PLF for the angle-of-attack of 0 deg. The dynamic damping coefficients in Fig. 3 with respect to the variation of both the angle-of-attack and the side slip angle for Mach number of 0.60 imply that the dynamic damping parameters for the Near PLF have very similar magnitude with those of the Far PLF. In this research, $C_{M_q}+C_{M_{\dot{\alpha}}}$, $C_{N_r}-C_{N_{\dot{\beta}}}$ and C_{L_p} are only presented. To predict $C_{M_{\dot{\alpha}}}$ or $C_{N_{\dot{\beta}}}$ alone, another approach such as considering the plunge motion of the PLF halves should be applied. Some data points in Fig. 4 have positive damping coefficients and it is uncertain that this is physically reasonable. More calculations will be made for these conditions with another approach to confirm their physical meaning and uncertainty.

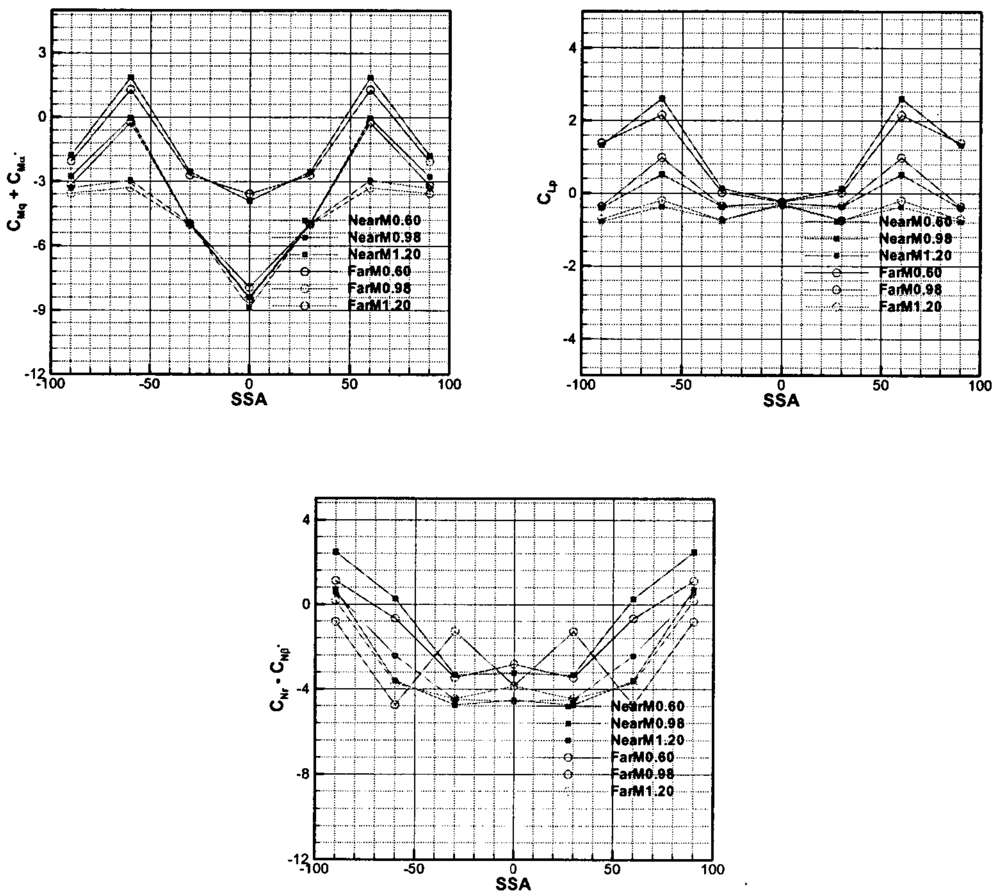

Fig. 3 Comparison of the dynamic derivatives between the Near and the Far PLF (AOA=0°)

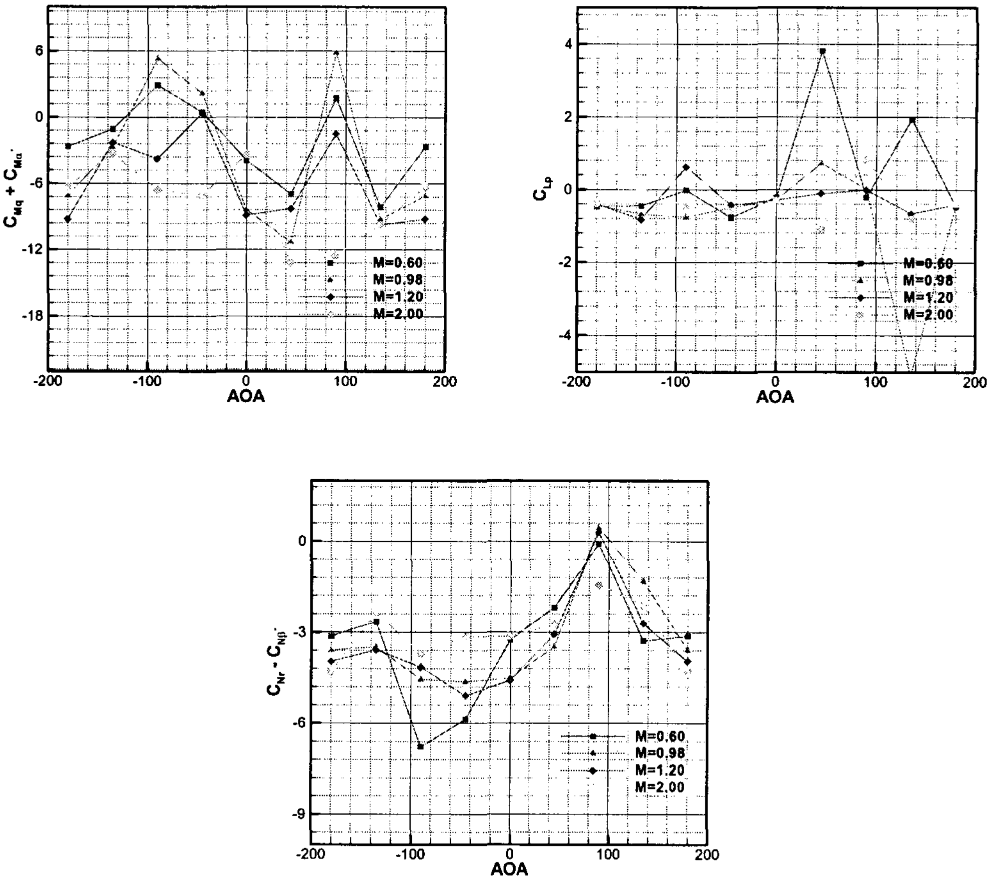

Fig. 4 The variations of the dynamic derivatives for the Near PLF (SSA=0°)

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