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.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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 airplance strip as Fig 1 shows.

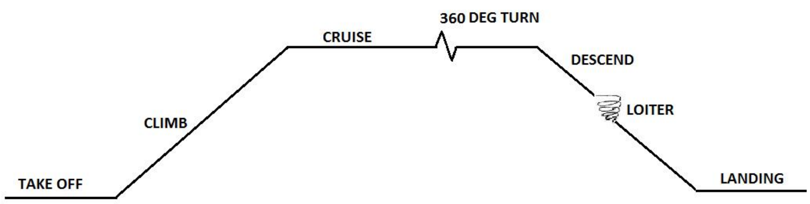


Figure 1.1: Mission Profile

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

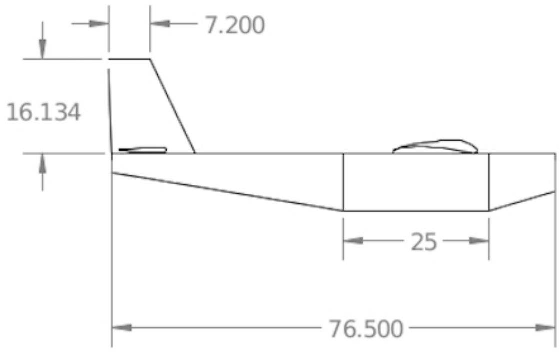
The second weight estimate was done by choosing our powerplant by taking data from the chosen airfoil. The chosen powerplant is

- 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))

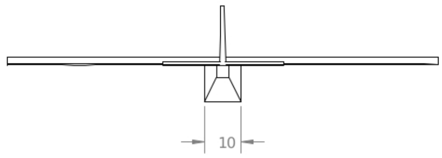
Taking into account the powerplant weight, the second weight estimate comes out to be 1.642 kg.

1.3.4 Views of the Designed Airplane

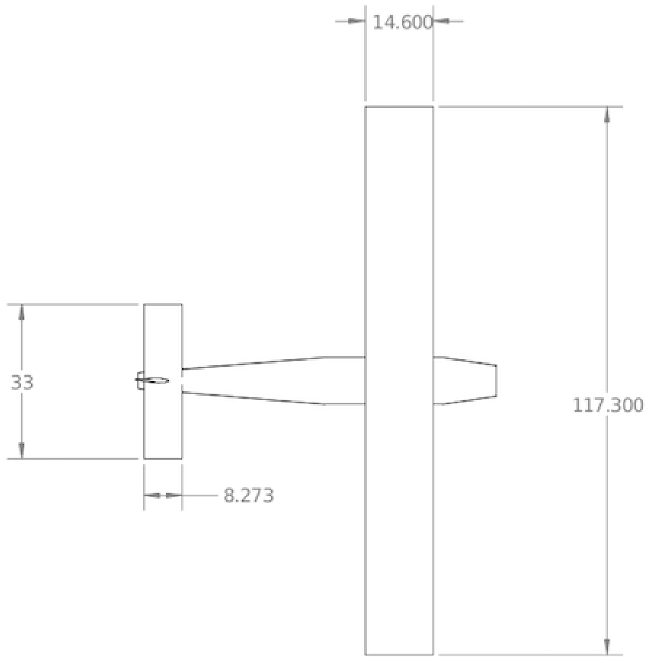
The three view configuration along with the 3D view is outlines in Fig 1.2



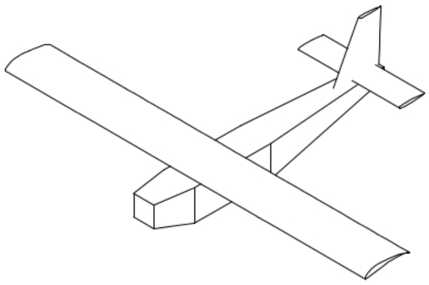
(a) Side View



(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.

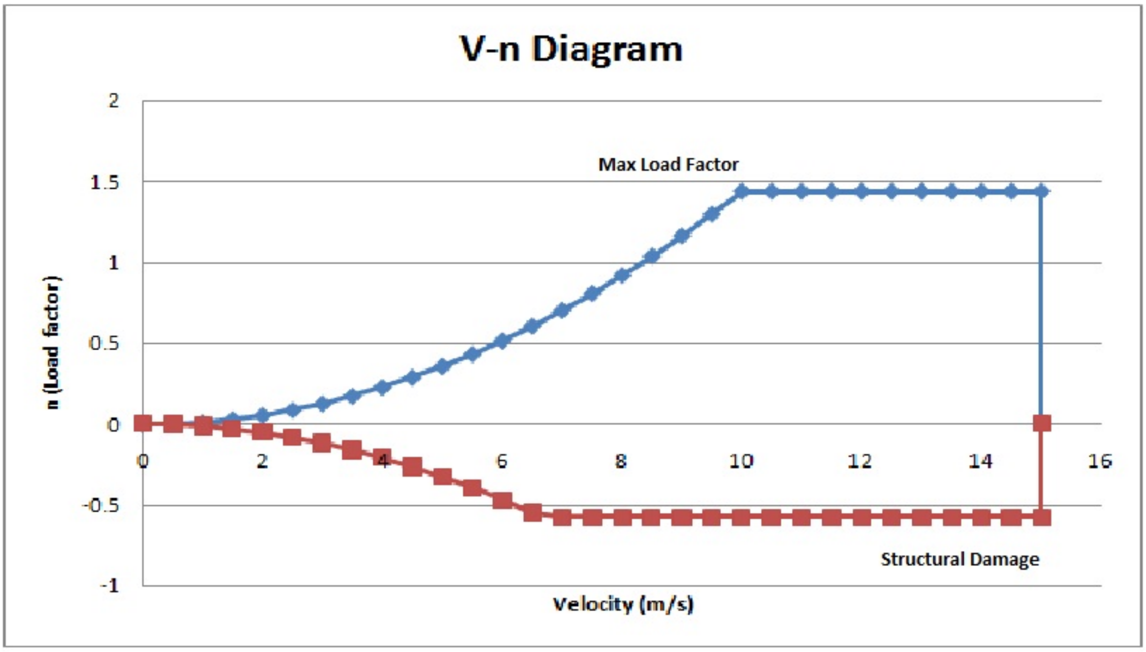


Figure 1.3: Flight envelope: V-n diagram for the given airplane.

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 $\int qdy = L(y)$

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

where, y is in mm.

The follwing 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

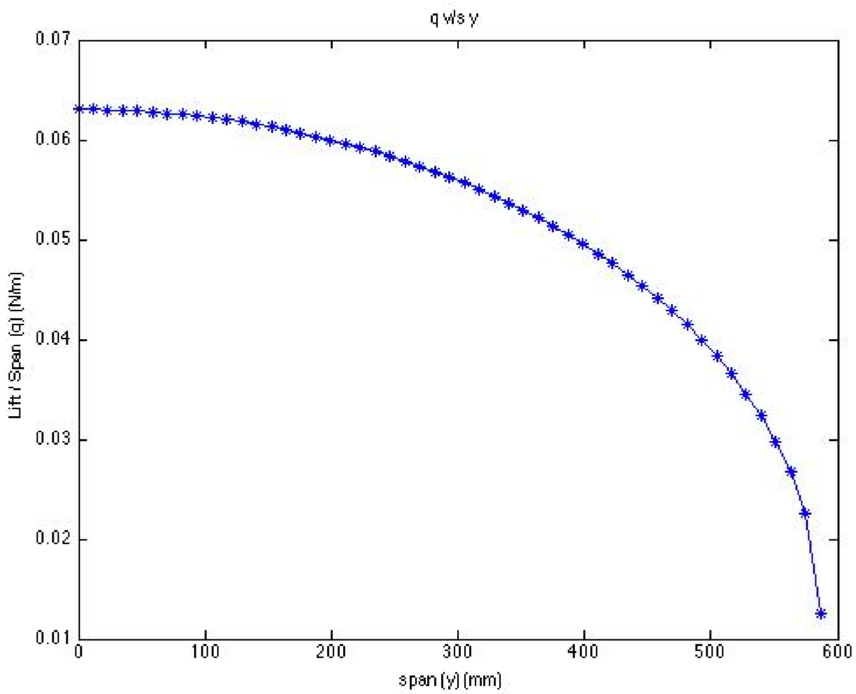


Figure 2.1: Lift Distribution per unit span of wing

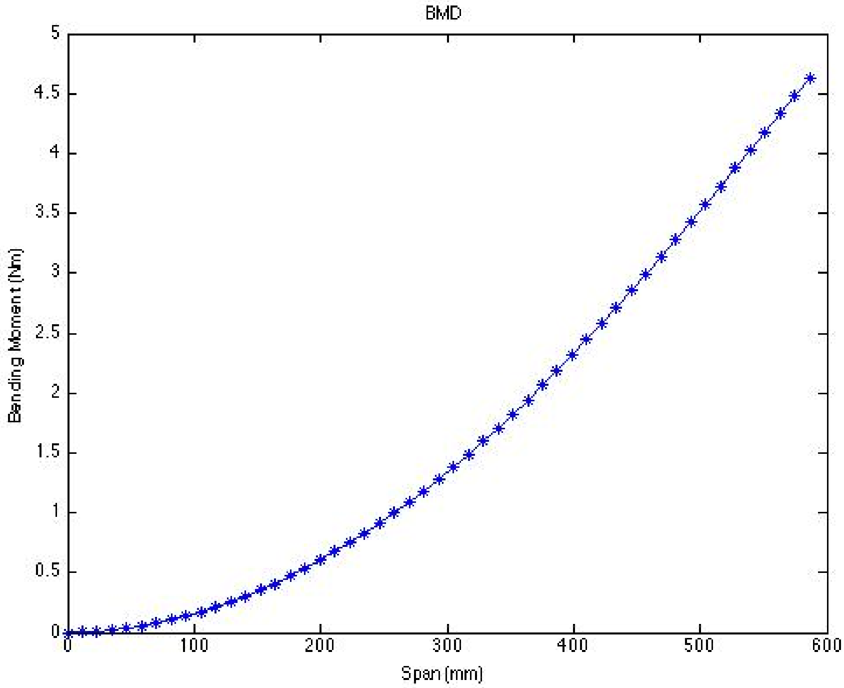


Figure 2.2: Bending Moment diagram due to lift

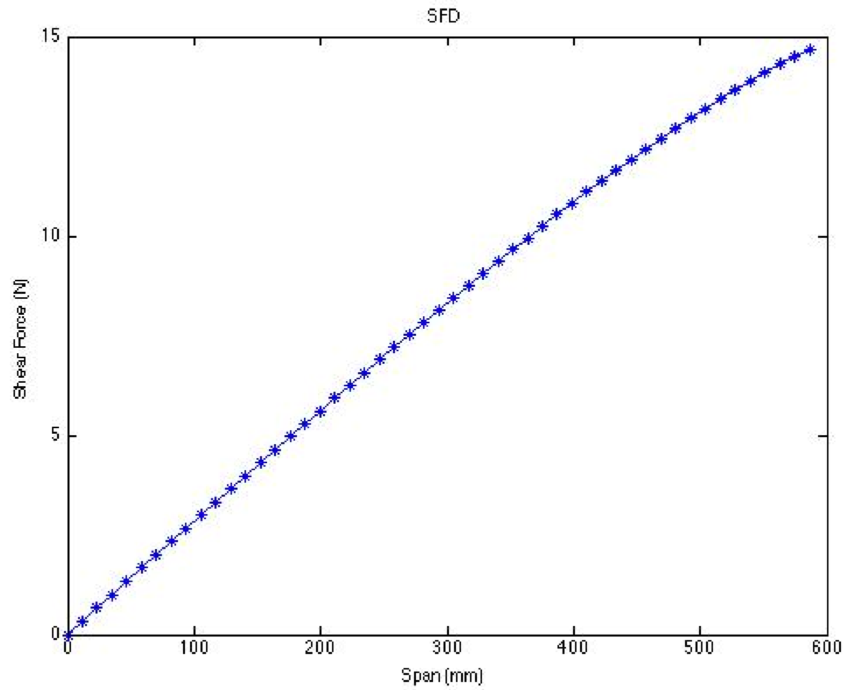


Figure 2.3: Shear force Diagram due to lift

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.

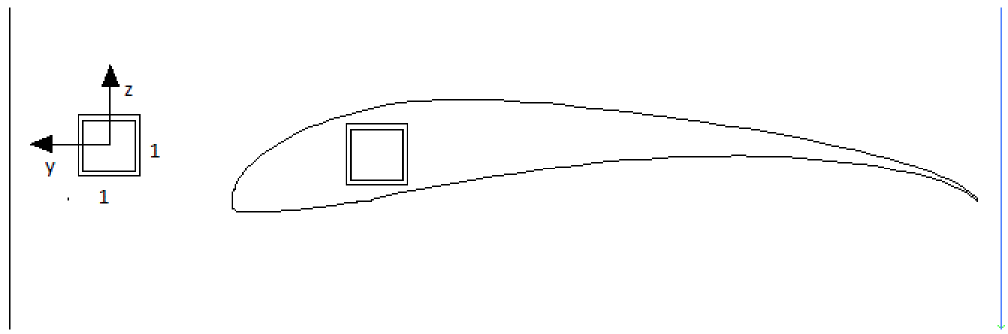


Figure 2.4: Spar cross section

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

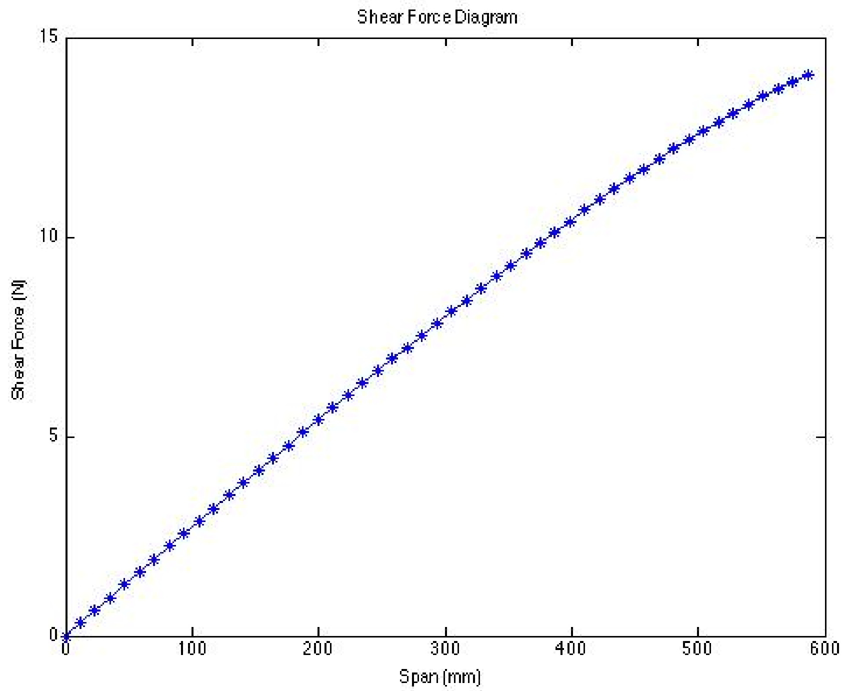


Figure 2.5: Shear force Diagram

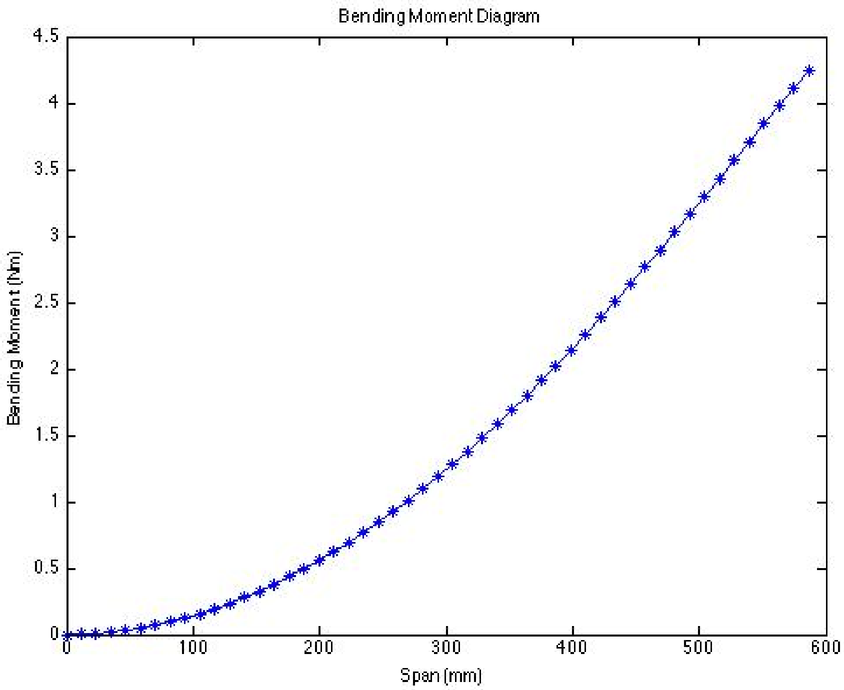


Figure 2.6: Bending Moment diagram

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

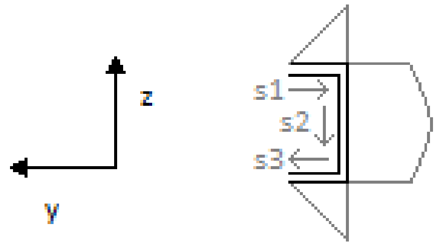


Figure 2.7: Shear flow around spar section

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 1st

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

Table 3.1: Fabrication work done until October 1st

REFERENCES

[1] Motor Specifications : http://rcbazaar.com/products/2442-avionic-c3536-kv1050-brushless-motor.aspx

[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