About the Angle of the Rocket Nozzle and its Thrust

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Abstract

The de Laval nozzle is a machine that is used to efficiently convert the thermal energy of a fluid into kinetic energy.

My Research Question is: How does the rocket nozzle's exiting angle (10°, 20°, and 30°) influence thrust (g)?

This is the most important object in a rocket engine. This study includes hydrodynamics, material science, and engineering to understand the behavior of subsonic and supersonic gas flow to create varying power outputs.

1 Introduction

The de Laval nozzle is a machine that is used to efficiently convert the thermal energy of a fluid into kinetic energy. It was invented in 1887 by Swedish engineer Gustaf de Laval and is widely used in industrial turbines, rocket engines, and aircraft engines. The de Laval nozzle is an example of a convergent-divergent nozzle; it is a type of convergent-divergent flow device that increases the velocity of a fluid jet without significantly increasing its pressure. For this reason, most of the rockets in the modern industry employ de Laval nozzle as their nozzle, CyroRocket.com
The design of a rocket nozzle is a compromise among numerous design parameters and trade-offs which include weight, complexity, mechanical strength, temperature resistance, thermal insulation, and performance, among others. The thrust that propels a rocket is produced by the nozzle, which is one of the most crucial parts of a rocket propulsion system because it helps the rocket engine run as efficiently as possible.
The primary purpose of a rocket nozzle is to accelerate the exhaust gases produced by the combustion chamber's burning of fuel and oxidizer. The hot exhaust gases are accelerated to a faster speed as they enter the nozzle after leaving the combustion chamber. The nozzle's converging-diverging shape, raising exhaust gas velocity, and the energy delivered from the combustion chamber to the nozzle, which raises exhaust gas pressure, both contribute to the acceleration of the gases. This increased pressure, referred to as back-pressure, is used to further accelerate the exhaust gases–Newton's third law, Devenport William J. 2021.

Nozzles also play an important role in controlling the direction of a rocket's thrust. By adjusting the angle of the exit cone, the rocket can be steered as desired. This is accomplished by creating vortices in the exhaust plume which turn the thrust to a desired direction.

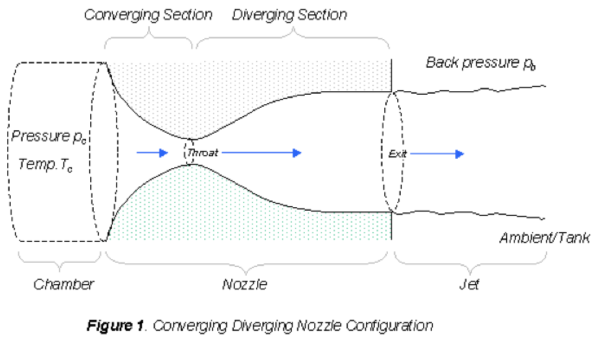

Figure 1: Image of a Typical de Laval Nozzle (Devenport William J. 2001)

In image 1, the nozzle is divided into 3 parts: nozzle top, nozzle throat, and nozzle bottom. The nozzle top is attached to the end of the chamber. The nozzle bottom is the final exit of the fuels or the combusts of fuels, and the nozzle throat is a small aisle that connects the nozzle top and the nozzle bottom. To explain why this shaped nozzle is so efficient, the fuel just came out from the chamber is a slow fluid. Under the law of continuous hydrodynamics, the speed of a subsonic fluid increases when the extent of the nozzle decreases; the speed of the fuel which is subsonic got accelerated as it passes through the nozzle top. The ideal speed of the fluid at the very end of the nozzle top is Mach1, from now on the law of continuous hydrodynamics is not applicable since the speed of the fluid is transonic or supersonic, Utah State University 2018. As stated, the nozzle throat is just a connector of the nozzle top and nozzle bottom. The speed of the fluid at the nozzle throat is Mach1. After passing the nozzle throat, the fluids face the nozzle bottom with a speed of Mach1. From transonic speed to supersonic speed, the speed of the fluid increases as the extent of the fluid increases, to maximize the speed of the fluid, the extent or the area of the nozzle bottom increases in a corn shape. Therefore, the speed of the fluid increases as it goes through the nozzle bottom. In other words, the speed of the fluid increases to Mach1 from the nozzle top to the nozzle throat, and it increases again at the nozzle bottom.

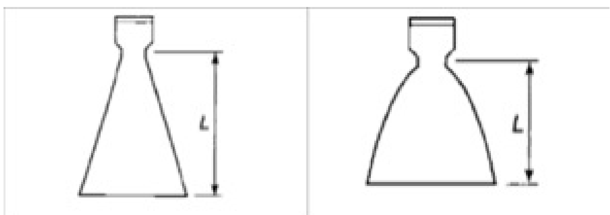

Figure 2: Two Typical Types of Rocket Nozzle, Bell-Shaped and Cone-Shaped(Baidya Raman et al. 2018)

$$\frac{A1}{A2} = \left(\frac{k+1}{2}\right)^{\frac{1}{k-1}} \left(\frac{p_2}{p_1}\right)^{\frac{1}{k}} \sqrt{\left(\frac{k+1}{k-1}\right)\left[1 - \left(\frac{p_2}{p_1}\right)^{\frac{k-1}{k}}\right]}$$

k: the specific heat ratio of the fuel, At: the extent or the area of the nozzle throat A2: the extent of the area of the nozzle bottom, p1: the pressure of the nozzle top, p2: the pressure of the nozzle bottom

The Rocket Thrust Equation incorporates the area of the rocket nozzle top and rocket nozzle bottom into one equation. In this equation, the area and the angle of the nozzle top are fixed to 25 times wider than the nozzle throat and 30 degrees. By using this equation, the independent variables, the exit angles of the rocket nozzle were decided. 30 degrees, 20 degrees, 10 degrees. Correspondingly, the length of the nozzle bottoms was selected by adjusting and modeling CAD.
In addition, the rocket nozzle performs a variety of other functions, such as supporting the rocket structurally, regulating the shape of the exhaust plume, and assisting in raising the rocket engine's overall efficiency. Furthermore, nozzles frequently have a number of characteristics that increase thrust while lowering drag. These attributes include of cooling mechanisms, internal baffles, and movable exit cones, according to Arrow Tech Associates.
In conclusion, a rocket nozzle is a part of a rocket engine that transforms the kinetic energy of thrust into the thermal energy of hot exhaust gases. It is intended to support structurally and increase the rocket engine's efficiency. Additionally, it aids in reducing drag, regulating thrust direction, and controlling the form of the exhaust plume.

2 Hypothesis

If the exit angle of the rocket nozzle (de Laval nozzle) increases, then the thrust produced by the nozzle and chamber of the rocket will decrease because the more acute the rocket is the chance of the separation of the rocket fuel decreases. When the rocket's nozzle is too wide, the flow of the rocket's fluid is not focused in a small area but separated widely. As the force of the water from a hosepipe increases as the hosepipe is narrower and is more focused on a small area with a small extent, the thrust produced by the rocket will decrease, as the rocket's fluid is separated into a wider angle, created by the wider exit angle of the rocket nozzle. In other words, the exit angle of the de Laval nozzle will affect the thrust by controlling the speed of exhaust that is able to exit the nozzle. A higher exit angle will result in a larger exit area, thus allowing more exhaust to escape, but creating less thrust. On the other hand, a lower exit angle results in a smaller exit area, thus restricting the exhaust, but creating more thrust.

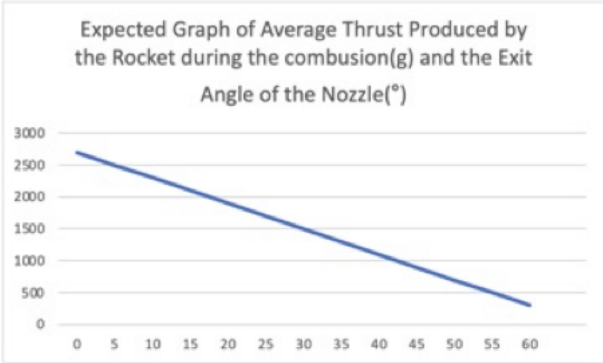

Figure 3: Expected Graph of the Exit Angle of the Rocket Nozzle and the Thrust of the Rocket.

3 Methodology

Inspiration of the method: `www.youtube.com/watch?v=TozJUbt2dio`
Inspiration: Measuring thrust with a Loadcell.

3.1 Materials

- 2020-sized Aluminum profile (12)
- 3030-sized Aluminum profile (1)
- Square Header bolt (20)
- Square nuts (20)
- 2cm thick nichrome wire
- Load Cell sensor up to 20kg
- HX711 amplifier
- Breadboard
- Wire
- Arduino Nano (It can be any Arduino)
- Laptop to run Arduino codes
- Boiling tube with a 1.25 cm radius (one per trial)
- Beaker
- Paper cup (any cup, unable to be reused)
- Cement (30g per trial)
- Water (55g per trial)

- Potassium Nitrates (13g per trial)
- Sucrose (7g per trial)
- Epoxy
- Lighter (Firer)
- 3D printer (and CAD files)
- 0.5cm thick copper rod (10cm per trial)
- PLA filaments
- Cellophane (one per trial)
- Chopsticks

3.2 Procedure

- Created a cube-shaped aluminum frame structure using 12 2020-sized aluminum profiles, one 3030-sized aluminum profile, 20 square-headed bolts, and 20 square nuts.

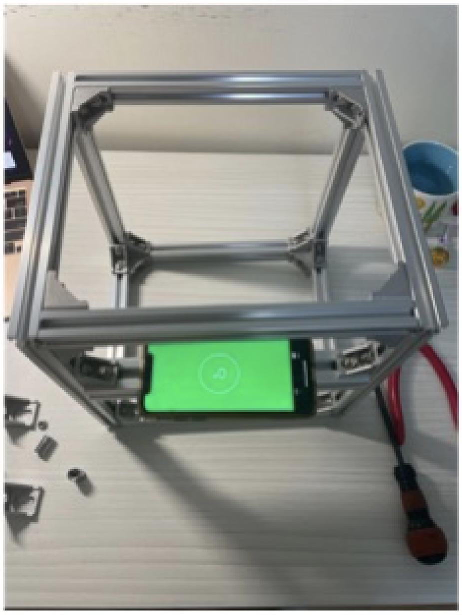

Figure 4: Picture of the Aluminum Structure and the Cellphone Measuring the Horizontality of the Structure.

- Connected HX711, Load cell, and Arduino.

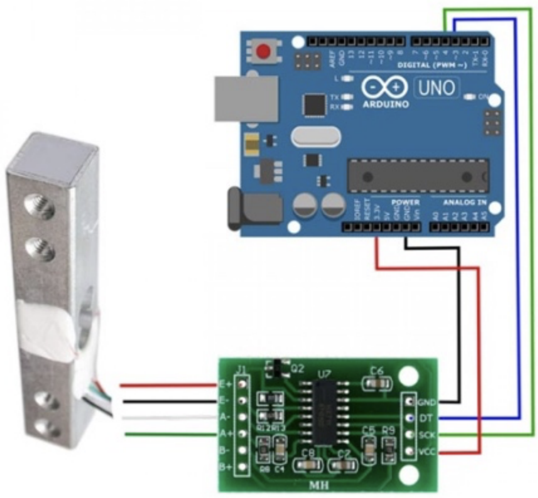

Figure 5: Picture of the Load cell, HX711, and Arduino Circuit (VEErobot 2019).

- Placed Loadcell in the Aluminum structure (under the 3030-sized aluminum structure)
- Connect Arduino to a laptop, and code it using a Arduino program
- Poured 40g of water into a beaker, then put a beaker on a heater
- Setted the temperature of the heater to 350 Celsius degrees.
- When the heater reaches 350 Celsius degrees, poured 13g of potassium nitrates and dissolve.
- When potassium nitrate is fully dissolved, poured 7g of sucrose and dissolve.
- When the water is almost vaporized, created a mold of fuels using cellophane and chopstick. Roll the cellophane into a shape of a cylinder with a radius of 1cm. And place a chopstick at the center of the base side.
- When the water is fully vaporized, poured the solution into the mold.
- Waited 1days to harden the fuel.
- Printed the nozzle of the rocket using a 3D printer and PLA filaments.

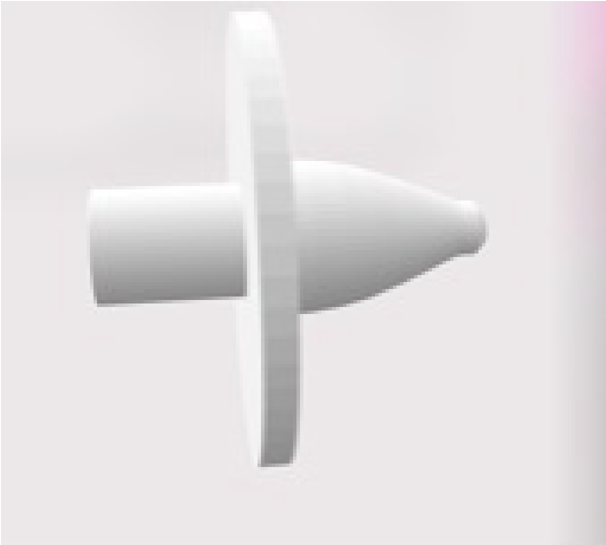

Figure 6: CAD-Mold Top

Figure 7: CAD-Mold Middle

Figure 8: CAD-Mold Bottom

- When all the 3D models are printed and structured using epoxy, placed 10cm of 0.5cm thick copper rod at the central hole of the mold.
- Poured 15g of water and 30g of cement into a paper cup and mixed it.
- Poured 10g of cement solution into the 3D printed molds.
- Waited for a day to harden the nozzle.
- Poured 45g of cement solution into a boiling tube to decrease the inner volume.
- Wait a day to harden the cement.
- When all the fuel, the cement in the boiling tube, and the nozzle are hardened, placed the fuel into the boiling tube and blocked the top of the boiling tube with the nozzle.
- When the settled boiling tube is ready, placed the boiling tube on the load cell placed in the aluminum structure and made the tube stable using a 2cm thick nichrome wire.
- Measured the weight (force) using the Load cell circuit.
- Ignited the fuel using a lighter.
- Continued measuring the force using the Load cell circuit.

The independent variable in this research: The exit angles of the rocket nozzle: nozzle 1, nozzle 2, nozzle 3
Exit angle: nozzle 1: 30 degrees, nozzle 2: 20 degrees, nozzle 3: 10 degrees

Evidence of controlling: the cad files of molds:

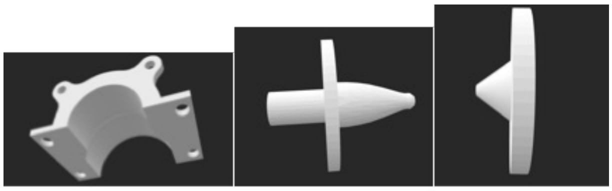

Figure 9: 30 Degrees

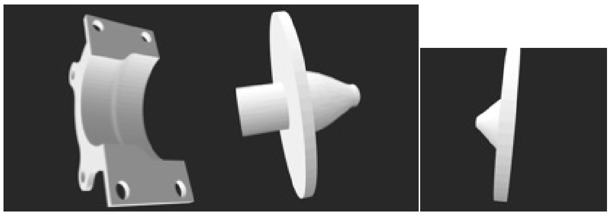

Figure 10: 20 Degrees

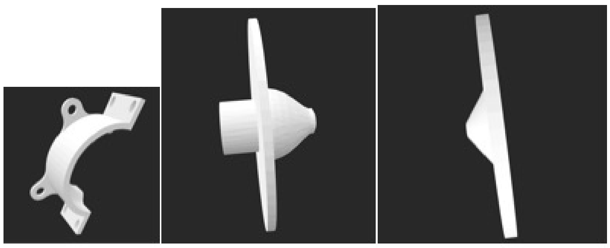

Figure 11: 10 Degrees

The dependent variable in this research: The thrust created by the nozzle and the fuel's combustion.
The rocket's thrust is the same as the rocket's power. The rocket uses this power as its main source of movement. This power is created as the gases created by the combustion of fuel pass through tiny nozzle hole that accelerates the gases. As the rocket is belching gases at a fast speed, under Newton's third law, the rocket is accelerated in the opposite direction of gases. Measuring the thrust of the rocket means measuring the efficiency of the rocket nozzle. The dependent variable, the rocket's thrust, is calculated using Load-cell sensor.

Controlled Variable: Humidity, Same fuel, Same nozzle entering angle, Same thickness of nozzle throat, Same volume of the chamber, Same air.
Humidity: Humidity plays a significant role in the combustion of fuels. With high humidity, the fuel does not catch fire easily, and even if it does catch fire, there is a high possibility of losing a fire. Humidity is controlled by executing this experiment at the time and places with humidity of 50%, the average humidity of Beijing winter (Statista Research Department, 2020)

The Same Fuel: To measure the efficiency of the fuel, the power created by fuel without nozzles should be the same. The same Fuel is controlled by using the same fuel: 13g of potassium nitrate, 7g of sucrose, 40g of water, and a day of solidifying.
The Same nozzle entering angle: The nozzle entering angle is one of the other factors of the nozzle that affects the thrust of the rocket. In this experiment, the nozzle entering angle is controlled by using the same angle of entering from the chamber to the nozzle of 30 degrees.
The Same Thickness of Nozzle Throat: The nozzle throat is another factor of the nozzle that affects the thrust of the rocket. In the experiment, the thickness of the nozzle throat is controlled by using the same thickness of 2mm.
The Same volume of the chamber: A significant volume of the chamber gives gases, combusted gases of fuel, to stay inside the chamber and does not come out through the nozzle. In this experiment, the volume of the chamber is controlled by using the same boiling tube with a 1.25cm radius and filling it up with 45g cement solution.
Same Air: The air plays a significant role in this experiment since it includes combustion. The same amount of oxygen and other gases are required. This is controlled by executing this experiment in Beijing on the same date.

Cautions:

- Wear goggles, gloves, and long sleeves.
- Cautions on using fire and Potassium nitrate.
- Relevant Safety issues were written before the experiment:


Relevant Safety Issues & Considerations: Action Plan

Figure 12: Safety Issue Notice

4 Data and Results

4.1 Raw Data Presentation

The Load cell circuit measures the weight (force or thrust) of the rocket.
The code of the Arduino measures the weight every 0.1 seconds.
Weights every 0.1 seconds are noted in Excel.
My Raw data measured the thrust produced by the rocket during the combustion of its fuel every 0.1 seconds.
Possible uncertainty: my data collecting sensor, Loadcell, had a few errors in measuring. Although Loadcell uses an electrical resistance value to measure the weight, which I found the most accurate way to measure the weight, there was a bit of latency when measuring the weight.
Also, the combustion of the fuel needed to be more consistent. Since the fuel was solidified for a long time, the ratio of the sucrose and potassium nitrate is not uniform all over the fuel, creating irregular fuel combustion.

Table 1: Static Fire Test Data (Representative Sample)

Time (s)	Thrust (N)	Impulse (N·s)
0.0	0.00	0.00
0.1	4.21	0.42
0.2	8.55	1.28
0.3	12.10	2.49
0.4	15.40	4.03
0.5	18.22	5.85
0.6	21.05	7.95
0.7	23.40	10.29
0.8	24.80	12.77
0.9	25.10	15.28

Note: Only the first 10 of 218 observations are shown. The complete dataset is available in .

In general, all three results, thrust measured by Loadcell, of three combustions reach their maximum value(peak) at the middle of the combustion and radically increase and decrease before and after their maximum value.
Nozzle three has combusted for the longest time: 21.6. Without any error, all three combustions should last for the same time-error

Central Value–Table 3:

Table 2: Central Values of Raw Data

	Mean (g)	Median (g)	Mode (g)
Nozzle 1 (30 degrees)	648.9	787.5	183
Nozzle 2 (20 degrees)	957.98	875	394
Nozzle 3 (10 degrees)	1435.51	1501	1023

Mean shows that the thrust of the rocket module with nozzle 3 is the strongest among the three on average. The average value increases as the exit angle of the rocket nozzle decrease.
The Median also shows that the thrust of the rocket module with nozzle 3 is the strongest among the three. Although the median value does not represent the entire data, it shows the middle point of every three data and allows us to compare those three. The median value of the thrust of the rocket module with nozzle 3 is the highest number among the three, representing that the medium force created by the rocket increases as the exit angle of the rocket decreases.
The mode is the most frequently appeared data. In this research, the mode does not mean anything more than its definition.

4.2 Processed Data

Standard Deviation in this research can represent the radicalness of the increase and decrease of the change in thrust. A high Standard Deviation means that data is more

Table 3: Extended Descriptive Statistics for Nozzle Performance

	Std. Dev.	**25% Quartile**	**75% Quartile**	**Maximum**	**Minimum**
Nozzle 1 (30°)	394.32	193.75 g	787.5 g	1235 g	13 g
Nozzle 2 (20°)	539.08	453.00 g	1163.0 g	2110 g	38 g
Nozzle 3 (10°)	539.95	1023.0 g	1913.5 g	2270 g	98 g

spread out; in this research, a high standard deviation further implies that the fuel has relatively less radically combusted than a low standard deviation. Unlike any other survey or data selection, since the rocket's thrust graph ultimately increases when the time approaches closer to the middle or peak time and decreases when the time moves further away from the center or peak time, the spread means the radicalness of the graph. The chart indicates that the order of standard deviation of the rocket module from small to big is a rocket module with nozzles 1,2 and 3. Suggests that the fuel in a rocket module with Nozzle 1 has combusted more radically, and the fuel in a rocket module with Nozzle 3 has combusted less radically.
Each 25 Quartile and 75 Quartile shows the lowest 25% of the data and the highest 25% of the data. This data shows that even in the lowest and highest 25% of the combustion, the thrust created by the rocket nozzle with the smallest exit angles has the strongest thrust.
The maximum value shows the peak of the thrust created by the combustion: 1235g, 2110g, and 2270g. The most intense thrust was created by the nozzle with the smallest exit angle. Another thing is that the difference in maximum value between a nozzle with an exit angle of 30 and a nozzle with an exit angle of 20 was more than five times larger (875, 160)
So does the minimum value. The minimum value shows the smallest value of the thrust. They offer a relationship that the thrust created by the rocket module with the smallest rocket nozzle exit angle creates the largest thrust. However, this is insignificant. The smallest value might defer at the very first igniting moment depending on how much fire the fuel caught in the first 0.1 seconds. Therefore, the minimum value is insignificant data to look at.
Also, the correlation coefficient is not appropriate data to calculate this data set. The correlation coefficient of the Average thrust created by the nozzle is noted in the graph section below.//

4.3 Data Presentation and Graph

[H]

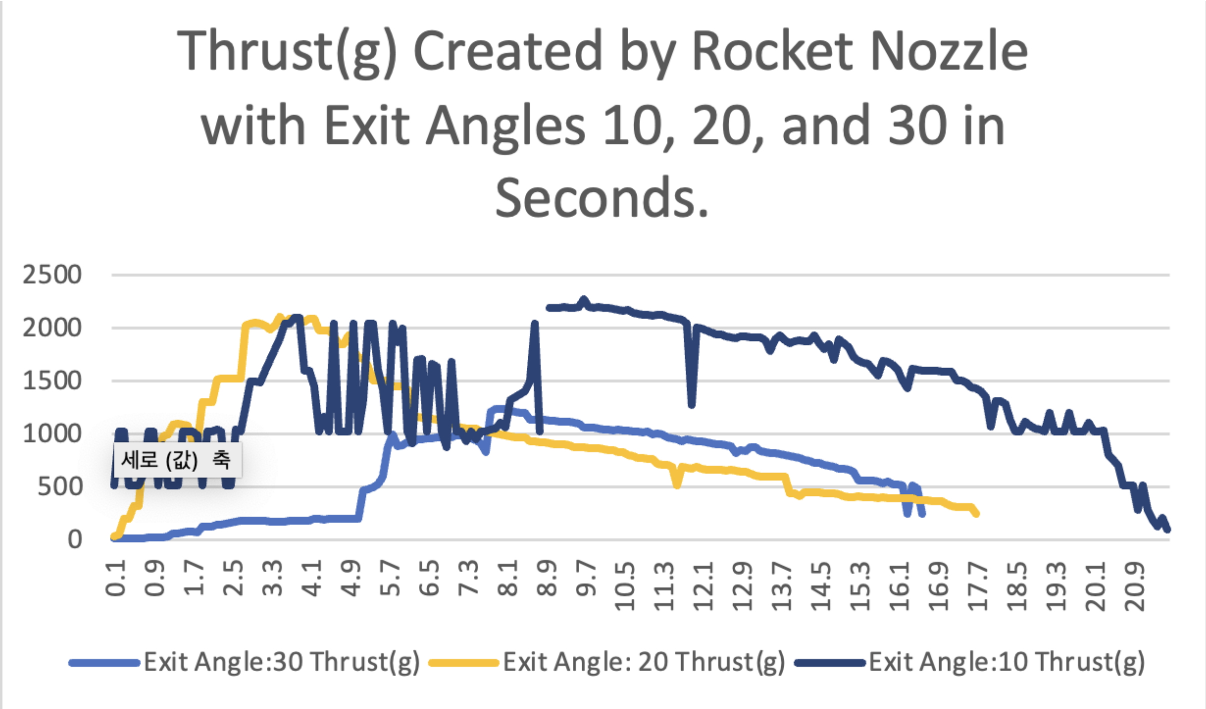

Figure 13: A line graph of a Thrust created by a rocket nozzle with an exit angle of 10, 20, and 30 in a second.

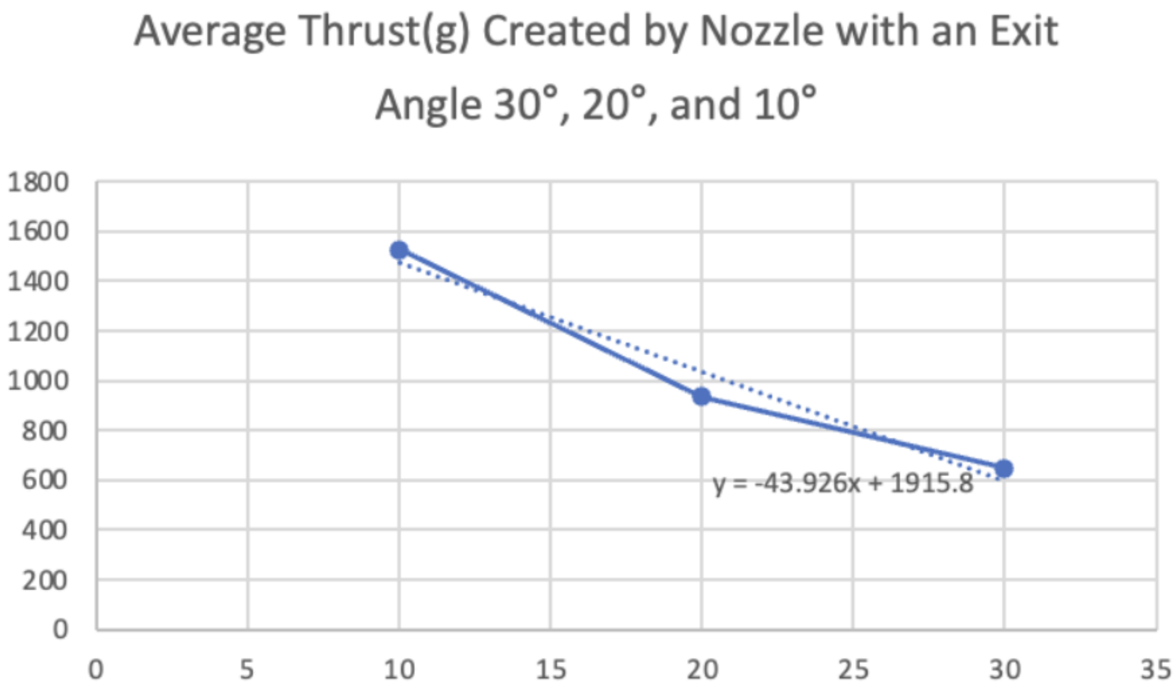

Figure 14: A line graph of the average thrust created by the nozzle with an exit angle of 30, 20, and 10.

5 Analysis

5.1 Inferential Analysis

Figure 13 suggests that the rocket's thrust graph is pretty irregular and varies. However, it still shows the general changes. For every three module rockets, the thrust reachers its maximum level at their middle of combustion, and radically increases and decreases before and after the middle of combustion.
Graph 1 to 3 shows how each combustion was and how radical it was.
To link with the previous data that indicates the radicalness of the graph, the standard deviation, the rocket module with rocket nozzle 1(30 degrees) has the smallest standard deviation of 394.321, the rocket module with rocket nozzle 3(10 degrees) has the largest standard deviation of 539.95 when the rocket module with rocket nozzle 2(20 degrees) has 539.08 as its standard deviation value. This implies that the rocket module with rocket nozzle 3(10 degrees) has the least radicalness among those three modules, and the rocket module with rocket nozzle 1(30 degrees) has the most radicalness among those three modules. Also, by observing specific numbers in detail, the gap between the radicalness of the rocket module with rocket nozzle 1(30 degrees) and the rocket module with rocket nozzle 2(20 degrees) is much larger than the gap between the radicalness of the rocket module with rocket nozzle 2(20 degrees) and the rocket module with rocket nozzle 3(10 degrees): 539.08-394.321=144.759, 539.95-539.08=0.87, and 144.759 are more than 166 times larger.

Potential reasons why rocket modules show different radicalness:

- **The fuel's proportion was not uniform inside each fuel:** Although the entire proportion of potassium nitrate and sucrose was perfect since the solidification time was too long, a few substances might have sunk at the bottom of the fuel and created a non-uniformed proportion of fuel–this is possible, but, since the solidification time for all three fuels were the same, all the non-uniformed proportioned fuels need to be non-uniformed in the same degree. Therefore, this does not fully explains the different radicalness of data.

- **The nozzle bottom's length difference has varied the oxygen's access:** Although every nozzle top part has the same length of 0.5cm, the length of the bottom part has increased and this was inevitable in a process of changing the exit angle of the rocket's nozzle. The length of nozzles with smaller exit angles is the longest, and the length of the nozzles with big exit angles is the shortest. In this case, nozzle 3 has the longest length, and nozzle 1 has the shortest length. This length difference and the volume difference that has derived from the length difference might affect the amount of accessible oxygen that fuels are exposed to. More oxygen is required to catch more fire in a short time effectively. In this case, the shorter length of the file would better increase the radicalness of the data, because a shorter length increases the exposure to air to fuels. The correlation ship works.

- **The depth fuses went through for each nozzle were different:** In the process of igniting fuels, fuses made out of strings with a dried solution of potassium nitrate and sucrose are attached and were used to effectively and easily start ionization. However, since the hole of the nozzle was too small, some parts of the fuses were not fitting in. As a consequence, the depth of the fuse reaching has differed. The deeper the fuse can reach, the easier and faster fuels catch fire. This might have played a significant role in varying the radicalness of the data.

- **The imperfectness of combining process:** While combining nozzles and boiling tubes, epoxy, and friction tape was used. Nozzles were surrounded by friction tape for 5 layers and put with epoxy inside the boiling tube. The problem is epoxy. Since epoxy is a slightly viscous fluid, even though only the nozzle was surrounded by epoxy, it flowed down and affected the fuel part.

Graph 4 gathers all graphs 1 to 3 in one graph and illustrates the differences. The graph suggests that the order of the rocket module with different nozzles that performed the strongest thrust is the rocket module with a nozzle 3(10 °), the rocket module with a nozzle 2(20°), and the rocket module with a nozzle 1(30°); the blue line is always below the 1500g line, whereas the other two colored lines are mainly placed above the 1500g line. Also, the rocket module that performed the highest thrust is the rocket with a nozzle 3(10°.) This suggests that the thrust of the rocket increases when the nozzle of the rocket decreases.
Graph 4 indicates that the rocket module with a nozzle 3(10°) combusted for the longest time. The rocket module with a nozzle 1(30°) finished its combustion before 16.9 seconds, and the rocket module with a nozzle 2(20°) finished its combustion before 18.5 seconds, whereas the rocket module with a nozzle 3(10°)'s combustion lasted more than 20.9 seconds. This is not included as the intention of the research. To guess the potential reasons for this irregular reaction time:

- **Fuel's irregularity:**Although every fuel was containing the exact same amount of potassium nitrate and sucrose, the proportion was non-uniformed as stated before.
- **The depth of fuses:** As stated before, the depth of the fuse plays a significant role in combustion. The more deep fuse can reach, the easier and faster fuel catches more fire. Different depths of fuses meeting with fuels affect the combusting time of fuels.
- **The nozzle bottom's length difference** has varied the oxygen's access although every nozzle top part has the same length of 0.5cm, the length of the bottom part has increased and this was inevitable in a process of changing the exit angle of the rocket's nozzle. The length of nozzles with smaller exit angles is the longest, and the length of the nozzles with big exit angles is the shortest. In this case, nozzle 3 has the longest length, and nozzle 1 has the shortest length. This length difference and the volume difference that has derived from the length difference might affect the amount of accessible oxygen that fuels are exposed to. More oxygen is required to catch more fire in a short time effectively. In this case, the shorter length of the file would better increase the combusting time of fuel of the data, because a shorter length increases the exposure to air to fuels. The correlation ship works here.

Graph 5 shows the average thrust created by rockets with different nozzles(10°, 20°, and 30°.) The graph is downside right, which means as the x-variables, the exit angle of the rocket nozzle(°), increase, the y-variables, the thrust produced by the rocket(g), decreases. The line of the best fit(trend line) of this graph is y = -43.926x + 1915.8, suggesting that as the exit angle of the rocket nozzle increase by 1° the average thrust produced by the rocket decreases by 43.926g in average. Another thing is the correlation coefficient value of -0.980424814 of the line of the best fit. If the correlation coefficient value is closer to either of negative one or one, the trend line shows more accuracy.

6 Conclusion:

Research Question: How does the rocket nozzle's (De Laval nozzle) exiting angle(10 °, 20 °, and 30 °) influence the Rocket's thrust(g)?

As the exit angle of the rocket module with a 1.25cm radius and 20g of KNSB fuel(65% of potassium nitrate+35% of sucrose) increases by 1°, the average thrust produced by the rocket decreases by 43.926g on average. Graph 5 "Average Thrust(g) Created by Nozzle with an Exit Angle 30°, 20°, and 10°" shows the overall tendency of relationships between my independent variable and dependent variable which are the exiting angle of rocket nozzle 10°, 20°, and 30°, and thrust(g) produced by the rocket. The function of the line of the best fit of graph 5 is y = -43.926x + 1915.8, meaning if the exit angle of the rocket module with 1.25cm radius and 20g of KNSB fuel(65% of potassium nitrate+35% of sucrose) increases by 1°, the average thrust produced by the rocket decreases by 43.926g in average. By this, if the exiting angle of the rocket nozzle in a rocket module with a 1.25cm radius and 20g of KNSB fuel(65% of potassium nitrate+35% of sucrose) is known, the thrust it can produce can be calculated.

Scientific reason: According to CyroRocket.com, the best exiting angle of a rocket nozzle is typically set at 15 degrees. This angle provides the greatest thrust efficiency and allows the rocket to reach higher maximum velocities. It helps the rocket to create maximum thrust with a minimum amount of wasted fluids. The 15-degree angle also helps reduce turbulence and maximizes the pressure within the rocket's combustion chamber. Another source says, according to Pavil, Albert J., and his colleagues (1987), the strongest thrust from the rocket is produced when the rocket nozzle is created in optimum design, exit angle in-between 15-20°. The reason why exit angles of rocket nozzles show their best performances at 15°, and not on any angles smaller than that is that, if the angle is smaller than 15°, the acceleration that nozzles can give to supersonic fluid is too weak, and is not enough. In order to meet the maximum acceleration of the supersonic fluid and creates the maximum speed is to design the exit angle of the rocket nozzle is 15°.

7 Evaluation

There was a lot of implementation in the experimental process, including using potassium nitrate, to downsize my entire experiment, creating an ignitor, coding Loadcell, and measuring my dependent variable. Among those, some of them are inevitable in order to conduct research to answer my research question, but there are some issues that can be improved.

Table 4: Error Analysis and Proposed Technical Solutions

Source of Error	**Significance**	**Proposed Solution**
Non-uniformed proportioned fuel.	Irregular force and speed of combustion.	Use refrigerant to solidify fuels faster. Quicker solidification ensures uniform distribution of potassium nitrate and sucrose.
Imperfect placement of epoxy.	Blocks fire/gas paths; causes slow starts and weaker force.	Structure nozzle inside boiling tube using bonds or lead (Pb) first, then cover with epoxy externally to prevent internal path blockage.
LoadCell/Weight sensor issues.	Inaccurate force sensing; data collection errors.	Add resistance to the circuit to prevent the HX711 amplifier from overloading the LoadCell with excessive current.
Fuse depth inconsistency.	Inconsistent thrust; irregular combustion timing.	Wet the yarn in KNSB solution and sweep by hand to prevent thick solid buildup, allowing the fuse to reach the fuel depth easily.

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