S. O. W. A. – A BIOMIMETIC STRUCTURE OF A DRONE PROPELLER INSPIRED BY AN OWL'S FEATHER

[1]PAWEŁ PRZEJCZOWSKI, [2]JAN PRZEPIÓRA, [3]PAWEŁ PASŁAWSKI, [4]MICHAŁ PIETRZAK, KRZYSZTOF LALIK

Faculty of Mechanical Engineering and Robotics, AGH University of Science and Technology, Al. Mickiewicza 30, 30-059 Kraków, Poland

E-mail: [1]przejczo@student.agh.edu.pl, [2]przepial@student.agh.edu.pl, [3]paslawsk@student.agh.edu.pl, [4]mpietrz@student.agh.edu.pl, [5]klalik@agh.edu.pl

Abstract - In this article, we present research of the pressure parameters, thrust force values, and flow of newly designed rotor propellers for a bicopter drone, the results of which can also be applied to macroscale objects such as wind turbine blades that can be used in drones or wind turbines. This project is inspired by nature, or more specifically, solutions observed in biological systems optimized over millions of years of evolution. The results of the research show that the nature-inspired propellers, which mimic the structure of an owl's feather, reduce the pressure in the area of the grooves and curved surface, which increases the thrust force value. This allows for satisfactory results while reducing sound emission.

Keywords - Nature, Biomimetism, Computational Fluid Domain, Drone, Technology

I. INTRODUCTION

Biomimetics [1] is the kind of the study, which based on the nature-inspired design and technology, has the potential to revolutionize the way we approach problem-solving and innovation. By emulating the efficiency, functionality, and adaptability of living systems, it is possible to create more sustainable, efficient, and effective solutions for a wide range of challenges. From drones with wings that mimic the movement of owl's feathers to self-healing materials inspired by the regenerative capabilities of some organisms, biomimetics is making waves in a variety of fields, including engineering, materials science, and robotics.[2]Owls are known for their silent flight, which allows them to hunt effectively without alerting their prey. This silent flight is made possible by a combination of factors, including the unique design of their feathers and the way in which they fly.

One of the key features of an owl's feathers is their serrated edges, which create a jagged edge that helps to break up the sound waves generated by the movement of the feathers through the air. This helps to reduce the amount of noise that is produced as the owl flies, making its flight nearly silent.[3]-[5]In addition to their serrated feathers, owls also have a special arrangement of feathers on their wings and tails that helps to further reduce noise. The feathers on the leading edge of the wing have a fluffy, downy texture that helps to absorb sound, while the feathers on the trailing edge are more rigid and help to deflect sound waves away from the owl's body. The feathers on the owl's tail are also arranged in a way that helps to dissipate sound waves, further reducing the noise produced during flight.Thrust force is the force that propels a drone forward through the air. It is created by the movement of air through the drone's propellers, and it plays a crucial role in the drone's ability to take offand change direction.There are several factors that can affect the thrust force of a drone. One of the most important is the size and shape of the propellers. Larger propellers or propellers with a more efficient shape will generate more thrust force, while smaller or less efficient propellers will generate less thrust.The speed of the propellers is also an important factor in determining thrust force. The faster the propellers rotate, the more thrust force they will generate. This is why many drones have a throttle control that allows the pilot to adjust the speed of the propellers.[6]-[7]The density of the air can also affect thrust force. In denser air, such as at sea level, the propellers will generate more thrust force. In less dense air, such as at high latitudes, the propellers generate less thrust force.The design of the drone itself can also impact thrust force. A drone with a more streamlined body will experience less drag and therefore generate more thrust force.

Overall, thrust force is a critical aspect of drone flight, and it depends on a variety of factors including propeller size, speed, and air density, as well as the design of the drone itself. By understanding and optimizing these factors, pilots can improve the performance and capabilities of their drones.There is a relationship between the pressure and sound emitted by drone propellers.[8] Propellers generate thrust by moving air through their blades, and the pressure of the air passing through the blades can affect the sound emitted by the propellers. Generally, higher pressure of the air passing through the propeller will result in a louder sound, while lower pressure will result in a quieter sound. This is because the movement of the air through the blades creates a vibration, which generates sound waves. The intensity of the sound waves is directly related to the pressure of the air passing

through the propellers.[9]

II. PROPELLER MODELS

The new drone propellers were designed to mimic the work of an owl's feather as closely as possible (Fig 1.). In order to compare the characteristics of the sound emitted by these wings, four types of drone propellers were created and subjected to simulated tests. The first of them, which serves as a reference point for the studies, does not have the characteristic structure of an owl's feather. The second propeller has grooves that cut the air as it rotates.[10] The next propeller has a toothed surface at the outlet of the flowing air. The last designed propeller has a structure combining the characteristics of the second and third variants. The simulated tests were designed to verify the values of the pressures flowing over the drone wings, compare them, and check in which cases the most favorable situation occurred, allowing their use in designing systems that reduce sound emission.[11],[12]

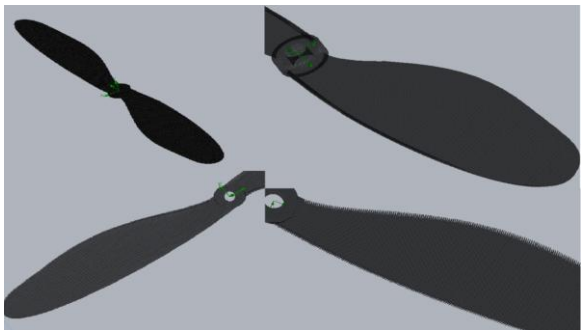


Fig 1. – designed drone propellers

III. MEASUREMENT STAND

A special measurement system shown in the Fig. 2 has been created to perform real-world measurements of thrust force in order to verify the values obtained in simulations. Its task is to determine how the value of thrust force changes with respect to the rotational speed set for the servo drive. In the project being carried out, the Siemens SINAMICS S120 servomechanism was selected due to its ability to set very high (up to 10,000 rpm) rotational speeds. The lift of the designed drone blades as the rotational speed increases allows the determination of the thrust force value.



Fig2. – measurementstand

The measurement system is made using tensometric beams connected to HX711 modules (Fig 2.), thanks to which the data is transmitted to the Raspberry Pi 4B minicomputer.[13] This device serves as an intermediary in sending data packets to the Siemens S7 - 1500 PLC controller using the MQTT protocol. The operation of tensometric beams is based on converting the change in the length of the beam into an electrical voltage value. The Fig 3. Shows the connection between main components of the measurement system.

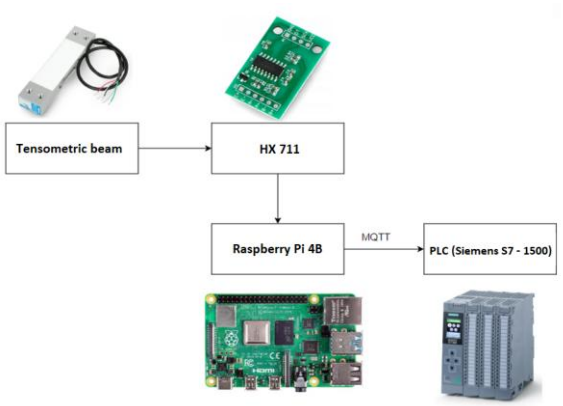


Fig3. Schematic of the measurement system

IV. NUMERICAL SIMULATION AND RESULTS

Simulation studies were conducted using Solid Works software with the Flow Simulation module. This software uses CFD, which can be used by engineers to simulate and analyze flows in a variety of systems. Air with standard density was used as the working factor. The rotational speed of 7200 revolutions per minute was set. The dimensions of the grid were generated automatically, considering a higher density in the area of the grooves, which significantly affected the results of the thrust and pressure parameters obtained. Fig 4. To Fig 7. presents the results of the simulation.[14]-[18]

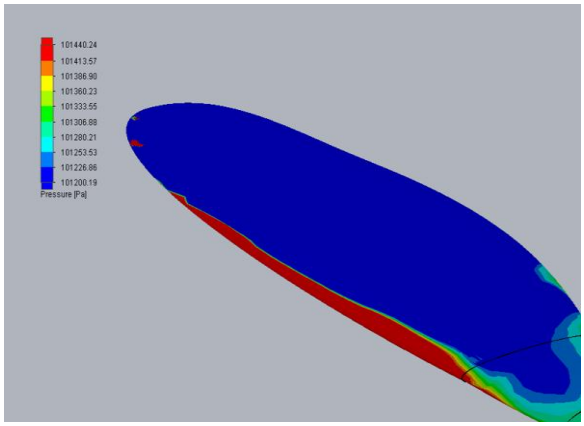


Fig 4. Propeller with no grooves on the surface

When the propeller does not have grooves, the inlet surface has a very high pressure compared to the rest of the wing. This causes a loud noise to be emitted.

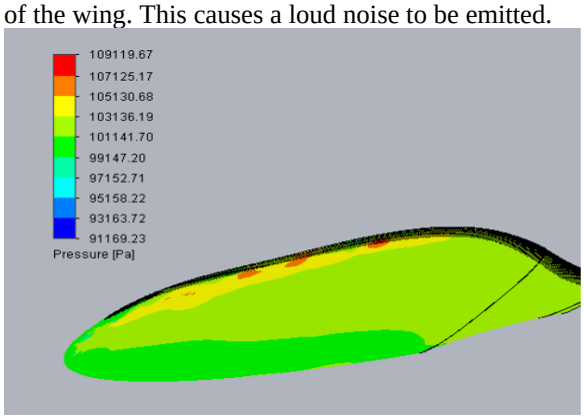


Fig 5. Propeller with grooves on inlet surface

In the case where the propeller has grooves on the inlet surface, it is possible to observe that the pressure distribution is milder than in the previous situation. This allows to conclude that the sound will spread more gently.

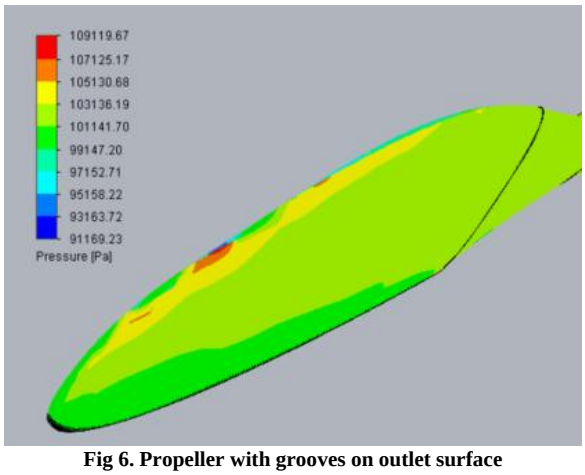


Fig 6. Propeller with grooves on outlet surface

The occurrence of grooves on the outletsurface has similar effects to the previous case.

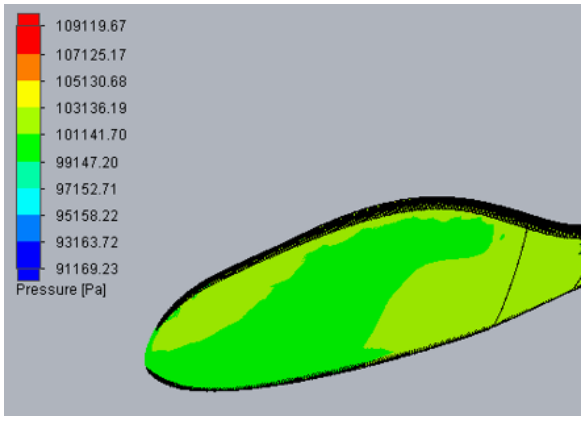


Fig 7. Propeller with grooves on inlet and outlet surface

In the case where grooves occur on both edges of the propeller, the pressure is very uniform, the result of which is the lowest sound emission. The average pressure value is the smallest among all simulations.The Fig 8. shows the measurements of the pressure values for one blade, which is a cross section of the propeller. In the absence of the characteristic owl's feather structure on the blade of the drone, the pressure at the point of air attack takes on the peak value. This causes the air flow to be more irregular than in other cases. The presence of grooves on the propeller surface results in significantly smaller differences on the pressure course chart. In the case of a model with grooves on the outlet surface, there is also a reduction in pressure compared to the case where no grooves are present. The combination of cases in which grooves appear both on the inlet and outlet surface gives intermediate results. Therefore, the most advantageous is the presence of grooves on the attack surface. It gives the best results and can contribute to a significant reduction in emitted sound.

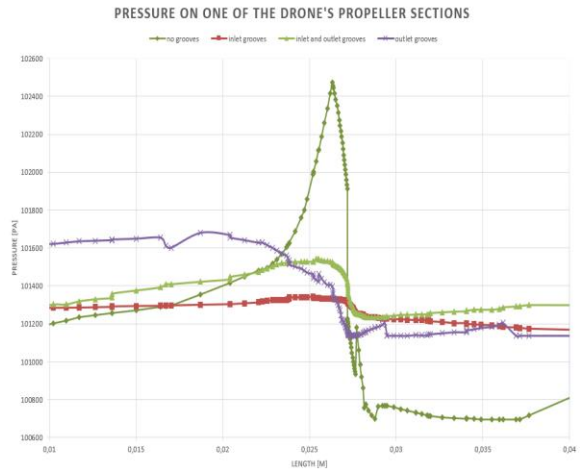


Fig 8. Pressure on one section

According to the basic research, which was to verify how the pressure value on the propeller and the thrust force change depending on its shape, the obtained results allow to state that if the drone wing has

characteristics that characterize the structure of an owl feather, the thrust force value changes significantly. The most favorable value was obtained for grooves on the rear wing surface and amounted to 12,604 N, which is about 30% higher than in the case of a regular drone blade. The presence of grooves on the inlet and outlet surface weakens the effect of strengthening the thrust force value, but this value is higher than in the simplest propeller construction.The analysis of data (Tab 1.) on the average pressure on the propellers emphasizes the previously drawn conclusions. The presence of grooves on both sides of the propeller significantly reduces the average pressure. In this case, an additional advantage is that the pressure on the propeller is distributed evenly, which causes the flowing stream of air not to fall into too much turbulence. In situations where grooves were placed on only one side, lower pressure prevailed when grooves were made on the inlet surface. Comparing both parameters for the simulations carried out, better parameters occurred in situations where the wing had characteristics characteristic of the structure of an owl feather.

Parameters/Case	no grooves	inlet grooves	outlet grooves	inlet and outlet grooves
Thrust force	9,514 N	10,852 N	12,604 N	9,761 N
Avg Total Pressure	104370,51 Pa	104332,95 Pa	104351,65 Pa	104315,27 Pa

Tab 1. Comparison of the thrust force values and average total pressure in different cases

V. CONCLUSION

The results achieved allow to determine that the use of inspired by the nature solutions in technical systems can significantly improve well-known devices and objects. The use of the conducted research may take place in the production of drones, which will significantly reduce their emission. This will allow their use in forest conditions, where it is not advisable to disturb observed animals. Another example of the application of such a solution may be the production of wind turbines. Improving their acoustic properties may result in a reduction in the requirements of the legal regulator as to the distance at which a given turbine can be located from human settlements. This will increase the area in which such turbines can be used and thus increase the share of Green Energy, which is consistent with the Sustainable Development strategy.

Based on the research, it has been found that the shape of the drone propeller blade has a significant impact on the pressure values and thrust force. The presence of grooves on both sides of the blade significantly reduces the average pressure and leads to a more evenly distributed pressure on the propeller, resulting in a smoother air flow and reduced turbulence. This can contribute to a significant reduction in emitted sound.

Further research may be necessary to fully understand the relationship between pressure on the propellers and sound emission in drone flight.

REFERENCES

[1] Sanchez, C., Arribart, H., &Guille, M. M. G. (2005). Biomimetism and bioinspiration as tools for the design of innovative materials and systems. In Nature Materials (Vol. 4, Issue 4). https://doi.org/10.1038/nmat1339

[2] Heers, A. M., Tobalske, B. W., & Dial, K. P. (2011). Ontogeny of lift and drag production in ground birds. Journal of Experimental Biology, 214(5).

[3] https://doi.org/10.1242/jeb.051177

[4] Bachmann, T., Klän, S., Baumgartner, W., Klaas, M., Schröder, W., & Wagner, H. (2007). Morphometric characterisation of wing feathers of the barn owl Tyto alba pratincola and the pigeon Columba livia. Frontiers in Zoology, 4. https://doi.org/10.1186/1742-9994-4-23

[5] Ito, S. (2009). Aerodynamic influence of leading-edge serrations on an airfoil in a low Reynolds number: A study of an owl wing with leading edge serrations. Journal of Biomechanical Science and Engineering, 4(1). https://doi.org/10.1299/jbse.4.117

[6] Henderson, L., Glaser, T., & Kuester, F. (2017). Towards bio-inspired structural design of a 3D printable, ballistically deployable, multi-rotor UAV. IEEE Aerospace Conference Proceedings. https://doi.org/10.1109/AERO.2017.7943970

[7] Usherwood, J. R., & Ellington, C. P. (2002). The aerodynamics of revolving wings I. Model hawkmoth wings. Journal of Experimental Biology, 205(11). https://doi.org/10.1242/jeb.205.11.1547

[8] Nonami, K. (2020). Present state and future prospect of autonomous control technology for industrial drones. In IEEJ Transactions on Electrical and Electronic Engineering (Vol. 15, Issue 1). https://doi.org/10.1002/tee.23041

[9] Yeong, S. P., & Dol, S. S. (2016). Aerodynamic optimization of micro aerial vehicle. Journal of Applied Fluid Mechanics, 9(5), 2111–2121. https://doi.org/10.18869/acadpub.jafm.68.236.25522

[10] Rezaeiha, A., Montazeri, H., &Blocken, B. (2019). On the accuracy of turbulence models for CFD simulations of vertical axis wind turbines. Energy, 180. https://doi.org/10.1016/j.energy.2019.05.053

[11] Shi, L., Zhang, C., Wang, J., & Ren, L. (2012). Numerical Simulation of the Effect of Bionic Serrated Structures on the Aerodynamic Noise of a Circular Cylinder. Journal of Bionic Engineering, 9(1). https://doi.org/10.1016/S1672-6529(11)60101-7

[12] Lalik, K., &Kozek, M. (2020). Innovative Acoustical Diagnostic System Compatible with Industry 4.0 Standards. Proceedings of the 2020 21st International Carpathian Control Conference, ICCC 2020. https://doi.org/10.1109/ICCC49264.2020.9257258

[13] Liang, Y., Liu, C., Zhao, Q., Lin, Z., Han, Z., & Ren, L. (2021). Bionic design and 3d printing of continuous carbon fiber-reinforced polylactic acid composite with barbicel structure of eagle-owl feather. Materials, 14(13). https://doi.org/10.3390/ma14133618

[14] Nandanwar, V. G., Kashif, M., &Ankushe, R. S. (2017). Portable Weight Measuring Instrument. Proceedings - 2017 International Conference on Recent Trends in Electrical, Electronics and Computing Technologies, ICRTEECT 2017, 2017-December. https://doi.org/10.1109/ICRTEECT.2017.23

[15] Christodoulou, K., Vozinidis, M., Karanatsios, A., Karipidis, E., Katsanevakis, F., &Vlahostergios, Z. (2019). Aerodynamic analysis of a quadcopter drone propeller with the use of

computational fluid dynamics. Chemical Engineering Transactions, 76. https://doi.org/10.3303/CET1976031

[16] Riglin, J., & Reid, B. (2021). Applied Computational Fluid Dynamics and Turbulence Modeling. AIAA Journal, 59(5). https://doi.org/10.2514/1.j060595

[17] Ehrich, S., Schwarz, C. M., Rahimi, H., Stoevesandt, B., &Peinke, J. (2018). Comparison of the Blade Element Momentum theory with Computational Fluid Dynamics for wind turbine simulations in turbulent inflow. Applied Sciences (Switzerland), 8(12). https://doi.org/10.3390/app8122513

[18] Subhas, S., Saji, V. F., Ramakrishna, S., & Das, H. N. (2012). CFD analysis of a propeller flow and cavitation. International Journal of Computer Applications in Technology, 55(16). https://doi.org/10.5120/8841-3125

[19] Tu, T. N. (2019). Numerical simulation of propeller open water characteristics using RANSE method. Alexandria Engineering Journal, 58(2). https://doi.org/10.1016/j.aej.2019.05.005

★★★