THE UNIVERSITY OF MELBOURNE

Capstone Project

Department of Mechanical Engineering

Scope of Works

2015

Project Title: UAV Development for Medical Transport

Date: 23/3/2015

Project Team Information

Identifier: **CP–CBU-155**

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1. Project

This project is titled “UAV Development for Medical Transport”.

This project is a sub-project of MASR (Melbourne Autonomous Search and Rescue), the official entrant into the UAV Outback Challenge 2016.

NOTE: The project’s scope is based on preliminary summary information for the challenge. There may need to be alteration once the full details of the challenge have been released

2. Objectives

The 2014 “UAV Outback Challenge - Search and Rescue” tasked competitors with identifying Outback Joe in a remote bush location, and air dropping a bottle of water to his location; this challenge was deemed solved. The 2016 “UAV Outback Challenge - Medical Express” rules are to be released in the coming weeks. In the absence of well defined rules, our objectives will be based on the 2014 challenge, and the limited information available on the competition web page.

In 2016, teams must build a UAV capable of travelling 10km to the GPS co-ordinates provided by Joe (a flooded, obstacle-rich clearing) and land, collect a blood sample, and return 10km to base. It is unlikely that a traditional fixed-wing or multicopter aircraft will be capable of meeting this challenge. “UAV Development for Medical Transport” will therefore focus on the development of a hybrid aircraft, modifying a fixed-wing airframe for both Vertical Take-Off and Landing (VTOL) and winged flight capabilities; an example aircraft is shown in Figure 1.

The aircraft must also be capable of analysing the landing site to identify obstacles, safe landing areas, and other hazards, and autonomously generate flight paths and choose a landing point. Finally, it must be able to communicate with the ground station throughout its flight, and intelligently decide which information is relevant/important to send.

Primary and secondary objectives are summarised in Table 1 and Table 2 respectively, which are drawn from the competition description above. The evaluations will be used to assess the overall performance of the team at the conclusion of the project.

#	Objective	Evaluation
P1	Develop UAV: Achieve stationary hover	Pass/Fail
P2	Develop UAV: Achieve vertical-to-winged transition	Pass/Fail
P3	Develop UAV: Achieve winged flight	Pass/Fail
P4	Develop UAV: Achieve autonomous flight	Pass/Fail

#	Performance Metric	Max/Desired Characteristics	Evaluation

S1	Cost of aircraft	$c_{max} =$ \$1800	$e_1 = 1 - c / c_{max}$
S2	Target flight range	$r_{des} = 20km$	$e_2 = r / r_{des}$
S3	Aircraft weight	$m_{max} = 4.5kg$	$e_3 = 1 - m / m_{max}$
S4	Communication range	$r_{des} = 10km$	$e_4 = r / r_{des}$
	Overall performance	$e_{total} = 1$	$e_{project} = \sum_i e_i / n_{objectives}$

3. Definition of starting point

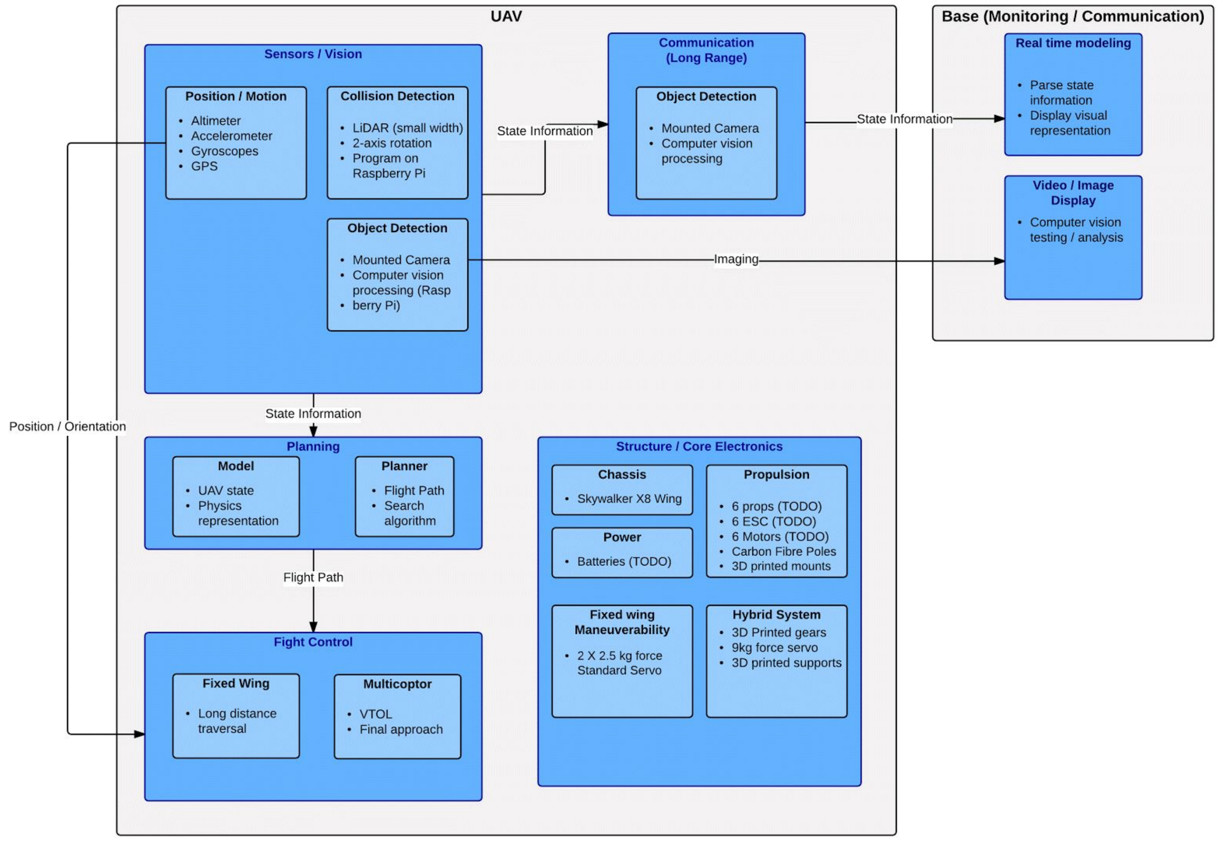
In 2014, students completed the project 'UAV Development for Search and Rescue', in order to compete in the 2014 UAV Outback Challenge. While the team did not compete in the challenge, the aircraft(s) developed for the challenge was passed on to us, with the final model capable of fixed wing, RC flight, but not autonomy.

In order to use this model for 'Medical Express', the aircraft will have to be converted to a hybrid Fixed-Wing/VTOL (per requirements from objectives above). The Appendix (7.1) contains an analysis of this model that indicates it will not be possible to convert to the hybrid VTOL/Fixed Wing aircraft required to complete the 2016 challenge. This year's team are therefore starting with a blank slate. The Appendix (7.2) shows our evaluation of several potential platforms to work with for 2015, which concluded the Skywalker X8 foam airframe (shown in Figure 2), is the best option; the airframe has been purchased, and work will proceed according to the task list and Gantt chart below.

4. Task descriptions

4.1. Component Diagram

High level overview of the different components required for the project.



4.2. Tasks

NOTE: The estimated time for a task is in hours needed for 1 person to complete the task, not in duration of passed time.

Administrative Tasks			
Task	**Items Required**	**Description**	**Estimated time**
Organise funding		Briefing document / contact and meetings	12 hours
Scope of work		Research of platforms + write up	48 hours
Ethics essays x 4		Due Mon 13th April	40 hours
Progress report 1		Due Mon 25th May	40 hours
Progress report 2		Due Mon 10 Aug	40 hours
Final report		Due Mon 5th October	80 hours

STAGE 1: Hover			
Task	**Items required**	**Description**	**Estimated time**
Plan overall design		Research, and select overall design related to reaching project goals.	32 hours
Procure wings		Research, select and purchase the fixed wing related to reaching project goals.	12 hours
Measure Wing		Determine dimensions for hardware	2 hours
Procure stage 1 hardware		Select and purchase hardware related to reaching Stage 1 goals.	4 hours
Design Mounts	Airframe	Design how the chosen motor will fit	8 Hours
Circuit Diagrams		Research / Design how the circuit will go together (with all components)	8 Hours
Build wing with servos	Servos	Put together the wing and purchased servos	6 Hours
Build motor testing rig		Put together frame for testing the motors	8 hours
Test individual motor thrust capacity	Motors	Test, troubleshoot and prove individual thrust capacities of each motor. Also balance each motor	6 Hours
	ESC		
	Batteries		
	Props		
	RC RX/TX		
	Charging System		
Build Mounts	Mounts	3D printing motor mounts	4 hours
	Poles		
Install all stage 1 hardware	Wires/Connectors	Install the thrust components and RX on the plane	16 hours
Test thrust systems & Battery		Test, troubleshoot and prove thrust systems and wiring is working effectively	2 hours
Basic monitoring setup		USB connected to aircraft, interface to pixhawk program	4 hours
Hover Test		Test, troubleshoot and prove we can hover at the required weight (tethered)	2 hours
Configure hover flight controls		Configure flight controller to maintain stable hover	8 hours
Test hover flight controls	Flight Control #1	Test, troubleshoot and prove we can maintain stable hover	4 hours

STAGE 2: Movement & Collision Detection			
Task	**Items Required**	**Description**	**Estimated time**
Procure stage 2 hardware		Research, select and purchase hardware related to reaching Stage 2 goals.	16 hours
Basic communications / monitoring	Raspberry Pi	Configure communications program for specific UAV components (Position, orientation,object range, object relative position)	16 hours
Test communications offline	Processing Unit Network TX/RX	Test, troubleshoot and prove communication systems work effectively	16 Hours
Test position systems	Altimeter GPS & Compass Airspeed Sensor	Test, troubleshoot and prove position systems are working effectively (GPS/compass/altimeter)	4 Hours
Test LiDAR standalone	LiDAR	Test, troubleshoot and prove LiDAR is working effectively	8 hours
Install stage 2 hardware		Install stage 2 hardware onto the drone	3 hours
Retest systems online		Test, troubleshoot and prove stage 2 hardware is working effectively	2 hours
flight controls for movement		Configure flight control to allow movement in all 3 directions	10 hours
Test flight controls		Test, troubleshoot and prove we can move in all 3 directions in stable hover	5 hours
Set up basic object avoidance		Set up a system with the sensors to avoid objects at low altitude	10 hours
Test basic object avoidance		Test, troubleshoot and prove we can avoid close range objects at low altitudes	5 hours

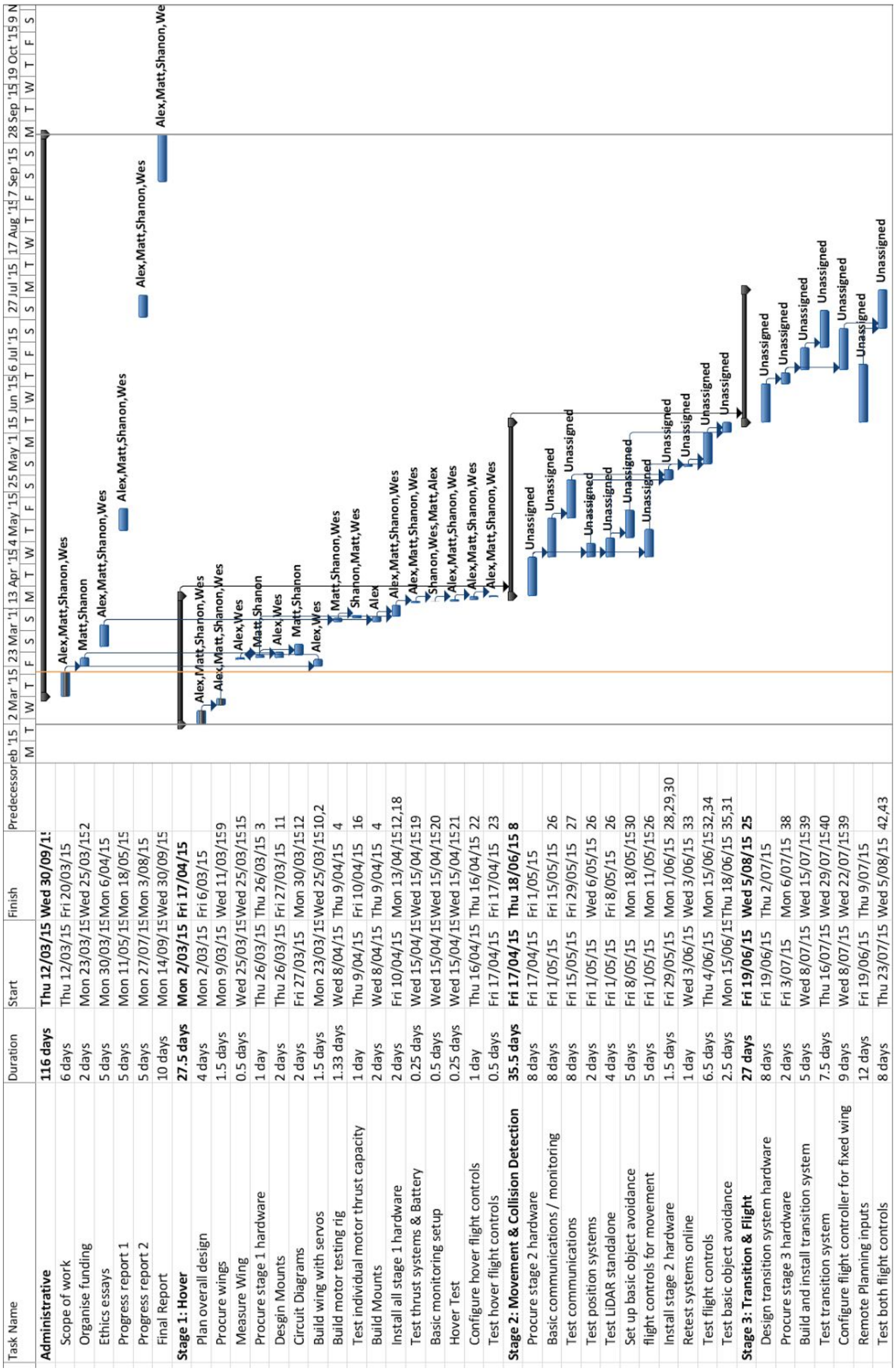
STAGE 3: Transition & Flight			
Task	**Items Required**	**Description**	**Estimated time**
Design transition system hardware		Design transition system to change from multicopter to fixed wing	16 Hours
Procure stage 3 hardware		Research, select and purchase hardware related to reaching Stage 3 goals.	4 hours
Build and install transition system	Heavy Servo	Build and install designed transition system	10 hours
	Gearing system		
	Base		
Test transition system		Test, troubleshoot and prove that the transition system works in the given conditions	15 hours
Configure flight controller for fixed wing	Flight Control #2	Configure flight controller to maintain stable flight and transition	18 hours
Remote Planning inputs		Create different states and orders the UAV can be given externally	24 hours

Test both flight controls		Test, troubleshoot and prove we can fly as a hybrid, and transition well.	16 hours

STAGE 4: Planning & Computer Vision			
Task	**Items Required**	**Description**	**Estimated time**
Stage 4 tasks depend on the details of the challenge which are expect to be released in the near future.			

5. Duration of tasks

NOTE: The following schedule is based on each of the 4 team members working a minimum of 2 hours a day on Mon, Wed, Thu, Fri (8 hours / week each).



Task Name	Duration	Start	Finish	Predecessor
Administrative	**116 days**	**Thu 12/03/15**	**Wed 30/09/1**	
Scope of work	6 days	Thu 12/03/15	Fri 20/03/15	
Organise funding	2 days	Mon 23/03/15	Wed 25/03/15	2
Ethics essays	5 days	Mon 30/03/15	Mon 6/04/15	
Progress report 1	5 days	Mon 11/05/15	Mon 18/05/15	
Progress report 2	5 days	Mon 27/07/15	Mon 3/08/15	
Final Report	10 days	Mon 14/09/15	Wed 30/09/15	
Stage 1: Hover	**27.5 days**	**Mon 2/03/15**	**Fri 17/04/15**	
Plan overall design	4 days	Mon 2/03/15	Fri 6/03/15	
Procure wings	1.5 days	Mon 9/03/15	Wed 11/03/15	9
Measure Wing	0.5 days	Wed 25/03/15	Wed 25/03/15	15
Procure stage 1 hardware	1 day	Thu 26/03/15	Thu 26/03/15	3
Desgin Mounts	2 days	Thu 26/03/15	Fri 27/03/15	11
Circuit Diagrams	2 days	Fri 27/03/15	Mon 30/03/15	12
Build wing with servos	1.5 days	Mon 23/03/15	Wed 25/03/15	10,2
Build motor testing rig	1.33 days	Wed 8/04/15	Thu 9/04/15	4
Test individual motor thrust capacity	1 day	Thu 9/04/15	Fri 10/04/15	16
Build Mounts	2 days	Wed 8/04/15	Thu 9/04/15	4
Install all stage 1 hardware	2 days	Fri 10/04/15	Mon 13/04/15	12,18
Test thrust systems & Battery	0.25 days	Wed 15/04/15	Wed 15/04/15	19
Basic monitoring setup	0.5 days	Wed 15/04/15	Wed 15/04/15	20
Hover Test	0.25 days	Wed 15/04/15	Wed 15/04/15	21
Configure hover flight controls	1 day	Thu 16/04/15	Thu 16/04/15	22
Test hover flight controls	0.5 days	Fri 17/04/15	Fri 17/04/15	23
Stage 2: Movement & Collision Detection	**35.5 days**	**Fri 17/04/15**	**Thu 18/06/15**	**8**
Procure stage 2 hardware	8 days	Fri 17/04/15	Fri 1/05/15	
Basic communications / monitoring	8 days	Fri 1/05/15	Fri 15/05/15	26
Test communications	8 days	Fri 15/05/15	Fri 29/05/15	27
Test position systems	2 days	Fri 1/05/15	Wed 6/05/15	26
Test LiDAR standalone	4 days	Fri 1/05/15	Fri 8/05/15	26
Set up basic object avoidance	5 days	Fri 8/05/15	Mon 18/05/15	30
flight controls for movement	5 days	Fri 1/05/15	Mon 11/05/15	26
Install stage 2 hardware	1.5 days	Fri 29/05/15	Mon 1/06/15	28,29,30
Retest systems online	1 day	Wed 3/06/15	Wed 3/06/15	33
Test flight controls	6.5 days	Thu 4/06/15	Mon 15/06/15	32,34
Test basic object avoidance	2.5 days	Mon 15/06/15	Thu 18/06/15	35,31
Stage 3: Transition & Flight	**27 days**	**Fri 19/06/15**	**Wed 5/08/15**	**25**
Design transition system hardware	8 days	Fri 19/06/15	Thu 2/07/15	
Procure stage 3 hardware	2 days	Fri 3/07/15	Mon 6/07/15	38
Build and install transition system	5 days	Wed 8/07/15	Wed 15/07/15	39
Test transition system	7.5 days	Thu 16/07/15	Wed 29/07/15	40
Configure flight controller for fixed wing	9 days	Wed 8/07/15	Wed 22/07/15	39
Remote Planning inputs	12 days	Fri 19/06/15	Thu 9/07/15	
Test both flight controls	8 days	Thu 23/07/15	Wed 5/08/15	42,43

6. End point

Successful completion of Stage 4 above will result in:

- Design and development of a functional UAV
- Proven UAV flight range of over 20km
- Development of mid-air collision avoidance mechanisms
- Ability to provide a Bill of Materials for UAV development
- Novel hybrid flight mechanism
- Development of a prototype entrant for the Outback Challenge 2016
- A sound foundation for the continuation of UAV development in 2016

7. Appendix

7.1. Analysis of 2014 Model

Research suggests that a Y6 configuration, with 3 sets of 2 coaxial motors (2 pairs at the front, 1 at the rear), is the best setup for this task, as shown on the FireFLY6 in Figure 1 above. However, due to its weight and construction, this is not possible on the 2014 model. Instead, it will have to be fitted in quadrotor formation, with four motors and rotors attached under the fuselage (Figure 2). To hover the aircraft (22kg) with 4 (3.5kg) motors equipped with 10cm propellers, in air with density 1.168 kg/m^3 would require

$$P = v_{air} \times F_{thrust} = \sqrt{F_{thrust}/(\rho_{air}\pi r_{prop}^2)} \times F_{thrust} = F_{thrust}^{(3/2)}/\sqrt{\rho_{air}\pi r_{prop}^2} = (mg)^{(3/2)}/\sqrt{N_{motors}^3 \rho_{air}\pi r_{prop}^2} = 2500W$$

This requirement is per motor, under ideal conditions (100% motor and rotor efficiency). A cost effective motor for this is the Turnigy RotoMax, which cost $90 on sale at HobbyKing, bringing the cost of motors alone to $360. However, more significant is that 75A is required per motor (combined current of 300A) along with a 10 cell (3.7V) battery. The most cost effective battery at HobbyKing capable of this is the Turnigy Nano-Tech 4400mah Lipo Pack at $81. With 4 motors at 75 Amps, this battery will last approximately

$$t_{batt} = 3600 \times 4400/(4 \times 75) = 53s$$

Assuming a single take-off/landing manoeuvre can takes at most t_{batt}, we would require four batteries to complete the challenge, costing $324 in total, with total extra weight of 4.8kg. However, we would require even more power to complete the fixed-wing, 10km flight to find Joe.

In addition to cost, the modifications necessary to make such a plane would be significantly harder, as the supports would need to hold a lot more weight, and the plane itself is made of wood and not foam. The design of the craft (as both a quadcopter and fixed wing aircraft) on the larger craft would have a significant amount of aerodynamic drag and be less efficient.

Last year's project was designed with a separate scope in mind, with a very different challenge where VTOL was not required It was also designed as a multi-platform craft, where the fixed wing was designed to manufacture, something we certainly don't plan on doing this year with the wing. With consideration to all of the above points, we believe that purchasing a foam model airframe to build off is the best course of action for the 2015 development.

7.2. Platform Selection

This section summarises the analysis and decision making process for our decision to purchase a foam plane model, instead of a ready made aircraft.

7.2.1. Part Costs

Item:	X8 (Maneuverability):	WEIGHT(g):	COST:	X8 (Endurance):	WEIGHT(g):	COST:
Wing	Skywalker X8 Wing	880	281	Skywalker X8 Wing	880	281
Battery	2 X Multistar 4s 10000MaH	1600	180	2 X Multistar 4s 10000MaH	1600	180
Motor	6 X Turnigy Multistar 2508-700Kv	612	252	6 X Turnigy Multistar 4225-610Kv	516	234
Prop	6 x 12x6 Carbon Fibre MR	114	39	6 x 12x6 Carbon Fibre MR	114	39
ESC	6 x 30 A ESC	150	40	6 x 20 A ESC	102	40
Flight Controls	2 x pixhawk	76	522	2 x pixhawk	76	522
Servos	2 X 2.5 kg Standard Servo	80	16	2 X 2.5 kg Standard Servo	80	16
RC TX/RX	Can Program Ours		0	Can Program Ours		0
BEC	CC BEC	29	29	CC BEC	29	29
Network TX/RX?	Undecided	50		Undecided	50	
Computer	Raspberry Pi 2	45	46	Raspberry Pi 2	45	46
Camera	HD Webcam (no plastic)	15	100	HD Webcam (no plastic)	15	100
LIDAR	Lidar Lite	17	120	Lidar Lite	17	120
PPM Controller	3DR PPM	10	20	3DR PPM	10	20
Airspeed Sensor	3DR Sensor	20	72	3DR Sensor	20	72
Accelerometer	included with Pixhawk	N/A		included with Pixhawk	N/A	
GPS+Compass	3DR GPS + compass	30	105	3DR GPS + compass	30	105
Mounts	3D Printed	50	N/A	3D Printed	50	N/A
Poles	Carbon Fibre Poles	150	50	Carbon Fibre Poles	150	50
Hybrid system:		50			50	
Gears	3D Printed	50	N/A	3D Printed	50	N/A
Heavy Servo	9kg Gear Servo	51	35	9kg Gear Servo	50	35
Supports	3D Printed	50	N/A	3D Printed	50	N/A
Lipo Charger	Owned	N/A	N/A	Owned	N/A	N/A
Misc	Wires, Payload	50	N/A	Wires, Payload	50	N/A
Total		**4179**	**1907**		**4034**	**1889**

Item:	Firefly 6 Combo	WEIGHT(g):	COST:	Firefly Standard	WEIGHT(g):	COST:
Wing	Firefly 6 Pro Combo	4100	2635	FireFly 6	2700	656
Battery	2 X Multistar 3s 5200MaH		82	2 X Multistar 3s 4000MaH		64
Motor	included			Power Pack		525
Prop	included			included		
ESC	included			included		
Flight Controls	included			2 x pixhawk		522
Servos	included			included		
RC TX/RX	included			Spektrum Dx7s		328
BEC	included			CC BEC		29

Network TX/RX?	Undecided			Undecided		
Computer	Raspberry Pi 2		46	Raspberry Pi 2		46
Camera	HD Webcam		100	HD Webcam		100
LIDAR	Ultrasonic Sensor 3m range		120	Ultrasonic Sensor 3m range		120
PPM Controller	included			3DR PPM Controller		26
Airspeed Sensor	included			3DR Sensor		72
Accelerometer	included			included with Pixhawk		
GPS+Compass	included			3DR GPS + compass	30	105
Mounts	included			included		
Poles	included			included		
Hybrid system:						
Gears	included			included		
Heavy Servo	included			included		
Supports	included			included		
Lipo Charger	Owned			Owned		
Misc	Payload			Payload		
Total		**4100**	**2983**		**2730**	**2593**

7.2.2. Platform Attributes

	X8 (Maneuverability)	X8 (Endurance)	Firefly 6 Combo	Firefly Standard
Flight Time (mins)	25.00	31.00	30.00	15.00
Hover Time (mins)	17.80	19.60	15.00	7.00
Movement Speed -Fixed Wing (km/h)	70.00	63.00	54.00	65.00
Movement Speed - Hover (km/h)	28.00	5.00	5.00	20.00
Fixed wing only flight range (km)	29.17	32.55	27.00	16.25
Flight Range (with hover) (km)	20.97	24.25	18.00	4.64
Payload (g) (structure limit only)	321.00	466.00	400.00	1,770.00

7.2.3. Performance Metrics

Empirical evaluation for selecting platform for 2015 Capstone project.

Performance Metric	**Max/Desired Characteristics**	**Evaluation Function**
Aircraft cost	$c_{max} = \$most\ expensive\ option$	$e_1 = 1 - c/c_{max}$
Flight range	$r_{des} = 20km$	$e_2 = r/r_{des}$
Aircraft weight	$m_{max} = weight\ of\ heaviest\ option$	$e_3 = 1 - m/m_{max}$
Hover velocity (Depends on wind speed)	$v_{des} = ?$	$e_4 = v/v_{des}$
Payload	$m_{payload} = m_{max} - m_{aircraft}$	$m_{payload} >= 500g:\ e_5 = 1$ $m_{payload} < 500g: e_5 = m_{payload}/500$
Overall	$e_{total} = \sum_i w_i e_i$	

Performance Metric	Weighting	X8 (Maneuverability):	X8 (Endurance)	Firefly 6 Combo	Firefly Standard
Aircraft Cost	0.25	0.37	0.37	0.00	0.13
Flight range	0.40	1.05	1.21	0.90	0.23
Max Aircraft weight	0.10	0.00	0.03	0.02	0.35
Hover Manoeuvrability	0.20	1.00	0.18	0.18	0.71
Payload	0.05	0.64	0.93	0.80	1.00
Total Performance Metric		**0.74**	**0.66**	**0.44**	**0.35**