UNIVERSITY OF MANITOBA

Engineering Design MECH 4860
Final Design Report
Buhler Versatile: Cooling Tower Design for Power Take Off Testing Dynamometer

Team #5: Big Roy
Supervisor: Dr. Chatoorgoon
Mechanical & Manufacturing Engineering

December 6th, 2010

Mathew Smith | Jared Bunkowsky | Andrew Bell

UNIVERSITY OF MANITOBA

University of Manitoba, Faculty of Engineering
Winnipeg, Manitoba R3T 2N2
October 29, 2010

Edward Lambert
Director of Engineering

Dear Mr. Lambert,

Please accept the accompanying report titled "Concept and Design Report for Buhler Versatile: Cooling Tower Design for Power Take Off Testing Dynamometer".

This report was written to design a cooling system that will be able to cool the new dynamometer in the Engineering Test Department at Buhler Versatile. It was written for Edward Lambert, director of Engineering at Buhler Versatile. This report was assigned in early September and has since been completed on December 6th, 2010.

The following report outlines the steps taken to develop a cooling system that will meet all of the outlined specifications supplied by Buhler Versatile. This report also provides details of various components required for a closed loop cooling system, as well as all the supporting calculations and production drawings required for implementation of the design. The primary areas covered in this report include: coolant selection, pumping requirements and selection, radiator design and control system analysis. The results of the analysis show that a six radiator cooling tower utilizing a 50/50 glycol water mixture should be employed to meet the necessary cooling requirements of the new dynamometer.

The team would like to thank the following people for their support and their time to help with the preparation of this report: Aidan Topping, Technical Communication Specialists University of Manitoba, Curtis Carrick, Teaching Assistant Engineering Design University of Manitoba. If there are any questions regarding the content covered in this report you may contact Andrew Bell

Sincerely,

Big Roy
Mechanical Engineering Design Team 5
Encl. ["Concept and Design Report for Buhler Versatile: Cooling Tower Design for Power Take Off Testing Dynamometer"]

Table of Contents

List of Tables

List of Figures

Abstract

The purpose of this project was to design a closed loop cooling system for Buhler Versatile's new water break dynamometer. The following report outlines the steps taken to develop a closed loop cooling system that will dissipate enough heat from the test dynamometer, which will allow the dynamometer to operate at maximum loading conditions. In addition, the report outlines steps taken to ensure the design meets or exceed all of the outlined specifications supplied by Buhler Versatile. This report also provides details of various components required for a closed loop cooling system, as well as all the supporting calculations and production drawings required for implementation of the design. The primary areas covered in this report include: coolant selection, pumping requirements and selection, radiator design and control system analysis. Each section outlines various alternatives and offers calculations and other supporting details for proof of concept.

The results of the analysis show that a six radiator cooling tower utilizing a 50/50 glycol water mixture should be employed to meet the necessary cooling requirements of the new dynamometer. A total cost was not found since some of the material costs are unknown along with some of the costs associated with the gearboxes and drive shafts. Due to time constraints a full payback period analysis was not performed.

1.0 Problem Definition and Background

Buhler Versatile Incorporated is a manufacturer of large agricultural tractors for use throughout North America and the world. The main product line for Buhler Versatile is the Four-Wheel Drive (4WD) articulated tractors, with power ratings ranging from 305 to 575 hp. Buhler Versatile requires the ability to test each new model to make sure the required specifications are met before mass production. Therefore, testing equipment and procedures are necessary to keep up with new designs [1].

The purpose of this project is to develop a cooling system to dissipate enough heat to allow a new dynamometer to work at maximum capacity. This new cooling system will allow Buhler Versatile the ability to test more powerful engine designs and configurations.

1.1 The Testing Facility at Buhler Versatile

The Buhler Versatile Engineering Department is divided into two separate groups: Research and Development, and the Testing Facility. In the Testing Facility, a dynamometer is used to test new engine designs by directly connecting the dynamometer with a driveshaft to the engine. In addition, many other system monitoring devices, such as fuel consumption sensors and temperature sensors, are attached, providing additional information on engine performance. The primary function of the dynamometer is to test new tractor and engine combinations for power output, reliability, performance, and emissions output. Recently, Buhler Versatile has expanded their 4WD tractor series to include models with higher horsepower ratings. However, the existing dynamometer was not capable of handling the loading conditions created by the increased horsepower engines. With future projects in mind, Buhler Versatile has purchased a new water brake dynamometer with an increased load capacity to facilitate the testing needs of future engine and tractor models [1].

1.2 The Water Brake Dynamometer Current System

In order to understand how to design a cooling system for this new dynamometer, we first need to understand how the dynamometer works. The water brake dynamometers create a load on the tractor by controlling the flow of water into the dynamometer housing.

Inside the housing, a centrifugal pump style impeller forces the water against the dynamometer housing, (called the stator) which has vanes mounted on it. The force of the fluid on the stator vanes creates a torque on the housing, which in turn is measured by a load cell. The measured force can be mathematically related to the power output of the tractor and engine. Due to the nature of the device, the temperature of the working fluid, the water, is increased to a much higher level and, as a result, must be cooled [2].

Currently, the water supply for the dynamometer is being provided from the city water source, passed through the dynamometer housing once, and then discharged into the sewer. There are two main issues with the present set-up. First, the city water source does not provide a sufficient flow rate to operate the dynamometer to its maximum load capability. Secondly, this system is not cost effective, as the water is simply ejected to the sewer in a once through system. This means Buhler Versatile has to pay for all of the water they use and expend [1]. It is obvious from an economic point of view that using a closed loop system for cooling the dynamometer will save money and allow Buhler Versatile to continue to be competitive.

Being able to test new tractor engines and configurations allows Buhler Versatile to develop tractors with more power, reliability, and performance, which will allow the company to stay competitive in the agricultural tractor market. A new working fluid system capable of providing sufficient flow and pressure, while maintaining dynamometer fluid inlet temperature under allowable constraints, is required to fulfill the needs of the new dynamometer project.

1.3 Target Specifications

As with all problems, there are certain terms and conditions that must be met in order for the solution to be accepted. In most situations these conditions are imposed by the very nature of the problem being solved, while others are conditions that arise from possible implementation or logistical complications of the solutions themselves. In either case, each possible solution must be measured against what conditions are met and how each constraint is satisfied.

In this project there have been specific criteria imposed by Buhler Versatile based on their available parts and space, while other limitations are due to the design of the dynamometer itself. The following sections list all constraining factors that must be met by our cooling system design.

1.3.1 Project Criteria and Target Specifications

In order for the project to succeed, any design developed must meet some specific criteria set out by Buhler Versatile. In particular, the following list of constraints must be met, or else the sponsors will not accept the design as feasible. The following list is not in any particular order.

1) No fluid will be discharged or added to the cooling circuit. The cooling system must be a closed system.
2) The cooling system must be stationary. In addition, individual components must have specific locations:
    a. Holding tank(s) must be inside the building to prevent the cooling fluid from becoming too cold during the winter months.
    b. The radiators must be set along side the building's exterior.
3) The cooling system must use as many in house parts as possible to minimize cost.
4) The budget for purchased parts must be under $2000.
5) The cooling system must be able to dissipate heat generated at maximum loading conditions (700 hp) on the dynamometer.
6) The cooling system coolant supply to the dynamometer must be able to maintain the necessary cooling requirement at a pressure between 60 psi and 150 psi.
7) The cooling system must be able to keep up with the daily load cycles, which include 8 hours running times at maximum power of 700 hp.
8) The system must operate in test bay temperatures ranging from 100 °F to 120 °F.
9) The cooling system must be able to reduce the outlet temperature from the dynamometer from approximately 160 °F to approximately 90 °F at the inlet of the dynamometer.
10) No air must enter the dynamometer from the cooling system, since the working fluid is also the cooling fluid.
11) Any air movement must be directed away from the exterior of the building.

12) The heat dissipating system (radiators) must be small enough so equipment may be moved between the building and the fence line.
13) The cooling system must take into account that the outlet from the dynamometer must be gravity fed. In other words, the outlet must be to atmospheric pressure and cannot have any pumps attached directly to the outlet nozzle.
14) The design must not violate any building or workplace safety codes.
15) The design must minimize the potential of environmental damage due to coolant leakage or spills by not allowing any coolant to escape from the system.
16) The design must be easily maintained, with isolation valves so equipment may be worked on without draining the system of coolant.
17) The city water cooling system must be maintained as a backup system. This means no coolant mixing may occur, as city water and closed system coolant must stay separate.

1.4 Project Objectives and Expectation

There are four main expectations the group has for the team's final design. The first expectation is that the project be completed on or before the given deadline of December 6th, 2010. Secondly, it is expected that the design will operate properly within the given restrictions. Thirdly, it is expected that the design will be of sufficient quality that the customer is able to use the design for the lifespan of the new dynamometer or longer. Finally, it is expected that the design should be detailed to include any and all information required for actual construction and implementation. The following sections outline some details on how the group will go about meeting our expectations in order of importance.

1.4.1 The Deadlines

The design team has placed top priority on the deadline imposed. This means that the entire design project will be completed on or before December 6th, 2010. In order to accomplish the deadlines, the group has developed a detailed schedule of the tasks involved with this project in order to stay on track and ensure that nothing is missed from the design. In addition, each group member has been assigned specific jobs within the group and each member is required to finish assigned work on or before the date agreed upon by the group. Since the group has only three members, the tasks have been assigned in advanced to allow each group member enough time to fit their part of the design into their individual schedules. Appendix A includes the Gantt chart for this project.

1.4.2 Proper Operation

The operation of the final design is important to the group, as well to the customer. It is expected that the design will function as intended by dissipating a sufficient amount of heat in order to accommodate the maximum operation of Buhler Versatile's new dynamometer. In addition to heat dissipation, the group must also provide a design that will meet all the design specifications specified in Section 2.3.1.

1.4.3 Quality Control of our Design

In addition to the operation of the design, we will also consider durability of the design process. We realize that Buhler Versatile's new dynamometer was purchased as a long term testing tool. In order to allow Buhler Versatile the continued long term use of the dynamometer, it is necessary to ensure that the design of the cooling system will last as long as or longer than the new dynamometer. Furthermore, the design must also withstand maximum horsepower test and reliable enough to endure years of extended use.

1.4.4 Implementation Details

With the expectation that this design will be used by Buhler Versatile, it is expected that, in addition to the cooling system design, the design will also include details required for implementation. These details comprise cooling system drawings, mounting structure details, utility routing, production drawings of any parts that need to be fabricated, bill of materials, and sources of any component of the system.

2.0 Conceptual Design Elements and Project Structure

The project was broken up into sub sections including: coolant, pumping, radiator and control sections. Each sub section employs different search techniques and idea generation methods, as well as different methodology for selecting ideas to develop further. Upon further investigation of these sub sections or micro-problems, one can see that the solution of these smaller problems will lead to the solution to the whole situation. The following sections outline the steps taken to generate possible solutions to satisfy each micro-problem.

3.0 Coolant Selection

To meet the specifications as outlined in the Taylor DL700 Dynamometer Operation and Maintenance Manual, the working fluid must be water based for the dynamometer to work properly. Due to this fact, the selection of coolant is limited. An initial selection process based on brainstorming, previous experience, research, and consultation with Versatile has led to the development of three options. The brainstorming process has allowed the group to explore alternative options for fluids or the possibility of changing between a summer and winter fluid. Again, since the dynamometer specifications are quite specific regarding the coolant fluid properties, any alternative fluid options other than water based solutions are not allowable and no further development was deemed necessary. The idea of changing fluids between summer and winter was determined to be an inefficient approach to prevent the freezing of the coolant. Changing the fluid twice a year (for winter and summer) would result in dynamometer and employee downtime, as well as an associated storage cost for the fluid that is not being used, and the cost of replacement if the fluid is disposed of.

The research obtained from textbooks, knowledge from previous experiences and the consultation with Versatile led us to the proposed fluids, which are water, a 50/50 ethylene glycol/water mix, and a 50/50 propylene glycol/water mix. The group decided to use a simple screening matrix to select which fluid should be further developed. Each beneficial characteristic is denoted by + while negative characteristics are denoted by - in the screening matrix. The totals are obtained by counting the number of + and – where one + factor will cancel one – factor. Due to the simplicity of this selection, the group decided not to use a scoring matrix to further refine the coolant selection criteria.

As tabulated in Table I, the propylene glycol received the best score. Due to the nature of the system, the factor with the most importance, and ultimately the greatest deciding factor in the type of fluid, is the ability to use the system during the winter.

TABLE I: CONCEPT SCREENING MATRIX FOR FLUID CHOICES [3]

	Water	Ethylene Glycol Mix	Propylene Glycol Mix
Toxic Effects to Environment/Food	+	-	+
Use In Winter	-	+	+
Heat Transfer Characteristics	+	-	-
Dyno Compatible	+	+	+
Cost Effectiveness (no fluid change all year)	-	+	+
Total	+1	+1	+3

As a result of the industrial nature of the system and the fact that there is no concern of contaminating any food systems or the environment, the fluid that will be recommended and pursued is the 50/50 ethylene glycol/water mix. This mixture is suitable for temperatures down to -37 °C [4], which provides the ability to use the system all year while maintaining excellent heat transfer characteristics.

4.0 Pump Selection

For the dynamometer cooling system, a pumping system is required to provide coolant to the dynamometer inlet, and also to remove coolant from the discharge of the equipment. One major technical requirement for the outlet of the dynamometer is that it must discharge to atmospheric pressure. This means that a pump or restriction may not be directly connected to the discharge connection. The outlet valve may be seen in Figure 1.

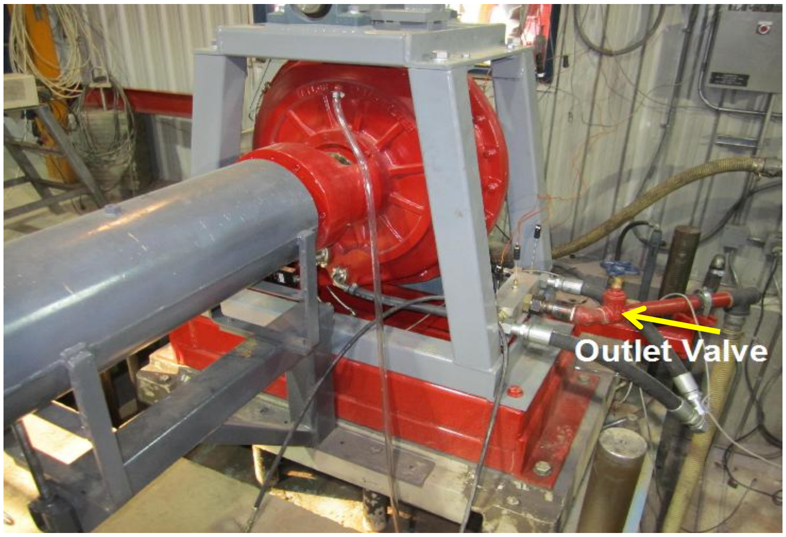


Figure 1: Current dynamometer setup [3]

Also, the space around the outlet of the dynamometer is quite restricted and contains electrical connections, which must be protected from being immersed in fluid. The dynamometer pit is shown in Figure 2. A collection tank open to atmospheric pressure will be placed in the dynamometer pit. Dimensions for a suitable poly-tank include: 72 in. long x 27 in. wide x 34 in. deep. The outlet of the dynamometer shall be directed into the tank, and the return pumping system will draw from this pit. Utilizing this collection tank enables the system to meet the conditions of an atmospheric discharge from the outlet of the dynamometer.

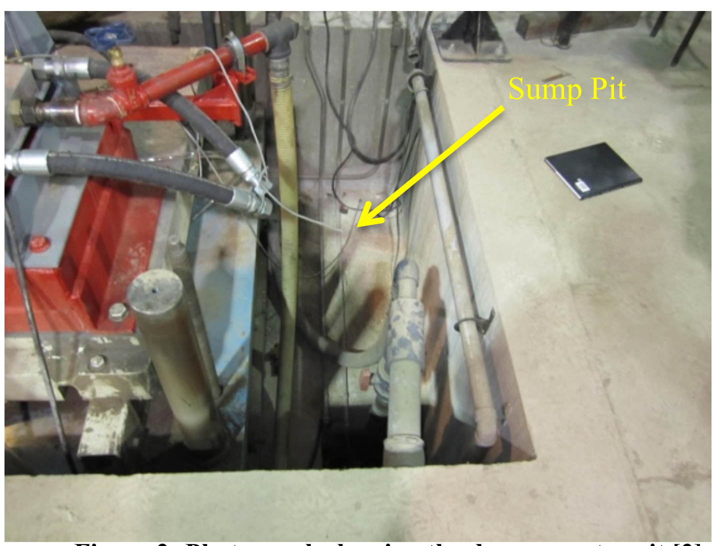


Figure 2: Photograph showing the dynamometer pit [3]

4.1 Equipment Placement

The orientation and placement of all mechanical equipment and sub-systems are crucial for an effective implementation of the proposed design. The location of the equipment must allow for continued access to the dynamometer bay room, without impeding the travel of rolling carts, workers, and small vehicles. The guidelines that have been provided by Versatile are quite stringent in order to meet the aforementioned constraints. A layout of the dynamometer bay has been provided in Figure 3 to illustrate the final locations of equipment to provide maximum accessibility while minimizing space requirements.

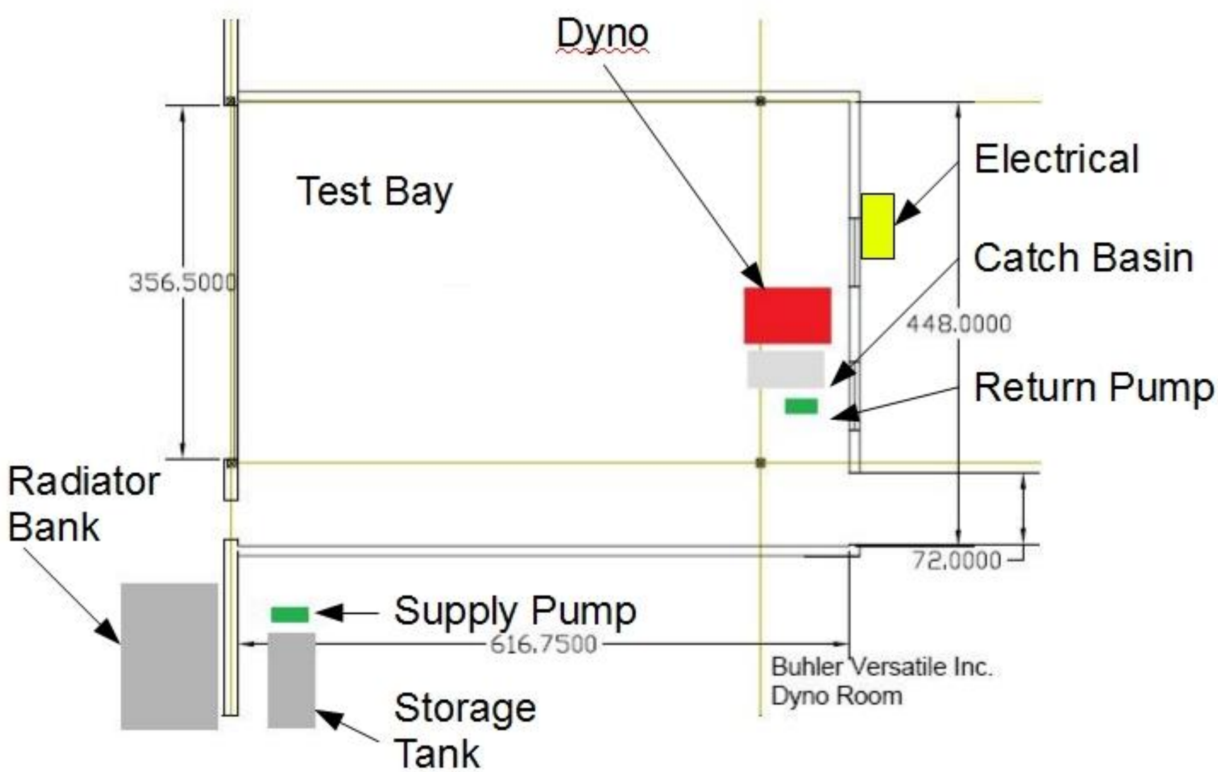


Figure 3: Equipment layout in test bay. All units in inches [3]

As shown in Figure 3, the radiator bank will need to be placed outside. There is ample room along the length of the building and this space is readily available for the project. The location of the equipment is in accordance of the Canadian Building Codes [5]. A location for the storage tank for the coolant has been proposed by Versatile as illustrated in Figure 3. Originally, the storage tank was to be located within the dynamometer bay, but due to high temperature conditions, the current proposed location shall be used. The storage tank will be provided by Versatile and will have sufficient storage capabilities for an effective recirculation system. The storage tank will be properly place to ensure there is sufficient net positive suction head (NPSH) available for the supply pump to ensure the pump does not cavitate. The specifications of the selected supply pump given in Appendix B provide the necessary details to ensure this does not occur. By using the supply pump recommended by this report, there should be no issues regarding cavitation.

An electrical box for housing the Variable Frequency Drives and controllers will be installed in order to protect the devices from the environment. The electrical boxes will be mounted outside of the dynamometer bay adjacent to the existing electrical equipment as noted in Figure 3. The final location and installation of the electrical system will be performed by a qualified journeyman electrician to ensure that the installation complies with the Canadian Electrical Code.

Piping will be run outside of the dynamometer bay and mounted on the walls to place it in a non-disruptive location as illustrated in Figure 4.

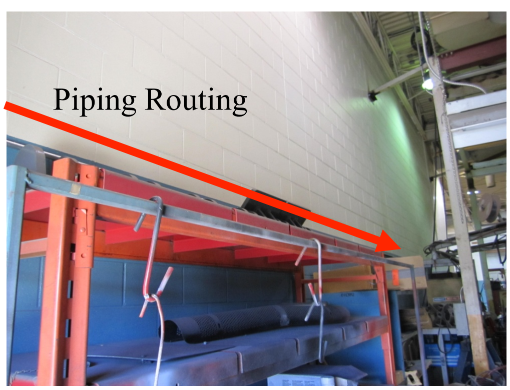


Figure 4: Photograph showing piping placement [3]

By placing the piping in this fashion, the height of the piping will be above any door spaces in order to not impede traffic and to comply with the National Fire Code. Versatile will be providing existing construction materials for the piping components. A schematic of the proposed piping route between the dynamometer, radiator bank and storage tank has been provided in Appendix C.

To ensure that no particulates or corrosion materials are introduced into the dynamometer, two options for piping materials which will be used are PVC and copper pipe. PVC pipe provided by Versatile should be used for all interior piping. This piping meets ASTM D 2665 and ASTM D1785 standard for pressure and temperature rating as provided in Appendix D. Care should also be taken to ensure the PVC pipe is able to expand and contract with changing temperature as shown in ASTM D2665 Table X1.1 in Appendix D. A recommended maximum support spacing of 3 ft is suggested to provide adequate support of the pipe at maximum operating temperature [6]. The PVC piping joints are also recommended to be glued instead of threaded so as to maintain adequate pressure ratings. Steel will not be used in the proposed system due to the possibility of corrosion and the resultant particulate. Copper may be utilized in the exterior environments as it does not become brittle like PVC in extreme weather conditions, although copper is more expensive when compared to PVC. A commercially available compression fitting to transition between the PVC and copper pipe should be utilized in order to avoid the use of threads. In the dynamometer installation, protection of the dynamometer will outweigh the cost of more expensive piping materials.

4.2 Pumping Concept

In order to develop a design concept of the pumping component of the project, a discussion of possibilities was held to brainstorm ideas. The team members' extensive knowledge of pumping systems was utilized to develop options of pump placement, types, and orientation. In addition an extensive search was conducted through literature and pump suppliers to provide additional information on pump curves and performance. Versatile has three pumps, which may be used in the project. The pumps are Monarch model BSE- S150 and two Monarch model BSE-S50. Upon consulting the operating curves for these pumps, as illustrated in Figure 5, it was determined that only the BSE-S150 model would only be suitable for the discharge pump and none of the above mentioned pumps would be capable of meeting the specifications of the supply pump.

The piping losses for the return system and radiator loop have been analyzed and detailed calculations are shown in Appendix E. As a result of the piping layout, the associated piping loses are found to be approximately 25 feet of water.

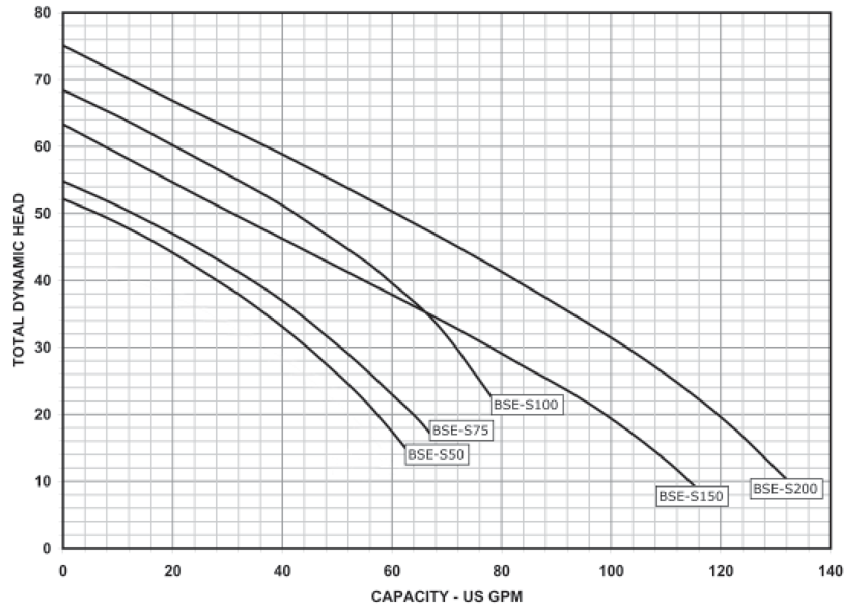


Figure 5: Pump curves for Monarch pumps [7]

As can be seen in Figure 5, the BSE-S150 pump is able to provide sufficient flow and pressure for the piping system. A manual throttling globe valve along with a properly rated pressure gauge is to be installed immediately down-stream of the discharge pump. The flow may be throttled so as to match the flow expelled by the dynamometer into the catch basin. The increase in pressure by the pump at lower flow rates will not harm the radiators downstream in the loop due to the resultant pressure drop from the throttling valve and associated piping losses, thus the radiators will be protected from being exposed to a pressure greater than their rating of 14 psi.

The discharge pump needs to be placed near or within the discharge coolant collection tank, as pumps generally can push the fluid better than they can pull the fluid. The options for considered placement of the discharge pump are detailed in TABLE II. The style of pump that will be considered will depend upon the type of control circuit that is chosen for the discharge fluid. In order to reduce cost, the pumps available for use from Versatile will be favored for implementation. Details of the control system are discussed in Section 7.0.

TABLE II: PUMP LOCATION OPTIONS [3]

Pump	Style Options	Location In System	Source
Supply Pump	Constant Speed	Next to Storage Tank	Supplier
	Centrifugal Impeller		
Discharge Pump	Variable Speed	Next to Dyno Pit	Versatile
	Constant Speed	Within Discharge Coolant Collection Tank	
	Centrifugal Impeller	Bottom of Dyno Pit	

It is recommended that the BSE-S150 centrifugal pump provided by Versatile be implemented for the discharge pump. In order to simplify the system, the pump should be operated at a constant speed in conjunction with the throttling valve to control the flow. The constant speed option is recommended, as implementing another feedback control loop to the discharge pump is quite complex when considering the non-linear operating characteristic of a centrifugal pump. The discharge pump should be mounted next to the dynamometer pit and draw the fluid from the collection tank. The recommended pump is self-priming, but a check valve should be installed on the suction line below the fluid surface, in order to prevent a loss of prime. Also, the fluid level in the collection tank should be operated at a level at least 45 cm above the suction inlet pipe [8].

The supply pump for the dynamometer is required to provide a flow of 75 GPM at a minimum pressure of 60 psi. This supply is at a constant rate and must be available whenever the dynamometer is rotating to provide coolant to the dynamometer in order to protect the seals and bearings from overheating. The supply pump will be placed next to the storage tank to provide a net positive suction head, (NPSH), to the inlet of the pump to prevent cavitation as discussed in Section 4.1. Local distributors, such as Baker Manufacturing, can supply a pump that meets the previously mentioned specifications. One such example is the Berkely model B58086MS1 7.5 hp model [9].

The quote for this pump model is $2445 with a 2 week delivery time. The performance curve for this Berkely pump model is given in Figure 6 and the specification sheet is provided in Appendix B.

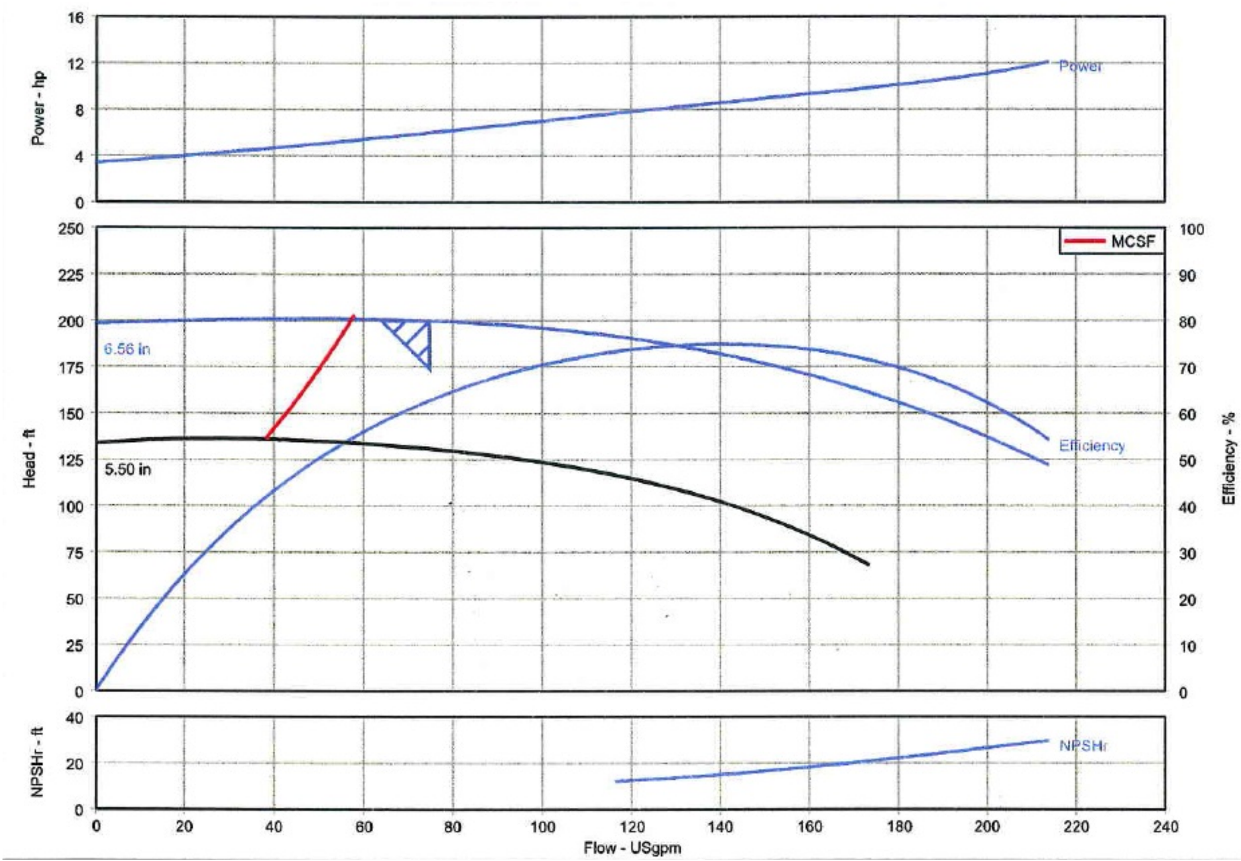


Figure 6: Pump data for Berkely model B58086MS1 7.5 hp [9]

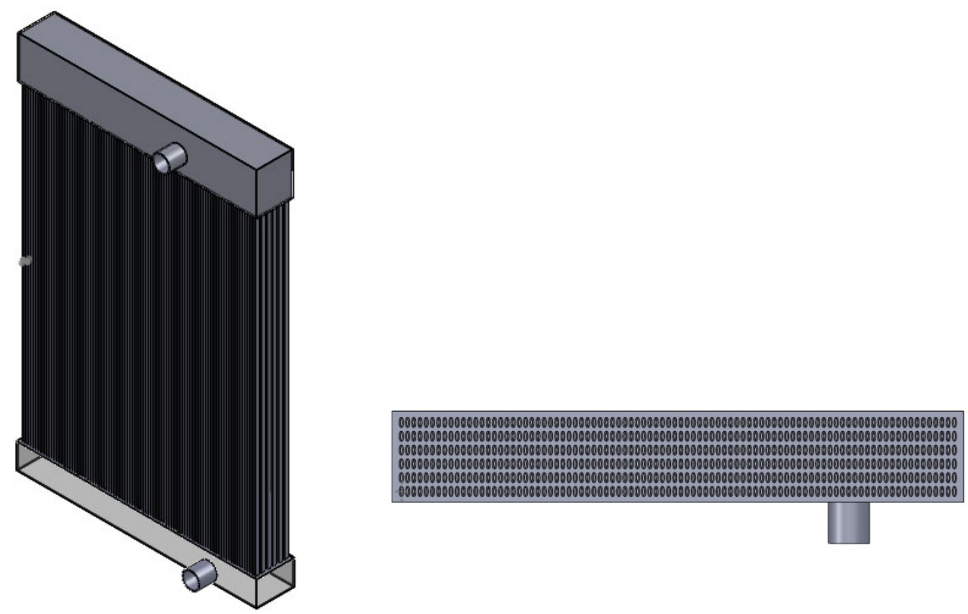
The Berkely model pump is recommended to be selected as it's performance allows for adequate flow and pressure as determined by the system characteristics. As detailed in Appendix E, the piping losses associated with the supply piping is found to be approximately 22 feet of water. Considering the piping losses, the recommended pump is still capable of providing sufficient flow.

5.0 Radiator Design

The problem constraints imposed by Buhler Versatile stipulate that the solution proposed by the team must use as many in-house parts as possible. This means that for the radiator bank the team must use radiators provided by Buhler Versatile. The number of radiators and the configuration they are to be assembled in will be discussed in this section. Four different possible configurations for the radiators were considered. A configuration utilizing two radiators per fan was found to be most practical for the application.

5.1 Heat Load Calculations and Air Flow Rate Requirements

A detailed calculation using the geometry of the available radiators is outlined in the following section. Each radiator consists of 540 thin walled tubes with elliptical cross sections. These tubes are arranged in a 6 x 90 grid pattern and are approximately 45 inches long. Details of the radiators are illustrated in Figure 7.



a) b)

Figure 7: a) CAD Model of supplied radiator b) Top view of the CAD model [3]

In the heat load calculations it was assumed the most extreme heat loading conditions to be in the summer months with an outdoor temperature of 35°C. This will ensure that even under the most extreme conditions the design will be able to handle the maximum heat load of Buhler Versatile's dynamometer, enabling Buhler Versatile the ability to test in any ambient temperature condition. For more information regarding the heat transfer properties of one radiator and the heat generated by the dynamometer refer to Appendix F.

To decide on how many radiators to use it was initially assumed that the airflow over the radiator tubes would be 10 m/s. This initial air speed was based on some sample data supplied by Buhler Versatile on their radiators. Calculations based on a value of 10 m/s gave a heat dissipation value of 201.62 kW per radiator. It was also calculated that the dynamometer operating with an inlet temperature of 25°C and an outlet temperature of approximately 77°C will produce 754.59 kW of heat. This means that an initial 4 radiators would be required to dissipate the heat generated by the dynamometer under the assumed operating conditions.

In order to size the fan necessary to provide 10 m/s air velocity the team had to look at the area between the tube bank. For the purposes of our calculations the area between the tubes in the radiator was approximated to be 1001.25 in^2 (6.953 ft^2). The required volumetric flow for each radiator is calculated in the following equations:

$$10\ {}^{m}/_{s} = 32.8\ fps \tag{1}$$

$$32.8\ fps \times 6.953\ ft^2 = 228.06\ {}^{ft^3}/_{s} \times 60\ {}^{s}/_{min} = 13{,}683.6\ cfm \tag{2}$$

By comparing the calculated airflow to the fan performance curves a motor size can be estimated. Fan performance curves provided by Buhler Versatile can be seen in Figure 8 on the next page. Unfortunately, it can be seen that due to the application of the fans to produce at 10 m/s air speed, a much higher horsepower motor is required than can be reasonably provided by small electric motors. However, if the required volumetric flow rate from the fan is kept to a minimum, the power required to drive the fans can also be reduced and therefore a smaller size of motor would be required. There are 6 radiators available for the project, so by using all 6 radiators the airflow through each radiator can be reduced. Therefore the remaining calculations are based off of using all 6 radiators.

The actual amount of heat generated by the dynamometer is unknown, so the calculations done initially were based on an inlet temperature and an exit temperature for the working fluid. This provided a heat dissipation load of 754.59 kW of heat or approximately 1015 hp of heat. This was good to get an initial guess of how many radiators to use based on inlet and outlet temperatures, however for required heat dissipation an assumed value of 700 horsepower is more reasonable. A value of 700 horsepower corresponds to 100% of the dynamometer load being converted to heat. This is obviously not possible, but is part of the safety factor. Since actual data is unknown, and all of the calculations are based on assumptions, the actual safety factor value is unknown. The heat dissipation required per radiator is calculated in the following equation:

$$Max\ Capacity\ of\ Dyno = 700\ HP = 521.99\ kW \quad (3)$$

$$Heat\ Diss. per\ radiator = \frac{521.99}{6} = 86.998\ kW \quad (4)$$

Referring to the radiator heat load calculations in Appendix F, a value of 87 kW per radiator corresponds to an air velocity of 2.5 m/s (8.2021 fps) through the radiator in order to cool the fluid from 77°C to 25°C. Using the same relations shown in Equation 2, an air velocity of 8.2021 fps give a volumetric flow rate of 3421.75 cfm per radiator.

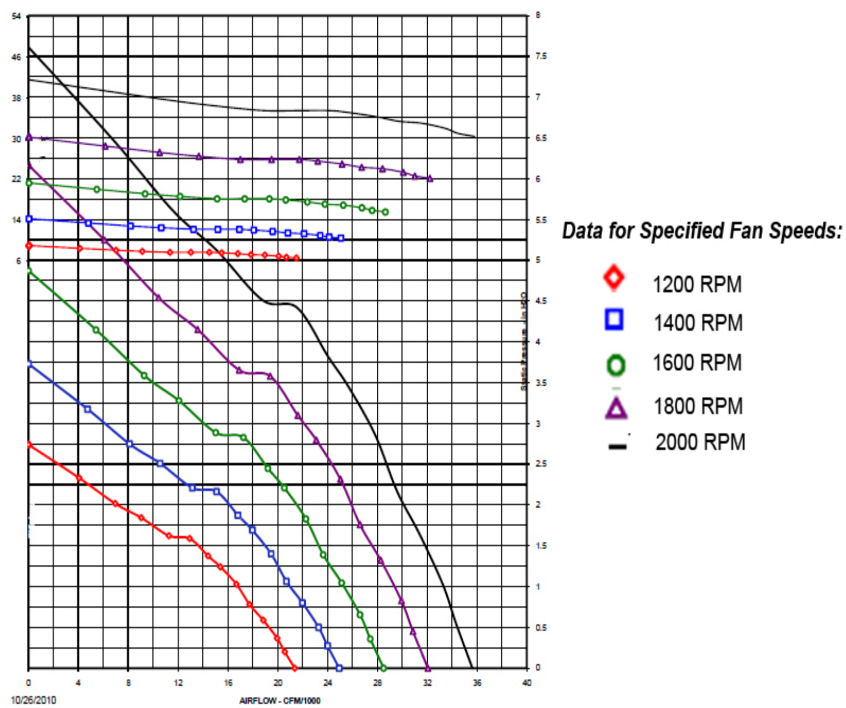
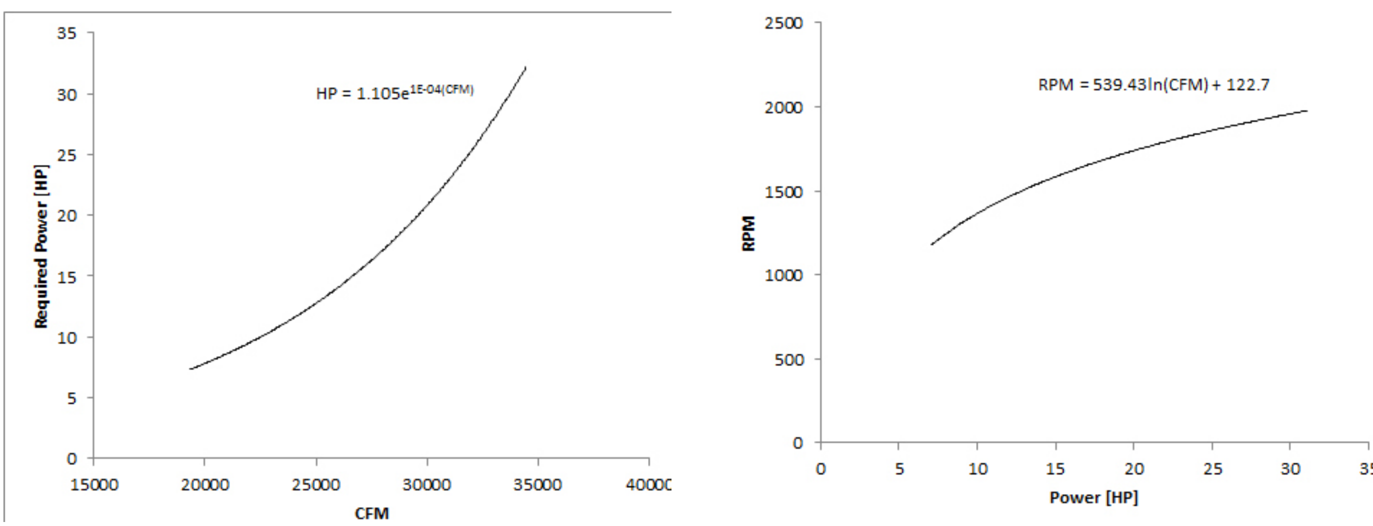


Figure 8: Fan performance curves [1]

A better picture of the fan performance curves is provided in Appendix F. It is easy to see that using one fan for two radiators corresponds to a required volumetric flow rate of 6843.5 cfm. The relationship used to calculate the required fan power is shown in Figure 9a. The power required to drive the fans for each pair of radiators is calculated below in Equation 5.

$$y = 1.0786e^{(1E-04)x} = 1.0786e^{(1E-04)(6843.5)} = 2.138\ HP \quad (5)$$

The cooling tower design utilizes three separate fans in order to provide the cooling tower airflow. In order to provide sufficient power for running the fans, three times the amount of power calculated in Equation 5 is required. The corresponding power required to drive the fans is 6.4 HP. At this point it is possible to choose a suitable electric motor. A 7.5 horsepower 575V 3-phase motor from Toshiba Industrial is utilized in this design to provide fan power. The part number for the motor is BY756FLT2OSW [10]. Specifications for the motor can be found in Appendix G. In addition to the required power to drive the fans, it was also necessary to determine the fan speed that corresponds with the amount of power and volumetric flow rate used. Figure 9 shows the relationship between fan speed and horsepower.



a) b)

Figure 9: a)CFM vs. Required power. b) HP vs. RPM of the cooling fan [3]

Substituting a required CFM of 6843.5 into the equation shown in Figure 9 we get a value of 361 RPM. To keep driveline gear reductions simplified the required RPM is rounded to 400 RPM. It is important to keep in mind that the calculations for the required air flow and heat dissipation is based on the radiators being operated at an ambient temperature of 35°C.

5.2 Cooling Bank Configuration Options

Now that six radiators will be used for the design, the configuration for the radiators must be decided. While choosing the configuration there are a few things consider. The first thing is the number of fans required for the configuration. The higher the number of fans, the more complicated the drive and control system will be. It would be preferable to keep the number of fans to either one or two, to limit the number of drive motors. Secondly, it would be preferable for the entire cooling bank to be as compact as possible. The cooling bank will be located in an alley outside the dynamometer bay where there is frequent machinery traffic, so it is desirable to use as little space as possible. It would also be preferable to use as little material as possible to keep the size and the cost of the cooling bank down. Finally, the complexity of the frame structure will be considered.

Research has indicated that there are four main configurations for mechanical draft fan coolers that we have considered. These four main configurations include a single-radiator configuration, a double-radiator configuration, a cell type configuration, and a roof type V-bank configuration [11]. These configurations will be discussed in the following Section 5.2.1.

5.2.1 Single-Radiator Configuration

The single-radiator concept consists of a single radiator in line with a fan. The concept is illustrated in Figure 10. The radiator can be positioned either horizontally or vertically with the fan either pushing (forced draft) or pulling (induced draft) the air through the radiator.

This design is the simplest design when considering the heat transfer calculations. Each radiator receives a specific amount of air flow determined by its corresponding fan. The complexity for this configuration lies in the fan drive system. The design requires six radiators, so there will be a need to drive six individual fans. In order to keep the number of fan drive motors down to one, the drive linkages would need to be intricate in order to run all six fans from one drive motor. The drive motor size will also increase for each fan that is added to the system, therefore this design configuration is not feasable.

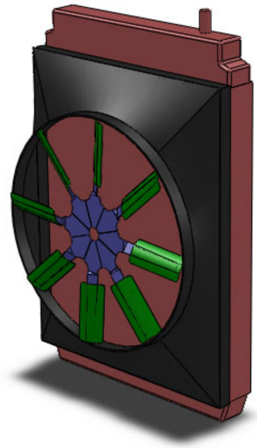


Figure 10: Single-radiator configuration [3]

5.2.2 Double-Radiator Configuration

The double-radiator configuration basically doubles the single-radiator configuration. It is illustrated in Figure 11. The idea behind this configuration is that two radiators can be used per fan, thus cutting down on the complexity of the fan drive system. Using six radiators with this design would mean that only three fans are required. However with the extra radiator in the air flow, there is an increase in the static pressure drop created by the radiators. This increase in static pressure drop must be matched by the fan, which in turn requires more power. It is also known that a fan operating at a higher static pressure drop will produce more noise. This is another undesirable effect of the double-radiator configuration.

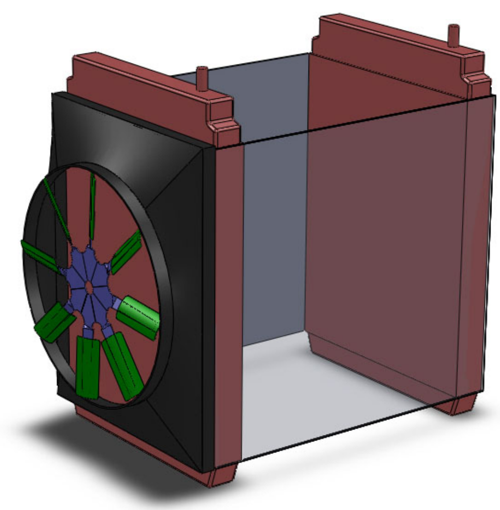


Figure 11: Double-radiator configuration [3]

5.2.3 Cell Type Configuration

The cell type radiator configuration utilizes several radiators for a single fan. This configuration is appealing because of the simple fan drive system that is required. Figure 12 illustrates visually what the cell type configuration looks like.

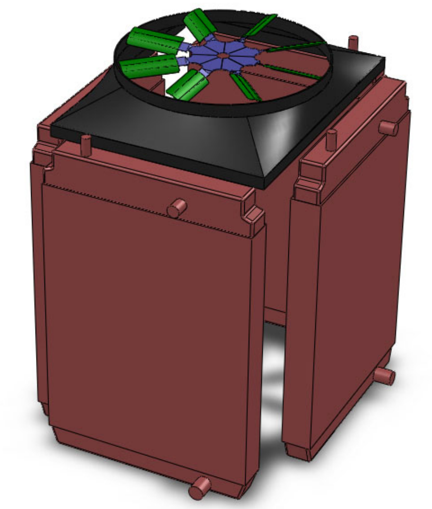


Figure 12: Cell type configuration [3]

As can be seen in Figure 12, the cell type configuration is most suitable where only four radiators are required. This would be a more suitable configuration if the design of the radiator could be modified. The radiator designs supplied by Buhler Versatile are pre-determined and cannot be modified, so the cell type configuration seems unfeasible. Also, in order for one fan to provide sufficient air flow for four radiators, a very large amount of power would be required.

5.2.4 Roof Type V-Bank

The roof type V-bank configuration is illustrated in Figure 13. This configuration has been aptly named because of the 'V' configuration of the radiators. This design works off the same principle as the cell type concept, but with only two radiators per unit. This configuration caters towards the idea of expansion in the future as the bank can be as many consecutive V's as required.

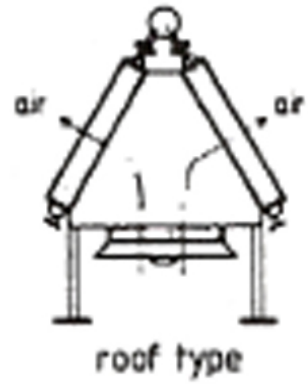


Figure 13: Roof type configuration [11]

The design proposed in this report takes the configuration illustrated in Figure 13 and rotates it 180 degrees so the fans are placed on top of the radiators. Figure 14 shows the alternative configuration.

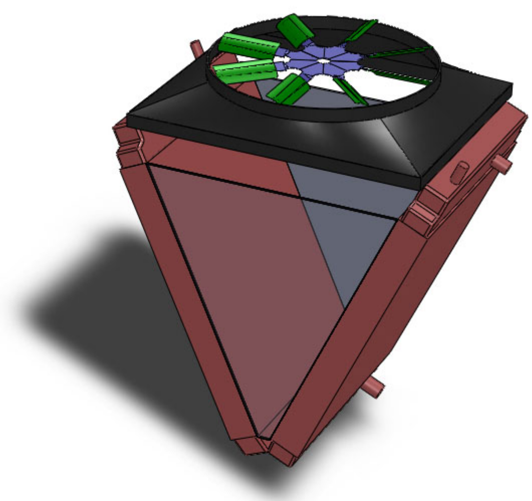


Figure 14: Alternative roof type configuration [3]

5.3 Design Selection

Initially, there were a few ideas generated for possible radiator configurations. In order to narrow down the initial concepts to a manageable number worth pursuing, a screening matrix was used. The results of the screening matrix are tabulated in Table III. Characteristics that are beneficial are denoted by + sign and negative denoted by – signs. All positive and negative characteristics are summed and the total scores compared. The concept with the highest score is one to continue to research. The scoring matrix ranked the concepts as follows:

1. Roof type V configuration
2. Cell type configuration
3. Double-radiator configuration
4. Single-radiator configuration

TABLE III: CONCEPT SCREENING MATRIX [3]

	Concepts			
Selection Criteria	**Single Rad**	**Double-Rad**	**Cell type**	**Roof-type V**
Use of Space	-	0	+	+
Simplicity	0	0	0	0
Aesthetics	-	+	+	+
# of Fans	-	0	0	+
# of Controllers	-	-	+	+
Frame complexity	-	-	-	0
Sum +'s	0	1	3	4
Sum -'s	5	2	1	0
Sum 0's	1	3	2	2
Net Score	5	-1	2	4
Rank	4	3	2	1
Continue?	**No**	**No**	**Yes**	**Yes**

Based on the screening matrix, the two configurations worth pursuing are the cell type configuration and the two-radiator V configuration. However, since the number of radiators needed is six, the cell-type configuration is eliminated. This leaves only one feasible configuration the V-Bank configuration.

5.4 Cooling Bank Design

In Section 5.2 the process used to choose a cooling tower design was outlined. In this section the design of the cooling tower frame will be discussed.

A major benefit of the roof-type radiator configuration is the possibility of expanding in multiples of 2 depending on the number of radiators required. In Section 5.1, which outlined the heat loading and required airflow per radiator, it was determined that six radiators are required to dissipate the amount of heat generated by the dynamometer. Figure 15 illustrates one type of cooling tower configuration which incorporates six radiators.

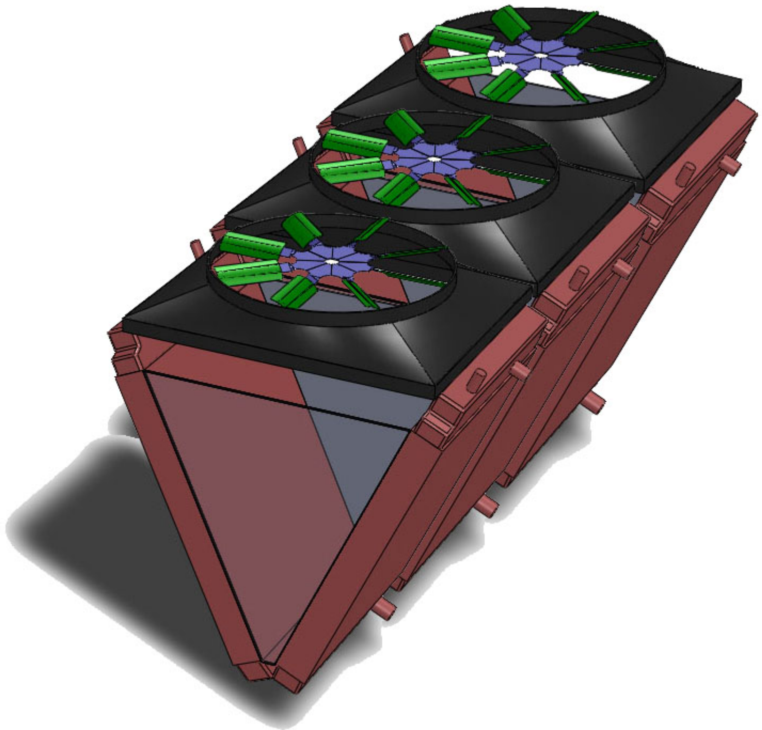


Figure 15: Basic Cooling Bank Configuration [3]

The radiators are to be connected in series in order to achieve maximum cooling of the fluid. This means that the output of the first radiator will be connected to the input of the second, and so on until finally exiting the sixth radiator.

In order to achieve this configuration a frame structure must be developed to support the radiators, fans and fan shrouds. When designing the support frame, four different criteria were considered. These four criteria were:

- Manufacturability;
- Serviceability; and
- Material availability.

Loading performance of the structure is beyond the scope of this project due to time constraints and as such, no loading analysis was performed on the structural components. However, the recommended design should utilize materials that meet the strength requirements to support the radiators. Figure 16 shows the support frame finished product.

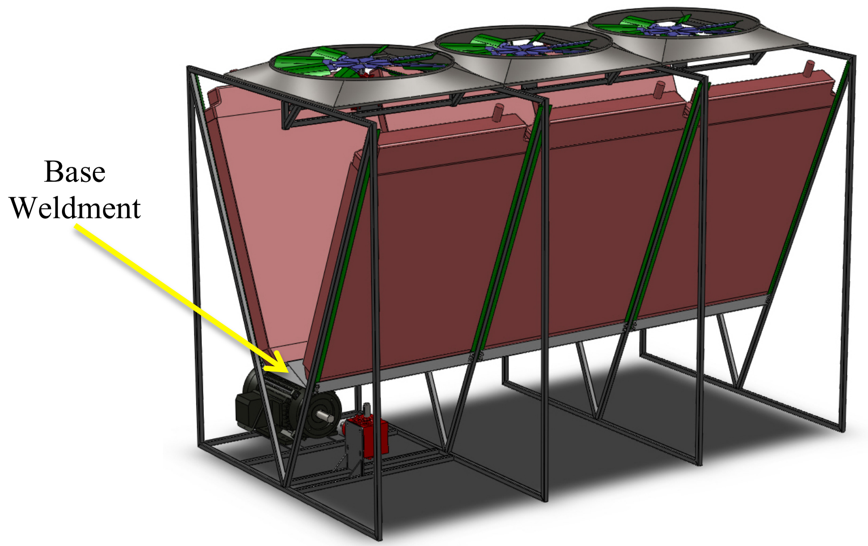


Figure 16: Cooling Tower Finished Product [3]

The support frame is based around a sheet metal weldment for the bottom support for the radiators. The weldment is where the geometry of the structure is based. It can be seen in Figure 17.

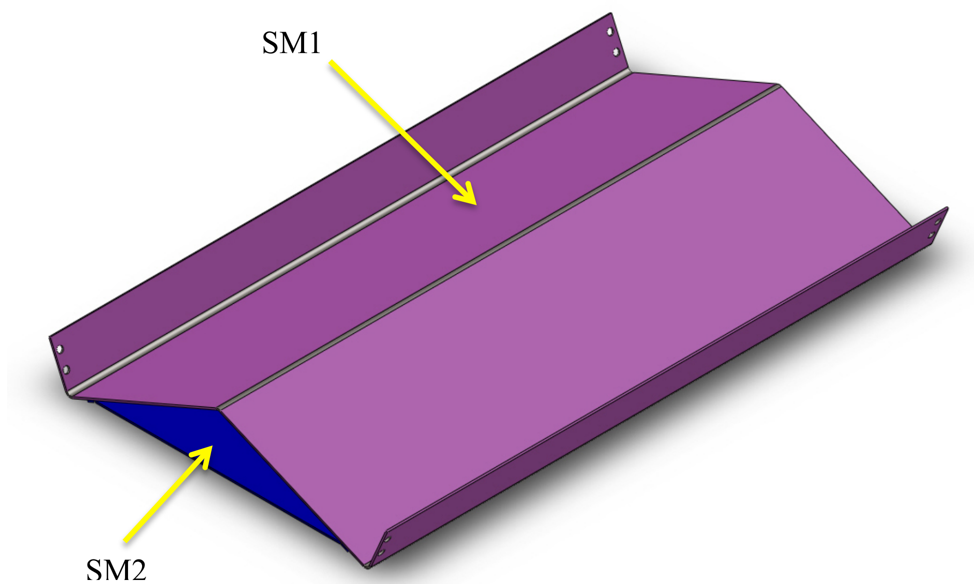


Figure 17: Base Weldment [3]

The part shaded in purple (SM1) is one sheet metal part, and the blue shaded part (SM2) is another sheet metal part. The two parts are welded together. Details of where the welds are located will be discussed later in this section. Both sheet metal parts are constructed from 12 gauge steel.

Dimensions outlining SM1 are illustrated in Appendix H. Eleven holes are drilled with size W drill bit. The part is to be bent from 12 gauge flat stock according to the bend radii and angles indicated on the drawing for the base weldment in Appendix H. Dimensions and bending specifications for SM2 are outlined in Appendix H. Figure 18 illustrates how part SM1 is welded to part SM2.

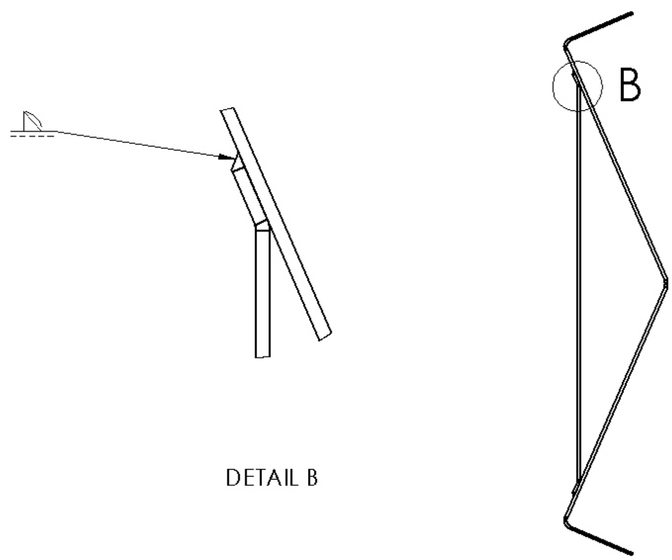


Figure 18: Base Weldment Weld Location [3]

Upward supports are created using 1 in. x 1 in. angle iron. There are six left-hand and six right-hand angle iron parts to create all of the upward supports. The left-hand and right-hand parts are shown in Appendix H. The upward support angle iron pieces are to be fastened to the base weldment using 3/8 in. grade 5 hardware. For each hole, a single 3/8 in. x 7/8 in. UNC hex head bolt is used along with a type B regular washer, a spring lock washer and hex nut. This hardware is assembled in a manner illustrated in drawing HA1 available in Appendix H. All hardware is to be torqued to 30 ft-lb as per SAE standards [12].

In order to raise the base weldment off the ground four support frames were designed. The support frames are to be constructed of 1 in. x 1 in. square tubing. More detailed drawings can be seen Appendix H.

Finally in order to attach the upward supports to the support fames, the angle iron supports attached to the four corners of the base weldments are to be welded to the angled pieces of the end support. Figure 19 illustrates the relation between the angle iron supports and the end support. The frame structure end product is illustrated in Figure 20.

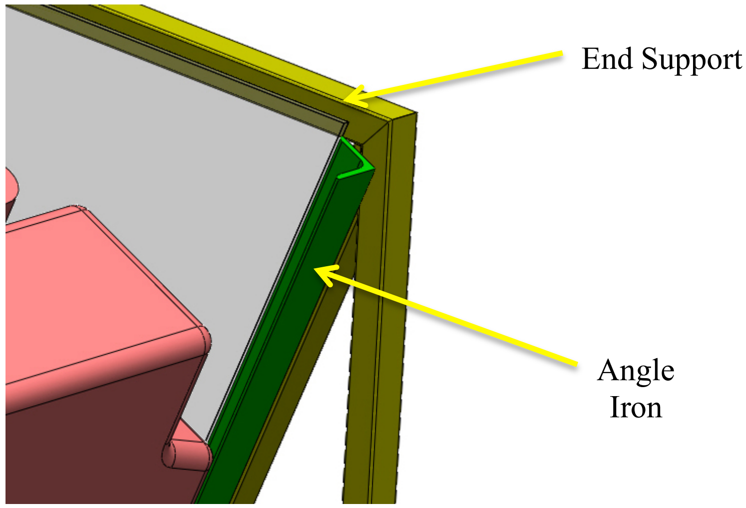


Figure 19: Support Frame Attachment [3]

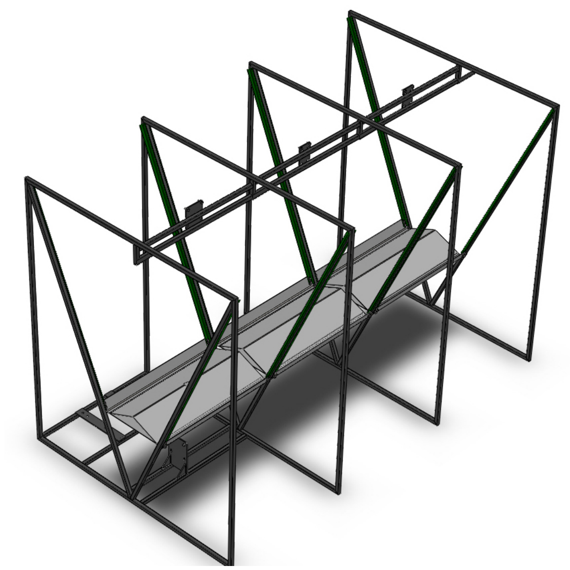


Figure 20: Final assembly of supporting frame structure for the radiators [3]

In order to drive each fan, a drive system needed to be designed. A series of gearboxes was utilized to transfer the power from the motor to each fan. It was determined in Section 5.1, which outlined the heat loading and required airflow per radiator, that each fan was required to operate at 400 RPM. The motor selected for this cooling tower operates at a speed of 1200 RPM, so a 3:1 speed reduction in required. Two 90-degree bevel gearboxes and two 3-way bevel gearboxes from Powerjacks Ltd. are used for this design. The driveline design is shown in Figure 21.

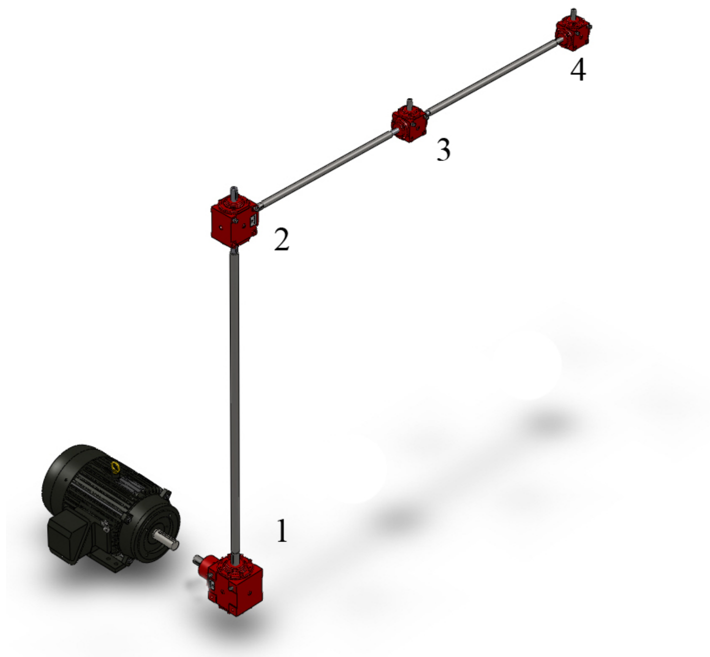


Figure 21: Gearbox and driveline design [3]

The first 90-degree bevel gearbox closest to the motor is a 3:1 speed reduction. The remainder of the gearboxes have 1:1 ratios. The horsepower ratings of each gearbox are different because the power transmission decreases after each fan. Gearbox 1 is rated at 7.75 HP, gearbox 2 is rated at 10.5 HP, gearbox 3 is rated at 4.2 HP and gearbox 4 is also rated at 4.2 HP. It is recommended that the driveshaft from the motor to gearbox 1 be rigid, using sliding couplers due to the high rotational speed. The remainder of the driveshaft's should use universal joints to join to each gearbox shaft.

5.4.1 Structure Bill of Materials

A bill of materials (BOM) for the cooling tower structure is outlined in Table IV and Table V outlines the required fasteners for the support structure.

TABLE IV: RAW MATERIALS BOM [3]

Raw Material		
12 Gauge Steel Sheet:	19.43	sq. ft
	12.97	sq. ft
1in. X 1 in. Angle Iron:	58	ft
1in. X 1 in. Square Tube:	87.08	ft

TABLE V: FASTENERS BOM [3]

Fasteners	
3/8" x 7/8" 16 Gr 5 Hex Bolt:	24
Flat Washer 13/32 ID X 1 OD:	24
Washer Lock Rite 16.5X10.40X2.5MM:	24
3/8" NC16 Hex Nut:	24

6.0 Control Systems

In order to cut down costs associated with the operation of the system, there will be two control systems included in this design. The first control is the fan control system. This will vary the speed of the cooling fan on the radiators based on applied heat loads. The second control system will be for synchronizing the two pumps in the system. In this section a control system consisting of a temperature sensor and a variable frequency drive will be discussed for controlling the cooling tower fans. A flow control will also be discussed for synchronizing the two pumps in the system.

6.1 Fan Controls

In order to cut down energy costs for operating the cooling system the design will be implementing a control system to control the fan speeds in the cooling bank. The fans will be controlled based on the temperature exiting the cooling bank. The method the design will employing is a three-phase Variable Frequency Drive (VFD) with a temperature sensor input. A VFD controls the speed of a three-phase motor by changing the frequency of the motor's supply frequency. The specific VFD that will be implemented is unknown at this time and will be determined when more specific details of fan performance are acquired. A basic outline of the control scheme is illustrated in Figure 22.

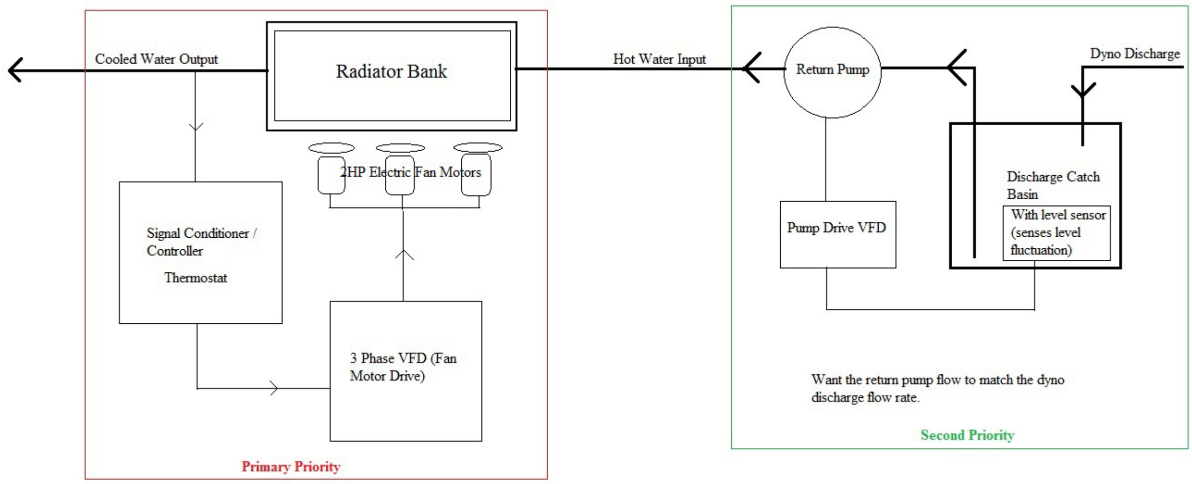


Figure 22: Control System Diagram [3]

The feedback loop from the cold water output of the radiator bank needs to have a temperature sensor and some kind of signal conditioner in order for the control system to operate properly.

6.2 Pump Controls

In order to ensure that the supply pump and the return pump are operating at the same flow rate the design requires that one of the pumps be controlled. The coolant return pump is best suited for this since the supply pump should be free to supply any necessary flow required for the dynamometer to produce testing loading conditions. The flow rate used is dependent on the specific test plan Buhler Versatile is performing. There are four different ways of controlling the coolant return pump. They are as follows:

- Variable speed pump
- Manual control valve
- Automatic control valve and
- Level control

6.2.1 Variable Speed Pump

The most desirable way to control the return pump would be to use a variable speed pump drive. With this method a level sensor with a potentiometer could provide feedback to the pump drive in order to determine if the pump flow should be increased or decreased. This would ensure automatic balancing of the coolant flows in and out of the dynamometer. However the cost associated with the pump drive controller would be a major disadvantage to implementing this type of system.

6.2.2 Manual Control Valve

A manual control valve is a design feature that could be employed in order to control the flow out from the return pump. The manual control valve would create increased resistance in the return pipe line. The increased resistance manipulates the operating point on the pump curve, resulting in less flow rate. The flow rate could be estimated using a pressure gauge on the high pressure side of the valve, giving some reference to the operating point of the pump. It is simple, but requires user input, which is undesirable. Low cost is a benefit to this concept.

6.2.3 Automatic Control Valve

The automatic control valve uses the same control scheme as the manual control valve. The difference is that instead of manually adjusting the valve to match the flow rates of both pumps, a controller would manipulate an electric valve. A PID controller has been used in similar applications to control tank levels, so the concept could be employed in Buhler Versatile's cooling tower application [13].

6.2.4 Level Control

The final approach to controlling the coolant return flow is to use a simple on-off level switch in the coolant discharge catch basin. This would be simple to implement and would require little user interaction. A major negative aspect is the possibility of reduced pump motor life due to constant starting and stopping of the pump.

6.2.5 Selection of the Pump Control Concept

Each pump control concept was put into a scoring matrix in order to determine which idea carried the most weight with respect to the particular application. The scoring matrix is shown in Table VI.

TABLE VI: PUMP CONTROL CONCEPT SCORING MATRIX [3]

		Concepts							
		Variable Speed Pump		Manual Control Valve		Automatic Control Valve		Level Control	
Selection Criteria	**Weight**	**Rating**	**W.S.**	**Rating**	**W.S.**	**Rating**	**W.S.**	**Rating**	**W.S.**
Simplicity	15%	2	0.3	5	0.75	2	0.3	4	0.6
Component Life	20%	5	1	3	0.6	4	0.8	2	0.4
Cost	20%	1	0.2	5	1	2	0.4	4	0.8
User Interaction	22%	5	1.1	1	0.22	5	1.1	4	0.88
Accuracy	23%	5	1.15	2	0.46	4	0.92	3	0.69
	Total Score	3.75		3.03		3.52		3.37	
	Rank	1		3		2		2	
	Continue?	**Yes**		**Yes**		**Yes**		**Yes**	

It can be seen that the variable speed pump received the highest ranking based on the scoring. However due to time constraints, the simplest concept (the manual control valve) was chosen for the system. This decision was a compromise agreed on by all team members.

7.0 Control System Design

In order to vary the speed of the fans in the cooling tower the use of a variable frequency drive (VFD) has been employed. The motor sourced in Section 5.1 requires 8 amps of current at full load in order to maintain 1200 RPM. The current requirement for the drive motor is the most important specification to consider when choosing the VFD. The variable frequency drive recommended for the cooling tower is an Alan Bradley VFD. It is rated for 7.5 horsepower and 9.9 amps. The catalogue number for the VFD is 22D-E9P9N104. An approximate cost for the VFD is $1500.

For the control system aspect of the project we have consulted with BSD Solutions [14] for some input and direction as control systems are not our group's area of expertise. An initial concept idea we received is illustrated in Figure 23. It utilizes three sensors and a Johnson A350P thermostat control. The Johnson thermostat varies an output signal proportional to an input temperature signal. This output signal is then sent to the VFD. The VFD then varies the fan motor output frequency based on the signal level received from the thermostat.

The control system outlined in Figure 23 responds to three different inputs. The first input that activates the fan drive system is the control switch relay (CSR). The CSR is an inductive sensor connected to the electric supply line for the sump return pump. The purpose of the sensor is to detect when the pump is activated and close the circuit enabling the VFD.

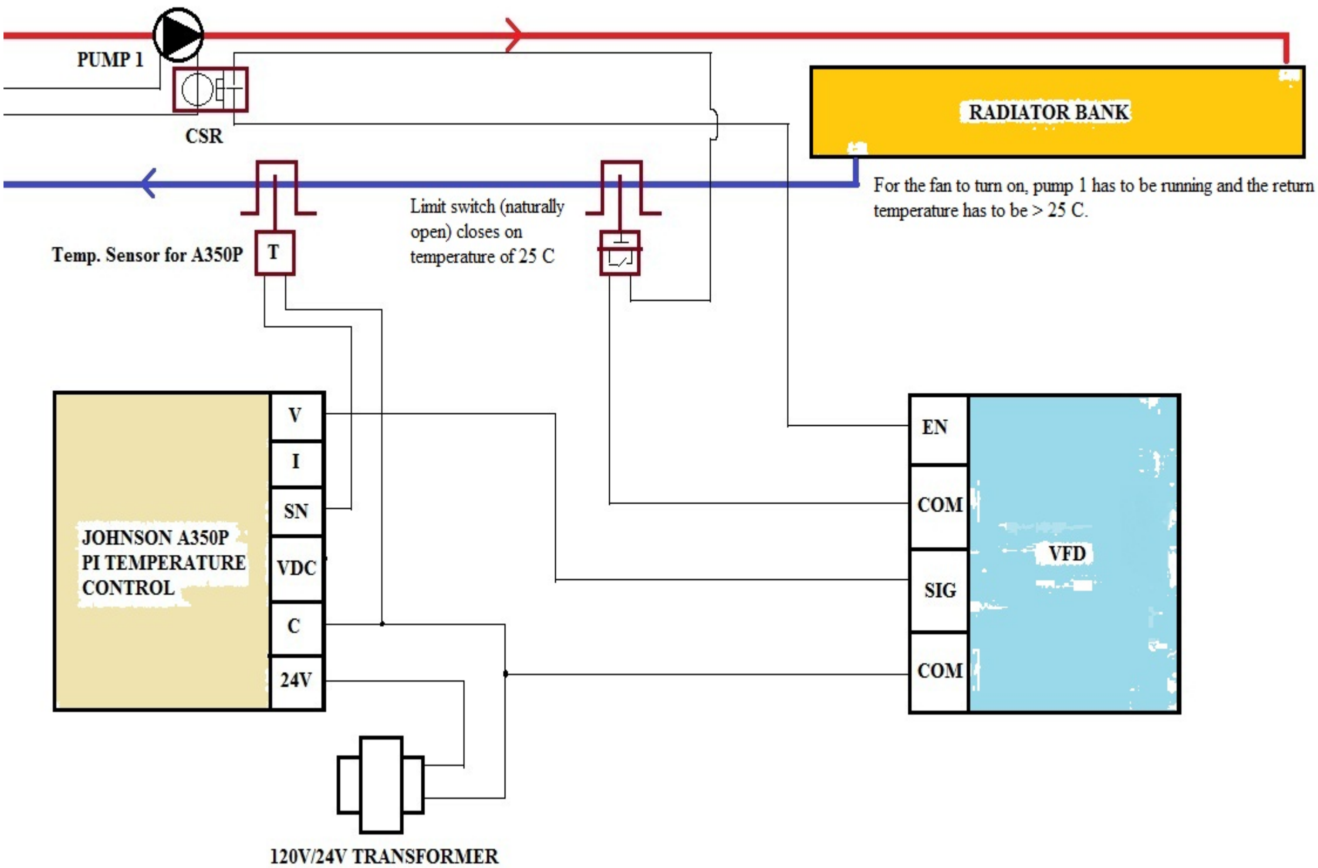


Figure 23: Control system schematic [3]

The CSR is connected in series with another limit switch that senses a minimum temperature of the cooling fluid temperature when exiting the cooling tower. The temperature sensing limit switch is naturally open and closes when a pre-defined temperature is reached. In other words, when the pumping system is activated the VFD is not fully activated until the cooling temperature reaches the set minimum. For this cooling tower a minimum temperature has been set to 25°C.

The Johnson thermostat is constantly reading the temperature, however the VFD is not enabled until the boundary conditions have been met. Most VFDs accept an input signal from 4 – 20 mA. The Johnson thermostat can be calibrated to output voltage in the same range. A manual for the Johnson thermostat is available in Appendix I.

8.0 Cost Analysis

The only costs associated with this portion of the design are the fan drive system and the material cost for the structure since Buhler Versatile supplies the other materials and the radiators. It is unknown what the cost for raw materials and fasteners is for Buhler Versatile, so only a quantity can be provided. The costs of the gearboxes are unknown; due to time constraints a response from distributors was unobtainable. Table VII summarizes the costs that have been obtained for this project.

TABLE VII: LIST OF OBTAINED VALUES OF VARIOUS DESIGN COMPONENTS [3]

System	Cost ($ US)
Toshiba 7.5hp electric motor for the fans6937	$2557
Allen Bradley VFD for 7.5hp electric motor	$1485
Berkley Centrifugal pump for the coolant supply	$2445
Copper Pipe Type M 12 ft length (3 lengths)	$450
Total	$6937

The operating cost for the electric motors used to operate the recirculation system and the cooling fans were calculated to determine the annul operating cost. For example, when running 65 tests per year, at 8 hours per test, it is calculated that 3700 kWh will be consumed per year by a 7.5 hp electric motor. These values are calculated assuming that the motor runs at full load for the duration of the testing time. Assuming a cost of electricity of 3.05₵ / kWh, an annual cost of $111.83 is calculated for both the fans and the supply pump. The smaller return pump will have an annual electoral cost of $21.89. Table VIII provides annual costs for running the new cooling system at maximum loading conditions.

TABLE VIII: NEW SYSTEM ANNUAL COSTS AT MAXIMUM LOADING [3]

System	Annual Cost
7.5 hp Fan Motor Electrical Costs	$111.83
7.5 hp Supply Pump Electrical Cost	$111.83
1.5 hp Return Pump Electrical Cost	$21.89
Total Annual Cost	$245.55

A cost analysis has been performed on the old method of passing city water through the dynamometer, then dissipating it to the sewer. Rates from the City of Winnipeg's Water and Waste Department web site were used in this analysis and can be seen in Table IX [16].

TABLE IX: WATER RATE FROM THE CITY OF WINNIPEG WEBSITE [16]

Per cubic metre per quarter	**2009**	**2010**
(Effective June 1, 2009, rates started being billed per cubic metre)	**rate**	**rate**
0 - 272	$1.25	**$1.29**
272.1 - 2,720	$1.08	**$1.12**
over 2,720	$0.91	**$0.95**

Buhler Versatile estimates that the dynamometer runs for approximately 520 hours per year. While running a test at 360 PTO-HP the required flow rate is 45 GPM [17]. A single 8-hour test running at 45 GPM will cost Buhler Versatile approximately $105.48 for water and $156.17 for sewer, giving a total cost per test of $261.65. Running the dynamometer for 520 hours per year corresponds to 65 tests per year. The total cost per year is then $5,557 for water and $10,151.11 for sewer, giving a total cost of $15,708.62 per year.

A full payback period analysis is not covered in this report since there are many costs still unknown. However, by comparing the annual costs of both systems, it is easy to see that the proposed closed loop cooling system has an annual cost savings of $15,463.07. Sample calculations are given in Appendix J for the old and new system cost analysis.

9.0 Competitors Products

Due to the unique nature of the design problem, only one competitor product was found. This product is made by the dynamometer manufacturer Taylor and is specifically produced to operate with their dynamometer products. This product is the Taylor Water Recirculation System, illustrated in Figure 24.

Figure 24: Taylor cooling system [18]

This system consists of many similar components to the proposed overall design concept using six radiators, but there are some extras that the reposed design concept does not include. The Taylor recirculation system uses an evaporative cooling tower, chiller, heat exchanger or radiators to dissipate the heat generated by the dynamometer.

Two basic recirculation system layouts from Taylor are depicted in Appendix K. The systems are much more complex than the proposed design for this project, and as such, are more effective in the specialized areas in which they are employed. Cost of such systems are unknown as Buhler Versatile would be required to consult with Taylor in order to obtain customized designs and pricing.

10.0 Conclusion

The following report outlined the steps taken to develop a closed loop cooling system that will dissipate the heat from the test dynamometer at Buhler Versatile, which will allow the dynamometer to operate at maximum loading conditions. This report also provides details of various components required for a closed loop cooling system, as well as all the supporting calculations and production drawings required for implementation of the design. The primary areas covered in this report include: coolant selection, pumping requirements and selection, radiator design and control system analysis. Each section outlines various alternatives and offers calculations and other supporting details for proof of concept.

The results of the analysis show that a six radiator cooling tower utilizing a 50/50 glycol water mixture is recommended to be employed to meet the necessary cooling requirements of the new dynamometer. The radiators, arranged in a V-Bank configuration, will offer ease of access as well as limit the space required. In addition, the V-Bank configuration allows two radiators to be cooled by one fan. The recommended supply pump is the Berkely B58086MS1

7.5 hp pump and the return pump is recommended to be Monarch BSE-S150. In addition, it is recommended to use PVC ASTM D-1785 schedule 40 pipe for all piping inside the building and transition to Type M copper pipe for outside use.

Due to time constraints a full payback period analysis was not performed. However, by comparing the annual costs of both systems, it can be seen that the proposed closed loop cooling system has an annual cost savings of $15,463.07. The proposed closed loop cooling system is recommended to be implemented at Buhler Versatile.

11.0 References

[1] E. Lambert. (private communication), Sept. 17, 2010.

[2] Taylor Dynamometer Incorporated, "*DL 700 Engine Dynamometer Operation & Maintenance Manual*." Milwaukee, WI: Taylor Dynamometer Incorporated, 2010.

[3] A. Bell, Team 5: Big Roy. *Engineering Design Class A01, Fall 2010.*

[4] J. Lima, G. Otterman. (1989, May). *Manual on selection and use of Engine Coolants and Cooling System Chemicals*. (4th Edition). [Online]. Available: http://books.google.ca [Oct. 25, 2010].

[5] Canadian Commission on Building and Fire Codes, National Building Code of Canada. 2005.

[6] The Engineering Toolbox. (2010, November), *PVC Pipes – Support Spacing*. [Online]. Available: http://www.engineeringtoolbox.com/support-space-pvc-pipes-d_790.html

[7] Monarch Industries. *BSE-S Series Spec Sheet*. Available: http://www.monarchpumpproducts.com/v4/media/pdf/SpecSheets/995679_BSE-S Series.pdf [Oct. 11, 2010].

[8] J. Gülich. (2010). *Centrifugal Pumps.* (2nd edition). [Online]. Available: http://books.google.ca/books [Nov. 17, 2010].

[9] B. Klassen. (private communication), Nov. 23, 2010

[10] Toshiba International Corporation - Industrial Division. (2010, November), *Motors : Low Voltage General Purpose*. [Online]. http://www.toshiba.com/ind/product_display.jsp?id1=6&id2=216&id3=223&id4=231

[11] P. Paikert, "*Heat Exchanger Manual."* New York; NY: Begell House Incorperated, 1998.

[12] Engineer's Handbook. (2010, Nov.). *Steel Bolt Torque Specifications Table*. [Online]. http://www.engineershandbook.com/Tables/torque.htm

[13] Muhd Asran Bin Abdullah, "Water Level in Tank using Level Sensor and PID Controller," B.A. Thesis, Dept. Electrical, Malaysia, Pahang, 2008.

[14] BSD Solutions, private communication, Oct. 22, 2010.

[15] PLC Hardware. (2010, Nov.). *Rockwell Automation: Drives: Component Drives: PowerFlex 40P Standard: 22D-E9P9N104*. [Online]. http://www.plchardware.com/Products/81/5398649/5398653/RA-22D-E9P9N104.aspx [Nov. 29, 2010]

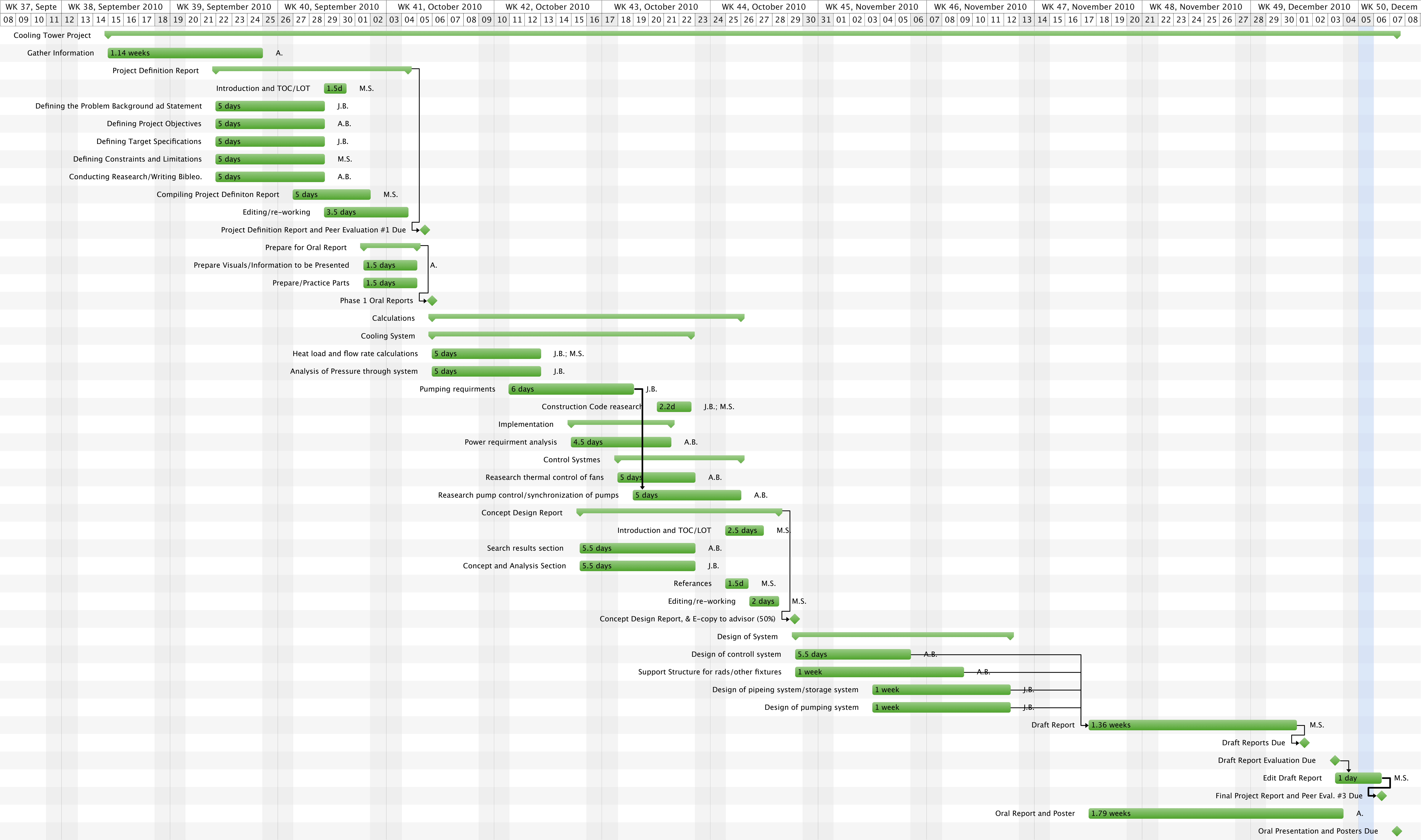
[16] City of Winnipeg. (2010, February), Winnipeg.ca (UD) : *Water and Waste : Billing : Water and Sewer Rates and Charges*. [Online]. http://www.winnipeg.ca/waterandwaste/billing/rates.stm

[17] A. Minaker. (private communication), Nov. 5, 2010.

[18] Taylor Dynamometer. (2010, October). “Water_Recirculation.jpg,” in *Water Recirculation Systems | Test Cell Water Recirculation Systems | Test Cell Design & Support Systems | Taylor Dynamometer* [Online]. Available: http://www.taylordyno.com/catalog/dyno-accessories/engine-dyno-accessories/water-recirculation-systems [October 25, 2010].

Appendix A

Project Gantt Chart



WK 37, Septe
WK 38, September 2010
WK 39, September 2010
WK 40, September 2010
WK 41, October 2010
WK 42, October 2010
WK 43, October 2010
WK 44, October 2010
WK 45, November 2010
WK 46, November 2010
WK 47, November 2010
WK 48, November 2010
WK 49, December 2010
WK 50, Decem
Cooling Tower Project
Gather Information 1.14 weeks A.
Project Definition Report
Introduction and TOC/LOT 1.5d M.S.
Defining the Problem Background ad Statement 5 days J.B.
Defining Project Objectives 5 days A.B.
Defining Target Specifications 5 days J.B.
Defining Constraints and Limitations 5 days M.S.
Conducting Reasearch/Writing Bibleo. 5 days A.B.
Compiling Project Definiton Report 5 days M.S.
Editing/re-working 3.5 days
Project Definition Report and Peer Evaluation #1 Due
Prepare for Oral Report
Prepare Visuals/Information to be Presented 1.5 days A.
Prepare/Practice Parts 1.5 days
Phase 1 Oral Reports
Calculations
Cooling System
Heat load and flow rate calculations 5 days J.B.; M.S.
Analysis of Pressure through system 5 days J.B.
Pumping requirments 6 days J.B.
Construction Code reasearch 2.2d J.B.; M.S.
Implementation
Power requirment analysis 4.5 days A.B.
Control Systmes
Reasearch thermal control of fans 5 days A.B.
Reasearch pump control/synchronization of pumps 5 days A.B.
Concept Design Report
Introduction and TOC/LOT 2.5 days M.S.
Search results section 5.5 days A.B.
Concept and Analysis Section 5.5 days J.B.
Referances 1.5d M.S.
Editing/re-working 2 days M.S.
Concept Design Report, & E-copy to advisor (50%)
Design of System
Design of controll system 5.5 days A.B.
Support Structure for rads/other fixtures 1 week A.B.
Design of pipeing system/storage system 1 week J.B.
Design of pumping system 1 week J.B.
Draft Report 1.36 weeks M.S.
Draft Reports Due
Draft Report Evaluation Due
Edit Draft Report 1 day M.S.
Final Project Report and Peer Eval. #3 Due
Oral Report and Poster 1.79 weeks A.
Oral Presentation and Posters Due

Appendix B

Supply Pump Specifications

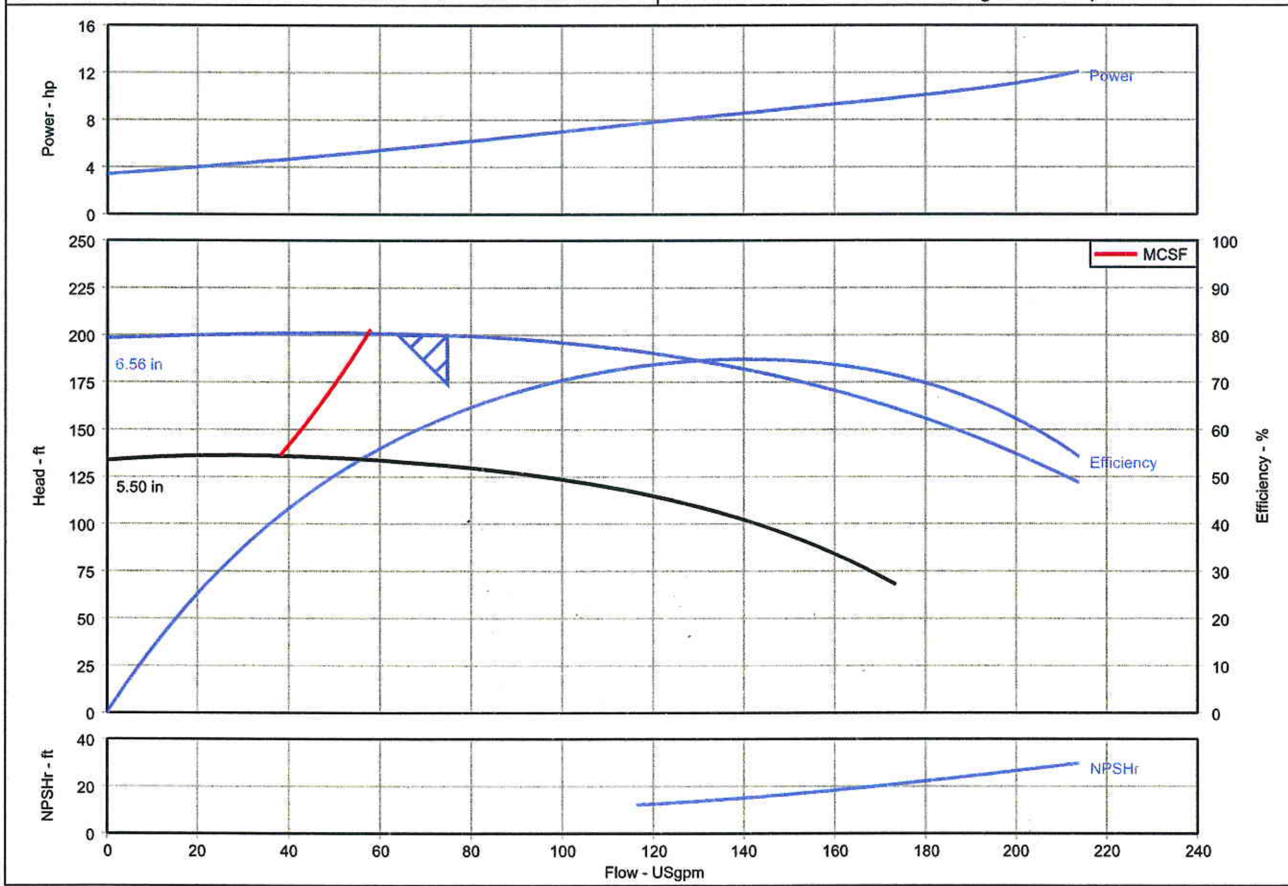
$ 2445 BS8086MS1 Sealed

Berkeley Electronic Catalog

Pump Performance Datasheet

Customer	:	Quote number	:
Customer reference	:	Size	: 1-1/2 x 2 x 6 M (B1-1/2TPM)
Item number	:	Stages	: 1
Service	:	Based on curve number	: 8888
Quantity	: 1	Date last saved	: 23 Nov 2010 8:32 AM

Operating Conditions		Liquid	
Flow, rated	: 75.00 USgpm	Liquid type	: --Water
Differential head / pressure, rated (requested)	: 200.0 ft	Additional liquid description	:
Differential head / pressure, rated (actual)	: 202.2 ft	Solids diameter, max	: 0.00 in
Suction pressure, rated / max	: 0.00 / 0.00 psi.g	Temperature, max	: 68.00 deg F
NPSH available, rated	: Ample	Fluid density, rated / max	: 0.998 / 0.998 SG
Frequency	: 60 Hz	Viscosity, rated	: 1.00 cP
Performance		-	:
Speed, rated	: 3,450 rpm	**Material**	
Impeller diameter, rated	: 6.56 in	Material requested	: Auto
Impeller diameter, maximum	: 6.56 in	Material selected	: Not specified
Impeller diameter, minimum	: 5.50 in	**Pressure Data**	
Efficiency	: 62.84 %	Maximum working pressure	: 87.05 psi.g
NPSH required / margin required	: - / 0.00 ft	Maximum allowable working pressure	: 150.0 psi.g
Ns (imp. eye flow) / Nss (imp. eye flow)	: 823 / 5,303 US Units	Maximum allowable suction pressure	: N/A
MCSF	: 57.57 USgpm	Hydrostatic test pressure	: N/A
Head, maximum, rated diameter	: 201.1 ft	**Driver & Power Data**	
Head rise to shutoff	: -1 %	Driver sizing specification	: Rated power
Flow, best eff. point (BEP)	: 140.3 USgpm	Margin over specification	: 0.00 %
Flow ratio (rated / BEP)	: 53.45 %	Service factor	: 1.00 (used)
Diameter ratio (rated / max)	: 100.00 %	Power, hydraulic	: 3.78 hp
Head ratio (rated dia / max dia)	: 98.92 %	Power, rated	: 6.02 hp
Cq/Ch/Ce [ANSI/HI 9.6.7-2004]	: 1.00 / 1.00 / 1.00	Power, maximum, rated diameter	: 12.12 hp
Selection status	: Acceptable	Minimum recommended motor rating	: 7.50 hp / 5.59 kW

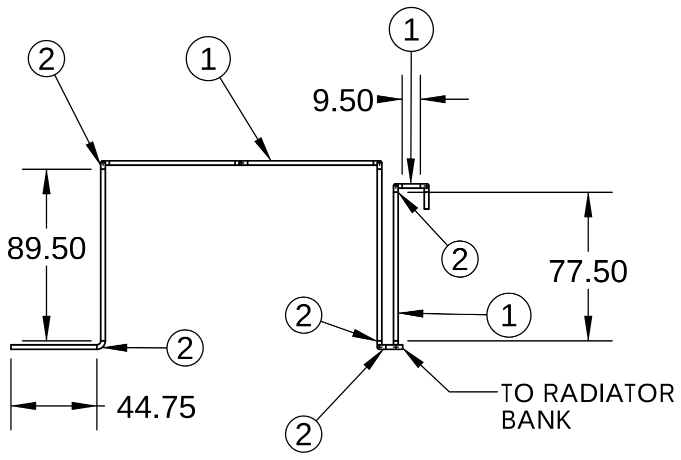


BERKELEY Pumps / Pentair Water ▫293 Wright Street ▫ Delavan, Wisconsin 53115
phone: 1-888-237-5353 ▫fax: 1-800-426-9446

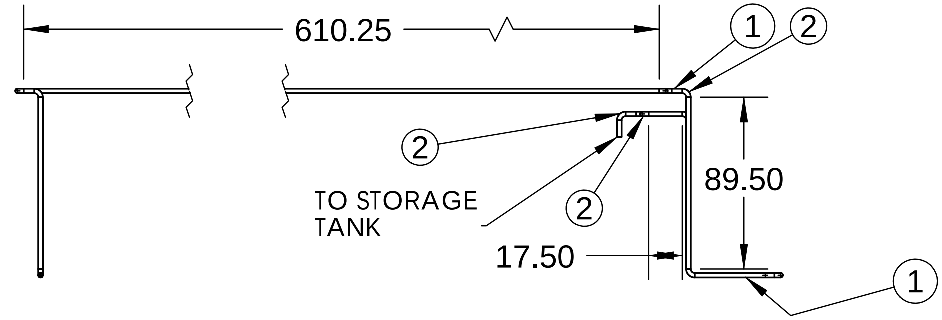
Appendix C

Pipe Routing

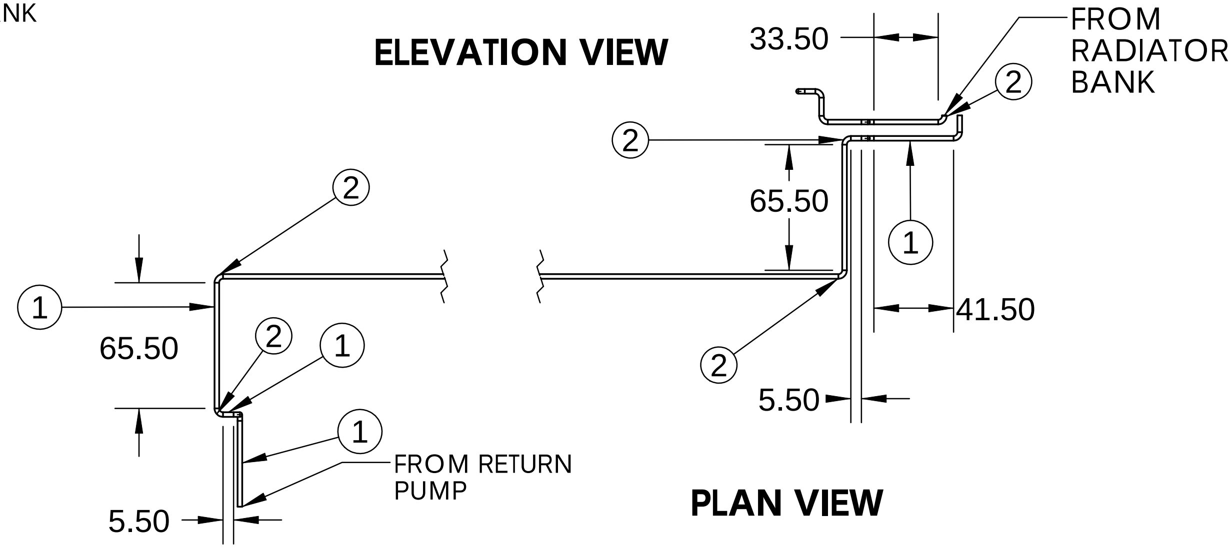
PART	DESCRIPTION	MATERIAL
1	NPS 2"-SCH. 40 PIPE	ASTM D1785
2	NPS 2"-SCH. 40 ELBOW-90 DEGREE-SOCKET END	ASTM D2665



SIDE VIEW



ELEVATION VIEW

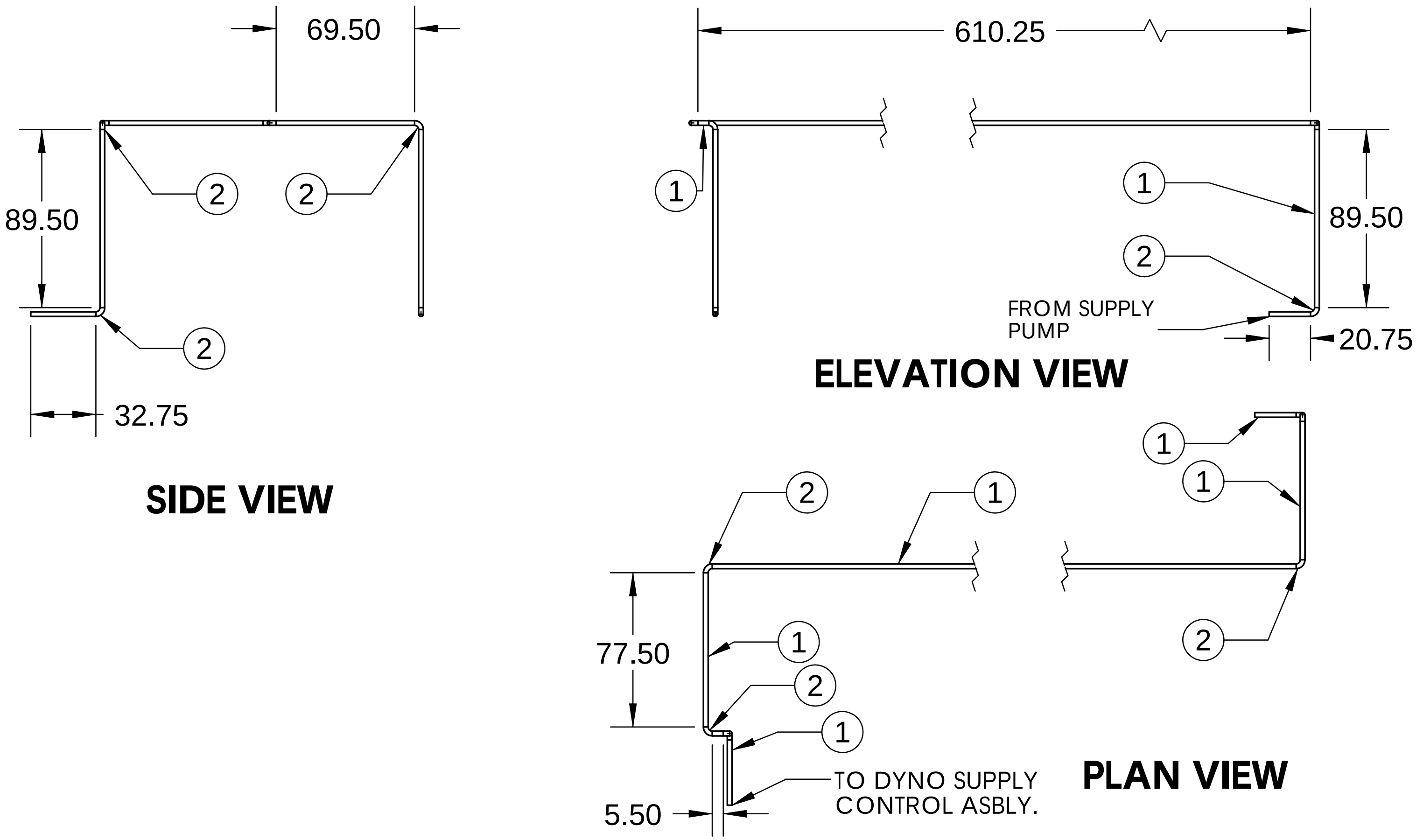


PLAN VIEW

				NAME	DATE	
		UNLESS OTHERWISE SPECIFIED:	DRAWN	JDB	29/11/2010	
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	CHECKED			TITLE:
			ENG APPR.			RETURN PIPING ARRGT. & DETAILS
			MFG APPR.			
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
		MATERIAL	COMMENTS:			SIZE A / DWG. NO. / REV
NEXT ASSY	USED ON	FINISH				
APPLICATION		DO NOT SCALE DRAWING				SCALE: 1:200 / WEIGHT: / SHEET 1 OF 1

4 3 2 1

PART	DESCRIPTION	MATERIAL
1	SCH. 40 NPS 2" PIPE	ASTM D1785 PVC
2	SCH. 40 NPS 2" 90 DEGREE ELBOW SOCKET ENDS	ASTM D2665 PVC



		NAME	DATE
DRAWN	JDB	29/11/2010	
CHECKED			
ENG APPR.			
MFG APPR.			
Q.A.			

UNLESS OTHERWISE SPECIFIED:

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

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

NEXT ASSY | USED ON

APPLICATION

DO NOT SCALE DRAWING

COMMENTS:

TITLE: **Supply Piping Arrgt. & Details**

SIZE **A** | DWG. NO. | REV

SCALE: 1:200 | WEIGHT: | SHEET 1 OF 1

4 3 2 1

Appendix D

ASTM Standards for Piping

Designation: D1785 – 06

An American National Standard

Standard Specification for Poly(Vinyl Chloride) (PVC) Plastic Pipe, Schedules 40, 80, and 120[1]

This standard is issued under the fixed designation D1785; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This specification covers poly(vinyl chloride) (PVC) pipe made in Schedule 40, 80, and 120 sizes and pressure-rated for water (see Appendix X1). Included are criteria for classifying PVC plastic pipe materials and PVC plastic pipe, a system of nomenclature for PVC plastic pipe, and requirements and test methods for materials, workmanship, dimensions, sustained pressure, burst pressure, flattening, and extrusion quality. Methods of marking are also given.

1.2 The products covered by this specification are intended for use with the distribution of pressurized liquids only, which are chemically compatible with the piping materials. Due to inherent hazards associated with testing components and systems with compressed air or other compressed gases some manufacturers do not allow pneumatic testing of their products. Consult with specific product/component manufacturers for their specific testing procedures prior to pneumatic testing.

NOTE 1—Pressurized (compressed) air or other compressed gases contain large amounts of stored energy which present serious saftey hazards should a system fail for any reason.

NOTE 2—This standard specifies dimensional, performance and test requirements for plumbing and fluid handling applications, but does not address venting of combustion gases.

1.3 The text of this specification references notes, footnotes, and appendixes which provide explanatory material. These notes and footnotes (excluding those in tables and figures) shall not be considered as requirements of the specification.

1.4 The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are for information only.

1.5 The following safety hazards caveat pertains only to the test methods portion, Section 8, of this specification: *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* A specific precautionary statement is given in Note 9.

NOTE 3—CPVC plastic pipes, Schedules 40 and 80, which were formerly included in this specification, are now covered by Specification F441/F441M.

NOTE 4—The sustained and burst pressure test requirements, and the pressure ratings in the Appendix X1, are calculated from stress values obtained from tests made on pipe 4 in. (100 mm) and smaller. However, tests conducted on pipe as large as 24-in. (600-mm) diameter have shown these stress values to be valid for larger diameter PVC pipe.

NOTE 5—PVC pipe made to this specification is often belled for use as line pipe. For details of the solvent cement bell, see Specification D2672 and for details of belled elastomeric joints, see Specifications D3139 and D3212.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D618 Practice for Conditioning Plastics for Testing

D1598 Test Method for Time-to-Failure of Plastic Pipe Under Constant Internal Pressure

D1599 Test Method for Resistance to Short-Time Hydraulic Pressure of Plastic Pipe, Tubing, and Fittings

D1600 Terminology for Abbreviated Terms Relating to Plastics

D1784 Specification for Rigid Poly(Vinyl Chloride) (PVC) Compounds and Chlorinated Poly(Vinyl Chloride) (CPVC) Compounds

D2122 Test Method for Determining Dimensions of Thermoplastic Pipe and Fittings

D2152 Test Method for Adequacy of Fusion of Extruded Poly(Vinyl Chloride) (PVC) Pipe and Molded Fittings by Acetone Immersion

D2672 Specification for Joints for IPS PVC Pipe Using Solvent Cement

D2837 Test Method for Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials or Pressure Design Basis for Thermoplastic Pipe Products

[1] This specification is under the jurisdiction of ASTM Committee F17 on Plastic Piping Systems and is the direct responsibility of Subcommittee F17.25 on Vinyl Based Pipe.

Current edition approved May 1, 2006. Published May 2006. Originally approved in 1960. Last previous edition approved in 2005 as D1785 – 05. DOI: 10.1520/D1785-06.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

D3139 Specification for Joints for Plastic Pressure Pipes Using Flexible Elastomeric Seals
D3212 Specification for Joints for Drain and Sewer Plastic Pipes Using Flexible Elastomeric Seals
F412 Terminology Relating to Plastic Piping Systems
F441/F441M Specification for Chlorinated Poly(Vinyl Chloride) (CPVC) Plastic Pipe, Schedules 40 and 80

2.2 *Federal Standard:*

Fed. Std. No. 123 Marking for Shipment (Civil Agencies)[3]

2.3 *Military Standard:*

MIL-STD-129 Marking for Shipment and Storage[3]

2.4 *NSF Standards:*

Standard No. 14 for Plastic Piping Components and Related Materials[4]
Standard No. 61 for Drinking Water System Components—Health Effects[4]

3. Terminology

3.1 *Definitions:* —Definitions are in accordance with Terminology F412 and abbreviations are in accordance with Terminology D1600, unless otherwise specified. The abbreviation for poly(vinyl chloride) plastic is PVC.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *hydrostatic design stress*—the estimated maximum tensile stress the material is capable of withstanding continuously with a high degree of certainty that failure of the pipe will not occur. This stress is circumferential when internal hydrostatic water pressure is applied.

3.2.2 *pressure rating (PR)*—the estimated maximum water pressure the pipe is capable of withstanding continuously with a high degree of certainty that failure of the pipe will not occur.

3.2.3 *relation between dimensions, design stress, and pressure rating*—the following expression, commonly known as the ISO equation,[5] is used in this specification to relate dimensions, hydrostatic design stress, and pressure rating:

$$2S/P = (D_0/t) - 1$$

where:

S = hydrostatic design stress, psi (or MPa),
P = pressure rating, psi (or MPa),
D_0 = average outside diameter, in. (or mm), and
t = minimum wall thickness, in. (or mm).

3.2.4 *standard thermoplastic pipe materials designation code*—the pipe materials designation code shall consist of the abbreviation PVC for the type of plastic, followed by the ASTM type and grade in Arabic numerals and the design stress in units of 100 psi (0.7 MPa) with any decimal figures dropped. When the design stress code contains less than two figures, a cipher shall be used before the number. Thus a complete material code shall consist of three letters and four figures for PVC plastic pipe materials (see Section 5).

[3] Available from Standardization Documents Order Desk, Bldg. 4 Section D, 700 Robbins Ave., Philadelphia, PA 19111-5094, Attn: NPODS.

[4] Available from NSF International, P.O. Box 130140, 789 N. Dixboro Rd., Ann Arbor, MI 48113-0140.

[5] ISO R161-1960, Pipes of Plastics Materials for the Transport of Fluids (Outside Diameters and Nominal Pressures) Part 1, Metric Series.

4. Classification

4.1 *General*—This specification covers PVC pipe made to and marked with one of six type/grade/design stress designations (see X1.2) in Schedule 40, 80, and 120 wall sizes.

4.2 *Hydrostatic Design Stresses*——This specification covers pipe made from PVC plastics as defined by four hydrostatic design stresses which have been developed on the basis of long-term tests (Appendix X1).

5. Materials and Manufacture

5.1 *General*—Poly(vinyl chloride) plastics used to make pipe meeting the requirements of this specification are categorized by means of two criteria, namely, (*1*) short-term strength tests and (*2*) long-term strength tests.

NOTE 6—The PVC pipe intended for use in the transport of potable water should be evaluated and certified as safe for this purpose by a testing agency acceptable to the local health authority. The evaluation should be in accordance with requirements for chemical extraction, taste, and odors that are no less restrictive than those included in NSF Standard No. 14. The seal or mark of the laboratory making the evaluation should be included on the pipe. See pipe marking requirement for reclaimed water systems.

5.2 *Basic Materials*—This specification covers pipe made from PVC plastics having certain physical and chemical properties as described in Specification D1784.

5.3 *Compound*—The PVC compounds used for this pipe shall equal or exceed the following classes described in Specification D1784; PVC 12454, or 14333.

5.4 *Rework Material*—The manufacturer shall use only his own clean rework pipe material and the pipe produced shall meet all the requirements of this specification.

6. Requirements

6.1 *Dimensions and Tolerances*:

6.1.1 Dimensions and tolerances shall be as shown in Table 1 and Table 2 when measured in accordance with Test Method D2122. The tolerances for out-of-roundness shall apply only to pipe prior to shipment.

6.2 *Sustained Pressure*—The pipe shall not fail, balloon, burst, or weep as defined in Test Method D1598, at the test pressures given in Tables 3-5 when tested in accordance with 8.4.

6.2.1 *Accelerated Regression Test*—The accelerated regression test shall be used in place of both the sustained and burst pressure tests, at the option of the manufacturer. The test shall be conducted in accordance with 8.4.1. The pipe shall demonstrate a hydrostatic design basis projection at the 100 000-h intercept that meets the hydrostatic design basis category requirement (see Tables 3-5 and Test Method D2837) for the PVC material used in its manufacture. (*Example:* PVC 1120 pipe must have a minimum 100 000-h projection of 3830 psi (26.40 MPa) and 85 % lower confidence limit (LCL).

6.3 *Burst Pressure*—The minimum burst pressures for PVC plastic pipe shall be as given in Table 6, when determined in accordance with Test Method D1599.

NOTE 7—Times greater than 60 s may be needed to bring large size specimens to burst pressure. The test is more difficult to pass using greater pressurizing times.

TABLE 1 Outside Diameters and Tolerances for PVC Plastic Pipe Schedules 40, 80, and 120, in. (mm)

Nominal Pipe Size	Outside Diameter	Tolerances		
		Average	Maximum Out-of-Roundness (maximum minus minimum diameter)	
			Schedule 40 sizes 3½ in. and over; Schedule 80 sizes 8 in. and over	Schedule 40 sizes 3 in. and less; Schedule 80 sizes 6 in. and less; Schedule 120 sizes all
⅛	0.405 (10.29)	±0.004 (±0.10)	. . .	0.016 (0.41)
¼	0.540 (13.72)	±0.004 (±0.10)	. . .	0.016 (0.41)
⅜	0.675 (17.14)	±0.004 (±0.10)	. . .	0.016 (0.41)
½	0.840 (21.34)	±0.004 (±0.10)	. . .	0.016 (0.41)
¾	1.050 (26.67)	±0.004 (±0.10)	. . .	0.020 (0.51)
1	1.315 (33.40)	±0.005 (±0.13)	. . .	0.020 (0.51)
1¼	1.660 (42.16)	±0.005 (±0.13)	. . .	0.024 (0.61)
1½	1.900 (48.26)	±0.006 (±0.15)	. . .	0.024 (0.61)
2	2.375 (60.32)	±0.006 (±0.15)	. . .	0.024 (0.61)
2½	2.875 (73.02)	±0.007 (±0.18)	. . .	0.030 (0.76)
3	3.500 (88.90)	±0.008 (±0.20)	. . .	0.030 (0.76)
3½	4.000 (101.60)	±0.008 (±0.20)	0.100 (2.54)	0.030 (0.76)
4	4.500 (114.30)	±0.009 (±0.23)	0.100 (2.54)	0.030 (0.76)
5	5.563 (141.30)	±0.010 (±0.25)	0.100 (2.54)	0.060 (1.52)
6	6.625 (168.28)	±0.011 (±0.28)	0.100 (2.54)	0.070 (1.78)
8	8.625 (219.08)	±0.015 (±0.38)	0.150 (3.81)	0.090 (2.29)
10	10.750 (273.05)	±0.015 (±0.38)	0.150 (3.81)	0.100 (2.54)
12	12.750 (323.85)	±0.015 (±0.38)	0.150 (3.81)	0.120 (3.05)
14	14.000 (355.60	±0.015 (±0.38)	0.200 (5.08)	. . .
16	16.000 (406.40)	±0.019 (±0.48)	0.320 (8.13)	. . .
18	18.000 (457.20)	±0.019 (±0.48)	0.360 (9.14)	. . .
20	20.000 (508.00)	±0.023 (±0.58)	0.400 (10.2)	. . .
24	24.000 (609.60)	±0.031 (±0.79)	0.480 (12.2)	. . .

TABLE 2 Wall Thicknesses and Tolerances for PVC Plastic Pipe, Schedules 40, 80, and 120,[A,B] in. (mm)

Nominal Pipe Size	Wall Thickness[A]					
	Schedule 40		Schedule 80		Schedule 120	
	Minimum	Tolerance	Minimum	Tolerance	Minimum	Tolerance
⅛	0.068 (1.73)	+0.020 (+0.51)	0.095 (2.41)	+0.020 (+0.51)	. . .	. . .
¼	0.088 (2.24)	+0.020 (+0.51)	0.119 (3.02)	+0.020 (+0.51)	. . .	. . .
⅜	0.091 (2.31)	+0.020 (+0.51)	0.126 (3.20)	+0.020 (+0.51)	. . .	. . .
½	0.109 (2.77)	+0.020 (+0.51)	0.147 (3.73)	+0.020 (+0.51)	0.170 (4.32)	+0.020 (+0.51)
¾	0.113 (2.87)	+0.020 (+0.51)	0.154 (3.91)	+0.020 (+0.51)	0.170 (4.32)	+0.020 (+0.51)
1	0.133 (3.38)	+0.020 (+0.51)	0.179 (4.55)	+0.021 (+0.53)	0.200 (5.08)	+0.024 (+0.61)
1¼	0.140 (3.56)	+0.020 (+0.51)	0.191 (4.85)	+0.023 (+0.58)	0.215 (5.46)	+0.026 (+0.66)
1½	0.145 (3.68)	+0.020 (+0.51)	0.200 (5.08)	+0.024 (+0.61)	0.225 (5.72)	+0.027 (+0.68)
2	0.154 (3.91)	+0.020 (+0.51)	0.218 (5.54)	+0.026 (+0.66)	0.250 (6.35)	+0.030 (+0.76)
2½	0.203 (5.16)	+0.024 (+0.61)	0.276 (7.01)	+0.033 (+0.84)	0.300 (7.62)	+0.036 (+0.91)
3	0.216 (5.49)	+0.026 (+0.66)	0.300 (7.62)	+0.036 (+0.91)	0.350 (8.89)	+0.042 (+1.07)
3½	0.226 (5.74)	+0.027 (+0.68)	0.318 (8.08)	+0.038 (+0.96)	0.350 (8.89)	+0.042 (+1.07)
4	0.237 (6.02)	+0.028 (+0.71)	0.337 (8.56)	+0.040 (+1.02)	0.437 (11.10)	+0.052 (+1.32)
5	0.258 (6.55)	+0.031 (+0.79)	0.375 (9.52)	+0.045 (+1.14)	0.500 (12.70)	+0.060 (+1.52)
6	0.280 (7.11)	+0.034 (+0.86)	0.432 (10.97)	+0.052 (+1.32)	0.562 (14.27)	+0.067 (+1.70)
8	0.322 (8.18)	+0.039 (+0.99)	0.500 (12.70)	+0.060 (+1.52)	0.718 (18.24)	+0.086 (+2.18)
10	0.365 (9.27)	+0.044 (+1.12)	0.593 (15.06)	+0.071 (+1.80)	0.843 (21.41)	+0.101 (+2.56)
12	0.406 (10.31)	+0.049 (+1.24)	0.687 (17.45)	+0.082 (+2.08)	1.000 (25.40)	+0.120 (+3.05)
14	0.437 (11.10)	+0.053 (+1.35)	0.750 (19.05)	+0.090 (+2.29)	. . .	. . .
16	0.500 (12.70)	+0.060 (+1.52)	0.843 (21.41)	+0.101 (+2.57)	. . .	. . .
18	0.562 (14.27)	+0.067 (+1.70)	0.937 (23.80)	+0.112 (+2.84)	. . .	. . .
20	0.593 (15.06)	+0.071 (+1.80)	1.031 (26.19)	+0.124 (+3.15)	. . .	. . .
24	0.687 (17.45)	+0.082 (+2.08)	1.218 (30.94)	+0.146 (+3.71)	. . .	. . .

[A] The minimum is the lowest wall thickness of the pipe at any cross section. The maximum permitted wall thickness, at any cross section, is the minimum wall thickness plus the stated tolerance. All tolerances are on the plus side of the minimum requirement.

[B] These dimensions conform to nominal IPS dimensions, with the exception that Schedule 120 wall thickness for pipe sizes ½ to 3½ in. (12.5 to 87.5 mm), inclusive, are special PVC plastic pipe sizes.

6.4 *Flattening*—There shall be no evidence of splitting, cracking, or breaking when the pipe is tested in accordance with 8.6.

6.5 *Extrusion Quality*—The pipe shall not flake or disintegrate when tested in accordance with Test Method D2152.

TABLE 3 Sustained Pressure Test Conditions for Water at 73°F (23°C) for PVC Plastic Pipe, Schedule 40

Nominal Pipe Size	Pressure Required for Test[A]			
	PVC1120 PVC1220 PVC2120	PVC2116	PVC2112	PVC2110
in.	psi			
⅛	1690	1360	1130	930
¼	1640	1310	1090	900
⅜	1310	1050	870	720
½	1250	1000	840	690
¾	1010	810	680	550
1	950	760	630	520
1¼	770	620	520	420
1½	690	560	460	380
2	580	470	390	320
2½	640	510	430	350
3	590	440	370	300
3½	500	400	340	280
4	470	370	310	260
5	410	330	270	220
6	370	300	250	200
8	330	260	220	180
10	300	240	200	160
12	280	220	180	150
14	270	220	180	150
16	270	220	180	150
18	270	220	180	150
20	260	210	170	140
24	250	200	170	140
in.	MPa			
⅛	11.65	9.38	7.79	6.41
¼	11.31	9.03	7.52	6.21
⅜	9.03	7.24	6.00	4.96
½	8.62	6.89	5.79	4.76
¾	6.96	5.58	4.69	3.79
1	6.55	5.24	4.34	3.59
1¼	5.31	4.27	3.59	2.90
1½	4.76	3.86	3.17	2.62
2	4.00	3.24	2.69	2.21
2½	4.41	3.52	2.96	2.41
3	4.07	3.03	2.55	2.07
3½	3.45	2.76	2.34	1.93
4	3.24	2.55	2.14	1.79
5	2.83	2.28	1.86	1.52
6	2.55	2.07	1.72	1.38
8	2.28	1.79	1.52	1.24
10	2.07	1.65	1.38	1.10
12	1.93	1.52	1.24	1.03
14	1.89	1.54	1.26	1.05
16	1.89	1.54	1.26	1.05
18	1.89	1.54	1.26	1.05
20	1.82	1.47	1.19	0.98
24	1.75	1.40	1.19	0.98

[A] The fiber stresses used to derive these test pressures are as follows:

	psi	MPa
PVC1120	4200	29.0
PVC1220	4200	29.0
PVC2120	4200	29.0
PVC2116	3360	23.2
PVC2112	2800	19.3
PVC2110	2300	15.9

TABLE 4 Sustained Pressure Test Conditions for Water at 73°F (23°C) for PVC Plastic Pipe, Schedule 80

Nominal Pipe Size	Pressure Required for Test[A]			
	PVC1120 PVC1220 PVC2120	PVC2116	PVC2112	PVC2110
in.	psi			
⅛	2570	2060	1720	1410
¼	2370	1900	1580	1300
⅜	1930	1540	1290	1060
½	1780	1430	1190	980
¾	1440	1160	960	790
1	1320	1060	880	720
1¼	1090	870	730	600
1½	990	790	660	540
2	850	680	570	460
2½	890	710	590	490
3	790	630	520	430
3½	730	580	480	400
4	680	540	450	370
5	610	490	400	330
6	590	470	390	320
8	520	410	340	280
10	490	390	330	270
12	480	380	320	260
14	470	380	320	260
16	470	370	310	260
18	460	370	310	250
20	460	370	300	250
24	450	360	300	250
in.	MPa			
⅛	17.72	14.21	11.86	9.72
¼	16.34	13.10	10.90	8.96
⅜	13.31	10.62	8.89	7.31
½	12.27	9.86	8.20	6.76
¾	9.93	8.00	6.62	5.45
1	9.10	7.31	6.07	4.96
1¼	7.52	6.00	5.03	4.14
1½	6.83	4.96	4.55	3.72
2	5.86	4.69	3.93	3.17
2½	6.14	4.90	4.07	3.38
3	5.45	4.34	3.59	2.96
3½	5.03	4.00	3.31	2.76
4	4.69	3.72	3.10	2.55
5	4.21	3.38	2.76	2.28
6	4.07	3.24	2.69	2.21
8	3.59	2.83	2.34	1.93
10	3.38	2.69	2.28	1.86
12	3.31	2.62	2.21	1.79
14	3.29	2.66	2.24	1.82
16	3.29	2.59	2.17	1.82
18	3.22	2.59	2.17	1.75
20	3.22	2.59	2.10	1.75
24	3.15	2.52	2.10	1.75

[A] The fiber stresses used to derive these test pressures are as follows:

	psi	MPa
PVC1120	4200	29.0
PVC1220	4200	29.0
PVC2120	4200	29.0
PVC2116	3360	23.2
PVC2112	2800	19.3
PVC2110	2300	15.9

7. Workmanship, Finish, and Appearance

7.1 The pipe shall be homogeneous throughout and free of visible cracks, holes, foreign inclusions, or other defects. The pipe shall be as uniform as commercially practicable in color, opacity, density, and other physical properties.

NOTE 8—Color and transparency or opacity should be specified in the contract or purchase order.

8. Test Methods

8.1 *Conditioning*—Condition the test specimens at 73.4 ± 3.6°F (23 ± 2°C) and 50 ± 5 % relative humidity for not less

TABLE 5 Sustained Pressure Test Conditions for Water at 73°F (23°C) for PVC Plastic Pipe, Schedule 120

Nominal Pipe Size	Pressure Required for Test[A]			
	PVC1120 PVC1220 PVC2120	PVC2116	PVC2112	PVC2110
in.	psi			
½	2130	1710	1420	1170
¾	1620	1300	1080	890
1	1510	1200	1000	830
1¼	1250	1000	830	680
1½	1130	900	750	620
2	990	790	660	540
2½	980	780	650	540
3	930	750	620	510
3½	810	640	540	440
4	900	720	600	490
5	830	660	550	450
6	780	620	520	430
8	760	610	510	420
10	770	620	510	420
12	710	570	480	390
in.	MPa			
½	14.69	11.79	9.79	8.07
¾	11.17	8.96	7.45	6.14
1	10.41	8.27	6.89	5.72
1¼	8.62	6.89	5.72	4.69
1½	7.79	6.21	5.17	4.27
2	6.83	5.45	4.55	3.72
2½	6.76	5.38	4.48	3.72
3	6.41	5.17	4.27	3.52
3½	5.58	4.41	3.72	3.03
4	6.21	4.96	4.14	3.38
5	5.72	4.55	3.79	3.10
6	5.38	4.27	3.59	2.96
8	5.24	4.21	3.52	2.90
10	5.31	4.27	3.52	2.90
12	4.90	3.93	3.31	2.69

[A] The fiber stresses used to derive these test pressures are as follows:

	psi	MPa
PVC1120	4200	29.0
PVC1220	4200	29.0
PVC2120	4200	29.0
PVC2116	3360	23.2
PVC2112	2800	19.3
PVC2110	2300	15.9

than 40 h prior to test in accordance with Procedure A of Practice D618, for those tests where conditioning is required.

8.2 *Test Conditions*—Conduct tests in the standard laboratory atmosphere of 73.4 ± 3.6°F (23 ± 2°C) and 50 ± 5 % relative humidity, unless otherwise specified in the test methods or in this specification.

8.3 *Sampling*—The selection of the sample or samples of pipe shall be as agreed upon by the purchaser and seller. In case of no prior agreement, any sample selected by the testing laboratory shall be deemed adequate.

8.3.1 *Test Specimens*—Not less than 50 % of the test specimens required for any pressure test shall have at least a part of the marking in their central sections. The central section is that portion of pipe which is at least one pipe diameter away from an end closure.

8.4 *Sustained Pressure Test*—Select the test specimens at random. Test individually with water at the internal pressures given in Tables 3-5, six specimens of pipe, each specimen at least ten times the nominal diameter in length, but not less than 10 in. (250 mm) or more than 3 ft (1 m) between end closures and bearing the permanent marking on the pipe. Maintain the specimens at the pressure indicated for a period of 1000 h. Hold the pressure as closely as possible, but within ±10 psi (±70 kPa). Condition the specimens at the test temperature of 73.4°F (23°C) to within 3.6°F (±2°C). Test in accordance with Test Method D1598, except maintain the pressure at the values given in Tables 3-5 for 1000 h. Failure of two of the six specimens tested shall constitute failure in the test. Failure of one of the six specimens tested in retest shall constitute failure in the test. Evidence of failure of the pipe shall be as defined in Test Method D1598.

8.4.1 *Accelerated Regression Test*—Test in accordance with procedures in Test Method D1598, using either free end or restrained end fittings. A minimum of six samples shall be tested. Test three specimens at a single pressure that will result in failures at or below 0.10 h. Test an additional three specimens at a single pressure that will result in failures at about 200 h. Generating additional data points to improve the LTHS or LCL, or both, is acceptable. No points shall be excluded unless an obvious defect is detected in the failure area

TABLE 6 Burst Pressure Requirements for Water at 73°F (23°C) for PVC Plastic Pipe, Schedules 40, 80, and 120

Nominal Pipe Size	Min Burst Pressures[A]					
	Schedule 40		Schedule 80		Schedule 120	
	PVC1120 PVC1220 PVC2120	PVC2112 PVC2116 PVC2110	PVC1120 PVC1220 PVC2120	PVC2112 PVC2116 PVC2110	PVC1120 PVC1220 PVC2120	PVC2112 PVC2116 PVC2110
in.	psi					
⅛	2580	2020	3920	3060	. . .	. . .
¼	2490	1950	3620	2830	. . .	. . .
⅜	1990	1560	2940	2300	. . .	. . .
½	1910	1490	2720	2120	3250	2540
¾	1540	1210	2200	1720	2470	1930
1	1440	1130	2020	1580	2300	1790
1¼	1180	920	1660	1300	1900	1490
1½	1060	830	1510	1180	1720	1340
2	890	690	1290	1010	1510	1180
2½	970	760	1360	1060	1490	1170
3	840	660	1200	940	1420	1110
3½	770	600	1110	860	1230	960
4	710	560	1040	810	1380	1080
5	620	390	930	720	1260	990
6	560	440	890	700	1190	930
8	500	390	790	620	1160	910
10	450	350	750	580	1170	920
12	420	330	730	570	1090	850
14	410	320	720	570	. . .	. . .
16	410	320	710	560	. . .	. . .
18	410	320	700	550	. . .	. . .
20	390	310	700	540	. . .	. . .
24	380	300	680	530	. . .	. . .
in.	MPa					
⅛	17.79	13.93	27.03	21.10	. . .	. . .
¼	17.17	13.45	24.96	19.52	. . .	. . .
⅜	13.72	10.76	20.27	15.86	. . .	. . .
½	13.17	10.27	18.76	14.62	22.41	17.52
¾	10.62	8.34	15.17	11.86	17.03	13.31
1	9.93	7.79	13.93	10.89	15.86	12.34
1¼	8.14	6.34	11.45	8.96	13.10	10.27
1½	7.31	5.72	10.41	8.14	11.86	9.24
2	6.14	4.76	8.89	6.96	10.41	8.14
2½	6.69	5.24	9.38	7.31	10.27	8.07
3	5.79	4.55	8.27	6.48	9.79	7.65
3½	5.31	4.14	7.65	5.93	8.48	6.62
4	4.90	3.86	7.17	5.58	9.51	7.45
5	4.27	2.69	6.41	4.96	8.69	6.83
6	3.86	3.03	6.14	4.83	8.20	6.41
8	3.45	2.69	5.45	4.27	8.00	6.27
10	3.10	2.41	5.17	4.00	8.07	6.34
12	2.90	2.28	5.03	3.93	7.52	5.86
14	2.87	2.24	5.04	3.99	. . .	. . .
16	2.87	2.24	4.97	3.92	. . .	. . .
18	2.87	2.24	4.90	3.85	. . .	. . .
20	2.73	2.17	4.90	3.78	. . .	. . .
24	2.66	2.10	4.76	3.71	. . .	. . .

[A] The fiber stresses used to derive these test pressures are as follows:

	psi	MPa
PVC1120	6400	44.1
PVC1220	6400	44.1
PVC2120	6400	44.1
PVC2116	5000	34.5
PVC2112	5000	34.5
PVC2110	5000	34.5

of the test sample, or there was a malfunction of the equipment. Characterize the data using the least squares regression described in Test Method D2837.

8.5 *Burst Pressure*—Determine the minimum burst pressure with at least five specimens in accordance with Test Method D1599. The time of testing of each specimen shall be between 60 and 70 s.

8.6 *Flattening*—Flatten three specimens of the pipe each at least 2 in. (50 mm) long, between parallel plates in a suitable press until the distance between the plates is 40 % of the outside diameter of the pipe or the walls of the pipe touch, whichever occurs first. The rate of loading shall be uniform and such that the compression is completed within 2 to 5 min. On removal of the load examine the specimens for evidence of splitting, cracking, or breaking.

9. Retest and Rejection

9.1 If the results of any test(s) do not meet the requirements of this specification, the test(s) shall be conducted again only by agreement between the purchaser and seller. Under such agreement, minimum requirements shall not be lowered, changed, or modified, nor shall specification limits be changed. If upon retest, failure occurs, the quantity of product represented by the test(s) does not meet the requirements of this specification.

10. Product Marking

10.1 *Quality of Marking*—The marking shall be applied to the pipe in such a manner that it remains legible (easily read) after installation and inspection.

10.2 *Content of Marking*:

10.2.1 Marking on the pipe shall include the following, spaced at intervals of not more than 5 ft (1.5 m):

10.2.1.1 Nominal pipe size (for example, 2 in. (50 mm)),

10.2.1.2 Type of plastic pipe material in accordance with the designation code prescribed in 3.2.4, for example, PVC1120,

10.2.1.3 Schedule (40, 80, or 120, whichever is applicable) and the pressure rating in pounds per square inch (megapascals) for water at 73°F (23°C) shown as the number followed by psi (for example, 200 psi (1.4 MPa)). When the indicated pressure rating is lower than that calculated in accordance with 3.2.3 (see Appendix X1), this shall be indicated by placing a star after the pressure rating,

10.2.1.4 ASTM designation D1785, with which the pipe complies,

10.2.1.5 Manufacturer's name (or trademark),

10.2.1.6 Production code with which the manufacturer can trace the year, month, day, shift, plant and extruder of manufacture for this product, and

10.2.1.7 Pipe intended for the transport of potable water shall also include the seal or mark of the laboratory making the evaluation for this purpose, spaced at intervals specified by the laboratory.

NOTE 9—Manufacturers using the seal or mark of a laboratory must obtain prior authorization from the laboratory concerned.

NOTE 10—It is common practice to dual mark Schedule 40 piping for potable water and DWV usage in which compliance with each applicable standard is met.

11. Quality Assurance

11.1 When the product is marked with this designation, D1785, the manufacturer affirms that the product was manufactured, inspected, sampled, and tested in accordance with this specification and has been found to meet the requirements of this specification.

12. Keywords

12.1 pressure pipe; PVC pipe; Schedule 40 pipe; Schedule 80 pipe; Schedule 120 pipe

SUPPLEMENTARY REQUIREMENTS

This requirement applies whenever a regulatory authority or user calls for product to be used to convey or to be in contact with potable water.

S1. *Potable Water Requirement*—Products intended for contact with potable water shall be evaluated, tested, and certified for conformance with ANSI/NSF Standard No. 61 or the health effects portion of NSF Standard No. 14 by an acceptable certifying organization when required by the regulatory authority having jurisdiction.

This requirement applies only to pipe to be used in systems that have not established other provisions for identification.

S2. *Pipe Marking Requirement for Reclaimed Water Systems*—Color identification of pipe shall be by *(1)* use of purple (violet) PVC material or *(2)* by use of continuous purple stripes printed lengthwise on opposite sides of the pipe. The pipe shall be marked RECLAIMED WATER at intervals of 5 ft. or less.

GOVERNMENT/MILITARY PROCUREMENT

These requirements apply *only* to federal/military procurement, not domestic sales or transfers.

S1. *Pipe for Reclaimed-Water System*—Pipe used in these systems shall be purple (violet) in color and it shall be marked **Reclaimed Water**.

S2. *Responsibility for Inspection*—Unless otherwise specified in the contract or purchase order, the producer is responsible for the performance of all inspection and test requirements specified herein. The producer may use his own or any other suitable facilities for the performance of the inspection and test requirements specified herein, unless the purchaser disapproves. The purchaser shall have the right to perform any of the inspections and tests set forth in this specification where such inspections are deemed necessary to ensure that material conforms to prescribed requirements.

NOTE S2.1—In U.S. Federal contracts, the contractor is responsible for inspection.

S3. *Packaging and Marking for U.S. Government Procurement:*

S3.1 *Packaging*—Unless otherwise specified in the contract, the materials shall be packaged in accordance with the supplier's standard practice in a manner ensuring arrival at destination in satisfactory condition and which will be acceptable to the carrier at lowest rates. Containers and packing shall comply with Uniform Freight Classification rules or National Motor Freight Classification rules.

S3.2 *Marking*—Marking for shipment shall be in accordance with Fed. Std. No. 123 for civil agencies and MIL-STD-129 for military agencies.

NOTE S3.1—The inclusion of U.S. Government procurement requirements should not be construed as an indication that the U.S. Government uses or endorses the products described in this specification.

APPENDIX

(Nonmandatory Information)

X1. SOURCE OF HYDROSTATIC DESIGN STRESSES

X1.1 The hydrostatic design stresses recommended by the Plastics Pipe Institute are used to pressure rate PVC plastic pipe. These hydrostatic design stresses are 2000 psi (14 MPa), 1600 psi (11 MPa), 1250 psi (9 MPa), and 1000 psi (7 MPa) for water at 73°F (23°C). These hydrostatic design stresses apply only to pipe meeting all the requirements of this specification.

X1.2 Six PVC pipe materials are included based on the requirements of Specification D1784 and the PPI-recommended hydrostatic design stresses as follows:

X1.2.1 Type I, Grade 1 (12454-B), with a hydrostatic design stress of 2000 psi (14 MPa), designated as PVC1120.

X1.2.2 Type I, Grade 2 (12454-C), with a hydrostatic design stress of 2000 psi (14 MPa), designated as PVC1220.

X1.2.3 Type II, Grade 1 (14333-D), with a hydrostatic design stress of 2000 psi (14 MPa), designated as PVC2120.

X1.2.4 Type II, Grade 1 (14333-D), with a hydrostatic design stress of 1600 psi (11.2 MPa), designated as PVC2116.

X1.2.5 Type II, Grade 1 (14333-D), with a hydrostatic design stress of 1250 psi (8.7 MPa), designated as PVC2112.

X1.2.6 Type II, Grade 1 (14333-D), with a hydrostatic design stress of 1000 psi (7.0 MPa), designated as PVC2110.

X1.3 The standard method for obtaining hydrostatic basis for thermoplastic pipe materials is Test Method D2837. Additional information regarding the test method and other criteria used in developing these hydrostatic design stresses may be obtained from the Plastics Pipe Institute, a division of The Society of the Plastics Industry, 355 Lexington Ave., New York, NY 10017. These hydrostatic design stresses may not be suitable for materials that show a wide departure from a straight-line plot of log stress versus log time to failure. All the data available to date on PVC pipe materials made in the United States exhibit a straight-line plot under these plotting conditions.

X1.4 The pipe is rated for use with water at 73°F (23°C) at the maximum internal pressures shown in Tables X1.1-X1.3. Lower pressure ratings than those calculated in accordance with 3.2.3 may be recommended, at the option of the pipe manufacturer, in which case the SDR shall be included in the marking. Experience of the industry indicates that PVC plastic pipe meeting the requirements of this specification gives satisfactory service under normal conditions for a long period at these pressure ratings. The sustained pressure requirements are related to these ratings through the slopes of the strength-time plots of these materials in pipe form.

X1.5 The hydrostatic design stresses recommended by the Plastics Pipe Institute are based on tests made on pipe ranging in size from ½ to 2½ in. (12.5 to 63.5 mm).

TABLE X1.1 Water Pressure Ratings at 73°F (23°C) for Schedule 40 PVC Plastic Pipe

Nominal Pipe Size	Pressure Ratings[A]			
	PVC1120[B] PVC1220 PVC2120	PVC2116	PVC2112[B]	PVC2110[B]
in.	psi			
⅛	810	650	500	400
¼	780	620	490	390
⅜	620	500	390	310
½	600	480	370	300
¾	480	390	300	240
1	450	360	280	220
1¼	370	290	230	180
1½	330	260	210	170
2	280	220	170	140
2½	300	240	190	150
3	260	210	160	130
3½	240	190	150	120
4	220	180	140	110
5	190	160	120	100
6	180	140	110	90
8	160	120	100	80
10	140	110	90	70
12	130	110	80	70
14	130	100	80	60
16	130	100	80	60
18	130	100	80	60
20	120	100	80	60
24	120	90	70	60
in.	MPa			
⅛	5.58	4.48	3.45	2.76
¼	5.38	4.27	3.38	2.69
⅜	4.27	3.45	2.69	2.14
½	4.14	3.31	2.55	2.07
¾	3.31	2.69	2.07	1.65
1	3.10	2.48	1.93	1.52
1¼	2.55	2.04	1.59	1.24
1½	2.28	1.79	1.45	1.17
2	1.93	1.52	1.17	0.97
2½	2.07	1.65	1.31	1.03
3	1.79	1.45	1.10	0.90
3½	1.65	1.31	1.03	0.83
4	1.52	1.24	0.97	0.76
5	1.31	1.10	0.83	0.69
6	1.24	0.97	0.76	0.62
8	1.10	0.83	0.69	0.55
10	0.97	0.76	0.62	0.48
12	0.90	0.76	0.55	0.48
14	0.91	0.70	0.56	0.42
16	0.91	0.70	0.56	0.42
18	0.91	0.70	0.56	0.42
20	0.84	0.70	0.56	0.42
24	0.84	0.63	0.49	0.42

[A] These pressure ratings apply only to unthreaded pipe. The industry does not recommend threading PVC plastic pipe in Schedule 40 dimensions in nominal pipe sizes 6 in. (150 mm) and smaller.

[B] See Appendix X1 for code designation.

TABLE X1.2 Water Pressure Ratings at 73°F (23°C) for Schedule 80 PVC Plastic Pipe

Nominal Pipe Size, in.	psi							
	PVC1120, PVC1220, PVC2120		PVC2116		PVC2112		PVC2110	
	Unthreaded	Threaded	Unthreaded	Threaded	Unthreaded	Threaded	Unthreaded	Threaded
⅛	1230	610	980	490	770	380	610	310
¼	1130	570	900	450	710	350	570	280
⅜	920	460	730	370	570	290	460	230
½	850	420	680	340	530	260	420	210
¾	690	340	550	280	430	210	340	170
1	630	320	500	250	390	200	320	160
1¼	520	260	420	210	320	160	260	130
1½	470	240	380	190	290	150	240	120
2	400	200	320	160	250	130	200	100
2½	420	210	340	170	260	130	210	110
3	370	190	300	150	230	120	190	90
3½	350	170	280	140	220	110	170	90
4	320	160	260	130	200	100	160	80
5	290	140	230	120	180	90	140	70
6	280	140	220	110	170	90	140	70
8	250	120	200	100	150	80	120	60
10	230	120	190	90	150	70	120	60
12	230	110	180	90	140	70	110	60
14	220	. . .	180	. . .	140	. . .	110	. . .
16	220	. . .	180	. . .	140	. . .	110	. . .
18	220	. . .	180	. . .	140	. . .	110	. . .
20	220	. . .	170	. . .	140	. . .	110	. . .
24	210	. . .	170	. . .	130	. . .	110	. . .
	MPa							
⅛	8.48	4.21	6.76	3.38	5.31	2.62	4.21	2.14
¼	7.79	3.93	6.21	3.10	4.90	2.41	3.93	1.93
⅜	6.34	3.17	5.03	2.55	3.93	2.00	3.17	1.59
½	5.86	2.90	4.69	2.34	3.65	1.79	2.90	1.45
¾	4.76	2.34	3.79	1.93	2.96	1.45	2.34	1.17
1	4.34	2.21	3.45	1.72	2.69	1.38	2.21	1.10
1¼	3.59	1.79	2.90	1.45	2.21	1.10	1.79	0.90
1½	3.24	1.65	2.62	1.31	2.0	1.03	1.65	0.83
2	2.76	1.38	2.21	1.10	1.72	0.90	1.38	0.69
2½	2.90	1.45	2.34	1.17	1.79	0.90	1.45	0.76
3	2.55	1.31	2.07	1.03	1.59	0.83	1.31	0.62
3½	2.41	1.17	1.93	0.97	1.52	0.76	1.17	0.62
4	2.21	1.10	1.79	0.90	1.38	0.69	1.10	0.55
5	2.00	0.97	1.59	0.83	1.24	0.62	0.97	0.48
6	1.93	0.97	1.52	0.76	1.17	0.62	0.97	0.48
8	1.72	0.83	1.38	0.69	1.03	0.55	0.83	0.41
10	1.59	0.83	1.31	0.62	1.03	0.48	0.83	0.41
12	1.59	0.76	1.24	0.62	0.97	0.48	0.76	0.41
14	1.54	. . .	1.26	. . .	0.98	. . .	0.77	. . .
16	1.54	. . .	1.26	. . .	0.98	. . .	0.77	. . .
18	1.54	. . .	1.26	. . .	0.98	. . .	0.77	. . .
20	1.54	. . .	1.19	. . .	0.98	. . .	0.77	. . .
24	1.47	. . .	1.19	. . .	0.91	. . .	0.77	. . .

TABLE X1.3 Water Pressure Ratings at 73°F (23°C) for Schedule 120 PVC Plastic Pipe

Nominal Pipe Size, in.	psi							
	PVC1120, PVC1220, PVC2120		PVC2116		PVC2112		PVC2110	
	Unthreaded	Threaded	Unthreaded	Threaded	Unthreaded	Threaded	Unthreaded	Threaded
½	1010	510	810	410	630	320	510	250
¾	770	390	620	310	480	240	390	190
1	720	360	570	290	450	220	360	180
1¼	600	300	480	240	370	190	300	150
1½	540	270	430	210	340	170	270	130
2	470	240	380	190	290	150	240	120
2½	470	230	370	190	290	150	230	120
3	440	220	360	180	280	140	220	110
3½	380	190	310	150	240	120	190	100
4	430	220	340	170	270	130	220	110
5	400	200	320	160	250	120	200	100
6	370	190	300	150	230	120	190	90
8	380	180	290	140	230	110	180	90
10	370	180	290	140	230	110	180	90
12	340	170	270	140	210	110	170	80
	MPa							
½	6.96	3.52	5.58	2.83	4.34	2.21	3.52	1.72
¾	5.31	2.69	4.27	2.14	3.31	1.65	2.69	1.31
1	4.96	2.48	3.93	2.00	3.10	1.52	2.48	1.24
1¼	4.14	2.07	3.31	1.65	2.55	1.31	2.07	1.03
1½	3.72	1.86	2.96	1.45	2.34	1.17	1.86	0.90
2	3.24	1.65	2.62	1.31	2.00	1.03	1.65	0.83
2½	3.24	1.59	2.55	1.31	2.00	1.03	1.59	0.83
3	3.03	1.52	2.48	1.24	1.93	0.97	1.52	0.76
3½	2.62	1.31	2.14	1.03	1.65	0.83	1.31	0.69
4	2.96	1.52	2.34	1.17	1.86	0.90	1.52	0.76
5	2.76	1.38	2.21	1.10	1.72	0.83	1.38	0.69
6	2.55	1.31	2.07	1.03	1.59	0.83	1.31	0.62
8	2.62	1.24	2.00	0.97	1.59	0.76	1.24	0.62
10	2.55	1.24	2.00	0.97	1.59	0.76	1.24	0.62
12	2.34	1.17	1.86	0.97	1.45	0.76	1.17	0.55

Standard Specification for Poly(Vinyl Chloride) (PVC) Plastic Drain, Waste, and Vent Pipe and Fittings[1]

This standard is issued under the fixed designation D2665; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope*

1.1 This specification covers requirements and test methods for materials, dimensions and tolerances, pipe stiffness, crush resistance, impact resistance, and solvent cement for poly(vinyl chloride) plastic drain, waste, and vent pipe and fittings. A form of marking is also included. Plastic which does not meet the material requirements specified in Section 5 is excluded. Installation procedures are given in the Appendix.

1.2 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

1.3 The text of this specification references notes, footnotes, and appendixes which provide explanatory material. These notes and footnotes (excluding those in tables and figures) shall not be considered as requirements of the specification.

1.4 The following safety hazards caveat pertains only to the test methods portion, Section 7, of this specification: *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D618 Practice for Conditioning Plastics for Testing
D1600 Terminology for Abbreviated Terms Relating to Plastics
D1784 Specification for Rigid Poly(Vinyl Chloride) (PVC) Compounds and Chlorinated Poly(Vinyl Chloride) (CPVC) Compounds
D2122 Test Method for Determining Dimensions of Thermoplastic Pipe and Fittings
D2412 Test Method for Determination of External Loading Characteristics of Plastic Pipe by Parallel-Plate Loading
D2444 Test Method for Determination of the Impact Resistance of Thermoplastic Pipe and Fittings by Means of a Tup (Falling Weight)
D2564 Specification for Solvent Cements for Poly(Vinyl Chloride) (PVC) Plastic Piping Systems
D3311 Specification for Drain, Waste, and Vent (DWV) Plastic Fittings Patterns
D4396 Specification for Rigid Poly(Vinyl Chloride) (PVC) and Chlorinated Poly(Vinyl Chloride) (CPVC) Compounds for Plastic Pipe and Fittings Used in Nonpressure Applications
F402 Practice for Safe Handling of Solvent Cements, Primers, and Cleaners Used for Joining Thermoplastic Pipe and Fittings
F412 Terminology Relating to Plastic Piping Systems
F1498 Specification for Taper Pipe Threads 60° for Thermoplastic Pipe and Fittings
F1866 Specification for Poly (Vinyl Chloride) (PVC) Plastic Schedule 40 Drainage and DWV Fabricated Fittings
F2135 Specification for Molded Drain, Waste, and Vent (DWV) Short-Pattern Plastic Fittings

3. Terminology

3.1 *Definitions*—Definitions are in accordance with Terminology F412, and abbreviations are in accordance with Terminology D1600, unless otherwise specified.

4. Significance and Use

4.1 The requirements of this specification are intended to provide pipe and fittings suitable for the drainage and venting of sewage and certain other liquid wastes.

NOTE 1—Industrial waste disposal lines should be installed only with the specific approval of the cognizant building code authority since chemicals not commonly found in drains and sewers and temperatures in excess of 180°F (82.2°C) may be encountered.

---

[1] This specification is under the jurisdiction of ASTM Committee F17 on Plastic Piping Systems and is the direct responsibility of Subcommittee F17.63 on DWV.
Current edition approved March 1, 2009 Published March 2009. Originally approved in 1968. Last previous edition approved in 2008 as D2665 – 08b. DOI: 10.1520/D2665-09.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

***A Summary of Changes section appears at the end of this standard.**

NOTE 2—This specification does not include requirements for pipe and fittings intended to be used to vent combustion gases.

5. Materials

5.1 *Basic Materials*—The pipe shall be made of virgin PVC compounds meeting or exceeding the requirements of Class 12454 as defined in Specification D1784. The fittings shall be made of virgin PVC compounds meeting or exceeding the requirements of Class 12454 as defined in Specification D1784 or Class 11432 as defined in Specification D4396.These plastics contain stabilizers, lubricants, and pigments.

5.2 *Rework Material*—The manufacturer shall use only his own clean pipe or fitting rework material, and the pipe or fittings produced shall meet all the requirements of this specification.

5.3 *Solvent Cement*—The solvent cement used to join pipe and fittings made to this specification shall meet the requirements of Specification D2564.

6. Requirements

6.1 *General*—The pipe and fittings shall be homogeneous throughout and free of visible cracks, holes, foreign inclusions, or other injurious defects. The pipe shall be as uniform as commercially practicable in color, opacity, density, and other physical properties.

6.1.1 The requirements in this section are intended only for use as quality control tests, not as simulated service tests.

6.2 *Dimensions and Tolerances*:

6.2.1 *Method*—All dimensions shall be determined in accordance with Test Method D2122.

6.2.2 *Dimensions*:

6.2.2.1 The outside diameter and wall thicknesses of pipe shall meet the requirements of Table 2. The pipe shall be in either 10 or 20-ft (3.05 or 6.1-m) lengths, unless otherwise specified, with an allowable tolerance of +½ , −0 in. (+13, −0 mm).

6.2.2.2 The patterns, dimensions, and laying lengths of fittings, including adaptors, shall meet the requirements of Specification D3311 and Table 1.

6.2.2.3 The patterns, dimensions, and laying lengths of Short-Pattern fittings shall meet the requirements of Specification F2135.

6.2.2.4 The spigot dimensions of fittings shall meet the requirements of Table 2.

6.2.2.5 For all fittings having taper pipe threads, threads shall conform to Specification F1498 and be gaged in accordance with 7.5. Fittings of nominal sizes not given in Specifcation F1498 shall not have threads.

6.2.2.6 Fabricated DWV fittings shall comply with F1866.

6.3 *Pipe Stiffness, Deflection Load and Flattening*:

6.3.1 *Pipe*—The minimum pipe stiffness at 5 % deflection shall be in accordance with Table 3. The pipe shall deflect by 60 % of the nominal outside diameter (flattening) without cracking, rupture, or other visible evidence of failure when tested in accordance with 7.4.

6.3.1.1 *Pipe Stiffness (PS)*—Three specimens shall be tested. If all three meet the PS requirement, the sample meets the PS requirement. If one or two fail, additional testing shall be conducted in accordance with 6.3.1.2. If all three fail, the sample does not meet the PS requirement.

6.3.1.2 *Pipe Stiffness and Lower Confidence Limit*—In the event that one or two of the specimens tested in 6.3.1 fail to meet the minimum PS requirement, the average pipe stiffness of eleven specimens shall meet or exceed the minimum requirement given in Table 3. The 99 % lower confidence limit (LCL) shall be within 15 % of the average value. The LCL shall be calculated using the Student's "*t*" distribution, with *N*-1 degrees of freedom, where *N* is the number of specimens. The critical *t* value shall be used to at least three significant digits. Alternatively, if the LCL exceeds the minimum PS requirement in Table 3, but is not within 15 % of the average, the sample meets the requirements of the pipe stiffness testing. The eleven specimens include the three tested under 6.3.1, and an additional eight with rotation by 35°, as specified in Test Method D2412, continuing throughout the remaining specimens.

6.3.1.3 The LCL based on testing eleven specimens is calculated as follows:

$$\text{LCL} = (\text{avg PS}) - \{2.76(\text{std. dev.})/\sqrt{(N)}\} \quad (1)$$

where:

$$(\text{avg PS}) = [\Sigma(\text{PS}_i)]/ \quad (2)$$

$$(\text{std. dev.}) = \left[\frac{\Sigma PS^2 - (\Sigma PS)^2/N}{N - 1}\right]^{1/2}$$

N = 11

6.3.1.4 The 15 % requirement is calculated as follows:

$$(Avg - LCL)/(Avg) \times 100 \leq 15\ \% \quad (3)$$

NOTE 3—The 5 % deflection criterion, which was arbitrarily selected for testing convenience, should not be considered as a limitation with respect to in-use deflection. The engineer is responsible for establishing the acceptable deflection.

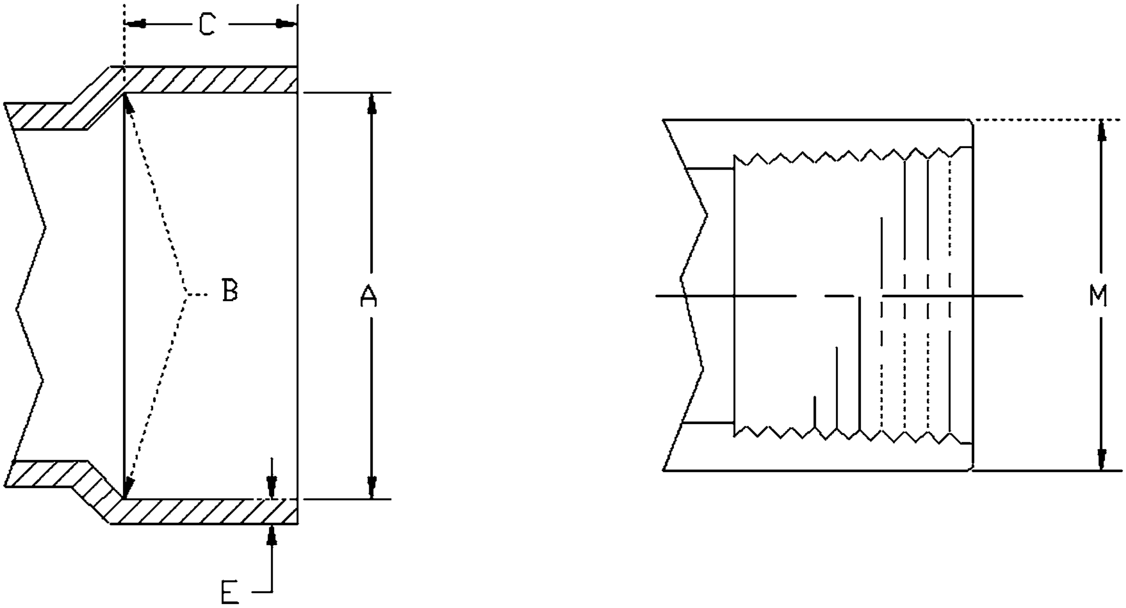
6.3.2 *Fittings*—Individual fittings unassembled shall withstand a minimum load of 750 lbf/ft (11 kN/m) of centerline length without cracking or other visible evidence of failure when tested in accordance with 7.4.

6.4 *Impact Resistance*—The minimum impact resistance of pipe and fittings, when tested at the time of manufacture, shall comply with Table 4. Test in accordance with Test Method D2444 using Tup C and Holder A for pipe and Tup A and Holder B for fittings. Use a 12-lb (5-kg) tup for testing pipe sizes 4 in. and smaller and a 20-lb (10-kg) tup for pipe larger than 4 in. Test fittings with a 12-lb (5-kg) Tup. Test couplings cemented to short pieces of pipe and allowed to dry for 24 h. For fittings larger than 4-in, a symmetric section cut from the hub or body with a minimum centerline length of 2 in. shall be permitted to be used rather than the entire fitting.

6.4.1 Test 10 specimens. When 9 or 10 specimens pass, accept the lot. When 2 or more specimens fail, test 10 additional specimens. When 17 of 20 specimens tested pass, accept the lot. When 4 or more of 20 specimens tested fail, test 20 addtional specimens. When 32 of 40 specimens pass, accept the lot. When 9 or more of 40 specimens fail, the lot does not meet the requirements of this specification.

TABLE 1 Dimensions and Tolerances for Fitting Sockets for PVC Plastic Drain, Waste and Vent Pipe Fittings

Table 1 Dimensions and Tolerances for PVC Schedule 40 Drain, Waste, and Vent Fittings



Nominal Pipe Size	A			B			C	E	Internal Threads	
	Socket Entrance Diameter			Socket Bottom Diameter			Socket Depth, min	Wall thickness min.[A]	Outside Diameter of Hub, M. min.	Thread length min.
	Average	Tolerance on Avg.	Out-of -Roundness	Average	Tolerance on Avg.	Out-of –Roundness				
					in. (mm)					
1¼	1.675 (42.54)	+0.010/-0.005 (+0.25/-0.13)	0.024 (0.61)	1.655 (42.04)	±0.005 (±0.13)	0.024 (0.61)	0.687 (17.44)	0.156 (3.96)	1.871 (47.52)	0.687 (17.44)
1½	1.915 (48.64)	+0.010/-0.005 (+0.25/-0.13)	0.024 (0.61)	1.894 (48.11)	±0.006 (±0.15)	0.024 (0.61)	0.687 (17.44)	0.156 (3.96)	2.127 (54.03)	0.687 (17.44)
2	2.390 (60.71)	+0.010/-0.005 (+0.25/-0.13)	0.024 (0.61)	2.369 (60.17)	±0.006 (±0.15)	0.024 (0.61)	0.750 (19.05)	0.156 (3.96)	2.634 (66.90)	0.750 (19.05)
3	3.520 (89.41)	+0.010/-0.005 (+0.25/-0.13)	0.030 (0.76)	3.492 (88.70)	±0.008 (±0.20)	0.030 (0.76)	1.500 (38.10)	0.219 (5.56)	3.841 (97.56)	1.187 (30.15)
4	4.520 (114.8)	+0.010/-0.005 (+0.25/-0.13)	0.030 (0.76)	4.491 (114.1)	±0.009 (±0.23)	0.030 (0.76)	1.750 (44.45)	0.250 (6.35)	4.907 (124.6)	1.28 (32.54)
6	6.647 (168.8)	+0.015/-0.010 (+0.38/-0.25)	0.060 (1.52)	6.614 (168.0)	±0.011 (±0.28)	0.060 (1.52)	3.000 (76.20	0.281 (7.14)	7.203 (183.0)	1.500 (38.10)
8	8.655 (219.8)	+0.030/-0.000 (+0.76/-0.00)	0.090 (2.29)	8.610 (218.7)	±0.015 (±0.38)	0.090 (2.29)	4.000 (101.6)	0.328 (8.33)	[B]	[B]
10	10.780 (273.8)	+0.025/-0.020 (+0.64/-0.51)	0.120 (3.05)	10.737 (272.7)	±0.015 (±0.38)	0.120 (3.04)	5.000 (127.0)	0.365 (9.28)	[B]	[B]
12	12.780 (324.6)	+0.030/-0.025 (+0.76/-0.64)	0.150 (3.81)	12.736 (323.5)	±0.015 (±0.38)	0.150 (3.81)	6.000 (152.4)	0.406 (10.3)	[B]	[B]

[A] The wall thickness is a minimum value except that a ±10% variation resulting from core shift is allowable. In such case, the average of the two opposite wall thicknesses shall equal or exceed the value shown in the table.
[B] Not applicable for these nominal sizes.

TABLE 2 Dimensions and Tolerances for Outside Diameters and Thicknesses of PVC Plastic Drain, Waste, and Vent Pipe

Nominal Pipe Size	Outside Diameter			Wall Thickness	
	Average	Tolerance on Average	Out-of-Roundness (maximum minus minimum)	Minimum	Tolerance
	in. (mm)				
1¼	1.660 (42.16)	±0.005 (0.13)	0.024 (0.61)	0.140 (3.56)	+0.020 (0.51) −0.000
1½	1.900 (48.26)	±0.006 (0.15)	0.024 (0.61)	0.145 (3.68)	+0.020 (0.51) −0.000
2	2.375 (60.33)	±0.006 (0.15)	0.024 (0.61)	0.154 (3.91)	+0.020 (0.51) −0.000
3	3.500 (88.90)	±0.008 (0.20)	0.030 (0.76)	0.216 (5.49)	+0.026 (0.66) −0.000
4	4.500 (114.30)	±0.009 (0.23)	0.100(2.54)	0.237 (6.02)	+0.028 (0.71) −0.000
6	6.625 (168.28)	±0.011 (0.28)	0.100 (2.54)	0.280 (7.11)	+0.034 (0.86) −0.000
8	8.625 (219.08)	±0.015 (0.38)	0.150 (3.81)	0.322 (8.18)	+0.039 (0.99) −0.000
10	10.750 (273.05)	±0.015 (0.38)	0.150 (3.81)	0.365 (9.27)	+0.044 (1.12) −0.000
12	12.750 (323.85)	±0.015 (0.38)	0.150 (3.81)	0.406 (10.31)	+0.049 (1.24) −0.000
14	14.000 (355.60)	±0.015 (±0.38)	0.200 (5.08)	0.437 (11.1)	+0.053 (1.35) −0.000
16	16.000 (406.40)	±0.019 (±0.48)	0.320 (8.13)	0.500 (12.7)	+0.060 (1.52) −0.000
18	18.000 (457.20)	±0.019 (±0.48)	0.360 (9.20)	0.562 (14.27)	+0.067 (1.71) −0.000
20	20.000 (508.00)	±0.023 (±0.58)	0.400 (10.20)	0.593 (15.06)	+0.071 (1.81) −0.000
24	24.000 (609.60)	±0.031 (±0.79)	0.480 (12.20)	0.687 (17.45)	+0.082 (2.09) −0.000

TABLE 3 Pipe Stiffness Requirements for PVC DWV Pipe[A]

Nominal Pipe Size, in.	Pipe Stiffness, min, psi (kPa)
1¼	1400 (9650)
1½	1010 (6960)
2	600 (4140)
3	510 (3520)
4	310 (2140)
6	150 (1030)
8	100 (690)
10	78 (530)
12	63 (430)
14	60 (415)
16	60 (415)
18	60 (415)
20	51 (350)
24	45 (315)

[A] Measured at 5 % deflection.

TABLE 4 Impact Resistance of PVC Plastic Drain, Waste and Vent Pipe and Fittings

Description	Impact Resistance, min., ft-lbf (J) 73°F (23°C)
All pipe sizes	60 (81)
All fitting sizes and types	15 (20)

6.4.2 Failure in the test specimens shall be shattering or any crack or break extending entirely through the pipe wall and visible to the unaided eye.

7. Test Methods

7.1 *Sampling*—A sample of the pipe and fittings sufficient to determine conformance with this specification shall be taken at random from each lot or shipment. About 40 ft (12 m) of pipe are required to make the tests prescribed. The number of fittings required varies depending on the size and type of fitting.

7.1.1 *Test Specimens*—Not less than 50 % of the test specimens required for any pressure test shall have at least a part of the marking in their central sections. The central section is that portion of pipe which is at least one pipe diameter away from an end closure.

7.2 *Conditioning*:

7.2.1 For referee purposes, condition the specimens prior to test at 73.4 ± 3.6°F (23 ± 2°C) and 50 ± 5 % relative humidity in accordance with Practice D618, Procedure A.

7.2.2 For routine quality control testing, condition the specimens at the temperature and humidity of the manufacturers testing facility for not less than 1 h or until the specimens are at the room temperature.

7.3 *Test Conditions*:

7.3.1 For referee purposes, conduct tests in the standard laboratory atmosphere of 73.4 ± 3.6°F (23 ± 2°C) and 50 ± 5 % relative humidity.

7.3.2 For routine control testing, conduct tests at the room temperature and humidity of the manufacturers testing area.

7.4 *Pipe Stiffness, Deflection Load, and Flattening*—Measure the pipe stiffness, the flattening of pipe and the deflection load of fittings in accordance with Test Method D2412. In the test for pipe, note the load when the initial diameter is reduced 5 % (pipe stiffness). Continue test until the diameter is deflected by 60 % of its original value (flattening). The rate of head approach shall be a minimum of 0.5 in./min

(12.5 mm/min). In case of disagreement, the referee test speed shall be 0.50 ± 0.02 in./min (12.5 ± 0.05 mm/min).

7.4.1 *Pipe*—Three specimens, each 6 ± ¼ in. (150 ± 3 mm) long, shall be tested. The ends shall be cut square and free of burrs and jagged edges. Each specimen shall meet the requirements of 6.3.1.

7.4.2 *Fittings*—Test three complete fittings. Each specimen shall meet the requirement of 6.3.2. Shim fittings to give full centerline contact with platens. Fittings having nonuniform diameters, such as reducers, shall be considered acceptable when the wall thickness at all points is equal to or greater than the wall thickness of pipe of the same material and diameter that meets the crush resistance requirements.

7.4.3 *Procedure*—Terminate the test when the diameter of pipe test specimens is reduced to 40 % of its original value or the pipe cracks or shows other evidence of visible failure. Terminate the test on fittings when the load reaches 750 lbf/ft (11 kN/m) of centerline length. Observe the load and deflection at the first evidence of cracking, if any. Record location and type of failure.

7.4.4 *Calculations*—For pipe, divide the load at failure (flattening) if such occurred, by the length of the pipe test specimen to obtain the flattening resistance. Express results in N/m or lbf/ft. Calculate the values for each specimen of pipe and fittings for conformance to the requirements of 6.3.1 and 6.3.2. For calculation of pipe stiffness, refer to the Calculation Section and the Appendix of Test Method D2412. Calculate the values for each specimen separately. Examine the results for each specimen of pipe for conformance to the requirements of Table 3.

7.5 *Threads*—All taper pipe threads shall be gaged in accordance with Specification F1498.

8. Retest and Rejection

8.1 If the results of any test(s) do not meet the requirements of this specification, the test(s) shall be conducted again only by agreement between the purchaser and the seller. Under such agreement, minimum requirements shall not be lowered, changed, or modified, nor shall specification limits be changed. If, upon retest, failure occurs, the quantity of product represented by the test(s) does not meet the requirements of this specification.

9. Product Marking

9.1 *Pipe*—The pipe shall be marked in letters not less than 3⁄16 in. (5 mm) high, in a contrasting color, and shall at least consist of the manufacturer's name or trademark, the designation ASTM D2665, the nominal pipe size, the symbol PVC, and the symbol DWV, spaced at intervals of not more than 5 ft (1.5 m).

NOTE 4—It is common practice to dual mark Schedule 40 DWV and potable water piping in which compliance with each applicable standard is met. This is NOT an acceptable practice when external recycled material is used in the manufacture of the pipe.

9.2 *Fittings*—Fittings shall be marked on the body or hub with the manufacturer's name or trademark, and the symbol PVC.

10. Quality Assurance

10.1 When the product is marked with this designation, D2665, the manufacturer affirms that the product was manufactured, inspected, sampled, and tested in accordance with this specification and has been found to meet the requirements of this specification.

11. Keywords

11.1 DWV; fittings; pipe; plastic; PVC; Schedule 40; thermoplastic

APPENDIX

(Nonmandatory Information)

X1. STORAGE AND INSTALLATION PROCEDURES FOR PVC PLASTIC DRAIN, WASTE, AND VENT PIPING

X1.1 *Storage*—Do not store pipe and fittings in direct sunlight for long periods. Store pipe in such a manner as to prevent sagging or bending. See X1.11.

X1.2 *Visibility of Marking*—Always position pipe and fittings so that identifying markings are readily visible to inspection when installed.

X1.3 *Solvent Cement*—Use solvent cements meeting the requirements of Specification D2564 and packaged in containers suitable for size of pipe being joined. Do not thin the cement. Discard cement that has thickened. Solvent cements are flammable. Keep away from heat, spark, and open flame. Avoid prolonged breathing of vapors. Prolonged contact with skin is harmful. Use with adequate ventilation and avoid contact with eyes and skin. For further information, see Practice F402.

X1.4 *Socket Fit*—PVC pipe and fittings are manufactured to close tolerances. Close tolerances are required to ensure satisfactory" interference" fit between the pipe and fitting during the solvent cement joining. Use only pipe and fitting combinations that give interference fits. Pipe loose in the socket may not properly fuse chemically. The allowable tolerances assure a forced fit and when solvent is applied will readily mate, thus assuring a chemical fusion equal in strength to pipe or fitting. Attempting to correct a loose fit after assembly by additional cement may result in an unsatisfactory joint.

TABLE X1.1 Thermal Expansion Table for PVC Plastic Pipe and Fittings

Length, ft	Temperature Change, °F (°C)						
	40 (22.2)	50 (27.8)	60 (33.3)	70 (38.8)	80 (44.4)	90 (50)	100 (55.6)
	Length change, in. (mm)						
20	0.28 (7.11)	0.35 (8.89)	0.42 (10.68)	0.49 (12.46)	0.56 (14.25)	0.63 (16.03)	0.70 (17.81)
40	0.56 (14.22)	0.70 (17.78)	0.84 (21.37)	0.97 (24.68)	1.11 (28.24)	1.25 (31.80)	1.39 (35.36)
60	0.84 (21.34)	1.04 (26.42)	1.25 (31.80)	1.46 (37.14)	1.67 (42.48)	1.88 (47.83)	2.09 (53.17)
80	1.13 (28.70)	1.39 (35.31)	1.67 (42.48)	1.95 (49.61)	2.23 (56.73)	2.51 (63.85)	2.78 (70.72)
100	1.39 (35.31)	1.74 (44.20)	2.09 (53.17)	2.44 (62.07)	2.78 (70.72)	3.13 (79.63)	3.48 (88.53)

X1.5 *Joining Technique:*

X1.5.1 *Cutting the Pipe*—Cut the pipe square with saws or pipe cutters designed specifically for this material; protect pipe and fittings from serrated holding devices and abrasion.

X1.5.2 *Deburring Pipe*—Remove burrs from inside and outside pipe edges.

X1.5.3 *Cleaning Joining Surfaces*—Wipe off all dust, dirt, and moisture from surfaces to be cemented with a clean, dry rag or paper towel. Remove gloss and any oily film from the pipe and mating socket with clean steel wool, fine abrasive paper, chemical cleaner, or primer. In case of conflicting solvent cementing instructions, the instructions of the cement manufacturer should be followed.

X1.5.4 *Application of Cement*—Use a natural bristle or nylon brush of adequate size (usually at least 1/2 the pipe diameter) or an applicator supplied with the can of cement. Apply a moderate even coating of cement in the fitting socket completely covering the pipe joining surfaces only. Heavy or excessive applications of cement may become an obstruction inside of the piping. Quickly apply a heavy even coat of cement to the outside of the pipe. Make sure that the coated distance on the pipe is equal to the depth of the fitting socket.

X1.5.5 *Assembly*—Make the joint as quickly as possible after application of the cement and before the cement dries. Insert the pipe into the fitting socket turning the pipe slightly to ensure even distribution of cement. Make sure that the pipe is inserted to the full depth of the socket. Remove excess solvent cement from the exterior of the joint with a clean, dry cloth. Reasonable handling of the assembly is permissible after 2 min. Do not attempt to disturb the pipe-fitting joint until after the cement has set; damage to the joint and loss of fit may result. Should the cement dry partially before joint is made up, reapply cement before assembling. Allow 15 min for joint to develop good handling strength.

X1.6 *Joints:*

X1.6.1 *Threaded Connection*—Do not cut threads on PVC drain, waste, and vent pipe. Molded threads are permitted. Use of adapter fittings for transition to threaded construction is necessary except in the case of cleanout plugs. The joint between the PVC pipe and transition fitting should be of the solvent cement type. Only approved thread tape or thread lubricant specifically intended for use with PVC plastic pipe should be used. Conventional pipe thread compounds, putty linseed oil base products, and unknown mixtures shall be avoided.

X1.6.2 *Connections to Traps*—Connect traps by means of approved threaded trap adapters.

X1.6.3 *Connection to Closet Flanges*—Install screw-type closet flanges in the drainage system by means of a threaded connection. Install caulk-type closet flanges in accordance with the procedure outlined in X1.6.6.

X1.6.4 *Connection to Nonplastic Pipe*—When connecting plastic pipe to other types of piping use only approved types of fittings and adapters, designed for the specific transition intended.

X1.6.5 *Thread Tightness*—Where a threaded joint is made, obtain tightness by maximum hand tightening plus additional tightening with a strap wrench not to exceed one full turn.

X1.6.6 *Transition to Bell-and-Spigot Pipe*—Make connections or transitions to bell–and–spigot cast–iron soil pipe and fittings, and to bell–and–spigot pipe and fittings of other materials, with approved elastomeric or mechanical compression joints designed for this use, or by utilizing caulked joints made with caulking materials designed and approved for these types of applications.

X1.7 *Alignment and Grade*—Align all piping system components properly without strain. Do not bend or pull pipe into position after being solvent welded. Grade of horizontal drainage and vent piping shall be as specified for other materials in the applicable code.

X1.8 *Supports and Spacing*—Hangers and straps should not compress, distort, cut or abrade the piping and should allow free movement of pipe. Support horizontal piping at intervals of not more than 4 ft (1.2 m), at end of branches, and at changes of direction or elevation. Supports should allow free movement. Maintain vertical piping in straight alignment with supports at each floor level or at 10-ft (3.1-m) intervals, whichever is less. Support trap arms in excess of 3 ft (0.9 m) in length as close as possible to the trap. Securely fasten closet rings with corrosion-resistant fasteners to the floor with top surface ¼ in. (6.4 mm) above the finish floor level. Stabilize the closet bends or stubs against all horizontal or vertical movement. Protect the pipe exposed to damage by sharp surfaces with grommets or sleeves of rubber or plastic.

X1.9 *Thermal Expansion*—Allow for thermal expansion and movement in all piping installations by the use of approved methods. Support but do not rigidly restrain piping at branches or changes of direction. Do not anchor pipe rigidly in walls. Holes through framing members should be adequately sized to allow for free movement. Thermal expansion for installations subject to temperature changes may be determined from Table X1.1. The linear expansion shown is independent of the diameter of the pipe. Buried piping or piping installed in the crawl space under a building is normally subject to less than the ambient temperature change. Do not install piping except vent piping through roofs, so as to be exposed to direct sunlight after installation.

X1.10 *Building Drains Under Floor Slabs*— Make trench bottoms smooth and of uniform grade with either undisturbed soil or a layer of selected and compacted backfill so that no settlement will be encountered. Pipe must bear on this material throughout the entire length of its barrel.

X1.11 *Exposed Piping*—Provide adequate support where piping is exposed to wind, snow, and ice loading. Plumbing vents exposed to sunlight shall be protected by water-base synthetic latex paints. Where surface temperatures exceed 140°F (60°C) piping shall be protected by means of shielding or some type of lightweight insulation. Exposure to sunlight during normal construction periods is not harmful. It is good practice to store pipe and fittings under suitable cover prior to installation.

X1.12 *Antifreeze Protection*—When necessary to protect traps and fixtures from freezing do not use petroleum products. Use only approved plastic pipe antifreeze packaged for this purpose or one of the following solutions:

X1.12.1 A60 weight % of glycerin in water mixed at 74°F (23°C).

X1.12.2 A22 weight % of magnesium chloride in water. Strong solutions of common table salt (sodium chloride) may also be used.

SUMMARY OF CHANGES

Committee F17 has identified the location of selected changes to this standard since the last issue (D2665-08b) that may impact the use of this standard. (Approved March 1, 2009.)

(*1*) 7.4 was revised.

Committee F17 has identified the location of selected changes to this standard since the last issue (D2665–08a) that may impact the use of this standard.

(*1*) Deletion of reference to molten lead caulked joints in X1.6.6.

Appendix E

Pressure Loss Calculations

System Pressure Analysis from R. Fox, P. Pritchard, A. McDonald, *Introduction to Fluid Mechanics,* Hoboken, NJ: John Wiley & Sons Inc, 2009, pp. 328-338.

Design For maximum flow rate:

$$Q = 75\ US\ gpm$$

Using schedule 40 PVC pipe with an inner diameter of:

$$D = 2.047\ in$$

The resulting velocity is:

$$V = 438.7\ ft/min$$

The previous values have been converted to metric to simplify the analysis.

Assuming a density and dynamic viscosity of:

$$\rho = 1.05x10^3 \frac{kg}{m^3}$$

$$\mu = 3.37x10^{-3} \frac{kg}{m \cdot s}$$

With a relative roughness of the PVC pipe to be:

$$e = 0.007\ mm$$

The non-dimensional Reynolds Number for the flow is calculated as:

$$Re = \frac{\rho V D}{\mu}$$

$$Re = 3.62x10^4$$

Therefore the flow in the pipe is turbulent as the current Reynolds Number is greater the 2300. The ration of relative roughness over the pipe diameter is used in conjunction with the Moody Diagram to find the friction factor of the flow:

$$f = 0.023$$

From the dimensions of the Dyno bay an approximate length of 27.5 m of pipe is to be used on the return pump system along with a globe valve and approximately 14, 90 degree radius elbows. Using the length of the pipe, and an equivalent length of the fittings, the losses of the system may be calculated, and are found to be:

$$h_l = 60.18\frac{m^2}{s^2}$$

The head losses of the radiators are approximated using each single pass in the radiator as one small pipe. The head loss across one radiator was determined, and accounting for six radiators is use, the total radiator losses are found to be:

$$h_{l\,radiator} = 6\frac{\mathrm{m}^2}{\mathrm{s}^2}$$

Assuming no change in elevation, and now using the water density to match the available pump curves, the pressure drop the system may be calculated from:

$$\Delta P = \rho\,(h_l + h_{l\,radiator})$$

$$\Delta P = 74.1\ kPa\ \ or\ 24.79\ ft\ of\ water$$

The system pressure may be compared to the pump curve for the Monarch pump BSE-S150. The curve shows that the pump will be able to provide sufficient flow at the estimated system pressure drop.

The same calculation may be carried out for the supply pump. The head losses are slightly less than the return pump, as there are no radiators, but the supply pump must be able to provide 75 US gpm at a minimum 75 psi.

The resulting pressure drop calculated for the supply pump system is found to be:

$$\Delta P = 63.39\ kPa\ or\ 21.2\ ft\ water$$

Appendix F

Heat Loss Calculations

The following calculations were performed based on formulas and concepts from:
F.P. Incropera, D.P. DeWitt, T.L. Bergman, and A.S. Lavine, *Fundamentals of Heat and Mass Transfer, Sixth Edition.* Hoboken, NJ: John Wiley and Sons, 2007.

Assumptions for Summer Conditions

Water (hot fluid)

Properties @ T_f

$$T_f = \frac{T_i + T_o}{2} = \frac{25 + 77.11}{2} = 48.05°C$$

$\rho = 9.87\times10^2\ kg/m^3$
$\mu = 5.5011\times10^{-4}\ kg/m\cdot s$
$C_p = 4066.2\ J/kg\cdot K$
$k = .64180\ W/m\cdot K$
$P_r = 3.4857$

To determine if the flow is fully developed:

(1) $Re_D = \frac{\rho V D}{\mu}$

(2) $x_{fd,h} = (.05)Re_D D$

(3) $x_{fd,t} = (.05)Re_D P_r D$

Heat Load Calculation Process:

(4) $Nu_D = 1.86\left(\frac{Re_D P_r}{(L/D)}\right)^{\frac{1}{3}}\left(\frac{\mu}{\mu_s}\right)^{.14}$

Assuming $\left(\frac{\mu}{\mu_s}\right)$ is equal to one.

(5) $h = \frac{Nu_D k_f}{D}$ for a single tube

(6) $h_o = h_h = \left(\frac{Nu_D k_f}{D}\right)540$ for the whole radiator

Air (cold fluid)

Properties @ T_i

$T_i = 35°C$ (summer air temperature)

$\rho = 1.1459\ kg/m^3$
$\mu = 1.8915\times10^{-5}\ kg/m\cdot s$
$C_p = 1.0067\times10^3\ J/kg\cdot K$
$k = .026710$
$P_r = .026710$

D_o=.0079m

N_L=90

N_T=6

S_T=.0097m

S_L=.0211m

C_1=.348

m=.592

C_2=.94

D_i=.008m

A_{tot}=1.131m^2

A_{tube}=.711m^2

$\dot{m}_a = \rho V(\,A_{tot} - A_{Tube}540\,)$

Heat Load Calculation Process:

(1) $Re_{eD,max} = \frac{\rho V_{max} D}{\mu}$

(2) $V_{max} = \frac{S_T}{S_T - D}V$

(3) $Nu_D = 1.13 C_1 C_2 \left(Re_{D,max}\right)^m P_r^{\frac{1}{3}}$

(4) $U = \frac{1}{A\left[\frac{1}{h_i A_i} + \frac{ln\left(\frac{D_o}{D_i}\right)}{2\pi k_s L} + \frac{1}{h_o A_o}\right]}$

(5) $C_L = \dot{m}_a C_{pc}$

(6) $C_{Lh} = \dot{m}_{wa} C_{ph}$

(7) $q_{max} = C_{Min}(T_{hi} - T_{ci})$

Where $T_{hi} \cong 345K$ and $T_{ci} \cong 300K$

(8) $NTU = \frac{U A_{Tot}}{C_{min}}$

(9) $\epsilon = 1 - e^{\left[\frac{1}{C_r} NTU^{.22} e^{\left[-C_r NTU^{.78} - 1\right]}\right]}$

(10) $q = \epsilon q_{max}$

50/50 Solution Coolent		
	Mass Flow Rate (kg/s)	C_p (J/kg *K)
	4.888	3348
Inlet Temperature (Degrees Celcus)	Temperature Difference	Q, dot (kJ/s)
25.00	46.11	754.59
26.00	45.11	738.23
27.00	44.11	721.86
28.00	43.11	705.50
29.00	42.11	689.13
30.00	41.11	672.77
31.00	40.11	656.40
32.00	39.11	640.04
33.00	38.11	623.67
34.00	37.11	607.31
35.00	36.11	590.94
36.00	35.11	574.58
37.00	34.11	558.21
38.00	33.11	541.85
39.00	32.11	525.48
40.00	31.11	509.12
41.00	30.11	492.75
42.00	29.11	476.39
43.00	28.11	460.02
44.00	27.11	443.66
45.00	26.11	427.29
46.00	25.11	410.93
47.00	24.11	394.56
48.00	23.11	378.20
49.00	22.11	361.83
50.00	21.11	345.47
51.00	20.11	329.10
52.00	19.11	312.74
53.00	18.11	296.37
54.00	17.11	280.01
55.00	16.11	263.64
56.00	15.11	247.28
57.00	14.11	230.91
58.00	13.11	214.55
59.00	12.11	198.18
60.00	11.11	181.82
61.00	10.11	165.45

62.00	9.11	149.09
63.00	8.11	132.72
64.00	7.11	116.36
65.00	6.11	99.99
66.00	5.11	83.63
67.00	4.11	67.26
68.00	3.11	50.90
69.00	2.11	34.53
70.00	1.11	18.17
71.00	0.11	1.80

Air Summer Extreme (50/50 Ethylene Glyol Water Solution)	Ts (Average of Inlet and outlet tem of Rad) (°C)	43.00
	Tf (°C)	39.00
	h, bar inner	235,658.92
	Mass flow rate (Coolent) (kg/s)	4.64
	C_h for Coolent	17,274.80

Air Velocity (m/s)	V, max air (m/s)	$R_{emax\ (Air)}$	$Nu_{D\ (AIR)}$	h, bar outer (air)	U	Air Mass flow rate (kg/s)	$C_{c\ (Air)}$	q_{max}	NTU	C_r	ε	q (J/S)	q (W)
3.50	20.78	10,328.22	78.32	260.75	103.90	1.68	4,629.43	208,324.38	0.87	0.27	0.54	112,088.38	112.09
3.75	22.27	11,065.95	81.59	271.62	107.72	1.80	4,960.10	223,204.70	0.84	0.29	0.52	117,080.94	117.08
4.00	23.75	11,803.68	84.77	282.20	111.40	1.92	5,290.78	238,085.01	0.81	0.31	0.51	121,879.24	121.88
4.25	25.23	12,541.41	87.86	292.51	114.95	2.04	5,621.45	252,965.32	0.79	0.33	0.50	126,497.92	126.50
4.50	26.72	13,279.14	90.89	302.58	118.39	2.16	5,952.13	267,845.64	0.77	0.34	0.49	130,949.89	130.95
4.75	28.20	14,016.87	93.84	312.42	121.72	2.28	6,282.80	282,725.95	0.75	0.36	0.48	135,246.59	135.25
5.00	29.69	14,754.60	96.74	322.05	124.96	2.40	6,613.47	297,606.26	0.73	0.38	0.47	139,398.24	139.40
5.25	31.17	15,492.33	99.57	331.49	128.10	2.52	6,944.15	312,486.58	0.71	0.40	0.46	143,413.99	143.41
5.50	32.66	16,230.06	102.35	340.75	131.16	2.64	7,274.82	327,366.89	0.70	0.42	0.45	147,302.10	147.30
5.75	34.14	16,967.79	105.08	349.83	134.14	2.76	7,605.49	342,247.20	0.68	0.44	0.44	151,070.03	151.07
6.00	35.63	17,705.52	107.76	358.76	137.05	2.88	7,936.17	357,127.52	0.67	0.46	0.43	154,724.57	154.72
6.25	37.11	18,443.24	110.40	367.53	139.88	3.00	8,266.84	372,007.83	0.65	0.48	0.43	158,271.92	158.27
6.50	38.59	19,180.97	112.99	376.17	142.65	3.12	8,597.51	386,888.14	0.64	0.50	0.42	161,717.74	161.72
6.75	40.08	19,918.70	115.55	384.67	145.35	3.24	8,928.19	401,768.45	0.63	0.52	0.41	165,067.23	165.07
7.00	41.56	20,656.43	118.06	393.04	148.00	3.36	9,258.86	416,648.77	0.62	0.54	0.40	168,325.21	168.33

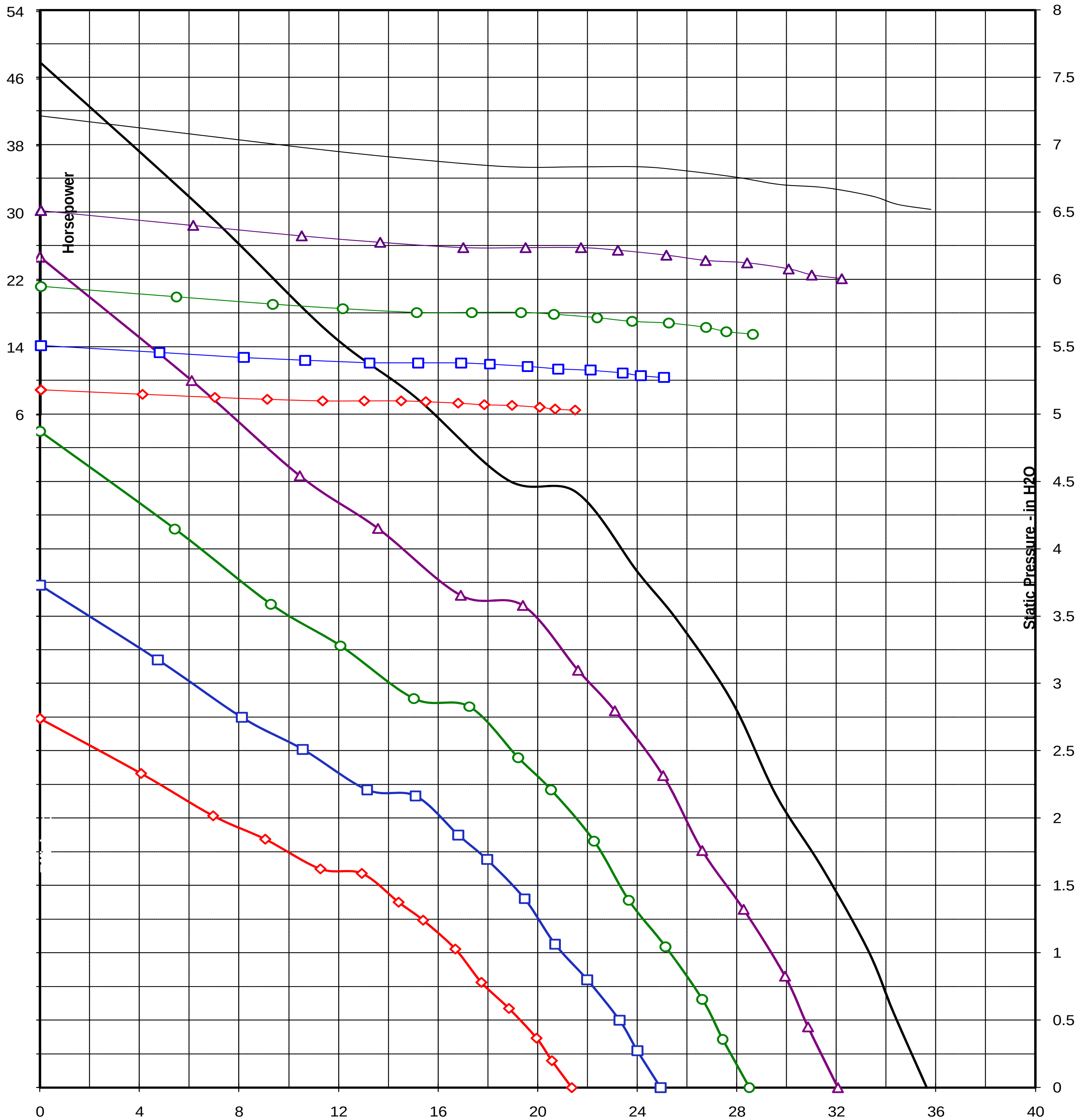
7.25	43.05	21,394.16	120.54	401.29	150.59	3.48	9,589.54	431,529.08	0.61	0.56	0.40	171,496.08	171.50
7.50	44.53	22,131.89	122.98	409.42	153.13	3.60	9,920.21	446,409.39	0.60	0.57	0.39	174,583.94	174.58
7.75	46.02	22,869.62	125.39	417.45	155.61	3.72	10,250.88	461,289.71	0.59	0.59	0.38	177,592.61	177.59
8.00	47.50	23,607.35	127.77	425.37	158.05	3.84	10,581.56	476,170.02	0.58	0.61	0.38	180,525.62	180.53
8.25	48.98	24,345.08	130.12	433.19	160.44	3.96	10,912.23	491,050.33	0.57	0.63	0.37	183,386.25	183.39
8.50	50.47	25,082.81	132.44	440.91	162.79	4.08	11,242.90	505,930.65	0.56	0.65	0.37	186,177.60	186.18
8.75	51.95	25,820.54	134.73	448.54	165.09	4.20	11,573.58	520,810.96	0.55	0.67	0.36	188,902.53	188.90
9.00	53.44	26,558.27	137.00	456.09	167.36	4.32	11,904.25	535,691.27	0.54	0.69	0.36	191,563.74	191.56
9.25	54.92	27,296.00	139.24	463.54	169.58	4.44	12,234.92	550,571.59	0.54	0.71	0.35	194,163.78	194.16
9.50	56.41	28,033.73	141.46	470.92	171.77	4.56	12,565.60	565,451.90	0.53	0.73	0.35	196,705.01	196.71
9.75	57.89	28,771.46	143.65	478.22	173.92	4.68	12,896.27	580,332.21	0.52	0.75	0.34	199,189.67	199.19
10.00	59.38	29,509.19	145.82	485.44	176.03	4.80	13,226.95	595,212.53	0.52	0.77	0.34	201,619.89	201.62
10.25	60.86	30,246.92	147.96	492.59	178.12	4.92	13,557.62	610,092.84	0.51	0.78	0.33	203,997.65	204.00
10.50	62.34	30,984.65	150.09	499.67	180.17	5.04	13,888.29	624,973.15	0.50	0.80	0.33	206,324.83	206.32
10.75	63.83	31,722.38	152.20	506.67	182.19	5.16	14,218.97	639,853.46	0.50	0.82	0.33	208,603.23	208.60
11.00	65.31	32,460.11	154.28	513.62	184.17	5.28	14,549.64	654,733.78	0.49	0.84	0.32	210,834.52	210.83
11.25	66.80	33,197.84	156.35	520.50	186.13	5.40	14,880.31	669,614.09	0.48	0.86	0.32	213,020.32	213.02
11.50	68.28	33,935.57	158.39	527.31	188.07	5.52	15,210.99	684,494.40	0.48	0.88	0.31	215,162.14	215.16
11.75	69.77	34,673.30	160.42	534.07	189.97	5.64	15,541.66	699,374.72	0.47	0.90	0.31	217,261.43	217.26
12.00	71.25	35,411.03	162.44	540.77	191.85	5.76	15,872.33	714,255.03	0.47	0.92	0.31	219,319.56	219.32
12.25	72.73	36,148.76	164.43	547.41	193.70	5.88	16,203.01	729,135.34	0.46	0.94	0.30	221,337.85	221.34
12.50	74.22	36,886.49	166.41	554.00	195.53	6.00	16,533.68	744,015.66	0.46	0.96	0.30	223,317.54	223.32
12.75	75.70	37,624.22	168.37	560.53	197.33	6.12	16,864.35	758,895.97	0.45	0.98	0.30	225,259.82	225.26
13.00	77.19	38,361.95	170.32	567.01	199.11	6.24	17,195.03	773,776.28	0.45	1.00	0.29	227,165.83	227.17
13.25	78.67	39,099.68	172.25	573.44	200.87	6.36	17,525.70	788,656.60	0.44	0.99	0.29	230,379.15	230.38
13.50	80.16	39,837.41	174.17	579.82	202.60	6.48	17,856.38	803,536.91	0.44	0.97	0.29	233,975.36	233.98
13.75	81.64	40,575.14	176.07	586.15	204.32	6.60	18,187.05	818,417.22	0.43	0.95	0.29	237,527.34	237.53
14.00	83.13	41,312.87	177.96	592.44	206.01	6.72	18,517.72	833,297.54	0.43	0.93	0.29	241,036.09	241.04
14.25	84.61	42,050.60	179.83	598.68	207.68	6.84	18,848.40	848,177.85	0.43	0.92	0.29	244,502.62	244.50
14.50	86.09	42,788.33	181.69	604.87	209.34	6.96	19,179.07	863,058.16	0.42	0.90	0.29	247,927.88	247.93
14.75	87.58	43,526.06	183.54	611.03	210.97	7.08	19,509.74	877,938.47	0.47	0.89	0.31	273,389.02	273.39

15.00	89.06	44,263.79	185.38	617.14	212.58	7.20	19,840.42	892,818.79	0.48	0.87	0.31	280,340.32	280.34
15.25	90.55	45,001.52	187.20	623.21	214.18	7.32	20,171.09	907,699.10	0.48	0.86	0.32	287,335.46	287.34
15.50	92.03	45,739.25	189.01	629.23	215.76	7.44	20,501.76	922,579.41	0.48	0.84	0.32	294,373.64	294.37
15.75	93.52	46,476.98	190.81	635.22	217.32	7.56	20,832.44	937,459.73	0.49	0.83	0.32	301,454.11	301.45
16.00	95.00	47,214.71	192.60	641.17	218.86	7.68	21,163.11	952,340.04	0.49	0.82	0.32	308,576.14	308.58
16.25	96.48	47,952.44	194.37	647.08	220.39	7.80	21,493.79	967,220.35	0.49	0.80	0.33	315,739.01	315.74
16.50	97.97	48,690.17	196.14	652.96	221.90	7.92	21,824.46	982,100.67	0.50	0.79	0.33	322,942.03	322.94
16.75	99.45	49,427.90	197.89	658.80	223.40	8.04	22,155.13	996,980.98	0.50	0.78	0.33	330,184.53	330.18
17.00	100.94	50,165.63	199.63	664.60	224.87	8.16	22,485.81	1,011,861.29	0.50	0.77	0.33	337,465.84	337.47
17.25	102.42	50,903.36	201.37	670.37	226.34	8.28	22,816.48	1,026,741.61	0.51	0.76	0.34	344,785.33	344.79
17.50	103.91	51,641.09	203.09	676.10	227.79	8.40	23,147.15	1,041,621.92	0.51	0.75	0.34	352,142.37	352.14
17.75	105.39	52,378.82	204.80	681.81	229.22	8.52	23,477.83	1,056,502.23	0.51	0.74	0.34	359,536.36	359.54
18.00	106.88	53,116.55	206.50	687.47	230.64	8.64	23,808.50	1,071,382.55	0.52	0.73	0.34	366,966.72	366.97
18.25	108.36	53,854.27	208.20	693.11	232.05	8.76	24,139.17	1,086,262.86	0.52	0.72	0.34	374,432.86	374.43
18.50	109.84	54,592.00	209.88	698.72	233.44	8.88	24,469.85	1,101,143.17	0.52	0.71	0.35	381,934.24	381.93
18.75	111.33	55,329.73	211.56	704.29	234.82	9.00	24,800.52	1,116,023.48	0.53	0.70	0.35	389,470.29	389.47
19.00	112.81	56,067.46	213.22	709.84	236.19	9.12	25,131.20	1,130,903.80	0.53	0.69	0.35	397,040.50	397.04

Airflow Performance Comparison Curves

Horton Inc.
201 W. Carmel Drive
Carmel, IN 46032
(USA) 317.249.4001

Test No.	Blades (No.)	Dia. (in)	Speed (R.P.M.)	Air ρ (lb/ft3)	Horton P/N	Customer P/N	Shroud Dia.	Shroud Type	Fan Imm.
— P8395	8	33.0	2000	0.075	412815	-	34.0	FLAT PLATE	50%
◇ P8395	8	33.0	1200	0.075	412815	-	34.0	FLAT PLATE	50%
□ P8395	8	33.0	1400	0.075	412815	-	34.0	FLAT PLATE	50%
○ P8395	8	33.0	1600	0.075	412815	-	34.0	FLAT PLATE	50%
△ P8395	8	33.0	1800	0.075	412815	-	34.0	FLAT PLATE	50%



10/26/2010

P-8395		33 in	HFS # 412815		2000 RPI	1	0.075 lb/ft3		70
PT#	ϕ	ψ	λ	Seff	Teff	CFM	Ps	Hp	dBA
1	.347	.000	1.02	.00	41.29	35629	0.00	30.48	
2	.334	.030	1.04	9.67	45.78	34294	0.56	31.08	
3	.324	.055	1.07	16.66	48.61	33267	1.02	32.07	
4	.306	.088	1.10	24.43	50.53	31419	1.63	33.06	
5	.288	.117	1.12	30.21	51.72	29571	2.17	33.45	
6	.271	.154	1.15	36.47	53.94	27826	2.86	34.31	
7	.250	.186	1.17	39.70	53.10	25669	3.45	35.12	
8	.234	.206	1.19	40.67	51.53	24026	3.82	35.54	
9	.210	.238	1.19	42.17	50.02	21562	4.42	35.54	
10	.183	.243	1.19	37.52	42.71	18790	4.51	35.54	
11	.147	.276	1.22	33.41	36.04	15094	5.12	36.41	
12	.113	.302	1.25	27.32	28.48	11603	5.61	37.46	
13	.066	.349	1.31	17.64	17.86	6777	6.48	39.17	
14	.000	.410	1.39	.00	.00	0	7.61	41.59	
P-8395		33 in	HFS # 412815		1200 RPI	1	0.075 lb/ft3		A
PT#	ϕ	ψ	λ	Seff	Teff	CFM	Ps	Hp	dBA
1	.347	.000	1.02	.00	41.29	21377	0.00	6.58	
2	.334	.030	1.04	9.67	45.78	20576	0.20	6.71	
3	.324	.055	1.07	16.66	48.61	19960	0.37	6.93	
4	.306	.088	1.10	24.43	50.53	18852	0.59	7.14	
5	.288	.117	1.12	30.21	51.72	17743	0.78	7.22	
6	.271	.154	1.15	36.47	53.94	16695	1.03	7.41	
7	.250	.186	1.17	39.70	53.10	15402	1.24	7.59	
8	.234	.206	1.19	40.67	51.53	14416	1.38	7.68	
9	.210	.238	1.19	42.17	50.02	12937	1.59	7.68	
10	.183	.243	1.19	37.52	42.71	11274	1.62	7.68	
11	.147	.276	1.22	33.41	36.04	9056	1.84	7.86	
12	.113	.302	1.25	27.32	28.48	6962	2.02	8.09	
13	.066	.349	1.31	17.64	17.86	4066	2.33	8.46	
14	.000	.410	1.39	.00	.00	0	2.74	8.98	
P-8395		33 in	HFS # 412815		1400 RPI	1	0.075 lb/ft3		G
PT#	ϕ	ψ	λ	Seff	Teff	CFM	Ps	Hp	dBA
1	.347	.000	1.02	.00	41.29	24940	0.00	10.46	
2	.334	.030	1.04	9.67	45.78	24006	0.27	10.66	
3	.324	.055	1.07	16.66	48.61	23287	0.50	11.00	
4	.306	.088	1.10	24.43	50.53	21993	0.80	11.34	
5	.288	.117	1.12	30.21	51.72	20700	1.06	11.47	
6	.271	.154	1.15	36.47	53.94	19478	1.40	11.77	
7	.250	.186	1.17	39.70	53.10	17969	1.69	12.05	

8	.234	.206	1.19	40.67	51.53	16819	1.87	12.19	
9	.210	.238	1.19	42.17	50.02	15094	2.16	12.19	
10	.183	.243	1.19	37.52	42.71	13153	2.21	12.19	
11	.147	.276	1.22	33.41	36.04	10565	2.51	12.49	
12	.113	.302	1.25	27.32	28.48	8122	2.75	12.85	
13	.066	.349	1.31	17.64	17.86	4744	3.17	13.43	
14	.000	.410	1.39	.00	.00	0	3.73	14.27	
P-8395		33 in	HFS # 412815		1600 RPI	1	0.075 lb/ft3		E
PT#	φ	ψ	λ	Seff	Teff	CFM	Ps	Hp	dBA
1	.347	.000	1.02	.00	41.29	28503	0.00	15.61	
2	.334	.030	1.04	9.67	45.78	27435	0.36	15.91	
3	.324	.055	1.07	16.66	48.61	26614	0.65	16.42	
4	.306	.088	1.10	24.43	50.53	25135	1.05	16.93	
5	.288	.117	1.12	30.21	51.72	23657	1.39	17.12	
6	.271	.154	1.15	36.47	53.94	22260	1.83	17.57	
7	.250	.186	1.17	39.70	53.10	20535	2.21	17.98	
8	.234	.206	1.19	40.67	51.53	19221	2.45	18.20	
9	.210	.238	1.19	42.17	50.02	17250	2.83	18.20	
10	.183	.243	1.19	37.52	42.71	15032	2.89	18.20	
11	.147	.276	1.22	33.41	36.04	12075	3.28	18.64	
12	.113	.302	1.25	27.32	28.48	9282	3.59	19.18	
13	.066	.349	1.31	17.64	17.86	5421	4.15	20.05	
14	.000	.410	1.39	.00	.00	0	4.87	21.29	
P-8395		33 in	HFS # 412815		1800 RPI	1	0.075 lb/ft3		C
PT#	φ	ψ	λ	Seff	Teff	CFM	Ps	Hp	dBA
1	.347	.000	1.02	.00	41.29	32066	0.00	22.22	
2	.334	.030	1.04	9.67	45.78	30865	0.45	22.66	
3	.324	.055	1.07	16.66	48.61	29941	0.83	23.38	
4	.306	.088	1.10	24.43	50.53	28277	1.32	24.10	
5	.288	.117	1.12	30.21	51.72	26614	1.76	24.38	
6	.271	.154	1.15	36.47	53.94	25043	2.32	25.02	
7	.250	.186	1.17	39.70	53.10	23102	2.80	25.60	
8	.234	.206	1.19	40.67	51.53	21624	3.10	25.91	
9	.210	.238	1.19	42.17	50.02	19406	3.58	25.91	
10	.183	.243	1.19	37.52	42.71	16911	3.65	25.91	
11	.147	.276	1.22	33.41	36.04	13584	4.15	26.54	
12	.113	.302	1.25	27.32	28.48	10442	4.54	27.31	
13	.066	.349	1.31	17.64	17.86	6099	5.25	28.55	
14	.000	.410	1.39	.00	.00	0	6.16	30.32	

Appendix G

Toshiba Motor Specifications

TOSHIBA Reliability in Motion

TOSHIBA INTERNATIONAL CORPORATION
INDUSTRIAL DIVISION
PO BOX 40906
HOUSTON TX 77240 (800) 231-1412
(713) 466-0277 FAX (713) 466-8773

SPARE PARTS (RECOMMENDED)

OTHER THAN THE GREASE USED FOR RE-GREASABLE BEARINGS, **TOSHIBA** ADVISES THAT THERE ARE NO "USE" PARTS. THE ONLY INSURANCE SPARES THAT **TOSHIBA** SUGGESTS FOR THESE SQUIRREL CAGE INDUCTION MOTORS ARE INDUSTRY STANDARD, AND COMMERCIALLY AVAILABLE ANTI-FRICTION BEARINGS, AS NOTED BELOW.

MOTOR COMPONENTS (SUCH AS TERMINAL BOXES, FAN COVERS, MACHINED PARTS) ARE AVAILABLE UPON SPECIAL REQUEST. IN THIS CASE, PLEASE ADVISE OUR ORDER ENTRY DEPARTMENT THE MODEL AND SERIAL NUMBERS (FOUND ON THE MOTOR NAMEPLATE) , AND A DESCRIPTION OF THE COMPONENT REQUIRED. THEY WILL THEN FURNISH THE CURRENT PART NUMBER, PRICE AND AVAILABILITY.

(NOTE: OUR INTERNAL PART NUMBERS ARE SUBJECT TO CHANGE WITHOUT NOTICE, AND ARE NOT PUBLISHED).

PLEASE ADVISE IF YOU HAVE ANY QUESTIONS.

CUSTOMER:
PURCHASE ORDER #
Customer Tag:

TOSHIBA FILE #
MODEL # BY756FLT2OSW
HP / RPM / ENCL / FRAME: 7.5 / 1200 / TEFC / 254TC
DRIVE END BEARING: 6309UU
OPPOSITE DRIVE END BEARING: 6208UU

Prepared By:
Date:

TOSHIBA INTERNATIONAL CORPORATION Industrial Division / Houston Motor Plant SQUIRREL CAGE INDUCTION MOTOR PERFORMANCE SPECIFICATIONS	INDEX	MPCF-1033
	SHEET NO.	1 of 1
	ISSUED	11/08/96
	SUPERSEDES	10/06/95
	REVISION	1
	WRITTEN BY	R. EVANS
	APPROVED BY	Jay Bugbee

Customer Tag:

CUSTOMER:
TIC SR No.:
Customer PO:

MOTOR NAMEPLATE DATA

H.P.:	7.5	VOLTS:	575	3 Ø /	60 Hz	S. RPM:	1200
FRAME:	254TC	ENCL:	TEFC	FLAMPS:	8.0	FLRPM:	1165.00
FORM:		S.F.:	1.15	NEMA DESIGN:	B	INSUL CLASS:	F
TYPE:	IKK	AMB.:	40.00	CODE:	G	DUTY:	CONT.
MODEL No.:	BY756FLT2OSW			kW:		Serial No.:	
NOM. EFF.:	FCKL1	MIN. EFF.:		P.F.:	88.5		

AMPERAGE	**TORQUES**	**** BEARINGS:**
Locked Rotor: 48.00	FULL LOAD (lb-ft.): 33.90	Drive End: 6309UU
	LOCKED ROTOR (%): 190.00	Opposite Drive End: 6208UU
	BREAK DOWN (%): 260.00	

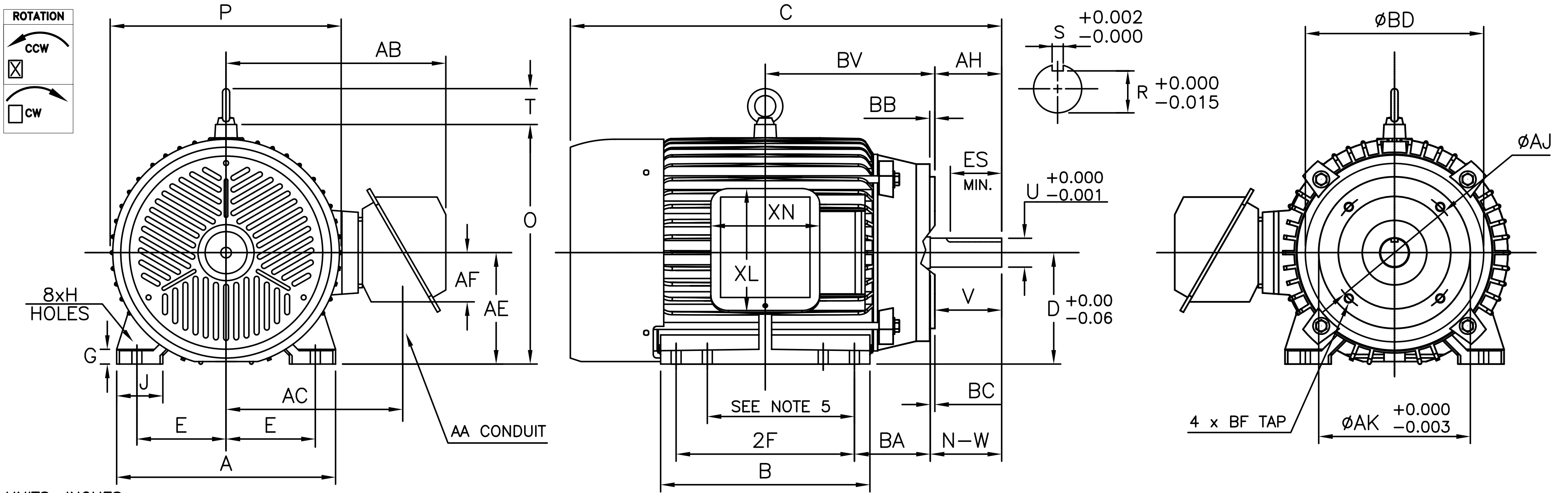
EFFICIENCY (%)	**POWER FACTOR (%)**
FULL LOAD: 89.8	FULL LOAD: 78.5
3/4 LOAD: 90.5	3/4 LOAD: 73.5
1/2 LOAD: 90.2	1/2 LOAD: 63.4

ALL CHARACTERISTICS ARE AVERAGE EXPECTED VALUES BASED UPON RATED VOLTAGE, FREQUENCY AND SINEWAVE POWER INPUT.

* TEMPERATURE RISE WILL BE CONSISTENT WITH INSULATION, AMBIENT AND SERVICE FACTOR AS DEFINED BY NEMA-MG-12.43 OR -20.40.

** BEARINGS ARE THE ONLY RECOMMENDED SPARE PART(S).

CERTIFIED BY:
DATE:



UNITS: INCHES

FRAME SIZE	FLANGE DIMENSIONS							
	AH	AJ	AK	BB	BC	BD	BF TAP	BV
254TC/256TC	3.75	7.250	8.500	0.29	0.25	10.00	1/2"−13UNC	9.50

FRAME SIZE	MOTOR DIMENSIONS										CONDUIT BOX						
	A	B	C	D	G	J	K	M	O	P	T	AA	AB	AC	AE	AF	XL	XN
254TC/256TC	12.3	11.7	24.2	6.25	0.8	2.3	0	0	13.4	13.0	2.0	1.25	12.3	9.9	6.25	2.8	7.0	6.1

FRAME SIZE	MOUNTING				SHAFT EXTENSION			KEY SEAT			BEARINGS		MAXIMUM WEIGHT
	E	2F	H	BA	N−W	V	U	R	S	ES	LS	OS	
254TC/256TC	5.00	8.25/10.00	0.56	4.25	4.00	3.75	1.625	1.416	0.375	2.88	6309UU	6208UU	310 lbs.

NOTES:
1. DIMENSION V REPRESENTS LENGTH OF STRAIGHT PART OF SHAFT
2. MAIN CONDUIT BOX MAY BE ROTATED IN 90° INCREMENTS
3. KEY DIMENSIONS EQUAL S x S x 2.88 (MOTOR SUPPLIED WITH KEY)
4. MOTOR WEIGHT SHOWN IS MAXIMUM HORSEPOWER IN FRAME
5. THIS DIMENSION EQUALS 2F FOR 254TC MOUNTING
6. STANDARD PRODUCT USE BI−DIRECTIONAL FAN. OPPOSITE ROTATION AVAILABLE ONLY BY CONNECTION CHANGE

CUSTOMER: ______ MOTOR MODEL NO.: BY756FLT2OSW

P.O. NO.: ______ HP: 7.5 VOLTAGE: 575 RPM(SYN.): 1200 Hz: 60

FRAME SIZE: 254TC PRODUCT TYPE: TEFC EQP III, EPACT, & HIGH EFFICIENCY

COMMENTS: ______

PER: ______ DATE: ______

TAG NO's.:

- [X] STANDARD (NO AUX. BOXES)
- [ ] RTD AUX. BOX
- [ ] SPACE HEATER AUX. BOX
- [ ] BEARING RTD's

TOSHIBA RESERVES THE RIGHT TO MAKE CHANGES OF TECHNICAL IMPROVEMENT AND THE DATA MAY CHANGE WITHOUT NOTICE [X] PRELIMINARY

DO NOT USE FOR CONSTRUCTION, INSTALLATION, OR APPLICATION PURPOSES UNLESS THE DRAWING IS MARKED AS CERTIFIED [ ] CERTIFIED

TOSHIBA

TOSHIBA INTERNATIONAL CORPORATION

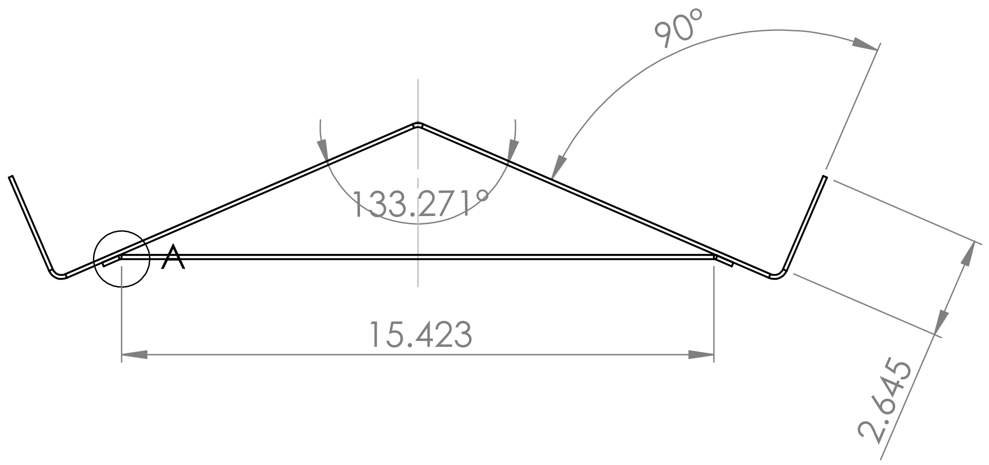
TOTALLY−ENCLOSED FAN−COOLED
HORIZONTAL FOOT−MOUNTED
3 PHASE INDUCTION MOTOR
F1 ASSEMBLY

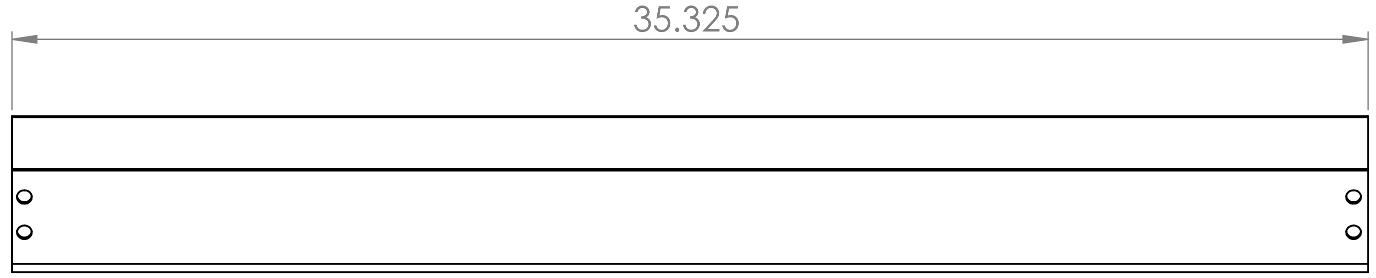
XT SERIES

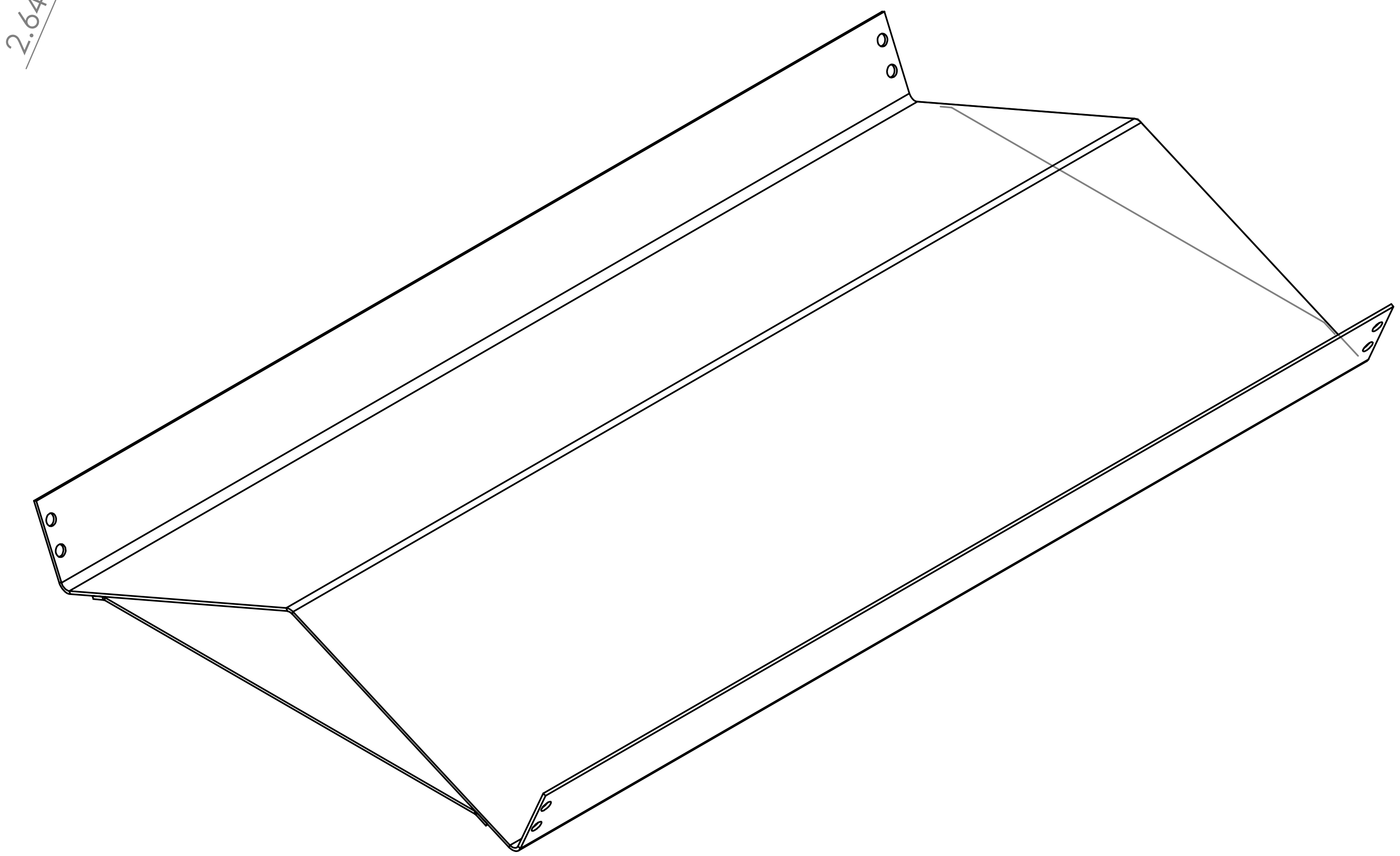
VISIT OUR WEBSITE AT:
www.toshiba.com/ind

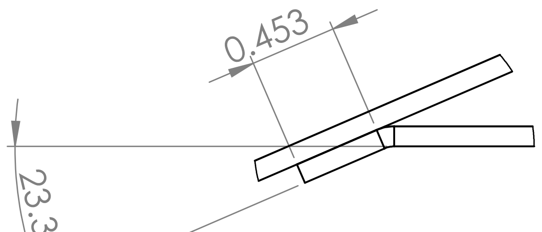
Appendix H

Draft Drawings of Design Elements









DETAIL A
SCALE 1 : 1

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

Dimensions in INCHES

	NAME	SIGNATURE	DATE
DRAWN	Andrew Bell		29/11/2010
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE: Base Weldment Isometric

MATERIAL: 12 Gauge Steel Sheet

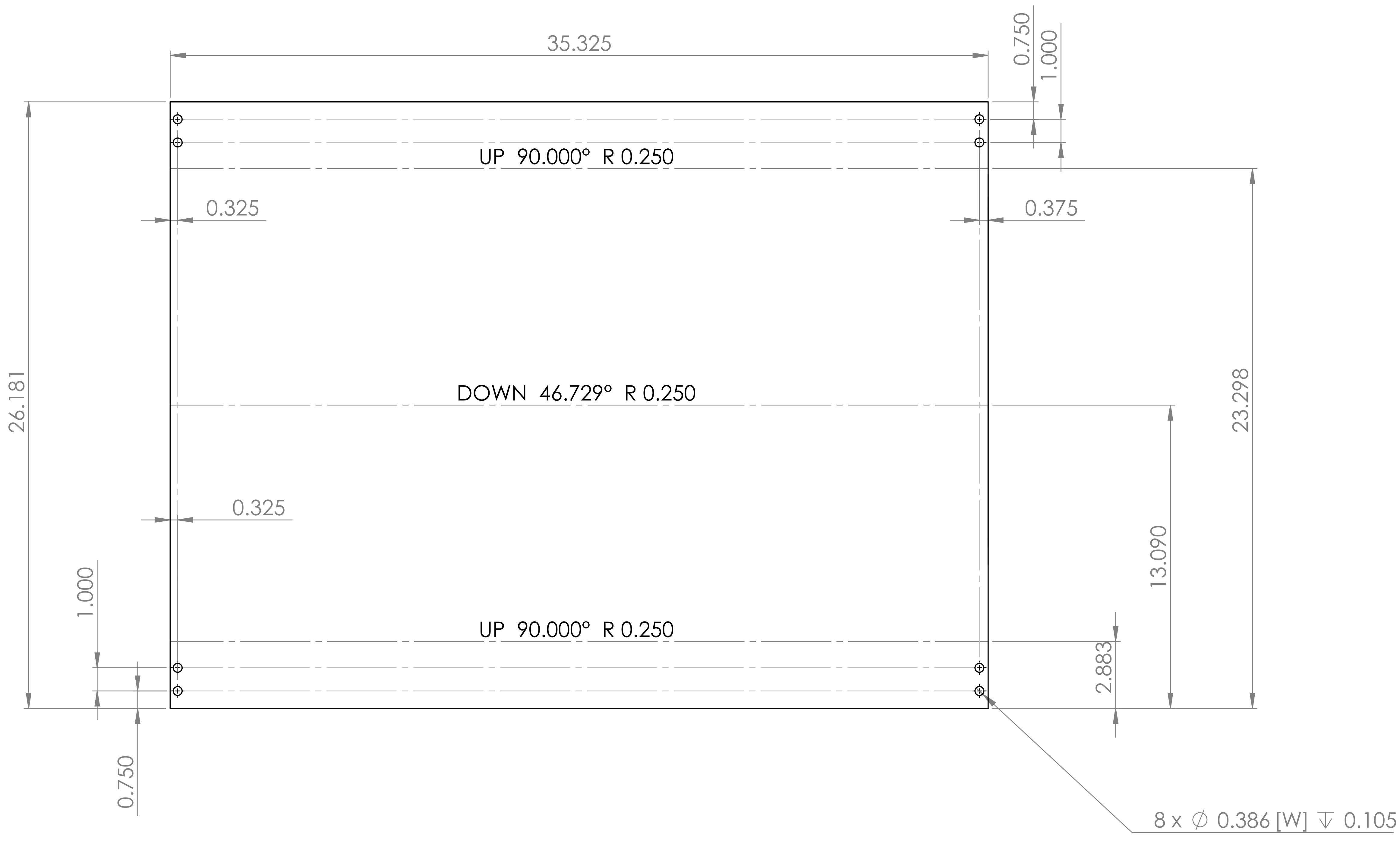
WEIGHT:

DWG NO. Base Weldment 1

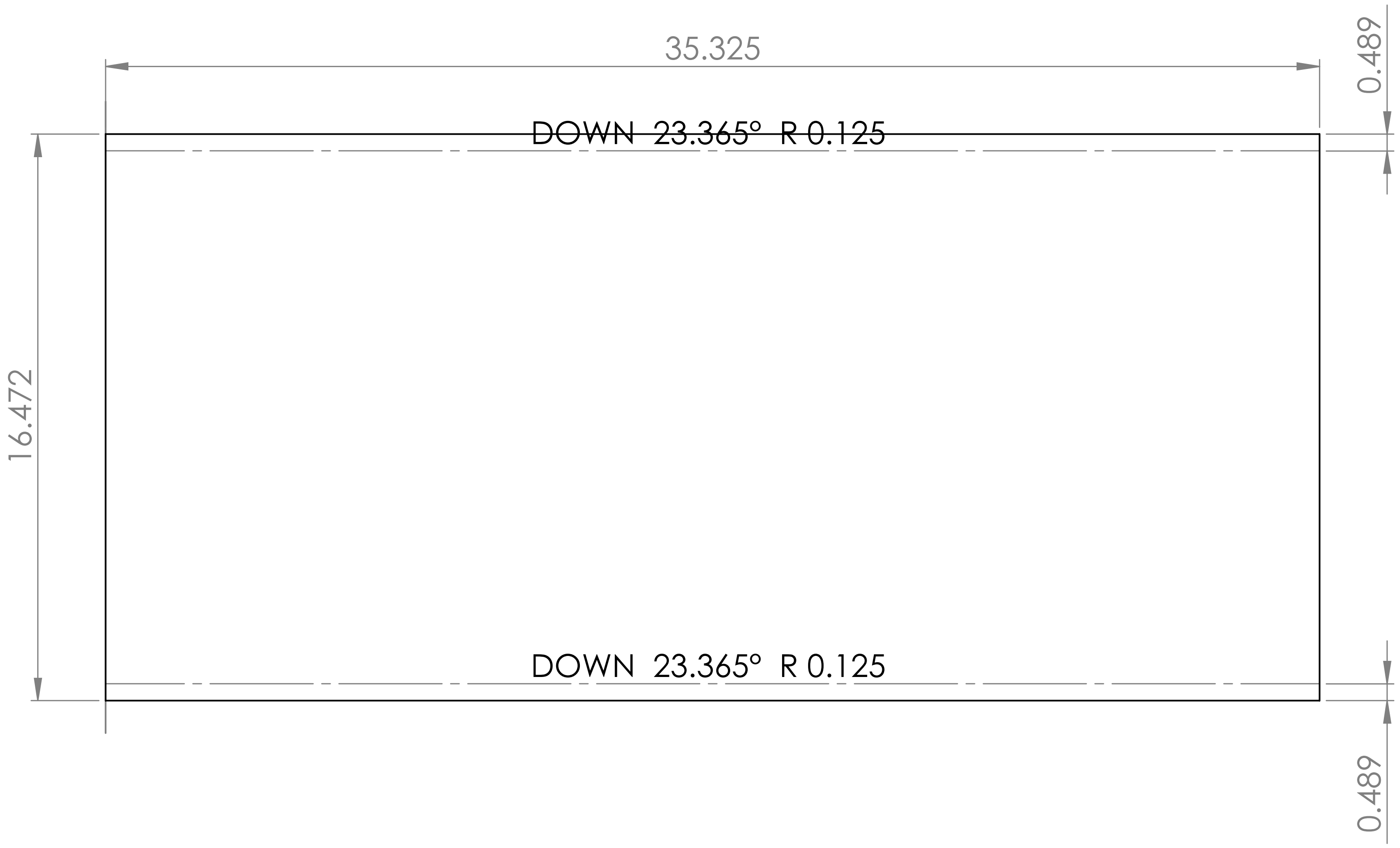
A3

SCALE:1:10

SHEET 1 OF 3



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:		FINISH:			DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION
						Dimensions in INCHES	
	NAME	SIGNATURE	DATE			TITLE:	
DRAWN	Andrew Bell		29/11/2010			BW1 - FLAT	
CHK'D							
APPV'D							
MFG							
Q.A				MATERIAL: 12 Gauge Steel Sheet		DWG NO. Base_Weldment_2.1	A3
				WEIGHT:		SCALE:1:10	SHEET 2 OF 3



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

Dimensions in INCHES

	NAME	SIGNATURE	DATE
DRAWN	Andrew Bell		29/11/2010
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

Base Weldment Isometric

MATERIAL:
12 Gauge Steel Sheet

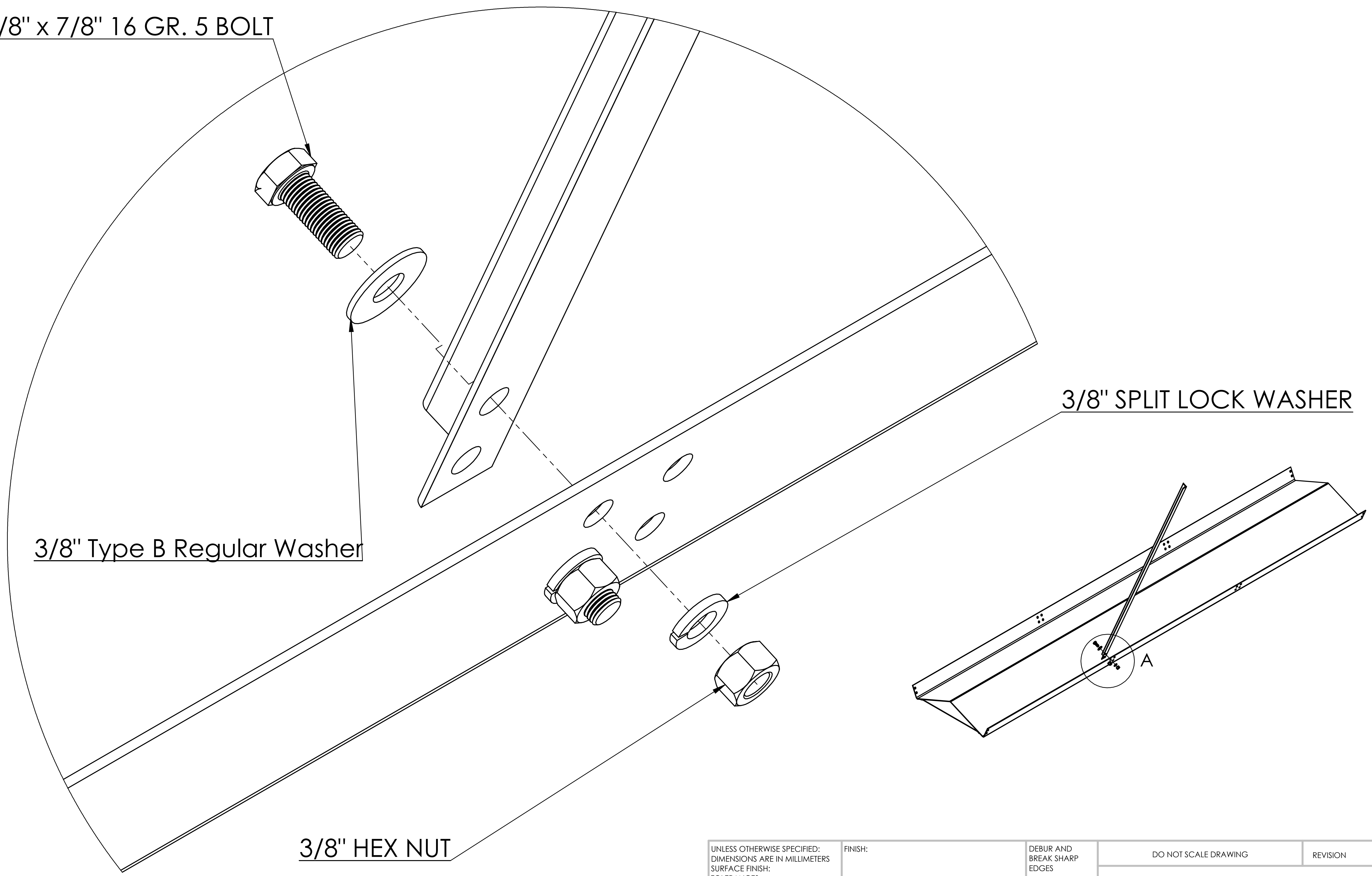
DWG NO.
Base_Weldment_2.1

A3

WEIGHT:

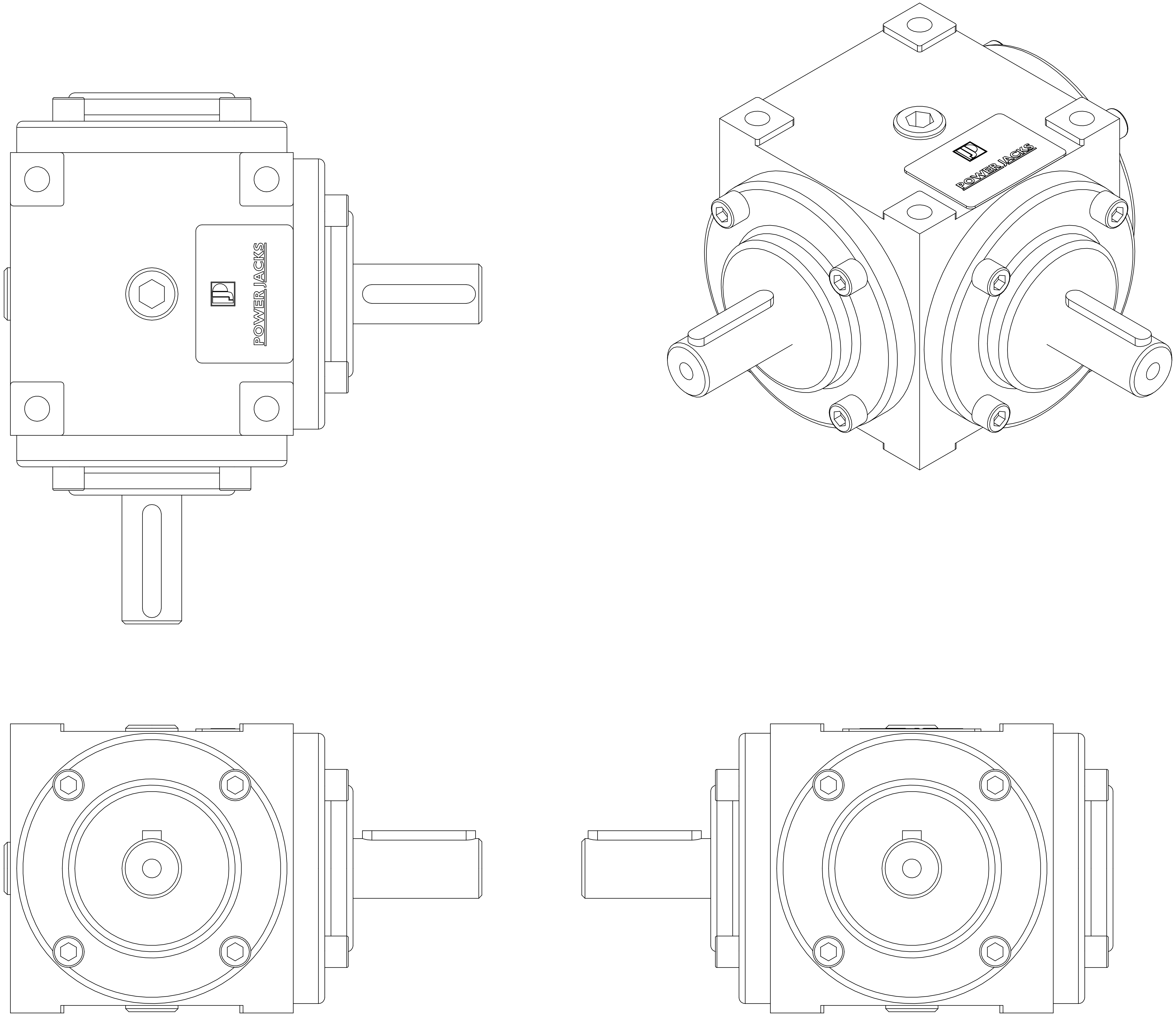
SCALE:1:10

SHEET 3 OF 3

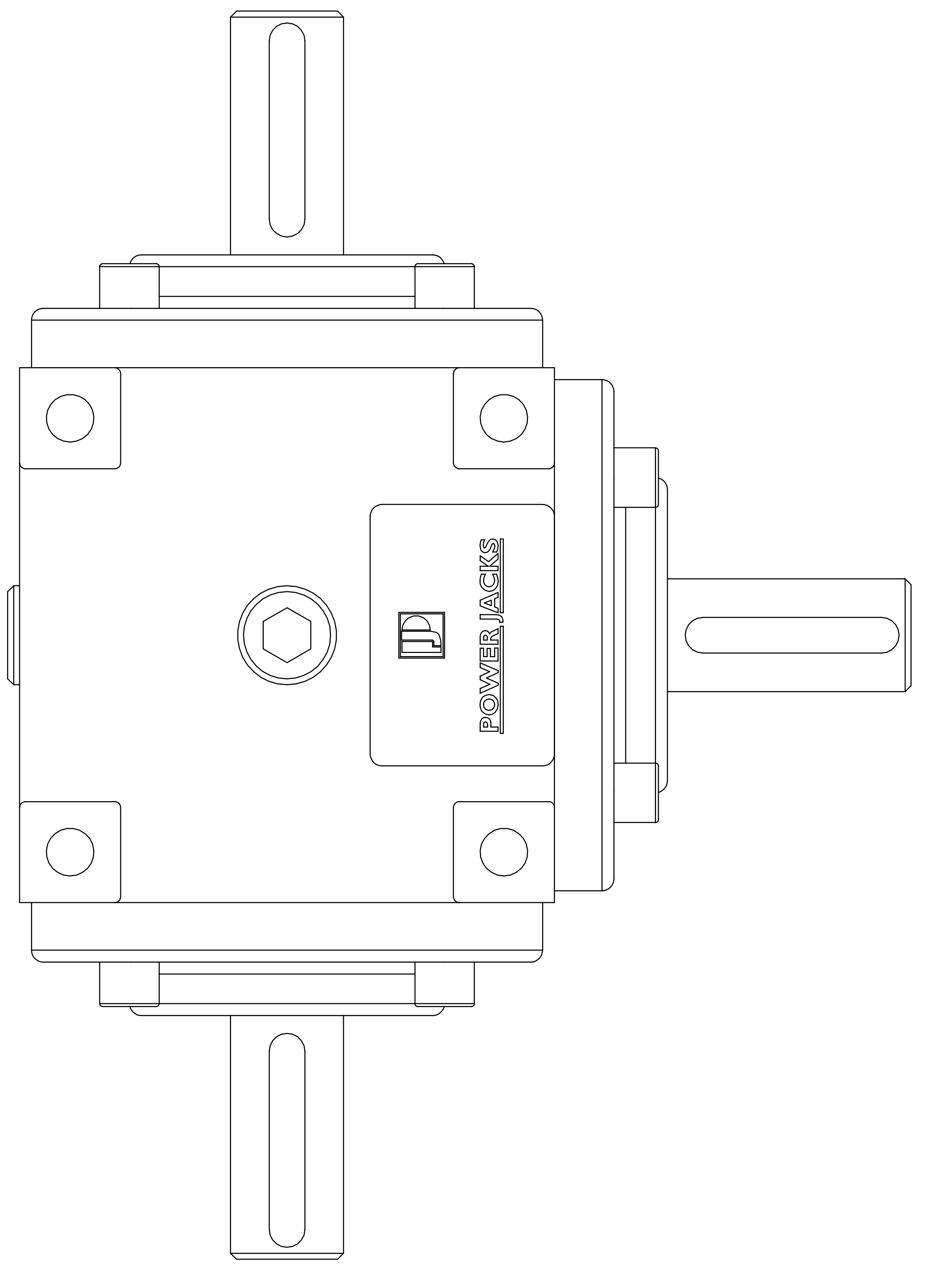


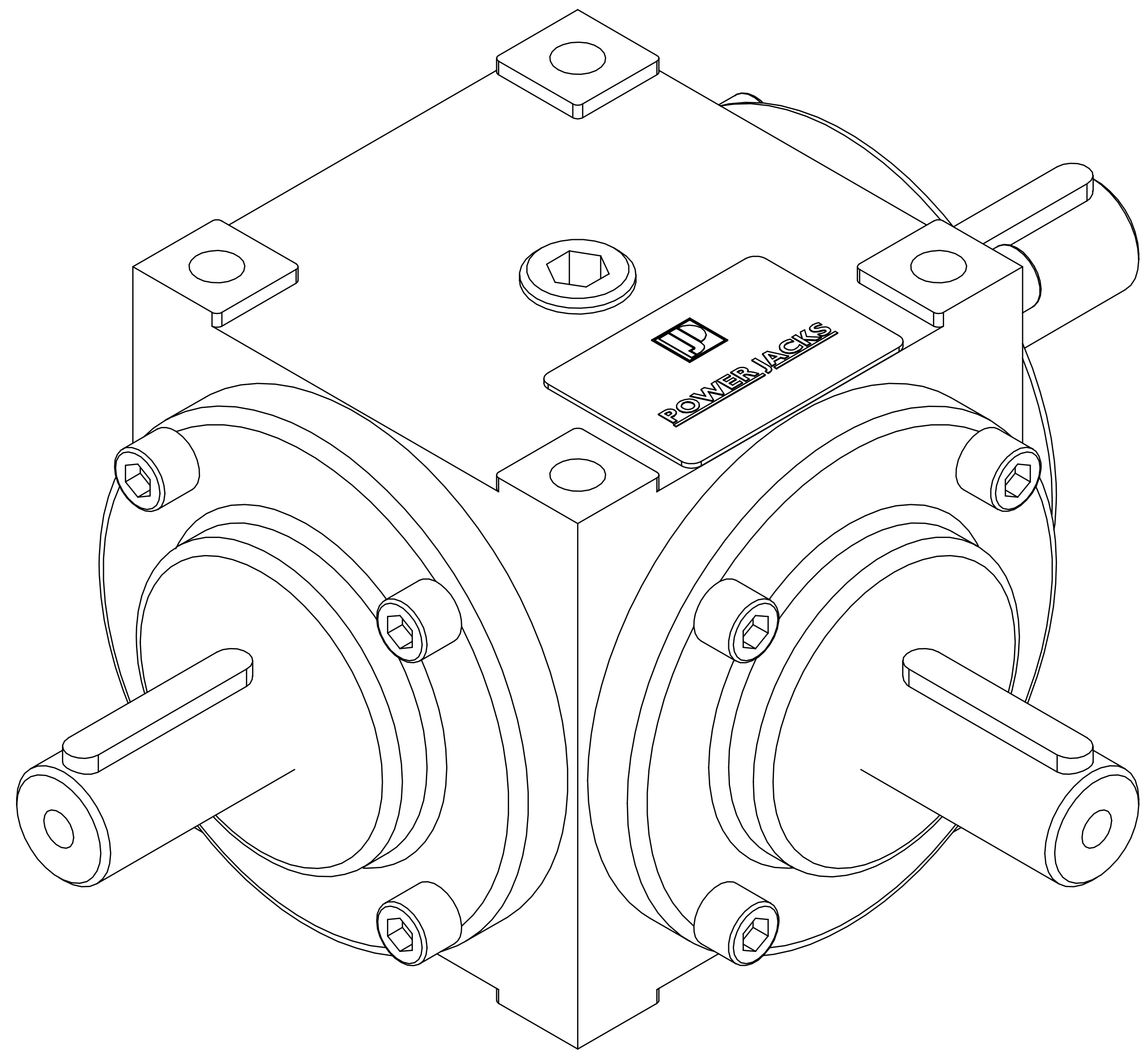
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:	DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION
	NAME / SIGNATURE / DATE		TITLE:	
DRAWN				
CHK'D				
APPV'D				
MFG				
Q.A	MATERIAL:		DWG NO. Exploded_fastener	A3
	WEIGHT:		SCALE:1:50	SHEET 1 OF 1

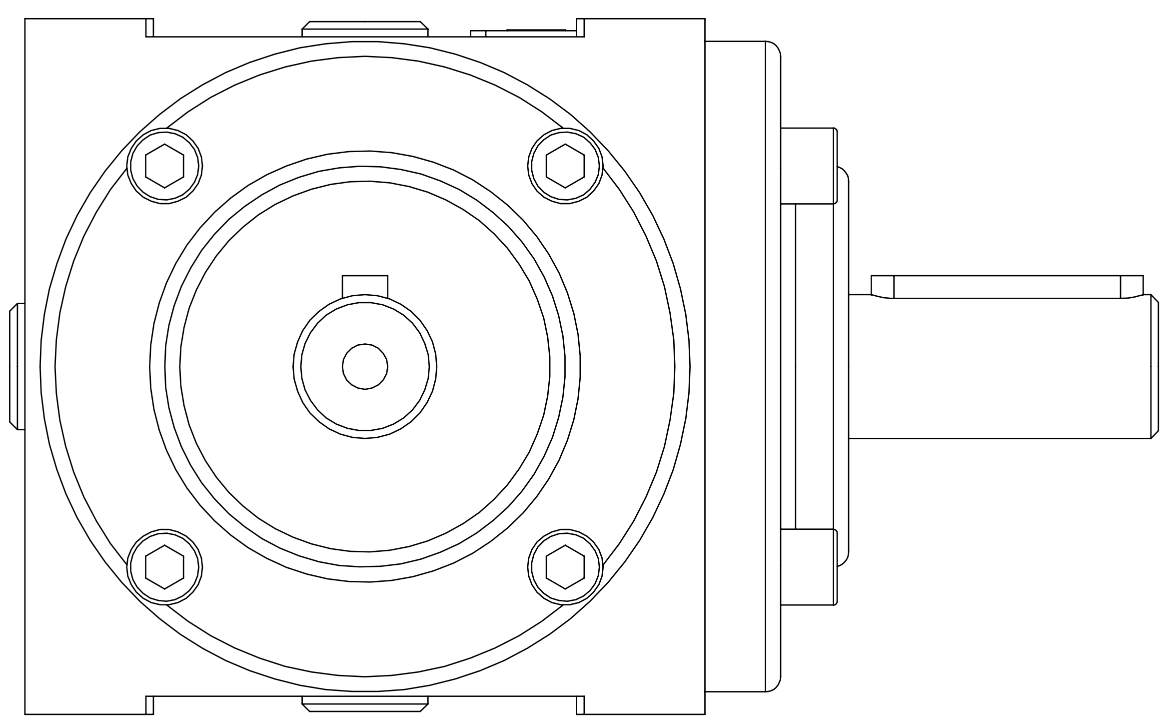
Power Jacks Series 35
2-Way Bevel Gearbox
Power Rating: 3.1 kW (4.2 HP)
1:1 Gear Ratio
Speed Rating: 500 RPM

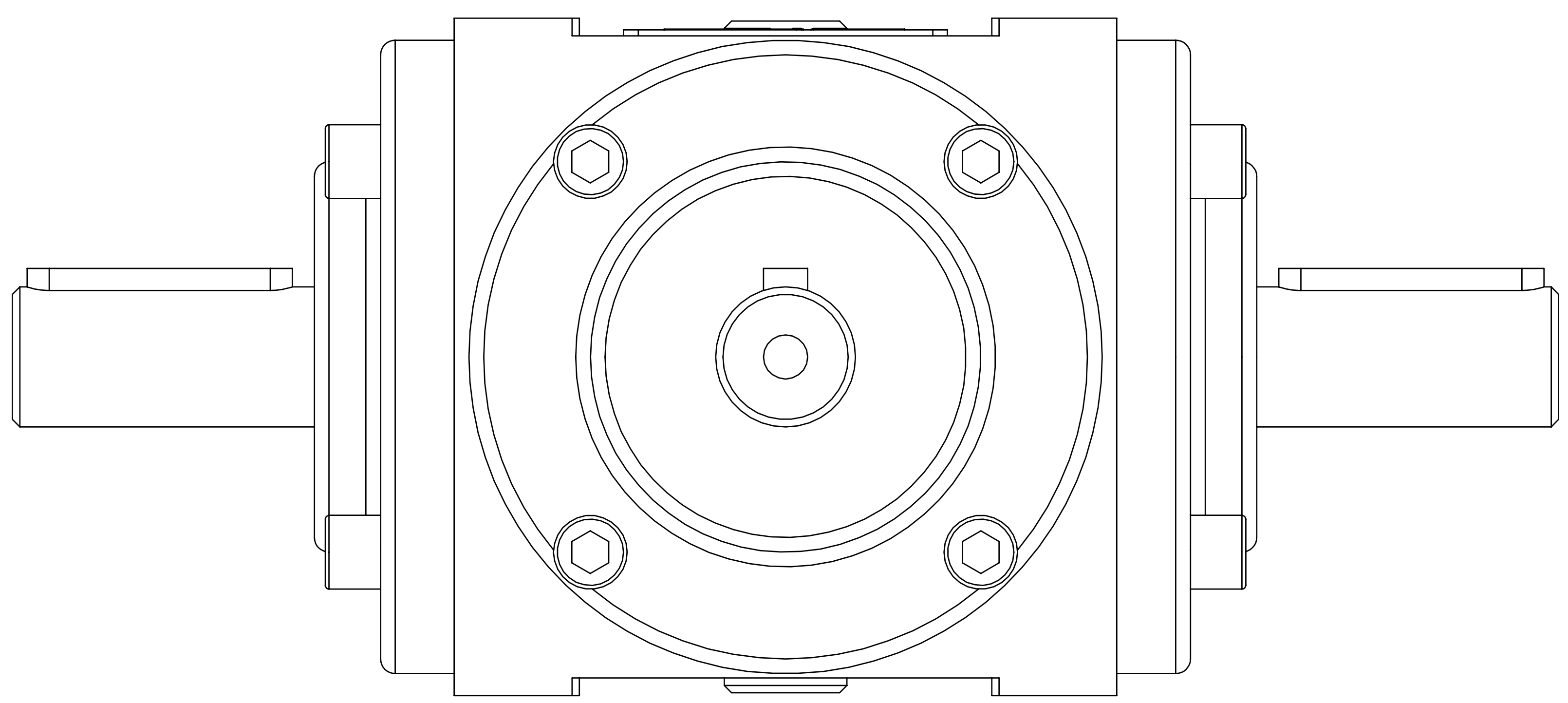


Power Jacks Series 35
3-Way Bevel Gearbox
Power Rating: 3.1 kW (4.2 HP)
1:1 Gear Ratio
Speed Rating: 500 RPM

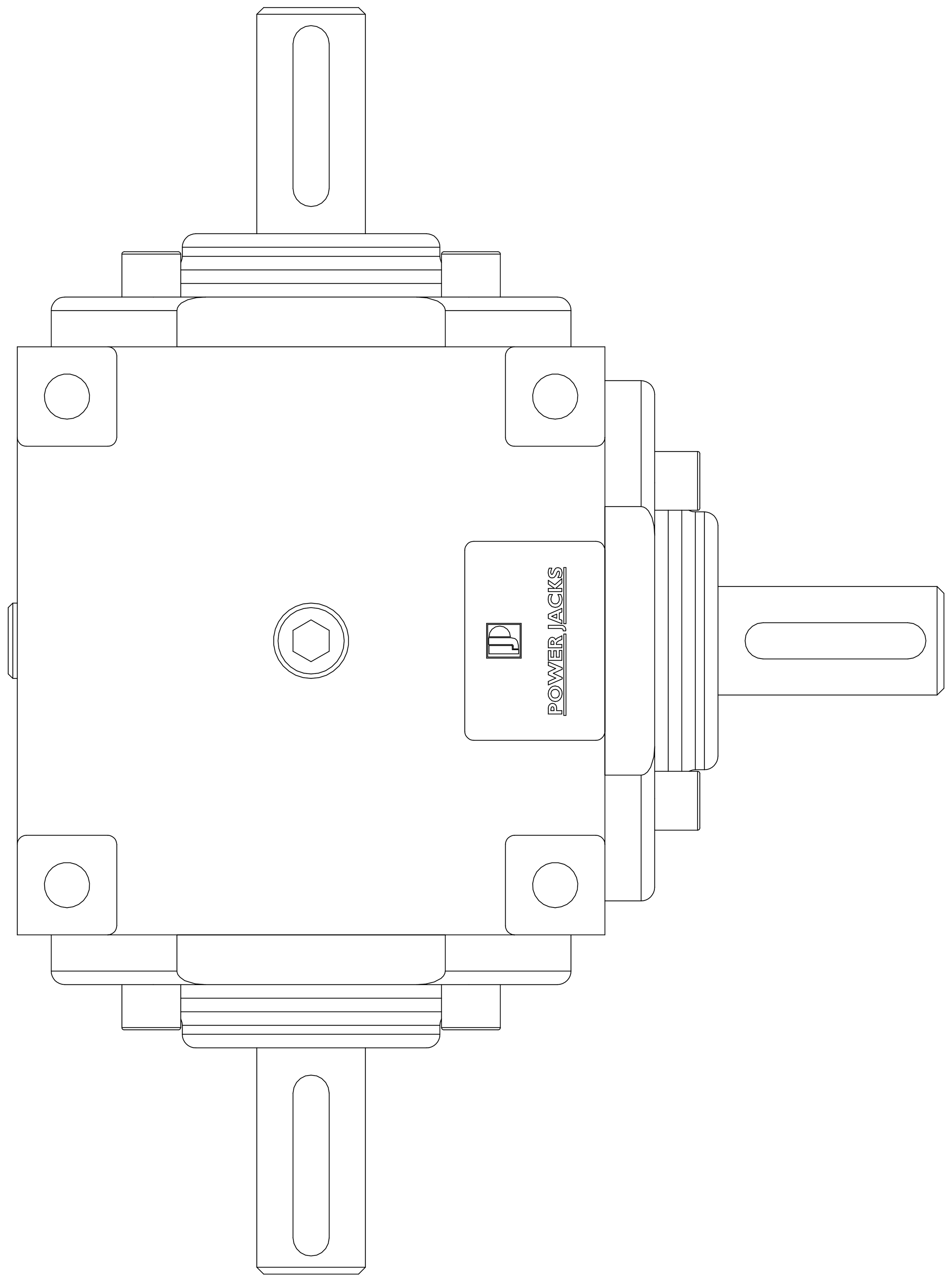


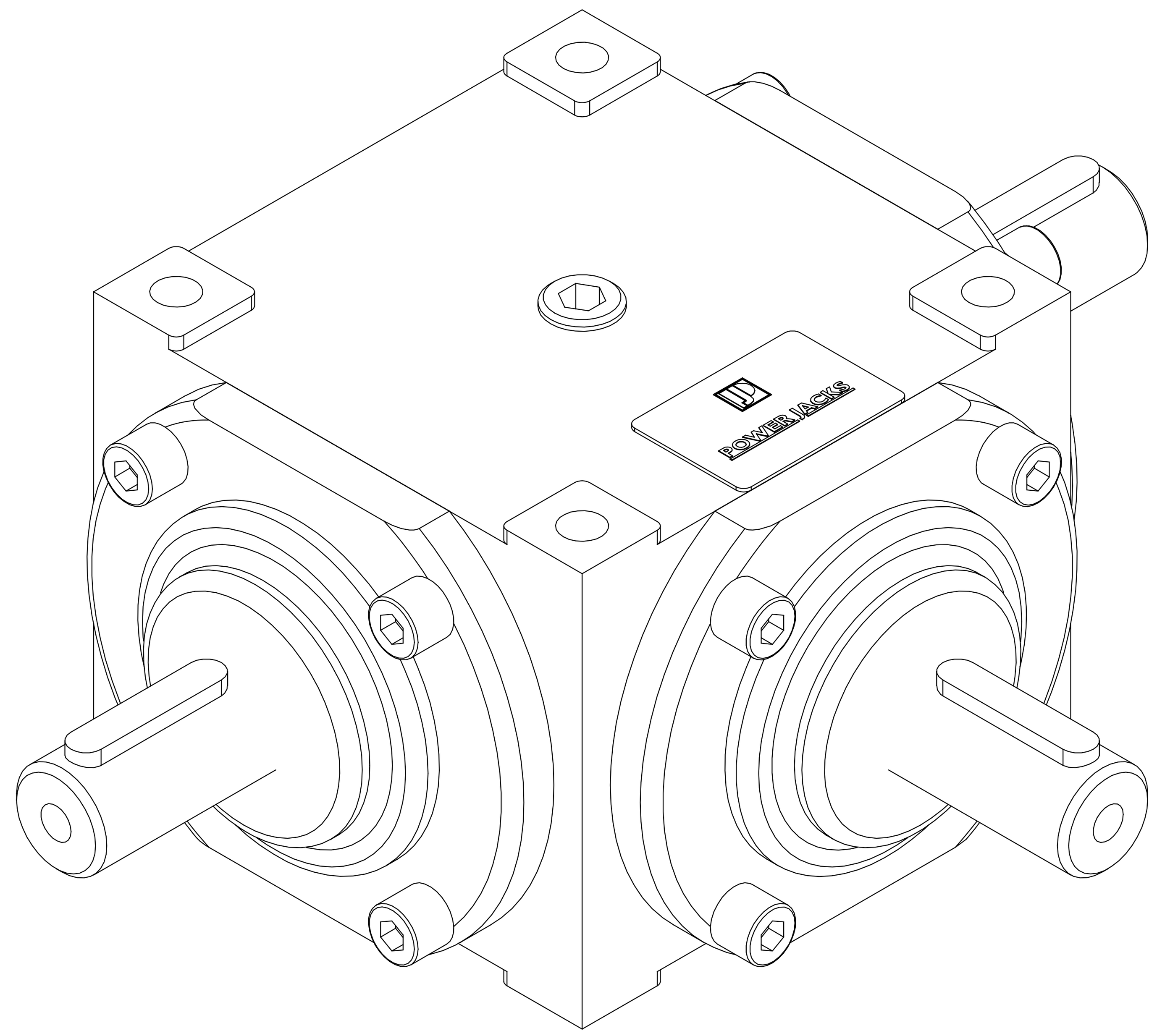


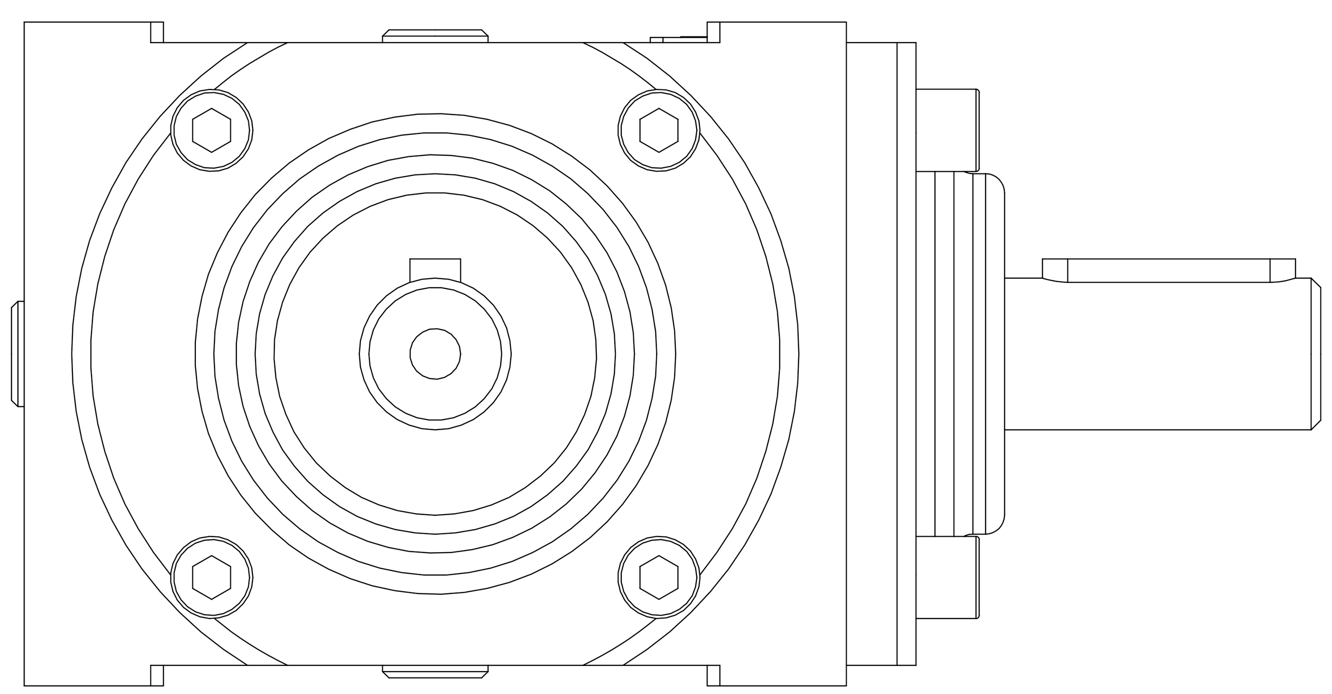


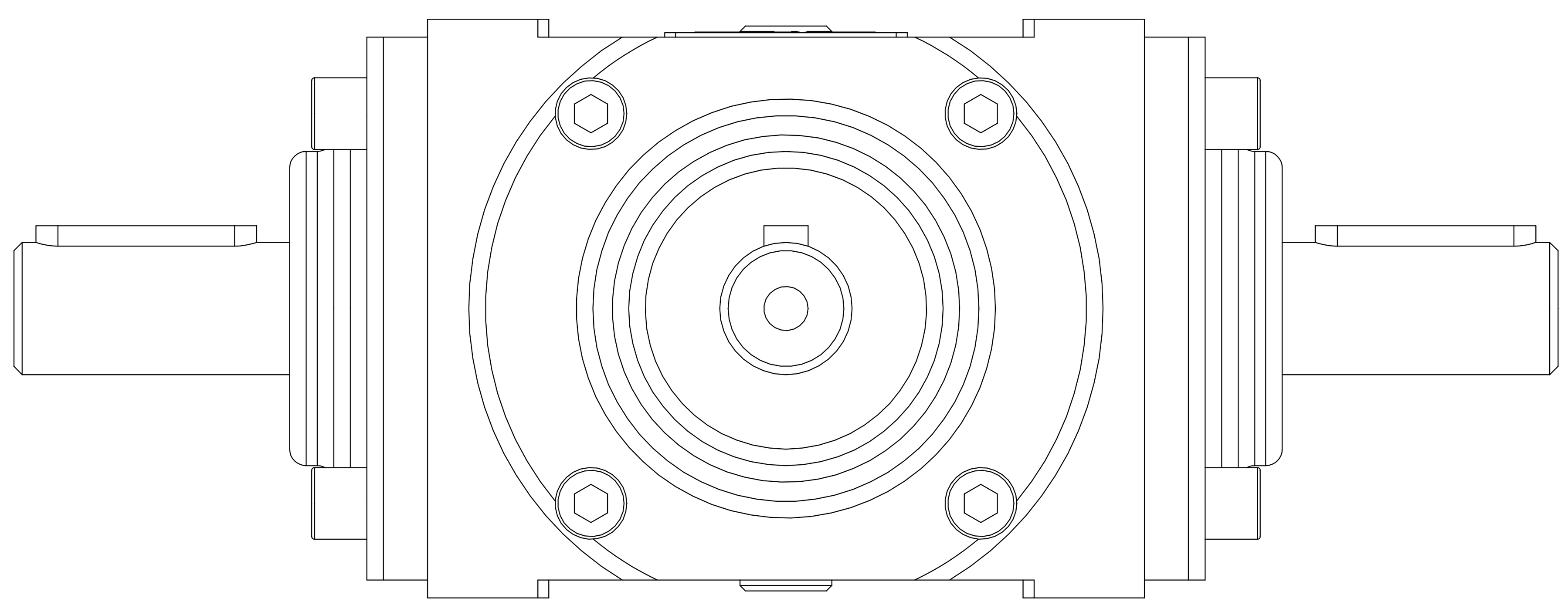


Power Jacks Series 37
3-Way Bevel Gearbox
Power Rating: 7.7 kW (10 HP)
1:1 Gear Ratio
Speed Rating: 500 RPM

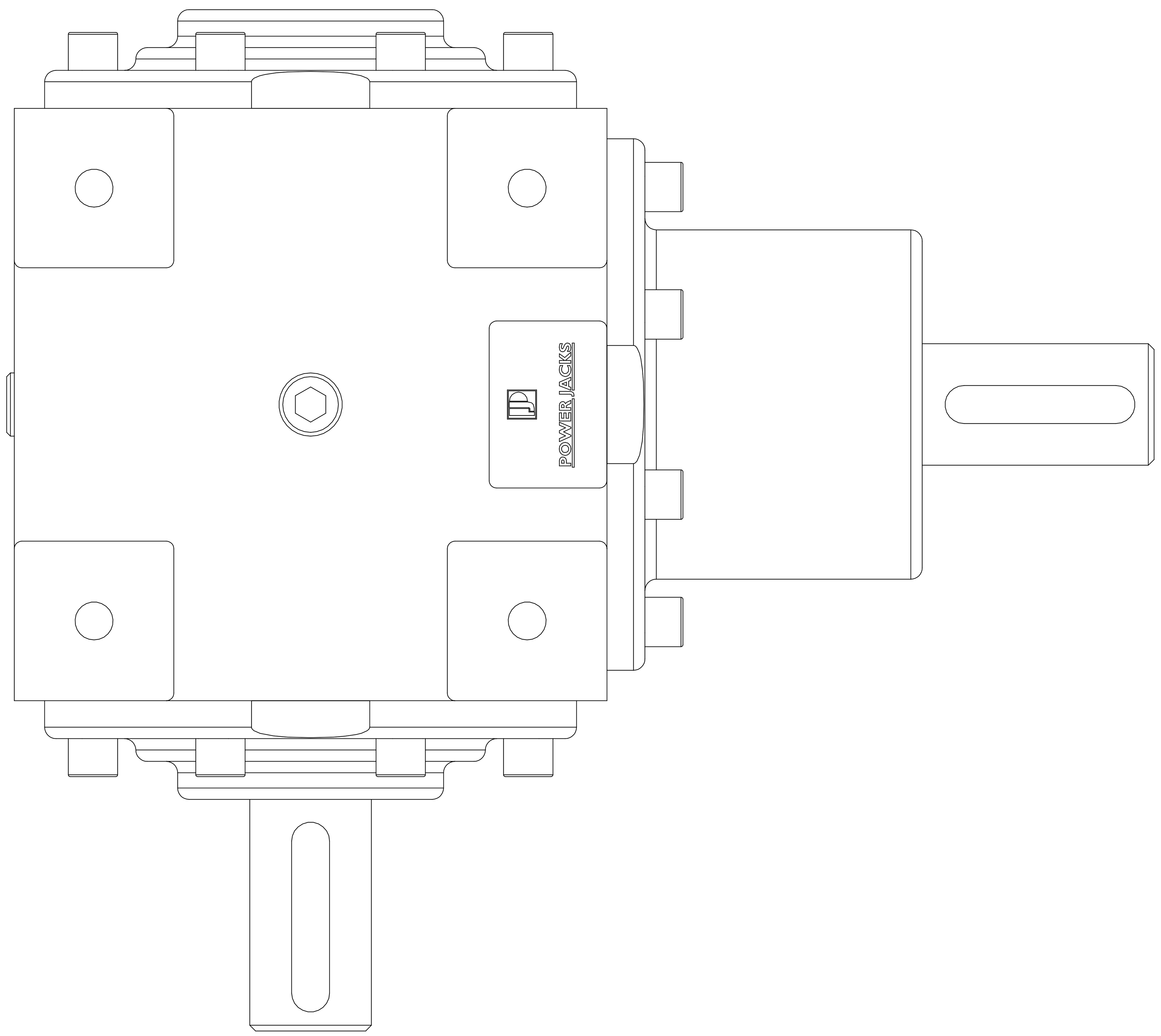


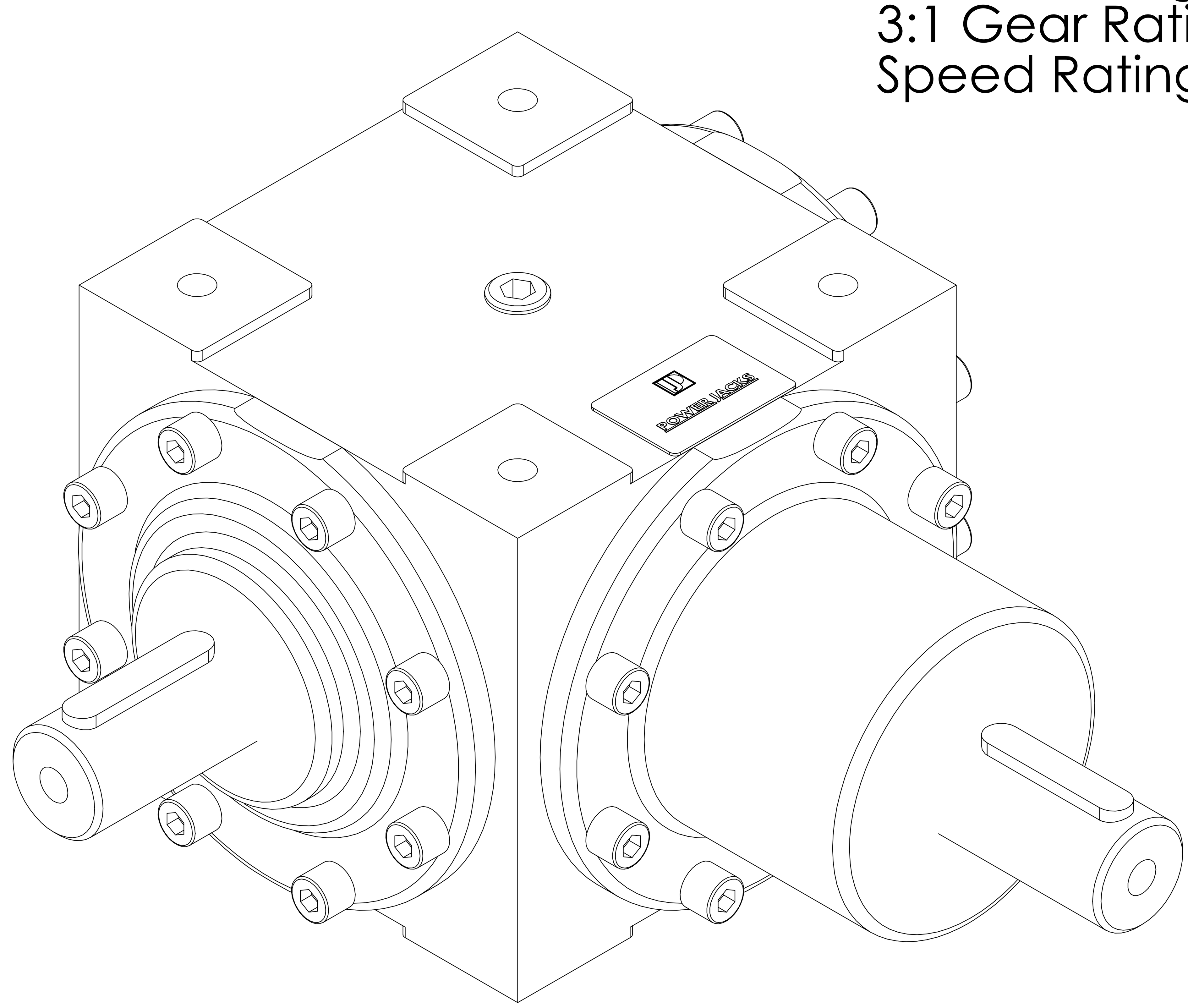


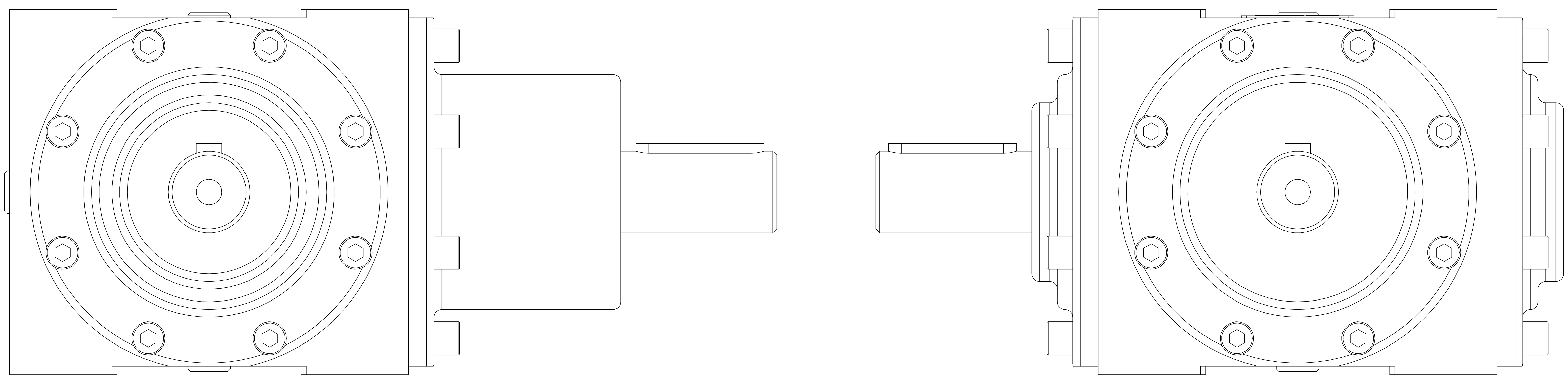


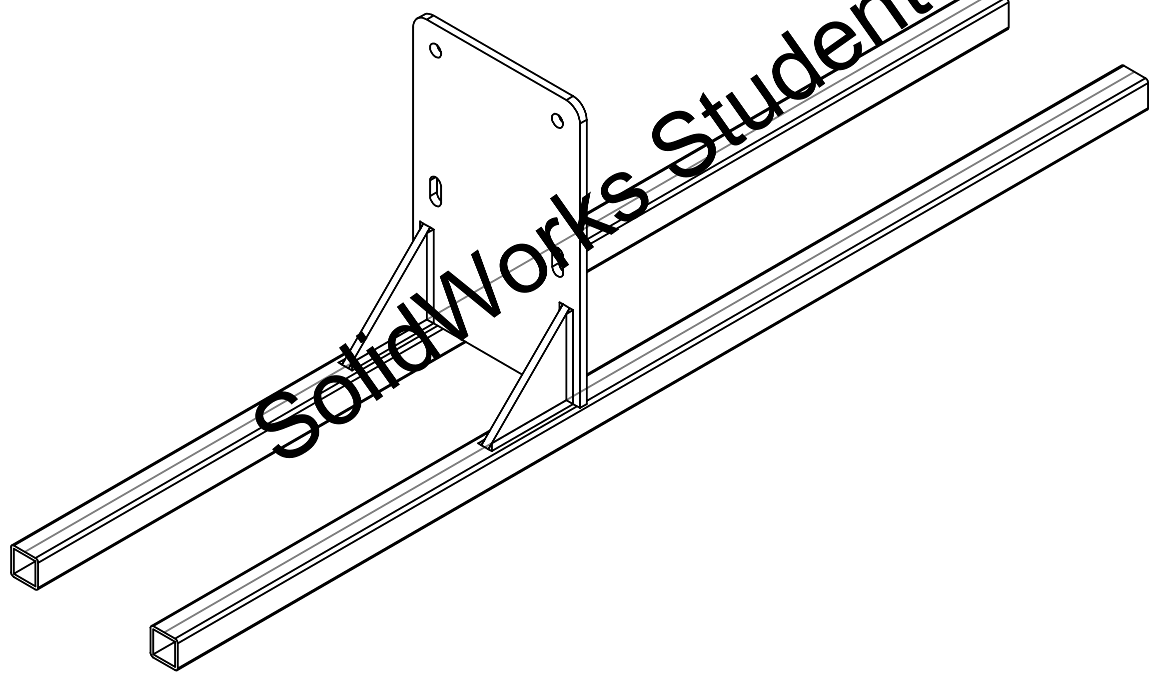


Power Jacks Series 38
2-Way Bevel Gearbox
Power Rating: 5.7 kW (7.75 HP)
3:1 Gear Ratio
Speed Rating: 1500 RPM

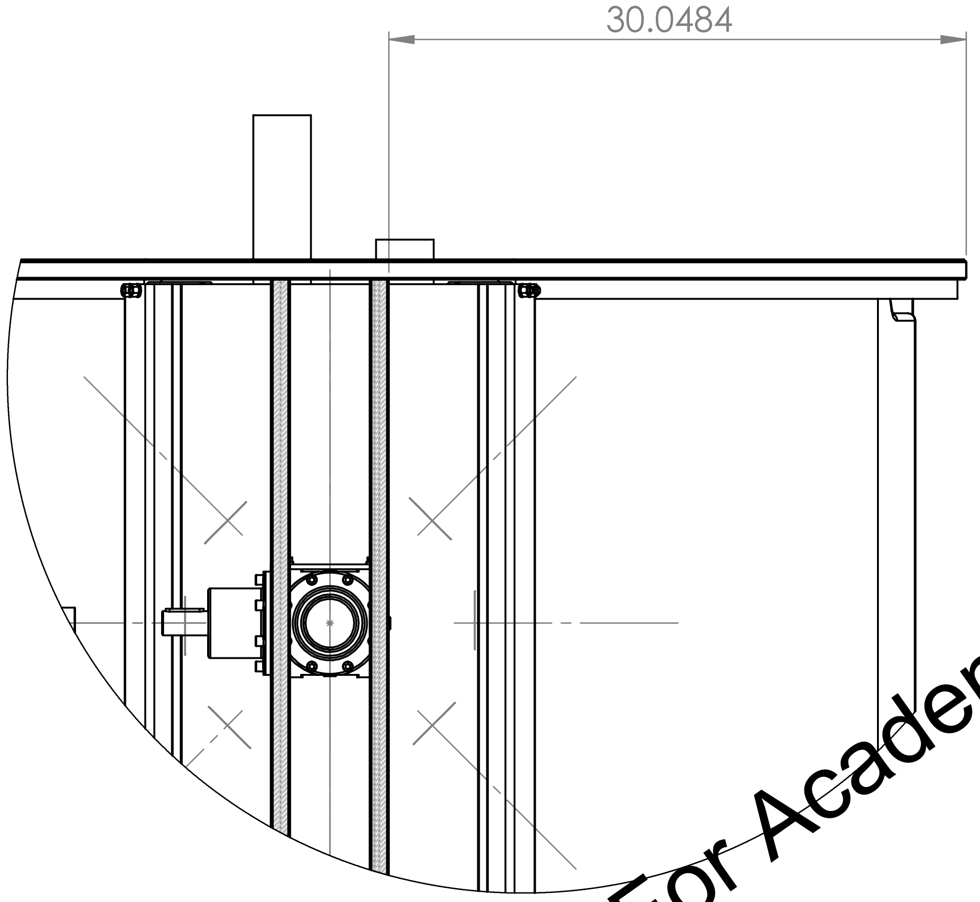




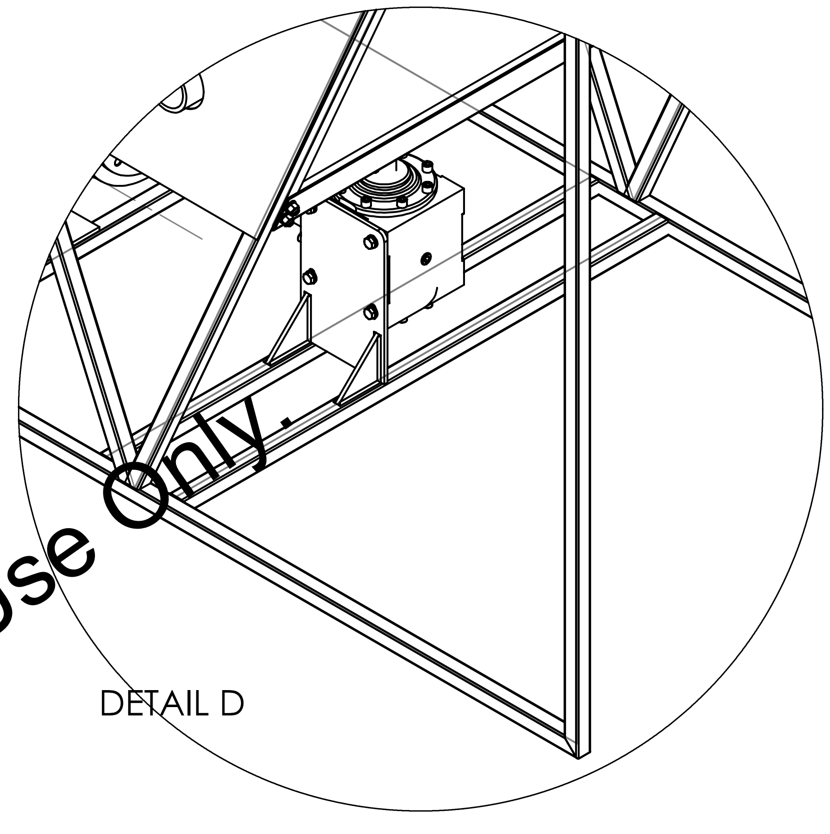




UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:		DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION	
				Dimensions in INCHES		
	NAME	SIGNATURE	DATE	TITLE:		
DRAWN	Andrew Bell		30/11/2010	Gearbox 1 Mount		
CHK'D						
APPV'D						
MFG						
Q.A			MATERIAL: Steel	DWG NO.	GM1	A3
			WEIGHT:	SCALE:1:10	SHEET 1 OF 2	

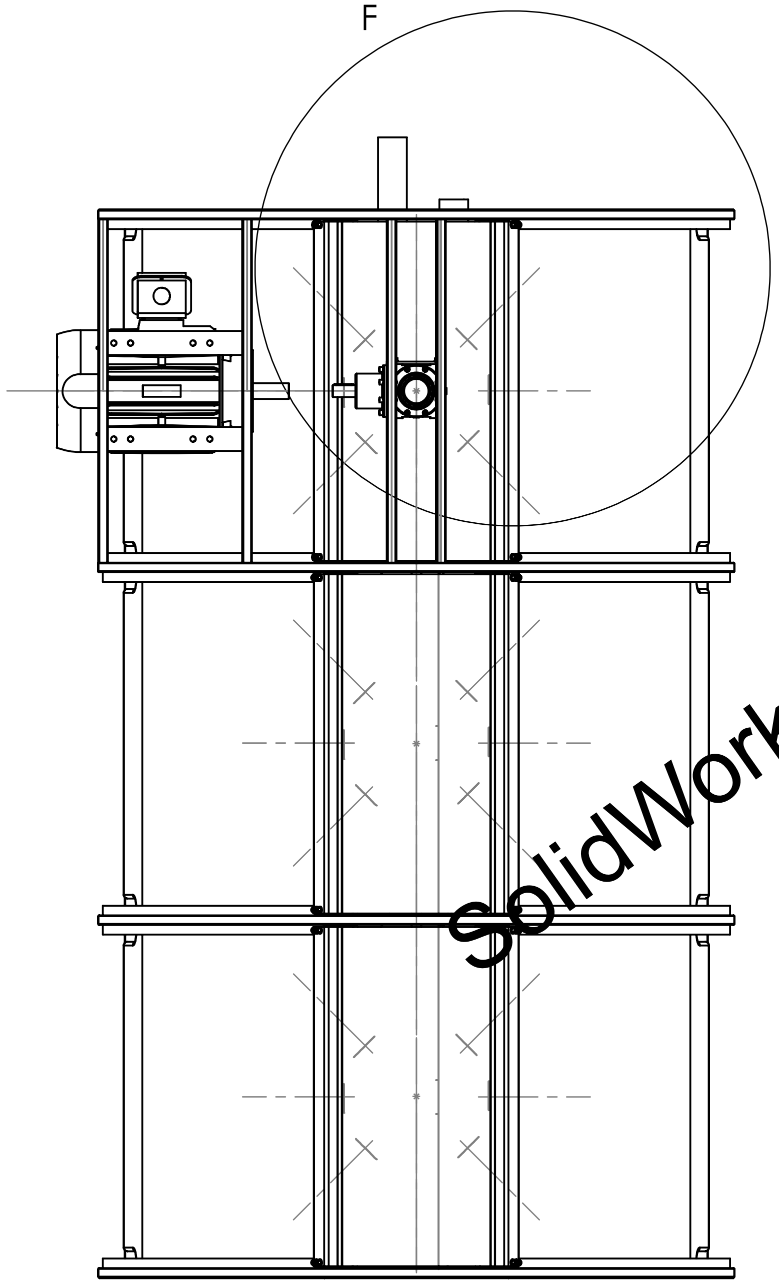


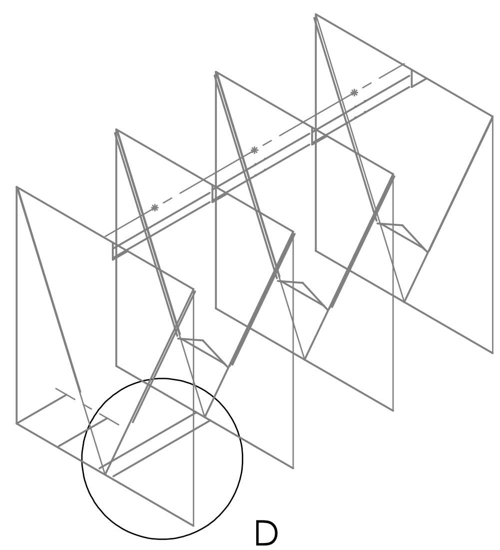
DETAIL F



DETAIL D

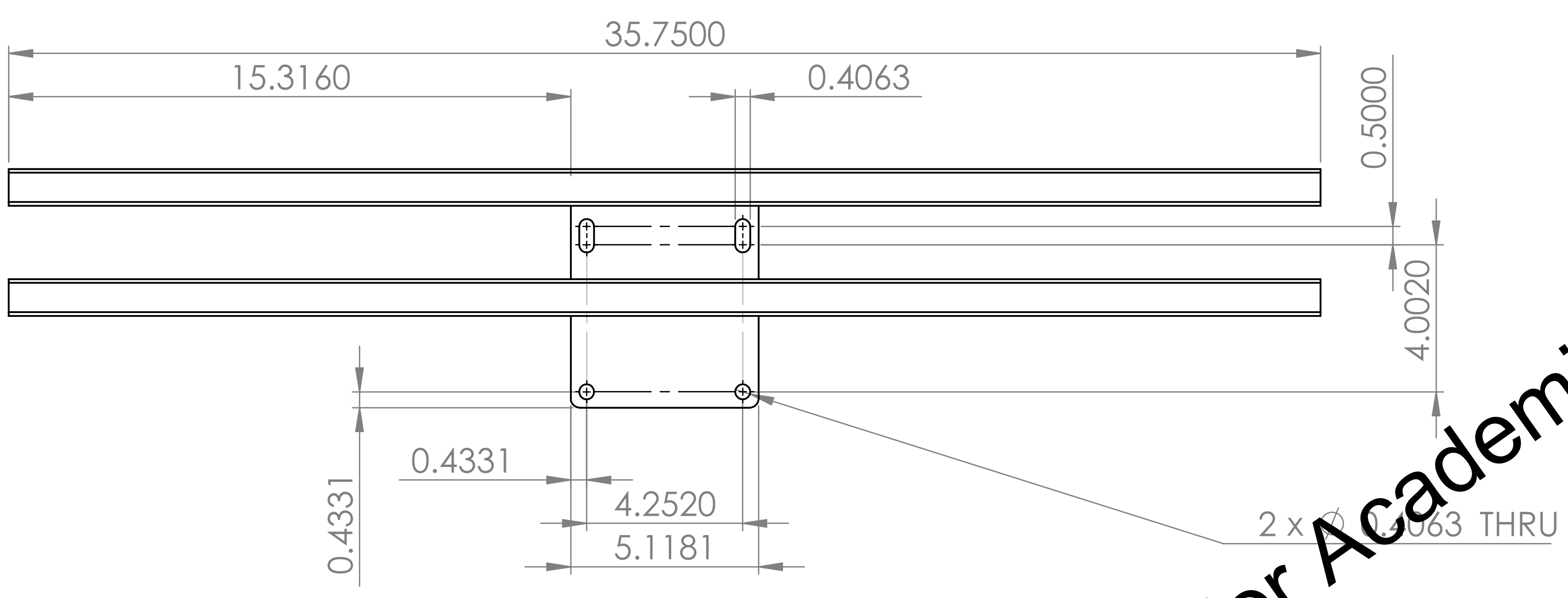
F

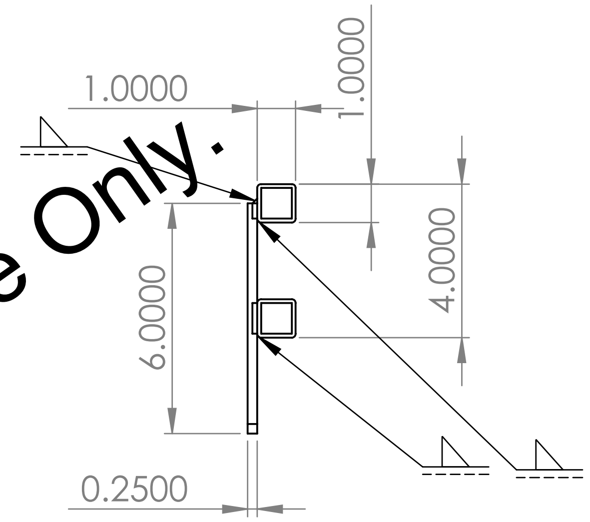


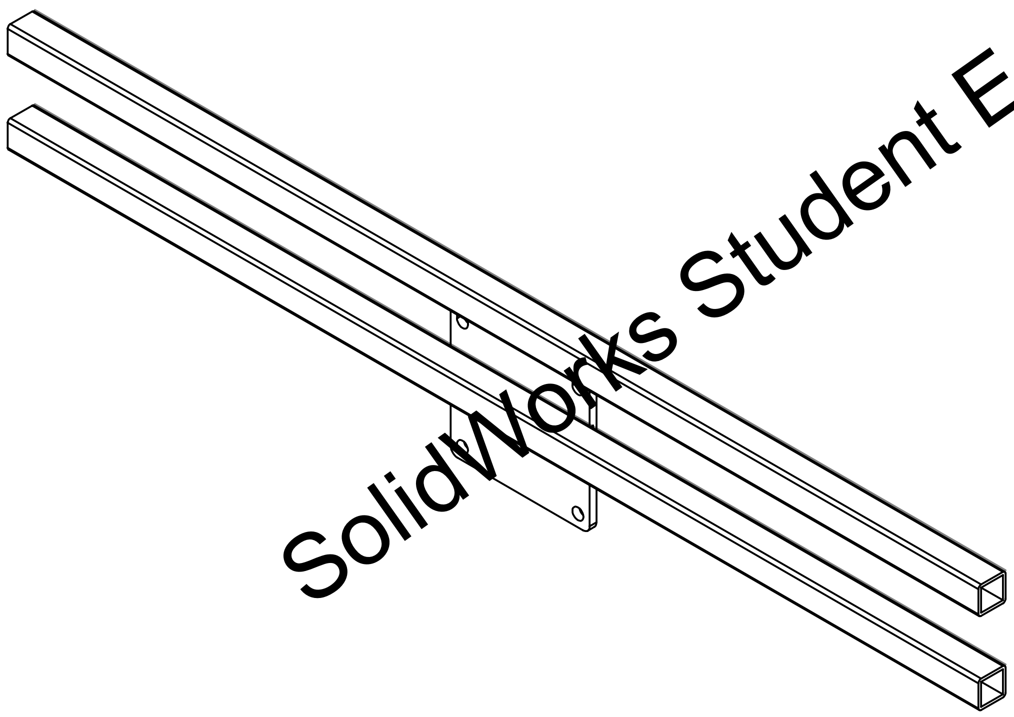


D

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:			DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING Dimensions in INCHES	REVISION
	NAME	SIGNATURE	DATE		TITLE:	
DRAWN	Andrew Bell		30/11/2010		Gearbox 1 Mount Placement	
CHK'D						
APPV'D						
MFG						
Q.A				MATERIAL:	DWG NO. GM1-2	A3
				WEIGHT:	SCALE:1:10	SHEET 2 OF 2

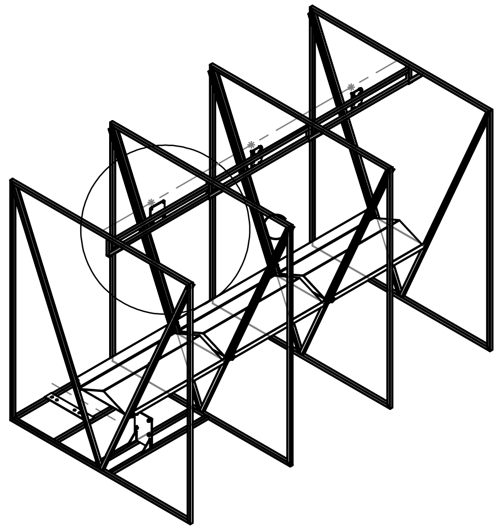


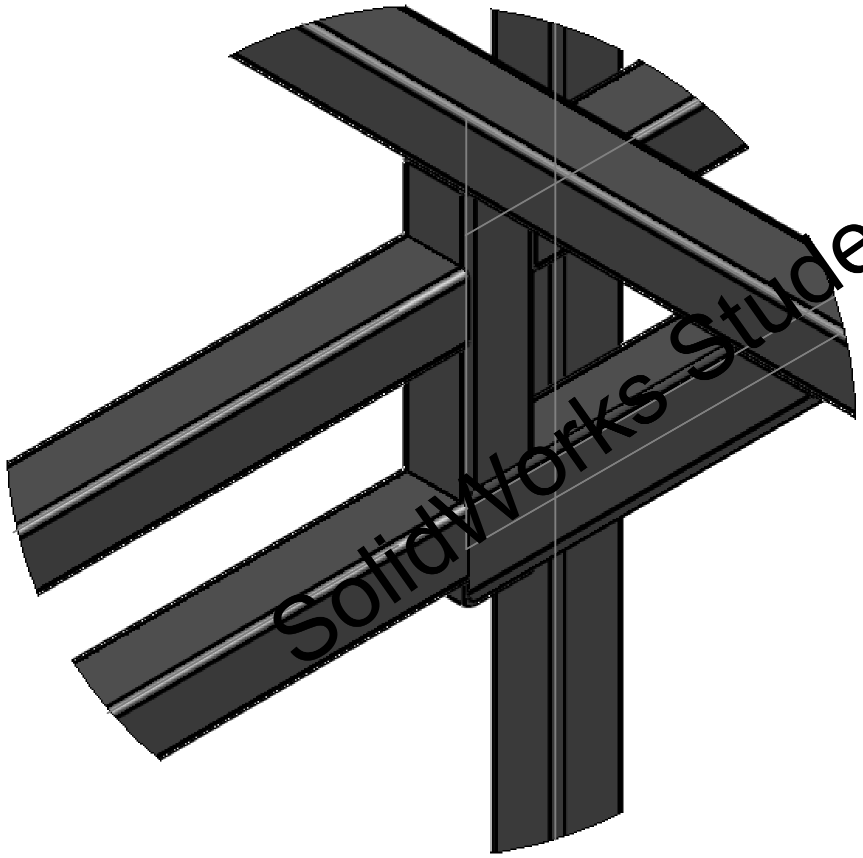




UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:		DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION
				Dimensions in INCHES	
	NAME	SIGNATURE	DATE	TITLE:	
DRAWN	Andrew Bell		30/11/2010	Gearbox 2 Mount	
CHK'D					
APPV'D					
MFG					
Q.A			MATERIAL: Steel	DWG NO. GM2	A3
			WEIGHT:	SCALE:1:5	SHEET 1 OF 2

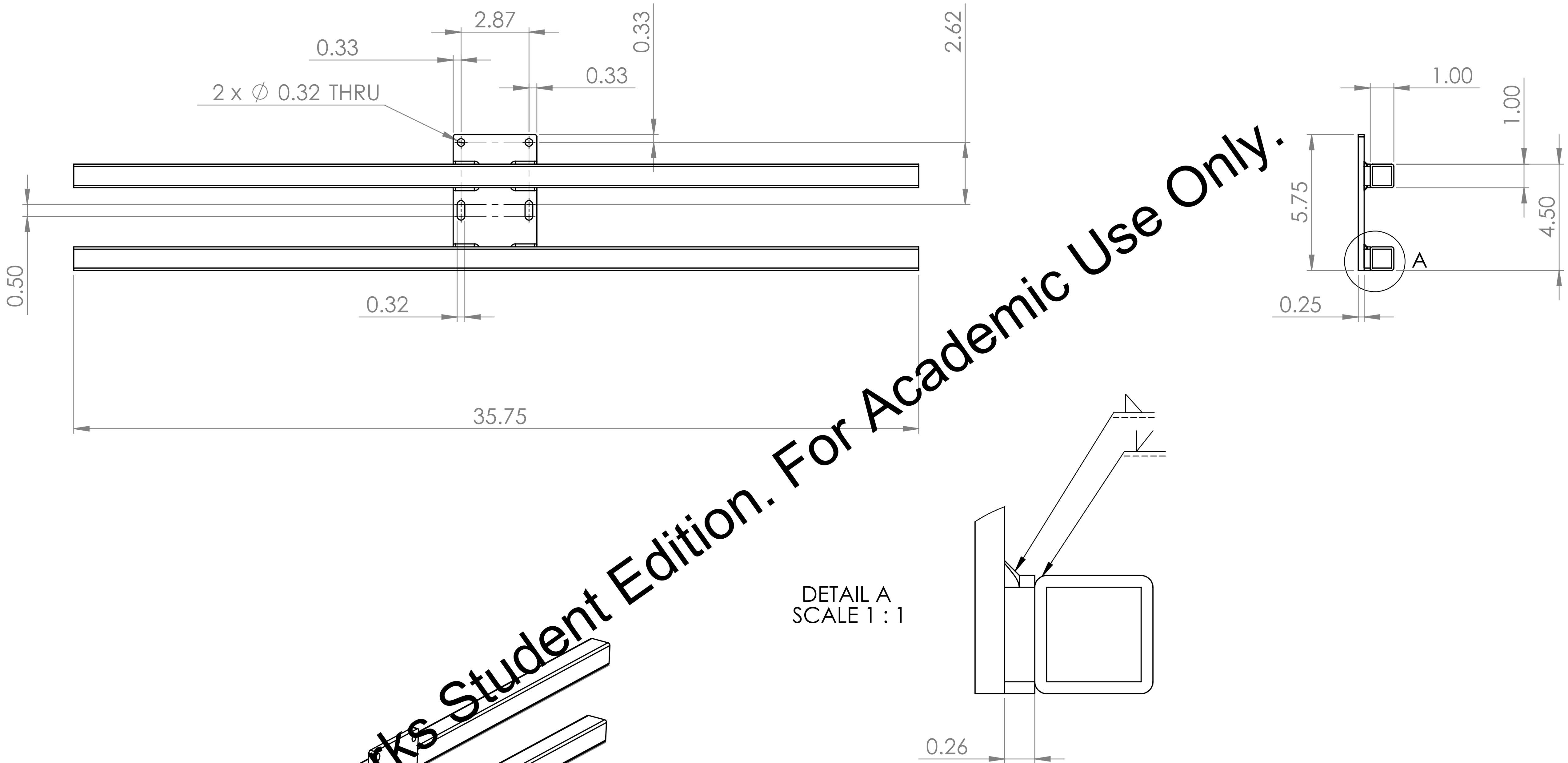
DETAIL C
SCALE 1 : 10

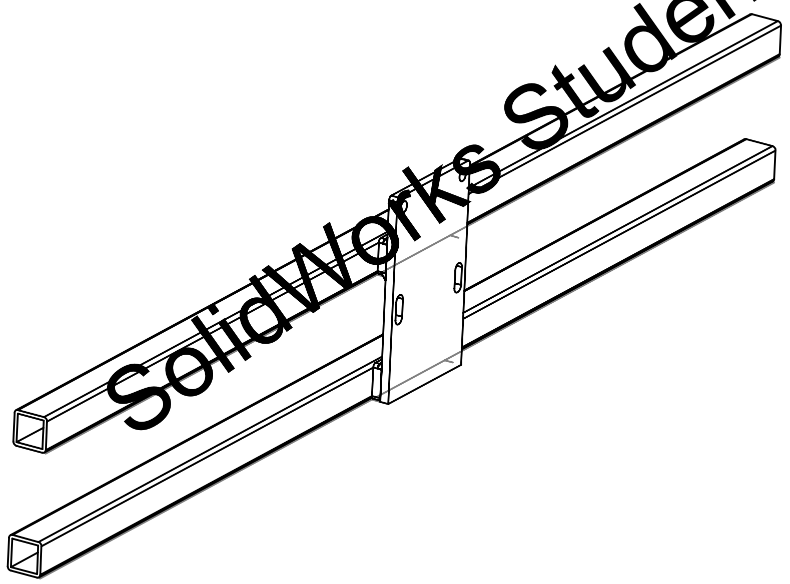




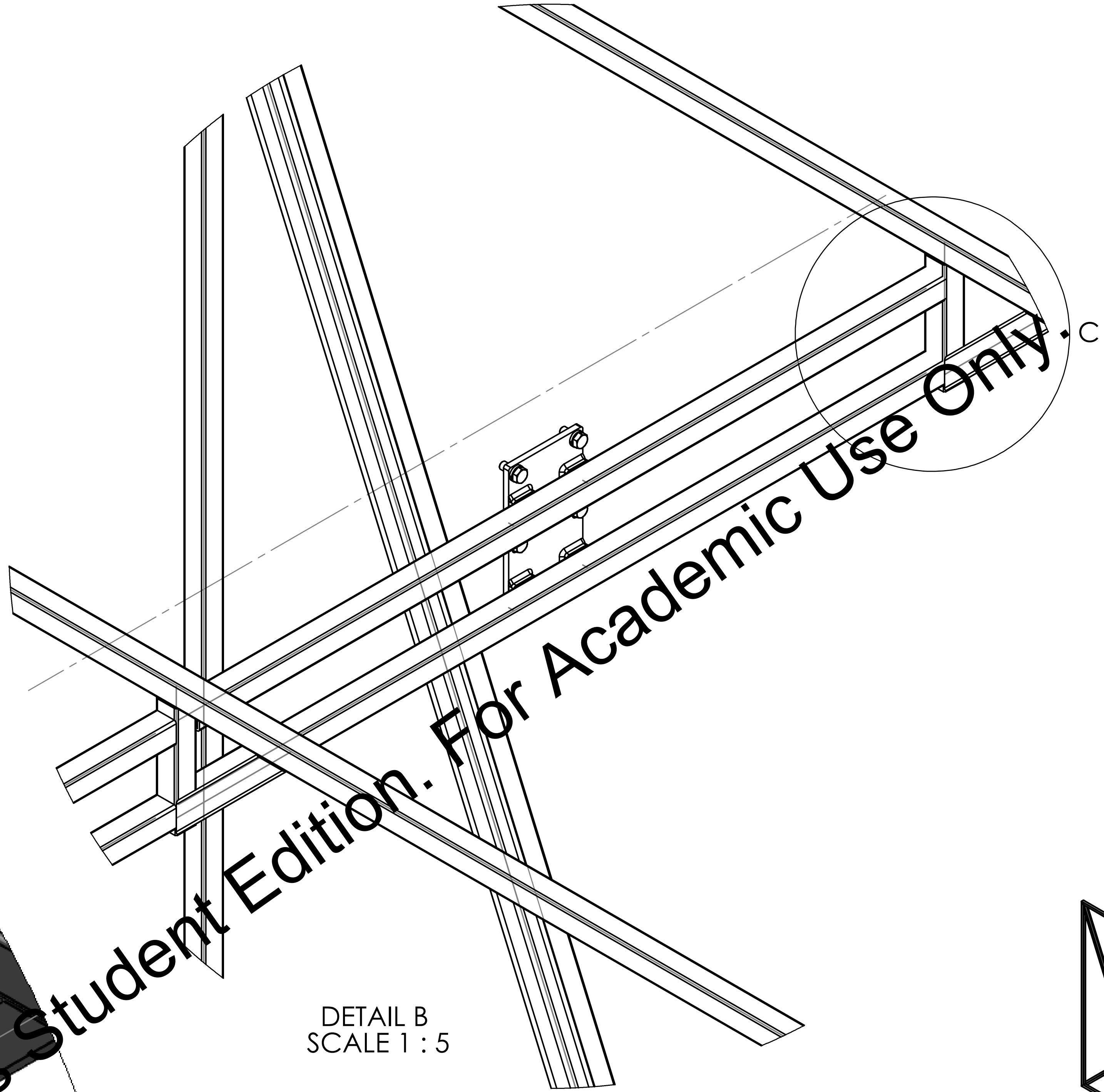
DETAIL D
SCALE 1 : 2

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:		FINISH:			DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION	
						Dimensions in INCHES		
	NAME	SIGNATURE	DATE			TITLE:		
DRAWN	Andrew Bell		30/11/2010			Gearbox Mount 2 Placement		
CHK'D								
APPV'D								
MFG								
Q.A				MATERIAL:		DWG NO.	GM2-2	A3
				WEIGHT:		SCALE:1:5	SHEET 2 OF 2	

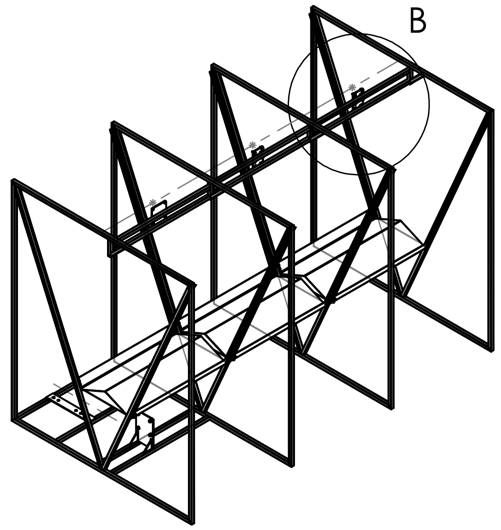


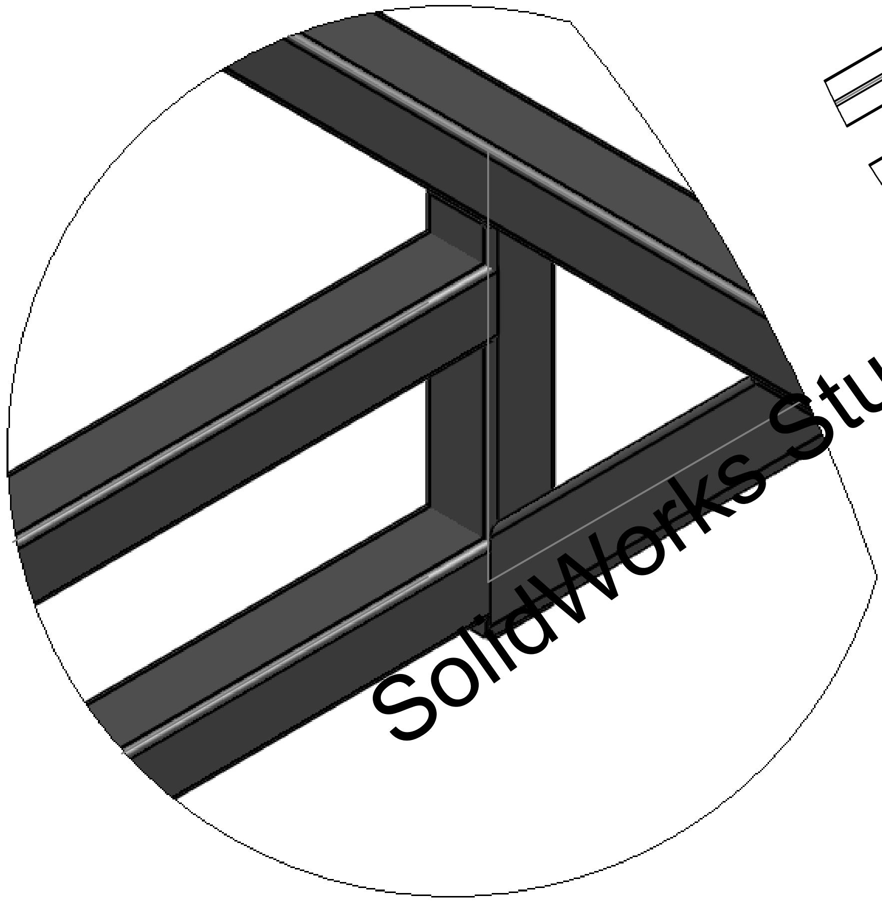


UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:		FINISH:			DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION
						Dimensions in INCHES	
	NAME	SIGNATURE	DATE			TITLE:	
DRAWN	Andrew Bell		30/11/2010			Gearbox 3 & 4 Mount	
CHK'D							
APPV'D							
MFG							
Q.A				MATERIAL: Steel		DWG NO. GM3-4	A3
				WEIGHT:		SCALE:1:10	SHEET 1 OF 2



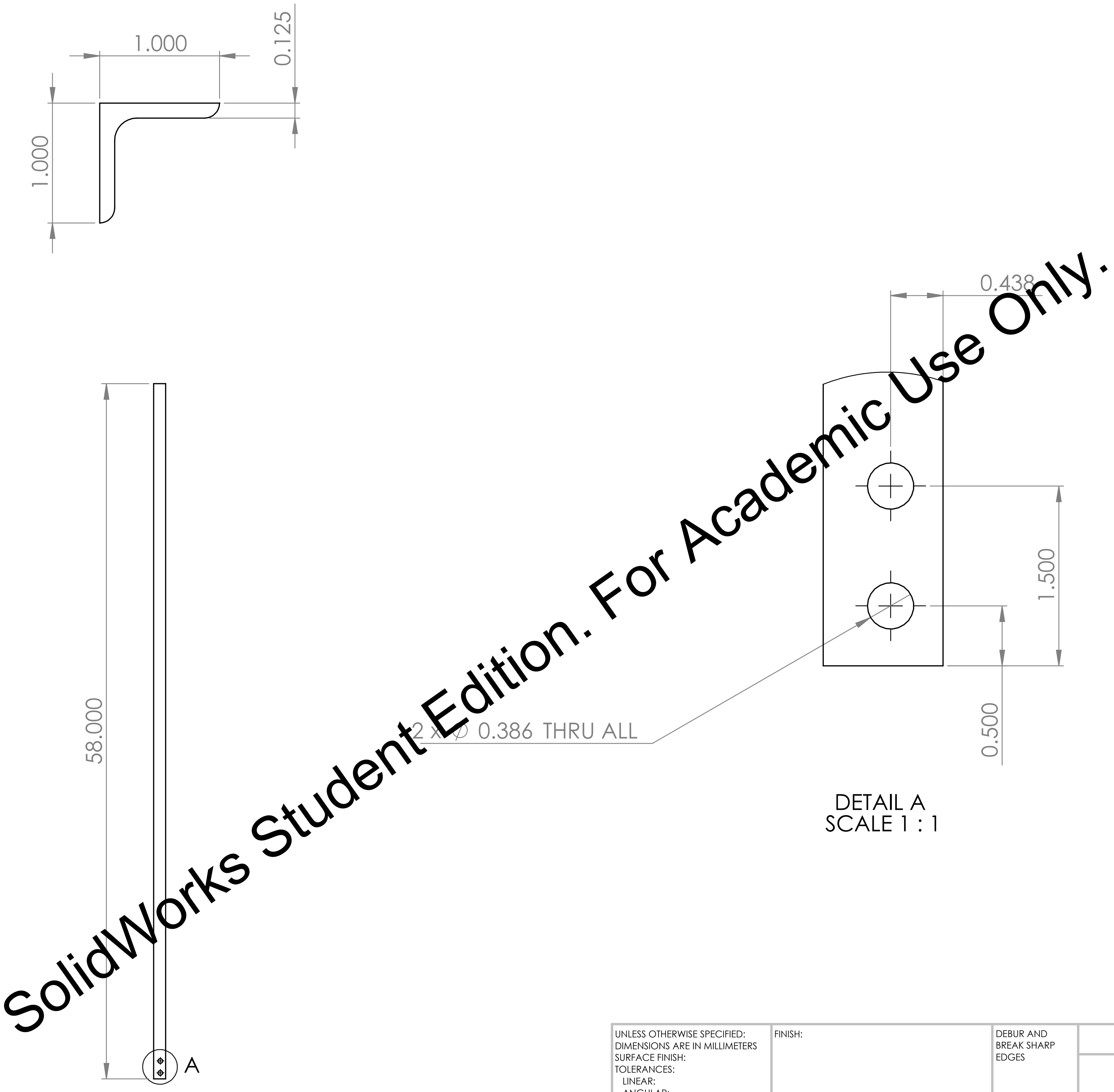
DETAIL B
SCALE 1 : 5





DETAIL C
SCALE 1 : 2

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:		FINISH:			DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING Dimensions in INCHES	REVISION
	NAME	SIGNATURE	DATE			TITLE: Gearbox 3-4 Mount Placement	
DRAWN	Andrew Bell		30/11/2010				
CHK'D							
APPV'D							
MFG							
Q.A				MATERIAL:		DWG NO. GM3-4-2	A3
				WEIGHT:		SCALE:1:10	SHEET 2 OF 2



6 of this part are required

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

Dimensions in INCHES

	NAME	SIGNATURE	DATE
DRAWN	Andrew Bell		29/11/2010
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

Left Angle Support

MATERIAL:
1.0" x 1.0" Steel Angle Iron

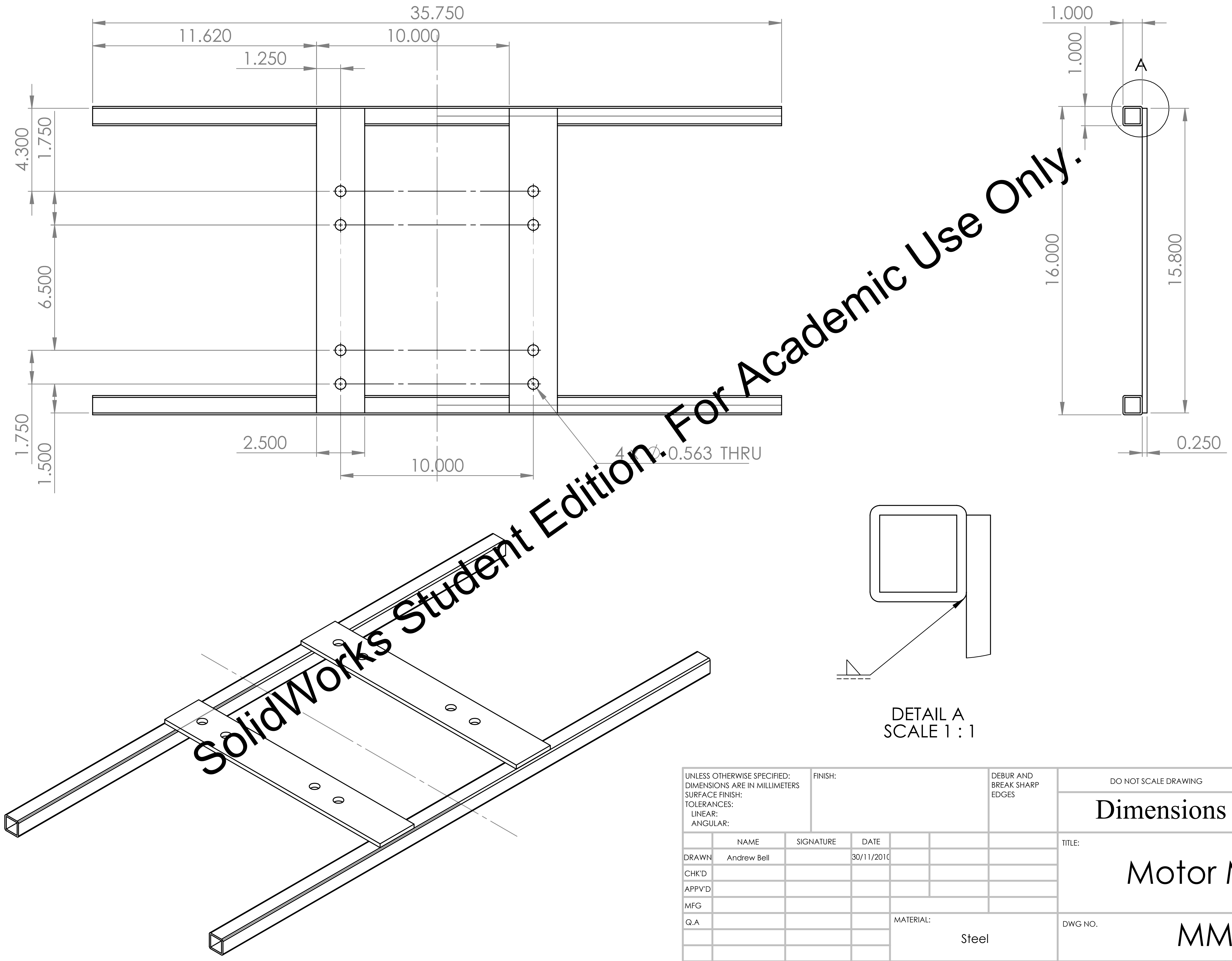
WEIGHT:

DWG NO.
LA1

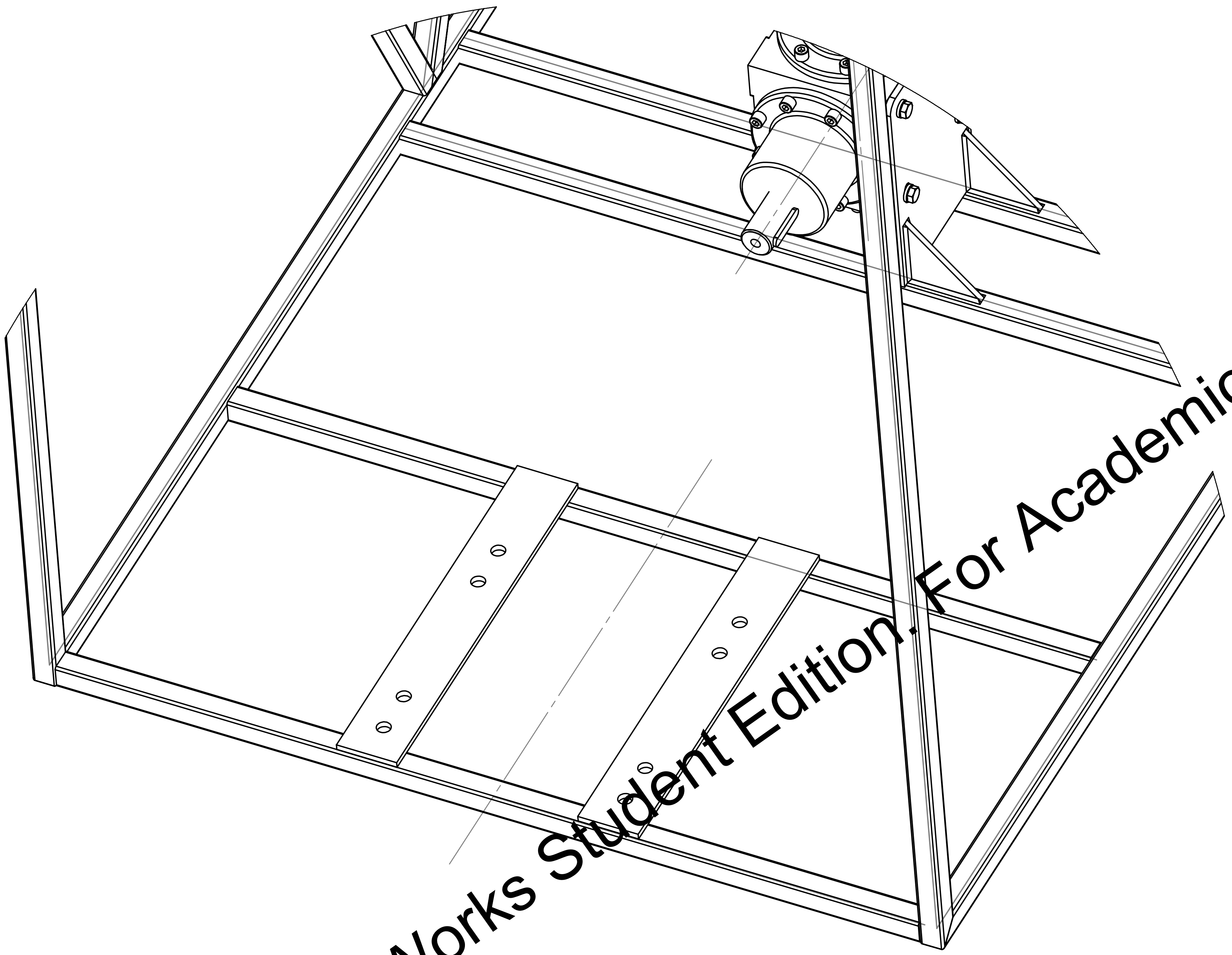
A3

SCALE:1:10

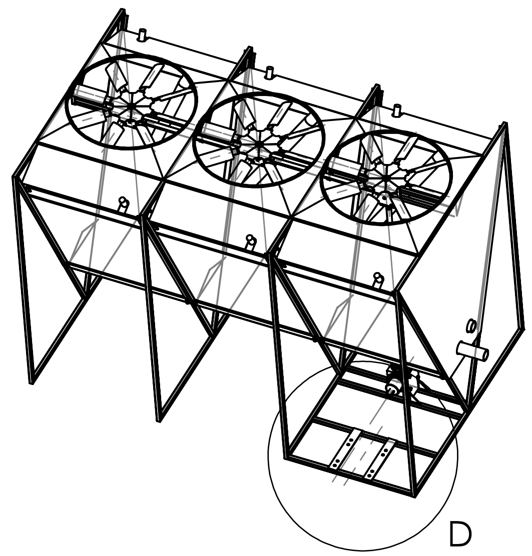
SHEET 1 OF 1



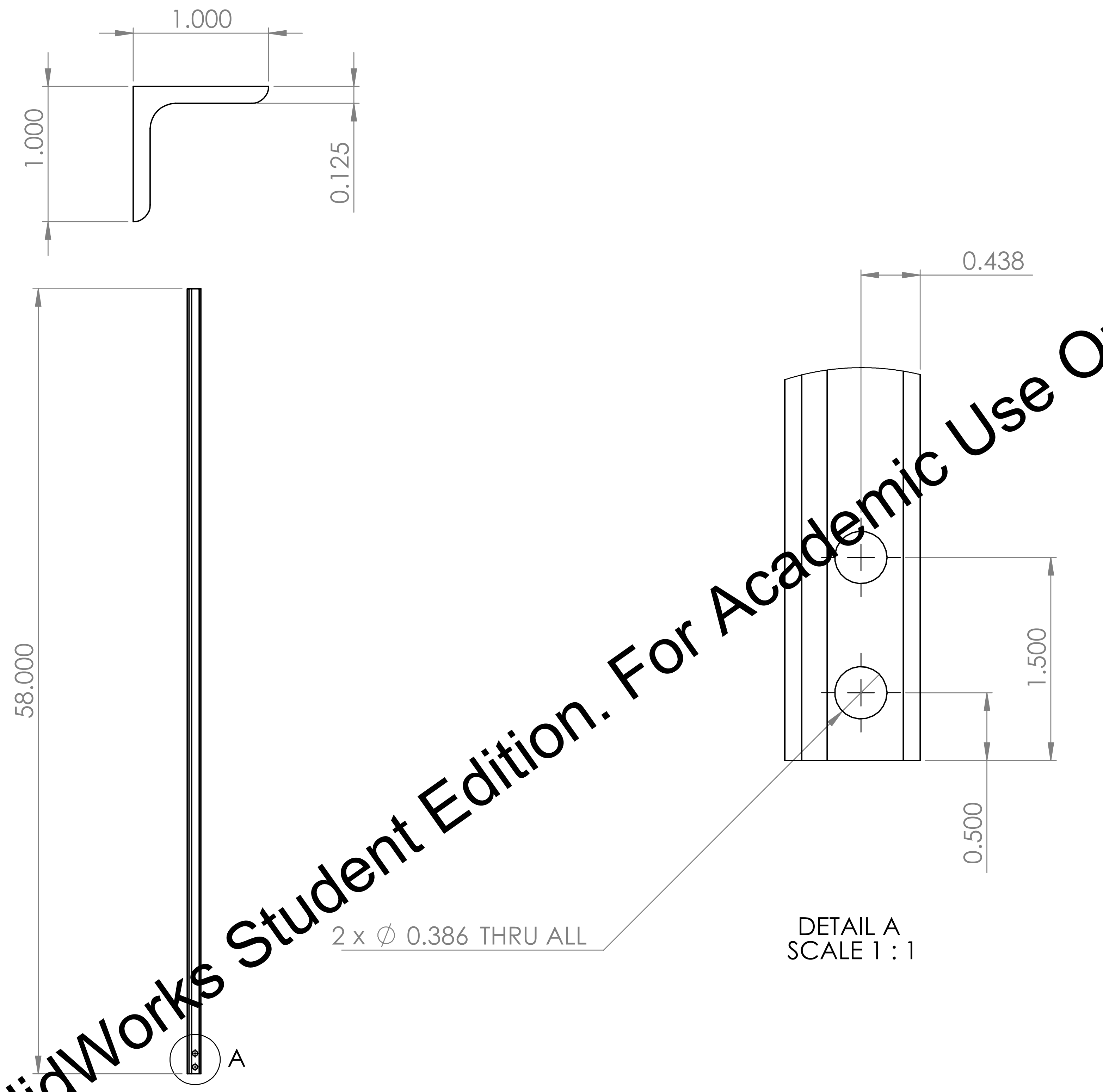
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:		DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION
				Dimensions in INCHES	
	NAME	SIGNATURE	DATE	TITLE:	
DRAWN	Andrew Bell		30/11/2010	Motor Mount	
CHK'D					
APPV'D					
MFG					
Q.A			MATERIAL: Steel	DWG NO. MM1	A3
			WEIGHT:	SCALE:1:10	SHEET 1 OF 2



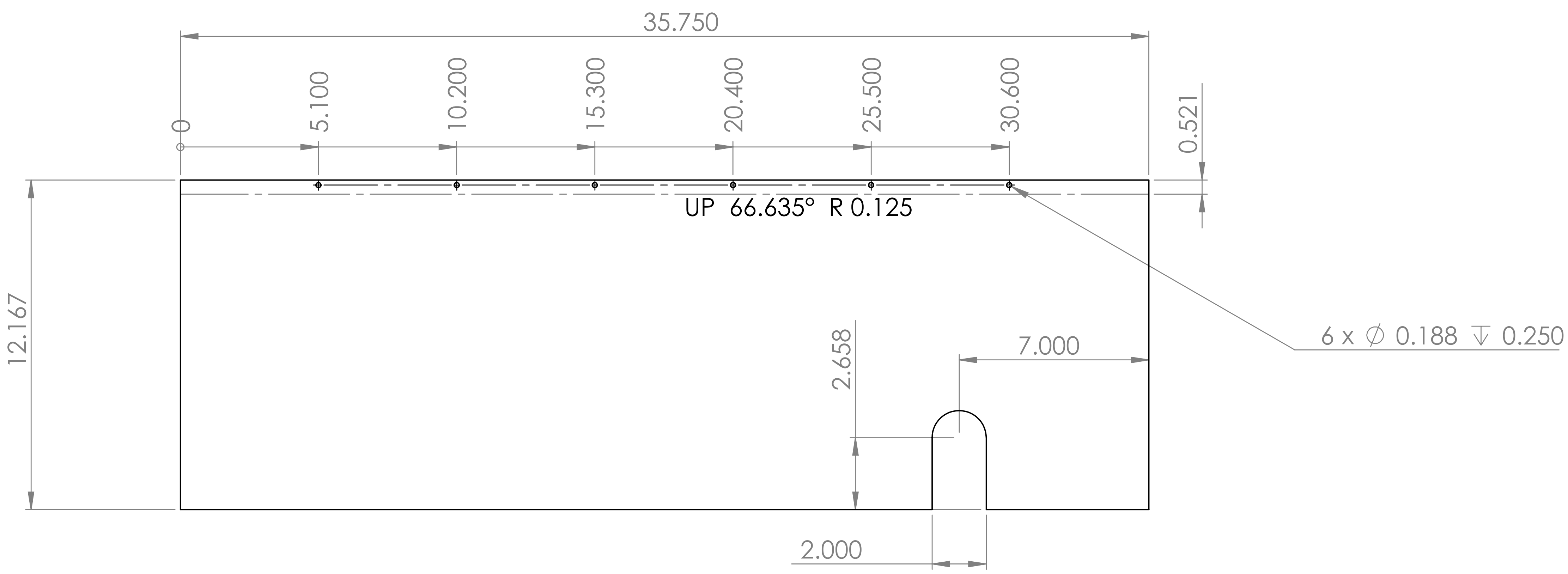
DETAIL D
SCALE 1 : 5

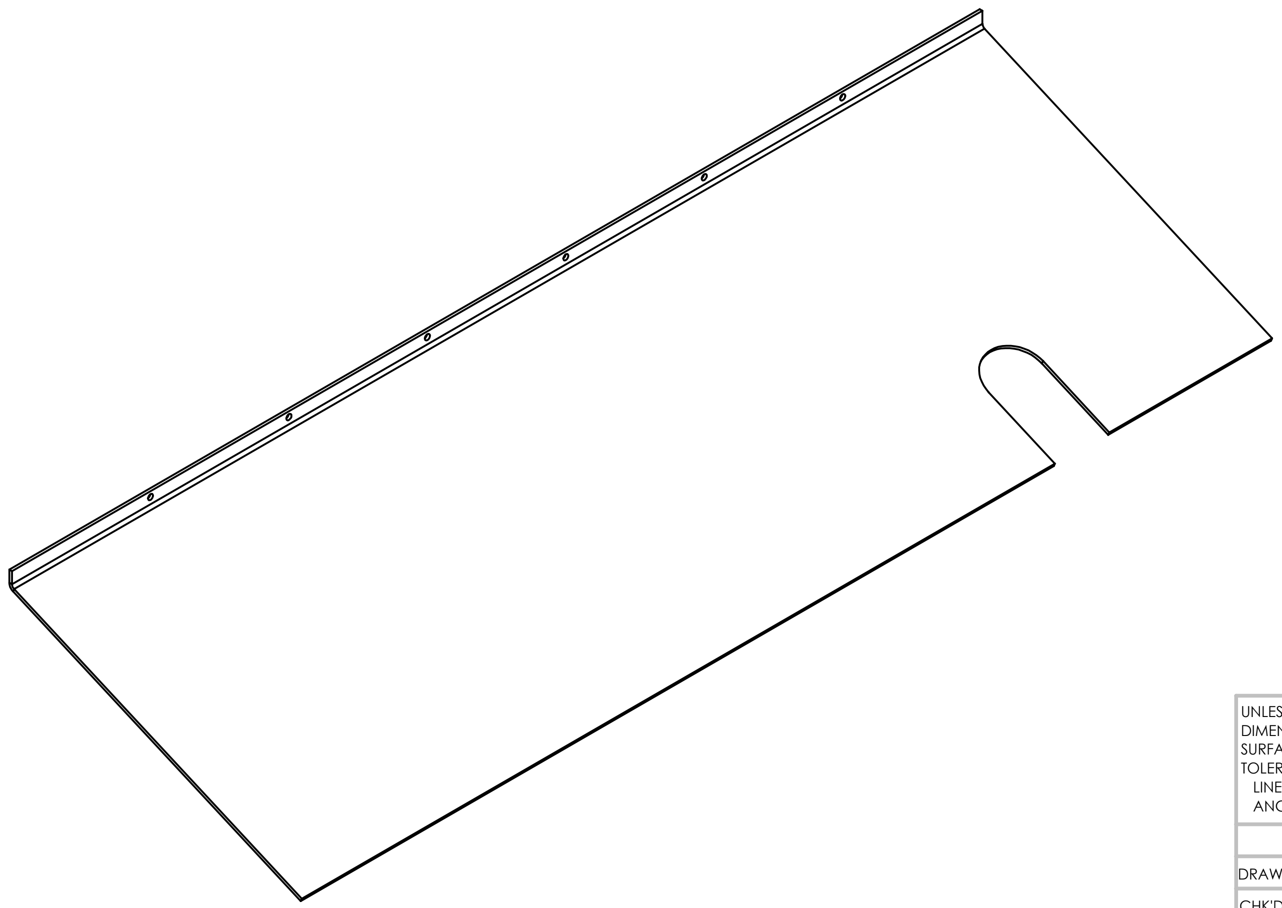


UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:		DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION	
				Dimensions in INCHES		
	NAME	SIGNATURE	DATE	TITLE:		
DRAWN	Andrew Bell		30/11/2010	Motor Mount Placement		
CHK'D						
APPV'D						
MFG						
Q.A			MATERIAL:	DWG NO.	MM2	A3
			WEIGHT:	SCALE:1:10	SHEET 2 OF 2	

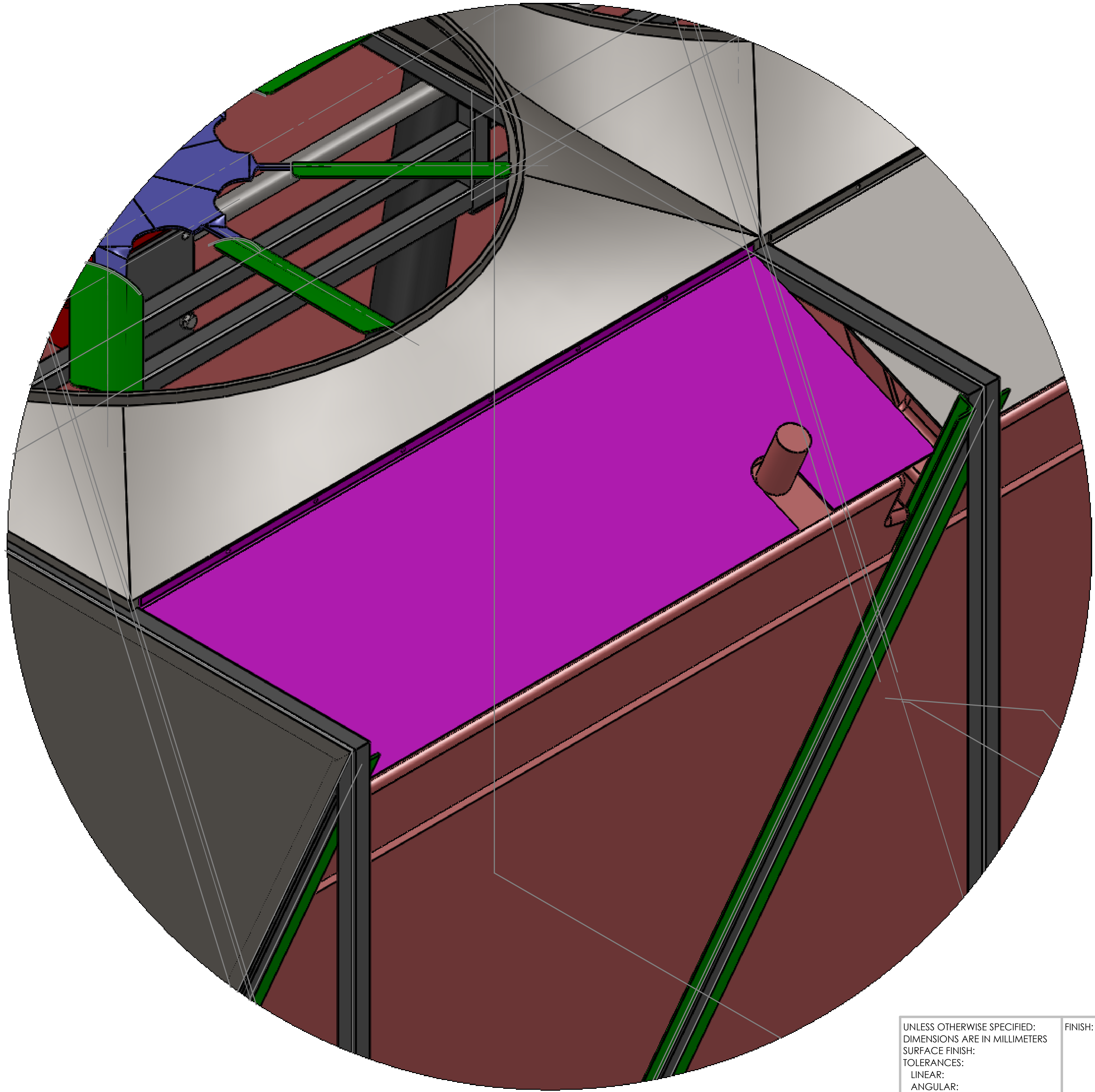


UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:		FINISH:			DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION
						Dimensions in INCHES	
	NAME	SIGNATURE	DATE			TITLE:	
DRAWN	Andrew Bell		29/11/2010			Right Angle Support	
CHK'D							
APPV'D							
MFG							
Q.A				MATERIAL: 1.0" x 1.0" Steel Angle Iron		DWG NO. RA1	A3
				WEIGHT:		SCALE:1:10	SHEET 1 OF 1



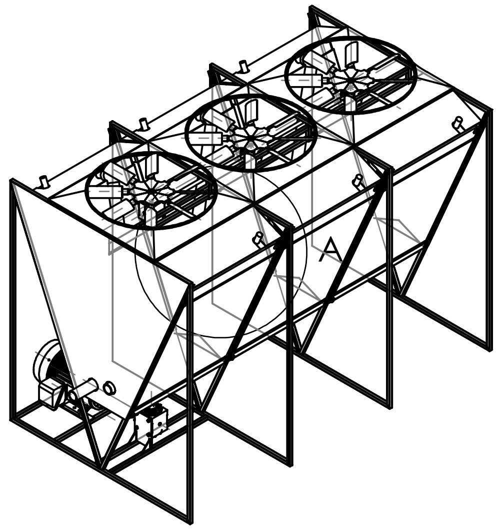


UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:		FINISH:		DEBUR AND BREAK SHARP EDGES		DO NOT SCALE DRAWING	REVISION
						Dimensions in INCHES	
	NAME	SIGNATURE	DATE			TITLE:	
DRAWN	Andrew Bell		29/11/2010			Sealer Panel	
CHK'D							
APPV'D							
MFG							
Q.A				MATERIAL: 16 Gauge Steel Sheet		DWG NO. SP1	A3
				WEIGHT:		SCALE:1:10	SHEET 1 OF 2

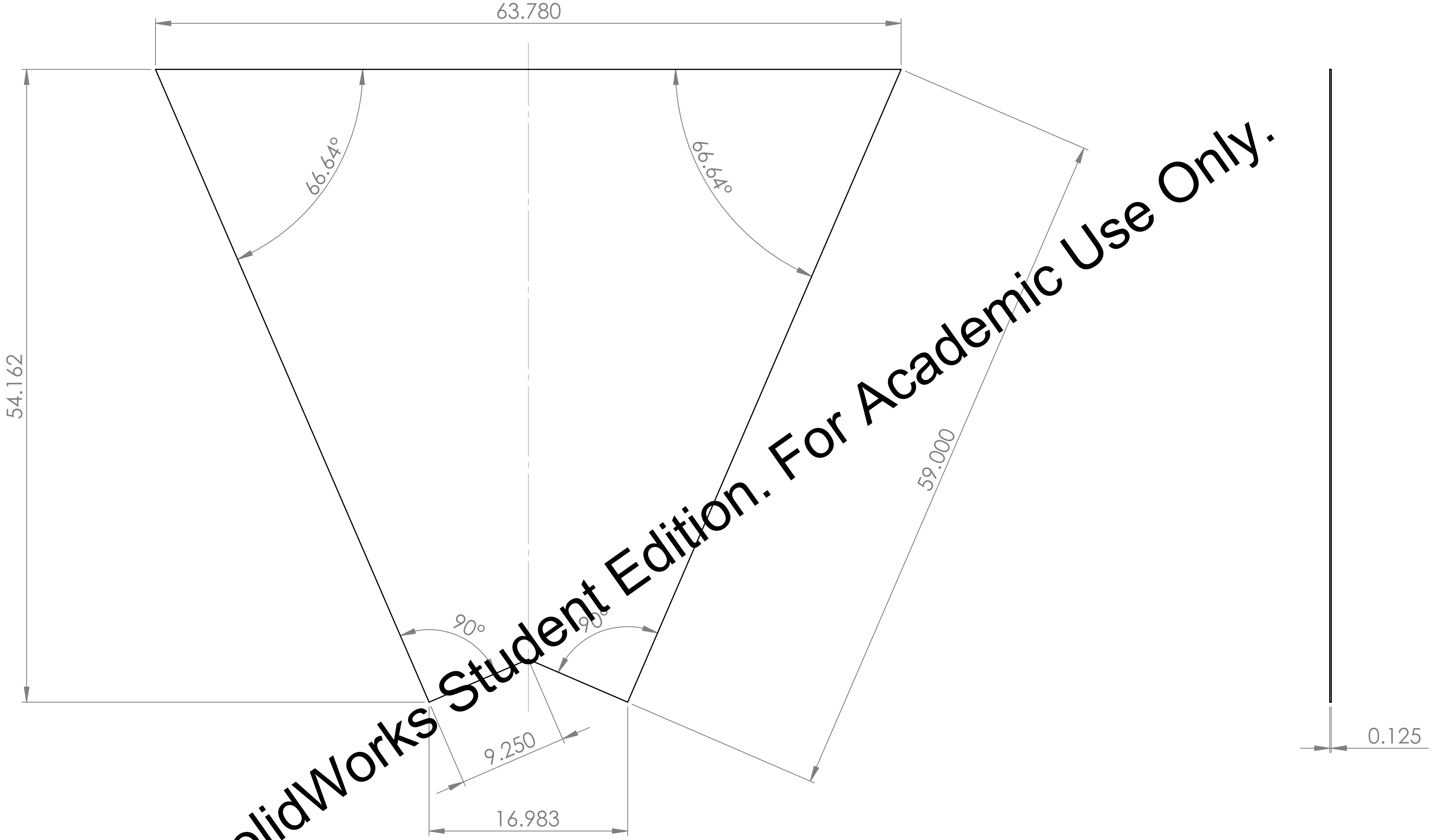


DETAIL A
SCALE 1 : 5

Sealer panels (x6) to be fastened to fan shroud with 1/4" self-tapping screws. Fastener placement not critical.

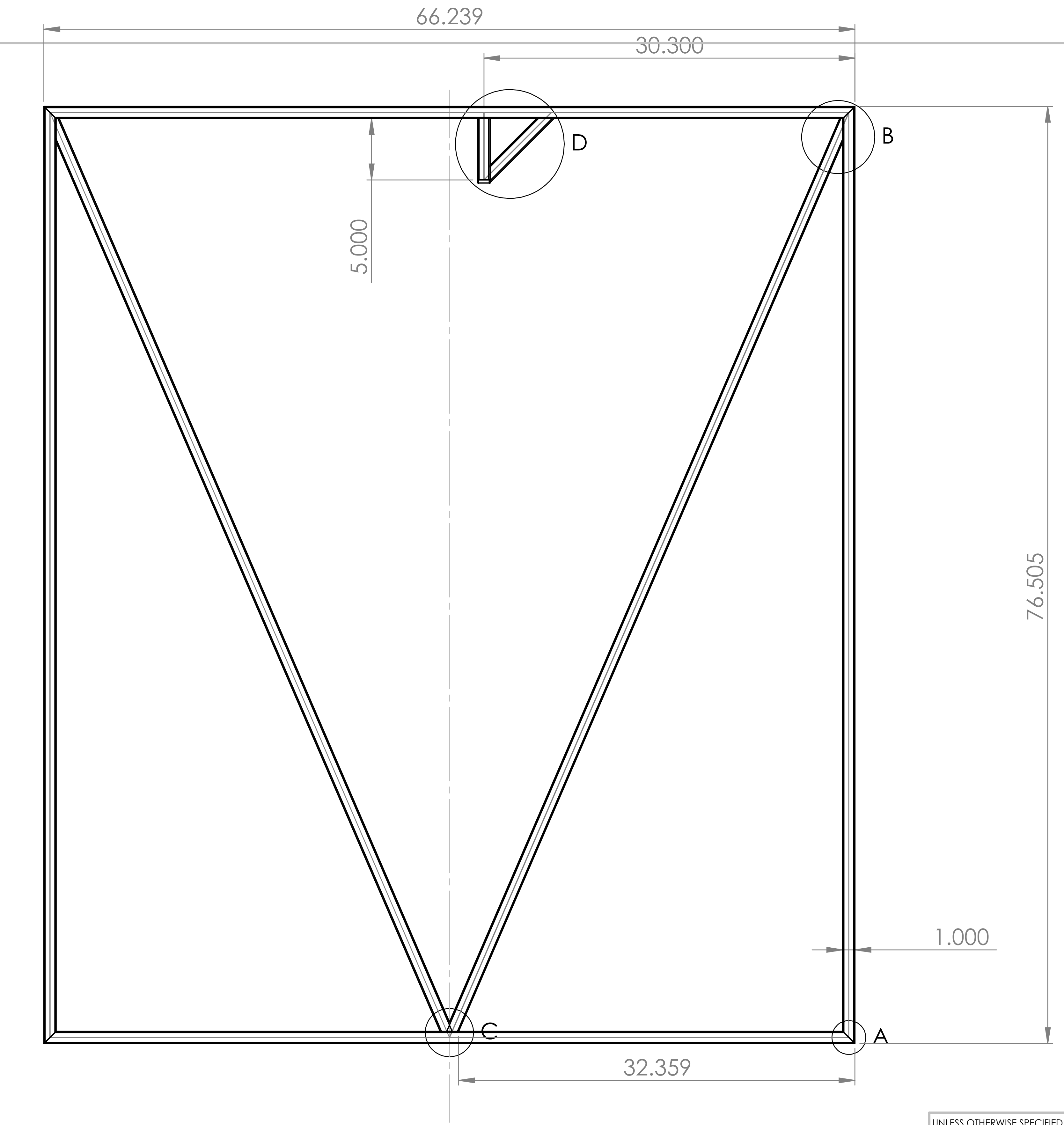


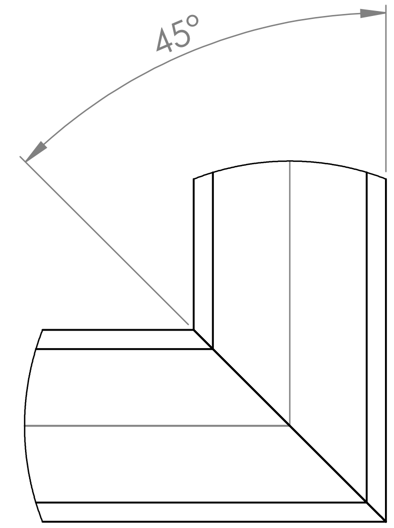
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:		DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION
				Dimensions in INCHES	
	NAME	SIGNATURE	DATE	TITLE:	
DRAWN	Andrew Bell		29/11/2010	Sealer Panel Placement	
CHK'D					
APPV'D					
MFG					
Q.A			MATERIAL:	DWG NO. SP1-2	A3
			WEIGHT:	SCALE:1:10	SHEET 2 OF 2



End sheets (x2) to be fastened to the outsides of the cooling tower with 1/4" self-tapping screws. Fastener placement not critical.

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:	DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION	
			Dimensions in INCHES		
	NAME	SIGNATURE	DATE	TITLE:	
DRAWN	Andrew Bell		30/11/2010	Side Panels	
CHK'D					
APPV'D					
MFG					
Q.A			MATERIAL: 16 Gauge Steel Sheet	DWG NO. SP1	A3
			WEIGHT:	SCALE:1:10	SHEET 1 OF 1





DETAIL A
SCALE 1 : 1

ITEM NO.	QTY.	DESCRIPTION	LENGTH
1	2	Sides	76.51
2	2	Top and Bottom	66.24
3	2	Inside Angles	81.26
4	1	Gearbox Mount 1	7.36
5	1	1 in. Sq. Tube Cap	
6	1	Gearbox Mount 2	5

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

Dimensions in INCHES

	NAME	SIGNATURE	DATE
DRAWN	Andrew Bell		29/11/2010
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

Support Frame

MATERIAL:
1.0" x 1.0" x 0.1" Sq. Tubing

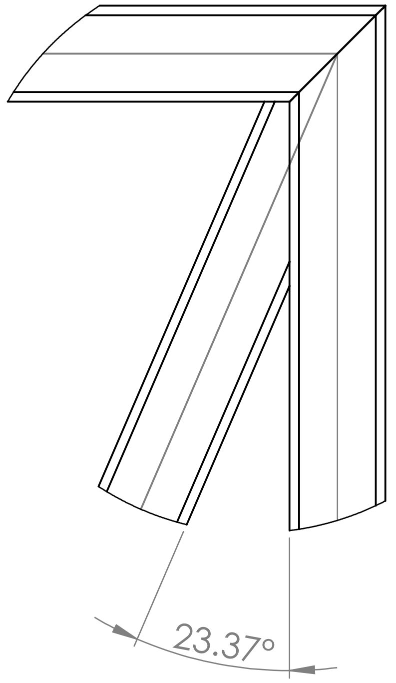
WEIGHT:

DWG NO.
SF1

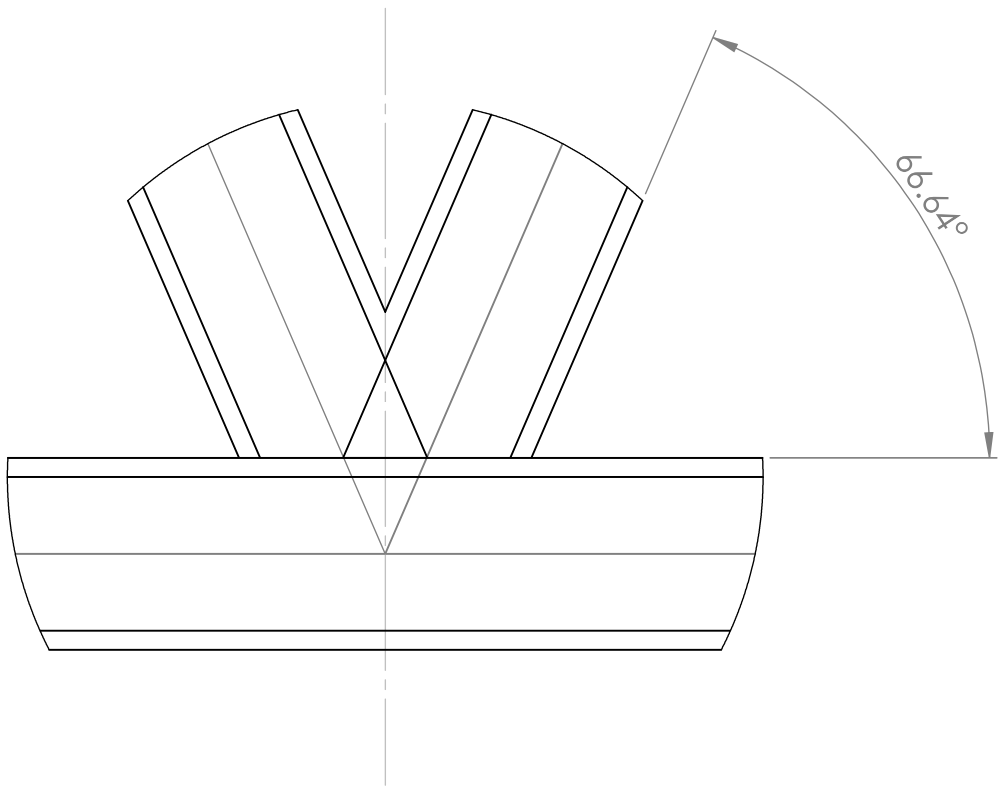
A3

SCALE:1:20

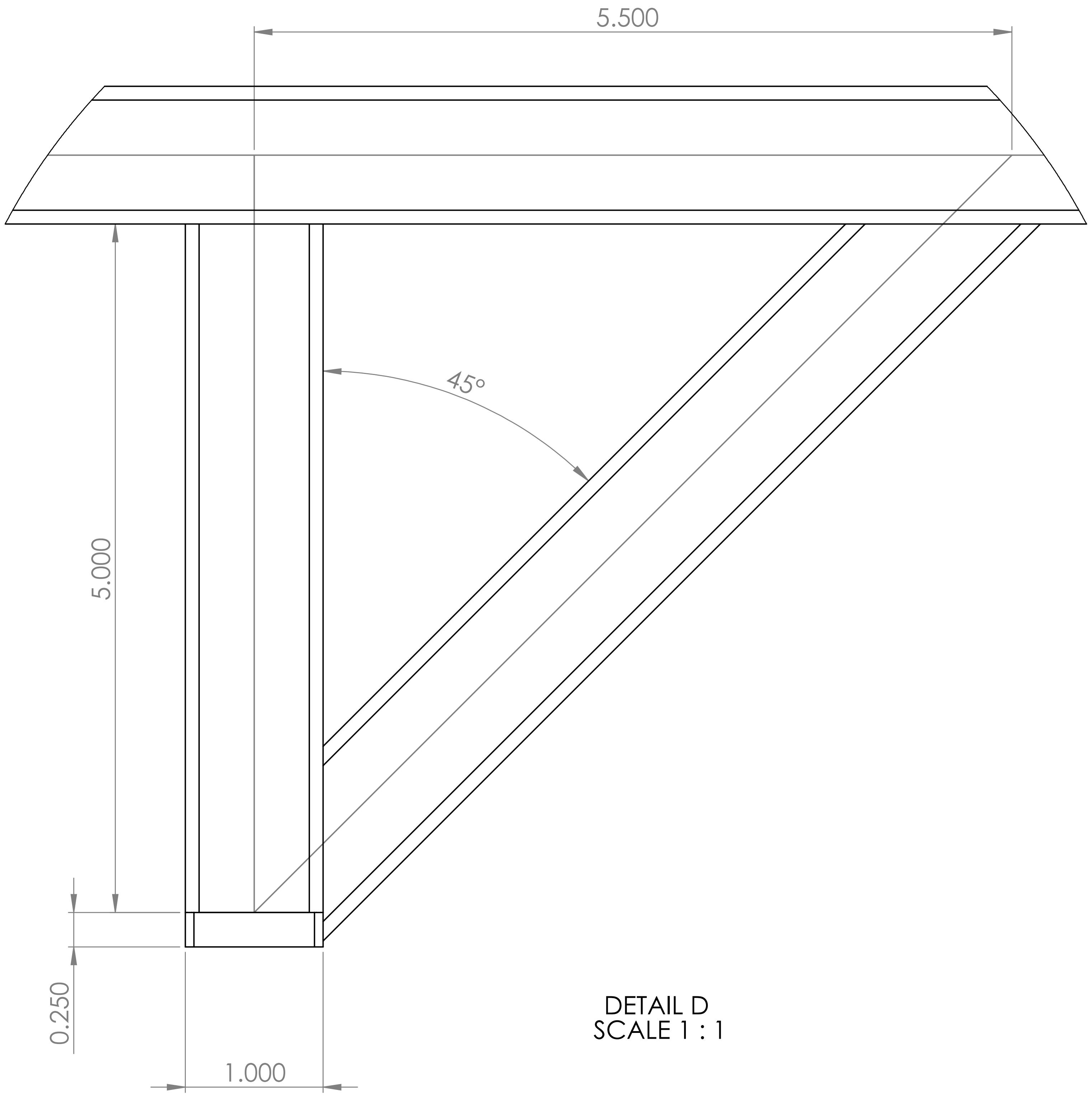
SHEET 1 OF 2



DETAIL B
SCALE 1 : 2



DETAIL C
SCALE 1 : 1



DETAIL D
SCALE 1 : 1

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:		DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING		REVISION
				Dimensions in INCHES		
	NAME	SIGNATURE	DATE	TITLE:		
DRAWN	Andrew Bell		29/11/2010	Support Frame		
CHK'D						
APPV'D						
MFG						
Q.A			MATERIAL: 1.0" x 1.0" x 0.1" Sq. Tubing	DWG NO.	SF1	A3
			WEIGHT:	SCALE:1:20	SHEET 2 OF 2	

Appendix I

Johnson Thermostat Specifications

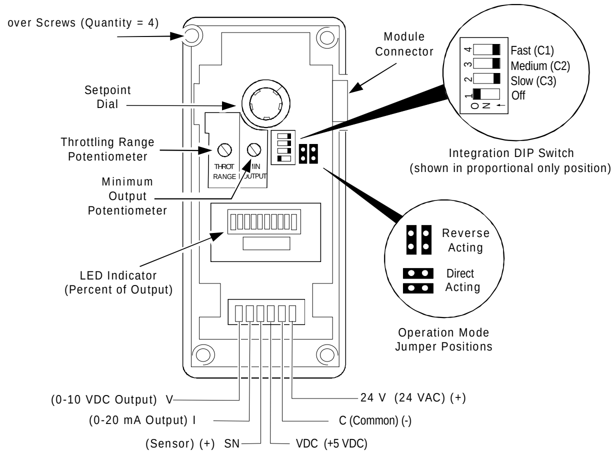
JOHNSON CONTROLS

Controls Group 507 E. Michigan Street
P.O. Box 423, Milwaukee, WI 53202
Code No. LIT-1922370

A350P Series

Electronic Proportional Plus Integral Temperature Control

A350P



Features

- field-selectable proportional only or proportional plus integral control
- plug-together connectors and 35 mm DIN rail mounting eliminate wiring between models and reduce installation costs
- ten segment LED displays percent of output signal
- field-selectable reverse or direct-acting mode
- minimum output adjustable from 0 to 60%
- two models cover a wide setpoint range of -30 to 250°F (-35 to 121°C)

Applications

- modulating heating and cooling valves
- maintain mixed air duct temperature via damper modulation

To Order

Specify code number from the selection chart, along with additional staging, power and display modules, and temperature sensing enclosures, if required.

Description

The A350P Electronic Proportional Plus Integral Temperature Control Series has two proportional outputs of 0 to 10 VDC and 0 to 20 mA. This control is used in conjunction with the A99B Series (PTC silicon) Temperature Sensors. Two controls cover a temperature range from -30 to 250°F with an adjustable throttling range (proportional band) of 2 to 30F°.

Proportional plus integral (PI) control is an option to hold setpoint regardless of load shifts on the system. A temperature sensor (A99BC-25C) is included with each A350P control. The S350 Staging Module, D350 Display Module, and Y350R Power Module can be used with the A350P.

Selection Chart

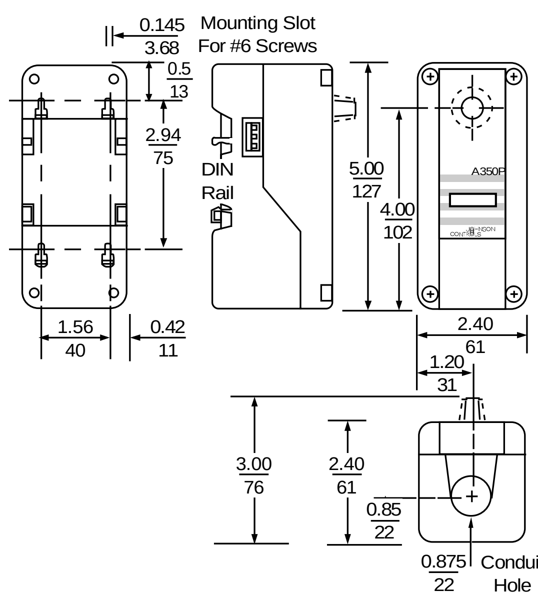
Code Number	Output Signal	Range	Throttling Range	Sensor (Included)
A350PS-1C	Proportional Voltage: 0 to 10 VDC and Proportional Current: 0 to 20 mA	-30 to 130°F -35 to 55°C	2 to 30F° 1 to 17C°	A99BC-25C
A350PT-1C				None
A350PS-2C		90 to 250°F 30 to 121°C		A99BC-25C

Specifications

A350P Electronic Temperature Control with Proportional Output		
Supply Voltage (a)	**Transformer**	20 to 30 VAC, 50/60 Hz, Class 2
	Y350R	120/240 VAC, 50/60 Hz
Proportional Output		0 to 10 VDC (550 ohm load minimum) and 0 to 20 mA. (600 ohm load maximum).
Minimum Output		Adjustable from 0 to 60% of the output span
Output Indication		A ten segment LED indicates percentage of output
Control Action		Direct or reverse action is jumper selectable
Power Consumption		3.2 VA
Integration Constant		Three selectable rates fast, medium, slow and an Off position
Ambient Temperature	**Operating**	-30 to 150°F (-34 to 66°C)
	Shipping	-40 to 185°F (-40 to 85°C)
Humidity		0 to 95% RH non-condensing
Case and Cover Material		NEMA 1, high-impact thermoplastic

(a) Only one voltage source may be used.

A350P Dimensions, in. (mm)



Appendix J

Sample Cost Analysis Calculations

Electrical Cost Analysis

Assumed electricity rate: 3.05₵ / kWh

Calculated electricity consumption of 7.5 HP fan motor and 7.5 HP pump:

$$P = \frac{VI(PF)}{1000}$$

Where:

- P = power consumption;
- V = voltage;
- I = current; and
- PF = power factor

With the following specifications for both the fan motor and supply pump motor we get:

- V = 575 V
- I = 8 amps
- PF = 0.885
- **P = 7.05 kW**

For the 1.5 HP Monarch return pump, the specs are as follows:

- Power output = 1.5 HP
- Assumed PF = 0.8

$$Power\ Consumed = \frac{Power\ Output}{PF} = \frac{1.5}{0.8} = 1.875\ HP = 1.38\ kW$$

Combining these values we can determine electrical power consumption as follows:

$$Electricity\ consumption\ per\ test = ((2\times 7.05\ kW) + 1.38\ kW)\times 8\ hours = 123.84\ kWh$$

$$Electrical\ cost\ per\ test = 123.84\ kWh\ \times 3.05\ \frac{₵}{kWh} = \$\mathbf{3.78}\ \boldsymbol{per\ test}$$

$$Electrical\ cost\ per\ year = \$3.78\times 65\ tests = \$\mathbf{245.70}\ \boldsymbol{per\ year}$$

Water Cost Analysis

City of Winnipeg water rates are as follows:

Volume [m^3]	Rate
0-272	$1.29
272.1 - 2720	$1.12
over 2720	$0.95

Sewer Rate: $1.91 / m^3

The current water flow rate being used while operating the dynamomter is 45 GPM, which is the maximum flow rate achievable. Using the following water consumptions we can calculate the water cost per test and per year.

$$Water\ consumption\ (8\ hour\ test) = 45\ GPM \times 60\ ^{s}/_{min} \times 8\ hours = 21600\ Gal.$$

$$Water\ consumption\ (per\ year) = 21600 \times 1{,}404{,}000\ Gal. = 5314.72\ m^3$$

Assuming all water used by the dyno is then discharged to sewer, the water and waste cost is calculated as follows:

$$Cost\ for\ first\ 0 - 272\ m^3 = 272 \times \$1.29 = \$350.88$$

$$Cost\ for\ 272.1 - 2720\ m^3 = 2447.9 \times \$1.12 = \$2741.65$$

$$Over\ 2720\ m^3 = (5314.72 - 2720) \times \$0.95 = \$2464.98$$

$$Sewer\ cost = 5314.72\ m^3 \times \$1.91 = \$10{,}151.12$$

$$\boldsymbol{Total\ Cost} = 350.88 + 2741.65 + 2464.98 + 10151.12 = \$\mathbf{15{,}708.63}$$

Which gives a difference in annual operating cost of **$15,462.93**.

Appendix K

Taylor Coolant System Configurations

Water Recirculation

Water Recirculation

Water Recirculation Systems

Taylor Dynamometer custom engineers Water Recirculation / Cooling Systems for single test cells or complete test facilities with multiple test cells and multiple heat source requirements. Water systems can be designed with above or below ground bulk water storage to use a selection of cooling devices. The Evaporative Cooling Tower is by far the most cost effective solution in most cases.

The Taylor Dynamometer Water Recirculation / Cooling Systems offer several significant benefits to our customers, such as;

- Reduced dynamometer operating costs through water conservation
- Reduced dynamometer maintenance costs with controlled, high-quality water supply
- Assured environmental-friendliness by discharging through evapora tion rather than drainage
- Assured dynamometer performance due to proper water pressure, volume, and cooling

Water Recirculation

The Water Recirculating / Cooling Systems designed by Taylor are intended primarily for use with dynamometers, though they can be used to conserve water with any heat-generating, water-cooled process equipment as well. Our engineers can easily accommodate your needs and ensure sufficient capacity is designed into the system.

A standard Water Recirculation System (WRS) from Taylor will include:

• **WRS Command and Control Center:** The WRS command center contains the system controller, motor starters and accessory connections. The command center can be programmed for the desired system start-up temperatures, failure notification, emergency shutdown and many other convenient options to best suit your application.

• **Pumps and motors:** Taylor Dynamometer will supply you with the best possible pumps for the application requirements. Some of the different styles of pumps used are centrifugal, vertical turbine, and centrifugal self-priming. All pumps are sized specifically to the application, related cooling volume and pressure requirements for proper system operation.

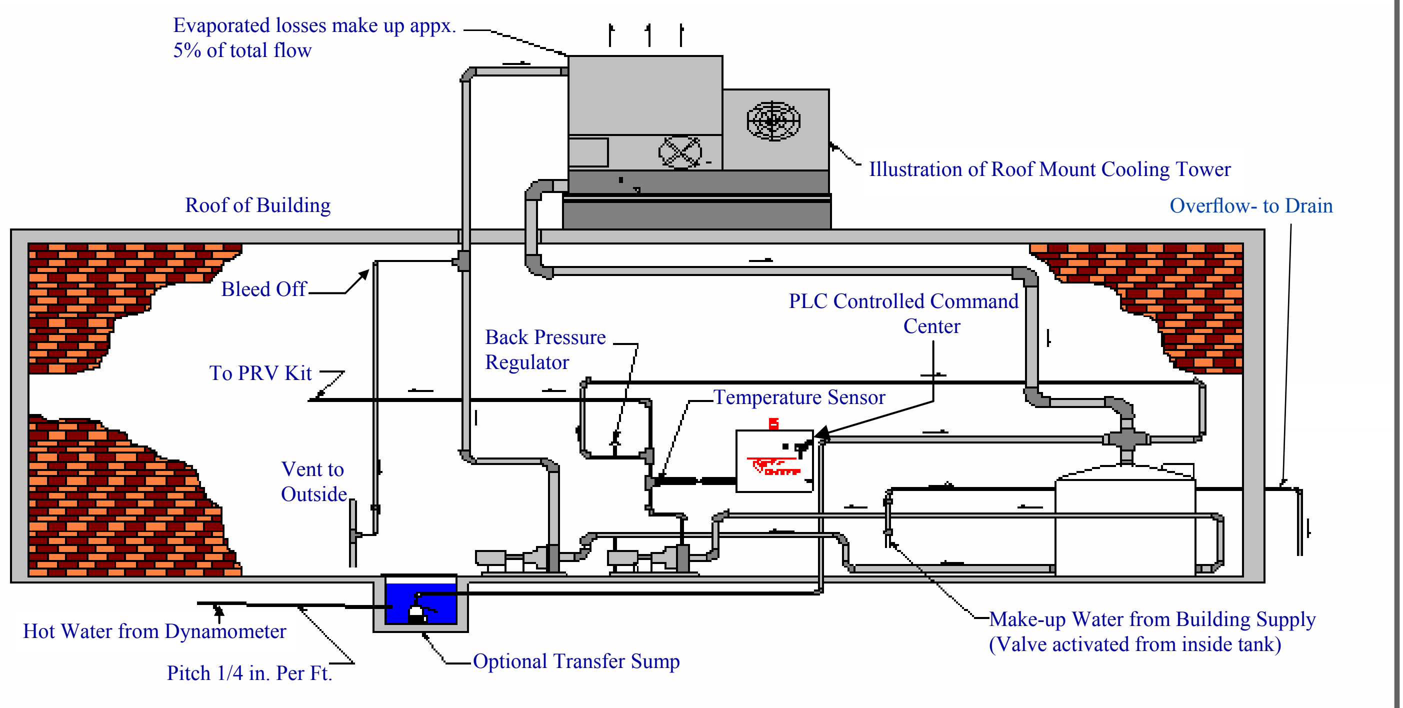
• **Evaporative Cooling Tower, Chiller, Heat Exchanger or Radiator:** The Evaporative Cooling Towers, Chillers Heat Exchangers and Radiators used by Taylor are all designed for optimum heat transfer and efficiency. All components used are suitable for outdoor service and may be installed on an unobstructed rooftop or on ground level. Systems may also be designed for indoor installation.

• **Specifications, Installation requirements, piping Schematics:** Taylor Dynamometer will provide specifications for each pump, motor and cooling device along with informational forms and Installation Information.

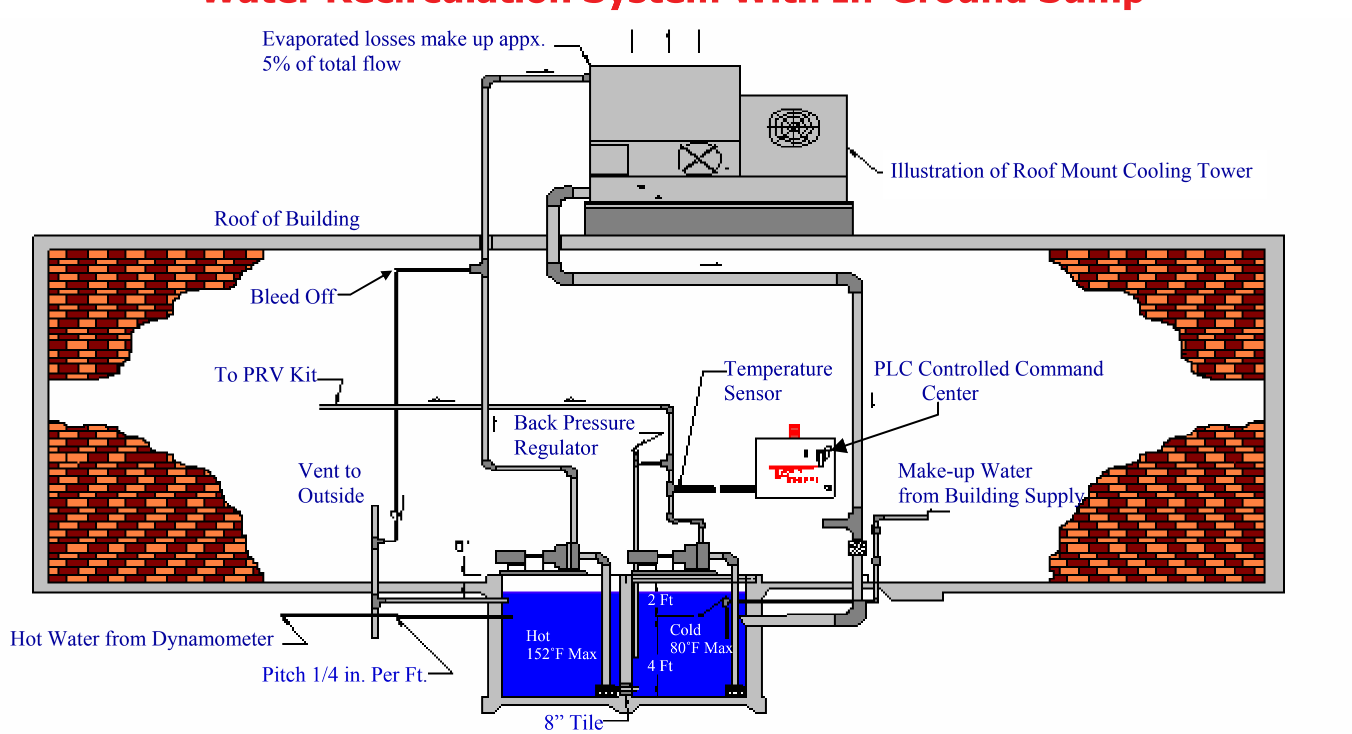
The customer is to supply the following components when purchasing a system from Taylor Dynamometer:

• Remote sump or above ground tank (if not purchased separately from Taylor Dynamometer)
• Common plumbing items, such as pipe, tile, fittings, gate valves and back flow preventer
• Common electrical items, such as wire
• Foundation for Evaporative Cooling Tower or other cooling device
• Deck plates/sump cover, when applicable.

Water Recirculation System With Above Ground Storage Tank



Water Recirculation System With In-Ground Sump



SMS0785V005