Numerical analysis of the influence of the number of blades on the dynamic performance of a drone

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Abstract. The use of Unmanned Aerial Vehicles and known under the generic name of drones is increasingly present in different economic sectors, due to the versatility they offer in solving specific problems. The specific problems to be solved, however, raise the need for the technical characteristics of the drones to be optimized according to the specific usage. In the case of drones used in technological processes in agriculture, they must offer a high autonomy, that can be increased by optimizing their weight. The paper proposes the study of the dynamics of the air flow according to the configuration of the drone rotor (2 and 3 rotor respectively) by numerical analysis methods for the further development of a drone that will be used in the phytosanitary treatment process of agricultural crops. The parameters evaluated and compared are the specific parameters for characterizing the airflow: velocity and relative pressure (at different nacelle's section, both in horizontal and vertical directions). The obtained results show that the most constant, dense and homogeneous velocity field was obtained from the 3-blade configuration of the rotor.

1. Introduction

Since ancient times, agriculture was the basic occupation of mankind. The main result of the agricultural activities was the production of food, with a huge role in the development of the human civilization. This more important nowadays as the world population is constantly growing. Thus, in the last 100 years there has been a massive population growth, respectively 4 times more due to: advanced medical procedures, a lower mortality rate and a continuous increase of productivity in the agricultural field. Historians estimate that around 1800 the world population had an approximate value of 1 billion, but after 1800, this changed fundamentally: the world population increased 7 times. Generally speaking, it is estimated that 108 billion people have ever lived on our planet [1].

In a study by United Nations Population Division, it was predicted that by the end of the 21st century, the population will reach 11 billion [2]. However, a study conducted by Sanjeev S. bring counterarguments regarding this prediction, arguing that global fertility will fall in 2020 below the replacement rate and the world population will reach a threshold of less than 9 billion by 2050, followed by a decline on long term [3]. Any of these theories, however, show that a huge volume of food will still be needed to meet the needs of the world's population.

The only constant in the agricultural processes that provide food since the beginning of human society is the limited agricultural area, which is why (in order to counteract the increase of worldwide pollution) in order to increase the production and productivity in agriculture modern methods and methodologies must be used. These principles can be found in the concept of Agriculture 4.0, a concept that includes development directions in order to achieve this goal. The concept of Agriculture 4.0 has brought with it an environment in which all the elements that compose it (Intelligent resources, Devices, Products or Machines, Data Transfer and Infrastructure, Data Analysis, People Processes and Systems) are in continuous and direct connection, reaching a very high level of coordination. For example, the use in agriculture of existing technologies that are used in other fields (e.g. Bluetooth, GPS, or RFID) leads to an agricultural supply with self-optimization function, due to the rapid and direct communication created between people and agricultural machinery.

One of the modern technologies used in the application of the Agriculture 4.0 concept is the use of UAVs (Unmanned Aerial Vehicles), with immediate applications in: the prevention and the treatments of agricultural crops, the monitoring of the vegetation status of the crops, the monitoring of environmental factors, transport, search and rescue , surveillance, security, etc.

At present, due to the use of UAV in the field of phytosanitary prevention and treatment of agricultural crops, there are developed many practical applications and carried out research for this purpose. The Food and Agriculture Organization of the United Nation [4] investigated their effect on agricultural production and how UAVs can simplify and facilitate the work of farmers by automating processes, which leads to correct and rapid decisions regarding: irrigation plants, pesticide treatments or establishing the degree of harvest.

Muraru et al. [5] dealt with the ways in which UAV use revolutionizes agriculture. Regarding the phytosanitary treatments a first essential role is the health of the crops and the identification of bacterial or fungal infections. By scanning the culture with visible light close to the infrared the drones can identify plants that reflect different amounts of green light. With this information, multispectral images are created that follow the changes of the plants and indicate their state of health. The faster the disease is discovered, the more crops can be saved and farmers can apply and monitor the remedies more accurately. Furthermore, Wen S. et. of [6] have investigated the possibilities of implementing artificial intelligence in the use of a UAV for plant and crop protection activities, and propose a system based on neural networks that optimize the spray process depending on the environmental conditions.

The conclusions drawn by Gupta et al. [7] regarding the immediate benefits of using drones in agriculture were related to reducing pollution, costs and losses, finding problems much faster, optimizing treatments, etc. Even if these benefits exist and are recognized, there are still some limitations regarding the large-scale applicability, limitations related to the cost and performance of the sensors used or the high price of a complete equipment.

The present paper aims to present the partial results of some researches carried out in order to optimize the spray process, by proposing to use the spray nozzles built inside a drone's rotor nacelle, compared to the classic systems that use a common ramp. spray. For this purpose, using numerical analysis methods, the effect of the number of blades (2 and 3) forming a drone rotor, on the dynamic air flow parameters (air flow velocity and pressure) was studied.

2. Material and Method

For the numerical analysis of the velocity and pressure fields caused by the air flow under the rotor of a drone that is intended to be used in the process of plant protection (agricultural crops), a model was developed using Solid Works software. The general geometrical dimensions of the model are: inlet platform diameter 550 mm, output platform diameter 550 mm, platform length 550 mm, blade diameter 450 mm, thickness of the platform walls: upper part 16 mm, lower part 1.58 mm and are shown in figure 1. As boundary conditions, the fluid flow was considered to be air with a density of 1.205 kg/m3, at an ambient temperature of 293.2 K (20°C). Rotor speed is 250 rad/s (2387 rpm).

The analysis of the velocity and pressure fields of the air flow was performed for the cases in which the rotor has 2 and 3 blades in design, and the measurements of the obtained values were made both in the horizontal plane and in the vertical plane of nacelle.

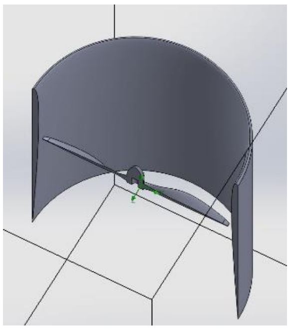

Figure 1. Simulation model (2-blade case).

3. Results and Discussions

The results obtained from computerized numerical analysis (CFD) are presented comparatively in Figures 2-17. It can be observed that differences in the speed and pressure field model appear depending on the number of blades of the rotor.

The graphs of the variation of the air flow velocity are shown in Figures 10-13. From the point of view of the measurements recorded in a vertical plane the maximum speed is 3.45 m/s for the 2-blade rotor case and 3.25 m/s for the 3-blade rotor case. The average speed values are 7.64 m/s for the 2-blade rotor case and 7.41 for the 3-blade rotor case.

The structure of the pressure field is shown in Figures 6-9. Horizontally and vertically for the 2-blade rotor case in figures 6-7 and for the 3-blade rotor case in figures 8-9.

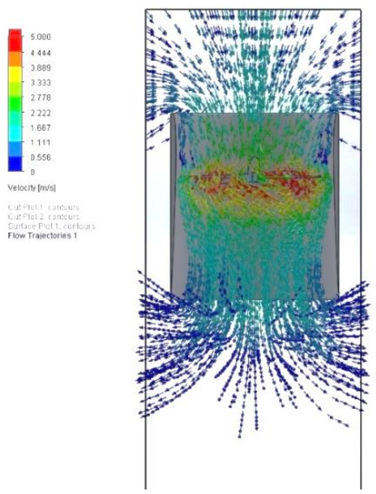

Figure 2. Velocity field in vertical section of nacelle (3-blades rotor case).

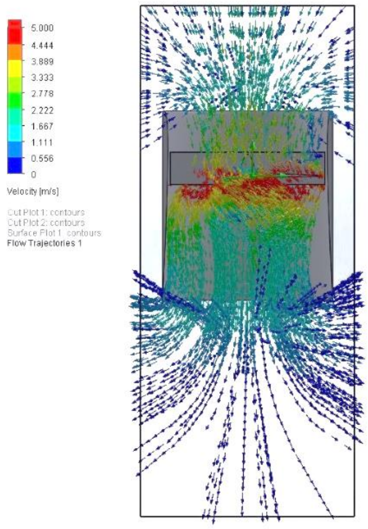

Figure 3. Velocity field in horizontal section of nacelle (2-blades rotor case).

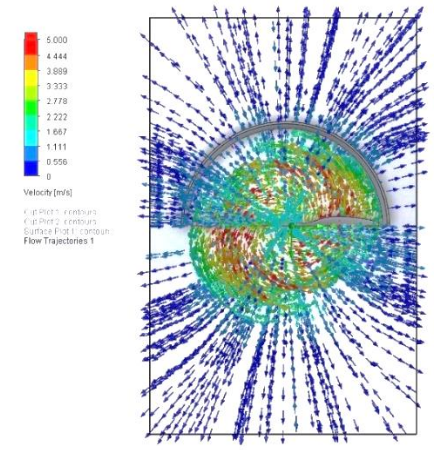

Figure 4. Velocity field in vertical section of nacelle (2-blades rotor case).

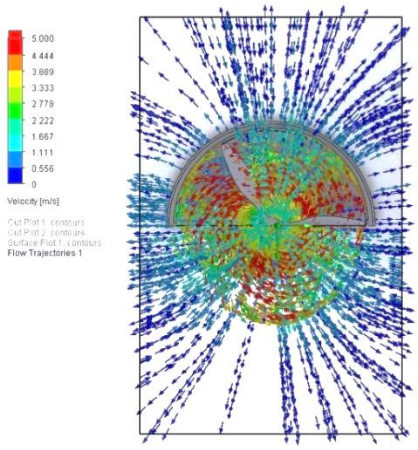

Figure 5. Velocity field in horizontal section of nacelle (3-blades rotor case).

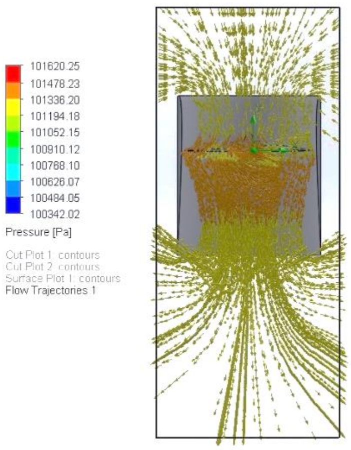

Figure 6. Pressure field vertical section of nacelle (3-blades rotor case)

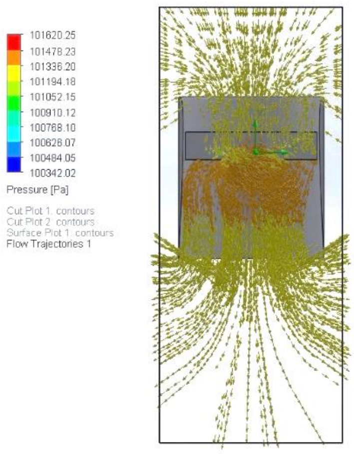

Figure 7. Pressure field in horizontal section of nacelle (2-blades rotor case)

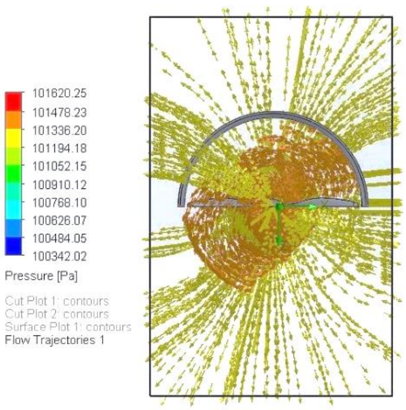

Figure 8. Pressure field vertical section of nacelle (2-blades rotor case).

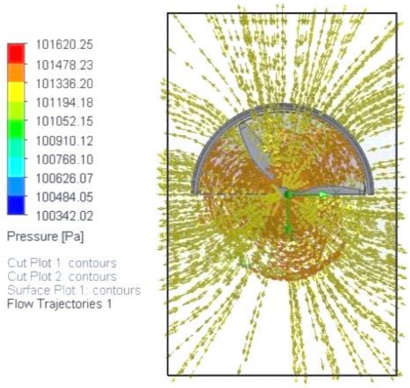

Figure 9. Pressure field in horizontal section of nacelle (3-blades rotor case)

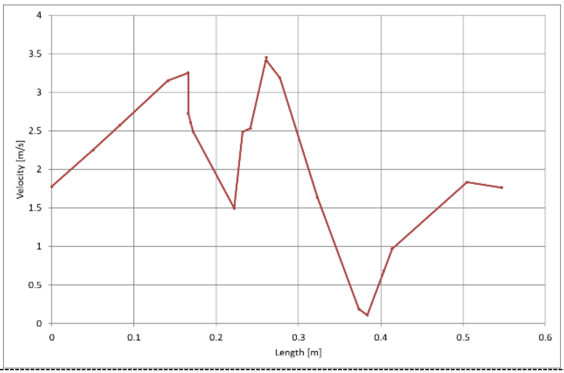

Figure 10. Air speed variation in vertical direction (2-blades rotor case).

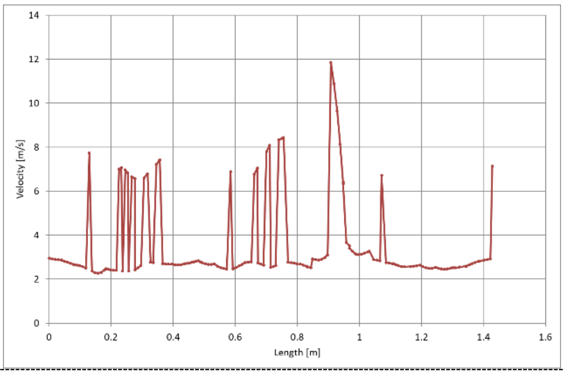

Figure 11. Air speed variation in horizontal direction (2-blades rotor case).

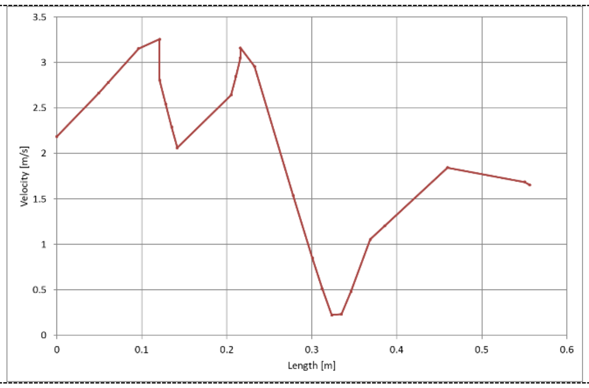

Figure 12. Air speed variation in vertical direction (3-blades rotor case).

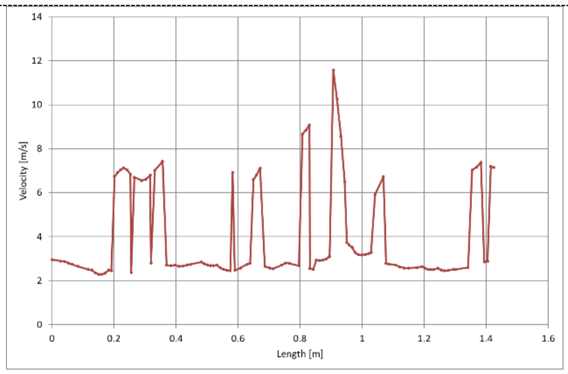

Figure 13. Air speed variation in horizontal direction (3-blades rotor case).

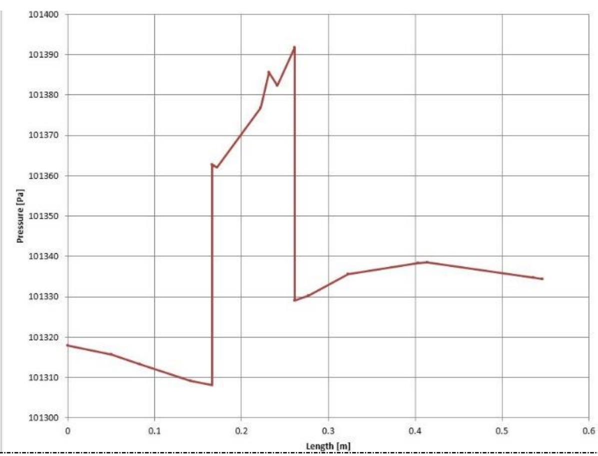

Figure 14. Pressure variation in vertical direction (2-blades rotor case).

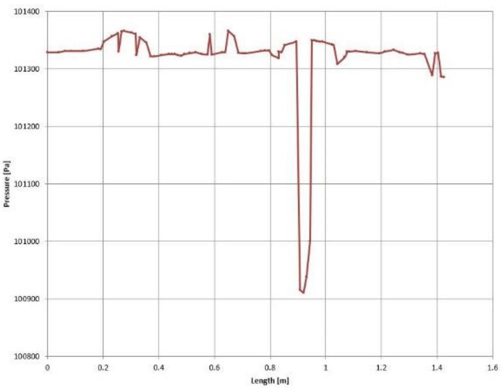

Figure 15. Pressure variation in horizontal direction (2-blades rotor case).

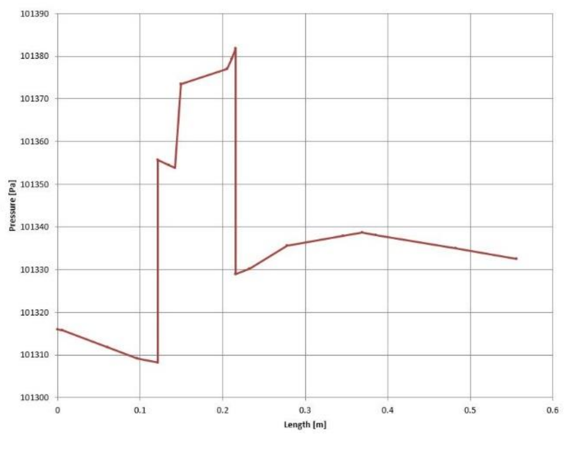

Figure 16. Pressure variation in vertical direction (3-blades rotor case).

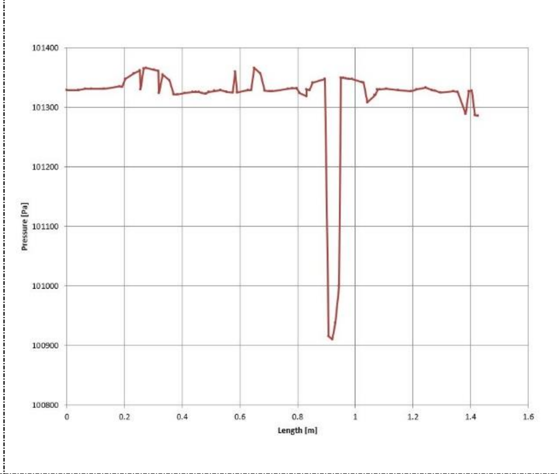

Figure 17. Pressure variation in horizontal direction (3-blades rotor case).

Regarding the pressure variation, the graphs are shown in Figures 14 - 17. The maximum pressure registered horizontally in the case of the 2-blade rotor case is the same as in the case of the 3-blade rotor case (101366 Pa), being recorded in the blade rotation area. In the case of the vertical plane, the following maximum values have been recorded: for the 2-blades rotor case a value of 101391 Pa respectively a value of 101381 Pa for the 3-blades rotor case.

From the point of view of the air-speed recorded at the exit of the rotor nacelle the highest values were obtained for the case of the 2-blade rotor. The average flow through the platform is 2.60 m/s for the 2-blade rotor and 2.45 m/s for the 3-blade rotor case. The relative difference between these values is relatively small by 5.77%.

The pressure fields created by the operation of the rotor at a speed of 2,387 rpm have different values for the studied cases. The highest uniformity of the pressure field is in the case of the 3-blade rotor case but the highest value of the air flow pressure appears in the case of the 2-blade rotor case. The average flow pressure through the nacelle is 101338.05 Pa for the 2-blade rotor case and 101326.89 Pa for the 3-blade rotor case. The relative difference between these values is 11.17%.

Based on the results obtained it can be said that in the case of a 2-blade rotor case can accommodate fewer nozzles spray a common rail of spraying of a drone, but the pressure of the jet is greater which results in the formation of a liquid jet with smaller droplets. In the case of a drone using a rotor with 3 blades in construction, it can accommodate more spray nozzles on the spraying common rail, but the droplet size of the resulting jet (that reach the crop/plant) will be higher.

4. Conclusions

Following the computerized numerical analysis on the influence of the number of blades of a UAV rotor (drones) used in the processes of plant protection in agriculture, the following conclusions can be issued.

UAVs are an emerging technology that offers high potential for use in agriculture with immediate beneficial effects on increasing agricultural productivity. Further studies are needed to improve their performance in order to reduce the costs of application and to obtain material benefits (cost reductions with exploitation).

It is necessary that in order to increase the values of the flow velocity and the pressure, a topological optimization of the shape of the platform will be carried out in the future, which will favor the geometry of the spray in order to make the area covered with the liquid used in the phytosanitary treatments of the crops as uniform.

The obtained results will be used further in the researches to optimize the geometric construction of the platform of a UAV used in the technological processes of protection of agricultural plants, in order to introduce spray nozzles in the construction of the platform and to eliminate the external common ramps currently used. This would eliminate the effect of the influence on the drone's displacement velocity spray and allow a more accurate dosage of the protective liquids used on agricultural crops.

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