Loughborough University Team 1 'Insert Cheesy Team Name'

BMFA Payload Challenge Team Report

Contents

1 Team Organisation & Schedule

1.1 Team Members

Rostislav- Responsible for the design of the main plane and creating CAD models of the aircraft

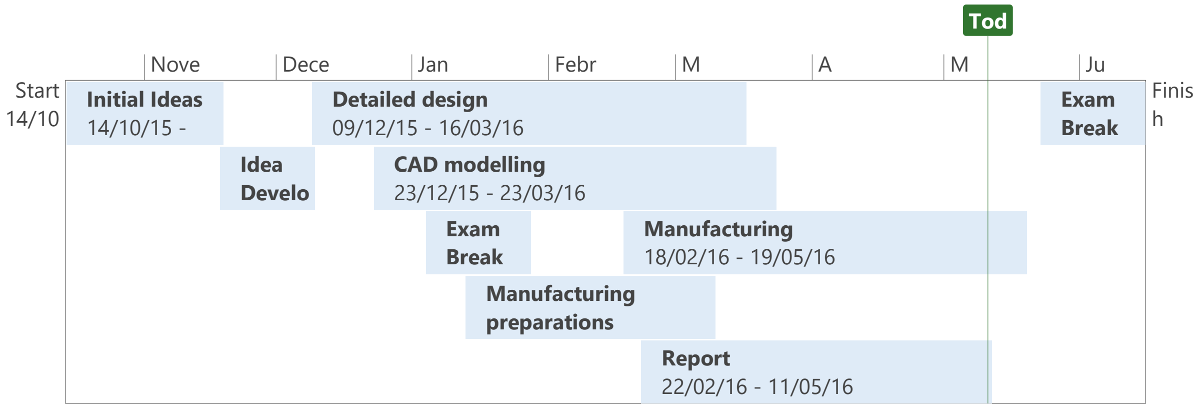
Edmund- Responsible for the design of the fuselage and empennage

Jordan, Jack & Rob- Team mentors

1.2 Schedule

Week Commencing	**Tasks**
12/10/2015	First meeting, meet the team and competition brief
19/10/2015	start with initial design ideas
26/10/2015	Compare ideas and discus pros and cons, develop ideas further
2/11/2015	Create a short list of different ideas, plan timescales for the project
9/11/2015	Select configuration and begin detailed concepts for specific parts
16/11/2015	Compare ideas, begin to set design for sections (wing & aerofoil)
23/11/2015	Split off into groups to develop individual sections
30/11/2015	Begin basic CAD modelling
7/12/2015	Feedback from individual sections and further discussions on interfacing and adjustments to design
14/12/2015	Discuss progress with CAD and begin detailed design of sections
Christmas Break	Individual work on detailed design & CAD
4/1/2016	Review of progress and evaluate the designs over Christmas
11/1/2016	Begin preparations for manufacture (ordering materials, designing any construction aids)
Exam Break	
1/2/2016	Slight adjustments of sections for interfacing
8/2/2016	Finalisations of sections
15/2/2016	Prepare CAD files for laser cutting and further preparation for manufacturing
22/2/2016	Begin manufacture of wing ribs
29/2/2016	Manufacturing of wing ribs on laser cutter
7/3/2016	Manufacturing
14/3/2016	Manufacturing & report tasking
Easter Break	Work on report
18/4/2016	Begin manufacturing of fuselage & report
25/4/2016	Manufacturing & report
2/5/2016	Begin manufacturing of empennage & payload containers
9/5/2016	Manufacturing & report finalisation
16/5/2016	Manufacturing
Exams!	
6/6/2016	Competition weekend
Exams!	

1.3 Gantt Diagram



2 Key Design Decisions

2.1 Mission Requirements

Main aim:

- The aircraft is to have as large a payload: Empty aircraft mass ratio.

Requirements:

1. Fixed wing aircraft (unlimited wingspan).
2. The aircraft must carry a spherical sensor with the following restrictions;
    - 150mm diameter sphere
    - Centreline of sphere between the fuselage centreline and 50mm below
    - Centre of sphere to be >400mm from propeller disk
    - The sphere must be detachable
    - Conical 60° field of view downwards from the sphere
3. The aircraft will be propelled by the specified battery and motor.
4. An isolator fuse must be fitted more than 100mm from the propeller angles more than 25° from the propeller arc and easily visible.

2.2 Main Configuration

During the design process, decisions are compromise by the performance, structural strength and the ease of manufacturing. For the competition we must try to push our design to be as light as possible, whilst at the same time be strong enough to cope with the loads associated with carrying a 4kg load and the manoeuvres of flight.

In order to achieve this, composite materials are widely used throughout as they provide very high strength to weight ratios.

A tail dragger is chosen as our gear configuration. This kind of gear configuration are often being used in small aircrafts and RC model planes. As the gears cannot be retracted, a tail dragger will reduce the parasite drag caused by the tail wheel. Moreover, a tail dragger will reduce damage to the aircraft if it undergoes a hard landing, hence make it structurally durable.

We have chosen a high wing dihedral as our wing configuration to provide good lateral stability.

2.3 Wing

A high wing was chosen as it is more stable in roll than a low wing and its joint does not pass through the fuselage reducing payload volume. It will reduce roll performance; however, this can be combated by the use of large ailerons. We chose to design a flat wing as it has no influence of roll stability of the aircraft and it is considerably easier to manufacture.

A fixed wing angle was chosen as it is simpler to implement and also gives good performance criteria. The alternative was for the design to have an adjustable wing setting to allow the performance of the wing to be optimised. However, an adjustable wing does not affect the maximum lift coefficient so the MTOW of the aircraft would still be the same.

For this reason, we decide to go for a fixed wing configuration as it would be much easier to assemble.

Tapering the wing reduces the wing bending moment and approximates an elliptical lift distribution more closely which is favourable in terms of induced drag reduction. Taper ratios lower than 0.6 are particularly prone to tip stalling therefore the chosen taper ratio was set above this value. Tapering about the quarter chord spar was elected as it allowed a single straight spar to be used, simplifying design and manufacture, as well as increasing span wise strength.

2.4 Aerofoil

High lift aerofoils offer increased payloads, shortened takeoff and landing distances and lowered stall speeds. Last year we performed analysis on several high lift, low Reynold's aerofoils from the Eppler, Wortmann and Selig families. They were ranked based on their maximum lift coefficient, minimum drag coefficient and pitching coefficient. The S1223 aerofoil was chosen as it has the highest lift coefficient. It also demonstrates a stable lift curve slope at the predicted operational number of approximately 175,000. A drawback of the S1223 is its large pitching coefficient which must be counteracted by the tail.

We found that this aerofoil performed extremely well as it produced lots of lift even at very low speeds. We decided to use it again in this year's competition as there was no need to change it because it performed so well. However, we did change the chord of the aerofoil as we believed that actually too much lift was produced by last year's wing. This was to increase the wing loading so hopefully the aircraft would exhibit better flying characteristics.

2.5 Control Surfaces

The control surfaces are in a conventional layout. Ailerons are located in the outer part of the wings. The rudder located at the horizontal stabilizer and the rudder at the fins. Flaps are not included in the control surfaces due to the additional weight and the lack of need due to a fairy long take-off and landing distance available. The aircraft is designed to be naturally stable, this to ease the pilot's workload while performing manoeuvres and also improving the chances of the aircraft making a successful flight without incident. Longitudinal stability is provided by having the centre of gravity located at between 25% and 30% along the chord of the main plane, this ensures that the aircraft will return to the trimmed attitude after a disturbance such as a gust. Lateral stability is provided by a high wing with a slight dihedral on the outer sections. The high wing and dihedral improves stability as when the aircraft is banked, sideslip occurs. In sideslip the dihedral causes the lower wing to present a larger area to the airflow and produce more lift. Furthermore a small sideways drag force is created due to airflow hitting the side of the fuselage. This causes the resultant aerodynamic force on the aircraft to move towards the lower wing. The resulting moment will roll the aircraft back to level. Having a high wing means the moment arm is greater meaning increased stability.

Although conventional aircraft would consider a high wing dihedral configuration to be too stable, since our aircraft is relatively light, severe weather conditions such as wind-shear might lead to a loss of control of the aircraft.

2.6 Landing Gear

As a team we opted for a tricycle landing gear arrangement in a tail dragger configuration. A benefit of this configuration is that the aircraft already sits at an angle of attack on the ground. This means that the aircraft won't have to rotate as much when it is taking off as the wing is already at incidence relative to the airflow. This configuration is also better for landing as the aircraft will be touching down on all three wheels. The fact that there will be three points of contact when touching down means that the landing forces will be distributed over the aircraft meaning that each wheel will experience less force. The wing will also be at roughly the correct attitude for landing when the main undercarriage and the tail wheel are level, making it easier to land the aircraft.

We also chose a fixed undercarriage that doesn't steer for our aircraft because it saves weight, as there is no need to add more components to allow actuation. Another benefit is that it preserves internal space of the aircraft which can be used for storing the payload instead of the landing gear. This configuration also reduces the complexity of the design as there are fewer components in the system. Fewer components increase the reliability of the landing gear as there are fewer things to fail or go wrong. As a result, the fixed landing gear will be cheaper and easier to manufacture compared to an actuating landing gear. There are aerodynamic forfeits to this design, but the other benefits far outweigh this problem.

2.7 Propulsion

The main limiting factor in the competition is the propulsion system which can dictate the maximum all up weight of any aircraft. The propulsion system assigned to this challenge consists of an E-flite Power 10 Brushless motor and an E-flite 40 Amp speed controller. The motor is rated for a maximum current of 42A at burst lasting no longer than 15 seconds to prevent overheating the motor. However, it is rated for a continuous current of 32A which is typically used at cruise for a maximum cargo load. It is intended to use just over 32A for cruise because the motor can be sustained at a safe operating temperature due to lots of cooling from the airflow as the motor is exposed at the front of the aircraft. For the purpose of heavy lift, a propeller was desired that could provide us with the maximum static thrust enabling fast acceleration during take-off. Ultimately, the APC 12x6E propeller was chosen as it has a very high static thrust and it can also sustain a constant temperature at a current load of 32A in static air. Full throttle bursts will be essential in accelerating to reduce take-off distance. The E-Flite Electronic Speed Controller (ESC) is designed for a maximum of 40A continuous current, but like many ESC's it is capable of providing higher current in bursts. This permits use of the APC 12x6E propeller for our motor which can reach a maximum of current draw of 42A at full throttle.

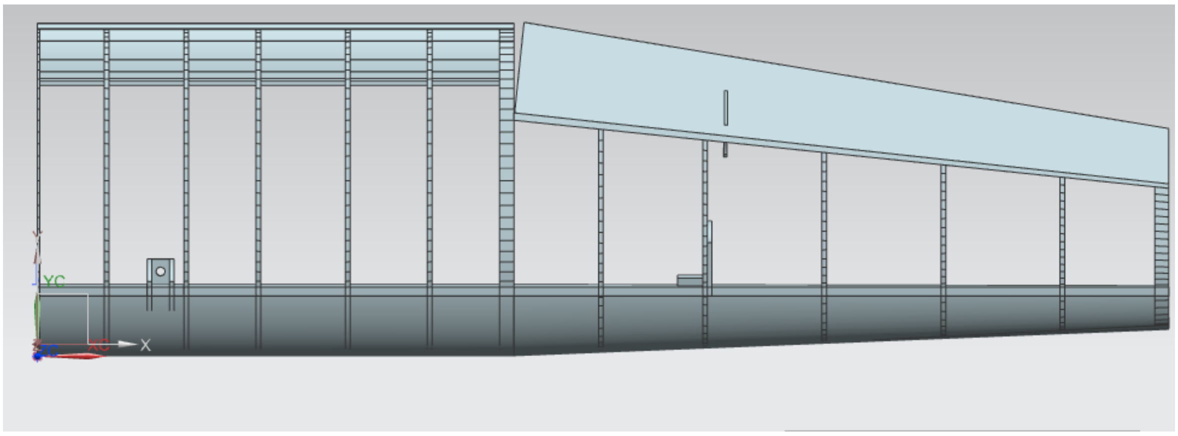
3 Structural Design

3.1 Wing

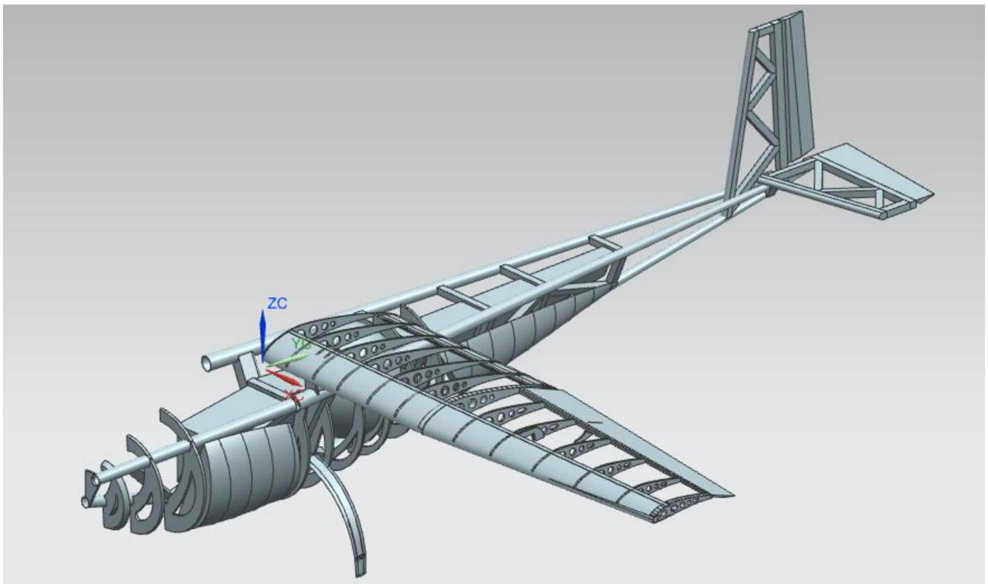
Attachment to Fuselage

There are many different methods to attach the wing to the fuselage. However, we wanted the attachment to be fairly solid and very strong. For this reason, we decided to use nylon bolts to secure the wing to the fuselage. These bolts would provide a sacrificial fixing and act as a safety device in the event of any accidents. In a scenario where the wing experiences extreme forces; the nylon bolts would shear and cause the wing to detach from the fuselage. This would hopefully prevent any damage to either the wing or the fuselage as the bolts would be sacrificed.

Structure

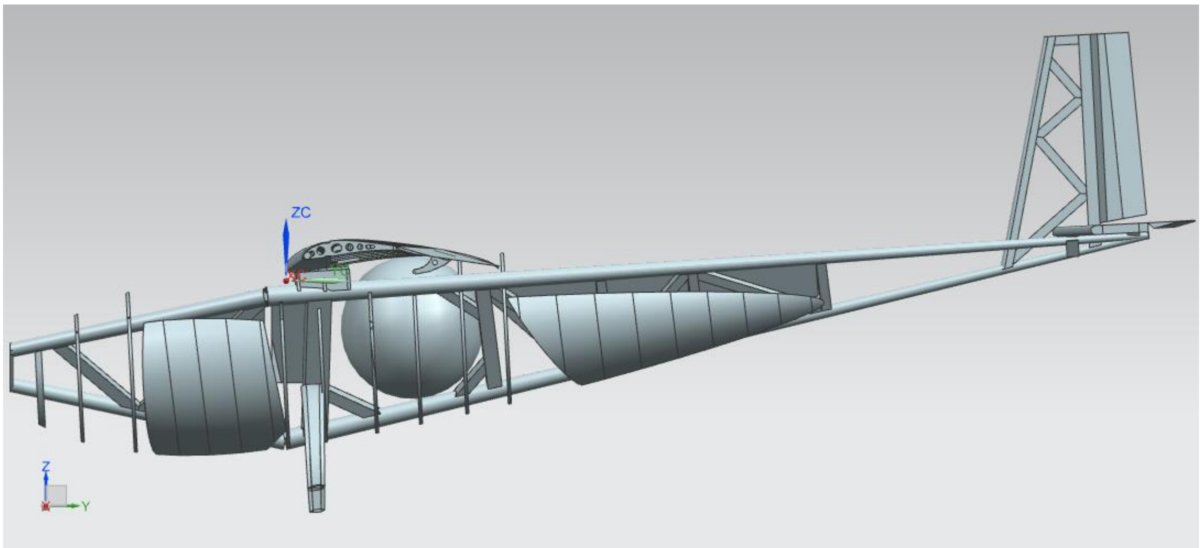


The main structural part of our wing is two continuous carbon fibre strips running along the top and bottom of the wing forming the main spar. There are also balsa shear webs in between these strips which create a sandwich structure. This design will make the wing very rigid as carbon fibre is extremely stiff. The ribs that create the aerofoil shape of the wing will be made from balsa. This is because balsa is extremely light so it will save a lot of weight compared to if any other material were used. However, lightening holes were also cut into the ribs in order to save weight as this material is not really needed. It is possible to use such a small amount of material because the ribs do not take any real loads, they just provide the profile of the wing. A wooden balsa dowel was used on the leading edge of the wing as this helps create the curved front section of the aerofoil. In order to increase the rigidity of the wing, a thin balsa sheet was curved around the front section of the wing. This balsa sheet ran from the bottom of the main spar, round the leading edge of the wing and finished at the top of the main spar. Adding this balsa sheet created a D-box in the front section of the wing which significantly increased the stiffness of the wing.



3.2 Fuselage

Our fuselage can be considered in two sections; first the section aft of the main plane consists of three carbon fibre booms arranged in a triange with trussing in between. The upper surface will have only perendicular trusses to allow for the insertion and removal of payload. The Fore-section is of a similar design with three booms, however circular frames connect between the three. This provides a streamlined shape and allows pleanty of internal space for payload. The ball is located below the wing and can be removed by detaching the wing and lifting through the gap.



Our initial ideas were to have a single boom which the components attached to, however this would require a large boom to withstand the loads which would be encountered in flight, this would be heavy and not ideal for the requirements. We then considered using two booms, although this would provide additional strength against longitudinal loads, it would provide little strength against normal loads from the fin and rudder. Therefore we settled on a tri-boom layout to provide a larger moment of inertia and better resistance to bending under loads.

3.3 Empennage

Empennage configuration plays an important roll in the performance of the aircraft. Modern Empennage configuration includes T-tail, V-tail, X tail etc. For the Empennage of the aircraft, we have chosen the conventional configuration, which is a fuselage mounted tail plane. This means that the two tail planes are attached on the body of the fuselage with a small angle or zero dihedral. This Empennage configuration is easy to manufacture and requires less accuracy compare to a V-tail or a X-tail empennage. A T-Tail Empennage is also easy to manufacture, but since the aircraft is mainly going to perform low speed performances, A T-tail Empennage will increase the difficulty in pitch control. A V-Tail or a X-Tail reduces the overall weight of the aircraft as they combined the fins and horizontal stabilizer in to one piece. However, the V-tail or the X-tail configuration is very difficult to manufacture and requires high accuracy. A V-tail or X-tail empennage is also slightly more difficult to control as the pitch and yaw control surface works as one

3.4 Landing Gear

The front landing gear is a commercial off the shelf unit. It is a carbon fibre construction so has a very high strength for a relatively little mass. However, as the carbon fibre is so stiff, it will offer very little in the way of shock absorption. This is very important as the landing gear has to dissipate very high impact loads on landing. For this reason, we will fit large diameter foam or rubber wheels that are capable of absorbing high loads. We haven’t deciding on this yet but we will get round to testing the two different types of wheel and making a decision closer to the competition.

As it is a fixed unit, it will be exposed to the airflow the whole time and create a lot of drag on the aircraft. We chose a landing gear unit that had a relatively low profile, in order to minimise the drag that it induced on the aircraft. Purchasing the product means we remove the need to produce a bespoke part ourselves, reducing manufacture costs. Also the part will be reliable as it has an established production method and design.

A smaller wheel was used for the tail of the aircraft as it does not take as much load as the main undercarriage. A benefit of having a smaller tail wheel is that it effectively increases the angle of attack of the wing when the aircraft is on the ground. This would assist the aircraft on take-off as it would not need to rotate as much during the take-off run. Another benefit of the smaller tail wheel is that it would save weight in the aircraft.

The main undercarriage will be attached to the aircraft at hard points on the fuselage. This is to ensure that the landing gear will be able to withstand the large forces from the impact upon landing. These hard points will help disperse any large loads that will be transmitted into the fuselage through the undercarriage. The tail wheel will be attached to the aircraft using carbon fibre thread and epoxy resin. It will be fixed to the main carbon booms that are the main structure of the fuselage. This assembly will not provide any suspension or shock absorption but that is not a big factor. We will use a similar type wheel to the main undercarriage meaning that it will provide a little bit of shock absorption. However, this is not as important as the forces going through the tail wheel are a lot less than those of the main undercarriage. The main function of the tail wheel is only to prevent any damage to the empennage of the aircraft upon landing, so suspension is not a big issue.

3.5 Payload

The payload will be carried both internally and externally. The internal payload will be contained in between the three booms that form the aircrafts fuselage and tail. There will be three separate containers that will fit together inside the frame to fill the whole section. The containers will be formed from depron sheeting which will be laser cut and formed into a triangular based pyramid to slot inside. Depron was chosen as it is light weight and will meet the requirement of the empty payload mass being less than 10% of the filled mass. The payload will enter through a screw top at the base of the pyramid, which when placed in the aircraft will end up at the front. The containers will fit in from the top and then slide backwards until secure inside the booms. Tests will be carried out to ensure the container has enough strength to support the payload when in flight. If it is discovered that more strength is needed, it is possible to add internal frames to prevent the walls from bucking. As the aircraft fuselage has no solid sides, this means that we will not be doubling up on these sections and will therefor reduce weight and retain maximum space for the payload.

To increase the capacity of the payload the aircraft can carry there is the option for under wing tanks. These tanks will be made from small water bottles that can be attached to strong points on the wing. If necessary, small coverings can be made to increase the aerodynamic properties of the tanks. As these tanks are removable it will mean that during the half payload flight no container will have to be half filled. This means we can minimise the amount the payload moved around the containers as the aircraft performs manoeuvres and keep the stability of the aircraft. These under wing tanks will be positioned close to the fuselage centre for a number of reasons. Firstly it will reduce the wing root bending moment meaning the wing structure can be kept as light weight as possible. Secondly, the mass moment of inertia is less resulting in more stability in the rolling plane of the aircraft.