A Golf Ball Launcher: An Engineering Dynamics Project

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Abstract

The purpose of this project was to design and build an apparatus capable of launching a golf ball. The apparatus was required to fulfill certain constraints as well as meet the target objective consistently. All aspects of the apparatus were analyzed using kinetic and kinematic principles of engineering dynamics learned in the classroom, including 2-D and 3-D rectilinear motion as well as energy analysis. A ramp was chosen for the design of the apparatus for repeatability of the experiment and stability/ruggedness of the mechanism. The ramp was built and analyzed using methods discussed herein. Numerical approximation methods produced accurate and repeatable launches of the golf ball, consistently meeting the target objective.

Introduction

The assignment given in a Dynamics class was to design, analyze, and construct an apparatus/mechanism that would launch a golf ball through a hole that was, at its center, a meter above the ground and a meter horizontally away from the launch point (refer to Figure 1). The design objective was to create a mechanism that was both durable and performed with repeatability. An important constraint on the assignment was to only use concepts of kinematics and kinetics that had been covered thus far in the class for the design and analysis of the mechanism. The available concepts included 2-D and 3-D rectilinear motion, including projectile motion, concepts of force, mass, and acceleration, including frictional forces, work, power, kinetic energy, potential energy, impact and systems of particles. Due to the aerodynamics of the ball and the small velocities involved in the experiment, aerodynamic drag was neglected.

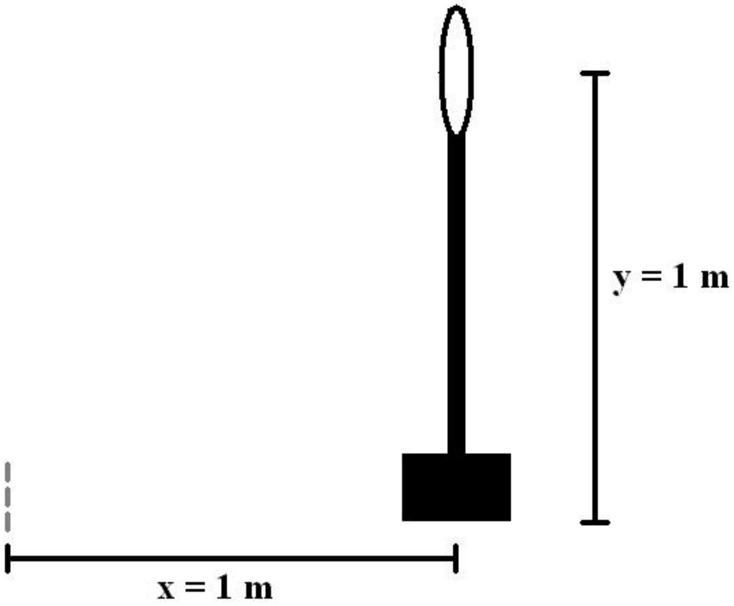


Figure 1: Target specifications

Design Alternatives:

Several design alternatives that would satisfy the required objectives and constraints were considered before the final design was chosen.

(1) The first, perhaps most obvious alternative, was some variation of a catapult. The principle would be to place the golf ball on some surface balanced across an axis that would be given an angular acceleration, resulting in projectile motion of the golf ball. The surface would be constrained but the ball wouldn't, so that when the launch surface stopped the ball would continue to travel with the same velocity, and then would travel over a path determined by projectile motion equations. An object dropped from a certain height (with a certain initial potential energy) to impact the launch lever would provide the energy necessary to launch the golf ball. This type of machine was ruled to be impractical since it would be difficult to ensure repeatability.

(2) Another alternative was to have the golf ball set on a tee at a certain distance away from the target. An object (such as a golf club) would be constrained on a pivot above the tee, so that when released, the object would swing down and hit the ball at a predetermined angle with a predetermined velocity. Energy loss due to impact would be calculated in a controlled environment (calculating the coefficient of restitution) and the angle of impact would be very precisely measured. Energy methods would be used to calculate the drop height necessary in order to obtain the proper velocity of the object just prior to striking the golf ball. The mass moment of inertia of the pendulum required to strike the golf ball would be difficult to calculate or to experimentally measure. With limited resources and a very limited budget, designing and building a pendulum apparatus with the ruggedness and precision required for this project was not feasible.

(3) The third alternative considered was a mechanism that would roll the golf ball off of a horizontal surface at a certain height, let it bounce off the ground, and through the target hole. The necessary initial horizontal velocity would be supplied by a ramp that would roll the ball down before rolling off the horizontal surface. The coefficient of restitution would need to be carefully measured for the ground surface at the test site where the golf ball would impact the ground. Since the test would be conducted outside on a patio with a very rough, inconsistent surface, this mechanism would not provide the required repeatability. The trajectory of the golf ball would be unpredictable when it bounces on the rough ground surface.

Final Design:

The final chosen design was a "ski-jump" style ramp (refer to Figures 2 and 3). The ramp was built with a smooth, minimal friction surface that the ball could slide and roll on with minimal energy loss. At the point of departure, the ball would leave the ramp with both vertical and horizontal initial velocity components. Energy losses due to non-conservative forces (such as friction) were assumed to be linearly dependent on the normal contact force between the ramp and the ball and independent of the velocity of the ball. Exit velocity of the ball off the ramp was determined using energy methods (accounting for frictional losses), while the flight path of the ball was determined using projectile motion equations.

Figure 2: Picture of final design

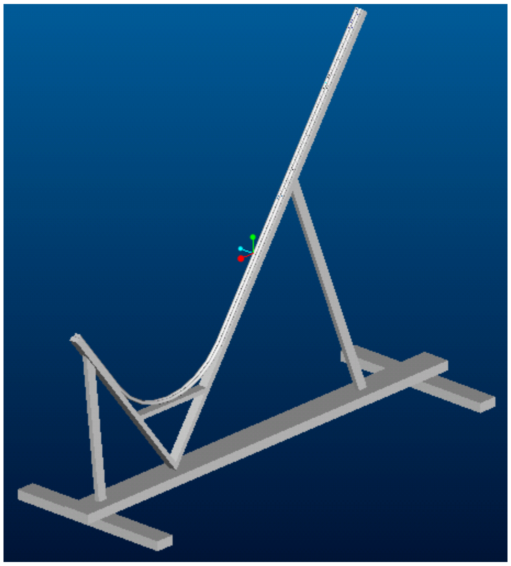


Figure 3: 3-D model of final design generated using Pro-E

Apparatus Construction

Construction:

For the ramp material we wanted a surface that would have minimal friction, and that also would bend smoothly so that there would be no obstructions/bumps to the golf ball as it rolls down the ramp. Most materials that we experimented with would kink when trying to bend them to create the curved track. We first tried a long piece of corner trim, which we found at a hardware store. It had some flexibility, but needed to be heated in order to bend. Ultimately the coating became too wrinkled to provide a smooth surface for the ball to travel on. Two ten-foot sections of ½" PVC pipe were ultimately used for ramp construction. The pipes were coated with a graphite lubricant to reduce frictional losses and cinched together to create a track for the golf ball (Figure 4). The coefficient of sliding friction was measured after the pipes were cinched together and coated with graphite. The pipes bent smoothly but they needed a rigid frame for structural reinforcement and to retain the curvature of the ramp.

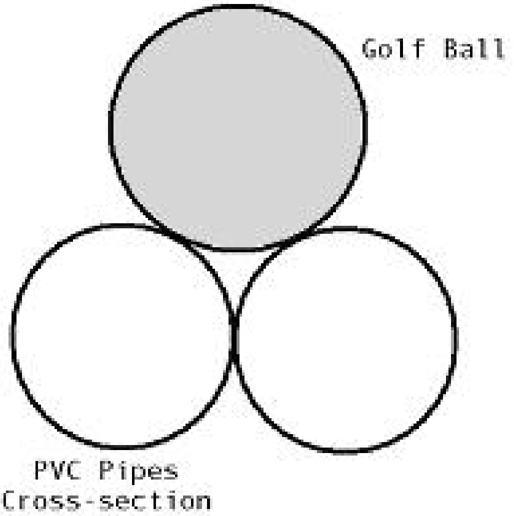


Figure 4: Cross-section of ramp with golf ball

Procedure

Prior to building the frame, the coefficient of kinetic friction was determined experimentally. The ramp was inclined (without any curvature) at a known angle and the time required for the ball to roll the length of the ramp was measured. The coefficient of kinetic friction was then determined to be 0.13.

Since it was difficult to constrain a perfectly circular arc in the bottom of the ramp, the frame was built and tested before the required golf ball drop height was precisely determined. After building the frame, the departure exit angle of our ramp was measured to be 53° with respect to the base of the frame. This angle could be changed with respect to the horizontal by raising the front or rear of the frame. Once the ramp was built, a digital picture was taken to record the frame dimensions.

An exercise target 1m above the ground and 1 m from the front of the ramp was used to experimentally find the initial drop position of the ball required to strike the target. As it turned out, our ramp was not tall enough! We needed to elevate and tilt our ramp (thereby changing the launch angle with reference to the horizontal) in order to get the golf ball to strike the target. The drop position, lift and tilt of the ramp were recorded to compare to theoretically obtained values.

Theory

Numerical approximation was used to calculate the drop position of the golf ball required to strike the specified target. A digital photo of the ramp allowed for numerical approximation of the different sections of the ramp (Figure 5). The straight sections of the ramp did not require numerical approximation techniques in order to apply energy and rectilinear motion equations, but the curved section was not perfectly circular and therefore needed to be approximated with short, linear segments.

A skeleton of the ramp was created from a digital picture of the ramp using digital imaging software. Eight straight 6” sections approximated the curved section of the ramp. The angle of each section was measured in reference to the horizontal base of the frame. The distance to the point of intersection of perpendicular bisectors of adjacent sections was used to estimate the radius of curvature of each section of the ramp (Figure 6). With the estimated radius of curvature for each section, the normal force was calculated and assumed constant for the length, L, of a section.

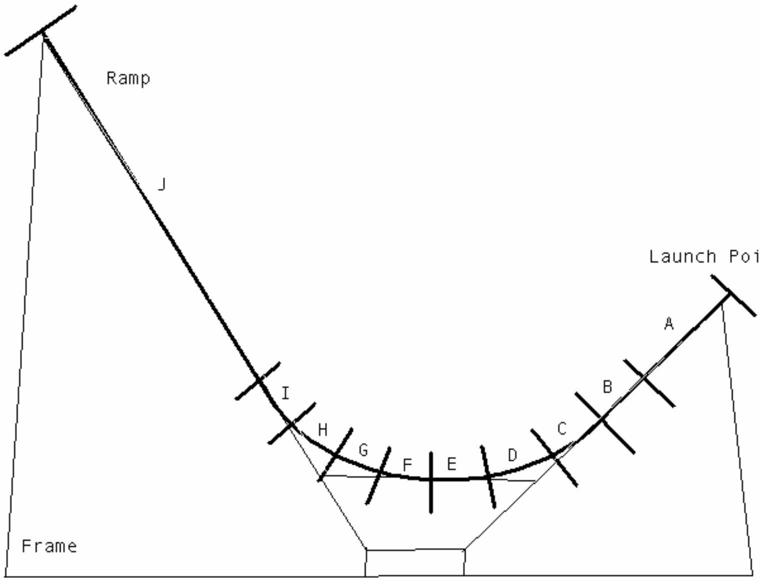


Figure 5: Skeleton view of the ramp showing sections for numerical approximation

The launch velocity, v_l, was calculated using the launch angle, θ_l, and launch height, h. The launch kinetic energy, T, was then calculated and energy methods were used to calculate the energy lost due to non-conservative forces (such as friction). Kinetic energy of the golf ball entering each section of the ramp was calculated using total energy conservation (potential, kinetic and non-conservative energy dissipation). Working backwards (from section A to section J), the entering kinetic energy of one section equals the exiting kinetic energy of the previous section. Since the golf ball has no kinetic energy when entering the first part of the ramp (section J), the required potential energy and drop position may be calculated instead. These equations were entered into a spreadsheet to avoid human, algebraic mistakes. The angle of each section was recorded in reference to the base so that absolute angles and the launch height could be easily changed as the entire ramp frame was lifted and tilted.

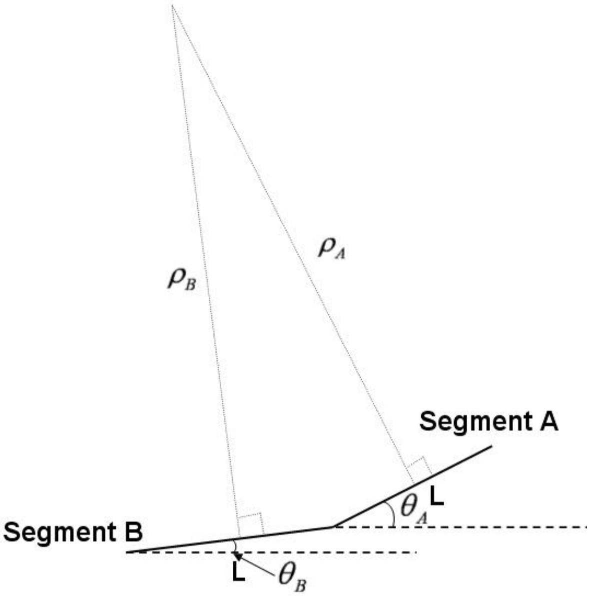


Figure 6: Approximation of radius of curvature using perpendicular bisectors of adjacent segments

Projectile motion equations for displacement:

Horizontal component: $x = tv_l \cos\theta$ (1)

Vertical component: $y = -\frac{1}{2}gt^2 + tv_l \sin\theta + h$ (2)

Combining (1) and (2), the initial launch velocity:

$$v_l = \sqrt{\frac{gx^2}{2(\cos\theta)^2 (x\tan\theta + h - y)}} \tag{3}$$

Radius of curvature for a segment along the curved portion of ramp:

$$\rho_B = \frac{1}{4}\left(\frac{L}{\tan\left(\frac{\theta_A - \theta_B}{2}\right)} + \frac{L}{\tan\left(\frac{\theta_B - \theta_C}{2}\right)}\right) \quad \text{(segment B)} \tag{4}$$

Normal contact force for a segment:

$$N = \frac{mv^2}{\rho} + mg\cos\theta \tag{5}$$

Energy Balance for a segment:

$$T_1 + V_{g1} + V_{e1} + U_{1-2} = T_2 + V_{g2} + V_{e2} \tag{6a}$$

$$V_{e1} = V_{e2} = 0 \tag{6b}$$

Kinetic energy:

Entering a segment:

$$T_1 = \frac{1}{2} m v_1^2 \tag{7}$$

Exiting a segment:

$$T_2 = \frac{1}{2} m v_2^2 \tag{8}$$

Potential energy:

Entering a segment (this value is arbitrary):

$$V_{g1} = 0 \tag{9}$$

Exiting a segment:

$$V_{g2} = -mgL \sin\theta \tag{10}$$

Energy dissipated by non-conservative forces:

$$U_{1-2} = \mu_k L N \tag{11}$$

Solving equation (6) with equations (7) – (11), the entering velocity:

$$v_1 = \sqrt{v_2^2 - 2gL\sin\theta - 2\mu_k L\left(\frac{v_2^2}{\rho} + g\cos\theta\right)} \tag{12}$$

Since the segment lengths and angles do not change as the ball rolls down the ramp, they are treated as constants and the entering velocity of the ball becomes a function of the exiting velocity required. The exiting velocity of the last segment (segment A) may be used to find the entering velocity of that segment. The exiting velocity of segment B equals the entering velocity of segment A. Using the exiting velocity of the first segment (segment J), the drop position may be determined.

Potential energy entering segment J:

$$V_{g2} = U_{1-2} - T_2 \tag{13}$$

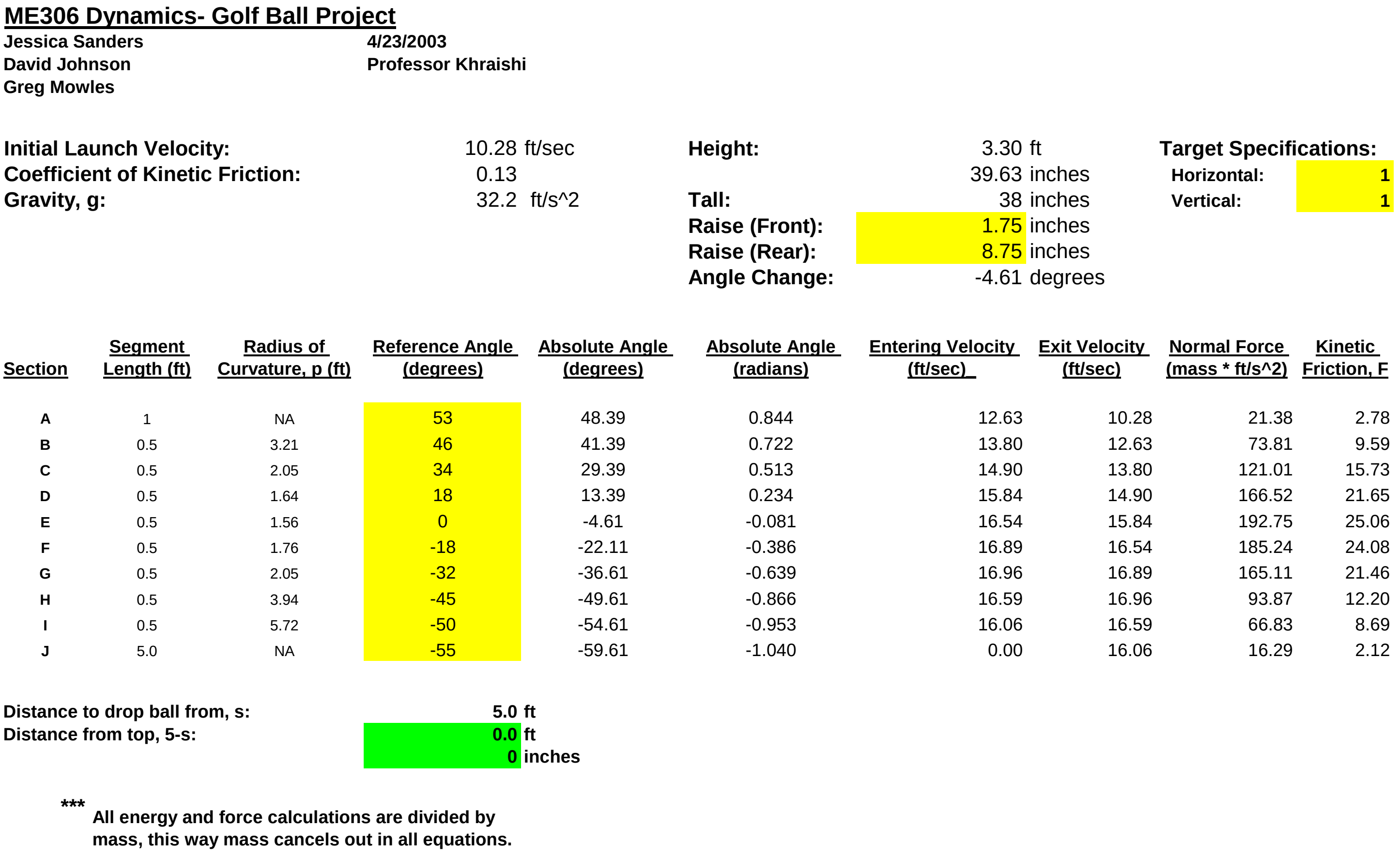
Substitute values for potential, kinetic and dissipated energy and solve for the length of segment J:

$$L = \frac{v_2^2}{2g(\sin\theta - \mu_k \cos\theta)} \quad \text{(segment J)} \tag{14}$$

The length of segment J determines the release position of the golf ball. A spreadsheet was used to perform repetitious calculations.

Results/Conclusion

The spreadsheet used for numerical approximation allowed the user to change several parameters of the experiment. Though the dimensions of the frame are fixed, the spreadsheet accounted for any lift or tilt. The greatest consistency was achieved during testing when the rear of the ramp was raised 8.75in and the front was raised 1.75in. The golf ball launcher performed accurately and precisely in testing and in use. Numerical approximation allowed accurate dynamic analysis of the motion of the golf ball and the spreadsheet enabled different target parameters to be quickly tested.



ME306 Dynamics- Golf Ball Project

Jessica Sanders	**4/23/2003**
David Johnson	**Professor Khraishi**
Greg Mowles	

Initial Launch Velocity:	10.28 ft/sec	**Height:**	3.30 ft	**Target Specifications:**	
Coefficient of Kinetic Friction:	0.13		39.63 inches	**Horizontal:**	**1**
Gravity, g:	32.2 ft/s^2	**Tall:**	38 inches	**Vertical:**	**1**
		Raise (Front):	1.75 inches		
		Raise (Rear):	8.75 inches		
		Angle Change:	-4.61 degrees		

Section	Segment Length (ft)	Radius of Curvature, p (ft)	Reference Angle (degrees)	Absolute Angle (degrees)	Absolute Angle (radians)	Entering Velocity (ft/sec)	Exit Velocity (ft/sec)	Normal Force (mass * ft/s^2)	Kinetic Friction, F
A	1	NA	53	48.39	0.844	12.63	10.28	21.38	2.78
B	0.5	3.21	46	41.39	0.722	13.80	12.63	73.81	9.59
C	0.5	2.05	34	29.39	0.513	14.90	13.80	121.01	15.73
D	0.5	1.64	18	13.39	0.234	15.84	14.90	166.52	21.65
E	0.5	1.56	0	-4.61	-0.081	16.54	15.84	192.75	25.06
F	0.5	1.76	-18	-22.11	-0.386	16.89	16.54	185.24	24.08
G	0.5	2.05	-32	-36.61	-0.639	16.96	16.89	165.11	21.46
H	0.5	3.94	-45	-49.61	-0.866	16.59	16.96	93.87	12.20
I	0.5	5.72	-50	-54.61	-0.953	16.06	16.59	66.83	8.69
J	5.0	NA	-55	-59.61	-1.040	0.00	16.06	16.29	2.12

Distance to drop ball from, s:	**5.0 ft**
Distance from top, 5-s:	**0.0 ft**
	0 inches

******* **All energy and force calculations are divided by mass, this way mass cancels out in all equations.**

Figure 7a: Spreadsheet used to calculate drop position (part a)

meter = 39.37 inches = 3.28 ft
meter = 39.37 inches = 3.28 ft

Energy Lost to Friction, U(1-2)	Entering Kinetic Energy (mass * ft^2/s^2)	Exiting Kinetic Energy (mass * ft^2/s^2)	Entering Potential Energy (mass * ft^2/s^2)	Exiting Potential Energy (mass * ft^2/s^2)
2.78	79.74	52.89	-24.07	0
4.80	95.18	79.74	-10.64	0
7.87	110.95	95.18	-7.90	0
10.82	125.50	110.95	-3.73	0
12.53	136.73	125.50	1.30	0
12.04	142.71	136.73	6.06	0
10.73	143.84	142.71	9.60	0
6.10	137.68	143.84	12.26	0
4.34	128.90	137.68	13.13	0
10.64	0.00	128.90	139.53	0

Figure 7b: Spreadsheet used to calculate drop position (part b)

Nomenclature

t	Time
x	Horizontal distance from base of ramp to target
y	Vertical distance of target above ground
g	Gravitational acceleration $\left(32.2\frac{ft}{s^2}\right)$
h	Launch height above ground
L	Segment length
θ	Segment angle
v	Instantaneous velocity of golf ball
v_l	Launch velocity
v_1	Velocity entering a ramp segment (according to Figure 5)
v_2	Velocity exiting a ramp segment (according to Figure 5)
ρ	Approximated radius of curvature of a segment
μ_k	Coefficient of kinetic friction
N	Normal force exerted on golf ball by ramp
T	Kinetic energy of golf ball
V_g	Gravitational potential energy

V_e	Elastic potential energy
U_{1-2}	Energy dissipated by non-conservative forces over a ramp segment

References

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