

ANALYSIS OF STABILITY DERIVATIVES IMPORTANT TO RECOVERY FROM SPIN

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Abstract. This paper describes the numerical analysis of light aircraft stability derivatives in a wide range of angles of attack, important for recovery from spin. Stability derivatives versus angle of attack and sideslip were calculated using a CFD software, based on Euler equation combined with boundary layer equations. The analysis was performed up to the 40 deg of angle of attack and up to 25 deg of sideslip.

Keywords: aerodynamics, CFD, spin.

1. Introduction

Spin is known to be a very complex and still dangerous phenomenon in aviation. Certain types of new designed aircraft are incapable to recover from some types of spin, mainly due to the empennage design, moment of inertia and aerodynamic features. Such a situation is unacceptable, especially for light general-aviation airplanes which by nature are flown by not very experienced pilots. A huge number of papers and reports devoted to spin technology have been published (Goraj, Baron 2002; Baron,

Goraj 2001; Bowman 1971, Goraj *et al.* 2002; Goraj 2001), but there are still a number of challenges and questions which cannot be easily solved and answered for an individual design project and aircraft prototype. It is mainly because the spinning motion is very complicated and involves simultaneous rolling, yawing and pitching while the airplane is at high angles of attack and sideslip. Since it involves strongly separated flows in the region beyond the stall, the aerodynamic characteristics of the airplane are strongly nonlinear and time dependent.

Numerical analysis of the spin should be made by a coupled CFD/Flight dynamics solver. Unfortunately, this method is very time-consuming. Therefore, we had to use one of the less-consuming methods of analysis for an aircraft's recovery from spin, which consists of an analysis of aircraft stability derivatives. Computations were made for a wide range of angles of attack and sideslip. This method allows making a preliminary assessment of the capabilities of aircraft recovery from spin.

1. Basic Consideration

The main goal of the study presented in the paper was to investigate the stability derivatives within a wide range of angles of attack and sideslip which are important for recovery from spin. A light aircraft in a classic configuration with a cruciform tailplane was selected as the object for this study. The layout of the aircraft considered is presented in Fig. 1.

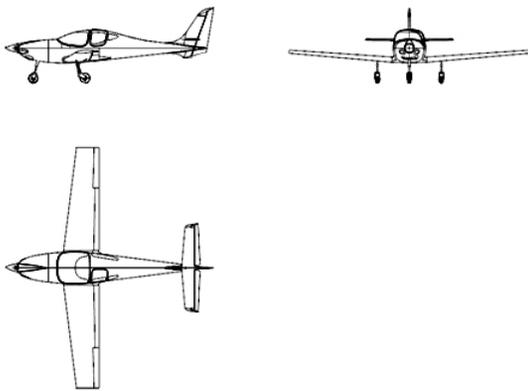


Fig. 1. Light aircraft

The whole work is focused mainly on the aerodynamic calculations of a light aircraft and its stability derivatives (Figat *et al.* 2013). The analysis starts from the creation of a CFD model. As a result of calculations, the aerodynamic characteristics versus the angle of attack and sideslip were obtained. Next, the change of the most important stability derivatives versus angle of attack and sideslip was investigated.

2. Aerodynamic Analysis

The preparation for aerodynamic calculations includes the creation of the CFD model, choice of the method of analysis and definition of a convention of the sign for the most important aerodynamic coefficients such as yaw moment coefficient C_n and roll moment coefficient C_l . Moreover, conventions of sign connected with the rudder and elevator deflection were defined as well.

2.1. The model

Aerodynamic calculations were performed for the complete model of the aircraft which is presented in Fig. 2.

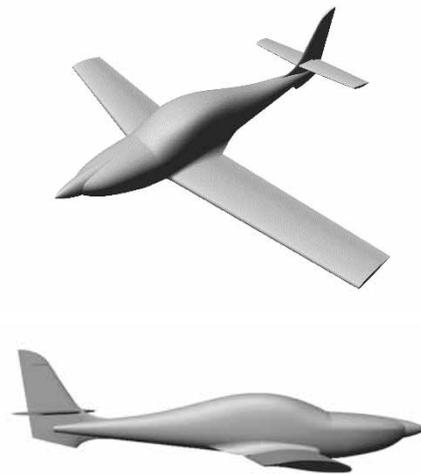


Fig. 2. The CFD model of a light aircraft

2.2. Numerical method

When selecting the software for numerical calculations one must remember that this software will be used at very high angles of attack, up to the 40 deg. It means we will enter overcritical angles of attack with complete flow separation on the vertical and horizontal stabilisers. Therefore, all computations were made by MGAERO (MGAERO user's manual) software. This software is based on the Euler equation (Anderson Jr. 1992) with a multi-grid acceleration scheme (Mavriplis 1992). The computational mesh is presented in Fig. 3.

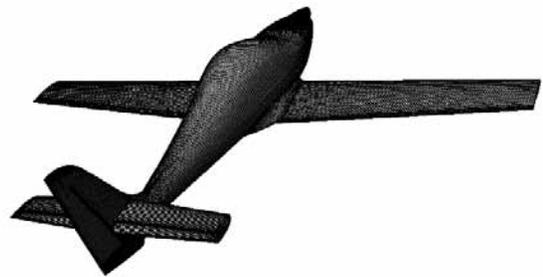


Fig. 3. Computational mesh

2.3. Sign conventions

Results of aerodynamic calculations were obtained by the aerodynamic solver presented in section 2.2. All the results were obtained in a specific coordinate system of the MGAERO software (MGAERO user's manual). According to it, the definition of sign convention is presented. Figs 4 and 5 present the positive value of aerodynamic coefficient C_n for the yaw moment coefficient and C_l for the roll moment coefficient versus the sideslip angle. Both aerodynamic moment coefficients are referred to the semi-span of the wing.

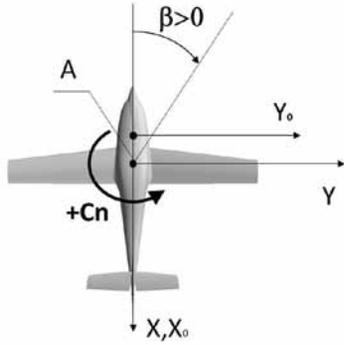


Fig. 4. Sign convention: yaw moment coefficient versus sideslip angle

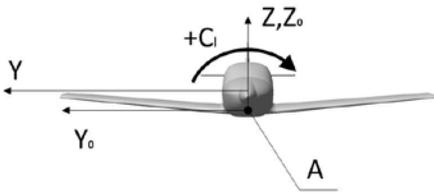


Fig. 5. Sign convention: rolling moment coefficient

According to the sign convention, the stability criterion for the spin recovery was established. The value (i.e. sign) of the stability derivatives which are the most important for the spin recovery should be satisfied by the following conditions:

$$\frac{\partial C_n}{\partial \beta} < 0; \quad \frac{\partial C_l}{\partial \beta} > 0;$$

It means that the derivative of the yaw moment with respect to the sideslip angle should be negative, but the derivative of the roll moment coefficient with respect to the sideslip angle should be positive. The fulfilment of both of these two conditions means that an aircraft has a satisfactory spin resistance.

3. Results

The computation schedule assumes that the basic aerodynamic characteristics for low angles of attack were obtained first. Next, the computation of stability derivatives was performed for the selected angles of attack and sideslip which correspond to the flight conditions in spin. The analysis was performed up to the 40 deg of angle of attack and up to 25 deg sideslip. Fig. 6. Cp distribution for the $\alpha = 20\text{deg}$ $\beta = 0\text{deg}$ and Fig. 7. Cp distribution for $\alpha = 40\text{deg}$ and $\beta = 25\text{deg}$ present the C_p distribution for the light aircraft considered.

3.1. Results of computations

The results of the computations of the aerodynamic coefficients: the side force, yaw moment and rolling moment, were obtained. The side force coefficient C_s (Fig.

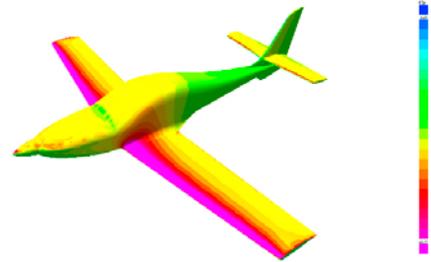


Fig. 6. Cp distribution for the $\alpha = 20\text{deg}$ $\beta = 0\text{deg}$

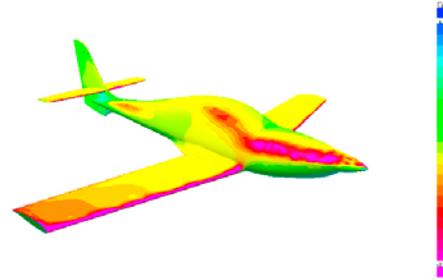


Fig. 7. Cp distribution for $\alpha = 40\text{deg}$ and $\beta = 25\text{deg}$

8 and Fig. 9) is presented first. The sign change is observed when the angle of attack is increasing. Next, the yaw moment coefficients C_n versus the angle of attack and sideslip are presented in Figs 10 and 11. The roll moment coefficients C_l courses are presented in Figs 12 and 13.

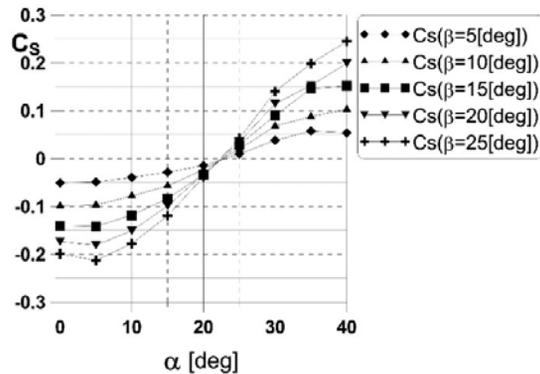


Fig. 8. Side force coefficient versus angle of attack

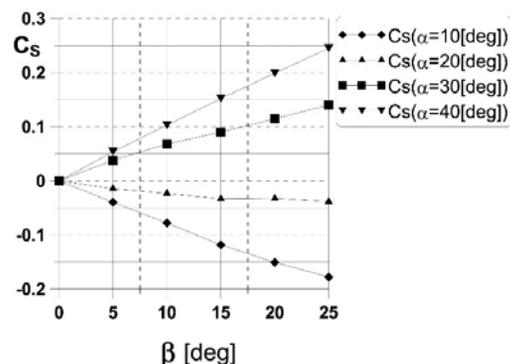


Fig. 9. Side force coefficient versus sideslip angle

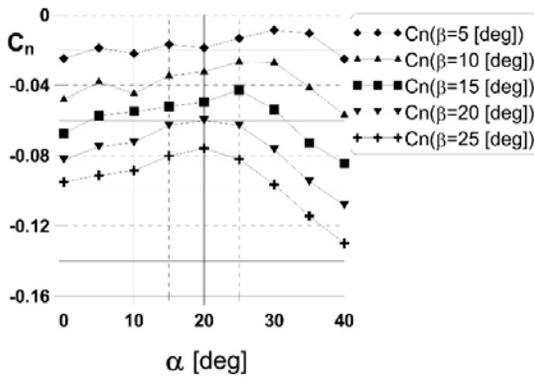


Fig. 10. Yaw moment coefficient C_n versus angle of attack

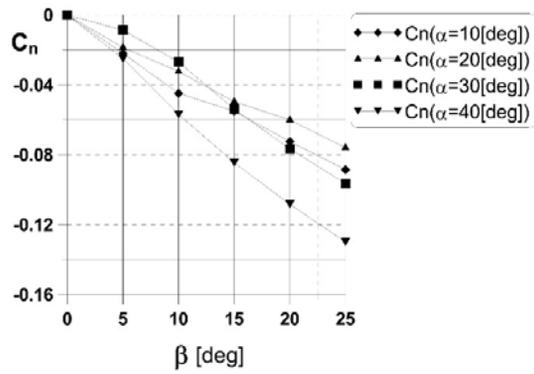


Fig. 11. Yaw moment coefficient C_n versus sideslip angle

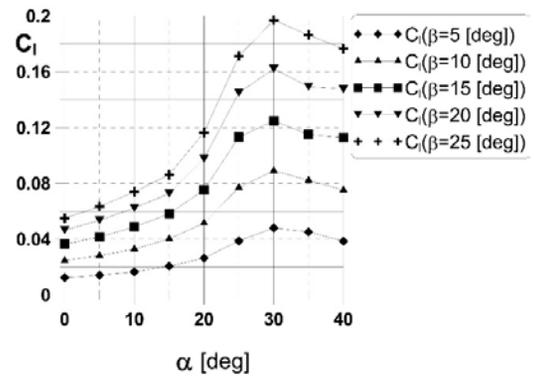


Fig. 12. Roll moment coefficient C_l versus angle of attack

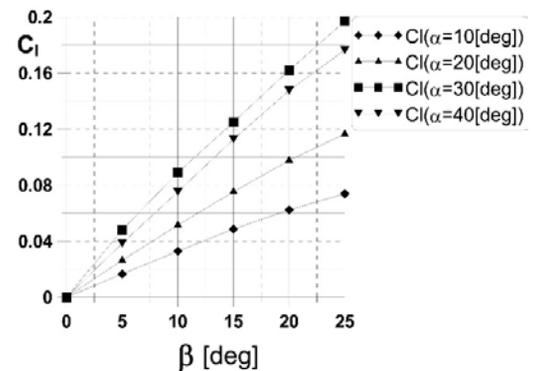


Fig. 13. Roll moment coefficient C_l versus sideslip angle

The results of the computations of aerodynamic coefficients reveal proper values and signs of force and moment coefficients (Figs 8–13). Only the side force coefficient changed the sign at higher angles of attack (about 22 deg).

3.2. Stability derivatives

The results of the aerodynamic calculations which were presented in section 3.1 allow to assess (calculate) the most important stability derivatives essential for an aircraft's behaviour and recovery from spin. Firstly, the efficiency of the vertical stabiliser versus the angle of attack was analysed (Fig. 14). This efficiency is represented by stability derivatives a_{v1} . The side force coefficient generated at the vertical stabiliser with respect to the sideslip and angle of attack reveals that vertical stabiliser efficiency decreases in the considered range of angles of attack but its sign is still correct (i.e. anti-spin properties are observed).

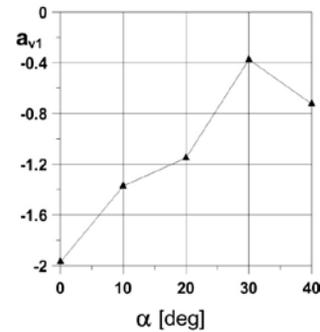


Fig. 14. Side force derivative of vertical stabiliser versus sideslip and angle of attack

Afterwards, the change in stability derivatives with respect to the sideslip was investigated (Figs 15–17). All the obtained results are acceptable (i.e. anti-spin properties are kept). The change in stability derivatives means that the aircraft's recovery from spin may be weak (poor), but the aircraft is, in theory, still stable. It means that its aerodynamic characteristics prevent the aircraft from entering into a spin. However, if the aircraft is spinning, these aerodynamic characteristics help to recover from the spin. Only the side force derivative changed the sign, but this stability derivative is less important for the dynamic behaviour of an aircraft in spin (i.e. spin is less sensitive to this derivative).

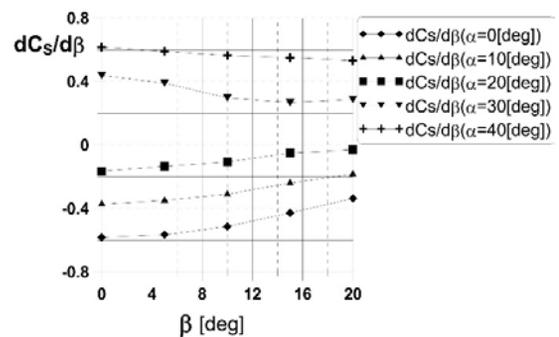


Fig. 15. Stability derivatives $\partial C_s / \partial \beta$ – side force coefficients versus sideslip angle

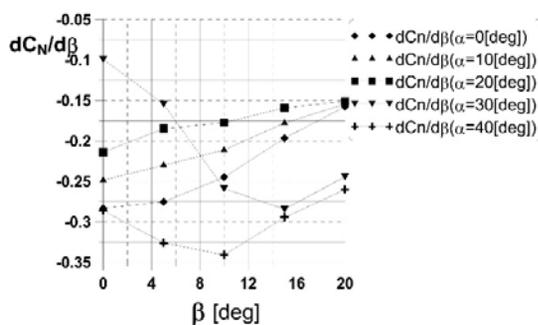


Fig. 16. Stability derivatives $\partial C_n / \partial \beta$ – yaw moment coefficients versus sideslip angle

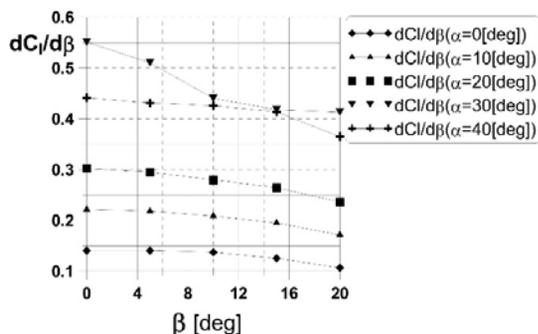


Fig. 17. Stability derivatives $\partial C_l / \partial \beta$ – roll moment coefficients versus sideslip angle

The results of computations of stability derivatives reveal that the aircraft is statically stable in the lateral direction. It means that the stability criterion is satisfied for the entire considered range of angles of attack and sideslips.

Conclusions

The paper presents the numerical analysis of light aircraft stability derivatives in a wide range of angles of attack important for recovery from spin. The analysis was performed up to 40 deg of angles of attack and up to a 25 deg sideslip. The general conclusion that the aerodynamic analysis and stability derivative calculations revealed is that the aircraft under consideration is directionally stable in a wide range of angles of attack. This is caused by the fulfilment of the stability criterion, defined in section 2.3, in the entire range of angles of attack and sideslip. It means that its aerodynamic characteristics allow both protecting the aircraft against the casual entry into spin and enabling a relatively easy recovery if for any reason the aircraft has entered into a spin.

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