INFLUENCE OF REGULAR CONTROL SYSTEM ON AIRCRAFT LOADS REPEATABILITY

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Abstract: The purposes of this work are the demonstration of aircraft loading specificity when regular control system (CS) operates and development of offers to minimize variable loads influencing on resource characteristics. Flight data measured on the modern aircraft are analyzed. Loading of control surfaces actuators is considered. Influence of spoiler deflections on plane units loading is shown. Results of analytical researches of CS influence on variable loads repeatability are presented.

1 LOADING OF CONTROL SURFACE ACTUATORS

The information about actuators loading is necessary

– to certificate the actuators and joints of their fastening to an airframe according to conditions of fatigue strength;

– to develop the equivalent loading programs for full scale fatigue tests (including wear and tear);

– to optimize mass characteristics of an airframe at designing under the specified life time.

Actuator functioning is basically defined by algorithms of the controllability and Stability Augmentation System (CSAS). These algorithms are constantly being improved, requirements to safety of flight are increasing, and reservation is being provided. Due to these reasons characteristics of the variable loading of actuators are being changed. The purpose of the present section is research of actuators loading on the basis of the analysis of experimental materials obtained on a modern aircraft.

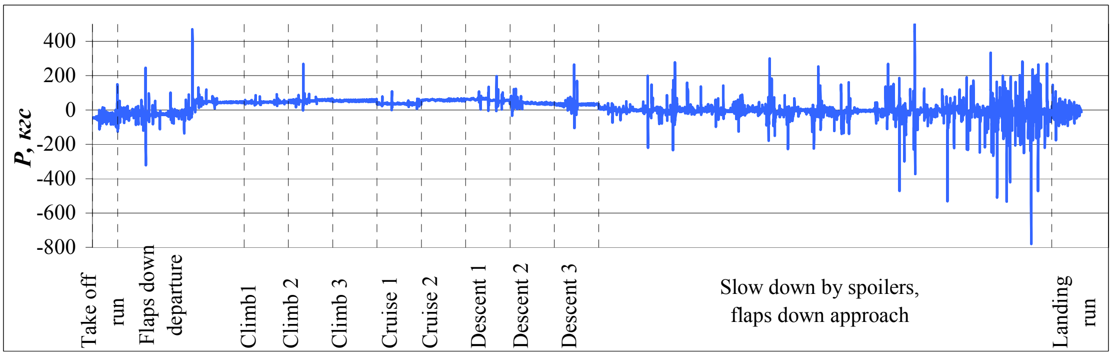

Figure 1: The force on a rod of aileron actuator during different stages of flight

Efforts in rods of actuators during all flight stages were registered. The example of time history of effort in an aileron actuator rod during a whole flight is resulted in fig.1. Ground stages, a slowing-down by spoilers, flaps down departure and approach are resulted completely. Besides, one minute fragments are given for flight when flaps, slats and spoilers are retracted: 3 fragments represent the climb, 2 – cruise, 3 – descent.

For all flight stages cumulative fatigue damages which were caused by action of efforts in rods of an actuator were defined using the "full cycles" method. The power kind of *S-N* curve (Wohler's curve) with index of power equaled to 4 (for metals), linear summation of fatigue damages and Oding's expressions defining equivalent zero-to-tension stress cycle with equal fatigue damage were used. Equivalent efforts in aileron actuator rod per flight stages which were averaged on 7 flights are resulted in fig.2. Apparently the greatest contribution to cumulative fatigue damage is brought by flaps down departure and approach and by slowing-down by spoilers. Here «Original sign» corresponds to the effort which gives stresses of the same sign, «Opposite sign» refers to the effort giving opposite sign stresses.

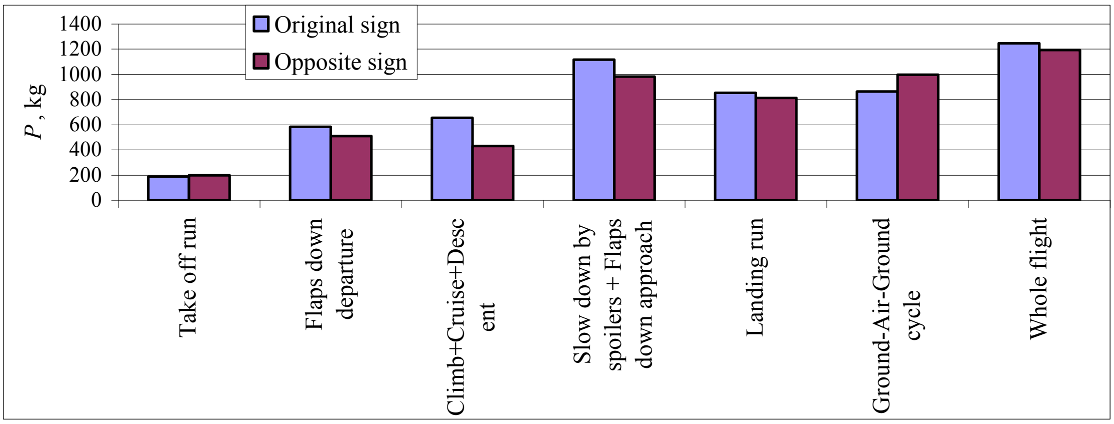

Figure 2: Equivalent forces on a rod of aileron actuator per flight stages

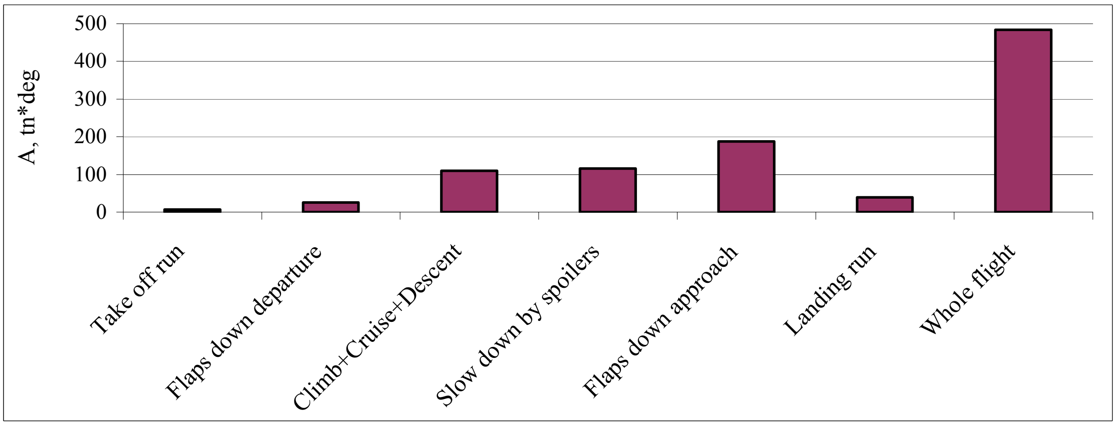

Figure 3: Work of effort in an aileron rod per flight stages

Wear and tear caused by action of a friction force during control surface rotation is directly proportional to the work which this force made through motion of an actuator rod. The distribution histogram of conventional work (which is proportional to real work) of an aileron actuator per flight regimes (integral of an effort in a rod along increment of an aileron deflection) is shown in fig. 3. Efforts in rods of actuators of elevator, rudder, spoilers and brake flaps which were obtained in strain measurements were processed similarly.

Processed results of flight tests show that fatigue damages of actuators and work of forces on rods through deflections of various surfaces essentially differ for each surface. It indicates on possibility of optimization of their weight. As an example conventional work of actuator rods of various control surfaces per whole flight is compared in fig. 4. These data show essential variation of work values.

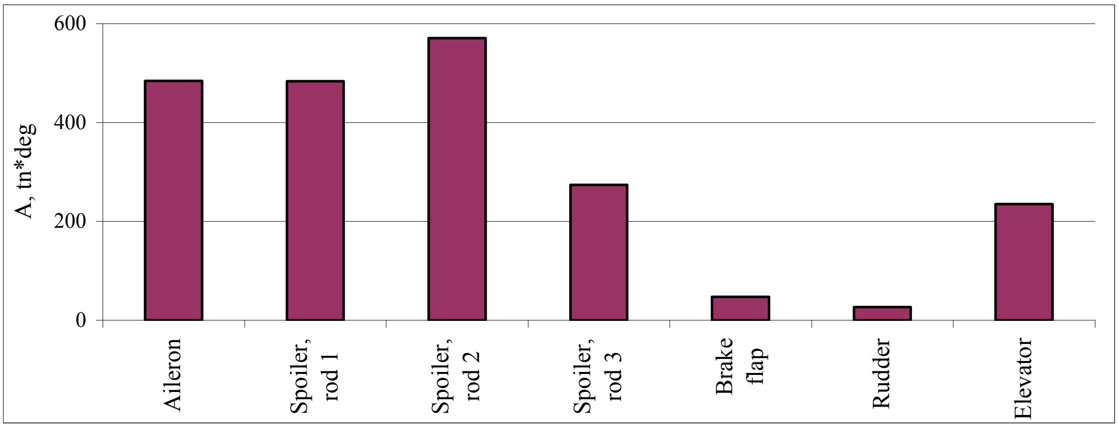

Figure 4: Work of efforts in control surfaces rods per whole flight

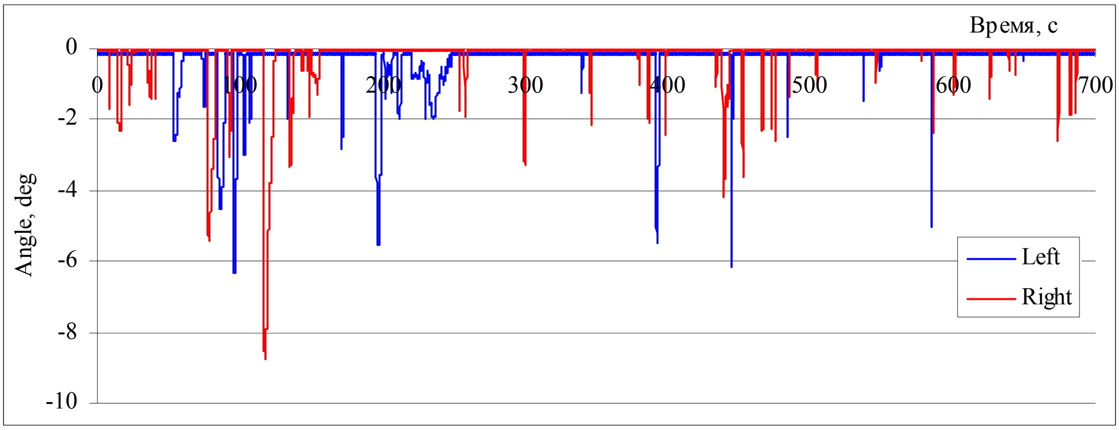

Figure 5: Angular deflections of right and left spoilers. Flaps down approach

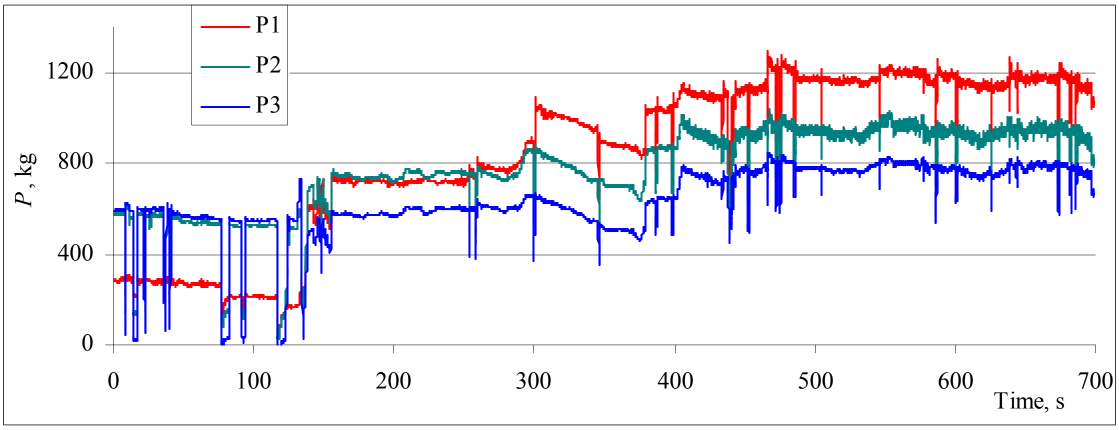

Figure 6: Efforts in three rods of right spoiler actuators. Flaps down approach

It is necessary to show some specificity of loads on spoilers in aileron mode. Angular deflections of right and left spoilers during flaps down approach are shown in fig. 5, and efforts in three rods of right spoiler actuators are resulted in fig. 6. Sharp spoiler deflections give considerable jumps in rods efforts and bring the big contribution both into structure fatigue damage and in wear and tear of actuators.

The statistics on repeatability of control surfaces deflections of transport aircrafts is used when it is necessary to make the estimation of fatigue damage of control surfaces and actuators while experimental data are absent. Cumulative exceedances of control surfaces deflections and of efforts in rods of actuators for different flight stages and for flight as a whole were defined and compared with the available statistical data. The exceedances of control surfaces deflections per whole air stage of flight which were obtained through processing of data written by emergency recorder of a transport aircraft of the previous generation (the plane 1) are presented in fig. 7. These exceedances are compared with exceedances per some air stages of flight which were obtained for the modern plane being considered in this article (the plane 2).

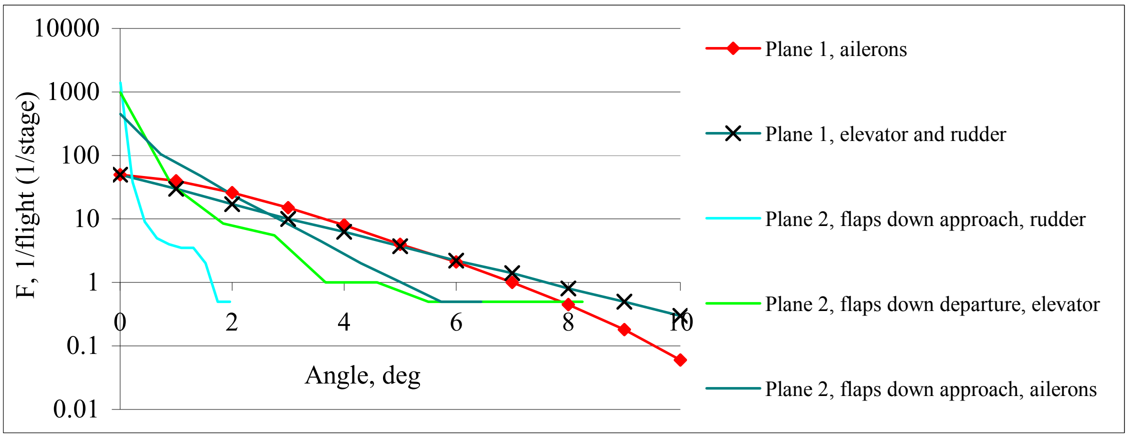

Figure 7: Cumulative repeatability of control surfaces deflection angles

This figure shows that for small deflections repeatability of control surfaces deflections of the plane 2 for separate flight regimes essentially exceed the repeatability of control surfaces deflections for transport aircraft of the previous generation for whole flight. This effect is caused by operation of CSAS. Taking into account the big exceedance of control surfaces deflections, the influence of CSAS on repeatability of variable loads on an airframe should be under consideration (the increase in repeatability of deflections definitely leads to increase in repeatability of variable loads on the actuator and joints of its fastening).

Some of aerodynamic control surfaces have 2 actuators. One of them is active; another (reserve) is in «damping» mode. As an example spectral densities of efforts, coherence function between efforts in these actuators are given in fig. 8, 9.

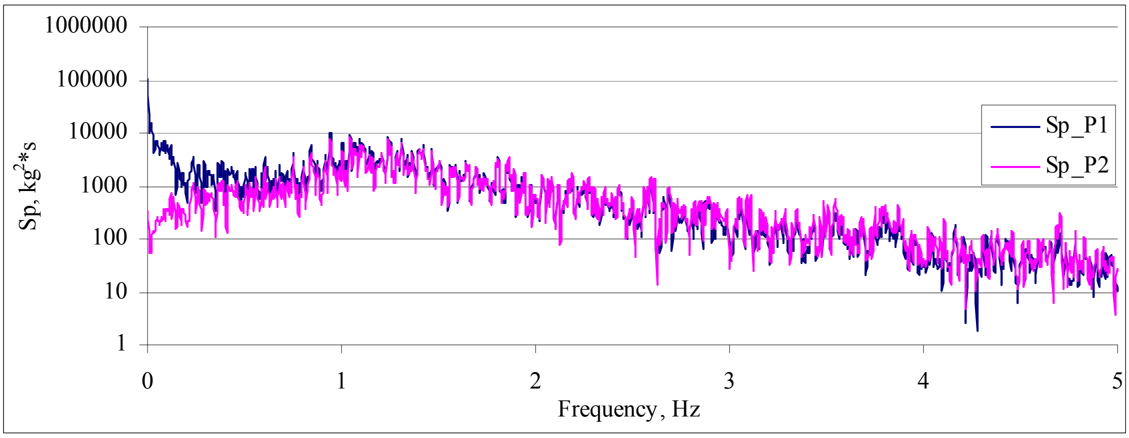

Figure 8: Spectral densities of efforts in rods of active and reserve elevator actuators

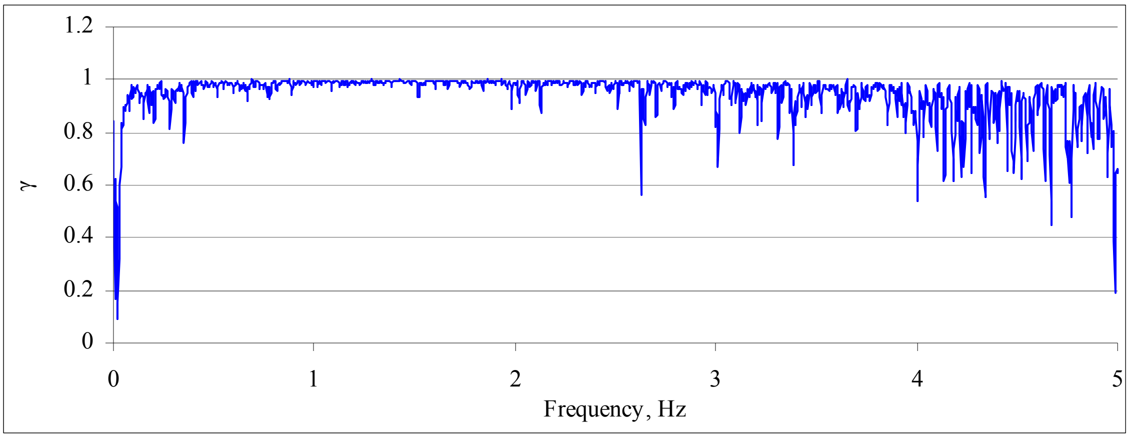

Figure 9: Coherence function between efforts in rods of active and reserve elevator actuators

It follows from the given information:

– Loads on active actuator considerably exceed loads on reserve actuator up to frequency about 0.2 Hz, for the higher frequencies they are almost identical and correlated.

– The peak of spectral density of effort around 1.3 Hz gives the main contribution into cumulative fatigue damage of actuators, their fastening joints and structure between actuators;

– The reserve actuator increases loads in the active actuator. It increases the cumulative fatigue damage of active actuator, joints of its fastening and structure of horizontal tail and elevator between actuators in more than ten times;

– If it is possible, it is necessary to reduce force of hydraulic resistance of the actuator which works in damping mode, and to optimise laws of CSAS management to minimize the variable loads.

2 SLOWING-DOWN BY SPOILER

Flight regimes with deflected spoilers are one of the most important when fatigue strength of an airframe is under consideration. For a flight regime with the let out mechanization (δ_{fl}=17 °, δ_{sl}=24 °) on fig. 10 records of transient responses on the bending moments in root section of horizontal empennage, in a fuselage aft section and in the fourth rail of the flap, showing change of these loading parameters are presented at a symmetric spoilers deviation.

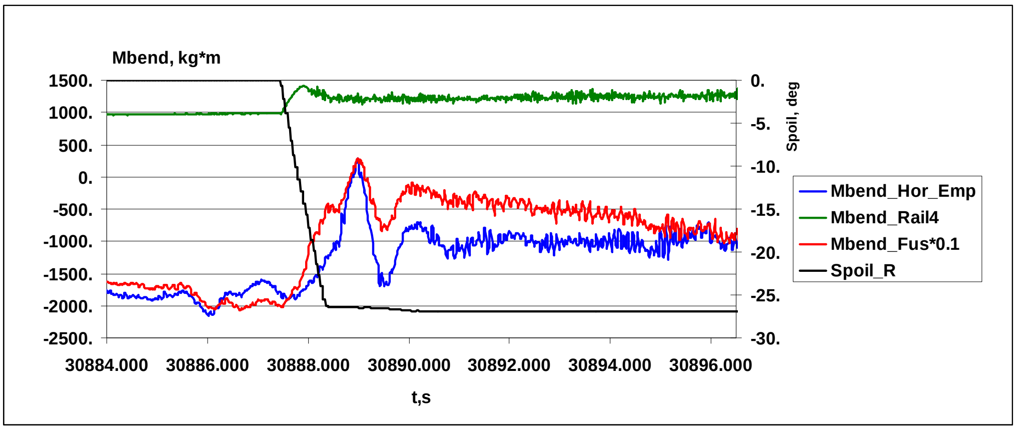

Figure 10: Transient responses due to spoiler deflection

It is visible that there is an essential change of loadings of functioning of horizontal empennage, a fuselage aft section and the rails of a flap connected with change of balancing of the plane. On fig. 11 time response on the bending moment in root section of horizontal empennage is in more details presented for deflected spoilers and after their retracting. The spoilers deflection results not only in change of loading of functioning, but also to change of a loading spectrum - to arising of high-frequency components of loading. Similar features take place and for the bending moment in a fuselage aft section and the bending moment in a flap rail.

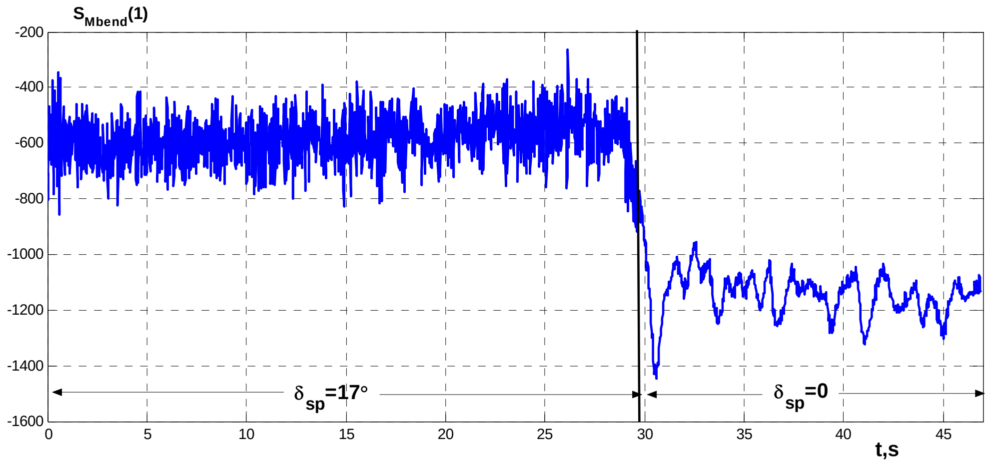

Figure 11: Transient response of bending moment in root section of the horizontal empennage

On fig. 12 - 14 spectral density of the bending moments in root section of horizontal empennage, in a tail compartment of a fuselage and in fourth rail of a flap for two flight regimes with the let out mechanization are presented: with the deflected and retracted spoilers.

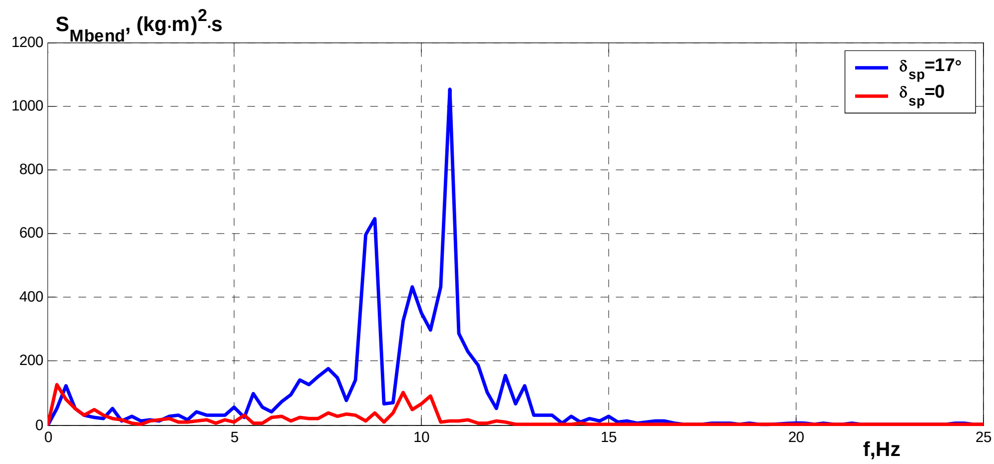

Figure 12: Spectral density of bending moment in body section of the horizontal empennage

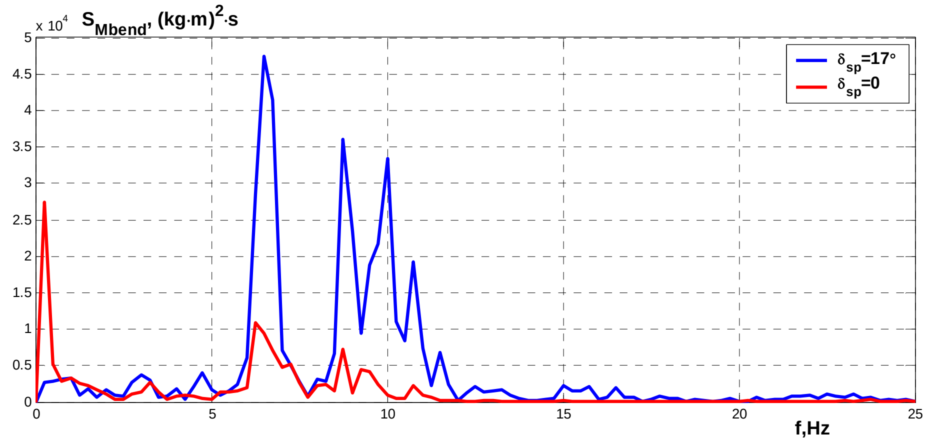

Figure 13: Spectral density of vertical bending moment in the fuselage aft section

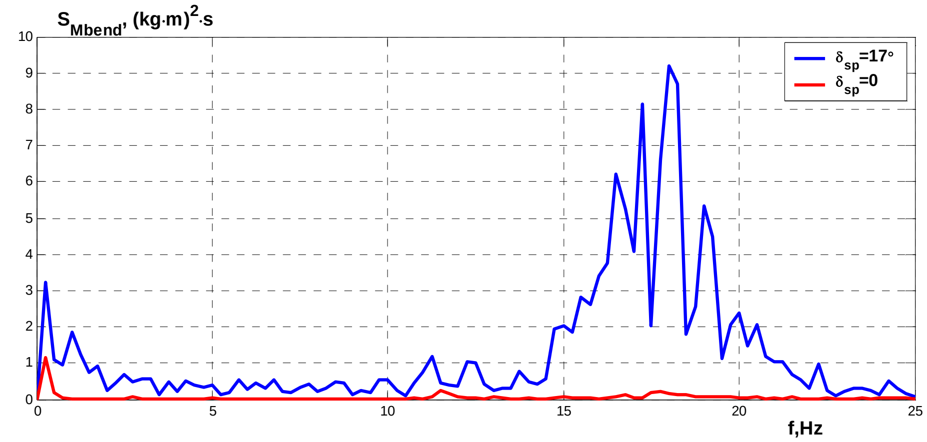

Figure 14: Spectral density of bending moment in the fourth flap rail

Stall-type flow caused by spoiler deflection leads to occurrence of loadings on considered elements of a construction as on frequencies of movement of the plane as rigid body, and in high-frequency area that specifies in excitation of elastic oscillation of a construction. High-frequency components of loadings practically are absent on flight regimes with δ_{sp}=0.

Spectral density of the bending moments in root section of a wing for the same of flight regimes are presented on fig. 15. The spoiler's deflection leads to increase in loadings at frequencies to 3 Hz and practically does not influence loadings in high-frequency area.

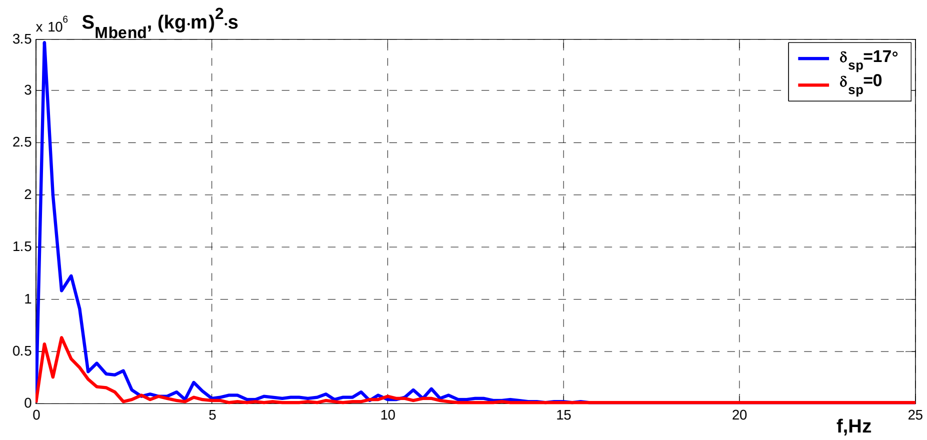

Figure 15: Spectral density of bending moment in body wing section

Stall-type flow caused by spoiler deflection leads to asymmetrical disturbances of an airframe. Time history of the bending moment in a root section of vertical empennage during different flight stages is shown in fig. 16. Spectral densities of this bending moment for flight stages corresponding to slowing-down by spoilers and retracted spoilers are resulted in fig. 17.

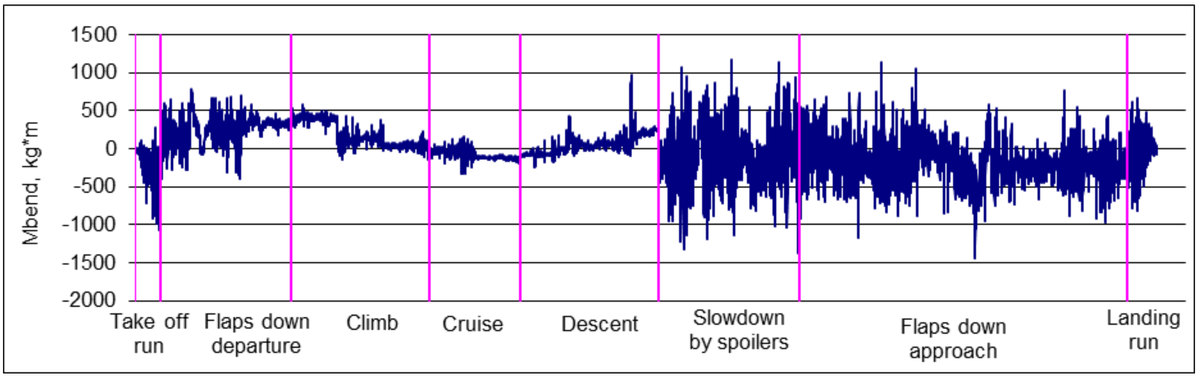

Figure 16: Bending moment in root section of vertical tail during different flight stages

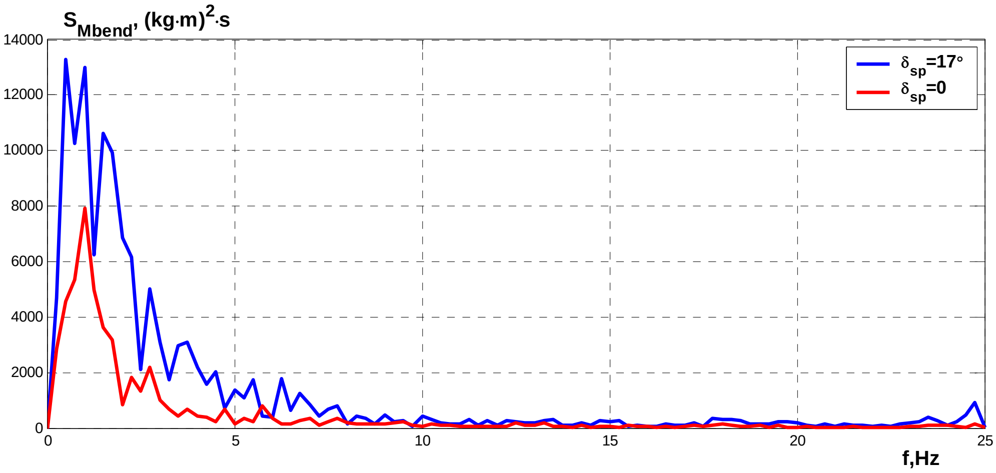

Figure 17: Spectral density of bending moment in body section of the vertical empennage

Spoiler deflection leads to appreciable increase in cyclic loadings at vertical empennage with frequencies less than 6 Hz.

Time histories of a torsion and a lateral bending moment in aft fuselage section are resulted in fig. 18, 19.

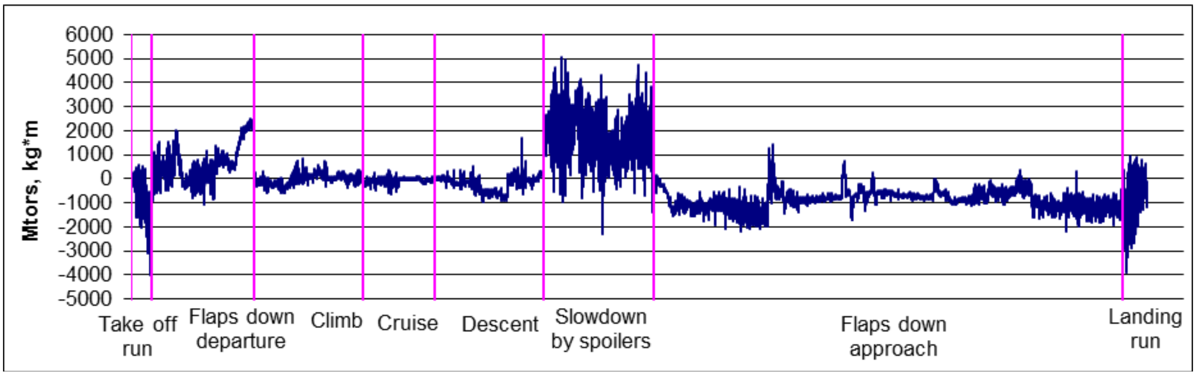

Figure 18: Torsion moment in cross section of fuselage tail part during different flight stages

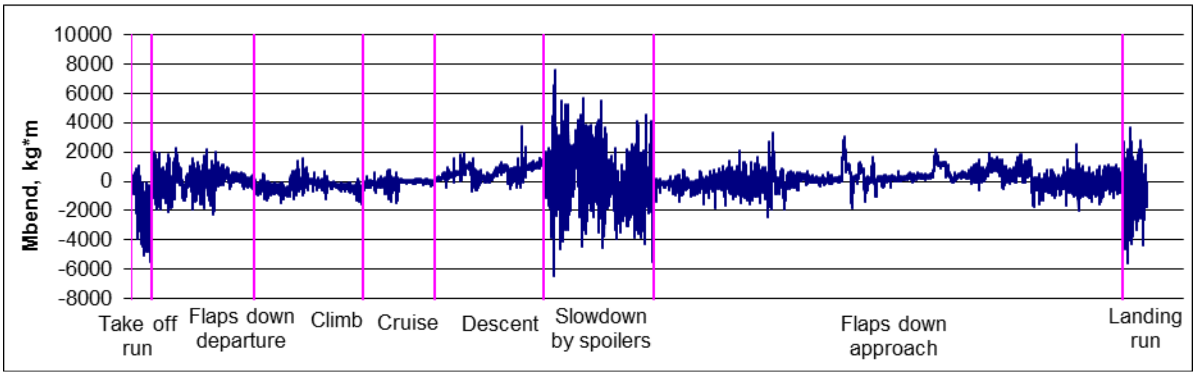

Figure 19: Lateral bending moment in cross section of fuselage tail part during different flight stages

Spoilers deflection leads to leads to appreciable increase in amplitude of cyclic loadings at a fuselage. On fig. 20 relations of fatigue damage of some elements of a plane construction for a time unit of flight with the deflected spoilers to fatigue damage with the retracted spoilers are presented. Stall-type flow at spoiler's deflection leads to essential increase in fatigue damage of considered elements of a plane construction.

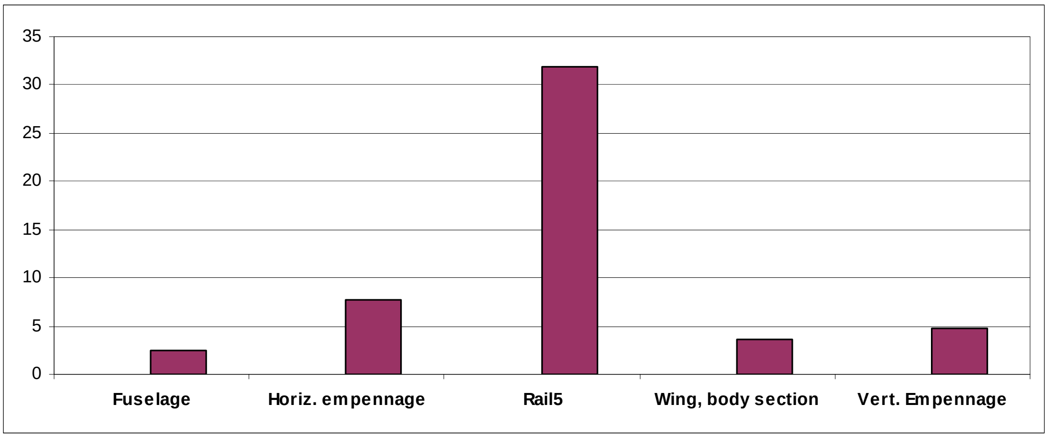

Figure 20 Influence of spoilers deflection on fatigue damage

The given above information shows necessity of very "accurate" use of spoilers, both during of slowing-down, and during of aileron mode. Possible ways of decrease in fatigue damage plane construction are:

– increase damping of low-frequency oscillation at a deflection of spoilers,

– refusal of a deflection of internal sections of the spoilers, making the greatest action on a flow of a aft part of a plane on slowdown stages.

3 RESEARCHES OF INFLUENCE OF CS ON REPEATABILITY OF LOADS CAUSED BY ACTION OF CONTINUOUS TREE-DIMENSIONAL ATMOSPHERIC TURBULENCE

Multidimensional turbulence is a process of simultaneous acting of vertical, lateral and longitudinal gusts on an aircraft. The intensities of these gusts are random fields, i.e. during each moment of time in each point of lifting surfaces of a plane the intensity of wind gust is different [1, 2]. The results of calculation for typical flight for considered aircraft are presented below. Experimentally received frequency characteristics of elevators, ailerons and rudder deflections to action of corresponding control signals were obtained when the autopilot was being switched on (stabilization channels were active).

The two-dimensional amplitude-frequency responses of the bending moment in root section of the wing and shear force in root section of the horizontal empennage to the vertical gust are presented in figs. 21,22. The frequency response of shear force in root section of vertical empennage to the lateral gust is resulted in fig. 23. Here L2 is a length of a gust wave in lateral direction; F1 is a time frequency of the gust along aircraft flight. Two variants of calculation are compared: CSAS channels are switched on and switched off. Appreciable influence of CSAS on loads, especially on loads on vertical tail at frequencies of rigid body and on the horizontal empennage at frequencies around 1.3 Hz are shown (fig. 22, 23).

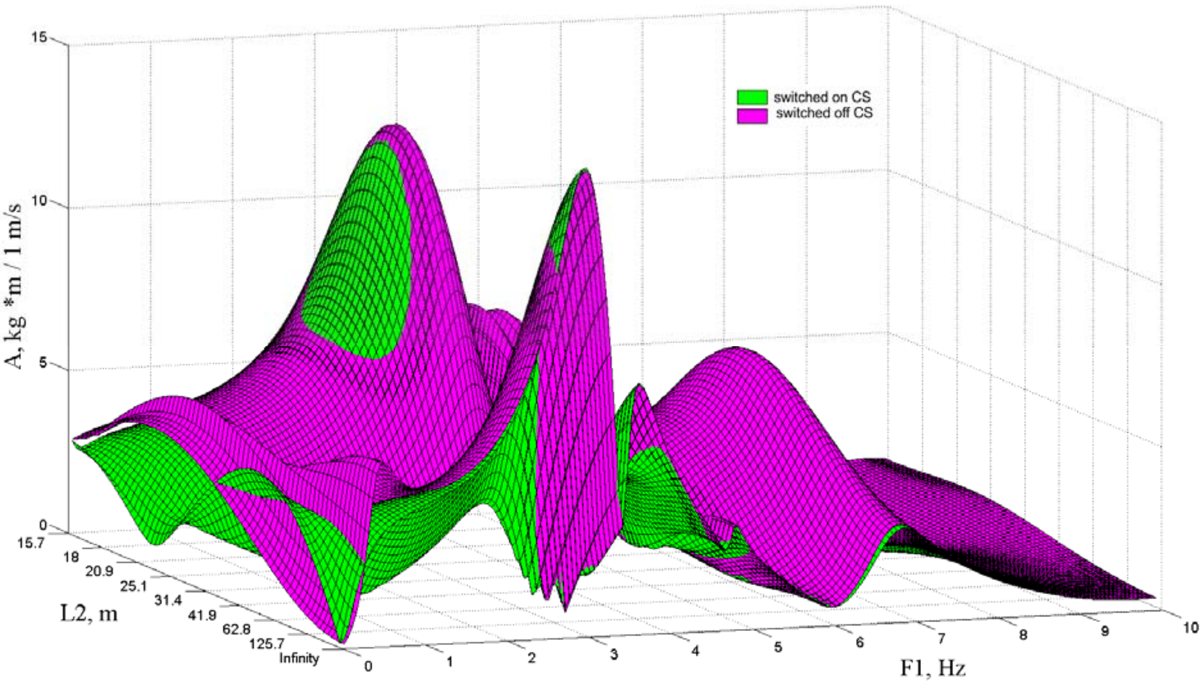

Figure 21: Amplitude-frequency response of the bending moment in root section of the wing to the vertical gust

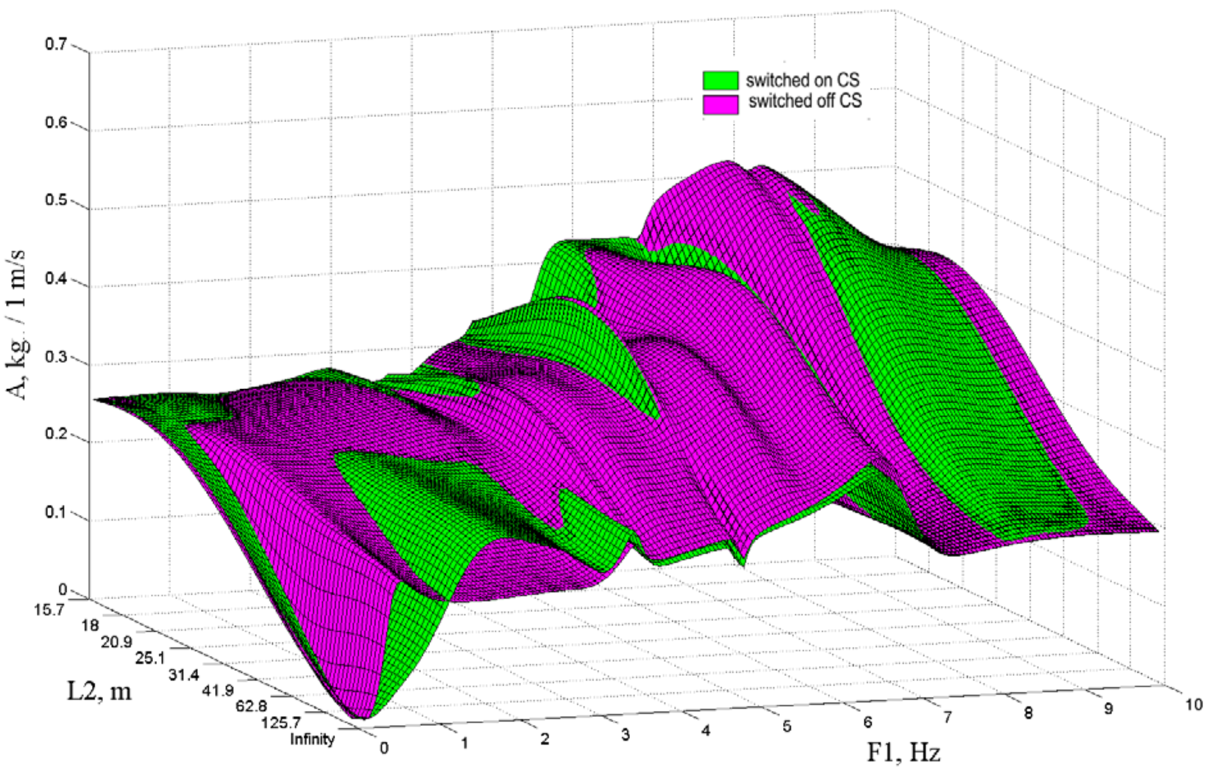

Figure 22: Amplitude-frequency response of the shear force in root section of the horizontal tail to the vertical gust

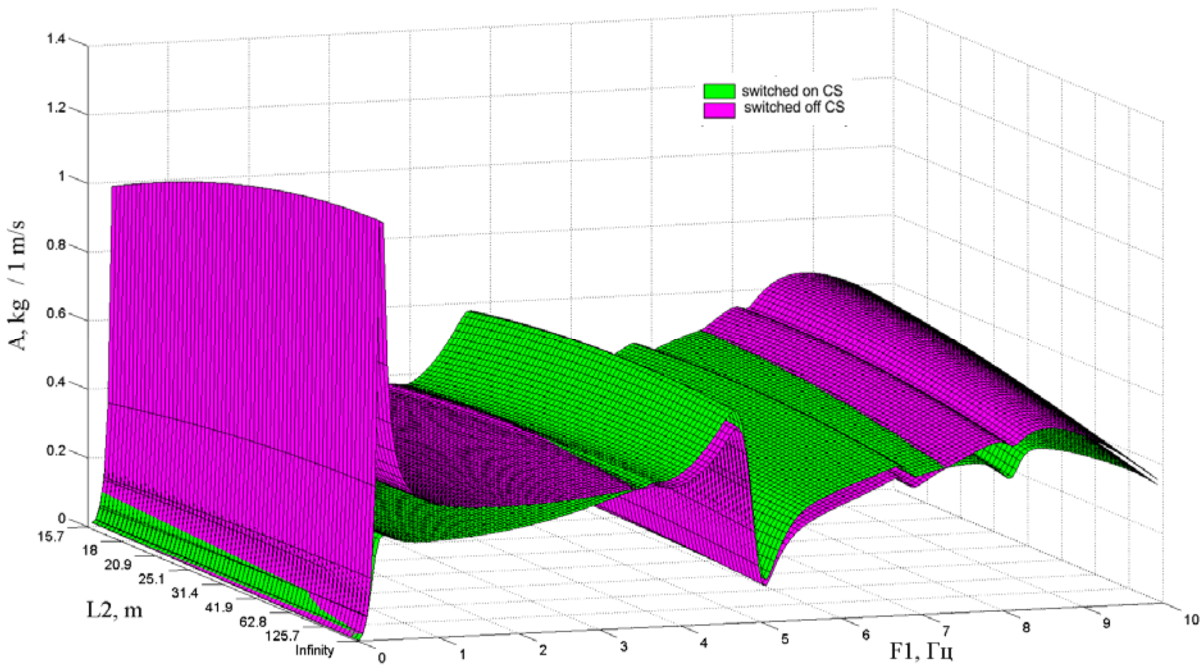

Figure 23: Amplitude-frequency response of the shear force in root section of the vertical tail to the lateral gust

The cumulative repeatability of control surfaces deflection angles per climb stage with retracted flaps are resulted in fig. 24. Comparison of dependences in fig. 24 with results presented in fig. 7 shows that CS gives essential increase in repeatability of control surfaces deflection angles for flight stages with appreciable stall flows (deflection of spoilers, flaps and slats).

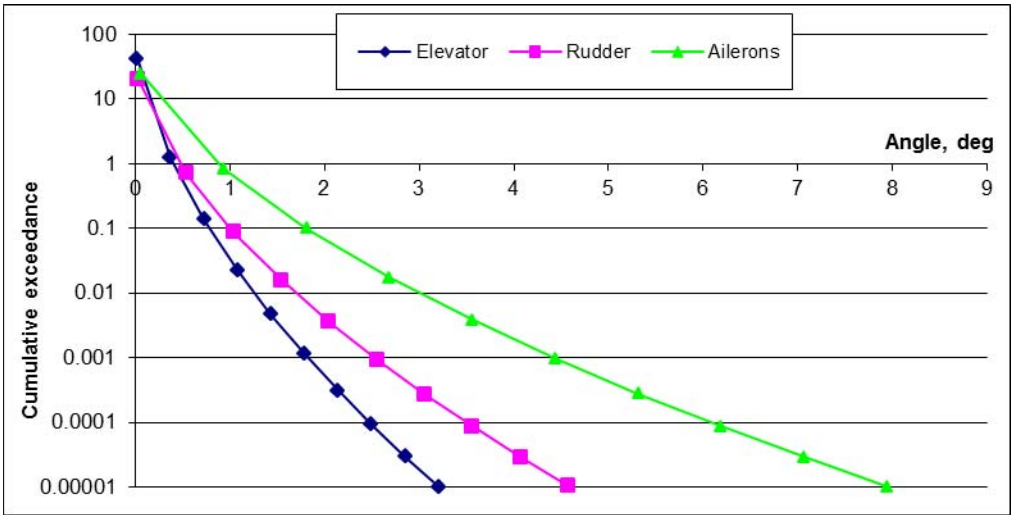

Figure 24: Cumulative repeatability of control surfaces deflection angles per climb stage

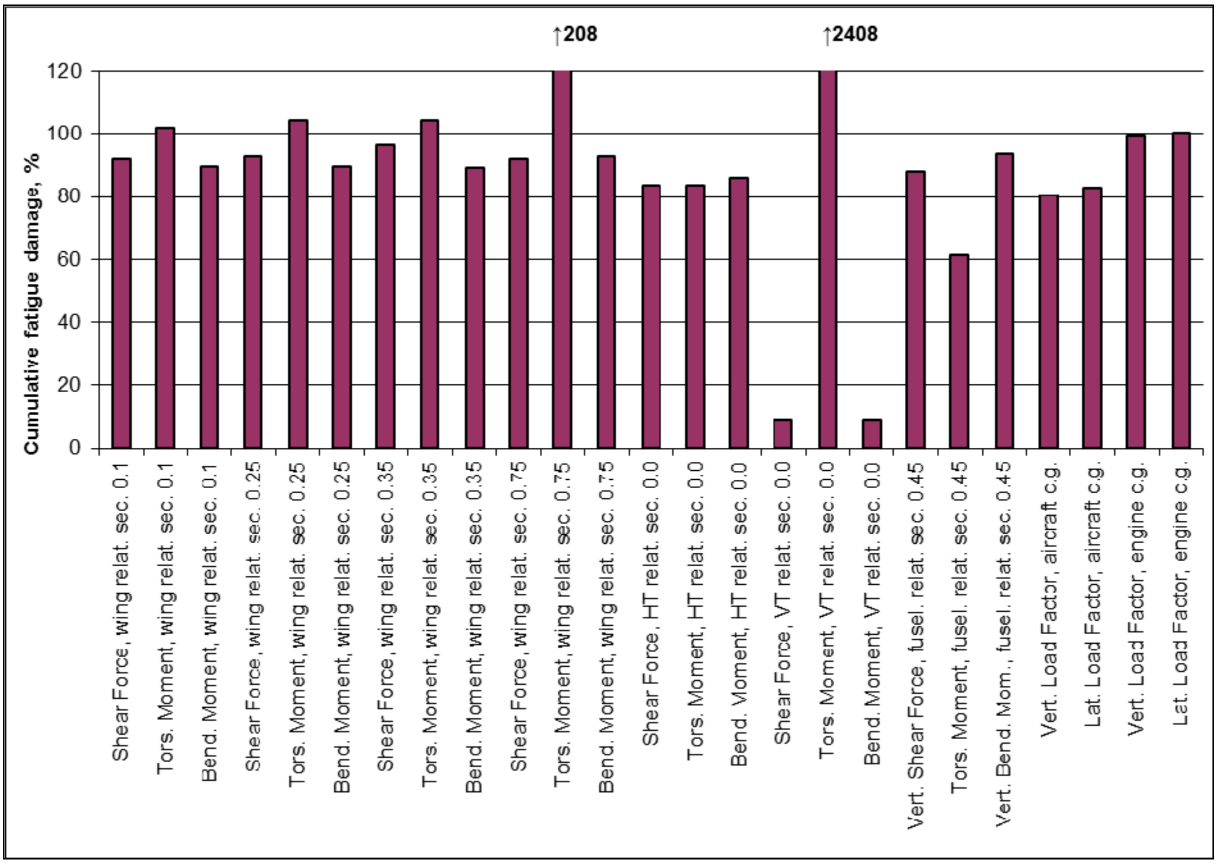

Figure 25: Climb. Influence of CSAS on cumulative fatigue damages

The ratio of cumulative fatigue damages corresponding to different loads in some sections of an airframe at flight in continuous turbulence with switched on CSAS to damages obtained with switched off CSAS is shown in fig. 25. The working CSAS gives the greatest decreasing of damages caused by the bending moment and shear force in root section of vertical empennage (in 10 times) and by the twisting moment in tail part of the fuselage (by 40 %). And CSAS gives the greatest increase of damages caused by the twisting moment in root section of vertical empennage (in 24 times) and in wing section near aileron (in 2 times).

4 REFERENCES

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