A Flexible Flying Surface for Multimodal Flight

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Unmanned Aerial Vehicles (UAVs) are quickly gaining in popularity in a range of fields such as search and rescue, exploration, as well as package delivery. However, the rigid design of these systems limits the possible flight modes that can be explored. By loosening these restrictions, we can hope to design flying vehicles that can achieve more agile and energy efficient flight. In this work, we utilize a set of embedded brushless motors, inertial measurement units, and thin mylar sheeting to produce a flexible flying surface that flies in both a folded and unfolded configuration. This mechanism possesses the ability to achieve multi-modal flight (flapping and hovering) while also allowing freedom for shape manipulation. We investigate the controls necessary for this mechanism, with current results showing that a modified proportional-integral-derivative (PID) controller can achieve basic flight. More experimentation will be conducted to produce stable flight with smooth shape control.

I. Introduction

Modern design challenges in aerospace are discovering never before seen boundaries in flight and and seeking more inspiration than ever from natural sources. This study focuses on the preliminary design and testing of a flexible flying surface for multimodal flight. Researchers have observed natural flyers and swimmers using flexible appendages to propel themselves through fluids or generate lift in the wild. Unlike many of today's solutions for navigating air and water, animals with the ability to swim and fly take advantages of flexible appendages to navigate efficiently. Could natural inspiration from evolution provide a reason to incorporate multimodal flight in today's UAV platforms?

It is known that jellyfish, among other aquatic species experience various benefits in efficiency for their distinct form of movement, in which they expand and contract their bell shaped bodies to propel themselves through the world's oceans. Attempting to incorporate a few of these principles into modern day flight solutions could reap similar efficiency or mobility benefits.

The flapping action seen in flying species is also seldom reflected in current flying and aquatic systems, but as evidenced by nature should provide some benefit in either efficiency or mobility for the animal. Some of the most important advantages of this motion seen in nature is the presence of passive energy recapture and suction thrust. [1]

add pic of bird and cite article on flapping flight maybe for final draft

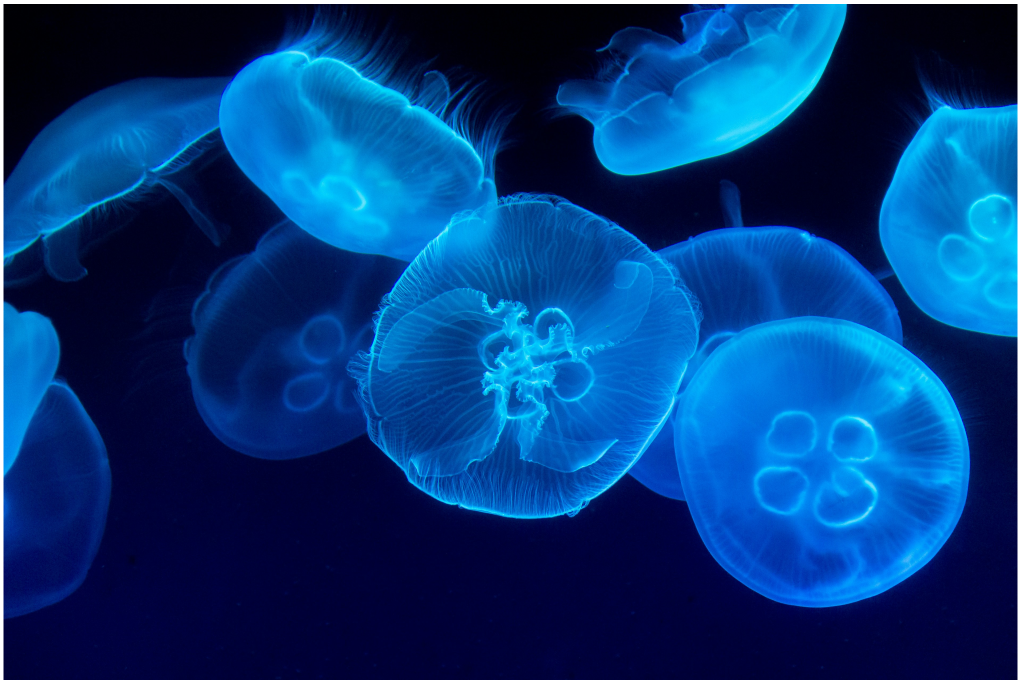
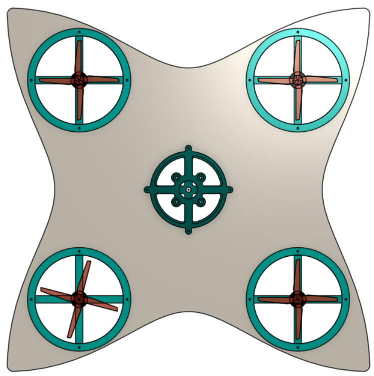


Fig. 1 Jellyfish

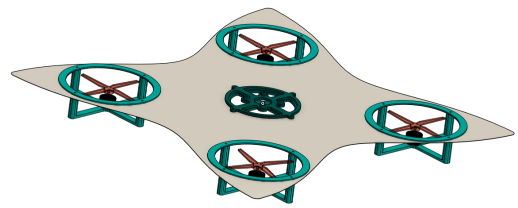
Applying inspiration of dynamics found in nature to conventional drones, which traditionally use rotors to generate lift and propel themselves through space, could prove to be a novel method for moving through the air and provide benefits that current systems are lacking. The main goals of this study are to extract any advantages that a drone with propellers embedded into flexible material. Creating an initial test-bed that is able to stably fly and perform maneuvers such as flapping, and deforming strategically during flight, then extract any advantages if any this form of device has. It will be interesting to observe any effects that are seen in nature and if energy transfer between flapping motion of the flexible sheet will aid motors in these processes providing more efficient flight, easier obstacle avoidance, and crash resiliency.

II. Methods and Design

The design of this project first began with the idea of a flapping wing on a hinge, which transitioned into a square mylar sheet with a propeller attached to each corner. The latest evolution of this project being fabricated consists of 12x12 in. star shaped sheet of 1 mm thick poly-carbonate that acts as the body of the drone. 3D printed PLA propeller and motor mounts as well as housing for electronics are attatched to the body using m2 screws. Each brushless motor will control its corresponding propeller and connect to the center of the drone where electronics are located.



(a) Top View



(b) Diagonal View

Fig. 2 Flying Carpet Concept CAD

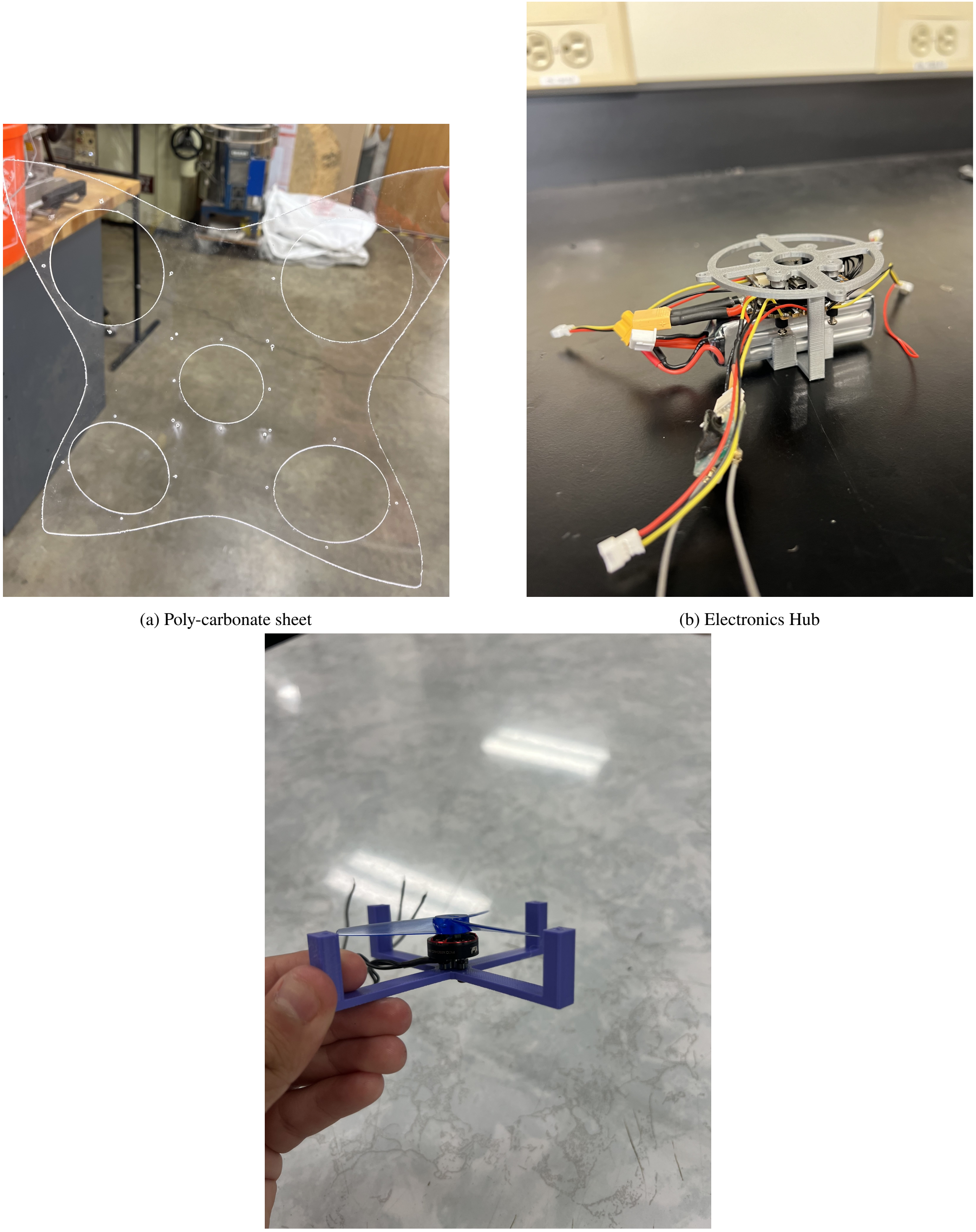
The star shape design seen in Figure 2, allows for decoupling of thruster action and provides natural folding modes for the structure of the drone. The hub in the center is the home of an on board flight controller, battery, and 4 in 1 ESC. Current work calls for investigating behavior of the drone with varying thicknesses of flexible material, starting with a semi-flexible version that has enough stiffness to withstand thrust from motors without folding in on itself.

III. Current Results

A. Hardware

The previous design of the Flying Carpet featured a 0.030 in. thick sheet of mylar as its body with 1340 drone motors and 2530 drone propellers. This design proved to be extremely hard to control and ultimately ended up folding in on itself when motors were turned on during testing. To combat this and have the best chance at achieving flight, while keeping the critical requiremnt of flexibility in the body of the drone, the mylar sheet was replaced with a sheet of 0.040 in. thick poly-carbonate, which is slightly more stiff than the previous one. Motors along with motor mounts were upgraded as well, with the mounts being made thicker for added robustness of the motor assembly setup. New 1440 drone motors along with 3025 drone propellers were purchased and their integration into the new design will add approximately 400 g of added thrust compared to the previous model, allowing for more wiggle room in terms of power usage and controls development.

Currently, progress is being made with creating two more prototypes off this drone. All hardware will be the same except for varying thickness of the poly-carbonate sheet used as the body. Each prototype will feature a body of 0.030 in. and 0.020 in. thickness respectively, giving a well controlled variation in the flexibility of the drones for flight testing. There is also progress being made on being able to connect the drones remotely to a computer instead of only using a remote control. Currently various hardware solutions are being explored.



(a) Poly-carbonate sheet

(b) Electronics Hub

(c) Motor Assembly

Fig. 3 Current version of Flying Carpet hardware

B. Control

Current progress on creating a control system for the drone is being made, with most of its focus being put on after the main test-bed of the drone is assembled. So far, it is understood that Beta Flight will be used to implement a controls algorithm that will be able to achieve stable flight of the test bed. Again, most of this progress will be made once the model is built and physical testing and experimentation is able to be done in lab. The priority is to achieve stable flight with the drone, being that it would be the first time that this would be the case. Then moving forward move on to more advanced maneuvers such as flapping or avoiding obstacles.

IV. Next Steps

Although the main goal is to achieve flight on a purely mechanical manner, that is, having the drone fly on its own without a very sophisticated physical or control mechanism, such methods will be explored. For example, different control algorithms can be made to achieve collaboration between thrusters to provide lift independently and not only stabilize the drone, but also provide multi modal flight via flapping and gliding. Additionally, work can be done on allowing the control algorithm to know what shape the drone is in during flight through the use of shape sensing using motion capture. These methods will be explored and potentially implemented in the coming weeks.

Firstly, the main goal of the summer is to achieve stable flight in a lab setting. From there, two more prototypes will be made, each more flexible than the other, and we will be able to observe the differences in difficulty between controlling each drone to inform creation of an adequate control algorithm for stable flight for the most extreme case. The next goal would be to achieve a flapping motion in which the drone can hover while making the body flap, introducing some bobbing in the stationary flight pattern. After these main milestones are achieved, it would be interesting to observe the difference in efficiency of flight between hovering and flying using a flapping motion. One potential method to observe this would be using voltage measurements of motors during flight over some period of time. Investigating efficiency would be one of the primary goals of continuing research after the summer, being that it can be observed as a potential benefit to using a flexible body.

V. Conclusions

In conclusion, progress that has been made on the project will be built upon for the remainder of the summer and possibly after. Achieving flight with propellers coupled with flexible materials is currently a challenging, but important problem in flight science and learning more about it will be fruitful for future work in the area. This project will provide much needed information on methods and challenges encountered when attempting to solve this problem through both mechanical and control methods.

References

[1] John H. Costello, J. O. D. B. J. G. K. N. L. K. R. S., Sean P. Collin, "The Hydrodynamics of Jellyfish Swimming," *Annual Review of Marine Science*, 2021.