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Optimization of material for the prototyping of Ornithopter UAV

Riya Tyagi[1], Vedansh Vedwal[2], Narendra Gariya[3], Dr Jyoti Joshi[4]

[1,2,3]Department of Mechanical Engineering, Graphic Era Deemed To Be University, Dehradun
[4]Assistant Professor, Department of Computer Science and Engineering, Graphic Era Hill University, Dehradun

ABSTRACT

The goal of the current study is to make the materials used to make Ornithopter unmanned aerial vehicles as efficient as possible (UAV). PTC Creo was used to model the ornithopter gearbox's 3D model. The 3D printing process is used to create the modeled gearbox. The literature is used to provide the calculations needed for the gearbox's design. The gearbox experiences extremely high loads and strains while flapping, hence methods other than 3D printing are being investigated in the field of additive manufacturing. PLA, TPU, PLA+, Nylon, ABS, and Carbon fiber are among the materials that were taken into account for the comparison analysis. All materials exhibit identical flapping speeds up to 4 Hz frequency, but after that frequency, the materials act differently. The investigation came to the conclusion that carbon fiber is a superior material to other materials. A CNC machine is used to prepare carbon fiber for the gearbox frame and the flaps. Future assembly and examination of the carbon fiber components for flapping mechanisms are possible.

Keywords:

INTRODUCTION

Undoubtedly a complex area of flight, flapping-wing flying has fascinated people for hundreds of years. It is still a somewhat uncharted area of flight today. Early attempts at flapping wing flight mostly drew inspiration from natural flyers such as birds, bats, and insects. Unmatched by any man-made systems, these biological entities have mastered low Reynolds number, unstable flows [1-3].

Leonardo da Vinci created his flapping-wing invention approximately 1500 A.D., which is when the flapping-wing flight was first invented [4]. In 1870, Gustave Trouve's ornithopter, which was propelled by a gunpowder-powered internal combustion engine, successfully completed its first flight, traveling 70 meters as part of a demonstration for the French Academy of Sciences. Soon, rubber band-powered, basic ornithopters were created. It has taken several hundred years for flapping-wing flight to develop. Today, competitions range from massive outdoor ornithopters with wingspans up to 2 meters in length to little indoor ornithopters with wings as light as paper.

All are excited to design and construct due to the countless variations that are conceivable. To be the first to create a compact (palm-sized), light-weight (15 gram), electrically driven ornithopter still poses a difficulty. This miniature aircraft weighs little and is around the size of a small bird. Due to the limitations in our understanding of the aerodynamics of flapping-wing flying for ornithopters of this size, this has proven to be more difficult. Finding a reliable power supply that can last through a long flight is another challenge [5].

The study's relevance to micro aerial vehicles (MAV) and the reasons why the work is an acceptable research area may be its most important parts given that a giant ornithopter bears little resemblance to the kinds of micro machines on which many researchers are focusing. Even while it does not considerably address the problems with energy storage and actuator downsizing that currently impede MAV development, a robot with a 0.8-meter wingspan is a significant step toward addressing the control concerns that these projects will soon face. We believe that despite the Phoenix being several orders of magnitude larger than the MAVs now under development, many of the issues with stabilizing and extracting agility from them have been preserved due to the scaling up [6].

By using a much larger robot, we can avoid obstacles that are getting smaller and instead focus on the dynamics and control problems that the Robot Locomotion Group is interested in. Instead of cooperating with academics to construct miniature machines, we are working together to set the foundation for the dynamics and control work that will be crucial to the next steps in these endeavors. By using readily available circuits and very cheap hardware, we are able to accomplish this. Even though the amount of research on controlling any type of flapping wing movement is still very tiny, any findings will be helpful additions as research moves forward. This does not entail that the dynamics will be the same; they could be as different as the differences between a hawk and a bee.

Gearbox Design

To find the optimal drive mechanism for smooth operation even in high drag reciprocation motion, the gearbox design is carefully considered several times with numerous iterations.

Iteration 1

Iteration 1 of the gearbox design was done to mimic the flapping design of large birds such as eagles and seagulls which have a wing design that moves in two degrees of freedom and has an articulate design. The design was constructed in Solidworks and analyzed using 3D printing manufacturing techniques.

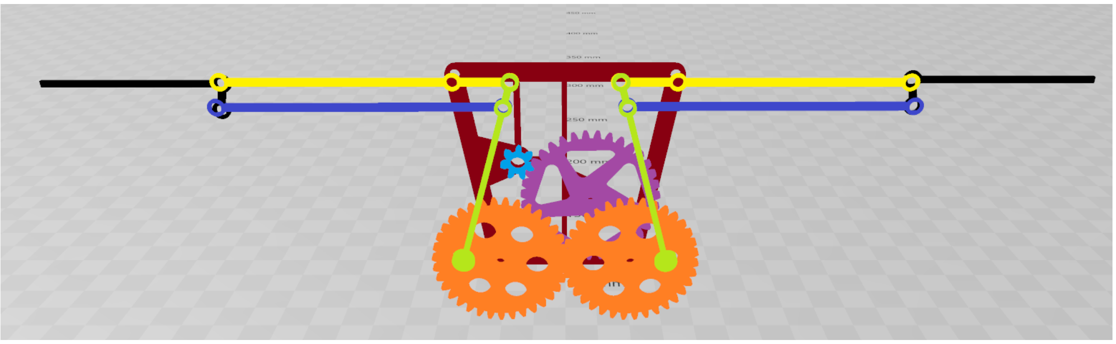

Figure 1. First design iteration

The concept underwent tests to see whether it would move smoothly or jerkily with each flapping motion, but it was abandoned because of the vast surface area that would produce considerable drag during flight.

Iteration 2

Iteration 2 of the gearbox design was created to fix the problems with iteration 1 and to cut down on the number of moving parts. Additionally, the design was created in Solidworks, and it underwent 3D printing-based analysis.

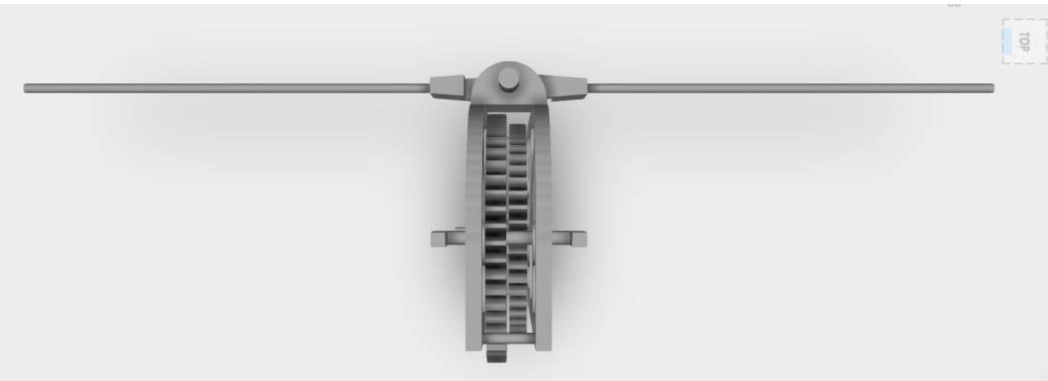

Figure 2. Second design iteration

The design has undergone tests for smooth motion and jerk with each flapping action, and the highest frequency of flapping is currently being tested.

Modeling

The current model (Iteration 2) is designed with the lift equation needed and flapping frequency obtained.

Motor selection – The motor that was chosen needs to have characteristics like low weight, high torque, and low current consumption because of the overall weight of the robot. After examining the alternatives and taking into account the attributes, Tmotor F2004 was chosen for the project. The information about the motor is given below.

Specifications

Test Item	KV1700	Weight (Incl. Cable)	16.4g
Motor Dimensions	Φ24.3*17.25mm	Internal Resistance	221mΩ
Lead	24#AWG 130mm	Configuration	12N14P
Shaft Diameter	3mm	Rated Voltage(Lipo)	6S
Idle Current(10V)	0.38A	Peak Current(60s)	21.2A
Max. Power(60s)	503W		

Figure 3. Motor specifications

Gear ratio selection – A gear ratio of 1:2 was required after choosing the motor to be used and figuring out the frequency of flapping. A compound drive of 1:5:5 was employed to get this ratio. The motor's maximum speed, which drives the final gear at 400 rpm 6.6Hz, is 18900 rpm without any load and 10000 rpm with gearbox load. This rpm and frequency are relatively close to the 5Hz frequency that we want. Figure 4 depicts the side view and exploded view of the current gearbox design.

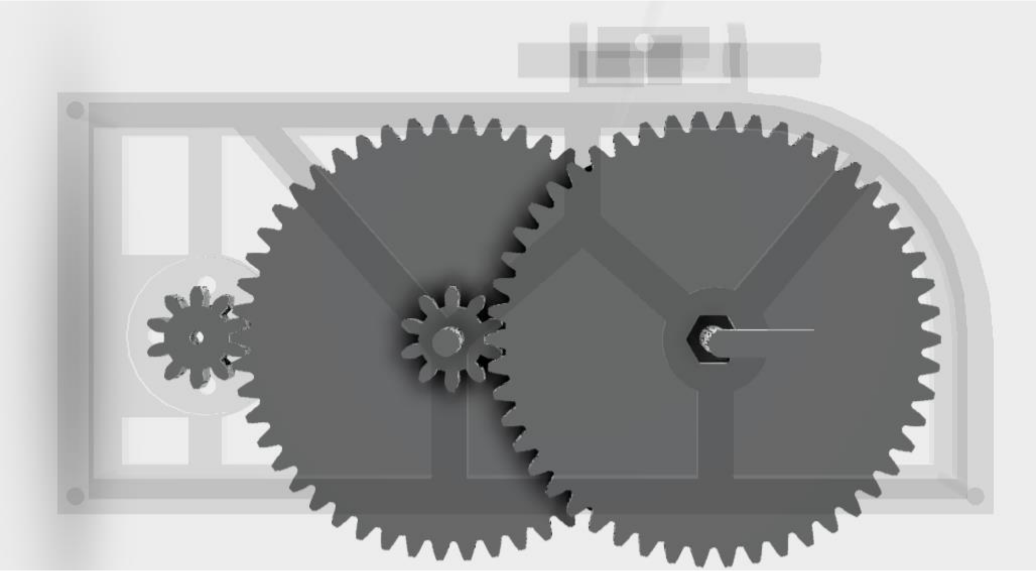

Figure 4. Gear train

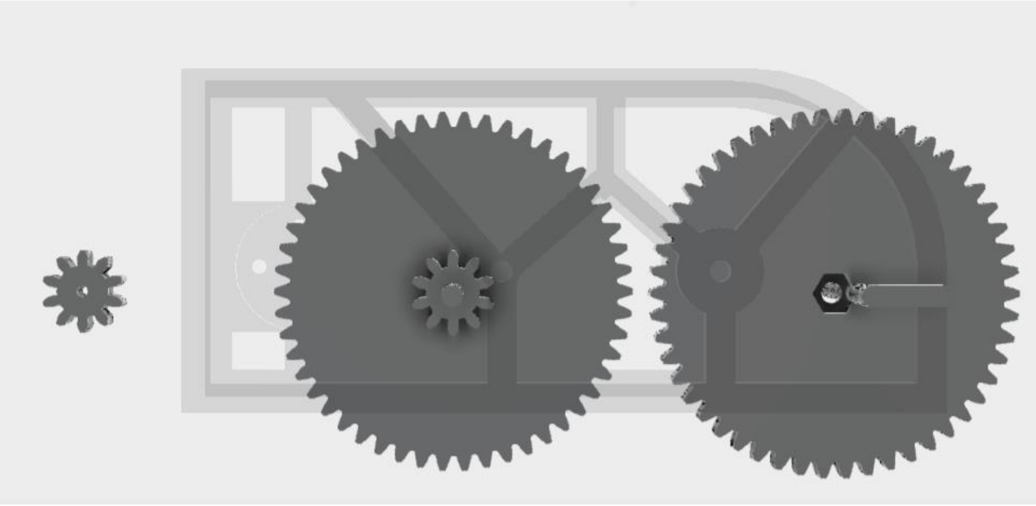

Figure 5. Gear train exploded

Final Gearbox and flapping mechanism – The final drive gear has a crank which moves the spars with the help of 2 ball end mechanisms to move the wings in a flapping motion to generate lift.

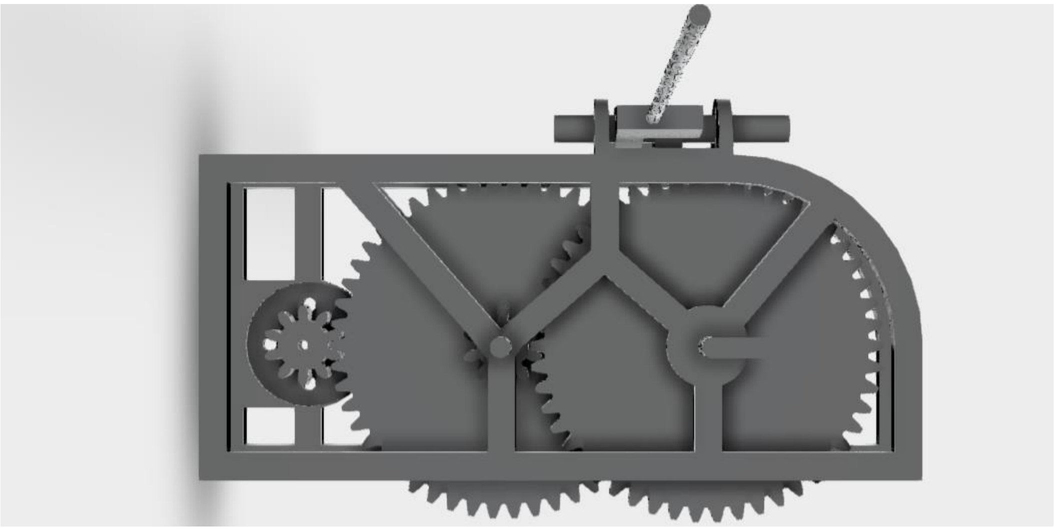

Figure 6. Drive mechanism side view

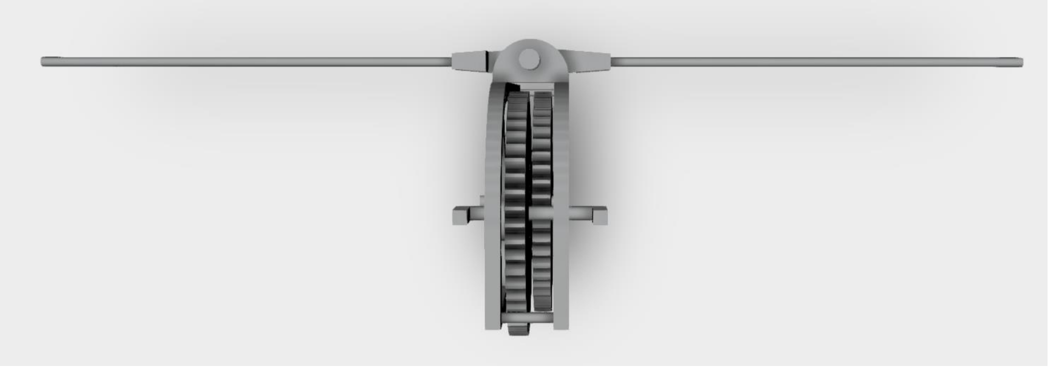

Figure 7. Drive mechanism front view

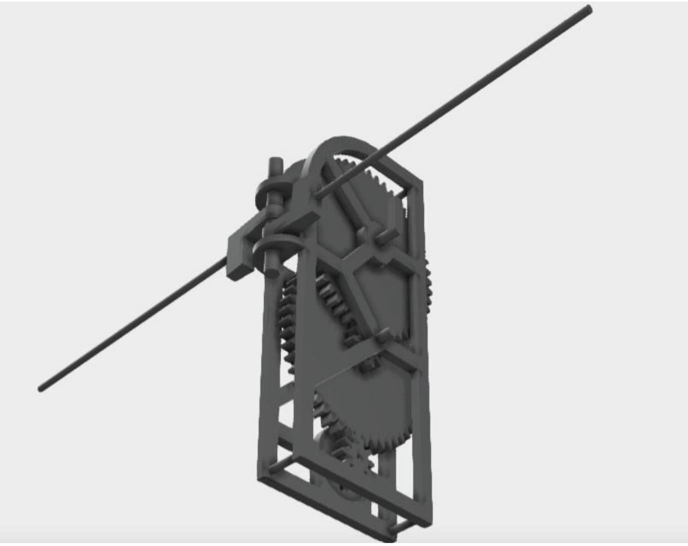

Figure 8. Drive mechanism oblique view

Calculations used in this study are mentioned below:
Initial Weight Estimations (based on available off-the-shelf parts)

Table 1. Parts list

Part used	**Model number/Material**	**Weight**
Drive Motor	Tmotor F2004	16.5g
Electric Speed Controller	Aikon 25Amp BL32	5.5g
Battery	GnB 450mAh 4s 100c	30g
Servo*2	Tower Pro SG90	16g
Flight Controller	Omnibus F4.4	5g
Gearbox	3D printed	35g
Body	Carbon Fibre	50g
Total	-	**158g**

Therefore it is concluded that the total lift should be equal to twice the weight of the robot. i.e. ~ **300g** and is given by the relation [6, 7],
Lift Equations

$$L = Amp^2 \times \pi^2 \times freq^2 \times C_L \times \rho \times c \times l^3 \div 3 \qquad (1)$$

Where

Amp – flapping angle, Freq – flapping frequency, C_L – lift coefficient, ρ - density of air, c – chord length, l – span of the wing fully open.

$$Flapping\ frequency = 3.03 \times (Mass\ of\ ornithopter)^{-0.36} \qquad (2)$$

Considering the above equation, we get flapping frequency as 5.88Hz

Taking the assumptions, Amp - 70º, Freq – 5Hz, C_L - 0.8, ρ – 1.225 kg/m^3
We get the equation as

$$2.448 \times 10^{-3} m^4 = c \times l^3 \qquad (3)$$

With the help of this, we can determine the chord length and span of the flapping wing using the appropriate aspect ratio.

The aforementioned equations are tested on several materials (PLA, TPU, PLA+, Nylon, ABS, and Carbon fibre) to determine the lift and flapping frequency.

Results and Discussion

Different materials were evaluated after the initial design and development stages to ensure the design's strength and integrity. The results of the testing are compiled in Table 2 below.

Table-2. Data obtained from the test for different materials

Material used	**Run Time (s)**	**Motor (RPM)**	**Flapping Frequency (Hz)**	**Current (Amp)**	**Temperature (Kelvin)**
PLA	330	8492	5.2	18A	79.36
TPU	165	10676	6	16A	79.79
PLA+	1345	7681	4.6	20A	85.37
Nylon	1735	11307	6.7	23A	81.38
ABS	2602	20110	13.2	30A	45.53
Carbon Fiber	1800	20400	13.4	25A	30.26

Testing on several materials revealed that nylon had the highest durability but also the largest current consumption. The gearbox's initial phase produced results that were acceptable, with a limited temperature range and acceptable flapping frequency.

Carbon fiber will undoubtedly be the most dependable material for the ornithopter's construction, according to the results of the above table. High tensile strength is provided by carbon fiber spars, which also help to keep the weight as low as feasible. High stiffness, good tensile strength, low weight, high chemical resistance, high-temperature tolerance, and minimal thermal expansion are only a few benefits of carbon fibers.

The production of moveable parts uses CNC machining.

Figure 9. Carbon fiber cutting on CNC machine

Figure 10. Gear profile cut out from carbon fiber sheets

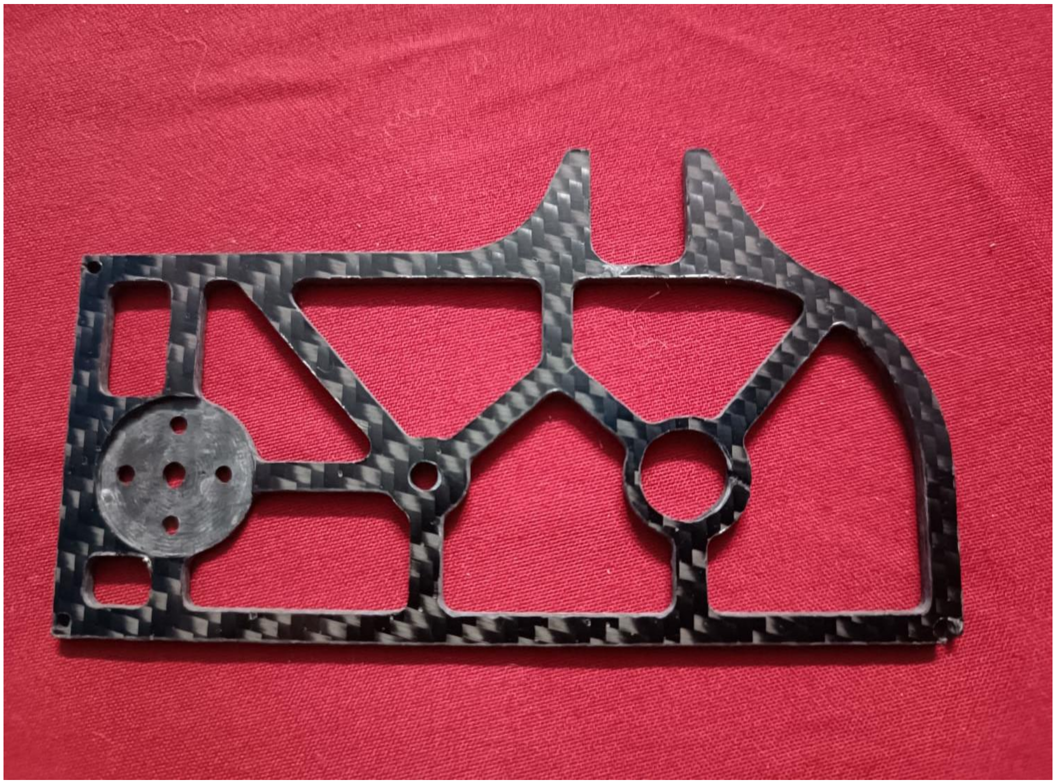

Figure 11. Left chassis with motor pocket

The stationary parts are 3D printed with ABS to save complexity and cost of the CNC machine

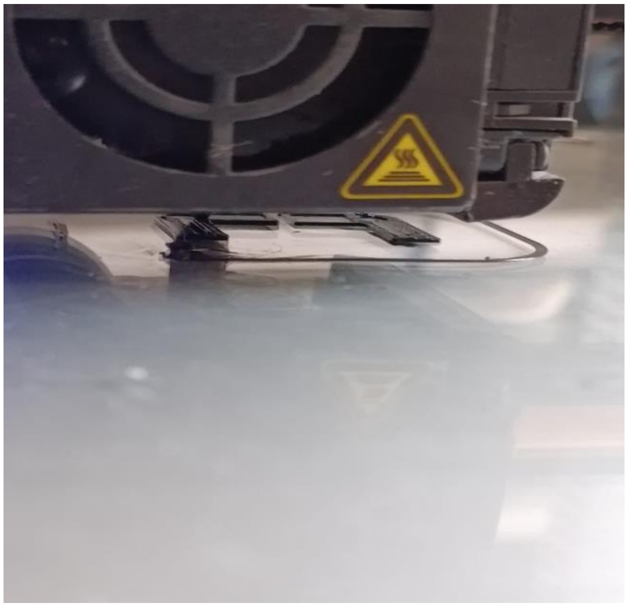

Figure 12. 3D printing spar lock

Now after assembling the parts, and filing them for smooth motion, the complete assembly of gearbox can be seen below.

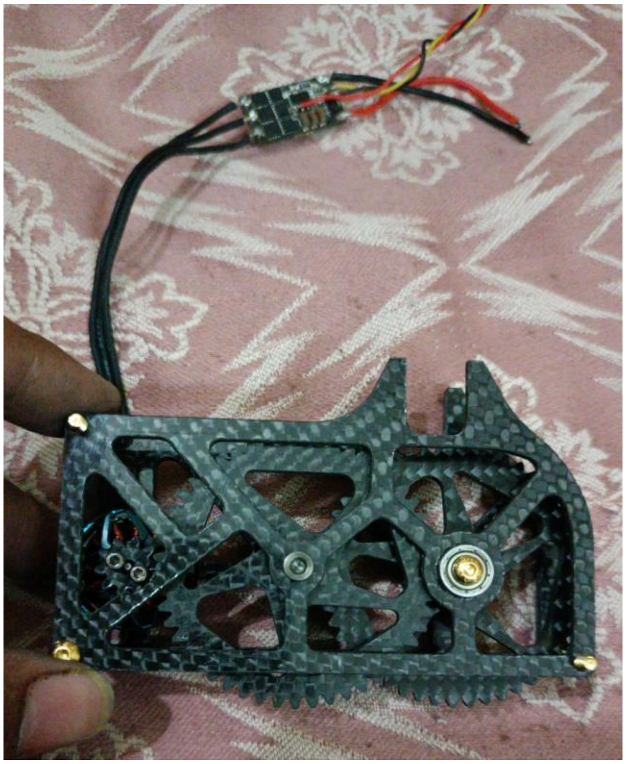

Figure 13. Right side profile of gearbox

Figure 14. Left side profile of gearbox

Conclusion and Future work

The prototype is prepared for test flights and autonomous operations after operating the gearbox and putting the parts together. The project assisted us in learning about various manufacturing processes, material strength, additive and subtractive manufacturing, and the flight characteristics and design of birds.

To improve flying times, accuracy, and efficiency, the project will test new stronger, and lighter materials in the future.

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