Preliminary Design of a LSA Aircraft Using Wind Tunnel Tests

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Section 1. Aerodynamic Design

Abstract: *This paper presents preliminary results concerning the design and aerodynamic calculations of a light sport aircraft (LSA). These were performed for a new lightweight, low cost, low fuel consumption and long-range aircraft. The design process was based on specific software tools as Advanced Aircraft Analysis (AAA), XFlr 5 aerodynamic and dynamic stability analysis, and Catia design, according to CS-LSA requirements. The calculations were accomplished by a series of tests performed in the wind tunnel in order to assess experimentally the aerodynamic characteristics of the airplane.*

Key Words: *aircraft design, Computer Aided Design, aerodynamics, wind tunnel*

1. INTRODUCTION

The aircraft development process consists in the following main steps: market analysis and customer requirements, mission specifications, conceptual and preliminary design, detailed design, prototype manufacturing, flight test, and finally the aircraft production. In the first stage, the aircraft structure is defined as concept, without precise calculations. Thus, the preliminary design phase tends to employ the outcomes of a calculation procedure. As the name implies, the initial parameters, which are established in this step, will be optimised during next stages of the design. Hence, the initial parameters have a significant influence on the detail design phase. These parameters are also used as input data to the 3D modelling of the aircraft, the base shape being one of the main results of the preliminary design. In a modern design process, the 3D model of the aircraft plays a crucial role.

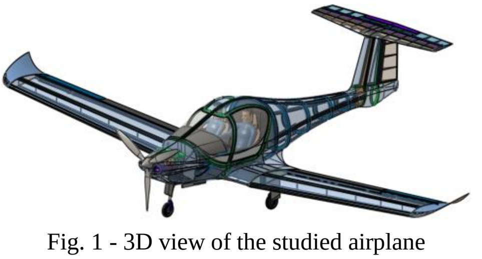

Fig. 1 - 3D view of the studied airplane

The base design of the studied aircraft, see Figures 1, 2 and 3 was also made by studying several airplanes in the same class of regulations CS-LSA [1], e.g. *Flight Design CTLSi*, *Czech Sport Aircraft*, *Evektor Harmony*.

These were analysed according to the general configuration, specific fuel consumption, flight range and main aerodynamic performances.

The preliminary design of the airplane was made with the aid of Advanced Aircraft Analysis (AAA), DARcorporation [2], a state of the art software in the field of aircraft design and analysis, and XFLr 5 [3] software.

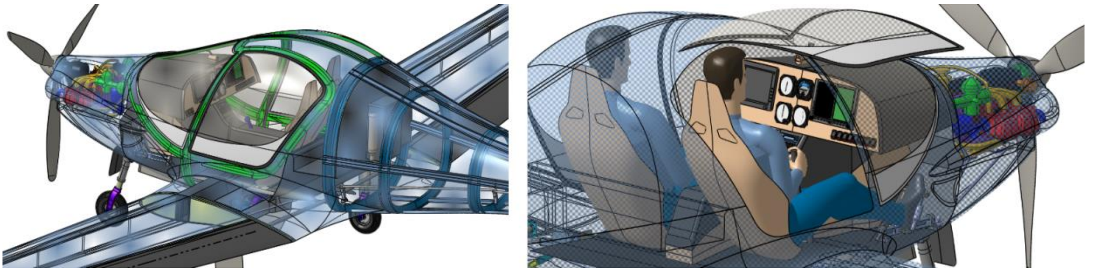

Fig. 2 - 3D view of the airplane - Details

The airplane, named *Sky Dreamer* [4], has the general characteristics shown in Table 1.

Table 1 - General characteristics of the airplane

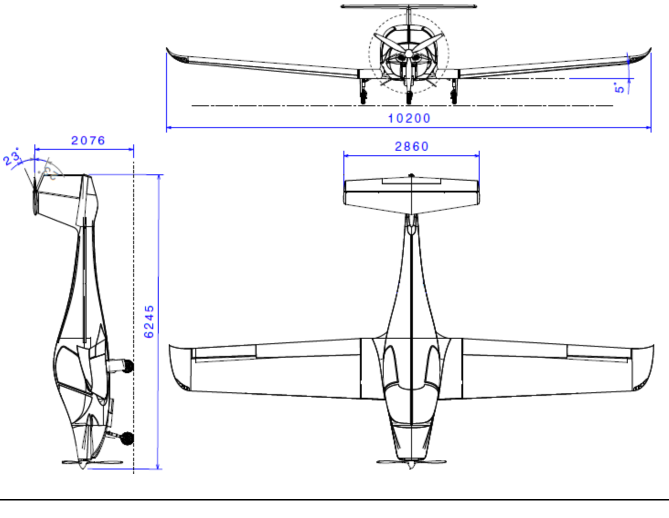

Fig. 3 - Top, Front and Lateral views of the airplane

Parameter	Value
Crew	Two
Empty weight Max. Take-off	315 kg 600 kg
Fuel capacity	100 L
Engine	Rotax 912iS
Maximum speed Cruising speed	290 km 205 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 [5]

In the first stage, the aerodynamic characteristics of the airplane were assessed for the following conditions: cruise flight with gear up at 3000 m in the following atmospheric conditions: temperature $t = -4.5\,°C$, pressure $p = 70100\,N/m^2$, density $\rho = 0.909\,kg/m^3$ and dynamic viscosity $\mu = 1.69 \cdot 10^{-5}\,kg/m\,s$.

The characteristic Reynolds number computed with the mean aerodynamic chord $AMC = 1.16\,m$ was $Re = 3.81 \cdot 10^6$.

The theoretically estimated aerodynamic performances based on XFLr 5 and AAA are shown in Figures 4 and 5.

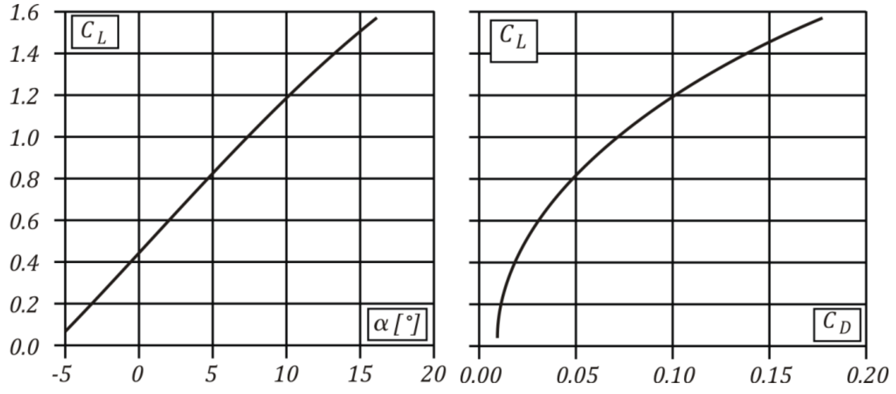

Fig 4 - Preliminary results according to XFLr 5 [3]

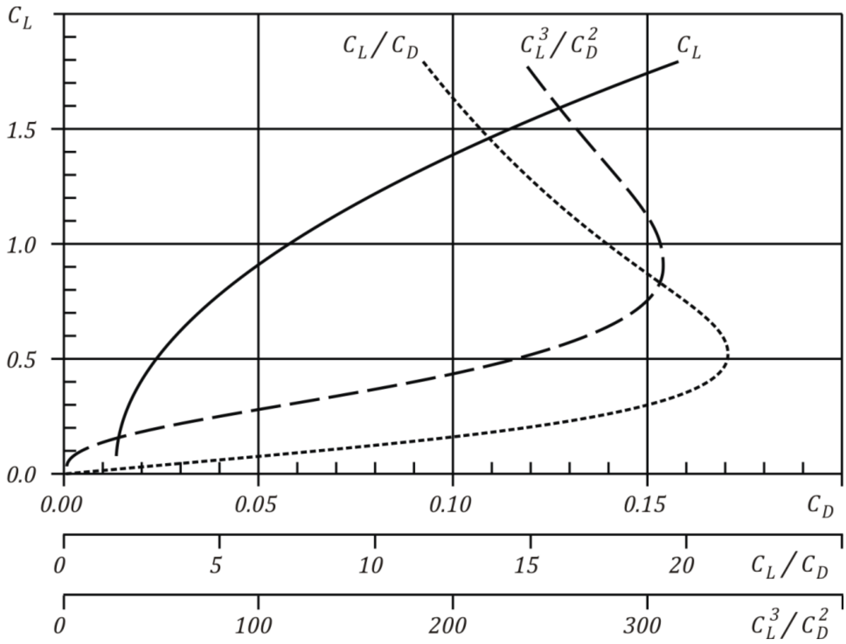

Fig. 5 - Preliminary results according to AAA [2]

According to [2], the relationship between drag and lift is expressed by the following equation.

$$C_D = 0.0122 + 0.0450 C_L^2. \quad (1)$$

2. WIND TUNNEL TESTS

In order to assess also experimentally the aerodynamic characteristics of the airplane, a 1:10 scale model was tested. The experiments were performed using the infrastructure of the Aerodynamics laboratory of Transilvania University of Brasov. The used wind tunnel, see Figure 6, 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%. It meets the requirements of the SAE (Society of the Automotive Engineers) [6]. It has a four-component strain-gauge balance with a PC-based system of data acquisition, and a moving belt device for ground effect simulation [7].

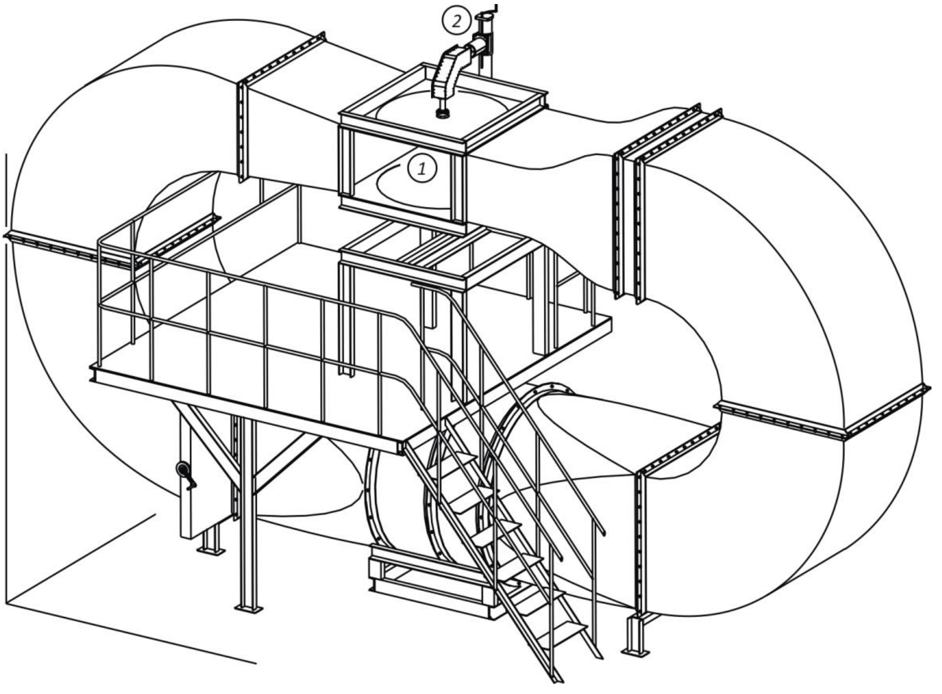

Fig. 6 - Axonometric view of wind tunnel test section and (2) aerodynamic (strain-gauge) balance

The aerodynamic strain-gauge balance used for measurements consists of a sting (used to support the model), the arm of the balance and two elastic elements (thin walls tubes), which are fixed on a frame. Details are shown in Figure 7.

Fig. 7 - The model within the wind tunnel test section

The aerodynamic forces (F) which are acting on the studied model are transmitted to the elastic elements and their deformations are taking over by the strain gages, which are glued on the elastic tubes. Finally, they are transmitted to the recording system which converts them into electrical signals, the values of the latter ones being displayed by the system of data acquisition.

Figure 8 shows the results concerning the calibration of this tensometric device. They describe the dependencies between the magnitude of the aerodynamics forces acting on the model and the values of the signals, lift (L) and drag (D), displayed by the data acquisition system

$$L = k_L\, F, \quad D = k_D\, F. \tag{2}$$

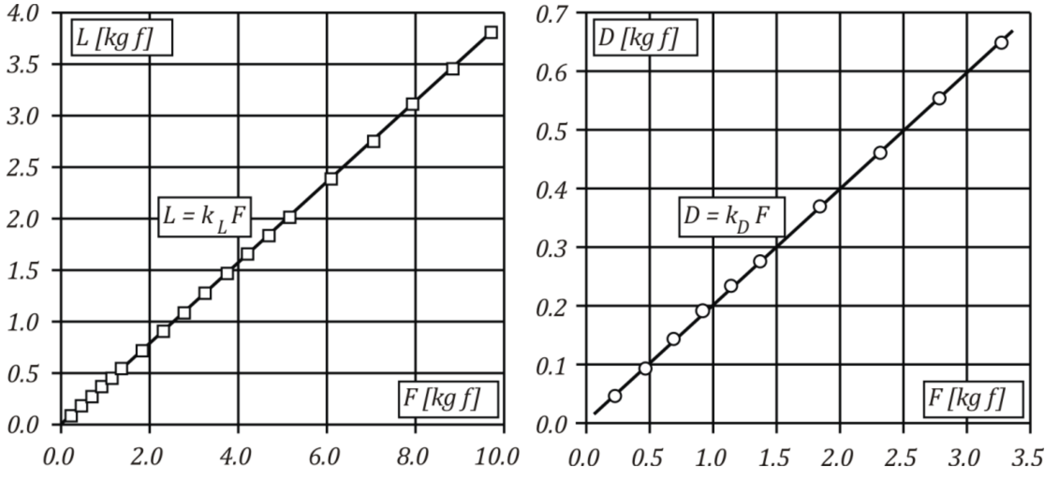

Fig. 8 - Calibration curves of the aerodynamic balance

In order to achieve variations of aerodynamic coefficients lower than 1e-03, thereby satisfying SAE requirements as stated in [5] ($\Delta C_D \leq \pm\, 0.001$), the sensitivity of the balance was set for the following values of calibration factors: $k_L = 0.4$ and $k_D = 0.2$.

3. RESULTS

After the calibration process of the balance, the model was tested for various values of the angle of attack (α).

The parameters of the airstream in the test chamber of the wind tunnel were the following: temperature $t = 26\,°C$, pressure $p = 94440\, N/m^2$, density $\rho = 1.010\, kg/m^3$ and dynamic viscosity $\mu = 1.84 \cdot 10^{-5}\, kg/m\, s$.

The characteristic Reynolds number computed with the mean aerodynamic chord $AMC = 0.116\, m$ was $Re = 2.17 \cdot 10^5$ (v =34 m/s).

The results are shown in Figure 9 after the following wind tunnel boundary corrections according to [8].

a) *Solid blockage correction:* there were applied corrections for wing and body, as following:

$$\varepsilon_w = \frac{(K_1 * \tau 1 * \mathrm{Va})}{C^{3/2}} = 1.269x10^{-3} \tag{3}$$

$$\varepsilon_b = \frac{(K_3 * \tau 3 * \mathrm{Vf})}{C^{3/2}} = 5.273x10^{-3} \tag{4}$$

$$\varepsilon = \varepsilon_w + \varepsilon_b = 6.541x10^{-3} \tag{5}$$

b) *Wake blockage correction:* the complete wake blockage results for a three-dimensional model are presented below:

$$\Delta C_{Dwing} = \frac{(K_1 * \tau 1 * Va)}{C^{3/2}} * CDp = 2.625x10^{-5} \quad (6)$$

$$\Delta CD_{body} = \frac{(K_3 * \tau 3 * Vf)}{C^{3/2}} * CDp = 1.091x10^{-4} \quad (7)$$

$$\varepsilon_{total} = \frac{S}{4 * C} * CD_0 + \frac{5 * S}{4 * C} * (CD_p - CD_i - CD_0) = -0.085 \quad (8)$$

where

$$CD_0 = CDp - (A_1 - A_2) * Cl\alpha_0^2 = 0.021 \quad (9)$$

where, A_1 and A_2 are constants

$$CD_i = A_1 * CLmax^2 - A_2 * Cl\alpha_0^2 = 0.053 \quad (10)$$

Also the measurements in the wind tunnel must meet the following condition:

$$\varepsilon_{total} = \frac{A_k}{4 * C} < 7.5\ \% \quad (11)$$

where A_k is the model front area and C the test section area. According to the wind tunnel analysis the value of ε_{total} ranges between 4.3027 and 6.8971 / varies from 4.3027 to 6.8971, which respects the prescribed condition:

c) Correction on the angle of attack and drag coefficient

$$\Delta\alpha w = \delta * \left(\frac{Sa}{C}\right) * CL \quad (12)$$

$$\Delta CDw = \delta * \left(\frac{Sa}{C}\right) * CL^2 \quad (13)$$

d) Dynamic pressure correction

$$qc = qA * [(1 + \varepsilon T)^2] \quad (14)$$

where qA is obtained from tunnel calibration.

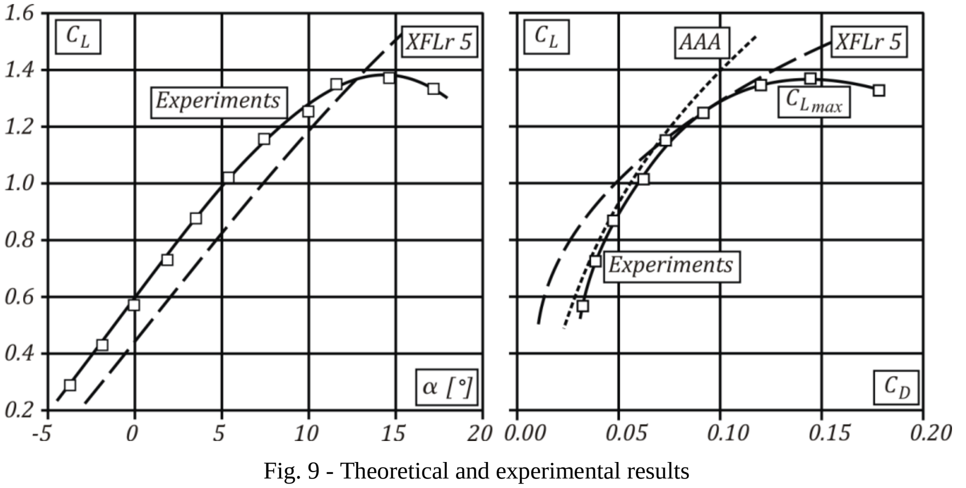

Fig. 9 - Theoretical and experimental results

4. CONCLUSIONS

According to the preliminary results, the studied airplane has ≈ 15.0 % higher aerodynamic performances comparatively to the top light sport aircrafts, in the same class of regulations CS-LSA.

Due to the higher aerodynamic performance it results lower fuel consumption and ≈10% higher flight range.

The errors between the preliminary calculation using software tools and the wind tunnel analysis were ≈ 10%. In order to check the current results, another model with a different fastening system and a lower interference for the tested model will be analyzed.

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