

Restore-L Satellite Servicing Internship Final Report

Giovanni Campos

Kennedy Space Center

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Giovanni A. Campos¹
NASA Kennedy Space Center, FL 32899

Nomenclature

<i>PTS</i>	=	Propellant Transfer Subsystem
<i>NASA</i>	=	National Aeronautics and Space Administration
<i>EDO</i>	=	Engineering Development & Operations facility
<i>NIFS</i>	=	NASA Interns, Fellows, and Scholars
<i>CAD</i>	=	Computer-Aided Design
<i>CNC</i>	=	Computer-Numerical-Control
<i>ACCLLP</i>	=	Apollo Challenger Columbia Lessons Learned Program
<i>lbf</i>	=	Pound-Force
<i>P</i>	=	Pressure
<i>f</i>	=	Pipe Friction Coefficient
<i>L</i>	=	Length of pipe
<i>D_i</i>	=	Inner Diameter
<i>ρ</i>	=	Density
<i>ω</i>	=	Flow velocity

Abstract

This paper reviews the Restore-L mission purpose and the necessary research and simulations to meet mission specification for the Propellant Transfer Subsystem (PTS). It is essential the PTS undergoes functionality testing, environmental testing, and calculations to understand the capabilities of the system. For the testing of components from PTS, a proper test setup is required. It is vital for test hardware, such as hoses and valves, to stay in place while the test is being performed. For the test hardware to operate correctly, positioning, orientation, and alignment are critical as well. In addition to the testing, calculations for pressure drop were explored. To meet requirements for test setups, designs for test hardware mounts were sketched, 3D modeled, and manufactured. Using fluid mechanics for calculations, a pressure drop equation was applied with known variables from mission specification. With the test hardware mounts designed and manufactured, the test setup was assembled with mounts installed. Test hardware mounts met all design requirements. Calculation for pressure drop were concluded and an answer was achieved. Meeting design requirement, mission specification, and calculating correct results allow the Restore-L mission to make further progress and help understand the effectiveness of the Propellant Transfer Subsystem.

¹ NIFS Intern, Exploration Payloads Branch (NE-L5), Kennedy Space Center. Educational Institution: CUNY New York City College of Technology

I. Introduction

Satellites have a crucial role in science when it comes to observing weather, measuring greenhouse gases, or studying stars. But all satellites have a lifespan, depending on how much propellant they have left. When a satellite is about to be decommissioned, engineers can use the last of its propellant to make one of two choices. The first choice is to send it back to earth, where the re-entry will burn up the satellites. Any surviving debris will land in the spacecraft cemetery located in the Pacific Ocean. The second choice is to send it farther into space, into a graveyard orbit [1]. With the Restore-L mission comes a third choice of refueling a live satellite to prolong its lifespan, even if the satellite was not designed to be serviceable. Restore-L will be a “robotic spacecraft equipped with the tools, technologies and techniques” that are necessary to complete this mission. To complete this goal, there are five key elements that need to be researched, designed, and tested. Those key elements are: 1) Autonomous, Real-Time Relative Navigation System, 2) Servicing Avionics, 3) Dexterous Robotic Arms, 4) Advanced Tool Drive and Tools, and 5) Propellant Transfer Subsystem. This paper will be focused on the Propellant Transfer Subsystem.

The Propellant Transfer Subsystem (PTS) is one of the key elements to bring the Restore-L mission to life. The system needs to transfer propellant to the satellite “at the right temperature, pressure, and rate” [2]. In order to achieve these requirements, functionality testing, environmental testing, and calculations involving fluid mechanics need to be completed. These tests and calculations are performed to simulate what the system will be going through in outer space during its mission.

Outside of the Restore-L mission, an additional task was completed for the internship. This task included the website development for the Apollo Challenger Columbia Lessons Learned Program (ACLLP).

II. Functionality Test

A. Purpose

The functionality test that was performed for PTS was a tensile test on a flex hose. The purpose of the tensile test was to determine if a custom made ¼ inch metal braided convoluted flex hose would plastically deform under static loading. The objective was to certify no plastic deformation at a weight of 200 lbf or less. Any weight above 200 lbf was for reference only.

B. Preparations

A quality check on the flex hose, length measurement method preparations, and the test setup were all essential for the preparation of this test.

The quality check was to detect any and all abnormalities on the flex hose that included, but was not limited to, dings on the steel braid, over/under weaving pattern mistakes, tear of a single/multiple steel braid(s), misalignment of the outer and inner braids, etc. Any of these abnormalities could have affected the results of the tensile test, which was why these abnormalities needed to be noted before the test was conducted. As seen in fig. 1, a section of the flex hose shows marked abnormalities with yellow tape. The most common abnormalities were minor dings on the steel braid.



Figure 1. Quality Check of the Flex Hose.

Image Credit: Giovanni Campos, NIFS Intern.

Continuing with the preparation of the test, the length measurement procedure was also arranged. A string was added to the flex hose as a reference for original length and a piece of tape marked off the end of that length, as seen in fig. 2. While the flex hose would stretch due to tension, the string would be unaffected by the load, keeping its original length.



Figure 2. String and Tape Datum. Image Credit:

Giovanni Campos, NIFS Intern.

The test setup was constructed using various items in the Engineering Development & Operations facility (EDO), such as, a step ladder, insulation foam, rope, and a wooden platform. Safety was incorporated into the test setup by covering all opening of the step ladder with insulation foam. In the circumstances the flex hose were to fail under static loading, any debris would have been contained within the setup.

One free end of the flex hose, attached with a kellem, was mounted to the top of the step ladder, while the other free end, also attached with a kellem, was mounted with the wooden platform. The wooden platform was created to hold the static load. 20 lbf and 50 lbf weights were used for the testing procedure. Figure 3 shows the initial state of the test before starting the procedure.



Figure 3. Tension Test Setup. Image Credit: Brian Nufer, NIFS Mentor.

C. Procedure

When the test was performed, the starting load was determined to be 80 lbf. To reach this load, extra weights were applied to the wooden platform, which weighed 62.2 lbf, to reach 80 lbf. Next, the load was adjusted to 100 lbf by adding a 20 lbf weight to the platform. From the 100 lbf load, increments of 50 lbf weights were added to the platform until a load of 450 lbf was achieved. Finally, a 100 lbf weight was added to the 450 lbf load to reach a final load of 550 lbf.

The length of the flex hose was measured and recorded for each loading and unloading of the weights. Two methods were used to record the lengths of the flex hose. The first was from collar-to-collar and the second was from Tape-Datum-to-collar. The second method used the string attached to the flex hose, using the tape at the end of it as reference.

D. Results

Table 1 shows the final measurements under different loading and unloading throughout the test. A gradual increase in length can be seen with each and every loading, but when unloaded, the length of the flex hose returned to 31.688 in (collar-to-collar) and 0.031 in (Tape Datum).

Table 1. Length measurements of flex-hose under different loads

Weight, lbf	Unloaded Length Collar to Collar, in	Loaded Length Collar to Collar, in	Unloaded Length Tape Datum, in	Loaded Length Tape Datum, in
0	31.688		0.000	
80	31.688	31.688	0.031	0.094
100	31.688	31.688	0.031	0.125
150	31.688	31.750	0.031	0.156
200	31.688	31.750	0.031	0.156
250	31.688	31.750	0.031	0.156
300	31.688	31.750	0.000	0.188
350	31.688	31.781	0.031	0.188
450	31.688	31.938	0.000	0.219
550	31.750	32.000	0.031	0.250

The maximum length (from collar-to-collar) for loaded length measurement was 32.000 in at the maximum load of 550 lbf. A gradual increase of the loaded length can be seen again in the graph from fig. 4. The initial unloaded length of the flex hose, 31.688 in, was consistent throughout the duration of the test, until the maximum loading of 550 lbf, which had a final unloaded length of 31.750 in. This shows that the flex hose did not have a significant change throughout the test.

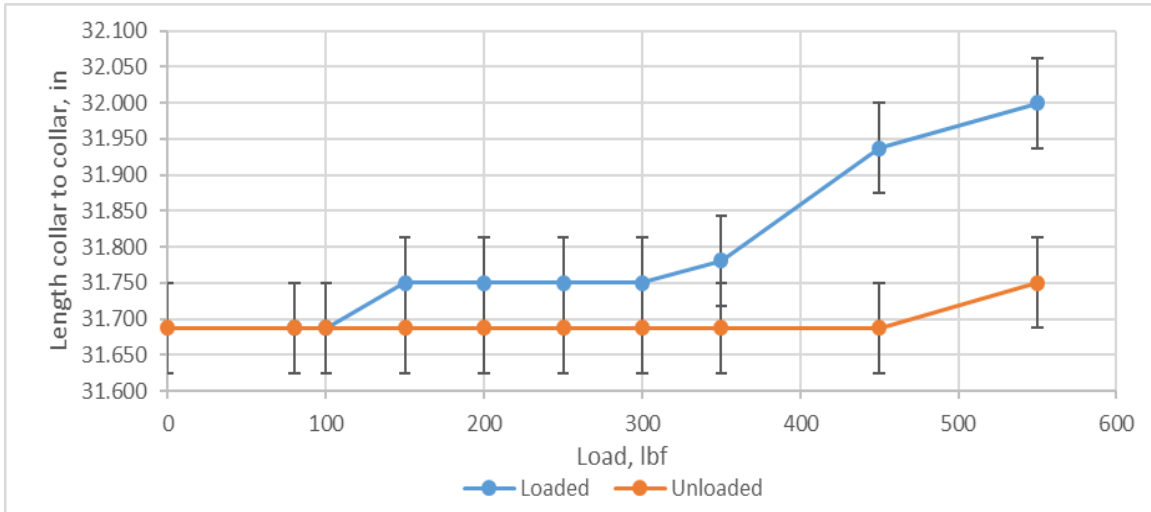


Figure 4. Length of Flex-hose using tape measure (collar-to-collar).

Using the second method (from tape-datum-to-collar), a maximum elongation of 0.250 in was recorded for loaded length. Again, a gradual increase in loaded length was noted as the test progresses in fig. 5. Once unloaded, the recorded measurements showed a difference from the original length of the string to the length the flex-hose returned to, which was 0.031 in. The initial unloaded length of the flex hose was 0.000 in, which also shows that the flex hose did not have a significant change throughout the test, meeting mission specification.

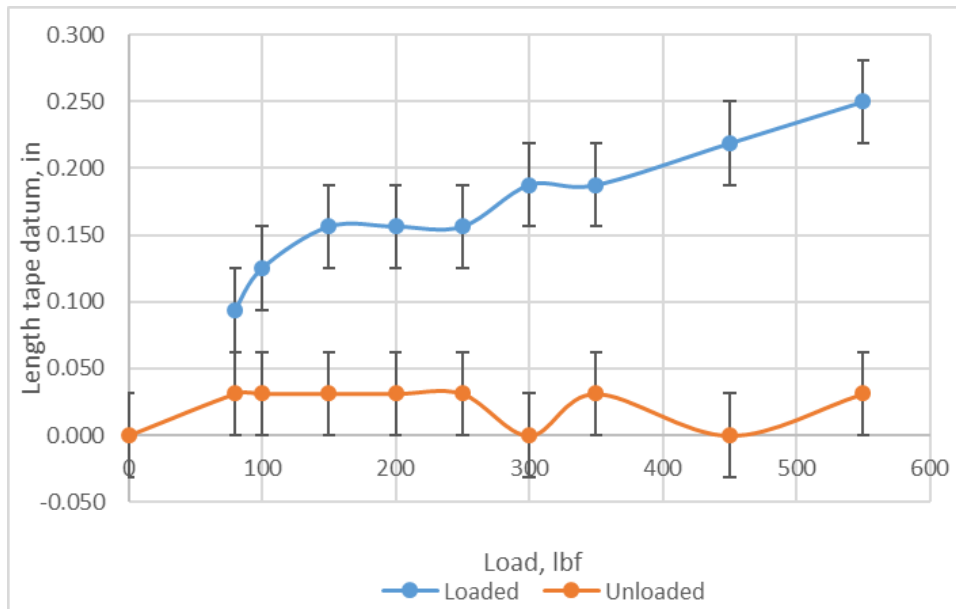


Figure 5. Length of Flex-hose using Tape Datum Method.

III. Environmental Test

A. Purpose

The environmental test for the Restore-L mission is a depressurization test on a Restore-L component that simulates the depressurization during launch. The test will be used to see how the effects of depressurization affected the component.

B. Preparations

Test preparations involved manufacturing for the test hardware that were requisites for the test. Examples of what was manufactured for test hardware were Teflon gaskets, a mounting platform, mounts for both a manual valve and a solenoid valve, and a control box for the electronics. New Teflon gaskets were required for the pressure vessel, manual valve, and solenoid valve flanges being employed to conduct the test. A mounting platform was made to install a manual valve and a solenoid valve for the test setup. To operate correctly, it was necessary for the manual valve to be held in place and in a 90 degree orientation, so mounts were designed to meet these design requirements. Mounts for the solenoid valve followed the same design requirements, with an additional requirement of having the mounts be adjustable in height. The adjustable height requirement was for ease of assembly, so the fittings of the manual valve and solenoid valve can be aligned properly when installed. Finally, a control box that holds the electronics for the test was also required to be manufactured.

C. Teflon Gaskets

Gaskets are placed in between the flanges of any pressurized component. For the purpose of this test, gaskets were imperative for the pressure vessel, manual valve, and solenoid valve flanges. Cutouts were made using an 8 ft x 4 ft Teflon sheet via waterjet.

It was determined that different sizes were desired for each hardware. Using Creo (3D Modeling Software), a sketch and design for the cutouts was conceptualized to expend as much of the Teflon sheet as possible, while preserving any reusable scrap. Figure 6 shows the layout of the cutouts using the software. The circular shapes, highlighted in pink, were the gaskets being implemented for the flanges. The square shapes, also highlighted in pink, were what was preserved after the manufacturing process.

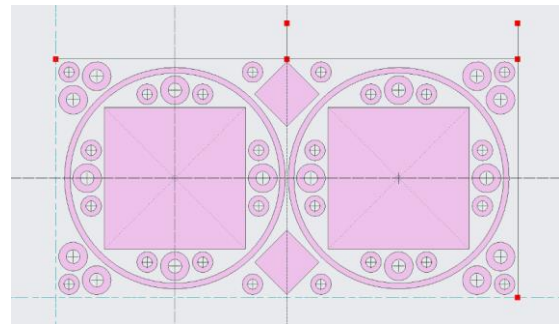


Figure 6. Teflon gasket sketch. Image Credit: Giovanni Campos, NIFS Intern.

After the Teflon layout was approved, the sketch file was converted into a DXF file for the waterjet and a PDF (see appendix 1) was made as a manufacturing reference.

The result from the waterjet are shown in fig. 7. Showing the three different sizes for the test setup. Figure 8 shows the gasket installed between two flanges from the manual valve.

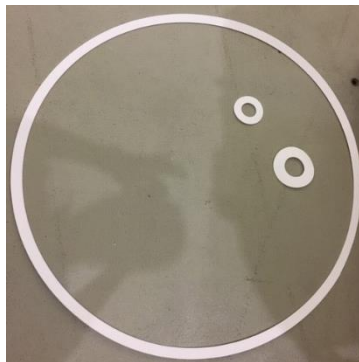


Figure 7. Teflon cutout results. Image Credit: Giovanni Campos, NIFS Intern.

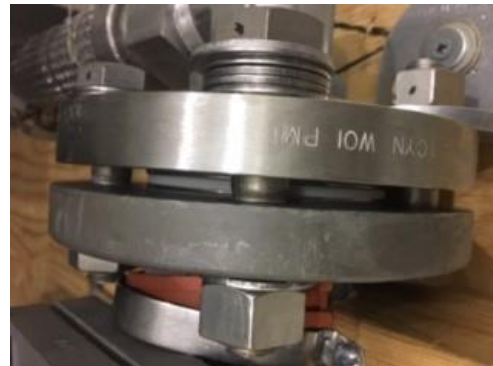


Figure 8. Teflon Gasket installed in between flanges. Image Credit: Giovanni Campos, NIFS Intern.

D. Mounting Platform

The mounting platform was a necessary application for the test setup. Designed for flexible placement and a solid brace for the manual valve and solenoid valve mounts. The materials used for the platform was lumber 2x4 and plywood.

Utilizing Autodesk Sketchable (Sketching Software), a sketch was finished to arrange the lumber 2x4 positions to create the sturdy platform. The dimensions referenced in fig. 9 were to assist in placement for the mounts when installed. Figure 10 shows the mounting platform installed with added legs to help with stability.

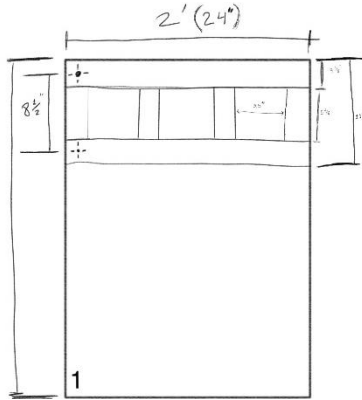


Figure 9. Mounting Platform Sketch, stiffener Placements.
Image Credit: Giovanni Campos, NIFS Interns.



Figure 10. Mounting Platform Installed. Image Credit: Giovanni Campos, NIFS Intern.

E. Manual Valve Mounts

The manufacturing for the manual valve mount was fulfilled with various material in the EDO facility. A sketch for this mount was designed with Autodesk Sketchable after locating the material that would be of best usage. The materials found were aluminum brackets and lumber 2x4.

As previously mentioned, the manual valve must be held in place and in a 90 degree orientation. With these requirements in mind, a sketch was made for the mount (fig. 11). The drawings depicted in the colors black and blue were brackets found in the EDO facility that were identical to each other and involved minor manufacturing. The same applied for the drawings depicted in the colors red and green. The final drawing, depicted in yellow, were created from the lumber 2x4 with cutouts matching the curved bottom of the manual valve.

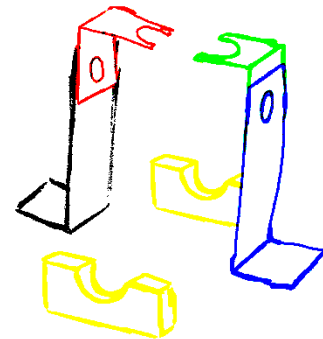


Figure 11. Manual Valve Mount Sketch. Image Credit: Giovanni Campos, NIFS Intern.

This was a hands-on manufacturing process. The tools capable of completing this process was a vertical/horizontal band saw and a hand drill. The band saw was appropriate to make the curved cutout from the lumber 2x4, while the drill handled the production of the necessary holes for installation on the mounting platform.

A modification was urgent for the mount after testing its rigidity by applying a force to the manual valve handle. As a result of the test, the manual valve was able to move back and forth, thus not meeting design requirements. Changes were made to ensure that the brackets would be rigid enough to resist force. This was fixed by adding a stiffener to the backside of the mount to ensure it was rigid enough to stay in place (fig. 12). In addition to the stiffener, an extra aluminum bracket was manufactured to help in rigidity of the manual valve mount by placing it by the flange on the valve right-hand side (fig. 13).



Figure 12. Stiffener to backside of the mount.
Image Credit: Giovanni Campos, NIFS Intern.



Figure 13. Extra Bracket attached to the Flange.
Image Credit: Giovanni Campos, NIFS Intern.

Once the changes were equipped, the manual valve was tested once more for a rigidity check. The design requirements were met in keeping the valve in place and in a 90 degree orientation. Figure 14 shows the Manual Valve fully installed. Figure 15 shows an overhead of the manual valve mount, where it sits upright, perpendicular to the ground.

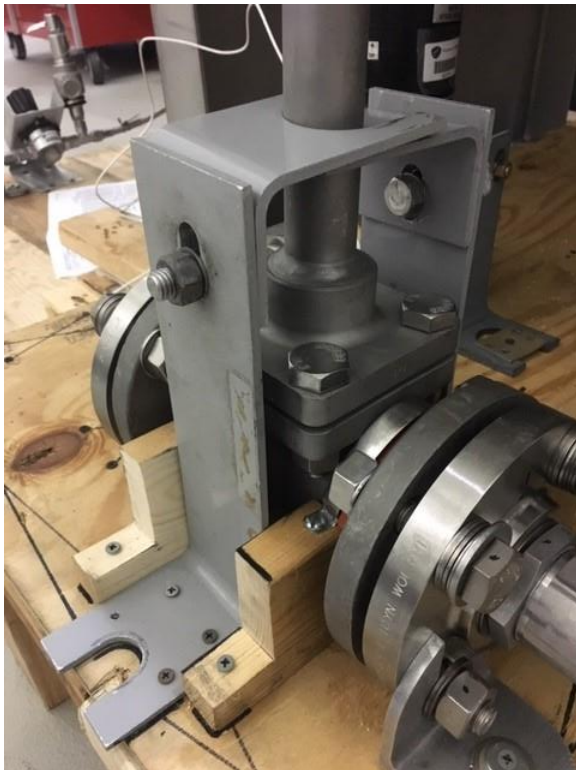


Figure 14. Manual Valve Mount.
Image Credit: Giovanni Campos, NIFS Intern.



Figure 15. Overhead of Manual Valve Mount.
Image Credit: Giovanni Campos, NIFS Intern.

F. Solenoid Valve Mounts

Similar to the process of the Manual Valve mount, the materials had to be located before a sketch could be conceptualized. The materials found for the solenoid valve mount were steel brackets and an aluminum L-channel Stock.

Following the same design requirements of the previous valve mount, with an additional requirement of having the mounts be adjustable in height, a rough sketch was designed. As seen in fig. 16, two assembled mounts will be placed at either side of the solenoid valve. An assembled mount consist of the top aluminum bracket, Solenoid Mount A, and the bottom steel bracket, Solenoid Mount B. The surface of Solenoid Mount A will act as a holder for the solenoid valve. The curve cutout was made to match the curved edges of the valve for ease of assembly. Solenoid Mount B required no manufacturing and came with pre-installed slots. Solenoid Mount B met with the adjustable height design requirement.

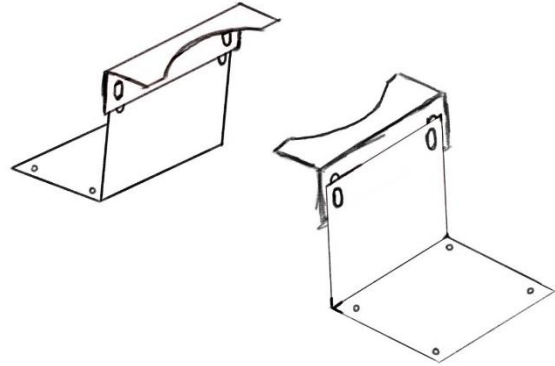


Figure 16. Solenoid Valve Mount Sketch. Image Credit: Giovanni Campos, NIFS Intern.

Following the sketch, a 3D model (fig. 17) was created for Solenoid Mount A and Solenoid Mount B. This was to obtain exact dimensions and to better visualize the mounts. A PDF of the full assembly (see Appendix 2) was made as a manufacturing reference.

The manufacturing process for Solenoid Mount A involved the aluminum L-channel stock. A PDF of the dimensions (see Appendix 3) was made as a manufacturing reference. This required the use of the vertical/horizontal band saw and hand drill.

When finally installed, the use of an insulation foam was needed to act as a foundation and to help properly align the fitting of the solenoid valve to the manual valve. The mounts kept the solenoid valve from moving, meeting design requirements. The final result of the Solenoid Valve mount is shown in fig. 18.

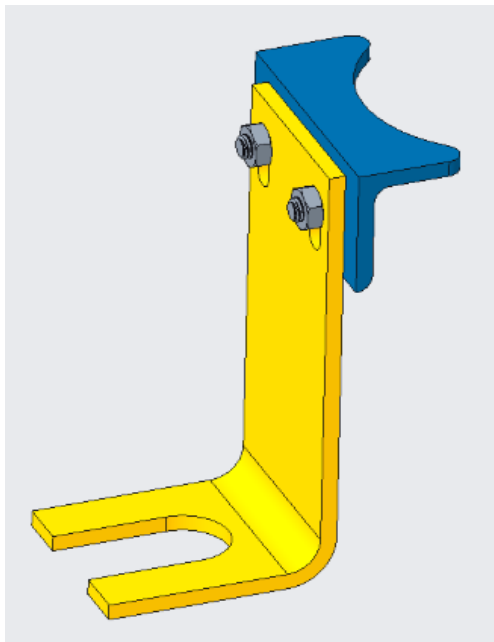


Figure 17. Solenoid Valve Mount Creo. Image Credit: Giovanni Campos, NIFS Intern.



Figure 18. Solenoid Valve Mount. Image Credit: Giovanni Campos, NIFS Intern.

G. Control Box

The control box required two manufacturing processes. The first is for the box itself to hold the electronic components in place. The second is a connector panel to hold a maximum of twelve 7-pin connector heads. The box requires two slot cutouts for the connector panel, so the connector heads can be accessible when mounted on to the box, and a hole cutout to act as a passthrough for any additional cables required for the electronic components.

Utilizing Creo, a Computer-Aided Design (CAD) model was generated from the manufacturer of the junction box, Hoffman A1412CH. Using the generated CAD model, the slots were created on the backside of the box and the hole passthrough was created on the right-hand surface from the slots. The connector panel was also created in Creo using measurement of the 7-pin connector heads and the newly created slots for the panel, as seen in fig. 19. Figure 20 shows the slots and hole design and placement relative to the box. Figure 21 shows the full assembly of the control box and the connector panel.

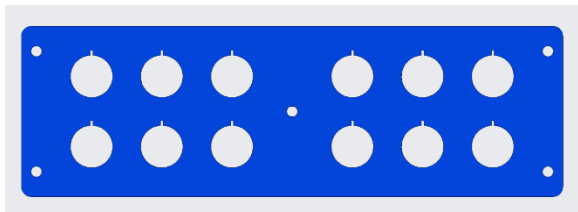


Figure 19. Connector Panel Creo. Image Credit: Giovanni Campos, NIFS Intern.

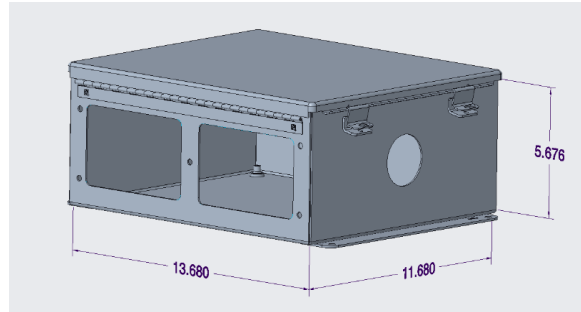


Figure 20. Control Box with cutouts Creo. Image Credit: Giovanni Campos, NIFS Intern.

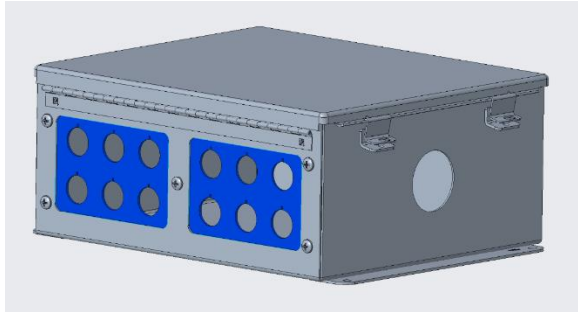


Figure 21. Control Box Assembly Creo. Image Credit: Giovanni Campos, NIFS Intern.

The CAD models were later converted to the appropriate file required to be machined. The control box will be milled out using a Computer-Numerical-Control (CNC) Milling Machine (STP file) and the connector panel will be cut out on the waterjet (DXF file). PDFs of the control box general dimensions (see Appendix 4), slot dimensions (see Appendix 5), the hole passthrough dimensions (see Appendix 6), and the connector panel dimensions (see Appendix 7) were all made as a manufacturing reference.

IV. Pressure Drop Calculations

A. Purpose

To aid in the Restore-L mission, calculations in fluid mechanics were made using liquids, water and hydrazine. Along with the calculation, the results can be confirmed with a simulation for water, but not for hydrazine. Although similar in properties, hydrazine is dangerous and must be handled with care and safety in mind. For this reason, water can be used as a substitute for hydrazine in a physical test.

B. Results

The following Equation was used to calculate pressure drop.

$$\delta P = f \times \frac{L}{D_i} \times \frac{\rho}{2} \times \omega^2 \tag{1}$$

P = Pressure

f = Pipe Friction Coefficient

L = Length of pipe

D_i = Inner Diameter

ρ = Density

ω = Flow velocity

With what is specified and given to follow mission requirements, the final calculations after using Eq. (1) for water and hydrazine were, $1.6 \frac{lb}{in^2}$ and $1.57 \frac{lb}{in^2}$ respectively.

V. Website Development

A. Purpose

Apollo Challenger Columbia Lessons Learned Program (ACCLLP) is directed by Michael Ciannilli. The purpose of this program is to gather all information on previous missions where tragedy struck. From every mistake and accident, there are lessons to be learned. Lessons that also repeat themselves in missions several years apart. This program increase awareness of past mistakes and can help prevent history from repeating itself. The task was to help in the development and update the ACCLLP website content.

B. Progress

In order to assist in the development of this website, Sitecore training and research on the Apollo, Challenger, and Columbia accidents were mandatory. Contents that were present, prior to my involvement, were modified, cleaned up, and made consistent throughout the website. Apollo 13 and Challenger contents were added to their respective pages to give more information on the purpose of the mission, the astronaut’s background, the lessons learned from the tragedy, and the accident reports. Figure 22 shows an example of the home pages of the updated content.

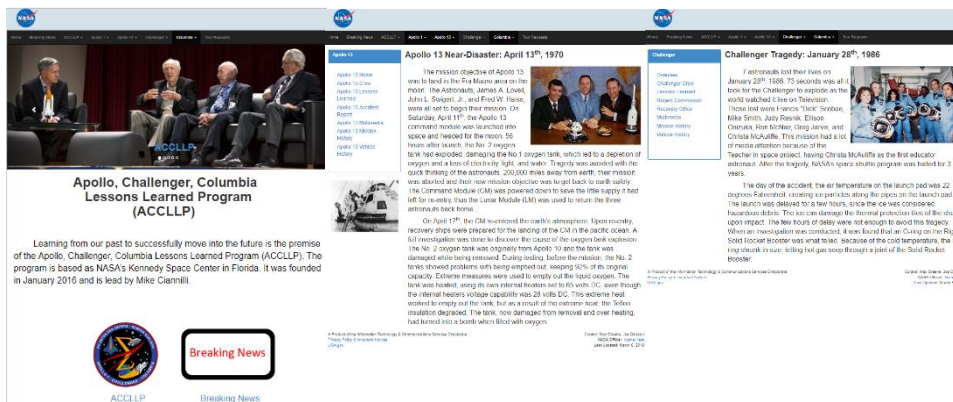


Figure 22. Example of Home pages for ACCLLP, Apollo 13, and Challenger. Image Credit: Giovanni Campos, NIFS Intern.

C. Future Work

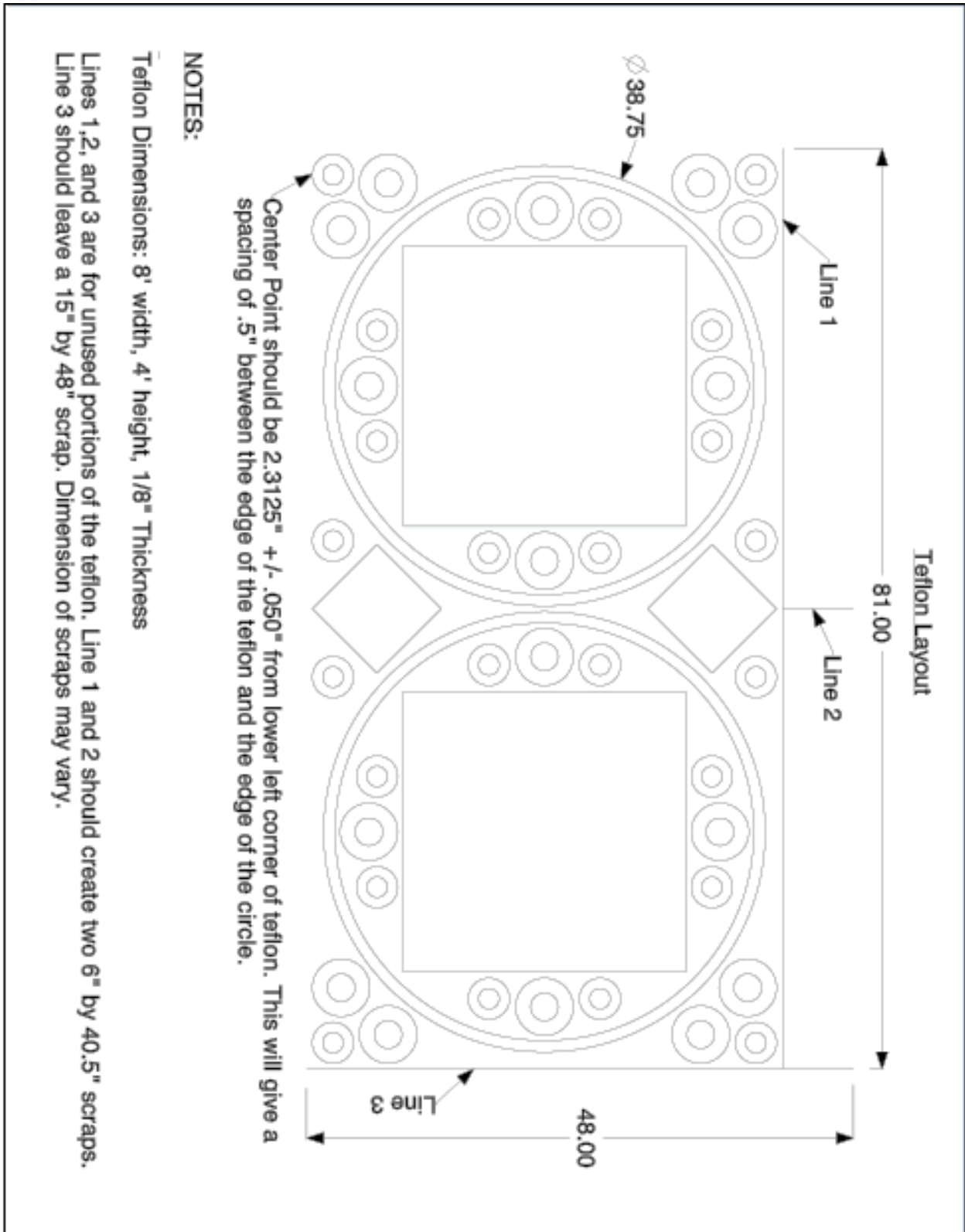
A possible plan to help with the future work of this program is to gather as many volunteers as possible to update the website and also increase the awareness of these lessons learned by having young and future engineers contribute to the project.

VI. Conclusion

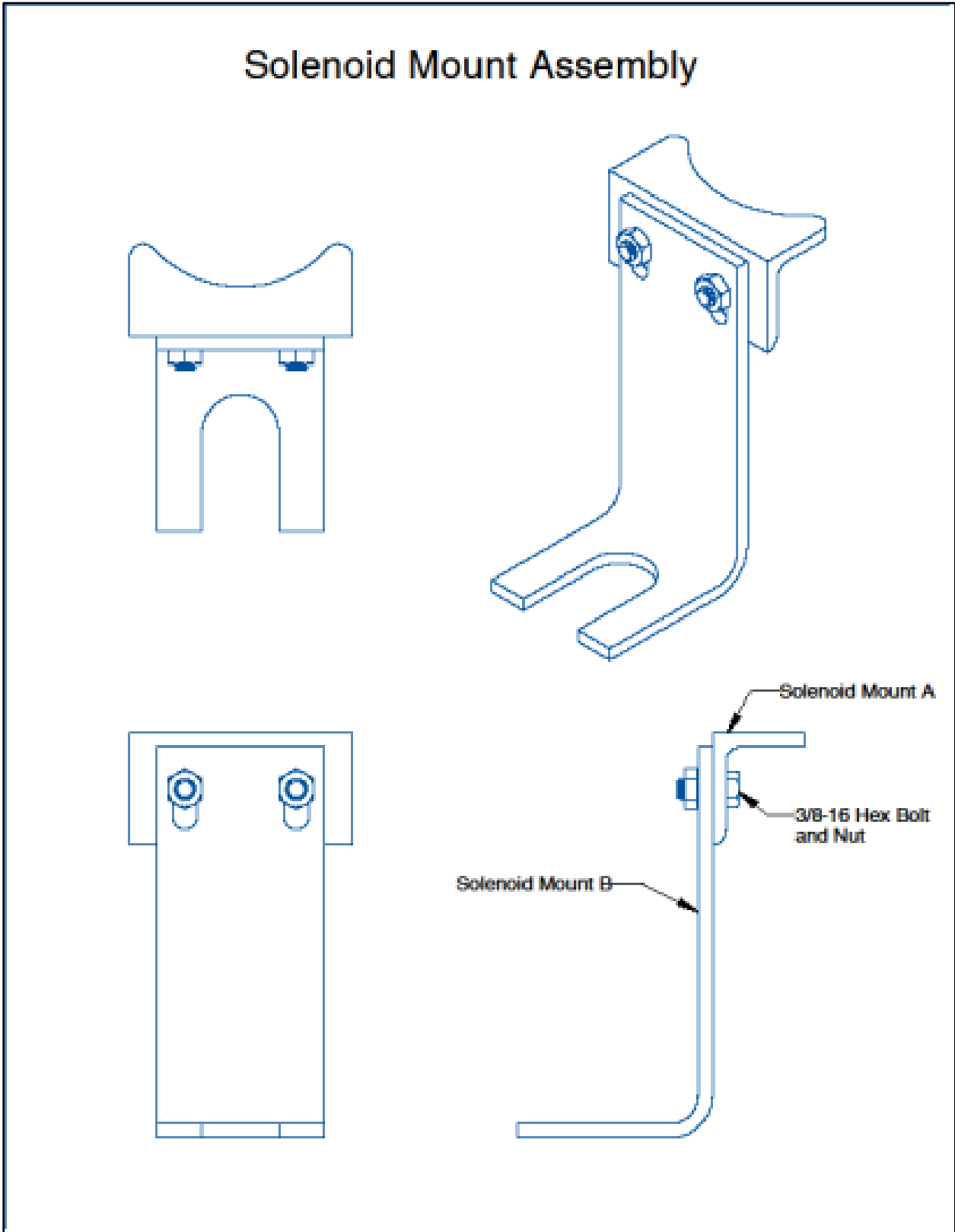
Simulating and understanding what the Propellant Transfer Subsystem will go through in outer space during its mission is now possible, with the conclusion of the functionality test, the environmental test preparations secure, and the answer to the pressure drop calculations solved. With the achievements of these tasks, the Propellant Transfer Subsystem continues to make progress, bringing the Restore-L mission closer to a reality. Soon, a robotic spacecraft will have the technology and ability to refuel current and future satellites, ending the decision of decommissioning these satellites and prolonging their lives instead. Once this goal is reached, Restore-L will allow satellites to continue functioning, gather new information on our planet, and study space for science.

Appendix

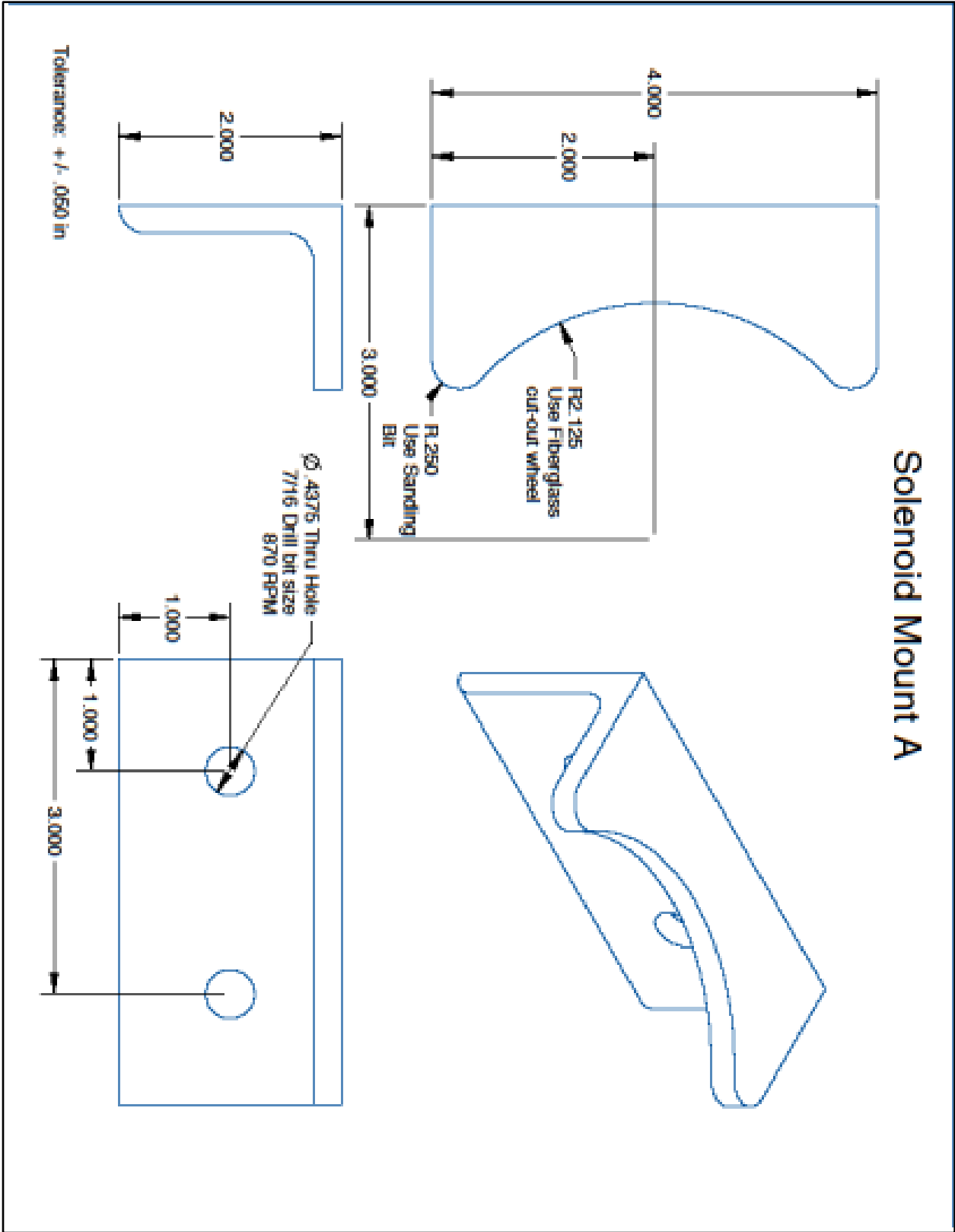
Appendix 1



Appendix 2



Appendix 3



Appendix 4

Control Box Cutouts

Notes:
1) Dimensions are in inches
2) Material is 14 Gauge Steel
3) Page 1: General Dimensions
4) Page 2: Slots Dimensions
5) Page 3: Hole Dimensions

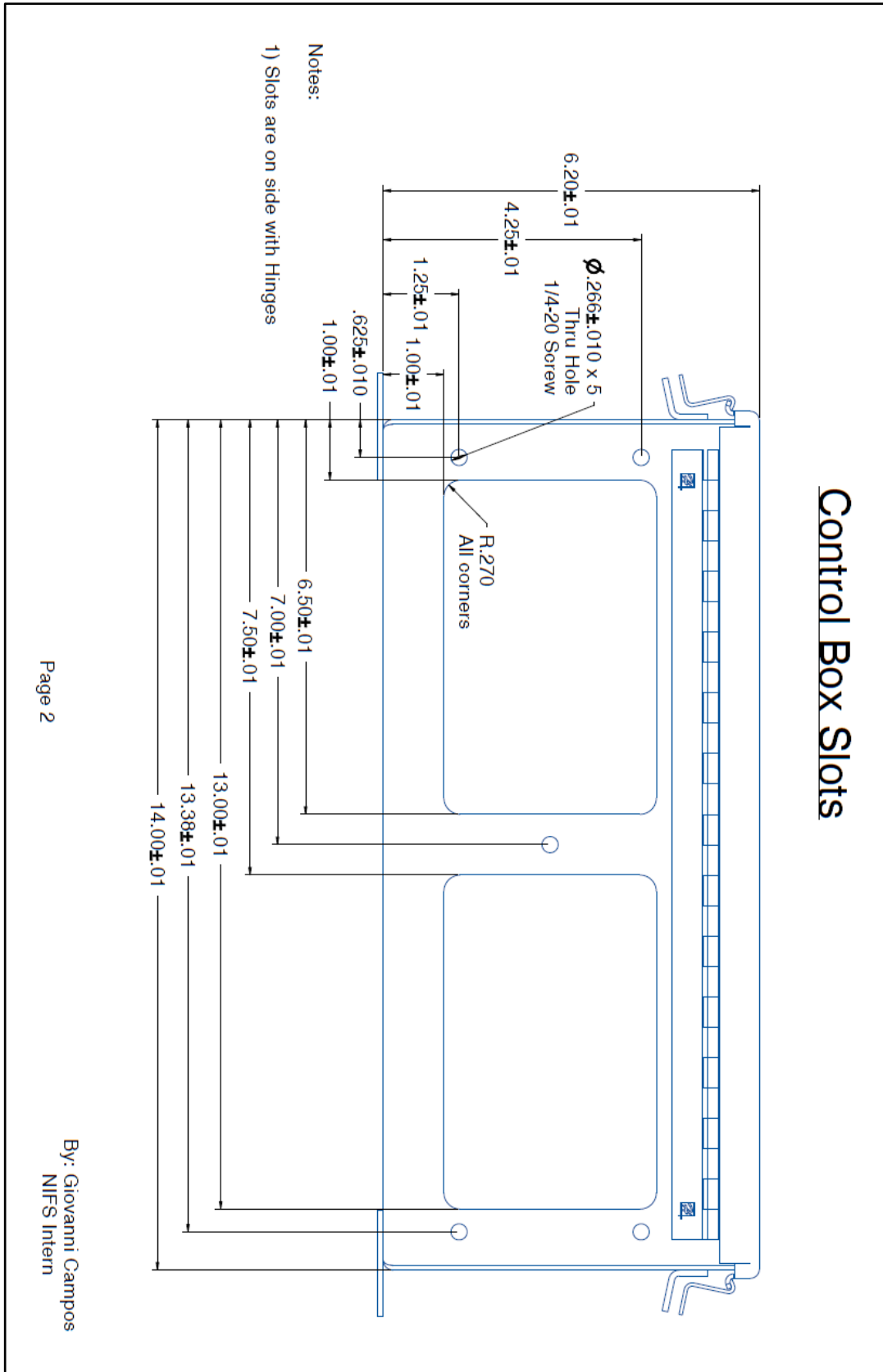
The technical drawings include:

- A top view showing a rectangular box with a width dimension of 14.00.
- A side view showing a height dimension of 6.20 and a depth dimension of 12.00.
- A perspective view of the box.

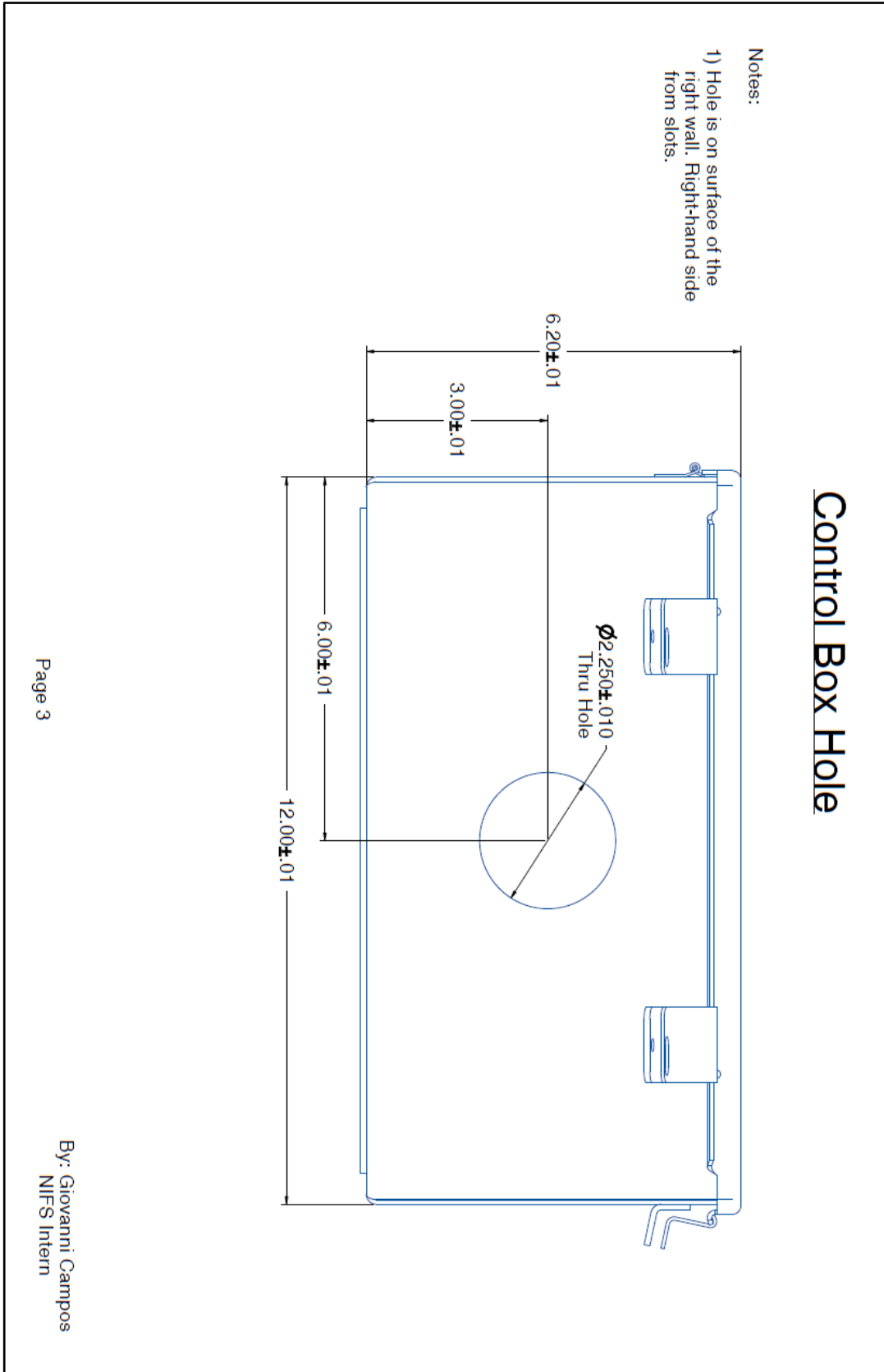
Page 1

By: Giovanni Campos
NIFS Intern

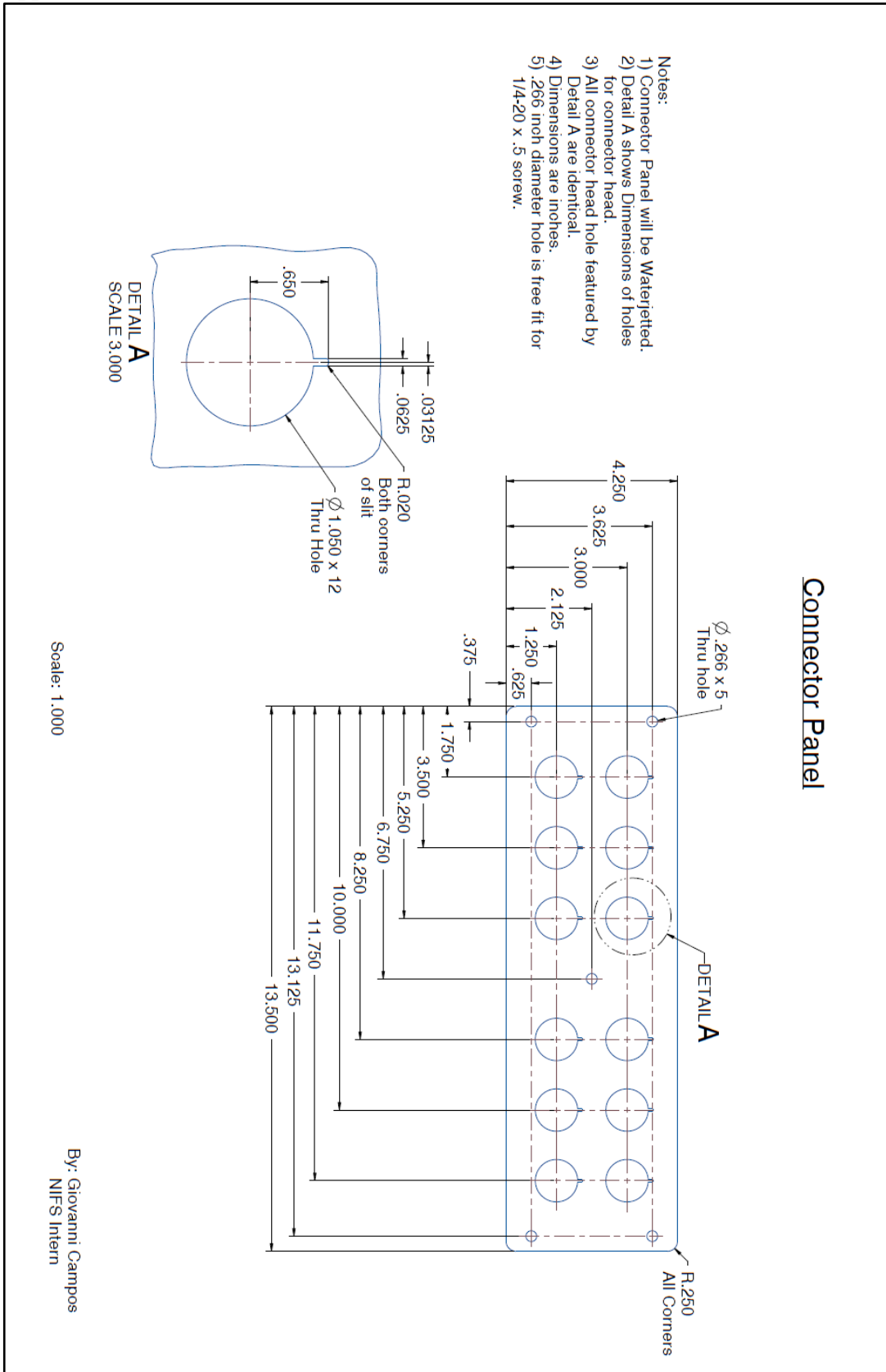
Appendix 5



Appendix 6



Appendix 7



Acknowledgments

The author would like to thank Brian Nufer and Amy Felt for their mentorship throughout this project, for using their experience, and for applying proper guidance for the completion of all tasks. The author would like to also thank Michael Ciannilli for the opportunity to be involved in the ACCLLP website development. Additional thanks go to the members of the NASA Exploration Payloads Branch for their input and support. Funding for this internship was provided by the NIFS program.

References

¹Erickson, K. and Doyle, H. (2019). *Where Do Old Satellites Go When They Die? | NASA Space Place – NASA Science for Kids*. [online] Spaceplace.nasa.gov. Available at: <https://spaceplace.nasa.gov/spacecraft-graveyard/en/> [Accessed 1 Apr. 2019].

²Reed, B. (2019). *Satellite Servicing Projects Division*. [online] SSCO. Available at: <https://sspd.gsfc.nasa.gov/restore-L.html> [Accessed 1 Apr. 2019].