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Alex Souvall
Utah State University

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Physics 4900 Senior Project

Final Report

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Sensor Design for In-Flight Testing of Small-Satellite Thruster

Alexander Souvall
Physics Department Utah State University

Faculty Mentors: JR Dennison and Stephen Whitmore
Physics and Engineering Departments, Utah State University

Background

CubeSats are small satellites which are frequently used in Low Earth Orbit (LEO) missions. They are cheaper alternatives to traditional satellites, and are versatile when conducting space research. Because of the increased usage of these satellites, cubeSats must re-enter the atmosphere within 25 years of deployment to regulate space debris and keep LEO space open for further missions [1]. Available propulsion options to accomplish atmosphere re-entry are one-time use systems, which do not allow for satellites to make adjustments in orbit; therefore, a multiple-restart system is in high demand. This capability would provide a higher rate of mission success, and allow for more diverse and complex mission objectives.

Hydrazine is the standard propellant used for small thrusters that require restart capabilities. Hydrazine is a hazardous and volatile propellant that requires extensive safety measures to implement, this makes small scale projects financially unfeasible. Therefore, a more economical cube-satellite propulsion system is essential to advancement in small thruster technology. The Utah State Mechanical Engineering department has designed a thruster which is cheap, has multi-start capability, and is fueled by a safe, 3D-printed solid hydrocarbon.

This new design will be flown on a Terrier Malemute sounding rocket provided by NASA to test its capabilities in space. To accurately determine the thruster performance, in flight tests will be conducted which will verify system performance and measure exhaust contamination particulates.

To help ensure a successful flight and show the capability of these thrusters on CubeSat missions, on-ground testing of the sensors, data acquisition systems, and thruster fuel grain will be conducted in a simulated space environment. The Space Survivability Testing Chamber (SSTC) designed by the Materials Physics Group at Utah State University will be used to provide an ultra high vacuum and high energy Beta-radiation environment, similar to what is experienced in LEO [2].

Sensor Design

A photometer was created by using a photo-resistor in a Wheatstone bridge circuit (see Fig 3). The photoresistor varies from 20 kΩ to 70kΩ, changing with the intensity of the light exposure. This high voltage eliminates much of the feedback in the wires and creates a clear signal[SD]. Using a *PicoBuck* LED driver, a Red-Green-Blue LED is pulsed to generate a signal for the

Figure 1. Test firing of thruster at Utah State University (left) and close up of 3D-printed fuel grain (right).

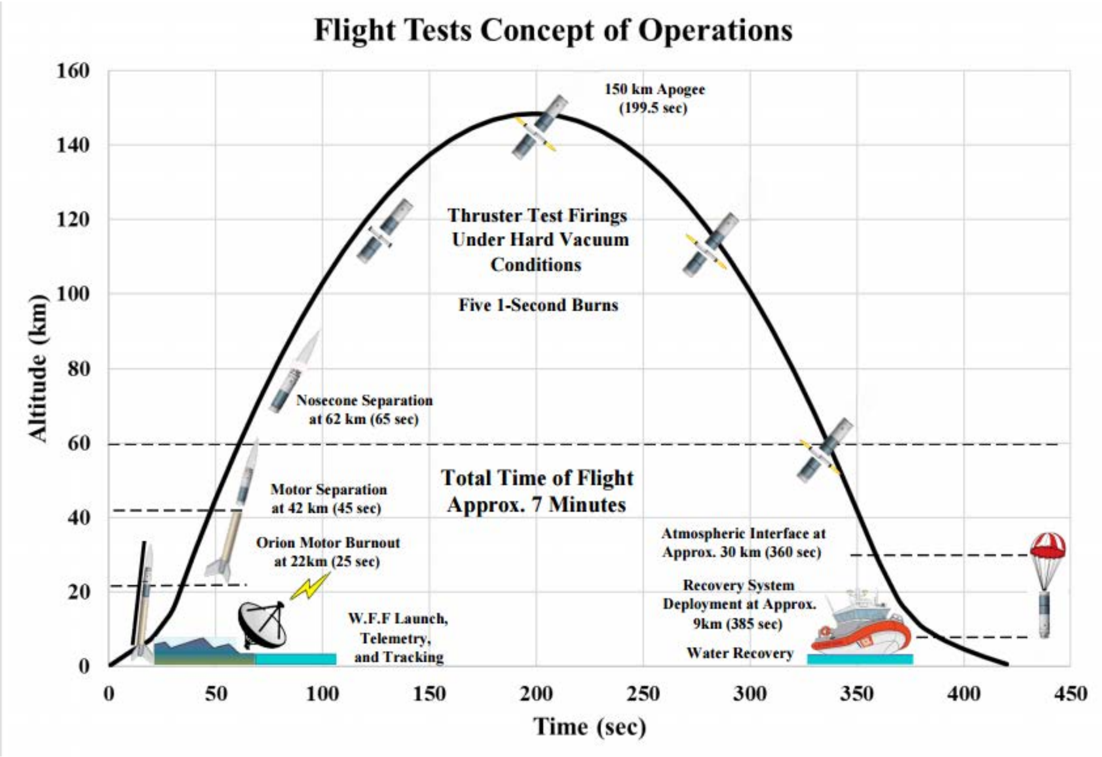

Figure 2. Sounding rocket flight overview and timeline.

photometer to measure. The photometer design is housed in a polycarbonate case which allows for a high transmission percentage (see Fig. 4), but will accumulate contaminates from the thruster plume. The light transmission through the case will decrease as this contamination accumulates (see Fig. 5).

A National Instruments, *myRio* board is used as an on-board computer to simultaneously pulse the LED, and record data from the photometer. The *myRio* was chosen because of it's large number of input and output channels, and because it is compatible with *LabVIEW* code rather than requiring custom low-level programming.

Proposed Testing

The objective of this research is to verify that the sensors will function as expected in a space environment and to discover any flaws with the design before mission launch. The proposed research is to take data on the intensity of light emitted from the LED's using the custom designed photometers, in a simulated space environment provided by the SSTC. The *myRio* will be used to simultaneously drive the LED's and take the data from the photoresistor circuits, just as it will during

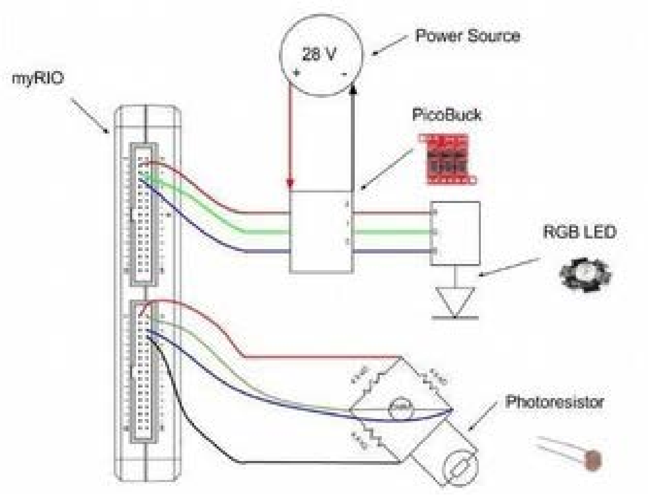

Figure 3. Diagram of Sensor Design

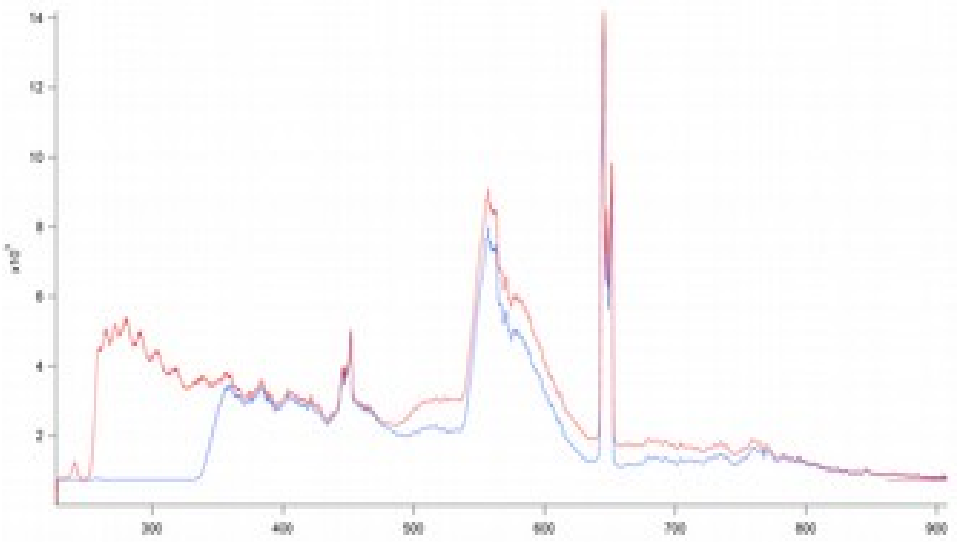

Figure 4. Solar Simulator spectra (Red), Transmission through polycarbonate (Blue)

flight. If failure or errors in system performance occur, the most likely cause will be from overheating of the *myRio* (or other electronics) due to their inability to effectively dissipate heat in a vacuum. Thermocouples will be attached to all critical components to take temperature measurements and determine at what temperature failure occurs, and determine an upper limit for operating time in a vacuum.

Another possible cause of failure is ionizing radiation. Microprocessors can experience single-event upset (SEU), or single-event effect (SEE) errors which cause a charge disturbance to alter the state of a memory bit or even permanently damage the device/circuit [3]. Additionally, the photoresistors in the photometer sensors may be sensitive to radiation and give erroneous readings. The entirety of the sensor system will be exposed to ionizing Beta-radiation during testing with minimal shielding to simulate a ‘worst-case’ scenario.

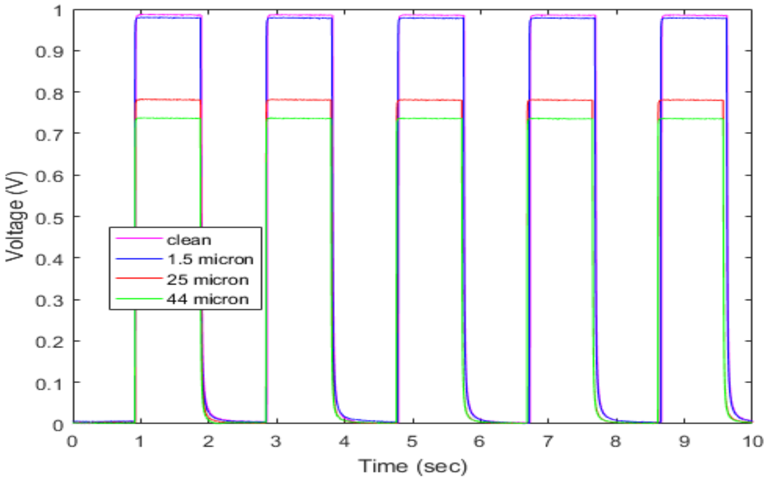

Figure 5. Data from the photometer with 3 different levels of contamination. Average contaminate diameter ranges from 0-44 microns.

Although it is not critical to determine mission success for the sounding rocket flight, the fuel grain, which is the most critical part of the thruster performance, will be exposed to radiation greater than what would be experienced in 1 year in LEO (~2 krad) in a separate test from the sensor system. If this thruster is utilized on small-sat missions, it will

Table 1. Equipment List

Item	Quantity	Description/Interest
myRio	1	Main piece of electronics. Concerned about arcing and overheating. Runs LED and takes data from photoresistor.
Photoresistor	2	Sensor for measuring LED output. May be sensitive to radiation
LED	1	Sends signal to photoresistor. Concerned about overheating.
Power Converter	1	Converts power supply to 12V for myRio and LED
Fuel Grain	2	Fuel and structure of thruster. Concerned about performance after exposure to radiation/vacuum
Thermocouples	5+	Measures temperature on electronics
Power Supply	1	Needed to run the system, and can be external to the system (not in vacuum/radiation)
Camera	1	Used to capture any arcs in the electronics during pump down
Feedthroughs	2	One needed for thermocouples. One for data and power In/Out
PicoBuck	1	Driver for the LED

be critical to know if ionizing radiation has any effect on the fuel grain. This fuel grain will be tested after exposure by firing it and confirming restart capability.

Procedure

The *myRio*, photometers, LED, and Pico-Buck power converter will be laid out on a 6 inch diameter plate (see Fig. 6). Because the Terrier Malemute system has on-board power, and a telemetry system to send recorded data, the *myRio* will be connected to the power supply and computer externally through vacuum feedthroughs, this will also allow manual control of the LED from a computer. Custom *LabVIEW* code will be written to control the LED output for both pulse rate and generate any RGB color scheme, as well as include a display for both the photometer sensors. These data will be written to a text file for further analysis after testing.

The whole system will be placed in the SSTC and brought to vacuum slowly. If arcing occurs or errors in system performance are noticed, it will be brought back up to pressure. Once 1/10 of atmospheric pressure is reached a 10 minute countdown will be started. Data will be taken until the countdown is finished, if erratic data is being taken then the testing will be stopped and brought back to pressure. If the full countdown is completed then it was a successful confirmation that the current design is sufficient for launch. If there is any forced cancellation of the test, or post testing damage is noticed, then a design change will be implemented. The cause of the failure will give direction for further design of the system.

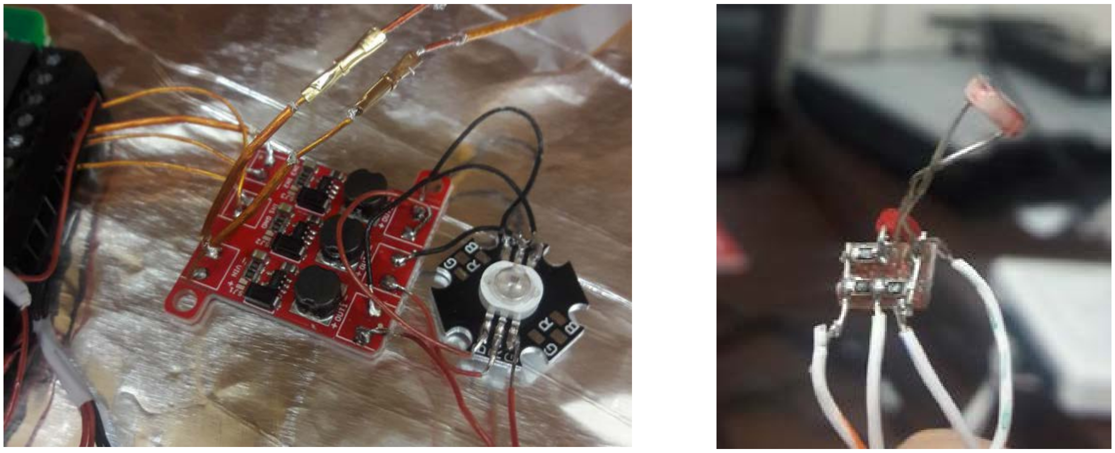

Figure 6. Wired LED with *PicoBuck* driver (left), and photometer (right)

Results of Testing

Days before the scheduled test, the *myRio* board was unresponsive. This was a serious issue, because all the code that had been written was now unusable. Additionally, this is the main device used to control the entire thruster during launch. As a replacement solution, a National Instruments *myDAQ* was used to replace the *myRio*. The *myDAQ* is a much simpler and less versatile piece of equipment, and another separate *LabVIEW* program had to be written to compensate. Eventually, the complete set of sensor data could be taken and LED pulse control was able to be implemented on the *myDAQ* board.

Once data could be taken, and the LED could be manually controlled from the computer, the final task to run the test was to make the system ultra-high vacuum compatible, and to run all the necessary connections through the feedthroughs. Because the *myDAQ* had to be operated from a USB connection, a UHV compatible USB cable was manufactured (see Fig 7).

Thermocouples were attached to the board and the entire system was placed into position to be irradiated (see figure 8). Electrical continuity of the wires was confirmed and a final system check was performed prior to pump down and test initiation. During this final system check, a successful connection to the computer was never accomplished. Despite thorough troubleshooting and retesting of electrical continuity, the final ability to control the device was never successful. It was determined that the problem was originating from the custom UHV wiring, when this was replaced by the standard USB wire, it worked as expected. But, despite all the electrical tests showing no problems, these custom wires would not work.

Before a solution was found, the SSTC had to be used for a new test, and further work on this system had to be postponed. Some success was found through the irradiation of the fuel grain. The critical location where fuel pyrolysis and ignition is initiated was exposed to over a year’s worth of radiation. This will be tested to see if there is any change in thruster performance in an external test.

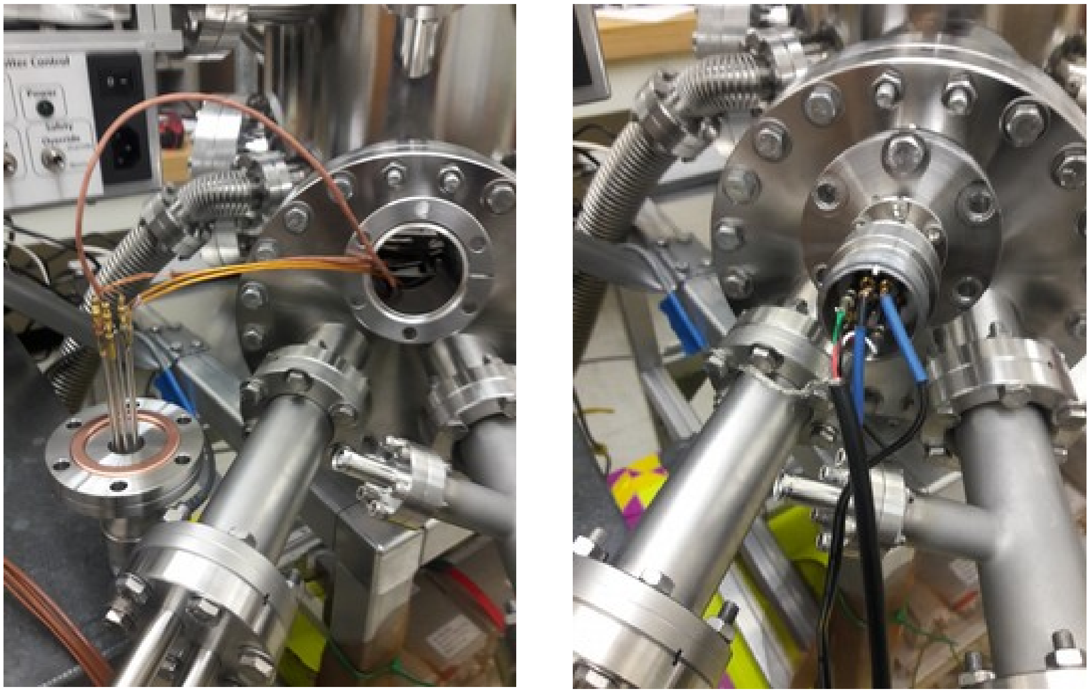

Figure 7. Internal wiring and connections to the UHV feedthrough (left), and external wiring (right) for power

Summary

In short, the test was never fully completed. Although all that was left after the sensors were designed, wired, programmed, and assembled, was to hit the ‘start’ button and to record data, it was not able to be completed at this time. Many lessons were learned in the process, however. These lessons include the importance of mitigating static discharge when handling sensitive electronic boards, the intricacies and challenges of programming two separate boards to do the same task, learning the importance of every detail including wiring, vastly improving skills at soldering, and becoming a much better troubleshooter to find obscure problems.

Unfortunately, there is still work to be done to complete this research and to achieve a final result about the performance and functionality of the sensor design in space conditions. The good news is that the system is ready to go, and the cause of the problems have been discovered. Additionally, the *myRio* will likely be repaired by the time that these tests can be attempted again, which will provide the more accurate simulation to what will be flown on the sounding rocket. For this reason, these tests would likely have been repeated regardless.

Future Work

In addition to the original testing being finished, there is further work that can be completed which will help advance this thruster technology. The control and ignition system have not been tested in vacuum conditions, and custom hardware would need to be designed to ensure that the vacuum chamber is not damaged from and out-gassing or arcing or ignition apparatus before these tests could be conducted. While it would not be possible to fire the thruster in UHV conditions, it

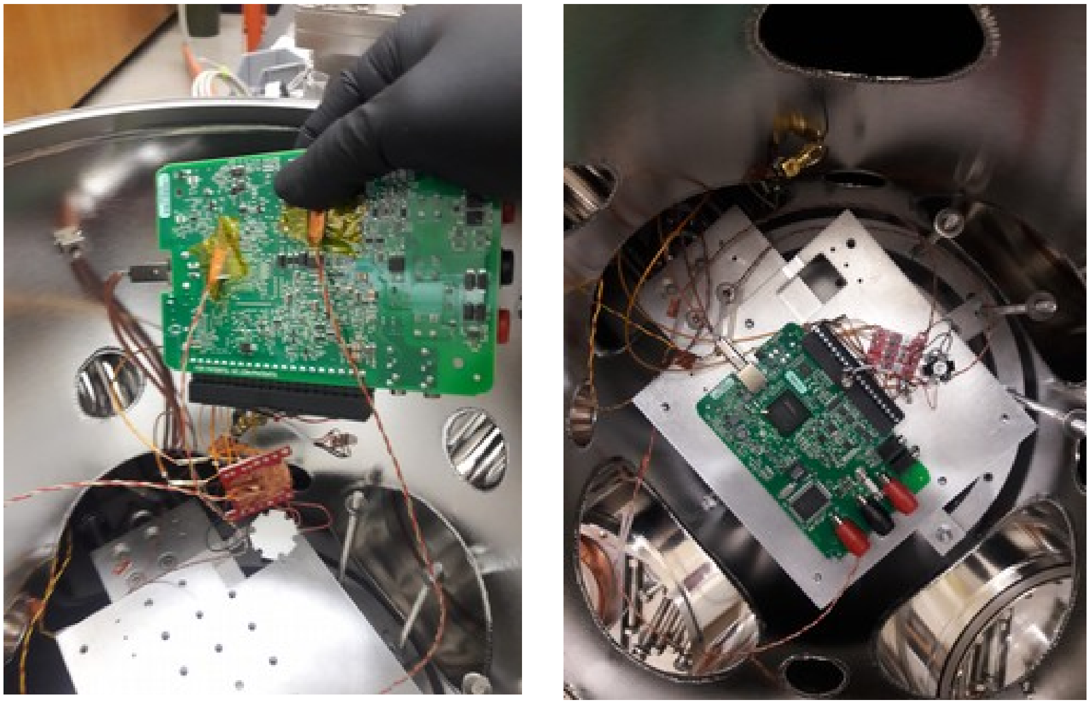

Figure 8. Completed system in the Space Survivability Testing Chamber with thermocouples attached.

is possible to expose the entire system to a UHV and ionizing radiation environment for longer term tests. This would be necessary to prove success of a multi-year orbit mission, rather than a 10 minute sounding rocket mission as was the purpose of this set of testing.

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