Application of Finite Element Models of Aircraft Structures for Aeroelastic Flutter Analysis

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Abstract:

Typical airframes are thin-walled structures, which guarantees that, despite relatively low weights, they are sufficiently stiff and durable. The need to maintain their lightness results from the specific use and the general requirement for economical operation, while maintaining the required stiffness and strength results from external loads in flight. The aircraft structure must meet specific design requirements imposed due to possible effects related to strength (static or fatigue), structural stability and aeroelasticity. For structural analyzes of the above-mentioned types of phenomena, discrete models have been successfully used for several decades, for which dedicated finite element method (FEM) algorithms are used [1, 2].

The introductory part of the paper contains a general description of the aeroelastic flutter phenomenon. Methods of solving the flutter problem are presented using analytical equations based on aerodynamic strip models (*Strip Theory*) and surface panel models taking into account local distributions of aerodynamic dipoles (*Doublet Lattice Method*). The methodology for modeling unsteady aerodynamics is complemented by a theory dedicated to slender aerodynamic bodies (Fig. 1), approximating the aerodynamic forces generated on vibrating fuselages, engine gondolas and additional suspended pods. (*Slender Body Theory*) [3, 4].

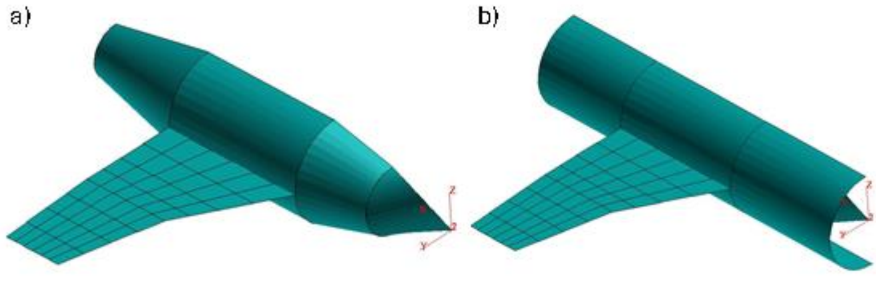
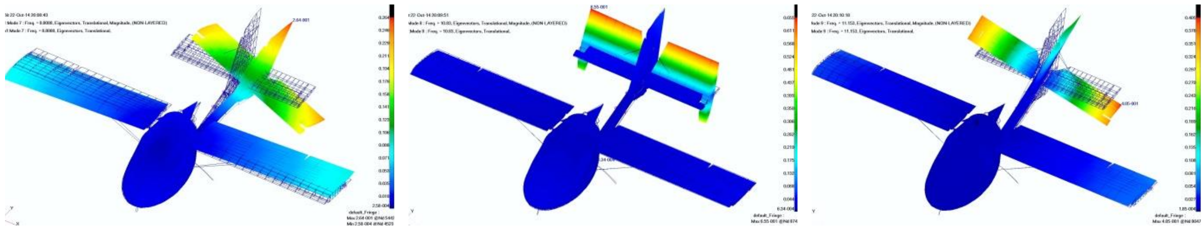


Figure 1. Simplified models of unstationary aerodynamics for the *DLM* and *SBT* methods
(with and without interference tube).

The main part of the study presents the methodology for modeling airframe structures using MSC Software (MD Nastran/Patran). Aspects of generating an element mesh based on adopted geometric models and the methodology of selecting material properties and mass discrete models for FEM are described. Selected structural models and application them in solving problems of natural vibrations and flutter are presented. Any thin-walled structure internally reinforced with longitudinal and transverse elements can be virtually recreated with the use of 2-dimensional elements (discs, plates, shells) and additional 1-dimensional elements (bars, beams). Models with specific mass and stiffness properties can then applied to solve detailed tasks in the field of statics, stability and dynamics of structures. Using the example of the presented light aircraft models, the modes of natural vibrations were determined for the boundary conditions corresponding to the free unconstrained structure (Fig. 2). Discrete models supplemented with a model of unsteady aerodynamic loads were then used to determine the critical parameters of self-excited flutter vibrations [5, 6, 7].



a) f_1=8.81 Hz b) f_2=10.83 Hz c) f_3=11.15 Hz

Figure 2. First three structural normal modes of a light patrol aircraft.

The computationally determined critical flutter speed will be as reliable as the mechanical properties of the numerical model are consistent with the real structure and, of course, provided that the correct configuration conditions for the aerodynamic models used are taken into account. The usefulness of discrete models for FEM depends on their adaptation to real structures in terms of geometry, mass and stiffness properties. In the process of adjusting the properties of the structural models, the need to achieve compliance of displacements with the results of static tests as well as frequencies and eigenmodes with the results of ground resonance tests was taken into account. The numerical model can be considered reliable and fully useful only after matching and demonstrating compliance of its mechanical features with analogous values determined experimentally for the real aircraft.

The presented methods and results were developed as effect of many research and developing works carried out in the Faculty of Mechatronics, Armament and Aerospace of the Military University of Technology (MUT) over last several or even more years. Currently, numerical aircraft model researches are still continued under the following university research grants carried out in the MUT: No. UGB 734/2024 entitled: *Structural design of light airplanes in terms of optimizing strength and aeroelastic properties of the airframe*, and No. UGB 734/2024 entitled: *Aerodynamic design of aircraft in terms of optimization of selected performance parameters*.

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