DEVELOPMENT AND ANALYSIS OF PROJECTILE LAUNCHER FOR THE LEARNING OF ENGINEERING DYNAMICS

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ABSTRACT

Engineering dynamics is essential in mechanical engineering. The teaching and learning processes for projectile motion in engineering dynamics are challenging. This paper aims to fabricate physical prototypes for supporting the learning processes that use operational conditions to support the theory. Two prototypes of projectile launchers are extensively designed based on the sling mechanism. The prototypes are tested for functionality, and the distance travelled by the object is measured based on the variability of launch angle. The experimental projectile parameters are evaluated by theoretical kinematic data for performance evaluation of the launcher. It is found that the proposed prototypes can be significantly used in the learning of engineering dynamics.

Keywords: engineering dynamics, projectile launcher, sling mechanism, teaching and learning

1.   INTRODUCTION

The concept of 2-dimensional projectile motion is the movement of a launched object in the air [1]. The movement is parabolic motion, which consists of a horizontal x-component and a vertical y-component [2]. The object travels in a vertical plane with an initial velocity and experiences a free-fall downward gravitational acceleration along the path [3]. Projectile motion is associated with specific parameters such as force, displacement, velocity, acceleration, and launch angle [4, 5]. The force of air resistance is taken into account with the use of a quadratic resistance law [6]. The projectile launcher can be designed with various functions and features to achieve the main objective with specific advantages and disadvantages.

Various types of mechanisms for projectile launchers have been developed recently. Figure 1(a) shows that a Vernier Projectile Launcher with the launch angle can be varied. This projectile launcher applies a two-dimensional kinematics concept, which has two axes, x-components and y-components. It is used to explore the concept of two-dimensional kinematics, such as setting launch angle and measuring speed. Different angles launch different heights or distances. Therefore, it is important to study the effect of the angle with other parameters. An optimal launch angle is the angle at which a projectile is launched that maximizes its horizontal distance traveled.

Figure 1(b) shows the ME-6800 Projectile Launcher, which has a variable launch speed and flexible launching positions. It is designed for short and long-range targets. The advantage is that it is easier to handle as the angle can be changed to achieve the target. The projectile is high in mobility as it can be moved anywhere without considering the shape. Figure 1(c) shows the Torsion Catapult that was used by the Romans in war. This sling launching mechanism has a more powerful output due to the large design of the sling. The cords must be pulled as low as possible, and the potential and elastic energy of the cord increase greatly, resulting in a more powerful output. Releasing the cords creates a lot of kinetic energy during launching.

Figure 1(d) shows the sling mechanism. The first concept of a sling was named the "Shepherd's Sling," which was created a hundred years ago. A sling was used as a weapon that could launch stones for war. Moreover, the sling was invented to perform jobs by increasing the projectile range and the speed of objects. Figure 1(e) shows an ancient weapon used during the war known as the trebuchet. It is built with a long arm to launch the projectiles. This design used heavy pulleys and leather straps. A quick release tension mechanism was used in nearly all catapults in ancient and mediaeval artillery. The trebuchet has a simple, collapsible construction with a completely adjustable starting velocity vector and a balanced launch platform.

(a)
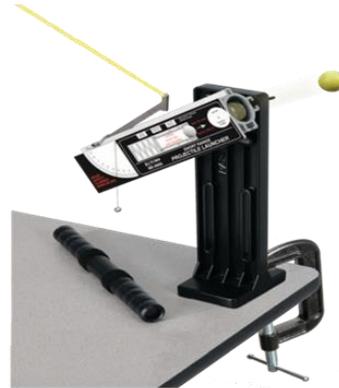
(b)
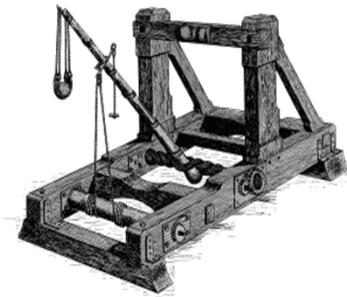
(c)

(d)

(e)

Figure 1: (a) vernier projectile launcher (b) ME-6800 projectile launcher (c) torsion catapult (d) Shepherd's sling   (e) trebuchet

The projectile motion is analysed using kinematic equations [8]. In some cases, frictional and air resistance are considered to be negligible. The parameters that can be obtained from the testing are velocity, time and horizontal distance [9] using Equation (1) to Equation (3). On the other hand, it is important to observe the relationships between these parameters from the launcher [10]. The two components in the 2-dimensional kinematic equation are the x-component and the y-component [3].

$$v = v_o + a_c t \tag{1}$$

$$s = s_o + v_o t + \frac{1}{2} a_c t \tag{2}$$

$$v^2 = v_o{}^2 + 2a_c(s - s_o) \tag{3}$$

In horizontal motion, the gravitational acceleration is zero. The velocity at any position is constant [11], and the position can be calculated using Equation (4) and Equation (5).

$$v_x = v_{o_x} \tag{4}$$

$$x = x_o + (v_o)_x t \tag{5}$$

The kinematic equations for vertical motion can be calculated using Equation (6) to Equation (9). A negative value of gravitational acceleration is used.

$$a_y = -g \tag{6}$$

$$v_y = v_{o_y} - gt \tag{7}$$

$$y = y_o + (v_o)_y t - \frac{1}{2} g t^2 \tag{8}$$

$$v_y{}^2 = (v_o)_y{}^2 - 2g(y - y_o) \tag{9}$$

In projectile motion, it satisfies the concept of conservation of energy. It states that the total energy is constant in any condition. The total energy from the sling is converted into potential and kinetic energy using Equation (10) to Equation (12). The mechanical energy is elastic energy from the sling, which is the combination of potential and kinetic energy.

$$E_{sling} = E_{potential} + E_{kinetic} \tag{10}$$

$$E_{sling} = mgh + \frac{1}{2} mv^2 \tag{11}$$

$$E_{sling} = \frac{1}{2} k s^2 \tag{12}$$

The purpose of this study is to develop projectile launchers for teaching and learning purposes in engineering dynamics. The projectile mechanisms are designed and the prototypes are fabricated using systematic processes in engineering design and analysis. The prototype functionalities are tested to obtain experimental results. The theoretical data is calculated using kinematic equations. Comparison studies are conducted to obtain a relationship between the launch angle and the horizontal distance of the object.

2.   MATERIALS AND METHODS

This work involves systematic processes, including designing and fabricating the prototype. The prototypes were tested, in which they attempted to determine the projectile parameters, such as launch angle and distance. The launchers were designed based on the concept of a sling mechanism. The first prototype A consists of four bases, which are the main base, support base, middle base, and extender base as visualised in Figure 2. Two rods are attached at the main base. The clip is connected with a holder clip at the middle base. The extender base is joined between the main base and the support base. A trigger mechanism sling is applied for launching an object accurately. The angle can be varied for significant output in the testing.
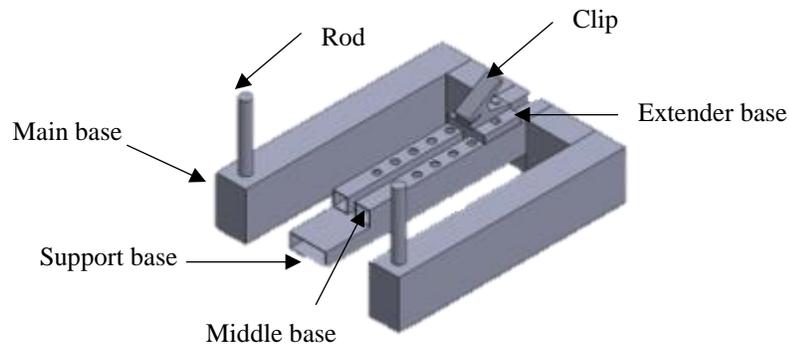

(a)

(b)

Figure 2: (a) isometric design (b) prototype A

Figure 3 displays prototype B with a trigger mechanism being employed to operate this launcher. Two springs are connected to the holder and stopper. The stopper is pulled inside the launching pipe by the trigger. The object is in a statically restrained condition inside the pipe due to the gravitational field. The elastic energy from the springs is produced when the trigger is released to launch the object. High launching energy exists from the two springs to transfer elastic energy. It is a portable launcher and the angle adjuster can be folded between the upper and lower bases when not in use.
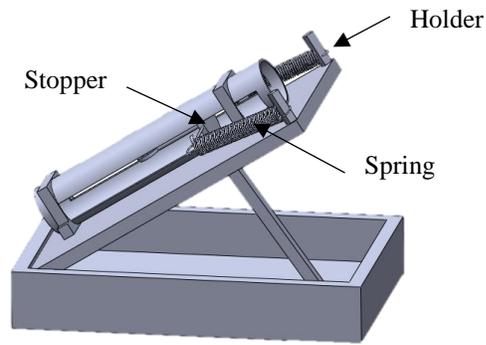
(a)

(b)

Figure 3: (a) isometric design (b) prototype B

3.   RESULTS AND DISCUSSION

Several data for each prototype have been recorded during the dynamic motion testing. The measured experimental data has been compared to theoretical data, which is calculated by using several parameters such as the weight of the object and the stiffness of the sling. The initial velocity and force to launch the object have been determined using the concept of projectile motion. An interesting testing output was obtained subsequently from the two prototypes.

Prototype A used an angle between 10° and 50° during the functionality testing. The launch angle affects the distance, and the discrepancy is quite acceptable. There was a slight discrepancy in each launch angle as presented in Table 1. The highest discrepancy of 0.14 metre is detected at 10° launch angle. Meanwhile, the lowest discrepancy of about 0.03 metre occurs at 40° launch angle. Taking a closer look at the data in Table 1, the results from experimental measurement agree well with the calculated value from theoretical analysis as depicted in Figure 4. The distance of the object is increased as the launch angle increases. However, the negative discrepancies exist at 40° and 45° angles. The experimental distance is less than the theoretical distance. Overall, it demonstrates that prototype A is functional.

Table 1: Measured and calculated parameter for prototype A

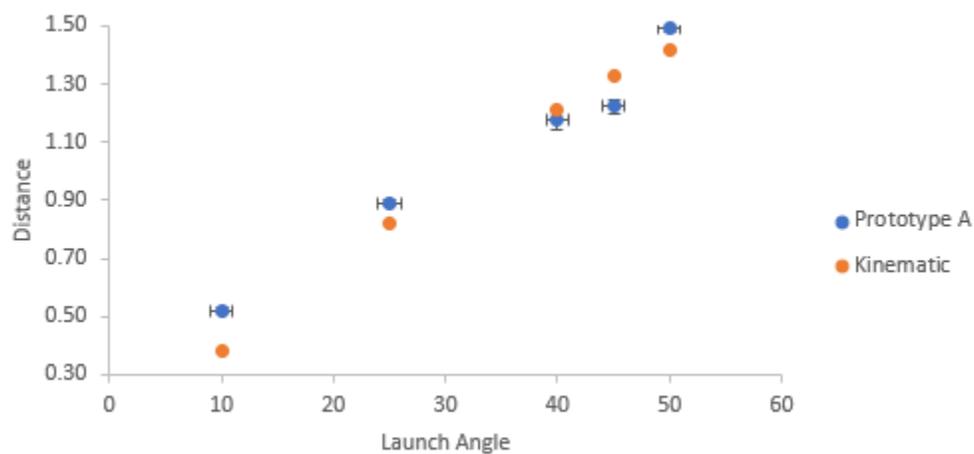| Launch Angle (°)	Experimental Distance	Theoretical Distance (m)	Discrepancy
10	0.52	0.38	0.14
25	0.89	0.82	0.07
40	1.18	1.21	-0.03
45	1.22	1.33	-0.11
50	1.49	1.42	0.07

Figure 4: Data analysis for prototype A

The results of the analysis on prototype B are summarised in Table 2. The distance is proportional to the launch angle. The discrepancy is quite large. The highest discrepancy of 0.36 metre is detected at a 20° launch angle. Meanwhile, the lowest discrepancy occurred at a 40° launch angle. Figure 5 displays the pattern results for prototype B between experimental and theoretical data. Initially, the distance of the object increases with an increase in launch angle between 10° and 40°. However, the distance for a 50° angle is slightly lower compared to the theoretical distance. In this practise analysis, this discrepancy may arise from the inconsistent pulling force at the trigger for this launch angle, thus resulting in different variations in the measured data.

Table 2: Measured and calculated parameter for prototype B

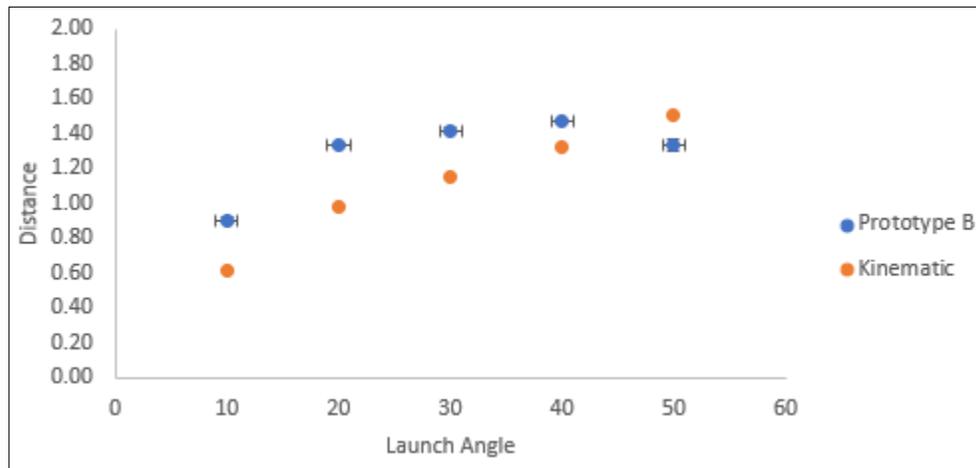| Launch Angle (°)	Experimental Distance	Theoretical Distance (m)	Discrepancy (m)
10	0.91	0.62	0.29
20	1.34	0.98	0.36
30	1.42	1.15	0.27
40	1.47	1.33	0.14
50	1.34	1.51	-0.17

Figure 5: Data analysis for prototype B

4.   CONCLUSION

In this paper, the teaching kit for learning projectile motion was successfully developed. The prototypes of projectile launchers were fabricated based on sling mechanisms. The parameters that have been analysed were distance and launch angle. From the testing, the experimental results have been compared with the theoretical data. The discrepancies were calculated for performance evaluation of the launcher. For the prototype A, there was a good agreement between measured and critical analysis. Meanwhile for prototype B, slightly difference due to the inconsistent pulling force at the trigger for this launch angle. Finally, it was found that the prototypes could be useful for teaching and learning purposes in engineering dynamics.

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