PROBLEMY MECHATRONIKI
UZBROJENIE, LOTNICTWO, INŻYNIERIA BEZPIECZEŃSTWA

PROBLEMS OF MECHATRONICS
ARMAMENT, AVIATION, SAFETY ENGINEERING

ISSN 2081-5891; E-ISSN 2720-5266 **https://promechjournal.pl/**

Research paper

The Influence of Atmospheric Conditions on a Glider's Lift Forces

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Received: June 30, 2023 / Revised: July 10, 2023 / Accepted: January 9, 2024 /
Published: June 30, 2024.

2024, 15 (2), 23-36; https://doi.org/10.5604/01.3001.0054.6095

Cite: Chicago Style

Wójcik, Antoni, Bartosz Moczulak, Jerzy Domański, and Wojciech Miąskowski. 2024. "The Influence of Atmospheric Conditions on a Glider's Lift Forces". *Problemy mechatroniki. Uzbrojenie, lotnictwo, inżynieria bezpieczeństwa* / *Probl. Mechatronics. Armament Aviat. Saf. Eng.* 15 (2) : 23-36. https://doi.org/10.5604/01.3001.0054.6095

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Abstract. The article presents the methodology and results of a simulation study on the air flow around a glider, focusing on the issue of changing the lift force and drag force in changing atmospheric conditions. The experiment was based on simulations in the SolidWorks Flow Simulation 2022 software suite. The model for simulation research was developed at the Faculty of Technical Sciences of the University of Warmia and Mazury in Olsztyn (Poland).

Keywords: glide ratio, drag force, lift force, atmospheric conditions

1. INTRODUCTION

Research on the influence of atmospheric conditions – such as temperature, humidity, wind direction and force – on the aerodynamic performance of a glider is crucial for obtaining an optimal approach (the distance that the glider can cover from a given altitude under given atmospheric conditions) during glider flights. Knowledge of these factors allows glider pilots to effectively plan their routes and minimize the risk of landing in difficult terrain [2, 3]. To fly safely and not be surprised by an unusual event in the air, pilots must know and understand the laws governing flight, resulting from the aircraft's flight mechanics. These laws are absolute for everyone and cannot be circumvented – they must be obeyed [4]. Factors such as humidity and temperature are inseparable, and they change not only the density of the air, but also its viscosity and thermal activity. This has a massive impact on the glider's performance and flight safety.

Currently, due to the disregard of atmospheric conditions, glider pilots are forced to leave a significant amount of altitude allowance to safely return to the airfield without additional thermal soaring. The pilot must use only some of the available glide ratio to ensure that changing atmospheric conditions, such as humidity or temperature, do not affect the safety of approach on the way back to the airfield to such an extent that the glider is forced to land in an unsuitable location [4]. Taking into account accurate atmospheric conditions and their impact on the glider's performance, even in navigation applications, could significantly increase the glider's performance and potential (including the gravitational one).

This article describes preliminary simulation studies, taking into account the impact of the numerical grid on the accuracy of calculations and the impact of selected parameters on the resulting lift and drag forces acting on a glider. A computer simulation will allow us to estimate the order of magnitude of forces, measurement ranges and/or possible unexpected behaviours of the wind stream [9]. Taking into account the proper layout of the computational grid is a critical factor in the subsequent analysis and interpretation of the results [5-8].

2. PURPOSE AND SUBJECT OF RESEARCH

The study aims to determine a correlation that could be used to precisely calculate the glide ratio (the number of kilometres a glider can fly from an altitude of one kilometre without the interference of air currents) in various atmospheric conditions. In practice, using this correlation would allow for the optimisation of glider flights, which would consequently contribute to increasing safety, reducing operating costs and improving flight efficiency.

This type of research is particularly important for glider pilots who usually operate at variable altitudes, where atmospheric conditions may be difficult to predict and control [4]. Proper understanding of the impact of these factors allows for better adaptation of the flight to changing conditions, which in turn contributes to increased safety during glider flights. The simulations were performed on the LAK-11 NIDA model (scale 1:1) developed in 1982.

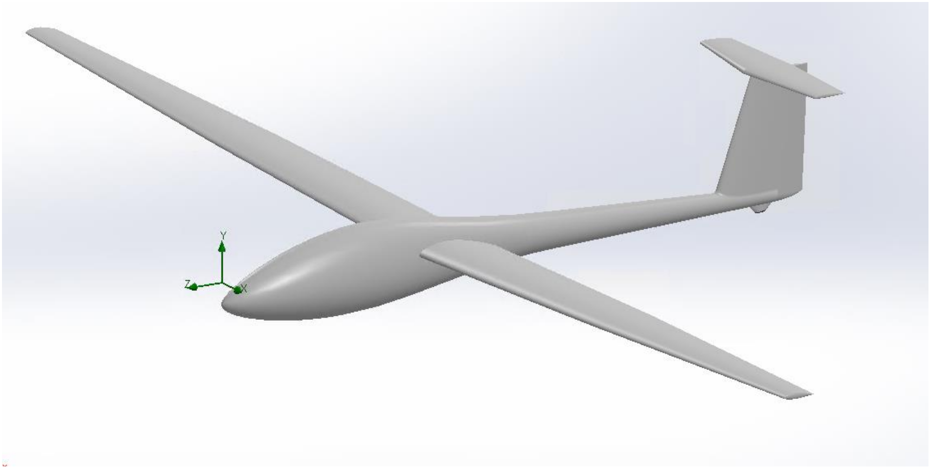


Fig. 1. 3D model of the tested glider [Proprietary study]

This glider has a wing span of 15 meters and a length of 6.76 meters. The manufacturer estimates its glide ratio in normal conditions (at a pressure of 1013.25 hPa and temperature 20°C) at 40-42. The basic specifications of the tested glider are presented in Table 1 [1].

Table 1. Specifications of the tested glider

Parameter	**Value**
Wing span	15 m
Fuselage length	6.76 m
Wing surface area	10.23 m^2
Wing form factor $\left(\frac{\text{wing length}^2}{\text{wing surface area}}\right)$	22
Empty weight	220 kg
Take-off weight	330 kg
Ballast weight	160 kg
Max. take-off weight	480 kg
Wing load	28.6 - 46.9 kg/m^2
Glide ratio	40 - 42
Max. glide ratio velocities	91 - 110 km/h
Min. descent speed	0.56 - 0.68 km/h
Slowest descent rate speed	73 – 88 km/h
Min. flight speed	65-78 km/h
Max. allowed air speed	270 km/h

3. SIMULATION TESTS – SENSITIVITY ANALYSIS

Initial numerical analyses were carried out in the Solid Works Flow Simulation computing environment for an ambient pressure of 1013.25 hPa, an ambient temperature of 20ºC (293.2 K) and a wind (air) speed along the assumed Z axis of 30 m/s. The *Flow type* was assumed to be *Turbulent and laminar*. The *Turbulence model* was assumed to have *Intensity* (2%) and *Turbulence length* (0.00048 m). The *Simulation type* was assumed as *External*, without taking gravity into account.

In the first step of the analysis of the airflow around the glider, several grid systems were prepared in order to analyse the sensitivity of the grid used for the lift force computation [5 - 8]. The global settings of the *Computational Fluid Dynamics* (CFD) mesh were adopted in accordance with the standard software settings, with a modified degree of mesh density in subsequent analysis variants. Additionally, the mesh was refined locally, around the glider model itself, taking the degree of density according to the available functionality of the CFD software. The view of the selected meshes used in the numerical analysis is shown in Fig. 2.

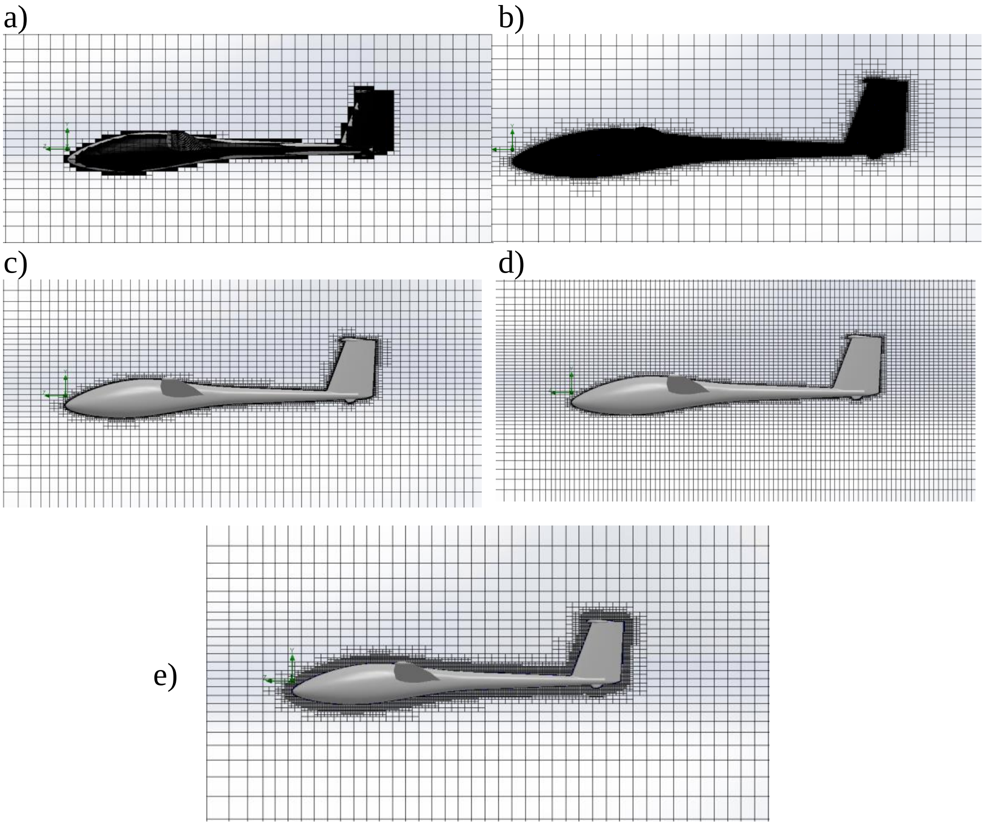


Fig. 2. Selected CFD mesh views:
(a) grid 1.1, (b) grid 1.5, (c) grid 2.5, (d) grid 4.3, (e) grid 5.4

The mesh selection was based on its gradual global and local thickening, depending on the capabilities of the CFD software. A total of 27 different levels of computational grid refinement were adopted, named as follows: the first digit – the global grid refinement level; the second digit – the local grid refinement level. Local mesh refinement is responsible for increasing the accuracy of the results near the glider's wall zone.

The authors adopted the criterion for selecting the target mesh based on the reduction in changes in the value of the glider's lift force and the duration of numerical computations. The adopted criterion was dictated by the need to relatively quickly analyse a number of different test configurations and the influence of several factors, i.e. temperature, relative humidity and wind angle. It was also assumed that individual parameters would be given in units, e.g. force [N], in order to later directly compare the results of computer simulations with experimental tests planned at a later stage of work.

The authors used the tested object on a real scale to develop a methodology for subsequent research on a laboratory scale in a wind tunnel. While experimental tests will be carried out on an appropriately scaled-down model in controlled conditions, the impact of varying environmental conditions on selected aerodynamic parameters necessitates the development of specific procedures on the 1:1 model. The results of the simulation tests are presented in Fig. 3.

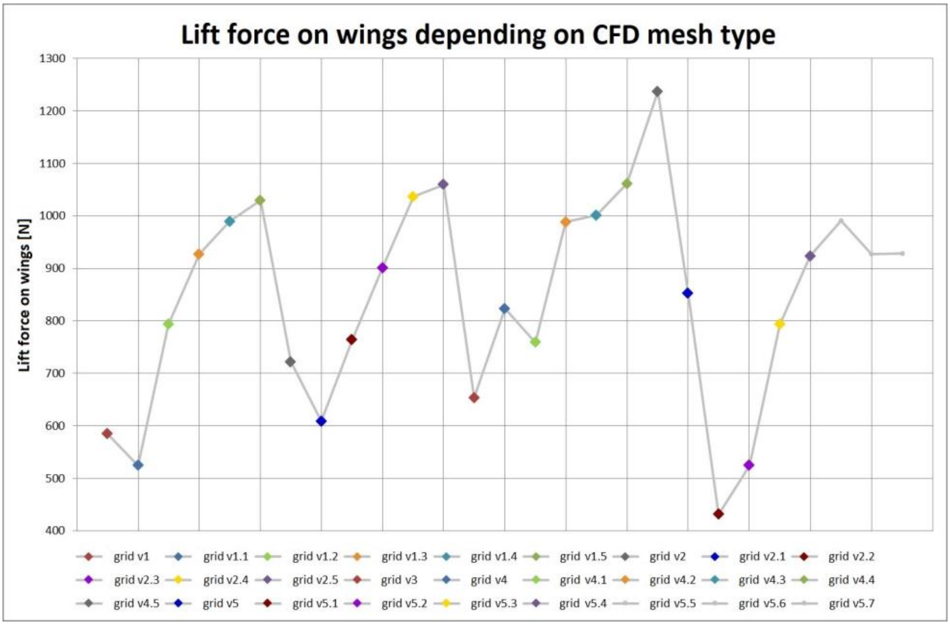


Fig. 3. The value of the glider's lift force depending on the selected computational grid [Proprietary study]

Based on the results presented in Fig. 3, it was found that the global mesh density, at the first level adopted by the authors, and the local mesh density, at the fifth level adopted by the authors, results in obtaining lift force values (mesh 1.5 – Fig. 1b) similar to the results obtained using higher CFD mesh densities.

Further increasing the mesh accuracy reached a certain maximum for the value, which was also determined for the mesh with the lower density level of individual finite volumes. The more accurate grid significantly accounts for the influence of the boundary layer on the value of the lift and drag forces, leading to an increase in the curve values. A decreased number of finite volumes reduces calculation time, enabling less time-consuming simulation tests for changes in numerous parameters and configurations, without significantly affecting the divergence of the results obtained. After taking into account these key issues, the authors adopted the CFD grid system identified as v1.5.

4. SIMULATION TESTS – VARIABLE LOAD CONDITIONS

In the next step, the authors decided to conduct simulations for the glider's various load states, changing the wind angle of attack (in the plane of symmetry) to emulate the change in the glider's position during flight. The glider's geometry remained stationary in relation to the *Cardinal Coordinate System* (CCS), so reading the indications of the forces generated (lift and drag) did not require additional calculations or transformations. The terms introduced for the adopted wind angles are shown in Fig. 4.

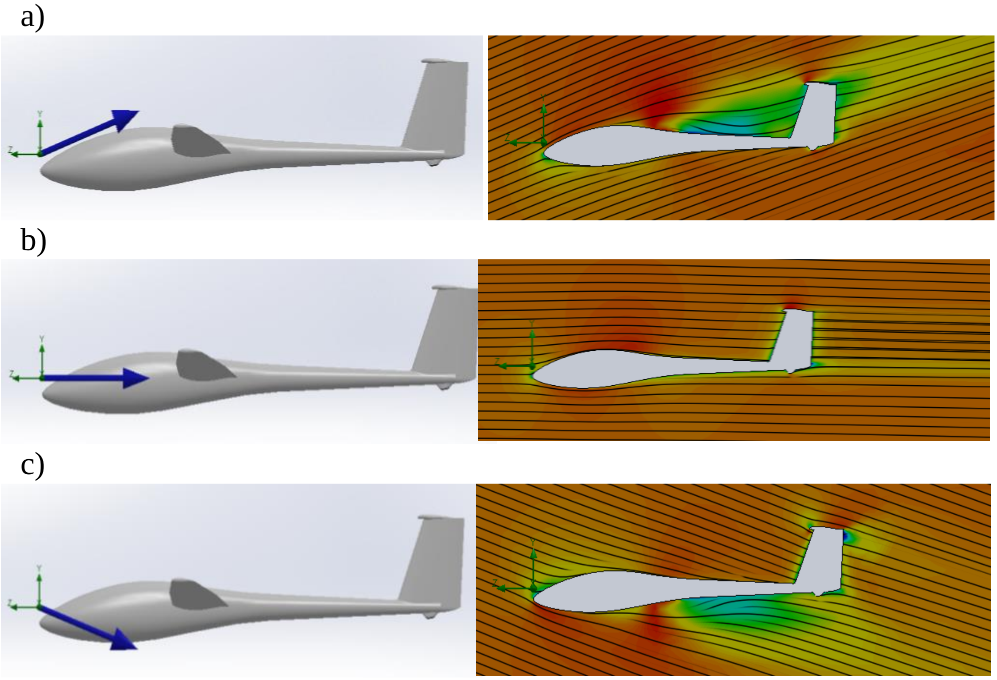


Fig. 4. Directions of the set wind speed: (a) +20°, (b) 0°, (c) -20°
[Proprietary study]

The directions with the "+" and "-" signs indicate the glider's ascent and descent, respectively. The wind speed of 30 m/s was assumed due to the practical use of such a cruising speed in real conditions. A flow analysis was performed for similar conditions to those used in the sensitivity analysis. The values of the drag and lift forces as a function of the wind angle are shown in Figs. 5 and 6.

Based on the results presented in Figs. 5 and 6, the wind angle clearly influences the values of the lift and drag forces acting on the glider. The values of individual forces take the expected course. These results will constitute a comparative basis for simulations taking into account variable atmospheric conditions, i.e., changes in temperature and relative humidity. Figure 5 shows the lift force values generated on the entire surface of the glider with the lift force values generated on its wings only. The lift force values on the wings also assume the predicted distribution, and their similar trend of changes proves that the simulations performed are correct. The reference points for individual wind angles are analogous and consistent with Fig. 4.

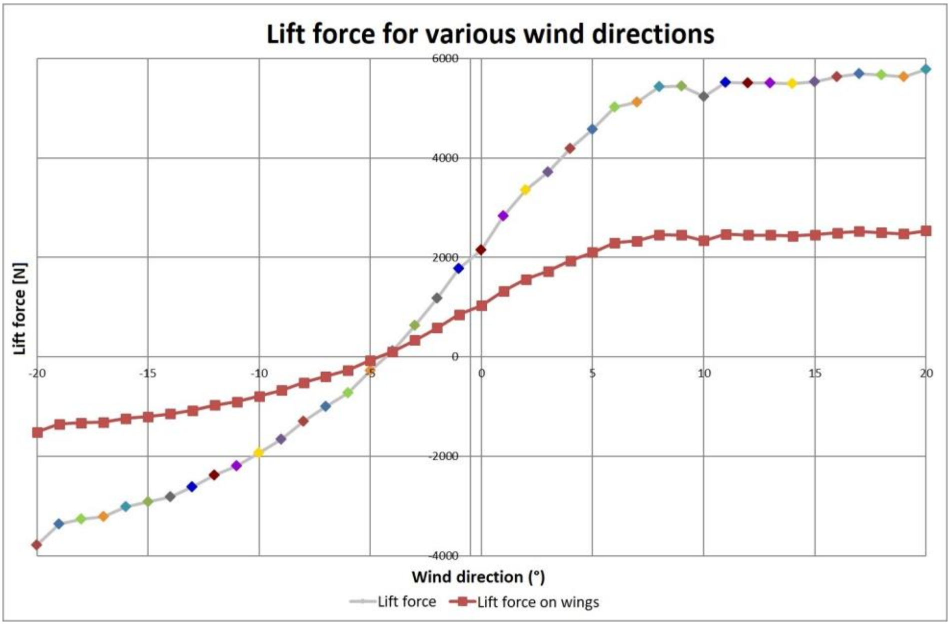


Fig. 5. The glider's lift force depending on the adopted wind angle
[Proprietary study]

Interestingly, the wings experience a sudden drop in the lift force at the 10° wind angle. The authors assume that this results from exceeding the critical angle of attack. After exceeding 10° of wind angle, the wings do not gain much more lift.

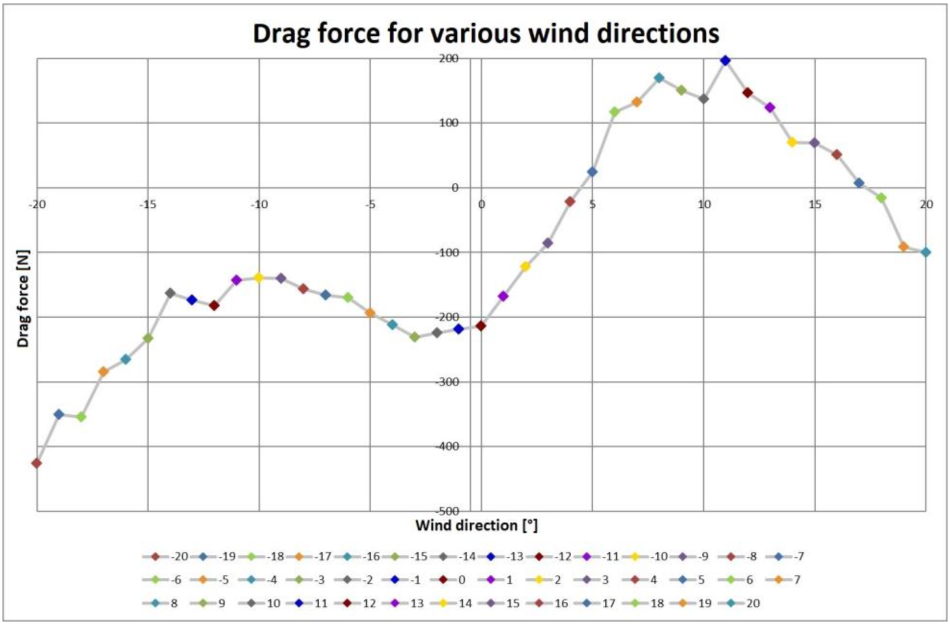


Fig. 6. The Glider's drag force depending on the adopted wind angle. [Proprietary study]

Figure 7 shows the pressure distribution on the glider surface for three selected configurations. Fig. 7a illustrates the glider's descent, corresponding to a position of -20°. Fig. 7b reflects the wind direction at an angle of 0°, while Fig. 7c shows the angle of +20°, which corresponds to the glider's climb.

The glider geometry is presented in an isometric projection to illustrate the lift force distribution (lower pressure zones on the wing surface) depending on the adopted configuration.

In Figure 7, an evident change in the position of the lower pressure zones on the wings can be observed. This, among others, proves that the simulations are correct and that there is a clear correlation between the wind angle and the forces acting on the glider during manoeuvres.

Flow simulation tests for various wind angles were carried out for constant and uniform atmospheric conditions. Next, it was decided to conduct several similar simulations, but for different air temperatures and relative humidities. The following ambient temperatures and relative humidity values were assumed: 10, 20, 30 °C and 10, 50 and 90 % (Table 2).

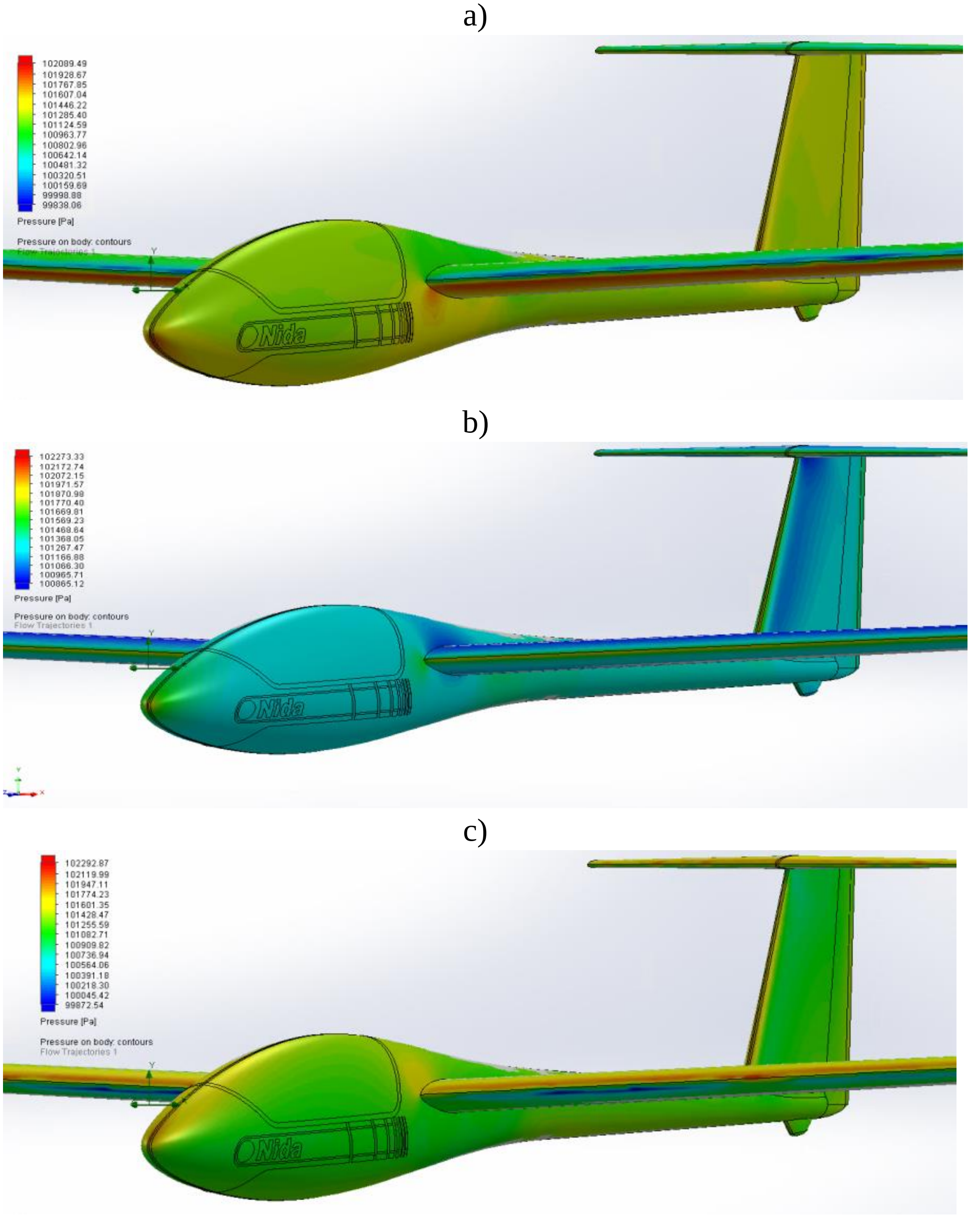


Fig. 7. Pressure distribution on the glider surface (selected wind direction position): (a) -20°, (b) 0°, (c) +20° [Proprietary study]

Table 2. Summary of variable atmospheric conditions in the CFD simulation

Variants studied in the CFD simulation		Temperature [ºC]		
		10	20	30
Relative humidity [%]	10	x	x	x
	50	x	x	x
	90	x	x	x

Figure 8 illustrates that within the wind angle range from -7° to +3°, there is no visible change in the lift force, despite the change in the atmospheric conditions. Looking at the wind angle range from -20° to -15° it can be concluded that air temperature has a much greater impact on the lift force than humidity. In the same part of the diagram (i.e. at a low wind angle), the glider achieves the highest lift force in warm air and high humidity, while at an angle of +20°, the strongest lift force is achieved in the test at both the lowest temperature and humidity. The "reversal" of the optimal conditions for obtaining the highest possible lift force occurs at a -4° of wind angle.

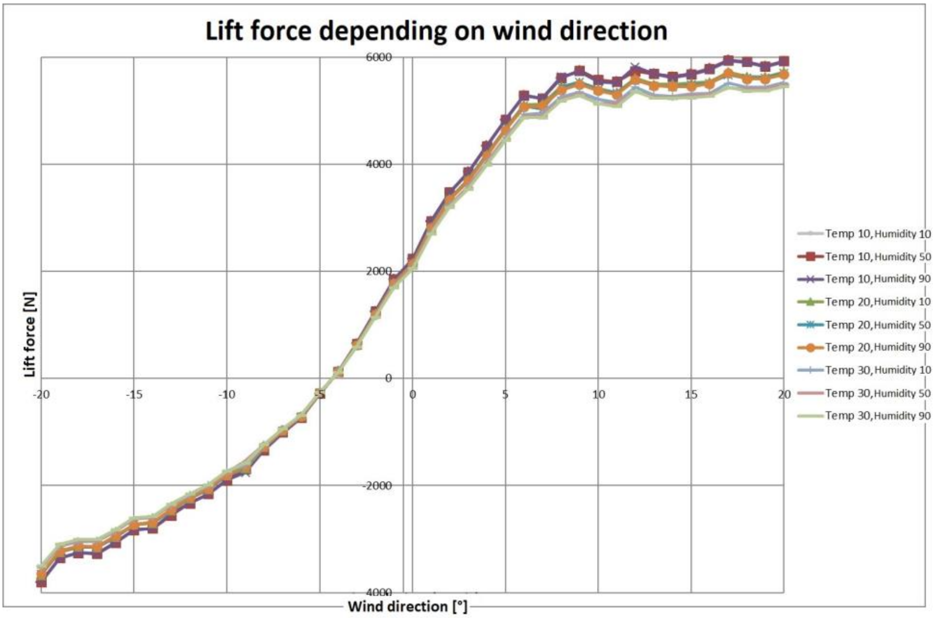
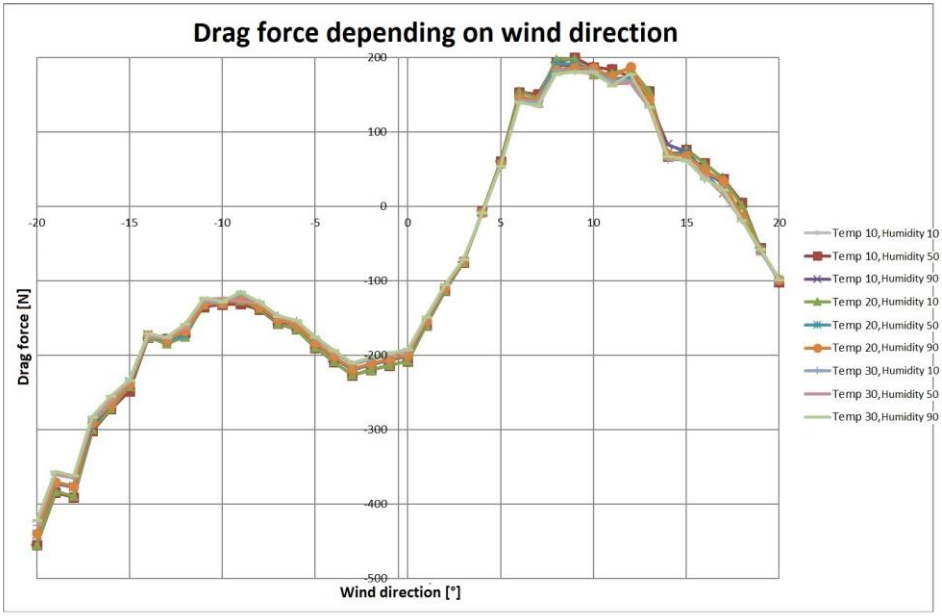


Fig. 8. The influence of air temperature and humidity variability on the values of the glider's lift force [Proprietary study]



Rys. 9. The influence of variability of air temperature and relative humidity on the values of the glider's drag force [Proprietary study]

In the above diagram of the relationship between the drag force and the wind angle (Fig. 9), one can also observe the change in the maximum value of the drag force depending on external conditions. Regardless of the wind angle, the drag force is greatest at the highest humidity. At negative angles (glider descent), the greatest drag force occurs at the highest temperature, while at positive angles (glider climb), the greatest drag force occurs at the lowest temperature.

Regardless of the wind angle, the drag force is greatest in the most humid conditions for a number of reasons, which the authors plan to investigate through further simulation and empirical studies in laboratory conditions. Firstly, air viscosity increases with humidity, which explains the increase in the drag force. However, as humidity increases, the density of the medium decreases, which, according to theory, should contribute to a decrease in the drag force. If other factors do not change when the density changes, this means that the increase in viscosity of the medium is much greater than the decrease in its density.

5. CONCLUSIONS

The simulation tests show a clear tendency for a change in the glider's lifting force and drag force depending on the wind attack angle. However, these trends become less clear when considering changing atmospheric conditions. They retain their variability only in selected orientations.

However, the presented analyses do not exhaust the topic of finding a correlation between the variability of flight conditions and its stability or, ultimately, flight glide ratio. The authors aim to verify the numerical model through empirical research in a wind tunnel in laboratory conditions. Therefore, the newly developed techniques and work methodology will contribute to creating a reduced-scale model of the glider (using incremental manufacturing techniques, including 3D printing) and its implementation on a test stand equipped with a wind tunnel. This will allow correlations between the studied phenomena to be found both through computer simulations and empirical research. Validation of the model will enable the extension of research to include the influence of atmospheric factors, side winds, the complex orientation of a glider in relation to the wind (flight direction), dynamic phenomena, and, consequently, determining the flight glide ratio. Comprehensive information about a glider's capabilities in various atmospheric conditions will significantly validate the proposed instructions for pilots.

FUNDING

The authors received no financial support for the research, authorship, and/or publication of this article.

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Wpływ warunków atmosferycznych na powstające siły nośne szybowca

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Streszczenie. W artykule przedstawiono metodykę badań symulacyjnych oraz wyniki przeprowadzonych badań opływu powietrza wokół szybowca, skupiając się na zagadnieniu zmiany siły nośnej oraz siły oporu w zmiennych warunkach atmosferycznych. W doświadczeniu wykorzystano symulacje w programie SolidWorks Flow Simulation 2022. Model do badań symulacyjnych opracowano na Wydziale Nauk Technicznych Uniwersytetu Warmińsko-Mazurskiego w Olsztynie

Słowa kluczowe: doskonałość aerodynamiczna szybowca, siła oporu, siła nośna, warunki atmosferyczne