SIMULATION OF DIVERGENCE AND FLUTTER INSTABILITIES OF ELASTIC PLATE IN SUBSONIC AND SUPERSONIC GAS FLOW

Anastasia Shishaeva[*,**], Vasily Vedeneev[*a)], Konstantin Kuznetsov[**] & Andrey Aksenov[**]
[*]*Insititute of Mechanics, Lomonosov Moscow State University , Moscow, 119192, Russia*
[**]*Tesis JSC, Moscow, 127083, Russia*

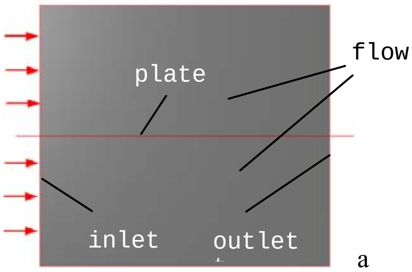
Summary Direct numerical simulation of response of elastic plate in uniform gas flow to an initial disturbance has been conducted. Unstable response can be of two types: static plate divergence in subsonic flow, and oscillatory instability (flutter) in supersonic flow. Flutter, in its turn, can be either single mode flutter at low supersonic Mach numbers, or coupled mode flutter at higher Mach numbers. Limit cycle oscillations (LCO) observed consist either of one plate mode (non-resonant LCO), or several modes being in internal resonance 1:2. Amplitudes of divergence and flutter, as well as modal structure of the flutter LCO, have been investigated in detail.

INTRODUCTION

Aeroelatic instability of plates in a gas flow has been studied in many papers in context of panel flutter problem [1]. It is known that in case of subsonic flow the primary instability type is static instability (divergence), whereas in supersonic flow instability is oscillatory (flutter). Flutter instability, in its turn, can be either coupled-mode flutter, or single-mode flutter. The first one occurs due to coalescence of eigenfrequencies and is studied in detail using aerodynamic piston theory. The other flutter type, single mode flutter, occurs at lower flow speeds and can be explained through negative aerodynamic damping concept. This flutter type was not studied until recent papers [2-4]. Preliminary nonlinear investigation shows that growth of limit cycle amplitude while entering flutter region is much more rapid for single mode than for coupled mode flutter. Therefore, single mode flutter can be more dangerous. Also, at single mode flutter 1:2 internal resonance between plate modes is possible, even more increasing LCO amplitude.
The goal of the present paper is to conduct fully nonlinear simulation of plate behaviour in a gas flow. We study region of parameters, where both single mode and coupled mode flutter occur, as well as case of divergence instability.

FORMULATION OF THE PROBLEM AND METHOD OF SOLUTION

We consider behaviour of a clamped elastic plate in a gas flow. The plate is flat and has three sections: leading and trailing sections are fixed and middle section of length L_p is free (Fig. 1b). Both sides of the plate interact with a gas flow. At t=0 we introduce initial out-of-plane disturbance of the plate, and calculate response of the plate-flow system at t>0.



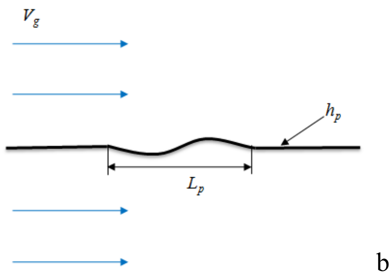


Fig. 1. Plate and flow configuration (a). Plate oscillations in the gas flow (b).

The plate is modelled using Mindlin (Timoshenko type) shell theory. Plate equations are solved using finite element method in Abaqus code. The gas flow is modelled by Navier-Stokes equations, which are solved using control volume method in FlowVision code. Connection between two codes is organized via “Co-simulation” mechanism available in Abaqus and “Multiphysics” mechanism available in FlowVision, as follows [5]. At each time step displacement increment obtained from the plate equations is transferred into FlowVision analysis, while pressure load obtained from the gas equations is transferred into Abaqus analysis.

RESULTS

Steel plate of length L_p=0.3 m and thickness 0.001 m in air flow was considered. Three types of the plate response were observed. The first one is stability: small initial plate deflections are damped (Fig. 2, a). The second is static divergence instability, observed for certain parameters in subsonic flow (Fig. 2, b). The third one is flutter instability (Fig. 2, c),

[a)] Corresponding author. Email: vasily@vedeneev.ru.

occurred in supersonic flows. From practical point of view, flutter is usually much more dangerous than divergence, that is why we will confine ourselves to observation of flutter results.

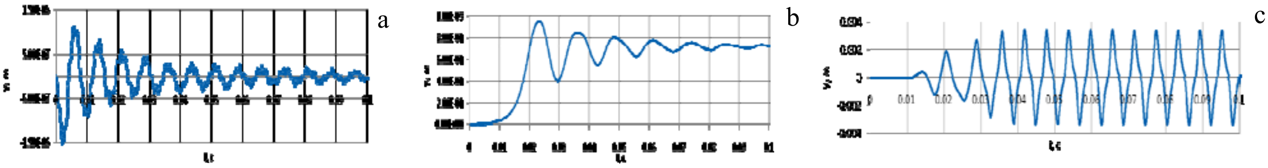


Fig. 2. Vertical plate deflection of a certain plate point versus time: stability (a), divergence (b), flutter (c).

Coupled mode flutter

Series of calculations have been conducted at *M*= 1.8 and varying gas pressure. When the plate reached limit cycle, spectral analysis was conducted in order to watch change of the plate eigenfrequencies. Results are shown in Fig. 3a and compared with frequency-domain analysis [4]. Coalescence of the 1st and 2nd eigenfrequencies occurs at *p*=74 kPa, leading to coupled mode flutter. Amplitudes of limit cycle oscillations are shown in Fig.3b.

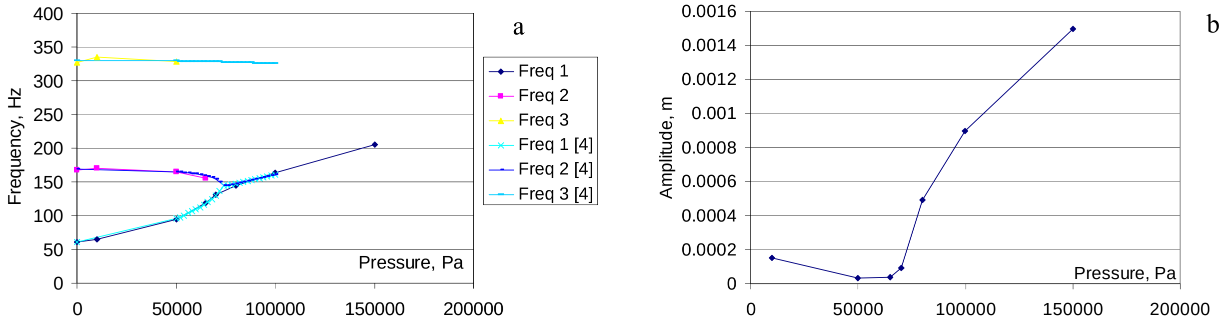


Fig. 3. 1st, 2nd, and 3rd plate frequencies vs gas pressure (a). Amplitude of the plate LCO vs gas pressure (b). *M*=1.8.

Single mode flutter

In order to observe single mode flutter oscillations, we chose *p*=50 kPa (stability at *M*=1.8, see Fig. 3b) and decreased flow speed. For small Mach numbers flutter occurred again, however its nature is of single mode type. At *M* close to 1 non-resonant LCO were observed (Fig. 4a), however at a little higher Mach numbers 1:2 resonant LCO occurred, which can be recognised by non-symmetric plate oscillations (Fig. 4b). It is seen that single mode flutter amplitude is several times higher than for coupled mode flutter (Fig. 3).

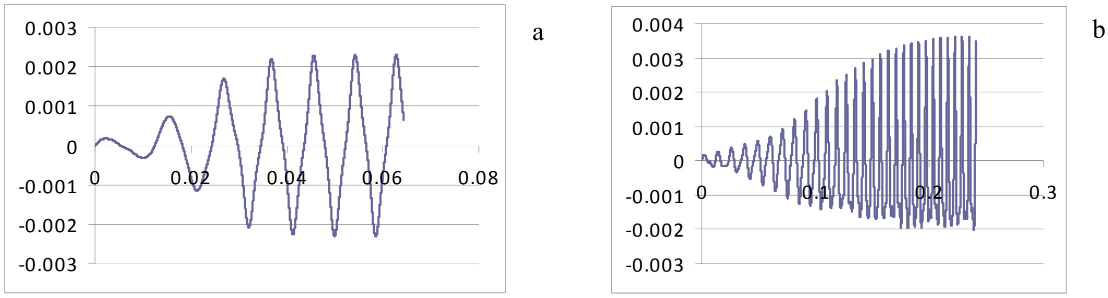


Fig. 4. Transient plate response (m) at *p*=50 kPa, *M*=1.08 (a), *M*=1.26 (b).

CONCLUSIONS

Various types of aeroelastic plate instability in a gas flow have been simulated through direct numerical calculations. Divergence, single mode flutter and coupled mode flutter have been observed. Amplitudes and frequencies of limit cycle oscillations have been studied. It is shown that limit cycle flutter oscillations can include 1:2 internal resonance.

The work is partially supported by grants of Russian Foundation for Basic Research (10-01-00256 and 11-01-00034).

References

[1] Dowell E.H.: Aeroelasticity of Plates and Shells Noordhoff, Leyden 1975.

[2] Vedeneev V.V.:.Flutter of a wide strip plate in a supersonic gas flow. *Fluid Dynamics* **5**: 805–817, 2005.

[3] Vedeneev V.V., Guvernyuk S.V., Zubkov A.F., Kolotnikov M.E.: Experimental observation of single mode panel flutter in supersonic gas flow. *J. Fluids and Structures*, **26**:764–779, 2010.

[4] Vedeneev V. V.: Panel flutter at low supersonic speeds. *J. Fluids and Structures*, 2012. doi:10.1016/j.jfluidstructs.2011.12.011

[5] A. Aksenov, D. Korenev, A. Shishaeva, D. Vucinic, Z. Mravak: “Drop-Test” FSI simulation with Abaqus and FlowVision based on the direct 2-way coupling approach. 2008 Abaqus Users’ Conference. Newport, Rhode Island (USA): Book of Abstracts. Newport, Rhode Island, 2008.