

Support of LAVA Testing and Integration Phase

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The Lunar Advanced Volatile Analysis (LAVA) subsystem is a part of the Regolith and Environment Science & Oxygen and Lunar Volatile Analysis (RESOLVE) Payload that will fly to the lunar pole on the Resource Prospector Mission (RPM) in 2019. The purpose of the mission is to characterize the water on the surface and subsurface of the moon in various locations in order to map the distribution. This characterization of water will help to understand how feasible water is as a resource that can be used for drinking water, breathable air, and propellants in future missions. This paper describes the key support activities performed during a 10 week internship; specifically, troubleshooting the Near Infrared Spectrometer for the Surge Tank (NIRST) instrument count loss, contributing to a clamp to be used in the installation of Resistive Temperature Detectors (RTDs) to tubing, performing a failure analysis of the LAVA Fluid Subsystem (FSS), and finalizing trade studies for release.

Nomenclature

LAVA	= Lunar Advanced Volatile Analysis
RESOLVE	= Regolith Environment Science & Oxygen and Lunar Volatile Analysis
RPM	= Resource Prospector Mission
RTDs or RTD	= Resistive Temperature Detectors or Detector
FSS	= Fluid Subsystem
ISRU	= In-Situ Resource Utilization
NSS	= Neutron Spectrometer System
SATS	= Sample Acquisition and Transfer System
NIRVSS	= Near Infrared Volatile Spectrometer Subsystem
OVEN	= Oxygen Volatile Extraction Node
NIRST	= Near Infrared Spectrometer for the Surge Tank
GCMS	= Gas Chromatograph – Mass Spectrometer
GC	= Gas Chromatograph
WDD	= Water Droplet Demonstration Unit
TEC	= Thermal Electric Cooler
ETU	= Engineering Test Unit
nm	= nanometers
SMA	= Sub Miniature A (a type of fiber optic cable connector)
RTV	= Room Temperature Vulcanizing silicone (used as an adhesive)
ARC	= Ames Research Center
ISOLAT – XXX	= Isolation Valve – numerical location signifier
REG – XXX	= Regulator – numerical location signifier
VLATs – XXX	= Latching Valve – numerical location signifier
VPZT – XXX	= Proportional Valve – numerical location signifier
RV – XXX	= Relief Valve – numerical location signifier
ORF – XXX	= Orifice – numerical location signifier
HTR	= Heater
PT – XXX	= Pressure Transducer – numerical location signifier
PT	= Pressure Transducer
WOA	= Work Order Authorization

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°C

= Degrees Celsius

I. Introduction

The Resource Prospector Mission (RPM), planned to launch in 2019, will seek to determine the viability of developing and sustaining human colonies on the moon and other planetary bodies. This concept of living off the land is called in-situ resource utilization (ISRU) and has become a key initiative at Kennedy Space Center. RPM will utilize the Regolith and Environment Sciences & Oxygen and Lunar Volatile Extraction (RESOLVE) Payload to extract lunar soil, or regolith, and analyze its water content. Under the current plan, the Neutron Spectrometer System (NSS) that is mounted at the front of the rover will detect the highest abundance of hydrogen, which would correlate to the presence of water. Then, the Sample Acquisition and Transfer System (SATS) will drill into the regolith and collect the samples that are recovered. While SATS is operating, the Near Infrared Volatile Spectrometer Subsystem (NIRVSS) will analyze the components near the drill site to provide real-time feedback on any change in the collected regolith. From SATS, the regolith will be transferred to the Oxygen Volatile Extraction Node (OVEN) which heats the regolith until all volatiles have entered the vapor phase. From there, the volatiles enter the Lunar Advanced Volatile Analysis (LAVA) subsystem. In LAVA, the volatiles can be transferred through the Fluid Subsystem (FSS) to a number of different instruments. They can be transferred to and stored in a surge tank; while in the surge tank, the volatiles can be analyzed by a near-infrared spectrometer for the surge tank (NIRST). From the surge tank, the volatiles can also be transferred to the gas chromatograph – mass spectrometer (GCMS) instruments. If water is detected, the volatiles can be transferred to the water droplet demonstration (WDD) assembly. In the WDD, the volatiles are cooled using a thermal electric cooler (TEC) to condense the water out of the vapor phase. Once liquid water appears, a camera will take an image of the first liquid water produced on another planetary body.

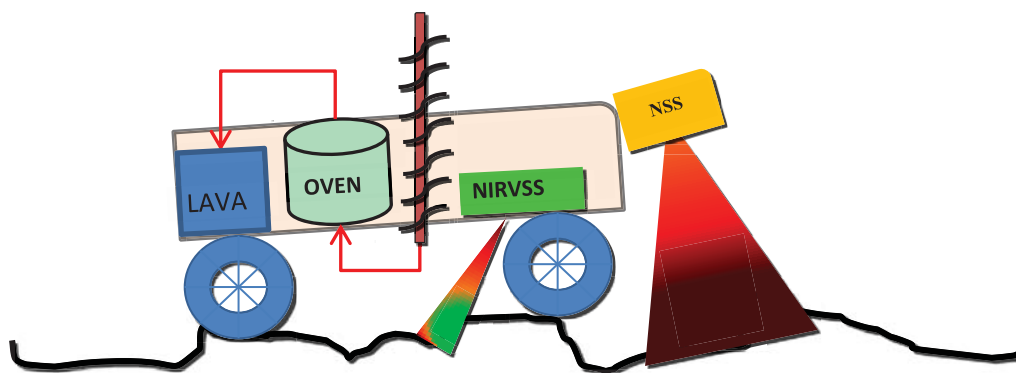


Figure 1. Simplified drawing of RESOLVE payload

The LAVA subsystem is now in the Engineering Test Unit (ETU) phase of the project life cycle. During this phase, the LAVA and OVEN Reactor subsystems are integrated with each other and the instruments on both perform tests similar to those to be performed on the surface of the moon. The goal is to characterize and prove the effectiveness of the instruments, and determine their ability to meet the goals of the project. The complex design of the LAVA subsystem has created many challenges for the team. Due to this, it has been the objective of this internship to help find solutions to problems as they arise during testing. This has included working to find the cause of the signal loss in NIRST, designing and evaluating a clamp to ensure consistent and secure installation of Resistive Temperature Detectors (RTDs) to FSS tubing, analyzing the failure modes of the FSS, and compiling trade studies written by the team into appropriate NASA trade study format for release to the public. This work has helped the team continue progressing towards completion of the ETU phase, as well as providing flight-forward knowledge and tools.

II. NIRST Trouble Shooting

A. NIRST Background

A spectrometer examines light emitted or absorbed by materials, helping to identify their composition¹. Comparing the near infrared spectral signature of what is in the LAVA FSS Surge Tank to the known near infrared spectral signature of water is one way to determine how much water is in the surge tank. The NIRST is made up of two optical fibers, multiple collimators, a black body emitter, and a detector. The raw data from the NIRST is collected as counts, an arbitrary unit, per wavelength. Through analysis of this data, the transmittance of each wavelength can be determined and compared to the spectral signature of water. The more counts detected, the more confident in the results the team can be due to the high signal to noise ratio. In other words, very low counts are not useful for scientific analysis because the spectral signatures will get lost in the noise of the system. Since February 2014, the counts have been decreasing. By June, the max counts seen in a test had gone from 110,000, as seen in Figure 3, to 37,000, as seen in Figure 4. Max counts must be above 100,000 to have a high enough signal to noise ratio to confidently use the data for scientific analysis. Testing was required to determine the factors contributing to the count loss.



Figure 2. NIRST integrated with surge tank

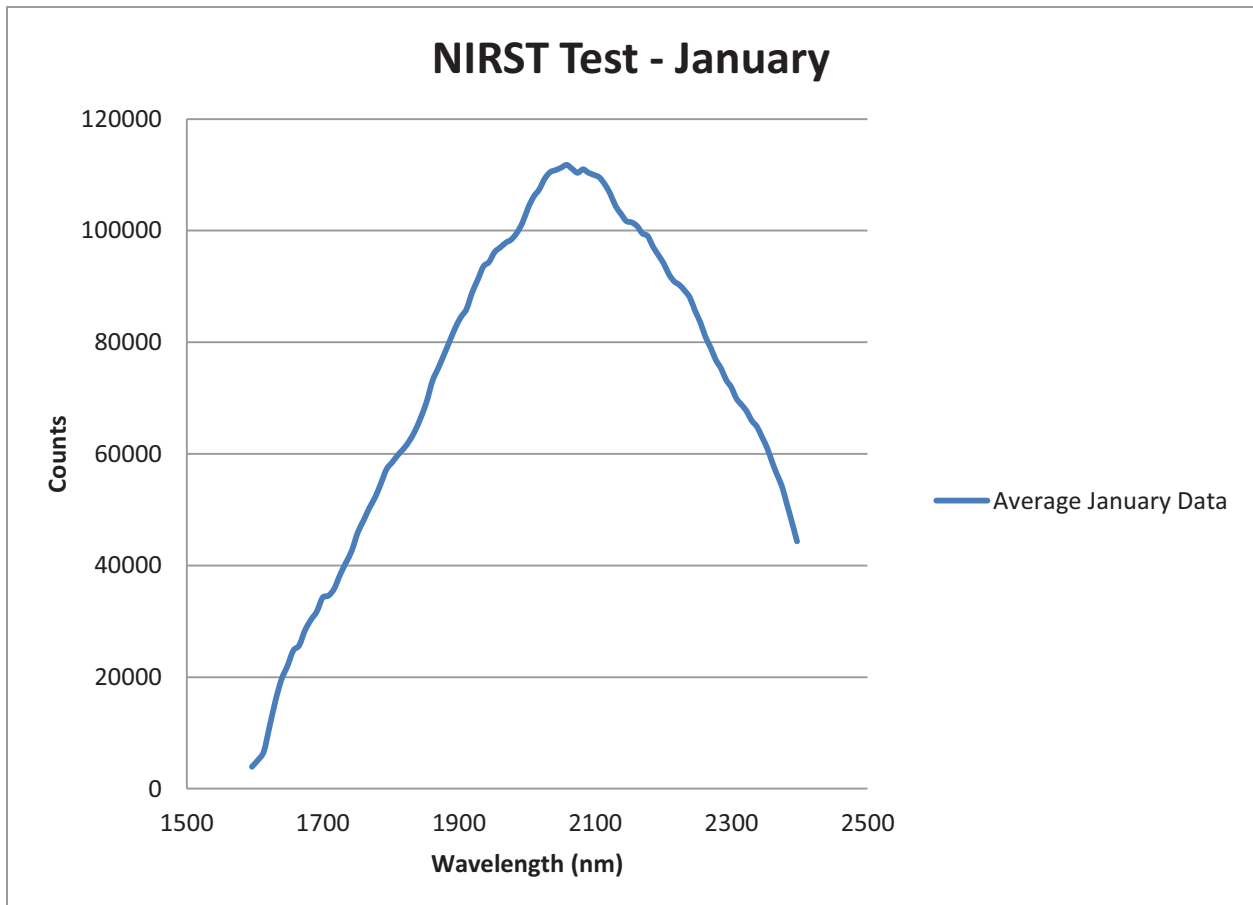


Figure 3. NIRST test in January showing max counts around 110,000

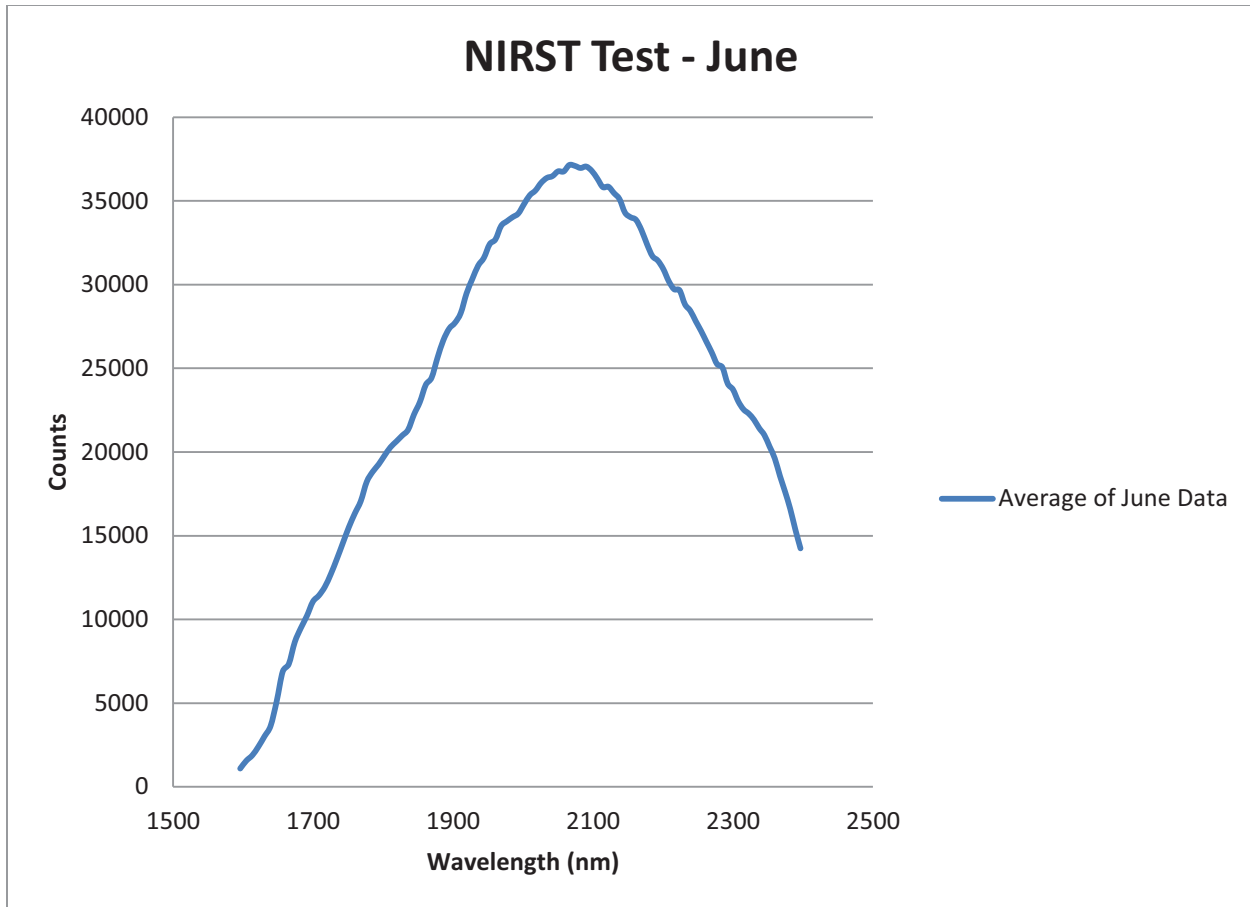


Figure 4. NIRST test from June showing max counts around 37,000

B. Expert Survey

A meeting was held with optics experts from Ames Research Center, owners of the NIRST instrument, to discuss the possible causes of the loss of signal. There were no clear events that corresponded to the stepped loss of counts. It was suggested that the collimators could be the problem as the emitter, optical fibers, and detector were previously tested and found to be functioning. The high temperature (152°C) and the shock from the valves opening and closing could have knocked the collimators out of alignment. Based on this suggestion, it was decided that the collimators needed to be taken out and inspected. The makers of the collimators offered to inspect the collimators for free, thus the collimators would be returned to the maker to have them undergo additional testing.

The tests that follow seek to conclude what caused the loss in counts. The detector and emitter, optical fibers, the surge tank, and the collimators were all tested to find the cause.

C. Testing

1. Emitter and Detector

An SMA to SMA fiber was installed on the NIRST in a loop back fashion to ensure the emitter and detector was working correctly. The SMA to SMA fiber was known to be a fully functioning fiber which enabled the emitter and detector to be directly tested. A NIRST Test procedure and work order authorization (WOA) was ran with the SMA to SMA fiber installed. Light was sent through the optical fiber into the detector and the counts for each wavelength were recorded. These were then compared to the expected results from the manufacturer of the emitter and detector to determine the health of the parts.

2. Surge Tank

NIRST fibers connect the Emitter and the detector to the top and bottom of the Surge Tank. The light travels through the sapphire windows and the contents of the surge tank. The NIRST fibers were uninstalled from the surge tank and the entire NIRST system was removed from the LAVA stack for further testing. A flashlight was shone into the top and bottom sapphire windows to see if there was any material deposited on the windows. Material

appeared to be deposited onto the bottom sapphire window internally to the surge tank. The bottom window was removed and photographs were taken. The bottom sapphire window was sent to the NASA Chemistry Lab to identify the residue on the window. The window was examined by optical microscopy and further analyzed by Fourier transform infrared spectroscopy³.

3. *Fibers*

With the NIRST removed from the LAVA stack, it was possible to perform testing on an optical bench top. The emitter and detector fibers were attached to the NIRST, and the other ends of the fibers were lined up on an optical bench using alignment fixtures. At first, the fibers were 3.5 inches apart. This distance is similar to the distance the fibers are separated when attached to the surge tank. A NIRST Test procedure and work order authorization (WOA) was ran with the fibers separated by this distance. The counts per wavelength were recorded for this configuration. The fibers were moved to within a few millimeters of each other and the counts per wavelength were recorded in this configuration.

4. *Collimators*

The NIRST collimators test was conducted with the NIRST removed from the LAVA stack. The emitter and detector fibers were attached to the NIRST, and the collimators were attached to the other ends of the fibers. The collimators were lined up 2.56 inches apart on an optical bench using alignment fixtures. A NIRST Test procedure and work order authorization (WOA) was ran with this configuration. The counts per wavelength were recorded. At the conclusion of the test, the collimators were returned to the manufacturer for more extensive testing

D. Results

1. *Emitter and Detector*

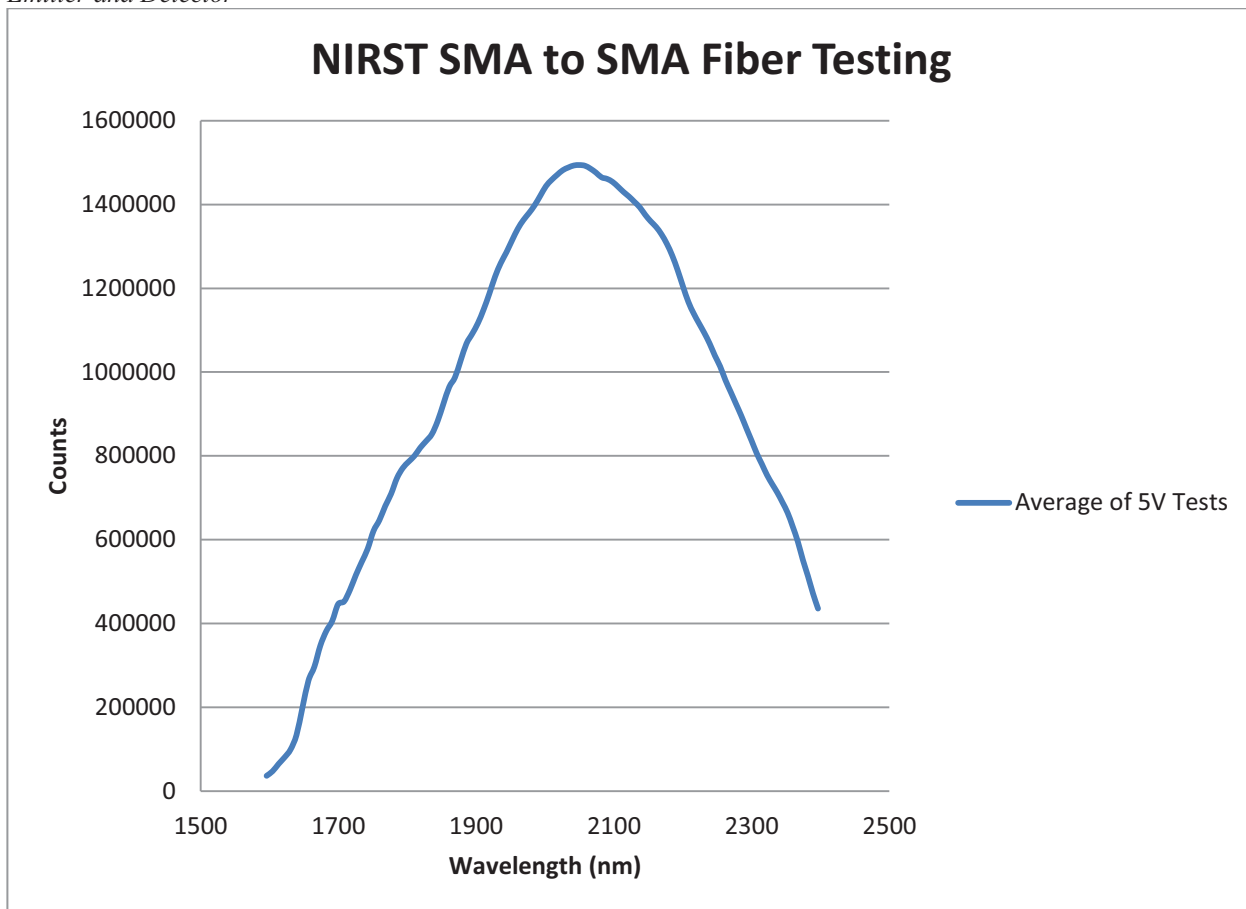


Figure 5. NIRST SMA to SMA Fiber testing with max counts around 1.5 million

As seen in Figure 5, the SMA to SMA fiber test resulted in a maximum count of 1.5 million. One and a half million counts is above the 100,000 threshold for suitable scientific analysis. This is a significant increase in counts compared to the number of counts seen when NIRST was integrated onto the stack.

2. Surge Tank

After removing the bottom sapphire window, debris was found on the internal surge tank side of the sapphire window. The debris found on the sapphire window can be seen in Figure 6. Also, a thin clear layer, not easily visible in Figure 6, appeared to be deposited onto the sapphire window. Optical microscopy showed the windows had a coating associated with a large amount of fine particles and fibers. Fourier transform infrared spectroscopy identified silicone associated with carbonate. Scanning electron microscopy showed a significant amount of skin cells which was consistent with the amount of biological salts. The large deposit was determined to be polytetrafluoroethylene, associated with silicone oil, and 100's of metal particles³.



Figure 6. Material deposited on bottom sapphire window

3. *Fibers*

Light from the emitter fiber projected a much wider diameter of light than the diameter of the detector fiber at 2.56 inches apart. Therefore, the detector was only receiving a fraction of the emitted counts. Since the goal of the test was to directly test the effectiveness of the fibers themselves, it was determined that the fibers could be moved to as close as a few millimeters apart. This decreased the projected diameter of emitted light that was outside the detector fiber's diameter and increased the number of counts as seen in Figure 7. The maximum count was found to be 1.3 million. Over one million counts is above the 100,000 threshold for suitable scientific analysis. This is a significant increase in counts compared to the number of counts seen when NIRST was integrated onto the stack.

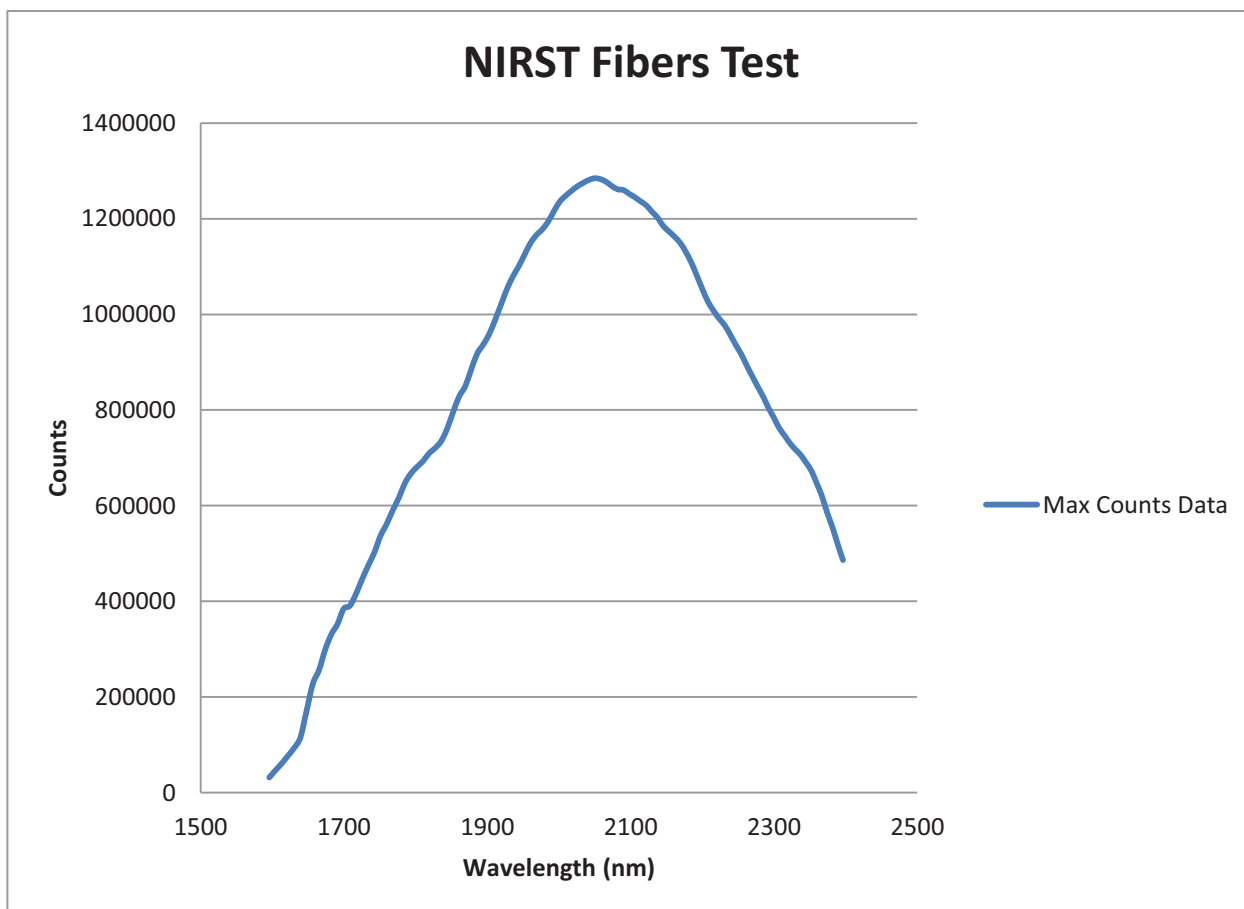


Figure 7. NIRST Fibers Test with max counts around 1.3 million

4. Collimators

Collimators focus light from the emitter to the detector with minimal divergence. Therefore, counts above the 100,000 threshold should be detected with 2.56 inches of separation between the emitter and detector fibers. As seen in Figure 8, the maximum count achieved was about 225,000, well above the 100,000 threshold. This is greater than the number of counts seen when NIRST was integrated onto the stack.

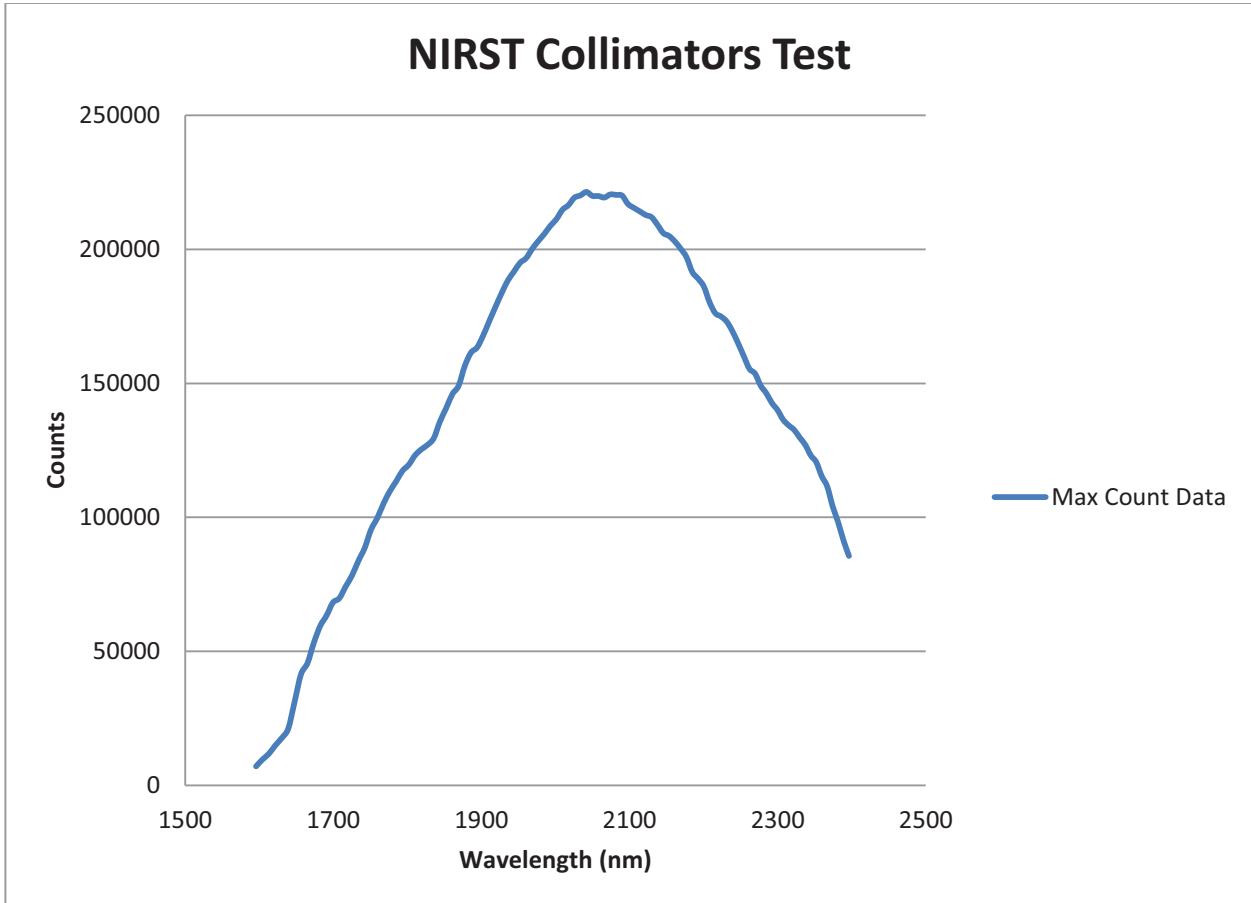


Figure 8. NIRST collimators test max counts around 225,000

The manufacturer of the collimators has reported that the collimators had failed; they no longer met divergence specifications. It appeared the thermal and mechanical shock testing they experienced while on the LAVA stack caused the collimators to fail due to the glue that was used by the manufacturer. A new set of collimators was ordered made with higher temperature glue.

E. Conclusion

Using the 100,000 count threshold as the standard of acceptability, it becomes clear which components are not responsible for the loss in counts. The emitter and detector test, and fibers test resulted in counts over one million, much greater than the threshold. Therefore, the emitter, detector, and the fiber optical cables are not affecting counts in a negative manner.

The material deposited on the sapphire window is believed to be blocking the path of light between the emitter and the detector. The deposited film and material is one factor leading to the loss in counts seen between February and June.

The collimators do not present as straightforward an answer. A maximum count of 225,000 was observed during optical bench testing; this data would be acceptable for scientific analysis. However, the manufacturer reported that the collimators had failed and the divergence from the collimators exceeded the specifications it was rated to maintain. The data must be reconsidered in light of this revelation. First, the failed collimators were still capable of

producing data that was above the established threshold. This data was gathered during testing on the optical bench where the collimator's alignment could be adjusted to achieve the best possible data. However, in reality the collimators are attached to the surge tank when integrated into the LAVA stack and their alignment is dictated by the tolerances to which the surge tank was machined and cannot be adjusted to accommodate a change in the optical path such as a change in the divergence of a collimator. Therefore, the counts were lost as the collimators divergence deteriorated. Based on this evidence, it can be deduced that the collimators were a contributing factor to the loss of counts seen between February and June.

In conclusion, the NIRST emitter, detector, and optical fibers have been ruled out as factors contributing to the count loss. The deposition of the material on the bottom sapphire window, and the failure of the collimators were contributing factors to the NIRST count loss. Several action items have emerged from this investigation. One, the next iteration of the surge tank should be designed in such a way that if some material should become trapped in the FSS, it will not come to rest on the sapphire window. This could mean placing the windows at an angle in the surge tank as opposed to their current placing on the top and bottom. Two, the post-machining cleaning procedure for the FSS manifold has been modified per the recommendation of the NASA Kennedy Space Center Chemistry Laboratory. The manifold will now be cleaned with first amyl acetate, then isopropanol, then detergent, and finally distilled water; sonication will occur after each cleaning. Cleaning the manifold in this manner is the optimal method for de-greasing the manifold and preventing the silicone from depositing on the sapphire windows. Three, the tolerances of the machined surge tank must be understood and controlled in order to ensure proper alignment of the NIRST components when connected to the surge tank. Four, the collimators must be more robust. If the collimators are going to fail due to the thermal and mechanical shock seen in ETU testing, they will certainly not withstand the loads experienced in flight from launch, to landing, and then roving. It may be necessary to consider a different model that can withstand the mission.

Further investigation can be done to determine exactly where the material that deposited on the sapphire window originated from and solutions to reducing its accumulation should be explored should it be a material native to the system. Also, the new collimators should be tested with the clean sapphire windows to establish a baseline for how the alignment in the surge tank impacts the counts. Finally, NIRST is a complex instrument with multiple failure points; moving forward the team will need to consider whether the benefits to science from having NIRST including in the instrument suite is worth the risk presented by the multiple failure points and increased mass.

III. RTD Clamp Design

A. RTD Installation Background

RTDs are used in the FSS to monitor the temperatures of the heated fluid lines. RTDs measure the changes in temperature as the resistance of the metal sensor responds to the temperature. The LAVA team uses RTV to adhere RTDs that are as small as a pin point to 1/8th inch outside diameter metal tubing. The assembly is cured in an oven at 67 °C for 2 hours to allow the RTV to harden, securing the RTD to the tube. The team has utilized best practices to standardize the installation of the RTDs, but variation is always an issue when intricate tasks are performed by hand. Therefore, it was assigned to develop a mechanism that would consistently secure the RTD into place while allowing it to cure.

The key design factors that needed to be considered were as follows: hold the RTD level and stationary, ensure 0.02 inches of RTV is between the RTD and the tubing, allow for RTV application around the circumference of the tube, be reusable, minimally contact the RTV, and survive 67 °C.

B. Design Iterations

It became clear that from a design perspective, the clamp would need to have three points of contact in order to secure the tube and the RTD itself. This idea can be seen in one of the early design sketches shown in Figure 9. This design features a clamp to hold the tube and then a lever arm to compact the RTD into the RTV.

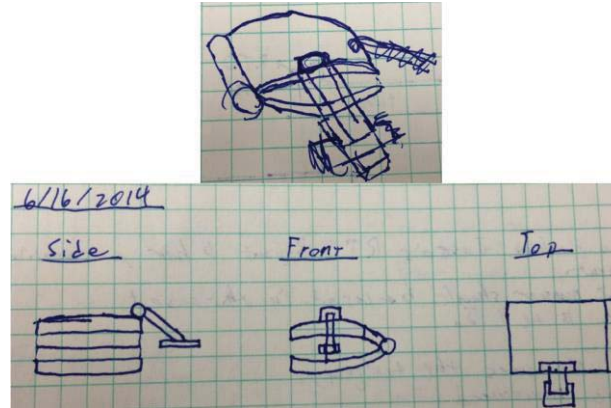


Figure 9. Early RTD clamp design

This design was presented to the team and a key fault in the design was discovered. The force applied to the RTD by the lever arm may not be the same every time and this would lead to inconsistent and potentially inadequate RTV between the RTD and the tubing.

To address this, the design sketched in a side view in Figure 10 was created. This design features an adjustable lever arm to clamp the RTD down, and an extension arm to contact the tubing. The extension would be precisely dimensioned so that when it contacted the tubing, the lever arm would push on the RTD, consistently leaving 0.02 inches of RTV between the RTD and tubing.

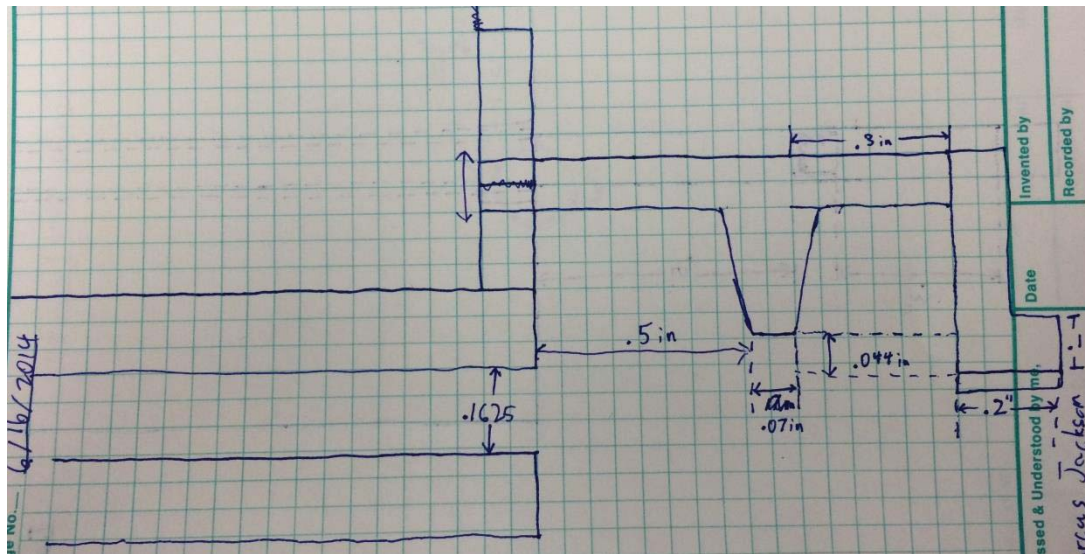


Figure 10. Adjustable RTD clamp design

Through discussions with the prototype shop team, the intricate nature of this design was determined to be too difficult to machine with their current capabilities. A simpler design that could meet all the design constraints and would be able to be machined in house was drafted in collaboration with the Prototype Lab team. Figure 11 shows a sketch of the side view of the design that was sent to the prototype shop to be modeled in computer aided design software and then 3D printed out of a polymer material. The new design was a metal block with the center cut out; there were also channels for the metal tube and wires from the RTD to pass through the clamp. The top of the cut out would compress the RTD, leaving the 0.02 inches of RTV between the RTD and the tube.

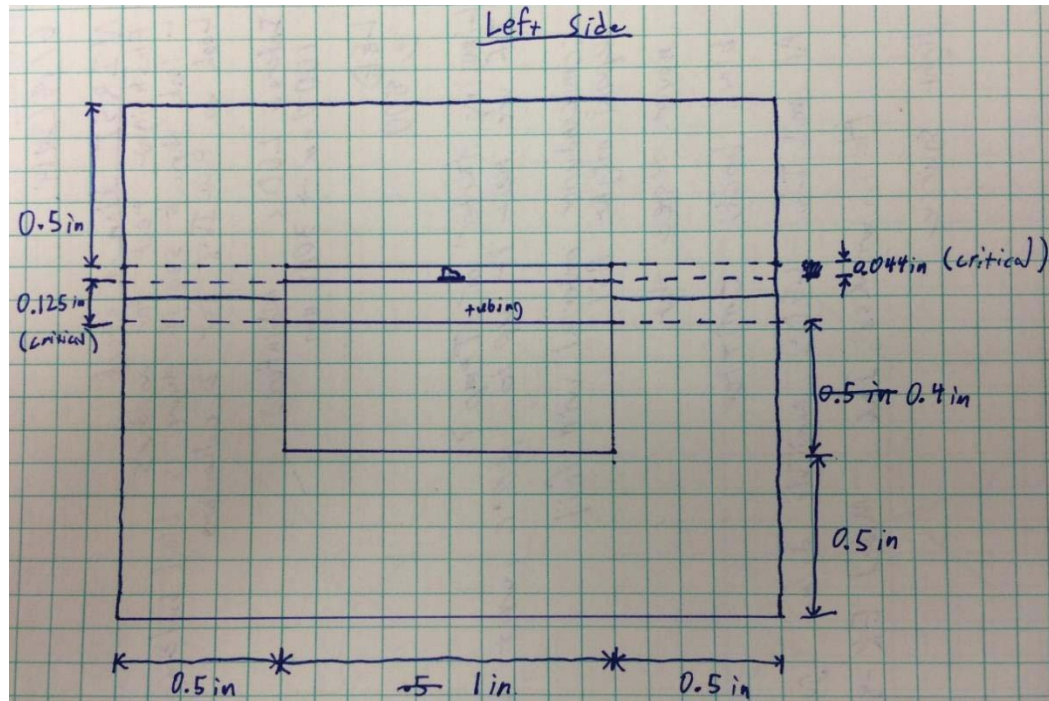


Figure 11. Last sketched RTD clamp design

C. Final Design

The following 3D model, Figure 12, was an interpretation and improvement upon the previously discussed drawings by an intern in the Prototype Lab. The final product will be made out of stainless steel which will be able to experience 67 °C without deformation and has a smooth surface that the RTV will minimally adhere to. The simpler design allows for greater tolerances during the machining process which ensures the RTD has 0.02 inches of RTV between it and the tubing; this will also make sure the RTD remains level with the tubing while it is clamped. Additionally, as highlighted in Figure 12, the design features room for RTV to be applied the entire circumference of the tube, and allows for the secure clamping of all components. As the design is refined through testing, this RTD clamp will be a valuable tool for the LAVA team.

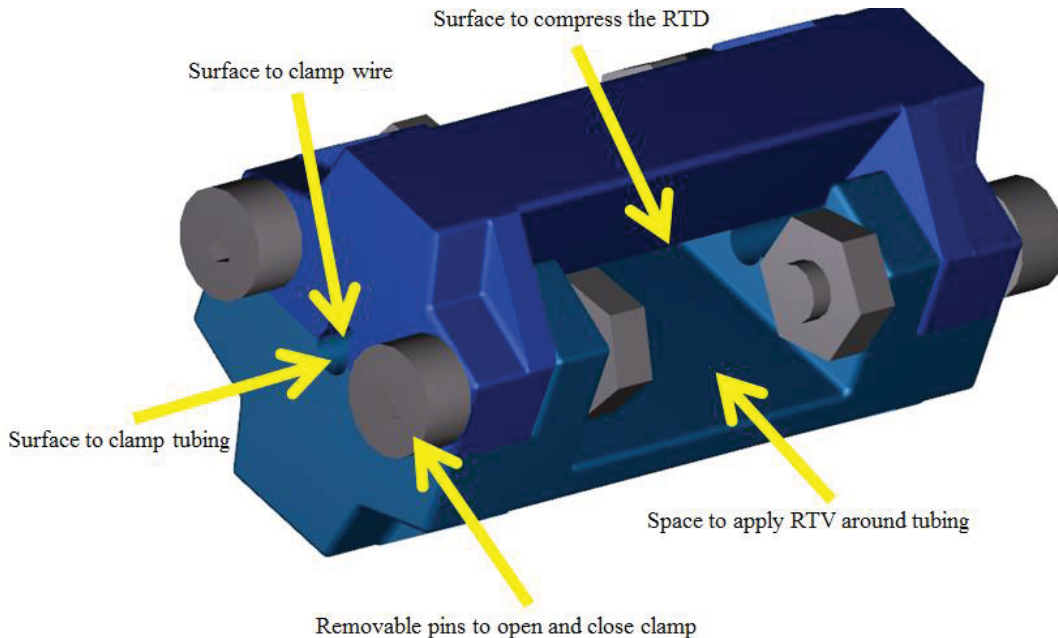


Figure 12. Final RTD clamp design

D. Future Developments

The 3D printed RTD Clamp will be tested to determine the design's effectiveness. A detailed test procedure has been created and the testing will take place after the submission of this paper. The procedure is meticulous so that it can easily be implemented during flight integration. This will help the team in the future to guarantee the quality of the process regardless of the entity tasked with the RTD installation. The test will seek to gain an understanding of how to best use the RTD clamp and determine if the design meets all the requirements. Based on this feedback, further testing can be conducted to further qualify the clamp's effectiveness, or a redesign could commence to remedy the deficiencies with the design. Further testing would include heating the tube after the installation process is completed to determine if the clamp installed RTDs provide consistent heat readings. Also, a stainless steel version can be made and tested to develop even more confidence in the product. The ultimate goal is to have a RTD Clamp ready to be implemented in flight.

IV. FSS Failure Mode Analysis

A. Request

The ARC Flight Project Office requested that the Kennedy Space Center LAVA team perform an analysis of the possible causes and effects of over-pressurize in the FSS. It was decided that all possible single, double, and triple-point failures would be investigated. Also, failures that could occur with no power or powered scenarios were to be included. This analysis was achieved through evaluation of the flight schematic and stepping through each potential point of failure. The results of this analysis are in the following section.

B. Analysis

1. No Power Scenarios

Single-Point Failures:

- ISOLAT-003 Fails: REG-003 regulates pressure
- ISOLAT-001 Fails: REG-001 regulates pressure
- ISOLAT-002 Fails: REG-002 regulates pressure

Double-Point Failures:

- ISOLAT-003 and REG-003 Fails: VLATs downstream will leak at 150 psi but will not latch open; GC affected; Manifold affected
- ISOLAT-002 and REG-002 Fails: VPZT-001 will break; VLATs downstream will leak at 150 psi but will not latch open; GC affected; Manifold affected; OVEN will burp if sealed, or pressure will blow out of OVEN if it is not sealed
- ISOLAT-001 and REG-001 Fails: RV-001 allows pressure to vent

Triple-Point Failure:

- ISOLAT-001 and REG-001 Fail, and ORF-003 is damaged beyond functionality: RV-001 will vent some pressure; VLATs downstream will leak at 150 psi but will not latch open; GC affected; Manifold affected; if sealed, OVEN will burp, if not sealed, pressure will blow out of OVEN

2. Powered Scenarios

Single-Point Failure:

- REG-003 Fails: ISOLAT-003 will contain pressure
- REG-002 Fails: ISOLAT-002 will contain pressure
- REG-001 Fails: ISOLAT-001 will contain pressure
- Any HTR could "Run Away": Power will be flowing to the HTR uncontrollably; can cut power to stop over pressurization; or can control downstream valves to relieve pressure

Double-Point Failure:

- REG-003 Fails and PT-010 Fails: Potential for over pressurization in tubing until another PT experiences the over pressurization; downstream valves can be controlled through software to regulate pressure; ISOLAT-003 can be closed
- REG-002 Fails and PT-009 Fails: Potential for over pressurization in tubing until another PT experiences the over pressurization; VPZT-001 will be damaged; downstream valves can be controlled through software to regulate pressure; ISOLAT-002 can be closed

- REG-003 Fails and PT-010 Fails: Potential for over pressurization in tubing until another PT picks up the over pressurization; downstream valves can be controlled through software to regulate pressure; ISOLAT-003 can be closed
- ISOLAT-003 and REG-003 Fails: Downstream valves can be controlled through software to regulate pressure and prevent system damage
- ISOLAT-002 and REG-002 Fails: VPZT-001 will be permanently damaged; VLATs downstream can be controlled through software to regulate pressure and prevent system damage

Triple-Point Failure:

- ISOLAT-001 and REG-001 Fail, and ORF-003 is damaged beyond functionality: RV-001 will vent a portion of the pressure; VLAT-001 can be controlled through software to relieve pressure and prevent system damage
- ORF-003, PT-001, and REG-001 Fails: Potential for over pressurization in tubing until another PT picks up the over pressurization; OVEN impacted; RV-001 will vent a portion of the pressure; Downstream valves can be controlled through software to relieve pressure; ISOLAT-001 can be closed

C. Path Forward

Based on this analysis, no single point failure mode exists that will cause harm to the system. Double and triple-point failures could potentially affect the FSS manifold. This analysis will be presented to the ARC Flight Project Office to fulfill the LAVA team's obligations. The ARC project office must determine if the possibilities outlined in this report are acceptable to carry based on the parameters of the mission. Also, the LAVA team now has a document to reference moving forward should this question arise at another time in the project's life. Further work can be done to determine methods to prevent damage to the FSS manifold should the double and triple-point failures be deemed unacceptable. Testing may also be performed to quantify the impacts of each failure that has the potential to harm the system.

V. Trade Study Release

A. Purpose

Kennedy Space Center has historically been an operations center for NASA projects. LAVA is one of the first subsystems to be developed for a lunar lander to come from the center. There is limited experience on center handling the engineering and scientific challenges presented by the nature of the project. To build the knowledge base for this project, trade studies have been performed by the team. These trade studies investigate critical design decisions and include selection criteria, alternate solutions, and recommendations².

These trade studies are considered engineering products of the design and development phase. As NASA products, there are strict guidelines and a specific format these documents must adhere to in order to be released by the team. A total of 10 trade studies were conducted by the LAVA team and the following is an explanation of the process involved in preparing them for release.

B. Process

1. Lunar Advanced Volatile Analysis Fluid Subsystem Pressure Transducer Trade Study Report

This trade study was previously in power point format. The information was transferred into the correct trade study format and the bullet point notes synthesized into paragraph form. Also, the abbreviations, acronyms, and symbols list was updated. The various requirements for a pressure transducer to be used for LAVA are outlined and a survey of the available pressure transducers that meet the requirements is recorded. A pressure transducer that best meets requirements is chosen.

2. Fluid Subsystem Active Relief Versus Passive Relief Trade Study Report

This trade study was already in the correct format and required minimal editing. The signatures for the document were updated. Also, the abbreviations, acronyms, and symbols list was updated. The pros and cons of an active or a passive relief design for the FSS was presented. Both designs were described in detail. A decision was reached based on the acceptable risks associated with the system.

3. Location of Calibration Gas Inlet to Gas Chromatograph and Mass Spectrometer Trade Study Report

This trade study was already in the appropriate format and required minimal editing. The signatures for the document were updated. Also, the abbreviations, acronyms, and symbols list was updated. The trade study investigates the possible locations for the Calibration Gas inlet into the GCMS. A location is selected based on the efficiency of the design.

4. Water Droplet Demonstration Unit Cold Finger Coating Trade Study Report

This trade study was already in the proper format and required minimal editing. The signatures for the document were updated. Also, the abbreviations, acronyms, and symbols list was updated. The need for a coating to protect the cold finger on the WDD from corrosives was considered and a decision was reached based on the assessed risk.

5. One Column Versus Two Column Gas Chromatograph Trade Study Report

This trade study was already in the correct format and required minimal editing. The signatures for the document were updated. Also, the abbreviations, acronyms, and symbols list was updated. The use of a one or two column GC and the respective carrier gas options for each are investigated. A decision is made based on the costs, mass, and power results.

6. Relative Humidity Versus Near Infrared Spectrometer for Secondary Water Measurement Trade Study Report

This trade study was already in the appropriate format and required minimal editing. The signatures for the document were updated. Also, the abbreviations, acronyms, and symbols list was updated. This trade study compares using a relative humidity type sensor or a Near Infrared, NIRST, instrument to perform a secondary water measurement of the water vapor in LAVA. Based on the ability to meet RESOLVE requirements, a recommendation is made.

7. Pump Versus No Pump For The Lunar Advanced Volatile Analysis Fluid Subsystem Trade Study Report

This trade study was already in the proper format and required minimal editing. The signatures for the document were updated. Also, the abbreviations, acronyms, and symbols list was updated. This trade study presents the implications of an FSS with versus without a pump. Through experimental analysis, a recommendation is made based on the perceived benefits to the system.

8. Gas Chromatograph – Mass Spectrometer Transfer Line Flows Trade Study Report

This trade study was originally a PDF in a basic scientific report format. The text, figures, and tables were adapted to meet the NASA format. Formatting updates similar to the other trade studies were completed. This trade study describes the setup of the GCMS flow lines in LAVA.

9. Resistive Temperature Detectors Versus Thermistors and Understanding Mounting Procedures Trade Study Report

This trade study was originally two related reports. One was a Power Point presentation explaining the RTD mounting procedure to be used for LAVA and the options available for RTDs. The other was a technical report that tested the RTDs using the mounting procedure described in the presentation and determined which had superior performance. Both were combined into one document that met the NASA requirements.

C. Status

The trade study reports have been completed and are being processed by export control. The recommendations in these trade studies will serve as important reference documents for the LAVA team during the various project reviews where they will be grilled for every decision they made. Also, future NASA projects will be able to review the lessons learned during LAVA's development to better determine their own path forward.

VI. Final Conclusions

This internship has offered the opportunity to work on a variety of interesting and challenging engineering tasks. Experience performing experiments was gained while troubleshooting the NIRST count loss. It is now known that the loss can be attributed to both the material deposited on the sapphire window in the surge tank and the failure of the collimators. The RTD clamp design will be evaluated and expectantly implemented for use in the future and during flight. It was rewarding to be able to use the design skills developed in undergraduate studies to create a tool that will support the team's continuing efforts. Performing a failure analysis of the FSS helped to better understand the system as a whole, and fluid systems in general. Additionally, the insights gained by this analysis will be available for review by project management to make informed design decisions and recommendations. Finally, working on the trade studies helped put the project in perspective and improve technical writing skills. Now the team will not have to spend valuable time on paperwork and can instead focus their efforts on the ETU testing. The work done during this internship will leave the LAVA team with tools and knowledge to continue on the mission to the moon.

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