Department of Mechanical Engineering

MINI AIRSHIP PATROL CRAFT

In partial fulfilment to the requirements for the

Degree of Bachelor of Engineering

Session 2003/04

National University of Singapore

Submitted by

NG KAY BOON

U006270J11
SUMMARY

This paper covers the basic idea behind the design of an airship. It covers three phases of design: conceptual, preliminary, detailed. The purpose is to look into the potential development of airship in the field of UAV. This project seeks to design, build and test a mini airship for patrol and surveillance in build-up areas.

To develop an airship as an UAV to handle the task of patrolling and surveillance, there is a need to justify the purpose of this project as investment of cash is involved. This paper will discuss on the justification of this project.

This design taps on the usage of vectored thrusting to propel the airship. This design has the capability of performing vertical take-off. The lifting gas, helium, which provides lift due to the differential in density, compensates the weight of the airship. A take-off or landing roll is not necessary for this design.

Calculations and estimations of performance values were done. Three flight tests were conducted to verify the results. Discrepancy is mainly due to the assumption of negligible skin frictional drag and negligible drag force is sustained by the gondola and tail fins. The theoretical calculation was based on form drag. The actual results show the design is capable of performing slow speed manoeuvring.

Table 1A: Airship Performance

<table>
<thead>
<tr>
<th>Performance</th>
<th>Cruise Speed (m/s)</th>
<th>Rate of Climb (m/s)</th>
<th>Rate of Turn (deg/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theoretical</td>
<td>1.22</td>
<td>0.66</td>
<td>32.5</td>
</tr>
<tr>
<td>Experimental</td>
<td>0.85</td>
<td>0.50</td>
<td>28.6</td>
</tr>
<tr>
<td>% Difference</td>
<td>30.3%</td>
<td>24.2%</td>
<td>12.0%</td>
</tr>
</tbody>
</table>
Flight tests (2 indoor, 5 outdoor) were conducted to quantify the airship in performing a surveillance role. For indoor flights, manoeuvrability and controllability are excellent. The outdoor flights proved otherwise as performance is affected by weather conditions. The relationship between the range (direct line of sight) of airship and the smallest observable object at that range is established. The area surveyed is also related to the range. The longer the range the larger is the area coverage and it is more difficult to spot a small object on the screen.

This project has demonstrated the potential of an UAV airship performing military roles. However, there is always a limitation to every design. Weather conditions have always been the nemesis of airships. Special considerations have to be taken note of. This is beyond the scope of this paper.

Figure 1A: Prototype of airship designed
ACKNOWLEDGEMENTS

The author will like to express his heartfelt gratitude towards his supervisor, Dr Gerard Leng S. B. for his guidance and counsel during the course of the project.

The author will also like to extend his gratitude to the staff of Dynamics Laboratory for their assistance for the duration of the project.

Assistance from the peers during the trial runs is deeply appreciated. Special thanks go to Mr Esmond Chua Boon How, Miss Ng Xin Ying, Miss Coleen Ng Wee Hoon, Miss Melody Yang Shu Fang and Mr Chee Tze Seng Simon for their aids during flight-testing phase.
# TABLE OF CONTENTS

SUMMARY .................................................................................................................................................. i

ACKNOWLEDGEMENTS .............................................................................................................................. iii

TABLE OF CONTENTS ................................................................................................................................. iii

LIST OF FIGURES ........................................................................................................................................ vi

LIST OF TABLES .......................................................................................................................................... ix

LIST OF SYMBOL ......................................................................................................................................... x

1. Introduction .................................................................................................................................................. 1

   1.1. Objectives ............................................................................................................................................... 2

   1.2. Organisation of thesis .............................................................................................................................. 3

2. Conceptual Design ..................................................................................................................................... 4

   2.1. Justification of project development .................................................................................................... 4

   2.2. Potential roles of airship UAV .............................................................................................................. 5

   2.3. Criteria for operation of blimp .............................................................................................................. 5

   2.4. Drafting of Airship design ................................................................................................................... 6

       2.4.1. Airship category .......................................................................................................................... 6

       2.4.2. Main components of the blimp ...................................................................................................... 6

       2.4.3. Structural category and shape of the gas envelope ................................................................. 7

       2.4.4. Shape of Gondola ......................................................................................................................... 8

       2.4.5. Propulsion System and Surveillance System ............................................................................. 8

       2.4.6. Empennage (Tail fins stabilizers) .............................................................................................. 9

       2.4.7. Conceptual Drawings .................................................................................................................. 9
Table of Contents

3. Preliminary Design .............................................................. 10
   3.1. Propulsion System Evaluation ....................................... 10
       3.1.1. Streamlining motor holders ................................ 10
       3.1.2. Determination of thrust force by propulsion system ...... 11
       3.1.3. Variable line of thrust ...................................... 11
   3.2. Estimation of payload ................................................... 12
   3.3. Dimension of envelope ............................................... 13
   3.4. Center of buoyancy and center of mass .......................... 14
   3.5. Performance of the airship ......................................... 15
       3.5.1. Maximum cruise speed ...................................... 15
       3.5.2. Maximum rate of climb ..................................... 16
       3.5.3. Maximum rate of turn ...................................... 17
       3.5.4. Maximum altitude ........................................... 18

4. Detailed Design ............................................................... 20
   4.1. Construction of prototype .......................................... 20
       4.1.1. Gondola ......................................................... 20
       4.1.2. Empennage ..................................................... 24
   4.2. Flight test ............................................................... 26
   4.3. Evaluation and quantification of prototype ....................... 28
       4.3.1. Quantification of prototype ................................. 28
       4.3.2. Evaluation of prototype ..................................... 32

5. Conclusions ................................................................. 34

6. Recommendations .......................................................... 36

References ............................................................................. 38
<table>
<thead>
<tr>
<th>Appendix A: Equipment data sheet</th>
<th>39</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appendix B: Selection of airship category</td>
<td>43</td>
</tr>
<tr>
<td>Appendix C: Selection of envelope shape</td>
<td>46</td>
</tr>
<tr>
<td>Appendix D: Material Selection for gas envelope</td>
<td>47</td>
</tr>
<tr>
<td>Appendix E: Specifications of motor</td>
<td>50</td>
</tr>
<tr>
<td>Appendix F: Modification of motor holders</td>
<td>51</td>
</tr>
<tr>
<td>Appendix G: Thrust force determination</td>
<td>53</td>
</tr>
<tr>
<td>Appendix H: Length to depth ratio of envelope</td>
<td>55</td>
</tr>
<tr>
<td>Appendix I: Lifting Gas</td>
<td>57</td>
</tr>
<tr>
<td>Appendix J: Center of buoyancy &amp; center of mass</td>
<td>58</td>
</tr>
<tr>
<td>Appendix K: Calculation of volume and area</td>
<td>59</td>
</tr>
<tr>
<td>Appendix L: Aerostatics</td>
<td>61</td>
</tr>
<tr>
<td>Appendix M: Scope of video camera</td>
<td>63</td>
</tr>
</tbody>
</table>
LIST OF FIGURES

1A Prototype of airship designed
2A Shape of gondola
2B Streamlined shape of the envelope
2C Arrangement of tail fins
2D Gondola and motors position
3A Motor holders
3B Mechanism for varying line of thrust
3C Variable line of thrust
3D Governing equation of shape profile of envelope
3E Projected area for different flight configuration
3F Graph of drag force experience by airship Vs velocity of airship
3G Resolving vectors for line of propulsion (Side View)
3H Graph of drag on airship Vs velocity of airship
3I Yaw motion
3J Graph of drag force Vs rate of turn
3K Graph of $\rho_{net}$, for a range of Off-Standard conditions Vs altitude
4A Dimension of gondola casing
4B Positions of holes to be drilled
4C Installation of ball bearings to reduce friction
4D Installation of carbon fibre rod
4E Circuit diagram of console
4F Mounting of surveillance
4G Dimensions of the tail fins
List of Figures

4H Engineering drawing of mini patrol airship
4I Experimental setup for tabulating resolutions.
4J Image taken at different flight altitudes
4K Graph of image dimension
4L Graph of range (m) Vs dimension(m)
4M Scope of wireless video camera
4N Road surveillance
6A 50ft UAV airship
A1 Micro speed controller
A2 Futaba receiver
A3 Micro servo S3107
A4 FM transmitter
A5 Wireless Video Camera
A6 voltage regulator circuit diagram
A7 Lithium Cell
A8 Setup for real time image transmission
B1 Structural category
C1 Graph of envelope area to sphere for same volume Vs len. to dep. ratio.
D1 Datasheet of Mylar
D2 Datasheet of Polyurethane
F1 Motor holders
F2 Experimental setup
F3 Graph of thrust force Vs voltage
G1 Graph of force Vs change in length of spring
List of Figures

G2 Experimental setup for determination of thrust force
G3 Graph of thrust force Vs supply voltage
K1 Governing equation of shape profile of envelope
K2 Volume tabulation
K3 Tabulation of surface area of the streamline profile
K4 Projected area for different flight configuration
M1 Experimental setup for determining scope
# LIST OF TABLES

1A  Airship performance
3A  Weight tabulation of airship components
4A  Experimental data of image resolution.
B1  Airship categories
B2  Assessment of the suitable of the 3 airship design concepts to military performance.
B3  Description of structural category of airships
F1  Experimental data of thrust force with varying voltage
H1  Variation of drag of bodies of revolution of constant volume with thickness ratio.
I1  Comparison of lifting gas
L1  International Standard Atmospheric conditions at sea-level
M1  Tabulation of results for scope angles
LIST OF SYMBOL

\( T \) \quad \text{Propulsive thrust force, N}

\( F_{tensile} \) \quad \text{Tensile spring force, N}

\( F_{\text{drag}} \) \quad \text{Drag force}

\( F_{\text{lift}} \) \quad \text{Lift force}

\( C_D \) \quad \text{Coefficient of drag}

\( C_L \) \quad \text{Coefficient of lift}

\( v \) \quad \text{Velocity, m/s}

\( A \) \quad \text{Surface area}

\( k \) \quad \text{Elastic spring constant}

\( L_{\text{net}} \) \quad \text{Net static lift, kg}

\( V_T \) \quad \text{Total gas volume of envelope, m}^3

\( \rho_{\text{net}} \) \quad \text{Net lift density, kg/ m}^3

\( \rho_{\text{air}} \) \quad \text{Air density, kg/ m}^3

\( l \) \quad \text{Maximum length of the airship, m}

\( d \) \quad \text{Maximum diameter of the airship, m}

\( R \) \quad \text{Range (direct distance between target and airship), m}

\( O_D \) \quad \text{Dimension of the smallest observable target on screen, m}

\( \theta_h \) \quad \text{Horizontal scope angle}

\( \theta_v \) \quad \text{Vertical scope angle}

\( d_h \) \quad \text{Horizontal scope distance}

\( d_v \) \quad \text{Vertical scope distance}
Chapter 1 - Introduction

1. Introduction

This paper will look into the conceptualization, implementation and validation of the potential role that mini patrol airship may undertake in the near future, especially so in military applications.

The history of airship dated back to 1783, when the Montgolfier sent up the first hot air balloon. Inventors began refining the design into steerable airships. The next lap occurred in the 1900s, when Count Ferdinand von Zeppelin developed the rigid airships. These airships fulfilled their military roles in both World Wars. Besides being used for military purposes such as patrolling, hunting submarines and escorting convoys, flying radar stations for coastal defense system, airships were also developed for commercial purposes. Its heyday period was ended in 1937 when the most famous airship, Hindenburg (804 ft in length, 135 ft in its largest diameter, cruising altitude of 650 ft, reaching a speed of 80 miles per hour), crashed in a disaster in an attempt to land. Triggered by the economic downturn, the development of airship came to a standstill.

In today's context, where technology is available, Unmanned Aerial Vehicles (UAVs), are given the spotlight. UAVs have proved their capability in the recent conflicts such as Iraq (2003), Afghanistan (2001) and Kosovo (1999). Till date most of the UAVs developed are either fixed or rotary wings. This project seeks to develop the potential role of an airship as an UAV in military application. The main purpose is in the arena of surveillance.
1.1. Objectives

The main objective of this project is to design, build and test a mini airship for patrol base, observation post in build up areas. The basic minimum function of the blimp is to send back real time data (graphics) to the operator on ground. The designed blimp is to function as an UAV. This project will also evaluate on other possible applications of the blimp.

The project will be broken down into 3 phases:

- Conceptual Design
  i. Justifying the need to develop this project.
  ii. Define the potential role of the airship functioning as an UAV
  iii. Setting the criteria for the operation of the airship.
  iv. Draft out the design of the airship.

- Preliminary Design
  i. Propulsion System Evaluation
  ii. Estimation of payload
  iii. Dimension of envelope
  iv. Determination of center of buoyancy and center of mass.
  v. Performance of the airship.
1.2. **Organisation of thesis**

The thesis is composed of six chapters. Chapter 1 introduces the project and defines the objectives of the project. Chapter 2 deals with the initial conceptual phase of design. Chapter 3 described the development of the preliminary design phase. Chapter 4 handles the last phase of design, detailed design. Detailed design includes test flights and the quantifying of prototype. Chapter 5 will concludes this thesis. Chapter 6 will discuss on the relevant recommendations.
2. Conceptual Design

In this phase of the design, it will touch on justifying the needs to develop this project, identifying the potential roles of the project blimp, setting the operation criteria and drafting out the design of the blimp.

2.1. Justification of project development

With the current technology, development of UAVs, is made possible. UAVs are cheaper to procure and they reduce the risk to pilot’s life. They can assume missions normally reserved for manned aircraft. UAVs played an important role in the recent conflict between U.S. and Iraq. They played the role of surveillance, transmitting data and images back to the operator, providing the U.S. army with upfront information of the enemy’s frontline. With this technology, it is possible to revive the airships as UAVs to perform military roles as its large counterpart has done in the past.

Emphasis has been placed on developing fixed and rotary wings UAVs. In Singapore, Singapore Technology has successfully developed Fantail UAV (rotary wing) and Multi-role UAV (fixed wing), for the purpose of military reconnaissance. Currently in the Republic of Singapore Air Force, only one fixed wing UAV is in operation, IAI Searcher. The current development has its disadvantages. In the event of a crash landing or air accidents, the sophisticated equipment on board is irretrievable. To launch and land the fixed wing UAVs, a large area is required. To develop an airship as an UAV is viable. Airships accidents are no longer fatal with the used of helium as the lifting gas. When the gasbag is puncture or in the event of engine failure, the airship will loss its lift and
starts descending gradually. The main components will still be retrievable. Moreover, with vertical take off and landing (VTOL) capability, it does not require a large space for launching and landing.

With the increasing threat from terrorists, there is a need to source on all potential methods to survey buildings, especially where Singapore is an urban forest. Airship UAV is another potential source besides the Fantail UAV.

2.2. Potential roles of airship UAV

i. Surveillance of building interior.

ii. Surveillance around build up areas. (patrol base, observation post)

iii. Mine seeking device

iv. Sending lethal payloads to enemy’s frontline.

This project will focus on developing the second potential.

2.3. Criteria for operation of airship

i. Low altitude operation

ii. Basic maneuvering capability (Climb, Descend, Fore, Aft, Yaw).

iii. Slow speed handling

iv. Handle payload of 20% of the total weight of the blimp components.

v. Bear the load of a wireless video camera with visual capability of 300m unobstructed.

vi. Provides over-the-next-building and around-the-corner perspective.

vii. Simplicity and low cost operation.
2.4. **Drafting of Airship design**

This section of the thesis will cover the approach on designing of the UAV airship.

2.4.1. **Airship category**

Based on the classification of the performance of airships, Category B type of performance is selected for this design. This category of airship is widely known as the “Vectored Thrust” airships. (*Appendix B*)

i. It has the modest degree of complication. It means that 100% of the lift force is provided by the lifting gas. Aerodynamic lift does not contribute to generating the lift force during operation.

ii. It overcomes low speed controllability to large extent.

iii. It provides a variable propulsion thrust line.

iv. Vectored thrust permits zero roll at take-off and landing.

2.4.2. **Main components of the blimp**

i. Gasbag (Envelope)

ii. Gondola (Console casing)

iii. Propulsion system

iv. Surveillance system

v. Power source

vi. Empennage (Tail fins stabilizers)

To be housed in the same casing known as Gondola
2.4.3. Structural category and shape of the gas envelope.

**Structural Category**

Considering all factors, the non-rigid structure is chosen for the gas envelope. With this non-rigid structure, it is known as the pressure airship. The pressure of the lifting gas within maintains the hull profile. No rigid structure is attached to distribute the payload. (*Appendix B*)

**Shape of gas envelope**

The shape of the envelope has a major influence on its overall performance. Envelope weight is proportional to surface area and lift is proportional to the volume. In an ideal case, the surface area should be as small as possible relative to the volume. Air resistance is also determined primarily by the surface area. A spherical shape provides optimum lift efficiency. Any deviation from this optimum should utilized shapes based on circular arc sections to minimize surface stress. From the comparison results in *Appendix C*, the conventional streamlined shape is selected. It is the most efficient shape for an immersed body moving through a fluid.
2.4.4. Shape of Gondola

The shape must be of a streamline body as such drag is reduced. It must not have sharp corners or rough surface. This is to reduce both flow separation (results in wake or turbulence formed, increasing the drag force) and skin friction drag. It must be able to house all the components. To meet the criteria, Model A is selected as the gondola for the airship.

![Figure 2A: Shape of gondola](image)

2.4.5. Propulsion System and Surveillance System

*Propulsion System*

The maneuverability of the airship depends solely on vectored thrusting. To fulfill the operation criteria, this design will require a minimum of three motors fixed with propellers. To allow reverse thrusting, 6-9 propellers are fixed to the rotating shaft of the motors. The line of thrust must be variable to produce the pitching motion.

*Surveillance System*

Wireless video camera with a built-in transmitter is to be installed into the system. The direct line of sight must be variable. It is to have a visual capability of 300m unobstructed.
2.4.6. **Empennage (Tail fins stabilizers)**

The bare hull of streamline form is directionally unstable, tending always to turn broadside on to the direction of motion. Tail fins are required to ensure the stability of the airship. They also act as flow straighteners, arranged in a cross configuration. Control surfaces (elevators, rudders) will not be installed on the tail fins, as they are not required to generate a pitching moment. Moving at a slow speed will also render the control surfaces ineffective.

2.4.7. **Conceptual Drawings**

![Figure 2B: Streamlined shape of the envelope](image)

![Figure 2C: Arrangement of tail fins](image)

![Figure 2D: Gondola and motors position](image)
3. Preliminary Design

This phase of the design process will deal with working on the selection, specifications and limitations of the airship.

3.1. Propulsion System Evaluation

In the design, the airship has two motors, one on each side, connected through a movable axle, that can tilt up or down. These motors will control the pitching motions, forward and reverse motions of the airship. The third motor is fixed to the lower vertical tail fin and it controls the yawing motion of the airship. Since this design is highly dependent on vectored thrusting for controllability, it is important to determine the maximum amount of thrust that the propulsion system can produced. From which, the performance of the airship can be determined. Mabuchi N20 motors are used for the system (Refer to Appendix E for motor specifications).

3.1.1. Streamlining motor holders

The motor holders will support the motors. From the experiment conducted (Appendix F), it is advantageous to streamline the holders. The amount of thrust force generated is larger by 0.40g with a 9% increased in the weight of the holder. The small increase in weight does not contribute significantly to the total payload.

Figure 3A: Motor holders
3.1.2. Determination of thrust force generated by propulsion system

The same method is employed to determine the thrust force (Appendix F). To verify the experimental results, a more conventional method is used. In this method an extension spring, of spring constant \( k = 1.983 \), is used to determine the thrust force generated by the motor with propeller fixed to it (Appendix G). Although both methods produce similar results, the conventional method is more accurate. It gives the direct relation between the thrust force and tensile force experience by the spring.

\[
T = F_{\text{tensile}} = k\Delta x
\]

3.1.3. Variable line of thrust

The variable line of thrust will enable the airship to perform climbing and descending motion. When the line of thrust remains horizontal, it allows the airship to propel forward or backward, depending on the direction of thrust.

![Figure 3B: Mechanism for varying line of thrust](image)
Chapter 3 – Preliminary Design

The line of thrust varies from $-80^\circ$ to $+80^\circ$. The setting of back thrust and with a line of thrust set at $+70^\circ$ will set the airship into a climb. The signal for the configuration is sent via a remote controller.

3.2. Estimation of payload

It is difficult to calculate the actual overall weight of the airship. An estimation of payload is important as it will determine the volume of lifting gas required and hence, the size of the airship. It will also affect the performance of the airship.

To account for the weight of the envelope material, an estimate of 100% of the total weight of components is added. Another 10% is added to account for the eventual changes or improvements and additions to the airship.

**Total Estimated Weight**  

\[ = 242.84 + 100\%(242.84) + 10\%(242.84) \]

\[ = 500g \]
Table 3A: Weight tabulation of airship components

<table>
<thead>
<tr>
<th>Components</th>
<th>Weight (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 x Mabuchi N20 Motors</td>
<td>15.3</td>
</tr>
<tr>
<td>3 x 6-9 propellers (Diameter = 0.08m)</td>
<td>2</td>
</tr>
<tr>
<td>3 x Motor holders</td>
<td>7.74</td>
</tr>
<tr>
<td>Futaba Micro Servo (S3107)</td>
<td>9</td>
</tr>
<tr>
<td>Futaba 4 channels Micro Receiver</td>
<td>11.3</td>
</tr>
<tr>
<td>Receiver Battery (NiCd 4.8V)</td>
<td>95.6</td>
</tr>
<tr>
<td>Micro Speed Controller, Wires, Switch</td>
<td>12.5</td>
</tr>
<tr>
<td>Wireless Video Camera</td>
<td>15.1</td>
</tr>
<tr>
<td>Energizer 9V battery</td>
<td>36</td>
</tr>
<tr>
<td>Carbon Fibre Rod with Pinion Gear</td>
<td>6.3</td>
</tr>
<tr>
<td>Driver Gear</td>
<td>1.1</td>
</tr>
<tr>
<td>Tail Fins (Empennage Stabilizers)</td>
<td>12.7</td>
</tr>
<tr>
<td>Gondola (polyvinyl chloride)</td>
<td>18.2</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>242.84</strong></td>
</tr>
</tbody>
</table>

3.3. Dimension of envelope

\[
\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1
\]

\[
\frac{x^2}{2a^2} + \frac{y^2}{b^2} = 1
\]

Figure 3D: Governing equation of shape profile of envelope
With the knowledge of the estimated weight of the airship, the dimension of the envelope can be derived. The governing equation of the shape profile is shown in Figure 3D. The length to maximum depth ratio of 2.27 is chosen (Appendix H).

At sea-level under ISA condition,

\[ L_{net} = V_T \rho_{net} = 0.5 \text{kg} \]

\[ V_T = \frac{0.5}{1.225 - 0.169} = 0.47 \text{m}^3 \]

\[ V_T = \pi ab^2 (1.609) = (1.609)(0.53)\pi a^3 \]

\[ a = 0.7 \text{m} \]

\[ b = 0.53a = 0.37 \]

\[ l = 2.404a = 1.7 \text{m} \]

\[ d = 2b = 0.75 \text{m} \]

The purchased envelope is made of polyurethane (vinyl) and has a dimension of 1.7m in length and maximum diameter (depth) of 0.75m. The capacity of the envelope when fully inflated is 0.50m³.

### 3.4. Center of buoyancy and center of mass

There is a need to determine the center of buoyancy and the center of gravity of the envelope. So that it will aid in ensuring the stability of the blimp at a later stage of construction. To determine the center of buoyancy, the centroid of the shape of the envelope must be determined. The volume of air displaced is exactly the volume occupied by the shape of the envelope. By finding the centroid of the envelope shape, it is equivalent of finding the center of buoyancy. From Appendix J, the position of the center of buoyancy is 0.817m from the head of the
airship and it lies on the line of revolution. The envelope is made of homogenous material, the center of mass will coincide with the center of buoyancy.

3.5. Performance of the airship

After all the components have been determined, the performance of the airship will be of interest. Performance includes maximum speed, maximum rate of climb, rate of turn, maximum flight altitude.

3.5.1. Maximum cruise speed

It is the maximum speed at which the airship is cruising at straight and level. The drag force sustain by the airship is estimated with the following equation.

\[ F_{\text{drag}} = \frac{1}{2} C_D \rho \, V^2 \, A \]

The coefficient of drag, \( C_D \) is estimated to be 0.35 (A value between that of a sphere - 0.39 and a streamline body - 0.05). The \( C_D \) is achieved at a Reynolds number of \( 10^4 \). From the graph in Figure 3E, with the maximum thrust achieved by propulsion of two motors (0.14N) at 5 volts, the maximum theoretical speed achievable is 1.22m/s. (Refer to Appendix K for calculation of projected area)
3.5.2. Maximum rate of climb

It is the maximum rate at which the airship ascends. The line of thrust is resolved into the vertical and horizontal components. Vertical component results in the lift thrust. The $C_D$ value is estimated to be 5.2. Maximum value occurs at the line of thrust of 80° with a rate of 0.66 m/s.
3.5.3. Maximum rate of turn

Only one motor is responsible for the yawing motion. The maximum thrust available for turning at full power (5V) is 0.07N. The $C_D$ value is estimated to be 5.2. From the graph in Figure 3H, the maximum rate of turn is 32.5°/s.

$$\frac{ds}{dt} = R \frac{d\theta}{dt}$$

$R=0.817m$  

0.07N  

Thrust from motor fixed at bottom tail fin

Figure 3I: (Top view) Yaw motion
3.5.4. Maximum altitude

From the manufacturer specifications, the airship can withstand an expansion of 10% of the total volume.

\[ V_T = 1.609 \pi ab^2 = (1.609) \pi (0.707)(0.375)^2 = 0.503m^3 \]

\[ V'_T = (1.1)V_T = 0.553m^3 \]

To avoid unnecessary stress on the envelope material, the airship should not exceed the altitude where the volume of the airship has increased to \(0.553m^3\).

Using the equation,

\[ L_{net} = V'_T \rho_{net} \]

The net lift density, \(\rho_{net}\), can be determined with net static lift, \(L_{net}\), remaining constant.

\[ \rho_{net} = \frac{L_{net}}{V'_T} = \frac{0.5kg}{0.553m^3} = 0.904kg/m^3 \]
Hence, $\rho_{\text{net}}$ cannot exceed $0.904\text{kg/m}^3$. A chart of relative density for a range of Off-Standard conditions against altitude is plotted to determine the maximum altitude achievable without over stressing the envelope material.

From the graph above, at $\text{ISA} +15$, the maximum altitude the airship can achieve is 1000m above sea level. Beyond which the envelope may over expand and causes a failure in the material. (Refer to Appendix L for detail calculation)

However there is a limitation to the maximum altitude. Futaba 6XAs 6-channel remote control system is used for transmission of signals. The maximum transmission range stated by the manufacturer is 100m unobstructed. Hence, the maximum altitude is more affected by the radio transmission range rather than by the limiting net lift density.
4. Detailed Design

Construction of the prototype will be the next phase of the design process. This is followed by indoor and outdoor flight tests. The chapter will end with evaluation and quantification of the prototype built.

4.1. Construction of prototype

The envelope is purchased off-shelf. The minimum dimensions are derived before purchasing (Section 3.3, Appendix H). Emphasis is placed on constructing the gondola and the empennage (tail fins).

4.1.1. Gondola

The gondola (Figure 4A) houses the propulsion system, surveillance system, power source and radio signal receiver. The main positions to be fixed are the holes as shown in Figure 4B. The equipments are installed in the following order;

a) Ball bearings and carbon fibre rods (Figure 4C & 4D).

b) Motors fitted with 6-9 propellers

c) Radio signal receiver, servo, micro controller.

d) Surveillance system (Figure 4E).

The 4.8V NiCd battery (powers propulsion system) and 9V alkaline battery (powers surveillance system) are replaced by a 8.4V lithium polymer cell. To protect the micro controller, a voltage regulator circuit is installed to step down the power voltage to 5V before feeding into the micro controller circuit. The wireless video camera continues to be powered by the 8.4V lithium polymer cell.
Chapter 4 – Detailed Design

Figure 4A: Dimension of Gondola Casing

Figure 4B: Position of holes to be drilled
Figure 4C Installation of ball bearings to reduce friction

Figure 4D: Installation of carbon fibre rod.

Figure 4E: Circuit diagram of console
Figure 4F: Mounting of surveillance system
4.1.2. Empennage

The tail fins are made of balsa wood with a thickness of 2mm. The fins are arranged in a cross configuration. A propeller motor will be installed on the lower vertical tail fin, will control the yaw motion of the airship.

![Diagram of tail fins dimensions](image.png)

**Figure 4G: Dimensions of the tail fins**
Figure 4H: Engineering drawing of mini patrol airship
4.2. Flight test

Flight tests are conducted indoor and outdoor. The objective of indoor flight test is for testing of the airship manoeuvrability. The results are excellent for indoor test. The airship is able to perform all manoeuvres as designed. During the test, obstacles are set. The airship is able to overcome the barrier (simulating flying over a building) and survey the surrounding (objects place beyond the barrier). It has also shown its capability of performing around-corner flight.

Outdoor flight test prove to be more challenging than indoor. The operation of the airship is susceptible to weather, especially wind. With the slightest breeze, it will affect the controllability. Hence, most of the outdoor test flights are conducted in the early hours of dawn when the weather is most calm. Under still air condition, the airship is able to climb up to 30m smoothly. It has demonstrated its capability of surveying the surrounding of a building and over-fly a building to survey a stretch of road.

In both scenarios, the main difficulty is getting the survey objects to be in focus (clarity of the objects). Before hand the operator must have knowledge of the range to be survey and set the focusing of the video camera before operating the airship for surveillance.

Flight tests were also done to verify the theoretical performance tabulated in Section 3.5. For cruise speed and rate of climb, the airship was flown for a known distance and height. The time was note down for the journey. The procedure was repeated 5 times and the average was taken. For cruise speed it
was found to be \(0.85\text{m/s}\). For the rate of climb it was \(0.5\text{m/s}\). In determining the rate of turn, the airship was made to complete five \(360^\circ\) turns. Time was noted for this manoeuvre. The test was repeated 5 times and the average taken was \(28.6\%\).

The discrepancies between the experimental and theoretical results are due to human errors (parallax and reaction error). However, a large fraction of the difference is due to the estimation made during theoretical calculations. Due to limited resources, test could not be conducted at wind tunnel to determine the \(C_D\) value for the whole airship. Secondly, projected area is used instead of the wetted surface area. Hence the value obtain is more known as form drag. Skin friction drag was not included in the calculation. The percentage difference for cruise, climb and turn are 30.3\%, 24.2\% and 12\% respectively.

The experimental results obtained are accepted for the operation of airship at low speed. Since it is required to perform surveillance, it is not necessary for the airship to move at high speed.
4.3. Evaluation and quantification of prototype.

To quantify the prototype as a UAV surveillance airship, the resolution of the image transmitted back to ground operator need to be determined. With the resolution known, the user can foresee the smallest object that can be detected at a specific range. If the dimension of the object to be survey is known, the flight altitude of the airship can be controlled such that the object remains detectable at the operating flight altitude.

4.3.1. Quantification of prototype

An experiment was carried out to determine the relationship between range and smallest observable object on an LCD screen (Image resolution is set at 320 x 240 ppi).
Table 4A: Experimental data of image resolution

<table>
<thead>
<tr>
<th>Flight Altitude (m)</th>
<th>4.500</th>
<th>9.000</th>
<th>13.500</th>
<th>18.000</th>
<th>22.500</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original dimension (m)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dimension of object on LCD screen (m)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resolution = 320 x 240 ppi</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.100</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0.200</td>
<td>0.002</td>
<td>0.001</td>
<td>0.0005</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0.300</td>
<td>0.003</td>
<td>0.002</td>
<td>0.001</td>
<td>0.0005</td>
<td>0</td>
</tr>
<tr>
<td>0.400</td>
<td>0.004</td>
<td>0.003</td>
<td>0.002</td>
<td>0.001</td>
<td>0.0005</td>
</tr>
<tr>
<td>0.500</td>
<td>0.005</td>
<td>0.004</td>
<td>0.003</td>
<td>0.002</td>
<td>0.001</td>
</tr>
<tr>
<td>0.600</td>
<td>0.006</td>
<td>0.005</td>
<td>0.004</td>
<td>0.003</td>
<td>0.002</td>
</tr>
<tr>
<td>0.700</td>
<td>0.007</td>
<td>0.006</td>
<td>0.005</td>
<td>0.004</td>
<td>0.003</td>
</tr>
<tr>
<td>0.800</td>
<td>0.008</td>
<td>0.007</td>
<td>0.006</td>
<td>0.005</td>
<td>0.004</td>
</tr>
<tr>
<td>0.900</td>
<td>0.009</td>
<td>0.008</td>
<td>0.007</td>
<td>0.006</td>
<td>0.005</td>
</tr>
</tbody>
</table>
From the graph plot in Figure 4J, it is observed the image resolution reduces to 0.0005m before becoming invisible to the naked eye. The dimension of magnitude of 0.0005m is used as a benchmark to indicate the smallest object that may be viewed or transmitted back to the operation ground. Hence, at a range of 19.45m the smallest observable image has an actual length magnitude of 0.2m.
From Figure 4K, the relation of range and the smallest object observable from the screen is established.

\[ R = (39.8)O_D + 10.9 \]

For example, the body length of a car is about 4m. The airship must be within the range of 170m for the car to be detected in the LCD screen.

Besides resolution, the other quantity that must be known is the scope of the camera. It refers to the area of coverage at a certain range. An experiment was set up in the lab to evaluate this quantity (Refer to Appendix M). The results from the experiment show that the horizontal \( \theta_h \) and vertical \( \theta_v \) angle from the direct line of sight are \( 24.6^\circ \) and \( 40.7^\circ \) respectively.
For example, at a range of 20m,

\[
\text{Area surveyed} = 2R \tan \theta_h \tan \theta_v \\
= 2(20)(\tan 24.6)(\tan 40.7) \\
= 15.75 m^2
\]

### 4.3.2. Evaluation of prototype

Airship UAV has advantages over fixed wing and rotary UAVs. Fixed wing aircraft cannot hover over a target and rotary wings UAV have sever vibration problems for camera use and have a limited payload. The airship is able to resolve the problems in one vehicle. A loss in control or motor failure means damage to the aircraft and to the expensive onboard equipment (e.g. camera), is almost guaranteed. In contrast, airship is not immediately placed into jeopardy by the loss of control. If subjected to heavy landing, the shock absorbing nature of the envelope protects the equipment against impact. If power is lost, the airship will descend slowly being only slightly heavy.

On the other hand, the envelope fabric is prone to damage is repeatedly inflated and deflated. Hence, to prolong the lifespan of the envelope, it is kept inflated. It will take up a lot of storage spaces. Secondly, the airship is extremely susceptible to weather conditions. Camera tasks can be difficult to achieve in breezy conditions.

With the surveillance system, the airship provides a birds’ eye view of the surrounding. It provides a good perception of the surveyed area. It allows the operator on the ground to detect moving vehicles based on the real-time image transmission (Figure 4N). From the results, it shows that is it possible to detect
vehicles. The only problem lies in recognizing the type of vehicle from the screen. The quality of the image is reduced by interference. The airship has the capability to over-fly a building and survey the surroundings beyond the building.

However, all the capabilities can achieve efficiency only during calm weather conditions (still air). Also problems are often encountered when there is radio signal interference. During interference, there will be a temporary loss of control and will greatly reduce the clarity of the image transmitted back to ground.

![Figure 4N: Road surveillance (Range: 26.5m, Flight altitude: 22.5m)](image)
Chapter 5 – Conclusions

5. Conclusions

The objectives of this project have been met. An airship is designed with the intention of operating it as an UAV. Flight tests carried out during the course of the project have shown that the airship designed is capable of performing the manoeuvres as stated in the criteria of the conceptual design phase. The airship has the VTOL (Vertical Take-Off and Landing) capability. The airship is able to perform patrolling task around build-up area with the aid of a string tie-down to it.

With a maximum thrust of $0.14N$, the airship has a cruise speed of $0.85m/s$ and a rate of climb of $0.50m/s$. With the operation of the tail fin motor (thrust of $0.07N$), it gives a rate of turn of $28.6\, ^\circ/s$. The performance is suitable for slow speed operation required for surveillance. However, there exists a barrier to counter the weather effects. This accounts for the aid of a tie-down string during operation. The airship design is incapable of countering the effects of wind.

With the relationship established experimentally, given the range, the area coverage under the surveillance system can be estimated. The smallest object that can be detected on the image transmitted to the screen can also be determined. For example, at the flight altitude of $22.5m$ (height of 5 storey building) with a range of $26.5m$, area coverage is $20.87m^2$. It is possible to survey a stretch of road and the vehicles can be easily spotted from the screen, as the smallest possible object to be detected on the screen is $0.4m$.

Despite the failure to perform efficiently under outdoor conditions, the ideas brought across are that developing the airship into an UAV has immense
potential, especially in the military field of application. As discussed in Section 4.3.2, that airship has advantages in terms of operation cost as compared to fixed and rotary wing aircraft. Airships are not susceptible to fatal crashes as that experience by fixed wing aircrafts.

The theoretical values calculated are based on ISA conditions and the effects of wind and superheat are not taken into account. In actual operating conditions, these effects do play a part in affecting the performance of the airship. However, these tabulated values are good estimates of the performance of the airship.
6. Recommendations

During the course of the project a form of contradiction has developed. On one hand, the project has shown the capability of the airship in military operation. It is therefore more advantageous than using a fixed wing aircraft. On the other, military task is referred to as a tactical mission. Hence, the “mini” airship designed may be too big for it to be stealthy and tactical; especially it is designed to operate at low altitude. The current designed dimension has difficulty in countering weather conditions. A smaller physical dimension will make it worse unless a strong and powerful motor powers it. However, to install these motors, meant an increase in net static weight, the net static lift must also increase to meet the demand, which will result in an increase in volume (therefore a respective increase in dimension). A recommendation for this issue is to fully develop an airship large enough (50ft in length) to bear the load of two powerful motors with the capability of countering weather effects (e.g. counter a headwind of 20knots). With these capabilities, the airship is capable of attaining a cruise altitude of 4000ft. A 50ft airship at 4000ft will be very difficult to spot. The actual dimension of a manned airship can easily hit 300ft in length. 50ft is only 1/6 of the 300ft so in this context is it still considered “mini”. However, the money invested will be increased by about 20 times the amount spends in this project ($1300).
The next recommendation is to improve on the stability and control in bad weather conditions. This is crucial if the airship is to operate in all-weather conditions.

Lastly, the surveillance system can be further improved. The focusing of the lens can be achieved through radio control. Hence, it requires a build-in receiver and a mechanism to set off the camera motion. To counter the stability problem during unfavourable weather conditions, a gyro stabilizing mechanism can be designed and installed into the system.

The next stage to be achieved is to attain the autonomous level, where programming is highly involved.
References

   Cambridge University Press, United Kingdom, 2000


8. LT. COL Donald E. Ryan, Jr., “The Airship’s Potential For Intertheater
   and Intratheater Airlift”, School of Advanced Airpower Studies, Air
   University, United States Air Force, Maxwell Air Force Base, Alabama,
   May 1992
Appendix A: Equipment data sheet

Micro Speed Controller

Figure A1: Micro Speed Controller

<table>
<thead>
<tr>
<th>Specifications Data of Speed Controller</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Three channel throttle control</td>
</tr>
<tr>
<td>• Drive three motors proportionally forward or reverse up to 1 amp for 4.8V</td>
</tr>
<tr>
<td>• Weight: 6 grams</td>
</tr>
<tr>
<td>• Power source: 4 cell Nicad battery operation from 2.8 to 5.4 volt</td>
</tr>
<tr>
<td>• High frequency (2 kHz) PWM</td>
</tr>
<tr>
<td>• High efficiency circuit for 99% transfer of power</td>
</tr>
<tr>
<td>• Power conservation software allows minuscule current draw with motors off or coasting</td>
</tr>
<tr>
<td>• Repeatable throttle and dead band performance</td>
</tr>
</tbody>
</table>

Futaba Micro Receiver R114F (4 Ch)

Figure A2: Futaba Receiver

<table>
<thead>
<tr>
<th>Specifications Data of Micro Receiver</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 Channels</td>
</tr>
<tr>
<td>Weight: 11.3 grams</td>
</tr>
<tr>
<td>Dimensions: 32 x 13 x 22mm</td>
</tr>
<tr>
<td>Frequency: 77MHz</td>
</tr>
</tbody>
</table>
Appendix A: Equipment data sheet

Futaba Super Micro Servo S3107

![Micro Servo S3107](image1)

**Specifications Data of Micro Servo**

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimension</td>
<td>21.8 x 11.0 x 19.8mm</td>
</tr>
<tr>
<td>Weight</td>
<td>9 grams</td>
</tr>
<tr>
<td>Operating speed (4.8v)</td>
<td>0.12 sec</td>
</tr>
<tr>
<td>Output torque (4.8v)</td>
<td>1.2 kg.cm</td>
</tr>
</tbody>
</table>

![Micro Servo S3107](image2)

Futaba 6XAS 6-Channel FM/PCM Transmitter

![FM Transmitter](image3)

**Specifications Data of Transmitter**

**Description:**

T6XAS PCM1024 Multifunction 6 channel transmitter may be used with any Futaba FM/PPM receiver. Works with Futaba PCM1024 receivers when the built-in PCM transmission option is selected. The liquid-crystal display panel allows rapid data input into its easy-to-read LCD display. The T6XAS system comes complete with programming for ACRO (aircraft) and HELI (helicopter) mixing and can accommodate virtually any model configuration. The compact ergonomically designed transmitter holds completely independent memories for 6 DIFFERENT MODELS. This radio has a memory backup chip, which enables it to keep the radio settings when the transmitter battery is removed for cycling. This Futaba radio is diode protected to prevent overcharging, which means that the battery cannot be discharged through the transmitter.

**Features:**

- The stick length and tension are adjustable.
- Switches are provided for Dual rates (D/R), Programmable mixers (PMX)
- Programming features include servo reversing for all channels
- Dual Rates for all 3 channels
Appendix A: Equipment data sheet

**Wireless Video Camera**

![Wireless Video Camera](image)

<table>
<thead>
<tr>
<th>Specifications Data of WVC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimension: 44x23x23mm</td>
</tr>
<tr>
<td>Weight: 19.3 grams</td>
</tr>
<tr>
<td>Output power: 10mW</td>
</tr>
<tr>
<td>Scan frequency: 50Hz</td>
</tr>
<tr>
<td>Transmission distance: 50m-100m (Without blockage)</td>
</tr>
</tbody>
</table>

**Voltage Regulator Circuit**

Enables the wireless video camera and speed controller to share a common power source. The lithium polymer cell has a voltage of 8.4V. The video camera taps directly from the original source. The voltage regulator circuit is used the step down the voltage to 5V before feeding it to the speed controller circuit.

![Voltage regulator circuit diagram](image)

**Figure A5: Wireless Video Camera**

**Figure A6: Voltage regulator circuit diagram**
Appendix A: Equipment data sheet

Lithium Polymer Cell

![Figure A7: Lithium Cell](image)

**Specifications Data of Lithium Cell**

<table>
<thead>
<tr>
<th>Dimension</th>
<th>52x34x6.2mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>21.1 grams</td>
</tr>
<tr>
<td>Output Voltage</td>
<td>8.4V</td>
</tr>
<tr>
<td>Capacity</td>
<td>1020mAh</td>
</tr>
</tbody>
</table>

System Setup

![Figure A8: Setup for real time image transmission](image)

- Signal from the Futaba transmitter controls the motion of airship.
- Signal receive is sent to the laptop to display real time images.
- Receiver for video camera.
- Signal is sent to the receiver.

Figure A8: Setup for real time image transmission
Appendix B: Selection of airship category

A large variety of airship types can be postulated. The airship types are categorized according to the degree of augmentation of the lifting gas static lift by means of direct powered lift.

Table B1: Airship categories.

<table>
<thead>
<tr>
<th>Airship Category</th>
<th>Description</th>
</tr>
</thead>
</table>
| A                | • No lift augmentation  
                  | • Non-variable propulsion thrust line  
                  | • Uses aerodynamic control to incline body axis, generating hull-lift using airspeed.  
                  | • Hull lift is used to supplement static gas lift to support initial heaviness at take-off and landing.  
                  | • Requires ground roll to achieve take-off and landing. |
| B                | • Partial lift augmentation  
                  | • Modest degree of complication  
                  | • Overcomes low speed controllability  
                  | • Variable propulsion thrust line |
| C                | • Total lift augmentation  
                  | • High degree of complexity  
                  | • Support payload by power lift |
Table B2: Assessment of the suitability of the three airship design concepts to Perform military roles

<table>
<thead>
<tr>
<th>Military Roles</th>
<th>Category A</th>
<th>Category B</th>
<th>Category C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Small</td>
<td>Large</td>
</tr>
<tr>
<td>Airborne Early Warning (AEW)</td>
<td>*</td>
<td>**</td>
<td>***</td>
</tr>
<tr>
<td>Anti-Submarine Warfare (ASW)</td>
<td>*</td>
<td>*</td>
<td>***</td>
</tr>
<tr>
<td>Mine Counter-Measures (MCM)</td>
<td>*</td>
<td>***</td>
<td>*</td>
</tr>
<tr>
<td>Command, Control, Communications, Intelligence (C3I)</td>
<td>*</td>
<td>**</td>
<td>***</td>
</tr>
</tbody>
</table>

Key: *** Most Suitable  ** Moderately Suitable  * Suitable

With all the descriptions of the 3 categories, it is more advantageous to select Category B airship. It fits into the design criteria as mention in **Section 2.3**.

**Structural Category Selection**

Figure B1: Structural Category
### Table B3: Description of structural category of airships.

<table>
<thead>
<tr>
<th>Structural Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rigid</td>
<td>• Carries external loading through a lightweight structural outer shell.</td>
</tr>
<tr>
<td></td>
<td>• Shell is divided into many compartments each housing a separate gasbag.</td>
</tr>
<tr>
<td></td>
<td>• Lifting-gas pressure is not required to maintain the shape of airship.</td>
</tr>
<tr>
<td></td>
<td>• Allows a lower internal gas pressure as compared to non-rigid airship.</td>
</tr>
<tr>
<td>Semi-Rigid</td>
<td>• A long structural keel is installed to share the bending load.</td>
</tr>
<tr>
<td>Non-Rigid</td>
<td>• No structural installation.</td>
</tr>
<tr>
<td></td>
<td>• Load is bear by the inflated gasbag.</td>
</tr>
<tr>
<td></td>
<td>• Hull profile is maintained by the lifting-gas pressure.</td>
</tr>
</tbody>
</table>

Non-rigid type of airship is selected. The designed payload does not require a metal structure for support. The strength of the gasbag material and the internal overpressure is more than sufficient to sustain the payload. Adding a structural support may enhance the stability but it also reduces the allowable payload.
Appendix C: Selection of envelope shape

Two types of shape are currently available in the market, conventional streamlined shape and lenticular shape. From the plot above, lenticular shape deviates the most from the optimum lift efficiency (spherical shape). It is difficult to compromise optimum lift and surface area (skin friction drag) for lenticular shape. For streamlined shape, optimum lift as well as surface area is compromised. Hence, streamlined shape is selected for this design.
Appendix D: Material Selection for gas envelope

Two types of material are of interest in this project; mylar and polyurethane (vinyl). The datasheet of the two materials are attached to this appendix. In comparison, mylar is denser than polyurethane. Hence, polyurethane is more applicable when payload is of concern. Polyurethane has low helium permeability (3% loss per day), good handling properties (more durable) and crease resistance giving a professional look. Polyurethane also has good weatherability. Polyurethane is more flexible than mylar as the material allows 10% expansion of the total volume. When punctured, the hole will propagate rapidly in mylar whereas with polyurethane the hole does not propagate. The advantage of mylar is that it is much cheaper than polyurethane reducing the cost of the project. Polyurethane is chosen as the material for gas envelope.
Appendix D: Material selection for gas envelope

Mylar®
Polyester Film

Physical-Thermal Properties

Mylar® polyester film retains good physical properties over a wide temperature range (-70 to 150°C [-94 to 302°F]), and it is also used at temperatures from -250 to 280°C (-423 to 536°F) when the physical requirements are not as demanding. Some physical and thermal properties of Mylar® are summarized in Table 1. Detailed information and other physical and thermal properties are described in the remaining pages of this bulletin.

Table 1

<table>
<thead>
<tr>
<th>Property</th>
<th>Typical Value</th>
<th>Unit</th>
<th>Test Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile Strength 5%</td>
<td>20 (20)</td>
<td>kg/mm²</td>
<td>ASTM D 82</td>
</tr>
<tr>
<td>Elongation (Ultimate) MD</td>
<td>10 (10)</td>
<td>%</td>
<td>ASTM D 82</td>
</tr>
<tr>
<td>Density</td>
<td>1.30</td>
<td>g/cm³</td>
<td>ASTM D 65</td>
</tr>
<tr>
<td>Tensile Strength 10%</td>
<td>400 (300)</td>
<td>kg/mm²</td>
<td>ASTM D 82</td>
</tr>
<tr>
<td>Elongation (Ultimate) TD</td>
<td>110</td>
<td>%</td>
<td>ASTM D 82</td>
</tr>
<tr>
<td>Surface Roughness Ra</td>
<td>38</td>
<td>nm</td>
<td>Optical profilometer</td>
</tr>
<tr>
<td>Heat Seal Strength</td>
<td>55</td>
<td>N/mm²</td>
<td>ASTM D 66</td>
</tr>
<tr>
<td>Flow Rate</td>
<td>0.21</td>
<td>gal/min</td>
<td>ASTM D 2967</td>
</tr>
</tbody>
</table>

Figure D1: Datasheet of Mylar
Appendix D: Material selection for gas envelope

Figure D2: Datasheet of Polyurethane

<table>
<thead>
<tr>
<th>Typical Property</th>
<th>ASTM Method</th>
<th>PT6100</th>
<th>PT6200</th>
<th>PT7500</th>
<th>PT9300</th>
<th>PT9200</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardness (Shore A)</td>
<td>D-2240</td>
<td>83</td>
<td>90</td>
<td>95</td>
<td>82</td>
<td>85</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>D-792</td>
<td>1.13</td>
<td>1.14</td>
<td>1.13</td>
<td>1.14</td>
<td>1.12</td>
</tr>
<tr>
<td>100% Modulus (MD/GD Ave.)</td>
<td>Mod. D-682</td>
<td>7.6</td>
<td>12.4</td>
<td>6.9</td>
<td>8.2</td>
<td>7.6</td>
</tr>
<tr>
<td>200% Modulus (MD/GD Ave.)</td>
<td>Mod. D-682</td>
<td>18.6</td>
<td>37.9</td>
<td>13.6</td>
<td>11.7</td>
<td>15.2</td>
</tr>
<tr>
<td>Ultimate Tensile</td>
<td>Mod. D-682</td>
<td>62.1</td>
<td>56.6</td>
<td>34.5</td>
<td>43.1</td>
<td>44.8</td>
</tr>
<tr>
<td>Ultimate Elongation</td>
<td>Mod. D-682</td>
<td>630</td>
<td>475</td>
<td>450</td>
<td>575</td>
<td>570</td>
</tr>
<tr>
<td>Tear Resistance</td>
<td>D-704</td>
<td>10.9mm</td>
<td>74.3</td>
<td>87.4</td>
<td>55.8</td>
<td>83.1</td>
</tr>
<tr>
<td>Processing Range</td>
<td>°C</td>
<td>170-204</td>
<td>159-210</td>
<td>169-210</td>
<td>171-182</td>
<td>190-204</td>
</tr>
<tr>
<td>Yield</td>
<td></td>
<td>23.46</td>
<td>34.6</td>
<td>34.6</td>
<td>34.6</td>
<td>30.2</td>
</tr>
</tbody>
</table>

Application Data **

- Inflates/Bladders: X X X X
- Medical: X
- Bell/Hose: X
- Hot Melt Adhesive Films/Tapes: X
- Transportation: X
- Coated Textiles: X X X X
- Foam Laminates: X X
- Protective Linings: X X X

** Dureflex® Polyether TPU Film Features:
- Excellent hydrolytic stability
- Excellent low temperature flexibility
- Tough/Durable
- Excellent abrasion resistance
- Excellent flex fatigue properties
- Bondable to a wide variety of substrates
- Colors available
- Weldable - RF, heat seal, ultrasonic
- Easy decoration, printability, fabrication
- Good resistance to fats, grease, solvents

---

**As with any product, the use of Dureflex® brand film sheet in a given application must be tested (including field testing) in advance by the user to determine suitability.
Appendix E: Specifications of motor

**MABUCHI MOTOR**

**FF-N20PA/PN**

*Typical Applications:* Audio and Visual Equipment, Car CD/MD Player, Camcorder

**Specifications:**

<table>
<thead>
<tr>
<th>MODEL</th>
<th>VOLTAGE</th>
<th>CURRENT</th>
<th>EFFICIENCY</th>
<th>TORQUE</th>
<th>OUTPUT</th>
<th>FRICTION COEFFICIENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>FF-N20PA-10190</td>
<td>3.0V</td>
<td>600mA</td>
<td>72%</td>
<td>0.12N.m</td>
<td>0.06W</td>
<td>0.05</td>
</tr>
<tr>
<td>FF-N20PN-08260</td>
<td>5.0V</td>
<td>800mA</td>
<td>65%</td>
<td>0.15N.m</td>
<td>0.10W</td>
<td>0.08</td>
</tr>
</tbody>
</table>

**Direction of Rotation:**

- 23.1 REF.
- 10.0 REF.
- 0.5 REF.

**Dimensions:**

- Shaft Length: 25.5mm
- ISO M14x0.7 Tapped Hole: 2 Places

**Weight:** 5g (APPROX)

---

National University of Singapore
Department of Mechanical Engineering
Appendix F: Modification of motor holders

Experiment objective: To determine if modifying the motor holder affects the generation of thrust.

The setup of the experiment is as shown above and the distance between the propeller and the electronic balance is fixed at 0.15m. The voltage of the power source is varied to obtain the corresponding thrust force (measured in grams, read off from the electronic balance).
Table F1: Experimental data of thrust force with varying voltage

<table>
<thead>
<tr>
<th>Voltage (V)</th>
<th>Current (A)</th>
<th>Modified Motor Holder</th>
<th>Unmodified Motor Holder</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>T_1</td>
<td>T_2</td>
</tr>
<tr>
<td>1.50</td>
<td>0.11</td>
<td>1.08</td>
<td>1.08</td>
</tr>
<tr>
<td>2.00</td>
<td>0.14</td>
<td>1.91</td>
<td>1.96</td>
</tr>
<tr>
<td>2.50</td>
<td>0.19</td>
<td>2.88</td>
<td>2.85</td>
</tr>
<tr>
<td>3.00</td>
<td>0.22</td>
<td>3.75</td>
<td>3.80</td>
</tr>
<tr>
<td>3.50</td>
<td>0.28</td>
<td>4.66</td>
<td>4.88</td>
</tr>
<tr>
<td>4.00</td>
<td>0.31</td>
<td>5.81</td>
<td>5.85</td>
</tr>
<tr>
<td>4.50</td>
<td>0.37</td>
<td>6.92</td>
<td>6.85</td>
</tr>
<tr>
<td>5.00</td>
<td>0.41</td>
<td>7.99</td>
<td>7.98</td>
</tr>
<tr>
<td>5.50</td>
<td>0.47</td>
<td>9.00</td>
<td>8.98</td>
</tr>
<tr>
<td>6.00</td>
<td>0.51</td>
<td>10.06</td>
<td>10.10</td>
</tr>
</tbody>
</table>

Weight before modification = 1.45g

Weight after modification = 1.58g

There is an increased of 9% of weight after modification. From the graph, it shows that there is an increase in thrust force with the used of modified motor holder. The average increased is 0.4g of thrust force. Hence, modification should be done to the motor holder to increase the generated thrust force. Also it has negligible effect on the payload, as the increased in weight is small.
Appendix G: Thrust force determination

Experimental objective: To determine the thrust force generated by Mabuchi N20 motor fixed with 6-9 propeller.

The spring constant, $k$, of the spring used in this experiment is determined. Spring force equation: $F_{\text{tensile}} = k\Delta x$

With the knowledge of $k$ value, the thrust force generated by the motor will be determined. The experimental setup is as shown in Figure G2.

The data is collected and plotted on a graph (Figure G3). From the graph the thrust force produced by one motor at a supply voltage of 5V is 0.072 N.
Appendix G: Thrust force determination

Motor is connected to the spring

Figure G2: Experimental setup for determination of thrust force

Figure G3: Graph of thrust force (N) Vs supply voltage (V)
Appendix H: Length to depth ratio of envelope

\[ C_L = \frac{F_{\text{lift}}}{0.5 \rho_{\text{air}} v^2 A} \quad C_D = \frac{F_{\text{drag}}}{0.5 \rho_{\text{air}} v^2 A} \]

In the above two expressions, only \( A \) is ambiguously defined. The lift of an aircraft is produced entirely by the wing. In this case, \( A \) represents the projected surface area of the wings. For airship, the lift is directly related to its envelope volume. Hence, \( A \) is represented by \((\text{Buoyant Volume}, V_T)^{2/3}\). However, with the large surface area of airship, skin friction drag is the largest fraction of the total drag. In many reports, \( A \) is the wetted surface area of the airship.

For body of revolution with a fixed diameter,

\[ d^2 \cdot l = \text{const} \]

It has been shown that for \( 0 < d/l \) (thickness ratio) < 0.35

\[ \frac{A}{l^2} = 2.33 \frac{d}{l} \quad V_T^{2/3} = 0.465 \left( \frac{d}{l} \right) \]

\( C_{DV} \) and \( C_{DA} \) are drag coefficients made non-dimensional by \((V_T)^{2/3}\) and surface area \( A \) respectively.

\[ \frac{C_{DV}}{C_{DA}} = \frac{A}{V_T^{3/2}} = 3.88 \left( \frac{l}{d} \right)^{1/3} \]

The variation of drag as the thickness ratio was examined. With the data from the experimentally derived pressure distributions, the contributions due to skin friction and form drag was calculated. Bodies of revolution on the basis of equal volume were compared.
Table H1: Variation of drag of bodies of revolution of constant volume with thickness ratio \((REF\ 1)\).

<table>
<thead>
<tr>
<th>(d/l)</th>
<th>(A/l^2)</th>
<th>Reynolds’s No. (\times 10^5)</th>
<th>(C_{DA})</th>
<th>(C_{DV})</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.05</td>
<td>0.114</td>
<td>2.360</td>
<td>0.00271</td>
<td>0.0285</td>
</tr>
<tr>
<td>0.10</td>
<td>0.229</td>
<td>1.491</td>
<td>0.00301</td>
<td>0.0251</td>
</tr>
<tr>
<td>0.15</td>
<td>0.342</td>
<td>1.138</td>
<td>0.00329</td>
<td>0.0240</td>
</tr>
<tr>
<td>0.182</td>
<td>0.413</td>
<td>1.000</td>
<td>0.00347</td>
<td>0.0237</td>
</tr>
<tr>
<td>0.20</td>
<td>0.456</td>
<td>0.940</td>
<td>0.00356</td>
<td>0.0236</td>
</tr>
<tr>
<td>0.25</td>
<td>0.570</td>
<td>0.810</td>
<td>0.00386</td>
<td>0.0237</td>
</tr>
<tr>
<td>0.30</td>
<td>0.692</td>
<td>0.716</td>
<td>0.00422</td>
<td>0.0244</td>
</tr>
</tbody>
</table>

From the table above, \(C_{DA}\) increases with \(d/l\) whereas \(C_{DV}\) has a minimum. Young suggest that the minimum occurs at \(d/l = 0.182\). An appropriate value from the table is \(d/l = 0.2\). This minimum indicates the airship must be very flat and with this ratio, it will incur a small drag penalty compared with the optimum. However, in the design, low drag is only one of the factors in optimising a design. The other point of consideration is that increasing the ratio thickness can reduce the structural bending moments.

Giving considerations to both factors, the thickness ratio is fixed to be between 0.4 to 0.5. With reference to Figure C1, thickness ratio of 0.45 (Fineness ratio = 2.2) does not cause a tremendous increase in surface area as compared to the optimum. With the estimation of payload, the volume of lifting gas is estimated which gives the volume of gas envelope when fully inflated. Selection of the gas envelope is based on these values. The gas envelope purchased has a fineness ratio of 2.27 (thickness ratio = 0.44).
Appendix I: Lifting Gas

Helium is selected as the lifting gas for this design. Despite the cost, it is the most efficient source of static lift for the airship and that it is safe as it is an inert gas.

Table I1: Comparison of lifting gases

<table>
<thead>
<tr>
<th>Gas</th>
<th>Density (kg/m$^3$)</th>
<th>Lifting Force (N/m$^3$)</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen</td>
<td>0.085</td>
<td>11.2</td>
<td>Inflammable, relatively cheap</td>
</tr>
<tr>
<td>Helium</td>
<td>0.169</td>
<td>10.2</td>
<td>Inert, relatively expensive</td>
</tr>
<tr>
<td>Hot Air</td>
<td>0.906</td>
<td>3.14</td>
<td>Inert, very cheap, relatively poor lift</td>
</tr>
<tr>
<td>Methane</td>
<td>0.756</td>
<td>4.5</td>
<td>Inflammable, relatively cheap</td>
</tr>
</tbody>
</table>

Helium gas does not come in pure form. To account for the impurity, the density is with the following formula. Helium gas purchased for this experiment has a purity of 99.999%. Hence, the density of helium is approximated to 0.169kg/m$^3$.

$$\rho_{He} = \left( k \times 0.169 + (1-k) \times 1.225 \right)$$

$k =$Percentage purity of helium
Appendix J: Center of buoyancy & center of mass

Archimedes Principle: Magnitude of the buoyant force acting on the body is equal to the weight of the fluid displaced by the body. Buoyant force passes through the centroid (center of buoyancy) of the displaced volume.

For composite body,

$$\bar{X} \sum V = \sum \bar{x}V$$

$$\bar{X}(0.50) = (-0.0552) + 0.1104$$

$$\bar{X} = 0.11m$$
Appendix K: Calculation of volume, surface area, projected area

The streamlined shape profile selected for this design is a composite shape. It consists of an ellipsoid and a modified ellipsoid. X-axis, is the axis of symmetry and the axis of revolution.

![Figure K1: Governing equation of shape profile of envelope](image)

<table>
<thead>
<tr>
<th>Volume Tabulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \frac{x^2}{a^2} + \frac{y^2}{b^2} = 1 )</td>
</tr>
<tr>
<td>( y = \sqrt{b^2 - \frac{x^2b^2}{a^2}} )</td>
</tr>
<tr>
<td>( V_1 = \pi \int_0^a \left( b^2 - \frac{x^2b^2}{a^2} \right) dx )</td>
</tr>
<tr>
<td>( V_1 = \frac{2}{3} \pi ab^2 )</td>
</tr>
<tr>
<td>( V_T = V_1 + V_2 = 1.609 \pi ab^2 )</td>
</tr>
</tbody>
</table>

![Figure K2: Volume tabulation](image)
In the calculation of drag force, the projected area of the streamline profile must be known. The projected area varies depending on the flight configuration.

From Figure K4, $PA_1$ is a circle of radius $b$. To obtain the area of $PA_2$, an integration of the governing equation is done with respect to $x$.

$$PA_1 = \pi b^2 = 0.442 \text{ m}^2$$
$$PA_2 = \frac{\pi}{2}ab + 0.589 = 1.005 \text{ m}^2$$
Appendix L: Aerostatics

An airship is dependent on the principles of buoyancy for its primary lift. The buoyancy is dependent on the density of the displaced fluid (along with the displaced volume). Hence, the properties of this displaced fluid are important. The airship operates in the atmosphere; hence properties of air are of concern in the airship operation.

Table L1: International Standard Atmosphere conditions at sea-level

<table>
<thead>
<tr>
<th>Properties</th>
<th>Symbol</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>$T_0$</td>
<td>288.15 K (15°C)</td>
</tr>
<tr>
<td>Pressure</td>
<td>$p_0$</td>
<td>101325 N/m$^2$</td>
</tr>
<tr>
<td>Density</td>
<td>$\rho_{a0}$</td>
<td>1.225 kg/m$^3$</td>
</tr>
</tbody>
</table>

The density and pressure is dependent on the temperature at the required altitude. ISA defines a series of temperature gradients which cover the regions of the atmosphere.

$$T_s = 288.15 - 0.0065 H_p$$

Density at ISA varies exponentially with temperature ratio.

$$\rho_s = \rho_0 \left( \frac{T_s}{T_0} \right)^{4.3}$$

Pressure at ISA similarly varies the temperature ratio.

$$p_s = p_0 \left( \frac{T_s}{T_0} \right)^{5.3}$$
An Off-Standard atmosphere is defined by a temperature difference from ISA. This temperature difference is constant for all altitudes. Pressure is the same for Off-Standard and Standard atmospheres. The density is dependent upon the ratio between Off-Standard and Standard conditions.

\[ \rho_A = \rho_S \left( \frac{T_s}{T_s + \Delta T} \right) \]

Net static lift is the gross static lift less the weight of the contained gases within the envelope volume.

\[ L_{\text{net}} = L_{\text{gas}} - M = V_T \rho_{\text{net}} \]
Appendix M: Scope of video camera

![Diagram of experimental setup](image)

This experiment also requires the setup of the receiver console (Refer to Figure A8). The only variable in this experiment is the range. The image of the wall with measuring tape is transmitted to the receiver and the signal is sent to the laptop. On the screen of the laptop, the horizontal and vertical distances are read off and recorded in a table. The experiment was repeated 5 times to obtain an average value of scope angle.

<table>
<thead>
<tr>
<th>Range, R (cm)</th>
<th>$d_h$ (cm)</th>
<th>$d_v$ (cm)</th>
<th>$\theta_h = \tan^{-1}\left(\frac{d_h}{2R}\right)$</th>
<th>$\theta_v = \tan^{-1}\left(\frac{d_v}{2R}\right)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>18.2</td>
<td>33.3</td>
<td>24.5</td>
<td>39.8</td>
</tr>
<tr>
<td>30</td>
<td>27.6</td>
<td>50.7</td>
<td>24.7</td>
<td>40.2</td>
</tr>
<tr>
<td>40</td>
<td>36.0</td>
<td>69.0</td>
<td>24.6</td>
<td>40.0</td>
</tr>
<tr>
<td>50</td>
<td>45.6</td>
<td>83.6</td>
<td>24.5</td>
<td>39.9</td>
</tr>
<tr>
<td>60</td>
<td>55.7</td>
<td>101.7</td>
<td>24.9</td>
<td>40.3</td>
</tr>
</tbody>
</table>

Hence, $(\theta_h) = 24.6^\circ$ and $(\theta_v) = 40.7^\circ$