Flight Control System Design and Analysis of a Light Sport Aircraft with Emphasis on Multibody Dynamics and Aerodynamic Analysis

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Abstract: *The present contribution is a companion paper of [9] which presents a preliminary design of the flight control system of a Light Sport Aircraft (based on previous wind tunnel analysis), validation process, aerodynamic simulations in ANSYS CFX and multibody dynamics in Adams. The main purpose of this study is to obtain knowledge on simulation software's, as Ansys and Adams, in order to design, calculate and improve the flight control mechanism of an ultralight aircraft.*

Key Words: *aircraft design, aerodynamics, wind tunnel, wingtip vortices, multibody-dynamics*

1. INTRODUCTION

The main purpose of this paper is to describe a method for design and calculation of the flight control system of a Light Sport Aircraft according to the CS-LSA certification requirements [1]. The detailed design of the flight control system has two main steps:

- Aerodynamic analysis, using ANSYS CFD solve,
- MBS (Multibody Dynamics) analysis in MSC ADAMS.

The aerodynamic analyses consist of acquiring experimental data and numerical simulations. For the wind tunnel experiments a 1/10 scaled model airplane was made in order to calculate the drag polar of the concept airplane. According to the obtained experimental data the computational model was calibrated in ANSYS. The wing drag polar and induced drag coefficient for different wing tip configurations were analysed. The analyses were followed by a validation process, based on Eppler wind tunnel results. Considering the wing validated CFD calculations a model for the aileron section was set, which has the same physical domain size and computational parameters.

According to the ASTM F2245-16a/5.7 requirements the analysis for the aileron, for different deflection angles has been established, obtaining the aerodynamic load curve of the aileron surface.

The obtained aerodynamic loads of the aileron surface were used as input data for the multibody dynamic analysis.

The flight control system of the aileron was calculated in accordance with the ASTM F2245-16a/5.7 requirements [12]. The diagram below shows the main steps of this scientific paper:

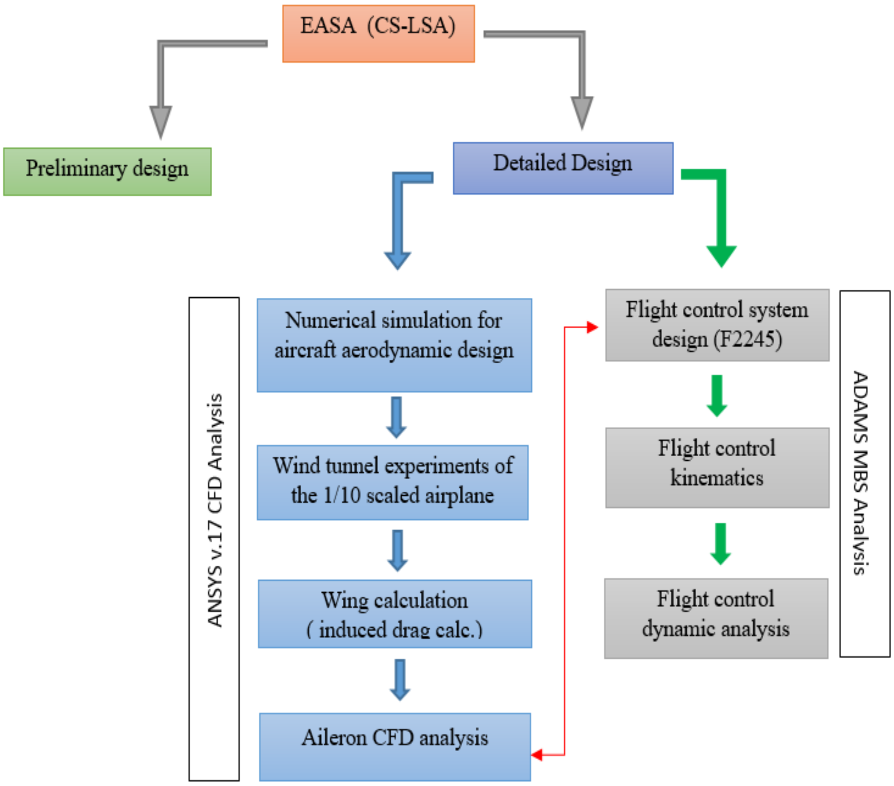


Fig. 1 - The flowchart of the flight control system analysis

The general characteristics of the presented airplane, named *Sky Dreamer* [9], are shown in Table 1.

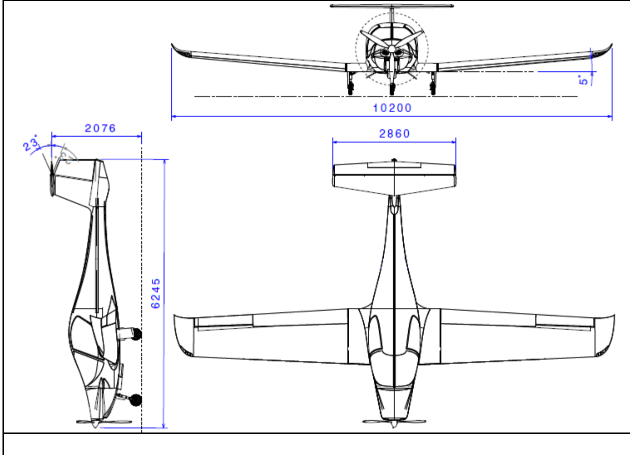


Fig. 2 - Top, Front and Lateral views of the airplane [9]

Table 1 - General characteristics of the airplane

Parameter	**Value**
Crew	Two
Empty weight	315 kg
Max.Take-off weight	600 kg
Fuel capacity	100 L
Engine	Rotax 912iS
Maximum speed	317 km/h
Cruising speed	226 km/h
Operational Range	1650 km
Service ceiling	5500 m
Length	6.45 m
Wing Area	11.5 m2
Wingspan	10.2 m
Wing Airfoil	Eppler 562 [3]

The preliminary design of the concept airplane was followed by a series of wind tunnel tests of a 1/10 scaled model airplane.

The experiments were performed using the infrastructure of the Aerodynamics laboratory of Transilvania University of Brasov.

The used wind tunnel, see Figure 3, has a closed test section of 1.2m x 0.6m x 1.2m, maximum velocity of 40 m/s and the turbulence lower than 0.5%, which meets the SAE (Society of the Automotive Engineers [4]) requirements.

The wind tunnel has a four-component strain-gauge balance with a PC-based system of data acquisition [5].

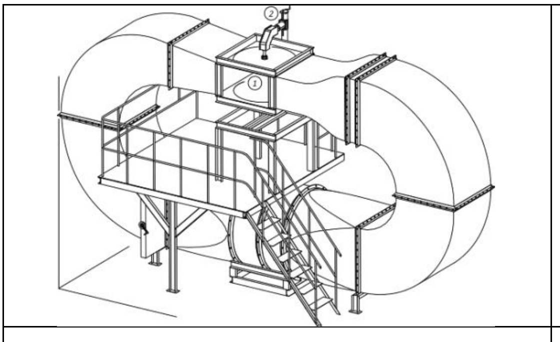


Fig. 3 - Axonometric view of wind tunnel test section and (2) aerodynamic (strain-gauge) balance [9]

Fig. 4 - The model within the wind tunnel test section

The results concerning the calibration of this tensometric device are shown in figure 4. They describes the dependencies between the magnitude of the aerodynamics forces acting on the model, and the values of the signals, lift () and drag (), displayed by the data acquisition system

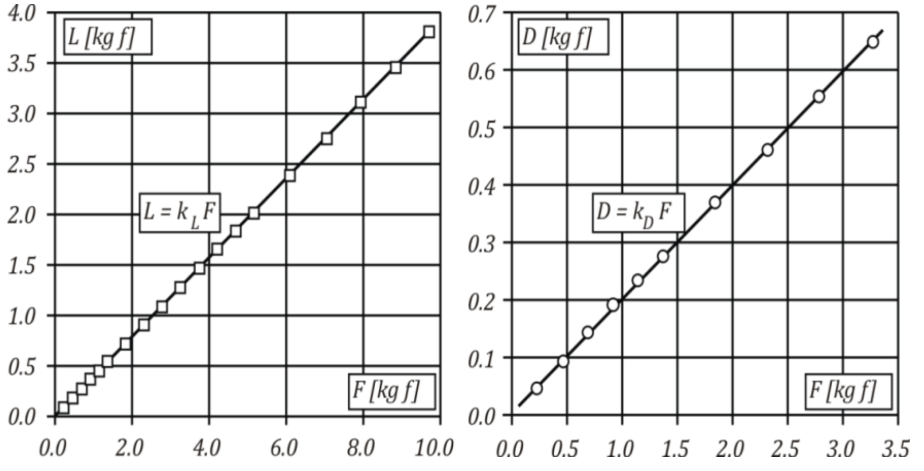


Fig. 5 - Calibration curves of the aerodynamic balance [9]

2. WIND TUNEL RESULTS

According to the wind tunnel results, the studied airplane has shown outstanding aerodynamic performances comparatively to other aircraft in the same class of certification, LSA. Due to the higher aerodynamic performance it results lower fuel consumption and 10% higher flight range.

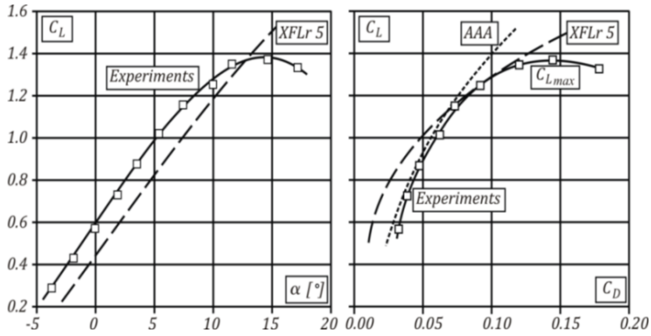


Fig. 6 - Theoretical and experimental drag polar results [9]

3. WINGTIP VORTICES

The wind tunnel experiments of the model airplane were followed by a detailed design process for different wing tip configurations [6, 7, 8]. Several physical domain sizes were analysed in order to reduce the adverse pressure effect between the body and the walls. The validations of the results were taken for the following domain size: front 6c (chord), up 6c, down 6c, back 12c. The analyses of the vortex structures have shown the formation of the wing tip vortices with the separation regions. The cut-off wingtip generates the highest vortices which are composed of three distinct structures. For the rounded wingtip the vortices are composed of two structures with lower vortex core, resulting a lower induced drag. The lowest vortices were obtained for the upswept winglet, where the wingtip vortices dissipate much faster and the vortex region is concentrated at the TE of the winglet [10].

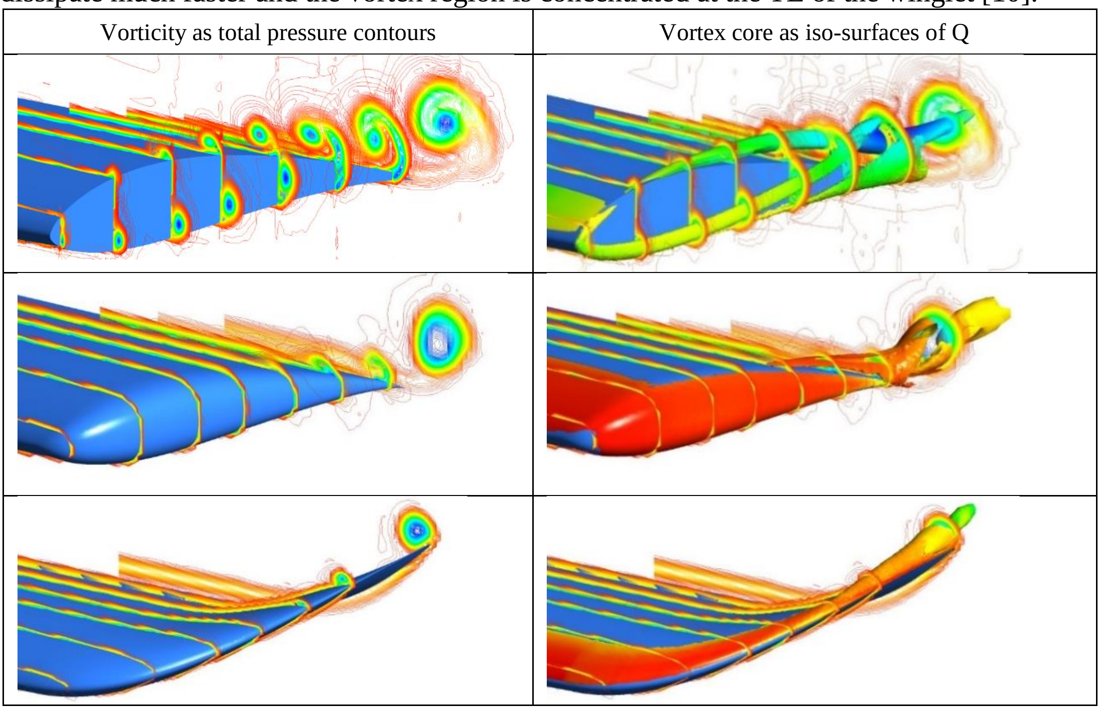


Fig. 7 - Vortex representation

A more accurate presentation of the wing tip vortices are shown in figure 8 which shows a comparison between the wing tip pressure coefficient variations for different sections lines.

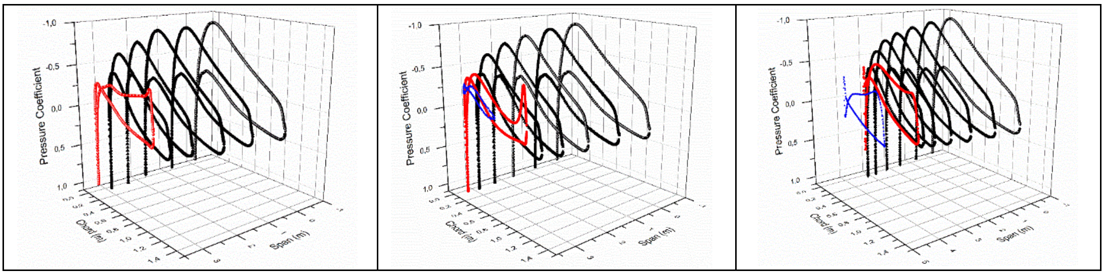


Fig. 8 - Pressure distribution for: cut-off, rounded wing tip and up-swept winglet

4. WINGTIP VORTICES RESULTS

The wing polar curve for the studied wingtip configurations and the values of the lift-induced drag coefficient for each case are presented in fig. 9 and table 2.

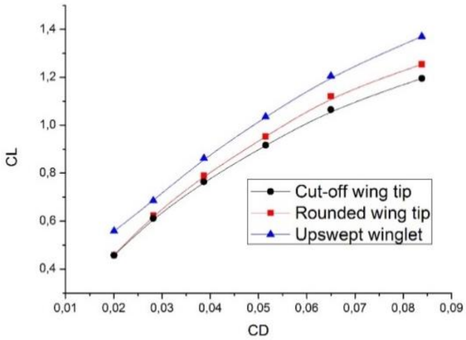


Fig. 9 - Wing polar curve for the studied wingtip configurations

Table 2 - The obtained induced drag values are as follows:

	Cut-of wing tip	Rounded wing tip	Upswept winglet
C_{Di} [11]	0.065529	0.06373	0.058383

From the analysis it can be observed that the rounded wing tip has an insignificant influence on the lift coefficient of the wing; instead the up-swept winglet has shown an approx. 12% improved lift coefficient and a 17% lower drag according to the cut-of wing tip.

5. AILERON CFX ANALYSIS

According to the wingtip CFD analysis a model for the aileron section was set with the same physical domain size and computational RANS SST model. The main purpose of the analysis was to obtain the resulting forces acting on the aileron surface for different flight conditions as specified in ASTM F2245-16a/5.7 The analysis was set to a grid point of 5.3e+06. The grid distributions around the wing and aileron surface are shown in Figure 10.

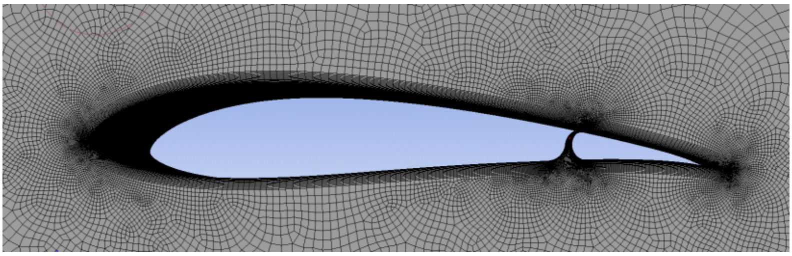


Fig. 10 - Mesh topology around the wing and aileron (Nodes 5,3e+06, elements 5,1e+06)

The analyses were performed in steady state, adiabatic, fully turbulent conditions, for a reference pressure and temperature of the air $p\infty$ = 1 At, T ∞ = 288.15 K. The reference velocity of free stream was v_∞ = 40 m/s (Re = 3.6e+06).

The SST (Shear Stress Transport) ω −k turbulence model widely used in aerodynamics was also used.

The pressure coefficient distribution for the aileron maximum operation angles are shown in fig. 11.

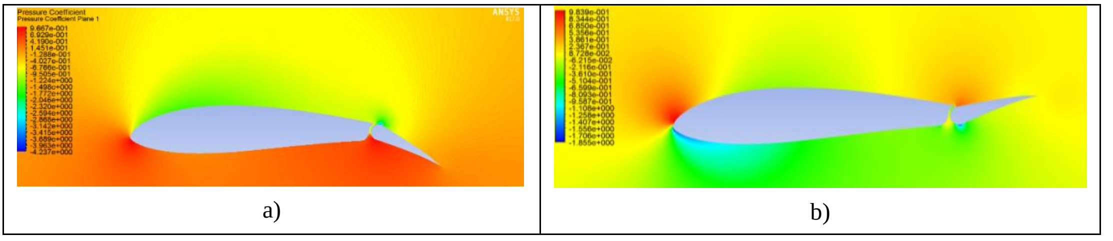


Fig. 11 - Pressure coefficient distribution around the wing and aileron cross-section
a) aileron max. negative deflection angle b) aileron max. positive deflection angle

The resulting aerodynamic forces acting on the aileron surface at manoeuvring and design dive speed conditions are shown in fig. 12.

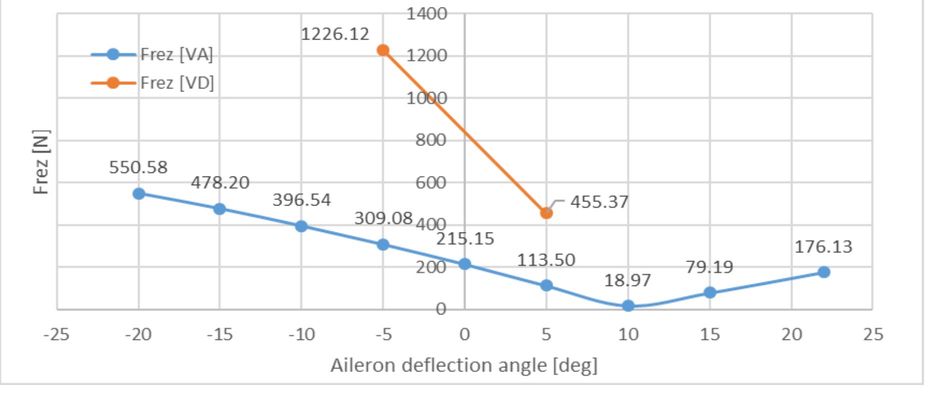


Fig. 12 - Resulting forces on the aileron for different deflection angle

6. FLIGHT CONTROL SYSTEM MBS ANALYSIS IN ADAMS

The primary and secondary flight control systems of the presented aircraft are shown in fig. 13.

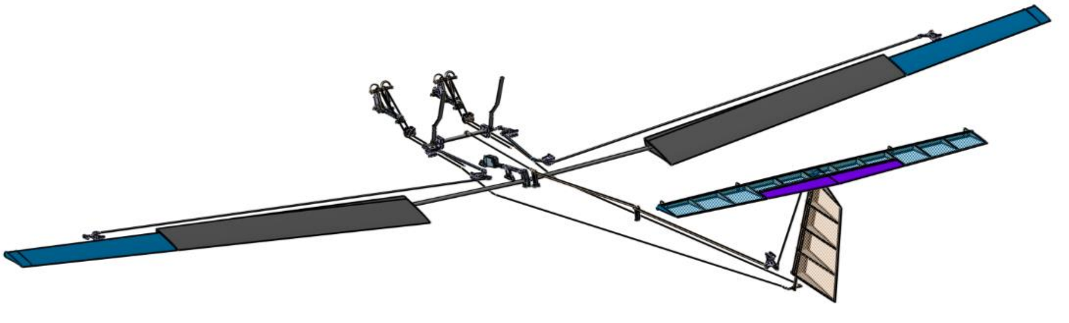


Fig. 13 - Aircraft flight control system

According to the CS-LSA requirements the airplane Manoeuvre & Gust diagram for MSL was calculated; the results are shown in fig. 14 [2].

[Vs] = 44 kts (23 m/s)
[VF] =39 kts (20 m/s)
[VA] = 88 kts (45 m/s)
[VG] = 89 kts (46 m/s)
[VC] = 122 kts (63 m/s)
[VD] = 171 kts (88 m/s)

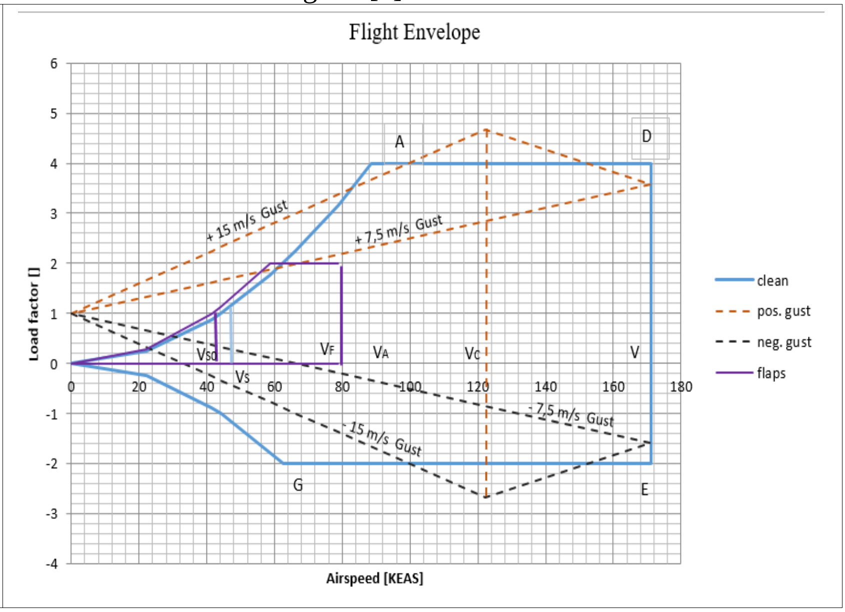


Fig. 14 - Aircraft Flight Envelope

The ailerons must be designed for control loads corresponding to the following conditions described in ASTM F2245-16a / 5.7.1.1 & 5.7.1.2 [12]:

- VA = 88 kts with aileron fully deflected,
- VD = 171 kts and one-third of the roll control full deflection.

The following simplified kinematic scheme was made in order to determine the kinematic variables: rotational motion, translational motion and general plane motion of the members.

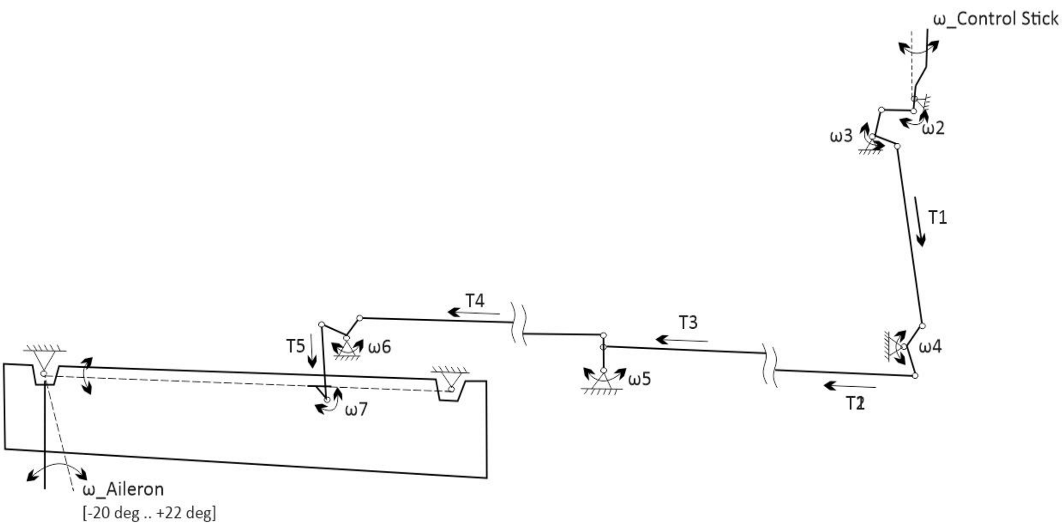
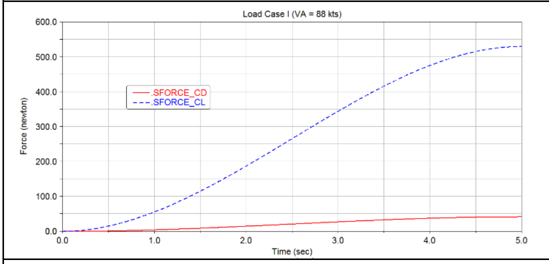
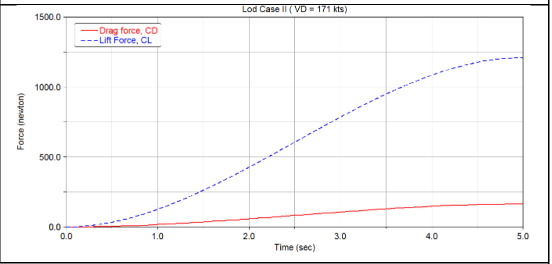
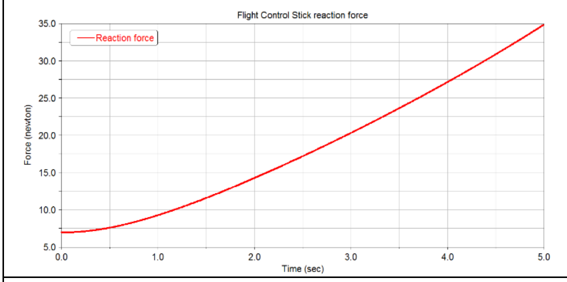
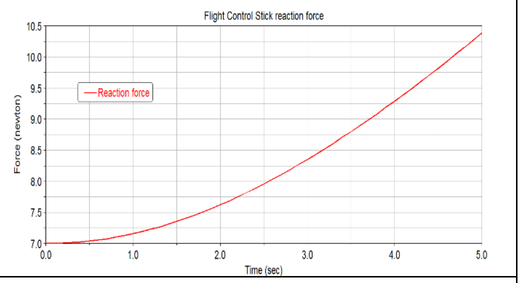


Fig. 15 The generalized kinematic scheme of the aileron control mechanism

The forces on the aileron flight control surface and the obtained reaction forces of the control stick for the specified load cases are shown in table 3.

Table 3 - Force and reaction force in the flight control system

<table>
<tr><th>Load case I. [VA]</th><th>Load case II. [VD]</th></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td colspan="2">Aileron Control surface aerodynamic forces</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td colspan="2">Flight control stick reaction force</td></tr>
</table>

7. CONCLUSIONS

Using the MSC Adams MBS Software several flight control mechanisms were simulated in order to improve the kinematic model and reduce the reaction forces in the mechanism.

The kinematic analysis was followed by dynamic simulation models, where the control stick reaction force and the connection joints reaction force were measured.

According to the obtained results from MSC Adams the reaction force on the control stick for the two load cases ranges between 10.5 N and 35 N. Accordingly, the aileron flight control system meets the ASTM F2245-16a / 4.5.1.2 requirements.

The presented method for the flight control system design is an alternative method to calculate a complex flight control mechanisms.

It shall be mentioned that there are quicker calculation methods, but using a well-defined MBS model, multiple flight control mechanisms can be simulated in a fraction of time, which significantly decrease the estimated design time.

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REFERENCES

[1] * * * EASA, Certification Specification and Acceptable Means of Compliance for Light Sport Airplanes, CS-LSA, European Aviation Safety Agency, 2013.

[2] J. Roskam, *Airplane Design, Part I. Preliminary Sizing of Airplanes*, University of Kansas, 1985.

[3] R. Eppler, *Airfoil Design and Data*, Springer Verlag, Berlin, 1990.

[4] * * * SAE, Aerodynamic Testing of Road Vehicle - Testing Methods and Procedures, SAE Information Report SAE J2084 JAN93, 1993.

[5] J. Barlow, W. Rae, A. Pope, *Low-speed wind tunnel testing*, Third Edition, USA, 1999.

[6] M. D. Maughmer, Design of Winglets for High-Performance Sailplanes, *Journal of Aircraft*, Vol. **40**, No. 6, , pp. 1099-1106, 2003.

[7] R. Nangia, M. Palmer, R. Doe, Aerodynamic Design Studies of Conventional and Unconventional Wings with Winglets, *24th AIAA Applied Aerodynamics Conference*, 2006.

[8] P. Margaris, I. Gursul, Vortex topology of wing tip blowing, *Aerospace Science and Tehnology*, **14**, pp. 143-160, 2010.

[9] N. Angi, A. Huminic, Preliminary Design of a LSA Aircraft Using Wind Tunnel Tests, *INCAS BULLETIN*, Volume **7**, Issue 4 (online) ISSN 2247–4528, (print) ISSN 2066–8201, ISSN–L 2066–8201, pp. 33-39, DOI: 10.13111/2066-8201.2015.7.4.3, 2015.

[10] J. Jeong, F. Hussain, On the identification of a vortex, *J. Fluid Mechanics*, **285**, pp. 69–94, 1995.

[11] J. D. Anderson, *Fundamentals of Aerodynamics*, McGraw-Hill Series in Aeronautical and Aerospace Engineering, ISBN 0-07—237335-0, 2001.

[12] * * * ASTM F2245-16a – Standard Specification for Design and Performance of a Light Sport Airplane.