

# Structural Design Technical Report

*A Report*

*submitted by*

**X GROUP**

*as part of the course*

**AS 5220: STRUCTURAL DESIGN**



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**19 SEPTEMBER 2014**



## **ACKNOWLEDGEMENTS**

We would like to thank Prof. HSN Murthy, Prof. Sriram, Prof. Rajesh, Prof. Joel, Manu (TA), Arjun (TA), Debolina (TA) and all those who helped in design and fabrication of the aircraft.



## **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 has been completed and is undergoing fabrication.



# TABLE OF CONTENTS

|   |            |
|---|------------|
| <b>ACKNOWLEDGEMENTS</b>   | <b>i</b>   |
| <b>ABSTRACT OF THE PROJECT</b>  | <b>iii</b> |
| <b>LIST OF TABLES</b>   | <b>vii</b> |
| <b>LIST OF FIGURES</b>  | <b>ix</b>  |
| <b>ABBREVIATIONS AND NOTATIONS</b>                                      | <b>xi</b>  |
| <b>1 INTRODUCTION</b>   | <b>1</b>   |
| 1.1 MISSION REQUIREMENTS . . . . .                                      | 1          |
| 1.2 CONFIGURATION CHOICE . . . . .                                      | 1          |
| 1.3 SUMMARY OF WORK DONE AS PART OF THE AERODYNAMIC<br>DESIGN . . . . . | 2          |
| 1.3.1 Data Obtained from Literature Survey . . . . .                    | 2          |
| 1.3.2 First Weight Estimate . . . . .                                   | 2          |
| 1.3.3 Second Weight Estimate . . . . .                                  | 3          |
| 1.3.4 Views of the Designed Airplane . . . . .                          | 3          |
| 1.3.5 V-n Diagram . . . . .   | 5          |
| 1.3.6 Some performance parameters . . . . .                             | 5          |
| 1.4 Bill of Materials with suggested Vendors . . . . .                  | 6          |
| <b>2 WING DESIGN</b>  | <b>7</b>   |
| 2.1 WING LOAD DISTRIBUTION . . . . .                                    | 7          |
| 2.2 Spar design . . . . .   | 10         |
| 2.2.1 Spar under bending stress . . . . .                               | 10         |
| 2.2.2 Spar under shear stresses . . . . .                               | 11         |
| 2.2.3 Spar under bucking stresses - web . . . . .                       | 13         |





## LIST OF TABLES

|     |                              |   |
|-----|------------------------------|---|
| 1.1 | Data of similar airplanes(5) | 2 |
| 1.2 | Aircraft cost estimation     | 6 |



## LIST OF FIGURES

|     |  |    |
|-----|--|----|
| 1.1 | Mission Profile . . . . .                                    | 1  |
| 1.2 | Three view and isometric view of the airplane . . . . .      | 4  |
| 1.3 | Flight envelope: V-n diagram for the given airplane. . . . . | 5  |
| 2.1 | Lift Distribution per unit span of wing . . . . .            | 8  |
| 2.2 | Bending Moment diagram due to lift . . . . .                 | 9  |
| 2.3 | Shear force Diagram due to lift . . . . .                    | 9  |
| 2.4 | Spar cross section . . . . .                                 | 10 |
| 2.5 | Shear force Diagram . . . . .                                | 11 |
| 2.6 | Bending Moment diagram . . . . .                             | 12 |
| 2.7 | Shear flow around spar section . . . . .                     | 13 |



## ABBREVIATIONS AND NOTATIONS

|          |                                |
|----------|--------------------------------|
| $2D$     | Two dimensional                |
| $3D$     | Three dimensional              |
| $\alpha$ | 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 |
| $\sigma$ | 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 airbase strip as Fig 1 shows.

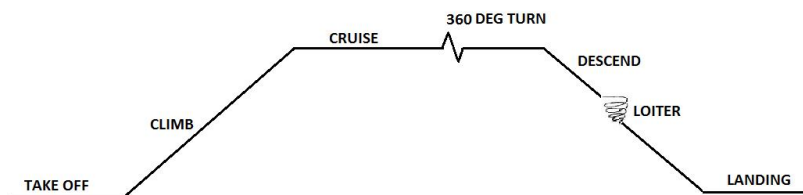


Figure 1.1: Mission Profile

### 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 characteristics, 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            | Worcester<br>I | Worcester<br>Polytec. II | Cincinnati<br>University | SAE MicroClass<br>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**

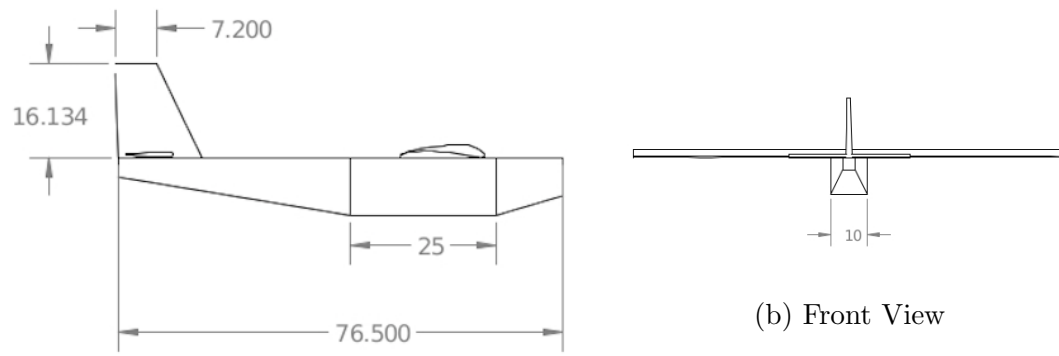
The second weight estimate was done by choosing our powerplant by taking data from the chosen airfoil. The chosen powerplant is

- 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.

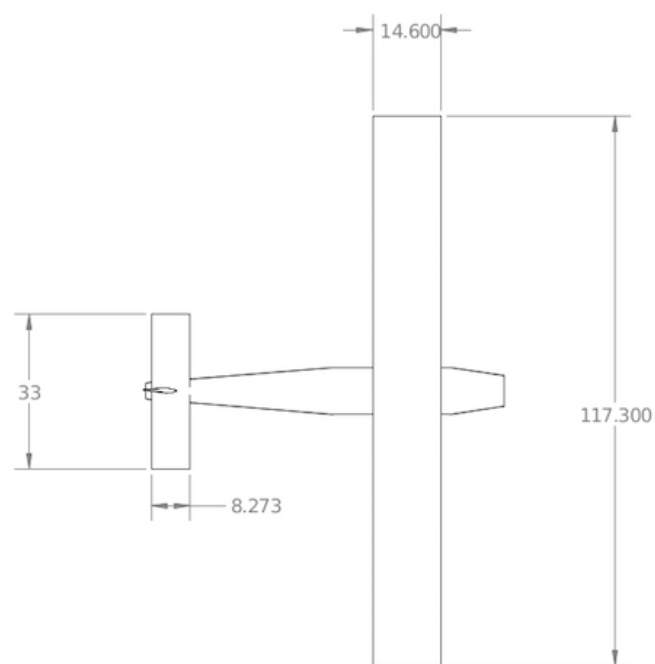
### **1.3.4 Views of the Designed Airplane**

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

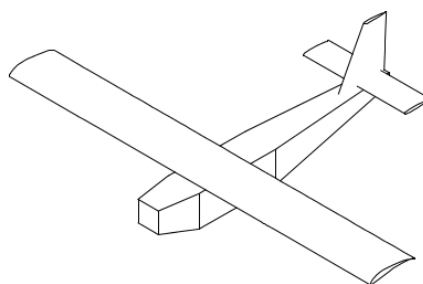


(a) Side View

(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.

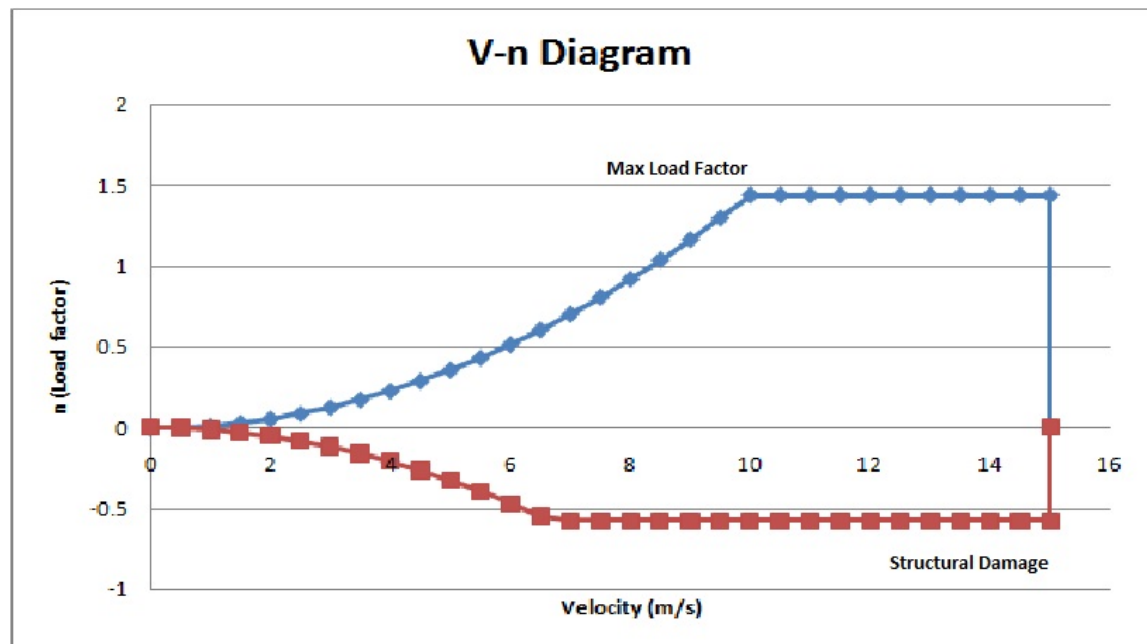


Figure 1.3: Flight envelope: V-n diagram for the given airplane.

### 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 :  $93.342 \text{ N/m}^2$

## 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.

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

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 elliptical approximation gives us

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

The lift per unit span of the wing is given by

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

Since we are designing for maximum loads, we consider loads during takeoff

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

Therefore,

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

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

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

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

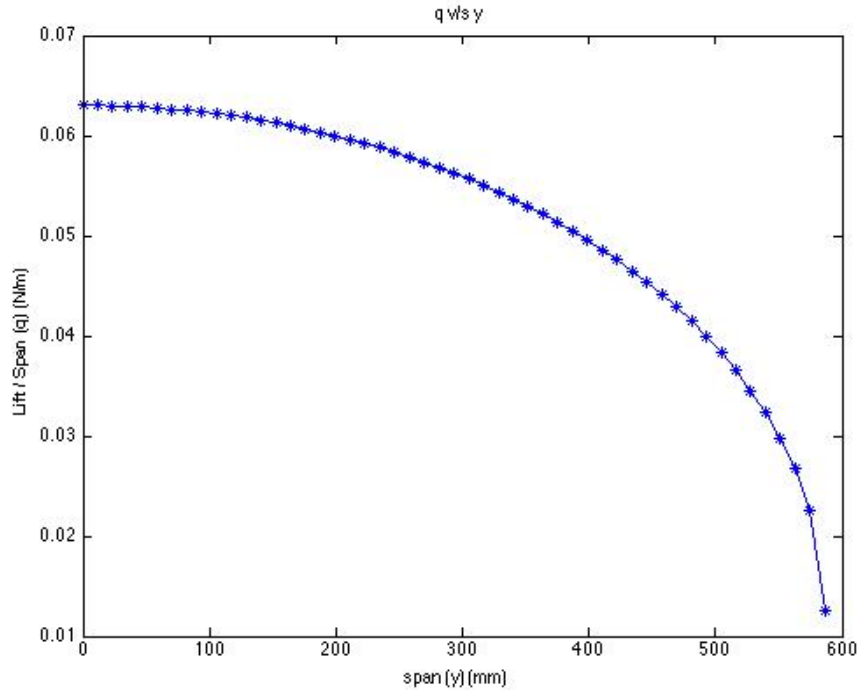


Figure 2.1: Lift Distribution per unit span of wing

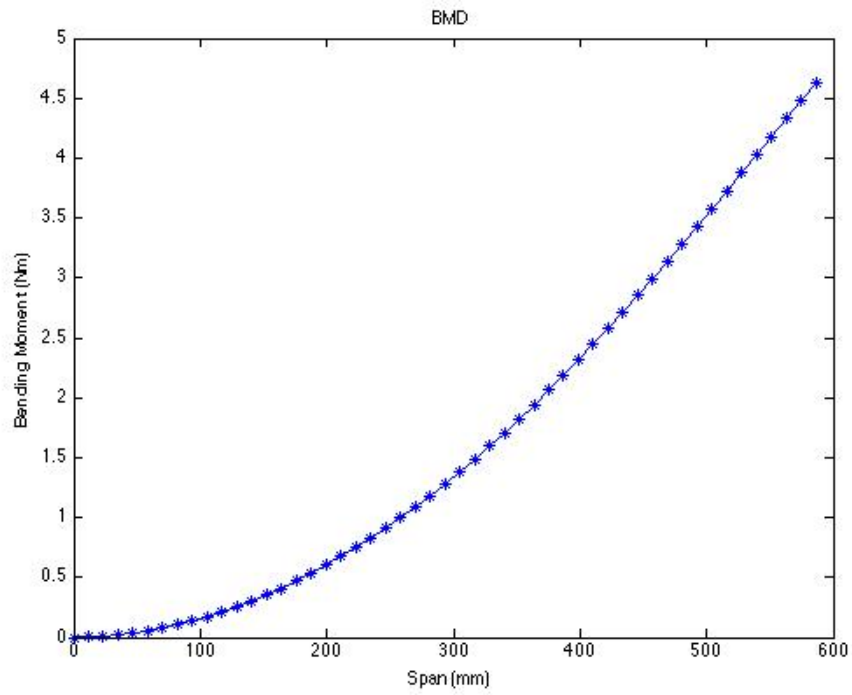


Figure 2.2: Bending Moment diagram due to lift

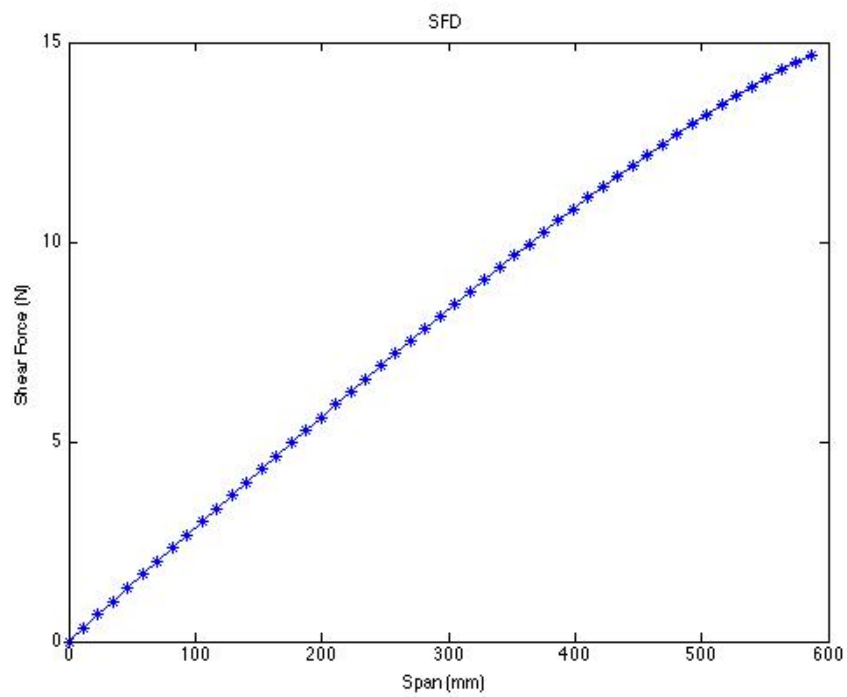


Figure 2.3: Shear force Diagram due to lift

## 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

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

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

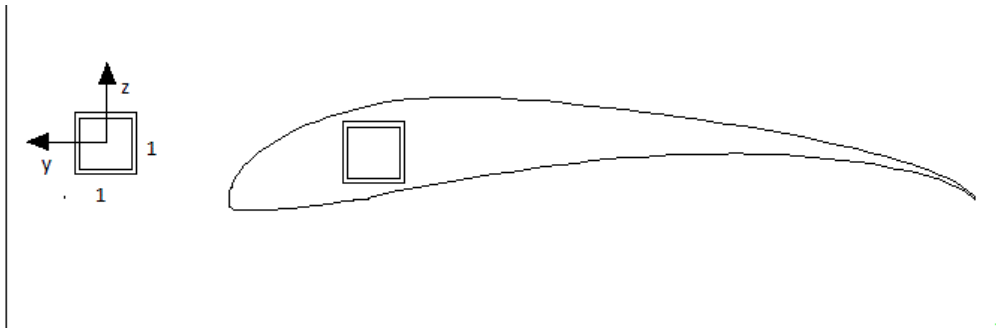


Figure 2.4: Spar cross section

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,

$$\sigma = \frac{M_z}{I_{yy}} \quad (2.7)$$

Using the spar cross section, we get  $I_{yy} = 2.16 \times 10^{-9} \text{ m}^4$ ,  $\sigma = 10.7$  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

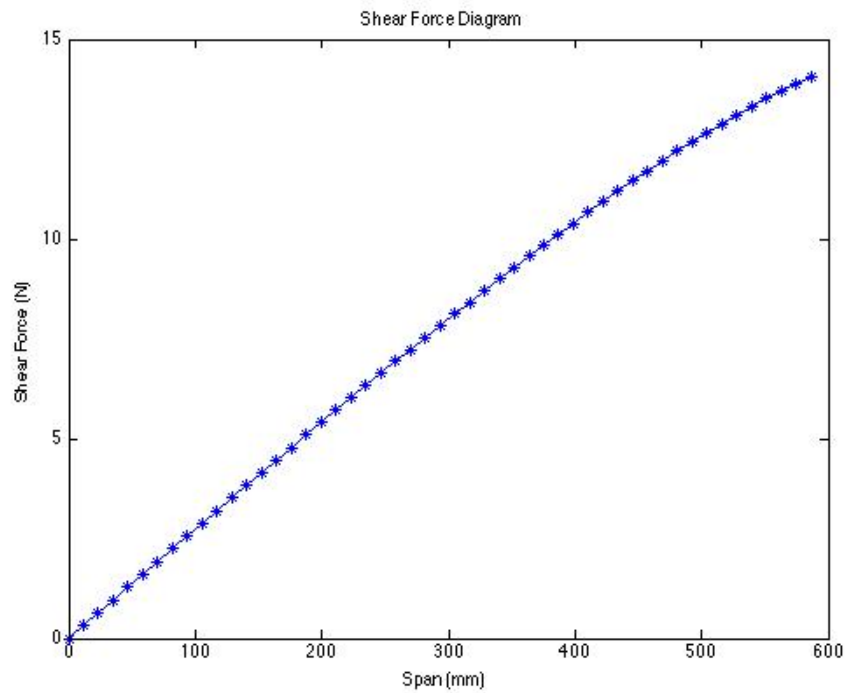


Figure 2.5: Shear force Diagram

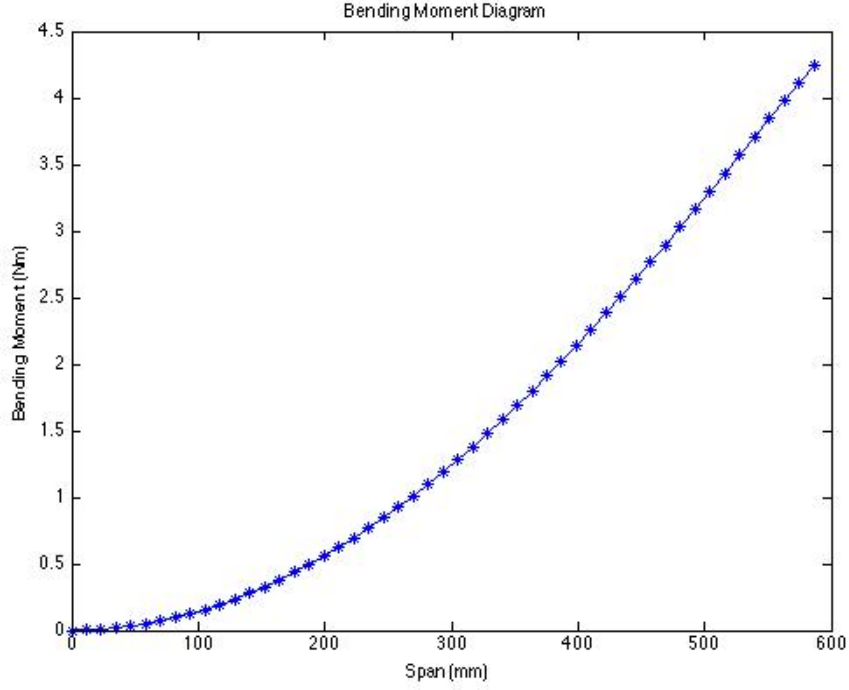


Figure 2.6: Bending Moment diagram

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

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

The shear flow through the section is given by

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

where,  $V_z = 14.06$  N,  $t = 1$  mm,  $T = 0.48$  Nm,  $A = 1$  cm<sup>2</sup>

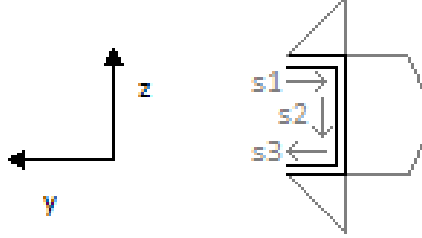


Figure 2.7: Shear flow around spar section

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

$$\tau_{max} = q_{max}/t \quad (2.10)$$

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

### 2.2.3 Spar under buckling stresses - web

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

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

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

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

## 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