A PROJECT REPORT

ON

"DESIGN AND DEVELOPMENT OF AN INDOOR AIRSHIP"

{GONDOLA (FIXED & SLIDING), AVIONICS, NOSE BATTEN}

Submitted by

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In partial fulfilment for the award of the Degree

Of

BACHELOR OF ENGINEERING

IN

MECHANICAL ENGINEERING

Under the guidance

of

Prof. Nawaz Motiwala

DEPARTMENT OF MECHANICAL ENGINEERING

ANJUMAN-I-ISLAM

KALSEKAR TECHNICAL CAMPUS NEW PANVEL,

NAVI MUMBAI – 410206

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ANJUMAN-I-ISLAM
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CERTIFICATE

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To the Kalsekar Technical Campus, New Panvel is a record of bonafide work carried out by him under our supervision and guidance, for partial fulfilment of the requirements for the award of the Degree of Bachelor of Engineering in Mechanical Engineering as prescribed by **University Of Mumbai**, is approved.

Project co-guide	**Internal Examiner**	**External Examiner**
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Head of Department	**Director**
(Prof. Zakir Ansari)	(Dr. Abdul Razak Honnutagi)

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APPROVAL OF DISSERTATION

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(Internal Examiner) (External Examiner)

____________________ __________________

Date: ___________

Declaration

We declare that this written submission represents our ideas in our own words and where others' ideas or words have been included, I have adequately cited and referenced the original sources. We also declare that we have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in my submission. We understand that any violation of the above will be cause for disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

(Signature)

(Name of student and Roll No)

Date:

Acknowledgment

After the completion of this work, we would like to give our sincere thanks to all those who helped us to reach our goal. It's a great pleasure and moment of immense satisfaction for us to express my profound gratitude to our guide **Prof. Nawaz Motiwala** whose constant encouragement enabled us to work enthusiastically. His perpetual motivation, patience and excellent expertise in discussion during progress of the project work have benefited us to an extent, which is beyond expression.

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Abstract

This research work aims at designing, development and fabrication of a remotely controlled indoor airship (gondola part) that could be used for camera surveillance, security and also can be used in opening ceremony to spray flowers, chocolate etc. This study shows selection of Gondola material, fabrication methods, and selection of suitable avionics parts. However there are many things which can be implemented in an airship. But in our case this is an indoor airship and a new thing which is sliding gondola is implemented in this airship to tilt the airship in case of pitch up & down and also in case of slight disturbance of center of gravity we can position the gondola in such a way that center of gravity coincides with the center of buoyancy.

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Abbreviation

AGL	Above Ground Level
AMSL	Above Mean Sea Level
AURORA	Autonomous Unmanned Remote monitoring Robotic Airship
BHP	Brake Horse Power
ESC	Electronic Speed Controller
GNVR	G.N.V. Rao envelop Profile for airship
GSM	Gram per Mean Square
GUI	Graphical User Interface
HTA	Heavier Than Air
LTA	Lower Than Air
IC	Internal Combustion
ISA	International Standard Atmosphere
LiPo	Lithium Polymer
KARI	Korea Aerospace Research Institute
NASA	National Aeronautics and Space Administration
NPL	National Physics Laboratory
PADD	Program on Airship Design and Development
PVC	Poly Vinyl Chloride
RC	Remotely Controlled
RF	Radio Frequency
SL	Sea Level
CG	Centre of Gravity

CHAPTER 1
Introduction

1.1Background

Airships are aerospace vehicles that get most of their lifting capability from 'static' lift using gases which are lighter than air, unlike aircraft that fly using the principles of dynamic lift i.e. wings (fixed or rotary). Airships are the most suitable aerial platforms for advertising and surveillance, as they offer advantages such as of long endurance, ability to hover with low noise and vibrations levels and low fuel consumption [1]. While most of the energy used by an airship is to propel it forward. Airships were widely used in the first half of the 20th century, for a variety of purposes, but the speed, power and glamour of conventional aircraft eclipsed the benefits of LTA vehicles for many years. Several studies are being carried out all over the world related to design, development and flight testing of unmanned, remotely operated and autonomous airships. The proposed objective of an airship varies from their use as high altitude platforms for the next generation of wireless communications system to transportation of large volumes over long distances. For better and safety flight many investigations have been launched worldwide to study the issues related to provision of operation capability to unmanned airships. The objective of this project is to design and fabricate a remotely controlled indoor airship that could be used for camera surveillance, security and also can be used in opening ceremony to spray flowers, chocolate etc. In the following subsections the classification, applications, and various components of an airship are explained in detail.

1.1.1 Classification of airship

There are four broad categories of airships viz. Rigid, Semi-Rigid, Non Rigid and Hot-Air airships.

Rigid Airships

As the name implies, rigid airships have an internal frame as shown in Fig1.1. The Zeppelins and the USS Akron and Macron are famous rigid airships [2]. The rigid structure, traditionally an aluminum alloy, holds up the form of airship. In general, rigid airships are only efficient when they are longer than 120 meters because a good weight to volume ratio is only achievable for large airships. For a small airship the solid frame would be too heavy. Use of composite materials may change this difficulty too.

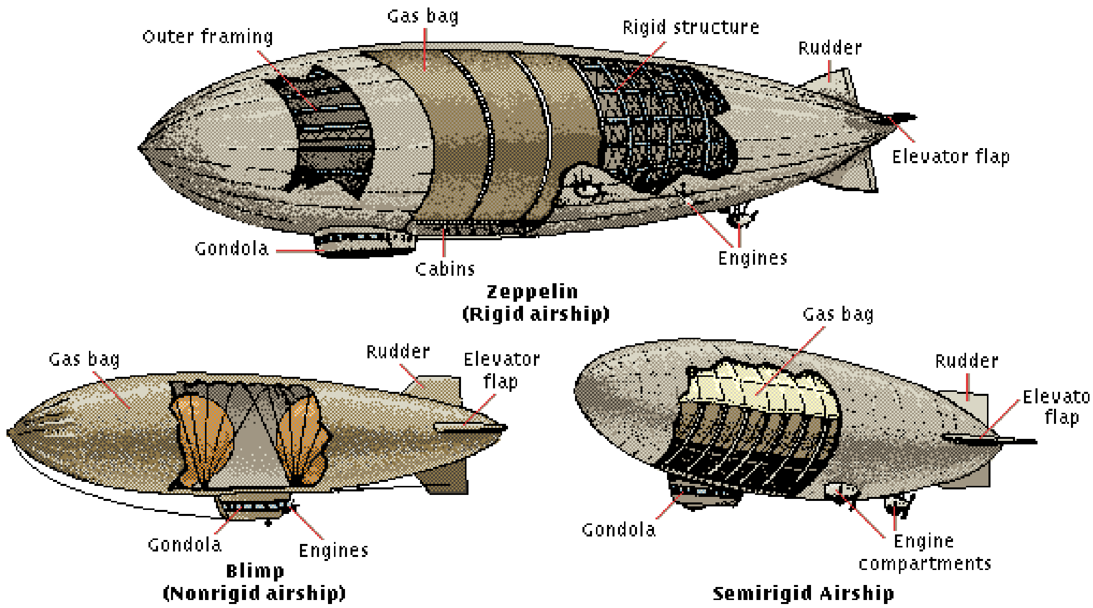


Figure 1.1Classification of Airship [3]

Semi Rigid Airships

Semi rigid airships are comprised of a rigid lower keel construction and a pressurized envelope above that as shown in Fig1.1. The rigid keel can be attached directly to the envelope or hung underneath it. The airship of Brazilian aeronaut Alberto Santos-Dumont was semi rigid [2]. One of the most famous representations of this type was Italia, the airship which General Umberto Nobile used on his attempt to reach the North Pole [2].

Non Rigid Airships or Blimps

Non Rigid airships, also known as blimps are basically large gas balloons as shown in Fig1.1. Their shape is maintained by their internal gas pressure. The only solid part is the passenger car and the tail fins. All the airships currently flying for publicity use are of this type; the Goodyear Blimps, MetLife blimps in U.S.A, the Fuji Blimp in Europe and the Vodafone blimp in India [2]. The main advantage of this type it is very easy for transportation.

Hot Air Airships

Hot air airships, also known as thermal airships, though technically are a part of non-rigid category, are counted as fourth type. Hot air airships are derived from traditional hot air balloons. Early models were almost like balloons with an engine and tail fins added. Very soon envelopes were lengthened and the tail fins and rudder were pressurized by air from the wash of propeller. Newer hot air airships maintain their shape with internal pressure in the envelope.

1.1.2 Applications of Airships

Following are the applications of an airship.

I. Advertising

The visual appearance of airship has always attracted the attention and the imagination of general public. This fascination with helium- filled airships creates the ultimate advertising vehicle and generates huge amount of money in revenue. As an eye in the sky, the airship provides good camera footage of outdoor events. Under special arrangements with T.V networks and cables, blimps carry the aerial camera without charge and reciprocally receive on air publicity at no cost [1].

Figure1.2 Airship used for advertising purpose [4]

II. Tourism

Figure1.3 Airship used for tourism purpose [5]

One of the most profitable and growing segments of the market where the need for the airship is more acute is tourism. There is an emerging demand to develop such an airship transport system in the commercial sector and it is considered that such a system could, in many ways, be utilized to stimulate interest in tourism and travel via lighter- than-air vehicles [1].

It can be used for scenic excursions exclusively or it can include transportation element, such as flying passengers to many attractive destinations or it could serve as inter island tourist routes, for example between the Hawaiian and Caribbean Islands without affecting the local environment. The impact of this type of travel transcends imagination [1].

Passengers in helicopters or aircrafts may enjoy comparable views but they will never experience the gentle pace of the airship, nor its spaciousness. Flight characteristics are smooth and unlikely to upset the passengers. Another surprise is the sound, or rather the lack of it. Engines can be cut for gentle and smooth ballooning over special scenic spots [1].

III. Other Civil Applications

- Aerial photography
- Forest Management
- Urban Energy Monitoring
- Hazard and Disaster Monitoring
- Industrial Heat Loss Monitoring
- Urban Planning
- Wildlife Studies
- Fire Spotting
- Soil Survey
- Pollution Monitoring
- Traffic Monitoring
- Resource Explorations

IV. Military Application

The need for improved surveillance techniques for military, government and scientific applications have increasingly led to the use of airships to meet specialized needs. Examples of operational duties performed by airships include:

- Command, control and communication Platform
- Precisely locate friendly and enemy forces
- Detect targets of an extended battlefield at minimal exposure to the enemy forces

- Real time targeting
- Navigation assistance
- Battle management
- Monitor radio conversations
- Maritime surveillance
- Border patrol /Law enforcement
- Mines detection

Figure 1.4 Airship used for Military purpose [6]

1.1.3 Components of Airship

The main components of an airship as shown in Fig 1.5 are as follows

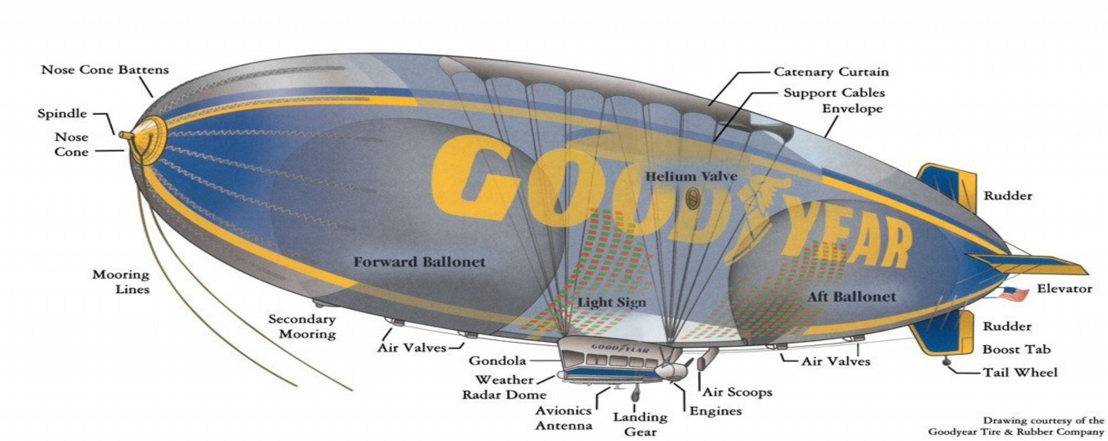


Figure 1.5 Components of Airship [7]

(a) Envelope

The envelope is the most crucial component of the airship and it integrates the aspects of aerodynamics, stability and payload. The envelope material has to be appropriately chosen to ensure adequate strength, durability, as well as low weight and ease for fabrication. There are various shapes of envelopes such as GNVR shape, a range of shapes given by NPL and Zhiyuan.

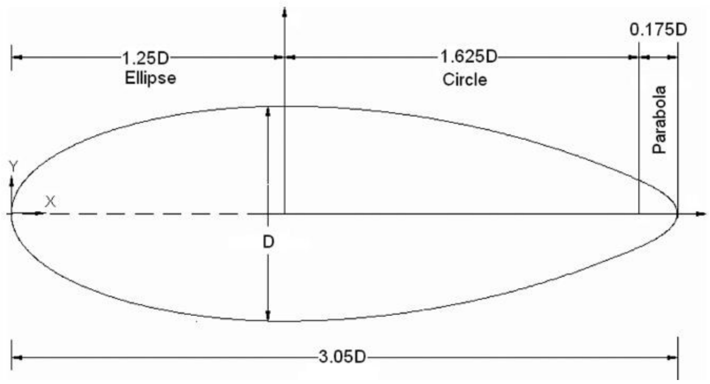


Figure1.6GNVR shape envelope [8]

GNVR shape consists of three standard sections, namely ellipse, circle and parabola and its entire geometry is analytically parameterized in terms of its max diameter D as shown if Fig1.6 whiles the NPL shape consists of two ellipsoids as shown in Fig1.7.

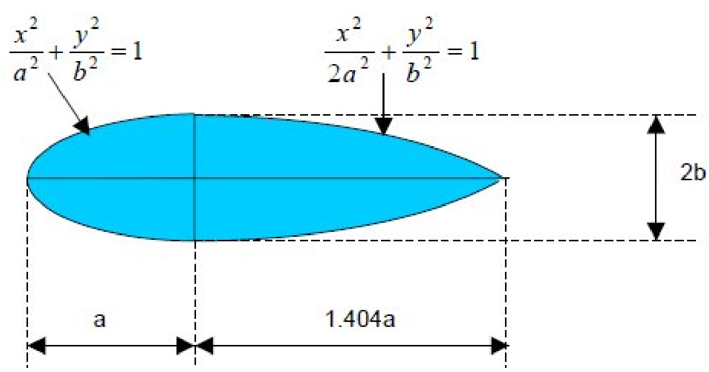


Figure1.7NPL shape envelope [9]

(b) Fins

The airship is directionally unstable, tending always to turn broadside on to the direction of motion so to ensure the stability of the airship tail fins are required. Apart from this the fins have effective control on the direction of airship, it keeps the blimp on its straight path and the extra power still allows for short turning when desired, and also keep the airship some distance away from the landing surfaces. There are different types of layout in which the fins are attached to envelope, which are as follows.

I. "X" type

In this type of configuration the takeoff angle is steeper, there is more ground clearance, less damage during ground strike etc. On the other hand it has more weight than "Y" type configuration as the number of fins is increased from three to four as shown in Fig1.8 and Fig1.9.

Figure 1.8 "X" type configuration for fin attachment [10]

II. "Y" type

It is less in weight as compared to "+" and "x" type layout. In this type the complete load of the aerodynamic forces comes on one fin while performing yaw motion. Hence it is suitable only for stationary Lighter Than Air (L.T.A) vehicles i.e. aerostats. Also rain and snow falling does not accumulate on fin.

Figure 1.9 "Y" type configuration of fin attachment [11]

III. “+” type or cruciform type

This arrangement is chosen to keep the tail out of the engines wake or to avoid complex interference drag. The loads of the aerodynamic forces are shared by two vertical fins for yaw motion and two horizontal fins while lifting.

Figure 1.10 “+” type configuration of fin attachment [12]

The choice of fin layout affects the number of fins, the total surface area and hence the weight of the fin structure. Based on the controllability criteria cruciform type is the most effective configuration.

(c) Gondola

It is also known as fuselage of airship. The gondola carries the airship payload and also houses the propulsion system. It is sized and designed such that it accommodates the receiver, battery package, fuel tank, engine and payload. The location for the attachment of gondola on airship must be carefully determined so as to keep the airship stable. The gondola may be an open structure or a closed one but the design should be such that it must be as light as possible so that it does not reduce the payload capacity of the airship. Open structure gondola and closed structure gondola are depicted in Fig1.11 and 1.12 respectively.

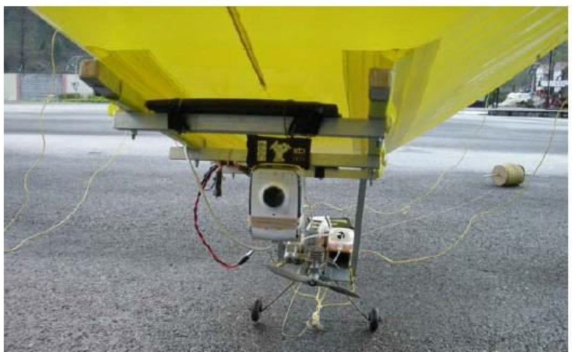


Figure 1.11 Open Structure Gondolas [9]

Figure 1.12 Closed Structure Gondola [13]

(d) Propulsion System

Propulsion systems are used in airship to provide the upward, forward and side thrust to the airship. Propulsion system of the airships are housed in gondola itself, except, in some of the cases where yaw motor is used to give the direct side thrust force is attached on the fin. There are some cases in which there is only one system which gives the action of both upward and forward thrust by swiveling the motors as required through thrust vectoring mechanisms as shown in Fig1.13 while

Figure1.13 Thrust Vectoring [14]

Yaw motion of airship is achieved through the use of control surfaces on the fins as shown in Fig1.14 or attaching a motor on the fin as depicted in Fig1.15, which provide the direct thrust force instead of depending on aerodynamic forces.

Fig1.14 Control surface on fin [9]

Figure 1.15 Airship with yaw motor mounted on fin [9]

(e) Surveillance Systems

Airships have been considered to be a highly viable airborne platform for aerial surveillance. The onboard surveillance equipment suite has to steadily focus on the desired area on the ground, from a particular altitude. The quality of the surveillance is directly related to the level of stability that the platform can offer. Hence the airborne platform must be able to hover at an altitude and stay steady without causing serious fluctuations to the dynamic surveillance data collection. The platform should be considerably inert to disturbances like crosswind, gust, wavering of the payload surveillance equipment due to maneuvering and induced vibrations by the platform itself.

(f) Power Source

Power Plant is of prime concern in the design of non-rigid airships. Design of power plant for non-rigid airship is affected by many parameters. Its sizing is primarily driven by the desired performance parameters such as max propeller speed, operating altitude, range and endurance. Other factors that affect the power plant design are engine location, symmetry of thrust, noise level, noise isolation, vibration isolation, fuel tank location. Aesthetics and ergonomics also play important role in the design process and lead to several compromises [13]. The power plant may be an engine may most probably an internal combustion engine or it may be battery operated, depending upon applications and various other factors listed above.

1.2 Motivation

A seminar was arranged by Mechanical Engineering Department. For final year students regarding final year project which was conducted by Dr. Rajkumar. S. Pant (Professor of Aerospace Engineering Department, IIT BOMBAY) which inspire us for selecting our final year project as indoor airship. At the same time another important point was the opportunity to do project work in an place like IIT.

From last decade the use of airship for various activities has increased tremendously and there are many ongoing projects worldwide on research and development of airships. However the boost in Lighter Than Air (L.T.A) Technology, its features such as low cost in operation, environment friendly and low manufacturing cost than that of Heavier Than Air (H.T.A) Vehicles, reduced complexity in design, vast field of application and scope for development has been a motivation to work in the field of LTA technology.

1.3 Aim and Objective

The aim and objective of the present study is to design and development of indoor airships, which can be remotely controlled. With the following objective

- It should be light in weight
- It should be strong
- Easy to attach or removal with envelope
- Offers negligible drag
- Nose battens should be light in weight and avoid damage to envelope
- Controlling range is upto 1 km

1.4 Literature Review

Till now very few researchers have carried out their work in the area of design of airships. The papers which deal with the present study of interest are discussed below.

Since more than a decade, several airships have been designed, fabricated and field tested by researchers in Lighter-Than-Air systems Laboratory in Aerospace Engineering Department at IIT Bombay under PADD (Program on Airship Design and Development). Three remotely controlled airship developed here, viz., *Micro*, *Mini* and *Macro* are shown in Fig 1.16- 1.18 respectively. A brief description of these airships is provided in the sub-sections that follow:

(a) *Micro* Airship

Gawale et al [2] gave the details of the envelope material to be selected along with the stress analysis and the fabrication of the same. *Micro* is non-rigid, Helium filled experimental aerial vehicle with envelope volume of 6.64 m^3.

Figure 1.16 Micro Airships [15]

The basic purpose of developing the *Micro* airship was to provide a first-hand exposure to issues related to airship design fabrication and operation. It also act flying platform for generation of airship design data and experimentation. The envelope material along with stress analysis and fabrication procedure for the same was considered. The design requirements specified for the *Micro* airship were very modest; it was required to have a payload capacity of 1.0 kg, while operating at a maximum speed of 30 kmph for 20 minutes, using an existing OSMG1415 IC engine, developing 0.41 BHP with a displacement of 2.49 cc. Due to constraints on storage space, it was required to be less than 5.00 m in length.

(b) *Mini* Airship

Subsequent to the successful development and flight demonstrations of *Micro* airship, the PADD team was invited by the Government of India to showcase their technology to the scientific community of India at a national science congress, and the PADD team developed the *Mini* airship for this purpose, which had an envelope volume of 8.64 m3, resulting in a payload capacity of 3.0 kg, and hence was capable of carrying out various missions, such as aerial surveillance. This airship was subsequently demonstrated at several other places.

Figure 1.17 Mini Airship [15]

(c) *Macro* Airship

Vishal Chaughle et al [9] describes the methodology followed for sizing of the envelope and various key components of airships and the procedure followed for in house fabrication and testing. They also highlighted the major issues that cropped up during the operation of airship in harsh environmental conditions of rain and mild snow as well as at night time. The *Macro* airship was designed and fabricated for flight demonstration at an international symposium on Snow and Avalanches, held at Manali, India in 2009. Also validation of airship design code and testing of video downlink for the recorded video of airship was done for the same.

Figure 1.18 Macro Airships [9]

A comparison of the key features of these three airships is provided in Table 1.1

Table 1.1 Comparisons of Micro, Mini and Macro Airships [9]

Parameter	Micro	Mini	Macro
Length(m)	4.99	6.42	8.0
Envelope Volume(m^3)	6.8	8.6	26.6
Payload(kg)	1.0	3.0	6.0
Endurance(min)	17	18	25
Max Speed(m/min)	7.0	10	12
Engine Power(HP)	0.41	0.6	2.0

Rajkumar S. Pant [16] has presented a methodology for arriving at the base specifications of non-rigid airship of conventional configuration. The methodology presented calculates the volume required to carry a user specified payload and also arrives at the mass breakdown. Also the Sensitivity of parameters such as pressure altitude, ambient temperature, cruising speed, helium purity level, engine power, envelope length to diameter ratio etc. to the payload available or envelope volume required using the above methodology is presented.

Gawale et al [17] presented a brief description of a methodology for sizing and baseline design calculations of an RC airship meeting some user specified requirements. The section on design in the paper provides details of the standard envelope profiles for RC airships, types of materials use for envelope and fins and their properties, basic buoyancy and aerodynamic calculations, followed by stabilizer and fin sizing, and description of the propulsion system. The section on fabrication describes the Radio Frequency (RF) sealing method for realizing the envelope and fins, and discusses important issues related to the system integration and testing.

1.5 Problem Definition

- To design and fabricate gondola by selecting light and strong material
- To maintain the C.G of airship with sliding gondola mechanism

1.6 Scope

The scope of present work includes,

a) Investigating the fabrication methods of various components of existing indoor airships.

b) Use of more light and strong material is possible.

c) Entire gondola of an indoor airship can be made sliding.

d) Controlling range of an airship can be improved. Improving on the limitations.

e) Design of nose batten can be improved.

CHAPTER 2

Basic Principle, Aerostatics and Aerodynamics

2.1 Basic Principle

As shown in Fig 2.1 the airship works on a simple principle where weight is overcome by the lift force generated by the L.T.A gas, while the drag force is overcome by the thrust through the motors.

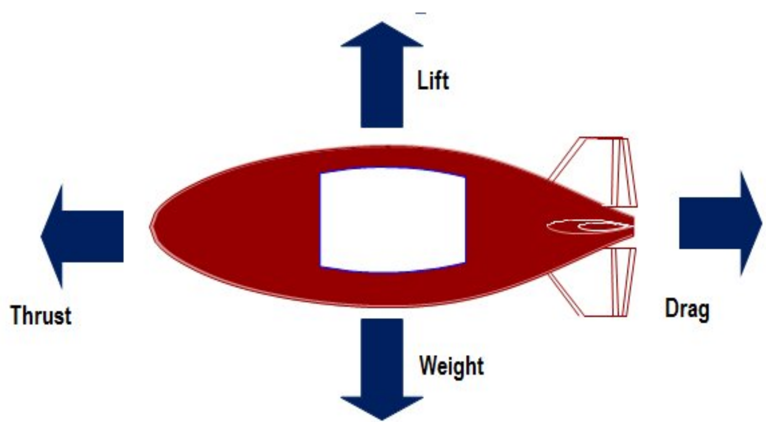


Figure 2.1 Basic Principle

The term aerostatics refers to the static buoyancy of any kind of body immersed in the atmosphere. Here the upward buoyancy force is equal to the weight of the fluid displaced, which in air may be taken as,

$$B = V\rho_a \tag{2.1}$$

Where, B is the upward buoyancy force acting on the body, V is the volume of the body and ρ_a is the mean density of the local atmosphere surrounding the body.

If weight, W of the body is made less than that of displaced air then there will be a net upward lift L given by,

$$L = B - W \tag{2.2}$$

The obvious case to be considered is that of a balloon incorporating a closed flexible envelope of volume V filled with gas of density ρ_g which is less than W_o for example hydrogen or helium therefore,

$$W = V\rho_g + W_o \quad (2.3)$$

Where W_o is the weight of envelope and all the attachments

Equations 2.2 and 2.3 can be combined to give:

$$L_d = V(\rho_a - \rho_g) - Wo \quad (2.4)$$

Where L_d is the disposable lift of the envelope.

The term (ρa-ρg) represents the gross lift per unit volume or "unit lift" of the combination of the gas in the envelope and the air outside it. At sea level in the International Standard Atmosphere (ISA), if the lifting gas is at the same temperature as that of the ambient atmosphere, pure hydrogen for example offers unit lift of 11.183N/m^3 while pure Helium, being twice as dense as hydrogen, generates a slightly lower unit lift of 10.359N/m^3.

So long as the gas in envelope is free to expand and the gas and the temperature remain same, disposable lift does not change with altitude. As the gas bag ascends, the gas and the air densities fall with decreasing pressure but gas volume increases in same ratio. Conversely, falling temperature tends to increase the densities but reduces the volume, so that the two effects again cancel out each other. In any real atmosphere the fall in pressure with altitude has more pronounced effect than the corresponding fall in temperature, so that during ascend the gas will continue to expand until the gas bag is completely filled and no further expansion is possible. The altitude at which this occurs is termed as "pressure height" because further ascend will cause the differential pressure across the skin of gasbag to increase, the lift however will decrease.

In conventional airships and balloon the gasbag skin, for minimum weight, is not designed for carrying stresses far in excess of those encountered below the pressure height, which is therefore regarded as an operational ceiling. If this height is exceeded in an emergency, safety valves release gas to protect the envelope against pressure rupture.

2.2 Aerodynamics

Aerodynamics forces occur when a body moves relative to air in which it is immersed. These forces are classified as steady when they are invariant with time or transient when they are not. The steady forces arise, for example, when a body is in uniform motion in a still atmosphere. Transient forces occur during maneuvers or owing to turbulence in the atmosphere. Aerodynamic forces and moments arise from local surfaces pressure, which, when integrated over the whole body, give the overall forces and moments. It is therefore necessary to determine the local pressures. The force on a very small area δA of a body is given by the product of the static pressure and δA. The application of Newton's Law to the motion of the fluid leads to Bernoulli's equation. For a non- viscous, incompressible fluid in steady motion this takes the form:

$$P_S + (\frac{1}{2}\rho V_S{}^2) = P_a + \frac{1}{2}\rho V^2 \qquad (2.5)$$

Where, P_S is the local static pressure, P_a is the static pressure, V_S is the local velocity at point under investigation, V is velocity of the fluid far removed from the body and ρ is density of the fluid everywhere.

2.2.1 Drag

It is a force opposing the motion of the airship. In order for airship to move , it should overcome the drag force. Drag is therefore of primary importance. Also the selection of the power plant is dependent on amount of drag.

2.2.2 The Bare Hull

It is advantageous to express all aerodynamics forces and moments on a body in non-dimensional form. Aerodynamic forces are divided by the head of the incident flow V and reference area A. Thus the lift C_L and the drag C_D coefficients are expressed as:

$$C_L = \frac{Lift}{\frac{1}{2}(\rho V^2 A)} \qquad (2.6)$$

$$C_D = \frac{Drag}{\frac{1}{2}(\rho V^2 A)} \qquad (2.7)$$

In these two equations only A is defined. The lift of the airship is produced almost entirely by wing so that the relevant area is the wing plan area. The lift of the buoyant airship is related directly to its volume so S is often chosen to be (buoyant volume)$^{2/3}$. However, owing to large surface area of buoyant airship, skin friction drag is the largest friction of the total drag. For these reasons many reports use force coefficients in which A is the surface area. Care must be taken when comparing non-dimensional coefficients taken from different publications to check whether same variables have been used. It is possible to determine a conversion factor between the two non-dimensional forms a particular class of shapes. For bodies of revolution of Length '□', Maximum diameter 'D' and with fixed volume,

$$D^2 □ = constant \qquad (2.8)$$

Young (1939)[18] calculated the variation of A/l^2 as in function of D/l. The ratio D/l is the thickness ratio of the body. Using the ratio D/*l,* however, produces simpler approximate formulae for drag. Although D/*l* is the ratio it is expressed by the value of D as a decimal of *l*. The result, for $0 < D/l < 0.35$ is almost a straight line.

$$\frac{A}{l^2} = 2.33\frac{D}{l} \quad (2.9)$$

Young (1939)[22] also showed that the volume satisfies the relation :

$$\frac{V}{l^3} = 0.465\left(\frac{D}{l}\right)^2 \quad (2.10)$$

If C_{DV} and C_{DA} and are the drag coefficients of a particular body made non- dimensional by $(Volume)^{\frac{2}{3}}$and surface area A respectively, then:

$$\frac{C_{DV}}{C_{DA}} = \frac{A}{(Volume)^{\frac{2}{3}}} = \mathbf{3.88}\left(\frac{l}{D}\right)^{\frac{1}{3}} \quad (2.11)$$

Minimum skin friction drag will result from minimum surface area. The variation of drag as thickness ratio, D/l, is varied is derived and examined by Young (1939) [18].

2.3 Aerostatics

An airship is dependent on the principles of buoyancy for its primary lift. The buoyancy is dependent on the density of displaced fluid and therefore the properties of this fluid are of great concern. In the case of an airship, the fluid in which it operates is atmosphere. The change in properties of atmosphere does matter, even in a relatively small region in which airship operates. It is therefore, extremely valuable to be aware of the changing properties of the atmosphere for understanding the aerostatics of an airship.

2.3.1 Buoyancy and Static Lift

These are several terms which are used extensively in aerostatics. The following are brief explanations of these terms.

Buoyancy (B)

Buoyancy is a force which is equal to the weight of the fluid which a partially or completely submerged body displaces. The force acts in the direction in the opposition to the weight i.e. vertically upwards. The term buoyancy is primarily used in hydrostatics, while in aerostatics the term static lift is used.

Gross Static Lift (Lg)

The gross static lift is the true equivalent of the term buoyancy and is equal to the weight of the air displaced by the envelope volume. So,

$$L_g = V_g \rho_a \tag{2.12}$$

Where V_g is the volume of envelope.

Net Static Lift (Ln)

The net static lift is the gross static lift less the weight of the contained gases and the self-weight of the envelope. So,

$$L_n = L_g - (W_g + W_e) \tag{2.13}$$

Where W_e is the self-weight of Envelope.

Centre of Gravity (CG)

The center of gravity is the point through which the weight of an object acts.

Centre of Buoyancy (CB)

The centre of buoyancy is the centre of gravity of the displaced fluid. It is the point through which the static lift acts.

Static Heaviness (SH)

The static heaviness is the amount by which the weight of an airship system exceeds the net static lift. The airship system comprises the airship vehicle and its systems, all the fluids (fuel, oil, motor, batteries etc.), the crew, payload and ballast. So,

$$S_H = W_{airship} - L_n \tag{2.14}$$

If the airship is equal to the net static lift, then it is said to be in equilibrium. The vehicle could also be statically light (or have a negative heaviness) if the net lift exceeds the airship weight. It is generally preferred for the airship to be heavy for control purposes, but it is also usually a requirement for the airship to quickly attain, or get near to equilibrium in case of emergency.

CHAPTER 3

Design and Development

3.1 Estimation of Volume or Payload

Pant, R.S [19] has given a methodology for arriving at the baseline specifications of a non-rigid manned airship. This methodology works in two ways, either it estimates the envelope volume required for designing an airship to carry a user-specified payload, or it estimates the payload that can be carried by an airship with a given envelope volume. The estimates in this work are mostly derived by obtaining trends for variations of the key design parameters using a database of nearly 21 existing airships, as listed in Appendix I. In some of the cases in which the relevant data was not given, it was extracted by using “Grabit” a MATLAB™ GUI script as shown in Appendix II. Fig 3.1 shows the flowchart of this methodology. In the present study it is planned to develop a similar methodology for outdoor remotely controlled airship.

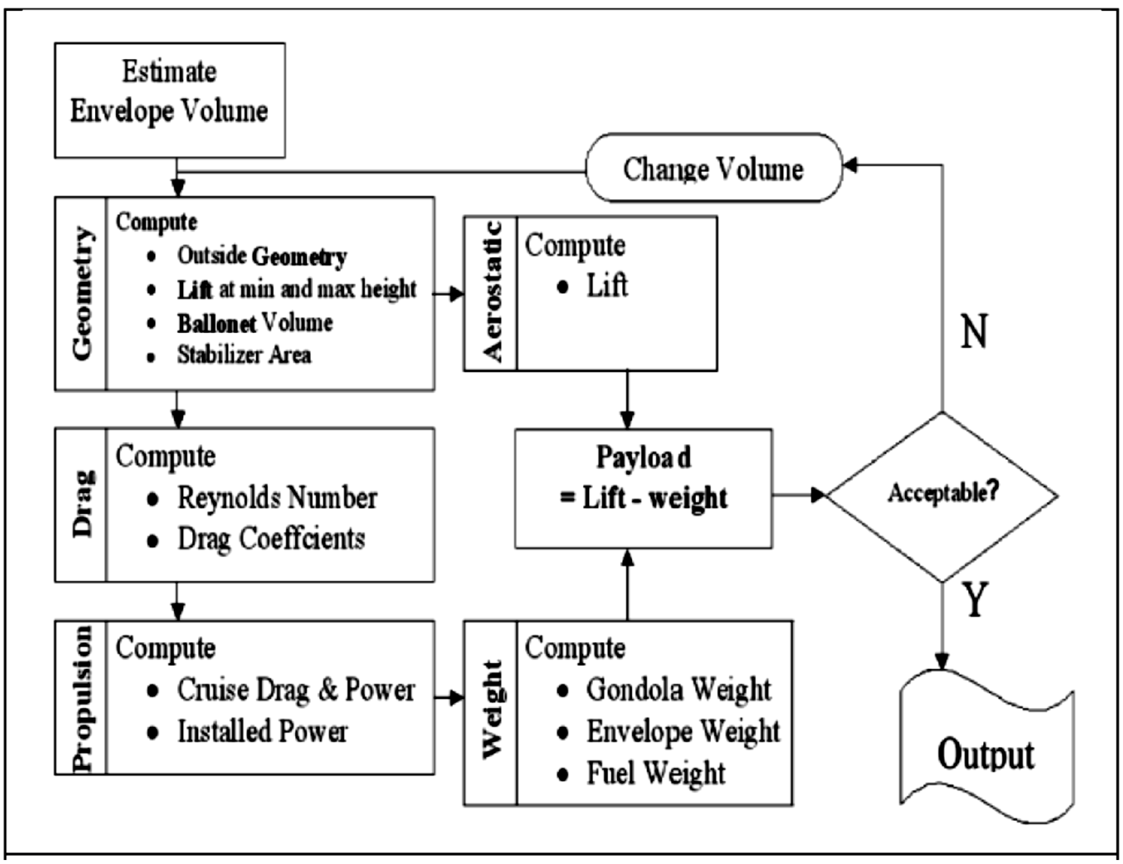


Figure 3.1 Methodology for arriving at the baseline specifications of airships [19]

3.2 Drag Estimation for Airships

Predicting CDV Variation for the General Class of Airship Envelope Shapes

Hoerner [20] in his book combined a lot of experimental data and proposed the follow

$$\frac{C_{DV}}{C_f} = 4(\frac{\mathrm{l}}{\mathrm{d}})^{\frac{1}{3}} + 6(\frac{\mathrm{d}}{\mathrm{l}})^{1.2} + 24(\frac{\mathrm{d}}{\mathrm{l}})^{2.7} \quad (3.1)$$

$$C_f = \frac{0.043}{\mathrm{Re}^{\frac{1}{6}}} \quad (3.2)$$

The constant in the C_f value is indicative of practical surface roughness.

Combining Equations 3.1 & 3.2 gives:

$$C_{DV} = \frac{[0.172(l/d)^{\frac{1}{3}} + 0.252(d/l)^{1.2} + 1.032(d/l)^{2.7}]}{Re^{\frac{1}{6}}} \quad (3.3)$$

$$Re = \frac{\rho v l}{\mu} \quad (3.4)$$

Where,

Cdv= Coefficient of drag

L= Length of airship in m.

D= Diameter of an airship in m.

Re= Reynold's number.

ρ= Density of fluid in kg/m³.

v= Mean velocity of stream in m/s.

μ= is the dynamic viscosity of the fluid in N·s/m².

The value of μ as per temperature 90°F is 0.000018673 Ns/m² given in the Appendix IX.

For zeppelin airship the approximate coefficient of drag is calculated as below

$$Re = \frac{1.125 \times 3 \times 4}{0.000018673}$$

$$Re = 7.2296 \times 10^5$$

$$C_{DV} = \frac{[0.172(3.0235)^{\frac{1}{3}} + 0.252(0.3307)^{1.2} + 1.032(0.3307)^{2.7}]}{7.2296 \times 10^5}$$

$$C_{DV} = 0.0388$$

3.3 Identification of Material for Gondola

Gondola construction materials are assessed based on their strength, weight and ease of manufacture. The properties of a number of materials are shown in Table 3.1 and 3.2

1. Thermoplastic and metal

parameter	Carbon fiber	Light density polyethylene	Acrylic sheet	Aluminium
Density	1750kg/m^3	950kg/m^3	1190kg/m^3	2700 kg/m^3
strength	3.5Gpa	25Mpa	65Mpa	100-350Mpa
Cost	Rs.1000-1200	Rs.300-350	Rs.103	Rs.115
Size	300*100*1.5mm	305*305*2.2mm	297*210*2	1kg
Reference	http://goo.gl/jO9Eu0	http://goo.gl/nSuaSM	http://goo.gl/PGOyB9	http://goo.gl/gFLH5

Table 3.1 Properties of Materials for Gondola

2. Woods and others

Parameter	Bamboo	Balsa wood
Density	350kg/m^3	150kg/m^3
Strength	16Mpa	19.9Mpa
Cost	-	Rs90-100
Size	-	100*100*2mm
Reference	etd.lsu.edu/docs/available/etd-04022004-144548/.../Li_thesis.pdf	http://goo.gl/3sdY2E

Table 3.2 Properties of Materials for Gondola

3.4 Design of Sliding Gondola

Gondola carries payload and all other equipment's it must be rigid enough to carry a load and must be enough to absorb the shock load during landing. Also it should be aerodynamically shaped to have drag during flight.

We know that gondola carries avionics as well as payload therefore it has comparatively more weight and we have to fix it very carefully at the center of gravity, even though we fix it properly but after some time there will be some variation in C.G because the gas continuously leaks from the envelope so there is a possibility for an airship to tilt a bit and to avoid this problem we need a sliding gondola, no matter where we fix the gondola if there is a variation in C.G then with the help of remote controller we can set the position of the gondola.

Secondly if we want to fly an airship from one point to another point and that another point is at an altitude then the airship will misbalanced but if we install sliding gondola then the variation in C.G can be controlled by changing the position of gondola and hence better control can be achieved. And at last sliding gondola offers pitching up and down of an airship so we can control pitching movement of airship.

Benefits of Sliding Gondola

1. If we use sliding gondola we don't have to worry about C.G, we can fix it after installing the sliding gondola.
2. We know the gas (Helium, Hydrogen etc.) continuously leaks from an envelope because of diffusion, because of that after sometimes if we observe then there is a possibility that the C.G of an airship may change and if we use sliding gondola instead of rigid gondola with the help of remote controller we can any time place the gondola so that the C.G of entire airship maintains.
3. We can pitch up and down of the airship, at any time we can slide the gondola backward and tilt the gondola accordingly with the help of remote control.

Figure3.2: Airship with sliding gondola

(Where the gondola doesn't slide backward)

Figures3.3: Airship with sliding gondola

(Where the gondola slides backward)

3.5 Design Fixed Gondola

The gondola or car is an aerodynamically shaped vessel, similar in principle to the fuselage of heavier-than-air craft, provided to house the crew, passengers and airship's general system. (Chamberlain, 1984), the term gondola may arise from early zeppelin terminology owing to their boat-like appearance. Certainly, some pervious airship gondolas have been used to enable airships to settle on water (Williams, 1974); an attribute that may be deemed highly desirable [21].

As airship size increases the proportion of gondola suspended mass to the overall airship mass increases, the gondola becoming more of a burden to support. At the same time the envelope's ability to support the suspended mass without significant distortions occurring diminished with increased size. As a result the gondola's length becomes increasingly important, to be able to spread the load over a sufficient length of the envelope [21].

Depending on overall configuration, the gondola may be designed to carry the propulsion and power units, fuel, ballast, water recovery system (if used), landing gear, electrical systems, avionics, envelope air supply, furnishings, general equipment, mission and other systems of the airship. As such it is the working centre of the airship and so should be designed for a variable interior arrangement. It should be located such that when fully laden the suspended weight centre of gravity (CG) is roughly below the lifting gas centre of buoyancy (CB). Variable masses (fuel, ballast, crew and passengers, etc.) should be located within the gondola maintain overall airship balance. The straight parts are much easier to manufacture than curved parts. However, the curved surface gives an airship a more aerodynamic and smooth finish. So, it is necessary to design a system, which should be easily manufactured and aesthetically look better [21].

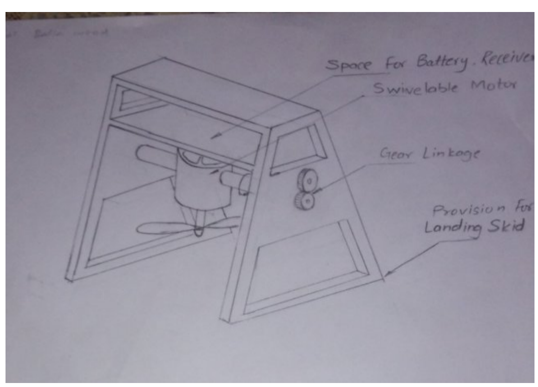


Figure 3.4 Conceptual sketch of Gondola

CHAPTER 4
Fabrication

4.1 Material Selection and Fabrication:

The material to be used for making gondola should be selected based on criteria such as strength, weight and ease of manufacture. After studying many materials shown in the table above we come across one material which is strong, light and aesthetically good looking called “Acrylic” from above Table 3.1. And open structure shape is selected for gondola construction as it conforms to the requirement. Fabrication is started by making conceptual prototype so as to compare size of gondola with the help of plastic corrugated sheet. After some refinements in the prototype gondola is fabricated as shown in Fig 4.1 (b). The gondola is designed in such a way that it has enough space for all equipments and ensures the uninterrupted rotation of lift and thrust propellers.

Figure 4.1 Prototype Gondola

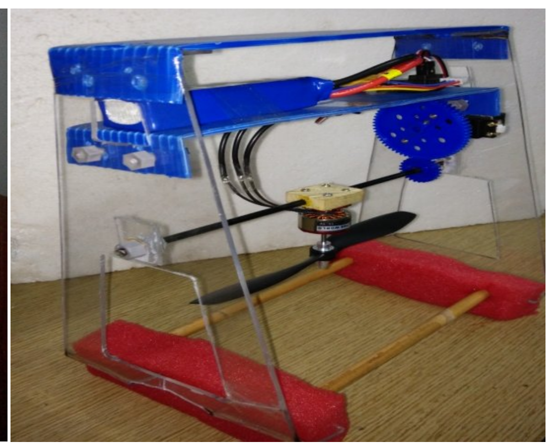


Figure 4.2 Fabricated Gondola

4.2 Attachment of Gondola:

Attachment of gondola with the envelope is one of the critical challenges while designing airship since whole gondola weight is concentrated on the bottom of an airship. After studying different attachments for e.g. Ribbon attachment, Velcro attachment etc. We selected one of the strong and ease to attach called “Fixed Attachment”. In this attachment patches are sealed with the envelope at some desired location through which wooden piece is passing. Our attachment is shown below:

Fig 4.3 Fixed attachment of gondola

Fig 4.4 Marking of Gondola Patches

4.3 Avionics (Propulsion System):

Avionic systems include communications, navigation, the display and management of multiple systems, and the hundreds of systems that are fitted to airship to perform individual functions.

These can be as simple as a search light for a police helicopter or as complicated as the tactical system for an airborne early warning platform.

Fig 4.5 Avionics of Airship [22]

The propulsion system of airship consists of two brushless DC motors, one of them are mounted on gondola as shown in Fig. 4.5 which is used for generating lift as well as forward for thrust. One motor is mounted on bottom fin, as shown in Fig. 4.6 which control yaw motion of airship. On servo motor is also used to swing main motor to acts as lift & thrust depending upon flying condition.

The all accessories were powered by one battery of 11.1V and 2200mah. Electronic Speed Controllers (ESC) compatible with the motors were used. The Yaw motor uses a 6A ESC and the thrust motor and lift fan use a 30A ESC both were powered by a 3S Lithium Polymer battery as per AppendixVII.

4.3.1 Selection of Main Motor:

Main motor i.e. Thrust motor is selected on the basis of drag facing by the airship hull. The thrust motor should be able to overcome drag offered by the airship. The drag calculated on the airship is as follows;

$$D = \frac{1}{2}\rho_{air} v^2 V^{\frac{2}{3}} C_{DV} \tag{4.1}$$

$$= \frac{1}{2} \times 1.125 \times 3^2 \times 3.6739^{2/3} \times 0.039$$

$$= 0.458\text{N or } 0.0466\text{kg}$$

Based on this value of drag the main motor i.e. thrust motor is selected from the Appendix III. The specification of the motor is given in the below table 4.1 and 4.2

Figure 4.6 Thrust and Lift motor for indoor airship

Parameters	Value
Weight (gm)	39
RPM / V	1200
Battery on of Cells (LiPo)	2-3
Max. Current (A)	15
Max. Power (W)	140
Suggested Propeller	9*4-10*5
Thrust (g)	580-710

Table 4.1 Lift and Thrust Motor Specifications

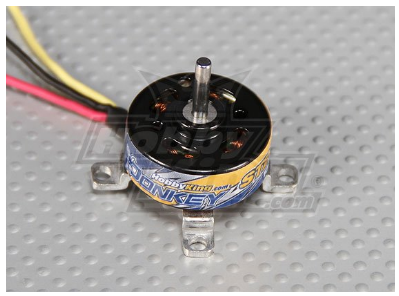


Fig 4.7 Yaw Motor for indoor airship

Parameters	Value
Weight (gm)	33
RPM / V	1550
Battery on of Cells (LiPo)	2
Max. Current (A)	10
Suggested Propeller	7*3.5
Thrust (g)	370

Table 4.2 Yaw Motor Specifications

4.3.2 Yaw Motor Attach To the Fin

Figure4.8 Yaw Motor Attach To the Fin

4.3.3 Thrust Vectoring System (Selection of Servo Motor)

Since only one motor is used for lift and thrust therefore it is required for swing the main motor through some angle in order to have lift or thrust depend upon flying condition this is achieved by swelling main motor with the help of servo through some gear arrangement.

Servo motor is selected on the basis of torque required to swing the shaft on which main motor is mounted. Torque required to swing the shaft due to two type of load.

I. Torque due to static load
II. Torque due to dynamic load

Torque due to static load will be minimum as compared to torque due to the dynamic load the torque due to dynamic load can be calculated as follows.

$$C = I * \omega * \omega_P \tag{4.2}$$

Where,

C = Gyroscopic torque

I = mk^2 =Moment of inertia of motor and propeller

ω = Angular velocity of propeller

ω_P = Precessional Angular velocity of servo motor

m = Mass of motor and propeller

k = Radius of gyration of propeller

N = rpm of propeller

$$I = 0.05886 \times (0.55 \times 0.1016)^2$$

$$I = 1.84 \times 10^{-4}\text{Nm}^2$$

$$\omega = \frac{2\pi N}{60} = \frac{2\pi \times 13320}{60} = 1394.86\, rad/s$$

$$\omega_p \frac{2\pi \times n}{60} = \frac{2\pi \times 33.33}{60} = 3.49\, rad/s$$

$$C = 1.84 \times 10^{-4} \times 1394.86 \times 3.49 = 0.8957\, Nm$$

$$C = 8.9757\, Kg - cm$$

The servo used should be greater than torque calculated above from the appendix IV. Hence we used servo shown below

Figure 4.9 Servo Motor

Table 4.3 Servo motor specification

Parameters	Value At 4.8V	Value At 6V
Weight	55	55
Standing Torque	13 kg.cm	15 kg.cm
Speed	0.31 sec/60 deg at no load	0.28 sec/60 deg at no load
Idle current	250mA at stopped	300mA at stopped
Running current	2000mA at no load	2200mA at no load
Operation travel	60°±10°	60°±10°

4.3.4 Connection of Motor with Receiver

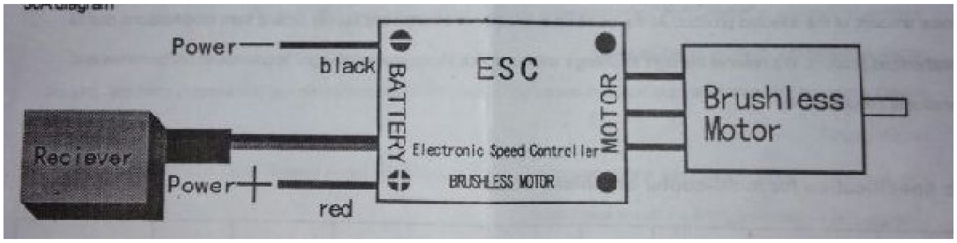


Figure 4.10 Schematic circuit diagram of motor connection

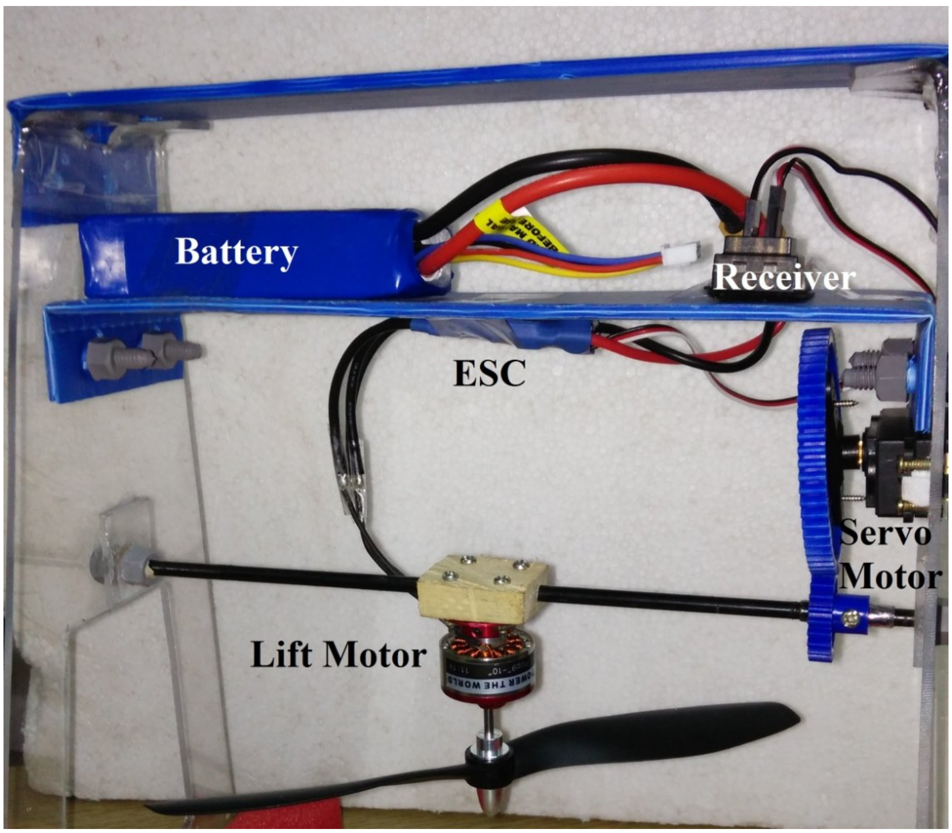


Figure 4.11 Actual connection

4.4 Remote Control Systems

Remote control system uses a transmitter and receiver, ESC (electronic speed controller) etc. ESC used is selected on the basis of current drawn from the main motor as shown in the Appendix VIII. Main motor i.e. thrust motor uses 30A ESC and Yaw Motor uses

A 5 channel Turnigy transmitter and receiver with controlling range of 1km are used to steer the airship. It is shown in Fig 4.8.

Figure 4.12 DYS 30A ESC

Figure 4.13 5 Channel Remote Control

4.5 Sliding Gondola

Sliding gondola moves on the track which can be controlled by remote. Sliding gondola is made up of plastic corrugated sheet in order to carry some payload. The payload capacity of sliding gondola is 150grams. Small micro servo is used to drop payload items which are flowers, chocolate, sparkles, playing cards etc. The location of gondola is near the nose of as airship shown below

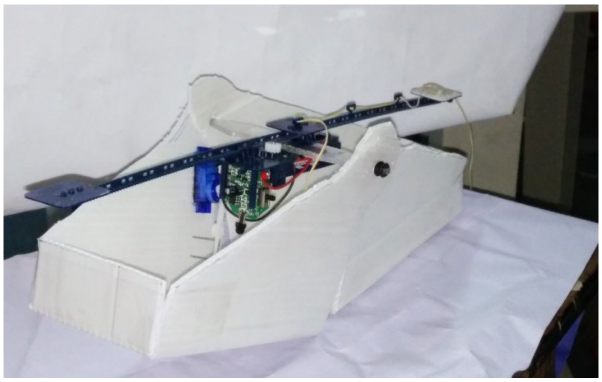


Fig4.14 Sliding Gondola

Fig 4.15 Attachment of Sliding Gondola

4.6 Nose Battens

Nose batons are used to provide rigidity at the nose. Non rigid airships need to membrane against the aerodynamic pressure during flight, to prevent it from imploding. In its simplest form the nose reinforcing comprises an external set of identical members arranges in a regular pattern, like the spokes of the wheel, around the envelope longitudinal center line. A light weight, rigid nose batten assembly for mooring a lighter than air vehicle consists of a semi cone shape structure, which includes a small base ring connecting the detachable outer ring through struts. This assembly is deployed upon inflation of the containment chamber (hull), and is freely collapsible during the deflation process. The use of collapsible nose battens on airships allows it to be collapsed and stored in a small space. The airship is attached to mooring mast by means of nose batons.

One of the major problems while designing nose baton is that there are the chances of bow stiffening shown in figure 4.13.

Figure 4.16 Nose Batten of an Airship [23]

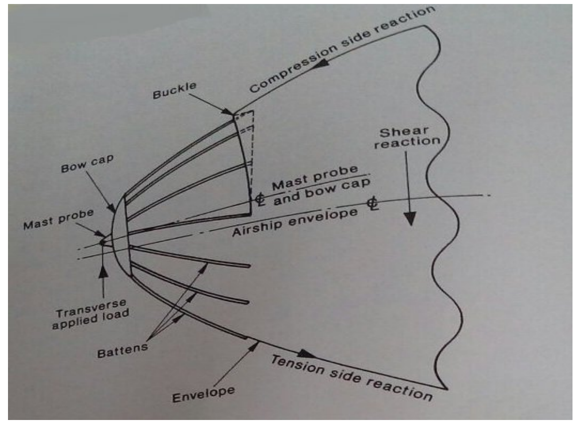


Fig 4.17 Deformed shape of bow stiffening [24]

When airship experiencing any forces (Bending) due to drag or some other reason airship may try to bend, its lower side will experience tension and upper side will be under compression then spoke of nose batten will try to insert into envelope so it may damage the envelope. It can be noted that chances of buckling is maximum at extreme fiber an minimum or zero at neutral axis hence we are designing nose such that there are more spoke at neutral axis with better rigidity of material so that problem of buckling can be avoided. Our Nose Batten is shown in fig 4.14.

Figure 4.18 Nose Batten attached to an airship

4.7 Mooring Mast

Due to buoyant nature of the airships and their large-size, there is a problem while ground-handling. An airship tends to have vertical oscillations when it is in the vicinity of ground. So, a ground-crew having several members is needed to handle an airship at ground and this manual-handling has several drawbacks. An airship is very sensitive towards atmospheric disturbances due to its large surface-area and large volume. Therefore, an airship cannot be completely constrained to move at ground in the presence of air-gusts, because constraining it, may lead to the damages to its delicate envelope. Therefore, what we need for its safe and secure ground-handling is a structure known as "Mooring Mast" [21].

Figure 4.19 Mooring Mast of an airship [25]

It holds an airship at ground in a safe condition using single-point mooring (only at the nose of the airship). Restraining the airship at several places (multipoint mooring) to overcome atmospheric gusts and turbulence is likely to introduce large loads at the restraining attachments, which may result in failure of the mooring structure. Whereas in single point mooring, the airship is constrained only at its nose and it is allowed to yaw, pitch and roll about this point. Such a mast enables limited three axes rotational/oscillatory motion to an airship in moored condition, which substantially reduces the structural load due to atmospheric gusts and random turbulence as shown in Fig 5.5. The airship must be free to swing and align itself with direction of ambient wind and there should not be exceptionally high loads on the airship itself and the mast structure in the moored condition of the airship. The airship is hinged to the mooring-point of the mast when not in use.

Figure 4.20 Airship Attached to Mooring Mast

4.8 Cost Analysis

Components	Price
Gondola Material (Acrylic Sheet)	200
Brushless motor and accessories	2000
Servo Motor and Gears	1200
Lithium Polymer Battery & Charger	2800
5 Channel Transmitter and Receiver	3500
Attachment Material (Cane and others)	500
Other Accessories (Tape, Glue etc)	300
Total	10500

Table 4.4 Cost Estimation

CHAPTER 5

Results and Discussions

5.1 Flight Testing of Indoor Airship

After the completion of the design and fabrication, the next objective is the fight testing of airship. The location chosen for flight testing is Structures Laboratory in IIT Bombay. The airship is steered in all directions for about 30 minutes in order to check its maneuvering capabilities as shown in Fig 5.1. The maximum speed achieved is estimated to be 4 to 5 m/s. The detailed specifications of the airship are listed in Table 5.1, while the weight breakdown is given in Table 5.2.

Parameters	**Specification**
Length[m]	3.8
Diameter[m]	1.3
Volume [m^3]	3.670
Surface Area [m^2]	13.490
Gross Lift [Kg]	4.111
Net Lift [Kg]	2.963
Fin Configuration	'+'type
Gondola Type	Open Structure

Table 5.1 Indoor Airship Details

Components	**Weight(Kg)**
Envelope	1.147
Avionics(Battery, Motors, Wires)	0.430
Fins	0.440
Gondola	0.170
Sliding Gondola	0.07
Gondola Attachment	0.13
Total	2.347

Table 5.2 Weight Breakdown of Indoor airship

5.2 Problems Encountered While Flying First Flight

The first problem that we encountered while testing of airship is rotation of main motor i.e. providing thrust upward. We experienced attachment of sliding gondola after correcting all problems we flight airship in yard of aerospace department of IIT-BOMBAY.

5.3 Flight Testing

Figure 5.1 Flight Testing

CHAPTER 6

Conclusion

A scaled model of an airship is fabricated in order to check permeability of material and the other parameters after successful testing and presentation of scale model finally the remotely controlled indoor airship(zeppelin shape) is designed fabricated and tested in **IIT-Bombay**. The new concept of sliding gondola along with fixed gondola has been designed and tested successfully. The result obtained by the methodology adopted for designed and fabrication found to be corrected. Design and fabrication of an airship is not as simple as it looks like.

Appendix I

Design Parameter of Different Airship

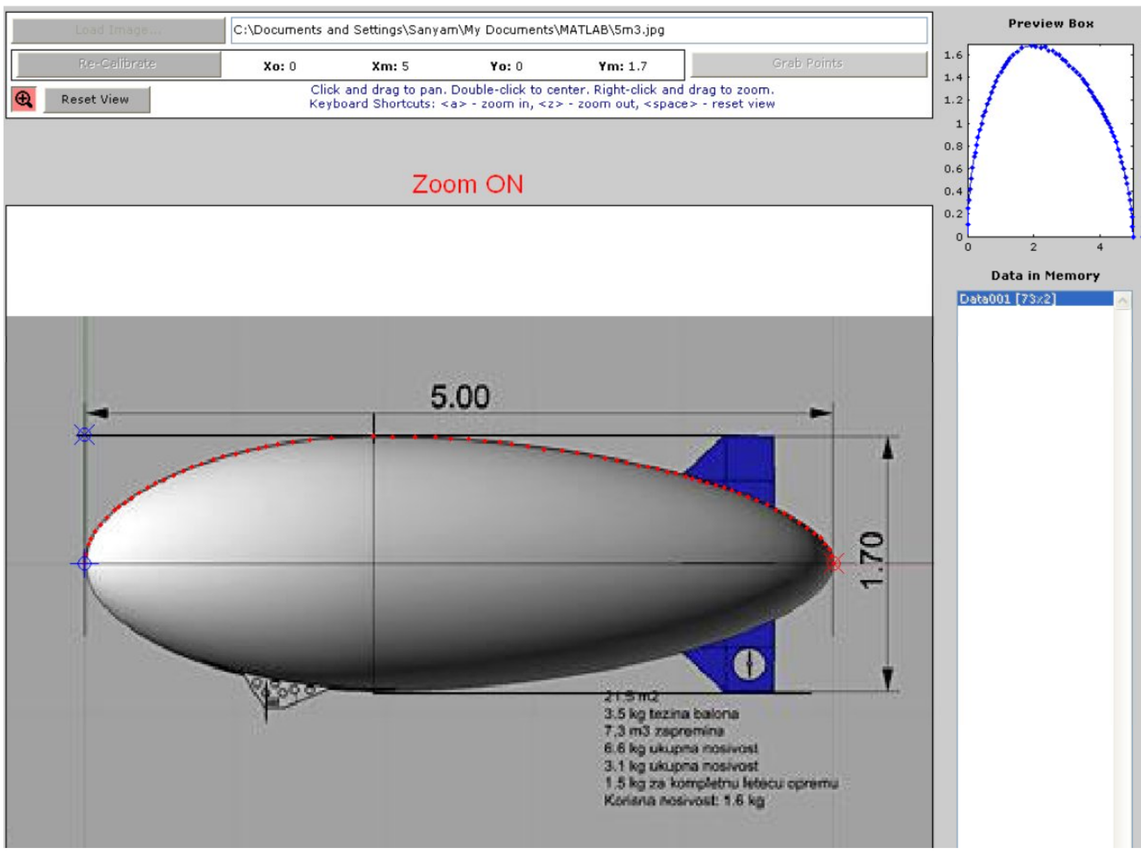
Volume (V) (ft3)	Length (l) (ft)	Diameter (d) (ft)	V/(d2*l) (ft2)	Surface Area (A)	A/(d*l)	Payload (lbs)
West Coast Blimp & Electronics						
130	13	5.2	0.3698225			
255	15	6.7	0.3787035			
319	18	6.7	0.3947922			
430	21	7	0.4178814			
787	25	8.6	0.4256355			
1510	30	10	0.5033333			
Galaxy Blimp						
3557.9	50	12	0.4941528	1553.54	2.589233	
1837	40	10	0.45925	1061.68	2.6542	
1230.54	35	8	0.5493482	745.78	2.6635	
926.43	30	7.5	0.5489956	592.611	2.633827	
Southern Blimp						
187	15	4.75	0.5525392	187.07	2.625544	1
348.63	18	6.08	0.5239443	283.19	2.587628	2
420	20	6.67	0.4720279	345	2.586207	3.5
563	22	7.5	0.4549495	433.42	2.626788	8
925	26	8.67	0.4732931	583.43	2.588191	12
1416	30	10	0.472	787.06	2.623533	30
China Advertising Balloon Ltd						
317.83	18.372	5.905	0.4961336			3.3065
441.43	19.685	6.56	0.5210972			7.1645
515.59	22.965	6.56	0.5217114			7.7155
628.6	22.965	7.217	0.5255264			9.9205
Aero Drum Ltd						
257.8	16.4	5.6	0.50126	231.42	2.519817	
535.37	23	6.6	0.5343654	385.26	2.537945	
RC Blimps						
163	14	4.833	0.498455	172.023	2.542387	
356	18	6.25	0.5063111	282.58	2.511822	
548	23.5	6.75	0.5118057	395.89	2.49576	
1000	32	7.83	0.5097139	628.54	2.508541	
Mini Zeppelin						
247.2	16.4	4.9				0.8818
282.52	18	4.9				1.102
317.83	19.5	5.4				3.306
565.03	21	5.9				5.07
635.66	25	6				4.409
882.86	29.5	7.2				7.716
953.49	33	7.5				13.22

Appendix II

Images and points used to extract shape data:

An example of the technique used to extract volume and surface area data from images where shape and length and max. diameter data was given. The method was verified for various known shapes. A case of verification is presented below.

Extracting the shape using "grabit" a MatlabTM GUI script:



Appendix III

Data Collected for Turnigy & Avionic Brushless Motor

Name	RPM	Maximum Current (Amp)	Weight (g)	Propeller Diameter	Thrust(g)	Website Link
Turnigy 1811 Brushless Motor 2000kv	2000	4.1	11	6*4	150	http://goo.gl/BS7F1K
Turnigy 1811 brushless Outrunner 2900kv	2900	5.8	12	6*4	165	http://goo.gl/IbrdXQ
Turnigy Park250 Brushless Outrunner 2050kv	2050	8	16	7*3.5	220-255	http://goo.gl/dMC6r4
Turnigy 3020 Brushless Outrunner Motor 1800kv	1800	12	25	6x3~9x4.7	250	http://goo.gl/Xx9C4S
Turnigy 3020 Brushless Outrunner Motor 1200kv	1200	6-8	25	7x3.5~9x4.7	300	http://goo.gl/l4lYP
Turnigy LD2816A Brushless Outrunner 1350kv	1350	10	26	7*4	245	http://goo.gl/l6NMsD
Turnigy 2730 Brushless Motor	1700	9	28	7x6~8x4.3	300-400	http://goo.gl/7YBUwB
Turnigy L2205-1350 Brushless Motor (100w)	1350	13.5	30	7*5	450	http://goo.gl/TyoJFE
Turnigy L2206A-1650 Brushless Motor (120w)	1650	17.8	36	7*5	620	http://goo.gl/dzrE6k

Turnigy L2210-1650 Bell Style Motor (250w)	1650	22	50	8*6	520	http://goo.gl/FFyHLI
Turnigy Aerodrive DST-1000 Brushless Outrunner motor 1000kv	1000	14	65	8*6	770	http://goo.gl/U3LbII

Turnigy 2205/34 1500kv Brushless Motor	1500	12	33	8*4.5 7.4v	360	http://goo.gl/7UGBpU
Turnigy 2627 Brushless 300-Size Heli Motor 4200kv	4200	22	39	APC4.1x4.5	360	http://goo.gl/Frgj7o
Turnigy L2210C-1200 Brushless Motor (150w)	1200	15.8	48	8*6	700	http://goo.gl/vL37lT
Turnigy 2632 Brushless Motor 1000kv	1000	8.5-13	51	8x3.8~10x4.7	440-690pull	http://goo.gl/ZJXmMk
Turnigy 2209/26 1130kv outrunner	1130	16	54.5	0843 - 11.1v	530	http://goo.gl/WHnSPm
Turnigy 2213 20turn 1050kv 19A Outrunner	1050	19	56	8040 P 9050 P 1060 P	538 810 650	http://goo.gl/GbAWIv
Turnigy 2615 EDF Outrunner 4800kv for 55/64mm	4800	34.3	66	7*6	690	http://goo.gl/O3EzBv
Turnigy Park450 Brushless Outrunner 1050kv	1050	18	66	11.1v - 9x5 P 11.1v - 8x4.3 P	800 640	http://goo.gl/fIiKui
Turnigy Park450 Brushless	890	14	67	9x6 ~ 11x3.8		http://goo.gl/w09XdK

Turnigy 4206 530kv Brushless Multi-Rotor Motor	530	20	68	6		http://goo.gl/9IDgO7
Turnigy D2836/8 1100KV Brushless Outrunner Motor	1100	18	70	7.4V/11x7 14.85V/7x3	1130	http://goo.gl/6r295B
Turnigy D2836/11 750KV Brushless Outrunner Motor	750	14	71	7.4V/12x6 11.1V/9x6	800	http://goo.gl/0opFb
Turnigy D3530/14 1100KV Brushless Outrunner Motor	1100	22	73	7.4V/12x6 14.8V/8x4	1100	http://goo.gl/4geFM9
Turnigy Park480 Brushless Outrunner 1320kv	1320	28	80	8x4.3 - 18.2A 9x5 - 25.2A	1000 1310	http://goo.gl/XwybRG
Turnigy Park480 Brushless Outrunner 850kv	850	28	80	9x5 - 8.6A 10x4.7 11.5A 11x4.7 - 19.5A	650 860 1140	http://goo.gl/9eDyw6
Turnigy L3010C-1300kv (420w)	1300	40.1	87	10*4.5	1650	http://goo.gl/5I0A7l
Turnigy L2855-2100 EDF Outrunner (900w)	2100	42	94	12*6	1400	http://goo.gl/BZdsyz
Turnigy L2855-2300 EDF Outrunner (450w)	2300	26	97	10*5	900	http://goo.gl/lpxNcC
Turnigy D3536/5 1450KV Brushless Outrunner Motor	1450	45	102	7.4V/9x6 14.8V/8x4	1380	http://goo.gl/UMhlWh
Turnigy D3536/8	1000	30	102	7.4V/11x5	1160	http://goo.gl/VT0mzL

1000KV Brushless				14.8V/10x6		
Turnigy 480S BL Inrunner Motor w/ Impeller 1500kv	1500	60	109	APC7x4, APC8x3.8	1080 1300	http://goo.gl/u3oMTr

Avionic M1826/31 KV1800 MICRO brushless motor	1800	20	18	Prop 6x4 E Pro 7x3.5 SF PROP - 8x3.8 SF	150 – 200 200 500-550	http://goo.gl/uSXZFJ
Avionic M2226/25 KV1800 MICRO brushless motor	1800	20	21	PROP - 6x4 E PROP - 7x3.5 SF PROP - 8x3.8 SF	200 300 500	http://goo.gl/iJ9FN0
Avionic M2028/12 KV2300 MICRO brushless motor	2300	20	22	PROP - 6x4 E PROP - 7x3.5 SF PROP - 8x3.8 SF	300-350 450-500 600-650	http://goo.gl/DXvSuU
Avionic M2230/15 KV1780 MICRO brushless motor	1780	20	27	PROP - 6x4 E PROP - 7x3.5 SF PROP - 8x3.8 SF	200-250 300-350 650-700	http://goo.gl/U35QZw
**Avionic PRO C2822 KV1200 brushless motor	1200	20-30	41	PROP – 7x3E PROP – 8x4E PROP – 9x6E	250 350 425	http://goo.gl/jlPW35

Avionic C2826 KV1900 brushless motor	1900	40	49	PROP – 8x4E PRO – 9x4.7E PROP – 8x4E	650 700 1200	http://goo.gl/KYGVe2
Avionic C2830 KV850 QUAD brushless motor	850	20-30	52	P - 9x3.8SF P - 9x3.8SF	350 750	http://goo.gl/13Rsbq
Emax FC 2822	1200	20-30	39	10*4	710	http://goo.gl/VT0mzL

Appendix IV

Data Collected for Servo Motor

NAME	WEIGHT	TORQUE	WEBLINK
TGY-375DMG Metal gear Digital Servo	11.4 g	2.3 kg.cm	http://www.hobbyking.com/hobbyking/store/__11626__TGY_375DMG_Metal_gear_Digital_Servo_w_Heat_Sink_2_3kg_11sec_11_5g.html
Turnigy TGY-EX5252MG	12.4g	2.8 Kg.cm	http://www.hobbyking.com/hobbyking/store/__66353__Turnigy_TGY_EX5252MG_12_4g_2_8kg_0_10sec_Twin_BB_Digital_Micro_Servo.html
HKSCM16-6 Single Chip Digital Servo (6V)	16g	2.0kgcm	http://www.hobbyking.com/hobbyking/store/__16264__HobbyKing_8482_HKSCM16_6_Single_Chip_Digital_Servo_16g_2_5kg_0_13s.html
Turnigy 380MAX Micro Servo (Metal Gear)	17.4g	4.1 kg.cm	http://www.hobbyking.com/hobbyking/store/__8760__Turnigy_380MAX_Micro_Servo_Metal_Gear_4_1kg_16sec_17_4g.html
Turnigy MX-331S	17g	3.0kg.cm	http://www.hobbyking.com/hobbyking/store/__47387__Turnigy_MX_331S_17g_3kg_0_12sec_Analog_Mini_Servo.html
HobbyKing™ HK7000MG Coreless Servo	19g	3.0kg.cm	http://www.hobbyking.com/hobbyking/store/__41643__HobbyKing_8482_HK7000MG_Coreless_Servo_3_5kg_19g_0_07sec.html
GWS Mini Park Series Servo	19g	3.6kg.cm	http://www.hobbyking.com/hobbyking/store/__4696__GWS_Park_HPX_Servo_19g_05sec_3_6kg_JR_Plug_.html
Corona DS339MG Digital Metal Gear Servo	32g	4.4kg.cm	http://www.hobbyking.com/hobbyking/store/__19957__Corona_DS339MG_Digital_Metal_Gear_Servo_4_4kg_32g_0_15s.html
The Hextronik 5010 servo	39g	6.5kg.cm	http://www.hobbyking.com/hobbyking/store/__3743__HXT_6_9kg_39_2g_16sec_Twin_bearing_Digital_Servo.html
Turnigy TGY-4409MD Metal Gear Digital Servo	44g	9.45kg.cm	http://www.hobbyking.com/hobbyking/store/__24578__Turnigy_TGY_4409MD_Metal_Gear_Digital_Servo_9_45kg_0_11sec_44g.html
TrackStar TS-D99X Digital	45g	10kg.cm	http://www.hobbyking.com/hobbyking/store/__52736__TrackStar_TS_D99X_Digital_1_10_Scale_To

			uring_Drift_Buggy_Steering_Servo_45g_10kg_0_08sec.html
BMS-616DMG+HS Super Strong Digital Servo for bugggy (Metal Gear)	46.5g	10.2kg.cm	http://www.hobbyking.com/hobbyking/store/__9443__BMS_616DMG_HS_Digital_Buggy_Servo_MG_10_2kg_12sec_46_5g.html
BMS-630MG Super Strong Servo	49 g	13.0kg-cm	http://www.hobbyking.com/hobbyking/store/__8739__BMS_630MG_Super_Strong_Servo_13kg_17sec_49g.html
SSV-9784MG / Heatsink Servo 53g / 13.6kg / .13sec	53g	13.6kg.cm	http://www.hobbyking.com/hobbyking/store/__7244__SSV_9784MG_Heatsink_Servo_53g_13_6kg_13sec.html
Turnigy TGY-S901D Metal Gear Digital Robot Servo 13kg / 0.14sec / 58g	58g	13kg.cm	http://www.hobbyking.com/hobbyking/store/__27556__Turnigy_TGY_S901D_Metal_Gear_Digital_Robot_Servo_13kg_0_14sec_58g.html
Turnigy Metal Gear Servo 60g/15.5kg/.16sec	60g	15.5kg.cm	http://www.hobbyking.com/hobbyking/store/__9617__Turnigy_Metal_Gear_Servo_60g_15_5kg_16sec.html
AeroStar ASI-613MG Coreless Digital Metal Gear Servo	61g	11.53 kg.cm	http://www.hobbyking.com/hobbyking/store/__35311__AeroStar_ASI_613MG_Coreless_Digital_Metal_Gear_Servo_61g_13_83kg_0_103sec.html

Appendix V

2 cell Battery Specification

Name	Capacity (mAh)	Weight (gm)	Links
ZIPPY Flightmax 500mAh 2S1P 20C	500	30	http://www.hobbyking.com/hobbyking/store/__6788__ZIPPY_Flightmax_500mAh_2S1P_20C.html
Turnigy 500mAh 2S 20C Lipo Pack	500	32	http://www.hobbyking.com/hobbyking/store/__9187__Turnigy_500mAh_2S_20C_Lipo_Pack.html
Rhino 750mAh 2S 7.4v 20C Lipoly Pack	750	45	http://www.hobbyking.com/hobbyking/store/__7306__Rhino_750mAh_2S_7_4v_20C_Lipoly_Pack.html
Turnigy nano-tech 950mah 2S 25~50C Lipo Pack	950	46	http://www.hobbyking.com/hobbyking/store/__20388__Turnigy_nano_tech_950mah_2S_25_50C_Lipo_Pack.html
ZIPPY Compact 850mAh 2S 35C Lipo Pack	850	50	http://www.hobbyking.com/hobbyking/store/__25506__ZIPPY_Compact_850mAh_2S_35C_Lipo_Pack.html
Turnigy nano-tech 1000mah 2S 20~40C Lipo AIRSOFT Pack	1000	51	http://www.hobbyking.com/hobbyking/store/__34530__Turnigy_nano_tech_1000mah_2S_20_40C_Lipo_AIRSOFT_Pack.html
Turnigy nano-tech 1200mAh 2S 25~50C Lipo AIRSOFT Pack (T-Connector)	1200	55	http://www.hobbyking.com/hobbyking/store/__67731__Turnigy_nano_tech_1200mAh_2S_25_50C_Lipo_AIRSOFT_Pack_T_Connector_.html
ZIPPY Flightmax 1000mAh 2S1P	1000	60	http://www.hobbyking.com/hobbyking/store/__6474__ZIPPY_Flightmax_1000mAh_2S1P_20C.html

20C			
ZIPPY Flightmax 1300mAh 2S1P 20C	1300	76	http://www.hobbyking.com/hobbyking/store/__6469__ZIPPY_Flightmax_1300mAh_2S1P_20C.html
Turnigy 1500mAh 2S 25C Lipoly Battery	1500	79	http://www.hobbyking.com/hobbyking/store/__26564__Turnigy_1500mAh_2S_25C_Lipoly_Battery.html
ZIPPY Compact 2200mAh 2S 25C Lipo Pack	2200	113	http://www.hobbyking.com/hobbyking/store/__21345__ZIPPY_Compact_2200mAh_2S_25C_Lipo_Pack.html
ZIPPY Traxxas 2200mAh 2S1P 30C Lipo Pack (Suits TRA2820)	2200	120	http://www.hobbyking.com/hobbyking/store/__37346__ZIPPY_Traxxas_2200mAh_2S1P_30C_Lipo_Pack_Suits_TRA2820_.html
Turnigy 4000mAh Spektrum DX8 Intelligent Transmitter Pack.	4000	133	http://www.hobbyking.com/hobbyking/store/__19481__Turnigy_4000mAh_Spektrum_DX8_Intelligent_Transmitter_Pack_.html
Turnigy Bolt 2400mAh 2S 7.6V 65~130C High Voltage Lipoly Pack	2400	135	http://www.hobbyking.com/hobbyking/store/__51507__Turnigy_Bolt_2400mAh_2S_7_6V_65_130C_High_Voltage_Lipoly_Pack.html
Rhino 2350mAh 2S1P 20C Lipoly Pack	2350	144	http://www.hobbyking.com/hobbyking/store/__7648__Rhino_2350mAh_2S1P_20C_Lipoly_Pack_.html
ZIPPY Compact 2700mAh 2S 35C Lipo Pack	2700	151	http://www.hobbyking.com/hobbyking/store/__21395__ZIPPY_Compact_2700mAh_2S_35C_Lipo_Pack.html

Appendix VI

3cell Battery Specification

Name	Capacity(mAh)	Weight	WebLink
Turnigy nano-tech 950mah 3S 25~50C Lipo Pack	950	69	http://goo.gl/NtuIpw
Turnigy nano-tech 1000mAh 3S 20-40C Lipo AIRSOFT Pack	1000	72	http://goo.gl/NAscr4
Turnigy 800mAh 3S 20C Lipo Pack	800	75	http://goo.gl/gb7mlM
Turnigy nano-tech 1200mAh 3S 25-50C Lipo AIRSOFT Pack	1200	80	http://goo.gl/ogDTB7
Rhino 1050mAh 3S1P 30C Lipoly Pack	1050	96	http://goo.gl/Tthqdr
ZIPPY Compact 1500mAh 3S 25C Lipo Pack	1500	113	http://goo.gl/QAYfiA
MultiStar Race Spec 3S 1400mAh 40-80C Multi-Rotor Lipo Pack For FPV Minis	1400	115	http://goo.gl/ek5mmk
ZIPPY Traxxas 1400mAh 3S1P 30C Lipo Pack (Suits TRA2823)	1400	121	http://goo.gl/iQilIX

ZIPPY Flightmax 1600mAh 3S1P 20C	1600	122	http://goo.gl/8CoLNf
ZIPPY Compact 1800mAh 3S 25C Lipo Pack	1800	134	http://goo.gl/1PMqMK
Turnigy 9XR Safety Protected 11.1v (3s) 2200mAh 1.5C Transmitter Pack	2200	139	http://www.hobbyking.com/hobbyking/store/__31315__Turnigy_9XR_Safety_Protected_11_1v_3s_2200mAh_1_5C_Transmitter_Pack.html
Turnigy nano-tech 2500mAh 3S1P 5~10C Transmitter Lipo Pack (Futaba 6EX and 3PKS)	2500	155	http://www.hobbyking.com/hobbyking/store/__23814__Turnigy_nano_tech_2500mAh_3S1P_5_10C_Transmitter_Lipo_Pack_Futaba_6EX_and_3PKS_.html
Rhino 2620mAh 3S 11.1v Low-Discharge Transmitter Lipoly Pack	2620	160	http://www.hobbyking.com/hobbyking/store/__7346__Rhino_2620mAh_3S_11_1v_Low_Discharge_Transmitter_Lipoly_Pack.html
MultiStar High Capacity 3S 3000mAh Multi-Rotor Lipo Pack	3000	195	http://www.hobbyking.com/hobbyking/store/__63534__MultiStar_High_Capacity_3S_3000mAh_Multi_Rotor_Lipo_Pack.html
ZIPPY Flightmax 2800mAh 3S1P 30C	2800	231	http://www.hobbyking.com/hobbyking/store/__14057__ZIPPY_Flightmax_2800mAh_3S1P_30C.html
ZIPPY Compact 2700mAh 3s 40c Lipo Pack	2700	235	http://www.hobbyking.com/hobbyking/store/__63393__ZIPPY_Compact_2700mAh_3s_40c_Lipo_Pack.html
ZIPPY Flightmax 3000mAh 3S1P 20C	3000	239	http://www.hobbyking.com/hobbyking/store/__8851__ZIPPY_Flightmax_3000mAh_3S1P_20C.html

Turnigy 3000mAh 3S 20C Lipo Pack	3000	253	http://www.hobbyking.com/hobbyking/store/__9265__Turnigy_3000mAh_3S_20C_Lipo_Pack.html
ZIPPY Compact 3700mAh 3S 25C Lipo Pack	3700	264	http://www.hobbyking.com/hobbyking/store/__21355__ZIPPY_Compact_3700mAh_3S_25C_Lipo_Pack.html
ZIPPY Compact 4000mAh 3S 25C Lipo Pack	4000	286	http://www.hobbyking.com/hobbyking/store/__21360__ZIPPY_Compact_4000mAh_3S_25C_Lipo_Pack.html
B-Grade 3300mAh 3S 30C Lipoly Battery	3300	300	http://www.hobbyking.com/hobbyking/store/__24776__B_Grade_3300mAh_3S_30C_Lipoly_Battery.html
Turnigy nano-tech 4000mah 3S 25~50C Lipo Pack	4000	333	http://www.hobbyking.com/hobbyking/store/__11927__Turnigy_nano_tech_4000mah_3S_25_50C_Lipo_Pack.html
Turnigy 4000mAh 3S 20C Lipo pack (Perfect for QRF400)	4000	340	http://www.hobbyking.com/hobbyking/store/__11612__Turnigy_4000mAh_3S_20C_Lipo_pack_Perfect_for_QRF400_.html

Appendix VII

4 cell Battery Specification

Turnigy nano-tech 850mah 4S 25~50C Lipo Pack	850	94	http://www.hobbyking.com/hobbyking/store/__18200__Turnigy_nano_tech_850mah_4S_25_50C_Lipo_Pack.html
Turnigy nano-tech 850mah 4S 25~50C Lipo Pack	850	94	http://www.hobbyking.com/hobbyking/store/__18200__Turnigy_nano_tech_850mah_4S_25_50C_Lipo_Pack.html
ZIPPY Compact 1000mAh 4S 25C Lipo Pack	1000	105	http://www.hobbyking.com/hobbyking/store/__21335__ZIPPY_Compact_1000mAh_4S_25C_Lipo_Pack.html
ZIPPY Compact 1300mAh 4S 25C Lipo Pack	1300	132	http://www.hobbyking.com/hobbyking/store/__21339__ZIPPY_Compact_1300mAh_4S_25C_Lipo_Pack.html
Turnigy 1300mAh 4S 30C Lipo Pack	1300	157	http://www.hobbyking.com/hobbyking/store/__9366__Turnigy_1300mAh_4S_30C_Lipo_Pack.html
ZIPPY Compact 1500mAh 4S 25C Lipo Pack	1500	148	http://www.hobbyking.com/hobbyking/store/__21341__ZIPPY_Compact_1500mAh_4S_25C_Lipo_Pack.html
Turnigy 1600mAh 4S 30C Lipo Pack	1600	177	http://www.hobbyking.com/hobbyking/store/__9457__Turnigy_1600mAh_4S_30C_Lipo_Pack.html
ZIPPY Compact 1800mAh 4S 35C Lipo Pack	1800	205	http://www.hobbyking.com/hobbyking/store/__25513__ZIPPY_Compact_1800mAh_4S_35C_Lipo_Pack.html
Rhino 2150mAh 4S 14.8v 30C Lipoly Pack	2150	240	http://www.hobbyking.com/hobbyking/store/__9320__Rhino_2150mAh_4S_14_8v_30C_Lipoly_Pack_.html
ZIPPY Flightmax	2200	250	http://www.hobbyking.com/hobbyking/store/__9943__ZIPPY_Flightmax_2

2200mAh 4S1P 40C			200mAh_4S1P_40C.html
Turnigy 2200mAh 4S1P 20C Lipo Pack	2200	247	http://www.hobbyking.com/hobbyking/store/__9270__Turnigy_2200mAh_4S1P_20C_Lipo_Pack.html
Turnigy 2200mAh 4S 30C Lipo Pack	2200	258	http://www.hobbyking.com/hobbyking/store/__9460__Turnigy_2200mAh_4S_30C_Lipo_Pack.html
Turnigy 2650mAh 4S 20C Lipo Pack	2650	265	http://www.hobbyking.com/hobbyking/store/__9182__Turnigy_2650mAh_4S_20C_Lipo_Pack.html
ZIPPY Compact 2700mAh 4S 35C Lipo Pack	2700	284	http://www.hobbyking.com/hobbyking/store/__21397__ZIPPY_Compact_2700mAh_4S_35C_Lipo_Pack.html
ZIPPY Compact 2700mAh 4S 25C Lipo Pack	2700	278	http://www.hobbyking.com/hobbyking/store/__21350__ZIPPY_Compact_2700mAh_4S_25C_Lipo_Pack.html
Turnigy 3000mAh 4S 20C Lipo Pack	3000	337	http://www.hobbyking.com/hobbyking/store/__9264__Turnigy_3000mAh_4S_20C_Lipo_Pack.html
ZIPPY Flightmax 3000mAh 4S1P 20C	3000	313	http://www.hobbyking.com/hobbyking/store/__8852__ZIPPY_Flightmax_3000mAh_4S1P_20C.html
Turnigy 3300mAh 4S 30C Lipo Pack	3300	385	http://www.hobbyking.com/hobbyking/store/__9501__Turnigy_3300mAh_4S_30C_Lipo_Pack.html
ZIPPY Compact 3700mAh 4S 25C Lipo Pack	3700	375	http://www.hobbyking.com/hobbyking/store/__21356__ZIPPY_Compact_3700mAh_4S_25C_Lipo_Pack.html

Appendix VIII

Data Collected for ESC

TURNIGY Plush 6A /.8bec/6g Speed Controller	6A	6g	http://hobbyking.com/hobbyking/store/__4318__TURNIGY_Plush_6A_8bec_6g_Speed_Controller.html
HobbyWing X-Rotor 10A OPTO ESC For Multirotor applications	10A	6.5g	http://hobbyking.com/hobbyking/store/__73078__HobbyWing_X_Rotor_10A_OPTO_ESC_For_Multirotor_applications.html
Hobbyking YEP 7A (1~2S) Brushless Speed Controller	7A	7g	http://hobbyking.com/hobbyking/store/__37944__Hobbyking_YEP_7A_1_2S_Brushless_Speed_Controller.html
HobbyKing® ™ Brushless Car ESC 10A w/ Reverse	10A	8g	http://hobbyking.com/hobbyking/store/__23766__HobbyKing_Brushless_Car_ESC_10A_w_Reverse.html
TURNIGY Plush 10amp 9gram Speed Controller	10A	9g	http://hobbyking.com/hobbyking/store/__4204__TURNIGY_Plush_10amp_9gram_Speed_Controller.html
Afro ESC 12Amp Ultra Lite Multi-rotor Motor Speed Controller (SimonK Firmware) Version 3	12A	10g	http://hobbyking.com/hobbyking/store/__55241__Afro_ESC_12Amp_Ultra_Lite_Multi_rotor_Motor_Speed_Controller_SimonK_Firmware_Version_3.html
Turnigy Multistar 10A V2 ESC With BLHeli and 2A LBEC 2-3S V	10A	11.4g	http://hobbyking.com/hobbyking/store/__65151__Turnigy_Multistar_10A_V2_ESC_With_BLHeli_and_2A_LBEC_2_3S_V.html
TURNIGY Plush 12amp (2A BEC) BESC	12A	13g	http://hobbyking.com/hobbyking/store/__2161__TURNIGY_Plush_12amp_2A_BEC_BESC.html
Afro Slim 20Amp Multi-rotor Motor Speed Controller (SimonK Firmware)	20A	13.7g	http://hobbyking.com/hobbyking/store/__42551__Afro_Slim_20Amp_Multi_rotor_Motor_Speed_Controller_SimonK_Firmware_.html
HobbyWing X-Rotor 20A OPTO ESC for Multirotor Applications	20A	14g	http://hobbyking.com/hobbyking/store/__73079__HobbyWing_X_Rotor_20A_OPTO_ESC_for_Multirotor_Applications.html
Turnigy 20A BRUSHED	20A	17g	http://hobbyking.com/hobbyking/store

ESC			/__9090__Turnigy_20A_BRUSHED_ESC.html
TURNIGY Plush 18amp Speed Controller	18A	19g	http://hobbyking.com/hobbyking/store/__4312__TURNIGY_Plush_18amp_Speed_Controller.html
Turnigy AE-20A Brushless ESC	20A	19g	http://hobbyking.com/hobbyking/store/__11615__Turnigy_AE_20A_Brushless_ESC.html
HobbyKing 10A ESC 1A UBEC	10A	20g	http://hobbyking.com/hobbyking/store/__21247__HobbyKing_10A_ESC_1A_UBEC.html
Turnigy 30A BRUSHED ESC	30A	21g	http://hobbyking.com/hobbyking/store/__6468__Turnigy_30A_BRUSHED_ESC.html
Hobbyking YEP 18A (2~4S) SBEC Brushless Speed Controller	18A	22g	http://hobbyking.com/hobbyking/store/__37945__Hobbyking_YEP_18A_2_4S_SBEC_Brushless_Speed_Controller.html
Turnigy AE-25A Brushless ESC	25A	25g	http://hobbyking.com/hobbyking/store/__11616__Turnigy_AE_25A_Brushless_ESC.html
HobbyKing 30A BlueSeries Brushless Speed	30A	28g	http://hobbyking.com/hobbyking/store/__13429__HobbyKing_30A_BlueSeries_Brushless_Speed_Controller.html
Hobby King 20A ESC 3A UBEC	20A	30g	http://hobbyking.com/hobbyking/store/__15202__Hobby_King_20A_ESC_3A_UBEC.html
Hobby King 30A ESC 3A UBEC	30A	32g	http://hobbyking.com/hobbyking/store/__15205__Hobby_King_30A_ESC_3A_UBEC.html

Appendix IX

Air Viscosity at Different Temperature

Temperature - *t* - (^oF)	Dynamic Viscosity - μ - $(lb_f\ s/ft^2) \times 10^{-7}$	Kinematic Viscosity - ν - $(ft^2/s) \times 10^{-4}$
-20	3.34	1.19
0	3.38	1.26
10	3.44	1.31
20	3.50	1.36
30	3.58	1.42
40	3.60	1.46
50	3.68	1.52
60	3.75	1.58
70	3.82	1.64
80	3.86	1.69
90	3.90	1.74
100	3.94	1.79
120	4.02	1.89
140	4.13	2.01
160	4.22	2.12
180	4.34	2.25
200	4.49	2.4
300	4.97	3.06
400	5.24	3.65

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