Design for Manufacturing, Reliability, and Economics

Team 8

Design an Unmanned Tilt-Rotor Aircraft for Multi-Mission Application

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4/01/2015

Table of Contents

Table of Figures

Table of Tables

1. Design for Manufacturing

Before generating parts for the final design, a test rig was created. This test rig was the multirotor component of the aircraft, which essentially is a tricopter. The vertical component from last year’s design was scrapped to create a tricopter prototype modeled after the design that would be integrated into final airframe. This early design also used the same yaw control mount design discussed later. It was easier to assemble due to the material being a combination of wood, aluminum, and carbon fiber. Adhering one piece to another was as simple as applying a screw.

The first step of building this aircraft was to embed the elevon servos into the wing and laying ribbon wire for possible future electronic additions. The wings were then fully assembled, adding the winglets and rods, then attached to the fuselage itself. After the main airframe is assembled, the next step is to integrate the multirotor component to the airframe.

The first component designed was the front motor mounts that attached the motors to the front two carbon fiber rods that protrude out of the aircraft. The motor mounts are three ABS plastic puzzle pieces that have holes matching the dimensions of the motor and rod.

The next piece of design work was the front mount that was to be the semi-rigid connection of the motors to the frame. This mount was designed with two ports to access or implement future electronics. The joints that hold the carbon fiber rods also encase two different kinds of bearings. The center two joints fully encase a ball bearing and the outer two hold a sleeve bearing. Two large access ports were adding for future sensor implementation.

The next main component to be designed was the rear motor mount, which consisted of two sub components. The first being the mount that connects the carbon fiber rod to the foam and the other connecting the rear motor to the arm, which was a specialized design. The first part is mounted to the foam using adhesive as well as being punched through the foam using a board on the other side. That rear mount also has the ability to adjust in angle for transitional flight so the aircraft maintains a neutral angle of attack during transition. The second part in this rear mount design is the yaw control mount. This piece is rigidly attached to a servo which spins about the rod, sitting on a ball bearing, to control the yaw of the aircraft.

It is important to note that all these mounts were made from ABS plastic using the laser cutter in the CISCOR/STRIDe lab workshop. There was no need for this group to use the machine shop, because they could generate all their parts themselves.

The main design, manufacture, and assembly of the aircraft did not take up as much time as anticipated. The parts that took the longest were certain additions that were unaccounted for in the original design, such as the landing gear. Since horizontal flight needed to be tested, the aircraft needed to be able to land horizontally as well, which can only safely be done using traditional landing gear. These were meant to be temporary, but figuring out where and how to mount them to foam took longer than expected.

One thing that could have improved the design was not using ABS for the large parts, like the front and rear mounts. This could have reduced overall weight, which is crucial.

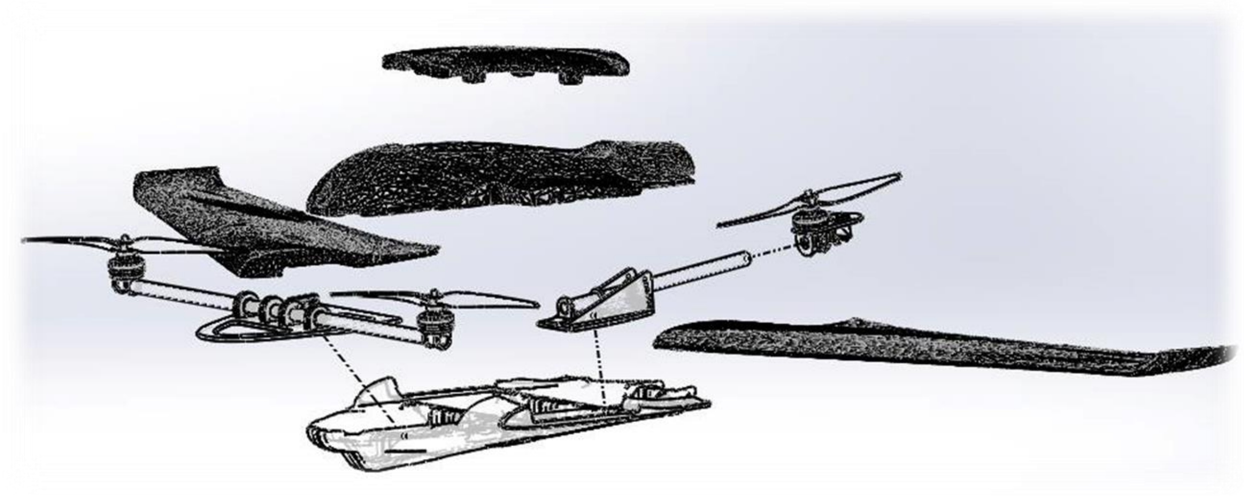

Figure 1 - Full Assembly (exploded view)

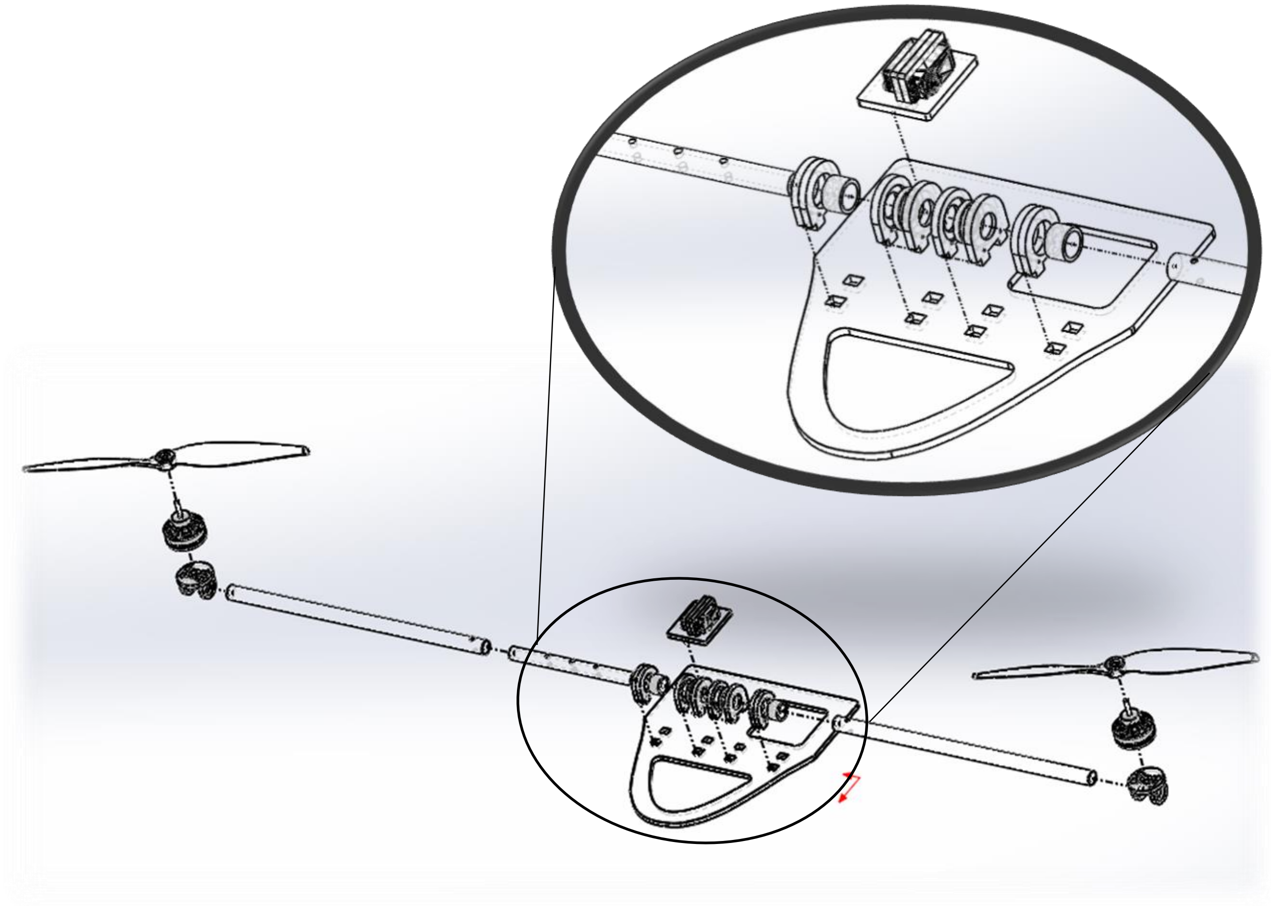

Figure 2 - Front Plate (exploded view)

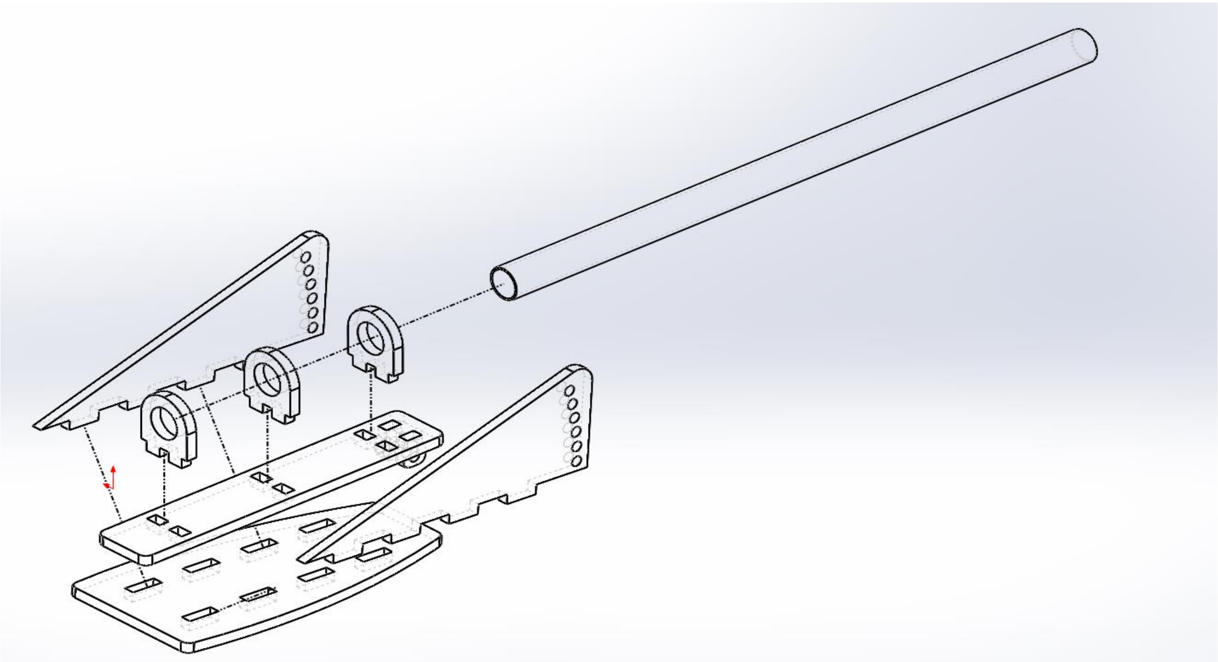

Figure 3 - Rear Mount (exploded view)

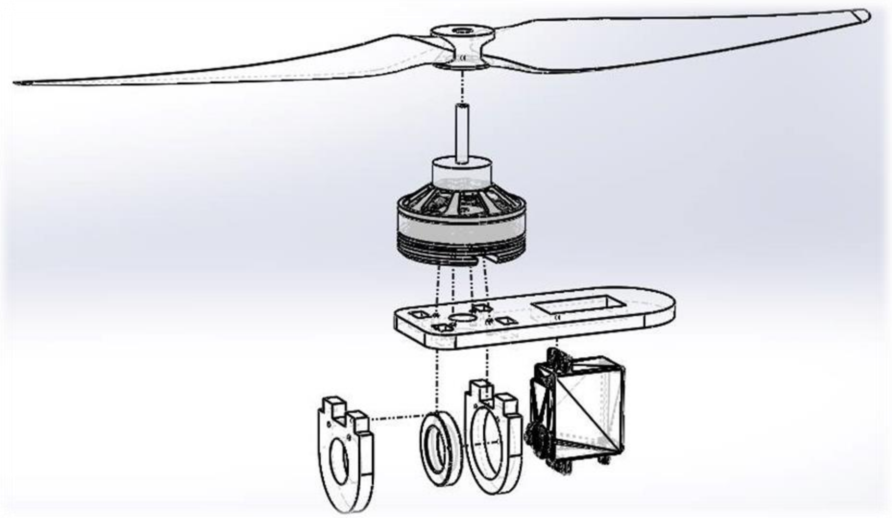

Figure 4 - Yaw Motor Mount (exploded view)

2. Design for Reliability

The prototype performed exceptionally well when it was used for the first time. Some parameters needed to be tuned in order to achieve better stability and flight, but this condition is universal within the realm of unmanned aerial vehicles. When considering the reliability over a range of uses, it is important to note the project's applicable scope. Keeping this in mind, this is not a product that will be used 10,000 or even 1,000 times. A more realistic expectation is a couple hundred missions. Some of the most important parts within our craft boast a large amount of reliability. The motors, for example, are brushless electric motors. Being brushless, they have less contacting parts when in motion, which increases the motors life expectancy. They also do not have the combustible complexities associated with liquid fuel motors. With the design, it would not have any issue meeting the desired reliability standard, given it is controlled by an experienced R/C pilot.

The main reliability concerns that are relevant within this project is the proper upkeep and storage of the Lithium Polymer batteries. These batteries are flammable and can ignite if punctured. They are to be stored in an approved LiPo pouch at a voltage of 3.85 volts per cell. If the batteries become puffy or damaged, they should be replaced immediately. This is the main concern when evaluating the reliability of the aircraft.

Planning for reliable flight with this design, computational fluid dynamics were performed on a representation of the aircraft. This was done through a program called XFOIL. The program allowed certain characteristics such as wind speed and coefficient of lift to be determined based upon the constraining parameters. From the determined airfoil, the relationship between the coefficient of lift and angle of attack was able to be determined and can be found in Figure 5. The calculations were based on an angle of attack of 5° and yielded an appropriate amount of lift at 12.5 m/s. From this, a visual representation of the pressure distribution was created for the craft when traveling at 12.5 m/s. Figure 6 shows this visualization. Along with analyzing the aerodynamic characteristics of the aircraft, an H-FMEA was conducted on the proposed design which can be found in Appendix A-1.

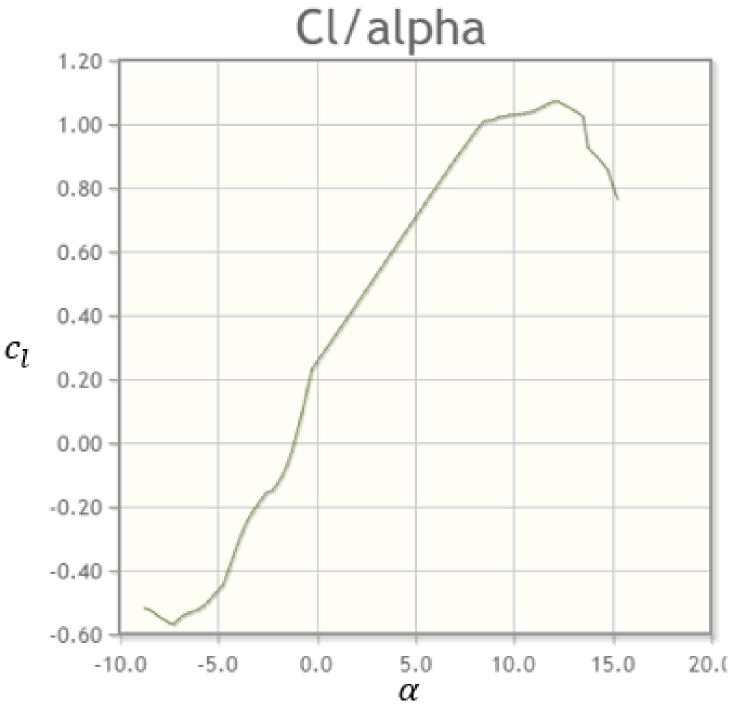

Figure 5 - Coefficient of Lift vs. Angle of Attack

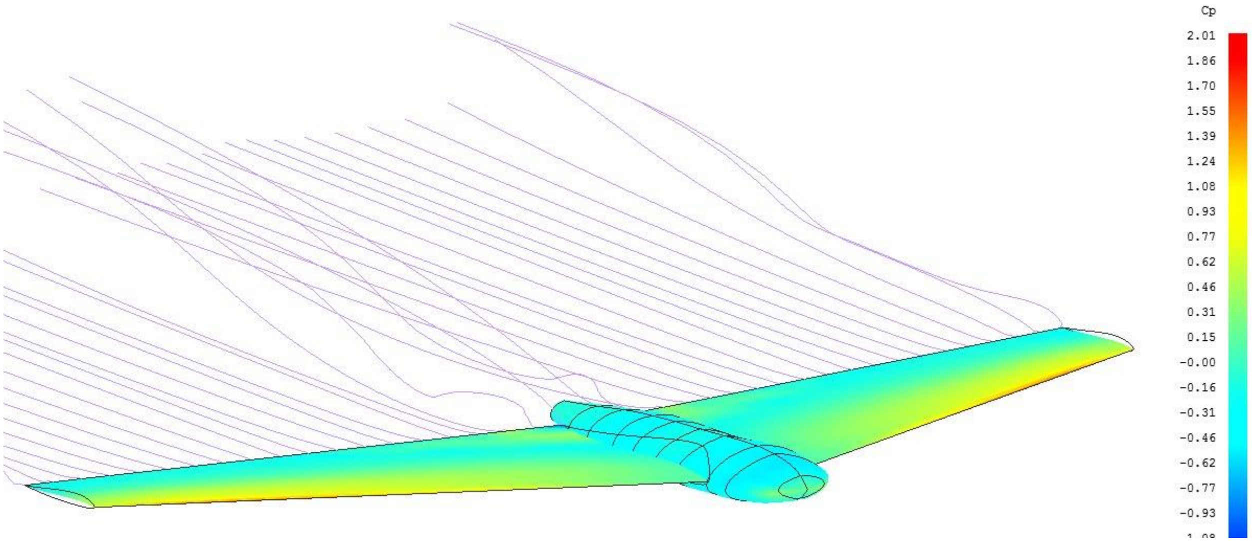

Figure 6 - Pressure Distribution on Aircraft

3. Design for Economics

How much does your whole product cost?

The entire project currently cost $781.55 for a completed aircraft and spare Skywalker fuselage.

How much do the components cost?

Located below is cost breakdown for the project and its components.

Table 1 - Cost Breakdown

Part	Quantity	Cost	Part Total Cost
HS-5625 Servos	2	39.99	79.98
HS-5245 Mini Servos	2	39.99	79.98
Skywalker Fuselage	2	216	432
ABS Sheet	1	18.42	18.42
Steel Needle Roller Bearing	2	6.86	13.72
Metric Steel Ball Bearings	2	13.25	26.5
Propeller Quick Detach	1	9.99	9.99
Carbon Fiber Propeller	1	57.99	57.99
Hitec Servo Hub	2	3.99	7.98
1/2 in OD Ball Bearing	1	1.99	1.99
Metric Steel Ball Bearings - Double Shielded	1	13.43	13.43
Timing Belt	1	13.68	13.68
Aluminum Tube	1	5.81	5.81
Black Epoxy	1	20.08	20.08

The team’s budget was $1500 and as previously stated the total money spent was $781.55 leaving $718.45 in the team’s budget.

Are there similar products like yours out on the market?

The most similar RC aircraft on the market to this vehicle is the Birds Eye View Aerobotics FireFLY6.

Figure 7 - FireFLY6 Aircraft

This aircraft is also capable of transition between vertical and horizontal flight while being both manually and autonomously controllable.

How much does it cost compared to our project?

The cost differences between the two aircraft are very distinct. The FireFLY6 cost $500 while not including many key components already figured into the project cost. These missing components include the Pixhawk microcontroller, motors, electronic speed controllers, propellers, batteries, and 7 channel radio/receiver. The Pixhawk microcontroller alone cost in excess of $200, and when fully assembled this commercial craft would cost at least $1300 with all its components. It’s important to note that the total project cost includes an extra fuselage, which would reduce the total cost by $216, far below the FireFLY6. In addition to costing less, the design would boasts higher payload ability and more autonomous capabilities at no extra cost.

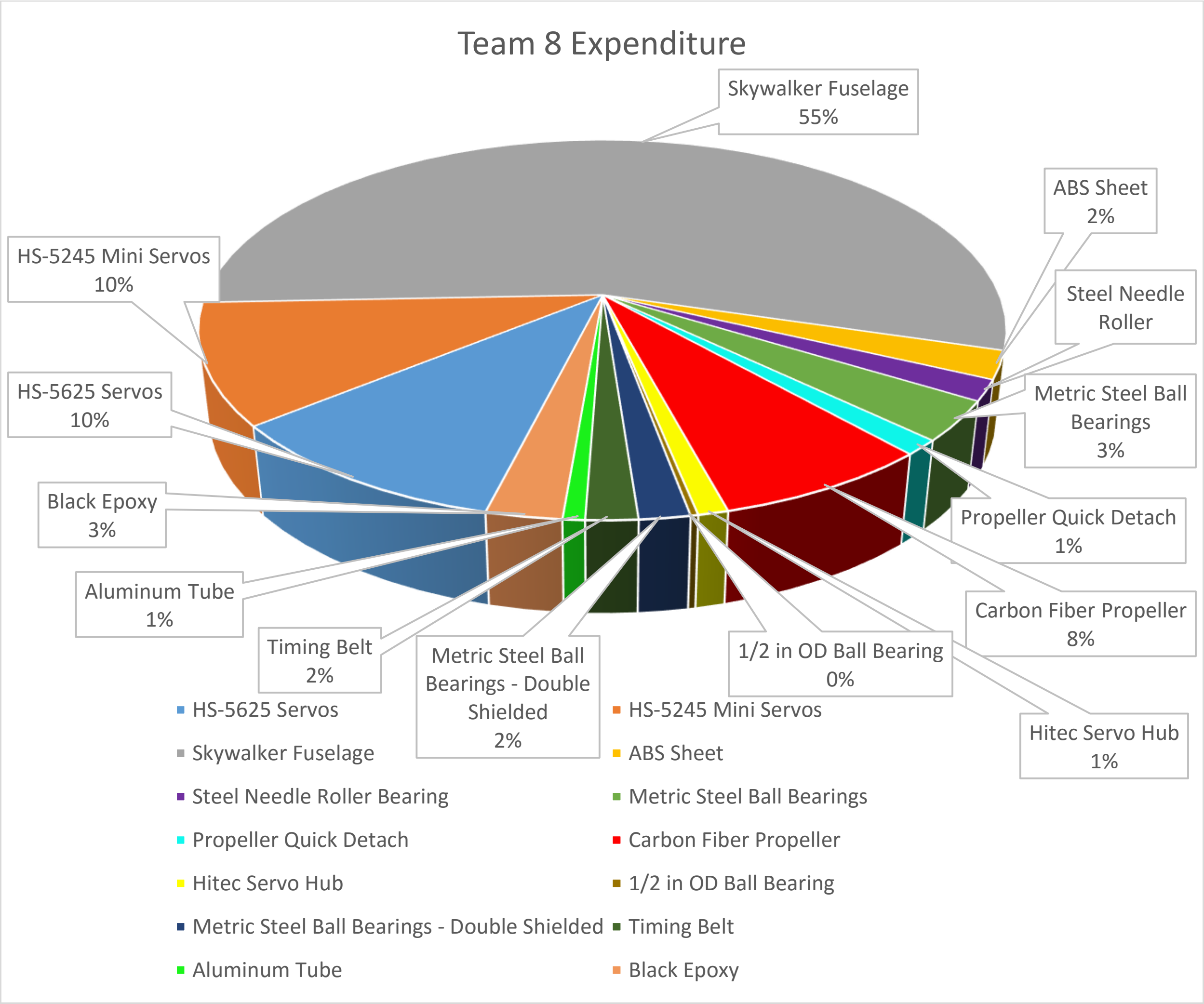

Figure 8 - Team 8 Expenditure

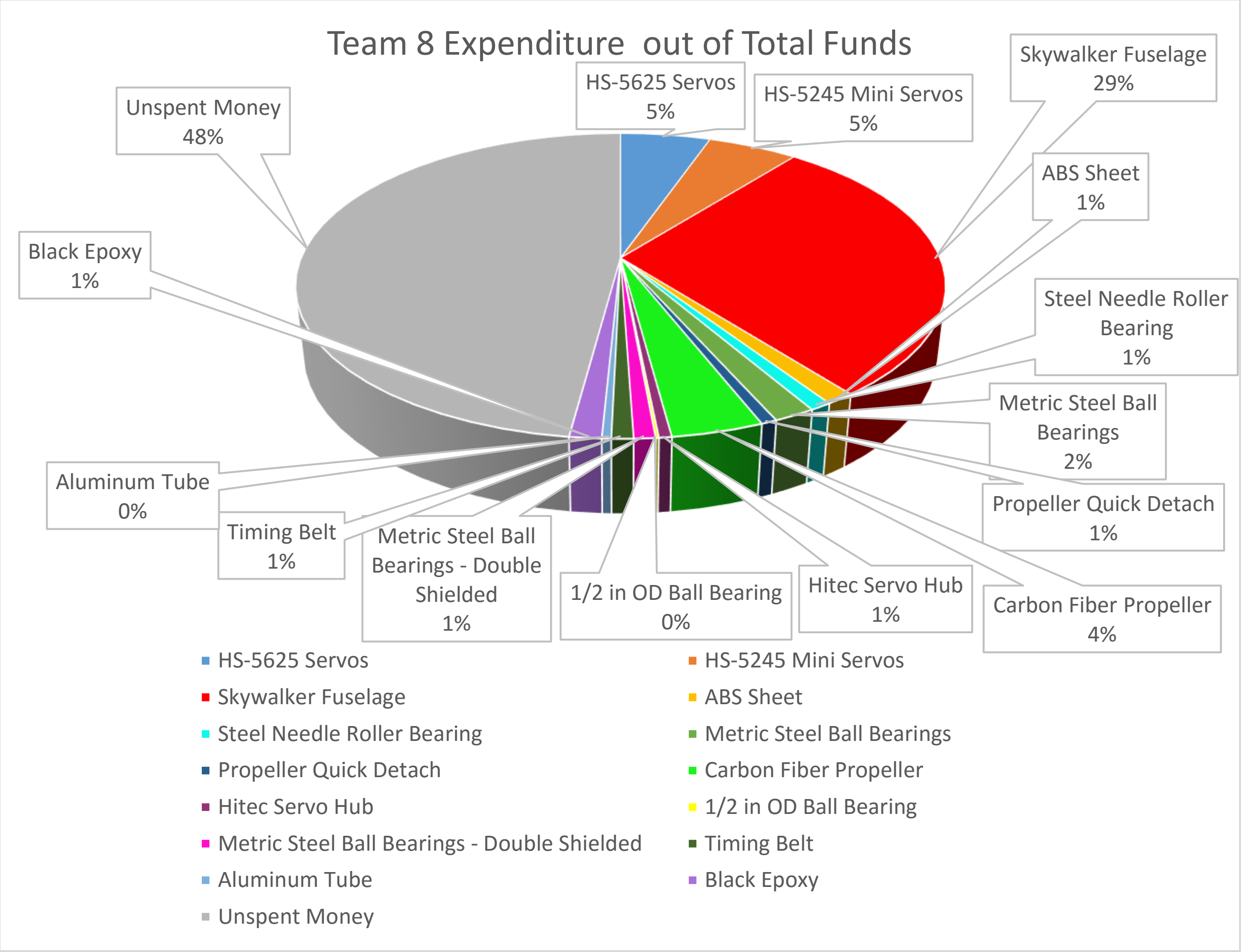

Figure 9 - Team 8 Expenditure out of Total Funds

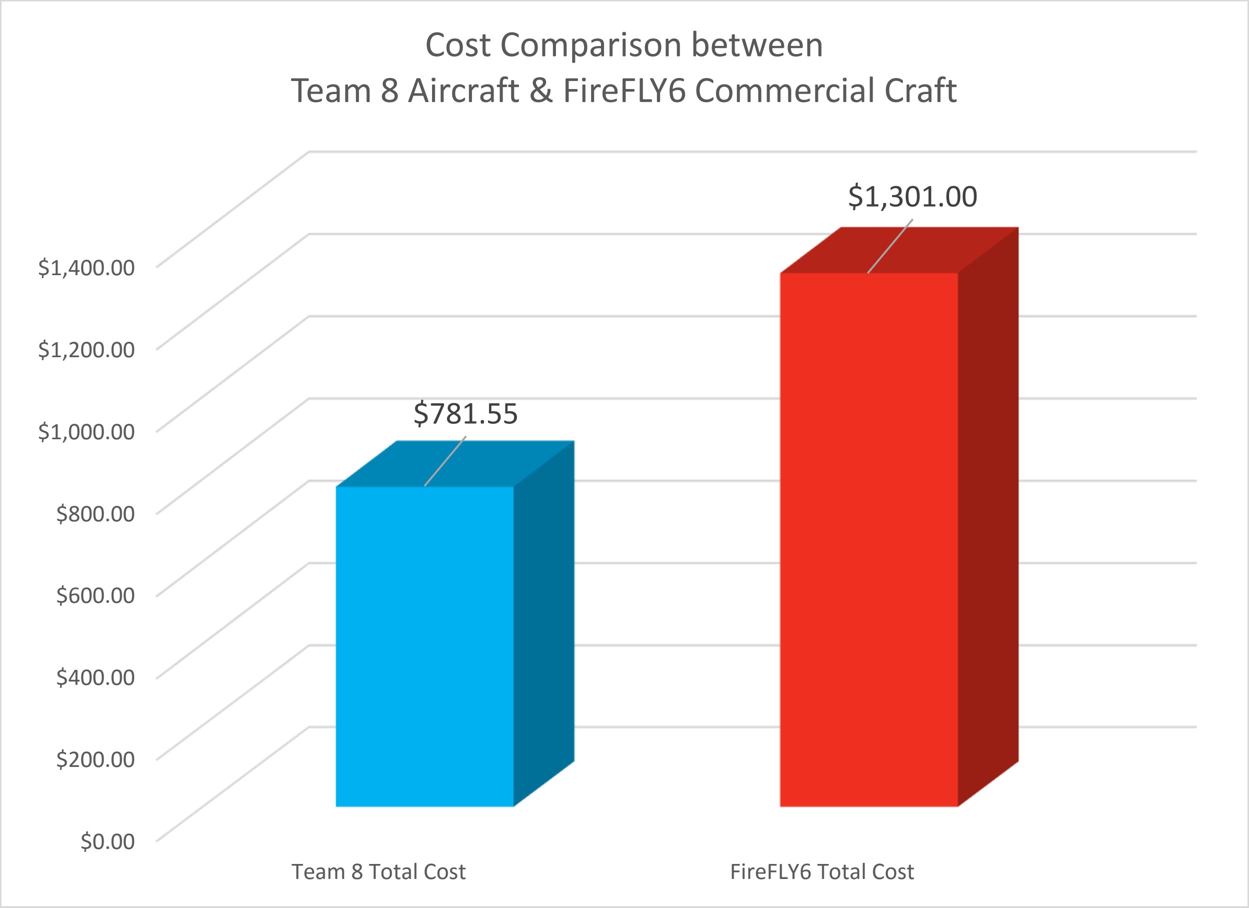

Figure 10 - Team 8 Aircraft vs FireFLY6 Cost

Appendix A-1

Hardware	Potential Failure Mode	S	Potential Cause of Failure	O	Potential Effect of Failure	Current Control	D	RPN	CRIT	Reccomended Actions
Flying Wing	Wing to body joint fracture	10	High speed vertical take off	3	Crash	Spotter	1	**30**	**30**	Reinforce connection
Transition Bar	Flexing of rods	3	High thrust from motors	7	Controller commands wrong control	Spotter	3	**63**	**21**	Reinforce bar
	Bar mounts failing	10	High thrust from motors	7	Loss of motor control	Spotter	1	**70**	**70**	Have mounts cover more area of bar
Tilt Rotor Mechanism	Gear teeth skipping	10	Soft gear material	7	Loss of zero position	Spotter	6	**420**	**70**	Use harder material for gears
Battery	Voltage below threshold	3	Flying for longer than allowed	3	Damage to battery	Low battery alarm	1	**9**	**9**	Once alarm goes off, land.
	Voltage above threshold	3	Faulty charger/user	3	Damage to battery. Possibly volatile.	Charger alarm	3	**27**	**9**	Take batteries off when fully charged
Electronic Speed Controller	Stop supplying voltage	10	Battery voltage too low	3	Motors stop running	Low battery alarm	1	**30**	**30**	Once alarm goes off, land.
	Fried ESC	10	Applied amperage above upper limit	1	Motors stop running	Using correct the ESC for chosen motor	1	**10**	**10**	N/A
Pixhawk Microcontroller	Supplies wrong control	7	Snags foreign object	1	Crash	Spotter	1	**7**	**7**	Fly in large open areas
Motors	Seized bearings	10	Deterioration of grease	1	Motors inoperable	Spotter	3	**30**	**10**	Taking care of motors