Solid Rocket Combustion

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Get Wet Assignment - MCEN 4151

September 18, 2026

Purpose

This image was created for the 'Get Wet' assignment and to fulfill its requirements. Since the goal was to play around with different flows, I also experimented with taking photos of varying shutter speeds of a creek. After not getting the desired pictures, focused was switched to solid rocket motors. The intent with the final image was to capture the beauty and power of solid rocket motor exhausts. But to also get comfortable with the camera equipment, photo techniques, and image editing.

Set Up & Procedure

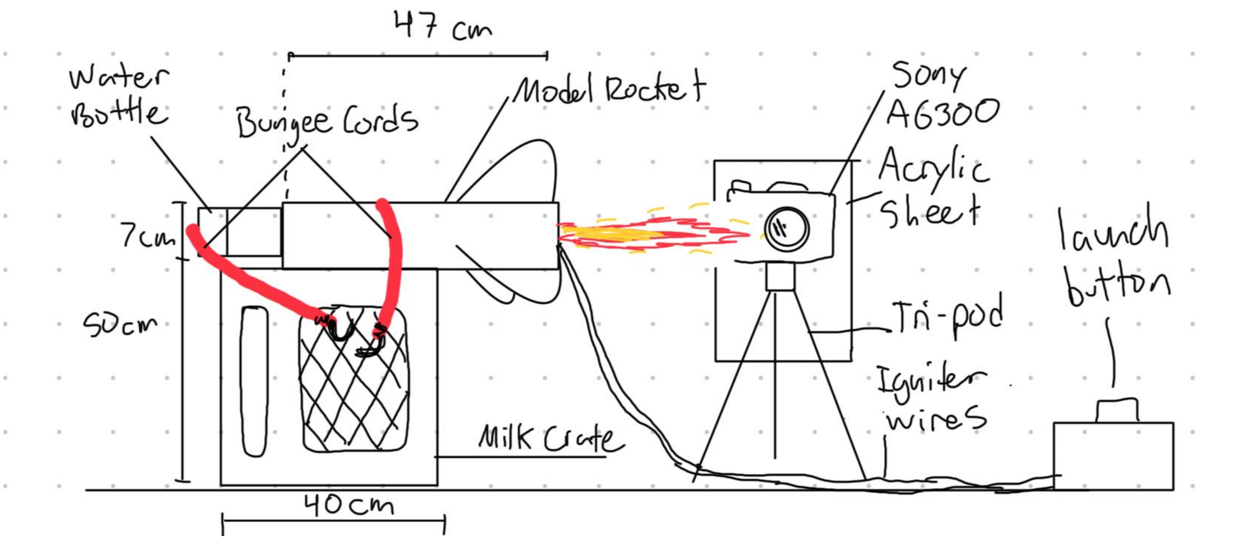
This experiment required a great deal of set up and prior equipment. The solid rocket motors used varied in power from the Estes A8-3, B6-4, and C6-5. All however, had the same diameter of 18mm and length of 70mm allowing for the test set up to remain constant throughout runs. The max force of these motors ranged from 10.7 to 15.3 newtons and burn durations from 0.8 to 1.6 seconds. All motors happened to have ejection charges, that light after the main burn, which are accounted for down below.

To hold these motors during ignition, a previous model rocket was selected as a base. The main issue was that the rocket was designed for a 29mm diameter rocket motor, so an adapter had to be fashioned. To step the diameter down from 29mm to 18mm, a custom inserted mount was laser cut from birchwood. Then the nose cone of the rocket could be removed and for extra weight, so the setup did not fly away, a filled water bottle was inserted into the other end of the rocket. The model rocket's flame-retardant cloth could be repurposed and wrapped around the end of the water bottle facing the engine for safety against the ejection charge.

Next, the model rocket setup could be mounted to a milk crate with bungee cords. One bungee was mounted to resist the engines thrust laterally and the other to hold the rocket down, which eliminated all movement. Finally, a second larger water jug was placed in the milk crate to weigh-down the entire set up.

Now a motor can be placed inside the homemade thrust stand and have the igniter wires inserted. These wires are long enough to run away from the set up to a safe distance. The igniters require a specific voltage and current to ignite given their resistance. The 9-volt batteries selected were too old and drained, so new ones had to be acquired. Even still the 2 9-volt batteries had to be used in series to maximize their current capacity to match the minimum all fire current of the igniters. This step and ignition were all assisted by my roommate so I could take the photographs.

The final part of this set up was the camera, which was mounted on my only tripod. Its height was the reason the thrust stand had to be elevated on the milk crate. To protect the camera lens from any errant sparks, a sheet of clear acrylic was placed in front of the lens mounted on a cardboard box. For the best results, this was done in a dark location at night with no lights in the background. For safety, each of us wore eye and hand protection. An ABC fire extinguisher was on hand, and a concrete surface with nothing flammable nearby was chosen as a firing location. With all of this in place the motor could be lit, and the photography could begin.



Photography Specs

This image was shot on a Sony Alpha 6300 Mirrorless camera system with a 24.2-megapixel APS-C sensor. The lens used was a Sigma 18-50mm f/2.8 DC DN Contemporary lens. The lens was approximately 50cm away from the motor while being roughly in line with the tip of the motor. While being set at a focal length of 45.9mm, which translates to a 68.85mm focal length with the APS-C sensor used. The final image was a size of 6020 pixels by 4024 pixels, and the original RAW photo was a size of 6000 pixels by 4000 pixels. The goal of the shot was to be as close as possible to the exhaust while still having most of the exhaust in the frame. The listed specifications are mainly just a byproduct of the camera I used.

However, the settings I did actively chose with a purpose are listed as follows. An aperture of f/4.0, a shutter speed of 1/640, and an ISO of 500. All of which were set by me in the cameras manual mode with the camera being in auto focus mode. These choices were set by taking photos of a lighter in the same conditions and using that as a reference. It was a tricky process as you could not see the subject in the view finder until the flame was lit. This made the process of photographing the exhaust hard as it was not known how it would show up in the frame until it was lit and then you only had a second to take the photo. Given the limited resources at my disposal, I would have liked to try a shorter shutter speed, to the camera's max of 1/4000, to try and freeze the exhaust as much as possible, which was my desired effect.

The image processing I did on this image mostly revolved around the exposure settings. Turning up the exposure allowed the image to sharpen up and see more of the exhaust lines in the image. On top of this I also played with the color calibration and color equalizer to get a warmer image and get more out of the red, orange and yellow colors, so they were bolder. That was the extent of the image manipulation. I would have liked to crop the image, but I did not like the crop and rotation options in Darktable, the image processing software used.

Before Photo After Photo

Science Behind the Flow

The flow itself is a main red orange converging column of thrust gas with numerous extraneous particles expanding out from the main column in a cone shape of similar color. Hot, high-pressure combustion products are accelerated through the nozzle, converting pressure and thermal energy into directed exhaust velocity, producing thrust. NASA describes this flow process and nozzle accelerated combustion, with the actual thrust depending on mass flow rate, exhaust velocity and exit pressure, (NASA Glenn Research Center, n.d). After leaving the nozzle, the exhaust interacts with the surrounding air through a shear layer. The plume therefore spreads and becomes less concentrated downstream as the ambient air is entrained until momentum is transferred from the exhaust to the surround fluid. Experimental studies of rocket plumes similarly describe the near-field plume as behaving like a free jet with turbulent mixing and entrainment, (NASA Glenn Research Center, n.d).

Given the camera settings listed above, the motor diameter in the picture can be approximated at 42 pixels, which gives the following scale and exposure time.

$$S = \frac{18\,mm}{350.8\,pixels} = 0.0513\,\frac{mm}{pixel} \qquad \Delta t = \frac{1}{640} = 1.56 \cdot 10^{-3} s$$

Using the visible streaks as flow tracers, a representative long streak close to the middle of the plume was approximately 1500 pixels long, which corresponds to:

$$L = (1500\,pixels) \cdot S = 76.97\,mm = 0.077\,m$$

The corresponding apparent streak velocity of the exhaust is therefore calculated as the following.

$$V = \frac{L}{\Delta t} = \frac{0.129\,m}{1.56 \cdot 10^{-3}\,s} = 49.35\,\frac{m}{s}$$

This velocity should be interpreted as an estimated velocity of the visible plume material, rather than the actual nozzle-exit gas velocity. The exhaust velocity varies drastically at different points in the flow, therefore the further out your streak line is from the center column the slower it will be. The image below shows how far my chosen streak line is as the closer to the column of thrust you are the harder it is to make out individual lines. This is solely a good estimating technique and to get an understating of the physics going on in the photo.

(PixelMeasures, n.d.)

Future Discussion

This image reveals the complexity of caricaturizing and modeling the flow from solid rocket motors. Overall, I like the colors I was able to capture, the completely dark background, and the shape of the exhaust. I don't love how I was not able to get the entire flow in frame. I also wish that I was able to capture the flow at max thrust. I think the physics are shown well by both the color and detailed amount of streak lines. I do wonder what this flow would look like in video form or on a high-speed camera? Those would be directions I would be interested in continuing. Along with using different motors as they can come in different exhaust colors. I think my intent to capture the flow of a solid rocket motor exhaust was well achieved.

Works Cited

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