MONTANA STATE UNIVERSITY

Department of Mechanical and Industrial Engineering

EMEC 489R Capstone: Mechanical Engineering Design I

NAVSEA Pressure Tank Flow Generation

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Prepared to Partially Fulfill the Requirements for EMEC 489R

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ACKNOWLEDGMENTS

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We are also grateful to Samantha Adamski for taking the initiative of being our main form of contact between NAVSEA engineers and our team. Her role in gathering and providing information was critical in our design process.

EXECUTIVE SUMMARY

The Naval Undersea Warfare Center Division, Keyport, Washington (NUWCDIVKPT) operates a test facility that has a 45 foot long, 12 foot diameter pressure tank. The tank is used to asses weapon system performance for a number of different types of systems including torpedoes, defense systems, unmanned undersea vehicles (UUVs), and submarine sonar systems. The tank currently lacks a capability to provide flow during testing limiting the ability to accurately replicate real-world conditions for the systems under test. Using an externally located pump, a piping system, a distribution tank, and mounting system, a system has been developed to provide flow.

The flow generation unit uses a Class 1 type geometry with an externally mounted pump. Discharge and suction piping will be divided between a single 24 inch access port that is located on the end of the tank. The discharge pipe will feed directly into a pressure vessel where the discharge momentum will be diffused via a conical diffuser mounted within the pressure vessel. The pressure vessel will then feed into a convergent nozzle with an exit diameter of 21 inch. A hexagonal grate will be installed at the end of the convergent nozzle to aid in the break down any large turbulent structures that may exist within the pressure vessel. The pressure vessel will be mounted to the inside of the tank via mounting brackets that will mount directly to the stiffening rib structure in the tank. The suction pipe will be located directly behind the pressure vessel.

This design is significantly less complex than other designs explored by the team. It allows for a large flow field with a uniform velocity profile and relatively low turbulent kinetic energy. With a single externally mounted pump, the system will be significantly easier to maintain, and have lower vibration transmissibility than designs incorporating submersible internally mounted pumps. This also allows for pressurization of the tank without the risk of compromising the pump seals.

The resulting flow generation unit is designed to replicate real-world conditions for the weapon systems, UUVs, and sonar systems under testing. The unit produces 6 knots of flow over a 10 foot long flow field that is 21 inches in diameter.

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Chapter I. Introduction

The Naval Undersea Warfare Center Division, Keyport, Washington (NUWCDIVKPT) has played a major role in protecting the world's maritime system. Threats to the safety of those are home and abroad are of continuous concern and the Naval Sea System Command (NAVSEA) provides a technical and tactical advantage over adversaries through engineering and combat systems.

NUWCDIVKPT operates a test facility that houses a pressure tank used to asses weapon system performance for different types of undersea systems. The team has been tasked with creating an internal flow-shaping structure design for the existing pressure tank that will be used to generate flow rates from 3 to 6 knots over a 10 foot flow field. In Capstone 1, the full scale model was designed and underwent testing and iteration. A scale model will be fabricated by the end of Capstone 2 in May of 2018 to be presented to NAVSEA. The scale model is to be produced using the project budget of 5000 USD.

Capstone 1 : Project Outline	
09/12/17 - 09/22/17	Initial meetings with advisor and NAVSEA. Project management planning, level 1 requirements, and problem statement defining.
09/23/17 - 10/13/17	Background research, preliminary design planning, and design specifications and alternative designs.
10/14/17 - 11/03/17	Design testing and iteration, preliminary design review, FMEA integration, and model generation.
11/04/17 - 12/01/17	Design testing and iteration, refining models, mechanics analysis and fluid calculations, assembly plan, budgeting.
12/02/17 - 12/11/17	Critical design review, drawing package, economic analysis, bill of materials and final report.
Capstone 2 : Project Outline	
Jan - Feb	Scale model planning and production, fabrication and assembly.
Mar - April	Scale model testing and iteration.
May	Final scale model prototype completed and design proposed to NAVSEA.

Chapter II. Problem Statement and Level 1 Requirements

At NUWCDIVKPT, a tank is being used to asses weapon system performance of a number of various systems including torpedoes, torpedo defense systems, unmanned undersea vehicles (UUVs), and submarine sonar systems. The tank currently lacks the ability to provide real-world flow conditions for the systems under testing. The primary objective of the project is to design an internal flow-shaping device to provide flow generation for the existing tank. The 45 foot long, 12 foot diameter tank can hold 34500 gallons of water. Currently included in the tanks design is an anechoic chamber, the ability to control pressure from ambient to 145 PSI and heating from ambient to 100 degrees Fahrenheit.

The Level 1 Requirements:

1. Create an internal flow-shaping structure design for the existing tank.
2. The device could be used to generate flow rates form 3 to 6 knots.
3. Report that includes a scalable design for the existing tank facility.
4. Scaled model of the existing tank integrating the new design to demonstrate the new capability.

By participation in the Capstone Project, the student Team Members do hereby assign their respective rights, titles, and interests in any research or other project outcome, including but not limited to copyright or patent rights if applicable derived from their work on this Capstone Project, to the Project Sponsor.

Chapter III. Background

Acoustics

When designing an underwater vehicle, acoustics play a pivotal role. With acoustic transmission characteristics better than air, water has the ability to propagate sound waves at speeds four to five times higher than air. When traveling through water, sound waves undergo less attenuation and are therefore able to propagate over large distances. Acoustic waves have a variety of underwater uses such as detecting and locating obstacles and targets, measuring the characteristics of marine environments (such as the topography of the seafloor, ocean currents, and hydrological structures), measuring the velocity of an object moving underwater, and signal transmission [1]. For these reasons, acoustics are of major concern for the team when challenged with developing the flow generator for the test apparatus. Physical phenomena such as cavitation and mechanical vibration produce large amounts of noise and will need to be well understood and addressed by the team.

Cavitation is the formation of water vapour cavities, small bubbles or voids. It usually occurs when a liquid is subjected to rapid pressure changes that cause the formation of cavities in the liquid where the pressure is relatively low. When subjected to higher pressure, the voids implode and can generate an intense shock wave [2]. Aside from the production of sound, cavitation also plays a major role is such things as, performance breakdown, vibration, and surface erosion [3]. There are several parameters used to characterize cavitation such as ambient conditions, advance ratio, the non-dimensional pressure coefficient, and the cavitation number. The advance ratio (J) is the ratio between the free stream fluid velocity (V) and the propeller tip speed (n) times the rotor diameter (D). This non-dimensional term is given by the equation [4]

$$J = \frac{V}{nD}$$

The non-dimensional pressure coefficient describes the relative pressures throughout a fluid flow field and is defined as

$$C_p = \frac{P_m - P}{\frac{1}{2}\rho V^2}$$

Where (V) is the free stream fluid velocity, (P_m) is the local pressure, (P) is the ambient pressure, and (ϱ) is the fluid density. This value can be compared to the cavitation number (σ_v). The cavitation number is the measure of the susceptibility of a flow to cavitate, and is defined as

$$\sigma_v = \frac{P_m - P_v}{\frac{1}{2}\rho V^2}$$

Where (P_v) is the vapor pressure of the fluid. Notice that as the local pressure approaches the vapor pressure the cavitation number converges to zero. Therefore it can be said that the smaller the cavitation number the more likely cavitation will occur [3].

Vibration also plays a key role in the design of underwater apparatuses. The team will need to focus on reducing mechanical vibration as much as possible. This can most likely be achieved through well balanced rotating parts, and vibration dampers.

Fluid Flow Concepts and Factors

Mathematical models, calculations, and fluid modeling software help to understand the way fluid behaves over an object. This allows for scientists to make changes to designs and develop different profiles to produce the best systems. Flow patterns depend on the characteristics of the fluid, speed, and the shape of the surface the flow is acting over. These characteristics can be described with viscosity, density, and compressibility. Since water is an incompressible fluid, these characteristics are more difficult to model and study [5].

There are two types of flow patterns that can be characterized as laminar and turbulent flow. Laminar flow happens when the fluid travels smoothly or in regular paths, also known as streamline flow [6]. The fluid on contact with the horizontal surface is stationary while the layers above this contact layer are sliding over one another. Laminar flow is generally on common where the flow channel is small, the viscosity is high, and the fluid is moving relatively slowly [7]. In turbulent flow, the fluid undergoes fluctuations where the speed is continuously changing in both magnitude and direction. Most forms of flow are turbulent are easily affected by changes in heat and pressure [8].

Flow is generally governed by three major concepts including Bernoulli's Principle, boundary layer effects, and drag. Bernoulli's Theorem provides a relation to the "amount the pressure, velocity, and elevation in a moving fluid, the compressibility and viscosity of which are negligible and the flow of which is steady, or laminar". It describes the total mechanical energy of the fluid using the fluid pressure energy, kinetic energy, and potential energy (assuming these parameters stay constant). The theorem applies if the fluid flow horizontally and any decrease in fluid pressure is associated with an increase in fluid velocity [9]. It is described by the following equation;

$$\frac{V^2}{2} + gz + \frac{P}{\rho} = constant$$

Boundary layer effects are described by the complex way hydrodynamic forces depend on the viscosity of a fluid. As a fluid moves over an object, the molecules on or right next to the surface of the object stick to the surface. The molecules just above the surface are slowed down due to the collision with the molecules that are sticking to the surface. The further away from the surface, fewer collisions occur due to the objects stuck to the surface. This effect creates a thin layer of fluid near the surface where the velocity of the fluid is zero. The distance between this zero velocity surface and the free stream value is the boundary layer [10]. There is a component of velocity that is perpendicular to the surface which displaces the flow above. The thickness of the boundary layer can be defined by this displacement which depends on the Reynold's Number. The boundary layer thickness can be calculated by the following equations;

$$\delta = \frac{5.0x}{\sqrt{Re_x}} \quad \text{for laminar flow}$$

$$\delta = \frac{0.37x}{{Re_x}^{1/5}} \quad \text{for turbulent flow}$$

$$\text{Where } Re_x = \frac{\rho u_0 x}{\mu}$$

Drag is an effect that is influenced by the shape of an object. Moving objects in a fluid experience a resistance, called drag, due to the viscous forces of air sticking to the surface. It is a force exerted by the fluid onto the object that resists motion through the fluid [11]. The drag coefficient describes drag forces and is dependent on the Reynolds number and is generated by a difference in velocity between the solid object and the fluid [11]. Another source of drag is caused by a phenomenon known as flow separation. When there is an abrupt change in shape of the object, the boundary layer becomes detached from the surface of the object and a region of low pressure turbulence is formed below it [12].

Characteristics of Tank Flow due to Submerged Flow Generators

All flow inducing apparatus come with some side effects such as cavitation, circular flow, induced turbulence, and noise. Axial flow impellers are used to induce flow perpendicular to the impeller plane. The pitch blade impeller is the most versatile impeller and was the standard until the development of the airfoil. Hydrofoils use the Bernoulli's principle in the design of its blade. The camber of the blade increases the efficiency of the impeller, reducing its power / pumping ratio. A more technical benefit is the laminar flow created by the camber of this impeller. This camber reduces turbulence (shear) substantially. That is why it is selected for shear-sensitive applications as well [13].

Submerged jets allow for variable velocity of flow to occur yet the amount of cavitation and turbulence vary. Low speed flow coming from an open pipe in submerged water creates very little turbulent flow but the flow pattern dissipates in the tank much faster than a higher velocity flow. Higher velocity flows create more turbulent flow towards the outsides of the tank as well as at the end of the flow cone. [14].

Flow inside of a tank do to any type of introduction of flow causes circulatory patterns to form around the sides of the tank. The shape of the tank only affects how the patterns behave.

Circulation of the flow by way of a pump system may allow for the circulatory patterns of the water to be dissipated to a degree [15].

Pumps

There are two primary types of pumps, kinetic and positive displacement. The former achieves flow generation by imparting momentum into the fluid by means of a rotating component. Positive displacement pumps generate flow by moving fixed volume cavities with mechanical force, thus forcing fluid through a system [16].

The three types of kinetic centrifugal pumps are axial flow, radial flow, and mixed flow pumps. Axial flow pumps have the highest flow rate capacities of any kinetic pump, though they are not able to achieve great discharge pressure. They are comprised of a propeller style impeller that moves fluid along the axis of rotation of the impellers driving shaft as seen in figure 1. Radial flow pumps, shown in figure 2, have the lowest flow rate capacity of any kinetic pump. However, they are able to achieve the greatest discharge pressure. Unlike axial flow pumps, radial flow pumps direct flow perpendicular to the driven shaft along the veins of the impeller. Mixed flow pumps are a compromise between the design characteristics of axial and radial flow pumps and are able to achieve intermediate discharge pressure and flowrate accelerating the fluid between parallel and perpendicular to the driven shaft. This combination can be seen in figure 3. The pump inlets must be correctly sized in order to achieve the desired flow characteristics for any given system when using using kinetic pumps [17] [18] [19].

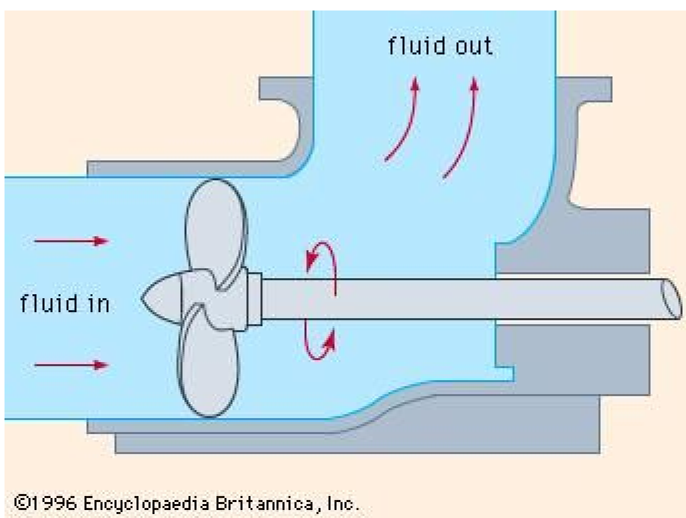

Figure 1: Axial pump design [20]

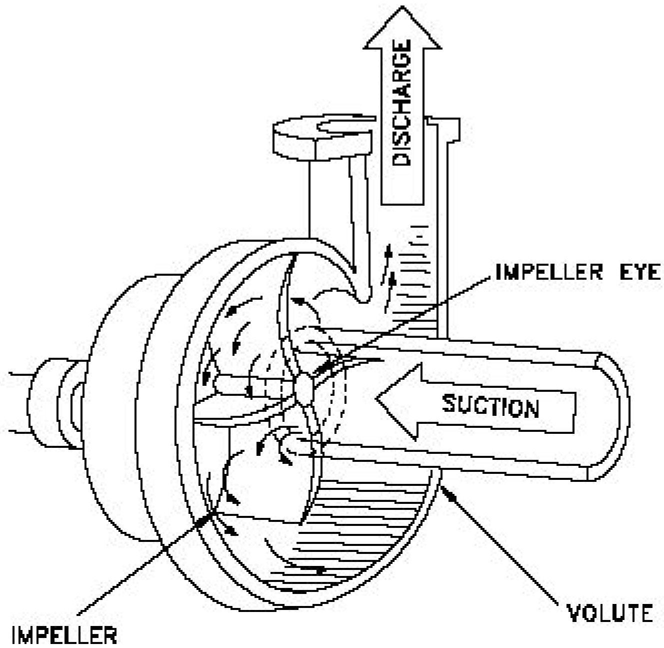

Figure 2: Radial pump design [21]

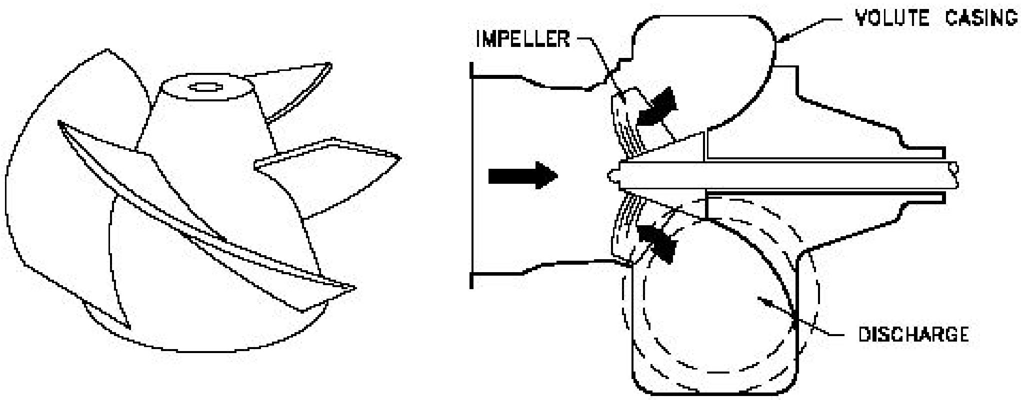

Figure 3: Mixed pump design [21]

Positive displacement can be achieved with rotary and reciprocating pumps. These pumps are exceptionally good at displacing viscous fluids and achieving specific, steady flows. The downside to positive displacement pumps is despite their ability to achieve a very large discharge pressure, they are not able to achieve high enough flow rates to be applicable for most industrial applications. Examples of these two pump types are depicted in figures 4 and 5 below [22].

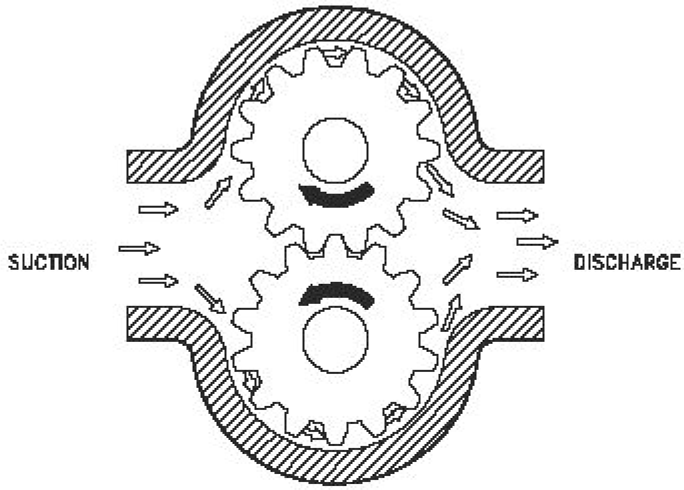

Figure 4: Rotary pump design [23]

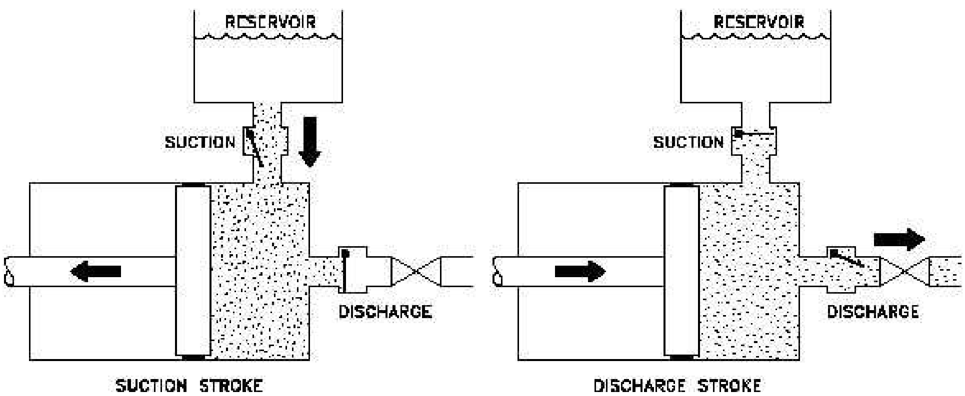

Figure 5: Reciprocating pump design [24, 25]

Pipes and Pipe Fittings

Pipes are rigid, hollow cylindrical structures designed to transport fluids. The size of a pipe is defined by two parameters: nominal pipe size (outer diameter) and schedule [26].

The schedule of a pipe determines the wall thickness with the outer diameter remaining constant. Table 1 lists the associated pipe dimensions for given nominal diameters and schedule based on ANSI/ASME B.36.10M and API 5L standards.

Table 1: ANSI/ASME & API Pipe Parameters [27]

Nominal Pipe Size	Outside Diameter	Inside Diameter	Wall Thickness	Center To End	Pipe Schedule	Weight Pounds
1/2	0.84	0.622	0.109	1.5	40	0.16
3/4	1.05	0.824	0.113	1.5	40	0.17
1	1.32	1.049	0.133	1.5	40	0.4
1 1/4	1.66	1.38	0.14	1.88	40	0.55
1 1/2	1.9	1.61	0.145	2.25	40	0.8
2	2.38	2.07	0.154	3	40	1.6
2 1/2	2.88	2.47	0.203	3.75	40	3.2
3	3.5	3.07	0.216	4.5	40	4.8
3 1/2	4	3.55	0.226	5.25	40	6.6
4	4.5	4.03	0.237	6	40	8.9
5	5.56	5.05	0.258	7.5	40	15.1
6	6.62	6.07	0.28	9	40	24
8	8.62	7.98	0.322	12	40	47.8
10	10.75	10.02	0.365	15	40	83.4
12	12.75	12	0.375	18	*	123
14	14	13.25	0.375	21	30	155
16	16	15.25	0.375	24	30	206
18	18	17.25	0.375	27	*	262
20	20	19.25	0.375	30	20	324
24	24	23.25	0.375	36	20	466
30	30	29.25	0.375	45	*	720
36	36	35.25	0.375	54	*	1,039
42	42	41.25	0.375	63	*	1,420
48	48	47.25	0.375	72	*	2,000

Pipes can be affixed in a variety of ways. However, most connection fittings such as compression fittings are only applicable on small pipe size diameters and are not suited for high pressure applications in a vibratory environment. Welded joints are best suited for permanent junctions between pipes and and pipe fittings of large diameter in high pressure scenarios. Commercially available pipe fittings include tees, wyes, reducers, and olets. Tees and wyes are pipe junction components with 3 ports. Reducers are components of variable diameter intended to join pipes of different diameters. Tees, wyes, and reducers are available in threaded and weldable formats. However, olets are only applied when there is not a suitable tee component. Pipe ends can either be welded or end with a flange with holes around the perimeter allowing the pipe end to be bolted to the desired component. Examples of these component are depicted in figures 6, 7, 8, 9, and 10 below [28].


Figure 6: Pipe tee [29]


Figure 7: Pipe wye [30]


Figure 8: Pipe olet [31]


Figure 9: Pipe reducer [32]


Figure 10: Flange [33]

Scaled Model Prototyping and Similitude

Scaled models of a prototype are a effective tool for determining the efficiency of a prototype without consuming as many resources as a full scale model. However there are many necessary considerations to ensure that results obtained correlate to a full scale system. Similitude is the state of similarity between a full scale system and model. There are a number of ways in which a model must be similar including ratios of length and velocity scale, fluid properties, and non dimensional parameters such as Reynolds, Froude and Mach numbers.

To obtain relevant results from a model is is necessary for it to be geometrically similar to the system. This implies that dimensions of a model will correspond to the full scale by a constant ratio. While generating a scaled physical geometry is simple, relating other flow characteristics between scales is more complicated and in some cases cannot be achieved. This can be a result of parameters such as gravity which are constant between models, or the availability of fluids with appropriate properties.

A distorted model is a model in which non dimensional parameters of the flow may not be the same. This can result in Froude and Reynolds numbers, as shown, that differ between the full scale system and model.

$$\frac{V_m}{\sqrt{g_m l_m}} = \frac{V}{\sqrt{gl}}$$

Froude Number Similitude

$$\frac{\rho_m V_m l_m}{\mu_m} = \frac{\rho V l}{\mu}$$

Reynold Number Similitude

For example, a large model with water as the working fluid may not have alternative fluids with which to conduct a model. If this is the case the following condition of similitude derived from the Reynolds number cannot be satisfied.

$$\frac{\mu_m/\rho_m}{\mu/\rho} = \frac{\upsilon_m}{\upsilon} = (\lambda_l)^{3/2}$$

While this distorted model will not produce perfectly correlating results through careful analysis, useful information can still be gathered. In this process, each case must be independently considered based upon its characteristics.

When generating a scaled model of a fluid system in a closed conduit, certain consideration can be made. In this type of system the flow field is dominated by inertial and viscous forces. As a results the Reynolds number is a key parameter of similitude. Geometric similarity always crucial and frequently includes a parameter called surface roughness. Surface roughness is particularly important in models of turbulent pipe flow in which pipe roughness makes an important contribution to the flow. If surface roughness is important, it is necessary that the model be smoother than the full scale system by same ratio as the length scale with a similar roughness pattern. Whereas, compressibility can generally be ignored for liquid and gas systems if Mach number of the full scale is below 0.3. Velocity scale of closed conduit system is determined by the density and viscosity scales. If the same fluid is used in the model the following relation between velocity and length scale is obtained.

$$\frac{V_m}{V} = \frac{l}{l_m}$$

As can be seen, when a model is smaller than the full scale system it is necessary for the models velocity to be greater. Finally, pressure differentials in a model must carefully be considered. The relationship between the full scale and model is expressed as:

$$\Delta P = \frac{\rho}{\rho_m}\left(\frac{V}{V_m}\right)^2 \Delta\rho_m$$

Despite the complexity of creating an accurate scaled model, the potential insight one can provide is an indispensible design tool. As long as a model is created with the desired insight in mind, considering all of the parameters of a system, it is possible to produce a model which will produce accurate results [34].

Occupational Safety and Health Administration (OSHA)

NAVSEA is considered a research, development, and test and evaluation entity where considerable flexibility regarding regulations and industry standards is allowed. However, the company is required to adhere to all Occupational Safety and Health Administration (OSHA) standards and all applicable security regulations. OSHA is an agency of the United States Department of Labor which was established by congress under the Occupational Safety and Health Act signed into law by President Richard M. Nixon [35]. The purpose of OSHA is to assure “safe and healthful working conditions for working men and women by setting and enforcing standards and by providing training, outreach, education and assistance” [35].

OSHA is a research agency that discovers and explores workplace hazards such as exposure to toxic or carcinogenic substances. The agency then uses the research to establish connections between diseases and work environment conditions [36]. This ensures that “no employee will suffer diminished health, functional capacity, or life expectancy as a result of his work experience” [36]. This also includes psychological factors involved in the workplace that may lead to health or safety issues for employees. These laws help ensure the usability and safety of the large pressure tank vessel. Pressure tanks require certification before operation to prevent system failure. Any changes to the structural integrity of the tank require recertification to ensure the tank meets safety regulations [37].

The goal of OSHA is to encourage joint labor-management efforts to reduce injuries, physiological issues, and disease that may arise from employment by reducing workplace hazards. This is enforced through training programs, medical criteria, OSHA inspectors, and set mandatory standards.

Chapter IV. Design Specifications

Level 1 Specifications

The Naval Undersea Warfare Center Division, Keyport, Washington has agreed to the Level 1 Requirements of the Pressure Tank Flow Generation Project. Questions were asked to the NAVSEA team about specifics for each requirement. The general specifications that follow are the response to those questions.

Level 1 Specifications:

1. Design a flow generation device that meets the following specifications:
    a. Flow is to be produced in the laminar regime with the smallest amount of disturbance to the tank environment. Disturbances include turbulence, cavitation, and excess sound.
    b. The device is to generate constant flow between 3 and 6 knots. Speed is not required to be variable.
    c. The flow field must encompass a 12-24 inch diameter and stretch to a length of 10 feet.
    d. The device must not interfere with existing apparatus’ and must be placed to one end of the tank not in the center.
    e. The generated flow field must be large enough to flow over the IVER autonomous underwater vehicle or other similar vehicles.
2. Design of a mounting unit to attach the flow generation device to the tank.
    a. The mounting unit must minimize impediment to flow.
    b. The mounting unit must replicate free-free structural boundary conditions.
        i. Vibration transmitted from the flow generation device through the mount to the tank should be mitigated.

The Level 1 Specifications are all that is required by the Capstone Group to ensure success of the project for NAVSEA.

Chapter V. Design Alternatives and Evaluation

Description

In this chapter, we will present a number of different design alternatives. These alternatives will be analyzed in order to help the team to develop a design that is best suited for our application. Turbulence and Velocity flow fields will be studied in great detail and will be large deciding factors for the final design. A design that is able to reduce turbulence within the flow field while still maintaining an adequate velocity field is highly desired. Each design will undergo a Computational Fluid Analysis in order to allow the team members to quantify the induced turbulence, velocity, and pressure gradients. In addition to the factors stated above, other factors such as complexity, ease of installation, system size, power usage, vibration, cost, cavitation, and time till fully developed flow will be taken into consideration. Presented designs categorized into two primary design groups, flow generation by pressurized internal tank structures internal tank structure and a flow field directly generated by a thrust producer.

Internal Tank Structure

The internal tank structure plays a vital role in the various flow field properties. Whether the fluid movement mechanism is directly coupled with the intended flow field or not could induce or reduce turbulence in the flow field. We will break the tank structure designs into two classes, Class 1 and Class 2. By dividing the tank into multiple sections and creating a pressure differential between the sections could allow for a low turbulent flow field at the desired outlet due to the pump not directly creating the flow field this will be referred to Class 1. Class 2 structures are ones that use the impellers velocity field as the intended flow field. Below we can see examples of each class.

Class 1 Example

By using a structure to separate the tank into two sections and then using pumps to create a pressure differential between the two parts of the tank. The resulting flow field should have minimal turbulence. This Implementation of multiple pumps or impellers, and large structures makes this design more complex than others presented before. But with those disadvantages comes the benefit of less turbulence within the flow field. Note the large pressure gradient displayed in figure 13.

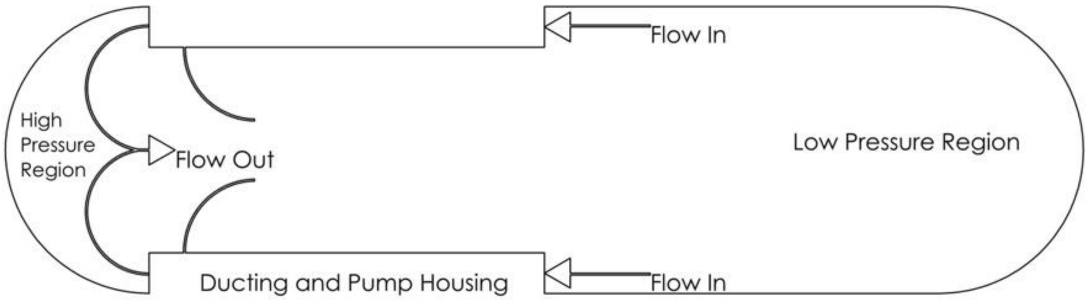

Figure 11: Example of Class 1 tank geometry

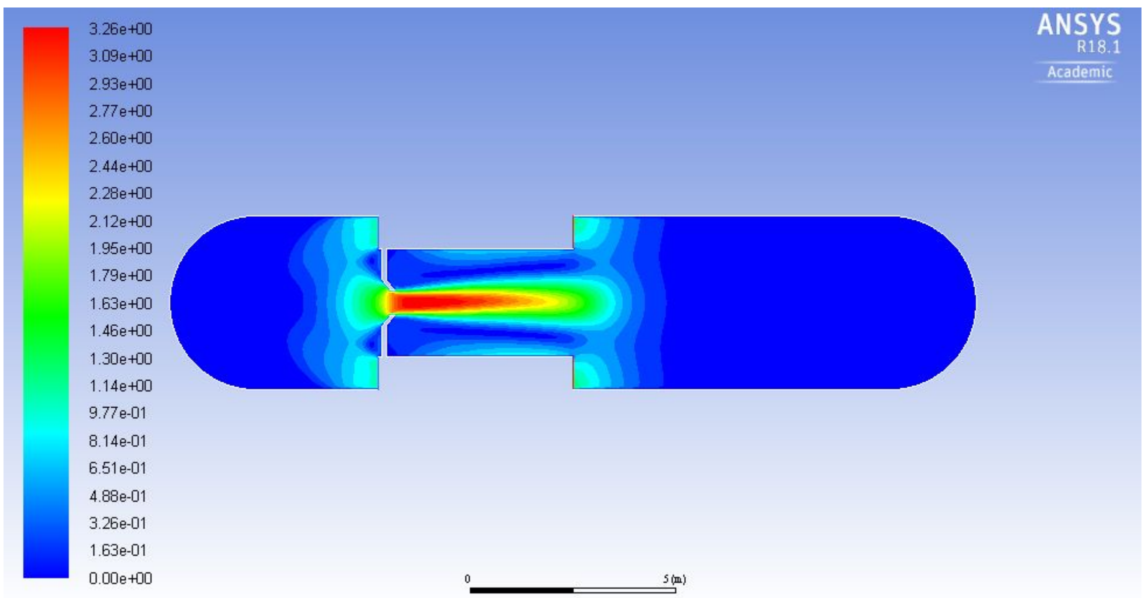

Figure 12: Flow field created by pressure differential

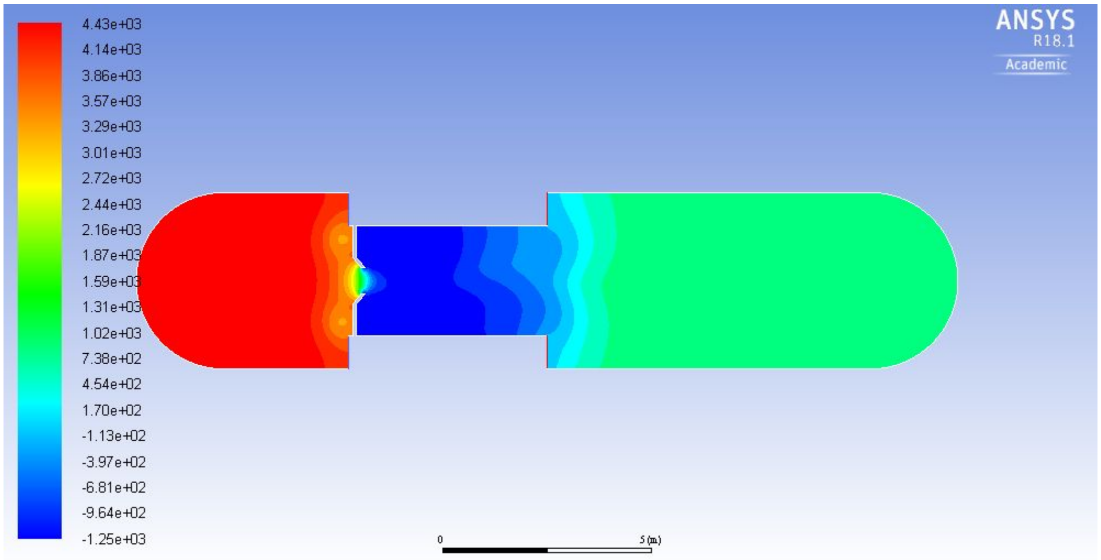

Figure 13: Example of pressure field created in Class 1

Class 2 Example

With a single impeller encased in a convergent nozzle with the outlet of the nozzle directly creating the flow field for the UUV. This design has a number of limitations. With the impeller being the main mechanism for the flow field generation it would create a large amount of turbulence within the flow field. Furthermore, the single impeller design would mean that in order to generate the desired flow velocities, the impeller would need to work harder than designs with multiple impellers. This means that this design would have a higher tendency to create mechanical vibrations, turbulence, and cavitation. However, with its drawbacks come some benefits. This design is much simpler in that it requires minimal mounting points and has very little structure when compared to other designs.

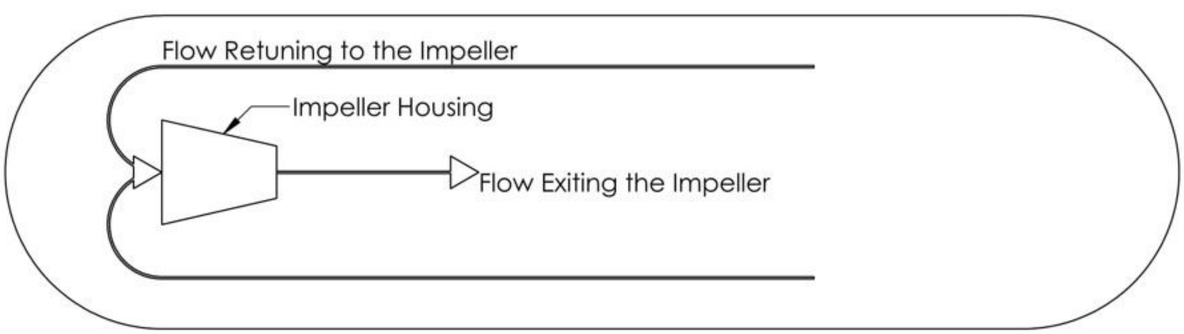

Figure 14: Design alternative 2 drawing

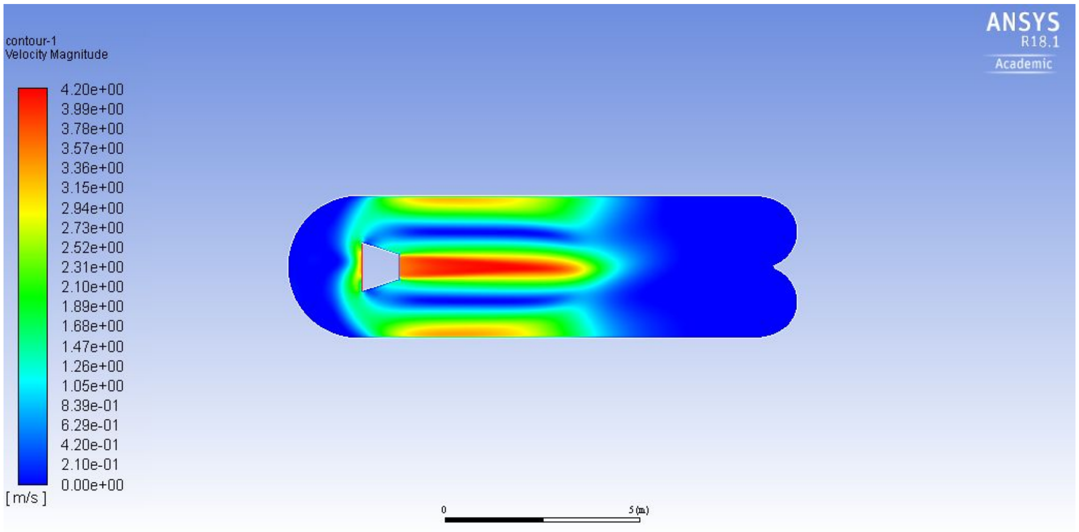

Figure 15: Velocity flow field created by impeller

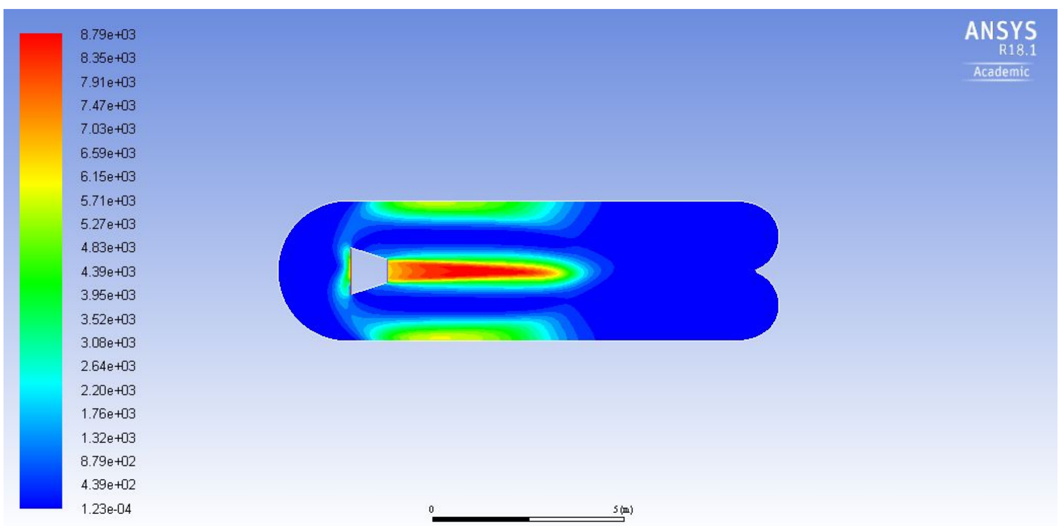

Figure 16: Example of pressure field created by Class 2 tank

Flow Generation

There are several methods to induce flow. The methods investigated by the team included impeller, propeller, magnetohydrodynamics, actuator pump, and natural convection due to heating.

The first mechanism investigated by the team was the impeller or propeller, With a high efficiency, relative simplicity and overall popularity, the impeller or propeller is an obvious choice when tasked with generating flow. However, they do have drawbacks. Due to the nature of the rotating blades cavitation is a common occurrence with these mechanisms. Propellers also have a tendency to generate flow fields with high turbulence. In addition, the rotational motion has the ability to produce large mechanical vibrations.

Magnetohydrodynamics is the movement of a conductive fluid by inducing a magnetic field. This method is not as efficient as some other methods. However, due to the fact that there are no moving parts, relatively low turbulence and vibration are induced. However, in order for the mechanism to work efficiently the water would need to have a high salinity level.

An actuator pump was also considered. This mechanism uses the collapsing of a volume to induce flow, such as a bike pump or syringe. The lack of rotating parts means that this mechanism would produce relatively low amounts of turbulence, vibration, and cavitation. However, this method would only be able to produce a flow field for a finite amount of time.

The final mechanism considered was natural convection through heating. This design would have a low efficiency due to most of the energy going to heat the water. With no moving parts, turbulence and vibration would be minimized. However, due to the closed system, this mechanism would induce a lot of heat into the tank.

Preliminary Designs

Utilizing the information stated previously in this chapter the team was able to produce the following design alternatives. These are not intended to be refined designs but rather examples of uses of the various design aspects.

Design Alternative 1

This design was one of the first design that had come to the minds of the team. It is the simplest of the four designs. With a single impeller encased in a convergent nozzle with the outlet of the nozzle directly creating the flow field for the UUV. This design has a number of limitations. With the impeller being the main mechanism for the flow field generation it would create a large amount of turbulence within the flow field. Furthermore, the single impeller design would mean that in order to generate the desired flow velocities, the impeller would need to work harder than designs with multiple impellers. This means that this design would have a higher tendency to create mechanical vibrations, turbulence, and cavitation. However, with its drawbacks come some benefits. This design is much simpler in that it requires minimal mounting points and has very little structure when compared to other designs.

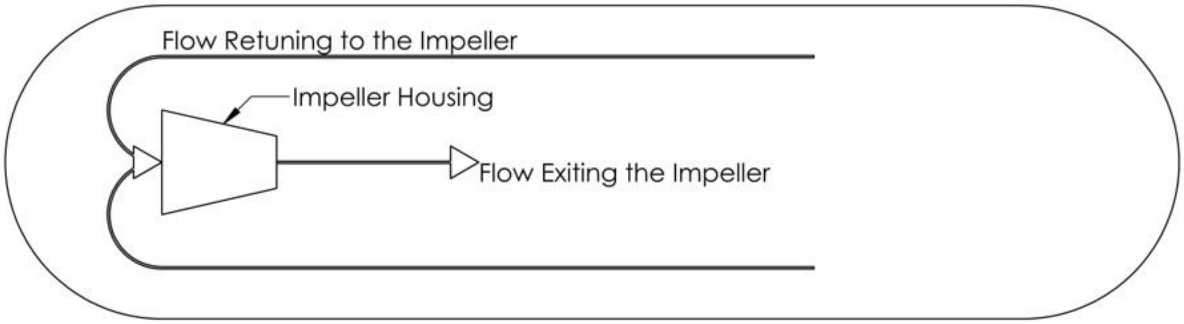

Figure 17: Design alternative 1 drawing

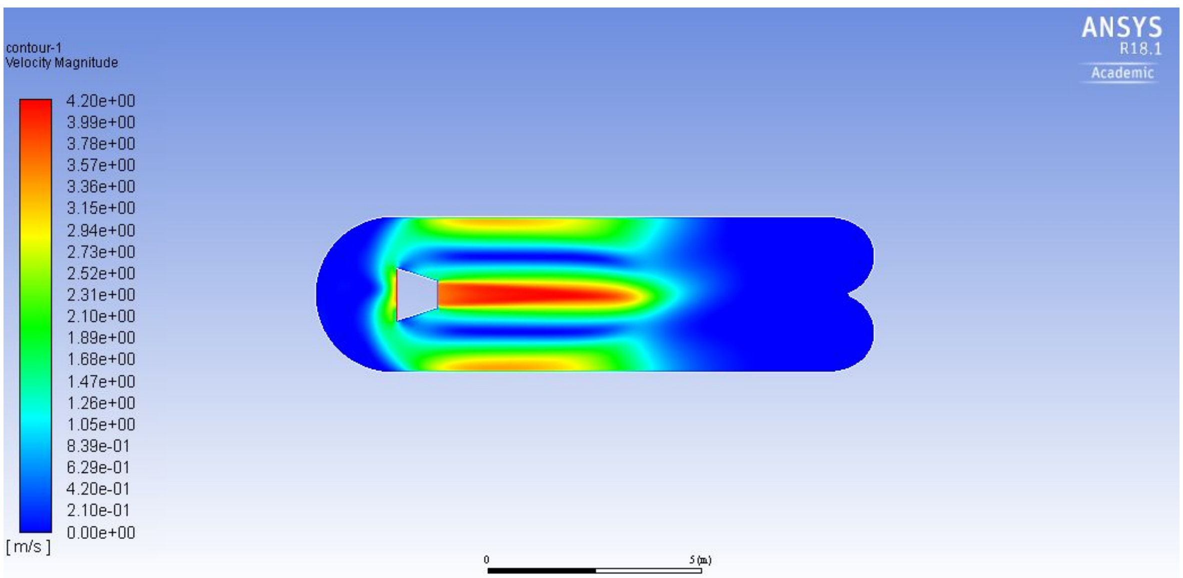

Figure 18: Velocity flow field of tank design 1

Design Alternative 2

This design is comprised of a series of radially arranged impellers which draw water in through ducting located behind the test specimen and afterwhich the flow is redirected 180∘ at which point convergent flows pass through a grid system to break down turbulent structures before they pass over the test subject.

An advantage of this system is that the grid structure results in a less turbulent flow field over the test subject. This however has negative implications, notably pressure head required to achieve desired flow rates in the flow field. This system could also potentially interfere with tank structures such as the protruding camera. The flow directing structure could obscure the camera's line of sight. In addition, this structure would be composed of almost entirely large custom components, resulting in a complicated and expensive construction process.

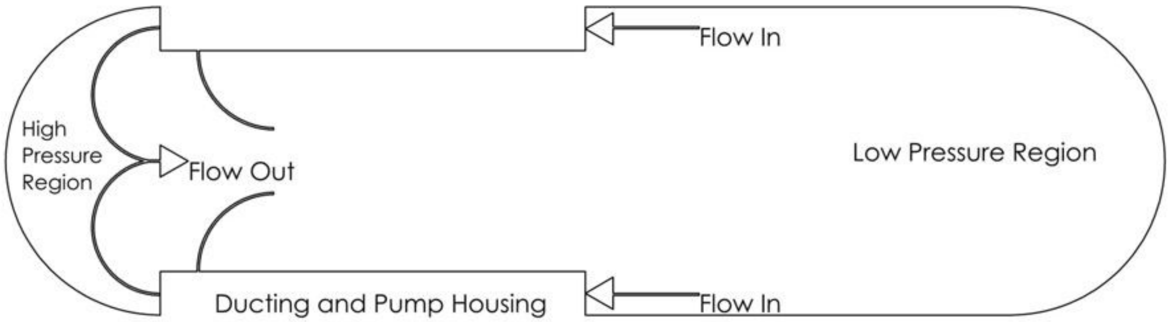

Figure 19: Design alternative 2 drawing

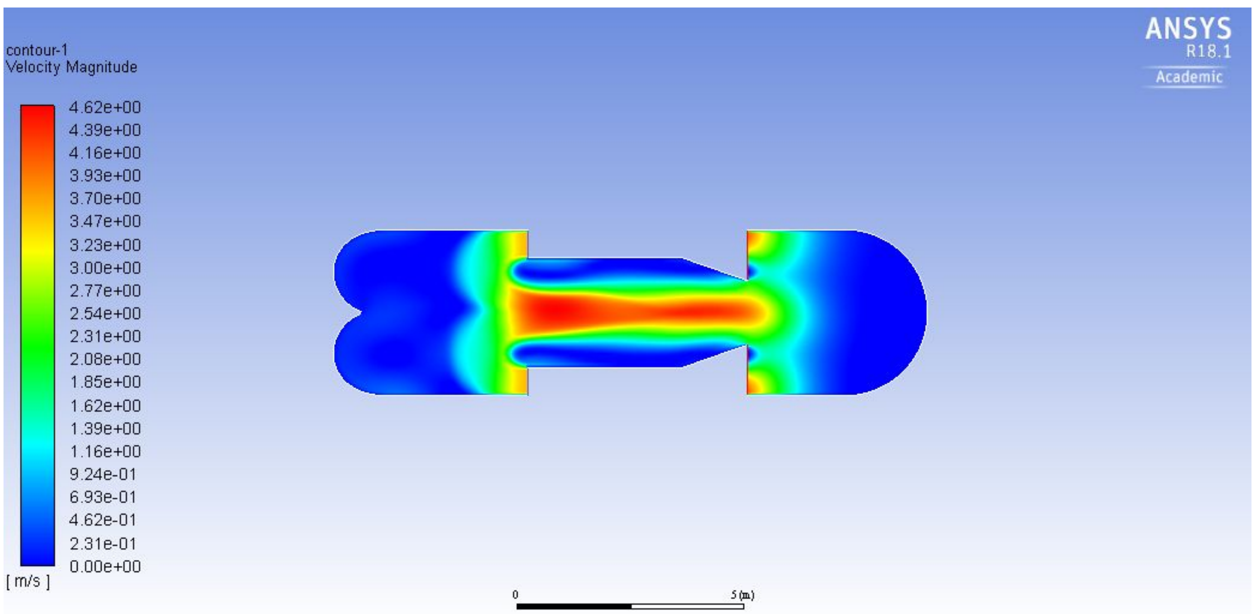

Figure 20: Velocity flow field of tank design 2

Design Alternative 3

This design was created with the sole intent to decouple the impellers from the flow field. By using a structure to separate the tank into two sections and then using impellers to create a pressure differential between the two parts of the tank. The resulting flow field should have minimal turbulence. This Implementation of multiple pumps or impellers, and large structures makes this design more complex than others presented before. But with those disadvantages comes the benefit of less turbulence within the flow field.

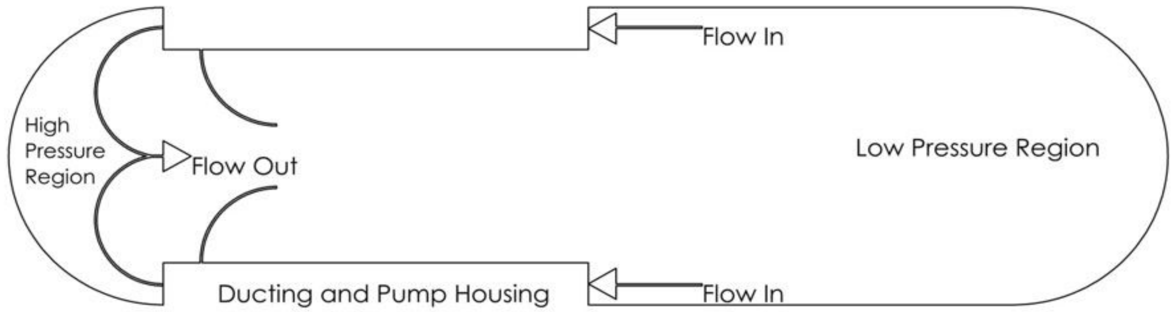

Figure 21: Design alternative 3 drawing

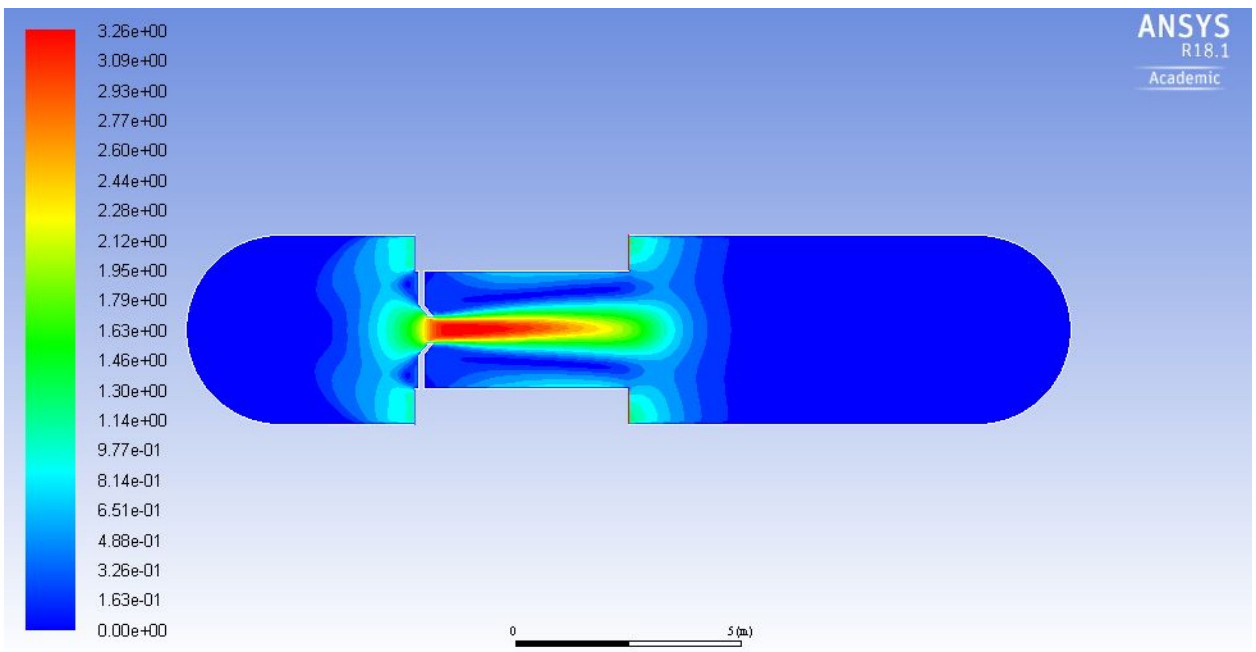

Figure 22: Velocity flow field of tank design 3

Chapter VI. Description of Design

For our final design, the team has chosen to use a Class 1 type geometry with a externally mounted pump operating at about 180HP moving around 11000 Gpm. Discharge and suction piping will be divided between a single 24 inch access port that is located on the end of the tank. The discharge and suction pipes are 10 inch nominal diameter schedule 40 pipes. This size of the discharge and suction piping were governed by the ports available and the pump head requirements calculated Appendix A. The discharge pipe will feed directly into a flow chamber where the fluid momentum from the discharge pipe will be diffused via a conical diffuser mounted within the flow chamber. The water will then feed into a convergent nozzle with an exit diameter of 21 inch. A hexagonal grate will be installed at the end of the convergent nozzle to aid in the breakdown of any large turbulent structures that may exist within the flow chamber. This chamber allows for a more uniform velocity profile at the flow field outlet when compared to models without one. A mount structure will support the flow chamber utilizing mounting brackets that will attach directly to the stiffening rib structures in the tank. References can be found in the drawing package assembled in Appendix E.

This design is significantly less complex than other designs that were explored. As seen in figures 23, it allows for a large flow field with a uniform velocity profile and relatively low turbulent kinetic energy. With a single externally mounted pump, the system will be significantly easier to maintain, and have lower vibration transmissibility than designs incorporating submersible internally mounted pumps. This also allows for pressurization of the tank without the risk of compromising the pump seals. The design has been simulated to provide a flow field that is over 10 foot in length and 21 inch in diameter with speeds up at 6 knots. The resulting flow field also has some of the lowest turbulent kinetic energy values that the team has been able to produce via simulation.

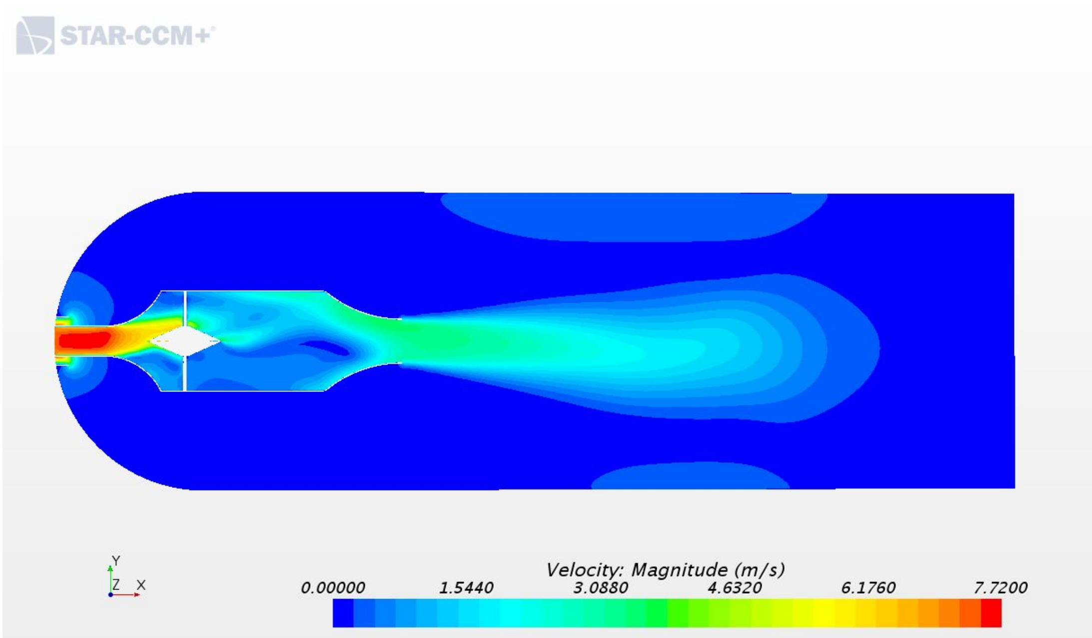

Figure 23. Velocity Magnitude

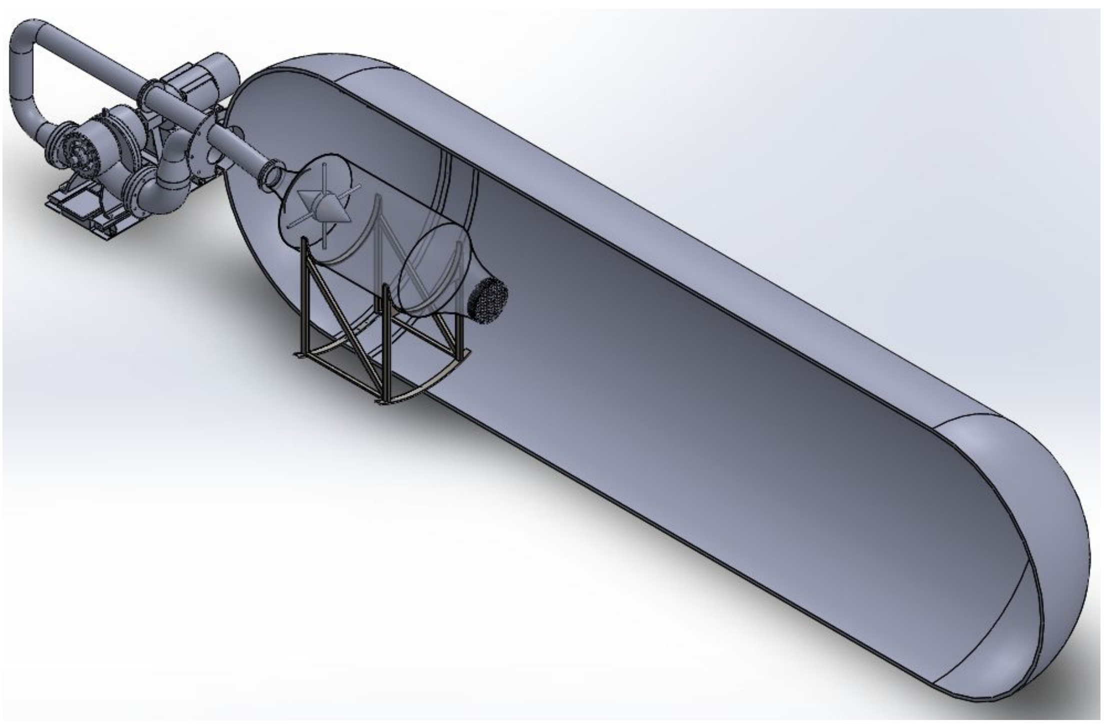

Figure 24. Final Design Assembly.

Chapter VII. Conclusions

The status of the Flow Generation Project is complete as of this point in the semester. Following the work done above, the Capstone Flow Generation Team is confident that the Level 1 Requirements have been fulfilled by the proposed solution. The design creates a flow structure that meets the velocity requirement. All parts of this design are scalable and work with the information given about the existing Keyport facility.

The designed structure and components have gone through iterations starting with a simple impeller. Ideas of augmentation using a casing to direct flow were introduced. This caused too much turbulence and vibrations which are not wanted by NAVSEA. A turbulence reduction structure was found to be useful as well as rubber interfaces to decrease vibrations. This design did not meet the Level 1 Requirements. Different ways to move water were investigated and the concept of a pressure differential was incorporated into the design. The idea of a casing was morphed into a separation wall the created a pressure differential at one end of the pressure vessel. The impeller was determined to be unaccommodating so pumps were researched. Keeping the pump(s) inside the tank and submersed proved to be difficult tasks due to the operating pressures of the tank. An external pump and a flange interface found on the pressure vessel structure at the NAVSEA facility became the best option to fulfill the Level 1 Requirements. A piping system, internal flow chamber, and mounting structure were added to the design to solidify the desired results. The final version of this design is found in the drawing package and details this system.

The final requirement is to design and build a scalable model. This will be accomplished next semester during the Capstone II course. The group plans to evaluate the design further by conducting more mechanical and fluids analyses. The mesh type of the models run during fluid calculations with be changed to bolster current models. Structural reinforcements and vibration mitigation will be a main objective of the team next semester. Future streamlining of the design will allow for better presentation and implementation. The team also plans on implementing a flow measurement device into the tank to track the velocity of the flow field. The team will work more closely with the engineering team at NAVSEA to determine validity of design and what manufacturing/assembly processes can be done at the Keyport facility to reduce complexity and cost.

This phase of the project presented real challenges for Capstone Team. The work put into the background research, structural and fluid analyses, and design concepts were done with care and integrity. The team is proud of what is accomplished as of this point and is eager to continue with the project into the Capstone II semester.

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APPENDIX A. Engineering Analysis

Fluid Flow Analysis

The team relied heavily on Computational Fluid Dynamics to determine the flow characteristics of each design model. These calculations were done using third party applications such as ANSYS Fluent, and STAR CCM+. These programs utilize a computational mesh and the Navier-Stokes equations to calculate the fluid flow. As seen below, Figure A.1 is the computational mesh of the final design. The pressure, turbulence, and velocity flow fields are shown in Figures A.2-4.

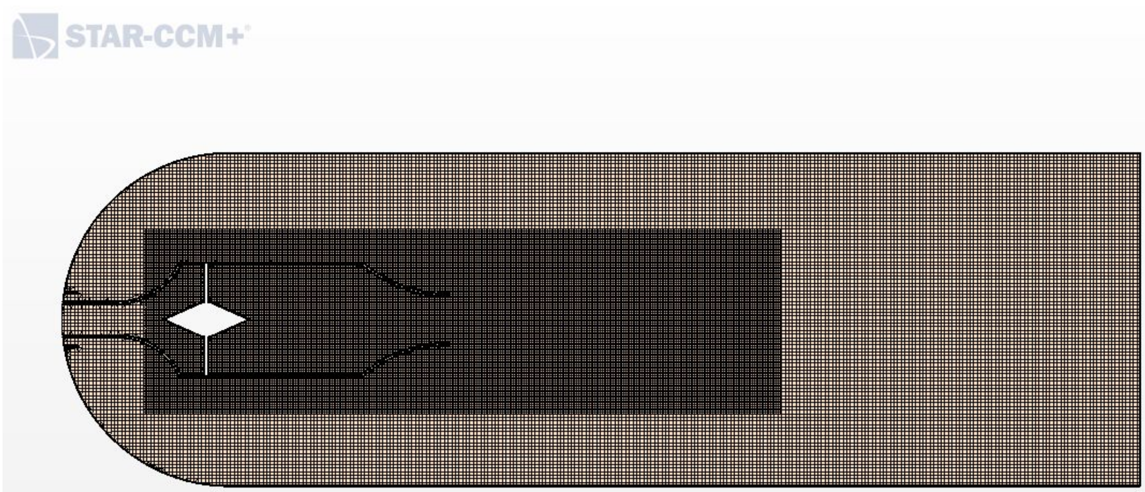

Figure A.1.Cross Section of 3D Computational Mesh

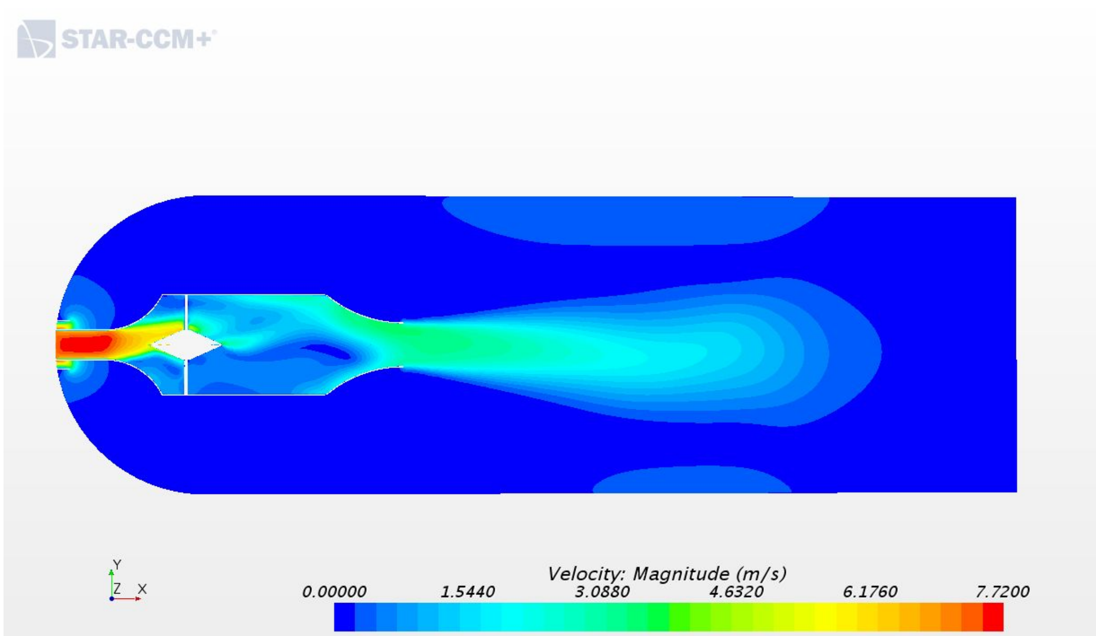

Figure A.2. Velocity Magnitude

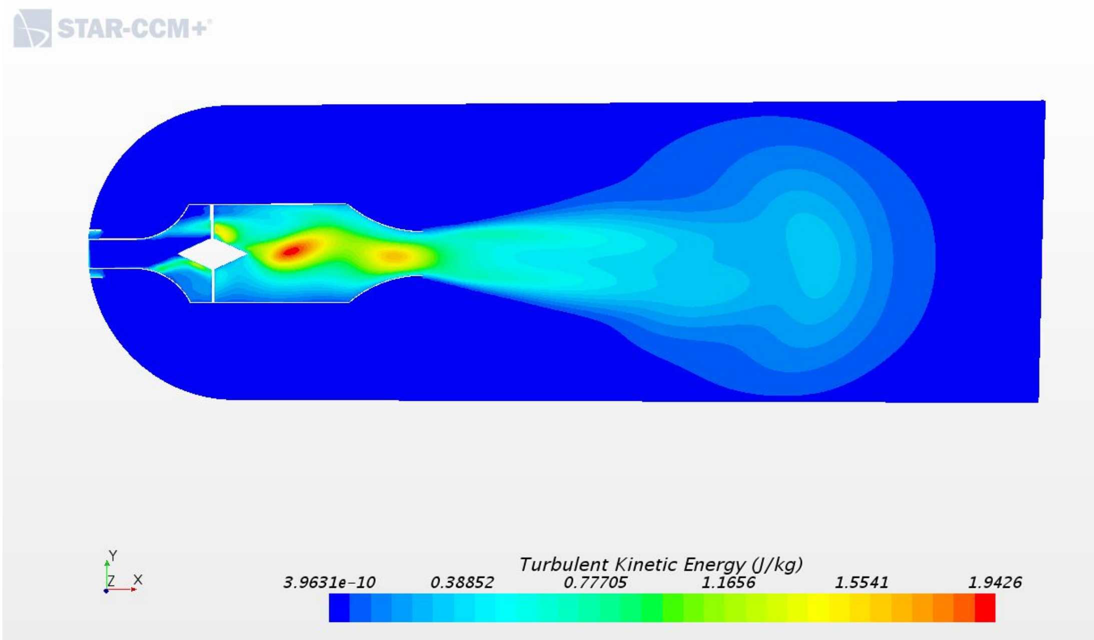

Figure A.3. Turbulent Kinetic Energy

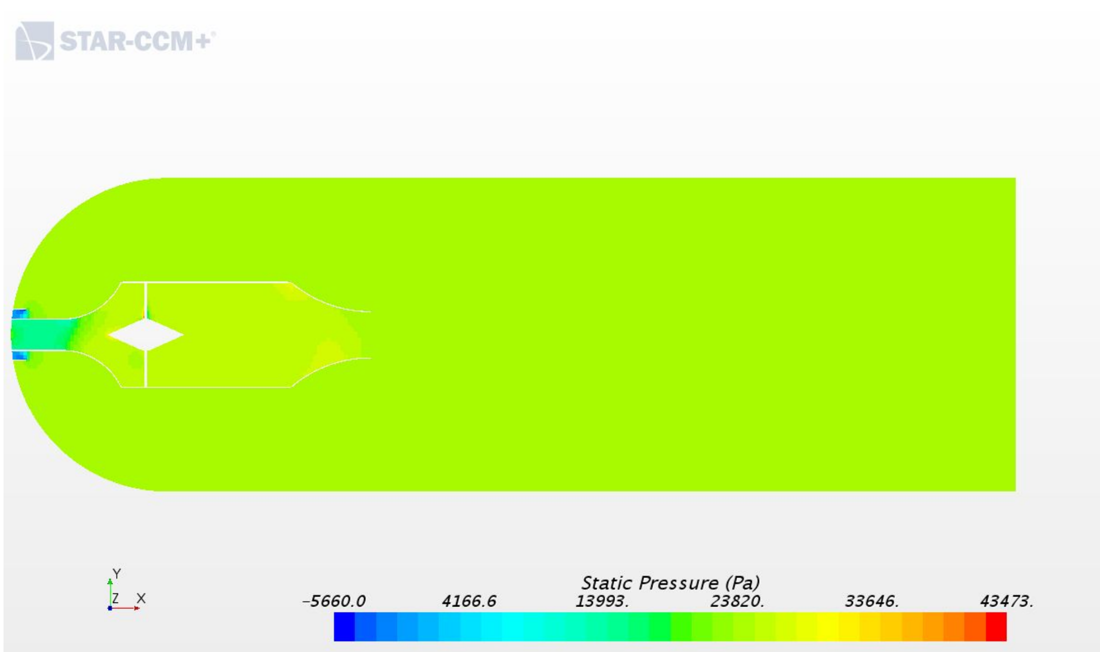

Figure A.4. Static Pressure

Mesh Independent Study

The computational mesh plays a major role in the outcome of the fluid calculations. For this reason a mesh independent study was conducted. Below we can see two separate computational meshes, each mesh was run with the same mathematical models and boundary conditions. The two solutions were then compared to insure that the mesh is not affecting the solution.

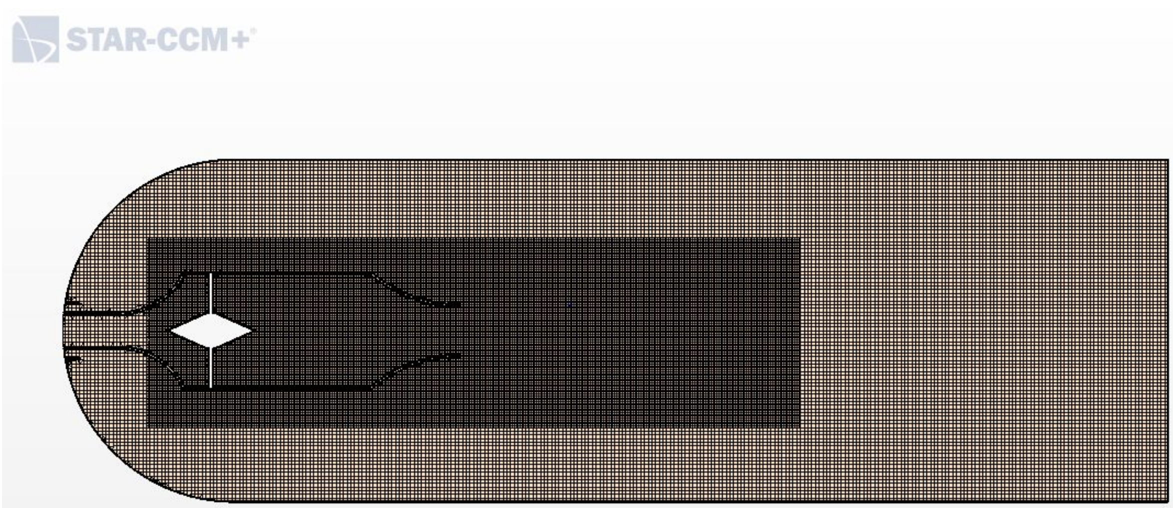

Figure A.5. Cross Section of Refined Computational Mesh

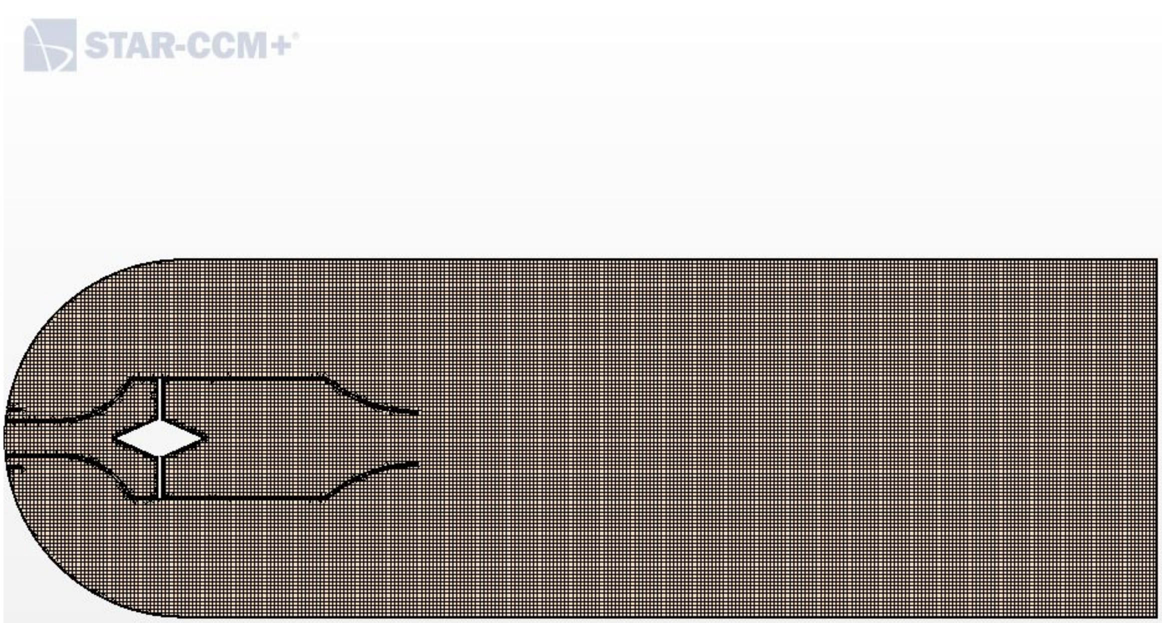

Figure A.6. Cross Section of Unrefined Computational Mesh.

Head Loss Calculations

To properly determine the operational conditions of the pump and piping system, calculations needed to be performed on the major and minor head losses in the system. The pumps volumetric output is directly dependent on the operational head. This can be calculated using a specialized derivation of Bernoulli's Energy Equation seen below. Because this in a computationally heavy iterative process, the team utilized Excel to run the calculations Figure A.7.

$$\left(\frac{P_s}{\rho} + \frac{V_s^2}{2} + gz_s\right) - \left(\frac{P_d}{\rho} + \frac{V_d^2}{2} + gz_d\right) = \sum_{n=1} f_n \frac{l_n}{D_n} \frac{V_n^2}{2} \tag{A.1}$$

$$\left(\frac{P_s}{\rho} + gz_s\right) - \left(\frac{P_d}{\rho}\right) = \sum_{n=1} f_n \frac{l_n}{D_n} \frac{V_n^2}{2} \tag{A.2}$$

$$\Delta P = P_s - P_d = \rho\left(\left(\sum_{n=1} f_n \frac{l_n}{D_n} \frac{V_n^2}{2}\right) - gz_s\right) \tag{A.3}$$

$$V_n = \frac{\dot{m}}{\rho\left(\pi \frac{D_n^2}{4}\right)} \tag{A.4}$$

$$Re = \frac{\rho V_n D_n}{\mu} \tag{A.5}$$

Constants	
Structure Diameter (ft)	1.75
Desired Flow Velocity (knots)	6
Density (slug/ft^3)	1.94
Pressure at Discharge End (lb/ft^2)	2352
Pressure at Suction end (lb/ft^2)	2205
Vapor Pressure@70F (lb/ft^2)	48
Kinematic Viscosity (s/ft^2)	0.0000121
Acceleration of Gravity (ft/s^2)	32.2

Ft to In Converter	
In	22
ft	1.833333333

Area Calculations	
Selected Suction Diameter (ft)	1.5
Min Area of Single Suction Pipe (ft)	1.7671459
Minimum Diameter of Ports (in)	12.727922
Selected Discharge Diameter (ft)	1.25
Area of Discharge Pipe (ft^2)	1.2271846
Available Area for Suction (ft^2)	1.914408

Velocity and Flow Rate Calcs	
Flow Velocity (ft/s)	10.13
Area of Structure Outlet (ft^2)	2.405
Voumetric Flow Rate (ft^3/s)	24.36
Mass Flow Rate (lb/s)	47.25

10" Suction Straight						
Length (ft)	Pipe Diameter (ft)	elocity (ft/s	eynolds Numbe	e/D	Friction Factor	Losses
1	0.84	44.5	5.95E+06	1.80E-04	0.0172	20.4
10" Elbow						
Length (ft)	Pipe Diameter (ft)	elocity (ft/s	eynolds Numbe	e/D	Friction Factor	Losses
16.8	0.84	44.0	5.92E+06	1.79E-04	0.0172	332.3
10" Suction Straight						
Length (ft)	Pipe Diameter (ft)	elocity (ft/s	eynolds Numbe	e/D	Friction Factor	Losses
1.2375	0.84	44.0	5.92E+06	1.79E-04	0.00172	2.4
10" Elbow						
Length (ft)	Pipe Diameter (ft)	elocity (ft/s	eynolds Numbe	e/D	Friction Factor	Losses
16.8	0.84	44.0	5.92E+06	1.79E-04	0.0172	332.3
14" to 10" Reducer (Sudden Contraction)						
Length (ft)	Pipe Diameter (ft)	elocity (ft/s	eynolds Numbe	e/D	Friction Factor	Losses
76.05	1.17	22.7	4.25E+06	7.81E-05	0.0179	298.6
10" Elbow						
Length (ft)	Pipe Diameter (ft)	elocity (ft/s	eynolds Numbe	e/D	Friction Factor	Losses
16.8	0.84	44.0	5.92E+06	1.79E-04	0.0172	332.3
10" Discharge Straight						
Length (ft)	Pipe Diameter (ft)	elocity (ft/s	eynolds Numbe	e/D	Friction Factor	Losses
2	0.84	44.0	5.92E+06	1.79E-04	0.00172	4.0
10" Elbow						
Length (ft)	Pipe Diameter (ft)	elocity (ft/s	eynolds Numbe	e/D	Friction Factor	Losses
16.8	0.84	44.0	5.92E+06	1.79E-04	0.0172	332.3
10" Discharge Straight						
Length (ft)	Pipe Diameter (ft)	elocity (ft/s	eynolds Numbe	e/D	Friction Factor	Losses
9	0.84	44.0	5.92E+06	1.79E-04	0.00172	17.8
Losses From Inner Section						
					ΔP (psf)	Losses
					784.37	404.3
						Total Losses
						Total ΔP
						4028.7

Figure A.7. Head loss calculations in Excel

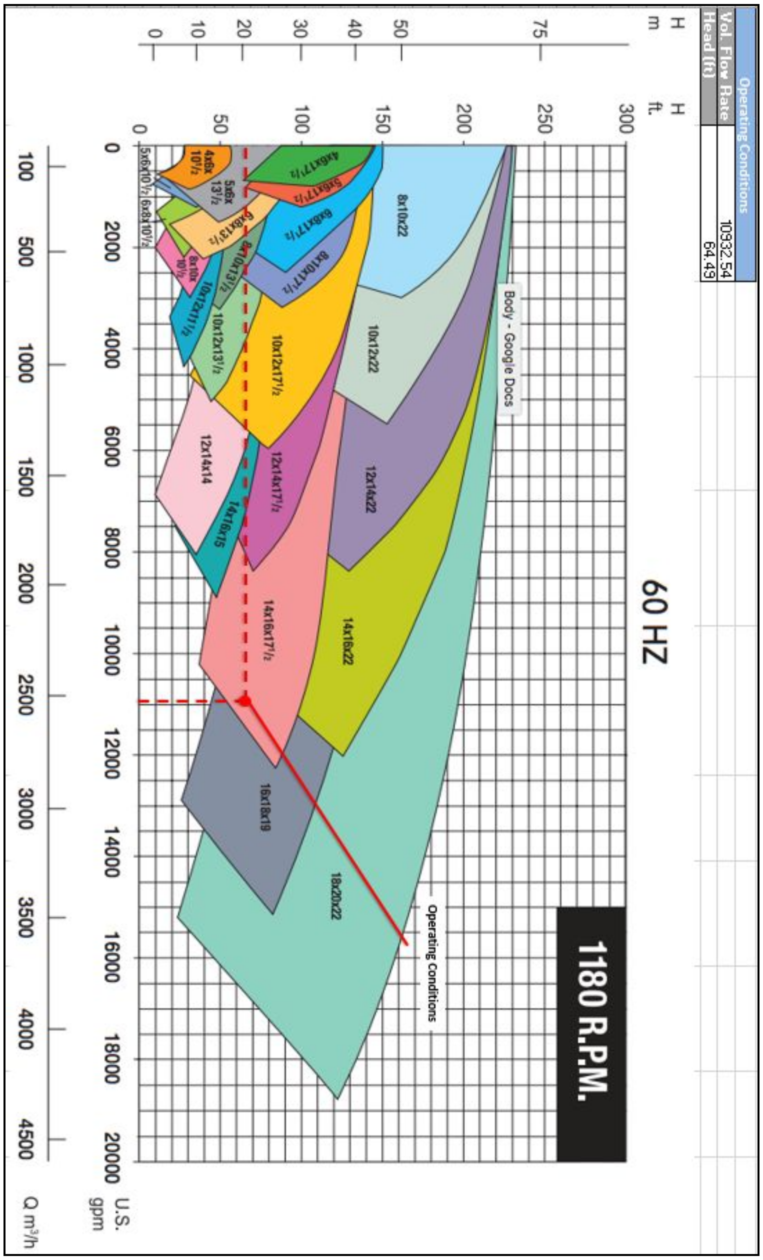

Figure A.8. Operating Conditions and Pump Curves

Mechanics Calculations

Flow Chamber Cylinder Mechanical Analysis

$D_{outer} := 48\ in$ $R_{outer} := \frac{D_{outer}}{2}$ $t := 0.25\ in$ $R_{inner} := R_{outer} - t$ $P := 23820\ Pa - 15000\ Pa$

$\sigma_{yield} := 31994\ psi$

Hoop Stress

$\frac{t}{R_{inner}} = 0.011$ Therefore thin walled pressure vessel equations within 5% accuracy. $\sigma_{hoop} := P \cdot \frac{R_{outer}}{t} = 122.806\ psi$

Longitudinal Stress

$\sigma_{longitudinal} := \frac{(P \cdot R_{outer})}{2 \cdot t} = 61.403\ psi$

Conclusion

The longitudinal and shear stress resulting from the differential pressure acting on the tank are negligible. This is already the smallest available pipe thickness, so it will be used.

Flow Chamber Framework Analysis

The vertical support members of the framework will be constructed of A500 rectangular steel tube unless analysis proves it unsuitable. The yield strength of this steel is 45,700 psi.

3x3x3/8 Tube

$W_{FC} := 1297.11\ lbf$ $A_{support} := 3^2\ in^2 - (3 - .375)^2\ in^2 = 2.109\ in^2$

$N_{supports} := 12$ $W_{pSupport} := \frac{W_{FC}}{N_{supports}} = 108.093\ lbf$

$\sigma_{axial} := \frac{W_{pSupport}}{A_{support}} = 51.244\ psi$ The maximum acceptable stress level is 1/2 of yield stress. This design would be overbuilt, and result in excessive construction and material costs.

$N_{supports} := 4$ $W_{pSupport} := \frac{W_{FC}}{N_{supports}} = 324.278\ lbf$

$\sigma_{axial} := \frac{W_{pSupport}}{A_{support}} = 153.732\ psi$ Due to this configuration being overbuilt, 4 supports of 3x3x11ga steel tube will be analyzed.

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3x3x11ga Tube

$$A_{support} := (3 \cdot 2)\ \mathbf{in}^2 - ((3 - .12)\ (2 - .12))\ \mathbf{in}^2 = 0.586\ \mathbf{in}^2 \qquad N_{supports} := 4$$

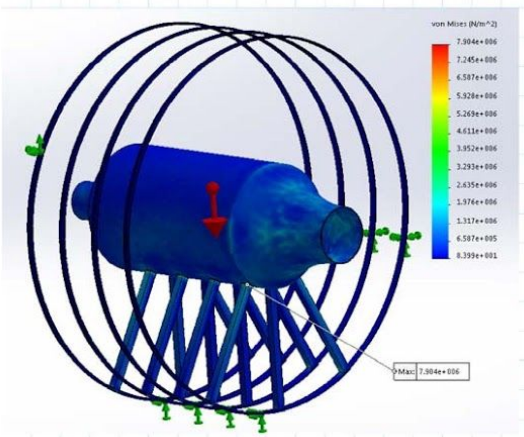
$$W_{pSupport} := \frac{W_{FC}}{N_{supports}} = 324.278\ \mathbf{lbf} \qquad \sigma_{axial} := \frac{W_{pSupport}}{A_{support}} = 553.753\ \mathbf{psi}$$

Conclusion

The supports will be constructed of this stock. While the induced stress due to the load of the flow chamber is well below 1/2 of yield stress, this size stock will be used to avoid failure from potential mishandling of the unit during installation and transportation. This also provides additional safety if there are any stress concentrations in the members as a result of the manufacturing process.

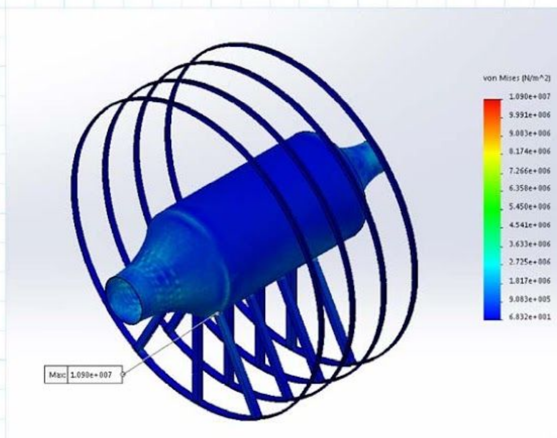
Computational Frame Analysis

Analysis of Static Loading



$$\sigma_1 := 7.904 \cdot 10^6\ \mathbf{Pa} = \left(1.146 \cdot 10^3\right)\ \mathbf{psi}$$

This first iteration of the design with radially aligned supports resulted in stress concentrations at the junction between the outer supports and tank, although acceptable.



$$\sigma_2 := 1.090 \cdot 10^7 \cdot \mathbf{Pa} = \left(1.581 \cdot 10^3\right)\ \mathbf{psi}$$

The second iteration incorporated structural tubes with thinner walls. The same stress concertations were still present.

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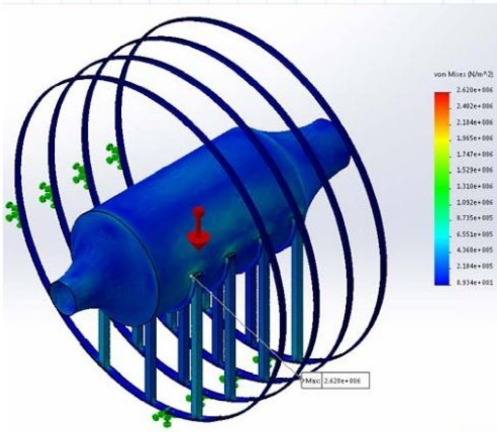
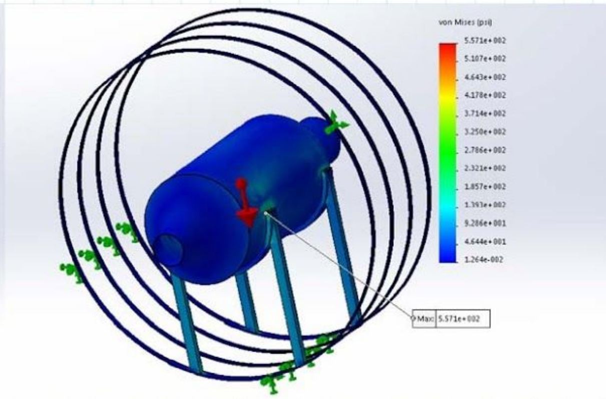




$\sigma_3 := 2.620 \cdot 10^6\ \boldsymbol{Pa} = 379.999\ \boldsymbol{psi}$

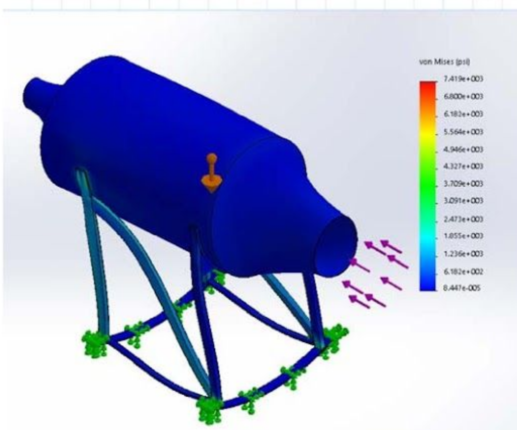
The third iteration incorporated the same type of structural tubing with vertically oriented supports. This resulted in a significant reduction of stress at welded joints.

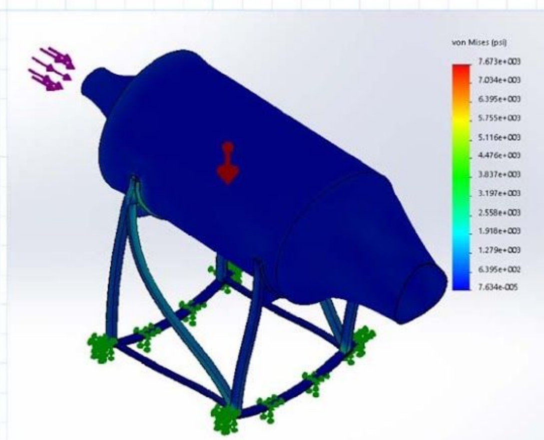
$\sigma_4 := 557.1\ \boldsymbol{psi}$

The final iteration reduced the number of redundant supports to four. This resulted in an acceptable, robust design using minimal, procurable material.

Analysis of Framework Under Other Types of Loads

In order to create a more robust frame capable of supporting unforeseen loading that could occur during transportation, storage supplementary reinforcements were incorporated. These include gussets at the junctions of the vertical support members, a tank saddle, and diagonal reinforcement beams.





$\sigma_5 := 7.419 \cdot 10^3\ \boldsymbol{psi}$

$\sigma_6 := 7.673 \cdot 10^3\ \boldsymbol{psi}$

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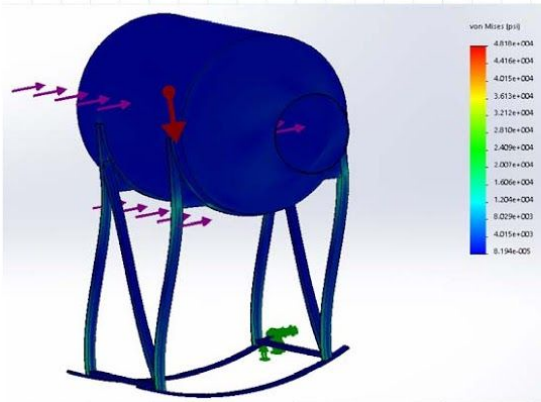
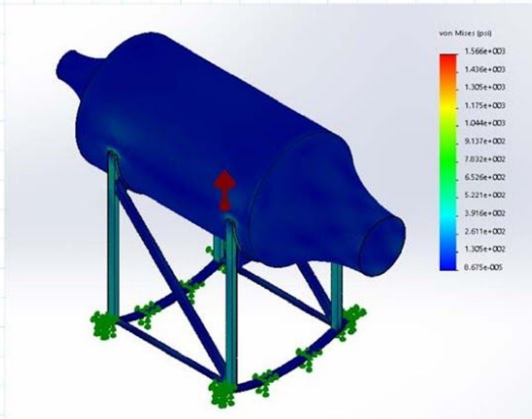


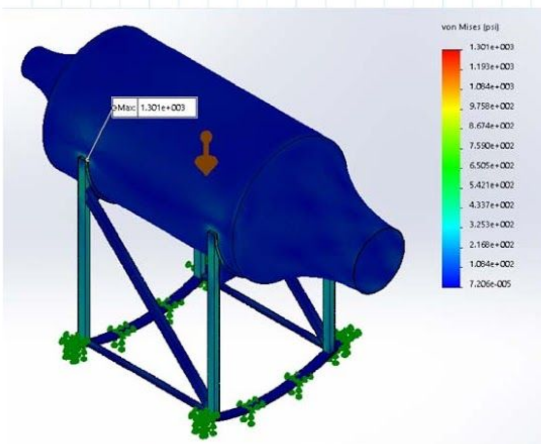


$\sigma_7 := 4.818 \cdot 10^4$ *psi*

$\sigma_8 := 1.566 \cdot 10^3$ *psi*

The model was analyzed under 2,000 lbf loads in 3 different directions and for the effect of lifting the unit by the base. The resultant stresses under these conditions remained within the design parameters. By meeting this condition, it was deemed this structural reinforcement of the tank was sufficient.

Conclusion of Final Frame Design



This is the results of FEA analysis of the final design of the frame under operating conditions. Robust and compliant with design criteria.

$\sigma_7 := 1.301 \cdot 10^3$ *psi*

Non-Commercial Use Only

APPENDIX B. Assembly and Installation Plan

All parts involved in the assembly of the flow generation device are commercially produced and purchased. The project is split into four main categories: inner distribution tank and mounting system, piping system, and pump. This is a recommended assembly plan for the Naval Sea Systems Command to take into consideration and augment at their discretion. The plan is to be applied to the pressure tank located in Keyport, Washington. Any actual manufacturing or assembly by the flow generation capstone group will be done on a scaled model of the original tank. All referenced parts and drawings can be found in Appendices D and E respectively. Parts are distinguished by the letters FG followed by a number.

Pre-assembly

Pre-assembly of the main structures of the flow generation device will need to occur only once. They have been designed to interact with the pressure vessel without interfering with pre-existing geometry. Drawing 3 represents the flow chamber sub-assembly consisting of two concave nozzles (FG6 and FG7) that are situated on opposite sides of a large pipe (FG16). The nozzles will be welded to the large pipe. A conical diffuser (Drawing 3.3.1) will be secured concentrically inside of the flow chamber using four 1.5 inch round bars (Drawing 3.3.2). A flange (FG5) will be installed on the nozzle facing the external pump by welding. A honeycomb structure (Drawing 3.2) used to reduce turbulence will be welded inside of the exit of the flow chamber.

The mounting structure for the flow chamber found in Drawing 4 must be welded together. This may be done from the top down starting with the saddles (Drawing 4.2) should be welded to the side supports (Drawing 4.3). The gussets (Drawing 4.6) should be welded in between the support and the saddle to insure proper angles and alignment. The lateral supports and side struts (Drawings 4.4 and 4.5) should then be used to join the two saddle structures. This is also done by welding. The rib interfaces (Drawing 4.1) should be welded underneath the side supports last to insure proper fit. A punch or drill hole will need to be made to the side of the center in the rib mounts to allow for later installation into the NAVSEA pressure vessel.

The piping system consist of a suction section and an outflow section. These will be attached to each other as well as the pipe and flow chamber by the use of flanges. The suction section of the pipe found in Drawing 7 consists of FG9, FG4 (16 inch version), standard 16 inch pipe (FG28), FG6, and FG27. These will be welded together in the same manner as shown in the drawing. The outflow section is broken down into two halves: the internal and external sections. The internal consists of a standard 10 inch pipe (FG27) connected to a flange (FG5). These will be welded together. This can be seen in Drawing 6. The external section of the pipe found in Drawing 5 consists of parts FG8, FG7, FG4, FG27, FG4, another section of 10 inch standard pipe, FG5, another FG5, and FG27. Following the Drawing, all parts will be welded besides the two flanges (FG5) which will be attached with a gasket and bolts (FG10). Drawing 8 is a steel plate that will be used to connect the piping systems to the pressure vessel. It should be made to the specifications shown on the drawing. This can be done by any fabrication systems that NAVSEA chooses. The internal, external, and suction sections of piping can be welded onto the plate as shown in Drawing 2. The flanges in the outflow piping section may be unbolted for transportation or installation purposes.

Pressure Vessel and Flow Generation Assembly Integration

The pressure vessel at the Keyport location acts as a shell that splits into two separate segments. The smaller segment that contains a 24 inch flange and port will be where the flow generation assembly will be placed. The distribution tank and mounts (Drawings 3 and 4) will be installed inside of this section. The facility possess a crane system that will be able to lift the distribution tank into place. The internal structure of the pressure vessel contains T-shaped stiffeners that run along the perimeter of the vessel. These will be used to attach the rib interfaces of the mounting system to the pressure vessel. A hole will be drilled or punched through the stiffener at the place where the hole was placed in the rib interface. A key will be used to keep these locked in place. The flow chamber can the be craned into place and rested inside the saddles of the mounting assembly. The flow chamber will later be tack welded to the mounting assembly once the piping system is in place. The internal piping system will be bolted by it flange to the flow chamber using a gasket and standard bolts (FG10). The flow chamber will need to be adjusted with the crane so that end of the pipe is flush with the face of the pressure vessels 24 in flange port.

All piping system parts and the pump can be craned into position using the facilities equipment. The steel plate found in Drawing 8 will be bolted (FG13) to the external flange face of the pressure vessel. This has already been welded to the external portions of the piping system so it must be put in place gently as to not damage the portion of the pipe inside the pressure vessel. The pressure vessel will most likely need to be closed at this point in the installation process so that the pump can be positioned under the piping system. This is assuming that the half of the pressure vessel the capstone team is working with moves when the pressure vessel opens and closes. The pump and suction piping can be secured using bolts (FG12). The external portion of the piping system can be mounted last at both ends by flanges. One attaches to pump and one to the other piping section using parts FG11 and FG 10 respectively. At this point, the system is complete and ready to use after the facilities engineers test of leaks or bad flange connections.

APPENDIX C. Project Management Plan and Project Schedule

Group Structure

The student team, composed of four members will be lead by the group leader. The group leader will facilitate progress during their tenure. Their responsibilities include: submission of weekly deliverables, updating the Gantt chart and notebook, writing the weekly progress memo and sending reminders for group meetings. The group leader will alternate every two weeks until each member has held the position, after which leaders will be decided by consensus.

Each team member is responsible for completing their delegated tasks by the agreed upon date. If members do not uphold their responsibility their shortcoming will be noted in their peer review.

Communication and Data Storage

The team will meet twice a week to delegate tasks, gauge progress, and discuss ideas. All teammates will show up to group meetings unless they have previously discussed with the team why they can not make the meeting. Our meetings will be held on Monday from 2-3 pm, in a predetermined location in the library. The second weekly meeting will be held on Tuesday from 2-3 pm in Roberts 201E with Dr. Erick Johnson our faculty advisor. The current group leader will be responsible for bringing the group notebook to each meeting and recording key discussion points.

The team has decided to utilize text messaging as the main form of communication between group members. Google Drive will be used as a cloud service to store all our progress, papers, memos, and other information. Contact information for the NAVSEA representatives, our MSU mentor, and extra contacts for teammates is also located on the drive. The Gantt Chart will be updated weekly. Any edited/new versions of files will be given a designation of version numbers 1.1, 1.2, etc. to avoid losing previous versions of information. All will be stored on the drive where it can be accessed by everyone. Dr, Johnson will also be given access to this drive.

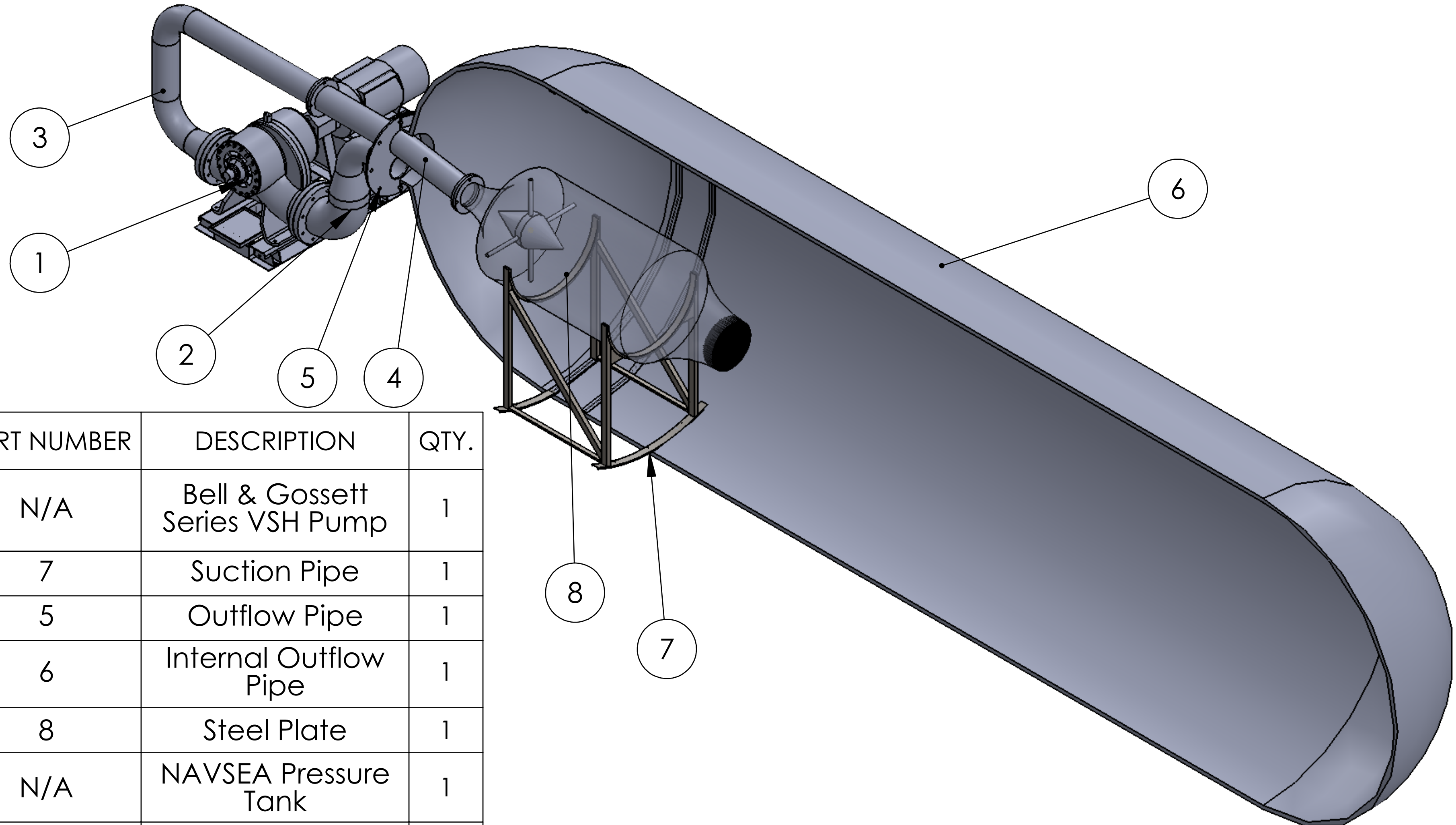
All teammates are required to communicate information and keep each other updated as often as possible. If a teammate is unable to complete a task, we have agreed to be open and speak with one another about helping to finish the assignment.

APPENDIX D. Purchased Parts List

Part Breakdown			
Part Description	Part Number	Quantity	Manufacturer/Supplier
Bell And Grosset VSX Water Pump	FG1	1	https://www.mrosupply.com/
24" Blind Flange	FG2	1	https://www.trupply.com
10" Schedule 40 Staight Pipe (ft)	FG3	13	https://www.metalsdepot.com
10" Schedule 40 Pipe Elbow	FG4	4	https://www.trupply.com
10" Flange CL150	FG5	4	https://www.trupply.com
10" to 16" Schedule 40 Reducer	FG6	1	https://www.trupply.com
10" to 14" Schedule 40 Reducer	FG7	1	https://www.trupply.com
14" Flange CL150	FG8	1	https://www.trupply.com
16" Flange CL150	FG9	1	https://www.trupply.com
10" Flange Gasket & Bolt Pack CL150	FG10	2	https://www.trupply.com
14" Flange Gasket & Bolt Pack CL150	FG11	1	https://www.trupply.com
16" Flange Gasket & Bolt Pack CL150	FG12	1	https://www.trupply.com
24" Flange Gasket & Bolt Pack CL150	FG13	1	https://www.trupply.com
10" to 48" Nozzle	FG14	1	http://fittings-en.com
48" to 21" Nozzle	FG15	1	http://fittings-en.com
48" Pipe	FG16	1	http://fittings-en.com
shipping for items above	FG17	1	http://fittings-en.com
Vertical Support	FG18	4	https://www.metalsdepot.com
Rib Interface	FG19	2	http://www.pacific-steel.com
Side Strut	FG20	2	https://www.metalsdepot.com
Saddle Mount	FG21	2	https://www.metalsdepot.com
Gusset	FG22	4	http://www.pacific-steel.com
Lateral Supports	FG23	2	https://www.metalsdepot.com
1.5" HR A36 Round Bar (ft)	FG24	6	http://www.strongholdfabrication.com/
Conical Diffuser (14" Solid Steel Stock) (ft)	FG25	2	http://www.strongholdfabrication.com/
1"X2"X21" Hexagonal Mesh	FG26	1	http://www.marcospecialtysteel.com
10" Pipe (ft)	FG27	8	https://www.metalsdepot.com
16" Pipe (ft)	FG28	3	http://www.saginawpipe.com

Figure D.1. Parts List

APPENDIX E. Engineering Drawings



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	N/A	Bell & Gossett Series VSH Pump	1
2	7	Suction Pipe	1
3	5	Outflow Pipe	1
4	6	Internal Outflow Pipe	1
5	8	Steel Plate	1
6	N/A	NAVSEA Pressure Tank	1
7	4	Mouting Assembly	1
8	3	Flow Chamber Assembly	1

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/16"
ANGULAR: MACH ± .5 BEND ± 1
TWO PLACE DECIMAL ± 0.03"
THREE PLACE DECIMAL ± 0.005"

INTERPRET GEOMETRIC TOLERANCING PER:

COMMENTS:

DO NOT SCALE DRAWING

Group:
NAVSEA Flow Generation

Members:
Nicholas Grochowski
Montana Marks
Joel Seeley
Raven Williams

DATE: 12/2017

MATERIAL:

MSU M.& I.E. DEPT.

TITLE: Full Assembly with Tank

SIZE: A | DWG. NO.: 1 | REV: A

SCALE: 1:60 | SHEET 1 OF 1

5 4 3 2 1

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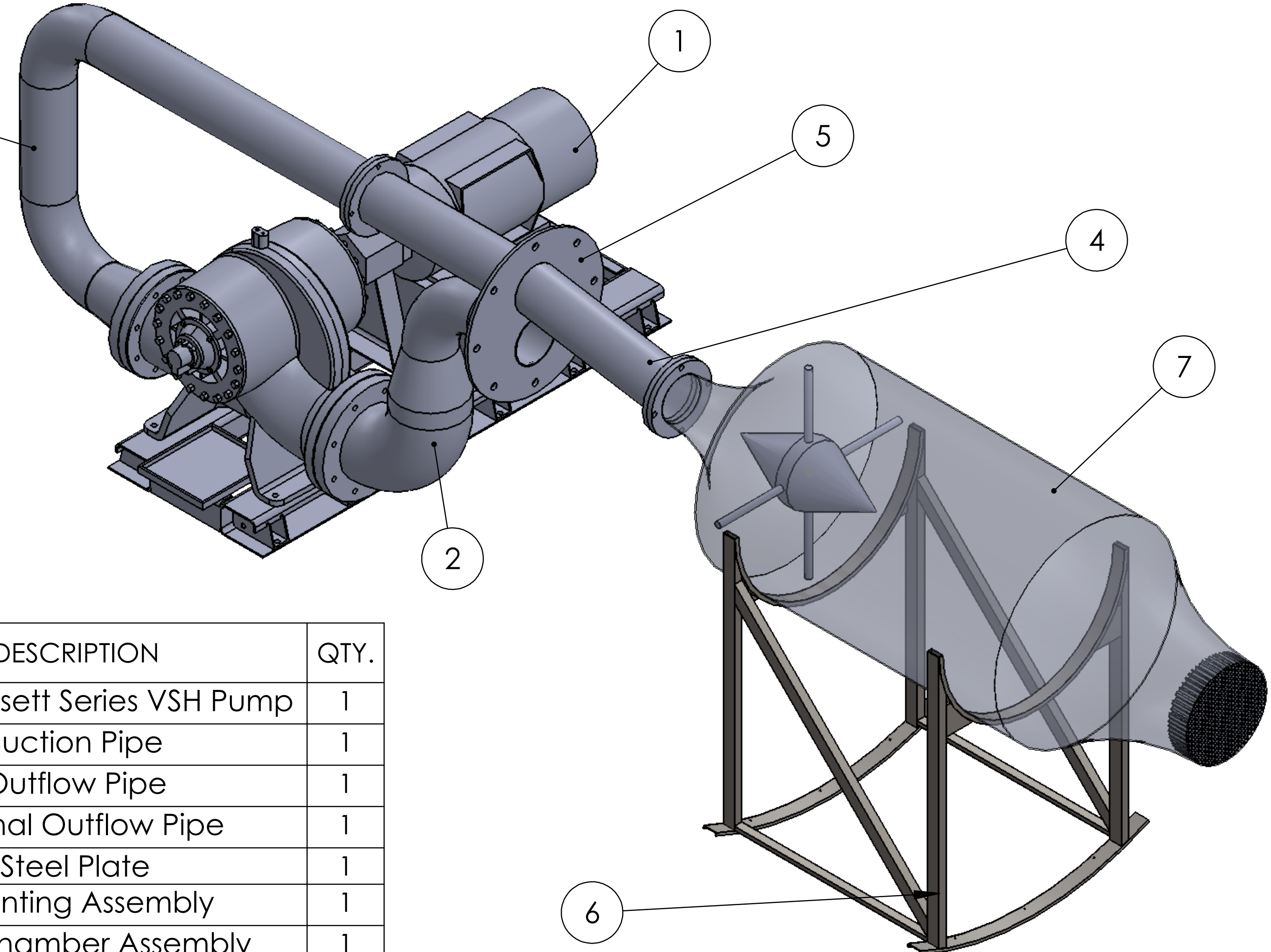

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	N/A	Bell & Gossett Series VSH Pump	1
2	7	Suction Pipe	1
3	5	Outflow Pipe	1
4	6	Internal Outflow Pipe	1
5	8	Steel Plate	1
6	4	Mounting Assembly	1
7	3	Flow Chamber Assembly	1

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/16"
ANGULAR: MACH ± 5 BEND ± 1
TWO PLACE DECIMAL ± 0.03"
THREE PLACE DECIMAL ± 0.005"
INTERPRET GEOMETRIC TOLERANCING PER:
COMMENTS:
DO NOT SCALE DRAWING

Group: NAVSEA Flow Generation

Members:
Nicholas Grochowski
Montana Marks
Joel Seeley
Raven Williams

DATE: 12/2017

MATERIAL:

MSU M.& I.E. DEPT.

TITLE: Full Assembly without Tank

SIZE: A | DWG. NO.: 2 | REV: A

SCALE: 1:30 | SHEET 1 OF 1

5 4 3 2 1

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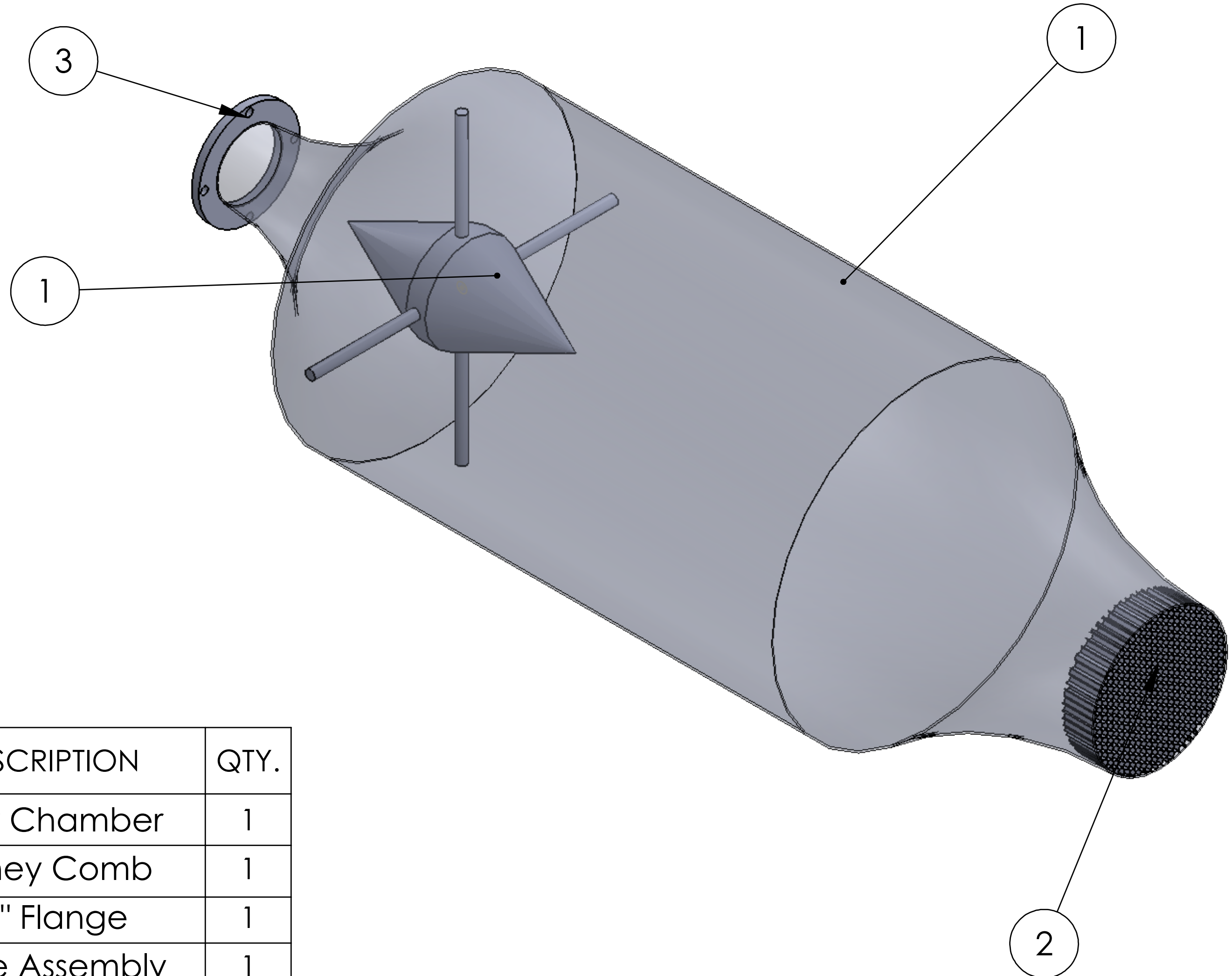

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	3.1	Flow Chamber	1
2	3.2	Honey Comb	1
3	N/A	10" Flange	1
4	3.3	Spike Assembly	1

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/16"
ANGULAR: MACH ± 5 BEND ± 1
TWO PLACE DECIMAL ± 0.03"
THREE PLACE DECIMAL ± 0.005"

INTERPRET GEOMETRIC TOLERANCING PER:

COMMENTS:

DO NOT SCALE DRAWING

Group:
NAVSEA Flow Generation

Members:
Nicholas Grochowski
Montana Marks
Joel Seeley
Raven Williams

DATE:
12/2017

MATERIAL:

MSU M.& I.E. DEPT.

TITLE:
Flow Chamber Assembly

SIZE A | DWG. NO. 3 | REV A

SCALE: 1:20 | SHEET 1 OF 1

5 4 3 2 1

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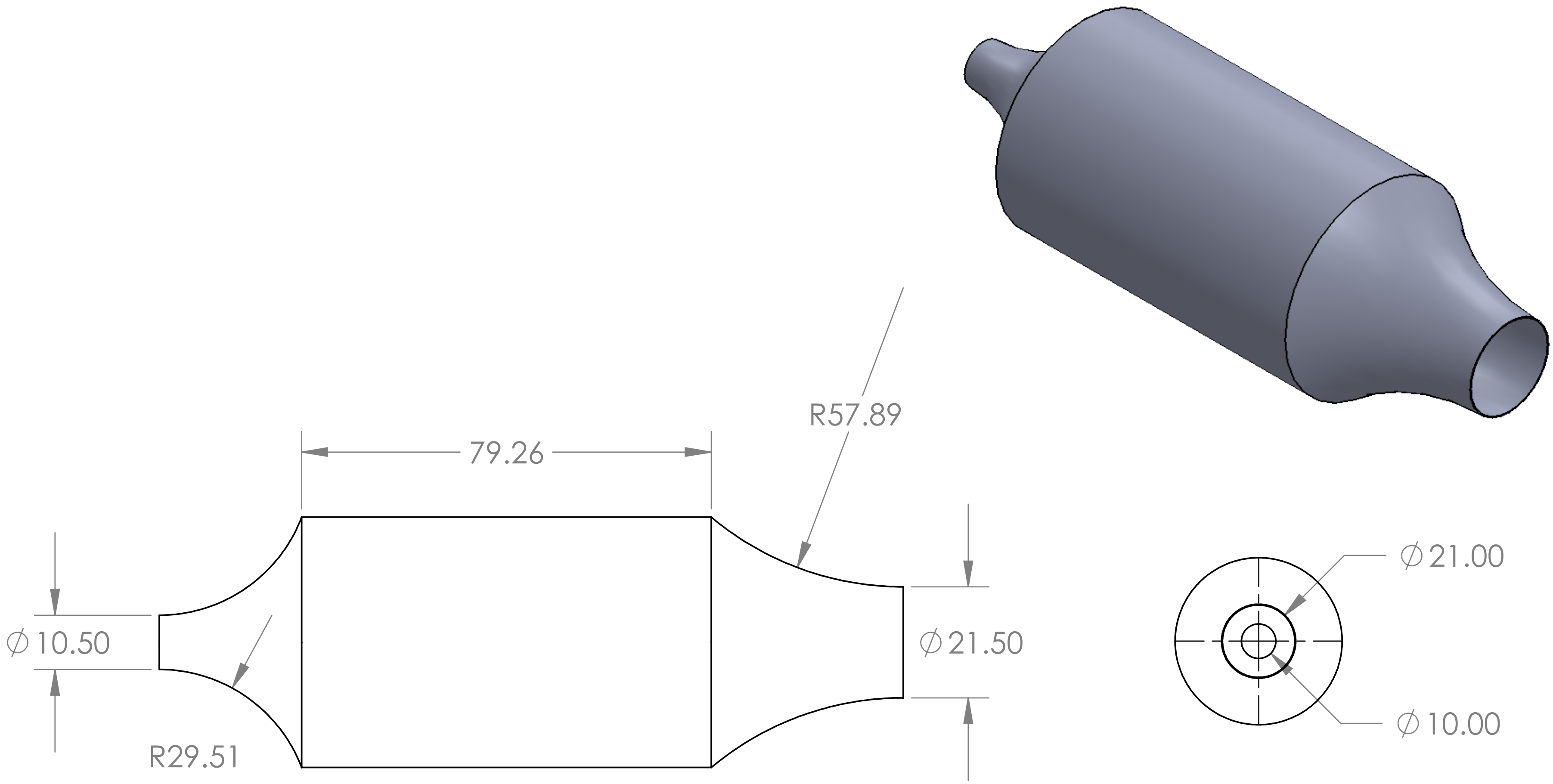

Tank has a uniform thickness of 0.25"

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/16" ANGULAR: MACH ± 5 BEND ± 1 TWO PLACE DECIMAL ± 0.03" THREE PLACE DECIMAL ± 0.005"	Group: NAVSEA Flow Generation	MONTANA MSU M.& I.E. DEPT.
INTERPRET GEOMETRIC TOLERANCING PER:	Members: Nicholas Grochowski Montana Marks Joel Seeley Raven Williams DATE: 12/2017	TITLE: Flow Chamber
COMMENTS:		SIZE A · DWG. NO. 3.1 · REV A
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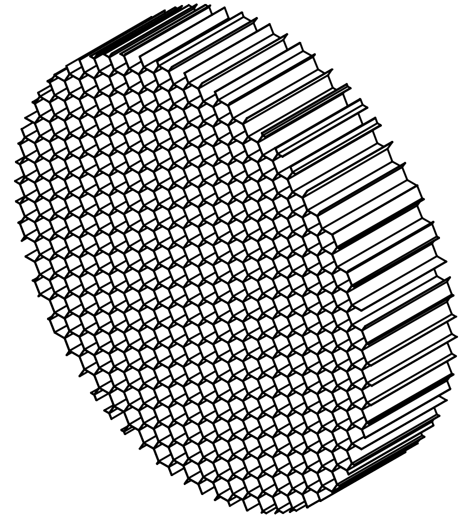
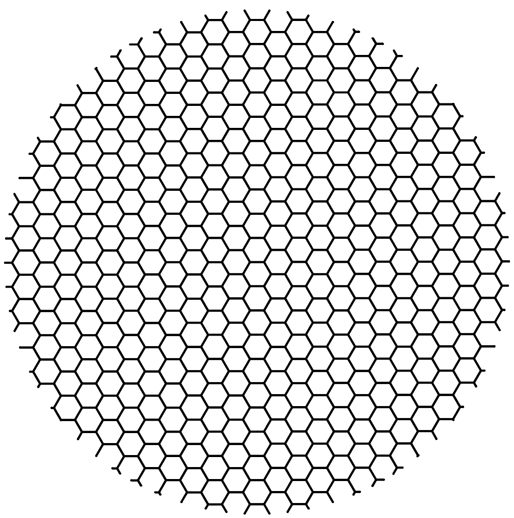


Honey Comb is cut to a diameter of 21"
and a depth of 5"



Hexagons are 0.58" in length and 0.01" thick

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/16" ANGULAR: MACH ± 5 BEND ± 1 TWO PLACE DECIMAL ± 0.03" THREE PLACE DECIMAL ± 0.005"	Group: NAVSEA Flow Generation		MONTANA MSU M.& I.E. DEPT.
INTERPRET GEOMETRIC TOLERANCING PER:	Members: Nicholas Grochowski Montana Marks Joel Seeley Raven Williams	DATE: 12/2017	TITLE: Honey Comb
COMMENTS:			SIZE A · DWG. NO. 3.2 · REV A
DO NOT SCALE DRAWING	MATERIAL:		SCALE: 1:8 · SHEET 1 OF 1

5 4 3 2 1

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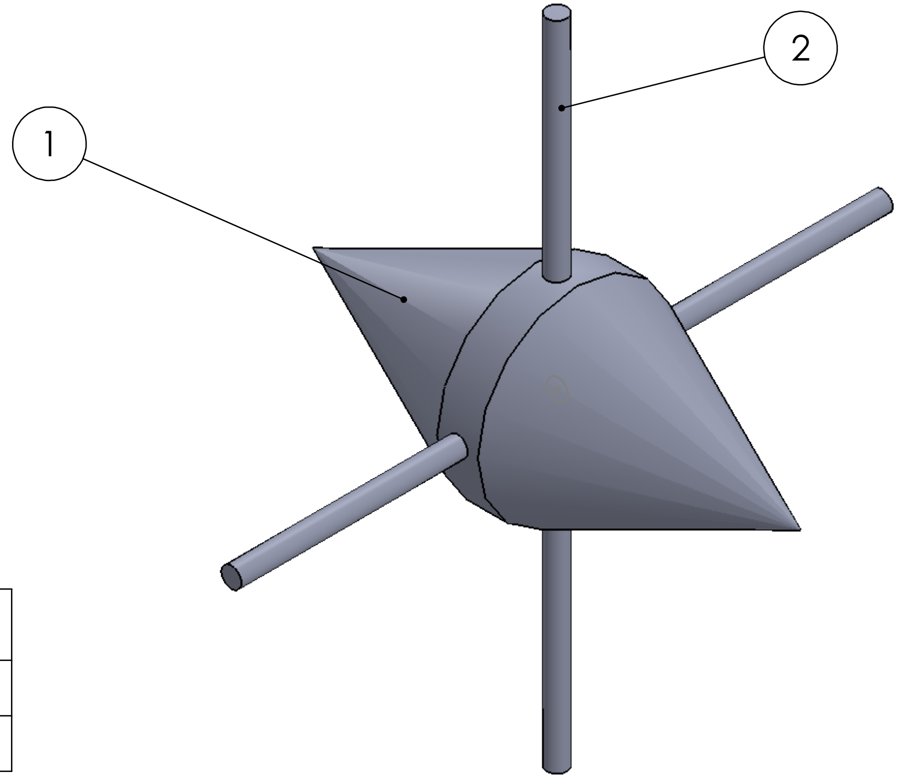

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	3.3.1	Spike	1
2	3.3.2	Spike Supports	4

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/16" ANGULAR: MACH ± 5 BEND ± 1 TWO PLACE DECIMAL ± 0.03" THREE PLACE DECIMAL ± 0.005"	Group: NAVSEA Flow Generation		MSU M.& I.E. DEPT.
INTERPRET GEOMETRIC TOLERANCING PER:	Members: Nicholas Grochowski Montana Marks Joel Seeley Raven Williams	DATE: 12/2017	TITLE: Spike Assembly
COMMENTS:			SIZE A · DWG. NO. 3.3 · REV A
DO NOT SCALE DRAWING	MATERIAL:		SCALE: 1:10 · SHEET 1 OF 1

5 4 3 2 1

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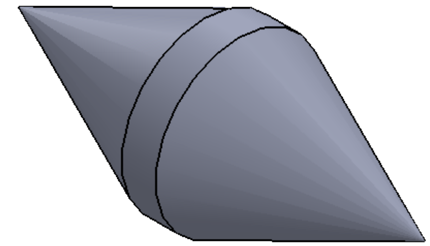

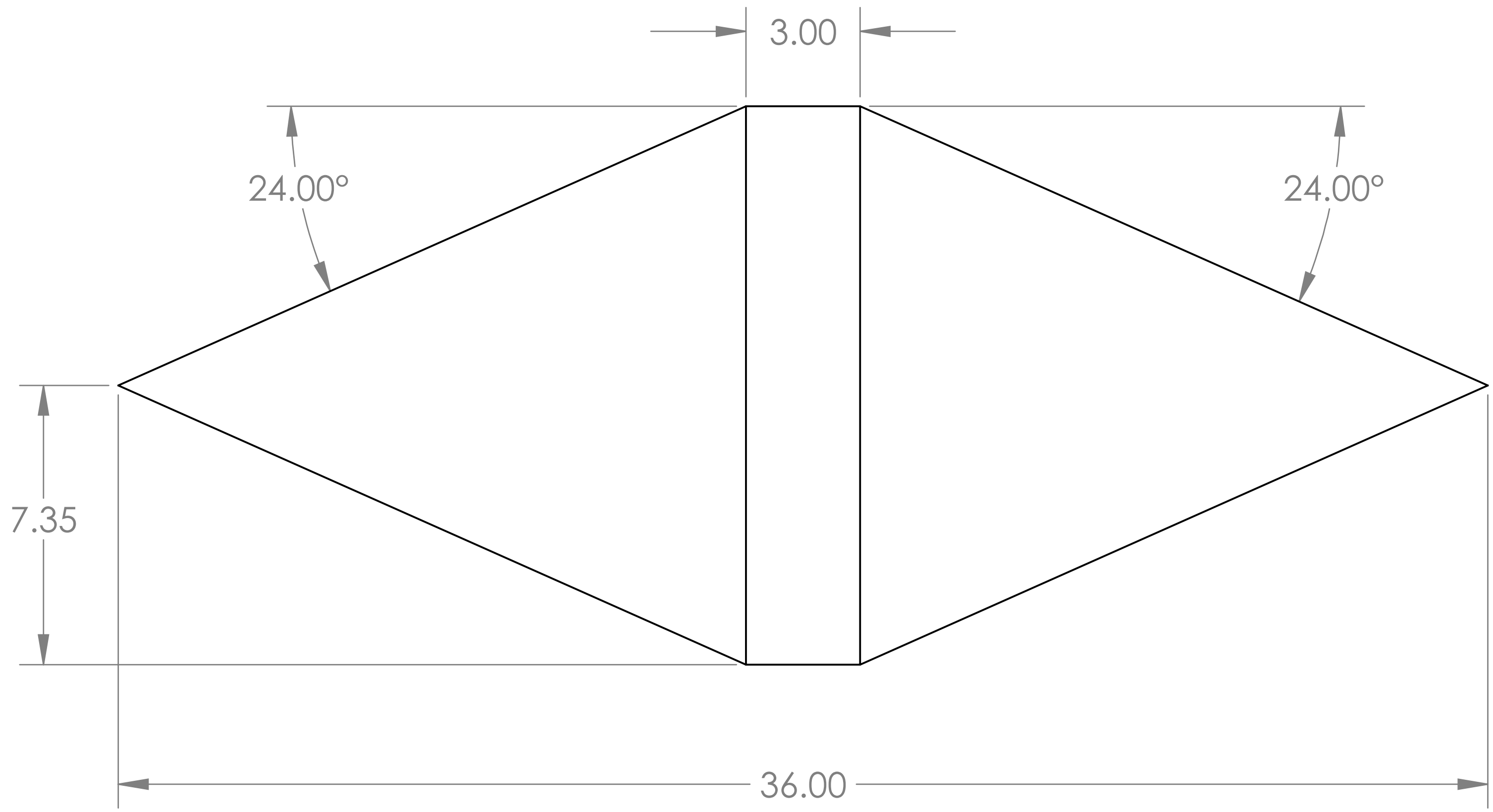

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ANGULAR: MACH ± 5 BEND ± 1
TWO PLACE DECIMAL ± 0.03"
THREE PLACE DECIMAL ± 0.005"
INTERPRET GEOMETRIC TOLERANCING PER:
COMMENTS:
DO NOT SCALE DRAWING

Group:
NAVSEA Flow Generation

Members:
Nicholas Grochowski
Montana Marks
Joel Seeley
Raven Williams

DATE: 12/2017

MATERIAL:

MSU M.& I.E. DEPT.

TITLE: Spike

SIZE A

DWG. NO. 3.3.1

REV A

SCALE: 1:5

SHEET 1 OF 1

5 4 3 2 1

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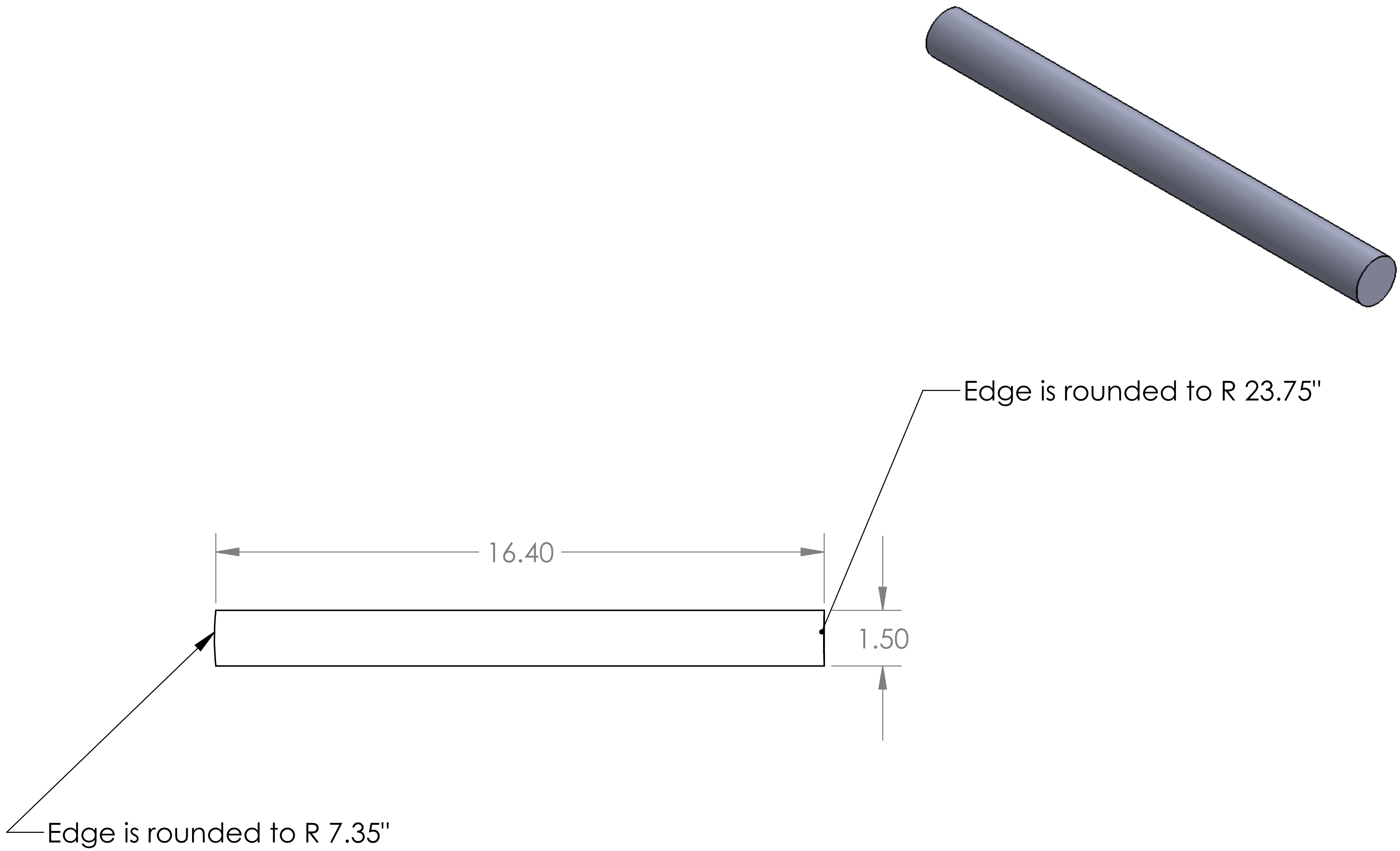

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INTERPRET GEOMETRIC TOLERANCING PER:	Members: Nicholas Grochowski Montana Marks Joel Seeley Raven Williams	DATE: 12/2017	TITLE: Spike Supports
COMMENTS:			SIZE A · DWG. NO. 3.3.2 · REV A
DO NOT SCALE DRAWING	MATERIAL:		SCALE: 1:4 · SHEET 1 OF 1

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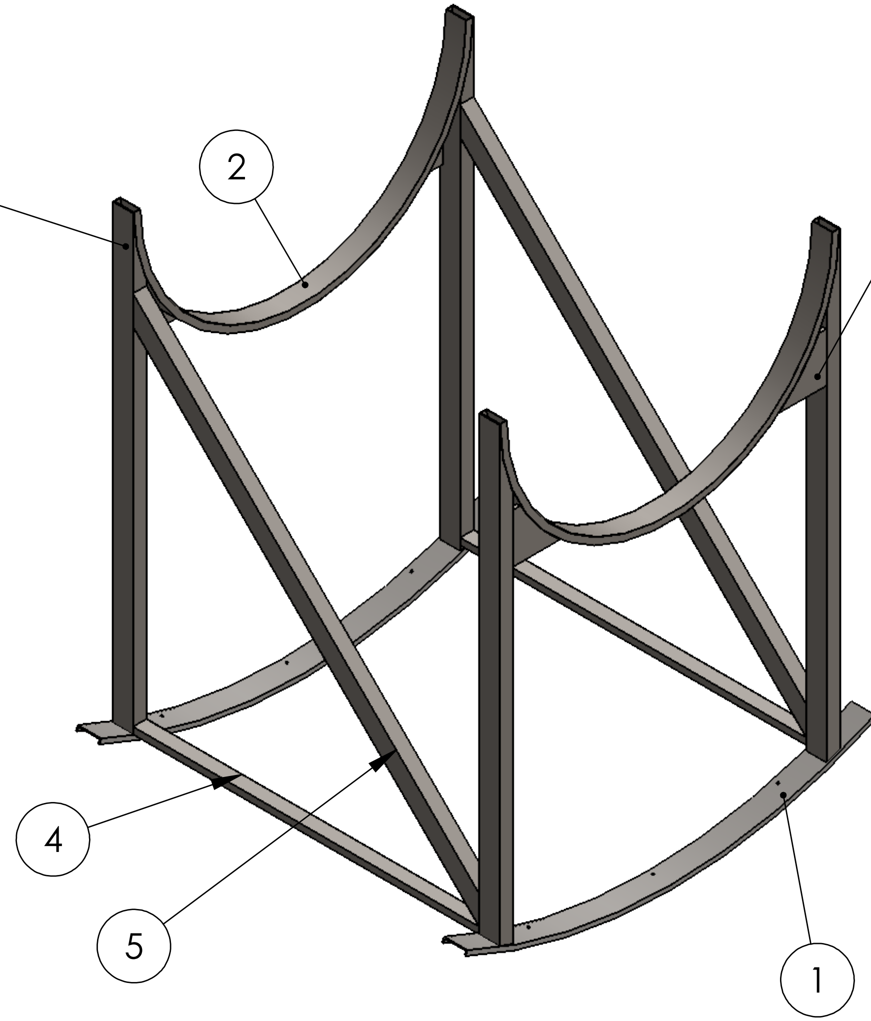

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	4.1	Rib Interface	2
2	4.2	Saddle	2
3	4.3	Side Support	4
4	4.4	Lateral Support Strut	2
5	4.5	Side Strut	2
6	4.6	Gusset	4

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/16"
ANGULAR: MACH ± 5 BEND ± 1
TWO PLACE DECIMAL ± 0.03"
THREE PLACE DECIMAL ± 0.005"
INTERPRET GEOMETRIC TOLERANCING PER:
COMMENTS:
DO NOT SCALE DRAWING

Group:
NAVSEA Flow Generation

Members:
Nicholas Grochowski
Montana Marks
Joel Seeley
Raven Williams

DATE:
12/2017

MATERIAL:

MSU M.& I.E. DEPT.

TITLE:
Mounting Assembly

SIZE: A
DWG. NO.: 4
REV: A
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SHEET 1 OF 1

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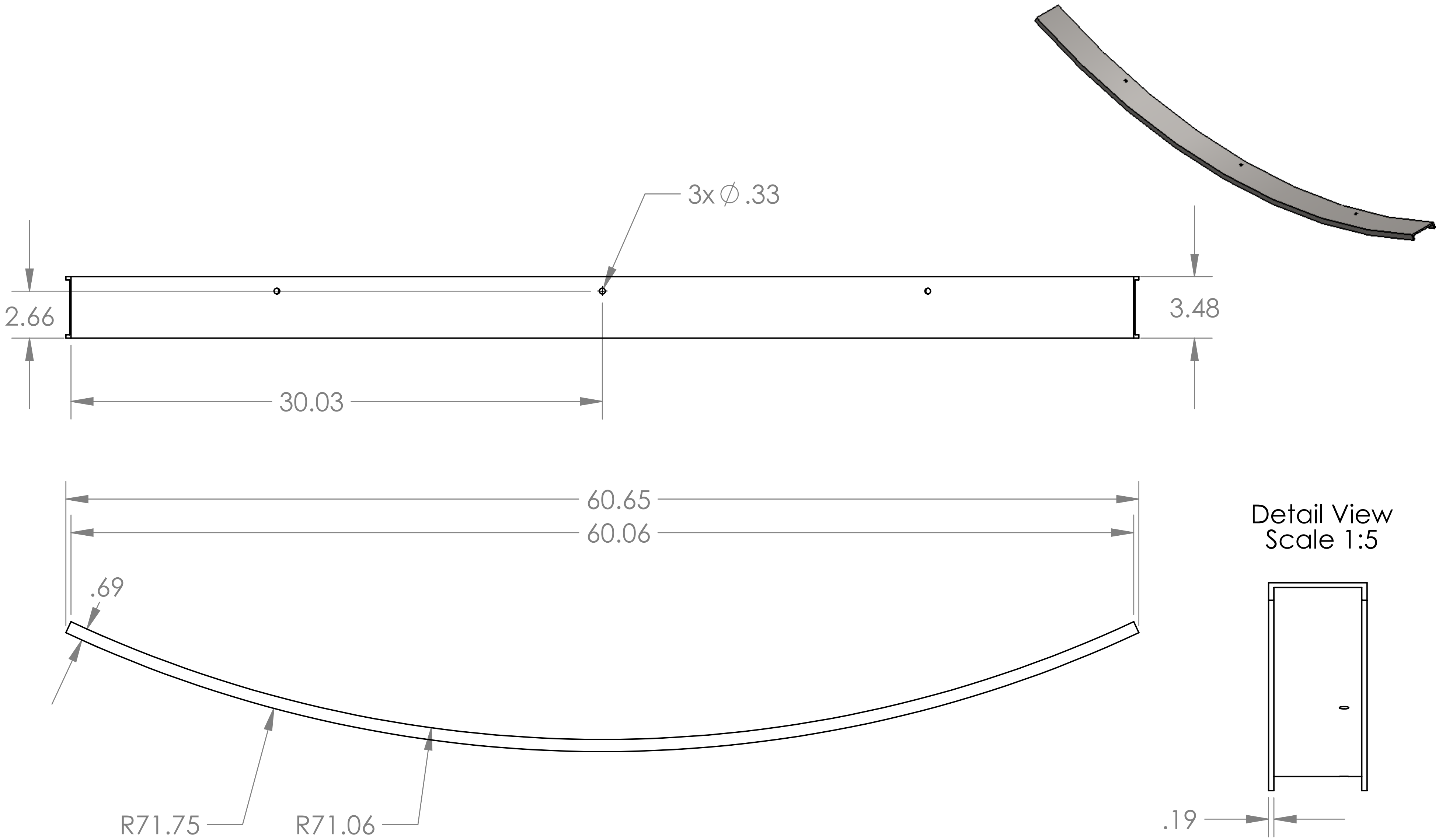

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ANGULAR: MACH ± 5 BEND ± 1
TWO PLACE DECIMAL ± 0.03"
THREE PLACE DECIMAL ± 0.005"
INTERPRET GEOMETRIC TOLERANCING PER:
COMMENTS:
DO NOT SCALE DRAWING

Group:
NAVSEA Flow Generation

Members:
Nicholas Grochowski
Montana Marks
Joel Seeley
Raven Williams

DATE: 12/2017

MATERIAL: ASTM A569 Hot Rolled Steel

MSU M.& I.E. DEPT.

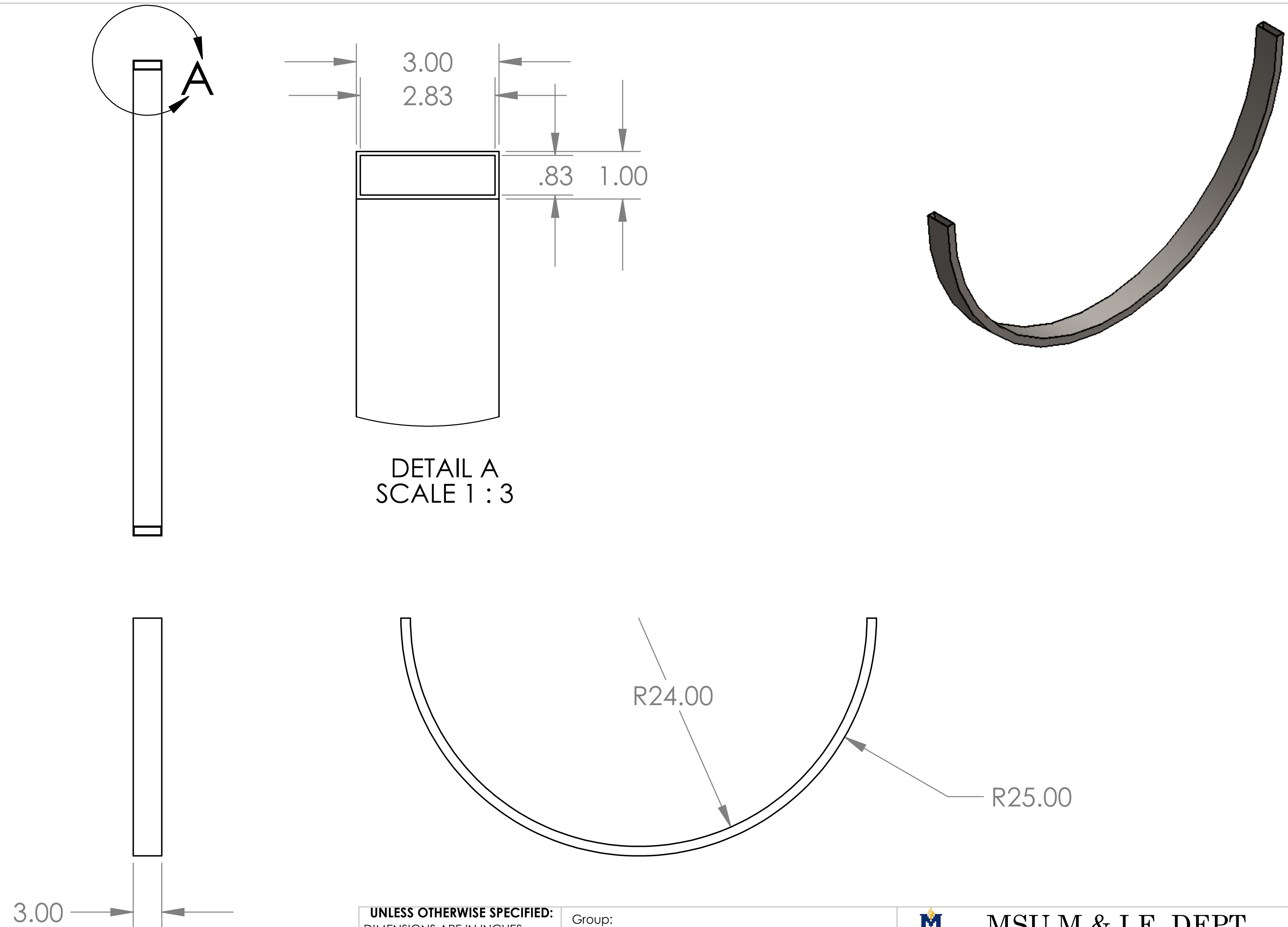
TITLE: Rib Interface

SIZE A | DWG. NO. 4.1 | REV A

SCALE: 1:8 | SHEET 1 OF 1

5 4 3 2 1

SOLIDWORKS Educational Product. For Instructional Use Only.



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ANGULAR: MACH ± .5 BEND ± 1
TWO PLACE DECIMAL ± 0.03"
THREE PLACE DECIMAL ± 0.005"

INTERPRET GEOMETRIC TOLERANCING PER:

COMMENTS:

DO NOT SCALE DRAWING

Group:
NAVSEA Flow Generation

Members:
Nicholas Grochowski
Montana Marks
Joel Seeley
Raven Williams

DATE: 12/2017

MATERIAL: 3x1x14ga A513 Steel Tube

MSU M.& I.E. DEPT.

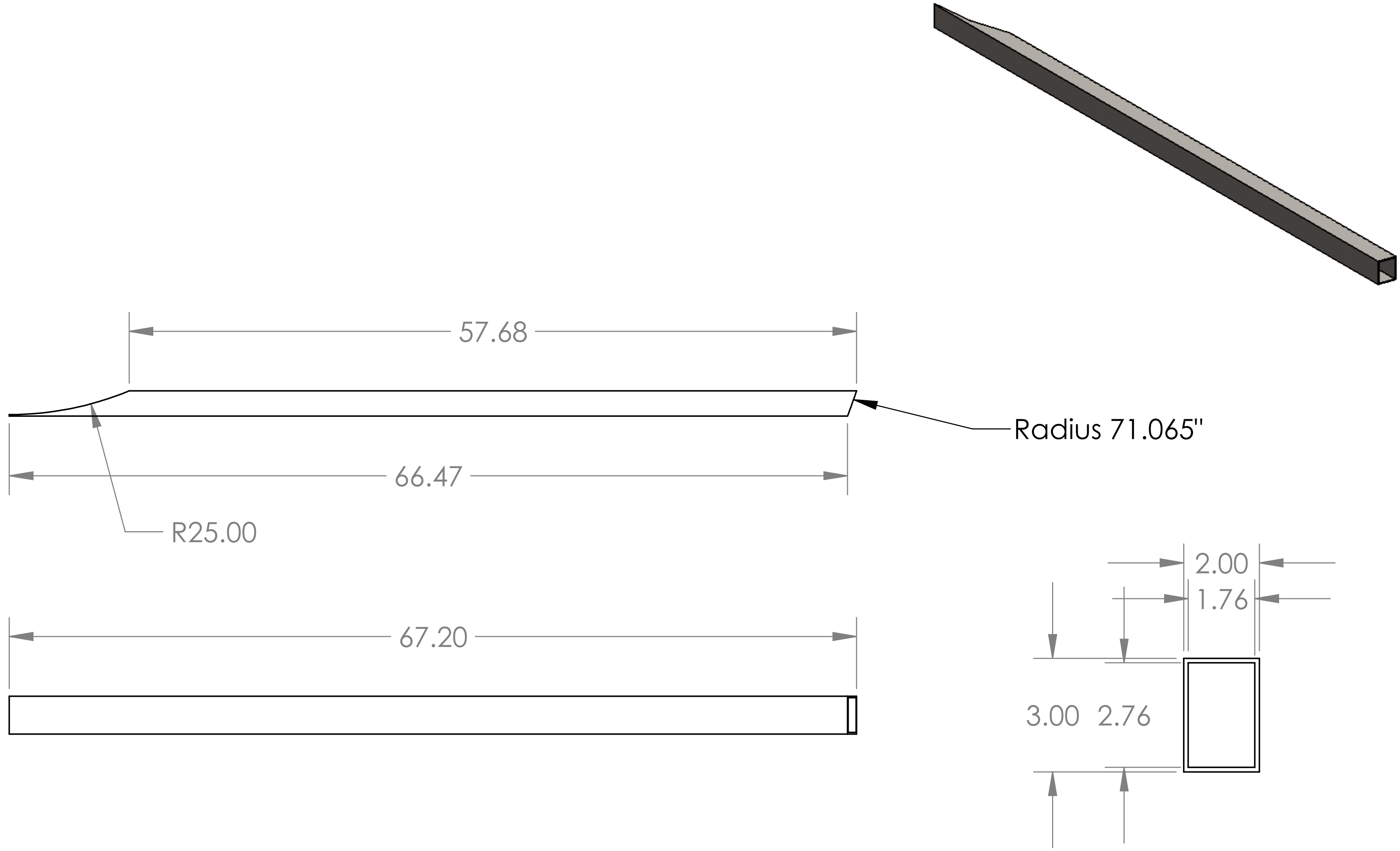
TITLE: Saddle

SIZE	DWG. NO.	REV
A	4.2	A

SCALE: 1:15 | SHEET 1 OF 1

5 4 3 2 1

SOLIDWORKS Educational Product. For Instructional Use Only.



UNLESS OTHERWISE SPECIFIED:	Group:		MSU M.& I.E. DEPT.
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/16" ANGULAR: MACH ± 5 BEND ± 1 TWO PLACE DECIMAL ± 0.03" THREE PLACE DECIMAL ± 0.005"	NAVSEA Flow Generation		TITLE: Side Supports
INTERPRET GEOMETRIC TOLERANCING PER:	Members: Nicholas Grochowski Montana Marks Joel Seeley Raven Williams	DATE: 12/2017	SIZE A — DWG. NO. 4.3 — REV A
COMMENTS:			
DO NOT SCALE DRAWING	MATERIAL: 3x2x11ga A500 Steel Tube		SCALE: 1:12 — SHEET 1 OF 1

5 4 3 2 1

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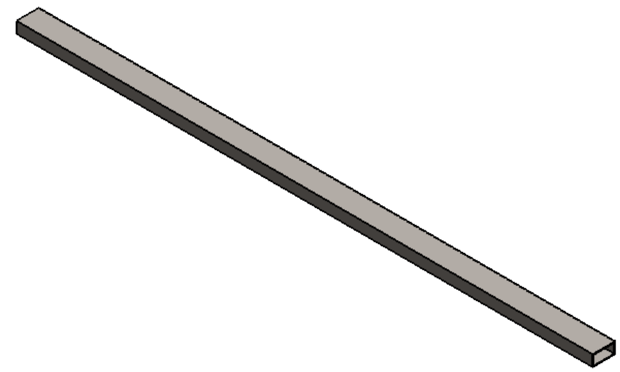

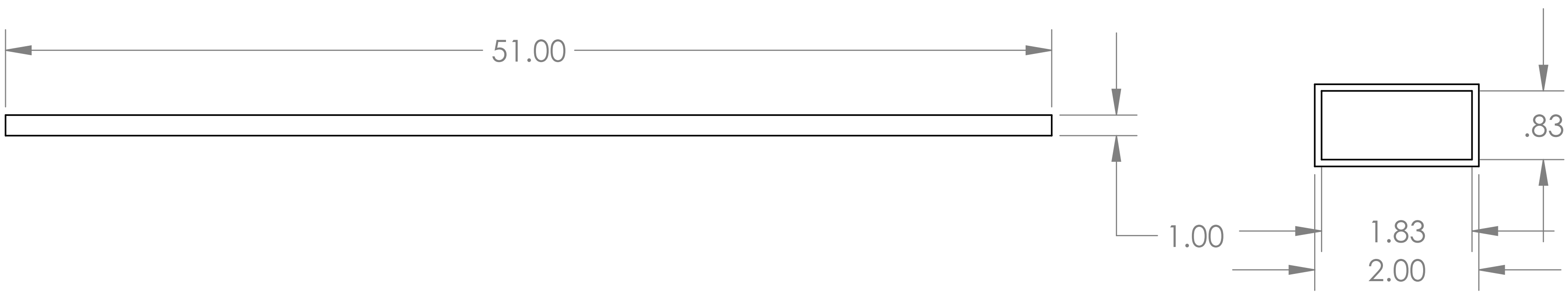

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TOLERANCES:
FRACTIONAL ± 1/16"
ANGULAR: MACH ± 5 BEND ± 1
TWO PLACE DECIMAL ± 0.03"
THREE PLACE DECIMAL ± 0.005"

INTERPRET GEOMETRIC TOLERANCING PER:

COMMENTS:

DO NOT SCALE DRAWING

Group:
NAVSEA Flow Generation

Members:
Nicholas Grochowski
Montana Marks
Joel Seeley
Raven Williams

DATE: 12/2017

MATERIAL: 2x1x14ga A513 Steel Tube

MONTANA

MSU M.& I.E. DEPT.

TITLE:
Lateral Supports

SIZE	DWG. NO.	REV
A	4.4	A

SCALE: 1:8 | SHEET 1 OF 1

5 4 3 2 1

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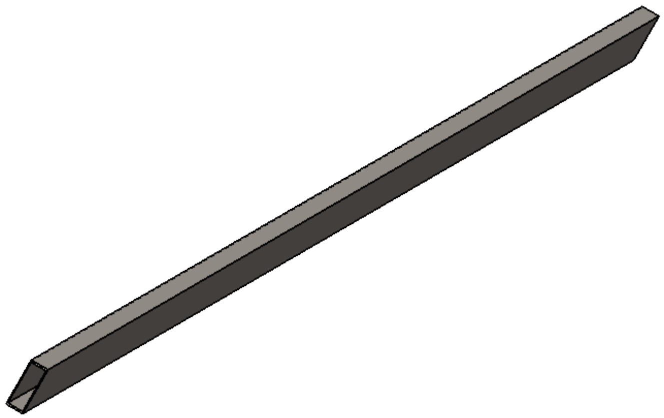
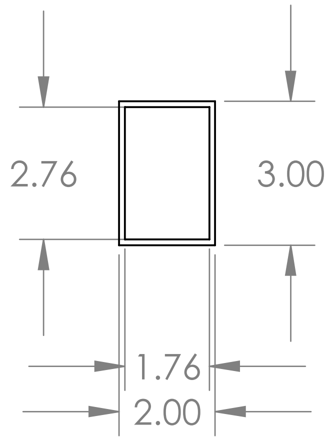


Detailed side view



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TOLERANCES:
FRACTIONAL ± 1/16"
ANGULAR: MACH ± 5 BEND ± 1
TWO PLACE DECIMAL ± 0.03"
THREE PLACE DECIMAL ± 0.005"

INTERPRET GEOMETRIC TOLERANCING PER:

COMMENTS:

DO NOT SCALE DRAWING

Group:
NAVSEA Flow Generation

Members:
Nicholas Grochowski
Montana Marks
Joel Seeley
Raven Williams

DATE:
12/2017

MATERIAL:

MSU M.& I.E. DEPT.

TITLE:
Side Strut

SIZE	DWG. NO.	REV
A	4.5	A

SCALE: 1:16 SHEET 1 OF 1

5 4 3 2 1

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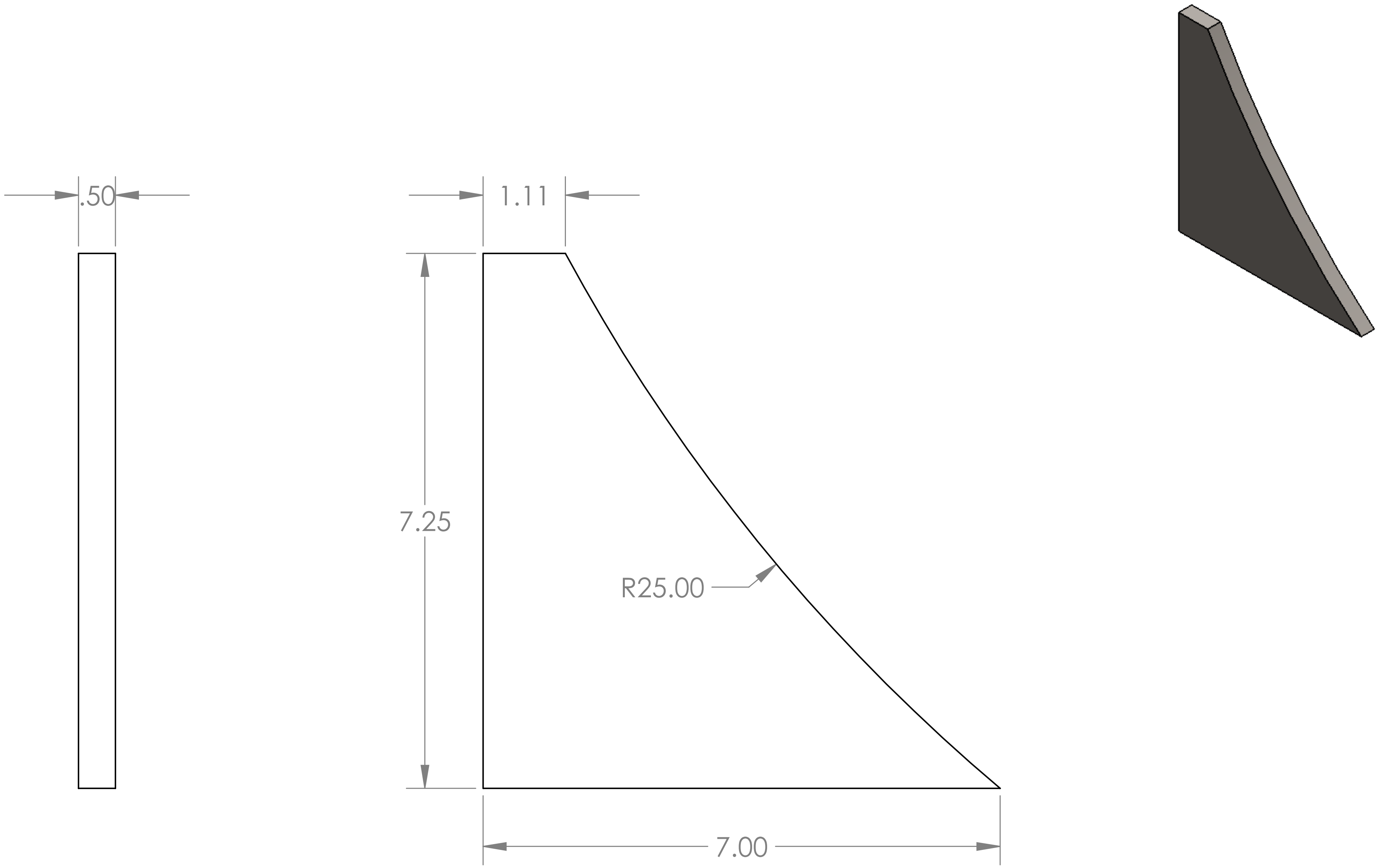

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TOLERANCES:
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ANGULAR: MACH ± 5 BEND ± 1
TWO PLACE DECIMAL ± 0.03"
THREE PLACE DECIMAL ± 0.005"

INTERPRET GEOMETRIC TOLERANCING PER:

COMMENTS:

DO NOT SCALE DRAWING

Group:
NAVSEA Flow Generation

Members:
Nicholas Grochowski
Montana Marks
Joel Seeley
Raven Williams

DATE:
12/2017

MATERIAL:

MSU M.& I.E. DEPT.

TITLE:
Gusset

SIZE	DWG. NO.	REV
A	4.6	A

SCALE: 1:2 SHEET 1 OF 1

5 4 3 2 1

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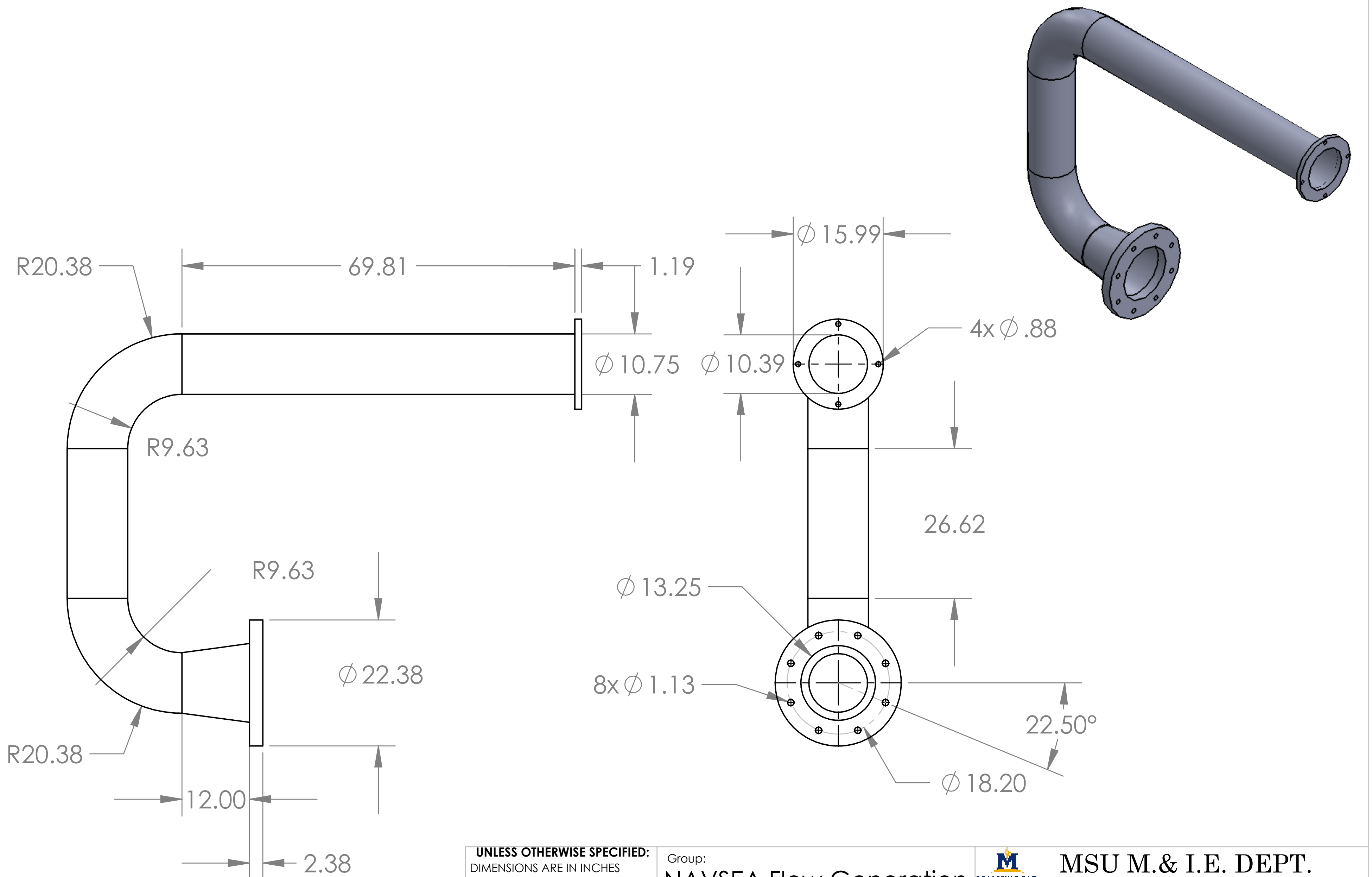

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INTERPRET GEOMETRIC TOLERANCING PER:	Members: Nicholas Grochowski Montana Marks Joel Seeley Raven Williams	DATE: 12/2017	TITLE: Outflow Pipe
COMMENTS:			SIZE A · DWG. NO. 5 · REV A
DO NOT SCALE DRAWING	MATERIAL:		SCALE: 1:24 · SHEET 1 OF 1

5 4 3 2 1

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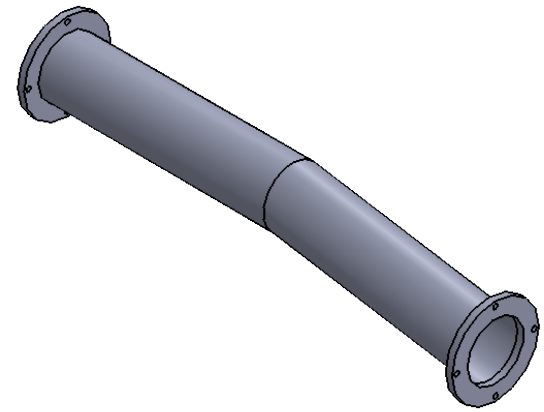

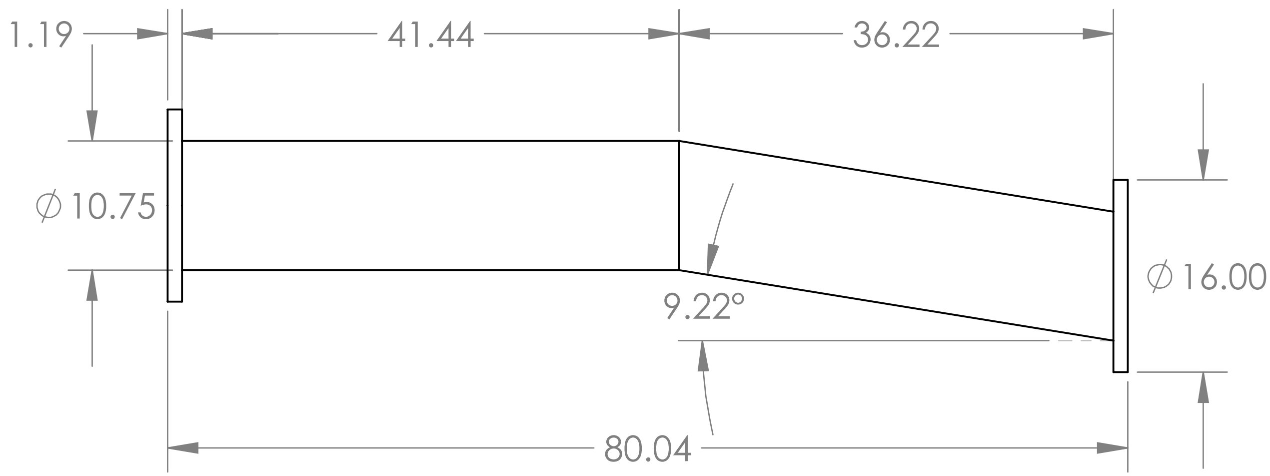

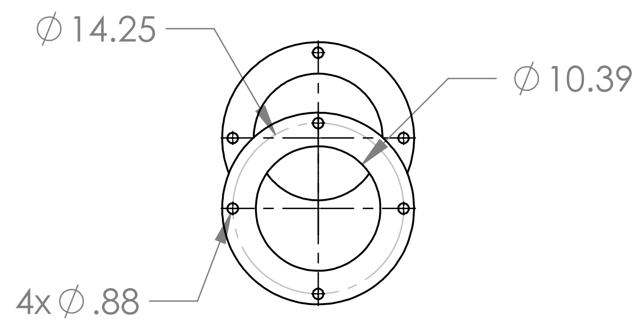

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/16" ANGULAR: MACH ± 5 BEND ± 1 TWO PLACE DECIMAL ± 0.03" THREE PLACE DECIMAL ± 0.005"	Group: NAVSEA Flow Generation		MSU M.& I.E. DEPT.
INTERPRET GEOMETRIC TOLERANCING PER:	Members: Nicholas Grochowski, Montana Marks, Joel Seeley, Raven Williams	DATE: 12/2017	TITLE: Internal Outflow Pipe
COMMENTS:			SIZE A · DWG. NO. 6 · REV A
DO NOT SCALE DRAWING	MATERIAL:		SCALE: 1:16 · SHEET 1 OF 1

5 4 3 2 1

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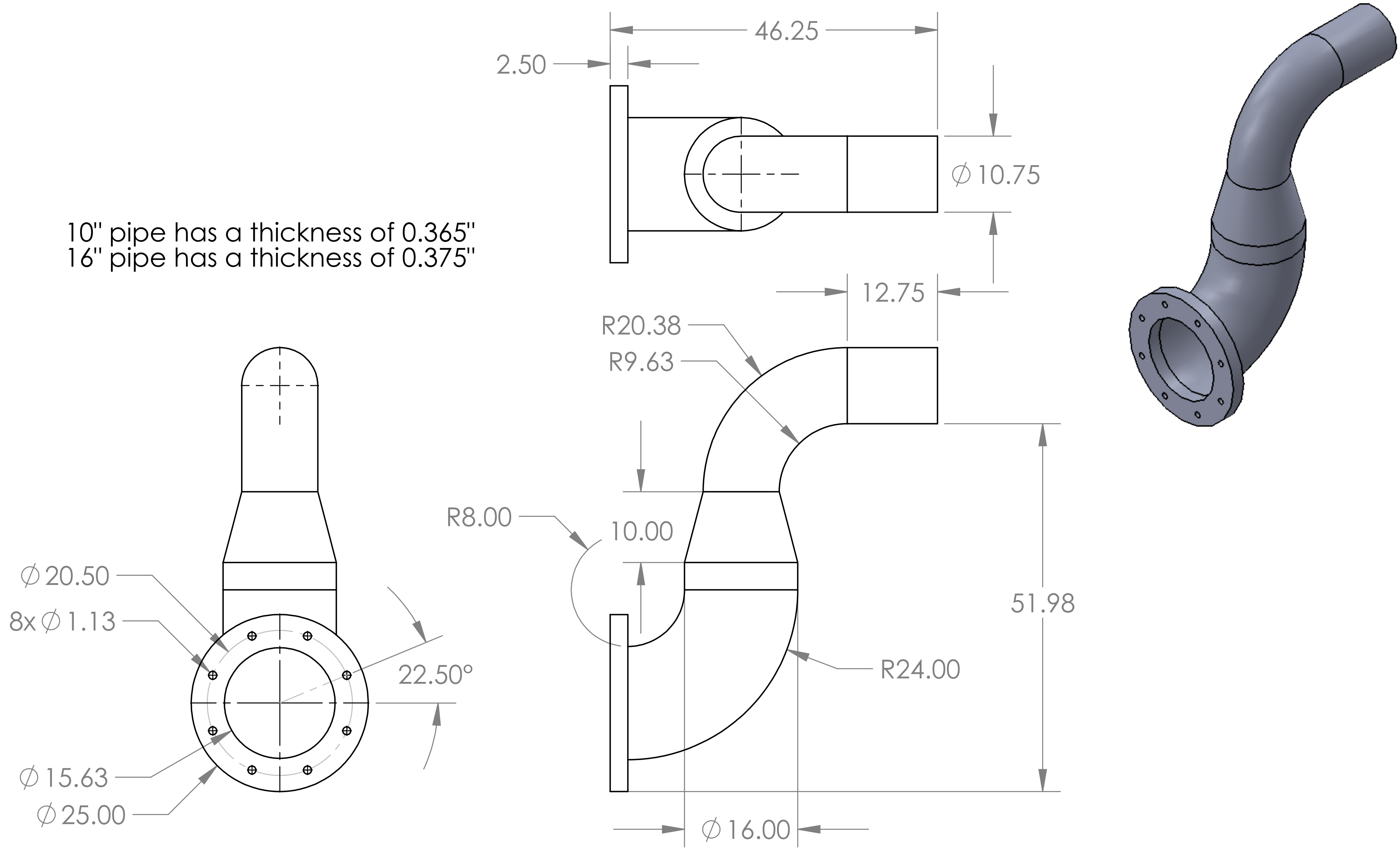
10" pipe has a thickness of 0.365"
16" pipe has a thickness of 0.375"



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/16" ANGULAR: MACH ± 5 BEND ± 1 TWO PLACE DECIMAL ± 0.03" THREE PLACE DECIMAL ± 0.005"	Group: NAVSEA Flow Generation		MSU M.& I.E. DEPT.
INTERPRET GEOMETRIC TOLERANCING PER:	Members: Nicholas Grochowski Montana Marks Joel Seeley Raven Williams	DATE: 12/2017	TITLE: Suction Pipe
COMMENTS:			SIZE A · DWG. NO. 7 · REV A
DO NOT SCALE DRAWING	MATERIAL:		SCALE: 1:20 · SHEET 1 OF 1

5 4 3 2 1

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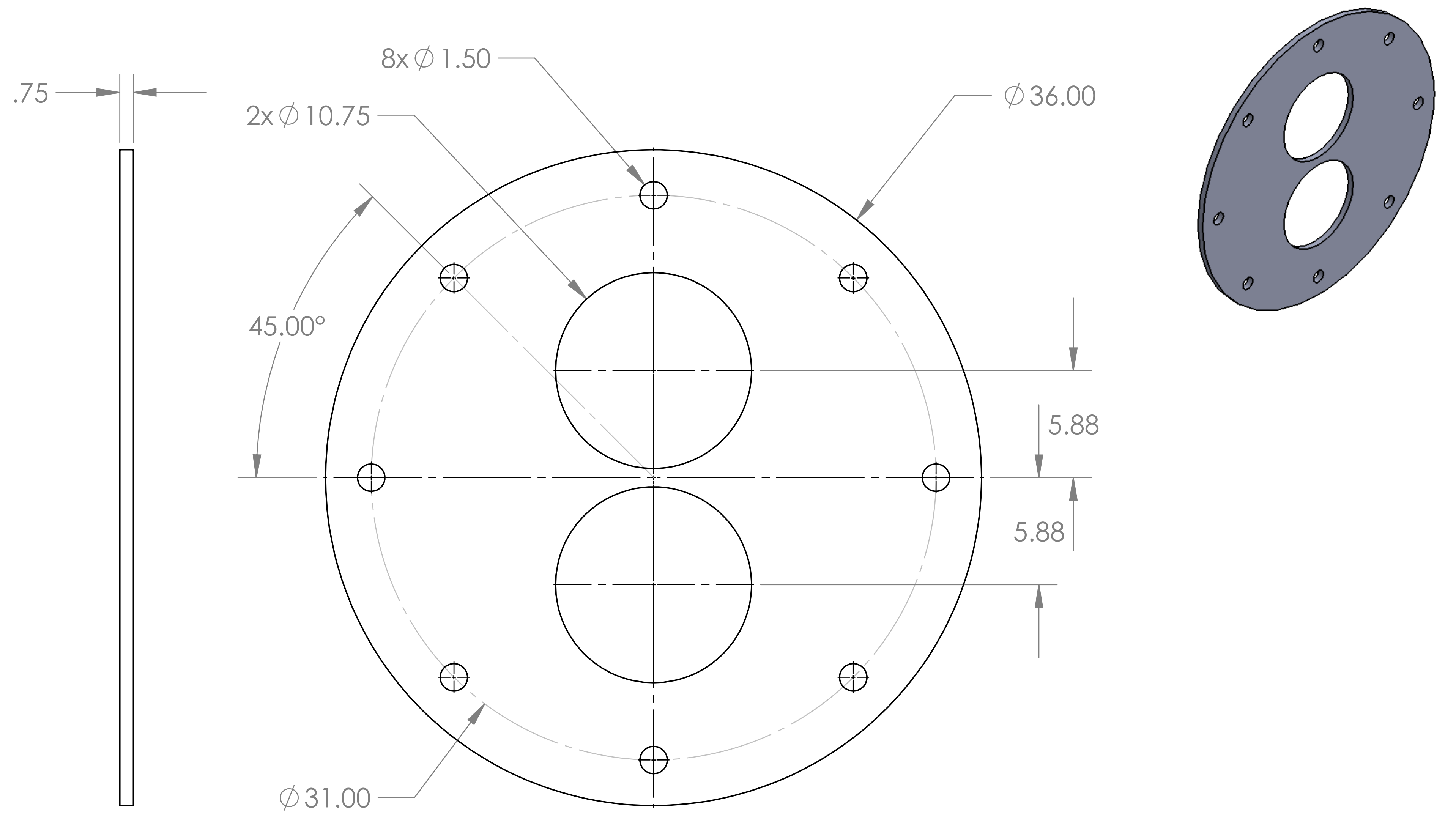

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/16"
ANGULAR: MACH ± .5 BEND ± 1
TWO PLACE DECIMAL ± 0.03"
THREE PLACE DECIMAL ± 0.005"
INTERPRET GEOMETRIC TOLERANCING PER:
COMMENTS:
DO NOT SCALE DRAWING

Group:
NAVSEA Flow Generation

Members:
Nicholas Grochowski
Montana Marks
Joel Seeley
Raven Williams

DATE:
12/2017

MATERIAL:

MSU M.& I.E. DEPT.

TITLE: Steel Plate

SIZE: A
DWG. NO. 8
REV A

SCALE: 1:8
SHEET 1 OF 1

5 4 3 2 1

SOLIDWORKS Educational Product. For Instructional Use Only.

APPENDIX F. Project Economics Analysis and Budget

Cost Analysis				
Part Breakdown				
Part Description	Part Number	Quantity	Individual Cost	Total Cost
Bell And Grosset VSX Water Pump	FG1	1	$ 20,000.00	$ 20,000.00
24" Blind Flange	FG2	1	$ 1,035.14	$ 1,035.14
10" Schedule 40 Staight Pipe (ft)	FG3	13	$ 60.00	$ 780.00
10" Schedule 40 Pipe Elbow	FG4	4	$ 233.07	$ 932.28
10" Flange CL150	FG5	4	$ 137.14	$ 548.56
10" to 16" Schedule 40 Reducer	FG6	1	$ 286.89	$ 286.89
10" to 14" Schedule 40 Reducer	FG7	1	$ 190.34	$ 190.34
14" Flange CL150	FG8	1	$ 287.28	$ 287.28
16" Flange CL150	FG9	1	$ 431.94	$ 431.94
10" Flange Gasket & Bolt Pack CL150	FG10	2	$ 33.93	$ 67.86
14" Flange Gasket & Bolt Pack CL150	FG11	1	$ 61.35	$ 61.35
16" Flange Gasket & Bolt Pack CL150	FG12	1	$ 81.48	$ 81.48
24" Flange Gasket & Bolt Pack CL150	FG13	1	$ 201.65	$ 201.65
10" to 48" Nozzle	FG14	1	$ 1,000.00	$ 1,000.00
48" to 21" Nozzle	FG15	1	$ 700.00	$ 700.00
48" Pipe	FG16	1	$ 500.00	$ 500.00
shipping for items above	FG17	1	$ 2,000.00	$ 2,000.00
Vertical Support	FG18	4	$ 29.46	$ 117.84
Rib Interface	FG19	2	$ 136.75	$ 273.50
Side Strut	FG20	2	$ 29.46	$ 58.92
Saddle Mount	FG21	2	$ 36.84	$ 73.68
Gusset	FG22	4	$ 24.79	$ 99.16
Lateral Supports	FG23	2	$ 15.84	$ 31.68
1.5" HR A36 Round Bar (ft)	FG24	6	$ 9.83	$ 59.00
Conical Diffuser (14" Solid Steel Stock) (ft)	FG25	2	$ 120.00	$ 240.00
1"X2"X21" Hexagonal Mesh	FG26	1	$ 300.00	$ 300.00
10" Pipe (ft)	FG27	8	$ 93.58	$ 748.64
16" Pipe (ft)	FG28	3	$ 126.39	$ 379.17
Shipping Breakdown				
Description				Total Cost
shipping for Part# FG3				$ 216.27
shipping for Part# FG4-FG13				$ 160.00
Shipping for Other Parts				$ 400.00
Building Breakdown				
Part Description		Hours	Hourly Cost	Total Cost
Fabrication/Welding		48	$ 100.00	$ 4,800.00
Machining		8	$ 100.00	$ 800.00
Installation		96	$ 100.00	$ 9,600.00
Total System Cost				$ 47,462.63

Figure F.1. Cost Analysis Calculations

The was only given a budget restriction of five thousand dollars to be used during the prototyping phase of Capstone II. There were no budget restrictions on the plan to produce a full scale assembly at the Keyport facility. Cost reduction and economics analysis were done to insure a safe and reliable device for NAVSEA.

APPENDIX G. Project Academic Assessment

Table G.1 : Table defining prior coursework that was utilized by the team in support of the project.

Prior Supporting Coursework		
Rating system: 10-high 1-low		
Course	**Comments/Notes**	**Rating**
EGEN 201	Statics helped with basic force analysis on structures.	6
EGEN 202	Dynamics helped with basic analysis on structures.	6
EMEC 205	Mechanics of Materials helped with analysis on materials and structures.	6
ETME 215/6	Manufacturing Processes helped with determining which parts are actually manufacturable and simplifying designs to make them easier to manufacture. It also helped with the machining process and determining tools that could be used to process parts.	4
EMEC 250	Material Science helped with understanding the properties of different materials and especially with understanding composites. This helped the team determine with materials were best suitable for the design.	5
EMEC 303	CAE II helped with writing code and using software to analyze parts.	3
EGEN 310R	Multidisciplinary Design helped with the design iteration process and gathering information. It also helped with formal report structure, FMEA, budgeting, and parts lists.	6
EGEN 335	Fluid Mechanics helped with understanding and defining equations for the piping system and the flow field. Calculating head losses and mass flow rates was crucial to understanding and defining the piping systems. It also helped with understanding how fluids move in space.	8
EMEC 341	Advanced Mechanics helped with combining all the information learned in 201 and 205. We were able to look into more complex analysis and calculations of different structures and materials.	8
EMEC 342	Machine Component Design helped with designing a support structure and the forces acting on the structure. It also helped with picking out fasteners and coatings and the calculations required for these parts.	8
EMEC 103/403	CAE III helped with modeling and designing parts in SolidWorks using different functions. It also showed us how to create proper part	10

	and assembly drawings for real world use. We were able to use SolidWorks to do basic structural analysis of brackets for mounting.	
EMEC 436	Computational Fluid Dynamics helped with fluid mechanics and geometry in Star CCM+ and ANSYS. This was the most helpful of all the courses as our project relied heavily on the large computational ability of these programs to test designs and models.	10
EMEC 445	Vibrations helped with determining how to mitigate vibrations in the tank through the mounting systems. It also helped with calculating and analyzing the vibrations caused by the pump.	6

APPENDIX H. Failure Modes and Effects Analysis

SEV = How severe is the effect on NAVSEA?
OCC = How frequent is the cause likely to occur?
DET = How probably is detection of cause?
RPN = Risk Priority Number, ranks concerns, calculated as SEV*OCC*DET

Where 1 is low priority and 10 is high priority.

Failure Modes and Effect Analysis (FMEA) - NAVSEA Flow Generation

Process Step Component or Subsystem	Potential failure mode	Potential failure effects	SEV	Potential causes	OCC	Current controls	DET	RPN	Actions recommended	New SEV	New OCC	New DET	New RPN
Grating System	Erode or rust. Break. Become Dislodged and interfere with pumps.	Increase in turbulance within flow field. Dislodging of grate could damage other parts.	7	Causes for such a failure could include but are not limited to: corosion, loose mounting.	1	Existing controls to prevent such a failure include proper mounting mechanism	4	28	Insure mounting will not become loose.	5	1	4	20
Water Pumps	A hardware failure of the pumps. Not set to manufactuing standards. Debris Intake.	If this happens, the flow field can become non uniform, slow, or breakdown completely.	10	Causes for such a failure include but not limited to: impeller damage, driveshaft failure, motor failure, loss of power.	3	Existing controls to prevent such a failure include reduce work load on pumps by increasing pump count and insure high quality.	10	300	Insure install of quality grade pump. Insure correctly installed. Insure proper maintenance. Install grates.	5	1	10	50
Electrical System	Diconnection of power supplied to pumps, short circuits.	If this happens, the pumps will stop moving water.	10	Causes for such a failure include but are not limited to, short circuit due to exposed wire. Disconnection of wire from power terminals on pump.	2	Waterproofing of system. Insulation of wires and system.	9	180	Insure proper install and water proofing of system. Insure cables aren't placed near sharp edges. Connections are securely fastened.	5	1	10	50
Pump Inlet Ducts	Collapse of inner walls due to pressure differential.	If this happens the pumps will not be able to draw the correct amount of water to produce the desired flow field.	8	Causes for such a failure would include a wall thickness that is not adequate to withstand the operational pressure gradients.	1	Caluculations of operational pressures allow for the selection of the appropriate wall thickness of the duct.	9	72	Run mechanics analysis on ducts to insure ability to withstand operational conditions.	5	1	9	45
Tank Pressure Wall/ Outlet Nozzle	Failure of wall due to pressure differential.	If this happens the pressure differential between areas will be compromized and the flow field will break down. This could lead to dislodging of sections and damage of the test UUV.	9	Causes for such a failure would include a wall thickness that is not adequate to withstand the operational pressure gradients.	2	Caluculations of operational pressures allow for the selection of the appropriate wall thickness of the wall.	8	144	Run material mechanics calculations to insure that wall thickness is adequate for operational conditions.	7	2	8	112
Main Body Mounting	Body becomes dislodged or bolts holding body may break. Water seal is compomised between pressure areas.	If this happens the flow field will break down. The housing, UUV, ducts, or pumps may impact tank wall and become damaged.	10	Causes for such failures could include inadequate mounting structures. Poor seal. Worn out seal. Improper install.	4	Caluculations of operational pressures allow for the calculation of expected forces and the selection of the appropriate hardware and support structures.	10	400	Run mechanics analysis on mounting structure to insure will be able to withstand operational conditions.	5	4	10	200
Pump & Duct Mounting	Shear failure of mounting bolts. Bolts coming loose.	If this happens, Duct could become dislodged and damage other structures. The duct could become loose and begin to vibrate.	7	Causes for such failures could include inadequate hardware or mounting structures. Poor seal. Worn out seal. Improper install.	2	Determine operational stresses on hardware and mounting structures. Select appropriate hardware and structure sizes.	8	112	Run mechanics analysis on mounting structure to insure will be able to withstand operational conditions.	4	2	8	64
Control System	Failure of speed contoller.	If this happens the pumps will shut down or turn off.	8	Causes for such failures could include compromise of waterproofing around electronics. Burnt or worn out electronics. Short Circuits.	2	Insure proper waterproofing of electronics. Keep all insulated wires away from sharp corners.	7	112	Insure multiple layers of water proofing.	5	2	7	70

APPENDIX I. Project Master Schedule Gantt Chart

The Gantt Chart illustrates the teams project schedule. It is used as a charting technique to show tasks, responsibility, relationships, and goals. It shows the start and finish dates of different tasks and elements that serves as a full summary of the project. The team kept this chart updated throughout the project and completion of items.

ID		Task Mode	Task Name	Duration	Start	Finish
1			**Week 1**	**4 days**	**Tue 9/12/17**	**Fri 9/15/17**
2			Weekly Progress Memo	1 day	Fri 9/15/17	Fri 9/15/17
3			Meet with Advisor	1 day	Fri 9/15/17	Fri 9/15/17
4			Meet with Navsea	1 day	Tue 9/12/17	Tue 9/12/17
5			**Week 2**	**6 days**	**Sat 9/16/17**	**Fri 9/22/17**
6			**Generate Intial Project Managemen**	**5 days**	**Sat 9/16/17**	**Thu 9/21/17**
7			Management Plan Document	3 days	Tue 9/19/17	Thu 9/21/17
8			Gantt Chart	2 days	Wed 9/20/17	Thu 9/21/17
9			Prepare Problem Statement	4 days	Mon 9/18/17	Thu 9/21/17
10			Progress Memo	1 day	Fri 9/22/17	Fri 9/22/17
11			**Background Chapter Preperation**	**0 days**	**Mon 9/18/17**	**Mon 9/18/17**
12			Information Discovery	3 days	Mon 9/18/17	Wed 9/20/17
13			Intergration of Information into D	2 days	Thu 9/21/17	Fri 9/22/17
14			**Week 3**	**6 days**	**Sat 9/23/17**	**Fri 9/29/17**
15			Background Research	5 days	Mon 9/25/17	Fri 9/29/17
16			Progress Memo	1 day	Fri 9/29/17	Fri 9/29/17
17			Draft of the Background Chapter	4 days	Tue 9/26/17	Fri 9/29/17
18			**Week 4**	**6 days**	**Sat 9/30/17**	**Fri 10/6/17**
19			Progress Memo	1 day	Fri 10/6/17	Fri 10/6/17
20			**Week 5**	**6 days**	**Sat 10/7/17**	**Fri 10/13/17**
21			Progress Memo	1 day	Fri 10/13/17	Fri 10/13/17
22			Preliminary Design Planning	5 days	Mon 10/9/17	Fri 10/13/17
23			Specifications and Alternatives Draft	5 days	Mon 10/9/17	Fri 10/13/17
24			**Week 6**	**6 days**	**Sat 10/14/17**	**Fri 10/20/17**
25			Update Master Project Schedule	1 day	Mon 10/16/17	Mon 10/16/17
26			Progress Memo	1 day	Fri 10/20/17	Fri 10/20/17
27			**Week 7**	**6 days**	**Sat 10/21/17**	**Fri 10/27/17**
28			Progress Memo	1 day	Fri 10/27/17	Fri 10/27/17
29			Course Review	1 day	Fri 10/27/17	Fri 10/27/17
30			Peer Review	1 day	Fri 10/27/17	Fri 10/27/17
31			Preliminary Design Reviews	4 days	Tue 10/24/17	Fri 10/27/17
32			**Week 8**	**5 days**	**Mon 10/30/17**	**Fri 11/3/17**
33			Group FMEA Integration	5 days	Mon 10/30/17	Fri 11/3/17
34			Progress Memo	1 day	Fri 11/3/17	Fri 11/3/17
35			**Week 9**	**6 days**	**Sat 11/4/17**	**Fri 11/10/17**
36			Gantt Chart	1 day	Fri 11/10/17	Fri 11/10/17
37			Progress Memo	1 day	Fri 11/10/17	Fri 11/10/17
38			**Week 10**	**6 days**	**Sat 11/11/17**	**Fri 11/17/17**
39			Progress Memo	1 day	Fri 11/17/17	Fri 11/17/17
40			**Week 11**	**6 days**	**Sat 11/18/17**	**Fri 11/24/17**
41			Progress Memo	1 day	Fri 11/24/17	Fri 11/24/17
42			**Week 12**	**6 days**	**Sat 11/25/17**	**Fri 12/1/17**

ID		Task Mode	Task Name	Duration	Start	Finish
43			Progress Memo	1 day	Fri 12/1/17	Fri 12/1/17
44			Draft Analysis	5 days	Mon 11/27/17	Fri 12/1/17
45			Manufacturing Plan	10 days	Tue 11/21/17	Fri 12/1/17
46			**Week 13**	**6 days**	**Sat 12/2/17**	**Fri 12/8/17**
47			Critical Design Review	5 days	Mon 12/4/17	Fri 12/8/17
48			Prepare Final Report Submission	5 days	Mon 12/4/17	Fri 12/8/17
49			Drawing and Maufacturing Plan	5 days	Mon 12/4/17	Fri 12/8/17
50			CDR Scheduling	5 days	Mon 12/4/17	Fri 12/8/17
51			**Week 14**	**2 days**	**Sat 12/9/17**	**Mon 12/11/17**
52			Complete Final Report	6 days	Mon 12/4/17	Mon 12/11/17
53			Complete Paperwork for Ordering of	1 day	Mon 12/11/17	Mon 12/11/17
54			Submit CDR video	9 days	Wed 11/29/17	Mon 12/11/17