Comparison in Propulsion and Cost of Sugar-Based vs. Estes Rocket Motors

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Abstract

Model rocket engines are mainly store-bought and utilize a black-powder propellant to fuel them. However, an alternate, homemade sugar motor propeller is being used by many rocketeers and serves as an alternate to common low-powered black-powder propellants. In this study, I have compared the pros and cons of producing your own sugar-motor propellant as opposed to buying a black-powdered propellant to demonstrate if engineering your own motor is really worth it. In this study, I constructed and tested the thrust of my own sugar motors. Then, I analyzed the performance, build quality, and time of the motors. Then, I compared the cost of the materials and the time it takes to make a motor. I found that while both serve as feasible alternatives for each other, they have benefits such as learning the basics of propulsion, being able to produce thrust to your needs, and more. This is important because people should be able to construct their own motors instead of buying it from companies as it teaches useful insights. However, if they really want to get to flying and care about the rocket, then buying one is better.

Introduction

Model rocketry offers an effective method for understanding the aerodynamics, engineering, and propulsion of scientific concepts. Over the years, participation in model rocketry has increased with the evolution of various means of participation. While serving as a practical tool for education, it also serves as a means of recreation and competition as many enjoy constructing and igniting a rocket. While the process of mechanically building the rocket is highly important, a crucial factor is the motor inserted into the engine mount. This determines the height, stability, exhaust, and safety of the rocket. The propeller of a rocket is chosen, usually based on the dimensions and weight of the rocket. However, the composition of a model rocket engine is pertinent to how the rocket performs once it is off the ground. A rocket that is aerodynamically effective may not achieve its maximum height and stability if it is paired with an incompetent motor. Therefore, the process of choosing or constructing a rocket motor is done with patience and consideration.

Various types of motors serve different functions due to their composition, mechanical complexity, and operations. For example, the difference between solid and liquid propellants have stark differences in performance and safety. Important aspects to consider while choosing which model rocket to employ are motor compatibility, aerodynamics, materials and construction, purpose of launch, ease of assembly, budget, recovery system, and regulations. Motor compatibility consists of the relationship between the airframe of the rocket and the thrust and delay timing of the motor. Aerodynamics refers to the shape and stability of the rocket which can be affected by the decrease of propellant in the rocket motor affecting the center of gravity or exhaust gases altering base drag. Materials and construction should be fit to handle the heat and exhaust of the motor as it is ignited. Purpose of launch may alter motor needs as recreational rocketry may be more lenient on how a rocket performs while a rocketry competition may require specific guidelines such as altitude or timing for a rocket to return to the ground. Ease of assembly may consist of literally constructing a motor from scratch or installing a store bought motor into a motor mount. It relates to the time and difficulty of fabrication and installation. Budget is simply the cost of the motor. A recovery system is usually a small explosive charge that the rocket engine produces in order to detach rocket joints and expel a parachute. This expulsion charge must be large enough for its required intent but not large enough to be destructive. Furthermore, certain launch sites limit motor classes and altitudes that the rocket can be extended up to. These rules are usually located in the NAR and tripoli guidelines and rocket motors must adhere to certain regulations depending on the location of launch. This paper will serve as a comparative example of these factors between two distinct types of motors: commercial and homemade.

The black powder propellant is a chemical propellant mainly used in model rocketry due to its effective performance, cheap production costs, and predictable combustion reaction. The chemical propellant originates from ninth century China, mainly for gunpowder and fireworks, and spread to Europe within the 13th century to be used in early rocketry development. However, today it is mainly used in model rocketry. This is because professional rocketry requires greater specific impulse, scalability, safety, mechanical strength, thrust shaping, and cleanliness. Despite its drawbacks, black powdered propellant remains widely effective for rockets under five hundred grams.

As modern rocketry grew in popularity, diverse methods of fueling a rocket emerged. One of the most prominent being the household sugar motor. In the late twentieth century, rocketeers popularized the sugar motors as a feasible method of propellant. This method was popular also due to its low cost, safety, and burning combustion as opposed to the black powdered propellant's exploding combustion.

The primary focus of this study is to compare the fabrication, delivery, thrust, and exhaust time of sugar based rocket motors and black-powdered based motors. An analysis that will then be drawn is in what cases a certain type of propeller is preferred.

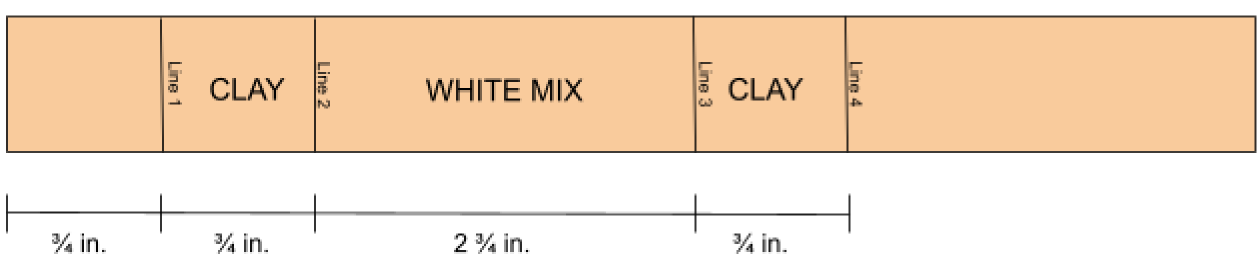
Methodology

Ingredients	Cost	Use time
IPEX 3/4 in. x 24 in. PVC DWV Schedule 40 Pipe	$3.16	4 x $0.79 per motor
3/4 in. x 48 in. Raw Wood Round Dowel	$4.14	Until Damaged

[Spectracide Stump Remover Granules 1 LB]	$9.88	23 x $0.43 per motor
[C&H Premium Cane Powdered Sugar - 2lbs]	$2.59	86 x $0.03 per motor
[Tidy Cats Cat Litter 24/7 Performance - 10 Lb]	$3.99	432 x $0.01 per motor
[DEWALT 7/32 in. Black and Gold Split Point Drill Bit]	$4.47	Until Damaged / Rusted
[Estes Rockets STARTECH™ Starters]	$6.99	6 x $1.17 per motor
[Estes Rockets Plugs for Standard Engines - (20 pack)]	$7.49	20 x $0.37 per motor
Total	$42.71	$2.80 per motor

Table 1: Ingredients, cost, and use time to construct a sugar motor

1. Equip a mask. Crush the stump remover into a fine powder using a mortar and pestle or another safe alternative.
2. Combine the fine stump remover with powdered sugar. Mix by shaking the mixture.
3. A wooden dowel is used as a hardener and a stencil. Measure the following increments onto an oak dowel using a marker:



4. Cut PVC tubing into 5” increments. Tape one side of the tubing and place it perpendicularly on a solid surface.
5. Place enough kitty litter into the PVC tubing until it reaches a vertical height of ¾ inches inside the tube. Use the dowel to measure the volume required. After the mixture is placed, use the dowel to ensure that line 3 aligns with the top of the PVC tube. Remove or add kitty litter as required.
6. When sufficient kitty litter is placed, use the wooden dowel to harden the mixture. This can be done by manually adding pressure on top of the dowel by hand or using a mallet.

If excessive mixture is hardened, the dowel can be twisted on the surface of the mixture to loosen it.

7. Harden the stump remover and powdered sugar mixture in small increments at a time. Repeat the process until the mixture is hardened and line 2 aligns with the top of the PVC tube.
8. Place kitty litter on top of the hardened mixture and harden until line 1 aligns with the top of the PVC tube.
    a. Note that the remaining ¾ inches may be used to place baking soda or other mixture to function as a recovery system. For safety purposes, this portion is omitted in the experiment.
9. Remove the tape at the base of the rocket motor. The base will be considered the bottom of the motor. Using a 7/32” drill bit, gently drill a nozzle along the middle of the tube through the bottom until the bit drills all the way through the mixture and reaches the upper layer of clay. This process must be done slowly and cautiously by hand to avoid the application of heat to the mixture.
10. Place a motor starter into the nozzle and plug the wires using starter plugs. Use the preferred type of motor ignition remote to ignite the motor.

For the purposes of this experiment, the sugar motor was placed upside down on an analog scale. It was placed within a secure bracket, inside another PVC tube and aligned against a stable piece of concrete. The bracket was first placed inside the scale. Then, the motor was placed into the bracket with the nozzle facing the sky. The scale was zeroed out. The motor was ignited and the force was recorded for every 0.033 seconds until the system stopped propelling. This data, from pounds, was converted to newtons and placed in a graph to be compared with the thrust of other commercial motors.

Safety

Rocketry opens up exposure to a number of dangers. This section will depict specific considerations to keep in mind when building a sugar motor or igniting a store bought motor.

When creating the sugar motors, it is safer to use a mortar and pestle to crush the potassium nitrate into fine powder as opposed to using a blender. This is because the friction from the blender subjects the chemical to heat and release of highly toxic gases. The stump remover itself has dust which may be mildly irritating to be exposed to so a use of mask and eye protection is recommended when grinding potassium nitrate into fine powder.

When mixing the powdered sodium nitrate with powdered sugar, it is important to avoid crushing the chemicals further. Simply shaking the mixture inside a closed form forms the intended product. The mixture becomes a highly reactive chemical that will burn if exposed to heat. Store the mixture in a cool, dry location to avoid spontaneous combustion. After solidifying the mixture inside the motor tube, slowly apply force using the drill but do not drill at full speed.

This will cause clumps to be removed from the mixture and may ignite due to the heat produced by friction. It is recommended to turn the drill by hand instead.

As for the store bought estes motors, the main components of safety to consider is storage. Similar to the sugar motors, the black powdered motors offer a controlled explosion. Therefore, they should also be stored in a cool, dry area without potential for pressure build up. Additionally, estes motors must be ignited by estes igniters and follow several safety guidelines.

When igniting any motor, an in-depth look at the guidelines for the area should be studied and a safe distance should be maintained from the launch site. If possible, avoiding the area of launch for a few minutes after ignition is recommended to avoid exposure to harmful exhaust gases.

The black powdered motors excel in safety as opposed to the sugar motors because the chemicals are professionally handled and there is minimal risk of injury. The process of mixing and solidifying chemicals subjects the user to risks of spontaneous combustions that are avoided in the commercial black powdered motors.

Results and Discussion

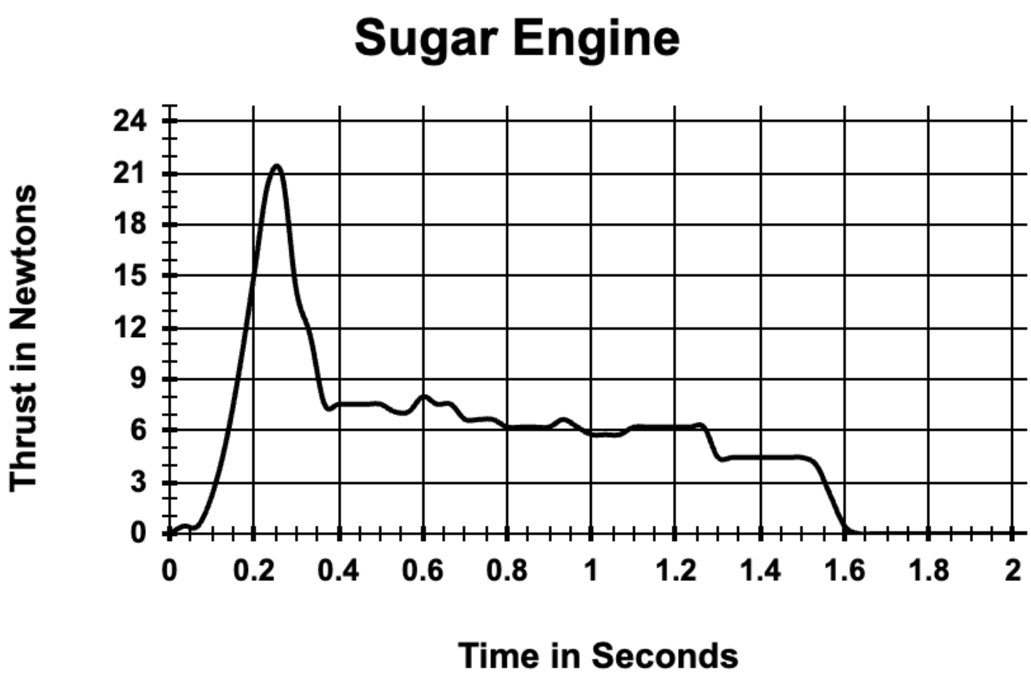


Figure 1: Data of sugar engine exported onto Excel Graph as a Thrust Chart

The sugar based engine shows considerable thrust performance. The peak thrust amounts to about 21 newtons with a burn time of 1.6 seconds. This is a sufficient amount of thrust to generate lift for most small sized rockets and the lower end of mid sized rockets.

The following graphs serve as a comparison for the sugar motor and generalizes its performance with a black powder engine designed to operate model rockets with similar weight.

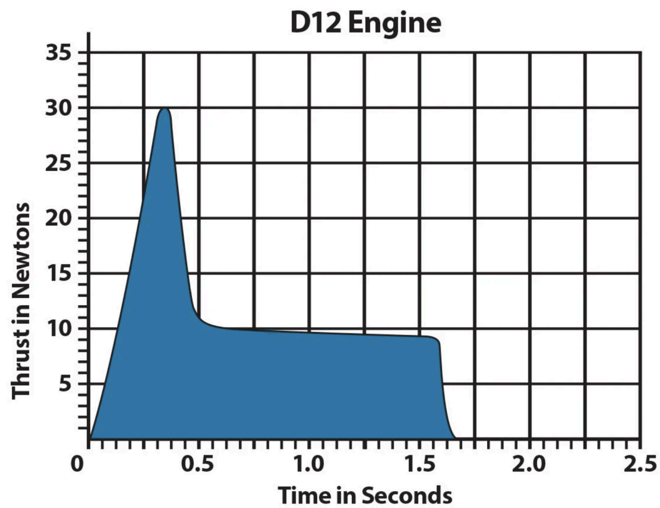


Figure 2: Official D12-5 Engine Thrust Chart published by Estes Motors [5]

The first comparison is between the sugar engine and the D12-5 engine from Estes. The D12-5 engine has a peak thrust of 32.90 newtons and a thrust duration of 1.60 seconds. The peak thrust of this motor exceeds that of the sugar motor. However, both motors have similar thrust durations. This results in the D12-5 engine having a better thrust performance for the same thrust durations, allowing the D12-5 to propel a greater mass up to the same altitude as the sugar motor.

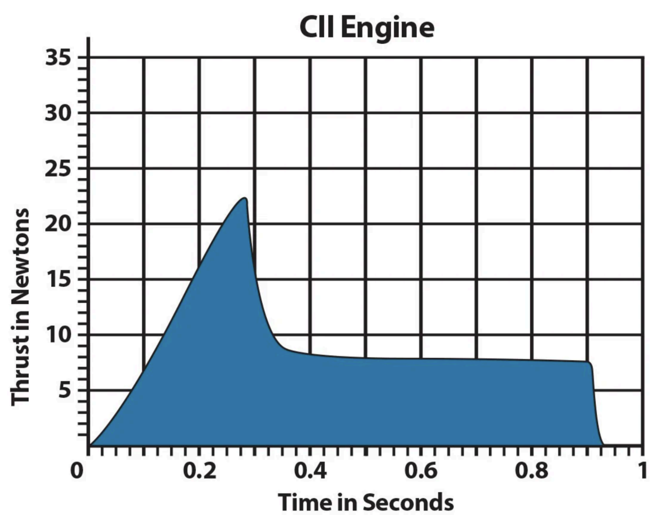


Figure 3: Official C11-5 Engine Thrust Chart published by Estes Motors [4]

The C5 engine has a peak thrust of 20.40 newtons and a thrust duration of 1.85 seconds. The sugar motor has a slightly greater peak thrust, but the C11-5 engine has a greater burn duration. This performance allows the C11-5 engine to perform slightly better than the sugar motor.

Generally, black-powdered motors amount to a greater total impulse than a sugar motor. This performance is drastic when comparing the sugar motor with the D12-5 engine. Nevertheless, when comparing the sugar motor with the C11-5 engine, the results are similar with the C11-5 performing slightly better. All of the model rocket engines demonstrate the ability to propel a mid sized rocket with sufficient consistency.

Comparison of costs for these motors also play a crucial factor when choosing between each one. These costs vary based on region as they may be subjected to various delivery charges, taxes, and available options. For the purposes of this experiment, the price of the motors are taken without tax or delivery charges to provide consistency. The ingredients used to construct the sugar motor were also chosen from popular chain stores due to their existence in numerous locations across the United States. The Estes motors being compared are sold in packs of two; Therefore, the prices of motors are given in increments of two. Additionally, Estes motors include starters and starter plugs in their packaging and this cost has been implemented to match the sugar motor. Below are the prices of motors in different quantities.

Motors	2	4	6	8	10
Estes D12-5	$14.99	$29.98	$44.97	$59.96	$74.95
Estes C11-5	$9.99	$19.98	$29.97	$39.96	$49.95
Sugar motor	$5.60	$11.20	$16.80	$22.40	$28.00

12	14	16	18	20	22
$89.94	$104.93	$119.92	$134.91	$149.90	$164.89
$59.94	$69.93	$79.98	$89.91	$99.90	$109.89
$33.60	$39.20	$44.80	$50.40	$56.00	$61.60

Table 2: Comparison of the purchasing price of the Estes D12-5, Estes C11-5, and sugar motor [4] [5]

Generally, constructing a sugar motor costs less than buying these two categories of Estes motors. The significance of the cost difference is relative to the budget available to purchase rocket motors. However, the time to receive these motors should also be considered. Sugar motors require either an online delivery or entering stores to purchase the parts unless a portion of the parts are already present. They take considerable time to construct as well. On the other hand, Estes motors may also require a wait for delivery. Occasionally, a lot of parts may also be out of stock in which case it may be ideal to consider other rocket motor companies.

For the sake of safety, black powder motors are the simpler and safer option. While they may have an explosive propelling method as opposed to the sugar motor's burning method, black powder propellants have a decreased risk of spontaneous combustion as they are stored in reliable containers and the chemicals are not directly exposed whereas sugar motors directly expose the flammable and dangerous chemicals. The process of constructing the sugar motors by hand poses additional safety concerns such as crushing and mixing the flammable potassium nitrate. Direct contact is effectively avoided when working with a black powder motors and a greater level of safety is developed when handling and igniting these motors.

Manufactured motors can be bought for almost any rocket type. Different classes of motors support the propulsion of rockets based on size and weight. However, sugar motors mostly support small and mid sized rockets. The decreased motor compatibility allows black powder motors to be a better option, especially when a specific thrust profile is expected from the motor.

When considering the aerodynamics of the motors, both motors have specific advantages. The black powder motors offer a consistent burn rate that quickly lifts the rocket off the ground. However, due to its shorter burn time, the weight depletes quickly shifting the center of gravity which negatively affects the aerodynamics of the rocket. This causes higher drag at peak speeds. As for a sugar motor, the burn rate is longer and the thrust gradually decreases as opposed to a short spike which suggests lower drag due to gradual acceleration.

The means of launching a rocket can help determine which motor to utilize. For example, participating in competitions which typically require a rocket to reach a specific altitude and land within a time frame may benefit from using black powder motors. This is due to its reliability and existent databases that can digitally predict altitude and time of descent. However, for educational or recreational purposes, both motors are capable of propelling the rocket to demonstrate a realistic view of thrust and aerodynamic principles. Despite this, black powder motors may have an advantage as they can produce a consistent burn rate while sugar motors may merge in clumps when solidifying inside the tube that might cause inconsistencies in thrust over time. This is however beneficial to demonstrate the results of unequal fuel consumption in professional rocketry.

Ease of assembly of a black powder motor is by far simpler and more straightforward than a sugar motor. By simply purchasing an estes motor, a step by step instruction manual advises a simple installation process that takes a few minutes to complete. On the other hand, a sugar motor requires hours of preparation time to develop a primary motor, and even more time to make an effective one to satisfy a rocket's purpose. However, if time is a consideration, then the delivery time of manufactured motors should be considered as well. Although a sugar motor may require two to three hours to produce at first, this can reduce over time due to familiarization to the process. A manufactured motor may take a few business days to deliver as most of them can only be purchased online. Therefore, while a sugar motor may take more time to produce, a manufactured motor actually takes more time to deliver.

The recovery system in a sugar motor can be extremely dangerous if the motor does generate lift for the rocket. A recovery system can be achieved by placing baking soda on top of the sugar based propellant. This emits an explosive charge strong enough to remove a parachute from a rocket. However, if the motor does not propel the rocket, the baking soda exploding on the ground poses serious physical risks. Additionally, if the required baking soda is miscalculated and does not produce sufficient ejection charge for the parachute, it poses a ground hazard and physical risks for the rocket as it develops into a free fall. The manufactured motors are far more reliable as they are consistently tested and adhere to safety regulations and offer a reliable recovery system (research the recovery system) as well as sufficient propulsion for the rocket. For reliability for a recovery system, a black powder motor offers countless benefits and safety factors over a sugar motor.

Conclusion

Both the commercial rocket motors and the homemade sugar motor contain individual advantages and drawbacks relative to the other. Commercial motors are capable of fueling various types of rocket models due to its explosive ignition process that allows them to contain mixture in diverse quantities to harness a smaller or larger explosion for proportional propulsion. This, however, enforces a greater drag on the rocket as the motor depletes in fuel quantity at a faster rate before reaching its highest elevation. Commercial motors also carry a greater degree of safety due to indirect exposure to chemicals and have a greater ease of assembly. They can be easily equipped to model rockets with the purchase of a complementary motor mount and a customer does not need to be involved with the materials and construction. Performance for commercial motors can be simulated and attained using digital softwares. The motors are reliable to initiate the recovery system and adhere to NAR regulations. However, they may be expensive to purchase in large quantities.

On the other hand, the sugar motor contains an assembly process that takes considerable time and effort. The assembly time and procuring the necessary ingredients can take a couple days. However, producing sugar motors are cheaper than ordering commercial motors off of the company websites. The rocket motors, however, can be more complicated to install in a rocket, often requiring custom engine mounts. A sugar motor may allow for a greater aerodynamic potential due to its gradual burning combustion system. However, the motor cannot harness a large amount of power even by increasing the fuel quantity because the fuel is consumed at a constant rate. The performance of a sugar motor is difficult to predict so the motor is unreliable for competitions. However, due to its spontaneity, it can be useful in educational settings. A sugar motor is relatively cheaper than a commercial motor with similar performance but the recovery system largely depends on the quality of the product and assembly. Choosing the materials for a sugar motor may also prolong the necessary preparation time. Sugar motors may not comply with NAR policies and regulations based on the launch site and external research time and preparation is also required to launch.

A rocket motor acts as a powerhouse to a rocket. It elevates an earthbound piece of engineering into the domain of flight. Understanding the mechanism of rocket motors unlocks several fields of physics and chemistry including combustion analysis, aerodynamics, and thrust calculations. It also stimulates creativity and learning. Understanding the difference of the safety, stability, and performance of different types of materials increases the capability to make safe and efficient decisions in professional settings. Employing different types of rocket motors–including ones that are handmade–are excellent methods to develop these skills. Additionally, understanding the appropriate uses of different motors amounts to fundamental thinking skills of utilizing relevant tools to make logical decisions. Therefore, in order to participate in rocketry, the motor should be chosen by defining the purpose and the results desired from the launch. Choosing the right rocket motor is more than a simple experiment, it is a process that requires considerable thought and analysis.

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