Lunar Lander Thermal Loading

Project Report - AAE418 - 2020

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Executive Summary

The purpose of this project was to create a means to measure temperature loading on a lander leg for either a lunar lander or a reusable rocket. In particular, the goal was to determine the effect that the rocket engine plume has on landing legs through the descent phase and to ascertain if any weight reductions can be made to improve overall craft performance. The current test rig is composed of a tube of aluminum with seven bolt-on thermocouples. These were then hooked up to a separate data logger. Non-reversible thermochromic paint and reversible thermochromic tape were also applied around each thermocouple. With the information acquired from a data logger, an animated display of the heating process is generated. The design was specifically made to allow for quick attachment to existing rocket engines.

Furthermore, there is also detailed design of a multi-use testing rig that will include a propane torch to simulate Masten Lunar Lander Exhaust Temperatures as well as basalt rocks beneath the exhaust to mimic lunar plume heating effects on the landing legs. Physical implementation of this design is currently planned to occur in Fall of 2020.

Introduction

Masten Space Systems is developing lunar landers for missions to the moon starting in 2021. The XL-1 lunar lander that is in the design finalizing phase is in partnership with the NASA CATALYST program to deliver 100kg to the lunar surface. The large lander Xeus is in the R&D phase for flights in the mid-2020s. While Masten finalizes their designs and performs terrestrial tests for the lunar vehicles, the problem of lunar lander legs being overheated by the engine plumes caught their attention. The mission of the Lunar Lander Thermal Loading team is to perform thermal tests to aluminum tubes that resemble the Masten lunar langer legs and investigate the tolerable temperature range for the lander legs.

ORIGINAL SYSTEM

Design Requirements

During the Spring of 2020 semester extensive correspondence with Masten Aerospace began to assure that the Lunar Lander thermal load analysis design could be properly implemented into one of Masten Aerospace's terrestrial Lunar Lander tests. Masten Aerospace has shared with the team the CAD of their Xodiac tank and legs as well as expected exhaust temperature and burn times. These Solidworks files have been uploaded to the sharedrive and all necessary angles and lengths for design can be derived from these drawings. Appendix A at the end of this document highlights some of the important dimensions and details needed for designing the Lunar Lander thermal load analysis system. Stefan Lamb has been the point of contact for the Lunar Lander Team.

Furthermore, Masten has asked that we conduct EMI testing prior to implementing into their lander, as well as design the data logger to be placed in the payload bay of their system. To comply with Masten's advice on placing the data logger in the payload bay of the launch test vehicle, we extended the thermocouple wires to 10 feet using flat pin thermocouple connectors. The accuracy of these connectors still needs to be tested compared to the old system.

Experiment Design

Working with the previous semester's testing leg, we wanted to test the system using an actual rocket engine instead of torches or heat guns. This way we would be able to see how the leg performed in a more realistic setting. To do this we got a contact at Zucrow Labs who allowed us to place our test leg next to their engine to see how it performed. Their engine was a small engine that had a short test time, but the team believed this to be a good test as the engine would still produce a high temperature exhaust. The plan was to place the test leg the same distance away from the engine as it was displayed in the CAD that Masten provided us; however, this required an addition to our testing leg so that we were able to connect to their test article at Zucrow.

The Zucrow test article was using 80/20 bars to support their engine, so the team also decided to use 80/20 bars to attach the test leg to the structure. The attachment used one approximately 3 ft long 80/20 bar that had a hinge joint on one end of it. The purpose of this hinge joint was to allow the angle the test leg stayed at during the test be variable. At the other end of the attachment, there was a smaller, approximately 1 ft long, 80/20 bar that was connected by two 90° joints that made a T-shape when assembled. The last 80/20 bar was approximately 6 inches and was attached to the 1 ft long bar on one of its ends using a 90° joint. The 6 inch long piece was placed on the same side of the 1 ft long bar as the 6 ft long bar. The hinge joint of the team's attachment would connect to the Zucrow structure, then the test leg would slide onto the 6 inch long piece of the attachment. This design allowed for easy removal of the leg. The attachment was also easy to remove as the hinge joint was the only piece that had to be taken off to remove our attachment from the structure. The results of the Zucrow test can be seen in the results section.

While on a meeting with Stefan Lamb from Masten, he said that the payload box on their Xodiac vehicle would be 10 ft from the legs of the vehicle. The original design had thermocouple wiring that would not satisfy this length, so additional wiring was ordered. The wiring would be delivered as one long wire instead of multiple wires of the desired length, so wire connectors were also purchased. The team was able to fully assemble the wires and the connectors before class was suspended due to the coronavirus. The next step after the assembly was to run a test to see that all the wires were connected properly and that data could still be pulled. From the same meeting with Stefan Lamb, he also expressed concerns due to EMI from the wires as they would run along the full length of the vehicle. This issue will be addressed in a later section of the report.

Results

We successfully attached last semester's test leg next to the engine set up at Zucrow Labs. While we did not collect any numerical data by measuring with the attached thermocouples, we were able to see the physical effects of the rocket engine plume on the test leg. We did not use our data logger because we were not able to complete EMI testing before using the system at Zucrow Labs. In addition, we were not allowed to take pictures or record video because there was sensitive design visible at the test cell we were visiting. Although there was thermochromic paint on the test leg, this paint did not melt during the test. While we were able to confirm the general physical effects of the system we were testing, no numerical data could be obtained. From the general physical effect analysis, as well as the lack of melting of our thermochromic paint, the team concluded that due to the small burn time of the test, as well as the lack of nozzle and large height above the ground the test was occuring at, that this test did not accurately simulate the proper environment for a lunar landing. This information drove the need to design a new testing rig to properly mimic the thermal loads experienced by the Masten's Lunar Lander legs.

NEW TESTING RIG

Design Requirements

The purpose of the designing and implementing the new testing rig is to obtain a system capable of performing thermal load analysis on a process that accurately mimics a scaled down version of a Masten Lunar Lander touching down on the moon. It was decided the most optimal way to complete this task was by construction of a testing rig that has vertical axis motion and is capable of producing exhaust at synonymous temperature and burn time to that of Masten's Xodiac system. By having vertical motion in the exhaust, a landing is simulated and a thermal plume can be accurately created. If instead the exhaust was held at a constant height, the system below the exhaust would undergo significantly more heating than realistic for the landing and the plume would differ greatly from that of an actual test with Masten's system.

Current System

The Lunar Lander exhaust will be mimicked by the use of a non-oxygen fed propane torch. This achieved an exhaust temperature of roughly 1400K and is easily accessible in hardware stores. Furthermore, propane torches can easily achieve the long burn time required by the Masten Lunar Lander system of roughly 180 seconds. All of this combined with the fact that it is easily the cheapest solution makes it the clear choice.To stabilize the exhaust, a hose clamp will be used on the handle of the propane torch piping and the clamp will connect to an 80-20 bar system that has 4 stabilizing legs on it.

To simulate the heating effects of the moon's surface, Basalt rocks will be placed on a steel slab under the exhaust. Basalt rocks are the same type of rocks found on the Moon's surface in lower elevation areas, which are primarily landed on during Lunar missions. Furthermore, below the rocks there will be a steel slab to assure that the stability system below the rocks does not melt.

We came up with multiple ways to simulate landing motion on our test rig. There are many different ways to move a test bed, but we have some important specifications for movement that need to be addressed. The two most important are capacity and speed. Specifically, we need to be able to lift a steel test bed and lava rocks at a speed of over 5 inches per second. This limited our options, as many of our ideas could not match one or both requirements. The preferred solutions are listed below.

The first method is an electric lifting table. This would give us the control we need already made in a prebuilt package. Many lifting tables are also able to reach the lift capacity we need, at an estimated 60 pounds. The downside; however, is they are not very fast. The fastest we were able to find is from McMaster-Carr, product number 8758T37. This table lifts at 3.25 inches/s, which is fast, but does not quite reach our specifications. The other issue is cost, this table comes in at $2500.

Similarly, we looked at pneumatic or hydraulic lifting tables. These can effortlessly lift the required load, although each has its drawbacks. Hydraulics that we found were never able to reach the speed requirement. Pneumatic lift tables might; however, it depends on the flow rate of shop air. If shop air is available, this could be an option but, the need for air limits the locations where a test could take place.

Next, we looked at pneumatic air cylinders. These come in a wide array of sizes and capacities. All cylinders found were capable of lifting the weight of the test bed. Air cylinders can also be limited to any speed required and, thus, we see them as a great option. The biggest drawback we found is that shop air is also required for this system.

Our final option is linear actuators. These are a very simple option and we found they are our favorite. Linear actuators come in an array of speeds and lift capacity which would allow us to move to any height with minimal setup time and cost. An image of our CAD model with linear actuators is attached in Appendix B. Specifically, a model from Progressive Actuators, the PA-15, gives us as much speed as is required. The drawback for this design, however, is that the faster actuators have lower lift capacities, so multiple actuators are required.

The CAD model for the general testing rig as well as the rig with linear actuators is in the share drive. If next semester's team decides that lifting tables are the way to go, then the original rig without actuators should be used, as long as it is made taller to fit the table.

Conclusion

Overall, this project was very successful in proving our objective of finding a means to measure thermal loading on a lunar lander leg. The test bed that was created effectively measured how heat was transferred to our mock leg. Both the thermocouple and the thermochromic paint worked well to measure the temperature of the leg. Extension of the thermocouples has been implemented and needs to be tested still.

As this is an ongoing project, we do not have any solid results as to how the rocket plume thermally affects the leg. We do have a way to test this, however, and our ideas for future tests as well as updates to the system can be found in the next section. We did, however, come away with very helpful information from these tests, as well as some lessons we have learned while trying to put the tests together. We confirmed that testing our system with a small test bed without a nozzle, synonymous to the one at Zucrow, will not produce valuable thermal loading results. This drives the need for a design of a new testing bed to generate valuable results prior to Masten Lunar Lander system integration.

Next Steps

While we already have a functional prototype, our next steps will be how to translate these experiments to be used on the rocket. This means that the next step for our project is to create a mounting rail for the thermocouples for attachment to the Masten launch vehicle. To do this, we have planned to cut a similar aluminum tube in half lengthwise. This will be the rail we will mount on the leg of the actual lander. The half cylinder design allows for room for electronics in the inner tube. This means that, while fabricating the rail, the next team will have to drill holes in the rail to bolt the thermocouples in the same location as we have on our prototype.

Furthermore, Masten Aerospace has informed us that they wish for our data logger to be placed inside of the payload box for testing. This requires the thermocouple wire to be extended. Extensions have already been purchased and prior to the classes being cancelled in Spring of 2020 they have been implemented into the system. Testing that the wires have been properly extended is essential work that must be done on the system.

Masten has also requested that EMI testing be conducted on the system prior to implementing it onto their Lunar Lander. More clarification and guiding steps about how to do this to their level of satisfaction is suggested.

We have already designed the rail for the experiment. The next team will have a few more design challenges. For instance, we do not have a way currently to capture video during testing. Our prototype senses temperature in three ways: thermocouples, thermochromic paint and thermographic tape. This means that most of our sensors are visual. To view these after the test, we will need a camera. This is an issue because the sensors are meant to be placed at the nearest point to the plume, this would require the camera to be placed in an area of extreme heat. There is also interest in recording footage of the lunar regolith's reaction to landing, which will require extra cameras.

We started working with RunCam 2 cameras to provide a visual of the paint melting. The cameras have a resolution of 1920x1440 at 30fps, 1080p at 60fps, and 720p at 120fps. The cameras need a micro sd card, we currently have 3, in order to take videos or pictures. The videos and pictures can be transferred via the sd card and a computer or through the app, however the app crashes frequently and is difficult to transfer videos. In future tests, make sure the cameras are fully charged and the sd cards are inserted. During future tests, determine the camera angles and placement that will best show the paint and thermocouples. Due to the difficulties with the app, and the lower quality of video, we started searching for, and suggest continuing to search for, a camera with better support, better video quality, and possible thermal imaging.

In terms of the MATLAB code and files attached with it, the LL_data.m file is the main script. This creates all the deliverables and print outs used for analyzing the data. The data logger outputs a .csv file, but the script is made to take a .txt file. So take the .csv file that the logger outputs, delete the first column and row as they are just labels, and then save it as a .txt. The other scripts in the folder are experiments with matlab functions that may be helpful in the future.

For the new testing rig, the system has been designed, but needs to be physically implemented in the near future. Furthermore, effects of the moon's atmosphere compared to that on Earth in terms of thermal loading from the plume on the leg also needs to be studied more in depth.

Appendix A

Important Xodiac System Information

Subject	Dimension
Approximate Burn Time	~180 (sec)
Approximate Exhaust Temperature	~1400 K
Angle of Leg Relative to Undercarriage of System	37.43 +/-.1 (deg)
Length of Leg	56.74 (in)
Diameters of Leg	0.112 (in)
Distance Between Legs	65.46 (in)

Appendix B: Images

Figure 1: Isometric view of testing rig with Linear Actuators

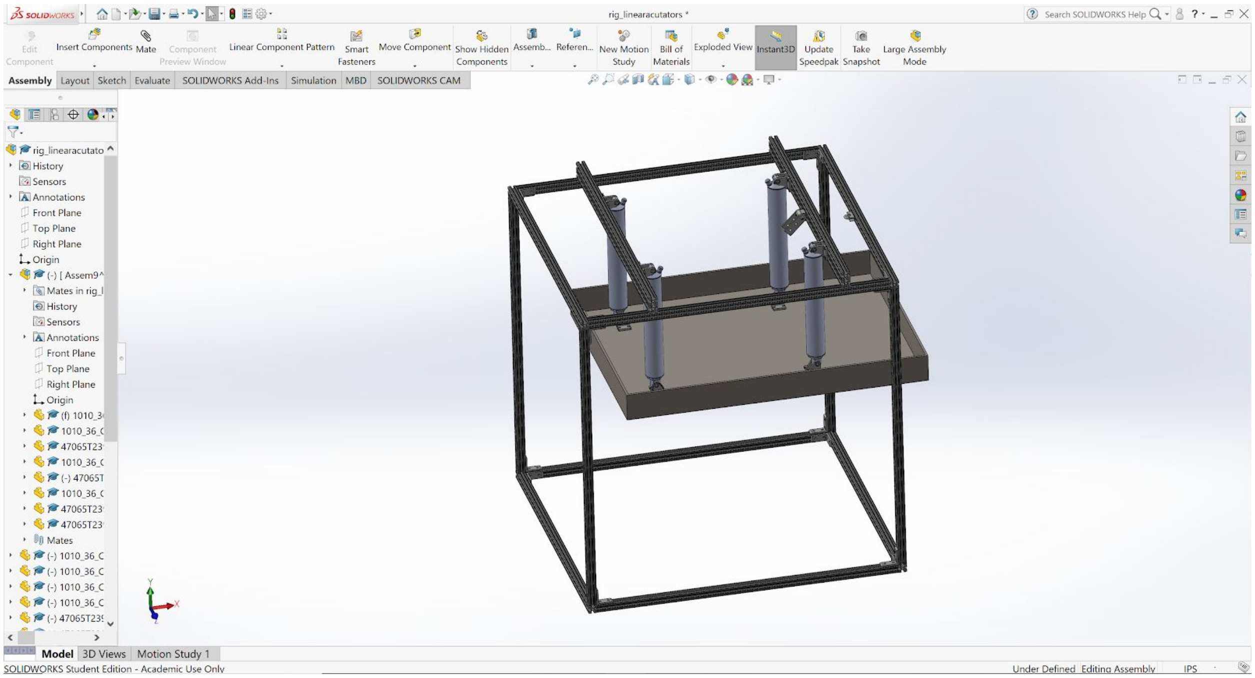
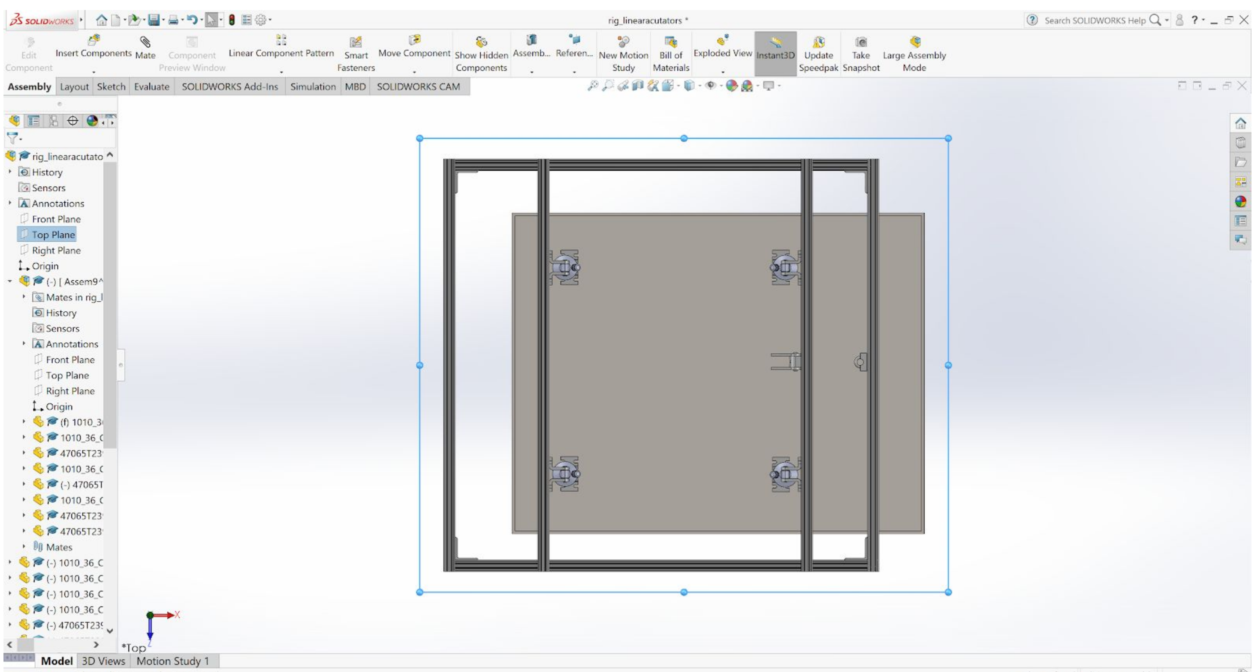


Figure 2: Top Down View of testing rig with Linear Actuators



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