Alternative Ejection Methods: An Investigation

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Abstract

It is important to note that this investigation is to be treated as an addition to the High Powered Rocketry Capstone project conducted over the course of this semester. The motivation itself stemmed from the realization of the need for additional precautions in the deployment of the quadcopter from the rocket. However, this system would have lasting effects through the existence of Oklahoma State University's High Powered Rocketry Club (HPR Club). The initial plans for this investigation was to cover the feasibility of using compressed Carbon Dioxide (CO_2) gas as an alternative method for ejection and deployment of component from within the rocket. This quickly changed to a general investigation of improvement to the current ejection system after it became clear that the usage of CO_2 created more problems and introduced more risks than could be reasonably outweighed by its possible benefits. Ultimately, this investigation concludes that it is best to continue the usage of black powder with some later experimentation into the usefulness of smokeless powder for local purposes.

Introduction

The flight of a rocket contains several stages, starting with its launch quickly followed by the boost phase, and after the fuel runs out it enters its coasting phase until it reaches its apogee also known as at its maximum altitude. Once the rocket reaches its apogee, it begins its descent leading to its recovery upon reaching the ground. The proposed alternative systems investigated would be a part of the integrated recovery system within the rocket where it ideally would be triggered at or around its apogee.

There were multiple requirements to be considered throughout the course of this investigation. By doing this, we discovered a set of constraints that ultimately lead to the decision to cease expected development of an alternate system. These constraints were; size, weight, complexity, cost, perceived effectiveness, and safety. A significant issue with any new system developed for these rockets is the initial size and weight. This topic is discussed at great length in the main Capstone paper attached in this submission. The Rockets flight is directly affected by this constraint so much so that even a couple hundred grams could reduce a maximum expected altitude by 200ft or more. This is a major concern when you are planning to compete in competitions that have an altitude requirement. Another major concern is factoring in the cost of the motors for the rocket. Increasing the motor size significantly increases the cost of the rocket which in return reduces the monetary resources of a rocketry organization.
This investigation looks at the continued use of gunpowder and how to reduce its more negative byproducts, the possible branch to smokeless powder for its significantly faster burn rate, and preferred idealized development of a compressed carbon dioxide gas (CO_2) based ejection system.

The research conducted for the purpose of this thesis comes from a wide variety of informal sources, particularly forum and online discussions mixed with the independent investigation and experimentations of others who have shared their findings to aid others following the same investigative paths. This was deemed necessary due to the lack of formal research and academic discussion of these topics in this field which limited the available resources to hobbyists, High Powered Rocketry enthusiasts and veterans, and other non-affiliated persons seeking to answer relevant questions. All of the data taken and analyzed in this way is viewed with a certain amount of skepticism, but the scope of the research done by these outside sources provides a lot of information that would take longer than the course of a semester to acquire and analyze by one person.

Constraints

The constraints that effect any of these methods as previously mentioned above are; size, weight, complexity, cost, perceived effectiveness, and safety. Each of these can dramatically affect the rocket and can reduce the chances of a successful flight.

Size and weight are the most critical initial requirements because of how much they affect the performance of the rocket during its flight. The size plays into the layout of other components with in the rocket, but more importantly the body diameter of the rocket, which is a key factor in determining the amount of drag is experienced in flight. Weight directly affects altitude and motor sizes which can dramatically change the associated costs of a flight as well as the abilities of it to fulfill its “mission”. There are a lot of other characteristics that fall under this constraint that should to be taken into consideration. One example of this would weight. If the weight of the system is off centered or not balanced, then the rocket can become unstable, wobbling/oscillating in flight during or immediately after the boost phase. In some cases, it can cause the rocket to corkscrew and in extreme cases it can cause the rocket to reach a critical angel that is unsustainable for flight which could lead to the rocket shredding itself under the force of the motor.

Of the constraints mentioned earlier, cost is one of the most limiting factors. With some of the higher-powered motors running $500 or more for a single launch, expensive internal systems will always be bypassed unless they can show a clear advantage in their utilization. Initial cost of development is one thing, but with every launch there is a small chance of the motor over pressurizing and exploding destroying the rocket in its entirety, or the rocket being destroyed in flight or even just being lost and unable to be found. All of this means that once a system is developed and built it cannot be treated as a "one and done" type of thing. There is an ever-growing possibility of the need to rebuild with every launch.

Complexity plays into the cost of the system as a whole. However, it is also a strong indicator of the availably for testing and the timing of its assembly. A system with a lot of specialized or moving parts needs a lot of verification and each component has a possibility of failure when subjected to the forces of a launch. These forces can include the 10 G's (10 times the force of gravity) experienced by the rocket and everything on board during the boost phase. The OSU High Powdered Rocketry Club averages approximately 15G's with some motors hitting the 20, 25, and sometimes 30G marks. All of these components create the need for a robustness to be built into every component of the rocket.

Safety is imperative for any system and given a place in the constraints here primarily because this system's entire job is to create a high pressure within the rocket body very quickly. In layman's terms and in most cases, an explosion provides the pressure change that is needed. Lastly, the perceived effectiveness constraint is a matter of personal opinion, primarily taking into account all of the above constraints.

Black Powder: Current Use and Possible Improvements

The usage of Black powder, also known as Gunpowder, is quite common in the field of high powered rocketry. It is cheap, easy to acquire, easy to ignite, and only requires a container to hold the amount deemed necessary to produce the desired effect. In its simplest form, the black powder charge sits in the base of the tube so the resulting high pressure to force everything

in front of it out of the rocket and allowing the parachute to open unhindered. The black powder is made up of Potassium Nitrate(Saltpeter), charcoal, and sulfur. This combination utilizes the charcoal and sulfur as reactants and the Potassium Nitrate as the oxidizer. With the addition of heat at the ignition, the reaction is self-sustaining as long as there is plenty of available black powder. This reaction yields byproducts that are approximately 57% solid and only 43% gaseous. This means that most of the initial volume of black powder introduced is retained and it is transformed to a fine powdery soot spread over the course of the its combustion.
This process is inefficient at best and to pressurize larger volumes inside of the rocket we would need a comparable increase in the amount of black powder.

Black powder is classified as a low explosive, meaning that the combustion moves through the material at less than the speed of sound. While burn times can be varied simply by changing the size of the grains, even at the smallest available grain sizes, commercially FFFFg(4F) and FFFFFg(5F) powder, the burn rate eventually plateaus. While fast to the naked eye, in the application of rocketry, this allows the resultant flames and high temperatures to spread throughout the body tube, and it could and quite commonly does damage the parachute, its connecting lines, the shock cord, and/or any payload. This slow burn time, when compared to other explosive materials, subjects the contents within the body of the rocket to this heat for an unnecessarily long time. Also, the desire to move away from black powder is reinforced because its solid byproducts are corrosive, and the soot can gunk up and damage electronic components. The electronic components are almost completely isolated from the detonation charges, save for a small hole mostly occupied by wires. Yet, there is always a noticeable amount of soot that enters the electronics bay coating its walls and the components. Knowing this, it is safe to assume that the electronics also are subjected to a portion of the heat from the combustion.

The work to improve the usage of the black powder has been continuous by the club itself as well as High Powered Rocketry enthusiasts alike. Most commonly, directing the explosions serves to significantly reduce the byproducts taken in by the electronics bay. Next, the addioun of a containment system that allows the black powder to complete most of its burn, generally a wrapping that allows some expansion with the gasses of combustion, before releasing the pressure to fulfill its required task can reduce the heat experienced by the ejection components. These improvements can reduce some of the damaging effects of the use of black powder, but they cannot do anything about the solid byproduct, soot and ash, or the heat produced that expands throughout the chamber.

Compressed Carbon Dioxide Gas Research

The initial goal of this thesis was to investigate the effectiveness of utilizing the compressed CO2 as a means for primary deployment within an ejection subsystem. This was an adequate starting point. However, the research soon branched due to the complexities of the problem at hand. The basis for this path was the knowledge that these systems do exist, and the elimination of gunpowder, subsequently eliminating any and all combustion within the enclosed space, would protect any potentially delicate systems/payloads carried by the rocket. The knowledge that that rocket would be carrying an autonomous vehicle of some sort created the desire to choose a method to deploy it from the rocket that had the highest possibility to ensure successful deployment while also reducing the possibility of damage to its structure or delicate electronics.

To simplify the investigation and design, the standard 12g airsoft cartridge, easily commercially available, was selected. The Compressed CO2 is stored in cartridges, which are comparatively thick-walled aluminum cylinders that contain 12grams of Carbon Dioxide, where at room temperature (70F) the gas is around 840psi. This is an exceptional amount of pressure and the existing nozzle on the cartridge is already very small. The research into existing systems that utilize these cartridges found a handful that were viable within the environment of a rocket. However, these systems were cost prohibitive. The most promising commercial candidate cost $400 and it was the guiding factor in this investigation to the creation and development of our own system.

There are two ways to deploy the required CO2. The first way would be to leave the cartridge un-punctured and to open it when required. The un-punctured option creates an issue with requiring a mechanism strong enough to puncture the seal on the cartridge and to not hinder the flow of the escaping gas. A mechanism that remained in the nozzle of the cylinder had the possibility to choke the flow even further. However, a mechanism that could quickly be removed after the puncture adds an additional step to the process increasing the complexity. As previously stated, there are versions of this system commercially available. They are a puncture with what is essentially a nail that is quickly removed after the puncture is completed. The point of the punch is suspended within a track held away from the cartridge via a spring. The driving force for the punch comes from two possible sources. The first, and the safest, is the version that holds the spring in tension. The second utilizes a black powder charge that is held behind the punch itself. When the release or igniter is triggered, the punch is driven into the cartridge for both versions. Once the gas is free, it forces the punch away where it is then held away from the cartridge by the spring it is attached to. The spring is supposed to ensure the punch doesn't get jammed into the opening of the nozzle.

There is a major concern with the fragility of the aluminum cylinders containing the compressed gas. In previous research conducted, it was found that the black powder method of releasing the gas had a decent chance of sending the punch at an angle and missing the opening, especially if the spring being used to guide it had suffered any deformation. There is also the danger of turning the compressed gas cylinder into a very small pipe bomb with the shock from the black powder causing a fracture along the cylinder itself. These systems, in their commercial form, were not developed for rocketry. In fact, they are used as a failsafe on multi-rotor drones. This means that the stresses that are built are in no way comparable to what would be expected of the device to survive upon its launch within a rocket.

The second method involves pre-puncturing the cartridge and having the release controlled by some form of a valve or mechanism. The pre-punctured option requires the usage of a small lightweight pressure vessel that is strong enough to contain the slightly expanded gas. This method looked the most promising due to the elimination of a puncturing device and the choice between using a solenoid or a mechanically actuated valve. In the idealized version of this, the unit would have a user insert and secure a cartridge which would be punctured upon insertion. Next, the gas fills its newly available volume, reducing the total pressure experienced by the internal walls of the system. When the time comes, a signal from the altimeters would cause the pressure to be released, thus forcing the ejection of whatever was needed out of the body of the rocket.

This design has its issues in the finding of a valve to release the gas when necessary. The use of a solenoid was quickly eliminated due to the ones being strong enough to handle the pressure were out of reach in terms of cost. A mechanically actuated valve through the use of a servo was decided to be the next best option. However, it significantly increased the weight of the system especially when considering the weight of the servo itself as well as the weight of an additional power source. Both combined would far exceed the expected weight of the recovery system. Manufacturing a small pressure vessel system was also considered and the usage of aluminum was considered but ultimately throughout due to weight concerns. The 3d printing of the pressure vessel and holder for this mechanism seemed like the best option, especially in the elimination of the complexity of manufacture. This idea was ultimately disregarded due to the material strength of any of the plastics available to 3d print with. The largest amount of pressure that was able to be tested by individual and non-affiliated hobbyists was approximately 7 Bar, or 101psi. Which in comparison to the expected 840psi of a CO_2 cartridge, creates a clear and significant gap in ability of the plastics compared to any metal pressure vessel.

Smokeless powder

The investigation into the use of smokeless powder requires a little clarification. Smokeless powder is a term assigned to a new generation of propellants/accelerants that were primarily developed to replace Black powder due to it inefficient burn and corrosive nature of its byproducts. The most common commercially available smokeless powders are primarily Nitrocellulose, which is also known as guncotton. For single based powders and for double-base powders, it can be combined with Nitroglycerine. Again, smaller grain sizes result in faster burn times and more complete combustion. This material would be preferable to gunpowder due to its by products being mostly gaseous under certain burn conditions.

The main issue with its utilization would be its containment required for an effective and efficient burn. Concisely stated by the laboratory of Molecular electrochemistry, "When ignited in an unconfined state, smokeless powder burns inefficiently with an orange colored flame. It produces a considerable amount of light brown noxious smelling smoke. It leaves a residue of ash and partially burned powder.", which is a reaction very similar to that of black powder. Higher pressures are required to increase the efficiency of the burn on the low end. To ensure a more complete burn, you would need at least 100psi with better results yielded at 200psi or higher.

Smokeless powder is utilized as a propellant for ammunition and "the common .223 Remington cartridge creates pressures in the range of 55,000 pounds per square inch, although that only exists for a very short time." as discussed by Tom Mchale at GunsAmerica on the topic of the benefits of reloading with smokeless powder. Reaching that level of pressure is fairly easy with the brass containment of a bullet casing reinforced with the steel of a gun barrel. However, it is a lot harder with a weight conscious standalone system. If it were so desired, a reinforced container could be designed to contain the powder for this application to ensure an efficient burn and ultimately replace black powder from the system, however more research and experimentation is needed.

Conclusion

With the above investigations concluded, it was determined that the most effective method for the ejection of either a payload and/or the recovery hardware would be the continued use of the black powder. The continued use of the black powder included the modifications to the system discussed in the Black Powder section of this paper. The overall complexity correlating to a more uncertain chance of success, massive size and weight increase, as well as the additional dangers that come with the CO_2 system make it a fruitless path of development. It is entirely possible to manufacture containers to utilize the smokeless powder. However, the weight savings would be minuscule when the stronger thus heavier container is taken into account. Still, the possibility of a cleaner and more efficient charge is appealing and would eliminate the required cleaning between flights.

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