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MECHANICS

Experimental Observation of Single-Mode Panel Flutter in a Supersonic Gas Flow

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Panel flutter is an important problem that appeared in aviation and rocket engineering more than half a century ago. Since that time, hundreds of articles and series of books devoted to this problem have been published [1–3]. The problem consists of two parts, namely, the elastic and aerodynamic parts. The elastic part has been investigated in detail for different statements, namely, for various shapes of the plates and shells, metallic and composite materials, linear and nonlinear behavior, etc. When simulating the aerodynamic part of the problem, on the contrary, simplifying assumptions on the locality of interaction between the flow and elastic construction are used. Most often, this is the "piston" theory, which is correct only for Mach numbers larger than 1.7. Only in a few investigations of panel flutter has a more exact theory of the potential gas flow admitting the correct consideration at lower Mach numbers been used.

In the panel flutter theory, two type of stability loss are known [2, 3]. The first one is the coupled-type flutter that appears because of the interaction of two eigenmodes of the plate. This type is investigated in detail using the "piston" theory, and good agreement with the experiment is observed at $M > 1.7$. The second type is the single-mode flutter (in the literature, it is also called high-frequency flutter). It can be described only using an exact aerodynamic theory of the potential flow and, according to the theory, it should appear at low supersonic Mach numbers. Up to now, detail investigations of this type of flutter were absent; moreover, doubts were expressed about its existence. Recently, the single-mode flutter was investigated in detail analytically [4–7] using the theory of global instability [8, 9], and a simple physical mechanism of its appearance was revealed. Then numerical calculations were carried out [10]. However, no experiments were performed in which the single-mode flutter could be revealed in explicit form. The goal of this work is experimental confirmation of the existence of single-mode panel flutter.

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SCHEME OF THE EXPERIMENTS

The experiment was performed in an A-7 supersonic wind tunnel at the Institute of Mechanics of Moscow State University [11] (section of the throat is 600×600 mm, the upper and lower walls are perforated, and side walls are without perforation). The experimental layout is shown in Fig. 1. The plate is made of steel and welded over the perimeter to a frame fixed on the lower wall of the tunnel. Welding is selected as the method of fastening the plate in order to obtain the smallest construction damping. The sizes of the free part of the plate are $300 \times 540 \times 1$ mm. The cavity under the plate is connected through drain ports with the flow region so that the pressure in the cavity equals the static pressure in the flow (i.e., the plate in the free state is not buckled). The plate size is selected so that the coupled-type flutter cannot be realized in this tunnel.

Generally, upon air flow around the plate in a wind tunnel, five excitation sources of large amplitude vibrations of the plate are possible:

(i) resonance caused by vibrations of the wind tunnel as a whole;

(ii) resonance held by pressure pulsations in the wind tunnel;

(iii) response to the noise excitation;

(iv) coupled-type flutter;

(v) single-mode flutter.

To reveal the precise excitation source, the motion of the plate was monitored by 12 strain gages glued on it from the cavity side, vibrations of the wind tunnel were monitored by a gage of vibrations mounted on the throat of the wind tunnel, and pressure pulsations in the throat of the wind tunnel were monitored by a pressure gage. The analysis of the spectra of these gages allows

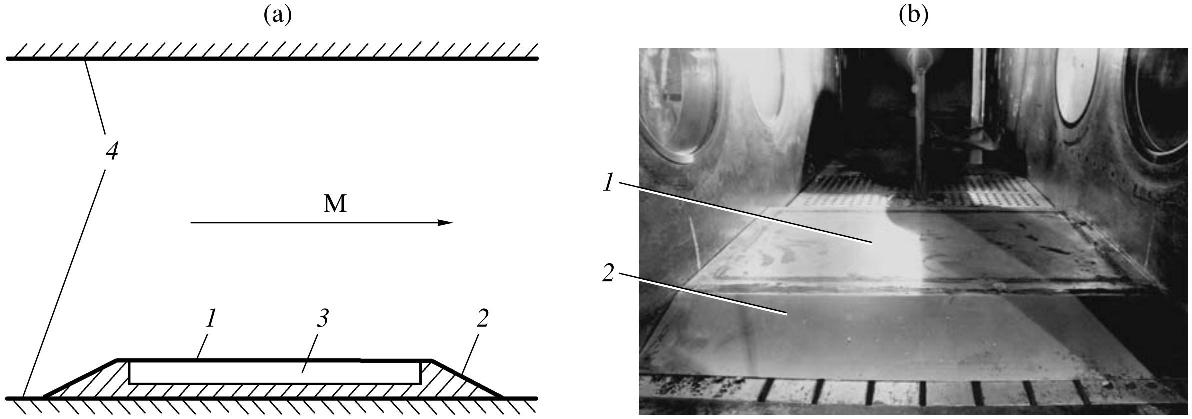

Fig. 1. (a) Experimental layout and (b) the model mounted in the tunnel. (*1*) Plate, (*2*) frame, (*3*) cavity, and (*4*) perforated tunnel walls.

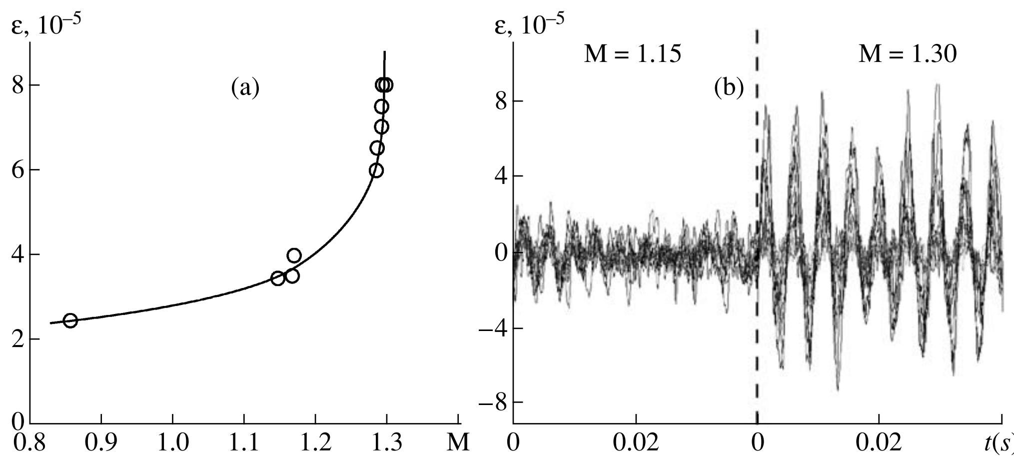

Fig. 2. (a) Amplitude of dynamic deformations of the plate as a function of the Mach number and (b) variation in dynamic deformations in time (the data from several strain gages are shown) in the mode M = 1.15 (stability) and 1.30 (flutter).

us to unambiguously determine the type of oscillations of the plate.

The Mach number of the air flow was determined by readings of the gages of the total and static pressures.

RESULTS

The investigation was performed for 11 operational modes of the tunnel in region $0.85 < M < 1.30$ and at $M = 3.0$. The amplitude of oscillations of the plate as a function of M is shown in Fig. 2a. It is evident that in region $1.2 < M < 1.3$, the amplitude of oscillations of the plate increases abruptly. Detailed analysis of the spectra read out from strain gages, the gage of vibrations of the wind tunnel, and the pressure gage shows that amplification of oscillations cannot take place because of the first four possible causes. Consequently, it takes place because of the appearance of the single-mode flutter.

The obtained experimental results agree well with the calculation by theory of [6]. For example, the modes theoretically most unstable with respect to flutter are the modes (1, 1) and (2, 1); the first number means the number of half-waves in the deflection in the flow direction, and the second number means that in the perpendicular direction. In the experiment, the highest peaks in the oscillation spectrum of the plate correspond to the same modes. Mode (2, 1) enters the region of instability at $M = 1.17$, mode (1, 1) at $M = 1.19$, and other modes at higher values of M. These values correspond to the experimental boundary of the flutter (Fig. 2).

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