SRM Submergent Nozzle Particle Breakup Analysis

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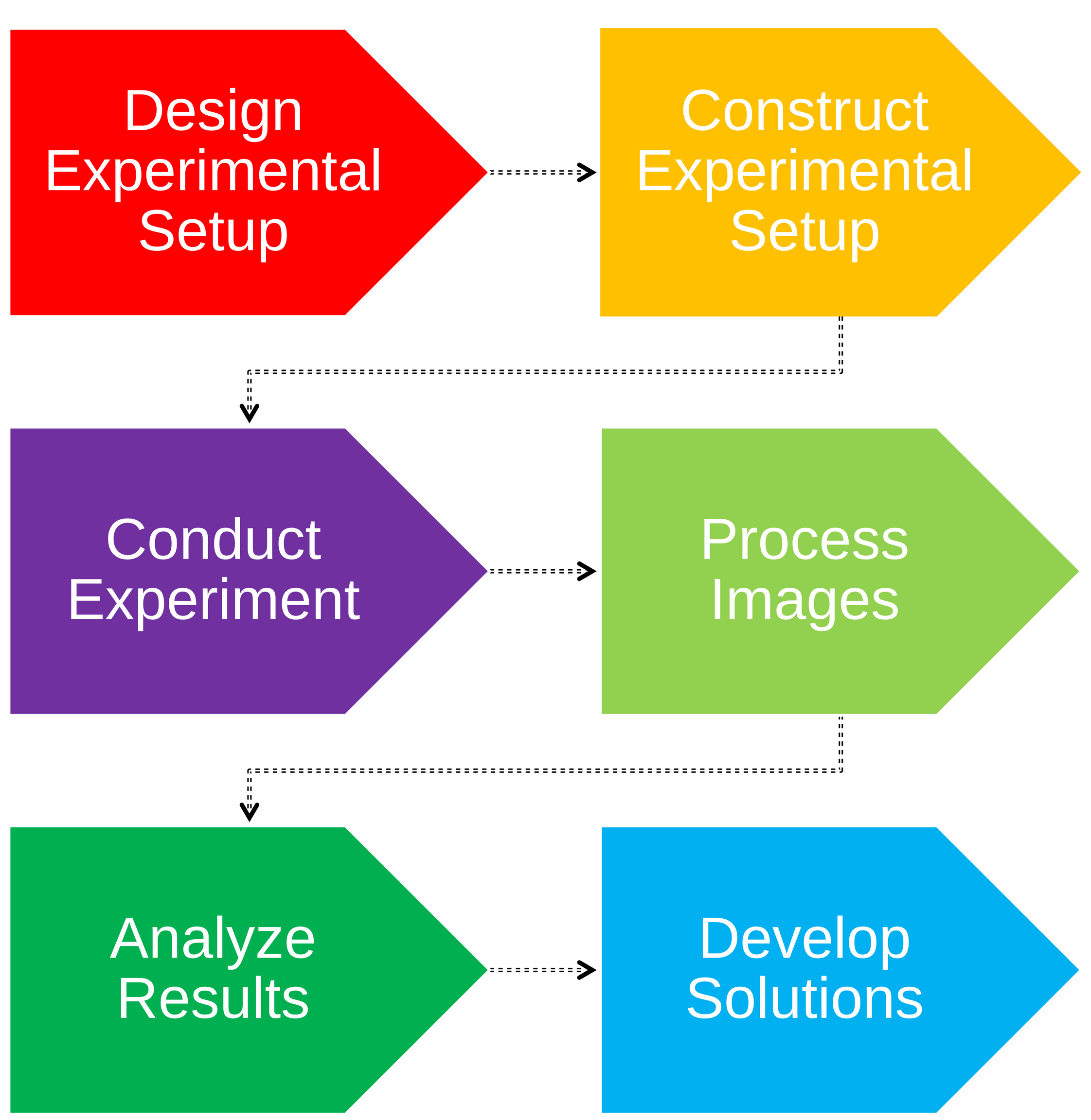
Background

Solid rocket motors primarily use aluminized composite propellants as fuel. As the propellant combusts, it forms aluminum oxide (Al_2O_3). At high temperature and pressure, the aluminum oxide tends to agglomerate into molten droplets which cover the nozzle walls and flow from the throat to the exit. By eroding the nozzle walls (specifically in the throat), the aluminum oxide conglomerate negatively effects the ballistic performance of the rocket. Proper investigation of this phenomenon is crucial to develop solutions to the solid rocket motor erosion problem.

Objectives

Previously, our groups has conducted research to investigate the particle break-up tendencies in the convergent-divergent nozzle of a solid rocket motor.[1] Currently, we are investigating the break-up tendencies in the submergent nozzle, a common nozzle used in SRMs that has “pockets”, altering the break-up of aluminum oxide (see Figure 2).

Approach



Methodology

Figure 1 shows the diagram of the experimental setup used to conduct the experiment. In order to simplify the experimentation, we utilized a two-phase flow of air and water to represent the aluminum composite propellant as it combusts and forms aluminum oxide and gas for thrust.

The nozzle is made of acrylic, so the break-up phenomenon is visible to the camera. A tank beneath the nozzle with connective hose supplies the water to the top of the nozzle. The air is supplied by a blower situated at the top of the setup. The speed of both the air and the water are adjusted to analyze the liquid break-up at different velocities. A backlight is placed behind the nozzle to illuminate the setup, making it easier for the camera to see the droplets and to analyze the break-up with MATLAB code. The camera, a Photron Mini UX50 (Figure 4), shoots at 2000 frames per second with a capture rate of 1.09 seconds and the image contrast is adjusted accordingly.

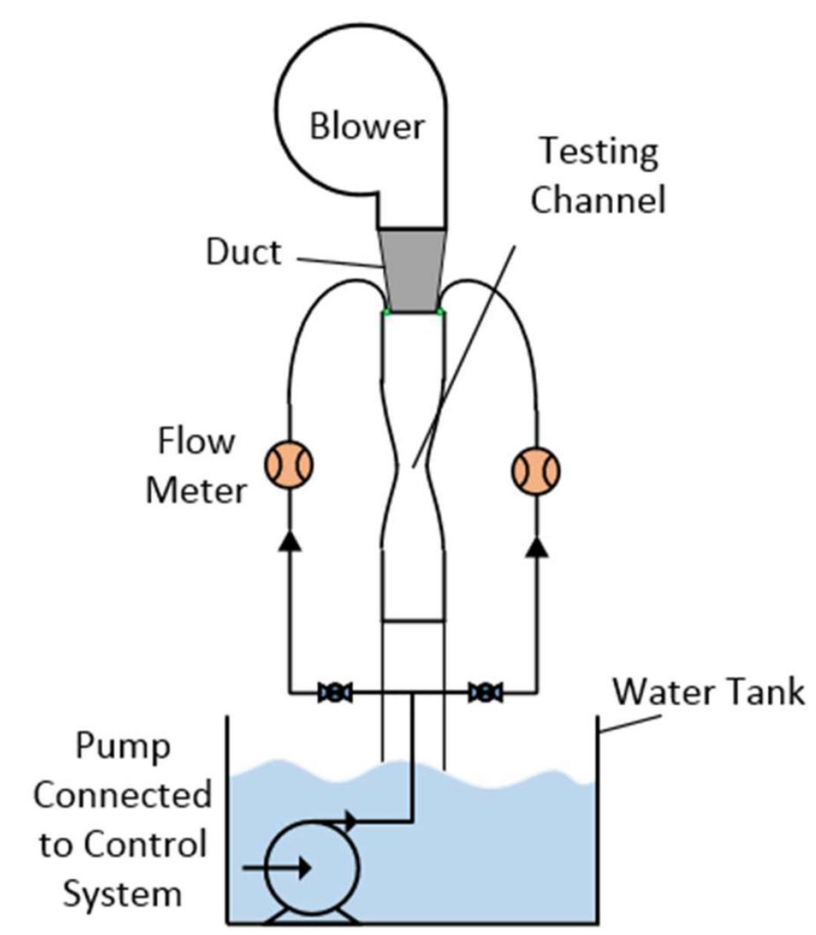


Figure 1 – Experimental Setup

Figure 4 – Photron Mini UX50

Currently, our team is on step 2 of the experimental process: construct the experimental setup. We are machining the acrylic to simulate a submergent nozzle. When that is finished, we will conduct the experiment, record the data, process the images using MATLAB, and analyze the results using a computational fluid dynamics (CFD) program, Star CCM+.

If the experimental results are similar to the results from Star CCM+, we can consider the program verified. This allows us to use the program by altering conditions such as extreme heat, extreme temperature, or surface tension that can not be achieved in the lab.

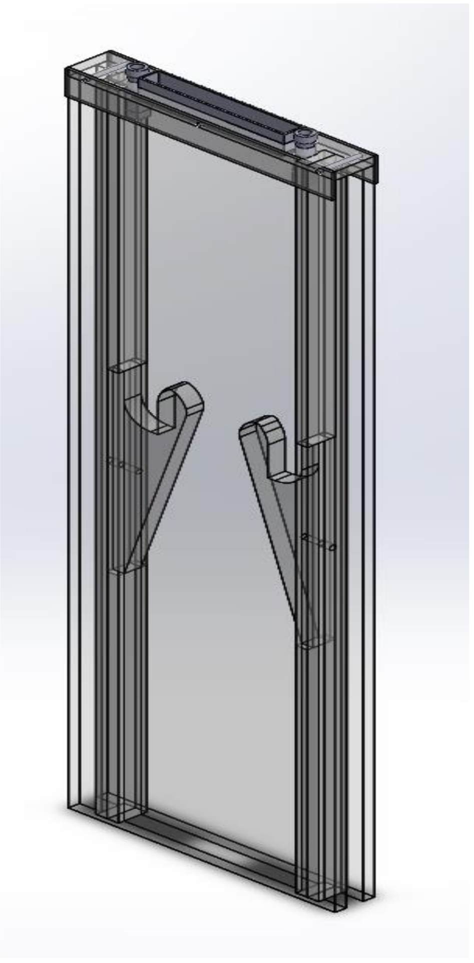


Figure 3 – Submergent Nozzle Design

Past Results

In the investigation of the CD nozzle, we were able to conclude that as air and water velocity increase, the breakup phenomenon increases in number and moves down the throat toward the exit. We were able to model the data in Star CCM+ and simulate the effects of reducing the aluminum composite’s surface tension by adding Strontium or Lithium; in general, the reduced surface tension increased the number of droplets formed per frame.[1]

Figure 2 shows an example of a raw image, a processed image, and the highlighted droplets to be considered.

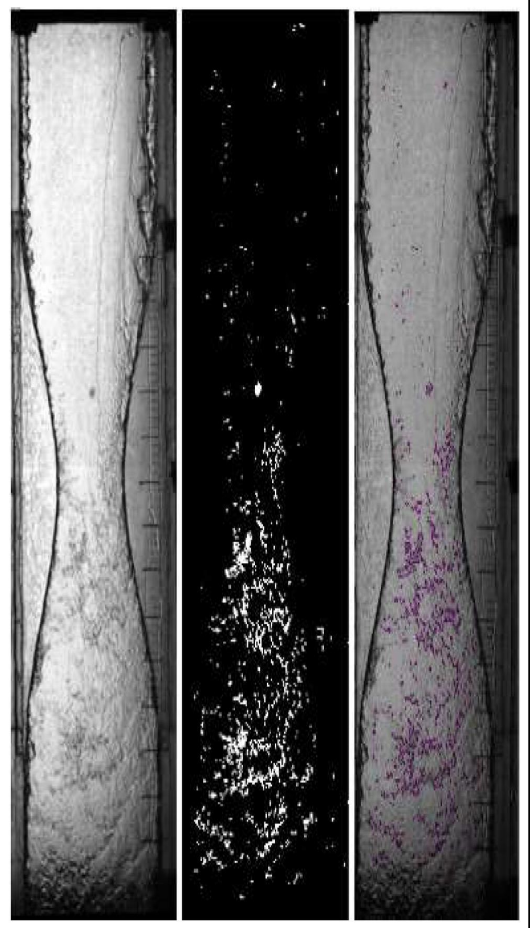


Figure 2 – CD Nozzle Results

Conclusions

The results of the study will reveal whether a submergent nozzle reduces the erosive effect of the aluminum oxide droplets when compared to the commonly used convergent-divergent nozzle.

In addition to the nozzle selection, a proper understanding of how different velocities of air and water effect the breakup tendencies within the nozzle is crucial to develop solutions to the erosion problem.

Space exploration is becoming a much more accessible industry and is on the verge of becoming commercial. A solution to erosion from aluminum oxide in solid rocket motors would cut immense costs because boosters have the capability to be reused for numerous trips. This study aims to develop a solution that will drive the space industry further into the (much more affordable) future.

Bibliography

1. **Abousabae, M., Casper, C., Amano, R.: Investigation of Liquid Droplet Flow Behavior in a Vertical Nozzle Chamber[thesis].[Milwaukee(WI)]: University of Wisconsin-Milwaukee; 2020.**
2. **Chen, W., Amano, R.: Investigation of Liquid Breakup Process in Solid Rocket Motor Convergent-Divergent Nozzle[thesis].[Milwaukee(WI)]: University of Wisconsin-Milwaukee; 2019.**

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