ISSN: 1231-4005
e-ISSN: 2354-0133
DOI: 10.5604/12314005.1213544

CFD ANALYSIS OF THE INFLUENCE OF FLAPS EXTENSION ON THE AERODYNAMIC CHARACTERISTICS OF THE M-28 BRYZA AIRCRAFT

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Abstract

The paper presents a modelling procedure of the M-28 Bryza wing with extended flaps and Computational Fluid Dynamics (CFD) simulations results preformed in order to assess the performance of the investigated wing for various flap extension rates. The M-28 Bryza is a two-engine high-wing aircraft used in the Polish Air Force for short distance airlift of people and equipment. The aim of this work was to determine the aerodynamic characteristics of the investigated wing. The CFD simulations were performed in order to investigate the influence of flap extension on lift and drag coefficients at various angles of attack. In order to validate the results of two different commercial CFD packages were used. The findings are presented in the form of flow visualization and aerodynamic characteristics. The typical and non-standard extension rates were investigated for low, moderate and high angles of attack. The results correlated with the limitations specified in the aircraft manual. The outcome of the presented work confirmed the feasibility of the presented methodology for its use as a supportive tool for providing additional information about airplane performance in standard and non-standard conditions of flight such as landing with one engine working. The results of work might prove useful for M-28 Bryza pilots and maintenance personnel as well as for educational purposes.

Keywords: *M-28 Bryza, aerodynamic characteristics, flaps, Computational Fluid Dynamics*

1. Introduction

Aircraft design has undergone significant changes since the times of the Flyer and the Wright Brothers. The design solutions in the field of aerodynamics were created by the trial and error methods or on the basis of testing in simple aerodynamic tunnels. Along with the development of the issue of aircraft aerodynamics, constructors began to design aircraft in a more conscious and precise way. However, after the creation of the prototype of an aircraft at the time, during the experimental investigation, the drawbacks of a given structure were detected and constant changes were being introduced. Building another prototype is a time-consuming and costly process. The development of technology brought help for designers in the form of modern CAD or CAE software packages. They are to modify the created models through a possibility of numerous design optimizations before creating the final prototype.

Owing to the development of CAE, not only the amount of human effort but also the costs of optimizing the design were reduced. Moreover, the progress and advancement in many fields of science were accelerated. The method of finite elements is an efficient calculation algorithm, which allows obtaining particular data on physical phenomena by means of the computational capabilities of the computer. Through an introduction of a number of simplifications and applying a simple action scheme, adapted to the way computers work, it enables a quick and reliable analysis of the problems of science and technology. Computational Fluid Dynamics (CFD), as an area using the method of finite elements [2], 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 computer numeric calculation methods [4, 6, 7, 8, 12-14] in order to determine the flow around the profiles, wings as well as the whole aircraft models.

The aim of this study was to use the software in the CAE technology to examine the changes of aerodynamic characteristics of the M-28 Bryza aircraft through extending its flaps. For this purpose, the authors used a wing model that had been built for the sake of a previous investigation.

The choice of this type of aircraft was caused by the fact that the airplane M-28 Bryza is used in the Polish Armed Forces to transport people and cargo over a short distance. It is also used for training purposes, securing practical training of officer cadets in the Polish military. This paper is addressed not only to future pilots of the M-28 Bryza aircraft, but also too many people immediately connected with the operations of this aircraft. The research findings add a new value to the database on the characteristics of the aerodynamic aircraft wing. They may be used as a basis to determine the main defects and identify major tendencies of their development.

2. M-28 Bryza aircraft characteristics

The origins of the aircraft M-28 Bryza date back to mid- seventies, when An-28 project, based on the An-14 Pchelka (Pszczółka), was made in the Antovov Design Bureau in Kiev. The first prototype version was simply an An-14 machine, equipped with new turboprop engines, TWD-10, however almost for six years of work, it underwent considerable modifications.

Fig. 1. An-14 Pchelka aircraft [9], M-28 Bryza aircraft model [5]

“Bryza 1” is equipped with two turboprop engines PZL-10S (TWD-10B) with five-blade propellers HC-B5MP-3D/M 10876 ANSK. The TWD-10B engine, which is adapted to operate with the Hartzell propeller, is marked as the PZL-10S engine. The airplane is all-metal, braced high-wing monoplane, with two-stabilizer empennage and fixed tricycle undercarriage with a forward steering wheel. The two-spar divided wing is composed of the centre section of the wing and two attached wings. It has full lift devices, two sections of slots, spoilers and flaps. In the front part of the fuselage, there is a comfortable glazed cockpit for two pilots.

The passenger compartment is located in the central part of the fuselage and ends in the rear hatch, whose covers can open up manually on the outside, or can be opened hydraulically inside, or they may be used as an entrance trap.

The aircraft is equipped with a heating installation and cabin ventilation, and also with an anti-icing installation. The aircraft has radio and pilotage-navigation devices mounted, which facilitate flight in difficult weather conditions during the day and night, and landing in conditions of poor visibility [15].

3. Computational analysis of the airplane wings, M-28 Bryza

3.1. Numerical analysis in SolidWorks software

In order to simplify the modelling procedure, we created several separate assembly configurations. It solved the problem of positioning the particular parts of the wing and the angle of attack of the airstreams in each test. In each configuration, we determined the corresponding positioning of the components, which was related to one of the analysed variants. Then, owing to the possibility of rotating all the assembly components, we determined the correct angle of attack of the axis to axis Z of the assembly. This axis corresponds to the direction of the airstream flow during the investigation. At any time, it was possible to move in-between the configurations, which automatically entailed an appropriate arrangement and positioning of the parts.

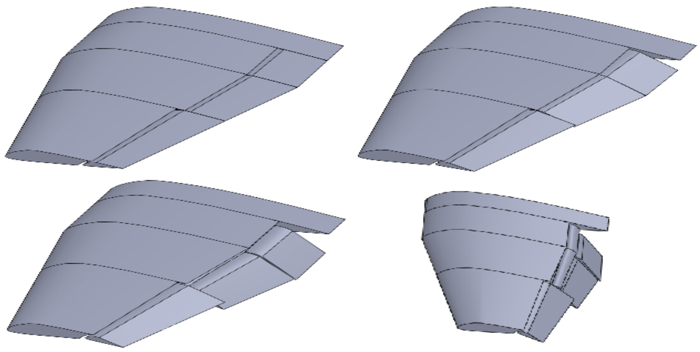


Fig. 2. M-28 wing aircraft in four flap configurations

The flow testing was conducted for the flap angles of 0, 15, 25 and 40 degrees (see models in Fig. 2). These are the regular operating values specified in the airplane flight manual [15] intended for an operational flight, take-off and landing with one engine as well as for standard landing. For each flaps setting we specified the flow velocity to meet the exploitation requirements of the M-28 aircraft included in the Flight Manual of the Bryza 1 [15].

The aerodynamic characteristics were determined after calculating the flow of the 3D wing model in a given configuration under the angles of attack equalling -15, -10, -5, 0, 5, 10 degrees. This made it possible to obtain the component force values of the resultant aerodynamic force arising under the influence of the flow and the coefficients Cz_a and Cx_a.

The SolidWorks Flow Simulation software package allows an in-depth visualization of the carried out analyses. Apart from the above-mentioned presentation of data, it enables to visualize the distribution of sizes such as pressure, air velocity or force on the surfaces by means of colour zones of the same potential or isoline.

In addition, the movement of air molecules can be shown by means of lines reflecting the trajectory or by separate points providing an image of their behaviour, e.g. in the area of the vortex.

3.2. Analysis in Ansys Fluent software package

Due to obtaining a comparative analysis, it was decided to analyse the 2D profile of the M-28 Bryza aircraft wing. In the Workbench environment, we prepared 4 separate projects for investigating the profiles with extended flaps by the angle of 0, 15, 25 and 40 degrees. The first step was to create and develop a preliminary division of the research area and generate a differentiated computing grid. In order to simplify the computational model, we disregarded to accurately reflect the slotted flaps and decided to conduct the examination of the plain profile with extended flaps without slots.

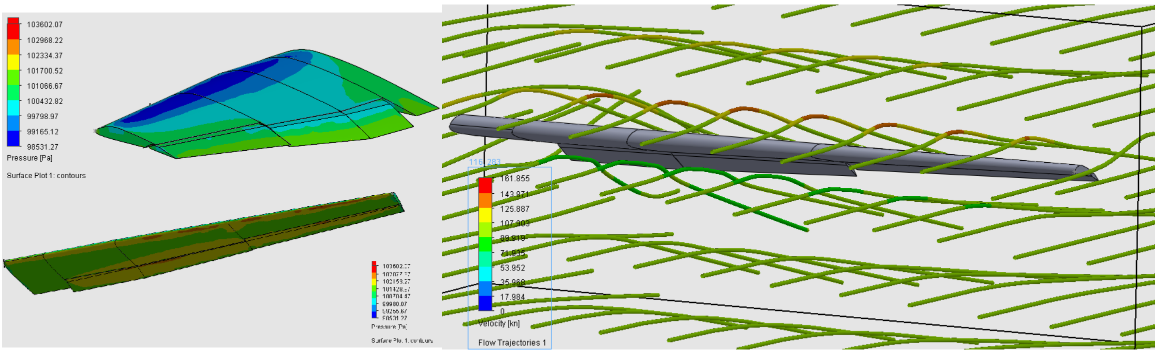


Fig. 3. Distribution of static pressure on the wing and the trajectories of airstreams with the velocity gradient

The grid, prepared for computations, was imported to the computational solver, which had the boundary and the initial conditions entered. On the basis of the research conducted by C. A. Baxevanou and D K. Fidaros [3] comparing the accuracy and efficiency of four models of turbulence and fifteen combinations of numerical schemes, we decided to carry out the current analysis by means of the model of turbulence k-ε.

The tests were made out separately for each variant of the flap extension by an angle of 0, 15, 25 and 40 degrees at angles, with the angles of attack equal to -15, -10, -5, 0, 5, 10, 20. In the ANSYS Fluent software, it is possible to extend the presentation base of the course of the investigation similarly to the SolidWorks programme. It may be in the form of a surface of the same potential of pressures (static, dynamic, total) or velocity. In addition, it is possible to present the case solution in the form of isolines, trajectories, vectors of e.g. velocities or illustrate the behaviour of individual molecules. The displayed examples of the physical values, which are of interest to us in a given test, have been presented in Fig. 4.

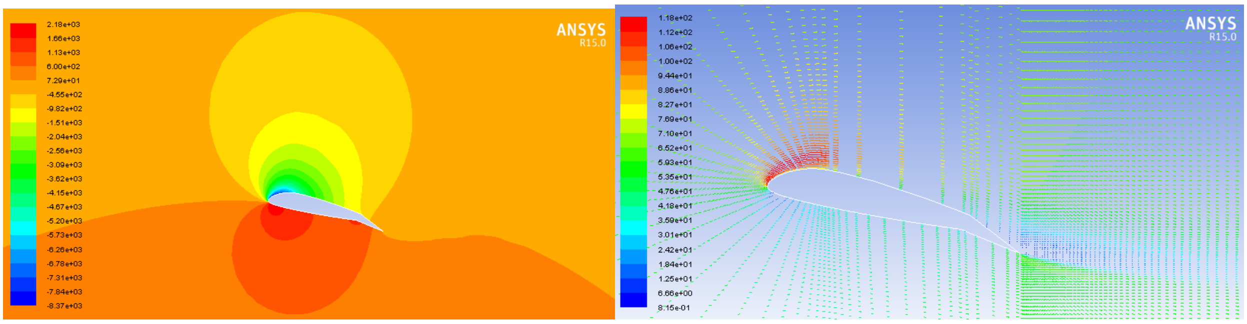


Fig. 4. Distribution of static pressure and the velocity of fluid around the M-28 aircraft profile

3.3. Comparison of simulations findings

3.3.1 Characteristics obtained for 3D model in SolidWorks

The comparison of the characteristics of the aerodynamic profiles of the M-28 aircraft wing, at various angles of extension, rely on the findings obtained in the ANSYS Fluent software, whereas the characteristics of the 3D model were obtained from the SolidWorks software package.

The SolidWorks programme enabled rapid and highly automated preparation of model wings for the 3D simulation. Another convenience was the fact that the discussed model was made by means of this software (the whole aircraft was made as in Fig. 2). The simulation findings are burdened with a greater computational error due to the inability to interfere in the creation of the computing grid. Despite a number of verifications of the initial conditions of the testing and the model characteristics, the obtained values of the coefficients Cz_a and Cx_a may be affected by quantitative errors, however their qualitative character is correct. Approximately consistent with the two-dimensional model obtained from the ANSYS Fluent programme for the M-28 Bryza wing profile.

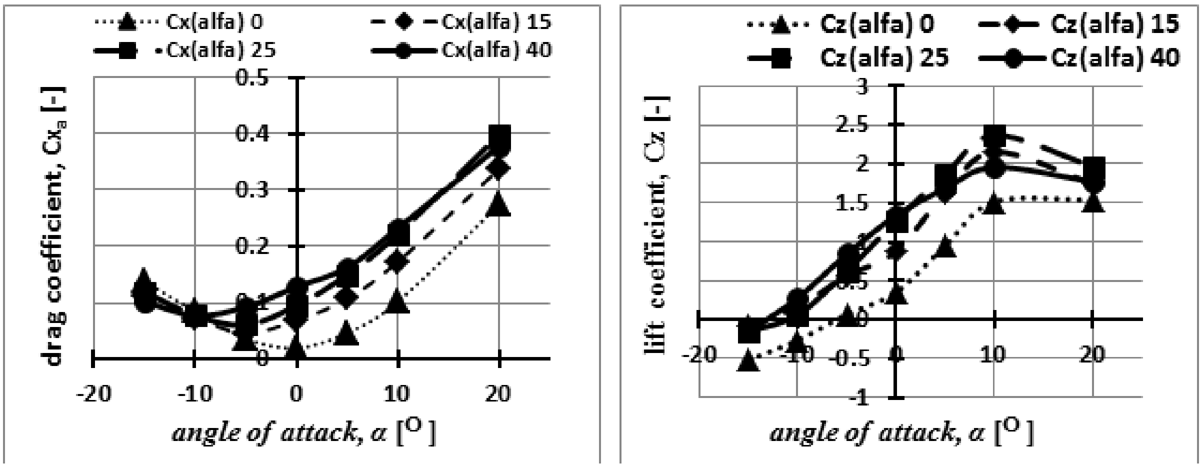


Fig. 5. Cx_a (α) and Cz_a(α) for various angles of flap extension

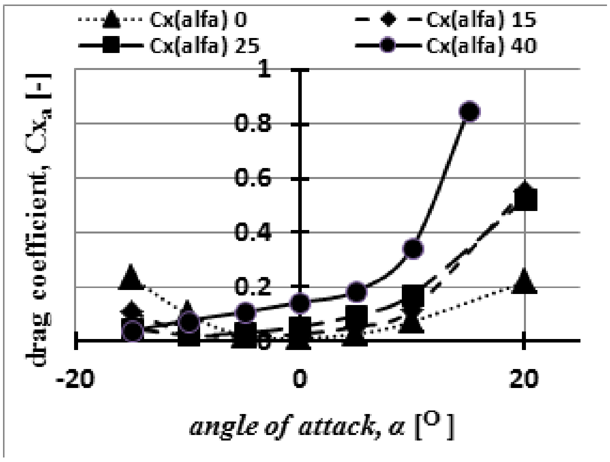
The values of the drag force coefficients are included in the interval 0.02 - 0.4 and do not show a significant increase, as a result of the rise in the angle of the flaps extension. The course of the dependencies of the drag force coefficient for various angles of flap extension has been shown in Fig. 5.

Moreover, the values of the lift force coefficient are included in the interval -0.56-2.4 and along with the growth of the flap extension angle, the course moves into higher values of Cz_a. For the flap extension angle equal to 10^o in relation to the flap extension angle equal to 0^o, it is possible to observe the shift of the characteristic “upwards”, on average, by the value of approximately 0.5. However, the remaining changes in the angle of the flaps extension do not cause so big changes in the coefficient of the drag force. The courses of the dependencies of the drag force for various angles of flap extension have been shown in Fig. 5.

3.3.2 Characteristics obtained for 2D model in Ansys Fluent

Fig. 6 shows the dependence of the drag force coefficient Cx_a (α) for different angles of the flap extension obtained in the Ansys Fluent software. It is clear that the characteristics move towards smaller angles of attack along with an increase of the angle of flap extension (increase of the lift force coefficient). This results in a decrease of the angle value of the smallest drag force (α_{ek}), and an increase of the drag force coefficient for the angles above this value. The results obtained numerically for the air profile confirm the course of changes in the characteristics of C_{za}(α), depending on the angle of the flaps extension. At the same time, the rise of the drag force was confirmed.

Figure 6 also shows the dependencies for the coefficient of the lift force Cz_a (α) for various angles of the flaps extension. It is clear that the characteristics are shifted upwards towards higher values of the lift force coefficient together with the increasing of the angle of flaps extension. In addition, we may observe decreased values of the angle at zero lift force. For flap extension angles of 25^o and 40^o, we may observe the moment of breaking the boundary layer in the decreasing Cz_a at higher angles of attack.



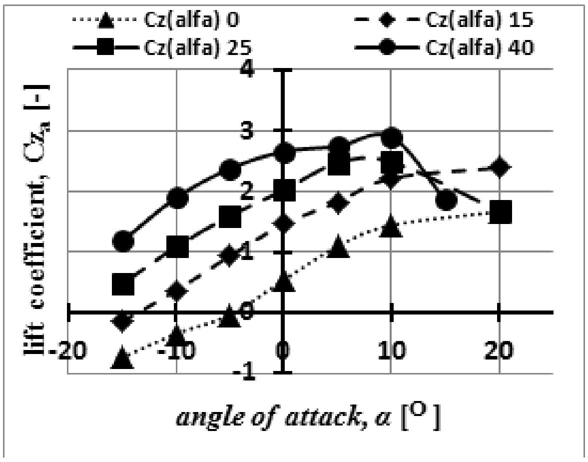


Fig. 6. Cx_a (α) and Cz_a(α) for various angles of flap extension

3.3.3 Conclusions of simulation investigations

After analysing the changes in the aerodynamic characteristics of the M-28 aircraft wing through sliding the flaps, it is possible to draw the following conclusions:

- the flap angle of 25º used during landing with one engine working. This extension safeguards the optimal ratio of Cz_a to Cx_a. It ensures sufficient lift force necessary for landing at low speed with smaller drag force, which was the case of the flap extension equal to 40º, as indicated in Fig. 5. and particularly visible for the same profile in Fig. 6,
- the flap extension angle of 40º allows obtaining high values of the lift coefficient at very low angles of attack. However, it generates a relatively high drag, which means that the landing can be made at low speed but with sufficient power from both running engines, particularly evident in the graphs obtained for the profile,
- the problem of premature air stripping at a greater angle of flap extension is solved by two sections of slots, disregarded in the study, which may account for the sharp drop in Cz_a in the graphs,
- the software ANSYS Fluent has proved to be an effective tool for conducting the research into changing the aerodynamic characteristics of the wing profiles by sliding the flaps. It should be noted that not all its capabilities have been used and further research into the aerodynamics of wings may bring additional interesting conclusions through the use of a more accurate reflection and including the all the lift devices for both the profile and the whole wing.

The manufacturer specifies the characteristics of a safe flight with minimal speed, in particular stages, including the change in flap extension for the M-28 Bryza aircraft (Tab. 1).

4. Conclusions

The outcome of this work is the findings of the aerodynamic characteristics of the M-28 aircraft wing, by means of numeric calculations. For this purpose, the authors used two CAE software packages: ANSYS Fluent and SolidWorks. In both programmes, the testing was made for various angles of flap extension: 0, 15, 25 and 40 degrees. The 0º extension is used during every operational flight; 15º is used for the M-28 aircraft during take-off; the extension of 25 and 40 degrees is used for the landing: with one engine not-working and one standard engine. For each configuration of the wings, we made approximately 7 simulations in each programme. We examined the airflow for various angles of attack of the wing, as follows: -15, -10, -5, 0, 5, 10 and 20 degrees.

The obtained results of the simulation testing studies 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 flow structures [11].

Tab. 1. Flight characteristics with minimum speed specified by the manufacturer

Weight [kg]	4,500	5000	5500	6000	6500	7000	7500
for the angle of flap extension 0° - operational flight							
Minimal velocities [km/h]	130	133	138	144	149	156	164
Required Cz_a [-]	**1.417**	**1.505**	**1.537**	**1.540**	**1.558**	**1.531**	**1.484**
Required α [°]	10	12	14	14	14	14	12
Numerical values	**Wing Cz_a≈1.52**				**Profile Cz_a=1.56**		
for the flap extension angle of 15° - take-off							
Minimal velocities [km/h]	114	118	122	126	132	137	142
Required Cz_a [-]	**1.843**	**1.911**	**1.967**	**2.012**	**1.986**	**1.985**	**1.98**
Required α [°]	6	6	7	8	7	7	7
Numerical values	**Wing Cz_a≈1.90**				**Profile Cz_a=2.02**		
for the flap extension angle of 25° - landing							
Minimal velocities [km/h]	106	110	114	118	123	126	131
Required Cz_a [-]	**2.132**	**2.199**	**2.253**	**2.294**	**2.287**	**2.347**	**2.326**
Required α [°]	2	2	3	3	3	4	4
Numerical values	**Wing Cz_a≈1.51**				**Profile Cz_a=2.25**		
for the flap extension angle of 40° - landing							
Minimal velocities [km/h]	102	104	107	110	113	118	125
Required Cz_a [-]	***2.302***	***2.461***	***2.557***	***2.639***	***2.700***	***2.676***	***2.555***
Required α [°]	-5	-4	-2	0	3	0	-2
Numerical values	**Wing Cz_a≈1.34**				**Profile Cz_a=2.66**		

Owing to the numerical calculations, it was possible to analyse the changes in wing characteristics through extending the flaps, using the numerical methods. It showed the regularities that may occur during the operation of the M-28 Bryza airplane. Therefore, the effect of this work is a valuable source of information for those interested in aircraft aerodynamics or, in the case of design analysis of the applicability of a similar type of aircraft (even Unmanned Aerial Vehicles [1]). Moreover, the research may be further expanded by an analysis of changes caused by a different configuration of the wing lift devices. The full data with regard to the aerodynamic possibilities of wings allow defining their drawbacks and presumable development trends aimed at improving their performance.

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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