Hydrodynamics of a Water Rocket

This investigation looks at the relationship of air pressure and displacement for a toy water rocket. The pressure is variable from 40 pounds per square inch (psi) to 120 psi in 20 psi increments. The angle of launch and the amount of water in each trials must remain the same.

Commented [A1]: Research design: A clear statement of the research question with variables identified. We assume that displacement means horizontal range (see the dependent variable below). Pounds per square inch is not the SI unit, but it probably is the only unit on the candidate's pressure gauge. There is no need to convert to pascals.

Introduction and Background

Air rocketry involves the flight of rockets utilizing compressed air as the motive force for the vehicle. This method for propelling rockets is an illustration on Newton's Laws of Motion.

Newton's First Law states that a body at rest remains at rest or a body in motion continues its motion in a straight line until it encounters an unbalanced force. When the rocket remains at rest on the launcher, the forces enacting the rocket are balanced because upward lifting forceby the launcher and force exerted by gravity reaches an equilibrium. Water is pressurized inside the rocket and then escapes in one direction, and in doing so provides an unbalanced force allowing the rocket to accelerate forwards.

Commented [A2]: Research design: A relevant but general observation.

Newton's Second Law, the acceleration of a given a body is proportional to the force acting on it, can be expressed mathematically with the following equation: $F = m\,a$. A more fundamental way of stating this is the Conservation of Momentum: $P = m\,v$, a general law of physics derived from Newton's Second Law which the momentum never changes in an isolated collection of objects.

Commented [A3]: Research design: The candidate means unbalanced force.

$$F = ma = \frac{m\Delta v}{\Delta t} = \frac{\Delta p}{\Delta t}$$

In an ideally isolated system, the law of Conservation of Momentum can be applied to the rocket launch where the downward momentum of the exhausting water equals in magnitude of the upward momentum of the rising rocket so that the total momentum of the system remains constant--in this case, zero.

Commented [A4]: Research design: The candidate should be aware of the notion of impulse. Also, as water leaves the rocket the mass changes, and so does the internal pressure. The situation is far more complicated than the candidate thinks.

ejected water mass x **ejected water velocity** = (**bottle + water) mass** x **bottle velocity**
–downward– –upward–

From the equation, increasing the pressure inside the bottle rocket produces greater force in the bottle pushing the water at a higher velocity hence creating a greater upward force of

Commented [A5]: Research design: The candidate needs to relate pressure to force.

the bottle. In short, according to the Conservation of Momentum law, the velocity of the rocket is proportional to the velocity of the fluid escaping from the rocket.

Commented [A6]: Research design: The situation is not so simple. A proportionality of momentum and velocity is not obvious in this experimental situation. Other factors are involved. Unless, of course, the candidate is stating the definition of momentum. This needs to be clear.

Newton's Third Law of Motion states that for every action there is an equal and opposite reaction, is demonstrated at the launch of water rockets. The small opening at the bottom of the bottle allows water to escape in one direction and in doing so provides force in the opposite direction allowing the rocket to travel. This force continues until the pressure forces the last of the water out of rocket. The reaction to this discharge of air is absorbed by the launcher.Because the launcher is relatively heavy, the reactive force applied during liftoff is insufficient to overcome the weight and fiction presented by the launcher.

Commented [A7]: Research design: Over time there is a changing force with changing pressure.

In real life, external factors are required to take into consideration. The rocket set is no longer an isolated system. The acceleration of the rocket gradually decreases due to the rocket needs to overcome aerodynamic drag. Travelling at just a few meters per second we are hardly awareof drag, but at higher speeds, drag dominates the motion of projectiles. Since the high speeds of the rocket encounters more air particles to overcome which hinders the travelling speed.

Commented [A8]: Research design: Again, the changes in pressure are not considered. The candidate also fails to fully explain how drag is affected by velocity.

Hypothesis

According to Newton's second law the larger the exerting force the higher the acceleration of the bottle. I predict that, when launched with a constant mass of water, increasing the pressure will increase the distance travelled of the air rocket. This is due to the increments in pressure raises the stored energy at launch which produces a greater thrust pushing the water out with higher speed. In addition, due to the presence of air resistance, the higher the velocity of the bottle faces a larger friction force of the air particles which gradually diminishes the acceleration rate as the pressure increases. Hence, instead of an ideally positively proportional relationship, I will predict a log relationship between the two variables of the pressure and distance travelled of the bottle rocket.

Commented [A9]: Research design: A log function can fit any data set. We will see how confused this claim is when we read the conclusion. While a hypothesis is not required for the research design, the inclusion of one can help when justifying the conclusion. However, a more quantitative approach should be taken by the candidate.

Variables

The **independent variable** (IV) in this experiment is the pressure in the bottle. It will be measured by adjusting the air pressure in 20 psi increments (40, 60, 80, 100 and 120psi).

Commented [A10]: Research design: A limited but realistic range. Is there a reason behind the selection of the range and interval of the independent variable?

The **dependent variable** (DV) will be the horizontal displacement of the rocket in metres.

The **controlled variables** and the reasons are listed below.

Controlled Variables	**How I ensure they are controlled**	**Significance**
volume of bottle used	The size of the bottle will be controlled at 500 ml by using the same bottle within each trial	The volume will affect the pressure inside
launch angle 45°	I will ensure this is constant by restraining the scale at 45°.	Different angles would result in difference distances; 45° is the maximum distance.
volume of water, 150 ml	The amount of water in the bottle will be fixed at 150 ml using the scale on the vessel.	The volume of water determines how log the rocket flies as well as the weight.
launching location	The apparatus will face the same direction in line to the playground to launch at 90°	This fixed location maximize reliability.

Commented [A11]: Research design: A comprehensive list.

Commented [A12]: Research design: Unclear what this angle is referring to.

Materials

- 500 ml plastic soft drink bottle
- Cap attachment for the Bottle
- 1.00 Litres of Water
- Graduated (Plastic) Cylinders
- 1 Pump with Pressure Gauge
- Measuring Tape for Large Distances

Method Steps

1. Prepare one set of materials as listed above.
2. Setup the test stand according to the test stand's specifications.
3. Fill the rocket with 150 ml of water.
4. Attach air supply to the rocket via the remotely activated release head.
5. Attach the rocket to the test stand.
6. Pressurize the rocket to the chosen pressure.
7. Launch.
8. Measure the displacement and record captured data.
9. Repeat two more trials for the same pressure value.
10. Alter the independent variable by 20 psi increments
11. Repeat 2–10.

Commented [A13]: Research design: We should know more about the pressure gauge and the method of measuring displacement.

Commented [A14]: Research design: The number of trials used should be justified.

Raw Data Table

Table 2: Displacement at each air pressure per trial

Pressure (±3 psi)	Displacement (±0.5 m)		
	Trial 1	Trial 2	Trial 3
40	5.87	3.4	4.88
60	10.2	11.25	10.8
80	13.47	11.85	13.47
100	15.6	12.36	12.95
120	18.1	16.7	18.2

Commented [A15]: Data analysis: The recoding of the data is clear and precise except for a few inconsistent significant figures.

Commented [A17]: Data analysis: Half a metre uncertainty in the raw data of a single displacement value is stated. This is rather large and requires justification considering individual measurements are recorded to the nearest centimetre.

Commented [A16]: Research design: How did the candidate obtain the pressure uncertainty?

Qualitative Observations

As the catch is released, the gas pushes the water out through the nozzle, the rocket begins to lift off. The speed is comparatively slow when the rocket still contains a heavy load of water on board. Water level has fallen as more water was expelled. The rocket generally travels in a straight line. Occasionally, however, other forces act on the rocket during the duration of its flight such as wind which could alter its flying track. In addition, since the investigating variable of this experiment is displacement, some trace may not travel in a straight line which may cause inaccuracy in my result collection. The rocket interferes with obstacles such as an enclosing wall or tree which will require a second trial.

Commented [A18]: Research design: Does the candidate mean the horizontal path is straight and that projectile path is in the same plane?

Sample Calculation

The average is calculated by adding a group of numbers and then dividing by the count of those numbers. Take the result for 40 psi as an example: the average of the displacements measured is the sum of each trial, corresponding 5.87, 3.4, 4.88 and then divide by 3, which is 4.72. Expressed mathematically:

$$\frac{5.87+3.47+4.88}{3}=4.72$$

Commented [A19]: Research design: Where did the "3.47" come from in the sample calculation below?

Processed Data Table

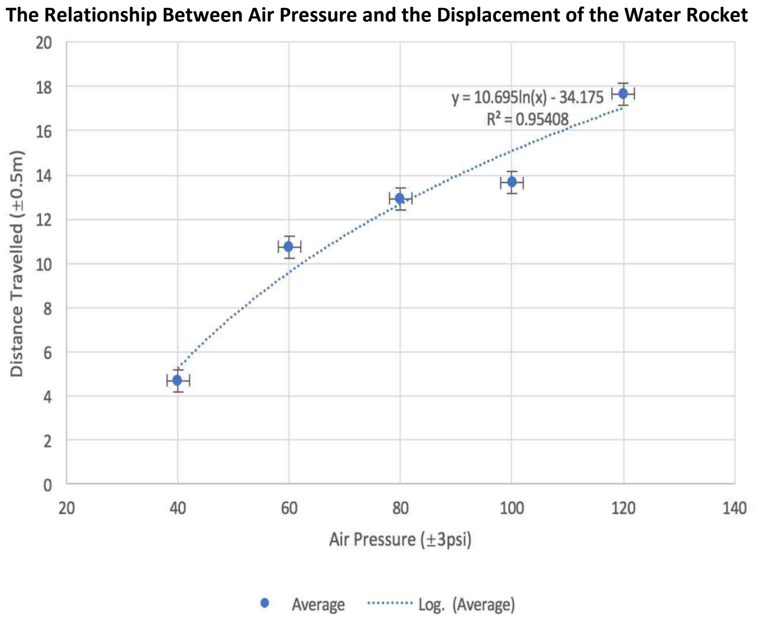
Commented [A20]: Data analysis: This table should include uncertainties. The candidate does not explain raw data value for displacement and does not consider the range of measurements to establish a range uncertainty. These issues are important.

Table 3: Average displacement travelled at each pressure.

Air pressure (psi)	40	60	80	100	120
Displacement (m)	4.717	10.75	12.923	13.667	17.667

Commented [A21]: Research design: Average displacement values should be rounded appropriately based on the precision of the raw data.

Graph of Results



Conclusion

I predicted that increasing the launch pressure will increase the displacements travelled of the air rocket launch with a log relationship. My hypothesis is supported according to the positive correlation between the two variables demonstrated in the graph. The coefficient of determination value is calculated to determine the reliability of the experiment. It can be seen on the graph R^2 = 0.95408. This signifies the strong correlation between the line of best fit and the data set demonstrating a positive log relationship between the air pressure at launch and displacement travelled. As greater force exerted by the pressure of the air particles insidethe bottle escaping with a higher acceleration. This pushes the water in the bottle quicker producing greater force. When launched with a constant mass of water, according to the Conservation of Momentum law, the faster the fluid can be expelled from the rocket, the higher the velocity of the rocket. The Newton's Third Law of Motion states that for every action there is an equal and opposite reaction; the stronger force exerted by

Commented [A22]: Data analysis: The graphed quantities and their scatter are relevant, but a best fit with logarithms makes no sense. And where did the uncertainty bars come from? Important details are missing. A zero on the air pressure axis would help visualize the trend.

Commented [A23]: Data analysis/conclusion: The candidate used the general form $y = A \ln (B x)$ to find a best fit equation line. Yes, the *r*-squared value is 0.954 but the same data can obtain a higher *r*-squared value of 0.971 using a quadratic equation. That would be better in the candidate's mind. But then a best fit linear line would yield a *r*-squared value of 0.959. There is no physical meaning to the candidate's final analysis. The candidate's best fit line is meaningless.

A line with a physical meaning is more important than a high *r*-squared value.

Commented [A24]: Conclusion: Of course a log function fits the data, as almost any data set can be informed. The prediction is not justified in any detail other than the original thought of being directly proportion and then accounting for air drag. In the end, the prediction is qualitative and obvious only.

Commented [A25]: Conclusion: Isn't this related to acceleration and not velocity (or speed in this case)?

the water, the greater the opposite force on the rocket.

In theory, in an isolated system, Newton's Law should predict a straight line. However, my obtained results reveal a trend of gradually declining increment rate of displacement. This is mainly due to the presence of air resistance:

- the air resistance increases along with the increments of velocity, essentially affecting the displacement of the rocket as the air pressure applied to the bottle increases.
- spinning high-pressure rockets tend to hinder velocity as the spinning action generates additional drag.

Commented [A26]: Conclusion: This may or may not be correct, depending on the equation used to best fit the data. How does the candidate know about air resistance when they do not understand the relevant physics? We repeatedly hear about Newton's laws, but no insight is given.

Evaluation

Commented [A27]: Evaluation: This is a thorough list and appreciation of possible factors that might affect the results. Only a brief and qualitative comment is made about how they would affect the results. Yes, uncertainty affects accuracy, but there is nothing here about the overall methodology. Part of the problem is that the candidate has no sound conclusion.

There were several factors in this experiment that creates uncertainty and affects the accuracy of the measured displacement. In order to talk about a problem, evidences and the methods to minimize these problems is provided in the following:

Commented [A28]: Evaluation: Comments and improvement do address procedural issues, so some credit is earned here.

Limitation	Significance	Improvement
Wind and thrust instabilities can cause the rocket to change its altitude of flight	Weather factors lower the reliability of the results and caused experimental errors. For example, in the trials for 40 psi the displacement traveled varied by 2.33 meters.	Process the experiment in a wider indoor environment, such as the gym, can to an extent avoid such concern.
The validity of the means chosen to examine the displacement	The measurement of displacement could be invalid and affects the accuracy. For example, the rocket fell on the other side of a tree and the tape measure needs to curve around the tree to make the measurement.	Errors are inevitable in all the stationary and dynamic measuring process that prevents us to get the real value of the measured quantity directly. We can reduce it by estimating the approximate value of the displacement over-measured. Based on the situation, we can make appropriate adjustments to the result ,and note the error value.
The volume of water is controlled completely manually	Uncertainties in measured quantities affects the reliability of results. A certain amount of water leak when installing the bottle on to the apparatus.	Draw scale marks on the bottle; this can reduce the levels of human errors of pouring inequivalent quantity of water. A certain amount of water leak when installing the bottle on to the apparatus
The displacement of the air rocket may be affected by air	Air resistance reduces accuracy of the results because it increases	This problem can be improved by reducing the effect of air

resistance	along with the increments of velocity, essentially affecting the displacement of the rocket.	resistance applied on the rocket through lowering the surface area of the rocket. To do this, we can apply a nose cone to the rocket to offerminimum aerodynamic drag.
Rocket model "wobbles" in flight	Through the experiment, the inconsistency of the rocket track canbe visually detected.	To provide stability during flight, we can apply fins on a rocket to allow the rocket to maintain its orientation and intended flight path.

Overall, I really enjoy performing the physics lab. I learned much, and my original hypothesis of a logarithmic function was proven to be true. The physical meaning of this equation is obvious: the greater the pressure the greater the range.

Commented [A29]: Evaluation: Being "true" is simply true by definition; there are a near infinite number of equations that can be used to fit the data set. Nothing was proved in this investigation other than the obvious and purely qualitative statement that greater pressure increases the range.

Commented [A30]: Conclusion. This is correct (but the explanation is confused).