Aerodynamic optimization of unmanned aerial vehicle for offshore search and rescue (SAR) operation

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Abstract. Workers on offshore oils rigs are constantly risking their lives due to the location of these rigs in the middle of the ocean. One of the biggest risks to these workers are falling from the rigs and drowning especially during bad weather. Operating UAVs can reduce the risks of injury, human errors and enhances inspections, surveying and emergency operations. The applications of UAVs in offshore tasks are discussed in this paper as well as the aerodynamic optimization of UAV’s propellers. Computational Fluid Dynamics (CFD) analysis and experimental procedures were conducted on multiple propeller alternatives to determine the drag and lift properties and selecting the optimal option based on the lift to drag ratio and desired output. The CFD analysis and the experimental test found that the medium sized (9.0 x 4.5 in) propellers were the optimal option with a drag to lift ratio of 1.75.

1. Introduction
An offshore platform requires a myriad of safety guidelines to prevent disasters. Nowadays, some companies demand the presence of an unmanned aerial vehicle (UAV) at their sites for multiple purposes including security and inspection. UAVs can be operated by trained personnel or pre-programmed to fly a certain path. Autonomous UAVs minimize the human operational role and offer quicker response time to emergency SAR operations.

During bad weather, offshore workers could be falling off oil rigs and means of search and rescue are costly and time ineffective. Technologies used for rescue rely on onshore rescue centers and at times colleagues who throw a floatation device [1]. UAV technology can greatly assist in delivering both cost and time effective solutions and will increase the rate of rescue success. It is intended to develop a small rotary UAV able to hover and deliver floatation device.

One of the major drawbacks of quadrotor is its high energy consumption. The matter becomes worst during windy weather especially on the oil rig offshore platform. Therefore, they are not recommended to operate in windy conditions as the battery power drains very quickly and eventually results in poor flight time. To extend the operation time without increasing battery capacity, the aerodynamic performance of a drone becomes very important [2-3]. The power consumption can be reduced by improving the designs of the propeller of the drone to increase the overall thrust. By modelling the propeller design of drone, its aerodynamics performance can be evaluated for further improvement through simulations and experiments. Factors including speed, versatility, fly-ability and design of the drone body as well as the propeller can affect the efficiency of the drone and the SAR operation [3-4]. A concept that is widely thought of is attaching a life buoy to the base of a drone and
dropping at near a swimmer in distress, however, the extra weight of the payload will affect the performance of the drone battery thus requiring extra optimization.

The goal of this work is to improve the hovering capabilities and increase the flight time of a UAV by modifying the propellers as well as determining the best alternative that will produce the highest lift to drag ratio.

2. Methodology

The generation of lift is mainly due to the diversion of air molecules by a solid body (i.e. propellers) in a certain direction. In drone, the propellers push the air downwards and consequently the air pushes the drone upwards, creating lift force. In a vertical plane, the drone can hover as well as changing altitude. Hovering is a result of creating lift force that is equal to the gravitational force downwards (i.e. weight). Turning the drone to a certain direction requires manipulating the amount of thrust the rotor can produce.

Figure 1 shows a drone turning to the right side and the red rotor indicates lower thrust production than the opposing green rotor which will lead to motion in that direction. The rotors are the components responsible for creating lift as well as turning the drone around and moving it forward.

Thrust to weight ratio (TWR) is an important parameter to take into consideration to calculate the efficiency of drone and can aid in preventing excessive thrust that will consume more energy. The TWR will indicate if a drone can lift a specific weight and the required power to do so, the equation can be simply stated as,

\[ TWR = \frac{T}{W} = \frac{\text{Thrust}}{\text{Weight}} = \frac{ma}{mg} = a \frac{g}{g} \]  

where \( m \) is mass of the drone and the payload, \( a \) is the drone acceleration and \( g \) is a gravitational acceleration. TWR decides if the drone will be able to perform as desired. For a drone to maintain flight steadily the TWR must be equal to unity and to produce turning effects with respect to the angle of attack, a TWR of minimum 1.3 must be achieved in order to perform the vertical acceleration (take-off) the TWR must be greater than 1. Drone manufacturers aim to produce drones that can create their products with a minimum TWR of 2, which means each rotor in a hexa-copter (6 rotors) must be able to produce approximately TWR of 0.33.

Wind is considered the toughest opponent to drone performance especially for offshore application. Wind blowing at high speeds will make it difficult for the drone to hold its position or maneuver as desired. Drag force is amplified if the wind is blowing in an opposite direction of the drone’s motion. The windy weather requires more power from the motors that can drain the battery faster. Adding an extra battery would increase the weight of the drone (i.e. additional payload). The maneuverability and flight time can be enhanced by modifying the propellers properties (size, shape, material) as well as streamlining the frame of the drone to reduce pressure and friction drags. Computational Fluid Dynamics simulation requires adding the wind speed of the region at which the drone will operate. The wind conditions at Upper Zakum Offshore Oil Field will be used for example.

Upper Zakum Offshore Oil Field is an oil field located 84 kilometers offshore of the capital Abu Dhabi (Figure 2). The field is producing 640,000 barrels of oil per day through a chain of oil wells and
2150 people working on 90 different platforms that increase the possibilities of danger occurring [5].

For the wind speed data for a day starting from 6:00 AM to 6:00 PM, the maximum wind speed reached was 17 km/h while the lowest was 8 km/h. As the season changes and is approaching summer, the wind speed decreases and fluctuates at a range between 10-11 km/h.

![Figure 2. Upper Zakum offshore oil field.](image)

The drone frame’s size and type must be able to withstand rough winds and high temperatures as well as being powerful enough to carry loads for survivors in distress. The frame used for this project is the DJI F550 frame, which is commercially available as shown in figure 3.

![Figure 3. DJI F550 frame kit.](image)

The program used for the CFD analysis is ANSYS (Fluent). The drawings of the chosen alternatives for propellers were exported as IGS format files from SolidWorks to ANSYS as shown in figure 4. Details of the CFD equations and turbulence models can be referred in [6-7].

![Figure 4. Imported propeller drawing with enclosure.](image)

3. Results and discussion

Multi-rotor drones provide the necessary functions for SAR operations. There are ranges of multi-rotor drones that can be used for the objective however some designs are more suitable than others after taking into considerations the conditions of operation and the added modifications that will result in the increase of weight. Multi-rotor drones are classified by the number of rotors attached and their configuration. A powerful drone with high stability and lifting capability is needed. The most suitable choices are the quad-, hexa- and octo-copters. Table 1 shows the decision matrix for initial evaluation.
Table 1. Decision matrix showing Hexa-copter as the preferred option.

|                | Quad-copter | Hexa-copter | Octo-copter |
|----------------|-------------|-------------|-------------|
| Power          | 3           | 5           | 5           |
| Loading capacity| 1           | 5           | 5           |
| Flight time    | 5           | 3           | 1           |
| Price          | 5           | 3           | 1           |
| Total score    | 14          | 16          | 12          |

Numerous improvements on current mechanical designs are derived through biomimicry. Biomimicry is an approach to innovation that seeks sustainable solutions to human challenges by emulating nature's time-tested patterns and strategies [8]. The idea of whale fin blade originate from whale flippers. Bumps on an airfoil are called tubercles and are said to consume 25% less energy than normal blades spinning at the same speed. An airfoil with tubercles technology is said to produce 32% less in drag and 8% increase in lift compared to a smooth end airfoil. The main idea behind the tubercles technology is to have steeper angles to enhance lift by pushing more air and prevent stalling.

Wind tunnel testing showed that the bumps at the edge of an airfoil created vortices that were deflected to the valleys between the hills and had opposite spins making sure that the airflow did not separate until the end of the airfoil which led to higher lift and less drag [9-10]. The work on this type of propeller (Figure 5) is currently in progress and the results will be presented in the subsequent publication.

Using equation (1) for TWR of 2.5 (taken into consideration of rough offshore winds as discussed in previous for Upper Zakum Offshore Oil Field) and the propeller chord length of 0.75 of its radius, the Reynolds number that is calculated from $Re = \rho VL/\mu$ is found to be around 20,000, which justifies the full turbulence condition in our model. The maximum coefficient of lift achieved throughout the 1000 iterations was 12.2 and a minimum of 3. The lift to drag ratio will be calculated on the numbers supplied by this test. It can be seen in the graph (Figure 6) that the coefficient of lift is higher than the coefficient of drag meaning that the drone lift force will be able to overcome the drag forces. The calculation resulted in a hovering thrust of 12.6 N.

Figure 5. Bumps on airfoil.

Figure 6. $C_L$ and $C_D$ vs. steps.
Figure 7 demonstrates the outlet velocity of the propeller that is the region where the air is accelerated into higher velocity. Figure 8 shows the streamline of the air particles as they come in contact with the rotating propeller. The figure illustrates the velocity at which the propeller is rotated, created sufficient lift forces during take-off and maneuvers. The red region is the region with the highest velocity opposed to the blue region that rotates at a lower velocity compared to the tip.

![Figure 7. Outlet velocity gradient.](image)

Figure 8 shows the complete drone prototype and its hovering capability, justified by all the parameters used in the previously mentioned simulations and analyses.

![Figure 8. Velocity streamlines.](image)

![Figure 9. Drone prototype.](image)

4. Conclusion
The objective of the project was to optimize the performance of drone propellers by increasing its flight time and enhancing its ability to combat harsh weather conditions for SAR. A hexa-drone frame type was chosen due to its design, power output potential and price. The 9.0 x 4.5 in propellers were the final choice due to their output aerodynamics performance. The advantage of this prototype is it is faster than its counterparts and has a greater flight time for longer operations, making it suitable for offshore SAR applications.
References

[1] Bureau of Labor Statistics. Oil and Gas Industry Fatal and Nonfatal Occupational Injuries. U.S. Bureau of Labor Statistics, Washington, DC (2010).

[2] Yeong, S. P., and S. S. Dol. Aerodynamic Optimization of Micro Aerial Vehicle. Journal of Applied Fluid Mechanics 9, no. 5, 2111-2121 (2016).

[3] Eid, Saif Eldin, and Sharul Sham Dol. "Design and Development of Lightweight-High Endurance Unmanned Aerial Vehicle for Offshore Search and Rescue Operation." In 2019 Advances in Science and Engineering Technology International Conferences (ASET), pp. 1-5. IEEE, (2019).

[4] Yeong, S. P., L. M. King, and S. S. Dol. A Review on Marine Search and Rescue Operations Using Unmanned Aerial Vehicles." World Academy of Science, Engineering and Technology, International Journal of Mechanical, Aerospace, Industrial, Mechatronic and Manufacturing Engineering 9 no. 2, 396-399 (2015).

[5] NA, "Upper Zakum Offshore Oil Field Development, Abu Dhabi," N.d N.d N.d [Online]. Available: https://www.offshore-technology.com/projects/upper-zakum-offshore-uae/. [Accessed 16 2018].

[6] Chan, H. B., T. H. Yong, P. Kumar, S. K. Wee, and S. S. Dol. The numerical investigation on the effects of aspect ratio and cross-sectional shape on the wake structure behind a cantilever. ARPN J. of Eng. and App. Sci. 11 (2016).

[7] Azeez, Abid Abdul, Sharul Sham Dol, and Mohammad S. Khan. "Effects of Cylinder Shape on the Performance of Vortex Induced Vibration for Aquatic Renewable Energy." In 2019 Advances in Science and Engineering Technology International Conferences (ASET), pp. 1-4. IEEE, (2019).

[8] Chear, C. K., and S. S. Dol. "Vehicle aerodynamics: drag reduction by surface dimples." International Journal of Mechanical, Aerospace, Industrial, Mechatronic and Manufacturing Engineering 9, no. 1 (2015).

[9] Dol, S. S., and M. A. M. Nor. "Flow visualization of the vortex shedding of a stationary circular cylinder by an improved smoke-wire technique." WSEAS transactions on fluid mechanics 1, no. 6 (2006): 745.

[10] Yong, T. H., and Sharul Sham Dol. "Design and development of low-cost wind tunnel for educational purpose." In IOP Conference Series: Materials Science and Engineering, vol. 78, no. 1, p. 012039. IOP Publishing, (2015).