DESIGN AND DEVELOPMENT OF GLIDER LAUNCHER

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DECLARATION

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

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TABLE OF CONTENTS

DECLARATION ii

ACKNOWLEDGMENT iii

LIST OF FIGURES vi

LIST OF TABLES ix

LIST OF SYMBOL x

ABSTRAK xii

ABSTRACT xiii

CHAPTER 1 INTRODUCTION 1

- 1.1 Overview 1
- 1.2 Motivation 3
- 1.3 Objectives 5
- 1.4 Scope of Work 6
- 1.5 Thesis Organisation 7

CHAPTER 2 LITERATURE REVIEW 8

- 2.1 Conceptual Designs 8
  - 2.1.1 Catapult Launcher 8
  - 2.1.2 Crossbow Launcher using Rubber Cord 12
  - 2.1.3 Bungee Catapult Launcher 14
- 2.2 Relevance between Literature Review and Current Project 17
- 2.3 Glider Launcher Design Decision 20

CHAPTER 3 METHODOLOGY 22

3.1 Preliminary Design 23
3.1.1 Pulling force.. 23
3.1.2 CAD Drawing and Design Specifications 27
3.2 Fabrication and Testing.. 31
3.2.1 Launching Rail.. 32
3.2.2 Cradle.. 33
3.2.3 Base and Elevation Adjuster.. 35
3.2.4 Trigger 36
3.3 Post Work Process 37
3.3.1 Improving Bungee Cords Safety 37
3.3.2 Fixing Bend Launching Rail.. 37
3.3.3 Increasing Structure Integrity of Elevation Adjuster............................ 38
3.3.4 Ballasting the Base and Elevation Adjuster 39
CHAPTER 4 RESULTS AND DISCUSSION 41
4.1 Launcher Assemble Configuration 41
4.2 Replacement for the Trigger Mechanism.. 43
4.3 Pulling Force Provided 44
4.4 Design Safety Factor.. 45
CHAPTER 5 CONCLUSION AND FUTURE WORK 46
REFERENCES 47
APPENDIX…………………………………………………………………..49

LIST OF FIGURES

Figure 1.1: Top Section Drawing of Catapult Launcher [1] 1

Figure 1.2: An Example of an American Army used Hand Launching Technique for AeroVironment RQ-11 Raven UAV [20] 5

Figure 2.1: Catapult Launcher attached on a Kite [5] 8

Figure 2.2: Catapult Launcher with a Toy Glider [6] 9

Figure 2.3: Mobile Catapult for Flying Bodies [7] 9

Figure 2.4: Frank Macy with a Catapult Launcher Model [8] 9

Figure 2.5: Catapult Launcher [9] 10

Figure 2.6: An UAV attached on Pneumatic Catapult Launcher [17] 10

Figure 2.7: Scan Eagle Mounted in SuperWedge Launcher (a) and SuperWedge being prepared for Operation (b) [18] 11

Figure 2.8: Robonic Kontio (type MC2555LLR) Pneumatic Launchers [18] 11

Figure 2.9: 12 kJ Portable Pneumatic Catapult [19] 11

Figure 2.10: Frank Ehling with a Crossbow Launcher [10] 12

Figure 2.11: The Proposed Launching Apparatus [15] 13

Figure 2.12: Crossbow Launcher and 3D Printed Gliders [16] 13

Figure 2.13: Crossbow Launcher attached with a Glider [11] 14

Figure 2.14: The High-Start Bungee Launcher Setup [12] 15

Figure 2.15: Bungee Catapult Functional Scheme [14] 16

Figure 2.16: Comparing Benchmark and Conceptual Design Launching Devices to Customer Requirement [14] 17

Figure 2.17: The Full Assembly Rendered Drawing 21

Figure 2.18: Orthographic Views of Glider Launcher Propose Design 21

Figure 3.1: Overview of the Project 22

Figure 3.2: Force Gauge Measurement [13] 24

Figure 3.3: Force Analysis [6] 26

Figure 3.4: Bungee Cords 27

Figure 3.5: Launching Rail 27

Figure 3.6: Orthographic Views of Launching Rail 28

Figure 3.7: Cradle Assembled on the Launching Rail 28

Figure 3.8: Orthographic Views of Cradle 29

Figure 3.9: Base Assembled with the Angle Elevation Adjuster 29

Figure 3.10: Orthographic Views of the Base 30

Figure 3.11: Trigger Assembled on the Launching Rail and its Positions 30

Figure 3.12: Orthographic Views of Trigger 31

Figure 3.13: Folded Launching Rail 32

Figure 3.14: 2 Metres Length of Launching Rail 33

Figure 3.15: Final Product of Cradle 35

Figure 3.16: Cradle on the Launching Rail 35

Figure 3.17: Elevation Adjuster Before and After Assembly 36

Figure 3.18: Base Before and After Assembly 36

Figure 3.19: Carabiner Hook Attached to the Bungee Cords 37

Figure 3.20: Obstacle on the Launching Rail 38

Figure 3.21: Fixed Launching Rail 38

Figure 3.22: Improved Elevation Adjuster 39

Figure 3.23: Ballasts in the Glider Launcher 39

Figure 3.24: Disassembly Compartments of the Launcher 40

Figure 4.1 Zero Degree of Launching Angle 41

Figure 4.2: 35 Degrees of Launching Angle 42

Figure 4.3: The Gliders attached on the Launcher 42

Figure 4.4: Front View of the Launcher 42

Figure 4.5: Iron Wire attached on the Cradle and Launching Rail.............................43

Figure 4.6: Bungee Cords that have been stretched on the Launcher 44

LIST OF TABLES

Table 2.1: Advantages and Disadvantages of the Catapult Launcher 18

Table 2.2: Advantages and Disadvantages of the Crossbow Launcher....................... 19

Table 2.3: Advantages and Disadvantages of the Bungee Launcher........................... 19

Table 2.4: Essential Requirements 21

Table 3.1: Bungee Stiffness Constant Result [13].. 24

Table 3.2: Information of Gliders that have been used in this project 32

Table 3.3: List of Material used for Cradle 34

Table 5.1: Summary of the Glider Launcher.. 46

LIST OF SYMBOL

L	Lift force
v	Velocity of glider
ρ	Air density
s	Wing area of glider
C_L	Coefficient of lift
F	Force
m	Mass of glider
a	Acceleration
v	Velocity
t	Time
R	Range
E	Lift to Drag Ratio
h_2	Height of Initial Gliding
h_x	Height of Final Gliding
K	Stiffness Constant
E	Young’s Modulus
A_0	Cross-sectional Area

L_0	Un-stretched Length
α	Launching angle
M	Total mass of cradle and glider
D	Drag force from the glider
K	Bungee’s stiffness constant
X	Stretched length of bungee cord
μ	Coefficient of friction
N	Normal force from the cradle
a	Acceleration
g	Gravitional force

Abbreviation

MTOW	Maximum Take-off weight
RATO	Rocket Assisted Take Off
UAV	Unmanned Aerial Vehicle
USM	Universiti Sains Malaysia

ABSTRAK

Projek ini bertujuan untuk mereka bentuk dan membina sebuah pelancar untuk peluncur tiada kuasa. Pelancar ini mampu membekalkan keadaan awal dengan konsisten dan memandu arah laluan untuk meluncur. Ciri-ciri pelancar buaian ini adalah untuk menyediakan satu kuasa pelancaran berterusan dan sudut pelancaran berterusan dan ketinggian dalam platfom yang sama. Spesifikasi reka bentuk pelancar yang tertumpu kepada reka bentuk pelancar lastik dengan menggunakan tali bungee sebagai penggerak kuasa dan mudah alih untuk membolehkan diguna dengan segera dan minimum masa dipasang. Justifikasi bagi setiap keputusan reka bentuk adalah dianggap, dan lukisan model yang dihasilkan dengan menggunakan perisian SolidWork. Pelancar baru yang dibina akan digunakan dalam Kelas Aerodinamik (ESA244) dimana ia akan melancarkan glider pelajar pada hari “Glider Test Day”. Konsep reka bentuk pelancar dianalisis dan dimuktamadkan bagi mencadang dan membina model pelancar yang berjaya.

ABSTRACT

This project aims to develop, design and build a launcher for unpowered glider. The launcher is capable in giving a consistent initial conditions and guide the glide path direction for the glider. The features of the glider launcher are to produce a constant launching force and provide a constant launching angle and height in a same platform. The design specifications of the launcher focused on the catapult launcher design with bungee cords as a power actuator and portable to allow quick deployment and minimum set-up time. Justification for each design decisions are considered, and the model drawing is generated by using SolidWork software. The design requirement is dependent on the fabricated gliders from students of Aerodynamic (ESA244) Class and it will be responsible to launch the student's gliders on the Glider Test Day. The design concepts of the previous glider launcher are analysed and finalised to propose and build a convenient glider launcher model.

CHAPTER 1 INTRODUCTION

1.1 Overview

The research on glider launcher had been started on early of the 19th century until now. Stevens (1930) invented a launching device for gliders, sail planes, model planes and similar motor less aircraft [1]. The primary objective of the invention is to provide a device that have a launching mechanism whereby a single assistant force may effectively launch the aircraft [1].

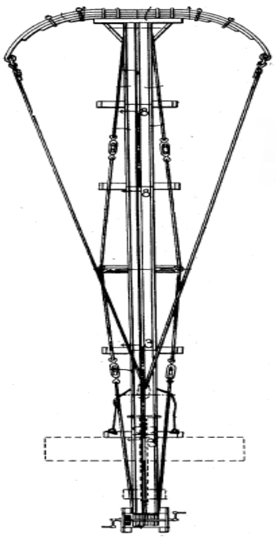

Figure 1.1: Top Section Drawing of Catapult Launcher [1]

Launching a non-powered glider can be performed in a few different ways and techniques. The examples of methods that are available for glider launching are as below:

1. Hand Launching Technique
2. Catapult Launcher
3. Pneumatic Catapult Launcher
4. Crossbow Powered Glider Launcher

5. Hi-start Bungee Launcher
6. Catapult Bungee Launcher
7. PVC Pedal Launcher with Bungee Launching Mechanism

The glider trajectory is influenced by the launching force. From equation (3), the range is the product of the aerodynamic efficiency and the loss of height during the glide [3]. The range can be increased by increasing the lift to drag ratio of the glider and the height interval $(h_2 - h_x)$ of the gliding flight [3]. Lift equivalence (1) from Anderson (1999) defined the lift increased if the velocity increased. The launch mechanism in the launcher applied the Newton's Second Law of motion which described the relationship between an object's mass and the amount of force needed to accelerate it. Equation (2) displayed that force is directly proportional to the acceleration by assuming the mass is constant as the mass is depended on the type of glider. Noted that acceleration is directly proportional to the velocity. The glider will have a potential to stall and crash if the force applied to the glider is below the minimum launch force to produce a required velocity for a particular glider to glide [4].

$$L = \frac{1}{2} v^2 \rho s C_L \tag{1}$$

where;

L = Lift force

v = Velocity of glider

ρ = Air density

s = Wing area of glider

C_L = Coefficient of lift

$$F = ma = m\frac{v}{t} \tag{2}$$

where;

F = Force

m = Mass of glider

a = Acceleration

v = Velocity

t = Time

The condition of wind and angle of launching can influence the glider launching. Launching a glider with its nose pointing upwards will be effective but if the wind is strong, the glider can get lifted directly upwards and taken backwards, completely out of control [4]. Angled the glider downwards slightly is acceptable but, again, if the wind is strong there's a chance that the glider will just get pushed into the ground by the wind, as it leaves from the gliding platform [4].

1.2 Motivation

The ESA 244 Class required the students of Aerospace Engineering in Universiti Sains Malaysia (USM) to have a hands-on group project which each group is needed to build an unpowered glider and it will be tested on the Glider Test Day based on its performance. The test looked-for the highest endurance and range glider where the glider needs to glide as far as possible and be in the air as long as possible.

Hand launching technique was previously practised on the test day where the students used their hand forces to launch their own gliders. The glider is released into flight directly from the hands of the contestant, without other assistance. The studies from Koppelaar and Wells (2005) revealed that the hand force produced by the human is used in many reports but it is always not accurately well-defined [2]. The research documented the strengths and weaknesses of different measurement methods for quantifying hand force in the field by using six different measurement methods which are:

1. Force and moment requirements of the given tasks
2. Force and moment exerted directly measured by force transducers
3. Muscle activity of muscles of the hand and forearm
4. Force matching on a dynamometer
5. Self-report using a visual analogue scale
6. Observation of the tasks with information

The research concluded that the observation of the tasks with information showed good results in this study but it should be interpreted with care, because only one participant was observed by four observers [2]. It defined that there is a lack of validity in measurement of hand force so it should not be used solely for any scientific assessment [2]. The limitation of giving a precise required force for the glider to launch make this technique is ineffective to be practised as the initial launching force is not consistent and initialised. Therefore the hand launching technique is not considered fair to conduct for the glider test.

To determine the range of gliding flight, the lift coefficient (C_L) is assumed to be constant as $C_L$depends on the type of glider. Height of initial gliding should be determined as equation of range for unpowered flight for the constant lift coefficient given by Ojha (1995) as below:

$$R = E\,(h_2 - h_x) \tag{3}$$

where;

R = Range

E = Lift to Drag Ratio

h_2 = Height of Initial Gliding

h_x = Height of Final Gliding

Consequently the gliding angle would also remain constant, hence the constant lift coefficient glide is synonymous to the constant angle glide [3]. The parameters such as launching angle and height of initial launching could not be initialised by performing hand launching technique therefore these seem to be imbalanced initial conditions supplied for the contestants. These measurements provide a high significance in launching to perform a required gliding range.

Figure 1.2: An Example of an American Army used Hand Launching Technique for AeroVironment RQ-11 Raven UAV [20]

1.3 Objectives

An efficient glider launcher is where the launcher is able to produce a consistent launching force that can give an initial velocity to the gliders to glide. Thus the launching device that can be used by the students of ESA 244 class for their Glider Test Day is a prime requirement for this project. The designs of the glider launcher must be applicable and appropriate with the main goal therefore the research works described in this project is performed based on the following objectives:

- To analyse the best design specifications for a glider launcher
- To produce a launching glider device that is ease to use by all students
- To fabricate a glider launcher that can produce a consistent launch force
- To provide a platform that can set up a constant launching angle and initial height for the glider to start launch

1.4 Scope of Work

The identified parameters of student's gliders such as the maximum mass and wingspan of the gliders are essential in the design requirement. The range of common mass on previous fabricated gliders is about 1 to 2 kg and had a maximum length of wingspan of 1 metre. The size of the glider launcher is specified for a glider of approximate 1 meters wingspan and with a maximum take-off weight of 5 kg as there is no fixed requirement for the constraint of mass in the previous student's gliders of ESA 244 project.

The launcher will give a consistent launching force to the student's gliders to make sure the gliders launch with a constant set up initial conditions. It will have an adjustable gliding platform where the initial conditions such as the angle of launching, height of launching and initial of the glide path direction can be modified and initialised. In addition, the launcher needs to be of a compact size with minimum set-up time to allow quick deployment and portable during the test day. A regular maintenance and inspection are needed to make sure the launcher is in perfect and functional condition therefore the launcher could be used in long term.

1.5 Thesis Organisation

This thesis is divided into 5 chapters where each chapter provides details on the overall project. In the first chapter, the topic overview, motivation, objectives and scope of work are stated to provide a general view of the whole project. In the Chapter 2, reviews from the previous design projects which are related to the current project are done for reference and to select the best design specifications of the new glider launcher. This project involve four phases of modelling which will be described in the methodology process in Chapter 3. There are design methodology, preliminary design, fabrication and testing and post work process. Chapter 4 presents the results from the experimental work and from there, analysis and comparison are carried out on related subjects. Finally, Chapter 5 will summarize and conclude the whole project.

CHAPTER 2 LITERATURE REVIEW

This chapter discusses on the conceptual designs from the previous inventions and researches of glider launcher. There are several types and design of launcher model which are used to launch Unarmed Aerial Vehicle (UAV) piloted with remote control and unpowered glider. This research is to find what the most suitable conceptual design that can accomplish the project’s objectives. The relevance between the literature review and the current project is summarized in the final chapter. The final selection design is summarise based on the best option for the recent project.

2.1 Conceptual Designs

2.1.1 Catapult Launcher

The earlier research about catapult launcher model was discovered by Robert King in 1972 who used a kite to attach a catapult toy glider launcher [5]. According to this invention the attachment and adjustment of all launcher parts can be easily affixed to a standard simple kite so the part which is lost or broken can be duplicated from plastic tubing, paper clips or a hair pin and no special tools are necessary to adjust or repair the parts [5].

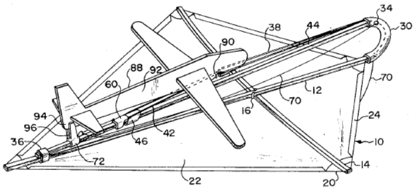

Figure 2.1: Catapult Launcher attached on a Kite [5]

An invention from Jerome Lemelson in 1977 related to a flying toy in the configuration of a glider which is moulded of light weight cellular plastic and a simple design structure that may be easily catapult launched [6]. The catapult launching device for such a glider was extremely simple in structure and capable of being produced at low cost to be practically operated [6].

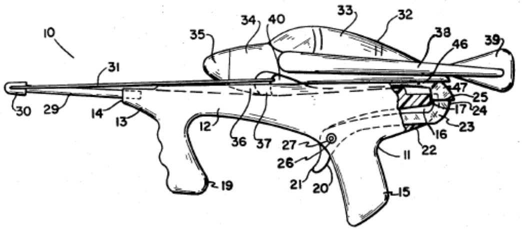

Figure 2.2: Catapult Launcher with a Toy Glider [6]

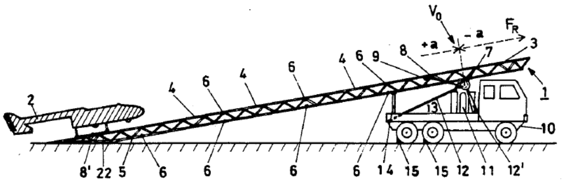

Figure 2.3: Mobile Catapult for Flying Bodies [7]

Martin (1990) invented a device for the acceleration of bodies on a longitudinal track, especially of aircraft for the purpose of launching [7]. The device has been found particularly useful for the catapult-like launching of flying bodies, particularly of unmanned aircraft [7]. Frank Macy in 2004 (figure 2.4) used a very tiny glider to attach with the catapult launcher.

Figure 2.4: Frank Macy with a Catapult Launcher Model [8]

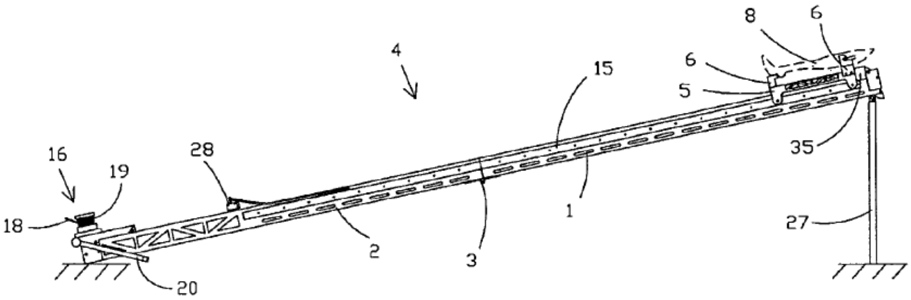

Figure 2.5: Catapult Launcher [9]

The latest invention from Rosenbaum in 2005 showed an embodiment of the apparatus which included two elongated tracks that were interconnected by a hinge to form a track system [9]. This study indicated that the small scale of catapult launcher worked very well with the gliders mass of 0.5 kg or lesser.

Figure 2.6: An UAV attached on Pneumatic Catapult Launcher [17]

The catapult launcher have been advanced as the pneumatic system come into the picture. The pneumatic launcher in Figure 2.6 has been developed to accelerate UAV-s and other aircraft with maximum take-off weight (MTOW) up to 40 kg and launch them at speeds up to 25m/s [17]. The figures below show a military UAV named Scan Eagle weighs 44 lbs. with a 10.2 foot wingspan and it is launched by the SuperWedge launcher [18]. The scale of the launcher can be seen in Figure 2.7.

(a) (b)

Figure 2.7: Scan Eagle Mounted in SuperWedge Launcher (a) and SuperWedge being prepared for Operation (b) [18]

This particular launcher uses pneumatics to assist with the launch and must be towed for transportation. Some advantages include rigidity and ease of transportation with use of a vehicle while the disadvantages include bulkiness, heaviness, difficulty to use in remote areas, and requirement of more than a single soldier on foot to transport [18]. The following figures are showing some of pneumatic launchers that have been industrialised for assisting UAV take-off;

Figure 2.8: Robonic Kontio (type MC2555LLR) Pneumatic Launchers [18]

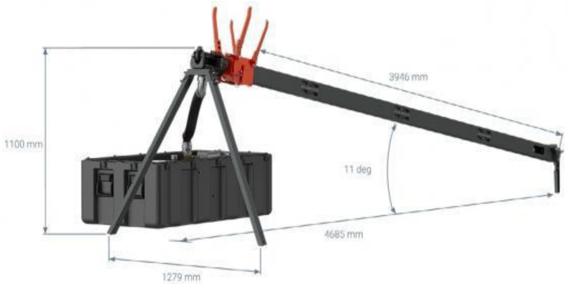

Figure 2.9: 12 kJ Portable Pneumatic Catapult [19]

2.1.2 Crossbow Launcher using Rubber Cord

Crossbow launcher is extremely low cost, rugged imaging platform suitable for small scale deployment and also an excellent for micro glider flying test . The first invention to our knowledge that a crossbow launcher has been used to launch gliders was by Frank Ehling in 1943 [10]. The altitude attained by this method corresponded with the pulling force from the bowstring [10]. The gun is made from pine and two strips are cemented on top to act as a runner for glider, the body of which fits into the slot between the strips [10].

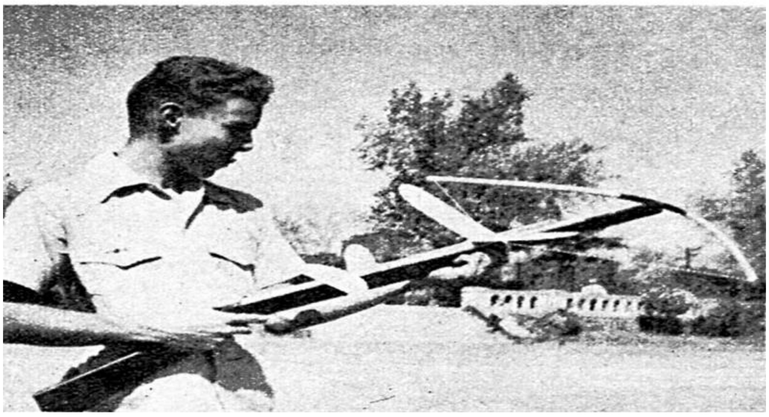

Figure 2.10: Frank Ehling with a Crossbow Launcher [10]

A project conducted by Panait A.M (2012) was deliberated on configuration of crossbow launching device for a micro scale glider. There is no engine present in the Skylark (glider’s name), the necessary kinetic energy coming from the crossbow launcher [15]. The proposed of this method is sufficient to launch a small (under 400 g) glider with an initial speed of up to 350 km/h on an angled trajectory and giving it sufficient power to reach altitudes of up to 60 meters or higher [15]. Figure 2.11 shows the proposed configuration for the launching device from Panait A.M;

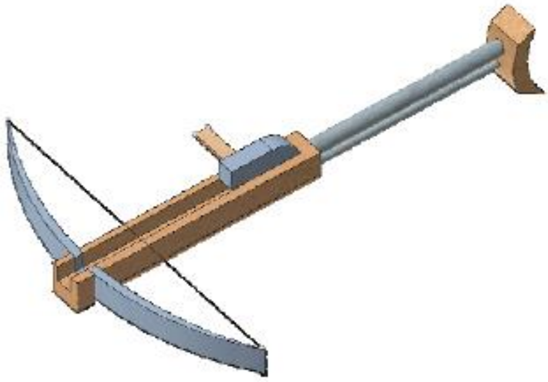

Figure 2.11: The Proposed Launching Apparatus [15]

An invention from Joseph Chafkin's group project in 2013 was to build a plane launcher. The final product (Figure 2.12) looked and worked very similarly to a crossbow, with a T-shaped piece of wood at the front of the gun running perpendicularly to the rest [16]. In place of a rubber band, they used super-durable vulcanized rubber surgical tubing, cutting it down to appropriate sizing. Two pieces of electrical tape were placed in the middle of the piece of rubber, indicating where the plane was to be fired from [16]. The glider design requirement is to have hook attached to allow it to be shot from a rubber band [16].

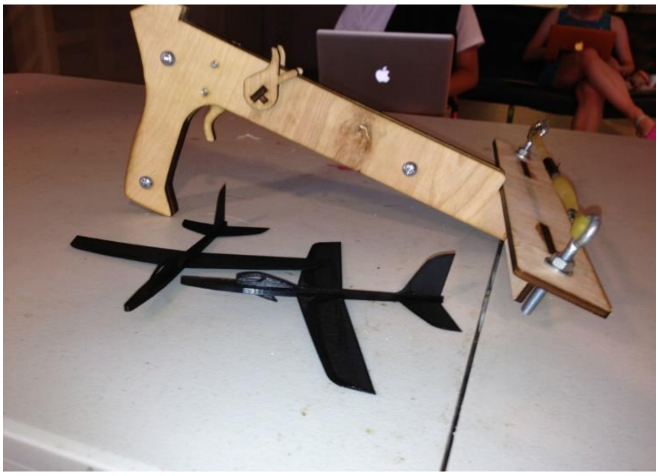

Figure 2.12: Crossbow Launcher and 3D Printed Gliders [16]

The idea of using a crossbow as a launch mechanism is to have a non-electronic device which means that the kinematic and potential energy that the plane used to fly came from rubber bands, air pressure and flywheel [11]. For the glider itself, the fabrication started with an aluminium strip and built a body with wings around it [11]. The figure below shows a crossbow launcher designed by Arnauddhont in 2014.

Figure 2.13: Crossbow Launcher attached with a Glider [11]

2.1.3 Bungee Catapult Launcher

There are a lot of bungee launcher designs but mostly of them are intended for the Unarmed Aerial Vehicle (UAV) rather than unpowered glider. Bungee catapult launcher is a simple system, noiseless and lightweight of launcher which used bungee cords as a power actuator. Bungee cords are stretched to store the potential energy and will be released during launch to transfer it into kinetic energy. The only method to launch an unpowered glider by using bungee cords is High-Start Bungee method which it is required a pilot to start walking backwards stretching out the tubing until there is enough tension for launch [12].

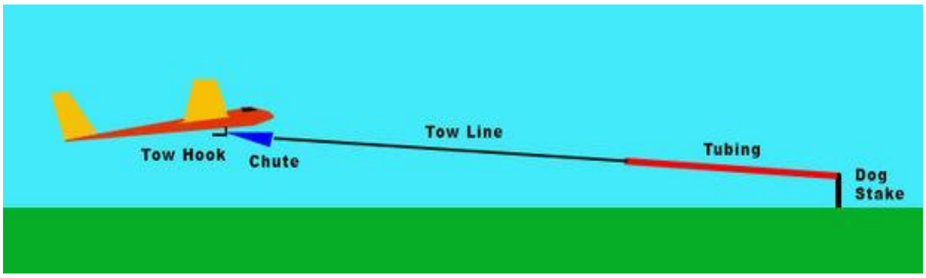

Figure 2.14: The High-Start Bungee Launcher Setup [12]

Sanghi, Sharma, and Raghava, (2015) built a launcher that is intended for UAV of 2.1 meters wing span with a maximum take-off weight of 10 Kgs and take-off speed requirement of 20 m/s [13]. In order to incorporate all the critical design requirements, various concepts were analysed:

- Electric Winch Powered catapult launcher
- Pneumatic Catapult launcher
- Bungee powered catapult launcher
- Electromagnetic rail launcher

The analysis showed that a bungee launcher is suitable for UAV’s up to 50 Kgs and it is a relatively cheap system compared to other systems [13]. The potential energy stored in the bungee can accelerates the cradle carrying the UAV along the rail and imparts the necessary take off speed [13].

With bungee catapult dynamic system design, the objective of this concept is to express for the minimal number of moving parts. For example the mass of the selected elements need to be minimum [14]. The launch ramp and the moving parts (cradle, rollers) must have sufficient rigidity so that the potential energy of elastic cords will not lose needlessly on the deformation work [14]. It can see from the researched that using a bungee launcher can produce a launch force to accelerate the weight of normal size of gliders.

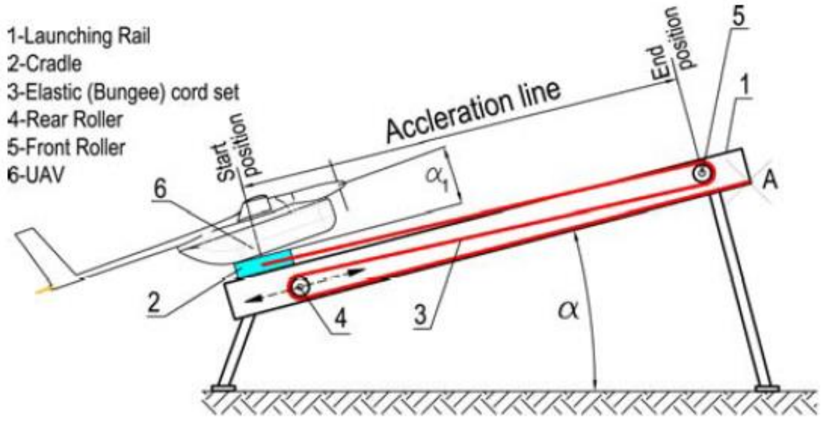

Figure 2.15: Bungee Catapult Functional Scheme [14]

Today, the bungee cord technology improves significantly for its elasticity power in comparison with the 90's [14]. The result of take-off mass and launching speed is increasing as the study from Universal Target Systems Ltd. developed the Aerial Target System MSAT-500 NG whose bungee catapult can launch a 105 kg UAV with a launching speed of 24m/s [14].

The histogram (Novaković and Medar, 2013) in the figure 11 represents the leading Bungee Cord Launching Device (326.8 points of total 394) in front of the Pneumatic Actuator Launching Device (320 points) and Rocket Assisted Take Off as known as RATO (279) as third [10]. Through this numerical analysis, and the comparison with the customer requirements and engineering targets, the bungee cord system was selected as the conceptual design for the launching device [10]. The results showed a potential of a pneumatic actuator conceptual design, as it scored similar results to the bungee cord design when compared to the customer requirements [10]. Pneumatic designs have a large number of sub-components, usually employed to magnify the speed of the actuator [10]. As a result, this design takes longer to set up and was chosen as unsuitable in the thesis scope.

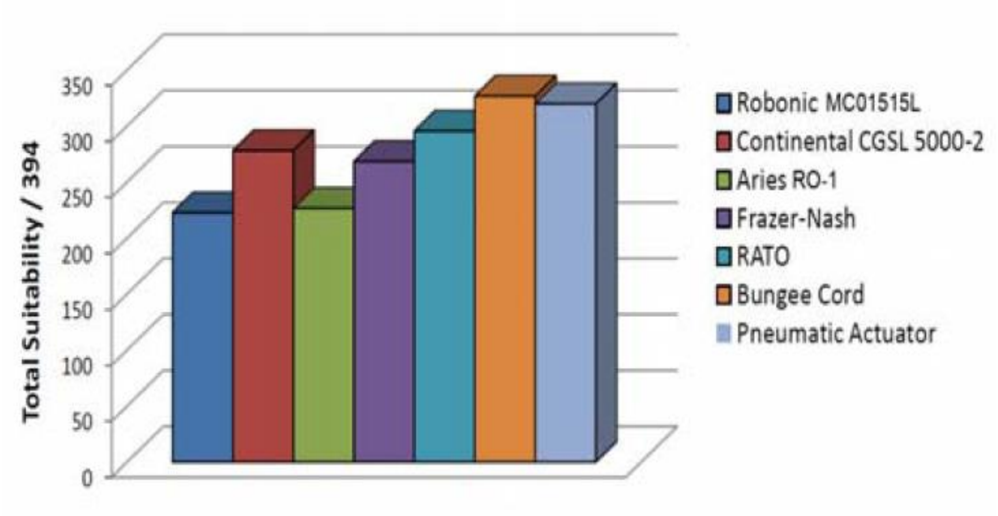

Figure 2.16: Comparing Benchmark and Conceptual Design Launching Devices to Customer Requirement [14]

The analysis from the study discovered that using bungee launcher is suitable and fulfilled all the essential requirements hence forward it was selected as the launch mechanism for the analysis [14].

2.2 Relevance between Literature Review and Current Project

Design studies and trade-off analysis are best practices to make decisions early in the product development process. The literature review revealed on the information about the previous inventions of glider and UAV launcher which are used to give some general ideas on selecting the best option specification for the design concept. Based on engineering observations and judgements from the previous conceptual designs, the information is analysed to find the design decision which is discussed in the next topic. The following analyses are categorised in respect to the advantages and disadvantages of their own specifications;

Catapult launcher

Advantages	Disadvantages
• Angle and height of launching are determined • Efficiently working with lightweight of glider • Give a strong vertical force to the glider	• Only create a small pulling force • Need a large dimension of catapult launcher to implement with average size of glider • Complicated parts to be maintained • Not portable if the parts cannot be dissembled • Vehicle carriage is needed to transport the average scale of pneumatics catapult launchers

Table 2.1: Advantages and Disadvantages of the Catapult Launcher

Crossbow launcher

Advantages	Disadvantages
• Easy to build • Lightweight and easy to carry • Low cost maintenance • Small space needed • Totally retains the airplane in all directions (gust of wind won't knock it off the launcher)	• Inconsistent angle and height during launching • Unable to provide high pulling force and not suitable for large glider • Require high safety handling • Can damage a bow by releasing without a load

• Have trigger mechanism to quickly release the airplane • Provides distance between the prop and the pilot	• Need to modify practically the gilder to be fit with the crossbow (a strip is necessary to launch a glider from the crossbow, this strip will glides through the flight groove) • Need a regularly maintenance for the string.

Table 2.2: Advantages and Disadvantages of the Crossbow Launcher

Bungee launcher

Advantages	**Disadvantages**
• Inexpensive • No gas or electric motors needed • Re-usable length of rubber tubing • This method can be handled by one person without assistance • It is lightweight and readily portable • Can avoids the noise and mess of power assists • Portable	• Need a huge area to perform this method) • Need an existence of wind to take an advantage of a "kiting effect" • In case of using a shorter tow line and stretch the bungee more than normal could make for a faster, quicker launch but more prone to failure and never as high • Rubber tubing can get brittle after too much time in the sun

Table 2.3: Advantages and Disadvantages of the Bungee Launcher

2.3 Glider Launcher Design Decision

The study from Sanghi, Sharma, and Raghava, (2015) the pneumatic launchers could be able to launch heavier UAV but their cost is significantly higher and come in a huge size. Since the exciting data from the literature review that bungee catapult can launch a 105 kg UAV with a launching speed of 24m/s [14], thus the choice of the design concept is focused on bungee catapult launcher as it fulfilled all the essential requirements and it was selected as the launch mechanism for this project. The features of the propose design should able to overcome the weaknesses of the previous design concepts. The characteristics of the new launcher are;

1. Inexpensive as no gas or electric motors needed
2. Lightweight and portable (capability of disassembly design)
3. Adjustable launching angle
4. Ease and safe to use by operator to launch specific glider
5. Reusable bungee cords and low cost maintenance

The range of common mass of glider launcher is from 3kg and up to 35 kg therefore the maximum launching device mass selected is 35 kg as considered the portable mass of a glider launcher is below than 35kg. It is also required that it has adjustable launch angle to provide for different type of gliders and wind conditions. Most importantly is the launching device should ensure the safety of the operator and must be easy to operate with low maintenance [13]. A primary list of essential requirements for the design is shown below in Table 2.1.

Parameter	**Value**
Maximum Glider Mass	2 Kg
Maximum Launcher Mass	35 kg

Gliding Angle	Adjustable (0 to 35 degree)

Table 2.4: Essential Requirements

In order to accomplish all the requirements of the design concepts, the decisions design concept are consist of:

1. Bungee cords (Pulling Force)
2. Launching Rail
3. Cradle
4. Base and Angle Elevation Adjuster
5. Trigger

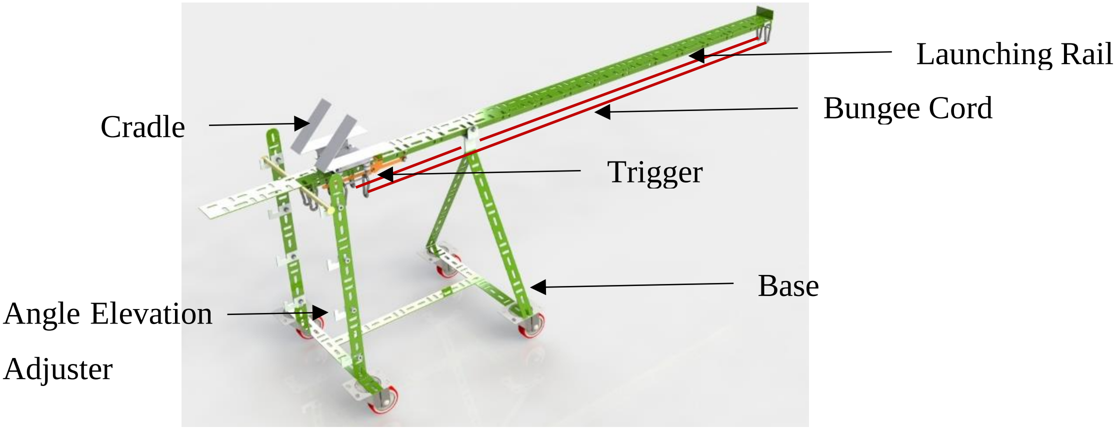

Figure 2.17: The Full Assembly Rendered Drawing

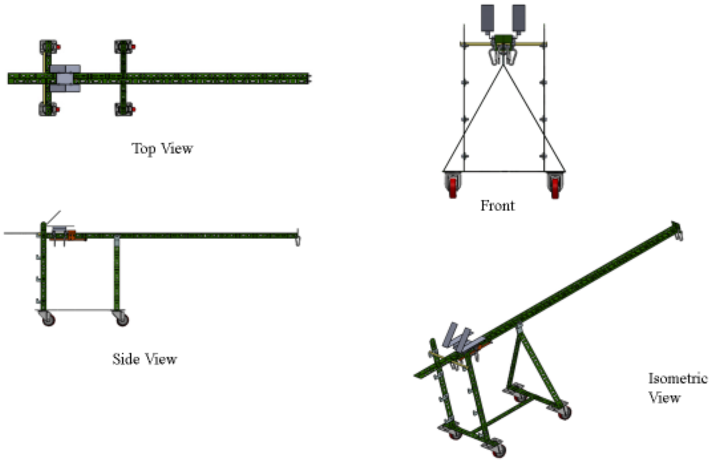

Figure 2.18: Orthographic Views of Glider Launcher Propose Design

CHAPTER 3 METHODOLOGY

The procedures of this project involved 3 phases which are Preliminary Design, Fabrication and Testing, and Post Work Process. The Design Methodology has been discussed on the chapter two where the critical decision of the propose design have been made. The overview of this project can be summarized in the flow diagram shown in Figure 3.1.

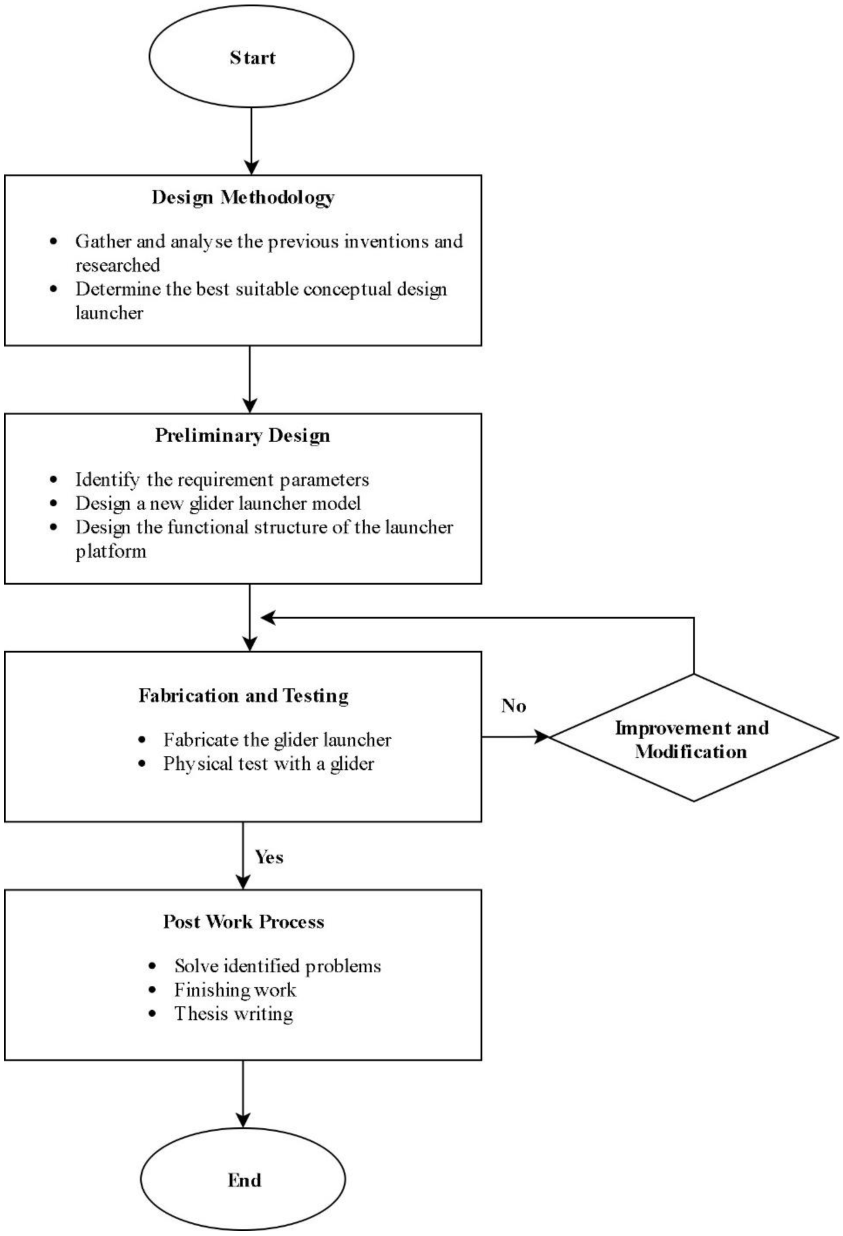

Figure 3.1: Overview of the Project

3.1 Preliminary Design

3.1.1 Pulling force

It is required to calculate the energy requirements of the bungees as the potential energy stored in the bungee cord will be transform to kinetic energy where the cradle moves along on the ramp length of the launcher [13]. The main variables to consider are:

- Mass of glider and launcher's cradle
- Angle of elevation
- Stiffness of bungee

Length and the number of bungee cords need to be determined after the bungee force required is calculated [13]. Almost all the bungees available in the market are not accessible in specific K value as it can be inferred from the given equation that it depends on the length of the bungee as well [9].

$$K = \frac{(E A_0)}{(L_0)(4)} \tag{4}$$

where E is Young's modulus, a material constant, A_0 is the cross-sectional area of the material and L_0 is the un-stretched length of the cord [13]. In order to derive the value of K, various types of bungees available in market has been tested by conducting an experiment and utilizing an instrument called force gauge to measure the value of the force at a given elongation [13]. The results of bungee stiffness constant from (Sanghi, Sharma, and Raghava, 2015) shows in the table below where the selected bungee cords with external diameter of 10 mm and internal diameter of 5 mm [13].

Force (N)	Un-stretched Length (m)	Elongated Length (m)	Stiffness Constant K (N/m)
200	0.5	3.2	75
400	1	6.5	72
100	0.2	1.56	74
500	1.2	7.8	75

Table 3.1: Bungee Stiffness Constant Result [13]

Figure 3.2: Force Gauge Measurement [13]

In order to calculate the force analysis (Figure 3.3), assuming several assumptions are as below:

Assumption 1

The catapult is a dynamic system considered as the kinetics of a particle. Since the glider and the cradle travel linearly on the inclined plane.

Assumption 2

The mass of the elastic cords is neglected.

Assumption 3

Stiffness of the elastic cords is constant. The value of the elastic cord was chosen as 74 N/m from the literature review.