FCFD ANALYSIS OF THE INFLUENCE OF WINGLETS ON THE AERODYNAMIC PERFORMANCE OF THE DA42 DIAMOND AIRCRAFT

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Abstract

The paper presents the application of Computer Aided Engineering software for an investigation of the aerodynamic performance of a small two-engine aircraft. In the presented study, the Computational Fluid Dynamics was applied in order to determine the influence of winglets on the aerodynamic performance of the DA42 Diamond aircraft. The numerical simulations were performed with the use of SolidWorks Flow Simulation software. In order to evaluate the influence of the winglets on the lift and drag force, two configurations of the selected aircraft were modelled: with and without winglets. The results of CFD simulations confirmed a reduction of induced drag caused by wingtips vortices dissipation introduced by winglets. The maximum reduction of the induced drag was achieved at high angles of attack. The authors visualized the structure of vortices in case of wings with and without winglets. A smaller volume of wingtip vortices in case of winglets application can be seen in the pressure distribution and streamline plots. The outcome of the presented work confirms the feasibility of Computer Aided Engineering for the assessment of aerodynamic performance of aircraft. The presented methodology can be used in the process of designing and optimisation of alternative configurations of aircraft. The results of work might prove useful for DA42 DIAMOND pilots and maintenance personnel as well as for educational purposes.

Keywords: DA42 Diamond aircraft, lift force, drag force, winglets, numerical simulation

1. Introduction

This paper attempts to use CAE software, using CFD (Computational Fluid Dynamics) to examine the changes in the arising aerodynamic forces of the DA42 Diamond aircraft, through the application of winglets.

Computational Fluid Dynamics (CFD) is an effective calculation algorithm, which allows obtaining data with regard to physical phenomena, using the computational capabilities of the computer. Through an introduction of a number of simplifications and applying a simple action scheme, adjusted to the manner computers work, it enables a quick and reliable analysis of the problems of science and technology [1]. Computational Fluid Dynamics (CFD) has permanently entered the tools to analyse aerodynamic problems, constantly increasing its importance in the face of the development of more sophisticated solutions. Quite frequently, it supports the theoretical and experimental scientific deliberations. Currently there are numerous studies using numerical methods [4, 6, 7, 9, 12-14] in order to determine the flow around the airfoils, wings as well as the whole aircraft models.

The choice of the aircraft type was determined by the fact that the DA42 Diamond has been used for training of young followers of Polish aviation. This paper is addressed not only to future pilots but also to many people immediately connected with the operations of this aircraft. The test results are an extension of knowledge on the application on winglets in a trainer.

2. Characteristics of the Diamond DA42

The DA42 Diamond is a four-seater two-engine aircraft manufactured in Austria. It was designed as a low-wing monoplane, with the T-type empennage (Fig. 1.) The airframe is built as a stressed skin structure, covered with composites reinforced with carbon and glass fibres. The aircraft has a retracting, hydraulically operated landing gear with a front wheel. The aircraft is, among others, part of the fleet of the Academic Aviation Centre at the Air Force Academy in Dęblin, where it is used to train pilots to obtain the IR/ME licence (multi-engine IFR authorisation), and during the training for the Commercial Pilot License (CPL).
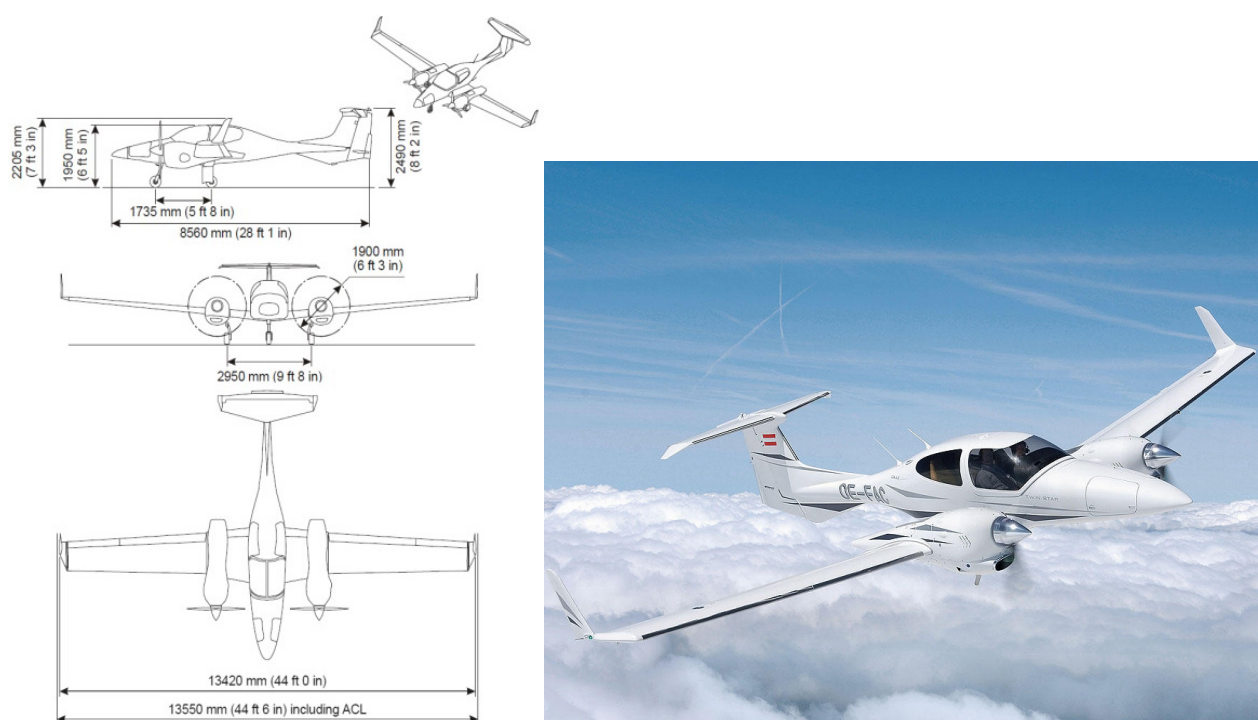

Fig. 1. Projections of Diamond DA42 [20]; view of Diamond DA42 during a flight [19]

The aircraft is powered by two high-pressure engines, Austro Engine E4-C, (also known as AE 300) assembled on the wings. The engine is an inline 4-cylinder, 4-stroke unit, 1991 cc, liquid-cooled. It uses the lubrication system with a wet sump. It is equipped with a turbocharger with an intercooler, Common rail fuel injection system and the Electronic Engine Control Unit (EECU) together with an integrated controller of propeller revolutions. The engine achieves the maximum power equal to 123.5 kW (164.95 KM) at sea level in the conditions of the International Standard Atmosphere; its maximum continuous output power is 113.6 kW (152.34 KM) under the same conditions. It weighs 185 kg, and the engine unit mass equals 1.498 kg/kW. The indications of the engine parameters are displayed on the integrated Garmin G1000 system displays. The engine via the reduction gear of 1:1.69 has got the propeller fixed, consisting of 3 MTV-6-R-C-F/CF 190-69 blades. The airscrew is 1.9 m in diameter. The blades are made of wood and are covered with glass-reinforced composite. The angle of the aircrew is adjustable from 13° to 80°, measured at a distance from the axis of rotation, which is equal to 75% of the radius of the airscrew. Both the left and right propeller turn clockwise, looking from the side of the pilot [20].

3. Characteristics of winglets

Winglets are small surfaces mounted at the wing tips. Their primary function is to dissipate edge vortices, which reduces the induced drag due to wings [8]. The vortices, which are a source of the induced drag [1] pose a threat to aircraft entering the area where they are present (particularly dangerous during take-off and landing since due to their high intensity, the pilot may totally lose control of the airplane).

The value of the induced drag depends upon the lift force of the aircraft and the wing plan form. The higher lift coefficient the bigger induced drag, since greater pressure difference entails an increase in the intensity of the flow around the wing tips. The dependence of the induced drag, form drag and total drag in the function of the airspeed is shown in the graph below, see Fig. 2.
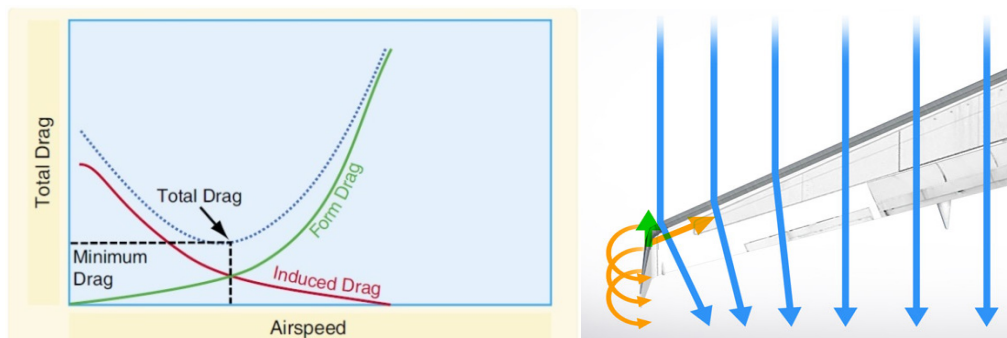

Fig. 2. Change in aircraft drags in the function of its speed [18]; the principle of the formation of forces on the winglet [17]

As it is shown in Fig. 2, induced drag achieves its maximum value, usually during take-off and approach to landing, when the aircraft speed is low, the approach angle is high and additionally it uses various wing lift devices, which may also raise the value of the lift force coefficient (especially the trailing-edge wing flaps).

Winglets, apart from posing a barrier to the airflow from the lower to the upper wing surface, are also elements responsible for generating minor lift force. However, due to the deviation of the streamlines over the upper surface of the wings towards the fuselage, the resulting force, which is perpendicular to the stream of the incoming air, is directed slightly in the direction of the aircraft flight. The component of the resulting force, which is directed parallel to the longitudinal axis of the aircraft (Fig. 2.) compensates for the losses, resulting from the induced drag [17].

Whitcomb [15] has developed design principles of effective winglets. They should be pointed almost vertically over the wing tips, tilted towards the tail of the aircraft. In order to minimize the interference drag resulting from the flow disturbances in-between the wings and the winglet, the angle of attack of the base should be located behind the place of the largest airfoil thickness of the wing tip. The winglet airfoil should effectively ensure the desired properties of the arising aerodynamic force for the speed and lift coefficients of the wings, for which the aircraft is designed. The airfoil should be designed in such a way that its stalling does not occur before the stalling of the wing with full lift devices.

Whitcomb [15] also demonstrated that in order to achieve the optimum compromise between reducing the induced drag and raising the airfoil drag and interference drag, as well as the bending moment, it is necessary to tilt the winglet by a small angle from the perpendicular away from the wing, and it is best to maintain a smooth transition between the wing and the winglet. In Whitcomb's research [15], adding a winglet led to an increase in the ratio of the lift force coefficient to the drag coefficient by approximately 9%, compared to the same wing without it. This was more than a double improvement in relation to extending the length of the wings of the same mass. In addition, the induced drag shrank by 20% [15].

3. Computational analysis of the M-28 Bryza wing

3.1. The DA42 Diamond in SolidWorks programme

In order to carry out the flow simulation, in the SolidWorks programme, we built a model reflecting the DA42 Diamond model with winglets, which it is manufactured with, and also a model with wings that are not finished with winglets. The model was built on the basis of accurate technical drawings and measurements made on the actual airplane. In addition, we decided to adopt the configuration with a retracted undercarriage, due to a short flight time with an extended landing gear.

In order to construct the wings, we used the airfoil Wortmann FX 63-137/20 – W4. This airfoil is used in real aircraft Diamond DA42.

A typical method used in the construction of the model was to extend the airfoils, where solids are formed through combining successive cross sections of particular elements by means of the leading curves (Fig. 3) [5].
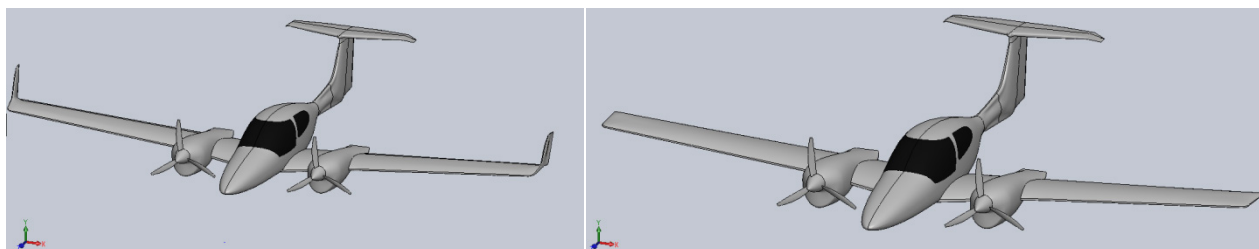

Fig. 3. The constructed DA42 model and the DA42 without winglets

The flow parameters have been selected in such a way that they reflect the phenomena occurring in reality with reference to the aircraft instruction manual (related to the economical speed) and the International Standard Atmosphere [16]. The selected speeds of the propeller revolutions are recommended in the instruction manual for the aircraft flights on selected flight altitudes.

Tab. 1. Parameters of the conducted numerical simulation

Parameter	I configuration	II. configuration	III configuration	IV configuration
Angle of attack	3°	13°	3°	13°
Altitude (MASL -metres above sea level)	0	0	5486.4 (18,000 ft)	5486.4 (18,000 ft)
Static pressure [Pa]	101325	101325	506.322	506.322
Temperature [K]	288	288	252.519	252.519
Velocity of uninterrupted flow [m/s]	68.936	68.936	77.167	77.167
Vertical component of velocity [m/s]	3.608	15.507	4.039	17.36
Horizontal component of velocity [m/s]	68.841	67.169	77.061	75.19
Angular velocity of airscrews [rpm]	2400	2400	2400	2400

The applied computational domain has been chosen in such a way that the air behind the airplane could achieve the characteristics of free flow. In addition, in order to reduce the time required to conduct the simulation, and the required computing power of the computer, the computational domain is divided into two equal parts, symmetrical in relation to the plane of symmetry of the aircraft.

3.2. The change in aerodynamic forces of the DA42 Diamond with and without winglets

As a result of the conducted simulations in the SolidWorks Flow Simulation, we have obtained results for the SL – sea level and FL – flight level (18, 000 ft) and for two angles of attack: 3 degrees – cruising and 13 degrees – critical, as indicated in Tab. 2.

Tab. 2. Simulation findings performed in SolidWorks

SolidWorks Flow Simulation								
Aircraft	With winglets (W)				Without winglets (WW)			
Configuration (altitude, angle of attack)	SL, 3°	SL, 13°	FL180.3°	FL180.13°	SL, 3°	SL, 13°	FL180.13°	FL180.13°
F_Y [N]	107.05	200.43	75.51	162.84	113.11	236.19	72.52	165.02
F_Z [N]	24.16	16.54	16.01	7.48	24.38	9.86	15.07	7.46
Angle of attack [°]	3	13	3	13	3	13	3	13
L [N]	**105.64**	**191.57**	**74.57**	**156.98**	**111.68**	**227.92**	**78.50**	**159.11**
D [N]	**29.73**	**61.20**	**19.94**	**43.92**	**30.27**	**62.74**	**20.04**	**44.39**
D_W/D_{BW}	**0.982**	**0.976**	**0.993**	**0.989**	-	-	-	-

The table has been divided into two sections – one with the results of model simulations with assembled winglets and the other for the model without winglets. Below there are lift force values (L) and drag force values (D). The winglets are used to reduce the drag force, therefore in the last line there are calculated ratios of the drag forces for the given configurations of simulations. The above values prove that the drag forces became diminished owing to the application of winglets, which points to the enhanced aerodynamic properties of the model with winglets as opposed to the model without them.

3.3. An example of the DA42 Diamond visualized in the SolidWorks programme

We presented the effects of a simulated flight in the conditions at sea level in accordance with ISA, where the angle of attack equals 13°. The lift force arising in the model with winglets was 191.57 N, while the drag force was 61.20 N. In the model without winglets but under the same conditions, the forces were 227.92 N and 62.74 N, respectively. Using winglets resulted in reducing the drag force; in this case, the improvement was 2.4%. However, it significantly diminished the lift force.

In this simulation, within the analysis of the distribution of static pressure around the aircraft wing, it is possible to observe the distribution of the pressure field, as in Fig. 4. The areas with overpressure and negative pressure are easy to distinguish. It can be noticed that the winglet constitutes a barrier for the flow of the lower surface of the wing and it prevents the formation of vortices.

The airflow around the wing tips of both models is presented in Fig. 5. In both cases, we may observe vortices generated behind the aircraft wing whose direction, as predicted, is from the bottom of the wing surface upwards. The particular colours represent changes in the velocity flow.

In case of the model with winglets, it is possible to observe that the air in front of the aircraft comes with the speed of free flow equal to 69 m/s. Next, the air speed around the model in the direct vicinity of the wing plan form is in the range of 35-73 m/s; then the air molecules move in the vortices behind the wings at the speed of approximately 51-62 m/s. Finally, they return to the laminar flow from at an initial speed of approximately 69 m/s. The situation is similar in the model without winglets.
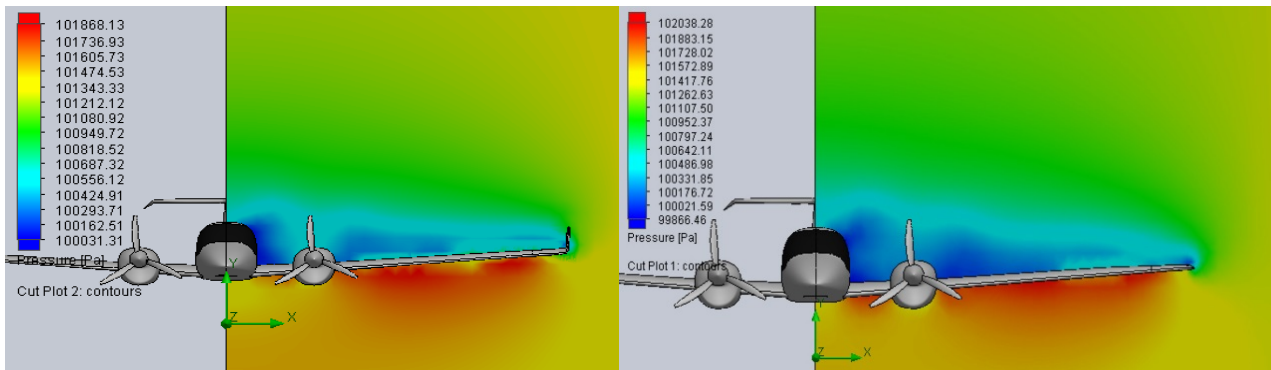
Fig. 4. The distribution of pressure around the DA42 Diamond wing with winglets
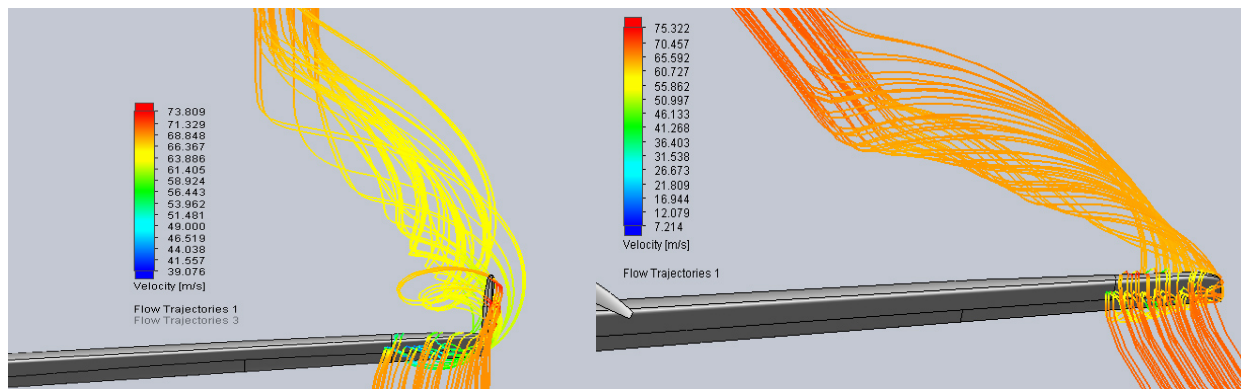

Fig. 5. The trajectories of air particles behind the Diamond DA42 with winglet and without winglet

While analysing the above illustrations of the airflow around the wing tips, one may make an impression that the vortices behind the wing without winglets are of lesser intensity; however, they are at a larger volume and therefore lead to the occurrence of a higher drag force. The values of the calculated forces clearly indicate that the aircraft equipped with winglets generates less drag.

3.4. Conclusions from the numerical calculations of the DA42 Diamond model

On the basis of the conducted investigation, we may formulate the following conclusions:
- the highest reduction in the total drag coefficient (2.4%) was obtained at a large angle of attack equal to 13° (within the exploitation degree of a given model),
- the obtained results lead to a conclusion that the efficiency of winglets rises with the increasing angle of attack. This is due to the increase in the intensity of the vortices behind the wings, which give rise to the forces reducing the drag on the winglet,
- the carried out simulations clearly indicated that the mounting of the winglet resulted in the reduction of drag. This means that the numeric computational methods used in the appendix Flow Simulation to SolidWorks, are able to determine the impact of winglets on the value of the drag force generated by the DA42 Diamond,
- the visualization of the flow around the aircraft brought about the expected results. The analysis of the pressure distributions, trajectory and velocity of flow in selected places on the surface and around the aircraft led to the conclusions that the obtained results are in accordance with the theoretical knowledge on aerodynamics and fluid mechanics with regard to aircraft flows,
- the aircraft model was built on the basis of detailed technical drawings and measurements made on real aircraft. Although minor differences between the modelled, and the actual details are possible, they do not have a greater impact on the results of the aerodynamic investigations,

- as a result of the conducted simulations, it was proved that fitting the winglet on the wing of the DA42 Diamond resulted in reduced total drag of the aircraft, despite an increase in airfoil drag caused by its addition,
- it is worth emphasizing that apart from the 12% difference in the lift force to the advantage of the model without winglets, the aircraft is exploited with winglets.

4. Conclusions

The study successfully demonstrated the effectiveness of the use of CFD to determine the impact of winglets on the change of forces on the DA42 Diamond. The visualized flow around the aircraft, whose parameters were calculated as expected, undoubtedly indicate the fact that the values of the drag force were properly calculated. However, the investigation of flows around the aircraft model with winglets seems to be a complicated mathematical calculation. The obtained results of the simulation testing can be considered as preliminary and need to be validated in the water or aerodynamic tunnel, and in this way the values which are of interest can be considered reliable and reflecting the actual phenomena. The results of the simulation may be also compared with the results of experimental visualization, using image anemometry PIV [10] in order to compare the layouts of speed, assessment of the selection of the model of turbulence and the credibility of the arising vortex structures [11].

Therefore, the effect of this work is a valuable source of information for those interested in aerodynamics of this aircraft due to lack of documentation about the performances on the part of the manufacturer.

The type of programmes, as SolidWorks presented in this paper, are a fast growing field of software. It seems natural that along with the progress of technology and the development of computers with ever-greater computing power, CAE family programmes will be capable of conducting more and more complicated simulations, carried out in a faster way.

The obtained results confirm the supposition that during the process of aircraft construction [2] computer software using CFD will prove to be a useful tool to support decisions, to allow editing the project and to verify the solutions. Still, it is necessary to build a prototype of the final design so that the research conducted on its basis could confirm the findings of computer simulations.

This article is a good example of using the CAE software to obtain reliable results of a physical problem. The obtained data are of didactic and research value.

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