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SIMULATION AND AERODYNAMIC ANALYSIS OF THE FLOW AROUND THE SAILPLANE USING CFD TECHNIQUES

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Abstract

In this paper, it was described the analysis and simulation process using the CFD technique and the phenomena that shows up in the engineering aero-spatial practice, directing the studies of simulation for the air flows around sailplane. The analysis and aerodynamic simulations using Computational Fluid Dynamics techniques (CFD) are well set as instruments in the development process of an aeronautical product. The simulation techniques of fluid flow helps engineers to understand the physical phenomena that take place in the product design since its prototype faze and in the same time allows for the optimization of aeronautical products' performance concerning certain design criteria.

Key words: sailplane, airfoil, CFD analysis, pressure, velocity

1. Introduction

The sailplane is a flying machine heavier than air, unequipped with a thrust generating device and by launching at a certain altitude shall fly in a continuous descending pattern [14].

The simplest movement of the sailplane is the uniform movement, that being glided flight in a straight line with constant speed.

The sailplane's flight is a flight with a permanent height loss [16]. The main forces that act upon a sailplane in flight are [10]: lift, drag and obviously the gravitational force that acts downward (fig. 1).

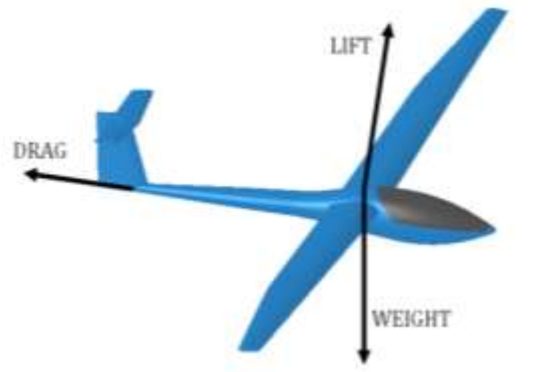

Fig. 1: The forces acting upon a sailplane

The main parts are the following: the wing, the fuselage, the stabilizers and the landing gear. The loadings at which the components from the sailplane's structure are subjected at are [23]:

- tension or compression (the triggers, the control cables, the wing skin);
- compression (the landing gear);
- bending (the wing spars);
- shearing force shows up in the moment the sailplane passes through the separation surface between an updraft and a downdraft;
- torsion - the wings during the flight are subjected to tensions around the spar.

In order to fulfil all the requirements, in the aeronautical manufacturing of sailplanes multiple material categories are used: wood, aluminium, steel, plastics, rubber and also composite materials: carbon fiber, fibreglass, fibreglass reinforced plastic or Kevlar [17].

Thanks to the technological development, the modern sailplanes have maximum glide ratios (the ratio between lift and drag) of over 60, which allows for a high performance (flight over 1700 km distance with average speeds of 150-200 km/h).

The airworthiness standards for flight acceptance, operation and service represent the regulatory documentation that asks for the exigencies and restrictions in the construction of aircrafts as well as the service limits to ensure the level of flight safety. The regulations characteristic for sailplanes are: CS 22 and JAR 22, these are applied to sailplanes and powered sailplanes on the categories utility and aerobatics: sailplanes with a maximum weight of 750 kg; single engine and a maximum weight of 850 kg and a maximum crew of two [6].

The study of sailplane aerodynamic in the technical literature is split into several fundamental research directions. One such is the development of UAV (Unmanned Aerial Vehicle) type small scale sailplanes or powered sailplanes used with different goals: environmental monitoring, earth work monitoring [15], climate monitoring, aerial photography, mapping and topography [22], earthquakes, pollution monitor [5], reconstruct building [13].

Another direction for research is the studies done by certain aviation specialist groups, within university research institutes, with the goal of developing new sailplane models having reduced weight and increased aerodynamic performance. The performances of these composite material sailplanes are analyzed experimentally in aerodynamic tunnels [4,8]. One modern research direction used by the aviation engineers is represented by the CFD analysis for sailplanes [7].

The objective of this paper is to make a preliminary characterization in terms of aerodynamics for a sailplane constructed from composite materials using the CFD simulation. From the CFD analysis of the sailplane results a first conclusion for the main aerodynamic parameters and for the simulation of flows around the sailplane.

2. Geometrical and aerodynamic aspects of the sailplane

The sailplane used in this paper represents a prototype and is part of the composite material sailplanes, especially fibreglass. The main characteristics are described in table 1.

Table 1: Sailplane characteristics

Characteristic	Value
Length	6,7 m
Height	4.5 m
Wingspan	14,2 m
Root chord	0,8 m
Tip chord	0,35 m
Airfoil	NACA 63(3)-618
Empty weight:	315 kg
Max takeoff weight	510 kg
Never exceed speed	290 km/h
Maximum glide ratio:	39:1
g limits:	+6.5 -4 at 180 km/h

For the aerodynamic analysis of the wing airfoil and drawing of the polar it shall be used JavaFoil software [19]. The wing airfoil is NACA 63(3)-618 (fig. 2).

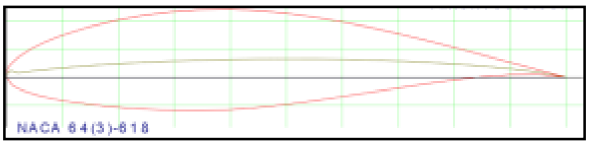

Fig. 2: Airfoil NACA 63(3)-618 [1]

The great range of aerodynamic airfoils and the multitude of direct implications over the performance of sailplanes that has the choice of the wing airfoil type require high attention. The variation of the aerodynamic coefficients (lift and drag coefficient) assumes a deeper study because the end results obtained are exceptionally important. For easily figuring out that, it should be found a parameter to which, giving more values, to be able to modify the other parameters that influence the aerodynamic coefficients. This is the angle of attack. If, for example (keeping the speed constant) varies the angle of attack for each value another distribution of pressures is obtained over the wing. According to this distribution is set the transition point where the boundary layer laminar flow is transformed into turbulent flow.

As the value of the aerodynamic coefficients depends on the pressure distribution over the wing, meaning that, altering the angle of attack, it can be found a function that is wholesome [12]. With the help of paired values α and Cl and α and Cd it is being constructed a graphical representation in a coordinate axis system in which on the abscissa axis is considered the angle of attack and on the ordinate axis the aerodynamic coefficient Cl (fig. 3).

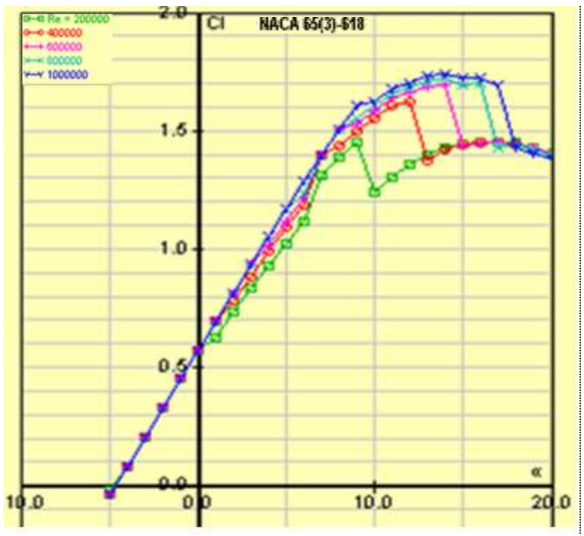

Fig. 3: Lift coefficient vs. drag coefficient [19]

Lift coefficient versus drag coefficient plot for the NACA 65(3) – 618 aerofoil at various Reynolds numbers between 200,000 and 1,000,000 and at various angles of attack between -5 and 20 degrees is described in fig. 4.

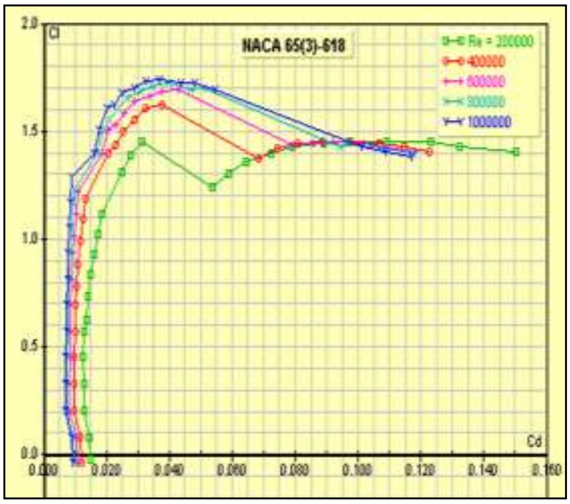

Fig. 4: Lift coefficient vs. angle of attack [19]

For the correct aerodynamic analysis before realizing the CFD simulation is necessary to know the airfoil of the wing and the variation of the aerodynamic coefficients for various angles of attack. Within the domain of these angles of attack the aerodynamic analysis of the studied sailplane can be made.

3. CFD analysis

The multiple applications of the CFD techniques are described considering the modeling of flows in the aerospace domain [18]. There are also various applications in other domains in which the CFD technique is being used like: architecture, automotive, process industry, civil engineering, semiconductor industry, steel industry, turbo machinery [11]. The process for performing a CFD technique is presented below so as to provide a reference for understanding the various conditions of a CFD simulation [21]. The CDF process [9] includes the following steps (fig. 5):

Fig. 5: CFD analysis process

In this paper it shall be made a CFD analysis using SolidWorks Flow 2013 software [2,3]. The SolidWorks Flow Simulation software presents a large range of physical models and various fluid flow models, covering a wide range of applications: liquid and gas flow with heat transfer; external and internal fluid flows; laminar, turbulent, and transitional flows; time-dependent flow; subsonic, transonic, and supersonic regimes [20].

After the design of the sailplane in SolidWorks 2013, this was framed into a parallelepiped fluid domain created as function of the total wingspan of the sailplane (L) considering the following constraints: in front, in the upper side and underside of the sailplane of 5L and in the back of it of 12L according to fig. 5.

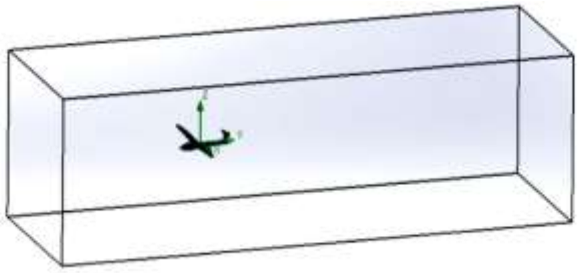

Fig. 6: Computational domain

Following the calculus algorithm and analysis CFD for the sailplane were determined the main aerodynamic parameters and their distribution. In the case of the sailplane's wing in motion it shall result lift and drag.

For the sailplane wing in this paper having asymmetric airfoil and the sailplane descending with a 0 degree angle of attack lift is created. The air flow lines over the wing of the sailplane shall compress thus increasing its speed and also the static pressure and diminish the dynamic pressure. As a result the pressure over the wing is smaller than the pressure under the wing. At the leading edge of the sailplane's wing where the air current is slowed the pressure difference is positive.

In figure 7 is described the pressure distribution over the entire sailplane, these falling between 99521 Pa and 104806 Pa.

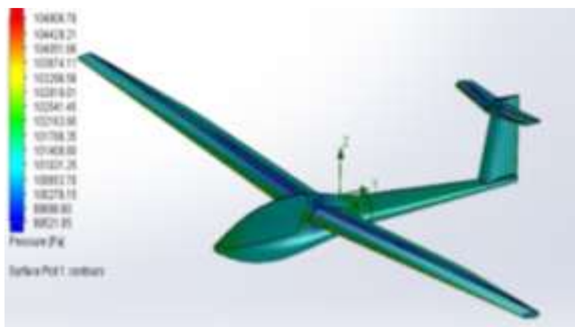

Fig. 7: The pressure distribution over the sailplane

It can be observed that the highest pressure as normal is in the areas: sailplane's nose, leading edge of the wings and horizontal stabilizers because in these areas the sailplanes meet the air current (fig. 8).

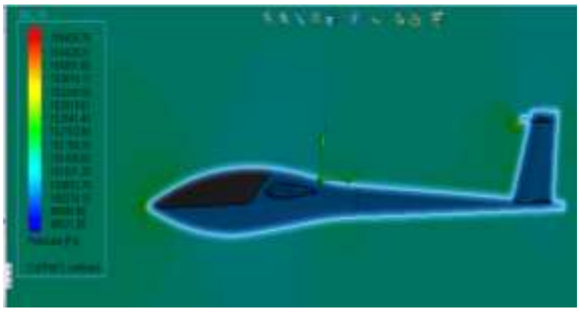

Fig. 8: Side view of the pressure distributions over the sailplane

Another important parameter determined is the velocity, so in fig. 9 is represented the distribution of the velocities along the sailplane. It can be noticed that the maximum velocity is 0.23 Mach.

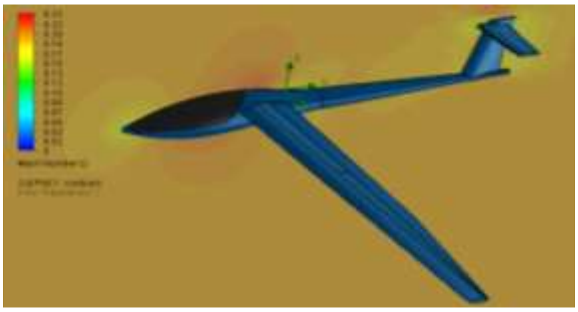

Fig. 9: Velocity distribution around the sailplane – section

The flow around the sailplane in terms of the velocity is shown in fig. 10. It displays the distribution of the velocity and shows the accelerated flow around the wing and the tail plane. As can be seen on the scale, the maximum velocity is 79.7 m/s which is almost 21% higher than the free flow velocity (65m/s) and gives a local Mach number of 0.23.

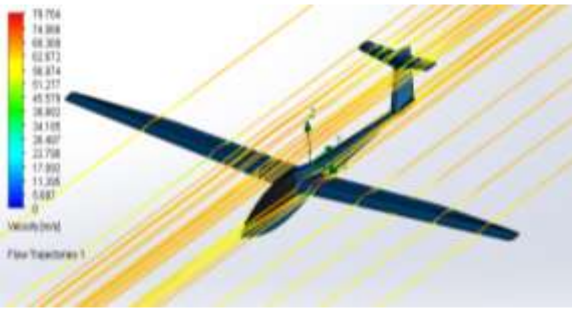

Fig. 10: Velocity distribution and flow trajectories around the sailplane

In figure 11 is described the fluid temperature and its trajectories around the sailplane. It can be noticed that where the flow velocity is higher, the temperature is smaller and the air becomes cooler and when the air is slowed the temperature increases.

Using Flow trajectories it is possible to view the flow streamlines. Flow trajectories provide a good view of the 3D fluid flow show how parameters change along each trajectory on the sailplane. As can be seen in fig. 11, still before meeting the sailplane's wing it can be observed a split in two of the air current: the upper one that passes over the wing and the lower one that passes under the wing. In the same time it can be observed that the flow over the wing is expanded and curved.

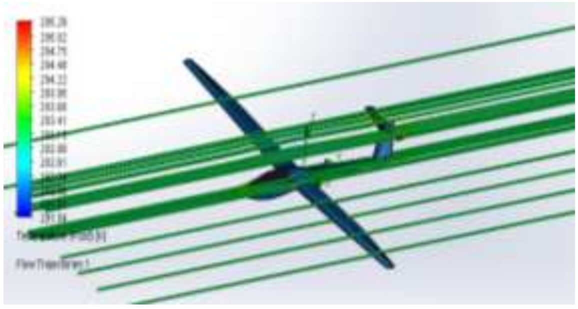

Fig. 11: The fluid temperature around the sailplane

Friction is a resistive force that occurs in joints and between components in contact. This value of friction coefficient is very important to the total drag since it isolates the areas of higher friction. In this way the things are very simple: the higher the friction coefficient the greater the drag. The values for the friction coefficient are presented in fig. 12.

Fig. 12: Friction coefficient

4. Conclusions

The sailplane's aerodynamic performances can be obtained through more methods: analytical methods – based on computations, experimental methods – made in wind tunnels and simulation methods using computerized fluid dynamics analysis (CFD). Using CFD analysis the design and preliminary aerodynamic analysis of a sailplane are done in a shorter time with minimal material costs.

The results of the CFD analysis from this paper represent only an important step in the preliminary design, which will be followed by multiple tests in the wind tunnel and various optimization methods for the sailplane design that shall lead to the final version. Through the aerodynamic analysis of the sailplane it has been obtained an important perspective for the preliminary design of the sailplane and the distribution of the main flight parameters (pressure, temperature, speed, and force on various axes).

The polar diagram of the wing airfoil represents an important result for knowing the sailplane's aerodynamic characteristics, from these being able to determine important characteristics like: minimum drag and maximum lift. From the results of the CFD analysis results a good aerodynamic configuration for the studied sailplane, without aerodynamic interference problems between the main components (wing-fuselage).

References

[1] Airfoil Database online: http://m-selig.ae.illinois.edu/ads/coord_database.html

[2] Andrikaitis, M. and Fedaravicius, A. (2012), Development of a finite element model of the sailplane fuselage, *Journal of Vibroengineering*, vol. 14(3), pp. 1390-1398.

[3] Andrikaitis, M. and Fedaravičius, A. (2014) Modal and flutter analysis of the sailplane LAK-17B using numerical methods, *Transport*, vol. 29(1), pp. 84-89.

[4] Boermans, L.M.M. (2006), Research on sailplane aerodynamics at Delft University of Technology. Recent and present developments. Netherlands *Association of Aeronautical Engineers NVvL.*

[5] Cho, J., Lim, G., Biobaku, T., Kim, S. and Parsaei, H. (2015), Safety and security management with Unmanned Aerial Vehicle (UAV) in oil and gas industry, *Procedia Manufacturing*, vol. 3, pp. 1343 – 1349.

[6] De Florio, F. (2011), *Airworthiness, Second Edition: An Introduction to Aircraft Certification*, Butterworth-Heinemann, Paris.

[7] Dube, L., McElroy, W. and Pepper, D. (2008), Use of COMSOL In Aerodynamic Optimization of the UNLV Solar-Powered Unmanned Aerial Vehicle, *Proceedings of the COMSOL Conference*, Boston.

[8] Elsinga, G.E. (2008), *Tomographic particle image velocimetry and its application to turbulent boundary layers*. PhD dissertation, Delft University of Technology, Delft, Netherlands.

[9] Goetzendor-Grabowski, T., Mieszalski D. and Marcinkiewicz, E. (2015), Stability analysis using SDSA tool, *Progress in Aerospace Sciences*, vol. 47(8), pp. 636–646.

[10] Gudmundsson, S. (2013), G*eneral Aviation Aircraft Design: Applied Methods and Procedures*, Butterworth-Heinemann, New York.

[11] Hansen, T., Modeling the Performance of the Standard Cirrus Glider using Navier-Stokes CFD, *Technical Soaring*, vol. 38 (1), pp. 5-14. http://www.mh-aerotools.de/airfoils/javafoil.htm

[12] Leifsson, L. and Koziel, S. (2015), *Simulation-Driven Aerodynamic Design Using Variable-Fidelity Models*, Imperial College Press, London.

[13] Li, M., Nan, L., Smith, N. and Wonka, P. (2016), Reconstructing building mass models from UAV images, *Computers & Graphics*, vol. 54, pp. 84–93.

[14] Pajno, V. (2010), *Sailplane Design - A Guide for Students and Designers, From Drafting to First Flight*, College Park Press, Varese.

[15] Polo, J., Hornero, G., Coen Duijneveld, García, A. and Casas, O. (2015), Design of a low-cost Wireless Sensor Network with UAV mobile node for agricultural applications, *Computers and Electronics in Agriculture*, vol. 119, pp. 19-32.

[16] Ramšak, M. (2012), Radio Controlled Sailplane Flight: Experimental and Numerical Analysis, *Strojniški vestnik - Journal of Mechanical Engineering*, vol. 58(3), pp. 147-155.

[17] Stefanović, Z. and Kostić, I. (2010), Analysis of the sailplane final approaches performed by cosinelaw speed variations. *Strojniški vestnik - Journal of Mechanical Engineering*, vol. 56(7-8), pp. 436-446.

[18] Tabatabaian, M. (2015), *CFD Module*, Mercury Learning & Information, Boston.

[19] The JavaFoil website (2015). [Online]. Available:

[20] The SolidWorks website (2015). [Online]. Available: http://www.solidworks.com/

[21] Tu, J., Yeoh, G. H. and Liu, C. (2012), *Computational Fluid Dynamics, Second Edition: A Practical Approach*, Butterworth-Heinemann, New York.

[22] Uysal, M., Toprak, A.S. and Polat, N. (2015), DEM generation with UAV Photogrammetry and accuracy analysis in Sahitler hill, *Measurement*, vol. 73, pp. 539–543.

[23] Zaharia, S. M., Martinescu, I. and Morariu, C. O. (2012), Life time prediction using accelerated test data of the specimens from mechanical element, *Eksploatacja i Niezawodnosc – Maintenance and Reliability*, vol. 14(2), pp. 99-106.