Structural Design Technical Report

A Report

submitted by

X GROUP

as part of the course

AS 5220: STRUCTURAL DESIGN

DEPARTMENT OF AEROSPACE ENGINEERING
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ABSTRACT OF THE PROJECT

The objective of this airplane design is to build an aircraft capable of carrying a payload much greater than its structural weight. The mission profile includes take-off, a 360 degree turn and landing on the same airplance strip.

So far the wing design and fuselage design have been completed and have undergone fabrication.

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ABBREVIATIONS AND NOTATIONS

$2D$	Two dimensional
$3D$	Three dimensional
α	angle of attack
b	wing span
c	chord length of the wing
S	area of the wing
q	lift per unit span of the wing
σ	Shear stress

CHAPTER 1

INTRODUCTION

This introduction chapter summarizes the main aerodynamic features of the airplane and the cost estimate to construct it.

1.1 MISSION REQUIREMENTS

The objective of this airplane design is to build an aircraft capable of carrying a payload much greater than its structural weight. The mission profile includes take-off, a 360 degree turn and landing on the same airplane strip as Fig 1 shows.

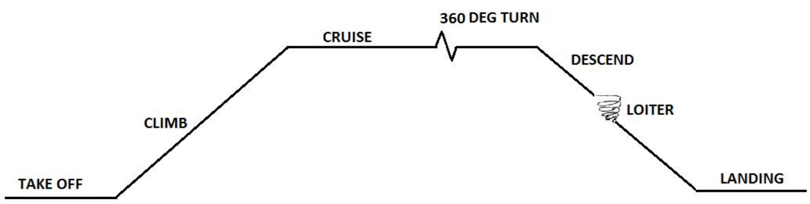


Figure 1.1: Mission Profile

1.2 CONFIGURATION CHOICE

Following are the salient features of the configuration considered:

- The airplane is a monoplane due to ease of construction and need for lesser thrust to counter induced drag.
- High wing of aspect ratio 8 was chosen because of stability considerations. Also, most of the similar airplanes have a high wing configuration.
- Airfoil was chosen to be S1223 because of its high lift characterestics, deep camber and thin wing. It is also highly suitable for low speed flights

- No wing sweep or taper was chosen due to ease of construction and the fact that the airplane wing operates only in the low speed regime
- A conventional tail was chosen as it provides adequate stability and control and is easier to construct than other complex tail configurations

1.3 SUMMARY OF WORK DONE AS PART OF THE AERODYNAMIC DESIGN

Brief description accompanied by data/weight estimates and diagrams.

1.3.1 Data Obtained from Literature Survey

Table 1.1 gives the details of existing aircrafts of similar configurations for which data were accessible.

Parameters	Worchester I	Worchester Polytec. II	Cincinnati University	SAE MicroClass Entry
Gross Weight(kg)	0.316	1.915	1.95	1.732
Payload Weight(kg)	0.163	1.530	1.632	1.284
Empty Weight(kg)	0.153	0.384	0.316	0.448
Powerplant Weight(kg)	85.4	0.185	0.3	0.368
Airfoil	S1223	S1223	S1223	S1223

Table 1.1: Data of similar airplanes(5)

1.3.2 First Weight Estimate

The first weight estimate of the aircraft was done based on data from our literature survey. The first weight estimate comes out to be 1.495 kg.

1.3.3 Second Weight Estimate

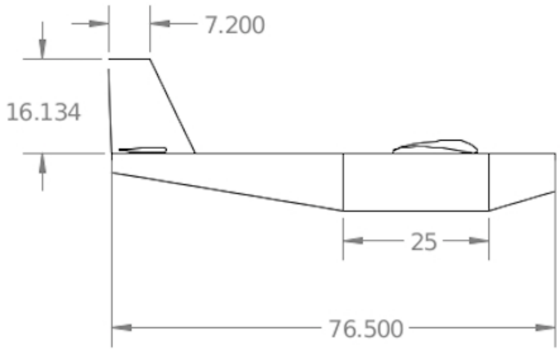
The second weight estimate was done by choosing our powerplant by taking data from the chosen airfoil. The chosen powerplant is

- Motor : Avionic C3536 brushless motor (see (1)) Prop : 11x7; 1.3 Kg thrust ; ESC 30A
- Battery : 3S Lipo; 11.1V 25C, 2200 MaH (see (2))

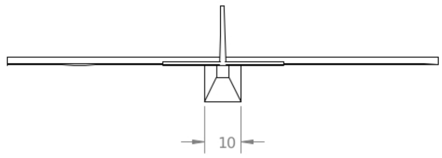
Taking into account the powerplant weight, the second weight estimate comes out to be 1.642 kg.

1.3.4 Views of the Designed Airplane

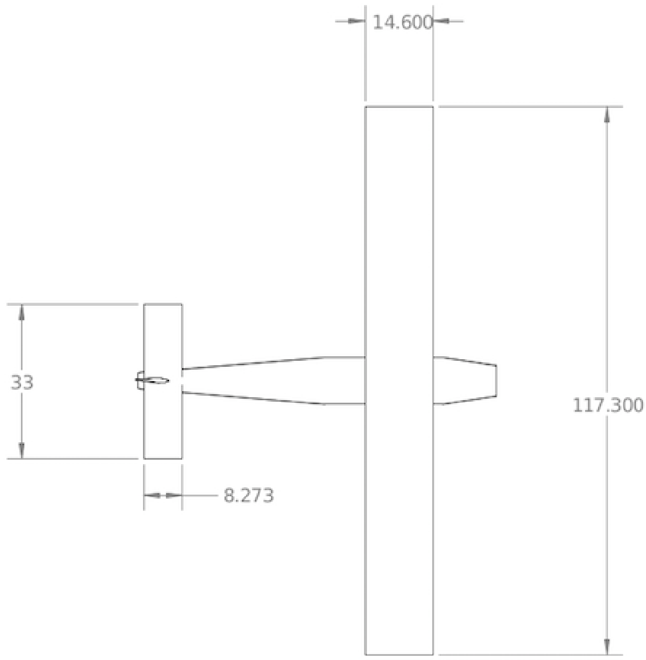
The three view configuration along with the 3D view is outlines in Fig 1.2



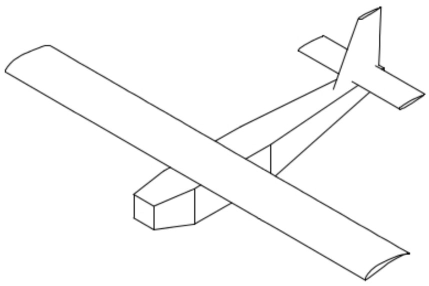
(a) Side View



(b) Front View



(c) Top View



(d) 3D View

Figure 1.2: Three view and isometric view of the airplane

1.3.5 V-n Diagram

Figure 1.3 shows the envelope of the final V-n diagram for the chosen aircraft.

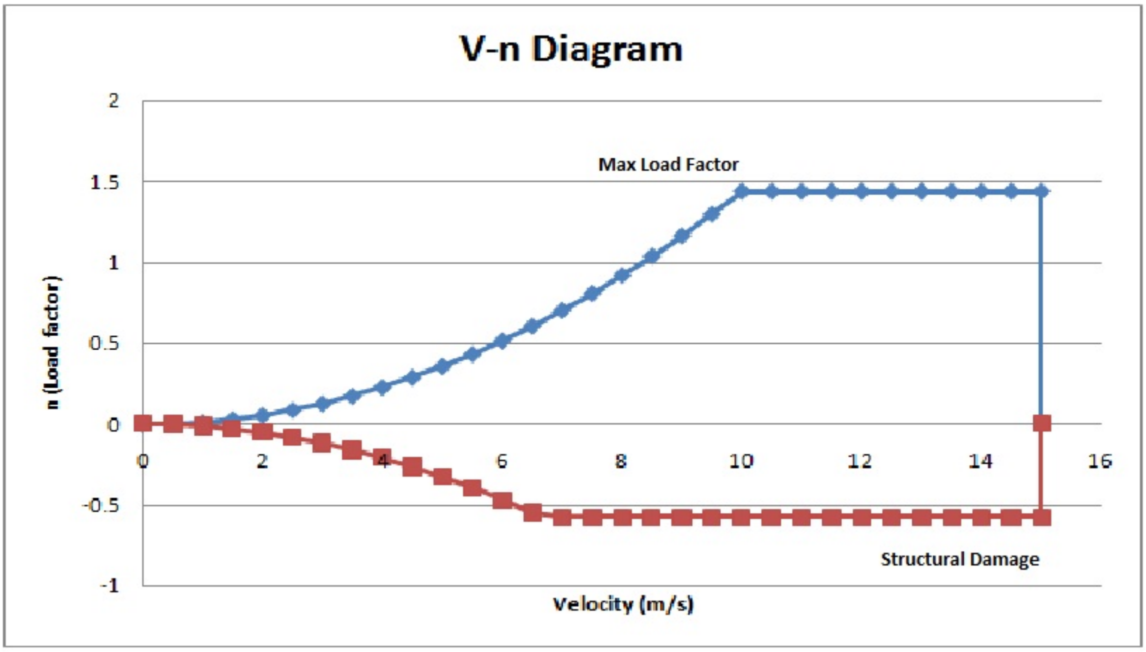


Figure 1.3: Flight envelope: V-n diagram for the given airplane.

1.3.6 Some performance parameters

A few important performance parameters are highlighted below

1. Thrust-to-weight ratio : 0.63 (Considering 80% efficiency)
2. Endurance : 4 min
3. Range : 2.4 km
4. Maximum Load Factor : 1.43
5. Take-off distance : 30 m
6. Landing distance : 50 m
7. Climb Angle : 6 deg
8. Wing Loading : 93.342 N/m^2

1.4 BILL OF MATERIALS WITH SUGGESTED VENDORS

Table 1.2 gives the details of the materials required for fabrication as well as suggested vendors and approximate cost

Component	Price(Rs)	Suggested Vendor
Motor	1400	See (1)
Battery	3395	See (2)
Balsa Wood	4000	
Aluminium	1000	
ESC(electronic speed controller)	1000	See (3)
Servo motors (4 Nos)	1860	See (4)
Propeller 11x7	200	RcBazaar
Miscellaneous	2500	
Total	15400	

Table 1.2: Aircraft cost estimation

CHAPTER 2

WING DESIGN

This report summarizes the wing design of the airplane

2.1 WING LOAD DISTRIBUTION

Schrenk method is one of the best and simple method for approximating the aerodynamic wing loading.
According to this method, the average of the actual chord and the chord of the semi-ellipse wing with the same span b and area S of the wing will be taken as the chord length at any point of the wing.

$$c(y) = \frac{c_{actual}(y) + c_{cell}(y)}{2} \tag{2.1}$$

and,

$$c_{cell} = \frac{4S}{\pi b}\sqrt{1 - \left(\frac{y}{b})\right)^2}$$

where, y is the coordinate measured from wing tip, c(y) is chord length as a function of y, c is the chord length of the wing (0.14m), b is half wing span (0.58m) and S is the area of the wing ($0.086m^2$)

Since the wing is rectangular, the chord length is same throughout the wing. Hence, the eliptical approximation gives us

$$c(y) = \frac{0.14 + c_{cell}}{2} \tag{2.2}$$

The lift per unit span of the wing is given by

$$q = \frac{1}{2}\rho V^2 C_l c(y) \tag{2.3}$$

Since we are designing for maximum loads, we consider loads during take-off

- $\rho = 1.23$ kg/m^3
- $V = 10.78$ m/s
- $C_l = 2.43$

Therefore,

$$q = 8.6 \times 10^{-5}(146 + \sqrt{586.5^2 - y^2}) \tag{2.4}$$

Using $\int q dy = L(y)$

$$L(y) = 8.6 \times 10^{-5} \left(146 + 0.315 \left[\frac{y}{2}\sqrt{586.5^2 - y^2} + \frac{586.5^2}{2} sin^{-1} \frac{y}{586.5}\right]\right) \tag{2.5}$$

where, y is in mm.

The following plots outline the shear force and bending moment diagrams. Fig.2.1 gives the lift distribution on the wing, Fig.2.2 gives the bending moment diagram and Fig.2.3 gives the shear force diagram

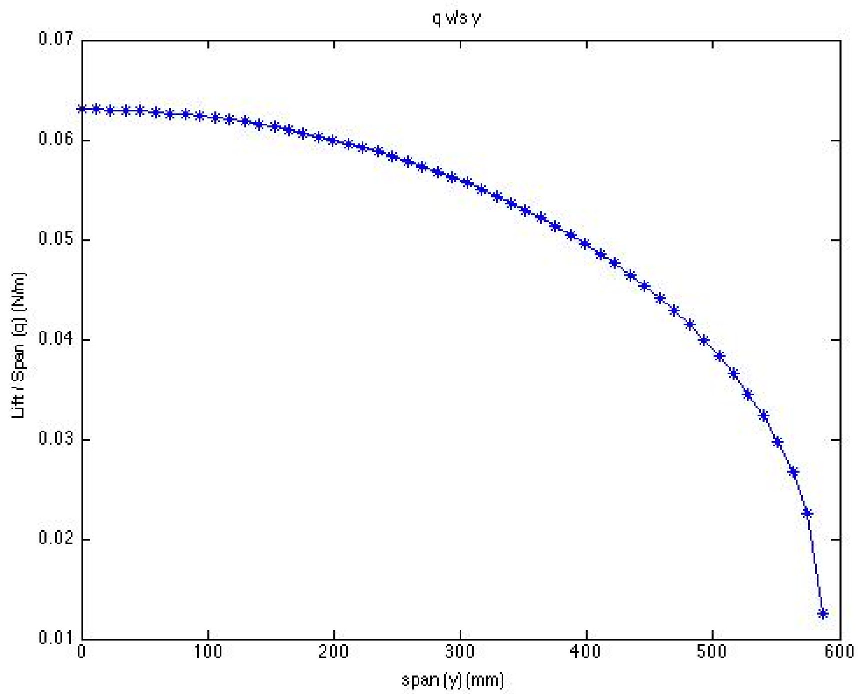


Figure 2.1: Lift Distribution per unit span of wing

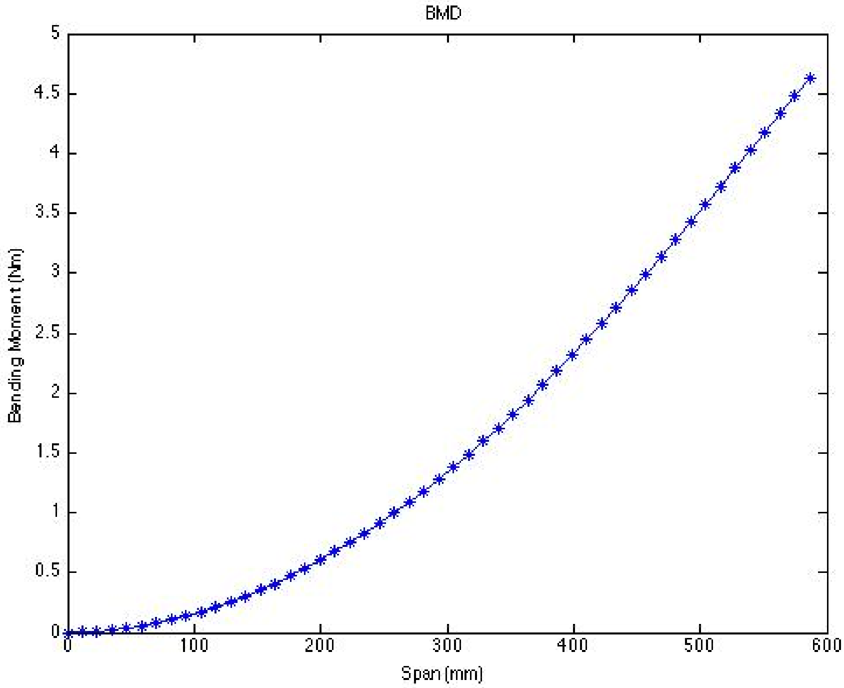


Figure 2.2: Bending Moment diagram due to lift

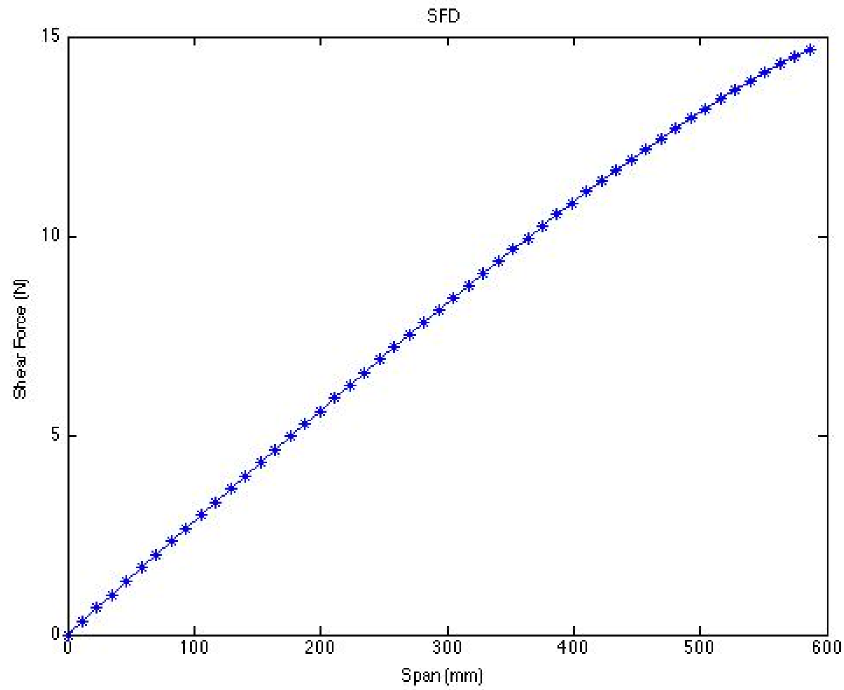


Figure 2.3: Shear force Diagram due to lift

2.2 SPAR DESIGN

The maximum yield strength of spar material aluminium is $\sigma_{yield} = 19$ MPa. Taking a box section as the spar section, we get moment of inertia of the section as

$$I_{yy} = 2\left(\frac{bd^3}{12} + \frac{btd^2}{4}\right) \tag{2.6}$$

where, b is the breadth and d is the depth of the rectangular box spar. Fig.2.4 shows the spar cross-section.

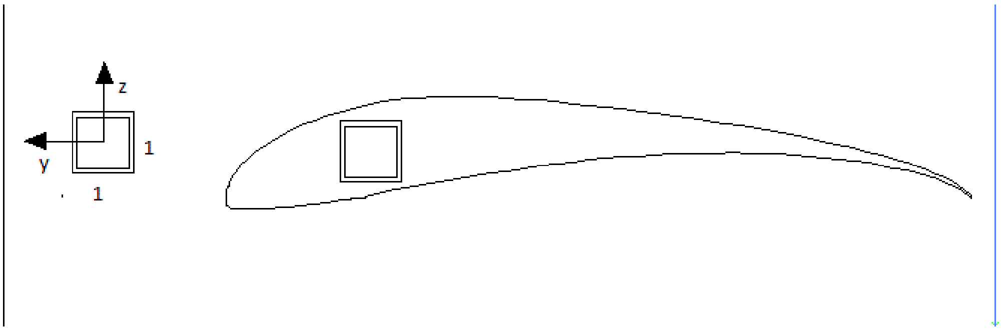


Figure 2.4: Spar cross section

We are using a spar section of 1cm by 1cm with a thickness of 1mm (least dimensions available on the market). Now, we need to check if this spar design is sufficient to carry all types of stresses.

2.2.1 Spar under bending stress

The maximum bending moment, M_{max} is 4.62 Nm,which is calculated from the bending moment diagram. Now,

$$\sigma = \frac{M_z}{I_{yy}} \tag{2.7}$$

Using the spar cross section, we get $I_{yy} = 2.16 \times 10^{-9}$ m^4, $\sigma = 10.7$ MPa .This value of bending stress is lesser than the yield stress with a factor of safety of almost 2. Hence, the spar is safe w.r.t bending stresses.

2.2.2 Spar under shear stresses

Now that we know the spar cross-section, we can plot the SFD and BMD including the weight of the aircraft. Using the thumb rule of 1 rib per chord of wing, we choose 8 ribs for the wing. Using balsa wood as the material, we get the ribs for the wing to weigh 1.8g. Similarly, we get the spar to be 108g. We neglect the weight of the ribs for simplicity.

The revised SFD and BMD are shown below

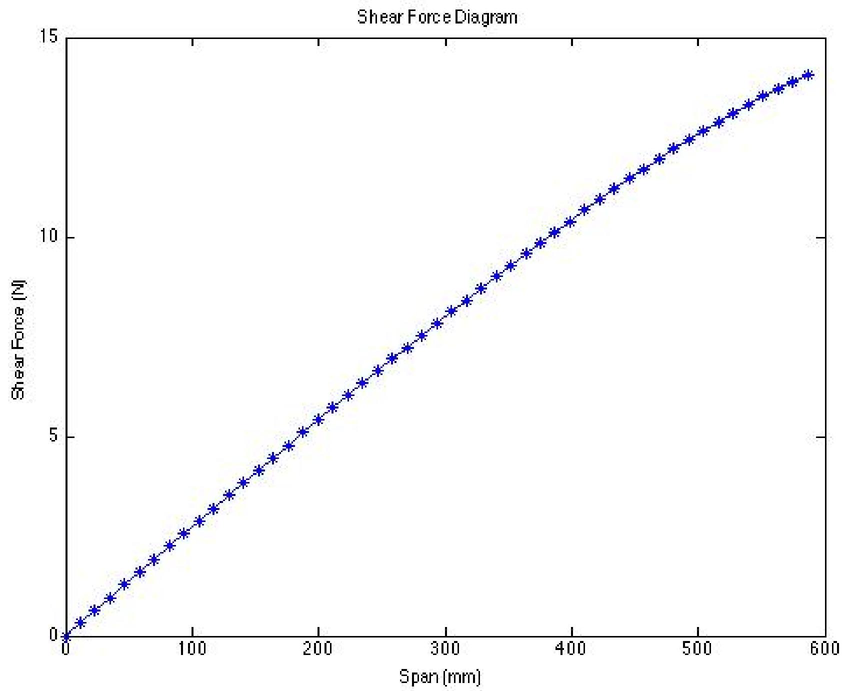


Figure 2.5: Shear force Diagram

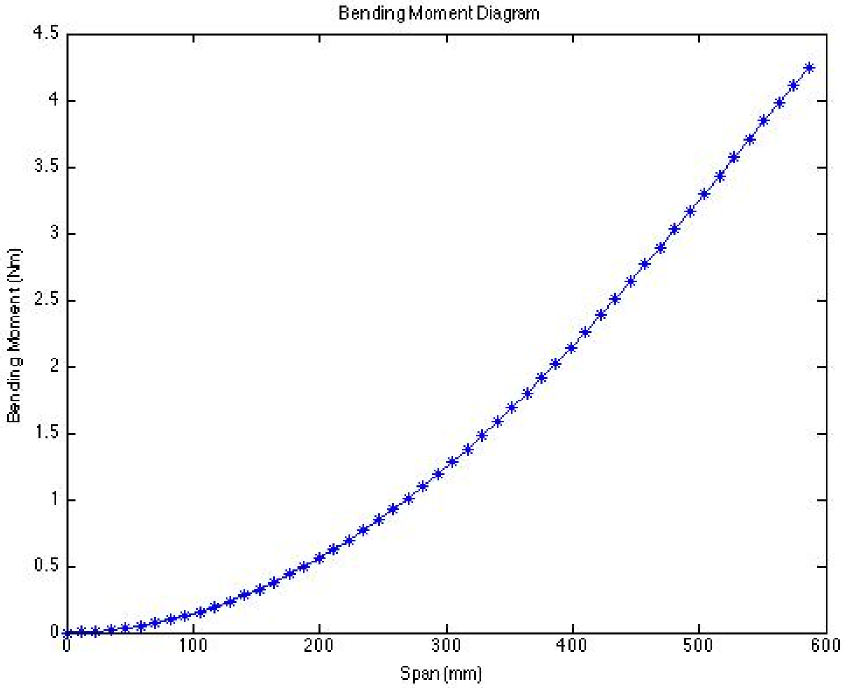


Figure 2.6: Bending Moment diagram

Shear stresses are caused by wing pitching moment (twist) and vertical forces. We can rule out twist due to lift forces as the spar runs through the aerodynamic center of the wing. The torque due to pitching moment is

$$T = \frac{1}{2}\rho v^2 S C_m c \tag{2.8}$$

The shear flow through the section is given by

$$q = -\frac{V_z t}{I_{yy}} \int y ds + \frac{T}{2A} \tag{2.9}$$

where, $V_z = 14.06$ N, $t = 1$ mm, $T = 0.48$ Nm, $A = 1$ cm^2

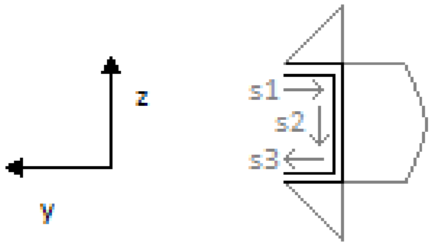


Figure 2.7: Shear flow around spar section

A standard shear flow analysis gives us

$$q_1 = -32.4s_1$$

$$q_2 = -6.48(5s_2 - 0.5s_2^2) - 162$$

where, s is in mm and as directed in 2.7. The maximum shear stress is calculated from the shear flow using

$$\tau_{max} = q_{max}/t \tag{2.10}$$

Looking at the shear flow, we get $q_{max} = 243$ N/m (at $s_2 = 5$ mm) and due to torque $q = 2398$ N/m, Hence, $q_{total} = 2641$ N/m and therfore $\tau_{max} = 2.641$ MPa

2.2.3 Spar under buckling stresses - web

To check if the spar web buckles, we use the following web buckling formula

$$\sigma_{max} = KE\left(\frac{t}{b}\right)^2 \tag{2.11}$$

Substituting, K = 3.67 and E = 70 GPa for Aluminium, we get $\sigma_{max} = 2.6$ GPa

The maximum stresses are far lesser than this. Thus, we conclude that no buckling problems will be encountered for the spar.

CHAPTER 3

FUSELAGE DESIGN

This report summarizes the fuselage design of the airplane

3.1 FUSELAGE DESIGN

The fuselage will take a certain amount of load during the flight. We need to design it in the most efficient way possible.
There are two ways to go about supporting these loads.

- The heavier way is to build the sides from thicker balsa by directly using them as sheets.
- The lighter way is to build the sides from thinner balsa and reinforce the inside with vertical supports and, to make it more efficient, addition of diagonal bracing between the verticals. Essentially building a truss that's sheeted on the outside.

The lightest way to build a fuselage (which also gives the best strength to weight) is to build truss-work sides with gussets at all joints and no sheeting. It requires more work, but results in lighter, stronger and more rigid (for their weight) than any other method in use.

3.1.1 Truss Structure

A truss is a structure that 'consists of two-force members only, where the members are organized so that the assemblage as a whole behaves as a single object'. Although this rigorous definition allows the members to have any shape connected in any stable configuration, trusses typically comprise five or more triangular units constructed with straight members whose ends are connected at joints referred to as nodes. In this typical context, external forces and reactions to those forces are considered to act only at the nodes and result in forces in the members which are either tensile or compressive forces.

3.1.2 Superior Alternative to Trusses

A better alternative to the trusses taking the load is to use aluminium rods as the primary load bearing component. The aluminium rods pass through the fuselage. They take all the loads and bending moments from the wings.
The truss model of the fuselage is present for visual requirements alone so that the RC airplane looks like a conventional scaled down aircraft.
The Aluminum rod chosen for the wing spar has high margins of safety as seen in Chapter 2. The aluminium spar section is 1cm by 1cm with a thickness of 1mm. As seen, since these Aluminium rods can withstand such high loads and moments generated by the wing, we are using the same aluminium rods for the fuselage construction (Also, since these are the least dimensions available in the market).

3.2 FABRICATION STATUS

An update on the fabrication work done until October 1^{st}

Stage	Status
Wing Fabrication	Complete
Fuselage Fabrication	Complete
Landing Gear	Under Fabrication

Table 3.1: Fabrication work done until October 1^{st}

CHAPTER 4

COMPLETE FABRICATION

This report summarizes complete fabrication process.

4.1 WING

This sections discusses about the wing section.

1. **Spar** : The spar is made of Aluminium rod of length 1.6 meters and having a cross-section of 1cm x 1cm
2. **Ribs** : Sixteen ribs are being used in the wing, each having thickness of 8mm and lenght 14.8cm, and have been made out of balsa wood.
3. **Aileron** : The Ribs have been cut at 20% from the trailing edge of the ribs. The control surface covers 60% of the wing span.
4. **Hinges** : The Aileron section is attached to the main wing ribs using CA Hinges. All the Aileron sections are connected by a sheet of balsa wood which is then connected to a Servo which controls its motion.

4.2 FUSELAGE

This sections discusses about the fuselage section.

1. **Frame** : As outlined in the previous chapter on Fuselage Design (Chapter 4), the fuselage frame is a truss structure.
2. **Primary Load Structure** : Aluminium rod has been used to take the primary loads being transferred to the fuselage.

4.3 HORIZONTAL TAIL

This sections discusses about the Horizontal section.

1. **Spar** : The spar is made of Carbon Fiber rod of length 0.5 meters and has a cross-section of 2mm x 2mm
2. **Ribs** : Eight ribs are being used in the wing, each having thickness of 8mm and lenght 8.2cm, and have been made out of balsa wood.
3. **Elevator** : The Ribs have been cut at 40% from the trailing edge of the ribs. The control surface covers 90% of the wing span.
4. **Hinges** : The Aileron section is attached to the main wing ribs using CA Hinges. All the Aileron sections are connected by a sheet of balsa wood which is then connected to a Servo which controls its motion.

4.4 VERTICAL TAIL

This sections discusses about the Horizontal section.

1. **Spar** : The spar is made of two Carbon Fiber rods. The main spar is a square Carbon fiber rod and is at an angle of $45°$ and has a cross-section of 2mm x 2mm. Additional vertical spar is being used to provide rigid support to the tail and is made of circular carbon fiber rod of length 16.2cm and cross-section having radius of 1.5mm
2. **Ribs** : Six ribs are being used in the wing, each having thickness of 8mm, and have been made out of balsa wood. The Ribs have been cut at varying length by keeping the taper ratio in mind.
3. **Rudder** : The Ribs have been cut at 3cm from the trailing edge of the ribs. The control surface covers 90% of the wing span.
4. **Hinges** : The Aileron section is attached to the main wing ribs using CA Hinges. All the Aileron sections are connected by a sheet of balsa wood which is then connected to a Servo which controls its motion.

Figure 4.1: Complete Fabrication

CHAPTER 5

ASSEMBLY

The final assembly of the aircraft is described in this chapter

5.1 WING AND FUSELAGE

The Wing is assembled with the fuselage be bolting the wing spar to the fuselage aluminium rod and the main fusleage bulkhead as figure(WHAT) shows. A total of three screws are used to restrict all relative motion between the two structures. Additionally, the fusleage aluminium rod is fastened to the truss by glue and wire to ensure no lateral motions.

5.2 TAILS AND FUSLEAGE

The vertical tail is placed on the aluminium rod using balsa pieces of wood for extra stability. The horizontal tail is also placed on the rod using balsa wood as figure(WHAT) demonstrates

5.3 MOTOR AND FUSELAGE

The motor is bolted to a square plywood frame held to the aluminium rod using L-clamps to dampen out motor vibrations and to ensure the rod is taking the load. The battery is placed right after the motor at the fuselage head with the ESC taped to the outside of the fuselage along with the reciever.

5.4 SERVOS

Servos in the wing are placed at mid-aileron span within the wing structure secured to the aluminium rod using double-sided tape. The tail servos are fixed to the fuselage to operate the elevator and rudder. All servo wires are connected via extension cables pulled to the reciever placed near the wing spar.

5.5 SKIN

The wing is covered with monokote, as are the horizontal and vertical tail. This was done primarily to preserve the airfoil shape which is quite crucial according to our aerodynamic calculations. The fuselage on the other hand is covered with the cheaper coroplast to ensure a more rigid framework (no complex shapes in the fuselage structure).

PUT FIGURE OF FINAL ASSEMBLED AIRCRAFT——————————————

CHAPTER 6

Flight Testing and challenges

6.1 TESTING

The airplane passed all ground tests which included servo tests and motor tests. The initial center of gravity of the plane was behind the wing spar making it tail heavy. The problem was partially corrected by placing a 100g weight at the nose. The result was still a little tail heavy. The problem could not be completely overcome due to our short nose length of fuselage. Hence, the moment arm of any weight was too less to influence the center of gravity unless the weight was more that 500g, which made our plane weight more than 1.5 kg (the rated thrust of the motor). Hence, to avoid any thrust related problems and placing of heavy weights at the nose, the slight tail heaviness was deemed acceptable.
Another minor problem faced was the strength of the servos. Though they worked, it was a possibility that the strain on them could render them unfit during flight. This issue was not served as anything major and hence was pushed aside.

The first flight test was unsuccessful. The aircraft took off the ground successfully, but went into an unrecoverable right turn after which it crashed head on to the ground damaging the wing spar, motor mount, propeller and the motor itself. ———INCLUDE CRASH PHOTOS AND EXPLAIN ———————

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[2] Battery Specifications : http://www.muav.in/?wpsc-product=battery-lipo-gens-ace-3s-rechargeable-11-1v-25-c-2200-mah

[3] ESC : http://www.muav.in/?wpsc-product=esc-rcforall-30-amps

[4] Servo : http://www.muav.in/?wpsc-product=hs-55s

[5] Airplane entries for the competition organized by SAE International