Flutter of Plate in One Side Flow

Lifeng WANG, Nana CHEN

State Key Laboratory of Mechanics and Control of Mechanical Structures, Nanjing University of Aeronautics and Astronautics, Nanjing 210016, China

Summary. Panel flutter is a self-excited vibration which caused by the air flow. The flutter of thin plate with in plane stress in low speed flow of one side is investigated. The critical flutter speed is obtained via the *V-g* method. Based on the flutter analysis, the plate will flutter, if the velocity of the flow is larger than 14 m/s. But, flutter does not occur even if the velocity of the flow is up to 24m/s. The aerodynamic pressure caused by the air flow can add an in plane stress to the plate. The in plane stress increase natural vibration frequency and critical flutter speed. Thus, flutter of a thin plate is not easy to occur in low speed flow at one side. The flutter of plate with in plane stress caused by lateral aerodynamic pressure in subsonic flow is predicted.

1. Introduction

High-supersonic aircraft, space reentry vehicles introduce many new problems for the designer [1]. One of the most important problems is the aerothermoelastic interactions of skin panels at very high velocities. The aerothermoelasticity deals with the dynamic behavior of elastic structures under the combined effects of aerodynamic, thermodynamic, elastic, and inertial forces. The mathematical modelling of these field interactions is a formidable task. Consequently, aerothermoelastic studies have been based on a number of simplifying assumptions. Most of the early work on panel flutter was restricted to supersonic speeds. It was recognized that geometrical nonlinearities can play an important role in flutter of panel. This led to a number of researches that emphasized the geometrically nonlinear aspects using a finite deflection plate theory combined with piston theory for generating the unsteady aerodynamic loads. These studies showed that when geometrical nonlinearities are considered, the linear stability boundary can be exceeded, thereby inducing stable limit cycle oscillations with finite amplitudes. Dowell has shown that nonlinear flutter of panel is capable of producing irregular behavior[2,3]. Latter, the problem was examined in the context of chaos theory by Sipcic [4]. Bein *et al*. studied the influence of various orders of piston theory on the stability boundary and limit cycle amplitudes [5]. It was found that a numerical solution of the unsteady Euler equations gives virtually identical responses as those obtained with the simpler piston theory for high Mach numbers. McNamara and Friedmann reviewed the researches on the areas of hypersonic aerothermoelasticity[6]. An overview of the problem and governing equation of aerothermoelastic was provided. Then, modeling approaches and coupling strategies for the fluid, thermal, and structural problems were reviewed. Potential future directions were also presented in the paper. Most of the existing aerothermoelastic panel flutter models, the lumped-capacity assumption is frequently used to capture the temperate distribution in the panels [7,8]. The consumed time of the heat conduction and the thermal resistance of the panels are neglected in these models. Hence, both the thermal stress in the panels and the temperature distribution, which are obtained by the above method, are not accurate. So, Li *et al* proposed an improved aerothermoelastic panel flutter model [11]. The history effects of aerodynamic heating on the outside surface are introduced in order to obtain the accurate internal force and moment produced by thermal stress. From the numerical results, it is found that the internal force and moment induced by thermal stress have a significant impact on the panel flutters.

All of the above studies on panel flutter is in supersonic even hypersonic. It is wide accepted that panel flutter is a typical supersonic aeroelastic phenomenon. Most of the above mentioned work is the theoretical or numerical researches on the flutter. So there is a need to carry out experiment research on the flutter of the panel. But the experiment of the panel flutter in hypersonic wind tunnel is very expensive. But the preliminary calculation showed that flutter will occur at lower speed flow if the plate is thin enough. In addition, the effect of heating on the panel is twofold. First, there is reduction in stiffness due to softening of the panel material. Second, thermal stress is generated due to mismatch in thermal expansion coefficients of the panel and support structure. These effects, in turn, affect the static and dynamic behavior of the panel. The latter effect that is the thermal stress is more important for the dynamics of the plate. But the thermal stress can be replaced by the initial stress. So panel flutter experiment in low speed wind tunnel is carried out to study the flutter of thin panel.

2. The Main Results

The flutter of the thin plate in a low speed flow is studied by wind tunnel experiment. The mechanical model of thin plate with two opposite sides fixed and two opposite sides free is established. The natural frequency and vibration mode of the thin plate are calculated by finite element method. The influence of aerodynamic heating on the properties of structural materials is considered. In the finite element analysis, thermal buckling of thin plates is happened at very small temperature increasing. The stiffness of the thin plate is increased by applying initial stress to the plate. The effects of temperature on the flutter speed of the thin plate are studied by finite element method.

A rectangle plate with one side a=0.465 m and other side b=0.5 m is used to study the panel flutter in low speed wind tunnel. The Young's modulus of the plate used in the experiment is 62GPa, the mass density is 2700kg/m^3, the Poisson ratio is ν =0.33. The wind tunnel experiment equipment can be seen in Figure 1. The critical flutter speed is 14m/s obtained via the *V-g* method as shown in Figure 2. Based on the flutter analysis, the plate flutter will occur, if the velocity of flow is larger than 14 m/s. The displacement at the centre of the plate of the plate can be seen in Figure

3. It is found that the amplitude of the displacement decreased with the increasing of the flow velocity. The flutter do not occur when the velocity of the flow beyond 14m/s even up to 24m/s. Further studies show that the different of velocity in the two side of the plate lead to additional lateral pressure. The additional lateral pressure will lead to in plane stress, which will increase the critical flutter speed. Therefore, the flutter characteristics of the thin plate with initial stress are studied.

Figure 1. Wind tunnel experiment equipment

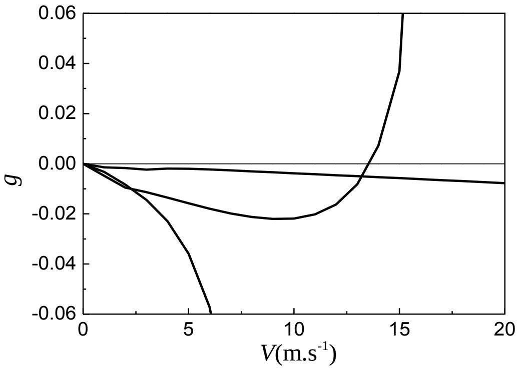

Figure 2. Critical Flutter speed via *V-g* method

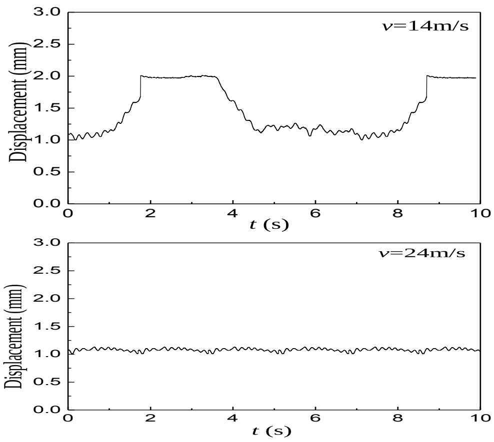

Figure 3. The displacement of the panel in wind tunnel

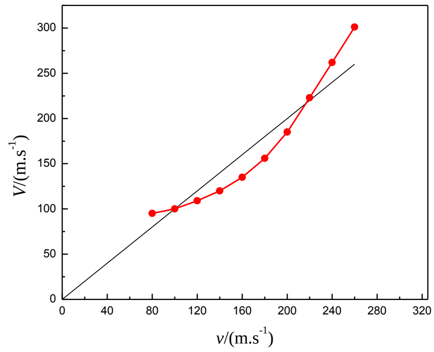

Figure 4. The flutter speed corresponding to the flow speed with in plane stress considered.

One question is raising that whether the panel flutter can occur in subsonic flow of one side. Figure 4 presented the flutter speed corresponding to the flow speed with in plane stress considered. Both side of the plate is 0.2 m. The thickness of the plate is 0.0004m. The Young's modulus of the plate used in the experiment is 62GPa, the mass density is 2700kg/m^3, the Poisson ratio is ν =0.33 also. Then the critical flutter velocity of flow is calculated via *V-g* method with in plane stress caused by lateral pressure taken into consideration as in Figure 2. From Figure 4, it can be seen that panel flutter will occur when the speed of the flow from 100m/s to 220m/s.

3. Concluding Remarks

The flutter of thin plate with in plane stress in low speed flow of on side is investigated. The critical flutter speed is obtained via the *V-g* method. Based on the flutter analysis, the plate will flutter, if the velocity of flow is larger than 14 m/s. But, flutter does not occur even if the velocity is up to 24m/s in wind tunnel experiment. The lateral aerodynamic pressure caused by the air flow can add an initial stress on the plate. The in plane stress has a great effect on flutter behaviors of the plate. The in plane stress increase natural vibration frequency and critical flutter speed. Thus, flutter of a thin plate is not easy to occur in low speed flow.

References

[1] Dorsey J. T., Poteet C. C., Chen R. R., Wurster K. E. (2002) Metallic Thermal Protection System Technology Development: Concepts, Requirements and Assessment Overview, 40th Aerospace Sciences Meeting, *AIAA* 2002-0502

[2] Dowell E. H. (1966) Nonlinear Oscillations of a Fluttering Plate. *AIAA Journal*, **4**(7):1267–1275.

[3] Dowell E. H. (1967) Nonlinear Oscillations of a Fluttering Plate II. *AIAA Journal*, **5**(10) : 1856–1862.

[4] Sipcic S. R. (1990) Chaotic Response of Fluttering Panel the Infuence of Maneuvering. Nonlinear Dynamics. 1:243–264.

[5] Bein T., Friedmann, P., Zhong, X., Nydick I. (1993) Hypersonic Flutter of a Curved Shallow Panel with Aerodynamic Heating. *AIAA*, 93-1318.

[6] McNamara J. J., Friedmann, P. P. (2011) Aeroelastic and aerothermoelastic analysis in hypersonic flow: Past, present, and future. *AIAA Journal* **49**(6):1089 –1122.

[7] Gee D. J., Sipcic S. R. (1999) Coupled thermal model for nonlinear panel flutter. *AIAA Journal*, **37**(5): 642–650.

[8] Pourtakdoust S. H., Fazelzadeh, S. A. (2005) Nonlinear aerothermoelastic behavior of skin panel with wall shear stress effect, *Journal of Thermal Stresses*, **28**(2):147–169.

[9] Li K. L., Zhang J. Z., Mei G. H., (2012) Aerothermoelastic model of panel flutter with consideration of the history effects of aerodynamic Heating, *International Journal of Applied Mechanics*, **4**(3):1250034