MECH 4860 –Engineering Design

Final Design Report

Modular Mounting Rack for Ladders and Water Tanks

Fort Garry Fire Trucks

Team 7

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December 7, 2015

-MECH4860 PROJECT FINAL REPORT SUBMISSION-

Dear Dr. Labossiere:

We are pleased to submit Team 7 Final Design Report: *Modular Mounting Rack for Ladders and Water Tank submitted to Fort Garry Fire Trucks*

This report presents the design process for developing a modular actuating mounting rack to transport ladders and water tanks for field use submitted to Fort Garry Fire Trucks. The report discusses the customer's needs, target specifications, constraints and limitations for the project. The recommended design will be clearly discussed in detail throughout the report. Additionally manufacturing drawings and Finite Element Analysis for the recommended design are all included as per client specification.

We thank you for your time.

Sincerely,

Adam Hebert, Zachary Clapa, Chantol Thompson and Yiqing Xu.

EXECUTIVE SUMMARY

PYRA was tasked by Fort Garry Fire Truck (FGFT), to create a modular support for the FGFT fire truck ladders and water tanks. Currently FGFT is using two separate systems, one that can be mounted in the middle of the firetruck; the other system mounts to the sides of the firetruck. None of the implemented systems are able to store simultaneously a portable water tank and ladders and actuate the equipment from an upright positon to a position where they are accessible by fireperson. The purpose of this project was to develop a rack which can support a top and side load of 500 *Lbs* for a total of 1000 *Lbs*. The rack was to be compatible with multiple FGFT firetrucks. The system was to lower ladders and portable water tanks to an accessible height by either electrical or hydraulic actuation and cost no more than $6500 US. The final design was to include computer aided design models of the design, finite element analysis of the design, manufacture drawings and bill of materials.

After consultation with FGFT, PYRA was able to develop a list of needs and related technical specifications for the final design. Subsequent to better evaluate technical specifications; the design was broken down into 6 separate components. After intensive concept screening of each component, a complete concept could be developed for the final design. Computer aided design models were generated for the concept then finite element analysis was done on each component of the complete design to ensure the component could support the required load. The design was then refined to ensure all components could be manufactured with standard aluminum profiles, sheet metal and standard steel profiles.

All components maintain a factor of safety of 2 when the required load is applied. The rack can be configured with the mounting in the middle of the fire truck or on the sides of the firetruck while simultaneously supporting a ladder rack and water tank rack. The design also moves the water tank rack and ladder from a raised position to a level that can be accessible by a fireperson within 40 seconds by implementing a La36 Linak electric actuator. Finally the total cost of the design is $4130.87.70US. This design meets the critical technical specifications, therefore PYRA is confident this design will meet client expectations and is functional within the design application.

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GLOSSARY OF TERMS

CAD – Computer-aided design

FEA – Finite Element Analysis

FGFT – Fort Garry Fire Trucks

MD – Major Deliverable(s)

WBS – Work Breakdown Structure

Zico – Ziamatic Corporation

FOS – Factor of Safety

QFD – Quality Function Deployment

1 INTRODUCTION

Fort Garry Fire Trucks (FGFT) is the largest Canadian manufacturer of fire apparatus, aerial ladders, water tankers and the other fire protection equipment [1]. FGFT customizes their products to meet their national and international clientele's needs. FGFT has requested that PYRA design a replacement for the current ladder access and portable tank system for the entire fleet of FGFT fire trucks.

1.1 Background

FGFT is currently implementing a ladder access and portable tank systems supplied by **Ziamatic Corporation (Zico)**. The Zico's rack systems lower the ladders or portable water tanks from the top or side of the firetruck to a convenient height for the equipment to be retrieved [1]. The existing systems can only be mounted from one place on the fire truck, either in the middle of the body of firetruck as seen in Figure I or at the sides of the body of firetruck. In addition, the current systems cannot store simultaneously a portable water tank and ladders.

Figure I: Current version of Zico ladder rack [1].

1.2 Project Objective

The main goal of this project is to design a modular actuating rack system to support a top load and a side load of 500 *Lbs* respectively for a total of 1000 *Lbs.* The design must be implementable with multiple FGFT's firetruck. The actuating system must be driven electrically or hydraulically depending upon the final details of the design. The design must not interfere or impede with any of the fire trucks current functions. The design should allow for safe and rapid equipment removal when the rack is in the horizontal position. The design should be optimized for cost and must be cheaper than the current system. The final design must include **Computer-aided design (CAD), Finite Element Analysis (FEA)** of the design, manufacturing drawings and bill of materials. The proposed design must be delivered to FGFT by December 7th, 2015.

1.3 Target Specifications

First client's needs were defined, then the metrics needed to evaluate these client needs were determined, finally PYRA was able to create a list of target specifications. These target specifications related the evaluations metrics to needs of the client. Ensuring all of FGFT objectives for this project were being considered during the entire design process.

1.3.1 Customer Needs

After consulting with FGFT, PYRA developed a list of needs that the design must have satisfied to meet the customer's objectives for this project. Table I lists the needs along with the importance rating.

TABLE I: CLIENT NEEDS WITH IMPORTANCE RATING.

Need #	Need	Descriptions	Importance
N1	Modular ladder rack	Design must be modular	4
N2	Support ladder and water tanks	Design must support ladder and water tanks	5
N3	Actuating	Design must have the capability to actuate	5
N4	Less expensive than current system	Design must be cheaper than current system	4
N5	Easy to install	Design must be easy for installation	3
N6	Versatile for FGFT applications	Design must be used for different types of fire trucks	2
N7	Safety	Design must meet the safety requirement	4
N8	Intuitive controls	Design must have intuitive controls	2
N9	Ladders and water tanks easily accessible	Design must have easily accessibility for ladder and water tanks	3
N10	Ladder and Tanks quick removable from transport position	Design must have capability for quickly removable for ladder and tanks from transport position	3
N11	Aesthetically pleasing	Design must have good appearance	2
N12	Good Manufacturability	Design must have good manufacturability	3
N13	Reliability	Design must have good reliability	3
N14	Minimize system weight	Design must have minimum weight for the system	3

The importance rating illustrates how essential each need is to the client. A rating of 5 is the highest possible score, while a rating of 1 demonstrates a need of the lowest priority. Client needs with an importance rating of 5 are needs that absolutely must be met in order for the design to be functional. Needs with an importance rating of 3 or less are still important, however the client and PYRA have decided that these needs are less important and could be potentially sacrificed if that sacrifice would allow more important needs to be met.

After discussions with the client, we knew that that our design had to be modular. The client placed a copious amount of emphasize on the modularity of the entire system. The client desired the design to be modular in order for the ladder and water tank rack to be versatile across multiple truck platforms. As a result, both N2 and N3 have an importance value of 5. An importance value of 4 was placed on N1, N2 and N3. N4 also has an importance of 4 since the client emphasized the importance of the design being cheaper than the current Zico systems installed on FGFT firetrucks. It was reasonable to assume the project would not be implemented if the design were more expensive than the Zico system. Therefore, N4 has an importance of 4. The safety of the system is also extremely important, so PYRA assigned an importance of 4 to N5. All other needs were assigned an importance value of 3 or lower.

1.3.2 Metrics

Once we established our client's needs, team PYRA created a list of metrics to determine how each need would be evaluated. These metrics are also ranked on a scoring system that 5 is the highest importance and 1 is the lowest. TABLE II displays unit for each metric as well as a marginal and ideal value for the metric.

TABLE II: LIST OF METRICS WITH MARGINAL AND IDEAL VALUES.

Metric #	Metric	Importance	Units	Marginal Value	Ideal Value
M1	Number of major components	4	List	<6	<3
M2	Load capacity	5	*Lbs.*	>1000	>2000
M3	Actuating	3	YES/NO	YES	YES
M4	System cost	4	US Dollars	<6000	<5000
M5	Install time	3	*mins*	20	15
M6	Number of compatible trucks	2	List	MO703	ENTIRE FLEET
M7	Payload height from ground	3	*Ft*	>3 , <6	>4,<5
M8	Ease of operation	3	YES/NO	YES	YES
M9	Maximum dynamic load	5	*Lbs.*	>1000	>2000
M10	Appearance	1	Subjective		
M11	Speed of actuation	3	*s*	<20	<15
M12	Manufacturability	3	YES/NO	YES	YES
M13	Life cycles	3	# of Cycles	>6000	>7000
M14	Weight	3	*Lbs.*	<300	<250

The metrics shown in TABLE II were determined by the team to be the parameters for the technical specifications. M1 describes the number of parts the design will contain in terms of actuating arms and rack pieces. M3, M8 and M12 are yes or no metrics that only have two possible values. M6 is a list metric that will be evaluated by a list of all the possible truck models that the ladder rack can be fitted to. M10 is a subjective metric with no attached value. Finally, all other metrics are expressed with a mathematical unit that best describes the assigned client need.

Once the needs and metrics were established independently. A relationship between customer needs and metrics was determined. The relationship between each metric and need is listed in *TABLE III*.

TABLE III: LIST FOR NEEDS AND METRICS.

Metrics / Needs	Number of major components	Load capacity	Actuating	System Cost	Install time	Number of compatible trucks	Payload height from ground	Ease of operation	Maximum dynamic load	Appearance	Speed of actuation	Manufacturability	Life cycles	Weight
Modular Ladder Rack	•													
Support Ladder and Water Tanks		•												
Actuating			•											
Less expensive than current system				•										
Easy to install					•									
Versatile for FGFT						•								
Safety								•	•					
Intuitive controls								•						
Ladders and water tanks easily accessible							•							
Ladder and tanks quickly removable from transport position											•			
Aesthetically pleasing										•				
Good manufacturability												•		
Reliability													•	
Minimize system weight														•

1.3.3 Preliminary Target Specifications

After the needs and metrics were analysed, the preliminary technical specifications were defined by the team based on personal team decisions in tandem with client input. TABLE IV lists the previously discussed metrics with the appropriate target specifications.

TABLE IV: METRICS AND TECHNICAL SPECIFICATIONS.

Metric #	Metric	Units	Technical Specification
M1	Number of Major Components	List	4
M2	Load Capacity	*Lbs.*	2000
M3	Actuating	YES/NO	YES
M4	System Cost	US Dollars	5000
M5	Install Time	*mins*	15
M6	Number of Compatible Trucks	List	ENTIRE FLEET
M7	Payload Height From Ground	*Ft*	4
M8	Ease of Operation	YES/NO	YES
M9	Maximum Dynamic Load	*Lbs.*	2000
M10	Atheistically Pleasing	List	
M11	Speed of Actuation	*s*	15
M12	Manufacturability	YES/NO	YES
M13	Life Cycles	Cycles	6000
M14	Weight	*Lbs.*	250

By establishing customer needs, then determining the technical specifications and target specifications to evaluate the client's needs, PYRA had a method to assess the degree the final design satisfied the project objectives.

1.3.4 Constraints and Limitations

The following were the known factors restricting possible solutions for the FGFT ladder access and portable tank systems: time, environment, equipment, cost and users.

1) **Time**

a. Deadline for final design selection, optimization and publish report of final design is December 7, 2015.

b. Oral presentation for final design is December 8, 2015.

2) Environment

a. Full design functionality in temperature ranges from -50 degrees to 40 degrees Celsius.

b. Full design functionality in all weather conditions including rain, sleet, snow and hail.

c. Full design functionality in all moisture levels (0 – 100%).

d. Full design functionality after repeated exposure to harsh or corrosive environments.

3) Equipment

a. Industry standard ladder – 170” x 22” x 9”

b. Standard expandable tanks – 125” x 29” x 7” (collapsed dimensions)

c. Limited number of structural mounting locations on fire trucks

d. The design will mount to all truck in Fort Gary Fire Trucks line-up.

e. Design packaged in currently available space between storage locations

f. In fully upright position, design recessed in fire truck footprint

4) Cost

a. Total cost of design, including manufacturing must not exceed $6,000.00 US.

5) Users

a. 5th percentile females to 95th percentile males (heights between 4’11” – 6’3”)

b. Users are of minimum require fitness level for Canadian fire fighters

6) Performance

a. Perform equally to current rack design.

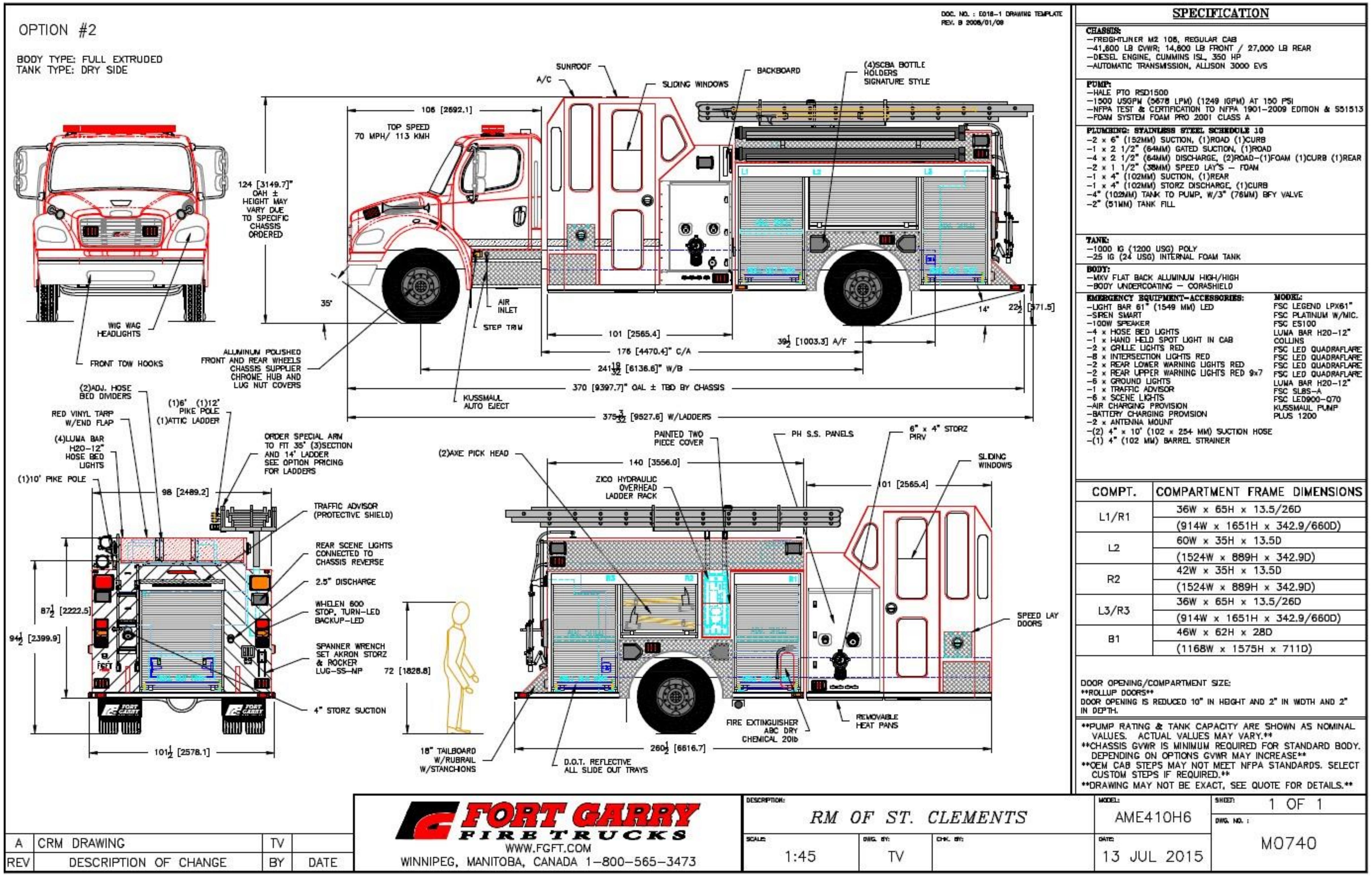


Figure 2: Technical drawing of current FGFT truck schematic. [2]

2 DETAILS OF DESIGN

The final design PYRA is purposing to FGFT, is an actuating ladder and tank rack that satisfies the client's needs discussed in section 1.3.1 of this report. The final design features six distinct sub-sections that each satisfies a need within the system, allowing for the entire design to achieve all of client's objectives for this project.

First the overall function of the design and the actual specification of the design will be discussed. Subsequently the six specific sections resulting from the concept generation portion of this project (*concept generation can be seen in Appendix A*) will be expanded on. The sections of the final design are: electric linear cylinder, main boom, actuating arms, horizontal ladder rack, vertical tank rack and lastly mounting. Each detailed explanation will illustrate how the individual component contributed to the overall final design, by describing how the component functions to meet the client's need and achieve target specifications.

2.1 Complete Final Design

The final rack design show in Figure 3 incorporates all the aspects necessary to adequately meet all the needs that are iterated in section 1.3.1 of this report. The ladder rack is position on the top of the fire truck in the upright position, while the water tank rack is positon adjacent to the firetruck. The actuating arms of the rack can be mounted either to the right and left side of the body of the fire truck as seen in Figure 3 or in the middle of the body of the fire truck.

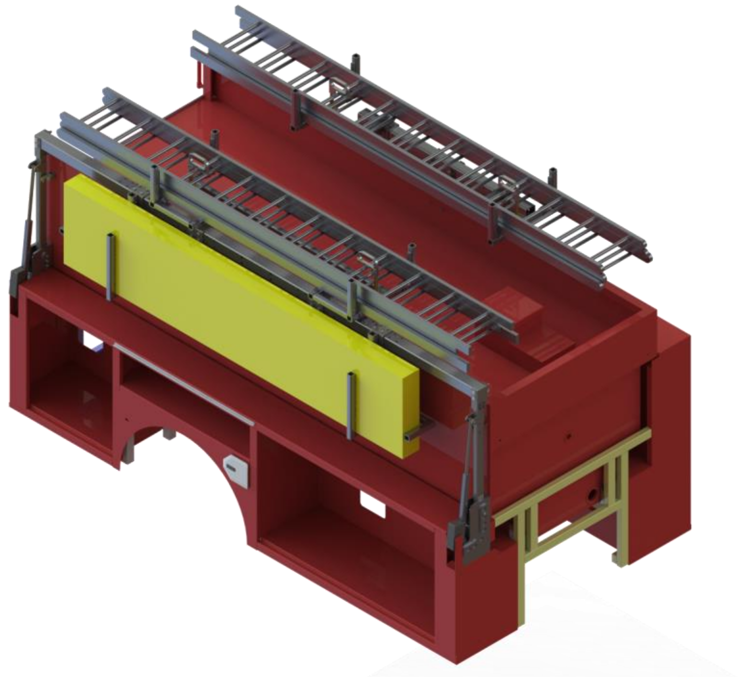


Figure 3: Render of complete assembly final design rack.

Each arm is attached to its own electronic cylinder and main mount. As shown in Figure 3, the actuating arm, electronic actuator and main mount are assembled to be one piece. This arrangement allows the entire system to be position to the desire configuration of FGFT. The main mount is the component used to fasten the entire design to the body of the firetruck. The ladder rack, water tank rack and arm configuration are all mounted to the main boom located on the top of the fire truck. Each component is mounted to the main boom with a unique mount manufactured from sheet metal. The actuation of entire system is done within 40 secs by a La36 Linak electric actuator. Once all the components had been chosen PYRA was able to determine a budget for the final design.

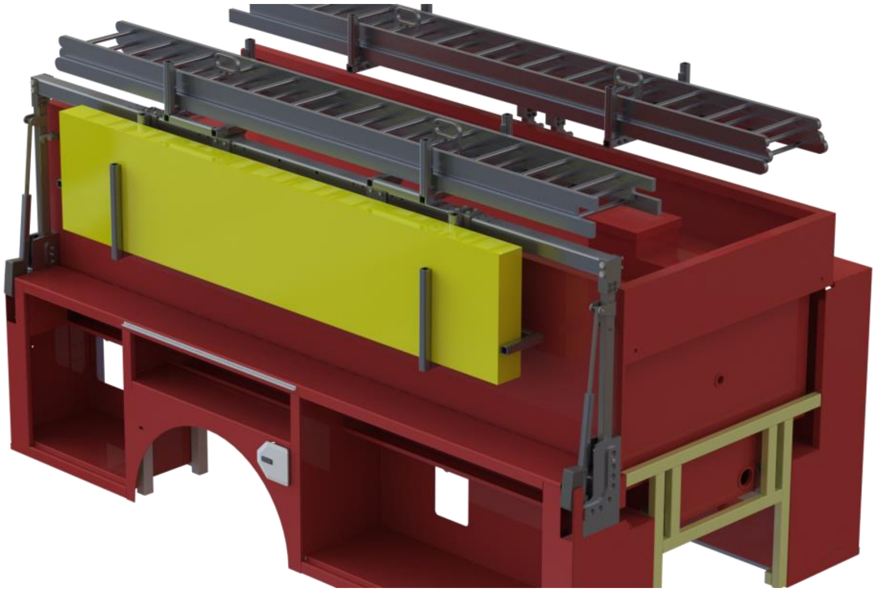


Figure 4: Side Mounted Final Design

Additionally an alternate configuration is possible with both mounts mounting to the middle of the main boom and only supporting the ladder rack. This configuration was requested by the client when only the ladder rack is necessary and must be mounting to the center of the fire truck body. All the components that make up the alternate configuration are the transferable from the original configuration thus making the design extremely modular and versatile. The configuration can be seen below in Figure 5.

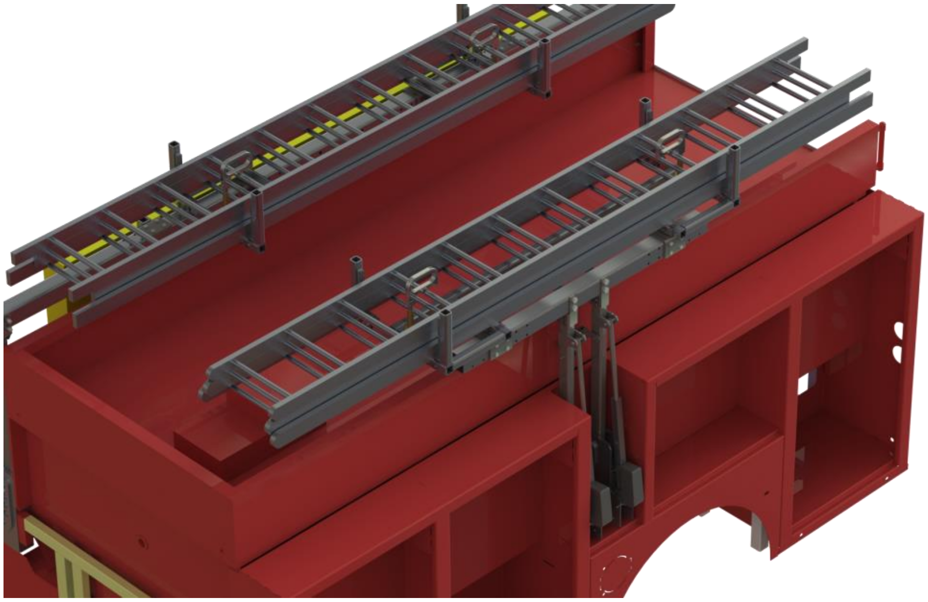


Figure 5: Center mounted alternate configuration

1.1 Cost

The total cost summary for the complete design is broken down in TABLE V.

TABLE V: TOTAL DESIGN COST

Item	Total (CAD)
Ladder Rack	$424.38
Water Tank Rack	$468.18
Actuator	$4000.00
Actuating Arm	$185.73
Main Boom	$374.36
Mounting	$620.69
Hardware	$457.90
Total	$6531.24

2.1.1 Metric values

When the fully assembled design was complete, comparison could be made between the actual value of the metrics for the design and the target metric established at the beginning of the project. The comparison between each metric for the design can be seen in TABLE VI.

TABLE VI: COMPARISON BETWEEN TARGET METRICS AND ACTUAL METRICS.

Metric #	Metric	Importance	Units	Marginal Value	Ideal Value	Actual Value
M1	Number of major components	4	List	<6	<3	6
M2	Load capacity	5	*Lbs.*	>1000	>2000	1500
M3	Actuating	3	YES/NO	YES	YES	YES
M4	System cost	4	US Dollars	<6000	<5000	$3943
M5	Install time	3	*mins*	20	15	1hr
M6	Number of compatible trucks	2	List	MO703	ENTIRE FLEET	N/A
M7	Payload height from ground	3	*Ft*	>3 , <6	>4,<5	6
M8	Ease of operation	3	YES/NO	YES	YES	YES
M9	Maximum dynamic load	5	*Lbs.*	>1000	>2000	1500
M10	Appearance	1	Subjective			Approved
M11	Speed of actuation	*3*	*s*	<20	<15	20s
M12	Manufacturability	3	YES/NO	YES	YES	YES
M13	Life cycles	3	# of Cycles	>6000	>7000	6500
M14	Weight	*3*	*Lbs.*	<300	<250	516 *Lbs.*

TABLE VI proves the feasibility of the design. All metric with an importance rating of 4 or 5 have an actual metric value within the marginal amount. Due to the in-house manufacturability of the design the total cost is even less than the target metric. With the actual value better or within the marginal value for the most important metrics, PYRA is confident the design will be functional within the design application and meet the client's needs.

Metrics not within marginal values are weight and install time. Considering these metrics have an importance rating of three and metric with the highest importance rating was meet. Sacrificing these metrics to meet other specifications was the best decision to develop a design that best meets FGFT needs.

Moving forward, the previously mentions section of the design will be individually described to allow for a clear and in depth understanding of the individual components and contribution to the complete design.

2.2 Horizontal Ladder Rack

The horizontal ladder rack is used to store the ladders or other equipment above the truck. The ladder rack moves from the top of the fire truck to an accessible height for instant access of the equipment. The final design for the horizontal ladder rack is shown in Figure 6.

Figure 6: Render of horizontal ladder rack with mounts for final design isometric view.

2.2.1 Specifications

The horizontal ladder rack can hold a maximum of three 170 *in* x 22 *in* x 9 *in* aluminum ladders above the truck as per client's specification. The rack consists of three parts, the base, the vertical post and the spring loaded handle mounts.

The base of the ladder rack was fabricated using six individual 2 *in* x2 *in* aluminum tubes welded together. The configuration of these tubes is the structural components of the ladder rack.

The aluminum ladders are retained in transit by two vertical posts and a ZICO spring loaded handle. The aluminum tubing is configured to be the vertical posts. These posts provide horizontal retention to the ladders throughout the truck operation and rack actuation. The vertical posts seen in Figure 6 are adjustable for various sizes of ladders with multiple fastening holes designed to be bolted to the ladder rack's base. The ZICO spring loaded handles provides a mechanical locking mechanism that vertically retains the ladders when the firetruck is in transit and during actuation of the rack. The ZICO handle is a component that is currently purchased by FGFT thus the supply line is already present.

The ladder rack satisfies the client's needs and technical metrics in several ways. First, the ladder can support the 500 *Lbs* while maintaining a factor of safety of 2. FEA optimization was used to determine the design for the ladder rack that would adequate support the required weight (*FEA specifications can be found in Appendix D).* Secondly the FEA optimization allowed the ladder rack to be optimized for weight, thus contributing to satisfying the client's need of low weight. Thirdly the ladder rack is modular due to the elementary design and its ability to be customized. Further customization is obtained by the several mounting locations options for the vertical posts and the ladder rack as a whole. The simplicity and flexibly of the design allows for the design to be configured as required from FGFT's clientele. Finally the ladder support is cost-effective. The ladder support is economical because the support is fabricated with standard aluminum profiles and the ladder can be entirely manufactured by FGFT. The internal manufacturability of the ladder support satisfies the client's need for manufacturing in this project. Although more needs are present, the horizontal ladder rack does not address those needs directly, these needs will be discussed in a later section.

2.2.2 Individual Components

The following section outlines the separate components fount in the ladder rack.

2.2.2.1 Zico Handle Mount

ZICO handle mount is used to fix the ZICO spring loaded handle to the ladder rack to provide vertical ladder retention when the rack is actuating. The mount for the Zico handle can be seen in Figure 7 and in the assembly in Figure 8.

Figure 7: Render of Zico handle mount isometric view.

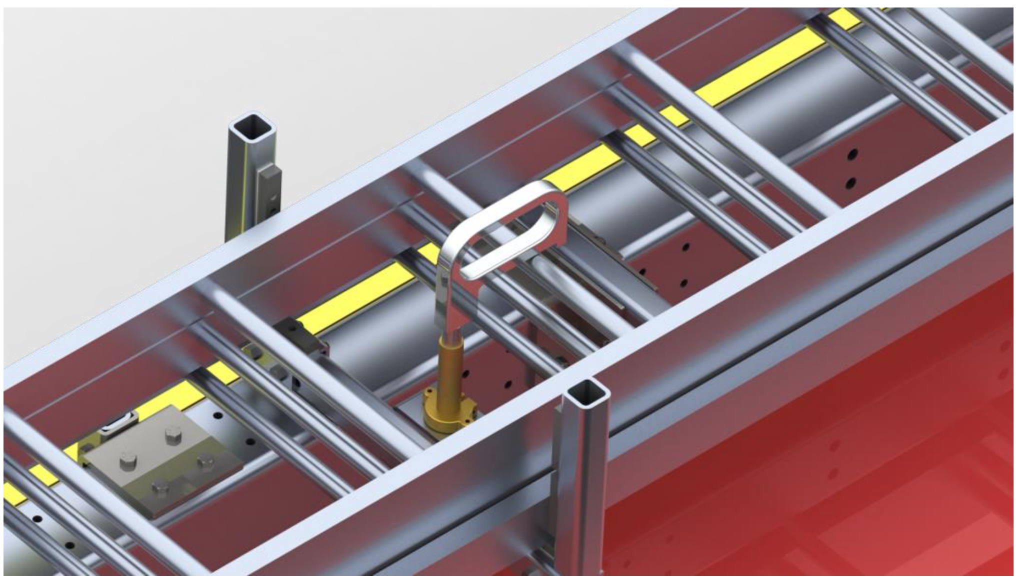


Figure 8: Render of ZIco handle mount in assemble retaining ladders isometric view.

2.2.2.2 Ladder Rack Vertical Post

The ladder rack vertical posts are used to provide the horizontal retention for the ladders. Rubber stoppers are placed on the inside of the posts to secure the ladders and dampen vibration while the truck is traveling. The vertical post is manufactured with standard 2 x 2 x ¼ in aluminum tubing, bended sheet metals and welding. Sheet metal is arranged in the desired configuration and 1 ft. of 2 x 2 x ¼ in aluminum tubing is welded on the top of base for the vertical post. The complete configuration of the vertical post can be seen in Figure 9.

Figure 9: Render of ladder support vertical post isometric view.

2.2.2.3 Base of Ladder Support

The base of the ladder support provides vertical retention of the ladders when the firetruck is in motion and when the entire rack is actuating. The base of ladder support is also the mounting surface for the entire ladder support; this includes the mounting for the vertical post, Zico spring-loaded handles and the mounts for the main boom.

The base is constructed using 6 pieces of 2x2x ¼ *in* aluminum square tubing. These 6 pieces are configured as shown in Figure 10.

Figure 10: Base of ladder support isometric view.

Once the required configuration is achieved the piece are welded together. Then the mounts for the ladder support can be bolted into the base. FGFT requires the overall design and its components to be modular. As previously mentioned the mounting location on the base of the ladder support allows the ladder support to be compatible with multiple models of FGFT firetrucks and cater to FGFT client's specific needs. Figure 11 shows the multiple mounting locations available for the various components of the ladder support.

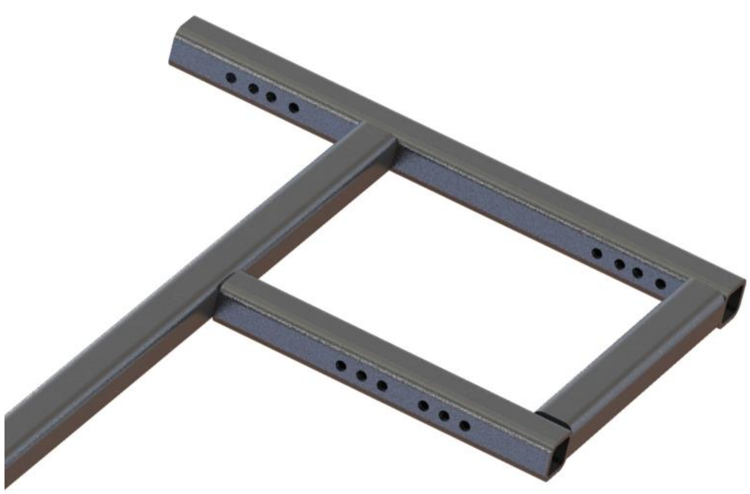


Figure 11: Zoom in view of ladder support based highlighting the mounting locations isometric view.

2.2.3 Cost

With the manufacturing process for each part and subassembly determined, the cost for the entire horizontal ladder support could be calculated. The cost break down can be found in Appendix D.

2.3 Water Tank Rack

The water tank rack is used to store a collapsed Husky portable water tank or other equipment adjacent to the truck in a safe storage position. After actuation the water tank rack is at an accessible height for removal of equipment. The final design of the water tank rack can be view in Figure 12.

Figure 12: Render of water tank rack for final design isometric view.

2.3.1 Specifications

The water tank rack can hold the Husky portable water tank with collapse dimensions of 125 *in* x 29 *in* x 7 *in* as per client specification. The main rack consists of 9 pieces of 2 *in* x2 *in* x1/4 *in* standard aluminum square tubing configured into a J shaped profile and 4 pieces 2 *in* x2 *in* x1/4 *in* standard aluminum square tubing configured into a hook profile as seen in Figure 12.

The J-Shaped profile is the component of the design that meets multiple needs specified by the client. The hook profile is the component that horizontal secures the portable water tank while the fire truck is in motion and actuation of the entire rack.

The water tank rack satisfies the client's needs and technical metrics in several ways. First, J-Shaped profile allow for safe retention of the water tank throughout actuation and truck operation. Second, the water tank rack can support 500 *Lbs* while maintain a factor of safety higher than 2. This specification was analysed and validated using FEA (*FEA specifications can be found in the Appendix C).* Thirdly the design is simple, allowing the rack to be used in several truck configurations. The rack can be completely manufactured at FGFT facilities because the support was design using only standard aluminum profiles and basic manufacturing process. Coincidently the water rack is inexpensive and lightweight. The water rack fulfills all the customer needs that relate to this component of the design.

2.3.2 Individual Components

The following section outlines the separate components fount in the water tank rack.

2.3.2.1 J-shaped rack

The main rack was designed with two holes on each arm of the J-arm as seen in Figure 13. The J-shaped arm is used to provide the vertical retention for the water tank. The structure is manufactured with standard 2 *in* x 2 *in* x ¼ *in* aluminum tubing, welding and drilling.

Figure 13: J-shaped profile of water rack view.

2.3.2.2 Horizontal Retention

A hook shape configuration was chosen to prevent the water tank from any unwanted dislodging from the rack in the event the fire truck had to make an unexpected stop or the vibrations do to the motions of the fire truck were large. The horizontal retention is mounted to the J-shaped profile as shown in Figure 14. The holes drilled into the surface of the horizontal retention allows for the piece to be bolted and adjusted to the required length. The structure is manufactured with standard 2 *in* x 2*in* x ¼ *in* aluminum tubing, welding and drilling. The horizontal retention can be seen in Figure 14.

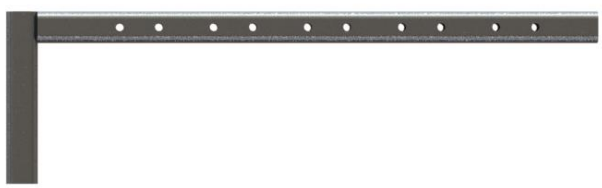


Figure 14: Render of horizontal retention, hook profile top view.

2.3.2.3 Configuration

The configuration of the water tank rack was designed to meet several of FGFT needs. First the configuration allows for the water tank to be transported while the firetruck is in transit and be quickly accessible when the entire rack is actuated down. Second, the geometry of the water tank rack was optimal in terms of weight and as mentioned in the previous section FEA was implemented to further optimize component weight. Finally the simplicity of the configuration allows the rack to be easily manufactured as per the client's request.

2.3.3 Cost

With the manufacture process for each part and subassembly determined, the cost for the entire water tank rack could be calculated. The cost for the Water Tank Rack is $468.18. The method of cost break down can be found in Appendix D

2.4 Main Boom

The main boom is the critical structural member for the entire rack design. The ladder rack, water tank rack and the actuating arms all bolt to the main boom via their respective mounts. The boom provides the final design with the rigidity, gives the design safe operation, reliability and good manufacturability. The man boom is shown in Figure 15.

Figure 15: Render of main boom for final design isometric view.

2.4.1 Specifications

The design of the main conforms to the needs specified by the client in various ways. First the main boom can support 1000 *Lbs* while maintain a factor of safely above 2. This specification was analysed and validated using FEA on the geometry of the main boom. The results from the FEA confirmed the 4”x4” aluminum square tubbing geometry would be able to withstand the required load defined in the needs analysis (*FEA specifications can be found in the Appendix C).* Second, the main boom is one member with holes drilled into the sides to allow the related mounting. Therefore the main boom can be completely manufactured at FGFT facilities because the rack was design using only standard aluminum profiles and basic manufacturing process. Finally, while the main boom has been optimized for weight savings the member itself is significantly heavier than other components of the design.

The main boom function is to provide sufficient stiffness to connect the mounts of both racks and the arm configuration together. The FEA previously mention, on the main boom validated the profile geometry of the main boom provides adequate stiffness while supporting both racks. The various sheet metal mounting brackets used to mount the different components to the main boom will be discussed in section 2.7.

2.4.2 Cost

The one member of the main boom was priced for material and using FGFT labour cost, the total cost for the main boom could be calculated. The total cost for the Main Boom is 374.36$. The cost break down method can be found in Appendix D.

2.5 Electric Linear Cylinder

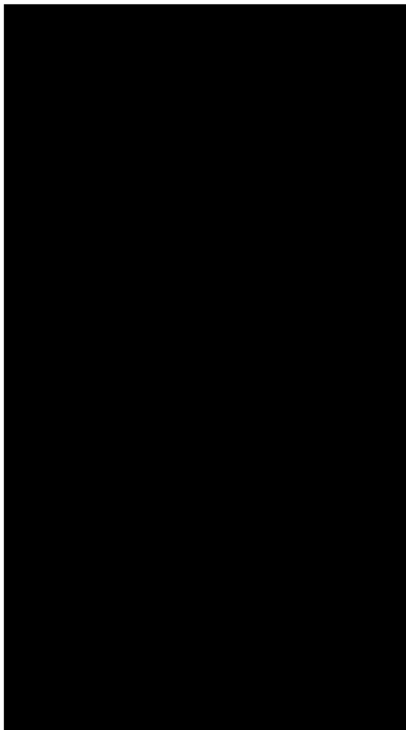
As specified in the needs and requirements, the ladder rack must support at minimum 1000lbs through its entire range of motion. In moving forward with these requirements is was assumed the maximum load on the end of each actuating arm would be 500lbs, 1000lbs distributed between the 2 arms equally. In addition to the 500 lb load, a 100lb load was added to the force on each arm in the calculations to take into account for the structures weight. The total structure weight does exceed 200 lbs, but an analysis of the components acting upon the arm in the worst loading cases was performed using Solidworks mass properties of each respective component.

The calculations for specifying a stroke length of a cylinder were performed using the solving software built into Microsoft Excel. The spreadsheets created require a number of inputs to solve for a stroke length taking into account the base length of each cylinder based supplier specifications. The variables entered in to the spreadsheet are: cylinder force as a fixed variable, cylinder base length equation specified by the cylinders manufacture and the length of the arm connecting the base to the main boom. Often, the base equation in the cylinders retracted state is stated as the stroke length + constant or in the case of some cylinders, constant plus a stroke length like so: 317.5mm + (Stroke Length x 1.25). After the require info was entered, the position of the cylinder base pivot and the cylinder top pivot is calculated with respect to the arms pivot point to counteract the 600 lbs load applied at the end of the arm in the down position (the worst case loading scenario throughout the arms actuating range). The spreadsheet calculates the loads in the down positons of the ladder rack, but does take into account the cylinder in the stroke length to ensure the calculated stroke length allows the rack to return to its fully upright position.

2.5.1 Cylinder

The cylinder selection was performed using the needs requirements of the rack design considering: actuation speed, packaging, resistance to the environment, manual release and feasibility.

Table VII LINEAR CYLINDERS

	**Joyce Dayton - ECAH6.5** • 22240N Thrust • Large foot print • Hand wheel for manual operations • 5 mm/s actuation • External motor
	Linak - LA37 • 15000N thurst load • Small foot print • Screw for manual operation • IP66 Rating • 3.5 mm/s actuation • Internal motor
	**Linak - LA36** • 10000N thurst load • Small foot print • Screw for manual operation • IP66 Rating • 11 mm/s actuation • Internal motor • Cold weather tested

The Joyce-Dayton ECAH62.5 electric cylinder offers advantageous thrust capabilities, but its overall size is too large for the compact packaging needed for the design. In addition the ECAH62.5's speed of actuation is too slow for the ladder rack application.

The Linak LA37 also had a desirable thrust load capability of 15000N in addition to many other aspects meeting the requirements listed above. The LA37's actuation speed of 3.5mm/s over the stroke required was simple too slow, taking approximately 1 minute and 30 seconds to bring the rack to its lowered position. Though after numerous iterations in excel solver using the specifications of the electric cylinders shown above in Table VII.

Also considering the requirements of the: packaging, actuation speed, temperature, manual release, etc. the Linak LA36 was found to be the most viable option. The LA36 has been tested in conditions exceeding -30 degrees Celsius, has a small package design through its internally housed motor, IP66 rating and has a manual release. The LA36 is restricted in its actuation speed of 11mm/s which translates into a total actuation time of 40 second, fully upright to a fully lowered position. Though the LA36 exceeds the initial actuation time requirements of the final design, it was determined to be the most feasible option considering time, cost, product availability and other needs requirements being met.

2.6 Actuating Arm

The arm configuration is the component of the design which connects the actuator and main boom. This connection enables the entire system to actuate from the upright position to an accessible height. The final design for the arm configuration can be seen in Figure 16.

Figure 16: Picture of arm configuration for final design.

2.6.1 Specifications

This actuating arm was design to achieve several of the client's needs. First the actuating arm was design to support the vertical load produced by rack statically during vehicle operation and dynamically during actuation. To meet the target specification the actuating arm would need to support a total load of 1500 *Lbs.* The structural integrity of the actuating arm is achieved by using 3"x2" carbon steel rectangular tubing. This rectangle cross section increases the stiffness in the direction of bending experienced by the arm. FEA optimization was used to verify the actuating arms could support a total of 1500 *Lbs* while maintaining a factor of safely above 2 (*FEA specifications can be found in the Appendix C*). Thirdly the FEA of the member for the arm allowed the weight to be optimized resulting in the member being as light weight as possible. The arm design is versatile which allows the rack to be used in several truck configurations. Also the rack can be completely manufactured at FGFT facilities because the arm was designed using only standard profiles and basic manufacturing processes. Finally, due to the ease of manufacturing and the standard profile of the member the arm configuration is relative inexpensive to fabricate.

The mounting locations for the arm configuration can be seen in Figure 16. These mounting locations allow for the arm to connect to the main boom and the actuator. The mounting location were dictated by the actuation geometry describe in section 0. All mounting locations are fabricated to accommodate mounts that are bolted into the main boom. The specification required for the mounts of the actuating arm will be explained in detail in section 2.7.

2.6.2 Cost

With the configuration of the actuating arm determined, the total cost for the Actuating Arm could be calculated. The cost for the arm is 185.73$. The cost breakdown method can be found in Appendix D.

2.7 Mounting

The mounting piece for the rack was designed to easily assemble all the different components of the design together, insuring the functionality of each component contributed to the overall design. Allowing design to come together and satisfy all the client's needs. There are five different sections of mounting including the main mount, ladder rack mount, water tank mount, arm configuration mount, and actuator mount.

The mounting functions the same for the ladder and water tank rack. These mounts fix one of the arms of rack components to the main boom. The main mount is the mount which fixes the entire rack to the firetruck. All mounts are made of ¼"or 3/8" steel plates with the exception of the main mounting system which is made of ¼" aluminum plate.

The mounting satisfies several needs specified by the client. Standard sheet metal geometry and material choice was crucial in meeting the client's manufacturability needs and lowering the overall system cost. (*For more manufacturing information see Appendix C)*. Secondly, each particular mount supports the load specified by the racks geometry and application. For the case of the water rack mount and ladder rack mount the experienced load will be the 500 *Lbs* requirement from the client and additionally the weight of the racks themselves*.* While the main mount is required to support the total 1500 *Lbs.* This load is composed of the equipment weight set by the client in addition to the racks material weight. This specification was analysed and validated using FEA on the geometry of each mount. The results from the FEA confirmed the configuration of each mount would be able to with stand the required load (*FEA specifications can be found in the Appendix C).* Finally the mounting configurations are elementary and all the mounts are configured from standard material resulting in high manufacturability and low cost

2.7.1 Components

There are several different mounts required for the final design. Each mount has its own specific configuration. The following section will describe specifications for the main mount, ladder rack mount, water tank mount, arm configuration mount, and actuator mount.

2.7.1.1 Main Mount

As previously stated the main mount is responsible for fixing the entire design to the body of the truck. Additionally the main mount is the component responsible for ensuring the entire design remains fixed to the fire truck when the rack is in the lowered position. The design of the main mount slightly changes between the two configurations of the entire rack.

2.7.1.1.1 Main Mount for Arms Being Mounts on the sides

The main mount is the component that fixes the entire rack to the fire truck. Additionally the main mount is the component responsible for ensuring the entire design remains fixed to the fire truck when the rack is in the lowered position. To achieve this, the actuating arm and the actuator are fixed to the main mount via zinc plated pins. The main mount can be seen in Figure

.

Figure 17: Render of main mount for side configuration isometric view.

2.7.1.1.2 Main Mount for Alternate Configuration

This mounting configuration allows the design to be mounted in the center of the body of the fire truck. Theses mounts have the same functionality as the main mounts which fasten to the side of the fire truck. However these mounts allow for the design to be mounted in the middle as well as on the sides of the fire truck. The design of this mount allows for the overall design to satisfy the customer requirement of modularity. The mount which can be secured in the middle of the firetruck is shown in Figure 18 .

Figure 18: Render of main mount for middle configuration from view.

2.7.1.2 Mounts for Horizontal Ladder Rack

The ladder rack mount fastens the ladder rack to the main boom. This mount is bent from ¼ *in* sheet metal and allows the horizontal ladder rack to be adjustable. The mounts for the ladder rack are shown in Figure 19.

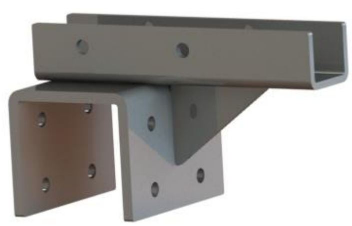


Figure 19: Render of mount for horizontal ladder rack isometric view.

2.7.1.3 Mounts for Water Tank Rack

As previously mentioned, the mounts for the water tank secures the water rack during the operation of firetruck. The design of the mounts for the water tank rack has been separated into two phases, the mount that secures the rack to the main boom and the mount that secures the horizontal retention to the J-shaped arms.

2.7.1.3.1 Mounts for Water Tank Rack to the Main Boom

The mounts for the water tank rack is the component that secures the water tank rack to the main boom. Two of these mounts are needed on each side of the water tank rack to secure the water tank rack is in a stable condition. The mount is made from 3/8 *in* and ¼ *in* bent steel plate that is welded together. The mount for the water tank rack is shown in Figure 20.

Figure 20: Render of mount for J-shaped arm to the main boom isometric view.

The water tank rack mount for the main boom was designed to meet several of the client's needs. First, each mount was able to support the required load of 500 *Lbs. FEA* optimization was used to verify the mounts for the arm could support a total of 500 *Lbs* each while maintaining a factor of safely above 2 (*FEA specifications can be found in Appendix D*). Second, the FEA done on the mounts allowed the mount to be optimized for weight. The mounting system of the ladder rack allows the overall design to have enough versatility to be compatible with multiply FGFT truck configurations. Also the mount can be completely manufactured at FGFT facilities because the mounts were designed using only sheet metal and basic manufacturing processes. Finally, due to the ease of manufacturing and the standard parts of the mount, the mount configuration is relative inexpensive to fabricate.

2.7.1.3.2 Mounts for Horizontal Retention

The current mount is the component that fixes the horizontal retention to the J-shaped structured of the water tank. This mount secures the piece that provides the horizontal retention to the water rack. The mount is made from ¼ inch bent steel plate that is welded together. The mount can be seen in Figure 21.

Figure 21: Render of mount for horizontal retention with J-shaped arm isometric view.

By securing the horizontal retention of the water rack, this mount enabled the overall design to satisfy a few of the technical specifications and client's needs. Having the horizontal retention fixed in place allows for the equipment within the water rack to be secure. Properly securing the equipment makes the design safe and reliable. Safety and reliability are two technical specifications FGFT require for the overall design to be implemented.

2.7.1.4 Mounts for **Actuating** Arm to Main Boom

The actuating arm mount is the mount fixed the actuating arm to the main boom through pins. The mounting locations are shown in the section for the Actuating Arm. The mounts for actuating arm to the main boom are shown in Figure 22.

Figure 22: Render of mount for actuating arm to main boom isometric view.

2.7.1.5 Mounts for Actuator to Actuating Arm

Two sheet metal plates act as a clevis for the electric cylinder to actuating arm interface. Both sheet metal plates weld to the actuating arm and allow for the Linak cylinder to fasten to the actuating arm via a zinc plated pin. A render of the clevis mount can be seen in Figure 23.

Figure 23: Render of mount for actuator to actuating arm isometric view.

2.7.2 Cost

Once the manufacturing process for each piece was determined the total cost of the mount was calculated. The cost for the mounting section as a whole is 620.69$. The cost breakdown method is found in Appendix D.

2.8 House of Quality

The Zico system is the current system being used by FGFT. PYRA was instructed by FGFT to insure the final design performance surpass or meet the current Zico system. Based on these instructions, the benching marking for the final design was done entirely from the two Zico systems FGFT is currently using. The Zico outside arm ladder system has the capability to carry a maximum weight of 300 pounds for the equipment [3]. The other system supplied by the Zico is a horizontal ladder and portable tank system [2].This system can carry a maximum weight of 500 pounds for the equipment [2].

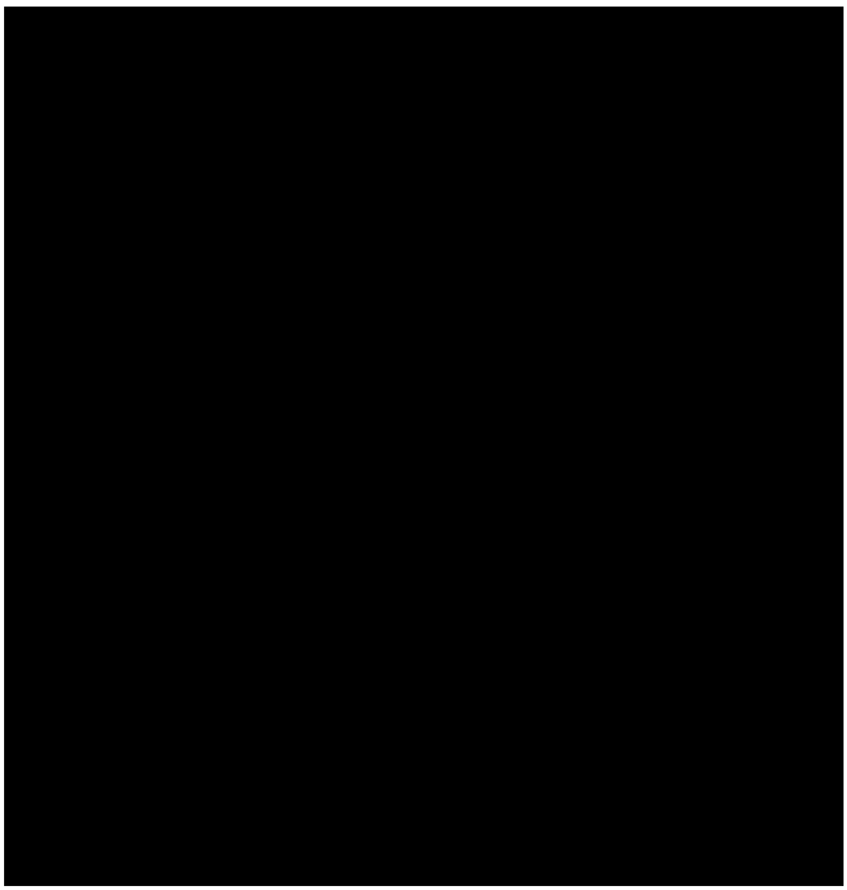


Figure 24: Zico outside Arm Ladder System [3]

The benchmarking was made among the three designs, Zico outside arm ladder system, Zico horizontal ladder and portable tank systems and PYRA'S modular rack design.

The evaluation for customer's needs was made among these three designs. A score of 5 demonstrates that the design is the best to meet the customer's needs while a score of 1 indicates the design does not meet the customer's needs. This benchmarking was used in the house of quality to identify how the design meet customer's needs compared with other competitors.

TABLE VIII: COMPETITIVE EVALUATION FOR CUSTOMER'S NEEDS.

Need #	Need	Imp	Zico Outside Arm Ladder System	Zico Horizontal Ladder and Portable Tank Systems	Modular Mounting Rack Design
N1	Modular ladder rack	4	4	4	4
N2	Support ladder and water tanks	5	2	4	5
N3	Actuating	5	5	5	4
N4	Inexpensive	4	2	3	5
N5	Easy to install	3	4	3	4
N6	Versatile for FGFT applications	2	4	5	4
N7	Safety	4	4	3	4
N8	Intuitive controls	2	4	4	4
N9	Ladders and water tanks easily accessible	3	3	4	4
N10	Ladder and Tanks quick removable from transport position	3	3	4	3
N11	Aesthetically pleasing	2	4	3	3
N12	Good Manufacturability	3	3	3	5
N13	Reliability	3	3	3	3
N14	Minimize system weight	3	2	3	2

The technical evaluation for target specifications was made among these three designs. A score of 5 demonstrates that the design is the best to meet the target specifications while a score of 1 indicates the design does not meet the target specifications.

Table IX: TECHNICAL EVALUATION FOR TARGET SPECIFICATIONS.

Metric #	Metric	Imp	Zico Outside Arm Ladder System	Zico Horizontal Ladder and Portable Tank Systems	Modular Mounting Rack Design
M1	Number of major components	4	3	4	3
M2	Load capacity	5	3	4	5
M3	Actuating	3	5	5	4
M4	System cost	4	2	3	3
M5	Install time	3	4	3	4
M6	Number of compatible trucks	2	4	4	4
M7	Payload height from ground	3	3	3	3
M8	Ease of operation	3	4	3	4
M9	Maximum dynamic load	5	3	4	5
M10	Appearance	1	3	3	4
M11	Speed of actuation	3	3	4	3
M12	Manufacturability	3	4	4	4
M13	Life cycles	3	4	4	3
M14	Weight	3	3	4	3

The house of quality was developed by determining the correlation between the customer's need and engineering metrics. Each client's need was compared to the engineering metric to determine the relation between client's needs and individual metrics. The scale for the correlation is 9,3,1 and 0, 9 represents a strong relationship, 3 represents a moderate relationship, 1 represents a weak relationship and a blank space represents 0 meaning there was no relationship between the engineering metric and the client's need. The top section or the roof of the house of quality represents the correlation between specific metrics. The scale for the correlations are ++, +, - and ▼. ++ represents a strong positive correlation which means as one metric improves the other will significantly improve as well. + represents a positive correlation meaning that as one metric is improve the other metric will improve as well. – represents a negative correlation meaning that as one metric is improve the other will worsen. ▼ represents a strong negative correlation meaning as one metric is improved the other metric is drastically worsened.

The house of quality to relate client’s needs to engineering specifications is shown in the Figure 25.

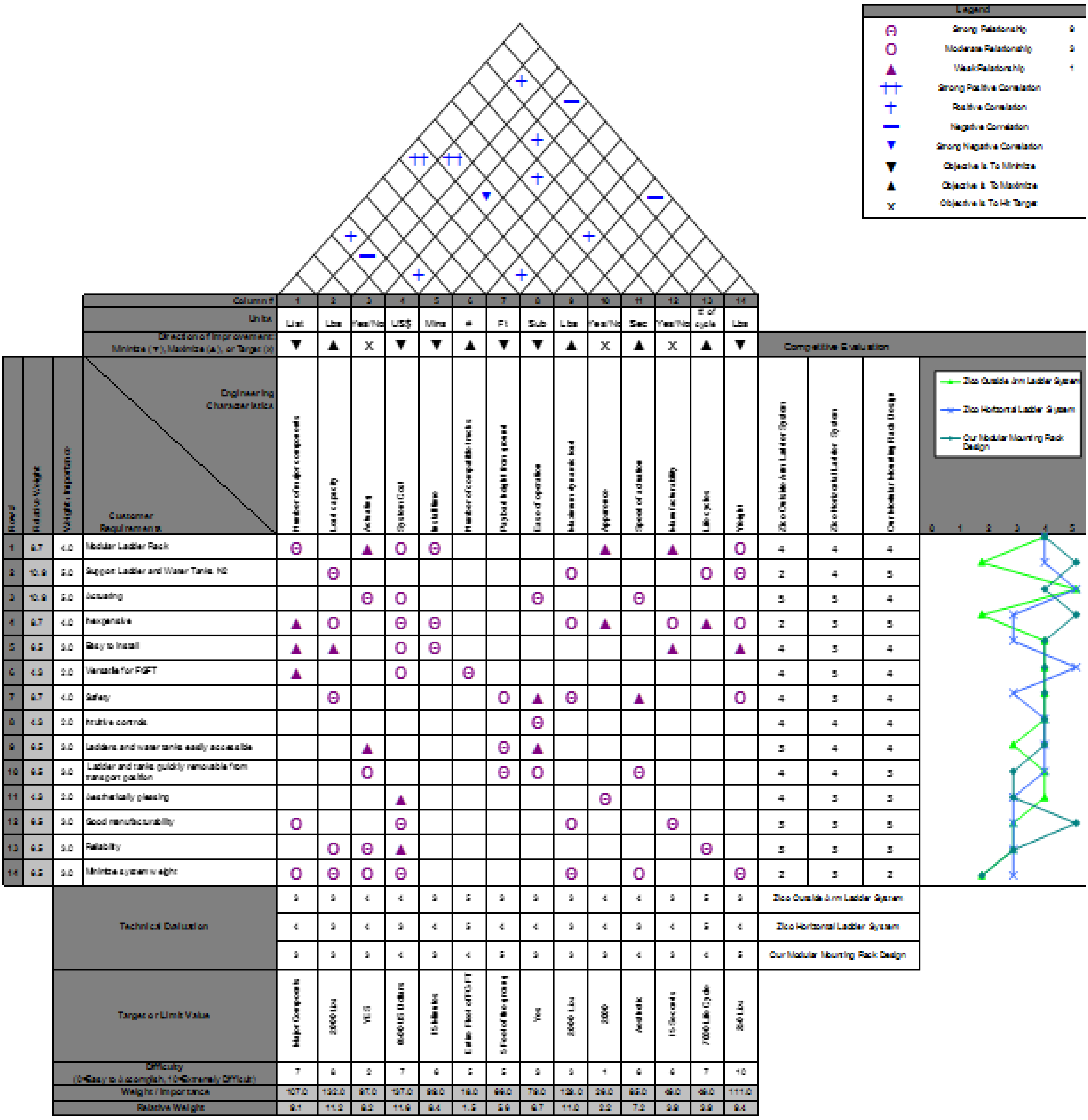


Figure 25: Completed House of Quality

3 CONCLUSION AND RECOMNEDATIONS

PYRA was tasked by Fort Garry Fire Truck, to create a modular support for the FGFT fire truck ladders and water tanks. FGFT required two separate racks to adapt to the configurations of FGFT's firetrucks. One rack could only be mounted in the middle of the firetruck; while the other rack could only be mounted to the sides of the firetruck. Also the implemented system is unable to move both a portable water tank and ladders concurrently from an upright positon to a position the equipment can be accessible by fireperson personal.

FGFT required an alternative solution that would support a top and side load of 500 *Lbs* for a total of 1000 *Lbs*. The support must be compatible with multiple trucks within the FGFT fleet. The system will lower ladders and portable water tanks to an accessible height by either electrical or hydraulic actuation. The final design will include computer aided design models of the final design, finite element analysis of the design, manufacture drawings and bill of materials.

There were several FGFT's needs and related technical specifications that dictated the design process. PYRA determine the most significant client need were the entire rack was modular, support the weight of the ladder and water tanks, actuating and less expensive than the current system. The subsequent technical specifications were used to evaluate the final design's feasibility. To improve the evaluations of the technical specifications, the design was broken down into 6 separate components to focus on the functionality of component to the design. After intensive concept screening of each component, two complete concepts could be developed for the final design. Computer aided design models were generated for each concept then finite element analysis was done on each component of the complete design to ensure it could support the required load. The design was then refined to ensure all components could be manufactured with standard aluminum profiles, sheet metal and standard steel profiles.

The final design meets the critical technical specifications determine on the onset of this project. First, all member maintain a factor of safety of 2 when the required load is applied to the design components. Second, the rack can be configured with the mounting in the middle of the fire truck or on the sides of the firetruck while simultaneously supporting a ladder rack and water tank rack. The design moves the water tank and ladder from a raised position to a level that can be accessible by a fireperson within 40 secs by a La36 Linak electric actuator which doesn't quite meet the required need as discussed in section 2.6.1. In addition all components are manufactured from standard aluminum or steel profiles or sheet metal. Finally the total cost of the design is $4130.97 US. Due to the fact this design meets the critical technical specifications; PYRA is confident this design will meet client expectations and is functional within the design application.

PYRA recommends that even further FEA be performed on the preliminary FEA performed for this report. In addition t to more FEA to further validate the design FGFT can further optimize the design for increased manufacturability as well as optimizing for weight. Lastly the Linak LA36 actuator chosen meets all but one of FGFT needs. The actuation time is double the time specified by the client therefor further inquiry into a custom actuator can be done to fulfill the final need of the design.

4. WORKS CITED

[1] FORT GARRY FIRE TRUCKS, " FORT GARRY FIRE TRUCKS," FORT GARRY FIRE TRUCKS, 2014. [Online]. Available: http://www.fgft.com/?section=10&page=47. [Accessed 3 10 2015].

[2] ZIAMATIC CORP, "HORIZONTAL LADDER ACCESS SYSTEMS," ZIAMATIC CORP, 2014. [Online]. Available: http://www.ziamatic.com/product/horizontal-ladder-access-systems/. [Accessed 3 10 2015].

[3] ZIAMATIC CORP, "Outside Arm Ladder Systems," ZIAMATIC CORP, [Online]. Available: http://www.ziamatic.com/product/oals-systems/. [Accessed 28 November 2015].

5. APPENDIX

Appendix

TABLE OF CONTENTS

A. CONCEPT GENERATION

The initial phase of the concept design indicated with a brainstorming session by the team. We decided to use a morphological approach and generated concepts for six separate components of the ladder rack.

For increased clarity throughout the concept generation, a diagram of a ladder rack design with identified components is shown in Figure 1. This identifies the individual components of the design which were discussed separately.

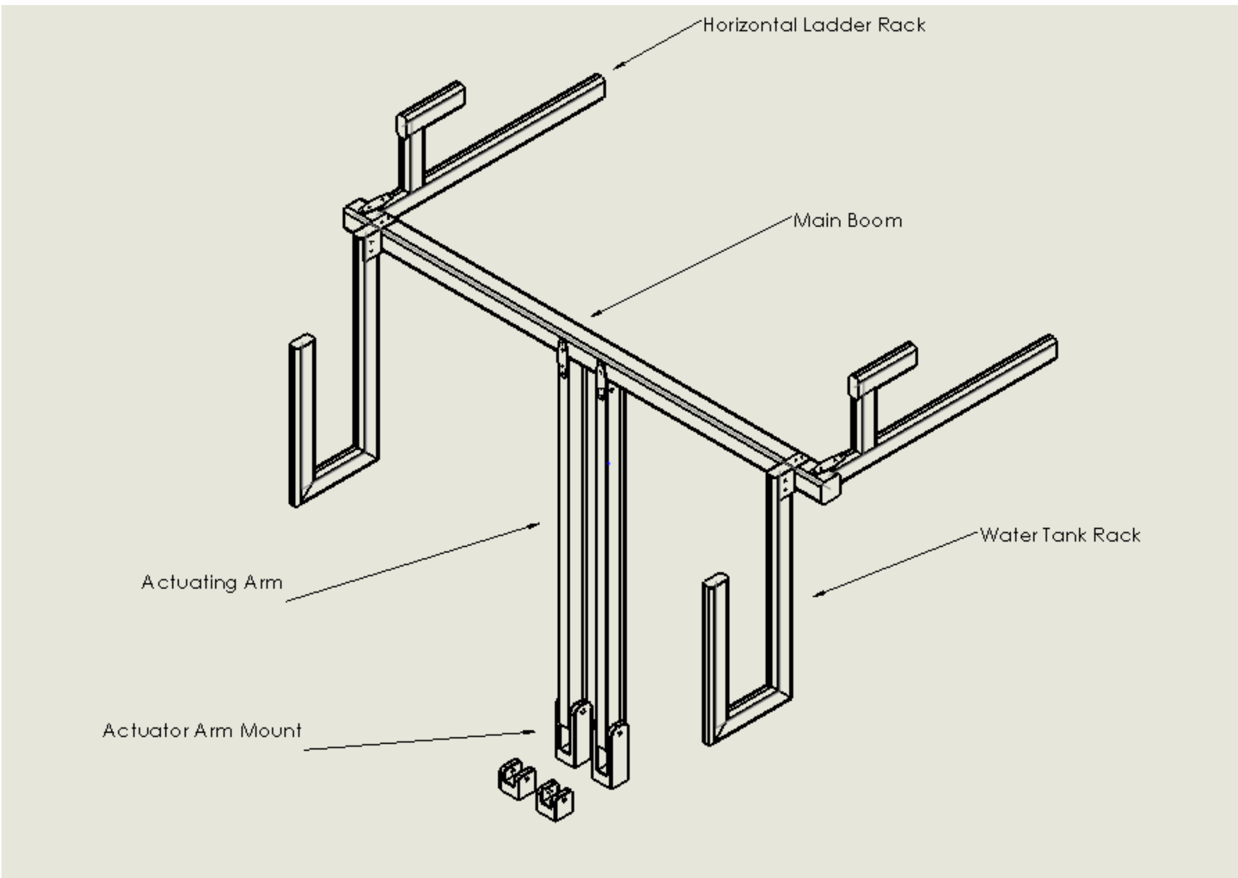
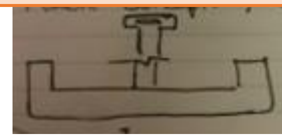
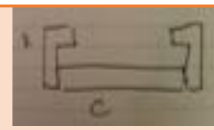
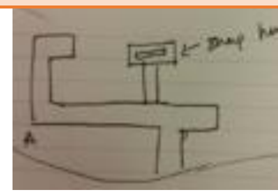
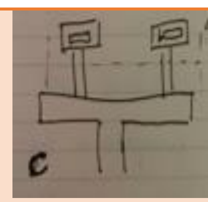
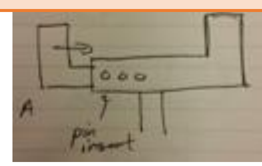


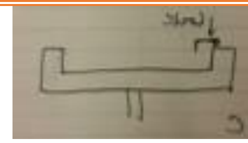
Figure 1: General design component identification.

A.1 Horizontal Ladder Rack

The first section that was broken down from the overall design was the portion that will actually support the ladder itself. This section has to stow the ladder in vehicle motion as well as stabilize the ladder through the actuating period when the ladder is lowered for removal. TABLE I listed the concepts that the team came up with during the brainstorming session.

TABLE I: HORIZONTAL LADDER RACK CONCEPT GENERATION.

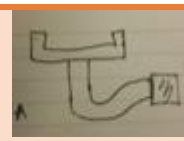
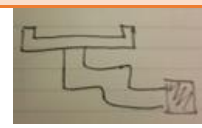
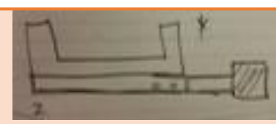
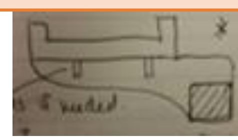
Concept Number	**Concept Name**	**Description**	Sketch
LR1	C channel ladder rack	-This concept features a c channel rack that inserts through the ladder rungs. -Will restrain the ladders with a spring loaded handle.	
LR2	C channel ladder rack with flip arms	-Features a variant of the c channel design but outside ladder rungs. -Side arms flip up to restrain ladders.	
LR3	J channel ladder rack	-This concept features a J channel ladder. rack which sees one arm wrap around the ladders. -Will restrain the ladders with a spring loaded handle.	
LR4	Flat bead ladder rack	-A flat surface is providing support for the ladders above the truck with mounting for spring handles. -Two spring loaded handles constrain the ladders on the flat bed.	
LR5	Adjustable C channel	-C channel ladder rack provides support on the outside of the ladders. -One side of the c channel is adjustable and can be moved to hold the ladders in place.	

LR6	C channel and lock	-Basic c channel which shows the ladders inside the outer arms. -Locking mechanism holds the outside of the ladder to minimizes ladder movement	

A.2 Mounting of Racks to Main Boom

We have decided that a main boom would be the best option to connect both the ladder and tank rack to the actuating arms which ultimately mount to the truck. The methods of attaching the ladder rack to the main boom were discussed. After our team brainstorming session, we formulated multiple concepts shown in TABLE II.

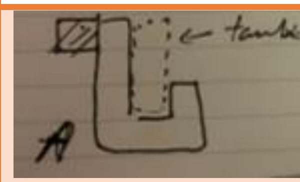
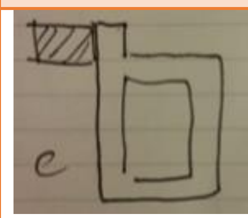
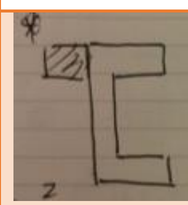
TABLE II: MOUNTING OF RACKS TO MAIN BOOM CONCEPT GENERATION.

Concept Number	Concept Name	Description	Sketch
CB1	Curved l arm connection	-This bent l shaped geometry features a curve to lower the overall height of the ladder rack.	
CB2	Stepped arm connection	-This step design move the ladder rack away from the main boom and higher to potential move the rack over any potential obstructions.	
CB3	Direct connection with adjustable pin	-An arm geometry that mounts straight into the main boom which allows for a simple pin mechanism to adjust the ladder rack.	
CB4	Gusset arm connection	-An arm design which features predominantly sheet metal gussets that fix directly onto the main boom.	

A.3 Water Tank Rack

The tank mounting section gave the details for the side mount that holds the portable water tank. Like the ladder rack, the tank rack would connect to the main boom that ultimately fixes the rack to the chassis of the fire truck. The tank mounting must allow for easy and safe removal while in the lowered position. The concepts developed for the water tank rack in the brainstorming process are listed in TABLE III.

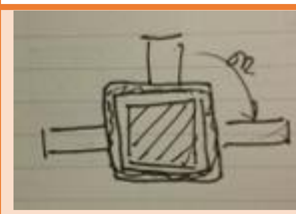
TABLE III: WATER TANK RACK CONCEPT GENERATION.

Concept Number	Concepts	Description	Sketch
WR1	J channel tank rack	-The j channel supports a rectangular water tank on the side of the truck directly attached to the main boom - To restrain the water tanks a cable can be added to reduce movement while driving.	
WR2	Enclosed tank rack	- This enclosed design completely surrounds the water tank. - Rack still attaches directly to boom and is on the side of the truck.	
WR3	C channel tank rack	- The c channel tank support provides support above and below rack. - Rack still attaches directly to main boom.	

A.4 Mounting Sleeve

In order to facilitate maximum adjustability and allow FGFT to have a versatile design that can be used across multiple truck platforms, a sleeve that would move across the boom to mount both ladder rack and tank rack was conceived. Only one design was conceptualized, the fastening method has been narrowed down to two possible methods. Either welding or bolting were be the method utilized to fasten the sleeve to the boom and the sleeve to the ladder or tank rack. Considering the concept was already decided, the sketch and description is shown in TABLE IV.

TABLE IV: MOUNTING SLEEVE CONCEPT GENERATION.

Concept Number	Concept	Description	Sketch
MS1	Mounting Sleeve	-The sleeve goes over the main boom and provides posts for the ladder and tanks racks can mount to. -Sleeve can be fixed on the boom by bolts of welding.	

A.5 Actuating Arm

The actuating arm is the vertical arms that ultimately support the entire rack system and mount to the chassis of the truck. The arms are the component in with the actuator would be attached to lower and raise the rack system. For better clarity, the sketch below depicted the actuating arms attached to the main boom. The actuating arms are the vertical components is shown in Figure 2.

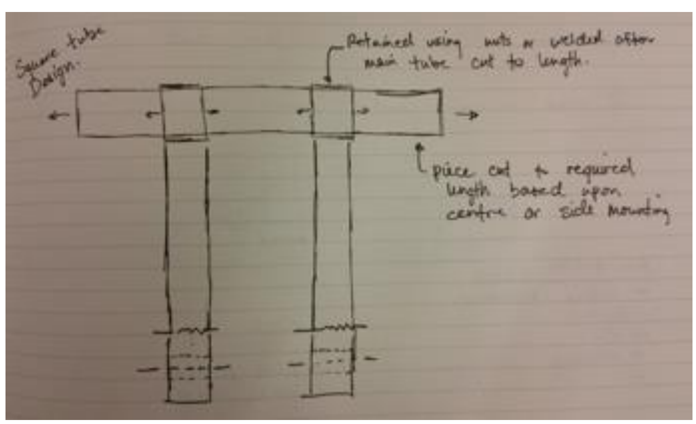
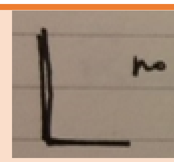
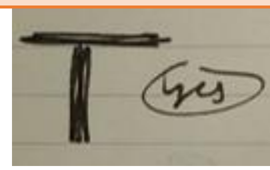
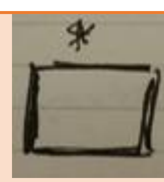


Figure 2: Actuating arm concept.

A.5.1 Arm Cross Section

The cross section of the actuating arm is crucial to our design. Because of this, the team brainstormed concepts for the cross section of the arm. The results of the team's brainstorming were shown in TABLE V.

TABLE V: ARM CROSS SECTION CONCEPT GENERATION.

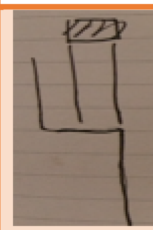
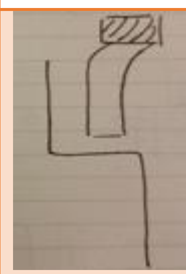
Concept Number	Concept	Description	Sketch
G1	L cross section	L cross section for actuating arm beam	
G2	T cross section	T cross section for actuating arm beam	
G3	Circular cross section	Circular cross section for actuating arm beam	
G4	I cross section	I cross section for actuating arm beam	
G5	Rectangular cross section	Rectangular cross section for actuating arm beam	

All these cross sections are relatively easy to purchase and are all available as standard aluminum profiles. The asymmetry of the L beam would have not been optimal in torsion and would have made analysis more complex [1]. The rectangular tube offers good bending and torsional stiffness [1]. The I-beam offers good bending and torsional stiffness for reduced weight while the T beam also offers good mechanical properties and occupies less space which can be advantageous for mounting purposes [1].

A.5.2 Beam Profile

The side profile of the beam is equally important as the cross section both for advantageous mechanical properties and the packaging of the entire ladder and tank rack system. The team brainstormed three different arm profiles which are shown in TABLE VI.

TABLE VI: BEAM PROFILE CONCEPT GENERATION.

Concept Number	Concept	Description	Sketch
BP1	Straight arm	Straight arm to support ladder rack assembly.	
BP2	Strait tapered Arm	Straight arm with tapper to reduce overall design weight.	
BP3	Straight arm withed curved top	Strait arm with curve to move ladder rack around a potential obstacle.	

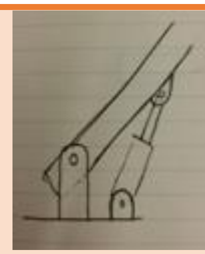
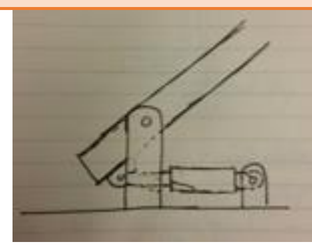
A.6 Arm Mounting and Actuation

Another critical component of the design is how the ladder rack with actuate in order to lower the payload from a storage height to a removal height. We splited this final design concept phase into two sub sections, the arm mounting and the actuation configuration.

A.6.1 Actuation Configuration

The team developed two possible linear actuating geometries which could potential accomplish the actuating need effectively. The two concepts are shown in TABLE VII.

TABLE VII: ACTUATING GEOMETERY CONCEPT GENERATION.

Concept Number	Concept	Description	Sketch
AG1	Linear actuator above pivot point	Linear actuator pulls arm down to lowered position.	
AG2	Linear actuator below pivot point	Linear actuator pushes arm down to lowered position.	

A.7 Method and Source of Actuation

Based upon research into the benefits of hydraulic and electric actuation systems, an electric system offers more benefits than a hydraulic system. The electric system offers better efficiency in a wider range of operating temperatures, with a higher power density than hydraulic systems [2]. Failure of a hydraulic system can result in leaks or spills of hydraulic oil, presenting potential risks to the environment [3, 2]. Conversely an electric system failure results in simply the failure of the system, with no other negative effects on the environment. Therefore electric systems are more environmental friendly than hydraulic system [3].

The electric system are actually cheaper than the numerous components required to produce an operational hydraulic system. Often hydraulic systems are thought to be less expensive than their electric counterpart because only the cylinders are priced out. In reality, the cylinder is only one component out of at least 5 required to operate a hydraulic system (cylinder, pump, hydraulic lines, reservoir and filter) [2].

Hydraulic systems use a working fluid, oil, to build up pressure within a cylinder using the hydraulic pump; in cold weather conditions oil has a very low viscosity making it difficult for cold weather operation. The ease of operation in all conditions, the higher efficiency, power density, environmentally friendly aspects of operation and failure modes are all factor contributing to the initial conceptual decision of moving forward with design and implementing an electrically actuated racking system.

TABLE VIII indicated a basic scoring of the actuation working principles, electric and hydraulic, which determined PYRA's decision to move forward with an electrical actuated system.

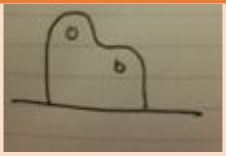
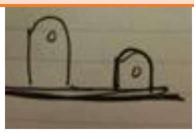
TABLE VIII: ACTUATION WORKING PRINCIPLE SCORING.

		Hydraulic Actuation	**Score**	**Electric Actuation**	**Score**
1	Efficiency	50%	3	85%-90%	4
2	Power density	Low	2	High	4
3	Size (Compact)	Bulky	2	Compact	4
4	Failure modes	Numerous	2	Minimal	3
5	Failure severity	High	2	Low	3
6	Number of components	High	2	Low	4
7	Maintenance	Medium	2	None	5
8	Component Life	Medium	4	Long	4
9	Accuracy	Low	2	High	4
10	System Cost	Medium	3	Low	4
11	Operation in various temperature	Poor (Cold)	3	Good	4
12	Environmentally friendly	Low	2	High	4
	Total Score		**29**		**47**

A.8 Actuating Arm Mount

The mount that connects the ladder rack to the chassis of the car is extremely important to the structural integrity of the entire design. The team chose two different designs shown in the TABLE IX.

TABLE IX: ACTUATING ARM MOUNT CONCEPT GENERATION.

Concept Number	Concept	Description	Sketch
AM1	Integrated arm and actuator	The arm mount has an integrated mounting point for the actuating device.	
AM2	Separate arm and actuator mount	Separate mounting for the arm and actuator provides the flexibility of changing the angle of the actuator in regards to the arm.	

B. CONCEPT SELECTION

The concept selection process was the technique used to narrow down concepts and ultimately refine the concepts brought into the final design section of the project. The following section goes into the process used by PYRA to arrive at the final concepts which acted as a base line for the final design.

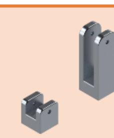
B.1 Completely Assemble Concepts

After meeting with our client, we were ready to develop completely assembled concepts for the final design. Using SCAMPER, TRIZ and further research, PYRA was able to modify or chose alternatives for each component that would maximize the function of the component while meeting customer needs. From this process, we develop Concept A, Concept B, Concept C and Concept D.

B.1.1 Concept A

The components for concept A can be seen in TABLE X.

TABLE X: COMPONENT BREAKDOWN OF CONCEPT A.

Component 1: **Ladder Rack**		
Concept	**Description**	**Picture**
J channel ladder rack	This concept features a J channel rack with one arm wrap around the ladders and would restrain the ladders with a spring loaded handle. This concept is more stable in removal position.	
Component 2 : Water Tank Rack		
Concept	**Description**	**Picture**
J-Channel with strap	This concept supports a rectangular water tank on the side of the truck directly attached to the main boom.	
Component 3 : Connections		
Concept	**Description**	**Picture**
Bolt	This concept connects rack to the main boom.	N/A
Component 4 : **Arm Cross Section**		
Concept	**Description**	**Picture**
I cross section	This concept provides favorable torsional and bending stiffness at an increased weight [1].	
Component 5 : Beam Profile		
Concept	**Description**	**Picture**
Straight arm	This concept provides the simplicity and good manufacturability to support ladder rack assembly.	
Component 6 : Actuating Arm Mount		
Concept	**Description**	**Picture**
Separate arm and actuator mount.	This concept provides the flexibility of changing the angle of the actuator in regards to the arm.	

B.1.2 Concept B

Concept B was develop by evaluating the components from Concept A to determine if any modifications or alterations could be made to further improve the function of that component.

A summary of all the components can be seen in TABLE XI.

TABLE XI: COMPONENT BREAKDOWN OF CONCEPT B.

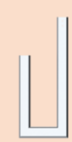
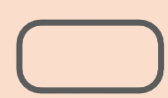
Component 1: **Ladder Rack**		
Concept	**Description**	**Picture**
C -Channel ladder rack	This concept features a c channel rack that inserts through the ladder rungs and would restrain the ladders with a spring loaded handle. This concept provides good ladder retention by spring handle and has high manufacturability with standard aluminum profiles.	
Component 2 : Water Tank Rack		
Concept	**Description**	**Picture**
J-Channel with Adjustable pin	This concept supports a rectangular water tank on the side of the truck directly attached to the main boom. This concept can support the tank with various sizes. This concept provides good ladder retention by spring handle and is more stable in ladder removal position.	
Component 3 : Connections		
Concept	**Description**	**Picture**
Bolt	This concept connects rack to the main boom.	N/A
Component 4 : **Arm Cross Section**		
Concept	**Description**	**Picture**
I cross section with two sheet metal on sides of web	This concept provides favorable torsional and bending stiffness at an increased weight [1]. The sheet metal on the sides can increase the stability for the arm.	
Component 5 : Beam Profile		
Concept	**Description**	**Picture**
Straight arm	This concept provides the simplicity and good manufacturability to support ladder rack assembly.	

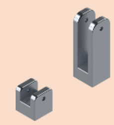
Component 6 : Actuating Arm Mount		
Concept Name	**Description**	**Picture**
Integrated arm and actuator	The arm mount has an integrated mounting point for the actuating device.	

B.1.3 Concept C

Concept C was developed using the same component from Concept A except the actuating arm cross section. PYRA chose to change the arm cross section to the square tubing. The components for concept C can be seen in TABLE XII.

TABLE XII: COMPONENT BREAKDOWN OF CONCEPT C.

Component 1: **Ladder Rack**		
Concept	**Description**	**Picture**
J channel ladder rack	This concept features a J channel rack with one arm wrap around the ladders and would restrain the ladders with a spring loaded handle. This concept is more stable in removal position.	
Component 2 : Water Tank Rack		
Concept	**Description**	**Picture**
J-Channel with strap	This concept supports a rectangular water tank on the side of the truck directly attached to the main boom.	
Component 3 : Connections		
Concept	**Description**	**Picture**
Bolt	This concept connects rack to the main boom.	N/A
Component 4 : **Arm Cross Section**		
Concept	**Description**	**Picture**
Rectangle tube cross section	This concept provides excellent bending stiffness and extremely good torsional stiffness [1].	
Component 5 : Beam Profile		
Concept	**Description**	**Picture**

Straight arm	This concept provides the simplicity and good manufacturability to support ladder rack assembly.	
Component 6 : Actuating Arm Mount		
Concept	**Description**	**Picture**
Separate arm and actuator mount.	This concept provides the flexibility of changing the angle of the actuator in regards to the arm.	

B.1.4 Concept D

Concept D was developed using the same component from Concept B except the actuating arm cross section. The arm cross section was change from the I-Beam with sheet metal side to the square tubing. The components for concept D can be seen in Table XIII.

Table XIII: COMPONENT BREAKDOWN OF CONCEPT D.

Component 1: **Ladder Rack**		
Concept	**Description**	**Picture**
C -Channel ladder rack	This concept features a c channel rack that inserts through the ladder rungs and would restrain the ladders with a spring loaded handle. This concept provides good ladder retention by spring handle and has high manufacturability with standard aluminum profiles.	
Component 2 : Water Tank Rack		
Concept	**Description**	**Picture**
J-Channel with Adjustable pin	This concept supports a rectangular water tank on the side of the truck directly attached to the main boom. This concept can support the tank with various sizes. This concept provides good ladder retention by spring handle and is more stable in ladder removal position.	
Component 3 : Connections		
Concept	**Description**	**Picture**
Bolt	This concept connects rack to the main boom.	N/A
Component 4 : **Arm Cross Section**		

Concept	**Description**	**Picture**
Rectangle tube cross section	This concept provides excellent bending stiffness and extremely good torsional stiffness [1].	
Component 5 : Beam Profile		
Concept	**Description**	**Picture**
Straight arm	This concept provides the simplicity and good manufacturability to support ladder rack assembly.	
Component 6 : Actuating Arm Mount		
Concept	**Description**	**Picture**
Integrated arm and actuator	The arm mount has an integrated mounting point for the actuating device.	

C. PRELIMINARY FEA ANALYSIS

Team PYRA used Solidworks FEA to validate all of the critical components of the ladder and tank rack. Multiple component based simulations were run for the most extreme loading cases that the ladder rack will experience while in used for multiple fire departments throughout Canada. The critical components most likely to fail are the main boom, the actuating arm mounts, truck mounts, the actuating arms, and the main water tank.

C.1 Main Boom FEA

The main boom is the key component to the entire design as it integrates the other components of the ladder and water rack. The design progressed through the concept development stage as previously mentioned in Appendix A. The initial design for the main boom was a 6x6 steel square tube that was designed using simple hand calculations. The 6x6 inch steel displayed a minimum FOS of 4.5 when put under the most extremely loading scenario which occurs when the ladder and water rack are in the vertical position. The discussed loading scenario features both the water and ladder rack acting on the main boom. This implies that the alternate configuration where the rack is situated on the opposite side of the truck will not be analysed. The reason for this is that the alternate configuration can be visually subjected to basic engineering principles and it can be clearly seen that the boom will not experience its maximum stress in this configuration.

After the initial FEA on the 6x6 steel beam, it was obvious the design could be optimized further to save weight thus making the design more efficient. The next design iteration was a 4x4 aluminum square tube show undergoing the previously mentioned loading scenario in Figure 3

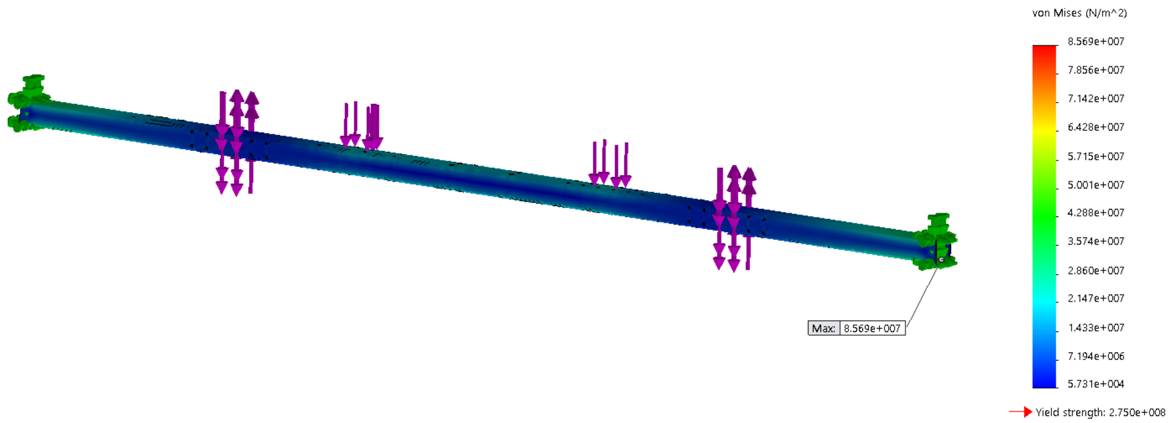


Figure 3: Main boom lowered position with max stress annotation

The figure above illustrates the critical loading scenario for the 4x4 aluminum beam. The fixed geometry was placed on the actuating arm bolt holes at the extremities of the beam. This is a slightly simplified scenario as the actuating arm will not be perfectly rigid. However the deflection will be so limited it is an acceptable assumption to fix the mounting locations where the actuating arm mount. The loading for both the ladder and water tanks are applied at the mounting location and are representative of the 500 *lbs* load requirement specified by the client and material weight of the respective racks. In Figure 4 we can see the minimum FOS for the main boom when the rack is in the vertical position. The iso clipping shows the minimum FOS to be 0.803 in the vicinity of the fixed geometry.

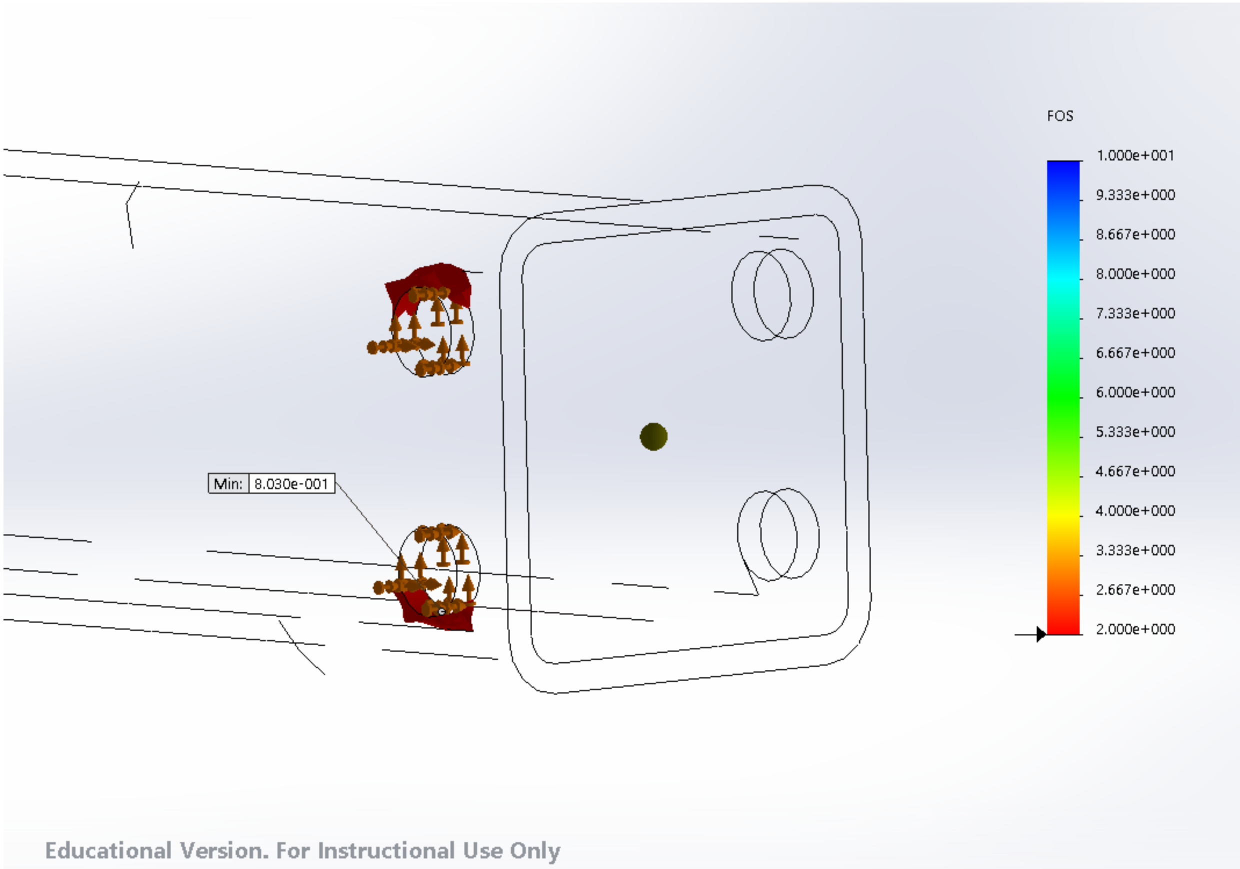


Figure 4: Iso clipping FOS below 2 for vertical rack position

Due to the nature of SolidWorks FEA and the minimum FOS being at the fixed geometry hole locations we can reasonably assume that this location is not representative of the actual minimum FOS. Since the stresses by the holes can be attributed to point loads and improper load distribution, PYRA looked at the stress behavior moving away from the mounting holes. It can be seen above that the areas will a FOS below 2 is extremely limited and therefore the 4x4 aluminum beam is sufficient. The figure below shows Iso clipping for below a FOS of 5 in the lowered rack position with the minimum FOS being 3.20.

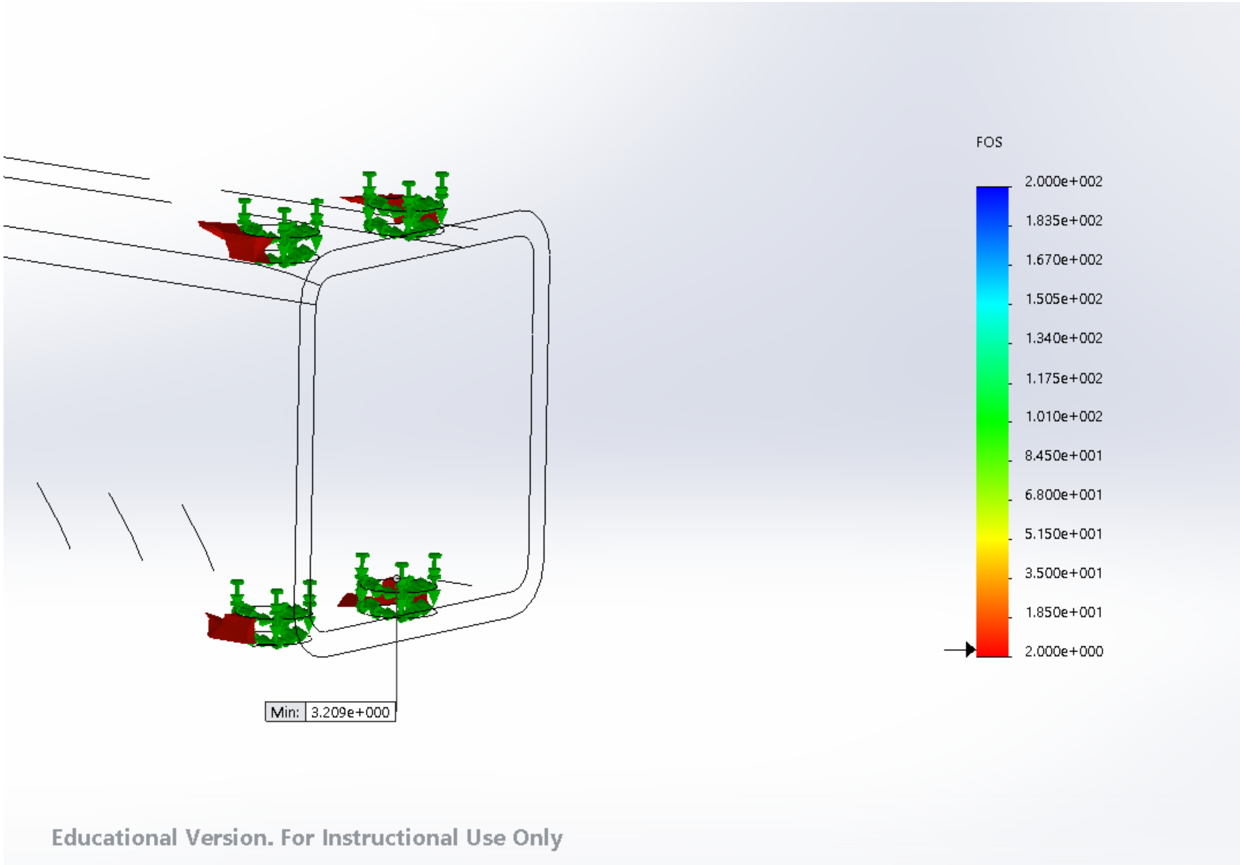


Figure 5: Iso clipping FOS below 5 for lowered rack position

C.2 Actuating Arm Mount

The actuating arm mount is the critical mount that attaches the main boom to the actuating arms. This mount will see the largest loads as it supports the entire rack weight. The two part mount is discussed in depth in the main report in the detailed design section. The initial design was validated using Solidworks FEA like the other critical components in the rack design. Below in Figure 6Figure 6 the stress distribution throughout the mount is shown in the lowered rack position. The lowered rack position is the scenario in which the mount sees its critical load and thus failure is the most likely. This assumption can be validated by inspection when one can surely see the stresses and bending in the mount increases as the rack actuates down.

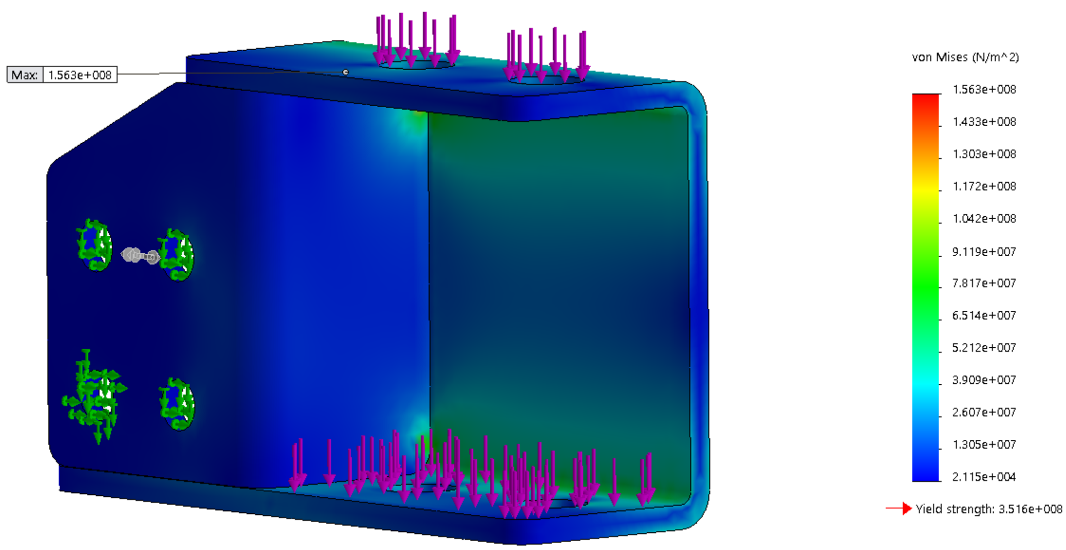


Figure 6: Stress distribution for the actuating arm mount in the lowered position

The fixed geometry in the simulation can be seen to be the mounting holes to the left in the figure above. These holes are mounted to the actuating arm and are assumed to be fixed thus simplifying the load scenario however still allowing for accurate representation of the actual lead scenario. As seen in the figure above the load is distributed on the face of the mount and additionally on the bolt holes on the top side of the mount. The nuts from the bolt will exert the local force on the top face while the main boom will rest on the lower face in this scenario applying a distributed load to the entire face.

The maximum stress von Mises stress can be seen to be $1.563e^{08}$ N/m^2. The same simulation is run for the identical critical load scenario and can be seen in Figure 7 with a FOS distribution. The figure shows an iso clipping for a FOS of below 5. The minimum FOS as seen in the annotation is 2.2489. This value is sufficient and thus validates the design. Although possible to optimize, with the focus being on manufacturability and cost this will be the final design for the actuating arm mounts.

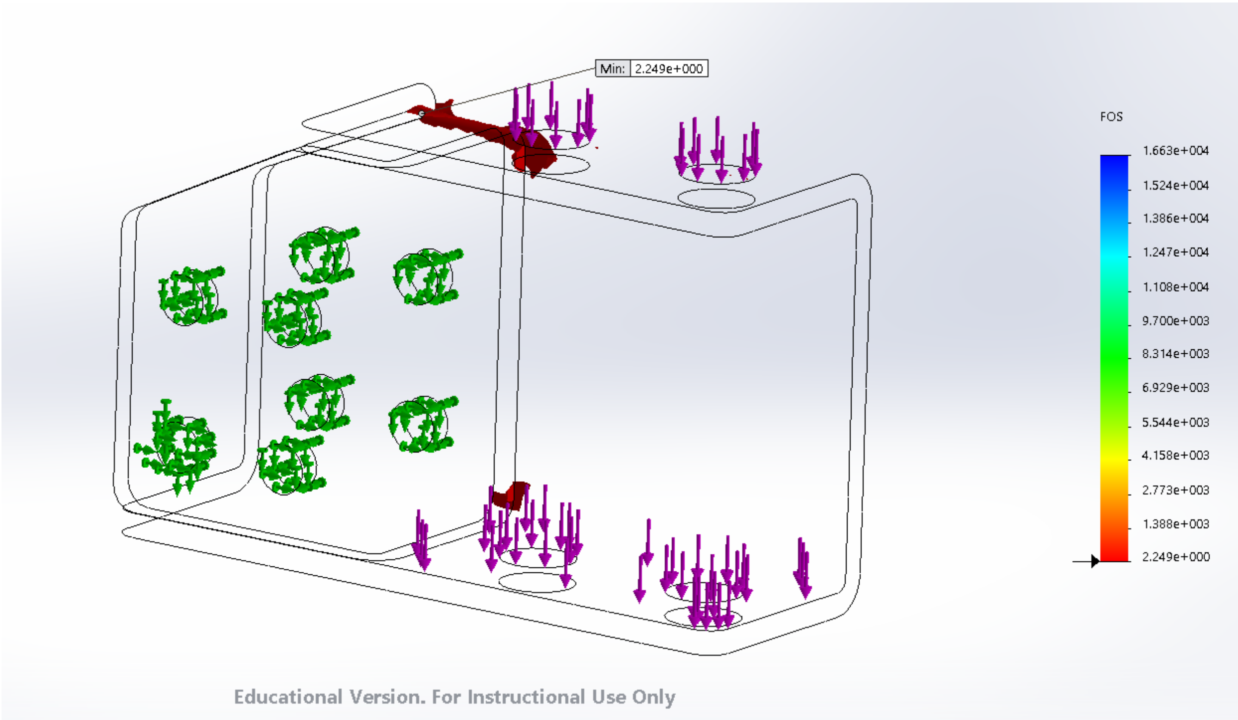


Figure 7: Actuating Arm Mounting FOS iso clipping below 5

However there is an alternate version of these mounts for when the rack is implemented on the other side of the truck with only the ladder rack installed in the main boom. The other configuration of the actuator arm mount was analyzed as well. The loading scenario is different from the mounting analyzed above since the rack only holds a ladder rack and thus the mounts experience the 500 *lbs* of equipment load and material weight. The mounting for the alternative configuration has a minimum factor of safety of 2.981 as shown in Figure 8. Fixtures and loads were applied accordingly similar to the methods above for the original actuating arm mount FEA while substituting loads seen by the alternate mount.

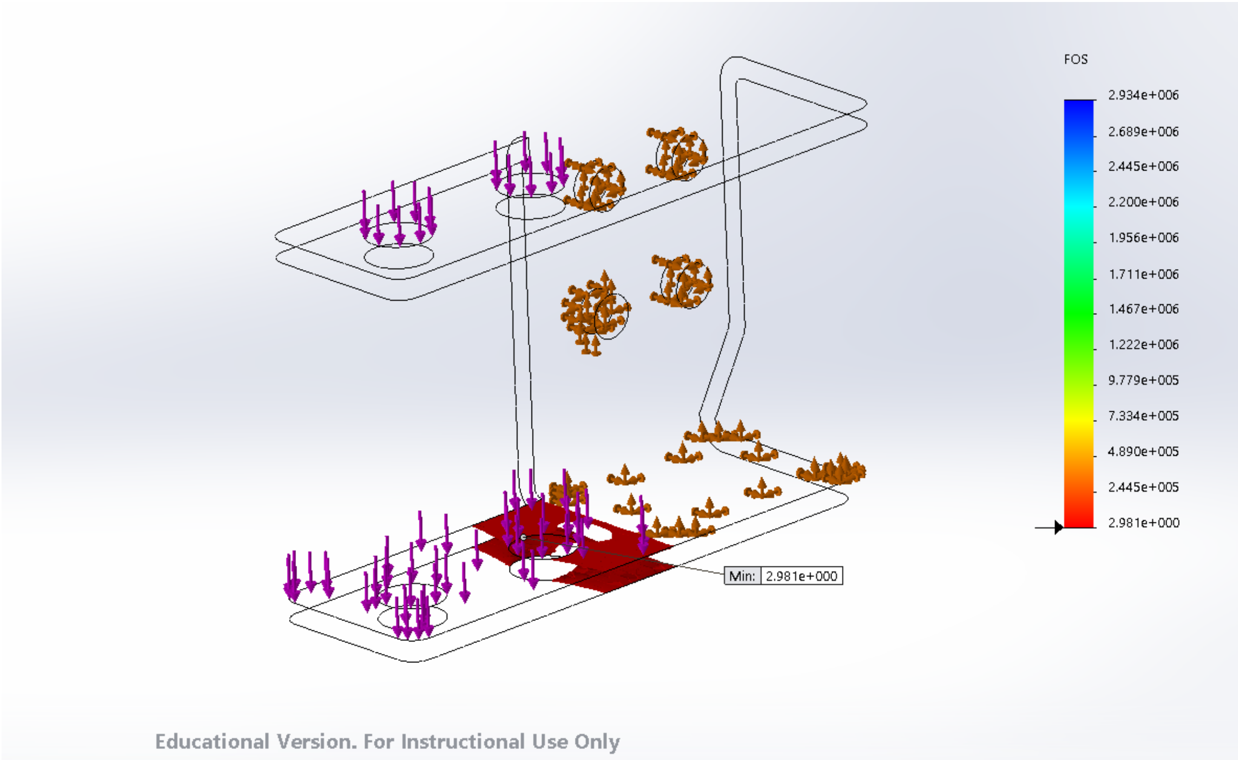


Figure 8: Iso clipping FOS below 5 alternate actuating arm configuration lowered position

C.3 Actuating Arm

One of the most critical components is the actuating arm that ultimately supports the ladder and water tank rack. The actuating arm was designed with steel tubing to insure adequate bending stiffness. The critical scenario experienced by the actuating are is the lowered position when the arm experience the max bending stresses. The 3x2 steel arm was subjected to 600 lbs of load which represents the total 1200 lbs split between the two arms. Additionally the fixed geometry is where the clevis pin mounts the arm to the main truck mount and additionally the mounting location for the Linak LA36 electric actuator.

The stress distribution is shown in Figure 9 .

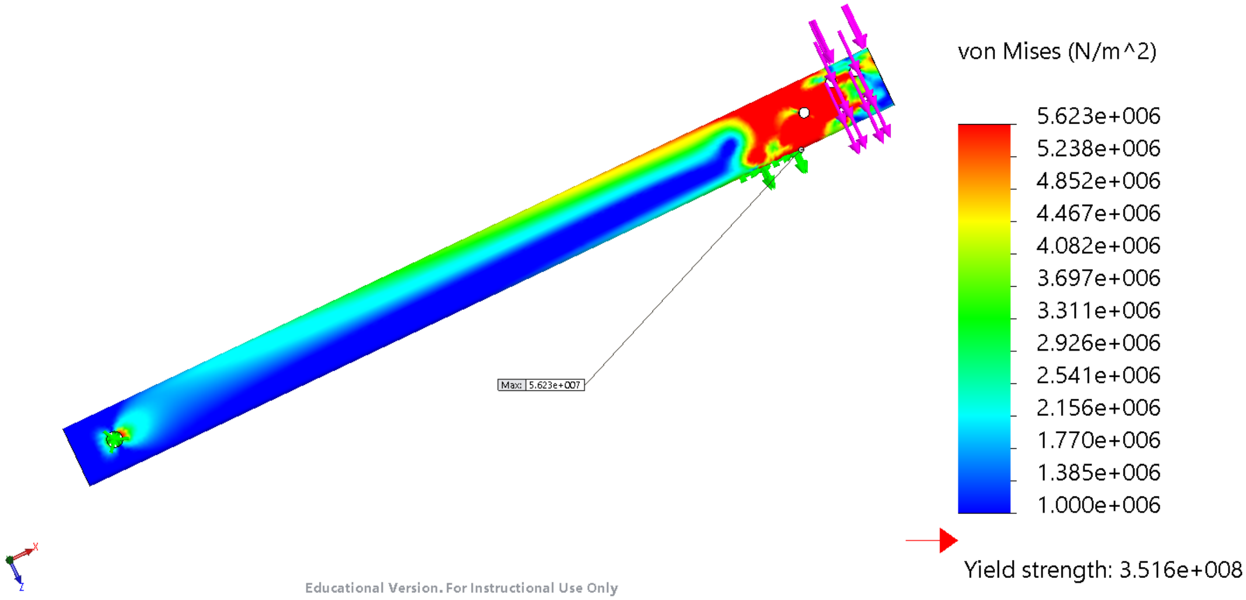


Figure 9: Stress distribution for actuating arm max stress annotation

The minimum FOS annotation can be seen in figure shown below. The actuating arm experiences a minimum FOS of 6.25 and thus exceeds the required FOS of 2 specified by the client. Although with this result there is ample room for optimization the nature of the component is such that we have deemed the maximum FOS a necessity. The actuating arm is a critical component thus a high FOS is warranted and material removal would decrease manufacturability and increase cost.

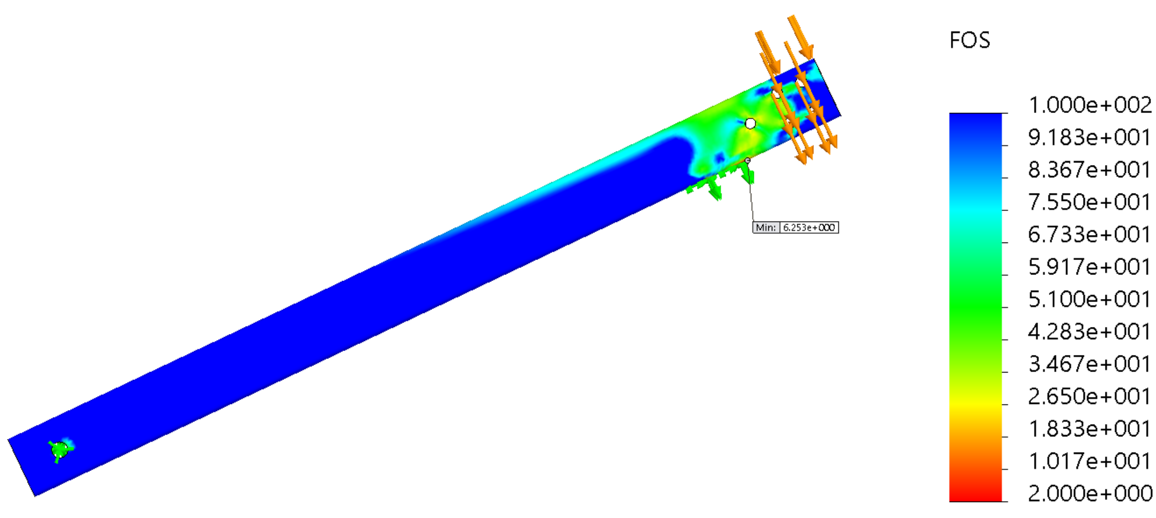


Figure 10: FOS distribution for actuating arm in lowered position

C.4 Main Truck Mount

The main truck mount is an obviously critical component that mounts the entire rack to the truck. The Mount went through multiple iterations that where progressed through inspection. The design that was brought into the FEA was the final design that was chosen. Solid works FEA was used to validate the design and demonstrate the minimum FOS requirement of 2. The FOS distribution throughout the mount is shown below in Figure 11

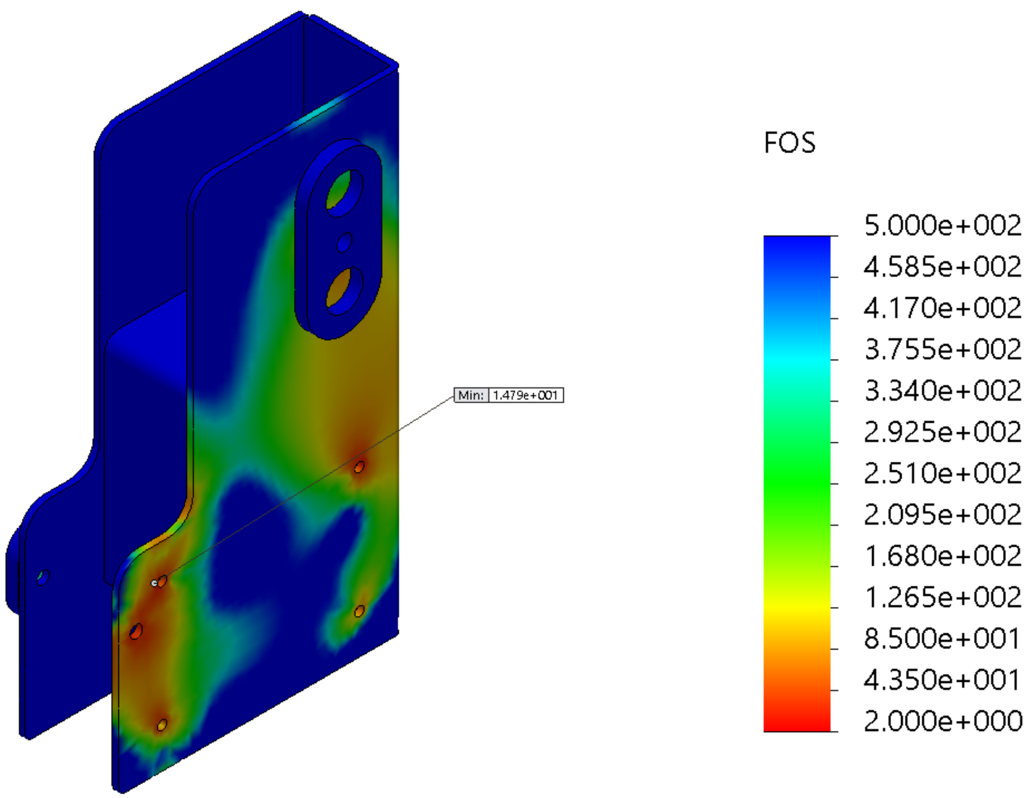


Figure 11: FOS distribution worst case loading scenario

The simulation parameters where adjusted to represent the scenario when the ladder rack is fully lowered and the largest moment is applies to the mount. As can be seen in the figure above the minimum FOS is over 14. Additionally minimum FOS is close to one of the pin holes which are expected for a FEA simulation. Stress raisers are present at the holes and cannot distribute the loads properly thus decreasing the factor of safety. However with that being the case the FEA simulations validate the mounting in regards to client needs. A stress distribution is shown below and illustrated the raised stresses at the clevis holes.

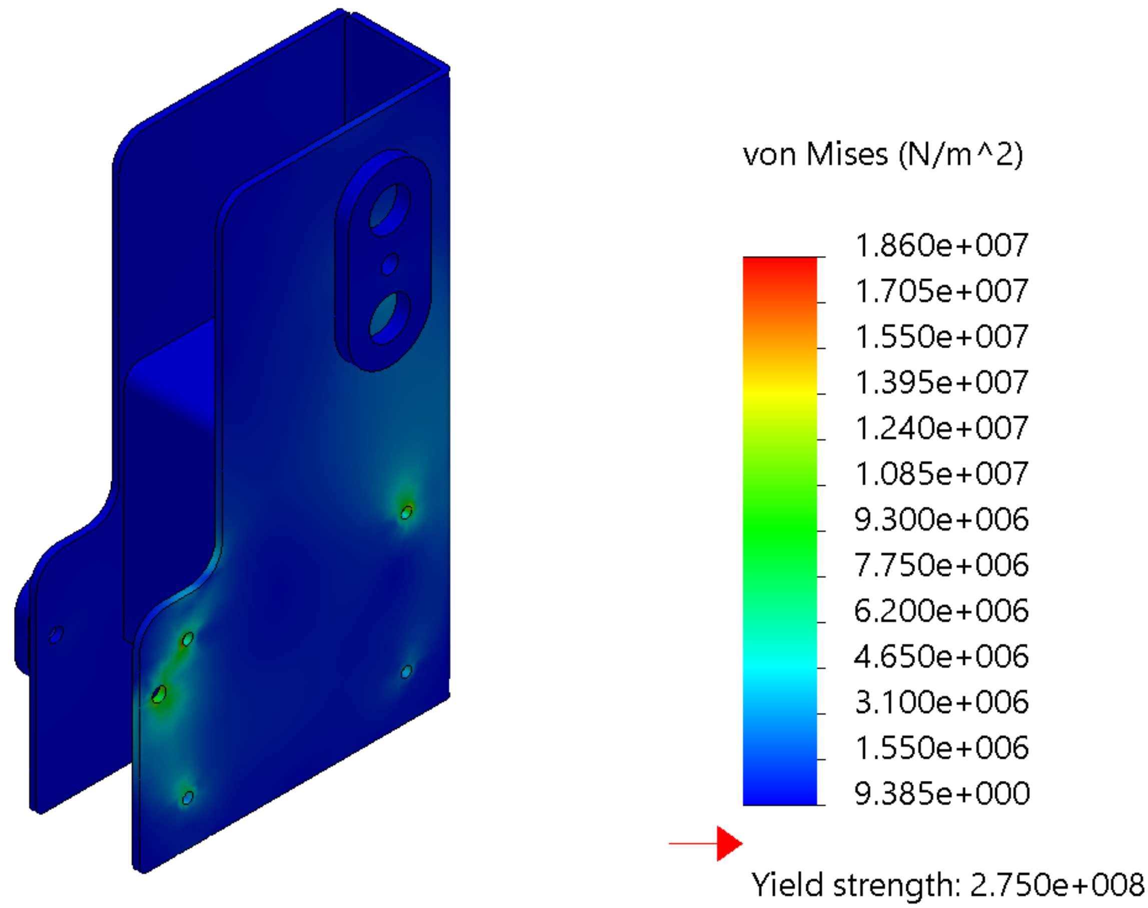


Figure 12: Stress distribution through mounting when rack is fully lowered

C.5 Water Tank Rack

The water tank rack was deemed a critical component for FEA because the J shaped brackets are in bending due to the water tank loads. A simulation was run fixing the geometry of the 2x2 aluminum tubes where the water tank rack mounts to the main boom mount. The 500 lbs load defined by the client was applied at the base of the rack to simulate the vertical loading scenario. The lowered loading scenario although upon initial inspection would seem the most critical in terms of bending the adjustable strap will provide a fixed geometry point on the outer arm of the water rack. This will minimize bending and will FEA simulation has proved to not be the critical loading scenario.

The vertical scenario FOS distribution along the water tank rack main structure is shown below in Figure 13. The minimum FOS is shown in the annotation below to be 6.776. This result yields the necessary results to validate the design and the use of 2x2 aluminum tubing.

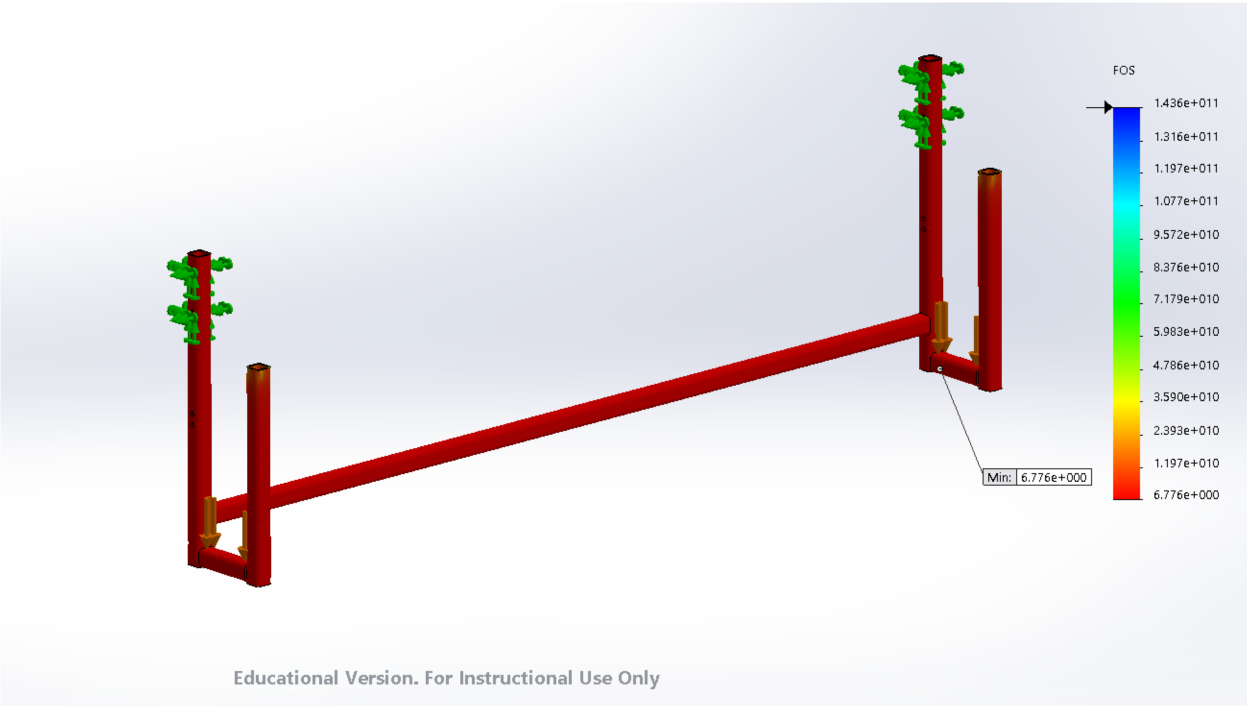


Figure 13: FOS distribution water tank rack

D. DETAILED COST

The costing for the final design was performed by contacting or utilizing tools from local material suppliers whenever possible. Costing was broken down into three major components; hardware, actuator and material/ manufacturing.

Hardware was costed by using the McMaster Carr online pricing. McMaster is a mainstream American fastener supplier and was used because of its higher prices and thus a conservative price estimate. Additionally the ZICO Adjustable Straps and ZICO Spring Handle where priced from Ziamatic Corp. Below is a Table XIV: Hardware Cost Summary indicating hardware pricing.

Table XIV: Hardware Cost Summary

Hardware	Amount	Price Per Unit	Price
0.5 13 Nyloc	50	$ 0.43	$ 21.55
0.5 13x3.25	32	$ 1.38	$ 44.10
0.5 13x5.5	21	$ 2.52	$ 52.84
0.75 10x6	4	$ 6.30	$ 25.20
0.75 10 Nyloc	4	$ 1.13	$ 4.52
0.625 Zinc pin 5.5	2	$ 3.99	$ 7.98
0.5 Zinc pin 4.5	2	$ 1.79	$ 3.57
0.5 Zinc pin 3	2	$ 1.11	$ 2.22
Zico Straps	2	$ 60.00	$ 120.00
Zico Spring Handles	2	$ 30.00	$ 60.00
		Price Total	$ 457.90

The material/ manufacturing were priced out from multiple sources. The manufacturing was priced by getting prices for bends and welds that were given by FGFT. FGFT said it would be 2 minutes per bend and 1 minute per inch of weld. A unit price for each operation could be calculated by using a rate of 65$/hour. The tubing material was priced using Online Metals, an American metal supplier with more expensive prices currently then New West Metals or Metal Supermarkets. This price gave us the most conservative cost estimate that will ensure the actual cost from New West Metals or Metal Supermarket. Likewise the sheet metal was calculated using a Canadian laser cutting provider calculator. Once again prices aired on the high side to avoid any discrepancies when purchasing occurs. Two examples of both material and manufacturing pricing for the water tank and ladder rack are shown in the tables below.

Table XV: Cost table for water tank rack

Material				Manufacturing					
Material	Length/ Area	Number of Parts	Total Legth/Area	Welding Linear Distance	Number of Bends	Perimeter Distance	Number of Plate Holes	Laser Cut Price	Manufacture Price
2x2 Aluminum Tube	98	1	98	16	0	0	0	0	$ 17.33
2x2 Aluminum Tube	33	2	66	0	0	0	0	0	$ -
2x2 Aluminum Tube	7	2	14	32	0	0	0	0	$ 34.67
2x2 Aluminum Tube	23	2	46	0	0	0	0	0	$ -
2x2 Aluminum Tube	35.75	2	71.5	16	0	0	0	0	$ 17.33
2x2 Aluminum Tube	11	2	22	0	0	0	0	0	$ -
0.25 Aluminum Plate	0.322222016	2	0.644444032	0	4	37.13	6	35.7	$ 44.37
0.25 Aluminum Plate	0.101562435	2	0.20312487	20	4	23.17	4	19.82	$ 50.15
Aluminum Tube Price		Price per foor	Total 2x2 Aluminum Tube Length		Welding Price per inch	Total Manufacture Price			
$ 227.28		$ 8.59	26.45833333	inches	$ 1.08	$ 163.85			
			Total Plate Area		Bending Price per Bend				
			0.847568902	inches^2	$ 2.17				

Table XVI: Cost table for ladder rack

Material				Manufacturing					
Material	Length/ Area	Number of Parts	Total Legth/Area	Welding Linear Distance	Number of Bends	Perimeter Distance	Number of Plate Holes	Laser Cut Price	Manufacture Price
2x2 Aluminum Tube	80	1	80	16	0	0	0	0	$ 17.33
2x2 Aluminum Tube	16.125	2	32.25	16	0	0	0	0	$ 17.33
2x2 Aluminum Tube	14	2	28	32	0	0	0	0	$ 34.67
2x2 Aluminum Tube	27.25	2	54.5	0	0	0	0	0	$ -
2x2 Aluminum Tube	12	4	48	32	0	0	0	0	$ 34.67
0.25 Aluminum Plate	0.14583324	2	0.29166648	0	4	18	3	17.1	$ 25.77
0.25 Aluminum Plate	0.206666534	4	0.826666138	0	8	31.82	4	44.6	$ 61.93
Aluminum Tube Price		Price per foot	Total 2x2 Aluminum Tube Length		Welding Price per inch	Total Manufacture Price			
$ 173.77		$ 8.59	20.22916667	feet	$ 1.08	$ 191.70			
			Total Plate Area		Bending Price per Bend				
			1.118332618	feet^2	$ 2.17				

Table XVII:Cost table for Main Boom

Material				Manufacturing				
Material	Length/ Area	Number of Parts	Total Legth/Area	Welding Linear Distance	Number of Bends	Perimeter Distance	Laser Cut Price	Manufacture Price
4x4 Aluminum Tube	184	1	184	0	0	0	0	0
Aumunum Tube Price		Price per foot	Total 4x4 Aluminum Tube Length		Welding Price per inch	Total Manufacture Price		
$ 279.58		$ 18.23	15.33333333	inches	$ 1.08	$ -		
			Total Plate Area		Bending Price per Bend			
			0	feet^2	$ 2.17			

Table XVIII: Cost Table for Mounting

Material				Manufacturing					
Material	Length/ Area	Number of Parts	Total Legth/Area	Welding Linear Distance	Number of Bends	Perimeter Distance	Number of Plate holes	Laser Cut Price	Manufacture Price
0.25" Steel Plate	0.382916422	2	0.765832843	0	4	47.03	8	23.62	32.28666667
0.25" Steel Plate	0.129861028	2	0.259722056	6.7	2	23.65	4	11.86	23.45166667
0.25" Steel Plate	0.520833	4	2.083332	0	8	49.76	8	49.4	66.73333333
0.25" Steel Plate	0.443055272	4	1.772221088	20	8	39.89	4	36.72	75.72
0.25" Steel Plate	0.055552	2	0.111104	14.6	0	13.11	0	5.24	21.05666667
0.25" Steel Plate	0.041458307	2	0.082916614	12.6	0	11.42	0	4.56	18.21
0.25"Aluminum Plate	1.7797472	2	3.5594944	0	2	75.74	6	33.9	38.23333333
0.25"Aluminum Plate	1.314582492	2	2.629164984	0	0	64.17	2	26.29	26.29
0.5"Aluminum Plate	0.37865632	2	0.75731264	65.94	0	81.23	9	75.56	146.995
0.5"Aluminum Plate	0.093194385	2	0.18638877	18.84	0	27.6	3	23.78	44.19
0.375" Steel Plate	0.030486092	4	0.121944366	20.096	0	17.22	3	27.84	49.61066667
0.25" Aluminum Plate	0.380971978	2	0.761943957	34.84	1	38.34	0	38	77.91
			Total Tube Length		Welding Price per inch				
			0	inches	1.08	$			
			Total Plate Area		Bending Price per Bend				
			13.09137772	feet^2	2.17	$			
			Total Manufacture Price						
			620.69	$					

Finally the actuators where priced using Linak a supplier that is already affiliated with FGFT. The pricing was not known for certain once the control box was included. Sales representative assured that the maximum price would be 1500$ US. The budget reflects this quote.

E. DESIGN DRAWINGS