Amirkabir Journal of Mechanical Engineering

Amirkabir Journal of Mechanical Engineering, 49(2) (2017) 117-120
DOI: 10.22060/mej.2016.758

Numerical Investigation of Environmental Parameters Effect on Dynamic Stability of a Reentry Capsule

R. Kamali Moghadam*, M. Shakeri

Aerospace Research Institute, Tehran, Iran

ABSTRACT: In this paper, 3D numerical simulation of unsteady flow around a re-entry capsule in forced pitching oscillation has been performed using sliding mesh technique. Effects of environmental parameters including angle of attack, Mach number and fluctuation frequency on dynamic stability of the capsule have been determined, after validation of the results and grid independency test. For this purpose, the results have been captured using the Fluent software and the flow field around the capsule has been studied at different conditions. The longitudinal dynamic derivatives required for stability analysis of the capsule in pitching oscillation are calculated. Moreover, effects of the mentioned parameters on the dynamic derivatives have been investigated. Using the sliding mesh for numerical simulation of the pitching oscillation of the Muses-C capsule which decreases the computational cost, studying of the effect of different parameters on the dynamic stability of this capsule and determination of the variation trend of dynamic stability at different conditions are some goals of the current investigation. Analyzing the results in the influence of various parameters indicates that increasing the mean angle of attack leads to an increase in the dynamic stability. Furthermore, the dynamic instability of the capsule is more critical at the subsonic flow than the supersonic flow, and the dynamic stability of the Muses-C capsule also increases with the increase of the oscillation frequency.

Review History:

Received: 14 September 2015
Revised: 21 February 2016
Accepted: 28 February 2016
Available Online: 2 October 2016

Keywords:

Parameter Study
Dynamic Stability
Reentry Vehicle
Forced Pitching Oscillation

1- Introduction

High speed of the capsules through the re-entry phase leads to some thermal and controlling problems. Study of the control and dynamic instability of these capsules always has attraction for many researchers due to the complex interaction of parameters related to the unsteady flow. One of the major problems for the bluff bodies is their instability at some speeds and under some specific environmental conditions. Thus, determination of instability conditions plays the key role through the capsules controlling process. Both the geometrical and environmental parameters affected the re-entry capsule stability. Therefore, in the present study, the environmental parameters effects, including the angle of attack, Mach number and the fluctuations frequency have been analyzed on the dynamic stability of the Muses-C reentry capsule.

2- Capsule geometry

The geometric dimensions of the Muses-C have been shown in Figure 1. Although this capsule has the static stability, both the experimental results and the numerical results of the present research indicate that this capsule has dynamically instability.

3- Grid specification

Due to complexity of the geometry, a hybrid mesh including the structured boundary layer grid near the wall and unstructured tetrahedral mesh at far field is created. The distance between the first nodes with the body surface is 0.0001 mm with a y+ of 25. The total number of 15 layers with the growth ratio of 1.1 is identified for the boundary layer grid. Totally, about 4.2 million cells have been used

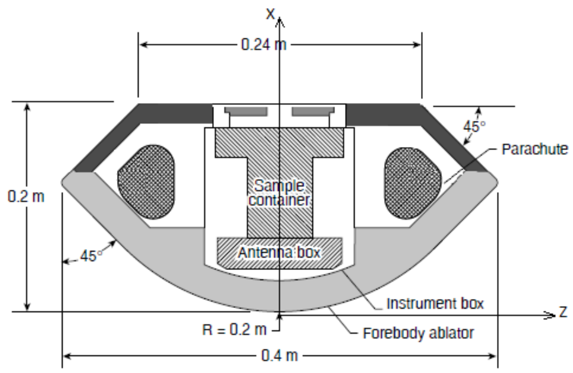

Figure 1. The geometry of Muses-C re-entry capsule [2]

in the present numerical simulation. The details of the mesh study have been mentioned in other studies of authors [3, 4].

4- Boundary conditions and solution setup

The 3D unsteady numerical simulation of the flow field has been carried out using the Fluent software. In this simulation, the density-based solver and the second order discretization method have been applied. The turbulence model is SST-k-w with time step of 0.0001 s. Both the implemented computational domain and boundary conditions are shown in Figure 2.

The sliding mesh technique has been applied for modeling of the forced pitching oscillations. A numerical code has also been developed to simulate the pitching motion of the capsule in unsteady flow based on Eq. 1.

$$\alpha(t)=\dot{\alpha}+\bar{\alpha}\sin(\omega t) \quad (1)$$

Validation of the numerical simulation of unsteady flow in the forced pitching oscillations with the Mach number of

Corresponding author, E-mail: rkamali@ari.ac.ir

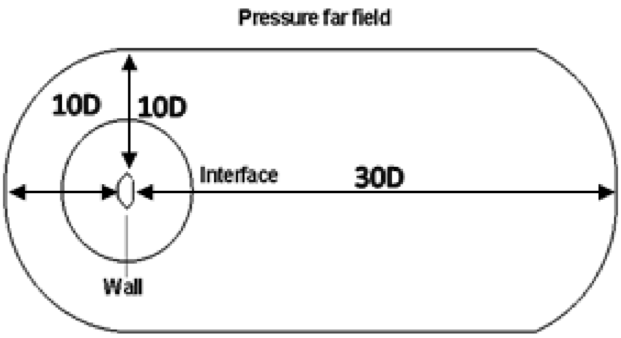

Figure 2. Computational domain and boundary conditions

1.3, zero mean angle of attack, the oscillation amplitude of 20 degrees and the reduced frequency of 0.112 (20 Hz) has been presented in references [3, 4]. In this study, the effects of three important environmental parameters, including the angle of attack, Mach number and the fluctuations frequency on the dynamic stability of the re-entry capsule have been studied.

5- Dynamic Stability Analysis

The governing equation for the forced pitching oscillation of the capsule is:

$$\ddot{\alpha} - (c_{m\dot{\alpha}} + c_{mq})\frac{\dot{\alpha}c}{2U} - c_{m\alpha}\alpha = f(t) \qquad (2)$$

The coefficient of the longitudinal dynamic derivatives has been selected as the determinative parameter of dynamic stability [3]. According to Eq. 2, positive value of this parameter represents the dynamic instability of the ballistic body. The longitudinal dynamic derivatives are summarized as [5]:

$$C_{m_{\dot{\alpha}}} + C_{m_q} = \frac{2V\int C_m d\alpha}{D\left(T/2\right)\bar{\alpha}^2\omega^2} \qquad (3)$$

6- Results and Discussion

It is indicated in Figure 3 that the greatest amount of the dynamic instability for the Muses-C capsule is exhibited at zero angle of attack and the dynamic stability increases at 5 degree angle of attack. This fact causes the designers set the center of mass off the center line of the re-entry capsule to maintain the re-entry angle of attack off zero at re-entering phase and guarantee its dynamic stability. It can be concluded from Figure 4 that, although the effect of Mach number on the dynamic stability of a body completely depends on its geometry and its angle of attack, the dynamic instabilities of re-entry bodies are more critical at transonic regime and the dynamic stability increases with the increase of the Mach number. For the Muses-C capsules, the maximum dynamic stability is observed at Mach number of 1.3 (transonic regime). The effect of the oscillation frequency on the dynamic stability is analyzed in Figure 5. It can be seen that, increasing the fluctuations frequency increases the dynamic stability.

7- Conclusions

Effects of the environmental parameters, including angle of attack, Mach number and the fluctuations frequency of on the dynamic stability of a re-entry capsule in forced pitching

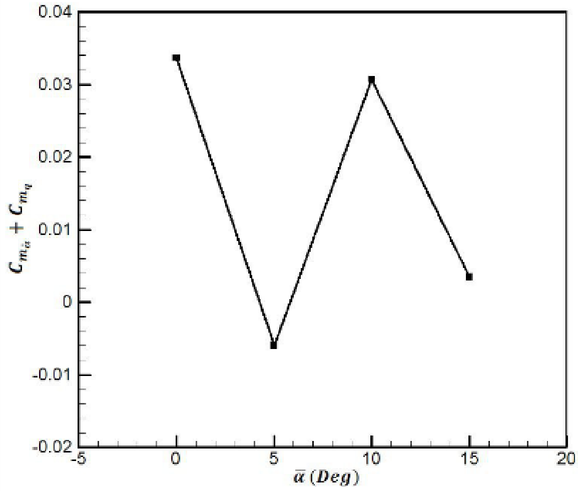

Figure 3. Damping coefficient variation with the angle of attack

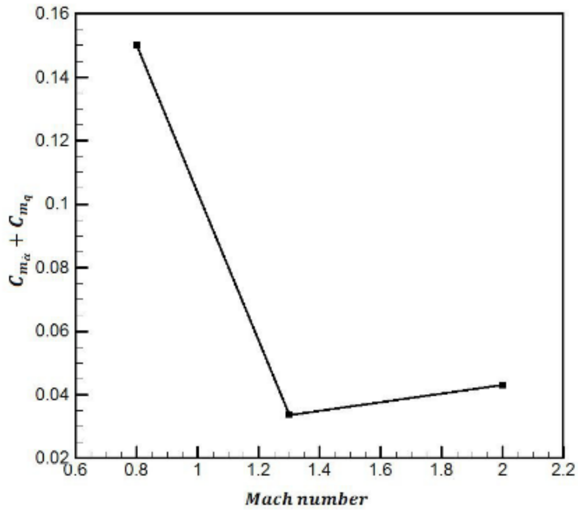

Figure 4. Damping coefficient variation with the Mach number

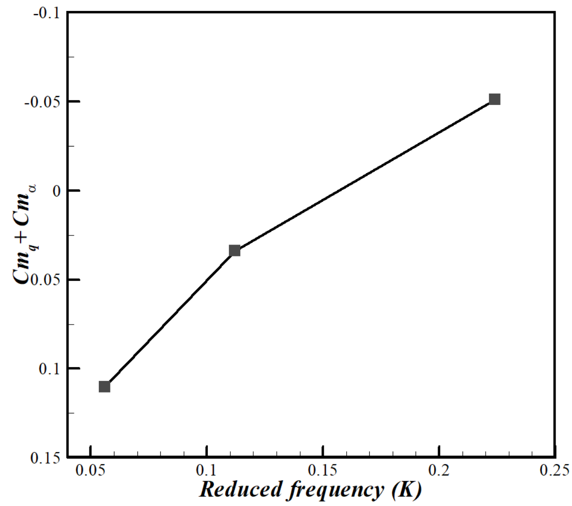

Figure 4. Damping coefficient variation with the frequency

oscillations have been studied. The aerodynamic moments around the body in the pitching oscillations has been obtained and the dynamic derivatives for investigating the dynamic stability of the capsules have been calculated. Dynamic stability analysis of the re-entry capsule shows that this geometry is dynamically unstable. The range of the capsule stability is presented in Table 1.

Table 1. Range of dynamic stability of the Muses-c capsule

Parameter	Dynamic stability limitation
Mean angle of attack	$4° < \alpha_m < 6°$
Reduced frequency	$K > 0.2$
Mach number	Unstable at α=0 , K=0.112

References

[1] D. Sugimoto, H. Nagai, K. Asai, K. Hiraki, Experimental study on dyanmics instability of re-entry capsule-shaped body using pressure sensitive paint, in: *48th AIAA aerospace sciences meeting*, 2010.

[2] P.N. Desai, R.A. Mitcheltree, and F. McNeil, Cheatwood sample returns missions in the coming decade, *51st International Astronautical Congress*, Brazil, 2000.

[3] M. Shakeri, *Dynamic Stability Analysis of a Reentry Space Capsule in Pitching Motion with Free and Forced Oscillations*, Master of Science thesis, Aerospace Research Institute, 2014.

[4] R. Kamali moghadam, M. Shakeri, Dynamic stability analysis of a conic reentry space capsoul in pitching motion with free and forced oscillations, in: *23th ISME Conference*, Tehran, Iran, 2015.

[5] F. Rasi marzabadi, R. Kamali moghadam, Longitudinal dynamic derivatives of an airfoil under pitching and plunging oscillations in wind tunnel, *Modares Mechanic Engineering Journal*, 14(10) (2014) 159-166.

Please cite this article using:

R. Kamali Moghadam and M. Shakeri, "Numerical Investigation of Environmental Parameters Effect on Dynamic Stability of a Reentry Capsule" *Amirkabir J. Mech. Eng.*, 49(2) (2017) 325-340.

DOI: 10.22060/mej.2016.758