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Design of Multi Material Drone Propeller: Numerical and Experimental Study

Malik N. Hawas[1*], Rafeaf Jumah Salman[2], Audai Hussein Al-Abbas[1]

[1] Power Mechanic Engineering Department, Al-Musaib Technical College, Al-Furat Al-Awsat Technical University (ATU), Kufa 54001, Iraq
[2] Department of Electrical Engineering Techniques, Al-Musayyib Technical Institute, Al-Furat Al-Awsat Technical University, Kufa 54001, Iraq

Corresponding Author Email: com.mlk@atu.edu.iq

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ABSTRACT

A study is conducted, it researches the design, making and bypass of the drone propeller. Discovering the streamlined qualities of the different propeller designs using the computational apparatus, the software is utilized. A mini-summarized propeller having such mechanisms was fabricated and the trials done confirmed their success. Whilst the multi material approach mitigates against lightness with strength, durability will be the weakest link in that process. With weight and streamlined failures, fragility is always a factor. This assessment should aid in overhauling current drone propulsion systems, such as durability and efficiency, to enhance performance and increase persistence. The FSI system was employed to study airflow patterns using fans and stress factors by printing parts with PLA, ABS and PGA printing materials. The air was channeled over the materials, simulating actual flight, to evaluate the materials' strength. The drone model DJI MINI 3 PRO was subjected to the experimental tests of the speed and the maximum height. The height of the fan in MINI 3 PRO could be higher with the maximum speed of 37.3 km/h and it would be 187 meters in MINI 2 PRO concerning this aspect. ABS material speeds and jumps higher than the PGA material. It turns out that the 3 PRO propeller fans have the highest thrust force of 5.1 m/s at the highest speed, which is different from the 2 PRO propeller fan that measures only 3.2 m/s. The 3 experiences 0.155 mm distortion, whereas the 2 produced 0.103 mm. PLA material has the least value of influence among all.

1. INTRODUCTION

The rising utilization of robot innovation has prompted a requirement for imaginative plan ideal models for drone propellers. Generally, propellers have been produced using single materials like plastics or metals, each with its benefits and restrictions. Multi-material plan has acquired consideration in designing, joining materials with unmistakable properties for lightweight, strong, and efficiently effective propellers. Progressions in computational apparatuses and reenactment procedures have altered the plan cycle. This study investigates the plan of a multi-material robot propeller, crossing over hypothetical plan and certifiable application, encouraging developments that rise above ordinary propeller plans. The importance of designing a multi-material drone propeller is of great benefit in the field of aircraft manufacturing, as it is a study of the best materials used in manufacturing for the benefit of companies specialized in the field of manufacturing drones. One of the most basic limitations of the propeller is the weight of the propeller compared to the size of the drone. Propellers must be designed with a small size and mass, and at the same time, with a strong material to enable them to fly faster.

The propeller assumes a significant part in the development of pushed in cutting edge Automated Flying Vehicles (UAVs) [1]. High level designing methodologies can further develop execution and lifetime in these frameworks. Composites like CFRP and GFRP are generally utilized because of their heap opposing limit and lightweight nature. Relative investigations have streamlined the exhibition and lifetime of the rotor part for cutting edge UAVs. High level mathematical systems, like FSI and CFD-MRF, have prompted the conclusion of GFRP as the best composite material. Epoxy-E-Glass UD and Epoxy-S-Glass-UD perform better compared to different composites. The multi-objective examination of MR-UAV airframes utilizing five prime casings developed, displayed, and computationally settled for three significant composite materials and one regular material [2]. The determination factors incorporate low-stress acceptance, less deformity, and high lifetime. The casings are computationally explored utilizing materials like GFRP, CFRP, KFRP, and Aluminum Composite. Instruments like CATIA and ANSYS Workbench are utilized, and framework intermingling tests approve computational techniques. The reasonable airframe and material are gotten in light of these variables. This examination researches the plan of a hexacopter drone with foldable arms for constant fine residue checking [3]. The plan centers around the propeller and foldable arm, which are key mechanical power transmission parts. The exploration utilizes limited volume technique (FVM) based streamlined attributes reenactment to work out and notice functional execution. The plan reasoning of involving carbon fiber composite material for the foldable arm is introduced, giving a hypothetical premise to multi-rotor UAV part improvement.

Presented a responsiveness investigation of a X8 multirotor drone with a 2 kW power module half-and-half framework [4]. It uncovers that a solitary setup can decrease power utilization by 700 W at 25 kg take-off mass, considering a more modest energy component framework. Top perseverance is found at a 0.67 energy framework weight portion, and a 3 L hydrogen chamber can supplant a 6 L at 300 bar for a 72-min perseverance. Further examination can extend the review to other framework varieties and exploratory testing. Examined the commotion from static contra-pivoting UAV propellers in an anechoic chamber [5]. The outcomes showed that connection tones were a prevailing supporter of the general commotion level, including rotor-alone tones and broadband clamor. A hypothetical model for the far-field connection tone commotion created by a contra-pivoting propeller was introduced, and it was found that the plentifulness and number of these tones could be diminished by utilizing contra-turning propellers with bungled sharp edge numbers. The concentrate likewise showed the legitimacy of the indoor static outcomes contrasted with an in-flight trial of a quadcopter with contra-turning propellers. The rising utilization of automated aeronautical vehicles (UAVs) has prompted expanded assumptions for enhancements in drive and energy the executives frameworks [6]. A review presents an elective arrangement utilizing a variable pitch propeller, which can expand the departure weight and further develop power effectiveness in drift flights. The investigation discovered that the maximal push expanded by 31% and the coefficient of pushed during drift expanded by 2.6% to 7.5% for different pitch points.

A virtual model has been created to gauge both static and dynamic push of a solitary and coaxial propeller in rambles [7]. The model, constructed utilizing open-source programming Qblade and OpenFoam, is solid and limits the requirement for full-scale tests. The model is approved with exploratory information, showing close gauges for single propellers and deviations for coaxial propellers because of choppiness and stream aggravation. The processed push information is adequately exact to be utilized in propeller choice, and future examinations recommend these models will lessen trial testing. Hydrodynamic power assessments on marine propellers utilizing hypothetical formulae and mathematical examination [8]. The point is to further develop execution by calibrating hydrodynamic powers. The review involves CATIA for applied plan and ANSYS Familiar 16.2 for mathematical reproduction. The hydrodynamic powers are analyzed for future work, featuring the significance of figuring out liquid way of behaving and ecological circumstances. The rising utilization of multi-rotors requires an intensive comprehension of their wake impacts, which can cause disastrous disappointments [9]. This study utilizes stream perception procedures to investigate wake profiles for different flight modes. Starting outcomes show huge wake in dropping flight, requiring remedies for in-situ sensors. Future PIV studies will investigate the effect of flight speed and rotor rotational speed on wake attributes.

The streamlined and acoustic exhibition of a changed wavy rotor for multi-copters [10]. The wavy rotor decreases apparent clamor in the center recurrence range and broadband commotion in the high recurrence range. The propelling edge diminishes commotion more than the withdrawing sharp edge, and the general sound strain level abatements by 1.4-2 dB. The significance of multi-rotor UAVs in different fields has prompted expanded center around streamlined features, sound decrease, and enhancing propeller plan [11]. This paper centers around lessening commotion actuated by the propeller, as minimal multi-rotor UAVs have low discovery likelihood however high drive-line clamor. A procedure is created to configuration low commotion and effective propellers for multi-rotor UAVs, taking into account factors like sharp edge thickness, tip misfortune, cutting edge stacking, movement element, and advance proportion. Sound decreases approaches, for example, driving edge brush and following edge tuft, are likewise considered. A PC helped plan and acoustic examination are led to accomplish low commotion. Circular robots are arising as a valuable device in both military and regular citizen applications [12]. A round confine is intended for a pusher quad-copter utilizing minimal expense 3D-printer materials. Recreations and tests are directed to upgrade the vehicle's exhibition and sturdiness. The enclosure obstruction is contrasted with wind current impedance, considering various arrangements for various missions.

This system can act as a structure for future round drone prototyping. Presented a multi-objective improvement plan strategy for high elevation carrier propellers, in light of vortex hypothesis and non-ruled arranging hereditary calculation II [13]. The model intends to plan a productive and lightweight propeller, taking into account factors like pitch point, harmony length, width, rotational speed, and sharp edge number. The ideal tradeoff among proficiency and not entirely set in stone by power, underlying strength, and assembling conditions. Tests and mathematical computations affirm the propeller's reasonableness for high height carriers' impetus frameworks.

Talks about the advancement of quicker drone propellers to further develop execution and adaptability [14]. The cycle includes displaying cutting edges and centers, assessing powers utilizing liquid elements reproduction devices, and 3D printing propellers. Tests confirm protection from powers and rates, and the produced push is contrasted and reproductions. Contrasting push and different propellers recognizes enhancements for drone execution. Models' propeller execution for miniature-elevated vehicles at low Reynolds numbers and angled stream utilizing innovative component energy hypothesis, vortex cross section strategy, and force hypothesis for sideways stream [15]. Results show that the two hypotheses foresee right powers and minutes, yet exactness diminishes in sideways stream. Joining information from pivotal stream with angled stream brings about more precise execution gauges. Researched the streamlined execution of a multirotor automated ethereal vehicle setup utilizing mathematical estimations and recreations. It tracked down that shared streamlined communications among rotors and a fuselage in drifting flight brought about higher inflow and precarious fluctuating-push varieties [16]. In forward flight, tip vortices and downwash stream from upstream rotors affected downstream rotors, causing expanded pitching and moving minutes. The review suggests considering these communications while planning dependability and mentality control calculations. The gap in previous research does not include full expansion regarding the numerical and experimental aspects, as this research paper presents two important aspects for unmanned aircraft with regard to improving the selection of materials from which propellers are made.

2. METHODOLOGY

2.1 Geometry

The drone was designed using an engineering program capable of designing the main dimensions of the drone, as well as the details of the propellers used, as in Figure 1. The SolidWorks program was used to design all the details of the drone according to the dimensions known from the company's website [17].

Figure 1. Geometry simulation

The DJI MINI 3 PRO drone was used and the jagged edges were reduced to reduce the MESH process. Two types of fans were also used for the MINI 3 PRO and MINI 2 PRO to demonstrate the clear improvements in the design process and models were designed on them [17].

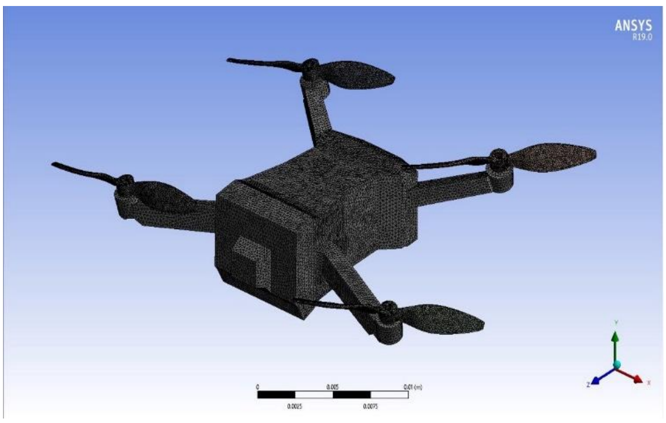


Figure 2. Mesh generated

2.2 Mesh

In this simulation and due to complicated geometry, a tetrahedron element type was selected to provide better predicted results for this unstructured grid. ANSYS was used to generate a mesh for this three-dimensional CFD model by providing input data in a single phase. The total number of cells used in this simulation was 6137260, as shown in Figure 2.

One of the requirements for simulation is to create a complex algorithm within the simulation domain. On this basis, a high-precision network is required to solve the specified equations. Then, work was done to increase the reliability of the network in order to reach a stable state for the results. Due to the multiplicity of models specified for the study that were simulated, it became necessary to work on more than one network and to increase the reliability of the network. The number of elements was 6137260 when the distortion reached its peak of 0.155 mm, as shown in Table 1.

Table 1. Grid independency test

Case Element	Node	Max Deformation (mm)
2313687	5407522	0.189
3935342	6055435	0.161
5086722	7365865	0.157
6137260	8818340	0.155

2.3 Boundary condition

The FSI system was used to see the airflow through the fans and calculate the amount of stress on them through the use of a group of printing materials used as Table 2, namely PLA, ABS, PGA, and to apply aerodynamic forces to see the changes that occur and the result of the endurance of these materials [18-20]. The selection of these materials was based on what is currently available in the markets and their popularity due to their cheap price and high quality. As for the simulation settings, the model was entered by the company and a mesh was made on it, then it was entered into the fluent program and the air speed obtained from the practical side was placed, the fan rotation speed, run for the cases, and the results came out, which will be reviewed in the Results Section.

Table 2. Material properties

Properties	Common Material		
	PLA	ABS	PGA
Tensile Strength (Mpa)	59	40	60
Modulus of Elasticity (Mpa)	3750	2600	6000
Density ($kg/mm^{3)}$)	0.00105	0.00125	0.00121

2.4 Governing equations

2.4.1 Continuity equation (Mass conservation)

The continuity equation ensures mass conservation in the flow field:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \vec{V}) = 0 \tag{1}$$

where,

- ρ = Fluid density (kg/m^3)
- $\vec{V}$ = Velocity vector of the fluid (m/s)

- t = Time (s)

For incompressible flows, the continuity equation simplifies to:

$$\nabla \cdot \vec{V} = 0 \tag{2}$$

This equation ensures that the mass entering a control volume is equal to the mass leaving it, which is crucial for simulating propeller airflow.

2.4.2 Momentum conservation (Navier-Stokes equations)

The Navier-Stokes equations represent the conservation of momentum, accounting for the forces acting on the fluid, including pressure, viscous forces, and external forces like gravity:

$$\frac{\partial(\rho\vec{V})}{\partial t} + \nabla \cdot (\rho\vec{V}\vec{V}) = -\nabla p + \nabla \cdot (\tau) + \rho\vec{g} + \vec{F} \tag{3}$$

where,

- $\vec{V}$ = Velocity vector (m/s)
- p = Pressure (Pa)
- τ = Stress tensor, accounting for viscous forces (Pa)
- $\vec{g}$ = Gravitational acceleration $(\mathrm{m/s^2})$
- $\vec{F}$ = External forces (e.g., propeller rotation) (N)

The stress tensor τ for a Newtonian fluid is given by:

$$\tau = \mu\left[\nabla\vec{V} + (\nabla\vec{V})^T\right] - \frac{2}{3}\mu(\nabla \cdot \vec{V})I \tag{4}$$

where,

- μ = Dynamic viscosity (Pars)
- I = Identity matrix

The Navier-Stokes equations govern the behavior of airflow around the rotating propeller blades, allowing Fluent to simulate the resulting aerodynamic forces like lift and drag.

2.4.3 Energy equation (Conservation of energy)

If heat transfer is involved, the energy equation is used to account for the conservation of thermal energy in the flow:

$$\frac{\partial(\rho E)}{\partial t} + \nabla \cdot (\vec{V}(\rho E + p)) = \nabla \cdot (k\nabla T) + \Phi \tag{5}$$

where,

- E = Total energy (J/kg)
- k = Thermal conductivity (W/m · K)
- T = Temperature (K)
- Φ = Viscous dissipation term, which accounts for the conversion of kinetic energy into heat due to viscosity

This equation ensures that energy (internal, kinetic, and potential) is conserved within the fluid.

2.4.4 Turbulence models

For propeller flows, turbulence is often significant, and Fluent uses turbulence models to approximate the turbulent effects. The two common turbulence models are:

a. $k - \varepsilon$ model

The $k - \varepsilon$ model is widely used for general turbulence modeling. It consists of two transport equations:

$$\frac{\partial(\rho k)}{\partial t} + \nabla \cdot (\rho k\vec{V}) - \nabla \cdot \left(\left(\mu + \frac{\mu_t}{\sigma_k}\right)\nabla k\right) + G_k - \rho\epsilon \tag{6}$$

where,

- G_k = Generation of turbulent kinetic energy due to velocity gradients
- μ_t = Turbulent viscosity
- σ_k and σ_e = PrandtI numbers for k and ϵ
- C_1 and C_2 = Empirical constants

b. **k − *ω*** SST model

2.4.5 Blade Element Momentum (BEM) theory

For rotor and propeller simulations, ANSYS Fluent can also apply Blade Element Momentum (BEM) theory, which combines momentum theory with blade element theory to estimate the lift and drag forces on each blade segment.

$$T - \sum \left(\frac{1}{2}\rho v^2 C_L A\right) - \sum \left(\frac{1}{2}\rho v^2 C_D A\right) \tag{7}$$

where,

- T = Thrust
- v = Relative velocity
- $C_{L_r} C_D$ = Lift and drag coefficients
- A = Blade element area

This allows Fluent to calculate the forces generated by the rotating blades and optimize propeller performance.

3. EXPERIMENTAL WORK

Where worked on the original model of the DJI MINI 3 PRO drone and changed the propellers by printing them using an ANYCUBIC printer with an accuracy of 0.1 mm, and then testing the speed of the drone experimentally, as well as the maximum height it could reach by changing these propellers (Figure 3).The material to be printed was added to the 3D printer after inserting the memory card containing the Gcode file and then setting the appropriate settings for printing, layer by layer, with a thickness of 0.2 mm and a nozzle diameter of 0.4 mm, and the material to be inserted was a tape diameter of 1.75 mm for all materials.

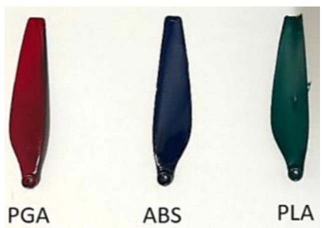


Figure 3. Printing propellers

The manufacturing process of the fans was carried out using a 3D printer to obtain the necessary accuracy for the fans using the three mentioned materials. As for the simulation program, the ANSYS program was used, where the flow side was simulated in FLUENT, while the structural side was simulated in structural, then linked together as fluid stricture interaction (FSI).

4. RESULTS AND DISCUSSION

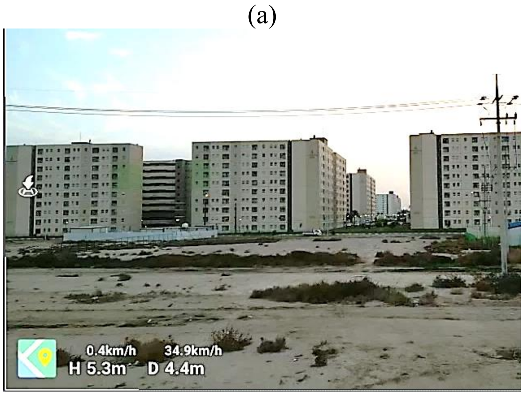
All the results obtained through the simulation program and experimental tests will be discussed, where the maximum height and maximum speed that can be reached through practical experiments will be identified, as will the air speed and lift forces, as well as the number of deformations and stresses that can be obtained through the ANSYS simulation program. The effectiveness of the materials used was confirmed by the speed of the drone, as well as the height it reached, by comparing it with different materials.

4.1 The effect of propellers type on altitude and speed

The sort and plan of a robot's propeller essentially influence its exhibition, effectiveness, and height capacities. High-proficiency propellers create more lift, while bigger breadth propellers give more lift. The material and weight of the propeller likewise impact its presentation. Propeller shapes and numbers influence wind current, effectiveness, and clamor level. Propeller type should be viable with the robot's engine determinations, and natural elements like air thickness, temperature, and moistness can likewise influence elevation execution. Propeller plans that give smoother push reactions can improve height dependability and control. Thusly, picking the right propeller plan and streamlining its boundaries can expand a robot's exhibition and elevation reach.

Figure 4 shows the large difference in maximum speed between the fans used, as the clear improvement in the design of the MINI 3 PRO fan can be seen. The maximum speed reached 37.3 km/h, while in the MINI 2 PRO the speed reached 34.9 km/h.

(a)



(b)

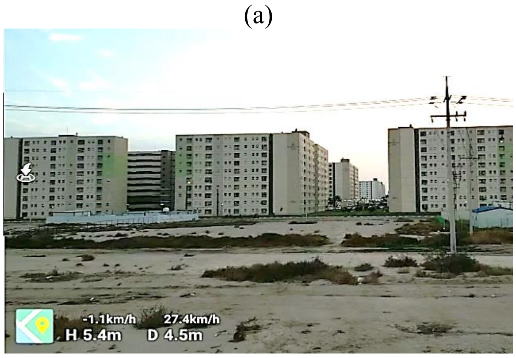
Figure 4. The speed image for experimental image of different type of propeller: (a) MINI 3 PRO; (b) MINI 2 PRO

The kind of propeller utilized on a robot fundamentally influences its speed execution. Its productivity in changing over engine power into push straightforwardly impacts the robot's speed. Bigger breadth propellers can create more push and lift, while higher pitch propellers produce push that is more forward. Sharp edge shape and number likewise influence speed and effectiveness. The ideal number of edges relies upon the particular application and wanted speed range. Material and weight likewise influence speed execution. Propeller type should be coordinated with the robot's engine details for ideal execution. Ecological variables like air thickness, temperature, and twist additionally influence speed execution. Flight elements additionally influence speed and solidness. Subsequently, picking the right propeller plan and enhancing its boundaries is urgent for accomplishing wanted speed execution. As for the height, the 3 PROreached 254 meters, and in the case of the 2 Pro, it reached a maximum height of 187 meters.

4.2 The effect of propellers material on altitude and speed

The propeller material utilized in a robot fundamentally influences its elevation capacities. Its weight, strength, sturdiness, adaptability, and reverberation all effect the robot's presentation. Lighter propellers can decrease weight, while heavier materials require more ability to pivot and produce lift. The material's solidarity and toughness additionally influence its presentation and life expectancy. The material's streamlined properties, like its surface completion and protection from natural variables, additionally influence its presentation. The consistency and nature of the propeller fabricating material additionally influence its equilibrium and balance. Normal materials utilized incorporate plastic, carbon fiber, and wood. Picking the right material and guaranteeing predictable assembling quality are urgent for upgrading height execution and flight dependability. As for Figure 5, which shows the effect of the printing material for the fans in improving speed performance, it may be noted that in the ABS material the speed reached 37.3 km/h, while in the PGA material it reached 27.4 km/h and in the PLA material it reached 19.8 km/h. The reason for this is that the ABS layer has a smooth surface compared to other materials.

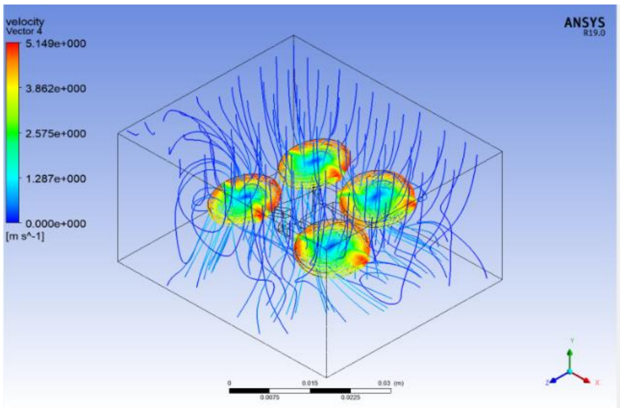
(a)



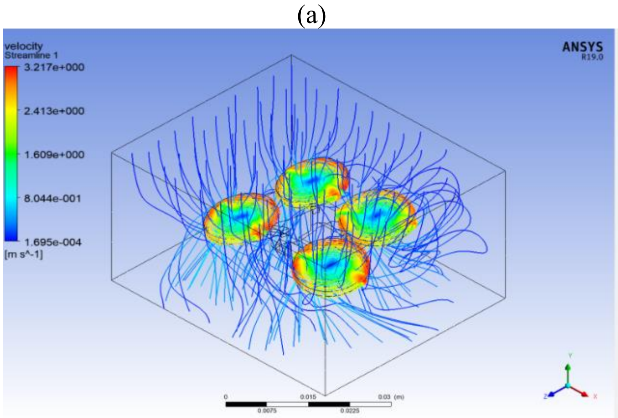
(b)

(c)

Figure 5. The speed image for experimental image of different type of material propeller: (a) ABS; (b) PGA; (c) PLA



(a)



(b)

Figure 6. Velocity contour of different type of propeller: (a) MINI 3 PRO; (b) MINI 2 PRO

The decision of propeller material essentially influences the speed abilities of robots and other airplane by impacting weight, strength, streamlined productivity, and toughness. Lighter materials like carbon fiber can lessen the heaviness of the propeller, considering further developed speed capacities. Materials with higher strength and unbending nature can endure streamlined powers at higher rates, adding to smoother wind current and diminished drag. Streamlined effectiveness is additionally impacted by the surface completion and streamlined properties of the propeller material. Materials with ideal reverberation attributes can keep up with better equilibrium and control, supporting reliable speed execution. Solidness and wear obstruction are vital for supported speed capacities over the long run. Subsequently, picking materials that balance lightweight development, high strength, and good streamlined properties is fundamental for enhancing speed execution and accomplishing wanted flight attributes. As for the height, it goes to the PGA material, which reached 275 meters, ABS to 254 meters, and PLA 220 meters, due to the durability of the PGA material, which has the ability to rise significantly.

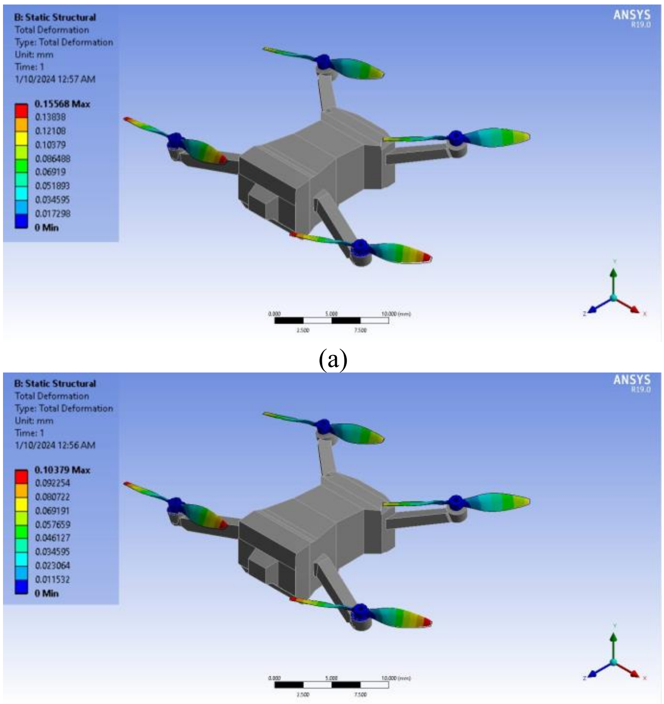
The kind of material that goes into the manufacturing of drone propellers i.e. ABS or PGA makes a large difference when it comes to characteristics that signify performance like speed, altitude or efficiency. To highlight these points again, ABS position seems to be undisputed as it has got much higher stiffness, strength, and endurance properties than PLA. Distortion read outs will deliver precise test data to engineering organizations allowing them to locate a propeller's shortfall, and eventually developing its improved design and performance. Final products of this type of propellers are made possible because of a clear comprehension of specific material properties, manufacturing processes and airflow effects.

4.3 The effect of propellers type on velocity air and lift force

The sort of propeller utilized on a robot or airplane essentially influences the air speed and lift force created. Propeller plan and cutting edge shape decide air speeds, bringing about more pushed and lift. Edge number and setup additionally influence wind stream speed and lift force. Propeller material and weight additionally influence streamlined execution. Propellers with lighter materials can accomplish quicker speed increase and higher air speeds, while lighter materials can improve push and lift. Propeller pitch and measurement additionally influence lift force. Streamlined productivity is vital for better air speeds and push age. By taking into account these variables, originators and designers can improve propeller execution for explicit applications and flight prerequisites. Through Figure 6, which shows the effect of air during the rotation of the fans through the simulation program, it is noted that the speed value reached 5.1 m/s and lift force 4853 Nin the 3 Pro. While it was 3.2 m/s and lift force 3964 N in the 2 Pro, and this indicates the acquisition of the largest lifting force for the 3 PRO type of fans.

4.4 The effect of propellers type on deformation

The kind of propeller utilized on a robot or airplane fundamentally influences its misshapening weakness. Material properties, cutting edge plan, ecological variables, functional circumstances, and assembling quality all assume a part in deciding deformity powerlessness. High-elasticity and unbending nature propellers, similar to carbon fiber composites, are less inclined to distortion. Sharp edge plan and thickness additionally influence distortion obstruction. Natural variables like temperature, mugginess, and climatic strain can prompt warm anxieties, prompting twisting. Functional circumstances, including velocity, load, and moving, can expand pressure and disfigurement. Producing quality and consistency additionally influence the underlying honesty and layered exactness of propellers. Subsequently, picking propellers intended to endure explicit applications and conditions is critical for keeping up with execution, effectiveness, and wellbeing. Figure 7 shows the distortion caused by the propellers, which comes as a result of the force of lift for the drone. As is evident, the amount of distortion reached 0.155 mm in the 3 Pro, while in the 2 PRO it reached 0.103 mm as a result of the large force of lift that acts as a reaction to the propellers and increases distort it.



(a)

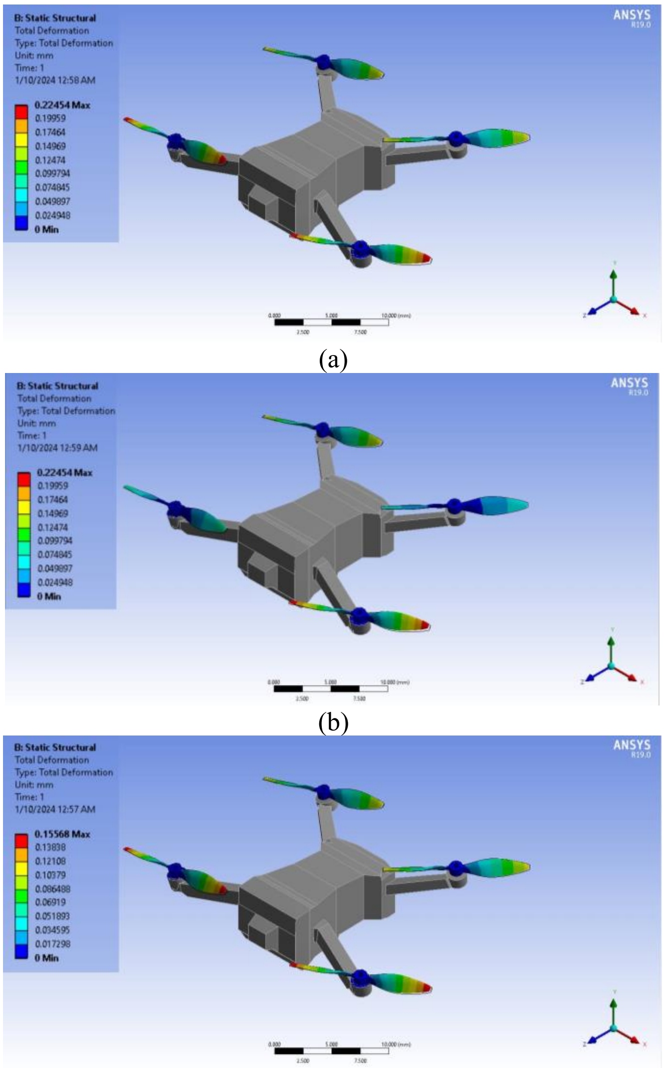
(b)

Figure 7. Deformation contour of different type of propeller: (a) MINI 3 PRO; (b) MINI 2 PRO

4.5 The effect of propellers material on deformation

Propeller material altogether influences their disfigurement opposition under different circumstances. High elasticity and inflexibility materials, similar to carbon fiber composites, are impervious to disfigurement than gentler or less unbending materials. Materials with higher versatility and adaptability can endure misshapening even more actually, decreasing the gamble of extremely durable harm or primary disappointment. Thickness and weight likewise influence deformity opposition and primary honesty. Lighter materials, similar to carbon fiber and high-level composites, offer positive deformity qualities because of their high solidarity to-weight proportions and primary soundness. Warm properties, including coefficient of warm extension and intensity obstruction, influence disfigurement vulnerability under temperature varieties. Material weakness and wear obstruction additionally affect misshapening qualities. Choosing materials with fitting mechanical and warm properties is critical for enhancing propeller execution, sturdiness, and security under different working circumstances. As for deformation according to the different materials the fan is manufactured from, it is evident from Figure 8 that the PLA material has the lowest deformation value, reaching 0.155 mm as a result of the strong physical properties of the material, which makes it superior to the rest of the manufactured materials.

PGA propellers are the lightest of the ABS propellers for it has the lowest density, this reduces the plane weight and improves its performance. ABS propellers have a less costly manufacturing price than those of PGA in an initial range, but the latter could represent advantages in the long term savings in terms of operation, especially if they were significantly more efficient in airborne stability and energy consumption. While designers of drone propellers are confronted with the trade-off series between weight, price, performance, and durability, they must make the decision which of the two materials, ABS and PGA, is the most suitable for the particular case and within the budgetary constraints.



(a)

(b)

(c)

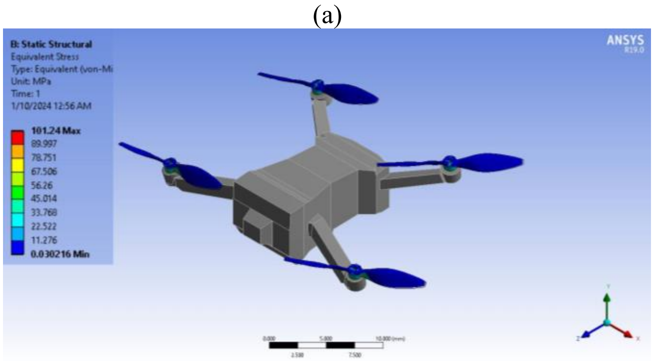
Figure 8. Deformation contour of different type of material propeller: (a) ABS; (b) PGA; (c) PLA

4.6 The effect of propellers type on stress

The kind of propeller utilized on a robot or airplane fundamentally influences the pressure dissemination and levels experienced during activity. Factors, for example, cutting edge plan, material, setup, functional circumstances, and assembling quality assume basic parts in deciding feelings of anxiety. Propellers with upgraded cutting edge profiles and ebb and flow can diminish pressure fixations and limit exhaustion risk. Propellers with adjusted edge arrangements can accomplish more uniform pressure circulation and diminished vibration levels. Functional circumstances, like speed, burden, elevation, and moving, can likewise influence feelings of anxiety. Propellers intended for explicit applications, like high velocity hustling or truly difficult work, are designed to endure these powers. Producing quality and consistency additionally influence the primary uprightness and stress obstruction of propellers. By choosing and planning propellers to endure explicit streamlined powers and functional necessities, specialists can improve pressure obstruction, execution, and wellbeing. It is known that the increase in deformation increases the stresses generated on the propellers, and thus it can be seen from Figure 9 that the deformation in the 3 PROreached 151 MPa, while in the 2 PRO it reached 101 MPa, and this indicates the strength of the drone's lift. As for the difference in materials, the amount of stresses remains the same due to the same force imported from the Fluent program.

What was obtained from the experimental side was that the best material that was used in terms of flight speed as well as altitude was PGA. On the numerical side, the best material that was able to withstand the pressure applied by the air was obtained, which is PGA.

(a)



(b)

Figure 9. Stress contour of different type of propeller: (a) MINI 3 PRO; (b) MINI 2 PRO

5. CONCLUSIONS

A research project focuses on the generation of CFD (Computational Fluid Dynamics) model of drone propellers, the fabrication process and bypass technology. For doing this task, a small, generalized propeller model was produced and then tested. The main purpose is to extend drones flight time and enhance their propulsion systems and efficiency. An airflow analysis based on a real-life stress test, with stress factors such as fans using PLA, ABS, and PGA printing materials was considered. The intention of the paper is to contribute to both superior performance and perseverance.

1. In the visuals there is a MINI 3 PRO fan, which turned into a real fan of the wind storm that provides a great deal of improvement in its design; the fan reaches the maximum speed of 37.3 km/h. The MINI 2 PRO fan is extended to the maximum height of 187 meters.

2. With an average speed of 37.3 km/h, the coating made of ABS produced the best results by far. On the other hand, the surface of the PGA coating was felt to be somewhat rougher of the two materials. When it comes to the achieved height, the PGA rockets reached 275 meters, 254 meters, and 220 meters accordingly.

3. The simulation conversation illustrated that the 3 PRO fans. Attained the more, their maximum speed was 5.1 m/s as compared to the 2 PRO fans who realized 3.2 m/s maximum speed.

4. The distortion of the drone is determined by the lift force as in the case of the 3 PRO at 0.155 mm and the 2 PRO at 0.103 mm. PLA material, on the other hand, shows the lowest deformation with its value being 0.155 mm. The good physical characteristics of PLA material cause these behaviors. The results show the clamping force of the drone increases as deformation is increased. The maximum load was 151 MPa for a 3 PRO and 101 MPa for a 2 PRO, which suggests that the drone is a micro-gravity environment.

The current work restrictions are the use of very high quality printers at very expensive prices at private institutions in factories to obtain models with very high accuracy and finer details, as this work can be developed in the future by using more types of materials in manufacturing.

Below some recommendations for future work:

1. Exploring different material combinations or propeller shapes, or testing the propeller in real-world conditions.
2. Study the technical aspects of the propeller design, including the aerodynamic profile.

REFERENCES

[1] Ramesh, M., Vijayanandh, R., Kumar, G.R., Mathaiyan, V., Jagadeeshwaran, P., Kumar, M.S., Raj Kumar, R. (2021). Comparative structural analysis of various composite materials based unmanned aerial vehicle's propeller by using advanced methodologies. IOP Conference Series: Materials Science and Engineering, 1017(1): 012032. https://doi.org/10.1088/1757-899X/1017/1/012032

[2] Aswin Kumar, V., Sivaguru, M., Rohini Janaki, B., Sumanth Eswar, K.S., Kiran, P., Vijayanandh, R. (2021). Structural optimization of frame of the multi-rotor unmanned aerial vehicle through computational structural analysis. Journal of Physics: Conference Series, 1849(1): 012004. https://doi.org/10.1088/1742-6596/1849/1/012004

[3] Wu, Y.T., Qin, Z., Eizad, A., Lyu, S.K. (2021). Numerical investigation of the mechanical component design of a hexacopter drone for real-time fine dust monitoring. Journal of Mechanical Science and Technology, 35(3): 3101-3111. https://doi.org/10.1007/s12206-021-0632-y

[4] Apeland, J., Pavlou, D.G., Hemmingsen, T. (2021). Sensitivity study of design parameters for a fuel cell powered multirotor drone. Journal of Intelligent Robot Systems, 102(1): 1-15. https://doi.org/10.1007/s10846-021-01363-9

[5] McKay, R.S., Kingan, M.J., Go, S.T., Jung, R., Kumar, R. (2021). Experimental and analytical investigation of contra-rotating multi-rotor UAV propeller noise. Applied Acoustics, 177: 107850. https://doi.org/10.1016/j.apacoust.2020.107850

[6] Podsędkowski, M., Konopiński, R., Obidowski, D., Koter, K. (2020). Variable pitch propeller for UAV-experimental tests. Energies, 13(20): 1-16.

https://doi.org/10.3390/en13205264
[7] Panjwani, B., Quinsard, D.G., Przemysław, P., Furseth, J., Koter, K. (2020). Virtual modelling and testing of the single and contra-rotating co-axial propeller. Drones, 4(3): 1-17. https://doi.org/10.3390/drones4030042
[8] Vijayanandh, R., Venkatesan, K., Raj Kumar, R., Senthil Kumar, M., Raj Kumar, G. (2020). Theoretical and numerical analyses on propulsive efficiency of unmanned aquatic vehicle's propeller. Journal of Physics: Conference Series, 1504(1): 012004. https://doi.org/10.1088/1742-6596/1504/1/012004
[9] Throneberry, G., Takeshita, A., Hocut, C.M., Shu, F., Abdelkefi, A. (2020). Experimental investigations on multi-rotor wake development and propagation. In AIAA Aviation 2020 Forum, 1: 1-8. https://doi.org/10.2514/6.2020-2741
[10] Yang, Y., Liu, Y., Hu, H., Liu, X., Wang, Y., Arcondoulis, E.J.G., Li, Z. (2020). Experimental study on noise reduction of a wavy multi-copter rotor. Applied Acoustics, 165: 107311. https://doi.org/10.1016/j.apacoust.2020.107311
[11] Vijayanandh, R., Ramesh, M., Raj Kumar, G., Thianesh, U.K., Venkatesan, K., Senthil Kumar, M. (2019). Research of noise in the unmanned aerial vehicle's propeller using CFD. International Journal of Engineering Advanced Technology, 8: 145-150. https://doi.org/10.35940/ijeat.F1031.0886S19
[12] Edgerton, K., Throneberry, G., Takeshita, A., Hocut, C.M., Shu, F., Abdelkefi, A. (2019). Numerical and experimental comparative performance analysis of emerging spherical-caged drones. Aerospace Science and Technology, 95: 105512. https://doi.org/10.1016/j.ast.2019.105512
[13] Jiao, J., Song, B.F., Zhang, Y.G., Li, Y.B. (2018). Optimal design and experiment of propellers for high altitude airship. Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering, 232: 1887-1902. https://doi.org/10.1177/0954410017704217
[14] Andria, G., Di Nisio, A., Lanzolla, A.M., Spadevecchia, M., Pascazio, G., Antonacci, F., Sorrentino, G.M. (2018). Design and performance evaluation of drone propellers. In 5th IEEE International Workshop on Metrology and Aerospace, Metroaerosp, Rome, Italy, pp. 407-412. https://doi.org/10.1109/MetroAeroSpace.2018.8453604
[15] Theys, B., Dimitriadis, G., Hendrick, P., De Schutter, J. (2017). Experimental and numerical study of micro-aerial-vehicle propeller performance in oblique flow. Journal of Aircraft, 54: 1076-1084. https://doi.org/10.2514/1.C033618
[16] Hwang, J.Y., Jung, M.K., Kwon, O.J. (2015). Numerical study of aerodynamic performance of a multirotor unmanned-aerial-vehicle configuration. Journal of Aircraft, 52: 839-846. https://doi.org/10.2514/1.C032828
[17] DJI Mini 3 pro - Fly Mini, Create Big. DJI. Retrieved from http://www.dji.com/global/mini-3-pro.
[18] Farah, S., Anderson, D.G., Langer, R. (2016). Physical and mechanical properties of PLA, and their functions in widespread applications—A comprehensive review. Advanced Drug Delivery Reviews, 107: 367-392. https://doi.org/10.1016/j.addr.2016.06.012
[19] Oosthuizen, G.A., Hagedorn-Hansen, D., Gerhold, T. (2013). Evaluation of rapid product development technologies for production of prosthesis in developing communities. Proceedings of SAIIE, 25: 4-7.
[20] Aloyaydi, B.A., Sivasankaran, S. (2020). Low-velocity impact characteristics of 3D-printed poly-lactic acid thermoplastic processed by fused deposition modeling. Transactions of the Indian Institute of Metals, 73: 1669-1677. https://doi.org/10.1007/s12666-020-01952-6