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# Design of Mobile Dialysis Treatment

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# Design of Mobile Dialysis Treatment

A Major Qualifying Project

Submitted to the Faculty of the

**WORCESTER POLYTECHNIC INSTITUTE**

In Partial Fulfillment of the Requirements for

the Degree of Bachelor of Science

in

Mechanical Engineering

by

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MIRAD Laboratory, April 29, 2015

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## *Abstract*

Hemodialysis is the most common and efficient treatment of kidney disease. This project focuses on developing a mobile dialysis vehicle to administer treatments to individuals in remote areas or during disaster situations. This can reduce the time taken to provide medical care to dialysis patients when standard treatment options may be unavailable. Federal regulations and standards were closely followed in determining the layout of items within the vehicle. The vehicle has all the equipment and supplies necessary to provide three sessions of dialysis treatment to two patients at a time before restocking is necessary. Storage containers, dialysis machines, and other components are designed to be modular, allowing plug-and-play installation and removal for easy maintenance and replacement.

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## *CHAPTER 1. THE NECESSITY OF A MOBILE DIALYSIS UNIT*

### **1.1 Introduction**

Worldwide, approximately 2.8 million individuals have been associated with some level of chronic kidney disease. In order to meet this criterion, an individual must have a glomerular filtration rate of less than 90 mL/min. Glomerular filtration rate is the estimation of how much blood passes through the capillaries surrounding the kidneys each minute, making filtration of the bloodstream possible. It is not until this measurement reaches a level of 30 mL/min that dialysis becomes necessary. Kidney failure accounts for the 9<sup>th</sup> leading cause of death in the United States. According to the American Kidney Fund, 420,000 Americans are classified with this disease, and this number is growing steadily. Dialysis treatments are also very expensive, and while insurance and Medicare do aid in the cost of treatment, \$2.9 million is spent by dialysis patients annually, amounting to \$88,000 per patient, per year [22].

Our developed design aimed to address the growing issue of kidney failure and the inability to administer treatment in certain cases. The project team developed a mobile dialysis center that is capable of administering dialysis treatment to six individuals per day. In addition to this primary object, several other goals were developed. First, a safe and comfortable environment had to be established and maintained. Next, the vehicle had to be designed to be modular; if any element of the design should fail or need maintenance, it should be easily removed and replaced. The primary objective of this project, however, was to provide a secondary treatment option for patients when standard methods may become unavailable. This becomes especially noticeable during natural disasters, or in the event of crisis situations. Two examples of these situations include Hurricane Katrina, and the Boston marathon bombings. During Hurricane Katrina, 26 of the 43 hemodialysis facilities within Louisiana were closed due to the storm, and these treatment centers remain closed

to this day. After the bombings in Boston, the city was shut down and only emergency vehicles were allowed to be on the roads. In both cases, a mobile unit capable of treating dialysis patients could be the difference between life and death for many people suffering from kidney failure.

When considering a mobile dialysis system, organization and physical constraints must be considered. Factors such as machine reliability, weight distribution, vehicle and passenger safety, and compliance with Federal regulations are all major considerations in the design process. Treatment must only be administered while the vehicle is stationary, but all systems onboard need to be capable of travel over potentially rough roads. Adequate cushioning and vibration damping must be in place on all sensitive equipment to protect the integrity of the systems onboard. All major items used during dialysis treatments are easily accessible from the exterior through the integration of various doors. These doors are placed next to items such as the water and waste storage tanks, the onboard generator, and each dialysis machine.

The proceeding chapters of this report provide a detailed framework of the team's design process in accordance with current engineering design standards. Chapter two establishes a general understanding of the dialysis process, and outlines current design solutions which aim to address the issue of portability. This information can be found in the chapter to follow in addition to the biomedical aspects associated with hemodialysis, including pressures and temperatures throughout the hemodialysis system. Chapter three of this report details the design of the vehicle itself, including technical drawings and descriptions. Also included in this chapter of the report is a finite element analysis on various mounting fixtures that exist within the vehicle. Finally, the report will be closed with concluding remarks and a summary of the outcomes of the designed device.

## *CHAPTER 2. THE NEED FOR A MOBILE DIALYSIS CENTER*

### **2.1 Introduction**

Individuals who have lost basic function of the kidneys are said to have developed chronic kidney disease (CKD). This loss of function is not always immediate, but is more often a gradual onset due to prolonged abuse of these vital organs. Healthy kidneys perform the functions of removing excess fluid from the body, as well as any waste that may be present within the bloodstream. With this basic operation affected in patients dealing with advanced stages of CKD, dangerous levels of fluid, toxins, and waste build up within the body. Unfortunately, there is no way to reverse kidney damage. The only method of treating the disease is to slow down its progression, preventing it from entering into more severe stages. If the ailment progresses to end-stage kidney failure, kidney transplants or, more commonly, artificial filtering through regular dialysis treatments becomes necessary to prevent fatality [14].

The number of individuals who are classified as suffering from some level of chronic kidney disease has been on the rise in recent years. Globally, it is estimated that approximately 2.8 million people have been diagnosed with end stage renal kidney disease; almost 420,000 of which live within the United States. Of this population, 89% use hemodialysis as their primary form of treatment [22]. Hemodialysis patients often rely on government provided centers to discretely receive medical attention. Patients often find it impossible to transport themselves to and from dialysis centers, as the treatment can be physically draining on the body. If a friend or family member is unable to escort the patient, an ambulance ride may be necessary to transport them to the treatment facility, greatly increasing the cost of the dialysis. A mobile vehicle could easily reduce or remove this transport need by bringing dialysis directly to the patient's location.

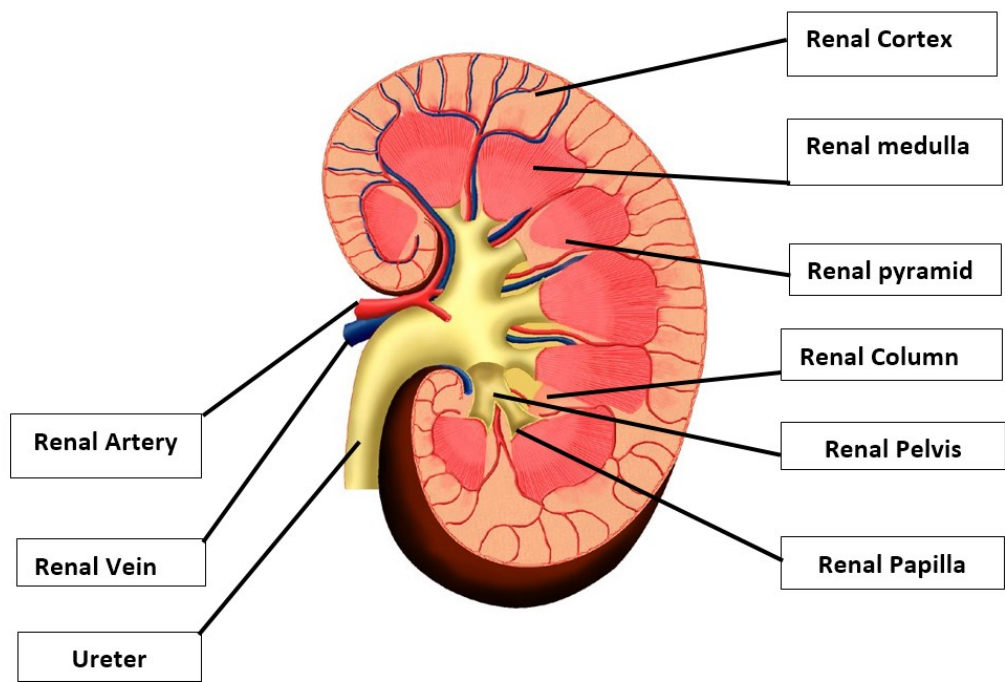
During unforeseen crises situations, transport to clinical centers can be difficult or impossible. This fact remains true for the case of natural disasters such as Hurricane Katrina where 26 of the 43 hemodialysis facilities within Louisiana were closed due to the storm. These care locations remain closed to this day. Through the development of an emergency response vehicle dedicated to treating hemodialysis patients, the dangers of prolonging medical attention in natural disasters and crisis situations can be reduced.

## **2.2 Kidney Structure**

The kidneys, a pair of bean shaped organs, are located within the posterior muscular region of the abdominal cavity. These organs, found along either side of the vertebral column, are responsible for maintaining a level of homeostasis within the body. Contrary to general assumption, the location of these organs is not mirrored along the spine. Instead, one kidney is positioned slightly higher than the other to accommodate for the presence of the liver on the right side of the body. To protect these vital organs from potential harm, the ribs and muscles of the back encapsulate the kidneys. In addition to this layer of muscle and bone, a layer of adipose tissue also acts as a protective padding. Lastly, there is a layer of fibrous connective tissue that surrounds each kidney, known as the renal capsule. This layer forms a strong outer shell that preserves the shape of the kidneys [14].

The bean-shaped structure of the kidney is not out of mere coincidence, but to make room for vital blood vessels and a waste removal system. As seen in Figure 1, a section seems to be pushed inward to make a concave feature. This region faces outward, with the ureter located close to the spinal cord, and is referred to as the renal hilus. This section allows for the renal artery and renal vein to gain access to the kidneys. The ureter exists in this area to transport the waste and water from the kidneys to be expelled from the body in urine [14]. There are three major sections

of a normal kidney, the renal medulla, the renal pelvis, and the renal cortex. Figure 1 labels these specific areas of the kidney. Following the stiff layer of the renal capsule, there is a section of soft, dense tissue. This region, known as the renal cortex, is the outermost portion of the actual kidney, the area between the renal capsule and the renal medulla. It is within this portion of the kidney that approximately one million filtering devices exist, called nephrons.



**Figure 1: Kidney Structure**

The renal medulla is located further into the kidney. Comprised of pyramidal tissue groupings referred to as renal pyramids, the renal medulla is the location where urine begins to form. Each kidney contains between eight and twelve of these renal pyramids. The base of this conical shape faces outward towards the outermost layer of the kidney. As a result, the tip of the renal pyramid faces inwards, in the direction of the kidney's concavity and the ureter. At this location a tiny hollow tube exists, called the minor calyx. The minor calyx collects traces of urine and merges into the major calyces, which then in turn forms the hollow renal pelvis. Urine exits

the kidney through the ureter which is connected to the renal pelvis, to then be collected and stored in the bladder [14].

## **2.3 Kidney Functions**

In their effort to maintain a relative state of equilibrium and balance within the human body, the kidneys perform a variety of functions. With the primary purpose of removing potential toxins and wastes from the bloodstream, the kidneys receive between one hundred and twenty and one hundred and fifty quarts of blood per day. As a byproduct of this excess waste and water removal, the kidneys produce one to two quarts of urine within this time frame. In addition to this fluid and contaminant elimination, the kidneys are also responsible for regulating blood pressure, levels of electrolytes, red blood cell production, acid-base control, and the synthesis of several hormones and enzymes [30].

### **2.3.1 Blood Waste Filtration**

The Kidneys can be characterized by their ability to remove excess water and toxins from the bloodstream in order to maintain a homeostatic level of basic health within the body. This primary function of the kidneys is made possible by tiny structures called nephrons. Within each kidney, over a million of these microscopic units exist to filter the blood and produce urine. In addition to this function, the nephrons also return nutrients from the urine such as sodium, potassium, and phosphorus to the body when levels are low. A nephron can be broken down into 2 main elements: the renal corpuscle and the renal tubule [14].



### 2.3.2 Water Level Homeostasis

Water removal is one of the greatest concerns of the kidneys in terms of waste items. Healthy kidneys are able to safely remove from 0.5 to approximately 1.5 liters per day. This accounts for a production of approximately one to two quarts of urine. Maintaining this level of water removal within the blood is important for creating a safe blood pressure within the body, through the establishment of a constant volume. A constant volume allows for appropriate pressures to exist within the bloodstream, supporting general circulation throughout the body [16, 30].

The amount of H<sub>2</sub>O that exists within the body is controlled through the kidneys' ability to change the liquid reabsorption rate. Reabsorption of water is made possible by the tubules of each nephron. Generally, the cells within the nephron tubules utilize the process of osmosis to reintroduce nearly all water present in the urine back into the body. A direct result of the reabsorption of water into the body is a concentrated level of urine. The process of reabsorption becomes possible due to the hormones antidiuretic hormone (ADH) and aldosterone. Aldosterone increases the level of water within the blood by heightening the number of sodium and chloride ions that are reintroduced. In addition, ADH encourages water channel proteins to be formed within the collection ducts of the nephrons. These collection ducts allow water to move from the urine into the tubule cells and finally back into the bloodstream.

In the case where there is an excess amount of water present within an individual, the heart begins to release the hormone atrial natriuretic peptide (ANP). Through secretion of this hormone, increased levels of sodium (Na<sup>+</sup>) and chloride (Cl<sup>-</sup>) ions become present. With an increased concentration of these ions, water becomes drawn into the urine through the process of osmosis, thus increasing the volume of urine [14].

### 2.3.3 Blood Pressure Monitoring

By regulating the amount of water that is found within an individual's bloodstream, the kidneys are able to control blood pressure. A large percentage of the chemical makeup of blood is water. With a heightened volume of H<sub>2</sub>O, the heart begins to deliver blood to the body at a faster and more vigorous rate, thus amplifying the blood pressure. On the other end of the spectrum, if the body becomes dehydrated, blood pressure decreases due to a lack of water volume present within the blood.

Sodium ions present within the bloodstream pull H<sub>2</sub>O molecules to these areas of high sodium concentration through osmotic pressure. When the blood pressure of an individual becomes too high, the kidneys release sodium ions in order to cause water to be drawn out of the body, decreasing volume levels. Inversely, the kidneys take in sodium ions in the event that blood pressure is too low, causing more water to be introduced into the body.

The levels of water and sodium ions within the blood are controlled through the excretion of the enzyme renin by the kidneys. Renin is released into the blood stream in the event that blood pressure becomes lowered. The enzyme signals the adrenal glands to release the hormone aldosterone. Aldosterone is responsible for stimulating kidney cells to begin the process of reabsorbing sodium and water. As a result, the body's blood pressure can be effectively maintained [14].

### 2.3.4 Acid/Base Regulation

Through their ability to control the amount of hydrogen ( $H^+$ ) and bicarbonate ions ( $HCO_3^-$ ) that are excreted into the bloodstream, the kidneys are able to monitor the pH balance within the body. The presence of these ions exists due to the breakdown of proteins within the liver and the reaction of carbon dioxide with water in the bloodstream. The glomerulus of the kidney filters out these ions from the blood in its effort to remove waste and produce urine. However, the tubule cells of the nephrons reintroduce the bicarbonate ions back into the body to neutralize excess amounts of hydrogen ions.

Bicarbonate ions neutralize hydrogen ions found within the bloodstream through the creation of carbonic acid. These new molecules that are formed are brought into the lungs where they are broken down into molecules of carbon dioxide and water. As an individual exhales, the water and carbon dioxide molecules are released from the body [14].

### 2.3.5 Electrolyte Level Monitoring

The maintenance of electrolyte levels is achieved through their excretion into the urine. Table 1 lists a variety of electrolytes that the kidneys are responsible for monitoring. Such electrolytes include but are not limited to sodium, potassium, calcium, chloride, phosphate, bicarbonate, and sulfate [29].

**Table 1: Electrolytes Monitored by the Kidneys**

<b>Name</b>	<b>Chemical Symbol</b>	<b>Function</b>
Sodium	Na <sup>+</sup>	Muscle Function, Neuron Function, Blood Pressure Regulation, Blood Volume Regulation
Potassium	K <sup>+</sup>	Muscle Function, Neuron Function, Blood Volume Regulation
Chloride	Cl <sup>-</sup>	Regulation of pH and cellular fluid balance, establishes the electrical component of neurons and muscle cells
Calcium	Ca <sup>2+</sup>	Composes bones and teeth, contraction of muscle tissue, responsible for the release of neurotransmitters by neurons, stimulation of cardiac muscle tissue
Magnesium	Mg <sup>2+</sup>	Responsible for the proper performance of enzymes that work with phosphate compounds

One specific electrolyte that the kidneys are responsible for is sodium. In order to maintain water levels, blood pressure, and homeostasis, the kidneys must ensure that sodium ions are kept at an appropriate level. This electrolyte is important to the function of muscles and neurons in addition to blood pressure and volume regulation. Almost all of the sodium ions are reabsorbed into the blood from the tubular filtrate within the proximal convoluted tubule and the ascending loop of Henle [14].

## **2.4 Failure Modes**

When the kidneys are unable to rid the body of contaminants and excess water, the host is said to suffer from chronic kidney disease (CKD). In this instance, the kidneys are no longer able to function at their full capacity. This loss of function does not necessarily happen all at one time, but is often the result of a gradual onset of symptoms due to illness or abuse.

When the kidneys suddenly cease to function properly, they are said to be suffering from acute renal failure. This form of kidney disease is common amongst individuals that are hospitalized due to severe sickness. If treated in a timely manner, the damage may be reversed,

resulting in the recovery of some or all function. This loss of function is often the result of a form of trauma, whether it is severe blood loss or due to a poison.

There are a few warning signs that one can look out for prior to seeing a doctor about possible failure. To begin, the affected person will find that they are having discomfort within their lower back. In addition, they will find they will become overcome with a feeling of fatigue/weakness. This will be a direct result of the toxin and fluid buildup that is occurring. Associated with this fluid buildup are often swollen ankles; where the fluid will be building up. Lastly, in later stages of kidney failure, they kidneys will grow a series of cysts upon them.

#### **2.4.1 Stages of Chronic Kidney Disease**

There are five stages of kidney disease that leads up to ultimate failure. The National Kidney Foundation has established these differences amongst failure stages in order to assist doctors in their efforts to evaluate the severity of each situation. Through this knowledge, certain tests and treatments can be administered to patients, allowing for optimal care.

The best way to measure the performance of a kidney is through its glomerular filtration rate, or GFR. This measurement is based off of several factors including the patient's age, race, gender and their serum creatinine level. Creatinine is a waste product of the muscles following physical activity. The creatinine levels act as an indicator of the kidney's ability to remove waste from the bloodstream.

**Table 2: Stages of Kidney Failure**

<b>Stage Number</b>	<b>Commonly Referenced as:</b>	<b>GFR Range</b>
Stage 1	n/a	90 mL/min
Stage 2	Mild CKD	60-89 mL/min
Stage 3A	Moderate CKD	45 – 59 mL/min
Stage 3B	Moderate CKD	30 – 44 mL/min
Stage 4	Severe CKD	15 – 29 mL/min
Stage 5	End Stage CKD	<15 mL/min

The chart above displays the different stages of kidney failure characterized by levels of glomerular filtration rate. As shown, the first few stages of the disease are not of great concern. It is not until stage 4 that a patient has to start preparing for dialysis treatment; planning for end stage renal failure must occur [7].

#### **2.4.2 Stages 1 and 2 of Kidney Failure**

The first stage of kidney failure is associated with normal kidney function. At this time, the individual will have a glomerular filtration rate of over ninety milliliters per minute. There are usually no symptoms indicating that the kidneys have been damaged. One often discovers that they have stage 1 chronic kidney disease when they are being tested for other ailments such as diabetes or high blood pressure. Ironically, these are the two leading causes of kidney disease. Despite the normality of this stage, there are a few indications of potential disease. Such signs include a rise in creatinine or urea in the blood, blood or protein in the urine, and a family history of the disease.

The second stage of kidney failure is identified as mild chronic kidney disease. At this stage, as shown within Table 2, the glomerular filtration rate of the kidneys is between sixty and eighty nine milliliters per minute. Creatinine levels are quite stable at this stage. At these two points

of chronic kidney disease, the goal is to evaluate the patient and check for the progressiveness of the disease. Following evaluation, the associated risks can be reduced. During the year following initial diagnosis, one must monitor creatinine levels, blood pressure, and activities that may create cardiovascular risk. In terms of creatinine, if levels fall more than 15% or rise over 20%, then further precautions must be taken. Sugar intake, certain medications, lack of physical exercise, and smoking can also play a role in this process [7].

### **2.4.3 Stage 3 of Kidney Failure**

It is at this stage of kidney failure that symptoms of the disease become more prevalent. There are two phases that make up stage three of failure: stage 3A and stage 3B. The two classifications are once again based on the glomerular filtration rate (GFR). Stage 3A occurs when the filtration rate is limited to 45 – 59 mL/min. In the case of stage 3B, the filtration rate ranges from 30 – 44 mL/min. Here, a noticeable buildup of toxins can be found in the blood. In both cases, the person is likely to develop associated complications including high blood pressure, a shortage of red blood cells, and early bone disease.

There are a variety of symptoms of stage 3 chronic kidney disease. Here, the individual will be beginning to experience a level of fatigue due to the high amount of toxins within the body. In addition, swelling of the ankles will occur due to the presence of excess fluid. The patient's urine will be an unusual dark orange or brown color, and urination will occur more frequently. Lastly, the person will experience some level of pain in the lower back along with problems sleeping due to muscle cramps [7].

As time progresses in the onset of stage 3 kidney failure, a nephrologist and dietician should be consulted. A nephrologist is doctor who is specialized in administering treatment to various

forms of kidney disease. Upon examination, the doctor will perform multiple tests to gather information regarding the necessary steps of treatment. As previously mentioned, the treatment process only acts to prolong the onset of further stages rather than reversing the current damage. The dietician is also important in this planning process; a specialized meal plan will be personalized to the patient. Foods prescribed to the patient often include items of high protein and potassium, fresh fruits and vegetables, lowered calcium consumption, and a decrease in items with sodium and carbohydrates.

#### **2.4.4 Stages 4 and 5 of Kidney Failure**

Stages 4 and 5 of kidney failure are the most severe. To begin, a person that is said to fall into the category of stage 4 kidney failure has a decreased glomerular filtration of between 15 and 30 mL/min. Due to this low filtration rate, these individuals have to begin planning for future treatment, whether it be a kidney transplant or ongoing dialysis treatments. With the decline of general kidney function, a large amount of waste becomes prevalent within the blood, resulting in a condition known as uremia. Other conditions may also be acquired such as high blood pressure, anemia, bone disease, heart disease, or other cardiovascular diseases.

Stage 5 kidney is the most severe instance. As displayed within Table 2, this is when the kidneys are only able to filter 15mL/min or less. During this stage of end stage renal disease (ESRD), almost all of the functions of the kidneys are lost. In order for the patient to continue to live, it becomes necessary to receive dialysis treatment or a whole organ transplant. Patients will often find themselves having the sensation of being extremely ill. Dialysis treatment has been reported to make individuals feel much better. This is due to the fact that the toxins that have been building up within the body are now able to be removed from the blood. The two types of dialysis that are offered to patients at this stage are hemodialysis and peritoneal dialysis.



The symptoms of this stage of failure are quite similar to those of prior stages, but there is a greater level of severity with each warning sign. To begin, extreme fatigue becomes apparent in suffering individuals along with lower back pain. Nausea and vomiting will also ensue in patients alongside a loss of appetite. Problems with nerve endings is also possible; a numbness or tingling of fingers or toes. For the latter stage, changes in skin color can also occur due to an increased pigmentation. Lastly, headaches and muscle cramps become frequent. Stage 5 victims often find that they produce little to no urine [7].

## **2.5 Hemodialysis Treatment Process**

For the past 50 years, Hemodialysis has been the most common method used to treat advanced and permanent kidney failure. 89% of patients with kidney failure – end stage kidney disease – need hemodialysis in order to clean the blood and remove excess fluids from the body [14]. Healthy kidneys clean your blood by removing excess fluid, minerals, and wastes, while producing hormones that keep your bones strong and your blood healthy. If the kidneys begin to fail, harmful waste starts to build, eventually poisoning the body. Blood pressure rises, the body retains excess fluids and the kidneys can no longer regenerate red blood cells.

There are three main types of dialysis treatment, peritoneal, hemofiltration, and hemodialysis [22]. Peritoneal dialysis is a more aggressive form of treatment for severe kidney failure. Hemodialysis is much more common and preferred by patients, due to the effectiveness and efficiency of the treatment. Hemodialysis treatment is performed for three to five hours every other day – three to four times a week. Patients can also undergo nocturnal dialysis for a longer duration in order to adhere to a normal daily life. Treatment is provided for patients through treatment centers around the world that specialize in dialysis treatments. Hospitals are also equipped to treat patients with kidney failure, but there are often issues with lack of vacancy.

Treatment can also be provided at the patients' home, where a specialized care provider supervises the treatment.

There are three main jobs of a hemodialysis machine, to pump blood and monitor the flow rate for safety, to clean the waste from blood, and to watch blood pressure and the rate of fluid removal from the body. During treatment, two needles are used to draw the polluted blood from the body and return the cleansed blood to the patient. The blood is drawn from the body a few ounces at a time in order to protect the patient from severe blood loss if any complications should arise during the treatment. The polluted blood is passed through a special filter called a dialyzer, which emulates the filtering functions of a working kidney.

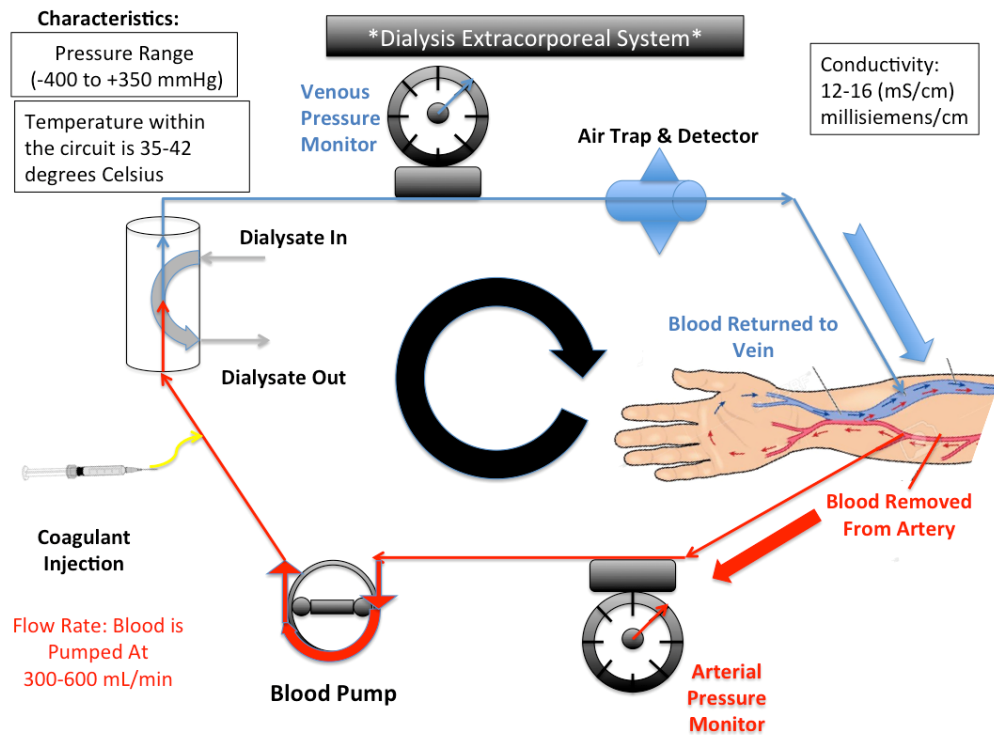


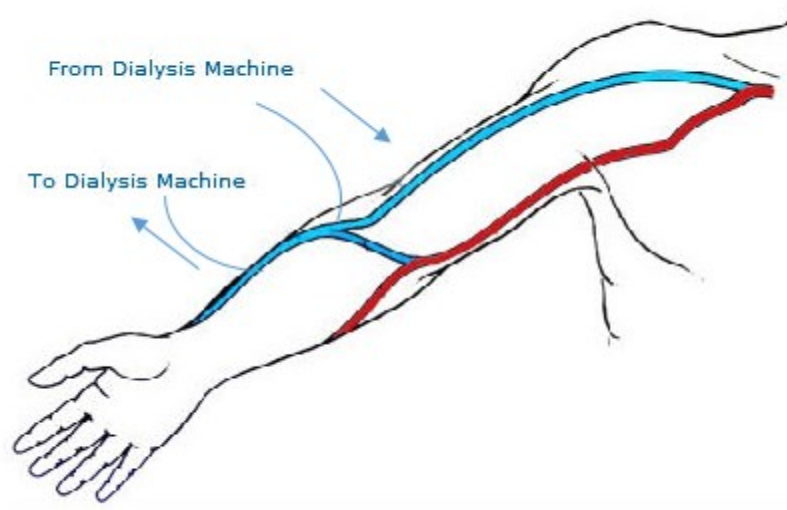
Figure 2: Flow Chart of Dialysis Treatment

Figure 2 below shows the typical path that the blood will take once outside the body. The unfiltered blood leaves the body from the AV fistula, located on the forearm. Arterial pressure is

read by the machine and observed by the care provider to determine the flow rate of the blood. Heparin is then mixed with the blood to prevent clotting while in the extracorporeal system before the dialyzer cleans the blood using both a filter and dialysate mixture. This fluid flows in the opposite direction to the blood. The machine also monitors the venous pressure of the blood after passing through the dialyzer. An air trap ensures that there are no air bubbles in the blood returning to the body to prevent embolisms from occurring.

Through the extracorporeal circuit described above, the flow rate of the blood fluctuates from 200 to 600 mL/min. The pressure varies from -400 mmHg to 350 mmHg and the temperature range is between 35 and 42 degrees Celsius to ensure the blood remains physiologically similar to normal body temperature. The dialyzer contains a filter that is selectively permeable, meaning that it allows fluids and waste, such as uremic toxins, to pass through. The dialyzer also prevents the exchange of blood components, such as microorganisms and endotoxins.

There are three major access points for connecting the dialysis machine to the body, including the arteriovenous grafts on the upper arm, venous catheters located near the collarbone, and the arteriovenous fistula located near the wrist as shown in Figure 3.

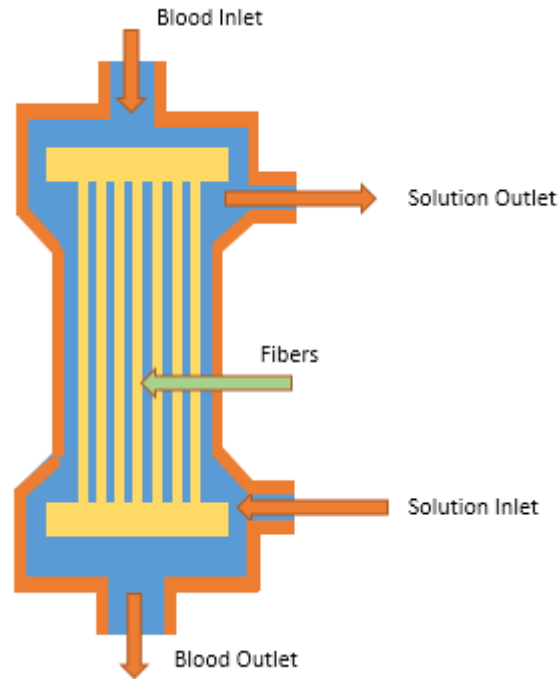


**Figure 3: Arteriovenous Fistula**

The safest access point is the AV fistula compared with grafts or venous catheters. The grafts and venous catheters have a high risk of infection, as well as a large chance of disconnection during treatment.

### **2.5.1 The Role of the Dialyzer**

Figure 4 is a drawing of a dialyzer, which is the filtering system used in any dialysis machine. When blood is removed from the body, it is passed through one side of this large canister, with a bicarbonate solution running in the opposite direction behind a membrane. Waste and extra fluids are removed from the blood and transferred to the dialysate, which is then carried out of the machine and disposed of. The canister consists of thousands of tiny microscopic fibers that the blood is pumped through, with the dialysate solution surrounding the fibers. The fibers allow the waste and excess fluid to pass from the blood to the dialysate with three important processes: diffusion, osmosis and hemofiltration.



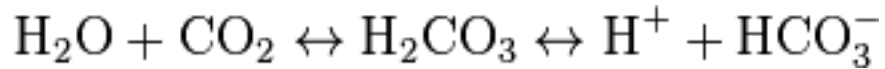
**Figure 4: Typical Dialyzer layout**

Diffusion within the dialyzer is controlled by the concentration gradient between solution and blood. Based on the prescription from the nephrologist, the concentration of the dialysate will be greater if more waste needs to be transferred. Concentrated solutions of acetate, sodium bicarbonate and acetic acid mixed with purified water helps doctors control the concentration or prescription administered to each patient. The dialysate has similar ions to blood but without the waste, which allows for an efficient transfer between the two fluids. The dialysate then carries away the waste from the blood while the blood returning to the body is clean and contains the necessary ions that would otherwise be produced by functional kidneys [6, 20, 30].

## 2.5.2 Water and Chemicals Required for Treatment

The mixing is generally controlled using conductivity control or volumetric control of the water and concentrated solutions. The average conductivity of the extra corporeal circuit is 12-16 millisiemens/cm. The control methods are done by measuring how well the fluid conducts electricity (conductivity) and how much water is mixed with each chemical solution (volumetric). To control the transfer of sodium, the doctor can vary the amount of sodium in the dialysate at different times in the treatment; this is called sodium profiling. Sodium profiling can also influence the rate of osmosis. This is where the exchange of water is controlled by changes in concentration gradient. During dialysis, osmosis is not the actual movement of water across the dialyzer membrane, but across cell membranes within the body; either from within the red blood cells to the blood plasma, or from within cells of the various tissues in the body to interstitial fluid. Ultrafiltration is where the solution is controlled by changes in pressure gradient between both sides of the dialyzer, otherwise known as convection. This process allows the doctor to control the patient's weight loss and the flow of dialysate through the machine. There are two flow controllers, one for the blood entering the machine and another controlling the dialysate.

The most common bicarbonate concentration used in dialysis centers is 35 mmol/L. Doctors are just beginning to realize the importance of individually adjusting the dialysate bicarbonate concentration for each patient so as to maintain the predialysis tCO<sub>2</sub> concentration above 23 mmol/L. Dialysis plays a major role in the maintenance of a potassium concentration in patients with end stage renal disease. Excess potassium is removed by using a dialysate with a lower potassium concentration, so that a gradient is achieved that favors movement of potassium.



**Figure 5: Conversion to and from Carbonic Acid**

Within the body, in order to maintain acid-base homeostasis the bicarbonate buffer system must be functional. When the kidneys fail, this process is performed through dialysis. As a buffer, bicarbonate tends to maintain a relatively constant plasma pH and counteract any force that would alter. In this system, carbon dioxide (CO<sub>2</sub>) combines with water (H<sub>2</sub>O) to form carbonic acid (H<sub>2</sub>CO<sub>3</sub>), which in turn rapidly dissociates to form hydrogen ions (H<sup>+</sup>) and bicarbonate (CO<sub>3</sub><sup>-</sup>). This equilibrium process needs no catalyst so the association and dissociation of protons helps maintain pH [6, 20, 30]. This can also be described through Le Chatelier's Principle, where the kidneys prevent excessively high pH buildup in the body or undergo a condition called alkalosis. When the pH is too high, the kidneys remove bicarbonate ions from the blood. The body's acid–base balance is regulated by buffering agents, the respiratory system, and the renal system, in order to keep the arterial blood pH between 7.38 and 7.42.

### **2.5.3 Testing the Effectiveness of Treatment**

To test the effectiveness of the treatment, doctors will run a series of tests on the blood of the patient before and after treatment. The most important information is found by using one of two formulas, URR or Kt/V. This is to observe if the treatments are removing enough waste. Both tests look at one specific waste product, called blood urea nitrogen (BUN), as an indicator of the overall level of waste products in your system. The purpose of testing the BUN is to detect elevated waste levels in the blood stream, which identifies reduced kidney function. The normal range for BUN is 7-20 milligrams per deciliter (mg/dl).

The purpose of testing the Urea reduction ratio is to measure how much urea was removed during a hemodialysis session. The target range should be greater than 65% reduction. This test is typically done once every two to four weeks (6-7 sessions). Testing Kt/V is a little different because it is a mathematical formula involving multiple variables. “K” is the clearance or the amount of urea your dialyzer has removed. The units for K are (liters/minute). “t” is the time or duration of treatment in (minutes). “V” is the volume of body fluid in (liters). For a hemodialysis patient, the target range for Kt/V is approximately 1.2. There are no units because the value is a representation of effectiveness of the treatment [20, 30].

#### **2.5.4 Dialysis Statistics**

The number of individuals who are classified as suffering from some level of chronic kidney disease (CKD) has been on the rise in recent years. Currently, it is estimated that over 2.8 million patients worldwide have been diagnosed with end stage renal disease; almost 420,000 of these people being within the United States, and 89% of this population stated that hemodialysis was their primary form of treatment. As a result, it has been estimated that the number of individuals associated with these diseases is increasing on an average of 5 percent each year within the United States and 7 percent globally. This growth can be due to a variety of reasons including higher life expectancies for end stage patients, the common ageing of populations, and the growing ability to treat individuals at remote locations.

As previously mentioned, the number of United States citizens that are affected by end stage renal disease is over four hundred thousand annually. Primarily, the individuals that are associated with this disease are often minorities or of low-0 income. As compared to the white population, African Americans are three and a half times more likely to be suffering from end stage kidney failure. In addition, Native Americans are 1.9 times more likely and Hispanics are 1.5 times more



likely than that of the white population. However, the mortality rate of this “cure” is higher than one would anticipate. Following one year of treatment, dialysis patients often have a 20-25 percent mortality rate, with a survival rate of 34 percent after five years [22, 30].

Currently, the treatment with the highest success rate for patients with ESRD is kidney transplantation. This organ transplant can come from either a live or deceased donor, but the process is not as simple as it appears. First, a proper donor must be identified. Within this process, the potential new kidney must be examined for both size and compatibility with the new host; ensuring that the body will not reject the new organ following surgery. After this extensive search, major surgery ensues. If the surgery is successful, the patient will be put on a lifetime regimen of medications to prevent any possible forms of rejection. Although this process is time consuming, those who are able to receive a transplant have the highest survival rates. For a time period of five years, over 80 percent of these individuals endure.

Despite the fact that the number of kidney donors within the United States is rising on an average of eight percent per year, most patients focus on dialysis as their main method of treatment. This is because there is a very large number of people that are seeking transplants. According to figures from 2011, more than ninety thousand patients were placed on the United States kidney transplant list. Compared to the twenty thousand available donors each year, the chances of receiving a transplant becomes very slim. As a result, patients often have to turn to other options to deal with the disease, and hemodialysis treatment is the most prevalent [7, 12, 29, 30].

## **2.6 Sanitation Practices**

Ambulances are used for the transportation and stabilization of sick and injured patients. They are also used for maintaining patient health and providing treatment in a timely manner. In order to maintain a disease free environment in an ambulance, proper sanitation is essential. Sanitation is integral in preventing and controlling the spread of diseases and growth of bacteria. Medical facilities such as hospitals, clinics, and dialysis centers, are continually exposed to innumerable contaminate materials, thereby predisposing patients to infections and re-infections through contact with unsterilized equipment, spilt fluids, or presence of air borne pathogens. Poor sanitation can lead to serious health consequences for both the patients and health officials, and may cost the health institutions a fortune in compensation to patients or in lawsuits. Proper sanitation is, therefore, essential to maintain a disease free environment in a mobile dialysis vehicle.

### **2.6.1 Bacterial Pathogens in Ambulances**

The patient compartment of an ambulance is vulnerable to many different forms of bacteria, germs, and pathogens that can live on objects and surfaces for an extensive period of time. These contaminated objects can infect people who come in contact with them, and aid in the spread of disease and infections. In a study conducted in Chicago in 2012 and reported in the American Journal of Infection Control, many of Chicago's ambulances were tested and came back positive for *Staphylococcus aureus* [27]. According to the Center for Disease Control (CDC), *Staphylococcus aureus* is a group of bacteria that can cause a number of diseases and infections, as well as possessing the ability to resist certain types of antibiotics [5]. In addition, several other studies have also been conducted showing that there are many different forms of bacteria that can live on the surfaces of ambulances. These bacteria include *clostridium difficile*, Norovirus and

Bacillus, among others [2]. The creation of a mobile dialysis vehicle will be vulnerable to many of these same bacteria, and have the potential to cause these same infections. Good cleaning and disinfecting practices are an important factor in maintaining and preventing the spread of infectious diseases.

## 2.6.2 Personal Protective Equipment

Personal protective equipment, or PPE for short, is important for both protecting the wearer from harmful bacteria and substances, as well as helping to prevent the spread of disease. PPE can be used as a secondary level of protection for the human body. Within the mobile dialysis vehicle there will be a number of different forms of PPE, to be used for the safety of both the patients and care providers. Some examples of PPE include masks, protective eyewear (goggles), aprons, booties, and plastic gloves. An example of the masks worn by care administrators to prevent the spread of harmful airborne disease is shown within Figure 6. Figure 7 shows an example of standard plastic gloves that are used to protect the hands of the care provider.



**Figure 6 (left): Personal Protective Equipment: Masks**



**Figure 7 (right): Personal Protective Equipment: Gloves**

Some of these PPE will be used and worn during the administration of dialysis in the mobile dialysis vehicle. There are many different levels of PPE that must be used in different conditions,

classified as Class A, B, C and D. For this project, only basic forms of PPE are needed. According to CDC and OSHA, the use of gloves and other protective garments are mandatory for care providers in order to provide protection against many pathogens, as well as to avoid inadvertent contact with bodily fluids and other contaminants [5]. In some instances, the used of a mask is important in order to protect the care provider against airborne pathogens like the common cold and tuberculosis, among others. If these PPE become contaminated with blood or other bodily fluids, they must be removed and be disposed of properly in a labeled biohazard bag which itself must be carefully disposed of.

### **2.6.3 Cleaning and Disinfecting of Ambulance**

Thorough cleaning of a mobile dialysis vehicle helps greatly to increase the safety of the patients and service providers from disease causing pathogens. Cleaning of the dialysis vehicle should, thus, follow a meticulous process. First, all surfaces must be wiped down with antiseptic wipes. The dialysis chair must be carefully cleaned to ensure that all folds and hidden surfaces are reached. The chair should be cleaned with soap and water, as well as methodically wiped down with disinfectant wipes. Second, any visible blood on exposed surfaces or floor of the vehicle should be fully cleaned and disinfected using a standard breach. Disinfectant agents and sprays must be applied carefully when wiping all surfaces. The steering wheel, door handles, monitoring equipment and control panels should also be cleaned and disinfected.



**Figure 8: Biohazard Container**



**Figure 9: Biohazard Bags**

The most crucial step in the cleaning process involves disposal of used material. All used non-reusable devices and contaminated equipment must be disposed of appropriately as instructed. For instance, body fluid contaminated devices including linen, gloves, and sharp equipment should be placed in biohazard bags and containers to be disposed of properly at a hospital or other facility. Figure 8 and Figure 9 show examples of properly labeled biohazard containers and bags that need to be used to dispose of used sharps and other contaminated materials.

**Table 3: Recommended Cleaning Products**

<b>Products</b>	<b>Uses On</b>
<b>Alcohols (70-95%)</b>	External Surfaces of Equipment
<b>Standard Bleach (dilution ratio of 1:10)</b>	External Surfaces and for Blood Spills
<b>Hydrogen Peroxide</b>	External Surfaces of Equipment, Floors, Walls, and Furnishings
<b>Quaternary Ammonium Compounds (Quats)</b>	Floors, Walls, Furnishings, and Blood Spills

Reusable materials that are contaminated should be placed in a biohazard bag for sterilization and reuse. Trash within the patient compartment of the vehicle will need to be emptied frequently after every transport and treatment to avoid the transfer of bacteria and other diseases. In order to clean and disinfect the ambulance there are many products currently available on the

market that can be used. Table 3 provides some recommended ambulance cleaning and disinfection products.

#### **2.6.4 Waste Management**

Healthcare facilities generally produce a significant amount of waste each day, and without proper waste management and disposal protocol, this waste can build up and pose a major threat to the health of the patients and healthcare providers, as well as the environment. On average, there are two types of waste that can be produced by a medical care facility. They are clinical and non-clinical waste. Clinical wastes are wastes that consist of or contain blood residues, bodily fluids, excretions, syringes, needles or sharp instruments, and other clinical supplies that may be hazardous to a person coming in contact with them [8]. Non-clinical wastes include all other types of waste.

In medical facility like a dialysis center where hemodialysis patient are treated three times per week, on average its dialysis patients can generate approximately 323 kilograms of waste per year, of which it is estimated that 271 kilograms will be clinical waste [15]. Clinical waste in a dialysis setting can be separated further into solid and liquid wastes. Solid wastes are generated during the dialysis process, while liquid wastes are produced from the used dialysate and other fluids associated with treatment including cleaning and disinfection supplies. Each of these types of waste must be disposed of differently. Similar to these dialysis facilities, the mobile dialysis vehicle will also generate waste. On average, hemodialysis can discharge about 120 liters of liquid waste over a 4-hour period, which can count for approximated 19,000 liters per year for each patient treated [13]. The dialysis vehicle is equipped with storage tanks designed specifically to store liquid waste generated from the dialysis treatments. Once all six treatments are completed, this tank will be removed and the liquid wastes will be disposed of through a sewer system. Once

empty, each tank will be cleaned and disinfected properly before being returned to the vehicle. In addition to the liquids, solid waste will be generated on the mobile dialysis vehicle and will be placed in biohazard bags and disposed of either at landfill sites or by incineration.

**Table 4: Materials Used per Dialysis Treatment**

<b>Items</b>	<b>Amount used</b>	<b>Type of Material</b>
<b>Dialyser (1.8m<sup>2</sup>)</b>	1	Plastic
<b>Blood lines</b>	1 set	Plastic
<b>Needles</b>	2	Plastic/metal
<b>Gloves</b>	2 Pair	Plastic
<b>Apron</b>	2	Plastic
<b>Preparation pack</b>	2	Plastic/ Paper
<b>Kidney dish</b>	1	Paper
<b>Syringe(10ml)</b>	3	Plastic
<b>Syringe(30ml)</b>	1	Plastic
<b>Dressing pack</b>	2	Cotton gauze
<b>Saline Infusion (500ml)</b>	2	Saline solution
<b>Saline Infusion (1000ml)</b>	1	Saline solution
<b>Bicarbonate Cartridge(720g)</b>	1	Bicarbonate powder
<b>Concentrate container</b>	1	Salt solution

It is critical that there are proper waste management protocols to be carried out daily to ensure the protection of the patient and healthcare provider. In addition, waste management will be necessary in the mobile dialysis vehicle to prevent the growth of bacteria and other germs that can cause infectious diseases. Table 4 shows the individual items that will be used in the mobile dialysis vehicle to administer a typical treatment to a single patient. All of these items need to be properly disposed after every treatment. Note that there are two dialysis machines installed onboard, and these numbers are for only one treatment.

## 2.7 Current Mobile Solutions

While the development of a mobile dialysis center is still a new concept, a few companies have sought to address the challenge. One such company called Odulair claims to be the first to develop a mobile dialysis center whose entire facility can be placed upon a trailer and towed to disaster locations. Another corporation, referred to as MMIC, sought to develop a self-contained hemodialysis facility that can provide on-sight treatment for up to six individuals simultaneously. This system functions within a trailer setting and can be transported by the means of a tractor, train, or ship.

### 2.7.1 Odulair Mobile Dialysis Unit

With over 40 different mobile medical and health units offered for sale, Odulair advertises itself as the “the **only** commercial manufacturer with **actual** experience building a mobile dialysis unit.” The unit, as depicted in Figure 10 below, allows for the treatment of up to six individuals at a time. The system aims to create a comfortable environment for the patient, providing them with relaxing chairs, optional trays and a television projector at every station. While the company boasts about its dialysis unit, it also offers a variety of other trailers for sale. Units such as mobile blood testing centers, mobile family practices, mobile MRI units, and mobile general surgery trailers are just some of the products offered by this healthcare facility. With a variety of chassis platforms to select from, the trailer is able to accommodate for most builds [24].





**Figure 10: Odulair Mobile Dialysis Unit**

Complying with codes outlined by U.S. healthcare, the design developed by Odulair provides the ability to administer on-site dialysis. As classified by the Food and Drug Administration (FDA), each chair has a minimum of 4 feet between one another, and is designed to be quite large and comfortable for the patient. Advertised for use in providing care to correctional facilities, disaster relief, and humanitarian purposes, this unit is quite capable. It does, however, have a few drawbacks.

One of the challenges associated with the dialysis trailer is its large and cumbersome length. Although the company offers a variety of chassis for the vehicle to be built off of, the overall length of the vehicle is still very large. A single examine room that is offered through Odulair still has an overall length of 32 feet, set on a 4x4 SuperDuty Truck Chassis [24].



**Figure 11: Odulair Dialysis Trailer**

The largest amongst the company's fleet of vehicles is 60 feet in length; this is a double expandable trailer that features multiple rooms. Figure 11 depicts the developed design of this mobile dialysis unit. As can be seen, this vehicle must be towed by a large rig capable of towing the 60 foot trailer with eighteen wheels. Due to this length, the vehicle becomes hard to maneuver around tight corners. Therefore, access to remote locations could be severely limited. In addition, the vehicle is more susceptible to becoming stuck during disaster situations.

### **2.7.2 MMC Mobile Dialysis Unit**

Located within the state of Vermont, MMIC is a company that produces a variety of medical units that are capable of administering treatment to individuals when primary options become unavailable. The company boasts that its systems are capable of administering treatment to patients within an hour of arrival. In addition, this setup of equipment can be performed by one operator. All of their developed designs are self-contained, allowing for treatment to go directly to where it is needed. As with the Odulair systems, MMIC had a primary goal of developing a dialysis unit that is capable of delivering treatment to disaster areas, correctional facilities, and for humanitarian purposes [19].

Within the developed dialysis design, as can be seen in Figure 12, MMIC seeks to treat up to six patients at a given instance. The overall unit utilizes a reverse osmosis system that is ready in reserve, having capabilities of regenerating pure water in the event that more patients need treatment. The design also features a nursing station, a handicapped accessible bathroom, and a lounge area for those that are administering the treatment. Holding tanks for water are also portable and can be easily exchanged in the event of failure or an update to the system. Air conditioning, communications systems, lighting and integrated power are built into the system.



**Figure 12: MMC Dialysis Unit**

Some of the benefits of this developed system include the ability to administer treatment within a short period of time. As previously stated, the whole system will be capable of being set up within an hour, with just the efforts of one individual. Next, the unit may be integrated with existing facilities. One of the main goals of this project was to deliver treatment to correctional facilities. This trailer can be placed next to a jail and allow inmates to receive regularly scheduled treatments. The trailer also offers a design that is easy to clean, allowing for overall cleanliness of the vehicle and prevention against the spread of blood-borne pathogens [19].

Although this system has been proven to be successful, once again, the size of the vehicle is very large. As previously mentioned, the vehicle must be transported through the aid of a tractor, train, or ship. In addition, it takes approximately an hour to set up. In the event of a drug overdose or an immediate crisis, patients would not be able to receive treatment for 60 minutes.

## CHAPTER 3. DESIGN AND ANALYSIS OF A MOBILE DIALYSIS CENTER

### 3.1 Design

#### 3.1.1 Chassis Selection

There are many different vehicles used for ambulances in the United States, and around the world. Some of these ambulance chassis in the United States are the Ford E-350, Ford F-450, and the Mercedes Benz Sprinter. The chassis selected for this project is the Ford F-750, with a more powerful engine and longer wheelbase allowing more interior space than the previously mentioned models. According to Ford, the engine produces 200 horsepower and up to 520 lb-ft of torque, with a Gross Vehicle Weight Rating (GVWR) of up to 37,000 lbs. This rating includes the weight of the chassis, engine, cab, and all additional equipment installed – it is essentially the maximum total weight that the manufacturer recommends. The front axle can support 10,000 lbs, with another 23,500 lbs rated for the rear axle. The suspensions comes from the factory as four wheel leaf springs, but can be customized depending upon the demand. Air ride suspension options often provide a smoother ride, and are available as an alternative to the leaf springs [10].

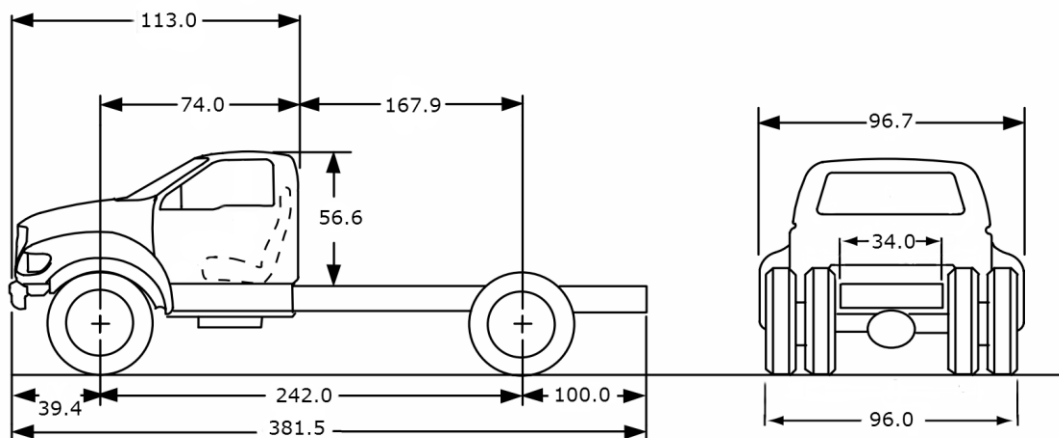


Figure 13: Ford F-750 Chassis Dimensions

Figure 13 shows the basic dimensions of the F-750 chassis selected for our vehicle, with all dimensions in inches. There are several variations of this chassis manufactured by Ford, but the version selected here has a 242 inch wheelbase, which is the normal distance between the axles. Total width of the vehicle is 96.7 inches, with a marginally narrower rear wheel tread distance, and the overall length minus the length of the cab is 268.5 inches. These constrain the dimensions of the box, which sits on the chassis above the rear wheels [28].

### **3.1.2 Walls and Framing**

The main compartment of the vehicle designed in this project is built out of aluminum 1060 alloy, providing adequate strength and reducing the weight of the vehicle significantly compared to metals such as steel. All outer and inner walls are made from one eighth inch thick aluminum sheet metal, which is then painted. The interior walls are also coated with a waterproof finish to repel liquid, including any bodily fluids like blood that may spill. The coating also allows for easy cleaning, which must occur after each treatment. The frame of the box itself can be seen in Figure 14 through Figure 18. The main support framing is made from aluminum 1060 alloy like the walls. It is comprised of hollow beams with a cross sectional square shape and wall thickness of one eighth inch. The outer dimension of these beams are a uniform two inches which, and combined with the sheet metal walls themselves, the outer walls are 2.25 inches thick. Insulation and soundproofing material is installed between the two walls and packed around the frame itself to increase patient comfort and climate control within the vehicle.

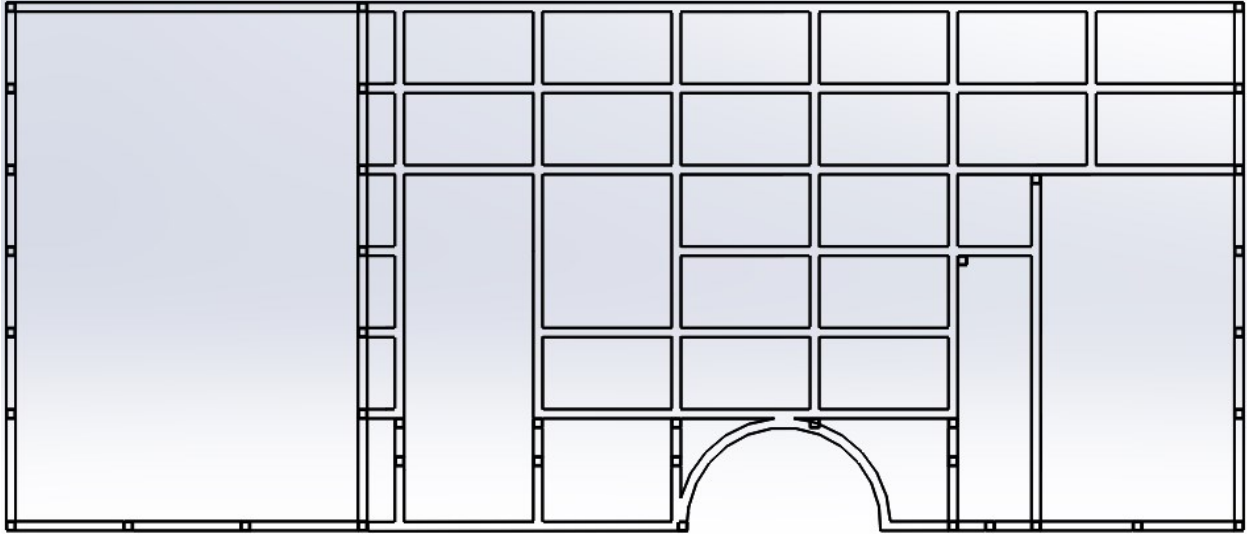


Figure 14: Left Side Outer Framing

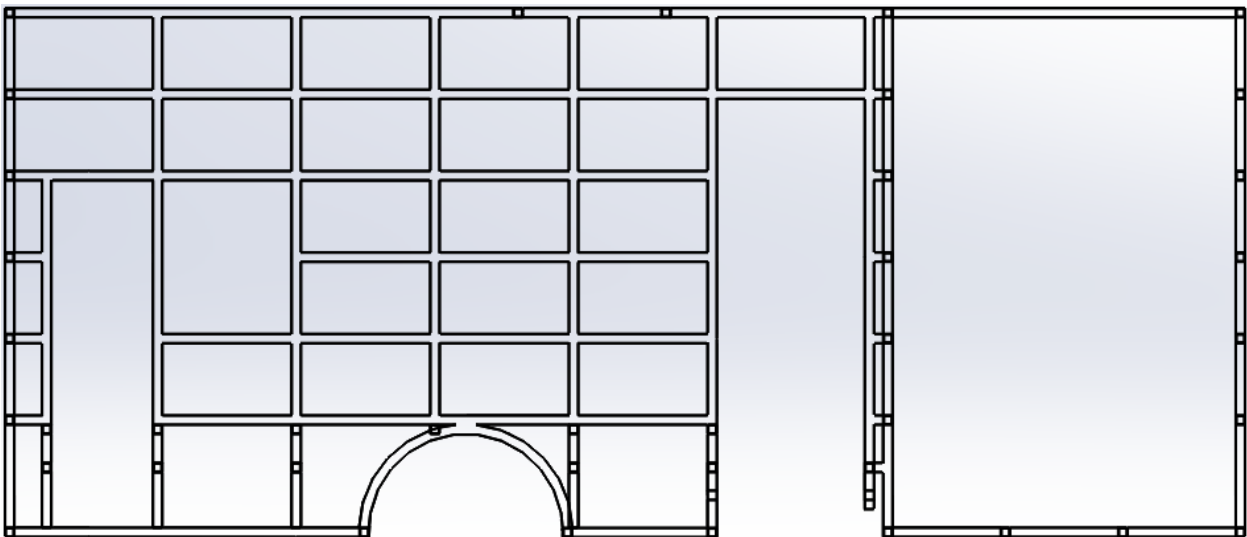
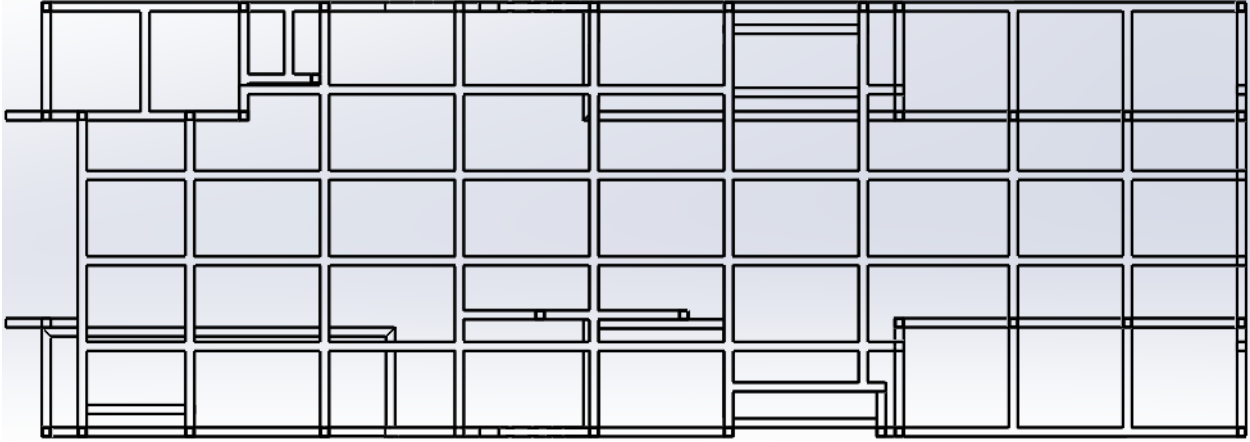
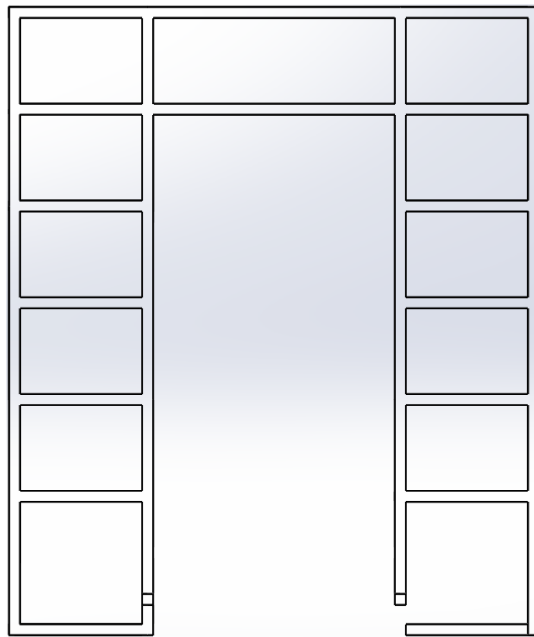


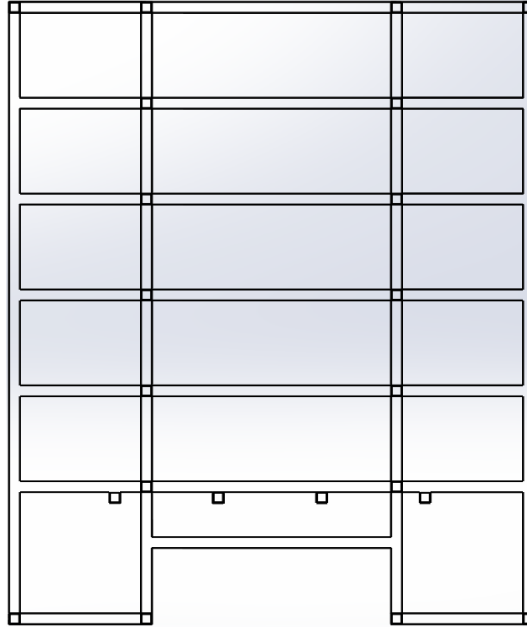
Figure 15: Right Side Outer Framing



**Figure 16: Top Down Floor Framing**



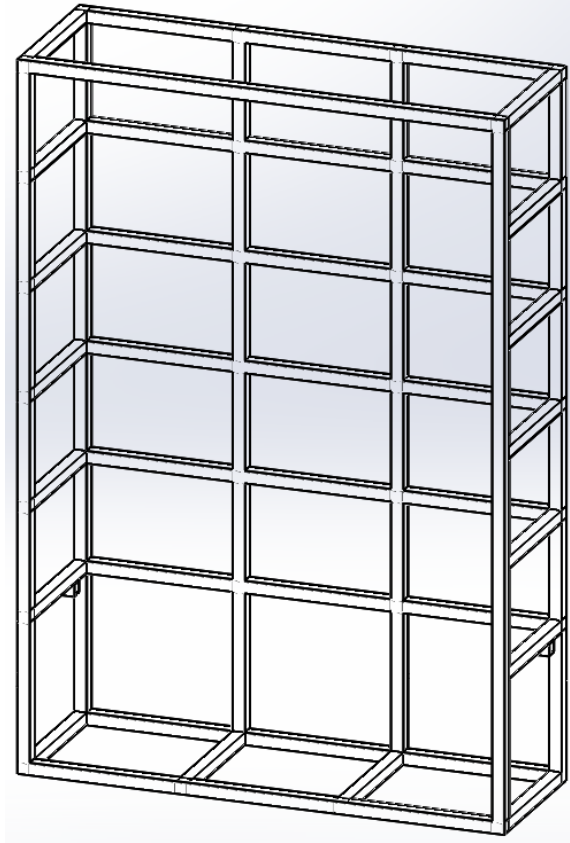
**Figure 17: Rear Outer Framing**



**Figure 18: Front Outer Framing**

The basic structure of the frame shown in Figure 14 through Figure 18 is a grid made up of 30 x 19 inch rectangles on all sides of the vehicle. All major features have an additional frame structure directly around them to provide support at the exact location where it is needed. This includes the side and rear doors, all storage containers and windows, and is demonstrated most clearly in Figure 14 and Figure 15. This framing completely surrounds storage compartments on each edge, not just in the exterior frame. In addition, the patient chairs are placed above existing supports in the floor to ensure patient safety.





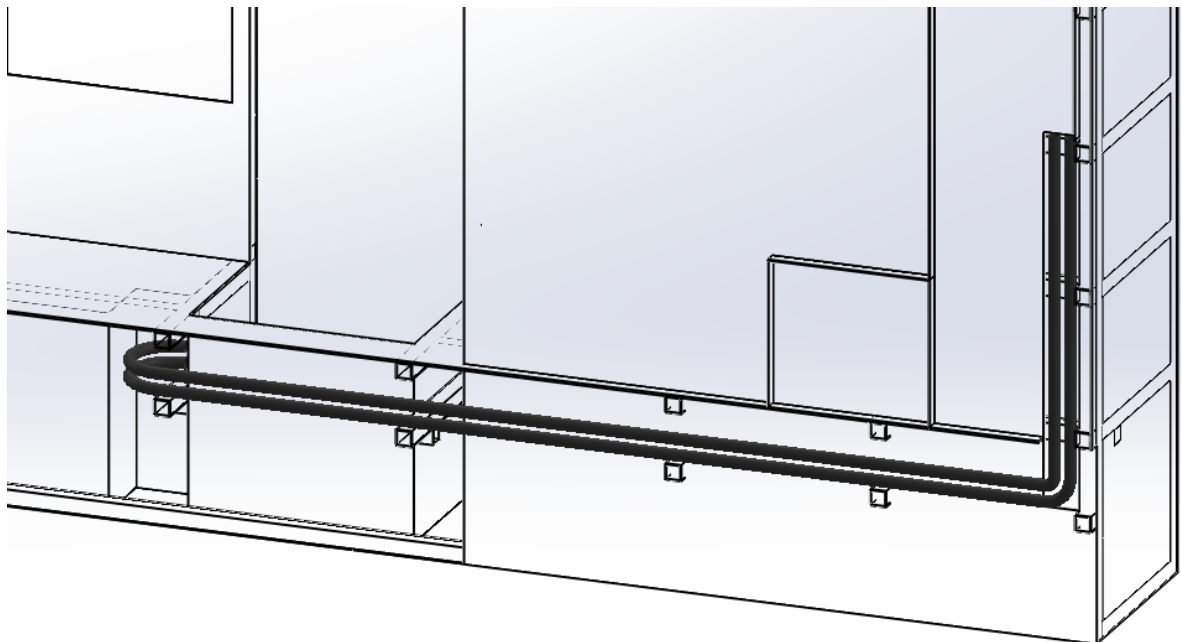
**Figure 19: Tank Storage Framing**

The water and wastewater tanks which are described later in this chapter are located at the front of the compartment. They are situated below the height of the floor, and the framing is not as uniform as that of the walls.

Figure 19 shows a diametric view of the framing as a grid system 25 inches wide by 17.5 inches high each, with supports closer together than the outer walls to account for the high weight of the water tanks. This framing on both sides of the vehicle are symmetrical, with large opening on the outside to allow easy installation and removal.

The floor of the interior of the vehicle is covered in vinyl planking made to look like hardwood, and is installed in sections that can be removed individually to allow for replacement

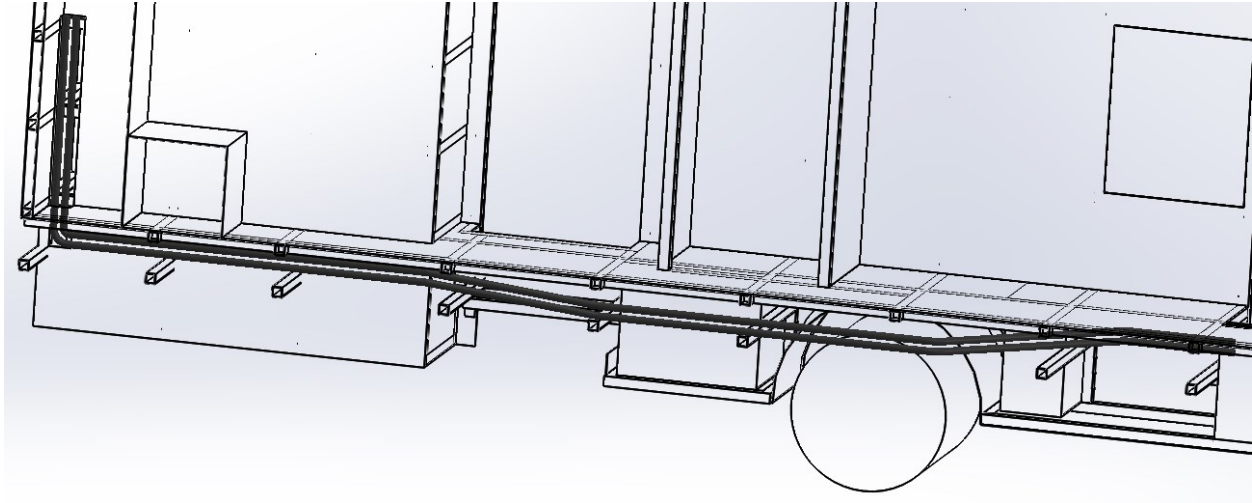
if necessary, although this should not need to be done often or at all. The rear wheels of the vehicle rise slightly above the top of the chassis, and this could cause a tripping hazard inside the vehicle. To deal with this, there is a 10.25 inch separation between the vehicle chassis and the interior floor, entirely above the top of the wheels, which ensures a flat floor throughout the vehicle. There is an eight inch clearance between the wheel itself and the frame allowing significant displacement in the shocks to keep the ride as smooth as possible. This extra space below the floor also serves as a place to run wires, plumbing, and insulation.



**Figure 20: Left Side Plumbing**

Figure 20 is a cutaway view of the left side of the vehicle's water and wastewater plumbing. The plumbing itself, shown in bold, consists of two parallel 1.5 inch PVC pipes. These pipes move water and wastewater between their respective tanks and the dialysis machine. Figure 21 shows the plumbing on the right side of the vehicle, again shown in bold. This plumbing is slightly more complicated than that on the left, as the pipes must travel around the rear right wheel. On both

sides, the pipes travel downwards from the tanks, behind the doors of a cabinet and below the floor to the dialysis machines, completely out of sight from the interior.



**Figure 21: Right Side Plumbing**

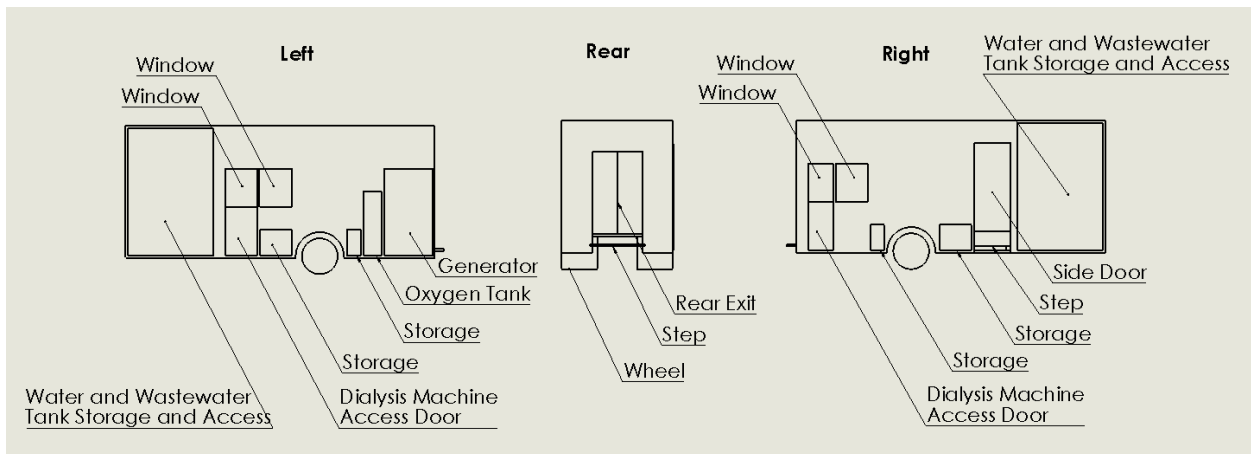
Because the floor is made in sections, as mentioned above, any work that may need to be done on these plumbing or wiring systems may be done at a reduced cost compared to removing and replacing the entire floor. The floor, as well as all interior walls, completely hides the framing from the inside of the vehicle so passengers do not see anything structural.

### **3.1.3 Vehicle Layout and Components**

Moving now into the design of the vehicle itself, Figure 22 shows and labels each external feature, including entrance and exit doors, storage compartments, and windows. There is dedicated storage room for all water and wastewater tanks, with an external garage style door to house them. The door lifts straight up in an accordion fashion to expose the tanks, which can be loaded with ease from the outside using a forklift, or by hand if empty. There is also dedicated storage for a standard M size oxygen tank. A generator and supplemental battery provides power to the vehicle during treatment sessions, allowing the main engine to be turned off. The diesel generator is loaded

at the rear of the vehicle, and mounted on rubber mounts to reduce vibrations when on. The housing is designed to allow generator installation or replacement with the use of an engine crane or other equivalent equipment.

The generator compartment is 42 x 22 x 73 inches, so any standard generator within these dimensions can be used. This design, however, was based upon a PowerLand Silent Diesel generator, which can provide a continuous 5500 Watts of power while operating. It weighs 378 pounds dry, and can run for 12 hours at 50% load on a single tank of fuel, which is more than enough for a dialysis treatment even if operating above that specified load. If the generator should fail during a treatment, the backup battery can provide sufficient power to the vehicle for long enough to safely terminate all ongoing treatments without endangering the patients. The main vehicle engine may also be used for power if necessary, but to avoid expensive wear and tear this should only be used as a backup.



**Figure 22: Exterior Layout with Labels**

The dialysis machines installed within the vehicle are accessible from the outside, allowing easy maintenance, replacement, and cleaning. They can of course be used from within the vehicle during treatments as well. Storage compartments located on the outside of the vehicle are designed

to provide space for equipment that is not immediately necessary for dialysis treatment. There are two exits in the vehicle, one on the right side and a larger double door exit at the rear. Each exit has two steps to get to the ground, with eight inch risers and 10 inch tread. Clearance to the ground is a somewhat larger 14 inch step, so care should be taken when entering or exiting the vehicle. At both exits, the bottom step is designed to fold up to reduce overall length and width when not in use. Windows are placed by the patient chairs to help reduce possible claustrophobia and increase the overall comfort of patients during long treatments.

Figure 23 shows the major exterior dimensions of the box, in inches. The overall height from the ground is 128.5 inches, assuming normal deflection in the vehicle shocks, which is smaller than all standard bridges and overpasses. As stated in the project objectives, the vehicle must be able to access remote locations, and being too tall would actively hinder this goal. There is a 14 inch ground clearance below the storage containers on the sides of the vehicle to ensure rough roads will not cause damage. The rear door is 44 inches wide by approximately 71 inches tall, abiding by Federal regulations and leaving enough clearance to load or unload all equipment stored within the vehicle. Dimensions for each external feature are shown in Figure 24 and Figure 25, with their locations relative to the ends of the box drawn in Figure 26 and Figure 27. All dimensions shown are in inches.

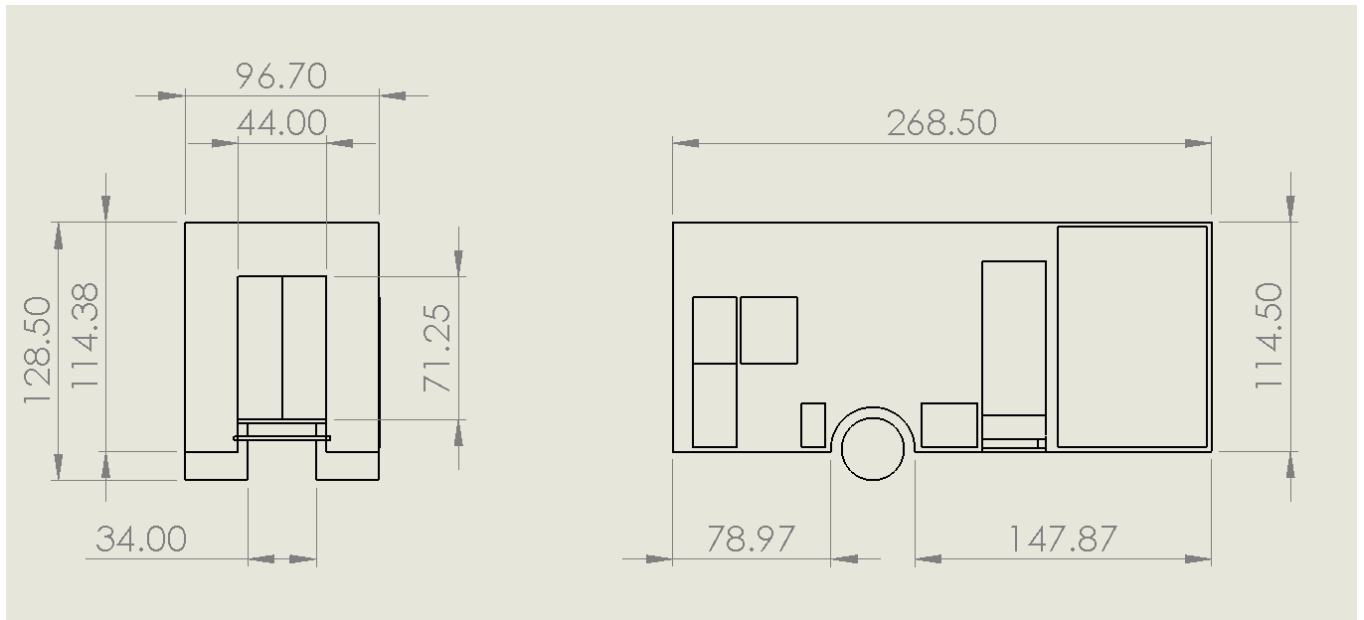


Figure 23: Exterior Dimensions

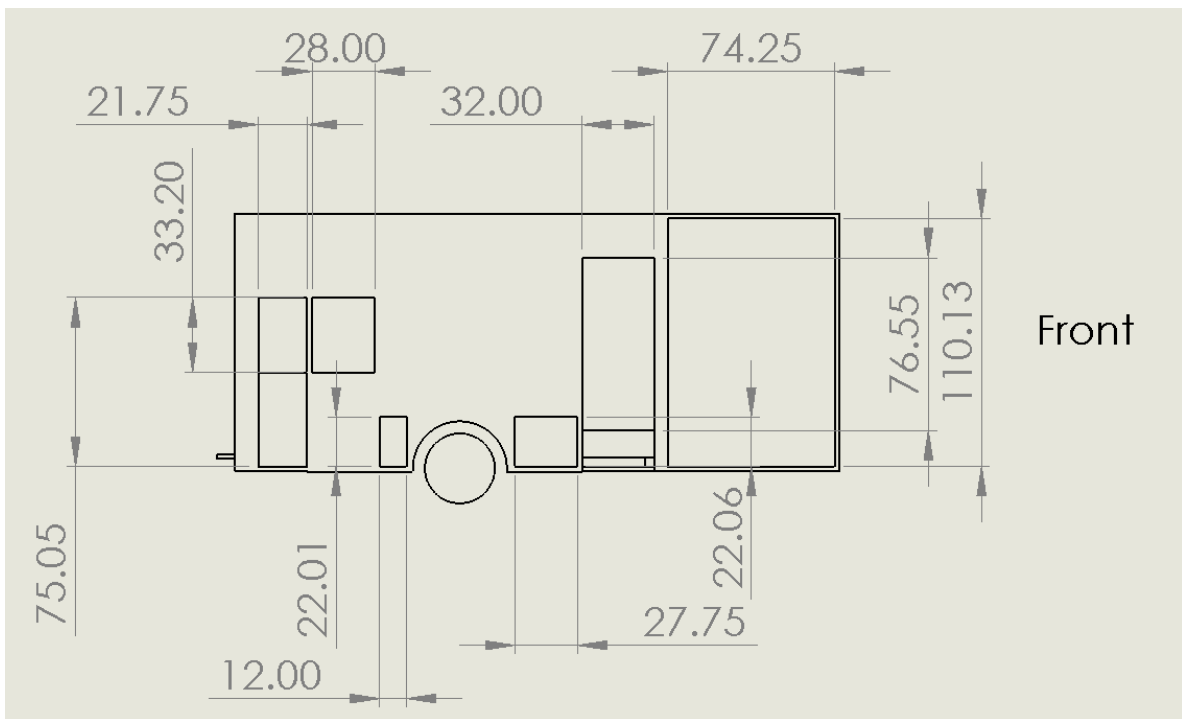
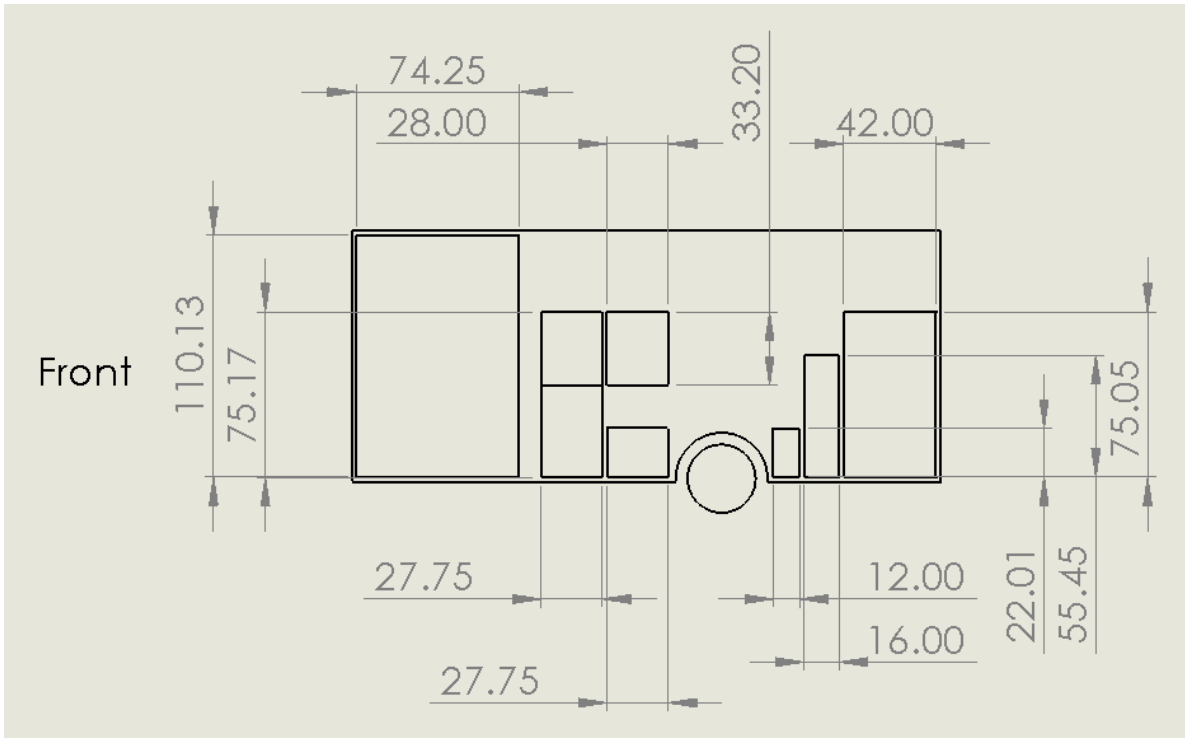
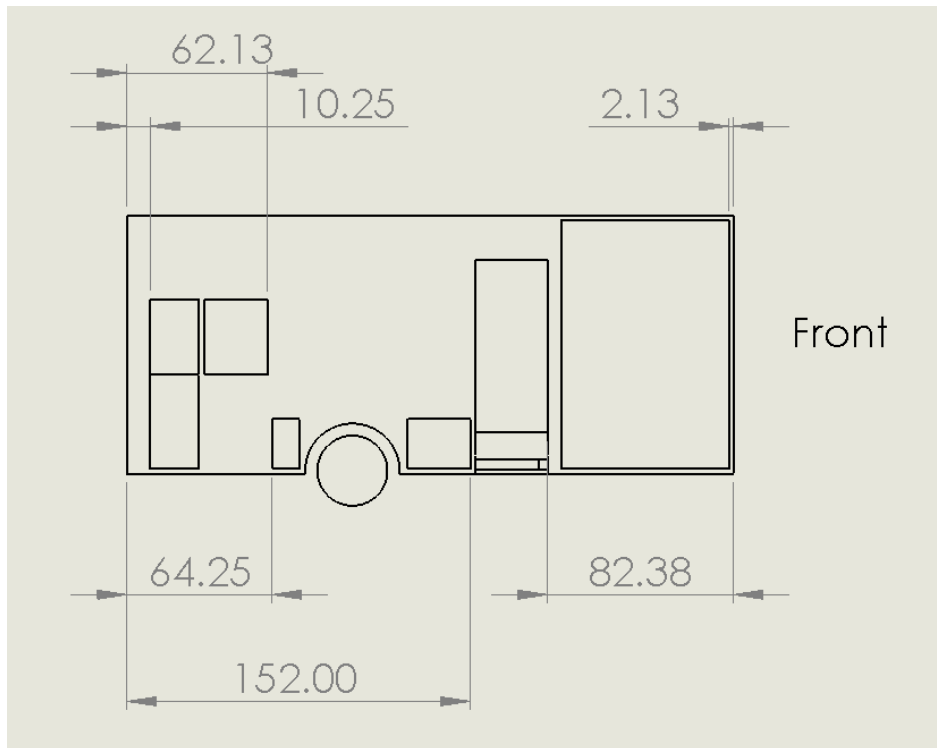


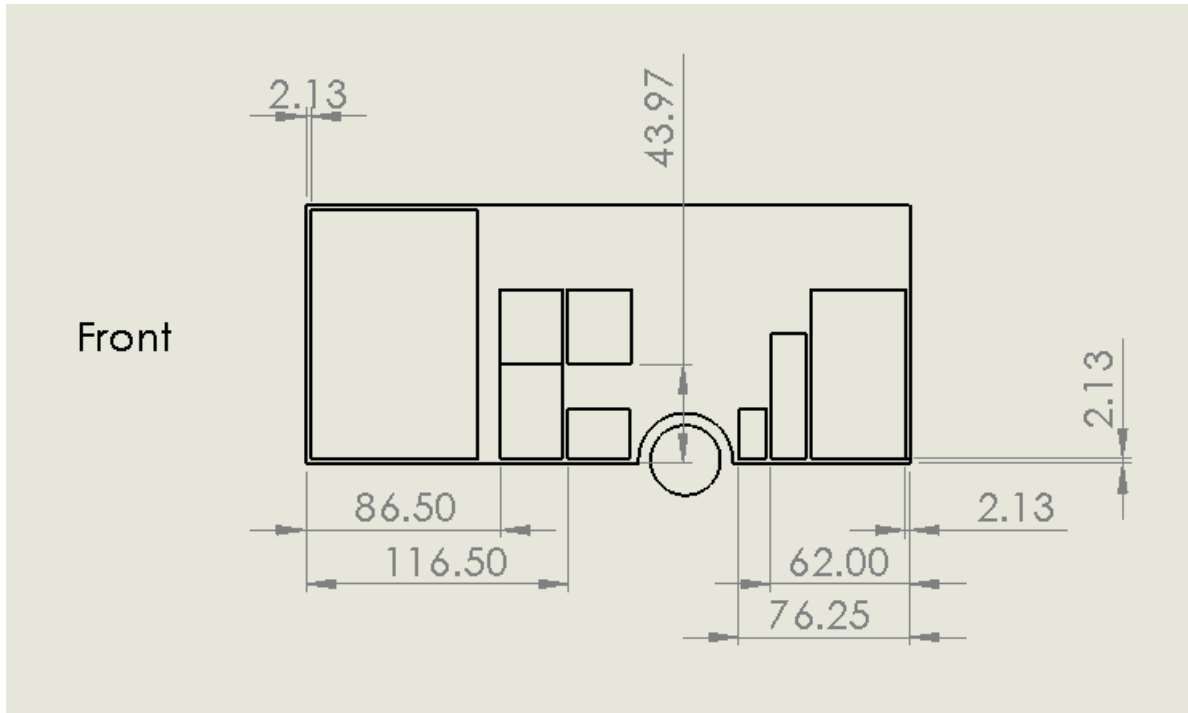
Figure 24: Right Side Door and Window Dimensions



**Figure 25: Left Side Door and Window Dimensions**



**Figure 26: Right Side Door and Window Locations**



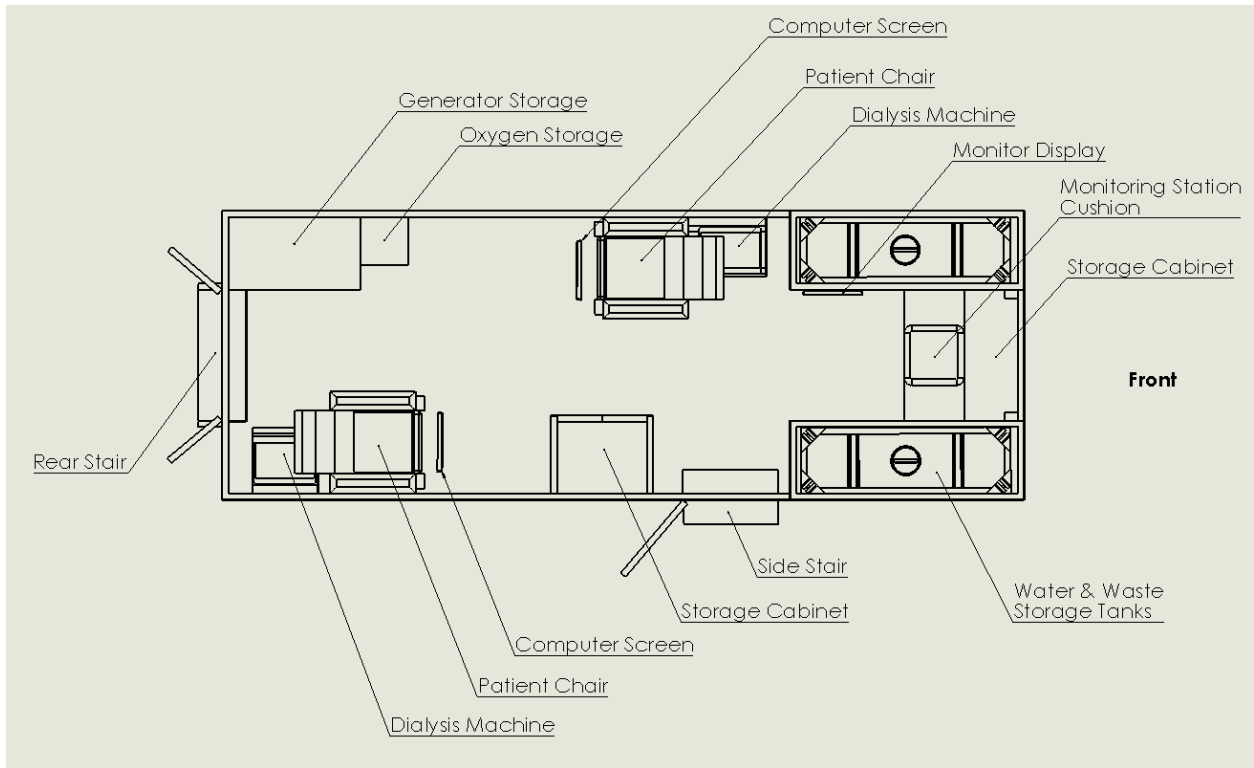
**Figure 27: Left Side Door and Window Locations**

Figure 28 shows the interior layout of the vehicle in the form of a floor plan, with major features labeled to help identify them. In accordance with the project objectives, the vehicle is equipped to administer up to three hemodialysis treatments to two patients at a time, for a total of six treatments, before restocking supplies. Storage compartments both inside and on the exterior of the vehicle provide space for all necessary equipment. The two patient stations are separated by a distance of more than 5.25 ft in accordance with FDA regulations and to avoid contamination that could occur between patients. Each station consists of a dialysis chair, a dialysis machine, a touch screen all-in-one computer, and two 180 gallon tanks. The two stations are located on opposite sides of the vehicle to help maintain a balanced layout. The screens by each patient chair are meant for entertainment, as dialysis treatments often take several hours to complete.

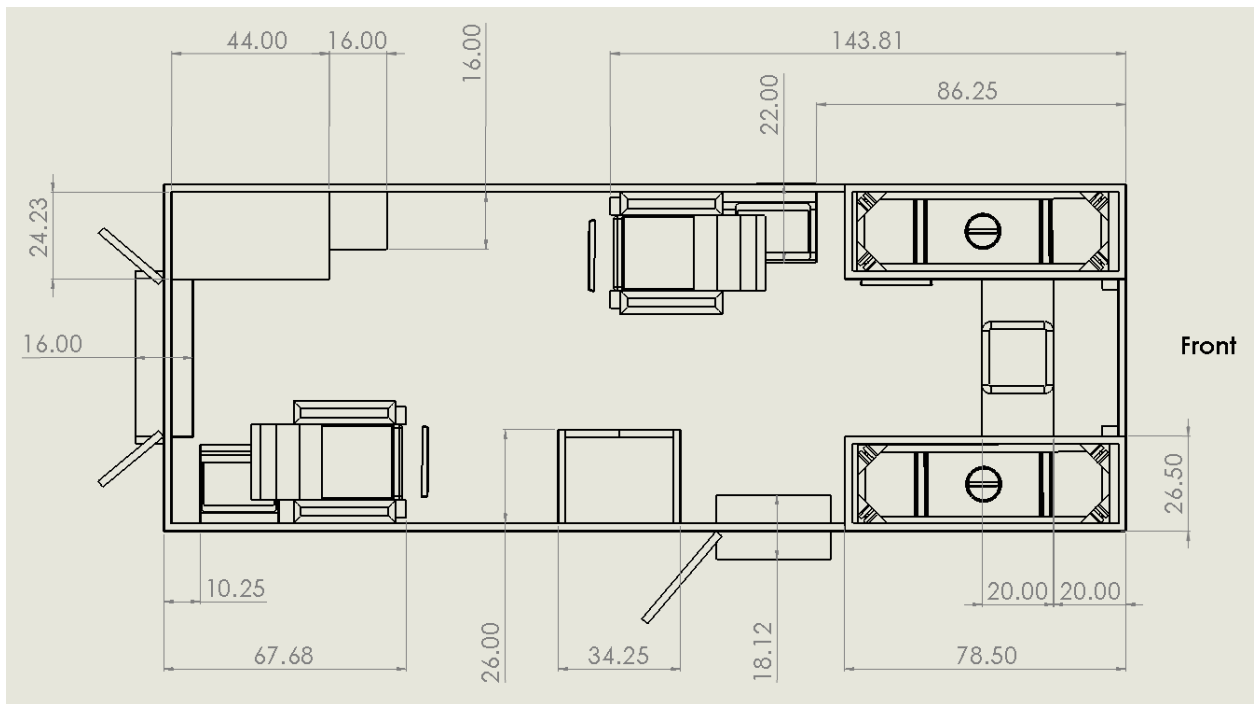


Climate control within the vehicle is also of concern, as dialysis treatments can be very taxing on patients. The Ford chassis comes from the factory equipped with air conditioning and heating, and these systems can easily be vented into the treatment room to maintain a comfortable temperature. A downside to this is that both systems require the main vehicle engine to be on in order to function, but insulating the walls, ceiling and floor of the vehicle will help reduce unwanted temperature change. The windows and doors can also be opened to provide more air flow if necessary.

A single monitoring station located between the storage tanks includes another all-in-one touch screen computer, which acts as the display for each of the dialysis machines. During treatment, the machines collect and display data about the patient and their treatment status, including blood pressure, heart rate, and blood flowrate through the machine. Machine settings can also be adjusted with this computer, allowing a simple and efficient way for the care provider to manage two patients at once. Waste baskets and biohazard disposal are located below the hinged seat cushion.



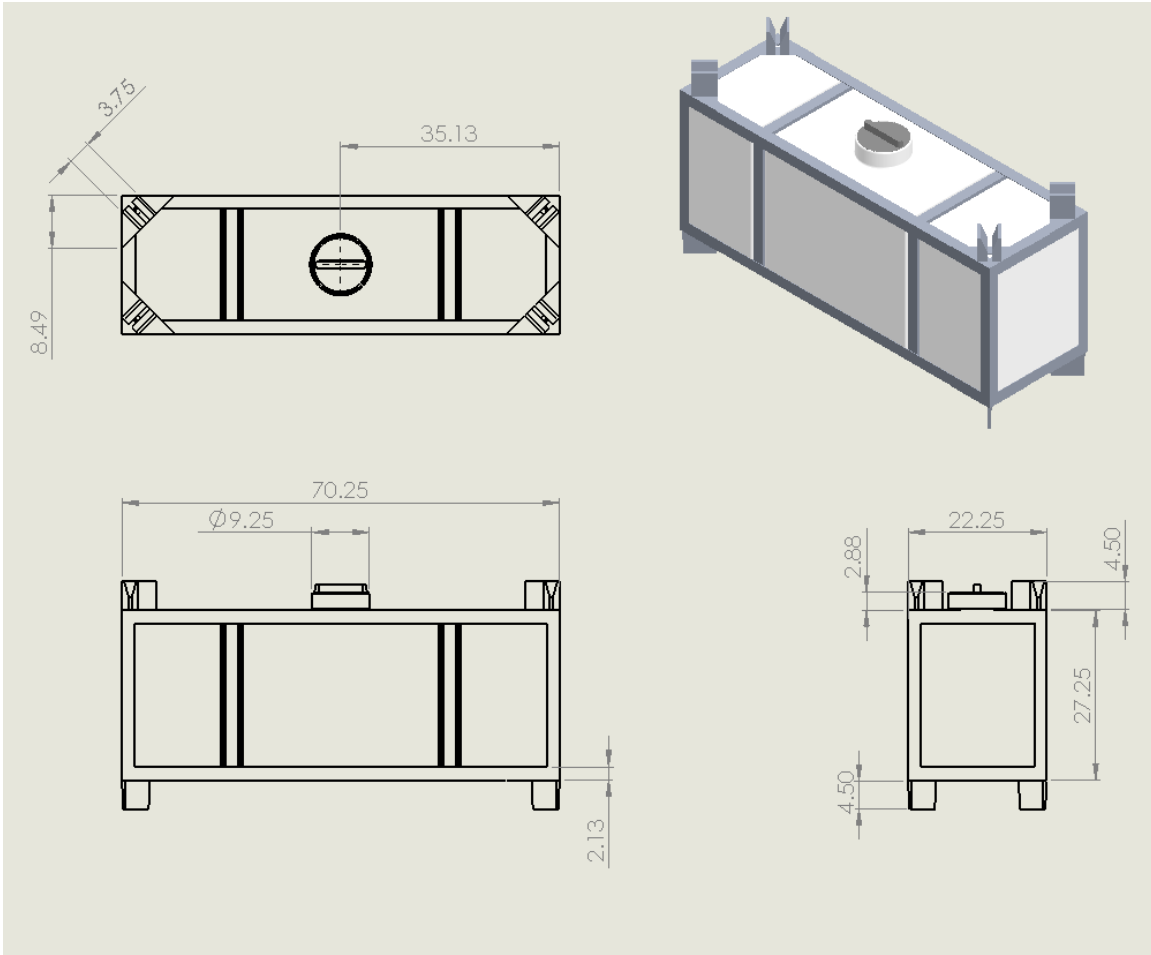
**Figure 28: Interior Layout with Labels**



**Figure 29: Interior Layout with Dimensions**

Tanks used to store purified water and wastewater are located at the front of the vehicle, placed on either side to be accessed directly from outside of the vehicle. These tanks, when full of water, are the heaviest component of the vehicle; even heavier than the entire frame. It was necessary to maintain a safe driving experience, and keeping these heavy components near the middle of the overall vehicle keeps the weight distribution from becoming vastly off center. If the vehicle should encounter slippery road conditions, an even weight distribution greatly helps to keep the driver from losing control.

This water is used in the dialysis treatment, and the tanks' vertical location allows a simple gravity fed water supply to each dialysis machine. The waste storage tanks are located at the lowest point in the vehicle, and while a water pump built into each dialysis machine is still needed to move the waste, the pump load is decreased by this location. Figure 30 details the dimensions of these 180 gallon water tanks, in inches. The full sized engineering drawing can be found in APPENDIX G. WATER STORAGE TANKS ENGINEERING DRAWINGS. The main tank walls are made from polyethylene with a wall thickness of 0.21 inches. The load bearing frame is made from aluminum 1060 alloy. Each empty tank weighs 135 pounds, allowing them to be loaded into the vehicle easily by two or three people, or using a forklift or other crane system.

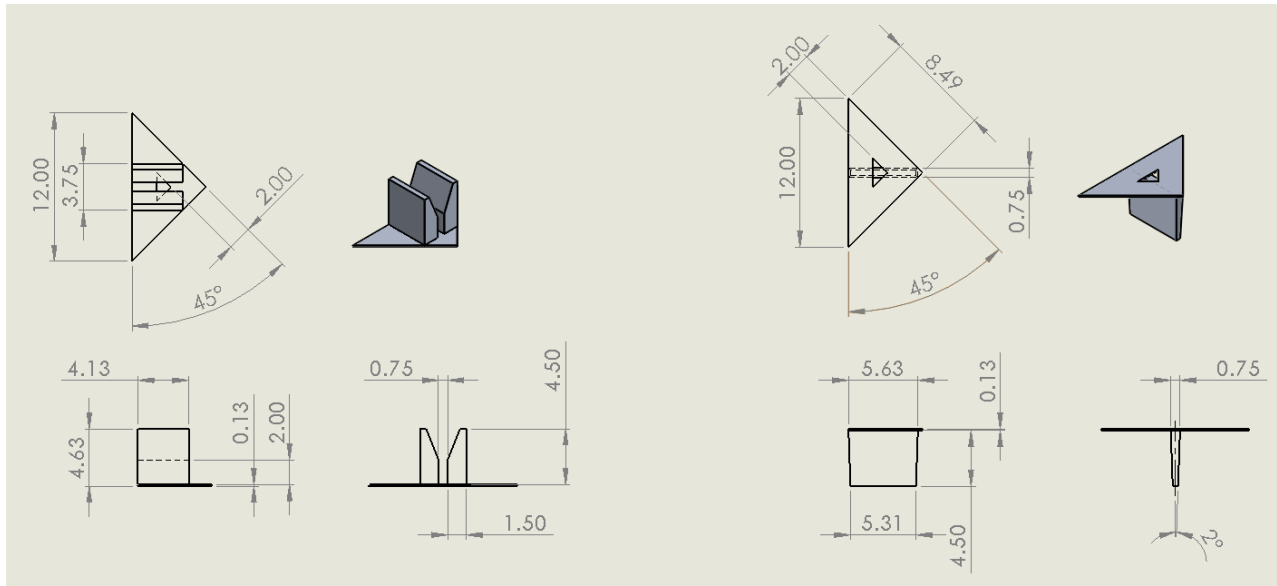


**Figure 30: Water/Waste Tank Dimensions**

Once loaded into the vehicle, empty tanks can easily be filled through a cap on the top. They must be filled with purified water, as it will come in close contact to patients' blood during dialysis, and any toxins or foreign substances in the water could be transferred to the patient with possibly catastrophic consequences. Most dialysis facilities have an all-inclusive system for purifying water, and it would be a simple task to add a hose or other system to pump water into the tanks. Wastewater must also be dealt with at a facility. This waste can either be drained from the tanks before they are removed for cleaning, or a crane or forklift may be used to remove the entire tank from the vehicle for replacement. In accordance with our objectives, each tank is fully modular to streamline the process of restocking the vehicle, reducing time and complexity. The

ability to easily swap out the fresh water tanks is also vital in keeping them sanitized, as bacteria and other organic substances can grow in the tanks if regular cleaning does not occur. Sanitation of the pipes themselves is simple enough as they can be disconnected at both ends and simply flushed with bleach and pressurized water. Between the two water tanks, the vehicle can provide 360 gallons of water to the patients, but only up to 305 gallons are needed for all six treatments. This leaves an extra 55 gallons, or 15%, as an error margin. This can account for a potentially under filled tank, or residual water left in the pumps and piping after treatment.

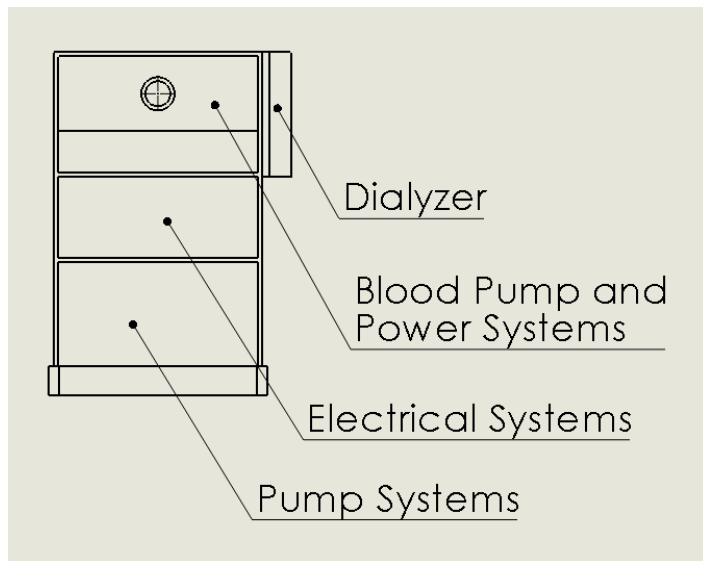
At each corner of each tanks there is an aluminum 1060 alloy fitting, as detailed in Figure 31. Note that as before, all dimensions are in inches. The female fitting on the left in Figure 31 is installed on the top of each tank, while the male fitting is affixed to the bottom. These fittings are designed with modularity in mind, and the tanks are able to be lifted straight off of each other with no resistance. A simple cotter pin through each fitting set is all that is needed to ensure the tanks will not accidentally come lose while the vehicle is in motion. The fittings are positioned at a 45 degree angle to the tank, as can be seen in Figure 30. This ensures that the tanks cannot move in any direction once they are in place in the vehicle. A simple ratchet strap secured to the vehicle frame and passed around each tank provides a second layer of security, making sure the tanks cannot tip to the side during cornering. A full sized engineering drawing of these fixtures can be found in APPENDIX F. WATER STORAGE TANK FIXTURE ENGINEERING DRAWINGS .



**Figure 31: Tank Fittings, Female (left) and Male (right)**

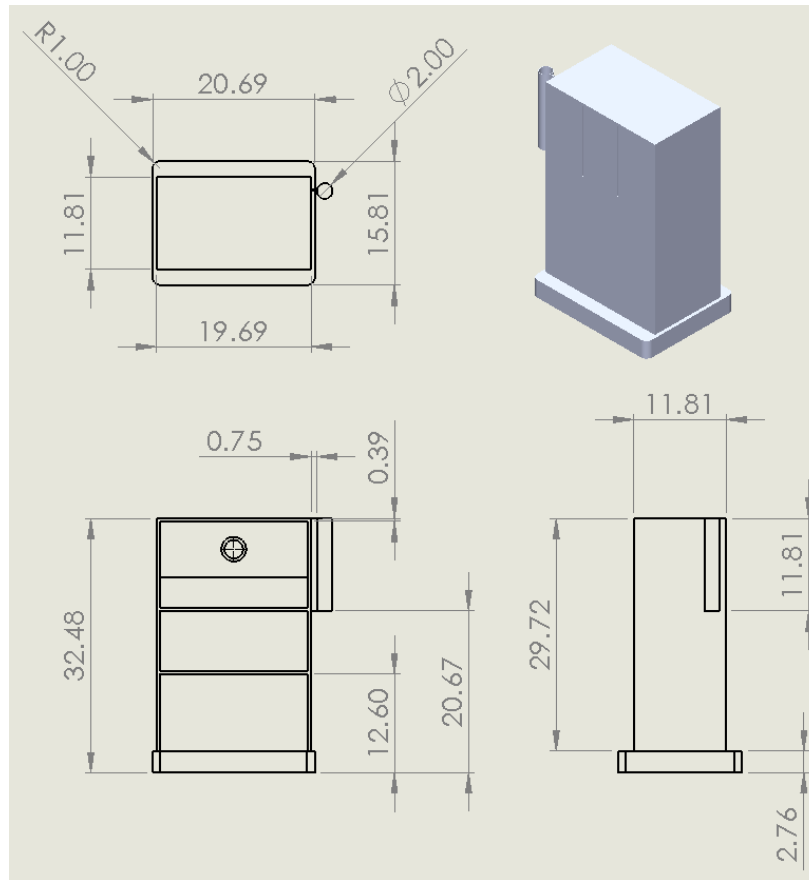
As stated above, the interior of the vehicle contains two patient chairs. These are commercially available Winco 6540 dialysis chairs, and can be reclined or allow the patient to sit up straight. Each chair can hold up to a 450 pound patient with a 25 inch wide seat, while only weighing 111 pounds itself. The maximum dimensions of the chair are 77 inches long reclined, by 36 inches wide, by 49 inches high with the backrest vertical. The outer material is non-absorptive, so that blood or other bodily fluids will not contaminate the chair between patients. Each chair is also equipped with a heater, which can help regulate individual patient comfort [17, 29].

The dialysis machines are located directly below the back rest of each patient chair. This reduces the length of blood tubing while maintaining a necessary egress width in front of the vehicle exits. Each machine is secured to the frame of the vehicle and installed in a compartment 10.5 inches below the interior floor allowing the patients the ability to fully recline their chairs above each machine.



**Figure 32: Dialysis Machine with Labels**

Figure 32 labels the major parts of the dialysis machine used within the vehicle. A preliminary goal of this project was to reduce the size of the machine by removing unused space and consolidating the displays. This goal was achieved, and as this figure shows, all excess space has been removed and the overall height of the machine has been decreased by 17.8 inches.



**Figure 33: Dialysis Machine with Dimensions**

Figure 33 details the size of the dialysis machine used within the vehicle, including the dialyzer attached, with all dimensions in inches. A standard sized engineering drawing can be found in APPENDIX E. DIALYSIS MACHINE ENGINEERING DRAWINGS . All wall thicknesses are 0.25 inches to ensure adequate support of the internal systems as well as vibration damping within the machine. The main machine chassis is made of aluminum to reduce the weight. Compared to a standard dialysis machine, the base size has been decreased. A large base size is unnecessary, as the machine is simply bolted to the vehicle frame instead of mounted on wheels as it would be in a stationary facility. As mentioned before, the display has been removed from this machine. The vehicle is equipped with a single display at a central location, saving space on each machine and the reducing the complexity of administering treatment. Another modification



was the reduction of empty space below all systems. This space helps increase the overall height of the machine to keep an integrated display accessible from standing height. By removing the display altogether, this extra height is unnecessary and has been removed as well.

During the design process, the water storage tanks proved to be the most cumbersome element. Water weighs more than 8.3 pounds per gallon. Refer to A for the complete MathCAD code used for the following calculations. Using the maximum water flowrate used in dialysis, the maximum amount of water needed per patient per treatment was found to be 50.7 gallons, and 304 gallons for all six treatments. This MathCAD code was also used to determine the optimal size of the tanks used in gallons and cubic inches, with dimensions as shown in Figure 30.



**Figure 34: 50 Gallon Cylindrical Storage Tank**

Cylindrical tanks, such as the one shown in Figure 34, were used in the early stages of the design as an attempt to keep the tanks useable by hand without the use of a forklift or crane. This proved to be unrealistic, as a full 50 gallon water tank weighs over 400 pounds. Using a large, complex array of small water tanks was considered, but this also proved to be irrational. Using

tanks small enough that they could be loaded or unloaded from the vehicle by one individual would require more than 40 tanks to hold just the water, and an equal number to contain waste. A load bearing rack, as well as very complicated plumbing would be necessary to utilize this vast number of tanks, and a full tank restock would be physically exhausting and time consuming. This effectively ruled out using human strength to load the tanks into the vehicle between treatments, leaving only the use of machinery as a viable option. Once the use of machinery was confirmed, the only logical solution was to reduce the number of tanks as low as possible. Using more tanks increases the total exterior volume needed to contain everything by adding unused space between the tanks. The option of using two tanks, one for water and one for waste, was considered briefly. This would result in the least amount of volume being taken to store the tanks, but would also make the storage containers permanently installed on the vehicle. To eliminate the risk of bacteria and other organisms growing within the tanks, it was imperative that they be installed with the ability to be removed for cleaning and replacement.

This constraint brought the design back to a modular system, and it was determined that using a system of four tanks would be the most efficient. One water tank and one waste tank would be placed on each side of the vehicle to maintain balance. As stated previously, the location of the storage tanks also helps to maintain vehicle stability by avoiding a disproportionate weight distribution. The tanks are located as low as possible in the vehicle to keep the center of gravity low.

### 3.2 Storage Tank Analysis

One of the primary concerns in developing a mobile dialysis center is to ensure the safety of both the passengers, patients, and those administering treatment. The developed design incorporates multiple objects of high weight that, in the event of an accident, could become lethal without proper mounting fixtures. All permanent items are bolted to the frame of the vehicle, and items that will be regularly changed and replaced are mounted with a special fixture described below.



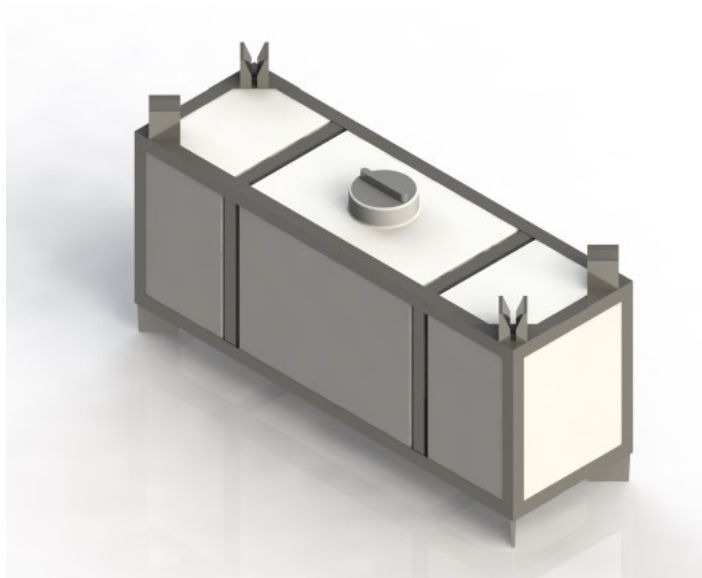
**Figure 35: Top View of Dialysis Unit**

The heaviest items within the vehicle are the water and waste storage tanks. One of each of these tanks is located on the left and right side of the vehicle, as can be seen in Figure 35. The water tank is located on top of the storage tank in order to allow gravity to aid in the process of delivering fresh water to the dialysis patients. The tanks themselves are comprised of a polyethylene material, with a load bearing frame built around the edges of the tanks made from an aluminum 1060 alloy. This material was selected instead of steel due to its light weight, yet it can still withstand a high amount of stress. The yield strength of this material is  $2.75742e+007$  N/m<sup>2</sup>, and the tensile strength is  $6.89356e+007$  N/m<sup>2</sup>. Mounting fixtures are located at each corner of

the tank, mounted at a 45 degree angles to prevent the tanks from slipping in any direction, and are machined from aluminum 1060 alloy.

### 3.2.1 Analysis of Fixtures

Prior to the addition of water or waste to any of these containers, it was determined that the dry weight of each of the 180 gallon tanks is approximately 135 pounds. Filling two of these four tanks with water, there is an addition of 1300 pounds. This results in a total weight of 1570 pounds on each side of the vehicle, coming to a total of 3140 pounds. This weight will be dispersed over each of the mounting fixtures, creating a total weight of 392.5 pounds, or 178 kilograms, on each mount.



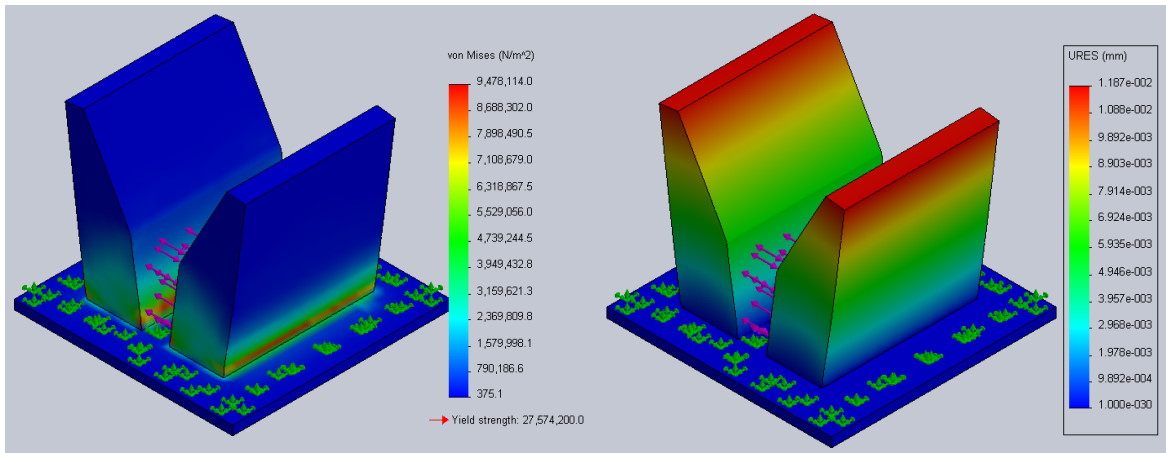
**Figure 36: Water and Waste Storage Tank**

As can be seen within Figure 36, each water tank will have a total of eight mounting fixtures, one placed at each corner. With such an extraneous force applied to each mounting fixture, it was necessary to perform a force analysis on each fixture. In the event of a frontal impact, assuming the vehicle was traveling at approximately 65 miles per hour, these heavy tanks could

potentially become dislodged. If these holding mechanisms are able to withstand the high force of the water tanks, items of lesser weight will not move from their original positions.

### 3.2.2 Analysis of the Top Mounting Fixture

Found at the top of each storage tank is a v-shaped structure. This fixture is approximately two inches thick on each side and 4 inches in height. The structure allows for another tank to be placed on top and securely fastened, preventing movement in any possible direction. There is a slight difference in size between the female fitting, shown in Figure 37, and the male fitting. This allows for more ease when the placing the tanks within the vehicle through aid of a forklift.



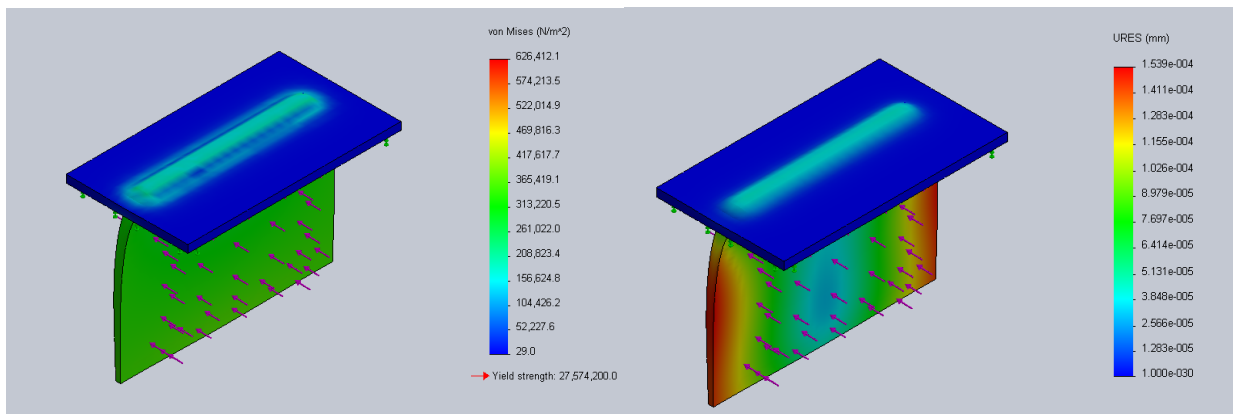
**Figure 37: Von Mises Stresses and Displacement of Top Mounting Fixture**

As can be seen in APPENDIX C. SIMULATION ON TOP TANK FITTING , each mounting fixture will have approximately 178 kilograms placed upon it. According to the KKK Federal standards, for a developed vehicle to be classified as an ambulance, it must be able to travel at a speed of 65 miles per hour. Considering this, if the vehicle were to withstand a frontal impact, it would decelerating quickly finally reaching a speed of zero miles per hour. Converting our weighting of the stacked tanks to a force, each mounting fixture will be undergoing approximately 5,915 Newtons of force during the collision.

Using advanced simulation software provided by SolidWorks, the analysis determined that the aluminum 1060 alloy selected for the top mounting fixture would not fail. As previously mentioned, the yield strength of this aluminum alloy is 27,574,200 N/m<sup>2</sup>. It was determined, as can be seen on the left side of Figure 37, that the material will only be withstanding a von Mises Stress of 626,000 N/m<sup>2</sup>. In addition, the right half of the same diagram displays the amount of physical displacement the fixture will undergo. This value was determined to be negligible, with a value of 1.187 \*10<sup>-2</sup> mm.

### 3.2.3 Analysis of the Bottom Mounting Fixture

A further analysis was conducted upon the male fitting of the storage tanks. This fitting, attached to the bottom corners of each tank, is sized to fit smoothly into the notches of the top fitting, as detailed in Figure 31. The design itself is approximately 4 inches long with a width of less than an inch.



**Figure 38: Von Mises Stresses and Displacement of Bottom Mounting Fixture**

Running the simulation through SolidWorks software, it was again determined that the component will not fail. Within the left image of Figure 38 is the von Mises Stress that will be experienced by the fitting. The yield strength of the material was already found to be over 27,000,000 N/m<sup>2</sup>, and the von Mises Stress experienced here will only be approximately 640,000

N/m<sup>2</sup>; this is well within our tolerance range. While the fixture will deform slightly, a value of  $1.639 \times 10^{-4}$  mm is considered negligible which confirms the integrity of the fixture through a frontal impact on the vehicle.

### 3.2.4 Bending Moment Analysis

Several calculations were performed to analyze the structural integrity of the vehicle's framing. Although it was important for the vehicle to feature a lightweight and cost efficient material for the framing, it also had to be able to withstand heavy weight without bending over the rear axle.

To begin, the heaviest objects within the vehicle were examined. As stated earlier in this report, the dry weight of each of the water and waste tanks is approximately 135 pounds. Applying the weight for the required amount of water and the weight of waste generated, it was determined that approximately 3093 pounds will exist at the front of the developed box, just behind the vehicle cab. This is considered as a distributed load at a location of 10.8 ft from the rear axle. Calculating the bending for these storage containers, it was determined that a value of approximately  $4.524 \times 10^4$  N\*m will be generated. Considering both the tensile strength of the 1060 aluminum alloy used and the cross sectional braces applied to the undercarriage of the box, bending was determined to be negligible. Further calculations for the dialysis chairs and machines can be found within APPENDIX A. BENDING MOMENT CALCULATIONS.

Although was confirmed that the developed design and utilized framing material is able to withstand the weight of all objects within the vehicle, cross framing also exists supporting the bottom of the vehicle. This provides the extra support that is necessary to ensure the integrity of the vehicle when maneuvering through hazardous and rough surfaces. Each of these structural

supports are welded together at a uniform distance of 28 inches between them. This is a measure to help evenly distribute the load amongst supports. In addition, the developed design will be sitting directly upon the Ford F-750 chassis, helping to alleviate the issue of bending.



## ***CHAPTER 4. CONCLUDING REMARKS***

This project designed a mobile dialysis unit capable of treating up to six patients per day. All equipment and materials needed for these treatments are stored onboard, and a full restock is only needed after all six patients have been treated. In the event of a natural disaster or other public disturbance like the Boston marathon bombings, for example, many people who rely on dialysis are not be able to receive their necessary treatments. Hurricanes such as Katrina and Sandy both shut down dialysis facilities across the country, and a declared state of emergency in Boston banned all civilian travel. The vehicle developed in this report is able to respond in these situations, and bring dialysis treatments directly to patients in need.

Additionally, patients often cannot drive themselves to and from a dialysis facility, as the process can be physically uncomfortable and draining. If this is the case, a two-way ambulance transport may be the only way for the patients to get to a facility, and this drives up the already high cost of treatment. The development of a mobile dialysis vehicle is therefore very beneficial, as it is able to drive to a patient's location to administer dialysis potentially right in their driveway.

The vehicle designed by this project team can administer three sessions of dialysis, two patients at a time, for a total of six treatments before restocking supplies. The vehicle is built on a Ford F-750 chassis, with a 242 inch wheelbase and a powerful diesel V8 engine. The body of the vehicle is made almost entirely out of aluminum alloy, resulting in a strong yet light frame. All major components of the vehicle, including water and waste tanks, dialysis machines, and generator, are designed to be modular. When each component needs to be refilled, repaired, or replaced, a simple plug-and-play operation is all that is needed. This reduces the turnaround time between treatments, as well as increases the overall simplicity of the design. A central monitoring station within the vehicle receives data from both installed dialysis machines, allowing one nurse

or doctor to easily and safely monitor up to two patients at a time from a single location. An onboard generator provides ample power to run both dialysis machines, as well as all onboard computers, pumps, and lights, without the main vehicle engine being turned on.

While there are other mobile dialysis units available on the market, the design detailed in this report tends to be simpler and cheaper to own and operate. The vehicle is smaller than competing designs, giving it the ability to travel on narrower roads, under shorter bridges, and reach more remote locations. Because of the smaller size and lighter frame, the vehicle designed and described in this report is also more fuel efficient and economical to operate than larger tractor trailer drawn units.

The project team has a few recommendations for future design options. To begin, in order to limit the amount of weight that must be carried by the vehicle, a reverse osmosis (R.O.) system could be incorporated. A reverse osmosis system is a method of utilizing a semipermeable membrane to filter large particles and toxins from a water supply. Through integration into the design, the R.O. could allow more individuals to be treated for dialysis without requiring restocking of materials. The ability to avoid storing all needed water onboard at once will greatly reduce the weight of the vehicle.

In addition, future Major Qualifying Projects can develop new dialysis chairs for the vehicle. The design currently features the commercially available Winco 6540, weighing only 111 pounds and capable of providing care to an individual weighing up to 450 pounds. These chairs, however, take up a substantial amount of room within the vehicle, especially in the reclined position. A new developed design that reduces the amount of occupied space within the vehicle would allow more room for care administrators to maneuver around the unit, and potentially allow

the integration of a third patient station. Despite the redesign, the practicality of the chair along with overall comfort must not be sacrificed. Lastly, to challenge the current dialysis chair standards, a cheaper method of weighing the patient while sitting in the chair would reduce the amount of movement necessary within the vehicle, resulting in a safer and more comfortable environment.

## APPENDIX A. BENDING MOMENT CALCULATIONS

### Moment Analysis

#### Water / Waste Storage

An Empty tank = 135 lbs

There are 4 empty tanks on board the vehicle

$$\text{Weight}_{\text{Empty}} := 135 \cdot 4 = 540 \quad \text{lbs}$$

Each tank holds 1,269.86 pounds of water

$$\text{Weight}_{\text{water}} := 1269.86 \cdot 2 = 2.54 \times 10^3 \quad \text{lbs}$$

Each individual has around 2.2 pounds of waste between treatments

$$\text{Weight}_{\text{waste}} := 2.2 \cdot 6 = 13.2 \quad \text{lbs}$$

$$\text{Total}_{\text{weight}} := \text{Weight}_{\text{Empty}} + \text{Weight}_{\text{water}} + \text{Weight}_{\text{waste}} = 3.093 \times 10^3 \quad \text{lbs}$$

---

Moment = Force \* Distance

At location A

$$\text{Force}_{\text{Tanks}} := 3093 \cdot \text{lbf}$$

$$\text{Distance}_A := 10.7875 \cdot \text{ft}$$

$$\text{Moment}_A := \text{Force}_{\text{Tanks}} \cdot \text{Distance}_A$$

$$\text{Moment}_A = 3.337 \times 10^4 \cdot \text{ft} \cdot \text{lbf}$$

$$\text{Force}_{\text{Tanks}} = 1.376 \times 10^4 \cdot \text{N}$$

$$\text{Distance}_A = 3.288 \cdot \text{m}$$

$$\text{Moment}_A = 4.524 \times 10^4 \cdot \text{N} \cdot \text{m}$$

Tank Material Information:

Material :	1060 Aluminum Alloy	
Shear Modulus	6.9*e10	N/m^2
Modulus of Elasticity	6.9e10	N/m^2
Tensile Strength	68,935,600	
N/m^2		
Yield Strength	27,574,200	N/m^2

**Dialysis Machine Analysis**

Dialysis Machine (Fresenius 2008-K)\* = 73 kg = 160.937 lbs

There are 2 machines onboard the vehicle

\*Based off of weighting of Fresenius 2008 - K model

---

Moment Analysis of Left Machine (Positive moment is taken to be counterclockwise)

Moment = Force \* Distance

At location A

$$\text{Force}_{\text{Machine}} := 160.937 \cdot \text{lbf}$$

$$\text{Distance}_A := 6.52125 \cdot \text{ft}$$

$$\text{Moment}_A := \text{Force}_{\text{Machine}} \cdot \text{Distance}_A$$

$$\text{Moment}_A = 1.05 \times 10^3 \cdot \text{ft} \cdot \text{lbf} \quad \text{Positively}$$

$$\text{Force}_{\text{Machine}} = 715.883 \cdot \text{N}$$

$$\text{Distance}_A = 1.988 \cdot \text{m}$$

$$\text{Moment}_A = 1.423 \times 10^3 \cdot \text{N} \cdot \text{m} \quad \text{Positively}$$

Moment Analysis of Right Machine (Positive moment is taken to be counterclockwise)

Moment = Force \* Distance

At location A

$$\text{Force}_{\text{Machine}} := 160.937\text{-lbf}$$

$$\text{Distance}_A := 5.8496\text{-ft}$$

$$\text{Moment}_A := \text{Force}_{\text{Machine}} \cdot \text{Distance}_A$$

$$\text{Moment}_A = 941.417\text{-ft}\cdot\text{lbf} \quad \text{Negatively}$$

$$\text{Force}_{\text{Machine}} = 715.883\text{-N}$$

$$\text{Distance}_A = 1.783\text{ m}$$

$$\text{Moment}_A = 1.276 \times 10^3 \text{ N}\cdot\text{m} \quad \text{Negatively}$$

### ***Dialysis Chair Analysis***

There are 2 Chairs onboard the vehicle

\*Based off of weighting of Winco 6540 Dialysis Chair

Weight of each empty chair is 111 lbs

Maximum weight with person in the chair = 561 pounds

---

Moment Analysis of Left Empty Chair (Positive moment is taken to be counterclockwise)

Moment = Force \* Distance

At location A

$$\text{Force}_{\text{Chair}} := 111\text{-lbf}$$

$$\text{Distance}_A := 3.7958\text{-ft}$$

$$\text{Moment}_A := \text{Force}_{\text{Chair}} \cdot \text{Distance}_A$$

$$\text{Moment}_A = 421.334\text{-ft}\cdot\text{lbf} \quad \text{Positively}$$

$$\text{Force}_{\text{Chair}} = 493.753\text{-N}$$

$$\text{Distance}_A = 1.157\text{ m}$$

$$\text{Moment}_A = 571.252 \cdot \text{N} \cdot \text{m} \quad \text{Positively}$$

Moment Analysis of Right Empty Chair (Positive moment is taken to be counterclockwise)

$$\text{Moment} = \text{Force} \cdot \text{Distance}$$

At location A

$$\text{Force}_{\text{Chair}} := 111 \cdot \text{lbf}$$

$$\text{Distance}_A := 3.1833 \cdot \text{ft}$$

$$\text{Moment}_A := \text{Force}_{\text{Chair}} \cdot \text{Distance}_A$$

$$\text{Moment}_A = 353.346 \cdot \text{ft} \cdot \text{lbf} \quad \text{Negatively}$$

$$\text{Force}_{\text{Chair}} = 493.753 \cdot \text{N}$$

$$\text{Distance}_A = 0.97 \cdot \text{m}$$

$$\text{Moment}_A = 479.073 \cdot \text{N} \cdot \text{m} \quad \text{Negatively}$$

Moment Analysis of Left Chair (w/person) (Positive moment is taken to be counterclockwise)

$$\text{Moment} = \text{Force} \cdot \text{Distance}$$

At location A

$$\text{Force}_{\text{Chair}} := 561 \cdot \text{lbf}$$

$$\text{Distance}_A := 3.7958 \cdot \text{ft}$$

$$\text{Moment}_A := \text{Force}_{\text{Chair}} \cdot \text{Distance}_A$$

$$\text{Moment}_A = 2.129 \times 10^3 \cdot \text{ft} \cdot \text{lbf} \quad \text{Positively}$$

$$\text{Force}_{\text{Chair}} = 2.495 \times 10^3 \cdot \text{N}$$

$$\text{Distance}_A = 1.157 \cdot \text{m}$$

$$\text{Moment}_A = 2.887 \times 10^3 \cdot \text{N} \cdot \text{m} \quad \text{Positively}$$

Moment Analysis of Right Chair (w/person)(Positive moment is taken to be counterclockwise)

Moment = Force \* Distance

At location A

$$\text{Force}_{\text{Chair}} := 561 \cdot \text{lbf}$$

$$\text{Distance}_A := 3.1833 \cdot \text{ft}$$

$$\text{Moment}_A := \text{Force}_{\text{Chair}} \cdot \text{Distance}_A$$

$$\text{Moment}_A = 1.786 \times 10^3 \cdot \text{ft} \cdot \text{lbf} \quad \text{Negatively}$$

$$\text{Force}_{\text{Chair}} = 2.495 \times 10^3 \cdot \text{N}$$

$$\text{Distance}_A = 0.97 \cdot \text{m}$$

$$\text{Moment}_A = 2.421 \times 10^3 \cdot \text{N} \cdot \text{m} \quad \text{Negatively}$$

### **Overall Moment Calculations: Chair, Machine, and Water/Waste**

$$\text{Moment}_{\text{Chairs}} := (2887.16 - 2421.287) \cdot \text{N} \cdot \text{m}$$

$$\text{Moment}_{\text{Chairs}} = 465.873 \cdot \text{N} \cdot \text{m}$$

$$\text{Moment}_{\text{Machine}} := (1422.945 - 1276.326) \cdot \text{N} \cdot \text{m}$$

$$\text{Moment}_{\text{Machine}} = 146.619 \cdot \text{N} \cdot \text{m}$$

$$\text{Moment}_{\text{Water}} := 52505.87 \cdot \text{N} \cdot \text{m}$$

$$\text{Total}_{\text{Bending}} := \text{Moment}_{\text{Chairs}} + \text{Moment}_{\text{Machine}} + \text{Moment}_{\text{Water}} = 5.312 \times 10^4 \cdot \text{N} \cdot \text{m}$$

(negatively)



## APPENDIX B. WATER TANK CALCULATIONS

$n := 3$	number of days between treatment
$W_{\text{day}} := 2.2$	Amount of fluid weight that is accumulated between treatments
$x := 2$	Number of Patients treated
$y := 3$	Number of Treatments per patient before mainenance

---

Determine the amount of water that is used per treatment:

$\text{flow}_{\text{rate}} := 800$  Expressed in mL per minute. The maximum value for this is 800 mL/min

$$\text{liters}_{\text{min}} := \frac{\text{flow}_{\text{rate}}}{1000}$$

$\text{liters}_{\text{min}} = 0.8$  The amount of water that is required per minute of dialysis treatment; measured in liters

$\text{liters}_{\text{hour}} := \text{liters}_{\text{min}} \cdot 60$  The amount of water that is required per hour of dialysis treatment; measured in liters

$\text{hours} := 4$  The number of hours per treatment

$$\text{liters}_{\text{treatment}} := \text{hours} \cdot \text{liters}_{\text{hour}}$$

$\text{liters}_{\text{treatment}} = 192$  The amount of water that is required per treatment; measured in liters.

---

Determine the amount of water that is utilized in between maintenancing first in liters. Then convert this total to gallons:

$$\text{liters}_{\text{total}} := \text{liters}_{\text{treatment}} \cdot (x \cdot y)$$

$\text{liters}_{\text{total}} = 1.152 \times 10^3$  The amount of water that is required by all patients receiving dialysis treatment; measured in liters.

$$\text{gallons}_{\text{total}} := \frac{\text{liters}_{\text{total}}}{3.78541}$$

$\text{gallons}_{\text{total}} = 304.326$  The amount of water that is required by all patients receiving dialysis treatment; measured in gallons.

If this amount of water were to be distributed between two tanks, each tank would have the following:

Let  $c$  be equal to the number of storage containers:

$$c := 2$$

$$\text{gallons}_{\text{pertank}} := \frac{\text{gallons}_{\text{total}}}{c}$$

$$\text{gallons}_{\text{pertank}} = 152.163$$

The amount of gallons per container

Determine the amount of weight that the storage container will be:

It has been told that a fork lift can lift a maximum of 4,000 lbs if the center of the load is 24 inches

It has been told that a fork lift can lift a maximum of 2,666 lbs if the center of the load is 36 inches

$$\text{Weight}_{\text{water}} := 8.3454 \quad \text{pounds per gallon of water}$$

$$W_{\text{tank}} := \text{gallons}_{\text{pertank}} \cdot \text{Weight}_{\text{water}}$$

$$W_{\text{tank}} = 1.2698626 \times 10^3 \quad \text{Weight in water per tank (pounds)}$$

$$W_{\text{total}} := \text{gallons}_{\text{total}} \cdot \text{Weight}_{\text{water}}$$

$$W_{\text{total}} = 2.5397251 \times 10^3 \quad \text{Total water weight within the vehicle (pounds)}$$

For quality assurance, let us assume assume a tank size of 175 gallons

Each gallon of water is equal to 231 cubic inches

For a tank size of 175 gallons:

$$\text{gallons} := 180$$

$$\text{in}_{\text{water}} := 231$$

$$\text{Volume} := \text{in}_{\text{water}} \cdot \text{gallons}$$

$$\text{Volume} = 4.158 \times 10^4 \quad \text{Required Volume of the tank in cubic inches}$$

Determine the dimensions of the storage container. The storage container will be in the shape of a rectangular prism:

$$\text{Length} := 72$$

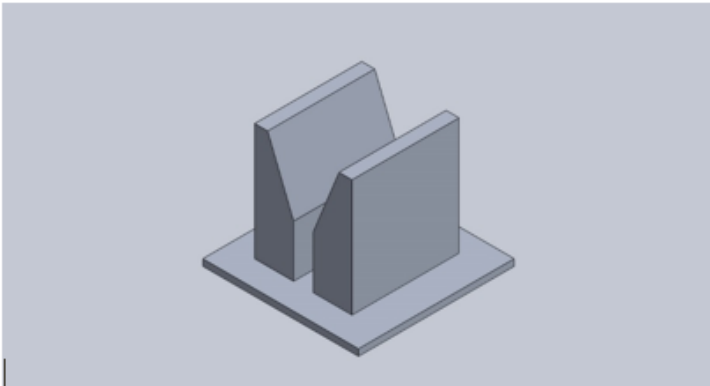
$$\text{Width} := 21$$

$$\text{Volume} = 4.158 \times 10^4$$

$$\text{Height} := \frac{\text{Volume}}{\text{Length} \cdot \text{Width}}$$

$$\text{Height} = 27.5$$

## APPENDIX C. SIMULATION ON TOP TANK FITTING



### Simulation of Tank Female Fitting

**Date:** Friday, April 10, 2015

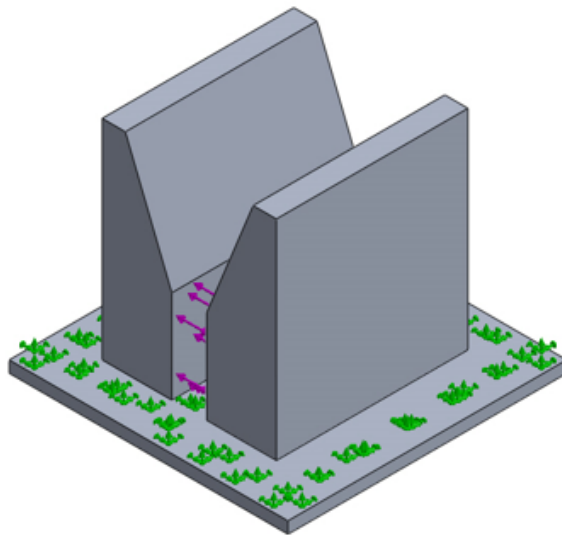
**Designer:** Solidworks

**Study name:** SimulationXpress Study

**Analysis type:** Static

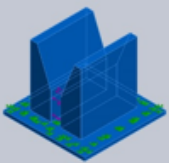
#### Description

An analysis of the top fitting for the water and waste storage tanks was conducted. The analysis shows that in the event of a 65 mile per hour crash experienced by the mobile dialysis treatment center, the high weight of the water tanks will not be a cause for failure. The designed mounting fixtures will be able to withstand a force greater, than that experienced during the accident. The material that is utilized here is aluminum 1060 alloy due to its lightweight and high yield strength.

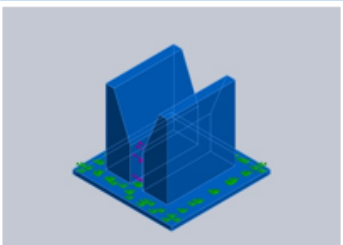


Model name: Tank Female Fitting  
Current Configuration: Default

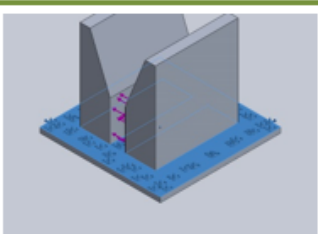
**Solid Bodies**

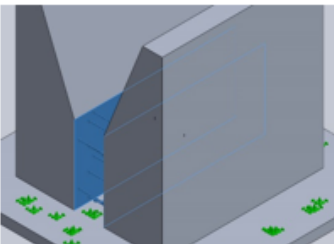
Document Name and Reference	Treated As	Volumetric Properties	Document Path/Date Modified
Boss-Extrude2 	Solid Body	Mass:2.40583 kg Volume:0.000891047 m <sup>3</sup> Density:2700 kg/m <sup>3</sup> Weight:23.5771 N	C:\Users\CL\Desktop\MQP\ Finite Element Analysis\Female Fitting\Tank Female Fitting.SLDPRT Apr 10 14:04:05 2015

## Material Properties

Model Reference	Properties	Components
	<p> <b>Name:</b> 1060 Alloy  <b>Model type:</b> Linear Elastic Isotropic  <b>Default failure criterion:</b> Unknown  <b>Yield strength:</b> 2.75742e+007 N/m<sup>2</sup>  <b>Tensile strength:</b> 6.89356e+007 N/m<sup>2</sup> </p>	<p>SolidBody 1(Boss-Extrude2)(Tank Female Fitting)</p>

## Loads and Fixtures

Fixture name	Fixture Image	Fixture Details
Fixed-1		<p> <b>Entities:</b> 1 face(s)  <b>Type:</b> Fixed Geometry                 </p>

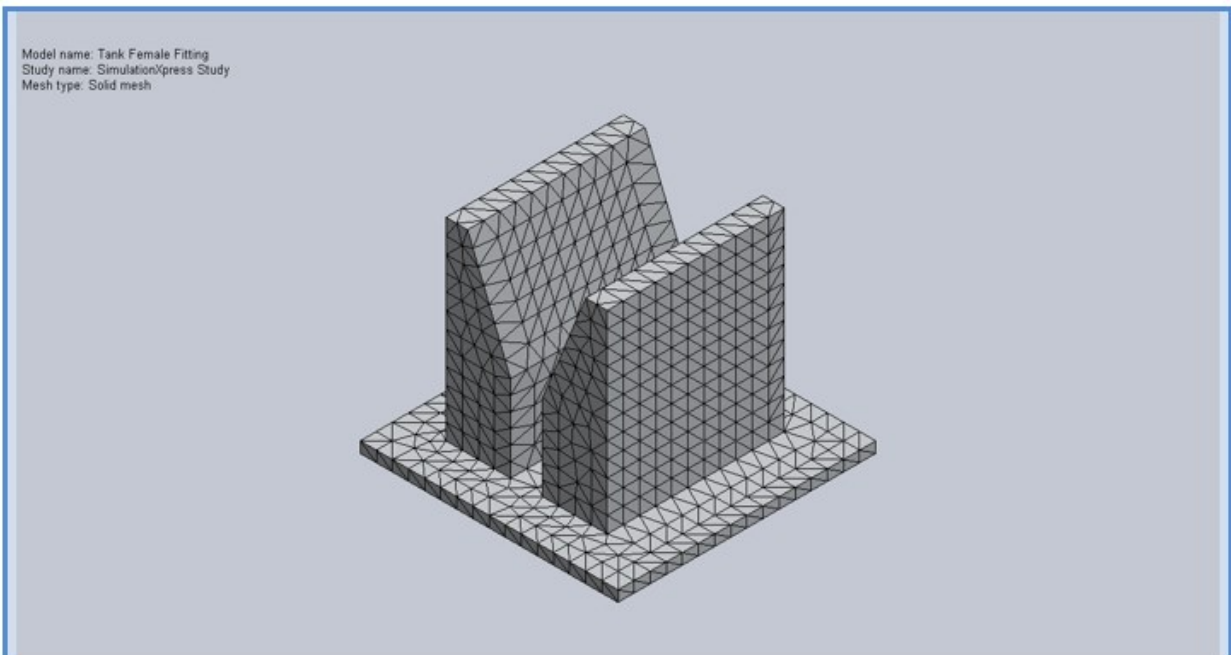
Load name	Load Image	Load Details
Force-1		<p> <b>Entities:</b> 2 face(s)  <b>Type:</b> Apply normal force  <b>Value:</b> 5914.58 N                 </p>

## Mesh Information

Mesh type	Solid Mesh
Mesher Used:	Standard mesh
Automatic Transition:	Off
Include Mesh Auto Loops:	Off
Jacobian points	4 Points
Element Size	0.378938 in
Tolerance	0.0189469 in
Mesh Quality	High

## Mesh Information - Details

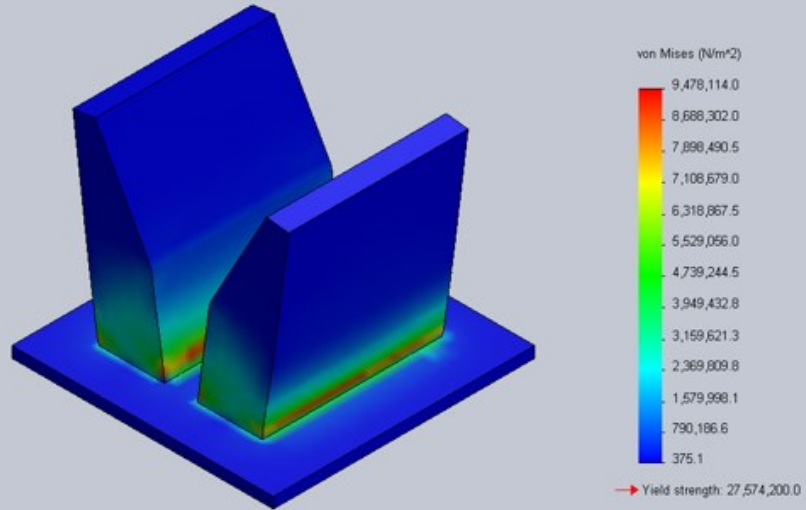
Total Nodes	12150
Total Elements	7257
Maximum Aspect Ratio	6.4406
% of elements with Aspect Ratio < 3	97.7
% of elements with Aspect Ratio > 10	0
% of distorted elements(Jacobian)	0
Time to complete mesh(hh:mm:ss):	00:00:01
Computer name:	JAMES-PC



## Study Results

Name	Type	Min	Max
Stress	VON: von Mises Stress	375.053 N/m <sup>2</sup> Node: 10015	9.47811e+006 N/m <sup>2</sup> Node: 11889

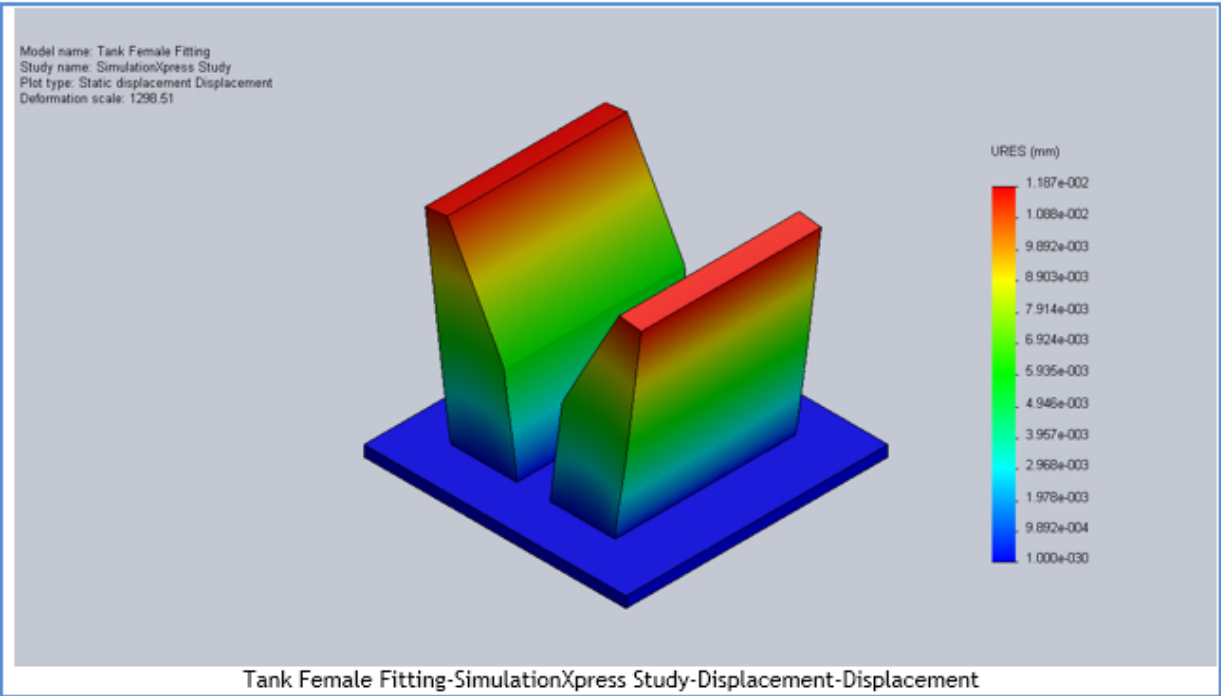
Model name: Tank Female Fitting  
 Study name: SimulationXpress Study  
 Plot type: Static nodal stress Stress  
 Deformation scale: 1296.51



Tank Female Fitting-SimulationXpress Study-Stress-Stress

Name	Type	Min	Max
Displacement	URES: Resultant Displacement	0 mm Node: 1	0.0118704 mm Node: 6929

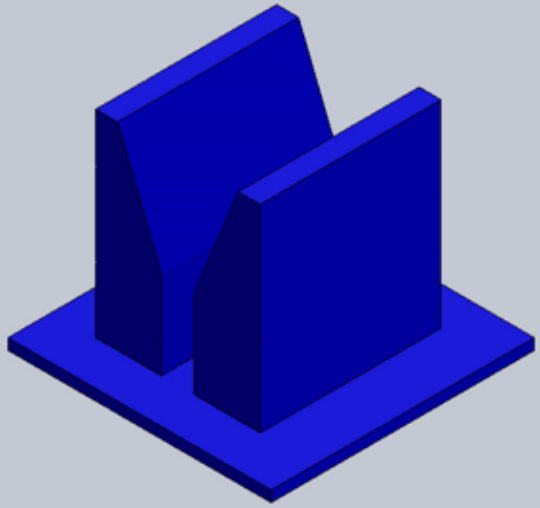




Name	Type
Deformation	Deformed Shape
<p>Model name: Tank Female Fitting            Study name: SimulationXpress Study            Plot type: Deformed Shape Deformation            Deformation scale: 1298.51</p> <p>Tank Female Fitting-SimulationXpress Study-Displacement-Deformation</p>	

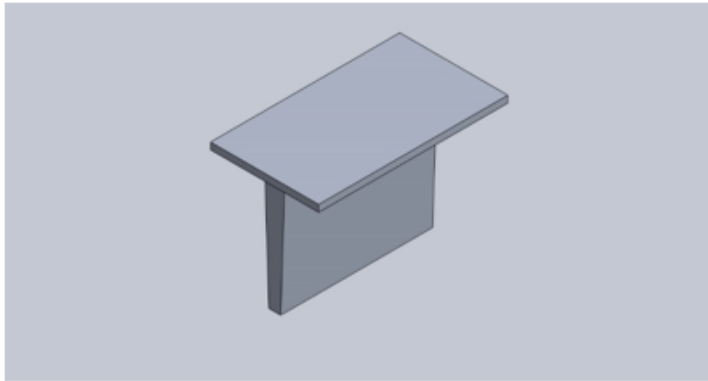
Name	Type	Min	Max
Factor of Safety	Max von Mises Stress	2.90925 Node: 11889	73520.9 Node: 10015

Model name: Tank Female Fitting  
Study name: SimulationXpress Study  
Plot type: Factor of Safety Factor of Safety  
Criterion: Max von Mises Stress  
Red < FOS = 3 < Blue



Tank Female Fitting-SimulationXpress Study-Factor of Safety-Factor of Safety

## *APPENDIX D: SIMULATION ON BOTTOM TANK FITTING*



### **Simulation of Tank Male Fitting**

**Date:** Friday, April 10, 2015

**Designer:** Solidworks

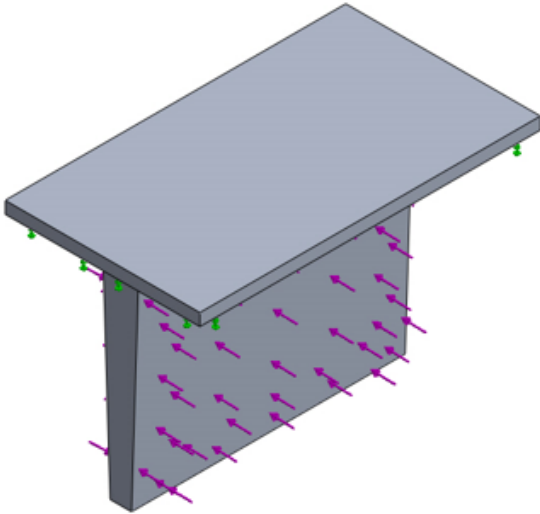
**Study name:** SimulationXpress Study

**Analysis type:** Static

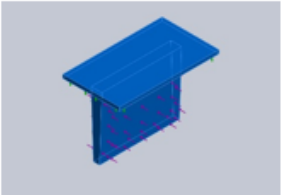
#### **Description**

An analysis of the bottom fitting for the water and waste storage tanks was conducted. The analysis shows that in the event of a 65 mile per hour crash experienced by the mobile dialysis treatment center, the high weight of the water tanks will not be a cause for failure. The designed mounting fixtures will be able to withstand a force greater than that experienced during the accident. The material that is utilized here is aluminum 1060 alloy due to its light weight and high yield strength.

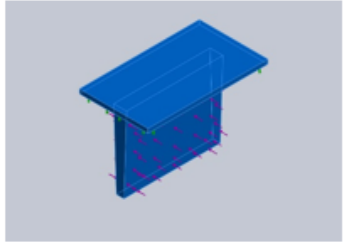
**Model Information**



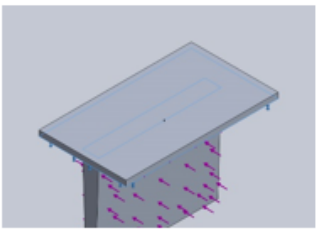
Model name: Tank Male Fitting  
Current Configuration: Default

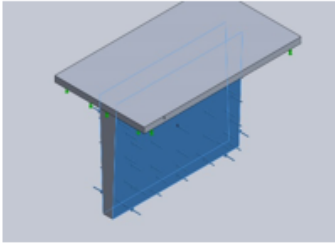
<b>Solid Bodies</b>			
Document Name and Reference	Treated As	Volumetric Properties	Document Path/Date Modified
Boss-Extrude2 	Solid Body	Mass:0.976088 kg Volume:0.000361514 m <sup>3</sup> Density:2700 kg/m <sup>3</sup> Weight:9.56566 N	C:\Users\CL\Desktop\MQP\ Finite Element Analysis\Male Fitting\tank Male Fitting.SLDPRT Apr 10 14:20:00 2015

## Material Properties

Model Reference	Properties	Components
	<p>Name: 1060 Alloy            Model type: Linear Elastic Isotropic            Default failure criterion: Max von Mises Stress            Yield strength: 2.75742e+007 N/m<sup>2</sup>            Tensile strength: 6.89356e+007 N/m<sup>2</sup></p>	<p>SolidBody 1(Boss-Extrude2)(Tank Male Fitting)</p>

## Loads and Fixtures

Fixture name	Fixture Image	Fixture Details
Fixed-1		<p>Entities: 1 face(s)            Type: Fixed Geometry</p>

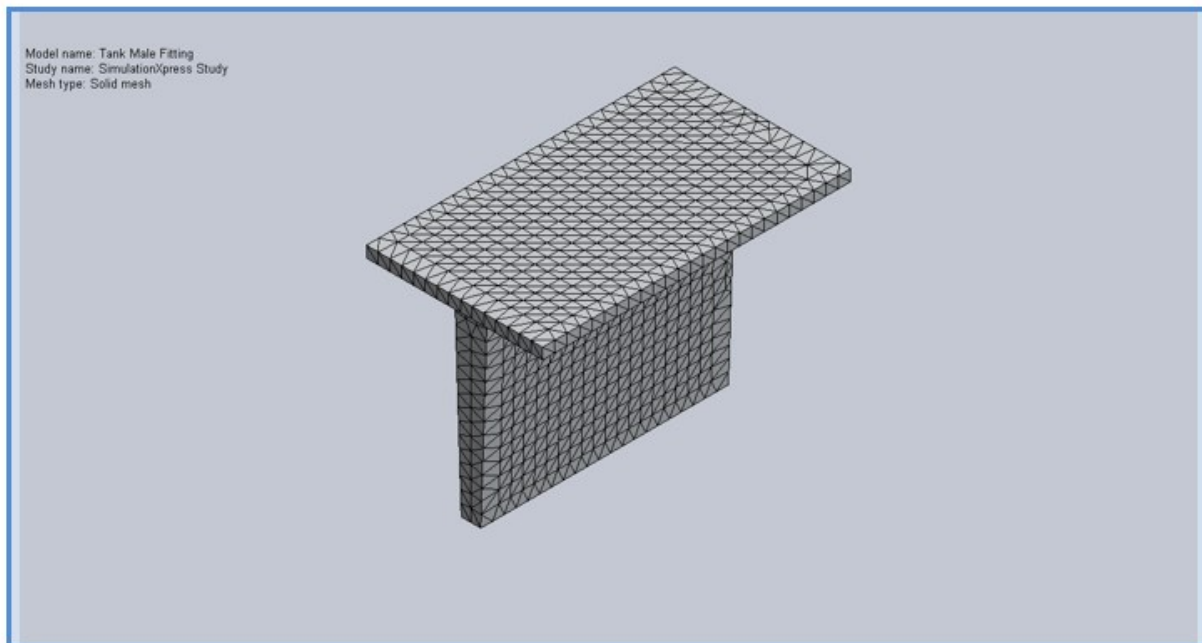
Load name	Load Image	Load Details
Force-1		<p>Entities: 2 face(s)            Type: Apply normal force            Value: 5914.58 N</p>

## Mesh Information

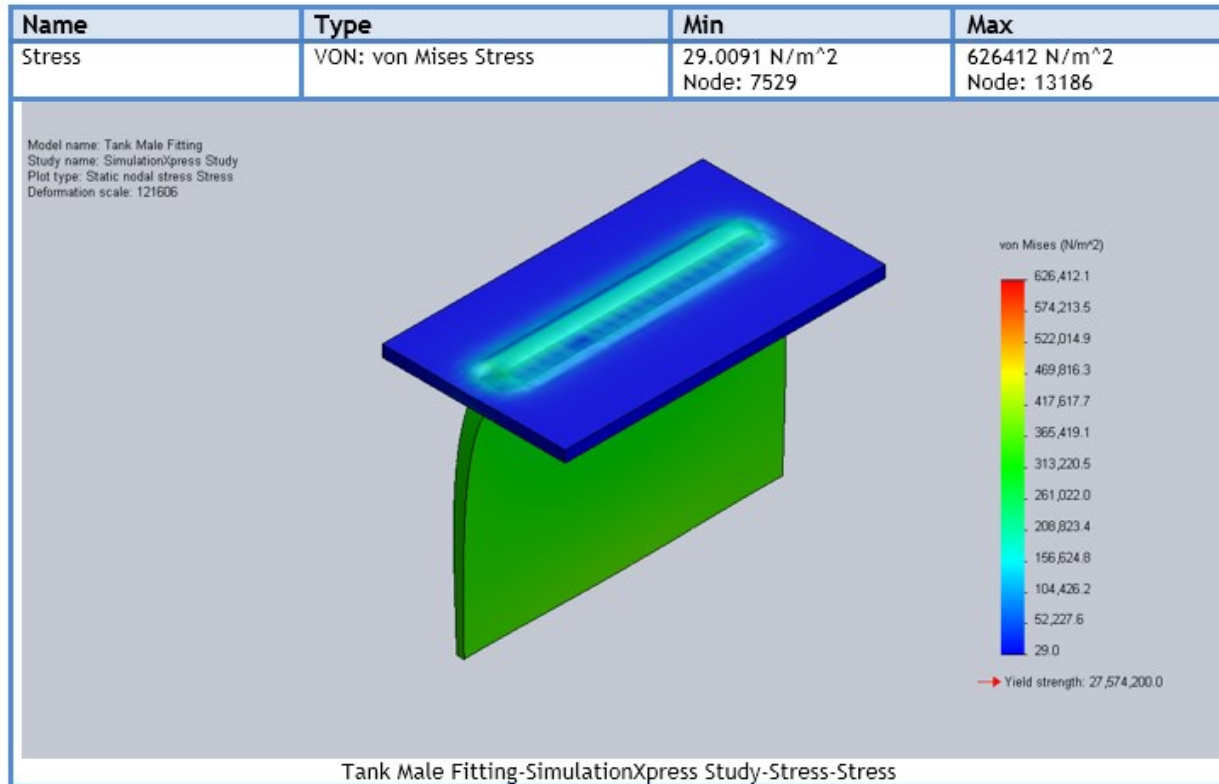
Mesh type	Solid Mesh
Mesher Used:	Standard mesh
Automatic Transition:	Off
Include Mesh Auto Loops:	Off
Jacobian points	4 Points
Element Size	0.280537 in
Tolerance	0.0140268 in
Mesh Quality	High

## Mesh Information - Details

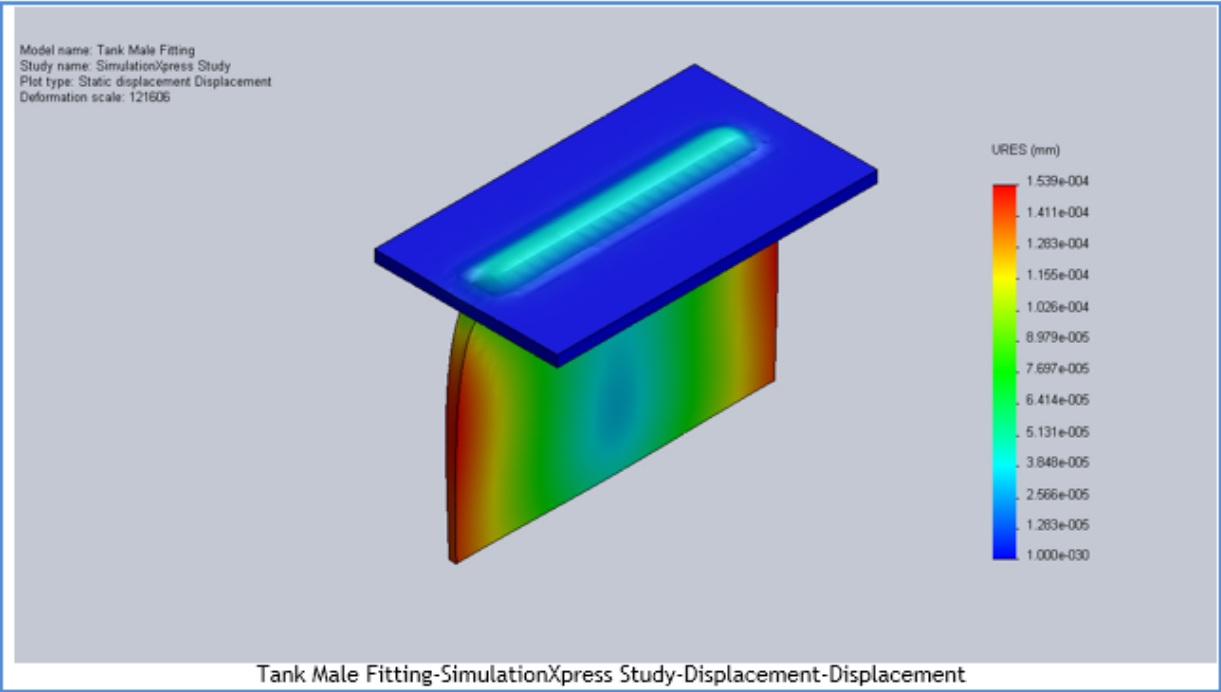
Total Nodes	13558
Total Elements	7899
Maximum Aspect Ratio	6.6729
% of elements with Aspect Ratio < 3	98.9
% of elements with Aspect Ratio > 10	0
% of distorted elements(Jacobian)	0
Time to complete mesh(hh:mm:ss):	00:00:01
Computer name:	JAMES-PC



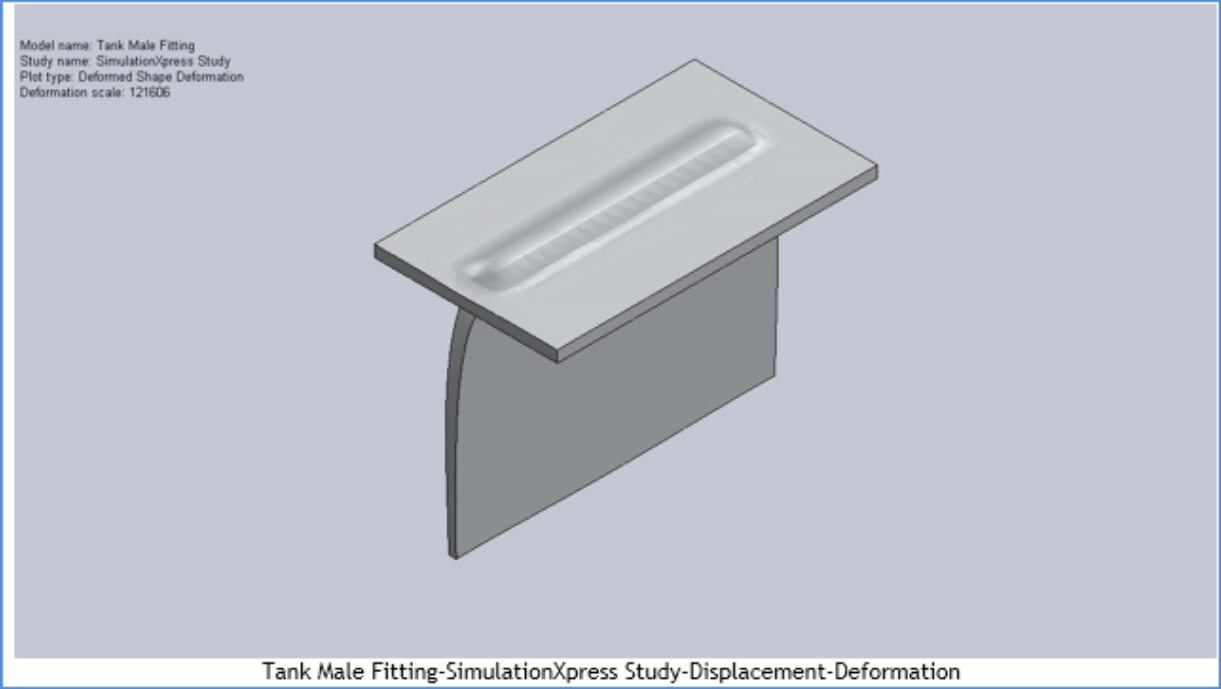
## Study Results



Name	Type	Min	Max
Displacement	URES: Resultant Displacement	0 mm Node: 20	0.000153934 mm Node: 13495



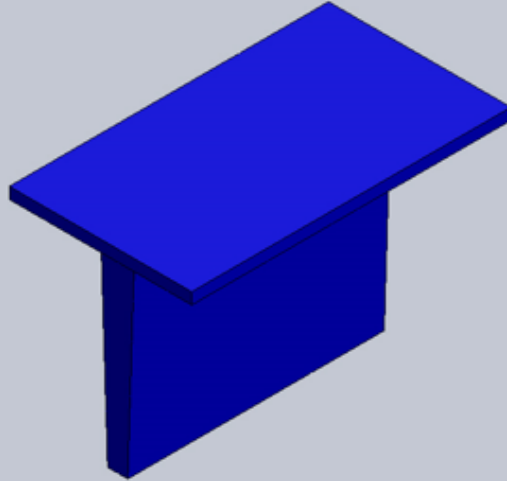
Name	Type
Deformation	Deformed Shape





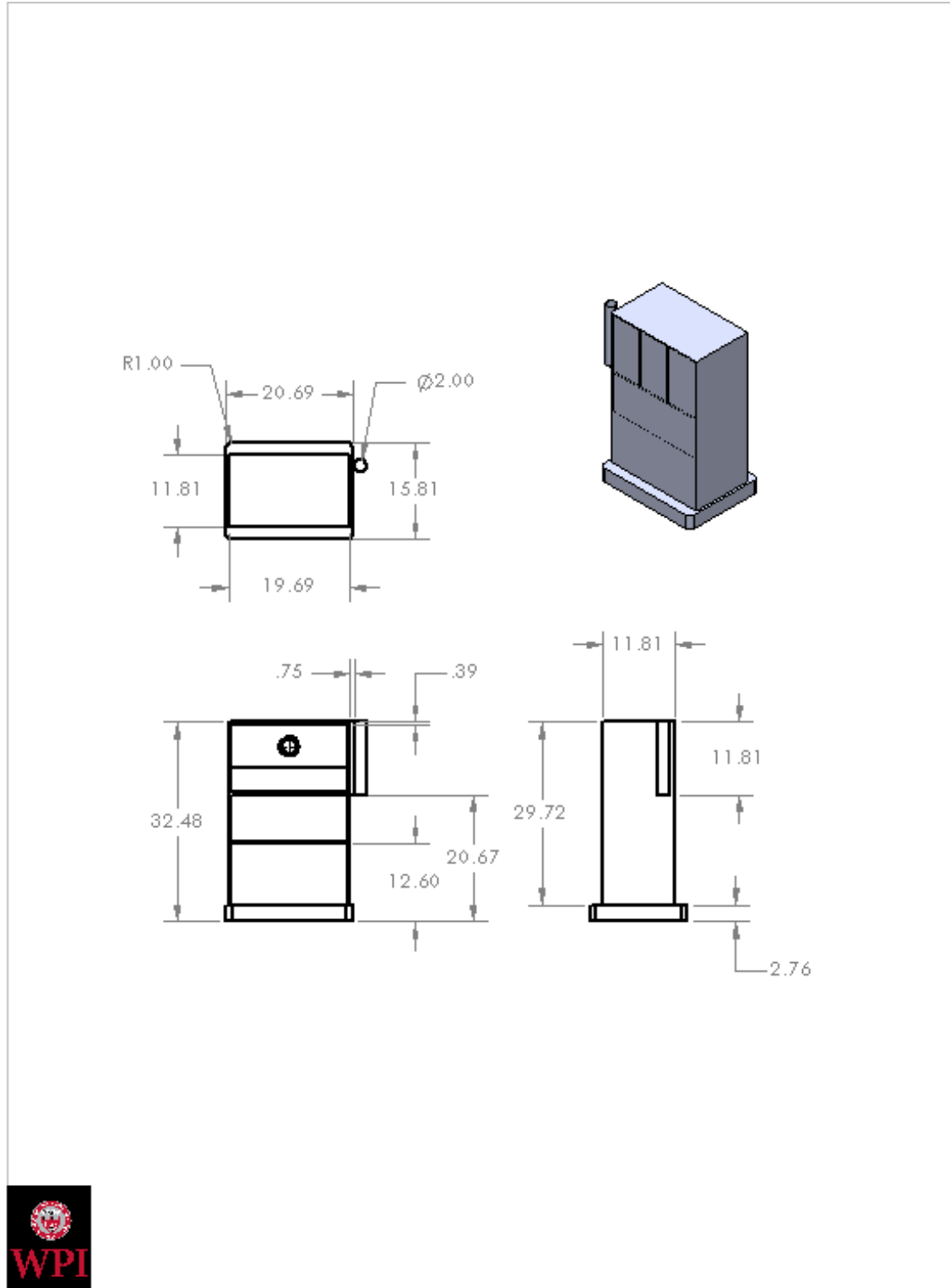
Name	Type	Min	Max
Factor of Safety	Max von Mises Stress	44.0193 Node: 13186	950536 Node: 7529

Model name: Tank Male Fitting  
Study name: SimulationXpress Study  
Plot type: Factor of Safety Factor of Safety  
Criterion : Max von Mises Stress  
Red < FOS = 45 < Blue

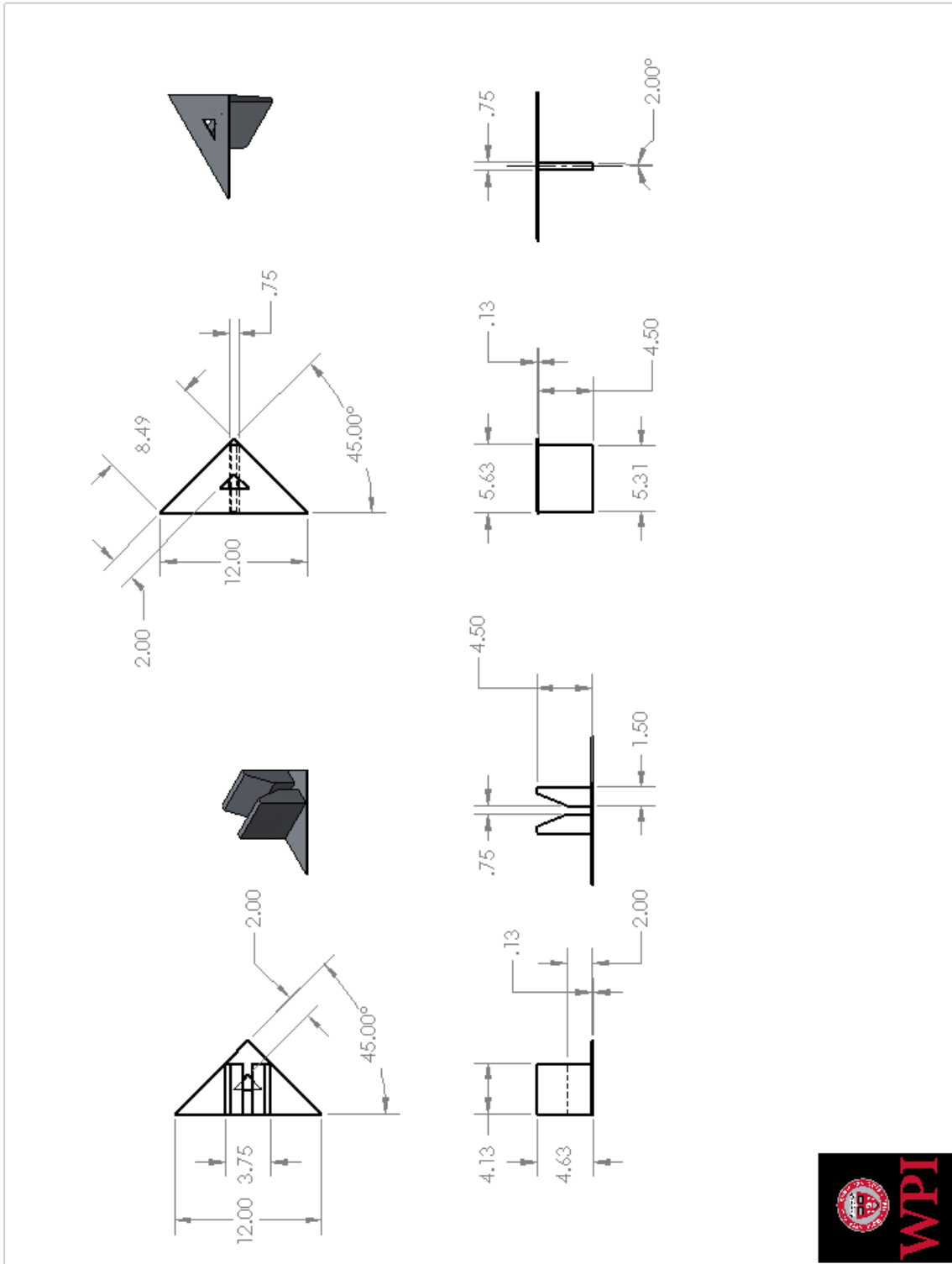


Tank Male Fitting-SimulationXpress Study-Factor of Safety-Factor of Safety

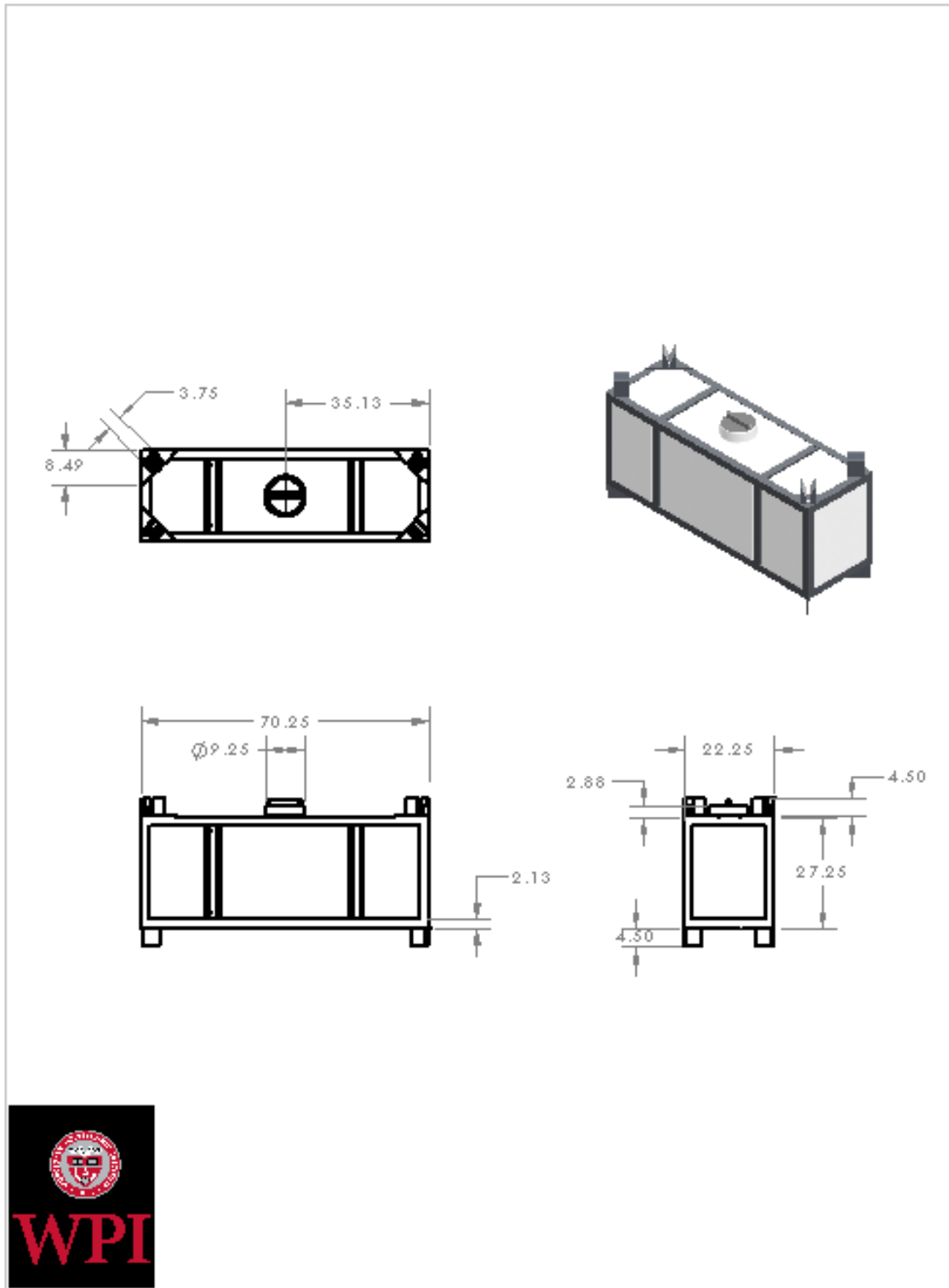
*APPENDIX E. DIALYSIS MACHINE ENGINEERING DRAWINGS*



**APPENDIX F. WATER STORAGE TANK FIXTURE ENGINEERING DRAWINGS**



*APPENDIX G. WATER STORAGE TANKS ENGINEERING DRAWINGS*



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