# Lab #2: Projectile Motion

Kylee McPhedrain 300225026
Kiyoshi Perkins 300199345
Kristy Smith 30020279

SPSC 1151-001
Presented to: Lara Duke
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**Questions:**

**1. Include all of the mathematical work for the three conditions.**

***see attached written paper***

**2. Using the peer-reviewed paper from RPA 3 (Linthorne, Gyzman & Bridgett, 2005) that addresses the projection angle of a projectile a long jumpers.**

**a. Write the APA reference**

Linthorne, N. P., Guzman, M. S., & Bridgett, L. A. (2005). Optimum take-off angle in the long jump. *Journal of Sports Sciences, 23(7),* 703-712. doi: 10.1080/02640410400022011

**b. What is the optimal projectile angle for that projectile?**

"For a projectile that is released with constant speed from ground level, the optimum projectile angle that maximizes the flight distance is 45°" (Linthorne, Guzman & Bridgett, 2005, p. 709). However, in this study the optimal angle of take off was studied from low, high and very high angles with the choice of take-off speeds and take-off heights for the participant (Linthorne et al., 2005). Linthorne et al. (2005) reports that optimal take off angles are dependent on an individual however, higher take-off speeds result in lower take-off angle, creating an optimal take-off angle anywhere from 20.2 degrees to 27 for the 3 participants studied.

Athlete 1 had an optimal angle of 20.9 degrees (plus or minus 0.7 degree), athlete 2 was 21.6 degrees (plus or minus 2.1 degrees) and athlete 3 was 25.4 degrees (plus or minus 1.6 degrees) (Linthorne et al., 2005).

**c. How did the author come to that conclusion?**

The author came to this conclusion by calculating the official distance of an athlete and plotted it as a function of the take-off angle (Linthorne et al., 2005). The optimum take-off angle, which is 45°, was plotted on the curve where the official distance was highest. To conclude, the author found in the study "that a long jumpers optimum take-off angle may be calculated by combining the equation for the range of a projectile in free flight with the measured relations between the take-off speed, height and angle for athlete" (Linthorne et al., 2005, p. 709). The standard of error was determined using the quadrature method (Linthorne et al., 2005). Participants were instructed to jump multiple times at low (0-30 degrees), high, and very high take-off angle, they were recorded using high-speed video cameras and measurements were taken (Linthorne et al., 2005).

**3. Draw the three condition's trajectories on one graph (draw xp on the x-axis and yp on the y-axis for each jump). You can draw these graphs by hand. Describe the differences or similarities.**

***Figure 1***

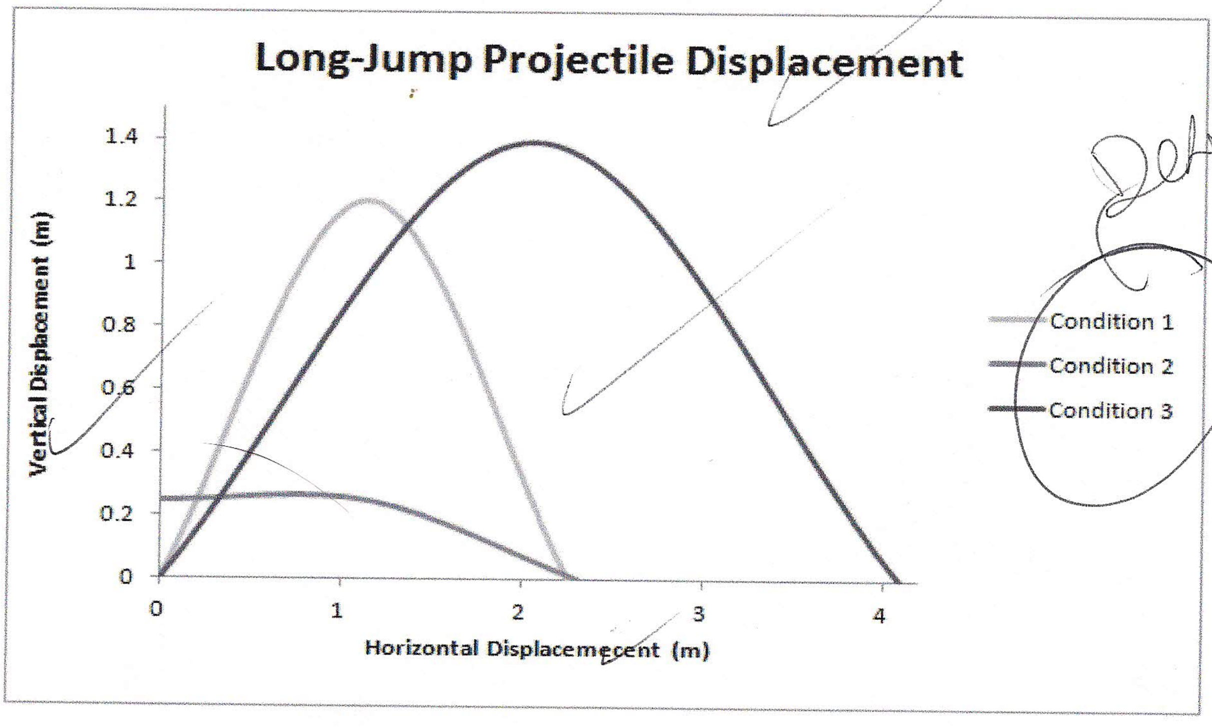



Figure 1 shows the horizontal and vertical displacements of the different long-jump conditions. Condition 1 is a long-jump from standstill, with a vertical displacement that begins and ends at ground level. Condition 2 is a long-jump beginning from a higher vertical displacement (0.25 m) and ending at the same level as Condition 1, ground level. Condition 3 is a long-jump with a running start, and a vertical displacement that begins and ends at ground level.

As seen in Figure 1, Condition 1 has the shortest horizontal displacement at 2.26 meters. Condition 2's horizontal displacement was ahead of Condition 1 by 0.06 meters, putting Condition 2 at 2.32 meters. Condition 3 had the longest horizontal displacement at 4.10 meters, making it 1.84 meters farther than Condition 1. This difference in distance can be attributed to the horizontal acceleration the projectile (i.e., the subject) maintained prior to the take-off point.

All conditions had varying takeoff angles. Condition 3 had the lowest angle of 18.67 degrees at takeoff. Condition 1 has a takeoff angle of 27.97 degrees. Condition 2 has the highest take-off angle, at 83.85 degrees. This is likely due to the subject undergoing flexion at the iliofemoral joint and flexion at the tibiofemoral joint, where the added mass near the subject's center of mass provided vertical velocity and horizontal velocity, resulting in such an abnormally high takeoff angle.

Both Condition 1 and Condition 3 had a resultant vertical displacement of 0 meters, due to their take-off and landing points being on the same elevation. Condition 1 did reach a maximal vertical distance of 1.20 meters from the ground level. Condition 3 reached a maximal vertical distance of 1.39 meters from the ground level. Condition 2's takeoff point was higher in elevation than the landing point, giving it a vertical displacement of 0.25 meters, making it the only condition to have vertical displacement.

**4. Explain how the following variables can affect maximum height and range:**

**a. Initial take-off velocity**

Initial takeoff velocity can affect maximum height based on the speed of the jumper. If the jumper runs straight through the takeoff destination, they are producing maximum speed, although no height is being achieved. Although, maximum height in the vertical direction can be achieved with a slower takeoff velocity (Linthorne et al., 2005). Also, initial take-off velocity can affect the range of the jump. If initial take-off velocity is at a higher speed, the farther the range will be, the slower the velocity the shorter the range. Higher velocities result in lower take-off angles and lower velocities result in greater take-off angles for long jump projectiles.

**b. Take-off angle**

The takeoff angle of a long jumper can affect their maximum height and range. Maximum height and range can be affected when the participant jumps at a 90-degree angle where height and range are restricted. Maximum height and range can also be affected when jumping at lower take-off angles as the jumper moves the trunk of the body ahead of the take-off foot where ultimately the height of the athlete's centre of mass is reduced and range is farther (Linthorne et al., 2005).

**c. Take-off height**

"The height of the jumper's centre of mass at take-off is determined by his body position" (Linthorne et al., 2005, p. 708). This quote directly relates to how the take-off height of a long jumper can affect maximum height and range. Take-off height can affect maximum height and range based on the direction of the jump. If the jumper completes a vertical jump upwards, maximum height is only achieved by the flexion and extension of his legs, whereas if the trunk of the body is tilted forwards towards the direction of the jump, maximum height will be altered. Maximum range is also determined by the take-off height of the jumper. If jump is made vertical, the range will stay constant. If the jump is made forwards, the maximum range will be different.

velocity
take-off angle

**5. Using figure 3.14 provide a verbal description of the factor most greatly impacted by training when the goal is to achieve maximum range with the projectile. Discuss the connection between your thinking and the details from the Linthorne et al., (2005) paper. (Hint: this response will contain at least two in-text citations).**

Relating to figure 3.14 in the text, horizontal velocity at takeoff is determined to be the factor that is most greatly impacted by training when the goal is to achieve maximum range with the projectile (Flanagan, 2014). Horizontal velocity determines how long the projectile will be in flight; the higher the velocity, the more time the projectile will be in the air which will give a greater range. $R = \frac{v^2 \sin 2\theta}{g}$ is the equation that determines the range of a projectile. As the velocity is squared in the equation, "doubling the velocity will lead to a four-fold increase in distance. The velocity term obviously has a bigger impact than any other term in the equation" (Flanagan, 2014, p. 46). The greater the horizontal velocity, the more distance is covered over a certain period of time. Therefore, in accordance to figure 3.14, horizontal velocity is close to the top of the hierarchical model, meaning the importance is greater. Linthorne et al. (2005) concludes that the range is more greatly affected by the take-off speed rather than the take-off angle. Higher take-off speeds are a result of a greater horizontal velocity. Additionally, Linthorne et al. (2005) found that more variations in official distance were calculated through variations in take off speed. These were due to inconsistencies in run-up and takeoff techniques, proving to have a greater impact on the range of a projectile (Linthorne et al., 2005).

In relation to our data collection, the greatest horizontal distance achieved by our jumping participant was during Condition 3, where the participant began with the running start before jumping. Therefore, a greater horizontal velocity allowed our participant to complete their greatest distance.

# References

Flanagan, S. P. (2014). *Biomechanics: A Case-Based Approach.* Burlington, MA: Jones & Bartlett Learning.

Linthorne, N. P., Guzman, M. S., & Bridgett, L. A. (2005). Optimum take-off angle in the long jump. *Journal of Sports Sciences, 23(7),* 703-712. doi: 10.1080/02640410400022011

Kristy Smith

# Lab 2 Projectile Motion

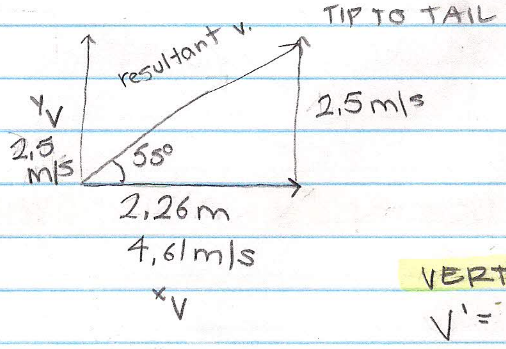
1) Mathematical work for 3 conditions:

## Condition 1

$p = 2{,}26m$

$t_{tot} = 0{,}49s$

$\measuredangle = 55°$




HORIZONTAL VELOCITY

$^{x}V = \frac{\Delta p}{\Delta t}$

$^{x}V = \frac{2{,}26m}{0{,}49s}$

$^{x}V = 4.61m/s$

VERTICAL VELOCITY

$V' = 0m/s$ (apex)

$V = ?$

$a = -9.81m/s^2$

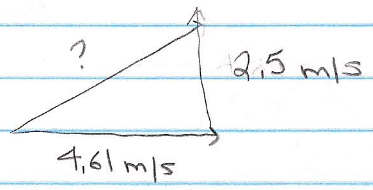
$t_1 = 0{,}25s$

$V' = V + at$

$0\,m/s = V + (-9{,}81\,m/s^2)\,0{,}25\,s$

$2{,}5\,m/s = {}^{y}V$

RESULTANT VELOCITY



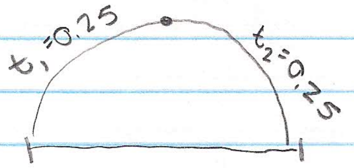

$a^2 + b^2 = c^2$

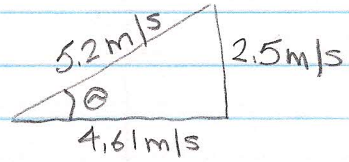
$4{,}61^2 + 2{,}5^2 = c^2$

$27{,}50 = \sqrt{c^2}$

$^{R}V = 5{,}2\,m/s$

CALCULATED ANGLE OF RELEASE




SOH CAH TOA

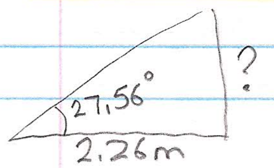
$\cos\theta = \frac{4.61m/s}{5{,}2m/s}$

$\theta = 27{,}56°$

VERTICAL DISPLACEMENT

0 m because he was starting on the ground

MAX HEIGHT




SOH CAH TOA

$\tan 27{,}56 = \frac{x}{2{,}26}$

max height $= 1{,}18m$

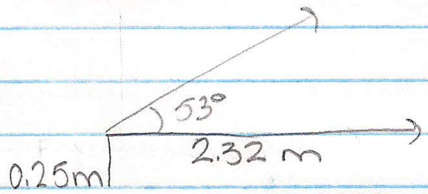
## Condition 2

$^{x}p = 2.32m$

$^{y}p = 0.25m$

$t_{tot} = 0.56$ sec

$\measuredangle = 53°$




**Horizontal Velocity $^{x}v$**

$^{x}v = \frac{\Delta p}{\Delta t}$

$^{x}v = \frac{2.32m}{0.56s}$

$^{x}v = 4.14$ m/sec

**Vertical Velocity instant before landing $^{y}v$**

$v' = 0$ m/s (apex)

$v = ?$

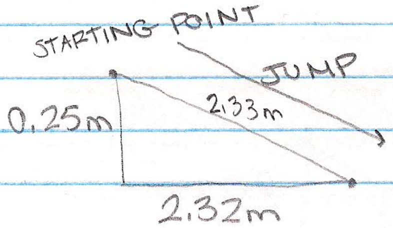
$a = -9.81\ m/s^2$

$t = 0.56s$

$v' = v + at$

$0m/s = v + (-9.81m/s^2)(0.56\ s)$

$5.49m/s = v$




$a^2 + b^2 = c^2$

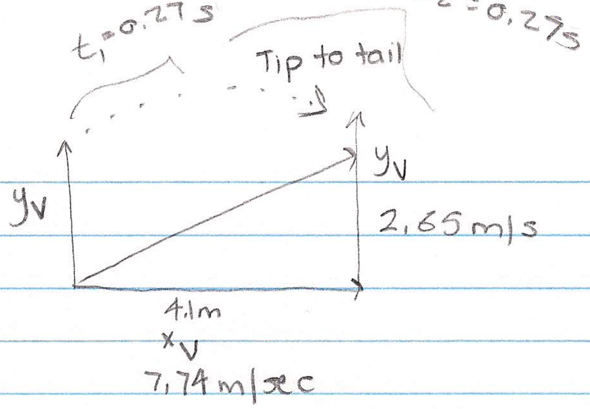
$0.25^2 m + 2.32^2 m = c^2 m$

$\sqrt{5.44}\ m = \sqrt{c^2}\ m$

$2.33\ m = c$

$t_1 + t_2 = t_{tot}$

$0.27s + \_ = 0.53s$




## Condition 3

$^x p = 4.1m$

$t_{tot} = 0.53\ s$

Est. $\angle = 62°$

### Horizontal Velocity $^x v$

$$^x v = \frac{\Delta p}{\Delta t} = \frac{4.1m}{0.53s} =$$

$$= 7.74 m/sec$$

### Vertical velocity $^y v$

$v' = 0\ m/s$ (apex)

$v = ?$

$a = -9.81\ m/s^2$

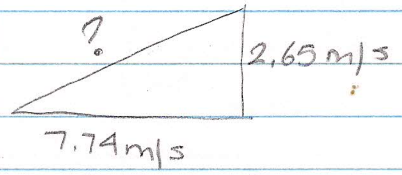
$t_1 = 0.27s$

$$v' = v + at$$

$$0 m/s = v + (-9.81 m/s^2)(0.27s)$$

$$2.65 m/s = v$$

### Resultant Velocity $^R v$




$$7.74^2\ m/s + 2.65^2\ m/s = c^2$$

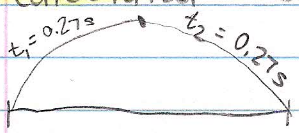
$$\sqrt{66.93\ m/s} = \sqrt{c^2}$$

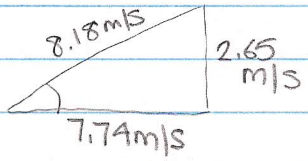
$$^R v = 8.18\ m/s = c$$

### Vertical Displacement $^y p$

0m because he jumped from the ground

### Calculated $\angle$ of release




$$\cos \theta = \frac{7.74 m/s}{8.18 m/s}$$

$$\theta = 18.88°$$

SOH CAH TOA

$t_{tot}$ = Δtime

t = feet on ground (begin)
t' = feet on ground (end)
$t' - t = t_{tot}$

Ipad : Bball #4.

**Data Sheet change**

centre of mass = trunk

**Condition 1: Jumping as far as one can from standstill**

Record the following:

| Jump | Horizontal displacement ($^xp$) | Total time in flight ($t_{tot}$) | Estimated Angle of Release |
|---|---|---|---|
| **Jumping for range** | 2.26m | 0.49 sec | 55° |


3.02 − 2.53 =

Fill out the table below by calculating the other variables using equations of uniformly accelerated motion. Include mathematical work with lab submission.

| Jump | Horizontal velocity ($^xv$) | Vertical velocity ($^yv$) | Resultant velocity ($^Rv$) | Vertical displacement ($^yp$) | Calculated Angle of release |
|---|---|---|---|---|---|
| **Jumping for range** | 4.61m/s | 2.5 m/s | 5.2 m/s | 0m | 27.56° |

Notes:

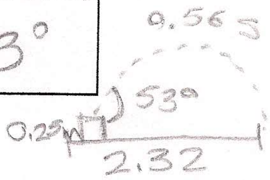
{Start on ground}

Max Height 1.18m

**Condition 2: Jumping as far as one can from a box without going up**

Record the following:

| Jump | Horizontal displacement ($^xp$) | Vertical displacement ($^yp$) | Total time in flight ($t_{tot}$) | Angle of release |
|---|---|---|---|---|
| **Jumping from a box** | 2.32m | 0.25m | 0.56 sec | 53° |




2.34 − 1.78 =

Fill out the table below by calculating the other variables using equations of uniformly accelerated motion. Include mathematical work with lab submission.

| Jump | Horizontal velocity ($^xv$) | Vertical velocity instant before landing ($^yv$) |
|---|---|---|
| **Jumping for range** | 4.14 m/s | 5.49 m/s. |

Notes:

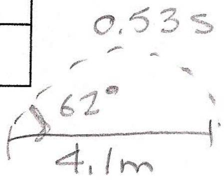
Shaw

**Condition 3: Jumping as far as one can from a running start**

Record the following:

| Jump | Horizontal displacement ($^{x}p$) | Total time in flight ($t_{tot}$) | Estimated Angle of Release |
|---|---|---|---|
| Jumping for range | 4.1m | 0.53 sec | 62° |

2.92 − 2.39 =




Fill out the table below by calculating the other variables using equations of uniformly accelerated motion. Include mathematical work with lab submission.

| Jump | Horizontal velocity ($^{x}v$) | Vertical velocity ($^{y}v$) | Resultant velocity ($^{R}v$) | Vertical displacement ($^{y}p$) | Calculated Angle of release |
|---|---|---|---|---|---|
| Jumping for range | 7.74 m/s | 2.65 m/s | 8.18 m/s | 0 m | 18.88° |

Notes:

| | |
|---|---|
| 1. | 12 /12 (4 per condition) |
| 2a. | 2 /2 |
| 2b. | 2 /2 |
| 2c. | 3 /4 |
| 3. | 3.5 /5 |
| 4a. | 1.75 /2 |
| 4b. | 2 /2 |
| 4c. | 1 /2 |
| 5. | 8 /8 |
| Data Collection and RPA 3: Present and working with team | 9 /9 |
| APA Format | 6 /7 |
| **Total** | 50.25 /55 |
| | **/10** |

**Feedback**

| A<br>100-85 | B<br>84-70 | C<br>69-55 | P<br>54-50 | F<br>< 50 |
|---|---|---|---|---|
| | | **Lab Write up Answers** | | |
| Demonstrates an excellent understanding of course theory by integrating course concepts throughout the responses. All sentences are written completely, with proper spelling and grammar. | Demonstrates a good understanding of course theory by using some course concepts throughout the responses. Majority of sentences (about 80%) are written completely, and/or minor spelling/grammar errors. | Sparse use of course terminology and/or terminology is weakly integrated throughout the responses. More than half of sentences (about 60%) are written completely, and/or major spelling/grammar errors. | Sufficient superficial evidence of understanding of course concepts to warrant a passing grade. Half of sentences (50%) are written completely, and/or spelling/grammar errors interfere with reading. | Responses fail to demonstrate an understanding of basic concepts. Less than half of the sentences (50%) are written completely, and/or spelling/grammar errors interfere with reading. |
| | | **APA Style Reference and Research Usage** | | |
| Demonstrates excellent integration of the information obtained from the literature when analyzing quality of the lab skill(s). | Demonstrates good integration of the information obtained from the literature when analyzing quality of the lab skill(s). | Sparsely integrated information from the literature when attempting to analyze the lab skill(s). | Little to no use of information from the literature for set up or analysis. | No literature incorporated in the lab analysis responses. |
| Proper referencing APA Style of the list and in-text citations. | Minor referencing errors of the list and in-text citations. | Disorganized references of the list and in-text citations. | | |