SMORE Revision: Ignition and User Interface

A Senior Project by:

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Abstract

The Static Methanol Oxygen Rocket Engine (SMORE) has undergone several revisions since its inception. This latest revision aimed to increase startup reliability and user safety in the operation of the rocket. The implementation of maintenance procedures, safeguards in the ignition system, as well as construction of a new control box and redesign of the igniter itself have accomplished these goals while keeping costs down and without modifying the current rocket setup. Startup reliability has increased drastically, so long as all other rocket setup procedures are followed properly. 250 subsequent firings of the rocket have proven an igniter reliability of more than 90%. All parts replaced and manufactured in this report have been well documented to ensure ease of maintenance in the future.

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I. Introduction

The Static Methanol Oxygen Rocket Engine (SMORE) was based off of a senior project in 1998 by Noelle Cahill that used guidance from a paper published in 1967 by Leroy J. Krzycki titled “How to Design, Build and Test Small Liquid-Fuel Rocket Engines.” As its name describes, the SMORE is a bipropellant rocket utilizing liquid methanol and gaseous oxygen. It’s situated vertically on a test stand, within which a load cell measures the upward force exerted by the rocket’s thrust. The SMORE has been updated over the years to utilize elements such as a more refined/safer fuel delivery system, a new combustion chamber, and improved pressure regulation system complete with electronic solenoid valves controlling fuel and oxidizer flow. However, despite several revisions it still does not implement a reliable ignition setup, and its user interface leaves much to be desired from an operation standpoint (namely rocket startup). In this revision, the current ignition setup will either be modified or replaced in favor of one that provides a reliability of 90% (ideally) and contains safeguards against a short circuit that can cause damage to the ignition coil and power source used. A new control box will also be created for the purpose of reliability and ease of operation, as well as operator safety. In addition to these two modifications, several miscellaneous fixes were also performed on the rocket. Items replaced were related to the sealing of fluids/gasses and were off the shelf parts whose part numbers/manufacture were recorded to ensure ease of procurement for future maintenance. To reiterate, the goal of the redesign at hand is to achieve a startup reliability of 90%, to implement safeguards against the shorting of the ignition coil and power supply, and provide improved safety for the test operator. The solution for rocket startup must be repeatable, inexpensive, and must be accomplished while not unreasonably modifying the current rocket setup.

II. Apparatus

Figure 1 is a schematic describing the SMORE system.[1]

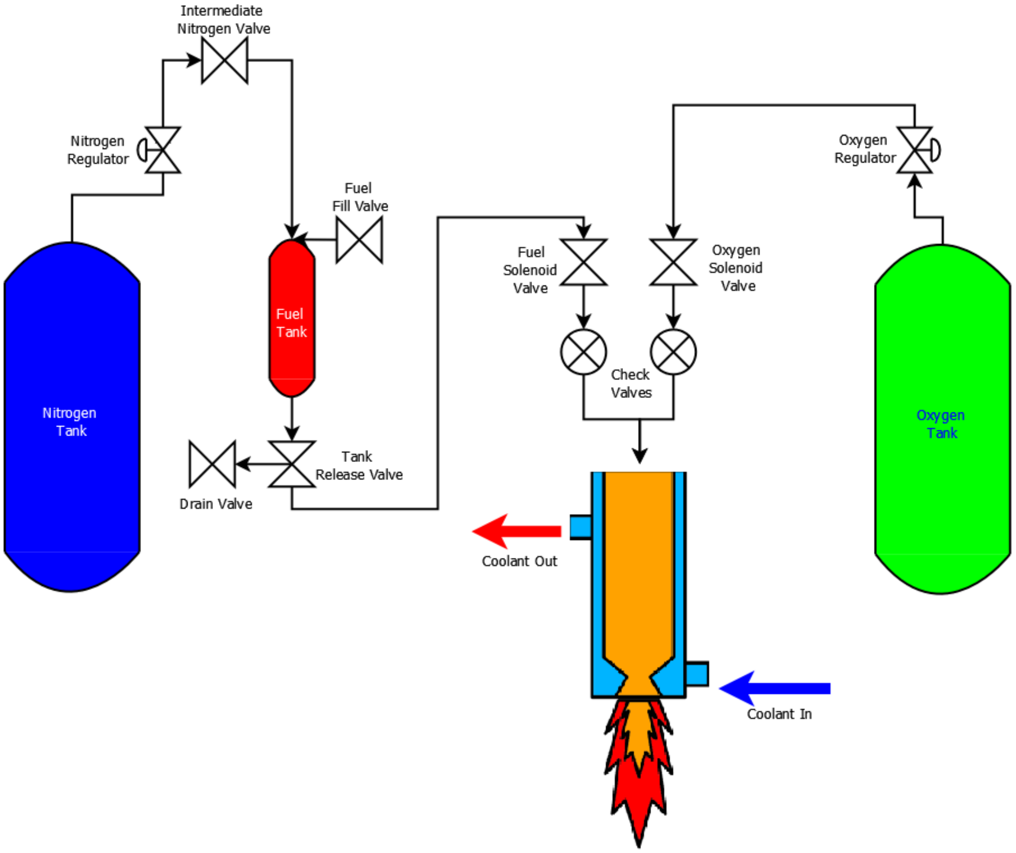

Figure 1. SMORE schematic detailing pressure fed system.

The SMORE is a pressure-fed bipropellant rocket using oxygen and methanol. The methanol is held in the fuel tank and is fed to the combustion chamber injector via nitrogen pressure in a blow-down system. Both nitrogen and oxygen tanks are pressure regulated and utilize in line check valves and electric solenoid valves (ESVs) to provide flow control from a switch box within the control room. The rocket itself is water cooled to maintain longevity of the copper combustion chamber, and coolant is fed and expelled with a simple garden hose. Data regarding performance and design of the rocket can be found in [2] and [3]. Figure 2 shows the portion of the SMORE this report is more concerned with – the three-piece assembly of the combustion chamber, injector plate, and cooling jacket.[2,3]

Figure 2. Injector plate, combustion chamber, cooling jacket. Assembled on left, exploded view on right.[2,3]

The left picture shows the components on the right (from top to bottom: injector plate, combustion chamber, cooling jacket) assembled. The interface between the injector plate and combustion chamber requires an aluminum washer for sealing. This acts as a crush gasket when the assembly is tightened using the four threaded rods and nuts shown. Tightening of these nuts also provides a watertight seal between the bottom of the combustion chamber and the inside of the cooling jacket. This watertight seal is also maintained towards the top of the assembly with the use of an o-ring placed within a groove machined into the diameter of the injector plate. These two sealing elements are crucial to rocket operation in that they provide secure containment of combustion and leak-free flow of coolant. It's important to note that these are consumable items, and their replacement will be covered later in the report.

III. Rocket Ignition

History

The SMORE igniter had its humble beginnings as a single 14 gauge copper wire placed a couple millimeters away from the nozzle exit (also copper). Using a DC motor to generate current, an electric arc was created between this wire and the grounded rocket while fuel and oxygen were turned on simultaneously. The main issue with this setup was that ignition occurred at the exit of the nozzle, not directly inside the combustion chamber. Fuel and oxygen pressures needed to be started very low and then throttled up manually once the flame had moved up into the chamber to create full, stable combustion inside the rocket combustion chamber. On top of that, the reliance of the wire being a very close distance to the nozzle exit made its placement/securing difficult and inconsistent, as any slight disturbance would knock the wire too far away from the rocket to create an arc. This proved to be a very unreliable and not very safe means of rocket ignition, as it left much room for user error.

The first redesign of the igniter came about in a previous senior project by Christian Soria.[2] This involved priming the combustion chamber with 30PSI of propane gas, and creating a "pilot light" of sorts using wires placed inside the combustion chamber. It was hypothesized that upon lighting the propane, oxygen and fuel flow could then be initiated to create stable combustion well inside of the combustion chamber. This method failed unfortunately, due to the fact that the oxygen and fuel were pressurized to 300PSI. The sudden introduction of pressures ten times that of the ignited propane immediately blew the flame out of the combustion chamber instead of lighting successfully. Although the implementation of propane was scrapped, the wiring concept and means of creating an electric arc inside of the chamber created in this revision have been built on in this current redesign. Soria's senior project utilized an automotive spark generator (MSD ignition coil) that produced a continuous arc between two copper wires when given a DC supply of 12V and 0.5A. One wire was connected to the spark generator by means of a transition to thicker copper wire secured to its spark plug receptacle output with electrical tape and the other to ground, while the other ends of both wires were stripped to expose a small amount of copper and then taped together as shown.

Figure 3. Igniter wires secured with tape.

The wires were then snaked up into the rocket combustion chamber, and remained up there by means of their own stiffness. This was the method used (minus the propane of course) to ignite the SMORE up until this current revision. Taping was a bit tricky due to the limited nozzle throat area – the combined thickness of the wires and tape had to be closely watched for the entire package to fit through the nozzle freely. While it performed much better than the previous iteration, it was still inconsistent in its operation, and had no repeatable means of ensuring that the wires are placed at the proper height and in the center of the combustion chamber. Ignition failures not only mean no data, but can also lead to a dangerous condition in which excess methanol is spewed out of the rocket. Some downtime is required in between failed runs due to large amounts of unburnt methanol expelled from the rocket needing cleanup.

Current Revision

Since the last design iteration, a fuse and diode have been placed in the ignition power circuit. The fuse will prevent damage to the ignition coil in the event of excess current being drawn due to a short between the wires inside the thrust chamber, and the one way electrical flow ensured by the diode is intended to protect the power supply in such an event as well. The power supply being used up to this point was determined to be too precise (and therefore expensive) for the needs of this setup. After speaking with the manufacturer of the ignition coil (MSD), it was confirmed that a 12V DC power source such as a car battery or car battery charger would be suitable for the task. The main advantage in implementing one of these is the fact that they simply cost less, and in the event of a failure could be more readily replaced. Fortunately for the SMORE (and the prop lab as well), Jeff Maniglia in working on his thesis to construct a railgun had recently set up 5V, 10V, and 12V DC power sources that contained a sufficient number of outputs to allow the SMORE ignition coil (as well as solenoid valves, control box, and DAQ) to use them.

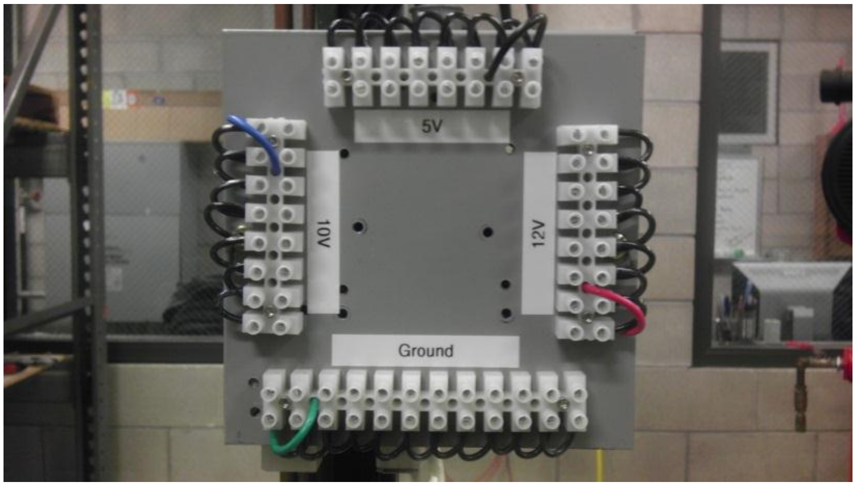

Figure 4. Power supply set up by Maniglia, utilized in part by the SMORE.

Since the MSD ignition coil had proven to be a reliable method to generate an electric arc capable of igniting the methanol/oxygen mixture at pressures above 300PSI, the igniter itself was taken on next. As mentioned previously, the latest design revision up to this point was many times prone to not lighting the flow of fuel due to placement issues. The first alternative considered was the use of an automobile spark plug. This would potentially give the easiest interface to the MSD ignition coil, and would also be inexpensive to the point where it could be replaced after each test if need be. Another advantage would be its capability of being hard-mounted in a set location, but this is where the spark plug proved troublesome. In order to integrate it to the top of the rocket engine, all the fuel and oxidizer hard lines would have to be rerouted, and this would unfortunately be beyond the scope of this project. If the spark plug were to come in through the side of the combustion chamber, issues would arise in sealing between the thrust chamber and cooling jacket area, as well as potential flow irregularities. Therefore, due to difficulty of integration into the current rocket design the spark plug was set aside. Another idea was to fasten rods inside of the combustion chamber, coming out of the injector hat and combustion chamber wall and ending in very close proximity to another. One part would then be grounded, and the other fed voltage from the MSD ignition coil. This would act as an internal spark plug of sorts, but would require that the injector hat and combustion chamber be electrically isolated from one another so a potential could be generated between the two rods inside. Needless to say, this would be a very complex task considering all of the metal to metal interfaces connecting both parts, as well as the water jacket running around both of them.

A third and much simpler idea was to build upon the current design of jamming wires up into the combustion chamber and having them blow out immediately following ignition/flow of high pressure fuel/oxygen. The wires would need to have a consistent means of being secured, centered, and held up stiff to a known height within the combustion chamber. The major constraints here were the small diameters of the rocket nozzle throat and exit (.243” and .465” respectively) and the fact that the wires would need to swing out of the way of the nozzle exit on ignition so as not to impede thrust or observation of the rocket exhaust, or catch fire. These constraints were clearly much more negotiable than those presented by the other two igniter design ideas, and it was decided without much hesitation to move forward with this attempt. The wires would need to be stiff enough to support themselves vertically (or a flame retardant stiffener rod would need to be secured to them) while remaining small enough in diameter to fit nicely through the nozzle throat. Initially, it was hypothesized that a cork or rubber stopper could accomplish the task of repeatedly securing the wires in the same spot in the combustion chamber. The wires would be fed snugly through the stopper, and the stopper would be placed firmly into the nozzle exit. The main issue anticipated with this modification pertained to the fact that the stopper was essentially plugging the nozzle exit, and there was also the question of whether or not the arc induced between the wires would be active for a long enough period of time to ignite the transient response of 300+PSI of methanol/oxygen. Despite these concerns, it was felt that the assumption that 300+PSI would pop out a cork placed in by hand was valid. Regarding the total time of arcing between the wires before they were shot out, the sparking frequency of the MSD ignition coil was to be determined. After speaking with an MSD representative, it was found that the ignition coil actually provided a continuous arc of

10000+V while supplied the appropriate amount of DC power discussed earlier (this was of course verified visually.) Therefore, due to the on-off nature of the igniter, time analysis of the ignition system was replaced with a much simpler empirical test to just see if it would work. Testing began with the selection of a size 000 tapered cork stopper with a single ~.210” hole drilled through its center. Wires used were 14 gauge solid copper wires (Mcmaster p/n 7125K413) that were stiff enough to support their own weight/shape in a vertical orientation. The wires were connected to the MSD ignition spark plug receptacle as done previously, and to a new ground location provided by the aforementioned power supply grid set up by Maniglia. The wires were then run through the hole in the cork about 3” and had their ends stripped very slightly to expose a minimal amount of copper to help prevent any possibility coming into direct contact with one another and causing a short circuit. Due to the space constraint of the nozzle throat, the wires were taped together with a sparing amount of 1mil Kapton tape.

Results/Refinement

The design revision proved immediately successful, causing stable ignition inside the combustion chamber while subsequently moving out of the way of the nozzle exit enough to remain intact for several more runs. Through experimentation it was found that ignition was successful every run, so long as the spark and fuel/oxygen were run properly via the control box (more on that subject in the coming sections of this report). The wires selected performed well enough to remain unchanged, but the cork stoppers were eventually upgraded to size 000 rubber stoppers containing two preformed holes, as shown in Figure 5.

Figure 5. Size 000 rubber stopper, two preformed holes.[4]

The two preformed holes eliminate the need for manually drilling a path for the wires to run through, thereby saving setup time. They also do a great job of holding the relatively stiff wires close enough together such that a slight twist of the wires by hand is sufficient to provide a close enough proximity between the end to accommodate a reliable arc. Further experimentation revealed that this igniter setup is very forgiving in its setup with respect to properly lighting the fuel/oxygen mixture inside the combustion chamber. It was found that the wires could be fed up out of the stopper anywhere from 1”- 3” and have a gap between them of several millimeters at their ends and still provide stable ignition. This is due to the fact that the MSD box provides a large enough voltage to enable an arc that’s rather robust. Final setup of the new igniter is as follows:

The wires are soldered to the ground wire and the MSD ignition coil wire and covered with heatshrink. An arbitrary length of wire may be used in this case – through experimentation thus far it has been seen that about 3 feet of wire will provide at least 15 startups before requiring replacement and soldering. Next, the ends of the wires are stripped very slightly (usually with a pocket knife) and are run through the size 000 rubber stopper for 2” +/- 1” – this length is very flexible relative to the internal length of the combustion chamber. The ends of the wires can then be twisted together very slightly to help ensure they remain in close proximity once placed inside the combustion chamber.

Figure 6. Igniter wires snaked through stopper, twisted together with stripped leads facing each other.

Finally, the stopper is placed snugly into the nozzle exit, and the wires are bent out of the way appropriately. The entirety of the igniter setup is attached to the test stand in a way such that it swings out of the way of the rocket exhaust a sufficient amount. While not the most aesthetically pleasing setup, it’s proven to be very robust thus far, having successfully ignited the fuel and oxidizer mixture in the combustion chamber every time it was set up according to this procedure.

Figure 7. Igniter placed in nozzle exit, secured by stopper.

In conclusion, the new revision of the igniter design has been empirically proven to provide a very reliable means of stable rocket ignition. When coupled with the ease of fuel control provided by the new control box described in the next section, the initial goal of 90% startup reliability has in fact been exceeded with respect to the ignition source (this is of course assuming all other procedures for rocket setup have been followed). Figure 8 shows a picture of the rocket before and during firing – it's made clear that the igniter moves well out of the way of the rocket exhaust while in operation.

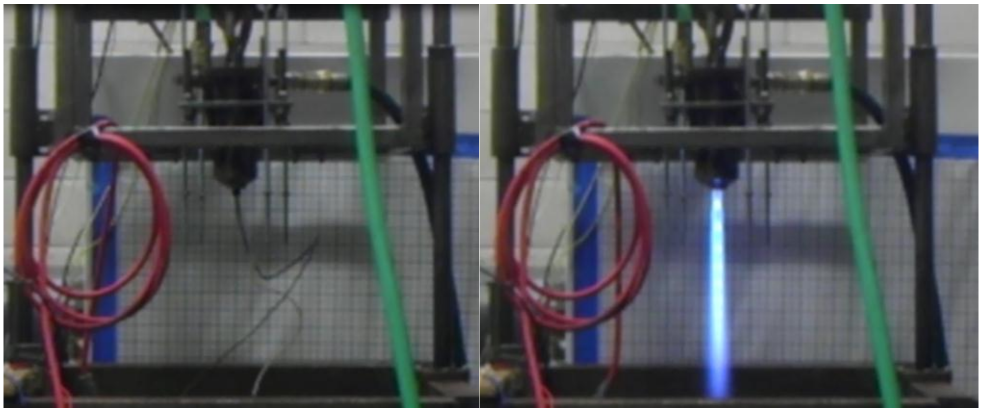

Figure 8. SMORE before firing and during operation.

IV. Control Box

The control box was looked into next, as it is the direct user interface to the SMORE. The box utilizes a master switch, a toggle switch for spark generation, and on/off switches for the electronic solenoid valves (ESVs) controlling fuel and oxygen flow. While this setup worked fine, it required that the operator flip both the fuel and oxygen switches at the exact same time while holding the spark toggle switch open in order to properly ignite the rocket. While this was not terribly difficult to accomplish with some practice, it was an operation that could easily be improved upon to lessen the potential for user error and enable much more consistent rocket startup. In response to these issues, it was decided that a new control box be made. This would improve upon the previous design by using a push-button toggle switch for the spark, and more importantly a main fire switch that would be wired in series to the fuel and oxygen switches. These switches would now arm the fuel and oxygen systems as opposed to simply opening their respective ESVs, and the ESVs could be opened individually or simultaneously using the fire switch. The box itself was also remanufactured using a 12” long, 5” wide 6061 aluminum c-channel (McMaster p/n 1630T362). The bottom legs and top of the c-channel were milled down slightly to ensure flat, even surfaces – this process is pictured below.

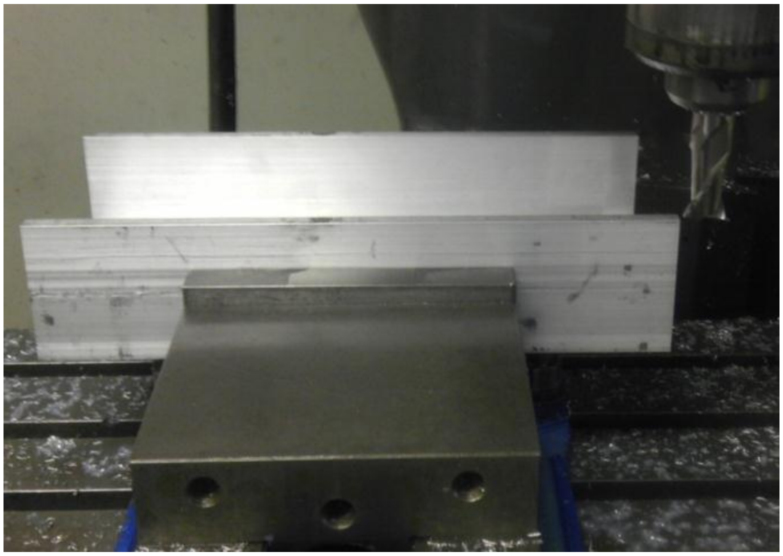

Figure 9. C-channel milled to ensure flat surfaces.

Following this, appropriately sized holes were drilled for the switches required, and the switches were wired and installed. The finished product is seen in Figure 10.

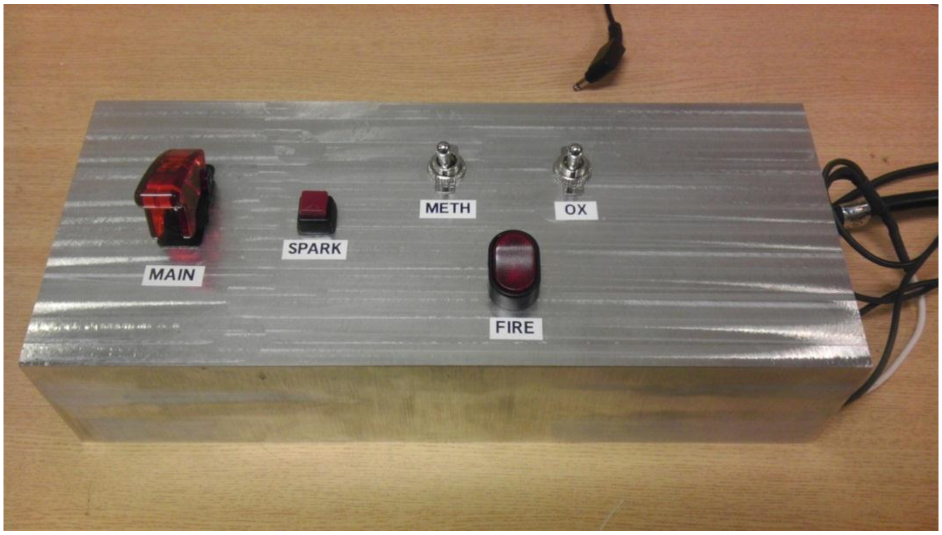

Figure 10. Finished control box.

To review, a new push-button toggle switch was added for spark control, and a fire switch was also added, wired in series with both the fuel and oxygen arm switches (both new switches were sourced from RadioShack). Again, this allows both ESVs to be opened at the exact same time by arming them and flipping the fire switch. In the event of a pressure test or the desired release of solely oxygen, just one of the ESVs can be armed and opened with the fire switch, allowing for individual control if need be. While the switches were spaced evenly, room was left open towards the right end of the new control box to accommodate any future additions for further control/data acquisition of the rocket.

V. Maintenance Items

In the interest of prolonging the use of the SMORE, several miscellaneous components of the rocket were replaced due to wear. A few of the compression fittings used for the oxygen hard lines were replaced to ensure no leaks, and also since the brass nuts securing them were beginning to round off. These fittings were easily sourced from McMaster (p/n 5220K205). The aforementioned combustion chamber sealing elements were looked into next, and are pictured below.[2]

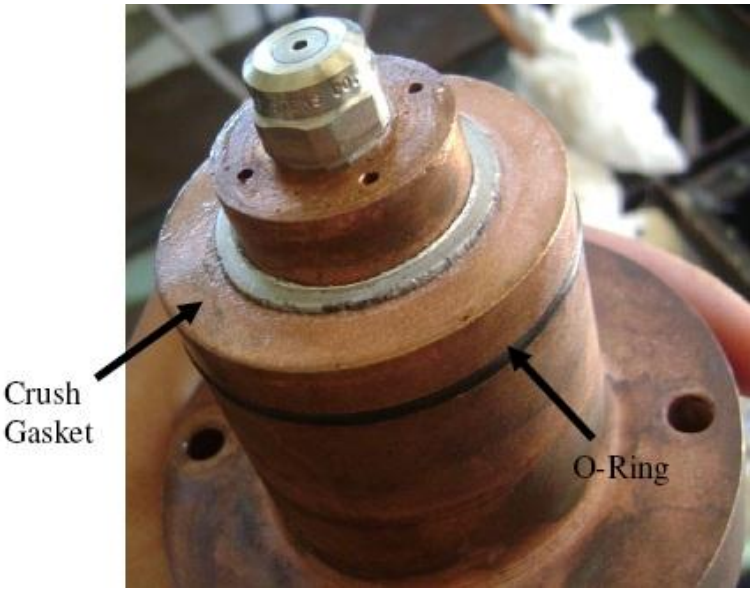

Figure 11. Rocket injector plate with o-ring and aluminum crush gasket.[2]

Because the SMORE had been disassembled/reassembled many times, it was likely that the aluminum washer was a bit worn out. Unfortunately, it appeared that the washer was a "custom part" with little documentation; a past SMORE report reads that it was obtained at an arbitrary auto parts store and then made to have a larger ID with a rotary grinder. Due to the lack of info on this part, its replacement then became a task to document its manufacture and proper dimensions. This will take out the trial and error experienced here for future replacement. A 1.5" OD, 1" ID tube of 6061 aluminum was purchased from McMaster, and the interior of the tube was turned using a boring bar.

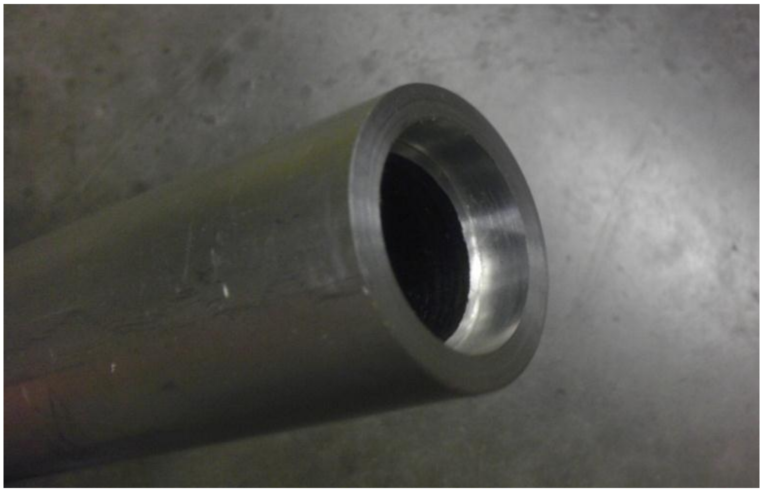

Figure 12. Aluminum tube used for manufacture of washers.

After a few attempts and fitment checks, a 1.14” ID was settled upon, and the tube was then parted in .100” increments (of course feeding in the parting tool slower will provide a smoother washer surface). The manufactured washer has performed well in sealing the combustion chamber for 250 runs thus far (stated by Kyle Johnson in thesis work using the SMORE), and future replacements can be made by simply utilizing the machined tube.

The final “maintenance part” looked into in this report was the o-ring creating a seal between the injector plate and combustion chamber. The original one was dried out and badly cracked upon inspection, and it was deemed necessary to replace. After some research, it was found that this part was also not documented well. A previous report only specified that the o-ring was a custom part that would need to be “cut to size”. Several types of o-rings of varying dimensions were ordered based on measurements of the injector plate groove in which they would be placed. All of these were tested by removal/reinstallation of the combustion chamber and cooling jacket and then the introduction of water as done for a live test to ensure no leaks were present. After numerous attempts, it was found that the best seal for the cooling jacket in use at the time was a size 220 EPDM o-ring (McMaster p/n 9557K489) with Teflon tape wrapped around it (three times), seen in Figure 13.

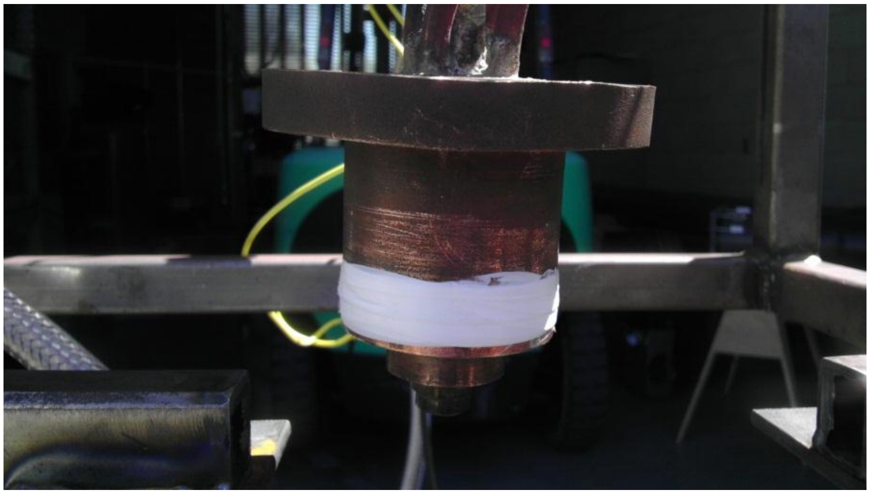

Figure 13. Sealing method for injector plate to cooling jacket interface.

This was not quite the desired solution, but given the selection of sizes readily ordered online, it was one of the better options created. This sealing setup worked well through the use of the old cooling jacket until it was replaced with a new one by Kyle Johnson, as part of his work on the SMORE towards his thesis. Fortunately, the tighter tolerances of the newly machined cooling jacket allowed for a complete seal of the injector plate interface using only the aforementioned o-ring.

While the SMORE does have a number of other small parts that could use replacing, the three discussed here were the most necessary to get the rocket running properly and safely. All parts replaced have been documented here with part numbers and/or steps to manufacture to ensure that future replacement is a much more straightforward process.

VI. Future Work

Through the course of this report it has been shown that the reliability of the SMORE has been increased greatly with regards to stable ignition and user control. Although the additions and modifications made to the rocket have all proven successful, there is always room for improvement. Of course many of the current setup steps of the SMORE can potentially be automated – oxygen/nitrogen pressure regulation and coolant flow control just to name a couple. However, this section is more concerned with improvements relating more directly to the topics covered in this project. The current wiring scheme for the ignition system does move away from the rocket plume a sufficient amount, but can be made more predictable in its function with the utilization of a hinge. This could be bolted to the rocket test stand frame and attached to the igniter wires in a manner that would ensure a consistently larger distance between the wires and rocket plume after their exit from the combustion chamber. Such a hinge would therefore benefit the ignition system by providing longer intervals between trimming and/or replacement of the igniter wires and stopper. Another basic potential improvement would be the implementation of a more efficient pressure test for the SMORE combustion chamber. The current method employed for this periodic test requires removal and reinstallation of the cooling jacket to insert an aluminum plate between it and the rocket nozzle exit, sealing the combustion chamber. Because the setup needs to be disassembled and reassembled once more to remove the aluminum plate after the pressure test, exact configuration of the rocket has been broken, and the reinstalled rocket assembly is technically not proven to be leak free. The development of a means to perform this test without rocket disassembly would alleviate this issue, not to mention saving the test operator a significant amount of time.

VII. Conclusion

Since its inception, the SMORE has been an ever-improving rocket setup. In this revision, usability was greatly increased by the development of a reliable, repeatable igniter setup and the creation of a new control box providing more user-friendly operation of rocket startup. The new ignition setup was built directly off of the previous method of insertion of wires into the combustion chamber, with the addition of a convenient rubber stopper and safeguards in igniter circuitry to prevent damage to its spark generator or power source in the event of a short circuit during operation. The new control box introduced the capability of simultaneously opening the two ESVs controlling fuel and oxidizer flow with just one switch, greatly reducing the potential for user error in rocket ignition. The coupling of these two improvements has met the initial goal of a 90% or greater reliability for stable ignition of the SMORE with respect to the systems implemented, while maintaining simplicity in design and low cost. This reliability claim is based off of about 250 firings of the rocket in which it was found that any failure to fire was due not to the igniter or control box, but instead to user error in rocket setup. Several consumable items were also replaced to ensure components of the rocket dealing with fluid flow and combustion remained sealed. These items – an o-ring, crush gasket, and oxygen hard line compression fittings – were all documented in this report to guarantee ease of maintenance in the future. These improvements and resulting repeatability of operation have allowed the rocket to be used in undergraduate lab experiments more effectively as well as in graduate research. Now that a reliable means of operation has finally been established for the SMORE, future projects can focus more towards tasks such as refined data acquisition and increases in performance.

Appendix

A. Parts

Rubber Stoppers: size 000, two hole, onlinesciencemall.com p/n STO30321lb

O-ring for injector plate: -220 EPDM, McMaster p/n 9557K489

Solid copper wire for igniter: McMaster p/n 7125K413

Brass compression fittings for oxygen hard lines: McMaster p/n 5220K205

References

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2. Soria, C., SMORE Phase 2: *An Upgrade in Valve Systems & Startup Procedure for a Small Methanol Oxygen Liquid Rocket Engine*. Senior Project Paper, Aerospace Engineering Department, California Polytechnic State University, CA 2010.

3. Morantz, C. N. and Sanchez, J. S., *Design, Construction and Testing of a Small Static Methanol/Oxygen Rocket Engine*. Senior Project Paper, Aerospace Engineering Department, California Polytechnic State University, CA, 2009.

4. Stock photo of size 000 rubber stopper with 2 holes. http://www.onlinesciencemall.com/rubber-stoppers-size-000.html#3. Accessed 2-7-13.