NAU Mixing Valve

Final Proposal

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2020

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DISCLAIMER

EXECUTIVE SUMMARY

General Atomics is currently using a mixing valve that is 144 pounds. NAU Mixing Valve Team has a goal to reduce the weight of the valve by 96 pounds to 48 pounds. This can be done by reducing the outlet diameter from 4 inches to 3 inches which will reduce material used, General Atomics already reduced the weight by 36 pounds by removing unnecessary flanges, and finally the greatest weight saving step is to change the material the valve is made from steel to titanium.

Titanium is about half as dense as steel is. Steel has a density, depending on the alloy, of about 8 grams per cubic centimeter. Titanium has a density, again depending on the alloy of 4.05 grams per cubic centimeter, density and weight are directly proportional so by switching the largest parts of the valve, that do not need to be welded, to titanium, this will dramatically reduce the weight. On top of reducing weight titanium is significantly less corrosive than steel. Corrosion is a big cause for concern with mixing valves because of the quickly moving fluids inside of the valve. Titanium is stronger than steel, however it is also much more expensive than steel, so it does need to be used judiciously.

The parts that are the best candidates for a material change are parts 4,5,8,9 and 10 from the bill of materials included in the appendix of this report. These parts make good candidates because they are large, so switching them to titanium will save a good amount of weight and they do not need to be welded to anything. Welding metals to a different kind of metal, I.e. steel to titanium does not work, so it needs to be fastened some other way, as we are not changing all parts of the valve to titanium, and our valve needs to fit the current actuator that General Atomics is using.

The requirements for our valve are discussed below in greater detail, but are as follows: The valve needs to pass a proof testing of 185psig, ideally under 36 pounds, stay under a maximum pressure drop of 8psi, and have two inlet flow rates and one outlet flow rates with an ability to change temperature quickly to accommodate the changing conditions of the working fluid.

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1 BACKGROUND

1.1 Introduction Summer

The NAU valve team is redesigning a valve for General Atomics. The goal of the project is to reduce the weight of the valve by 96 lbs in total. General Atomics reduced the weight by 36 lbs and we need to reduce it by an additional 60 lbs. This can be done by replacing the material of the valve, removing flanges and thinning out the walls of the valve as well as switching to the 3 inch outflow valve.

1.2 Project Description

The project is to create a mixing valve for General Atomics with two flow rates as inlets and one flow rate as the outlet. General Atomics is currently using an Armstrong valve and the NAU mixing valve team is trying to dramatically reduce the weight. The team has spent time researching the complications of switching 5 parts of the valve to titanium, and we have come up with solutions to allow us to switch the heaviest parts to titanium.

The following is from the project statement given by General Atomics:

Requirements:

1. Max operational internal fluid pressure = 125 PSIG

2. Proof tested to 185 psig with no deformation

4. Maximum pressure drop 8 psid at a given flow rate.

5. Balanced port design, constant flow through out valve swing

6. Set points programmable from a hotter temperature to a lower temperature

7. Allowable materials = Electropolished Stainless Steel 316L, descaled Titanium (Specs available from GA)

9. Allowable polymers = Viton, Teflon

10. Fluid connections per 21F02, 10F21 Hydraflow drawings

11. Design may use EMECH/Armstrong G1 actuator or other design

13. If alternate actuator is selected, power and interfaces must be same as the G1 unit

A lot of the values are proprietary and confidential, so some of the values were taken out of the project statement given the terms of the NDA. The project deliverables

2 REQUIREMENTS

This section discusses the requirements the team has considered as customer requirements and engineering requirements given by the client, General Atomics. The functional decomposition of the mixing valve will also be discussed, which includes the black box model, functional model and house of quality diagram. The code and regulations that are needed to complete this project are also discussed at the end of this section.

2.1 Customer Requirements (CRs)

Five customer requirements have been determined in order for the mixing valve project to be successful. All requirements must be met, if one requirement fails, so does the team. A failure can result in a total system loss, including more than the mixing valve component and must be avoided at all costs. These requirements are listed in order in the table shown below.

Table 1: Customer Requirements

	Customer Requirement
1	Cost Within Budget
2	Durable and Robust Design
3	Reliable Design
4	Safe to Operate
5	Work With Actuator

The first customer requirement is to remain under the $2500 budget. For the project to be successful all cost resources used to include machine costs, materials and any unforeseen problems must remain below this limit. Any dollar amount above the $2500 limit will result in a failure and the mixing valve will need to be redesigned and the objective is failed.

The next customer requirement involves the design being durable and robust. Meaning that a durable design must be able to withstand wear, pressure and damage. For the design to be robust, the design must be sturdy and strong. If the design can’t withstand the durability conditions or fails any robust conditions, then the design will fail. If the design fails under these requirements, then so does the main objective of reducing the weight of the mixing valve. This leads into the third customer requirement, reliable design.

The mixing valve must be reliable to use, meaning the material quality is good and so is performance, otherwise no one will need it. The valve must be trusted to ensure engineering requirements, shown in the next section, to complete the task it’s needed for. This requirement ensures that the original mixing valve conditions are met, and the weight reduction objective will be successful.

Operation safety is the fourth customer requirement and is necessary, so operators or bystanders don't get hurt. This is a critical requirement, so persons don't get hurt and lawsuits are avoided. Any loss of life will be tragic, and a lawsuit will put the design extremely over budget. If this was to occur both the operation safety and budget requirements failed, along with the objective. Safety factors will be calculated for all aspects of the mixing valve to ensure the safety of anyone nearby.

The last requirement, the actuator must be compatible with the mixing valve, also ensures the main objective is met. The current mixing valve is compatible with the actuator and will continue to be with the redesign proposal. If the actuator is not compatible with the mixing valve proposal, then the it will need to be redesigned. All in all, the actuator must be compatible with the mixing valve so it can be implemented in General Atomics projects.

2.2 Engineering Requirements (ERs)

Engineering requirements have been provided/expected by the client, General Atomics. These engineering requirements can be seen in the table below and are discussed in more detail within this section. These requirements are essential to the functionality of the mixing valve device and all must be met with equal or greater expectations. This table consist of two columns, the first is the engineering requirement and the second column quantifies that engineering requirement. Some values are not displayed due to confidentiality reasons and don't have a value/substance in the table, which is shown below in Table 2.

Table 2: Engineering Requirements

Engineering Requirement	Quantifiable Value/Substance
Weight Reduction	96 lbs
Max Operational Internal Pressure	*Value Not Displayed*
Max Tested Internal Pressure	*Value Not Displayed*
Outlet Fluid Temperature Accuracy	*Value Not Displayed*
Allowable Materials	Electropolished Stainless Steel 316L
	Descaled Titanium
Operational Fluids	Water
	Fluid Not Displayed
	Fluid Not Displayed
	Fluid Not Displayed
Allowable Polymers	Viton
	Teflon
Flow Rate	*Value Not Displayed*

The first requirement is the weight reduction of the mixing valve. This is one of the main goals for this project and therefore was placed on the top of the table, shown above. The team must reduce the mixing valve by a minimum of 96 pounds to accomplish this requirement. The client, General Atomics, needs a lightweight mixing valve for various programs to meet system level requirements. General Atomics currently uses an Armstrong mixing valve weighing 144 pounds, but in order to meet new system requirements, the team must reduce this weight to a minimum of 48 pounds. The device must still operate as expected with no deformations from the modifications proposed by the team. Meaning that the reliability and durability must not be compromised by these modifications, or the device fails.

The second requirement listed is the max operating internal pressure. This operational internal pressure is the pressure that the internal fluids experience within the main chamber of the mixing valve. The current operational internal pressure is **value not displayed** PSI in gauge pressure. Meaning the device pressure gauge ignores atmospheric pressure and represents an atmospheric pressure with a value of zero. This requirement is another essential aspect to ensure that the durability of the device does not fail, and reliability of the device does not decrease. The device must be able to operate at this constant pressure over many cycles without deformations.

The next requirement listed is the max tested internal pressure. This tested internal pressure is the max pressure that the internal fluids experience within the main chamber of the mixing valve. The current tested internal pressure is **value not displayed** PSI in gauge pressure. This requirement ensures that the mixing valve can withstand a much greater pressure with no deformations than what the valve is currently being operated at. This requirement ensures that the durability remains equivalent and the operating pressure of **value not displayed** PSI gauge is within a good factor of safety. The reliability of the device is also an important consideration and this requirement, if successful, ensures that the device is not compromised.

Another requirement is the flow rate, and this is the flow rate that the mixing valve experiences. The mixing valve has two inlets, the hot and the cold. These inlets combine to give a max flow rate of **value not displayed** gallons per minute at the exit. The inner components of the valve rotate to ensure that the mixing valve has the right exit temperature, discussed more in the next requirement. In other words, the inner components close and open portions of the inlet valves, but the flow rate remains constant. The durability and reliability both apply in a similar way for this requirement. The components must be able to withstand the max flow rate of **value not displayed** gallons per minute in order to avoid deformations.

As previously stated in the above requirement, the exit fluid temperature must remain at a constant temperature. This temperature accuracy must be within **value not displayed** °C, meaning the sensitivity of the mixing valve must respond fast and accurately. The inner components change how much fluid is allowed to flow from both the hot and cold inlets to ensure a constant temperature with this accuracy. This requirement is important so the temperature sensitive components can receive a constant fluid temperature from the mixing valve. Reliability and durability aspects don’t apply to this requirement since this has no real effect on the mixing valve. The exit temperature can change, and the components of the mixing valve won’t be affected.

The sixth requirement lists the operation fluids that the mixing valve must be able to perform with. These fluids are water and other three fluids that can’t be disclosed. It’s important to understand the corrosive behavior that each of these fluids can cause on the materials of the mixing valve. These materials must be able to withstand any negative consequences the fluid can propose on the device. It's also important to understand how these fluids react under different pressures/temperatures and if this affects the mixing valve in anyway. The reliability and durability during operations could decrease if these fluids aren't known entirely.

The seventh requirement lists the allowable materials that the mixing valve can consist of. These materials are Electropolish Stainless Steel 316L and Descaled Titanium. In other words, the mixing valve can only be modified by these metals. The thermo conductivity/resistance, tensile strength, elasticity, melting temperatures and corrosive resistance must be known for both these materials. These aspects can affect the reliability and durability of the mixing valve. The operating fluids and allowable materials must be crossed examined to determine if they will cause any failures.

The eighth and final requirement lists the allowable polymers that the mixing valve can consist of. These polymers are Viton and Teflon. In other words, the mixing valve can only be modified by these polymers when it comes to other components like gaskets. The thermo conductivity/resistance, elasticity, tensile strength, corrosive resistance, and melting temperatures must be known for both these polymers. The polymer specifications can affect the durability and/or reliability of the mixing valve. How the polymers and the operational fluids react to each other must also be accounted for to ensure a failure does not occur. These are the proposed requirements given by General Atomics and the team must modify the mixing valve in a way to ensure all are met to expectations.

2.3 Functional Decomposition

This section discusses the functional decomposition of the mixing valve. The valve can be broken down into two main components. The first is the mixing valve itself. The valve has hot and cold fluid flow coming in and a mixed cool temperature coming out. The fluid is regulated by a turret inside he valves. The turret is moved by an electrical actuator and mixes the water with mechanical energy. The mixing valve was functional decomposition was completed by creating both a black box model and functional model. The Black box model is shown and discussed in the section below.

2.3.1 Black Box Model

This section contains and discusses the black box model created for the functional decomposition. The Black box model can be seen below in Figure 1. The purpose of the mixing valve is to mix fluid, more specifically regulate the temperature of a fluid. The inputs and outputs for the system are shown as three different types of arrows, only two are used in the black box model.. The bold arrows indicate materials going in and out of the valve and in Figure 1 indicate fluid. The thin horizontal arrow indicates electrical energy entering the system and the vertical thin arrow indicate mechanical energy in from the actuator. The dashed arrow indicates the signal leaving system, not shown. Figure 1 can be found below.

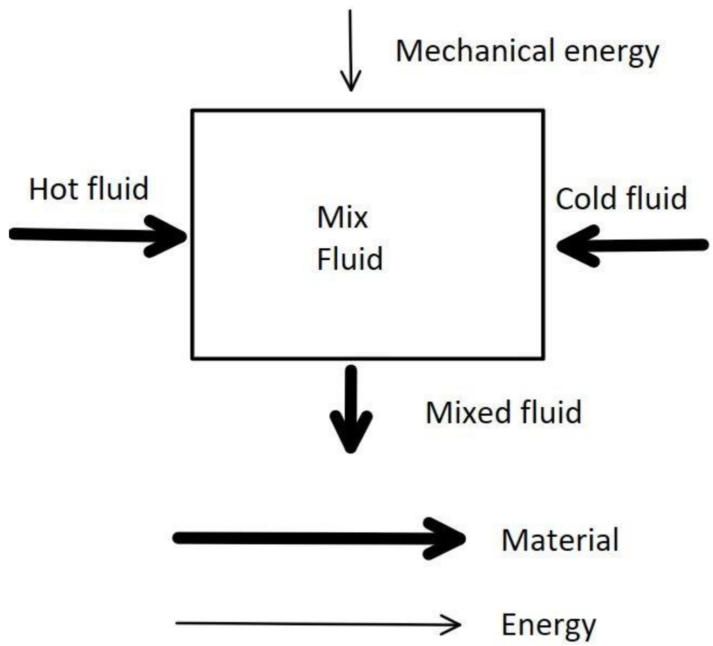

Figure 1: The Black Box Model of the mixing valve.

As shown above in Figure 1 the Black Box Model is a simplified way of viewing the mixing valve system as a single function with inputs and outputs. For the purposes of decomposition, the black box model was a good start but ultimately simplified. In the next section the black box model is expanded into all pertaining subsystems into a functional model.

2.3.2 Functional Model/Work-Process Diagram

This section discusses the functional model created to better understand the mixing valve. The functional model shown below in Figure 2 is a more detailed version of the Black Box Model previously discussed showing all sub systems involved and what in and outputs each sub system individually has. This method provides a deeper understanding of the mixing valve system, Figure 2 can be seen below.

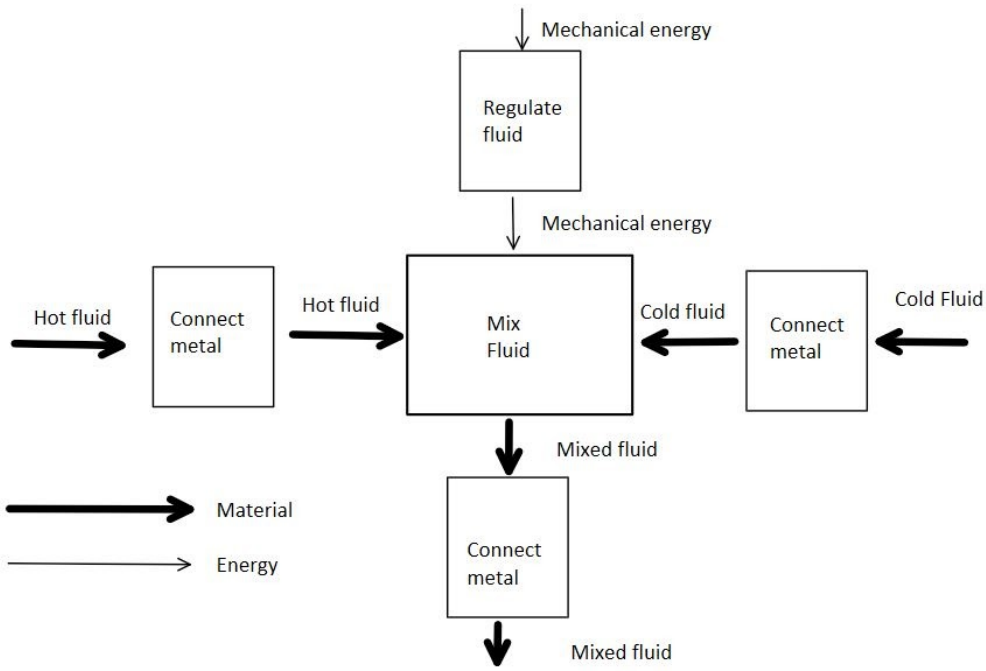

Figure 2: Functional model of mixing valve and subsystems.

Shown above in Figure 2 are five different types of subsystems. Staring from the top is the turret inside of the valve that rotates to regulate the temperature of the mixed fluid out. This is done inside the valve housing so in the functional model on mechanical energy in from the actuator and out to the valve itself is shown. The fluid flows into the next subsystem, the valve body shown in the center.

The mixing valve body is the center of the functional model. The valve body has three inputs and a single output. Two of the inputs are hot and cold fluid before they are mixed. The third input is mechanical energy from the turret that physically mixes the ratio of hot and cold fluid. The output is the mixed cool fluid.

The next and final three subsystems are the connections for the metal pipes to the metal valve. The hot, cold, and mixed fluid must either enter or leave the valve. For the functional model this shows a single material arrow in and the same single material arrow out for each case. The simplicity yet heavy weight of this subsystem made it a good subsystem to modify. General Atomics is currently using a valve with modified connections that use couplings instead of flanges.

2.4 House of Quality (HoQ)

The NAU Mixing Valve team did not use a House of Quality (QFD) due to the fact that the client provided all engineering requirements. The QFD, originally created, contained engineering requirements, but could not be given customer requirements due to the confidential nature of the project. The engineering requirements will be the main resource referred to; as the main goal of the project is to reduce weight of the current, functioning mixing valve, and replacing it with a lighter valve that still meets all engineering requirements.

2.5 Standards, Codes, and Regulations

The following table are the ASTM standards most applicable to a mixing valve for General Atomics. Most of the standards are for testing and checking for corrosion, which is very important because when there is a quickly moving working fluid, over time this can cause a lot of corrosion. Testing is also applicable because General Atomics will be proof testing the valve at 185 psig. ASTM and ASSE standards are shown in Table 3, shown below [1][2].

Table 3: Standards of Practice as Applied to this Project

Standard Number or Code	Title of Standard	How it applies to Project
ASTM G4-01	Standard Guide for Conducting Corrosion Tests in Field Applications	Will help us test our valve to ensure the titanium will not corrode under the conditions we plan to put it under.
ASTM G46-94	Standard Guide for Examination and Evaluation of Pitting Corrosion	Will help us evaluate the inside of the valve during maintenance to ensure no corrosion is taking place.
ASSE 1069	Automatic Temperature Control Mixing Valves	Our valve's inlet temperature will constantly be changing depending on the conditions of the flow.
ASTM G58-85	Standard Practice for Preparation of Stress-Corrosion Test Specimens for Weldments	We need to weld parts of our valve together and welding can change the strength of a material, and this will help us test the part to ensure the weld did not compromise the part.
ASTM G190	Standard Guide for Developing and Selecting Wear Tests	Will help our team select the proper testing methods for our mixing valve.
ASTM G171	Standard Test for scratch hardness of materials using a diamond stylus	Titanium is prone to scratching, so this test can help determine how much the surface needs to be coated to protect it.

3 Testing Procedures (TPs)

Since summer courses at NAU are online and the NAU Mixing Valve Team will not be physically building the mixing valve, all testing will be done virtually. Design tools, such as SolidWorks Flow Simulation, will be utilized to test the functionality of the designed mixing valve. Different aspects of the valve can be specified in Flow Simulation, meaning the flow through the mixing valve will be simulated accurately and realistically. All testing will be done with the guidance of General Atomics and the capstone mentor.

3.1 Testing Procedure: SolidWorks Flow Simulation

SolidWorks Simulation will give the mixing valve team the ability to test certain engineering requirements by using known inputs: external/internal analysis, known fluids, maximum velocity, etc. The specifications of the inputs that are needed will be analyzed further in the second half of the project. Once inputs are known, SolidWorks can simulate flow and will make views of different engineering requirements available (ie. velocity within the valve, pressure throughout the valve, etc.). This will be the main tool used, as it will help to test characteristics that apply to the engineering requirements: the pressures within the valve, temperatures throughout the valve, testing for different fluids, and the volumetric flow rate throughout the valve. Performing these tests in SolidWorks Flow Simulation will give the team visual results that will show whether the design meets the required engineering requirements.

3.1.1 Testing Procedure 1: Objective and Resources Required

Access to the valve assembly in SolidWorks is all that is required in order to utilize this design tool. Then, the SolidWorks Flow Simulation Wizard can be opened, and new projects can be chosen. When creating a new project, details of the desired flow are required in order to obtain accurate results from the simulation. The team will consult will the capstone mentor and General Atomics when choosing these flow specifications so that the results are accurate and sufficient. Once flow specifications are made, the user can choose where the flow enters the valve and can then run the software in SolidWorks for the chosen calculations. SolidWorks then runs through many iterations of these calculations and will display a window showing the user that calculations are complete after a few minutes of processing time. With this done, aspects of the flow within the valve (velocity, pressures, heat, temperature, flowrates, etc.) can be displayed on the valve assembly. Once the flow characteristics are complete, goals can be set (Figure 1 in Appendix D).

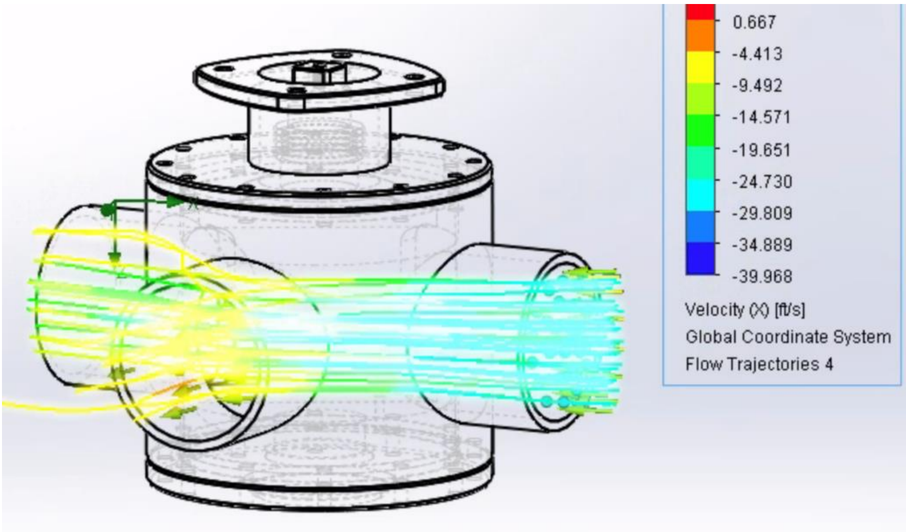

Figure 3: Example Velocity Flow Visual

The figure above is an example of what can be obtained using SolidWorks Flow Simulation. Figure 3 shows velocity within the valve. This example only shows flow entering the valve one-way (the right side flowing to the left). The team will need to learn more about this design tool so that two-way flow can be analyzed within the valve. Current demonstrations and flow visuals were created with the help of online resources [3][4]. Different “goals’ can be visualized like velocity is in Figure 3. Goals created for the mixing valve can be found in Figure 1 in Appendix D.

3.1.2 Testing Procedure 1: Schedule

While running SolidWorks Flow Simulation is not very time consuming, the process of performing the correct analysis can take critical thinking. The mixing valve team will spend time consulting with General Atomics to ensure the calculations found in Simulation are appropriate. Once the final assembly of the valve is complete, analysis can be done in a reasonable time period. The team’s general schedule is to have the first, initial analysis done within the first two weeks of the second half of the design project. This will allow time for improvements and changes to be made. The simulation will need to be done for each design alternate to ensure all proposed models meet the engineering requirements. SolidWorks, being a useful design tool, will be able to test all engineering requirements by creating different “Global Goals” to analyze, allowing all engineering requirements to be tested and visualized in the same assembly. With concept generation done, it is expected that this will be the focus during the second half of capstone and will be done in a timely manner. Tests will likely be performed regularly, as the team must ensure, using Flow Simulation, that each version of the mixing valve meets the engineering requirements. Before testing can be done, the mixing valve assembly will need to be scaled down to have a 3 inch inlet and outlet port. Once this is finished, the NAU Mixing Valve team will begin refining the completed SolidWorks model according to engineering requirement and General Atomics’ needs.

4 Risk Analysis and Mitigation

4.1 Critical Failures

It is possible that the mixing valve design will have critical failures when being re-designed into a smaller valve composed of different materials. Failures being monitored are thermal expansion effects, required wall thickness, bolt wall thickness, machining challenges, and potential weld failure. The team is working to ensure none of these initial concerns will be problematic while designing the new lightweight mixing valve. Most analyses have been under guidance from both General Atomics and the capstone mentor. Note that some analyses contain theoretical values for demonstration purposes, as some actual values are confidential and cannot be included in the final design report.

4.1.1 Potential Critical Failure 1: Thermal Expansion

The NAU Mixing Valve team analyzed the effects of thermal expansion within the mixing valve. A main concern, with switching valve components to titanium, is that the titanium will expand differently than stainless steel. This is caused by the difference in their linear thermal expansion coefficients [5][6][7]. This means that, when exposed to the same temperature changes, both materials will expand a different length or area, which could be problematic where titanium components meet stainless steel. Titanium and stainless-steel pieces will meet at the inlet and exit ports, which could cause the valve to have leaks due to the different expansion of these two materials. Calculations for thermal expansion were made to be theoretical, as some known values are confidential. *All values calculated are completed for theoretical values*. Equation 1 (below), is found from *Materials Science and Engineering* [7].

$$\frac{\Delta \boldsymbol{l}}{\boldsymbol{l_0}} = \propto_{\boldsymbol{l}} (\boldsymbol{T_f} - \boldsymbol{T_0}) \quad \textbf{(1)}$$

Equation 1 shows how linear thermal expansion can be analyzed within the mixing valve. The change in length can be solved if the initial length, coefficient of linear thermal expansion, and temperature change are known. The mixing valve team utilized this equation to ensure a material switch would not cause leaks in the new mixing valve design. The figure below shows a general comparison between the three materials, under a steady temperature increase.

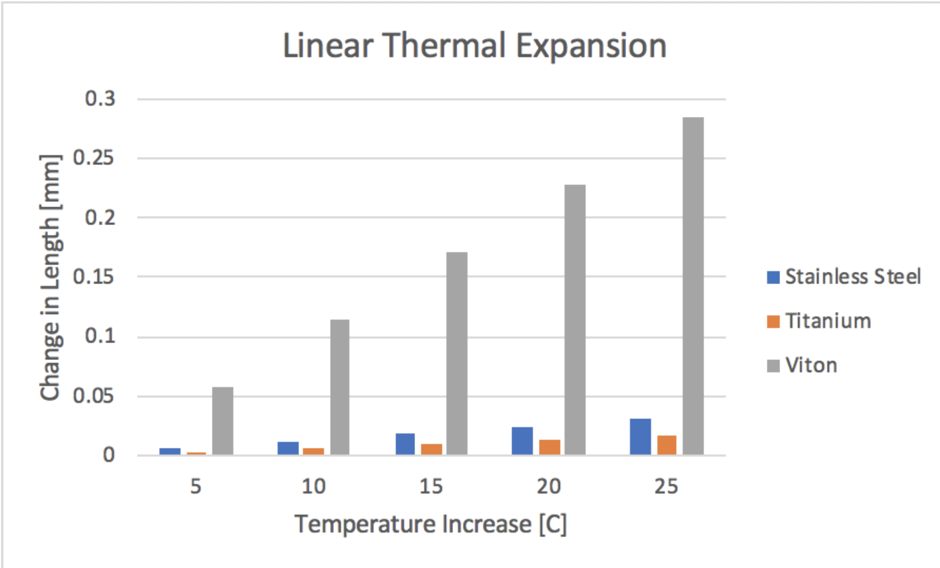

Figure 4: Linear Thermal Expansion Visual

Figure 4 shows the relationship of thermal expansion between Grade 5 Titanium, Stainless Steel, and Viton (O-Ring material). By examining the graph, the Viton will expand far more than the two metals will. This figure was created by analyzing the expansion of the three materials for temperature increases from 5-25, in increments of 5, using a Thermal Expansion design tool created.

After analyzing the thermal expansion effects on the mixing valve, it was determined that switching components to titanium will not be problematic, as the difference in thermal expansion will not be greater than the tolerances allowed, and the metals will not expand more than the O-Rings. The Viton O-rings will expand approximately 10 times as much as both Grade 5 Titanium and 316 Stainless Steel. An example problem, showing how calculations for Figure 4 were solved, can be found in Appendix A.

4.1.2 Potential Critical Failure 2: Machining Titanium Concerns

It is important to understand the basics of how titanium is machined in order to better understand how to design the new mixing valve. All the weight reduction will be a result of reducing mass. Some of the mass reduction will be from changing the material from stainless steel to titanium, due to reduction in material density [8]. The rest of the mass reduction will be a result of making parts geometrically smaller by thinning out the valve walls and altering the connections. All physical machining for the mixing valve will be done by the client themselves, although the team still felt it important to understand the process.

When researching how to machine titanium the most common consensus among all sources was that titanium is more difficult to machine than steel. There are multiple factors contributing to this. The first factor is that during the titanium machining process the tools get hotter than when machining other metals like stainless steel. This leads to a more complicated and timely process than conventional milling in order to prevent work hardening, tool wear, and fires.

There are a few ways to increase productivity, reduce tool wear, without altering the materials properties. A combination of increasing the number of flutes, cutting so chips cut thick to thin, and keeping the radial engagement low will increase productivity by keeping the temperature of the tool cooler [9]. Cutting so chips cut from thick to thin is shown in Figure 2. The reasoning for his is to have the thick portion of the metal chip absorb the heat during the largest impact and giving it a brief cool down period before its next impact. This is the same reason increasing the number of flutes will keep the tool cooler as well [10].

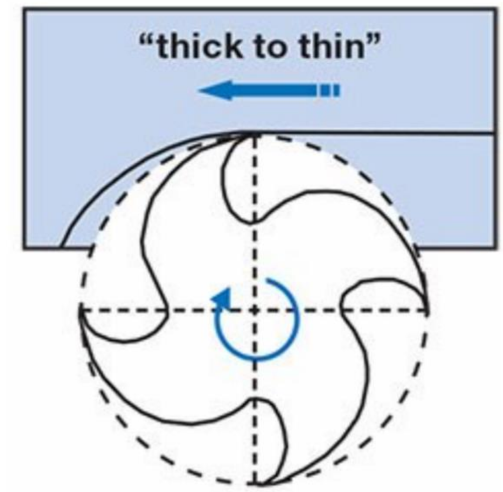

Figure 5: How to create metal chips thick to thin

It is important to note that machine titanium can be dangerous, and caution must be taken to avoid fires. Titanium chips are unstable and can catch fire with one spark [11]. The fire will be a chemical fire so do not attempt to put it out with water. Titanium shavings, if fine enough can even spontaneously combust just due to oxygen alone, so all recommended safety measures should be taken [12].

Some ways to reduce tool wear are keep radial engagement low, engage into the part in an arc, and leave on a chamfer. The time when a tool is damaged the most is when it first contacts a part. The best way to minimize the damage is to come into the part in an arc shape rather than straight on. This same concept applies to the angle that the tool contacts the part, which is the radial engagement. When leaving a part, the tool is all prone to damages well, to reduce this, tool should enter and leave the part in a chamfer. Even if a chamfer is not required the tool should leave the part in a chamfer shape anyway and have it removed later [9].

4.1.3 Potential Critical Failure 3: Wall Thickness Pressure Analysis

The NAU Mixing Valve Team was tasked with designing a valve that can withstand a maximum up 185 psi. This section determines minimum thickness for the mixing valve walls. The mixing valve body was modeled as a cylindrical pressure vessel [8]. The analysis is formatted in a modified given, find, solution format. It is modified because the calculations are all preformed in a MATLAB live script and the givens can be changed. A benefit of using a MATLAB code to determine thickness is that the calculations are determined quickly and for various diameters and pressures. The code also determines the internal stresses, hoop and axial stresses, after the thickness is determined. The two materials that should be considered are 316 stainless steel and titanium.

Four assumptions were made for this analysis. The first two are steady state conditions and uniform properties. The third assumption is welded tube connections, and the fourth is that the valve is being modeled as a cylindrical pressure vessel. The assumptions are not ranked in order of significance. Assumptions two, three and four had the most influence on the calculations. Assumption three pertains to the mixing valve because the inlets and outlets will be welded on. The assumptions were used to determine the equations for thickness and the internal stresses, which can be found below.

The first equation is for Radius. This is a simple equation that only requires diameter to be known. The radius equation is shown below as Equation 2.

$$\mathbf{R = D/\ 2} \qquad \mathbf{(2)}$$

Equations 2 and 3 below are both equations for determining thickness. Equation 2 is used when $P < 0.385SE$ [11]. P is design pressure. R is the radius previously solved for with Equation 1. S is the max allowable stress. For the valve design S has been set to the max yield strength. For titanium the max yield strength is 128000 psi, and for 316 stainless steel it is 42100 psi [2-3].

$$\mathbf{t = PR/\ (SE - 0.6P)} \qquad \mathbf{(3)}$$

The variable E is for the weld factor. The valve will have welds on it to attach the inlets and outlet so E will be 0.85. This is a prompt in the code in case calculations for a seamless valve are desired.

$$\mathbf{t = PR/\ (2SE + 0.4P)} \qquad \mathbf{(4)}$$

The second thickness equation, Equation 3 shown above, has the same variables as Equation 3. The difference is Equation 3 is used when $P < 1.25SE$ [11]. Once the thickness was determined the hoop and axial stresses could also be determined using Equations 4 and 5 respectively.

$$\textbf{Hoop Stress} = \mathbf{P\ D\ /\ (2\ t)} \qquad \textbf{(5)}$$

Hoop stress, shown above in equation 4, is also called circumferential stress. This is because the circumferential stress is like a hoop around the inside of the pressure vessel [12]. For the valve this would the internal stress on the side walls.

$$\textbf{Axial Stress} = \mathbf{P\ D/(4\ t)} \qquad \textbf{(6)}$$

The axial stress equation is shown above in Equation 6. Axial stress is also called longitudinal stress. The axial stress inside the cylinder is pushing on the top and bottom of the valve [11]. From inspection, the axial stress is expected to be exactly half of the hoop stress due to that four on the bottom of the equation.

The results from the code are clear, the code itself can be found in Appendix B. When the code is run, the user receives four prompts. The first prompt is for max design pressure. The pressure must be in psi. The second prompt is for the outer diameter of the valve in inches. The next two prompts are questions that can be answered by inputting either a 1 or 2. The third prompt asked about welds. The fourth prompt asks if the user requires stainless steel or titanium. The prompts and respective inputs can be seen below in Figure 1.

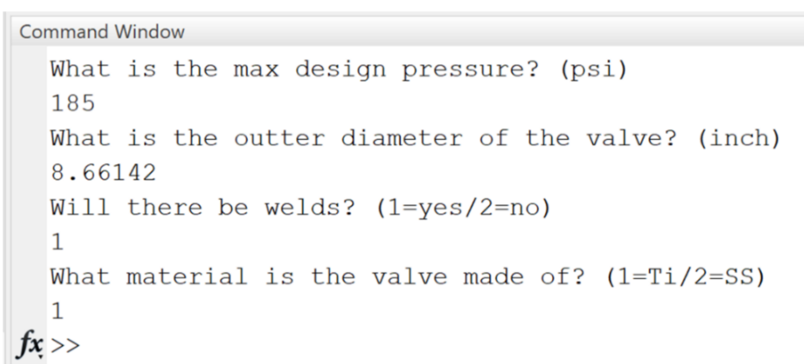

Figure 6: Command window prompts for Matlab live script inputs

The inputs shown above are the values for how the valve it is currently modeled in titanium. The diameter of 8.66 inch is equivalent to the 220 mm, which is the outer diameter of the valve. The max design pressure of 185 psi is an engineering requirement. The outputs can be seen below in Figure 7.

```
The min wall thickness is 0.007374 inch

The hoop stress is 108689 psi
The axial stress is 5.434450e+04 psi
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Figure 7: Outputs from MATLAB live script for thickness, hoop stress, and axial stress

Figure 7 above shows the outputs from the MATLAB live script. The thickness results shown above were surprising low. The minimum wall thickness to prevent yielding from the internal pressure is only 0.0074 inch. This is about 0.19 mm, much too small to make a valve out of. The hoop stress is twice as much as the axial stress as to be expected. This means there are other factors driving the thickness of the valve.

In conclusion, the results from the analysis were not as expected but still make sense. A value of 0.0074 inch for the wall thickness is impracticable. There is no way to assemble a valve with walls that small and ductile. What the results do show is that the internal pressure requirement is not a driving factor for the valve wall thickness. The internal pressure is a body force as it is throughout the volume of the valve. The driving forces for the wall thickness are going to be surface forces like the ones that occur during assembly and use. Examples of these forces can be from clamping it, bolting it, or moving it around. This also means more analysis is going to be required in order better determine the optimal wall thickness of the valve. The MATLAB code for determining stresses will be helpful moving forward with the design but is not currently very useful.

4.1.4 Potential Critical Failure 4: Bolt Wall Thickness

Currently 24 M10 bolts attach the main top and bottom plates to the mixing valve chamber. These bolts must have enough strength to withstand the max pressure with no deformations. The goal of the project is to reduce the mass of the mixing valve and the M10 bolts can prove beneficial in achieving this goal. The bolt pattern for both the top and bottom plates will be evaluated to see if the number of bolts can be reduced from 12 by increasing the distance between each bolt. This requires understanding the strength of the bolt to see if it's possible to reduce the number without deformation. The amount of material that is needed around the bolt holes will be evaluated too. This calculation will help determine if the thickness of the chamber walls can be reduced without causing deformations. Reducing the number of bolts and the thickness of material around the bolts can prove beneficial for the goal of this project.

The type of screws that are currently being used in the 4-inch mixing valve can be seen below in Figure 8. This photo was taken and sent from the client, General Atomics. The screw heads are labeled as F593C bolts.

Figure 8: Bolt Head

F593C are bolts that are manufactured from cold drawn 304 Stainless Steel screws [13]. AISI is the most common and versatile type of steel. It is mainly used in applications such as pans, sinks, flatware, dairy production equipment's, or in this case a mixing valve. This steel has good corrosion resistance, except when exposed to chloride environments. Corrosion and pitting can occur if the steel is exposed to this environment. This steel shows good resistance to oxidation, even when exposed to temperatures as high as 870℃. These are the bolts that will be used to determine if the wall thickness can be reduced and the number of bolts within the bolt circle.

The volume of the material must be converted to a mass. This is done by multiplying the density of the material by the volume, in result the mass can be found, as shown below [14].

$$W(kg)=V\rho \tag{7}$$

The mass that was calculated is in kg, but the team is calculating values of mass in pounds. The mass is converted to pounds by the constant shown below in Equation 8 [15].

$$W(lbs)=W(kg)*0.00220462 \tag{8}$$

Based on the diameter of the head screw, 18mm, and the diameter of the screw hole, 10mm, the following cylinder is reduced from the previously assumed dimensions of 22mm thick chamber walls to 18mm. This new 18mm thick wall is classified as the corrected cylinder. The volume of the inlet and exit holes are subtracted from the outer volume. This gives the volume of the actual material that is used in the cylinder chamber walls. This Volume is used further in Table 4.

Table 4: Cylinder Mass for Stainless Steel and Titanium

Material	Design	Volume in m^3	Desnity of Steel (kg/m^3)	Mass (kg)	Mass (lbs)
Stainless Steel	Original Cylinder	2.093	8000	16744	36.91415728
	Corrected Cylinder	1.683	8000	13464	29.68300368
Titanium	Original Cylinder	2.093	4520	9460.36	20.85649886
	Corrected Cylinder	1.683	4520	7607.16	16.77089708

In Table 5, the volume is converted to m^3 and the density of steel and titanium are known. By using Equation 7, the mass can be found and is then converted to pounds by Equation 8. Titanium and Stainless-Steel mass values are compared in Table 5, below.

Table 5: Cylinder Mass by Material

Material	Original Cylinder (lbs)	Corrected Cylinder (lbs)	Mass Reduced (lbs)
Steel	36.91415728	29.68300368	7.2311536
Titanium	20.85649886	16.77089708	4.085601784

The original material mass of the Stainless-Steel cylinder was 36.914 pounds and the corrected material mass was 29.68 pounds. By reducing the wall thickness of the cylinder chamber, the mass can be reduced by 7.23 pounds. When the material is switched to Titanium, the original material mass is 20.86 pounds and the corrected material mass is 16.77 pounds. Titanium shows a 4.09-pound mass reduction by changing the wall thickness. When the material is changed from Stainless-Steel to Titanium and the wall thickness is reduced, the total mass savings are 20.14 pounds.

Next, the mass of the bolts is determined to see if it would be worth reducing the number of bolts used to attach the top and bottom plates. Currently 12 bolts are used to attach each of the top and bottom plates, 24 bolts total. The mass per screw for 304 Stainless Steel is 0.048 pounds. The following table, Table 6, Shows the total mass based on the quantity of screws.

Table 6: Bolt Mass Based on Quantity for Stainless Steel

Mass of 24 (lbs)	Mass of 20 (lbs)	Mass Reduced (lbs)
1.15163705	0.959697541	0.191939508

When the Stainless-Steel bolts are reduced from 24 to 20, the mass savings are 0.19 pounds. Thus, the mass reduction is found by reducing the number of bolts by four, and these values are minimal. Since the mass reduction is a fraction of a pound, and more mass will be added to the chamber if the bolt holes are removed, the number of bolts will not be reduced.

All in all, the number of bolts will remain the same. The wall thickness can be reduced from 22mm to 18mm based on the screw calculations. Further stress calculations will need to be conducted on the main cylinder chamber from the max internal pressure. By reducing the wall thickness of the Stainless-Steel cylinder chamber, the mass can be reduced by 7.23 pounds. Titanium shows a 4.09-pound mass reduction by changing the wall thickness. When the material is changed from steel to titanium and the wall thickness is reduced, the total mass savings are 20.14 pounds. These calculations will prove to be beneficial when trying to complete the capstone goal, of reducing the mass of the mixing valve.

4.1.5 Potential Critical Failure 5: Weld Failure

Since the valve will not be machined out of a solid block of material, it will have to be welded together. The valve has to be able to withstand a pressure of 185 psi. A potential critical failure for the design is failure at the welds. A quick analysis was conducted on transverse fillet welds in order to prevent this from happening [16]. Figure 9, below, shows a diagram of the shape of the weld and the assumption that were made.

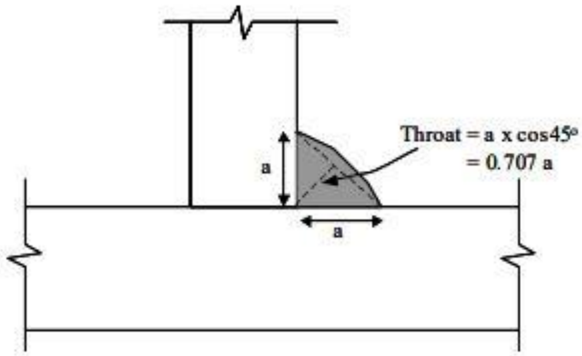

Figure 9: Weld Diagram

The most critical section of the weld is the throat, since the less amount welding material is located here. The weld will span the perimeter of the pipe. Reducing the inlet diameter down to three inches and keeping the same wall thickness, the outside diameter of the pipe is 3.5 inches.

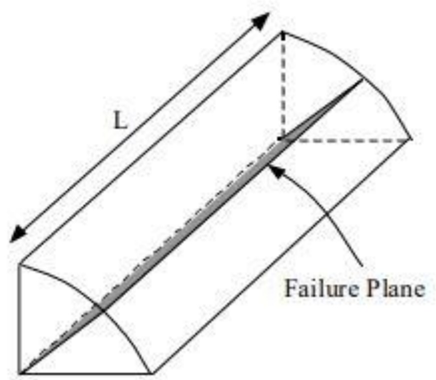

Figure 10: Weld Failure Plane

The tensile strength of a transverse fillet weld analyzed by using equation 9.

$$F = A\ x\ \sigma_T \quad (9)$$

The minimum area of the weld can be analyzed using equation 10.

$$A = 0.707a\ x\ a \quad (10)$$

The tensile strength of the weld must match the tensile strength of the base material. Since the plan is to use titanium for the valve shell, the tensile strength is 128 KSI [S5]. Using the known valve, the minimum height of the weld is 0.002 inches. Given that the weld can withstand the internal pressure of the valve without much material, the welds are a low risk in the design.

4.2 Risks and Trade-offs Analysis

Welding is the best way to fasten metals together safely, however it is not without flaws. Our valve needs to be able to withstand 185 psig within the valve, and welded points are weaker than the solid points of the part. However, this is a low risk trade off because welding is the most secure way to fasten metals. The next possible failure is the bolt connections, there are 24 bolts connecting the top of the valve to the bottom, and the valve needs to be able to run at 185 psig with no damage or deformation. Bolts are a very strong temporary attachment method, but they are not as strong as solid metal and the part can fail at the point of attachment. Using bolts is necessary to keep the valve together, so the risk and the weaker point is worth the benefit of being able to hold the valve together. The NAU valve team plans to thin out the walls of the valve to reduce weight. Of course, thinning out walls of the valve does weaken the integrity of the metal, however we have run calculations to ensure that the walls are not too weak and can withstand there pressure forces we need them to.

5 DESIGN SELECTED – First Semester

After completing the concept generation process, the NAU Mixing Valve team decided to continue developing the 3 inch, stainless steel/titanium mixing valve. This design allows the valve to be lightweight and will likely not jeopardize the structural integrity of the valve. Testing still needs to be done, using SolidWorks Flow Simulation, to ensure that the mixing valve will not fail or deform when a different material is put under the same conditions. This section will contain the description of the chosen design and the implementation plan for future work (to be done in the second half/semester of capstone).

5.1 Design Description

The third concept generated is a mixing valve with stainless steel and titanium components, like concept 2, but re-designed to work with a 3 inch valve housing. The same five components mentioned in Figure 11 will be the top candidates to be switched to titanium. This is subject to change as the team does more research and based on how much weight savings that can be attained by only changing these five parts. As stated above, General Atomics helped the team pick these five components, but there are more components that could be converted to titanium if the weight savings is needed.

Table 7: Pros and Cons of 3 Inch Stainless Steel-Titanium Mixing Valve

Pros	Cons
Titanium is 56% as dense as Stainless Steel	Not as much weight savings as a full titanium design
Titanium is non-corrosive because it produces an oxidized protective layer	Stainless Steel parts may not be compatitble with Titanium parts
Potential to use less material of titanium, thus redudcing weight.	Stainless Steel's modulus of elasticity is almost double the modulus of Titanium
Cost to switch is less than changing the entire valve to titanium	Titanium is more expensive to buy
Reduces chance of threatening the integrity of the design	Titanium is more expensive to machine
Provides good weight reduction	

Many of the pros and cons are similar to those in Full System Designs 1 and 2. Titanium is will still allow the mixing valve team to meet the engineering requirements, while providing weight savings. Making the change from a 4 inch valve to a 3 inch valve will allow for a lot of weight savings, which is practical because we were told the inlet and exit pipes the valve connects to are of 3 inch diameter. The current valve being used is a 4 inch diameter valve and is adapted to the 3 inch pipes. Changing the valve diameter would allow the valve to be mated to the other pipes easier, while providing weight savings.

No major changes have been made to this proposed design since the PDR: most time was spent creating the SolidWorks Assembly (Figure 11) and performing mock tests using Flow Simulation (Figure 3). Going forward, the team will be scaling the valve down to the desired size and testing each version to ensure the valve meets all posted engineering requirements. All calculations going forward are likely to be completed using SolidWorks. Calculations for the valve will be completed starting next semester, as the next semester the team will be focusing on creating drawings and ensuring all parts meet requirements. All relevant calculations done on the mixing valve are included in this report.

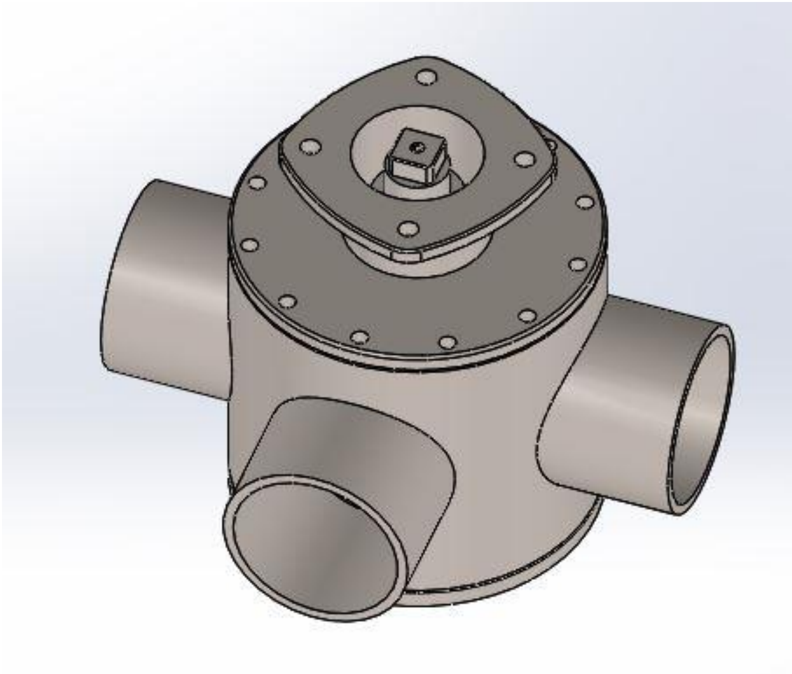

Figure 11: Mixing Valve Assembly

The mixing valve SolidWorks assembly, Figure 11, is a model that has been in the works this semester. Dimensioning will be changed in the upcoming months, as the team will be working to decrease weight by modifying parts of the valve while ensuring the engineering requirements are met. The team is still in the process of learning SolidWorks Flow Simulation which, once learned, will serve as the most important tool of the design, and more modifications can then be created and validated. Possible changes that will be made after creating this assembly are the internal parts and the inlet/exit ports. Creating the assembly has led to the realization that some parts may need more modification than others if they are to be functional in the valve system.

5.2 Implementation Plan

The current Armstrong valve has three, 4 inch diameter inlets that connect to the rest of the system. The plan is to reduce the all the inlet diameters down to three inches in order to reduce weight and eliminate the use of a reducer downstream. Additionally, the plan is to reduce the height of the main valve chamber to maintain the ratio between the internal components and the valve inlets. The material used for this design will be titanium (Grade 5) and stainless steel (316L).

Moving forward, the team plans to simulate the effects of flow and pressure within the valve using SolidWorks Simulation. The valve is currently undergoing flow simulations to ensure modifications have not comprised the functionality. Once the valve has passed all the required tests, General Atomics will receive the drawing files for manufacture. General Atomics will manufacture and assemble the valve at their facility.

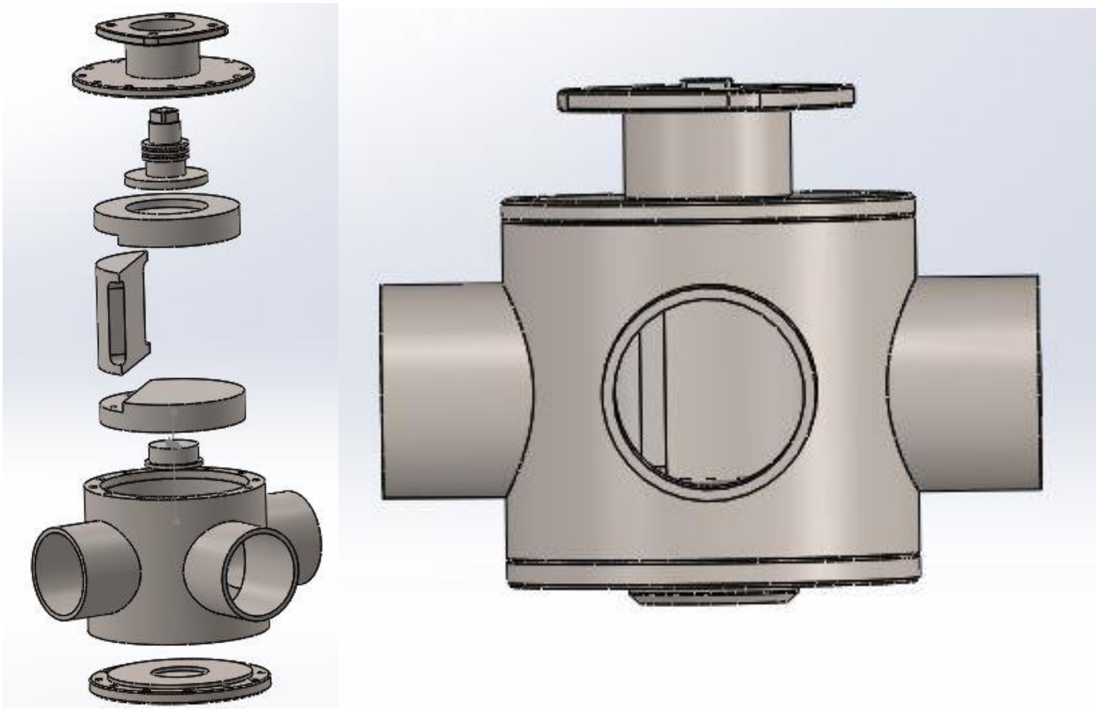

Figure 12: Exploded View and Assembly View of Mixing Valve

Ideally most of the parts will be machined using a CNC mill and CNC lathe. The valve parts will be assembled using bolts for the internal components and welding for the main shell of the valve. Since we are not manufacturing a prototype of valve and General Atomics has not disclosed the machinery that is at their disposal, we cannot conclude the exact procedures of creating the valve. The bill of materials for this valve design is found in the appendix.

6 CONCLUSIONS Summer

In conclusion, the NAU mixing valve team is reducing weight of the valve by 96 lbs. General Atomics has already reduced the weight of the valve by 36 lbs by removing unnecessary flanges, and the NAU team plans to change five parts to titanium to reduce weight, thin out the walls of the valve to reduce material, as well as move to use a 3 inch pipe outlet instead of a 4 inch, which will also reduce weight by removing material. There are added complications with moving to use titanium, the biggest one being welding. It is not feasible to weld titanium to steel, so we could only switch parts to titanium that were attached to a steel part with a different fastening method than welding. Titanium is stronger than steel, and it is less corrosive, which is good for a valve with a quickly moving working fluid. Titanium is also much more expensive than steel, so it needs to be used as sparingly as possible to stay within a reasonable budget.

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8 APPENDICES

8.1 Appendix A: Thermal Expansion Example Problem

Problem Statement: Compare the thermal expansion between three materials, exposed to the same ambient conditions: Grade 5 Titanium, 316 Stainless Steel, and Viton (O-Ring) increasing from 0 degrees Celcius and 15 degrees Celcius. (Random Values)

Given:

$\alpha_{\text{Stainless Steel}} = 1.6 * 10^{-5}\left[\circ C^{-1}\right]$

$\alpha_{\text{Titanium}} = 8.6 * 10^{-6}\left[\circ C^{-1}\right]$

$\alpha_{\text{Viton}} = 1.5 * 10^{-4}\left[\circ C^{-1}\right]$

$T_1 = 0[\circ C]$

$T_2 = 15[\circ C]$

$l_0 = 3'' = 0.0762[m]$

Find:

Change in length due to thermal expansion.

Solution:

GENERAL EQUATION

$\Delta l = l_0\, \alpha_l (T_2 - T_1)$

For Stainless Steel:

$\Delta l = (0.0762[m])(1.6 * 10^{-5}\left[\circ C^{-1}\right])(15 - 0)[\circ C] * 1000$

$\Delta l = 0.01829[\text{mm}]$

For Titanium:

$\Delta l = l_0\, \alpha_l (T_2 - T_1)$

$\Delta l = (0.0762[m])(8.6 * 10^{-6}\left[\circ C^{-1}\right])(15 - 0)[\circ C] * 1000$

$\Delta l = 0.00983[\text{mm}]$

For Viton:

$\Delta l = l_0\, \alpha_l (T_2 - T_1)$

$\Delta l = (0.0762[m])(1.5 * 10^{-4}\left[\circ C^{-1}\right])(15 - 0)[\circ C] * 1000$

$\Delta l = 0.17076[\text{mm}]$

Explanation:

As we can see, the thermal expansion in Viton is much more than that of Stainless Steel and Titanium.

8.2 Appendix B: MATLAB Code for Wall Thickness

Appendix B:

Live Script:

Author: Rob Stevenson

ME 476 Individual analysis

Pressure Vessel Wall Thickness

Due Date: 2/29/20

Code Purpose: To determine the wall thicknesses and stresses of a mixing valve. For modeling purposed the valve is being treated as a cylindrical pressure vessel. This code will take inputs, listed below, and produce three ouputs. The thickness, t, is for the most of the valve walls. Thesecond output is the circumferential stress, also called hoop stress. The third output is the axial or longitudinal stress.

Units must be BG and in the units prompted.

Assumptions:

1) Steady State

2) Uniform properties

3) Welded tube connections

4) Model valve as a cylinder

Given:

Inputs:

P ; % Design Pressure

D ; % Outside Diameter of valve

E ; % Tube Welding Factor

S ; % Maximum Allowable Stress

R ; % radius

Find:

Outputs:

t ; % thickness for body of valve

hoop_stress ; % hoop stress

```
axial_stress ; % axial stress
```

Solution:

```
clear clc

% initialize and request inputs
P   = input('What is the max design pressure? (psi) \n')                    ;    % Design Pressure
D   = input('What is the outter diameter of the valve? (inch) \n')          ;    % Outside Diameter of valve
E   = input('Will there be welds? (1=yes/2=no) \n')                         ;    % Tube Welding Factor
S   = input('What material is the valve made of? (1=Ti/2=SS) \n')           ;    % Maximum Allowable Stress

% determine raduis
R = D/ 2 ;

% determine tube welding factor
if E == 1
    E = 0.85  ;   % welds
elseif E == 2
    E = 1     ;   % seamless
end

% determine max allowable stress
if S == 1
    S = 128000  ;    % titanium (psi)
elseif E == 2
    S = 42100   ;  % stainless steel (psi)
end
```

Determine wall Thickness by using for loop since there are two eqautions depending on the value of P.

```
% loop to determine t
```

```
if P < 0.385*S*E
t = (P*R)/(S*E-0.6*P)
elseif P < 1.25*S*E
t = (P*R)/(2*S*E+0.4*P)
end
```

Determine internal stresses

```
% determine hoop stress, (circumferential stress)
 hoop_stress = (P*D)/(2*t)
hoop_stress = 217674
% determine longitudinal stress, (axial stress)
 axial_stress = (P*D)/(4*t)
axial_stress = 108837
```

Display results with units

```
 fprintf('The min wall thickness is % inch\n', t)
The min wall thickness is  3.680648e-03nch
 fprintf('The hoop stress is %d psi\n', hoop_stress)
The hoop stress is 217674 psi
 fprintf('The axial stress is %d psi\n', axial_stress)
The axial stress is 108837 psi
```

8.3 *Appendix C: BOM*

Bill of Materials			
Part	Description	Quantity	Material
1	Nameplate	1	316 Stainless Steel
2	Wear Ring	2	Carbon Reinforced PTFE X
3	Gland Nut	3	316 Stainless Steel
4	Body Base Plate	1	Titanium

5	Body Base Plate	1	Titanium
6	Bonnet	1	316 Stainless Steel
7	Spindle	1	316 Stainless Steel
8	Turret Top Plate Disc	1	Titanium
9	Turret lower Plate Disc	1	Titanium
10	Turret Seal Support	1	Titanium
11	Turret Trunnion	1	316 Stainless Steel
12	Turret Seal	1	Glass Reinforced PTFE X
13	Turret Seal Bush	2	316 Stainless Steel
14	Mixer Insert	1	316 Stainless Steel
15	Needle Roller Thrust Bearing	1	Cr-C Steel X
16	U Hammer Drive Screw	2	316 Stainless Steel
17	Spindle Cap Screw	4	316 Stainless Steel
18	Gland Nut Locking Screw	1	316 Stainless Steel
19	Bonnet/Base Plate/Body Bolt	24	316 Stainless Steel
20	Turret Seal Cap Screw	2	316 Stainless Steel
21	Turret Lower Plate Cap Screw	4	316 Stainless Steel
22	Turret Trunnion Cap Screw	2	316 Stainless Steel
23	O-Ring Gland External	1	EPDM 75 X
24	O-Ring Gland Internal	1	EPDM 75 X
25	O-Ring Spindle Seal	2	EPDM 75 X
26	O-Ring Body Seal	2	EPDM 75 X
27	O-Ring Turret Seat Seal	1	EPDM 75 X
28	Thrust Washer	2	C-Cr Steel X
29	O-Ring Mixer Insert	1	EPDM 75 X
30	Spindle Handle	1	316 Stainless Steel

8.4 *Appendix D: SolidWorks Flow Simulation Inputs*

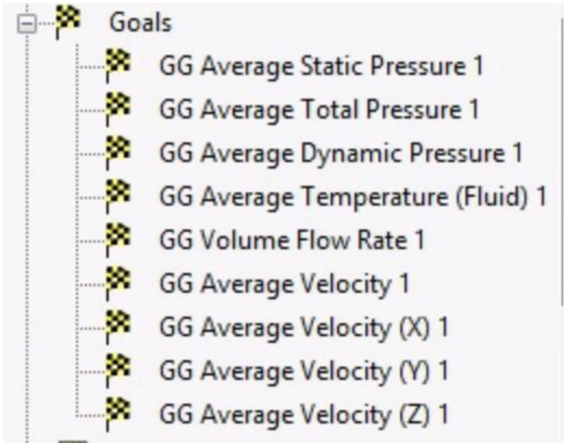

Figure 1: Goals Entered into SolidWorks for Mixing Valve