DESIGN, RECONSTRUCTION, AND EVALUATION OF A DYNAMOMETER FOR QUARTER SCALE

by

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ABSTRACT

This project discusses the design, reconstruction, and evaluation of a dynamometer. A new test stand for the Quarter Scale team would improve the testing of the engines and the Continuously Variable Transmission (CVT). All the readings will be done electronically in order to provide the most accurate data collection.

The dynamometer will be a closed hydraulic system for ease of use. This system will be able to test all of Quarter Scale engines. The data collected will be used to determine which engines are in the best condition, and which may need to be fixed. With the new design, the Quarter Scale team will also be able to experiment and determine the best springs to use in conjunction with the CVT.

Testing demonstrated that the dynamometer needs more long term testing before data can be used in the confines of a Quarter Scale report. Initial testing shows that the dynamometer does work on the bases of providing a good test stand for future of Quarter Scale.

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INTRODUCTION

Background.

The Quarter Scale Tractor Design team at Cal Poly has been designing and building tractors since 1999. All of the designs are based around the same 16Hp Briggs and Stratton engines shown on Figure 3. Over the course of time, the team has acquired 8 engines. Each design also uses a Continuously Variable Transmission (CVT) shown below on Figure 2 , to provide a mechanical advantage. Until now, the assumption has been that these products perform according to their specifications, and have not been worn down over several years of use. A few years ago, some students built a very rudimentary test stand to test the engines using a tachometer and a spring connected to the dynamometer (Figure 1). This test stand was developed by students whose knowledge was not passed down to other quarter scale members. There has been a lot of speculation among subsequent Quarter Scale teams about how to use the test stand, but the proper procedure is unknown. There are also many missing parts that may have been necessary for the test stand to work properly.

Figure 1: Old Quarter Scale dynamometer

Justification.

The results of the dynamometer tests will enable the Quarter Scale team to use the engine and CVT more efficiently. Knowing which engine provides the most horsepower will allow the team to install the best engines on the new tractor design. If an engine tests poorly, the team will be able to fix it or have it repaired professionally at a machine shop. The engines sit for many months between pulls, construction, and the team has engines which are not used every year. Engines that are not used often have a higher chance of breaking during a pull. Therefore, the dynamometer also serves as an engine test-run system. By running an engine under a variety of speeds and conditions, it can be listened to and inspected visually before it is installed on the tractor. Although the CVT is utilized in the Quarter Scale designs, it is an untested device. By testing the CVT reactions with different centrifugal springs in the driver, the team will be able to develop the data needed to make future tractors run more smoothly. The results from the testing will be used as a baseline for future designs.

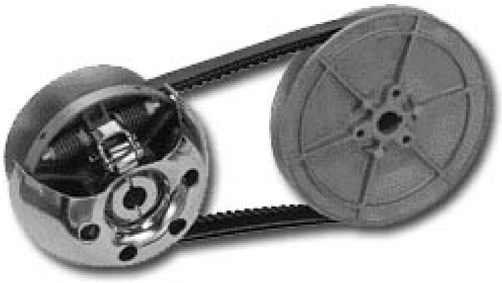

Figure 2: CVT used in Dynamometer stand

Objectives.

The objective of this senior project is to design, construct, and test a new dynamometer for the Quarter Scale team. The dynamometer will only need gasoline and an outlet to function. There will be an operator station for the controls which will run the engine and dynamometer. There will be an easily accessible wire hook-up for the engines. One operator will be able to easily run the system. The data from dynamometer will be recorded on a computer for future analysis.

Figure 3: 16Hp Briggs and Stratton Engine

LITERATURE REVIEW

A search was performed to identify the types of dynamometers used by companies in today's market. Circle Track is a company in racing technology that is recognized for their hydraulic, water, AC, and DC dynamometers. According to Circle Track, water dynamometers are the most cost effective and the easiest to use. DC dynamometers are used for high torque low speed applications. AC dynamometers can be used for a wide variety of applications; however, they are expensive and very few are sold in the US. Another dynamometer manufacturer, Dynesystems Inc., also recommends water dynamometers because of their low inertia. However, the company also mentions a disadvantage of water dynamometers, in that they can be hard to control and have high maintenance. The Kahn Company recommends a hydraulic dynamometer over the water dynamometer because the hydraulic model uses a closed system, reducing the potential problems associated with outside variables.

Further research was conducted to review the designs of test stands on the market. A company named Land and Sea builds the small engine test stand shown in Figure 4. The stand uses a water brake dynamometer with a rugged steel structure. The engine mount on the stand is adaptable to many types of engines and bearings. There is an operator's station available that gives the operator easy access control of the dynamometer stand. The stand has tires for mobility and vibration dampeners. There is a manual-style throttle with an electric option. The information gathering software can process many different types of data. The data collection options include exhaust temperature, accelerometers, knock sensors, airflow turbines, air temperature, humidity, barometric pressure, fuel, and oil transducers. This range of sensors gives a large advantage to the user because they are able to test so many different aspects of their engine. Some of these characteristics will be implemented in the new Quarter Scale dynamometer.

Figure 4: Land and Sea Water Brake dynamometer

A compression load cell was purchased from Measurement Specialties shown in Figure 5. The load cell is used in compression due to the force from dynamometer lever arm. The middle button is the point at which a load needs to be applied. The load cell is able to measure from 0 to 250lbs. The load cell is rated with a 2.5x over-weight load, so it has a large safety factor and will not break easily. It has superior resolution and uses a full bridge to measure stress. The unamplified output will span from -20 to 20mV. This makes the product easy to use with any computer data acquisition system.

Figure 5: Load cell purchased from Measurement Specialties

Proximity sensors were purchased from Automation Direct to measure the speed of both the shafts from the dynamometer. Since the shafts are rotating, pulses are used to measure their speeds. The speed is calculated with a formula which uses the frequency per "cycle" (one cycle is one tooth on the sprocket) and the amount of teeth on the sprocket. The sensors must be placed within 2-4 millimeters of the object they are detecting because of their low power input. The sensors in Figure 6 clamp down onto a stationary object using nuts along their body and measure the speed of a moving object a short distance away. Many large machines, including trains and tractors, use proximity sensors to calculate speed with no slip.

Figure 6: Proximity Sensor for speed

PROCEDURES AND METHODS

Design Procedure

Main Frame. The main frame must be designed with a static weight of 500 lbs including the test engine and other hardware and a safety of factor of 1.5. The frame is made of 2”x2”x1/16” steel square tubing, with an overall dimension of 22”x34”x41.5”, as shown on Error! Reference source not found. The frame is built like a table on four legs. The legs are spaced 41.5 inches apart, and in between are two cross members that are 37.5 inches long. The cross members are 12 ¾ inches below the top of the frame. The second placement of the engine is here along with the CVT driver and secondary CVT shaft. This precise dimension of 12 ¾ inches is caused by the design constraint of the CVT belt needing a center-to-center distance of 12 ¾ inches.

CVT. The continuous variable transmission has an infinite number of gear ratios between its maximum and minimum values. This is done by a belt acting on each pulley to make one smaller and the other larger. The belt constraint of the CVT requires that the shaft-to-shaft distance is 12.75 inches. The test bench was designed so there would be plenty of available room below the dynamometer for the CVT. This means that no extra attachments need to be added to the side of the frame, and allows for an efficient use of space. The CVT would be put in line from dynamometer to engine to not waste additional space. The engine will be difficult to put in place but CVT test will require only one engine to be used.

Cross Member Brackets. The cross member brackets are designed to hold the bearings in place and not deflect due to the force the engine exerts onto the shaft. The brackets are made from angle iron, which was chosen due to its rigid design and ease in cutting and welding. The shaft of the engine is exactly 5.373 inches above the main frame. There is a shim between the cross member bracket and the bearing in order to align to main dynamometer shaft and secondary CVT shaft. The shim was used so that there is some flexibility when the bearings are replaced. The shim does not interfere with the strength of the bracket as long as the bearing is securely tightened. The cross member brackets for the smaller bearings are constructed out of 1.5”x1.5”x1/8” angle iron and the cross member brackets for the larger bearings are constructed out of 2”x2”x1/8” angle iron. In Figure 24 and Figure 25 shows the three pieces assembled for both sizes of angle iron. The brackets form a bridge over the two frame rails on the top and bottom. On the top level, the bracket nearest to the engine will be removable so that parts can be swapped along the shaft more easily. At the base of the leg, the tab shown in Figure 7 will be added to secure the bracket.

Figure 7: Tab on removable bracket

Engine Mount. The engine mount is designed to hold the engine secularly to the main frame with 8x5/16" bolts. The mount is made from 10 gauge sheet metal and has a width of 22 inches between the flanges. Two 2"x18" flanges are on each of the long sides. The flanges are bent 90˚ downward. This gives structural stability to the sheet metal piece.

Holes for the engine bolts are drilled in the center of the mount. The mount has two slots on each end to connect to the main frame. The slot is designed to allow the user to make adjustments depending on which coupler is being used and to move the engine into place. All the holes use the same 5/16 inch bolts for ease of removing the mount and engine.

Load Cell Lever Arm. The lever arm is designed to support the full torque of the dynamometer. This is an estimated for 200lbs with a 10 inch lever arm. The lever arm will use 3 existing holes on the outside of the dynamometer to attach to. The lever arm will be one piece of 10 gauge sheet metal that has a small rounded point to push directly upon the load cell shown in Figure 36 Using SolidWorks Cosmos the stress points were found on the lever arm shown in Figure 8. The program states the largest stress will be 1.03×10^4 psi but the yield strength is 3.2×10^4 psi. This will mean the design is adequate with a large safety factor.

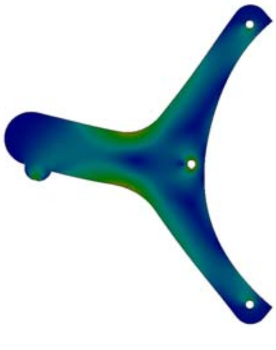

Figure 8: Cosmos of Lever Arm

Load Cell Assembly. The load cell is a 1.25 inch by 0.4 inch button load cell (as shown above in Figure 5). It contains two small 3mm threaded holes on the bottom. The load cell needs to be 4.25 inches above the frame in order to intersect the lever arm. The load cell assembly is composed of the cell base, the load cell column, and the load cell itself (see Figure 33 and Figure 32 in Appendix C). The load base is constructed to connect the load cell to the load cell column. The load cell based has four holes. Two of the holes are drilled at #19 with one side counter sunk. The load cell rests on this side, so it must be bolted down to the column first. The other two holes are #30 and bolt directly to the load cell. In order to allow the load cell to bolt to the base, keyways were cut on opposite sides of the column, as shown in Appendix C.

To hold the load cell assembly in place, a slot reinforced with rectangular tubing was cut and welded into the frame. The slot allows for the height of the load cell to be adjusted if adjustments are made to the dynamometer. If the load cell is adjusted, the lever arm is still fixed 10 inches from the center of the dynamometer, so no new measurements will be needed for torque arm length. The inside of the slot measures approximately 1-½” x ½” with a 1/8 inch wall thickness.

Main Dynamometer Shaft. The main shaft is 1-inch cold-rolled round steel. This shaft is strong enough to withstand the forces created by the CVT. At the dynamometer impeller, two ¼” roll pins must be inserted into the shaft to hold the impeller in place. The shaft also needs keyways for the CVT, the sprocket sensor, and the coupler. The keyway and holes are show in Figure 22 in Appendix C. The shaft is supported by three bearings. The driven CVT is held in place by two collars on either side. These collars also ensure that the key will not vibrate out of place. The key on the sensor sprocket is held down by an allen screw, while another allen screw holds the shaft in place. The coupler has the same features to hold itself and the key in place.

Secondary CVT Shaft. The secondary shaft is designed based on the constraints of the CVT, the sprocket sensor, and the coupler. The CVT driver has a bore of 1-1/8 inch, while the engine shaft, sprocket sensor, and coupler have 1 inch bores. The bearings currently used by Quarter Scale have 1-inch bores, so it would be optimal to use that diameter shaft. Therefore, due to this unique circumstance, the part of the 1-1/8 inch shaft was cut down to 1 inch to fit the bearings, the sprocket sensor, and the coupler, while the rest of the shaft was left at 1-1/8 inch for the CVT as shown in Figure 23. On one side of the CVT is a 1 inch bearing, and on the other side is the sprocket sensor and then another 1 inch bearing. Collars are also placed on either side of the CVT in order to keep the key from vibrating out of the keyway and to provide a backup in case the CVT starts to move.

Bearings. The bearings were chosen based on their life rating in the Browning Catalog. In the appendix B we see that the life rating on it is hours for all the 1 inch bearings. There are two 2 inch bore bearings that are connected to the dynamometer on the main shaft. These require no calculations because they do not rotate since the dynamometer will only move a 1 or 2 degrees. Further down the main shaft there is a 1 inch bearing. On the secondary CVT shaft there are two 1 inch bearings located on either end of the CVT.

Operator Control Station. The test stand was designed to give the operator easy access to full control of the dynamometer and engine. The stand has a manual flow control dial, a throttle control, a choke on/off, an emergency stop, and the key ignition to start the engine. These controls are mounted on an 11"x5" flat plate. Under the plate is stowed the control driver for the throttle, the flow control device, and other hidden wires. A computer stand is mounted overlooking the controls so that the operator can monitor the information recorded by the sensors while observing the engine. There is enough area to add new components depending on future demands. The end of the stand sits 1 foot from the side of the main frame. Since the operator needs to be a safe distance from the test bench, and the computer stand must not exceed the frame widths, the stand design uses hinges. Although the hinges are steel, they could be subjected to considerable weight, if the weights of the controls, the laptop, and the operator are considered. Therefore, gussets have been added to the station to ease the pressure on the hinges.

Controls. The controls on the test stand are designed for to maximize the ease of use in controlling the dynamometer and the engine. In Figure 9 we can clearly see what the control station may look like. On the left is a flow control valve which controls the amount of hydraulic fluid going through the dynamometer. This valve is designed to handle 15 GPM and can withstand up to 2000 psi. It takes approximately seven turns to go from fully open to fully closed. The engine has three main controls. The first control on the bottom left is the choke. The choke needs to be turned on for start up and then turned off. Below the choke is the key start. In order to turn the engine on and off, as well as supply it with a continuous flow of electricity, the original key switch from the engine is used. The dial to the left of the key switch is the control for the throttle. This dial is connected to a potentiometer which controls the servo driver. The driver controls the speed and position of the servo. Underneath the dial is a black plate which rates the percentage the engine is running at from 0 to 100. The potentiometer works with the servo to control the throttle and keep it at a constant speed so that the testing data is accurate. At the bottom of the station is a red off button. Once the bottom is pressed it will need to be turned to be activated. The reason for this extra step is that grounding the magneto for a few seconds may not stop the engine from reactivating. The turning, and resulting constant depression, is a manual way to ensure the engine will turn off.

Figure 9: Control Station

<u>Hydraulics</u>. The hydraulics are designed to transfer fluid from the reservoir to the pump to the flow control and then back to the reservoir shown below in Figure 10. This entire process uses three hoses and six fittings. Since the make and the model of the dynamometer are unknown, the pressure and flow rate from the system are also unknowns. However, because the impeller design of the dynamometer makes it a non-displacement pump, excess pressures are not a high risk. If fluid was completely blocked from exiting the dynamometer, it would still be able to free spin. This will cause a pressure build up, but not as much as would be caused by a displacement pump.

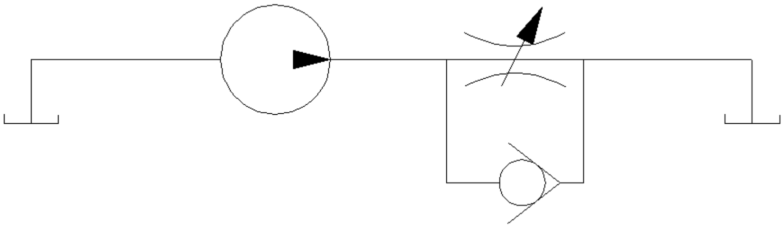

Figure 10: Hydraulic Schematic

Reservoir. The reservoir is designed so it can store and reuse the hydraulic fluid for the dynamometer. Since the tank is not a pressurized, no special considerations need to be made for strength. The design should accommodate a volume (in gallons) of three times the flow rate (in GPM). However, the flow rate of the dynamometer is unknown. This design estimates the maximum flow rate at 4 GPM, so the reservoir is designed to hold 12 gallons. With the space available the reservoir will be 8x17x20 inches.

Proximity Sensors. The proximity sensor needs to be 4mm away from the 17 tooth sprocket to read each tooth. In order to put a bracket in under the sprocket a small bracket should be made with a bolt holding it tightly in place under each cross member next to the 17 tooth sprocket. The bracket will be made as shown in Figure 6

Engine Wire Connections. The Quarter Scale engines have been used for many years, and so there is a lot of wear on the engine components. The electrical connections from the engine to the key start have not been used because there is no standard connection. There were six original wires coming from the engine. One is used to ground the kill switch, and the other five are for the carburetor solenoid, the starter solenoid, the battery, ground and the choke solenoid. The ground wire is not necessary because the key housing is grounded to the frame. This design combines these wires into a 6-pin female molex, the choke solenoid can be added to the molex if one exists. The molex allows the wires to be combined into one wire connection for fast and easy connection. In . The throttle's servo connections are 22 AWG lines that are connected separately. Overall, there only needs to be two connections from the engine. A 9-pin was not chosen because the throttle may be changed to manual control.

Engine Starter and Fuel. The engine starter requires a large amount of DC current. Therefore, the 120 VAC from the wall is not sufficient to start it. A inverter could be used, but they are expensive and large. In order to be more cost effective, a 12 volt motorcycle battery with 180 cold cranking amps was purchased shown on the left in Figure 11. A large amount of cranking amps is essential so the engine will start smoothly. The battery is enclosed so there will be no problems with leakage, and it may be positioned in direction. To ensure the battery does not die, a 1.5 amp charger was added to the dynamometer. This charger can automatically power the battery as long as it's connected to a wall outlet.

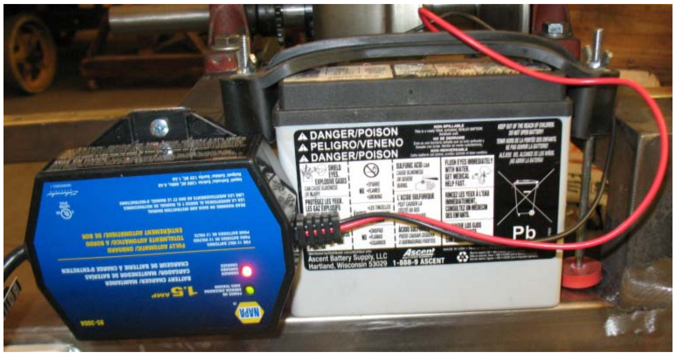

Figure 11: Battery and Charger

The fuel tank is necessary for the engine to work properly. The tank is clear to easily see the amount of fuel. The odd shape of the tank requires certain brackets to be made as of Figure 26. The lines going to the engine are also clear to see where the fuel is going.

Figure 12: Fuel Tank

Construction Procedure

Main Frame. The top of the frame is constructed from 4 pieces of 2”x2”x1/16” square tubing shown Figure 21 in Appendix C. Two pieces are 41.5 inches long with a 45 degree angle cut into each end. The other two pieces are 22 inches long and with a 45 degree angle cut into both ends. These four pieces were laid out as a rectangle, then welded along each seam, then ground and smoothed. Four legs were cut at 32 inches, flat on each end, and were welded to the corners of the rectangle. The corners were not smoothed, because cutting into the weld would weaken the joint. Two cross members were welded to the legs parallel to the frame and 12-¾ inches below the top of it.

Cross Member Brackets. There are two types of brackets, one with 1.5 inch angle iron and one with 2 inch angle iron. Each bracket is built in three pieces. The center piece on both brackets is 22 inches long and cut at a 45 degree angle. Each leg has one 45 deg cut to line up to the long piece. Looking at Figure 24 and Figure 25 we can see the assembly of each bracket. In Figure 13 we see that each bracket was held down with clamps and welded together. Later each bracket was drilled out 1/2" holes for the bearings. Each of these pieces will be stood straight up directly welded to the frame except for the 1.5 inch angle iron on top of the frame. Looking at Figure 34 we can see the placement on the frame of the cross member brackets.

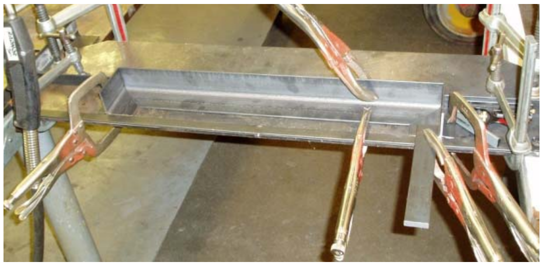

Figure 13: Construction of Bracket

<u>Frame Holes</u>. A transfer punch was used to pinpoint the precise location of the frame holes. Once the locations were set, the 9/16 inch frame holes were drilled and the 9/16 inch sleeves were welded in place. After the weld was ground and smoothed on both the entrance and exists, the 5/16 inch holes in the sleeves were re-drilled to remove any weld beads.

<u>Engine Mount</u>. The engine mount was first created in SolidWorks shown in Figure 27 and then transferred into a CNC plasma machine, which cut an 1/8 inch piece of sheet metal in the shape of the engine mount. This flat design was put into the press and each flange was bent downward at 90°. The holes to mount the engine drilled in the center of the frame rails with the engine shaft aligned with the main dynamometer shaft.

<u>Lever Arm</u>. The lever arm was first designed on Solid Works and transferred to AutoCad as a drawing. This drawing was loaded on to the CNC plasma and cut out from 16 gauge sheet metal. Using a transparency paper to scale of the lever arm the holes will be transferred punched and drilled out. This was than assembled on the dynamometer on the outside of the casing toward the engine on the left side facing the engine. This was assembled using 3 bolts that already exist on the dynamometer.

<u>Load Cell Assembly</u>. The load cell base was the first piece made from 1.25 inch solid round stock. It is cut down to a height of approx 9/16 inch. Both ends are than cut down on a lathe perpendicular to the shaft. After the piece is but flat on a mill and two holes using a #30 drill bit are cut ½ inch away from each other from the center of the shaft in a straight line. Two other holes are than cut out using a #19 drill bit. Each hole will be 90 degree from the first cut ¾ inch separation symmetrically from the center. One side will then be counter sunk one both holes.

The load cell column is cut from a 1.25 inch solid round stock. It is than cut to a height of 3.25 inches. Both ends are than cut down on a lathe perpendicular to the shaft. The shaft will be laid down in a mill. Using a 5/16 end mill bit cut a keyway the whole length of the shaft ½ inch deep through the middle of the shaft. The same should be done on the opposite side. The shaft will be stood upright and drilled with two holes ¾ inch apart symmetrically from the center using a # 21 drill bit. It would go approximately 9/16 inch deep. This will then be tapped with a 10-32 about 9/16 inch deep. The shaft should than be put into the lathe and the opposite side will have a 5/16 inch hole drilled into the center approximately an 1.25 inches. This would then be tapped with a 5/16-18 tap as deep as possible.

Main Dynamometer Shaft. The main shaft is 23.5 inches long. After the shaft was cut to length, the keyway was cut out using a mill. The keyway is 13.5 inches long and was milled using a ¼ inch ream and cutting to a depth of 1/8 inch. This took 25 passes, cutting .005 inch at a time. After the keyway was cut, two perpendicular holes were cut 5.82 inches and 4.19 inches, respectively, from the end of the shaft. These holes are each a ¼ inch in diameter to insert roll pins.

Secondary CVT Shaft. The secondary shaft was cut to 14-½ inches using a lathe so that the cut would be perfectly straight and smooth. The shaft was then cut down to a 1 inch diameter for a length of 1 ½ inch from the end. The cuts were made with the lathe in .005 inch increments for 25 passes. The other end of the shaft was then cut down to a 1 inch diameter for a length of 5-¾ inches. After both sides were cut and smoothed, the shaft was put on a mill to cut the keyways. One of the keyways was cut into the longer 1 inch diameter section of the shaft and the other was cut into the 1-1/8 diameter section. Both were 1/8 inch deep ¼ inch keyways.

Operator Control Station. The test stand was made from 2”x2”x1/16” square tubing and 1/2”x1/2”x1/8” square tubing. The larger tubing was used to match the frame. The smaller tubing was used so that there would be more space inside the station. The larger tubing is used to build the two control station box supports from the frame. Each arm consists of a 3 inch length of tubing hinged to the frame at 90°. This length has a 45° end cut and is welded to similarly cut 4 inch length of tubing at 90°. The two arms are spaced 8 inches apart with two lengths of the smaller tubing. The frame of the operator station can be seen in Figure 29. The frame was covered by a piece of bent sheet metal with the seams were TIG. The dimensions of it were slightly larger of that of the frame shown on Figure 30

Reservoir. The reservoir is cut from a 16 gauge 48"x57" piece of sheet metal. The corners are cut out in 13.5 inch squares, leaving a cross which was bent into an open-topped box using the pan bender. The corners were then welded on the outside with a TIG and on the inside with MIG to ensure it was sealed. Figure 3 shows the reservoir built with 5 walls. The reservoir will be filled with water to check for leaks. Once the seams are finished, holes are cut into the reservoir for fittings and the fittings are welded in place than checked for leaks again. The lid 8"x17" lid is then cut from 16 gauge sheet metal and a breather cap is added. The lid is than welded to the rest of the reservoir.

Figure 14: Reservoir with 5 walls welded

Proximity Sensor Brackets. The bracket to hold the proximity sensors is 16 gauge sheet metal cut into a 2-½"x1" piece and bent 90° on the long side. As shown in Figure 31, there is a ½ inch hole centered ¾ inch away from the one end and a 5/16 inch hole ½ inch from the opposite end. The 90° bend is ¾ of an inch from the 1/2 inch hole. The sensor bracket is mounted onto the cross member bracket centered under the sensor sprocket.

Testing Procedure

Priming Dynamometer. Before the dynamometer can be secured into place for testing it must be primed by filling the it with hydraulic fluid. When the dynamometer has been securely closed with impeller inside and all fittings and hoses tight, the dynamometer is ready to be primed. First, the dynamometer must be put on its side with the shaft facing straight up. The dynamometer can rest on the dynamometer cross members. Second, a small drain plug on the side of the dynamometer casing is removed. Third, the tank must be pressurized with a pressure regulator set to not exceed 3psi. This can be done many ways. Removing the filler cap and using a new cap with a fitting for the regulator is an easy solution. This will force hydraulic fluid up through the hose into the dynamometer where air will exit through the drain plug. Eventually in a few minutes hydraulic oil will start to come out from the drain. Finally, close the drain plug and remove the pressure regulator. The dynamometer can be put back into place and ready for testing.

Engine Assembly. Before an engine test can be performed, some assembly is required to ensure proper testing. Figure 35 shows the full assembly of the main shaft for reference. First, all the collars, the sprocket sensor, and the driven CVT must be removed from the main shaft. This is done by loosening the allen screws that hold all the components onto the shaft. Before removing the collars and CVT, remove the bolts from the bracket nearest the engine and remove it. Then the collars, CVT, the CVT key, and the sprocket sensor can be removed. Once the CVT has been removed, replace the bracket and the sprocket sensor, making sure to align the sensor correctly. The next step is to place the engine mount between the frame rails. The engine should then be put onto the engine mount so that the engine shaft is lined up with the main shaft. The engine mount and engine should then be locked in place with 5/16 inch bolts with a washer on either side and a lock washer with a nut on the bottom side. Next, install the coupler on the main engine shaft and tighten the allen screws until the Para flex coupler is tight. The 6 pin female connector on the engine should be connected to the one from the operator station with the throttle 3 pin connector and the choke plug. The stop button should be depressed and the choke turned on. The flow control valve should be opened wide so that there is no load on the engine. The throttle should be set to idle. The engine is then started by turning the key as one would in a car. Once the engine is started, the choke should be turned off. The engine should be on for at least 5 minutes before recording any data. This is to warm up the engine and the hydraulic fluid so there is no change in viscosity during testing.

Engine Data Gathering. After the engine has been started and warmed up, the data collection begins. Check the load sensors and speed sensors to make sure they are functioning properly. For the dynamometer test, the engine should be set at a certain throttle and the load should be increased by turning down the flow downstream of the dynamometer. Next, the flow should turned to fully open and the throttle should be turned up incrementally by 100 rev/min until full throttle is accomplished. After all the data is recorded, the engine should be turned off and disconnected from wires and couplers. It is important to remove the engine carefully, because it will be hot.

CVT Assembly. For the CVT testing, the CVT must be put back onto the main shaft with the collars and key check Figure 35 for reference. A belt must be added over the driven CVT before the bracket is replaced. To put the secondary shaft on, it should be assembled similar toward the main shaft as shown on Figure 37. The belt on the driver gear can be slipped under the CVT. Afterwards each bearing should be bolted down and the belt will fit snug. The engine mount and engine are then replaced, aligned with the secondary shaft, and tightened in place as with the engine assembly. All the electrical lines must then be connected. The first time the engine is started, the choke should be used.

CVT Data Gathering. After the engine is warmed up it, it is easy to check if the CVT has been activated by observing if the main shaft is rotating. To see where the CVT engages, throttle the engine up very slowly. Once the main shaft is moving keep the throttle constant and turn down the flow. By observing the change in speed and load being applied we can evaluate the CVT. After the test is finished, the engine should be turned off and the CVT driver removed by taking the bolts out of the bearing and disassembling the secondary shaft. The CVT can then be opened so that the springs can be changed. The CVT should then be reinstalled and the test repeated. For repeated tests, the procedure is the same except that the engine may not need to be choked again.

RESULTS

After setting up the stand one motor was configured with a servo throttle system, choke solenoid and wire harness. It took no more than 30 seconds to connect the engine to the stand and a few more minutes to secure the engine. Before turning on the engine, the throttles, choke, and kill switch were tested to ensure there would be no problems. The dynamometer was primed before the test to ensure there would be enough fluid for the test. Once the engine was cranking, fuel was vacuumed up from the fuel tank to the engine. The engine started after 15 seconds, then the choke was turned off and the engine stayed running. The data was given in Hz and mV. Using the dynamometer's constants, the data was converted to rpm, torque, HP, and Brake HP (BHP). Three separate tests were performed, and the results were graphed as "Torque and RPM over time" and "HP vs. RPM dynamometer Test". The tests are listed sequentially from Figure 15 to Figure 20.

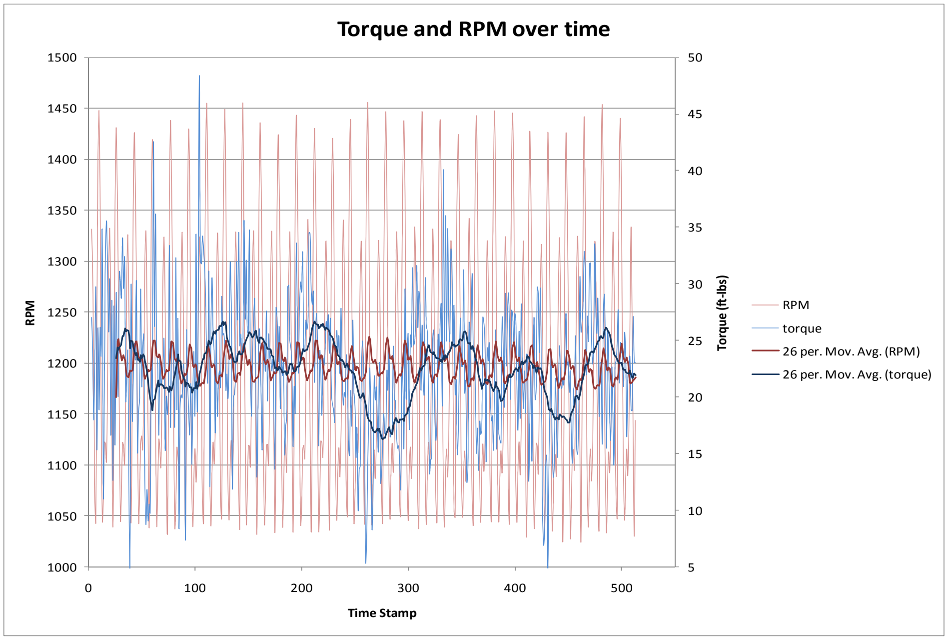

Figure 15: Test 1 of Torque and RPM over time graph

The first test was data collection at a constant speed. The test showed that there is a lot of variation due to the sensors having static interference. To make the results clearer on the graph, an average trend line was used in Microsoft Excel. In Figure 15, the rpm looks like a sinusoidal wave, which could be caused by wires having loose connections. Since the idle speed of the engine is around 1500 rpm, and the average test speed is 1200 rpm, it is clear that there are inaccuracies in the data collection. In Figure 16 the max HP on the trend line is around 6 HP. Because of the variation in the results, the data for test one was somewhat inconclusive.

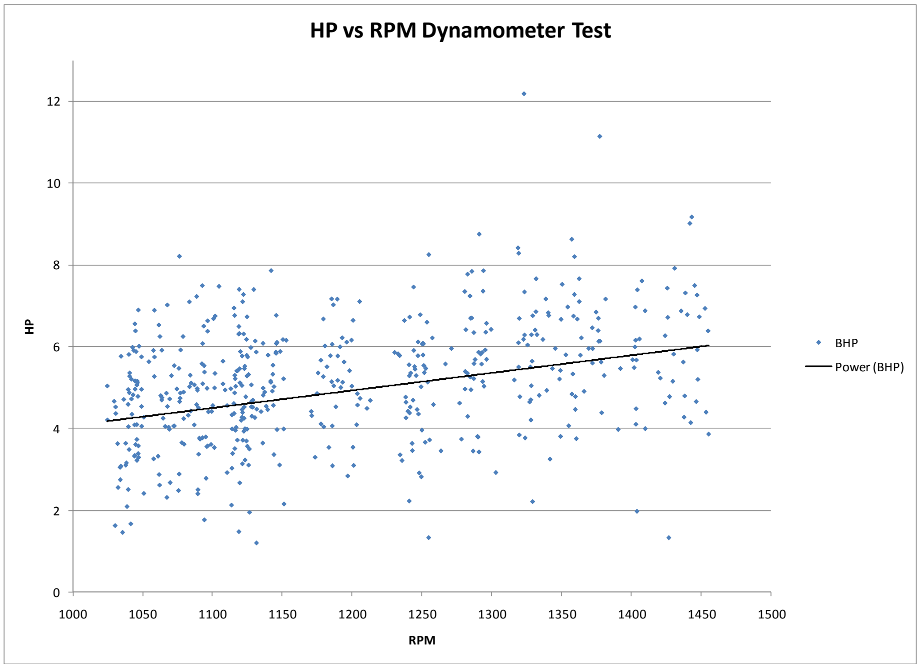

Figure 16: Test 1 of HP vs RPM dynamometer test

The second test, shown in Figure 17, shows a clearer trend line, with the rpm rising slowly from about 1900 rpm to about 2100 rpm. When the engine was turned off at the end of the test, the data dropped off sharply toward zero. The data is concise compared to that of the first test. With not much variation in the speed this was a much better test. The torque however had lots of variation because of the vibration caused by the dynamometer. Using a trend line the torque trends can be seen to not move coherently with the rpm. It is obvious that the torque works because when the engine was shut off there was no more load and the torque dropped. The torque dropped after the rpm because the fluid moving in the dynamometer was still causing a torque.

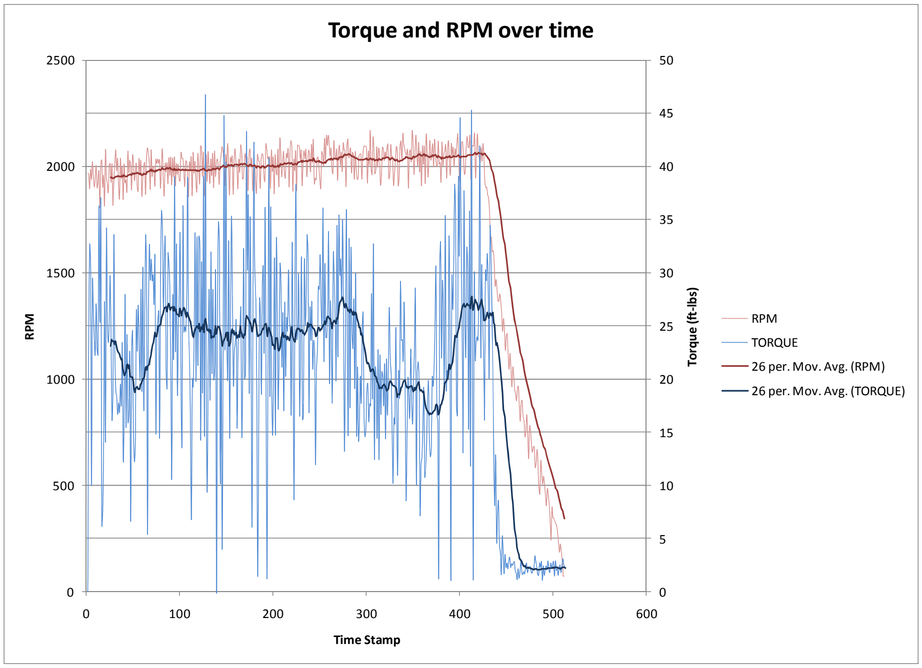

Figure 17: Test 2 of Torque and RPM over time graph

The variation in HP in Figure 18 is due to the start up and shut down of the engine being included in the data. Once the engine reached 2000 rpm, the HP averaged 9 HP, but there is a large range around this value. Though this graph was not ideal, it showed it is not ideal to include the start or stop of the engine in the analysis of the test data.

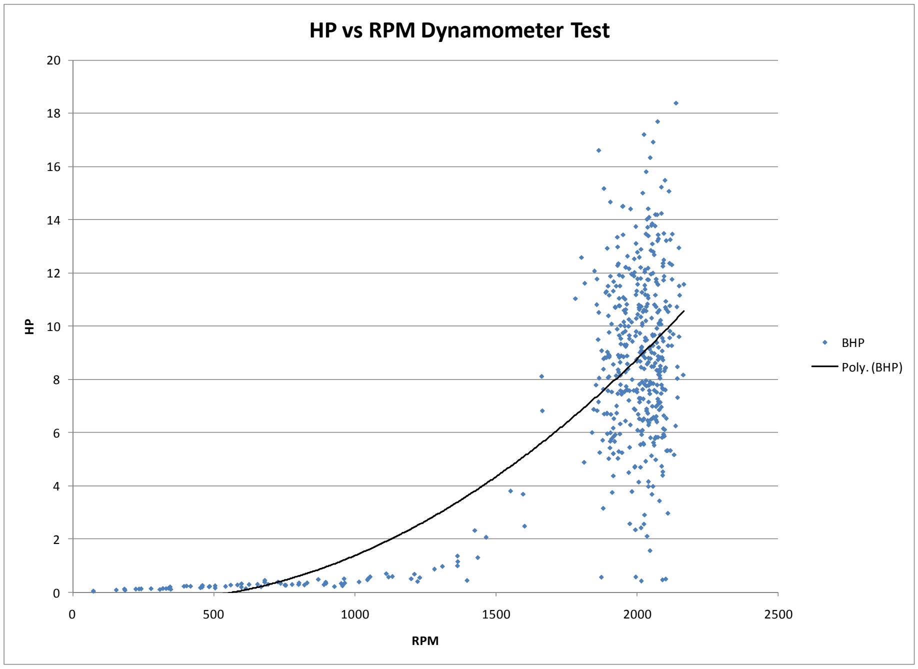

Figure 18: Test 2 of HP vs RPM dynamometer test

The third test was different than the others because the flow was cut from the outlet of the dynamometer to give the engine something to work against. In Figure 19 shows there is still a lot of variation in both the rpm and torque. The average rpm fluctuated from about 1600 rpm to about 3500 rpm. As the flow was cut, the torque increased and as flow was restored the torque decreased. Between the 400-500 time stamp we see both the rpm and torque rise due to the closure of the flow and throttling the engine. This graph showed how controlling the flow affected the torque. However, as in the first test, there is a lot of variation in the calculated HP (Figure 20).

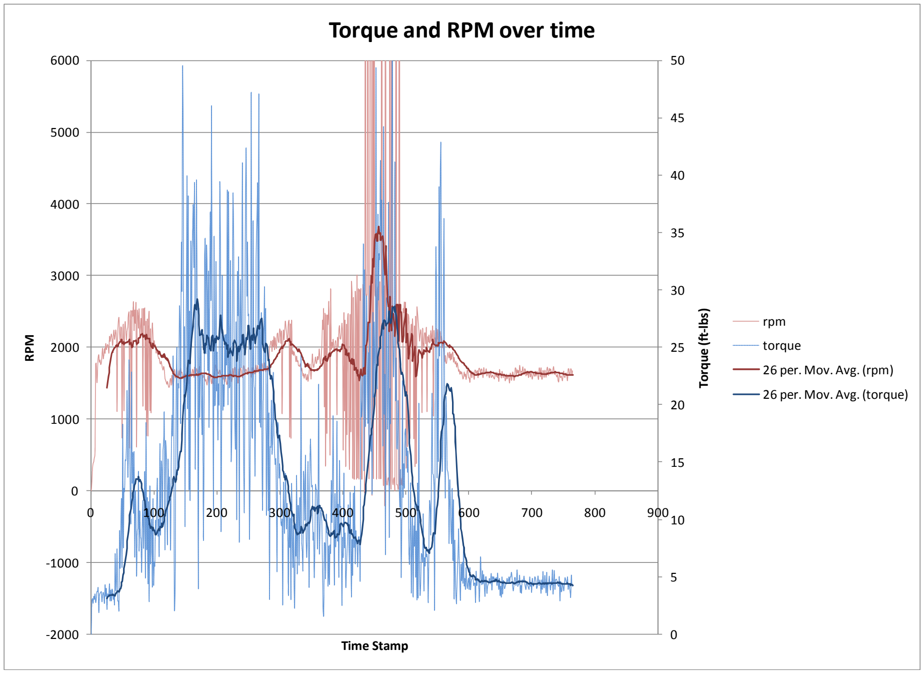

Figure 19: Test 3 of Torque and RPM over time graph

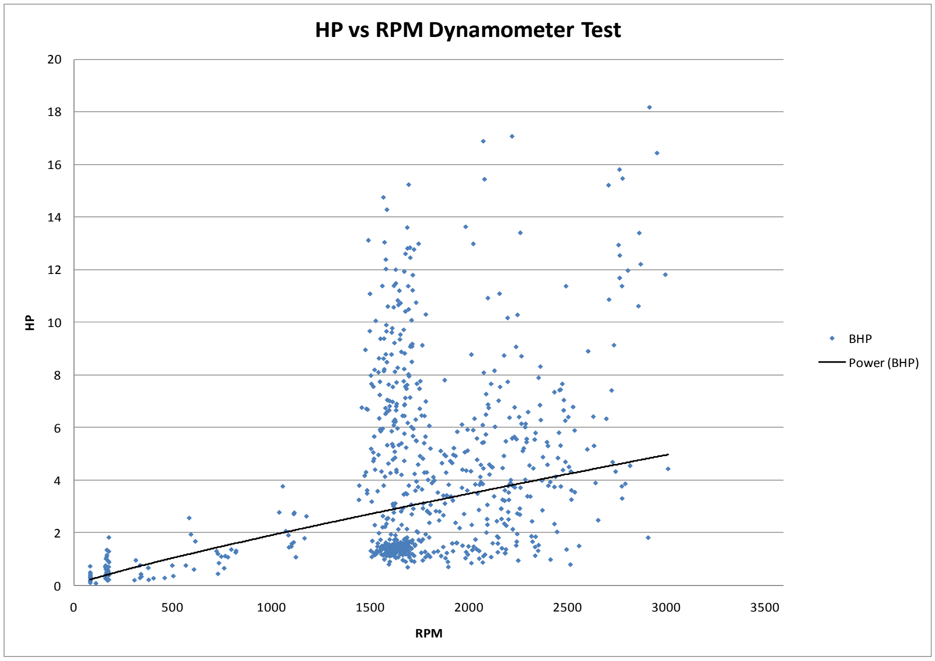

Figure 20: Test 3 of HP vs RPM dynamometer Test

DISCUSSION

During testing the largest problem seen was the heating of the dynamometer. The dynamometer was designed to be cooled from the hydraulic fluid. It seems that the rate of heat transfer is not high enough and therefore the dynamometer has been heating up fast. It looks only 10 min of running the dynamometer before the it was at a temperature of 200 F. The fluid was still cool but could cause future problems if there is any flash point due to the temperature of the dynamometer.

During construction one of the most difficult elements was to align the main shaft with the engine shaft. This became more difficult during construction because the large cross members was cut 5/16 inch short. Sleeves were put into place to raise the dynamometer to the right height. However, the shafts never perfectly lined up, and were off by 1/16 inch. The addition of the D flex coupler solved the misalignment problem.

After completion of the dynamometer, the engine was started and it was discovered that there was not enough suction in the line to get the dynamometer primed. This was a large oversight that makes operating the dynamometer more difficult than the initial design anticipated. To overcome this obstacle, the tank was pressurized to force the hydraulic fluid up the hoses into the dynamometer.

After the dynamometer was built it was tested. The first thing that became apparent was that there was lots of vibration in the frame. This vibration did not start on the initial startup of the engine, but when the dynamometer was started. The vibration is caused by the lever arm vibrating on the load cell. This could be reduced with the use of some dampeners.

RECOMMENDATIONS

After reviewing the design and construction, there are many recommendations that can be made for this design. The first recommendation is to get a positive displacement pump with an auto primer. A displacement pump is more efficient than the impeller pump, and this higher efficiency would mean the data collected is more accurate. If the test bench was upgraded to include a displacement pump, new components would need to be added, including a pressure relief valve, heat exchanger, and potentially a larger tank, depending on the flow rate. With the exception of one bracket, the rest of the test bench structure would remain the same.

On the current design, being able to prime the pump without disassembly would improve efficiency. Priming the pump is the most difficult task in the testing procedure. With a hand pump or motor this task would be much easier. A new pump could also have an auto-prime function.

Another design recommendation is to equip the other engines with a choke, throttles, and a single wire connection. This will enable easy and fast hookups. There is no standard to the many engines Quarter Scale uses and this has caused problems when new students need to hookup an engine. Many engines cannot be used anymore because of burnt and broken components. Using the dynamometer as a base design, standardization can be accomplished easily.

The servo controlled throttle system is not being used to its fullest. The engine may not get to full throttle with the servos because the weakness in torque it produces. During the test it was easy to see that the throttles did not work as properly as they should have. A new servo with more torque or a manual style throttle is recommended.

An additional recommendation is to have an electronic display with connections to all the sensors. These sensors could include fluid temperature, flow rate, and exhaust temperature. These readouts will show more trends and allow for a more in-depth understanding of how the engines perform. If the sensors were already hooked up to the control station it would be very easy for anyone to use the test stand.

The dynamometer is meant to be used by only safety-trained Quarter Scale members. The most dangerous parts of the dynamometer are the rotating parts. In a failure situation, keyways that are not screwed down could be shot out due to centrifugal forces. Securely tightening all allen screws will drastically reduce the risk of any parts flying. The CVT also presents a risk because of the high speed of its internal parts. Safety shield are recommended to be put on with the same specifications as the Quarter Scale handbook illustrates.

Although the data recorded has a large amount of variation, it is clear that HP can be measured using the hardware and software available. Further calibration of the software and refining the test bench-computer interface would improve the precision of the results.

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APPENDICES

Appendix A: How the project meets requirements for BRAE major

Major Design Experience

This BRAE senior project incorporates a full-scale design experience. This design started from an idea on paper and was developed to the point where it can be used by the Quarter Scale design team for future quarters.

Synthesis and Analysis. The components of this design include calculations for bending and shear stress. The components were re-evaluated throughout the construction of the project and changed as necessary.

Construction, Testing, and Evaluation. The dynamometer stand was designed using 3D modeling software (SolidWorks). The construction took place in the BRAE labs and was evaluated using National Instruments Signal Express.

Capstone Design Experience. The BRAE senior project is an engineering design project based on the knowledge and skills acquired in the coursework studied throughout the BRAE curriculum. This project incorporates knowledge and skills from these key courses:
BRAE 129 Lab Skills/Safety
BRAE 133 Engineering Graphics
BRAE 151 AutoCAD
BRAE 152 SolidWorks
ENGL 149 Technical Writing for Engineers
ME 211/212 Engineering Statics/Dynamics
CE 204/207 Strength of Materials
BRAE 234 Mechanical Systems
IME 141 Welding
BRAE 421/422 Equipment Engineering
Design Parameters and Constraints

Physical. The outside of the structure is at a max of 22” x 41.5” to conserve space.

Ethical. N/A

Social. N/A

Political. N/A

Aesthetic. N/A

Appendix B: Design calculations

Calculations for Torque

$$\text{Torque} = \frac{\text{HP}}{\text{Speed}} = \frac{16\text{hp x } 550\text{ftlbs x } 60\text{s}}{3600\text{rpm x } 2\text{x } \pi \text{ rad}}$$

Torque=23ft-lbs

Calculation for CVT Torque (Max)

CVT ratio=3.41
23ft-lbs x 3.41=80ftlbs

Calculation for Over Hung Load (OHL)

Torque arm=10in=.833ft
Factory of safety=1.5

$$\text{OHL} = \frac{\text{torque(ftlbs)x F}}{\text{torque arm(ft)}} = \frac{80\text{ftlbs x } 1.5}{.833\text{ft}} = 143\text{lbs}$$

OHL=143lbs

Reservoir Unit Volume

$$8\text{in x } 17\text{in x } 20\text{in x} \frac{7.48\text{gal}}{\text{ft}^3} \text{x} \frac{\text{ft}^3}{(12\text{in})^3} = 11.8\text{gallons}$$

Heat Transfer to Hydraulic Fluid

Heat transfer=50% of total HP
Specific Heat of hydraulic oil=.5BTU/lb-F

$$16\text{hp} \times 50\% \times \frac{\text{lb}-\text{F}}{.5\text{BTU}} \times \frac{\text{gal}}{8.35\text{lb}} \times \frac{\text{tank}}{12\text{ gal}} \times \frac{2545\text{BTU}}{\text{HP}-\text{hr}} \times \frac{\text{hr}}{60\text{min}}$$

Heat transfer=6.7F/hr

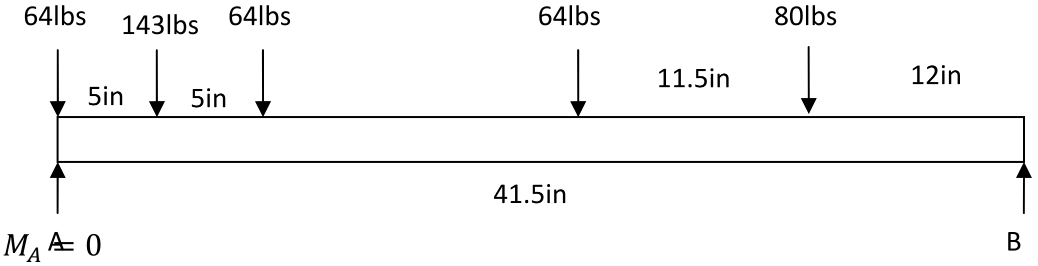
30 min max before reaching 200 F

Tension of CVT Belt

$$\text{Force} = \frac{\text{Torque}}{\text{dia gear}} = \frac{23\text{ftlbs}}{1.44\text{in}} \text{x} \frac{12\text{in}}{\text{ft}}$$

Tension of CVT belt=192lbs

Calculation for Dynamic loading on Frame Rail



$$M_A = 0$$

$$= (143\ lb)(5\ in) + (64lb)(10in) + (64lb)(18in) + (80lbs)(29.5in) - B(41.5in)$$

$$B = 117lbs$$

$$\Sigma F_y = 0 = A - 64 - 143 - 64 - 64 - 80 + 117$$

$$A = 297lbs$$

Bearing Life

$$\mathrm{L}_{10} = \mathrm{c}/\mathrm{p}^3\,\frac{16667}{\mathrm{n}}$$

c=2801
p=297
n=3600

$$\mathrm{L}_{10} = 2801/297^3\,\frac{16667}{3600}$$

$$\mathrm{L}_{10} = 3885\mathrm{Hrs}$$

RPM Calculation for data

Hz=teeth/sec

$$\mathrm{rpm} = \mathrm{Hz} \times \frac{1\ \mathrm{rev}}{17\mathrm{teeth}} \times \frac{60\mathrm{s}}{\mathrm{min}}$$

Torque Calculation for data

Set the parameters from 0 to 100mV

$$\mathrm{torque(ft - lb)} = \mathrm{Volt} \times \frac{1\ \mathrm{lb}}{.0004\mathrm{v}} \times 10\mathrm{in} \times \frac{1\ \mathrm{ft}}{12\mathrm{in}}$$

HP Calculation using RPM and Torque

$$HP = RPM \times TORQUE(ft - lbs) \times \frac{2\pi rad}{rev} \times \frac{min}{60s} \times \frac{s}{550ft - lbs}$$

Appendix C: Construction Drawings

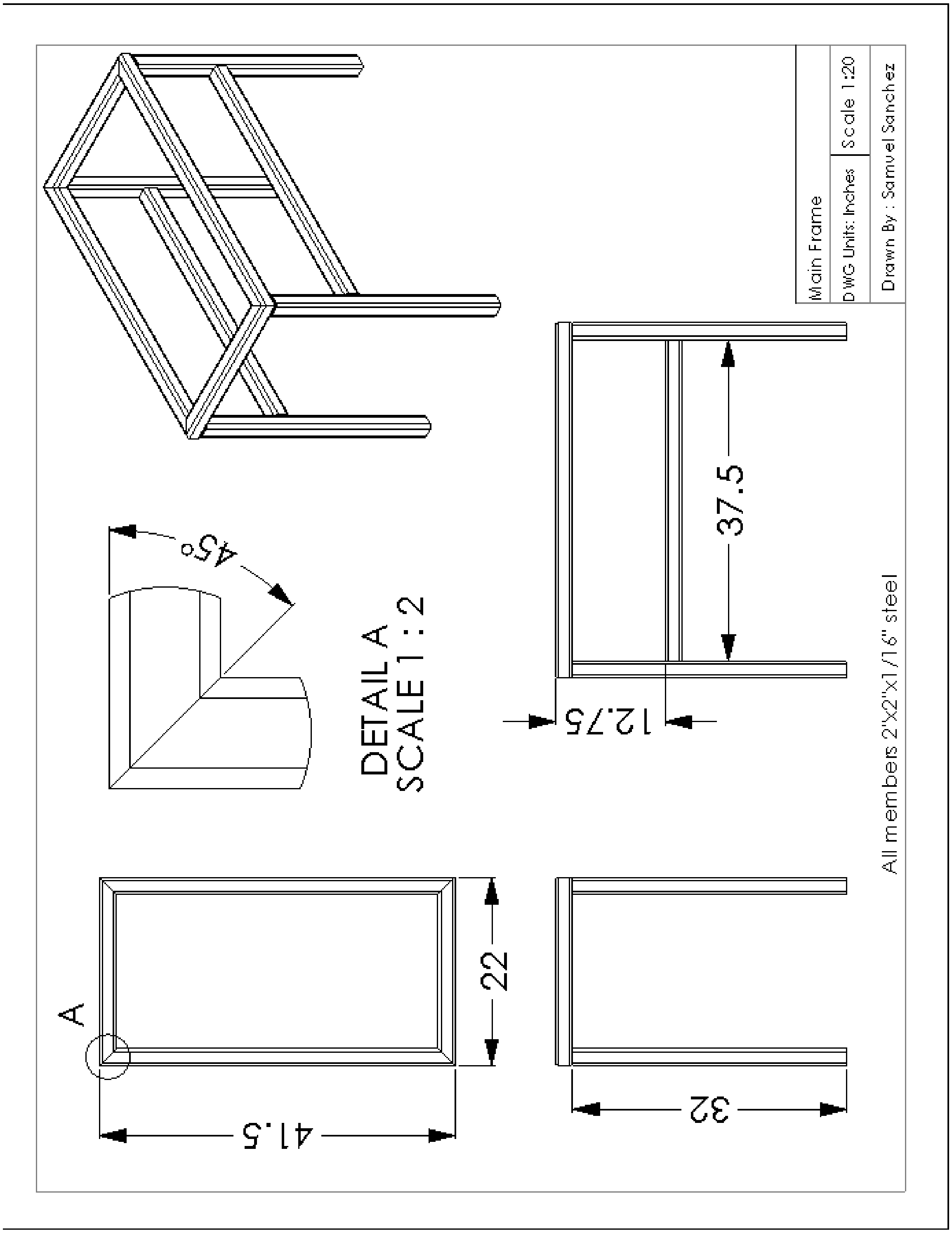


Figure 21: Main Frame

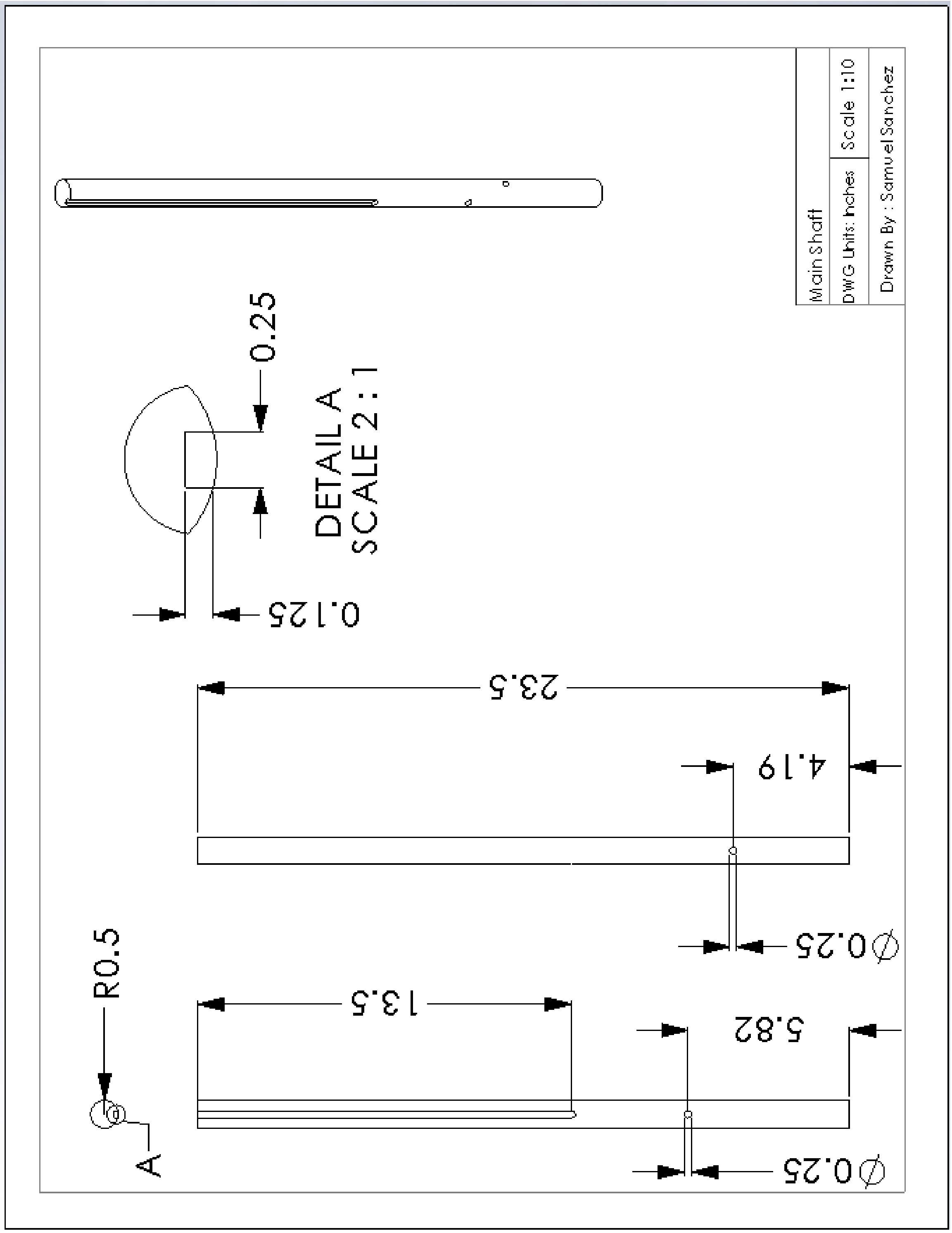


Figure 22: Main Shaft

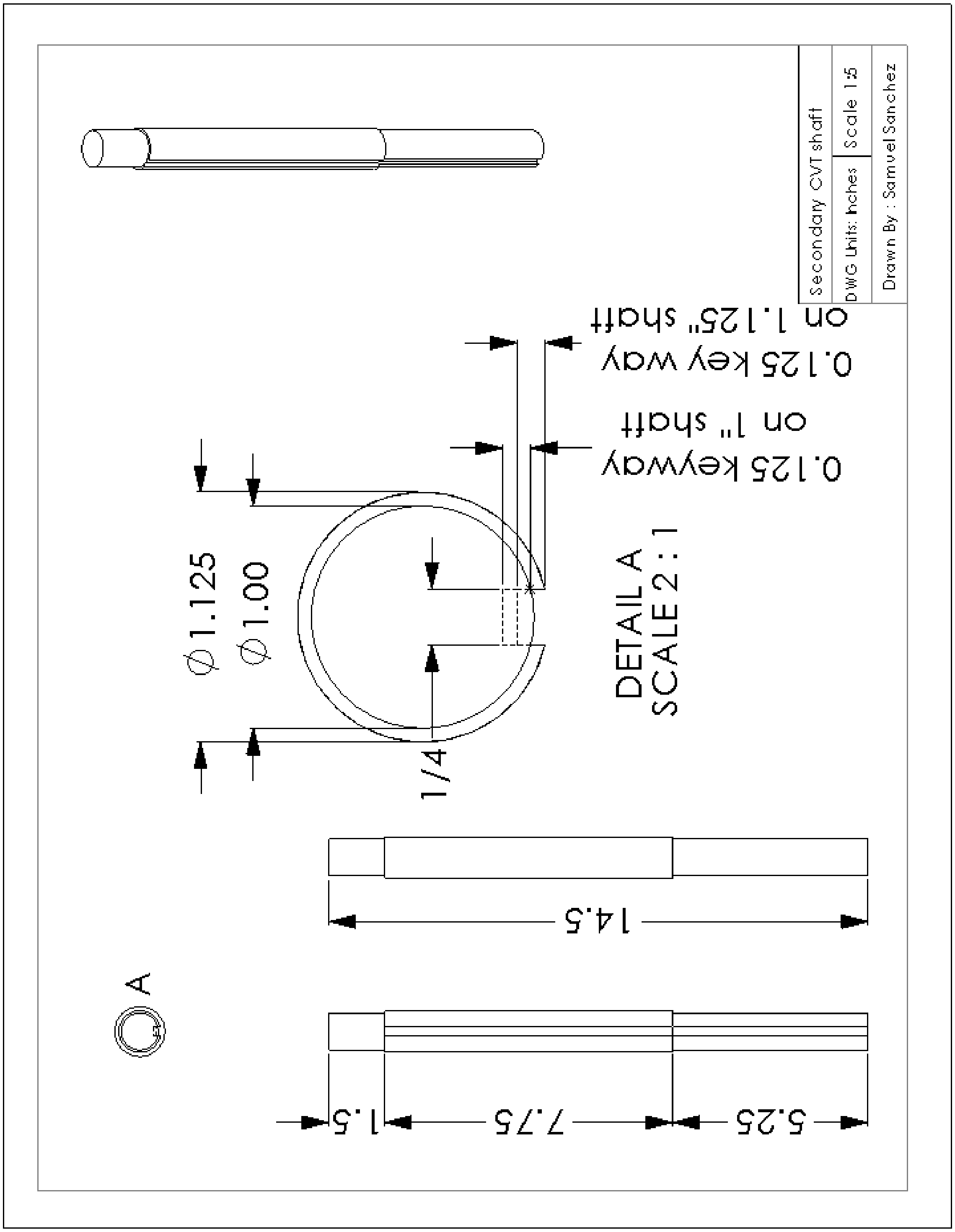


Figure 23: Secondary CVT Shaft

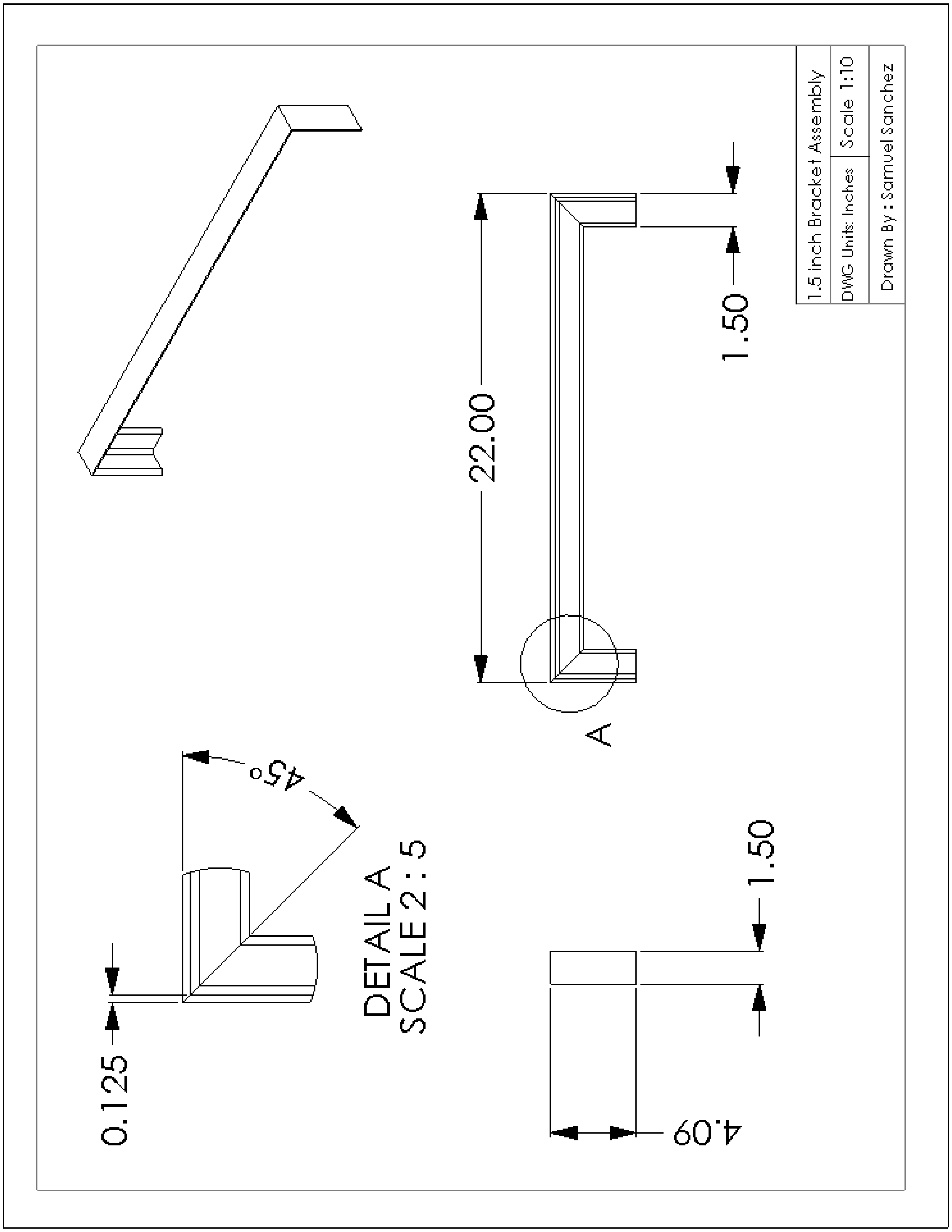


Figure 24: 1.5 inch Angle Bracket Assembly

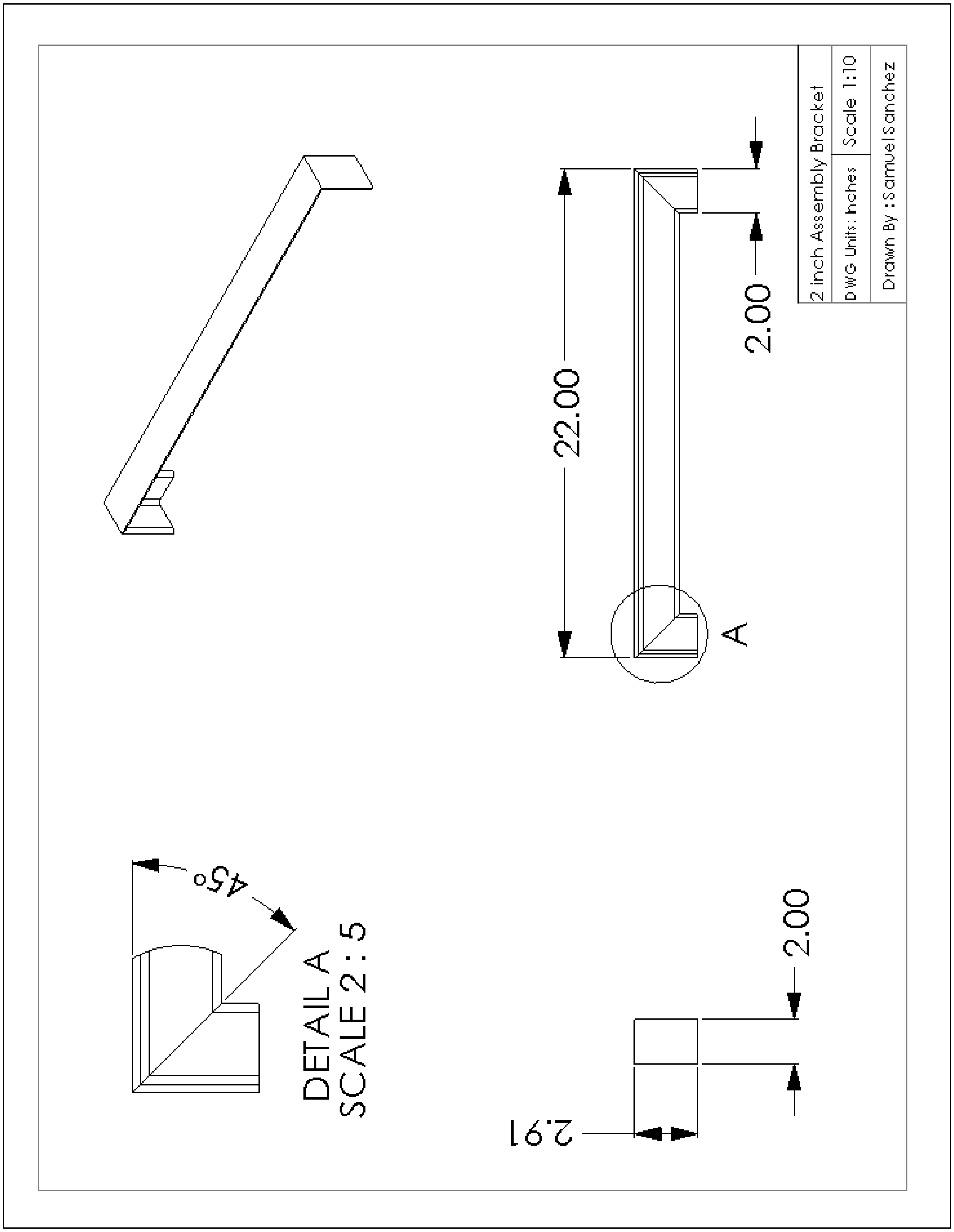


Figure 25: 2 inch Angle Bracket Assembly

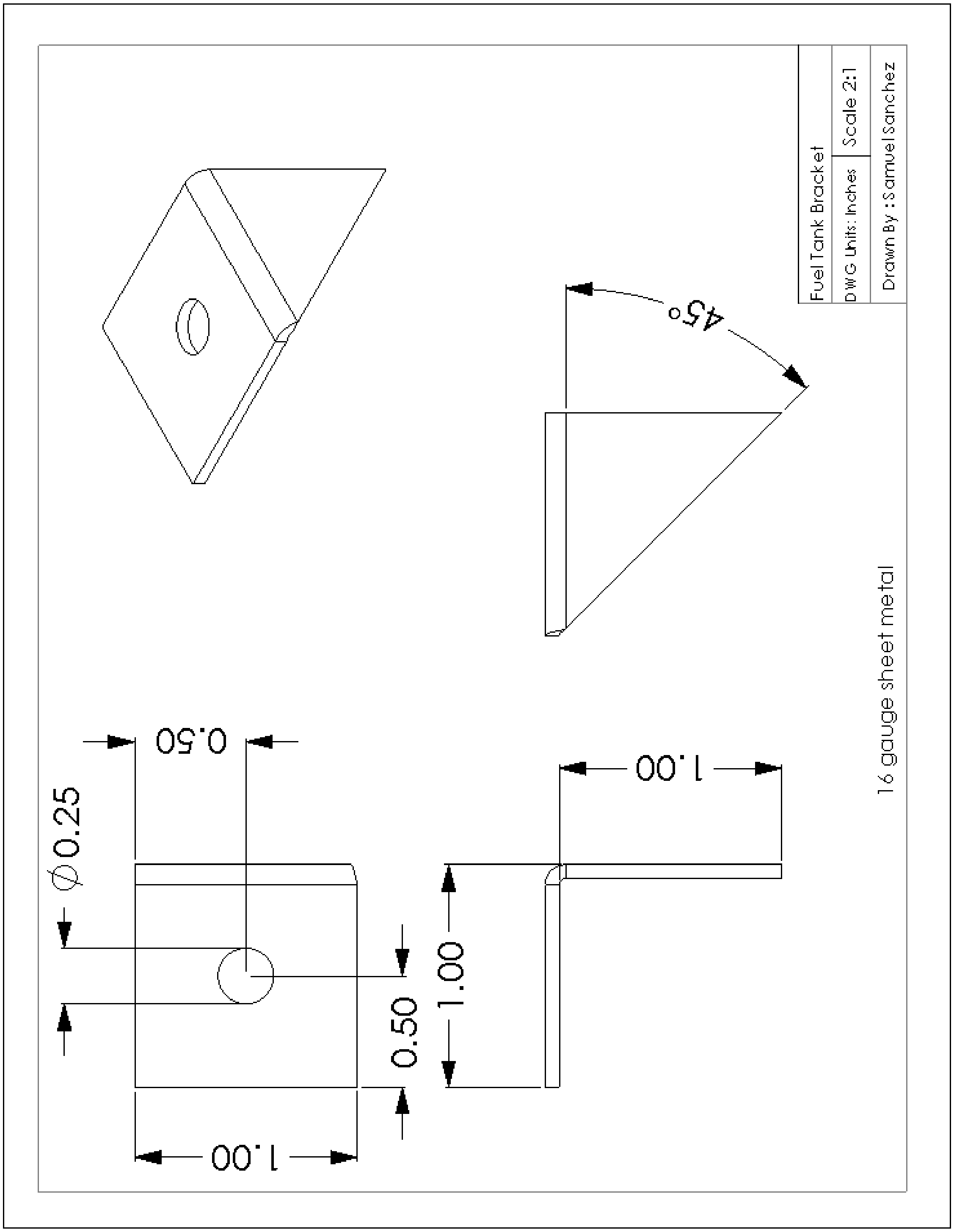


Figure 26: Fuel Tank Bracket

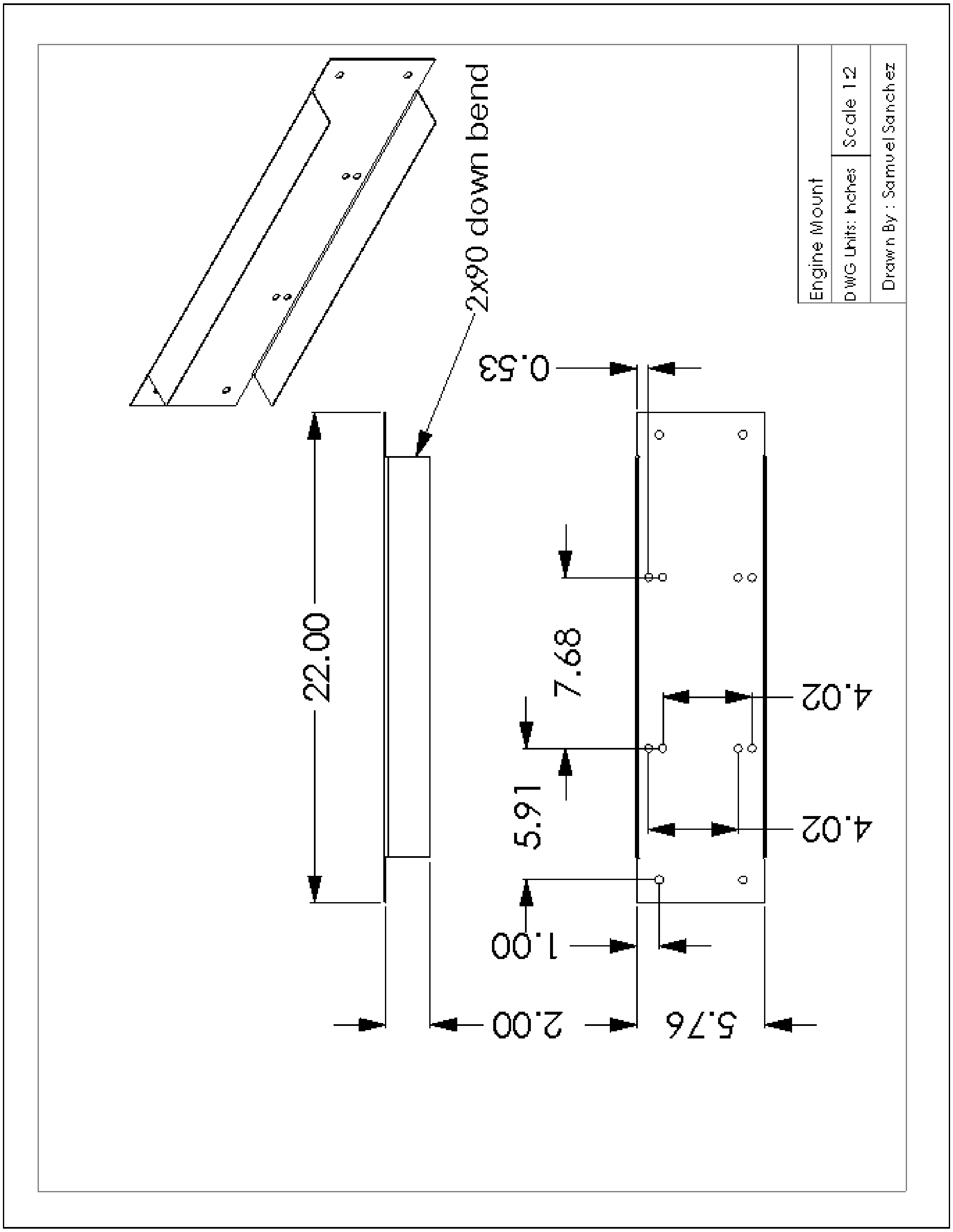


Figure 27: Engine Mount

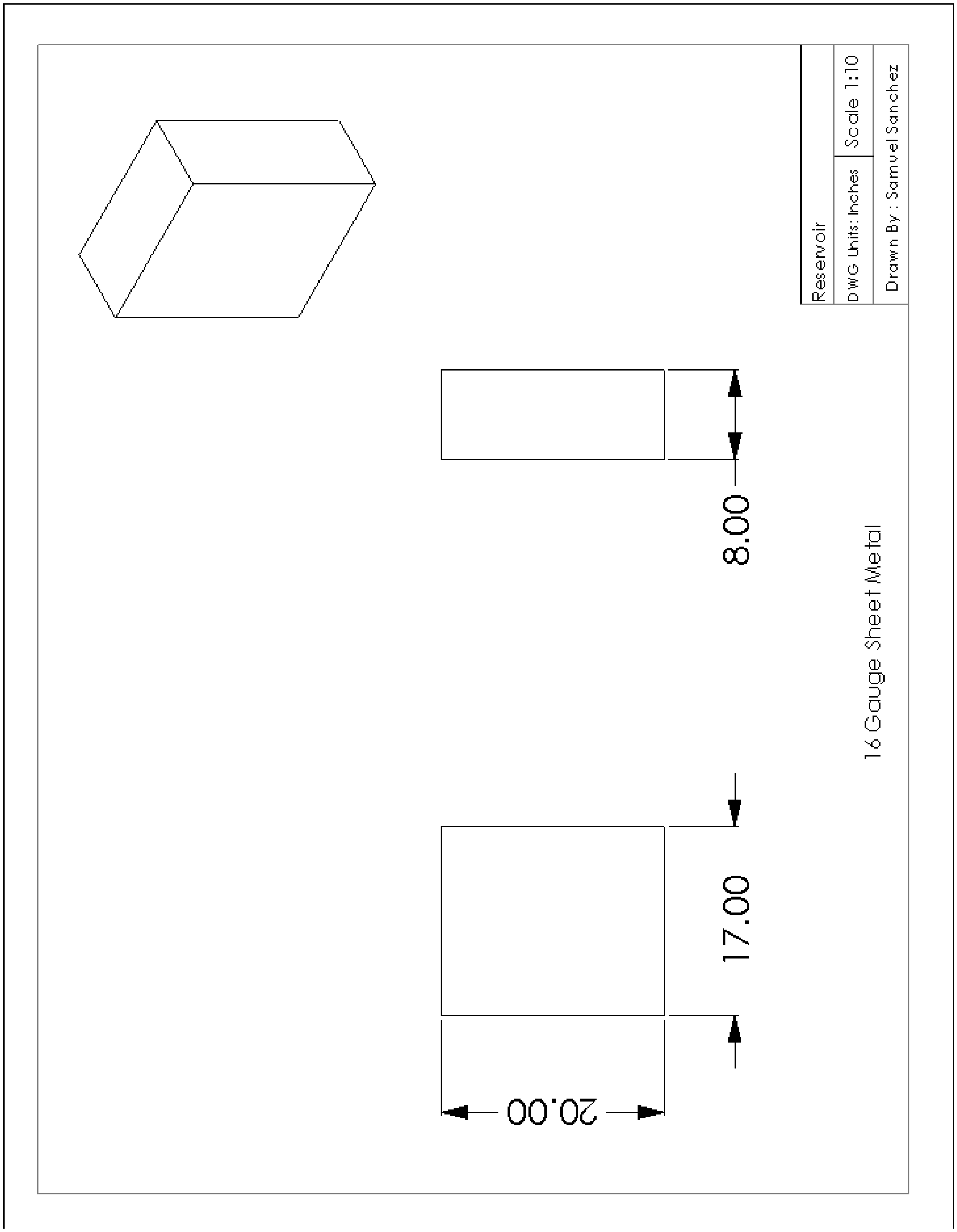


Figure 28: Reservoir

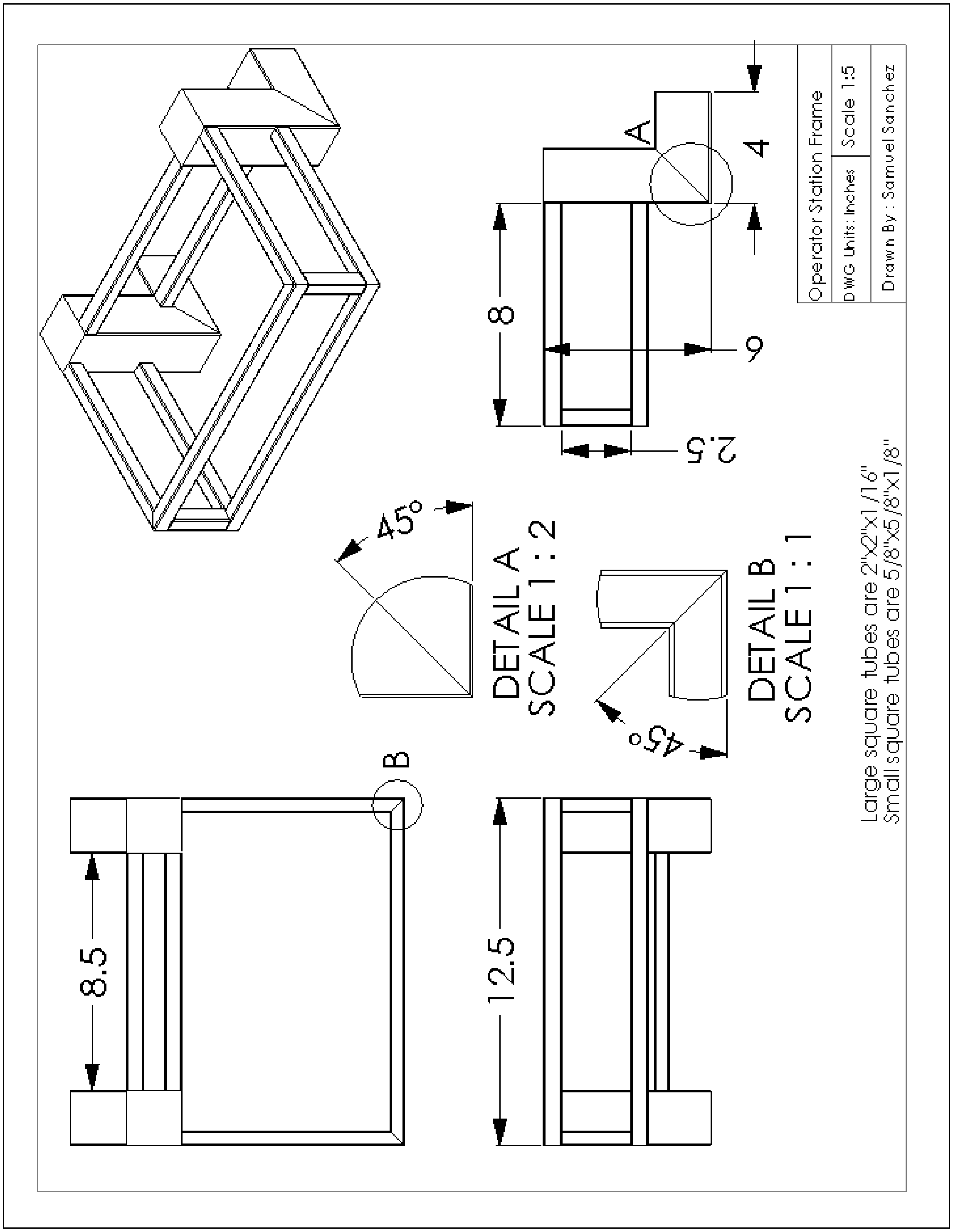


Figure 29: Operators Station Frame

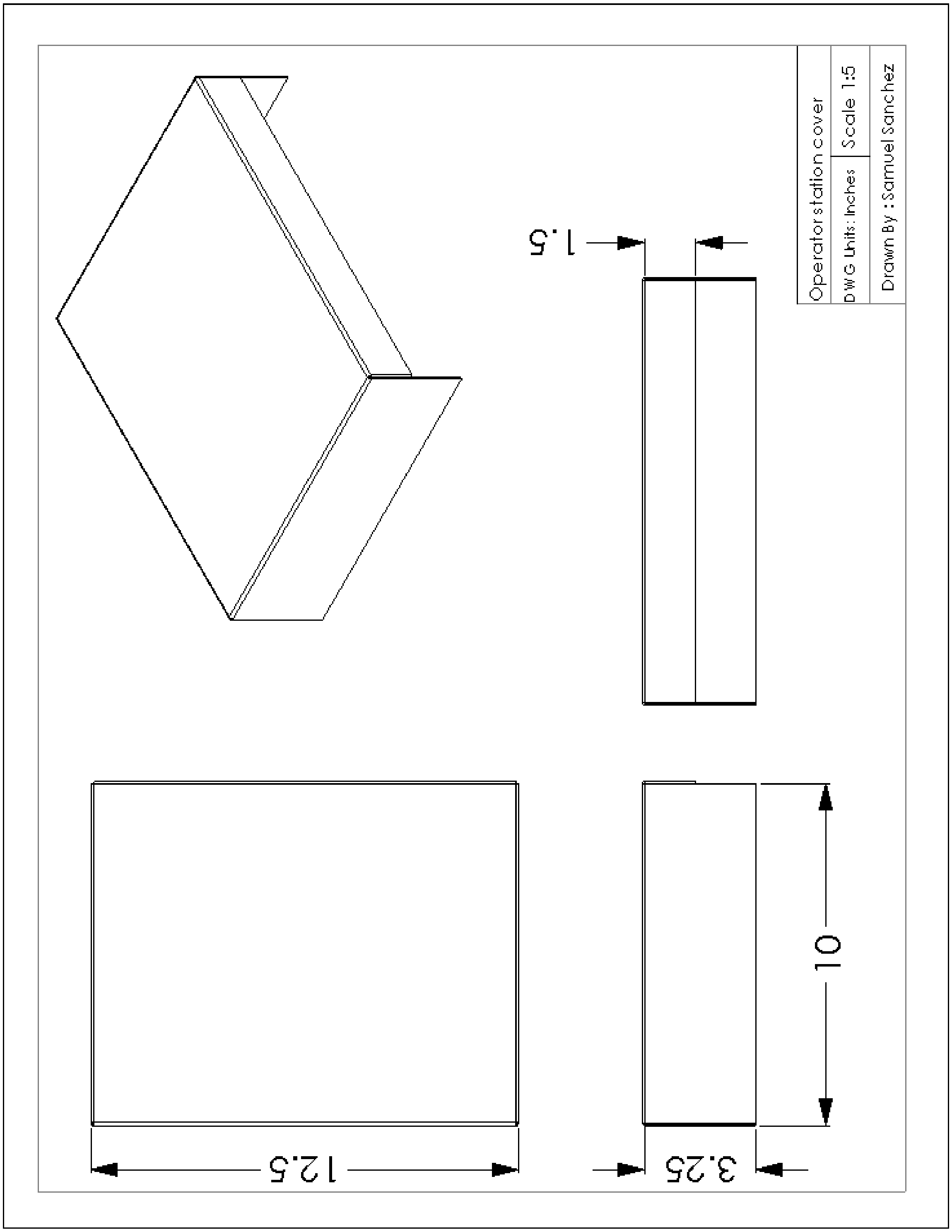


Figure 30: Operator Station Cover

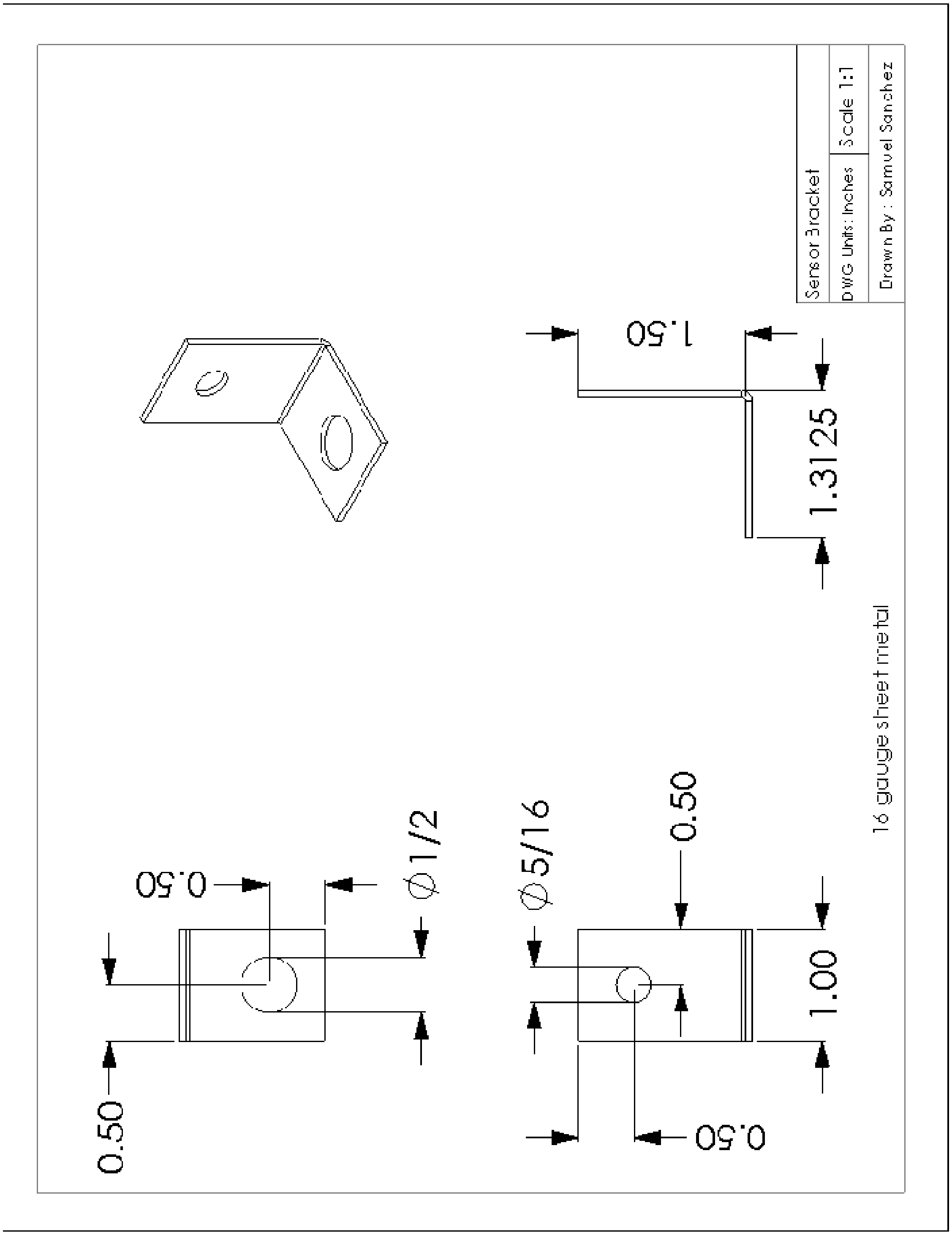


Figure 31: Sensor Bracket

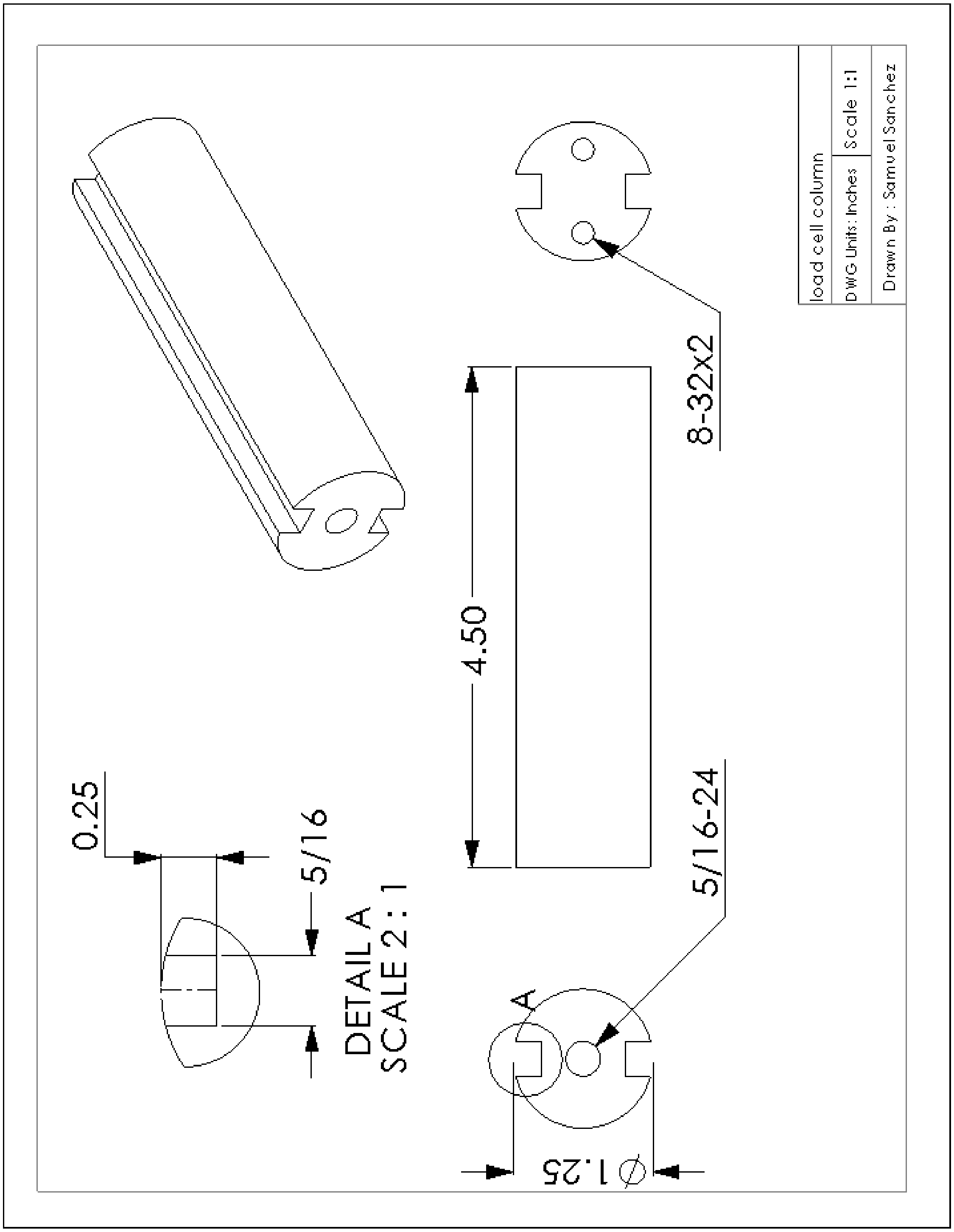


Figure 32: Load Cell Column

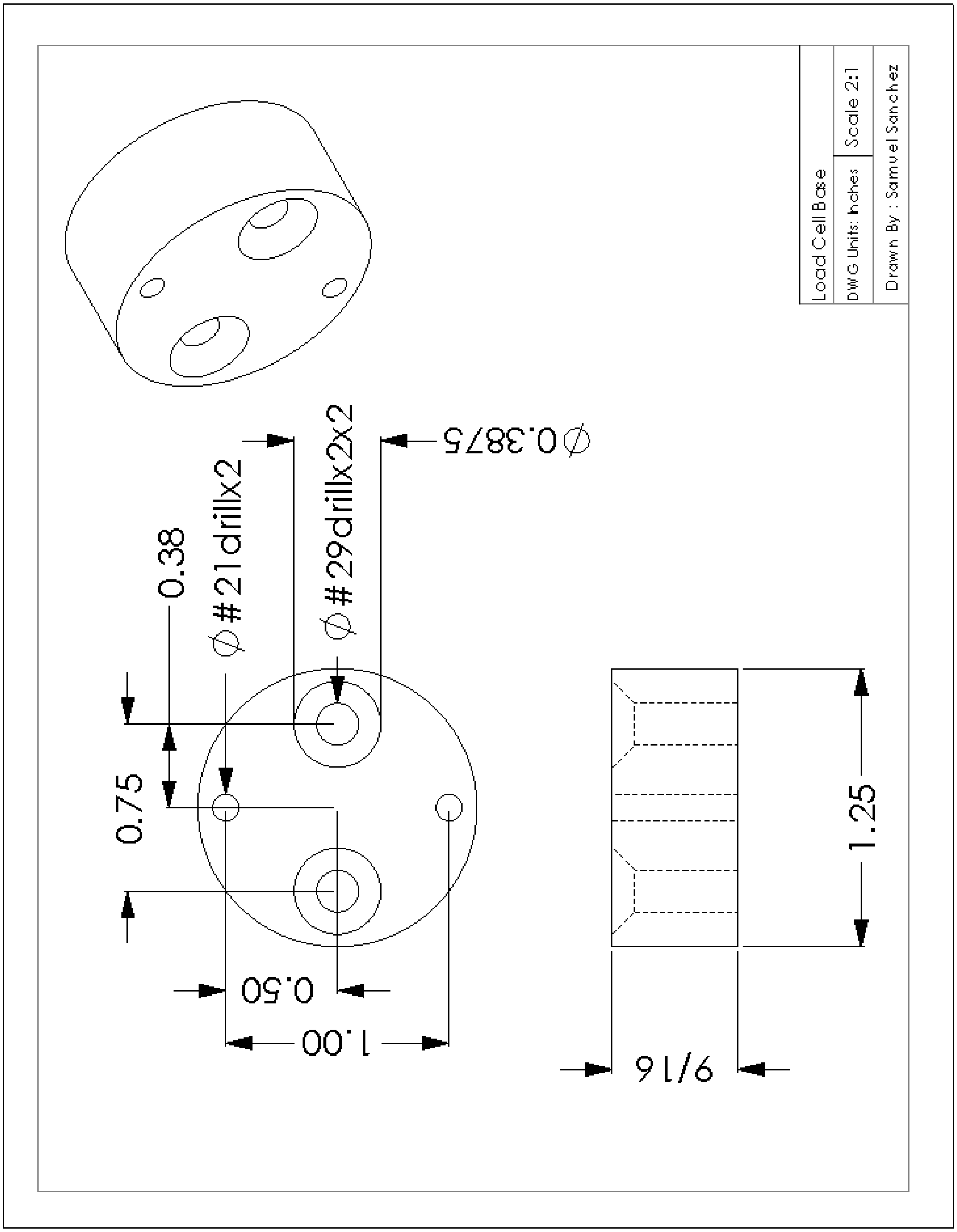


Figure 33: Load Cell Base

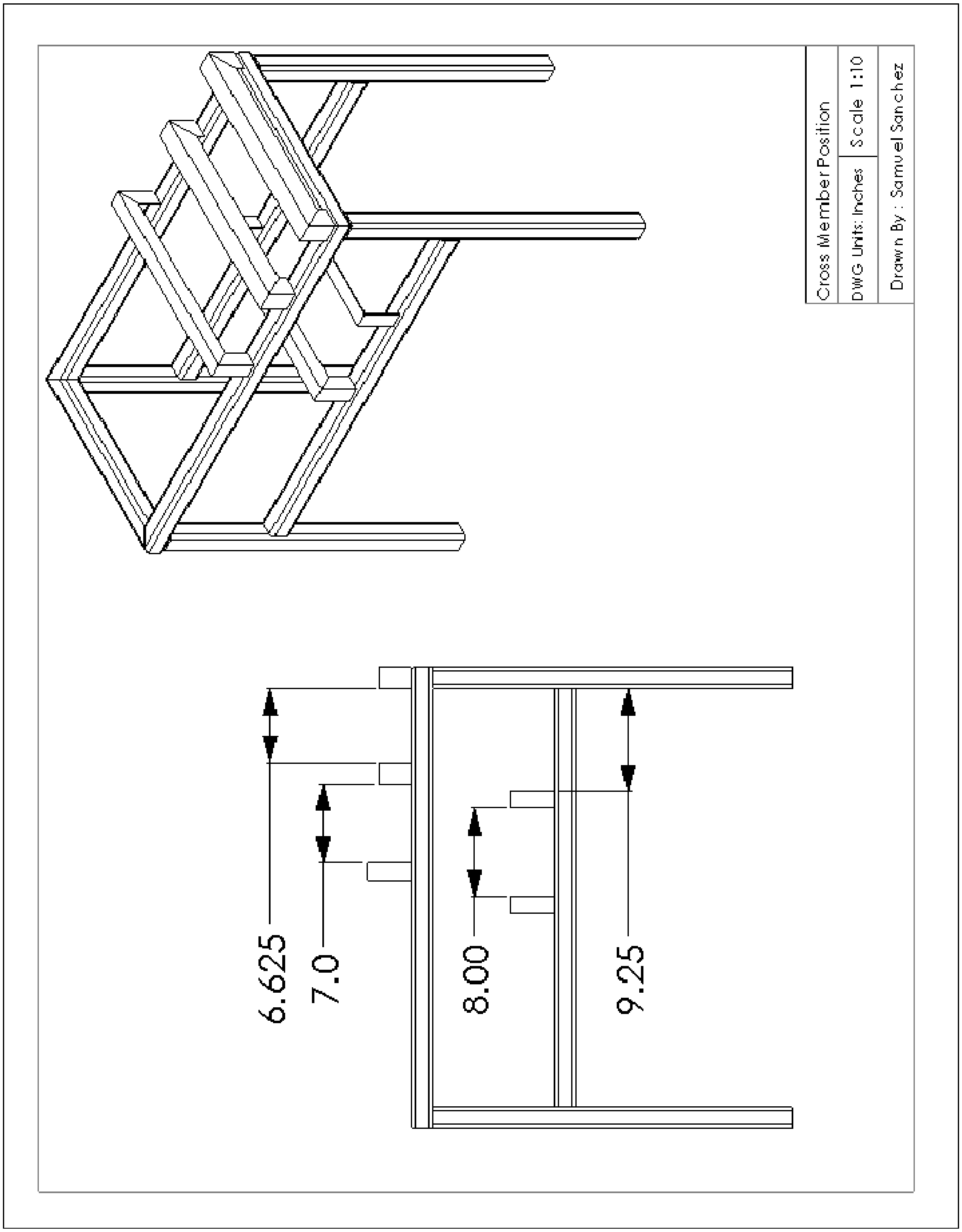


Figure 34: Cross Member Position

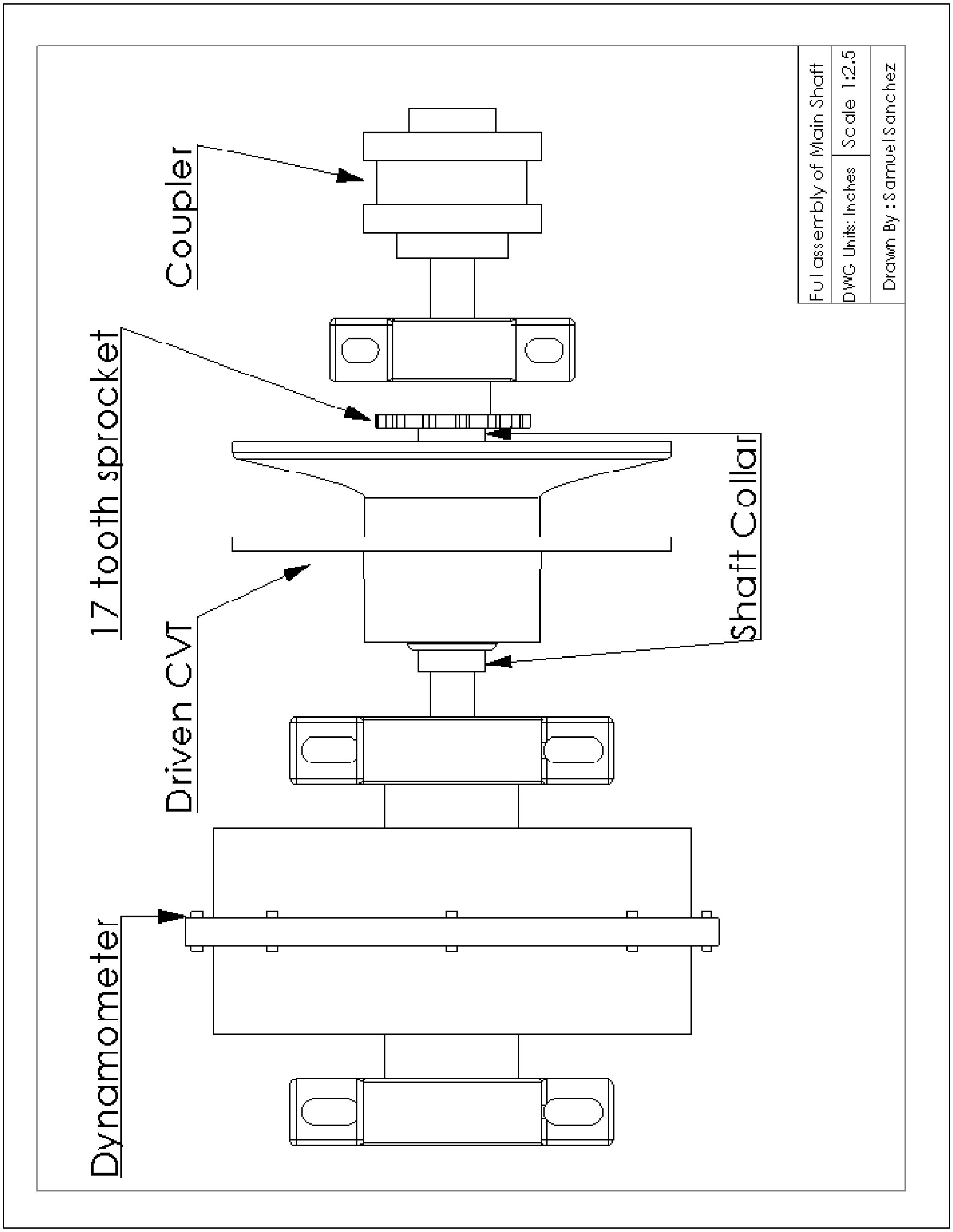


Figure 35: Full Assembly of Main Shaft

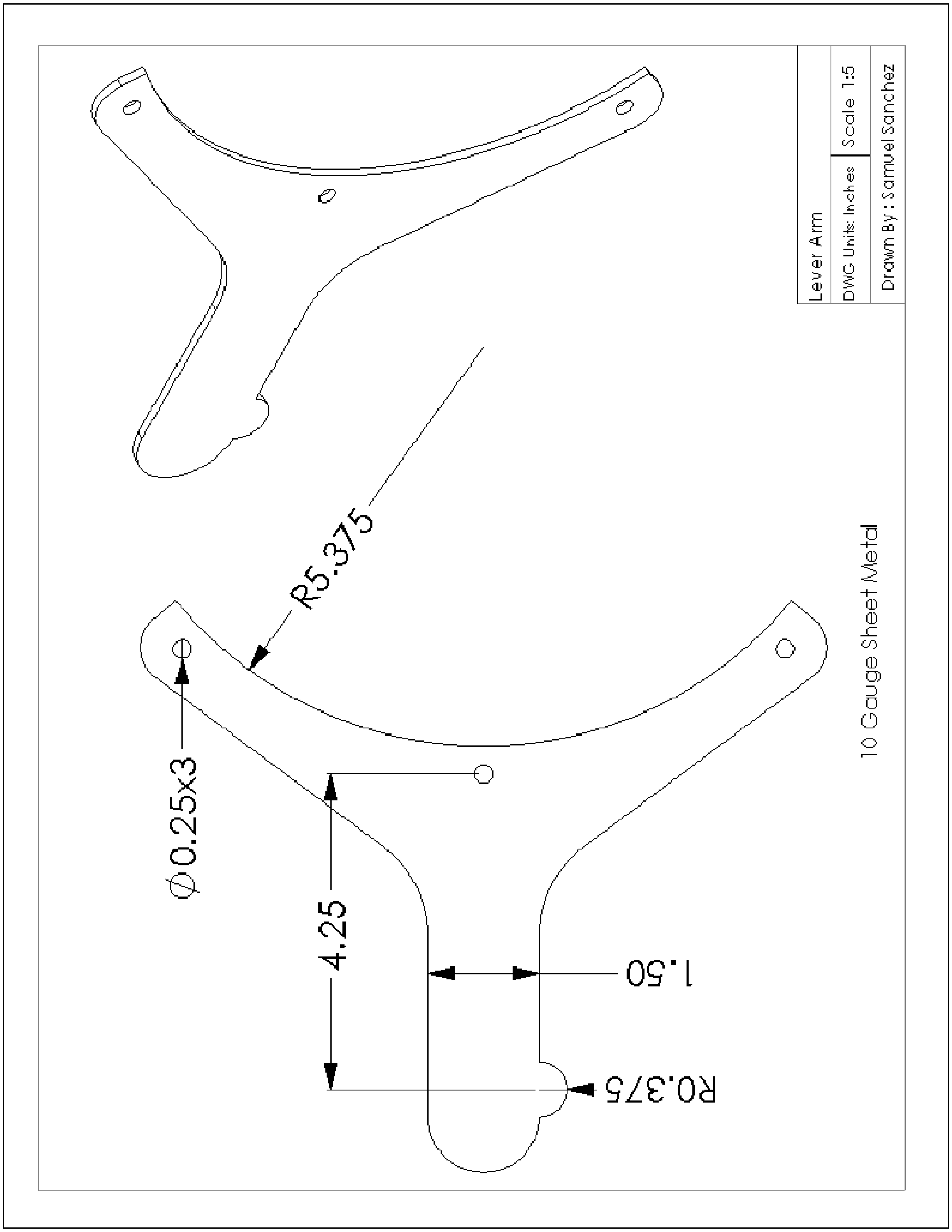


Figure 36: Lever Arm

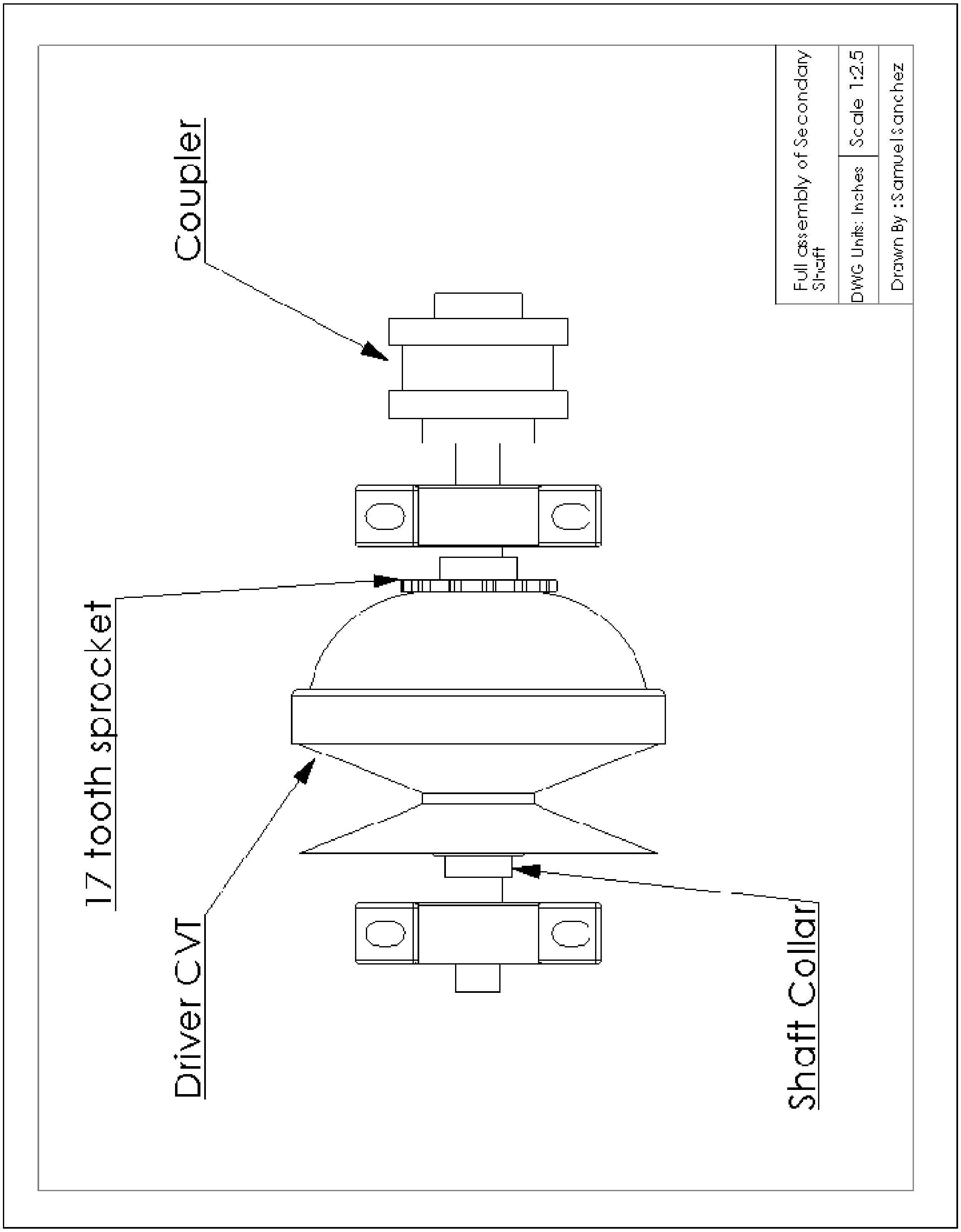


Figure 37: Full Assembly of Secondary Shaft