GENERAL CHARACTERISTICS OF THE FLUTTER AND ITS INFLUENCE ON THE STABILITY OF THE AIRCRAFT

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Annotation: This article explores the general characteristics of the flutter phenomenon and its effect on aircraft stability in flight. The main goal of this work study the main problems of the mechanics of composite materials, problems of the aerospace industry, such as deformation, durability, vibration and dynamic stability of structures made of composite materials.

Key words: flutter, composite materials, viscous-hard, blades, continuity deformation, aerodynamic forces.

Air instabilities, which can be catastrophic, result from the relationship between aerodynamic forces, structural (elastic, viscoelastic) forces and inertial forces. Wing, panel and aileron flutter, buffeting, aileron divergence and reversal are, among many others, typical cases of aeroelastic phenomena in aeronautical engineering. Such examples include vibrations of long-span bridges, cable jumps, and impacts on buildings.

The first aircraft were very far from rigid structures, but it is inevitable from the outset that the theory of aircraft dynamics must be based on the assumption of rigidity. This was adequate in many cases, but inadequate in others. Thus, the failure of aircraft due to the oscillation and separation of the wings and tails was found to be mainly dependent on the elasticity of the structure. In general, structural elasticity is important when airspeed is high and structural rigidity is low. Therefore, in any application in which this highly desirable relationship between airspeed and stiffness is maintained, aeroelastic calculations must be performed.

Aeroelasticity is a branch of applied mechanics that deals with the interaction of aerodynamic, inertial and structural forces. It is devoted to the behavior of an elastic body in an air flow, in which there is a significant feedback interaction between deformation and flow. The main problems of aeroelasticity are the determination of both the response and the stability of an elastic body. Aeroelasticity plays an important role in many industrial problems such as the flow of liquids or gases past plates in nuclear reactors. This is important when designing airplanes, helicopters, rockets, suspension bridges, power lines, tall buildings, chimneys, and even brake lights. Galloping power lines in icing and wind conditions is currently a classic aeroelastic problem. As a preliminary discussion of the problems studied by aeroelasticity, it is convenient to consider what forces are involved in this subject. The name itself defines in meaning two forces, namely, aerodynamic forces and elastic forces; and only they appear in studies of non-accelerated motions, such as problems of stable rolling or aileron reversal. However, flutter fields and shock fields introduce a third and no less important type, namely inertial forces. Some of the problems associated with the three types of forces mentioned above are highlighted; For this purpose, we will use the famous "triangle of forces" [1], shown in Fig. 1. Three types of forces are placed separately at the vertices of an equilateral "triangle of forces", where the initials indicate the corresponding forces. Each item is connected to the corresponding vertices and is placed inside the triangle when connected to three vertices. So flutter (F) and buffering (B) are located inside the triangle. On the other hand, aileron reversals (R) and divergences (D) occur outside of the triangle since they are not related to inertial forces.

ISSN 2277-3630 (online), Published by International journal of Social Sciences & Interdisciplinary Research., under Volume: 11 Issue: 12 in December-2022
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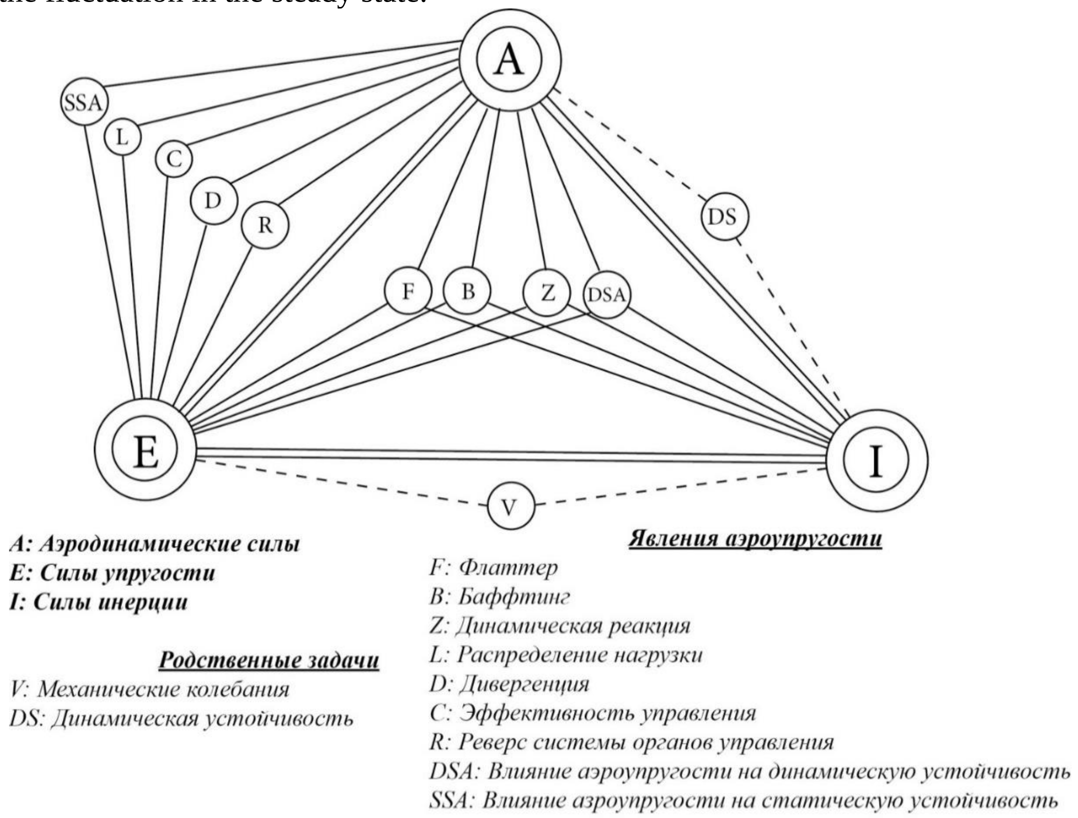
By divergence, we mean an infinitely slow movement that occurs at a critical rate of divergence, although we can make a connection between divergence and flutter.

Aeroelastic analysis methods differ depending on the time dependence of the involved inertial and aerodynamic forces. For the analysis of flight performance and maneuvering loads, when aerodynamic loads change relatively slowly, quasi-stable methods are used. The rest of the problems are dynamic, and the methods of analysis differ depending on the time dependence of the course or simply the fluctuation in the steady state.



Rice. 1. Triangle of aeroelastic forces

The redistribution of air loads caused by structural deformation will change the lifting efficiency of airfoils compared to a rigid vehicle. Simultaneous analysis of the equilibrium and compatibility between external air loads, internal structural and inertial loads and the total flow disturbance, including the disturbance resulting from structural deformation, leads to the determination of the equilibrium aeroelastic state. If the air loads tend to increase the overall flow disturbance, the lifting efficiency is increased, if they decrease the total flow disturbance, the efficiency is reduced. In the limiting case of increasing lifting efficiency, there is a critical rate at which the rate of change of air loads with deformation is equal to the rate of change of the structural response, and there is no statically stable equilibrium state; at higher speeds, the deformation will increase to the point of failure of the structure. This critical speed is called the divergence speed. The divergence problem can be viewed either as a special case of flutter, or as a relatively simple problem per se. There is a limit, a wing approaching its diverging speed will quickly change its lift.

The degree of change in efficiency and load distribution on a straight wing depends on its torsional stiffness and the distance along the chord between the aerodynamic center of the wing and the center of its twist. Divergence can occur on a straight wing if the aerodynamic center of the airfoil is located ahead of the center of twist. Sweep has a significant effect on efficiency and load transfer to the extent that it is also determined by the bending stiffness of the surface, while the effectiveness

ISSN 2277-3630 (online), Published by International journal of Social Sciences & Interdisciplinary Research., under Volume: 11 Issue: 12 in December-2022
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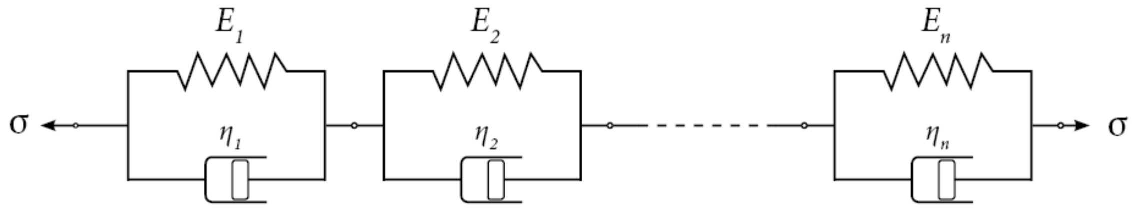
of the stabilizers also depends on the stiffness of the fuselage. The camber of a swept-back wing has a significant stabilizing effect on divergence, to the point that only a slight sweep is required to eliminate the possibility of divergence. This effect can be explained by noting that, for example, an upward deflection of the wing due to, say, a gust of wind tends to reduce the angle of attack or unload the wing and thus tends to counteract the response to the gust.

Thus, to prevent flutter, the designer has the ability to change the stiffness and placement of masses (included in the design) or special balancers. If it is not possible to provide sufficient rotational rigidity, the prevention of flutter of controls is associated with their balancing, i.e. with the location of additional weights to change the inertial links [1].

Many works in this direction are devoted to cantilever wings in bending and torsion around its elastic axis. Bending in the direction of the chord is neglected due to the high rigidity. Nonlinear effects and bowing in the chord direction are often included in the aeroelastic study of rotorcraft. Discussions about aeroelasticity with a rotational wing can be found in Dowell [1], Crespo da Silva and Hodges [2]. Hauenstein et al. [3] show how structural non-linearities can lead to complex motions, including chaos. This formulation does not include material, geometric, and inertial non-linearities, and it is assumed that the wing is in an extensional state. The deformation of the wing is presented in the form of generalized coordinates and mode shapes. Modes can be found using experiments, analytical tools, energy methods, or finite element methods. For complex geometries or anisotropic materials, it is advantageous to use the finite element directly with fluid dynamics equations to determine strains. The use of composite materials has opened up many possibilities in the field of aeroelastic material design. It is well known that composite materials exhibit anisotropic behavior and exhibit a relationship between different modes of structural deformation. As a consequence of this anisotropic property, the stiffness of the composite structure can be effectively controlled, resulting in an aeroelastic fit of aircraft wings.

To construct the constitutive relation of the rheological medium at
uniaxial deformations often use the simplest structural elements that clearly and simply represent the qualitative behavior of the material. There are various models of viscoelasticity [4]. For example, the Kelvin model consists of several rows of nodes interconnected in series (Fig. 2).



Rice. 2. Generalized Kelvin model

The full one-dimensional deformation of the Kelvin model consists of the sums of deformations at individual nodes.

In this case, the equation $\dot{\varepsilon} = \dfrac{\dot{\sigma}}{E} + \dfrac{\sigma}{\eta}$ takes the following form

$$\{\partial_t / \mathrm{E} + 1/\eta\}\sigma = \{\partial_t\}\varepsilon,$$

and the equation $\sigma = E\varepsilon + \eta\,\dot{\varepsilon}$ takes the form

$$\sigma = \{\mathrm{E} + \eta\partial_t\}\varepsilon$$

where the corresponding operators are in brackets.

With these relations, we can write the model defining the overall deformation of the structure

ISSN 2277-3630 (online), Published by International journal of Social Sciences & Interdisciplinary Research., under Volume: 11 Issue: 12 in December-2022
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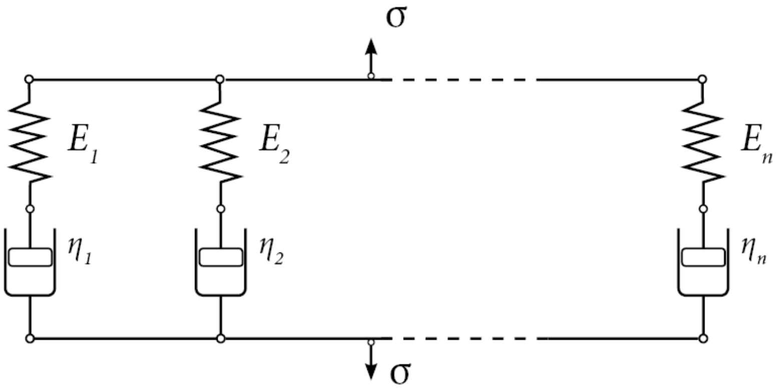
as follows:

$$\varepsilon = \frac{\sigma}{\{E_1 + \eta_1 \partial_t\}} + \frac{\sigma}{\{E_2 + \eta_2 \partial_t\}} + \cdots + \frac{\sigma}{\{E_n + \eta_n \partial_t\}}. \quad \text{(one)}$$

Similarly, for the generalized Maxwell model (Fig. 3), in which the nodes are connected in parallel, we can write the following relationship:

$$\sigma = \frac{\dot{\varepsilon}}{\{\partial_t / E_1 + 1/\eta_1\}} + \frac{\dot{\varepsilon}}{\{\partial_t / E_2 + 1/\eta_2\}} + \cdots + \frac{\dot{\varepsilon}}{\{\partial_t / E_n + 1/\eta_n\}}. \quad (2)$$



Rice. 3. Generalized Maxwell model

Many works have been published on various aspects of the viscoelastic behavior of composite plates [5, 6, 7, 8, 9].

The destabilizing effect of internal friction is considered in detail in [10,11]. An analysis of the loss of stability of viscoelastic plates under dynamic loading in a nonlinear formulation with a weak singular relaxation kernel is presented in [12, 13]. The dynamic stability of fiber-reinforced multilayer rectangular plates using the first-order shear deformation theory was carried out in [14]. The viscoelastic body model used to describe material damping was discussed in [14]. This connects the problem of stability of elastic systems with the problem of viscoelastic systems [13, 14]. To solve such typical problems, the Bubnov-Galerkin method is usually used. It is important to study the instability of a viscoelastic system, taking into account the lateral compressive force.

The problem of flutter has been studied most fully in relation to the wings and empennage of aircraft, for which flutter is of great importance. The so-called classical flutter with small angles of attack (<15°) takes place here.

For the blades of steam and gas turbines and axial compressors, a stall flutter with large angles of attack plays the role. This type of flutter has been studied much less. The problem here is further complicated by the presence of aerodynamic interaction between oscillating neighboring blades.

The flutter phenomenon is closely related to the flexural-torsional mode of oscillation. Consider a wing whose line of flex centers lies closer to the leading edge than the line of centers of gravity. When the wing moves down, the relative flow velocity is the sum of the horizontal velocity of the flow and the vertical velocity due to the lowering of the wing. This increases the angle of attack. When the wing moves up, the angle of attack decreases accordingly (Fig. 4)

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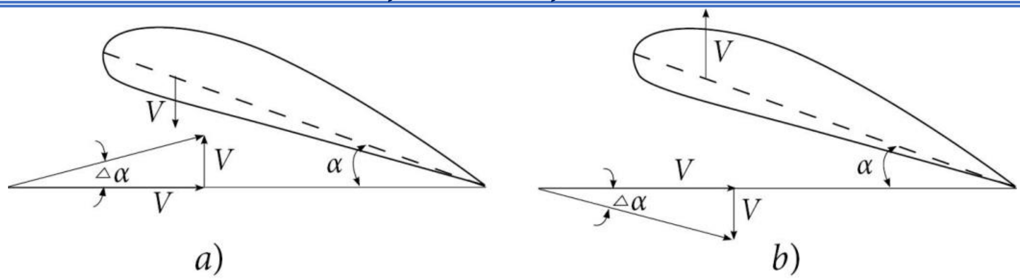


Rice. 4. Ratio of speed to angle of attack

The lift force of the wing is approximately proportional to the angle of attack (Fig. 5). Thus, for purely flexural vibrations of the wing, the additional lift is directed against the motion and causes damping of the vibrations.

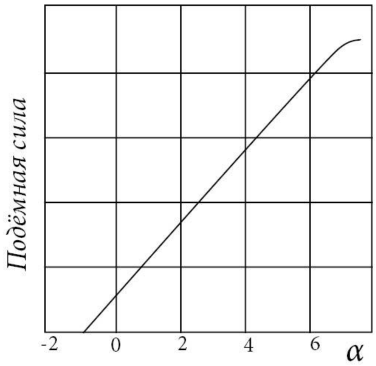
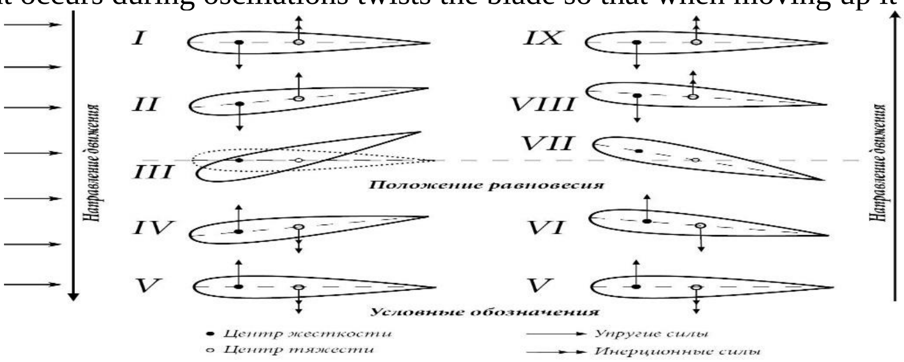


Рис. 5. Отношение подъёмной силы к углу

With bending-torsional vibrations of the wing we are considering, the elastic restoring force applied to the center of the bend and the inertial deflecting force applied to the center of gravity create a moment. This moment, as can be seen from Fig. 6, the wing is twisted in such a way that when the wing moves down, the angle of attack decreases, and when the wing moves up, it increases. In this case, the additional lifting force is directed in the direction of motion. Consequently, the flow imparts energy to the oscillating wing. In addition, the point of application of the aerodynamic force (center of pressure) may coincide with the center of the bend. In this case, a moment of lifting force arises. The center of pressure usually lies approximately ¼ of the profile chord from the leading edge. If the center of the bend lies farther from the leading edge than the center of pressure, then the additional moment of lift that occurs during oscillations twists the blade so that when moving up it increases.



Rice. 6. Directions of elastic and inertial forces when changing the state of the wing

Thus, the exciting forces increase. To avoid the appearance of flutter, it is necessary to determine the critical velocity of oscillations that occur in the structure under study. For calculation, aerodynamic forces and moments should be introduced into the equation of bending-torsional vibrations.

Based on the above analysis, it seems interesting: the development of a mathematical model and methods for solving in viscoelastic formulations of all those problems of aerostability that are now solved in an ideal elastic approximation, the development of methods for solving the flutter problem, which make it possible to study experimentally determined numerical values of bending,

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torsional stiffness and masses along the span of the wing, and the study of the flexural-torsional flutter of the hereditarily deformable wing of the aircraft. These studies are very important when the center of gravity and the axis of rigidity in each section of the wing do not coincide.

Conclusion and recommendations.

The development of specific recommendations for designers to ensure that structures do not break and are safe when exposed to various types of static, dynamic and aerodynamic loads in all modes of operation during a certain period of operation is today a very relevant, global problem. To solve this problem, it is recommended:

1. To develop and substantiate numerical methods for solving the problem of aeroviscoelastic stability based on the vortex theory based on the hypothesis of "replacing the wing with a vortex surface".

2. On the basis of the modern apparatus for the numerical solution of weakly singular integral and integro-differential equations [43], to investigate the phenomenon of divergence and flutter of hereditarily deformable elements of orthotropic thin-walled structures according to the piston theory of Ilyushin A.A.

3. Develop and substantiate a numerical method for solving singular integro-differential equations (1.14), and also, in possible cases, construct an analytical form of its solutions, which is very important when solving the dynamic problem of aeroviscoelastic stability using methods based on the hypothesis of "small distance asymptotics".

4. Develop a clear recommendation to designers so that the aircraft structures do not collapse, the flight is safe under the influence of various kinds of static, dynamic and aerodynamic loads in all operating modes during a given period of its operation.

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