Group W15

16351: Flight & Spaceflight 2 Report

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1. Abstract

This report explains the detailed design process and manufacture of the BMFA aircraft of Group W15. It discusses the approach the team took to tackle the open ended design challenge and how each part of the aircraft was carefully considered. This report discusses the optimisation and performances of the designed aircraft. The aircraft is designed to have a payload to mass ratio of 2.27. This is achieved by lifting the maximum payload of 4kg and reducing the weight of the aircraft through careful design. The aircraft uses a Selig 1223 wing profile with a chord of 0.3m and span of 2.07m. The fuselage carries the payload and optical sensor. The aircraft has a static margin of 27.4% and a take-off distance of 42.3m.

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2. Nomenclature

Description	Symbol
Reynolds Number	Re
Tail volume coefficient	$\bar{V}$
Change of downwash with lift	$\frac{d\varepsilon}{d\alpha}$
3D Tailplane lift curve slope	$a_{1T\text{-}3D}$
3D Wing lift curve slope	$a_{1W\text{-}3D}$
Wingspan	b
Centre of gravity	C.O.G.
Battery capacity	C_B
Endurance	E
Non-dimensional location of centre of gravity	h_g
Non-dimensional location of neutral point	h_n
Non-dimensional location of centre of lift	h_α
Current drawn by motor	I
Distance between aerodynamic centres of wing and tailfin	L_f
Distance between aerodynamic centres of wing and tailplane	L_t
Mass of components	m
Mean aerodynamic chord	mac
Range	R
Non-dimensional static margin	S.M.
Wetted area of tailfin	S_f
Wetted area of tailplane	S_t
Wetted area of wing	S_w
Cruise Velocity	V_C
Distance from datum	x

3. Introduction

This report will describe in detail the design and manufacture of the Group W15 aircraft entry to the BMFA competition. The competition is a weight lifting challenge and requires teams to build a lightweight aircraft capable of carrying a heavy load [1]. The points scoring process for the performance of the aircraft is a ratio of the maximum payload to the empty mass of the aircraft. The payload is water and has a mass of up to 4kg. The aircraft will fly with no payload before it is increased to its maximum. The aircraft is required to complete a take-off in the required distance (61m), a circuit, and a landing. The primary aspect that has influenced the design was the aircraft's payload to weight ratio.

This report will explore the process undertaken by Group W15 to design and manufacture an aircraft which meets the rules, and is optimised for maximum performance.

The competition also scores points for the design of the aircraft. This includes a technical document, technical drawings and a presentation on the design.

The competition is in York on the 11th and 12th of June and a variety of international teams compete. Group W15 are from the University of Strathclyde and consist of third year students studying Aero-Mechanical Engineering. This project is part of the curriculum and teaches the students about aircraft design. The students are given 12 weeks to design the aircraft and 12 weeks to manufacture it. This report will cover what the team have done within the entirety of the design and manufacture stages.

4. Design Philosophy

The challenge involves designing and building a light weight remote controlled aircraft capable of flying with a heavy payload. The power source is electric and the payload is up to **4kg** of water. After looking at the results from previous years it was decided that to maximise this ratio, the aircraft needed to be designed with the core philosophy of carrying the maximum payload. Alongside this, the design philosophy was focussed around minimising the take-off distance and creating a design which was easy to manufacture.

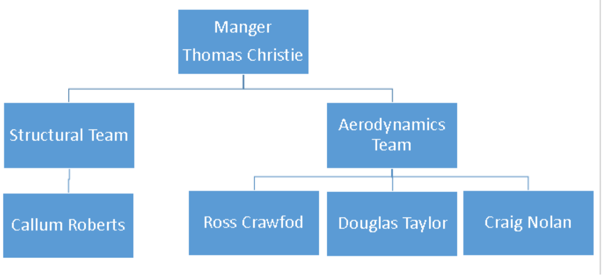

Figure 1: Team Structure

To maximise the efficiency of the design process, the management structure of Group W15 can be seen above in **Figure 1**. Thomas Christie was also a member of the Structural Team.

This team structure allowed for effective aerodynamic design of the aircraft whilst the structural integrity of the design was considered simultaneously. Communication between the teams was key to an integrated design process.

From research into previous designs for the BMFA competition, and speaking to people with experience with RC aircraft design, it was clear to the team that the two most important factors to consider were the location of the centre of gravity and the distance to take-off. These factors are key to making sure the aircraft can compete at the competition and maintain stable flight.

The layout of the aircraft was subject to the rules of the competition. A simulated optical sensor (represented by a polystyrene ball) must also be fitted in to the aircraft to meet the required rules. The sensor had to be 150mm in diameter and located inside the fuselage of the aircraft. The centre of the sensor had to be located within 50mm of the horizontal fuse datum and more than 400mm away from the propeller disk centre. It must also be closed off from the elements and detachable. No external elements of the airframe can be within a 60^{o} conical view vertically down from the sphere.

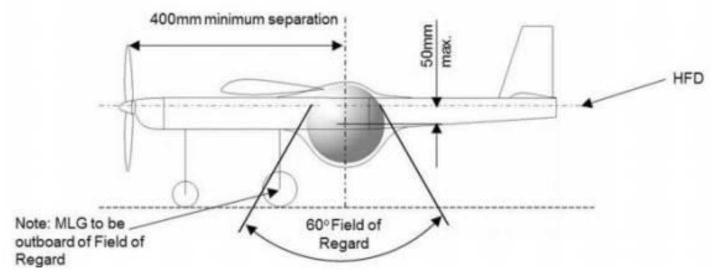

Figure 2: Graphical representation of rules regarding simulated optical sensor

The aircraft was designed to lift the maximum 4kg payload. From this the lift required was calculated and the wing designed to achieve this while still remaining as light as possible. The geometry of the fuselage was dictated by the size and shape of the spherical sensor and payload while following the design philosophy to be as simple as possible for manufacturing. The aerodynamic aspects were designed to give the aircraft the required performance, stability and control.

The aircraft was designed using a Microsoft Excel spreadsheet so that if a value was changed, all the dependant values changed accordingly. The CAD software (Autodesk Inventor) allowed for a quick visual representation of the design that assisted in choosing the geometry and layout of the aircraft. The procedure implemented allowed for a structured process in regards to the design of the aircraft, which made trying multiple iterations to perform optimisation possible.

5. Design

5.1. Payload

The payload was designed to be within the fuselage as this would be the easiest method for manufacture. The payload was positioned over the centre of gravity so that the static margin would remain the same with zero and maximum payload. The wings are designed to be easily detachable from the fuselage in order to access the payload from above the aircraft.

5.2. Propeller Choice

For the heavy lift challenge an important factor that was considered was the static thrust that the propeller generated. The propeller had to achieve a high enough static thrust in order to take-off in the required distance with maximum payload. Three propellers were considered in the initial concept designs of the aircraft. These were as follows (dimensions in inches, length x pitch): 12x6, 12x8 or 11x5.5.

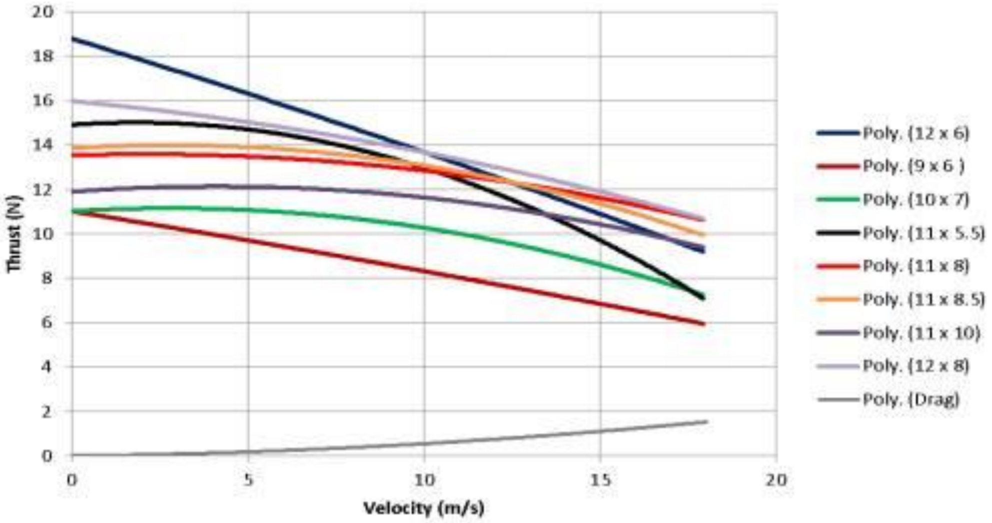

Figure 3: Thrust curves for various propellers

These were initially selected because of the high static thrust characteristics that they possess. Experimental data was taken for these propellers, along with others, and compared on a graph of thrust against velocity.

It was necessary to determine the maximum velocity achievable by the propeller in order to ensure our flight envelope was large enough. For this stage the 11 x 5.5 propeller was ruled out due to the low thrust produced at high speeds, as this would create a much lower maximum velocity than required. The 12 x 8 propeller gave a higher maximum velocity than the 12 x 6 but it gave a lower static thrust. Since the aircraft was optimised for take-off, a higher static thrust is required and therefore the 12 x 6 propeller was selected. The maximum velocity was calculated to be **27 m/s** for the 12 x 6 propeller.

5.3. Wing Section

Many aerofoils were considered before choosing the final profile. Experimental data compiled by Selig, Donovan and Fraser in their report regarding aerofoils at low speeds was considered to allow for an appropriate wing profile to be chosen by comparing their maximum lift coefficients to angles of attack [2].The following characteristics were desired for the wing section:

- Maximum lift coefficient was of utmost importance for the plane
- Low drag was desired but of less importance than the lift coefficient
- A soft, predictable stall was ideal, although it was unlikely that a high angle of attack would be achieved during a typical flight

The final decision was that the Selig 1223, as seen below in **Figure 4**, would be the profile used for the wing design.

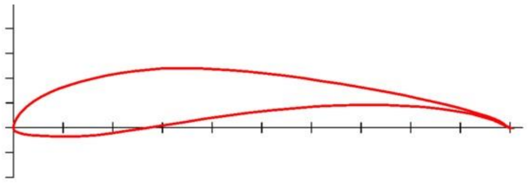

Figure 4: Selig 1223 Aerofoil Profile

This profile was chosen due to its high maximum 2D lift coefficient of **2.1**. This allows the aircraft to lift more weight compared to other profiles and allows a high payload to mass ratio. It was also noted that this profile had high drag and moment coefficient values, however these were not issues to our design.

5.4. Wing Aspect Ratio

With the values decided upon for both the wing span and chord, the wing's aspect ratio was found to be **6.9**. As the aspect ratio of a wing is increased, the total lift to drag ratio decreases. However, higher aspect ratio wings are more susceptible to greater bending stresses and thus may experience warping during flight that could affect the aircraft's stability. An aspect ratio of 6.9 is a good balance of these characteristics.

5.5. Tailplane Section

The tailplane profile that was chosen for the aircraft was the Flat Plate-PT (Fraser) with a span of **0.7m** and a chord of **0.25m**. The main factor that influenced this choice was the ease of manufacturing a flat wooden plate in comparison to any other standard aerofoil section. It had a maximum lift coefficient of **0.7** which was an acceptable value for the design, as it is bigger than the required coefficient to rotate during take-off.

5.6. Tail Volume Coefficient

The tail volume coefficient is a ratio of tailplane geometries to wing geometries. This non-dimensional parameter is a very important specification in terms of stability. Typically, this value is usually around 0.5, however, values as high as 0.9 are acceptable so long as the plane remains stable. In the case of the aircraft being designed the value was found to be **0.74**.

5.7. Static Stability

The centre of gravity of the plane is a point on the aircraft where it will be perfectly balanced, at zero velocity. For the centre of gravity to be calculated the mass and distance from the datum of each component was known. The datum was the leading edge of the wing. The distance from the datum to the centre of gravity was calculated using **equation 1**:

$$C.O.G = \frac{\sum m \times x}{\sum m} \tag{1}$$

The neutral point is the name given to the aerodynamic centre of a plane where the moments produced by the wing and the tailplane balance. The non-dimensional neutral point was calculated using the **equation 2**[3]:

$$h_n = h_\alpha + \bar{V} \times \frac{a_{1T-3D}}{a_{1W-3D}} \times (1 - \frac{d\varepsilon}{d\alpha}) \tag{2}$$

The static margin determines how the plane will fly and how stable it is in the air. It is given by the difference between the neutral point and the centre of gravity of the plane. The non-dimensional static margin is given by this same difference but is instead referred to the mean aerodynamic chord of the wing, and was determined using **equation 3**[4]:

$$S.M. = h_n - h_g \tag{3}$$

The static margin for the final design was **27.4%**.

5.8. Fuselage and Wing

The fuselage design adhered to the simplistic design philosophy. The fuselage was a cuboid with a tapered nose and rear. The volume of the payload along with all of the other components required to fit inside the plane were calculated in order to determine the minimum volume the fuselage had to be. The wing is attached using bolts which can be easily removed to access the fuselage to alter the payload.

5.9. Spar Design

To lift the maximum payload of 4kg, stated in the 'Design Philosophy', it was necessary to have a spar strong enough to withstand the combination of the weight of the fuselage and the lift generated during flight. The spar should be able to take the maximum loads during flight without failure. The ribs in the wing were built into the design, primarily, to act as templates to form the shape of the Selig-1223 profile and not to distribute any of the load.

5.10. Shear and Bending Stresses

To calculate the stresses in the spar four main assumptions were made before analysis. The spar was modelled as a cantilever beam. The maximum velocity was used to calculate the largest lift force applied to the wing and this force was assumed to be a distributed load. A safety factor of 1.5 was used and a maximum loading factor of 3g.

Using the four assumptions and the 'The Engineering theory of Bending' the stress at the root was calculated to be **671 N mm^{-2}.** This value was calculated for a carbon fibre tube with an outer diameter of **8mm** and an inner diameter of **6mm** [6]. Since carbon fibre has an ultimate tensile strength of **750 N mm^{-2}**, this was deemed an acceptable value. An important factor in the wing design was to keep the weight as low as possible so carbon fibre fitted well with this philosophy.

5.11. Tailboom

The tailboom was analysed in the same way as the spar using the 'Engineering Theory of Bending'. This allowed the dimensions required to withstand the loads generated by the tailplane to be calculated. The tailboom was modelled as a cantilever beam, fixed at the fuselage end. The tailboom was designed to be a carbon-fibre tube with the same dimensions as the spar to reduce complications in ordering the carbon and to give the tailboom more rigidity.

6. Optimisation

6.1. Wing

The dimensions of the wing were initially estimated so that it was possible to perform some preliminary calculations. When the optimisation stage was reached, the aim was to reduce the dimensions of the wing as much as possible. The minimum lift required was the lift produced at take-off velocity. Using Excel, a spreadsheet was created to calculate the size of wing that generated this required lift. Many different wing configurations were considered and the wing dimensions were decided to be a span of **2.07m** and a chord of **0.3m**.

6.2. Take-Off

As mentioned in the 'Design Philosophy', the aircraft design was optimised for take-off. Optimising in this case meant designing the aircraft to take off in the minimum distance possible. Using the selected wingspan and chord, a graph was created plotting wing lift coefficient against take-off distance. From this, the optimal wing lift coefficient and, therefore, the optimum wing rigging angle for the shortest take-off distance were determined. The optimum wing rigging angle of the chord was **-4°** relative to the horizontal fuse datum.

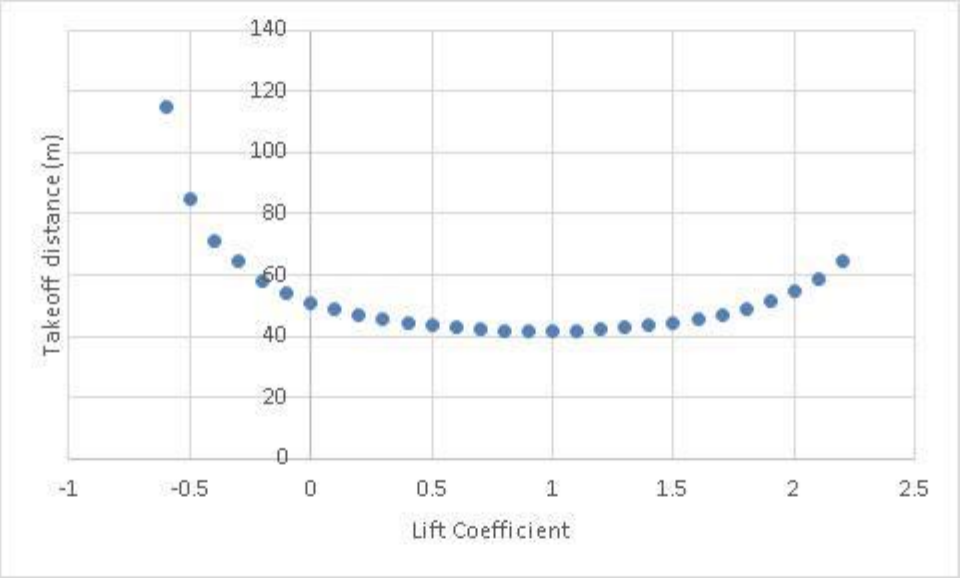

Figure 5: lift coefficient vs take-off distance

6.3. Elevator Angles to Trim

The initial design of the tailplane had very small trim elevator angles **(1.0° and -5.0°)**. Therefore, the design of the tailplane had to change in order to increase the angles to trim. This was done by decreasing the tailplane effectiveness from **4.5** to a sufficiently low number. The tailplane was then designed to have a chord length of **0.25m** and a thickness of **5mm**. The elevator was set to be **25%** of the tailplane chord as this compared closely with the design of many other aircrafts [7]. This gave an elevator chord length of **0.0625m**. The ratios between these three dimensions were used to determine the tail effectiveness using experimental data. The value obtained for tail effectiveness was **3.9** and this gave acceptable elevator angles to trim **(1.4° and -7.0°).**

6.4. Fuselage Shape

The aircraft was initially decided to have a cylindrical fuselage because it gave low drag coefficients. However, for manufacturing purposes the design was changed to a rectangular shape for ease of construction. In addition to this the nose surface area was reduced to a smaller area to decrease the losses in the static thrust generated by the propeller. This development is seen in **Figures 6, 7 and 8**.

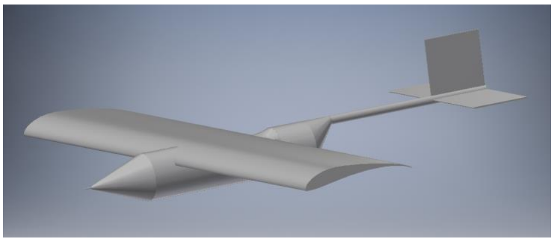

Figure 6: Initial Concept Design

Figure 7: Initial Detailed Design

Figure 8: Final Design after Optimisation

7. Performance

7.1. Endurance

The endurance of the aircraft is dependent upon the capacity of the battery and the current drawn whilst operating with the selected propeller. The endurance was calculated by dividing the capacity of the battery by the current. The current drawn by the motor is **32A** and the battery capacity is quoted as **2200mAh**. These values gave a total endurance of **4 minutes and 7.5 seconds**.

7.2. Range

The range of the aircraft is the distance it can travel without running out of charge. This was calculated by multiplying the value for endurance by the cruising speed, giving a range of just above **5.3km**.

7.3. Take-Off

For a lift coefficient of **0.7** and a wing rigging angle of **-4º**, the take-off distance was calculated to be **42.3m** when carrying maximum payload.

7.4. Climb out

Using the JAR 23 rules of aviation, the climb out of an aircraft is defined as the distance to clear 35 feet (11m) altitude. The distance is taken from after aircraft achieves flight. The calculation for climb out was given in the aero design notes provided [8]. For this calculation, maximum payload was assumed. The climb out distance was determined to be **32.4m**.

7.5. Maximum Rate of Climb

The rate of climb depends upon 3 main factors; thrust generated by the propeller, drag experienced by the aircraft and the aircraft's airspeed. A polynomial equation was used to plot a graph of the rate of climb against the airspeed to determine a value for the maximum rate of climb at maximum payload which was determined to be **2.59ms^{-1}**.

7.6. Payload to Mass Ratio

As mentioned in the ‘Introduction’, the aim of the challenge is to maximise the payload to mass ratio. The best way to do this is to maximise the weight of the payload and keep the empty mass of the plane as low as possible. The design methodology that was undertaken was that the maximum payload of 4kg would be carried and through the design the empty mass of the plane would be reduced as much as possible. The empty mass of the plane came to **1.765kg** giving a payload to mass ratio of **2.27.**

8. Manufacturing

8.1. Materials

The aircraft is predominantly constructed from various types and thicknesses of wood. The wood used in this design included balsa, lite-ply and birch-ply. The wood used for each part depended on what was required from it; for example, balsa wood is light and was used in aspects of the plane that do not require a lot of strength. Other materials that were used within our design included Solar-film lite, polystyrene foam and carbon fibre rods. All the materials listed were ordered in advance with the lab technician and the order was recorded in a cost sheet to keep track of the £75 budget available.

8.2. Tools

The tools used were dependent on the type of wood being cut. If the material was balsa wood, the scalpel was used. This allowed for quick and precise cuts when used in conjunction with the safety rules. When used for cutting the Solar Film Lite, the scalpel blade was replaced to provide a neater cut. When either lite ply or birch wood was required to be cut, one or multiple of the various saws were used depending on the type of cut necessary. If a long section of cutting was required, the band saw was used. The fret saw was used to cut large holes in the material, for example the weight saving holes present in the fuselage.

Hand files provided an easy means of removing small amounts of material and shaping sections of the aircraft. They were also used to remove unwanted material in areas inaccessible by the saws. The hand files used ranged from small needle files of various shapes to larger wood files. The larger wood files were used for removing large volumes of material in the areas not accessible by the saws. The needle files were primarily required for final touches. Sandpaper was used in the same fashion as the files but provided a much smoother finish and allowed for a more precise removal.

The hot-wire cutter, which consisted of a small DC power supply and a thin high resistance wire, was used for easily cutting foam. It worked by passing a current thought the thin wire and therefore heating it to a temperature possible of slicing the foam with minimal effort.

8.3. Glue

The fast setting super glue “Zap-a-gap” was used and was useful on components that experienced relatively low stress and could be held in place manually whilst it quickly set. This made work quicker. Speed bond super glue was stronger but the glue took longer to dry than “Zap-a-Gap” therefore the parts had to be clamped in place. Epoxy resin similarly had to be clamped as it took the longest time to set. This was the strongest glue available and was used in high stress areas such as the fuselage.

8.4. Wrapping

Most of the aircraft’s surfaces had to be wrapped for aerodynamic benefits. In the case of the fuselage it was to cover weight saving holes and for the wing the wrapping created the aerofoil surface across the full wing. The method of skinning used was shrink wrapping using a material called Solar-film Lite; a very thin polypropylene film. Care was taken to make sure that the iron was not too hot at the tacking and bonding stage as it risked puncturing the material. Once the film had been attached to the outer surfaces of the aircraft, the iron temperature was raised from 80°C to 120°C and it was then hovered over the weight saving holes of the aircraft so that the material shrinks and tightens over this gap.

Wrapping around many corners with the same sheet was avoided where possible as each corner gave potential for the material to be stretched out of shape and for creases to form. It was important to avoid creases as these would cause drag. When two panels overlap it was important that the uppermost surface was facing away from the direction of airflow. This is to stop the air catching underneath an overlap and causing the skin to come away from the surface.

8.5. Laser Cutting

Parts of the design that were required to be accurately produced were cut using a laser-cutting machine. The machine was adjusted to cut different types of wood and many thickness variations. Computer aided drawings from the detailed design of the plane were converted to a drawing exchange file (DXF) in order for the laser cutter to recognize them.

8.6. Jigs

The jigs were thin steel rods that were longer than the wingspan of the plane. The purpose of the jigs were to hold all the ribs in place so that they can be glued exactly in the correct position. Two jigs were used to hold the ribs in place whilst they were being glued to the spar. Additional holes had to be cut in each rib to allow the jigs to pass through them.

8.7. Wing

The wing consisted of three different types of ribs; a half rib where the ailerons were to be connected, a full rib for the main shape of the wing and two stronger mounts that were used to fix the wing to the fuselage. All ribs were made of balsa wood and the mounts were made of lite ply wood. The components were all laser cut and their respective distances from the fuselage were measured and marked onto the jig. Spacers were also manufactured to ensure the ribs were separated correctly.

The spar was designed to be a hollow carbon rod. However, a long enough rod could not be purchased so instead three 1m rods were purchased. The spar was split into three parts, two 535mm sections either side of a 1m section. The remaining material was used for the tailboom. It was glued together using epoxy glue and ply wood inserts in the rod to add extra stiffness.

Once the spar was constructed, the ribs were then glued into position using the epoxy glue. Balsa wood spacers were used along the leading edge of the wing to provide extra strength and to maintain a smooth leading edge. Balsa wood was also added across the top of the wing between the ribs in order to add strength to the overall wing before it was wrapped, whilst also ensuring the skin followed the profile of the ribs. After the wing had been strengthened and the servos had been wired and placed in ply wood mounts between ribs, the wing was wrapped in the solar film mentioned previously. It was important to make sure that all the wing modifications were completed before wrapping as it would be very difficult to make any further changes after the wrap was completed.

8.8. Tailboom

The tailboom was made of two cut carbon rods and was made similarly to the spar with epoxy resin and wooden inserts. The tailboom was joined to the tailplane by inserting it into a block of balsa wood with an 8mm hole drilled into it and glueing together. This guaranteed a large contact area between the block and the tailboom. The block was made with a slope on the top to give the tailplane the setting angle of **-4.4 °** relative to HFD. The tailplane was glued to the block and secured using skewers. Mounts for the servos were made from 3mm lite ply and were also attached to the block. The tailboom was then inserted and glued into an 8mm hole in the back of the fuselage with further support inside.

8.9. Tailplane and Fin

The tailplane was assembled using strips of 5mm thick balsa wood. Balsa wood was selected for its lightweight properties. Since the tailplane should not experience high stresses, the relative weakness was deemed acceptable.

In order to further save weight the tailplane was manufactured by glueing strips of wood together instead of having a solid wooden block. Each strip had a width of 15mm and was cut to size using scalpels. A 45° join was made for the corners to create a larger contact area, therefore ensuring a better join when glueing.

The wood was glued using Speed Bond super glue, and clamped to ensure that there was no movement whilst the glue was setting.

After glueing the outer perimeter, ribs and triangular corner supports were added to strengthen the structure. The trailing edge of the tailplane was then filed down to a point. The fin was constructed in a similar way to that of the tailplane.

8.10. Elevator and rudder

The elevator and rudder were manufactured with 5mm thick pieces of balsa wood in a similar way to the tailplane and fin. The pieces were then filed down to create a teardrop profile in the direction of the airflow in order to reduce form drag. Hinges were glued into the leading edge of the elevator and fin and then inserted and glued into the trailing edge of the tailplane and fin respectively. With all hinge joints, cocktail sticks were inserted through both sides of the hinge as a fail-safe for the glue.

8.11. Undercarriage

The undercarriage was identified as a high stress area, and should therefore be made from strong materials to avoid failure during landing. With a total payload and plane mass of 5.7kg, the rear wheels' structure can experience very high stress, since these are the first to touch the ground. Therefore, this was made of fibreglass with a carbon fibre coating. The front wheel structure does not impact the ground with as great a force as the back wheels but will still experience high stress, and so this was made from steel with a coil incorporated within its structure for suspension.

A tricycle undercarriage arrangement was used consisting of two large wheels aft of the centre of gravity, and one smaller wheel in front of the centre of gravity. It was identified that the wheelbase should be as long as possible, to avoid the nose or tail hitting the ground on take-off or landing. The wheelbase should also be wide to give lateral stability, therefore ensuring the wings do not trim the ground during take-off or landing.

8.12. Fuselage

The fuselage was constructed from 3mm thick lite ply wood. It comprised of 4 sides, a rear plate and a plate that separated the fuselage from the contents of the nose. All of the components of the fuselage were laser cut to ensure maximum accuracy. The laser cutter was unable to penetrate the entire thickness of the wood and instead marked an outline. A fret saw was then used to cut the components out. The parts had slots and were assembled like a jigsaw, increasing the contact area for the glue. The sides of the fuselage were glued together using epoxy resin, as they would be subjected to large stresses. A setsquare was used to ensure that the sides were glued perpendicular to each other and clamps were used so that the structure held its shape.

8.13. Nose

The nose was manufactured in the same way as the fuselage and with the same thickness of wood. The top panel was hinged to the fuselage to allow access to the electrical components inside the nose. A foam shelf was constructed which was placed inside the nose to secure the electronic speed controller, receiver and battery. The shape of the shelf was cut using a hot wire cutter and a scalpel was used to remove extra foam to allow the components to sit within the shelf itself.

8.14. Motor Mount

The motor mount had to be built to be strong because of the vibrations from the motor. This part also withstands the entire driving force of the motor. It was therefore constructed using two 3mm thick birch plywood sections that were glued together. The shape of the mount was cut using a razor saw and four holes were drilled so that the motor could be bolted to the mount. The mount was then glued to nose using epoxy resin.

8.15. Difficulties

The holes that were drilled for the bolts in wing mounting were obscured by the leading edge of the wing. The leading edge was therefore sanded down to allow access to the mounting point for the wing at the roots. On top of this, the ribs situated at the tips of the wing were bending once the skin had been applied. To solve this, additional balsa wood braces were added between the two ribs at both ends of the wing. Furthermore, the skin between these ribs sagged considerably in the middle. To minimise this, cocktail skewers were inserted between the ribs at the top and bottom in order to keep the profile of the wing.

A problem encountered during manufacturing was that the aircraft was heavier than it was expected to be. Effort to improve this was done by removing sections from parts of the fuselage under low stress.

9. Conclusions

Throughout this class, Group W15 have considered many aspects of aircraft design and manufacture. The design is for the BMFA competition, the aircraft meets all the required rules and has been optimised to score well. Through a design process, the team have produced an aircraft to match the set targets and have followed the design philosophy. The final completed aircraft had an empty mass of **1.765kg** which gave it a payload to mass ratio of **2.27**. The take-off distance was **42.3m** which was significantly below the allowed distance of 61m and with a maximum rate of climb **of 2.59ms^{-1}**. The static margin was slightly greater than desired with a value of **27.4%.**

This project was part of the curriculum of 16351: Flight and Spaceflight 2 and 16309: Aero-Design 2 and has taught the students the importance of communication and teamwork whilst working through an engineering design project.

10. References

[1] - BMFA. (2015). *BMFA Payload Challenge 3*. Retrieved from BMFA: https://bmfa.org/DesktopModules/Bring2mind/DMX/Download.aspx?Command=Core_Download&EntryId=1461&language=en-GB&PortalId=0&TabId=1506

[2] - Selig, Donovan, & Fraser. (1989). Airfoils at Low Speeds. Virginia Beach: H. A. Stokely.

[3] - tripod, (2015). *Neutral-Point*. Retrieved from tripod.com: http://ciurpita.tripod.com/rc/notes/neutralPt.html

[4] - Raymer, D. P. (2012). In *Aircraft Design: A Conceptual Approach* (p. 607). Playa Del Rey, California, United States of America: American Institute of Aeronautics and Astronautics.

[5] - Raymer, D. P. (2012). In J. A. Schetz (Ed.), *Aircraft Design: A Conceptual Approach* (5th ed., pp. 542-574). Playa Del Ray, California, United States of America: American Institue of Aeronautics and Astronautics

[6] - Blackburn Model Supplies. (2016, April 21). *Stockists of radio controlled model airplanes. Specialists in balsa wood supplies*. Retrieved from Balsa Mart http://balsamart.co.uk/store/index.php?main_page=product_info&cPath=208_212&products_id=1276

[7] - Raymer, D. P. (2012). Aircraft Design: A Conceptual Approach. In J. A. Schetz (5th ed., p162). Playa Del Ray, California, United States of America: American Institute of Aeronautics and Astronautics.

[8] - Stickland, M. T. (2003). *Aero Design 1.* Glasgow: The University of Strathclyde.