FINAL DEVELOPMENT, TESTING, AND FLIGHT PREPARATION OF THE RIGIZABLE INFLATABLE GET-AWAY-SPECIAL EXPERIMENT (RIGEX)

THESIS

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AFIT/GAE/ENY/07-J14

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Wright-Patterson Air Force Base, Ohio

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THESIS

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Abstract

The purpose of this research is to support the final development of the Rigidizable Inflatable Get-Away-Special Experiment (RIGEX). The RIGEX program is an experimental initial step in developing large-scale rigidizable inflatable structures, which can be utilized in space applications. The primary intent of RIGEX is to verify and validate ground testing of inflation and rigidization methods for inflatable space structures against a zero-gravity space environment. This is performed by designing a Canister for All Payload Ejections (CAPE) experiment to collect data on space rigidized structures for validation of ground testing methods.

The results presented in this thesis provide documentation needed to meet the requirements set forth by the National Aeronautics and Space Administration (NASA) for launching a payload into space. This thesis establishes a process for appropriately ground testing the components of RIGEX in an environment similar to space and explains future testing required. Methods for charging and testing the performance of the onboard inflation system are also discussed. Additionally, the steps taken to replace the onboard imaging system are explained. Throughout the course of assembling the RIGEX protoflight model, several complications were encountered and the design was modified, which are presented along with an as-built final assembly drawing package. Lastly, the procedure for handling RIGEX during its future progression is illustrated.

To my Family and Friends

Acknowledgments

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Thanks also go to the numerous personnel that support the RIGEX project, without them the project would not be possible. Thanks to the insight of Mr. Wilbur Lacey and Mr. Jay Anderson the laboratory work and testing was safe and successful. Special thanks go to Mr. John Hixenbaugh and Mr. Chris Zickefoose for their willingness to explain anything no matter how busy they may be. I would like to thank Mr. Jason Vangel, "Turk" for his skills and patience in overcoming the obstacles of building the experiment. I would like to the points of contact, Mr. Dan Pohlabel at Dysinger and Mr. Dwayne Conley at TechMetals, and Mr. Brian Clack at Swagelok for their excellent communication with their services or acquiring parts. I would like to thank the personnel of the Space Test Program, Mr. Carson Taylor, Mr. Scott Ritterhouse, Maj. Matthew Budde, and Ms. Theresa Shaffer for offering their invaluable wisdom and recommendations during the project.

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Zachary R. Miller

Table of Contents

PAGE

PAGE

PAGE

PAGE

PAGE

PAGE

List of Figures

PAGE

PAGE

PAGE

PAGE

List of Tables

PAGE

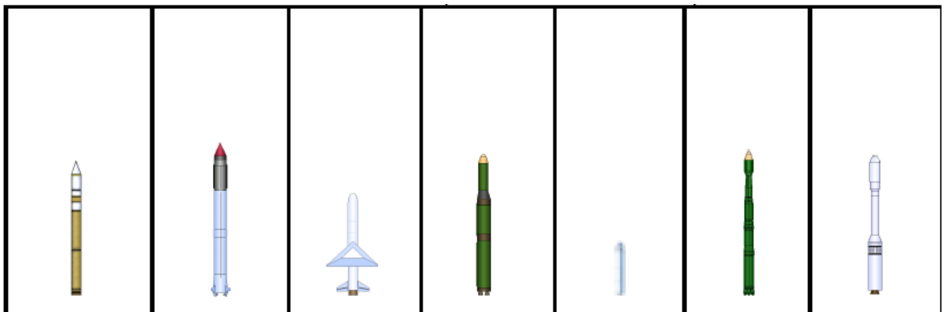
FINAL DEVELOPMENT, TESTING, AND FLIGHT PREPARATION OF THE RIGIZABLE INFLATABLE GET-AWAY-SPECIAL EXPERIMENT (RIGEX)

I. Introduction

Space is the ultimate high ground; the final frontier. Space exploration offers a wealth of opportunities to advance technology, promote discovery, and advance humankind. The rapid progression of the scientific and engineering feats required to reach space and tap into its abundant resources has been astounding. However, such lofty attempts are still limited by practical considerations such as weight, cost, and physical dimension.

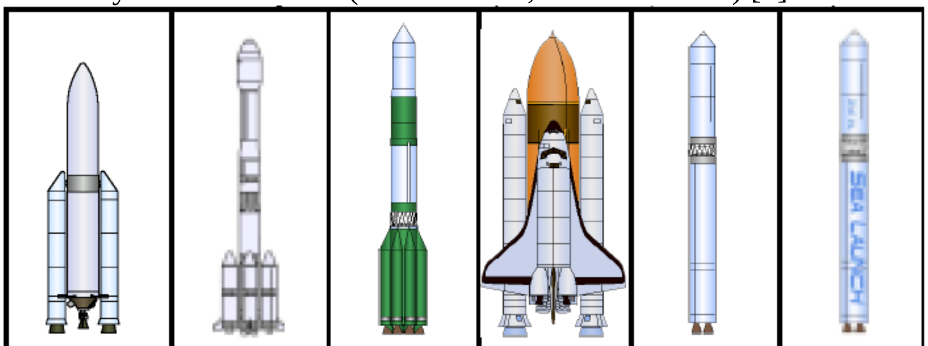
Exploring space is expensive, and as payload weights increase, costs increase dramatically. The estimated cost of launching a spacecraft that only requires a small launch vehicle (5,000 lbs. or less) from the United States to Low-Earth Orbit (LEO) is approximately $13,000,000 to $24,000,000 as seen in Table I-1. The projected cost of launching a spacecraft with a heavy launch vehicle (larger than 25,000 lbs.) to LEO is over $300,000,000, as stated in Table I-2

Table I-1: Small Launch Vehicles (5,000 lbs. or less to LEO) [9]



Vehicle name	Athena 2	Cosmos	Pegasus XL	Rockot	Shtil	START	Taurus
Country/Region of origin	USA	Russia	USA	Russia	Russia	Russia	USA
LEO capacity lb (kg)	4,520 (2,065)	3,300 (1,500)	976 (443)	4,075 (1,850)	947 (430)	1,392 (632)	3,036 (1,380)
Reference LEO altitude mi (km)	115 (185)	249 (400)	115 (185)	186 (300)	124 (200)	124 (200)	115 (185)
GTO capacity lb (kg)	1,301 (590)	0	0	0	0	0	988 (448)
Reference site and inclination	CCAFS 28.5 deg.	Plesetsk 62.7 deg.	CCAFS 28.5 deg.	Plesetsk 62.7 deg.	Barents Sea 77-88 deg.	Svobodny 51.8 deg.	CCAFS 28.5 deg.
Estimated launch price (2000 US$)	$24,000,000	$13,000,000	$13,500,000	$13,500,000	$200,000*	$7,500,000	$19,000,000
Estimated LEO payload cost per lb (kg)	$5,310 ($11,622)	$3,939 ($8,667)	$13,832 ($30,474)	$3,313 ($7,297)	$211 ($465)	$5,388 ($11,687)	$6,258 ($13,768)
Estimated GTO payload cost per lb (kg)	$18,448 ($40,678)	N/A	N/A	N/A	N/A	N/A	$19,234 ($42,411)

Table I-2: Heavy Launch Vehicle (more than 25,000lbs. to LEO) [9]



Vehicle name	Ariane 5G	Long March 3B	Proton	Space Shuttle	Zenit 2	Zenit 3SL
Country/Region of origin	Europe	China	Russia	USA	Ukraine	Multinational
LEO capacity lb (kg)	39,648 (18,000)	29,956 (13,600)	43,524 (19,760)	63,443 (28,803)	30,264 (13,740)	34,969 (15,876)
Reference LEO altitude km (mi)	342 (550)	124 (200)	124 (200)	127 (204)	124 (200)	124 (200)
GTO capacity lb (kg)	14,994 (6,800)	11,466 (5,200)	10,209 (4,630)	13,010 (5,900)	0	11,576 (5,250)
Reference site and inclination	Kourou 5.2 deg.	Xichang 28.5 deg.	Baikonur 51.6 deg.	KSC 28.5 deg.	Baikonur 51.4 deg.	Odyssey Launch Platform 0 deg.
Estimated launch price (2000 US$)	$165,000,000	$60,000,000	$85,000,000	$300,000,000	$42,500,000	$85,000,000
Estimated LEO payload cost per lb (kg)	$4,162 ($9,167)	$2,003 ($4,412)	$1,953 ($4,302)	$4,729 ($10,416)	$1,404 ($3,093)	$2,431 ($5,354)
Estimated GTO payload cost per lb (kg)	$11,004 ($24,265)	$5,233 ($11,538)	$8,326 ($18,359)	$23,060 ($50,847)	N/A	$7,343 ($16,190)

The actual size of the spacecraft is limited by the static envelope of the launch vehicle and also directly affects the cost. There have been several major developments in space launch capabilities such as the Evolved Expendable Launch Vehicle (EELV) program; the Atlas V and Delta IV. The heavy-lift versions of Atlas V and Delta IV both consist of three cores strapped together and have a stretched payload fairing of 5.4 m and 5.1 m as seen in Figure I-1 and Figure I-2. A spacecraft's structure cannot exceed payload fairing width unless it modifies its shape once in orbit.

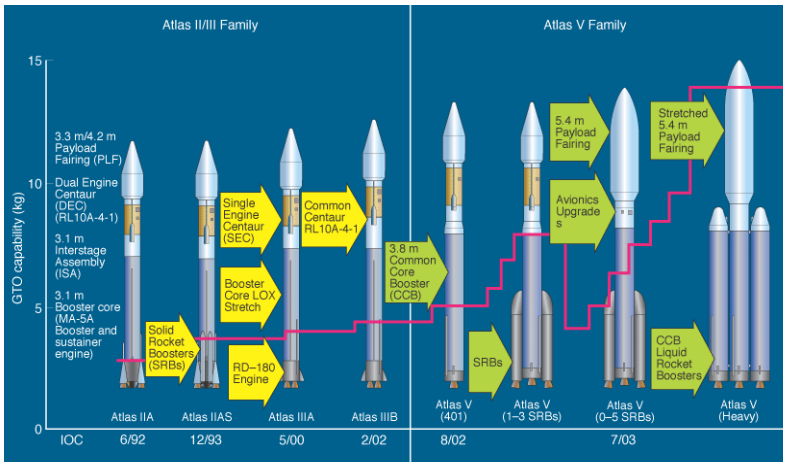


Figure I-1: Evolution of the Atlas V family [15]

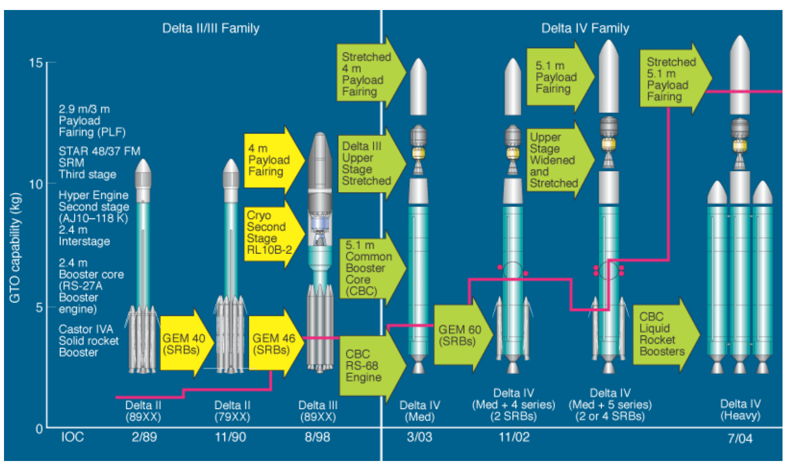


Figure I-2: Evolution of the Delta IV family [15]

Rigidizable Inflatable Get-Away-Special Experiment (RIGEX) was developed by the Air Force Institute of Technology (AFIT) to address these of weight and size issues limiting spacecraft today. By developing structures composed of rigidizable inflatable material, volume and mass can be cut down without having to sacrifice size or capability, and by doing so, reducing the cost.

1.1 Space Motivation

The RIGEX project hopes to overcome the limitations of volume and weight restrictions on objects placed in orbit without sacrificing their large size and structural support. Inflatable structures have been developed and tested over the last several decades, and enough data has been gathered to demonstrate their efficiency, reliability, and cost-saving potential. However, inflatable structures have yet to be proven in the space environment. One early attempt includes an aluminum laminate inflatable structure configured as a satellite antenna, shown in Figure I-3.

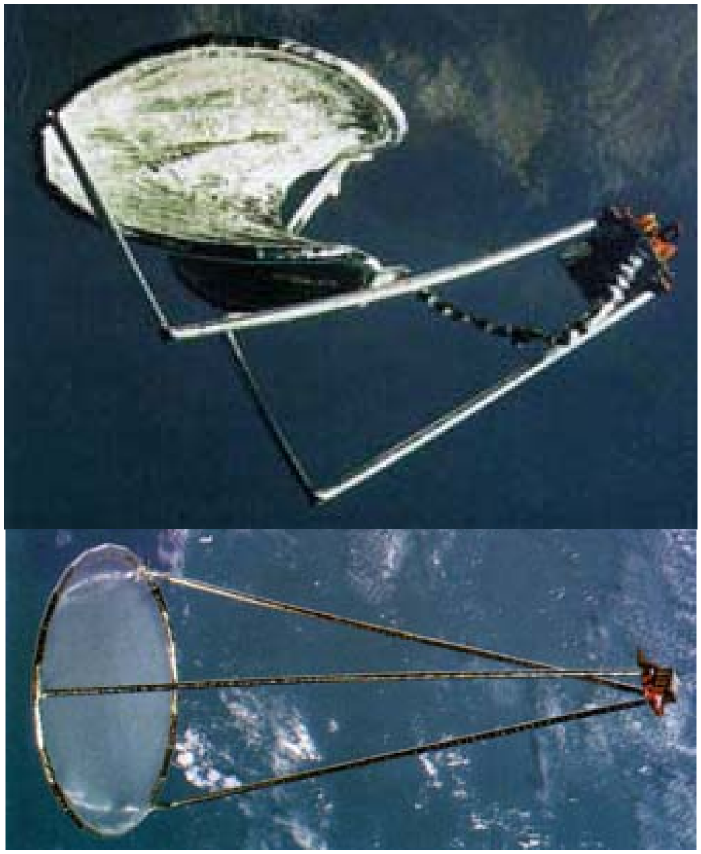


Figure I-3: The Inflatable Antenna Experiment [13]

The RIGEX project hopes to not only advance the use of inflatable structural elements in space, but to take advantage of the properties of rigidizability as well. The proprietary material used in RIGEX only requires minimal pressures to become inflated. Once deployed, the material becomes rigid, and no longer requires pressurization to maintain structural support. Rigidity without pressurization is invaluable in reducing the additional costs, weight, and complexity that would be otherwise required to maintain an inflated structure in the harsh space environment.

1.2 RIGEX Overview

The RIGEX program is an initial step in developing large-scale rigidizable inflatable structures, which can be utilized in space applications. The primary intent of RIGEX is to confirm that methods for inflation and rigidization of inflatable space structures, proven in initial ground testing, are valid in flight. Data on the modal properties and deployment performances of three rigidizable inflatable tubes in the space environment will be analyzed and compared to data gathered in the AFIT lab.

The rigidizable, inflatable tubes were designed and manufactured by L'Garde Inc., located in Tustin, California. The tubes are composed of a proprietary composite material made from carbon fibers coated with a polyurethane based resin. On each end of the tubes are aluminum caps, one end has an opening while the other is completely sealed. The surface of the tubes is also lined internally and externally with Kapton tape. These tubes have a glass transition temperature (T_g) of 125^o Celsius (C). When the tubes are heated above this temperature, they become malleable, and below this temperature they become stiff. Hence, the rigidized configuration of the tube is also known as Sub-T_g. A picture of these tubes in both configurations can be seen in #1 and #4 of Figure I-4.

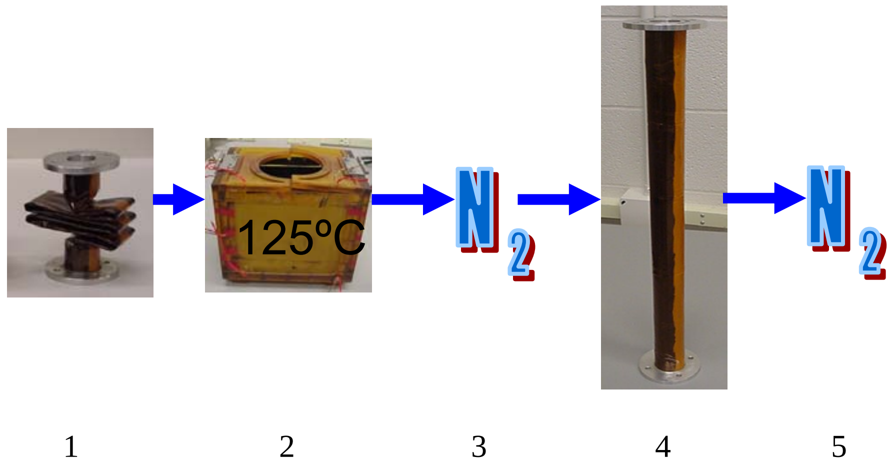


Figure I-4: Concept of Operation [11]

The tubes are provided by L'Garde in a stowed configuration using a z-fold as seen in #1 of Figure I-4. The tubes are secured to the RIGEX structure at the cap with the open end, which is where two piezoelectric patches are placed opposing each other. At other end, an accelerometer is attached and left free in a cantilevered configuration. In the stowed configuration, the tubes are enclosed by an oven onboard RIGEX (#2 of Figure I-4). The doors on this oven are kept closed with a spring-loaded latch controlled by an electrically actuated shape memory alloy pin-puller.

The concept of operation is a sequence of five events, which are depicted in Figure I-4. First, the tube is heated in the oven to 125°C. Once the tube reaches its T_g the oven shuts off. Simultaneously the pin puller activates, releasing the latch holding down the oven doors, and the tube is inflated with gaseous nitrogen. As the tube deploys, the pressure inside the tube and temperature is recorded with pressure transducers and thermocouples. Digital photographs are also taken for further documentation. Pressure is maintained in the tube while it cools. After the temperature drops below 125°C, the tube becomes rigid, and the nitrogen is vented. Finally, the onboard computer signals activation of the piezoelectric patches at the base of the tube, subjecting the tube to vibratory forces that are recorded by the accelerometer on the free end. The entire process is then repeated for the next tube, until all three tubes have been deployed. All the data gathered during the experiment is stored internally on a PC-104 computer board, except for the images, which will be stored separately to three different memory cards.

RIGEX was originally intended to fit into the National Aeronautics and Space Administration (NASA) Get-Away-Special (GAS) canister. In 2004, NASA decided to discontinue the use of the GAS canister as payload bay container for future Space Shuttle missions. In conjunction with the Department of Defense (DOD) Space Test Program (STP), Muniz Engineering Incorporated developed the Canister for all Payload Ejections (CAPE), which is shown in Figure I-5. CAPE was created in the response in the need for "a single ejecting platform capable of ejecting payloads with requirements that are not compatible with current NASA developed ejection systems [24]." RIGEX was redesigned to mount in CAPE with the CAPE Mounting Plate custom designed by AFIT. Overall, the change from using the GAS canister to the CAPE canister was beneficial to the RIGEX design because of increased weight limits and an enlarged usable dimensional envelope.

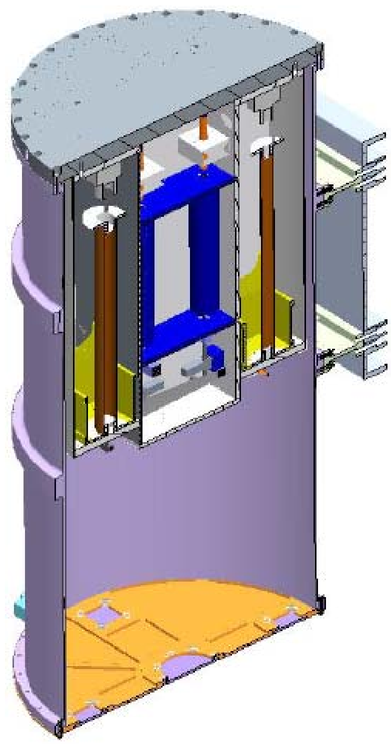


Figure I-5: Canister for All Payload Ejections [12]

The physical configuration of RIGEX is shown in Figure I-6. The experiment can be fitted with eight lifting handles that will be used during ground movement, but must be removed before flight. The experiment will attach to CAPE with a 1.5” thick aluminum plate, which has a cut-out for the cables that attach to the power distribution plate (PDP) and ground lug inside RIGEX. These cables connect to the shuttle to provide power for the experiment. Inside the experiment, there are five sections; four outer bays of similar size and one bay in the center. Three of the outer bays contain identical hardware: a rigidizable inflatable tube inside an oven, four oven controllers, latching mechanism for the oven with a pin puller, a camera with two LEDs for illumination, and appropriate instrumentation. The fourth bay consists of the flight computer along with the PDP that provides power to the experiment. The central bay contains the inflation system, which consists of three pressure vessels and other associated pressure hardware. The entire experiment is housed in a shroud, which contains the internal components that could come loose during launch or reentry.

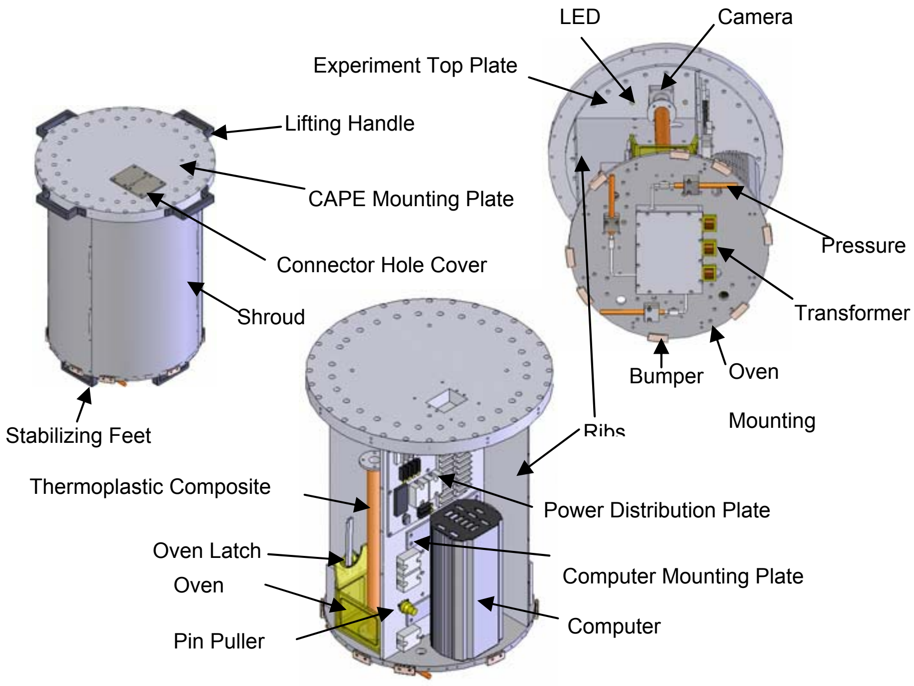


Figure I-6: The Physical Layout of RIGEX [11]

1.3 Experiment Objectives

The RIGEX mission has been the same since it was first formed by DiSebastian when he began research on the project. The mission statement of the RIGEX payload, as presented in DiSebastian's thesis, is to "verify and validate ground testing of inflation and rigidization methods for inflatable space structures against a zero-gravity space environment [7]."

In order to meet DiSebastian's mission statement, the primary objective of RIGEX is as follows:

- Design a Canister for All Payload Ejections (CAPE) experiment to collect data on space rigidized structures for validation of ground testing methods.

Meeting this objective is essential for mission success, but is not the only objective of RIGEX. Secondary objectives identify the tasks required to improve the quality of the experiment. These secondary objectives are as follows:

- Return inflated/rigidized structures to the laboratory for additional testing
- Enable application of rigidized structures to operational space systems
- Implement systems engineering principles into experiment's design

Even though minor changes have occurred to these objectives as the program matured, they essentially remain the same as goals stated by DiSebastian in 2001.

The purpose of RIGEX is defined by these objectives, yet the development of the project is guided by other constraints. These constraints primarily involve the method of transportation to space. Since the data being recorded from the experiment will not be transmitted back to the shuttle or streamed real-time to ground support, the RIGEX payload must be recovered in order to process the data. This narrows the possible launch vehicle for RIGEX down to the space shuttle, which dramatically increases requirements due to crew safety concerns.

1.4 Thesis Summary

This thesis implements the final design that is used to fabricate a protoflight model of RIGEX and provides necessary documentation in support of the attempt to meet the qualification requirements for launch into space set forth by NASA.

The original work covered by this thesis includes design and procedural developments. The design developments include the integration of the new data imaging system and the completion of the final drawing package of RIGEX. The procedural developments discussed include the thermal vacuum (TVAC) testing plan, the process for charging the inflation system and the details of handling and configuring RIGEX for transportation.

While Chapter 1 supplied an explanation of the concept and purpose behind RIGEX, Chapter II describes in detail the evolution of the RIGEX program. Chapter II provides information on the research completed by each student at AFIT that has previously worked on RIGEX. The key contributions made by these students are highlighted in this to convey an overall image of the growth and condition of the project before the final developments recorded in Chapter III.

Chapter III documents the required modifications made to the RIGEX design. This chapter covers alterations made to the computer aided drafting (CAD) model of RIGEX to produce a final CAD drawing package of the overall assembly. A majority of these changes made were to the previously designed structure of the RIGEX assembly because internal components were upgraded and/or relocated. In particular, the entire digital imaging system was replaced. The detailed steps taken to complete this task are also discussed in Chapter III.

Chapter IV identifies the requirements and preparation of the final testing of RIGEX at AFIT. This chapter illustrates the purpose and process of testing RIGEX in a space like environment with a vacuum chamber and thermal variation. This chapter also covers the components of the final inflation system onboard RIGEX along with the methods of filling and testing the system. Additionally, the apparatus devised to effectively fill the inflation system by creating an internal vacuum is described.

Chapter V concludes the document by presenting the decisions made to address complications encountered during the overall construction of the protoflight model and discusses the future phases of the RIGEX project. These future phases include the final testing required for RIGEX and transportation between AFIT and the space centers in Texas and Florida. The proposed ground flow at these locations along with the steps to handle RIGEX between its different configurations is also described.

II. RIGEX History

Since its inception in 2000, several analyses have been presented by AFIT students who have dedicated their research to the development of the RIGEX project. Through their efforts, RIGEX has evolved from its preliminary design into the fully analyzed protoflight model that this thesis presents. To appreciate this, these initial efforts must first be recognized.

2.1 DiSebastian [7]

The RIGEX project was created with initial research completed by AFIT student Captain John DiSebastian. DiSebastian developed a preliminary design for testing the rigidizable inflatable tubes, working along with L'Garde Incorporated and Defense Advanced Research Projects Agency (DARPA). This initial design incorporated eight subsystems, including the mechanical structure, inflatable structure, inflation system, rigidization system, electrical power system, command and control, data handling and sensors. For each subsystem, DiSebastian determined a preliminary component selection and layout. This experimental configuration became the core blueprint for the overall RIGEX assembly. This initial design, shown in Figure II-1, was intended for integration in the GAS canister, which was previously used in the space shuttle program.

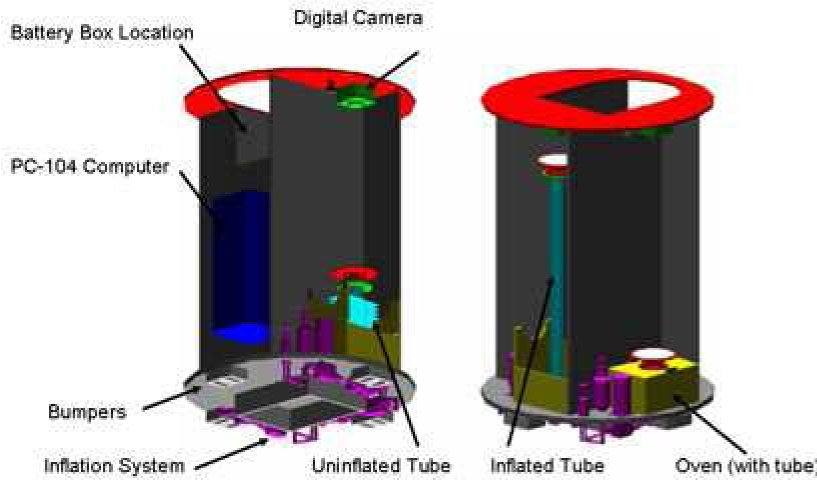


Figure II-1: DiSebastian's Preliminary Design [7]

In order to devise a profile for effectively testing the rigidizable inflatable tubes, DiSebastian began by analyzing system engineering (SE) approaches commonly employed in the engineering community. These SE approaches included the Space Mission Analysis and Design (SMAD) model, the Institute of Electrical and Electronic Engineers (IEEE) model and the Hall's model. After thorough consideration, the SMAD model from NASA was ultimately chosen. In addition, DiSebastian performed analyses for the potential data storage, weight, and cost of RIGEX as the project develops. DiSebastian concluded his work with a concept of the experimental operation during flight. This set of events is described in a Main Event Calendar, depicted in Table I-1. Ultimately, DiSebastian is responsible for laying the foundation for further development of the RIGEX project by defining the mission statement, objectives, requirements, and constraints.

Table II-1: DiSebastian's Main Event Calendar [7]

Event	Description
1	Activate environmental heaters at 50,000 feet
2	Shuttle crew activates experiment
3	Computer boot-up & diagnostic
4	Reset primary timer to Zero
5	Activate Environmental sensors
6	Check failsafe file and skip to appropriate point of experiment
7	Begin inflation process (inflate 3 tubes sequentially)
8	Begin venting process (vent 3 tubes sequentially)
9	Begin excitation process (excite 3 tubes sequentially)
10	Deactivate environmental sensors
11	Mark final failsafe point
12	Shutdown computer
13	Shuttle crew deactivates experiment

2.2 Single [30]

The second AFIT student to the continue work on RIGEX was Captain Thomas Single. Single conducted the first experimental analyses for RIGEX focusing on tube characterization and vibration testing. Single performed ground testing of the rigidizable, inflatable tubes that serves as a basis for comparison for the tubes in the zero-gravity space environment, which is an essential requirement dictated in the mission statement presented by DiSebastian.

Single conducted analyses on the characteristics of the rigidizable, inflatable tubes with three 50" long and six 20" long samples supplied from L'Garde Incorporated. Unique imperfections were discovered and documented for each of these sample tubes. The seam on the tubes appeared to add a slight amount of stiffness, which was due to the manufacturing process of joining the two ends of the carbon composite to form the tube. After further testing, the orientation of this seam proved to be insignificant. Other irregularities in the tubes included height, diameter, weight, and surface properties. Some of these properties are displayed in Table II-2. The short tubes are denoted with an "S" and "L" for the long tubes. Notice the absence of tubes S01 and L02; this is due to their severe imperfections. These imperfections caused excessive leaking when pressurized and had to be removed from testing.

Table II-2: Single's Analyses of Tube Physical Properties [30]

Tube	Property	
	Average Diameter (in)	*Mass (g)*
S02	1.55	199.13
S03	1.57	194.90
S04	1.42	197.79
S05	1.53	190.34
S06	1.38	197.64
L01	1.43	245.02
L03	1.59	247.25

After the imperfections were identified on each of the test tubes, Single conducted a series of three sets of vibration tests. The primary intent of these tests was to accurately determine the modal properties (natural frequency and damping coefficients) of the tubes at various temperatures and internal pressure levels. The first set of vibration tests were conducted in ambient conditions using the vibration facility shaker at AFIT. These tests were conducted at varying internal tube pressures. These tests verified the proportional relationship between the tube length and natural frequency. The longer tubes had a lower natural frequency than the shorter tubes. A summary of the natural frequency results can be found in Table II-3. The second set of tests were carried out with the use of piezoelectric patches attached to the base of the tube and a Polytec Scanning Vibrometer

(PSV). The third set of vibration tests were conducted in a vacuum chamber with temperatures varying from 25°C to 95°C in 10° increments. As anticipated, the increased temperature softened the tube, lowering its natural frequency and raising its damping coefficient. A summary of these results are shown in Table II-4. Through all these tests, it was found that the internal pressure of the tubes had little effect on the modal properties. Comparing the results of all the testing, the first, second, and third tube bending modes were approximately 51, 62 and 231 Hz.

Table II-3: Single's Test Results Using Shaker Excitation [30]

Tube	Mode #	Frequency (Hz)	Damping (%)
S02	1	32.12	2.16
	2	61.26	1.8
	3	230.22	1.19
S04	1	31.63	2.43
	2	60.87	1.67
	3	229.59	1.27
L01	1	24.4	2.4
	2	55.4	4.95
	3	117.0	0.7
L03	1	24.5	1.95
	2	56.8	1.96
	3	115.7	0.46

Table II-4: Single's Test Results Using Vacuum Chamber [30]

Temperature ($^\circ C$):	**25**	**35**	**45**	**55**	**65**	**75**	**85**	**95**
Mode **1** (**Hz**):	51.18	51.1	50.81	50.08	49.13	47.74	46.59	45.55
Mode **2** (**Hz**):	64.25	63.78	63.43	62.82	62.61	62.4	62.23	62.15
Mode **3** (**Hz**):	231.58	231.42	235.05	227.89	229.14	229.26	229.77	222.98

Thanks to the work done by Single, the irregularities in the rigidizable, inflatable tubes from L'Garde Incorporated have been identified and assessed. Single also helped lead to a better understanding of the modal properties of the tubes and how they are affected by different settings. These initial tests provided pivotal data that will compare spaceflight test data for critical performance analysis of the rigidizable inflatable tubes in space.

2.3 Philley [25]

The experimental analysis continued with Captain Thomas L. Philley; the third AFIT student to work on RIGEX. L'Garde Incorporated provided improved rigidizable inflatable tubes lined with Kapton on the carbon composite surfaces internally and externally, which improved pressure retention. Philley conducted vibration analysis for these new tubes along with deployment testing. In order to facilitate these tests, Philley also built a working prototype of RIGEX. Philley concluded his efforts with initializing the coordination of AFIT with the DOD Space Test Program (STP).

In order to simulate flight conditions as closely as possible, the use of a thermal vacuum (TVAC) chamber was implemented. At that time, the TVAC chamber at AFIT was not very large. Since the test required a working prototype, this prototype was required to fit in the existing TVAC chamber. Therefore the RIGEX prototype was a quarter-structure, including only one full bay comprised of a rigidizable inflatable tube, inflation system, oven, and digital camera. An image of this prototype can be seen in Figure II-2.

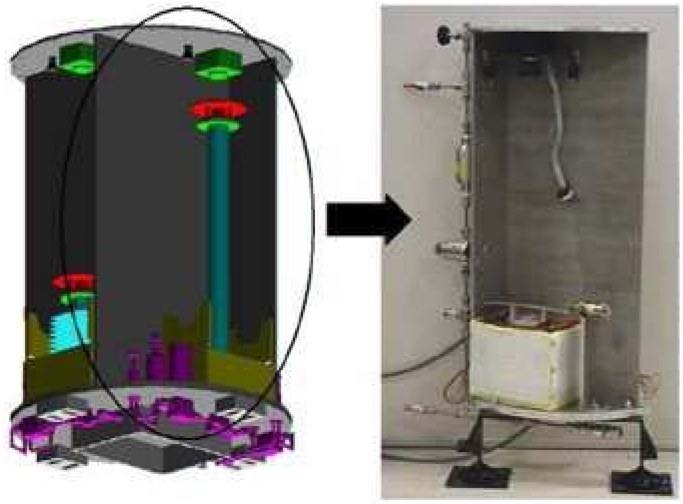


Figure II-2: Philley's Prototype (Quarter-Structure) [25]

The deployment of the new tubes was tested twice by Philley in the quarter structure. Neither test was completely successful. The first failed mainly due to a manufacturing error with the tubes. The testing at AFIT was configured for 20" tubes, but the new tubes from L'Garde were actually 24" in length. This was not discovered until the first deployment test due their initial folded configuration. An image of this discovery during the first deployment is seen on the left in Figure II-3. In this image, one can observe that the location of the digital camera interfered with the inflation of the tube. Another anomaly discovered during the first test was that there was an unusually high pressure in the tube of 6 psig, instead of the expected 4 psig. The excessive pressure was believed to be due to a faulty pressure regulator. These complications were corrected for the second deployment test. The digital cameras were relocated, the pressure regulator was reset for 4 psig, and a flow control valve was installed. During this second test, the tubes did properly inflate but only reached an internal pressure of 2.5 psig. The low pressure resulted from a combination of the flow control valve, pressure regulator, and a leak in the new tubes. An image from this second test can be seen on the right in Figure II-3. These tests not only functionally verified the heating system and inflation system but proved that small fluctuations in the internal pressure of the tubes have little or no effect on their inflation.

Figure II-3: Philley's First and Second Deployment Test [25]

Next, Philley conducted vibration testing on the new rigidizable inflatable tubes using piezoelectric patches attached to the base of the tube set up in three different configurations. The configurations included table-mounted, stand-mounted, and structure mounted, both inside and outside the vacuum chamber. A summary of these test results can be seen in Table II-5. These tests provided the natural frequencies and damping coefficients for the new tubes in numerous configurations.

Table II-5: Philley's Vibration Test Results [25]

First Bending Mode				
Parameter	Mount Location			
	Table	Stand	Structure	Vacuum Tank
Natural Frequency (Hz)	59.6875	37.5	60.3125	60.625
Damping Ration (%)	0.78	0.83	0.52	1.04
Second Bending Mode				
Parameter	Mount Location			
	Table	Stand	Structure	Vacuum Tank
Natural Frequency (Hz)	660	542.1875	654.0625	651.25
Damping Ration (%)	0.64	0.32	0.53	0.57

Fortunately, Philley was previously assigned to STP and was able to begin the initial process of preparing RIGEX for the DOD Space Experiment Review Board (SERB). The approval from SERB was essential for RIGEX to become an actual shuttle mission.

With Philley's deployment test, the operational concept of RIGEX put forth by DiSebastian was validated. Philley's vibration tests provided new data, which replaced the original ground test data that would be used as a comparison for experimental data in space. In the process of creating these test, Philley also created the first RIGEX prototype, which could be used for further testing. Finally, Philley is responsible for beginning the coordination with STP that is essential for the launch of RIGEX becoming a reality.

2.4 Holstein [13]

In 2003, further development of RIGEX commenced with the addition of three new AFIT students. One of these students, Captain Ray Holstein, was given the responsibility of continuing the vibration testing. Since thorough testing of the rigidizable inflatable tubes had already been completed by Single and Philley, Holstein focused his research on the structure for RIGEX. Holstein performed both a finite element analysis (FEA) and experiments in his vibration testing.

Holstein first created drawings of the RIGEX structure using computer aided design (CAD) software called *ProENGINEER*. An initial RIGEX structure was fabricated with these drawings. These CAD drawings were then imported into an FEA program called *ABAQUS* to create finite element (FE) models. These FE models were created for both the quarter-structure and full structure of RIGEX. After the mass properties along with the boundary and loading conditions were assigned, Holstein performed eigenanalysis. In addition to the full RIGEX assembly, Holstein created FE models of the rigidizable inflatable tubes and performed eigenanalyses as well. An image of these can be seen in Figure II-4. In doing this, the natural frequency and damping coefficients of the tubes measured by Single and Philley were validated.

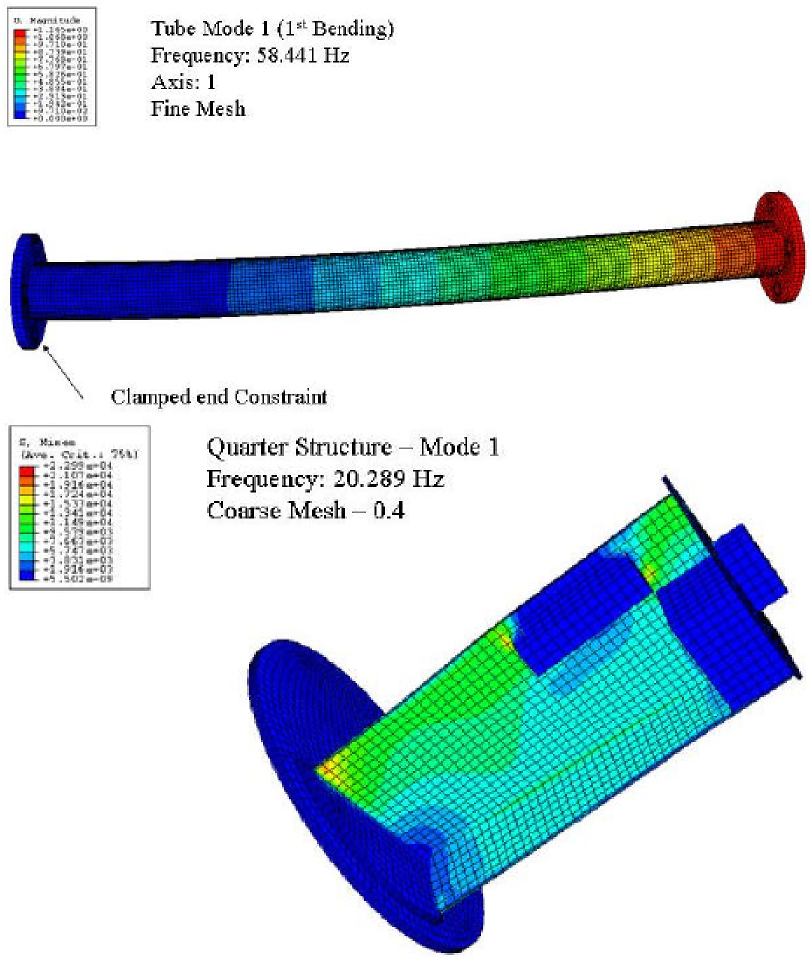


Figure II-4: Holstein's Eigenanalyses of the FE Models in *ABAQUS* [13]

Holstein also conducted stress analyses on the RIGEX structure. These analyses lead to the discovery of the high stress concentration on the experimental top plate near the computer access hole when RIGEX is place under a heavy load. An image of this stress concentration can be seen in Figure II-5. In order to resolve this problem, the computer access hole was eliminated and the experimental top plate was thickened.

Table IV-5: Temperature Profile for Component Testing in TVAC [26]

	Temperature Limitations			
	Lower Limit	Allowable Deviation	Upper Limit	Allowable Deviation
Survivable Temperatures (°C)	-60	(-5/+0)	74	(+5/-0)
Functional Temperatures (°C)	-45	(-5/+0)	45	(+5/-0)

The components were placed on an aluminum plank that were then bolted down to the platen of the vacuum chamber with copper mesh between the aluminum plank and the platen to help promote conduction. Once all the components had been situated, the next step was to connect all the wiring between the wiring connection interfaces inside the chamber and all the components as well as the wiring between the components themselves. Outside of the chamber all the wiring between the RIGEX space shuttle power emulator and 5 VDC power supply was connected.

To test the local temperature at certain components, thermocouples were positioned near the location of these individual components. The thermocouple wiring was connected to the wiring connection interfaces inside the chamber. Then a connection was made from the wiring connection interfaces outside the chamber to the thermocouple wiring interfaces on the data acquisition system. A computer set up with *LabVIEW* software version 8.2 [4] was used for logging the data read from the thermocouples. *LabVIEW* is a graphical program development application from National Instruments used to integrate engineering tasks such as interfacing computers with instruments, collecting, storing, analyzing, and transmitting measured data, developing a program in a graphical environment, and providing an effective user interface [4].

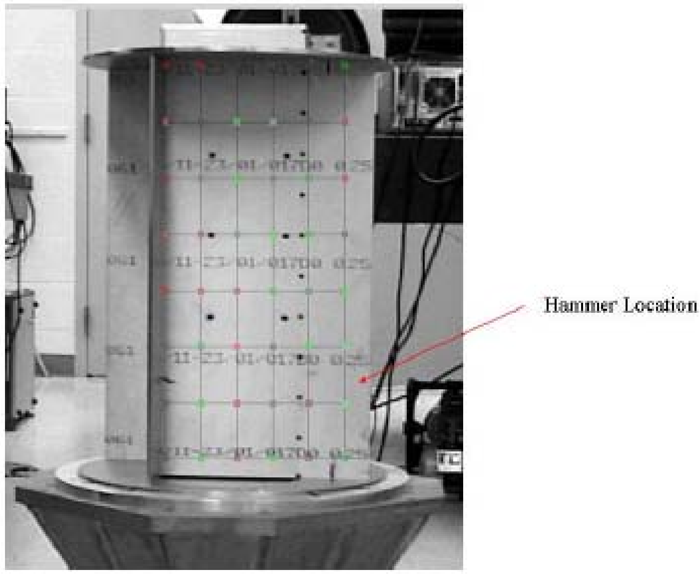


Figure II-6: Holstein's Experimental Ping Test Setup [13]

Holstein developed the first FE model of RIGEX and conducted both eigen and stress analysis of RIGEX when subjected to vibrations. These analyses confirmed original modal properties for the tubes and the stress analysis lead to identification of critical stress concentrations on RIGEX. Even though Holstein's experimental vibration test results varied from his FEA results, they still provided future AFIT students a working range for expected natural frequencies of RIGEX.

2.5 Lindenmuth [16]

Of the three AFIT students to join the RIGEX project in 2003, Captain Steve Lindenmuth was the second. Lindenmuth concentrated on further development of the heating system and inflation system. Lindenmuth also continued the coordination of AFIT with STP after Philley.

Lindenmuth refined the heating system by first conducting a test to provide more insight to the distributional heating of the rigidizable inflatable tubes. Lindenmuth conducted a full deployment test of a tube fitted with six thermocouples, which were attached to the quarter structure and placed inside the vacuum chamber. The data from this test not only helped determine the tube's heating profile, but the ideal location of the thermocouples for flight. A depiction of this heating profile can be seen in Figure II-7. The results also showed that location #2 reached the final temperature the slowest while location #3 reached the final temperature the fastest.

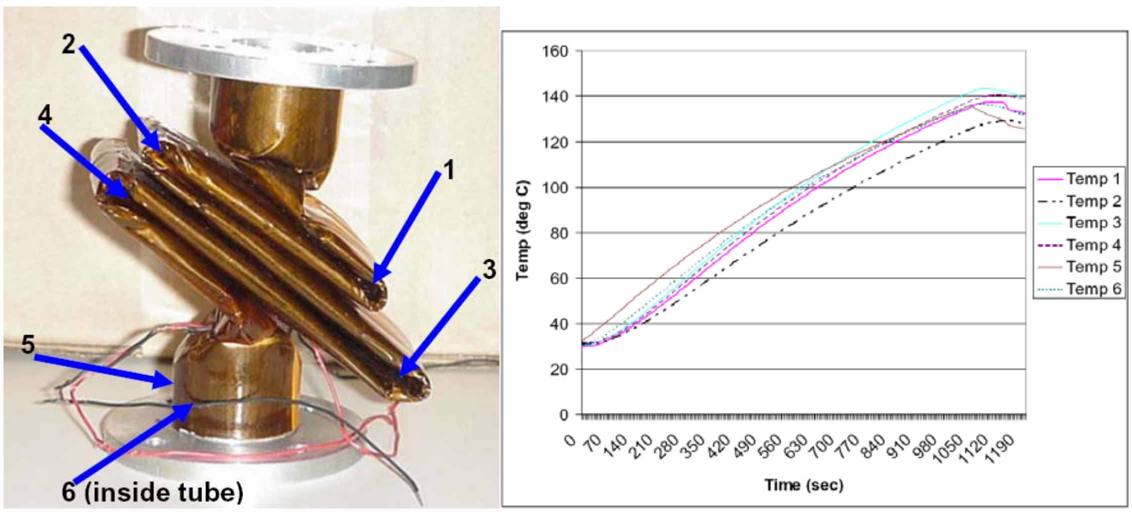


Figure II-7: Lindenmuth's Tube Heating Profile [16]

The second test Lindenmuth performed on the heating system was to provide functional verification of the piezoelectric patches after exposure to extreme temperatures. This test began with the attachment of the piezoelectric patches to the tubes followed by the application of voltage. This was done to initially check the functionality of the piezoelectric patches before they were heated. Then the tube was placed in an oven and heated above its T_g. The tubes were eventually cooled and voltage was reapplied to the piezoelectric patches to determine functionality after testing. The piezoelectric patches still worked and proved capable of surviving harsh temperatures.

Lindenmuth also refined the inflation system on RIGEX with inflation tests conducted for two purposes; one, to ensure proper inflation of the tubes, and second, to determine the retention of system pressure. By inflating the tubes on the structure, he identified an interference with the actual components of the inflation system. The interference resulting from this poor deployment can be seen in Figure II-8. Because of this the inflation system was moved to the computer bay. Lindenmuth also proved effective retention of pressure in the system over a long period with only minor leaks. He did this by fully charging the system and recording pressure over five days.

Figure II-8: Lindenmuth's Inflation Test [16]

Lindenmuth's work supported advancements in both the heating and inflation system. Lindenmuth created an effective heating profile for the tubes and in doing so, simplified the sensing requirements. Design modifications to the inflation system were identified and made because of Lindenmuth's inflation testing. Lindenmuth also help identify causes of potential leaks and provided recommendations for improvement of the inflation system. Finally, Lindenmuth presented RIGEX to the SERB. Even though RIGEX was placed 31st out of 41 missions, funding from STP was secured.

2.6 Moody [18]

The last of three AFIT students to enroll in the RIGEX program during 2003 was Lieutenant Dave Moody. As Holstein conducted FEA and vibration testing and Lindenmuth revised the inflation and heating system, Moody, an electrical engineer (EE), decided to focus his attention on the command and control subsystem. Moody redesigned the computer to have two microprocessors. He also built the initial software for this camera and validated it with post-test data analysis.

The original computer design had a slow microprocessor board, which directly affected the rate at which images were taken with the data imaging system. In order to speed up the data imaging system, Moody added a second microprocessor in half by adding a second processor specifically for the imaging system, which was called the imaging computer. The first processor was labeled the Data Acquisition System. Besides designing the layout of these computers Moody also designed the initial wiring configuration.

Upon completion of the new computer design, Moody wrote the C++ code for running the experiment. He used the calendar of main events put forth by DiSebastian as a guideline. He modified the code such that each phase of the experiment will be conducted for each tube, one at a time. Moody was able to verify that his code was successful by post-processing test data.

Moody's efforts made it possible to process images more quickly with the imaging system by redesigning the layout of the computer. He also developed the flight software to run RIGEX and tested it by perfecting the data analysis process used before and after the experiment. In effect, Moody provided improvements to the design, which help prepare it for implementation to flight hardware.

2.7 Moeller [17]

When AFIT student Captain Chad Moeller began work on RIGEX in 2004 NASA had decided to discontinue the use of the GAS canister and replace it with CAPE. As discussed in Chapter I, CAPE has several advantages over the GAS canister, particularly in increased weight and size limits. With this enlarged envelope, RIGEX went through RIGEX went through another iteration of design modifications. Specifically, Moeller focused his work on the modification of the inflation system and completing the thermal characterization of the rigidizable inflatable tubes by characterizing the cooling profile.

In addition to the increased space and weight limits, an option to connect to the shuttle for power was made available. This eliminated the requirement of a battery source, which weighed approximately 80 lbs and occupied 1500 in^3. With the current inflation system being the high-risk factor of mission success, Moeller utilized this new space when forming his design modifications to the inflation system.

Moeller's design involved the breakdown of the inflation system into two separate sections for each individual tube being inflated. The first, the storage section, consisted of the pressure vessel, a pressure transducer and all the tubing before the solenoid valve. The second was comprised of the rigidizable inflatable tube itself, a pressure transducer and all the piping after the solenoid valve. These two sections are depicted in Figure II-9. By comparing the volume of these two sections, Moeller was able to determine a range of pressure vessel sizes that would sufficiently inflate a tube without over-pressurizing it when the solenoid was activated. Eventually, a 500 cc vessel was nominated as the pressure vessel of choice.

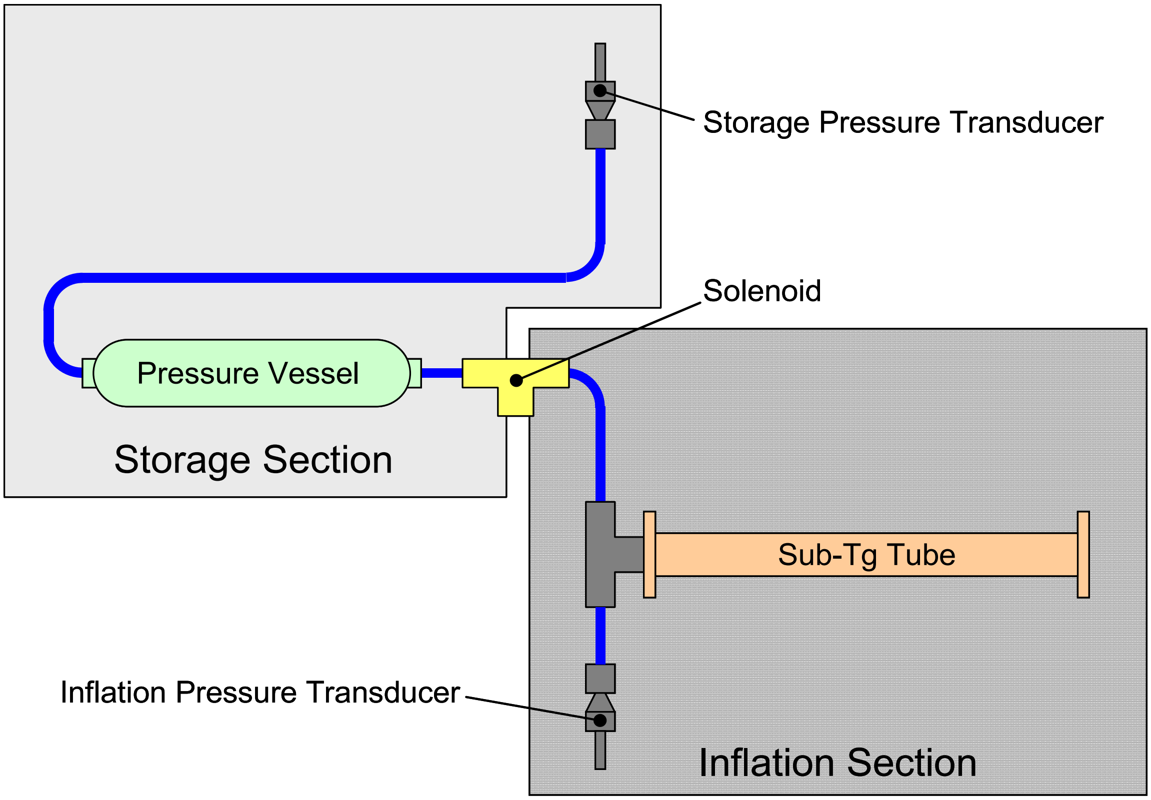


Figure II-9: Diagram of Moeller's Divided Inflation System [17]

Following recommendations presented by Lindenmuth for improving the inflation system, Moeller enlarged the pressure vessel for each system. This setup with larger tanks made it possible to lower the pressure in each subsystem to atmospheric pressure, 1 atm (14.7 psi). Since the internal pressure would be equalized with the atmospheric pressure outside, this nearly eliminated all leaking tendencies at mean sea level (MSL). In doing this, the need for a pressure regulator and pressure relief valve was also eliminated, which reduced potential leakage points. Moeller conducted tests to verify these predictions and found only one leak, which occurred after the tubes were inflated and waiting to be vented. This flaw was caused by the connection between the metal and plastic components of the tubing.

Later, using the same setup as Lindenmuth, Moeller conducted experimental testing to monitor dissipation of heat across the tubes. These test results are summarized in Figure II-10. With the primary heat transfer of space being radiation, Moeller calculated the thermal energy stored in the tubes at maximum temperature and derived an analytic expression for temperature as a function of time. By comparing these results Moeller determined an accurate cooling profile for the tubes.

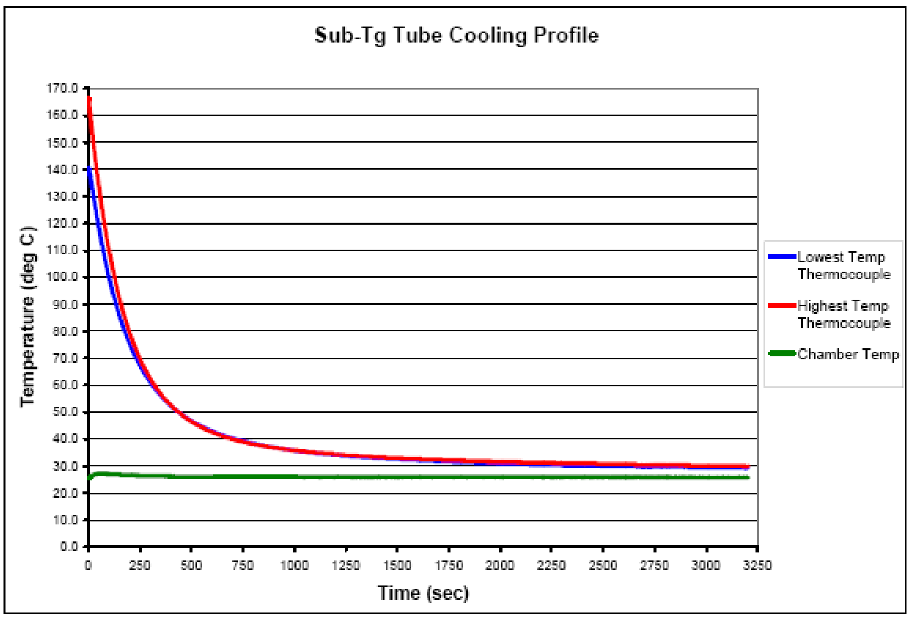


Figure II-10: Moeller’s Tube Cooling Profile [17]

Moeller’s work is a direct result of the first iteration of required changes for RIGEX to transition from the GAS canister to CAPE. His improvements to the inflation system practically eliminated the concern of leakage prior to launch. With the establishment of an accurate cooling profile, Moeller, along with the previous work of

Lindenmuth, provided a better understanding of how the tubes will behave thermally throughout the entire space mission.

2.8 Helms [12]

In 2005, three more students at AFIT began work on the RIGEX project. The first student was Lieutenant Sarah Helms who followed on with the AFIT-STP coordination. Helms continued the work of Single, Philley, and Holstein with vibration testing of the oven assembly. A depiction of the test setup for the oven is shown in Figure II-11. She also returned focus to the development of the structural model.

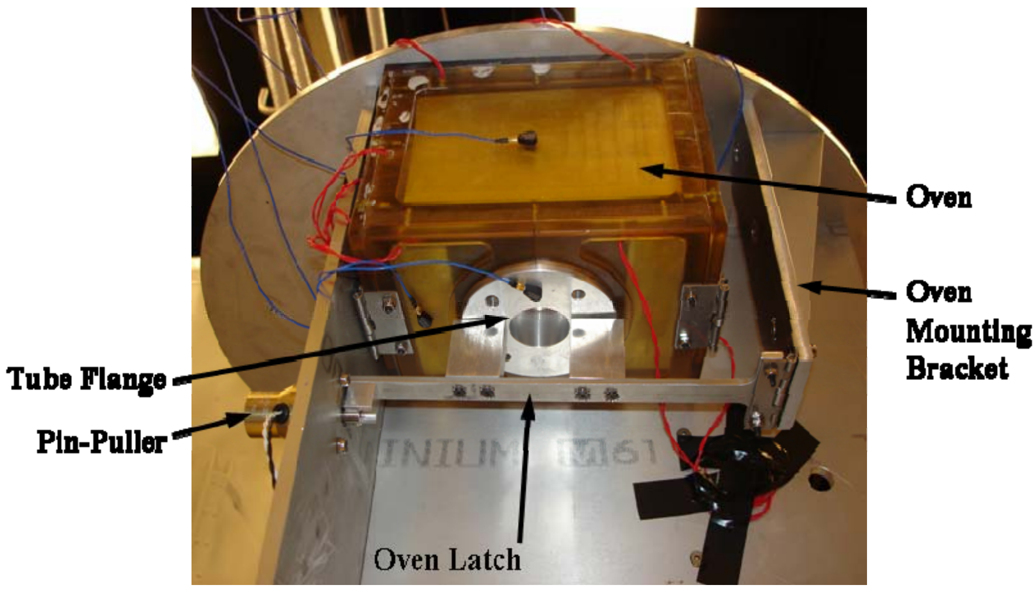


Figure II-11: Helms' Random Vibration Test Setup for Oven Assembly [12]

With the change to CAPE, RIGEX not only had to be modified but several new documents were required to be completed. Helms oversaw and processed this documentation, which was essential in the AFIT-STP-NASA coordination. The topics covered included payload design development, safety documentation, and payload specific integration documentation. Helms also assisted with the preparation of RIGEX for the Preliminary Design Review (PDR) and Phase I Safety Review in September of 2005.

Helms conducted random vibration tests of the prototype RIGEX oven assemblies not for acceptance data but rather for structural integrity verification using a new electrodynamic vibration table at AFIT with an MB Dynamics control software. The overall testing was not a complete success due to the unexpected failure of the structural model caused by shearing of seven bolts. These failed bolts are pointed out in Figure II-12. Two modifications to the RIGEX structure were undertaken because of these failures, which were the increased thickness of the aluminum plates and replacement of larger bolts for the structural assembly.

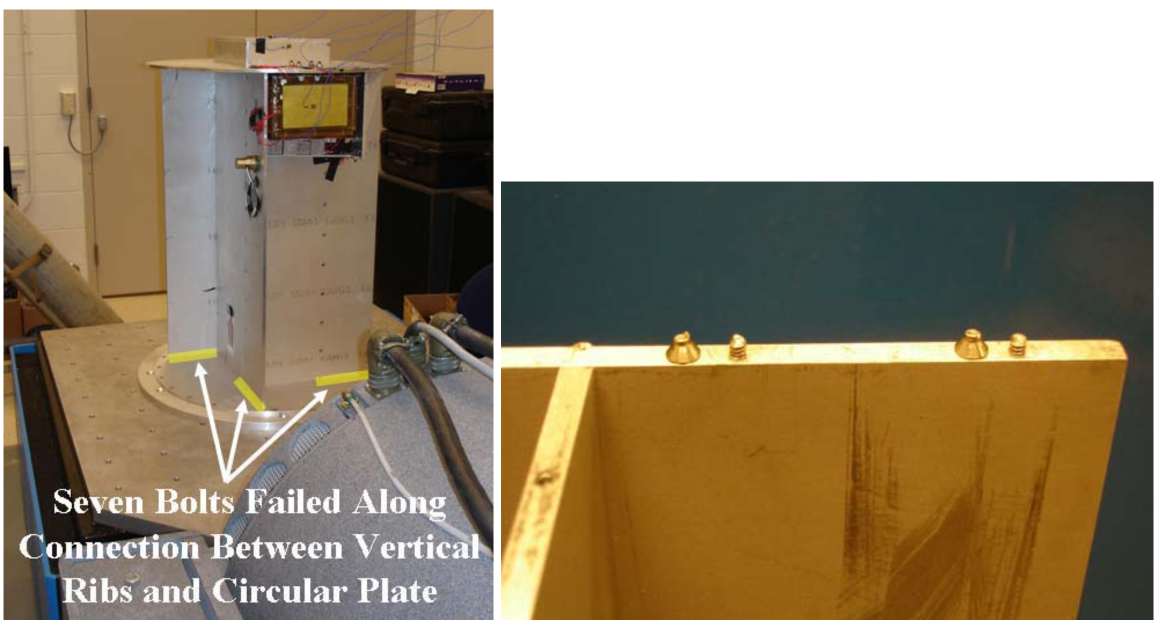


Figure II-12: Structural Failure During Helms' Vibration Testing [12]

With these modifications, further development of the RIGEX structural model was required. This was done using an analytical approach using the finite element modeling and post-processing (FEMAP) software. A full RIGEX FE model, with and without the shroud attached, can be seen in Figure II-13. Through extensive testing and comparison the RIGEX FE model results were validated and a first natural frequency of roughly 242 Hz was determined for the RIGEX flight model.

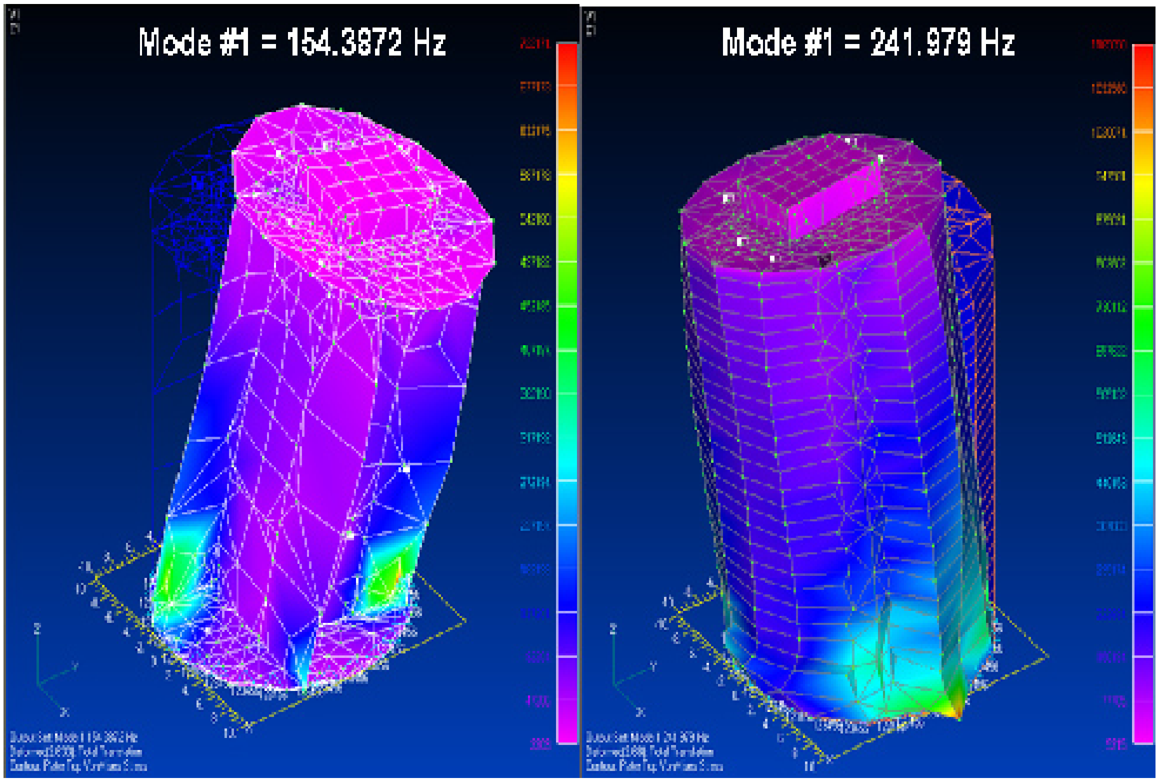


Figure II-13: Helms' Full RIGEX FEM in NX Nastran With and Without Shroud [12]

With the work of Helms, the RIGEX launch integration process had been laid out and documentation was provided to help prepare RIGEX for the Phase II Safety Review. Even though the random vibration testing resulted in a failure, it ultimately lead to a better understanding regarding the strength of the prototype oven assemblies, structural response to random vibrations, not to mention further understanding of the new laboratory equipment. The FEA documentation provided AFIT and STP with adequate structural verification data for launch.

2.9 Goodwin [10]

The second AFIT student to join the RIGEX program in 2005 was Captain Jeremy Goodwin. Goodwin was responsible for several design modifications required for RIGEX to fit into CAPE. One of these modifications included the addition of a shroud to protect CAPE. Goodwin also performed a containment analysis with the shroud.

Goodwin's modifications were mainly focused on the mechanical and electrical subsystems. Using *SolidWorks* software, Goodwin created a detailed CAD model of the RIGEX structure with all its associated components attached. An image of this model is displayed in Figure II-14. In doing this, Goodwin also produced the first drafts of the drawings required for fabrication of the structural aluminum parts. An updated electrical architecture was also composed, which consisted of removing the internal battery and connecting to the orbiter power supply. Goodwin's modifications to RIGEX also included minor alterations to the inflation and command and data handling system.

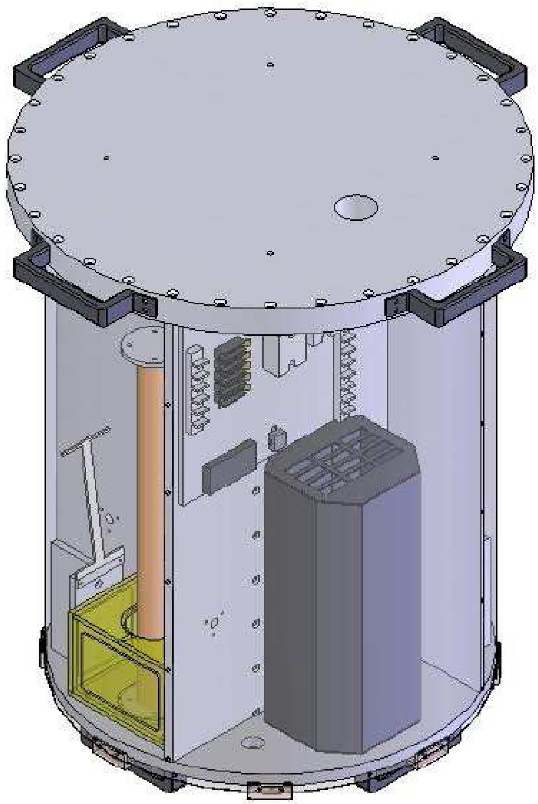


Figure II-14: Goodwin's Design Modeled in SolidWorks [10]

In order to ensure will not be damaged CAPE in the event of a component coming loose, a shroud was attached. To determine the required thickness of this shroud, Goodwin performed a containment analysis for possible tube failure during both reentry and over-inflation. A summary of these test results is shown in Table II-6. With a planned thickness of 0.075", the analysis indicated a factor of safety over 200% for the locations requiring the highest thickness.

Table II-6: Goodwin's Containment Analysis Results [10]

Description	Shuttle Acceleration (g)	Tube/Endcap Acceleration (g)	Shroud Thickness (mm)	Margin over 1.91mm (%)
Shuttle/tube accelerate at 6.5g's	6.5	6.5	0.55	346
Shuttle/tube accelerate at 13g's	13	13	0.79	241
Tube overpressurization at Shuttle acceleration of 6.5g's	6.5	195	0.66	289
Tube overpressurization at Shuttle acceleration of 13g's	13	195	0.81	236

The work completed by Goodwin provided several critical modifications that RIGEX required to become an acceptable CAPE payload. Goodwin also initiated the first steps toward creating an updated drawing package, which would continue to be updated with following students. The initial design requirements for the shroud were a direct product of Goodwin's research.

2.10 Gunn-Golkin [11]

The third and most recent AFIT student to finish work on the RIGEX project is Lieutenant Anna Gunn-Golkin. In her short time at AFIT, Gunn-Golkin composed a comprehensive structural and bolt analysis for RIGEX, along with an overall description of the final design. Gunn-Golkin finished her work with a mass properties analysis and an initial design of the shuttle emulator.

In order to conduct a structural analysis of RIGEX, Gunn-Golkin first updated the CAD model of RIGEX in *SolidWorks*. In an attempt to satisfy all the NASA requirements for the structural integrity of payloads in space, this model incorporated all the current modifications to RIGEX. An image of this model is seen in Figure II-15. Gunn-Golkin also presented a revised drawing package for the aluminum components being manufactured for the protoflight model of RIGEX. After the structural model was modified, a final FEM of RIGEX was created. Using NX Nastran software to perform a modal analysis of RIGEX, the fundamental frequency was determined to be roughly 185 Hz.

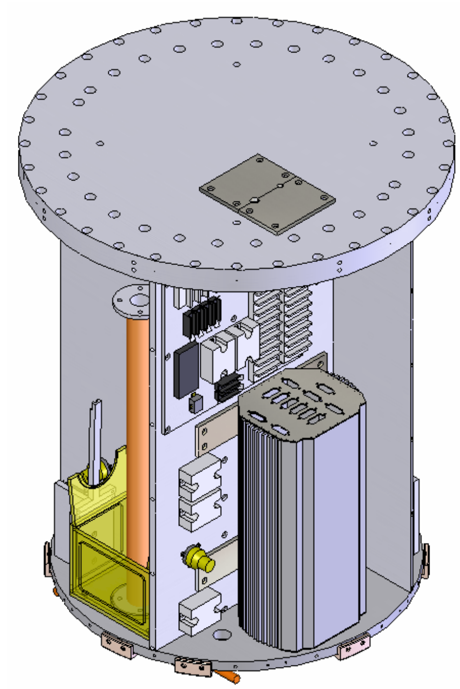


Figure II-15: Gunn-Golkin's Modified Design Modeled in SolidWorks [11]

From the FE static analysis, the maximum stress on the aluminum structure, maximum loading at all bolt locations, and maximum deflection of the shroud and bumpers were predicted. A summary of the bolt loads can be found in Table II-7. Once the FEA for the loads transferred through critical bolts on RIGEX was completed, Gunn-Golkin proceeded with a strength and separation analysis. To increase accuracy of the bolt analysis, the assumptions made were very conservative. This resulted in required torque ranges with small deviation, reducing the likelihood of error during building.

Table II-7: Gunn-Golkin's Linear Static Analysis of Bolt Loads [11]

Location	Value	Force (lbs)
Constraint Bolts	Max Axial	1180.3
	Max Shear	428.4
"Z-axis axial" bolts	Max Axial	2.3
	Max Shear	70.9
"Y-axis axial" bolts	Max Axial	9.1
	Max Shear	115.1
"X-axis axial" bolts	Max Axial	4.9
	Max Shear	145.3
Shroud Coord 1 Bolts	Max Axial	2.6
	Max Shear	26.5
Shroud Coord 2 Bolts	Max Axial	2.7
	Max Shear	28.1
Shroud Coord 3 Bolts	Max Axial	4.7
	Max Shear	32.2
Shroud Coord 4 Bolts	Max Axial	2.5
	Max Shear	13.1
Shroud Coord 5 Bolts	Max Axial	4.34
	Max Shear	24.5
Shroud Coord 6 Bolts	Max Axial	3.0
	Max Shear	21.0
Shroud Coord 7 Bolts	Max Axial	2.2
	Max Shear	18.8
Camera	Max Axial	8.6
	Max Shear	10.6
Computer	Max Axial	84.8
	Max Shear	167.3
Power Distribution Plate	Max Axial	50.4
	Max Shear	85.1
Oven	Max Axial	33.6
	Max Shear	80.0
Oven Mounting Bracket and Latch	Max Axial	20.3
	Max Shear	47.1

Gunn-Golkin finally concluded with an analysis of mass properties of RIGEX using the *SolidWorks* software, determining an overall weight and center of gravity (CG). With the work of Gunn-Golkin, her structural analysis identified the requirements for any final modifications to the structure, and her bolt analysis provided an acceptable range for each bolt pattern on RIGEX. This resulted in a complete set of drawings detailing the overall assembly, and basic manufacturing requirements. Overall, Gunn-Golkin's efforts helped quickly mature the final design of RIGEX in order to start production of protoflight model.

2.11 RIGEX Overview Summary

This chapter summarized, the key contributions made by each student at AFIT to the overall growth of RIGEX, beginning with the preliminary design by DiSebastian and ending with the protoflight model by Gunn-Golkin. Through numerous iterations, the RIGEX project has transformed from an idea into a real flight model. A summary of key contributions made by each student is illustrated in Figure II-16.

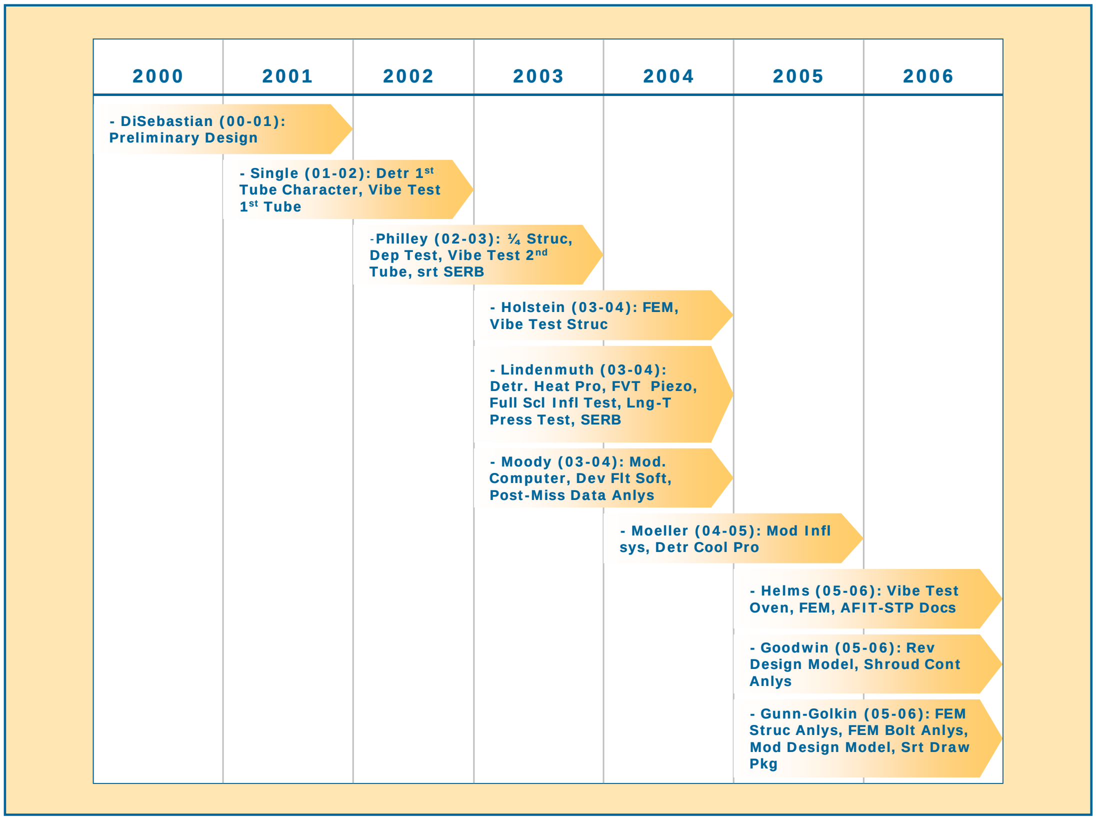


Figure II-16: Timeline of RIGEX Program with Student Foci

III. *RIGEX Design Modifications*

The final design of RIGEX was presented by in 2006. As production began in 2007 some complications arose. The assembly of RIGEX was divided into three waves. Wave one was the main structure and inflation system. Wave two was placement of most internal components, including the electrical subsystem. Wave three was the addition of the CAPE mounting plate and the shroud along with all its associated hardware. The wave assemblies are illustrated in Appendix A. During the wave two assembly, there were alterations made to the structure and infrastructure of RIGEX, including new holes due to the addition of electrical components or required movement of components to accommodate fit interferences. This chapter covers the changes that were made to the *SolidWorks* CAD models to include the modifications made to the protoflight model and help complete a final drawing package. These changes include creation of new drawings for the new components added to protoflight model, detailing of old drawings for components, and revising the placement of components to as-built. This chapter also discusses in detail the steps taken to integrate a completely new data imaging system into RIGEX. These steps include programming, determining the recording method, and modifying the CompactFlash interface, power connection and aluminum enclosure of the new cameras.

3.1 Final Drawing Package

The final drawing package is composed of annotated drawings, including technical specifications, of each component designed by AFIT. In accordance with the requirements of NASA, the drawing package of RIGEX had to be up to date. This included a model of RIGEX that was as-built, meaning that any changes done to the RIGEX design during the final building process needed to be included in the drawing package. As stated before, there were several holes that had to be added, either simply because more components were added or components were moved. Also, some of the pieces designed and fabricated by AFIT did not effectively serve their purpose. These pieces were either modified or redesigned completely. In addition to these changes, the components that were added had to be included in the final drawing package.

A snapshot of this final updated RIGEX assembly model can be seen in Figure III-1, and the complete drawing package can be viewed in Appendix A.

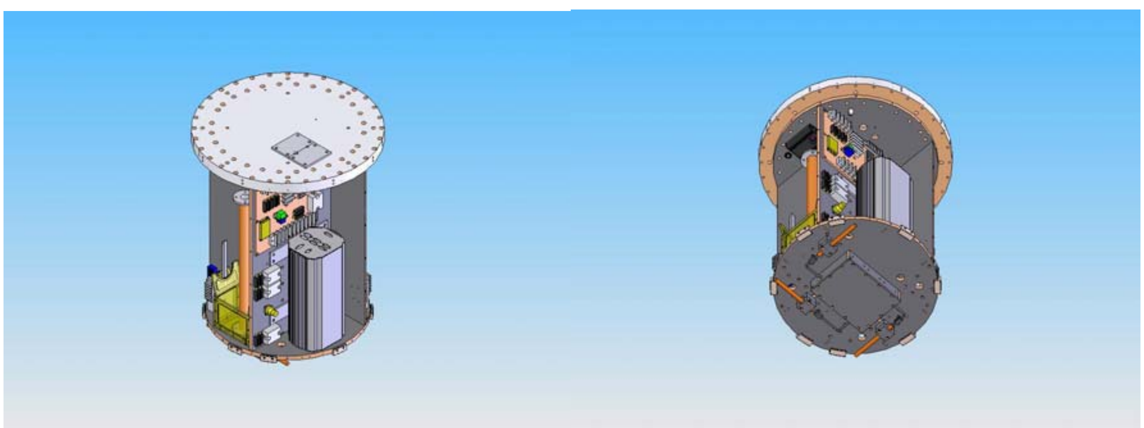


Figure III-1: Updated RIGEX Assembly Model

3.1.1 Methodology

Drawing packages can be generated through many techniques, but the most common is through Computer Aided Design (CAD). CAD is the use of a wide range of computer-based tools that assist engineers, architects and other design professionals in preparing drawings, specifications, parts lists, and other design-related elements through special graphics and calculations [5].

CAD originally meant computer aided drafting because CAD was envisioned as a substitute for a drafting board. Today CAD is used by manufactures, architects and engineers to accomplish a myriad of complex design tasks. Engineers especially benefit from its use, as it can incorporate three-dimensional (3D) models and two-dimensional (2D) drawings easily. Engineers also use CAD for conceptual design and layout, saving valuable time [5]. CAD is used for numerous architecture, engineering and construction (AEC) purposes, including building engineering, civil engineering, infrastructure, construction and many others. Mechanical engineering applications include design of automotive vehicles, aerospace, consumer goods, machinery, ship building and bio-mechanical systems. CAD is used in electronic design automation (EDA) purposes such as electrical and digital circuit design, power systems engineering and power analytics. CAD systems clearly have vast capabilities [5].

***3.1.2 SolidWorks* [31]**

SolidWorks is a 3D CAD program developed by a subsidiary of CATIA maker Dassault Systems, *SolidWorks* Corporation. *SolidWorks* is a Microsoft Windows-based application that uses a parametric approach in creating models and assemblies [31]. Parameters are values of a model that determine the size, shape and behavior numerically or geometrically. Dimensions are an example of numeric parameters, and can relate to each other to capture design content through equations. The program includes shape-based and operations-based features. Examples of shape-based features include slots, holes, bosses and add or remove material. These features usually start with 2D or 3D sketches. The operation-based feature does not have sketches, and includes filleting, chamfering and shelling to apply a draft to a part. When using feature-based nature *SolidWorks* you can go back to a previous design and apply prior changes to the section on which you are currently working [31].

When modeling in *SolidWorks*, you first start with a 2D or 3D sketch made up of lines, arcs, conics, and alpines. Dimensions are used in the creation of adding a defined size and location of the geometry. These can be controlled separately or by parameters outside of the sketch. Relations are used to identify tangency, parallelism, perpendicularity, and concentricity [31].

3.1.3 SolidWorks Drawings of RIGEX

In the final RIGEX drawing package, components were designed in *SolidWorks* for two purposes. Some of the parts were fabricated at AFIT or designed by AFIT and sent out for production. These parts were created in *SolidWorks* in order to provide a 3D model of each part that could be put together to generate a full assembly. These 3D models were also transposed into annotated drawings to provide engineering specifications for each part created. The second reason for designing the parts in *SolidWorks* was to easily manage all of the parts that were not designed or created by AFIT, including those ordered from separate vendors or provided by STP. With true 3D representation of all the components in RIGEX the location and configuration of each could be chosen before production. These 3D representations could also be assigned mass properties. After every component of RIGEX was acquired, the components were measured and their 3D models assigned an appropriate mass. This made it possible to determine an overall mass and Center-of-Gravity (CG) for the assembly. With this information, an analysis of the full assembly could be conducted with a Finite Element Modeling (FEM) program. This analysis was conducted by NASA in 2007.

3.1.3.1 Creation of Drawings for New Components

Some parts in the final RIGEX drawing package had to be created from scratch, either because there was no adequate previous design from which to work, or a new design was so drastically different that it was easier to start over.

3.1.3.1.1 Oven Controllers

During the finalization of the RIGEX assembly at AFIT, a run-away heater experiment was conducted. This experiment revealed that the heaters were capable of reaching dangerously high temperatures. To prevent this, Resistance Temperature Detectors (RTDs) were placed in each oven. The RTDs are sensors used to measure temperature by correlating the resistance of the RTD element with temperature [35]. These RTDs are then connected to the oven controllers. The oven controllers monitor the RTDs and control the power being supplied to the oven accordingly. These oven controllers were a new addition to the RIGEX design and were added into the 3D model with mass properties for proper analysis of the final assembly (.see Figure III-2).

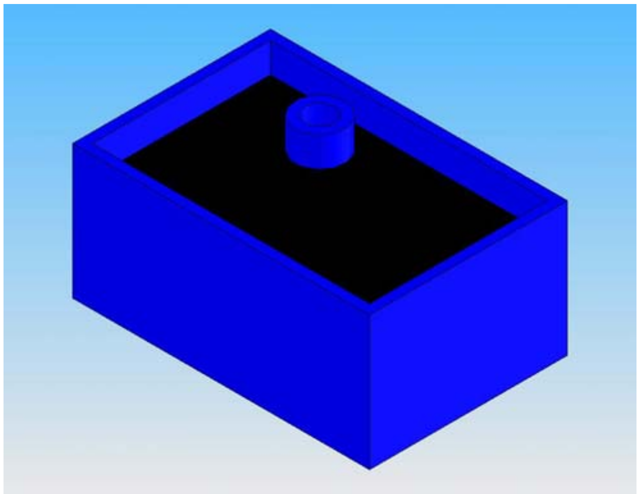


Figure III-2: Oven Controllers

3.1.3.1.2 Cameras

As previously stated, the data imaging system was completely replaced. All old cameras in the RIGEX model were removed, and new cameras were added to the *SolidWorks* CAD model with their appropriate mass properties, seen in Figure III-3. Each camera was attached to the RIGEX assembly with an aluminum enclosure. The cameras were also weighed, and the 3D model was assigned a mass. The aluminum enclosures were made up of three parts; an extrusion and two end plates. The three pieces were replicated using the engineering specifications provided by the vendor and then assembled together. These pieces were also measured and provided mass properties in *SolidWorks*. The aluminum enclosures then had to be modified with holes to allow for the location of fasteners and a hole for the lens.

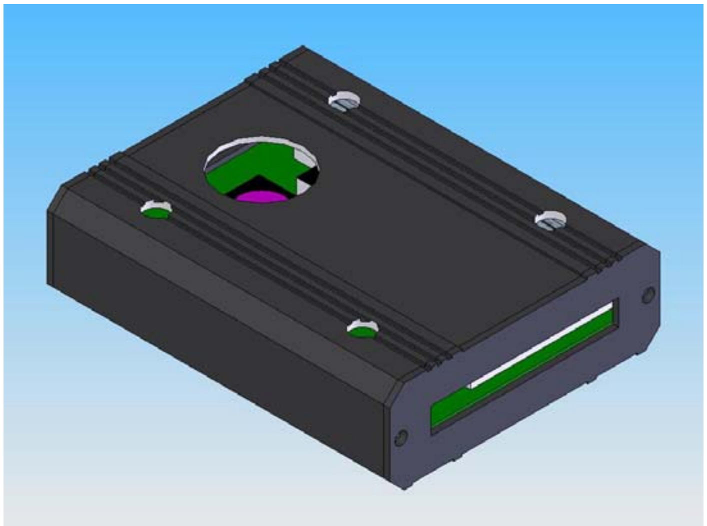


Figure III-3: Camera

3.1.3.1.3 Shroud Fastening Blocks

When the shroud (which helps contain any components that may come loose during flight and protects the inside of RIGEX) was built, a design flaw was discovered. In the original design the shroud was intended to overlap one inch and have two aligning holes that were secured with fasters. After the shroud was built and fit checked, it was discovered that the thick shroud caused the fasteners to protrude past the Delrin bumpers, which protect RIGEX from contacting CAPE (see Figure I-6). Therefore a new method of connecting the seam was created. It incorporated the use of 6 aluminum blocks that attached inside the shroud along the seam with a faster connecting to each side of the seam. These six aluminum blocks had to be measured and also modeled in *SolidWorks,* as seen in Figure III-4. Annotated drawings are located in Appendix A.

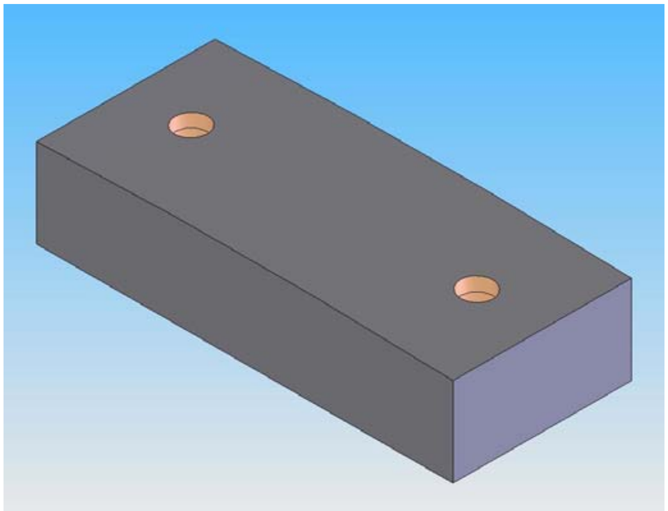


Figure III-4: Shroud Seam Bracket

3.1.3.1.4 Pressure Transducer Mounting Blocks

When the pressure transducer mounting blocks were created they were fit-checked only to discover they did not fit around the pressure transducers. After checking the machined part with the drawings in *SolidWorks* it was noted that the parts were manufactured correctly, but were poorly designed. New mounting blocks that would effectively fit around the pressure transducers had to be re-fabricated, and in order to do this the design had to be changed. The inner diameter of the mounting block receptacle had to be enlarged, and as a result, the holes for fastener placement had to be relocated. The new design was so different from the original that it was easier to start over and draw the new mounting block from scratch. After these new mounting blocks for the pressure transducers were designed, annotated drawings (provided in Appendix A) were created to give engineering specifications and help with the machining. Images of the newly designed transducer mounting blocks can be seen in Figure III-5.

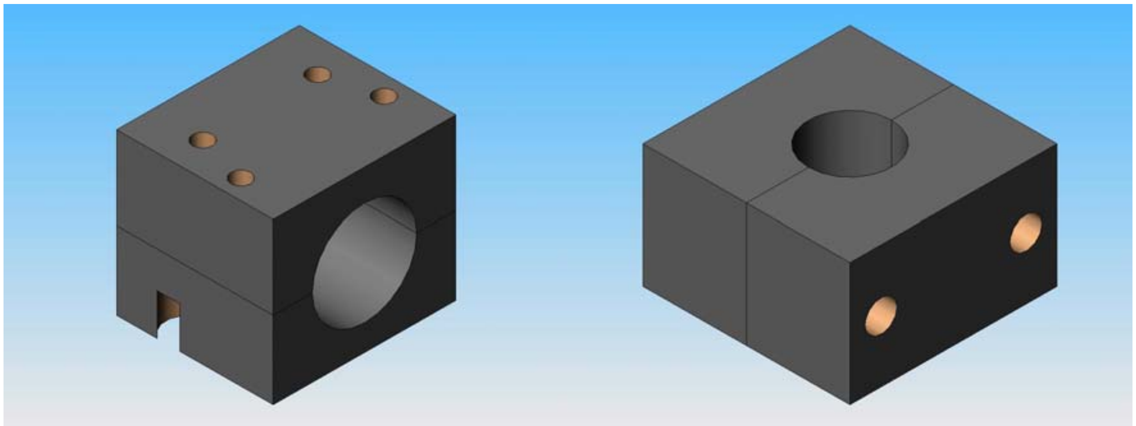


Figure III-5: Pressure Transducer Mounting Block

3.1.3.2 Detailing of Components to RIGEX

Some of the components in the RIGEX assembly that were already designed previously had to be updated. The ovens and LEDs had to be updated due to the lack of detail.

3.1.3.2.1 Ovens

The previous model of the oven assembly only included seven crude panels for the two doors, front, back, left, right and bottom sides. After the destruction of two of the ovens during the run-away heater test, only one oven assembly was left. Using the remaining oven as a template, CAD models of the seven panels were modified to include the extruded cuts and wiring holes. The *SolidWorks* model of each panel was also updated to include all the threaded holes along each edge where the #4-40 socket head cap screws were used to connect the panels. After the 3D models were completed, the annotated drawings, located in Appendix A, were generated to assist in the manufacturing of the new ovens. A *SolidWorks* image of the oven design is depicted in Figure III-6.

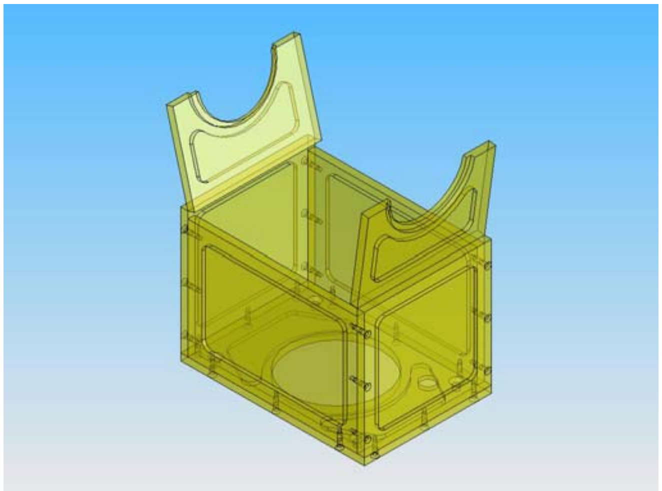


Figure III-6: Oven Assembly

3.1.3.2.2 LEDs

In order for the cameras to effectively record footage of the tubes in space, Light -Emitting Diodes (LEDs) are required to provide a source of illumination. These LEDs were originally intended to be attached to the structure with epoxy. Due to the easy availability of socket head cap screws in the AFIT lab, and the relative scarcity and expense of space rated epoxy, it was later decided that the LEDs would be attached with #6 socket head cap screws. In order to effectively model the LEDs in *SolidWorks*, the model of the LEDs needed to be updated with more detail to include the placement of the fasteners. The original model of the LEDs was simply a disk with a hemisphere in the center, as in Figure III-7, left. The new model of the LEDs incorporated the true hexagonal shape of the LEDs being used, and the holes where the fasteners would be placed, as seen in Figure III-7, right. The new models were also updated with correct mass properties.

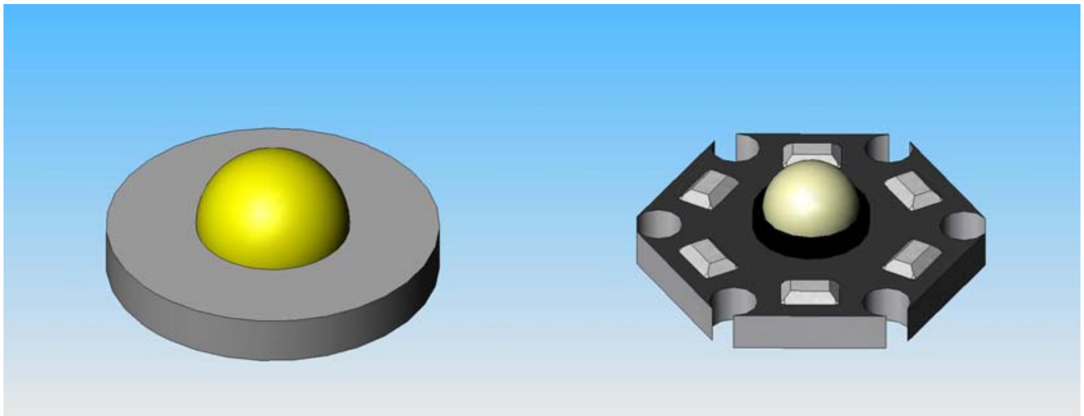


Figure III-7: Original (Left) and New (Right) LEDs

3.1.3.3 Revising Component Placement to As-Built

One of the most difficult problems keeping the top level assembly drawing package up to date is following all the alterations that occur while it is being built. As discussed before, a major requirement for the drawing package of RIGEX is to update the model as-built. This means that every time a hole is added or moved, the change must also be replicated in the *SolidWorks* model as well. These holes were all added using a 3D feature in *SolidWorks* called the Hole Wizard. Note that component images in this section are shown without computer or pin puller attached.

3.1.3.3.1 Experimental Top Plate

With the replacement of the cameras, the original holes had to be moved to a new location in each bay so that the lens of the camera was centered over the tubes. The holes for attaching the LEDs had to be added as well. Two holes had to be added for the p-clamps that are fastening the pigtail cables to the experimental top plate. The through-holes for the pigtail cables had to be enlarged as well. Due to a potential failure of the bolts connecting the experimental top plate to the ribs, the bolts were changed. When this happened, the countersunk holes had to be changed to larger counter bore holes to accommodate the new socket head cap screws with washers. This complication is discussed in further detail in Chapter V. Once these modifications were completed on the *SolidWorks* 3D model, they were then incorporated into the annotated drawings (Appendix A). The top plate can be seen in Figure III-8.

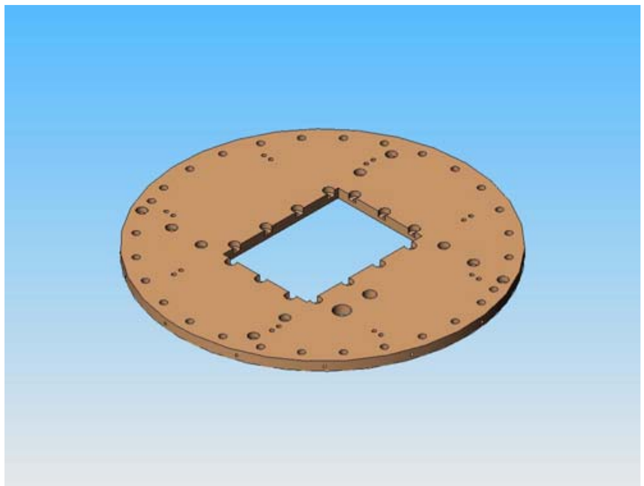


Figure III-8: Experimental Top Plate

3.1.3.3.2 Large Rib with Computer

On the large rib, where the computer is mounted, several holes were added. Three sets of holes for #6 socket head cap screws were added for the addition of three two-fuse holders, each requiring two holes for fasteners. One hole for a ¼" socket head cap screw was added to attach the ground lug. Four holes were added toward the inside of the plate for #6 socket head cap screws to attach an additional terminal block. The holes for the pin puller on the rib had to be relocated and modified because they did not in reality match the corresponding holes on the pin puller itself. These holes in the original model were too wide, allowing the head of the fastener to pull through. The holes were therefore rotated 25^{o} (see Appendix A, drawing # RIGEX-2006-3-D for an illustration), and counter bored on the opposite side for three #4 socket head cap screws. This rib can be seen in Figure III-9. Once these modifications were completed on the 3D model, they were then incorporated into the annotated drawings. These drawings are located in Appendix A.

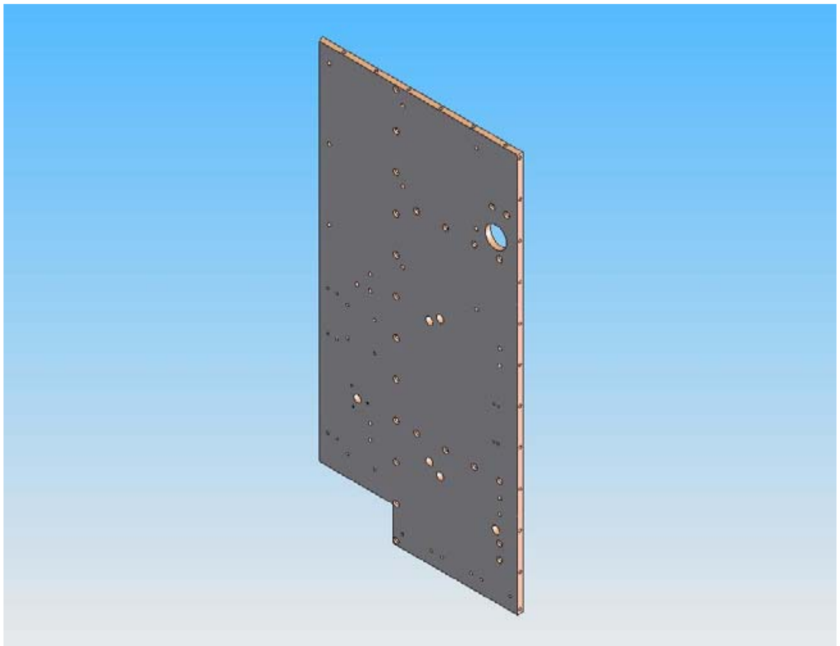


Figure III-9: Large Rib for Computer

3.1.3.3.3 Small Rib with Pin Puller

The small rib with a pin puller had four holes for #6 socket head cap screws added to attach four oven controllers. There were also four holes added for #2 socket head cap screws to attach two 1-ohm resistors. In addition, the holes for the pin puller had to be relocated and modified. Just as mentioned previously for the holes in the large computer rib, the holes in the small rib with a pin puller were rotated 25^{o} and counter bored on the opposite side for three #4 socket head cap screws. Once these modifications were completed on the 3D model (Figure III-10), they were then incorporated into the annotated drawings, viewed in Appendix A.

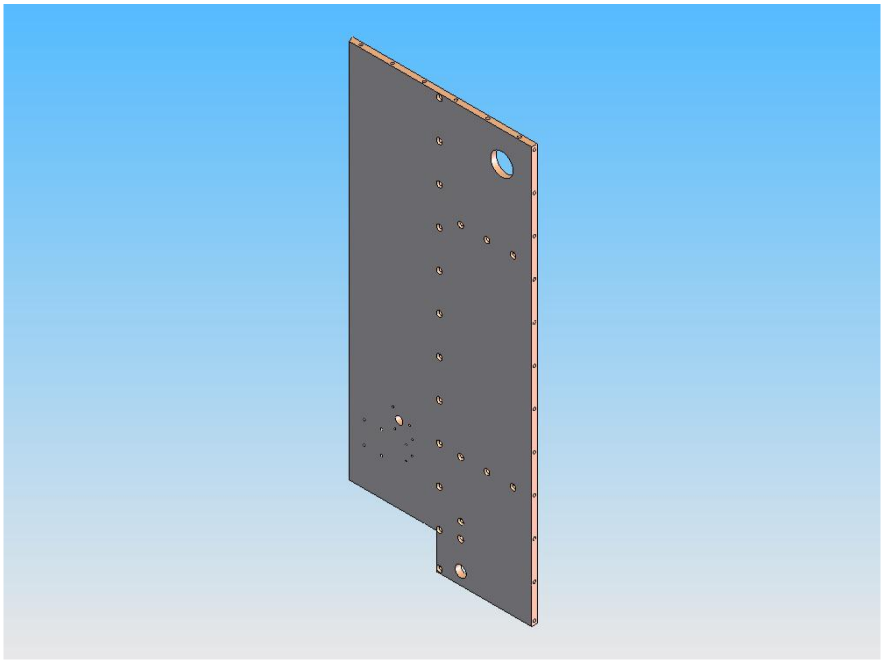


Figure III-10: Small Rib With Pin Puller

3.1.3.3.4 Large Rib

The other large rib had the same additions as the small rib with a pin puller. Four holes for #6 socket head cap screws added to attach four oven controllers. Four holes were added for #2 socket head cap screws to attach two 1-ohm resistors. Holes were rotated 25^{o} and counter bored on the opposite side for three #4 socket head cap screws to attach the pin puller. This change was made for the same reasons as described for previous ribs. Once these modifications were completed on the 3D model, they were then incorporated into the annotated drawings. Refer to Appendix A for a collection of the annotated drawings. The 3D image of the large rib is seen in Figure III-11.

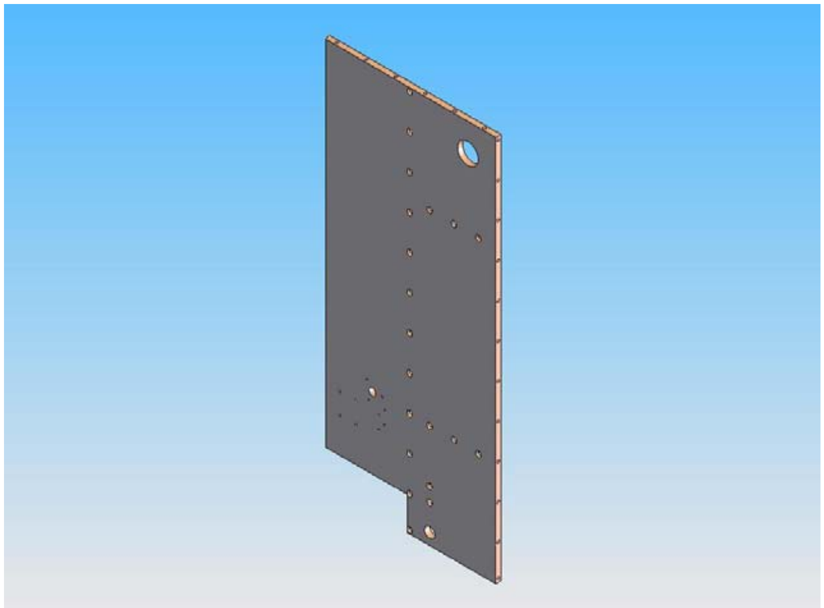


Figure III-11: Large Rib

3.1.3.3.5 Small Rib without Pin Puller

The small rib without a pin puller had only two sets of holes added. Four holes for #6 socket head cap screws added to attach four oven controllers, and four holes added for #2 socket head cap screws to attach two 1-ohm resistors. Once these modifications were completed on the 3D model (Figure III-12) they were then incorporated into the annotated drawings, as seen in Appendix A.

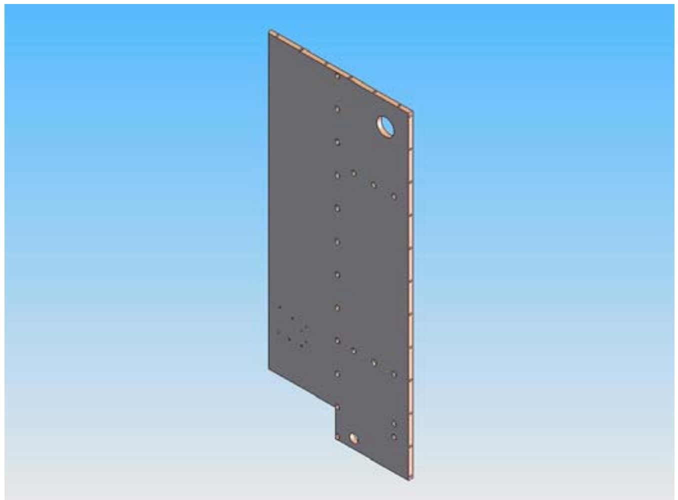


Figure III-12: Small Rib Without Pin Puller

3.1.3.3.6 Oven Mounting Plate

On the oven mounting plate, two holes were added per bay for the location of the fasteners being used to secure the transformers. These modifications were completed on the 3D model, as in Figure III-13. They were then incorporated into the annotated drawings, noted in Appendix A.

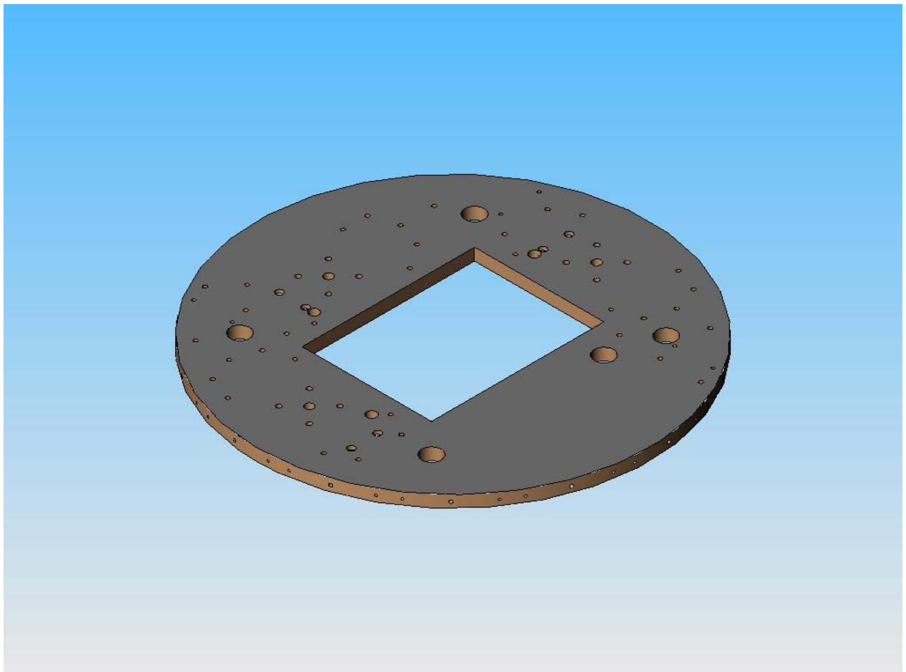


Figure III-13: Oven Mounting Plate

3.1.3.3.7 Shroud

When the new method for connecting the seam of the shroud was created, new holes were added to the shroud. Six new holes were added on each side of the seam to the shroud. Once these modifications were completed they were incorporated into the annotated drawings, which can be found in Appendix A. Figure III-14 shows the 3D model for the shroud.

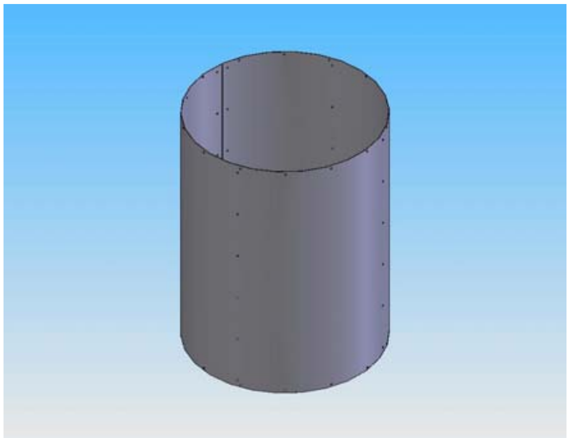


Figure III-14: Shroud

3.1.3.3.8 Power Distribution Plate

The power distribution plate was originally designed without holes. The intended design was to be left blank and to be updated after the electrical components were installed. Several holes were added for #4, #6, and #8 socket head cap screws to hold fuse holders, terminal strips, the leech socket relay and other electrical components. All these holes were adding into the 3D model of the power distribution plate with Hole Wizard, and then incorporated into the annotated drawings. These drawings, including component placement, are compiled in Appendix A. 3D modeling of the power distribution plate is shown in Figure III-15.

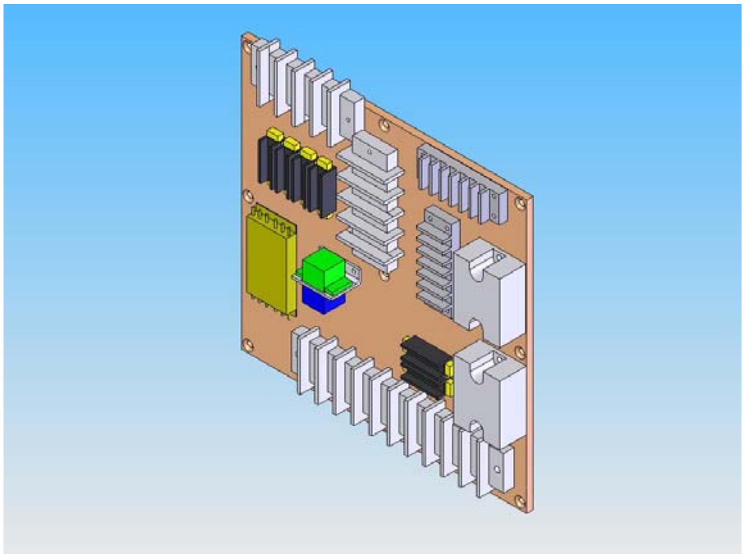


Figure III-15: Power Distribution Plate

3.1.3.3.9 Oven Bracket

All three oven brackets had holes added on each side. On one side there were four holes added for #6 socket head cap screws to attach a terminal strip. On the other side, holes for two #6 socket head cap screws were added, which secured the 4-fuse holder. These holes were input into the 3D model (Figure III-16). This model was then included in the new annotated drawings, displayed in Appendix A.

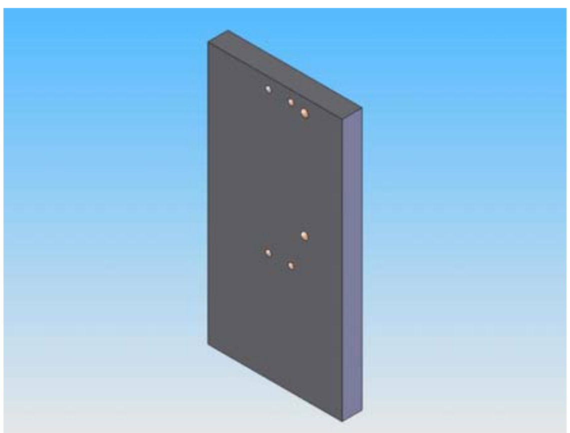


Figure III-16: Oven Mounting Bracket

3.2 Data Imaging System

The original imaging cameras had become obsolete, and new higher quality cameras were purchased. The new cameras were thought to be easier to integrate into RIGEX, and capable of withstanding the conditions of space. In this section, the cameras chosen for the new imaging system are described, as well as the process of integration into the RIGEX assembly.

3.2.1 Eye-C

The Eye-C controller, manufactured by Tern, was the camera chosen for the data imaging system. The Eye-C is C/C++ programmable and supports logging to PC-compatible file-systems through an integrated CompactFlash interface. The board acts as a smart camera capable of recording in Quarter Video Graphics Array (QVGA)/ Video Graphics Array (VGA) black-white, Red Green Blue (RGB), or Luminance/Chrominance (YUV) [2].

The onboard complementary metal–oxide–semiconductor (CMOS) image sensor with its wide angle lens has 640x480 active pixels. The pixel clock runs at 20 MHz, making the hardware frame capture period approximately 40 ms. This allows for an acquisition of up to 25 frames per second (fps). Real-time image captures are made available to the user application at a peak rate of 10 fps and only 3 fps is available for indefinite acquisition and processing, such as including storage to a CompactFlash memory card [8].

With the Eye-C, images are captured by two C function calls. Data from the image is available to the application with full resolution, full color/grayscale detail. Any pixel can be directly accessed from this memory buffer. By programming the Eye-C with custom algorithms the user can capture images, analyze any pixels within zones of interest, and make control decisions based on that image processing result in real-time [8].

For easy storage, the images are saved in Windows bitmap (bmp) format. Using the provided FAT16 file system support, nearly fifty thousand images should have been stored on a 2 gigabyte (GB) CompactFlash memory card [8]. However, this was not the case. After further investigation, it was found that the camera would store a maximum of 1 GB memory.

The Eye-C controller consists of a 16-bit 40 MHz x86 Central Processing Unit (CPU), an onboard regulator, 512 KB Flash, battery backed static random access memory (SRAM), 1 MB image First In, First Out (FIFO), an image sensor, two RS232 ports and a CompactFlash interface. There is also a real time clock that is backed up with the battery and three 16-bit timer/counters. With a switching regulator onboard the Eye-C is capable of accepting a wide range of power from 8 to 35 V. At 12 V the Eye-C consumes approximately 120 mA. The two RS232 ports can handle up to a 115,200 baud rate with high reliability [8]. A detailed layout of all the components on the Eye-C controller can be seen in Figure III-17.

In summary, the Eye-C camera was selected for the RIGEX project because it had a stand-alone capability when provided with a power source, thus remaining independent from the on-board computer. It was also capable of capturing sufficiently detailed and rapidly sequenced images while in the extreme conditions of space.

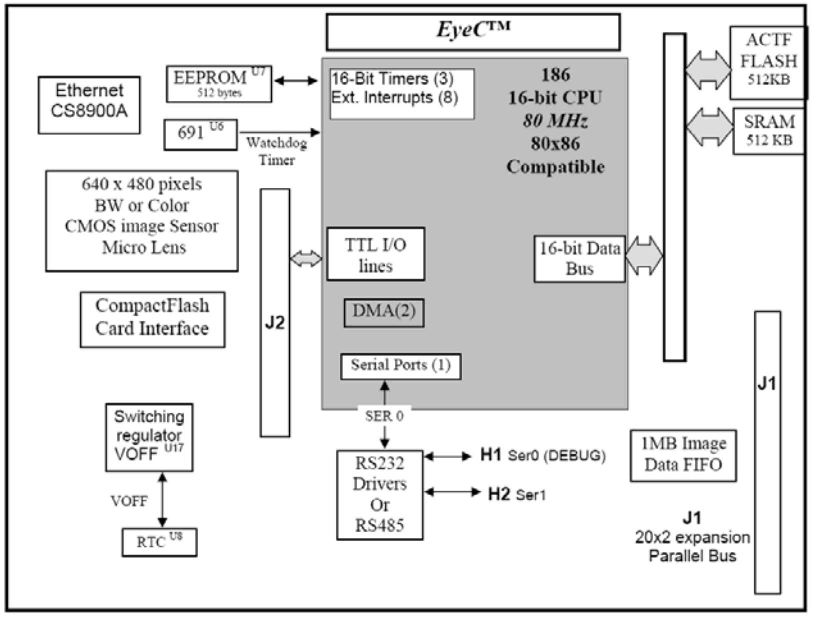


Figure III-17: Functional Block Diagram of the Eye-C [8]

3.2.2 Integration of Eye-C to RIGEX

3.2.2.1 Programming of Eye-C

For RIGEX, it was decided that the Eye-C controllers would most effectively serve their purpose by independently recording images of the tubes and storing them on a CompactFlash memory card. This meant that the image processing boards from the old data imaging system setup could be removed from the RIGEX computer. This also meant that the Eye-C had to be programmed to perform this function.

In order to communicate with the Eye-C controllers, special software from Tern, *C++ Tern Lite Edition*, was required. The Eye-C controllers were first connected to the computer configured with *C++ Tern Lite Edition* through DB9 cables with a COM port connection and a RS232 port connection. A picture of the connections on the Eye-C can be seen in Figure III-18 below. The connection to the serial port 0 was for the debug cable to upload the application on the controller. The serial port 1 was for the secondary cable that would run a program called *Eye-C Viewer*. After the sample application provided was installed, run and debugged, the Eye-C Viewer program could be opened. Once the correct COM port, baud rate, and file name was set, pictures were taken from the Eye-C. Using these pictures as references, the CMOS sensors were set to focus by turning the outer ring around the lens.

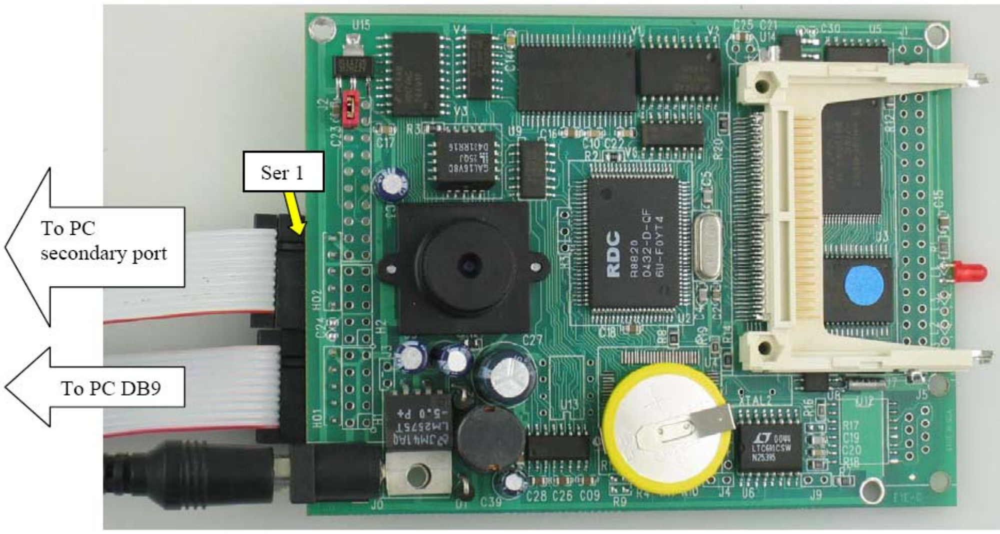


Figure III-18: Connections to Eye-C [8]

Once the focus of the lenses was set, the Eye-C controllers could be programmed for their intended purpose. Using sample codes provided with the software, an application was generated for the Eye-C controller to command it to run independently and store its data to a CompactFlash memory card. A sample of this code is provided in Appendix B.

To develop the application software for the Eye-C controllers for stand-alone operation two steps had to be made, as seen in Figure III-19. The application had to be downloaded, run, and debugged. After step one, a stand-alone field test had to be conducted. In order to do this, first the Eye-C was powered down, and the *C++ Tern Lite Edition* software was closed. The application now resided in the battery-backed SRAM starting at an address of 0x08000. While the power to the Eye-C controller was off, the Step 2 jumper (seen in Figure III-20) was removed. A connection to the Eye-C controller through serial port 0 was made with *Hyper Terminal*. At power-on, the ACTF was sent to Hyper Terminal. Using the command "G08000" the application was executed. The Step 2 jumper was reinstalled to its original location and power was cut to the Eye-C controller. After this, every time the power was restored to the Eye-controller, the application would be executed. This was done to all three Eye-C controllers. A stand-alone field test was then conducted for all three controllers by powering on the controllers with a properly formatted CompactFlash memory card installed for several seconds. Power was then cut and the memory cards were checked for data. All three Eye-C controllers successfully returned images in bmp format.

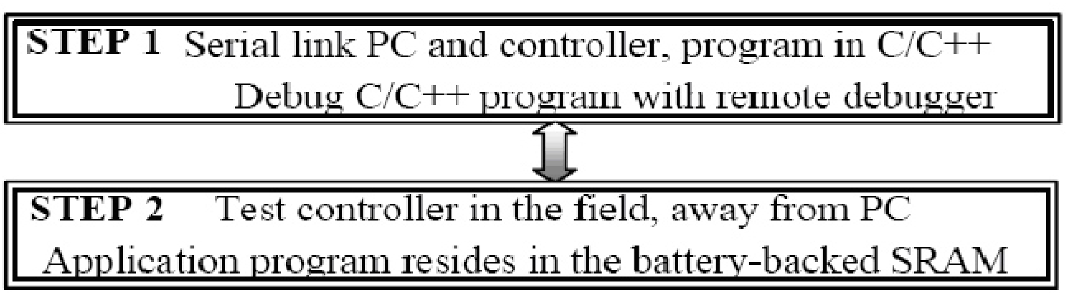


Figure III-19: Development of Application Software [8]

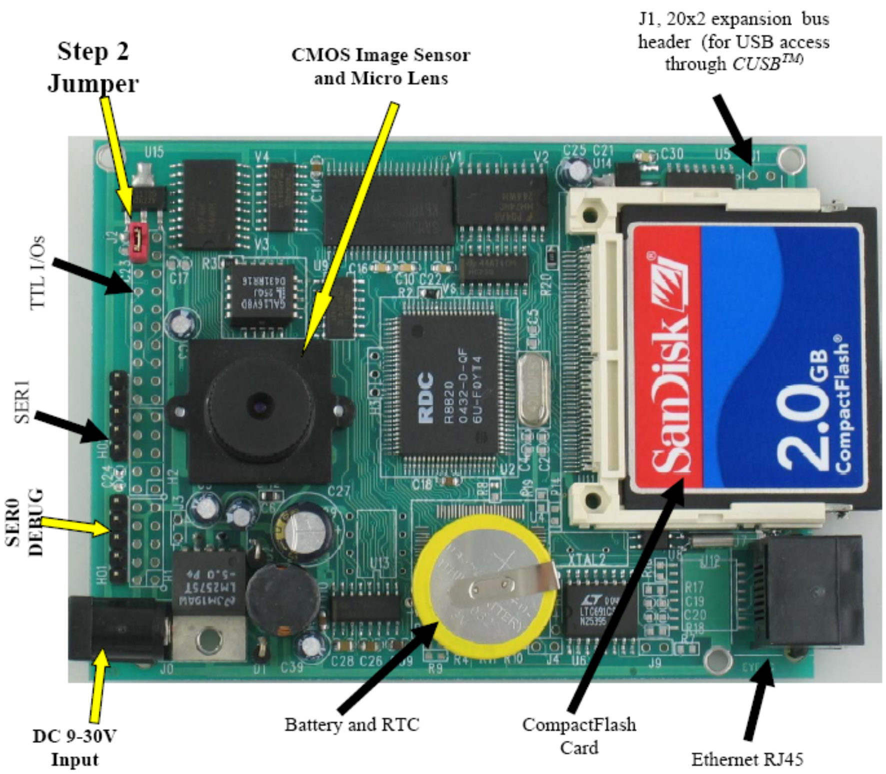


Figure III-20: Physical Description of the Eye-C [8]

3.2.2.2 Determination of Recording Method

The Eye-C cameras were capable of recording images in VGA and QVGA. With VGA the active pixels were 640 x 480 and with QVGA the active pixels were 320 x 240. A test was run to record images in both modes. The images obtained were of comparable quality, and since the QVGA mode allowed faster acquisition, it was selected for use during the experiment. Some sample images from this test in the QVGA mode are displayed in Figure III-21.

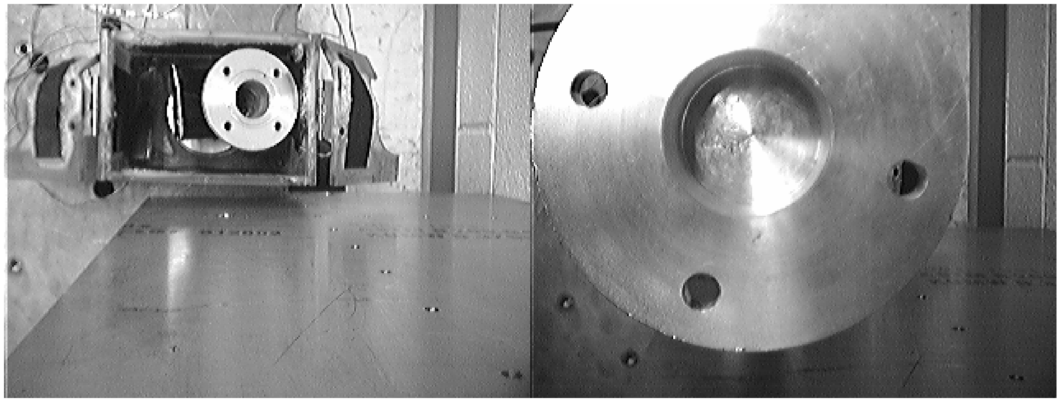


Figure III-21: Tube Deflated and Folded / Fully Expanded with QVGA

A second test was conducted to determine the true fps with the Eye-C at AFIT. This test was performed by placing a stopwatch capable of reading to the hundredth of a second in front of the CMOS sensor. The Eye-C camera ran for several minutes. After comparing several frames it was determined that the true fps of the Eye-C controller storing images to the CompactFlash memory card was approximately 9/10 of a second. Some sample images from this test are displayed below in Figure III-22.

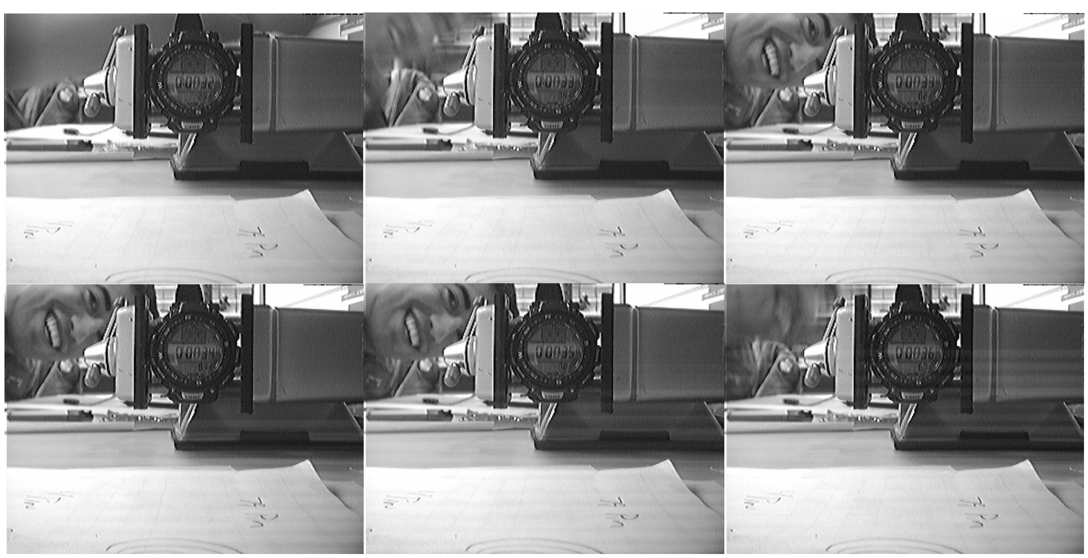


Figure III-22: Images of Setup with Stopwatch

A third test was run to determine if the images on the memory card would be erased if the power was reset. The images were saved on the memory card in a standard sequential order. The question was that if the power to the Eye-C controller was reset, would that order start over at zero when new images were saved to the memory card? To determine this, the same setup with the stopwatch was used. The power to the Eye-C camera was reset five times in 30 second intervals. After analyzing the images on the card, it was found that pictures existed from each of the five intervals. Whenever power is restored to the Eye-C controllers it begins storing images where it last left off. This is believed to be due to the onboard real time clock that stamps each image with an internal time of creation.

If the card becomes full, the camera simply stopped recording new images. It was suspected that if the battery is removed from the Eye-C, the image capturing program stored on the SRAM will be erased, and the real time clock reset. However, this has not yet been tested.

3.2.2.3 Modification of CompactFlash Interface and Power Connection

When the Eye-C arrived from Tern, it originally had a thin aluminum housing around the interface for the CompactFlash memory card. The aluminum housing enclosed a system of linkages for ejecting the memory card. These linkages connected to a large plastic ejector arm. After placing the Eye-C in the aluminum enclosures it was discovered that it no longer fit with this ejector arm attached. Using a small Phillips screw driver, these card ejector systems were simply popped off. An image of removing these ejector systems is displayed in Figure III-23.

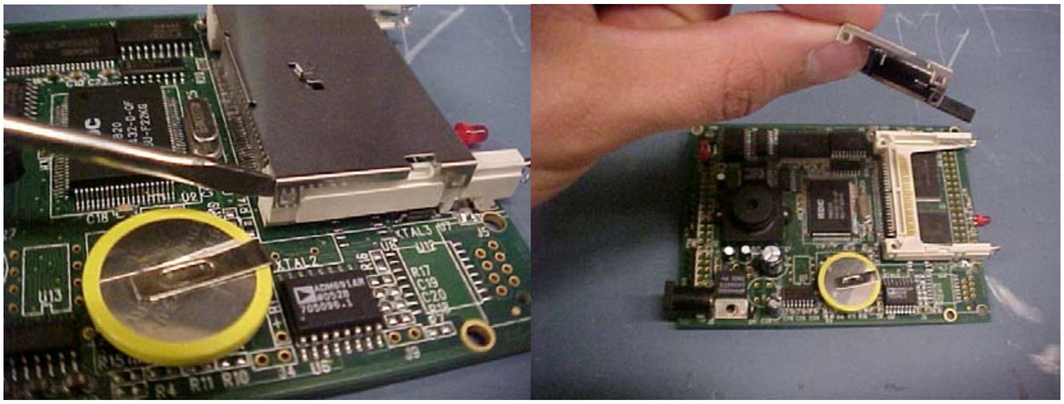


Figure III-23: Removal of Ejector System

The first arrangement of the Eye-C cameras in RIGEX intended to use stock power connection, as seen in Figure III-20. After further testing, it was found that the power connections did not actually fit through the end plates of the provided aluminum enclosures. The factory push pin connector was square, while the hole in the end plate was round. The first attempt to resolve this problem was to use a Dremel tool and round out the power input to fit in the circular hole. This modification can be seen in Figure III-24. This attempt was successful except that it exposed the positive lead. This positive lead had to be insulated or the boards could be shorted out. This was not possible due to the additional dimension that the insulation would require, as there was no room between the positive lead and the endplate.

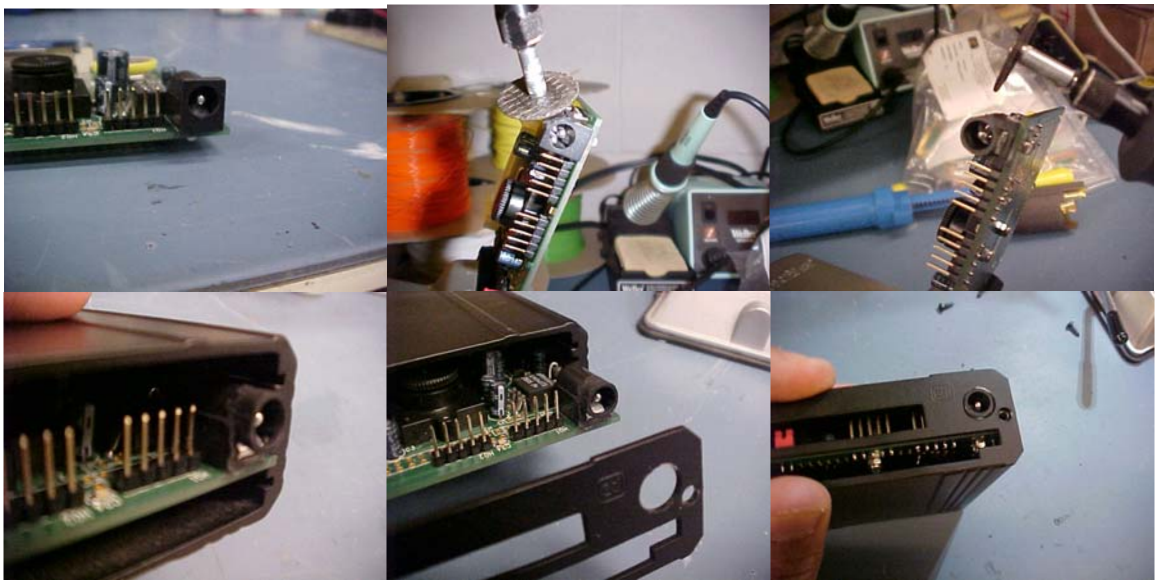


Figure III-24: Modification of Factory Push Pin Connector

The second effort was to replace the pushpin connector with a power terminal. This did in effect work except that the only power terminals that were found at AFIT were from bench stock. These had to be cut down and modified to fit on the Eye-C cameras. This modification can be seen in Figure III-25. The fact that these power terminals were modified from bench stock would end up leading to a complication in acquiring approval from STP, since these terminals did not have a certificate of compliance [21]. The importance of this documentation process is explained in Chapter IV.

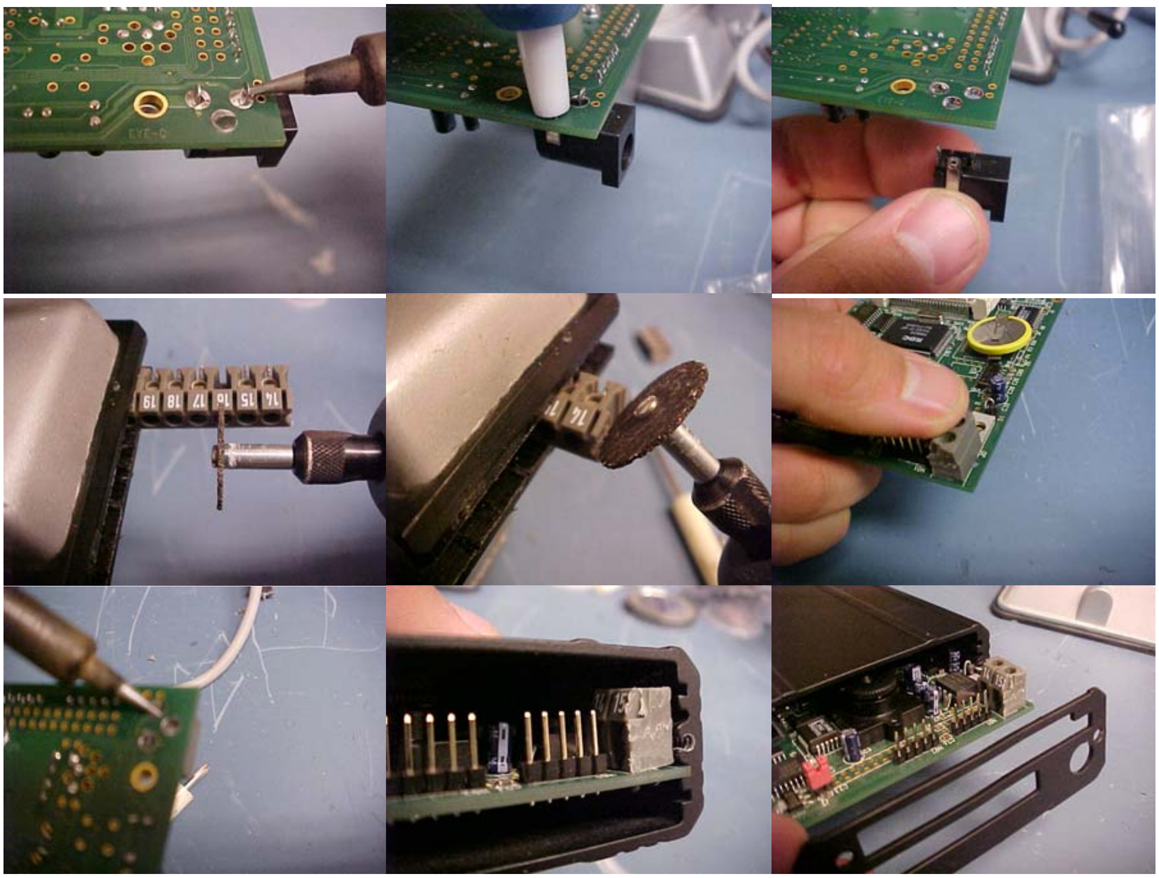


Figure III-25: Replacement of Pushpin Connector with Modified Power Terminal

The final solution was to remove the power connection all together. The power wires were soldered directly to the boards, and tension-relief mechanisms were attached with epoxy along the ribs adjacent to the cameras. An image of the final design is displayed in Figure III-26.

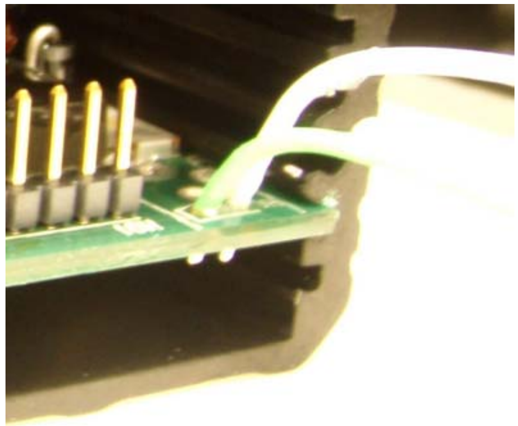


Figure III-26: Power Wires Soldered Directly to Eye-C Board

3.2.2.4 Aluminum Enclosures

The Eye-C controllers on RIGEX require an aluminum enclosure not only for mounting to the experimental top plate but also for protection. On reentry, it is possible that several components will become loose and begin violently bouncing around inside RIGEX. This is partially the reason for the shroud. In order to successfully retrieve data for analysis, which is stored on the CompactFlash memory card of each Eye-C, the memory cards must be undamaged. To ensure their survivability, each Eye-C controller will be housed in an aluminum enclosure. As mentioned before, the Eye-C cameras did not actually fit in the aluminum enclosures provided by Tern as intended. The Eye-C camera board is exactly four inches and so is the aluminum extrusion that houses it, which can be seen in Figure III-27. On each end of the aluminum extrusion two different end plates, which can be seen in Figure III-28, are used that interfere with protruding items on the Eye-C boards. Until the power adapter was removed, it extended past the edge of the board and did not fit in the hole on End Plate B. On the other end, the LED power indicator extends past the edge of the board, and End Plate A did not have a cut-out for this LED.

Figure III-27: Eye-C Camera and Aluminum Enclosure [8]

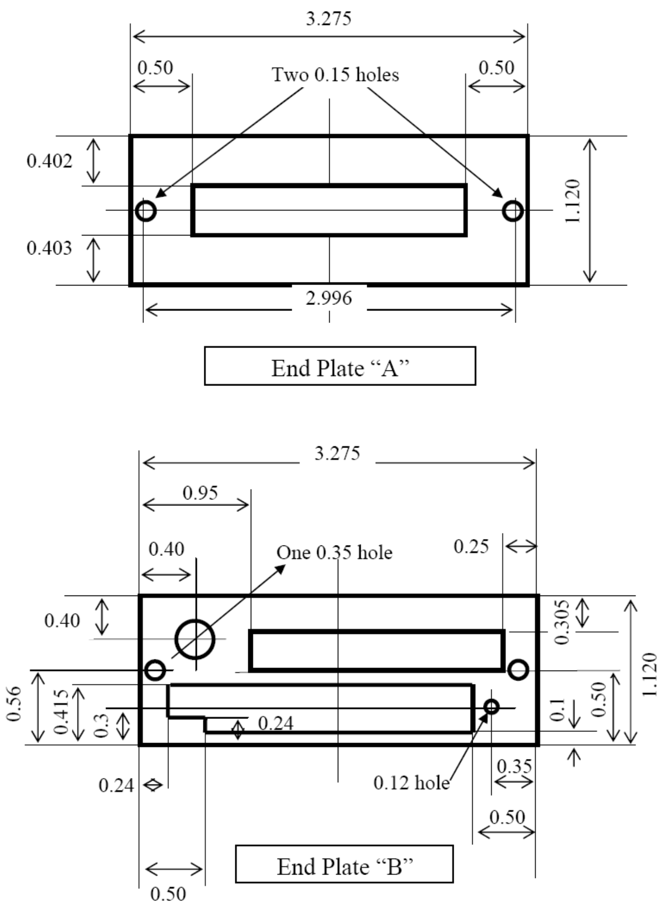


Figure III-28: Annotated Drawings of Endplates [8]

The interference with power input was solved when it was removed, but the interference with the LED remained. The only solution was to modify End Plate A. Using a Dremel tool, a cut-out was made for the LED, which can be seen in Figure III-29. This made it possible for the end plate to attach flush against the aluminum.

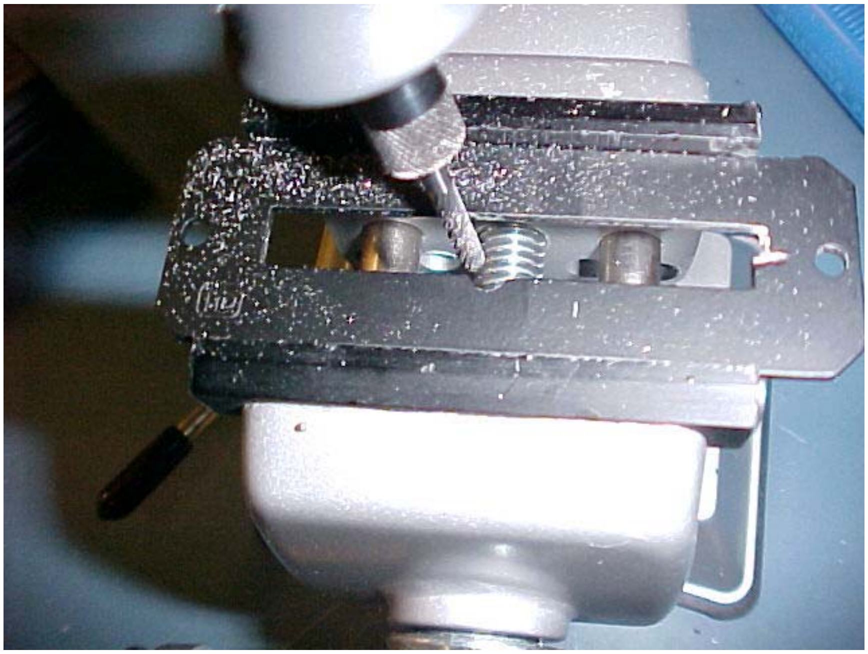


Figure III-29: Adding Cut-Out for LED with Dremel Tool

Another issue with the aluminum enclosures that was not addressed until the final preparation of RIGEX was the exterior coating. All three enclosures including the extrusion, endplates and screws were covered with black paint. This was overlooked due to the incorrect assumption that they were anodized. When this discovery was made, the first approach was to find out the composition of the paint and how it was applied. After thorough searching, it was determined that Tern does not make nor modify any part of the enclosure for the Eye-C boards, which were actually manufactured for the R-Box (another Tern controller). The Eye-C enclosure is a RS-3010 aluminum extrusion cut to a 4" length, modified specifically for Tern (RS-3010-4020-TRN) along with two machined end panels and screws, which are manufactured by a company called Extrusion Technology (Xtech). The enclosure includes two machined end panels and screws, all pieces powder coat painted, overspray allowed, which means that they were washed, tumbled, pre-washed, racked, electromagnetically charged, painted, and then baked. The paint used by Xtech is XT-002 Black Powder Coat - Smooth. Xtech purchased the paint from Morton Paint Company, one of the 8 major business segments of U.S. Chemical & Plastics (USC) that specialize in developing specialty coatings for the automotive repair and refinishing market. It was finally decided that it was nearly impossible to determine the actual chemical properties of the paint. The next step was to remove the paint. After several attempts at sandblasting and applying paint thinner, the paint still remained on the enclosures.

The final decision was made to order new bare aluminum enclosures from Xtech directly, without any coating. The enclosures were ordered and delivered to AFIT. Since the enclosures were directly ordered from Xtech, the end plates were blank and had to be modified along with the blank extrusion. These blank pieces can be seen in Figure III-30. On End Plate A the same cut-out from the original plate was added along with the cut-out for the LED. On End Plate B, only a small hole was drilled for the power wires since the power connector on the Eye-C boards was removed. On the aluminum extrusion there were four holes added on the bottom for the fasters along with four through holes on the top. On the top a 1” holes was added for the CMOS sensor. These modifications can be seen in Figure III-31.

Figure III-30: Aluminum Enclosures with Blank Endplates and Extrusions

Figure III-31: Aluminum Enclosures with modifications to Endplates and Extrusions

After all the modifications were made to the bare aluminum enclosures at AFIT, they needed to be treated. Just as all the other aluminum pieces fabricated at AFIT, they were sent to TechMetals to be anodized (see 5.1.2). The 4-40 x 3/8 pan head screws that secure the endplates to the extrusion did not have to be treated since they were made of stainless steel. When they were returned, a final design for the aluminum enclosures of the Eye-C was finally completed. A picture of the anodized pieces is seen in Figure III-32. An assembly of these enclosures with the Eye-C can be seen below in Figure III-33.

Figure III-32: Aluminum Enclosures after Being Anodized

Figure III-33: Aluminum Enclosure Assembled Together with Eye-C Inside

3.2.2.5 Final Preparation

After the Eye-C cameras were programmed and all the complications with the power input and aluminum enclosures were resolved, the Eye-C cameras had to be prepared for flight. The cameras were checked out in a vacuum chamber at extreme temperatures specified by NASA to ensure survivability and functional ability in the harsh space environment. This testing is discussed in further detail in Chapter IV. Due to potential outgassing from different electrical components on the Eye-C boards, they had to be conformally coated (see 5.1.6). After these steps were taken the Eye-C cameras were inserted into the aluminum enclosures and finally integrated into the RIGEX assembly.

3.3 Design Modifications Summary

Even with the exceptional efforts of past AFIT students, the changes required during the wave two assembly could not have been predicted. The final drawing package, as submitted in this thesis, consists of a previous drawing package updated with all of the modifications discussed in this chapter. These modifications include creation of new component drawings, detailing of existing component drawings, and updating component placement on the final assembly, as built. This top level assembly drawing package of RIGEX can be found in Appendix A.

The data imaging system underwent a total transformation from the old, bulky, computer dependent cameras to the compact, independent Eye-C cameras. Integration of these cameras to RIGEX was a culmination of programming the Eye-C controllers, determining the specifics of their application, hardware modifications and developing an acceptable aluminum enclosure.

IV. Final Preparation and Testing of RIGEX at AFIT

Before RIGEX can be finished and shipped to Houston, it must undergo final testing and preparation at AFIT. At AFIT, two final tests will require a Thermal Vacuum Chamber (TVAC), one will test certain components in RIGEX and the second will test the overall assembly of RIGEX. The inflation system on RIGEX must be filled with nitrogen before shipment. To ensure that there will be a sufficient amount of nitrogen in the tanks when it is time to inflate the tubes, a leak test must also be performed.

4.1 Final Testing of RIGEX components in a Thermally Controlled, Vacuum Environment

To conduct any type of experimental research in space through NASA, there are several requirements that must be met. One such requirement is certification. According to the Aeronautical Quality Clause by *NASA QC02-N CERTIFICATE OF COMPLIANCE (C of C) [NASA AQC05]*: "an organization shall provide certification with each shipment that attests the parts or assemblies conform to the order requirements [21]." As seen in Table IV-1, there are several items of information such as an order number, a purchase order, an address of the manufacturer, the original manufacture's lot number, the unit of measurement, and the authenticity that a Certificate of Compliance (COC) must contain. All this must be included to be considered valid by NASA.

Table IV-1: Requirements of Certification [21]

Certification must contain the following:
Customer's Order number (JPL's)
Line number from the Contract/Purchase Order
Part number as identified in the Contract/Purchase Order
Name and address of manufacturing or processing location
Manufacturer's lot number, heat lot number, batch number, date code, and/or serial number/s (if applicable)
Quantity and unit of measurement (each, box, case, gallons, etc.)
Be signed and dated by an official of the company.

If a part or assembly does not have a COC that states the manufacture has tested the part or assembly, then it must be tested and documented before it can be used. One major concern for testing is the harsh environment of space. The majority of components that make up RIGEX have a COC stating their capability in the environment of space that is valid with NASA. A few components either have COCs that are not acceptable or just do not have one. These components must be tested in a TVAC to simulate the effects of space and determine their performance in a vacuum environment with extreme temperatures.

4.1.1 Methodology

Thermal vacuum testing is one of the most critical environmental tests for space applications. It is used to detect workmanship deficiencies and determine the overall flight-worthiness of a space vehicle by subjecting it to flight-like operating conditions [29]. According to MIL-HDBK-340, "… Thermal vacuum testing is vital in ensuring successful mission operations of units, subsystems and vehicles, which operate at high altitudes. For upper stage and space vehicles it represents the essential conditions of the operational environment. Thermal vacuum testing provides assurance that the unit, subsystem or vehicles will operate successfully within expected thermal extremes of its mission environment."

Although thermal vacuum testing is a widely used and an historically accepted practice, its validity is still questioned. Thermal vacuum testing is very costly and time consuming. Another method used at ambient pressure is a system level thermal cycle (TC) test.

The purpose of a system level TC test is to detect defects in the material, process or workmanship of the space vehicle hardware by exposing it to thermal stresses. This is done by subjecting the hardware to an environment where the temperature cycles from hot to cold extremes [29]. The thermal cycle test is conducted at ambient pressure. The thermal vacuum testing screens for the same defects searched for in the thermal cycle test as well as occurrences that would only be found in a vacuum environment. Such occurrences include outgassing, multipacting, and corona/arcing, which only occur in a thermal vacuum condition. Outgassing occurs when a material that is placed in a vacuum environment and is subjected to heat, emits gas or water vapor inherent to the material [6]. Multipacting is a phenomenon of resonant electron multiplication [19]. Corona or arcing is the energy transfer through the spontaneous growth of electrically conductive single crystal structures. These are also known as whiskers. Pure tin, which is used to plate most common electronic connectors, is highly susceptible to this phenomenon as seen in Figure IV-1. In a metal vapor arc, the solid metal whisker is vaporized to plasma, which is highly conductive, capable of carrying hundreds of amperes and ultimately results in an electrical failure [20].

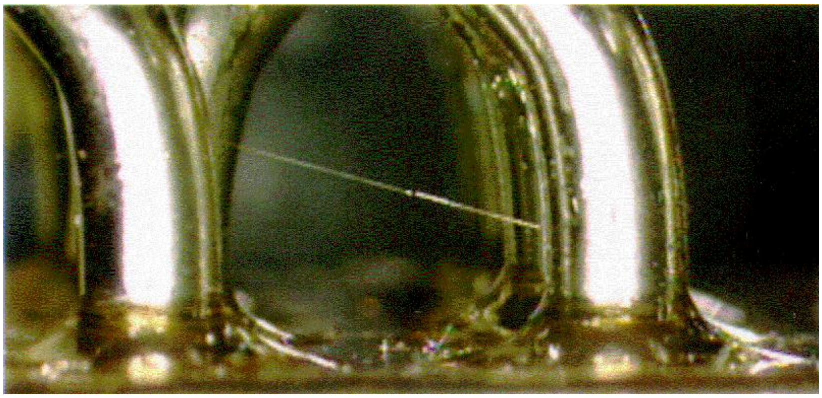


Figure IV-1: Tin Whiskers [20]

Both the TVAC testing and TC testing play an important role in screening for a wide range of defects. TVAC testing focuses on performance verification while TC testing focuses on environmental stress screening. A comparison of these tests can be seen in Table IV-2 . Of both tests, the TVAC test truly exercises the subject in an environment that simulates operation conditions in space.

Table IV-2: Thermal Test Objective Comparison [29]

Test Objectives	TVAC	TC
Electrical intermittence	X	X
Orbital Environment Performance	X	
Thermal Control	X	
Arcing	X	
Multipacting/Corona	X	
Material Outgassing	X	
Latent Defect/Failure Propagation	X	X
Thermal Stress Effects	X	X
Integration Hardware Verification	X	X

Another purpose of using a TVAC for space vehicles is vacuum bakeout. Using a chamber set to a high vacuum (10^{-5} Torr), hardware can be effectively baked to minimize contamination from outgassing [33]. For these reasons, TVAC testing was undertaken. Space Simulator Vacuum System.

The Space Simulator Vacuum System at AFIT was manufactured by PHPK Technologies, which was founded in 1911 and is now a major supplier of cryogenic and high vacuum equipment. PHPK Technologies specializes in custom systems that are built in an ASME Section VIII, Division 2 approved facility with all welding personnel and procedures ASME Section IX certified.

The Space Simulator Vacuum System is composed of three modules: the Vacuum Chamber, the Thermal Control Unit (TCU), and the Operator Interface Enclosure. Each module will be discussed separately in following sections. This system was designed and tested to meet the performance requirements found in Table IV-3.

Table IV-3: Space Simulator Vacuum System Performance Requirements

Temperature Range:	-60°C to +100°C
Ramp Rate:	2°C/Min.
Test Article Size:	30" wide x 30" tall x 36" long
Modular Construction:	To fit through 70" wide hallways and 7'-0"
Vacuum Chamber:	Leak tested to 1×10^{-9} Std cc/sec helium

4.1.1.1 Vacuum Chamber

The vacuum chamber is 60” in diameter and approximately 60” long. The chamber is constructed of 3/8” thick 304 series stainless steel mounted to a painted steel base. See Figure IV-2. The chamber is equipped with penetrations at several locations to allow wiring to pass into the chamber for data and power. These penetrations include CF type knife edge sealing flanges and QF o-ring flange and clamp designs, which are all recognized by the American Vacuum Society as high vacuum sealing devices. On top of the chamber there are two pressure relief devices that will relieve pressure at approximately 1 to 3 psig..

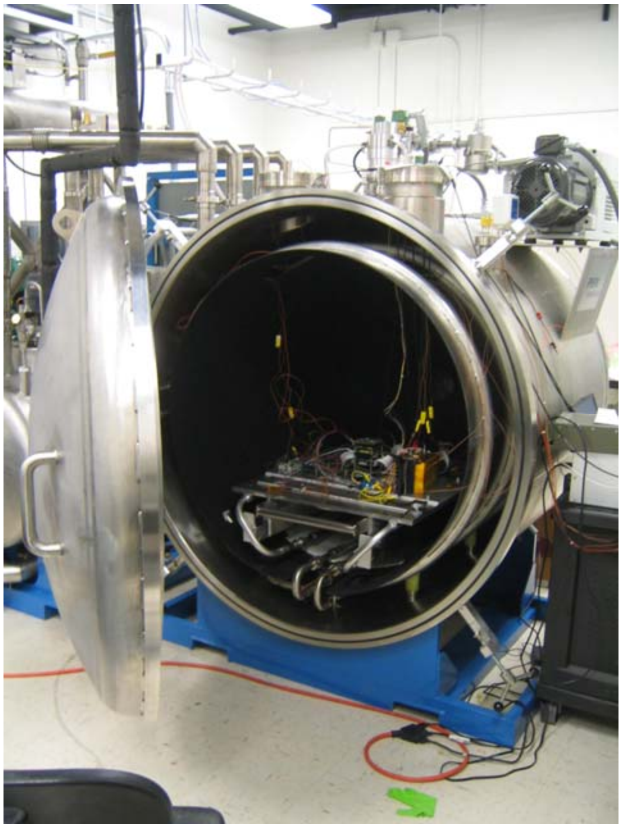


Figure IV-2: Vacuum Chamber

On one end of the chamber, there is a hinged door that opens the full 60” diameter. The chamber is sealed using a 3/8” diameter o-ring along the metal edge when the door is closed and the clamping system is engaged. When the chamber is pumped to the desired vacuum, the door clamps are no longer necessary to provide pressure on the seal. In addition, the clamps should not be tightened while under a vacuum because when the chamber is brought back to ambient conditions it may be difficult to remove them. The clamps may also be damaged due to overloading. The hinges for the door on the chamber are commercially manufactured ball bearings, which allow smooth movement of the door.

Inside the chamber there are three temperature controlled structures: the thermal shroud, the platen and the inner door. These structures are constructed of aluminum and are traced with D-shaped aluminum tubing within which the thermally controlled heat transfer fluid flows. The inside surfaces of the thermal shroud and the inner door are also painted with vacuum compatible low emissivity black paint. Care must be taken not to scratch or spill any fluids on these structures while working inside the chamber. The platen is not treated and is capable of holding up to a 200 lb test article. The platen can be manually pulled out for ease of loading and unloading test articles. All three structures can be removed for cleaning inside the chamber if necessary [26].

4.1.1.1.1 Vacuum Controller

The CC-10 is the vacuum controller in Space Simulator Vacuum System at AFIT. The CC-10 is a self-contained, compact digital wide range vacuum gauge and controller. The CC-10 is capable of providing measurements from atmospheric pressure to 10^{-9} Torr using two sensor types. A crystal sensor is used to measure from atmospheric pressure to

10^{-4} Torr and a double inverted magnetron cold cathode is used to measure from 10^{-3} to 10^{-9} Torr [27].

4.1.1.1.2 Vacuum Roughing Pump (VP03)

The vacuum roughing pump in the Space Simulator Vacuum System at AFIT is a D40B model two stage rotary vane pump by Leybold. The roughing pump is equipped with an exhaust filter model AF by Leybold Vacuum Products. A mole sieve unit equipped with an electric heater for regeneration is included in the vacuum line to prevent oil migration from the vacuum pump. The vacuum roughing pump is installed on top of the chamber to provide a rough vacuum system and to provide a backing vacuum pump for the turbomolecular pump. The vacuum roughing pump is designed to pump the chamber down to a vacuum of 1.0×10^{-3} Torr [27].

4.1.1.1.3 Vacuum Turbomolecular Pump (TP01)

The vacuum turbomolecular pump in the Space Simulator Vacuum System at AFIT is a 151C model from Leybold Vacuum Products. The turbo pump is rated at 1 horsepower. The turbo pump is mounted on top of the chamber to achieve the highest vacuum possible quickly. The ultimate vacuum in the chamber is dependent upon the amount and type of contamination inside the chamber along with the amount of outgassing from the test article inside the chamber [27].

4.1.1.1.4 Regulators

The regulators in the Space Simulator Vacuum System at AFIT are type 700 precision air pressure regulators by ControlAir Inc. The regulators provide accurate control for an application that requires a high flow capacity. An aspirator tube adjusts the air supply in accordance with the flow velocity. With the use of the aspirator tube, regulated pressure is maintained under varying flow conditions. Constant output pressure, even during wide supply pressure variations, is due to a poppet valve balanced by a rolling diaphragm [27].

4.1.1.2 Thermal Control Unit (TCU)

The thermal control unit consists of cryogenic valves, cryogenic piping, a liquid circulating pump, a heater, a heat exchanger, and an expansion tank, as seen in Figure IV-3. There is also a cold box, which is a static vacuum insulated vessel constructed of ¼” thick stainless steel. This cold box allows for frost-free operation during cold runs and allows protection from hot piping during hot runs. This is where most of the cryogenic piping and valves are mounted. The piping near the pump and the flex hose at the inlet of the pump, which has a conical strainer welded into it, both are mechanically insulated to allow for pump removal. The heater, seals and plugs on the cryogenic valves are designed to be replaced without breaking the static vacuum. The only component that is not accessible is the heat exchanger, which typically does not require repair.

Figure IV-3: Thermal Control Unit (TCU)

4.1.1.2.1 Liquid Circulating Pump

The liquid circulating pump in the Space Simulator Vacuum System at AFIT is an Isochem GMC8-AAK-KKFC model sealless magnetic drive gear pump manufactured by Pulsafeeder. The pump is designed to circulate HFE-7200 heat transfer fluid by 3M throughout the system at a minimum pressure differential of 40 psig [27].

4.1.1.2.2 Thermal Fluid

The thermal fluid in the Space Simulator Vacuum System at AFIT is HFE-7200 Novec engineered fluid by 3M. Some technical specifications of the fluid in provided in Table IV-4.

Table IV-4: Technical Specifications of HFE-7200 [27]

Selection Guidelines (Equipment operating temperature)	Low
Boiling Point (°C)	76
Pour Point (°C)	-138
Vapor Pressure (Pa)	15.7×10^3
Density (kg/m^3)	1420
Coefficient of Volume Expansion (°C^{-1})	0.0016
Kinematic Viscosity (cSt)	0.41
Absolute Viscosity (centipoise)	0.58
Specific Heat (J kg^{-1} °C^{-1})	1220
Heat of Vaporization @ B.P. (J/g)	119
Dielectric Strength (kV, 0.1" gap)	~40
Dielectric Constant (1KHz)	7.3
Volume Resistivity (Ω cm)	10^8

4.1.1.2.3 Heater

The heaters in the Space Simulator Vacuum System at AFIT are industrial flanged immersion heaters manufactured by Wiegand. The terminal enclosure of the heaters is moisture resistant and explosion resistant.

4.1.1.3 Operator Interface Enclosure

The operator interface enclosure controls all of the remote operated devices in the system. It is made up of an SCR module, power switches, 230/120 Volt transformer, turbomolecular pump controller, and a chamber control assembly. The SCR module controls the heater in the thermal control unit. The power switches control the main power supply and disconnect to all systems. The 230/120 Volt transformer powers the

120 Volt devices. The turbopump controller is electrically connected to the chamber control assembly and enables the remote start/stop function of the pump. The chamber control assembly includes the operator interface graphic screen which entails eight different screens described below that control the vacuum system and report all indications of the system. The operator interface graphic screen can be seen on the operator interface enclosure, in Figure IV-4

Figure IV-4: Operator Interface Enclosure

4.1.1.3.1 The Vacuum Enclosure Overview Screen

The HMI vacuum enclosure screen graphically shows the heater, cooler exchanger and flow control valves in its P and I diagram. Real time data is shown for the temperature, the flow and the valve output valves. Alarms are shown in the alarm banner. When the alarm Triangle starts flashing red, clicking on the red triangle will bring up the alarm summary. The push buttons on the bottom of the screen allow the operator to navigate to other screens.

4.1.1.3.2 The Fluorinert Temperature Controller Screen

The vacuum enclosure has two controllers. The first is Loop 0; it is used for the SCR Heater. The second is Loop 1; it is used for the Cooling Exchanger Valve. The Segment Temperature Setup Screen is determined by the controller's set point. Under the controller there are data entry windows for tuning parameters including proportional, integral, and derivative.

4.1.1.3.3 The Segment Temperature Setup and Trend Screen

For cycling temperatures in the chamber there are ten segments that are available for ramp rate, dwell temperature and dwell time (zero = segment skipped over). The heating and cooling is located in each segment. They are controlled by the Programmable Logic Controller (PLC) and compare the current chamber temperature and set the dwell temperature. Once the dwell temperature is set and reached, there is a default soak time of 60 seconds before the dwell time is activated. The elapsed time of each segment is displayed on the lower right corner of the screen. The real-time trend screen under the segment entry shows segment step number and temperature values for the Fluorinert to Chamber Temperature (TE10), the Platen Temperature (TE15), the Cylinder Shroud Temperature (TE16), and the End Shroud Temperature (TE17). Real-time trend screens advance in ten second increments.

4.1.1.3.4 The Vacuum Chamber Overview Screen

The vacuum chamber screen graphically displays the vacuum chamber and PI diagram. The temperature and pressure is shown in real-time. The pumps and valves that are controlled from this screen include; the roughing pump, the turbopump, valve FV02, valve FV06 and valve FV10.

4.1.1.3.5 The Chamber Controller Screen

The three controllers are; Loop 2 the cylinder flow, Loop3 the end shroud flow and Loop 4 the platen flow. The controllers balance temperature in a specific area and control the TE 110 Fluorinert temperature supply. The data entry window under the controller includes proportional, integral, and derivatives used for tuning the parameter.

4.1.1.3.6 The Temperature Historical Screen

The vacuum chamber temperatures and the step numbers are historically trended against time in this screen.

4.1.1.3.7 The Alarm Summary Screen

The HMI alarm summary screen is a summary of alarms generated by the PLC. An active unacknowledged alarm will flash, and an active acknowledged alarm will stop flashing.

4.1.1.3.8 The Login Screen

If this security feature were enabled, this screen would allow the user to log in using the on-screen keyboard.

4.1.2 Component Testing.

As stated in the beginning of this chapter, it must be documented that every component of RIGEX is capable of withstanding the environmental elements of space. If the component does not have the proper paperwork from its manufacture stating that it is capable of withstanding the environmental elements it must be tested before being launched into space. On the final assembly of RIGEX there are six different components that must meet this requirement. The ovens that will heat the tube specimens to their glass transition temperature, the oven controllers, the solid state relays that will supply the oven controllers, the computer that will control the entire autonomous system of the RIGEX experiment, the cameras that will provide the secondary documentation during the expansion of the tube specimens and the LEDs that will provide illumination for the cameras.

4.1.2.1 Test Setup

To assess if these six components could withstand the environmental elements of space they were tested in the Space Simulation Vacuum System by PHPK Technologies. Each one was required to undergo testing through a temperature profile provided by NASA for the expected mission parameters. These are displayed in Table IV-5. Each component must endure the survivable temperatures, with the cold boundary located at -65^{o}C to -60^{o}C and hot boundary located at 74^{o}C to 79^{o}C, under a vacuum without becoming defective. They also must be able to perform their designated task in a vacuum at the functional temperatures with the cold boundary located at -50^{o}C to -45^{o}C and hot boundary located at 45^{o}C to 50^{o}C.

Table IV-5: Temperature Profile for Component Testing in TVAC [26]

	Temperature Limitations			
	Lower Limit	Allowable Deviation	Upper Limit	Allowable Deviation
Survivable Temperatures (^oC)	**-60**	**(-5/+0)**	**74**	**(+5/-0)**
Functional Temperatures (^oC)	**-45**	**(-5/+0)**	**45**	**(+5/-0)**

The components were placed on an aluminum plank that were then bolted down to the platen of the vacuum chamber with copper mesh between the aluminum plank and the platen to help promote conduction. Once all the components had been situated, the next step was to connect all the wiring between the wiring connection interfaces inside the chamber and all the components as well as the wiring between the components themselves. Outside of the chamber all the wiring between the RIGEX space shuttle power emulator and 5 VDC power supply was connected.

To test the local temperature at certain components, thermocouples were positioned near the location of these individual components. The thermocouple wiring was connected to the wiring connection interfaces inside the chamber. Then a connection was made from the wiring connection interfaces outside the chamber to the thermocouple wiring interfaces on the data acquisition system. A computer set up with *LabVIEW* software version 8.2 [4] was used for logging the data read from the thermocouples. *LabVIEW* is a graphical program development application from National Instruments used to integrate engineering tasks such as interfacing computers with instruments, collecting, storing, analyzing, and transmitting measured data, developing a program in a graphical environment, and providing an effective user interface [4].

4.1.2.2 FVT

A functional verification test (FVT) of the components was conducted three times: once at ambient temperature and pressure, and twice under a vacuum; once at the low limit of the functional profile and once at the high limit of the functional profile. The FVT Ambient setting were conducted first to ensure that all the proper connections have been made. After the FVT had been completed the chamber was sealed and put under a vacuum. A representational diagram of how the chamber would be cooled and then heated is portrayed in Figure IV-5.

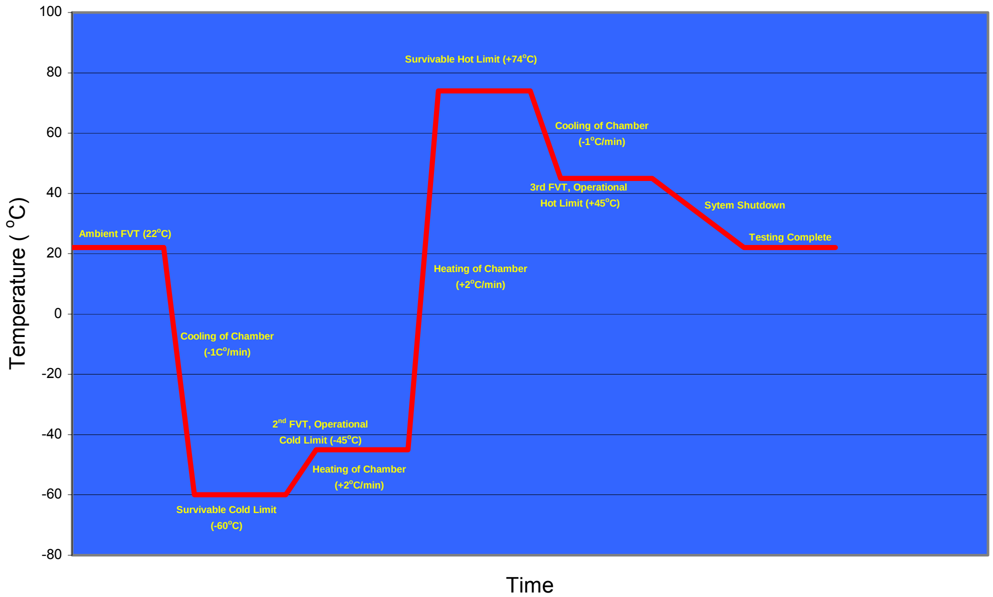


Figure IV-5: Temperature Profile of TVAC Testing

To conduct the ambient FVT, the power supply was activated and set to an output of 5 VDC. The emulator was turned on and a visual feedback with the DC-13 DN was assessed. After completion, the chamber was closed and prepared for the vacuum FVTs.

The vacuum roughing pump was activated from the vacuum chamber overview screen on the operator interface enclosure. Once the chamber reached $5x10^{-5}$ Torr, the turbo pump was activated. The turbo pump will not operate unless there is a sufficient flow of water running through it, due to overheating. After a high vacuum was achieved, the thermal control system was implemented. The circulating liquid pump was activated from the vacuum enclosure screen and monitored to ensure that at least 12 GPM was flowing through the pump. After all the information including ramp rate, dwell temperature, and dwell time was entered for each segment on the segment temperature setup and trend screen, the cycle was started.

The temperature in the chamber was lowered slowly to the survivable cold limit and remained there until the components had reached -60^{o}C. Then the temperature was raised to the operational cold limit and remained there until the components had reached -45^{o}C. This is when the second FVT was conducted just as before. After a successful FVT, the chamber temperature was raised to the survivable hot limit and remained there until the components have reached 74^{o}C. After all the components had successfully reached 74^{o}C the chamber will be lowered down to the operational hot limit. Once all the components being tested reached 45^{o}C the third and final FVT was conducted. After completion, all the temperature limits had been successfully met and the thermal control system was shutdown. The chamber was allowed to cool naturally to conserve the gaseous nitrogen. Once the temperature of the chamber returned to room temperature, the appropriate valves were opened to introduce air into the chamber to allow the chamber pressure to rise and equalize with the atmospheric pressure.

4.1.2.3 Results

The components were subjected to an extreme survival cold limit then brought up to the operating cold limit and the second FVT was conducted. The readings of the local thermocouples placed on the components being tested are listed in Table IV-6. The system was then taken up to the survivable hot limit and brought down to the operating hot limit. Once this temperature was reached the third FVT was conducted. Readings from the thermocouples placed at each component being tested are given in Table IV-6. After the FVT was complete the chamber was slowly brought back to ambient conditions and shutdown.

Table IV-6: Thermocouple Readings

Thermocouples		Cold Oper. Limit	Hot Oper. Limit
Chan #	Location Description		
0	Tube Fold (Inside Oven)	-52.27	45.54
1	LED mounting	-43.43	31.22
2	Oven Controller	-33.55	51.03
3	Mounting Plate	-47.83	49.05
4	Solid State Relay	-42.66	45.93
5	Camera Board	-50.52	48.35
6	Processor Board	-48.84	47.98
7	DAQ Board	-48.1	47.35

Following the indications from the DS-13 on the Shuttle Emulator, all three FVT were completed successfully. Once the chamber was shut down, the components were taken out so the data imaging system could be analyzed for results. The memory card seemed to be corrupted and was unable to be read. The cameras were still functioning properly after the testing, so it can be assumed that the only damage was to the memory cards themselves. After further discussion, it was concluded that the CompactFlash memory cards were poorly manufactured, generic products and that industrial grade cards with higher rated operating limits would solve this problem. Industrial cards with specifications for operating within the required temperature profile limits were purchased, and formatted to work with the Eye-C cameras.

4.2 Final Preparation and Performance Testing of RIGEX Inflation System

4.2.1 Introduction

The inflation system that is now employed on the current RIGEX configuration has gone through many changes. The first inflation system was created initially by DiSebastian, which consisted of one tank pressurized to approximately 400 psi. Then it evolved through testing that was conducted with Lindenmuth. The final system, which consists of three tanks only pressurized to 14.7 psi (1 atm), was designed by Moeller. A layout of the components for one of the three setups is displayed in Figure IV-6 and each component is described in Table IV-7.

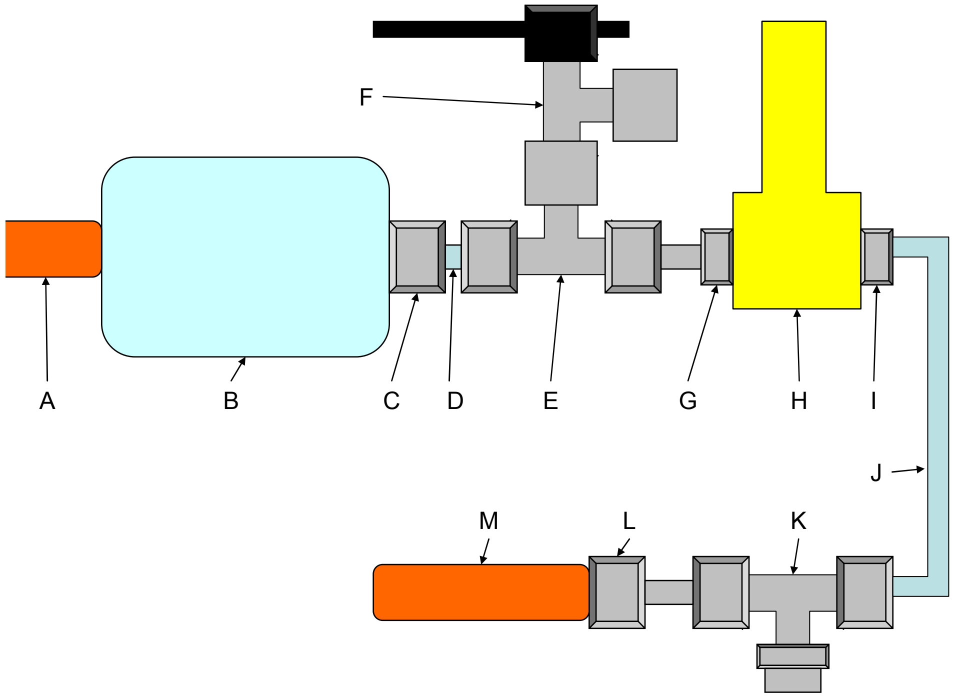


Figure IV-6: Inflation System Component Layout

Table IV-7: Component Description of Inflation System

A	Pressure Transducer
B	Tank
C	Male Connector with 1/4" NPT Thread
D	1/4" Stainless Steel Tubing
E	1/4" Male Connector with Branch, 1/4" NPT Thread
F	Angle Pattern On-Off (2-Way) Valve with Stainless Steel bar
G	Male Adapter with 1/8"NPT Thread
H	Solenoid
I	Male Connector with 1/8" NPT Thread
J	1/4" Stainless Steel Tubing
K	Male Connector with Positional Branch, SAE Straight Thread
L	Female Adapter with 1/2" NPT Thread
M	Pressure Transducer

4.2.1.1 Piping

The piping used in final RIGEX assembly is ¼" inch stainless steel tubing manufactured by Swagelok. The stainless steel tubing is used to connect the male connector with a ¼" NPT thread branch, which integrates the fill valve in the system to the male connector on the tank. The stainless steel tubing is also used to connect the male connector with the position branch, which screws into the bottom of the oven mounting plate and to the male connector on the solenoid. The stainless steel tubing is bent using a manual tube bender to fit through the RIGEX structure. Note the tubing is not bent as drawn in Figure IV-6.

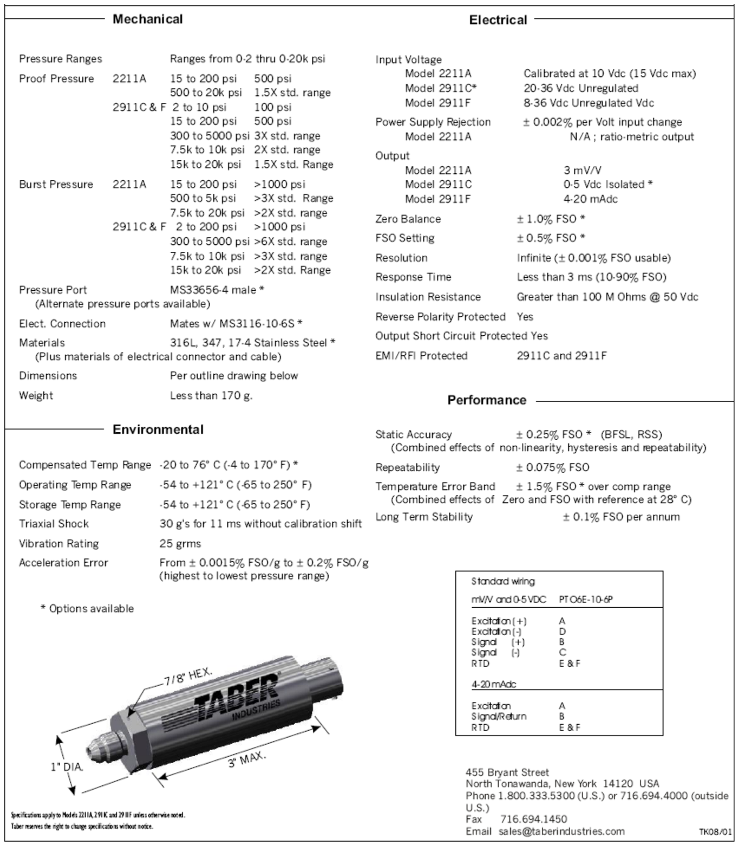
4.2.1.2 Pipe Fittings

There are several pipe fittings used in the inflation system. There are four male connectors used: a male connector with a ¼" NPT thread to connect the tank to the stainless steel tubing, a male connector with 1/8" NPT threads to connect the stainless steel tubing to the solenoid, a male connector with a ¼" NPT thread branch that connects the fill valve to the rest of the system, and a male connector with a positional branch, which has SAE straight threads that connects the stainless steel tubing to the oven mounting plate and pressure transducer. There is one female adapter with ½" NPT threads that connects the pressure transducer to the inflation system through the male connector with the positional branch near the tubes. There is one male adapter with 1/8" NPT threads that connects the solenoid to the union. The fill valve is an angle patter On-Off (2-way) valve. Originally, they were fitted with the stock nylon handles and were changed to the stainless steel bar handles, which allowed more room for maneuvering in the small environment of the center chamber. These handles are removable, and will only be installed temporarily for the filling procedure.

4.2.1.3 Pressure Transducers

The pressure transducers in the system are 2911 models from Taber Industries. The pressure transducers were designed using finite element analysis and other computer modeling tools to provide optimum performance. The pressure transducers provide isolation from induced stresses generated from installation torque, temperature excursions, vibration and shock. The pressure transducers also provide protection from high over-pressure [28].

The pressure transducers are very reliable and highly accurate due to the manufacturing techniques. The pressure transducers are welded and calibrated at the factory to meet the MIL-STD 461 EMI standards. The pressure transducers are also engineered for severe vibration and shock environments. The technical specifications of the pressure transducers can be seen in Figure IV-7 [28].



Mechanical

Pressure Ranges		Ranges from 0-2 thru 0-20k psi	
Proof Pressure	2211A	15 to 200 psi	500 psi
		500 to 20k psi	1.5X std. range
	2911C & F	2 to 10 psi	100 psi
		15 to 200 psi	500 psi
		300 to 5000 psi	3X std. range
		7.5k to 10k psi	2X std. range
		15k to 20k psi	1.5X std. Range
Burst Pressure	2211A	15 to 200 psi	>1000 psi
		500 to 5k psi	>3X std. Range
		7.5k to 20k psi	>2X std. range
	2911C & F	2 to 200 psi	>1000 psi
		300 to 5000 psi	>6X std. range
		7.5k to 10k psi	>3X std. range
		15k to 20k psi	>2X std. Range
Pressure Port (Alternate pressure ports available)		MS33656-4 male *	
Elect. Connection		Mates w/ MS3116-10-6S *	
Materials (Plus materials of electrical connector and cable)		316L, 347, 17-4 Stainless Steel *	
Dimensions		Per outline drawing below	
Weight		Less than 170 g.	

Environmental

Compensated Temp Range	-20 to 76° C (-4 to 170° F) *
Operating Temp Range	-54 to +121° C (-65 to 250° F)
Storage Temp Range	-54 to +121° C (-65 to 250° F)
Triaxial Shock	30 g's for 11 ms without calibration shift
Vibration Rating	25 grms
Acceleration Error	From ± 0.0015% FSO/g to ± 0.2% FSO/g (highest to lowest pressure range)

* Options available

Electrical

Input Voltage	
Model 2211A	Calibrated at 10 Vdc (15 Vdc max)
Model 2911C*	20-36 Vdc Unregulated
Model 2911F	8-36 Vdc Unregulated Vdc
Power Supply Rejection	± 0.002% per Volt input change
Model 2211A	N/A ; ratio-metric output
Output	
Model 2211A	3 mV/V
Model 2911C	0-5 Vdc Isolated *
Model 2911F	4-20 mAdc
Zero Balance	± 1.0% FSO *
FSO Setting	± 0.5% FSO *
Resolution	Infinite (± 0.001% FSO usable)
Response Time	Less than 3 ms (10-90% FSO)
Insulation Resistance	Greater than 100 M Ohms @ 50 Vdc
Reverse Polarity Protected	Yes
Output Short Circuit Protected	Yes
EMI/RFI Protected	2911C and 2911F

Performance

Static Accuracy (Combined effects of non-linearity, hysteresis and repeatability)	± 0.25% FSO * (BFSL, RSS)
Repeatability	± 0.075% FSO
Temperature Error Band (Combined effects of Zero and FSO with reference at 28° C)	± 1.5% FSO * over comp range
Long Term Stability	± 0.1% FSO per annum

Standard wiring	
mV/V and 0-5 VDC	PT O6E-10-6P
Excitation (+)	A
Excitation (-)	D
Signal (+)	B
Signal (-)	C
RTD	E & F
4-20 mAdc	
Excitation	A
Signal/Return	B
RTD	E & F

7/8" HEX.
TABER INDUSTRIES
1" DIA.
3" MAX.

Specifications apply to Models 2211A, 2911C and 2911F unless otherwise noted.
Taber reserves the right to change specifications without notice.

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TK08/01

Figure IV-7: Technical Specifications of Pressure Transducers [28]

There are two pressure transducers on each inflation system, with a total of six on RIGEX, one located near the input the oven mounting plate where the tubes attach and one on the end of the tanks. Once the pressure system is activated, nitrogen gas that is held from the solenoid back to the tank will flow through the system up through the oven mounting plate and into the rigidizable inflatable tubes. The pressure transducers will monitor the pressure in the system and will activate the solenoid when they read equal pressure and the venting process will begin.

4.2.2 Charging of Inflation System

In order to fill the tanks on the RIGEX, a system of hoses and fittings along with a vacuum gauge connected to a vacuum pump and a nitrogen source had to be created. The layout of this apparatus can be seen in Figure IV-8.

Figure IV-8: Layout of Filling System

The tanks on RIGEX have to be filled with pure Nitrogen gas. The tanks also have only one opening. The other is being occupied by a pressure transducer. The only way to fill the tanks with pure nitrogen is to first vacuum out the air. To do this, a system was required with two connections: one going to a vacuum and one going to a nitrogen source, connected through a valve to switch between the two.

4.2.2.1 Setup

The filling system starts with a male connector with ¼” NPT threads connected to a steel braided hose with ¼” pipe ends. The steel braided hose is then connected to a ¼” three-way union, which is connected to a vacuum gauge. This is not a regular pressure gauge. The gauge is capable of reading pressures from -30 in. Hg to 30 psi, which can be seen in Figure IV-9. The ¼" three-way union is also connected to a three-way valve with a nylon handle through the common port. The other two ports, which can be switched back and forth, are connected to the nitrogen and vacuum source. The nitrogen source is connected through a steel braided hose with ¼" pipe ends and is regulated to 1 atm (14.7 psi) through a Swagelok regulator. The vacuum is created using a vacuum pump. The vacuum pump is connected using s standard vacuum hose with standard vacuum fitting. The vacuum hose is connected to the three-way valve through a metal sleeve that fits into the vacuum hose and screws into a large metal block with female ends that then connects to a male adaptor with 1" NPT threads and a ¼" pipe end.

Figure IV-9: Vacuum Gauge

4.2.2.2 Pressurizing System

The inflation system in RIGEX will only be pressurized to 1 atm (14.7psi) with nitrogen gas. To complete this task, the filling system will be connected to one of the fill valves on the inflation system of RIGEX. The three-way valve will be set with the opening to the vacuum source. The valve on the nitrogen tank will be opened. The three-way valve will be set to the nitrogen temporarily to flush the air out of the hose. The three-way valve will then be closed. The fill valve on the inflation system of RIGEX will be opened. The vacuum pump will then be turned on. The vacuum gauge will be used to monitor the vacuum in the setup. Once a sufficient vacuum is met, the three-way valve will be switched to the nitrogen source and then the vacuum pump will be turned off. When a pressure of 1 atm has been established with the nitrogen, the fill valve on the inflation system of RIGEX will be closed. The three-way valve will be switched back to the vacuum source. The filling system can then be disconnected from the fill valve and connected to the next fill valve on the inflation system. This process will be repeated until all three tanks are filled with nitrogen. After this is complete, the flight plugs will be inserted into the fill valves, adding a secondary method to contain the nitrogen should the fill valves fail.

4.2.3 Inflation System Performance Test

Once the inflation system onboard RIGEX is charged (1 atm of nitrogen), there will be an extensive amount of time before it is activated to inflate the tubes. While at approximately mean sea level (MSL) the system will not likely leak, due to the fact that it is pressurized to ambient conditions of 1 atm (14.7 psi). Once in space the inflation system will be under a vacuum and have much higher potential to leak. The inflation system will have to be able to wait several days in a vacuum before it is activated. During this time it is critical that the inflation system does not leak. In order to ensure that the inflation system onboard RIGEX complies, it must be tested in a vacuum before it is launched.

The inflation system on RIGEX was divided into two sections by Moeller. The first section was the storage section, which included the storage vessel and all the tubing before the solenoid valve. The second section was the inflation section, which consisted of the rigidizable inflatable tube and the stainless steel tubing after the solenoid. The nitrogen gas will be contained in the first section, from the solenoid back to the tank until the time of inflation. To test the inflation system from the solenoid to the tank, the pressure transducers already onboard will be used. The pressure transducers connected to the tanks will be rewired to connect to a wiring interface on a data acquisition system.

4.2.3.1 Test Setup

In order to effectively test the performance of the inflation system on RIGEX it must be placed under a vacuum since it is only charged to 1 atm. The entire RIGEX structure must be placed inside the Space Simulator Vacuum System. Once the RIGEX structure is placed on the platen inside the vacuum chamber, the wiring will be connected between the pressure transducers attached to the tanks, and the wiring connection interfaces inside the chamber. Outside the chamber, the wiring is connected between the wiring connection interfaces on the chamber and the wiring connection interface on the data acquisition system. This data acquisition system will be composed of the same setup with data logging to the computer configured with *LabVIEW*.

4.2.3.2 Inflation System Leak Test

In a similar fashion as seen in the previous section, the chamber door will be closed and sealed. Under mode three of system operations for the Space Simulator

Vacuum System, the roughing pump and turbo pump will be used to create a high vacuum. Controlling and monitoring these pumps will be done from a vacuum chamber overview screen on the operator interface enclosure. Once under a high vacuum, the pressure in the storage section can be monitored and recorded on the data logging computer. RIGEX must remain under a vacuum with continuous monitoring for at least 48 hours to ensure accurate results. If after 48 hours no pressure loss is recorded, the performance of the inflation system can be deemed successful. If a pressure loss is recorded, RIGEX must be removed from the chamber and inspected. After inspection and all repairs are made RIGEX will then be placed back under a vacuum and tested again.

4.3 Final Preparation and Testing Summary

For final preparation of RIGEX at AFIT, a TVAC testing process was selected, which can be seen in *RIGEX SPACE SIMLUATOR VACUUM SYSTEM COMPONENT TESTING (TP-03)*, located in Appendix C, Select components were tested in the Space Simulator Vacuum System following a survivable and operational temperature profile. All components proved to be successful except for the cameras. This was due to the failure of the memory cards, which were replaced with industrial grade components capable of meeting the temperature requirements set by NASA.

Also, for the final preparation of RIGEX at AFIT, a method of charging the inflation system was chosen, which can be seen in *RIGEX INFLATION SYSTEM NITROGEN FILLING PROCEDURE (RP-09)*. This procedure is detailed in Appendix

D. In addition, a course of action was determined for testing the inflation system on RIGEX for leaks, also described in Appendix D.

Even after these accomplishments, several tasks still remain to complete RIGEX. These tasks are discussed in the Chapter V.

V. Conclusion and Future of RIGEX

Over the course of the past year, the RIGEX team at AFIT has taken a design, finalized it, and produced a protoflight model. This was not a simple undertaking, but rather a taxing endeavor that encountered several complications along the way, which are discussed in this chapter. Each of these impediments had to be assessed and a solution determined and implemented. In the process, AFIT has acquired knowledge and equipment that will help with the development of future space payloads.

With the final RIGEX assembly almost complete, the project still faces many barriers. These include final TVAC testing, vibration testing, and electrical testing of RIGEX. Additionally, RIGEX must also bear the stress of numerous phases of transportation described in this chapter before it ever reaches the launch site.

5.1 Complications to Finalization of RIGEX at AFIT

During the final phases of completing RIGEX at AFIT, several complications arose. Some of these problems, such as the drawing package and the data imaging system, have been mentioned in Chapter III. AFIT encountered several other obstacles that have not yet been mentioned. Some include the poor accuracy of the aluminum parts that were manufactured at the AFIT machine shop, the incorrect treatment of the machine aluminum parts, and the determination of a new method for securing the seam of the shroud. In addition, a new method of torquing fasteners to RIGEX had to be determined, the integrity of the connection of the ribs to the experimental top plate was uncertain, and the first attempt to conformally coat the electrical components of RIGEX failed.

5.1.1 Fabrication of Aluminum Parts

The aluminum parts that make up the RIGEX structure and infrastructure were design by Gunn-Golkin in 2006. The aluminum parts were first fabricated by the AFIT machine shop. When a fit check was conducted, it was found that several of the fabricated parts did not fit. After discussion, it was decided that the parts needed to be remade. The parts were then contracted out to a local machine shop in the Dayton area with much more precise machinery that could manufacture the parts with accuracy to within thousandths of an inch. The parts include the four ribs, the experimental top plate, and the oven mounting plate.

5.1.2 Alodining and Anodizing

Alodining is a chemical application of a protective chromate conversion coating on aluminum [3]. The purpose of alodining is to provide good protection against corrosion even when scratched. When exposed to salt spray, untreated 2024 aluminum usually corrodes in less than 24 hours, but with alodining it can last 150 to 600 hours. Alodining also provides an excellent electrically conductive surface. The third purpose of alodining is to help promote the adhesion of paint. In some circumstances, it can be substituted as a primer [3]. Some benefits of alodining include adding no measurable weight and not altering the dimensions of parts. There is essentially no cleanup after application and there is no electricity or skill required to apply it. This makes the treatment of fabricated parts very simple. Some disadvantages of alodining are that two large tanks (which are capable of immersing the parts being treated) are required for the best possible job. Also, a temperature of 21°C must be kept for treatment and an alodined surface is not as durable as an anodized or painted part [3].

Anodizing is an electrochemical process that thickens and toughens the naturally occurring protective oxide of aluminum [1]. The main purpose of anodizing is to provide a protective layer over machined aluminum parts against corrosion. Anodizing is also used to harden the exterior of aluminum parts. In addition, anodizing provides an electrical insulation to aluminum parts. Some of the benefits of anodizing include its durability. Anodizing is a reacted finish with an underlying aluminum that has an incredible adhesion, thus giving increased longevity. Anodizing is stable. It is a non-toxic, heat-resistant, chemically safe finish that provides stability to ultraviolet rays and does not chip or peel. Anodizing is also aesthetically pleasing. It can be produced in several colors and produces a surface that is very easy to clean [1]. Some disadvantages include the added dimensions to parts that are treated. Anodizing is a chemical treatment that sinks into the metal and also increases the thickness of a part. Anodizing is very difficult to reverse. Once treated, the best method of removal is to physically remove the layering by aggressive sanding or grinding.

Every aluminum part of the RIGEX structure and infrastructure had to be alodined. After alodining, some parts were anodized as well. Any area on the aluminum parts that was intended to be in contact with another part was treated with alodine only to help promote conductivity throughout the structure. Other areas of each aluminum part were anodized to help protect them from scratches during installation and subsequent corrosion while RIGEX awaits launch.

TechMetals, a local company in the Dayton area that specializes in engineered metal finishes, was chosen for the task of treating the fabricated aluminum parts. All the aluminum parts to be treated were taken to TechMetals with detailed instructions.

When the aluminum parts were brought back to AFIT for inspection, there were areas on some of the aluminum parts that were treated incorrectly. Two of the ribs had edges that were anodized when they were only to be alodined. The small rib with a pin puller has 5 of its 6 edges anodized by mistake. The edge that contacts the experimental top plate, the edge that contacts the shroud, the two edges that contact the oven mounting plate and the edge that contacts the bottom rectangular plate. The large rib also had 5 of its 6 edges anodized by mistake. The edge that contacts the experimental top plate, the edge that contacts the small rib with a pin puller, the edge that contacts the bottom rectangular plate, and the two edges that contact the oven mounting plate had errors. These anodizing mistakes are annotated in Figure V-1. The dark black lines represent the edges that were anodized by mistake. The yellow lines show the inner alodine-to-alodine connections between parts.

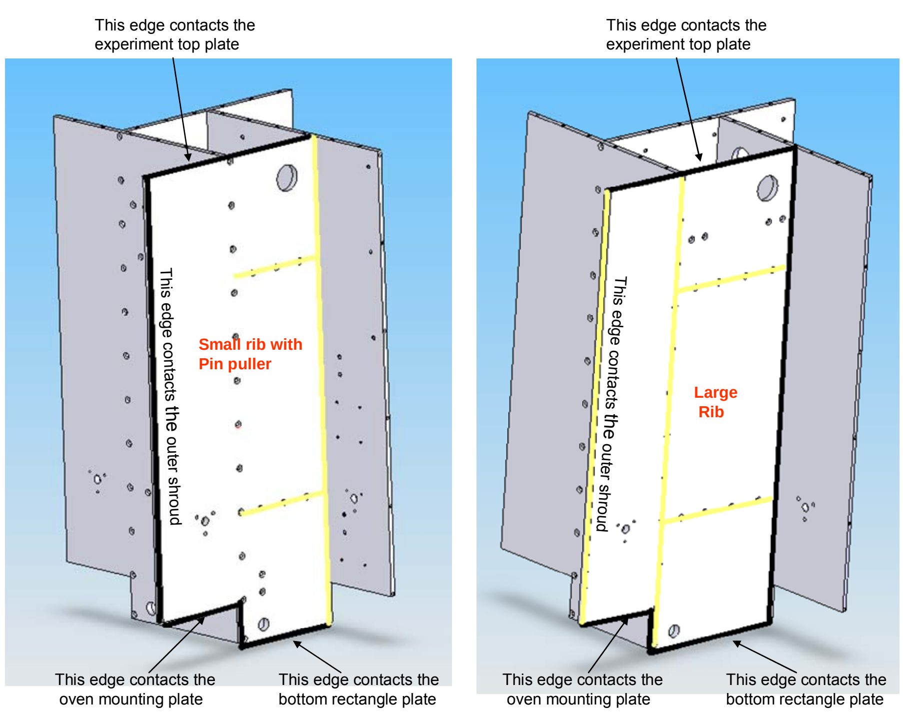


Figure V-1: Anodizing Mistakes

There were few options as to how to treat this problem. One was to remake the ribs that were incorrectly treated, which would be time consuming and costly. Another option was to attempt to remove the anodizing using a grinder or mill. This method would end up altering the dimensions of the ribs and putting the structure of RIGEX out of tolerances. The third option, which was the simplest and most cost efficient, was to leave the ribs is as, and to simply conduct a resistance test between the ribs. There must be a sufficient conduction throughout the structure for grounding to occur, and this can be determined with an Ohm meter. This method that was finally chosen and the ribs found to have a low resistance, proving that the ground was well conducted through the other connections in the ribs.

5.1.3 Shroud

As previously mentioned in Chapter III, the shroud had to be modified. After the first design was fabricated, it was tested. This led to the discovery that the two fasteners securing the seam of the shroud protruded too far past the static envelop of CAPE. In fact they extended even past the Delrin bumpers. The solution was to cut the shroud so that it did not overlap. After this cut was made, a new method of securing the seam had to be determined. One idea was to attach the shroud with the seam located over one of the ribs. In order for this to be possible, the seam had to be cut in a zigzag pattern, alternating after each hole along the rib. This idea is demonstrated in Figure V-2. This method of attachment was never implemented.

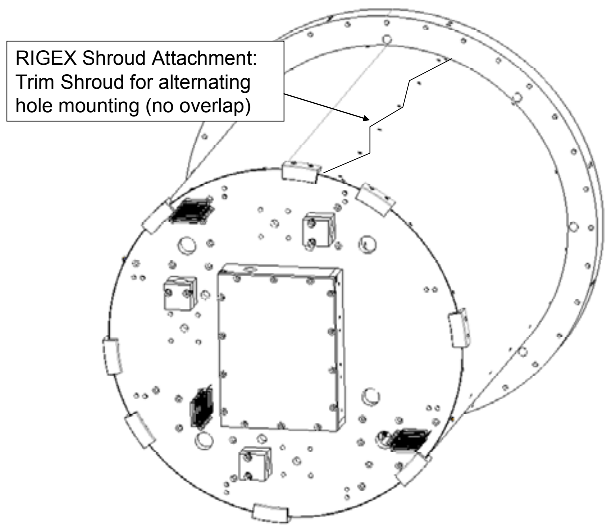


Figure V-2: Zigzag Approach for Attaching Shroud

The method of attachment that was finally chosen consisted of six aluminum blocks curved to the inner diameter placed along the seam. The location of these blocks can be seen in Figure V-3. Each of these curved aluminum blocks had two heli-coiled holes for the button head screws on each side of the seam, which can be seen in Figure V-3. For these blocks to effectively connect the two sides of the joint on the shroud, the seam must be cut straight with the six holes equally spaced on each side. The finished product of this design can be seen in Figure V-4.

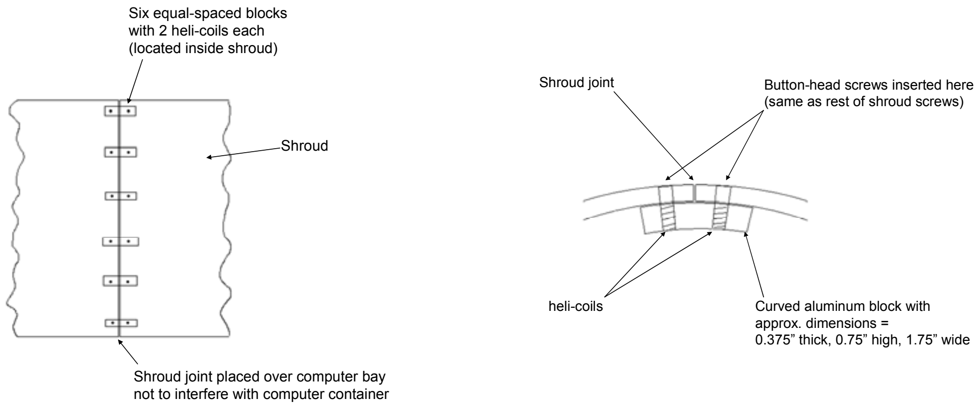


Figure V-3: Shroud Joint Concept

Figure V-4: Final Design of Seam

Another issue that was not previously addressed was the attachment of the shroud to the ribs. The ribs did not mate with the shroud in a perpendicular manner so that when the button head screws were tightened, they were placed under a bending load. This concept can be seen in Figure V-5. This would ultimately lead the head of the screws shearing off. To solve this dilemma new triangular washers were custom made at the AFIT machine shop. An illustration of these washers in use is displayed in Figure V-6.

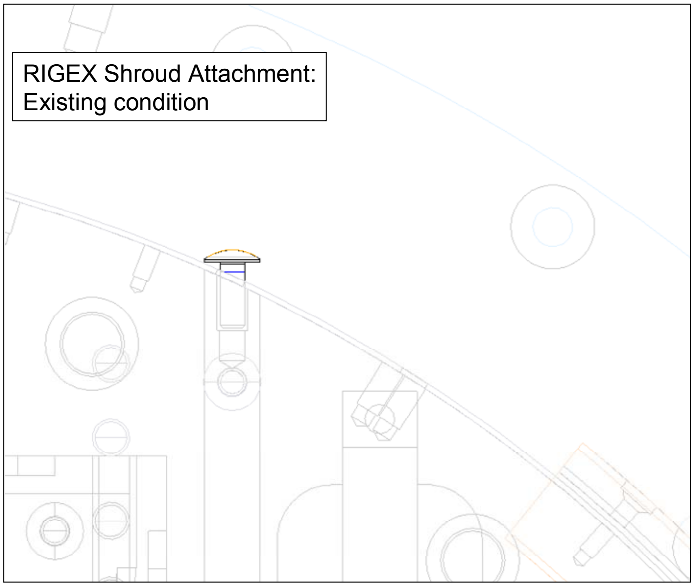


Figure V-5: Old Concept of Shroud Attachment

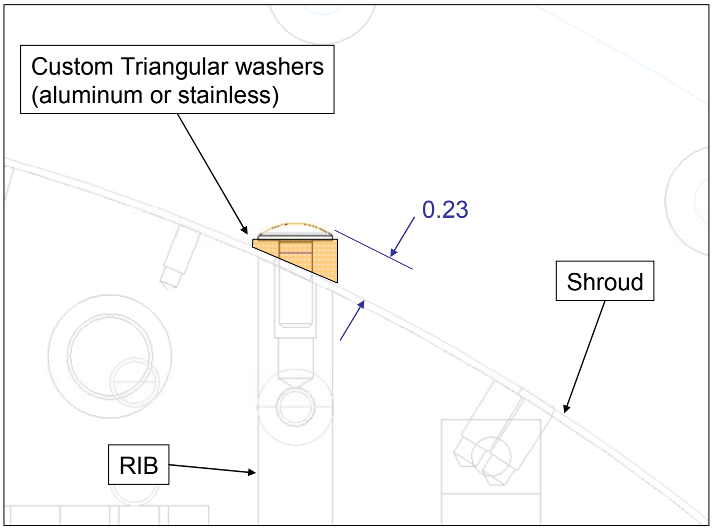


Figure V-6: Triangular Washers

5.1.4 Torquing Fasteners

When the assembly of wave one began, a complication arose with tightening the fasteners that connected the ribs together. The fasteners used were countersunk #2 Phillips screws. A torque wrench with a #2 Phillips bit was used to measure the precise amount of force applied to each fastener. After tightening down only a few of the fasteners the bits started failing. These bits either started to twist out of shape or shear off. After the replacement of several bits the method of tightening the fasteners was reanalyzed. It was found that by applying more force to the center of the toque wrench while turning, the bits would function without failing for a dramatically longer period. An image of the fasteners being tightened down with more force being exerted on the center of the torque wrench can be seen in Figure V-7.

Figure V-7: Tightening Fasteners with Torque Wrench

5.1.5 Fasteners to Experimental Top Plate

The entire structure of RIGEX is connected using several different types of fasteners that were selected by Gunn-Golkin in 2006 for their different tensile strengths. After thorough analysis from STP, is was found that two fasteners that connect RIGEX to the experimental top plate were in a negative margin, meaning the two joints could possibly fail by shearing the threads from the aluminum and pulling out of the rib. This would lead to a critical failure in flight that would be unacceptable.

Several solutions to this problem were presented. One idea was to drill and tap more holes in the ribs connecting RIGEX to the experimental top plate. Another idea was to create a clearance hole and add a locknut to the critical fasteners. The solution that was finally chosen entailed the replacement of the countersunk fasteners with longer counter bored socket head cap screws with special countersunk washers. The replacement was chosen for all the fasteners that connect the ribs to the experimental top. This eventually created another problem with the experimental top plate. Increasing the diameter of the counter bore in the holes in the experimental top plate near the inner rectangular cut-out meant that it would protrude beyond the edge. In doing this, there would be a sharp edge created where each of these counter bores overlap the inner edge of the experimental top plate. The location of these counter bores is pointed out in Figure V-8.

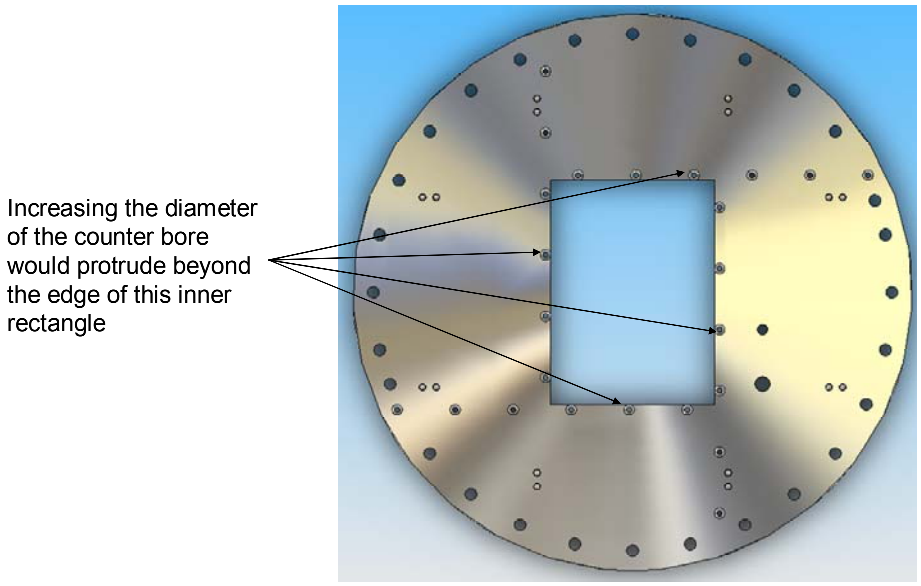


Figure V-8: Location of Counter Bores On Experimental Top Plate

The solution to this problem was to open the counter bores all the way to the edge. This idea is illustrated in Figure V-9. By extending the counter bore for its entire diameter all the way to the edge, the sharp edge was eliminated.

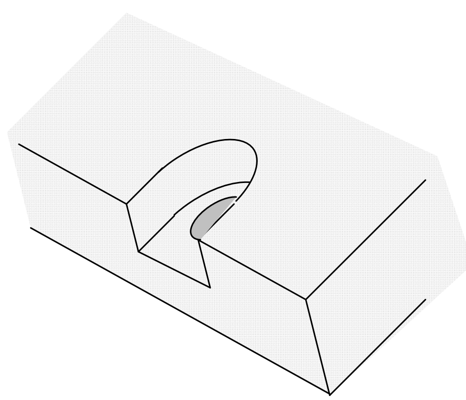


Figure V-9: Counter Bore Near Edge

5.1.6 Conformal Coating of Electrical Components

In accordance with STP all electrical components had to be conformal coated to reduce the chance of outgassing. The conformal coating is a special epoxy based coating that is comprised of a resin and hardener designed specifically for electrical applications. When the correct portions are weighed and mixed together, the compound has a time window for applying before it cures. When the compound cures, a rubberized coating is left on the applied product, providing effective electrical insulation. After storage, the hardener partially crystallizes and it was recommended by the manufacturer to heat the hardener to dissolve these crystals. Caution to not overheat (above 50^{o}C) is advertised due to a possible explosion. Because of this possible risk, the first batch of conformal coating was made by extracting some of the hardener with a syringe that was then heated in a beaker. It was then mixed with resin and applied to the electrical components. Images of the conformal coating being applied to the electrical components of RIGEX can be seen in Figure V-10. After several days of curing, the conformal coating still had not set. This phenomenon was realized later to be a result of improper mixing. The heating of the hardener is required for the entire container to thoroughly mix the ingredients. Still exercising caution against an explosion, a second batch was made by warming the hardener through conduction from hot water. This was first tested on a sample specimen. When this batched proved to be successful, the rest of the electrical components were recoated after the old conformal coating was meticulously removed.

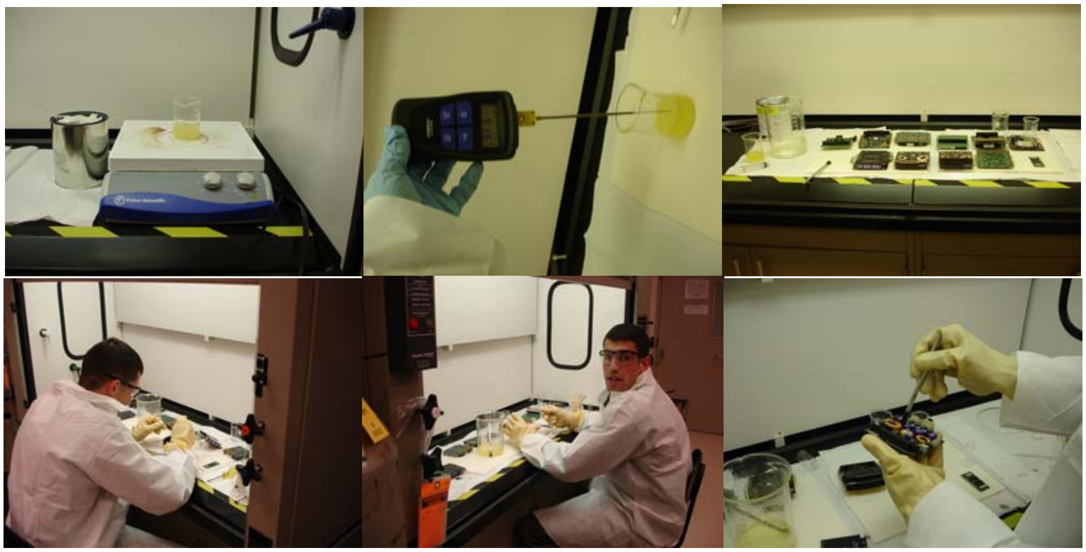


Figure V-10: Applying Conformal Coating

5.2 Final Testing of RIGEX

RIGEX is expected to launch in payload bay 13 on Space Shuttle flight (STS) 123. This will be the twenty-fifth space shuttle mission to visit the International Space Station (ISS). The current launch date for this mission is February 2008, but this possibly will change to January 2008 due to an ISS requirement. The Endeavor, which is the space shuttle expected to be used for this mission, will deliver Kibo, the first Japanese Logistics Module, and Dextre, the Canadian robotics system, to the ISS [22]. In order for RIGEX to fly on this mission, several tests must still be conducted at AFIT and Johnson Space Center (JSC).

5.2.1 Final TVAC Testing of Entire RIGEX Assembly

Before RIGEX can be packed up and shipped to JSC for testing, it must still go through more testing at AFIT. Just as the individual components of RIGEX were tested in the TVAC chamber, the final assembly of RIGEX has to be tested as well. RIGEX must be placed under the same conditions in the TVAC chamber and a full test run must be performed to ensure the overall performance of the experiment. Once this test is performed with successful results, RIGEX can be packed and sent to JSC for final testing.

5.2.2 Vibration Testing at JSC

RIGEX must be shipped to JSC for its final testing before flight. RIGEX is expected to sit for several months during shuttle preparations before for it is actually launched into space, followed by a violent launch phase. To ensure that RIGEX is fit for launch, it must go through dynamic environmental testing, as expressed in NASA document NSTS 37329, Rev. B. NASA document NSTS 37329, Rev. B states that, "as a part of the Space Shuttle Program (SSP) cargo element (CE) integration process, a series of structural analyses will be performed to verify the structural compatibility of the CE with the Orbiter and with other CEs in the cargo bay manifest[23]."

As stated by O'Neal in *DEVELOPMENT AND TESTING OF THE RIGIDIZABLE INFLATABLE GET-AWAY-SPECIAL EXPERIMENT*, vibration testing for RIGEX will take place at the Vibroacoustic Test Facility (VATF), Building 49, at JSC in Houston, TX. The RIGEX Vibration Test Plan was developed by the RIGEX Payload Integration Engineer, Taylor Carson [32]. A copy of this document is provided in Appendix E. The document provides the particulars of how vibration testing will be conducted for the RIGEX payload, which consist of the RIGEX assembly mounted inside the CAPE assembly. The CAPE-RIGEX assembly will be mounted in payload bay 13 of the orbiter on the starboard side on a Small Payload Accommodation (SPA) Beam. Vibration testing will be conducted with the CAPE-RIGEX assembly attached to a surface that will effectively simulate the SPA Beam [32]. The intent of this dynamic environment testing is to qualify the Cape-RIGEX for flight. Every effort will made to perform the vibration testing with the CAPE-RIGEX assembly as similar to flight as possible. There will be two distinct differences between the flight and testing. The pigtail cables for flight will not be installed, rather Ground Support Equipment (GSE) cables, which will be fastened with a p-clamp, will be used instead. The three composite sub-T_g tubes used in testing will be identical but not the same tubes used for flight.

5.2.2.1 Random Vibration Environment

Dynamic environmental testing consists of the following parts: a random vibration test and two structural stiffness tests; one before and after the random vibration test. The random vibration test simulates the random vibrations experienced during launch by varying the excitation frequencies over prescribed ranges of input frequencies. The maximum expected flight level (MEFL), which was determined from NASA document NSTS 21000-IDD-SML; to be used for random vibration testing is 6.8 Grms [32]. The CAPE-RIGEX assembly will undergo random vibration testing for each axis. The protoflight vibration test (PVT) levels for the CAPE-RIGEX assembly are displayed in Table V-1. These PVT test levels include specific levels of random vibration that the CAPE-RIGEX assembly will experience in each axial direction, also known as the auto spectral density (ASD).

Table V-1: Random Vibration Test Levels [32]

X-Axis	
FREQ (Hz)	**ASD (G^2/Hz)**
20.00	**0.010000**
80.00	**0.040000**
500.00	**0.040000**
2000.00	**0.010000**
Y-Axis	
FREQ (Hz)	**ASD (G^2/Hz)**
20.00	**0.010000**
45.00	**0.060000**
600.00	**0.060000**
2000.00	**0.010000**
Z-Axis	
FREQ (Hz)	**ASD (G^2/Hz)**
20.00	**0.010000**
70.00	**0.050000**
600.00	**0.050000**
2000.00	**0.010000**

5.2.2.2 Structural Stiffness Verification (Sine Sweep Test)

Structural Stiffness Verification tests, as reported in *DEVELOPMENT AND TESTING OF THE RIGIDIZABLE INFLATABLE GET-AWAY-SPECIAL EXPERIMENT* by O'Neal, will be done before and after each random vibration test to verify no damage has occurred. These tests are also known as sine sweep tests. The first sine sweep test is performed three times, once in each axial direction. In this test the natural frequency of the CAPE-RIGEX assembly will be determined, which is expected to be above 35 Hz. The sine sweep test results will also be used to create frequency response data. This data can be thought of as the payload's fingerprint. After the CAPE-RIGEX assembly completes the random vibration test a second sine sweep test will be conducted. The data collected during this second sine sweep test will also be used to create frequency response data, a second payload fingerprint. The fingerprints of the first and second sine sweep tests are compared to determine if the payload has endured the random vibration levels to which it was subjected and has survived.

5.2.2.3 Instrumentation Locations

Data from these tests will be collected through the use of a series of accelerometers installed on the CAPE-RIGEX assembly at several locations. Both tri-axial and single axis accelerometers will be used. The placement of these accelerometers can be seen in Figure V-11. The tri-axial accelerometers are shown as red circles and the single axis accelerometers are shown as blue triangles. The most critical accelerometers will be #6 and #7, which will be located on the oven mounting plate where the cantilever effect will be greatest.

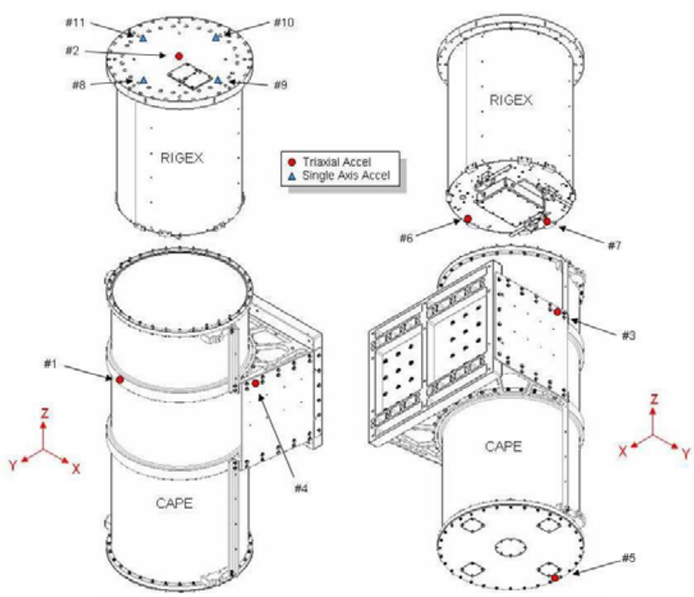


Figure V-11: Instrumentation Locations [32]

5.2.3 EMI Testing

The performance of electrical systems or equipment can be severely degraded due to unwanted signals that are either conducted or radiated from another electrical source. This is more commonly known as electromagnetic interference (EMI). "Electromagnetic compatibility (EMC) is the ability of systems to function as designed, without malfunction or unacceptable degradation of performance due to EMI within their operational environment. Any electrical, electromechanical, or electronic equipment must not adversely affect the performance of any other equipment or system as a result of EMI and vice versa [34]."

The electrical systems onboard RIGEX must comply with the EMC standards set forth in the NASA document SL-E-0002-BOOK 3, Vol. 1. Not only can EMI generated by electrical systems onboard RIGEX affect the performance of RIGEX itself, but the electrical systems involved with the shuttle as well. This could result in a complete mission failure. To ensure safe and dependable system performance of the electrical components on RIGEX, it will undergo EMI testing at JSC.

5.3 Transportation of RIGEX

To facilitate a successful testing of RIGEX, several details had to be addressed. Through weekly teleconferences between AFIT and STP, the fine points of the ground flow plan for RIGEX at JSC were decided. This ground flow plan includes how RIGEX will be received, processed, and tested at JSC, more specifically the movement of RIGEX during these phases. A flow chart of the ground flow for RIGEX during the vibration testing is illustrated in Figure V-12. Upon arrival at JSC, RIGEX will be unpacked and the ground cables will be installed. A post-ship FVT will be conducted before sending to the VATF. At the VATF a pre-vibe FVT will be performed. RIGEX will then be placed in CAPE for the vibe testing. After a successful vibe test a post-vibe functional test will be performed. RIGEX will then be transported to the EMI test facility.

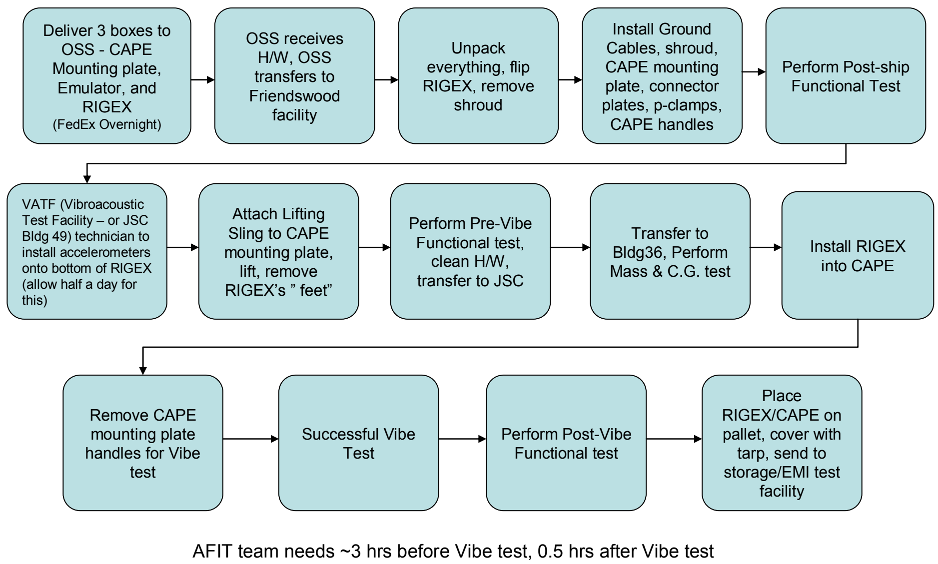


Figure V-12: Ground Flow of RIGEX at Vibe Facility

When RIGEX arrives at the EMI test facility a pre-EMI functional test will be performed. RIGEX will then be placed in the EMI chamber and the EMI test will be carried out. If RIGEX passes the EMI test, it will be removed from the chamber, packed and shipped back to AFIT. If RIGEX does not pass, it will be reset and tested again. A flow chart of these steps is shown in Figure V-13.

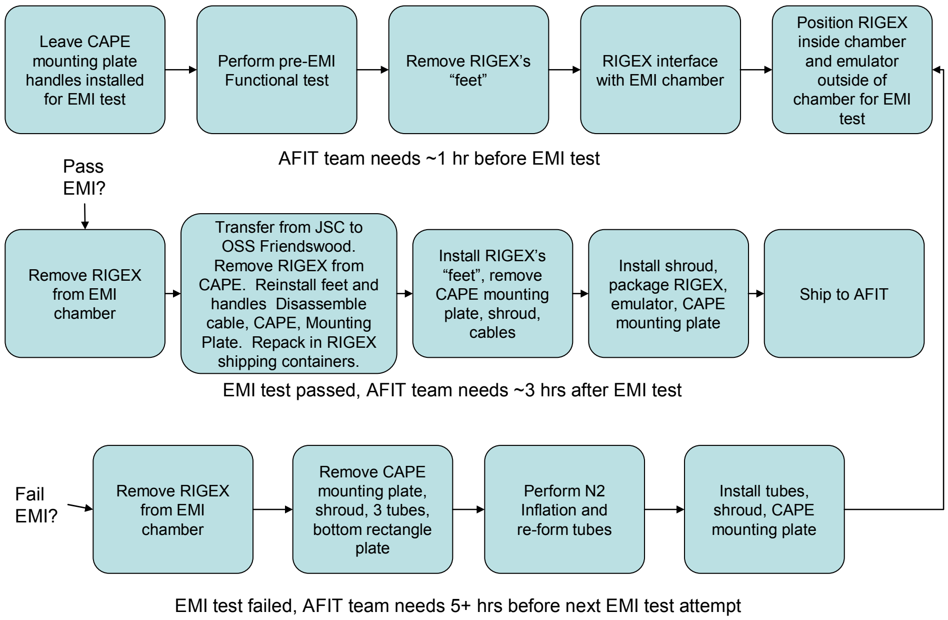


Figure V-13: Ground Flow for RIGEX at EMI Facility

Through the same manner AFIT and STP determined the details of the ground flow for RIGEX at the Kennedy Space Center (KSC) through numerous teleconferences. A ground flow plan was establish for prior to and after launch. A flow chart of the pre-launch ground flow for RIGEX at KSC can be seen in Figure V-14. Each step is color coded to indicate the responsibility of each task. Upon arrival, all three shipping containers will be opened and RIGEX will be assembled. This is followed by an overall inspection of the interior and exterior RIGEX. The flight cables will be installed and a post-ship FVT will be performed. After this RIGEX will be cleaned, photographed and prepared for integration into CAPE. Once in CAPE the wiring will be routed and a second FVT will follow. After this, the CAPE-RIGE assembly will be cleaned again, photographed and wrapped in Kapton. The CAPE-RIGEX assembly will then be installed in the payload bay of the orbiter on the SPA beam. A final electrical test and IVT will complete the ground flow for RIGEX at KSC before flight.

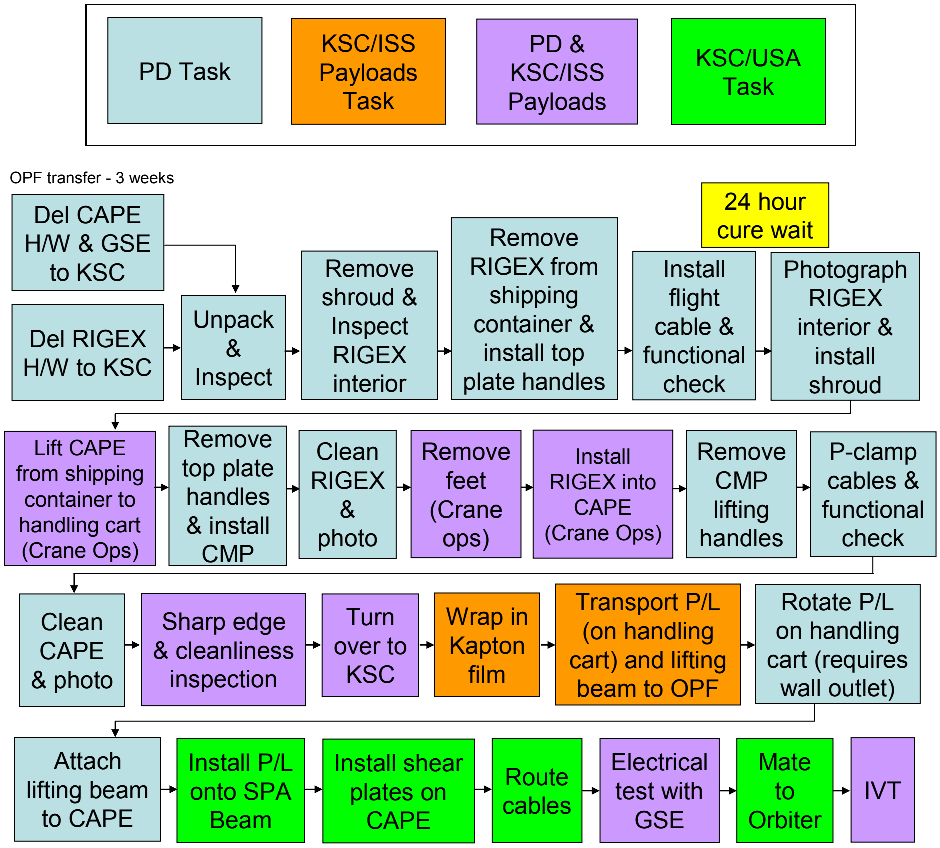


Figure V-14: Pre-Flight Ground Flow of RIGEX at KSC

Following the return of the orbiter, RIGEX will undergo several phases of the post-flight ground flow at KSC. A flow chart of the phases is shown in Figure V-15. RIGEX will be disconnected and removed from the orbiter. The CAPE-RIGEX assembly will then be inspected and photographed. RIGEX will then be detached and removed from CAPE. Following this, the interior and exterior of RIGEX will be inspected and photographed. The flight cables and memory cards on the cameras will be removed. Finally RIGEX will be packed and shipped back to AFIT for analysis of data.

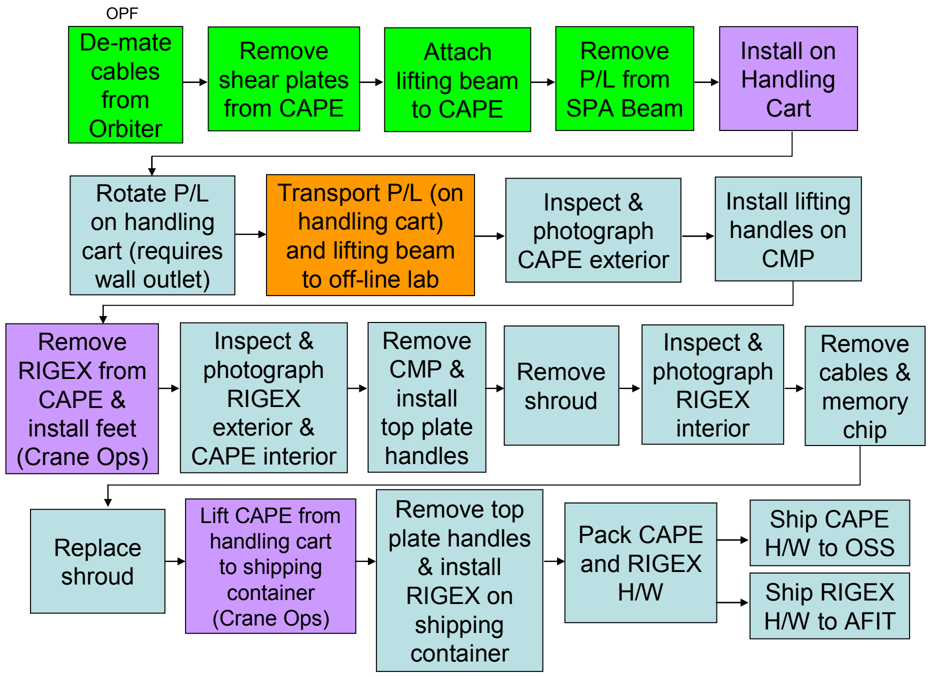


Figure V-15: Post-Flight Ground Flow of RIGEX at KSC

5.3.1 Shipping Containers

RIGEX will be shipped in three separate containers to JSC and KSC. The shuttle emulator will be shipped in a wooden crate with an inner dimensions of 25” long, 25” wide and 8.5” high capable of supporting 25 lbs. The CAPE mounting plate along with the lifting handles, wiring cover plates and bolts connecting CAPE mounting plate to the experimental top plate of RIGEX will be shipped in a wooden crate with an inner dimensions of 25” long, 25” wide and 2” high capable of supporting 70 lbs. A schematic of these shipping containers is displayed in Figure V-16.

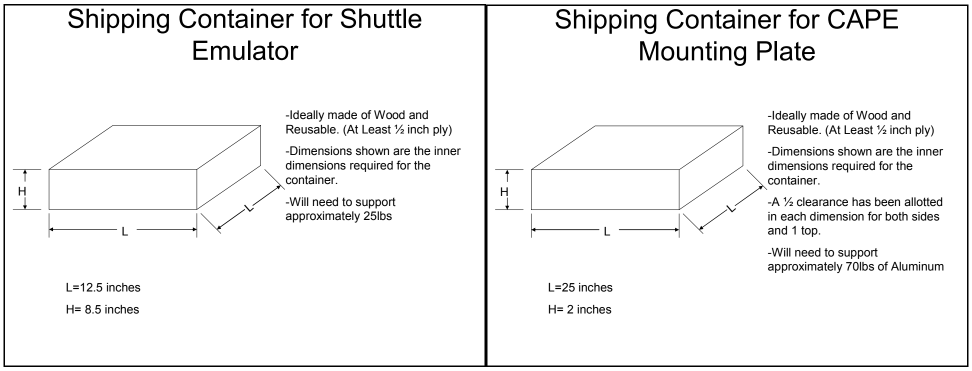


Figure V-16: Wooden Crate Specifications for Emulator and CAPE Mounting Plate

To pass the Air Transportation Association (ASA) criteria and meet the pertinent MIL-STD 810 specifications, the RIGEX assembly will be shipped in a third container. This clam shell type container is custom made by Keal Cases Inc. The exterior shell is a tough, durable, structural resin laminated to a base material called ArmorCell. The ArmorCell exterior is secured by a frame work composed of 6063 aluminum alloy [14]. The interior is lined with foam to account for load and shock absorption requirements, which can be seen in Figure V-17. The case is comprised of two upper panels and a foundation with a removable inner floor substructure. The bottom of the container also has swivel casters to allow for RIGEX to be easily relocated without lifting. A layout of the base of the container with this inner floor substructure is displayed in Figure V-18. The inner floor is connected to the bottom of the shipping container with four large hex bolts. This inner floor will also be secured to the experimental top plate of RIGEX while it is in its inverted position during shipment. This inner floor will be coated with Kapton to prevent contamination to RIGEX during shipment. Between the inner floor substructure and the base of the shipping container are four large polyurethane donuts. These polyurethane donuts make up the internal suspension system on the container to provide additional protection to RIGEX during shipment. All three outer sections of the case secure together with standard recessed spring-loaded twist latches. These latches are constructed of steel and are placed at critical closure points. This provides maximum torque upon closure to prevent accidental opening during shipment [14].

Figure V-17: Interior of Keal Case

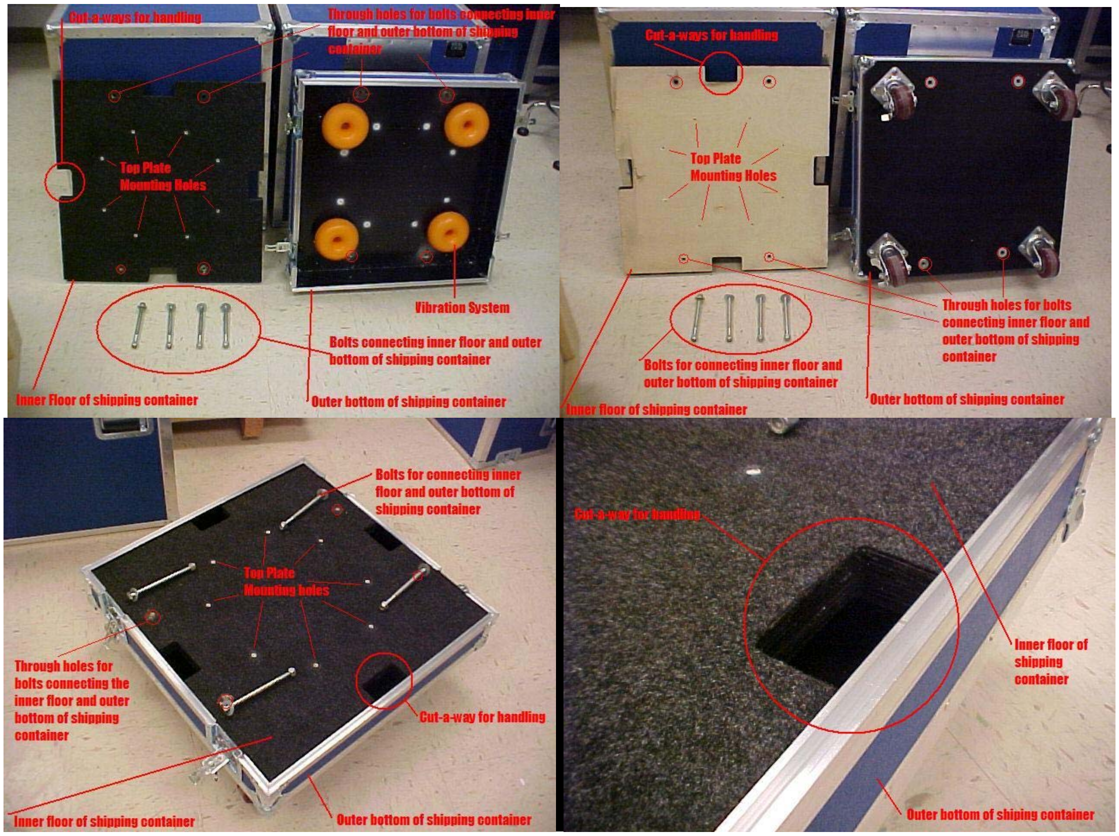


Figure V-18: Schematic of Base of Keal Case with Inner Floor Substructure

There is a large gap between the bottom of the shipping container and the inner floor; this is partially due to the required clearance for the internal suspension system. Even after accounting for this clearance there is ample space to provide a location for additional components to be shipped. This is where the pigtail cables, the lifting handles for the experimental top plate, the fasteners for the lifting handles, and the additional fasteners for the shroud will be located.

5.3.2 Handling of RIGEX

RIGEX will undergo several phases throughout the transportation and handling in which it will be configured differently. During shipment of RIGEX, it will be inverted in the Keal case and the feet will remain on the oven mounting plate. When RIGEX arrives at its destination, several steps must be followed in order to prepare it for integration into CAPE. These steps are illustrated in Figure V-19 and are explained in detail within the *RIGEX HANDLING PROCEDURE (RP-08)* located in Appendix F. First, the upper panels must be removed followed by the shroud. Then the bolts securing the inner floor substructure are to be removed as well. RIGEX can then be lifted with web straps attached to the feet on the oven mounting plate. In order to flip RIGEX, the inner floor substructure must be removed. To do this, RIGEX is to be lowered onto a block or structure that will provide enough clearance to reach underneath and safely remove the fasteners holding the inner floor substructure to the experimental top plate of RIGEX. Once this is complete RIGEX can then be lifted and placed on an approved rubber mat. Using one web strap attached to a foot along with the assistance of two AFIT personnel, RIGEX can be gracefully laid on its side. At this time the lifting handles can be attached to the experimental top plate of RIGEX. Using the same approach with one web strap now attached to the uppermost lifting handle and two AFIT personnel assisting, RIGEX can be placed right side up. Once RIGEX is right side up the lifting handles can be removed. The pigtail cables can then be fitted through the experimental top plate attached to the PDP. At this point the CAPE mounting plate can be attached to the experimental top plate followed by the wiring cover plates and lifting handles for the CAPE mounting plate. In this configuration RIGEX can now be attached to the lifting sling and placed in its appropriate location for storage. If RIGEX is ready to be integrated into CAPE, it must first be lifted and placed on a block or structure to provide sufficient clearance to safely remove the feet on the oven mounting plate. Once these feet are removed, RIGEX is ready for placement in CAPE.

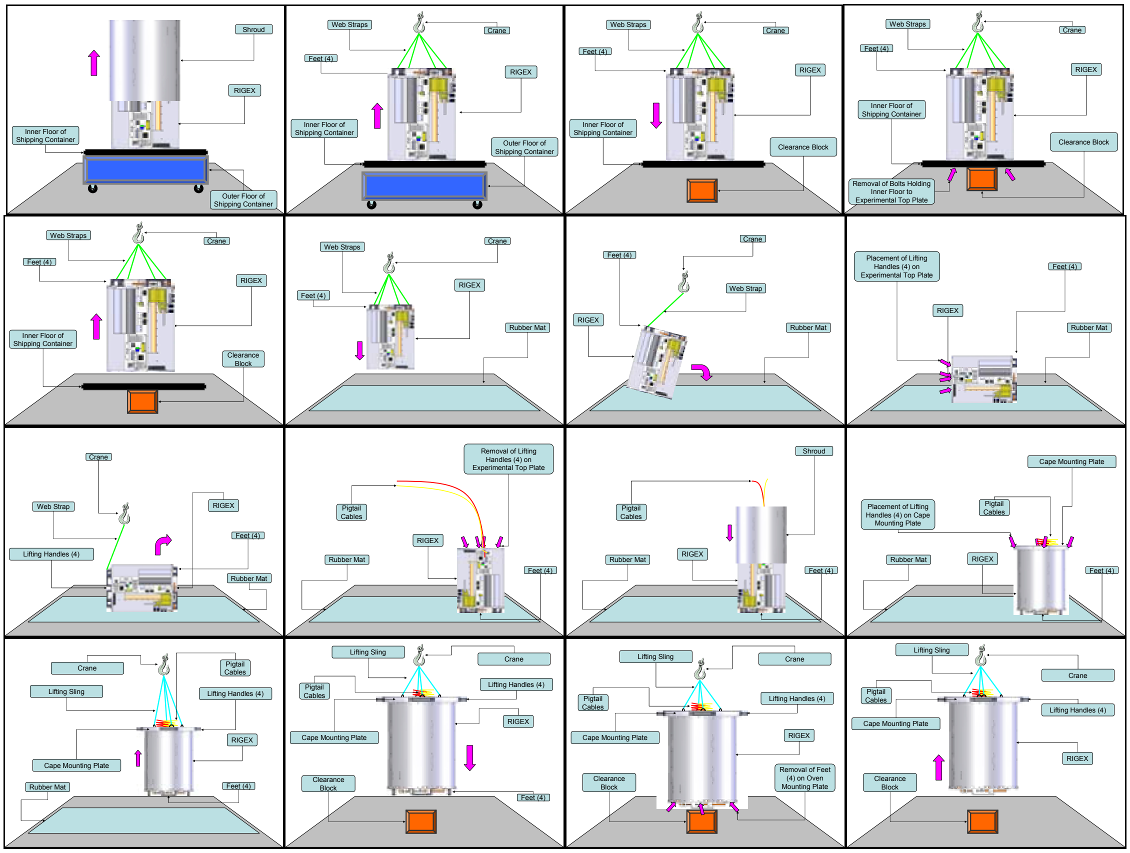


Figure V-19: Unpacking of RIGEX

When RIGEX has been tested or returned from flight, it must yet again go through several steps to be prepared for packing in the Keal case so it can be shipped back to AFIT. A detailed illustration of these steps can be seen in Figure V-20 and further explained in Appendix F. If the feet are not installed on the oven mounting plate, this task must be completed first. To do this, RIGEX needs to be placed on a block or structure that will provide enough clearance to safely attach the feet to the oven mounting plate. After the feet are attached to the oven mounting plate RIGEX can be lifted and placed on the rubber mat. Then the CAPE mounting plate can be removed along with the lifting handles and wiring cover plates. Once the CAPE mounting plate is detached from the experimental top plate, the shroud can be separated and removed from RIGEX. Following this, the pigtail cables can be disconnected from the PDP and removed. RIGEX must be flipped back to an inverted position in order to be placed in the shipping container. To accomplish this, the lifting handles must be attached first to the experimental top plate. Then using one web strap attached to a lifting handle on the experimental top plate and with two AFIT personnel assisting, RIGEX can be carefully laid on its side just as before. Before flipping RIGEX upside down, the lifting handles on the experimental top plate need to be attached. In a similar fashion using a web strap attached to the uppermost foot on the oven mounting plate, two AFIT personnel will lift RIGEX to an inverted position. Attaching the rest of the web straps to the remaining feet on the oven mounting plate, RIGEX can then be lifted and placed on a block or structure with the inner floor substructure of the shipping container centered on top. This block or structure must provide sufficient clearance to safely reach under the inner floor and reattach the fasteners securing it to the experimental top plate. Before returning RIGEX in the shipping container, the pigtail cables, lifting handles for the experimental top plate, and shroud fasteners must be placed in the bottom. Once the inner floor is securely fastened and the extra components are situated in the base of the shipping container, RIGEX can be lifted and set on top of the suspension system located inside the case. The shroud can then be slid back over RIGEX and secured with a few fasteners to prevent it from shifting during shipment. After this the upper panels of the Keal case can be returned and the latches can be tightened down.

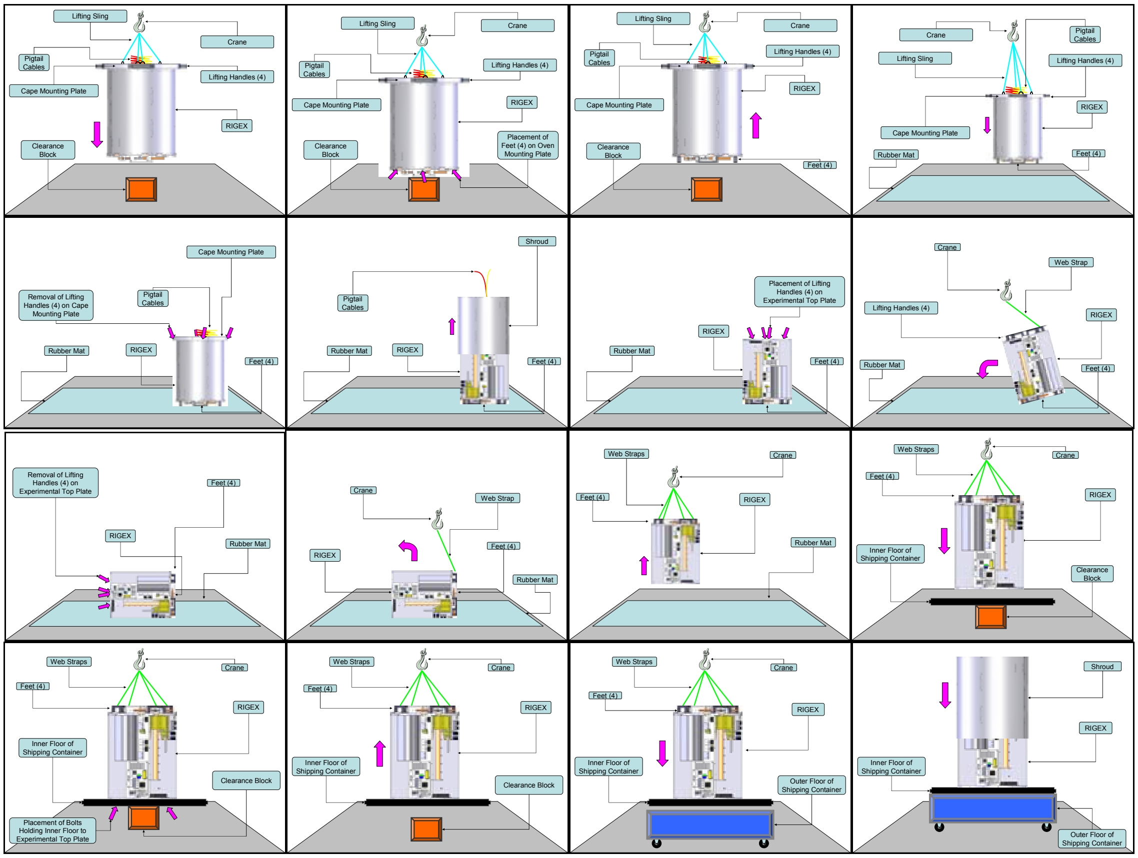


Figure V-20: Packing of RIGEX

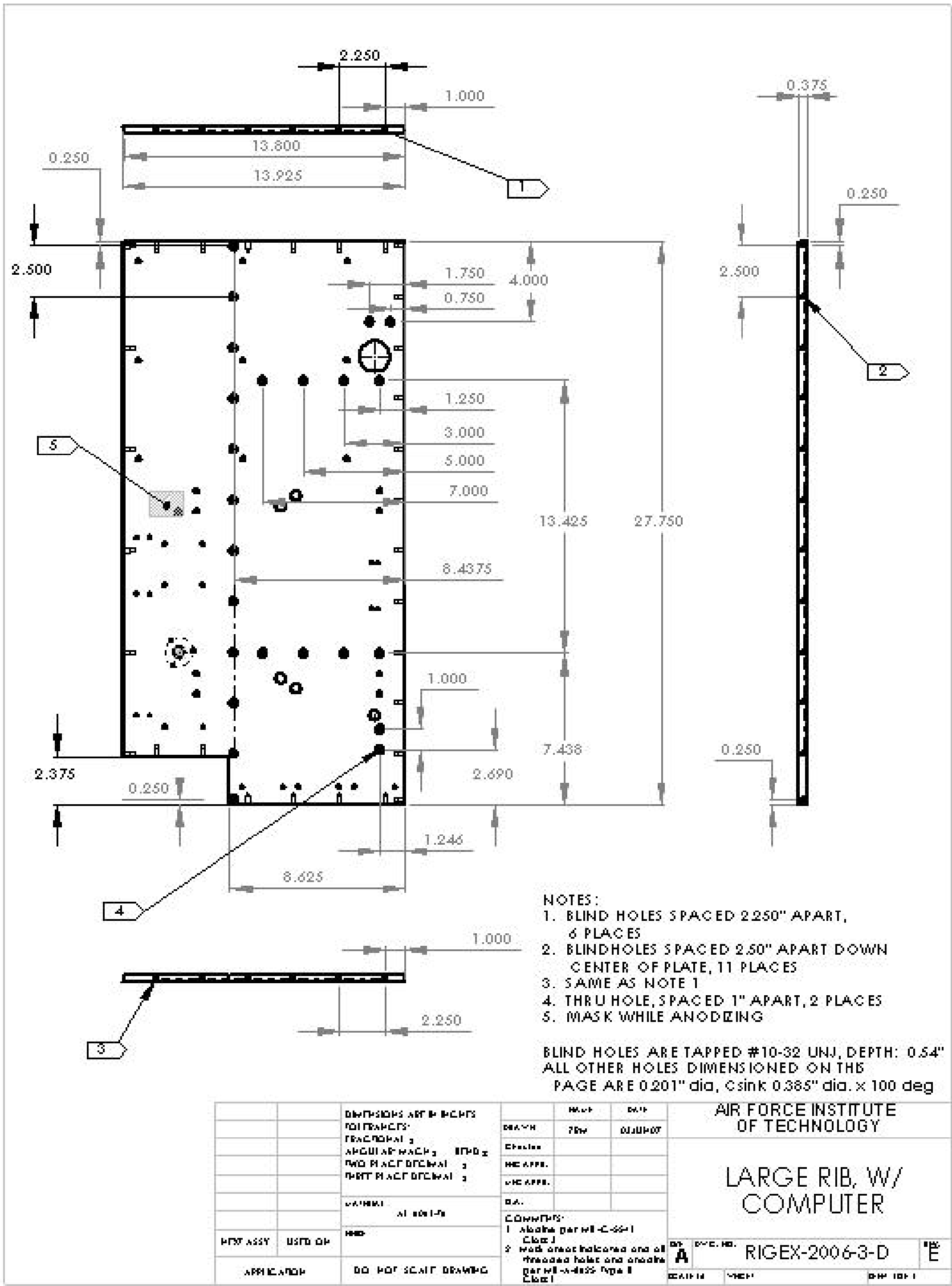
5.4 Discussion and Future Summary

It is probable that RIGEX will successfully pass all of the requirements of space qualification testing and survive all the stages of transportation. In the event of a test failure or damage in shipment, RIGEX will be returned to AFIT for analysis of the failure or damage. RIGEX will then either be retested, repaired or the design will be modified again. Passing all the testing required for space flight qualification will ensure the continued existence of the RIGEX program and provide a reassurance of launch.

The development of RIGEX, despite taking longer than expected, has provided future AFIT students with many opportunities to gain knowledge and experience by designing, building, testing and finalizing RIGEX at AFIT. With RIGEX nearing completion, the project still faces many challenges. It is also important to note that through the course of this year, the RIGEX team at AFIT has overcome numerous trials and tribulations. RIGEX has laid the anchor for official space qualification testing and launching for AFIT, which has developed into a dexterous facility, capable of designing, constructing and testing future space payloads.

Appendix A: Top Level Assembly Drawing Package

WAVE1	RIGEX-WAVE1-P	RIGEX-WAVE1-D		
QUANTITY	**PART OR IDENTIFICATION #**	**DRAWING #**	**NOMENCLATURE OR DECRIPTION**	**MATERIAL**
1	RIGEX-2006-3-P	RIGEX-2006-3-D	Large Computer Rib	Al
1	RIGEX-2006-4-P	RIGEX-2006-4-D	Large Rib	Al
1	RIGEX-2006-5-P	RIGEX-2006-5-D	Small Rib w/ Pin Puller	Al
1	RIGEX-2006-6-P	RIGEX-2006-6-D	Small Rib w/o Pin Puller	Al
1	RIGEX-2006-7-P	RIGEX-2006-7-D	Oven Mounting Plate	Al
1	RIGEX-2006-8-P	RIGEX-2006-8-D	Bottom Rectangle Plate	Al
6	##	N/A	Pressure Transducer	SS
3	##	N/A	N2 Pressure Tank	SS
3	##	N/A	1/4" MNPT to 1/4" tube fitting	SS
3	##	N/A	Pipe T for gas	SS
3	##	N/A	Fill Valve	SS
3	##	N/A	1/8" MNPT to 1/4" tube adaptor	SS
3	##	N/A	Solenoid	SS
3	##	N/A	1/8" NPT to 1/4" tube fitting	SS
3	##	N/A	Pipe T under tubes	SS
3	##	N/A	1/4" FNPT to 1/4" tube adaptor	SS
A/R	##	N/A	1/4" OD Tubing	SS
3	RIGEX-2006-18-P	RIGEX-2006-18-D	Pressure Transducer Mount to Bottom of Oven Plate (inside)	Al
3	RIGEX-2006-19-P	RIGEX-2006-19-D	Pressure Transducer Mount to Bottom of Oven Plate (outside)	Al
2	RIGEX-2006-9-P	RIGEX-2006-9-D	Inflation System Mounting Plate	Al
3	RIGEX-2006-20-P	RIGEX-2006-20-D	Solenoid Mount	Al
3	RIGEX-2006-21-P	RIGEX-2006-21-D	Pressure Transducer Mount to Ribs (inside)	Al
3	RIGEX-2006-22-P	RIGEX-2006-22-D	Pressure Transducer Mount to Ribs (outside)	Al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2.500
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3.000
5.000
7.000
13.425
27.750
8.4375
1.000
7.438
2.690
0.250
2.375
0.250
1.246
8.625
1.000
2.250
1
2
3
4
5
NOTES:
1. BLIND HOLES SPACED 2.250" APART, 6 PLACES
2. BLINDHOLES SPACED 2.50" APART DOWN CENTER OF PLATE, 11 PLACES
3. SAME AS NOTE 1
4. THRU HOLE, SPACED 1" APART, 2 PLACES
5. MASK WHILE ANODIZING
BLIND HOLES ARE TAPPED #10-32 UNJ, DEPTH: 0.54"
ALL OTHER HOLES DIMENSIONED ON THIS PAGE ARE 0.201" dia, Csink 0.385" dia. x 100 deg
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RIGEX-2006-3-D
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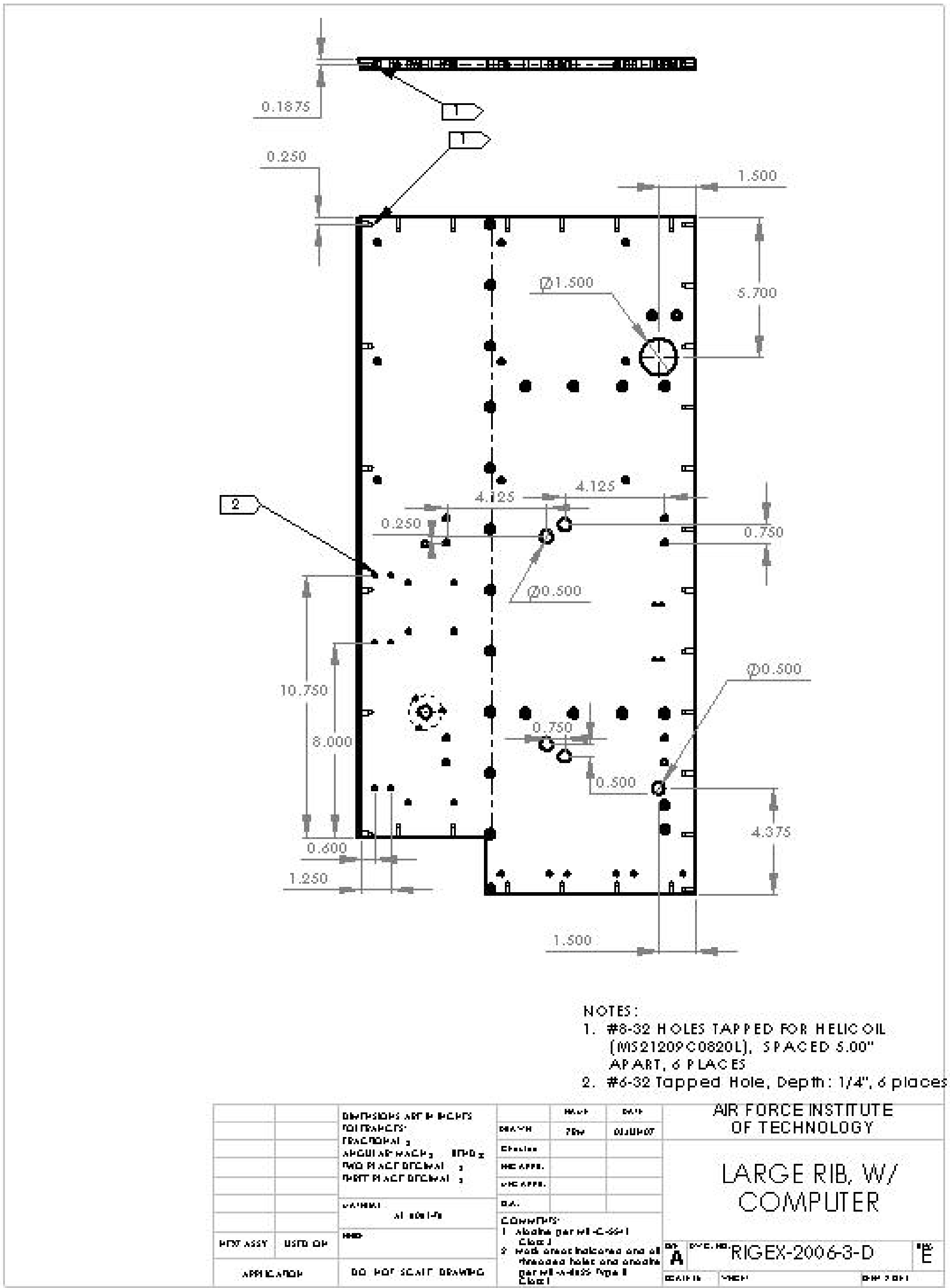
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10.750
8.000
0.750
0.500
4.375
0.600
1.250
1.500
NOTES:
1. #8-32 HOLES TAPPED FOR HELICOIL (MS21209C0820L), SPACED 5.00" APART, 6 PLACES
2. #6-32 Tapped Hole, Depth: 1/4", 6 places
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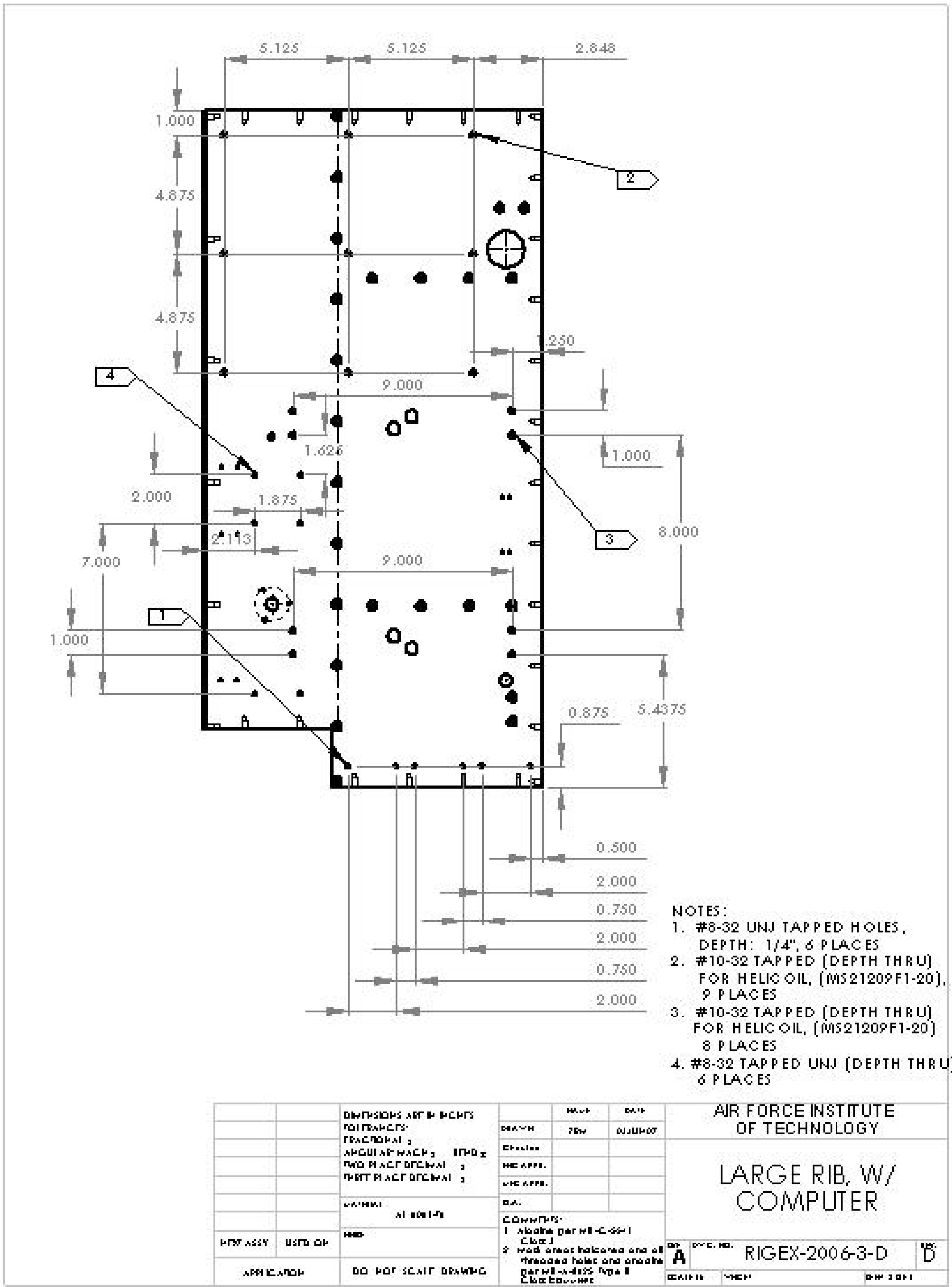
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NOTES:
1. #8-32 UNJ TAPPED HOLES, DEPTH: 1/4", 6 PLACES
2. #10-32 TAPPED (DEPTH THRU) FOR HELICOIL, (MS21209F1-20), 9 PLACES
3. #10-32 TAPPED (DEPTH THRU) FOR HELICOIL, (MS21209F1-20) 8 PLACES
4. #8-32 TAPPED UNJ (DEPTH THRU) 6 PLACES
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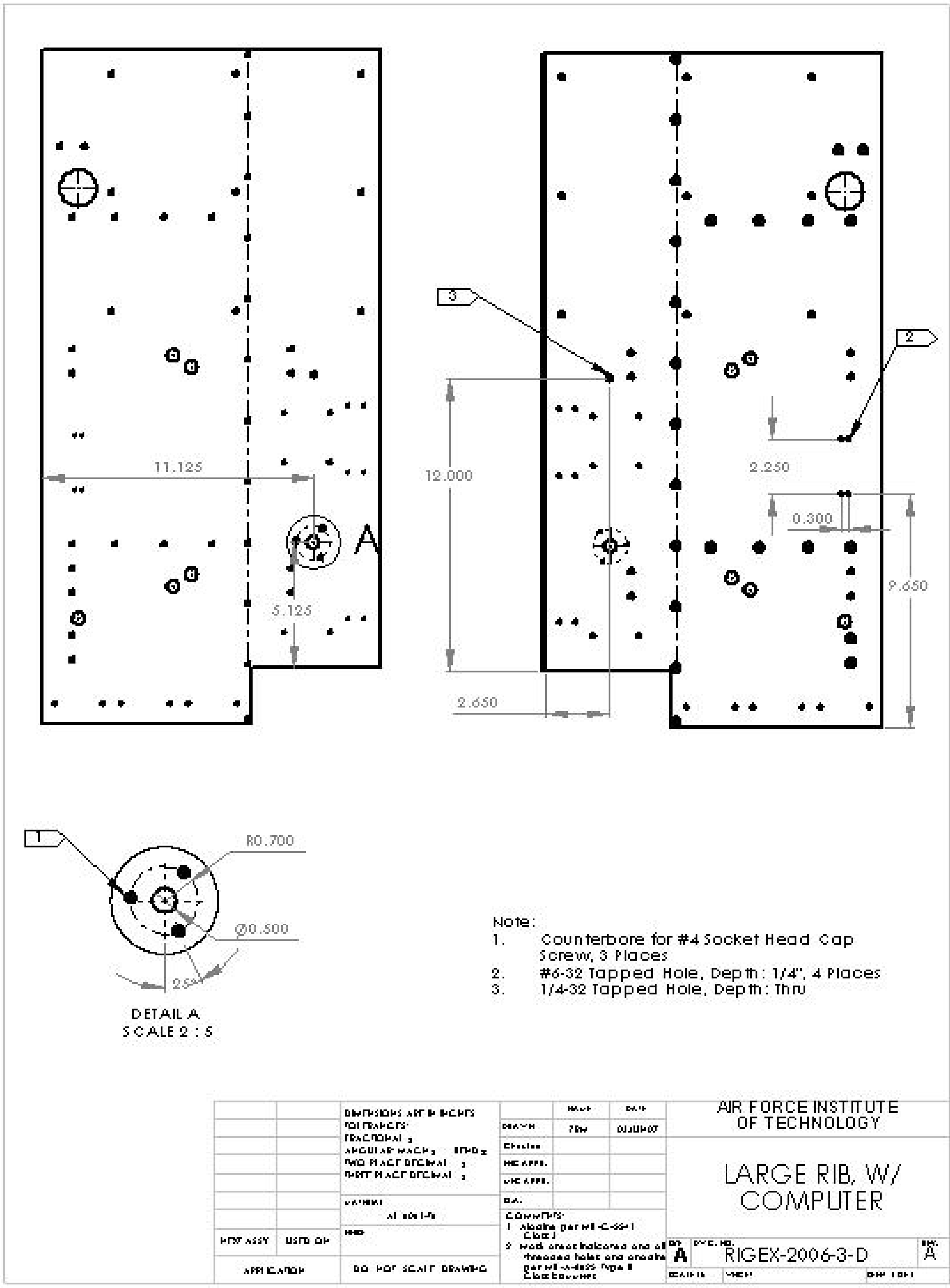
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0.300
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SCALE 2 : 5
Note:
1. Counterbore for #4 Socket Head Cap Screw, 3 Places
2. #6-32 Tapped Hole, Depth: 1/4", 4 Places
3. 1/4-32 Tapped Hole, Depth: Thru
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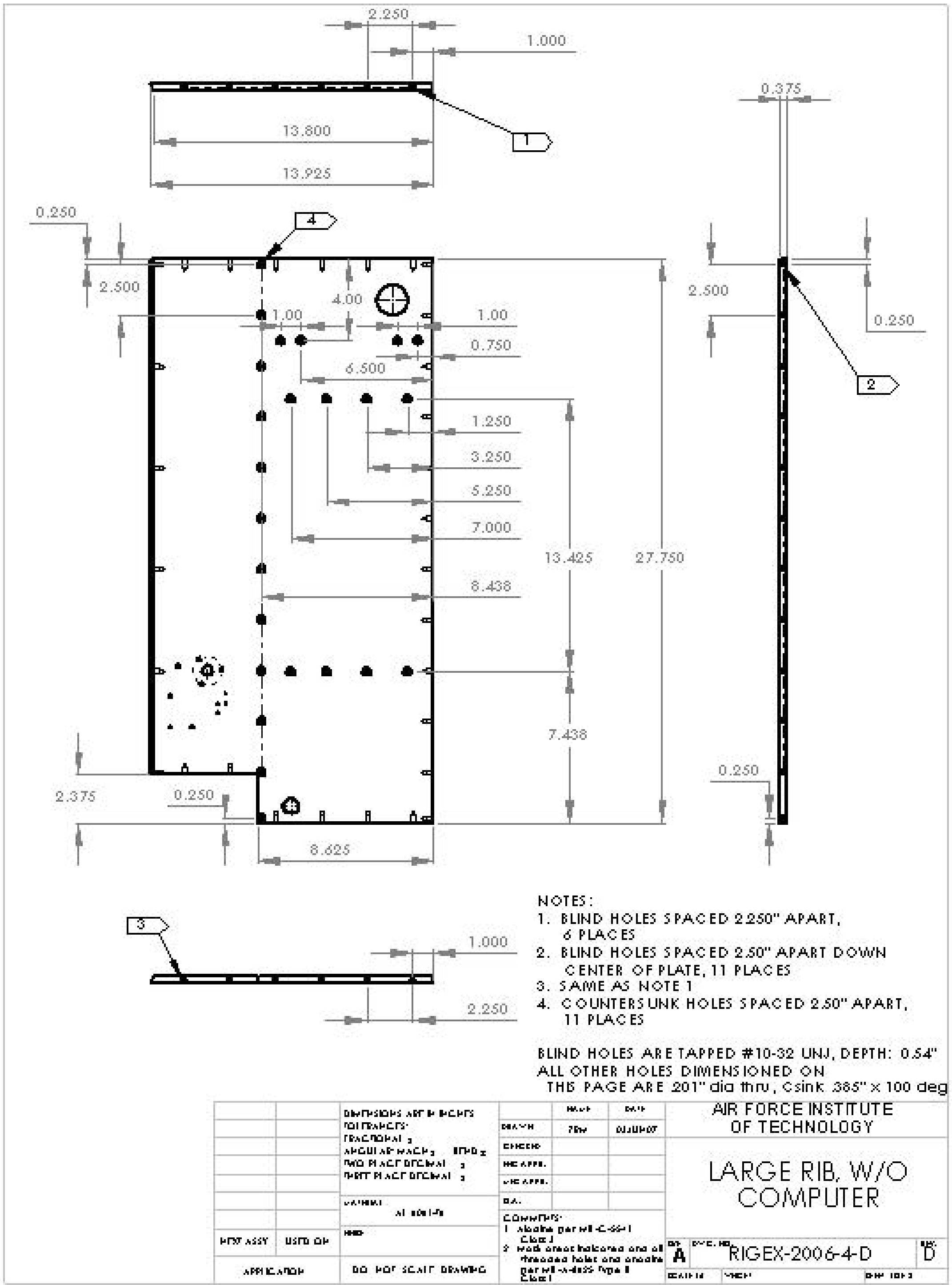
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1.00
0.750
6.500
2
1.250
3.250
5.250
7.000
13.425
27.750
8.438
7.438
0.250
2.375
0.250
8.625
NOTES:
1. BLIND HOLES SPACED 2.250" APART, 6 PLACES
2. BLIND HOLES SPACED 2.50" APART DOWN CENTER OF PLATE, 11 PLACES
3. SAME AS NOTE 1
4. COUNTERSUNK HOLES SPACED 2.50" APART, 11 PLACES
3
1.000
2.250
BLIND HOLES ARE TAPPED #10-32 UNJ, DEPTH: 0.54"
ALL OTHER HOLES DIMENSIONED ON THIS PAGE ARE .201" dia thru, Csink .385" x 100 deg
AIR FORCE INSTITUTE OF TECHNOLOGY
LARGE RIB, W/O COMPUTER
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
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RIGEX-2006-4-D
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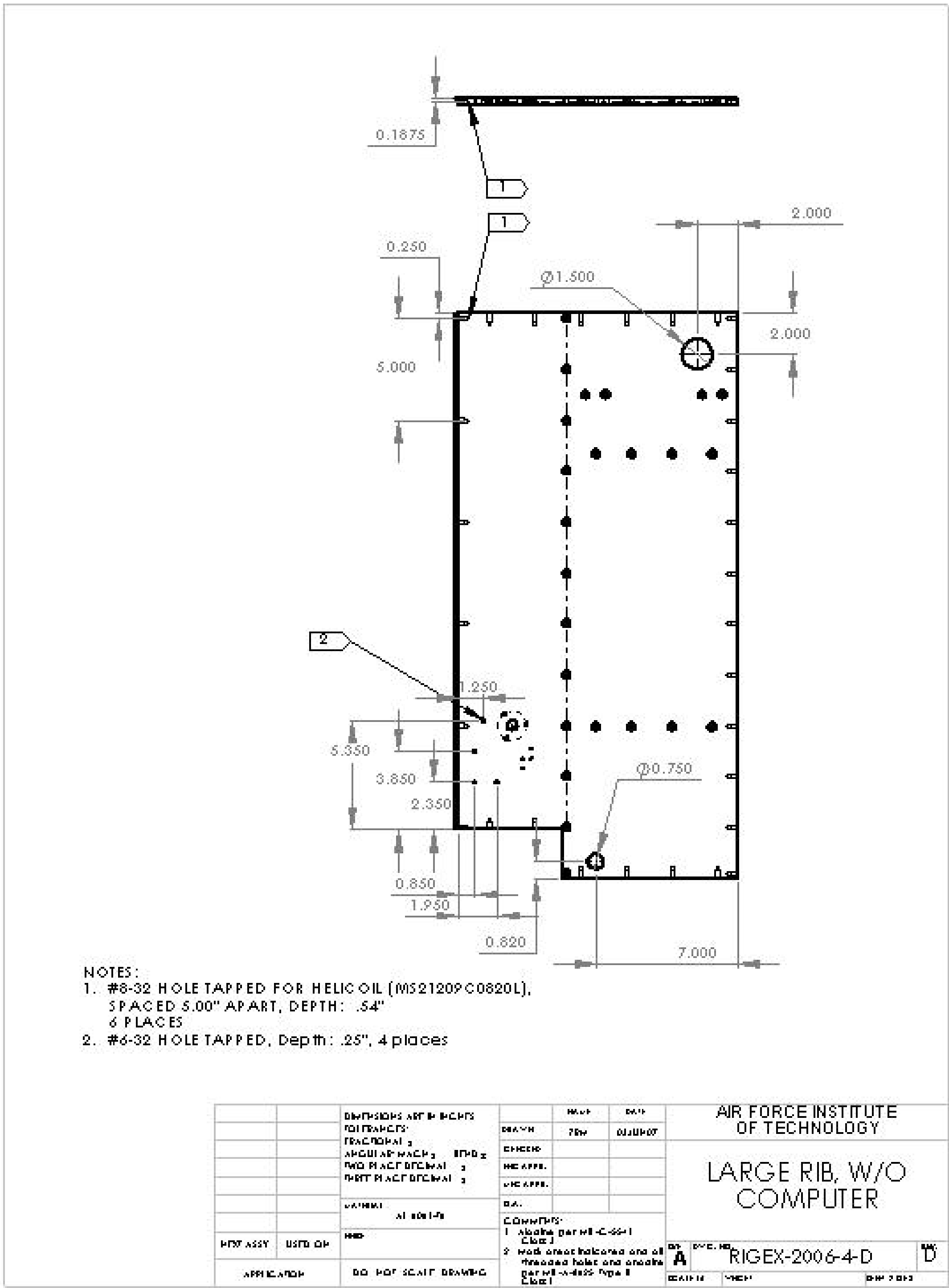
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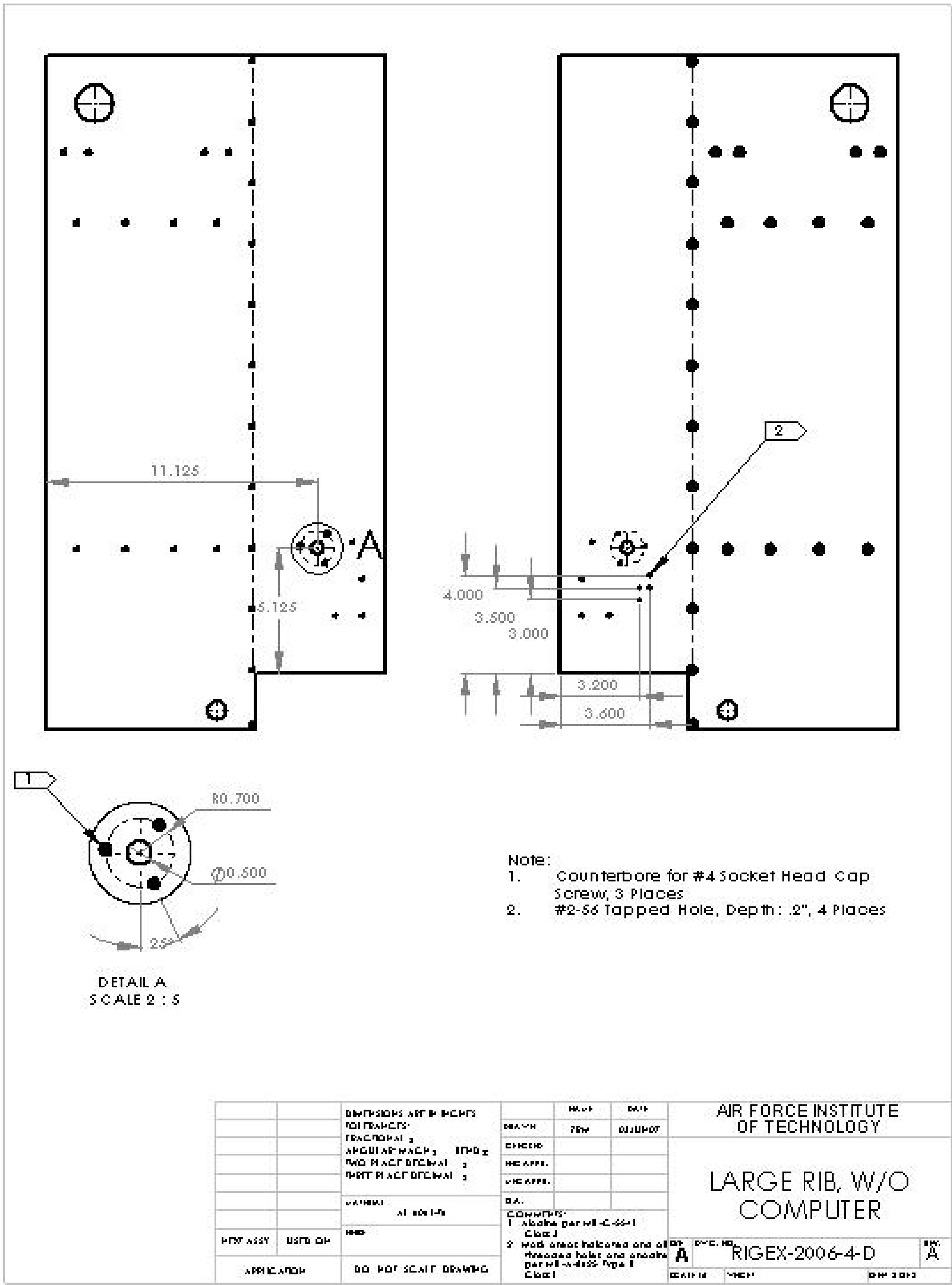
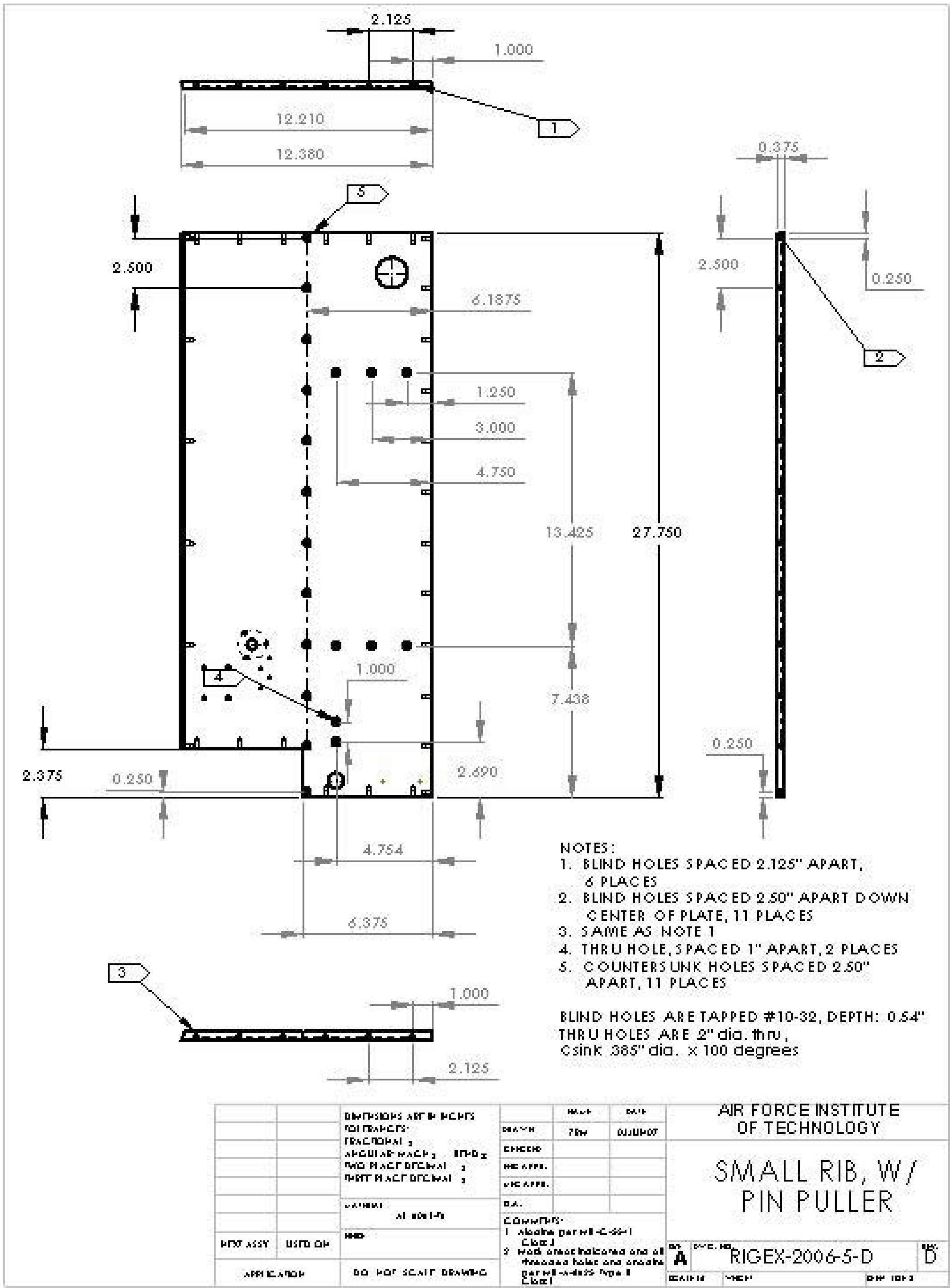
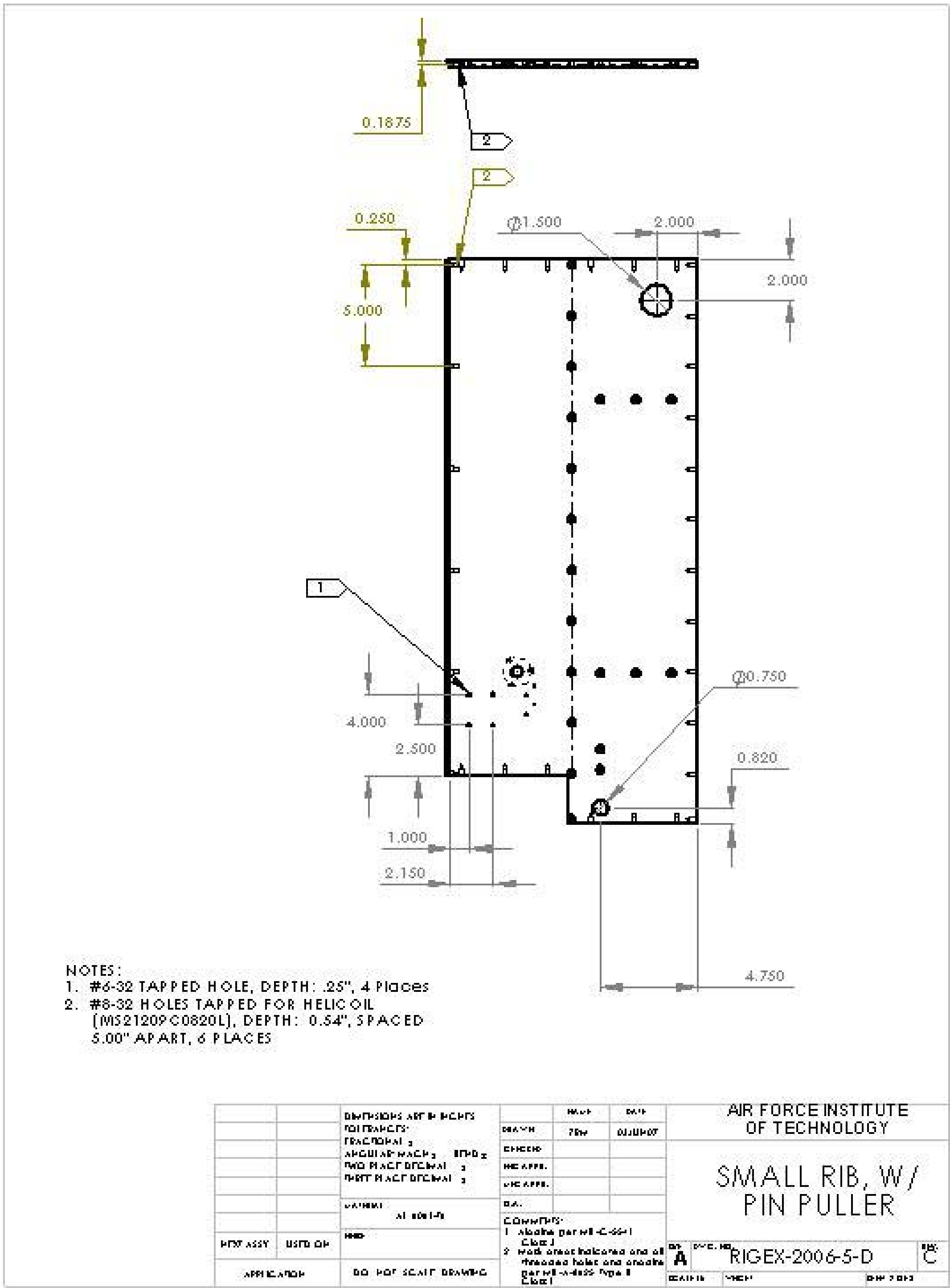
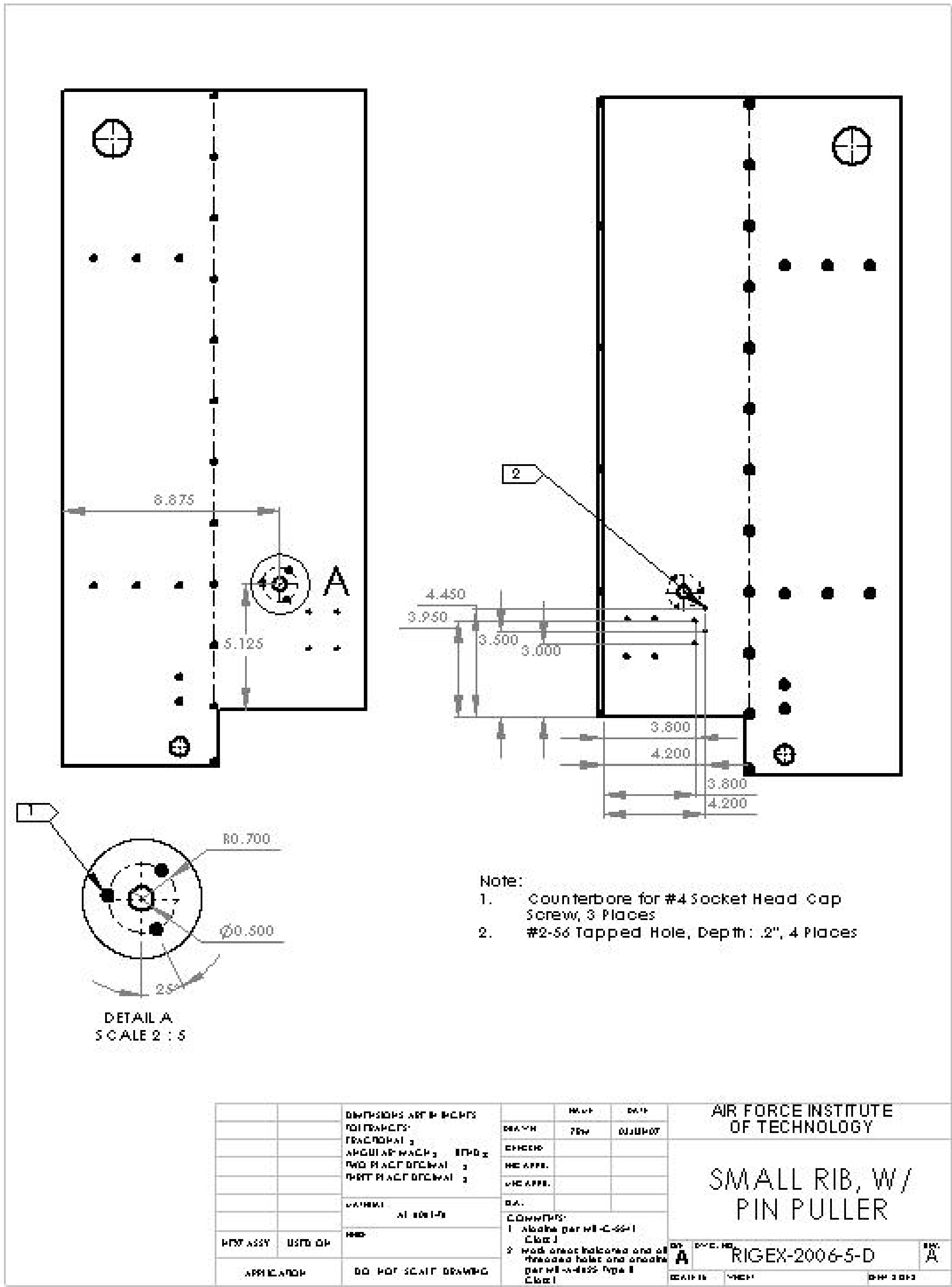
1
2.000
0.250
Ø1.500
2.000
5.000
2
1.250
5.350
3.850
Ø0.750
2.350
0.850
1.950
0.820
7.000
NOTES:
1. #8-32 HOLE TAPPED FOR HELICOIL (MS21209C0820L),
SPACED 5.00" APART, DEPTH: .54"
6 PLACES
2. #6-32 HOLE TAPPED, Depth: .25", 4 places
AIR FORCE INSTITUTE
OF TECHNOLOGY
LARGE RIB, W/O
COMPUTER
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
A
RIGEX-2006-4-D
D

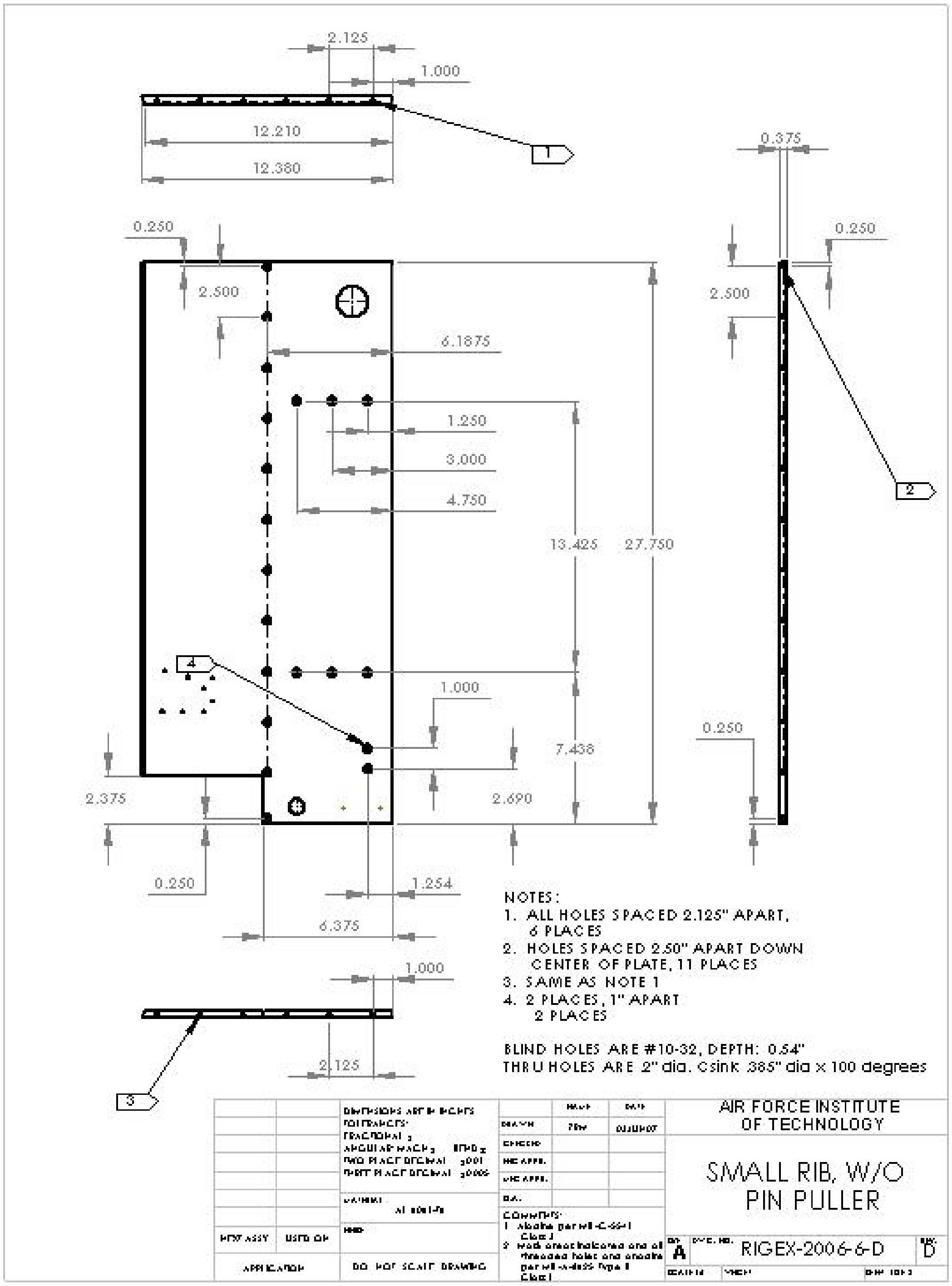

11.125
A
5.125
2
4.000
3.500
3.000
3.200
3.600
1
R0.700
Ø0.500
25°
DETAIL A
SCALE 2 : 5
Note:
1. Counterbore for #4 Socket Head Cap Screw, 3 Places
2. #2-56 Tapped Hole, Depth: .2", 4 Places
AIR FORCE INSTITUTE OF TECHNOLOGY
LARGE RIB, W/O COMPUTER
RIGEX-2006-4-D
DO NOT SCALE DRAWING
APPLICATION
NEXT ASSY
USED ON



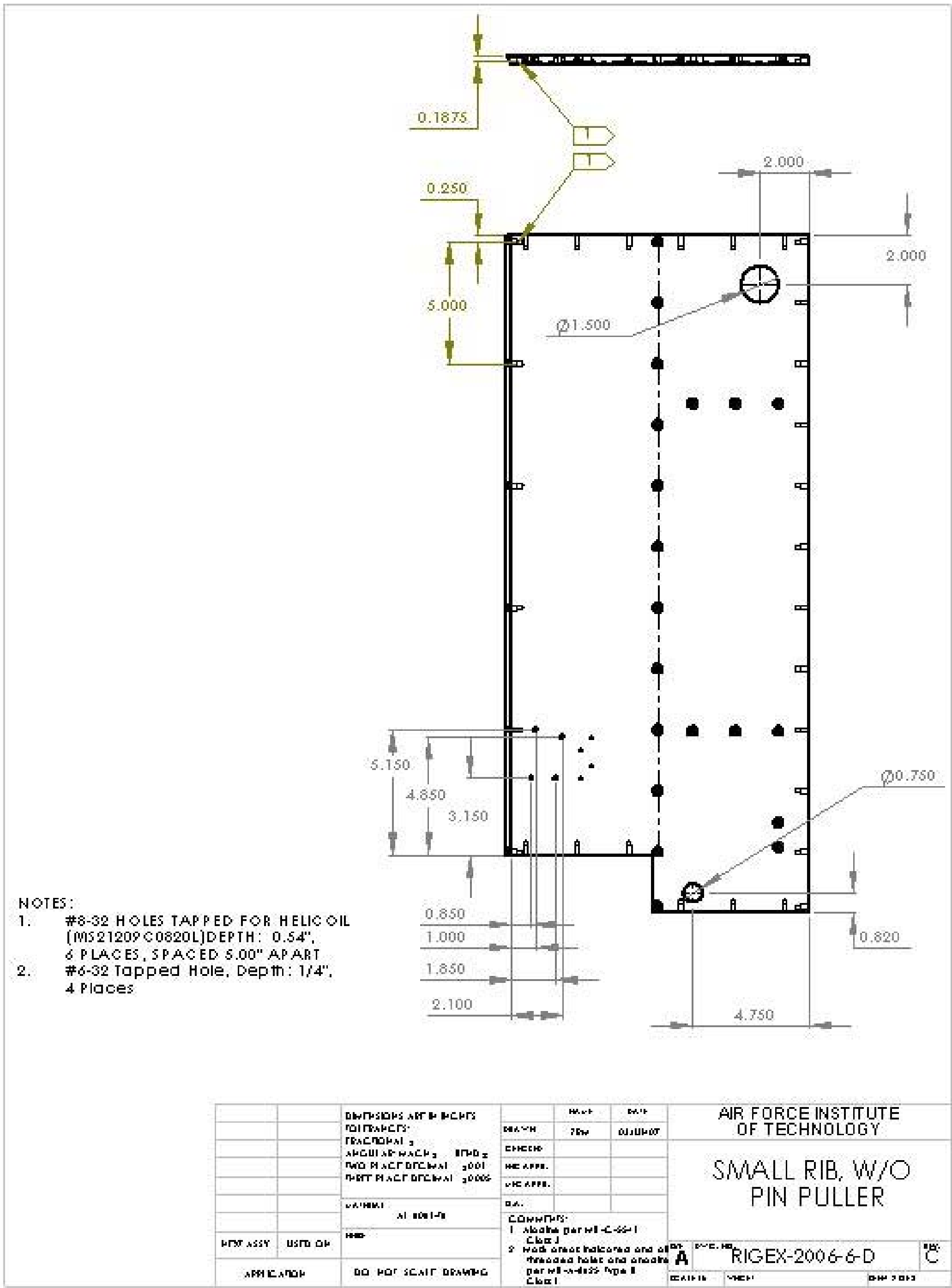
2.125
1.000
12.210
12.380
0.375
2.500
0.250
6.1875
1.250
3.000
4.750
13.425
27.750
1.000
7.438
2.375
0.250
2.690
4.754
6.375
1.000
2.125
NOTES:
1. BLIND HOLES SPACED 2.125" APART, 6 PLACES
2. BLIND HOLES SPACED 2.50" APART DOWN CENTER OF PLATE, 11 PLACES
3. SAME AS NOTE 1
4. THRU HOLE, SPACED 1" APART, 2 PLACES
5. COUNTERSUNK HOLES SPACED 2.50" APART, 11 PLACES
BLIND HOLES ARE TAPPED #10-32, DEPTH: 0.54"
THRU HOLES ARE .2" dia. thru, Csink .385" dia. x 100 degrees
AIR FORCE INSTITUTE OF TECHNOLOGY
SMALL RIB, W/ PIN PULLER
A
RIGEX-2006-5-D
D
APPLICATION
DO NOT SCALE DRAWING

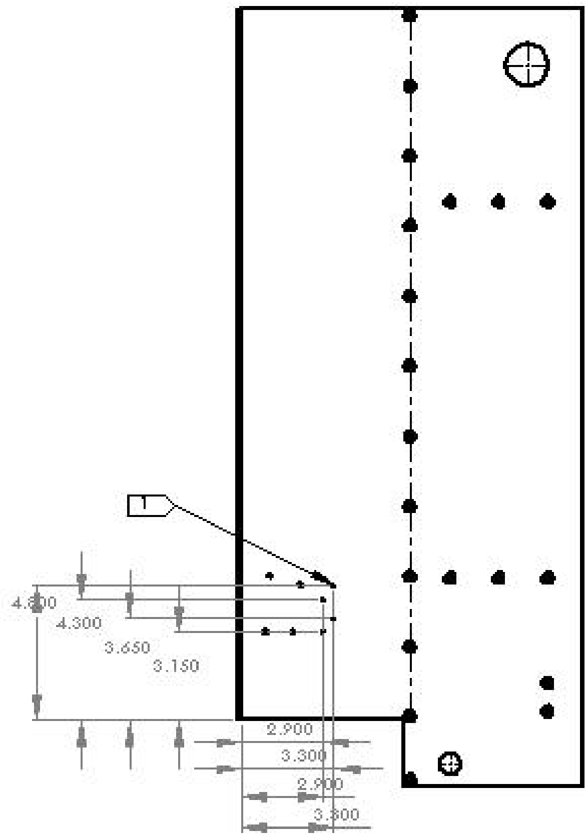

0.1875
2
2
0.250
5.000
Ø1.500
2.000
2.000
1
Ø0.750
4.000
2.500
0.820
1.000
2.150
4.750
NOTES:
1. #6-32 TAPPED HOLE, DEPTH: .25", 4 Places
2. #8-32 HOLES TAPPED FOR HELICOIL (MS21209C0820L), DEPTH: 0.54", SPACED 5.00" APART, 6 PLACES
AIR FORCE INSTITUTE OF TECHNOLOGY
SMALL RIB, W/ PIN PULLER
A
RIGEX-2006-5-D
C
DO NOT SCALE DRAWING
APPLICATION
USED ON


8.875
A
5.125
4.450
3.950
3.500
3.000
3.800
4.200
3.800
4.200
R0.700
Ø0.500
25°
DETAIL A
SCALE 2 : 5
Note:
1. Counterbore for #4 Socket Head Cap Screw, 3 Places
2. #2-56 Tapped Hole, Depth: .2", 4 Places
AIR FORCE INSTITUTE OF TECHNOLOGY
SMALL RIB, W/ PIN PULLER
RIGEX-2006-5-D
DO NOT SCALE DRAWING



2.125
1.000
12.210
12.380
1
0.375
0.250
2.500
6.1875
1.250
3.000
4.750
13.425
27.750
2
4
1.000
7.438
2.690
2.375
0.250
1.254
6.375
3
NOTES:
1. ALL HOLES SPACED 2.125" APART, 6 PLACES
2. HOLES SPACED 2.50" APART DOWN CENTER OF PLATE, 11 PLACES
3. SAME AS NOTE 1
4. 2 PLACES, 1" APART 2 PLACES
BLIND HOLES ARE #10-32, DEPTH: 0.54"
THRU HOLES ARE .2" dia. Csink .385" dia x 100 degrees
AIR FORCE INSTITUTE OF TECHNOLOGY
SMALL RIB, W/O PIN PULLER
A
RIGEX-2006-6-D
D
DO NOT SCALE DRAWING
APPLICATION


0.1875
0.250
5.000
2.000
2.000
Ø1.500
Ø0.750
5.150
4.850
3.150
0.850
1.000
1.850
2.100
0.820
4.750
NOTES:
1. #8-32 HOLES TAPPED FOR HELICOIL (MS21209C0820L)DEPTH: 0.54", 6 PLACES, SPACED 5.00" APART
2. #6-32 Tapped Hole, Depth: 1/4", 4 Places
AIR FORCE INSTITUTE OF TECHNOLOGY
SMALL RIB, W/O PIN PULLER
A
RIGEX-2006-6-D
C
DO NOT SCALE DRAWING
APPLICATION



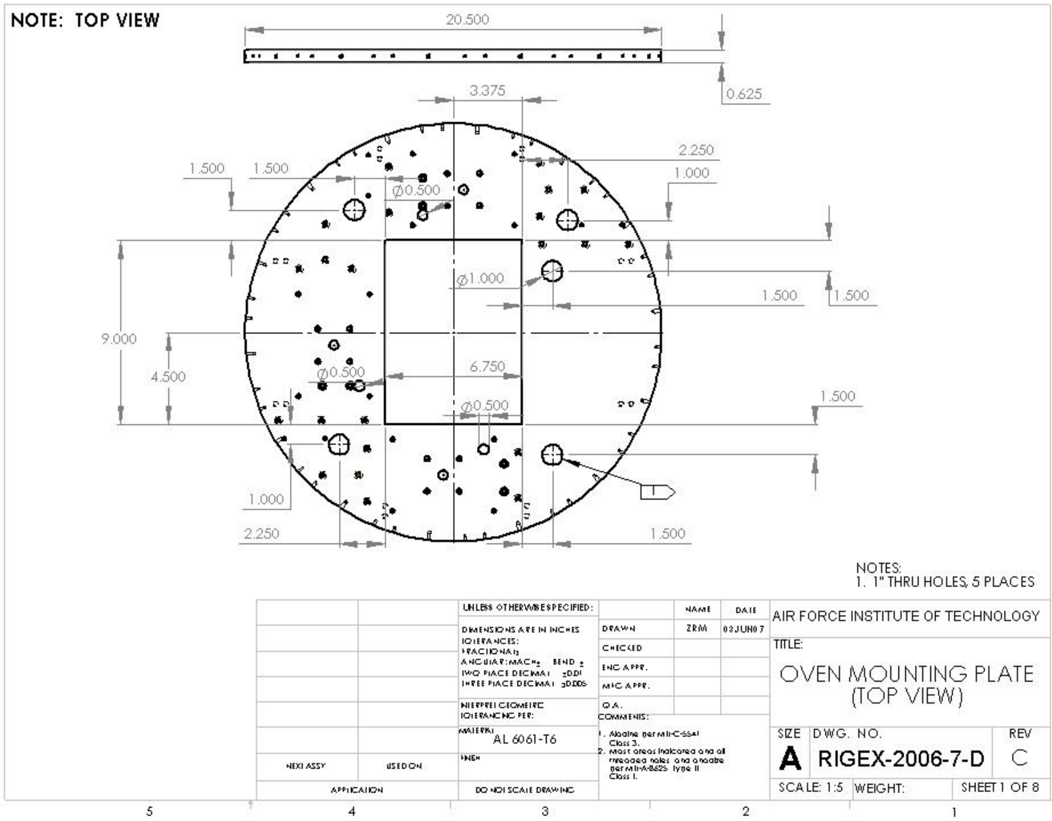
Notes:
1. #2-56 Tapped Hole, Depth .2", 4 Places

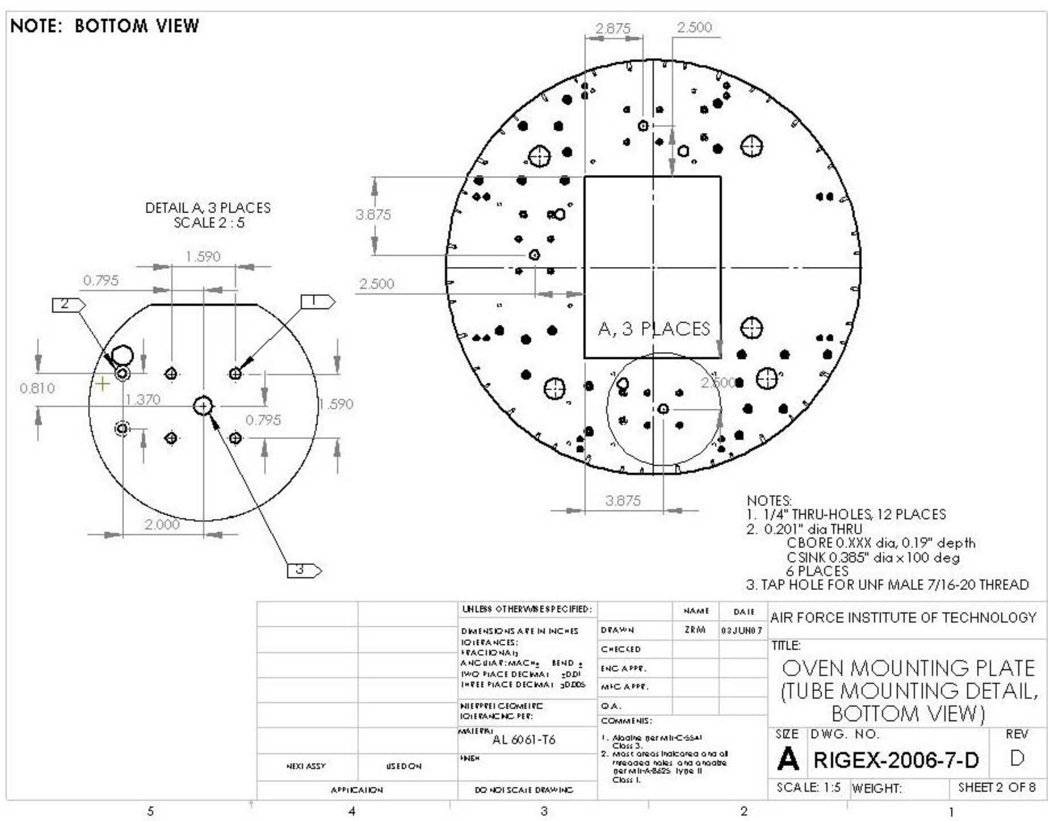
AIR FORCE INSTITUTE OF TECHNOLOGY

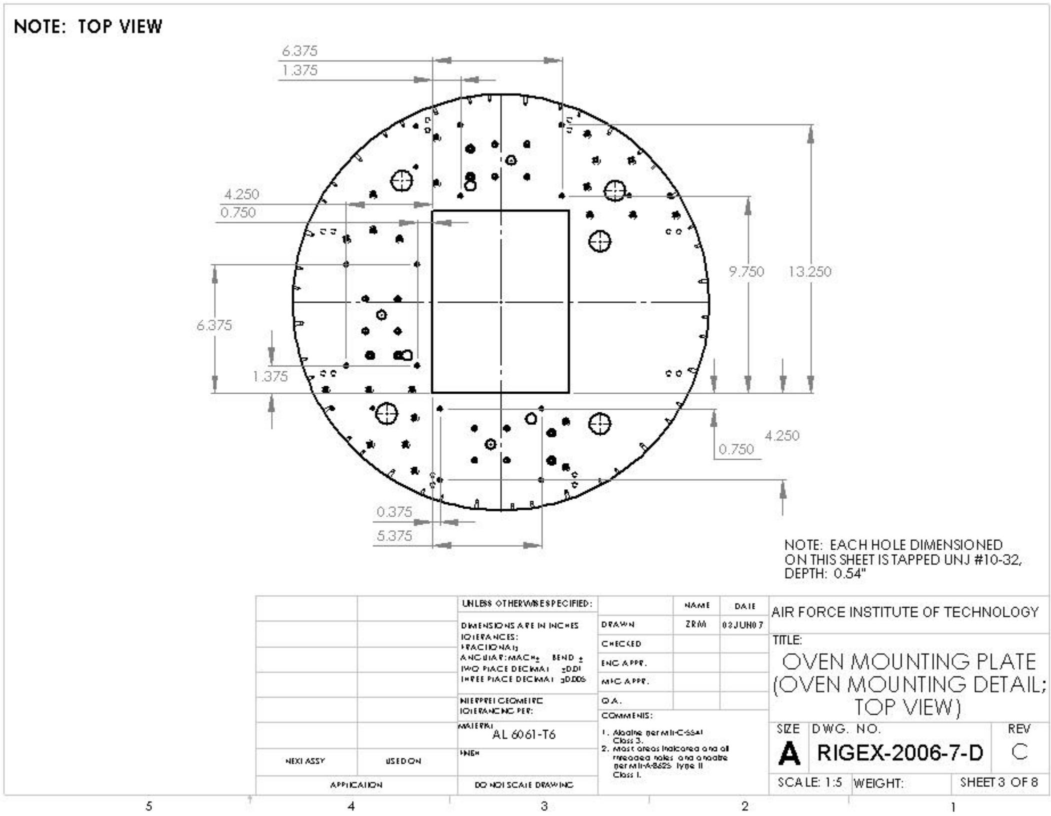
SMALL RIB, W/O PIN PULLER

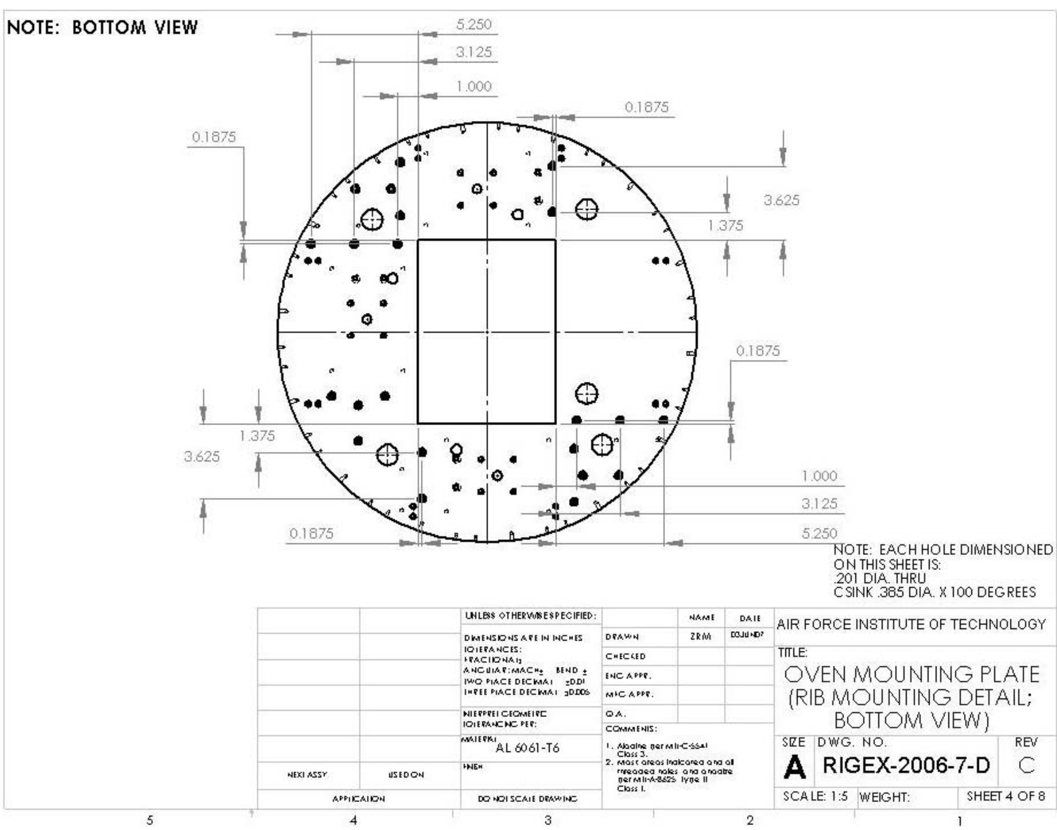
RIGEX-2006-6-D

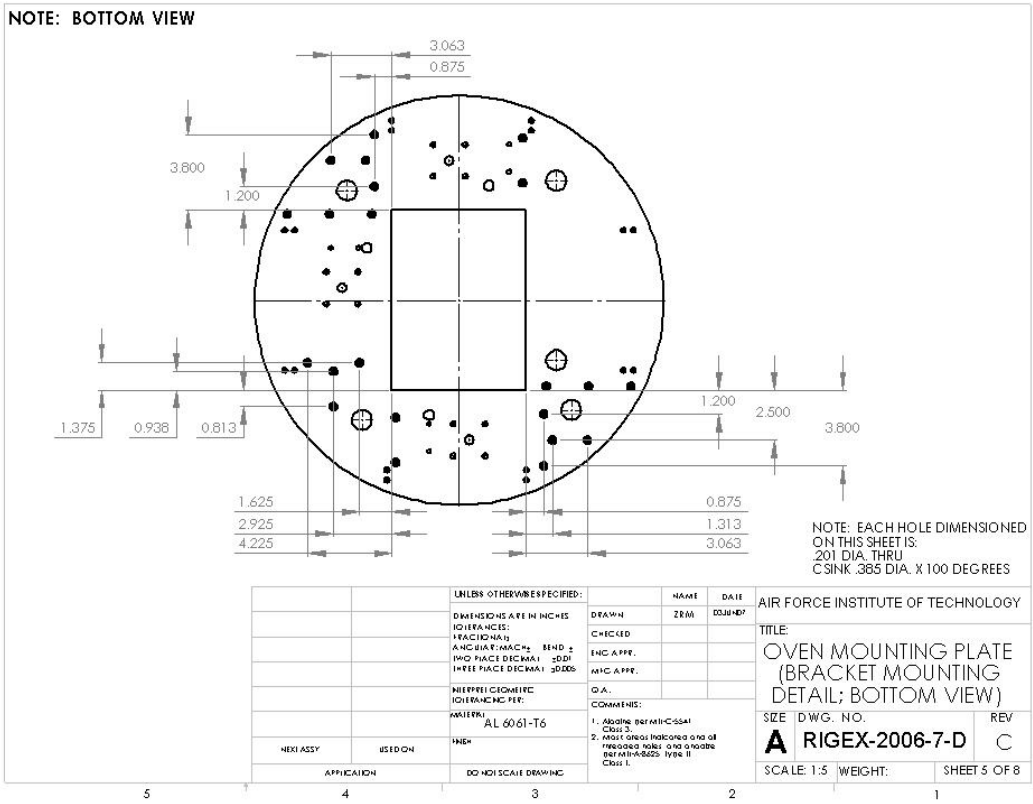
DO NOT SCALE DRAWING

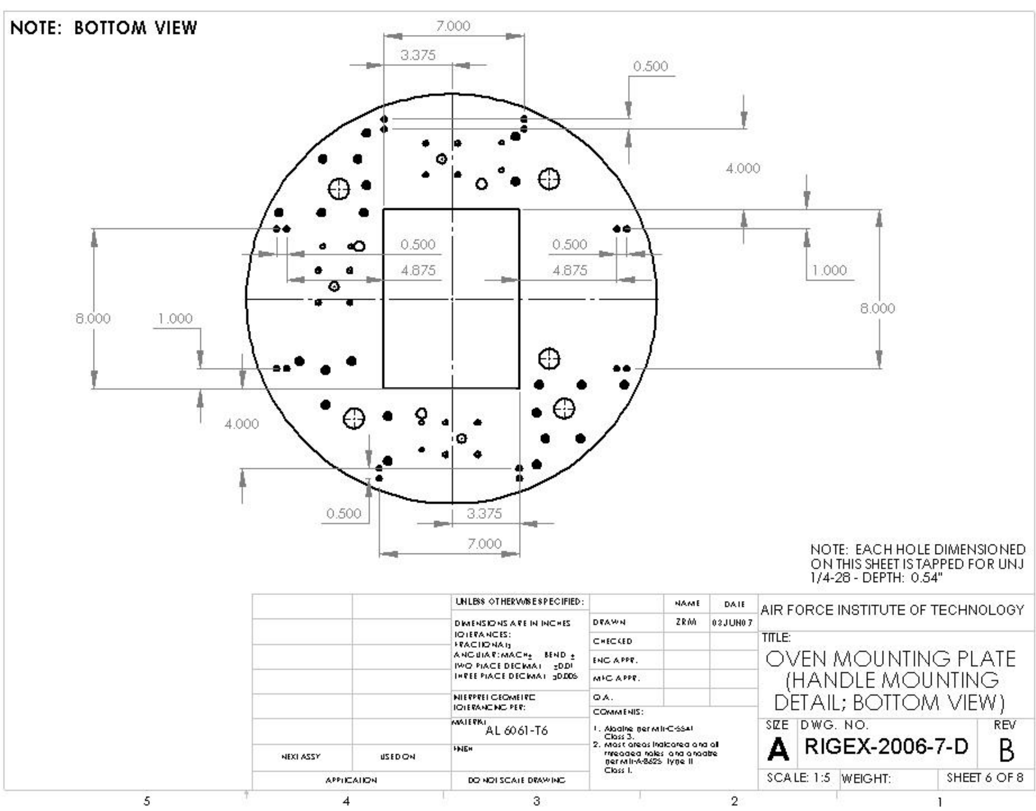

NOTE: TOP VIEW
20.500
0.625
3.375
2.250
1.000
1.500
1.500
Ø0.500
Ø1.000
1.500
1.500
9.000
4.500
Ø0.500
6.750
Ø0.500
1.500
1
1.000
2.250
1.500
NOTES:
1. 1" THRU HOLES, 5 PLACES
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DRAWN
ZRM
03JUN07
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
MATERIAL
AL 6061-T6
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
AIR FORCE INSTITUTE OF TECHNOLOGY
TITLE:
OVEN MOUNTING PLATE
(TOP VIEW)
SIZE
DWG. NO.
REV
A
RIGEX-2006-7-D
C
SCALE: 1:5
WEIGHT:
SHEET 1 OF 8
5
4
3
2
1

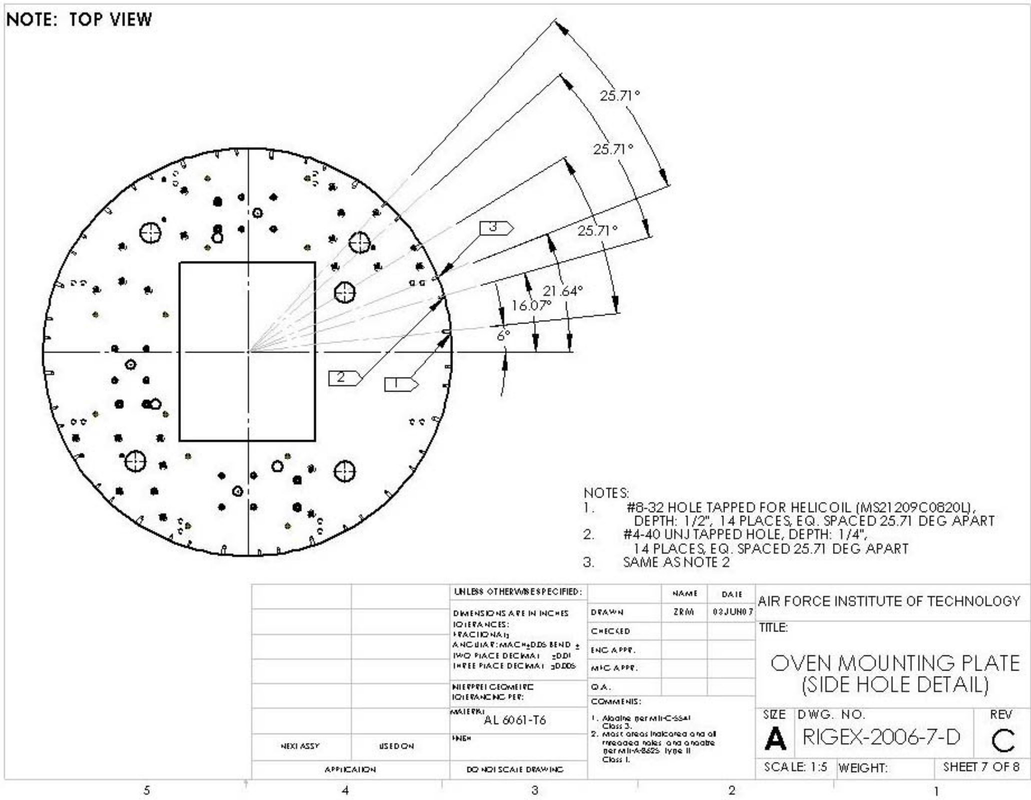

NOTE: BOTTOM VIEW
2.875
2.500
DETAIL A, 3 PLACES
SCALE 2 : 5
3.875
1.590
0.795
2
1
2.500
A, 3 PLACES
0.810
1.370
1.590
0.795
2.500
2.000
3.875
3
NOTES:
1. 1/4" THRU-HOLES, 12 PLACES
2. 0.201" dia THRU
CBORE 0.XXX dia, 0.19" depth
CSINK 0.385" dia x 100 deg
6 PLACES
3. TAP HOLE FOR UNF MALE 7/16-20 THREAD
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DRAWN
ZRM
03JUN07
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
MATERIAL
AL 6061-T6
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
AIR FORCE INSTITUTE OF TECHNOLOGY
TITLE:
OVEN MOUNTING PLATE
(TUBE MOUNTING DETAIL,
BOTTOM VIEW)
SIZE
DWG. NO.
REV
A
RIGEX-2006-7-D
D
SCALE: 1:5
WEIGHT:
SHEET 2 OF 8
5
4
3
2
1

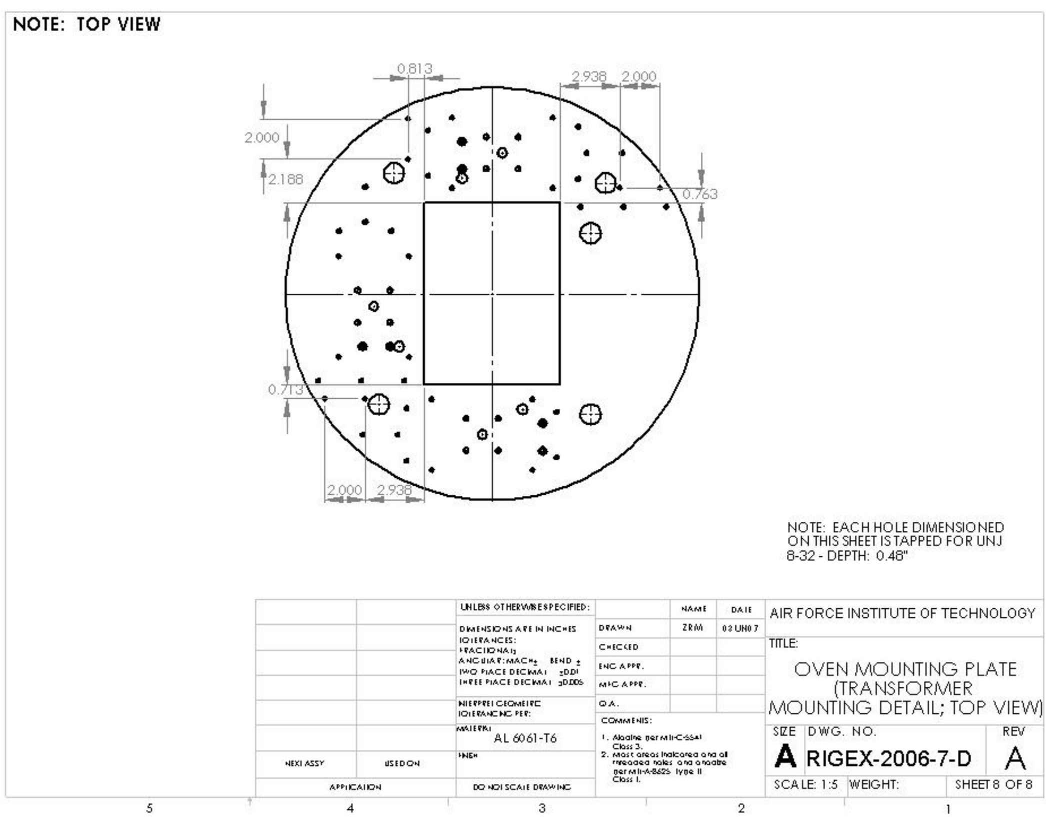

NOTE: TOP VIEW
6.375
1.375
4.250
0.750
6.375
1.375
9.750
13.250
4.250
0.750
0.375
5.375
NOTE: EACH HOLE DIMENSIONED ON THIS SHEET IS TAPPED UNJ #10-32, DEPTH: 0.54"
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DRAWN
ZRM
03JUN07
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
MATERIAL
AL 6061-T6
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
AIR FORCE INSTITUTE OF TECHNOLOGY
TITLE:
OVEN MOUNTING PLATE (OVEN MOUNTING DETAIL; TOP VIEW)
SIZE
DWG. NO.
REV
A
RIGEX-2006-7-D
C
SCALE: 1:5
WEIGHT:
SHEET 3 OF 8

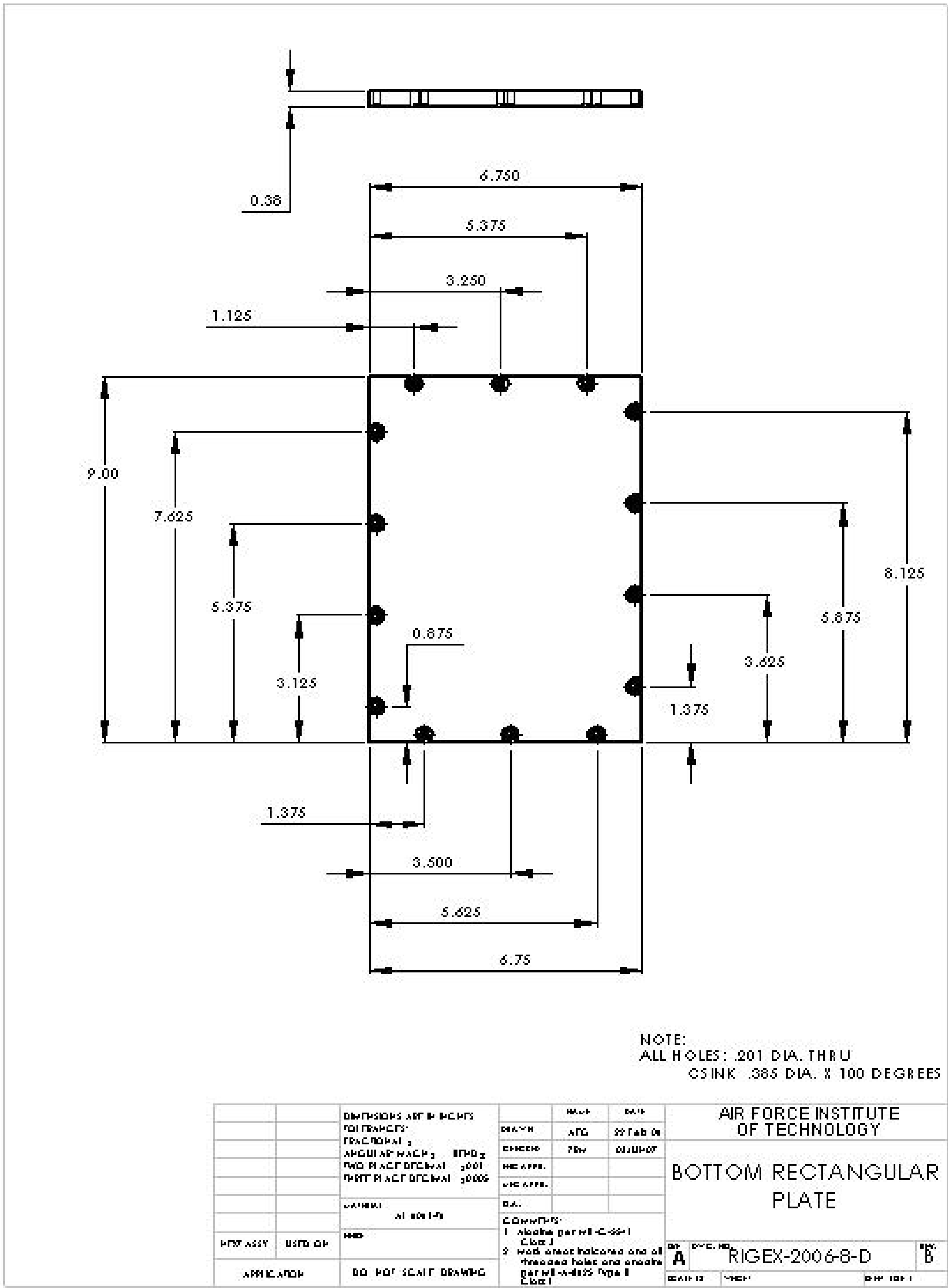

NOTE: BOTTOM VIEW
5.250
3.125
1.000
0.1875
0.1875
3.625
1.375
0.1875
1.375
3.625
1.000
3.125
0.1875
5.250
NOTE: EACH HOLE DIMENSIONED ON THIS SHEET IS: .201 DIA. THRU CSINK .385 DIA. X 100 DEGREES
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DRAWN
ZRM
03JUN07
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
MATERIAL
AL 6061-T6
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
AIR FORCE INSTITUTE OF TECHNOLOGY
TITLE:
OVEN MOUNTING PLATE (RIB MOUNTING DETAIL; BOTTOM VIEW)
SIZE
DWG. NO.
REV
A
RIGEX-2006-7-D
C
SCALE: 1:5
WEIGHT:
SHEET 4 OF 8

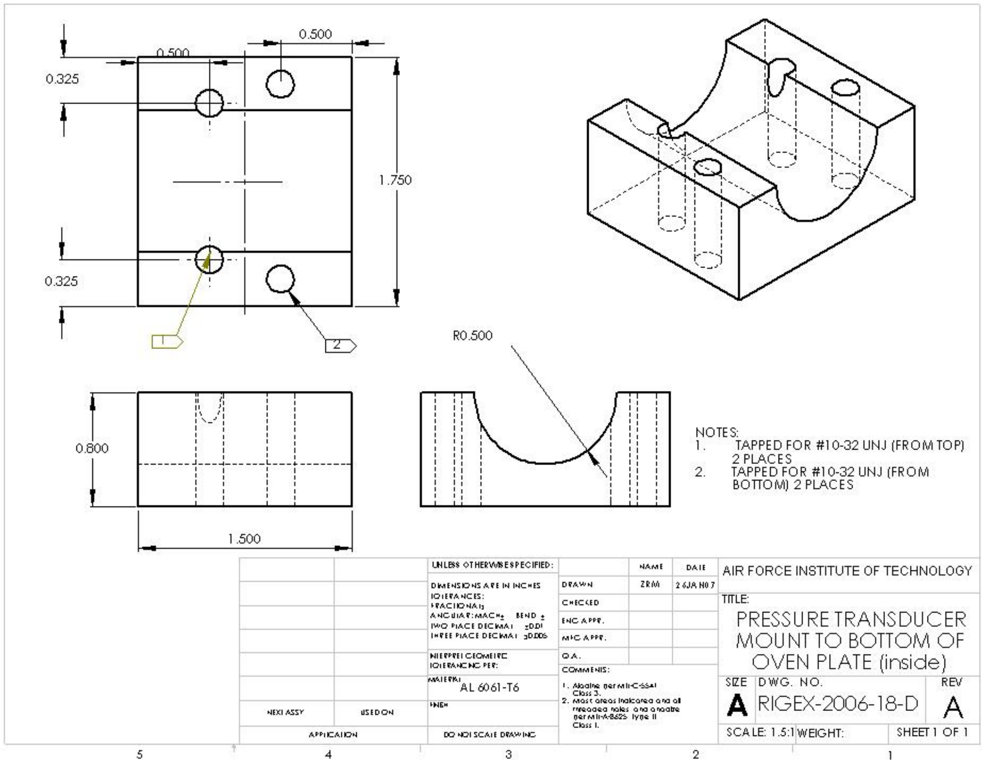

NOTE: BOTTOM VIEW
3.063
0.875
3.800
1.200
1.375
0.938
0.813
1.625
2.925
4.225
1.200
2.500
3.800
0.875
1.313
3.063
NOTE: EACH HOLE DIMENSIONED ON THIS SHEET IS: .201 DIA. THRU CSINK .385 DIA. X 100 DEGREES
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DRAWN
ZRM
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
MATERIAL AL 6061-T6
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
AIR FORCE INSTITUTE OF TECHNOLOGY
TITLE:
OVEN MOUNTING PLATE (BRACKET MOUNTING DETAIL; BOTTOM VIEW)
SIZE
DWG. NO.
REV
A
RIGEX-2006-7-D
C
SCALE: 1:5
WEIGHT:
SHEET 5 OF 8

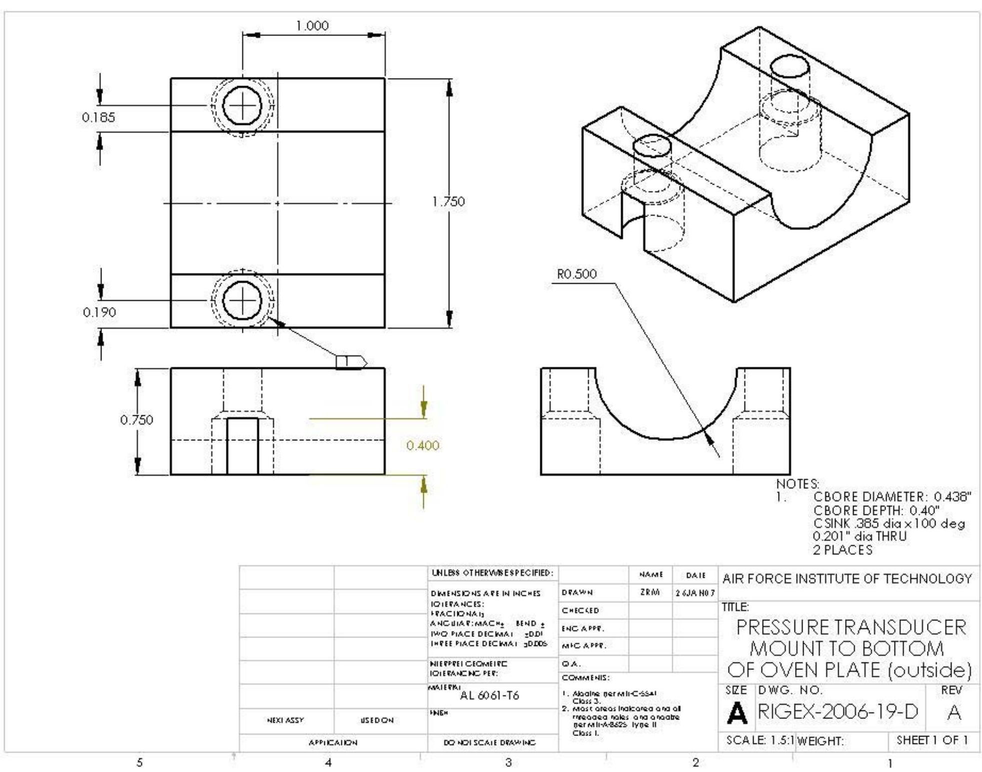

NOTE: BOTTOM VIEW
7.000
3.375
0.500
4.000
0.500
4.875
0.500
4.875
1.000
8.000
8.000
1.000
4.000
0.500
3.375
7.000
NOTE: EACH HOLE DIMENSIONED ON THIS SHEET IS TAPPED FOR UNJ 1/4-28 - DEPTH: 0.54"
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DRAWN
ZRM
02JUN07
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
MATERIAL AL 6061-T6
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
AIR FORCE INSTITUTE OF TECHNOLOGY
TITLE:
OVEN MOUNTING PLATE (HANDLE MOUNTING DETAIL; BOTTOM VIEW)
SIZE
DWG. NO.
REV
A
RIGEX-2006-7-D
B
SCALE: 1:5
WEIGHT:
SHEET 6 OF 8

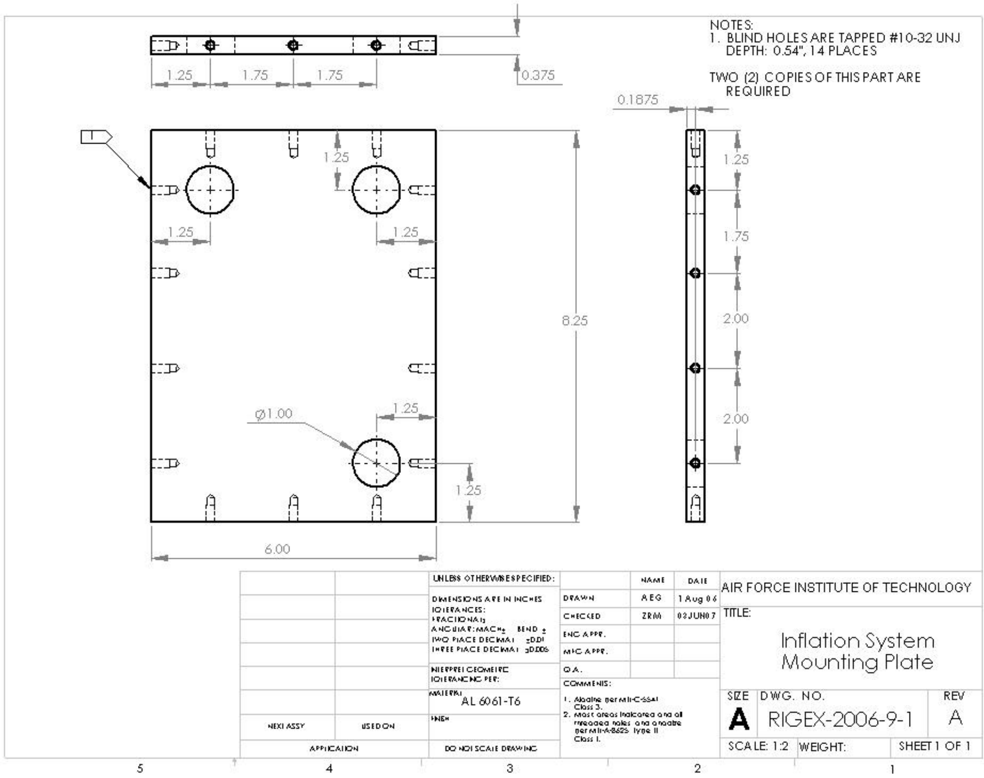

NOTE: TOP VIEW
25.71°
25.71°
25.71°
21.64°
16.07°
6°
1
2
3
NOTES:
1. #8-32 HOLE TAPPED FOR HELICOIL (MS21209C0820L), DEPTH: 1/2", 14 PLACES, EQ. SPACED 25.71 DEG APART
2. #4-40 UNJ TAPPED HOLE, DEPTH: 1/4", 14 PLACES, EQ. SPACED 25.71 DEG APART
3. SAME AS NOTE 2
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
NAME
DATE
DRAWN
ZRM
03JUN07
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
MATERIAL
AL 6061-T6
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
AIR FORCE INSTITUTE OF TECHNOLOGY
TITLE:
OVEN MOUNTING PLATE
(SIDE HOLE DETAIL)
SIZE
DWG. NO.
REV
A
RIGEX-2006-7-D
C
SCALE: 1:5
WEIGHT:
SHEET 7 OF 8
5
4
3
2
1

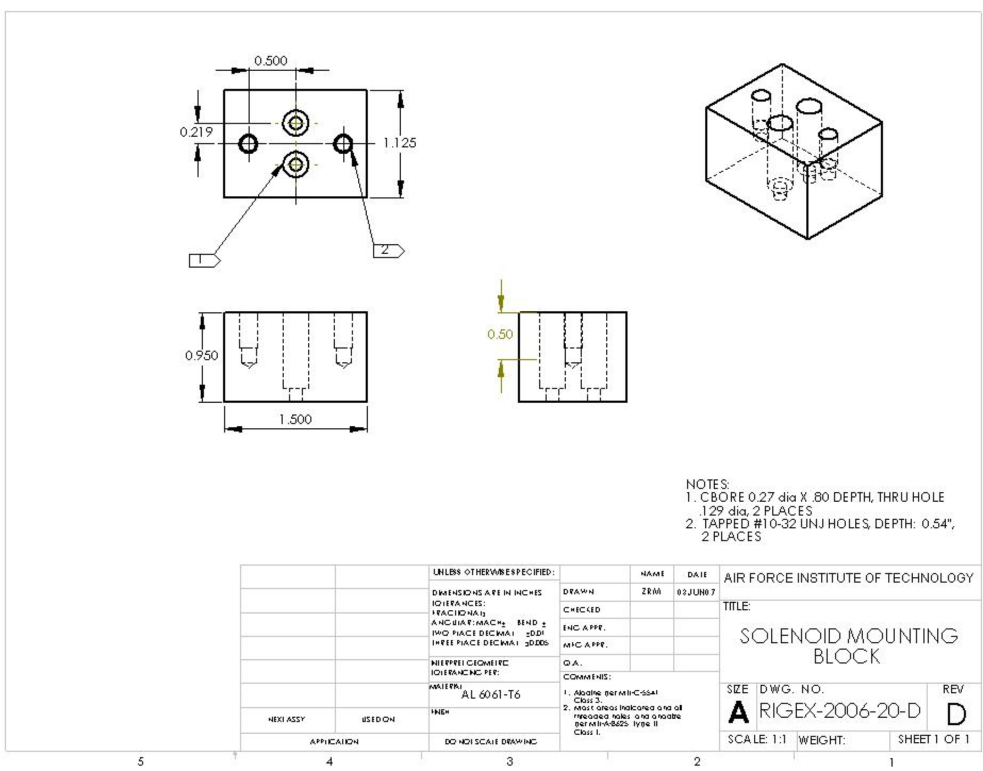

NOTE: TOP VIEW
0.813
2.938
2.000
2.000
2.188
0.763
0.713
2.000
2.938
NOTE: EACH HOLE DIMENSIONED ON THIS SHEET IS TAPPED FOR UNJ 8-32 - DEPTH: 0.48"
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
NAME
DATE
DRAWN
ZRM
03JUN07
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
MATERIAL
AL 6061-T6
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
AIR FORCE INSTITUTE OF TECHNOLOGY
TITLE:
OVEN MOUNTING PLATE
(TRANSFORMER
MOUNTING DETAIL; TOP VIEW)
SIZE
DWG. NO.
REV
A
RIGEX-2006-7-D
A
SCALE: 1:5
WEIGHT:
SHEET 8 OF 8
5
4
3
2
1

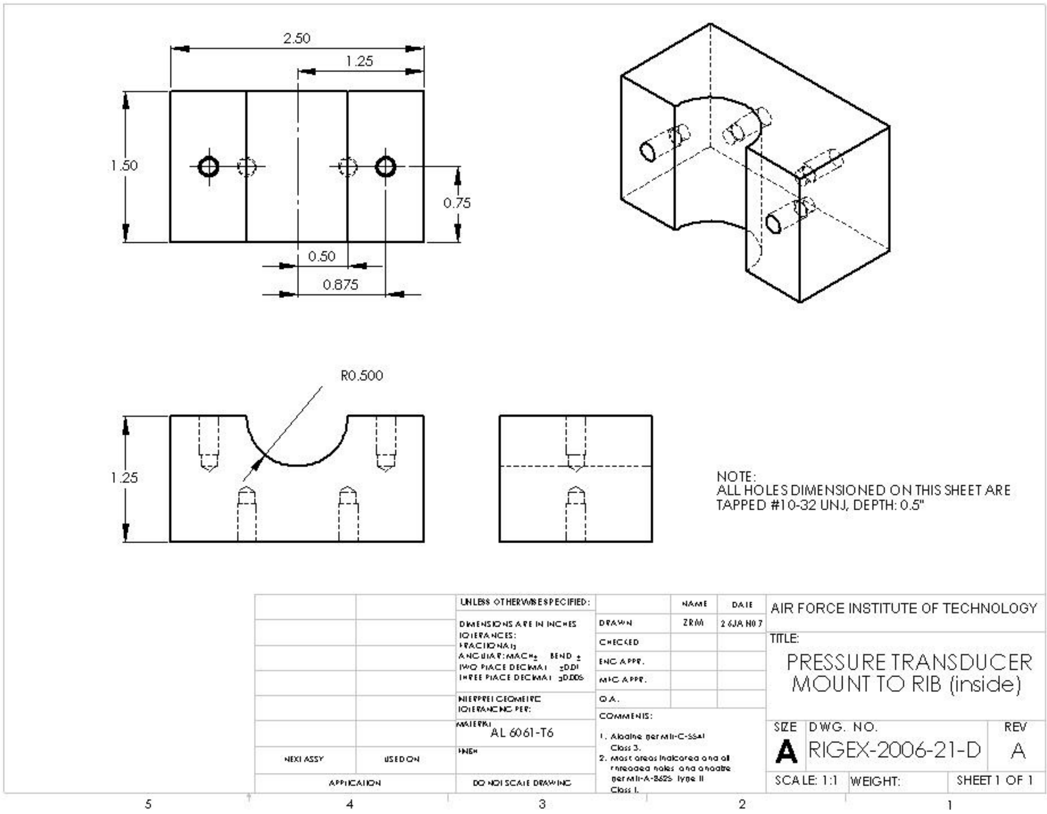

0.38
6.750
5.375
3.250
1.125
9.00
7.625
5.375
3.125
0.875
8.125
5.875
3.625
1.375
1.375
3.500
5.625
6.75
NOTE:
ALL HOLES: .201 DIA. THRU
CSINK .385 DIA. X 100 DEGREES
AIR FORCE INSTITUTE
OF TECHNOLOGY
BOTTOM RECTANGULAR
PLATE
A
RIGEX-2006-8-D
B
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING

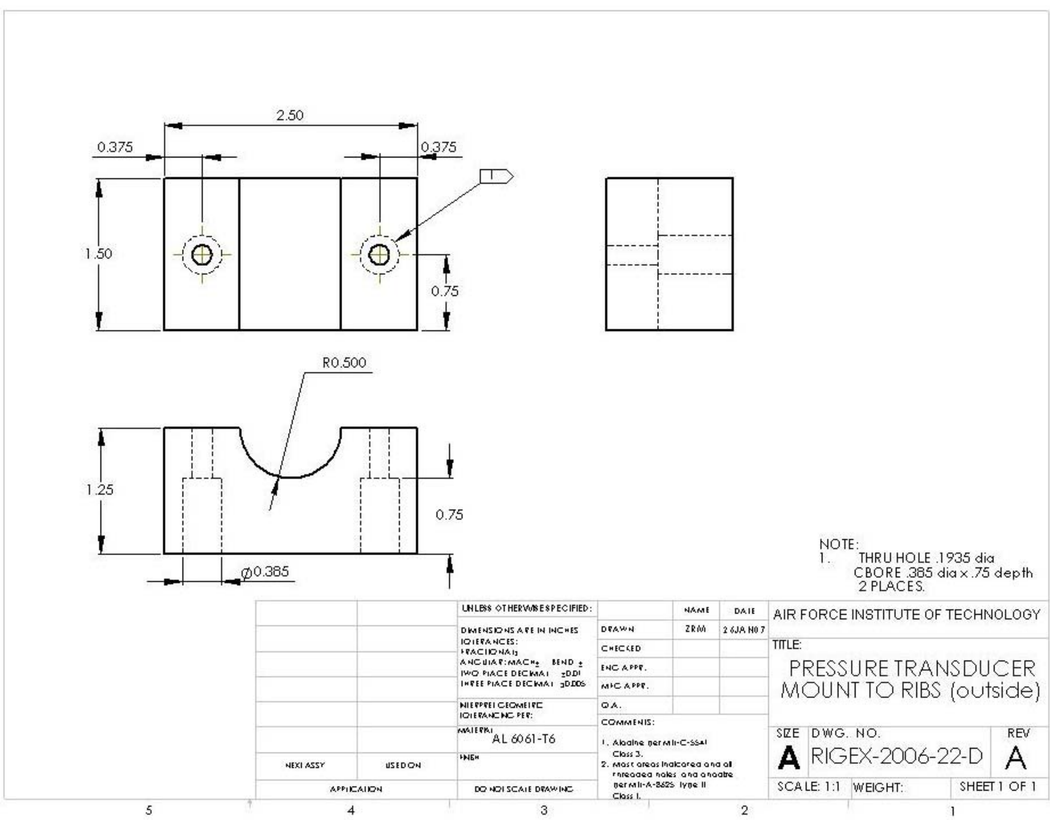

0.500
0.500
0.325
1.750
0.325
1
2
R0.500
0.800
1.500
NOTES:
1. TAPPED FOR #10-32 UNJ (FROM TOP) 2 PLACES
2. TAPPED FOR #10-32 UNJ (FROM BOTTOM) 2 PLACES
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
NAME
DATE
DRAWN
ZRM
26JAN07
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
AL 6061-T6
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
AIR FORCE INSTITUTE OF TECHNOLOGY
TITLE:
PRESSURE TRANSDUCER MOUNT TO BOTTOM OF OVEN PLATE (inside)
SIZE
DWG. NO.
REV
A
RIGEX-2006-18-D
A
SCALE: 1.5:1
WEIGHT:
SHEET 1 OF 1
5
4
3
2
1

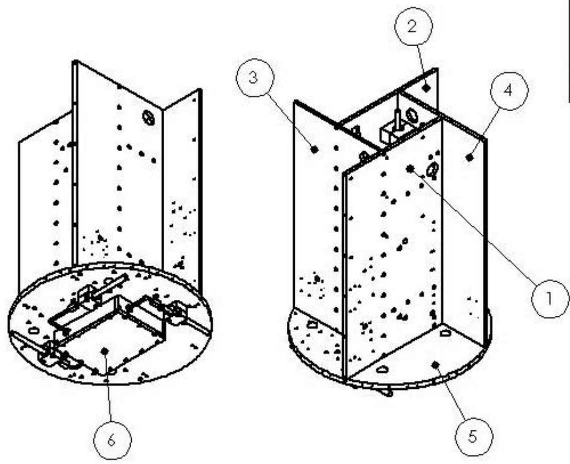

1.000
0.185
1.750
0.190
1
R0.500
0.750
0.400
NOTES:
1. CBORE DIAMETER: 0.438"
CBORE DEPTH: 0.40"
CSINK .385 dia x 100 deg
0.201" dia THRU
2 PLACES
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
NAME
DATE
DRAWN
ZRM
26JAN07
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
AL 6061-T6
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
AIR FORCE INSTITUTE OF TECHNOLOGY
TITLE:
PRESSURE TRANSDUCER MOUNT TO BOTTOM OF OVEN PLATE (outside)
SIZE
DWG. NO.
REV
A
RIGEX-2006-19-D
A
SCALE: 1.5:1
WEIGHT:
SHEET 1 OF 1
5
4
3
2
1


NOTES:
1. BLIND HOLES ARE TAPPED #10-32 UNJ DEPTH: 0.54", 14 PLACES
TWO (2) COPIES OF THIS PART ARE REQUIRED
1.25
1.75
1.75
0.375
0.1875
1.25
1.25
1.25
8.25
Ø1.00
1.25
1.25
6.00
1.25
1.75
2.00
2.00
AIR FORCE INSTITUTE OF TECHNOLOGY
TITLE:
Inflation System Mounting Plate
AL 6061-T6
SIZE A
DWG. NO. RIGEX-2006-9-1
REV A
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1


0.500
0.219
1.125
0.950
1.500
0.50
NOTES:
1. CBORE 0.27 dia X .80 DEPTH, THRU HOLE .129 dia, 2 PLACES
2. TAPPED #10-32 UNJ HOLES, DEPTH: 0.54", 2 PLACES
AIR FORCE INSTITUTE OF TECHNOLOGY
TITLE:
SOLENOID MOUNTING BLOCK
AL 6061-T6
SIZE A
DWG. NO. RIGEX-2006-20-D
REV D
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1


2.50
1.25
1.50
0.75
0.50
0.875
R0.500
1.25
NOTE:
ALL HOLES DIMENSIONED ON THIS SHEET ARE TAPPED #10-32 UNJ, DEPTH: 0.5"
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
NAME
DATE
DRAWN
ZRM
26JAN07
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
AL 6061-T6
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
AIR FORCE INSTITUTE OF TECHNOLOGY
TITLE:
PRESSURE TRANSDUCER MOUNT TO RIB (inside)
SIZE
DWG. NO.
REV
A
RIGEX-2006-21-D
A
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1
5
4
3
2
1


2.50
0.375
0.375
1.50
0.75
R0.500
1.25
0.75
∅0.385
NOTE:
1. THRU HOLE .1935 dia CBORE .385 dia x .75 depth 2 PLACES.
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
NAME
DATE
DRAWN
ZRM
26JAN07
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
AL 6061-T6
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
AIR FORCE INSTITUTE OF TECHNOLOGY
TITLE:
PRESSURE TRANSDUCER MOUNT TO RIBS (outside)
SIZE
DWG. NO.
REV
A
RIGEX-2006-22-D
A
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1
5
4
3
2
1



Item #	DRAWING #	NOMENCLATURE OR DECRIPTION	QUANTITY
1	RIGEX-2006-3-D	Large Computer Rib	1
2	RIGEX-2006-4-D	Large Rib	1
3	RIGEX-2006-5-D	Small Rib w/ Pin Puller	1
4	RIGEX-2006-6-D	Small Rib w/o Pin Puller	1
5	RIGEX-2006-7-D	Oven Mounting Plate	1
6	RIGEX-2006-8-D	Bottom Rectangle Plate	1

Notes:
1. Assembly of the Wave #1 Subassembly is outlined in RP-1

2. Pressure system components shown in the pictures to the left are part of the RIGEX Inflation System. A detailed sketch of the RIGEX Inflation System is shown on page 2 of this document.

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES

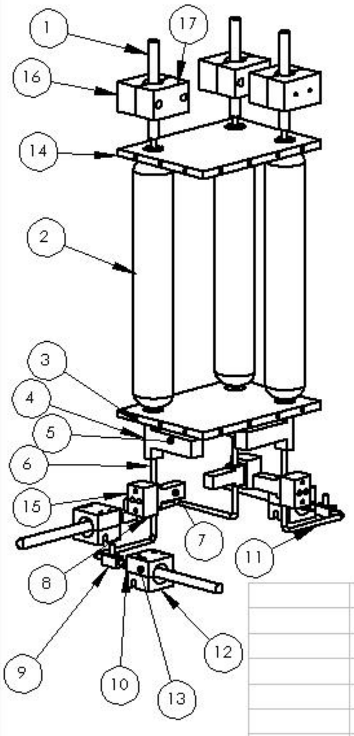
DRAWN ZRM 03JUN07

AIR FORCE INSTITUTE OF TECHNOLOGY

TITLE: RIGEX WAVE 1 ASSEMBLY

SIZE A DWG. NO. RIGEX-WAVE1-D REV A

SCALE: 1:1 WEIGHT: SHEET 1 OF 2



Item #	DRAWING #	NOMENCLATURE OR DECRIPTION	QUANTITY
1	N/A	Pressure Transducer	6
2	N/A	N2 Pressure Tank	3
3	N/A	1/4" MNPT to 1/4" tube fitting	3
4	N/A	Pipe T for gas	3
5	N/A	Fill Valve	3
6	N/A	1/8" MNPT to 1/4" tube adaptor	3
7	N/A	Solenoid	3
8	N/A	1/8" NPT to 1/4" tube fitting	3
9	N/A	Pipe T under tubes	3
10	N/A	1/4" FNPT to 1/4" tube adaptor	3
11	N/A	1/4" OD Tubing	A/R
12	RIGEX-2006-18-D	Pressure Transducer Mount to Bottom of Oven Plate (inside)	3
13	RIGEX-2006-19-D	Pressure Transducer Mount to Bottom of Oven Plate (outside)	3
14	RIGEX-2006-9-D	Inflation System Mounting Plate	2
15	RIGEX-2006-20-D	Solenoid Mount	3
16	RIGEX-2006-21-D	Pressure Transducer Mount to Ribs (inside)	3
17	RIGEX-2006-22-D	Pressure Transducer Mount to Ribs (outside)	3

NOTES:
1. Inflation System is assembled in conjunction with the Wave #1 Subassembly.

2. Manufacture specifies the following installation techniques: All NPT fittings should be wrench-tight and all Compression fittings should be tightened 1 and 1/4 turn past finger-tight

3. Swagelok Teflon tape used on all NPT fittings

4. Staking compound used on all fittings to prevent back-out

5. Use of Viton between Nitrogen Pressure Tank and Inflation System Mounting Plate illustrated on page 3 of this document

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES

DRAWN ZRM 03JUN07

AIR FORCE INSTITUTE OF TECHNOLOGY

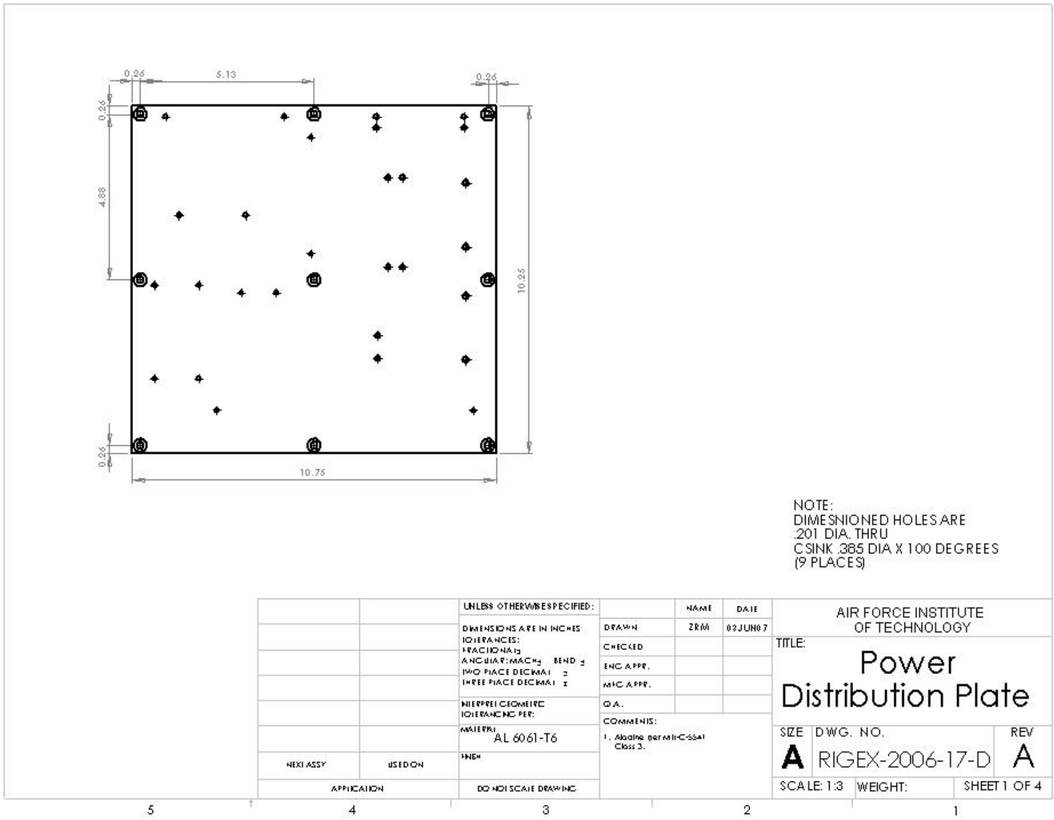
TITLE: RIGEX WAVE 1 ASSEMBLY

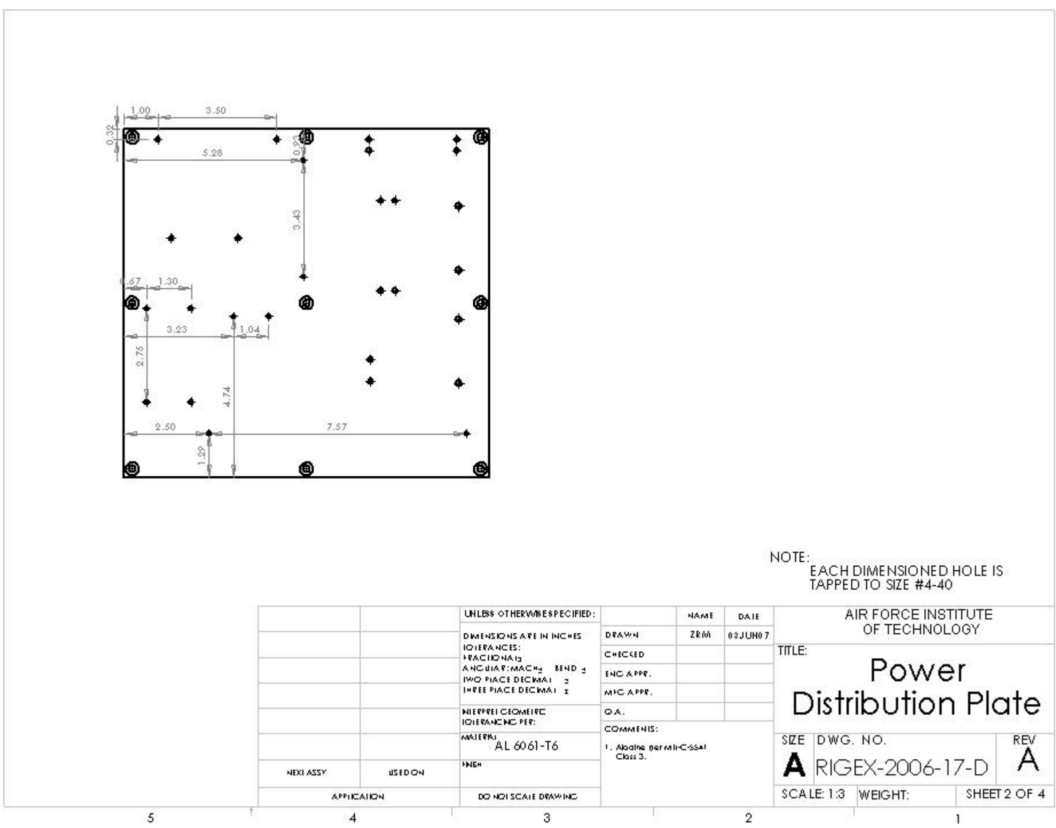
SIZE A DWG. NO. RIGEX-WAVE1-D REV A

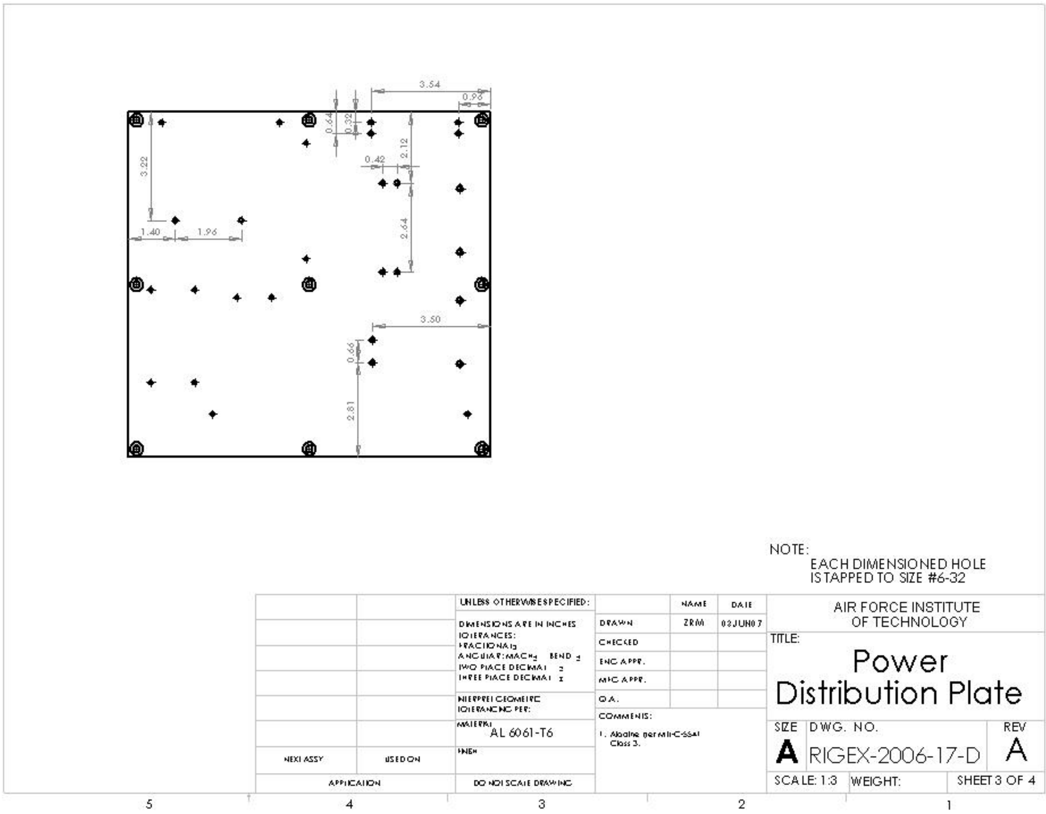
SCALE: 1:1 WEIGHT: SHEET 2 OF 2

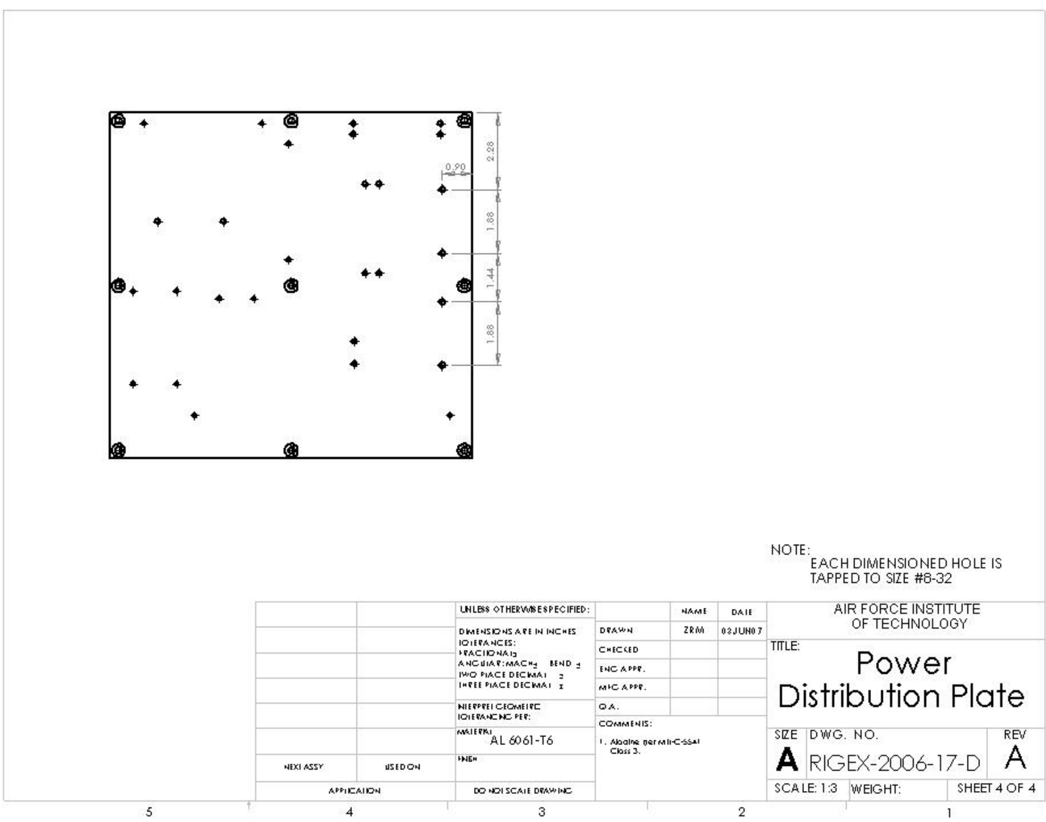
WAVE2	RIGEX-WAVE2-P	RIGEX-WAVE2-D		
QUANTITY	**PART OR IDENTIFICATION #**	**DRAWING #**	**NOMENCLATURE OR DECRIPTION**	**MATERIAL**
1	RIGEX-WAVE1-P	RIGEX-WAVE1-D	Wave 1 Subassembly	N/A
1	RIGEX-PDP-P	RIGEX-PDP-D	Power Distribution Plate Subassembly	N/A
1	RIGEX-COMP-P	RIGEX-COMP-D	Computer Subassembly	N/A
1	RIGEX-OVEN-P	RIGEX-OVEN-D	Oven Box Subassembly	N/A
1	RIGEX-2006-2-P	RIGEX-2006-2-D	Experiment Top Plate	Al
3	RIGEX-2006-10-P	RIGEX-2006-10-D	Oven Bracket Piece 1	Al
3	RIGEX-2006-11-P	RIGEX-2006-11-D	Oven Bracket Piece 2	Al
3	RIGEX-2006-12-P	RIGEX-2006-12-D	Oven Latch	Al
3	##	N/A	Oven Latch Hinge	SS
3	##	N/A	L'Garde Tube	CLASSIFIED
3	##	N/A	Pin Puller	N/A
3	##	N/A	Fuse Block	N/A
3	##	N/A	Solid State Relay	N/A
3	##	N/A	Fuse Block	N/A
3	##	N/A	Transformer	N/A
3	##	N/A	4 Fuse Block	N/A
12	##	N/A	Oven Controller	N/A

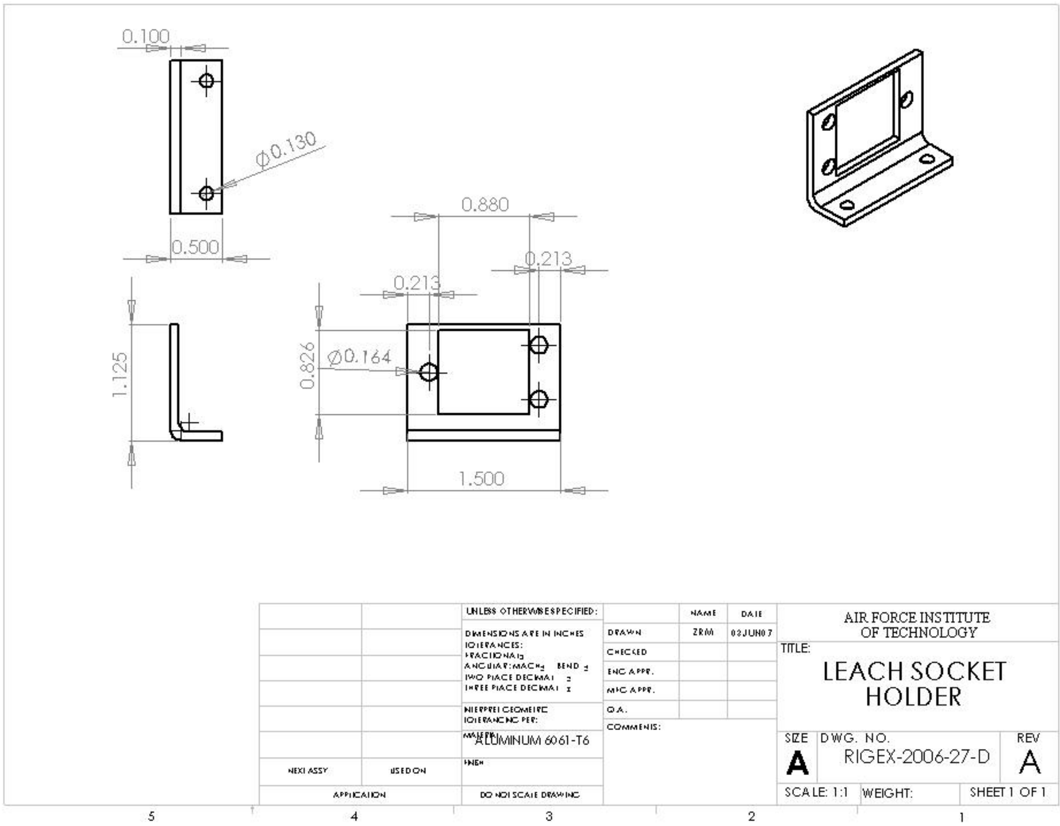
	QUANTITY	PART OR IDENTIFICATION #	DRAWING #	NOMENCLATURE OR DECRIPTION	MATERIAL
PDP Subassembly	1	##	N/A	EMI Filter	N/A
	2	##	N/A	Power Relay	N/A
	1	##	N/A	8AWG 10p Terminal Block	N/A
	1	RIGEX-2006-17-P	RIGEX-2006-17-D	Power Distribution Plate	Al
	2	##	N/A	8AWG 4p Terminal Block	N/A
	1	##	N/A	4Fuse Block	N/A
	1	##	N/A	2 Fuse Block	N/A
	1	##	N/A	22AWG 6p Terminal Block	N/A
	1	##	N/A	YC Relay	N/A
	1	RIGEX-2006-27-P	RIGEX-2006-27-D	Leach Socket Holder	AL
	1	##	N/A	Leach Socket	N/A
Computer Subassembly	1	##	N/A	Computer Container	Al
	2	RIGEX-2006-23-P	RIGEX-2006-23-D	Computer Mounting Plate	Al
	1	##	N/A	Computer Container Lid	Al
	1	##	N/A	Computer Container Bottom	Al
Oven Box Subassembly	3	RIGEX-OVENBB-P	RIGEX-OVENBB-D	Oven Bottom	Ultem
	6	RIGEX-OVENSS-P	RIGEX-OVENSS-D	Oven Small Side	Ultem
	6	RIGEX-OVENLS-P	RIGEX-OVENLS-D	Oven Large Side	Ultem
	6	RIGEX-OVENDD-P	RIGEX-OVENDD-D	Oven Door	Ultem

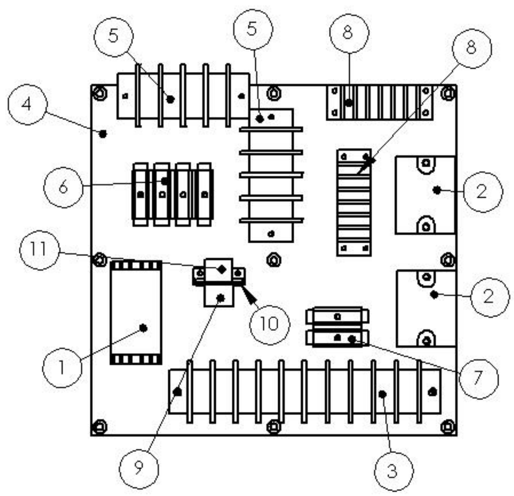

0.26
5.13
0.26
4.88
10.25
10.75
NOTE:
DIMESNIONED HOLES ARE
.201 DIA. THRU
CSINK .385 DIA X 100 DEGREES
(9 PLACES)
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DIMENSIONS ARE IN INCHES
DRAWN
ZRM
03JUN07
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
MATERIAL
AL 6061-T6
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
AIR FORCE INSTITUTE
OF TECHNOLOGY
TITLE:
Power
Distribution Plate
SIZE
DWG. NO.
REV
A
RIGEX-2006-17-D
A
SCALE: 1:3
WEIGHT:
SHEET 1 OF 4


1.00
3.50
0.32
5.28
3.43
0.67
1.30
3.23
1.04
2.75
4.74
2.50
7.57
1.29
NOTE:
EACH DIMENSIONED HOLE IS
TAPPED TO SIZE #4-40
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DIMENSIONS ARE IN INCHES
DRAWN
ZRM
03JUN07
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
MATERIAL
AL 6061-T6
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
AIR FORCE INSTITUTE
OF TECHNOLOGY
TITLE:
Power
Distribution Plate
SIZE
DWG. NO.
REV
A
RIGEX-2006-17-D
A
SCALE: 1:3
WEIGHT:
SHEET 2 OF 4

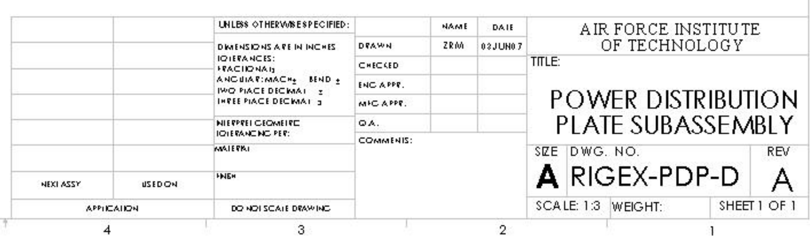

3.54
0.96
0.64
0.32
3.22
0.42
2.12
1.40
1.96
2.64
3.50
0.66
2.81
NOTE:
EACH DIMENSIONED HOLE IS TAPPED TO SIZE #6-32
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
MATERIAL AL 6061-T6
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
ZRM
03JUN07
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
AIR FORCE INSTITUTE OF TECHNOLOGY
TITLE:
Power Distribution Plate
SIZE
A
DWG. NO.
RIGEX-2006-17-D
REV
A
SCALE: 1:3
WEIGHT:
SHEET 3 OF 4
5
4
3
2
1

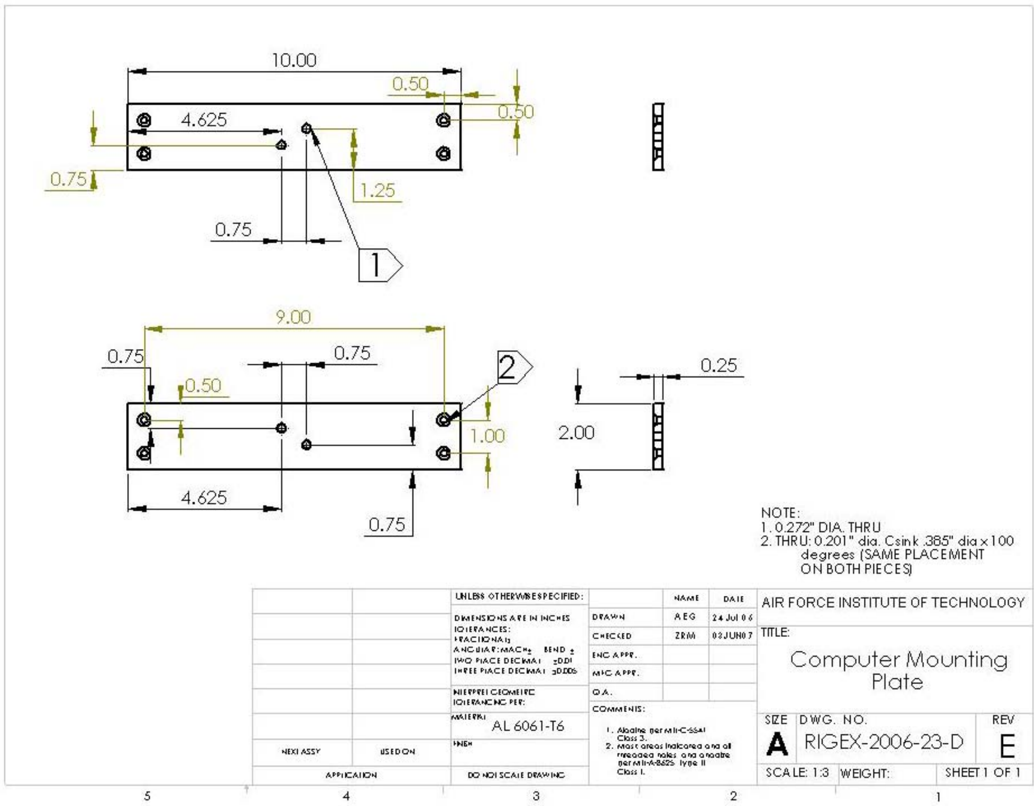

2.28
0.90
1.88
1.44
1.88
NOTE:
EACH DIMENSIONED HOLE IS TAPPED TO SIZE #8-32
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
MATERIAL AL 6061-T6
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
ZRM
03JUN07
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
AIR FORCE INSTITUTE OF TECHNOLOGY
TITLE:
Power Distribution Plate
SIZE
A
DWG. NO.
RIGEX-2006-17-D
REV
A
SCALE: 1:3
WEIGHT:
SHEET 4 OF 4
5
4
3
2
1

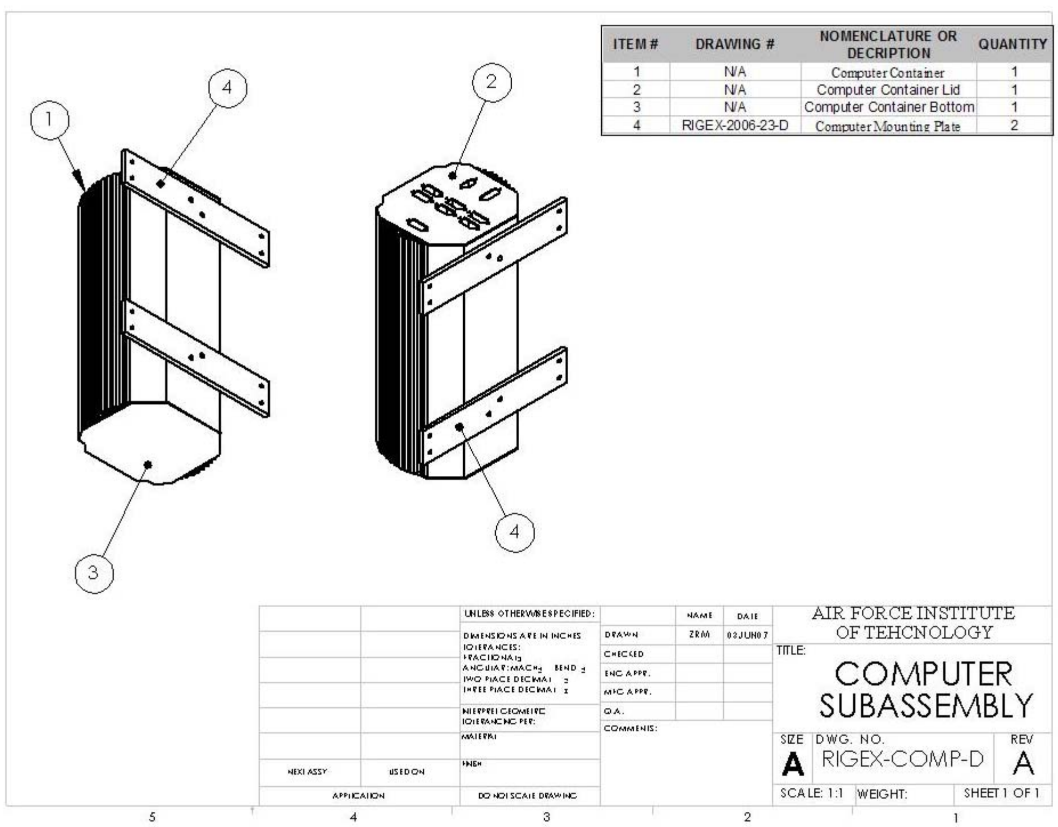


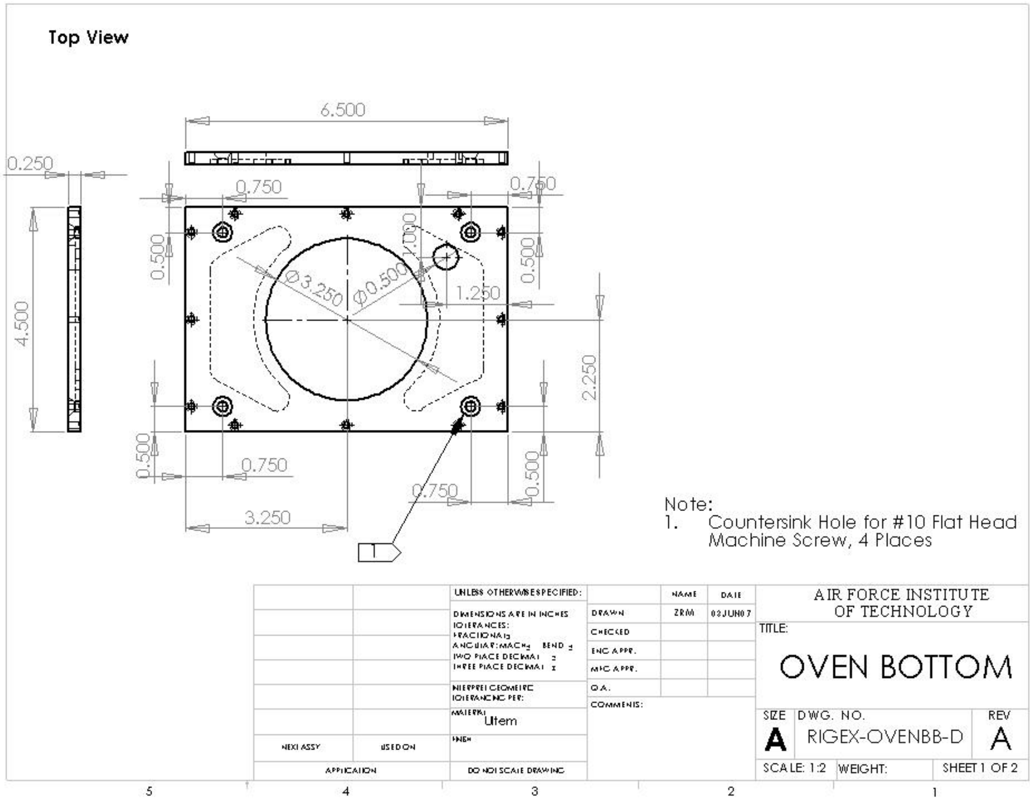


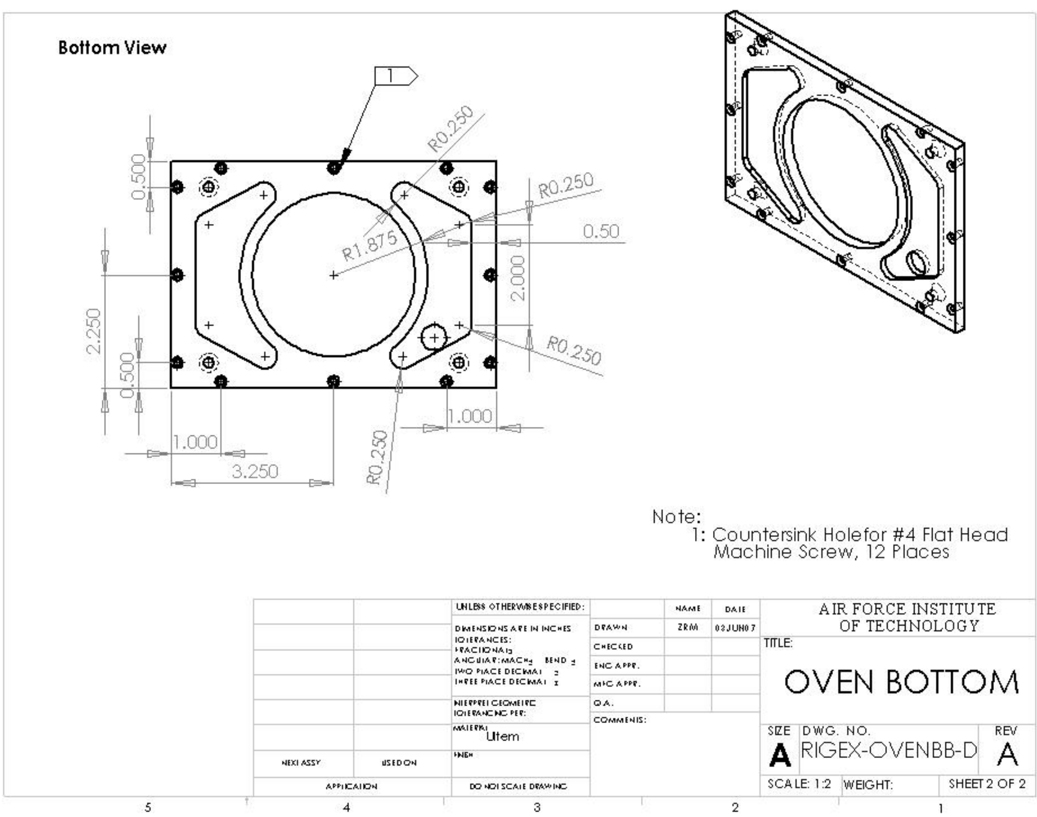
ITEM NO.	Drawing #	DESCRIPTION	QTY.
1	N/A	EMI Filter	1
2	N/A	Power Relay	2
3	N/A	8AWG 10p Terminal Block	1
4	RIGEX-2006-17-D	Power Distrobution Plate	1
5	N/A	8AWG 4p Terminal Block	2
6	N/A	4 Fuse Block	1
7	N/A	2 Fuse Block	1
8	N/A	22AWG 6p Terminal Block	1
9	N/A	YC Relay	1
10	RIGEX-2006-27-D	Leach Socket Holder	1
11	N/A	Leach Socket	1

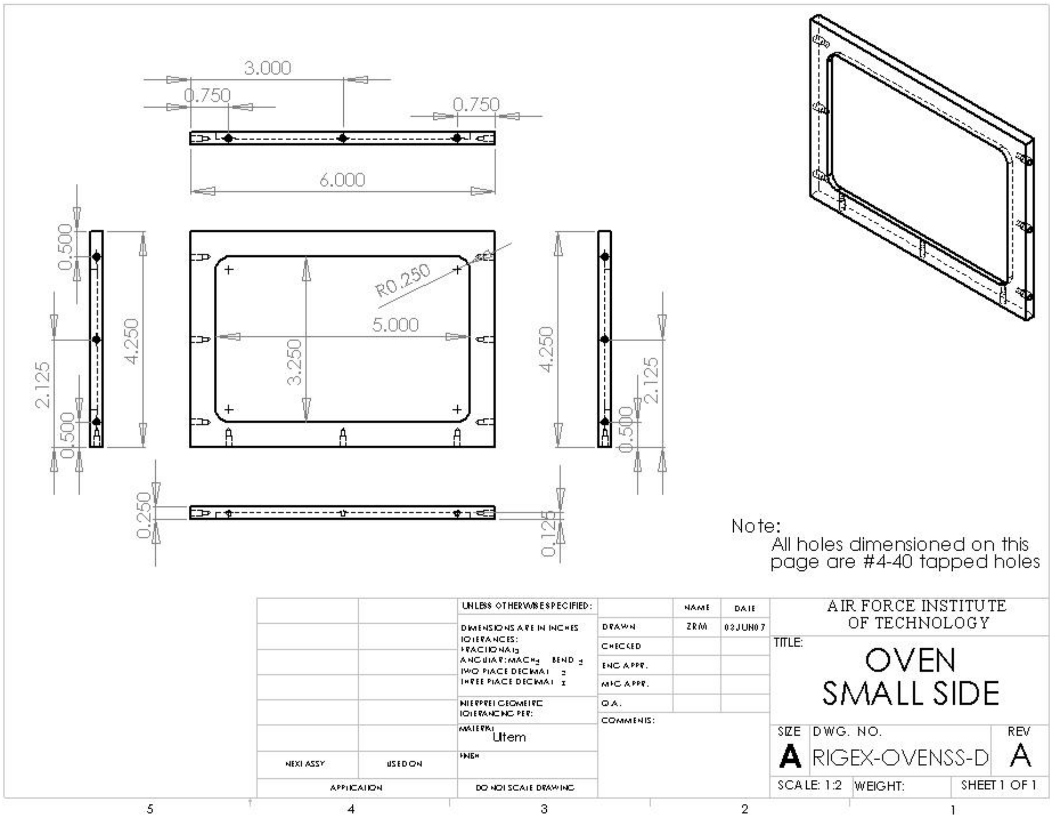


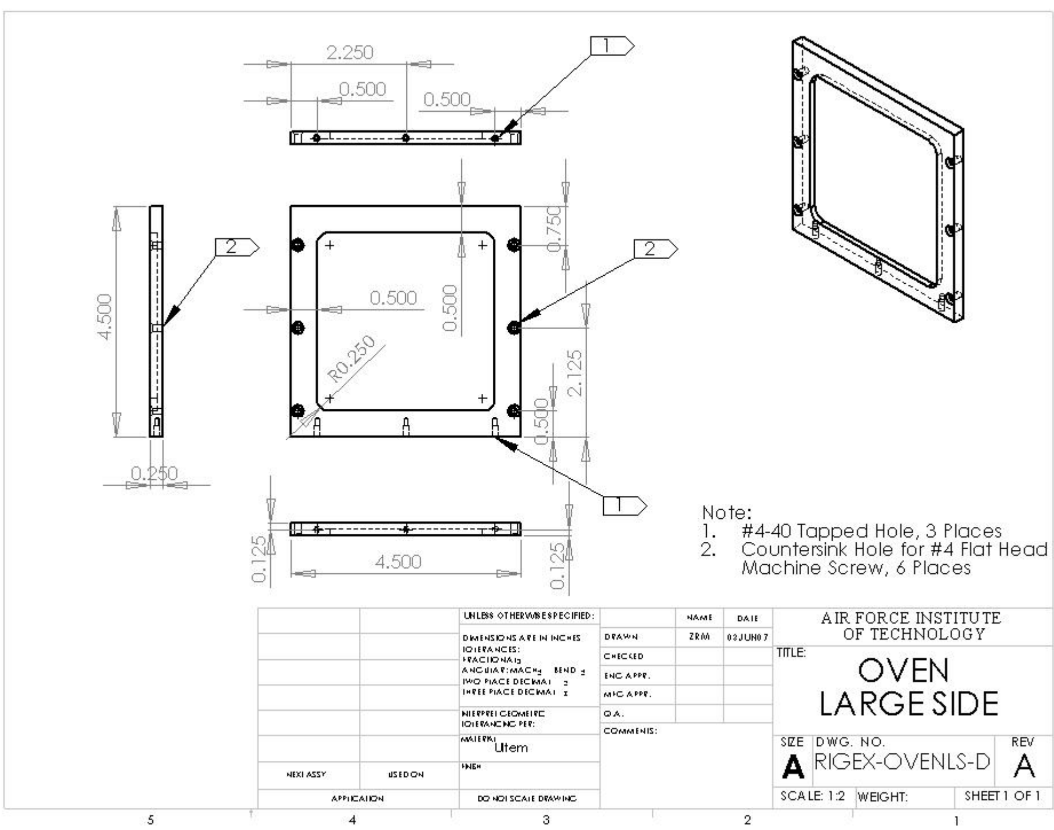

10.00
0.50
0.50
4.625
0.75
1.25
0.75
1
9.00
0.75
0.75
0.50
2
0.25
1.00
2.00
4.625
0.75
NOTE:
1. 0.272" DIA. THRU
2. THRU: 0.201" dia. Csink .385" dia x 100 degrees (SAME PLACEMENT ON BOTH PIECES)
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DRAWN
AEG
24 Jul 06
CHECKED
ZRM
03JUN07
AIR FORCE INSTITUTE OF TECHNOLOGY
TITLE:
Computer Mounting Plate
MATERIAL
AL 6061-T6
SIZE
A
DWG. NO.
RIGEX-2006-23-D
REV
E
SCALE: 1:3
WEIGHT:
SHEET 1 OF 1
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING

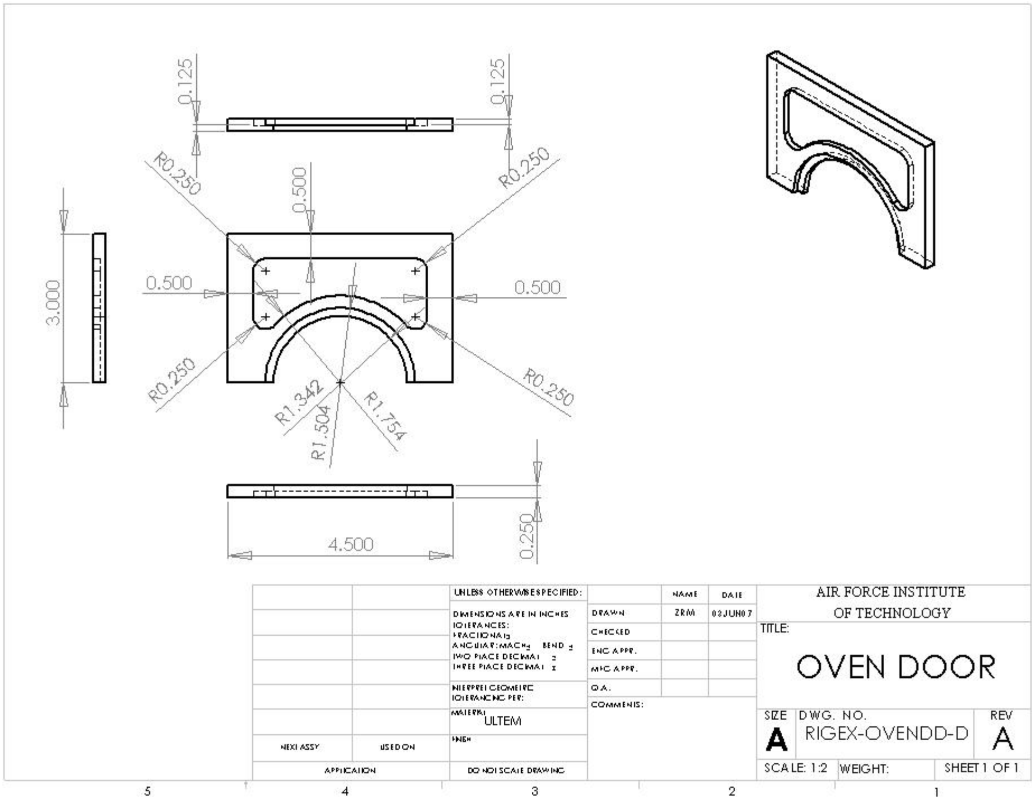

ITEM #
DRAWING #
NOMENCLATURE OR DECRIPTION
QUANTITY
1
N/A
Computer Container
1
2
N/A
Computer Container Lid
1
3
N/A
Computer Container Bottom
1
4
RIGEX-2006-23-D
Computer Mounting Plate
2
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DRAWN
ZRM
03JUN07
AIR FORCE INSTITUTE OF TEHCNOLOGY
TITLE:
COMPUTER SUBASSEMBLY
SIZE
A
DWG. NO.
RIGEX-COMP-D
REV
A
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING

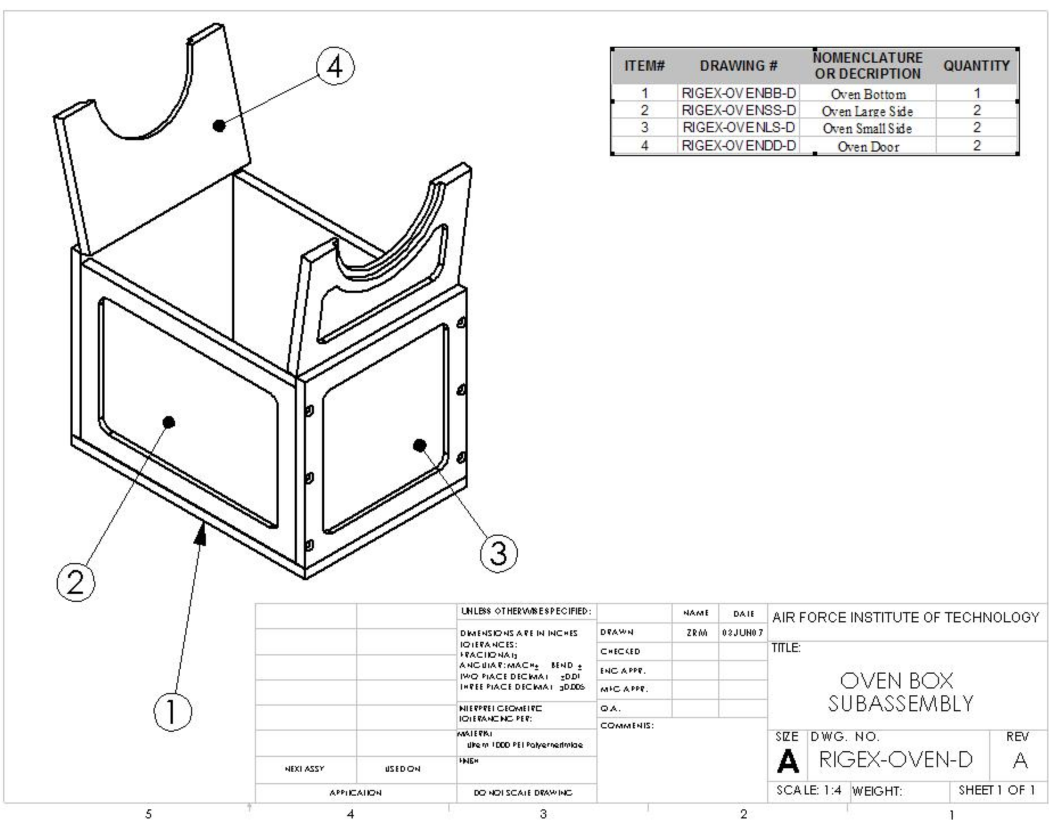

Top View
6.500
0.250
0.750
0.750
0.500
1.000
0.500
Ø3.250
Ø0.500
1.250
4.500
2.250
0.500
0.750
0.500
0.750
3.250
1
Note:
1. Countersink Hole for #10 Flat Head Machine Screw, 4 Places
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
NAME
DATE
DRAWN
ZRM
03JUN07
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
MATERIAL
Ultem
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
AIR FORCE INSTITUTE OF TECHNOLOGY
TITLE:
OVEN BOTTOM
SIZE
A
DWG. NO.
RIGEX-OVENBB-D
REV
A
SCALE: 1:2
WEIGHT:
SHEET 1 OF 2
5
4
3
2
1


Bottom View
1
R0.250
0.500
R0.250
0.50
R1.875
2.000
2.250
0.500
R0.250
1.000
1.000
3.250
R0.250
Note:
1: Countersink Holefor #4 Flat Head Machine Screw, 12 Places
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
NAME
DATE
DRAWN
ZRM
03JUN07
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
MATERIAL
Ultem
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
AIR FORCE INSTITUTE OF TECHNOLOGY
TITLE:
OVEN BOTTOM
SIZE
A
DWG. NO.
RIGEX-OVENBB-D
REV
A
SCALE: 1:2
WEIGHT:
SHEET 2 OF 2
5
4
3
2
1

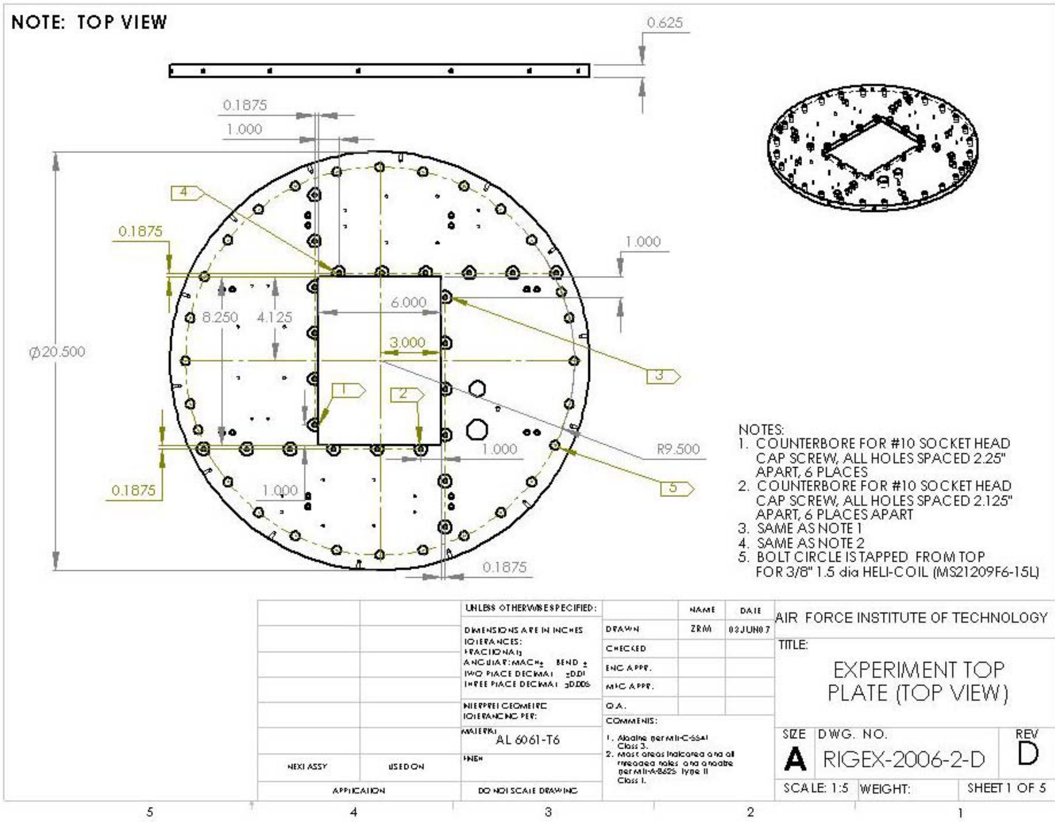

3.000
0.750
0.750
6.000
0.500
4.250
2.125
0.500
R0.250
5.000
3.250
4.250
2.125
0.500
0.250
0.125
Note:
All holes dimensioned on this page are #4-40 tapped holes
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DIMENSIONS ARE IN INCHES
DRAWN
ZRM
03JUN07
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
MATERIAL
Ultem
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
AIR FORCE INSTITUTE OF TECHNOLOGY
TITLE:
OVEN
SMALL SIDE
SIZE
DWG. NO.
REV
A
RIGEX-OVENSS-D
A
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1
5
4
3
2
1

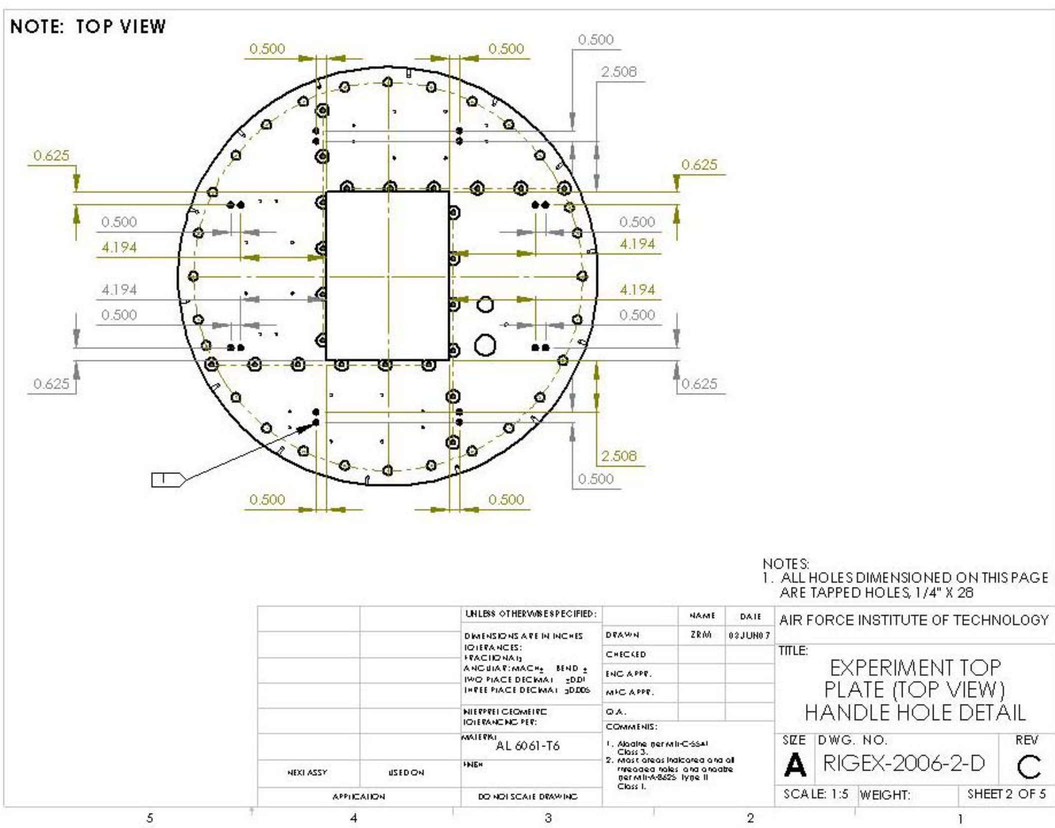

2.250
0.500
0.500
1
4.500
2
0.750
0.500
0.500
2
R0.250
2.125
0.500
0.250
1
0.125
4.500
0.125
Note:
1. #4-40 Tapped Hole, 3 Places
2. Countersink Hole for #4 Flat Head Machine Screw, 6 Places
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DIMENSIONS ARE IN INCHES
DRAWN
ZRM
03JUN07
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
MATERIAL
Ultem
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
AIR FORCE INSTITUTE OF TECHNOLOGY
TITLE:
OVEN
LARGE SIDE
SIZE
DWG. NO.
REV
A
RIGEX-OVENLS-D
A
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1
5
4
3
2
1

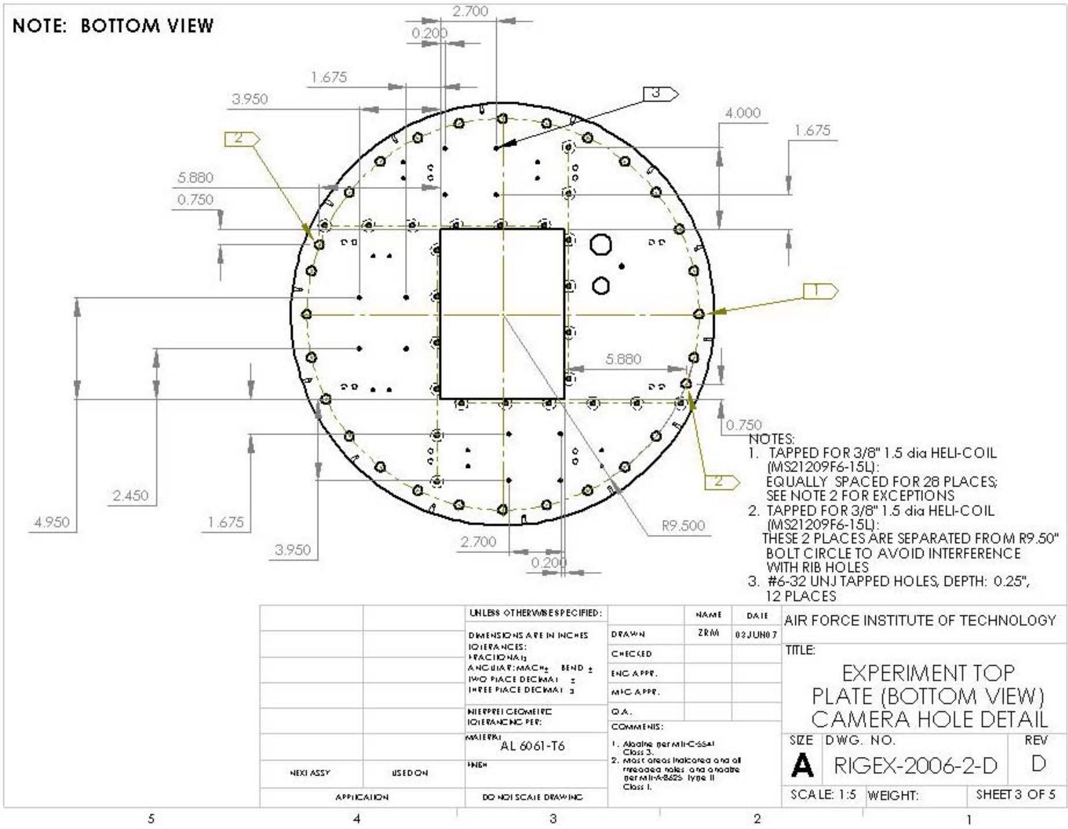


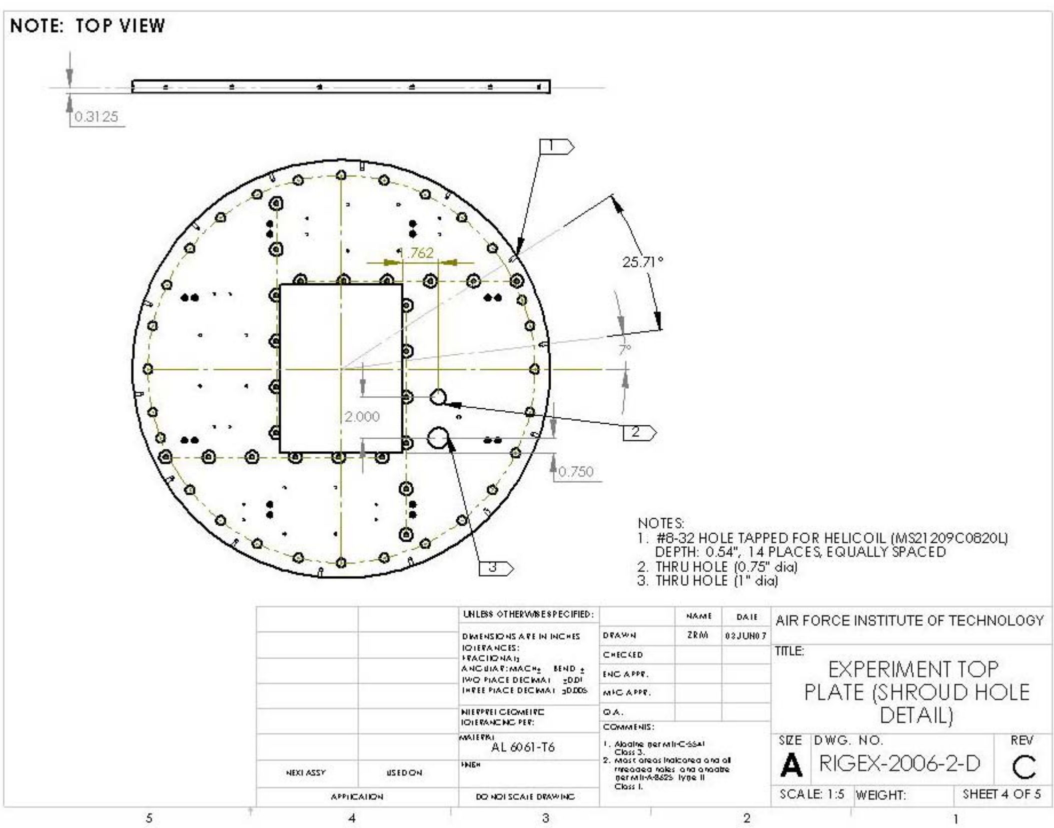


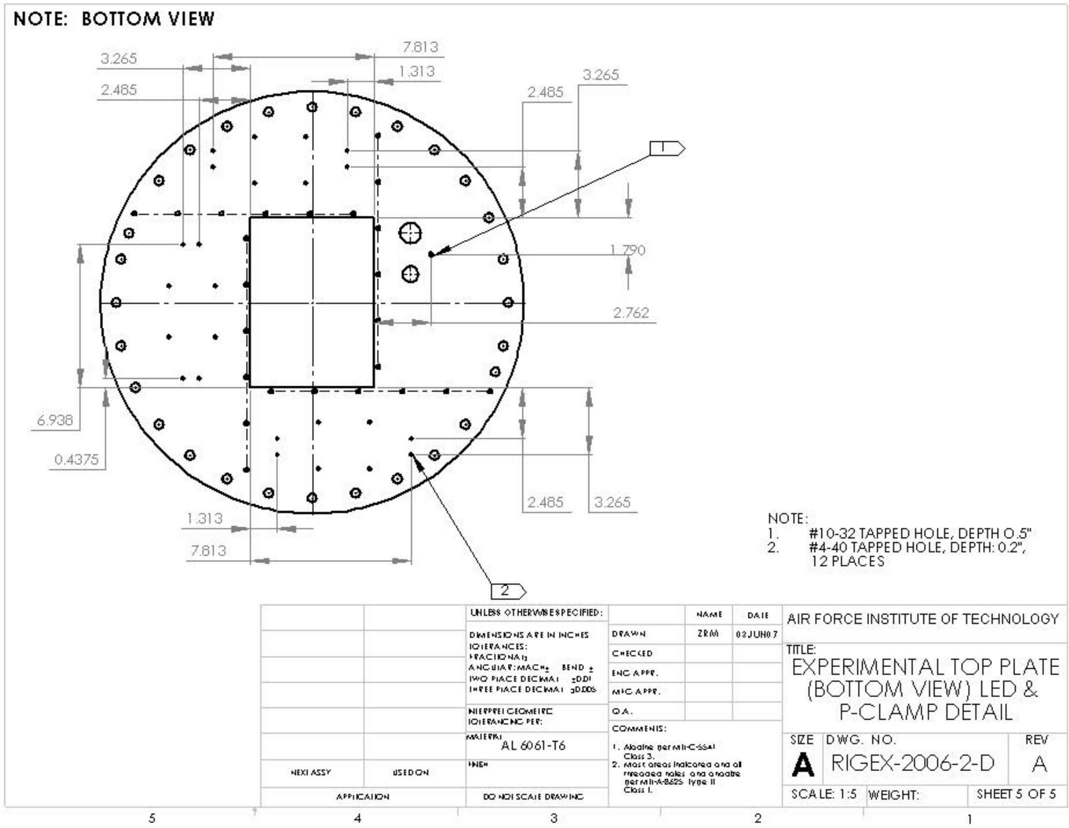
ITEM#	DRAWING #	NOMENCLATURE OR DECRIPTION	QUANTITY
1	RIGEX-OVENBB-D	Oven Bottom	1
2	RIGEX-OVENSS-D	Oven Large Side	2
3	RIGEX-OVENLS-D	Oven Small Side	2
4	RIGEX-OVENDD-D	Oven Door	2

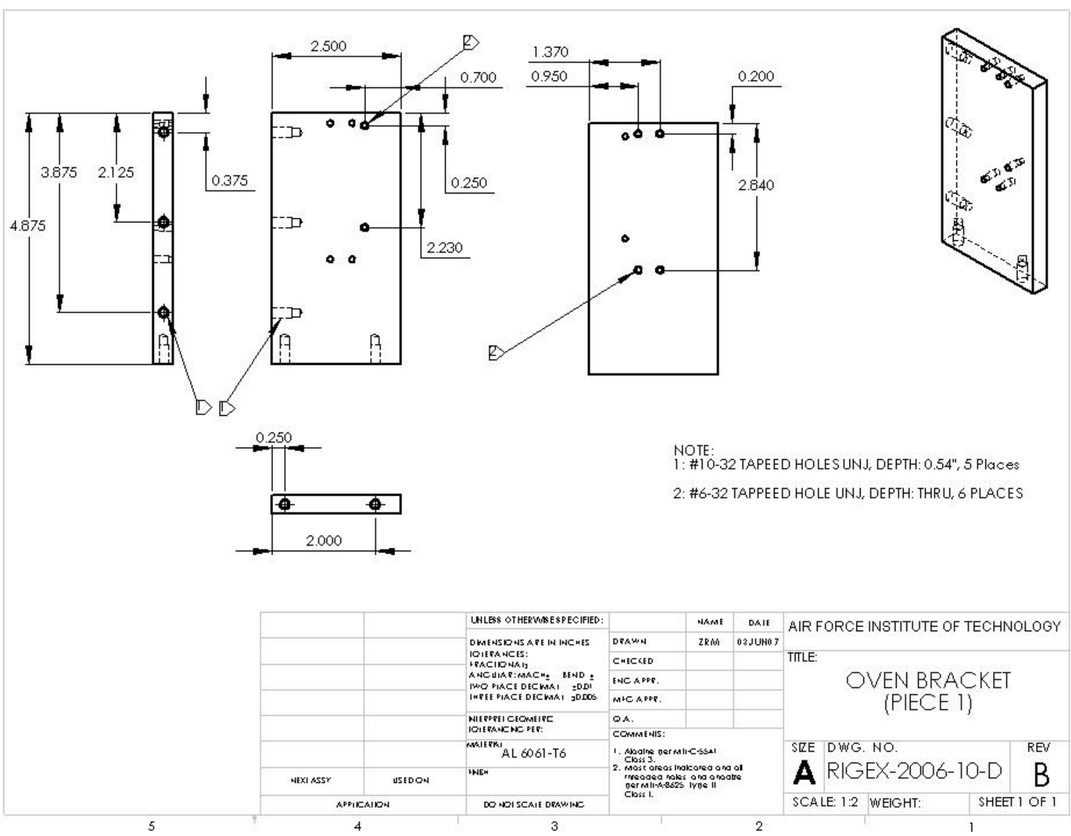

NOTE: TOP VIEW
0.625
0.1875
1.000
0.1875
1.000
8.250
4.125
6.000
3.000
Ø20.500
R9.500
1.000
0.1875
1.000
0.1875
NOTES:
1. COUNTERBORE FOR #10 SOCKET HEAD CAP SCREW, ALL HOLES SPACED 2.25" APART, 6 PLACES
2. COUNTERBORE FOR #10 SOCKET HEAD CAP SCREW, ALL HOLES SPACED 2.125" APART, 6 PLACES APART
3. SAME AS NOTE 1
4. SAME AS NOTE 2
5. BOLT CIRCLE IS TAPPED FROM TOP FOR 3/8" 1.5 dia HELI-COIL (MS21209F6-15L)
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
DRAWN ZRM 03JUN07
MATERIAL AL 6061-T6
AIR FORCE INSTITUTE OF TECHNOLOGY
TITLE:
EXPERIMENT TOP PLATE (TOP VIEW)
SIZE A
DWG. NO. RIGEX-2006-2-D
REV D
SCALE: 1:5
WEIGHT:
SHEET 1 OF 5

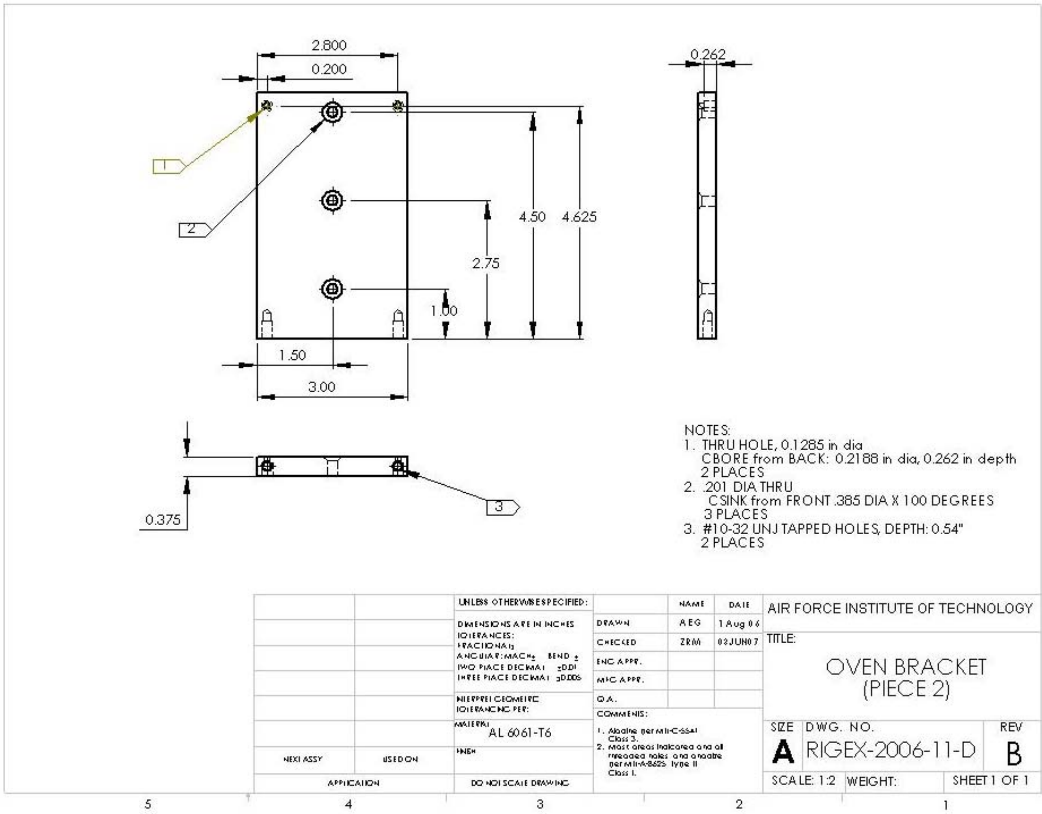

NOTE: TOP VIEW
0.500
0.500
0.500
2.508
0.625
0.625
0.500
4.194
4.194
0.500
0.500
4.194
4.194
0.500
0.625
0.625
2.508
0.500
0.500
0.500
NOTES:
1. ALL HOLES DIMENSIONED ON THIS PAGE ARE TAPPED HOLES, 1/4" X 28
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
DRAWN ZRM 03JUN07
MATERIAL AL 6061-T6
AIR FORCE INSTITUTE OF TECHNOLOGY
TITLE:
EXPERIMENT TOP PLATE (TOP VIEW) HANDLE HOLE DETAIL
SIZE A
DWG. NO. RIGEX-2006-2-D
REV C
SCALE: 1:5
WEIGHT:
SHEET 2 OF 5

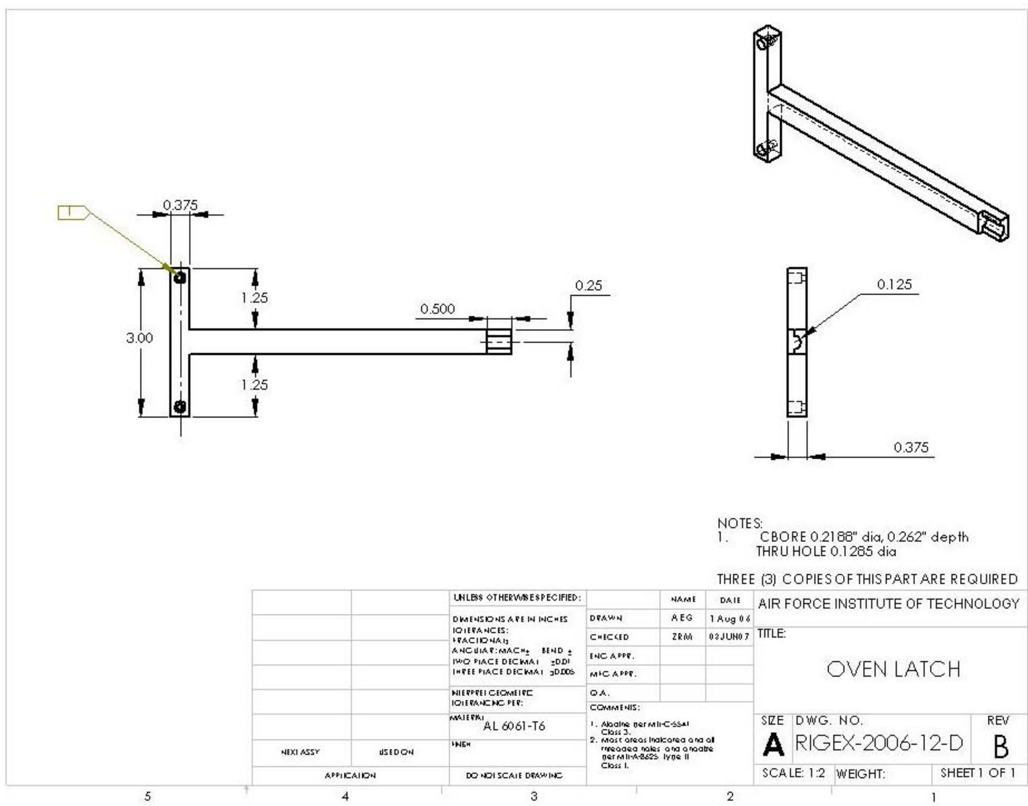

NOTE: BOTTOM VIEW
2.700
0.200
1.675
3.950
4.000
1.675
5.880
0.750
5.880
0.750
2.450
4.950
1.675
3.950
2.700
0.200
R9.500
NOTES:
1. TAPPED FOR 3/8" 1.5 dia HELI-COIL (MS21209F6-15L): EQUALLY SPACED FOR 28 PLACES; SEE NOTE 2 FOR EXCEPTIONS
2. TAPPED FOR 3/8" 1.5 dia HELI-COIL (MS21209F6-15L): THESE 2 PLACES ARE SEPARATED FROM R9.50" BOLT CIRCLE TO AVOID INTERFERENCE WITH RIB HOLES
3. #6-32 UNJ TAPPED HOLES, DEPTH: 0.25", 12 PLACES
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
DRAWN ZRM 03JUN07
AL 6061-T6
AIR FORCE INSTITUTE OF TECHNOLOGY
TITLE:
EXPERIMENT TOP PLATE (BOTTOM VIEW) CAMERA HOLE DETAIL
SIZE A DWG. NO. RIGEX-2006-2-D REV D
SCALE: 1:5 WEIGHT: SHEET 3 OF 5

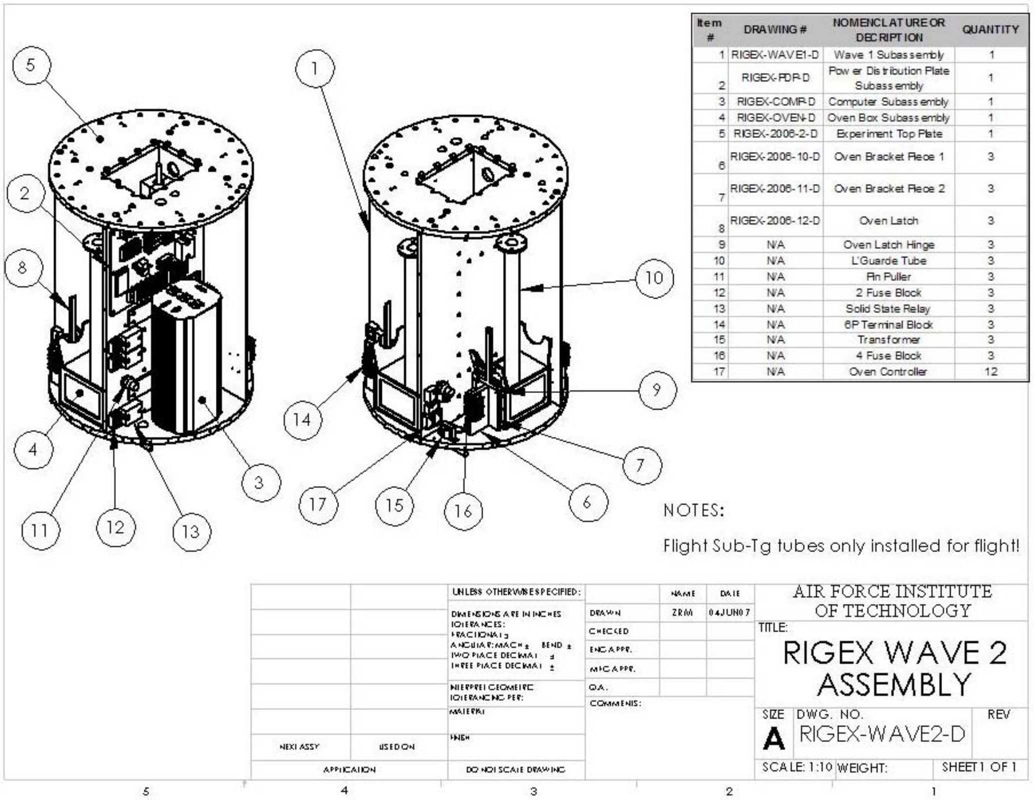

NOTE: TOP VIEW
0.3125
.762
25.71°
7°
2.000
0.750
NOTES:
1. #8-32 HOLE TAPPED FOR HELICOIL (MS21209C0820L) DEPTH: 0.54", 14 PLACES, EQUALLY SPACED
2. THRU HOLE (0.75" dia)
3. THRU HOLE (1" dia)
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
DRAWN ZRM 03JUN07
AL 6061-T6
AIR FORCE INSTITUTE OF TECHNOLOGY
TITLE:
EXPERIMENT TOP PLATE (SHROUD HOLE DETAIL)
SIZE A DWG. NO. RIGEX-2006-2-D REV C
SCALE: 1:5 WEIGHT: SHEET 4 OF 5


NOTE: BOTTOM VIEW
7.813
3.265
1.313
2.485
3.265
2.485
1.790
2.762
6.938
0.4375
2.485
3.265
1.313
7.813
1
2
NOTE:
1. #10-32 TAPPED HOLE, DEPTH 0.5"
2. #4-40 TAPPED HOLE, DEPTH: 0.2", 12 PLACES
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
MATERIAL AL 6061-T6
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
ZRM
03JUN07
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
AIR FORCE INSTITUTE OF TECHNOLOGY
TITLE:
EXPERIMENTAL TOP PLATE (BOTTOM VIEW) LED & P-CLAMP DETAIL
SIZE
DWG. NO.
REV
A
RIGEX-2006-2-D
A
SCALE: 1:5
WEIGHT:
SHEET 5 OF 5
5
4
3
2
1


2.500
1.370
0.950
0.700
0.200
3.875
2.125
4.875
0.375
0.250
2.230
2.840
0.250
2.000
NOTE:
1: #10-32 TAPEED HOLES UNJ, DEPTH: 0.54", 5 Places
2: #6-32 TAPPEED HOLE UNJ, DEPTH: THRU, 6 PLACES
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
MATERIAL AL 6061-T6
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
ZRM
03JUN07
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
AIR FORCE INSTITUTE OF TECHNOLOGY
TITLE:
OVEN BRACKET (PIECE 1)
SIZE
DWG. NO.
REV
A
RIGEX-2006-10-D
B
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1
5
4
3
2
1

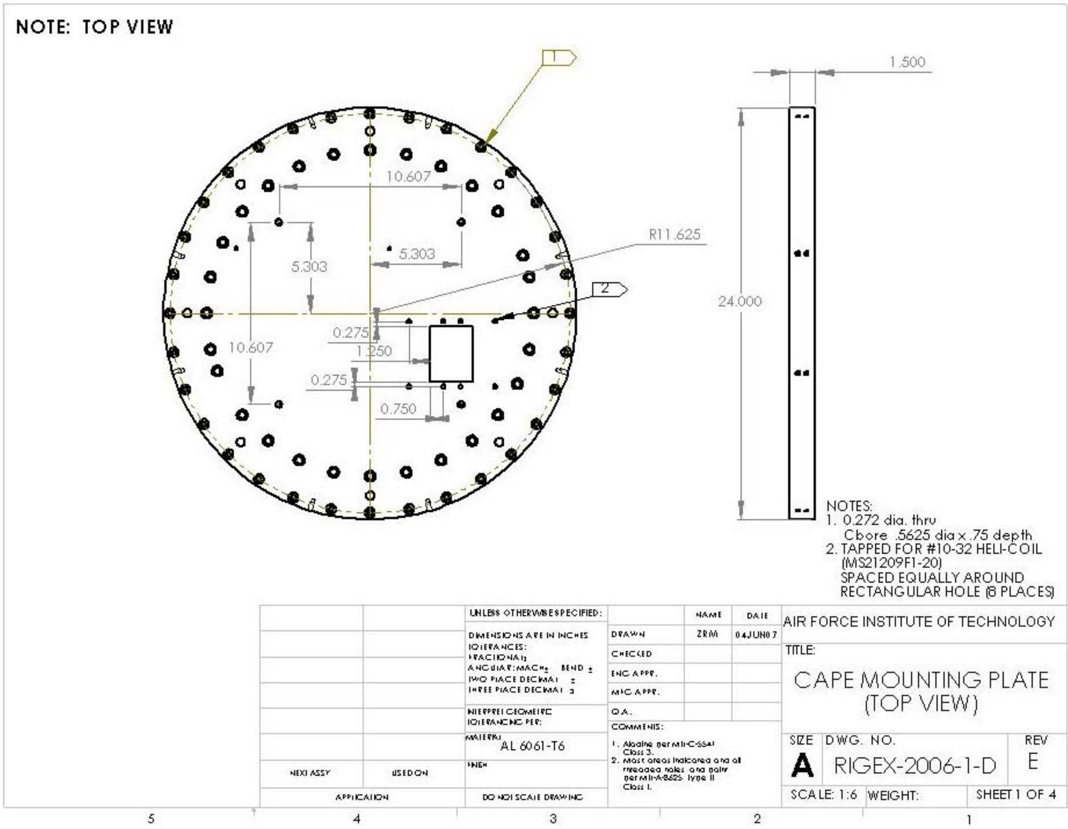

2.800
0.200
0.262
4.50
4.625
2.75
1.00
1.50
3.00
0.375
1
2
3
NOTES:
1. THRU HOLE, 0.1285 in dia
CBORE from BACK: 0.2188 in dia, 0.262 in depth
2 PLACES
2. .201 DIA THRU
CSINK from FRONT .385 DIA X 100 DEGREES
3 PLACES
3. #10-32 UNJ TAPPED HOLES, DEPTH: 0.54"
2 PLACES
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DRAWN
AEG
1 Aug 06
CHECKED
ZRM
03JUN07
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
MATERIAL
AL 6061-T6
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
AIR FORCE INSTITUTE OF TECHNOLOGY
TITLE:
OVEN BRACKET
(PIECE 2)
SIZE
DWG. NO.
REV
A
RIGEX-2006-11-D
B
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1
5
4
3
2
1

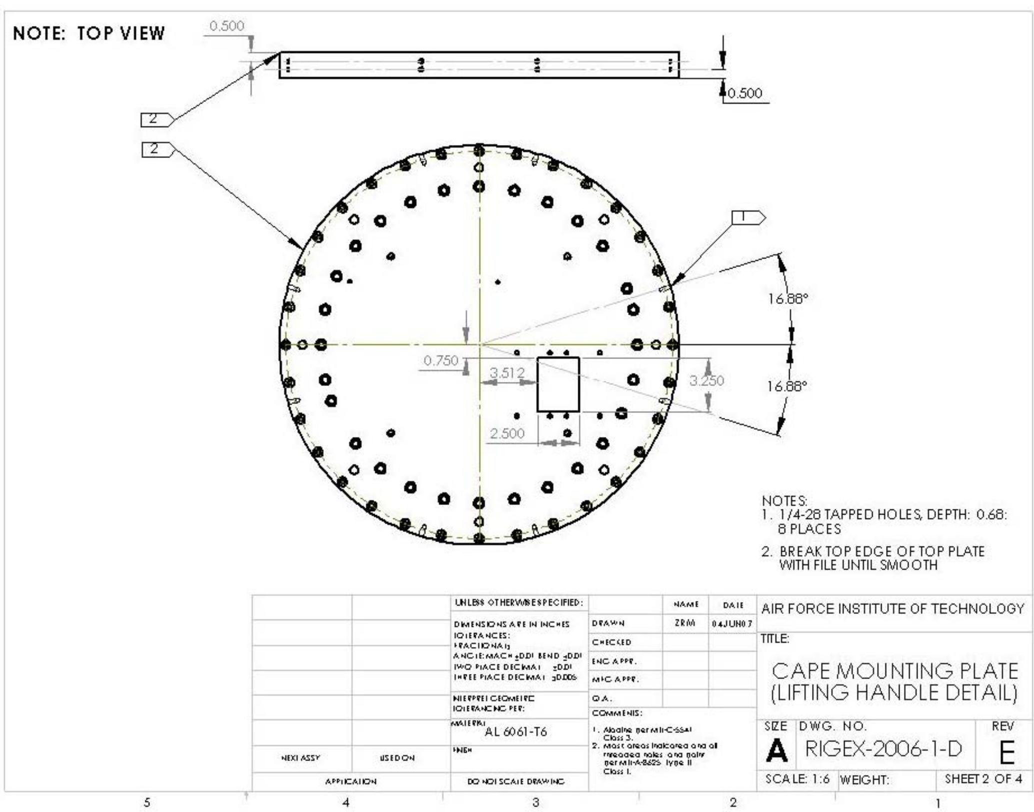

1
0.375
3.00
1.25
1.25
0.500
0.25
0.125
0.375
NOTES:
1. CBORE 0.2188" dia, 0.262" depth
THRU HOLE 0.1285 dia
THREE (3) COPIES OF THIS PART ARE REQUIRED
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DRAWN
AEG
1 Aug 06
CHECKED
ZRM
03JUN07
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
MATERIAL
AL 6061-T6
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
AIR FORCE INSTITUTE OF TECHNOLOGY
TITLE:
OVEN LATCH
SIZE
DWG. NO.
REV
A
RIGEX-2006-12-D
B
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1
5
4
3
2
1

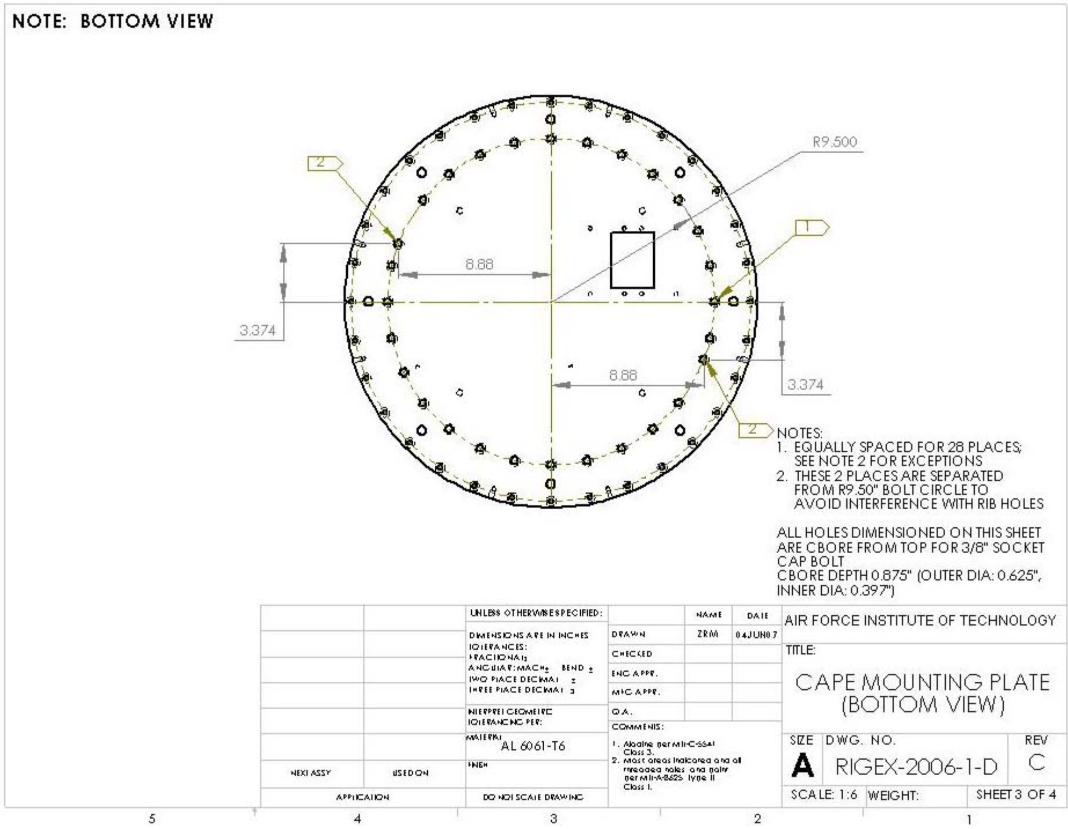


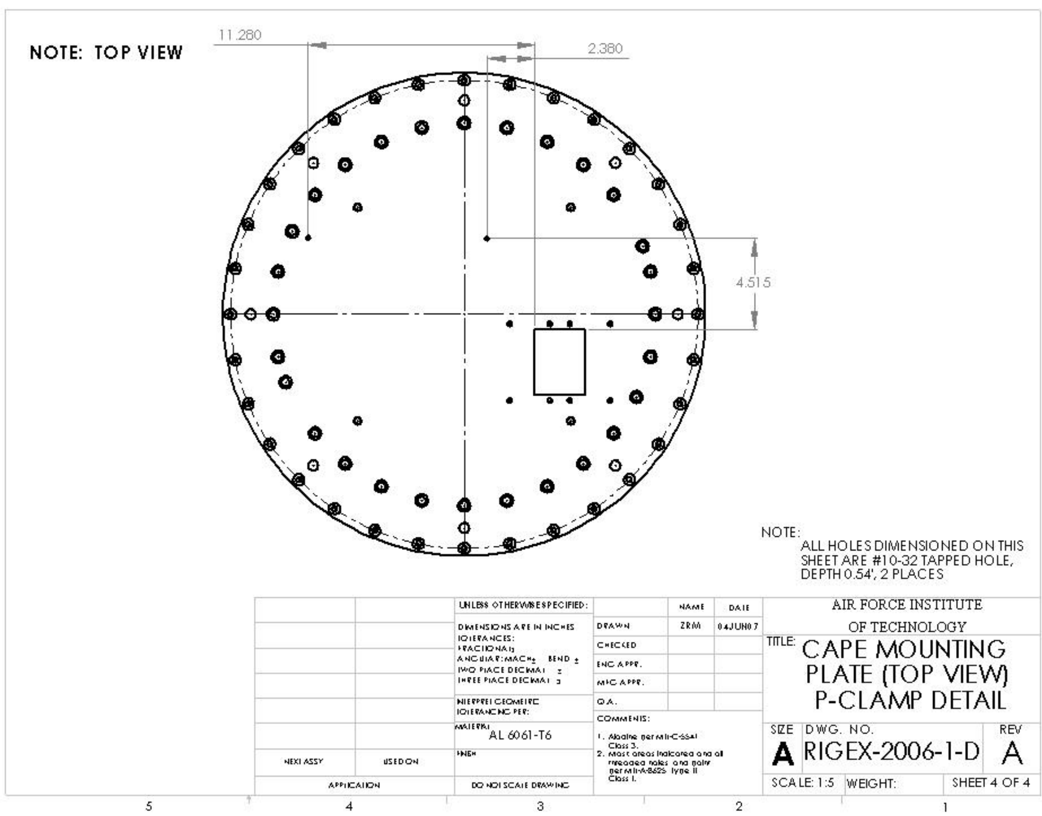
Item #	DRAWING #	NOMENCLATURE OR DECRIPTION	QUANTITY
1	RIGEX-WAVE1-D	Wave 1 Subassembly	1
2	RIGEX-PDP-D	Power Distribution Plate Subassembly	1
3	RIGEX-COMP-D	Computer Subassembly	1
4	RIGEX-OVEN-D	Oven Box Subassembly	1
5	RIGEX-2006-2-D	Experiment Top Plate	1
6	RIGEX-2006-10-D	Oven Bracket Piece 1	3
7	RIGEX-2006-11-D	Oven Bracket Piece 2	3
8	RIGEX-2006-12-D	Oven Latch	3
9	N/A	Oven Latch Hinge	3
10	N/A	L'Guarde Tube	3
11	N/A	Pin Puller	3
12	N/A	2 Fuse Block	3
13	N/A	Solid State Relay	3
14	N/A	6P Terminal Block	3
15	N/A	Transformer	3
16	N/A	4 Fuse Block	3
17	N/A	Oven Controller	12

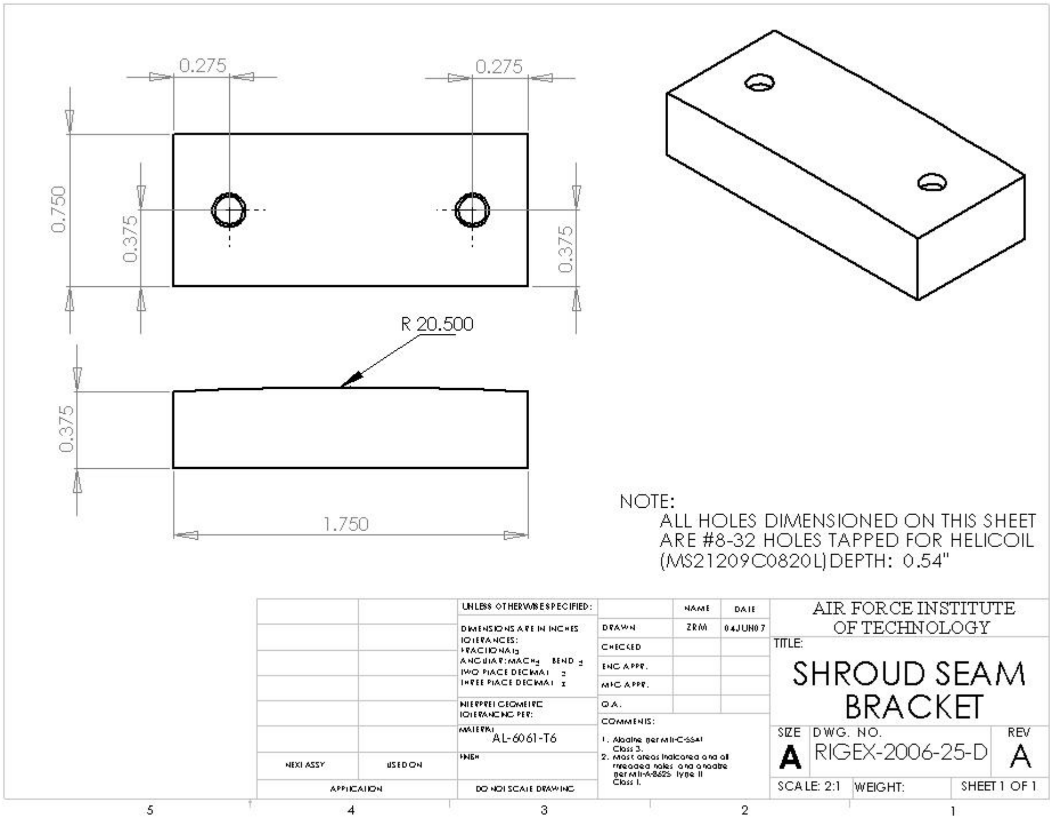
WAVE3	RIGEX-WAVE3-P	RIGEX-WAVE3-D		
QUANTITY	**PART OR IDENTIFICATION #**	**DRAWING #**	**NOMENCLATURE OR DECRIPTION**	**MATERIAL**
1	RIGEX-WAVE2-P	RIGEX-WAVE-2-D	Wave 2 Subassembly	N/A
1	RIGEX-2006-1-P	RIGEX-2006-1-D	CAPE Mounting Plate	Al
6	RIGEX-2006-25-P	RIGEX-2006-25-D	Shroud Seam Bracket	Al
1	RIGEX-2006-15-P	RIGEX-2006-15-D	Shroud	Al
2	RIGEX-2006-24-P	RIGEX-2006-24-D	Connector Hole Cover Plate	Al
24	RIGEX-2006-26-D	RIGEX-2006-26-D	Angled Washer	Al
8	RIGEX-2006-16-P	RIGEX-2006-16-D	Bumper	Delrin

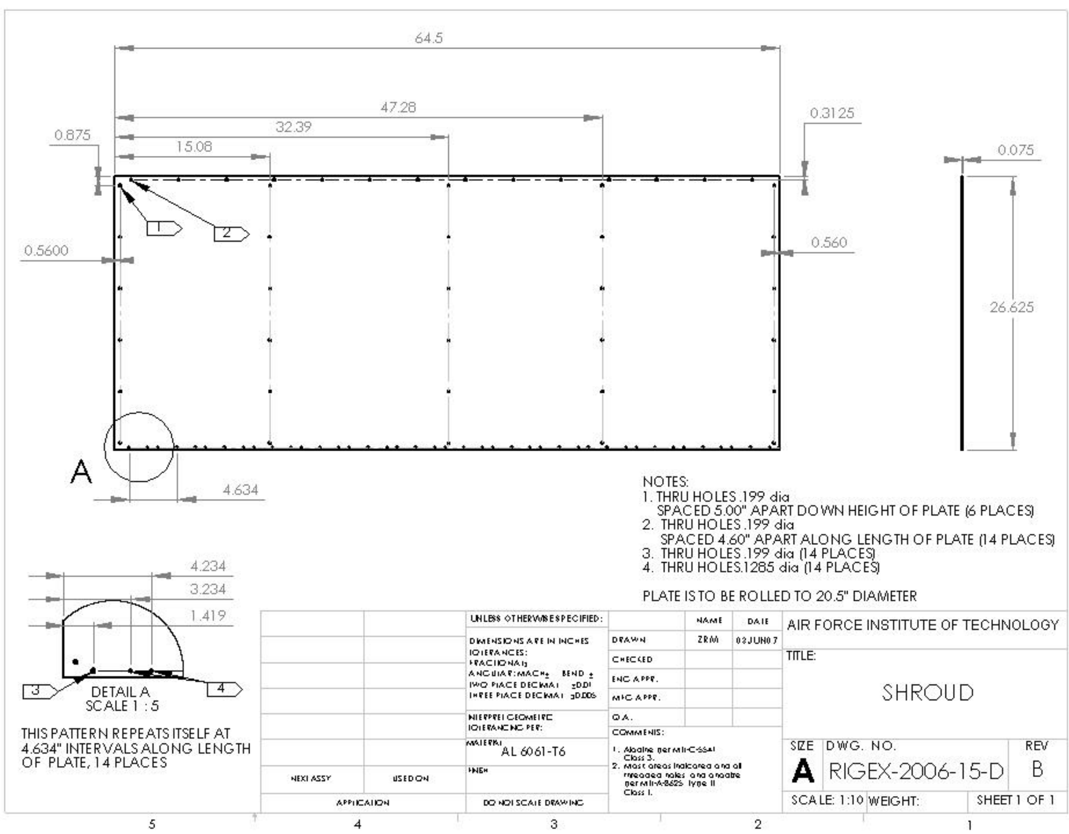

NOTE: TOP VIEW
1
2
10.607
5.303
5.303
R11.625
0.275
1.250
10.607
0.275
0.750
1.500
24.000
NOTES:
1. 0.272 dia. thru
Cbore .5625 dia x .75 depth
2. TAPPED FOR #10-32 HELI-COIL
(MS21209F1-20)
SPACED EQUALLY AROUND
RECTANGULAR HOLE (8 PLACES)
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
NAME
DATE
DRAWN
ZRM
04JUN07
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
MATERIAL
AL 6061-T6
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
AIR FORCE INSTITUTE OF TECHNOLOGY
TITLE:
CAPE MOUNTING PLATE
(TOP VIEW)
SIZE
DWG. NO.
REV
A
RIGEX-2006-1-D
E
SCALE: 1:6
WEIGHT:
SHEET 1 OF 4
5
4
3
2
1

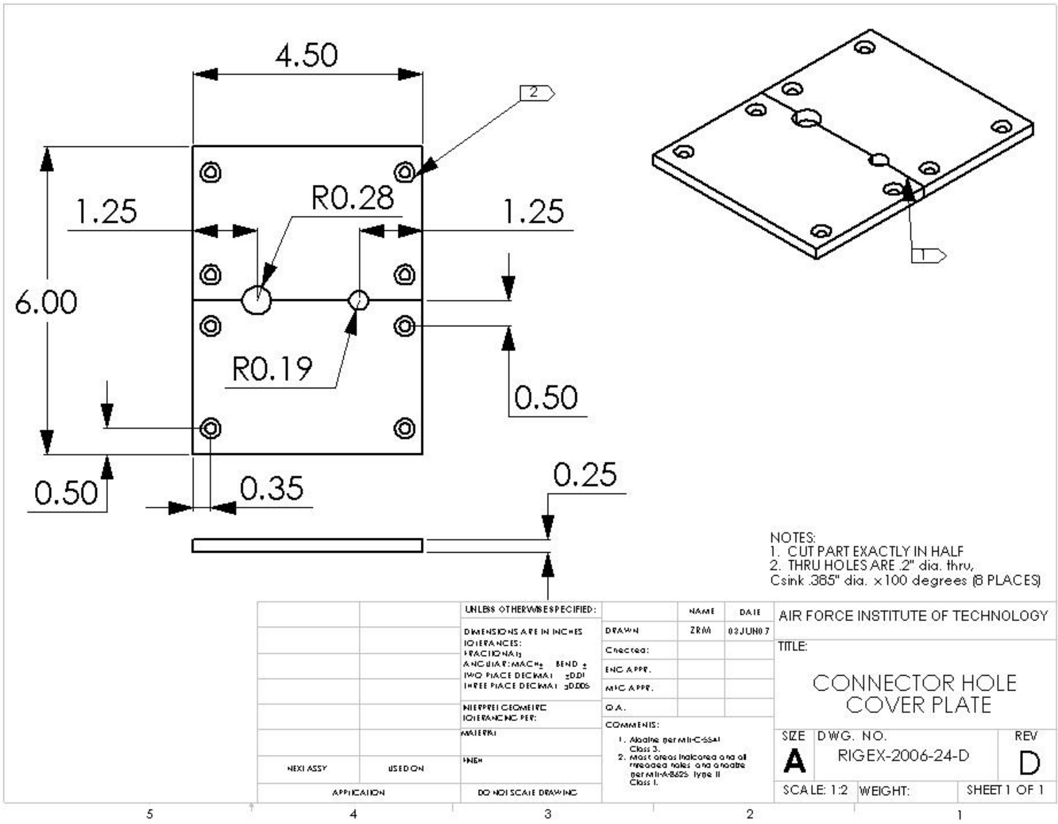

NOTE: TOP VIEW
0.500
0.500
2
2
1
16.88°
16.88°
0.750
3.512
3.250
2.500
NOTES:
1. 1/4-28 TAPPED HOLES, DEPTH: 0.68:
8 PLACES
2. BREAK TOP EDGE OF TOP PLATE
WITH FILE UNTIL SMOOTH
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
NAME
DATE
DRAWN
ZRM
04JUN07
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
MATERIAL
AL 6061-T6
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
AIR FORCE INSTITUTE OF TECHNOLOGY
TITLE:
CAPE MOUNTING PLATE
(LIFTING HANDLE DETAIL)
SIZE
DWG. NO.
REV
A
RIGEX-2006-1-D
E
SCALE: 1:6
WEIGHT:
SHEET 2 OF 4
5
4
3
2
1

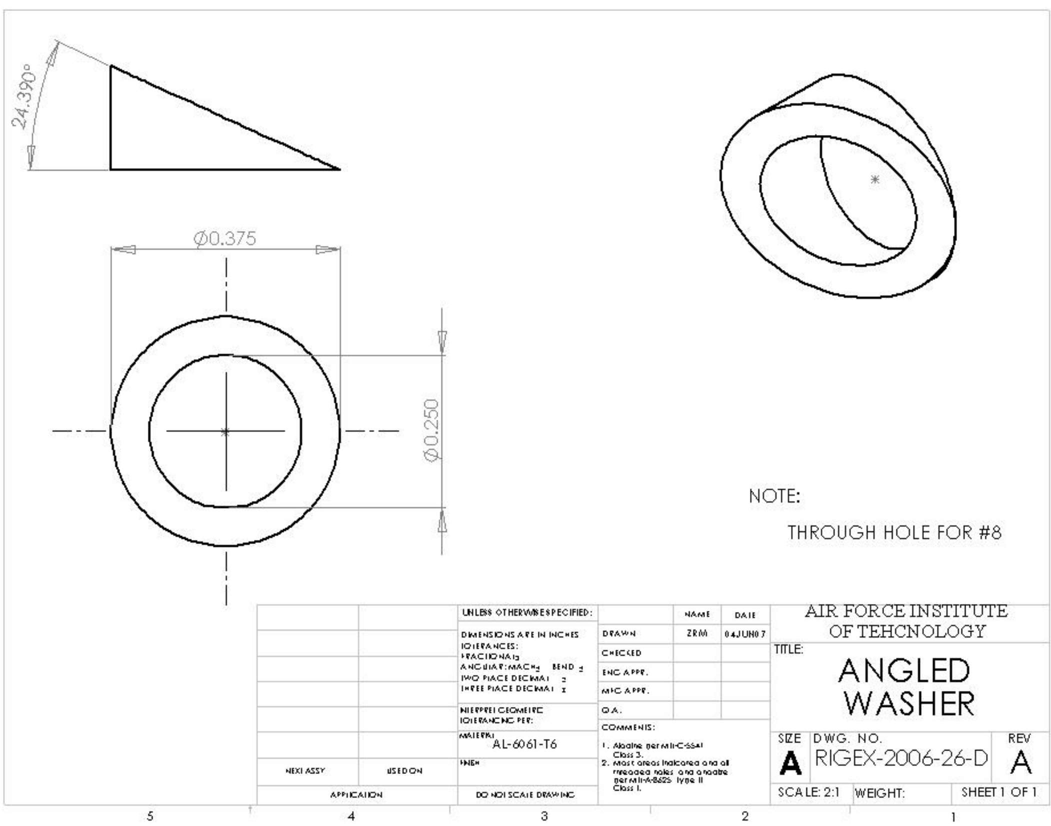

NOTE: BOTTOM VIEW
R9.500
2
1
8.88
3.374
8.88
3.374
2
NOTES:
1. EQUALLY SPACED FOR 28 PLACES; SEE NOTE 2 FOR EXCEPTIONS
2. THESE 2 PLACES ARE SEPARATED FROM R9.50" BOLT CIRCLE TO AVOID INTERFERENCE WITH RIB HOLES
ALL HOLES DIMENSIONED ON THIS SHEET ARE CBORE FROM TOP FOR 3/8" SOCKET CAP BOLT
CBORE DEPTH 0.875" (OUTER DIA: 0.625", INNER DIA: 0.397")
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DIMENSIONS ARE IN INCHES
DRAWN
ZRM
04JUN07
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
AL 6061-T6
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
AIR FORCE INSTITUTE OF TECHNOLOGY
TITLE:
CAPE MOUNTING PLATE (BOTTOM VIEW)
SIZE
DWG. NO.
REV
A
RIGEX-2006-1-D
C
SCALE: 1:6
WEIGHT:
SHEET 3 OF 4
5
4
3
2
1

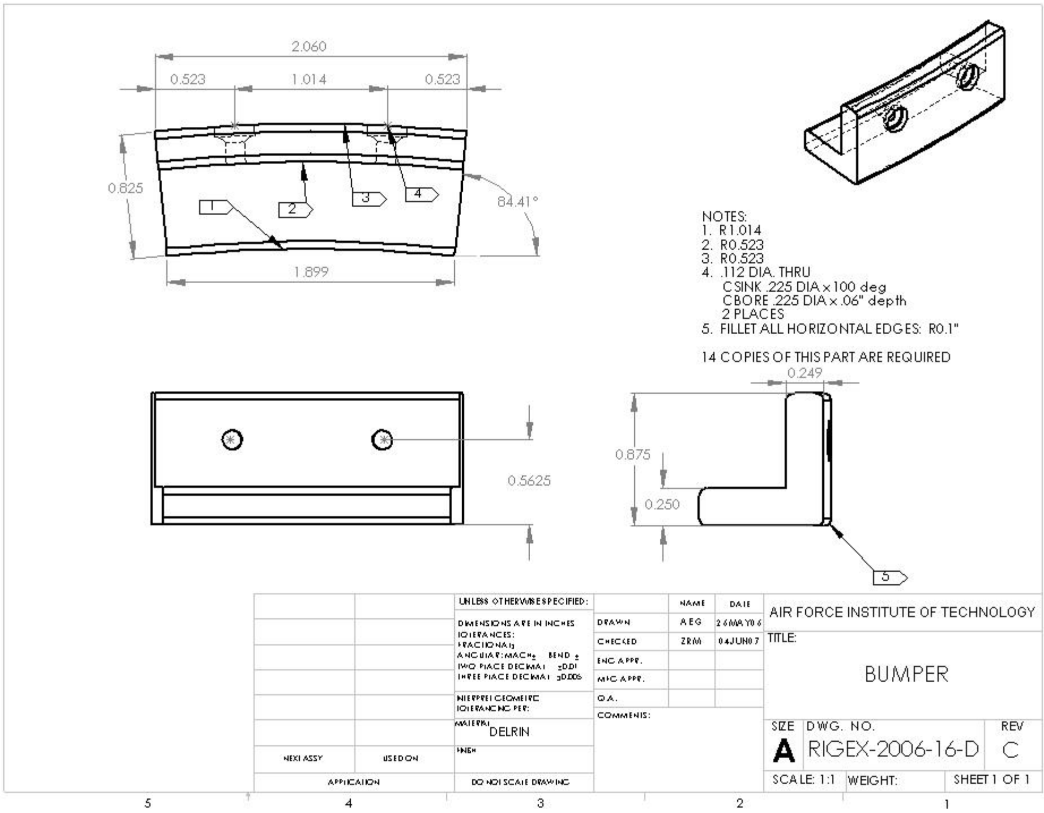

NOTE: TOP VIEW
11.280
2.380
4.515
NOTE:
ALL HOLES DIMENSIONED ON THIS SHEET ARE #10-32 TAPPED HOLE, DEPTH 0.54", 2 PLACES
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DIMENSIONS ARE IN INCHES
DRAWN
ZRM
04JUN07
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
AL 6061-T6
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
AIR FORCE INSTITUTE OF TECHNOLOGY
TITLE:
CAPE MOUNTING PLATE (TOP VIEW) P-CLAMP DETAIL
SIZE
DWG. NO.
REV
A
RIGEX-2006-1-D
A
SCALE: 1:5
WEIGHT:
SHEET 4 OF 4
5
4
3
2
1

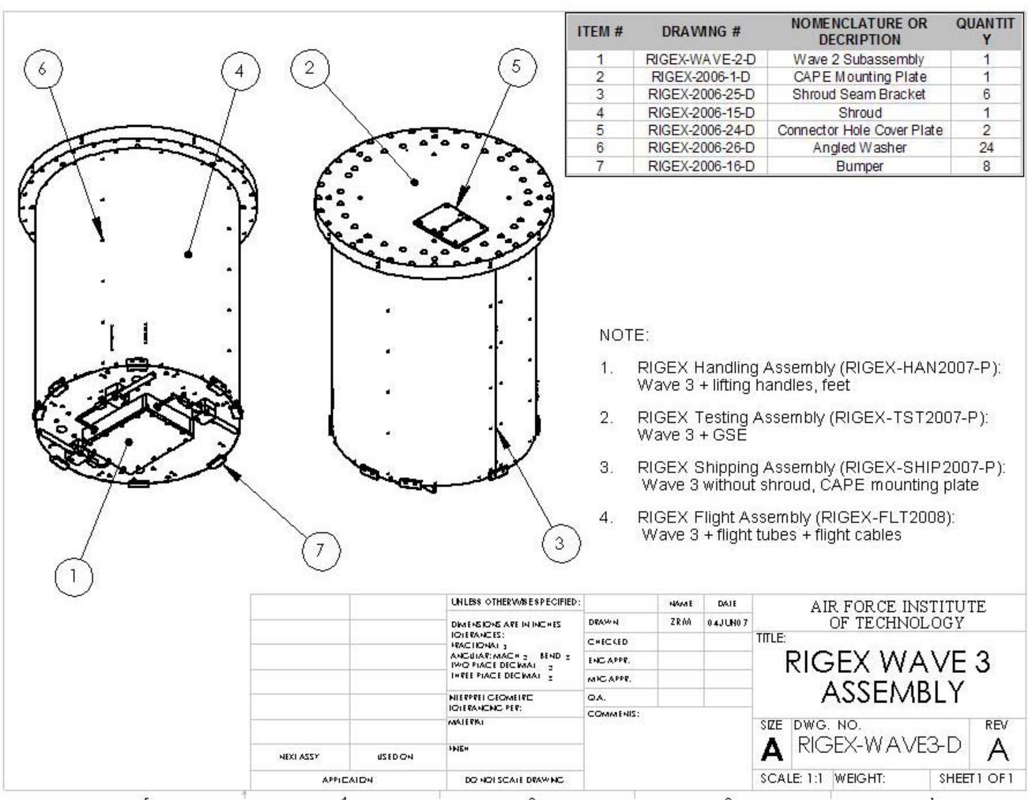

0.275
0.275
0.750
0.375
0.375
R 20.500
0.375
1.750
NOTE:
ALL HOLES DIMENSIONED ON THIS SHEET ARE #8-32 HOLES TAPPED FOR HELICOIL (MS21209C0820L) DEPTH: 0.54"
UNLESS OTHERWISE SPECIFIED:
DRAWN ZRM 04JUN07
AIR FORCE INSTITUTE OF TECHNOLOGY
TITLE:
SHROUD SEAM BRACKET
AL-6061-T6
SIZE A
DWG. NO. RIGEX-2006-25-D
REV A
SCALE: 2:1
WEIGHT:
SHEET 1 OF 1


64.5
47.28
32.39
15.08
0.875
0.3125
0.075
0.5600
0.560
26.625
A
4.634
NOTES:
1. THRU HOLES .199 dia SPACED 5.00" APART DOWN HEIGHT OF PLATE (6 PLACES)
2. THRU HOLES .199 dia SPACED 4.60" APART ALONG LENGTH OF PLATE (14 PLACES)
3. THRU HOLES .199 dia (14 PLACES)
4. THRU HOLES .1285 dia (14 PLACES)
PLATE IS TO BE ROLLED TO 20.5" DIAMETER
4.234
3.234
1.419
DETAIL A
SCALE 1 : 5
THIS PATTERN REPEATS ITSELF AT 4.634" INTERVALS ALONG LENGTH OF PLATE, 14 PLACES
UNLESS OTHERWISE SPECIFIED:
DRAWN ZRM 03JUN07
AIR FORCE INSTITUTE OF TECHNOLOGY
TITLE:
SHROUD
AL 6061-T6
SIZE A
DWG. NO. RIGEX-2006-15-D
REV B
SCALE: 1:10
WEIGHT:
SHEET 1 OF 1


4.50
6.00
1.25
R0.28
1.25
R0.19
0.50
0.50
0.35
0.25
2
1
NOTES:
1. CUT PART EXACTLY IN HALF
2. THRU HOLES ARE .2" dia. thru, Csink .385" dia. x100 degrees (8 PLACES)
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
NAME
DATE
DRAWN
ZRM
03JUN07
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
AIR FORCE INSTITUTE OF TECHNOLOGY
TITLE:
CONNECTOR HOLE COVER PLATE
SIZE
A
DWG. NO.
RIGEX-2006-24-D
REV
D
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1


24.390°
Ø0.375
Ø0.250
NOTE:
THROUGH HOLE FOR #8
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
NAME
DATE
DRAWN
ZRM
04JUN07
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
MATERIAL
AL-6061-T6
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
AIR FORCE INSTITUTE OF TEHCNOLOGY
TITLE:
ANGLED WASHER
SIZE
A
DWG. NO.
RIGEX-2006-26-D
REV
A
SCALE: 2:1
WEIGHT:
SHEET 1 OF 1





ITEM #	DRAWING #	NOMENCLATURE OR DECRIPTION	QUANTITY
1	RIGEX-WAVE-2-D	Wave 2 Subassembly	1
2	RIGEX-2006-1-D	CAPE Mounting Plate	1
3	RIGEX-2006-25-D	Shroud Seam Bracket	6
4	RIGEX-2006-15-D	Shroud	1
5	RIGEX-2006-24-D	Connector Hole Cover Plate	2
6	RIGEX-2006-26-D	Angled Washer	24
7	RIGEX-2006-16-D	Bumper	8

NAME	PART NUMBER	CONFIGURATION DESCRIPTION
Wave 1 Subassembly	RIGEX-WAVE1-P	Wave 1 Assembly Complete, main structure intact
Wave 2 Subassembly	RIGEX-WAVE2-P	Wave 2 Assembly Complete, main structure and various subassemblies
Wave 3 Subassembly	RIGEX-WAVE3-P	Wave 3 Assembly Complete
RIGEX Handling Assembly	RIGEX-HAN2007-P	Wave 3 + lifting handles, feet
RIGEX Testing Assembly	RIGEX-TST2007-P	Wave 3 + GSE
RIGEX Shipping Assembly	RIGEX-SHIP2007-P	Wave 3 without shroud, CAPE mounting plate
RIGEX Flight Assembly	RIGEX-FLT2008	Wave 3 + flight tubes + flight cables

Appendix B: Code for Eye-C Cameras

```
#include <dos.h>
#include <string.h>
#include <stdio.h>
#include <stdlib.h>
#include "ae.h"
#include "fileio.h"
#include "filegeo.h"
#include "mm16.h"
#include "ser1.h"
#include "fn.h" // use RTC
#include "eyec.h"
// 320x240+54+256x4=77,878 bytes=152+1 sectors
#define NUM_SECTORS 153
extern unsigned int EYEQ16A[];
extern unsigned char ovt_init_Qbw[];
unsigned int n_clusters;
struct fs_descrip* log_file;
unsigned long end_sector;
unsigned long current_sector;
unsigned long s_per_c;
unsigned long c_size;
unsigned long max_c;
unsigned int max_files;
int l_index = 0;

struct fs_descrip* filesys_init(void);
void err(void);
struct fs_descrip* l_retval = NULL;
char filename[11]; // img511.bmp
char realTime[14], tmp[10];
int hour, minute, second, month, date, year;
unsigned char stat;

struct ff_geo *l_geo;
unsigned char retval;
unsigned int i,j,k,r;
unsigned char sta, m, n, ledd, dat;
unsigned char adat[24];

void main(void)
{
        ae_init();
  clka_en(1);
  outport(0xfff2, 0);    // AUXCON, MCS, Bus 16-bit
        pio_init(3, 0);
//   outport(0xffa0,0x80bc);    // UMCS, 512K ROM, 0 wait states, disable AD15-0
```

```
        outport(0xffa2,0x7fbc);         // 512K RAM, 0 wait states
        outport(0xffa4,0x0074); // PACS, base 0, 0 wait

  ledd=0;   led(0);  stat=0xff;

// for(i=0; i<128; i++){
//   dat=eyec_ovt_rd(i);
//          }
for(i=0; i<0x80; i++){
  eyec_ovt_wr(i, ovt_init_Qbw[i]); // 320x240, QVGA, YUV, BW
        }
for(i=0; i<2; i++){   // Warm up camera
  led(1);
        stat= img_state(); // warm up camera, at least 1 second after power on.
  if(stat==0) stat=0x01;
  else stat=0;
  eyec_acq_img(stat); // FST high, starting acquire one frame image data
  delay_ms(900);
  led(0);
        }

  if ( fs_initPCFlash() != 0)
        err();
        l_geo=fs_GetGeometry();
        s_per_c=l_geo-> g_SectorsPerCluster; // Number of sectors in each cluster,
        max_c=l_geo-> g_MaxClusters;        // Total available clusters for data.
        n_clusters=(unsigned int)(NUM_SECTORS/s_per_c)+1; // image data
size/hardware related !
  max_files=(unsigned int)(max_c/n_clusters); // max. numbers of files
  if(max_files > 511) max_files=511; // FAT16 limit
while(l_index < max_files)
{
  led(1); // 20 MHz PCLK, 640x480x2=614,400 PCLKs for 30 ms
        stat= img_state(); // warm up camera, at least 1 second after power on.
  if(stat==0) stat=0x01;
  else stat=0;
  eyec_acq_img(stat);  // acquire one frame image data
  log_file = filesys_init();
  if ((log_file == NULL) || (log_file->ff_status != fOK)) err();
  current_sector = fs_XlateToSector(log_file->ff_current); // Sector address
  end_sector = current_sector+NUM_SECTORS;
  fs_fclose(log_file);

if( write_sectors(current_sector, 1) ) // prepare to write 256 words
{
        while( ! data_request() );
```

```
  while( busy() );
for(i=0; i<27; i++){  // 27 words only
  data_write(EYEQ16A[i]); // 320x240 8-bit BMP
  }
for(i=0; i<114; i++){  // 114x2 words of 8-bit Grey Level LUT (256x2 words)
  k=i+(i<<8);
  data_write(k);
  data_write(i);
  }
 data_write(0x7272); // make it 27+114x2+1=256 words in CF, LUT 0x72=114
  while( busy() );
  sta=status(); // DRQ
        }
current_sector++;

if( write_sectors(current_sector, 1) ) // prepare to write 256 words
{
        while( ! data_request() );
  while( busy() );
  data_write(0x0072); // complete LUT 114
for(i=115;i<242;i++){ // 242-115=127 words of 8-bit Grey Level LUT(256x2 words)
  k=i+(i<<8);
  data_write(k);
  data_write(i);
  }
  data_write(0xf2f2); // LUT 0xf2=242
}
current_sector++;
  while( busy() );

delay_ms(800);
  if(img_state() != stat){
                led(0);
        delay_ms(200);
        led(1);
        delay_ms(200);
        stat=img_state();
                    }// wait one frame image acquisition done
  led(0);
        eyec_en_fifo();

if( write_sectors(current_sector, 1) ) // prepare to write 256 words
{
        while( ! data_request() );
  while( busy() );
  data_write(0x00f2); // complete LUT 242
```

```
for(i=243;i<256;i++){ // 256-243=13 words of 8-bit Grey Level LUT(256x2 words)
  k=i+(i<<8);
  data_write(k);
  data_write(i);
  }
for(i=0;i<229;i++){  // 256-26-1=229 words
// Each word holding 2 pixels of 8-bit Y for 229 times, 458 pixels written
  adat[0]=inportb(RDF); // Y
        adat[1]=inportb(RDF); // U
  adat[2]=inportb(RDF); // Y
        adat[3]=inportb(RDF); // V
  r = adat[0]+(adat[2]<<8); // Two pixel word
  data_write(r);  //
//      sta=status(); // DRQ
                } // end of for(i=0;i<229;i++){
//      sta=status(); // DRQ
}
current_sector++;
  while( busy() );

// 320x240-458=76,342 pixels left, needs 38,171 words, 149 sectors
// prepare CF 1-sector-write, 256x149 words,
// each pixel needs 8-bit Y byte, 2 pixels in one word
//
for(j=0; j<149; j++){
 if( write_sectors(current_sector, 1) ) // prepare to write 256 words
 {
//      while( ! data_request() );
//      while( busy() );
 for(i=0; i<256; i++){
  adat[0]=inportb(RDF); // Y
        inportb(RDF); // U
  adat[2]=inportb(RDF); // Y
        inportb(RDF); // V
  r = adat[0]+(adat[2]<<8); // Two pixel word
  data_write(r);  //
                } // end of if(i=0; i<256
   } //  end of if( write_sectors(current_sector, 1) )
   current_sector++;
        while( busy() );
//  sta=status(); // DRQ
  }  // end of if(j=0; j<149
 } // end of while(l_index < max_files)

sta=status(); // DRQ
}       // end main
```

```
struct fs_descrip* filesys_init(void)
{
  while(l_index < max_files)
  {
         sprintf(filename, "img%d.bmp", l_index++);
    if ((l_retval = fs_fopen(filename, O_WRONLY)) != NULL)
    {
         if (l_retval->ff_status == fOK)
         break;
       fs_fclose(l_retval);
       l_retval = NULL;
    }
  }
         if (l_retval == NULL)
         return NULL;
//
// wkday,year10,year1,mon10,mon1,day10,day1,hour10,hour1,min10,min1,sec10,sec1
// unsigned char time_now[13]={3,0,5,0,6,2,2,1,6,1,8,0,0};
// rtc1_init(time_now); // Only need to run once for setting up RTC
//
         rtc1_rds(realTime);
         tmp[0]=realTime[1];
  tmp[1]=realTime[2];
  tmp[2]=0;
  year=atoi(tmp)+2000;
         tmp[0]=realTime[3];
  tmp[1]=realTime[4];
  tmp[2]=0;
  month=atoi(tmp);
  tmp[0]=realTime[5];
  tmp[1]=realTime[6];
  tmp[2]=0;
  date=atoi(tmp);
  tmp[0]=realTime[7];
  tmp[1]=realTime[8];
  tmp[2]=0;
  hour=atoi(tmp);
  tmp[0]=realTime[9];
  tmp[1]=realTime[10];
  tmp[2]=0;
  minute=atoi(tmp);
  tmp[0]=realTime[11];
  tmp[1]=realTime[12];
  tmp[2]=0;
  second=atoi(tmp);
```

```
 fs_StampTimeHMSMDY(l_retval, TDMODIFIED, hour, minute, second, month, date,
year);

//        fs_StampTimeHMSMDY(l_retval, TDMODIFIED, 10, 23, 59, 6, 23, 2005);
  fs_callocate(l_retval, n_clusters);
  if (l_retval->ff_status != fOK)
  {
          fs_fclose(l_retval);
    l_retval = NULL;
  }
  return l_retval;
}

void err(void){
// fs_fclose(log_file);  // We have an open file with reserved sector addresses;
while(1){
          led(1);
          delay_ms(800);
          led(0);
          delay_ms(800);
          }
}
```

Appendix C: RIGEX TVAC Component Testing Procedure

Air Force Institute of Technology
Wright-Patterson Air Force Base

RIGEX
SPACE SIMLUATOR VACUUM SYSTEM COMPONENT TESTING (TP-03)

Prepared by:

____
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Approved by:

____
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Change Log

Rev. Ltr. Change	Justification and Description of Change	Affected Pages	Effectivity (Serial #)	Release Date	Change Approval (*Initial & Date*)
IR	Initial Release	All	All	9MAY2007	N/A
IR	Include space to record time, temp and vacuum level	14 - 20	6.2	17MAY2007	
IR	Segment 3 and 4 switched	16	6.2g	17MAY2007	
IR	Match temperature ranges	15 - 16	6.2F – 6.2G	17MAY2007	
IR	Temperature ranges inserted for reference	18 - 21	6.2K – 6.2X	17MAY2007	
IR	Modify backfill procedure to include N_2	21	7.2D	17MAY2007	
IR	Inserted Note: Ensure Gaseous Nitrogen is hooked up and pressurized	14	6.2D	17MAY2007	
IR	Inserted Note: Ensure Liquid Nitrogen is hooked up and pressurized	17	6.2H	17MAY2007	
IR	Add shading to non-action sequences	All	All	18MAY2007	
IR	Inserted Note:	18 - 21	6.2K – 6.2X	18MAY2007	
IR	Inserted Step:	18 - 21	6.2L–6.2CC	18MAY2007	

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Seq #	Instructions	Date	Tech	Insp
1.0	**Scope**			
	This purpose of this procedure is to dictate step by step how components of RIGEX are to be tested prior to flight in the Space Simulator Vacuum System designed by PHPK Technologies for AFIT/ENY. The primary intent is to know that the components will endure the extreme environmental elements expected to be exposed to during flight. The components must withstand the specified survival temperatures (positive and negative) under a vacuum. The components must also function while at the specified operational temperatures (positive and negative) under a vacuum			
2.0	**Materials and Components**			
2.1	**Components being Tested:** • Oven Solid State Relay (SSR) • Camera • LED's • Computer • Oven • Oven controllers			
2.2	**Equipment Needed**			

Seq #	Instructions	Date	Tech	Insp
2.2A	Space Simulator Vacuum System • Vacuum Chamber • Thermal Control Unit (TCU) • Roughing pump (VP03) • Turbomolecular Pump (TP01) • Circulating Pump • Vacuum Valves • Flow Meter • N_2 Gas System			
2.3A	Component Monitoring System • Aluminum Plank • Copper mesh • Wiring for: 1. Power 2. Command 3. RTD's 4. Thermocouples • Thermocouples • Data Acquisition Computer Interface • Laptop setup with Labview • Emulator			
3.0	**Controls and Instrumentation**			
3.1	**Operator Interface Enclosure (Fig. 16)** Controls all remote operated devices			
3.1A	Chamber Controls Assembly Includes: • Operator interface graphic with labeled switches • PLC • Interface relays for safety interlocks • 24VDC power supply			
3.1B	The Leybold turbomolecular pump controller • Electronically connected to the Chamber Controls Assembly • Remote start/stop function capable			
3.1C	The 230/120 volt transformer for powering the 120 volt devices.			
3.1D	The main power supply and disconnect to all systems			

Seq #	Instructions	Date	Tech	Insp
3.1E	The SCR module that control the heat			
3.2	**Interlocks, Alarms, Shutdowns**			
3.2A	Turbo Pump (TP01) On: • FV02 Open • FV06 Closed • FV10 Closed • SV09 Closed (turbopump controller) • VP03 On			
3.2B	Roughing Pump (VP03) On: • No Interlocks			
3.2C	FV06 Open: • FV02 Closed • FV10 Closed • VP03 On			
3.2D	FV02 Open: • FV06 Closed • FV10 Closed			
3.2E	FV10 Open: • FV06 Closed • FV02 Closed			
3.2F	Heating/Cooling Cycle: • FE105 $\geq$ 12GPM • Liquid Pump On			
3.2G	TE15, TE100, TE110: • Temp > 130°C • Heater Shutdown + Alarm			
3.2H	FE105: • Flow < 12GPM • LN2 & Heater Shutdown • Alarm			
3.3	**Operator Interface Graphic Screen**			

Seq #	Instructions	Date	Tech	Insp
3.3A	HMI Vacuum Enclosure Overview Screen (Fig. 5) • Graphically shown in its P&I Diagram: I. Heater II. Cooler Exchanger III. Flow Control Valves • Real time data is shown for: I. Temperature II. Flow III. Valve output values • Alarms shown in alarm banner the Alarm Triangle flashes red (to bring up alarm summary click on red triangle) • Pushbuttons on bottom of screen allow operator to navigate to other screens			
3.3B	HMI Fluorinert Temperature Controller Screen (Fig. 6) • Vacuum enclosure has two controllers: I. Loop 0 for the SCR Heater II. Loop 1 for the Cooling Exchanger Valve • Controller's set point determined by the Segment Temperature Setup Screen • Data entry window under controller for tuning parameter: I. Proportional (P) II. Integral (I) III. Derivative (D)			

Seq #	Instructions	Date	Tech	Insp
3.3C	HMI Segment Temperature Setup and Trend Screen (Fig. 7) • For cycling temperatures in the chamber (ten segments available) for: I. Ramp rate II. Dwell temperature III. Dwell time (zero= segment skipped over) • To repeat cycle press ON underneath REPEAT • To start cycle press START underneath CYCLE • Heating/cooling in each segment is controlled by PLC by comparing current chamber temperature and set dwell temperature • The temperature is ramped up at the set ramp rate • Once the set dwell temperature is reached there is a default soak time of 60 seconds before the dwell time is activated • Elapsed time of each segment displayed on lower right of screen • Real-time trend screen under segment entry showing segment step number and temperature values for: I. TE10 Fluorinert to Chamber Temperature II. TE15 Platen Temperature III. TE16 Cylinder Shroud Temperature IV. TE17 End Shroud Temperature • Real-time trend screen advances in 10 second increments • To pause screen press RESUMED (Data will not be lost) • To resume real-time displayed data press PAUSED • Scaling values changed by Y axis zoom			

Seq #	Instructions	Date	Tech	Insp
3.3D	HMI Vacuum Chamber Overview Screen (Fig. 8) • Graphically displays vacuum chamber and PI diagram • Temperature and pressure shown in real-time • Pumps and valves controlled from this screen: I. Roughing Pump (VP03) II. Turbopump (TP01) III. Valve FV02 IV. Valve FV06 V. Valve FV10 • Prior to starting Turbo Pump insure the correct valves are open or closed for proper operation (refer to FV valve interlock matrix)			
3.3E	HMI Chamber Controller Screen (Fig. 9) • Three controllers: I. Loop 2 – Cylinder Flow II. Loop 3 – End Shroud Flow III. Loop 4 – Platen Flow • Controller's balance temperature in specified areas and control the TE110 Fluorinert Supply Temperature • Data entry window under controller for tuning parameter: I. Proportional (P) II. Integral (I) III. Derivative (D) • Change operation mode by pressing AUTO/MANUAL pushbutton			
3.3F	HMI Temperature Historical Screen (Fig. 10) • Historically trended against time I. Vacuum Chamber temperatures II. Step numbers • To locate timeframe for data to be reviewed use SCROLL BACKWARD/FORWARD pushbuttons • Daily files generated for future review I. Stored on hard drive II. Appear on desktop in \WPAFB\DLGLOG\RSVIEW folder III. File format – YYYMMDD0000 (MS Excel) IV. Current day file constantly updated by RSView			

Seq #	Instructions	Date	Tech	Insp
3.3G	HMI Alarm Summary Screen (Fig.11) • Summaries of alarms generated by PLC • Active unacknowledged alarms flash • Active acknowledged alarms stop flashing • To acknowledge alarms press ACKNOWLEDGE ALL • To remove alarms from alarm summary list press RESET			
3.3H	HMI Login Screen (Fig. 12) • Security feature not activated for WPAFB i. Supervisor – password required for login • To login press LOGIN to bring up login screen Press LOGIN KEYBOARD and then enter ID and password on pup-up keyboard. (Supervisor should close keyboard) • To stop RSView press PROJ SHOW to bring up project screen. Press STOP PROJECT then press X to close screen.			
4.0	**System Operations**			
4.1	**Chamber Operations (Fig. 13 & 14):** Chamber equipped for operating independently in any of the three modes as follows.			
4.1A	Mode One (*High Vacuum mode without heating or cooling.*) Mode requires the operation of: • Roughing pump (VP03) • Turbopump (TP01) The vacuum roughing pump (VP03) must be running and the turbo pump roughing valve (FV06) must be opened. Additionally, the chamber must be roughed down to approximately $5x10^{-2}$ Torr. At this point the turbo pump can be switched "on" from the touch screen operator interface panel.			

Seq #	Instructions	Date	Tech	Insp
4.1B	Mode Two (*Heating and cooling mode with medium vacuum.*) Mode requires the operation of: • Roughing pump (VP03) • Thermal Control Unit (TCU) The roughing pump can be started at any time. Once a medium or "rough" vacuum is achieved (approximately $5x10^{-2}$ Torr) the TCU heating and cooling mode can be initiated.			
4.1C	Mode Three (*Heating and cooling mode with high vacuum.)* Mode requires the operation of • Roughing pump (VP03) • Turbopump (TP01) • Thermal Control Unit (TCU) Follow the combination of mode one and mode two above.			

Seq #	Instructions	Date	Tech	Insp
4.2	**Thermal Control Unit (TCU) Operation (Fig. 16):** • All operations controlled from operator graphic touch screen • Three significant manual valves that must be opened prior to starting the liquid pump. I. HV-103 II. HV-105 III. HV-110 • Verify heat transfer fluid pressurized to 30 – 35 psig • Heat transfer fluid split into three zones in the chamber: I. Cylinder shroud II. End shrouds III. The platen • Return flow control valves automatically throttled by PLC to maintain constant temperature of three zones I. FCV-100 II. FCV102 III. FCV-103 (the platen return – full open at all times) • Prior to hot/cold thermal cycling vacuum chamber must be pumped down to approximately $5x10^{-2}$ torr • Liquid nitrogen introduced into system through FCV-109 is controlled automatically by OLC based on heat transfer fluid supply temperature to the chamber • Liquid nitrogen should be supplied at a max pressure of 40 psig (Fig. 20) • Nitrogen gas vented through 1.5 inch NPT fitting on top of the TCU I. Piped outside of building ○ Line constructed of stainless steel or copper ○ Fitted with low pressure loss check valve			

Seq #	Instructions	Date	Tech	Insp
5.0	**Test Setup**			
5.1	**Test Setup for Components**			
5.1A	The test setup steps may be performed out of order. All Setup steps are to be completed prior to beginning functional tests for components			
5.1B	This procedure assumes that the computer boards have already been connected properly			
5.1C	Position and attach components being tested onto aluminum plank			
5.1D	Attach aluminum plank to the Platen inside the vacuum chamber with copper mesh between the metal to help promote conduction (see Fig. 15)			
5.1E	Connect wiring between thermocouple board on computer and thermocouple breakout board (see Fig. 1)			
5.1F	Connect wiring between relay board on computer and left relay breakout board (see Fig. 1)			
5.1G	Connect wiring between relay board on computer and right relay breakout board (see Fig. 1)			
5.1H	Connect wiring between thermocouple breakout board (0A to 0B) (see Fig. 1 & 2)			
5.1I	Connect wiring between thermocouple breakout board (1A and 1B) and aluminum plank (see Fig. 1 & 2)			
5.1J	Connect wiring between thermocouple breakout board (2A and 2B) and oven (see Fig. 1 & 2)			
5.1K	Connect wiring between thermocouple breakout board (3A and 3B) and oven (see Fig. 1 & 2)			

Seq #	Instructions	Date	Tech	Insp
5.1L	Connect wiring between left relay breakout board (4) and (+) 12 VDC on HE104 Power Board on computer (see Fig.1, 3)			
5.1M	Connect wiring between left relay breakout board (5) and Camera (see Fig.1 & 3)			
5.1N	Connect wiring between left relay breakout board (8) and (+) 12 VDC on HE104 Power Board on computer (see Fig.1 & 3)			
5.1O	Connect wiring between left relay breakout board (9) and (+) LED's (see Fig.1 & 3)			
5.1P	Connect wiring between left relay breakout board (44) and (+) 12 VDC on HE104 Power Board on computer (see Fig.1 & 3)			
5.1Q	Connect wiring between left relay breakout board (45) and (+) DS-13 UP connection on Left Wiring Interface inside chamber (see Fig.1,3 & 24)			
5.1R	Connect wiring between left relay breakout board (48) and (+) 12 VDC on HE104 Power Board on computer (see Fig.1 & 3)			
5.1S	Connect wiring between left relay breakout board (49) and (+) DS-13 DN connection on Left Wiring Interface inside Chamber (see Fig.1, 3 & 24)			
5.1T	Connect wiring between right relay breakout board (4) and (+) 5 VDC on HE104 Power Board on computer (see Fig. 1 & 4)			
5.1U	Connect wiring between right relay breakout board and (+) oven solid state relay (see Fig. 1 & 4)			
5.1V	Connect wiring between HE104 Power Board on computer and LED's (see Fig. 1)			
5.1W	Connect wiring between HE104 Power Board on computer and Camera (see Fig. 1)			
5.1X	Connect wiring between HE104 Power Board on computer and Oven Solid State Relay (see Fig. 1)			

Seq #	Instructions	Date	Tech	Insp
5.1Y	Connect wiring between HE104 Power Board on computer and Emulator connection on Left Wiring Interface inside chamber (see Fig. 1 & 24)			
5.1Z	Connect wiring between HE104 Power Board on computer and Emulator connections on Rear Wiring Interface inside chamber (see Fig. 1 & 26)			
5.1AA	Connect wiring between Solid State Relay and SSR connections on Left Wiring Interface inside chamber (see Fig. 1 & 24)			
5.1BB	Connect wiring between Solid State Relay and Emulator connection on HE104 Power Board (see Fig. 1)			
5.1CC	Connect wiring between Solid State Relay and Oven Solid State Relay (see Fig. 1)			
5.1DD	Connect wiring between oven solid state relay and oven controllers #1 and #2 (see Fig. 1)			
5.1EE	Connect wiring between oven controllers #1 and #2 and oven controllers #3 and #4 (see Fig. 1)			
5.1FF	Connect wiring between oven controllers #1 and #3 and #4 to oven (see Fig. 1)			
5.1GG	Connect wiring between oven controllers # through #4 to RTD's (see Fig. 1)			
5.1HH	Connect wiring between Emulator connections on Left Wiring Interface outside chamber and Emulator (see Fig. 28 & 34)			
5.1II	Connect wiring between SSR connection on Left Wiring Interface outside chamber and 5V DC Power Supply (see Fig. 28 & 33)			
5.1JJ	Connect wiring between Emulator connections on Rear Wiring Interface outside chamber and Emulator (see Fig. 30 & 34)			

Seq #	Instructions	Date	Tech	Insp
5.1KK	***Caution:*** *To avoid possible hardware damage, when working with electronic components ensure a good ground*			
5.2	**Test Setup for Thermocouples**			
5.2A	Position 1st set of thermocouples at locations (see Fig. 1): • Camera • Oven controller #2 • Oven controller #3 • Oven controller #4			
5.2B	Position 2nd set of thermocouples at locations (see Fig. 1) • Oven controller #1 • Oven • Oven Solid State Relay • VGA Board on Computer • Thermocouple board on Computer			
5.2C	Connect wiring of 1st set of thermocouples to thermocouple connections on Thermocouple Wiring Interface inside chamber (see Fig. 1 & 23)			
5.2D	Connect wiring of 2nd set of thermocouples to thermocouple connections on Right Wiring Interface inside chamber (see Fig. 1 & 25)			
5.2E	Connect wiring between 1st set of thermocouple connections on Thermocouple Wiring Interface outside chamber and wiring interface on Data Acquisition System (see Fig. 27 & 31)			
5.2F	Connect wiring between 2nd set of thermocouple connections on Right Wiring Interface outside chamber and wiring interface on Data Acquisition System (see Fig. 29 & 31)			
6.0	**Component Testing**			

Seq #	Instructions	Date	Tech	Insp
6.1	**Ambient Functional Verification Test (VFT)**			
6.1A	Activate Power Supply and set output to 5 VDC			
6.1B	Turn on Emulator			
6.1C	Look for visual feedback with DS-13 DN indication Indication Observed__________			
6.1D	Turn off Emulator master switch			
6.2	**Vacuum Functional Verification Test**			
6.2A	Ensure all wires are clear of door			
6.2B	Close door to chamber			
6.2C	Tighten down door clamps			
6.2D	Under mode three, begin by opening the turbo pump roughing valve (FV06) and activating the roughing pump (VP03) from the HMI Vacuum Chamber Overview Screen on the Operator Interface Enclosure (see Fig. 8) **Note:** Gaseous Nitrogen source must be hooked up and pressurized to actuate valves.			
6.2E	The chamber must be roughed down to approximately $5x10^{-2}$ Torr before the turbopump is activated. Once this pressure is reached turn on the turbopump from the HMI Vacuum Chamber Overview Screen on the Operator Interface Enclosure (see Fig. 8) **Note:** Prior to operating turbopump ensure a flow of water has been establish through pump			

Seq #	Instructions	Date	Tech	Insp
6.2F	*Survivable Profile:* • -60°C (-5°C /+0°C) to +74°C (+5°C /-0°C) *Operational Profile:* • -45°C (-5°C /+0°C) to +45°C (+5°C /-0°C)			

Seq #	Instructions	Date	Tech	Insp
6.2G	On the HMI Segment Temperature Setup and Trend Screen of the Operator Interface Enclosure (see Fig. 7) set the segments as followed: Segment 1: Ramp Rate: 1°C/min Dwell Temp: -60°C Dwell Time: 30 mins Dwell Time to increase if components temperature has not reached -60°C Segment 2: Ramp Rate: 2°C/min Dwell Temp: -45°C Dwell Time: 30 mins Dwell Time to increase if components temperature has not reached -45°C Segment 3: Ramp Rate: 2°C/min Dwell Temp: 74°C Dwell Time: 30 mins Dwell Time to increase if components temperature has not reached 74°C Segment 4: Ramp Rate: 2°C/min Dwell Temp: 45°C Dwell Time: 30 mins Dwell Time to increase if components temperature has not reached 45°C			

Seq #	Instructions	Date	Tech	Insp
6.2H	When the chamber reaches a high vacuum initiate the heating / cooling mode of the TCU from the HMI Segment Temperature Setup and Trend Screen of the Operator Interface Enclosure (see Fig. 7). Record start time. Record the temperature of the platen on the HMI Vacuum Chamber Overview Screen. Record the vacuum level on the HMI Vacuum Chamber Screen. Start Time__________ Temperature__________ Vacuum Level__________ **Note**: Liquid Nitrogen source must be hooked up and pressurized to cool chamber. Also Prior to starting cycle turn on liquid pump (P104) and ensure a flow of at least 12 GPM from the HMI Vacuum Enclosure Screen on the Operator Interface Enclosure (see Fig. 5)			
6.2I	Start logging thermocouple reading on the Data Recording Computer (see Fig. 32)			
6.2J	When chamber reaches the dwell temperature of segment one record time, temperature of the platen, and vacuum level. <u>Chamber @ Dwell Temp #1:</u> Time__________ Temperature__________ Vacuum Level__________			

Seq #	Instructions	Date	Tech	Insp
6.2K	When components being tested reach -60°C (-5°C /+0°C) record time, temperature of the platen, vacuum level Components @ -60°C: Time__________ Temperature__________ Vacuum Level__________ **Note:** Components being tested may or may not reach -60°C (-5°C /+0°C) within 30 minutes. If the dwell time is about to expire extend the dwell time on the HMI Segment Temperature Setup and Trend Screen			
6.2L	Using the HMI Segment Temperature Setup and Trend Screen end segment one (regardless of dwell time left) and proceed with segment two			
6.2M	When chamber reaches the dwell temp of segment two record time, temperature of the platen, and vacuum level. Chamber @ Dwell Temp #2: Time__________ Temperature__________ Vacuum Level__________			

Seq #	Instructions	Date	Tech	Insp
6.2N	When components being tested reach -45°C (-5°C /+0°C) record time, temperature of the platen, vacuum level and conduct Functional Verification Test (FVT) Components @ -45°C: Time__________ Temperature__________ Vacuum Level__________ **Note:** Components being tested may or may not reach -45°C (-5°C /+0°C) within 30 minutes. If the dwell time is about to expire extend the dwell time on the HMI Segment Temperature Setup and Trend Screen			
6.2O	Activate Power Supply and set output to 5 VDC			
6.2P	Turn on Emulator			
6.2Q	Look for visual feedback with DS-13 DN indication Indication Observed__________			
6.2R	Turn off Emulator master switch			
6.2S	When FVT is finished, using the HMI Segment Temperature Setup and Trend Screen end segment two (regardless of dwell time left) and proceed with segment three			

Seq #	Instructions	Date	Tech	Insp
6.2T	When chamber reaches the dwell temp of segment three record time, temperature of the platen, and vacuum level. Chamber @ Dwell Temp #3: Time__________ Temperature__________ Vacuum Level__________			
6.2U	When components being tested reach 74°C (+5°C /-0°C) record time, temperature of the platen, vacuum level and proceed back down to ambient temperature. Components @ 74ºC: Time__________ Temperature__________ Vacuum Level__________ **Note:** Components being tested may or may not reach 74°C (+5°C /-0°C) within 30 minutes. If the dwell time is about to expire extend the dwell time on the HMI Segment Temperature Setup and Trend Screen			
6.2V	Using the HMI Segment Temperature Setup and Trend Screen end segment three (regardless of dwell time left) and proceed with segment four			
6.2W	When chamber reaches the dwell temp of segment four record time, temperature of the platen, and vacuum level. Chamber @ Dwell Temp #4: Time__________ Temperature__________ Vacuum Level__________			

Seq #	Instructions	Date	Tech	Insp
6.2X	When components being tested reach 45°C (+5°C /-0°C) record time, temperature of the platen, vacuum level and proceed with Functional Verification Test (FVT) Components @ 45°C: Time__________ Temperature__________ Vacuum Level__________ **Note:** Components being tested may or may not reach 45°C (+5°C /-0°C) within 30 minutes. If the dwell time is about to expire extend the dwell time on the HMI Segment Temperature Setup and Trend Screen			
6.2Y	Activate Power Supply and set output to 5 VDC			
6.2Z	Turn on Emulator			
6.2AA	Look for visual feedback with DS-13 DN indication Indication Observed__________			
6.2BB	Turn off Emulator master switch			
6.2CC	When FVT is finished, using the HMI Segment Temperature Setup and Trend Screen end segment four (regardless of dwell time left) and proceed with system shutdown			
7.0	**System Shutdown**			
7.1	**TCU Shutdown**			
7.1A	Stop Cycle from HMI Segment Temperature Setup and Trend Screen			
7.1B	Stop liquid pump (P104) from HMI Vacuum Enclosure Overview Screen on Operator Interface Enclosure			

Seq #	Instructions	Date	Tech	Insp
7.2	**Chamber Shutdown**			
7.2A	When chamber has reached ambient temperature loosen door clamps but do not disengage			
7.2B	Stop all vacuum pumps			
7.2C	Close FV-06			
7.2D	To reduce buildup of condensation first backfill chamber to approximately 50 torr with Gaseous Nitrogen then fill remaining with air. Open FV-10 to introduce gas and allow chamber pressure to rise and equalize with the atmospheric pressure			
7.2E	Disengage door clamps and open chamber door			
8.0	**Disassemble Test Setup**			
8.1	**Disassemble Thermocouples**			
8.1A	Disassemble steps may be performed out of order.			
8.1B	Disconnect wiring of 1st set of thermocouples to thermocouple connections on Thermocouple Wiring Interface inside chamber (see Fig. 1 & 23)			
8.1C	Disconnect wiring of 2nd set of thermocouples to thermocouple connections on Right Wiring Interface inside chamber (see Fig. 1 & 25)			
8.1D	Disconnect wiring between 1st set of thermocouple connections on Thermocouple Wiring Interface outside chamber and wiring interface on Data Acquisition System (see Fig. 27 & 31)			

Seq #	Instructions	Date	Tech	Insp
8.1E	Disconnect wiring between 2nd set of thermocouple connections on Right Wiring Interface outside chamber and wiring interface on Data Acquisition System (see Fig. 29 & 31)			
8.1F	Remove 1st set of thermocouples at locations (see Fig. 1): • Camera • Oven controller #2 • Oven controller #3 • Oven controller #4			
8.1G	Remove 2nd set of thermocouples at locations (see Fig. 1) • Oven controller #1 • Oven • Oven Solid State Relay • VGA Board on Computer • Thermocouple board on Computer			
8.2	**Disassemble Components**			
8.2A	Disassemble steps may be performed out of order.			
8.2B	Disconnect wiring between thermocouple board on computer and thermocouple breakout board (see Fig. 1)			
8.2C	Disconnect wiring between relay board on computer and left relay breakout board (see Fig. 1)			
8.2D	Disconnect wiring between relay board on computer and right relay breakout board (see Fig. 1)			
8.2E	Disconnect wiring between thermocouple breakout board (0A to 0B) (see Fig. 1 & 2)			
8.2F	Disconnect wiring between thermocouple breakout board (1A and 1B) and aluminum plank (see Fig. 1 & 2)			

Seq #	Instructions	Date	Tech	Insp
8.2G	Disconnect wiring between thermocouple breakout board (2A and 2B) and oven (see Fig. 1 & 2)			
8.2H	Disconnect wiring between thermocouple breakout board (3A and 3B) and oven (see Fig. 1 & 2)			
8.2I	Disconnect wiring between left relay breakout board (4) and (+) 12 VDC on HE104 Power Board on computer (see Fig.1, 3)			
8.2J	Disconnect wiring between left relay breakout board (5) and Camera (see Fig.1 & 3)			
8.2K	Disconnect wiring between left relay breakout board (8) and (+) 12 VDC on HE104 Power Board on computer (see Fig.1 & 3)			
8.2L	Disconnect wiring between left relay breakout board (9) and (+) LED's (see Fig.1 & 3)			
8.2M	Disconnect wiring between left relay breakout board (44) and (+) 12 VDC on HE104 Power Board on computer (see Fig.1 & 3)			
8.2N	Disconnect wiring between left relay breakout board (45) and (+) DS-13 UP connection on Left Wiring Interface inside chamber (see Fig.1,3 & 24)			
8.29O	Disconnect wiring between left relay breakout board (48) and (+) 12 VDC on HE104 Power Board on computer (see Fig.1 & 3)			
8.2P	Disconnect wiring between left relay breakout board (49) and (+) DS-13 DN connection on Left Wiring Interface inside Chamber (see Fig.1, 3 & 24)			

Seq #	Instructions	Date	Tech	Insp
8.2Q	Disconnect wiring between right relay breakout board (4) and (+) 5 VDC on HE104 Power Board on computer (see Fig. 1 & 4)			
8.2R	Disconnect wiring between right relay breakout board and (+) oven solid state relay (see Fig. 1 & 4)			
8.2S	Disconnect wiring between HE104 Power Board on computer and LED's (see Fig. 1)			
8.2T	Disconnect wiring between HE104 Power Board on computer and Camera (see Fig. 1)			
8.2U	Disconnect wiring between HE104 Power Board on computer and Oven Solid State Relay (see Fig. 1)			
8.2V	Disconnect wiring between HE104 Power Board on computer and Emulator connection on Left Wiring Interface inside chamber (see Fig. 1 & 24)			
8.2W	Disconnect wiring between HE104 Power Board on computer and Emulator connections on Rear Wiring Interface inside chamber (see Fig. 1 & 26)			
8.2X	Disconnect wiring between Solid State Relay and SSR connections on Left Wiring Interface inside chamber (see Fig. 1 & 24)			
8.2Y	Disconnect wiring between Solid State Relay and Emulator connection on HE104 Power Board (see Fig. 1)			
8.2Z	Disconnect wiring between Solid State Relay and Oven Solid State Relay (see Fig. 1)			
8.2AA	Disconnect wiring between oven solid state relay and oven controllers #1 and #2 (see Fig. 1)			
8.2BB	Disconnect wiring between oven controllers #1 and #2 and oven controllers #3 and #4 (see Fig. 1)			

Seq #	Instructions	Date	Tech	Insp
8.2CC	Disconnect wiring between oven controllers #1 and #3 and #4 to oven (see Fig. 1)			
8.2DD	Disconnect wiring between oven controllers # through #4 to RTD's (see Fig. 1)			
8.2EE	Disconnect wiring between Emulator connections on Left Wiring Interface outside chamber and Emulator (see Fig. 28 & 34)			
8.2FF	Disconnect wiring between SSR connection on Left Wiring Interface outside chamber and 5V DC Power Supply (see Fig. 28 & 33)			
8.2GG	Disconnect wiring between Emulator connections on Rear Wiring Interface outside chamber and Emulator (see Fig. 30 & 34)			
8.2HH	Detach aluminum plank from the Platen inside the vacuum chamber and remove copper mesh between the metal (see Fig. 15)			
8.2II	Detach components being tested from aluminum plank			
8.2JJ	***Caution:*** *To avoid possible hardware damage, when working with electronic components ensure a good ground*			

Figures

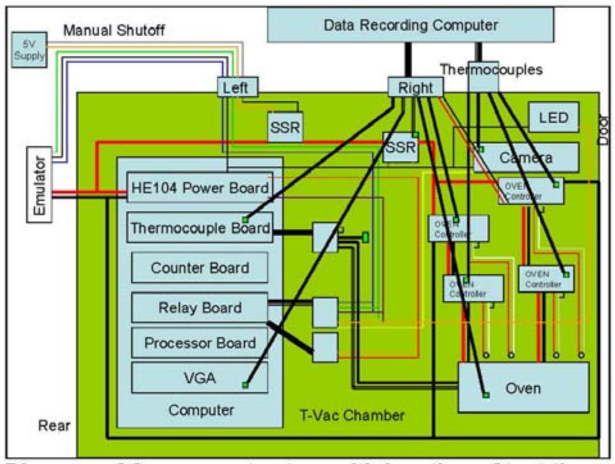


Figure 1: Diagram of Component set up with location of test thermocouples

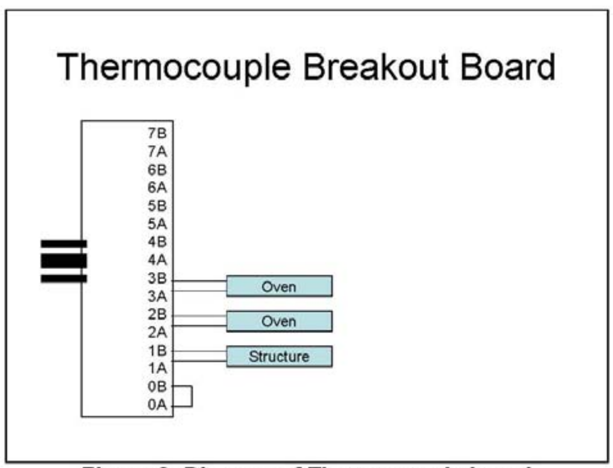


Figure 2: Diagram of Thermocouple board

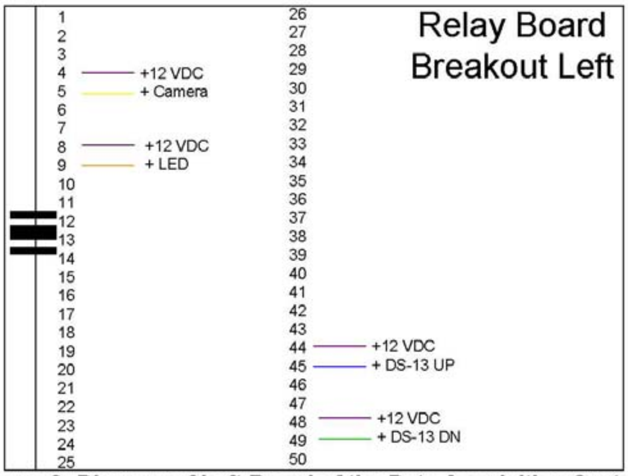
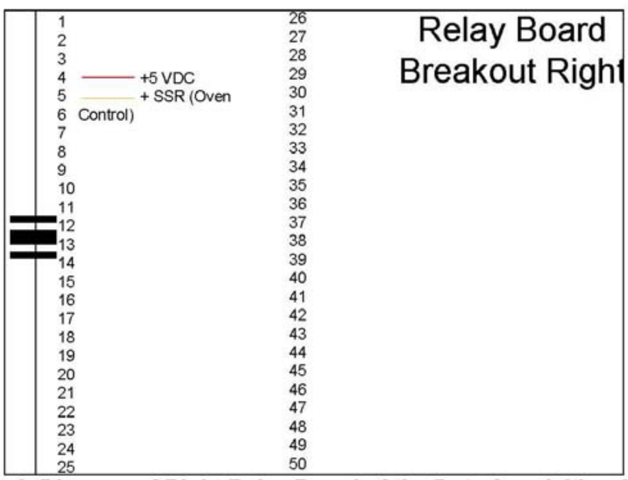


Figure 3: Diagram of Left Board of the Data Acquisition System



Firgure 4: Diagram of Right Relay Board of the Data Acquisition System

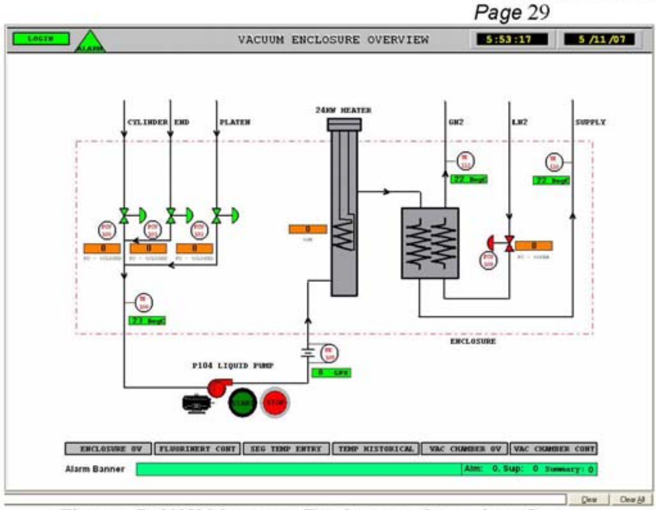


Figure 5: HMI Vacuum Enclosure Overview Screen

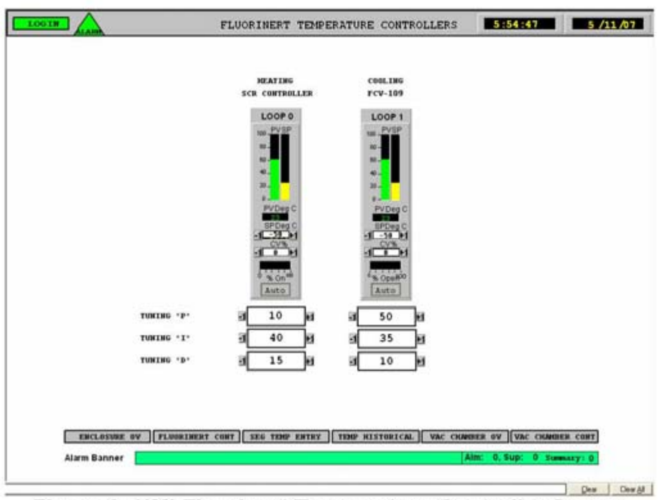


Figure 6: HMI Flourinert Temperature Controller Screen

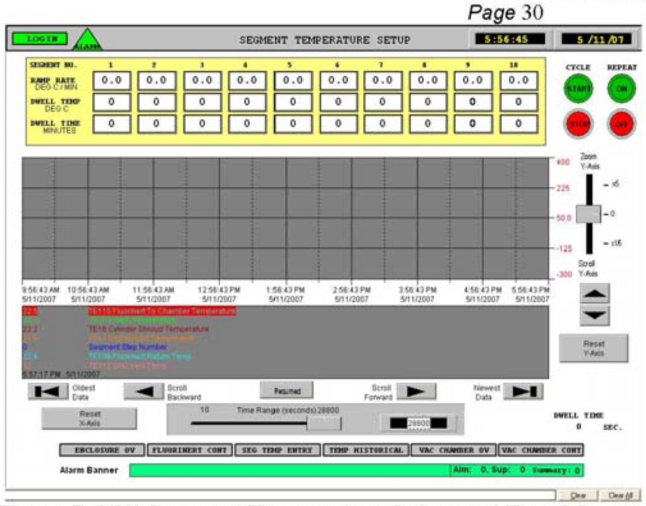


Figure 7: HMI Segment Temperature Setup and Trend Screen

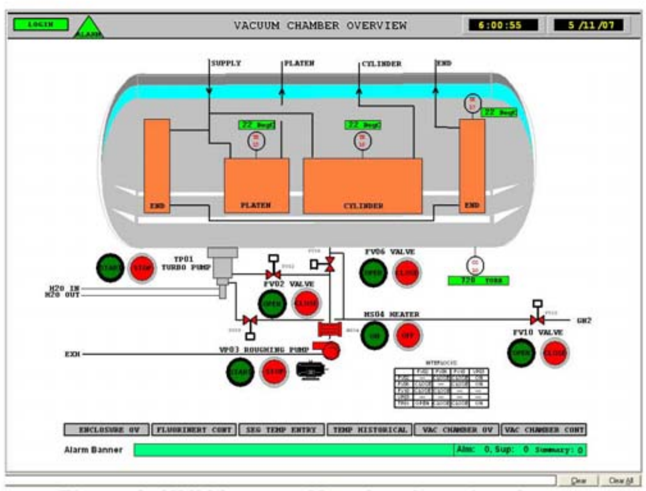


Figure 8: HMI Vacuum Chamber Overview Screen

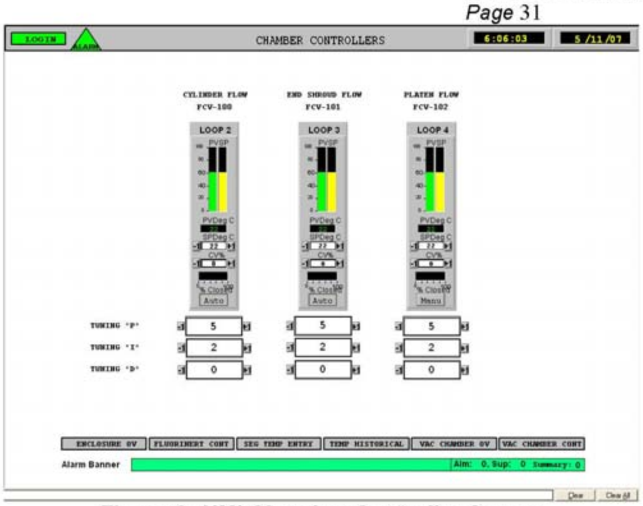
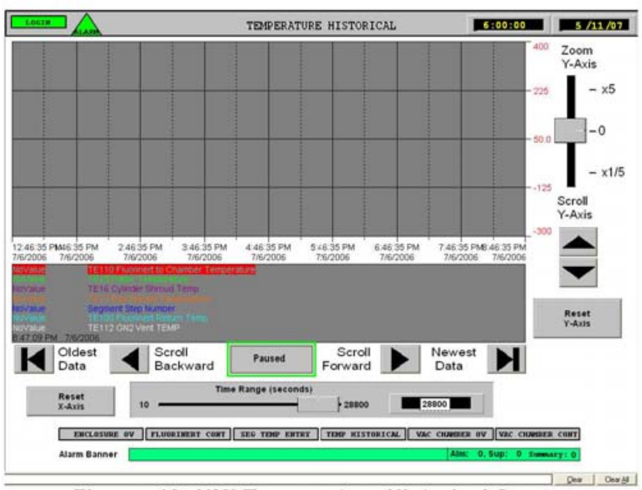


Figure 9: HMI Chamber Controller Screen



Firgure 10: HMI Temperature Historical Screen

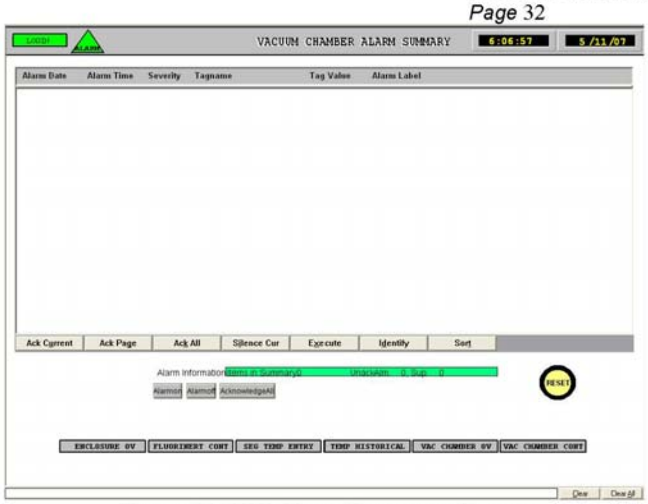


Figure 11: HMI Alarm Summary Screen

Figure 12: HMI Login Screen

Figure 13: Exterior of Vacuum Chamber

Figure 14: Interior of Vacuum Chamber

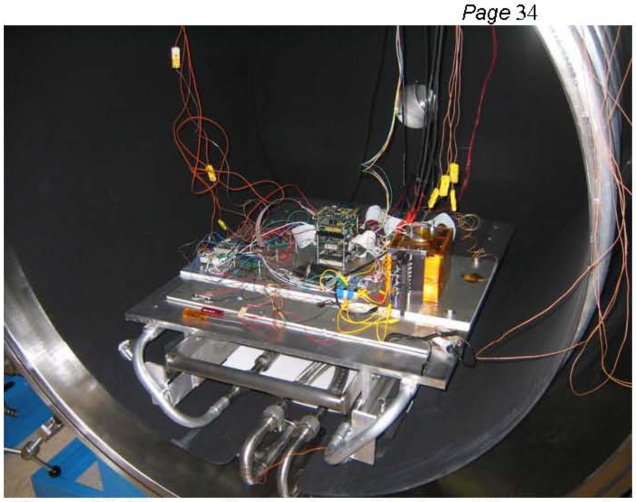


Figure 15: Platen with Aluminum Plank and Components

Figure 16: Thermal Control Unit (TCU)

Figure 17: Operator Interface Enclosure

Figure 18: Roughing Pump (VP03)

Figure 19: Turbo Pump (FV06)

Figure 20: Liquid Nitrogen Source

Figure 21: Gaseous Nitrogen Source

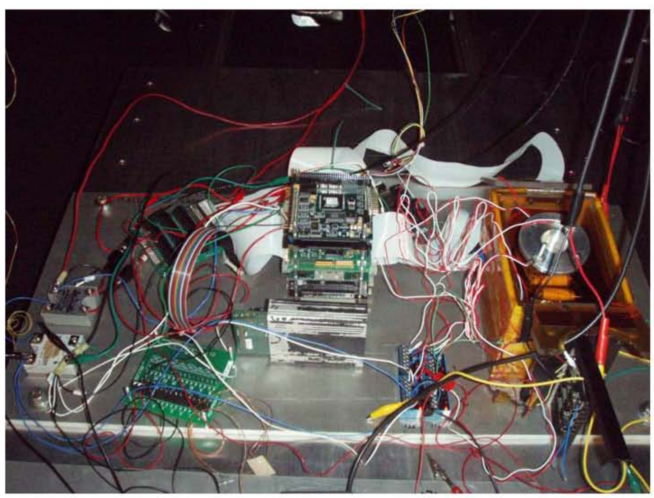


Figure 22: Test Set Up of Components, Thermocouples and RTD's

Figure 23: Connection of 1st Set of Thermocouple Wires to Thermocouple Wiring Interaface Inside Chamber

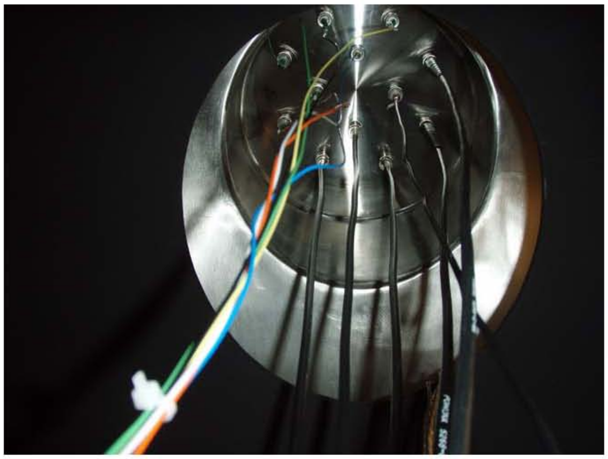


Figure 24: Connection of Emulator, SSR, and RTD Wires to Left Wiring Interface Inside Chamber

Figure 25: Connection of 2nd Set of Thermocouple Wires to Right Wiring Interface Inside Chamber

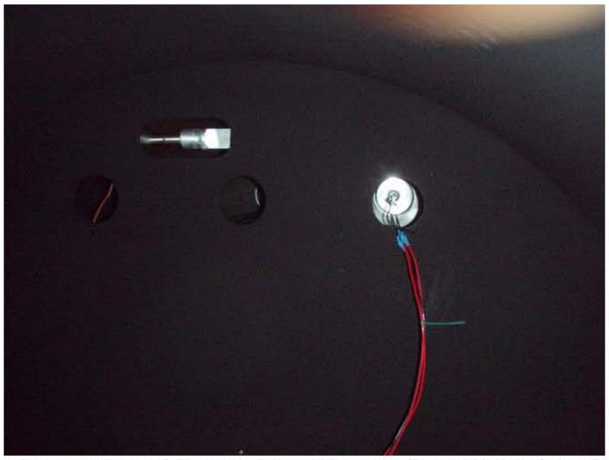


Figure 26: Connection of Eummulator Wires to Rear Wiring Interface Inside Chamber

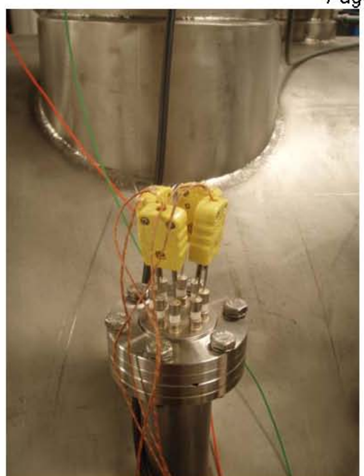


Figure 27: Connection of 1st Set of Thermocouple Wires to Thermocouple Wiring Interface Outside Chamber

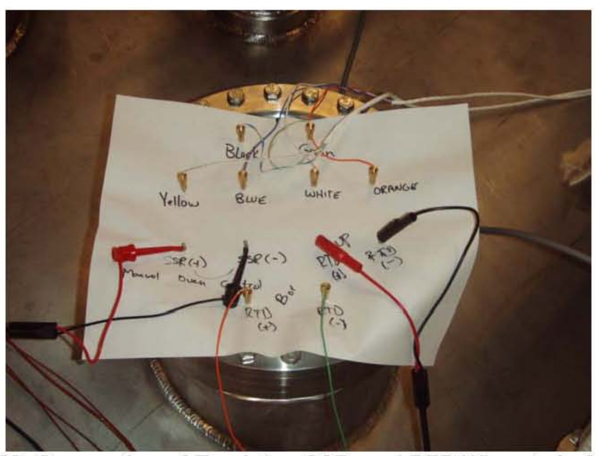


Figure 28: Connection of Emulator, SSR, and RTD Wires to Left Wiring Interface Outside Chamber

Figure 29: Connection of 2nd Set of Thermocouple Wires to Right Wiring Interface Outside Chamber

Figure 30: Conection of Emulators Wires to Rear Wiring Interface Outside Chamber

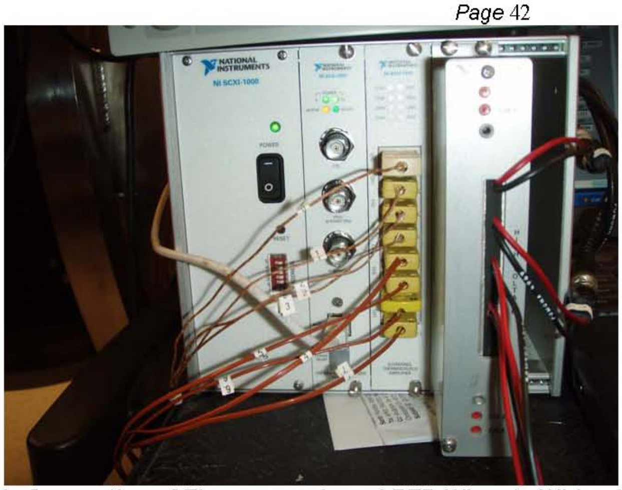


Figure 31: Connection of Thermocouple and RTD Wires to Wiring Interface on Data Acquisition System

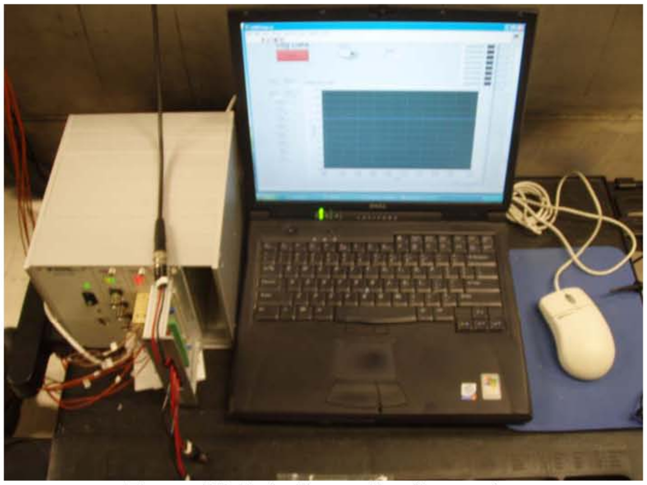


Figure 32: Data Recording Computer

Figure 33: Connection of Wires to DC Power Supply

Figure 34: Connection of Wires to Emulator

Appendix D: RIGEX Inflation Filling Procedure

RIGEX N_2 Filling Procedure
Document #: RP-09
Release Date: 17MAY2007
Revision Date:

Air Force Institute of Technology
Wright Patterson Air Force Base

RIGEX INFLATION SYSTEM
NITROGEN FILLING PROCEDURE (RP-09)

Prepared by:

____
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Approved by:

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RICHARD COBB
RIGEX Principal Investigator
AFIT/ENY

AFIT ENY RIGIX N2 Filling Procedure (RP-09).DOC

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Change Log

Rev. Ltr. Change	Justification and Description of Change	Affected Pages	Effectivity (Serial #)	Release Date	Change Approval (*Initial & Date*)
IR	Initial Release	All	All	17MAY2007	N/A

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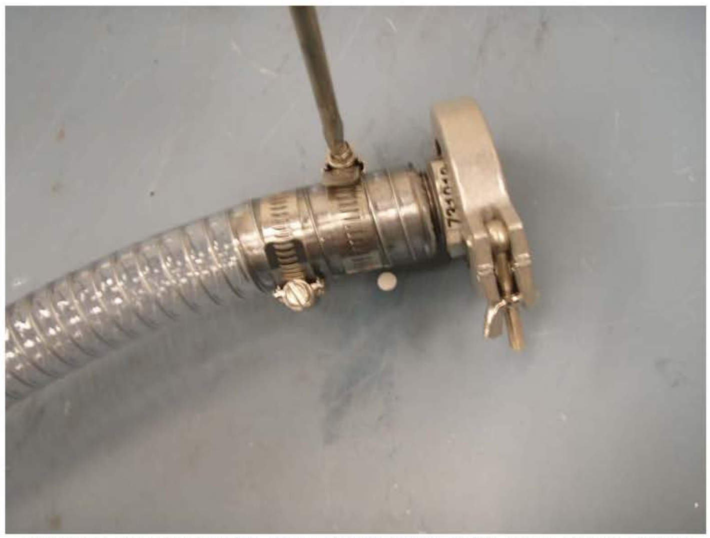
Seq #	Instructions	Date	Tech	Insp
1.0	**Scope**			
	The purpose of this procedure is to dictate step by step how to fill the inflation system on RIGEX. The primary intent is to explain the process of filling gaseous nitrogen into the tanks on RIGEX by setting up a configuration of hoses connecting the inflation system to a vacuum pump and a nitrogen source. To fill the inflation system of RIGEX with gaseous nitrogen the air must be vacuumed out first. Once the system is under a vacuum the gaseous nitrogen can be added. To ensure the integrity of the system a pressure rentention test will be conducted in a vacuum chamber.			
2.0	**Materials and Components**			
2.1	**Inflation System onboard RIGEX**			

Seq #	Instructions	Date	Tech	Insp

2.2	**Equipment Needed**
	• Steel braided Hoses:
	  ○ 7' with ¼" Male Adapters
	  ○ 3' with ¼" Male Adapters
	• Vacuum Pump Hose:
	  ○ 7' Standard
	• Standard Vacuum Pump Fitting
	• Hose Clamps (4)
	• 1.5" Hose to 1.5" NPT Threads Male Connector
	• 1.5" to 1" NPT Threads Female Connector
	• ¼" Male Adapter with 1" NPT Threads
	• Three-way Valve with ¼" Compression Fitting (2) and ¼" NPT Threads (1)
	• ¼" Female Adapter with ¼" NPT Threads
	• ¼" Three-way Union
	• ¼" Male Connector with ¼" NPT Threads (2)
	• Pressure/Vacuum Gauge (-30in.Hg to 30 psi)
	• High pressure Regulator
	• Vacuum Pump
	• Gaseous Nitrogen Source
	• Screwdriver
	• 7/16" Open-end Wrenches (2)
	• 7/8" Open-end Wrench
	• Teflon Tape
	• Space Simulator Vacuum System
	• Data Logging System
	• Wiring			

Seq #	Instructions	Date	Tech	Insp
2.3	**Additional Documents Needed:** RIGEX SPACE SIMLUATOR VACUUM SYSTEM COMPONENT TESTING (TP-03)			
3.0	**Setup of Connections for Nitrogen Source and Vacuum Pump**			
3.1	**Connecting Vacuum Pump Hose to Vacuum Pump Fitting:**  Figure 1: Connecting Vacuum Pump Hose to Vacuum Pump Fitting			
3.2	Using Screwdriver attach standard vacuum pump fitting to vacuum pump hose with hose clamps (2) (see Fig. 1)			

Seq #	Instructions	Date	Tech	Insp
3.3	**Connecting Male Connecter to Vacuum Pump Hose:**  Figure 2: Connecting Male Connector to Vacuum Pump Hose			
3.4	Using Screwdriver attach Male Connector (1.5" Hose to 1.5" NPT Threads) to vacuum pump hose with hose clamps (2) (see Fig. 2)			

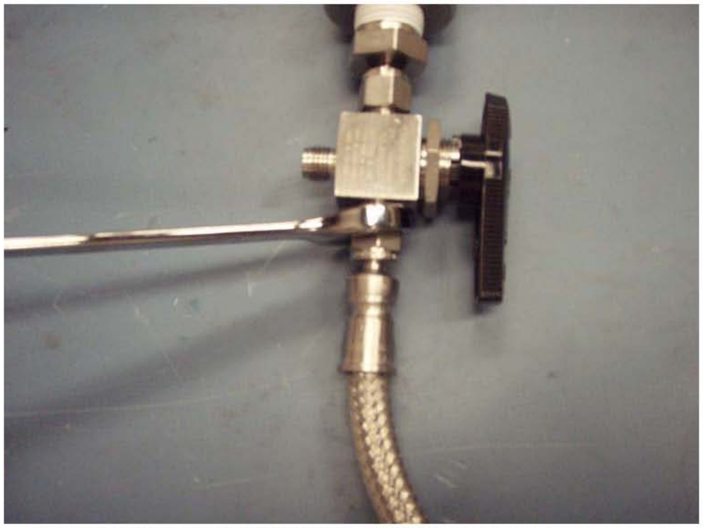
Seq #	Instructions	Date	Tech	Insp
3.5	**Connecting Male Connector to Female Connector:**  Figure 3: Connecting Male Connector to Female Connector			
3.6	Wrap Male Connector (1.5" Hose to 1.5" NPT Threads) with Teflon tape			
3.7	Twist Male Connector (1.5" Hose to 1.5" NPT Threads) into Female Connector (1.5" to 1" NPT Threads) (see Fig. 3)			

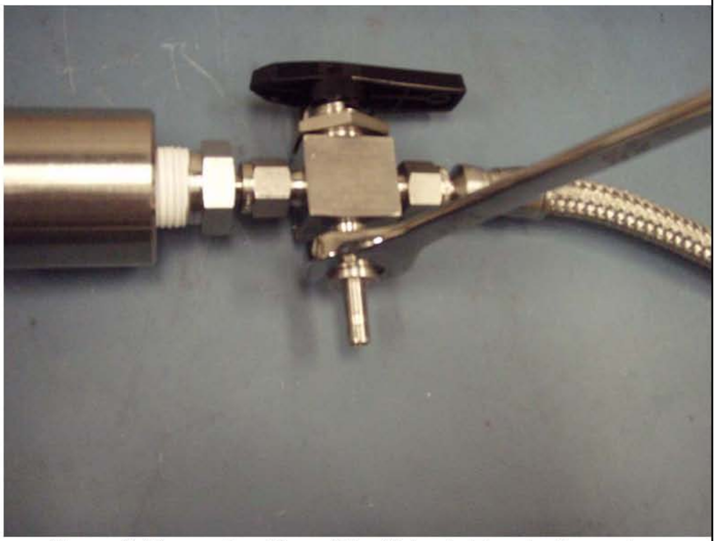
Seq #	Instructions	Date	Tech	Insp
3.8	**Connecting Male Adapter to Female Connector:**  Figure 4: Connecting Male Adapter to Female Connector			
3.9	Wrap Male Adapter (¼" with 1" NPT Threads) with Teflon tape			
3.10	Using 7/8" open-end wrench twist Male Adapter (1/4" with 1" NPT Threads) into Female Connector (1.5" to 1" NPT Threads) (see Fig. 4)			

Seq #	Instructions	Date	Tech	Insp
3.11	**Connecting Male Connector to 7' Steel Braided Hose:**  Figure 5: Connecting Male Connector to 7' Steel Braided Hose			
3.12	Using 7/16" open-end wrenches (2) secure Male Connector (¼" with ¼" NPT Threads) to ¼" male adapter on 7' steel braided hose (see Fig. 5)			

Seq #	Instructions	Date	Tech	Insp
3.13	**Connecting 7' Steel Braided Hose:**  Figure 6: Connecting 7' Steel Braided Hose			
3.14	Wrap Male Connector (¼" with ¼" NPT Threads) with Teflon tape			
3.15	Using 7/16" open-end wrench twist Male Connector (¼" with ¼" NPT Threads) on 7' steel braided hose into high pressure regulator (see Fig. 6)			

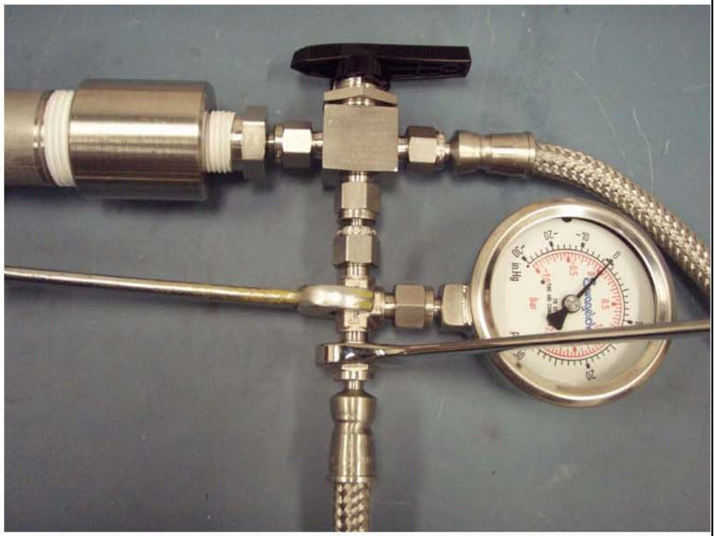
Seq #	Instructions	Date	Tech	Insp
3.16	**Connecting Three-Way Valve to Vacuum Pump Hose:**  Figure 7: Connecting Three-Way Valve to Vacuum Pump Hose			
3.17	Using 7/16" open-end wrench secure three-way valve to ¼" Male Adapter on 7' standard vacuum pump hose (see Fig. 7)			

Seq #	Instructions	Date	Tech	Insp
3.18	**Connecting Three-Way Valve to 7' Steel Braided Hose:**  Figure 8: Connecting Three-Way Valve to 7' Steel Braided Hose			
3.19	Using 7/16" open-end wrench secure three-way valve to ¼" Male Adapter on 7' steel braided hose (see Fig. 8)			

Seq #	Instructions	Date	Tech	Insp
3.20	**Connecting Three-Way Valve to Female Adapter:**  Figure 9: Connecting Three-Way Valve to Female Connector			
3.21	Using 7/16" open-end wrench secure three-way valve to Female Adapter (¼" with ¼" NPT Threads) (see Fig. 9)			

Seq #	Instructions	Date	Tech	Insp
3.22	**Connecting Three-Way Union to Female Adapter:**  Figure 10: Connecting Three-Way Union to Female Adapter			
3.23	Using 7/16" open-end wrenches (2) secure three-way union (¼") to Female Adapter (¼" with ¼" NPT Threads) (see Fig. 10)			

Seq #	Instructions	Date	Tech	Insp
3.24	**Connecting Three-Way Union to Pressure/Vacuum Gauge:**  Figure 11: Connecting Three-Way Union to Pressure/Vacuum Gauge			
3.25	Using 7/16" open-end wrench secure three-way union (¼") to pressure/vacuum gauge (-30in.Hg to 30 psi) (see Fig. 11)			

Seq #	Instructions	Date	Tech	Insp
3.26	**Connecting Three-Way Union to 3' Steel Braided Hose:**  Figure 12: Connecting Three-Way Union to 3' Steel Braided Hose			
3.27	Using 7/16" open-end wrenches (2) secure three-way union (¼") to ¼" Male Adapter on 3' steel braided hose (see Fig. 12)			

Seq #	Instructions	Date	Tech	Insp
3.28	**Connecting Male Connecter to 3' Steel Braided Hose:**  Figure 13: Connecting Male Connector to 3' Steel Braided Hose			
3.29	Using 7/16" open-end wrenches (2) secure Male Connector (¼" with ¼" NPT Threads) to ¼" male adapter on 3' steel braided hose (see Fig. 13)			
4.0	**Charging Inflation System**			
4.1	Connect vacuum pump hose to vacuum pump			
4.2	Connect high pressure regulator to gaseous nitrogen source			
4.3	Set high pressure regulator to 1 atm (14.7 psi)			

Seq #	Instructions	Date	Tech	Insp
4.4	Turn on nitrogen source to bleed out air in hose **Note:** Ensure three-way valve set to nitrogen			
4.5	Turn off nitrogen at three-way by turning to vacuum.			
4.6	Using 7/16" open-end wrenches secure ¼" male adapter on 3' steel braided hose to fill valve on RIGEX inflation subsystem			
4.7	Open fill valve on RIGEX inflation subsystem			
4.8	Turn on vacuum pump. Record time and pressure from pressure/vacuum gauge (-30in.Hg to 30 psi) TIME:__________ Pressure: __________			
4.9	When a sufficient vacuum is reached. Record time and pressure. TIME:__________ Pressure:__________			
4.10	Turn three-way valve to nitrogen			
4.11	Turn off vacuum pump			
4.12	When pressure equalizes to 1atm (14.7 psi) record time and pressure. TIME:__________ Pressure:__________			

Seq #	Instructions	Date	Tech	Insp
4.13	Close fill valve on RIGEX inflation subsystem			
4.14	Close off nitrogen from three-way valve by switching back to vacuum pump			
4.15	Using 7/16" open-end wrenches disconnect ¼" male adapter on 3' steel braided hose from fill valve on RIGEX inflation subsystem			
4.16	Repeat steps 4.6 to 4.15 again both of the other two RIGEX inflation subsystems			
4.17	Vacuum pump on (2nd): TIME:__________ Pressure: __________			
4.18	Vacuum is reached (2nd): TIME:__________ Pressure:__________			
4.19	Pressure equalizes to 1atm (14.7 psi) (2nd). TIME:__________ Pressure:__________			
4.20	Vacuum pump on (3rd): TIME:__________ Pressure: __________			

Seq #	Instructions	Date	Tech	Insp
4.21	Vacuum is reached (3rd): TIME:__________ Pressure:__________			
4.22	Pressure equalizes to 1atm (14.7 psi) (3rd). TIME:__________ Pressure:__________			
4.23	When all three RIGEX inflation subsystems are filled turn off nitrogen source and disconnect high pressure regulator.			
4.24	Store filling system until required to refill RIGEX inflation subsystem			
5.0	**Pressure Retention Test**			
5.1	**Note:** For detail instructions on operation vacuum chamber refer to: RIGEX SPACE SIMLUATOR VACUUM SYSTEM COMPONENT TESTING (TP-03)			
5.2	Place RIGEX in Space Simulator Vacuum System			
5.3	Connect wiring between pressure transducers onboard RIGEX near pressure vessels and wiring interfaces inside vacuum chamber			
5.4	Connect wiring between wiring interfaces outside chamber and wiring interface on data logging system.			

Seq #	Instructions	Date	Tech	Insp
5.5	Close door to chamber and place under vacuum. Record time and pressure: Time__________ Pressure:__________			
5.6	Using *Labview* on data logging computer begin recording pressure levels for the three inflation subsystems onboard RIGEX			
5.7	When a high vacuum is reached record time and pressure: Time:__________ Pressure:__________			
5.8	Continue logging pressure levels on data acquisition system			
5.9	Upon completion of testing at a high vacuum record time and pressure: Time:__________ Pressure:__________			
5.10	Return vacuum chamber to ambient pressure and open door			
5.11	Disconnect all wiring between pressure transducers and wiring interfaces inside chamber			
5.12	If any inflation subsystem fails to retain pressure remove RIGEX from vacuum chamber and inspect for leaks			
5.13	Repair leaks where necessary and refill RIGEX inflation subsystem following steps in sequence 4			

Seq #	Instructions	Date	Tech	Insp
5.14	Return RIGEX to the vacuum chamber and retest pressure retention of RIGEX inflation system following steps 5.3 to 5.11.			
5.15	Upon return of acceptable pressure readings from all inflation subsystems onboard RIGEX while under vacuum, testing is complete			

Appendix E: RIGEX Vibration Test Plan

Rigidizable Inflatable Get-Away Special Experiment Vibration Test Plan

Document No: RGX20079002

DoD Shuttle/ISS Human Spaceflight Payloads

MEI TECHNOLOGIES
Merging Excellence and Innovation
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Houston, TX 77058

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Date: 1 May 2007

Revision: Rev IR

DoD Space Test Program
2101 NASA Parkway JSC-ZR
Houston, TX 77058

Rigidizable Inflatable Get-Away Special Experiment Vibration Test Plan

Revision: IR

Prepared by:	Carson Taylor RIGEX Payload Integration Engineer	Date:

Reviewed by:	Scott Ritterhouse RIGEX Payload Integration Engineer	Date:

Reviewed by:	Darren Bromwell STP Lead Safety Engineer	Date:

Approved by:	Matthew Budde, Major, USAF DoD Human Spaceflight Payload Manager DoD Space Test Program	Date:

Change Record

Rev.	Date	Originator	Approvals	Description
NC	4/26/2007	C. Taylor		Draft
IR				

Table of Contents

List of Figures

List of Tables

1. INTRODUCTION

1.1 Purpose

The scope of this document is to provide a test plan for random vibration testing of the Rigizable Inflatable Get-Away Special Experiment (RIGEX) payload, which consists of the RIGEX Assembly mounted inside of the Canister for All Payload Ejections (CAPE) Assembly.

The main objective of the test plan is to perform a vibration test to qualify the CAPE-RIGEX Assembly for flight in the Orbiter payload bay on STS-123, where it will be mounted in Bay 13 on the starboard side via a Small Payloads Accommodation (SPA) Beam.

Dynamic environment tests will be conducted with the CAPE-RIGEX Assembly, mounted on a rigid surface to simulate the interface with the SPA Beam in the Shuttle cargo bay. No structural issues or concerns have been identified.

1.2 Points of Contact

The RIGEX information is provided in Table 1.

Table 1: Space Test Program (STP) Points of Contact

Position	Name	Organization	Phone E-mail
RIGEX Cargo Bay Lead PIE	Scott Ritterhouse	MEI	(281) 483 3529 Scott.d.Ritterhouse@nasa.gov
RIGEX Back up PIE	Carson Taylor	OSS	(281) 483 3491 Carson.a.Taylor@nasa.gov
RIGEX Safety Engineer	Theresa Shaffer	MEI	(281) 483 8669 theresa.m.shaffer@nasa.gov
RIGEX DoD Payload Mgr	Matthew Budde, Major, USAF	STP	(281) 483-0361 matthew.j.budde@nasa.gov

1.3 Compliance Documents

- NSTS 37329, Rev. B, *Structural Integration Analyses Responsibility Definition for Space Shuttle Vehicle and Cargo Element Developers*
- CAPE-FCP-0002 *CAPE/RIGEX Fracture Control Plan*
- CAPE-MSVP-0001 *CAPE/ICU Mechanical Systems Verification Plan*

2. PAYLOAD DESCRIPTION

2.1 CAPE-RIGEX Assembly Description

The CAPE-RIGEX Assembly is attached to a SPA (Small Payload Accommodations) Beam on the Orbiter Sidewall, in Bay 13 starboard for STS-123. The CAPE Assembly includes an outer Canister that acts as the interface between the Orbiter Sidewall and RIGEX. The RIGEX Assembly is bolted to the upper flange of the CAPE Canister with 32X ¼-28 bolts, and is not an ejectible payload.

The CAPE Canister has a twenty-two (22) inch inner diameter and is 54 inches long. It is closed at the bottom end by an End Cap bolted to the integrated flange on the cylinder. The RIGEX 'CAPE Mounting Plate' also acts as the lid at the upper end of the Canister and the rest of the RIGEX structure is cantilevered from this Plate inside.

The Mounting Plate of the CAPE Assembly will interface with the SPA Beam utilizing the bolt pattern on the SPA Beam.

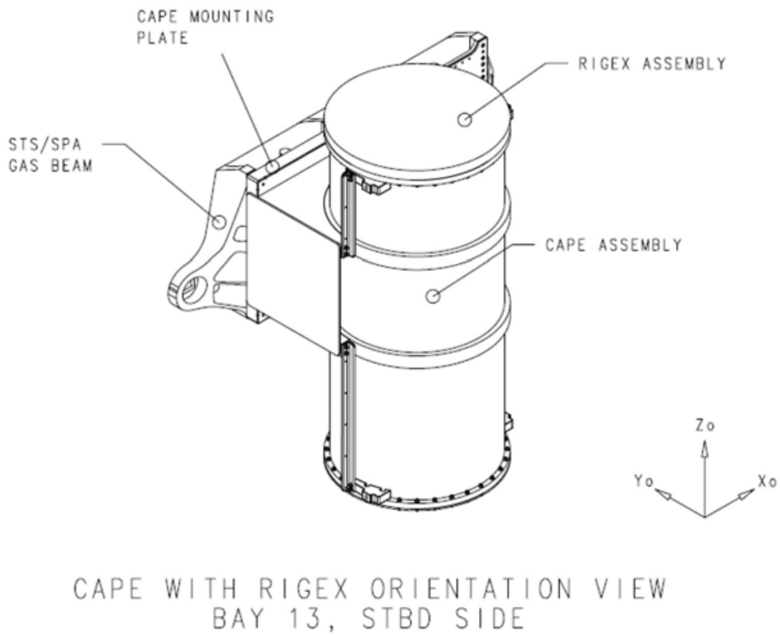


Figure 1: CAPE-RIGEX Assembly Mounted to Bay 13 SPA Beam (Figure by Boeing)

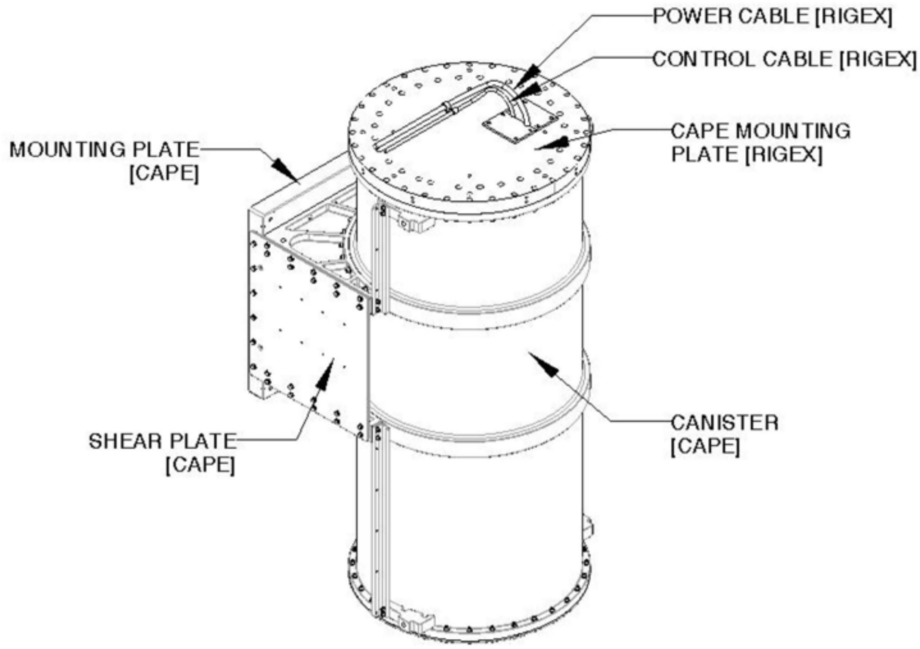


Figure 2: CAPE-RIGEX Assembly

2.2 RIGEX Assembly Description

RIGEX is a Cargo Bay Payload experiment exploring the use of inflatable and rigidizable structures for use on operational space systems. RIGEX is being developed by graduate students at the Air Force Institute of Technology (AFIT).

The Orbiter crew will initiate the experiment and one tube at a time will heat, inflate, cool/rigidize, and vent. Data and pictures will be collected internally by RIGEX. Mechanical properties of the rigidized structure will be assessed by exciting each tube using a piezoelectric patch on the cantilevered end to obtain modal characterization data.

The RIGEX primary structure consists of a top and bottom plate and four vertical outside compartments surrounding an inner compartment as shown in Figure 3. All primary structure consists of 6061-T6 aluminum alloy, and is assembled using NAS fasteners with locking features such as locking helicoils, patchlock bolts, or locking nuts. Three of the outer compartments will house an individual tube/oven assembly and the fourth outer compartment will house the avionics. The nitrogen gas storage cylinders will be housed in the inner compartment.

In order to protect RIGEX during ground processing and protect the inner coating of the CAPE canister, a 0.075" 6061-T6 aluminum shroud is being added that will enclose the outer diameter of RIGEX experiment from the top plate to the bottom plate. Soft bumpers of Delrin will be attached to the bottom plate of the RIGEX experiment in order to protect the CAPE inner coatings during ground processing. Ground Support Equipment (GSE) handles are mounted to the CAPE Mounting Plate and the Oven Mounting Plate for ground operations and to provide a stable footing for RIGEX ground operations outside of the CAPE. Handles will be removed for flight.

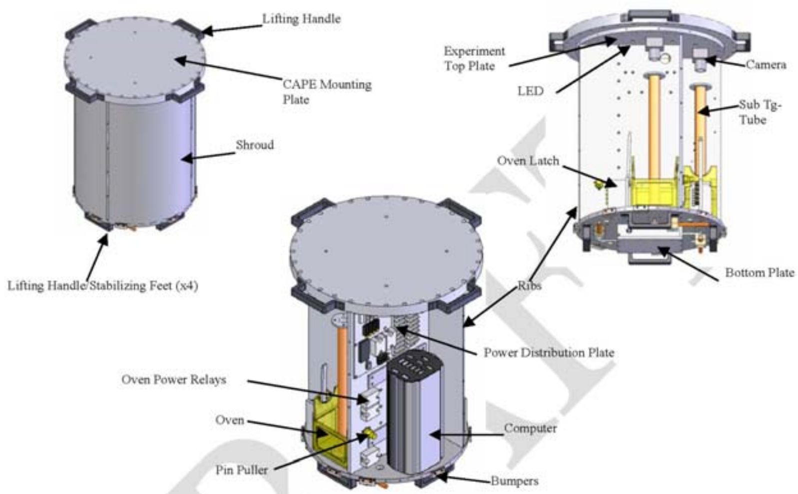


Figure 3: RIGEX Assembly (cables not shown)

2.3 Differences Between the Flight Article and Test Article

The test article will consist of all flight hardware with the following exceptions:

1) Pigtail cables visible in Figure 2 will be GSE test cables rather than the flight cables. Flight cables will be routed along the CAPE Cable Guide and along the Shear Plate mounting fasteners as shown in Figure 4. Each cable will be restrained eight or nine P-clamps for flight. For testing, each of the GSE cables will be restrained with one P-clamp after it emerges from the CAPE Mounting Plate. The remaining cable length will be coiled and restrained nearby using temporary means (i.e. tape) as necessary for vibration testing.
2) The three composite Sub-Tg tubes (labeled in Figure 3) will not be the flight tubes, but will be identical to the flight tubes. These will be replaced with the flight tubes at AFIT following the vibration and EMI testing.

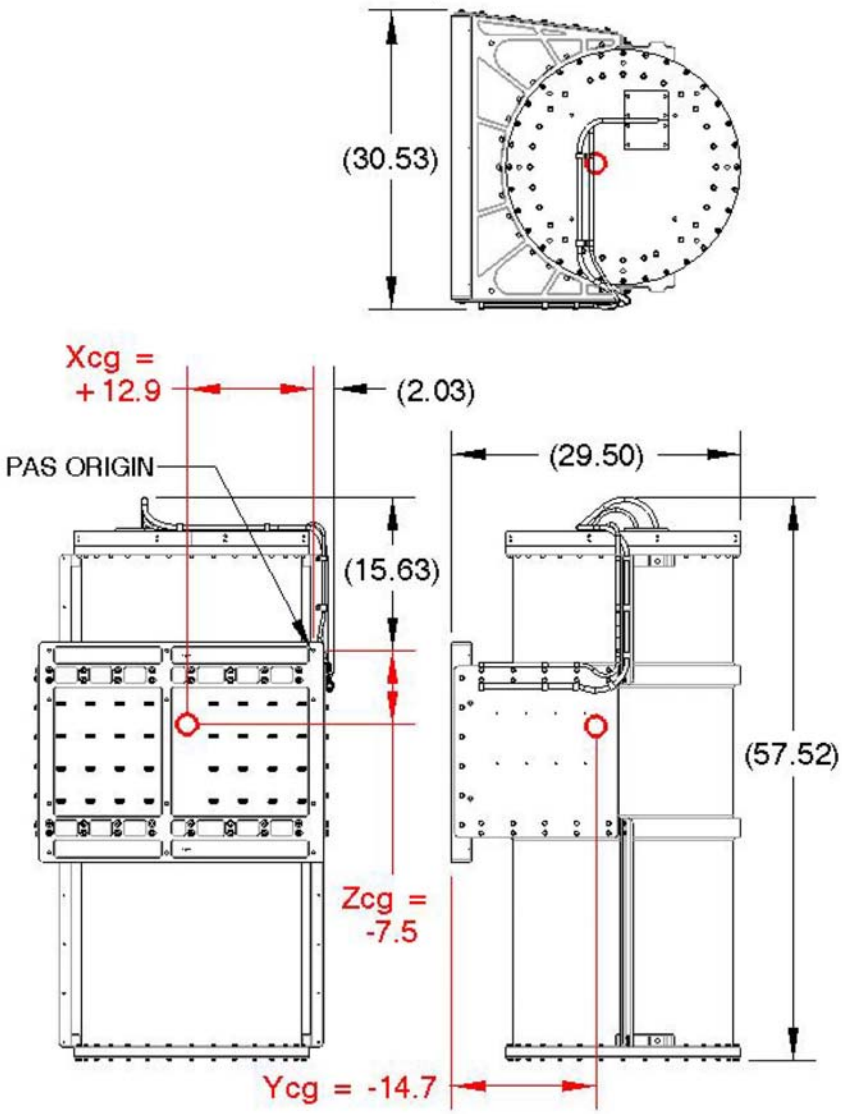


Figure 4: Test Article Dimensions

3. INTEGRATED TEST

3.1 Test Requirements Review

As soon as possible and prior to the test program, Space Test Program (STP) personnel will meet with the facility personnel and review the test requirements, discuss the test flow, and establish the working relationships between STP and the facility personnel.

3.2 Test Readiness Review

Prior to the start of the test, a Test Readiness Review (TRR) will be conducted between STP personnel and the test facility personnel. The purpose of the TRR will be to ensure that the hardware is ready for testing and the facility is ready to conduct the test. Items reviewed at the TRR will include the Test Requirement Document (i.e., the test plan or task preparation sheet), Test Article Hazard Analysis, TRR Summary Sheet (verifies that there are on issues with the test), Drawings as required, and any personnel certifications required.

3.3 Test Fixture

The STP will provide the Vibration Adapter Plate, part number MGSE20075002-301, required to mount the CAPE-RIGEX Assembly to the vibration shaker head during testing. The test facility will provide certified lifting and handling equipment for this plate as required. The Vibration Adapter Plate has many holes with 3/8-24 UNF threads suitable to use as lift points, which weighs approximately 215 lbs. The twelve-hole pattern marked with bubble number 2 in Figure 5 are the holes used for mounting the CAPE-RIGEX Assembly to the Vibration Adapter Plate.

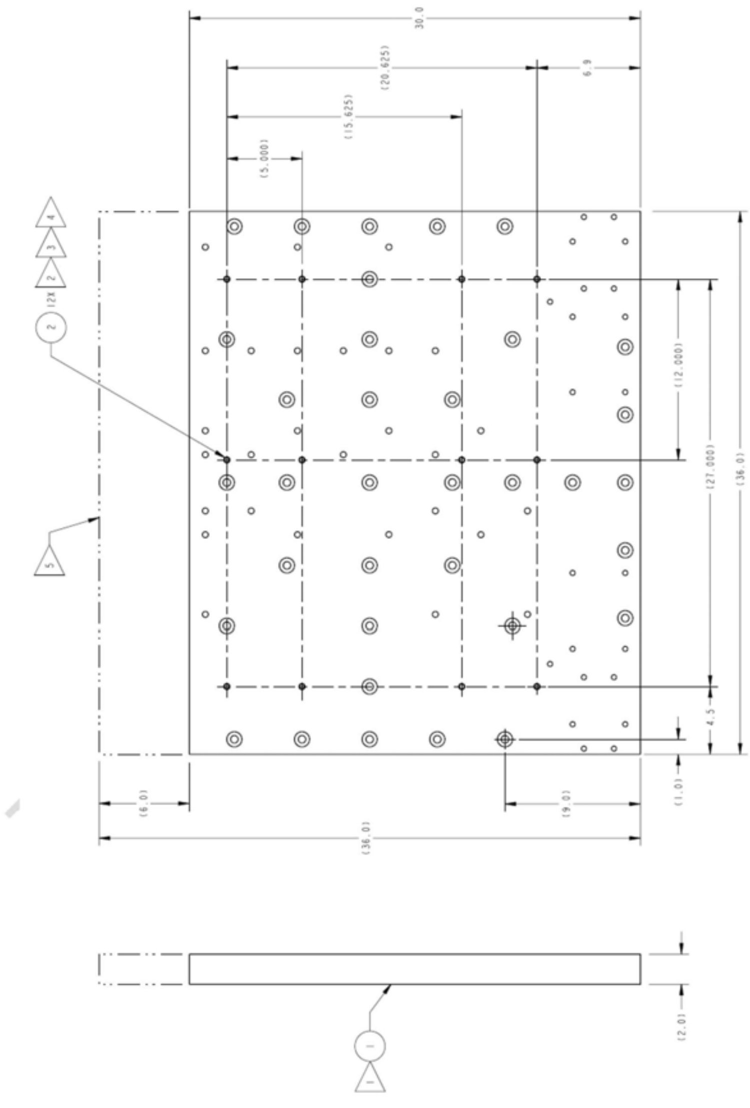


Figure 5: Test Fixture: Vibration Adapter Plate

3.4 Structural Stiffness

The design goal for the CAPE/RIGEX is to have a natural frequency above 35 Hz. The fundamental frequency verification shall be submitted to the JSC Structures Working Group (SWG) and the model verification will be required per NSTS 14046 para 5.1.1.3.2 if the fundamental frequency is below 35 Hz for the sidewall. The CAPE/RIGEX fundamental frequencies are assessed at the payload to GAS Beam interface, which are assumed to be fixed.

If the fundamental frequency is less than 35 hertz for the sidewall and dynamic model verification is required, a test plan will be submitted to the SWG for review and approval at least 60 days prior to the tests. In addition, a detailed model correlation report will also be submitted to the SWG for review and approval. If the first fundamental frequency is below 35 hertz, the design limit load factors in NSTS 21000-IDD-SML, Table 4.0.4.2.4-1can not be used for the CAPE/RIGEX.

3.5 Structural Stiffness Verification (Sine Sweep Test)

The fundamental frequency will be verified by sine sweep testing pre and post vibration testing as allowed by NASA-STD-5002 para 4.2.6.i. The results of this will be compared to the predicted frequencies of the FEM. The sine sweep tests will consists of a series of 0.25 G sweeps in each axis from 10 to 200 Hz (20 to 200 Hz minimum) at maximum rate of 2 oct/min (0.5 oct/min minimum). Preliminary analysis shows that a 0.25 G sine sweep up and down be adequate to determine if the system will react in a linear fashion. However, a real-time assessment will be made as to whether additional sweeps at alternate levels will be conducted if deemed necessary to assess system non-linearities. The test will be conducted in the following manner:

1. Measure and record the torque values of the bolts connecting the test article to the vibration table.
2. Sine Sweep at 0.25 g from 10 to 200 Hz and from 200 to 10 Hz (minimum 20 to 200 Hz) at a maximum rate of 2 oct/min (minimum of 0.5 oct/min).
3. Perform vibration test.
4. Sine Sweep at 0.25 g from 10 to 200 Hz and from 200 to 10 Hz (minimum 20 to 200 Hz) at a maximum rate of 2 oct/min (minimum of 0.5 oct/min).
5. Brief examination of test data.
6. If needed, repeat sweep at higher level to check linearity and repeatability before continuing.
7. Switch to next axis and repeat steps 1-6.
8. Switch to next axis and repeat steps 1-6.

3.6 Random Vibration

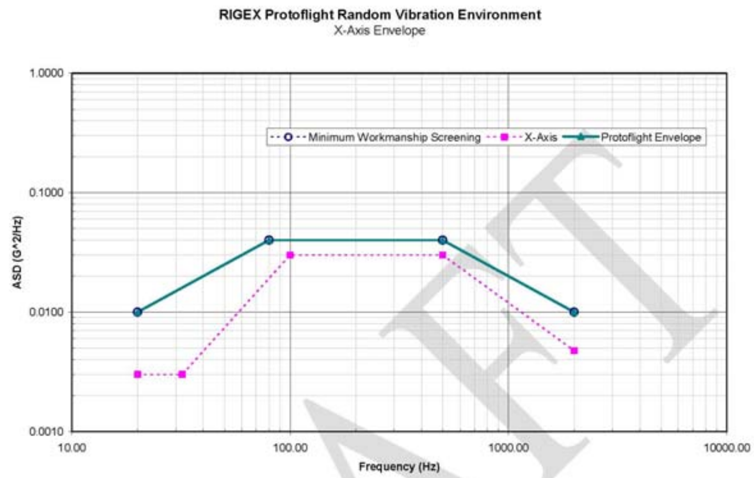
3.6.1 Random Vibration Environment

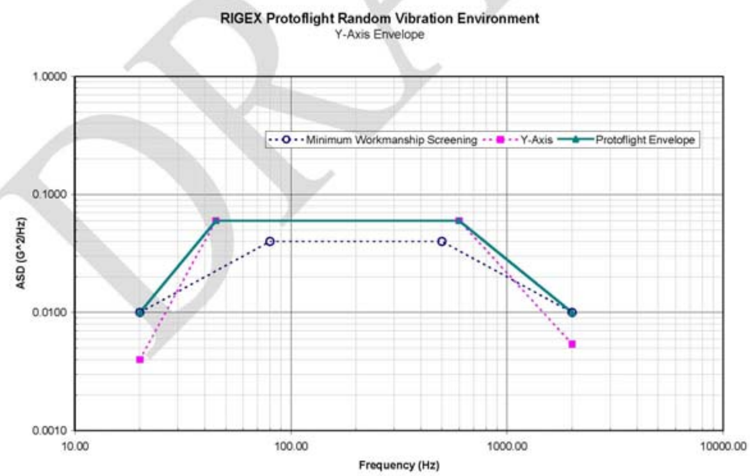
The maximum expected flight level (MEFL) for CAPE/RIGEX is developed using the random vibration environment in NSTS 21000-IDD-SML Table 4.1.6.2.2-1 for all three axes. The workmanship level is defined in NASA-STD-7001 Table 1, which corresponds to 6.8 Grms. The protoflight vibration test (PVT) level for CAPE/RIGEX will envelope these levels in each axis. All of these levels are tabulated below in Table 2, and derived as shown in Figure 6. It should be noted that the PVT level for CAPE/RIGEX does not add 3 dB to the spectra as NASA-STD-7001 states since JSC does not require it to be added.

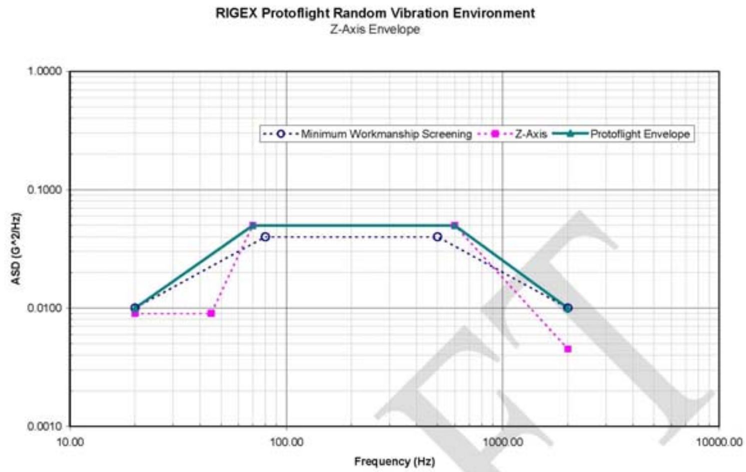
Table 2: Random Vibration Test Levels

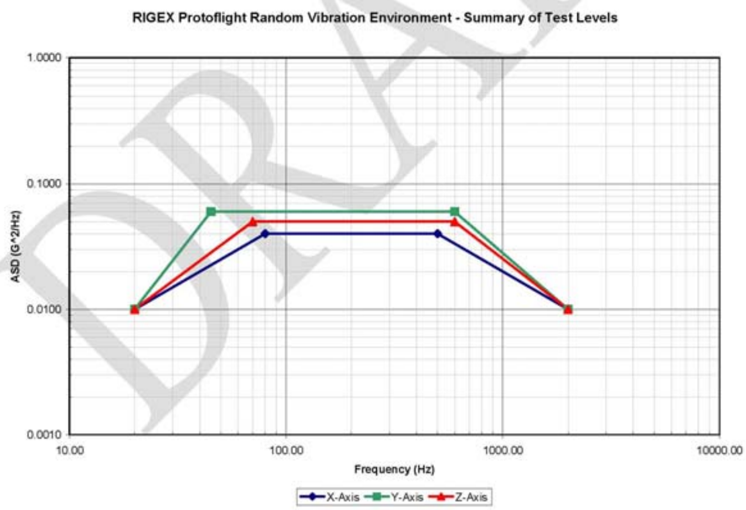
FREQ (Hz)	ASD (G^2/Hz)
X-Axis	
20.00	0.010000
80.00	0.040000
500.00	0.040000
2000.00	0.010000
Y-Axis	
FREQ (Hz)	**ASD (G^2/Hz)**
20.00	0.010000
45.00	0.060000
600.00	0.060000
2000.00	0.010000
Z-Axis	
FREQ (Hz)	**ASD (G^2/Hz)**
20.00	0.010000
70.00	0.050000
600.00	0.050000
2000.00	0.010000

Figure 6: Sidewall Random vibration design conditions for CAPE/RIGEX






RIGEX Protoflight Random Vibration Environment
Z-Axis Envelope
Minimum Workmanship Screening
Z-Axis
Protoflight Envelope
ASD (G^2/Hz)
1.0000
0.1000
0.0100
0.0010
10.00
100.00
1000.00
10000.00
Frequency (Hz)


RIGEX Protoflight Random Vibration Environment - Summary of Test Levels
ASD (G^2/Hz)
1.0000
0.1000
0.0100
0.0010
10.00
100.00
1000.00
10000.00
Frequency (Hz)
X-Axis
Y-Axis
Z-Axis

3.6.2 Random Vibration Environment Verification

The CAPE-RIGEX Assembly will be tested to the protoflight levels as shown in Table 2 and Figure 6, in each axis for 60 seconds in accordance with NASA-STD-7001 Para 4.2.1. The CAPE-RIGEX Assembly will be in flight configuration with the exceptions as listed in Section 2.3 of this document.

Sine sweep testing will be done before and after each random vibration test to verify no damage has occurred per section 3.5 of this document.

The Vibration test for each axis shall start at -12dB and increase in 3dB increments until 0 dB is reached.

3.6.3 Force Limit

Force limiting is not required or planned.

3.7 Roles and Responsibilities

3.7.1 Hardware Provider

The hardware provider will designate a test director and associate test director. The test director and associate test director shall have the authority to make changes to the test procedure during the test.

3.7.2 JSC Test Facility Personnel

The test facility will provide all calibrated tools required for the test and any technician required to conduct the test. Quality Engineer and Quality Assurance personnel will be provided by the test facility for the Space Test Program as required. All riggers for moving the hardware will be provided by the test facility.

3.8 Description of Test Set Up

3.8.1 Test Set Up

The test set up is shown in Figure 7.

3.8.2 Instrumentation Locations

The CAPE-RIGEX Assembly test article will be instrumented with a series of tri-axial and single axis accelerometers. A total of over 20 channels will be available for recording data during the testing. Control accelerometer data channels are included as part of the available channels. The accelerometer locations were chosen using engineering judgment; these locations are shown in Figure 7 and described in Table 3. The accelerometers shown as red circles are tri-axial accelerometers and those shown as blue triangles are single axis accelerometers.

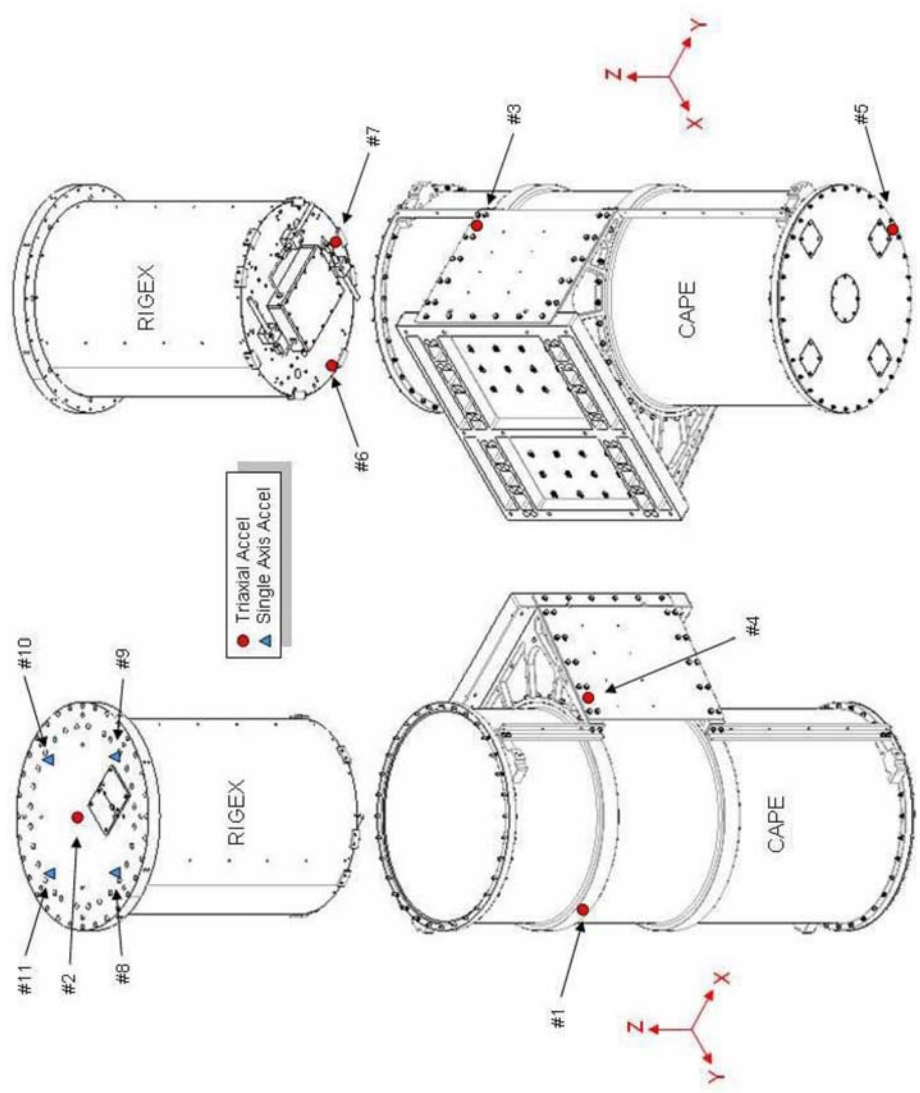


Figure 7: Instrumentation Locations

Table 3: Accelerometer Locations

Channel	Type	Locations	Direction
1	Tri-Axial	Shown as #1 in Figure 7. CAPE Canister, first rib down from the CAPE Lid	X
2	Tri-Axial	Shown as #1 in Figure 7. CAPE Canister, first rib down from the CAPE Lid	Y
3	Tri-Axial	Shown as #1 in Figure 7. CAPE Canister, first rib down from the CAPE Lid	Z
4	Tri-Axial	Shown as #2 in Figure 7. Mounted as close as possible to the center of the CAPE Lid	X
5	Tri-Axial	Shown as #2 in Figure 7. Mounted as close as possible to the center of the CAPE Lid	Y
6	Tri-Axial	Shown as #2 in Figure 7. Mounted as close as possible to the center of the CAPE Lid	Z
7	Tri-Axial	Shown as #3 in Figure 7. Right Shear Plate, corner near Upper Cable Guide	X
8	Tri-Axial	Shown as #3 in Figure 7. Right Shear Plate, corner near Upper Cable Guide	Y
9	Tri-Axial	Shown as #3 in Figure 7. Right Shear Plate, corner near Upper Cable Guide	Z
10	Tri-Axial	Shown as #4 in Figure 7. Left Shear Plate, corner near Upper Cable Guide	X
11	Tri-Axial	Shown as #4 in Figure 7. Left Shear Plate, corner near Upper Cable Guide	Y
12	Tri-Axial	Shown as #4 in Figure 7. Left Shear Plate, corner near Upper Cable Guide	Z
13	Tri-Axial	Shown as #5 in Figure 7. CAPE Endcap (at bottom), 180 deg from Mounting Plate	X
14	Tri-Axial	Shown as #5 in Figure 7. CAPE Endcap (at bottom), 180 deg from Mounting Plate	Y
15	Tri-Axial	Shown as #5 in Figure 7. CAPE Endcap (at bottom), 180 deg from Mounting Plate	Z
16	Tri-Axial	Shown as #6 in Figure 7. RIGEX bottom surface, under computer bay (toward CAPE Left Shear Plate)	X
17	Tri-Axial	Shown as #6 in Figure 7. RIGEX bottom surface, under computer bay (toward CAPE Left Shear Plate)	Y
18	Tri-Axial	Shown as #6 in Figure 7. RIGEX bottom surface, under computer bay (toward CAPE Left Shear Plate)	Z
19	Tri-Axial	Shown as #7 in Figure 7. RIGEX bottom surface, same orientation as #5 on CAPE	X
20	Tri-Axial	Shown as #7 in Figure 7. RIGEX bottom surface, same orientation as #5 on CAPE	Y
21	Tri-Axial	Shown as #7 in Figure 7. RIGEX bottom surface, same orientation as #5 on CAPE	Z
22	Single Axis	Shown as #8 in Figure 7. Mounted on CAPE Lid, along bolt circle to RIGEX Top Plate, at 180 deg from Mounting Plate	Z
23	Single Axis	Shown as #9 in Figure 7. Mounted on CAPE Lid, along bolt circle to RIGEX Top Plate, at 90 deg from Mounting Plate (toward Left Shear Plate)	Z
24	Single Axis	Shown as #10 in Figure 7. Mounted on CAPE Lid, along bolt circle to RIGEX Top Plate, at 0 deg (toward Mounting Plate)	Z
25	Single Axis	Shown as #11 in Figure 7. Mounted on CAPE Lid, along bolt circle to RIGEX Top Plate, at 270 deg (toward Right Shear Plate)	Z

3.8.3 Excitation Method, Levels, and Application Points

Sine Sweeps will be measured by accelerometers at several locations on the CAPE-RIGEX Assembly hardware which will determine the natural frequencies of the structure.

3.9 Boundary Conditions

3.9.1 Support Structure

The test article does not have any support structure. Therefore, there is no support structure that can participate in the test frequency range.

3.9.2 "Free-Free" Test

Not Applicable. The test set up does not require a suspension system.

3.10 Test Reports

The test facility will prepare a test report detailing all test data collected in their standard format for flight hardware. Typically the test report is completed within ten working days after the test has been completed. This test report will include all data collected from the accelerometers, phase angle data associated with the instrumentation, control accelerometer data, and any anomalies encountered during the testing. The test report will also include any pictures that were taken of the test article and the test set up.

4. LINEARITY

Any significant non-linearities will be identified where the data collected allows.

5. TEST SPECIMEN MATH MODEL

A finite element model (FEM) of the CAPE-RIGEX Assembly is constructed and used to predict natural frequencies and mode shapes of the overall system. The CAPE-RIGEX Assembly FEM is shown in Figure 8.

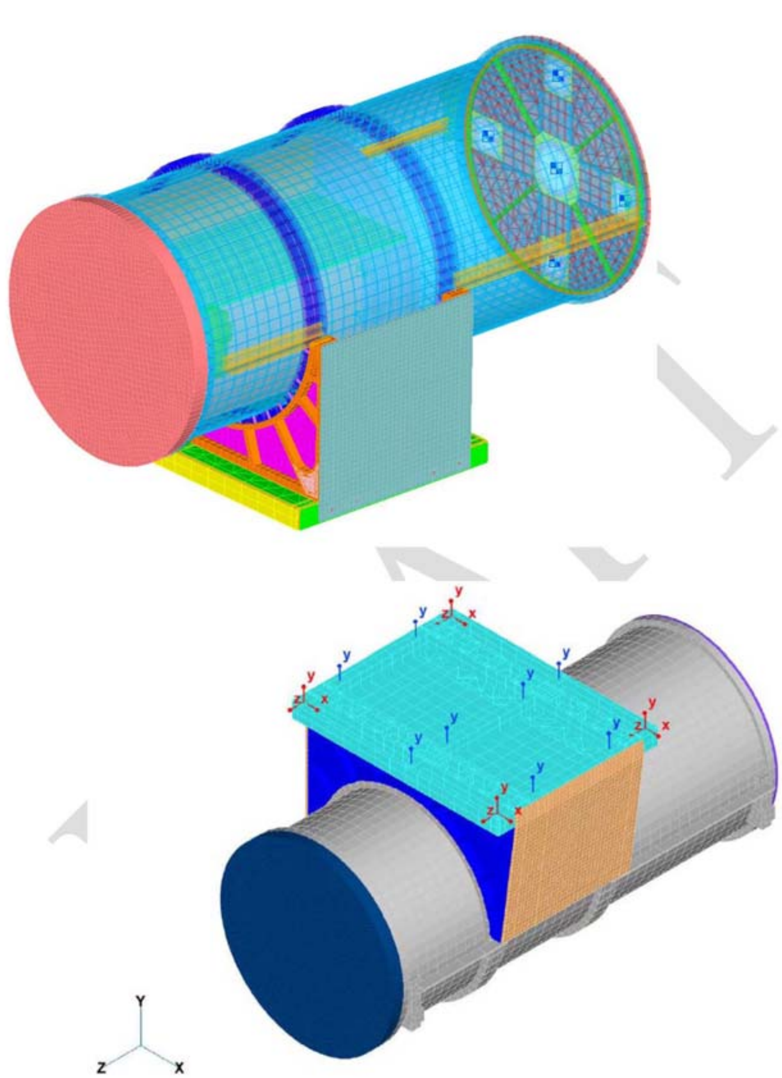


Figure 8: Finite Element Model of CAPE RIGEX (2 views)

6. PRETEST ANALYSIS AND RESULTS

Table 4 and Figure 9 show the preliminary modal analysis of the CAPE-RIGEX system. Analysis indicates one frequency below 35 Hz – at 30.22 Hz – but the mass fraction associated with this mode is only 2%, and therefore it may be considered not significant. The first two dominant modes are are at 55.3 Hz – although this also has a fairly low mass fraction of 6% -- and 68.2 Hz.

Table 4: CAPE-RIGEX: Natural Frequencies with Mass Fraction

MODAL EFFECTIVE MASS FRACTION							
MODE	FREQUENCY	T1		T2		T3	
NO.	Hz	FRACTION	SUM	FRACTION	SUM	FRACTION	SUM
1	30.22	0.00	0.00	0.02	0.02	0.00	0.00
2	55.31	0.06	0.06	0.00	0.02	0.01	0.01
3	68.16	0.27	0.33	0.00	0.02	0.01	0.02
4	83.54	0.34	0.67	0.00	0.02	0.00	0.02
5	97.06	0.00	0.67	0.01	0.02	0.49	0.51
6	102.75	0.00	0.67	0.40	0.43	0.00	0.51
7	123.26	0.00	0.68	0.00	0.43	0.00	0.52
8	146.04	0.00	0.68	0.05	0.48	0.28	0.80
9	152.16	0.01	0.68	0.00	0.48	0.00	0.80
10	166.35	0.00	0.68	0.00	0.48	0.02	0.82

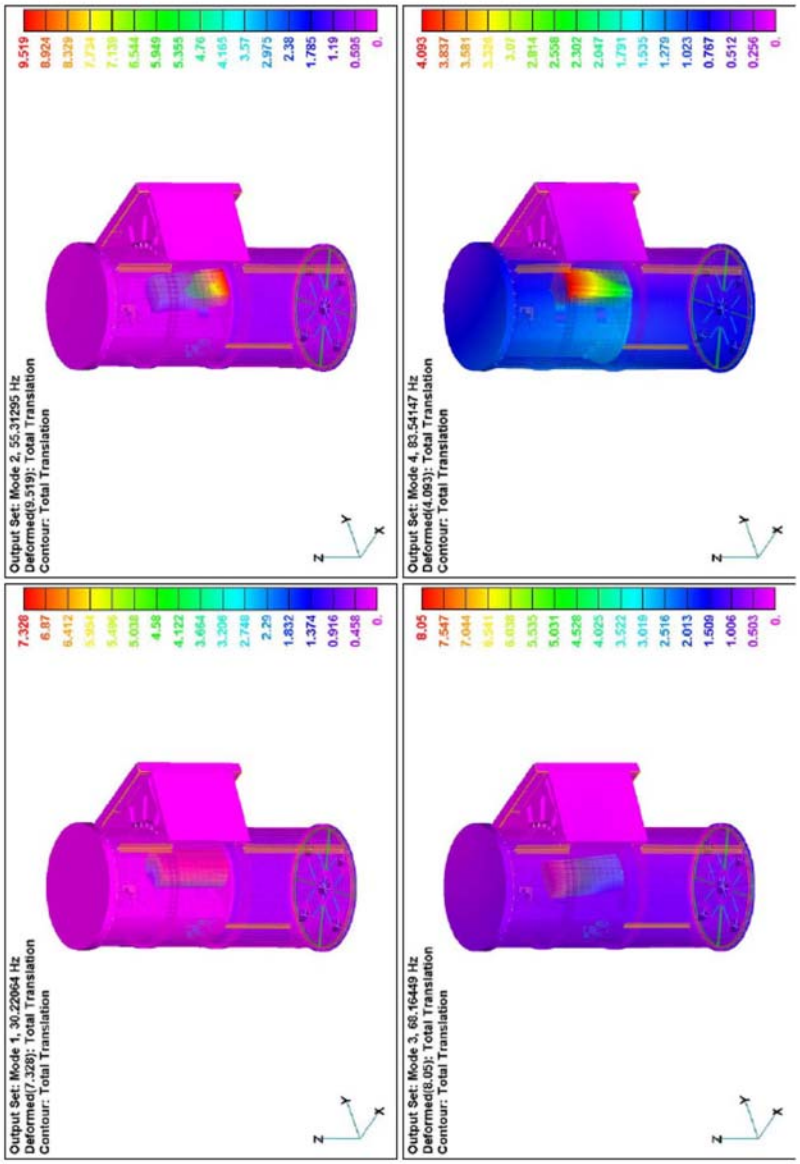


Figure 9: Preliminary Modal Analysis of the CAPE-RIGEX Assembly

7. CORRELATION ANALYSIS

Update FEM model's mass, CG, stiffness to reflect test article and test results.

ACRONYMS

AFIT	Air Force Institute of Technology
CAPE	Canister for All Payload Ejections
CG	Center of Gravity
DoD	Department of Defense
FEM	Finite Element Model
GSE	Ground Support Equipment
JSC	Johnson Space Center
NASA	National Aeronautics and Space Administration
PIE	Payload Integration Engineer
RIGEX	Rigidizable Inflatable Get Away Special Experiment
SPA	Small Payload Accommodation
STP	Space Test Program
SWG	Structures Working Group
TRR	Test Readiness Review
USAF	United States Air Force

Appendix F: RIGEX Handling Procedure

Air Force Institute of Technology
Wright Patterson Air Force Base

RIGEX
HANDLING PROCEDURE (RP-08)

Prepared by:

Zachary R. Miller
Ensign, USN
AFIT/ENY

Approved by:

RICHARD COBB
RIGEX Principal Investigator
AFIT/ENY

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Change Log

Rev. Ltr. Change	Justification and Description of Change	Affected Pages	Effectivity (Serial #)	Release Date	Change Approval (*Initial & Date*)
IR	Initial Release	All	All	04JUN2007	N/A

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Seq #	Instructions	Date	Tech	Insp
1.0	**Scope**			
	The purpose of this procedure is to dictate step by step how RIGEX is to be handled at the different locations that it will undergo a change of configuration. The primary intent is to explain safe methods of unpacking and repacking RIGEX at Johnson Space Center (JSC) and Kennedy Space Center (KSC). 1. Steps may be performed out of order or omitted with Engineering concurrence. 2. This document may be redlined (with initials and date) by any of the signatories on the coversheet or by a designated representative listed here:______________. 3. Where uncontrolled tools are specified (i.e. "9/16 open-ended wrench"), these may be read as guidelines and not requirements. Equivalent alternates may be substituted.			
2.0	**Materials and Components**			

Seq #	Instructions	Date	Tech	Insp

2.1	**Components Being Shipped/Used for Procedure: (Refer to Shipping List)**
	• Emulator, part# RIGEX_EGSE_1
	• CAPE Mounting Plate, part # RIGEX-2006-1-P
	  ○ Lifting Handles (4), part # RIGEX-2006-14-P each attached with standard 1/4"-28 x 1/2" long screws (4 per handle)
	  ○ Connector Cover Plates (2), part # RIGEX-2006-24-P each attached with NAS1189E3P12B (Flat Screw w/ Patchlock: #10-32, 3/4" long) fasteners (4 per cover)
	• Bag of NAS1351N6-20 (Flat Screw w/ Patchlock: 3/8-24, 1" long, A286) fasteners (24)
	• RIGEX Shipping Assembly, part # RIGEX-SHIP2007-P
	  ○ Feet (4), part # RIGEX-2006-13-P each attached with standard 1/4"-28 x 1/2" long screws (4 per foot)
	  ○ NAS8402-7 (Flange Button Screw: #8-32, 4/9" long) fasteners (10) and triangular washers (10), part # RIGEX-2006-
	• Pigtail Cables (2)
	• P-Clamps (2)
	• Lifting Handles (4) for Experimental Top Plate
	• Bag of standard 1/4"-28, 1/2" long screws (16)
	• Delrin Bumpers and Bumper Fasteners
	• Bag of remaining NAS8402-8 (Flange Button Screws: #8-32, 4/9" long) fasteners (42)
	• Bag of remaining Triangular Washers(26)			

Seq #	Instructions	Date	Tech	Insp

2.2	**Shipping Containers**
	• Emulator Container
	  ○ Wooden Crate
	• Cape Mounting Plate Container
	  ○ Wooden Crate
	• RIGEX Shipping Container
	  ○ Keal Case			

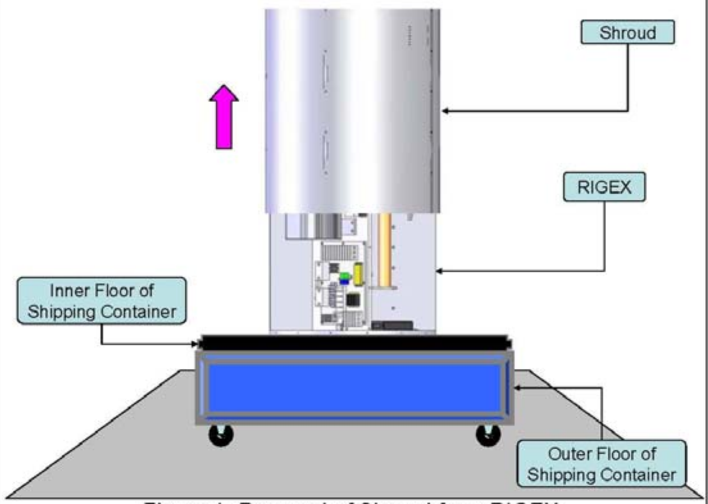
2.3	**Equipment Needed:**			

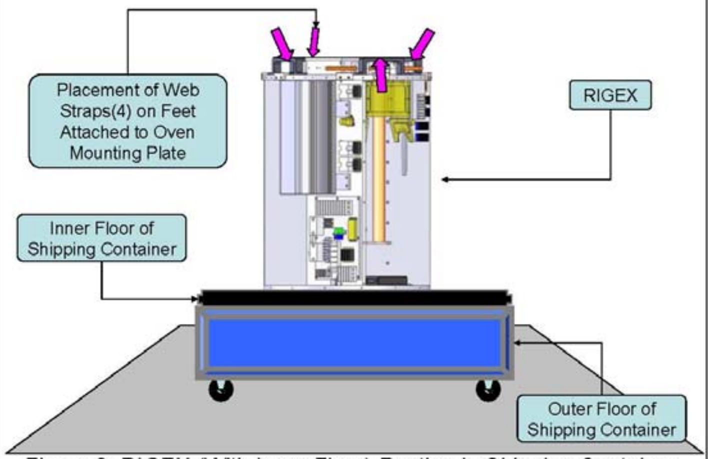
2.3A	Being Provided by AFIT:
	• Rubber Mat
	• Kapton Tape
	• Torque Wrenches
	  ○ Large (0 – 600 in*lbs)
	  ○ Medium (0 – 150 in*lbs)
	  ○ Small (0 – 24 in*lbs)			

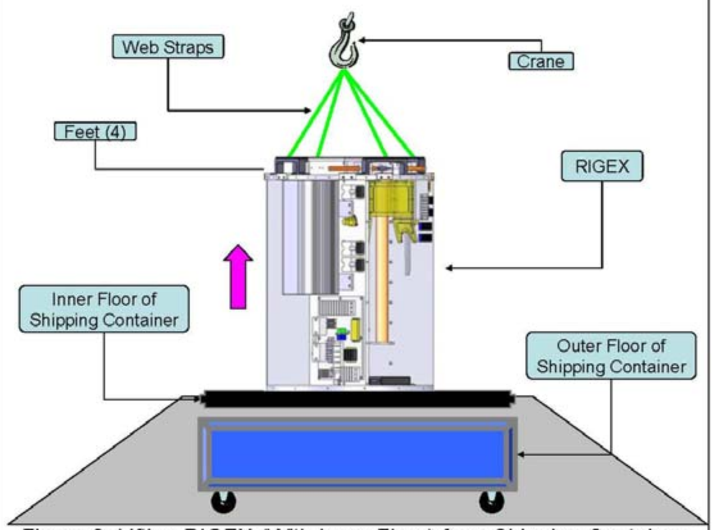
2.3B	Being Provided by JSC or KSC or STP:
	• Phillip Screwdriver (#2 & #3)
	• Clearance Block
	• 3/8" Drive Socket Set
	  ○ #2 Phillips
	  ○ #3 Phillips
	  ○ 3/4" Hex Socket
	• ¼" Drive Socket Set
	  ○ #2 Phillips
	• 3/8" Drive Socket Wrench
	• 9/16" Open-End Wrench
	• Fork Lift with Crane adaptor hook
	• Web Straps
	• Lifting Sling
	• Diagonal Cutters
	• Zip-Ties
	• Additional P-Clamps (4)
	• NAS1351N3-8 (Socket Head Cap Screw: #10-32, 1/2" long) fasteners(3)
	• NAS620C10L (Standard: #10) washers (3)
	• Latex gloves			

Seq #	Instructions	Date	Tech	Insp
2.4	**Additional Documents Needed** • Wave 3 Assembly(RP-1B) • Functional Verification Test Procedure (RP-10) • Shipping List			
3.0	**Unpacking of RIGEX**			
3.1	**Note:** This Procedure assumes personnel handling components are wearing latex gloves to reduce the chances of contamination due to body oils			
3.2	**Emulator**			
3.2A	Remove any shipping labels on shipping container that might interfere with opening of wooden crate			
3.2B	Using #2 Phillips screwdriver carefully remove screws holding lid of the wooden crate			
3.2C	Remove lid from wooden crate			
3.2D	Remove packing material inside shipping container			
3.2E	Remove Emulator from shipping container and set aside until needed (FVT,IVT & EMI)			
3.2F	Put packing material back inside shipping container			
3.2G	Replace lid and reinstall screws			
3.2H	Store wooden crate until time to return-ship to AFIT			
3.3	**CAPE Mounting Plate**			
3.3A	Remove any shipping labels on shipping container that might interfere with opening of wood crate			
3.3B	Using #2 Phillips screwdriver carefully remove screws holding lid of the wooden crate			
3.3C	Remove lid from wooden crate			
3.3D	Remove packing material inside container			

Seq #	Instructions	Date	Tech	Insp
3.3E	Remove bag of NAS1351N6-20 (socket-head cap screw, 1.25" long) fasteners (24) that connect CAPE Mounting plate to Experimental Top Plate			
3.3F	Remove CAPE Mounting Plate, with lifting handles (4) and wiring cover plates (2) still attached, and set aside until ready to attach to Experimental Top Plate of RIGEX			
3.3G	Put packing material back inside shipping container			
3.3H	Replace lid and reinstall screws			
3.3I	Store wooden crate until time to return-ship to AFIT			
3.4	**RIGEX**			
3.4A	**Note:** Depiction of interior of RIGEX should be used as a reference only for RIGEX without the shroud			
3.4B	Remove any shipping labels on shipping container that might interfere with opening of container.			
3.4C	Record status of shock indicators. Nominal _______ Failed _______ **Note:** If any are failed, a thorough visual inspection is required, noting any damage.			
3.4D	Remove Zip-Ties and unlock all latches around shipping container			
3.4E	Remove both sides of upper casing on shipping container			

Seq #	Instructions	Date	Tech	Insp
3.4F	Removal of Shroud from RIGEX  Figure 1: Removal of Shroud from RIGEX			
3.4G	Using #2 Phillips screwdriver remove NAS8402-8 (Flange Button Screw: #8-32, 1/2" long) fasteners (10) and triangular washers (10) used during shipment to hold shroud to RIGEX. **Note:** Locations of fasteners includes; one on each side of Experimental Top Plate and Oven Mounting Plate, six along seam of Shroud			
3.4H	Remove Shroud (see Fig. 1)			

Seq #	Instructions	Date	Tech	Insp
3.4I	RIGEX (With Inner Floor) Resting in Shipping Container  Figure 2: RIGEX (With Inner Floor) Resting in Shipping Container Note: Only 2 webstraps required, 4 optional			
3.4J	Attach web straps to feet on the oven mounting plate of RIGEX (see Fig. 2)			
3.4K	Using socket wrench with 3/4" hex socket, remove the four bolts connecting the inner floor and the outer floor of shipping container. Secure nuts underneath with 3/4" open-end wrench.			

Seq #	Instructions	Date	Tech	Insp
3.4L	Lifting RIGEX (With Inner Floor) from Shipping Container  Figure 3: Lifting RIGEX (With Inner Floor) from Shipping Container			
3.4M	Using a crane lift RIGEX (with inner floor) high enough to separate the outer floor of the shipping container from the inner floor of the shipping container (see Fig. 3)			

Seq #	Instructions	Date	Tech	Insp
3.4N	Lowering RIGEX (With Inner Floor) onto Clearance Block			
3.4O	While suspended from crane maneuver clearance block under RIGEX (with inner floor) (see Fig. 4)			
3.4P	Lower RIGEX (with inner floor) until it is safely resting on clearance block **Note:** Keep slight tension in web straps for stability.			

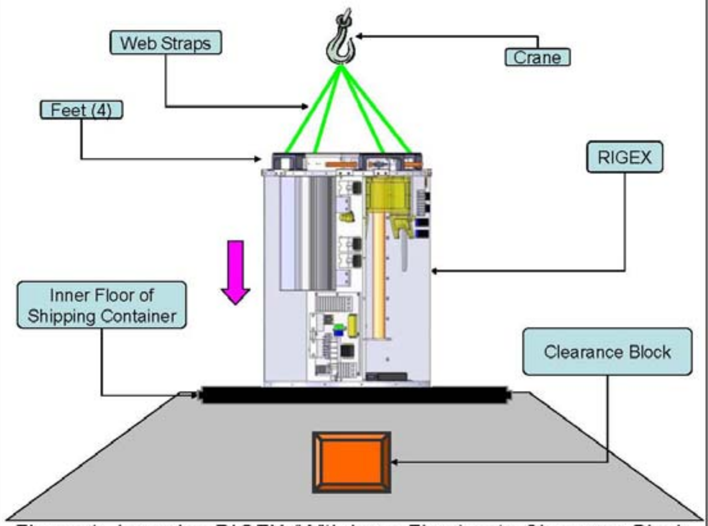
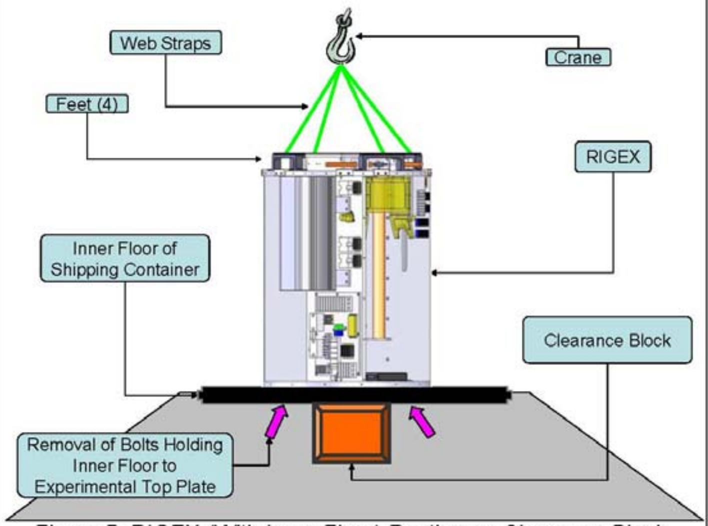
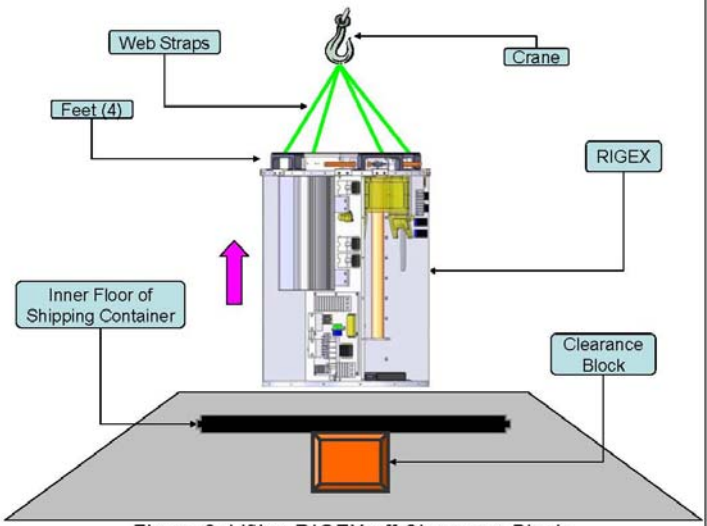
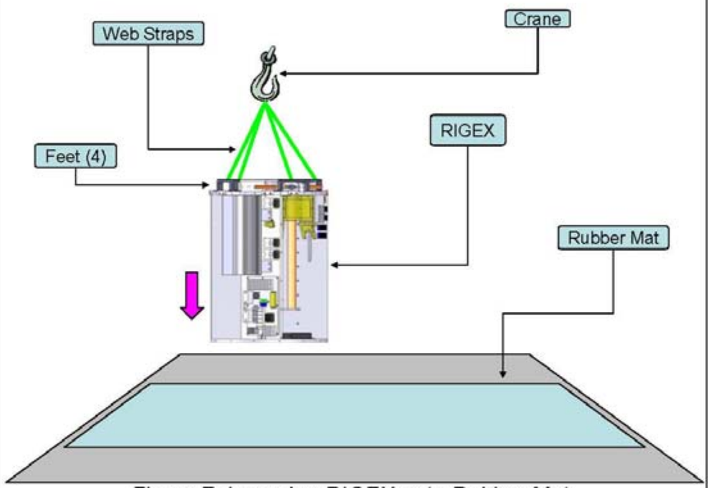
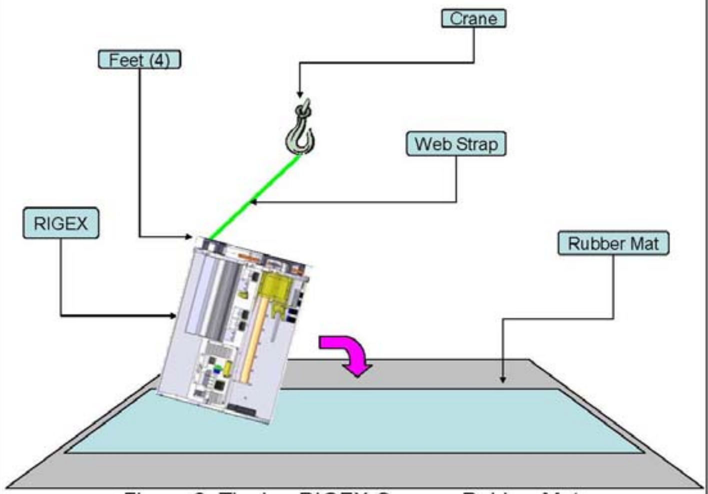


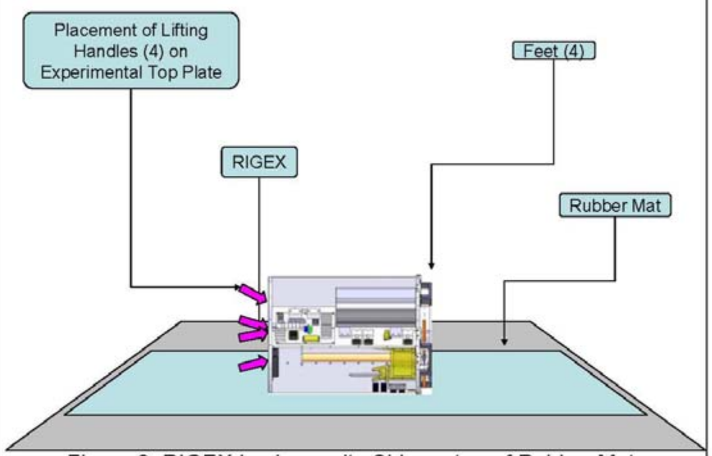
Figure 4: Lowering RIGEX (With Inner Floor) onto Clearance Block

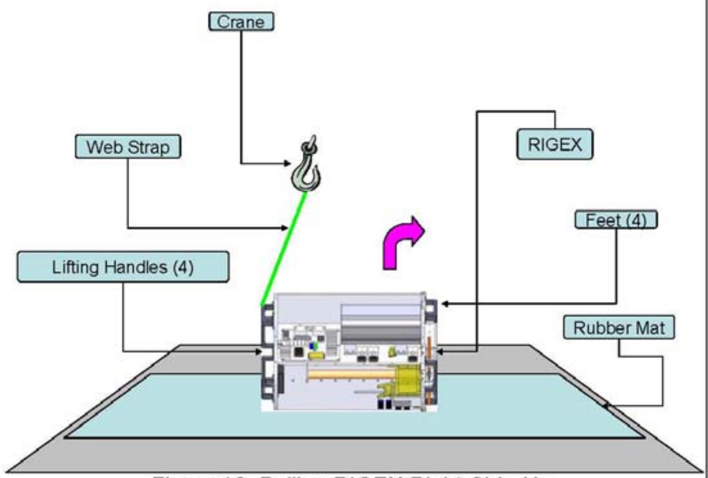
Seq #	Instructions	Date	Tech	Insp
3.4Q	RIGEX (With Inner Floor) Resting on Clearance Block  Figure 5: RIGEX (With Inner Floor) Resting on Clearance Block			
3.4R	Using socket wrench with 7/16" socket, reach under the inner floor of shipping container and remove bolts and washers: 1/4"-28, 2 1/4" long (8) connecting the Experimental Top Plate of RIGEX to the inner floor of the shipping container (see Fig. 5, 34 & 35) Bag, tag and store bolts. **Note:** Keep slight tension in web straps for stability.			

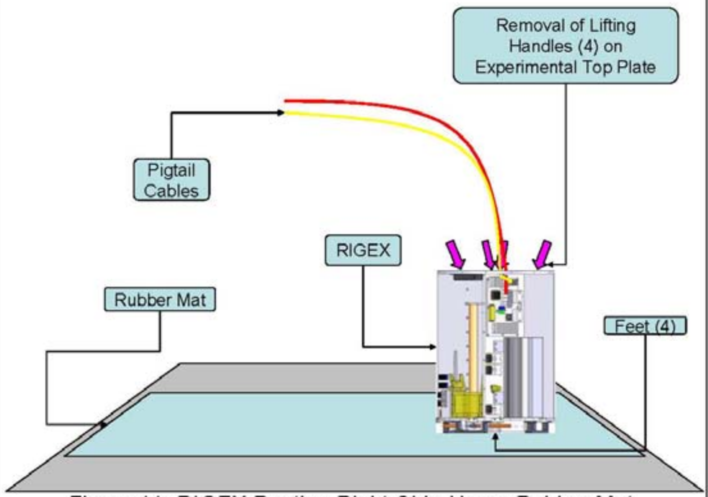
Seq #	Instructions	Date	Tech	Insp
3.4S	Lifting RIGEX off Clearance Block  Figure 6: Lifting RIGEX off Clearance Block			
3.4T	Using crane lift RIGEX off clearance block, leaving inner floor of shipping container centered on top of clearance block (see Fig. 6)			
3.4U	While suspended from crane, remove floor and clearance block, and maneuver rubber mat under RIGEX. Note: Position RIGEX at far end of mat.			

Seq #	Instructions	Date	Tech	Insp
3.4V	Lowering RIGEX onto Rubber Mat  Figure 7: Lowering RIGEX onto Rubber Mat			
3.4W	Lower RIGEX until it is safely resting on rubber mat (see Fig. 7)			
3.4X	Reposition web strap so it is only attached to one foot on Oven Mounting Pate.			

Seq #	Instructions	Date	Tech	Insp
3.4Y	Tipping RIGEX Over on Rubber Mat  Figure 8: Tipping RIGEX Over on Rubber Mat			
3.4Z	While RIGEX is still connected to crane with web strap, use the assistance of the crane operator and two personnel (with one on each side holding a foot handle) to gracefully tip over RIGEX and lay it on its side on top of the rubber mat (see Fig. 8)			
3.4AA	Remove web strap from the foot on the oven mounting plate of RIGEX **Note:** Personnel should hold RIGEX in place to keep from rolling.			

Seq #	Instructions	Date	Tech	Insp
3.4BB	RIGEX Laying on its Side on top of Rubber Mat  Figure 9: RIGEX Laying on its Side on top of Rubber Mat			
3.4CC	Using medium torque wrench with #3 Phillips bit attach a lifting handle to Experimental Top Plate of RIGEX with standard 1/4"-28, 1/2" long screws (4 per lifting handle) (see Fig. 9). Attach to topmost position. Torque to 20 in*lb above running torque. **Note:** Lifting Handles can be found in sub floor of RIGEX shipping container Mfr:____________ Cal ID: ____________ Due date: ___________			

Seq #	Instructions	Date	Tech	Insp
3.4DD	Attach web strap to one lifting handle (top-most) on Experimental Top Plate of RIGEX			
3.4EE	Pulling RIGEX Right-Side-Up  Figure 10: Pulling RIGEX Right-Side-Up			
3.4FF	WARNING: Ensure point of pivot is on one of the feet. While RIGEX is connected to crane with web strap use the assistance of two personnel, with one on each side holding a lifting handle, to carefully pull RIGEX to the upright position. (see Fig. 10)			

Seq #	Instructions	Date	Tech	Insp
3.4GG	RIGEX Resting Right-Side-Up on Rubber Mat  Figure 11: RIGEX Resting Right-Side-Up on Rubber Mat			
3.4HH	Remove web strap from lifting handle on Experimental Top Plate			
3.4II	Using #3 Phillips screwdriver remove the lifting handle from the Experimental Top Plate of RIGEX by removing standard 1/4"-28, 1/2" long screws (4 per lifting handle) (see Fig. 11) Bag, tag and store handle and fasteners.			

Seq #	Instructions	Date	Tech	Insp
3.4JJ	Attach Pigtail Cables and run FVT: follow Functional Verification Test Procedure (RP-10) **Note:** Pigtail Cables can be found in sub floor of RIGEX shipping container **Note:** Add as-run copy of RP-10 to this document			
3.4KK	Attaching Shroud to RIGEX			

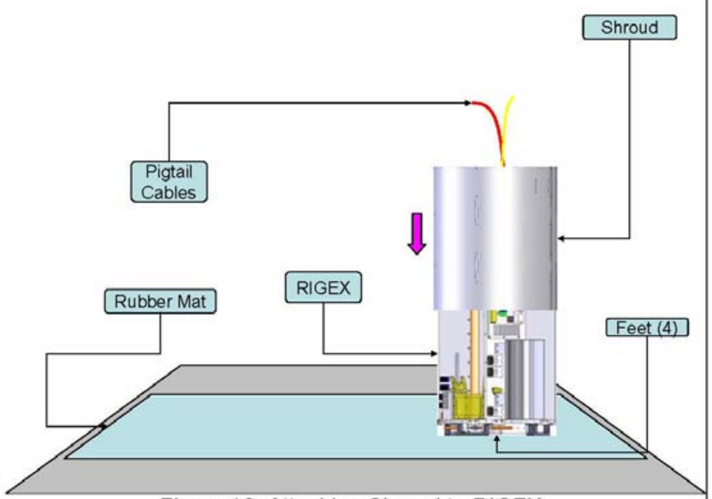
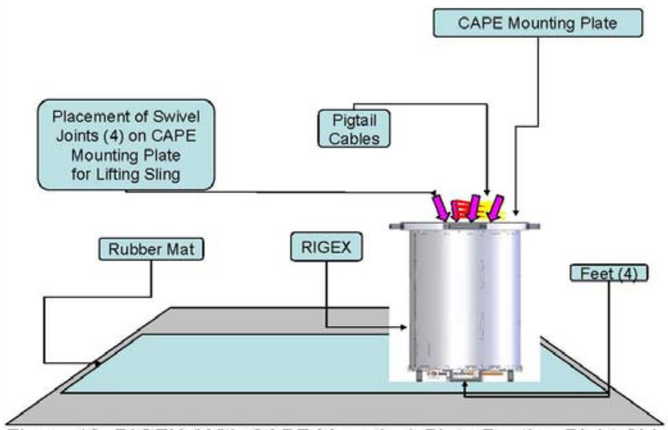


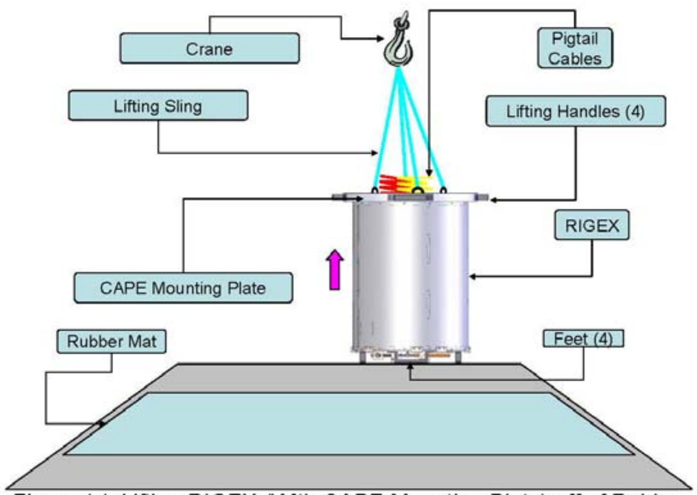
Figure 12: Attaching Shroud to RIGEX

Seq #	Instructions	Date	Tech	Insp
3.4LL	Slide Shroud over Pigtail Cables and onto RIGEX (see Fig. 12)			

Seq #	Instructions	Date	Tech	Insp
3.4MM	Attach Shroud and Bumpers to RIGEX: follow Seq# 3.2 to 3.6 of Wave 3 Assembly Procedure (RP-1B) **Note:** Bumpers, bumper fasteners, shroud fasteners and triangular washers can be found in subfloor of RIGEX shipping container **Note:** Add as-run copy of RP-1B to this document			
3.4NN	Using #2 Phillips screwdriver remove outboard connector cover from CAPE Mounting Plate by removing the NAS1189E3P12B (Flat Screw w/ Patchlock: #10-32, 3/4" long) fasteners (4)			
3.4OO	Place CAPE Mounting Plate on top of RIGEX using three personnel; two personnel supporting CAPE Mounting Plate from attached lifting handles (4) while third person guides pigtail cables through access hole on CAPE Mounting Plate			
3.4PP	Secure CAPE mounting plate and outboard Connector Cover (attached to CAPE mounting plate) to the Experimental Top Plate of RIGEX: follow Seq# 4.1 to 4.2 of Wave 3 Assembly Procedure (RP-1B) Note: Inboard Connector Cover will already be attached			

Seq #	Instructions	Date	Tech	Insp
3.4QQ	RIGEX (With CAPE Mounting) Plate Resting Right-Side-Up on Rubber Mat  Figure 13: RIGEX (With CAPE Mounting) Plate Resting Right-Side-Up on Rubber Mat			

Seq #	Instructions	Date	Tech	Insp
3.4RR	Using medium torque wrench with #10 hex bit secure Pigtail Cables to CAPE Mounting Plate with P-Clamps (4). For attaching P-Clamps (STP Provided) use NAS1351N3-8 (Socket Head Cap Screw: #10-32, 1/2" long) fasteners (2) and NAS620C10L (Standard: #10) washers (2). Running torque should be 2-13 in-lbs. Applied torque should be 24-28 in-lbs above running torque. Running ____ + Applied ____= Total ____ **Note:** For testing purposes, Cables will be restrained with only one P-clamp each at the location closest to the Connector Covers. Mfr:____________ Cal ID: ___________ Due date: ___________			
3.4SS	Coil up rest of Pigtail Cables and secure down to CAPE Mounting Plate with Kapton tape			
3.4TT	If RIGEX is not being inserted into CAPE at this time, stop here. Unpacking procedure is finished. If RIGEX is being inserted into CAPE proceed with sequence 3.5. In both cases, assign part # and serial # to RIGEX: RIGEX-TST2007-P, ser. # 001.			
3.5	**CAPE Installation Preparation**			
3.5A	Attach the swivel joints (4) of the lifting sling to the four .25 x 20 inch holes in the CAPE Mounting Plate. (see Fig. 13 & 35) Torque to 100-125 in-lbs above running torque. Mfr:____________ Cal ID: ___________ Due date: __________			

Seq #	Instructions	Date	Tech	Insp
3.5B	Lifting RIGEX (With CAPE Mounting Plate) off of Rubber Mat  Figure 14: Lifting RIGEX (With CAPE Mounting Plate) off of Rubber Mat			
3.5C	Using crane lift RIGEX (with CAPE Mounting Plate) off the rubber mat (see Fig. 14)			
3.5D	While suspended from crane maneuver clearance block under RIGEX			

Seq #	Instructions	Date	Tech	Insp
3.5E	Lowering RIGEX (With CAPE Mounting Plate) onto Clearance Block			

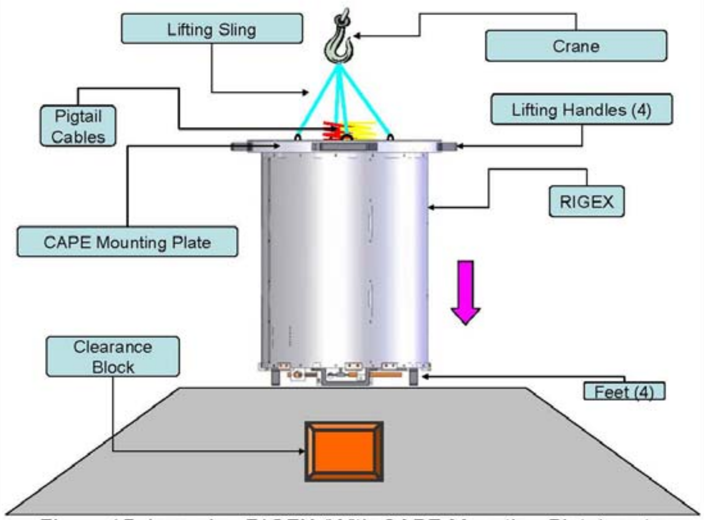
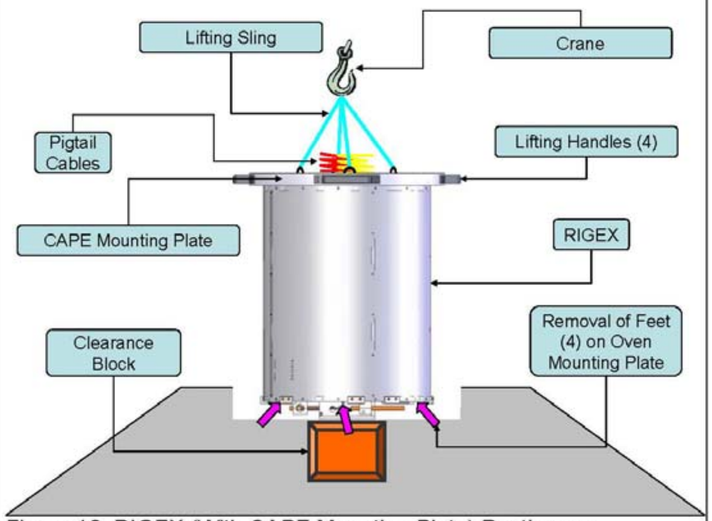
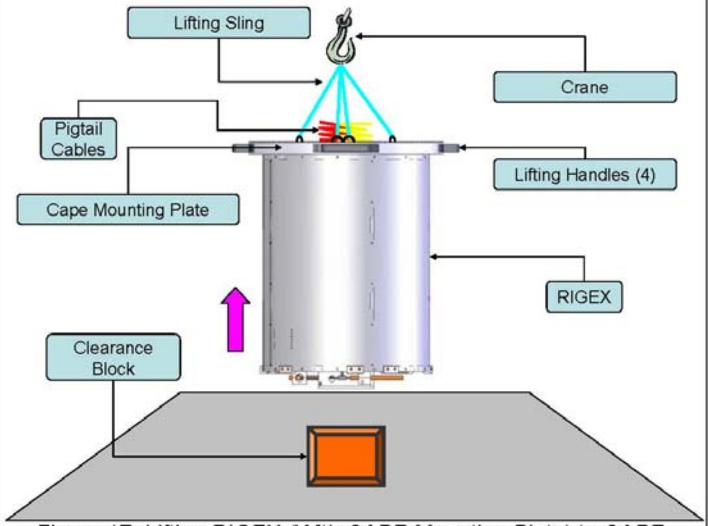
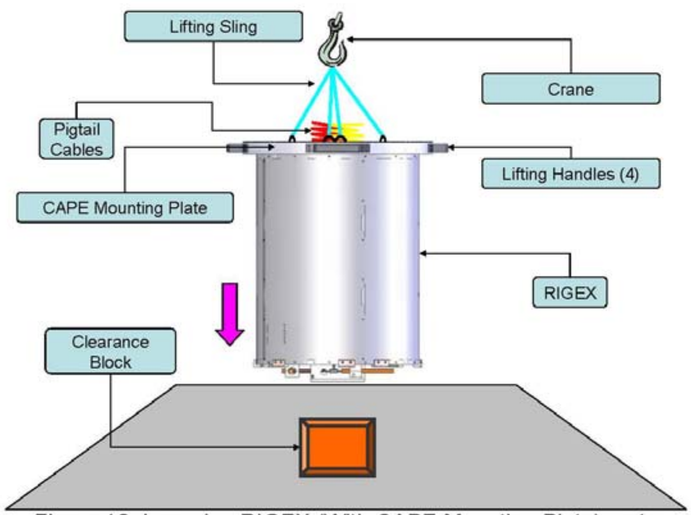


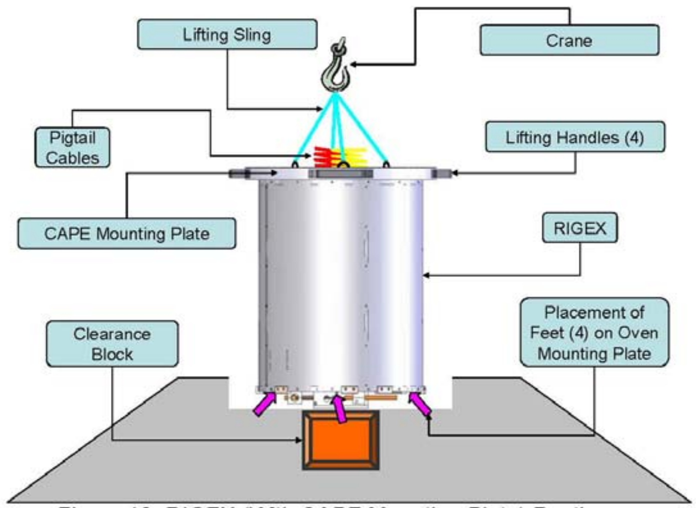
Figure 15: Lowering RIGEX (With CAPE Mounting Plate) onto Clearance Block

Seq #	Instructions	Date	Tech	Insp
3.5F	Lower RIGEX (with CAPE Mounting Plate) until it is safely resting on clearance block (see Fig. 15)			

Seq #	Instructions	Date	Tech	Insp
3.5G	RIGEX (With CAPE Mounting Plate) Resting on Clearance Block  Figure 16: RIGEX (With CAPE Mounting Plate) Resting on Clearance Block			
3.5H	Using socket wrench with #3 Phillips bit remove feet (4) from Oven Mounting Plate on RIGEX by removing standard 1/4"-28, 1/2" long screws (4 per foot) (see Fig. 16) **Note:** Keep lifting sling under slight tension for stability.			

Seq #	Instructions	Date	Tech	Insp
3.5I	Lifting RIGEX (With Cape Mounting Plate) to CAPE  Figure 17: Lifting RIGEX (With CAPE Mounting Plate) to CAPE			
3.5J	**Note:** Using crane, RIGEX (with CAPE Mounting Plate) can now be lifted in its current configuration (see Fig. 17) and maneuvered for mounting to CAPE			
3.5K	**Note:** Remove lifting handles from cape mounting plate after installation into CAPE			
4.0	**Repacking of RIGEX**			
4.1	**Note:** This Procedure assumes personnel handling components are wearing latex gloves to reduce the chances of contamination due to body oils			

Seq #	Instructions	Date	Tech	Insp
4.2	**Note:** This procedure starts with RIGEX (with CAPE Mounting Plate) suspended from a crane with lifting sling and lifting handles attached to CAPE Mounting Plate			
4.3	**RIGEX**			
4.3A	Prior to packing RIGEX obtain clearance block, rubber mat, and shipping containers			
4.3B	While suspended from crane maneuver clearance block under RIGEX			
4.3C	Lowering RIGEX (With CAPE Mounting Plate) onto Clearance Block  Figure 18: Lowering RIGEX (With CAPE Mounting Plate) onto Clearance Block			
4.3D	Lower RIGEX (with CAPE Mounting Plate) until it is safely resting on clearance block (see Fig. 18)			

Seq #	Instructions	Date	Tech	Insp
4.3E	RIGEX (With CAPE Mounting Plate) Resting on Clearance Block  Figure 19: RIGEX (With CAPE Mounting Plate) Resting on Clearance Block			
4.3F	Using medium torque wrench with #3 Phillips bit attach feet (4) to the Oven Mounting Plate on RIGEX with standard 1/4"-28, 1/2" long screws (4 per foot). Torque to 20 in*lbs above running torque. (see Fig. 19) **Note:** Keep lifting sling under tension for stability. Mfr:____________ Cal ID: ___________ Due date: ___________			

Seq #	Instructions	Date	Tech	Insp
4.3G	Lifting RIGEX (With CAPE Mounting Plate) off Clearance Block			

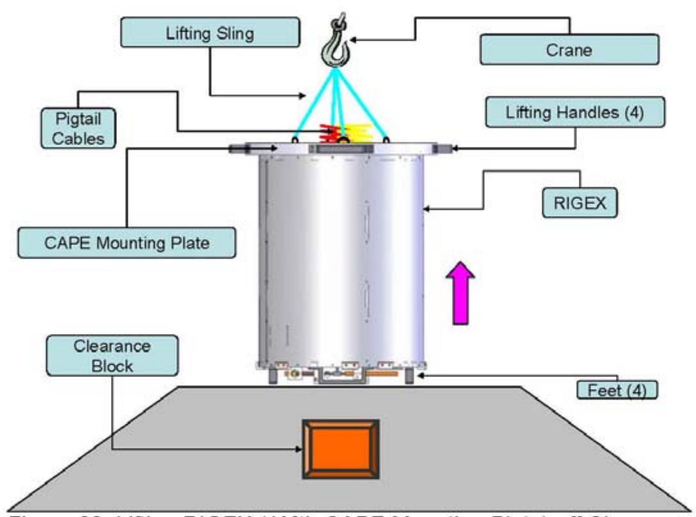
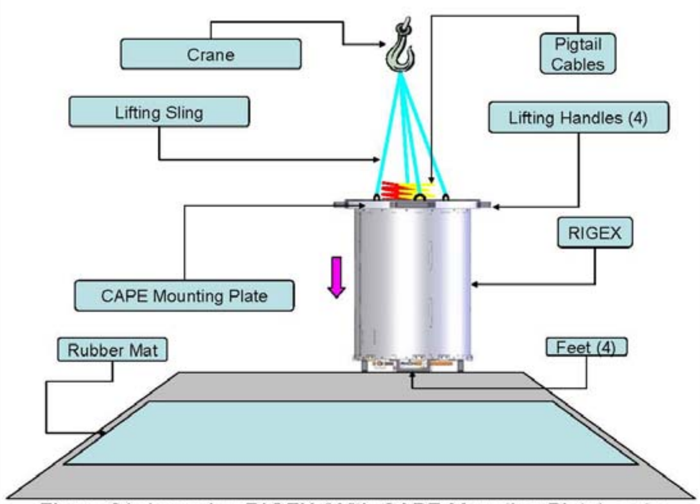
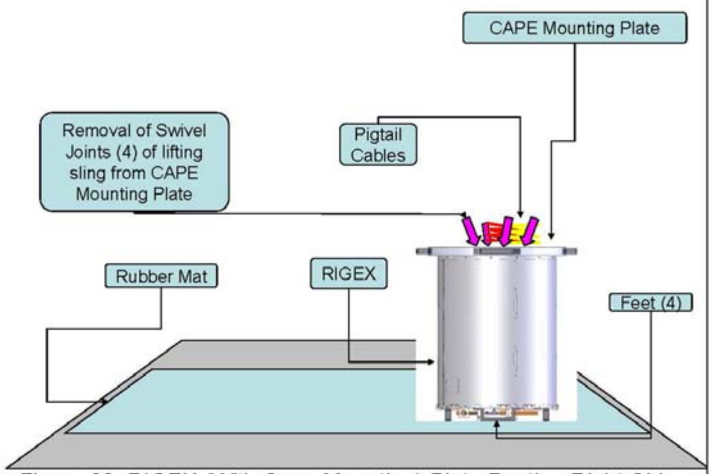


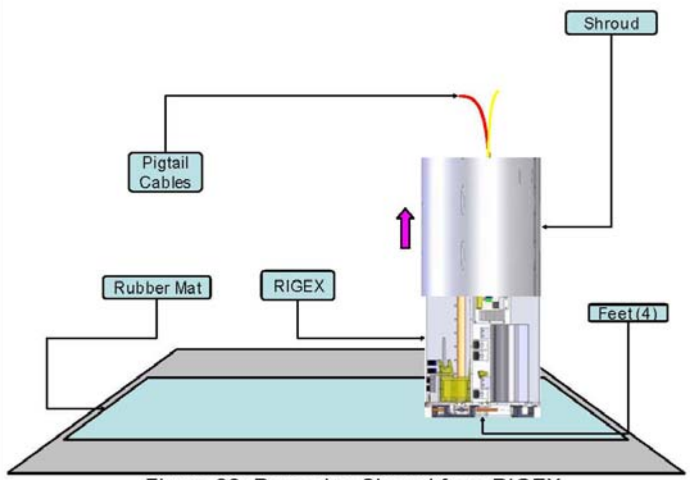
Figure 20: Lifting RIGEX (With CAPE Mounting Plate) off Clearance Block

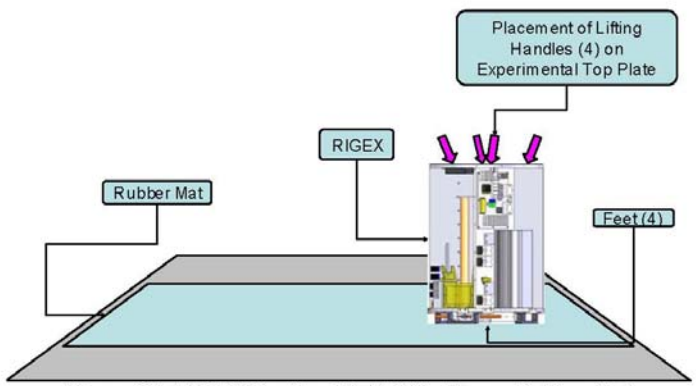
Seq #	Instructions	Date	Tech	Insp
4.3H	Using crane lift RIGEX (with CAPE Mounting Plate) off clearance block (see Fig. 20)			
4.3I	While suspended from crane maneuver rubber mat under RIGEX			

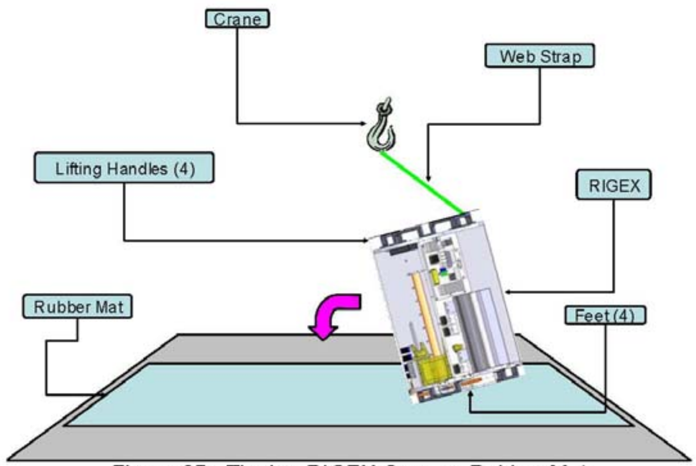
Seq #	Instructions	Date	Tech	Insp
4.3J	Lowering RIGEX (With CAPE Mounting Plate) onto Rubber Mat  Figure 21: Lowering RIGEX (With CAPE Mounting Plate) onto Rubber Mat			
4.3K	Lower RIGEX until it is safely resting on rubber mat (see Fig. 21)			

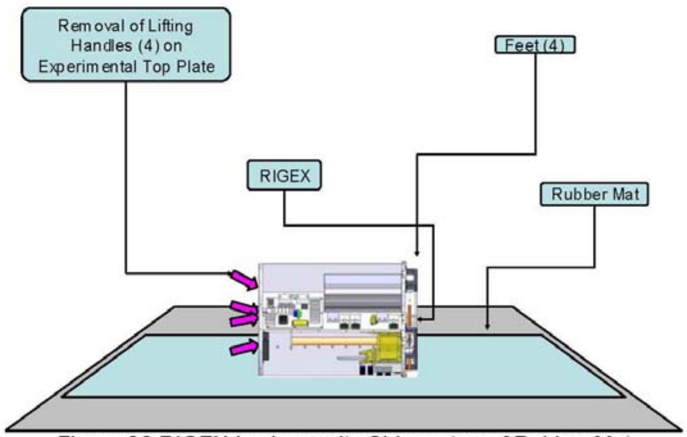
Seq #	Instructions	Date	Tech	Insp
4.3L	RIGEX (With Cape Mounting) Plate Resting Right-Side-Up on Rubber Mat  Figure 22: RIGEX (With Cape Mounting) Plate Resting Right-Side-Up on Rubber Mat			
4.3M	Detach the swivel joints (4) of the lifting sling from the four .25 – 20 inch holes in the Cape Mounting Pate. (see Fig. 36)			
4.3N	Using #2 Phillips bit remove P-Clamps from CAPE Mounting Plate by removing NAS1351N3-8 (Socket Head Cap Screw: #10-32, 1/2" long) fasteners (2) and NAS620C10L (Standard: #10) washers (2). Bag, tag and give to STP.			

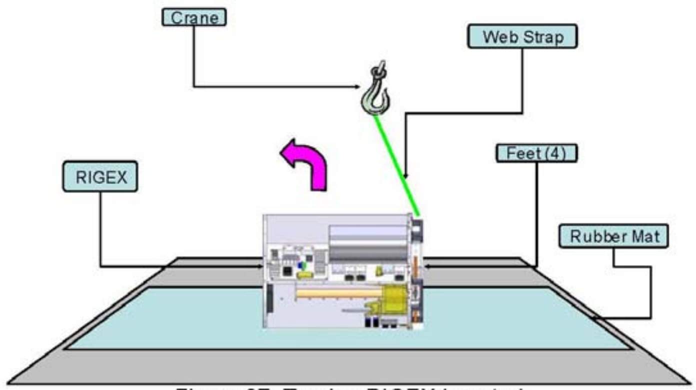
Seq #	Instructions	Date	Tech	Insp
4.3Na	Remove outboard connector cover from CAPE mounting plate by removing 4 NAS1189E3P12B with #2 phillips screw driver.			
4.3O	Guiding cables through hole, remove CAPE Mounting Plate and place in CAPE Mounting Plate shipping container. refer to Seq# 4.1 to 4.2 of Wave 3 Assembly Procedure (RP-1B). Bag, tag and place fastener in subfloor of RIGEX shipping container.			
4.3P	After removing CAPE Mounting Plate from RIGEX reinstall outboard connecter cover with NAS1189E3P12B (Flat Screw w/ Patchlock: #10-32, 3/4" long) fasteners (4 each). Use medium torque wrench with #2 Phillips bit. Torque to 20 in-lbs above running torque Mfr:____________ Cal ID: ___________ Due date: ___________			

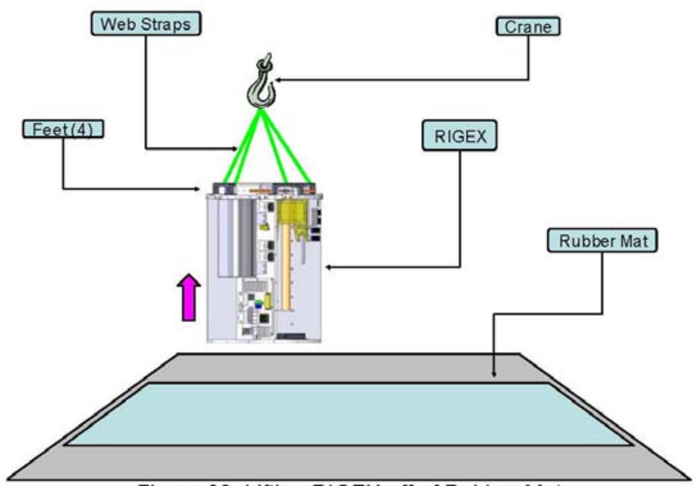
Seq #	Instructions	Date	Tech	Insp
4.3Q	Removing Shroud from RIGEX  Figure 23: Removing Shroud from RIGEX			
4.3R	Remove shroud and bumpers: refer to Seq# 3.3 to 3.6 of Wave 3 Assembly Procedure (RP-1B). Bag, tag and place fasteners and bumpers in sub floor of RIGEX shipping container			
4.3S	Slide off Shroud (see Fig. 23)			
4.3T	Remove Pigtail Cables: refer to Seq#3 of Functional Verification Test Procedure (RP-10) **Note:** Pigtail Cables are to be stored in sub floor of RIGEX shipping container			

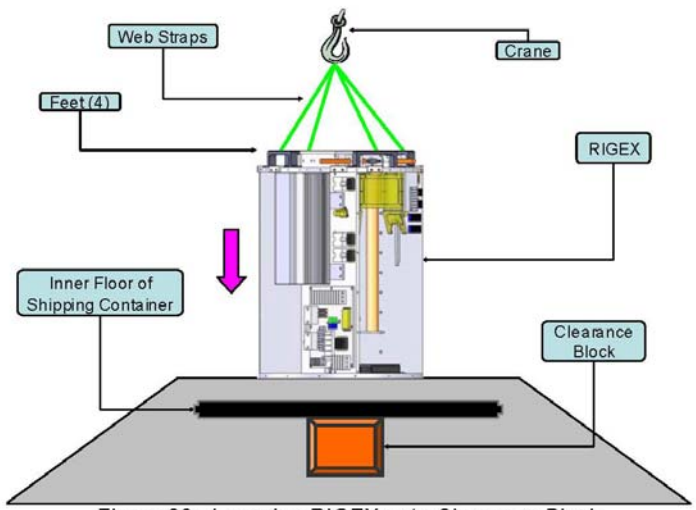
Seq #	Instructions	Date	Tech	Insp
4.3U	RIGEX Resting Right-Side-Up on Rubber Mat  Figure 24: RIGEX Resting Right-Side-Up on Rubber Mat			
4.3V	Using medium torque wrench with #3 Phillips bit attach lifting handle to Experimental Top Plate of RIGEX with standard 1/4"-28, 1/2" long screws (4 per handle) (see Fig. 24). Torque to 20 in*lbs above running torque. Note: Attach handle opposite the anticipated pivot point.			
4.3W	Attach web strap to lifting handle on Experimental Top Plate of RIGEX			

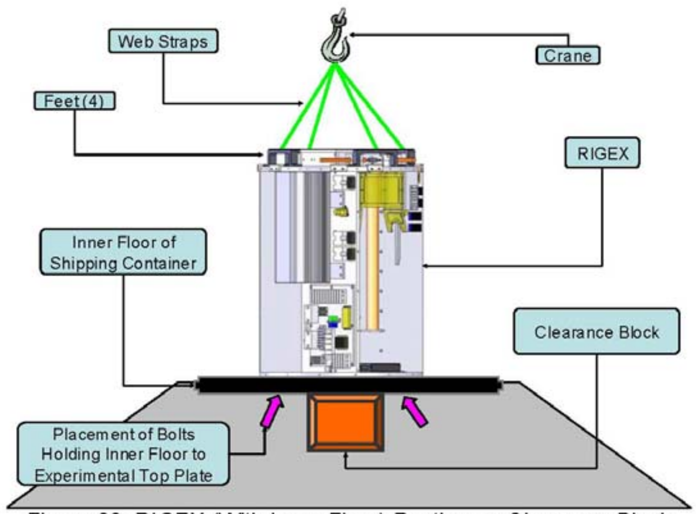
Seq #	Instructions	Date	Tech	Insp
4.3X	Tipping RIGEX Over on Rubber Mat  Figure 25: Tipping RIGEX Over on Rubber Mat			
4.3Y	While RIGEX is connected to crane with web strap use the assistance of two personnel, with one on each side holding a foot handle, to gracefully tip over RIGEX and lay it on its side on top of the rubber mat (see Fig. 25)			
4.3Z	Remove web strap from lifting handle on experimental top plate of RIGEX **Note:** Personnel should hold RIGEX in place to keep from rolling			

Seq #	Instructions	Date	Tech	Insp
4.3AA	RIGEX Laying on its Side on top of Rubber Mat  Figure 26 RIGEX Laying on its Side on top of Rubber Mat			
4.3BB	Using #3 Phillips Screwdriver remove lifting handle from Experimental Top Plate by removing the 1/4"-28, 1/2" long screws (4 per handle) (see Fig. 26). Bag, tag and place fasteners in sub floor RIGEX shipping container **Note:** Lifting Handles are to be stored in subfloor of RIGEX shipping container			
4.3CC	Attach web strap to foot (top-most) on oven mounting plate of RIGEX			

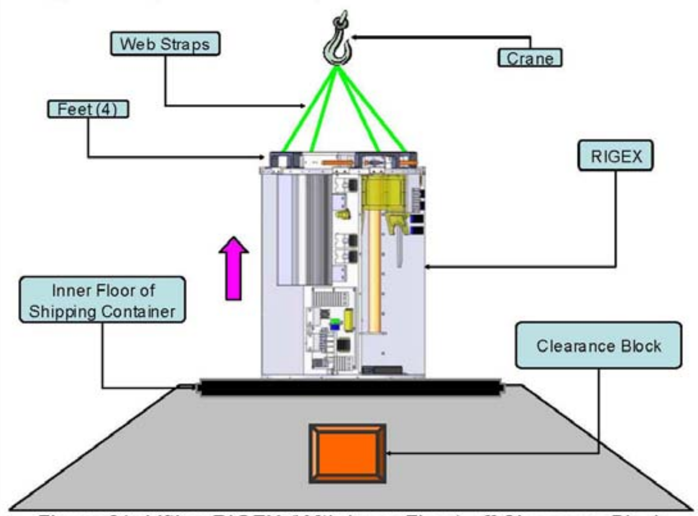
Seq #	Instructions	Date	Tech	Insp
4.3DD	Turning RIGEX Inverted  Figure 27: Turning RIGEX Inverted			
4.3EE	While RIGEX is connected to crane with web strap use the assistance of crane operator and two personnel (with one on each side holding a lifting handle) to carefully turn over RIGEX to an inverted position. (see Fig. 27)			
4.3FF	Attach web strap to the one remaining foot on the Oven Mounting Plate			

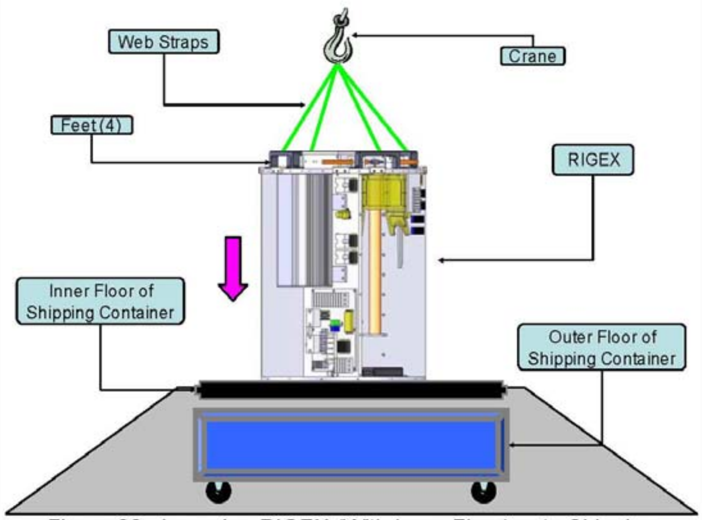
Seq #	Instructions	Date	Tech	Insp
4.3GG	Lifting RIGEX off of Rubber Mat  Figure 28: Lifting RIGEX off of Rubber Mat			
4.3HH	Using crane lift RIGEX off the rubber mat (see Fig. 28)			
4.3II	While suspended from crane maneuver clearance block and inner floor of shipping under RIGEX			

Seq #	Instructions	Date	Tech	Insp
4.3JJ	Lowering RIGEX onto Clearance Block  Figure 29: Lowering RIGEX onto Clearance Block			
4.3KK	Lower RIGEX until it is safely resting on clearance block with the inner floor between (see Fig. 29) Note: Align holes on Experimental Top Plate with holes on inner floor of shipping container using reference circle drawn on subfloor carpet			

Seq #	Instructions	Date	Tech	Insp
4.3LL	RIGEX (With Inner Floor) Resting on Clearance Block  Figure 30: RIGEX (With Inner Floor) Resting on Clearance Block			

Seq #	Instructions	Date	Tech	Insp
4.3MM	Using medium torque wrench with 7/16" socket, reach under the inner floor of shipping container and attach Experimental Top Plate of RIGEX to the inner floor of the shipping container with bolts (1/4"-28, 2 1/4" long (8)) and washers (1/4" flat washers(10)). WARNING: 2 washers are required (2 locations) to avoid contact with camera housing. Locations are marked on underside of subfloor. Torque to 20 in*lbs above running torque. (see Fig. 30, 34 & 35). **Note:** Keep slight tension in web straps for stability. Mfr:____________ Cal ID: ___________ Due date: ___________			

Seq #	Instructions	Date	Tech	Insp
4.3NN	Lifting RIGEX (With Inner Floor) off Clearance Block  Figure 31: Lifting RIGEX (With Inner Floor) off Clearance Block			
4.3OO	Verify all components stored in subfloor of RIGEX shipping container: refer to packing list			
4.3OOa	Set aside (4) shroud fasteners for use in step 4.3XX before proceeding.			
4.3PP	Using crane, lift RIGEX (with inner floor) off the clearance block and set aside block (see Fig. 31)			
4.3QQ	While suspended from crane maneuver outer floor of shipping container under RIGEX (with inner floor)			

Seq #	Instructions	Date	Tech	Insp
4.3RR	Lowering RIGEX (With Inner Floor) onto Shipping Container  Figure 32: Lowering RIGEX (With Inner Floor) onto Shipping Container Note: 2 webstraps required, 4 optional			
4.3SS	Lower RIGEX (with inner floor) until it is safely resting inside of shipping container (see Fig. 32) Note: Ensure clocking is correct.			
4.3TT	Using socket wrench with 3/4" hex socket, attach the four bolts connecting the inner floor and the outer floor of shipping container. Secure nuts underneath with 3/4" open-end wrench. Tighten until 5-6 threads are visible beyond nylock nut.			
4.3UU	Remove web straps (2) from feet on oven mounting plate of RIGEX			

Seq #	Instructions	Date	Tech	Insp
4.3VV	RIGEX with Upper Sides of Shipping Container Removed			

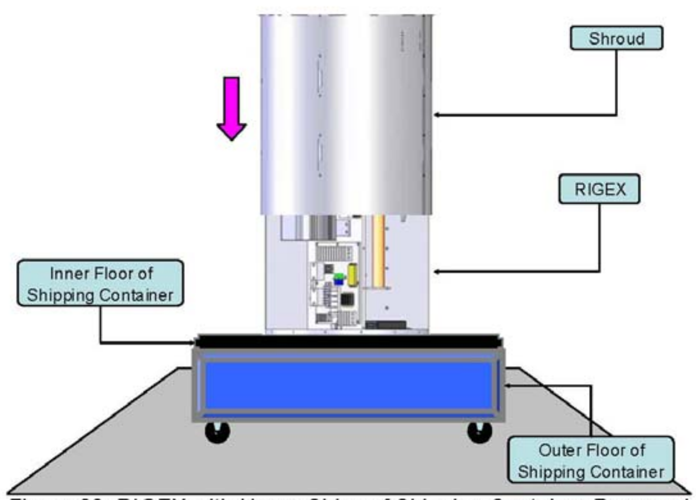


Figure 33: RIGEX with Upper Sides of Shipping Container Removed

Seq #	Instructions	Date	Tech	Insp
4.3WW	Slide shroud over RIGEX (see Fig. 33)			
4.3XX	Using small torque wrench with #2 Phillips bit attach shroud to RIGEX with NAS8402-7 (Flange Button Screws: #8-32, 4/9" long) fasteners (4) for shipment. Torque to 20 in*lbs above running torque. **Note:** Locations of fasteners includes; one on each side of Experimental Top Plate one on oven mounting plate, one along seam of Shroud Mfr:____________ Cal ID: ___________ Due date: ___________			

Seq #	Instructions	Date	Tech	Insp
4.3YY	Place both sides of upper casing back on shipping container			
4.3ZZ	Lock all latches around shipping container and secure with Zip-Ties			
4.3AAA	Add Shock Indicators			
4.4	**Emulator**			
4.4A	Remove lid and place Emulator in shipping container			
4.4B	Insert packing material inside container			
4.4C	Place lid on top of wooden crate			
4.4D	Using #2 Phillips Screwdriver carefully tighten down screws to hold lid of the wooden crate			
4.5	**CAPE Mounting Plate**			
4.5A	Remove lid and place CAPE Mounting Plate, with lifting handles (4) and wiring cover plates (2) still attached, in shipping container			
4.5B	Place bag of NAS1351N6-20 (Flat Screws w/ Patchlock: 3/8-24, 1" long, A286) fasteners (24) that connect cape mounting plate to experimental top plate container			
4.5C	Insert packing material inside container			
4.5D	Place lid on top of wooden crate			
4.5E	Using #2 Phillips Screwdriver carefully tighten down screws to hold lid of the wooden crate			

Figures:

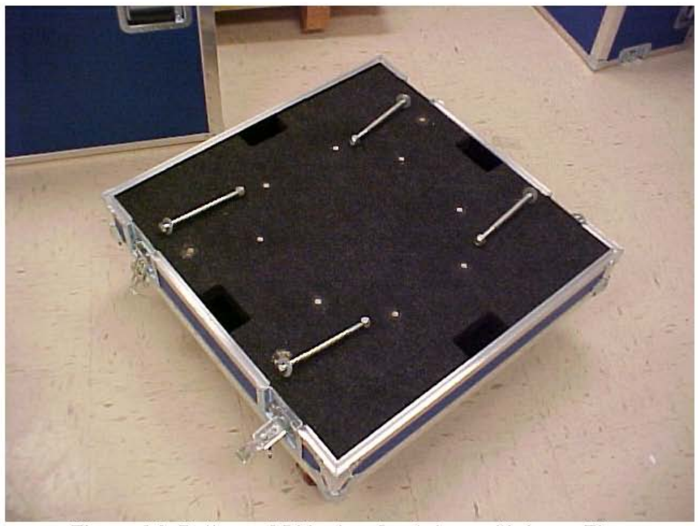


Figure 34: Bottom of Shipping Container with Inner Floor

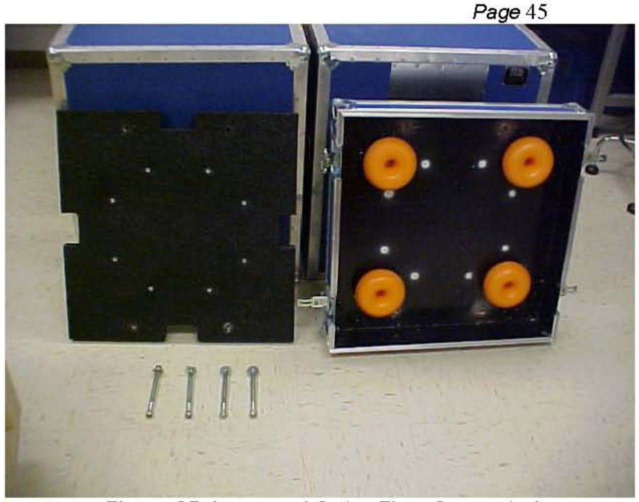


Figure 35: Inner and Outer Floor Separated

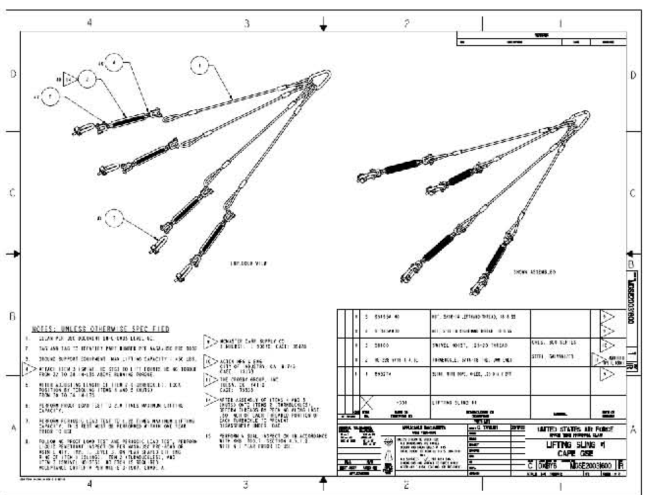


Figure 36: Lifting Sling

Bibliography

1.) *Anodizing… The Finish of Choice.* Aluminum Anodizers Council. http://www.anodizing.org/what_is_anodizing.html

2.) *C-Eye*. Tern INC. copyright 2006. www.tern.com/portal/content.asp?contentid=630

3.) Charlie Wagner. *Alodining.* The Leading Edge. 10 July 1997. http://www.eaa1000.av.org/technicl/corrosion/alodine.htm

4.) Cicek, Ismail PHD Student. *"LabVIEW"*. Mechanical Engineering Dept. of Texas Tech University. http://www.turkishnews.com/itumuk/info/petek/aralik_ocak/Labview.htm

5.) *Computer-aided design*. Wikipedia, The Free Encyclopedia. 30 May 2007. www.en.wikipedia.org/wiki/CAD

6.) *Contamination Outgassing Testing; ASTM E 595 / IPC-TM-650 2.6.4.* Integrity Testing Laboratory. 2006. http://www.itlinc.com/contamination_outgassing.htm

7.) DiSebastian, John D., Captain, USAF. *RIGEX: Preliminary Design of a Rigidizable Inflatable Get-Away-Special Experiment*. Master's Thesis, Air Force Institute of Technology (AFIT), Wright-Patterson AFB OH, March 2001.

8.) *EyeC™ Technical Manual*. Tern INC. Davis, CA. 22 September 2005 http://www.tern.com/portal/library/eyec.pdf

9.) Futron Corporation. *Space Transportation Costs: Trends in Price Per Pound to Orbit 1990-2000.* Technical report, Bethesda MD, September 2002. http://www.futron.com/pdf/resource_center/white_papers/FutronLaunchCostWP.pdf

10.) Goodwin, Jeremy S., Captain, USAF. *Detailed Design of the Rigidizable Inflatable Get-Away-Special Experiment*. Master's Thesis, Air Force Institute of Technology (AFIT), Wright-Patterson AFB OH, March 2006.

11.) Gunn-Golkin, Anna E. 2nd Lieutenant, USAF. *Structural Analysis of the Rigidizable Inflatable Get-Away-Special Experiment.* Master's Thesis, Air Force Institute of Technology (AFIT), Wright-Patterson AFB OH, September 2006.

12.) Helms, Sarah K., 2nd Lieutenant, USAF. *Development and Testing of an Inflatable, Rigidizable Space Structure Experiment*. Master's Thesis, Air Force Institute of Technology (AFIT), Wright-Patterson AFB OH, March 2006.

13.) Holstein III, Raymond G., Captain, USAF. *Structural Design and Analysis of a Rigidizable Space Shuttle Experiment*. Master's Thesis, Air Force Institute of Technology (AFIT), Wright-Patterson AFB OH, March 2004.

14.) How We Protect. Keal Cases, INC. copyright 2003. http://www.kealcases.com/HowWeProtect.htm

15.) Kendall, Randy. "EELV: The Next Stage of Space Launch". *The Aerospace Crosslink*. http://www.aero.org/publications/crosslink/winter2004/07.htm

16.) Lindemuth, Steven N., Captain, USAF. *Characterization and Ground Test of an Inflatable Rigidizable Space Experiment*. Master's Thesis, Air Force Institute of Technology (AFIT), Wright-Patterson AFB OH, March 2004.

17.) Moeller, Chad R., Captain, USAF. *Design and Ground-Testing of an Inflatable-Rigidizable Structure Experiment in Preparation for Space Flight*. Master's Thesis, Air Force Institute of Technology (AFIT), Wright-Patterson AFB OH, June 2005.

18.) Moody, David C., 1st. Lieutenant, USAF. *Microprocessor-Based Systems Control for the Rigidized Inflatable Get-Away Special Experiment*. Master's thesis, Air Force Institute of Technology (AFIT), Wright-Patterson AFB OH, March 2004.

19.) *Multipacting.* Inverse Problems Group. 7 September 2004. http://www.rni.helsinki.fi/research/em/EM_multipacting.htm

20.) National Aeronautics and Space Administration http://nepp.nasa.gov/npsl/Prohibited/tin_prohibition.htm

21.) National Aeronautics and Space Administration Aerospace Quality Clause 05. *CERTIFICATE OF COMPLIANCE (C of C).* QC02-N. California Institute of Technology; Jet Propulsion Laboratory. 2000.

22.) National Aeronautics and Space Administration. *Mission Information; STS-123*. Nevills, Amiko. 17 April 2007. http://www.nasa.gov/mission_pages/shuttle/shuttlemissions/sts123/index.htm

23.) National Aeronautics and Space Administration. *Structural Integration Analyses Responsibility Definition for Space Shuttle Vehicle and Cargo Element Developers.* NSTS37329 Rev. B. Houston: Johnson Space Center, January 2001.

24.) Nicholas , A.C., S.E Thonnard, I. Galysh, P. Kalmanson, and B. Bruninga. " An Overview of the ANDE Risk Reduction Flight," AAS 05-401. American Astronautical Society. 2005.

25.) Philley, Thomas Lee, 1st Lieutenant, USAF. *Development, Fabrication, and Ground Test of an Inflatable Structure Space-Flight Experiment*. Master's thesis, Air Force Institute of Technology (AFIT), Wright-Patterson AFB OH, March 2003.

26.) PHPK Technologies. *"Operation and Maintenance Manual for the Space Simulator Vacuum System for The Air Force Institute of Technology at Wright Patterson Air Force Base Volume I.* PHPK Work Order 06-1552. Customer Order NO. FA-8601-06-P0184.

27.) PHPK Technologies. *Operation and Maintenance Manual for the Space Simulator Vacuum System for The Air Force Institute of Technology at Wright Patterson Air Force Base Volume II.* PHPK Work Order 06-1552. Customer Order NO. FA-8601-06-P0184.

28.) *Pressure Transducer Series 2; Bonded Foil Sensing Technology*. Taber Industries. North Tonawanda, New York. http://www.taberindustries.com/Transducer/Scans/Series2.pdf

29.) Quintero, Andrew H.; Welch, John W.; Wolf, Helmut. *Perceptiveness of Thermal Vacuum Testing.* 18th Aerospace Testing Seminar, 16-18 March 1999.

30.) Single, Thomas G., Captain, USAF. Experimental Vibration Analysis of Inflatable Beams for an AFIT Space Shuttle Experiment. Master's thesis, Air Force Institute of Technology (AFIT), Wright-Patterson AFB OH, March 2002.

31.) *SolidWorks*. Wikipedia, The Free Encyclopedia. 29 May 2007. www.en.eikipedia.org/wiki/solidworks

32.) Taylor, Carson. *Rigidizable Inflatable Get-Away-Special Experiment Vibration Test Plan*. RGX20079002 IR. DoD Shuttle/ISS Human Spaceflight Payloads. Johnson Space Center, Houston, 1 May 2007.

33.) *Thermal Vacuum Testing*. Swales Aerospace. www.swales.com/engineering/therm_vac.html

34.) Tran, Eushiun. *Environment/ EMC/EMI*. Carnegie Mellon University. Spring 1999. http://www.ece.cmu.edu/~koopman/des_s99/environment/

35.) *What is a Resistance Temperature Detector (RTD)?* Omega Engineering. http://www.omega.com/rtd.html

Vita

Ensign Zachary R. Miller attended Albemarle High School in Charlottesville, VA and graduated in June 2002. In June 2002, he entered undergraduate studies at the Virginia Military Institute in Lexington, VA. As a cadet, ENS Miller was a tri-athlete competing in football in the fall, boxing in the winter and lacrosse in the spring. ENS Miller was also the drummer for the Jazz Ensemble at Washington and Lee University and an active member of the Trident Society in the Naval Reserve Officer Training Corps (NROTC). He graduated with a Bachelor of Science degree in Mechanical Engineering with a minor in Mathematics and a concentration in Aerospace Engineering in May 2006. He was commissioned as a naval officer upon graduation from the U.S. Naval Academy.

ENS Miller's first assignment was to the Air Force Institute of Technology (AFIT) as part of the Immediate Graduate Education Program (IGEP) for Navy ensigns. In June 2006, he entered the Graduate School of Engineering and Management at AFIT to gain a Master's Degree in Aeronautical Engineering, concentrating on digital avionic systems and air weapons. During his time in Dayton, OH he completed the Naval Introductory Flight Screening (IFS) at the aero club on Wright-Patterson Air Force Base (WPAFB) and attained his private pilot license. Upon graduation, he will be assigned to Naval Air Station (NAS) Pensacola to begin flight training as a naval aviator.

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14. ABSTRACT

The purpose of this research is to support the final development of the Rigidizable Inflatable Get-Away-Special Experiment (RIGEX). The RIGEX program is an experimental initial step in developing large-scale rigidizable inflatable structures, which can be utilized in space applications. The primary intent of RIGEX is to verify and validate ground testing of inflation and rigidization methods for inflatable space structures against a zero-gravity space environment. This is performed by designing a Canister for All Payload Ejections (CAPE) experiment to collect data on space rigidized structures for validation of ground testing methods.

The results presented in this thesis provide documentation needed to meet the requirements set forth by the National Aeronautics and Space Administration (NASA) for launching a payload into space. This thesis establishes a process for appropriately ground testing the components of RIGEX in an environment similar to space and explains future testing required. Methods for charging and testing the performance of the onboard inflation system are also discussed. Additionally, the steps taken to replace the onboard imaging system are explained. Throughout the course of assembling the RIGEX protoflight model, several complications were encountered and the design was modified, which are presented along with an as-built final assembly drawing package. Lastly, the procedure for handling RIGEX during its future progression is illustrated.

15. SUBJECT TERMS

Inflatable Structures, Space Systems, Space Shuttle Payload, Rigidizable Structures, Computer Aided Design, Drawing Package, Data Imaging System, Thermal Vacuum Testing, Pressure Retention Testing, Vibration Testing, Canister for All Payload Ejections, Get-Away-Special

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