Development of algorithms for calculating of natural frequencies, modes and critical flutter speed of aircraft with high aspect ratio wing

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Abstract

There were performed adaptation of the aeroelastic calculation model and the algorithm design for solving problems of aeroelasticity in MSC.Nastran by comparing with the results of calculations, obtained from the domestic programs. Calculations of frequencies and modes of natural vibrations, critical flutter speeds were performed for the high-aspect-ratio cantilevered wing of the medium-range aircraft as an example.

1. Introduction

Expanding the scope of “TUPOLEV” on new projects, the unification of applied software products and the need for cooperation with enterprises of the United Aircraft Corporation have led to the need for development and verification of software systems purchased by “TUPOLEV”.

At present, when calculating the strength of aircraft, the CAE-system MSC.Nastran, based on the finite element method (FEM), is extensively used. Mainly this refers to the calculations of the stress-strain state and to some extent to the calculations of the dynamic strength.

The submitted paper is devoted to adapt the traditional aeroelastic mathematical model, designed in “TUPOLEV”, for calculating the aeroelastic characteristics of the aircraft using algorithms of the module MSC.FlightLoads. Verification of CAE-systems MSC.Nastran / MSC.FlightLoads in case of flutter analysis is accomplished by comparing the results obtained in domestic programs (in this case, in the system IMAD, which is the standard of the enterprise).

2. Flutter calculation methods

In IMAD the FE-model of the elastic aircraft is used, which is presented as the “tree” structure with a limited capacity to create a closed circuit, using elements "beam", "thin panel". MSC.Nastran allows the user to modeling the three-dimensional structure of the aircraft (in this case) using an extensive database of finite elements (FE), which significantly expands the possibilities for creating mathematical models.

In IMAD definition of eigenvectors and eigenvalues of partial modes of the substructure is performed by the method of Lanczos, for the entire structure the modal synthesis method is used. In MSC.Nastran calculating natural vibration frequencies and mode shapes of the structure is executed by using the solver SOL 103 (NORMAL MODES), in this work the Lanczos method is used.

The module MSC.FlightLoads built-in MSC.Nastran is designed to solve the problems of aeroelasticity. For the flutter analysis the solver SOL 145 (FLUTTER) is used, which offers four methods: «PK», «PKNL», «K», «KE». The method «PK» closely corresponds to domestic calculating procedures. The main advantage of «PK» is that it gives eigenvalues and eigenvectors directly for specified values of the speed. «PKNL», like «PK», enables a detailed investigation of the flutter (the calculation is performed for the given combination of parameters). In «K» and «KE» eigenvalues and eigenvectors are calculated for specified values of the reduced frequency (Strouhal number).

Both MSC.Nastran / MSC.FlightLoads and IMAD apply the double-lattice method for calculating the aerodynamic characteristics at subsonic flow (Mach number $M < 1$), taking into account the compressibility of the flow and unsteady flow. There is the possibility of modeling aerodynamics, using slender body theory to represent the lifting characteristics of each body such as the fuselage, nacelle.

In MSC.Nastran / MSC.FlightLoads and in IMAD the aeroelastic calculation model is represented as a combination of the elastic-mass model and the aerodynamic model, connected by using spline interpolation. The interactive checkout of splines is applied (by visualizing natural modes it defines how displacements are transferred from the elastic-mass model to the aerodynamic model).

It should be noted that a significant disadvantage of the module MSC.FlightLoads (as opposed to domestic systems) is the absence of an automated interface of visualization of flutter calculation results (root locus, vector diagram), which leads to increasing of postprocessing time.

3. Aeroelastic calculation model

The object of research was the high-aspect-ratio cantilever-fixed wing of the medium-range aircraft (with the same initial data for both systems), Figure 1. The elastic-mass model was schematized by the system of two weightless beams having variable stiffness; beams were directed along the elastic axis of the wing and were loaded with concentrated masses and moments of inertia. The number of beam finite elements was 16, concentrated masses - 12, aerodynamic boxes - 203.

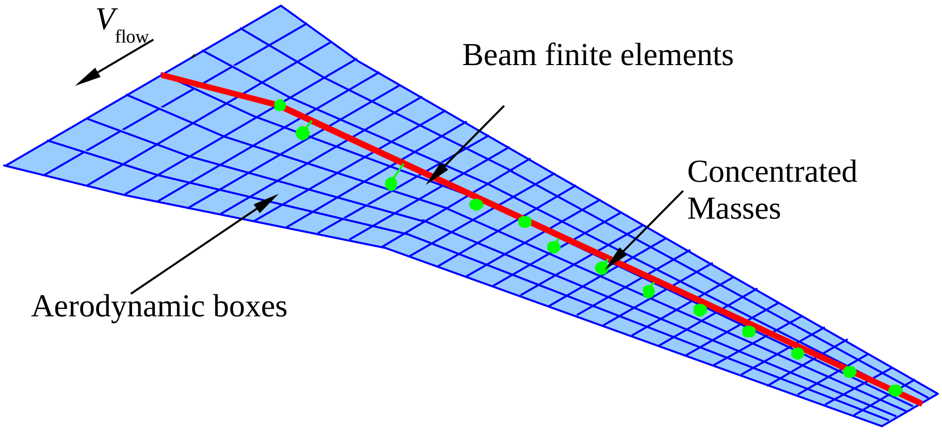


Figure 1: Mathematical model of the cantilever-fixed wing

4. Calculation of frequencies and modes of natural vibrations

Natural frequencies of the cantilever-fixed wing, obtained by mentioned systems, indicated a good match, as shown in Table 1.

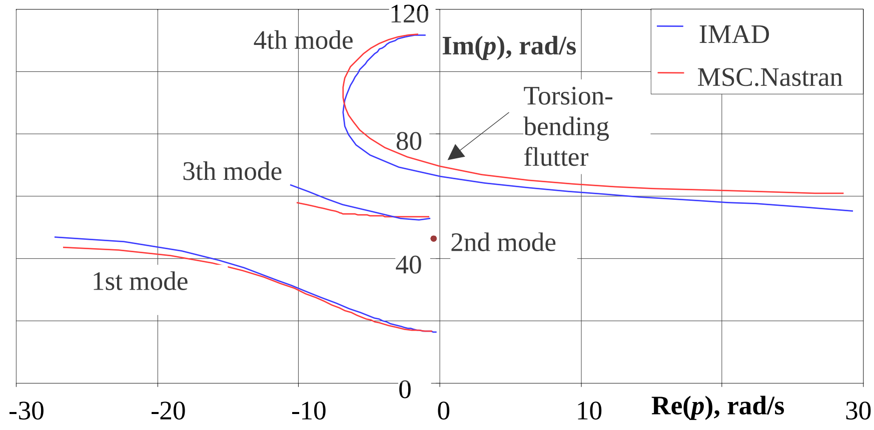
Table 1: Relative frequencies of natural vibrations

№	Mode	MSC.Nastran/ IMAD
1	First wing vertical bending	1.0038
2	First wing horizontal bending	1.0041
3	Second wing vertical bending	1.0083
4	First wing torsion	1.0034

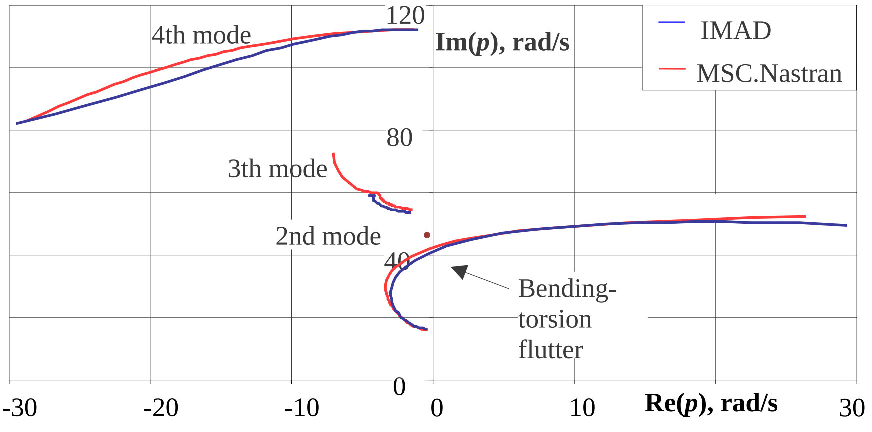
5. Calculation of flutter critical speeds

Flutter analysis was performed for two altitudes and Mach numbers: (H=0 km, M=0.1) and (H=10 km M=0.88). Unsteady aerodynamics was used at critical values of the Strouhal number, the structural damping g was taken into consideration (logarithmic decrement $\delta = \pi g$, $\delta = 0.05$). Figure 2 shows root loci - the modes as a function of the air speed. As it can be seen, both computational methods were correctly reflected the change of "flutter" modes and showed a similar behavior of the locus diagrams.

Figure 3 presents the dependence of logarithmic decrement δ on speed. From this figure it follows that the critical flutter speed of the wing is much higher than $1.2V_D$, i.e. margins of safety is much higher then standardized. Moreover, for both systems the “damping ratio” curves practically coincided.

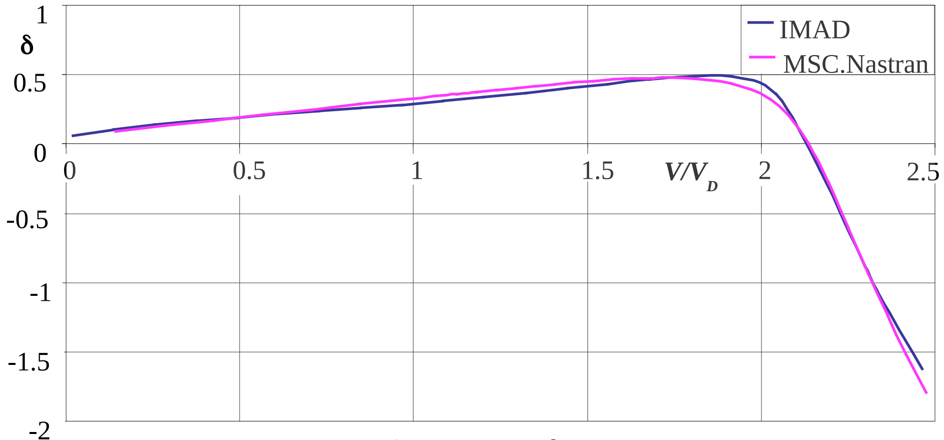


a) M=0.1 H=0 km

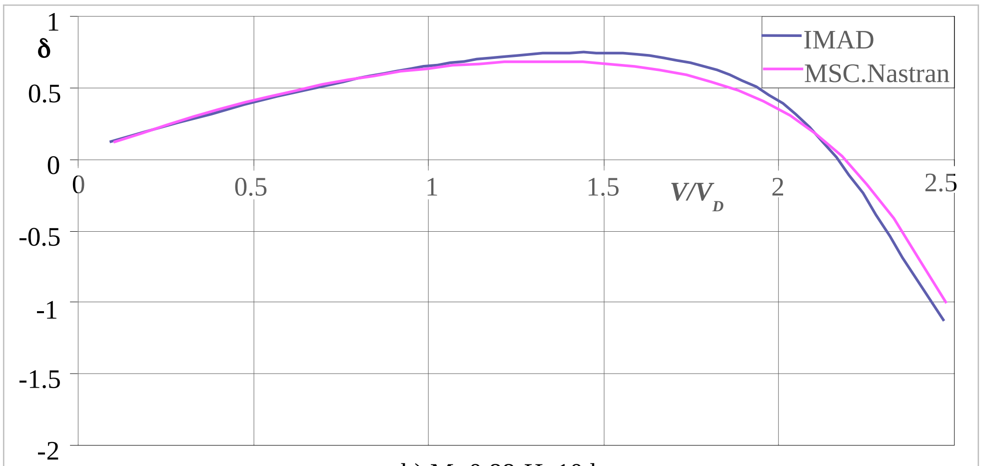


b) M=0.88 H=10 km

Figure 2: Root loci



a) M=0.1 H=0 km



b) M=0.88 *H*=10 km

Figure 3: Velocity-damping diagrams

6. Conclusions

Studies of flutter showed that the CAE-system MSC.Nastran in the area of subsonic speeds gave the results well coincident with the calculations carried out by existing standard techniques.

The calculation results of natural vibration frequencies and mode shapes of the cantilevered wing, critical flutter speeds and frequencies both in MSC.Nastran and in the domestic program IMAD indicated a good compliance.

The practical result is the working-out of algorithms for creating the aeroelastic model and solving the flutter problem in MSC.Nastran / MSC.FlightLoads.

The paper shows good prospects for the application of MSC programs in flutter analysis for various structural and aerodynamic configurations of aircraft during the detailed design, using implemented in MSC.Nastran / MSC.FlightLoads the calculation methods and the extensive database of finite elements.

References

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