NOPI Vacuum Manifold

Final Proposal Report

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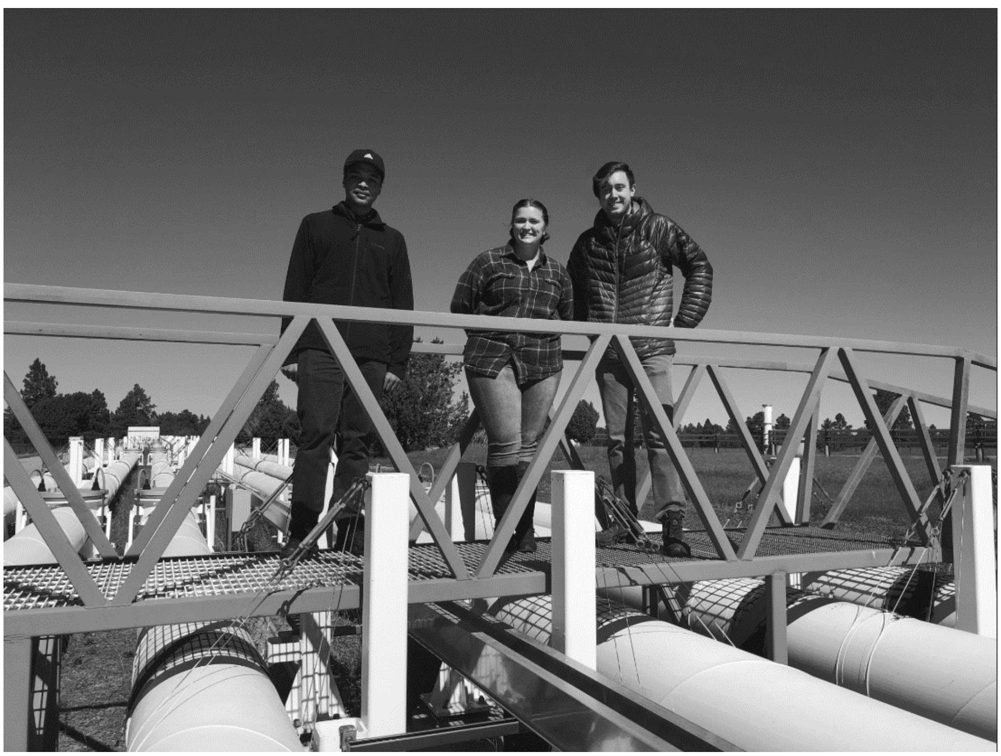

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DISCLAIMER

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EXECUTIVE SUMMARY

The Navy Precision Optical Interferometer (NPOI) Capstone team was created due to concerns over the projected service life of the current Fast Delay Line (FDL) vacuum manifold system. The expected failure point of the original manifold was the vertically positioned bellows which were subjected to loading conditions beyond what they were originally designed to withstand. These loads were expected to eventually lead to a tear in the thin walls of the bellows which would have caused air to disperse into the FDL tank potentially leading to the destructions of the optical equipment inside. Due to this looming threat the purpose of the team was to redesign, implement, and test a new vacuum manifold for the FDL's at NPOI. The parameters that the team had to follow as requested by the client is that the new manifold would be safe, reliable, repairable, built within budget, be easy to use (i.e., no need for new employee training), and allow for future project integration. In addition, part of the design requirement was to move where the manifold connected to the FDL tank such that would no longer attach to the "snoot" of optics pipe. These expectations from our client where used to define the engineering characteristics that are design would follow. These engineering requirements were used when initially choosing the design of the manifold from the concepts that were generated. The final design that resulted after concept evaluation and multiple design iterations was that the manifold connected to the FDL tanks via the current ribbon cable interconnect. To do this a custom interface was designed, after several iterations, by the team to connect the standardized parts of the rest of the manifold to the custom ribbon cable interconnect allowing for connection to the FDLs. From the interface, the manifold would have a 90° miter elbow to direct the piping upwards. From this elbow a tee branch would be connected. From this branch a cross pipe was attracted that held the two standard 26pin ribbon cable connections as well as a small pressure valve which is attached to the pressure sensor. The other section of the tee is also connected to a different larger pressure valve. This larger valve connected to another tee which would connect to a bellows and a long section of straight pipe. This pattern was repeated for all six tanks with the last tank having an extra blanking plate at the end of the tee to maintain the vacuum. The first tank had its pipe connected to bellows which through a series of 12.6in pipes and 90° non-miter elbows lead to the original vacuum pump system. To support the manifold, rods where made such that they would connect to the FDL support structure that was already in place. From this rod a 3D printed part would be used to allow the cross section from earlier to rest on it. This 3D part will in theory help to reduce the vibrations. The results from our design have not been validated at NPOI due to supply shortages causing us to be unable to build the manifold currently. However, when the manifold is built the testing procedures have already been made to validate that our manifold conforms to the engineering requirements that were set.

TABLE OF CONTENTS

Contents

1 BACKGROUND

1.1 Introduction

The Navy Precision Optical Interferometer (NPOI) is the world's largest optical interferometric-based observatory. NPOI currently operates with a combination of up to six Siderostats (a flat mirror device used to collect and direct starlight) stations that are reconfigurable to produce unique and interesting sets of data. NPOI combines starlight collected by the six stations to synthesize a much larger telescope. This, in effect, makes NPOI the world's largest optical telescope. To minimize photon loss and atmospheric abortions which could contaminate datasets the entire array is held in a vacuum.

"Fast Delay Lines" (FDLs) are used to account for variation in light path length between Siderostat stations. The FDL system, like most of the NPOI, must maintain a vacuum for operation. To achieve vacuum, a manifold connecting and isolating each delay line to a greater vacuum system is in operation. The existing structure is old and failing. Should the current manifold fail the NPOI facility would shut down until a solution could be made. A system-wide shutdown would negatively affect the scientists working at NPOI, the night operations team, the military and civilian clients who utilize NPOI data, ongoing visiting programs who utilize NPOIs unique delay lines, and the engineering team responsible for system performance.

The Director of NPOI, Jim Clark, has personally undertaken the responsibility of sponsoring an NAU Capstone team. This team is tasked with designing, manufacturing, installing, and validating a new FDL vacuum manifold system before the current system experiences a catastrophic failure. This is a time-critical and costly endeavor that, when complete, will eliminate the FDL manifold as a point of extreme concern to all parties. This project will deliver a system that will be utilized 24/7 to help produce real scientific data and potentially lead to new scientific discoveries.

1.2 Project Description

Following is the original project description provided by the sponsor [1]

> "An NAU capstone project would be charged with designing, analyzing, and possibly manufacturing a new vacuum manifold for the Fast Delay Lines. The new manifold would be separate from the vacuum snoots allowing for shorter down times when working at the front of the tanks. Additionally, the relocation of the vacuum manifold would eliminate forces on the snoots reducing potential for vacuum failure. The proposed manifold would be required to interface with the existing bulkhead plates, greatly reduce risk of vacuum failure, partition each of the six delay lines so an individual tank can be vented without disrupting operation of other delay lines and reduce maintenance time when working on the FDL carts. Other considerations include location of the vacuum pump to reduce/eliminate vibrations that effect optics cart performance, and access to partitioning valves. Above and beyond features could include a data logging system for vacuum performance utilizing the existing sensor array. Currently, vacuum pressure is recorded by hand in a notebook. Development of a sensor package to research any correlation between vacuum performance with humidity and temperature changes in the room could be useful for continued engineering development. The scope of this project requires analysis of material properties, hydrostatic loading, cycle degradation prediction, cost optimization, and FEA evaluation to generate a fully engineered final product. Construction, assembly, and installment of the proposed manifold could be included in the capstone requirements requiring students to learn manufacturing processes and evaluation of final system."

2 REQUIREMENTS

This section of the report outlines the requirements that our new design must meet based on the given customer requirements. This is done by creating engineering requirements to match each of the customer requirements and discretizing the functionality of the manifold into parts. Finally, the codes and standards that our manifold should abide by is also addressed.

2.1 Customer Requirements (CRs)

The first and most important customer requirement is safety. The volume of evacuated space at NPOI represents an increased opportunity for catastrophic failure. Any sudden breach to the vacuum system could result in serious injury to nearby people and damage to the vacuum protected optics inside the system. Safety is taken seriously at NPOI. An example of system redundancy are the support cables holding the Long-Delay-Lines (LDLs) outside the FDL building. The design supports each end of pipe with two braded steel cables. One cable is rated to hold the weight of the pipe, yet a total of 4 cables are used to increase redundant safety at a low financial cost. The result is a minimum factor of safety of 4 supporting the LDL system. Our client emphasized there is no weight or size limitation to the new vacuum manifold allowing the Capstone team to primarily design for safety. This is the 1st requirement which weighs 50% in the overall decision making prosses.

The next requirement provided by the client is increased reliability and service life over the old system. The FDLs are a mission critical component to NPOI. If the carts are not held in vacuum, the system cannot be operated, and no data collection can occur. The vacuum manifold is the component responsible for maintaining FDL vacuum and therefore is a critical component of the interferometer. By designing a new manifold, the team will increase the reliability over the current system, and by optimizing the materials used the team will provide a solution that will last the duration of the NPOI's mission lifetime. This is the 2nd requirement which weighs 12.5% in the overall decision making prosses.

Our client pointed out the necessity for regular system maintenance and instituted a requirement for maintenance accessibility. Presently, the vacuum manifold must be physical disconnected from the FDL tank when cart maintenance is required. This operation is time intensive, requires skilled personnel, and presents a risk to the overall system due to the number of components being disassembled. The new manifold must allow for cart access and decrease the disassembly of optical and vacuum components. This is the 3rd requirement which weighs 12.5% in the overall decision making prosses.

The fourth requirement is the that the team is to stay within the budget allocated to us by NPOI. This is desired because it challenges us to create something meaningful from limited resources and it also ensures that the materials used could be replaced without great cost to NPOI in the future if needed. This is the 4th requirement which also weighs 12.5% in the overall decision making prosses.

The fifth requirement is that the new manifold should be easy to use. This is desired because it would be a hassle for the client to have to retrain his employees in the operation of the system.

The last requirement is to allow for future project integration. The NPOI instrument is not only an operational observatory, but a testing ground for new and exciting types of experiments and technology. It is unknown what requirements future programs might have for the NPOI facility; therefore, it is necessary to provide integration and access points within our design. This fundamental feature of the new manifold is already being utilized by replacing the existing electrical passthrough to accommodate more electrical connectivity per the client's request. This is the 5th requirement which weighs 12.5% in the overall decision making prosses.

2.2 Engineering Requirements (ERs)

For each of the CR's previously listed at least one engineering requirement was made to correlate to it. For safety, the ER is factors of safety (FS). Because the cost of materials increases with the FS used, the team decided that a FS of 2.5 ± .5 would be the target value to ensure safety and keep costs low. This is lower than some FS used elsewhere at NPOI, but this decision is justified because of the limited budget.

The client budget expectation was matched together with manufacturing lead time and with project cost. For manufacturing lead time are goal was to have it be under four weeks plus or minus three days. In terms of project cost the goal was to have it be 10000$±4000$ because it is our goal to stay within budget and if possible be under.

Both reliability and repairability were incorporated into a minimize downtime ER. The hope for this would be that the maintenance would be reduced to 2 ± 1 hours for a disassembly and reassembly of the manifold system which would be less than the time needed for the original manifold.

The new vacuum manifold must provide sufficient flow rate to evacuate one FDL line over the course of one day. Constriction in the pipe, poor geometric design, and insufficient vacuum power could reduce the team's ability to deliver a system capable of meeting this design requirement. Analysis and validation of the completed system will be done to evaluate the systems performance and influence final design.

The last ER that was created was leak rate. The original system at NPOI was able to hold an operational vacuum for five days. Our manifold must at least match this value but preferably go beyond that.

2.3 Functional Decomposition

2.3.1 Black Box Model

To understand what goes into our system, a black box model was created that visualized the material, energy, and signal inputs into our vacuum manifold and the also the corresponding outputs. This helps to visualize the project by giving a broad overview of what are system is supposed to being doing and what inputs are required to make it work. The final black box model can be seen in Figure 1 below. Compared to the preliminary report the addition of a digital output signal was added to represent the pressure sensor.

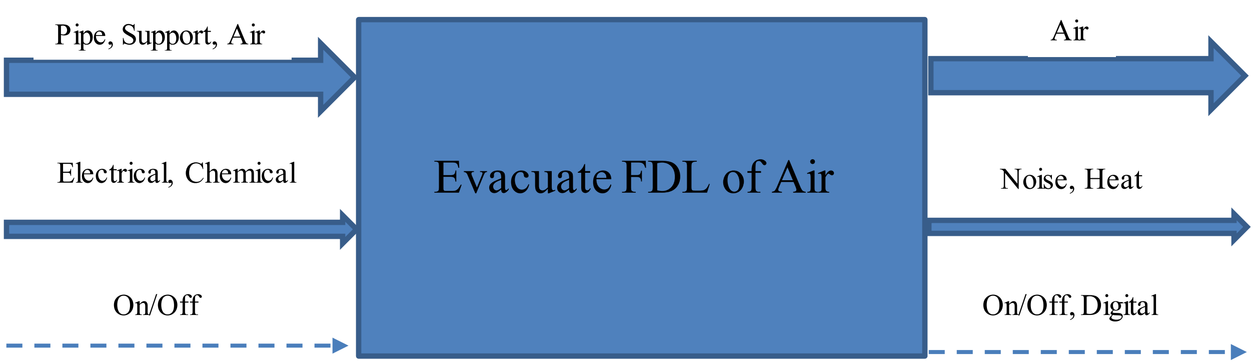


Figure 1: Black Box Model for Vacuum Manifold

2.3.2 Functional Model/Work-Process Diagram/Hierarchical Task Analysis

The functional model helps the team by giving a more detailed view of how each of the systems inside of the vacuum manifold work and how the various parts work together. The decomposition uses the same three inputs from the black box model of material, energy, and signal. The decomposition that was made for the vacuum manifold can be seen in Figure below. A change that has occurred was the addition of a control valve for the pressure sensor. This was done in accordance to a request of the client to have each pressure sensor be able to be removed from the FDL tanks without compromising the vacuum.

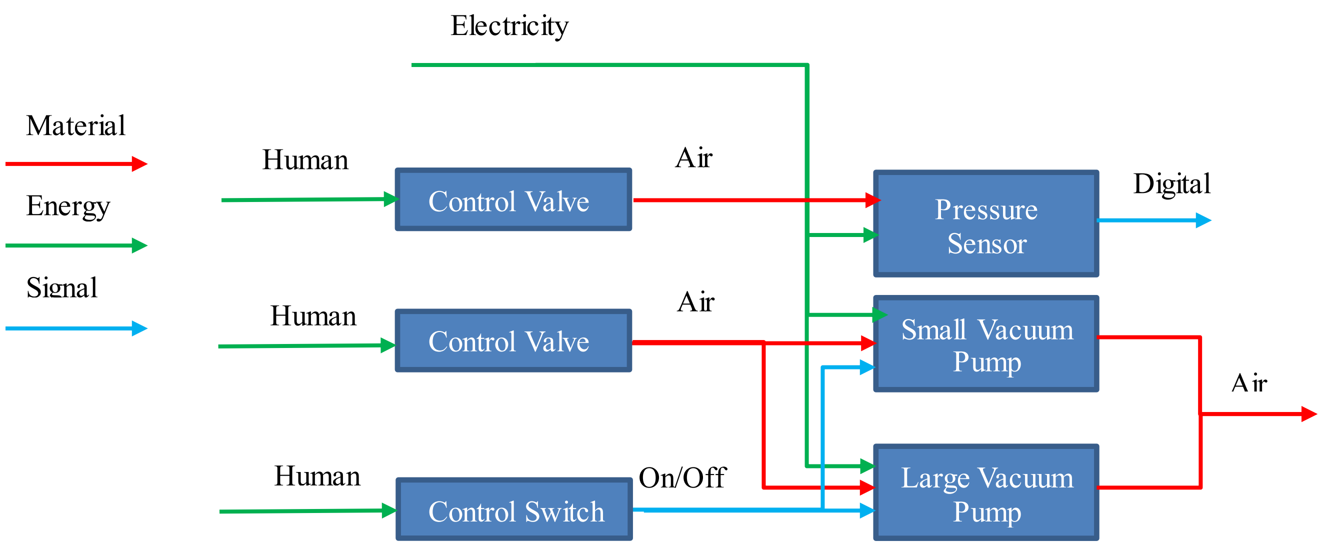


Figure 2: Function Decomposition for Vacuum Manifold

In addition to the functional decomposition, a hierarchical chart was created to show the breakdown of the vacuum manifold system to its lowest manageable parts. This was done in order to visualize the parts of the system and how they come together to achieve the end goal of a fully working vacuum manifold. The hierarchical chart can be seen in Figure 3. In a similar fashion to the function decompositions an extra branch was added to the hierarchy chart to represent the pressure sensor subsystem of the manifold.

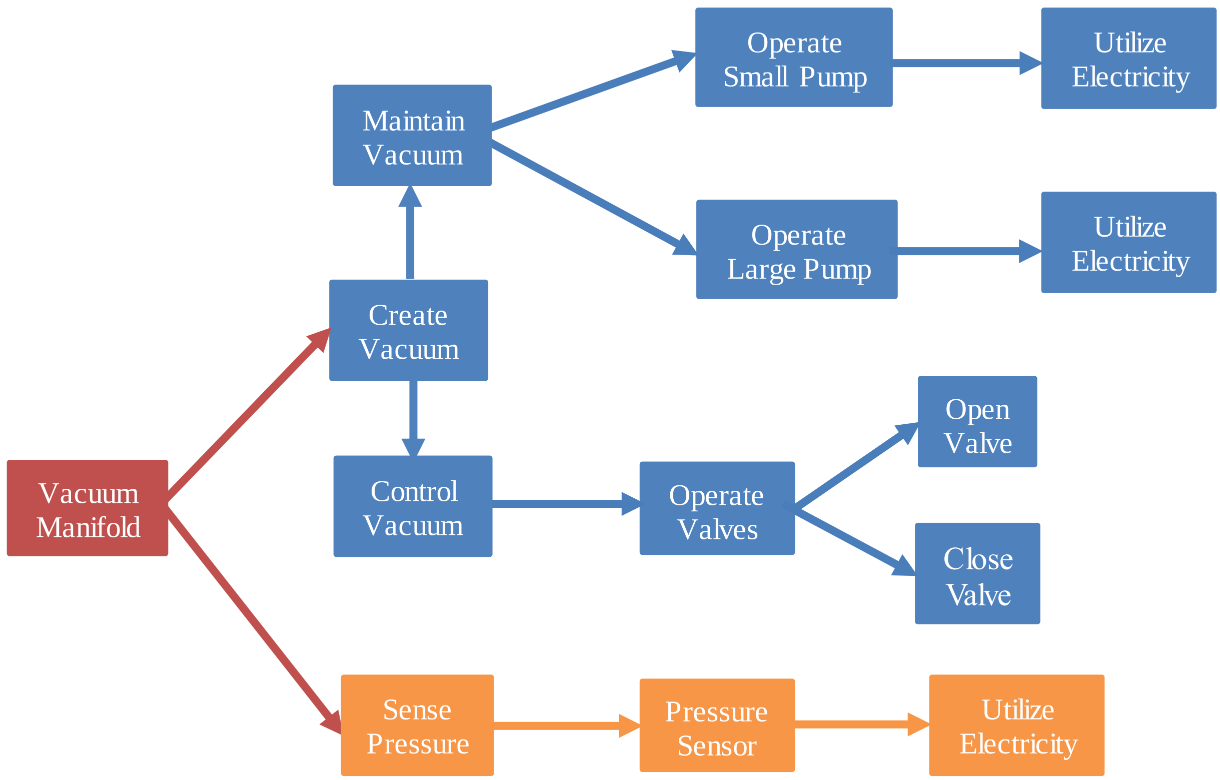


Figure 3: Hierarchical Chart of Vacuum Manifold

2.4 House of Quality (HOQ)

As previously mentioned in Section 2.1 and 2.2, we had a total of seven CRs that had an equal number of ERs corresponding to them. To evaluate which engineering requirement had the highest technical importance to this project regarding satisfying the customer requirements, a house of quality was used to compare them. In the HOQ, for customer requirements, safety has a weight of nine, cost is three, ease of use is three, reliability is nine, repairability is nine, longevity is three, and future project integration is one. Using these weights and the relevance to each of the engineering requirements it was found that the three most important ER are the factors of safety, followed by project cost and finally minimize downtime. The three systems that were used to benchmark against the current system is the Laser Interferometer Gravitational-wave Observatory (LIGO), the Vacuum Tower Telescope (VTT), and the 1-meter Swedish solar telescope (SST). These three systems were used as benchmarks because they utilize vacuums systems to gather observation data. Technically none of these comparisons are a perfect match to NPOI but they all offer decent standings on how other vacuum systems operate in the world. The completed house of quality can be seen in appendix A.

2.5 Standards, Codes, and Regulations

As engineering students it's important that our design holds to accepted standards in industry. The standards that directly apply to our project our shown in Table 1.

Table 1: Standards of Practice as Applied to this Project

Standard Number or Code	Title of Standard	How it applies to Project
ISO 19685:2017	Specifications, calibration, and measurement uncertainties for Pirani gauges	Our project uses a Pirani gauge (I think)
ISO 2861:2020	Dimensions of clamped-type quick-release couplings	Clamps are used throughout the manifold to attach adjoining pieces.
ASME P-15.7	Code of Ethics Engineers	It's a policy all engineers should follow in ever project

The importance of ISO 19685:2017 to our project is that as part of installing the Pirani gauges used on our vacuum manifold, we will most likely have to calibrate them. Because of this, it is important that we follow the established guidelines from this standard to ensure that the equipment that is installed for our client gives proper and accurate data. Failure to properly calibrate the gauges can lead to the emergency shutoff system of NPOI prematurely activating or causing lost observational time as they wait for the system to get to an acceptable vacuum level according to the gauge. ISO 2861:2020 is another important guideline to follow because every standard section of pipe that is used in our manifold needs to be clamped with a quick-release style of coupling. Although are team will not be making the clamps, it is important that we verify that the clamps that we order fall within the standards set to ensure that they work properly. Proper verification of the clamps ensures that the joints of the manifold are not able to have large leaks allowing for longer operation without vacuum pumps on as well as ensuring that the vacuum pumps can be run at lower RPMs during normal operation. The final code that our team must follow is ASME P-15.7. This is the general engineering code of ethics that should always be used (in some variation depending on the organization) when working on a project. This applies to us too because are project can have real consequences if we fail to follow these practices.

3 Testing Procedures (TPs)

An important step in making sure that our final design works is testing it to compare to each of our engineering requirements, from section 2.2. The procedures and methods we will use to test the system will be outlined in this section of the report. Many of the systems we are working with are unique and do not currently have industry standard testing procedures. We, as a team, will work to develop testing procedures for our system so that it better interfaces with existing structures.

3.1 TP 1: Safety Analysis (Factors of Safety) {1}

Engineers are expected to design components and systems before the manufacturing process to save time and money on expensive replacement. Sometimes physical testing of components can be performed to increase the certainty of design. Given the projects limited budget and time constraints strictly an analytical analysis will be conducted to insure feasibility of design. This section of the report outlines how theoretical analysis will be conducted.

3.1.1 TP 1: Objective

The objective of this testing procedure is to test under what conditions the manifold that we have created would fail allowing us to calculate its factor of safety based on known loading conditions. Because many of the parts that were ordered are both expensive and time consuming to replace it is not possible to test them to failure. Instead, the pieces will have to be evaluated analytically to understand what conditions they can withstand and get individual and system wide factors of safety. Certain cheaper items where spares are handy at NPOI, like blanking plates and centering rings/clamps, could be tested physically. However, these components are in use around the array and have a long track record of quality performance.

3.1.2 TP 1: Resources Required

Software and computer applications like Solidworks enable the team to perform "finite element analysis" for specific subcomponents under simulated loading conditions. This method allows the team to design parts and system geometries to optimize for everyday use and to failure. Indeed, designing to failure allows the team to submit confidence values along with projected safety factors elevating clients trust in the overall design. FEA also allows the team to perform optimization analysis for specific components enabling us to save money on part manufacturing and component selection.

3.1.3 TP 1: Schedule

Because of shipping constraints, we are not currently in possession of any of our parts. Because of this we cannot be certain of the true material properties the components have. However, evaluation of components can be performed now assuming material properties. For our individual analysis some assumptions will be made. If any properties change these parameters may be updated in the FEA program and revaluated to provide a more accurate evaluation of component performance. These simulations can be completed within a day for individual parts but may take longer to simulate the entire manifold depending on how powerful the computer we are running the simulation on is. This should be completed towards the beginning of the second semester if our parts arrive at some point before it starts.

3.2 TP 2: FDL Evacuation (Pump Flow Rates) {4,5}

3.2.1 TP 2: Objective

The objective of this test is to see if the new manifold design can evacuate the air of the FDLs in a similar time to the original. Doing this test involves removing the air from one or more of the FDLs using the same vacuum pump system that the original system used. Once the vacuum pump has been turned on a timer will be started. Once the FDL reaches a working vacuum of 30mTorr the timer can be stopped. This number can then be used to identify the rate the pumps operate at. This can then be compared to the original design to see if any improvements have been made. Up to six tests can be done initially, as each FDL will have to be at atmospheric pressure when we are installing our new manifold, without completely disrupting work at NPOI. Alternatively, the team can evaluate the time to evacuate all six delay lines at once.

We expect the rate of evacuation to be different for each delay line due to variations in assembly material and humidity in the tanks. We also expect variation between the new and old manifold system. We recognize the new manifold is not optimized for evacuation speed but rather modularity and compatibility with the existing structure. Therefore, it is expected the new system will be slower to evacuate the FDL tanks compared to the old manifold. This is not a failure of design, and the team points out the function of the manifold is primarily to maintain vacuum.

3.2.2 TP 2: Resources Required

In order to do perform this test the full new FDL vacuum manifold has to be installed at NPOI. Additionally, the main array roughing pump used to evacuate high pressure atmosphere and the turbo pump must be operational and connected to the new manifold.

Because the team is utilizing components from the existing structure, mainly the vacuum valves, we are unable to test in parallel with the old system.

3.2.3 TP 2: Schedule

Once again, this test cannot happen until all the manifold parts have arrived and we have assembled the full device. The installation of the new system is predicted to take one full week of work and coordination with other active projects at NPOI. As before, if the parts come in late December, we should be able to complete this test towards the beginning of the semester. These tests will take a considerable amount of time to run due to the large volume of air inside the FDL tanks and as such it may take a full week of pulling vacuum. Characterization of the pull-down rate will take place over the next few years by operations staff at the facility. Variations in humidity and atmospheric pressure alter the performance of the system and therefore a true understanding of system performance will take over one year to evaluate. This is not explicitly part of the capstone project but is important information of technicians at NPOI to monitor the systems performance and health of the vacuum pumps.

3.3 TP 3 Front Plate Disassembly (Minimize Downtime) {6}

3.3.1 TP 3: Objective

This test aims to understand how long it takes to remove the front plate of a FDL with our new design and compare it too how it was. Many maintenance operations require the front of the FDL tank to be removed. The current manifold interfaces with the front of the tank and therefore is part of the current disassembly and reassembly time. The new manifold will not interface with the front plate and therefore is expected to reduce downtime during maintenance.

3.3.2 TP 3: Resources Required

To accomplish this test, the old manifold has to be removed from the snoot and the bottom portion of our new manifold that is closest to the front plate should be installed. In addition, an employee of NPOI that is familiar with removing the front plate is needed to ensure that the lack of experience from some of the team members does not skew the results.

The completed new manifold is not required for this test.

3.3.3 TP 3: Schedule

Like the previous test this one is also planned for the start of the second semester. This test is being pushed to second semester due to ongoing visiting science work utilizing the FDL systems. Once these projects are complete, time to work with the FDLs will allow the team to conduct important research. The ongoing projects are scheduled to let up at the start of next semester.

Because the entire manifold assembly is not needed for this test it can happen before any of the other mentioned tests. If desired, and time permitting, the team could time disassembly and reassembly of the current system. We would then remove the section of vacuum manifold and run the test again. This would emulate not needing to remove the vacuum manifold like in the new design.

3.4 TP 4: Leak Rate {7}

3.4.1 TP 4: Objective

This test aims to understand how quickly the new manifold would lose its vacuum and where major sources of leakage occur on the structure. In order to test the leak rate of the entire manifold a section of it would need to be isolated after achieving vacuum and the data from the pressure sensor would need to be recorded until it reached a critical pressure of 30mTorr. From the time it took to reach this pressure the overall leak rate can be found. If this method cannot be used due to time constraints, the leak rate of the manifold can also be calculated by using the given leak rates from Kurt J Lasker on the various parts [2]. To cheek for the major sources of leakage on the manifold a He leak test can be performed. This test involves spraying some He gas on a joint and then using a spectrometer next to the vacuum pump to see if any He enters the system.

The vacuum manifold is not the primary concern for leakage. The seals used in the FDL tanks are nonstandard and known to leak. Additionally, the reported leak rate from the manufacturer is for significantly higher vacuums compared to the vacuum at NPOI. This test is useful in identifying any error in assembly or faulty components utilized in the new manifold.

3.4.2 TP 4: Resources Required

To perform the full-scale leak rate, test the entire new manifold must be built and installed. Should the team wish to test only the components of the new manifold as an assembly a test could be performed disconnected from the array. If the new manifold leaks at a concerning rate, and the location of leak cannot be easily determined, the use of a Helium Leak tester can be used. NPOI has this devise on site. The He tester should only be utilized if the point of failure cannot be determined.

3.4.3 TP 4: Schedule

Like the previous test this also relies on having the pieces of the manifold. Most likely the test will be performed after the manifold has been attached to the FDLs. If this is this case it would mean that this would be the last test performed as it would have to come after the flow rate test. The full-scale test could take up to five days if our new system is as good as the original vacuum system. The He leak test would take a couple of days to test the various joints.

4 Risk Analysis and Mitigation

An important step in the design project is accessing the risk of failure that the proposed design has and finding ways to mitigate it. To do this a failure mode and effect analysis (FMEA) was performed on selected design. The finalized FMEA for the design can be seen in Appendix B. Most of the failure modes identified result in failure to maintain vacuum pressure. Some components support the manifold structure and failure could result in loss of vacuum pressure and the collapse of the system.

4.1 Critical Failures

4.1.1 Potential Critical Failure 1: Small Vacuum Leak

Small vacuum leaks are expected for not only the new manifold but also the FDL tanks. The current system requires 24/7 pumping to maintain vacuum pressure of 5 mTorr. We would consider leak rates that maintain operation pressure for 3 days without pumping negligible. Leak rates that lose vacuum pressure sooner than 3 days, and especially audible leaks to be small vacuum leaks. This type of failure is not catastrophic to system health but does require attention. Often improper assembly can be blamed for poor matting connections. It is also not uncommon for an O-Ring to go bad. These types of leaks can be found by listening for air whistling or by seeing frost on vacuum components. Bellows are notorious for frosting around small punctures. The first step is to reseat matting components. Then change O-Ring. If the below is damaged, then replacement is necessary. Mitigation would include proper assembly, clean surfaces before assembly, check for defects before assembly, take special care of fragile hardware such as bellows, O-Rings, matting surfaces, and brass components.

[Provide a brief description of the potential failure here, how that failure could be caused, the effect of the failure, and then discuss how the failure can be mitigated.]

4.1.2 Potential Critical Failure 2: Sudden Vacuum Loss

Suddenly losing vacuum is an unexpected and unlikely event. Regardless this event could happen and poses an extreme safety threat to people and machinery. Sudden vacuum loss could happen during improper operation of valves, if components were flawed before assembly, or if people abuse (climb on, hit, sit, shake) the manifold. Worst case scenario someone is pulled into the vacuum where serious injury or death is plausible. The more likely outcome of sudden vacuum loss is sand/oil blasting of optical components housed inside the FDL tanks. These components can cost thousands of dollars and take time to rebuild and align to the rest of the array. To mitigate this threat the new manifold is designed with large factors of safety, the valves are positioned out of the way of tour groups, and an operations guide will be provided along with the new manifold.

4.1.3 Potential Critical Failure 3: Support Disconnect

Should several companies fail simultaneously it is possible for the main horizontal section of the manifold to fall. This would result in structural loss, broken hardware, and loss of vacuum. This would be an incredibly unlikely event requiring several pipes to disconnect/server, the brass interface to spontaneously fracture, or the bellows to split. Events that could cause this include abuse from operators, neglect during assembly, or running into the manifold with the crane/other large objects. To mitigate this the team has designed in factors of safety, moved the manifold away from the heavy front plates and crane operations, and will be implementing an external support structure.

4.1.4 Potential Critical Failure 4: Electrical Discontinuity

The move to industry standardized electrical connectors should automatically reduce this risk over the existing design. Regardless, internal disconnect could result in loss of control of the optics cart and/or shorting 1000 volts of electricity to the FDL tank. These events pose a threat to the sensitive carts housed in the FDL tanks and to people touching the manifold/FDL tank when the system is turned on. Mitigation includes software control of high-power components, a new wiring harness which allows for regular inspection of connectors, and the new design provides engineers access to the electrical pass through for easy repair especially when compared to the existing system. The proposed new system increased the number of conductors available to engineers which may be used in future projects.

4.2 Risks and Trade-offs Analysis

As identified by the FMEA analysis the majority of the failure modes result in a loss of vacuum and subsequent damage to the optical components on the FDL cart. By nature, the geometric layout of the new manifold is not optimized for flow rete. However, the geometry also directs particles carried by sudden depressurization events into the side walls of the FDL structure. This means particles have a more complex path to colliding with the optical surfaces when compared to the current manifold design.

As discussed above, flow rate optimization is not critical for the success of this manifold. Should flow rate optimization become a requirement the team would most likely increase the risk of damage to the optical components of the system. There is a distinct tradeoff between flow optimization and protection of delicate scientific equipment. There are no plans being made to alter the current design and therefore, at the expense of efficiency, the manifolds inherent design protects the internal systems from failure.

The manifold is designed to operate under static loading conditions. Operation of the manifold is necessary and accomplished by way of high-pressure vacuum valve integrated into the support structure. Operation of these valves changes the pressure loading of the system. Additionally, during physical operation of the valves people may induce unpredictable loading. Some concept variations moved the location of the isolation valves over to one side of the structure. This reduced the opportunity for operators to apply full body weight onto the valve when in contact with the knob. This design was not selected as more components were needed to make it work. The cost and increased number of seals would decrease the overall reliability of the system.

To mitigate failure due to changing pressure loads the system is designed to be statically stable for all loading conditions. Additionally, an external support structure will be implemented. This structure removes loading from the brass interface and is positioned directly under where an operator would interface. This structure reduces the risk of mechanical failure. This structure is also asked to be a mechanism to transfer mechanical vibration. Ideally the support structure would be isolated but without isolation thermal stress and vibration may be imposed onto and though the structure. Evaluation and thoughtful design of the structure must be performed to insure a cohesive fit with the system. Otherwise, this structure could decrease the instrument's performance and ultimately reduce reliability of the new manifolds.

There are several commonly used types of O-Rings used in industry. The Capstone team has selected Viton across the design space. Although the vacuum manifold is not exposed to harsh chemicals or ultra-high vacuum this material is selected for several reasons. Primarily, vacuum seals are used in many locations along the array. Other materials are susceptible to ultraviolet radiation from the sun. If the team were to introduce another O-Ring material, they could become confused with other applications and lead to the failure of another system. Additionally, Viton is a long-lasting solution. This manifold should last 30 years of continual operation without substitution of components. Other materials would be more cost effective for this project, but the risk associated with mixing materials and types of O-Rings into the existing supply surpasses the threshold of tolerance the team has set for a safe and cohesive installation with the existing interferometer systems.

5 DESIGN SELECTED – First Semester

This section contains the details of the final design that the team has chosen to build as well as the plan to implement the design into NPOI.

5.1 Design Description

This final design utilizes the FDL electrical feedthrough located near the front of the FDL tanks. The existing feedthrough screws into a welded shoulder creating a vacuum seal. By utilizing the feed through the team moves the manifold out of the way of other critical operations, improves upon the existing custom electrical components and replaces them with industry standard equipment, and by utilizing industry standard components the new manifold can be integrated with other vacuum systems at NPOI. An isometric view of the entire model is shown in Figure 4. An exploded view on one tank of the model can be seen in Figure 5. In addition to ensure that our model would not interfere with anything built in the FDL room, the majority of the room was modeled and can be seen in Figure 6.

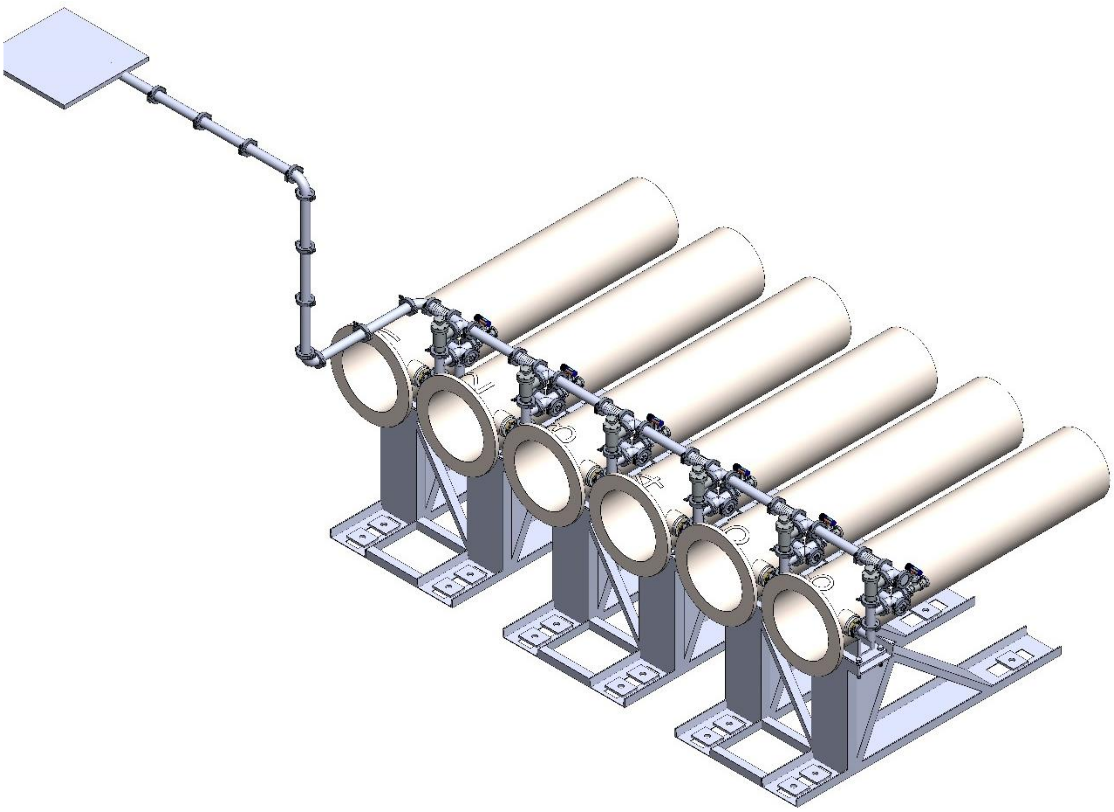


Figure 4: Isometric View of CAD

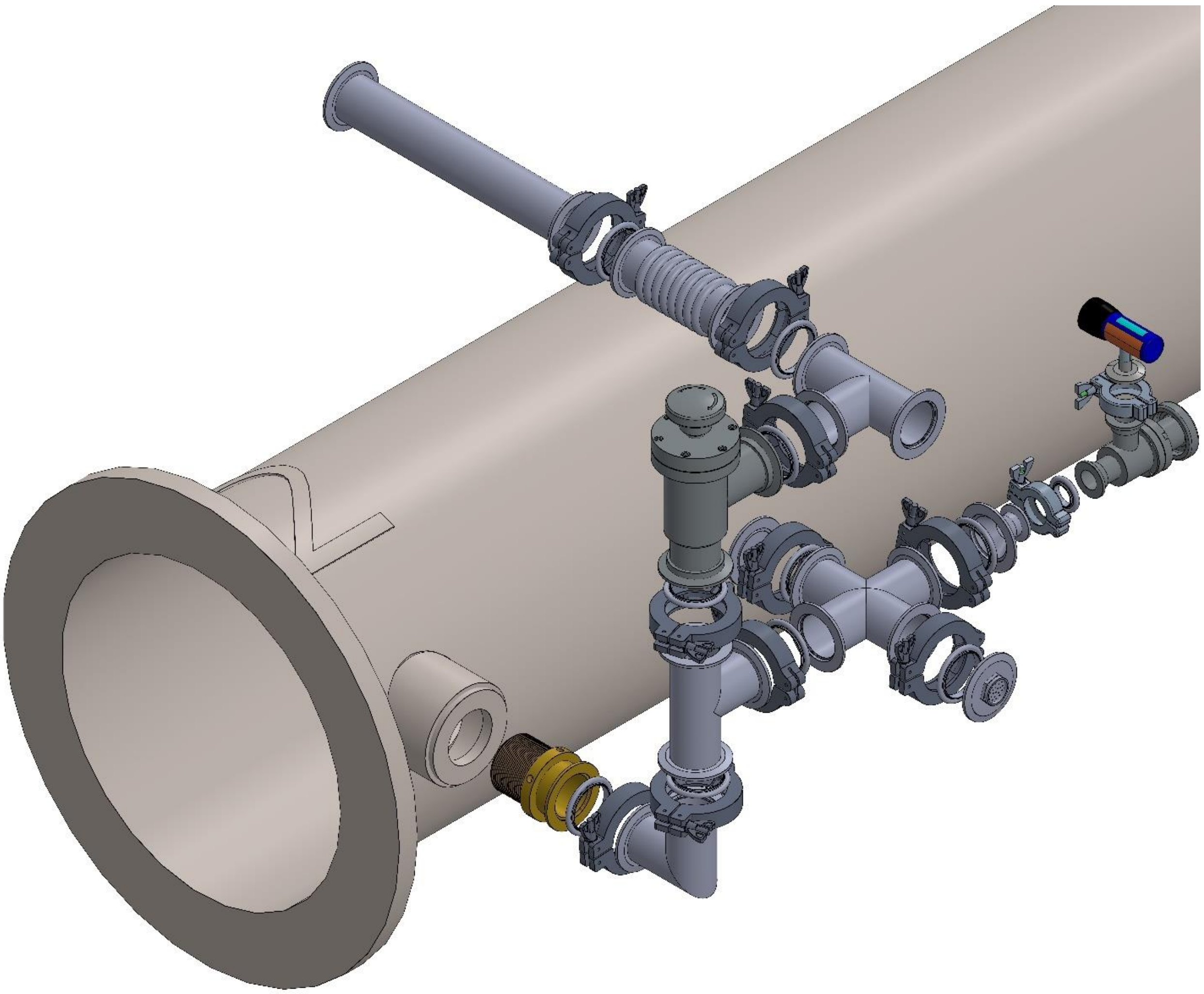


Figure 5: Exploded View of Repeating Section of Manifold

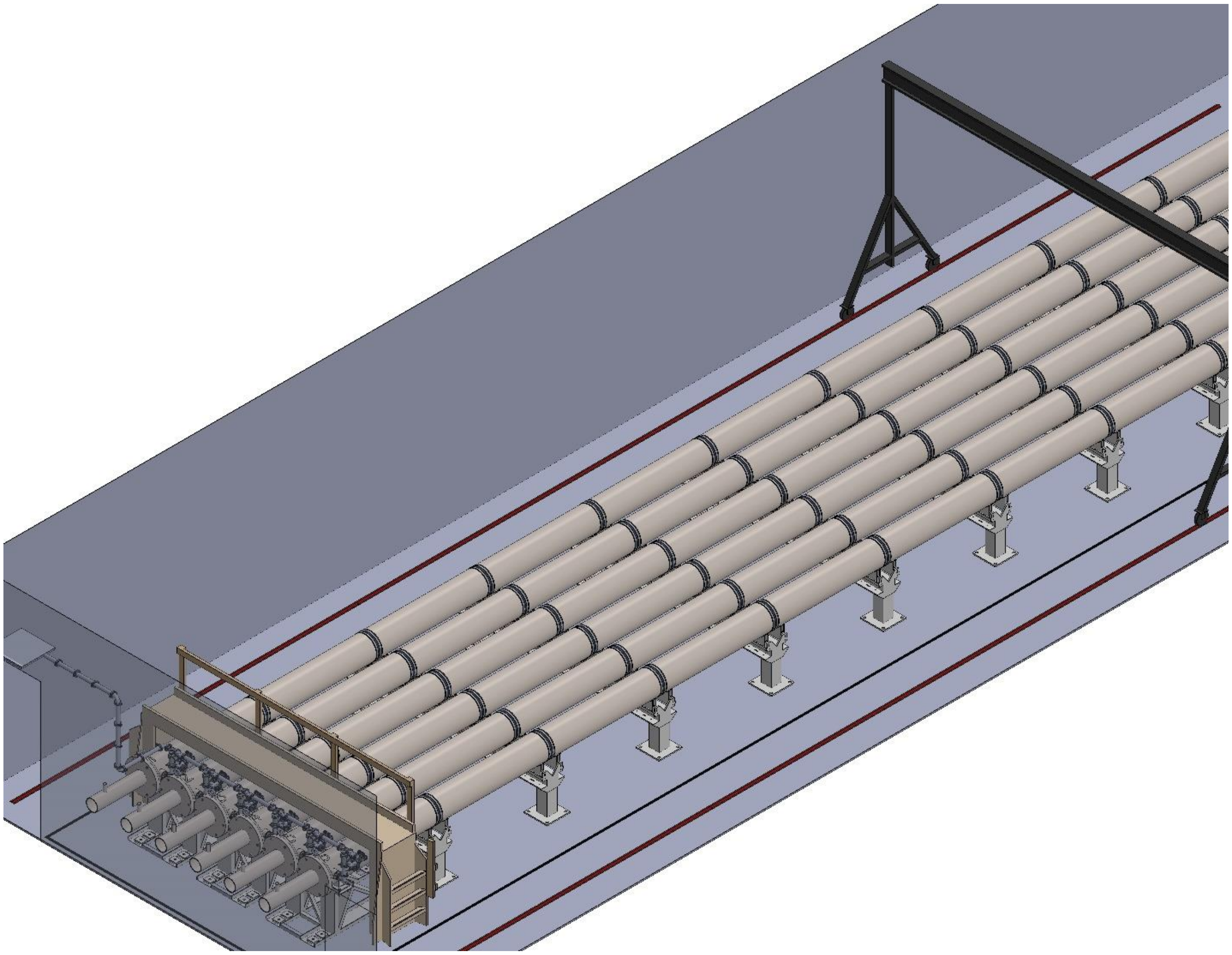


Figure 6: Manifold in Modeled Room

An important part of the design that was changed was the interface that the team is using to connect to the original cable pass through. Due to ordering issues, we investigated new ways of building the part that would allow us to use the brass stock that was available at NPOI. The new design that was created can be seen in Figure 7.

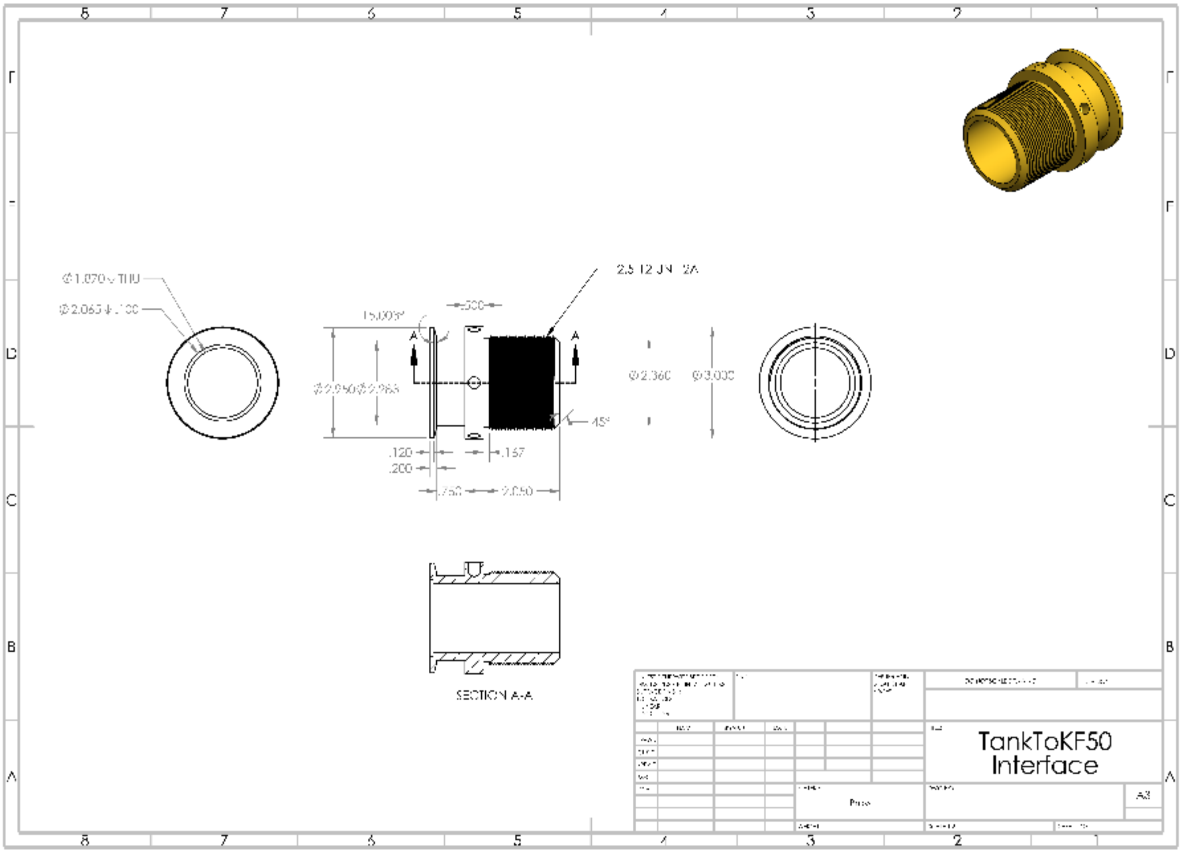


Figure 7: New Ribbon Cable Interface

Using this new information, we made a prototype of the interface which is shown in Figure 8.

Figure 8: Prototype of Interface

To ensure that this interface works with the standardized parts that we are using for the rest of the manifold we tested connecting it to a spare piece of pipe at NPOI as well as a nut with the corresponding threads. The nut is important as the classification for the threaded connection is 2A (a lose but not sloppy fit) and the nut allows us to hold the work piece in the lathe during the manufacturing prosses. The results are shown in Figure

Figure 9: Testing Interface Prototype

All other engineering drawings can be seen in Appendix C.

5.2 Implementation Plan

The final implementation of the design will be a first article functional prototype. Due to budget and time restrictions the team will only produce one iteration of functional hardware to be implemented at the NPOI. System integration will be a time consuming prosses which will require the array to come offline for approximately 1-2 weeks. To minimize downtime the team will have all components on hand and as many preassembled sections as logistically feasible.

The new manifold system will be constructed primarily from Kurt J. Lesker hardware, the current list of ordered components can be seen in Appendix E. Additional hardware is required to mate to the existing vacuum pumps. By ordering from a known company, the team has reduced the number of custom parts, the complexity of design, and increased the reliability of hardware. Most components are made from stainless steel. The custom team interface will be manufactured by members of the Capstone team.

Originally, the team planned to outsource the manufacture of these components, but budget restrictions required in-house manufacture. Brass is used to eliminate seizing when threading into the stainless steel FDL tank.

Budget and time are the limiting factors to design alteration. The team is working with detailed SolidWorks modes of the proposed system along with the client to ensure the new manifold will integrate without significant interruption to the NPOI mission. The utilization of CAD is the primary resource during the development of the new vacuum manifold. Additional tooling includes but is not limited to: physical space for pre-and-final assembly at NPOI; machine tools at NAU and NPOI for interface component; supply of material such as brass and steel to make manifold components sourced from NPOI stock and McMaster; FEA for design evaluation and optimization built into SolidWorks; 3D printer for in hand prototyping located at students' homes; the client, engineers, and technicians' input for design ergonomics and flaw identification. The team notes many of the components and raw material are being sourced from NPOI stockpile and will not affect the budget. Thus far the team has presented information to the class assuming the team would be responsible for sourcing all the necessary hardware. Fortunately, regular meetings with the client and NPOI project managers have allowed the team access to necessary resources.

As stated in prior sections the original plan was to start assembly late November and early December. Due to global supply chain issues the assembly of the new manifold will take place at the start of next semester. Assuming all parts are on hand the team will plan to start assembly week 2 of being back to school. Assuming one week of assembly and an additional week of pumping down by week 4 the new manifold will be in place. During this time the team will work to calibrate pressure sensors and collect data regarding system performance. Much of this project is optimized over current working conditions and therefore a series of maintenance tests will be performed in week 5 and 6 to understand the ergonomics of the new system. To accompany the new manifold the team will construct a user manual and operations guide. This will be developed once the new system is in place. The client has requested, if time permits, alterations to additional sections of the FDL system. Assuming the team can stay on track, the additional projects could serve as supplemental to the ongoing data analysis and system performance evaluation of the new vacuum manifold. The remainder of the semester will be focused on meeting Capstone requirements and compilation of our work into a master engineering document to be provided to the client and as testimonial to our work toward degrees in Mechanical Engineering.

6 CONCLUSIONS

This Capstone team is charged with developing and implementing a new vacuum manifold system to interface with the Navy Precision Optical Interferometer Fast Delay Line system. The new manifold is responsible for maintaining vacuum pressure 24/7 of the FDL system and will be used by engineers, scientists, and technicians thought its service life. The new manifold will replace the existing failing manifold and will work to increase safety for personnel and improve quality of science produced by the NPOI.

This report showcases the completed work of the NPOI Capstone team thus far in the semester. The scale and scope of the project mandates the continuation of work into the second semester. Outlines of the work to be completed are also provided in this report and the approximate timeline for the work to be completed.

The initial goal of the project was to assemble a working prototype at NPOI by the end of first semester. Delays in shipping because of global supply chain disruptions have delayed the construction of the prototype to the second semester.

The technical and financial challenges associated with physical testing of individual components is not within the scope of the project. Theoretical analysis of subcomponents will substitute for physical evaluation. Theoretical analysis includes FEA simulation which allows the team to optimize component design and selection.

To further increase the reliability of the system a failure mode analysis was performed for each of the systems subcomponents. This analysis was used to make stronger design choices and optimize safety and reliability while staying within the prescribed budget. Only a few critical components have the potential of total system collapse. The evaluation indicates total system failure to be an extremely unlikely event and shows the new manifold will perform better than the existing system. The other most common failure mode is loss of vacuum. At every interface between components exists the possibility of vacuum loss. The most common mode of failure is slow leak which may be a result of incorrect installation or faulty components. Should a component fail suddenly there exists the potential of system blowback damaging the optical components inside the FDL system. To combat this unlikely event the new manifolds geometry is such that spray would be directed to the walls of the tank rather than directly at the optical components.

The final design utilizes industry standard components for the main structure. A custom interface replacing the current ribbon cable connection is utilized for both pulling the vacuum and the electrical connection. This interface is being made by the team members on manual machine tools and will be constructed from brass to allow for a lubricant free threaded connection with the FDL tanks. The replacement of the ribbon cable increases system reliability as the new electrical connection will utilize industry standard vacuum rated connections. By moving the manifold interface to the side of the FDL tanks we decrease down time for regular maintenance by not needing to dismantle part of the manifold. Six isolation valves are used to compartmentalize each tank so maintenance can be performed on one tank without affecting the rest. Additional valves are used to isolate the pressure sensors so they can be calibrated without disrupting system operations.

7 REFERENCES

[1] Wyatt Clark, “ME 476 Project Proposal.” Flagstaff, Az., Jul. 2021.

[2] “Kurt J. Lesker Company | Enabling Technology for a Better World | Vacuum Science Is Our Business.” https://www.lesker.com/index.cfm (accessed Nov. 13, 2021).

APPENDICES

7.1 Appendix A: House of Quality

House Of Quality		Factors of Saftey {1}	Manufactureing Lead Time {2}	Project Cost {3}	Smaller Pump Flow Rate {4}	Main Pump Flow Rate {5}	Minimize downtime {6}	Leak Rate {7}	Customer Competitive Assessment: 1 Worst	2	3	4	5 Best
Improvement Direction		*	↓	↓	*	*	↑	↑					
Customer Requirements (Design Requirements)	Importance												
Safty	9	9	1	9					A			BD	C
Cost	3	9	9	9			1	3		C	ABD		
Ease of use	3			1	3	9	3			AC	BD		
Relyability	9	9		3			3	9		A		BC	
Repairability	9	1	1	3			9	1	A	C	BD		
Longjevity	3	9	1	3	1			3		A		BCD	
Furture project intagration	1		1	3		1	1			ABCD			
Technical Importance: Absolute		147	34	102	28	81	84	96					
Technical Importance: Relative		35%	8%	27%	1%	4%	19%	7%					
Target Value		2.5±.5	28±3	10K±4K	2.1	350	2±1	≤5					
Units		N/A	Days	US$	m^3/hr	m^3/hr	hr	mTorr/Day					
Design Competitive Assessment	Worst: 1			C			A						
	2		A										
	3	BD	BCD	ABD			BCD	ABD					
	4	A			AD	ABD							
	Best: 5	C			BC	C		C					

Key	
Original	A
VTT	B
LIGO	C
SST	D

7.2 Appendix B: Failure Mode and Effect Analysis

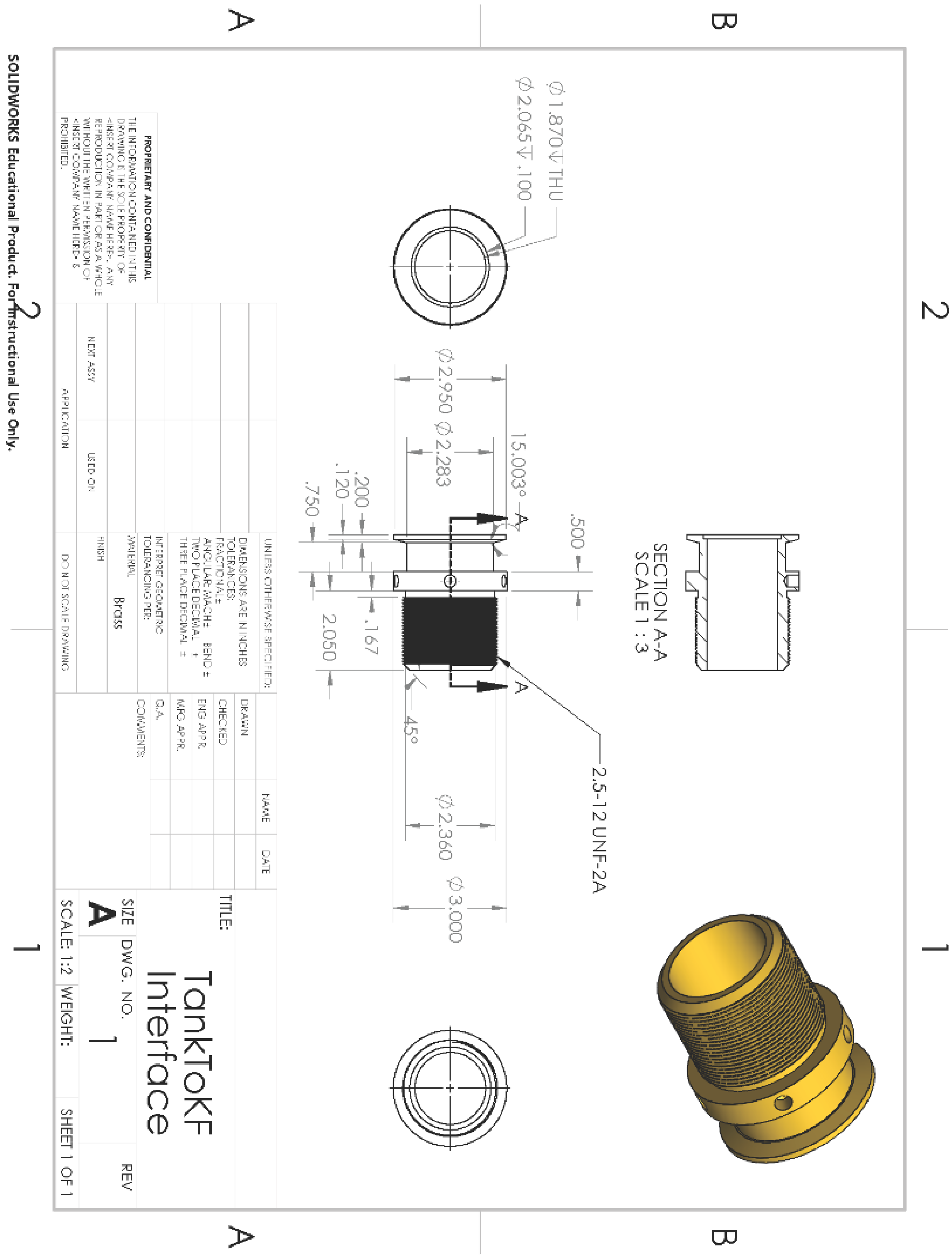
Product Name		Development Team: Alex McClinton, Cydny Clark, Wyatt Clark					Page No of			
System Name							FMEA Number			
Subsystem Name							Date			
Component Name										
Part # and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Severity (S)	Potential Causes and Mechanisms of Failure	Occurrence (O)	Current Design Controls Test	Detection (D)	RPN	Recommended Action
1 "Interface"	Thermal Fatigue, Stress Fracture, Pressure vessel callops, Max bending stress exceded	Loss of vacuum, Destruction of optical componates	10	Poor design, Assembly error, User error, Fatigue loading	1	Use *He* leak test to determine rate of leak. Visual and auditory inspection.	5	50	Replace seal and O-Ring.If no improvement replace complete componate.
QF50-200E90M "Miter 90 Elbow"	Scratched matting surface	Loss of vacuum, Destruction of optical componates, damage to manifold	8	Manufactureing defect, Impropor handaling of hardware	1	Use *He* leak test to determine rate of leak. Visual and auditory inspection.	5	40	Replace O-Ring(s).If no improvement replace complete componate.
QF50-200-ARV "Centering Ring Al Viton"	UV/thermal/age/chemical degridation, scratch/cut, not proporly tightened -> tearing	Loss of vacuum, Destruction of optical componates	4	Manufactureing defect, Impropor handaling of hardware, environmental	2	Use *He* leak test to determine rate of leak. Visual and auditory inspection.	4	32	Replace O-Ring(s).
QF50-200-C "Al Clamp"	Over tighten, hinge failure	No QF seal, Loss of vacuum	4	Manufactureing defect, Impropor handaling of hardware, environmental, load cycles	2	Visual	5	40	Replace Clamp
QF50-200-T "SS Tee"	Scratched matting surface	Loss of vacuum, Destruction of optical componates, damage to manifold	8	Manufactureing defect, Impropor handaling of hardware	1	Use *He* leak test to determine rate of leak. Visual and auditory inspection.	5	40	Replace O-Ring(s).If no improvement replace complete componate.
QF50-200-X "SS 4-way Cross"	Scratched matting surface	Loss of vacuum, Destruction of optical componates, damage to manifold	8	Manufactureing defect, Impropor handaling of hardware	1	Use *He* leak test to determine rate of leak. Visual and auditory inspection.	5	40	Replace O-Ring(s).If no improvement replace complete componate.
QF50XQF25C "SS Reducing Full Nipple"	Scratched matting surface	Loss of vacuum, Destruction of optical componates, damage to manifold	8	Manufactureing defect, Impropor handaling of hardware	1	Use *He* leak test to determine rate of leak. Visual and auditory inspection.	5	40	Replace O-Ring(s).If no improvement replace complete componate.

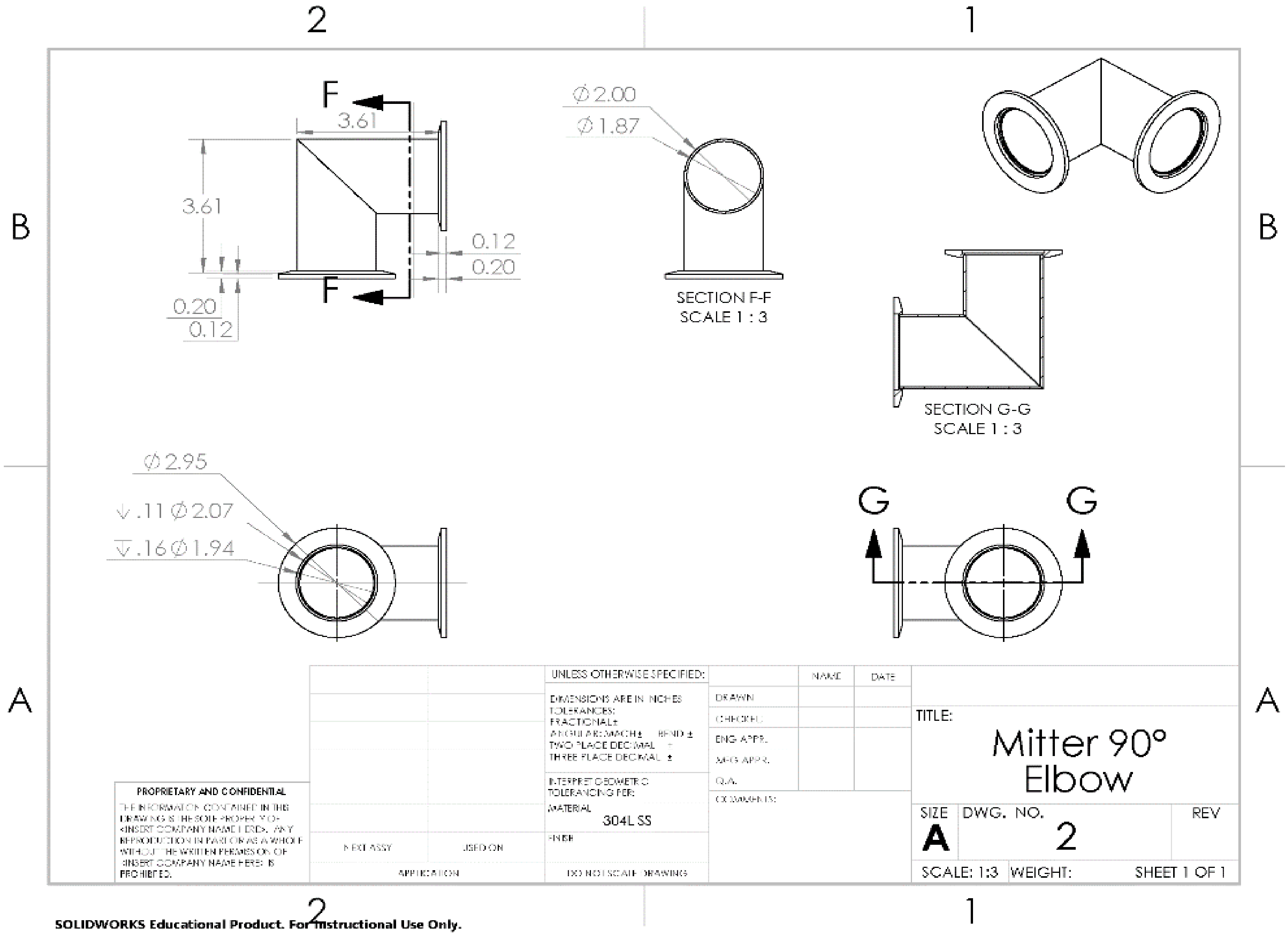
WF25-100-SRV "SS Centering Ring 25mm"	UV/thermal/age/chemical degridation, scratch/cut, not proporly tightened -> tearing	Loss of vacuum, Destruction of optical componates	4	Manufactureing defect, Impropor handaling of hardware, environmental	2	Use *He* leak test to determine rate of leak. Visual and auditory inspection.	4	32	Replace O-Ring(s).
QF25-100-C "Al Clamp 25mm"	Over tighten, hinge falure	No QF seal, Loss of vacuum	4	Manufactureing defect, Impropor handaling of hardware, environmental, load cycles	2	Visual	5	40	Replace Clamp
SA0100MVQF "SS RT Angle Valve"	Scratched matting surface, Damage the diaphram, Lubercant depletion	Loss of vacuum, Destruction of optical componates, damage to manifold, damage to sensor	8	Manufactureing defect, Impropor handaling of hardware, Impropor maintnance	2	Use *He* leak test to determine rate of leak. Visual and auditory inspection.	5	80	Replace O-Ring(s). Lubercate. If no improvement replace complete componate.
KJL275196 "VAC Gauge"	Not calibrated, exposure to fluid, electrical malfunction, scratched matting surface, age	Loss of vacuum, Destruction of optical componates, damage to manifold, incorect emergency shutoff of system	5	Manufactureing defect, Impropor handaling of hardware, Impropor maintnance	3	Use *He* leak test to determine rate of leak. Visual and auditory inspection. Strange calibration results/readings	5	75	Replace O-Ring(s). Calibrate. If no improvement replace complete componate.
SA0200MVQF "SS RT Angle Valve"	Scratched matting surface, Damage the diaphram, Lubercant depletion	Loss of vacuum, Destruction of optical componates, damage to manifold, damage to sensor	8	Manufactureing defect, Impropor handaling of hardware, Impropor maintnance	2	Use *He* leak test to determine rate of leak. Visual and auditory inspection.	5	80	Replace O-Ring(s). Lubercate. If no improvement replace complete componate.
QF50-200-SB "Blanking Plate SS"	Scratched matting surface	Loss of vacuum, Destruction of optical componates	7	Manufactureing defect, Impropor handaling of hardware, environmental	2	Use *He* leak test to determine rate of leak. Visual and auditory inspection.	5	70	Replace O-Ring(s).If no improvement replace complete componate.
MH-QF-D06 "6" Bellows SS Thin"	Scratched matting surface, puncture wall	Loss of vacuum, Destruction of optical componates, collaps of manifold, human casualty	8	Manufactureing defect, Impropor handaling of hardware, environmental	2	Use *He* leak test to determine rate of leak. Visual and auditory inspection. Look for Ice.	5	80	Replace O-Ring(s).If no improvement replace complete componate.
QF50-200-NL "12.6" SS"	Scratched matting surface	Loss of vacuum, Destruction of optical componates, damage to manifold	8	Manufactureing defect, Impropor handaling of hardware, environmental	1	Use *He* leak test to determine rate of leak. Visual and auditory inspection.	5	40	Replace O-Ring(s).If no improvement replace complete componate.

8 Appendix C: Bill of Materials

Item Name	Price (USD)	Quantity	Total Price (USD)	Source
3in DiaBrass Stock (3.75in segments)	0	6	0	NPOI
TankToKF50 Interface	0	6	0	Machined by team with NPOI equipment
Mitter 90° Elbow	96	6	576	Kurt J Lesker
Centering Ring QF 50	12	61	732	Kurt J Lesker
Centering Ring QF 50	0	11	0	NPOI
QF 50 Clamp	17	61	1037	Kurt J Lesker
QF 50 Clamp	0	11	0	NPOI
Tee Pipe	146	12	1752	Kurt J Lesker
Cross Pipe	220	6	1320	Kurt J Lesker
KF50To25 Reducer	81	6	486	Kurt J Lesker
Centering Ring QF 25	9	6	54	Kurt J Lesker
QF 25 Clamp	9	12	108	Kurt J Lesker
QF 25 Pressure Valve	355	6	2010	Kurt J Lesker
Pressure Sensor	175	6	1050	Kurt J Lesker
QF 50 Pressure Valve	0	6	0	NPOI
Blanking Plate QF 50	20	13	260	Kurt J Lesker
6in Bellows	123	6	738	Kurt J Lesker
12.6in Pipe	89	13	1157	Kurt J Lesker
90° Elbow	95	3	285	Kurt J Lesker
Blanking Plate Feedthrough	0	12	0	Machined by team with NPOI equipment
Total	11565			

9 Appendix D: Engineering Drawings





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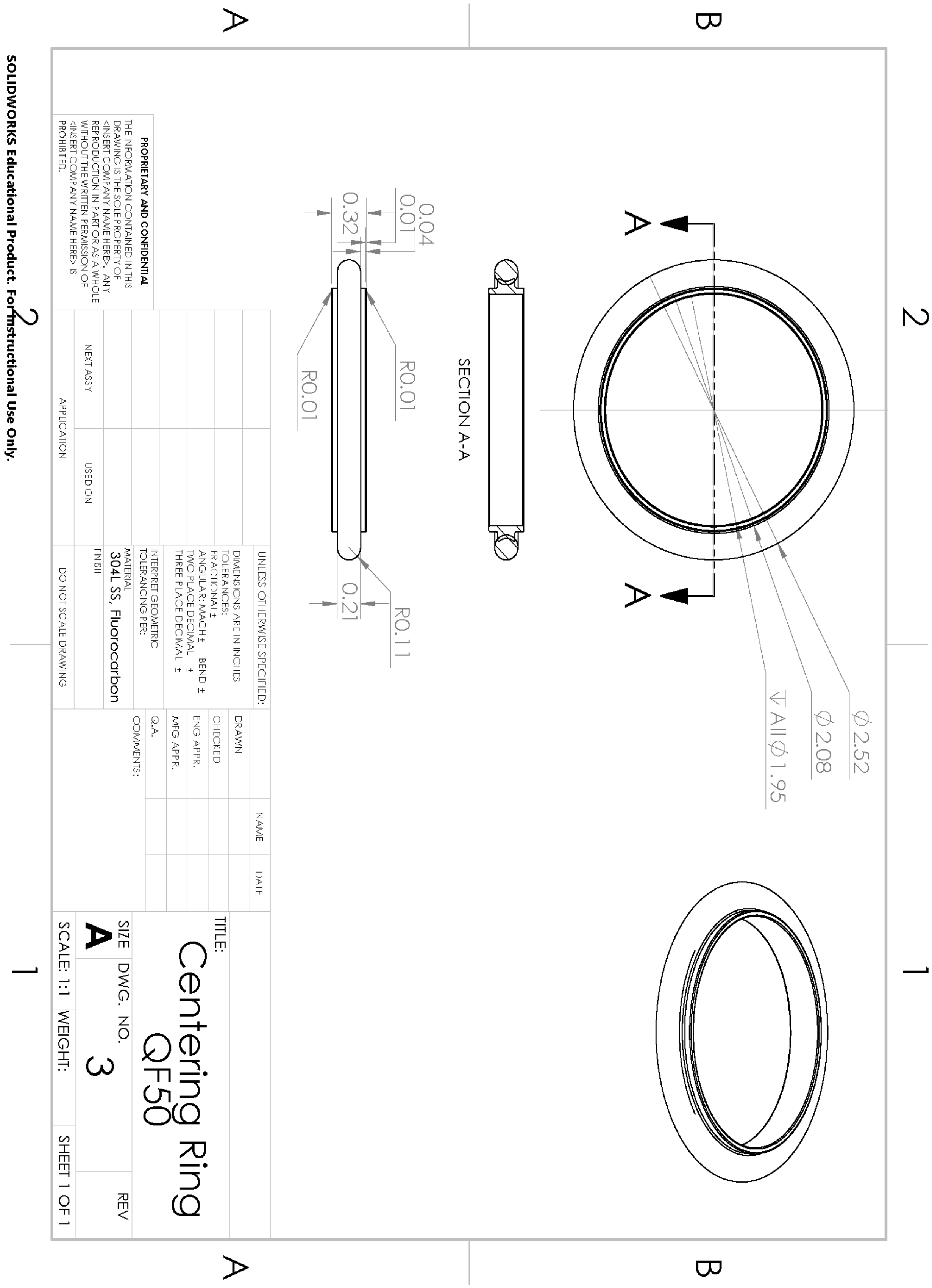
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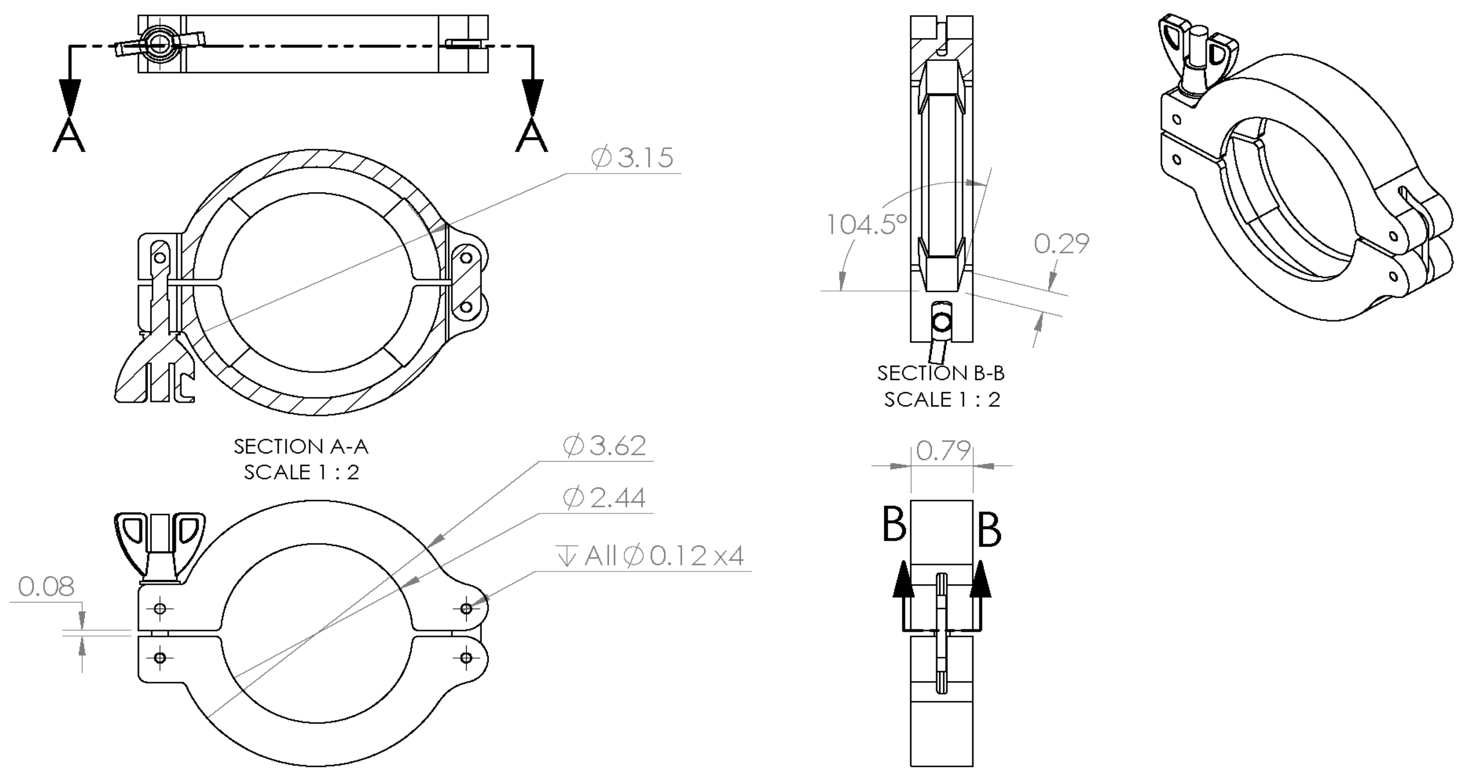

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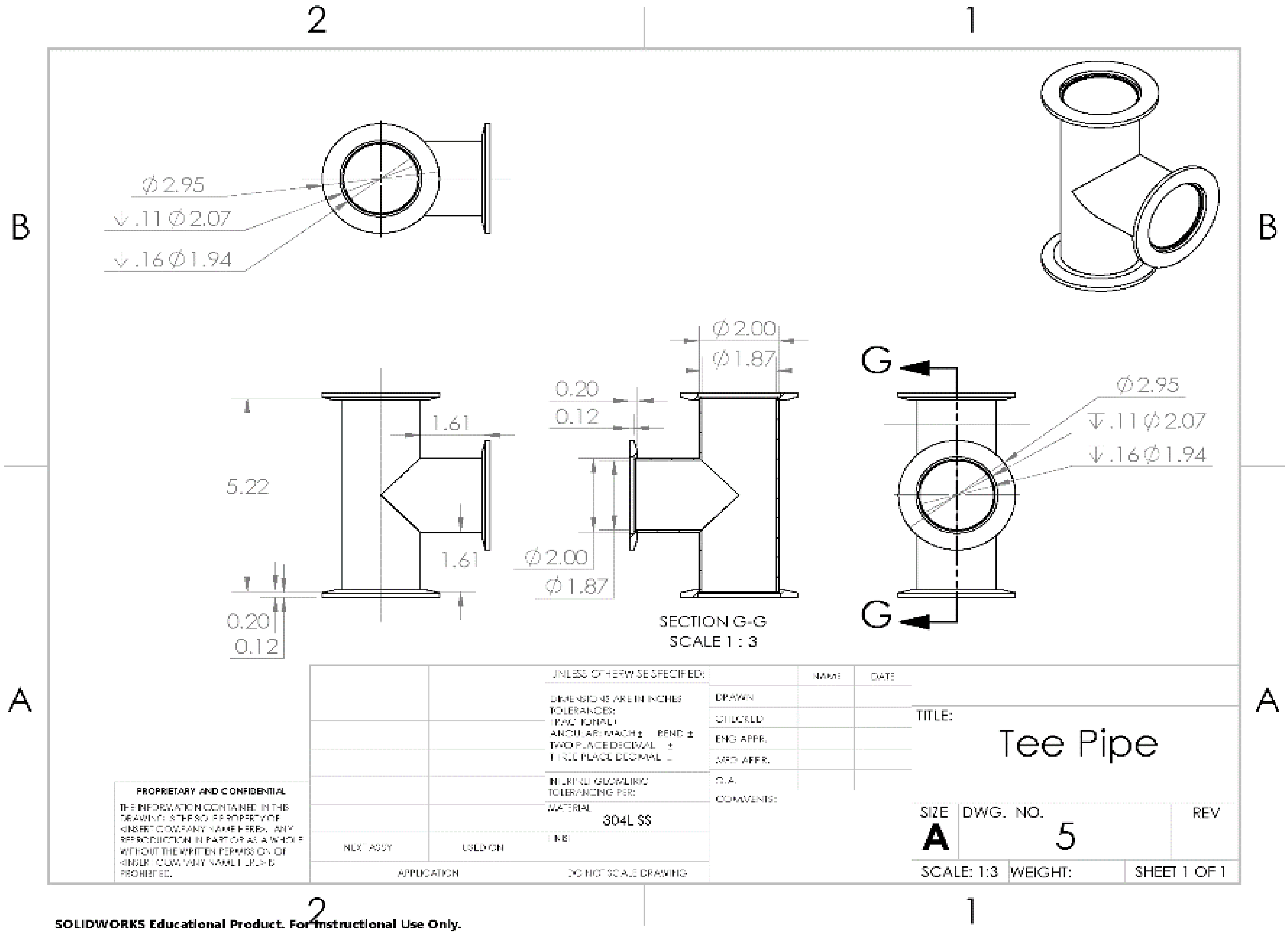
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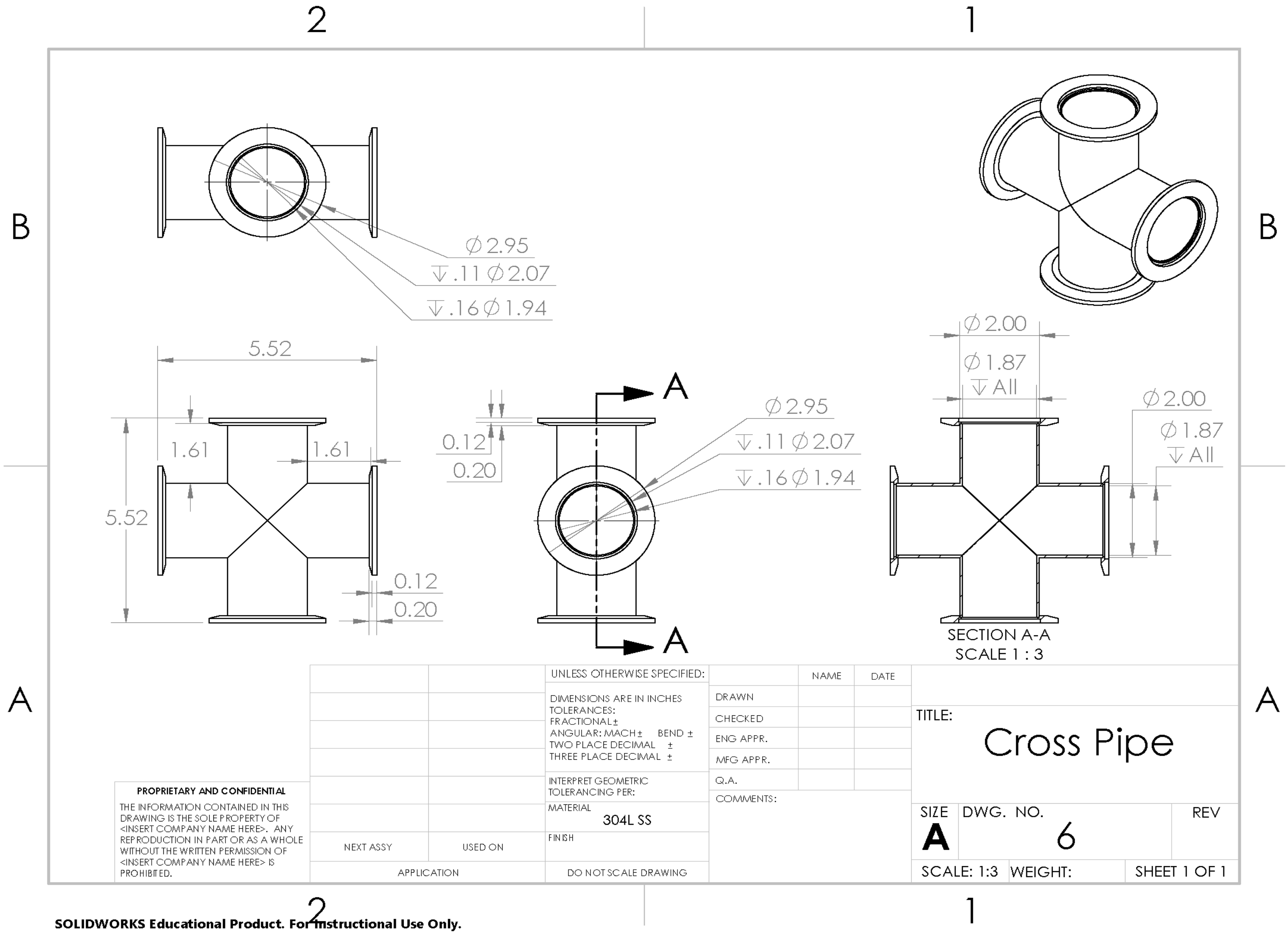
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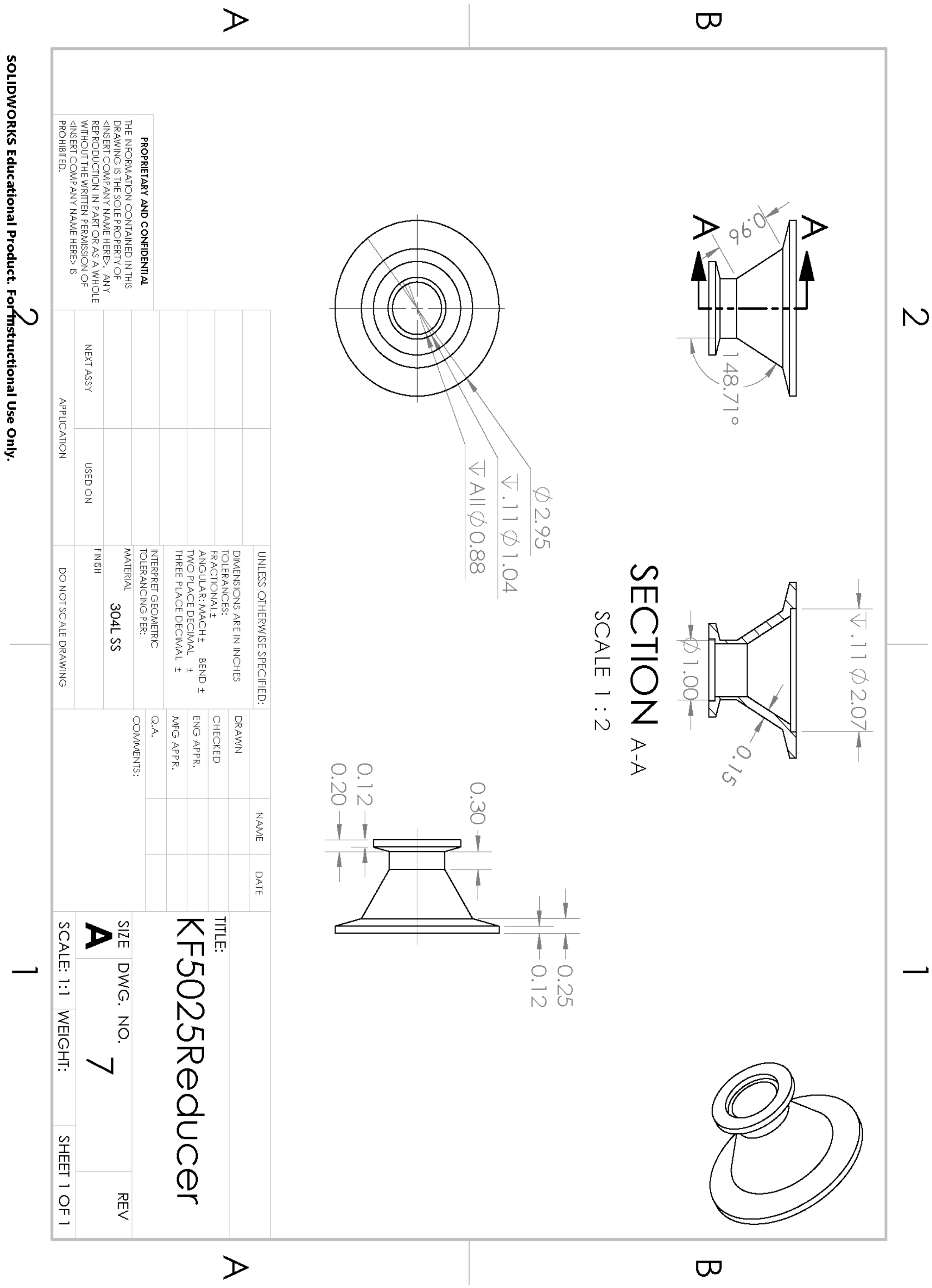

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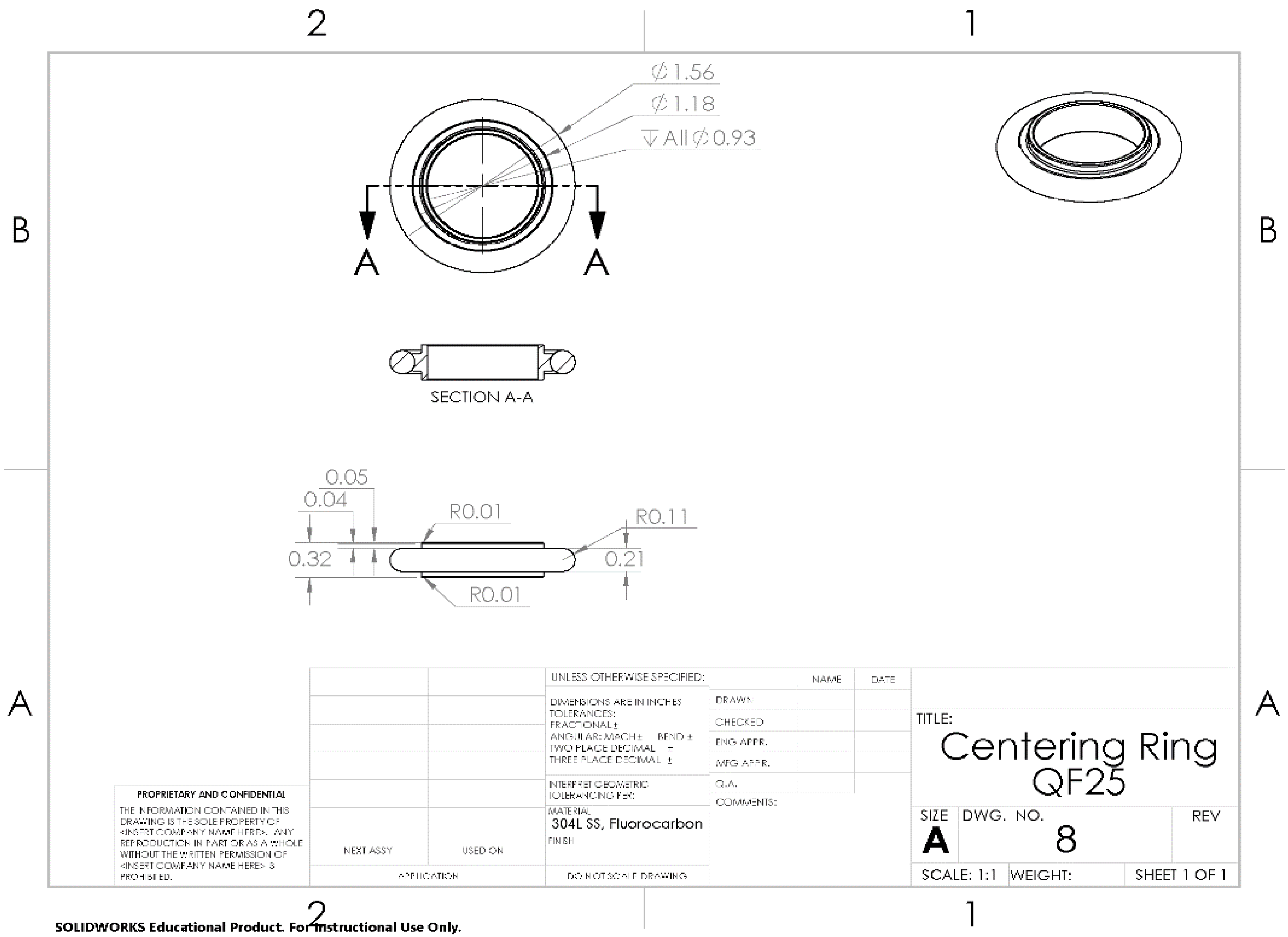
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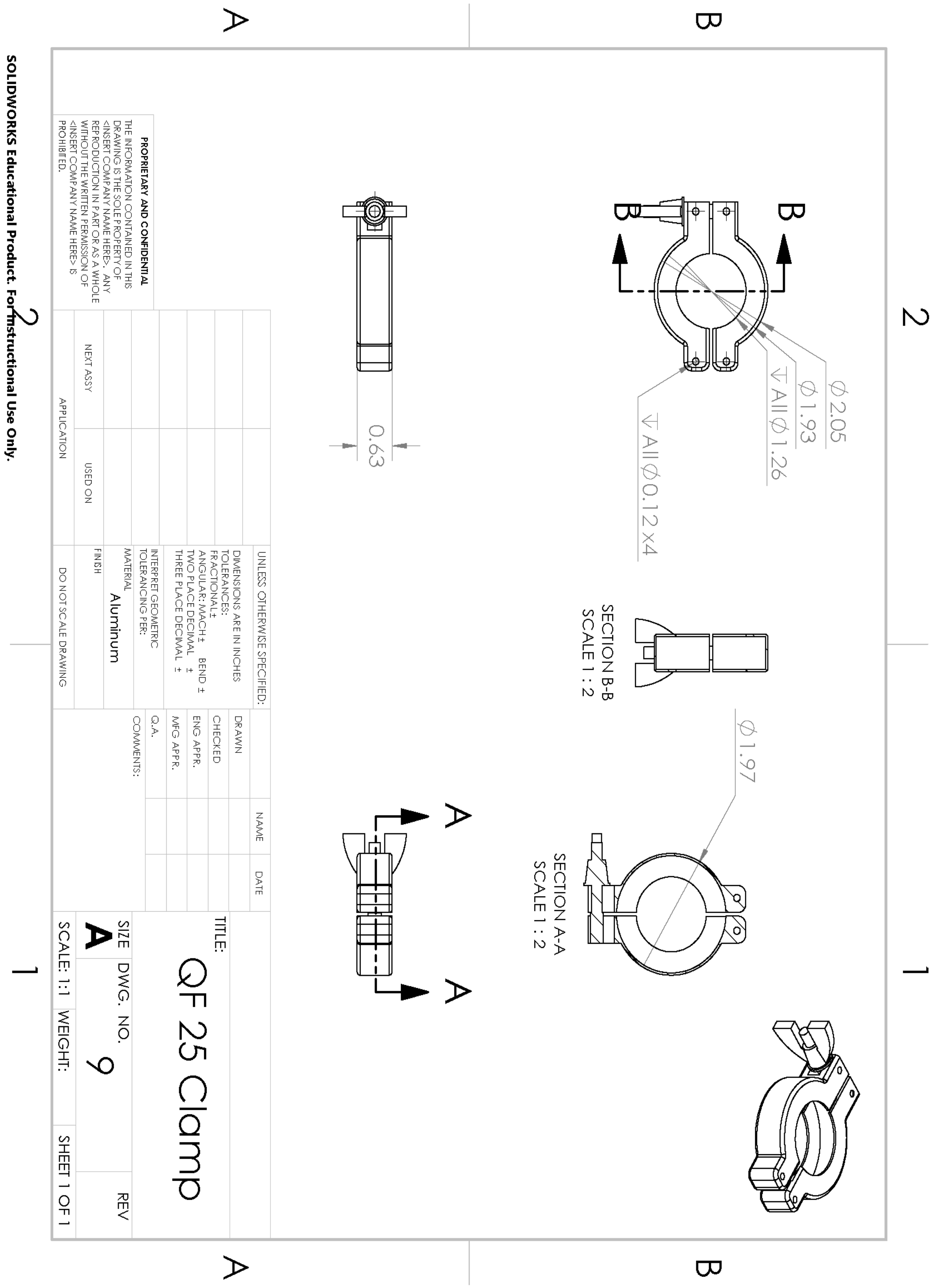
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Centering Ring
QF25
SIZE
A
DWG. NO.
8
REV
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1
SOLIDWORKS Educational Product. For Instructional Use Only.



⌀2.05
⌀1.93
↧ All ⌀1.26
↧ All ⌀0.12 x4
B
B
SECTION B-B
SCALE 1 : 2
⌀1.97
SECTION A-A
SCALE 1 : 2
0.63
A
A
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Aluminum
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
QF 25 Clamp
SIZE
A
DWG. NO.
9
REV
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1
NEXT ASSY
USED ON
APPLICATION
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.
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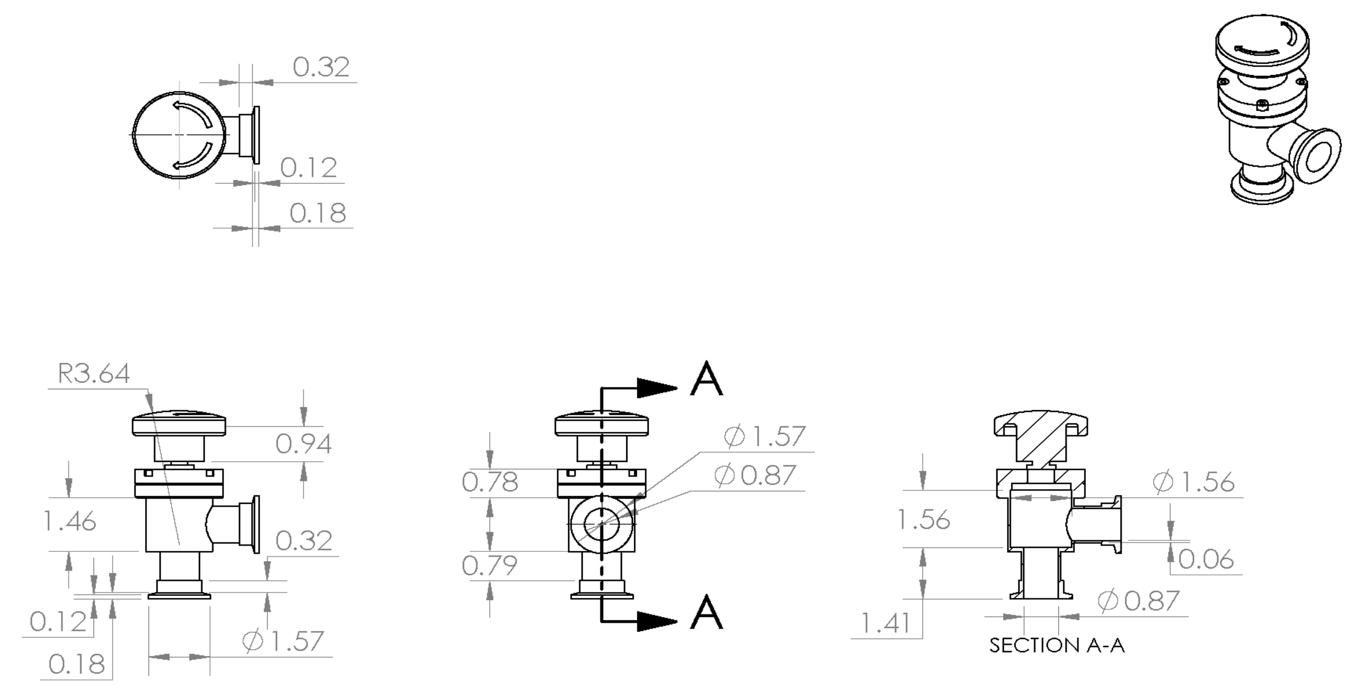

		UNLESS OTHERWISE SPECIFIED:		NAME	DATE
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL± ANGULAR: MACH± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN		
			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL 304L SS	COMMENTS:		
NEXT ASSY	USED ON	FINISH			
APPLICATION		DO NOT SCALE DRAWING			

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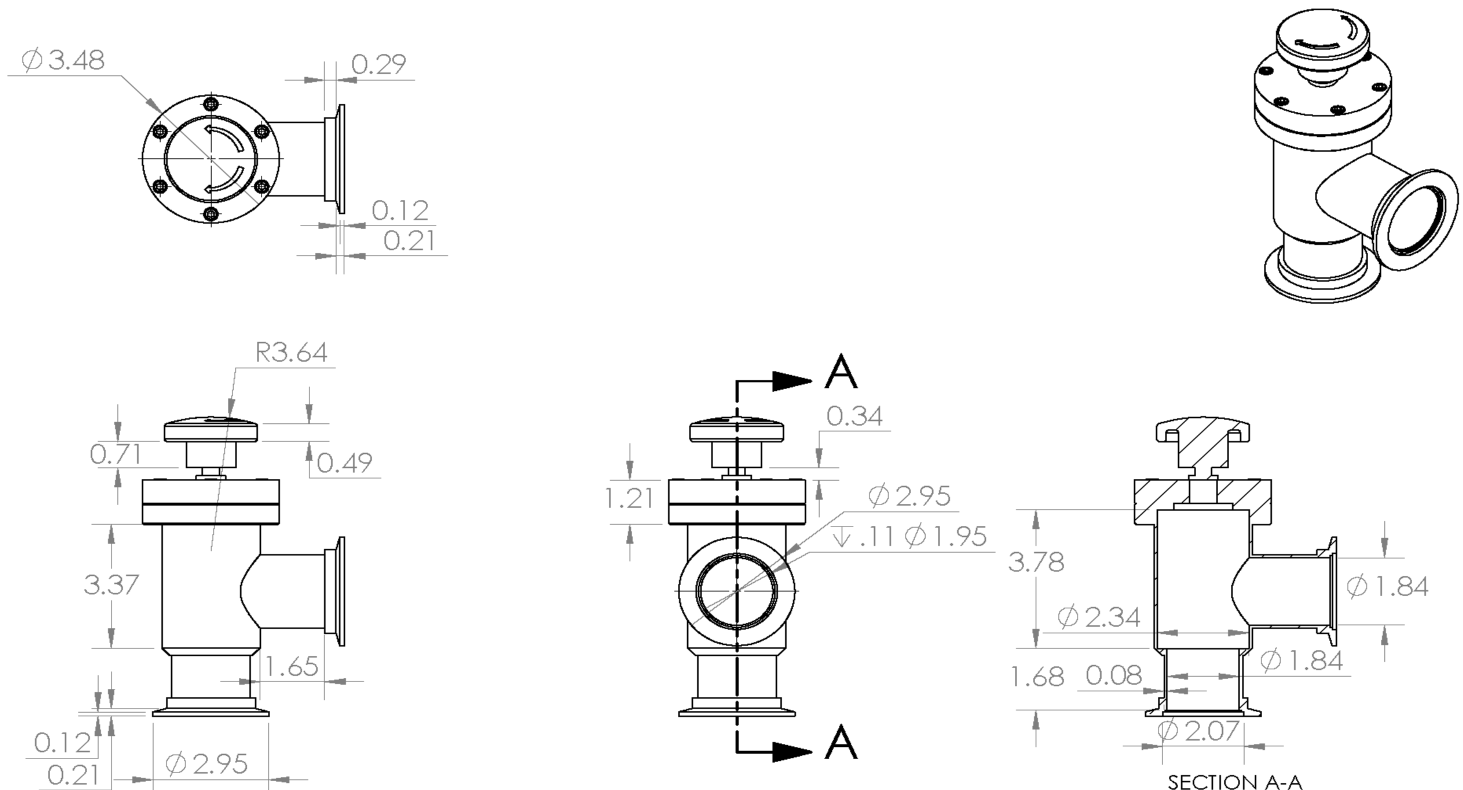
TITLE:

QF 25 Pressure Valve

SIZE	DWG. NO.	REV
A	10	
SCALE: 1:4	WEIGHT:	SHEET 1 OF 1



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NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL 304L SS

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

QF 50 Pressure Valve

SIZE	DWG. NO.	REV
A	12	

SCALE: 1:4 WEIGHT: SHEET 1 OF 1

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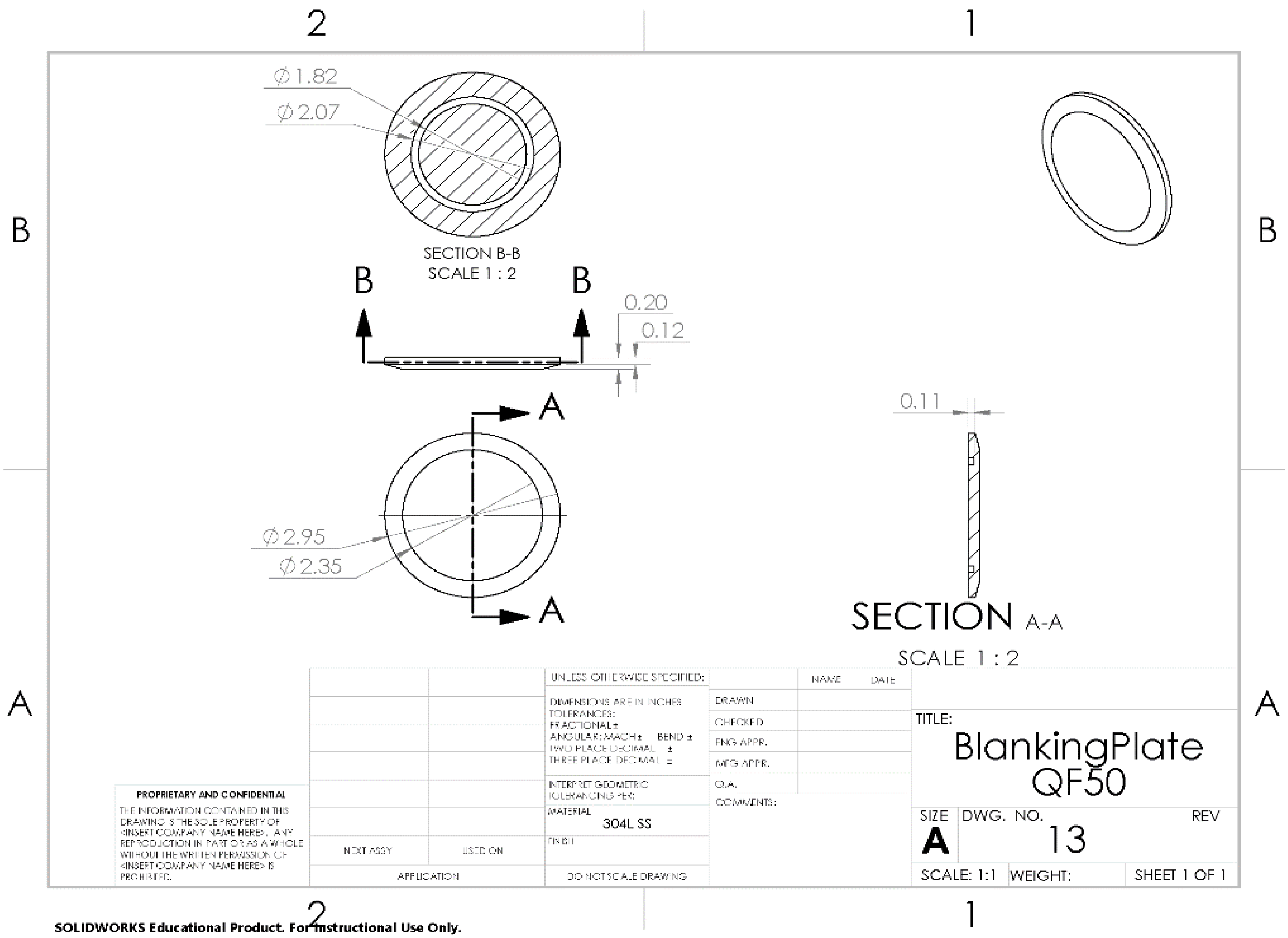

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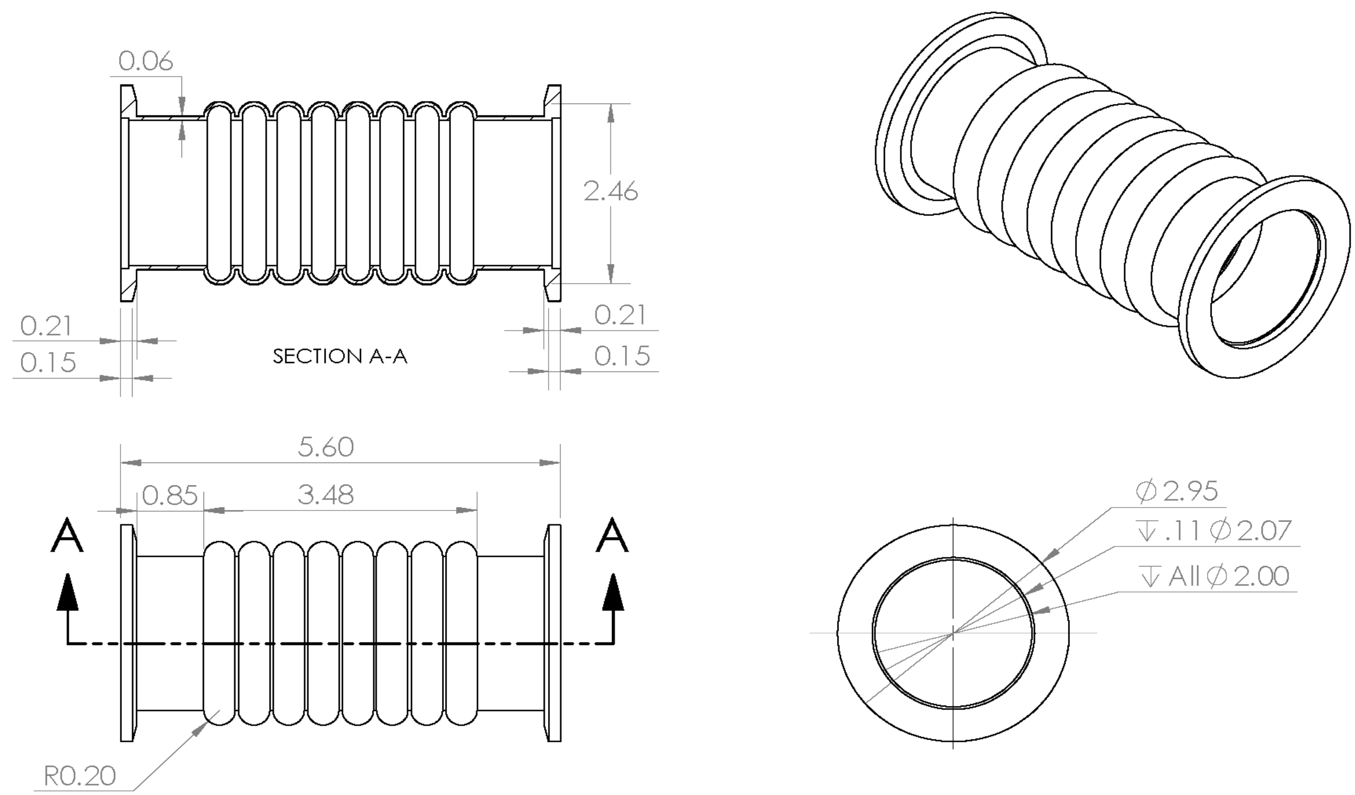

UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN			TITLE: 6in Bellows
	CHECKED			
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL 304L SS	COMMENTS:			SIZE A · DWG. NO. 14 · REV
FINISH				
DO NOT SCALE DRAWING				SCALE: 1:2 · WEIGHT: · SHEET 1 OF 1

NEXT ASSY	USED ON
APPLICATION	

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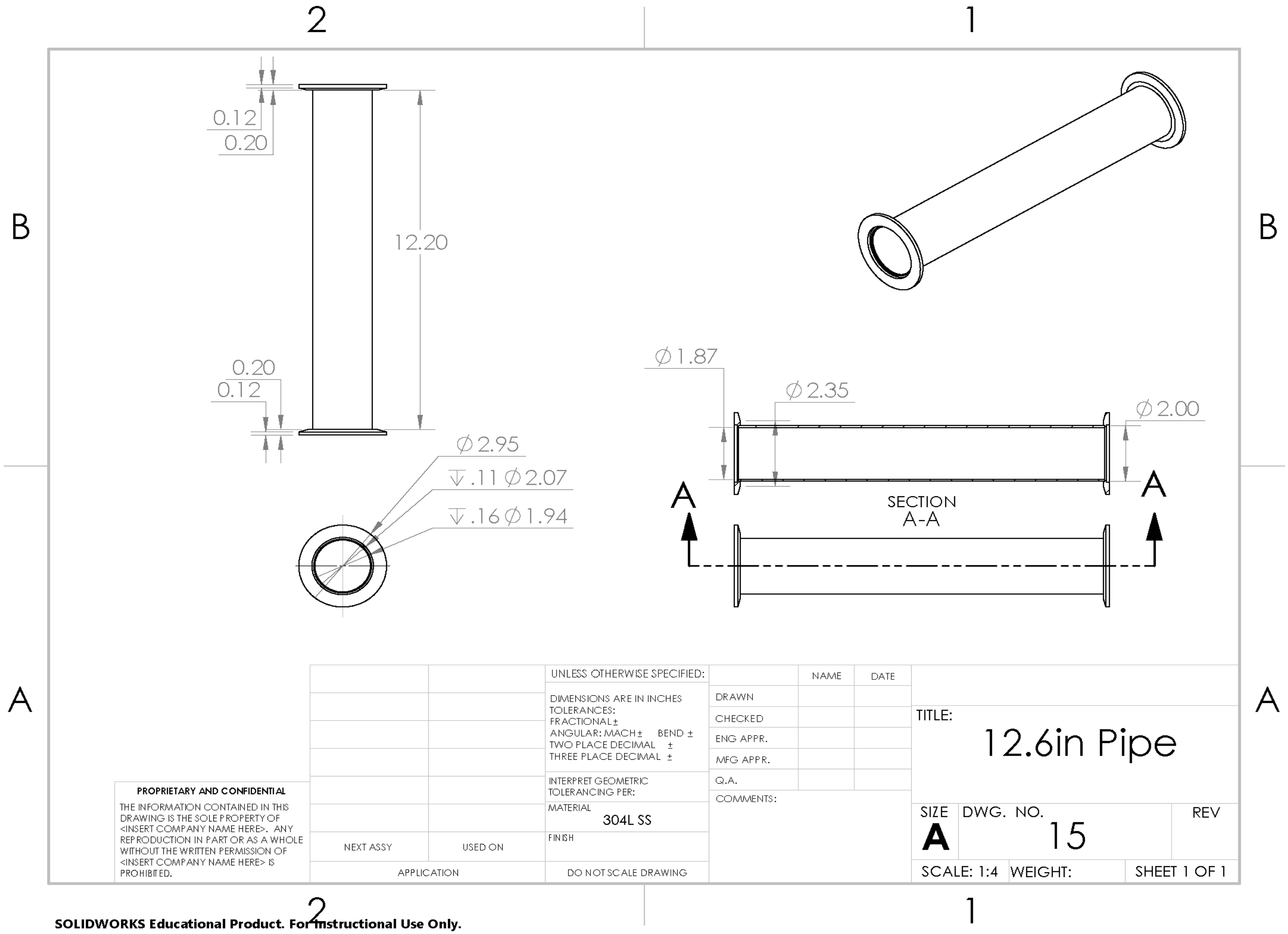
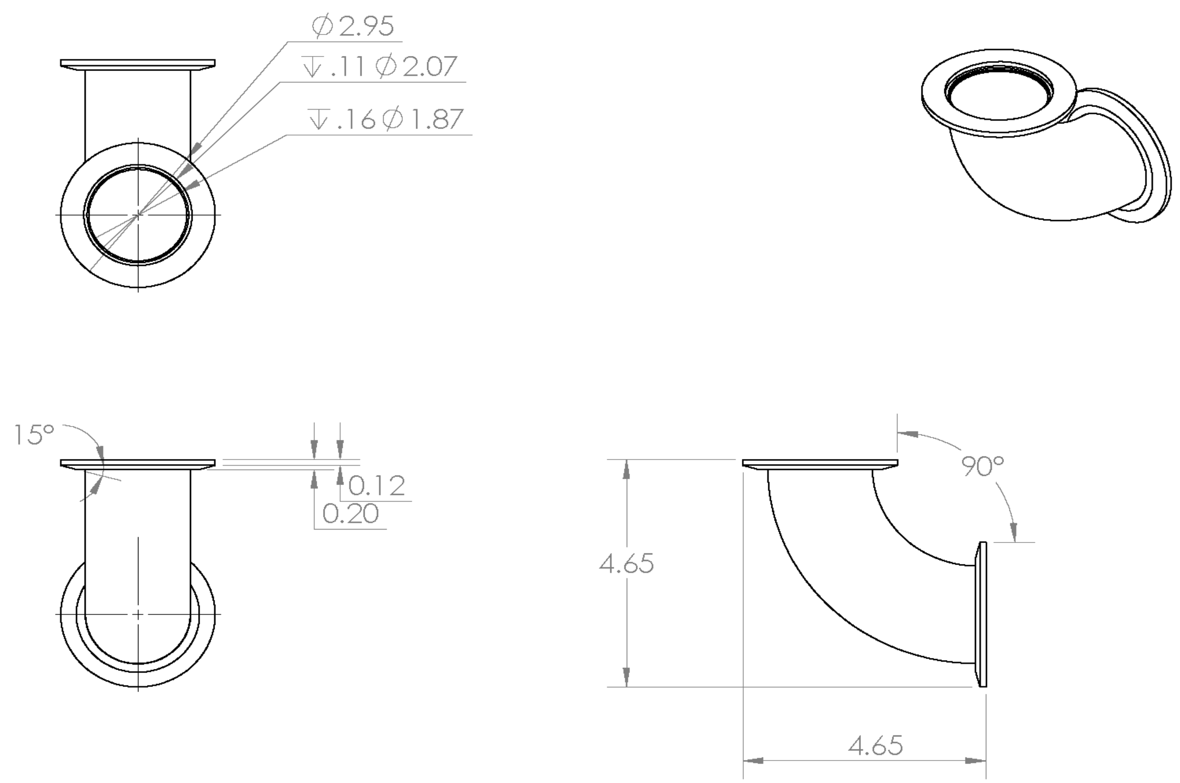


SOLIDWORKS Educational Product. For Instructional Use Only.



		UNLESS OTHERWISE SPECIFIED:		NAME	DATE
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL± ANGULAR: MACH± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN		
			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL 304L SS	COMMENTS:		
NEXT ASSY	USED ON	FINISH			
APPLICATION		DO NOT SCALE DRAWING			

TITLE: 90° Elbow

SIZE A | DWG. NO. 16 | REV

SCALE: 1:2 | WEIGHT: | SHEET 1 OF 1

10 Appendix E: Kurt J. Lesker Order Confirmation

Kurt J. Lesker Company

Confirmation

Order number SO10-0047026-1
Date 9 Nov 2021

Kurt J. Lesker Company
1925 Route 51
Jefferson Hills, PA 15025
United States

Toll free number	0014123879200
Telephone	0014123879200
Fax	
Internet address	www.lesker.com
E-mail	sales@lesker.com
Federal tax ID	25-1193626

Remit to:
Check: P.O. Box 951677, Cleveland, OH 44193
ACH: PNC Bank, ABA 043000096, Account 1135830997
Wire TT: PNC Bank, 500 First Avenue, Pittsburgh, PA 15219 USA
SWIFT: PNCCUS33, Account 1135830997
Remittance Advice to: AR@lesker.com
Telephone: +1 (800) 245 1656

Invoice to:
Lowell Observatory
1400 W Mars Hill Rd
Flagstaff, AZ 86001
United States

Ship to:
Lowell Observatory
David Noble / NPOI
1400 W Mars Hill Rd
Flagstaff, AZ 86001
United States

Order contact	Accounts Payable, 928.774.3358, purchasing@lowell.edu
Sales contact	Mike Valentich, 412-387-9032, michaelv@lesker.com

Order number	SO10-0047026-1
Customer PO Number	26944
Customer	C108047
Date	09 Nov 2021
Payment terms	Net 30 days
Mode of delivery	UPS-Ground
Terms of delivery	FOB Shipping Point - Prepay & Add
Currency	USD

Quantity	Unit	Item number description	Availability	Backorder qty	Unit price	Amount	Estimated shipment date
12.00	EA	SKU0140104 QF50-200-T EUDF-SUPP TEE,SS,QF50 FLGS,2"OD TUBE, "A"-2.76". **Item commodity code:** 7307.29.0000 **ECCN code:** 2B999K	In Stock		146.15	1,753.80	11/10/2021
6.00	EA	SKU0140111 QF50-200-X EUDF-SUPP CROSS,4-WAY,SS,QF50 FLGS,2"OD TUBE,"A"-2.76". **Item commodity code:** 7307.29.0000 **ECCN code:** 2B999K	4 Weeks	6.00	219.70	1,318.20	12/6/2021
30.00	EA	SKU0140065 QF50-200-C EUDF-SUPP CLAMP,ALUMINUM,QF50,CAST 2" **Item commodity code:** 7616.99.5195 **ECCN code:** 2B999K	Stock 1-2 Day Delivery	27.00	16.60	498.00	11/10/2021
6.00	EA	SKU0140092 QF50-200E90M EUDF-SUPP ELBOW,90 DEG,MITRED,SS,QF50 FLGS,2"OD TUBE,"A"-2.76". **Item commodity code:** 7307.29.0000 **ECCN code:** 2B999K	11 Weeks	2.00	96.40	578.40	1/24/2022

Continued on next page

The Kurt J. Lesker Company is a Woman Owned and Operated ISO:9001 certified Small Business.

Kurt J. Lesker Company

Confirmation

Order number SO10-0047026-1
Date 9 Nov 2021

Quantity	Unit	Item number description	Availability	Backorder qty	Unit price	Amount	Estimated shipment date
6.00	EA	SKU0134464	In Stock		123.30	739.80	11/10/2021

MH-QF-D06
EUDF-SUPP FLEX HOSE,SS,6"OAL,QF50 FLGS, 2"ID,.012"WALL
Item commodity code: 8307.10.0000
ECCN code: 2B999K

Quantity	Unit	Item number description	Availability	Backorder qty	Unit price	Amount	Estimated shipment date
61.00	EA	SKU0140060	In Stock		12.25	747.25	11/10/2021

QF50-200-ARV
EUDF-SUPP CENTERING RING,ALUM,QF50,FKM
Item commodity code: 7609.00.0000
ECCN code: 2B999K

Quantity	Unit	Item number description	Availability	Backorder qty	Unit price	Amount	Estimated shipment date
6.00	EA	SKU0140185	In Stock		80.80	484.80	11/10/2021

QF50XQF25C
EUDF-SUPP REDUCING FULL NIPPLE,CONICAL, SS,QF50 TO QF25
Item commodity code: 7307.29.0000
ECCN code: 2B999K

Quantity	Unit	Item number description	Availability	Backorder qty	Unit price	Amount	Estimated shipment date
6.00	EA	SKU0140081	15 Weeks	6.00	89.10	534.60	2/21/2022

QF50-200-NL
EUDF-SUPP NIPPLE,SS,LONG,QF50 FLGS,2"OD TUBE,"A"-12.60".
Item commodity code: 7307.29.0000
ECCN code: 2B999K

Quantity	Unit	Item number description	Availability	Backorder qty	Unit price	Amount	Estimated shipment date
6.00	EA	SKU0144899	In Stock		335.00	2,010.00	11/10/2021

SA0100MVQF
EUDF-SUPP RT ANGLE VALVE, SS, QF25 FLG, MANUAL, 1" PORT, FKM SEALED
Item commodity code: 8481.80.3090
ECCN code: 2B999K

Quantity	Unit	Item number description	Availability	Backorder qty	Unit price	Amount	Estimated shipment date
6.00	EA	SKU0139650	In Stock		8.80	52.80	11/10/2021

QF25-100-C
EUDF-SUPP CLAMP,ALUMINUM,QF25,CAST 1"
Item commodity code: 7616.99.5195
ECCN code: 2B999K

Quantity	Unit	Item number description	Availability	Backorder qty	Unit price	Amount	Estimated shipment date
6.00	EA	SKU0139689	In Stock		8.80	52.80	11/10/2021

QF25-100-SRV
EUDF-SUPP CENTERING RING,SS,QF25,FKM
Item commodity code: 7307.29.0000
ECCN code: 2B999K

Quantity	Unit	Item number description	Availability	Backorder qty	Unit price	Amount	Estimated shipment date
6.00	EA	SKU0129225	7-8 Weeks	6.00	175.00	1,050.00	12/28/2021

Continued on next page

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Kurt J. Lesker Company

Confirmation

Order number SO10-0047026-1
Date 9 Nov 2021

KJL275196
GAUGE, CONVECTRON EQUIVALENT, 10E-4 TO 1000 TORR, KF25, INTERCONNECT CABLE SOLD SEPERATELY
Item commodity code: 9026.20.0000
ECCN code: EAR99

Miscellaneous charges

Code	Description	Amount
HND	Handling	50.00
	Misc. charges value	50.00

Notes

Sales balance:	USD	9,820.45
Misc. charges:	USD	50.00
Sales tax:	USD	901.61
Total:	**USD**	**10,772.06**

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