DEVELOPMENT AND ANALYSIS OF HIGH ALTITUDE BALLOON PERFORMANCE CALCULATOR

By

HAIKAL BIN JAMALUDIN

Thesis submitted in fulfillment of the requirements for the Bachelor Degree of Aerospace Engineering (Honors)

June 2021

ENDORSEMENT

I, Haikal Bin Jamaludin hereby declare that I have checked and revised the whole draft of dissertation as required by my supervisor.

(Signature of Student)

Date: 27 June 2021

(Signature of Supervisor)

Name: DR NORILMI AMILIA ISMAIL
Date: 7 July 2021

(Signature of Examiner)

Name: DR 'AIFFAH BINTI MOHD ALI
Date: 11 July 2021

DECLARATION

This thesis is the result of my own investigation, except where otherwise stated and has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any other degree.

(Signature of Student)

Date: 25 June 2021

ACKNOWLEDGEMENT

First and foremost, I would like to offer my highest gratitude to my supervisor, Dr. Norilmi Amilia Ismail who has been my source of knowledge and advice throughout this project. With her support, I managed to learn about everything required in making this project. I also would like to thank all who have been there whenever I need help. During my journey to finish this study, I was helped by many people and friends, hence I would again express my gratitude to those who lend their helping hands when I was in difficulty. Lastly, I would like to thank my family for always supporting me until I finished this project.

DEVELOPMENT AND ANALYSIS OF HIGH ALTITUDE BALLOON PERFORMANCE CALCULATOR

ABSTRACT

A high altitude balloon is an unmanned balloon that is loaded with gases that lift more than air and is released into the upper atmosphere for any scientific endeavor. It is difficult to calculate the LTA gas performance in order to select the best balloon performance, and a calculator is required to predict the balloon performance prior to launching the high altitude balloon, as both of these topics will be covered in this paper. This project's technique began with research on the HAB and LTA gases. The technical specification data will be obtained from the manufacturer in order to determine the parameters for the HAB's performance. Using the parameters gathered from the implemented computation, a graphical user interface will be developed. The results will then be compared among the manufacturers using the GUI. The interface for the calculator, as well as a comparison of the HAB performance, will be displayed in the results. Because the lift produced by Hydrogen gas is more than that produced by Helium gas, the ascension rate of Hydrogen gas is greater than that of Helium gas. As the launch volume grew, the ascension rate increased due to more lift produced on the balloon with higher volume upon release. Because the pressure within the balloon is greater on the balloon with more capacity at release as it expands quicker, the burst height will drop as the launch volume increases. The descent rate of a parachute with a bigger payload will be quicker than for a lighter payload due to the increased drag produced by the payload, and the descent rate at higher altitude will be faster due to the lower density at higher altitude. Finally, the LTA gases may be distinguished using the GUI. We were also able to investigate the MATLAB program and create a graphical user interface for the balloon performance. Finally, the HAB performance may be predicted utilizing the GUI development.

PEMBANGUNAN DAN ANALISIS KALKULATOR PRESTASI BALON ALTITUD TINGGI

ABSTRAK

Belon ketinggian tinggi adalah belon tanpa pemandu yang sarat dengan gas yang mengangkat lebih dari udara dan dilepaskan ke atmosfer atas untuk sebarang usaha ilmiah. Sukar untuk mengira prestasi gas untuk memilih prestasi belon terbaik, dan kalkulator diperlukan untuk meramalkan prestasi belon sebelum melancarkan belon ketinggian tinggi, kerana kedua-dua topik ini akan dibahas dalam makalah ini. Teknik projek ini dimulakan dengan penyelidikan belon dan gas. Data spesifikasi teknikal akan diperoleh dari pengeluar untuk menentukan parameter untuk prestasi belon. Dengan menggunakan parameter yang dikumpulkan dari pengiraan yang dilaksanakan, antara muka pengguna grafik akan dikembangkan. Hasilnya kemudian akan dibandingkan di antara pengeluar dengan muka pengguna grafik. Antara muka untuk kalkulator, dan juga perbandingan prestasi belon, akan ditunjukkan dalam hasilnya. Oleh kerana pengangkatan yang dihasilkan oleh gas Hidrogen lebih banyak daripada yang dihasilkan oleh gas Helium, maka kadar kenaikan gas Hidrogen lebih besar daripada gas Helium. Ketika volume pelancaran meningkat, kadar kenaikan meningkat kerana lebih banyak daya angkat yang dihasilkan pada belon dengan jumlah yang lebih tinggi semasa dilepaskan. Kerana tekanan di dalam balon lebih besar pada balon dengan lebih banyak kapasitas saat dilepaskan ketika mengembang lebih cepat, ketinggian pecah akan turun seiring peningkatan volume peluncuran. Kadar keturunan parasut dengan muatan yang lebih besar akan lebih cepat daripada muatan yang lebih ringan kerana peningkatan seretan yang dihasilkan oleh muatan, dan kadar keturunan pada ketinggian yang lebih tinggi akan lebih cepat kerana kepadatan yang lebih rendah pada ketinggian yang lebih tinggi. Akhirnya, gas dapat dibezakan menggunakan muka pengguna grafik. Kami juga dapat menyiasat program MATLAB dan membuat antara muka pengguna grafik untuk prestasi belon. Akhirnya, prestasi belon dapat diramalkan menggunakan pengembangan muka pengguna grafik.

LIST OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

HAB	High Altitude Balloon
LTA	Lighter Than Air
GUI	Graphical User Interface

LIST OF NOMENCLATURE

bd	Burst diameter
Cd	Balloon Cd
d	Launch Diameter
d_P	Launch Diameter
F_B	Buoyancy
F_D	Drag
F_G	Gross Lift
F_L	Free Lift
F_N	Neutral Lift
ga	Gravitational Constant
h	Burst Height/Altitude
m_b	Balloon mass
m_p	Payload mass
P	Pressure
P_O	Pressure Initial
ρ_a	Density of Atmospheric Pressure
ρ	Density
hel/g	Density of Helium Gas
hyd/g	Density of Hydrogen Gas
r	Launch Radius
S	Area
t	Time to Burst
V_B	Burst Volume
V_L	Launch Volume
V_R	Burst Volume Ratio
v	Ascent Rate
v_d	Descent Rate
W	Weight
π	Pi

CHAPTER 1

INTRODUCTION

1.1 Overview

This chapter establishes the general concept of High Altitude Balloon its application. The current problems that need to be solved by this project are discussed, and the research's objectives are presented. The thesis outline presents the flow and brief description of each chapter in the thesis.

1.2 Background

Before the beginning of the space era, balloons had one significant advantage over airplanes as they could ascend to the very top of the sky, where there is insufficient air to produce lift for wings or to sustain air-breathing engines. As a result, these lighter-than-air vehicles promised to become vital research instruments, allowing for the investigation of a wide range of geophysical phenomena in the upper atmosphere. Several balloonists perished between 1875 and 1927 when ascending to heights where the air was too thin, and the pressure was too low to support life (Piccard, 1938).

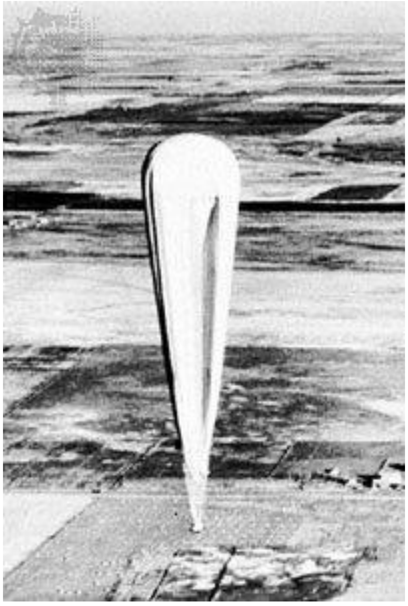

Figure 1.1: Ascent of a Piccard balloon (Britanica *et al.* 2021)

Piccard's passion for ballooning and curiosity in the high atmosphere prompted him to develop a spherical, pressurized aluminum gondola that would allow ascension to vast heights without the use of a pressure suit in 1938 (Piccard, 1938). Balloon-based experiments assisted in early studies of the distribution of cosmic rays in the atmosphere and also provided for the first direct measurement of the stratosphere (Yajima *et al.* 2004). Cosmic ray studies, air sampling for detecting atomic explosions, photographic flights over foreign territory, astronomical views above the troposphere disturbances, and even aerodynamic testing of free-falling payloads were all part of early high-altitude studies with plastic balloons (Xu & Brown, 1987). Above the range of airplanes but below the range of orbiting satellites, a balloon is the sole stable platform for any sort of observation. It's also the only aircraft that doesn't pollute the environment and can sit relatively stationary at altitudes that helicopters can't reach. Since then, the use of HABs has continued to thrive and become an integral part of astrophysical, planetary and climatic studies, including radiation investigations in near-space environments (Lawrence *et al.* 2018), surveillance of atmospheric ozone levels (Hofmann *et al.* 1987) and measurement of electric fields within the stratosphere (Gurubaran *et al.* 2017)

High-altitude balloons are unmanned balloons, normally loaded with Helium or Hydrogen, which after release, climb to the stratosphere, typically at an altitude of between 60,000 and 100,000 feet (Voss, 2009). It has long been used for scientific entry to lower and upper atmospheres, including the troposphere and the stratosphere. There are different ways of entry to the stratosphere, including meteorological rockets (Imshenetsky *et al.* 1976), fixed-wing aircraft (Smith *et al.* 2009), mountaintop observatories (Smith *et al.* 2011), and high-altitude weather balloons (Bryan *et al.* 2014). However, HABs are unmatched in their affordability, flexibility, and high payload-to-vehicle-mass ratio. In comparison, payloads may also be reused. Larger HABs, usually referred to as scientific balloons, can carry a payload of up to 3,600 kg while remaining up for weeks or months. At the same time, smaller HABs, generally referred to as meteorological balloons, typically carry payloads weighing a few kilograms, and can be launched by hand, making them suitable for amateur use. Both forms of HABs can climb to the stratosphere to achieve altitudes between 17 and 35 km above sea level (Smith & Sowa, 2017).

Two high-altitude balloons took off from Kampar, Perak, on September 1, 2019. The first balloon, which took off at 9:00 a.m., contained a payload for space photography as well as an electronic module to be tested in the near-space environment. This hydrogen-filled balloon soared for almost 50 minutes before landing 30 kilometers southwest of its launch site. The second helium-filled balloon was launched at 10.30 a.m., carrying a Shape Memory Alloy (SMA) experiment module as well as a communication and tracking module. This balloon soared to a height of up to 23 km before bursting and landing around 16 km away from the original payload's touchdown point (Goh, 2019)

1.3 Problem Statement

The idea is to keep the volume of the balloon as stable as possible based on the strongly positive differential pressure between the lift gas and the atmosphere. However, the stability of volume depending on other factors such as material efficiency. There should be a high strength of material to withstand high pressures on balloon film and a light film due to the restricted gross mass framework (Sherif & Weiliang, 2008). Thus, a modern concept that gathers the allowable benefits of all types is the new objective of longer life, higher payload weight, and higher altitude stability, eliminating complex structures and problems with material challenges (Sherif & Weiliang, 2008).

The balloon's performance needed to be calculated before the actual flight take place to predict the outcome of the balloon as the plan for recovery can succeed but the calculation using hand and simple calculator might not give a suitable outcome. Thus, having a calculator that solving the performance of the HAB will be great. Using a computer, to be precise a MATLAB software, graphical user interface (GUI) gives a lot of advantages. One of them is seamless integration with existing MATLAB computational power, user interactivity, and real-time measurement (Scott, 2006). So, any difficulties on the high altitude balloon project can be reduced (Sherif & Weiliang, 2008).

1.4 Objectives

This study will examine the performance of the high altitude balloon that includes the launch volume, ascent rate, and burst height. The project objective will study the lighter than air (LTA) for the performance of the balloon. Objectives that are to be achieved in this project, include:

1. To determine lighter than air (LTA) gas performance of for high altitude balloon.
2. To develop and improve a graphical user interface (GUI) for the onsite operation using the existing calculation of high altitude balloon performance.

1.5 Thesis Outline

This thesis is subdivided into five chapters and structured as stated below:

The LTA gas for the balloon was described in Chapter 1 to guarantee that the high altitude balloon's performance was excellent. This chapter also informed readers about high altitude balloons and provided a brief history of the HABs' development. At the end of Chapter 1, the usage of the Matlab software as a tool for estimating the performance of the high altitude balloon is described.

In Chapter 2, the associated literature is examined to show what researchers have done so far to improve the high altitude balloon's performance. Not only are the LTA qualities mentioned in the evaluations, but also the conventional high altitude balloon design system. The engagement with the balloon design system helps to eliminate the difficulties that affect the balloon's performance. The engagement with the balloon design system helps to eliminate the difficulties that affect the performance when studying the balloon's performance.

The methods and approaches employed in this research, as well as the equations employed, are discussed in Chapter 3. It includes the parameters of the balloons and their surroundings, as well as the calculations and coding in Matlab software and the experiment preparation required to meet the project's goal.

The findings of the trials and the discussion are covered in Chapter 4. The results will be compared to actual outcomes from other manufacturers and researchers who have suggested similar ideas in the past. Based on the findings, the association between various manipulated factors would be investigated.

Ultimately, in Chapter 5, the importance of the study as a basis for future high altitude balloon performance prediction will be discussed. Based on the parameter correlation in the experiments, a conclusion should be reached. Some recommendations for future study include conducting more experiments, improving performance, and developing graphical tools for performance prediction.

CHAPTER 2

LITERATURE REVIEW

The relevant literature is reviewed to demonstrate what researchers have done so far to improve the performance of high altitude balloons. The traditional high altitude balloon design system, as well as the LTA characteristics, are mentioned in the reviews. Participation in the balloon design system aids in the elimination of problems that impact the performance of the balloon.

2.1 Conventional High Altitude Balloon System

A standard balloon system is designed around a commercially available Helium, or Hydrogen filled weather balloon to carry a payload aloft. The core elements of a standard high altitude balloon system are shown in Fig. 2 (Shane *et al.* 2009). System incorporation is important to make sure the project is successful and that all goals are fulfilled. The overall system design of HAB can be divided into five subsystems, namely, balloon and navigation, communication, onboard data handling (OBDH) and payload, structure or bus, and thermal subsystems (Shaqeer & Norilmi, 2007).

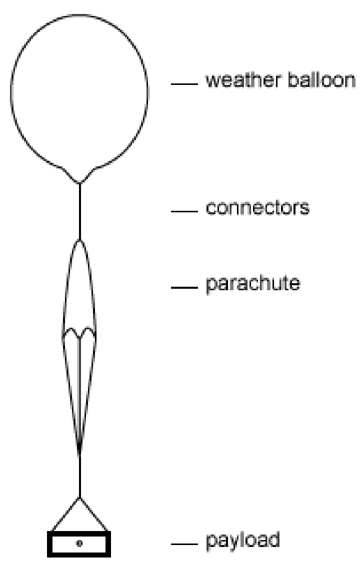

Figure 2.1: Standard high altitude balloon design (Rachel, 2016)

The balloon is then released and rises towards the stratosphere. The external environment's pressure is lower than the pressure within the balloon throughout its ascent. Because of the pressure differential, the balloon will begin to inflate until it can no longer sustain the internal pressure and bursts.

2.2 Balloon

The balloon's material is chosen depending on the objective or application. Some heavy-payload high-altitude balloons are constructed of nylon bonded to polyester film, while most research balloons are composed of very thin polyethylene or latex. Some of these polyethylene films are only a tenth of a millimetre thick. The seams are strengthened with load-bearing tape to carry weight (Piccard, 2018). The size of the balloon is the priority in choosing the balloon as it must be able to carry the payload of the project. The weather station is normally used a latex balloon to fly radiosonde. As indicated in Table 1 burst data from Kaymont (TOTEX) and Table 2 Hwoyee burst data, balloons are classified based on their weight in grams rather than their physical measurements. The balloons of all sizes have the same thickness rubber skin.

Balloon Size (g)	100	300	350	500	600	800	1000	1200	1600	2000
Neck Diameter (cm)	≤4.5	≤6.4	≤6.4	≤6.4	≤6.4	≤6.4	≤7.7	≤8.3	≤8.3	≤8.3
Diameter at Burst (cm)	180	380	410	500	580	680	750	850	1050	1100
Average Burst Altitude (m)	16000	19000	21000	27000	28000	30000	32000	33000	36000	38000
Average Ascent Rate (m/min)	200	≥340	≥340	≥340	≥340	≥340	≥340	≥340	≥340	≥340

Table 2.1: Kaymont (TOTEX) burst data. (UK High Altitude Society, 2017)

Balloon Weight (gr)	200	300	350	450	500	600	700	800	1000	1200	1500	2000	3000
Diameter at Release (cm)	117	123	125	130	133	142	146	150	157	179	185	195	212
Volume at Release (cu.m)	0.83	0.97	1.03	1.1	1.22	1.5	1.63	1.76	2.01	2.99	3.33	3.89	4.97
Diameter at Burst (cm)	300	378	412	472	499	602	653	700	786	863	944	1054	1300
Volume at Burst (cu m)	14.1	28.3	36.6	55.1	65.1	114.2	145.8	179.6	254.3	336.5	440.5	613.1	1150.3
Bursting Altitude (km)	21.2	24.7	25.9	27.7	28.4	30.8	31.8	32.6	33.9	33.2	34.2	35.4	37.9
Cd	0.25	0.25	0.25	0.25	0.25	0.3	0.3	0.3	0.3	0.25	0.25	0.25	0.25

Table 2.2: Hwoyee burst data. (UK High Altitude Society, 2017)

The weight difference between various size balloons is due to the size of the mold on which the balloon was created. A bigger mould needed the use of more latex, resulting in a heavier finished balloon. This also implies that the balloon will expand to a greater diameter before it burst (Barlow & Fred 1988).

The balloon works usually filled with lifting gas such as Helium or Hydrogen to the desired altitude based on the mission. The balloon itself needed to be handle with care to avoid any damages to the balloon, and it also should be kept out of the sun as long as possible as UV rays can damage the materials. After the filling is done, the balloon then releases and ascends as the balloon expands to space where it creates too much pressure on the latex, and the balloon will burst. Other balloons contain devices that progressively remove the gas from the balloon, allowing the balloon to descend to the ground at a predictable rate. These alternatives allow teams more control over their flight but need more elaborate setups.

2.3 Payload system

The payloads of each mission change depending on the scientific and technological objectives. Cameras, data sensors, and tracking devices are constantly present. A telescope, spectroscope, pointing and stabilization platform, specific sensors such as a Geiger counter, or an astrological setup are all examples of additional equipment (Korff, 1958). The payload is attached to the parachute and linked to the balloon line. The payload is made of polystyrene, which is lightweight, waterproof, and capable of floating. The modules are stacked within the bus. The power supply is located at the bottom level, the OBDH and the payload are situated at the centre level, and the communication devices are placed at the top of the stack. The heat packs shall be kept at the bottom of each stack plate. Temperature and humidity sensors as well as the antenna are located outside the container for better connectivity (Shaqeer & Norilmi, 2007).

The payload must securely contain because by the time the balloon burst, the payload might go through several G's of force. The payload may experience a violent event. The payload also needs to be contained in a structure that protects it from harsh thermal conditions at high altitudes and high impacts during landing. The payload is kept warm under different atmospheric conditions by the use of a thermal subsystem unit. It is important to develop a sensor system based on a high-altitude balloon to offer ambient temperature, height position, and attitude information, working current, and video surveillance to offer a suitable working environment for the near-space detection load.

2.4 Parachute

The objective of having a parachute is to enable the payload to land safely on the ground after the balloon burst. It must be optimized in such a way that it will produce enough drag to slow down the descent rate, at the same time it is not too big so that the weight is reduced.

When inflated, the standard parachute that usually being used has a conical or hemispherical form. There are several varieties of parachutes, each with its own set of benefits in certain uses. The following is a summary of several common (and not-so-common) varieties of parachutes, with a focus on the first (flat circular) for HAB launches (Brian, 2016). Table 2.3 show the type of parachute.

TYPE	CONSTRUCTED SHAPE PLAN	CONSTRUCTED SHAPE PROFILE	$\frac{D_c}{D_o}$	INFLATED SHAPE $\frac{D_p}{D_o}$	DRAG COEF C_{D_o} RANGE	OPENING FORCE COEF C_X (INF MASS)	AVERAGE ANGLE OF OSCILLATION, DEGREES	GENERAL APPLICATION
FLAT CIRCULAR	D_c		1.00	0.67 TO 0.70	0.75 TO 0.80	~1.7	±10 TO ±40	DESCENT, OBSOLETE
CONICAL		D_c	0.93 TO 0.95	0.70	0.75 TO 0.90	~1.8	±10 TO ±30	DESCENT, M < 0.5
BICONICAL		D_c	0.90 TO 0.95	0.70	0.75 TO 0.92	~1.8	±10 TO ±30	DESCENT, M < 0.5
TRICONICAL POLYCONICAL		D_c	0.90 TO 0.95	0.70	0.80 TO 0.96	~1.8	±10 TO ±20	DESCENT, M < 0.5
EXTENDED SKIRT 10% FLAT		D_c, 0.1 D_c	0.86	0.66 TO 0.70	0.78 TO 0.87	~1.4	±10 TO ±15	DESCENT, M < 0.5
EXTENDED SKIRT 14.3% FULL		D_c, 0.143 D_c	0.81 TO 0.85	0.66 TO 0.70	0.75 TO 0.90	~1.4	±10 TO ±15	DESCENT, M < 0.5
HEMISPHERICAL		D_c	0.71	0.66	0.62 TO 0.77	~1.6	±10 TO ±15	DESCENT, M < 0.5, OBSOLETE
GUIDE SURFACE (RIBBED)	D_c		0.63	0.62	0.28 TO 0.42	~1.2	0 TO ±2	STABILIZATION, DROGUE, 0.1 < M < 1.5
GUIDE SURFACE (RIBLESS)	D_c		0.66	0.63	0.30 TO 0.34	~1.4	0 TO ±3	PILOT, DROGUE, 0.1 < M < 1.5
ANNULAR		D_c	1.04	0.94	0.85 TO 0.95	~1.4	<±6	DESCENT, M < 0.5
CROSS	D_c		1.15 TO 1.19	0.65 TO 0.72	0.60 TO 0.85	1.1 TO 1.2	0 TO ±3	DESCENT, DECELERATION

Table 2.3: Type of parachute (Knacke, 1991)

The payload line/string needs to be not more than 22.68 kg test line to meet the safety regulations. There are three common methods for attaching the parachute to the payload and balloon as follow:

2.4.1 Inline Parachute

Inline parachute is suggested for possibly all flights because, during ascension, the strain from the weather balloon will draw the parachute closed, reducing drag. The strain will be relieved when the weather balloon breaks, and the parachute will be free to unfold. The payload string will be attached to the bottom of the parachute, and the balloon string will be attached to a specific loop on the canopy's top.

2.4.2 Mid-Point Parachute

The second most popular technique is the Mid-point parachute, it's an excellent one if the parachute doesn't have a loop at the top of the canopy. Both the payload and balloon strings will be attached to the bottom of the parachute using this approach. During ascension, the parachute will dangle and drag with the payload line. This adds a little more drag, but not much. The parachute remains open the entire time.

2.4.3 Low-Point Parachute

The Low-Point Parachute is the least popular approach, although it is still possible if the canopy does not include a loop. In this approach, the payload will be attached directly to your balloon, and the parachute will be attached to the bottom of the payload. This approach causes the payload to drag, but this time below the payload.

2.5 Lighter than air (LTA) gases

Lighter than air (LTA) gases, often known as lifting gases, have a lower density than regular atmospheric gases and rise above them. Aerostats are necessary to generate buoyancy, notably in lighter-than-air aircraft such as free balloons, moored balloons, and airships. Only specific gases that are lighter than air can be used as lifting gases. The LTA gas must have a lower density than the dry air, which density is roughly 1.29 g/L at standard temperature and pressure (STP) and an average molecular mass of 28.97 g/mol.

Only 14 gases and vapours have density of less than one, which means they are lighter than air. Acetylene, ammonia, carbon monoxide, diborane, ethylene, Helium, Hydrogen, hydrogen cyanide, hydrogen fluoride, methane, methyl lithium, neon, nitrogen, and water are some of these. Nine of these gases are combustible. In addition, seven of these gases have densities of 0.75 or higher. When the density is so near to one, these gases will mix rather than ascend in the air.

Gas	Formula	Molecular weight [g/mol]	Vapor density
Hydrogen	H^2	2.016	0.07
Helium	He	4.003	0.14
Methane	CH^4	16.043	0.55
Ammonia	NH^3	17.031	0.59
Water	H^2O	18.016	0.62
Hydrogen Fluoride	HF	20.006	0.69
Neon	Ne	20.180	0.70
Methyl lithium	$LiCH^3$	21.980	0.76
Acetylene	C^2H^2	26.038	0.90
Hydrogen cyanide	HCN	27.026	0.93
Diborane	B^2H^6	27.670	0.96
Carbon monoxide	CO	28.005	0.97
Nitrogen	N^2	28.013	0.97
Ethylene	C^2H^4	28.054	0.97

Table 2.4: Vapor density of the lifting gases that are lighter than air.

Hydrogen and Helium are normally the lifting gases used for high altitude balloons (Voss, 2009). The comparison between Hydrogen and Helium is interesting in terms of operating efficiency. Since Helium has a molecular weight almost twice that of Hydrogen, Helium technically supplies about 93 percent of the hydrogen lift in the air (Albert *et al.* 1987). The lifting power of both Hydrogen and Helium depends on the temperature, pressure, and humidity.

In practical operation, it is difficult to obtain or preserve 100% purity of any gas, giving Helium about 88% of the hydrogen lift during operation. To be aware of changing atmospheric pressures and gas impurities, airship models frequently conservatively estimate helium lifts at 0.96 kg/m3 and hydrogen lifts at 1.08 kg/m3 (Dumas *et al.* 2012)

2.6 Forces And Lifts

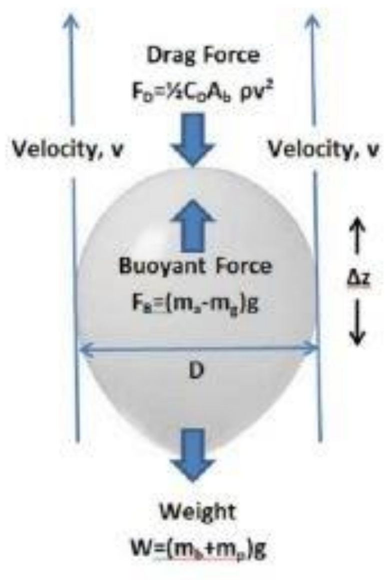

Figure 2.2: Vertical forces on the balloon (Voss *et al.* 2012)

Some forces need to be taken into account for the motion of the balloon. As shown in the figure above, the forces are the drag force, buoyant force, and the weight of the balloon. Some lift forces are fundamentally present for the balloon motion which are the gross lift, free lift, and neutral lift. Where the gross lift is the total lift provided by the lifting gas enclosed by the balloon, the neutral lift is the lift left after taking the payload into account and the free lift is the lift measured at the balloon neck without the payload attached (Voss *et al.* 2012).

The upward buoyant force or the gross lift is,

Buoyant Force = Gross Lift

$$F_B = (m_a - m_g)g \quad (1)$$

Where the, m_a is the balloon fill equivalent atmospheric mass that is displaced by the balloon gas, m_g and g is the acceleration of gravity. The balloon gross mass and the total weight are,

$$m_G = (m_b + m_P)g \quad (2)$$

$$\text{Weight, } W = (m_B - m_P)g \quad (3)$$

The neutral lift or nozzle lift and the free lift that is the net lift with the payload attached are,

$$F_N = F_B - m_b g \quad (4)$$

$$F_L = F_B - w = F_B - m_G g \quad (5)$$

When the balloon is release, it accelerates to a constant upward speed based on force balance between the free lift force and the drag force where,

$$F_L = F_D \quad (6)$$

And the drag force is,

$$F_L = \frac{1}{2} C_D A_b \rho_a v^2 \quad (7)$$

Where the ρ_a is the atmospheric density, v is the balloon upward velocity, C_D is the drag constant of proportionality, which is generally between 0.25 and 0.3, and A_b the cross-sectional area of the balloon, which may also be expressed as,

$$A_b = \pi \frac{D^2}{4} \quad (8)$$

The velocity during parachute descent may be estimated by considering A as the parachute area, and the descending terminal velocity can be determined by requiring that the drag force equal the entire parachute and payload weight.

$$m_G g = F_D = \frac{1}{2} C_D A_b \rho_a v^2 \quad (9)$$

Solving for v gives the falling terminal velocity, v_T

$$v_T = \left(\frac{2mg}{C_D A \rho}\right)^{\frac{1}{2}} \quad (10)$$

Where the Drag Coefficient, C_D , is between 0.5 to 0.8 (Seifert & Mcintosh, 2011) for the parachute.

.

2.7 Launch Volume

The volume required before the balloon is released into space is also known as the launch volume. The smaller the initial volume, the higher it may climb, and vice versa. The reason for this is because as the balloon ascends, it will expend until it reaches its maximum diameter, at which point it will burst. As mentioned before, the smaller the initial volume, the higher it can climb but it can only carry a small payload as a trade-off. So, to carry more payload or larger payload the initial volume needed to be high (Brian, 2016).

When the balloon is filled, the initial diameter is defined by the point at which the internal balloon pressure of the gas equals the external pressure from the atmosphere. When the balloon is released, the diameter increases because the outside pressure decreases as the balloon rises.

The amount of volume affects the burst altitude and affects the climb rate, time of flight, and the stability of the balloon to climb. Figure 2.3 shows the comparison of the climb rate and the burst altitude compared to the initial volume. Based on Figure 2.3, the lower the initial volume, the balloon will burst at a higher altitude, but the climb rate will be lower and vice versa (Brian, 2016).

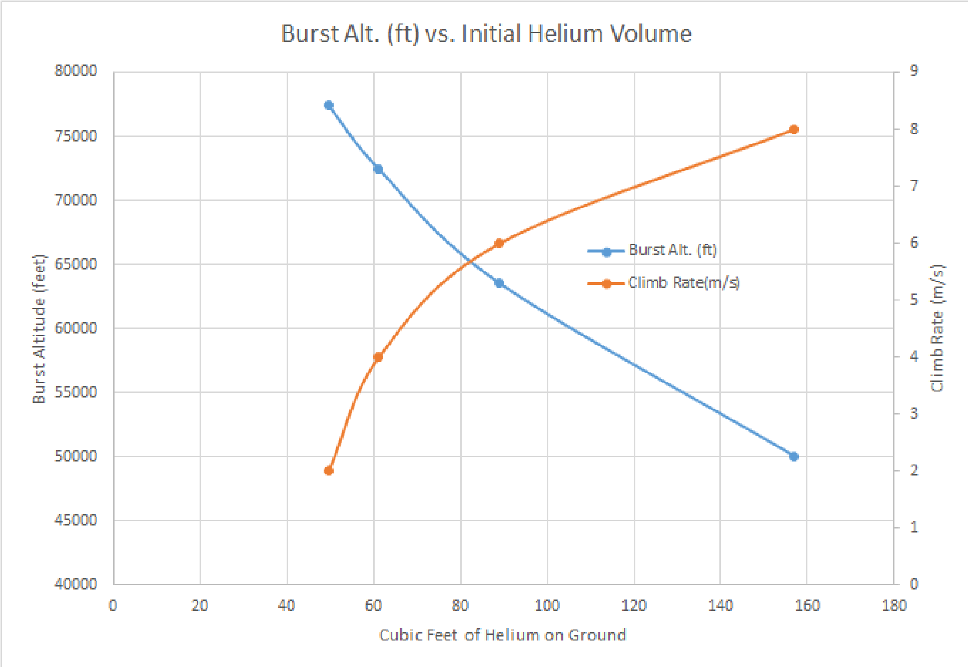

Figure 2.3: The comparison of effect between the climb rate and the burst altitude compared to the initial volume (Brian, 2016)

2.8 Ascent Rate

Ascent rate is the time of the balloon as they go up to space. It starts as soon as the balloon is released from the ground and increasing as it went up (Voss *et al*. 2012). the ascent rate is also known as the velocity where the unit is m/s. Using the gas law equation for an ideal gas,

$$PV = nRT \tag{11}$$

Where the *P* is the pressure, *V* is the volume of the balloon, n is the number of moles of the lifting gas, *R* is the gas constant, and *T* is the temperature of the balloon internally. Both sides of the gas law equation are multiplying by the average molecular mass of air, the density of air can be solved as,

$$\rho_a = \frac{M_a P_a}{R T_a} \tag{12}$$

The volume of the balloon can be solved if the fill gas parameters designated by the subscript is used,

$$V_b = \frac{m_g R T_g}{M_g p_g} \quad (13)$$

Where V_b is the function of the balloon radius when approximated to the volume of a sphere. Applying Newton's law, F=ma, with suitable approximations (Bachman), the dynamic motion of the balloon may be solved using a second-order equation. For steady-state, a=0, the sum of forces is zero with the drag force equalled by the lifting force. So, the steady-state ascent rate can be solved as

$$v_b = \sqrt{\frac{\pi D^3(\rho-\rho_B)g/6-(m_B+m_P)g}{C_D\rho\pi D^2/8}} \quad (14)$$

The vertical velocity of the balloon as it approaches its burst height may also affect balloon performance since it influences the pace at which the volume of the balloon changes. Changes in volume during shorter periods put additional strain on the material, increasing its likelihood to burst. As a result, if the balloon is 'going up hot,' or swiftly ascending into the atmosphere, it is conceivable that it will explode sooner than it would have if it had taken a more gradual rise (McNamara, 2016).

2.9 Burst Altitude

Burst altitude is the height of the balloon to burst when the pressure inside is higher than the pressure outside. The common altitude for high altitude balloons is around 10km to 40 km, where it's located in the troposphere and stratosphere. The balloons ascend past the tropopause and into the stratosphere. The tropopause is the barrier that separates the lower layer of the atmosphere from the upper layer of the atmospheric (troposphere), and it is an atmospheric area between the troposphere and the stratosphere. Temperatures in the troposphere range from 62°F to -60°F and stretch from 6km to 12km (McNamara, 2016). The tropopause's altitude fluctuates with sea-surface temperature and season and over shorter periods, ranging from 10–12 km at the North and South poles to 17 km over the equator (Near Space Research, n.d). Several variables will affect the burst altitude: balloon manufacturer, size, time of launch, and the ascent velocity.

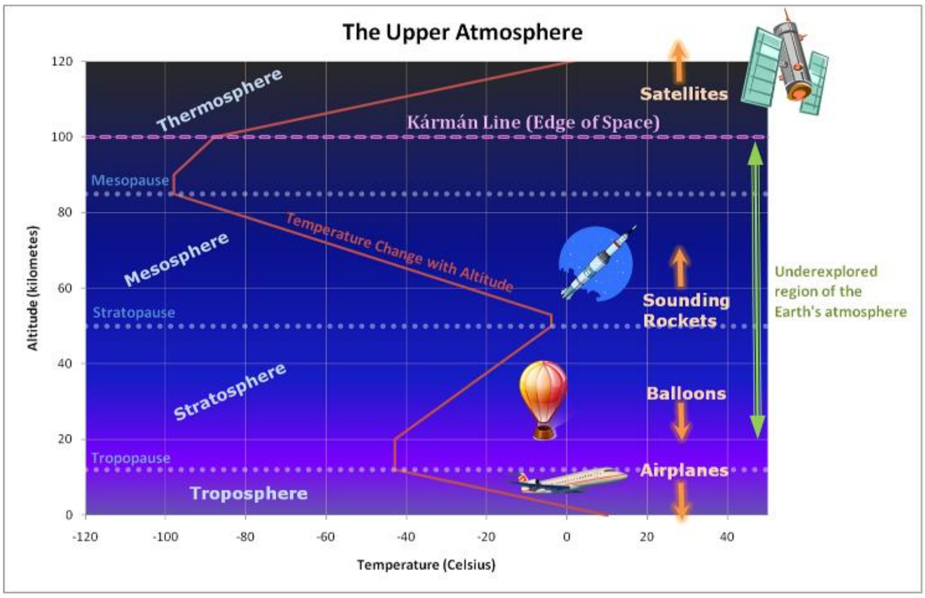

Figure 2.4: Layers of the atmosphere, displaying common gadgets that function at various levels. Courtesy of Trevecca University (Near Space Research, n.d).

2.9.1 Manufacturer

The balloon created by the company Kaymant Consolidated Industries, Zhuzhou Rubber Research & Design Institute Co., Ltd, and PAWAN Meteorological Balloons will be compared.

Kaymont balloons are manufactured by Kaymont Consolidated Industries, a company producing latex balloons for almost thirty years. The United States Space Program utilizes its balloons, and they are also used for high-altitude rocket launch and other types of HAB research

Zhuzhou Rubber Research and Design Institute Company, Ltd. manufactures Hwoyee brand balloons. They have been producing meteorological balloons since 1964 and are said to be China's largest manufacturer. Even though they create a wide range of balloons, HAB researchers frequently utilize the 1600 g sounding balloon composed of natural latex rubber.

PAWAN, a balloon manufacturer from India has been in business for over forty years and is one of the oldest and most respected producers of high-quality Weather Balloons. Various WMO Member Nations in Europe, Africa, South America, the Indian Ocean, and the Pacific Ocean Islands have come to rely on PAWAN Meteorological Balloons for their exceptional quality, affordable cost, and on-time delivery.

With the balloon mass of 1000 g from all three manufacturers, there are some differences in the burst altitude. This proves that different manufacturers will affect the burst altitude due to its different ways to produce the balloon, the amount of latex uses by each manufacturer, and other factors. Table 2.5 shows the balloon mass and burst altitude for three different manufacturers.

Manufacturer	Balloon mass,g	Burst altitude
Kaymont	1000	33.9
Hwoyee	1000	32
Pawan	1000	31

Table 2.5: The burst altitude from 3 different manufacturers.

2.9.2 Time Of Flight

The time of the flight may also be the factor that influencing the balloon burst altitude. Flights were divided into ‘day' and ‘night' flights for this study, which were differentiated by nautical twilight. The nautical twilight occurs when the sun's center is twelve degrees below the horizon referred to figure below (USNO, 2011).

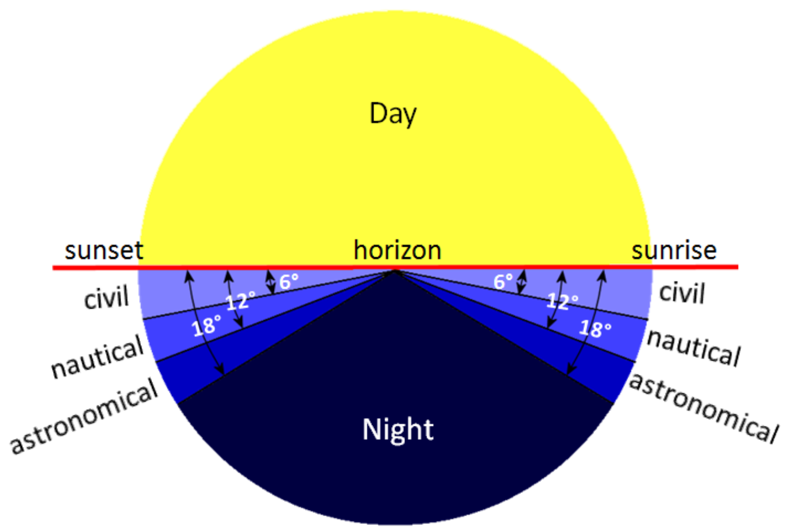

Figure 2.5: Twilight's categories are represented as a diagram. Nautical twilight was utilized to differentiate between day and night flights in this investigation. (Sioux, n.d.)

During the day, for launch and landing, the sun must be less than twelve degrees below or above the horizon. It is a night flight if the sun is more than twelve degrees below the horizon at the time of launch and landing.

As mentioned before, day and night may affect the burst altitude because of the UV light. UV light is known to be detrimental to latex. UV radiation induces brittleness in latex, and if this occurs when the material is under strain, as it is for most of a flight, it might produce a point of fatigue, further damaging the material (Morton, 2013). UV light may affect the balloon's function in another way. This concept arose from the fascinating scientific phenomenon known as emissivity, described as a material's capacity to radiate energy (Serway & Vuille, 2014). This feature is material-dependent; however, an object's hue may also impact its capacity to absorb radiation. For example, a white object, such as a standard weather balloon, can reflect the majority of the UV light directed at it. As a result of the convective energy transfer, the air surrounding the balloon warms up (Agrimson *et al*, 2016).

Another element to consider is the temperature difference between day and night because many materials are known to behave differently at various temperatures. The temperature may fall under the glass transition temperature of the natural latex used to make the balloon. The glass transition temperature is cooled, and the material becomes glassy and brittle (Shackelford, 2000). This effect may cause the balloon to burst faster, especially given the pressure and volume fluctuations the balloon undergoes throughout its ascension.

2.10 Descent Rate

The rate of descent is the opposite of the ascent rate where the aircraft experience a decreasing altitude. In this case, the parachute is the tool for reducing the speed of the payload through an atmosphere by creating drag or rather an aerodynamic lift after the balloon burst at a certain altitude. When a high-altitude balloon descends, the parachute typically opens at 18 km when there is enough air in the atmosphere to open the parachute. Most payloads will float for more than 100 miles and may take more than an hour to descend. The descent rate will determine the landing area of the payload carried by the parachute. Therefore, it is one of the important parameters in high altitude balloon to assist the payload retrieval.