DECONSTRUCTION: VISIBILITY OF AN EMERGENCY FLARE

Problem: *What physical factors should be optimized to maximize the visibility of an emergency flare?*
Emergency flares are used for signalling distress in wilderness or maritime emergencies, and are launched high into the air where they burn brightly for rescuers.

Factor	Potential effect	Measuring and controlling
Launch speed	Increasing the launch speed would increase the maximum height of the flare: $v_v^2 = {v_0}_v^2 + 2a_v s_v \therefore s_v = \frac{v_v^2 - v_{0_v}^2}{2a_v}$ where $v_v^2 = 0 \therefore s_v = \frac{-v_{0_v}^2}{2a_v}$ The flare being higher in the sky could make it more visible during its flight, especially if there are mountains or tall buildings in the way, unless it is launched too high to see (such as above the clouds). Increasing the launch speed would also increase the time to maximum height: $v_v = v_{0_v} + a_v t \therefore t = \frac{v_v - v_{0_v}}{a_v}$ where $v_v = 0 \therefore t = \frac{-v_{0_v}}{a_v}$ The flare taking longer to reach maximum height increases the time of flight, so the flare could be visible in the sky for longer. However, increasing the launch speed would increase air resistance, so the effect of increasing launch speed could be less at higher values.	The effect of launch speed could be investigated by pointing a projectile launcher, which has multiple speed settings, directly upwards. The precise launch speed could be measured using a light gate positioned at the launch end of a projectile launcher, or by analysing slow-motion video of each launch. The visibility of a flare in this case would be measured as maximum height (and/or time), it is not necessary for the projectile used to be an actual flare, and the same formulas would apply to a small-scale launch in a classroom as to real flares, so the experiment should be mostly valid. Some assumptions need to be made that would decrease validity, such as the flare's mass remaining constant. In reality a flare's mass gets lighter over time as it burns fuel.
Launch angle	Increasing the launch angle would increase the vertical component of initial velocity: $v_{0_v} = v_0 sin\theta$, assuming v_0 is kept constant. This would increase the maximum height: $s_v = \frac{-v_{0_v}^2}{2a_v}$ (see above for derivation) A higher maximum height could increase visibility, as explained for launch speed. However, increasing the launch angle would decrease the horizontal component of the initial velocity, which reduces range: $s_H = v_{0_H} t$ (since $a_H = 0$) This is unlikely to have a significant impact on visibility since the horizontal travel is probable small compared to the potential distance of rescuers.	The effect of launch angle could be measured by launching a projectile at a constant speed from a projectile launcher. The angle could be measured using a protractor or by using trigonometry, and the maximum height could be measured by analysing slow-motion video footage or by using teamwork to track the height reached by the projectile. Care would have to be taken to keep the launch height and speed constant, which could be difficult if the launcher is too simple. The assumptions and limitations of representing this situation in a classroom are the same as for launch speed (see above).
Projectile shape	Making the shape more streamlined could decrease drag force (and therefore drag acceleration, assuming mass is held constant) since it would decrease the projected area and the drag coefficient: $F_d = \frac{1}{2}\rho v^2 C_d A$ Decreasing drag would allow the flare to reach a higher maximum height and therefore potentially be more visible for the reasons discussed above.	Maximum visibility in this case could be measured by dropping or launching a projectile horizontally, since the assumption is that the benefit occurs from maximum height. This does make the experiment less like real life but attaching fins to a projectile would make it difficult to fit into a standard launcher, since it has essentially become a glider. Shape could be

Commented [TB1]: The total size of the Deconstruction and Design is four pages. There is no word count limit, but the font size must be 10 or larger.

Commented [TB2]: Clearly state the problem that will be deconstructed, and briefly include any information needed to provide context.

Commented [TB3]: Consider a range of factors (potential independent variables) that could be expected to have a reasonable effect relevant to the problem.

Commented [TB4]: Clearly describe a range of practical approaches throughout your deconstruction, including how variables could be measured.
Be critical, for example consider the limitations of representing a real-world problem in a classroom experiment.

	Complex shapes such as fins could allow the flare to glide after reaching maximum height, which could allow it to stay in the air longer and travel further horizontally, potentially becoming visible to farther away rescuers.	considered in terms of size of fins attached, for example 3D-printed or cut from cardboard and glued onto a simple fuselage.
Projectile mass	Making the flare heavier would decrease the effect (acceleration) of air resistance (drag), assuming the forces remain the same: $a = \frac{F}{m}$ This would potentially have similar effects as the more streamlined shape, explained above. However, a heavier flare would probably have a slower launch speed (assuming the same launch force), which could reduce the benefits of the increased mass.	Projectile mass could be easily changed by putting heavy objects inside the projectile, and measured by using an electronic balance. Care would need to be taken that the mass does not change other properties of the projectile, such as its size or the way it tumbles as it travels. The changing mass would make it difficult to keep launch speed constant, so the "flare" might have to be dropped from a height (see above).
Parachute	Having a parachute automatically deploy at maximum height would increase the air resistance during the falling part of the flare's motion. This would increase the time that the flare remains in the air, which would improve the visibility of the flare. However, adding a parachute to the flare could have unintended negative effects such as slower launch speed due to increased mass, and a risk that the parachute could catch fire or block some of the flare light. The benefits of a parachute could also be limited if the flare only burns for a short time.	This would be difficult to test experimentally in a classroom environment. The independent variable would probably be the size of the parachute, and it would be difficult to create "flare" projectiles with differently sized parachutes whilst keeping everything else constant. Creating a mechanism to reliably deploy the parachute at the correct time would also be difficult, especially if the flight time is small, which it is in a classroom.

The independent variable chosen for this investigation is: **launch speed**, since fewer assumptions need to be made compared to other choices above and equipment exists to reliably launch and measure the projectile whilst keeping constant the other factors listed above

Commented [TB5]: Explain reasons for the choice of independent variable to investigate (this will be longer if practical considerations are discussed in less detail above).

The dependent variable is the **maximum height** the projectile reaches, since it is being measured to determine how it changes when the launch speed is changed.

Commented [TB6]: List the relevant variables, giving reasons. This can be done either in the Deconstruction or in the Design.

Factors that will be held constant:

- Launch angle: this will be kept directly upwards for all launch speeds.
- Projectile mass: the same projectile will be used for all launch speeds.
- Acceleration of the projectile due to gravity: nothing needs to be done as it is a physical constant at any single location on Earth.

Factors not able to be controlled:

- Air resistance: In an ideal method this experiment would be performed in a vacuum to eliminate this factor entirely, but that is not realistic in a school context. Air resistance should be minimal because the projectile is moving at low speeds, and somewhat consistent because the shape of the projectile and density of air are unlikely to change.
- Projectile shape: Unfortunately, the projectile is likely to rotate unpredictably as it launches, and our projectile launcher does not launch perfect spheres. The projectile may experience different forces due to air resistance from trial to trial.

Stanley Rorgan

Design: Maximum Height of a Flare

Aim:

To investigate the relationship between the launch speed and the maximum height of a flare launched directly upwards.

Hypothesis:

The maximum height h reached by a flare launched directly upwards will be proportional to the square of the speed v_0 at which it was launched.

$v_v^2 = {v_0}_v^2 + 2a_v s_v \;\; \therefore s_v = \frac{v_v^2 - v_{0_v}^2}{2a_v}$ where $v_v^2 = 0, \therefore s_v = \frac{-v_{0_v}^2}{2a_v}$

In this case, $s_v = -h$, so this relationship can be described by the equation $h = \frac{{v_0}^2}{2g}$ where g is the acceleration due to gravity. Since g is constant, $h \propto v_0^2$

Equipment:

- Sticky tape
- Measuring tape or metre ruler
- Projectile launcher with projectile
- Light gate with computer
- Stand with clamp

Procedure:

1. Use sticky tape to hold the projectile launcher against a wall, resting on the ground, pointing directly upwards.
   This approach helps the launcher stay in the same spot, so that the angle and launch height are constant.
2. Use sticky tape to attach the measuring tape to the wall. The measuring tape should be aligned straight up and down, and its zero mark should line up with the top of the projectile launcher.
   The note about the zero mark is important so that the measurements are accurate.
3. Clamp the light gate onto the stand so the projectile will pass through the light gate. The light gate should be just above the top of the projectile launcher, and should not obstruct the motion of the projectile.
   Having the light gate immediately at the launch point should consistently give the fastest speed.
4. Use the measuring tape to measure the length of the projectile that will break the gate beam.
   The projectile may be an irregular shape so this is important since speed is based on length/time.
5. Connect the light gate to the computer and set the software up to record speed, entering the length of the projectile measured in step 4.
   It is crucial that the "speed" setting is chosen at this step, rather than time or acceleration.

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Commented [TB8]: Include clear headings for sections.

Commented [TB9]: Be as specific as possible to *this* investigation

Commented [TB10]: A statement of what you expect to happen, written as if it will be true. Include a specific mathematical relationship.

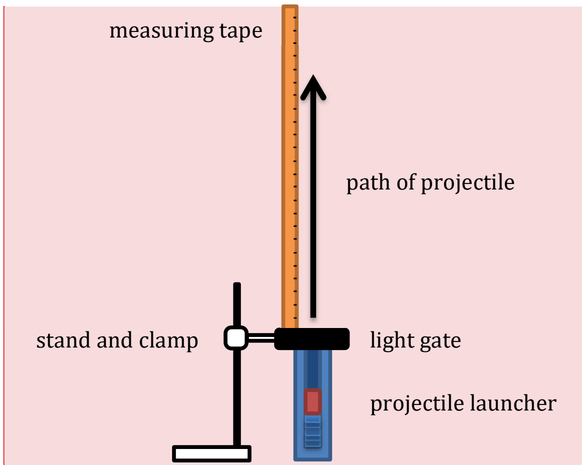
Commented [TB11]: Define symbols for variables used. Include a logical explanation for your hypothesis.

Commented [TB12]: Dot point list. Include all the things that you need to bring to where you do the prac.

Commented [TB13]: Numbered steps, worded as instructions. Include as many details as you can.
Anyone should be able to exactly repeat your experiment by following this method.

Commented [TB14]: Include justification of decisions made, such as which values to use or how to perform steps.

6. Place the projectile in the launcher and pull back to the first notch.
   The first notch is the lowest speed. Starting the instructions this way should make them logical to follow.
   Safety note: Ensure before launching that no one is going to be in the path of the projectile.
   The projectile launcher is low speed and not sharp but it is launching upwards so it could hurt your eyes.
7. Launch the projectile, watching carefully to track its height. Record the height it reaches.
   This should work because the projectile launches directly upward right beside the measuring tape.
8. The most recent measurement from the light gate is the launch speed. Record this.
   Our software automatically records speed each time the beam is broken.
9. Repeat steps 6-8 five times.
   The steps before 6 are one-time setup, so we don't need to repeat them. Five repeats should allow us to reduce random error by averaging, but six might take more time than we have available.
10. Repeat steps 6-9 for the second, third, fourth and fifth notches.
    This gives us a total of five speeds, which should provide a confident pattern. There are actually seven notches but the sixth and seventh ones might hit the ceiling.



Results:

Notches	Speed v_0 (ms^{-1})	v_0^2 (m^2s^{-2})	Max height (m)	Expected height (m)
1				
2				
3				
4				
5				

The results would be analysed on a graph with maximum height on the y-axis and launch speed squared on the x-axis. If the hypothesis is correct, a line of best fit should be a straight line through the origin.

Commented [TB15]: Include safety precautions.

Commented [TB16]: Keep the method concise by saying this instead of rewriting instructions.

Commented [TB17]: Include a clearly labelled scientific diagram.

Commented [TB18]: Include an empty table of results to be filled during the experiment.
Variables in columns, with independent on the left and dependent on the right. Units in brackets in the column headings.

Commented [TB19]: Include a description or example of how the results would be analysed and what is expected.

Stanley Rorgan

REPORT: MAXIMUM HEIGHT OF A FLARE

AIM:

Commented [TB20]: Sections that are already attached as part of the Design do not need to be included in the Report (if included, they are ignored for the word count).
If the method followed was different from the one in the Design, it must be included in the Report.

To investigate the relationship between the launch speed and the maximum height of a flare launched directly upwards.

HYPOTHESIS:

The maximum height h reached by a flare launched directly upwards will be proportional to the square of the speed v_0 at which it was launched.

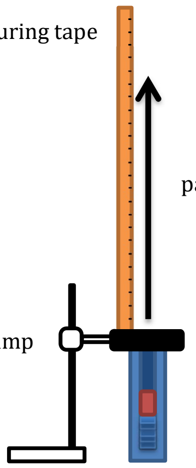
EQUIPMENT:

- Sticky tape
- Measuring tape or metre ruler
- Projectile launcher with projectile
- Light gate with computer
- Stand with clamp

PROCEDURE:

1. Use sticky tape to hold the projectile launcher against a wall, resting on the ground, pointing directly upwards.
2. Use sticky tape to attach the measuring tape to the wall. The measuring tape should be aligned straight up and down, and its zero mark should line up with the top of the projectile launcher.
3. Clamp the light gate onto the stand so the projectile will pass through the light gate. The light gate should be just above the top of the projectile launcher, and should not obstruct the motion of the projectile.
4. Use the measuring tape to measure the length of the projectile that will break the gate beam.
5. Connect the light gate to the computer and set the software up to record speed, entering the length of the projectile measured in step 4.
6. Place the projectile in the launcher and pull back to the first notch.
   Safety note: Ensure before launching that no one is going to be in the path of the projectile.

7. Launch the projectile, watching carefully to track its height. Record the height it reaches.
8. The most recent measurement from the light gate is the launch speed. Record this.
9. Repeat steps 6-8 five times.
10. Repeat steps 6-9 for the second, third, fourth and fifth notches.



RESULTS:

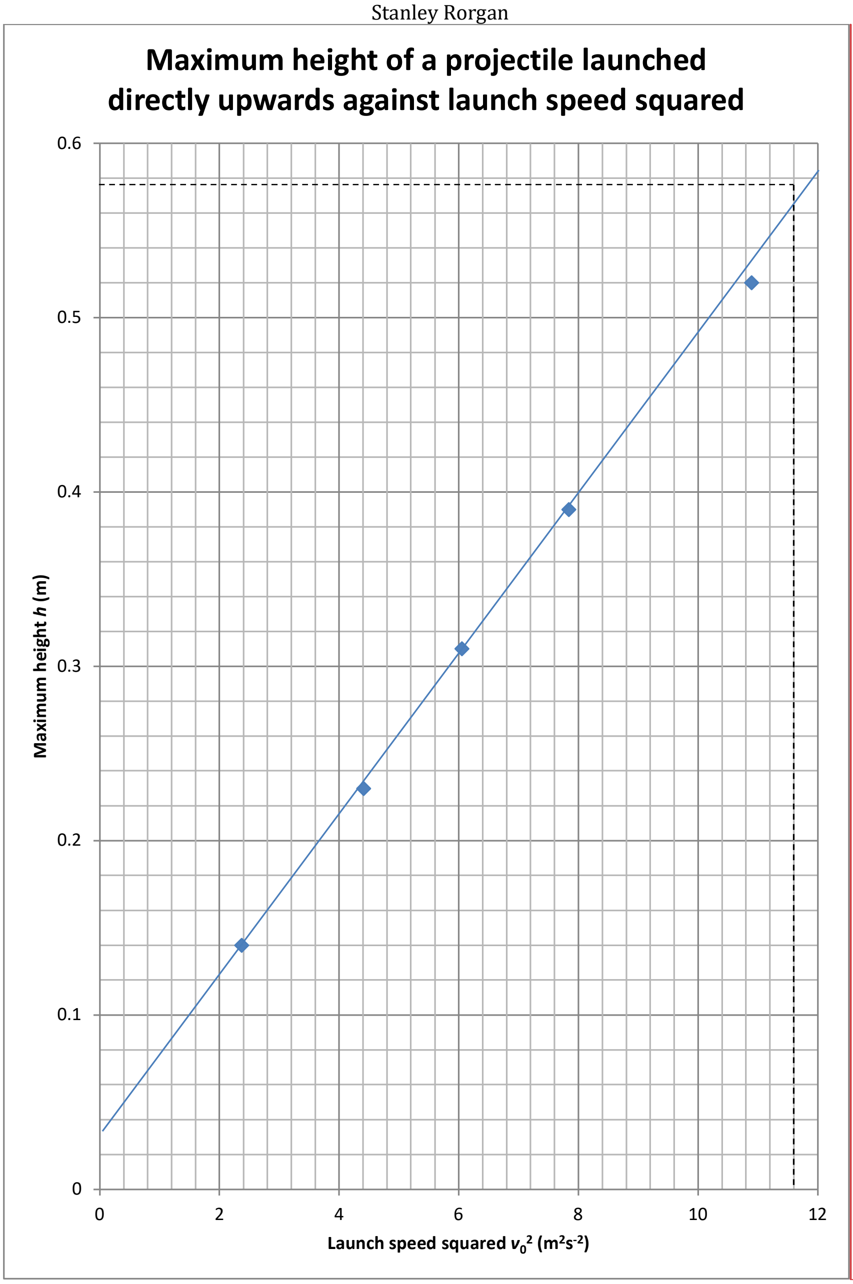
Notches	Speed v_0 (ms^{-1})	v_0^2 (m^2s^{-2})	Max height (m)	Expected height (m)
1	1.5	2.4	0.14	0.12
2	2.1	4.4	0.23	0.23
3	2.5	6.1	0.31	0.31
4	2.8	7.8	0.39	0.40
5	3.3	11	0.52	0.56

Commented [TB21]: You *must* include a table of results.

Commented [TB22]: Make sure your decimal places are appropriate for the experiment.

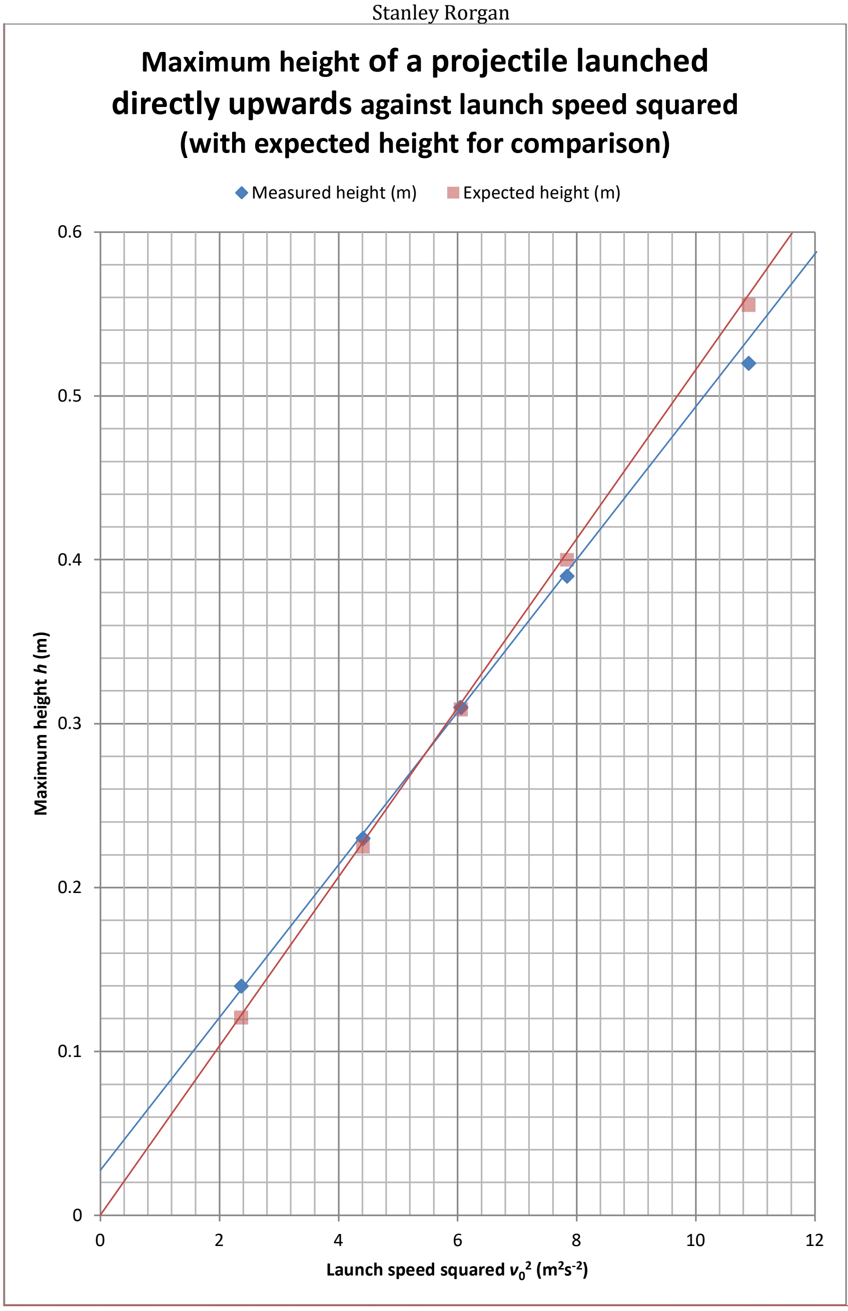
Commented [TB23]: Make sure your significant figures are consistent.

Stanley Rorgan



Commented [TB24]: Graphs can be drawn by hand or using the computer.
However you do it, follow these rules:

- The graph should fill the page.
- Include a title (descriptive and specific to this experiment) and axis labels.
- Independent variable on horizontal axis, dependent on vertical axis.
- Choose major and minor axis scales sensibly.
- Draw linear lines of best fit manually
- Include dashed lines to show the values you used to calculate the slope (these should be far apart and on the line of best fit, not data points).
- If you include an R^2 value, explain it.



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CALCULATIONS:

The hypothesis for this investigation is derived as follows:

The equation $v^2 = v_0{}^2 + 2as$ describes the vertical motion of a projectile.

At maximum height, the speed $v = 0$ and displacement $s = h$, $\therefore 0 = v_0{}^2 + 2ah$

For this investigation, acceleration due to gravity is $-g$, considering negative to be downwards and positive to be upwards.

$\therefore 0 = v_0{}^2 - 2gh$

$\therefore 2gh = v_0{}^2$

$\therefore h = \dfrac{v_0{}^2}{2g}$

The values for expected maximum height in the results table were calculated using this formula.

According to the hypothesis, the line of best fit should have the form $y = mx$, where y is h, m is the slope and v_0^2 is x. From the graph of maximum height against launch speed, the slope can be calculated using $m = \frac{rise}{run}$, using the points (0.0, 0.04) and (11.6, 0.555):

$$m = \frac{0.555 - 0.04}{11.6 - 0.0}$$
$$= \frac{0.51}{11.6}$$
$$= 0.044 \text{ m}^{-1}\text{s}^{2}$$

According to the hypothesis, the slope of the graph should be equal to $\frac{1}{2g}$. The magnitude of gravitational acceleration g in Adelaide is 9.797 ms^{-2} according to Wolfram|Alpha knowledgebase, 2012. This means the expected slope is $\frac{1}{2\times 9.797} = 0.051 \text{ m}^{-1}\text{s}^{2}$.

The percentage error can be calculated using $percentage\ error = \frac{expected - meas}{expected} \times 100$

$$percentage\ error = \frac{0.051 - 0.044}{0.051} \times 100 = 14\%$$

Commented [TB26]: The Calculations section **is** included in the word count.

Commented [TB27]: The original hypothesis must be based on something solid, not just a guess.

Commented [TB28]: Use properly formatted equations and formulae.

Commented [TB29]: Determine the equation of the line of best fit so you can compare it to the hypothesis.

Commented [TB30]: Read values from graphs to decimal places appropriate to the graph scale.

Commented [TB31]: When you calculate the gradient, include its units.

Commented [TB32]: Feel free to get information from the Internet, library, or qualified experts; just don't forget to reference properly!

Commented [TB33]: If you have a 'true' or 'expected' value, you should always calculate the percentage error.

DISCUSSION:

The measurements taken during the investigation were reasonably reliable. There is evidence of this in that even though the data supports a linear pattern, there is some scatter present around the line of best fit. This indicates the presence of random error, since there is no pattern to the variation between the measurements and the expected values.

The most likely source of random error in this investigation is the method used for measuring the maximum height reached. Although the projectile's motion was along the measuring tape, the projectile was only at its maximum height for an instant, making the judgement by eye very approximate. The measuring tape had 1 mm increments but it would be inappropriate to record data using that detail, since the projectile is about 4 cm in length and is spinning and moving quickly, so measurements could easily be off by a cm or more, both too high and too low. This is certainly sufficient to explain the amount and pattern of scatter around the line of best fit, which is both above and below the line of best fit and is at most about 1 cm from the line. If a video camera was used to record and play back the motion of the projectile, measurements could use the available resolution of the measuring tape and therefore improve the reliability of the results.

Another possible source of random error could be that the projectile spins as it travels. Since the projectile is an irregular shape, somewhat rectangular, and certainly not spherical, this would mean that its length as it passes through the light gate is inconsistent. The light gate relies on the length of the projectile to calculate its speed, so this would cause random error in the launch speeds recorded. In this case, there is a portion of the projectile that only has a length of 2 cm rather than 4 cm, so it is possible that some values could be as much as twice as fast as they should be, although these erratic measurements would have their effect reduced by averaging with the other values. Since this error would increase apparent speed, it would make some height values seem much lower than they should be, which could possibly explain the fifth value being lower than expected. To improve this, the procedure could be changed to use two light gates, one above the other, instead of just one. This way initial speed would be determined by the time it takes for the front edge of the projectile to travel, meaning the shape of the projectile would not have as great an effect on the measurement of its speed. A limitation of this change is that it would decrease the accuracy of the measurement, since it would record an average speed over that first period rather than just at the beginning of the projectile's launch.

The projectile launcher had seven notches, but only five of these were used during the investigation. If the full range of available launch speeds were used, or all measurements were taken more times and averaged, the effect of random error on the fit might be reduced by the larger sample size.

The results of this investigation appear to be mostly accurate. The slope of the line of best fit is quite close to the expected slope according to theory, with a percentage error of only 14%. However, the line of best fit does not pass through the origin, instead intercepting the vertical axis at 0.04 m. Physically this would be

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It should include:
- Possible sources of uncertainty, including random and systematic errors and uncontrolled factors.
- Reliability, accuracy, and validity of results, including sample size, precision, random error, systematic error, and uncontrolled factors.

Commented [TB36]: Remember to use formal, impersonal language. For example, you would *not* say "so it was hard for us to measure" here.

impossible since a projectile with no speed should not be able to go upwards at all. This apparent shift in the data could be due to the presence of systematic error.

One possible source of systematic error is that the light gate was calibrated incorrectly. One possible reason for this is an inaccurate measurement of the length of the projectile, since the light gate software uses the length to calculate the speed. If the length of the projectile entered was slightly shorter than the true value, all speed measurements would be slightly slower than the true values, since the projectile would pass through the gate in more time than the software expects. The measuring tape used to determine the length of the projectile has a 1 mm resolution, so even if the measuring tape is correctly calibrated, the length could potentially be inaccurate by half a mm, which is approximately 1% of the projectile's length. This would cause all speed measurements to be affected in the same way (too fast or too slow), so this cannot explain the tilted line of results which shows heights that are higher than expected for low speeds and lower than expected for high speeds. In any case, potential error due to projectile length could be improved by measuring it with an instrument of finer resolution, such as a vernier caliper.

Commented [TB37]: Discuss specific possible effects of error in the context of the evidence in the data.

A more likely source of systematic error is air resistance. Since air resistance is greater at higher speeds, it would cause all height values to be decreased, with a larger amount of error for heights at higher speeds. The graph shows height values that are close to (or slightly higher than) expected for low speeds, but increasingly lower than expected at high speeds. This indicates that air resistance is likely to be causing systematic error, but it is difficult to be confident with only five data points. If the sixth and seventh notch could have been used, there would be more evidence to consider whether this is an effect caused by air resistance.

The results appear to be valid for a projectile launched directly upwards, assuming minimal air resistance. The pattern of results shows lower maximum heights at higher speeds, which is consistent with the force of air resistance increasing with speed. The equipment chosen was able to consistently record the required measurements without significant influence from other factors. The sample size was sufficient to confidently draw a line of best fit through the data.

Commented [TB38]: Validity is how appropriate the method and results are for achieving the aim.

There is no guarantee that the same relationship is true for a flare launched outdoors at high speed. For example, whilst Comet (2025) flares are launched directly upwards, they include a self-propelled rocket, so they are not true projectiles. In addition to this, Comet flares reach a height of 300m so they must be travelling at much greater speeds than the projectiles used in this investigation. These differences are significant, so the conclusion of this investigation can only be partially applied to real-world rocket flares, in the sense that higher vertical launch speeds are likely to produce higher maximum heights, but not the mathematical relationship.

CONCLUSION:

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Commented [TB40]: The conclusion is like a short version of your whole report. Someone should be able to read the aim and then skip to the conclusion and get a good idea of what happened. Include justification for the conclusion and recognise any limitations.

The results mostly support the hypothesis that the maximum height of a projectile launched directly upwards is directly proportional to the launch speed, as the pattern of data supports a linear fit. The scatter is quite large, indicating low reliability. The slope calculated from the line of best fit, 0.044 $m^{-1}s^2$, is 14% different from the theoretical slope $\frac{1}{2g}$, indicating reasonable accuracy. The line of best fit did not pass exactly through the origin; this is evidence against support of the hypothesis but is most likely due to systematic error.

Commented [TB41]: Reliability is how similar the results would be if the measurements were repeated.

Commented [TB42]: Accuracy is how close the results are to the true or expected values.

A number of factors could potentially have caused error. The most likely of these was the measurement of the maximum height by eye, but the irregular shape and imprecise length measurement of the projectile may also have contributed. The occurrence of error could be reduced by using a video camera, two light gates, and a vernier caliper. The effect of random error could be reduced by taking a greater number of measurements.

Commented [TB43]: Precision is the detail to which a quantity can be consistently measured.

Whilst these results support a hypothesis about the low-speed projectile in this investigation, they cannot be used to support a conclusion about the mathematical relationship between launch speed and maximum height for rocket flares launched in real life, especially since rocket flares are self-propelled rather than true projectiles.

Word count: 1496

Commented [TB44]: Not all the report is included in the word count. The sections included are the introduction (which includes the aim and hypothesis, or an investigable question), the calculations and discussion (which include the analysis and evaluation), and the conclusion. Maximum is 1500 words.

References:

Commented [TB45]: Remember to follow the reference formatting guidelines.

Comet Marine Distress Signals 2025, Parachute Rocket Red, https://comet-marine.com/our-products/parachute-rocket-red/, accessed 27th Jan 2025

Wolfram|Alpha knowledgebase 2012, Wolfram|Alpha Widget: Gravitational Fields, http://www.wolframalpha.com/widgets/view.jsp?id=d34e8683df527e3555153d979bcda9cf, accessed 5th December 2012