**Hybrid Motor Design**

**Environmental Impact of Rocketry**

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By
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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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## Introduction

In my capstone the problem being addressed is how to further understanding of hybrid rocket motors. We will be designing and testing a hybrid rocket motor with two main experimental features. My capstone involves 3D-printing the oxidizer injector allowing for more complex possibly more efficient never before tested geometries, in addition the fuel grain structure will be varied during different hot fires to test how the structure of the fuel grain effects the motor. These two factors could help to improve the efficiency of the motor, allowing for greater thrust with less fuel and fewer environmental impacts.

The sociotechnical problem I am going to address in my STS research is the level of greenhouse gas emissions rockets have, do, and will produce in the future. Climate change is a significant issue and rocket emissions could become a significant problem in the future. Because rocket emissions are likely to increase in the future it is important to understand and quantify them to better understand how to deal with them. By quantifying them we can know how much of a problem they will be, as well as potentially which specific greenhouse gases we will need to target when redesigning more sustainable rockets.

My capstone and my sociotechnical problem are related in that both are about rockets. My capstone could help to make hybrid rocket motors more efficient which would help in reducing greenhouse gas emissions from hybrid motors. Hybrid rockets are uncommon in comparison to liquid and solid rockets but if their efficiency could be significantly improved, they could become more common. It’s also possible that efficiency gains in hybrid motors could filter over to solid or liquid motors (though it is

more likely to filter to liquid than solid motor due to the similarity between liquid and hybrid motors) thus allowing for efficiency gains in all or a significant proportion of rocket motors. This would allow for a decrease in emissions from all or most rockets rather than just hybrid rockets. Every little bit of greenhouse gas that we avoid pumping into the atmosphere helps reduce the future effects of climate change and reduce the financial and human costs that it will cause.

My capstone could help to improve the efficiency of rockets, my sociotechnical problem is quantifying rocket greenhouse gas emissions, my capstone could help to reduce greenhouse gas emissions from future rockets.

**Hybrid Motor Design**

The problem we are trying to solve is a need to further understanding and design capabilities of hybrid rocket motors.

A hybrid rocket motor is a rocket motor that uses both liquid and solid propellant instead of one or the other. Solid rocket propellant consists of solid oxidizer and fuel mixed together homogeneously, as soon as the propellant is heated up enough it will begin to ignite. Liquid rocket propellant consists of separately stored liquid oxidizer and fuel that are pumped into the combustion chamber for mixture and ignition. Hybrid rocket propellant consists of a solid fuel and a liquid oxidizer, the oxidizer is pumped into the combustion chamber which contains the fuel.

Solid rockets, once fired, cannot be turned off nor can they be throttled whereas liquid rockets can be throttled and can be turned off, this is an advantage of liquid rockets that hybrid rockets inherit. Solid rockets are simpler and cheaper than liquid

rockets, with hybrid rockets landing in between them with regards to simplicity and cost. Hybrid rockets could form a happy medium between solid and liquid rockets.

Our capstone project to develop a hybrid rocket motor could help to improve understanding of hybrid rockets, specifically through variation of the fuel grain structure and through resin 3D-printing the oxidizer injector allowing for more complex, and ideally more efficient, geometries. We're using a resin 3D-printing method that allows us to 3D-print ceramic, which is what the oxidizer injector is made out of. More efficient oxidizer injection via more complex injector geometry would make our rocket more efficient overall, the same is true of more efficient fuel grain structure. If none of the more complex injector geometries nor the fuel grain structures are more efficient than the simpler ones then we will know what not to do.

The fuel that we are using in our hybrid rocket motor is ABS plastic because it is easy to 3D-print thus allowing us to be creative and complex with our fuel grain geometries. We're using nitrous oxide for our oxidizer because it is relatively available and is oxygen rich.

We hope that our capstone will serve as a platform that future students at the University of Virginia will be able to expand upon for their own projects. Our motor is H class (relatively small), we are hoping to make the mount for our motor adjustable to multiple different motor sizes so that future students using it will not be as limited in their designs and could potentially develop larger motors.

**Environmental Impact of Rocketry**

My research question is how rockets impact the environment, specifically with regards to greenhouse gas emissions. This question is important because climate change is an existential threat to humanity and as rocket launches increase with the further commercialization of space their impact on the Earth's climate will only rise in magnitude as time goes on (Our World in Data, 2023). Barring significant technological developments—which are closer to being sci-fi dreams than reality—such as space elevators or mass drivers, our only method of reaching space is and will continue to be rockets, thus their climactic impact is of great import as space travel frequency increases in the future. My topic is specifically rockets used in commercial and government spaceflight, rockets used by militaries in conflicts will not be considered, nor will I consider fireworks or any sort of rocket other than those used to bring people and cargo into space.

Climate change is caused by the emission of greenhouse gases causing the Earth to trap a greater proportion of the Sun's heat, thus heating up the oceans and atmosphere. The primary greenhouse gas emitted by humans is carbon dioxide. The growth in carbon emissions has slowed substantially and will soon, or may already have, peak (Ritche 2023). So long as the trend of fighting carbon emissions continues, the extreme impacts of climate change can be mitigated though at this point it is unlikely that they can be avoided entirely. Currently the largest sources of greenhouse gas emissions are electricity generation and transportation, both of which are under significant scrutiny and incentive to decarbonize and are well on their way through efforts such as green energy and electric vehicles (EPA, 2024). The reason these industries are under such scrutiny is in part because of the large fraction of emissions

they encompass rather than just the absolute level of their emissions. With the most carbon intensive industries quickly decarbonizing, the total number of greenhouse gas emissions shrinks thus increasing the percentage for which other industries are responsible.

Even if the number of rocket launches does not rise drastically in the coming years—which it will—then rocket launches would still make up a more significant fraction of carbon emissions. Because rocket launches are very likely to increase in frequency in the future not only will their fraction of carbon emissions increase but so too will their absolute number of carbon emissions. While it's obvious why carbon emissions growing in absolute terms is a problem, it may be less clear why growing in fractional terms is a problem as well. The reason it's a problem is because it will put further focus of citizens and governments on the actions of the aerospace industry as they see that it becomes a more attractive target for emissions reductions. Increasing in fractional terms is not an environmental issue per se but is rather an issue for the industry; whereas, increasing in absolute terms is certainly an environmental issue and will be problematic for avoiding the issues associated with climate change. Because of the extent to which rocketry will grow as an emission source in both fractional and absolute terms it is vitally important to quantify the level of emissions it generates, because there is no way to know how many resources to allocate towards a problem if you can't quantify the problem.

Greenhouse gases are a byproduct of combustion, carbon dioxide is a very common combustion byproduct alongside water. Usually, carbon dioxide and water are not the only byproducts, but they are near universal in rocket combustion. Water is

typically seen as a less pernicious gas with regards to climate change, however its global warming potential is higher than that of carbon dioxide. The reason it is seen so favorably compared to carbon dioxide is that it usually doesn't stay in the atmosphere for long periods of time and the water cycle brings it into oceans, rivers, and the water table. Rockets also generate soot which can be called black carbon that causes other ecological issues alongside worsening climate change. This mechanism by which rockets generate greenhouse gases—that is as a byproduct of combustion during launch—is another reason as to why it is so important that the level of emissions rockets generate is known. As rockets go up, they spew exhaust higher in the atmosphere than most other emissions sources. These gases, when released higher in the atmosphere, stay in the atmosphere for a longer period of time and contribute more to climate change than they would have had they been released nearer to the ground such as if they had been released by airplanes, cars, or stationary power generation. (Piesing 2022)

The problem will be analyzed by looking at the number of rocket launches that have occurred in the past and using that limited dataset to extrapolate future lunch numbers, then by combining that data with the emissions data for rockets it will be possible to calculate the impact of past and future rocket launches on the environment and estimate to what degree it impacts the climate. The exact method of extrapolation can vary as multiple methods can be useful, as such I will likely make multiple models. Rocket emissions take the form of more than just carbon dioxide, so it is also important to quantify not only the warming potential as a whole but the distribution of which greenhouse gases rockets release. By finding this data and extrapolating it it will be

possible to not only estimate the greenhouse gas emissions of rocket launches but to also estimate which gases are the most important to decrease the emission of for the rocketry industry.

**Conclusion**

My capstone is the design and testing of a hybrid rocket motor, my STS deliverable is an estimate of past and future greenhouse gas emissions from rockets. The STS problem is the extent to which rockets will impact the climate going forward, this can be ameliorated by better understanding them and being able to estimate how much rocket emissions will increase over time. Climate change will have huge impacts on society, from heat waves to sea level rise to an increase in natural disaster there will be a huge cost both human and monetary that could have been avoided had action been taken earlier to solve climate change. The expected results of my future paper are tables and charts showing the expected impact of rockets on the amount of greenhouse gases in our atmosphere over the course of the next several years.

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