INFLUENCE OF THE STRUCTURAL ELASTICITY ON THE STATIC AND DYNAMIC EFFECTIVENESS OF CONTROL SURFACES WITH THE GEARED TAB

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Keywords: aeroelasticity, structural dynamics, geared tab, control surface, frequency response.

Abstract: Aeroelastic computational model of the transport aircraft with geared tabs on control surfaces is investigated in the paper. It is shown that the geared tab can significantly increase control surface (CS) effectiveness due to the structural elasticity. Main results of the paper are following. At low rotation stiffness of the control surface the geared tab can significantly increase CS effectiveness due to elastic deformations. It is useful structural flexibility development for problems of the aircraft control in the flight dynamics (example of the “active aeroelasticity”). For the aeroelastic stability problem with control system frequency responses rising reduces stability margin of the closed loop in the range of the elastic oscillation frequencies. The method of the analysis is shown and numerical estimations of above-mentioned effects are presented.

1 INTRODUCTION

Geared tab is used to reduce hinge moment on the control surface. It may be used both in the case of mechanical linkage and in the case of power-operated control systems. It’s usually considered that geared tab reduces the main CS effectiveness. However in case of the low rotation stiffness of the main CS the geared tab can significantly increase the effectiveness of CS and the paper is devoted to the study of this phenomenon.

Influence of the structural elasticity on the control surfaces effectiveness is investigated on the example of the high-wing transport aircraft with four engines on pylons under the wing and with T-tail. This aircraft has a set of significant features from the viewpoint of aeroelasticity characteristics:

- dense set of elastic oscillation frequencies (there are about 30 symmetric and anti-symmetric elastic oscillations modes in the frequency range up to 7 Hz);
- large aerodynamic balance of the main control surfaces;
- low rotation stiffness of CS (rotation frequencies are in the range of the lowest modes of structural elastic oscillations);
- geared tabs on the control surfaces.

The features of the creation of the aircraft aeroelastic computational model in ARGON system is considered in the paper, including aerodynamic model correction on the basis of wind tunnel test results. Comparative analysis of the calculation results of the CS static effectiveness and frequency responses due to harmonic deflection of CSs with and without geared tab (gt) is considered.

2 AIRCRAFT COMPUTATIONAL MODEL

The first level model of the multidisciplinary program complex ARGON was used for the calculation's analysis. Aircraft computational scheme is the set of thin elastic surfaces which are coinciding under the form with medium surfaces of the real aircraft aggregates. Aerodynamic properties of the fuselage are modeled with a help of two lifting surfaces: in horizontal and vertical planes (on the scheme "cross"). Engines are modeled under the scheme "cross" too. Only right half-model is considered, the left one is supposed symmetric.

Geometrical scheme consists of 22 aggregates; 1 – horizontal fuselage; 2-4 – vertical fuselage; 5-7, 14-16 – the wing console with the center-wing section and the aileron; 8 – internal engine in the horizontal plane; 9 – internal engine in the vertical plane; 10 – external engine in the horizontal plane; 11 – external engine in the vertical plane; 12, 18-19 – horizontal tail with elevator; 13, 20-22 – vertical tail with rudder.

The rudder, the elevator and ailerons are selected as deflecting surfaces. Aerodynamic scheme and partition on the elementary panels (872 on the half-aircraft) are shown on the Figure 1.

Elastic-mass properties of the structure are described on the basis of the Ritz polynomial method. Longitudinal motion with symmetric deformations accounting and side motion with accounting of anti-symmetric deformations are considered separately. 11 elastic surfaces are used for the elastic-mass properties presentation: fuselage, center-wing section, internal part of the wing up to kink, external part of the wing, aileron, stabilizer, rudder, tail, elevator, internal engine with pylon, external engine with pylon.

Degrees of freedom for the bending and for the torsion of fuselage, wing and tail at two planes are set. Deformations of engines and rudders are not taken into consideration. Surfaces are connected to each other by 6-component springs. The engine on the pylon oscillations are modeled at the expense of the spring component flexibility (this spring connects pylon with engine at its center of masses).

Stiffness and masses distribution on aggregates has been set in beam approach. Summarized number of degrees of freedom in polynomial Ritz method (on the half-structure) is 116 for symmetric deformations calculation and there are 140 degrees of freedom for the anti-symmetric deformations calculation.

General view of the elastic-mass computational model is shown on the Figure 2.

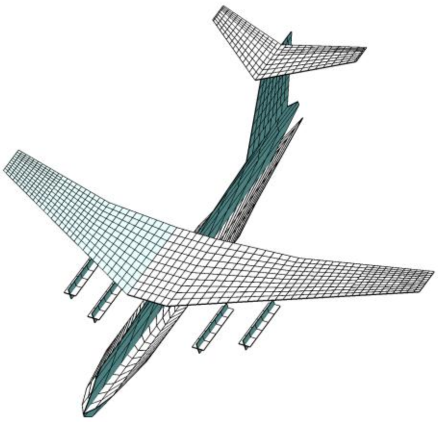

Figure 1: Aircraft aerodynamic scheme

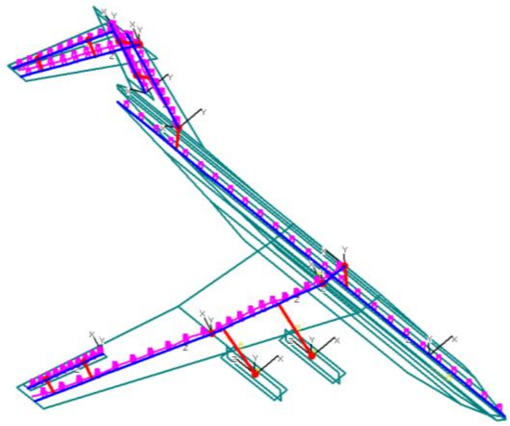

Figure 2: Aircraft elastic-mass computational scheme

3 MODAL ANALYSIS

For analysis of the aircraft structure stiffness and dynamic features frequencies and modes calculations without flow are fulfilled. One of the main features of the aircraft modal characteristics is the very dense spectrum of the elastic oscillations frequencies. There are about 30 symmetric and anti-symmetric oscillations modes in the frequency range up to 7 (Table 1).

	Frequency, Hz	
№	Symmetry	Anti-symmetry
1	1.816	2.022
2	2.238	2.222
3	2.272	2.504
4	3.018	2.593
5	3.582	2.917
6	3.654	3.035
7	3.854	3.203
8	3.865	3.662
9	4.847	3.868
10	5.128	4.652
11	5.318	4.743
12	5.755	5.011
13	6.141	5.215
14	–	6.289
15	–	6.669

Table 1: Elastic oscillations frequencies of the aircraft structure

The other important feature is that frequencies of the control surfaces rotation are low and there are in the range of the lowest elastic oscillations frequencies:

- ailerons 3.0 Hz
- elevator 5.2 Hz
- rudder 3.2 Hz

Such low control surfaces oscillations frequencies are caused by the low stiffness of the control linkage, control gears and its attachment unit's flexibility.

4 CORRECTION OF THE CONTROL SURFACE COMPUTATIONAL SCHEME

Control surfaces mathematical model with low rotational frequency (with low rotational stiffness) has a prominent feature in case of high aerodynamic compensation availability. In this case application of doublet-lattice method on the aerodynamic calculation can lead to aerodynamic overcompensation, that is can lead to the positive derivative of the hinge moment coefficient m_h^δ, that'll cause static and dynamic instability on the aeroelasticity characteristics calculation. Therefore in such cases it's necessary to pay attention to the correctness of hinge moments determination.

The well-known method of the linear aerodynamics correction for control tasks correction was applied in this paper. Control surfaces area before the rotation axis was reduced for the coordination of the hinge moment coefficients and experimental data received during rigid model testing in the wind tunnel. Control efficiency at such correction is reduced about 10-15%. This reduction is a positive result of the correction as usually calculation on linear aerodynamics gives uprated values (on 10-15%) of the control efficiency in comparison with the more accurate calculation or an experiment. As a result mathematical model of the aircraft has been received, which is suitable for the analysis of the static and dynamic aeroelastic characteristics including frequency responses of control system sensors due to control surfaces deflection.

5 STATIC EFFECTIVENESS OF CONTROL SURFACES WITH THE GEARED TAB

The main control surface in the roll channel is aileron with the geared tab, which deflects to the opposite side from the aileron deflection and reduces hinge moment. The typical law of the geared tab deflection is shown on the Figure 3. In spite of concerning the small size of the geared tab it renders noticeable influence to the aileron static effectiveness because of its small stiffness on rotation.

In the ARGON-system direct calculation of the spline CS effectiveness is not provided. For each CS δ-task separately solved on the unit deflection of this CS. So geared tab influence is considered as follows. It is considered, that roll moment coefficient $m_x^{\delta a+gt}$ due to aileron deflection with the geared tab might be presented as a sum of two items. The first of these items is caused by the aileron deflection $m_x^{\delta a}$ (including undeflected surface of the geared tab), and the second item is caused by the geared tab deflection $m_x^{\tau\, gt}$. Considering the geared tab deflection law

$$\tau_{gt} = K_{gt}\,\delta_a \tag{1}$$

It is possible to receive expression for the total effectiveness

$$m_x^{\delta_{a+gt}} = m_x^{\delta_a} + K_{gt} m_x^{\tau_{gt}} \tag{2}$$

The dependence of all these characteristics on the dynamic pressure (which characterizes an influence of the structure elasticity) for limiting Mach number M=0.77 is shown on the Figure 4. Aileron efficiency reduces very quickly at dynamic pressure rising, as one would expect on such small stiffness on rotation, In case of limiting dynamic pressure $q \approx 20$ kPa aileron effectiveness is less than 3% of the one for the rigid structure.

At the given geared tub deflection angle the aileron deflects to the opposite side because of a small stiffness on rotation. So geared tab efficiency changes sign (control reverse occurs) already on small dynamic pressure (Figure 4, the curve “GT”). As a result at efficiencies summation by equation (2) with negative coefficient K_{gt} aileron roll efficiency considerably increases at moderated and large dynamic pressure (Figure 4, curve "Aileron + GT"). It is necessary to note that for the rigid structure, naturally, availability of the geared tab decreases aileron efficiency, that we can see on the Figure 4 at q=0. Analogous results of the geared tab influence on the CS yaw efficiency are shown on Figure 5. Geared tab availability significantly increases CS efficiency at moderated and large dynamic pressure.

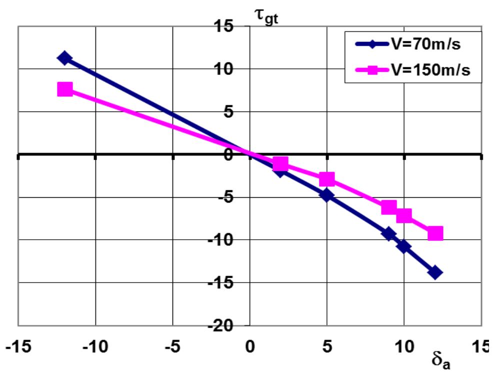

Figure 3: Dependence of the geared tab deflection angle on the aileron deflection angle

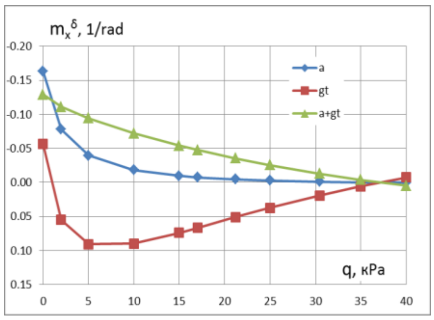

Figure 4: Influence of the elasticity of the aileron with the geared tab on the roll efficiency

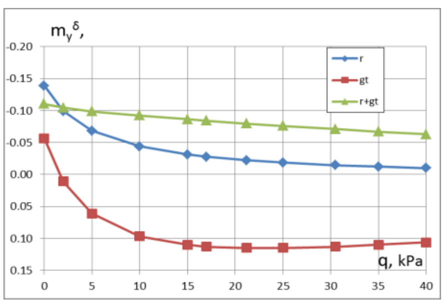

Figure 5: Influence of the elasticity on the rudder with the geared tab yaw efficiency

6 DYNAMIC EFFECTIVENESS OF CONTROL SURFACES WITH THE GEARED TAB

Doublet-lattice method is used for the aerodynamic forces determination. Frequency responses calculations are made at the frequency domain including aerodynamic forces interpolation by the Strouhal number (reduced frequency).

Frequency responses of the angular roll velocity due to drives rods were considered in the roll channel. Control links flexibility plays important role in the control efficiency. Frequency responses by the aileron angle deflection due to drive rod harmonic effect are shown on the Figure 6 (without geared tab accounting). We can see that on the high speeds control links flexibility reduces control efficiency at several times.

The geared tab availability gives additional singularities to frequency responses calculations in the roll channel. In the given system ARGON program versions usage of the CS with the geared tab for frequency responses calculations does not provided. It is due to considerable complicating of control co-ordinate forming algorithms of the CS deflection.

The geared tab influence is considered as follows. It is considered, that angular roll velocity ω_x, caused by aileron with the geared tab drive rod oscillations, can be presented as a sum of two items. The first of them is caused by the effect of the control signal of the rod drive at a whole aileron deviations (including undeflected geared tab surface), and the second item is caused by the geared tab deflection. It is considered that the geared tab deflection law (1) concerns to the aileron deflection angle δ_a (but not to the rod deflection δ_r). So at given angle δ_r at first the angle δ_{gt}, (which is caused by an only rod effect) is determined; in this case frequency response δ_a/δ_r (Figure 6). Then the geared tab deflection angle τ_{gt} is determined by the equation (1). Further we can determine additional aileron deflection δ_{a+gt}, which is caused by the geared tab action, using frequency responses δ_a/τ_{gt} (Figure 7). The summarized aileron deflection will determine the total geared tab deflection, which matches to equation (1), and we can determine the component to the angular roll velocity, using frequency responses ω_x/τ_{gt} (or φ_x/τ_{gt}). It might be note, that geared tab efficiency on the angular roll velocity at high flight speeds is noticeable more than the efficiency of the aileron rod drive deflection.

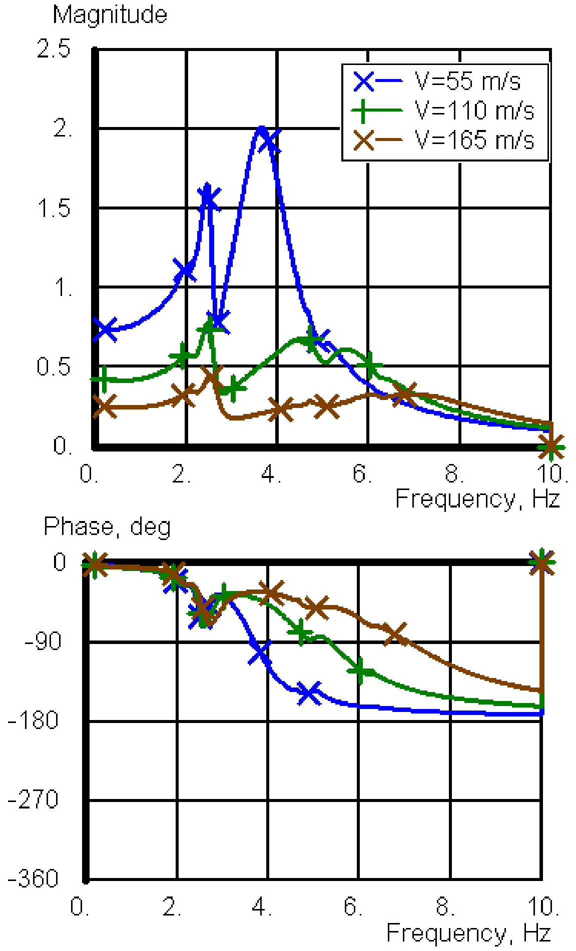

Figure 6: FR $\delta_a/\delta_{r\ a}$

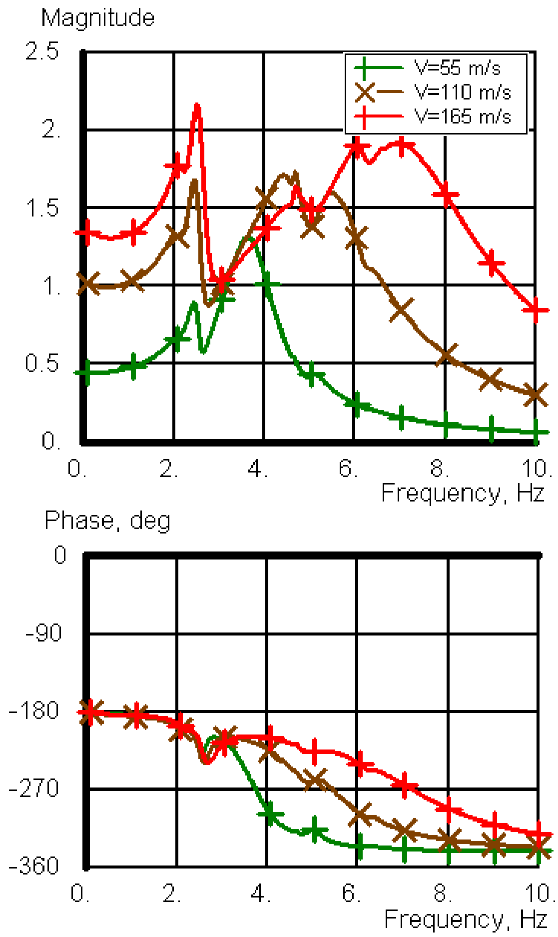

Figure 7: FR δ_a/τ_{gt}

Block diagram which is used in further calculations is shown on the Figure 8; in these calculations for a convenience at first roll angle φ_x is determined and then (by differentiation) – roll rate ω_x.

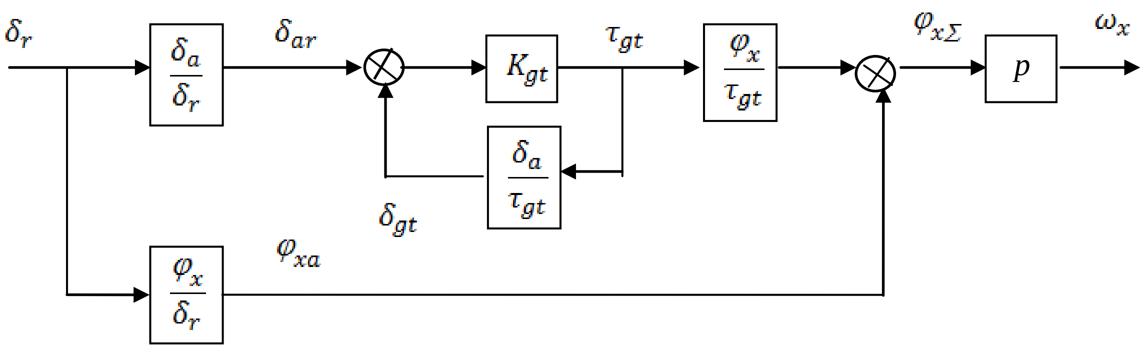

Figure 8: Block diagram for the FR calculation with accounting the geared tab

FR comparison ω_x/δ_r without and with accounting the geared tab at different flight speeds are presented on Figures 9, 10. We can see, that with the flight speed rising the geared tab availability significantly increases quasi-static and dynamic efficiency of ailerons by the roll at the range of low oscillations frequencies.

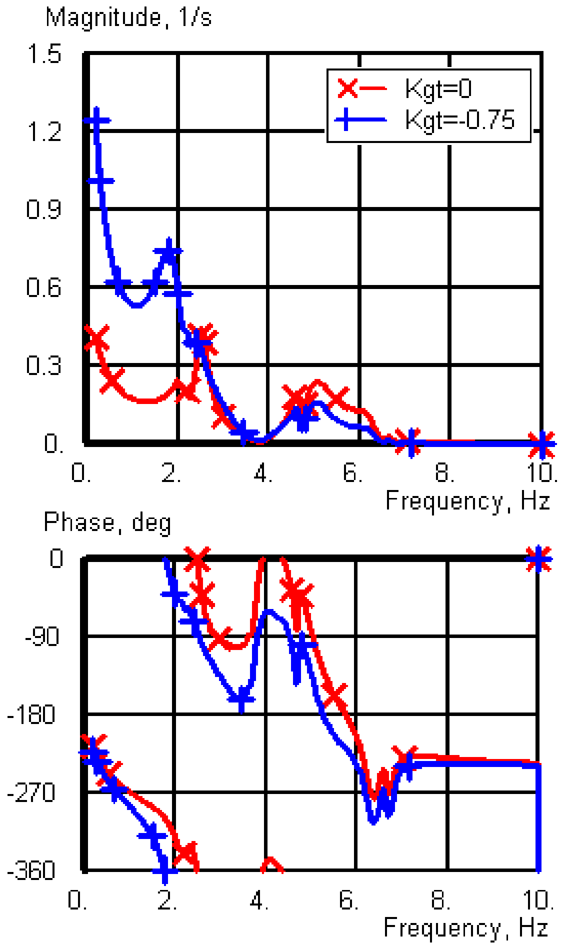

Figure 9: FR ω_x/δ_r comparison with and without accounting the geared tab, V=110m/s

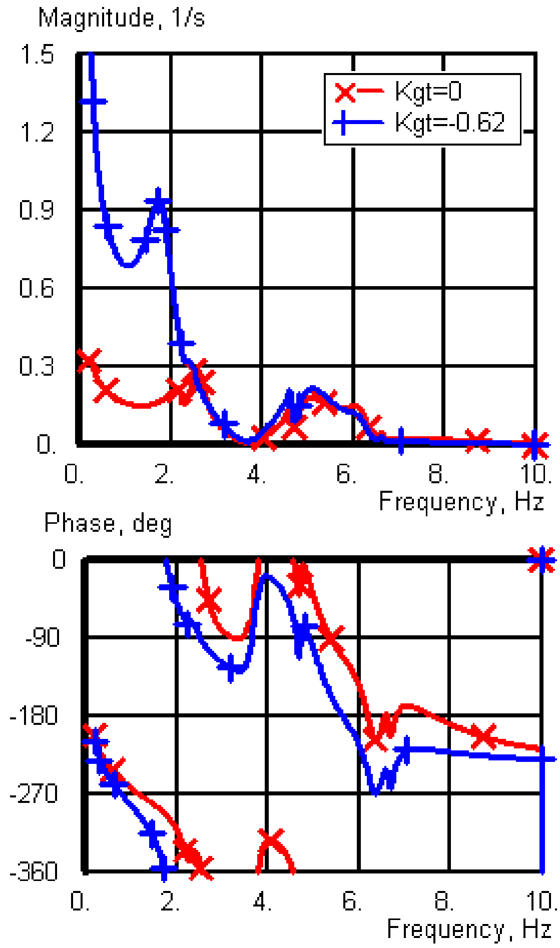

Figure 10: FR comparison ω_x/δ_r with and without accounting the geared tab, V=165m/s

In the yaw channel FR of the angular velocity and FR of the side load fracture due to CS drive rod were considered. In this case the control linkage plays a great role for the control efficiency. The geared tab influence to the rudder efficiency by the angular yaw velocity and the side q-load were investigated at the same algorithm as for the roll channel. In this channel on the flight speed rising the geared tab availability significantly increases quasi-static and dynamic rudder efficiency at the range of low oscillations frequencies.

7 CONCLUSION

Thus main results of this paper are following. At the low CS rotational stiffness the geared tab presence can essentially increase CS efficiency caused by elastic deformations. It is a useful elastic structure development for problems of the aircraft control as a rigid body. For the aeroservoelasticity problem with a control system structure responses rising at the elastic frequencies range can complicate closed loop stability provision. Analysis method of above mentioned effects is considered and some numerical estimation is presented in this paper. These results should be considered at projecting calculations and an aircraft certification.

8 REFERENCES

[1] Aviation of common application. Recommendations for designers. V. Mikeladze, TsAGI, 1996.

[2] D. Evseev, F. Ishmuratov, V. Chedrik and oth. Program complex of aerostrength aircraft design ARGON. TsAGI Scientific notes, 1991, v. XXII, № 5.

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