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Investigation of viscosity influence on transonic flutter

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Abstract

The paper is devoted to computational study of transonic flutter when the viscosity can influence significantly on dynamic aeroelasticity characteristics of aircraft. The work has been done in the direction of development of methodology and software, which are used in ARGON (TsAGI) system for multidisciplinary analysis and optimization in airplane design. Considerable attention is paid to the validation of the proposed software. Experimental results of the NASA Common Research Model in the European Transonic Wind Tunnel (ETW) are used for comparison with computations. The results of flutter analysis are presented for the passenger middle range airplane with the high aspect ratio wing and the engine under the wing. Comparisons of aeroelasticity characteristics in transonic flow are carried out for cases of a set of Mach and Reynolds numbers. The computational results presented in the paper show the essential influence of transonic features on flutter characteristics.

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*Keywords:*flutter; aeroelasticity; viscosity; Reynolds number

1. Introduction

Modern airplane represents an elastic structure that is exposed to unsteady aerodynamic loadings. The increase in speed of flight entails increase of all aerodynamic loadings on lifting surfaces of the airplane that in turn, causes growth of elastic deformations. In this case angles of attack of a wing appear distinct from angles of attack at a rigid wing. Due to change of angles of attack there is the redistribution of aerodynamic loads caused by deformations of

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the airplane structure. Thus, at high speeds of flight it is natural to expect not only usual direct influence of loading on deformations, but also return influence of deformations on loads values. This correlation of loads and deformations at increase of flight speed is the reason of beginning of rather dangerous phenomenon of dynamic aeroelasticity-flutter of a wing or of a horizontal/vertical tail.

The types of the airplane configurations developed for different purposes in many cases bring into specific problems of aeroelasticity and require a development of new technologies for aeroelasticity analysis. For example, the supersonic airplanes with small aspect ratio wings are very different from transonic aircraft with high aspect ratio wings and thin supercritical airfoils.

The measurements of derivatives of aerodynamic forces and moments on vibrating wings and lifting surfaces, which are necessary for dynamic analysis and flutter computation, show their significant dependence from a scaling effect at transonic speeds, in particular, from Mach (M) and Reynolds (Re) numbers (Lambourne, 1960; Nakamura and Woodgate, 1972; Edwards, 2008; Blackwell, 1968).

Numerical determination of unsteady transonic flow is far difficult then the computation of subsonic or supersonic flows. Firstly, the basic equations in partial derivatives are nonlinear, and it is necessary to modeling of the moving shock waves. Secondly, flow field represents a mixed type with local supersonic regions. Dimensions of supersonic regions depend on time because of moving shocks waves, which should be determined with the enough accuracy as the part of a solution. In some cases, the local supersonic regions compress up to zero and vanish together with shock wave during the period of flutter vibrations. Accordingly shock waves move on the wing surface changing in strength. These moving shock waves play important role in arising of nonlinear transonic flutter at Mach number near one. There are a set of mechanisms of interaction of an airplane elastic structure with unsteady transonic flow that cause the structure vibrations. It is worth mentioning that the supercritical transonic airfoils are optimized for providing high lift to drag ratio in cruise regime of flight. On the upper surface of such wings the flow has rather small gradients of speed, density and Mach number on the bigger part of the airfoil chord. Therefore, comparably small deviations of flow parameters from optimized value may lead to an essential flow reconstruction. For example, small change of the angle of attack or Mach number can generate big displacement of shock waves and separation zones on chord. These changes considerably change a distribution of the aerodynamic loads.

Interaction of the shock wave with the boundary layer influences significantly on nature of the shock motion on the wing surface. It is important to take into account this phenomenon in dynamic aeroelasticity problems. The shock movement in viscous flow considerably differs from the movement in the flow of an ideal gas when the angle of attack increases. When an airplane model is tested in wind tunnel at low Reynolds numbers, the boundary layer on the most of the streamline surface is laminar, while in flight at high Reynolds numbers the boundary layer is turbulent.This difference influences on the boundary layer thickness and on the conditions at which the separation of the boundary layer occurs. If the boundary layer is turbulent, the separation typically does not occur near the trailing edge of the wing, but if the boundary layer is laminar separation may occur in the adverse pressure gradient in the tail part of the profile. This may result in essential influence of the scale effects. Therefore, experimental results obtained in wind tunnels on small models with laminar boundary layer must have careful usage versus the flight conditions in which the turbulent flow is dominating.

The systematic study of an influence of the Reynolds number (so-called scaling effect) began in the 1950-th, when aircraft began to appear high transonic flight speeds (Lambourne, 1960; Nakamura and Woodgate, 1972; Edwards, 2008). A special impetus to the research was given by publication, in which comparison of the wind tunnel tests and flight experiments of C-141 aircraft, conducted by NASA in 1966 was given. These results demonstrated large differences between the results of the wind tunnel and flight tests(Blackwell, 1968). The wind tunnel tests of the model were carried out for a fixed transition point, located in the front part of the airfoil, in accordance with the position of the point of transition to full-scale flight of the aircraft. However, the thickness of the boundary layer on the wing of the airplane in flight is considerably less than in wind tunnel test. The thinner boundary layer causes the shock wave downstream movement toward the trailing edge of the wing and the flow separation area reduction. The experimental results (Blackwell, 1968; Dowell, 1973; Ballmann, 2008; Ballmann, 2013)have shown that the Reynolds number variation from the full-scale test values to values in the wind tunnel tests causes a significant change of the shock wave position and the size of the separation region of the boundary layer. During computational research of aeroelasticity and loads the effects of viscosity and boundary layer should be included in consideration in order to analyze such aeroelasticity phenomena as transonic flutter and limit cycle oscillations. The comprehensive testing and verification should be provided for the used computational methods of unsteady aerodynamics by comparison with experimental data in analysis of static and dynamic aeroelasticity