AEROELASTIC PROPERTIES OF ACTIVE WINGLETS

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Keywords: *static aeroelasticity, flutter, active winglets*

Abstract

The influence of active winglets on aeroelastic properties of the wing was studied. The characteristic features of winglets in question are a high sweep angles (back and forward) and them being positioned in the same plane as a main wing. The implementation of such of winglets allows to increase the control efficiency and reduce the loads on some flight regimes. The flutter properties were also investigated.

1 Introduction

One of the most effective ways to create competitive advanced airplanes, especially the passenger ones, is to increase lift-to-drag ratio, which in particular is achieved by higher wing aspect ratio and use of winglets [1].

Another option is to increase primary structure's load ratio. All this decreases relative stiffness of airplane lifting structures, which in turn reduces aileron roll control efficiency, aggravates problem of flutter, as well as structure fatigue due to higher unsteady gust and maneuver loads. Meanwhile, it is the concept of active aeroelasticity [2] that can be a promising solution to all these problems. [3, 4, 5, 6]

To achieve this goal, the very effective control surfaces on the wing are needed. Traditional ones like ailerons are not suitable for the task due to rapid drop of their control effectiveness with growth of dynamic pressure and Mach number. So far, mainly external ailerons and differentially deflected wing leading edges were considered as advanced controls to realize the concept of active aeroelasticity. [7, 8]

2 Active winglet based on raked wing-tip

Beside these, an active winglet may be proposed for implementation. What already is in use is a so-called raked wingtip that extends beyond the wing span and lies in the same plane, but at a bit higher (by 5-10%) leading edge (LE) sweep angle compared to the wing [1]. This study considers the said wingtip, that allows lift-to-drag ratio to be increased by 10%, and which at the same time is used as a control surface. Its pivot axis lies in the wing-plane and is perpendicular to the aircraft longitudinal axis.

The specific feature of the considered active winglet version is that its leading edge sweep angle exceeds by 15° the main wing sweep, although its absolute value does not exceed 70°. The winglet span is no less than 10% of the wing semispan, and its tip chord is no less than 30% that of its root chord. [9]

3 Computational model

Results of theoretical research on static aeroelasticity of the elastically-scaled reference model (Fig. 1) for transonic wind tunnel tests (dynamic pressure scale is about 2) are presented below. Analysis was performed with the use of ARGON multidisciplinary software, and illustrates comparative possibilities to solve the problems of control of an advanced plane with a high aspect ratio swept wing by means of various control surfaces exploiting structural elasticity.

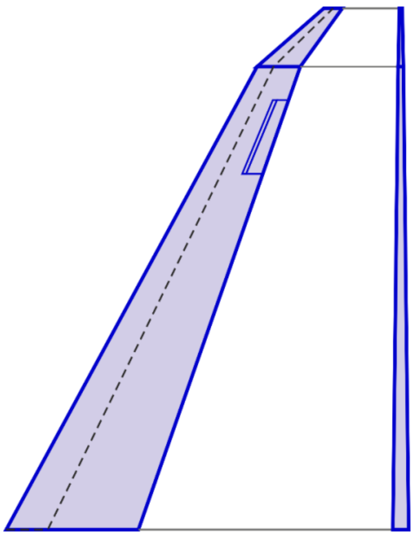

Fig. 1. Computational model, swept back winglet variant

The use of elasticity is the main focus of Active Aeroelastic Wing (AAW) concept. ARGON code is well suited for fast computations of different aeroelastic properties of aircraft or other objects. In this study, ARGON is used to calculate the loads for several load cases, the control efficiency and flutter performance.

4 Control effectiveness

Presented in Fig. 2 is the computational model for which roll moment derivative with respect to ordinary aileron deflection angle were calculated as functions of dynamic pressure at different Mach numbers (Fig. 3).

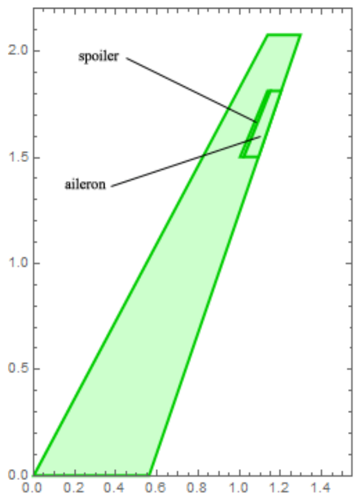

Fig. 2. Computational model of the wing with no winglet

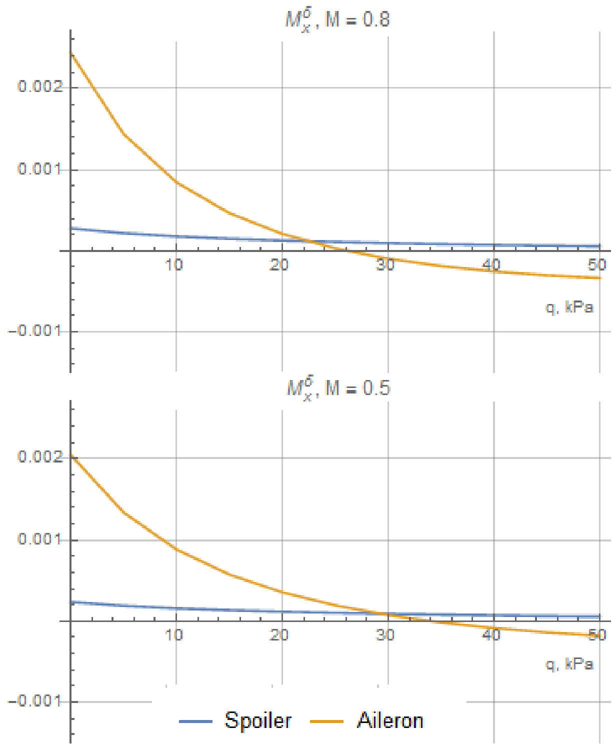

Fig. 3. Roll moment derivative with respect to angle of deflection of an ordinary aileron versus dynamic pressure at different Mach numbers

Apparently, the effectiveness of an ordinary aileron considerably decreases with growth of dynamic pressure, with aileron reversal occurring at around Mach number of 1 because of adverse bending and torsional wing deformations.

On the other hand, active winglets make it possible to exploit structural elasticity and offer much better control effectiveness at high dynamic pressures. The swept back active winglet reaches the critical speed of control reversal pretty early and can be deflected in opposite direction at speeds higher than reversal speed. This makes it possible to keep the roll control effectiveness after the point at which each control surface loses its effectiveness. This effect is shown by dashed line on the last plot in Fig. 4. The effect is somewhat harder to exploit as it requires a complex control laws and greatly complicates the control system. Swept forward winglet exploits the structural elasticity in a different way. Since its main body is located further forward compared to the local stiffness axis, it just doesn't reach the critical reversal speed and retains adequate roll control effectiveness within the range of the allowed flight parameters as can be seen in the figure. This effect doesn't require control laws more complex than those needed for the aileron. This makes it more favorable than the swept back active winglet in this regard.

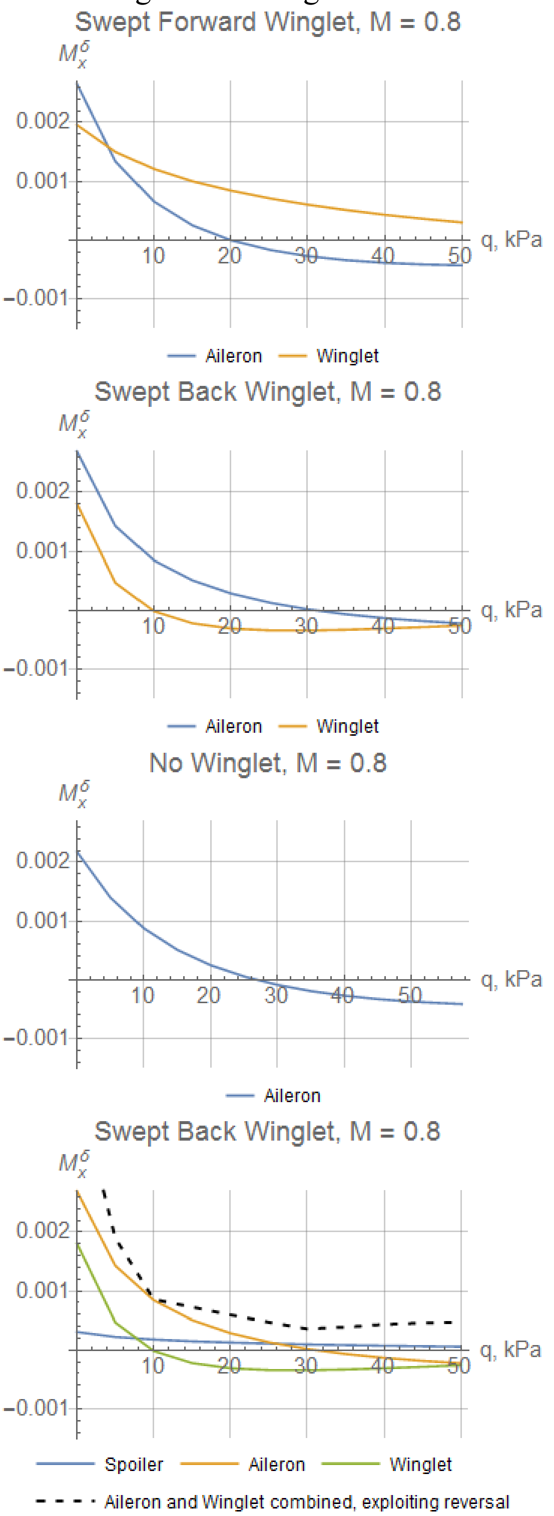

Fig. 4. Roll moment derivatives with respect to angle of deflection of an aileron and the active winglets

It is worth to mention that the swept forward winglet in passive mode reduces the aileron roll control effectiveness and makes it reach the reversal earlier as it aerodynamically acts as a destabilizer for the outer sections of the wing. Swept back winglet increases the critical speed of the aileron reversal acting as a stabilizer. Both of these effects can be seen in Fig 4.

The dependencies of derivatives m_z^{Cy}, C_y^α, m_z^α with respect to the dynamic pressure are shown in Fig. 5-6.

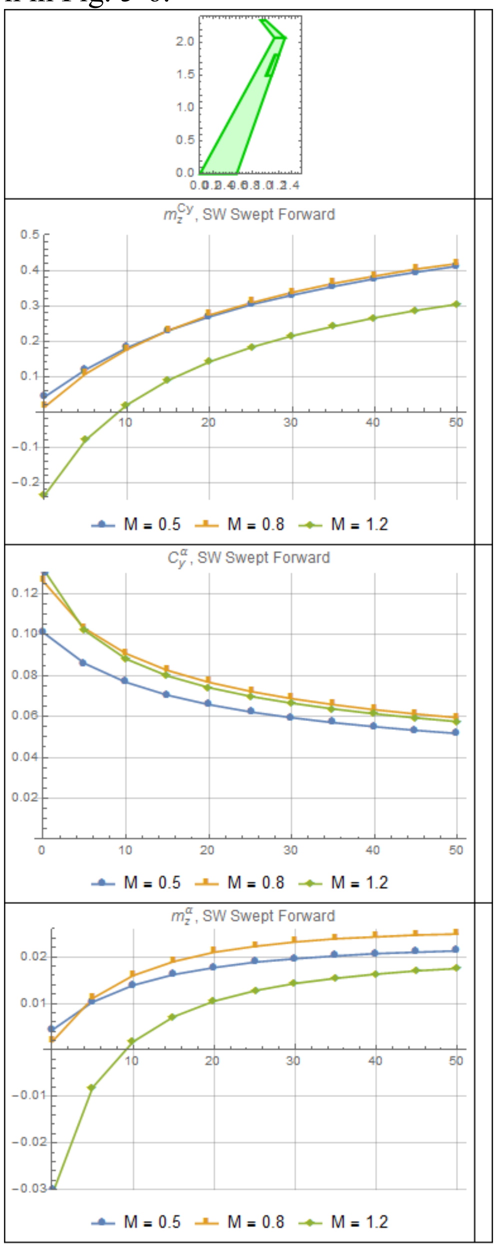

Fig. 5. Computational model dependencies of aerodynamic derivatives with respect to dynamic pressure for a wing with swept forward winglet

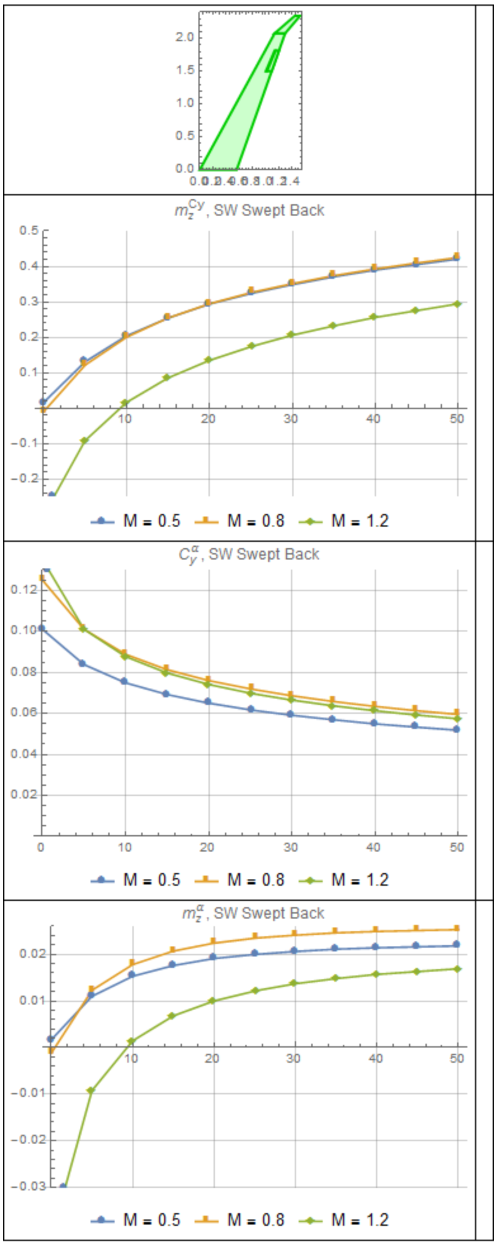

Fig. 6. Computational model dependencies of aerodynamic derivatives with respect to dynamic pressure for a wing with swept back winglet

5 Loads

Using active winglets as control surfaces produces spanwise load distribution another that caused by an aileron. For some regimes the resulting loads caused by deflection of an aileron and active winglet by the same angle in the same direction may be of opposite sign. This offers the opportunity to reduce the loads at flight regimes critical for structural strength by deflecting the aileron and active winglet simultaneously as can be seen in Fig. 7-10.

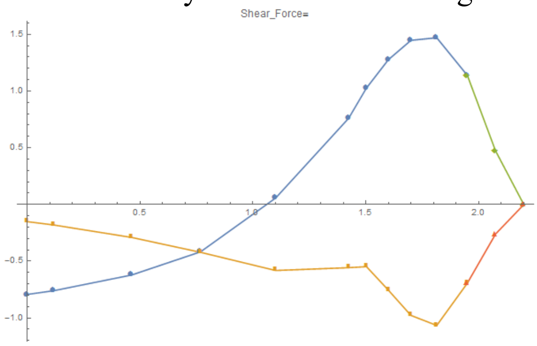

Fig. 7. Distributions of the shear force from the aileron (red/brown lines) and active winglet (green/blue) deflection by 10°, variant of swept forward winglet

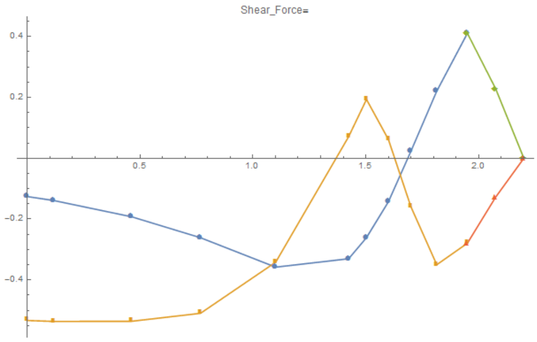

Fig. 8. Distributions of the shear force from the aileron (red/brown lines) and active winglet (green/blue) deflection by 10°, variant of swept back winglet

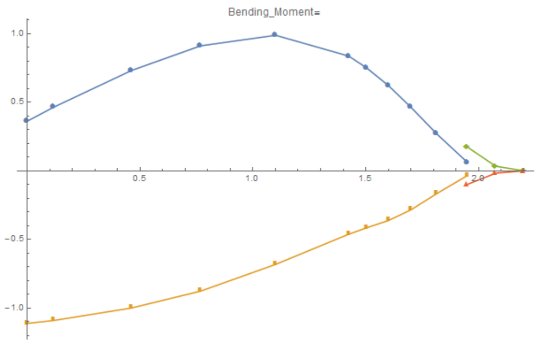

Fig. 9. Spanwise distribution of bending moment resulting from aileron (red/brown lines) and active winglet (green/blue) deflection by 10°, variant of swept forward winglet

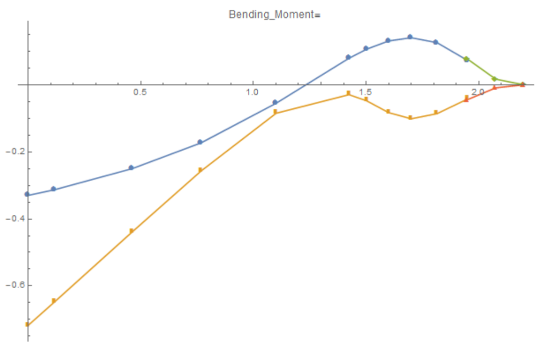

Fig. 10. Spanwise distribution of bending moment resulting from aileron (red/brown lines) and active winglet (green/blue) deflection by 10°, variant of swept back winglet.

For some flight regimes, the control surfaces can be used not only for roll control but to reduce the loads. Fig. 11 shows the effect is considerable and can be used to reduce the structural weight of the wing. Both aileron and active winglets can be used in this manner. The total wing structural weight reduction by up to 4% can be achieved in this way.

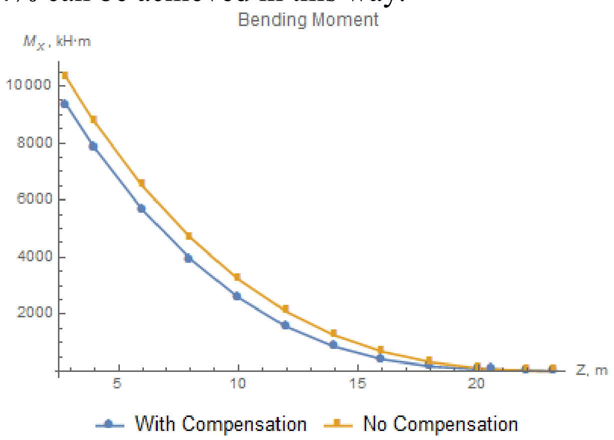

Fig. 11. Spanwise bending moment distribution with and without load compensation

6 Flutter performance

Flutter characteristics (Fig. 12-14) are among the determining factors to choose winglet type. Placing mass aft the stiffness axis tends to reduce critical flutter speed of the aircraft with clean wing with no engines. Swept-back monoplane winglets considerably reduce critical flutter speed. Swept-forward monoplane winglets affect the flutter speeds to the least extent (Fig. 13). It is necessary to search for a solution of a problem of a flutter in the long term on ways of active use of deflectable winglets as means of a flutter suppression.

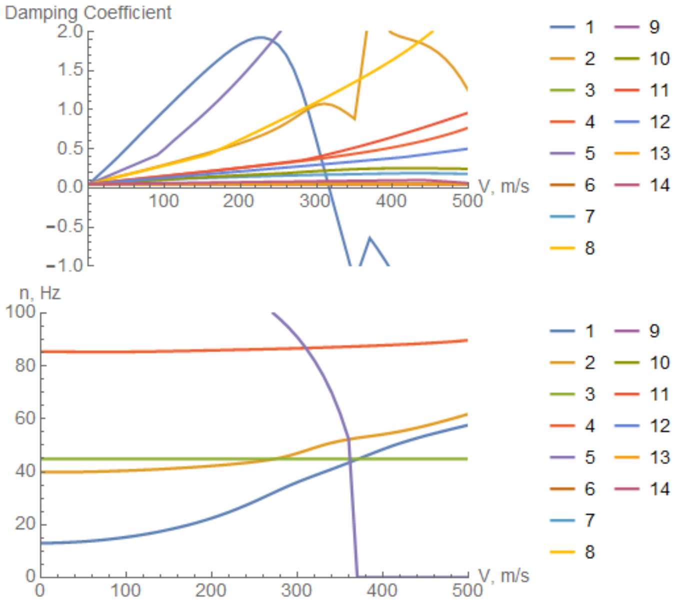

Fig. 12. Flutter properties of the wing without winglet

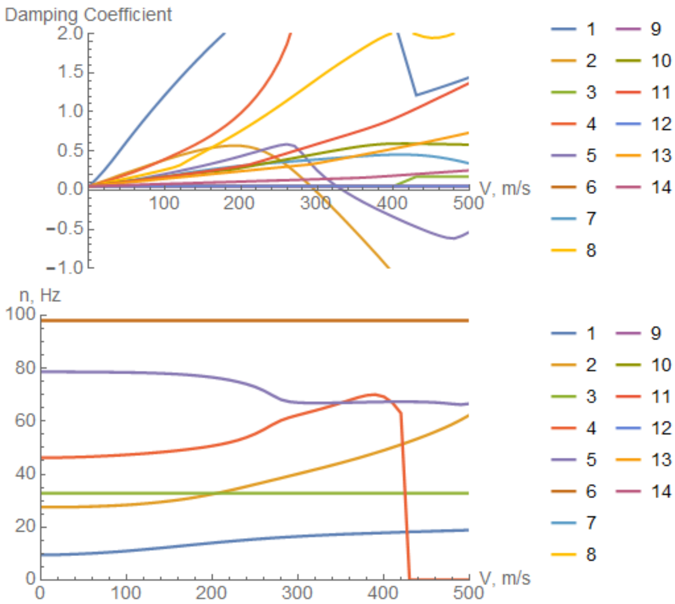

Fig. 13. Flutter properties of the wing with swept forward winglet

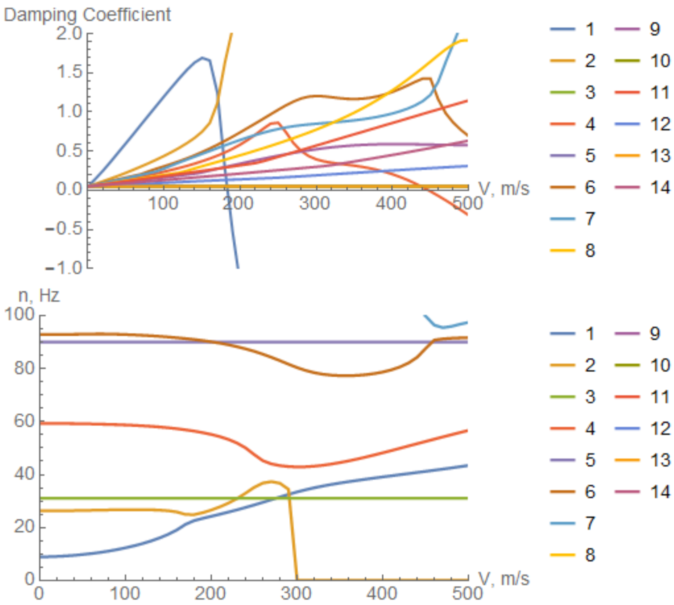

Fig. 14. Flutter properties of the wing with swept back winglet

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