UNIVERSITY OF STRATHCLYDE

Flight & Spaceflight 2

BMFA Weight Challenge Report

Report

For

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April 2016

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1 ABSTRACT

Contained within this report is the design process used during the development of an aircraft entering the BMFA Heavy Lift Competition. The project was completed over a 24 week interval. The report details the theory used when designing the aircraft, such as the design philosophy, the manufacturing processes that were used when constructing the aircraft and discusses changes that were made to the aircraft design as the manufacturing process continued.

During the manufacturing process it was realised that the original fuselage design was impractical. As a result, the fuselage was redesigned to be square and the payload containers were purchased instead of constructed. The Selig 1210 was selected as the most suitable aerofoil for the aircraft, and a flat plate was chosen as the tailplane aerofoil. This simplified the manufacturing process.

The final weight of the aircraft is 1.8kg which is far heavier than the original estimate of 1.4kg. Therefore the payload/empty aircraft ratio is 2.25 at max payload. The stability of the aircraft was originally estimated to be approximately 14% for both maximum and minimum payloads, however due to inaccurate weight estimates the final static margins were 15% and 23% respectively. The stall speed increased from 9.4m/s to 9.8m/s and the maximum velocity is approximated as 21.8m/s.

2 INDEX

3 NOMENCLATURE

C_{Lmax}	Max Wing Lift Coefficient
C_{mo}	Wing Pitching Moment
S	Wing Area
Λ	Wing Sweep
λ	Wing Taper
$\bar{\nabla}_A$	Aileron Volume Coefficient
c_T	Tailplane Chord Length
b_T	Tailplane Span
$\bar{\nabla}_{fwd}$	Tail Volume Coefficient Min Payload
$\bar{\nabla}_{aft}$	Tail Volume Coefficient Max Payload
$S_{\eta\ rig^\circ}$	Tailplane Setting Angle relative to HDF
HFD	Horizontal Duse Datum line
$\eta_{f\ cg\ min}$	Max Payload, Min C_L, Elevator Angle
$\eta_{f\ cg\ max}$	Max Payload, Max C_L, Elevator Angle
$\eta_{r\ cg\ min}$	Min Payload, Min C_L, Elevator Angle
$\eta_{r\ cg\ max}$	Min Payload, Max C_L, Elevator Angle
K_s	Static Margin
C_{DO}	Parasite Drag Coefficient
k	Induced Drag Factor
$a_{1T\ 3D}$	3D Tailplane Lift Curve Slope

4 INTRODUCTION

The objective of this project was to build an aircraft that has to be designed to adhere to BMFA Weight Challenge specifications[1]. The main aim was to design and manufacture an aircraft which can carry up to 4kg of liquid payload, and to reach the highest possible payload/ weight ratio. This process was iterative, and it was acknowledged that planning to work to a strict time schedule was important in achieving the aims set out.

As stated by the specifications, the aircraft must complete one circuit whilst carrying a liquid payload of 0kg, 2kg and 4kg. Furthermore, a 150mm Polystyrene ball contained in a fairing had to be included in the design and was required to be at least 0.4m away from the centre of the motor. The theory used when designing the aircraft will be presented in the report. The results from investigations and calculations executed will also be discussed in detail.

The report will close with the conclusion and recommendations gathered from the results.

5 DESIGN PHILOSOPHY

During the early stages of the design process, the aircraft take off parameters were considered to be the most important. This focus was quickly shifted so that the in-flight stability and control of the aircraft became the primary factor of concern instead. This is reflected in the core design of the aircraft, which was designed with consistent stability in mind.

The design concept was to store the payload in the fuselage. Originally, the payload was to be shared across four cylindrical containers, 0.17m in diameter and 0.04m thick. However, as discussed later in the report, the fuselage and payload containers had to be altered due to manufacturing restrictions. Thus the fuselage was made of white foam and bottles were used as payload containers instead. Removing the aft cone allows easy access to the bottles, this means that they can be inserted/ removed from the aft of the aircraft. Changing the order that the full and empty bottles are loaded allows the aircraft centre of gravity to be manipulated to suit the aircrafts' needs. The polystyrene ball that had to be incorporated into the design, is located near the aft of the fuselage. This can be inserted into its correct position using the same opening as the cylinders.

6 PROPULSION

The propeller for the aircraft was chosen in accordance to the BMFA Heavy Lift challenge specifications, this meant that the aircraft was required to produce the greatest thrust possible. To achieve this, the propeller with the largest diameter was required. Thus the 12x6e propeller was chosen for the aircraft.

Originally, a theoretical approach was used to derivate the thrust curve. This was done using the software Moto-Calc. [10] However, the thrust curve produced by Moto-Calc suggested that the aircraft would have significantly less thrust than was initially anticipated. Empirical data was then considered, from which it was found that the propeller would produce the required thrust. It was decided that the empirical data provided a more accurate representation of the actual thrust curve. The thrust curve produced by the empirical data is provided in Figure 1.

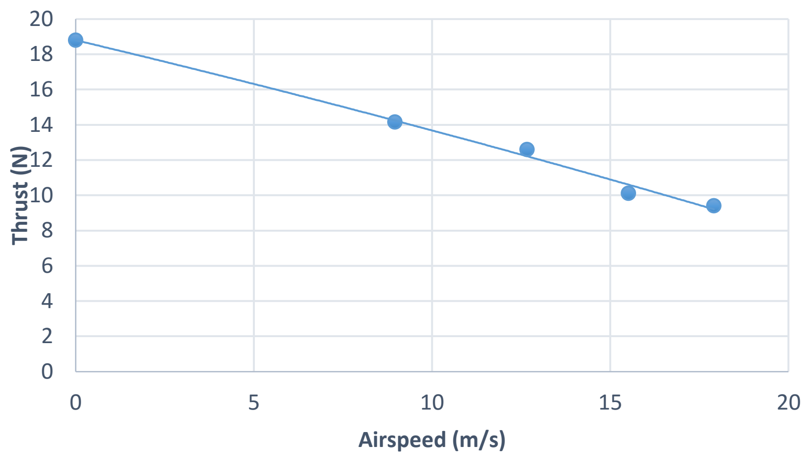

Figure 1

7 FUSELAGE STRUCTURE

The fuselage was originally to be made from a cylindrical carbon fibre skeleton with a cone on either end to streamline the structure. The skeletal design was to consist of eight thin rods running the length of the fuselage with eight carbon fibre rings spread along the length holding these together. The rods were to attach into a circular piece of birch plywood at either end, thus keeping the structure in shape. However due to the cost associated with this, it was decided that the fuselage required redesigning.

The material was changed to white foam as it is extremely lightweight and much more affordable, and the body was wrapped in a fibreglass coating to increase the aircraft durability and strength. The original design also used a cylindrical shaped body, however it was more convenient and spacious for the water containers when the fuselage had a rectangular body. A laser printer was used to cut out sections of light ply creating a template for shaping the various sections of white foam.

In order to create the whole fuselage body, six sections of 200mm x 200mm x 100mm and one 200mm x 200mm x 50mm section of white foam were cut using the hot wire in the laboratory. The templates were made from light ply and so would not be damaged from the hot wire, thus by following the outline of the templates the foam sections were cut to the desired shape. Epoxy was used to the glue each section together thus the fuselage body was complete. The whole body was then sanded to make it more streamlined and evenly shaped.

The front sheet of plywood was attached to the foam using epoxy which was also attached to the box which houses the motor. This means that forces will be transferred throughout the entire fuselage. The box was stored within the forward cone. The Aft cone was also cut out from the white foam using the hot wire cutter, and was glued together using epoxy as well.

The undercarriage was attached to a light play running the length of the fuselage to spread the load. This allowed the forces to be distributed throughout the fuselage thus minimising the risk of damage. However, a thicker plate may need to be added in the future to ensure that the bolts are secure.

Once the undercarriage was mounted to the fuselage, the body was coated in fibreglass. Eze Kote was used to harden the foam before the coating took place. Afterwards, a brush was used to evenly coat the resin onto the fibreglass. The process was also repeated for the front and after cone to increase their strength and durability properties as well.

The original design for the nose box was to have the box protruding half way or 75mm through the nose cone. The other 75mm would be made up by a prop shaft extension. It was found that this was very inefficient because the prop shaft extension is very difficult to make and can easily go wrong. For this reason it was chosen to make the box the full length of the cone so the motor could be fitted at the very front of the plane. This meant that cooling was easier and the prop shaft was not required. The original box was manufactured entirely from birch ply. This made the box heavy and expensive. It was decided to only manufacture the front plate, where the motor was mounted, from birch ply. The rest was manufactured from lite ply, hence saving a lot of weight and money thus made the design more efficient.

8 WING SECTION

Several factors were considered as key elements when choosing a wing section for the aircraft. A high C_{Lmax} would decrease the stall speed and the take-off speed, thus allowing the aircraft to take-off at lower speeds. This is desirable due to the expected large mass of the aircraft. The effect of the Reynold's number must also be considered, as the presence of a hysteresis loop would cause significant problems for the aircraft, such as tip stall. A soft stall would also be preferred as it allows for easier stall recovery. After the consideration of these factors, the FX-74-CL5-140 was chosen as it had the high C_{Lmax} that is required to carry the large payload.[2] However, this was quickly replaced following the discovery that the section suffered from a hysteresis loop at the chosen Reynolds number (200,000). As a result, the Selig 1210 was chosen as the new wing section.[3] This section also had a suitable C_{Lmax} (1.8), and did not suffer from a hysteresis loop at the chosen Reynold's number. Furthermore, the Selig 1210 demonstrated a softer stall than the FX-74-CL5-140.

The S1210 has a relatively large wing pitching moment, C_{mo}=-0.25.[4] Therefore a large tailplane volume was required for the aircraft. The wing span and root chord were originally set to be 1.5m and the 0.2m respectively therefore the wing area, S=0.3m^2 and the wing aspect ratio was 7.5. After some preliminary calculations, it was realised that the wing area was too small and did not provide the aircraft with enough lift to take-off within the desired distance. To account for this, the wing area was doubled. This increased the overall drag of the aircraft, however the benefits of the increased wing area, outweighed the adverse effects of the higher induced drag. The new wing span and chord length were set as 2m and 0.3m respectively, thus the new wing area was 0.6m^2 and the new aspect ratio was 6.67. These values were offered the best compromise between the amount of lift and amount of drag generated.
Wing sweep and taper were set as Λ=0° and λ=1. As the design was to be kept as simple as possible.

The wing rigging angle was optimised for the take-off run. Originally, a 0° rigging angle was chosen, this was quickly discarded due to the lack of lift generation. A 6° wing rigging angle relative to the HFD was chosen, as it offered the best compromise between the lift coefficient for the take-off run and the induced drag created. To set the wing at this angle, three mounts were made – two in front of the wing and one at the trailing edge along the centre of the wing. The centre of the D-box section of the wing contains two wooden rods, 8mm in diameter and each are glued to two light plywood squares, going through one which is attached to the front of the spars, and glued in place to the second as the back plate. These rods would be slotted into the two front wing mounts while the aft mount would anchor the wing down to the fuselage. The aft mount was manufactured with light plywood and the rear of the wing would sit, while the forward wing mounts were made with 3mm light plywood. The leading face of the Fwd wing mount was slanted to reduce drag, and is attached with epoxy.

The aileron volume coefficient was to be $0.03 < \bar{\nabla}_A < 0.044$.[5] Thus, a coefficient of 0.042 was eventually selected.

8.1 Wing Design

After selecting the Selig 1210 as the desired wing section. Work began on designing the different components to make up the wing. First the rib design and dimensions were calculated using compufoil. The software helped in the placement of the spars as well as the d-box and size of the lightening holes and the overall number of ribs required was also calculated. Fourteen ribs were used for the 2m wing span. Then the length and width of the ailerons are 600mm in length and 60mm wide. Shorter ribs were designed to accommodate for this part of the wing. Two spars 5mm by 5mm were inserted through the ribs. A web was connected between the spars throughout the length of the wing to increase strength. Mounts were also designed to hold the servos that controlled the ailerons.

8.2 Wing Materials

The wing was mainly constructed from balsa as it is lightweight, and was glued together using white wood glue. Each part of the wing and its associated material can be seen in Table 1 below

Part	Material
Rib	Balsa 5mm
Leading edge	Balsa 12mm
Leading edge sheet	Balsa 1.5mm
Trailing edge	Balsa 5mm
Aileron	Balsa 3mm
Servos mount	Light ply 3mm

Table 1

8.3 Wing Manufacture

The ribs were created by importing the design from Creo into a laser cutting machine. This method was used to achieve the smoothest and cleanest possible cut as it was important to keep the wing section shape. Originally there were two different types of rib designed. One was the full rib and the other was the shortened rib that allowed room for the ailerons. Unfortunately due to the shape of the Selig 1210 in that it was very thin at the trailing edge it was not possible to laser cut to such a high precession without burning the balsa. Therefore only the shorter rib was laser cut, and the trailing edge was sanded manually.

Two extra ribs were cut to make the ribs at either end of the wing twice as thick and they were glued together using white wood glue. After all the ribs were in place at the correct distance apart, the top and bottom spars were glued using white glue as well. Once the glue had dried, work began on attaching the webbing. This was done by cutting balsa rectangles that spanned the distance between each rib and the height between both spars. These parts were also glued on using white glue.

In the design, the leading edge was 12mm thick, however the thickest available balsa was 9mm – thus it was it required at least 2 sheets of balsa. First a 9mm sheet of balsa was glued to the front of the ribs using white glue. Once this had dried it was sanded down to follow the shape of the leading edge and a 1.5mm thin sheet of balsa the span of the wing was added to the top and bottom of the ribs. This sheet went from the 9mm leading edge to the spars. To complete the leading edge, another 9mm thick balsa sheet was glued to the front. This was then sanded down to the final leading edge shape using a foam cut out of the leading edge as a sanding block.

Next the ailerons were made using a sheet of balsa 3mm thick and sanded down to the Selig 1210 shape. The ribs parallel to the aileron were notched on to a 10mm wide bar of balsa to allow for the aileron to be hinged to it. The trailing edge was also made using a sheet of balsa which was sanded down and then notched in to the remaining central ribs.

Two holes were drilled in the centre of the leading edge and two small wooden rods were pushed through until they met the spar webbing to allow the wing to be mounted to the fuselage. Also two small holes were drilled in the trailing edge to add a second mounting point for the wing. The servos mounts were then attached to the webbing and then connected to the ailerons. Finally the wing was wrapped using Solar film.

9 TAILPLANE SECTION

A flat plate was chosen to be the tailplane section.[6] The wing span and chord length were originally set to be 0.15m and 0.25m respectively. However, the large wing pitching moment required a larger tailplane area for compensation. As a result, the chord and span were increased so that c_T=0.23m and b_T=0.4m.

The volume coefficients were calculated as: $\bar{V}_{fwd}$=0.45 and $\bar{V}_{aft}$=0.45. This was expected, as the centre of gravity moves an insignificant amount between maximum and minimum payload.

The tail setting angle of the tailplane was determined using the pitching moment equation in conjunction with the wing and tailplane 3D lift-curves.[7] Using the equation gave η_{Tmax}=-0.47/rad (-27°), and so the tailplane setting angle relative to the HFD was -11°. This suggested that the tailplane was hopelessly inefficient, consequently the tail volume coefficient, $\bar{V}$ was increased. This was achieved by increasing the span of the tailplane to 0.63m which resulted in the new tail volume coefficients, $\bar{V}_{fwd}$=0.543 and $\bar{V}_{aft}$=0.525. Using the new volume coefficients within the pitching moment equation gave $\eta_{\mathrm{Tmax}} = -0.269/\mathrm{rad}\ (-15°)$, thus the new tailplane setting angle relative to the HFD became $S_{\eta\ rig°}$=1°. The tailplane was now significantly more efficient.

$\eta_{T\ min}$ was calculated to be $\eta_{T\ min}$=-0.311/rad. This allowed the maximum and minimum elevator angles for maximum and minimum payload to be calculated. The results are summarised in Table 2.

Tailplane Elevator Angles	
$\eta_{f\ cg\ min}$	$-1.6°$
$\eta_{f\ cg\ max}$	0.6°
$\eta_{r\ cg\ min}$	$-7.1°$
$\eta_{r\ cg\ max}$	3.0°

Table 2: Tail-plane Elevator Angles

This data is shown graphically, in

Figure 2

From the data gathered, the tailplane lift coefficient to rotate was calculated to be $S_{CL\ Tr}$=-0.5.[8] The elevator angle that is required in order for the aircraft to rotate, relative of the tail-plane setting angle and the downwash produced from the main wing. For the aircraft, the elevator angle was calculated to be 2.2°.[9]

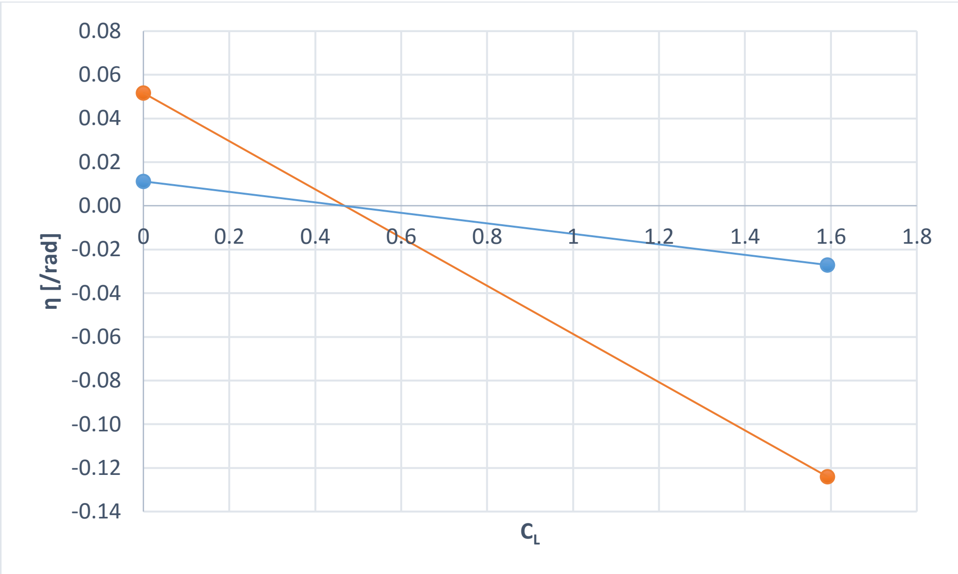

Figure 2 Maximum and Minimum Elevator Angles

9.1 Tailplane Materials

The tailplane was to be attached to the aircraft by a carbon fibre rod. Carbon fibre was chosen to ensure that the tail plane was strong enough to withstand the expected lift forces acting on it. Balsa wood was used as the main material for the tailplane, elevator, fin and rudder.

9.2 Tail plane Design & Manufacture

On manufacturing, the tailplane was changed significantly in order to make it light weight and cost effective. This meant the tailplane was constructed using smaller sections of balsa and joining them together in order to get the desired dimensions needed for the technical data to be correct. The sections were glued together using an epoxy resin in order to keep the structure both strong and durable.

Small prism shapes made from balsa were attached to the sides of the fin firmly in order to keep it perpendicular to the tail plane. To connect the elevator to the tail plane and the rudder to the fin, small equal sized slits were put in the balsa. Small tabs were then added as they securely join the sections together and allow the elevator and rudder to move in pitch and yaw as required. The size of the fin and rudder were also increased as it did not affect any of the aerodynamics or flight stability, as the increase in weight was marginal.

A bracket made of balsa and plywood was used as the connection between the tailplane and the connecting rod. Stronger wood was used since it has to support the weight of the tail plane. This was glued with epoxy resin to the underside of the tail plane and had a hollow section in the centre for the connecting rod.

9.3 Tailplane Servos

The two tailplane servos are each mounted on a doubled-up plywood piece in a c-shape, similar to the wing servo mounts, in front of the tailplane on the bracket support.

9.4 Tailboom

The original design was to have the tailboom connected into the back plywood plate of the fuselage. However, there would have been a considerable amount of stress on the plywood plate and a permanently fixed tailboom would be difficult to achieve, especially when the aft cone is required to be removable. Upon further consideration, a tailboom mount was created that would be fixed on top of the aft end of the fuselage. The tailboom mount was made of blue foam and shaped using a hot wire cutter. Additionally, an 8mm hole was drilled into the tailboom mount where the tailboom, a carbon fibre rod, would fit into. Epoxy glue was used to permanently fix the rod in the mount.

10 UNDERCARRIAGE

The undercarriage is an important part of an aircraft as it essential during takeoff and landing. To ensure the strength of the undercarriage is suitable, it was constructed using fibre-glass strips with a strong epoxy-resin glue.

As the height of the aircraft wing was already predetermined, a pre-made undercarriage was not available and so it was manufactured using a custom mould. Strips of the fibre-glass had to be carefully marked out and cut using fabric scissors and placed within the mould and then evenly coated in the epoxy-resin. This was repeated several times to increase the strength of the undercarriage. After testing, it was found that the strength of the undercarriage was suitable for take-off and landing.

11 ASSEMBLING THE AIRCRAFT

Once all of the major aircraft sections were complete, the aircraft was assembled so that the measurements could be completed to evaluate the most up to date Centre of Gravity. This also prepared the aircraft for the installation of components such as the servos or battery, and the associated wiring, as discussed in 12 Component Installation and Wiring.

Most of the aircraft sections were brought together using glue such as epoxy. For example, the tailplane was attached to the Tail Boom and hence the Tail Rod Connector using epoxy resin, and the undercarriage plate was attached to the base of the fuselage by using epoxy resin as well. The wing was successfully mounted using the connectors that had been glued onto the top of the fuselage using epoxy, this had to be removed and reattached 4cm aft later, due to stability issues, however the wing still mounted without issue after the fix. Finally, the Fwd and Aft cones were attached by using strips of velcro at each side.

12 COMPONENT INSTALLATION AND WIRING

Once the bulk of the Aircraft was assembled, the servos for the Rudder, Aileron and the Elevators were installed. The control surfaces were attached to the control rod over the hinge line, to ensure that they would operate as efficiently as possible. The rudder and elevator servos were attached using light ply wood, which was glued to the leading edge of the tailplane. Once the servos rudder and aileron servos were in place, they were tested using the supplied controller and receiver, this allowed the elevators to be zeroed at the correct orientation thus ensuring that the servos (and hence the control surfaces) would rotate as desired.

The wiring in the wing was completed before the wing was wrapped, as the wires from each servo was to be routed to the centre of the wing, and out of an gap that was left to allow the wires to reach the fuselage and hence the receiver. The elevator servos were also attached using light ply wood using the same ‘C-shaped’ design that the other servos used. The servos were installed in opposing orientations to allow the elevators to rotate in opposing directions when the aircraft is banking during flight. Similarly to rudder and aileron servos, once the installation was complete the newly installed elevator servos were tested and then zeroed to ensure that the control surfaces were reaching their maximum and minimum rotation angles as desired. Once the calibration was complete the rest of the wing was wrapped as discussed in “Wing Section”.

Other components that required installation included the Battery, Motor, Speed Controller and the Receiver. It was suggested that the motor be attached facing forwards, by mounting motor backplate to the front of the Fwd Nose Cone, this would mean that the motor would be left outside and exposed. However, as the project progressed it was decided that the motor should be rear mounted instead, by attaching the backplate to the inside of the Fwd Nose Cone – this is possible as the motor itself is reversible. The benefits from this include that there will be less drag generated by having an exposed component on the front of the aircraft, furthermore, moving the battery did not affect aircraft stability meaning that there will be little repercussions with this change. The original design had the controller on the floor of the Fwd Nose Box, however it was found that the wires would not bend enough to fit the speed controller easily this way, thus the speed controller was mounted to the roof of the Fwd Nose Cone using velcro. This gave the wires enough room to bend, room to avoid contacting the rotating motor, while still allowing air to reach the controller from the hole which was cut from the Fwd Nose Cone as discussed in “Fuselage Structure”. The receiver was stored near the aft of the Fwd Nose Box, as this had easy access to all of the incoming cables from the servos as well as the battery, speed controller, etc. Unfortunately, the battery was larger than originally anticipated, and would not fit in the Fwd Nose Box as originally intended. Instead the battery was located at the front of the fuselage, attached by velcro to the front panel connecting the Fwd Nose Cone and the Fuselage. Due to the shape of the front panel, the wires from the battery were able to be routed straight into the Fwd Nose Box in the same way that the servo wiring was routed.

Unfortunately changing the locations of weights such as these changed the Centre of Gravity, and thus greatly affected the stability of the aircraft. As stated in “Stability and control” the wings were moved aft approximately 4cm to resolve the stability issues. This had no adverse effect on the preinstalled wiring for the Elevator servos, as the wires already had a generous amount of slack.

Once the receiver was secured into position, the wires that had been routed through the fuselage were secured in place as well, so that they will not be damaged as payload is added or removed from the fuselage. To do this, the wires were bundled together using cable ties, and attached to the roof of the fuselage using more velcro. The wires themselves were routed through a space between the bottles carrying the payload. As the Aft Nose Cone is attached to the main fuselage using velcro, the wires were able to be fed through the small gap that is created by the layer of velcro between the cone and fuselage, thus it was not necessary to drill any extra holes to route wires from the tailplane into the fuselage.

13 STABILITY AND CONTROL

Great care was taken with the positioning of the payload containers as they were crucial for the aircraft centre of gravity, and hence aircraft stability. The undercarriage was positioned about the centre of gravity, to minimise the impact on overall aircraft stability.

Initially, two payload containers of equal mass were located at both sides of the 150 mm polystyrene ball as it was believed that this would yield a favourable centre of gravity and neutral point. However, this configuration provided a low static margin, K_s<5%, and the neutral point did not lie within the 25% to 45% wing chord range. Thus the payload containers were re-arranged.

As stated earlier, the 150mm ball had to be placed 0.4m from the centre of the motor. Hence the payload containers were located in front of the ball. This made the aircraft slightly more stable, however the static margin was still not within the desired range. To obtain results closer to the target static margin, the position of other masses were considered; such as the motor, tailplane, and wings. It was observed that many of the masses could not be moved a significant amount from their original positions. For example, components that were inside the nose cone such as the speed controller and receiver could not be altered. On the other hand, compacting the masses throughout the aircraft would allow the static margins to increase.[15]

This was finally achieved by decreasing the length of the tailboom from 0.25m to 0.2m, as this brought the mass of the tailboom and the tailplane closer to the centre of the aircraft. This gave static margins of approximately 14% for both maximum and minimum payload and so the configuration of the aircraft was stable. However, as stated in “Tailplane Section”, the tailplane angle was changed drastically. This impacted the values, $a_{1T\,3D}$ and $\overline{\nabla}$, and so the stability and control values were re-evaluated.

However, as more parts of the aircraft were manufactured it became clear that the initial mass estimates were very inaccurate, thus the initial design calculations did not offer a suitable representation of the aircraft's stability. Inserting the final masses into the stability and control model, yielded a static margin <10%. Thus masses would need to be moved around to find a stable configuration. A stable configuration was ultimately found by moving the positioning of the wing 0.04m aft. Following this change, the maximum and minimum neutral points aligned with one another. The final results for the Stability and Control of the aircraft are summarised in **Error! Reference source not found.** and Table *5*, where the datum was taken from the propeller tip.

Table 3 stability and control

Stability & Control	**Zero Payload**	**Max Payload**
Non dim location of CoG aft of datum	1.360	1.434
Location of tailplane aero centre aft of cg	0.675m	0.652m
Location of Neutral Point aft of datum	0.476m	0.475m
Location of Neutral Point aft of wing leading edge	0.116m	0.115m
Non dimensional location of Neutral Point aft of datum	1.588	1.583
Non dimensional location of Neutral Point aft of wing leading edge	0.388	0.383

Table 4 static margin new

Static Margin	
Static Margin (Min Payload)	0.231
Static Margin (Max Payload)	0.150

These results satisfy the conditions which were set, as the minimum and maximum payload static margins were between the 10% and 25%. The maximum and minimum payload neutral points were calculated to be 40% of the wing chord, thus they were within their estimated range of 25% to 45%.

14 PERFORMANCE ESTIMATION

The drag and the thrust of the aircraft were calculated before the performance of the aircraft could be estimated. The thrust created by the aircraft was obtained through the experimental data discussed in "Propulsion"

The original design of the aircraft had no Aft body, and so an undesirable pressure drag was generated. Adding an Aft body increased the overall mass of the aircraft, however the benefits from the decrease in drag vastly outweighed the disadvantage of the extra weight.

The drag induced by the aircraft was calculated using an estimated airspeed and the surface areas of the aircraft which were exposed to air-flow. To calculate the parasite drag coefficient, the skin-friction drag, profile drag,[16] form drag and interference drags were calculated and totalled.[17] From this, the parasite drag coefficient was found to be C_{DO}=0.034, and so the induced drag factor was calculated as k=0.060.

Performance Estimations	
V stall (max payload)	9.8 m/s
V max (max payload)	21.8 m/s
Max rate of climb (max payload)	1.809 m/s
Endurance	3.3 min
Distance to clear 11m (max payload)	34.4 m
Distance to takeoff (max payload)	39.2 m

Table 5

As the value for V_{stall} is relatively low, the take-off speed is low. This was beneficial for the aircraft as it has a large mass when carrying maximum payload. Thus the aircraft adhered to BMFA rules, as it could take off within the required 61m.

By comparing V_{STALL}=9.8m/s and V_{MAX}=21.8m/s, it was shown that the aircraft has a suitable flight envelope. Once the aircraft travels 34.4m horizontally, it can clear 11m vertically. The range of the aircraft was calculated to be 0.6miles. The endurance of the aircraft was calculated to be 3.3 min. This is satisfactory for the purpose of this aircraft.

Overall, the aim of the competition was to have the greatest payload/empty aircraft mass ratio. The final weight of the aircraft was measured to be approximately 1.8kg, which is much larger than anticipated. Thus the payload/ empty aircraft mass ratio of the aircraft was calculated as 2.25.

15 CONCLUSIONS

The final aircraft design adhered to the rules established by the BMFA Heavy Lift Challenge Document. It was calculated that the aircraft could carry up 6 kg of payload and still complete a successful take off run; therefore the aircraft will successfully take off when carrying its 4 kg of liquid payload. Splitting the payload across four bottles proved beneficial, as the centre of gravity and static margins became easier to manipulate to suit the aircraft's needs.

The final design adhered to the design philosophy that was originally set out, thus the aims and objectives were met. The distance to take off is approximated to be 39m and the take-off speed is 9.8m/s. The overall mass of the aircraft was measured to be approximately 1.8 kg, and the payload/ empty aircraft weight ratio was calculated to be 2.25.

16 REFERENCES

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3. Summary of Low-Speed Airfoil Data Volume 1– Michael S. Selig, James J. Guglielmo, Andy P. Broeren and Philippe Giguere – S1210– pg. 170 – 174

4. Summary of Low-Speed Airfoil Data Volume 1– Michael S. Selig, James J. Guglielmo, Andy P. Broeren and Philippe Giguere – Table 3.1: Airfoils Sorted by Category– pg. 24

5. bmfa stability and control surface sizing – Matthew Stickland – pg.2

6. Aerofoils at Low Speeds – Michael S. Selig – Flat Plate – pg.229-230

7. notes on calculation of tail setting and elevator range – Matthew Stickland

8. BMFA tailplane sizing to rotate – Alistair Sutherland

9. Aero-Design 1 Notes – Matthew Stickland – pg.71

10. Moto-Calc Available at http://www.motocalc.com/

11. EPP Foam Density - RC Foam Foam Weights Available at http://www.rcfoam.com/depron-and-epp-foam-density-a-depron_epp_density.html

12. S1210 – Max Thickness Available at http://airfoiltools.com/airfoil/details?airfoil=s1210-il

13. Wing Production - Alasdair Sutherland - pg. 2

14. Sectors and Segments of Circles Available at http://www.regentsprep.org/regents/math/geometry/gp16/circlesectors.htm

15. BMFA Stability & Control Calculation – Matthew Stickland

16. ESDU 79019b

17. ESDU 79015b

18. Wetted Area Calculations Available at http://adg.stanford.edu/aa241/drag/wettedarea.html

19. Spherical Segment Available at http://mathworld.wolfram.com/SphericalSegment.html

20. Surface Area of an Ellipsoid Available at http://www.web-formulas.com/Math_Formulas/Geometry_Surface_of_Ellipsoid.aspx

17 APPENDICES

Wing

Span: 2m

Chord: 0.3m

Wing Area Attached to Fuselage: 0.54m^2

Area Exposed to Air[18]: 0.54 x 2 x 1.2 = 1.296m^2

Fuselage

Area of Gap for 'Sensor' Ball: $\pi\left(\frac{D}{2}\right)^2 = \pi\left(\frac{0.075}{2}\right)^2 = 0.004418\text{m}^2$

Polystyrene Ball Area Exposed (60^o) [19]: $2\pi \times \left(\frac{D}{2}\right) \times h = 2\pi \times \left(\frac{0.15}{2}\right) \times 0.075 = 0.035343\text{m}^2$

Nose Area Exposed[20]: p≈1.6075 (Knud Thomsen), a=0.15m, b=0.2m, c=0.2m, therefore

$$4\pi\left(\frac{a^pb^p+a^pc^p+b^pc^p}{3}\right)^{\frac{1}{p}} = 0.210695\text{m}^2$$

Constant Section Area Exposed:

$$\left(2\pi \times \frac{D}{2} \times h\right) - 'Gap' + 'Ball' + \pi\left(\left(\frac{D}{2}\right)^2 - \pi \times \left(\frac{d}{2}\right)^2\right) = 0.470669m^2$$