Roy Campbell
FP Innovations, FERIC Division`
Roy.Campbell@fpinnovations.ca
Dear Mr. Campbell,

Subject: Wild Fire Sprinkler System Phase 3 Deliverables
Alberta Genuine Designers have completed the detailed design stage for the Wild Fire Sprinkler Project. The final chosen design, named the Fire Cobra, has been fully designed. This report contains the following requested deliverables:

- Phase 3 Design Report
- Detailed Design Drawings
- Completed Design Calculations

The requirements set out by the client at the beginning of the design process have been met by Alberta Genuine Designers. This Detailed design report describes how these requirements were met, and where applicable, calculations are shown to prove the accuracy of this concept to FP Innovations requested design. A final project schedule is contained within this report showing the hours spent on the project, and the workload for all completed tasks.

The final completed project is completed, with a final budget for 417.5 hours, and a total engineering cost of approximately $38155.

AGD would like to thank you for the opportunity to complete the requested design. It is recommended that a prototype be built to test the accuracy of the calculations, and to complete the remaining testing outlined in the report. If you have any questions regarding this report, please feel free to contact me by phone at (1-780-909-6162) or by email at JMoore1@ualberta.ca.

Best Regards,

Jesse Moore, on behalf of Alberta Genuine Designers

CC: Yongsheng Ma, U of A
Charles Weir, AGD
Alexander Dufour, AGD
Chris Languedoc, AGD
Evrhetton Gold, AG

Mec E 460 - Phase III Detailed Design

FP Innovations

Wildland Fire Fighting Sprinkler: Fire Cobra

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April 5, 2012

Alberta Genuine Design

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Executive Summary

Alberta Genuine Designers has designed a fire fighting sprinkler that is intended to improve upon existing fire sprinklers. The name of this sprinkler is the Fire Cobra. The primary design improvements are mobility of water throw height and distance using manipulated nozzle dimensions via a flexible hose attachment. Increased flow exit velocity to allow higher throw distance from the sprinkler in order to reach the tree canopies extending up to 21 meters. A sprinkler support has also been designed to allow for versatile mounting options.

Through robust design, the Fire Cobra will be able to uphold to the rigors of fighting forest fires. Durability of materials, and strength of the methods of manufacturing involving over designed welds and fittings, will allow the fire sprinkler to take the difficult circumstances that it will see over its life.

With an entire design weight of 3.83 kg this design lowers the weight of current sprinklers in use making it easier to carry around difficult terrain. A final prototype cost of $510 and mass production cost of $280 makes the cost of building this fire sprinkler comparable current sprinkler costs of $280. Sprinkler support piece will have a prototype cost of $140. All these considerations make the Fire Cobra an optimal improvement over existing designs, with a design that allows maneuverability and maximizes throw distance, while keeping costs down, this design can easily replace those currently be used in the field today.

A critical analysis has been done to verify the performance of this using advanced software such as ANSYS and FloXpress. Hand calculations have also been done to confirm the results. The analysis confirms that the Fire Cobra is ready to be prototyped for further testing to validate its performance.

Introduction

Alberta Genuine Design has been tasked with the design of an innovative sprinkler head to assist in forest fire fighting efforts. Sprinkler systems are used in practice to help control the movement of the blaze for both wildfires and prescribed burns. Current equipment is limited in capability. Because of this, FP Innovations is looking for a better design. The Fire Cobra has been designed to improve in all areas over existing designs such as increasing throw height and distance, allowing adjustability, and providing a lighter and more rugged sprinkler.

Design Objective

The objective of this design is to provide a water sprinkler for use in fighting, and preventing natural as well as prescribed forest fires. The primary objective of this sprinkler is to maximize the vertical and horizontal throw distances when the water leaves the nozzle, and to make the nozzle angle adjustable as required. All of the client's specifications were met and are as follows:

- The System is to be designed to have a maximum throw height of 21 meters, which was set by FP Innovations.
- The client specified that the system must have a minimum of setup steps in order to reduce setup time and complexity.
- The sprinkler head must be adjustable for changing environmental conditions such as tree height.
- The sprinkler will also be mounted in a variety of locations, so the support must be versatile and mountable on dimensional lumber, buildings, and into the ground.
- The weight of the sprinkler must be minimized to allow ease of use.
- The design must be able to withhold operating pressures up to a maximum of 300 psi.

The final design is capable of achieving the desired throw ranges. The final design is easy to setup since standard connections are used. The final design is capable of adjusting the nozzle angle to reach higher distances. The sprinkler mounting device has been designed to adapt to a wide variety of scenarios. The full system assembly, setup, and operation can be seen in Appendix C.

Sprinkler Design

Fire Cobra Design

The Fire Cobra concept improves over existing fire sprinklers in several ways. The first and most important method of improving over existing designs is by implementing an adjustable nozzle. This is accomplished through the adjustable support arms shown in Figures 1 to 3 below. By manipulating the position of the screws on the provided sliding bar mechanism, the direction that the flexible hose is pointing can be adjusted to any angle desired. The arms are made of galvanized steel to ensure that the arms are strong enough to support the nozzle force as water is flowing through it. Brass was selected for the tee, nipple, and reducer due to its high corrosion abilities.

By directing a small amount of separate flow through the rotation nozzle, the main flow is uninterrupted and the secondary flow will cause the rotational impact arm to swing, impacting the main body of the sprinkler, and consequentially turning the main nozzle through a small angle. The Fire Cobra design decreases the amount of fluctuation in nozzle diameters, and shifts in flow direction throughout the nozzle body, which decreases pressure loss, thereby increasing velocity at the nozzle exit.

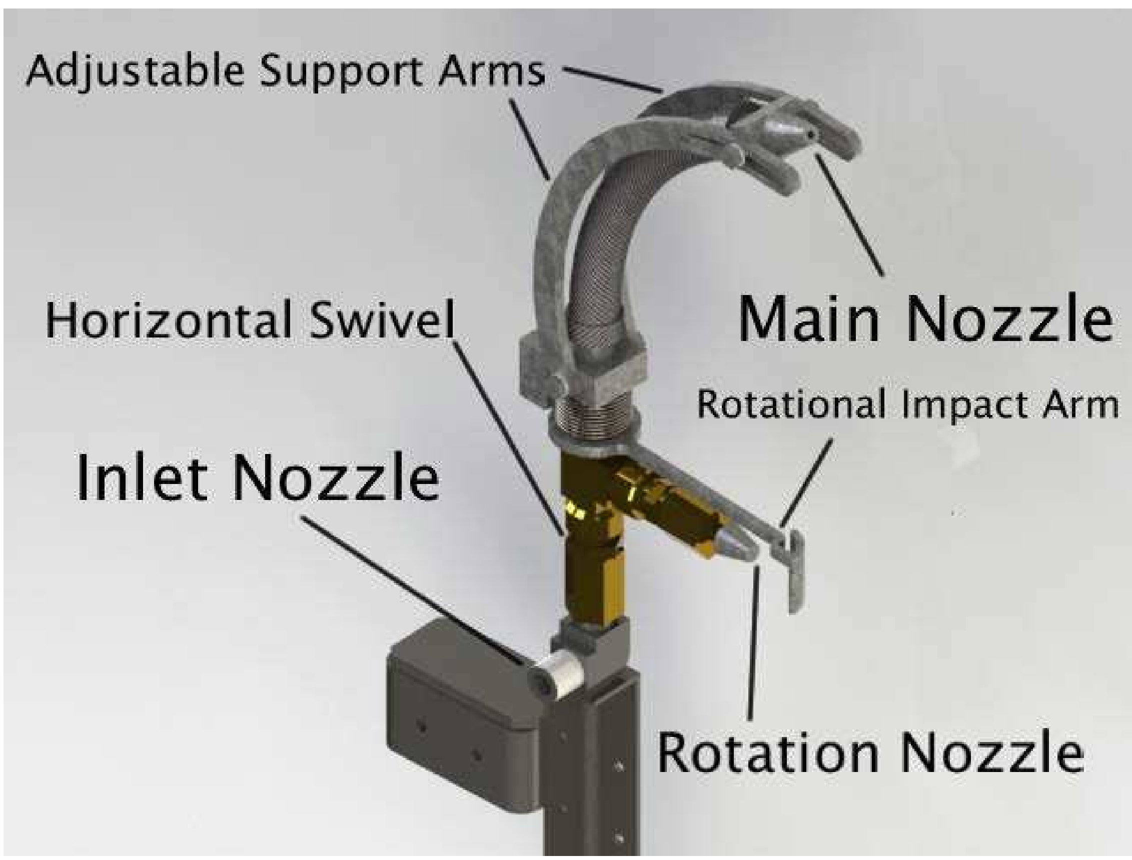


Figure 1 - Solid model of Fire Cobra

Sprinkler Support Design

The design of the sprinkler support is one of simplicity and ruggedness. The main body of the support is made from angle iron. One sharpened end allows it to be staked firmly into the ground. Holes in the body allow for it to be mounted to the side of a tree. In addition, a holder made of simple rectangular steel tubing, is attached at the side of the main body which allows for placement on top of a 2"x 4" piece of vertical lumber. The holder dimensions could easily be swapped for alternate ones during final fabrication. The numerous holes in the holder and body allow for many mounting scenarios on various surfaces. The holder is capped in order for the support to be stomped or driven with a hammer into the ground. In addition, the top of the main body is also capped and various sprinkler mounting designs can be applied. Overall the design will prove strong, durable and versatile. Figure 2 below shows the sprinkler support.

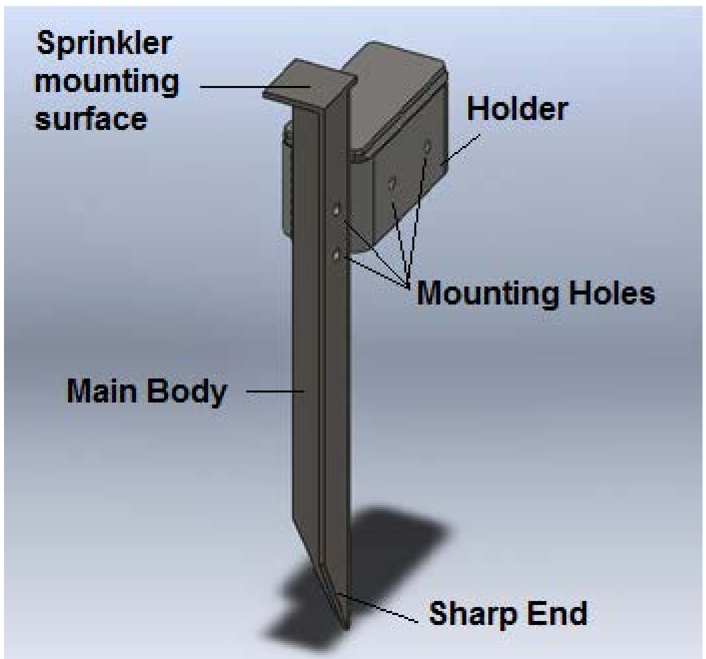


Figure 2 - Solid model for Sprinkler Support

Full Assembly

The Fire Cobra sprinkler head is attached to the sprinkler support by welding the base of the elbow to the mounting surface of the support. The welds will roughly be around 0.388 mm big and have been designed to withstand a significantly large force to insure the welds do not fail. The welding calculations can be viewed in Appendix A. Figure 3 below shows the resulting assembly of the entire sprinkler and Figure 4 below shows an exploded view illustrating how each part is to be assembled.

Figure 3 - Full sprinkler assembly

Figure 4 - Exploded view of sprinkler assembly

Detailed Design Calculations

Computational Fluid Dynamics

Given the accuracy of the results obtained between the hand calculations and the Solid Works FloXpress results in Phase Two, it did not feel necessary to do an entire computational fluid dynamics analysis on the entire sprinkler. Instead, more effort was put towards finding a solution to the flow distribution in the tee as it is currently not known. A local model of the tee can be made, and more computational effort can be done specifically on the tee. Limited resources are available to gain a better idea as to what the actual flow distribution is within a tee with two outlets. Several past studies [5, 6, and 7] have attempted to find a solution. These studies suggest that the flow distribution highly depends on the geometry and flow regime at the junction. These studies also suggest that flow separation will likely occur at the horizontal branch due to a weaker adverse pressure gradient present to deliver the flow horizontally. This separation will result in recirculation of the flow as the fluid flows into this outlet. Figure 5 below shows the resulting velocity profile within the tee obtained from ANSYS CFX at the finest mesh:

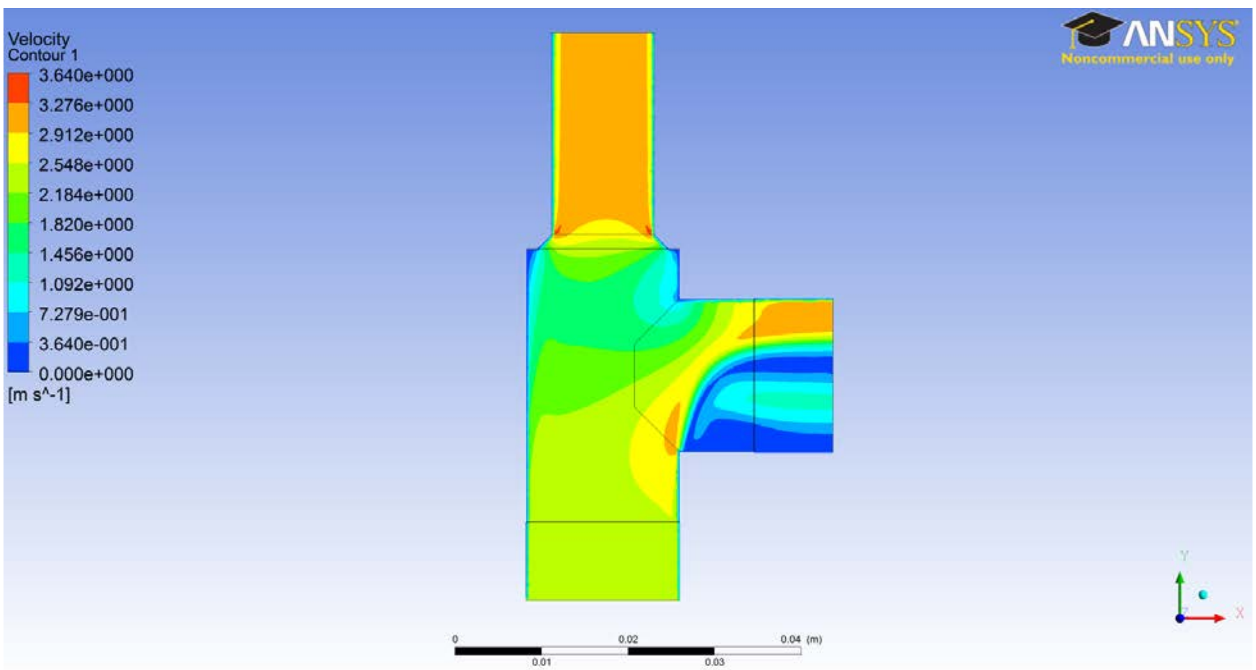


Figure 5 - Velocity profile within tee

The blue contours at the branch outlet strongly suggest that recirculation is occurring at this outlet as expected. The outlet velocities appear to converge to a very similar value at each outlet as well, although the flow distribution is clearly different. ANSYS is able to determine the maximum flow rate at each outlet. Using these results, ANSYS finds that about 75.9% of the inlet flow goes to the top branch, and about 24.1% of the inlet flow goes to the horizontal branch. Goudarzizadeh [7] has found a solution that relates the discharge ratio of flow rate to the horizontal branch and the ratio of the separation height and total height of the branch arm. The results can be viewed below in Figure 6:

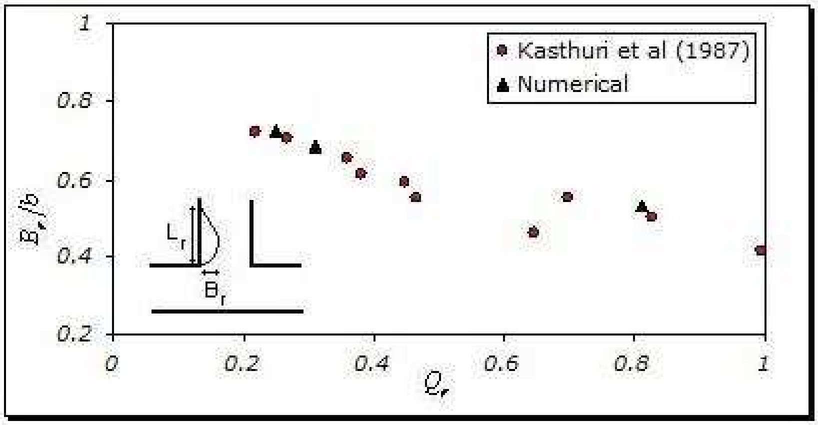


Figure 6 - Discharge ratio of branch arm versus ratio of separation height and branch height [7]

From inspection in Figure 5, the separation height (the height of the highest blue contour) is approximately 70% to 75% of the branch size. Figure 6 suggests that the percent of flow discharge in the branch outlet, Q_r, is about 25% to 30% of the inlet flow rate. Although the setup in this study is slightly different, the results obtained from ANSYS appear to agree well with these results. However, further verification of these results may be necessary in the future. A more in-depth discussion of the analysis done in ANSYS CFX can be viewed in Appendix A.

Sprinkler Performance

With the flow distributions known, the hand calculations and FloXpress simulations are re-done at both junctions: the junction from the top outlet to the main nozzle, and the junction from the branch outlet to the rotation nozzle. Table 1 below shows a summary of the results:

Table 1 – Summary of outlet velocities from FloXpress and hand calculations

	Hand Calculations (m/s)	FloXpress (m/s)
Top Junction	31.016	28.800
Horizontal Junction	31.345	31.373

The results seem to agree rather well between the hand calculations and the FloXpress results; especially those from the horizontal junction. Consequently, the results appear reliable and accurate. The resulting pressure loss within the sprinkler head is estimated to be around 2.908 psi, and is quite small. View Appendix A for further discussion for the calculations done and Appendix B for the FloXpress reports.

Horizontal and Vertical Throw Distances

With the outlet velocity at the main nozzle found, the resulting horizontal and vertical throw distances can be approximated by using the basic projectile motion equations. Table 2 below summarizes the resulting distances using the output velocity with FloXpress since this value is the smaller of the two and will provide a more conservative estimate:

Table 2 – Summary of required velocities and resulting horizontal throw distances

Angle (°)	Vertical Throw (m)	Horizontal Throw (m)
30	10.569	36.611
35	13.908	39.726
40	17.467	41.633
45	21.138	42.275
50	24.808	41.633
55	28.367	39.726
60	31.706	36.611
65	34.725	32.385
70	37.330	27.174
75	39.443	21.138
80	41.000	14.459

Using the projectile motion equations may reduce the accuracy of the calculated results since they do not consider drag and body forces, wind effects, and, more importantly, the stream breaking up into droplets during its projectile motion. However, these results strongly indicate that the required throw distances, as requested by the client, can easily be achieved at the specified operating conditions. View Appendix A for the above calculations.

Finite Element Analysis

The required force to hold the nozzle in place was found to be around 52.667 N. With this force known, a finite element analysis was done to determine the maximum bending stress that will occur at the base of the arm where it is fixed. The analysis is simplified by assuming that the nozzle force is split evenly between the two arms, so only one arm needs to be analyzed. Figures 7 and 8 below show the resulting stress and deflection contours produced by ANSYS:

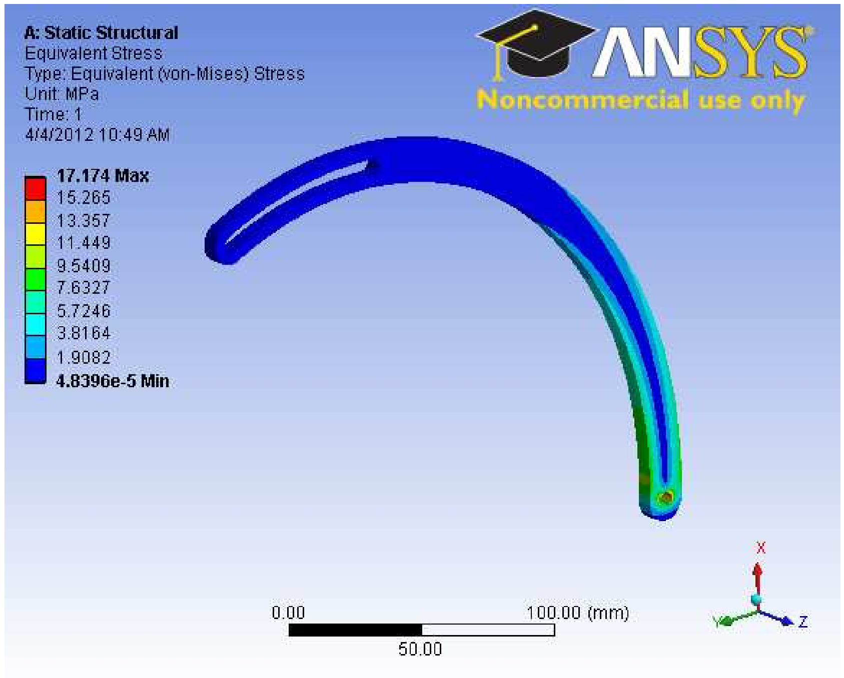


Figure 7 - Von Mises stress contours of support arm

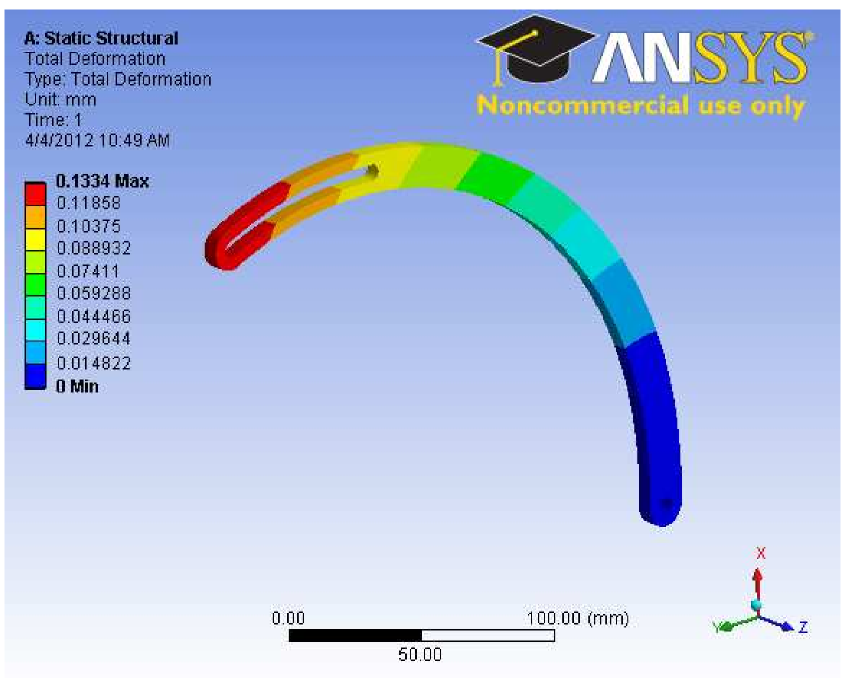


Figure 8 - Deflection contours of support arm

The maximum stress is about 17.174 MPa, and the maximum deflection is about 0.13340 mm. Since the yield strength of galvanized steel is roughly 203.9 MPa, yielding is not expected to occur within the arm. The maximum stress occurs at the fixed slot at the bottom of the support, and deflection is the greatest at the free end. View Appendix A for a more in-depth discussion regarding this analysis.

Manufacturing Cost Analysis

The costs are significantly higher than the target $175 cost to manufacture. Detailed estimates were made for a one-off prototype design, the details can be seen in Table 3 and final cost is $510. The design has also been estimated for manufacturing costs based off of a mass production of 200 sprinklers, the estimated cost is about $280 (details in Table 4), drastically lower than the cost of a one off prototype, although still higher than the target cost of $175. The cost to manufacture a prototype support piece will be $140 (detailed description in Table 5).

Through further design modifications and selection of parts the costs could be decreased through larger orders with manufacturers. As with a larger 200 part order, Swagelok would be replaced with a much more cost effective part in the assembly in order to reduce the cost; this is to be looked in to after prototype designs are confirmed to work as required.

Table 3 - Cost of Building Prototype

Fire Cobra Prototype				
Item	Description	Unit Price	Units	Total
1	Swagelok 1/2" Brass Elbow (Part ID: S-8-E)*	$19.89	1.0	$19.89
2	Swagelok 1/2" Brass Street Tee (Part ID: B-8-ST)	$27.78	1.0	$27.78
3	Swagelok 1/2" x 1/4" Brass Reducer (Part ID: B-8-HRN-4)	$7.79	1.0	$7.79
4	Swagelok Brass Pipe Coupling (Part ID: B-8-HCG)	$10.35	1.0	$10.35
5	MEG 1/4" Stainless Steel Spray Nozzle (Part ID: Be-85-200)	$6.95	1.0	$6.95
6	1/2" Stainless Steel Braid Flexible Hose	$67.11	1.0	$67.11
7	1/2" LD Nozzle	$6.95	1.0	$6.95
8	Brass Swivel Joint	$20.00	1.0	$20.00
9	Carbon Steel	$10.00	1.0	$10.00
10	Machining	$55.00/hr	5.0	$275.00
11	Welding	$55.00/hr	1.0	$55.00
		Total Estimate:		$510.00

Table 4 - Cost of Mass Production

Fire Cobra Manufacturing Cost				
Item	Description	Unit Price	Units	Total
1	Swagelok 1/2" Brass Elbow (Part ID: S-8-E)*	$19.89	1	$19.89
2	Swagelok 1/2" Brass Street Tee (Part ID: B-8-ST)	$27.78	1	$27.78
3	Swagelok 1/2" x 1/4" Brass Reducer (Part ID: B-8-HRN-4)	$7.79	1	$7.79
4	Swagelok Brass Pipe Coupling (Part ID: B-8-HCG)	$10.35	1	$10.35
5	MEG 1/4" Stainless Steel Spray Nozzle (Part ID: Be-85-200)	$6.95	1	$6.95
6	1/2" Stainless Steel Braid Flexible Hose	$67.11	1	$67.11
7	1/2" LD Nozzle	$6.95	1	$6.95
8	Brass Swivel Joint	$20.00	1	$20.00
9	Carbon Steel	$10.00	1	$10.00
10	Galvanizing	$1.98	8	$15.84
11	Journeyman Machinist (Cut and Shape Carbon Steel)	$28.00	0.5	$14.00
12	Inspection	$28.00	0.1	$2.80
13	Unskilled Labor (Put Assembly Together)	$15.00	0.3	$4.50
		Primary Estimate:		$213.96
		Overheads (30%) of Cost:		$64.19
		Total Estimate:		$280.00

Table 5 – Cost of Sprinkler Support Piece

Sprinkler Support				
Item	Description	Unit Price	Units	Total
1	A36 L-Shape Steel Angle (1"x1"x1/8")	$ 1.25/ft	1	$1.25
2	A500 Steel Rectangular Tubing (4"x2"x1/4")	$ 14.31/ft	1	$14.31
3	1/4" A36 Steel Plate	$ 13.78/sqft	1	$ 13.78
4	Machining	$ 55.00/hr	1	$ 55.00
5	Welding	$ 55.00/hr	1	$ 55.00
		Total Estimate:		$ 140.00

System Setup

The Sprinkler system was designed to be versatile and allow for many different configurations. The configurations are based on the setup shown in Figure 9 below. In this general setup the pump is fed by a water source that can be a lake, pond, creek, and even a man-made reservoir that is filled using a helicopter in remote areas. The pump feeds into the main header, which is a large loop that provides pressure to both ends of the sprinkler arrangement, thus reducing pressure drop along the line. Along the main header branch tees are installed to attach the individual supply lines that go directly to each sprinkler head. The sprinklers will be places such that there is approximately 20% overlap in wetted areas to allow for changes in wind conditions and ensure that there are no dry patches for the fire to pass through the fire line. Once the system is setup and running an operator can walk around to each sprinkler head and adjust it to optimize the height for that particular scenario.

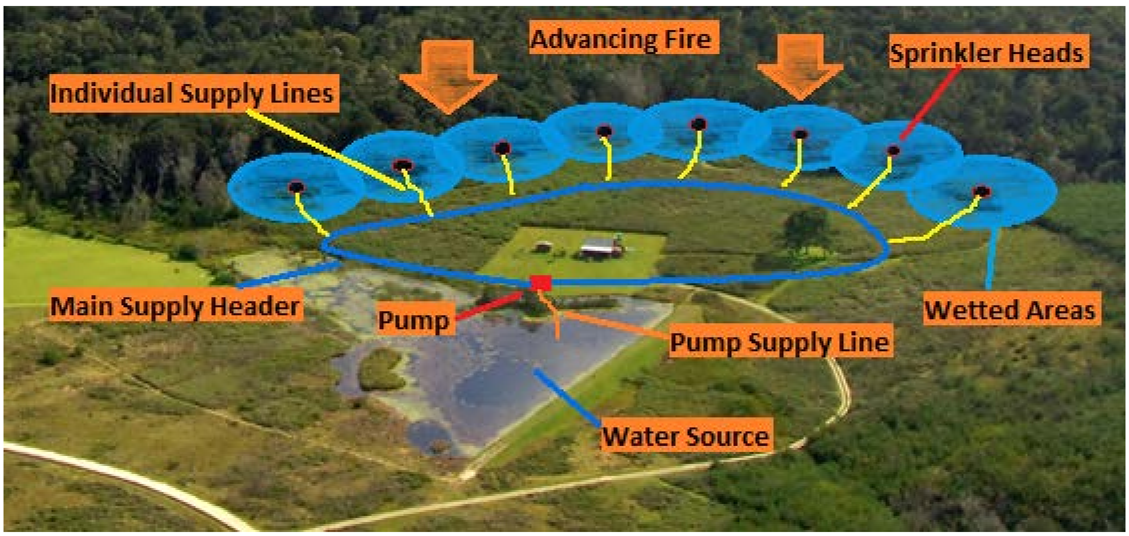


Figure 9 - Sprinkler Setup and Arrangement

**Note that the image is not to scale and that its purpose is to demonstrate the setup arrangement.*
***The background photo came from [3]*
****A detailed list of assembly, setup, and startup steps are in Appendix G*

Design Compliance Matrix

The Design matrix is shown in Table 6. Through discussions with the client and choices by the AGD design team, this matrix was put together in terms of the design importance of each item required. Each design component was given an importance factor from 1-5, with 5 being the most important design considerations and 1 being the least important.

The chart includes the aspect required, the required numerical or conditional values, who made the design decision, the importance factor of that design discussed previously, and any comments on these values with respect to satisfying the design spec or not.

Table 6 - Updated Design Specifications with Notes and Client Approval

Item #	Component/ System Description	Design Specification / Requirement	Safety Factor	Design Authority	Design Importance (1-5)	Design Compliance
1	***Performance***					
1.1	**Target Flow Distances**	**Throw Water specified Distances for safe distance**				
1.1.1	Vertical	Vertical throw is to be a minimum of 7m with possible adjustability of varying conditions with max goal of 21m.	-	FP-Innovations	5	The Goal of 21 m was achieved by all 3 concepts
1.1.2	Horizontal	Horizontal throw variable with height- maximize for spacing of sprinkler	-	FP-Innovations	3	The Goal of a minimum of 6 m was achieved by all concepts
1.1.3	Rotational	180 Deg. minimum with adjustability for varying conditions	-	FP-Innovations	4	All concept achieve a full 360 Deg. Rotation
1.2	**Target Flow Rate**	**Required Flow Per Head**				
1.2.1	Volumetric Flow Rate	minimum of 40 l/min, the flow rate will be determined by the pump size	-	AGD	4	The concepts were sized to the Wajax Mark 3 with a flow rate of 36 l/min
1.3	**Pressure**	**Operating Pressure Range**				
1.3.1	Operating Pressure	Will operate at a maximum operating pressure of 100 psi	3	AGD	5	Operating pressure achieved
2	***Sprinkler Features***					
2.1	**Water Source**	Water Pump Source				
2.1.1	Water Pump	Wajax Mark 3 or Wajax BB4 [7]	-	FP-Innovations	5	Sprinklers sized to these Specifications

Item #	Component/ System Description	Design Specification / Requirement	Safety Factor	Design Authority	Design Importance (1-5)	Design Compliance
2.2	**Sprinkler Dimensions**	**Size of the sprinkler**				
2.2.1	Height	To be kept to a minimum for ease of pack ability	-	AGD	2	All concepts kept to a minimum size for pack ability
2.2.2	Width	To be kept to a minimum for ease of pack ability	-	AGD	2	
2.2.3	Weight	Less than 79 lbs.	-	AGD	3	All concept systems are under 79 lbs
2.2.4	Distance between heads	A distance for allowance of crossover of approximately 20%	-	AGD	4	Depends on vertical settings of sprinkler heads
2.3	**Life Expectancy**	**Life Expectancy of the sprinkler**				
2.3.1	Life Expectancy	To be designed for an operational life of 10 years with minimal maintenance	-	AGD	4	Use of non-corrosive materials to maximize life expectancy
2.3.2	Reliability	Interchangeable parts for easy of repair in field	-	AGD	4	Parts kept to a minimum and simple to improve reliability
2.4	**Cost**	**The cost to manufacture**				
2.4.1	One off, Prototype	$500 for prototype	-	FP-Innovations	2	Prototype to be built during phase 3
2.4.2	Mass Production	Approximately $150 for manufacturing plus engineering cost estimate	-	FP-Innovations	3	Further analysis to be done during phase 3
2.5	**Material**	**Material for sprinkler heard**				
2.5.1	Prototype material	Aluminum for ease of machining	-	AGD	4	aluminum and stainless steel purchased fittings

Item #	Component/ System Description	Design Specification / Requirement	Safety Factor	Design Authority	Design Importance (1-5)	Design Compliance
2.5.2	Production material	Chosen to reduce cost and reduce corrosion	-	AGD	3	Phase 3
3	***Sprinkler Setup and Operation***					
3.1	**Time**	**Time for Sprinkler setup / Operation**				
3.1.1	Sprinkler setup time	Under 10 min/sprinkler head	-	AGD	3	
3.1.2	Sprinkler run time	Continuous operation without human intervention	-	FP-Innovations	5	Designed to be continuous with no intervention
3.2	**Setup**	**Sprinkler setup requirements**				
3.2.1	Number of setup steps	A minimum to reduce setup time	-	AGD	3	Kept to a minimum for all concepts
3.2.2	Number of startup steps	A minimum to reduce startup time	-	AGD	3	Kept to a minimum for all concepts
4	***Environmental Conditions***					
4.1	**Operating Conditions**	**Environment to be operated in**				
4.1.1	Temperature Range	Above freezing	-	FP-Innovations	3	Materials were chosen to resist corrosion
4.1.2	Protection	Materials should be chosen to prevent corrosion	-	AGD	3	
4.2	**Mounting Conditions**	**Required mounting locations**				
4.2.1	Ground mounting	The base has to have the ability to be staked into the ground	-	FP-Innovations	5	A mounting system has been designed to fit all mounting situations
4.2.2	Tree mounting	The base is able to be nailed to a tree or mounted to dimensional lumber	-	FP-Innovations	5	

Item #	Component/ System Description	Design Specification / Requirement	Safety Factor	Design Authority	Design Importance (1-5)	Design Compliance
4.2.3	Building mounting	The base has to have the ability to be nailed or fastened to a building	-	FP-Innovations	4	
5	***Safety***					
5.1	**Safety constraints**	**Safety components / requirements**				
~~5.1.1~~	~~Pressure relief valve~~	~~no rv required, open system~~	~~-~~	~~AGD~~	~~3~~	~~Not required~~
5.1.2	Noise Levels	Sprinkler heads cannot exceed 85 dB	-	AGD	3	Further analysis to be done for phase 3
5.1.3	System weight	Goal of system weight below 51lbs	-	NIOSH	4	System concepts total less than 51 lbs.
6	***Maintenance***					
6.1	**Parts**	**Replacement parts**				
6.1.1	Interchangeable parts	Parts are to be interchangeable between sprinkler heads to reduce downtime	-	AGD	3	All concepts are made of mostly interchangeable parts
6.2	**Maintenance**	**Maintenance requirements**				
6.2.1	Maintenance requirements	Required maintenance to be kept to a minimum to reduce operating costs	-	AGD	2	No foreseeable required maintenance
6.2.2	Tools	All tools to perform maintenance and replace parts to be standard imperial sizes	-	AGD	4	All concepts only require simple tools for assembly and repair

Revision	Description	Client Approval	Date
0	Initial Release	Changes needed as per client request	2/2/2012
1	Revision	Changes made and approved	2/2/2012
2	Team Revision	N/A	4/3/2012
3	Final Revision	Changes approved by client	4/4/2012

Schedule Update

Project work took significantly longer than expected in phase 3. This was mostly due to necessary calculations that needed to be made to describe the end function of the sprinkler. Computational fluid dynamics, stress analysis, movement calculations and solid modeling encompassed the bulk of the work. Problems occurred which resulted in additional time spent on vital aspects of the functionality of the device. In result, the estimated project work hours were far surpassed leaving no time to construct a prototype. The lead-time for parts necessary to construct the prototype was also too long in order to complete the construction in sufficient time for testing to be done. Table 7 below shows the breakdown of each phase estimated time, actual time and revised time. Please note that Phase 3 was broken into two sections showing estimated time for both project work and prototyping. Some initial work on the poster phase shows that the estimated time can be revised to be done in less time.

Table 7 - Engineering Cost Analysis

Junior Engineer/Industrial Designer costs						
Project Component	**Estimated hours (hrs)**	**Initial Estimated cost ($)**	**Actual hours (hrs)**	**Actual cost ($)**	**Revised Estimated hours (hrs)**	**Revised Estimated cost ($)**
Phase 1	92.5	$8,325	92.5	$8,325	n/a	n/a
Phase 2	170	$15,300	151	$13,590	n/a	n/a
Phase 3	156	$14,040	155	$13,950	n/a	n/a
- Project Work	114	$10,260	155	$13,950	n/a	n/a
- Prototyping	42	$3,780	0	0	n/a	n/a
Poster	18	$1,620	n/a	n/a	10	$900
TOTAL	436.5	$39,285	398.5	$35,865	408.5	$36,765
Intermediate Engineer costs						
Project Component	**Estimated hours (hrs)**	**Initial Estimated cost ($)**	**Actual hours (hrs)**	**Actual cost ($)**	**Revised Estimated hours (hrs)**	**Revised Estimated cost ($)**
Phase 1	4	$600	4	$600	n/a	n/a
Phase 2	3	$450	3	$450	n/a	n/a
Phase 3	2	$300	2	$300	n/a	n/a
Poster	n/a	n/a	n/a	n/a	n/a	n/a
TOTAL	9	$1,350	9	$1,350		$1,350

The above data has been assembled in graphical format in Figure 10. The estimated and actual hours for phase 3 include only the project work portion and not the prototyping. The total recorded actual hours for phase 3 can be found in Appendix D.

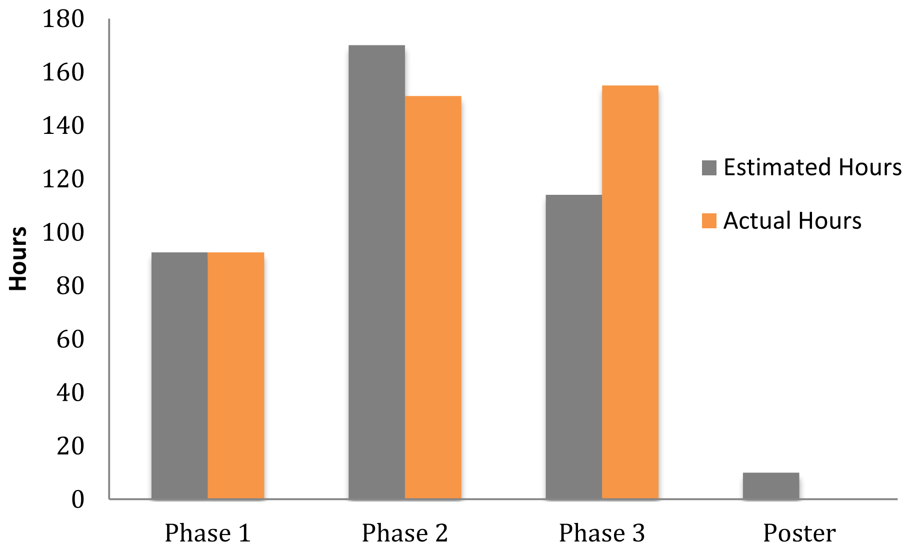


Figure 10 - Graphical Summary of Engineering Project Hours

Future Work

The Fire Cobra will require testing and optimization prior to commercial use. It is recommended that a prototype be built and the torsion spring in use be manipulated with different constant values and preload angles to find the angle that will best fit the angular speed requirements of FP Innovations. Although the results using ANSYS for both the tee flow and arm stress seem satisfactory, further analysis should definitely be considered on both to further confirm the accuracy of the results obtained. Prototype testing can also further confirm the accuracy of these results.

Water dispersion will have a large effect on the maximum height and distance the prototype sprinkler will reach. The water starts to disperse from the main stream it will slow down very quickly, and the input pressure and flow rate should be optimized through testing of the Wajax Mark 3 pumps to give the farthest water throw height. Future testing should be done on the prototype to witness how this will affect the actual throw distances.

Conclusion

The Fire Cobra design has been completed and checked through engineering analysis and computational methods and appears to meet the required design specs. Therefore, the concept is ready to be prototyped for further testing. It is recommended that the client, FP Innovations, enter into prototype testing with provided detailed drawings in order to confirm these calculations through real world tests. Once the calculations have been confirmed, torsion springs can be tested to ensure adequate response speed of the moving sprinkler head and the design can be tweaked for mass production to lower costs.

Appendix A – Calculations

Flow Distribution within Tee

Objective

To determine the resulting flow rate distribution within the Swagelok Tee at each outlet.

Solution Method

A CFD analysis will be done on the tee to examine the flow distribution in the tee. A mesh dependency analysis is done to verify the accuracy of the results obtained. The maximum mass flow rates at each outlet can be found from ANSYS CFX at the best refined grid.

Known

- Inlet flow rate 0.0006 - m^3/s
- Operating pressure - 75 psi (517106 Pa)

Assumptions

- Flow is steady.
- Flow is incompressible.
- Flow is fully developed.
- Pressure is roughly the same at each outlet.

Sketch

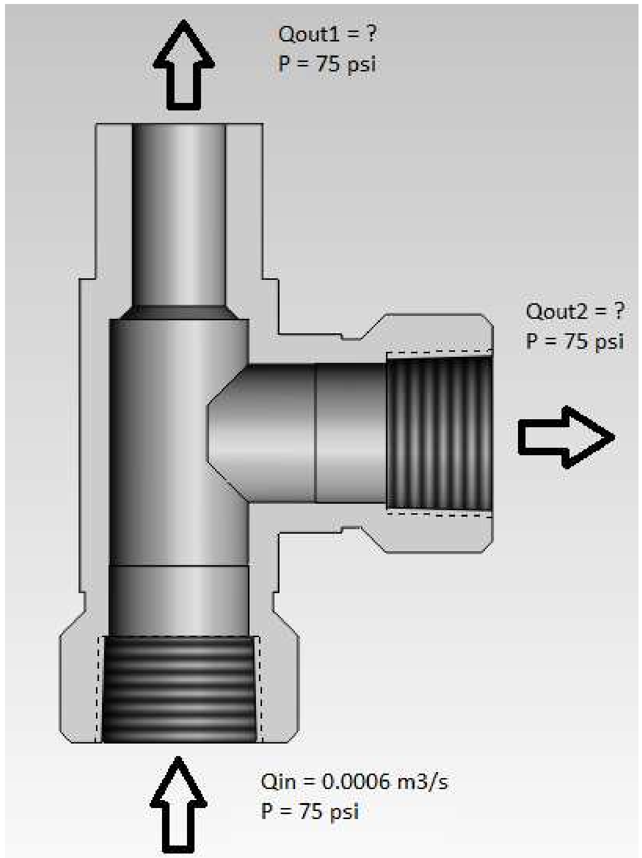


Figure 11 - Schematic of tee and boundary conditions

Analysis

Since FloXpress cannot determine the flow with two outlets, ANSYS CFX will be used instead for this analysis. The analysis was carried out by first importing the solid model of the tee into Design Modeler and creating a control volume out of the inner surface of the tee. This was done by selecting all of the inner faces of the tee (except the female threaded portions) and using the Fill command to generate a fluid domain out of the selected faces.

The resulting geometry is then meshed using a very coarse grid. After the results have been obtained at this coarse mesh, the mesh is further refined to a much finer mesh. The results at each refinement will be determined in order to verify that the results obtained are converging to a value and not diverging.

After meshing, the appropriate boundary conditions must be applied within the Setup phase. A summary of the appropriate boundary conditions at each face can be viewed above in Figure 11. The bottom inlet was simply specified as an inlet, and the top outlet was specified to be an outlet. Although the horizontal branch is technically an outlet, it is specified to be an opening since the fluid will likely be re-circulating through this domain due to the predicted recirculation. An opening will deal with this recirculation much better instead of a basic outlet boundary condition. The rest of the surfaces are treated as no-slip walls. Table 8 below lists the other input parameters during the Setup phase:

Table 8 - Input parameters in ANSYS CFX Setup

Parameter	Input
Fluid	Water
Reference Pressure	75 psi
Turbulence Model	Shear Stress Transport
Advection Scheme	High Resolution
Transient Mode	Steady State
Residual	0.0001

The reference pressure is specified to be 75 psi since it is the operating pressure. The turbulence model was selected to be Shear Stress Transport to help accurately capture the flow separation that is likely to occur at the tip of the horizontal branch of the tee. The advection scheme was chosen to be High Resolution to ensure a strong performance between the coarse and fine meshes. The residual, the difference between two solutions that are obtained at successive time steps, is specified to be 0.0001.

With the boundary conditions applied and the other necessary parameters specified, ANSYS can now obtain a solution to the flows at each inlet. As previously mentioned, the results will first be obtained at a very coarse grid, and then the results will continue to be found for successively finer grids. Theoretically, the results should start to converge as the grid is refined to a much finer grid. In this case, the grid is simply refined by slowly decreasing the element size successively at each refinement step. The coarse grid was refined five successive times. Figure 12 below illustrates a logarithmic-linear plot of the maximum velocities obtained at each outlet as a function of the number of nodes. A log-linear plot is used to better observe convergence.

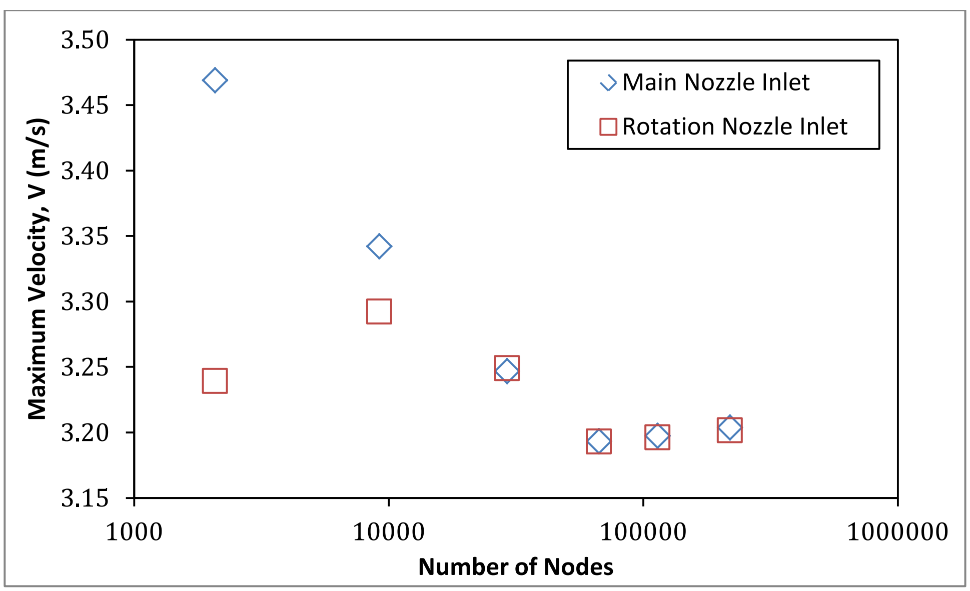


Figure 12 - Plot of maximum velocities at each outlet

This figure strongly suggests that the results obtained have definitely converged to a steady value at the finest grid obtained. Interestingly, the inlet and outlet velocities appear to be converging to an equal value. Figure 13 below respectively show the resulting velocity and pressure contours within the tee at the finest grid obtained.

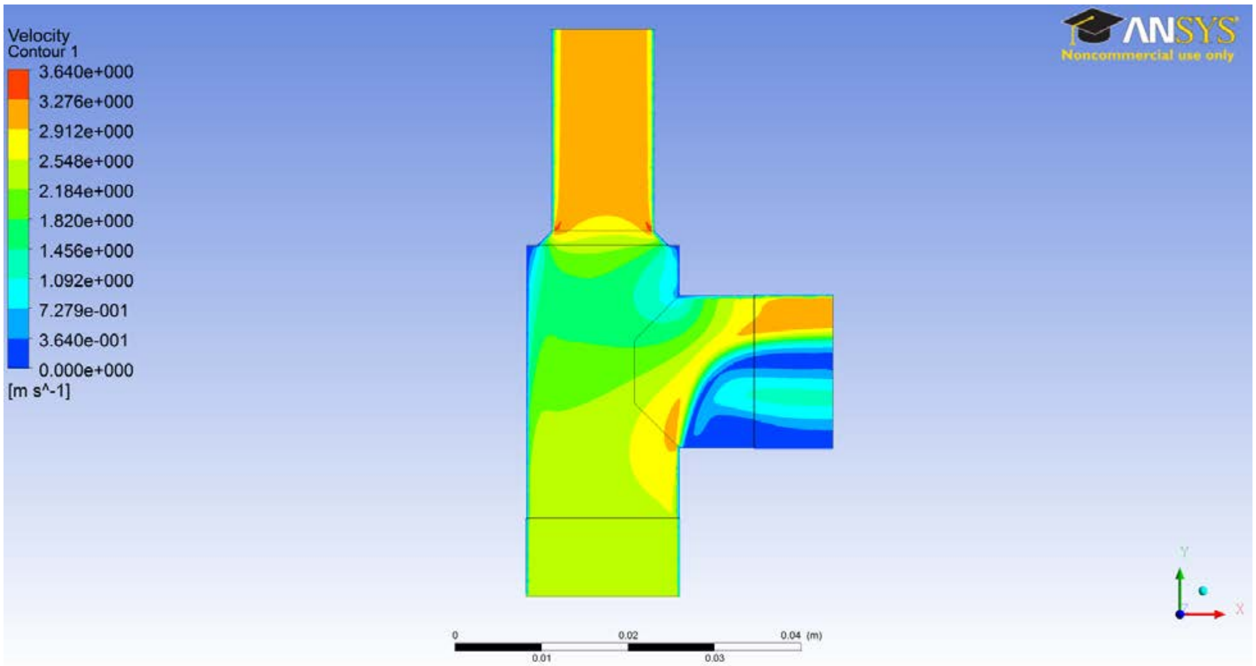


Figure 13 - Velocity contour within the tee at finest mesh

Figure 13 above clearly shows that there is indeed some recirculation that is occurring at the horizontal branch as seen by the blue contours. Previous studies [5, 6] have shown similar phenomenon for both laminar and turbulent flows, so the velocity profile obtained above appears to be accurate and is physically correct.

Although the maximum velocities at each outlet converge to a specific value, the maximum mass flow rates at each outlet will be used instead of the maximum velocities since Figure 13 above clearly shows that more flow is going to the top outlet instead of the branch outlet. At the finest mesh obtained, the maximum flow rates at the top outlet and branch outlet are found to be 0.001296 kg/s and 0.000411 kg/s. Therefore, the resulting flow distributions are approximately

$$\%Q_{top} = \frac{Q_{top}}{Q_{top} + Q_{branch}} = \frac{0.001296\ \frac{kg}{s}}{0.001296\ \frac{kg}{s} + 0.000411\ \frac{kg}{s}} = \mathbf{0.759}$$

$$\%Q_{branch} = \frac{Q_{bottom}}{Q_{top} + Q_{branch}} = \frac{0.000411\ \frac{kg}{s}}{0.001296\ \frac{kg}{s} + 0.000411\ \frac{kg}{s}} = \mathbf{0.241}$$

Conclusion

These results show that approximately 75.9% of the flow is distributed to the top outlet, and 24.1% of the flow is diverged to the horizontal branch. These results clearly indicate that more flow is going to the main nozzle at the top than to the horizontal nozzle. Intuitively, this makes sense since more flow is likely to be delivered to the top given the geometry of the layout. The results here seem to agree quite well with those obtained by Goudarzizadeh [7]. Goudarzizadeh found that the flow rate distribution in the horizontal branch is roughly 25% to 30% of the total inlet flow rate at the given flow separation height. Nevertheless, it would be wise to further investigate the accuracy of these results through experimental methods or even with another computational fluid dynamics analysis to confirm if similar results are obtained. In the process, other information such as the reattachment length in the horizontal branch may be of interest in the future.

Outlet Velocities and Nozzle Diameters

Objective

To determine both of the outlet velocities and diameters at each nozzle and compare the results to velocities found from FloXpress.

Solution Method

The total head loss within the system can be done by summing the frictional losses and minor losses within the system. Knowing the head loss, the maximum outlet velocity can be determined by using a modified form of Bernoulli's equation at a given operating pressure. This procedure is done twice at each junction: the one to the main nozzle and one to the rotation nozzle.

Known

- Operating pressure – 75 psi (517107 Pa)
- Operating flow rate – 36 liter/minute (0.000600 m^3/s)
- Fraction of flow rate delivered to top branch – 0.759
- Fraction of flow rate delivered to horizontal branch – 0.241
- Hose Diameter – 0.5' (12.7 mm)
- Hose Length – 6.5' (165.1 mm)
- Nipple Inlet Diameter – 12 mm
- Nipple Length – 92 mm
- Roughness Height for Brass – 0.0015 mm [2]

Assumptions

- Water is at ambient conditions (20°c and 101.325 kPa).
- Flow is steady and incompressible.
- Flow is fully developed at sprinkler head entrance.
- Hose is smooth ($\varepsilon = 0$)

Sketch

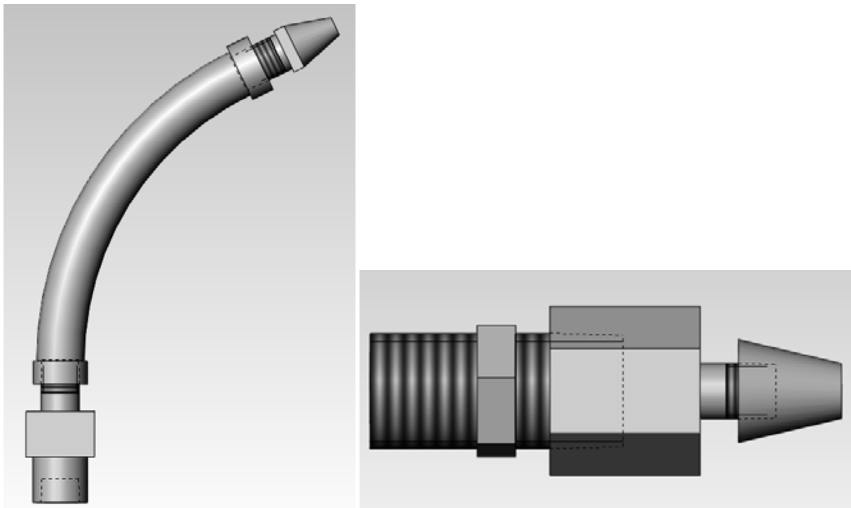


Figure 14 - Schematic of sections to be analyzed

Analysis

The inlet velocity at both junctions can easily be determined from the definition of the flow rate:

$$V = \frac{Q}{A} = \frac{4Q}{\pi D^2} \quad (1)$$

Where Q is the flow rate, and D is the diameter. From the CFD analysis, it was found that 75.9% of the flow is diverged to the top. With these values known, the resulting velocity is:

$$V = \frac{4(0.759 * 0.0006 * \frac{m^3}{s})}{\pi(0.0127m)^2} = 3.595\frac{m}{s}$$

Next, the Reynolds number can be determined. Knowing the Reynolds number can determine the flow regime as well as help determine the friction factor for this flow. The Reynolds number is defined as:

$$Re = \frac{\rho V D}{\mu} \quad (2)$$

Where ρ is the fluid density and μ is the dynamic viscosity of the fluid. At ambient conditions (20°c and 101.325 kPa), the density and dynamic viscosity of water are known to be 998 kg/m^3 and 1.002e-3 kg/ms respectively [2]. Thus, the Reynolds number is:

$$Re = \frac{(998\,\frac{kg}{m^3})(3.595\,\frac{m}{s})(0.0127m)}{(1.002 \cdot 10^{-3}\,\frac{kg}{ms})} = 45473$$

So the flow within the sprinkler head is turbulent. With the Reynolds number known and the roughness height known, the friction factor can be determined from:

(3)

$$\frac{1}{\sqrt{f}} = -1.8\log\left(\frac{6.9}{Re} + \left(\frac{\varepsilon/D}{3.7}\right)^{1.11}\right)$$

Where ε is the roughness height of the sprinkler head material, and is assumed to be zero since it is incredibly small for a rubber hose. Rearranging, the friction factor is:

$$\frac{1}{\sqrt{f}} = -1.8\log\left(\frac{6.9}{45473}\right) = 6.87404$$

$$f = \frac{1}{6.87404^2} = 0.021163$$

The minor losses from the inlet and to the top nozzle are found from summing each of the minor loss coefficients in the system. The losses in this section involve a threaded tee union to the hose (K = 0.08), a threaded tee with line flow (K = 0.9), and an elbow (K = 0.9)[1]. The total minor losses are then simply:

$$\sum K = K_{threaded\ union} + K_{threaded\ tee,line} + K_{elbow} = 0.08 + 0.9 + 0.9 = 1.88$$

With the friction factor and total minor losses known, then the total head loss in this junction can be found from:

$$h_L = \left(f\frac{L}{D} + \sum K\right)\frac{V^2}{2g} \qquad (4)$$

Where g is the acceleration due to gravity (9.81 m/s²) and L is the length of the tube. Thus, the total head loss from the swivel joint and system is found to be:

$$h_L = \left(0.021163\frac{0.1651m}{0.0127m} + 1.88\right)\frac{(3.595\,\frac{m}{s})^2}{2(9.81\,\frac{m}{s^2})} = 1.722\ m$$

Since the operating gauge pressure is known to be 75 psi, or 517107 Pa, and the inlet velocity to be 1.263 m/s, the outlet velocity can be estimated using a modified form of Bernoulli's equation. It is defined as:

$$\frac{P_1}{\rho g} + \alpha\frac{V_1^2}{2g} + z_1 = \frac{P_2}{\rho g} + \alpha\frac{V_2^2}{2g} + z_2 + h_L \qquad (5)$$

Where z is the vertical distance from the datum (the inlet), α is a correction factor for fully developed turbulent flow (1.05), subscript 1 denotes the inlet point, and the subscript 2 is the outlet point. Since the outlet is open to atmospheric pressure, then the Pressure difference P_1 and P_2 is simply the gauge pressure within the sprinkler head. The head loss in this case is the head loss found in the junction from the swivel outlet to the top nozzle, and not the total head loss. Rearranging, the outlet velocity is:

[1] Loss coefficient values taken from Cengel & Cimbala

$$V_2 = \sqrt{\frac{2g}{\alpha}(\frac{P_{gage}}{\rho g} + \alpha\frac{V_1^2}{2g} - z_2 - h_L)}$$

$$= \sqrt{\frac{2\left(9.81\frac{m}{s^2}\right)}{1.05}(\frac{517107\ Pa}{\left(998\ \frac{kg}{m^3}\right)\left(9.81\frac{m}{s^2}\right)} + 1.05\frac{\left(3.595\frac{m}{s}\right)^2}{2\left(9.81\frac{m}{s^2}\right)} - 0.3048m - 1.722m)}$$

$$= \mathbf{31.016\ \frac{m}{s}}$$

Rearranging Equation (1) above, the required outlet diameter of the top nozzle is:

$$D = \sqrt{\frac{4(0.759 * 0.0006\frac{m^3}{s})}{\pi\left(31.016\frac{m}{s}\right)}} = 4.324\ mm\ \cong \mathbf{\frac{3}{16}\ inch}$$

The outlet velocity and required outlet diameter for the rotation nozzle can be calculated in a similar manner that was done here. The CFD analysis found that this junction receives approximately 24.1% of the total flow rate received at the inlet. The Velocity for this junction is then:

$$V = \frac{4(0.241 * 0.0006 * \frac{m^3}{s})}{\pi(0.0120m)^2} = 1.279\frac{m}{s}$$

The corresponding Reynolds number is:

$$Re = \frac{(998\ \frac{kg}{m^3})(1.278\ \frac{m}{s})(0.0120m)}{(1.002 \cdot 10^{-3}\ \frac{kg}{ms})} = 15281$$

The resulting friction factor is then:

$$\frac{1}{\sqrt{f}} = -1.8\log\left(\frac{6.9}{15281} + \left(\frac{0.0015/0.012}{3.7}\right)^{1.11}\right) = 2.92462$$

$$f = \frac{1}{2.92462^2} = 0.11691$$

This junction involves a threaded nipple union (K = 0.08), a threaded 90° bend (K = 0.9) and a threaded tee with branch flow (K = 2.0). The sum of the loss coefficients is then:

$$\sum K = K_{threaded\ union} + K_{threaded\ tee,branch} + K_{elbow} = 0.08 + 2.0 + 0.9 = 2.98$$

The corresponding head loss is:

$$h_L = \left(0.11691\frac{0.095m}{0.012m} + 2.98\right)\frac{(1.279\frac{m}{s})^2}{2(9.81\frac{m}{s^2})} = 0.326\ m$$

Finally, the outlet velocity at the rotation nozzle is:

$$V_2 = \sqrt{\frac{2\left(9.81\frac{m}{s^2}\right)}{1.05}\left(\frac{517107\ Pa}{\left(998\ \frac{kg}{m^3}\right)\left(9.81\frac{m}{s^2}\right)} + 1.05\frac{\left(1.278\frac{m}{s}\right)^2}{2\left(9.81\frac{m}{s^2}\right)} - 0.326m\right)} = \mathbf{31.345}\ \frac{\boldsymbol{m}}{\boldsymbol{s}}$$

The required nozzle diameter is then:

$$D = \sqrt{\frac{4(0.241 * 0.0006\frac{m^3}{s})}{\pi\left(31.016\frac{m}{s}\right)}} = 2.424\ mm\ \cong \frac{\mathbf{1}}{\mathbf{8}}\ \boldsymbol{inch}$$

<u>Conclusion</u>

The outlet velocity at the top nozzle is approximately 31.016 m/s and requires an outlet diameter of about 4.324 mm, or about 3/16" in terms of standard sizes. The outlet velocity at the bottom nozzle is about 31.345 m/s and required an outlet diameter of 2.424 mm, or approximately 1/8". The respective FloXpress values for the top nozzle and bottom nozzle are roughly 28.800 m/s and 31.373 m/s, so it is safe to conclude that the results obtained are relatively accurate.

Objective

To determine the required velocity to achieve the required vertical throw.

Solution Method

If the streams are treated as particles or a continuous projectile, then the basic equations describing a projectile path can be used to determine the required velocity.

Known

- Outlet velocity – 28.8 m/s
- Maximum Vertical Throw – 21 m
- Maximum Horizontal Throw – 6 m

Assumptions

- Drag and body forces are negligible
- Wind effects are negligible

Sketch

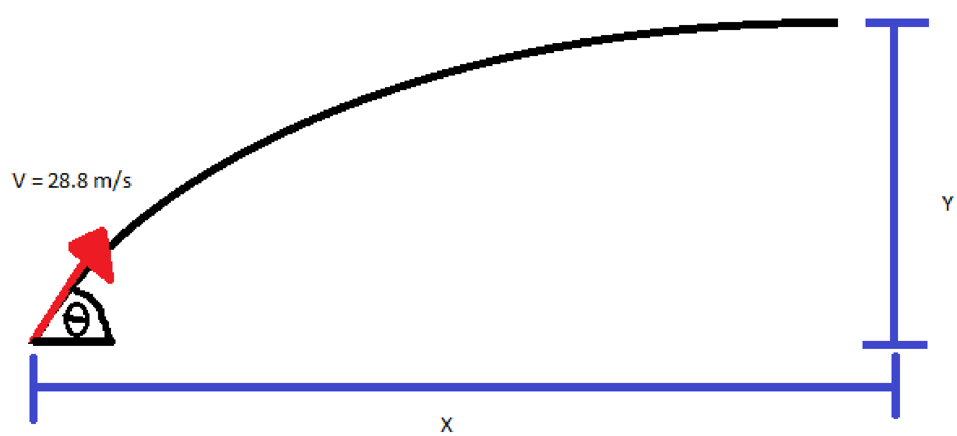


Figure 15 - Projectile motion of sprinkler stream

Analysis

At the maximum point of trajectory, the y-component of velocity is zero. The required water speed to achieve the maximum height is simply:

$$y_{max} = \frac{v_o^2 sin^2(\theta)}{2g} \quad (1)$$

Where g is the acceleration due to gravity (9.81 m/s^2), θ is the nozzle angle, and y is the vertical throw distance. The horizontal range that the stream achieves at the maximum height can be found by:

$$x = \frac{v_o^2 \sin(\theta)\cos(\theta)}{g} \quad (2)$$

With the velocity calculated from before, the resulting horizontal and vertical throw distances can be determined over a series of angles. Table 9 summarizes the results obtained at various angles:

Table 9 - Summary of required velocities and resulting horizontal throw distances

Angle (°)	Vertical Throw (m)	Horizontal Throw (m)
30	10.569	36.611
35	13.908	39.726
40	17.467	41.633
45	21.138	42.275
50	24.808	41.633
55	28.367	39.726
60	31.706	36.611
65	34.725	32.385
70	37.330	27.174
75	39.443	21.138
80	41.000	14.459

Conclusion

The FloXpress velocity calculated was used instead of the value calculated by hand since the FloXpress value is smaller, so this value will produce a more conservative estimate. Regardless, it appears that the required vertical and horizontal throws can be achieved at about an angle of around 45. These calculations, however, do not consider the fact that the flow is likely to separate from a stream into individual particles, so the actual values might actually be smaller than those found here. Nevertheless, it appears that the required throw values can be achieved.

Pressure Loss within Sprinkler Head

Objective

To determine the total pressure loss within the sprinkler head.

Solution Method

The total head loss in each junction has been previously calculated while calculating the respective outlet velocities, so the pressure loss can easily be calculated with the total head loss known.

Known

- Head loss through top junction – 1.722 m
- Head loss through bottom junction – 0.326 m

Assumptions

- Water is at ambient conditions (20°C and 101.325 kPa).
- Flow is steady and incompressible.
- Flow is fully developed at sprinkler head entrance.

Analysis

The total pressure loss is simply defined by:

$$\Delta P_L = \rho g h_L$$

Where ρ is the fluid density, g is the acceleration due to gravity, and h_L is the total head loss. The head losses were calculated previously, so the resulting pressure loss within the sprinkler head is:

$$\Delta P_L = \left(998\ \frac{kg}{m^3}\right)\left(9.81\ \frac{m}{s^2}\right)(1.722\ m + 0.326\ m) = 20050\ Pa = \mathbf{2.908\ psi}$$

Conclusion

The total pressure loss within the sprinkler head is incredibly small in comparison to the operating value of 75 psi and is almost negligible.

Nozzle Force

Objective

To determine the total clamping force that is required to keep the top nozzle fixed.

Solution Method

Create a control volume within the nozzle, and use Newton's second law to derive the force as a function of the nozzle angle.

Known

- Operating Pressure – 75 psi (517107 Pa)
- Inlet Velocity – 3.595 m/s
- Outlet Velocity – 31.016 m/s
- Inner Nozzle Diameter – 12.7 mm
- Outlet Nozzle Diameter – 4.324 mm

Assumptions

- Water is at ambient conditions (20°c and 101.325 kPa).
- Flow is steady and incompressible.
- Flow is fully developed.
- Frictional forces are negligible.
- Body forces are negligible.
- Nozzle is surrounded by atmospheric pressure, so subtracting atmospheric pressure results in dealing with gauge pressures.

Sketch

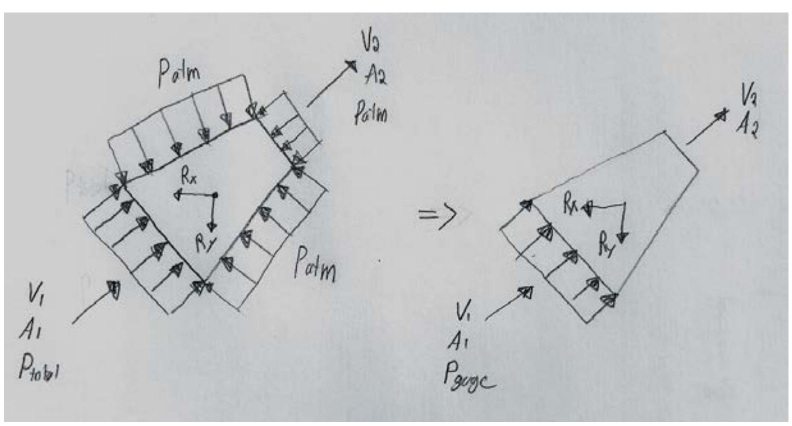


Figure 16 - Pressure forces on Main Nozzle

Analysis

Both the inlet speed and outlet speed are known, so we can go straight to Newton's second law. Since the nozzle is at an angle, Newton's second law will have to be applied in the vertical and horizontal direction. Newton's second law is generally defined as:

$$\sum F = \frac{d}{dt}\int_{cv} \rho V dV_{cv} + (\beta m\dot{V})_{out} - (\beta m\dot{V})_{in}$$

Where F denotes the sum of the external forces acting on the control volume, the integral denotes the transient change of linear momentum in the control volume, and the *out* and *in* subscripts denote the momentum flux out and in of the control volume respectively. The term $\dot{m}$ denotes the mass flow rate, and is simply defined by the product of the fluid density, velocity, and cross sectional area. β is called the momentum flux factor, and is used to compensate for any non-uniform velocity profiles. To obtain a conservative estimate, it is assumed to be 1.03. Since the flow is steady, the integral term in the equation above disappears. Applying this expression in the vertical and horizontal direction will allow an expression of the reaction force as a function of the nozzle angle is possible. In the positive x-direction:

$$\sum F_x = (\beta \dot{m} V_x)_{out} - (\beta \dot{m} V_x)_{in} = \beta \rho A_2 V_2^2 Cos(\theta) - \beta \rho A_1 V_1^2 Cos(\theta) = PA_1 Cos(\theta) - R_x$$

Rearranging, the horizontal reaction force is:

$$R_x = PACos(\theta) - \beta \rho A_2 V_2^2 Cos(\theta) + \beta \rho A_1 V_1^2 Cos(\theta) = \left[PA_1 - \frac{\pi}{4}\beta \rho D_2^2 V_2^2 + \frac{\pi}{4}\beta \rho D_1^2 V_1^2\right] Cos(\theta)$$

Inserting the known values, the horizontal component as a function of the nozzle angle is:

$$R_x = \left[(517107\ Pa)\left(\frac{\pi}{4}\right)(0.0127m)^2 - \frac{\pi}{4}(1.03)\left(998\ \frac{kg}{m^3}\right)(0.004324m)^2\left(31.106\ \frac{m}{s}\right)^2 + \frac{\pi}{4}(1.03)\left(998\ \frac{kg}{m^3}\right)(0.0127m)^2\left(3.595\ \frac{m}{s}\right)^2\right] Cos(\theta) = 52.667 Cos(\theta)\ [N]$$

Similarly, the vertical reaction force is found to be:

$$\sum F_x = (\beta \dot{m} V_x)_{out} - (\beta \dot{m} V_x)_{in} = \beta \rho A_2 V_2^2 Sin(\theta) - \beta \rho A_1 V_1^2 Sin(\theta) = PA_1 Sin(\theta) - R_y$$

Rearranging and substituting the known values, the vertical reaction force is:

$$R_y = PASin(\theta) - \beta \rho A_2 V_2^2 Sin(\theta) + \beta \rho A_1 V_1^2 Sin(\theta) = \left[PA_1 - \frac{\pi}{4}\beta \rho D_2^2 V_2^2 + \frac{\pi}{4}\beta \rho D_1^2 V_1^2\right] Sin(\theta)$$

$$= \left[(517107\ Pa)\left(\frac{\pi}{4}\right)(0.0127m)^2 - \frac{\pi}{4}(1.03)\left(998\ \frac{kg}{m^3}\right)(0.004324m)^2(31.106\ \frac{m}{s})^2 + \frac{\pi}{4}(1.03)\left(998\ \frac{kg}{m^3}\right)(0.0127m)^2(3.595\ \frac{m}{s})^2\right] Sin(\theta) = 52.667 Sin(\theta)\ [N]$$

By knowing the horizontal and vertical reaction forces as a function of the nozzle angle, it is easier to determine which angle will produce the largest reaction force. The total reaction force is found by simply vector summing each individual force component. Table 10 below shows the resulting horizontal reaction force (R_x), vertical reaction force (R_y) and total reaction force (R_{tot}) over the entire range of the sprinkler head orientations.

Table 10 - Reaction forces for various nozzle angles

Angle (°)	Rx (N)	Ry (N)	Rtot (N)
0	-52.667	0.000	52.667
5	-52.467	-4.590	52.667
10	-51.867	-9.146	52.667
15	-50.873	-13.631	52.667
20	-49.491	-18.013	52.667
25	-47.733	-22.258	52.667
30	-45.611	-26.334	52.667
35	-43.142	-30.209	52.667
40	-40.345	-33.854	52.667
45	-37.241	-37.241	52.667
50	-33.854	-40.345	52.667
55	-30.209	-43.142	52.667
60	-26.334	-45.611	52.667
65	-22.258	-47.733	52.667
70	-18.013	-49.491	52.667
75	-13.631	-50.873	52.667
80	-9.146	-51.867	52.667
85	-4.590	-52.467	52.667
90	0.000	-52.667	52.667

Conclusion

Although the individual reactionary forces obviously change with angle position, the total reaction force does not seem to depend on the angle. This makes sense since each of the pressure force and momentum force vectors all depend on the same angle orientation as the nozzle. The total force at each angle is about 52.667 N, or around 11.84 lbf. Note that this result is only valid for neglecting the weight of the nozzle, although it can easily be neglected since it weighs about 0.37 pounds (from Solid Works). Although this is not a significantly huge force, it further enforces the fact that redesigning the arm to hold a force should be considered.

Impact Arm Analysis

Objectives

- To determine the torque acting on the impact arm as a result of impact arm spring preload and water stream impulse.
- To determine the rotation angle the impact arm will provide to the sprinkler body.
- To determine impact arm frequency of rotation.

Known

- Nozzle Diameter (D) is 0.00244 m
- Nozzle output flow rate (Q) is 0.000145 m^3/s
- Distance from impact arm pivot point to water jet contact point (r) is 0.14093 m
- Water density (ρ) is 1000 kg/m^3
- Spring preload angle (θ_p) is set at 2 ^{o}. (Chosen to optimize design)
- Spring constant (C) is 0.02 Nm/rad. (Chosen to optimize design)
- Lateral distance from impact arm contact point to the water stream (h) is 0.0101 m
- Acceleration due to gravity is 9.81 m/s^2
- Coefficient of friction in swivel joint of sprinkler assembly (μ) is 0.5.
- Radius of swivel joint (d) is 0.0127 m.
- Sprinkler assembly and impact arm properties are shown below in Table 11:

Table 11 - Known Sprinkler Mass Values

Component	Io	mass	r	I
	($kg\text{-}m^2$)	**(kg)**	**(m)**	**($kg\text{-}m^2$)**
Sprinkler	0.00394	3.83	0.02	0.00615
Impact Arm	0.00103	0.18	0.03	0.00115

Assumptions

- Exit stream diameter is equal to nozzle diameter.
- The full of diameter of water stream hits the impact arm.
- Upon contact with the impact arm, the stream of water deflects at a 90^o angle from its original path.
- Friction occurring at swivel joint can be approximated the same as friction acting along a distance equal the circumference of the joint.

Sketch

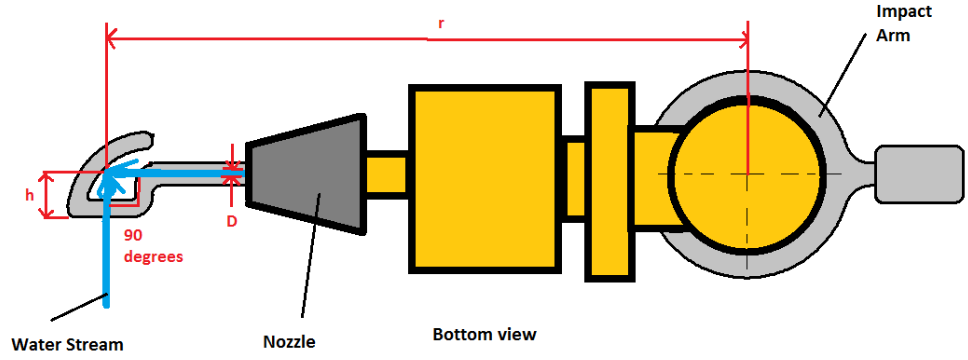


Figure 17 - Pertinent Dimension Définitions (Botton View)

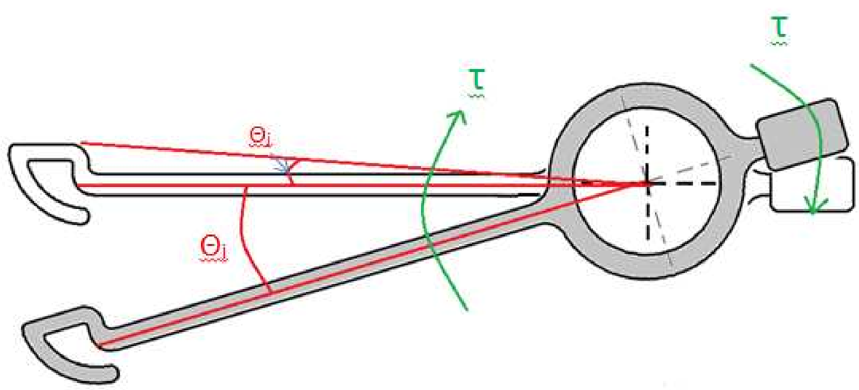


Figure 18 - Rotation of the Impact Arm (Top View)

Analysis

Torque acting on the impact arm as a result of the water stream impulse is measured as:

$$\tau_j = \rho Q V r$$

Velocity of the water stream is determined from stream diameter and flow rate:

$$V = \frac{Q}{A} = \frac{Q}{\frac{\pi D^2}{4}}$$

Torque acting on the impact arm caused by the spring at the point of impact against the sprinkler body is:

$$\tau = \tau_0 + C\theta_i$$

Where θ_i is the angle traveled by the impact arm from maximum point of spring loading. The following expression has been derived by Kincaid [4].
τ_0 is the preloaded torque of the spring [Nm]

$$\tau_0 = \theta_p C$$

$$\theta_i = \sqrt{{\theta_p}^2 + 2\theta_2\theta_j} - \theta_p$$

Where θ_2 is the difference between water stream impulse torque and spring preload torque over the spring constant

θ_j is the water stream impulse angle, which is the angle the impact angle must rotate until no there is more contact with the water stream

$$\theta_2 = \frac{(\tau_j - \tau_0)}{C} = \frac{\tau_j}{C} - \theta_p$$

$$\theta_j = \tan^{-1}\left(\frac{h}{r}\right)$$

Energy is constant in the system and equal to the full moment arm energy τ, initially:

$$\frac{1}{2}I{\omega_o}^2 = \tau$$

Assuming that the force of friction acts along a mass of length 2πr, Velocity is given as:

$$v(t) = v_o - \frac{Ft}{2m}$$

Where F is the frictional force acting from the swivel joint:

$$F = \mu mg$$

Then ω(t) is given as:

$$\omega(t) = \omega_o - \frac{Ft}{2md}$$

Solving for ω(t) =0 gives the time of the rotation:

$$t = \frac{\omega_o 2md}{F}$$

The angle of deflection of the sprinkler assembly from each hit of the impact arm can be calculated by integrating angular velocity:

$$\theta_{max} = \omega_o t - \frac{Ft^2}{4md}$$

The frequency of the moving impact arm was then determined based on the equation derived by Kincaid [4].

$$t(\theta) = 2\left(\frac{I}{C}\right)^{0.5} sin^{-1}[(\frac{\theta}{2\theta_o})^{0.5}]$$

Where:

I=Mass moment of Inertia
C=Torsional Spring Constant
θ_i=Angle of rotation measured from position of maximum extension
$\theta_o = (\theta_i + \theta_p)$ = Sum of preload angle and maximum extension angle

Solving for the maximum time of rotation at the largest swing angle of the impact arm and multiplying that by two to get a full period of motion:

$$t_{rotation} = 2t_{max}$$

And the frequency of rotation in Hz is

$$f = \frac{1}{t_{rotation}}$$

Results:
All values were calculated in tabulated below in table 12:

Table 12: Consolidated Analysis Results

Impact Arm Torque					
V (m/s)	θ_j (º)	θ_2 (º)	τ_j (Nm)	θ_i (º)	τ (Nm)
30.97	4.10	29.56	0.63	13.70	0.31
Sprinkler Body Rotation					
ω (rad/s)	t (s)	Θ_{max} (º)			
10.11	0.05	15.15			
Impact Arm Rotation Frequency					
$t(\theta\ i)$ (s)	f (Hz)				
0.08	11.95				

Conclusion:
By assuming all the energy from the spring and bar mechanism is translated into the initial velocity of the moving sprinkler, the total deflection can be determined for each hit. The preload angle for the spring was chosen to be minimized while the spring constant was based on values from Kincaid [4]. To complete the final design of the sprinkler, a spring needs to be chosen or fabricated to meet the stated values in the analysis requirements. Excel was used to compute the result values and additional preload angles were analyzed and by doing so it shows that spring constant and preload angle can be changed to achieve different sprinkler movement results. The results proved to agree within commonly known sprinklers in use today.

Sprinkler Hose Support Arm Stress Analysis

Objective

To determine the maximum stress on the arm support due to the nozzle force.

Solution Method

ANSYS will be used to determine both the maximum deflection and the maximum Von Mises stress that is found at the base of the arm.

Known

- Maximum Nozzle Force – 52.667 N
- Yield Strength of Galvanized Steel – 203.9 MPa (from Solid Works Database)
- Diameter and Length of pin joint – 6.35 mm

Assumptions

- Force is split evenly between both arms
- Force is applied perpendicularly to tangential surface
- Material is isentropic

Sketch

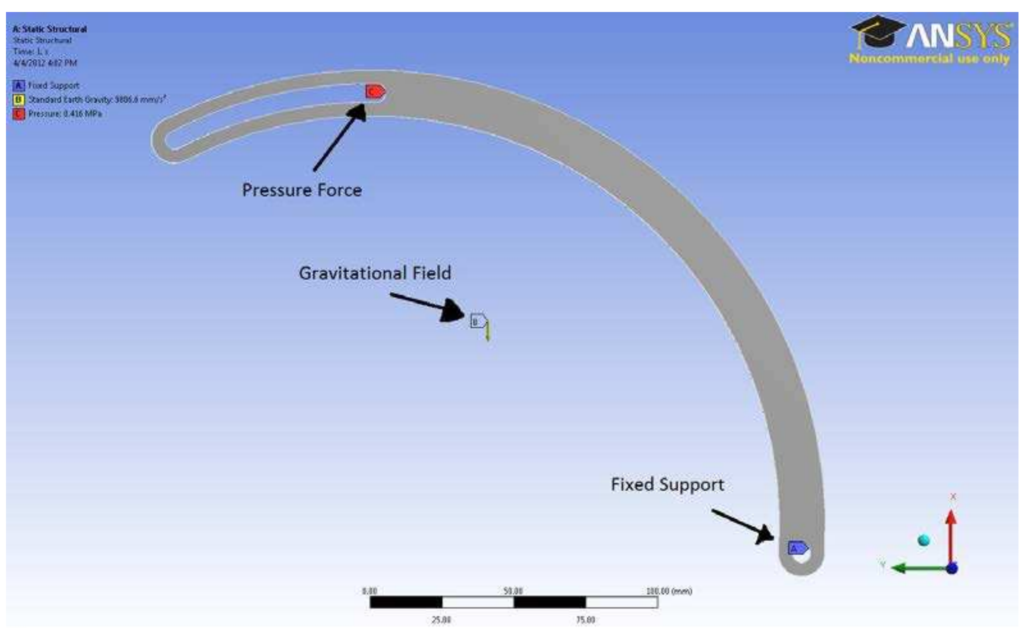


Figure 19 - Model setup for ANSYS

Analysis

By assuming that the force is evenly split between the two support arms, the analysis that is required can be simplified by considering only one arm. Figure 19 above shows how each of the loadings and constraints were applied. The stress acting on the upper half of the joint is calculated to be:

$$\sigma = \frac{F}{A/_2} = \frac{F}{(\pi DL)/_2} = \frac{F}{(\pi DL)/_2} = \frac{26.3335\ N}{(\pi * 6.35 * 6.35)/_2} = 0.416\ MPa$$

The lower hole is fixed to prevent rotation. The body effects are also included by inserting a gravitational field into the simulation. ANSYS can now solve for the maximum stress and deflection with the loadings and constraints applied. A mesh dependency is done by refining the meshing within the entire body. Figures 20 and 21 below show the resulting maximum Von Mises stress and the maximum deflection over each refinement step.

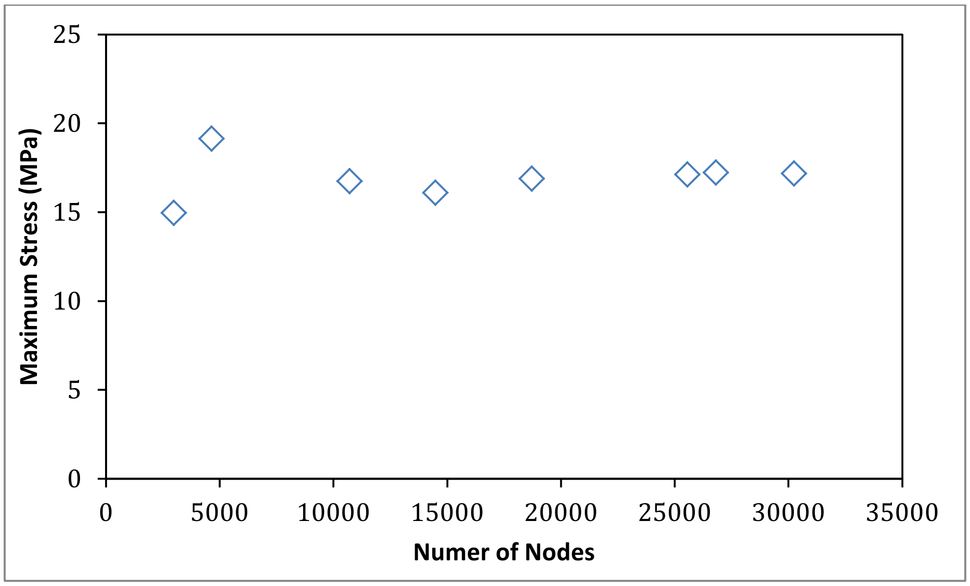


Figure 20 - Convergence of maximum Von Mises stress

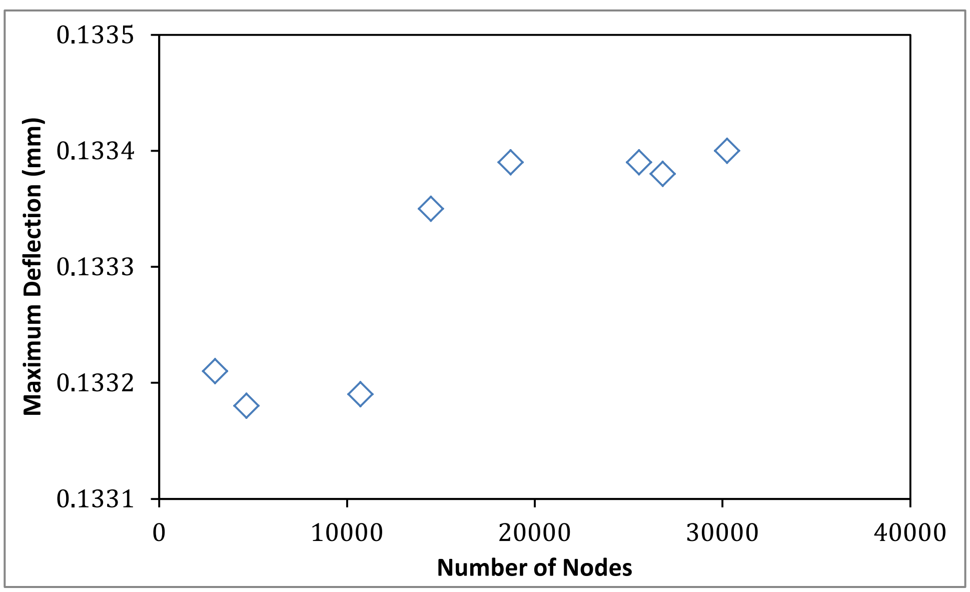


Figure 21 - Convergence of maximum deflection

Both Figures 20 and 21 above demonstrate that convergence has been reached for the maximum stress and deflection. Therefore, the results obtained seem reliable and accurate enough. The maximum deflection is found to be about 0.1334 mm, and the maximum Von Mises stress is found to be 17.174 MPa. The maximum stress is found at the pinhole of the arm, and the maximum deflection is found at the free end near where the force is applied. Figures 22 and 23 below show the resulting contour plots of both the stress and deflections, respectively, within the arm.

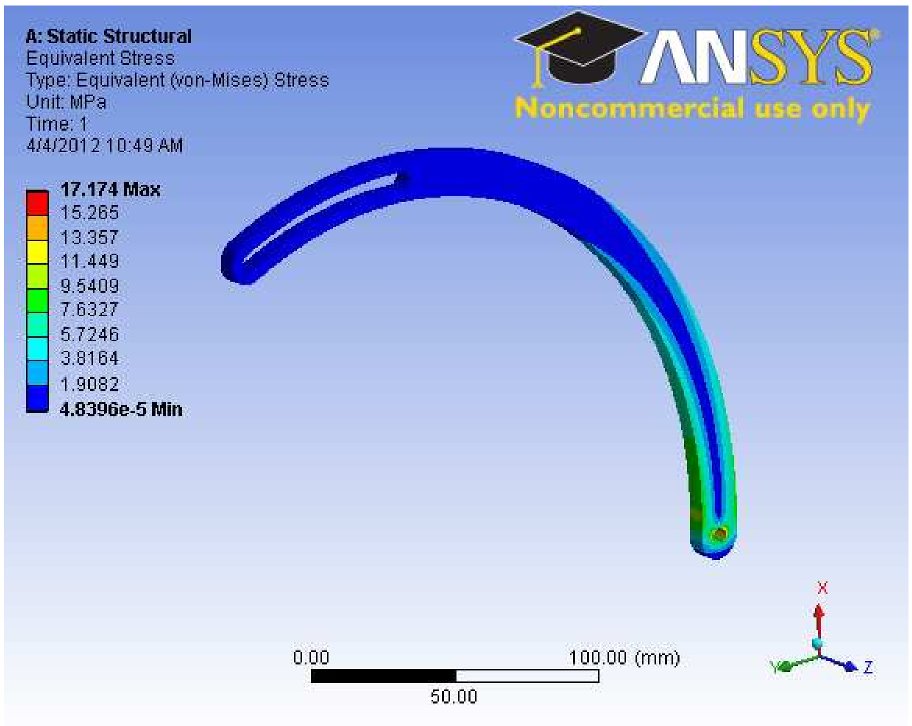


Figure 22 - Von Mises stress contours

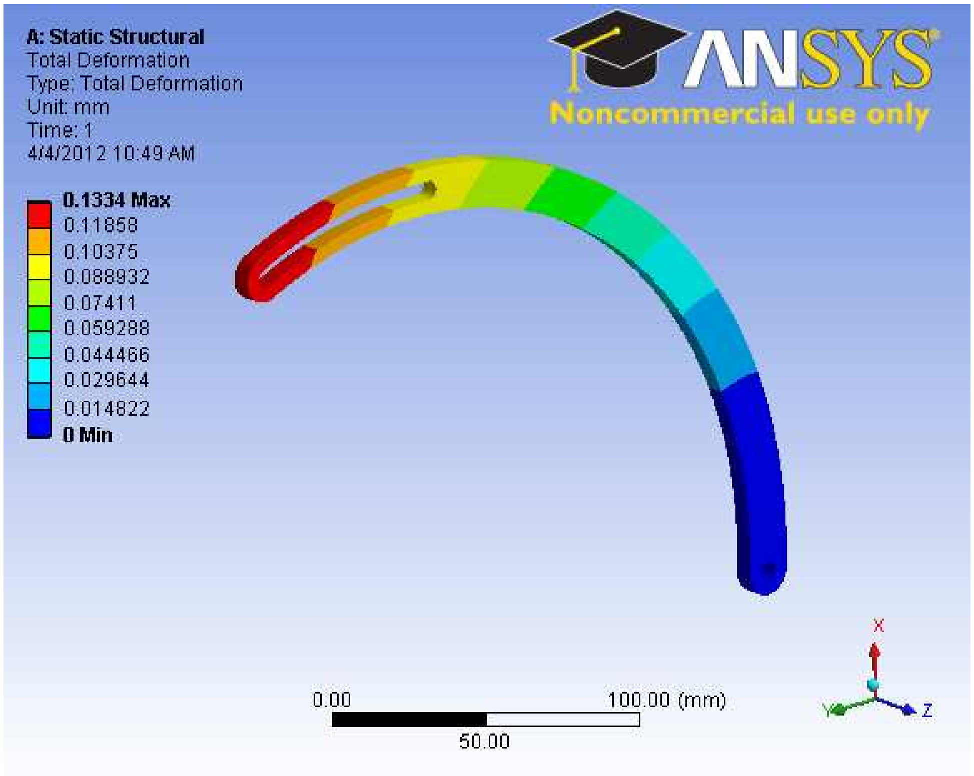


Figure 23 - Deflection contours

Conclusion

The maximum stress was found to be 17.174 MPa, and is significantly less than the yield strength of Galvanized Steel. Therefore, failure within the arm is not expected at the specified loading conditions. Despite the accuracy and steady convergence of the results obtained at finer meshes, further analysis should be considered to further confirm the accuracy of these results through either another analysis or through experimental methods.

Welding Calculation

Objective

To determine the weld thickness required that will allow the weld holding the stake holder to the sprinkler to support a force of 10 kN.

Known

- The length of all the welds
- The yield strength of the weld material is 345 MPa

Assumptions

- The member itself does not fail, the failure occurs at the weld.
- Direct shear in the weld is given by V/A, where V is 10 kN, and A is 2(34.9+57.2)*t.
- Distortion Energy Theory Applies
- Center Of gravity is at the center of the block as all welds are symmetrical.

Sketch

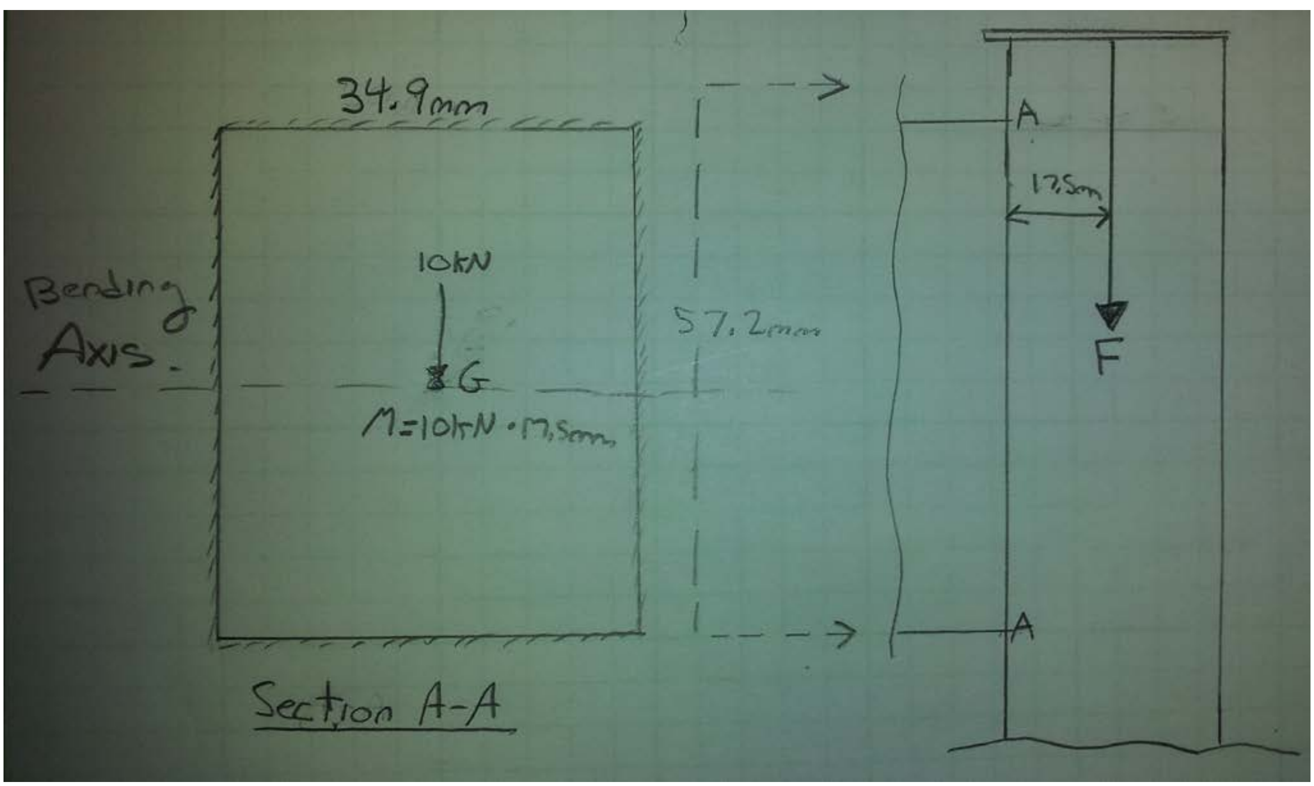


Figure 24 - Welding free body diagram

Analysis

The Load applied is equivalent to the same load acting through the center of gravity of the weld, plus a clockwise torque of 10kN(17.5mm)=175 Nm=Mc

Assumption 4 gives:

X=17.45mm
Y=28.6mm

Calculate the Moment of Inertia of the welds about the bending axis

$I_1 = 2th(w^2) = 0.139t\ m^4$
$I_2 = 2t(h^3) = 0.374t\ m^4$
$I_t = I_1 + I_2 = 0.515t\ m^4$

The Tensile Bending Stress is given as:

$$\sigma = \frac{Mc}{I_t} = \frac{9744}{t} Pa$$

And the transverse shear stress on all the welds is:

$$\tau = \frac{V}{A} = \frac{54290}{t}\ Pa$$

Using Mohr's Circle to determine the maximum stress:

$$\tau_{max} = \sqrt{0.5\sigma^2 + \tau^2} = \frac{54730}{t}\ Pa$$

Using distortion energy theory to calculate the required thickness to support 10kN and solving for thickness t:

$$\frac{54730}{t}\ Pa = 345(0.58)Mpa$$

$$t = 0.274\ mm$$

However, since the geometric relationship between weld size and required thickness is as follows, required thickness is:

$$t_{req} = \frac{t}{0.707} = 0.388\ mm$$

Conclusion

The required thickness to withstand a large force is very small for the weld. As a welding thickness will well exceed 0.388mm, the setup will allow for a very large force to be applied to the sprinkler and the system will not fail at the weld.

Appendix B – FloXpress Analysis Reports

Solid Works FloXpress Report – Main Nozzle

SolidWorks FloXpress is a first pass qualitative flow analysis tool which gives insight into water or air flow inside your SolidWorks model. To get more quantitative results like pressure drop, flow rate and other, you will have to use Flow Simulation. Please visit www.solidworks.com to learn more about the capabilities of Flow Simulation.

Model

Model Name: F:\LEXAR\Mec E 460\CFX\Assem1.SLDASM

Fluid

Water

Inlet Volume Flow 1

Type	Volume Flow Rate
Faces	<1lid1-1@Boss-Extrude1>
Value	Volume Flow Rate: 0.0005 m^3/s Temperature: 293.20 K

Environment Pressure 1

Type	Environment Pressure
Faces	<1mainnozzlelid-1@Boss-Extrude1>
Value	Environment Pressure: 101325.00 Pa Temperature: 293.20 K

Results

Name	Unit	Value
Maximum Velocity	m/s	28.800

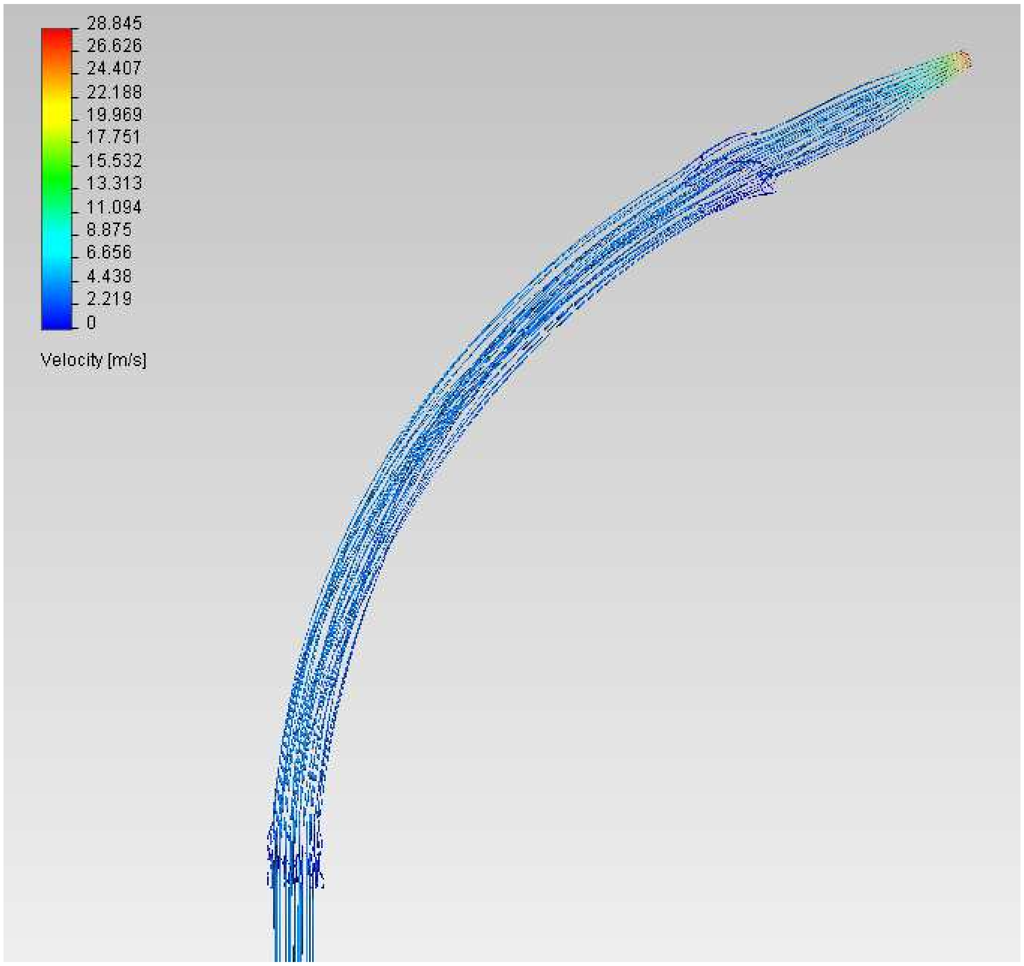
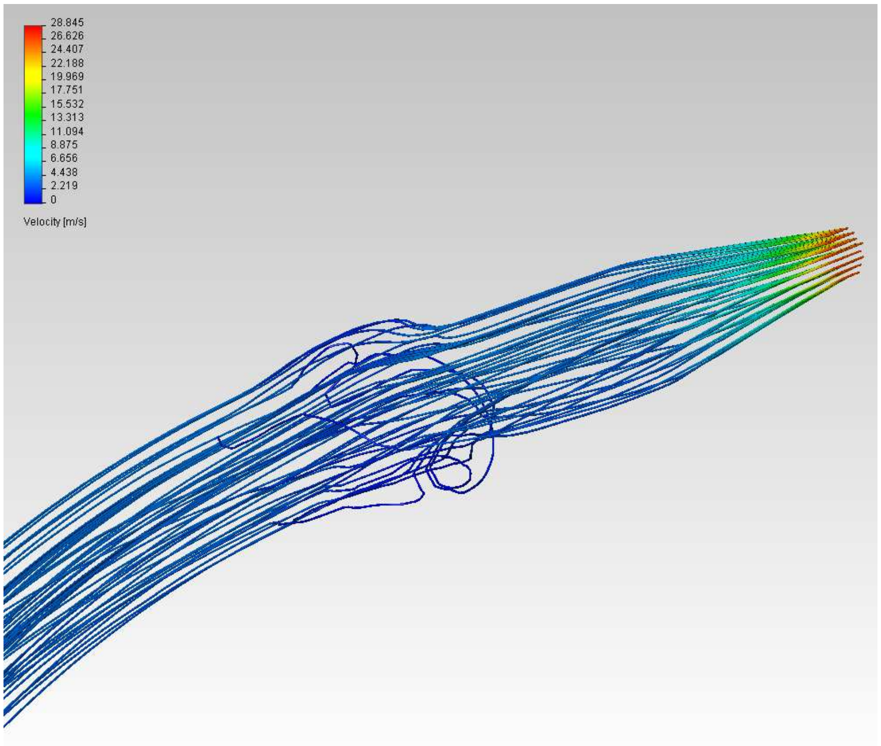


Figure 25 - Main Stream Flow Analysis from FloXpress



**Note the small amount of turbulence was caused by the interface between fittings and did not have a significant effect on pressure loss*

Figure 26 - Nozzle Flow Analysis Using FloXpress

SolidWorks FloXpress Report – Rotation Nozzle

SolidWorks FloXpress is a first pass qualitative flow analysis tool which gives insight into water or air flow inside your SolidWorks model. To get more quantitative results like pressure drop, flow rate etc. you will have to use Flow Simulation. Please visit www.solidworks.com to learn more about the capabilities of Flow Simulation.

Model

Model Name: F:\LEXAR\Mec E 460\CFX\Assem1.SLDASM

Fluid

Water

Environment Pressure 1

Type	Environment Pressure
Faces	<1lid2-1@Boss-Extrude1>
Value	Environment Pressure: 618431.00 Pa Temperature: 293.20 K

Environment Pressure 1

Type	Environment Pressure
Faces	<1rotation nozzle lid-1@Boss-Extrude1>
Value	Environment Pressure: 101325.00 Pa Temperature: 293.20 K

Results

Name	Unit	Value
Maximum Velocity	m/s	31.373

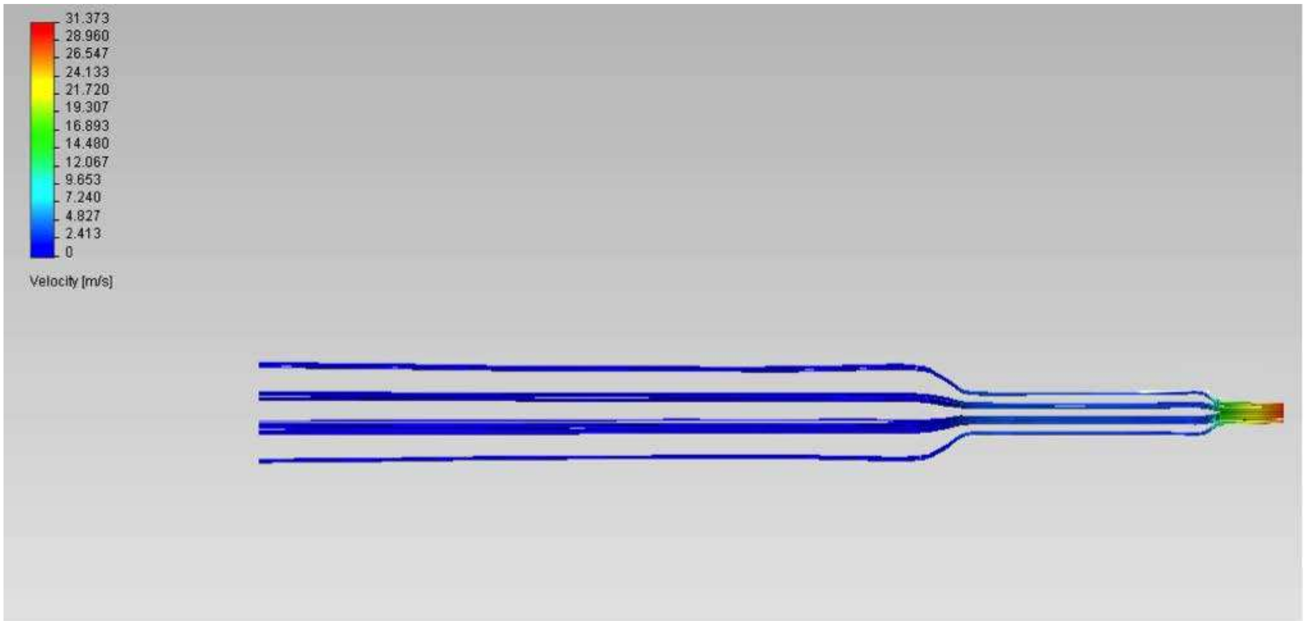


Figure 27 - Flow up to the Rotational Nozzle Using FloXpress

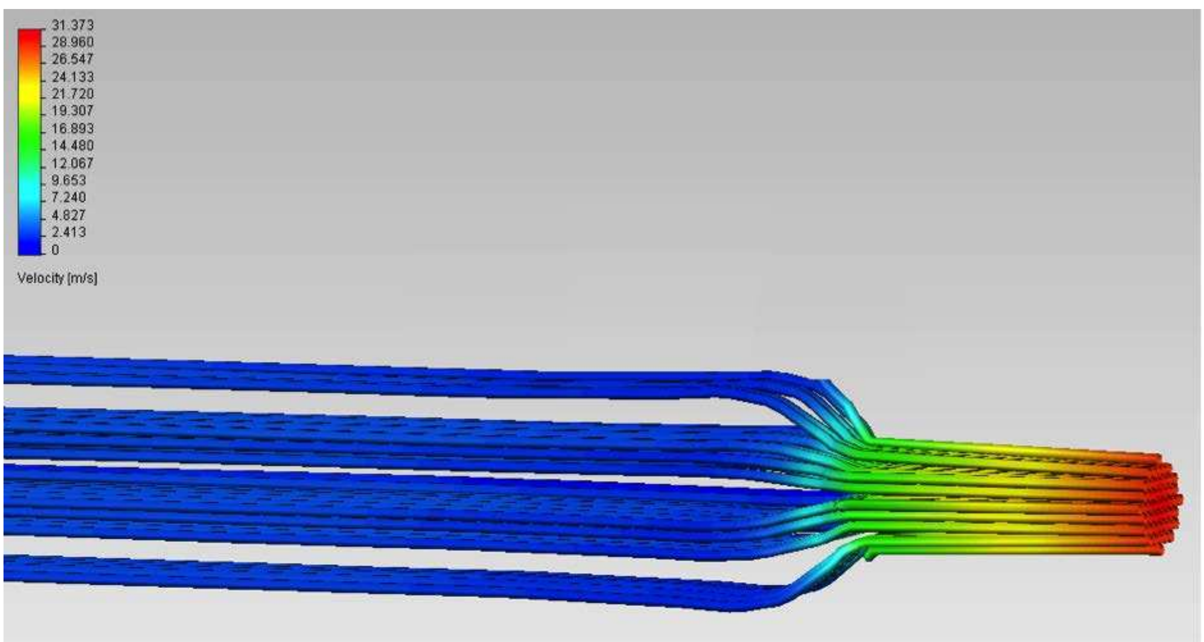


Figure 28 - Rotating Nozzle Flow Analysis Using FloXpress

Appendix C – Assembly, Setup and Operation

Assembly

The sprinkler assembly is done in the manufacturing phase. The assembly of the sprinkler requires the assembly of all manufactured and purchased parts. These steps were included in the cost under machining time. The machinist will complete the assembly of the sprinkler before mass production begins. The assembly of the sprinkler only requires basic wrenches to assemble all the fittings and a press to press the brass bushing into the rotational arm.

Setup

The setup of the sprinkler, and the supply lines of the sprinkler system, was designed to have the least amount of steps and all the steps were to be simple. The setup of the system requires a main header line to be laid out in a loop with both ends coming back the pump. Along the trunk line there are 8 takeoff tees that are installed during the setup of the trunk line. From each of these takeoff tees a smaller line will be run to each sprinkler head. The setup steps required for the sprinkler head very depending on the location:

- If the sprinkler is setup on the forest floor the main steak can be pounded directly into the ground and the small supply line attached to the sprinkler.
- If the sprinkler is to be attached to the side of a building or large fence post the spike has holes in the side where screws or nails can fasten the support to the structure. Then the supply line can be attached of the sprinkler
- If the sprinkler requires a more complex mounting system, a simple support can be quickly be made out of dimensional lumber and the mount on the sprinkler is designed to fit a 2X4. Then the sprinkler supply line can be attached.

Once the setup of all the sprinkler heads has been done the system can be turned on and an operator can go around to each of the heads and adjust them to the correct height of the treetops.

Operation

The system has been designed to be run without operator intervention after startup. The system only requires an operator to be present to startup of the system. This allows the operator to setup and start the system and then leaves the system running while they retreat to a safer location.

Appendix D - Phase 3 Recorded Hours

Expand All | Collapse All	Owner	Total Done
Phase 3	AGD	155h
Cover Letter	Jesse	2h
Write Cover Letter	Jesse	2h
Executive Summary	Jesse	3h
Draft executive summary	Jesse	2h
Final pass and proof of executive summary	Jesse	1h
Design Report	AGD	24h
Description of final design	Jesse	7h
Product/Manufacturing Cost Analysis	Alexander	6h
Considerations, future R&D and design influences	Chris	4h
Self-Evaluation	Charles	2h
Appendices	Evrhetton	5h
Design Compliance Matrix	AGD	7h
Update Design Specification Matrix	Charles	6h
Obtain Client Approval	Chris	1h
Project Management	Alexander	6h
Update Project Schedule	Alexander	4h
Record project work hours	Alexander	2h
Detailed Design Calculations	AGD	57h
Calculations 1	Alexander	12h
Calculations 2	Jesse	10h
Calculations 3	Chris	7h
Computer Aided Calculations	Chris	28h
Detailed Design Drawings	AGD	56h
Manufacturing Part Drawings	Evrhetton	3h
Purchased Parts	Evrhetton	4h
Schematics	Alexander	4h
Redesigning of Parts	Evrhetton	6h
Detailed Sub-Assembly Drawings 1	Charles	23h
Detailed Sub-Assembly Drawings 2	Evrhetton	8h
Final General Assembly Drawing	Evrhetton	8h
Prototype	AGD	0h
Prototype Assembly	Evrhetton	0h
Test Prototype and Record Results	Alexander	0h
Project Poster	AGD	2h
Determine Poster Layout	Evrhetton	2h
Rehearse Presentation	AGD	0h

Figure 29 - Phase 3 Logged Hours

Appendix E - Detailed Design and Assembly Drawings

Assembly Drawing Tree

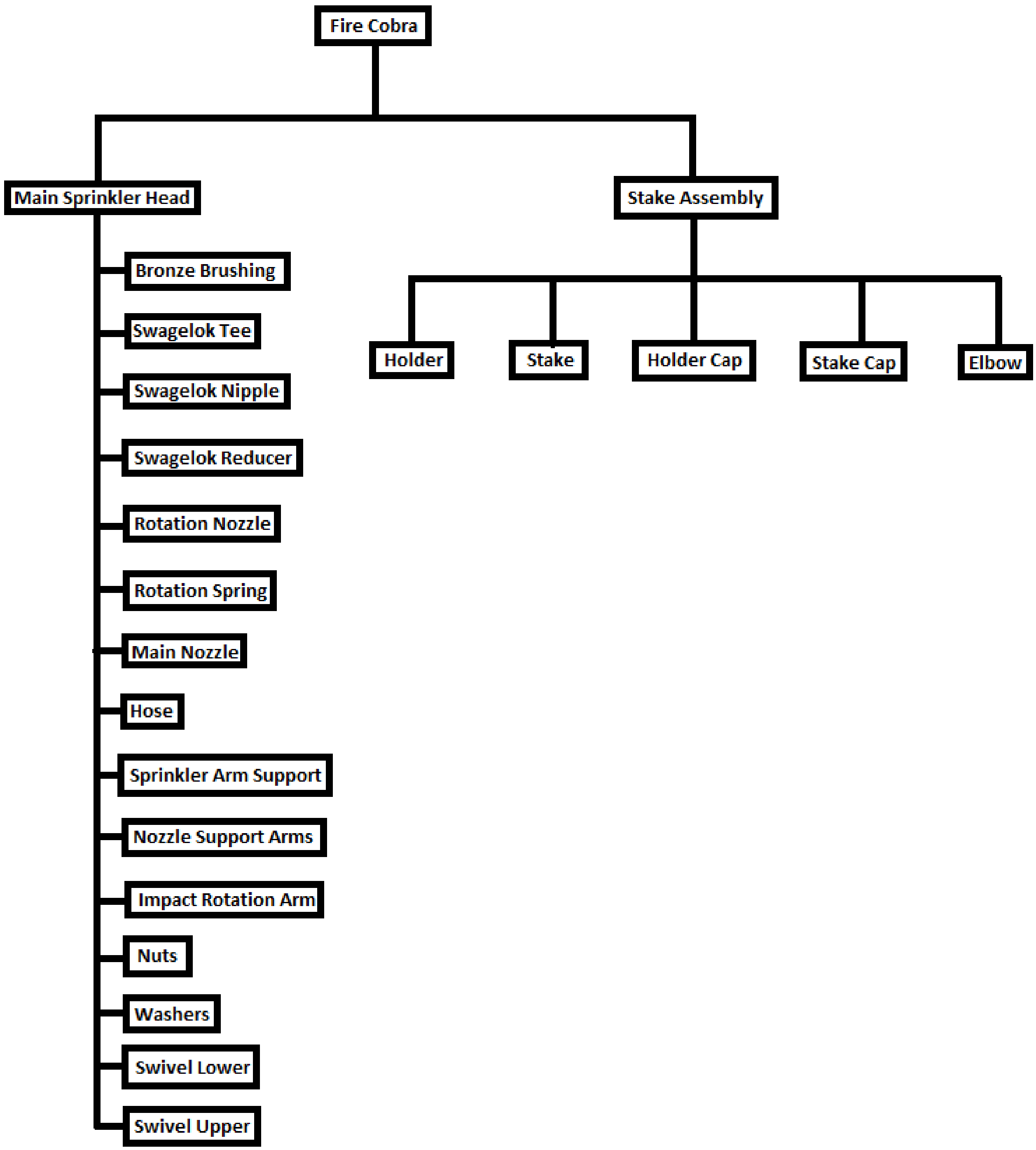
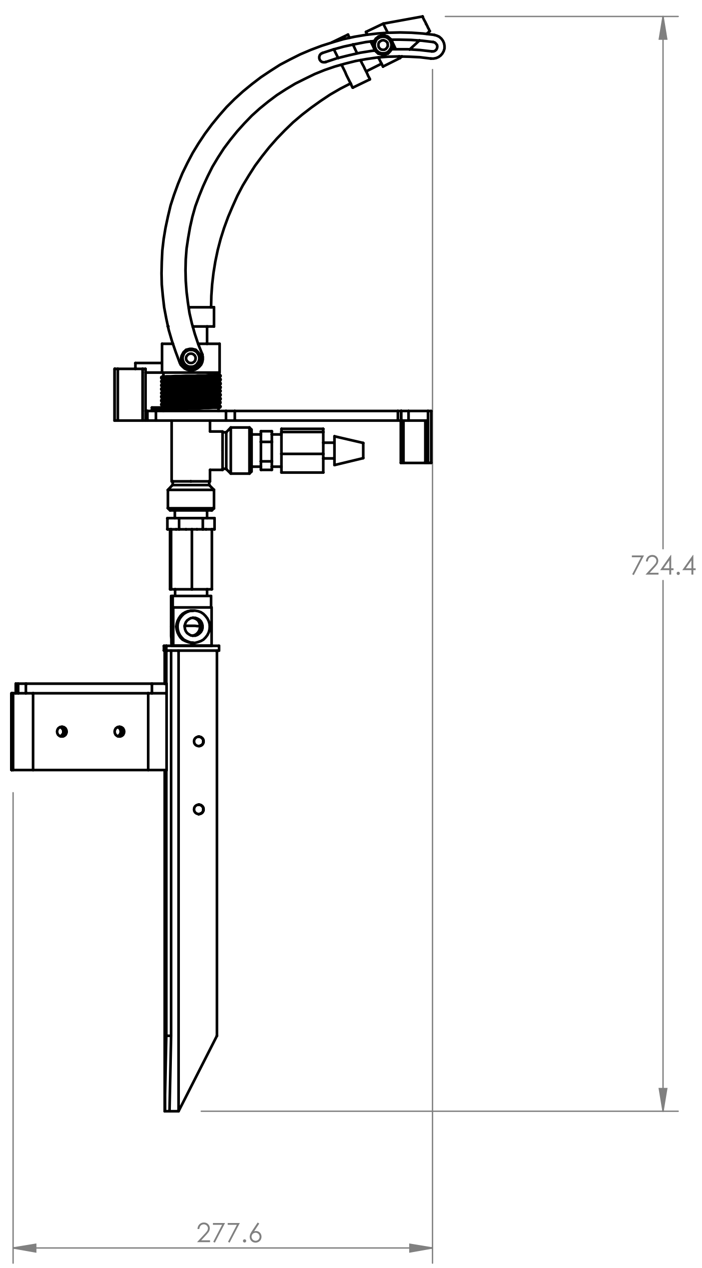
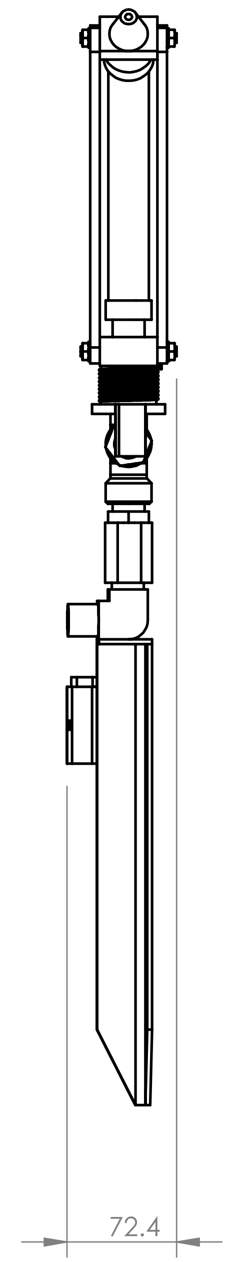
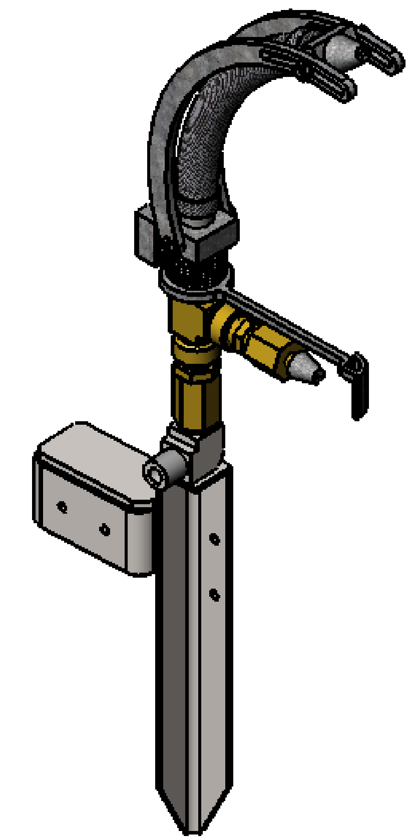


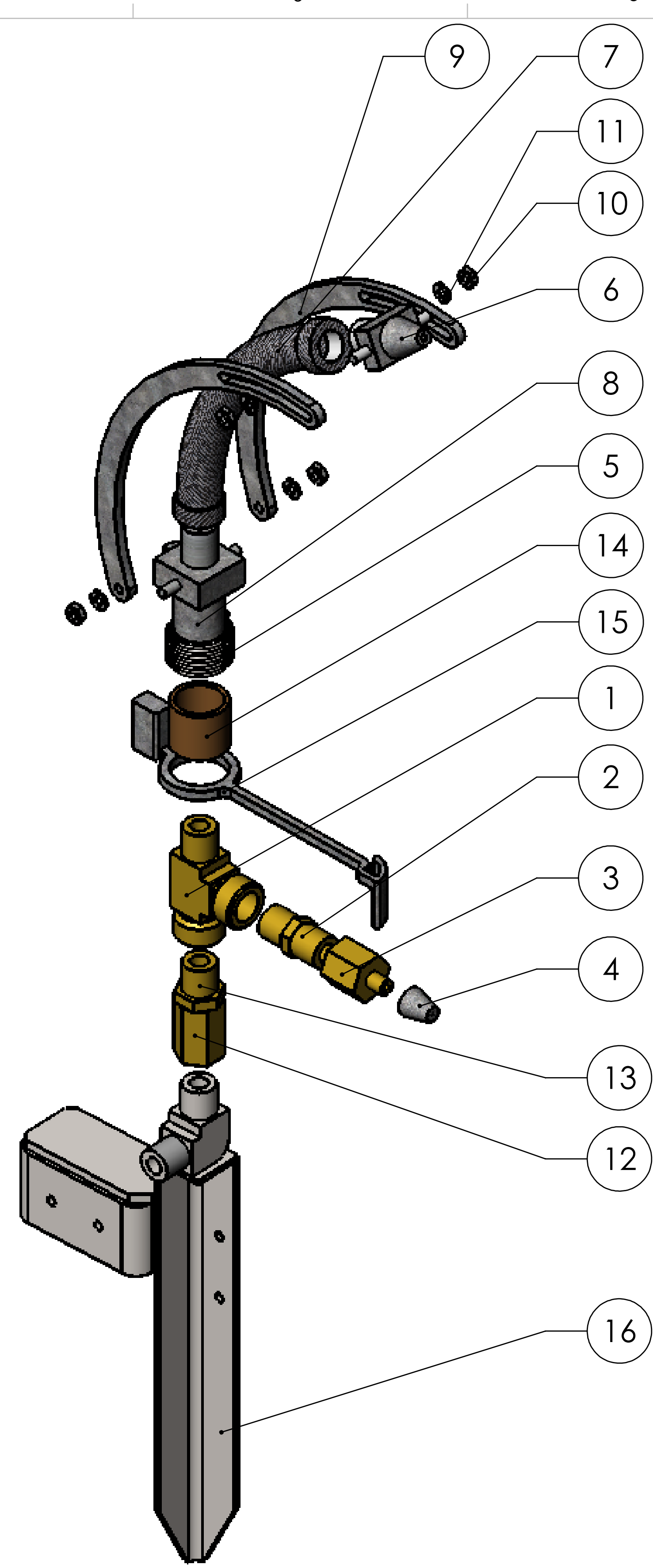
Figure 30 – Fire Cobra Part Assembly Tree

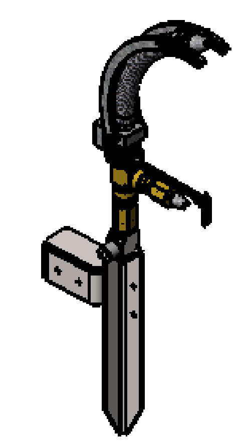






Mec E 460 Instructor: Winter 2012 Comments:	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MM TOLERANCES: ANGULAR: ± 0.5° LINEAR X = ± 0.5 X.X = ± 0.1 X.XX = ± 0.025 SURFACE FINISH µm 0.6 DO NOT SCALE DRAWING	DRAWN BY: Charles Weir	AGD
		Student #	TITLE: Sprinkler Assembly
		Lab Day	
		SM By	SIZE B
MATERIAL:		TA Initials	Assignment Number AGD-001-0001
FILE NAME: Assem1		MEC33-W27 Tuesday, April 03, 2012 3:50:25 PM Friday, February 24, 2012 6:41:14 PM	REV 1
			SCALE: 1:5
			Mass: 3.83 kg
			SHEET 1 OF 1





ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Swagelok Tee	1/2" Swagelok Tee	1
2	Swagelok- nipple	1/2" Swagelok Nipple	1
3	Swagelok Reducer	1/2"X1/8" Swagelok Reducer	1
4	Rotation Nozzle	Rotation Nozzle	1
5	Rotational Spring	1 1/2" Torsional Spring	1
6	Main Nozzle	Main Sprinkler Nozzle	1
7	Hose	6"X1/2" Flexible Hose	1
8	Sprinkler Arm Support	Sprinkler Arm Support	1
9	Nozzle Support Arm	Nozzle Support Arm	2
10	Nut	1/4" UNC Nut	4
11	Washer	1/4" Washer	4
12	Swivel Lower	1/2" Swivel (Upper Part)	1
13	Swivel Upper	1/2" Swivel (Upper Part)	1
14	Bronze Bushing	1 1/4"X1 1/2" Bronz Bushing	1
15	Impact Rotation Arm	Impact Rotation Arm	1
16	Stake Assembly	Stake Assembly	1

Mec E 460

Instructor:

Winter 2012

Comments:

MATERIAL:

FILE NAME: Assem1

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MM
TOLERANCES:
ANGULAR: ± 0.5°
LINEAR
X = ± 0.5
X.X = ± 0.1
X.XX = ± 0.025

SURFACE FINISH μm 0.6

DO NOT SCALE DRAWING

DRAWN BY: Charles Weir

Student #

Lab Day

SM By

TA Initials

MEC33-W27

Tuesday, April 03, 2012 3:50:25 PM
Friday, February 24, 2012 6:41:14 PM

AGD

TITLE: Sprinkler Assembly Exploded

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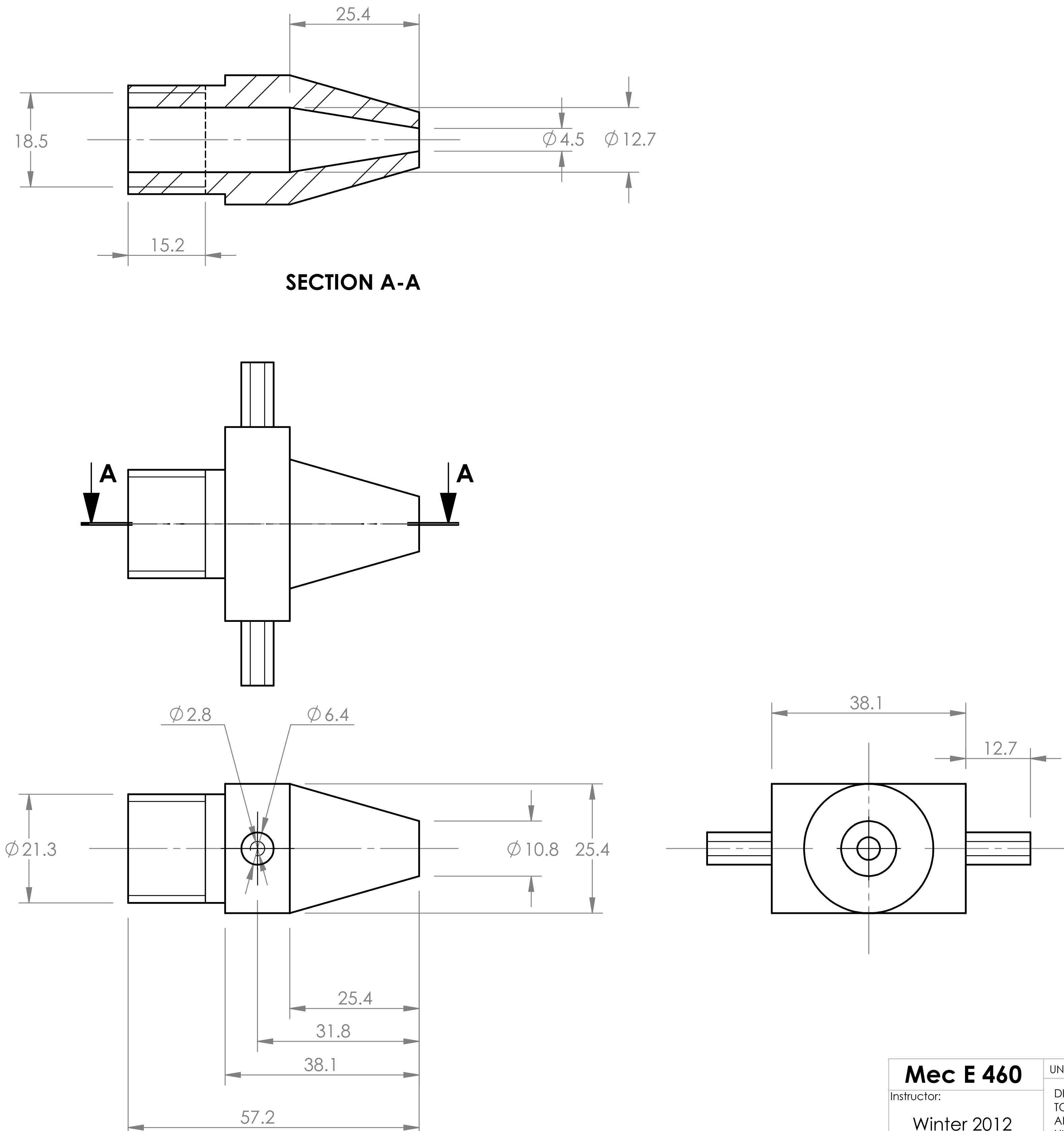
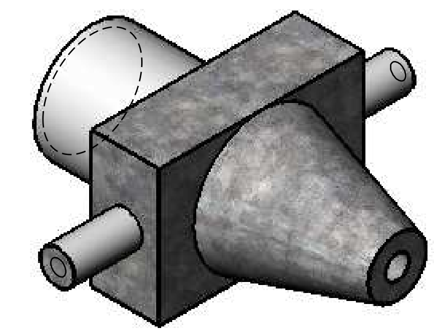
SCALE: 1:4 | Mass: 3.83 kg | SHEET 1 OF 1





Mec E 460

Instructor:

Winter 2012

Comments:

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MM
TOLERANCES:
ANGULAR: ± 0.5°
LINEAR
X = ± 0.5
X.X = ± 0.1
X.XX = ± 0.025

SURFACE FINISH µm 0.6

DO NOT SCALE DRAWING

MATERIAL:
Galvanized Carbon Steel

FILE NAME:
MainNozzle

DRAWN BY:
Charles Weir

Student #

Lab Day

SM By

TA Initials

MEC33-W27

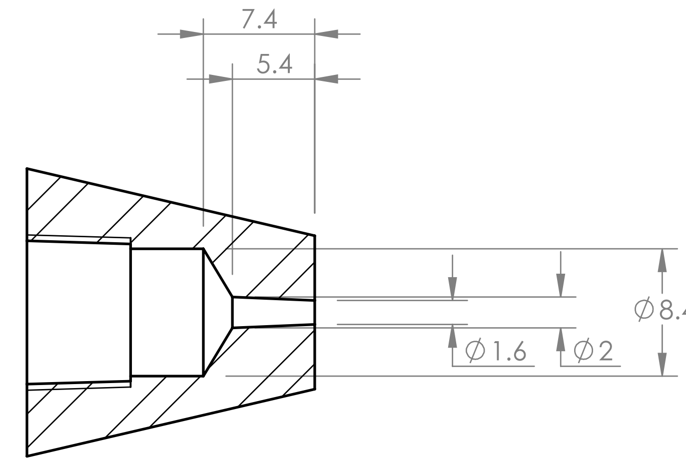
Tuesday, April 03, 2012 2:38:07 PM
Saturday, February 25, 2012 4:10:13 PM

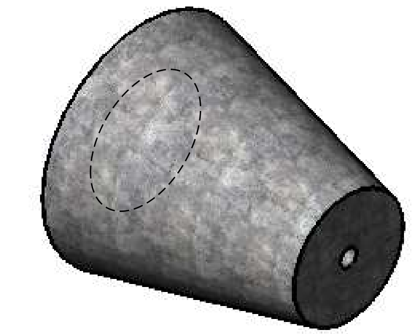
AGD

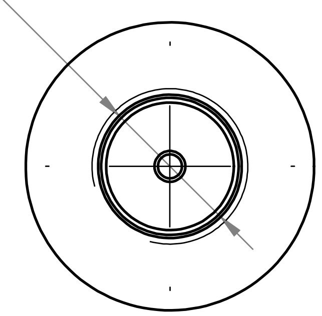
TITLE:
Main Nozzle

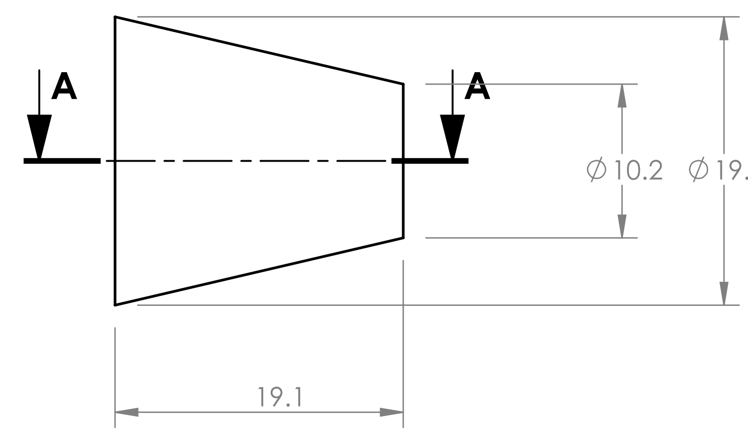
SIZE B | Assignment Number | REV 1

SCALE: 1:1 | Mass: 167.83 g | SHEET 1 OF 1









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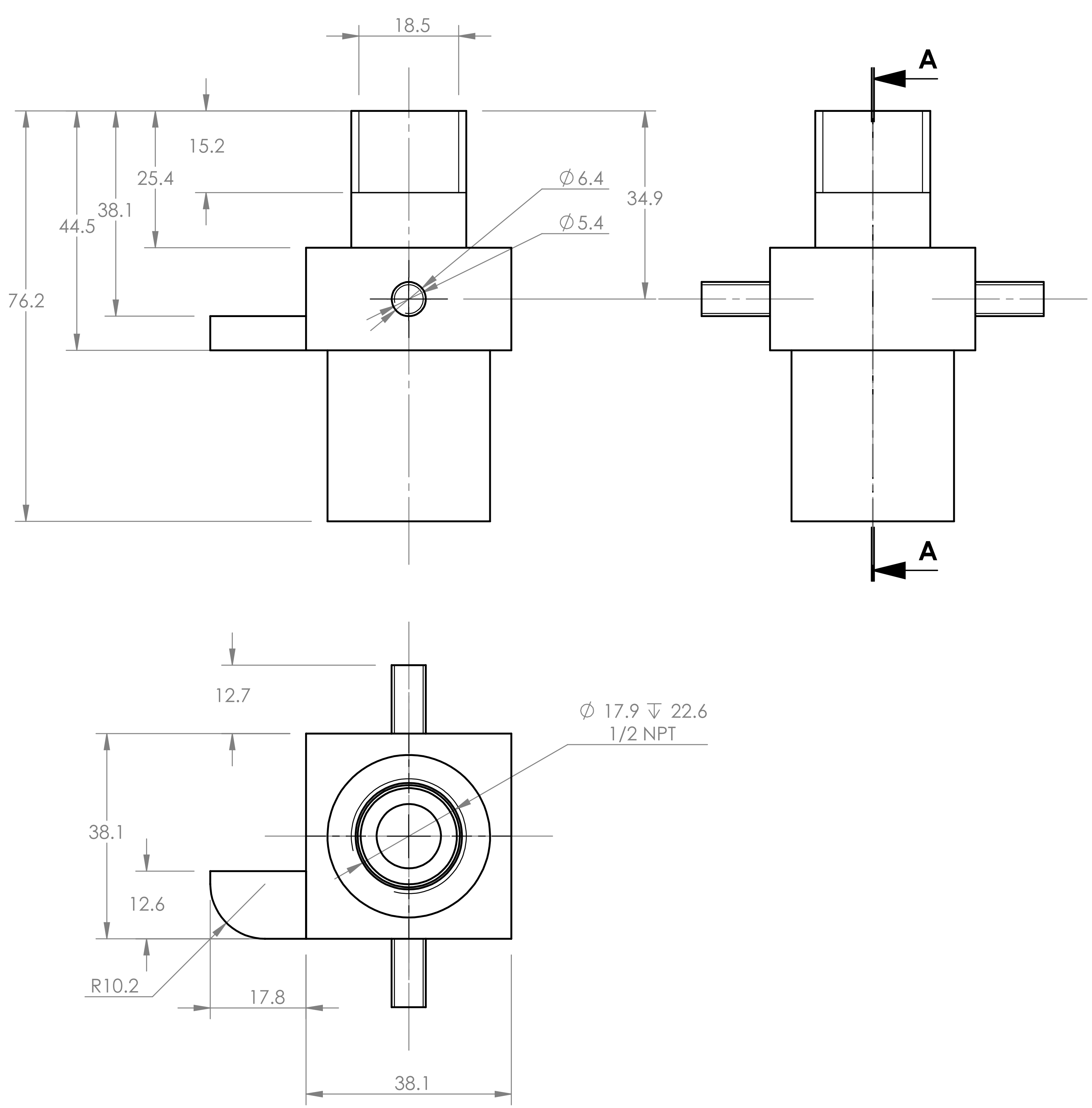
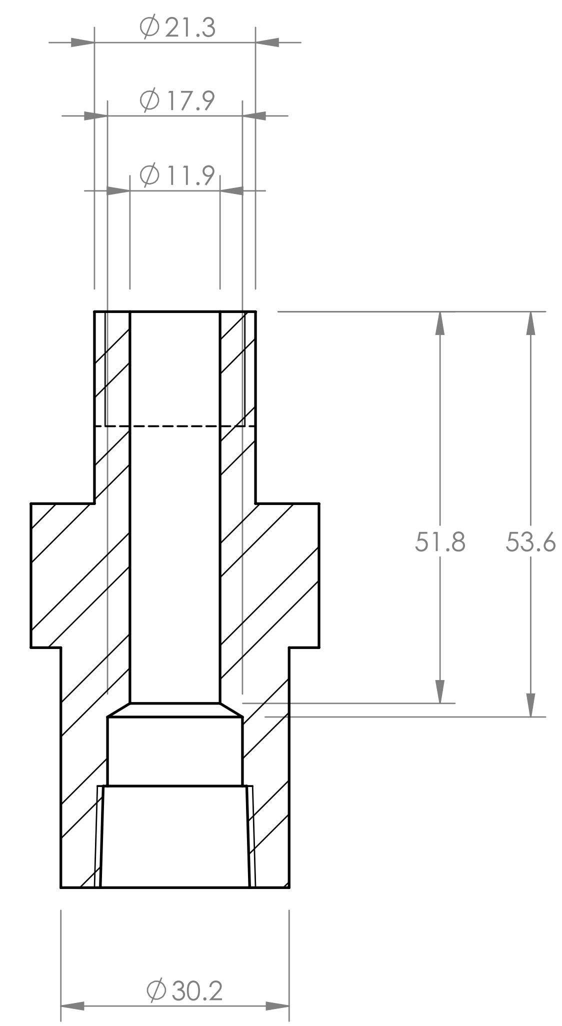
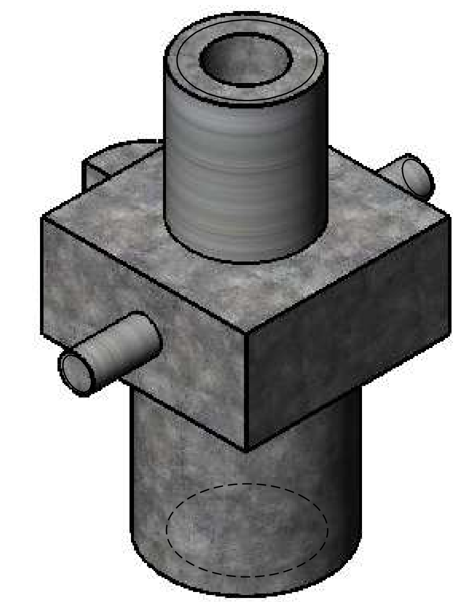
MATERIAL: Galvanized Carbon Steel FILE NAME: Rotation Nozzle		MEC33-W27 Tuesday, April 03, 2012 2:38:07 PM Saturday, February 25, 2012 3:06:18 PM	SIZE B · Assignment Number AGD-001-0004 · REV 1 SCALE: 2:1 · Mass: 18.14 g · SHEET 1 OF 1





SECTION A-A



Mec E 460

Instructor:

Winter 2012

Comments:

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN MM
TOLERANCES:
ANGULAR: ± 0.5°
LINEAR
X = ± 0.5
X.X = ± 0.1
X.XX = ± 0.025

SURFACE FINISH µm 0.6

DO NOT SCALE DRAWING

MATERIAL: Galvanized Carbon Steel

FILE NAME: support1-1

DRAWN BY: Charles Weir

Student #

Lab Day

SM By

TA Initials

MEC33-W27

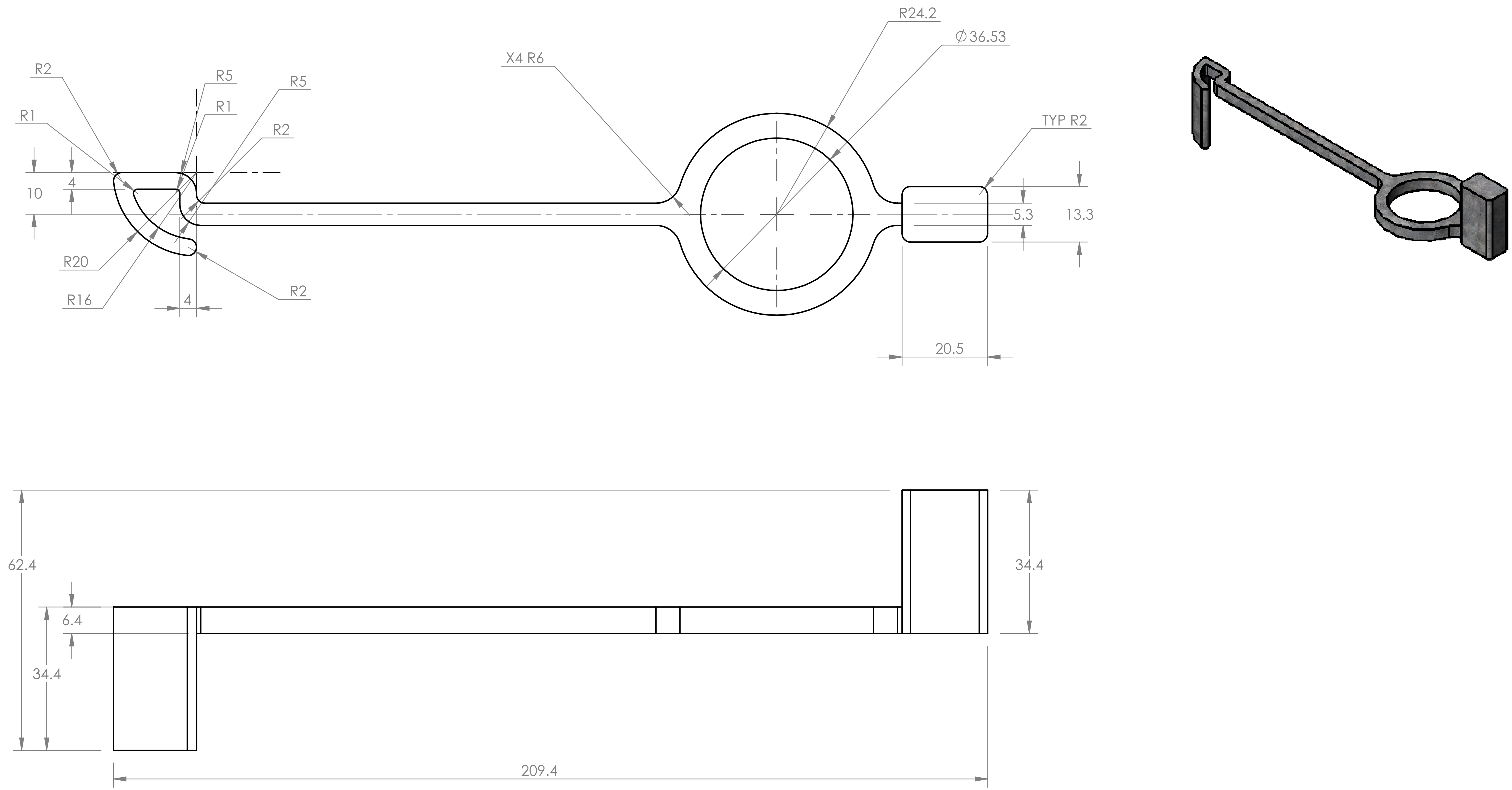
Tuesday, April 03, 2012 2:38:07 PM
Friday, February 24, 2012 7:11:31 PM

AGD

TITLE: Srinkler Arm Support

SIZE	Assignment Number	REV
B	AGD-001-0005	1

SCALE: 1:1 | Mass: 376.48 g | SHEET 1 OF 1



Mec E 460
Instructor:
Winter 2012
Comments:

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MM
TOLERANCES:
ANGULAR: ± 0.5°
LINEAR
X = ± 0.5
X.X = ± 0.1
X.XX = ± 0.025
SURFACE FINISH µm 0.6
DO NOT SCALE DRAWING

MATERIAL:
Galvanized Carbon Steel
FILE NAME:
Impact Rotation Arm

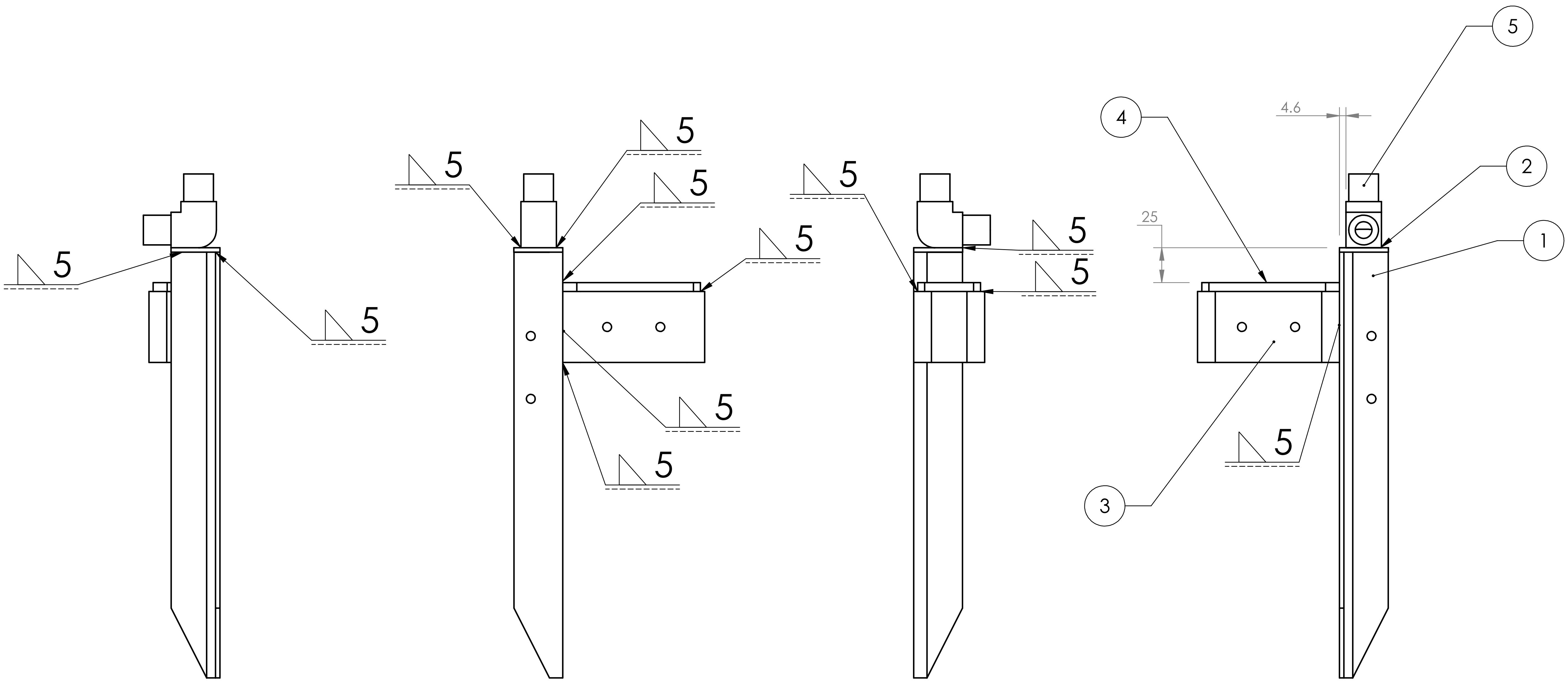
DRAWN BY:
Charles Weir
Student #
Lab Day
SM By
TA Initials
MEC33-W27
Tuesday, April 03, 2012 2:44:03 PM
Monday, April 02, 2012 12:22:56 PM

AGD

TITLE:
Sprinkler Swing Arm

SIZE	Assignment Number	REV
B	AGD-001-0006	2

SCALE: 1:1 | Mass: 179.39 g | SHEET 1 OF 1



Note	Comment
1	See Welding Spec for welding procedure

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Stake	Main Stake Support	1
2	Stake Cap	Stake Cap for Mounting Sprinkler	1
3	Holder	Holder to Mount to Dimentional Lumber	1
4	Holder Cap	Holder Cap	1
5	Swadgelok	1/2" Swadgelok tee for sprinkler mount	1

Mec E 460
Instructor:
Ackerman\Nobes\Stout
Winter 2011
Comments:

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MM
TOLERANCES:
ANGULAR: ± 1°
LINEAR
X = ± 1
X.X = ± 0.1
X.XX = ± 0.025

DO NOT SCALE DRAWING

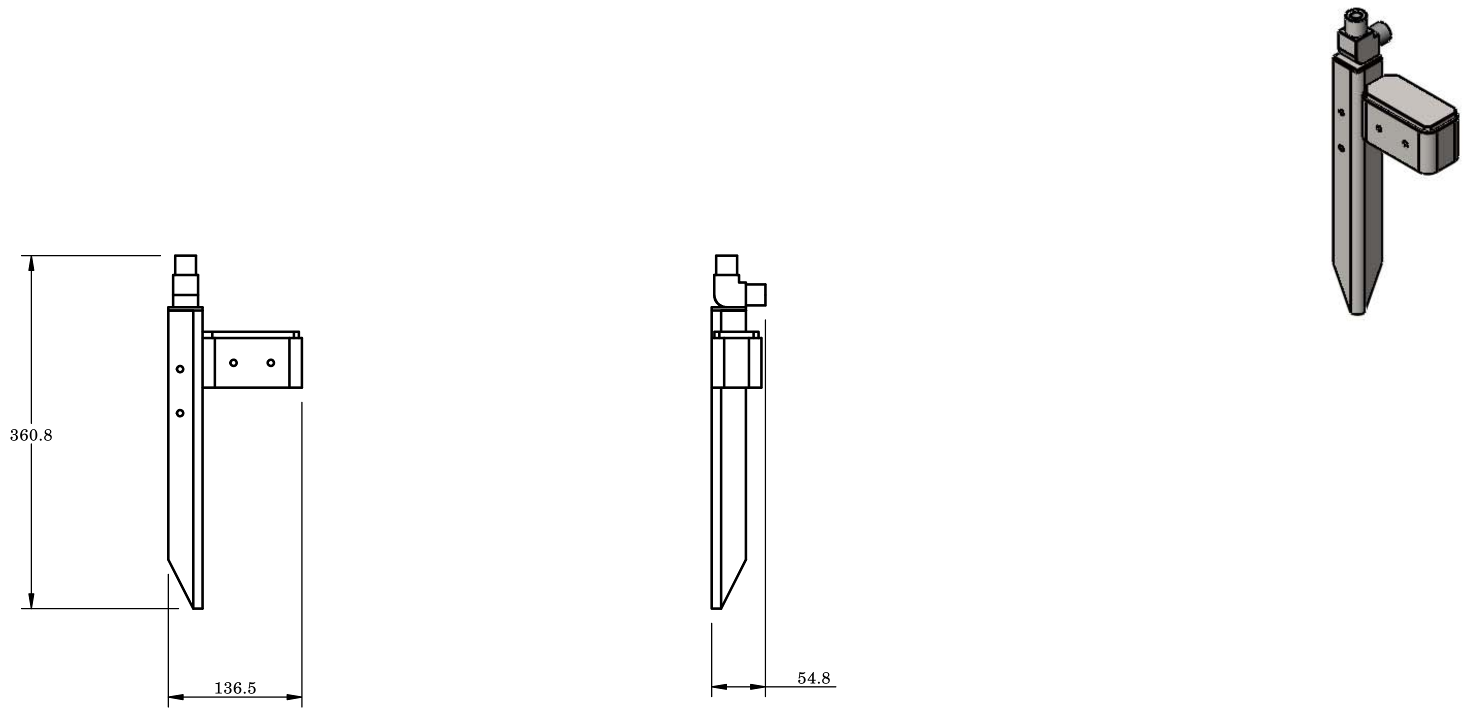
MATERIAL:
Galvanized Carbon Steel
FILE NAME:
Steak assem

DRAWN BY:
Charles Weir
Student #
Lab Day
SM By
TA Initials
MEC33-W27
Tuesday, April 03, 2012 2:38:06 PM
Monday, April 02, 2012 9:56:23 AM

AGD
TITLE:
Stake Weld Assembly

SIZE	Assignment Number	REV
B	AGD-001-0007	1

SCALE: 1:3 | Mass: 1.344 kg | SHEET 1 OF 1



Mec E460

Instructor:

Winter 2012

Comments:

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN MM
TOLERANCES:
ANGULAR: ± 0.5°
LINEAR
X = ± 0.5
XX = ± 0.1
XXX = ± 0.025

SURFACE FINISH µm 0.6

DO NOT SCALE DRAWING

MATERIAL:

FILE NAME: Steakassem

DRAWN BY: Alexander Dufour

Student #

Lab Day

SM By

TA Initials

MEC33-W29

Thursday, April 05, 2012 4:14:58 PM
Monday, April 02, 2012 9:56:23 AM

The Department of Mechanical Engineering
UNIVERSITY OF ALBERTA

TITLE:

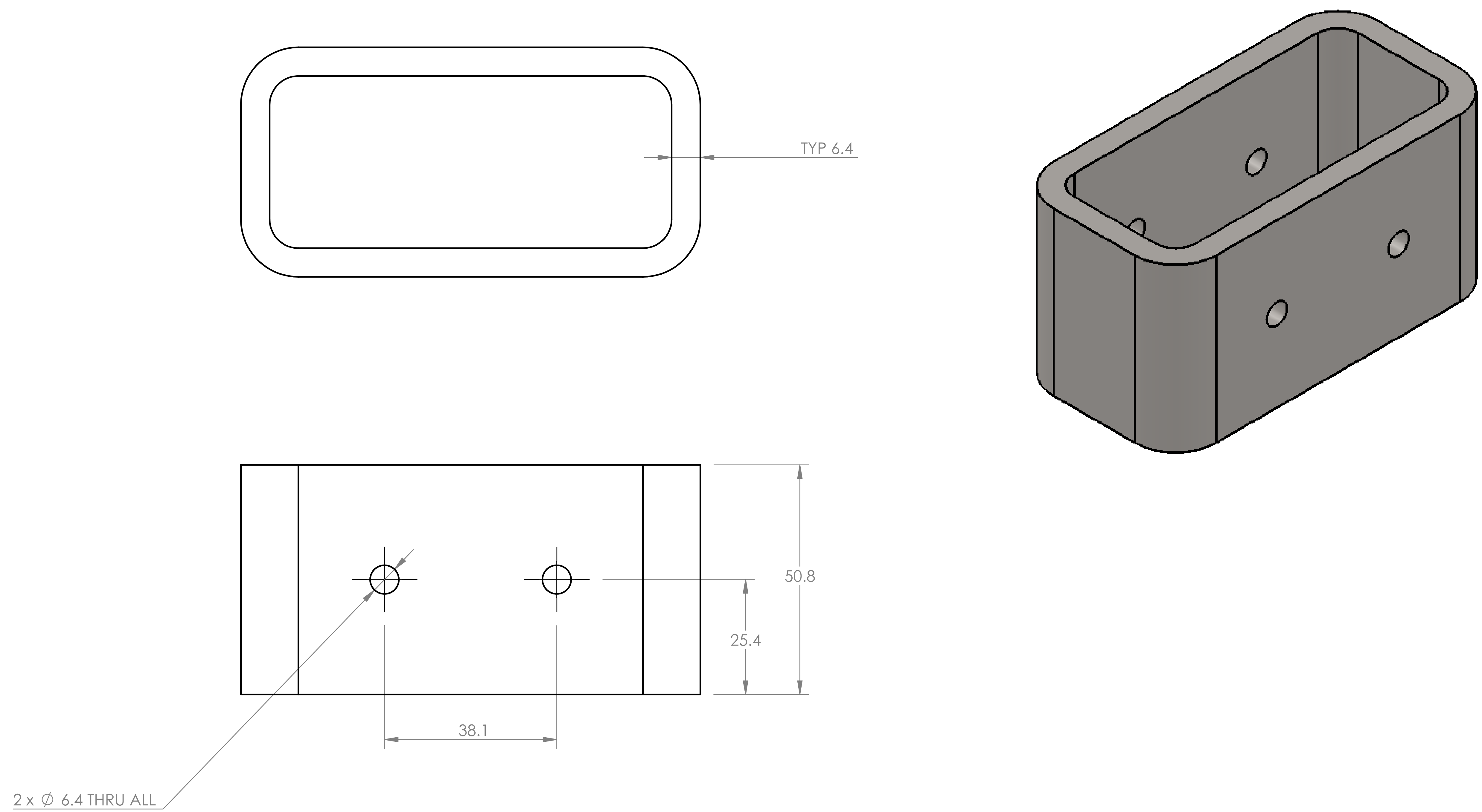
Stake Assembly

SIZE **B**

Assignment Number **AGD - 001- 0013**

REV

SCALE: 1:5 | Mass: 1.58 kg | SHEET 1 OF 1



Mec E 460
Instructor:
Winter 2012
Comments:

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MM
TOLERANCES:
ANGULAR: ± 1°
LINEAR
X = ± 1
X.X = ± 0.1
X.XX = ± 0.025

DO NOT SCALE DRAWING

MATERIAL:
2"X4"X1/4" Carbon Steel Box Tube

FILE NAME:
Holder

DRAWN BY:
Charles Weir

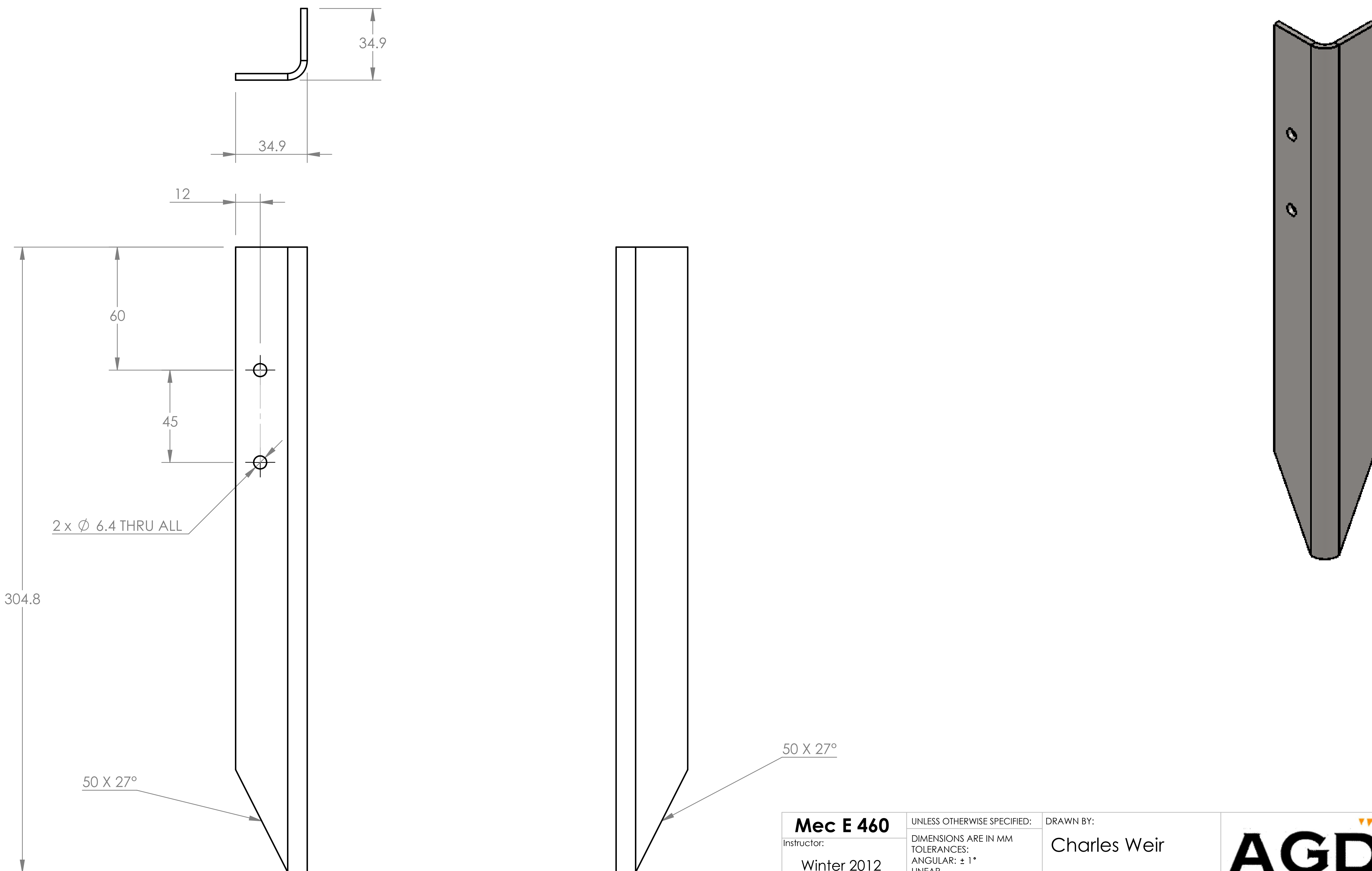
Student #
Lab Day
SM By
TA Initials
MEC33-W27
Monday, April 02, 2012 5:08:54 PM
Tuesday, March 06, 2012 12:34:13 PM

AGD

TITLE:
Holder

SIZE: B
Assignment Number: AGD-001-0008
REV: 1

SCALE: 1:1 | Mass: 655.59 g | SHEET 1 OF 1



Mec E 460
Instructor:
Winter 2012
Comments:

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MM
TOLERANCES:
ANGULAR: ± 1°
LINEAR
X = ± 1
X.X = ± 0.1
X.XX = ± 0.025

DO NOT SCALE DRAWING

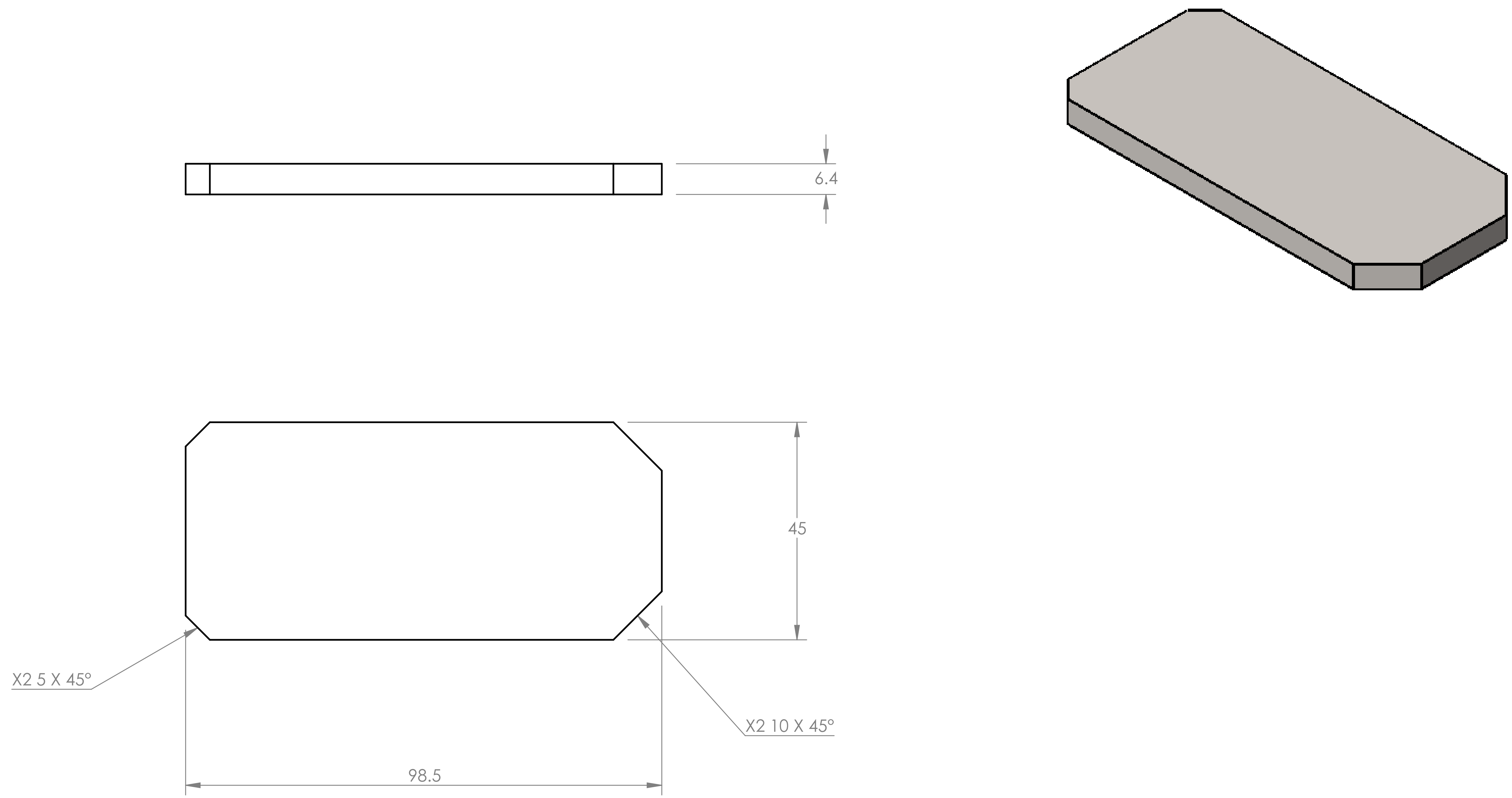
MATERIAL:
1 1/2" X 1 1/2" X 1/8" Angle Iron
FILE NAME:
Stake

DRAWN BY:
Charles Weir
Student #
Lab Day
SM By
TA Initials
MEC33-W27
Monday, April 02, 2012 5:09:10 PM
Tuesday, March 06, 2012 12:15:34 PM

AGD
TITLE:
Stake

SIZE	Assignment Number	REV
B	AGD-001-0009	1

SCALE: 1:2 | Mass: 444.52 g | SHEET 1 OF 1



Mec E 460

Instructor:

Winter 2012

Comments:

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN MM
TOLERANCES:
ANGULAR: ± 1°
LINEAR
X = ± 1
X.X = ± 0.1
X.XX = ± 0.025

DO NOT SCALE DRAWING

MATERIAL:
Cut from 1/4" carbon Steel Plate

FILE NAME:
cap, cap

DRAWN BY:
Charles Weir

Student #

Lab Day

SM By

TA Initials

MEC33-W27

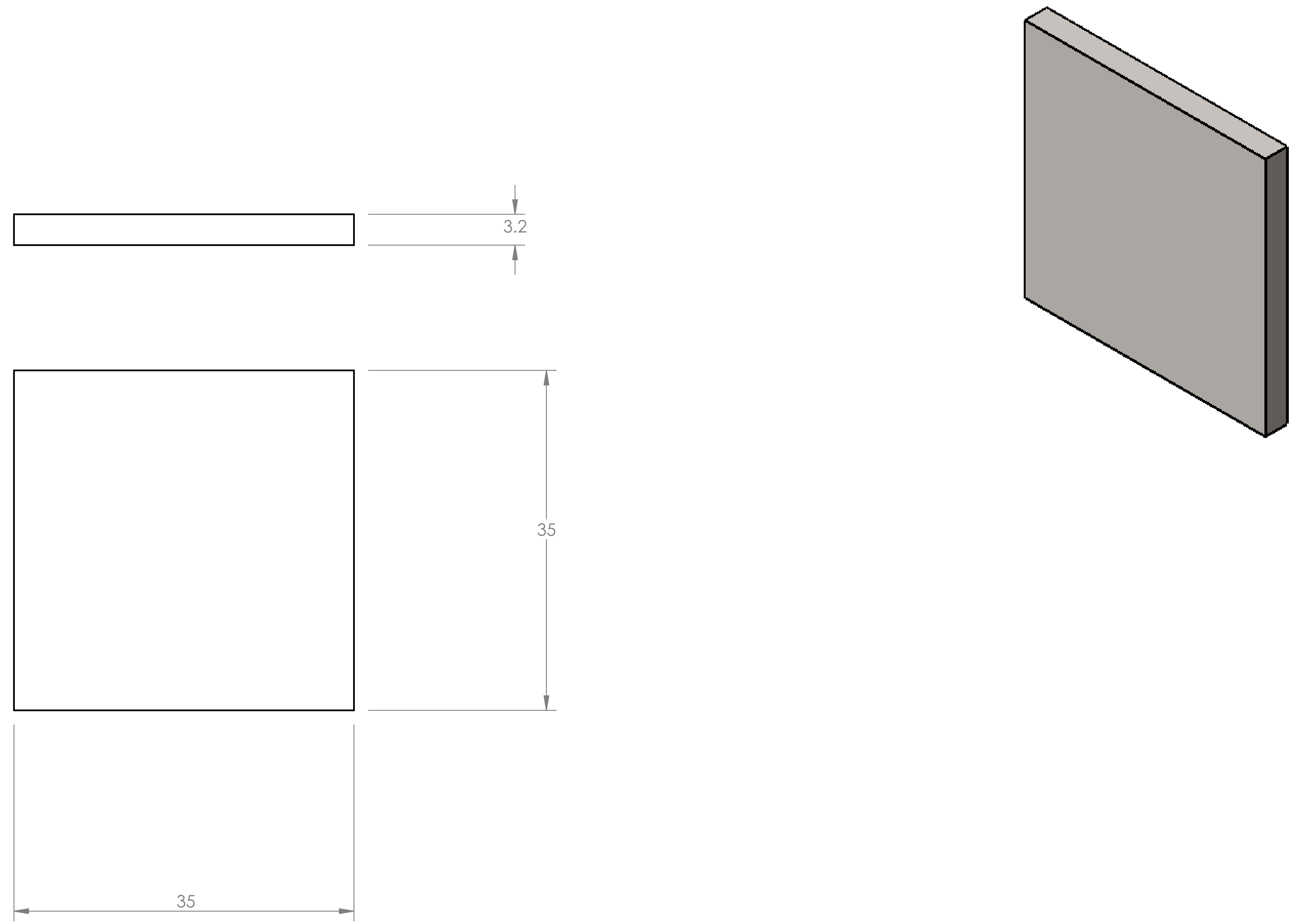
Monday, April 02, 2012 5:08:17 PM
Monday, April 02, 2012 10:05:50 AM

AGD

TITLE: Holder Cap

SIZE	Assignment Number	REV
B	AGD-001-0010	1

SCALE: 1:1 | Mass:213.35 g | SHEET 1 OF 1



Mec E 460

Instructor:

Winter 2012

Comments:

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN MM
TOLERANCES:
ANGULAR: ± 1°
LINEAR
X = ± 1
X.X = ± 0.1
X.XX = ± 0.025

DO NOT SCALE DRAWING

MATERIAL:
Cut From 1/8" Carbon Steel Plate

FILE NAME:
Steak Cap

DRAWN BY:
Charles Weir

Student #	
Lab Day	
SM By	
TA Initials	

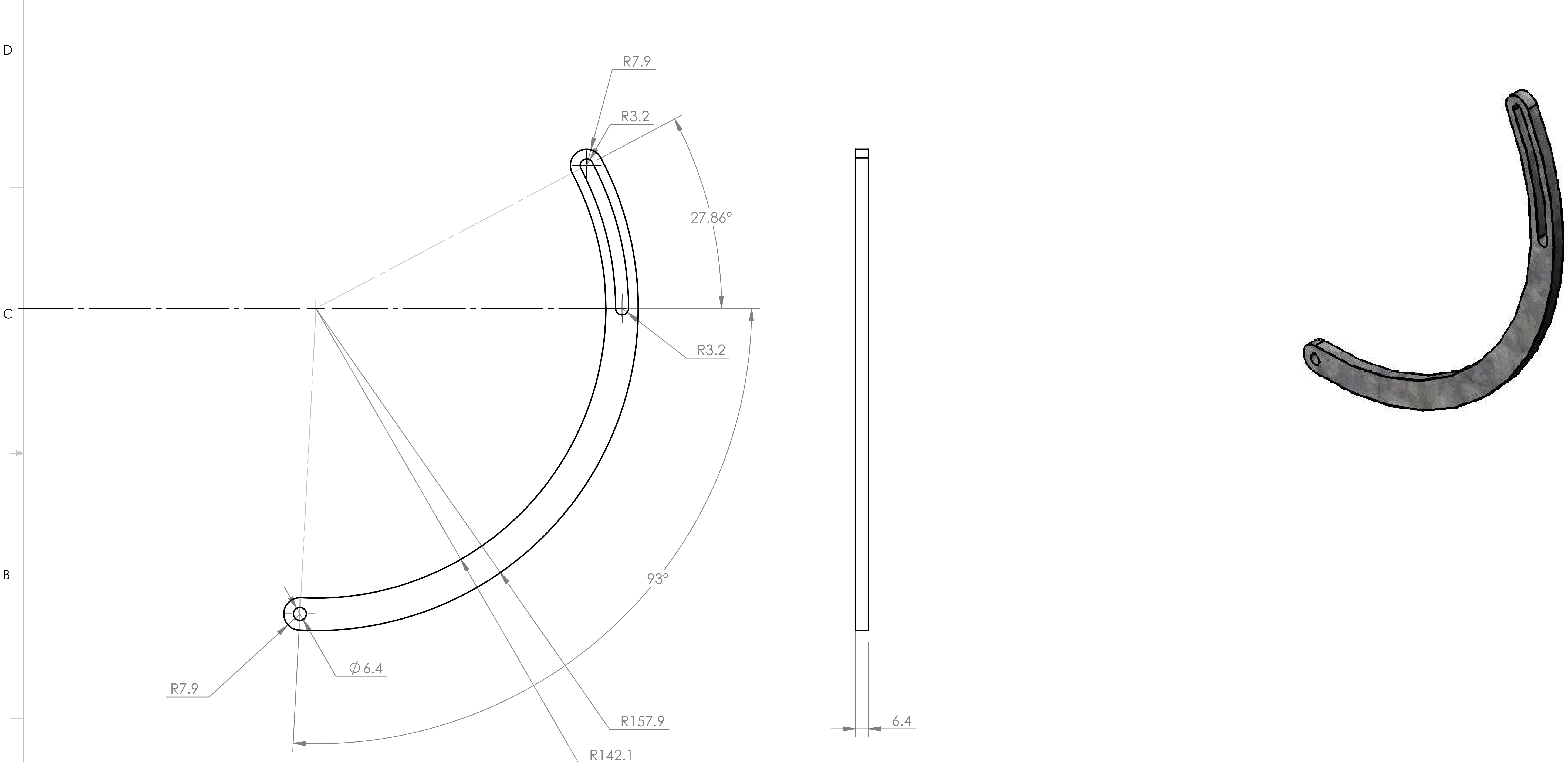
MEC33-W27
Monday, April 02, 2012 5:09:04 PM
Monday, April 02, 2012 9:54:05 AM

AGD

TITLE:
Stake Cap

SIZE	Assignment Number	REV
B	AGD-001-0011	1

SCALE: 2:1 | Mass:30.34 g | SHEET 1 OF 1



Mec E 460

Instructor:

Winter 2012

Comments:

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN MM
TOLERANCES:
ANGULAR: ± 0.5°
LINEAR
X = ± 0.5
X.X = ± 0.1
X.XX = ± 0.025

SURFACE FINISH µm 0.6

DO NOT SCALE DRAWING

MATERIAL:
1/4" Carbon Steel Plate Galvinized

FILE NAME:
arm2

DRAWN BY:
Charles Weir

Student #

Lab Day

SM By

TA Initials

MEC33-W27

Tuesday, April 03, 2012 2:38:07 PM
Monday, April 02, 2012 12:39:56 PM

AGD

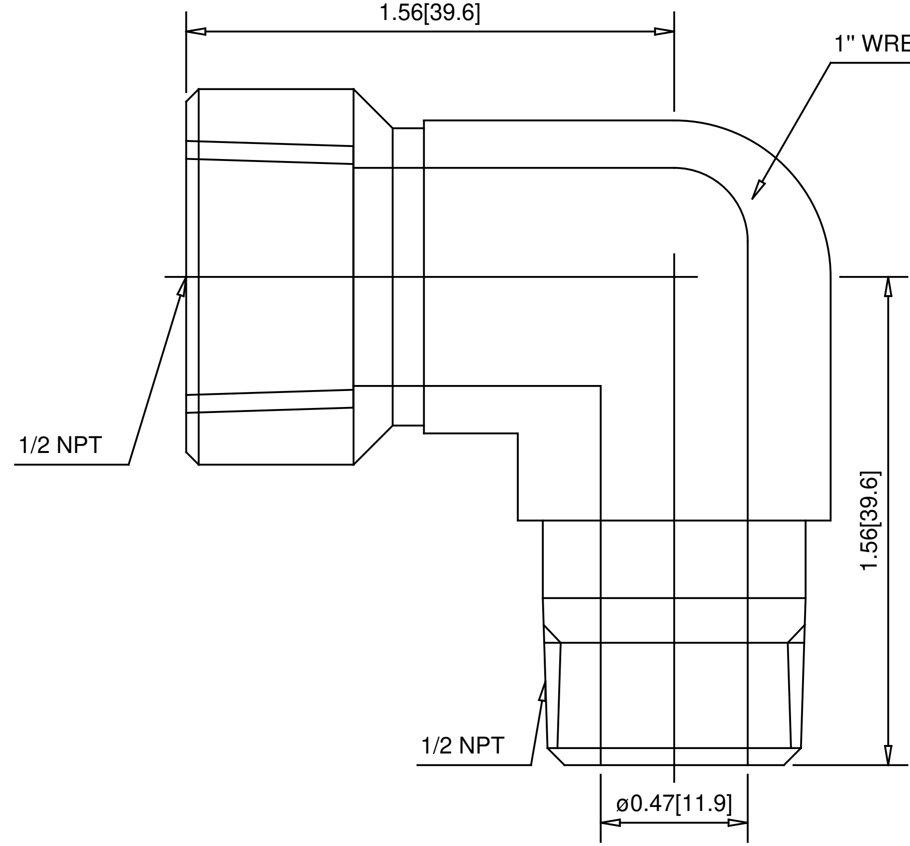
TITLE:
Nozzle Support Arm

SIZE	Assignment Number	REV
B	AGD-001-0012	1

SCALE: 1:2 | Mass: 234.62 g | SHEET 1 OF 1

Appendix F - Vender Drawings and Spec Sheets

PART NO. B-8-SE



CUSTOMER DRAWING

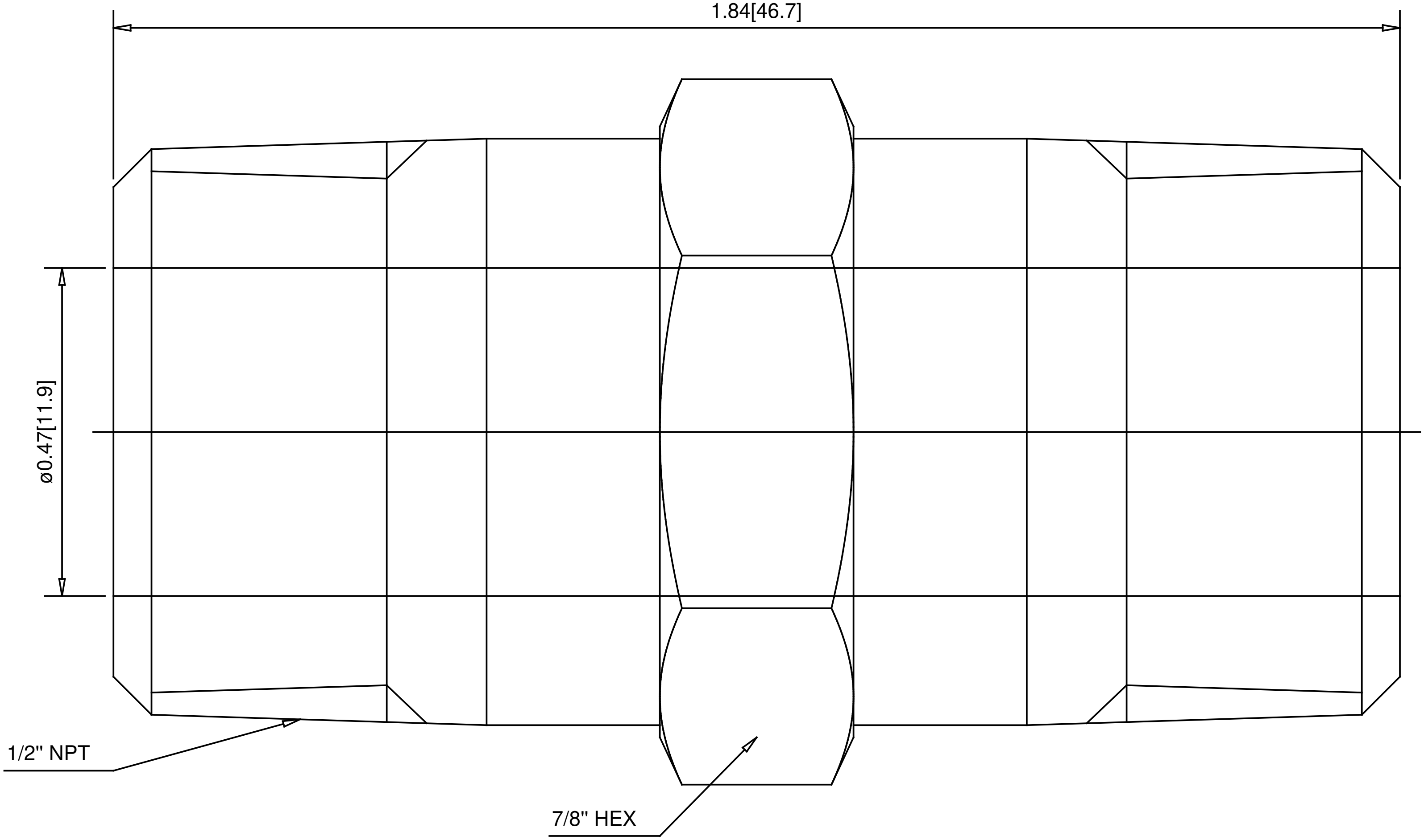
- DRAWING NOT TO SCALE
- DIMENSION ARE INCHES NEXT TO [MILIMETRES]
- DRAWING IS SUBJECT TO CHANGE WITHOUT NOTICE.
- ALL ASSEMBLED NUTS AND FERRULES ARE SHOWN AT FINGER TIGHT DIMENSIONS.
- ALL HEX CALL-OUT ARE ACROSS FLATS.

TITLE

Female Street Elbow, NPT

PART NO. B-8-SE

PART NO. B-8-HN



CUSTOMER DRAWING

Swagelok

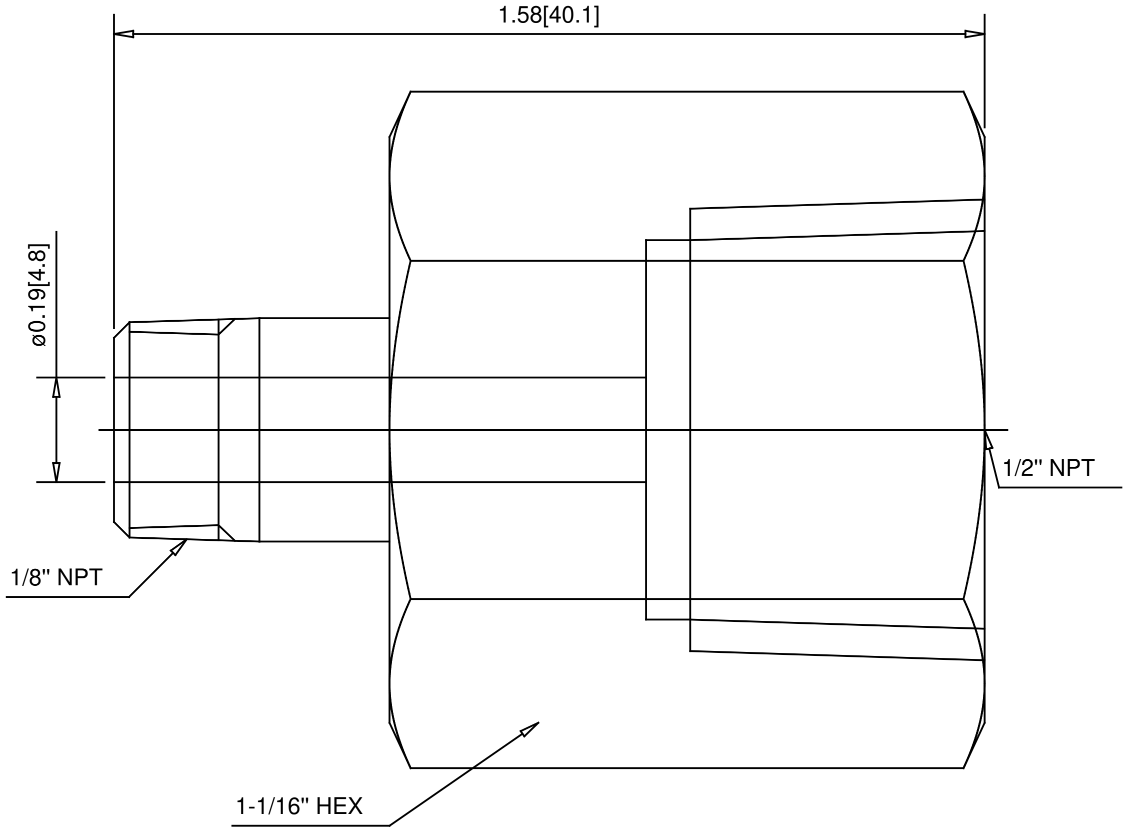
- DRAWING NOT TO SCALE
- DIMENSION ARE INCHES NEXT TO [MILIMETRES]
- DRAWING IS SUBJECT TO CHANGE WITHOUT NOTICE.
- ALL ASSEMBLED NUTS AND FERRULES ARE SHOWN AT FINGER TIGHT DIMENSIONS.
- ALL HEX CALL-OUT ARE ACROSS FLATS.

TITLE

Male Hex Nipple, NPT

PART NO. B-8-HN

PART NO. B-8-RA-2



CUSTOMER DRAWING

Swagelok

- DRAWING NOT TO SCALE
- DIMENSION ARE INCHES NEXT TO [MILIMETRES]
- DRAWING IS SUBJECT TO CHANGE WITHOUT NOTICE.
- ALL ASSEMBLED NUTS AND FERRULES ARE SHOWN AT FINGER TIGHT DIMENSIONS.
- ALL HEX CALL-OUT ARE ACROSS FLATS.

TITLE

Female to Male Reducing Adapter, NPT

PART NO. B-8-RA-2

ST-340 Swivel Coupings (High flow)

Applications:

1/2" live swivel is perfect for connecting to trigger, booms, etc.

Features:

- Stainless steel and brass versions
- Double PTFE slide rings for easy movement

Order	Inlet	Outlet	Flow Rate	Bearing	Pressure	Temp	Weight
200340515	1/2" MNPT	1/2" FNPT	42 GPM	PTFE	3625 PSI	195 F	.25 lb
200340025	1/2" MNPT	1/2" FNPT	42 GPM	PTFE	3625 PSI	195 F	.25 lb

References

Main Report
[1] http://www.gov.ns.ca/natr/forestprotection/wildfire/bffsc/lessons/lesson4/backtank.asp
[2] http://en.wikipedia.org/wiki/Firefighting
[3] http://wikitravel.org/upload/shared/1/17/Platbos_Reserve_Aerial_Tsitsikamma_Backdrop.jpg
[4] Kincaid, D.C, "Impact Sprinkler Pattern Modification", ASAE, 1991
[5] Rao, L. et al., "Experimental Study of the Division of Flow in an Open Channel", Conference on Hydraulics and Fluid Mechanics, 1968
[6] Hayes, R. et al., "Steady Laminar Flow in a 90 Planar Branch", Computers & Fluids, 1989
[7] Goudarzizadeh, R. et al., "Three Dimensional Simulation of the Flow Pattern at the Lateral Intake in Straight Path, using Finite-Volume Method", World Academy of Science, Engineering, and Technology, 2010

Appendices
[1] Walker, James. *Physics Third Edition.*
[2] Cengel, Yunus. Cimbala, John. *Fluid Mechanics, Fundamentals and Applications, Second Edition.*