International Forum on Aeroelasticity and Structural Dynamics
IFASD 2017
25-28 June 2017, Como - Italy

SOME SPECIAL MODELLING TECHNIQUES FOR PREPARATION OF AEROELASTIC STICK MODELS

Jiri Cecrdle[1]

[1] Aeronautical Research and Test Institute (VZLU)
Beranovych 130, Prague, 199 05, Czech Republic
cecrdle@vzlu.cz

Keywords: IFASD, aeroelasticity, stick model, full-span model.

Abstract: Submitted paper deals with aeroelastic simple beam computational models, so called stick models. Stick models are simple, effectively usable and suitable for variation of parameters or for updating according experimental results. Therefore, stick models are ordinarily used for aeroelastic analyses. However, in some specific cases, special elements or modelling patterns must be used. Paper describes special modelling techniques, namely 1) Model of control surface and tab without stiffness parameters, 2) Common model of symmetric and antisymmetric vibrations for control surface and tab flapping modes and, 3) Common model of symmetric and antisymmetric vibrations for twin-engine aircraft engine vibration modes. These techniques are demonstrated on the example the full-span stick model of a twin turboprop commuter aircraft.

1 INTRODUCTION

Aeroelastic analyses of aircraft structures are usually performed using simple dynamic structural models (stick models). Dynamic models employ dynamic elements like beam, rod, spring, damper, concentrated mass, etc. Stiffness characteristics of structural parts are modelled by means of massless beam elements, and inertial characteristics are modelled by concentrated mass elements with appropriate moments of inertia. Models also include spring elements, various conditions, multi-point constraints and auxiliary elements (controls suspension, visualization, etc.). Stick models are simple, effectively usable and suitable for variation of parameters. The relation between the parameters of particular vibration modes and structural parameters is usually clear. Therefore, stick models can be simply updated according experimental results (ground vibration test, static tests, etc.) either directly or using some method of multidisciplinary optimisation. Considering the conventional aircraft structure with high or middle aspect ratio wing, stick model schematisation is sufficiently accurate; and therefore, is ordinarily used. However, in some specific cases, special elements or modelling patterns must be used. This paper is focused on the description of three special modelling techniques: 1) Model of control surface and tab without stiffness parameters, 2) Common model of symmetric and antisymmetric vibrations for control surface and tab flapping modes and, 3) Common model of symmetric and antisymmetric vibrations for twin-engine aircraft engine vibration modes. These techniques are demonstrated on the full-span stick model of a twin engine commuter aircraft.

2 MODEL OF CONTROL SURFACE OR TAB WITHOUT STIFFNESS PARAMETERS

Stiffness parameters of structural parts as a wing, fuselage or tail units are modelled using massless beam elements. Stiffness parameters include usually bending, in-plane bending and torsion. Control surfaces and tabs are usually modelled in the same way, i.e., using massless beam elements connected to the main surface or to control surface. In this case, control surface or tab has stiffness parameters and the deformation modes of a control surface or tab are simulated. However, in many cases, no stiffness data of control surface or tab structure are available, especially at the early stage of an aircraft development. Unavailability of data is also typical for small aircraft development.

Provided no stiffness data of control surface or tab structure are available, modelling without stiffness must be applied. In this case, control surface (tab) is, in fact, rigid body with a single degree-of-freedom (flapping mode). However, control surface (tab) does not add any stiffness to the system and its deformation follows the deformation of a main surface. Figure 1 shows the examples of deformation modes of a wing, in which, aileron and aileron tab are modelled without stiffness parameters.

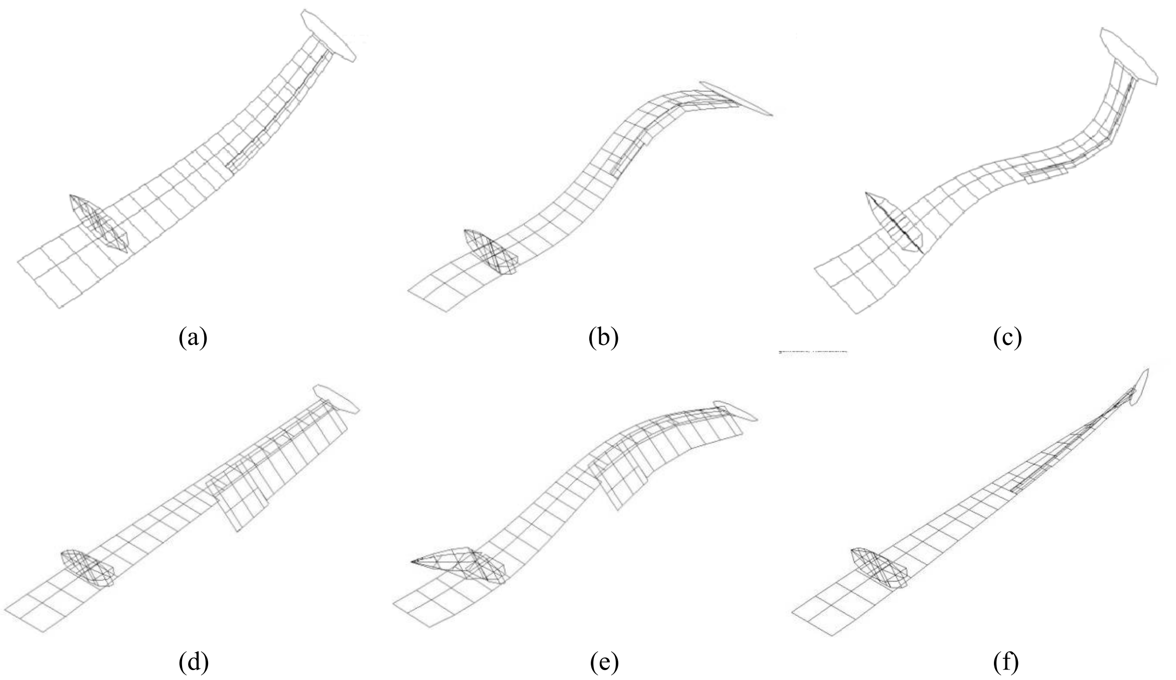


Figure 1: Examples of wing modes, aileron and tab modelled without stiffness, (a) 1st bending, (b) 2nd bending, (c) 3rd bending, (d) aileron flapping, (e) engine yaw, (f) 1st wing torsion.

If you are submitting more than one paper, please submit each paper separately. Control surface suspension points at the rotation axis are connected to the main surface using multi-point constrains. Control surface is divided into the spanwise segments in order to obtain a smooth deformation. Nodes on the rotation axis are connected using a rigid body element for the rotational degree-of-freedom around the rotation axis with the actuation point. In addition, each node is connected to the neighbouring suspension points using an interpolation constraint element. The dependent degrees-of-freedom are represented by the remaining five degrees-of-freedom while the independent degrees-of-freedom are represented by all six ones. The coefficients of interpolation are proportional to the distance of a node and a particular suspension point. Scheme of this modelling pattern is shown in the following sections as a part of schemes for control surfaces and tabs.

As obvious from figure 1, the deformation curve of aileron and tab is not perfectly smooth. The shape of deformation curve can be improved by using of more points for interpolation (not only suspension points), however in the practical applications, in which just lower order modes are included to flutter solution, the practice of usage of the suspension points only gives acceptable results in terms of the aileron (tab) deformation curves.

3 COMMON SYMMETRIC AND ANTISYMMETRIC MODEL FOR CONTROL SURFACE AND TAB FLAPPING MODES

In the most cases, half-span models are used for aeroelastic calculations. In the plane of symmetry, either symmetric or antisymmetric boundary condition is applied. In addition, reduction of mass and stiffness data as well as the correction of aerodynamic forces is applied. Half-span model makes the analysis simpler as symmetric and antisymmetric modes are analysed separately. This practice is acceptable as flutter instability has a character of either symmetric or antisymmetric vibrations and combination of both symmetric and antisymmetric modes together within single flutter instability is not feasible.

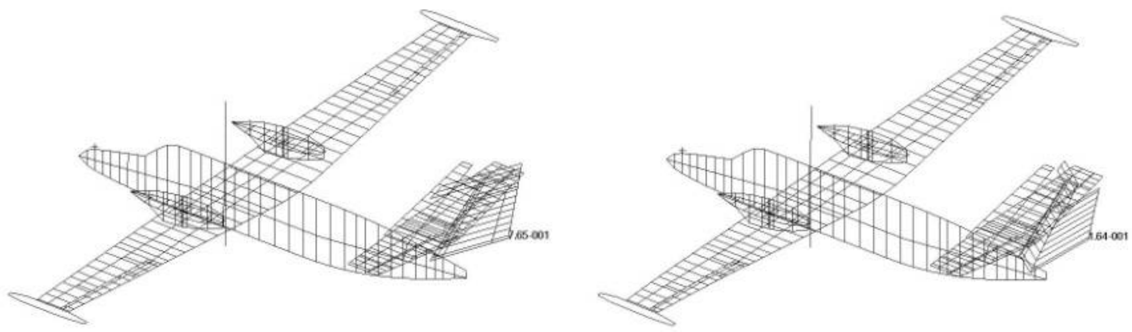
As apparent, the usage of half-span models assumes the symmetry of an aircraft structure in terms of mass, stiffness and aerodynamics. Although, the symmetry is more or less ensured, there are usually small unsymmetries, e.g., due to a single side installation of a tab. Such small unsymmetries can be treated by making the analysis on a half-span model using specifications (mass, aerodynamics, etc.) of both port and starboard side. Such an approach is conservative as the result of the unsymmetric structure is expected within those ones given.

However, the usability of half-span models is limited. The noticeably unsymmetrical cases, e.g., unsymmetrical pod configurations, failure states, etc. as well as some specific issues must be analysed using a full-span model. Provided that the full-span model is used, both symmetric and antisymmetric vibrations of control surface and tab flapping must be modelled. Basically, control surface (tab) vibrates symmetrically at some natural frequency and antisymmetrically at another natural frequency.

For this purpose, a detailed model of a control system can be used; however, detailed model is complicated. In addition, modelling of a complete control system requires detailed data of a control system, which are not often at disposal. Finally, such a model is not suitable for updating as the relation between structural parameters and modal parameters is complicated.
Another option is to use the simple modelling patterns for the specific configurations of control surfaces and tabs, which are simple and suitable for updating according experimental results. These modelling patterns are described in the following section for each configuration of a control surface and tab.

3.1 Rudder with tab

This is the standard pattern also used for half-span models (we consider a single-rudder configuration). The system includes two modes, which are shown in figure 2. Control surface and tab actuations are realised using rotational spring elements. Stiffness constants of these springs ($K_{\delta 1}$, and. $K_{\delta 2}$) determine control surface and tab flapping frequencies. The remaining degrees-of-freedom are fixed by rigid body elements. The scheme of this pattern (for control surface and tab modelled without stiffness) is shown in figure 3.



(a) (b)

Figure 2: Rudder flapping (a) and rudder tab flapping (b) modes

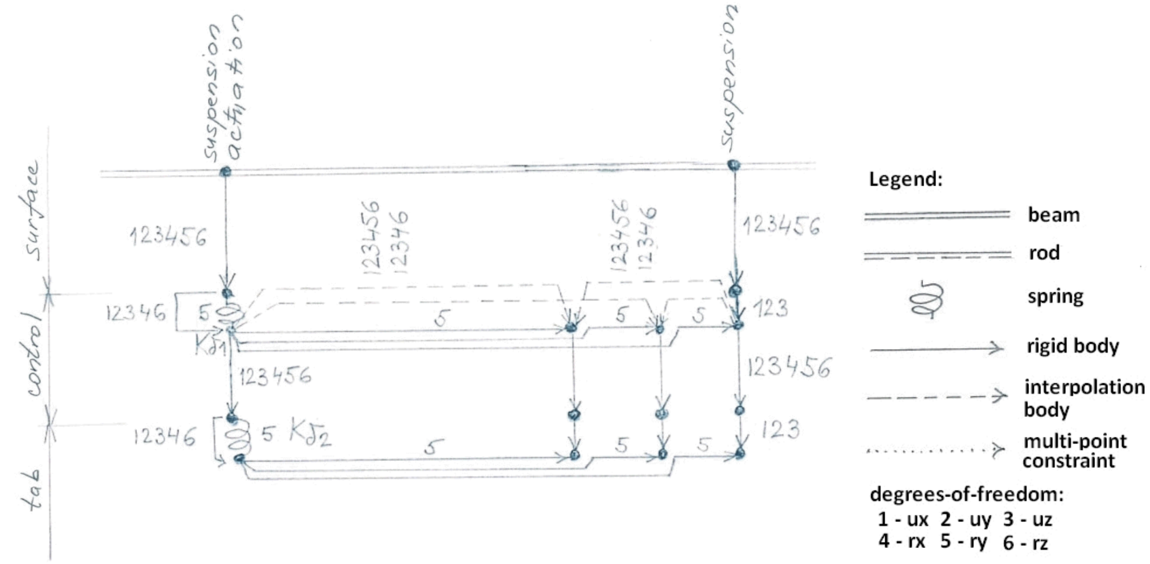
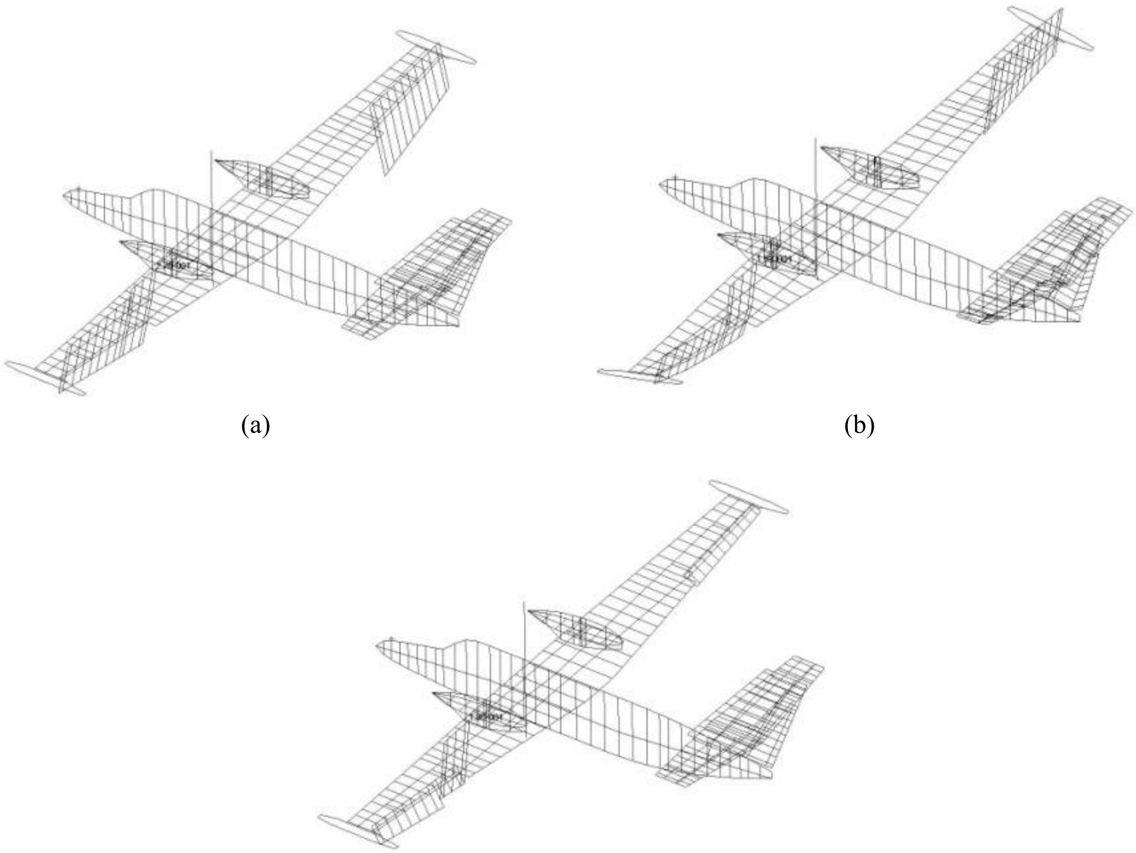


Figure 3: Scheme of pattern for rudder with tab

3.2 Ailerons with a single-side tab

For ailerons, two modes of vibration are to be modelled. Considering the fixed stick condition, ailerons are vibrating antisymmetrically (common movement of ailerons) with the lower frequency as the complete control system is involved in this mode and symmetrically with the higher frequency, because only a part of the control system, which is inside a wing is involved in this mode. Tab is considered at a single side only (here on the port side) as is typical for smaller aircraft. The system includes three modes, which are shown in figure 4.

Actuation system is modelled using a single grounded spring element and a pair of rod elements oriented according the rotation axis. Rods connect the actuation points of both left and right aileron. Grounded spring is connected to the middle node at the plane of symmetry. The system includes only a single degree-of-freedom; remaining ones are omitted from the analysis or constrained by rigid body elements. In order to obtain the antisymmetric vibrations at the lower frequency, a multi-point constrain changing the sign of rotational deformation is included on a single side. Spring constant of the grounded spring element $K_{\delta 1}$ and the torsional stiffness of rod elements (GI_k) determine natural frequencies of both modes.



(a) (b)

(c)

Figure 4: Antisymmetric aileron flapping (a), symmetric aileron flapping (b) and aileron tab flapping (c) modes

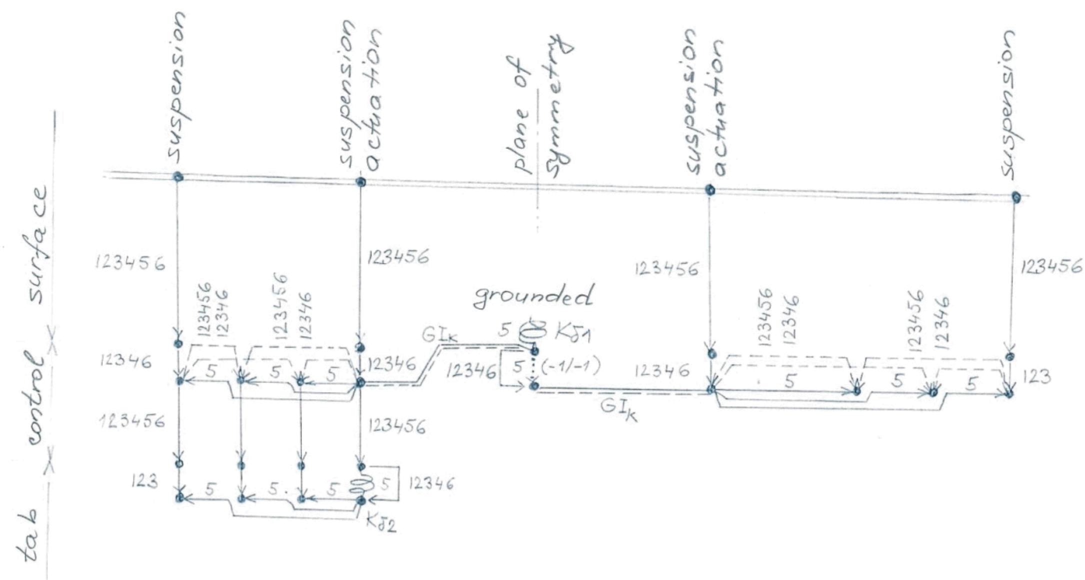


Figure 5: Scheme of pattern for ailerons with a single-side tab (for legend see figure 3)

Spring constant is decisive for the antisymmetric one while rod torsional stiffness is decisive for the symmetric one. Note, that there is also cross-influence; and therefore, both parameters must be determined as a pair to set both frequencies. Tab is included on a single side only and the actuation is realised using a rotational spring element, as described in section 3.1 and the spring constant of this element ($K_{\delta 2}$) determines tab flapping frequency. The scheme of this pattern (for control surface and tab modelled without stiffness) is shown in figure 5.

3.3 Elevator with tab on both sides

For elevator, two modes of vibration are to be modelled as well. Considering the fixed stick condition, elevator vibrates symmetrically (common movement of elevator) with the lower frequency as the complete control system is involved in this mode and antisymmetrically with the higher frequency, because only a connection structure of both sides of elevator is involved in this mode. Tab is considered on both sides of elevator. The system includes four modes, which are shown in figure 6.

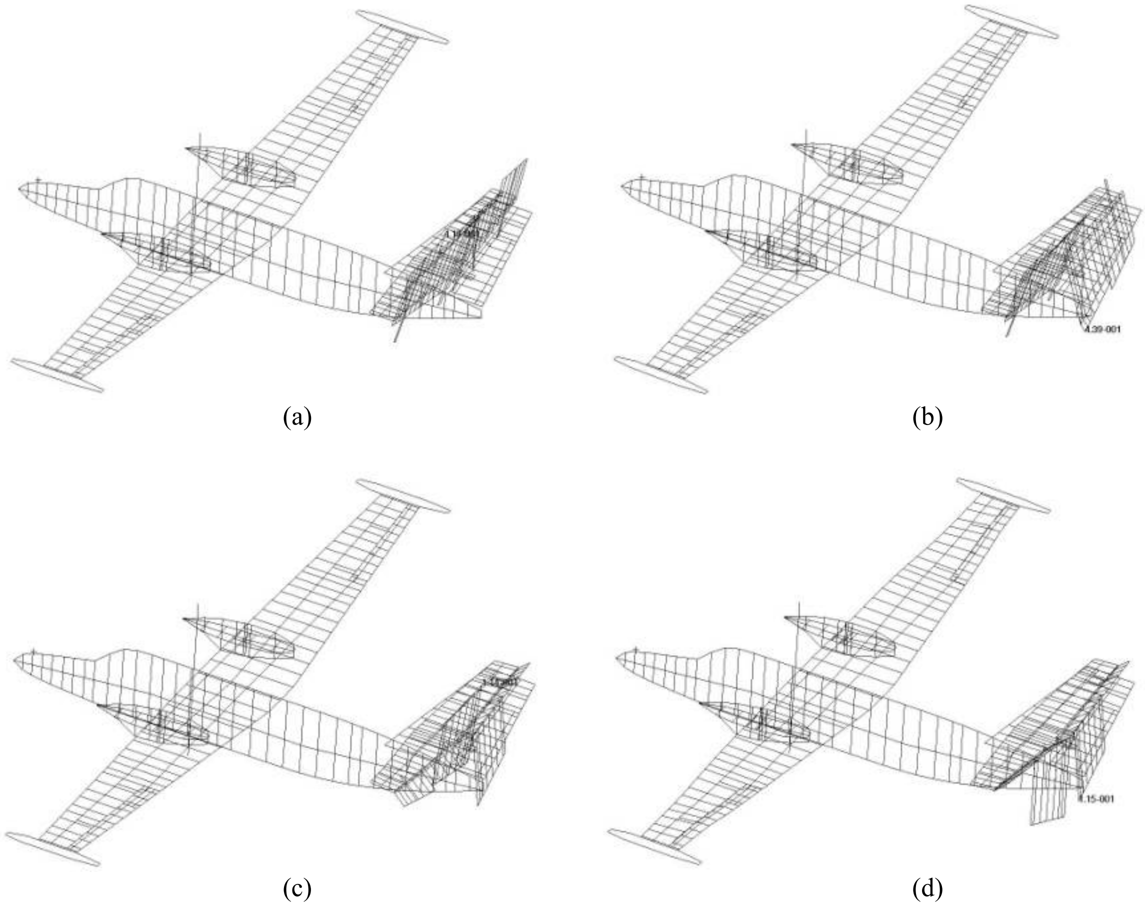


Figure 6: Symmetric elevator flapping (a), antisymmetric elevator flapping (b), antisymmetric elevator tab flapping (c) and symmetric elevator tab flapping (d) modes

Actuation of both elevator and tab are realised in the same manner as described for ailerons (excluding the multi-point constrain changing the sign of rotational deformation - for elevator). The scheme of this pattern (for control surface and tab modelled without stiffness) is shown in figure 7.

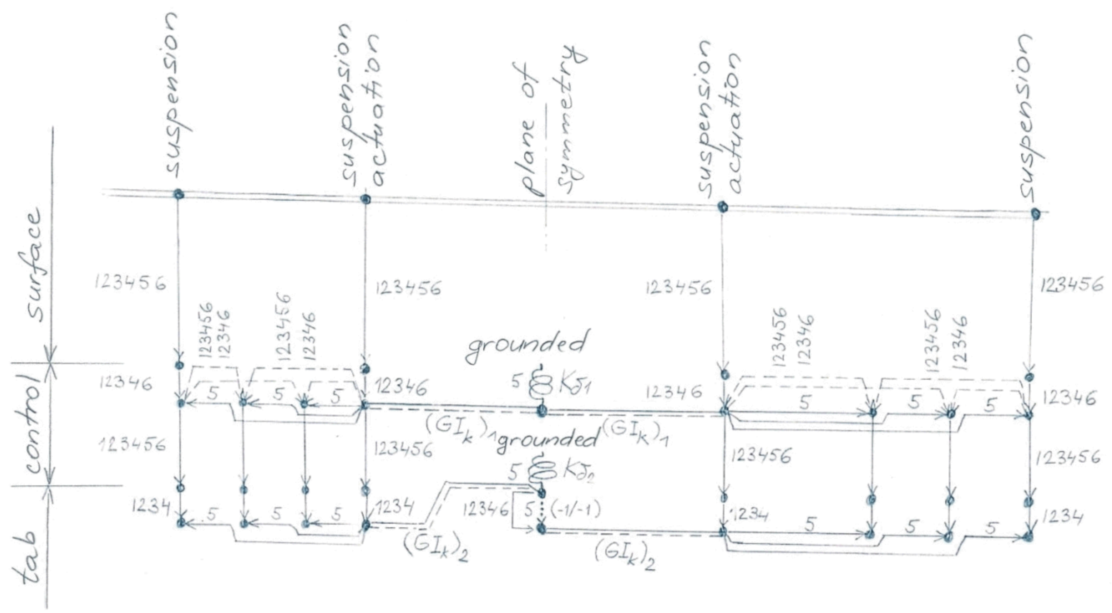


Figure 7: Scheme of pattern for elevator with tab on both sides (for legend see figure 3)

4 COMMON SYMMETRIC AND ANTISYMMETRIC MODEL FOR TWIN-ENGINE AIRCRAFT ENGINE VIBRATION MODES

Considering a twin wing-mounted engine aircraft, symmetric and antisymmetric vibrations of engines must be also modelled on a full-span model. These vibrations include pitch and yaw, symmetric and antisymmetric engine vibrations, i.e., four modes in total. Modes have the diverse natural frequencies and the diverse node point stations. The typical mode order by frequency is: 1) Symmetric pitch, 2) Antisymmetric pitch, 3) Symmetric yaw and, 4) Antisymmetric yaw. The node points are typically stationed from the rear to the front in the order: 1) Symmetric pitch, 2) Symmetric yaw, 3) Antisymmetric pitch and, 4) Antisymmetric yaw. Engine vibration modes are shown in figure 8.

Each engine vibration mode is modelled using a pair of grid points placed at the node station. The appropriate degree-of-freedom, i.e., pitch or yaw rotation of a symmetric mode is connected to a grounded spring element while the one of antisymmetric mode is connected to a system of two rod elements, which are oriented in the appropriate direction. These elements are placed at the station of the node point of the appropriate mode. Also, grounded spring is connected to the middle point of rod elements pair. The remaining degrees-of-freedom are constrained using rigid body elements. Systems for pitch and for yaw modes are separate. The scheme of this pattern is shown in figure 9. Note that orientation of coordinate axes is here considered as: x-longitudinal, y-vertical and z-lateral.

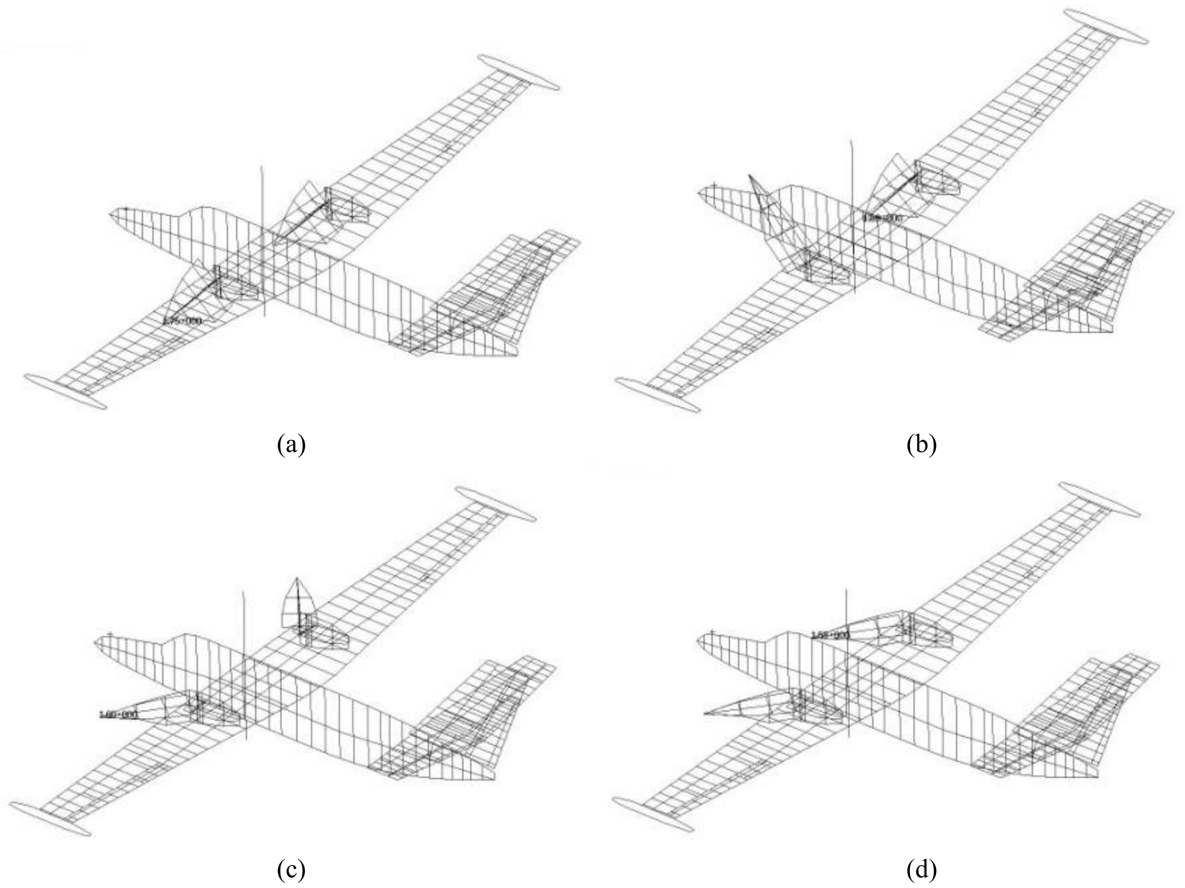


Figure 8: Engine vibration modes: Symmetric pitch (a), antisymmetric pitch (b), symmetric yaw (c) and antisymmetric yaw (d).

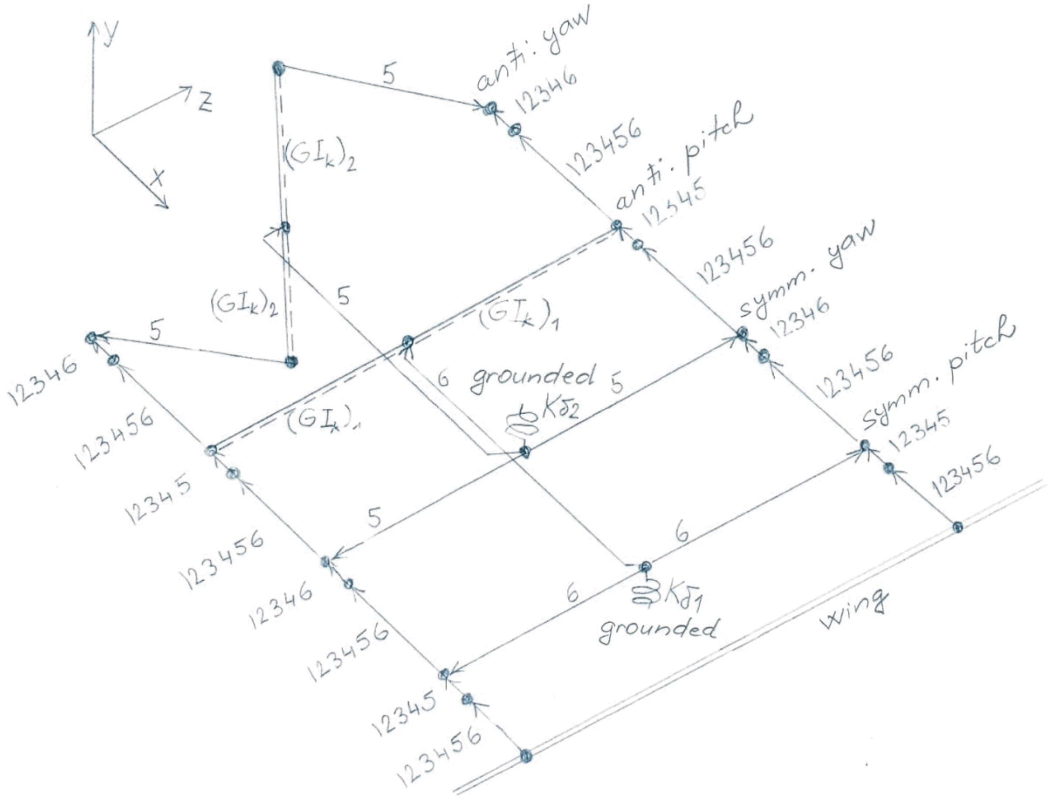


Figure 9: Scheme of pattern for engine suspension with four degrees-of-freedom (for legend see figure 3)

5 CONCLUSION

This paper presented some special modelling techniques, applicable for preparation of aeroelastic stick models, including:

1) Model of control surface and tab without stiffness parameters,

2) Common model of symmetric and antisymmetric vibrations for control surface and tab flapping modes,

3) Common model of symmetric and antisymmetric vibrations for twin-engine aircraft engine vibration modes.

The described schemes are simple, effectively usable and suitable for variation of parameters. The relation between the characteristics of particular vibration modes and structural parameters is clear. Therefore, parameters can be simply updated according experimental results either directly or using some method of multidisciplinary optimisation. The application is demonstrated on the example of a twin wing-mounted engine turboprop commuter aircraft.

6 REFERENCES

[1] Čečrdle, J. (2016). Application of Whirl Flutter Optimization-based Solution to Full-span Model of Twin Turboprop Aircraft, In: Proceedings of 7th European Congress on Computational Methods in Applied Sciences and Engineering, June 5 - 10, 2016, Crete, Greece, Vol II, pp.3293-3309.

[2] Čečrdle, J. (2016). Updating of Finite Element Model of Aircraft Structure According Results of Ground Vibration Test, *Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering*, 230(7), 1348-1356.

COPYRIGHT STATEMENT