MEC 470 **Design of Machines and Mechanisms** **Spring 2021**

Final Design Project

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~Abstract~

The primary objective of this design project is for the students to understand and design the aerial ladder on a firetruck. In which, they focused on 3 primary degrees of freedom which includes the tiller motor, the hydraulic lift, and the hydraulic extender. The students then modeled and developed the mechanisms in Solidworks© and produced a dynamic simulation, static simulation, and FBD on the models. Secondary objectives were, understanding the process of the method of Assembly and Required Time, Tools, and Expertise it would take to manufacture the subsystems. Additionally, the students needed to do cost analysis, and calculate the ROI based on information from the secondary objective and the materials used. Lastly, the students understood the engineering design challenges that needed to be acknowledged but were not incorporated in this project.

List of Tables

Table 1: Inspection Requirements …………………………………………………………………………… 20

Table 2: Parts List of All Parts Required to Machine and Assemble the Entire Aerial Apparatus Split into Sections with Links …………………………………………………………………………………………………….. 24

List of Figures

Figure 1: Provided Image of Ladder Truck to Represent Goal of Project ……………………………………….. 2

Figure 2: Video Link of How the Ladder Extension and Contraction Pulley System Works Supplied by the Elizabeth Township Fire Department ………………………………………………………………………………………….. 5

Figure 3: Solidworks Render of Completed Tiller Rotational System …………………………………………… 11

Figure 4: Contracted Aerial Ladder Assembly with the Basket Attached ………………………………………… 14

Figure 5: Extended Aerial Ladder Assembly with the Basket Attached ...………………………………………… 14

Figure 6: Full Assembly Extended ……………………………………………………………………………… 15

Figure 7: Full Assembly of The Aerial Ladder Contracted …………………………………………………….... 15

Figure 8: Solidworks Stress Analysis on the 9,200 lbs Equivalent Loading on the Base Section with Gravity …... 16

Figure 9: Solidworks Stress Analysis on the 3,000 lbs Equivalent Loading on the Mid-Section with Gravity …… 17

Figure 10: Solidworks Stress Analysis on the 400 lbs Loading on the Fly Section with Gravity ………………… 18

Figure A.1: Side and Front Views of the Dimensioned Drawing of the Base Section of the Aerial Ladder ……... 38

Figure A.2: Top View of the Dimensioned Drawing of the Base Section of the Aerial Ladder ………………….. 39

Figure A.3: Side and Front Views of the Dimensioned Drawing of the Mid-Section of the Aerial Ladder ……… 40

Figure A.4: Top View of the Dimensioned Drawing of the Mid-Section of the Aerial Ladder …………………... 41

Figure A.5: Side and Front Views of the Dimensioned Drawing of the Fly Section of the Aerial Ladder ……….. 42

Figure A.5: Top View of the Dimensioned Drawing of the Fly Section of the Aerial Ladder ……………………. 43

Figure A.6: Top and Side Views of the Dimensioned Drawing of the Aerial Ladder Platform …………………... 44

Figure A.7: Section View of the Dimensioned Drawing of the Aerial Ladder Platform …………………………. 45

Figure A.8: Dimensioned Drawing Aerial Ladder Basket ……………………………………………………... 46

Figure A.9: Dimensioned Drawing of the Tiller Gear ...……………………………………………………………47

Figure A.10: Dimensioned Drawing of the Pinion Gear in the Tiller Mechanism ...………………………………48

Figure A.11: Dimensioned Drawing of the Wheel Holding Plates for the Extension System …………………….. 49

Figure B.1: Drawing of Low-Carbon Steel Rectangular Tube Used as Truss Beams for Base, Mid, and Sections of Ladder and Basket, Angular Lift, and Attachment Subsystems Provided by McMaster-Carr ……………………... 50

Figure B.2: Drawings for Alloy Steel Rods That Will be Used as Rungs Throughout the Ladder Provided by McMaster-Carr ………………………………………………………………………………………….... 50

Figure B.3: Drawing of Support Piece Used for Each Section of Ladder Provided by McMaster-Carr …………...51

Figure B.4: Drawing of Support Pieces for Rungs on Each Section of the Ladder Provided by McMaster-Carr … 51

Figure B.5: Drawing of Wheel Shaft Used on Base and Mid Section Provided by McMaster-Carr …………….... 52

Figure B.6: Drawing for First Wheel Plate Used on Base and Mid Section Provided by McMaster-Carr ………... 52

Figure B.7: Drawing of Second Wheel Plate Used on Base and Mid Section Provided by McMaster-Carr …….... 53

Figure B.8: Drawing of Holding Plate on Base Section Provided by McMaster-Carr ……………………………..53

Figure B.9: Drawing of Holding Plate on Mid Section Provided by McMaster-Carr ……………………………...54

Figure B.10: Drawing of High-Capacity Wheel for Base and Mid Section Provided by McMaster-Carr ……….....54

Figure B.11: Drawing of Low-Carbon Steel Rectangular Tube Used on Fly Section Provided by McMaster-Carr .55

Figure B.12: Drawing of Ground Low-Carbon Steel Sheet Used on Basket, Angular Lift, and Attachment Subsection Provided by McMaster-Carr ………………………………………………………………………. 55

Figure B.13: Drawing of Hydraulic Lift Cylinders Used in Basket, Angular Lift, and Attachment Subsystems Provided by Magister Hydraulics …………………………………………………………………………….... 56

Figure B.14: Drawing of SAE Zinc Yellow-Chromate General Purpose Washer for 0.75” Diameter Flat-H Bolt Provided by McMaster-Carr ……………………………………………………………………………………... 56

Figure B.15: Drawing of Low-Carbon Steel Rod Used to Make Pins for Rotation System Provided by McMaster-Carr …………………………………………………………………………………………………....57

Figure B.16: Drawing of ¾”-10 Zinc Yellow-Chromate Plated, High-Strength Steel Cap Screw-Grade 8 with Partial Threads and 5” Long Provided by McMaster-Carr …………………………………………………………..... 57

Figure B.17: Drawing of ¾”-10 Zinc Yellow-Chromate Plated, High-Strength Steel Cap Screw-Grade 8 with Partial Threads and 10” Long Provided by McMaster-Carr ……………………………………………………….. 58

Figure B.18: 2D Drawing of 50 Series Hydraulic Motor (Part No. 50MH38DBCSC) Used in Rotation System Provided by Cross Manufacturing ……………………………………………………………………………….. 58

Figure B.19: Drawing of Shaft and Key of 50 Series Hydraulic Motor (Part No. 50MH38DBCSC) Used in Rotation System Provided by Cross Manufacturing ………………………………………………………………………. 59

Figure B.20: Drawing of Cross Section of Slewing Bearing (Part No. HS6-25P1Z) Used in Design Provided by Kaydon Bearing ………………………………………………………………………………………….. 59

Figure C.1: Solidworks Rendering of the Base Section of the Aerial Ladder …………………………………….. 60

Figure C.2: Solidworks Rendering of the Mid-Section of the Aerial Ladder ……………………………………... 60

Figure C.3: Solidworks Rendering of the Fly Section of the Aerial Ladder ………………………………………. 61

Figure C.4: Solidworks Rendering of the Basket Attached to the Aerial Apparatus …………………………….... 61

Figure C.5: Solidworks Rendering of the Customized Tiller Gear for the Rotation Mechanism of the Aerial Apparatus ……………………………………………………………………………………………….... 62

Figure C.6: Solidworks Rendering of the Customized Pinion for the Tiller Rotation Mechanism of the Aerial Apparatus ……………………………………………………………………………………………….... 62

Figure C.7: Solidworks Rendering of the Custom Built Platform of the Aerial Apparatus ……………………….. 63

Figure C.8: Solidworks Rendering of the Hydraulic Motor for the Tiller Rotation Mechanism of the Aerial Apparatus ……………………………………………………………………………………………….... 63

Figure C.9: Solidworks Rendering of the Aerial Apparatus with a Viewpoint from the Basket Looking Down to the Bottom …………………………………………………………………………………………………..... 64

Figure D.1: Technical Data for Hollow Steel Beams Used in Ladder Sections Provided by OnlineMetals (From Top Left to Bottom Right: 3” x 5” x ¼”, 2” x 3” x ¼”, 3” x 4” x ¼”, 1” x 5” x ¼” Cross Sections) …………………... 65

Figure D.2: Technical Data Sheet for API GL-5 80W-90 Gear Oil (Lubricant for Gear/Rotation System) ………. 66

Figure D.3: Technical Data Sheet for 50 Series Hydraulic Motor (Part No. 50MH38DBCSC) by Cross Manufacturing Inc. …………………………………………………………………………………………. 67

Figure D.4: Technical Specifications for Slewing Bearing (Part No. HS6-25P1Z) Provided by Kaydon Bearing .. 68

Figure D.5: Thrust-Moment Diagram of Kaydon Bearing ………………………………………………….... 68

Figure D.6: Technical Data Sheet of Rosenbauer Fire Truck Provided by Secaucus Fire Department …………..... 69

Figure D.7: Technical Drawing of E-ONE Fire Truck Provided by Richardson Fire Department ………………... 70

Figure D.8: Technical Drawing of Extendable Ladder (Not on Fire Truck) ………………………………………. 70

Figure D.9: Specifications of Extendable Ladder for Everyday Use …………………………………………..... 71

Figure D.10: Technical Drawing of Tiller Truck with Rear-Mounted Basket ……………………………………..72

Figure D.11: Technical Drawing of Fire Truck with Rear-Mounted Aerial ……………………………………….. 73

Figure D.12: Drawing of Patented Fire Truck Extendable Ladder From 1894 …………………………………….74

Figure D.13: Technical Drawing of Patent for Retractable and Extendable Ladder From 1895 (U.S. Patent Office) …… 75

Figure D.14: Drawing of Aerial Ladder Fire Fighting Apparatus Provided by U.S. Patent Office (2004) ……….. 76

Figure D.15: Technical Data Sheet and Drawing of Hydraulic Lift Cylinders Provided by HydratechIndustries ... 77

Figure D.16: Drawing of Hydraulic Lift Cylinders in Use ……………………………………………………....78

Figure D.17: Drawing of Hydraulic Lift Stabilizing System ……………………………………………….... 78

Figures E.1: Handwritten Design Process for Gear Rotation System ……………………………………..79-83

Figures E.2: Handwritten Design Process for Lift Cylinder ………………………………………………………. 84

Figure E.3: Handwritten-Exploded Diagram of How the Contraction of the Ladder Pulley System Works ……....85

Figure E.4: Handwritten-Exploded Diagram of How the Extension of the Ladder Pulley System Works ………..86

Figure E.5: Images of the Rotation System and Ladder in Warehouse Provided by Secaucus Fire Department …. 87

List of Equations

(1) - $p_c = \frac{\pi d}{N}$………………………………………………………………………………………….... 7

(2) - $p_b = p_c \cdot cos\theta$……………………………………………………………………………………… 7

(3) - $p_d = \frac{N}{d}$…………………………………………………………………………………………….... 7

(4) - $a = \frac{1}{p_d}$…………………………………………………………………………………………….... 7

(5) - $b = \frac{1.250}{p_d}$…………………………………………………………………………………………… 7

(6) - $W = \frac{T \cdot n}{5252}$…………………………………………………………………………………………….... 8

Table of Contents

I. **Introduction** 1
II. **Proposed Design and Analysis** 4
III. **Method of Assembly and Required Time, Tools, and Expertise** 12
IV. **Cost Analyses** 24
V. **Systems Engineering Challenges** 28
VI. **Overall Experience Gained by Team** 31
VII. **Conclusion & Recommendations** 33
VIII. **Bibliography** 34
IX. **Appendices** 37

I. Introduction

a) Scenario

The firetruck plays an integral role when it comes to saving lives in an emergency. Primarily, the most notable part of a firetruck is its ladder which can allow firefighters to reach extreme heights to rescue patrons. The students were tasked to generate a highly competitive design with a profit margin set at 150%. In order to properly achieve this task, the students were inspired by the three degree of freedom fire truck ladders that are the industry standard. The subsystems that these DOF consisted of included the tiller, ladder extension and the angle lift mechanisms. Additionally, the students noted that other factors that needed to be considered include the Cost, safety, reliability, power requirements, spatial requirements, method for assembly, durability and expected life, Required time of deployment and general maintenance. By including these factors, the students would be able to closely emulate the design of a competitive product, thus achieving the task at hand.

The students were also required to consider factors concerning the town in which the ladder trucks would operate in. The truck producing company considered the production of 500 - 1,000 trucks for small towns having populations of 3 to 4 thousand people with 90+% of the buildings being between 2 to 5 stories tall. The truck company is looking for an affordable system for these low budget towns and must have a fully functional and completely safe lifespan of 30+ operating years. The company that wins the bid for the ladder design will also be given a contract to produce 500 working models of the proposed design/systems. An example of what the students were asked to achieve was provided as shown in **Figure (1)** below.

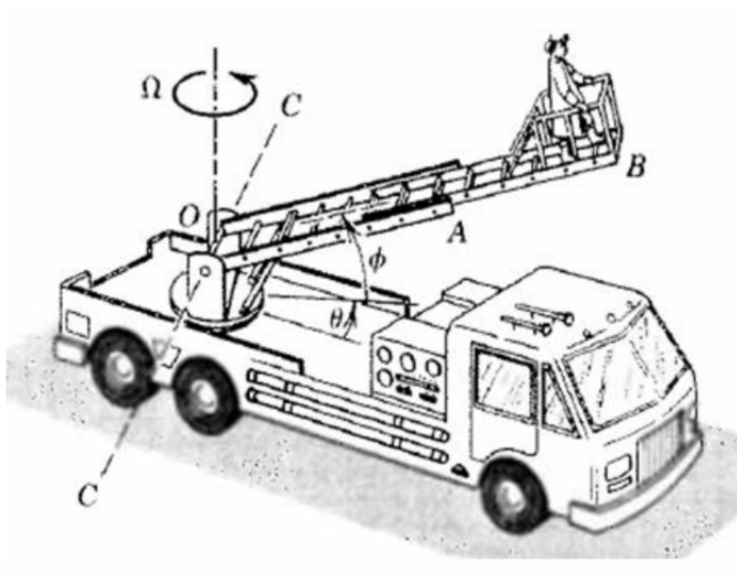

Figure 1: Provided Image of Ladder Truck to Represent Goal of Project

b) Specifications/Performance Requirements

The ladder had to meet certain specifications and performance requirements in order to be considered "fully functional" and ready for the bid. The entire system must rotate at a rate of 2.5 to 3 inches per second to simulate quasi-static conditions. In the case of this ladder, the student designers have chosen that the system rotate at 3 inches per second, which will then be used to model the entire rotation system (which will also be dependent on the gear's radius). The entire system will be installed and operated from above the bed of the trucks with a well-secured and stable area covered with a 5 ft. by 5 ft. by 1.5 ft. thick AISI 1020 steel section beneath (for installation of the ladder's base support system). The area under this plate provides an opening of 2.5 ft. for the installation of the components of the powertrain. The stabilizing boot of the truck is assumed to be fully designed and would be constructed by the truck company to satisfy the triangle of stability requirements (based on the worst case scenarios of the ladder system).

The hydraulic system of the ladder is required to rise 60 degrees from the center-line of the ladder in the collapsed position and the rotational system is required to be able to at least rotate 105° clockwise and counterclockwise, however, it should also be able to rotate the full 360°. This means that the rotation system must have closed-loop capabilities to be able to attain such precision and delicate controls. Regarding extension, the ladder system needs to be able to expand 75 ft. from the base of the ladder assembly. A basket/bucket must also be attached to the end of the ladder which must be capable of housing 3 adults (including the rescue personnel) and pets. The dimensions of the baskets are NOT added for the extension requirements. In addition to the dead weight of the entire assembly, the system (and all subsystems part of it) must be able to handle an additional live weight of 700 pounds (excluding factor of safety considerations). The system also needs to be "independently" electric powered either by the use of batteries or a (gasoline powered) generator. A final, additional requirement is that all parts sourced for the design must be from US-made materials/US-based companies.

II. Proposed Design and Analysis

a) Ladder Extension Subsystem

When embarking on this project, the students knew that they needed to design multiple subsystems. For the ladder extension subsystem, multiple methods were considered to extend the ladder. Firstly, a hydraulic lift system was examined. After consulting with numerous fire stations, fire truck manufacturers and customer support representatives, it was determined that the majority of extension systems were run by a single push pole rod and sheep carrier system. This system utilized pulleys and steel rope to extend the ladder and was determined by the assumption that it was cheaper, lighter weight, and was the industry standard.

The final proposed design can be seen in Figure (2) below. The pulley system can be broken down into two subsystems: the extension and contraction of the ladder. The video shows the extension of the aerial ladder. In the system, there are pulley ratios which allow for the fly section to be extended at a faster rate than the mid section. Both, the extension and contraction of the ladder is controlled by the hydraulic cylinder that has two pulleys on the end that control each subsystem.

Figure 2: Video Link of How the Ladder Extension and Contraction Pulley System Works Supplied by the Elizabeth Township Fire Department

A visual of the two subsystems for extension and contraction can be found in Appendix E.4 and E.5 in an exploded view for an easier representation. The two subsystems are combined into one and another one is added to the other side of the ladder to prevent torsional stress from imbalanced weight.

To allow for there to be a secure connection between the three sections, there is a 15% length overlap. To reach the 75 feet requirement, the three sections were chosen to be 28.75 feet long for the base and fly sections of the ladder and 32.5 feet for the mid- section. This allows for a 3.75 foot overlap on each section. They stack on top of each other in a drawer-like fashion with rollers that support the weight of the sections and allow for the aerial apparatus to extend and contract. The rollers can be shown in Appendix B.10. The mid and base sections have support plates to prevent the following section from pivoting off.

b) Angular Lift Subsystem

When dealing with the development of the Angular Lift Subsystem, it was important for the students to understand the live and dead load stresses on the ladder. Once determined, the students were inspired by other similar subsystems found on large machinery such as cranes, dump trucks and excavators. It was determined that this lift needed to support 28635 lb-force at 56 inches from the pivot point. As a result, the group concluded that a twin set up of double acting hydraulic cylinders were needed to achieve the goals of this subsystem. These lifts were chosen primarily because it had a stroke distance 16 inches which was over the required stroke distance of 14.88 inches. Additionally, this lift has a retracted dimension of 17.5 inches which was slightly over the found length of 17.35 inches. When fully extended, the angular lift subsystem will cause the ladder to extend to an angle of 61.82°, which was over the initial 60.00° requirement. To power the hydraulic system, the team plans on using a hydraulic engine that has the capability to work at a max pressure of 10000 psi. By using a Coupler, The hydraulic pump would have the capabilities of splitting the pressure so that both hydraulic cylinders are able to meet their Max pressure at 3000 psi. As for powering this hydraulic pump, The unit will be connected via PTO to be powered by the fire truck battery. Additionally, if need be, the pump could be reconnected to external power source if necessary.

c) Tiller Subsystem

Similar to the Angular Lift Subsystem, the students were inspired by designs that are commonly seen in the industry today and take advantage of the systems seen in large machinery when it came to the development of the tiller subsystem. The simplest design that was settled upon was the use of one large external ring gear with a double pinion-double motor setup and a slewing bearing underneath to handle the rotation of the system. As mentioned in the **Introduction**, the opening for the installation of the turntable was 2.5 ft. It was assumed that this was a circular opening, thus allowing the external gear to rest on top of this rather than being housed inside the torque box. The 30 inch diameter represents the circle created by the center of the 15 0.75 in diameter bores surrounding the external gear. The base circle of the gear is designed to be 31.5 inches in diameter (giving a 1.5 inch thickness for the outer ring) with the pitch circle having a diameter of 32 inches. After settling on the idea that the gear would have 108 teeth with a 20° pressure angle, the circular pitch, diametral pitch, base pitch, addendum, and dedendum were calculated using the following equations:

$$p_c = \frac{\pi d}{N} \quad \textbf{(1)}$$

$$p_b = p_c \cdot cos\theta \quad \textbf{(2)}$$

$$p_d = \frac{N}{d} \quad \textbf{(3)}$$

$$a = \frac{1}{p_d} \quad \textbf{(4)}$$

$$b = \frac{1.250}{p_d} \quad \textbf{(5)}$$

Using **Equation (1)** the circular pitch was found to be 0.931 inches. Using **Equation (2)** the base pitch was found to be 0.875 inches. Using **Equation (3)** the diametral pitch was found to be 3.375 inches. Using **Equation (4)** the addendum was found to be 0.3 in. Lastly, with the use of **Equation (5)** the dedendum was found to be 0.37 inches. The face height of this outer portion of the gear will be 4 inches. These calculations can be found in **Appendix E Figure (E.1)**. Since these precise specifications cannot be found so easily on the market, in addition to Solidworks' Gear Toolbox not providing a diametral pitch of 3.375 in, the gear and pinion had to be hand modeled and custom built for the manufacturing stage of the operation.

The inner portion of the gear would have a thickness of 2 in, thus providing an outer diameter of 28.5 in. and an inner diameter of 24.5 in. This portion would be stepped up 1.4 in from the top surface of the outer ring. with the entire face height of this inner section being 2.5 in. This stepped-up inner portion is where the platform subsystem will sit on top of. The inner portion has 24 0.75" threaded bores located 1 in from each edge with a counterbore on the underside to make sure it is flush with the bottom surface and to ensure that the bores are machined properly. The drawing of the gear can be found in **Appendix A Figure (A.9)**.

Using the *Design of Machinery* textbook, written by Professor Robert L. Norton, **Table 9-4a**, it was determined that for a pressure angle of 20°, the minimum number of teeth the pinion needed was 18. Using this as the starting point, this provided our design with a gear ratio of 6 which is well within reason. Considering that the most a gear ratio should be for one stage is 10:1, having a 6:1 ratio works perfectly. Assuming the rate of rotation to be 3 in/s, with a pitch radius of 16", this provided an output RPM of 1.7904. Factoring in the gear ratio, this gave the pinions an RPM of 10.7424. Factoring the gear ratio into the 32" diameter of the gear also gave the pinion a 5.33" pitch circle diameter with the same circular pitch, diametral pitch, base pitch, addendum, and dedendum as the gear. After the gear trains were fully designed, the two motors for the design needed to be chosen.

By calculating the required horsepower needed to move the ladder 14 ft out (midsection of the ladder in the extreme position and with a safety factor of 2 applied), it was found that for the system to rotate at 3 in/sec, the required horsepower was 79.08 hp. This was then used to calculate the required torque for both the gear and the pinion using the following equation (from *Fundamentals of Machine Component Design* textbook written by Robert C. Juvinall and Kurt M. Marshek):

$$W = \frac{T \cdot n}{5252} \qquad \textbf{(6)}$$

The required torques of the gear and pinion were found to be 231,964.4 lb-ft and 38660.734 lb-ft respectively. Since a double pinion-double motor setup is being used, this means that each motor must supply only 39.51 hp and each pinion must supply only 19330.367 lb-ft of torque. The way the dual system works is by having the motors work in unison to create the full 360° which would relieve stress on one motor and allow a more balanced and efficient system. To allow for the precise movement of 105° clockwise and counterclockwise, the students were aware that the motor needed to have closed-loop capabilities. This led to the decision to utilize a hydraulic motor with servo valve controls. The servo valve controls would make use of a basic hydraulic circuit to effectively control the amount of working fluid/pressure, thus controlling the RPM and output power produced by the hydraulic motors. This would also allow the ladder to fully stop and rotate back and forth depending on the input of the user. To match the specified criteria, the motor chosen was a 50 series gear hydraulic motor (Part No. 50MH23-DBCSC) produced by Cross Manufacturing. The maximum output power of each motor is 100 hp, therefore even if one fails, the other can compensate and continue the operation (even though it would apply an immense amount of stress on the pinion and wear down the motor). The motor itself is also fairly compact, the dimensions are 5.75" x 6.46" x 5.96" with a ⅞" shaft diameter and a 1-⅝ sized keyway. The drawing of the motor and the drawing of the motor's shaft can be seen in **Figure (B.18)** and **Figure (B.19)** of **Appendix B** respectively and the bill of materials can be found in **Figure (D.3)** of **Appendix D**. The motors and pinions would be fixed onto the bed of the truck (with the hydraulic cables and hydraulic circuit hidden under the torque box), allowing the gear to be the one rotating rather than the pinions rotating around the gear. The energy source of the hydraulic motors come from a P.T.O. device (power take-off) which transfers power from the transmission of the truck's engine and redirects it to a secondary source. This would allow a more efficient system overall by simply relocating and redirecting energy.

The accessories for the gear train and motors include the slew bearings, washers, and bolts. The slew bearing that would be utilized is provided by Kaydon Bearing's gearless HS6-25P1Z bearing. This slew bearing has a 29.5" outer diameter (which would sit in the swivel unit) and be bolted to the gear underneath it to reduce friction and allow the rotation to flow smoothly. The drawings can be found in **Appendix B, Figure (B.20).** The bill of materials and thrust-moment diagram for the slew bearing can also be found in **Figures (D.4)** and **(D.5)** of **Appendix D** respectively. There will be 2 types of bolts used for the rotational subsystem; both types are ¾"-10 zinc yellow-chromate, grade 8 steel, hex head with partial threads, however, they vary in length. The first type will be 5" long and used on the stepped up portion of the inner diameter of the ring alongside SAE zinc yellow-chromate, grade 8 steel 0.75" washers. The attachment platform (where the hydraulic cylinders sit) is also designed to be mounted onto the gear and since it also has a 2.5" face height, the 5" bolts will fasten the two parts together. The second type will be 10" long and fasten the external gear and slew bearing to the bed of the truck. The threads lie within the torque box and will anchor the entire aerial system. The drawings for the SAE washers, 10" bolt, and 5" bolt can be seen in **Figures (B.14)**, **(B.16)**, and **(B.17)** of **Appendix B** respectively. The low carbon steel rods will be used to make the 5 10" anchor pins that will also help anchor the tiller system to the truck. The ratio of bolts to pins on the external gear should be 2:1. The drawing of the low carbon steel rods can be found in **Figure (B.15)** of **Appendix B**. The chosen lubrication for the gear assembly is API GL-5 80W-90 gear oil provided by Sunoco and Lucas Oil. The lubricant was chosen due to its high performance during high torque operations. This type of lubricant is also commonly used and compatible with these types of systems. The technical data sheet for the lubricant can be found in **Figure (D.2)** of **Appendix D**. The completed assembly of the tiller system can be seen below in **Figure (3)**.

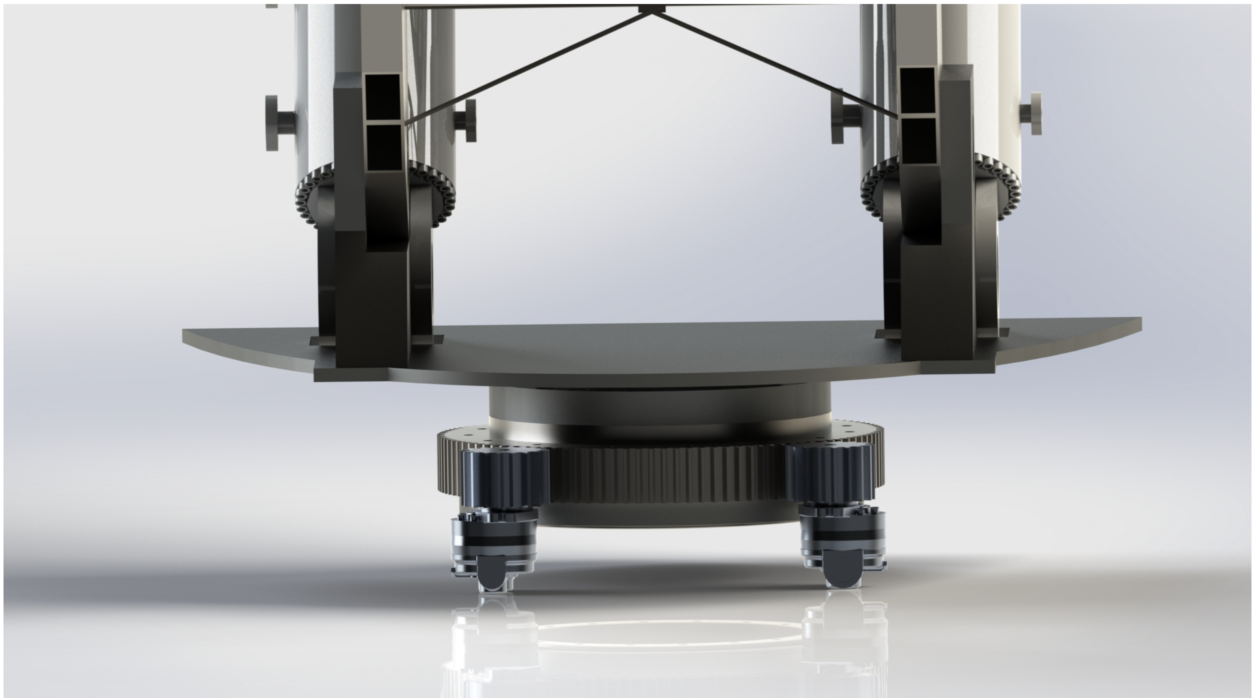

Figure 3: Solidworks Render of Completed Tiller Rotational System

III. Method of Assembly and Required Time, Tools, and Expertise

a) Manufacturing & Method of Assembly

The first and most crucial step is to machine the sheets, plates, and rods into the necessary dimensions. Through the use of CNC mills and welding machines, the custom diameters, tolerances, and dimensions are formed while also controlling and managing waste production. The assembly then makes use of jigs (under the watchful eye of machinists) to guide the parts into position and weld the individual beams and rods to form the separate segments of the ladder and subsystems. The assembly process makes heavy use of overhead cranes to lift the heavy sections of the aerial in order to move them around into their desired position; once the 3 individual sections are fully welded and outfitted with the necessary attachments, the large sections of the aerials are lifted into place and each section is put into the next after all of the sliders are installed. Once they are properly positioned, the hydraulic lift system and pulleys are installed onto the ladder. From here the extension portion of the ladder can be tested for functionality and any adjustments can be made before it is installed onto the bed of the truck.

Once the ladder satisfies all the extension and weight requirements, the hydraulic cylinders, gears, and pinions need to be properly lubricated by hand for installation. Overhead cranes are then once again used to lift the entire assembly and position it over the bed of the truck (in this case, the attachment subsystem will hover over the swivel unit/torque box located on the mid section of the truck). With the assistance of a floor worker and electrician, the aerial is lowered down very slowly while the workers ensure that the pins line up and fall into the right place without any obstructions or damages/scratches to either the ladder or the truck itself. Considering that the parts are custom and therefore very expensive and costly (from an economic and time sensitive sense), it is crucial that the pins of the swivel anchor are lined up properly with the large external gear. Once the aerial is completely lowered, the cable connections for the swivel unit, hydraulics, and energy source are made and the assembly is bolted down. The truck can then be taken to test all 3 dimensions of freedom in an open, free space. (*Largest Fire Truck Manufacturer*, n.d.)

To properly construct the specified design of the ladder system, the manufacturing process utilizes both machine tools and human workers to complete the assembly. Hard working American machinists and workers are the backbone of our society and are an integral part of developing machines such as the ladder system. It is estimated that in order to properly develop the system, it would take five workers around one and a half months (~1200 man hours total) to complete. These workers must also be well versed in machining techniques with at least a few years experience and the completion of similar projects. This process is also very similar to the standard manufacturing and assembly process that current aerial ladder designs follow, therefore, the manufacturing company would not need to change many of their current operations in order to complete the design of this ladder.

The initial assembly of the aerial apparatus starts with the ladder itself. The three sections are stacked as shown in **Figures (4) and (5)** below. The basket is attached to the fly section of the ladder using two hydraulic cylinders which are controlled by a gyro-sensor and arduino to ensure that the basket is parallel to the ground. For a safety feature (not shown in figures) a chain is attached to either side of the basket to the fly section in case of hydraulic failure. The chains also prevent anyone from falling off of the ladder and act as a hand rail when they reach the top.

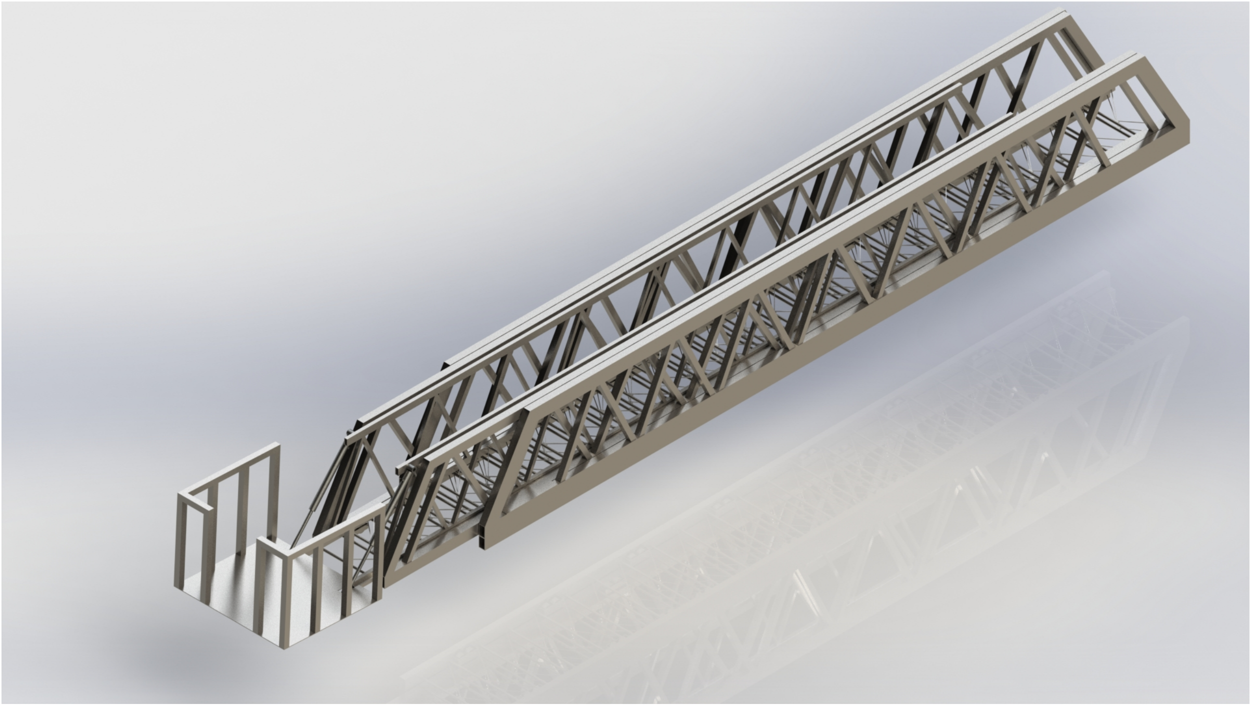

Figure 4: Contracted Aerial Ladder Assembly with the Basket Attached

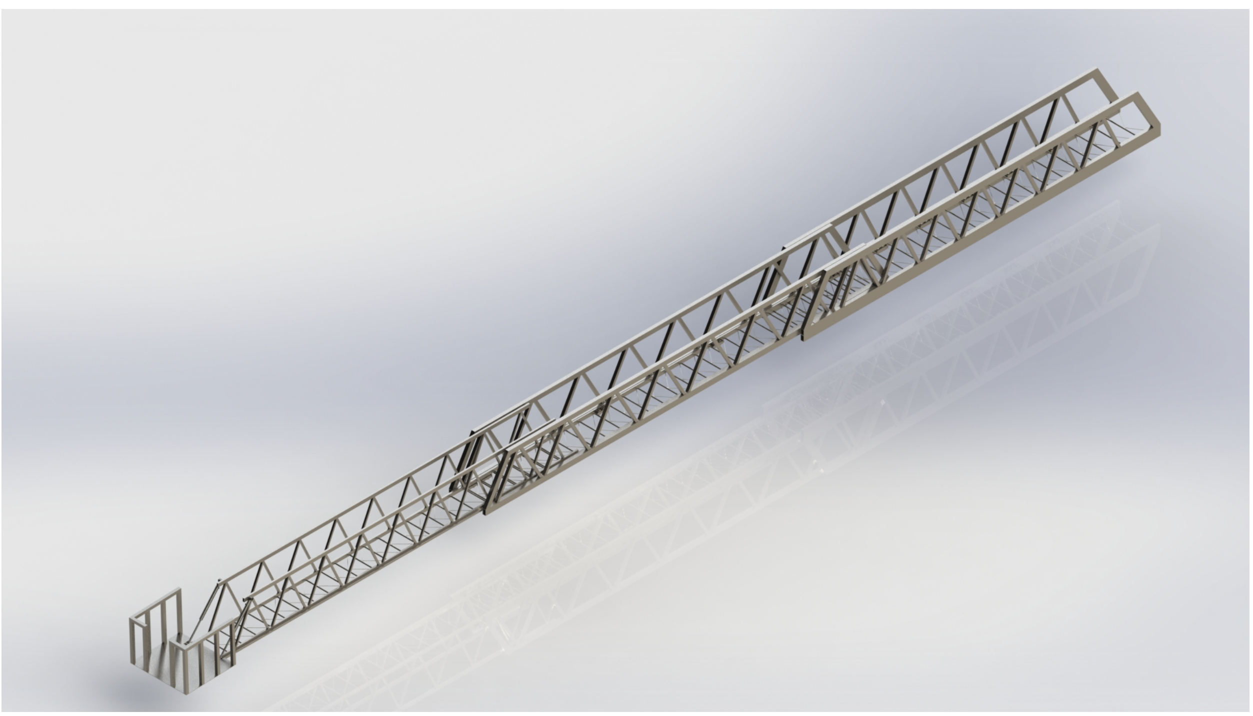

Figure 5: Extended Aerial Ladder Assembly with the Basket Attached

The aerial ladder is fixed to a platform and two hydraulic cylinders that lift the ladder. The platform is bolted onto the tiller gear that sits on a slewing bearing that is driven by two hydraulic motors. The final assembly of the aerial apparatus can be seen in Figures (**6) and (7)**.

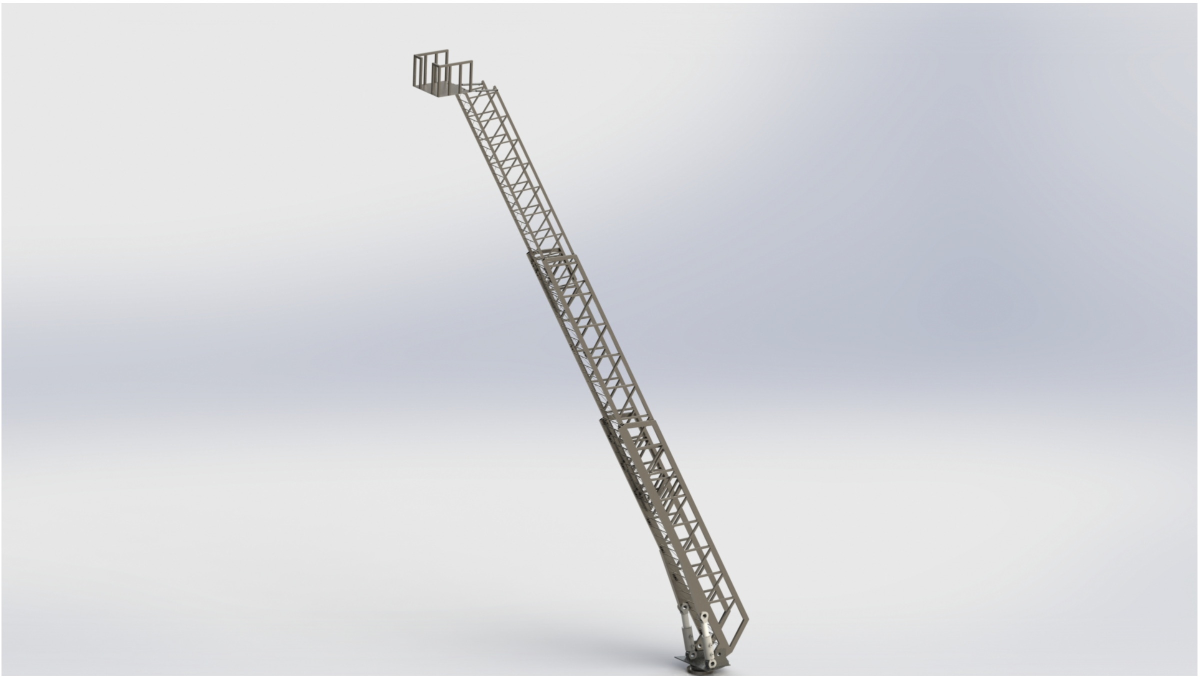

Figure 6: Full Assembly Extended

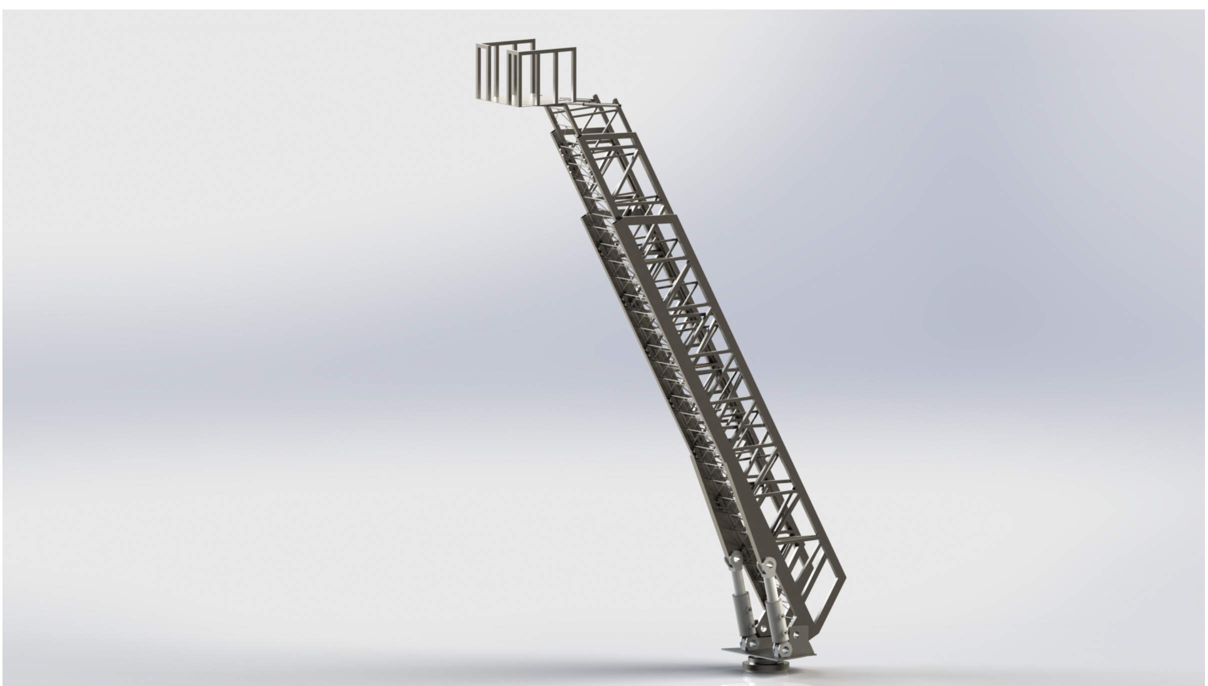

Figure 7: Full Assembly of The Aerial Ladder Contracted

b) Maintenance and Safety Features

To ensure the safety of the firefighters who risk their lives every day and the people that make up the community, stress tests were employed for the extreme condition of the aerial ladder being extended fully at a 0° incline. The equivalent load on the base section due to the weight of the mid and fly sections is calculated to be 9,200 lbs at the end of the base section. The Solidworks loading simulation can be seen in **Figure (8)** below. The maximum stress that is experienced is 1.454 x 10^8 N/m^2 which gives a factor of safety of 4.27.

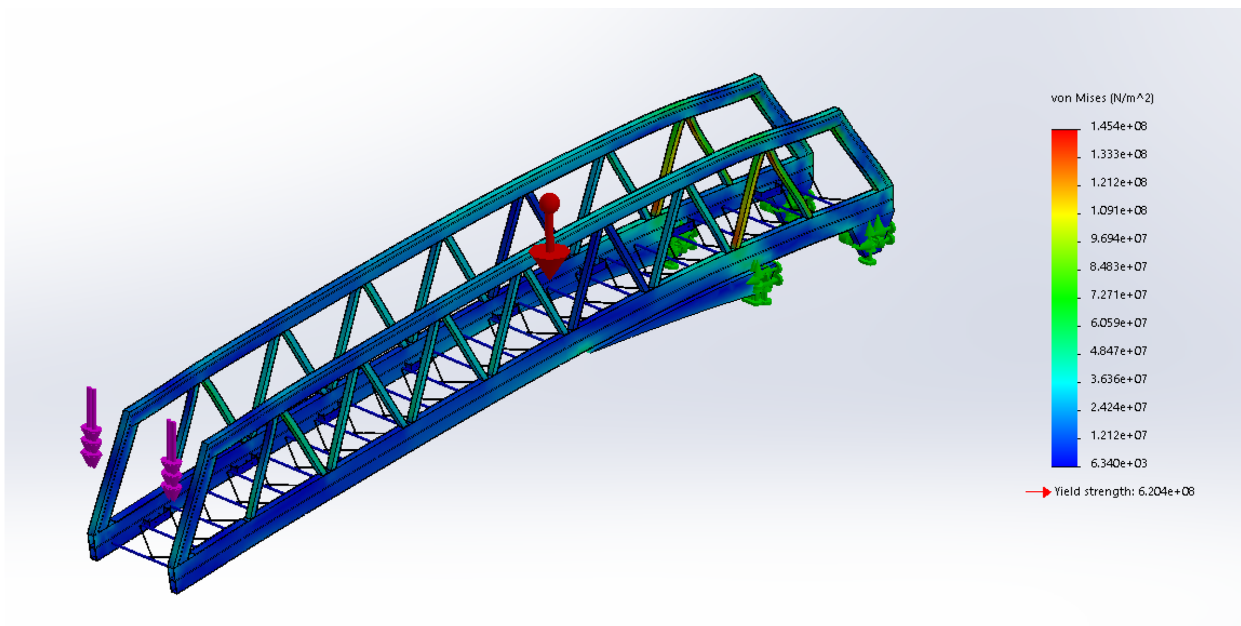

Figure 8: Solidworks Stress Analysis on the 9,200 lbs Equivalent Loading on the Base Section with Gravity

The equivalent loading for the mid-section is calculated to be 3,000 lbs and the loading analysis is shown in **Figure (9)** below. The maximum stress experienced on the mid-section is 8.686 x 10^7 N/m^2 giving a factor of safety of 7.14.

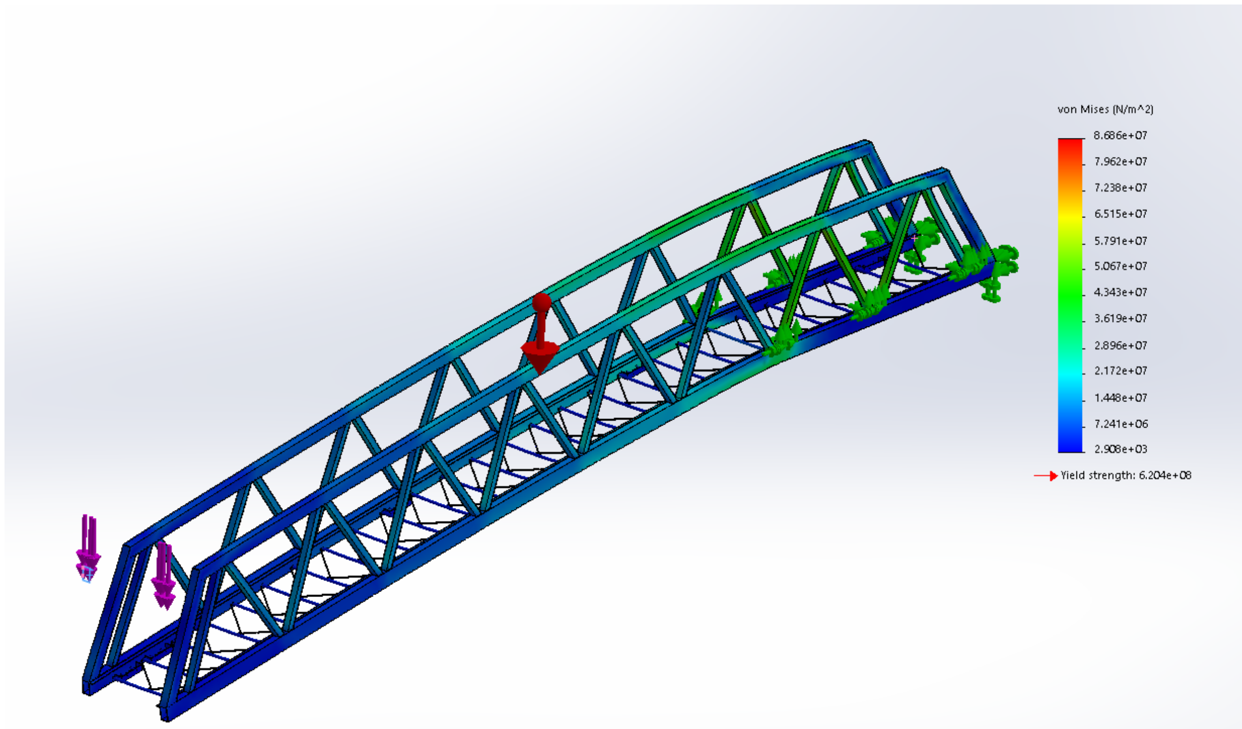

Figure 9: Solidworks Stress Analysis on the 3,000 lbs Equivalent Loading on the Mid-Section with Gravity

The loading on the fly section of the aerial ladder is 400 lbs due to the weight of the basket at the end of it. With the loading and gravity, the stress analysis can be seen in **Figure (10)** below which has a maximum stress of 8.11 x 10^7 N/m^2 and a safety factor of 7.65.

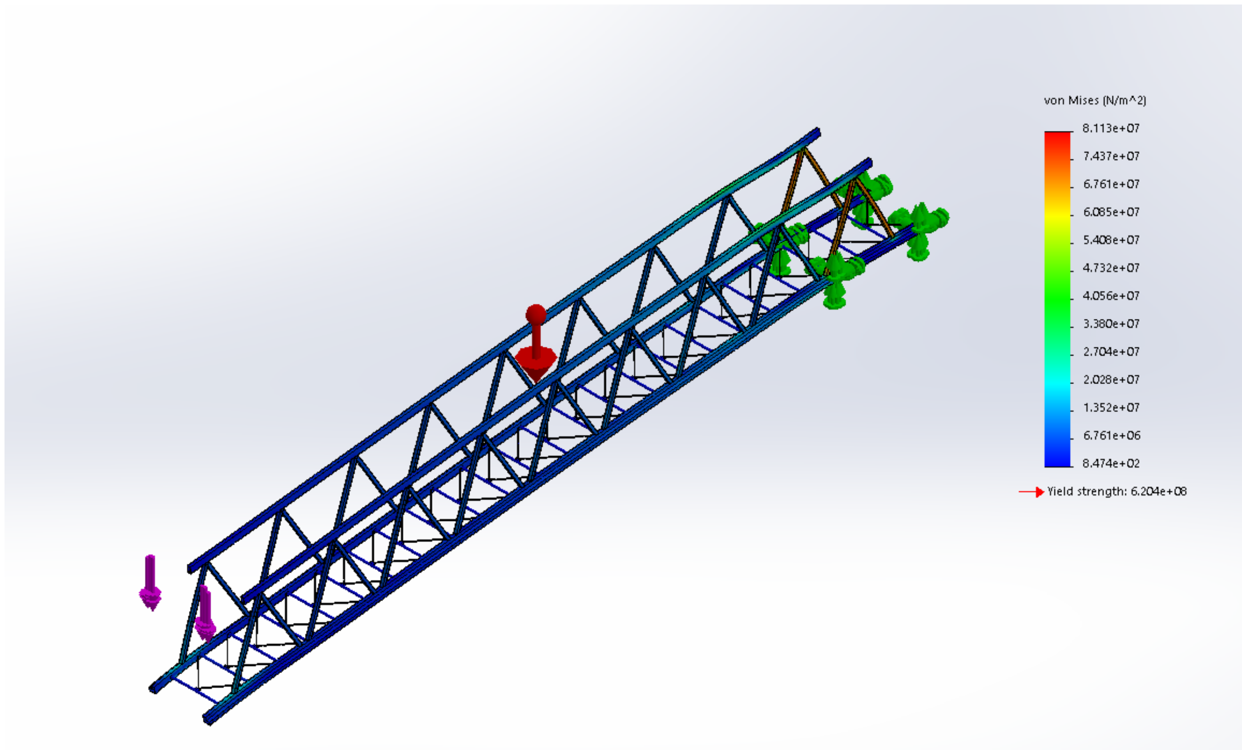

Figure 10: Solidworks Stress Analysis on the 400 lbs Loading on the Fly Section with Gravity

At the extreme condition, the aerial ladder itself has a safety factor of 4.27. This safety factor increases when the apparatus is lifted since there is less bending load and more axial loading which the ladder is designed to withstand these loads better and at a higher capacity.

Considering that a fire truck is a rescue device, safety is a crucial aspect that must be prioritized in the design process. For example, when the students were faced with the decision of where to mount the ladder, it was decided to arrange the turntable and the bucket on the middle back of the truck respectively. This decision primarily stemmed mainly due to its safety benefits over the alternative set up of having the bucket in the front of the truck. This gives the truck a lower travel height (which also brings the center of gravity down) and allows the entire truck to fit firehouses with smaller height clearances, assumed to be the average case when considering the primary target demographic. By placing the basket on the rear also provides an easy access point for firefighters to enter and climb the ladder. In contrast, by having a front mounted ladder, rescue personnel would need to climb up the rear, walk all the way across the truck along the rungs of the ladder and into the basket. By doing so, the service personnel would be subjected to a higher rate of accident and injury. Placing the bucket on the rear eliminates unnecessary, and potentially dangerous, steps and streamlines the process allowing for faster response/rescue times. Another reason for this design choice is that it does not obstruct the driver and officer's view. Most trucks with the overhang design have their baskets protrude about 6 to 8 inches in front of the truck. During the students numerous calls to fire stations, it was discovered that many local firefighters that were contacted had experienced or knew of stories of many fatal traffic accidents that were caused by this issue. Due to the factors listed above, it was decided that the mid-mount and rear placement design would be our primary approach in development.

As mentioned previously, approximately 85% to 90% of the ladder will be made of high-strength steel alloy. To ensure that the ladder meets the 30+ year operating lifespan, the steel must be hot dipped galvanized steel to ensure the ladder will have rust prevention and anti-corrosion properties. This is beneficial to the truck because it will experience environmental conditions for 30+ years. The steel must undergo weekly maintenance as well to guarantee that the steel stays in excellent condition. The bolts and washers chosen for the design also have safety in mind. The bolts and washers are zinc yellow-chromate plated; this gives them anti corrosion resistance in wet environments, thus allowing the system to last longer. This process is extremely important considering the bolts and washers are holding the aerial down onto the bed of the truck and preventing it from falling off of it.

Another safety consideration is that the motors are powered from a P.T.O. (Power Take-Off) which transfers power from the transmission of the engine to a secondary source to power the motors. This design also keeps safety in mind due to the fact that the P.T.O. can only be used when the truck is in neutral via safety interlocks. Additionally there is also a back up 12 volt pump in case of failure in the engine or P.T.O. however, it overheats quickly and is only used to move the aerial into a safe position if/when failure occurs.

Regarding maintenance of the aerial, the ladder must follow a strict routine to keep it in pristine working condition. The hydraulic cylinders, turntable system, swivel, pulleys, and gears must be lubricated with the specified lubricants on a weekly basis. Usually a ¾ of a cup to one cup of the lubricant should be used to make sure that the parts are well coated. It is ***very*** important that this be done on a weekly basis, for the introduction of friction and corrosion would severely hinder the functionality of the aerial. It was also specified that the ladder is to be coated with metal paint, colored paint, and then a clear coat, protective enamel paint for the finish. In this case, the paint must be reapplied every 3-4 months. Every 6 months, the aerial must be cleaned with a solvent-type (biodegradable) cleaner to remove any old lubricant, dirt, or debris. After the solvent is applied, the ladder must be thoroughly washed with water and dried while paying careful attention to areas where water may be pooled (PDF Aerial Maintenance, n.d.). After 25, 50, and 200 hours of operation (in addition to the standard annual one), the ladder must be inspected for any imperfections. **Table 1** pictured below displays how each part of the aerial ladder should be inspected. (PDF of AWS Ariel Operator, n.d.)

Table 1: Inspection Requirements

Item Number	Item To Check/Service	Procedure
1	Safety Decals	● Make sure that all safety decals and other operational decals are in place. ● Check that all decal fasteners are not damaged or missing.
2	Auxiliary Equipment	● Check that all auxiliary equipment is securely mounted on the aerial and/or platform (basket). ● Check that all equipment mounting fasteners are secure; not damaged or missing.
3	Lubrication	● Perform all aerial lubrication as specified in “Lubrication Specifications” on page 5-16.
4	Aerial Ladder Sections	● Inspect for unusual scratches, and damaged or missing parts on each aerial ladder section.

5	Waterway	• Inspect for unusual scratches, leaks, and damaged or missing parts on the waterway tubing.
6	Sheaves and Carrier Assembly	• Check the sheaves and carrier assembly for damage, and whether it travels properly through the guide brackets while the aerial is extending and retracting.
7	Cable Tension	• Check for proper cable tension. Adjustments can be made at the cable anchor point. • See service group 8300-P-033, Wire Rope (Cable) Replacement/Adjustment.
8	Hydraulic Pressure Lines	• Check hydraulic pressure lines for leakage at fittings and at crimp-on ends. • Check for proper hose routing and for any signs of wearing or chafing.
9	Conduit Track	• Check operation and tension of plastic conduit track. Check for excessive wear and proper routing of hoses and cables through the plastic conduit track
10	Hydraulic Oil Level	• NOTE: The aerial must be cradled with all stabilizers in the stowed position to obtain a proper oil reading. • Check the oil level as displayed on the Command Zone Information Center (CZIC) display. • Verify that the oil is at a safe working level. • Display must not indicate “Low Oil Level.” Verify oil level in hydraulic reservoir site glass matches level shown on Command Zone Information Center (CZIC) display.
11	Electrical Wiring and Components	• Inspect electrical wires and components for loose connections, corrosion, arcing, missing or damaged mounting hardware, chafing or wear.
12	Non-Slip Surfaces	• Check non-slip surfaces for wear, loose or missing mounting hardware, debris, and obstructions
13	Proximity Switches	• Check proximity switches for damage, loose or missing mounting hardware, and loose connections. • Check that proximity switches are adjusted properly.
14	Breathing Air System (if equipped)	• Check breathing air system for leakage and proper operation. • To test for leakage: Open tank valve to charge low-pressure side. • Close tank valve and note the pressure on the low-pressure side. • Leave the system set for one hour. After one hour is elapsed, check the gauge for pressure drop.
15	Equipment Mounting	• Check that equipment mounted on ladder is secure. • Check for cracks, wear, or other damage to mounting devices. Ensure that unauthorized equipment mounting has not been added.
16	Rung Covers	• Check that rung covers are secure and do not turn
17	Rung Alignment	• Check for proper operation of rung alignment indicator
18	Ladder	• Check display of ladder load capacity for acceptable tolerance.
19	Cab Controls	• Check operation of: PTO Neutral Safety Switch: Verify the operation of the neutral safety interlock. Check by shifting the transmission into drive or reverse; the PTO should disengage in both gears. PTO Parking Brake Interlock: Verify the operation of the parking brake interlock. Check for PTO disengagement with the transmission in neutral and the parking brake released. Basket Leveling: Check for proper leveling by performing the following procedure. NOTE: The basket leveling feature works only

		when the aerial is fully stowed and the Aerial Master switch is in the OFF position. 1. Position the apparatus on a suitable grade (driveway apron, etc.). 2. Activate the basket leveling switch and watch for basket movement. 3. Return the vehicle to a level surface (garage floor, etc.). 4. Activate the bas
20	Stabilizer Controls	● Check for proper operation of stabilizer controls. ● Check engine high-idle operation while operating stabilizers.
21	Aerial Interlocks and Indicators	● With the stabilizers stowed, try to operate the aerial up function using the turntable control console controls. ● If there is no aerial movement or increase on the system pressure gauge, the interlock is functioning properly
22	Stabilizer Jack Safety Pins (if equipped)	● Check the stabilizer jack safety pins for proper fastening to the beam and for proper insertion into the holes on the inner jack box

When it comes to the maintenance of the angle lift subsystem, it is important to keep track of the condition of the hydraulic oil. It is known that the majority of hydraulic failures occur when the oil is not clean. To prevent this, high-efficiency filters should be installed and changed regularly based on the use of the system and the condition of the oil. It is important to note that the oil should be changed every 3 years. Additionally, the lift cylinder should be checked regularly. This check would include documenting the condition of the cylinders and a possible cause for the condition. For instance, seal wear could be a cause from too much friction on the rod which would in turn accelerate corrosion. Another way to properly maintain the subsystem is to rotate the cylinders every 2 months. This is an important process because the use of a non-rotated cylinder would increase internal contamination or failure when exposed to extreme conditions. Lastly, the oil level should be checked bi-weekly and the external lubrication should be applied weekly.

One important factor that the students considered regarding the aggressiveness of the maintenance schedule was how often the truck was used. As per the given specifications, it was determined that the primary target demographic town included those with mid-to-lower income rates. When understanding the relationship between socioeconomic factors and fire risk, the students were able to take advantage of a 1997 study from the Federal Emergency Management Agency from the United States Fire Administration and the National Fire Data Center. It was concluded that the rate of fire is caused based on three conditions: the first is from “Human Action” such as carelessness, the second is from “Non-Human Action” such as family structure, demographics, and economics, and the third is Exterior fires such as fires due to the environment. For this project, the students decided to focus their analysis on the relationship of Housing Affordability rates and the rates of fire. According to the study, households that 50% more of income goes to housing costs, the lack of “disposable” income makes it more likely that proper investments to maintain and purchase fire protection devices would not be made. Additionally, households with lower disposable income who fail to pay utilities, might compensate with using less fire-safe methods which pose a higher risk of causing a fire. Because these factors are present, it could be determined that the engine would be used more often than in towns with a higher rate of income.

IV. Cost Analyses

The list of all the parts used in the manufacturing of one aerial apparatus can be found in **Table 2** below. The table is split by the section of the aerial apparatus that the parts listed underneath are used for. Each part has a link for reference and the running total of the materials is $57,094.98. The cost of labor will consist of 600 man hours for machining and welding and another 600 man hours for the entire assembly. The estimated hourly wage for the specialized machinists and welders is $65 and the wage for the assembly team is estimated to be $20. The estimated cost of labor is calculated to be $51,000 bringing the total cost of the aerial apparatus to $108,094.98. With the assumption that when mass-producing 500 apparatuses there is a 5% discount for the materials cost, the total cost of mass-production is $105,240.23 per aerial apparatus.

Table 2: Parts List of All Parts Required to Machine and Assemble the Entire Aerial Apparatus Split into Sections with Links

Base Section				
Part Name	**Description**	**Quantity**	**Price**	**Total**
Truss Beams	2.5"x2.5" hollow 1/8" wall beam (35.5" long)	23	$53.69	$1,234.87
Rollers	2" 2200 lb Capacity Roller (Bearing Built in)	32	$68.02	$2,176.64
Bottom Beam	3"x5" .25" wall (28.75' long x 4)	6	$489.47	$2,936.82
Top Small Beam	3"x2" .25" wall steel (389 in x 2)	4	$315.30	$1,261.20
Top Big Beam	3"x4" .25" wall steel (389 in x 2)	4	$975.76	$3,903.04
Rungs	1" diameter 36" long (24 rungs)	6	$122.99	$737.94
Support Piece	2"x.75"x.25"steel connector piece (24 pieces) (2"x24" plate)	1	$27.50	$27.50
Support for Rungs	.25"x.25"x25"steel beam (48 Pieces) Using 12"x30" 0.25" thick Plate	1	$144.16	$144.16
Wheel Shaft	0.5" Diameter 2.75" long (32)	1	$111.76	$111.76
Wheel Plate 1	0.25" thick 3"x3" Plate (32)	1	$226.41	$226.41
Wheel Plate 2	0.25" thick 3"x9.375" Plate(16) (uses 3"x72" plate)	3	$74.78	$224.34
Holding Plate	25"x3.5"x.25" (2)	1	$84.15	$84.15
				TOTAL
				$13,068.83

Mid Section				
Part Name	**Description**	**Quantity**	**Price**	**Total**
Truss Beams	2.5"x2.5" hollow 1/8" wall beam (39" long 32)	18	$53.69	$966.42
Rollers	2" 2200 lb Capacity Roller (Bearing Built in)	20	$68.02	$1,360.40
Bottom Beam	3"x5" .25" wall (32.5' long x 2)	4	$489.47	$1,957.88
Top Beam	3"x4" .25" wall steel (434 in x 2)	4	$975.76	$3,903.04
Rungs	1" diameter 29.5" long (27 rungs)	6	$122.99	$737.94
Support Piece	.25"x.75"x.25"steel connector piece (27 pieces)	1	$27.50	$27.50
Support for Rungs	.25"x.25"x19"steel beam (54 Pieces) Using 12"x30" 0.25" thick Plate	1	$144.16	$144.16
Wheel Shaft	0.5" Diameter 2.75" long (20)	1	$111.76	$111.76
Wheel Plate 1	0.25" thick 3"x3" Plate (20) -> Uses Plate from Base Section	0		$0.00
Wheel Plate 2	0.25" thick 3"x9.375" Plate (10) (uses 3"x72" plate	2	$74.78	$149.56
Holding Plate	1.25"x390"x.25" (2)	12	$36.40	$436.80
				TOTAL
				$9,795.46
Fly Section				
Part Name	**Description**	**Quantity**	**Price**	**Total**
Truss Beams	1.5"x1.5" hollow 1/8" wall beam (37.5" long 36)	5	$237.42	$1,187.10
Top Beam	1.5"x3" hollow 1/4" wall beam 301" long (2)	9	$91.58	$824.22
Bottom Beam	L shaped beam 3"x3" half L with 1/4" walls 345" long (2)			
Bottom Beam Part 1	1.5"x3" rectangular tubing with 1/4" thick walls 345" long (2)	10	$91.58	$915.80
Bottom Beam Part 2	1.5"x1.5" square tubing with 1/4" thick walls 345" long (2)	3	$237.42	$712.26
Rungs	1" diameter 36" long (24 rungs)	7	$122.99	$860.93
Support Piece	.25"x.75"x.25"steel connector piece (24 pieces)	1	$27.50	$27.50
Support for Rungs	.25"x.25"x17"steel beam (48 Pieces)	1	$144.16	$144.16
				TOTAL
				$4,671.97
Basket				
Part Name	**Description**	**Quantity**	**Price**	**Total**
Railing	2.5"x2.5" hollow 1/8" wall beam (total length of 481.75")	7	$53.69	$375.83
Bottom Plate	4.5'x4' Plate 1/4" thick	1	$488.39	$488.39
Hydraulic Plate	0.5" thick custom cut Plate (2) (made from 0.5" thick 48"x12" plate)	1	$311.75	$311.75
Hydraulic Cylinder	Link	2	$161.00	$322.00

Gyro Sensor	Link	1	$60.00	$60.00
Hydraulic Position Sensor	Link	2	$135.00	$270.00
Arduino Micro Controller	Link	1	$19.99	$19.99
Hydraulic Pump	Link	1	$239.00	$239.00
				TOTAL
				$2,086.96
Extension System				
Part Name	**Description**	**Quantity**	**Price**	**Total**
Hydraulic Cylinder	Link	2	$261.00	$522.00
Pulleys	3000 lbs payload pulley	8	$80.39	$643.12
Steel Plate	Steel Plate to Hold the two Pulleys on the Hydraulic Cylinder	1	$144.16	$144.16
Steel Cable	1" Diameter 120 ft long x 2 (purchased per foot)	240	$15.31	$3,674.40
Hydraulic Pump	Link	1	$239.00	$239.00
				TOTAL
				$5,222.68
Angular Lift Subsystem				
Part Name	**Description**	**Quantity**	**Price**	**Total**
Hydraulic Lift Cylinder	Cylinder, hyd, 3 In Bore x 16 In Stroke	2	$362.62	$725.24
Hydraulic Pump	Electric Hydraulic Pump Single Manual Valve 10,000 PSI	1	$239.00	$239.00
				TOTAL
				$964.24
Platform				
Part Name	**Description**	**Quantity**	**Price**	**Total**
Steel Plate Stock - 2.5 Inch	2.5 inch THICK A36 Steel Plate (24x24 inch)	1	$1,019.92	$1,019.92
Steel Plate Stock - 1 inch	1 inch THICK A36 Steel Plate (53x36)	2	$1,541.19	$3,082.38
Steel Stock 5.5 inches	Low-Carbon Steel Rod, 5-1/2" Diameter	1	$268.92	$1,019.92
				TOTAL
				$5,122.22
Fasteners and Gear Train				
Part Name	**Description**	**Quantity**	**Price**	**Total**
Bolt 1	Zinc Yellow-Chromate, Hex Head, Partial Thread, 3/4"-10, 10", 0.75" Dia.	10	$11.01	$110.10
Bolt 2	Zinc Yellow-Chromate, Hex Head, Partial Thread, 3/4"-10, 5", 0.75" Dia.	24	$5.02	$120.48
SAE Washers	Zinc Yellow-Chromate, Grade 8 Steel, 0.812" ID, 1.469" OD, 0.25" T	2	$11.91	$23.82

Low-Carbon Steel Rods	3/4" Diameter 6' Long	1	$45.87	$45.87
50 Series Hydraulic Motor	50MH38DBCSC 3.8 cu in, 5.75" x 6.46" x 5.96", 7/8" Shaft Dia.	2	$434.65	$869.30
Kaydon Slew Bearing	HS6-25P1Z, 29.45" OD, 21.03" ID, 26.93" OD Outer, 25.28" ID Inner	1	$2,750.00	$2,750.00
Lucas Oil SAE 80W-90 Oil	SAE API GL-5 80W-90 Gear Oil	0.0011	$533.56	$0.59
Metal Sheets	6" Thick A36 Steel, 48" x 48" x 6"	1	$8,443.46	$8,443.46
Diesel Generator	Diesel Generator	1	$3,799.00	$3,799.00
				TOTAL
				$16,162.62

V. Systems Engineering Challenges

When developing the subsystems for the ladder, the students faced various engineering challenges. First and foremost, sourcing parts for each subsystem was a hassle because most consumer based companies do not sell products of this scale. Not only were they difficult to source, but it was also difficult to see what exactly these systems needed in order to function properly since many companies prefer to keep this information private (to prevent competitors and spies from acquiring company secrets) and it is not easily accessible or attainable. For instance, in the development of the tiller mechanism, the slew bearing had to be custom ordered from a distributor that primarily dealt with selling parts for large equipment such as cranes and industrial turntables. This was also the case for the gear train as well; no manufacturer had gears designed to fit the provided specifications, therefore the entire gear train (gear and pinions) had to be custom-made. Additionally, when it came to the development of the angular lift subsystem, the hydraulic lift cylinder had to also be custom built because there were no manufacturers that developed the required lift capabilities and stroke length to achieve the subsystem's goal. In response, the students found a custom manufacturing plant that allowed the consumer to manually change the specifications of the product.

When it came to the development of the ladder extension subsystem, the primary challenge that the students faced was finding a way to extend the ladder. The group's first approach was to use multiple hydraulic lift cylinders in each section. However, after calling various industry professionals, the students realized that the industry standard was to use both a combination of a hydraulic lift system in tandem with a pulley system to leverage some of the dead load. Additionally, developing a smooth transition for the multiple ladder extensions to slide onto one another proved to be a challenge. To get around this, the students developed a sliding rack mechanism such as one seen in a drawer for clothes. The last biggest challenge that was considered was the mechanism to keep the bucket level with the ground. Although the students considered using a parallelogram linkage, due to reliability and dead load goals, it was determined that the best approach was to use a computer controlled hydraulic cylinder and a gyroscope sensor to control the angle of the bucket platform.

Regarding the rotational aspect of the ladder, the primary difficulty was due to deciding what would be the simplest design to rotate the entire system. The students originally thought of using a worm and gear type assembly, however, after seeking professional advice, it was decided that utilizing a double pinion-double motor system would be more efficient. One benefit of this approach is that it would be the easiest to implement and the most simplistic approach. Another major challenge that needed to be solved was which part of the gear system would be fixed to the bed of the truck. When considering the placement of the motor, the initial design had the motors and pinions fixed on the platform subsystem while the bearing part of the truck would be attached to the truck. After careful consideration, it was determined this approach would be ineffective because if ran, the motors would move a non fixed gear. By choosing to fix the gear to the truck and the inner slewing bearing to the platform system, the mechanism would work properly. One flaw with this approach is that the pinions would be the ones to drive the rotation of the entire system. Over time this immense load would end up wearing down the pinions and motors, thus reducing its lifespan substantially. As mentioned in the previous section, the solution was to fix the motors and pinions to the bed of the truck with the slew bearing underneath the gear. This way the gear can still be anchored to the truck, but with the addition of the slew bearing and swivel unit housed underneath, the external gear can drive the rotation of the system and easily handle the load better than the pinions.

Although the students were able to solve a vast majority of the challenges at hand, there were challenges that were considered but not pursued due to time constraints and limited computer processing power. These challenges primarily included the development and mechanics of the pulley and hydraulic extension boom lift for the ladder extension subsystem and the swivel unit that would be below the slew bearing located in the torque box.

VI. Overall Experience Gained by Team

The team was able to demonstrate and put into practice valuable skills and knowledge that will be utilized in the engineering world. For example, the students made heavy use of Solidworks simulations and modeling which has basically become an industry standard in the past few years. It is almost an unavoidable skill that all mechanical engineers will ***have*** to use in their careers which is why it is very beneficial to be practicing these skills now. Students were also able to fully understand the design process and work through the numerous challenges that come with it. As described in many texts, it is crucial to constantly be going through the design process due to the fact that more exposure to it will allow quick solutions in the future due to gained experience in the past. A key part of the design process is background research; the students had to conduct hours of research to fully understand and comprehend the complex system of a fire truck ladder and its systems. For something that seems so simple to understand and is basically seen on a consistent basis regardless of where people live, people do not truly understand how intricate the design of the system is or how important it is to make sure that it works properly until they are faced with designing it. A fire truck is a device meant for rescue; for it to do its job, the ladder must be first and foremost, safe and functional or else it could cost people their lives. Students were able to understand the gravity of the situation and put in their best effort to ensure a safe design while also understanding that this is a challenge that engineers face ***everyday***.

Although the students were able to gain knowledge and enhance their technical skills, they also made excellent use of soft skills. For example, each member of the team was able to get in contact with a number of local fire departments, fire department engineers, and fire truck manufacturers such as Pierce, E-ONE, Kaydon, etc. Students were able to engage with and learn from many people in the industry that face these challenges everyday as a full-time job. Each person that was spoken to was more than willing to help and the students were eager to learn and gain an in-depth understanding of each system. Utilizing soft skills allowed the students to create a more comprehensive and in-depth design that could not have been made without reaching out to real-life engineers.

VII. Conclusion & Recommendations

The design of the aerial ladder was successfully able to replicate the given specifications and performance criteria for the scenario. The ladder is able to extend 75 ft. total (excluding the basket), rotate 61° above the horizontal axis and 3° below the horizontal, and rotate 360° clockwise and counterclockwise. The final cost of the ladder came out to be a mass-produced cost of $128,631.18. Considering our initial estimate (with professional consultation) was assumed to be within the range of $100,000 to $150,000, the final cost was well within expectations. The aerial apparatus performed well under the loading circumstances that were employed on each section with a final safety factor of 4.27 at the worst possible loading condition.

Regarding recommendations, the installation of a LED light system on the rungs, platform, and basket would allow visibility during night time operations. This aspect of the ladder was completely overlooked, however, due to the simplicity of the design, can be easily installed. The ladder can also be outfitted with a hose and nozzle; this would be more challenging, however, it is doable. The possibility of a different platform could also be designed. In this new iteration, the hydraulic lifts could be set in a place that is lower than the pivot point, therefore, it would be able to have a greater angle below the horizontal. Although the ladder can be improved and outfitted with more accessories, the ladder has a simplistic enough design where consumers can easily make any changes and adjustments to fit their needs or wants. With the ladder meeting all the requirements and exceeding the provided expectations, the system is ready to be pitched for the company.

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IX. Appendices

Appendix A ~ Solidworks Drawings

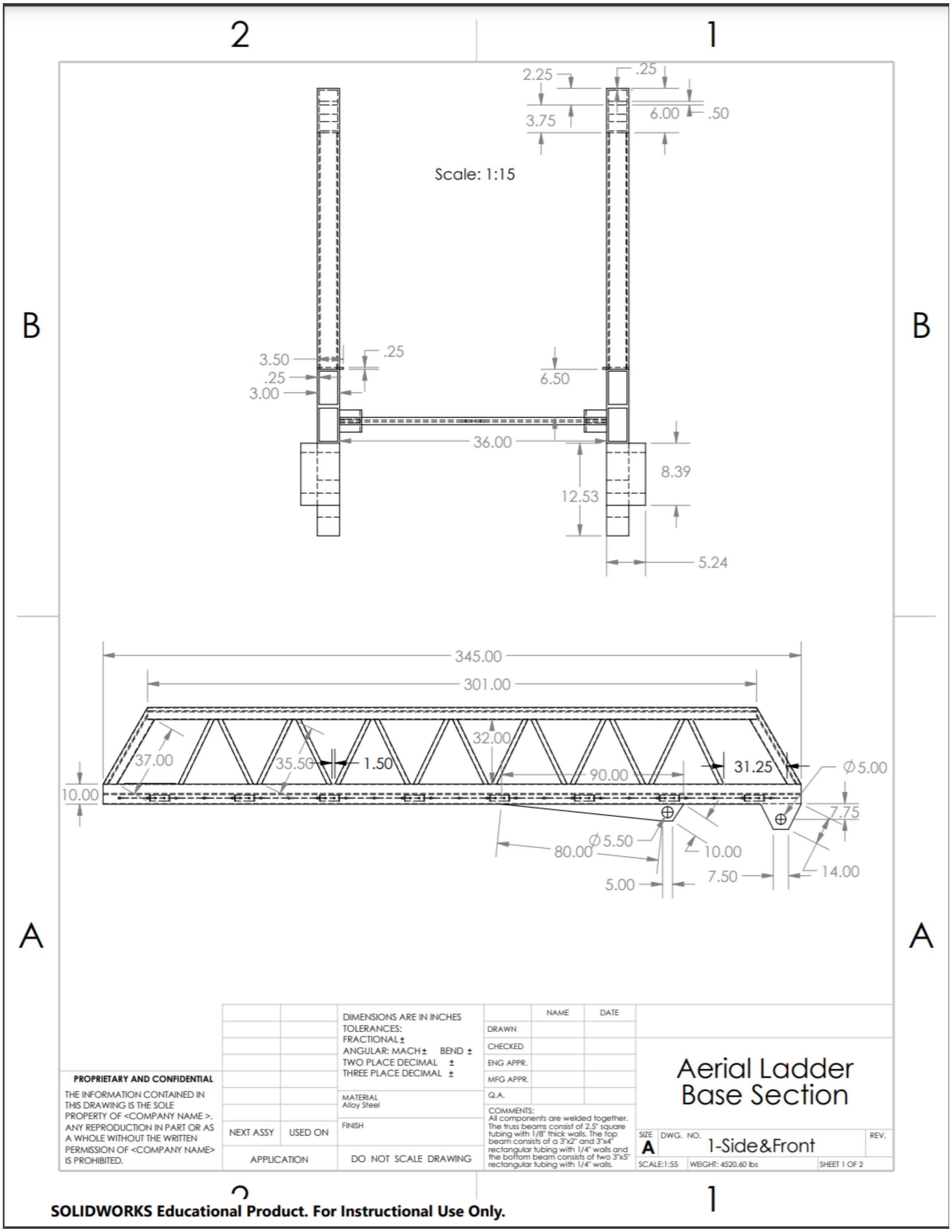


Figure A.1: Side and Front Views of the Dimensioned Drawing of the Base Section of the Aerial Ladder

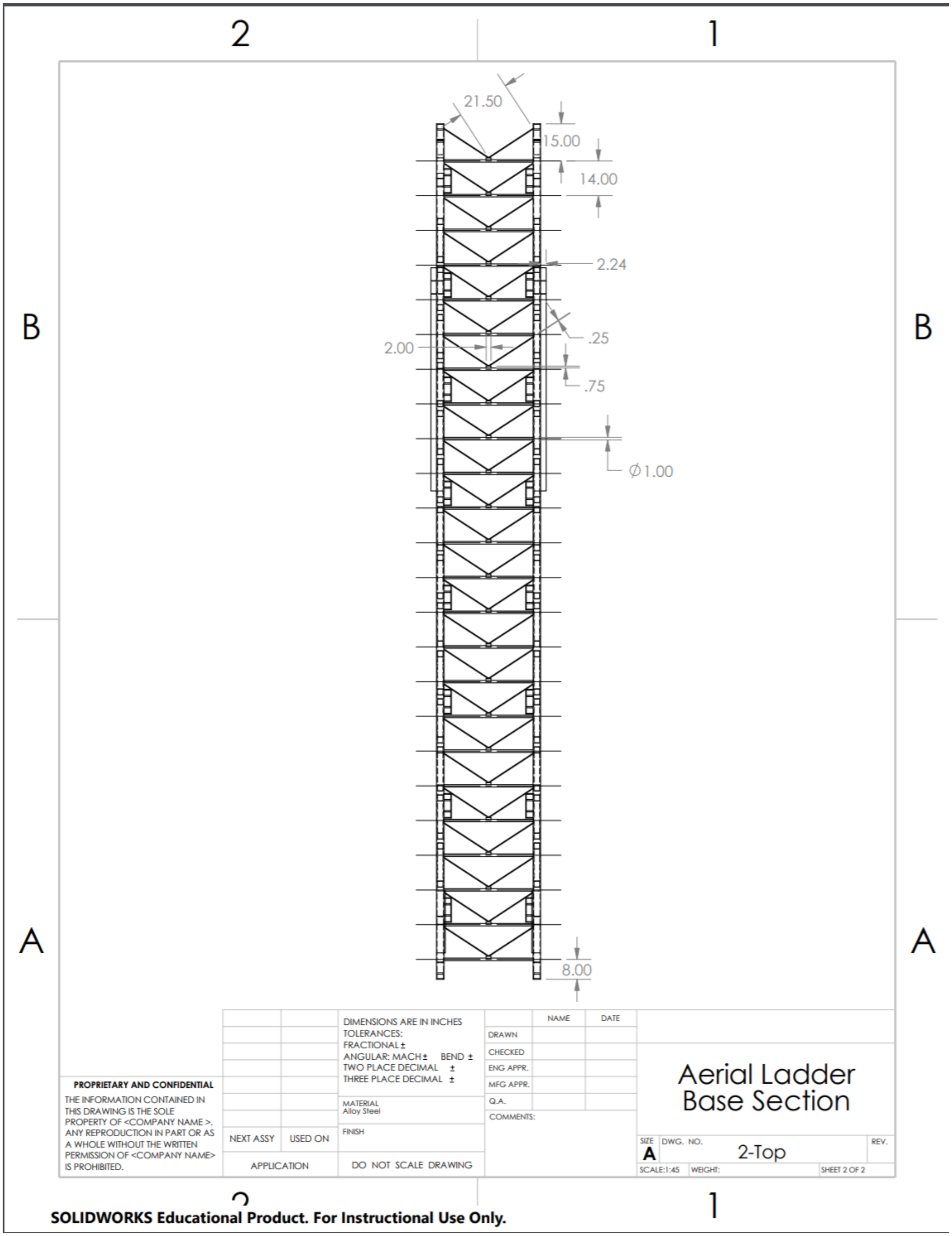


Figure A.2: Top View of the Dimensioned Drawing of the Base Section of the Aerial Ladder

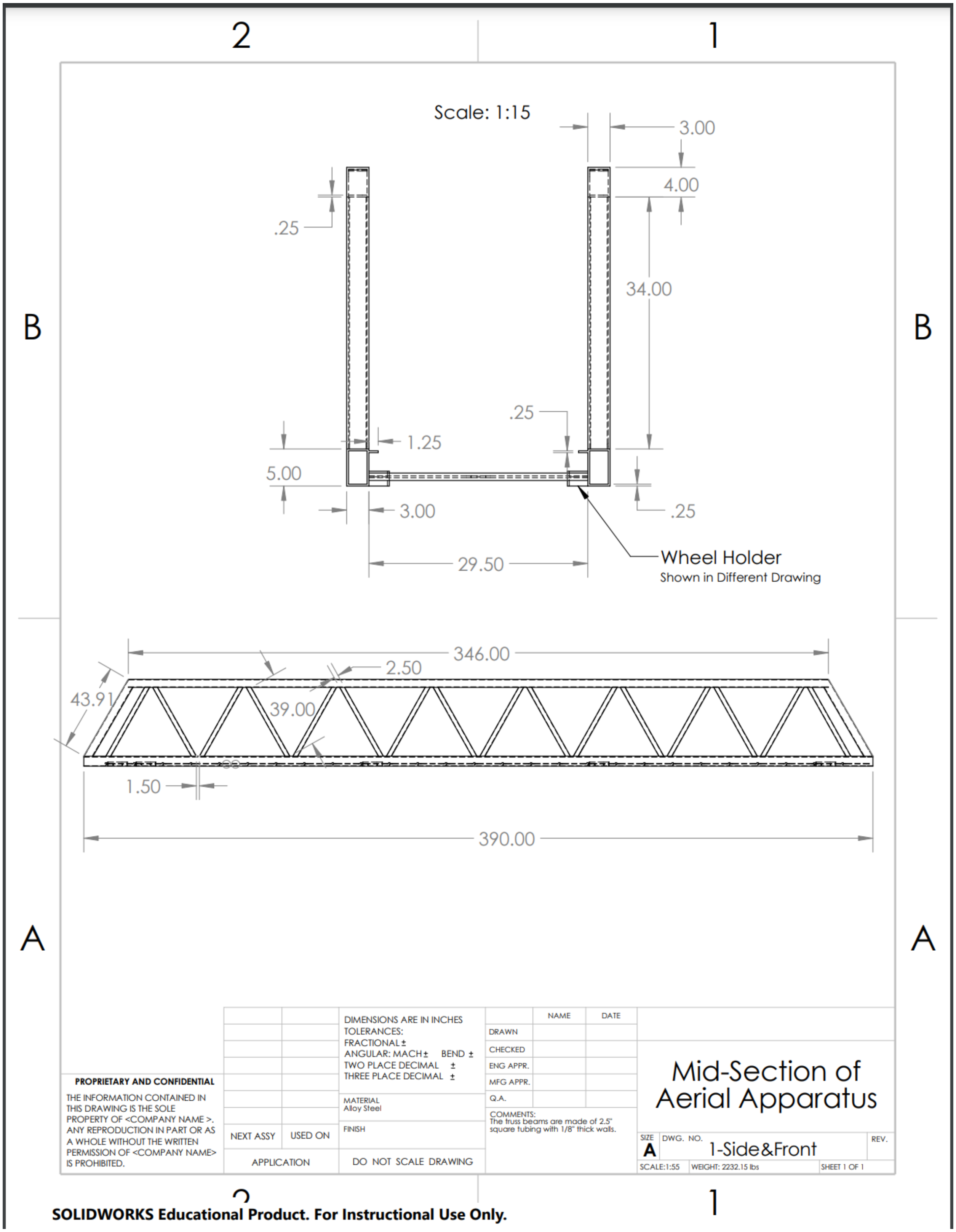


Figure A.3: Side and Front Views of the Dimensioned Drawing of the Mid-Section of the Aerial Ladder

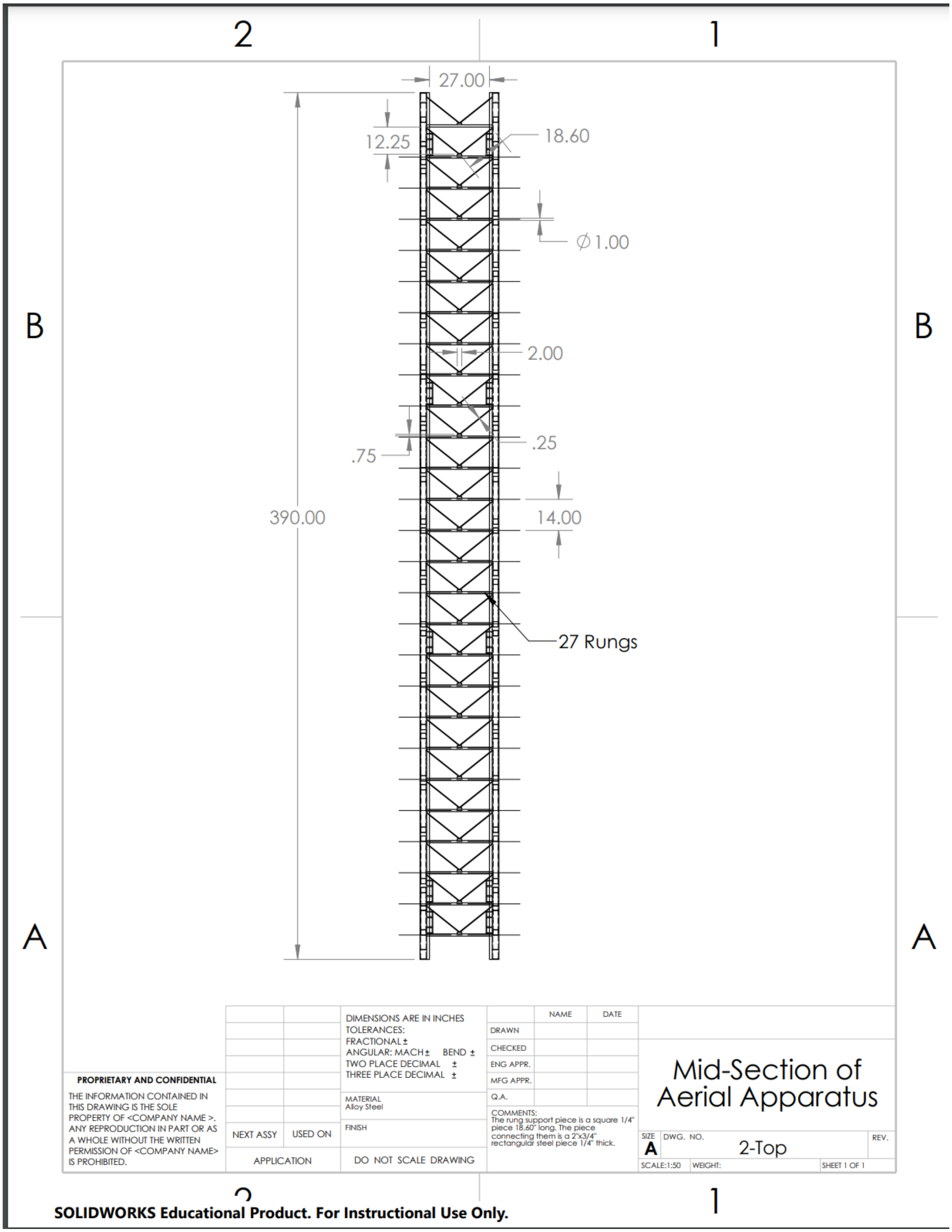


Figure A.4: Top View of the Dimensioned Drawing of the Mid-Section of the Aerial Ladder

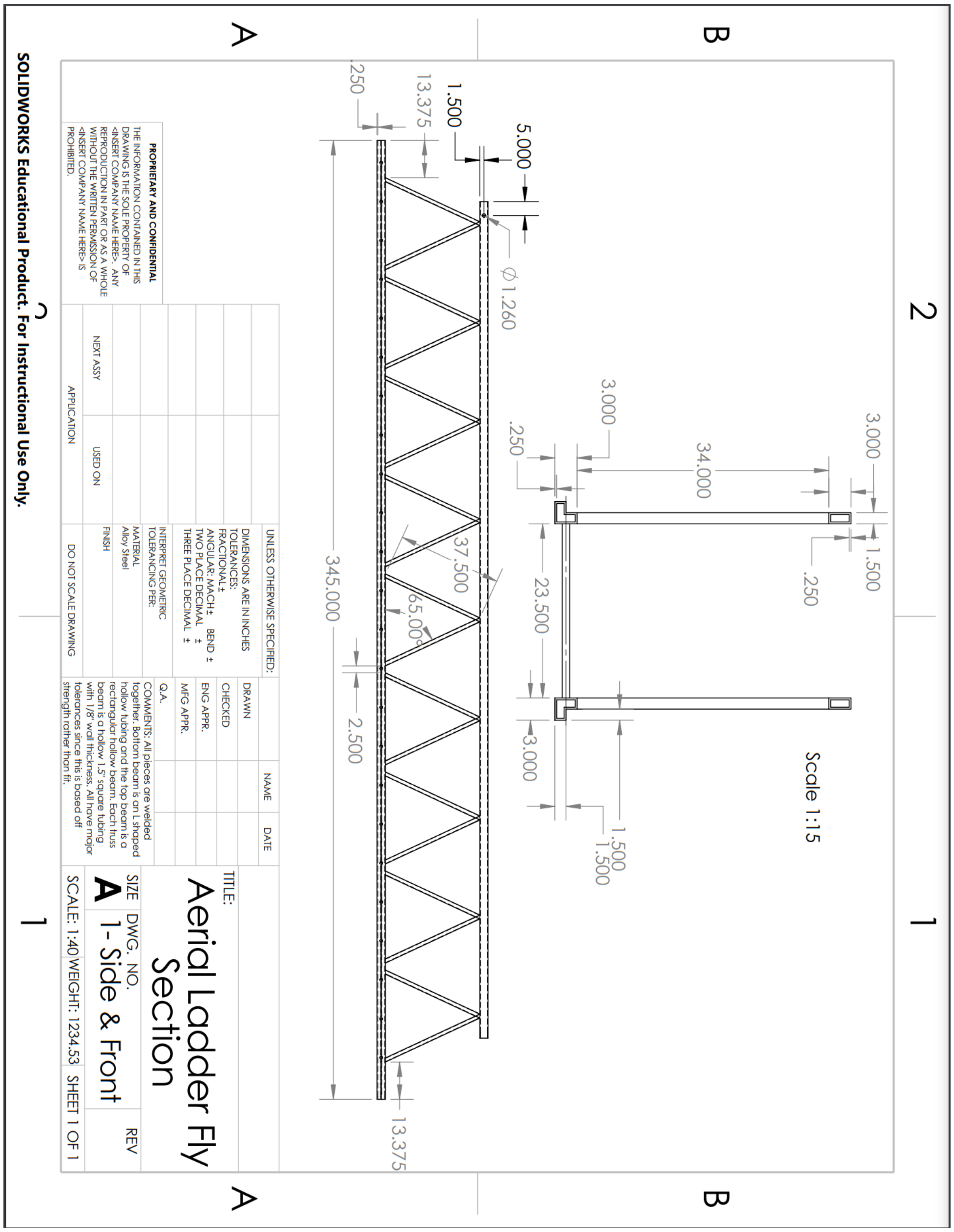


Figure A.5: Side and Front Views of the Dimensioned Drawing of the Fly Section of the Aerial Ladder

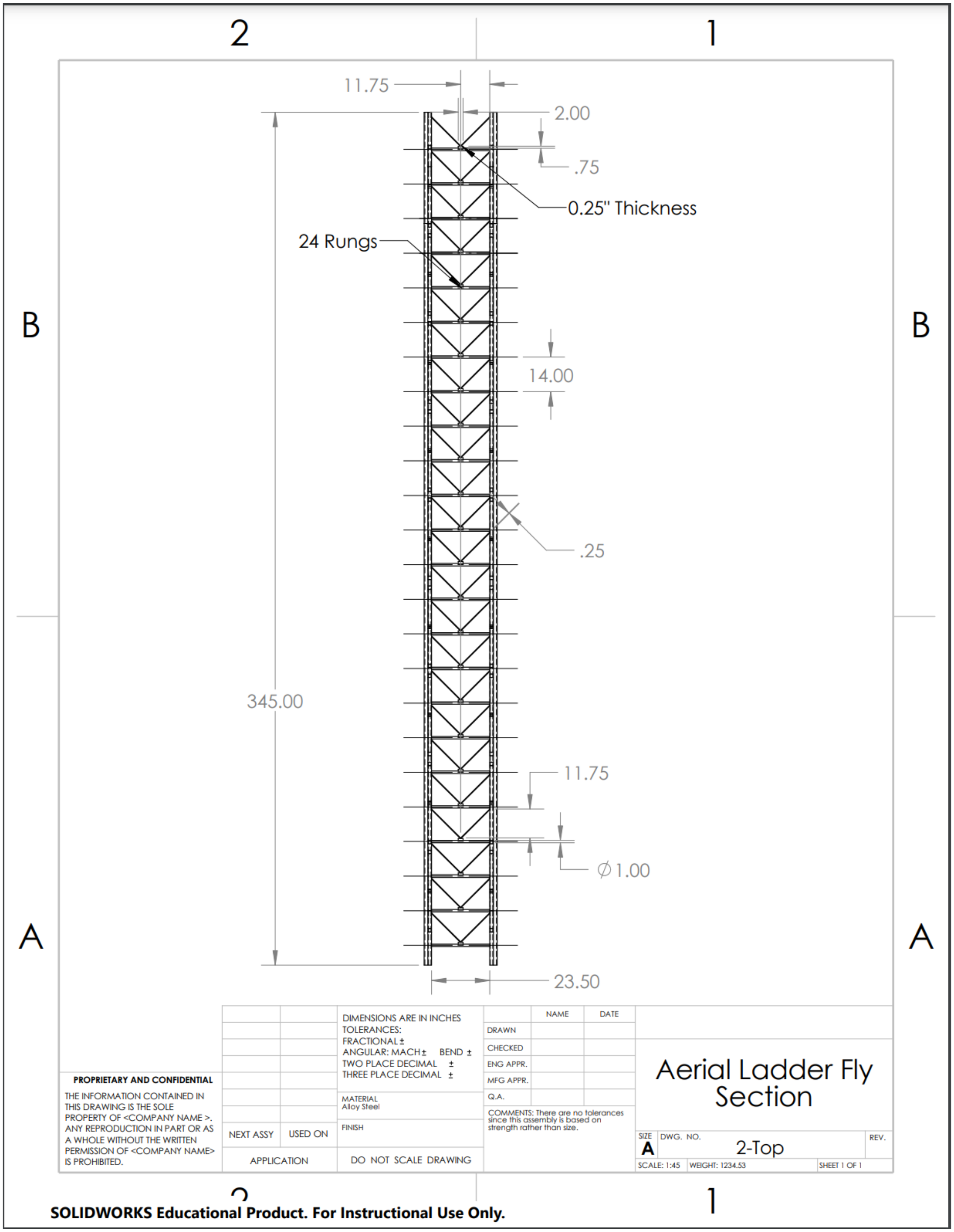


Figure A.5: Top View of the Dimensioned Drawing of the Fly Section of the Aerial Ladder

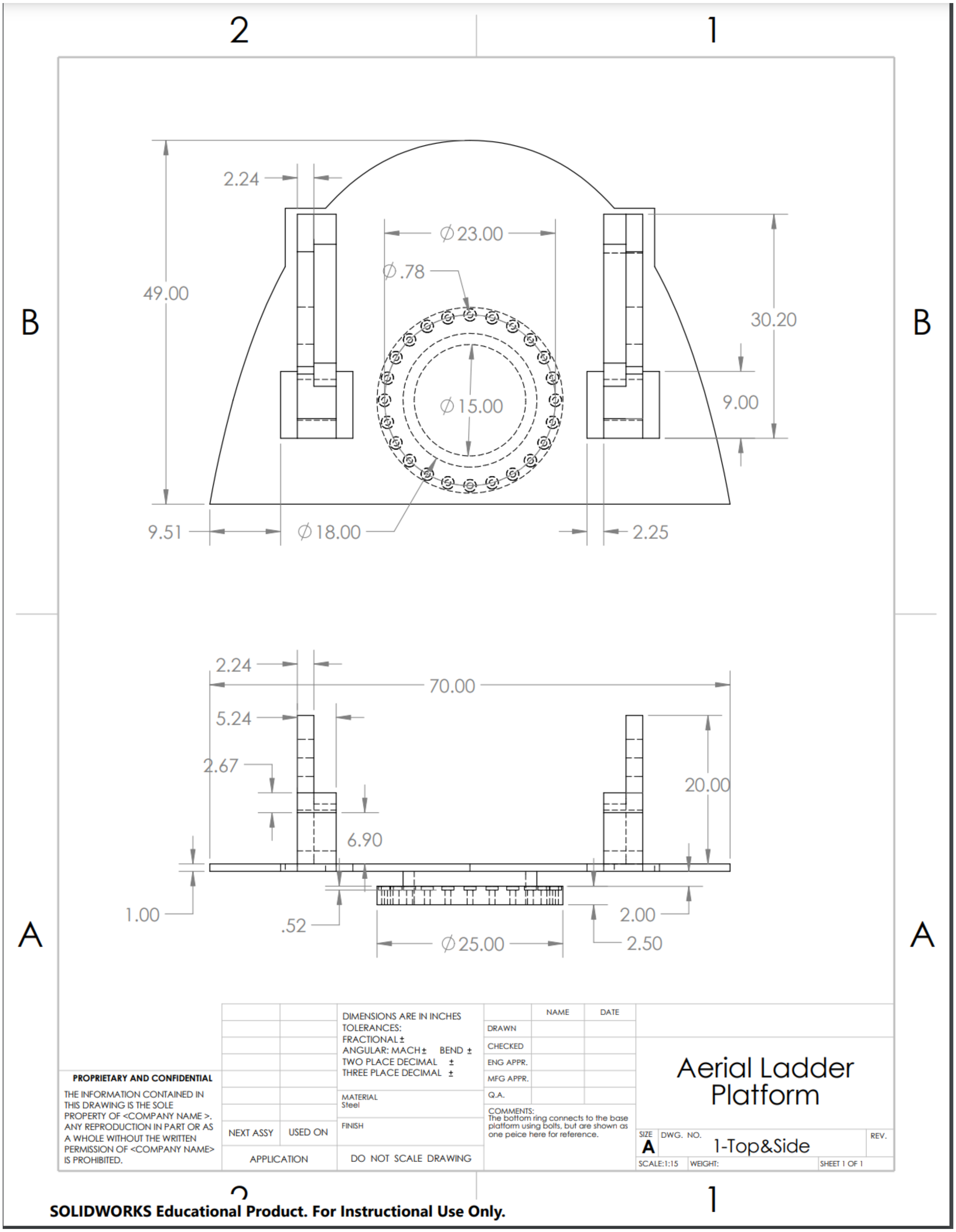


Figure A.6: Top and Side Views of the Dimensioned Drawing of the Aerial Ladder Platform

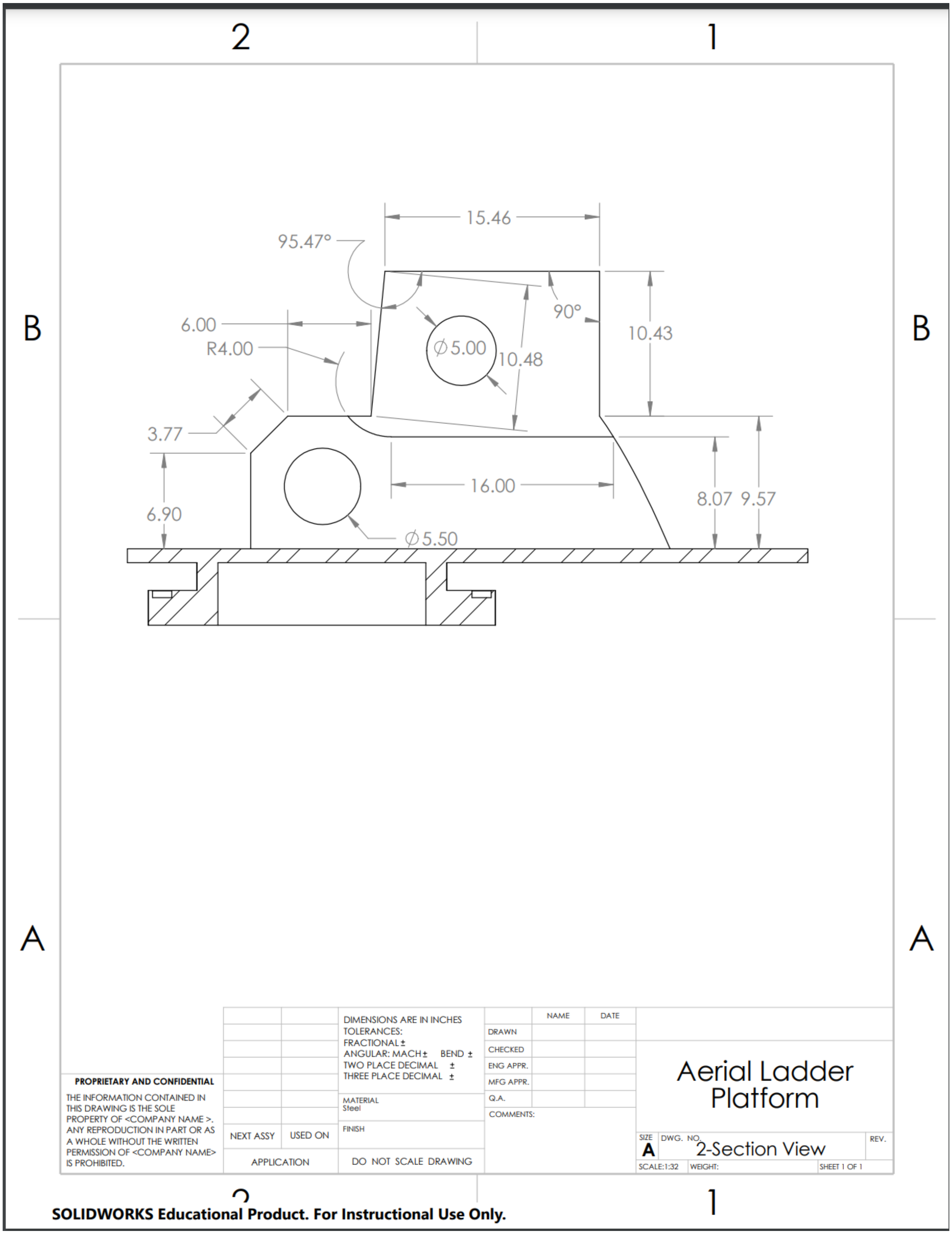


Figure A.7: Section View of the Dimensioned Drawing of the Aerial Ladder Platform

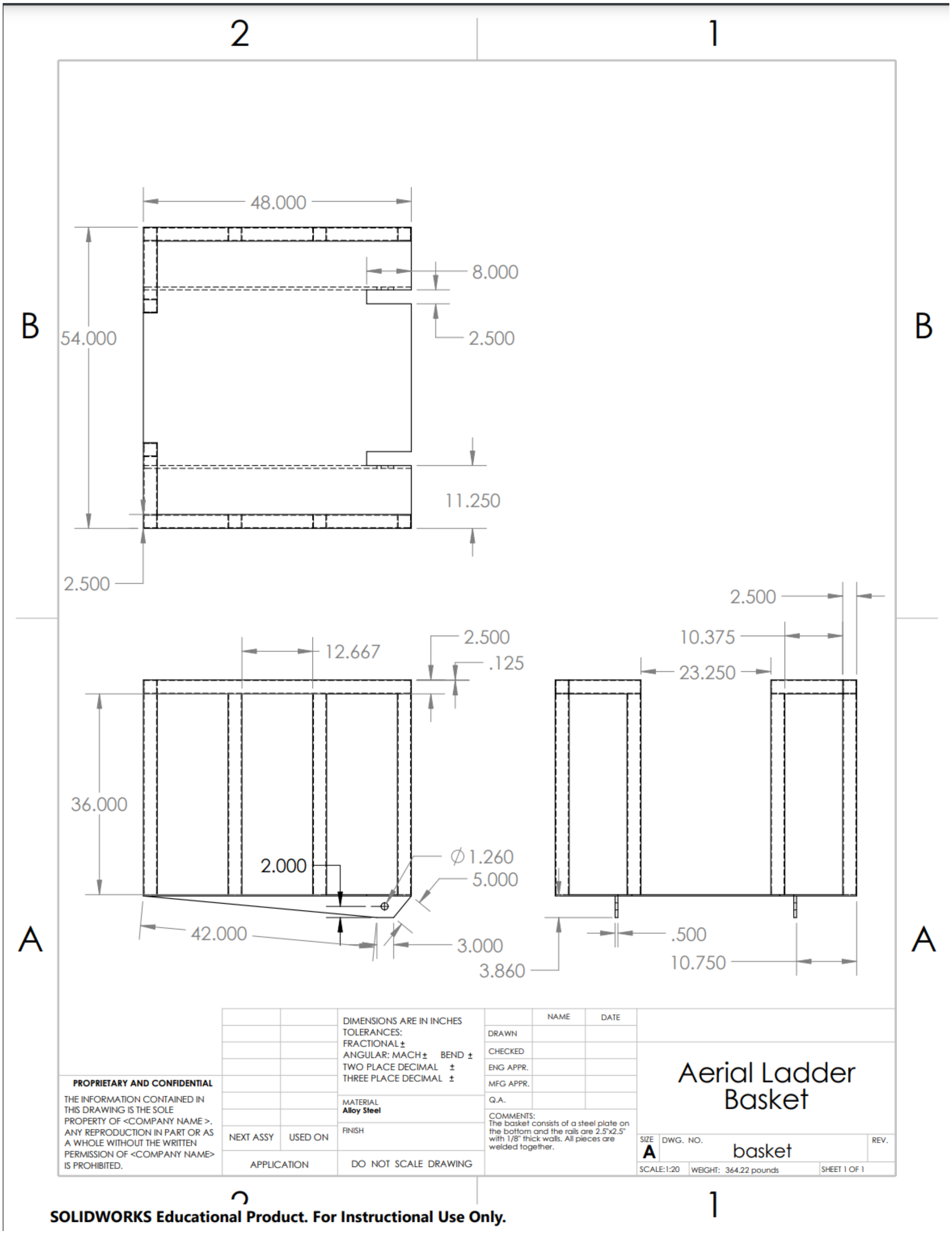


Figure A.8: Dimensioned Drawing Aerial Ladder Basket

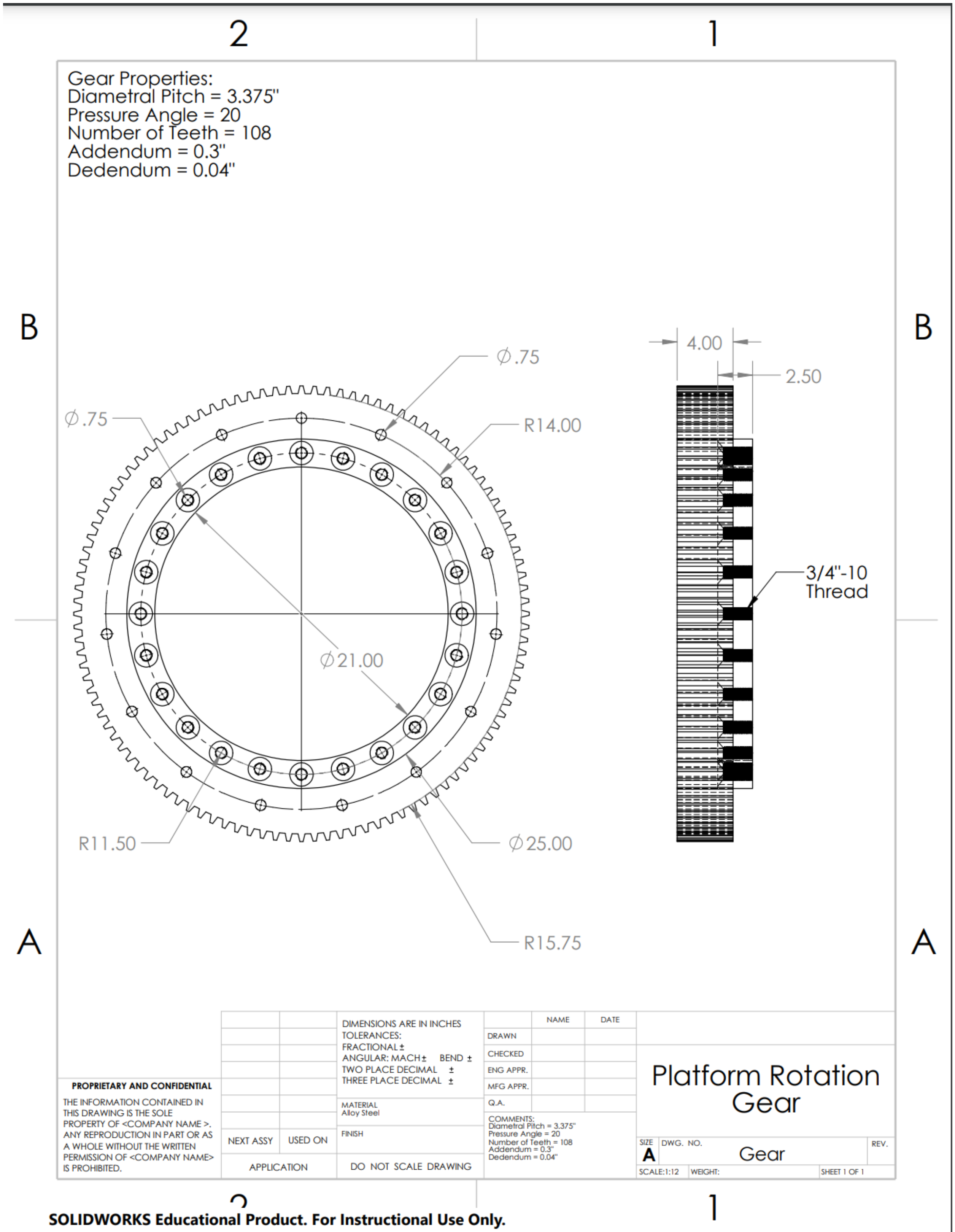


Figure A.9: Dimensioned Drawing of the Tiller Gear

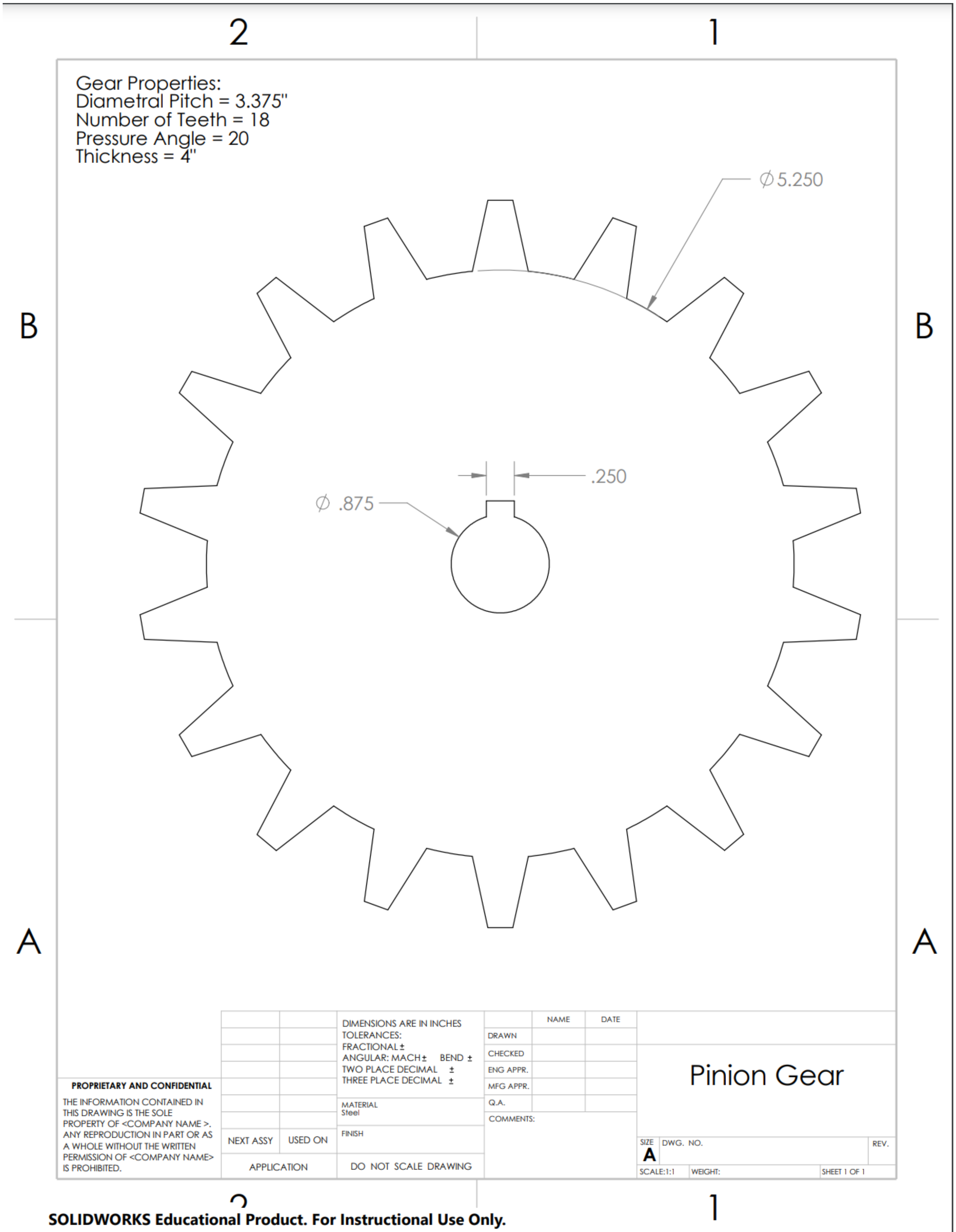


Figure A.10: Dimensioned Drawing of the Pinion Gear in the Tiller Mechanism

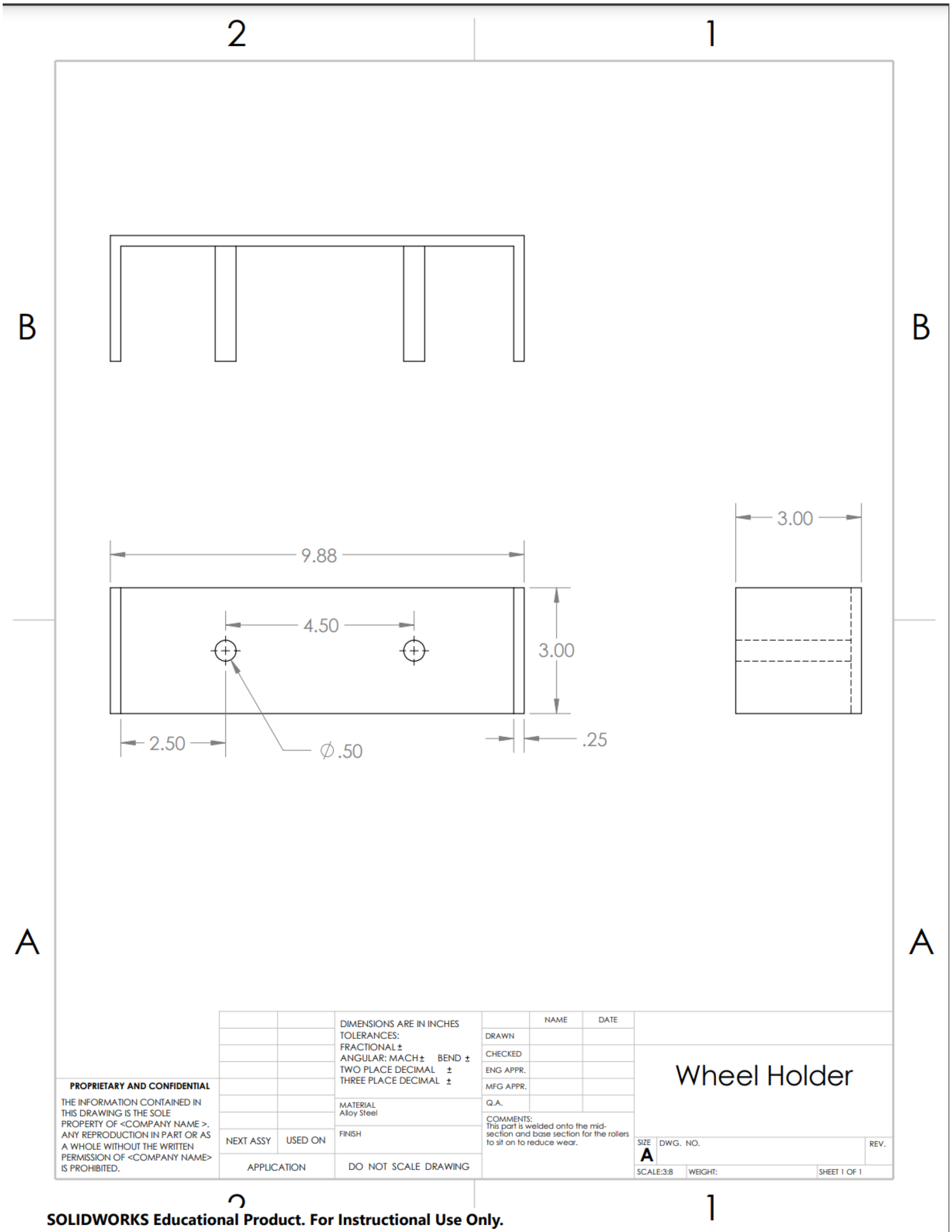


Figure A.11: Dimensioned Drawing of the Wheel Holding Plates for the Extension System

Appendix B ~ Drawings From Parts List

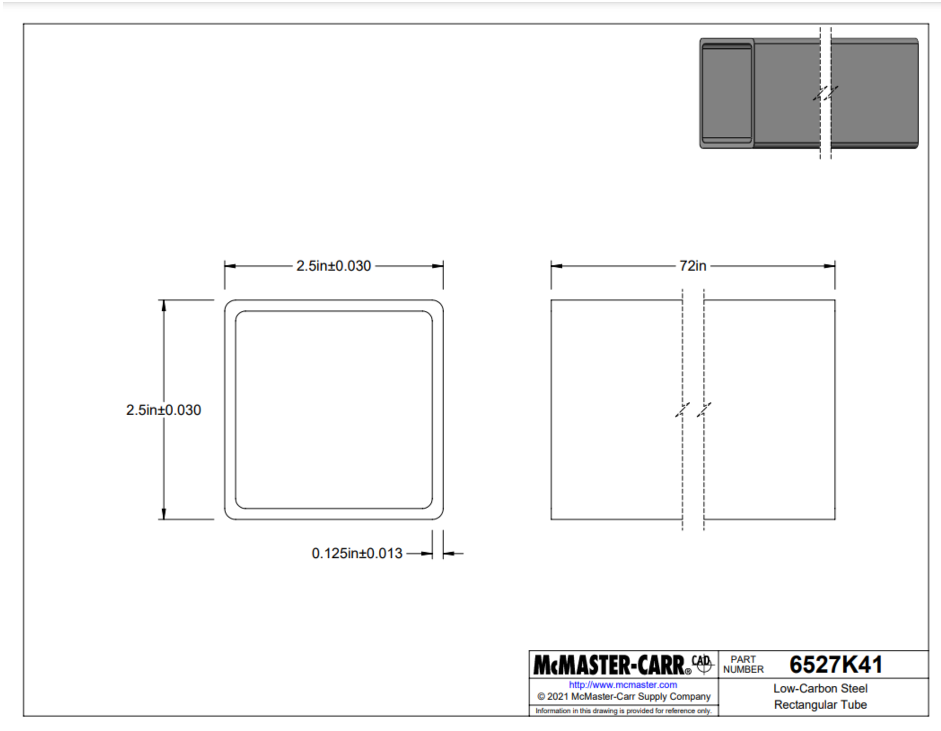


Figure B.1: Drawing of Low-Carbon Steel Rectangular Tube Used as Truss Beams for Base, Mid, and Sections of Ladder and Basket, Angular Lift, and Attachment Subsystems Provided by McMaster-Carr

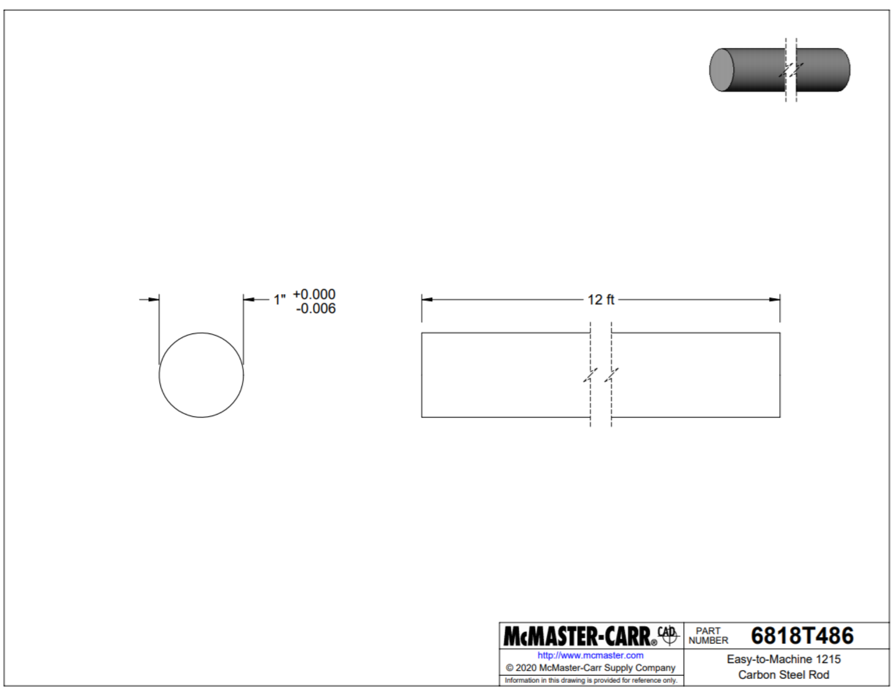


Figure B.2: Drawings for Alloy Steel Rods That Will be Used as Rungs Throughout the Ladder Provided by McMaster-Carr

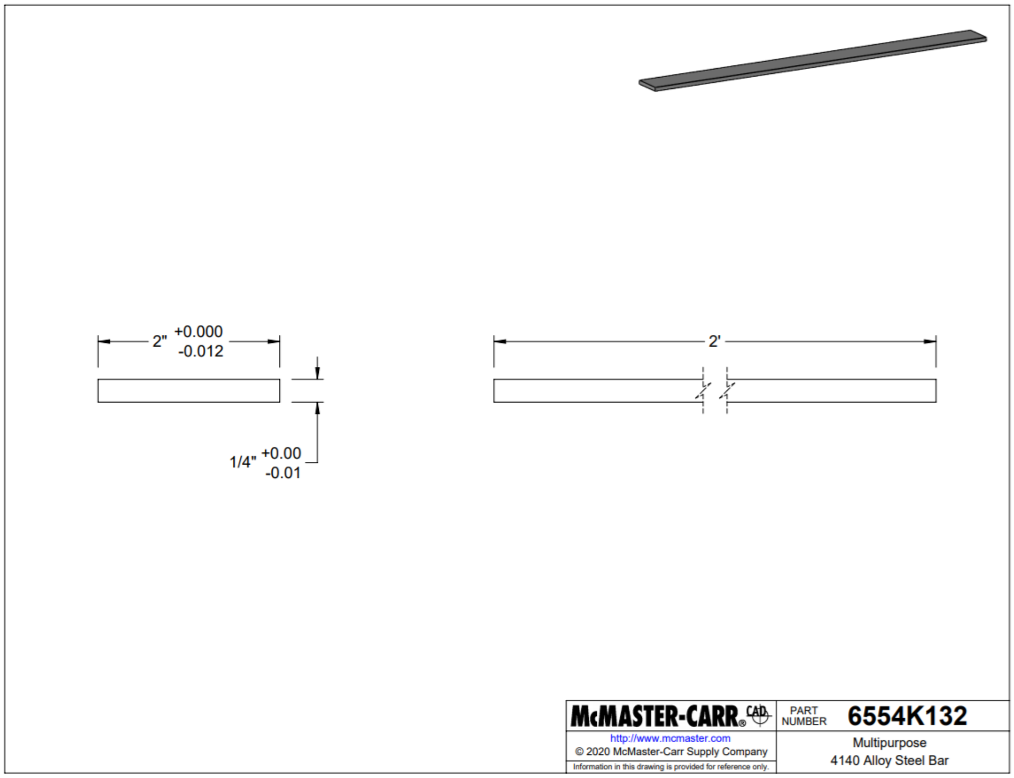


Figure B.3: Drawing of Support Piece Used for Each Section of Ladder Provided by McMaster-Carr

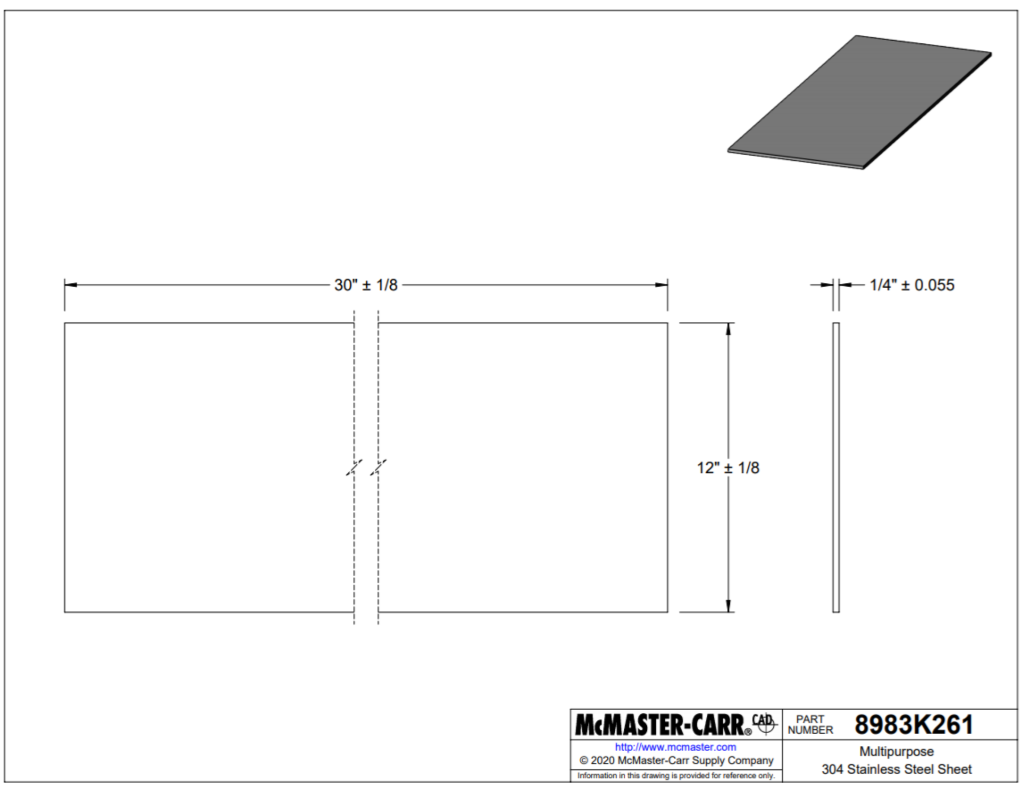


Figure B.4: Drawing of Support Pieces for Rungs on Each Section of the Ladder Provided by McMaster-Carr

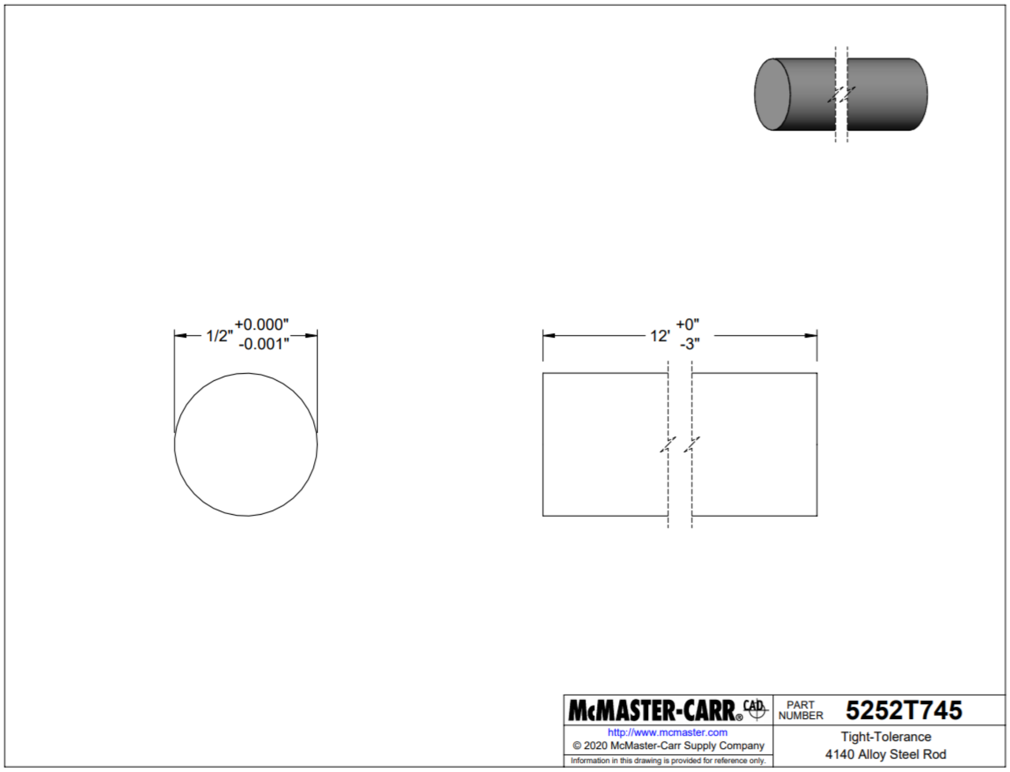


Figure B.5: Drawing of Wheel Shaft Used on Base and Mid Section Provided by McMaster-Carr

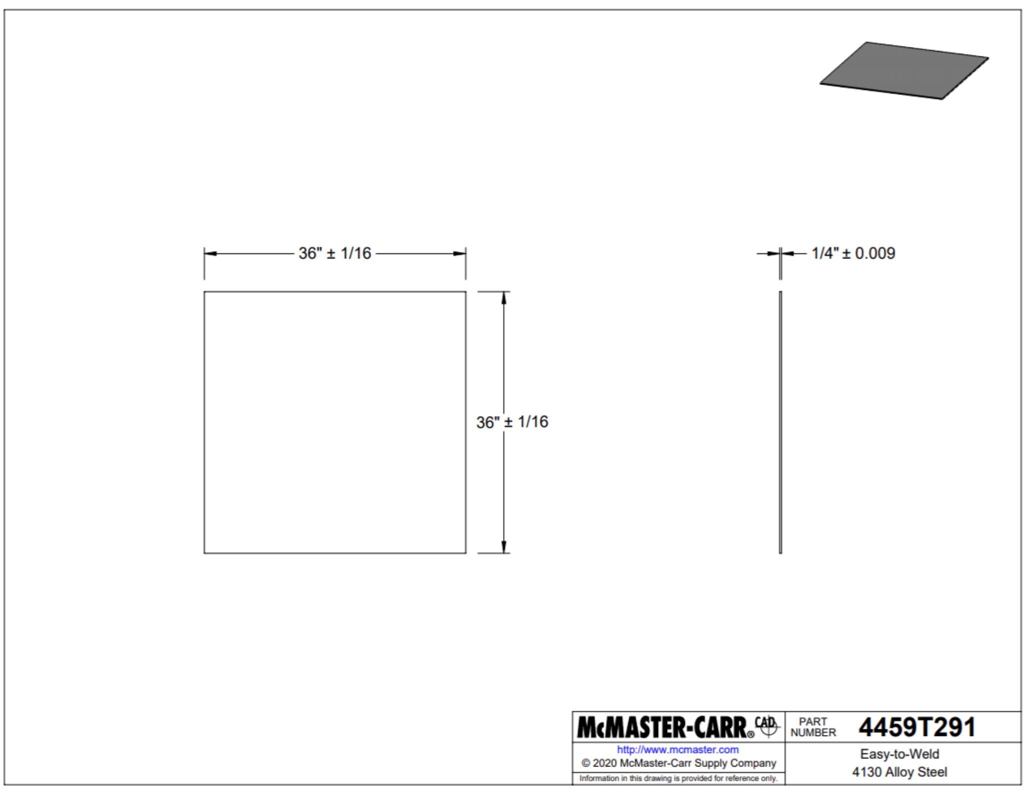


Figure B.6: Drawing for First Wheel Plate Used on Base and Mid Section Provided by McMaster-Carr

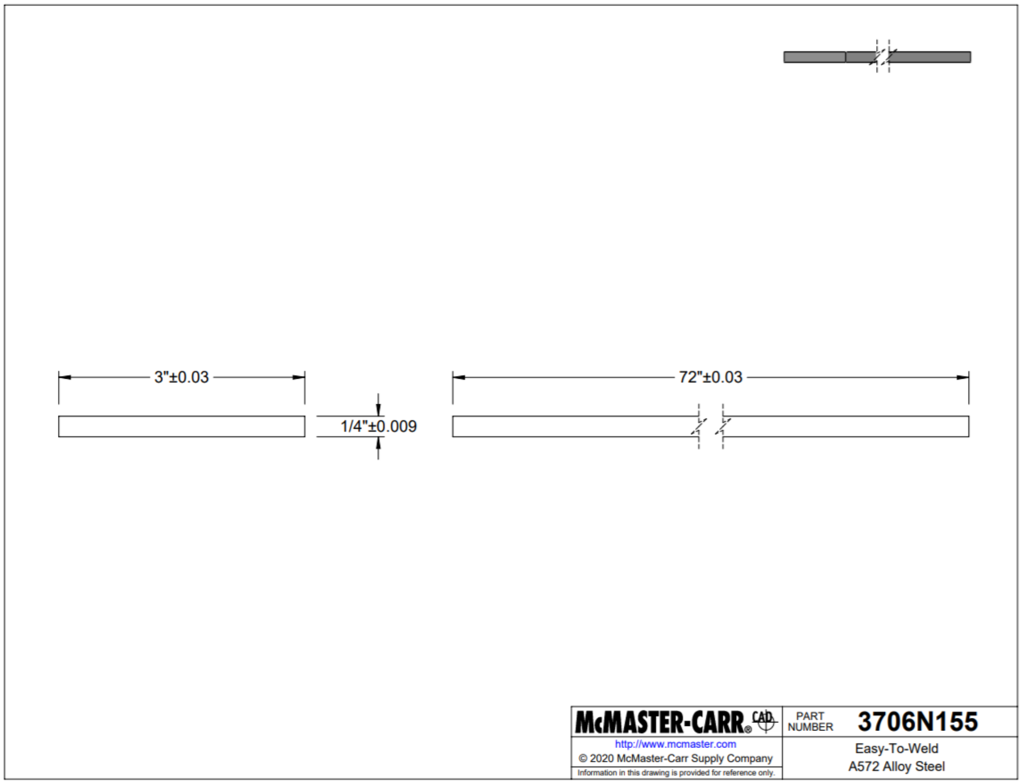


Figure B.7: Drawing of Second Wheel Plate Used on Base and Mid Section Provided by McMaster-Carr

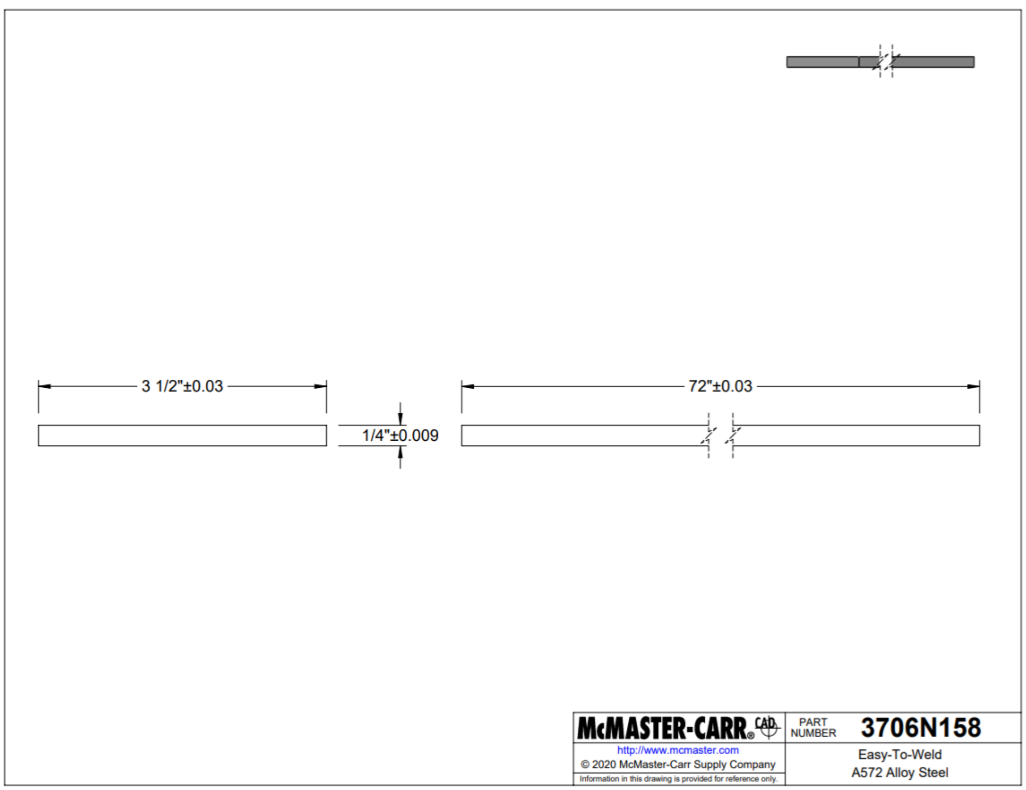


Figure B.8: Drawing of Holding Plate on Base Section Provided by McMaster-Carr

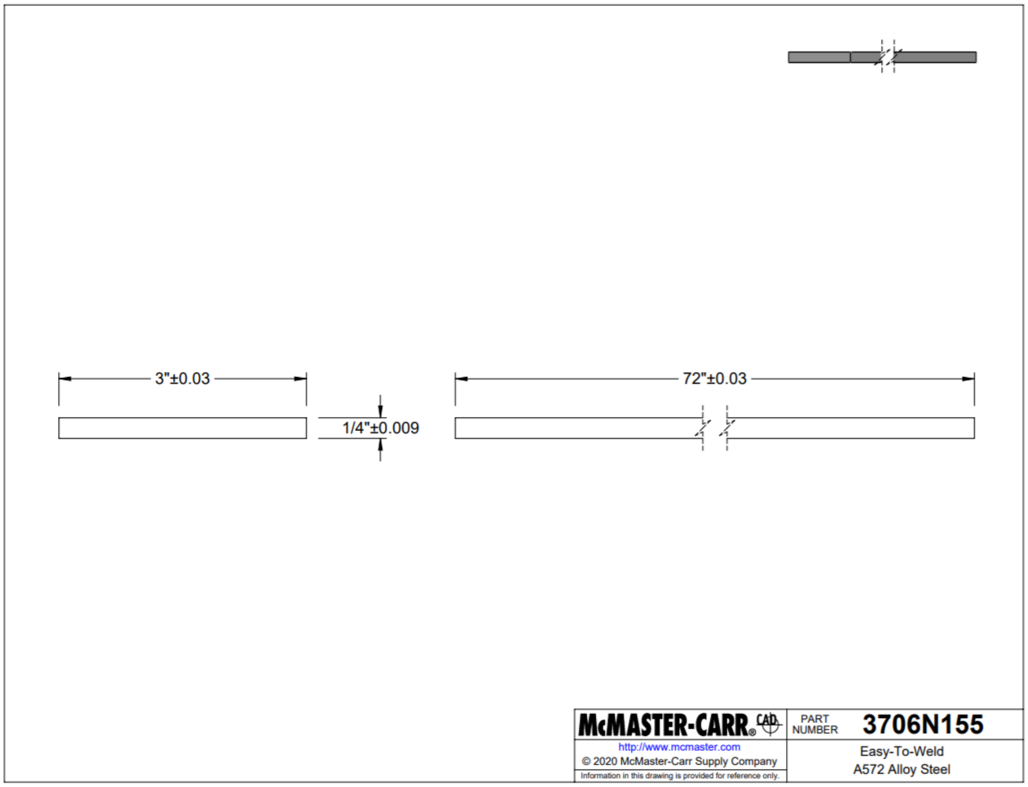


Figure B.9: Drawing of Holding Plate on Mid Section Provided by McMaster-Carr

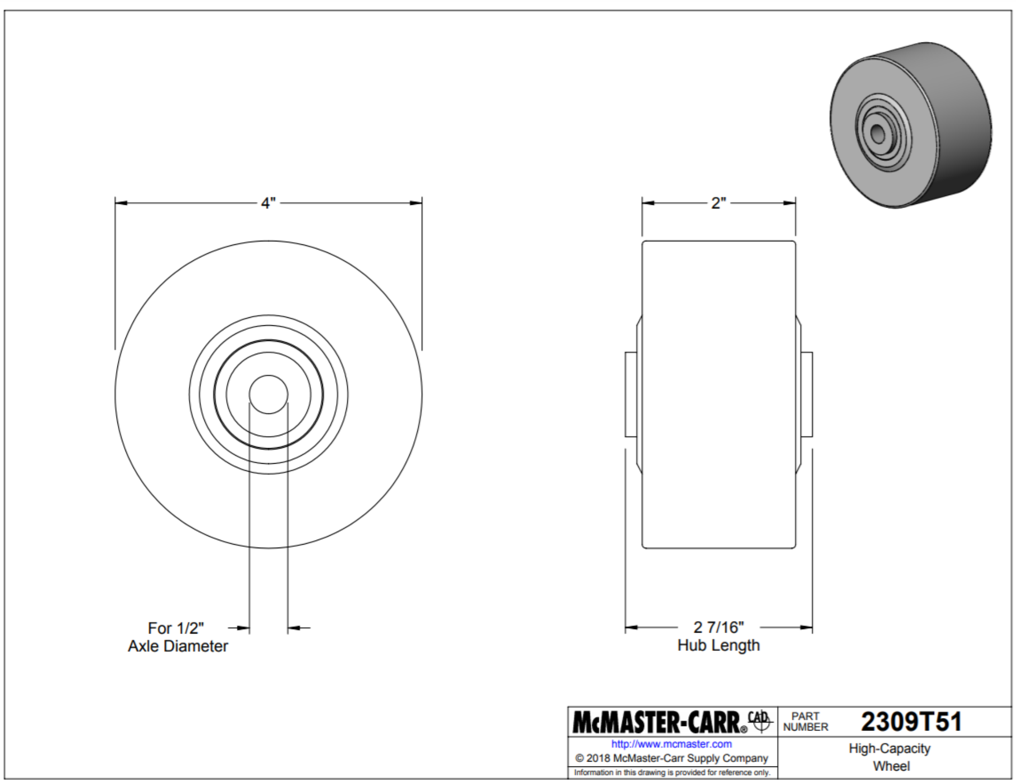


Figure B.10: Drawing of High-Capacity Wheel for Base and Mid Section Provided by McMaster-Carr

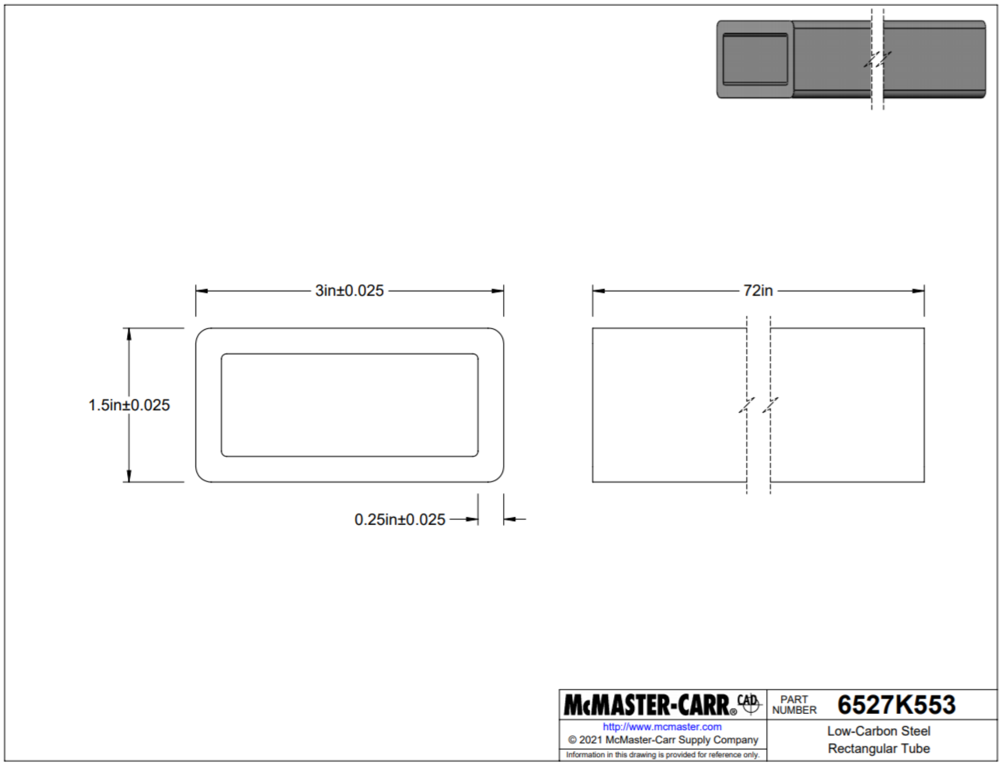


Figure B.11: Drawing of Low-Carbon Steel Rectangular Tube Used on Fly Section Provided by McMaster-Carr

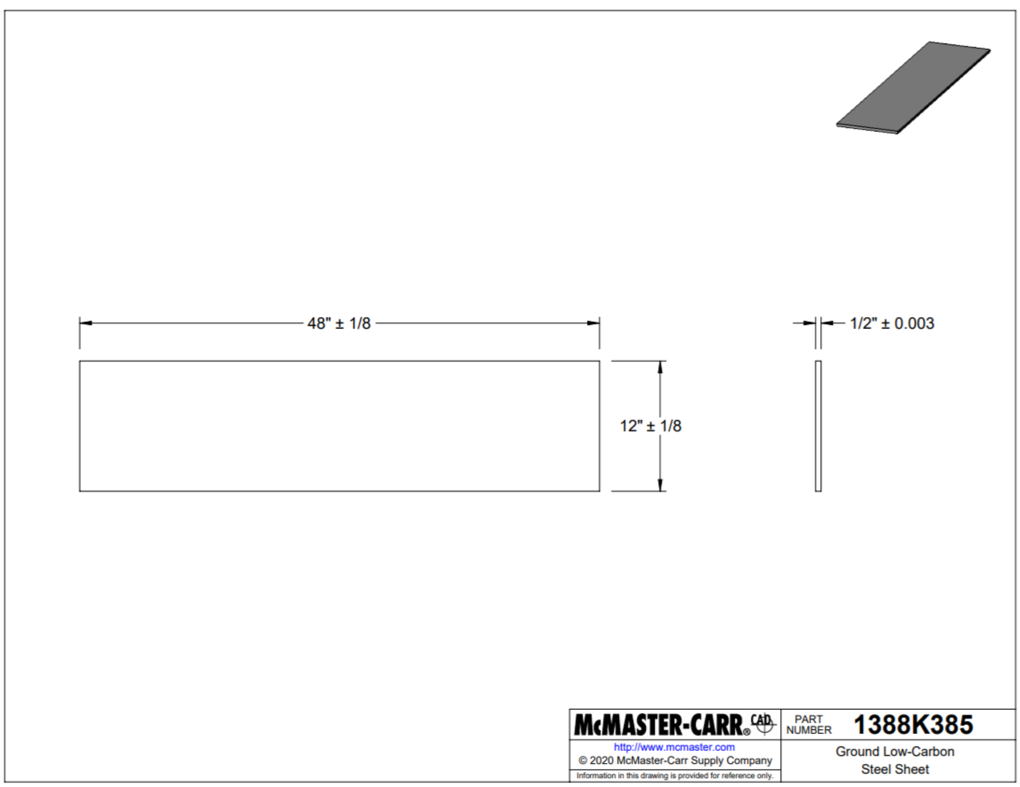


Figure B.12: Drawing of Ground Low-Carbon Steel Sheet Used on Basket, Angular Lift, and Attachment Subsection Provided by McMaster-Carr

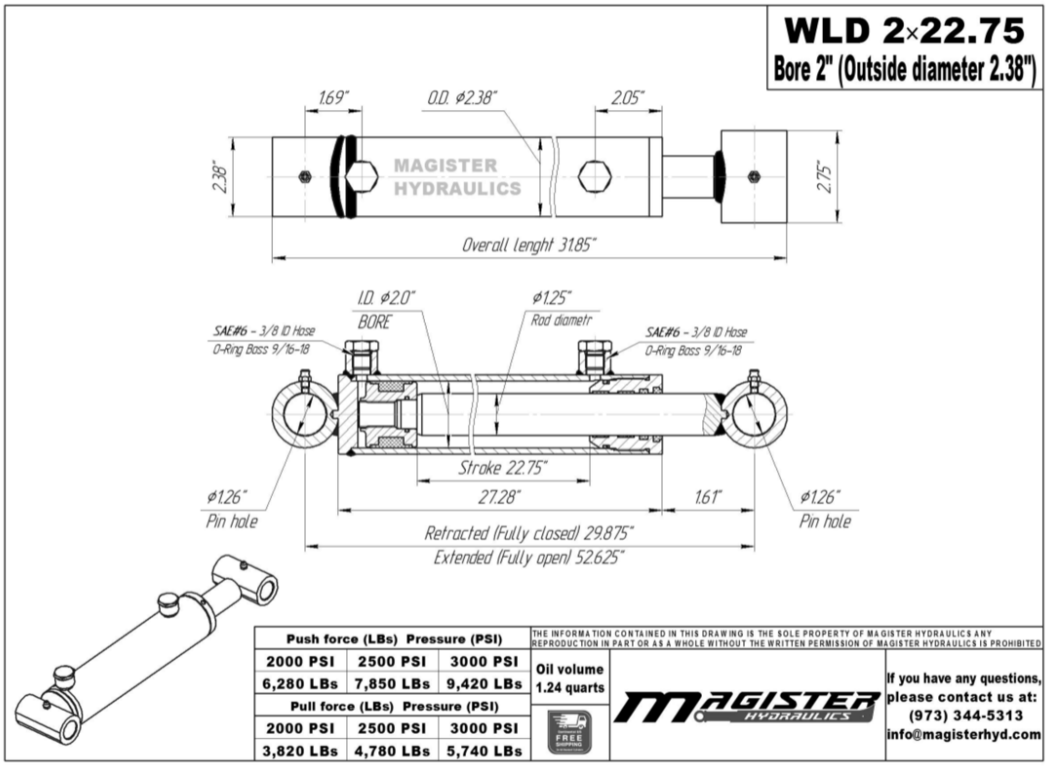


Figure B.13: Drawing of Hydraulic Lift Cylinders Used in Basket, Angular Lift, and Attachment Subsystems Provided by Magister Hydraulics

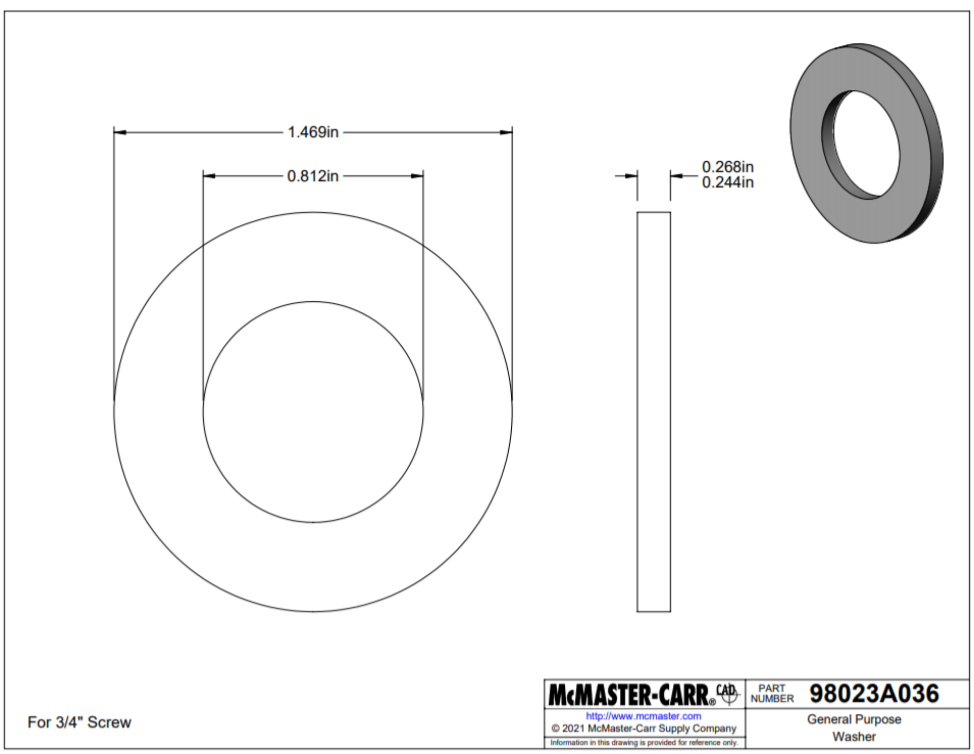


Figure B.14: Drawing of SAE Zinc Yellow-Chromate General Purpose Washer for 0.75” Diameter Flat-H Bolt Provided by McMaster-Carr

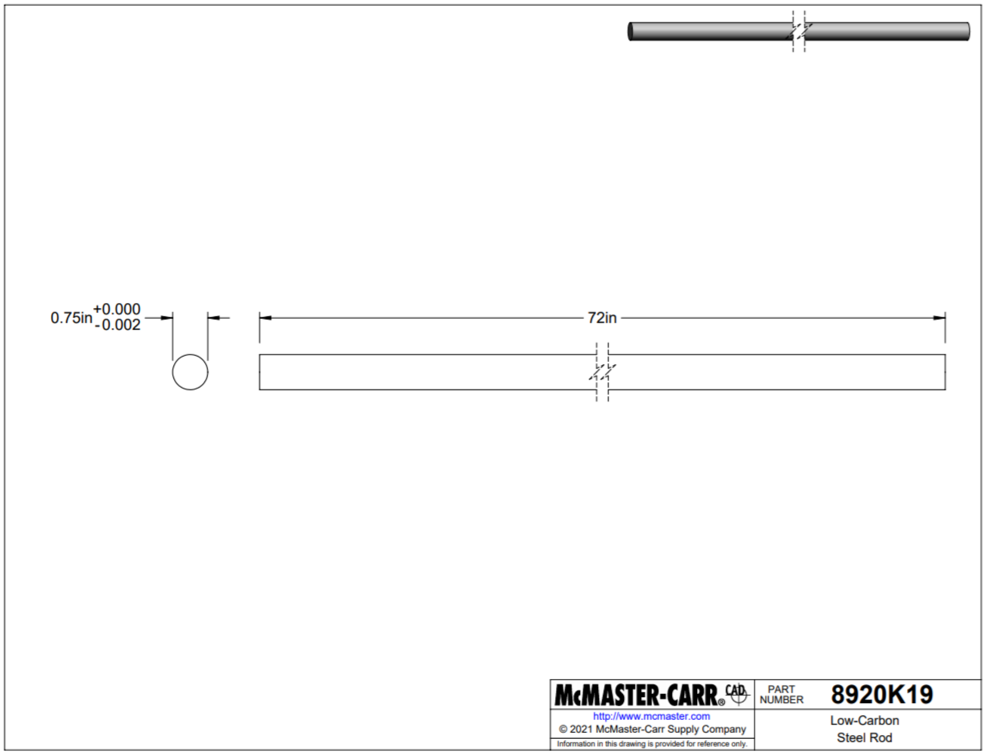


Figure B.15: Drawing of Low-Carbon Steel Rod Used to Make Pins for Rotation System Provided by McMaster-Carr

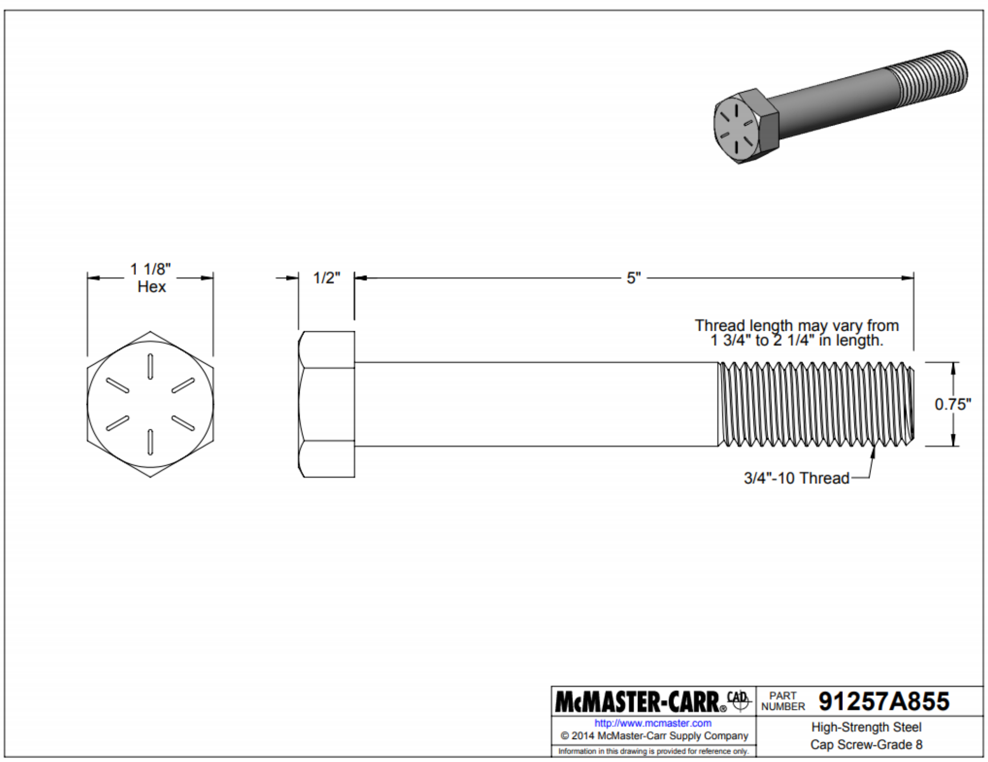


Figure B.16: Drawing of ¾"-10 Zinc Yellow-Chromate Plated, High-Strength Steel Cap Screw-Grade 8 with Partial Threads and 5" Long Provided by McMaster-Carr

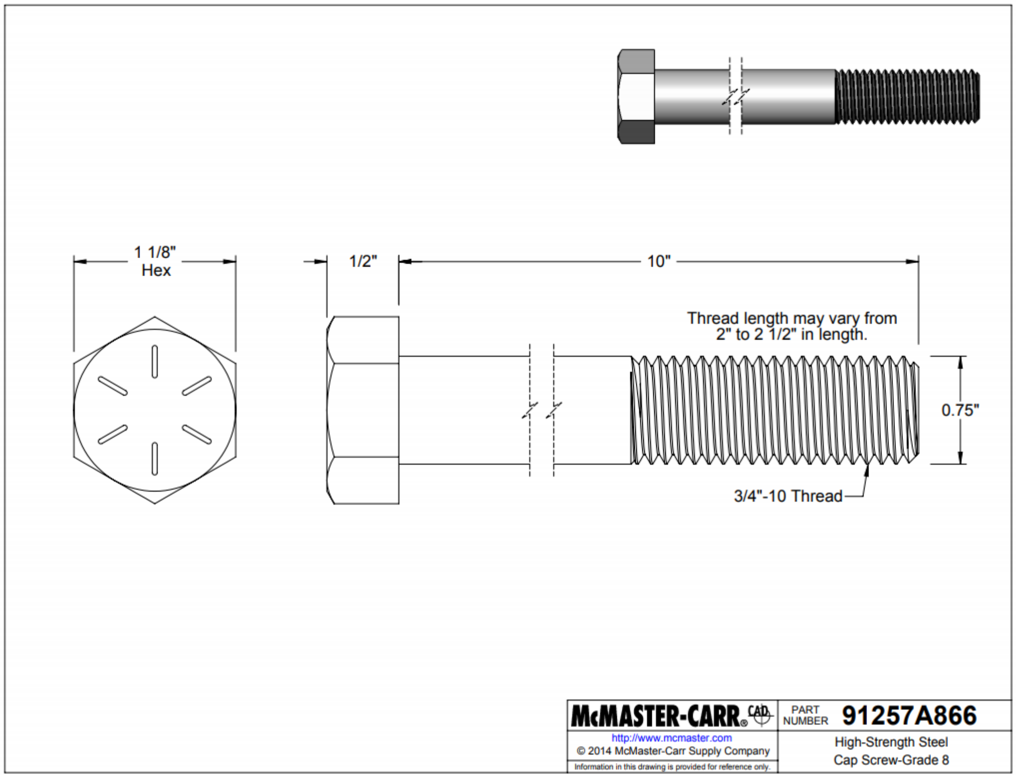


Figure B.17: Drawing of ¾"-10 Zinc Yellow-Chromate Plated, High-Strength Steel Cap Screw-Grade 8 with Partial Threads and 10" Long Provided by McMaster-Carr

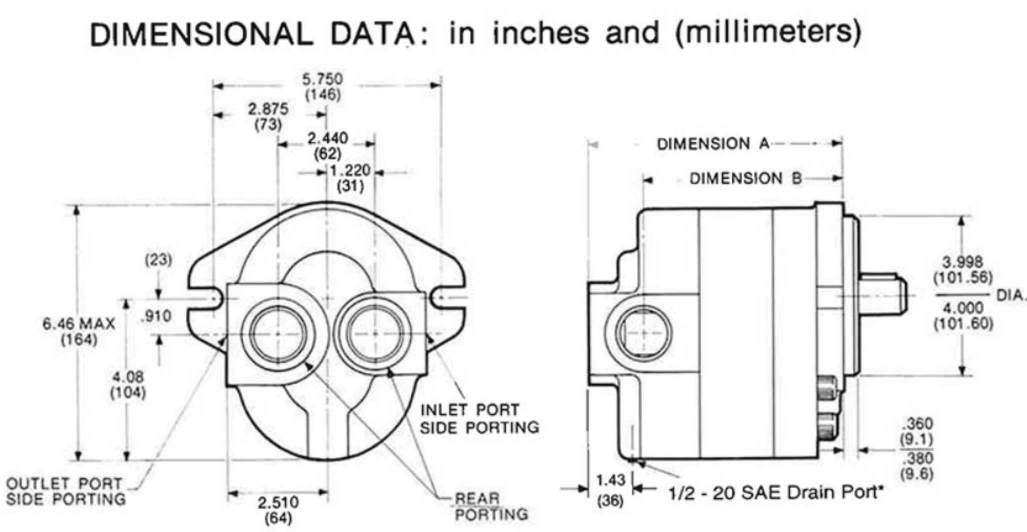


Figure B.18: 2D Drawing of 50 Series Hydraulic Motor (Part No. 50MH38DBCSC) Used in Rotation System Provided by Cross Manufacturing

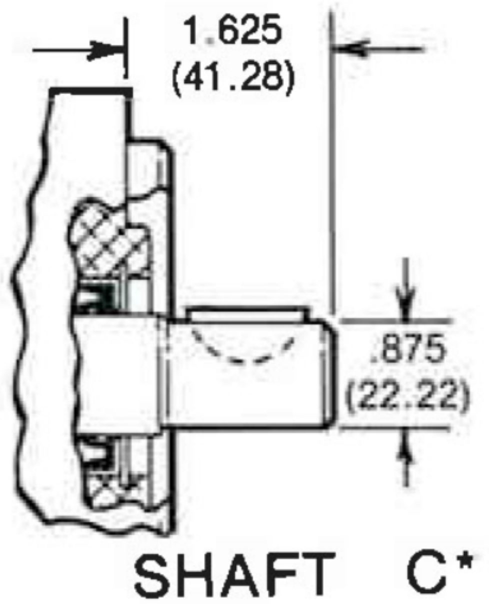


Figure B.19: Drawing of Shaft and Key of 50 Series Hydraulic Motor (Part No. 50MH38DBCSC) Used in Rotation System Provided by Cross Manufacturing

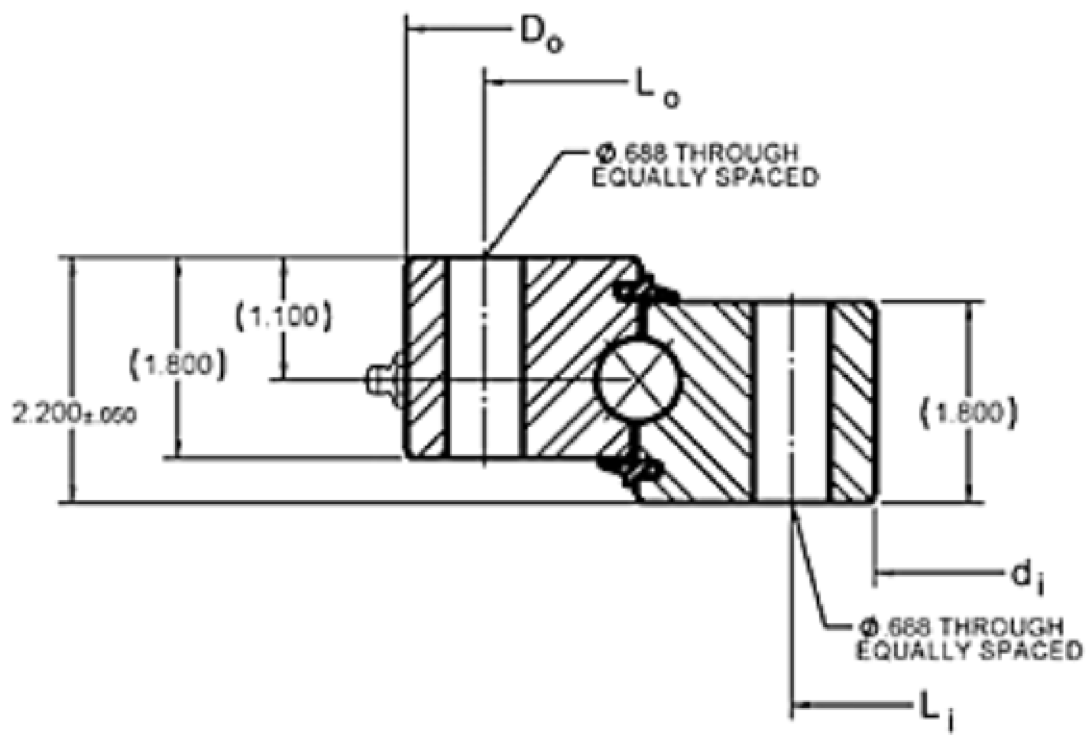


Figure B.20: Drawing of Cross Section of Slewing Bearing (Part No. HS6-25P1Z) Used in Design Provided by Kaydon Bearing

Appendix C ~ Renderings

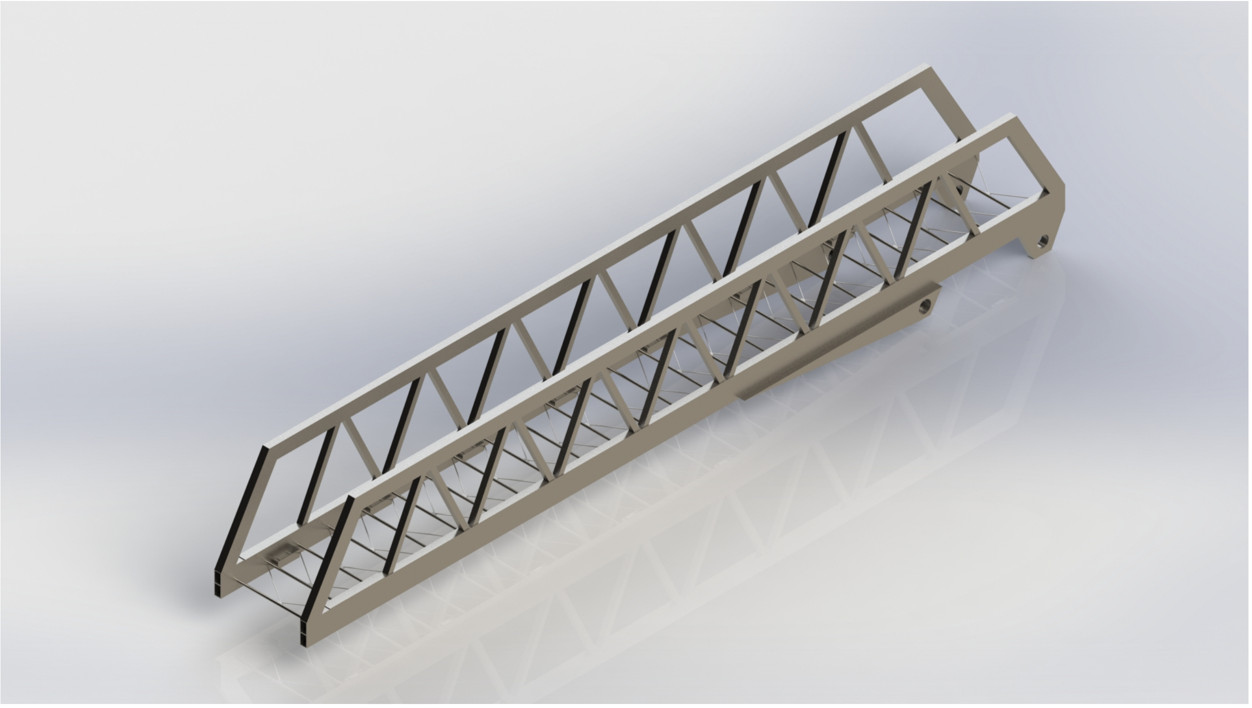


Figure C.1: Solidworks Rendering of the Base Section of the Aerial Ladder

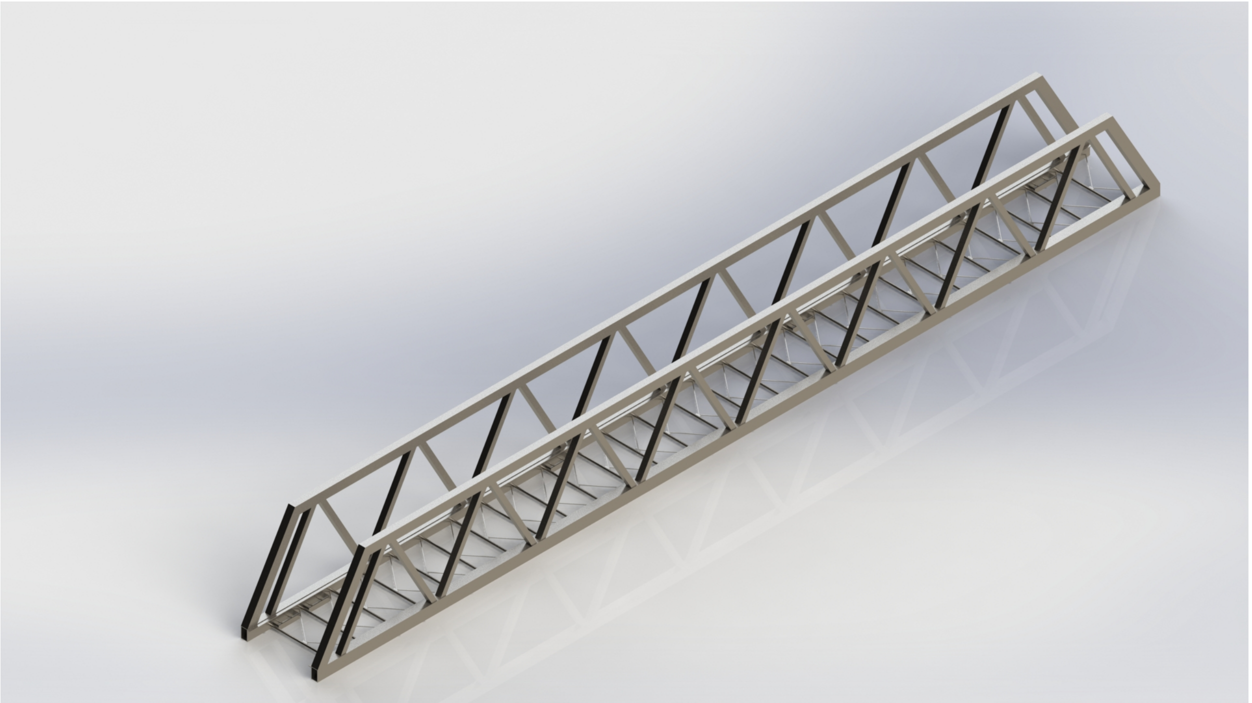


Figure C.2: Solidworks Rendering of the Mid-Section of the Aerial Ladder

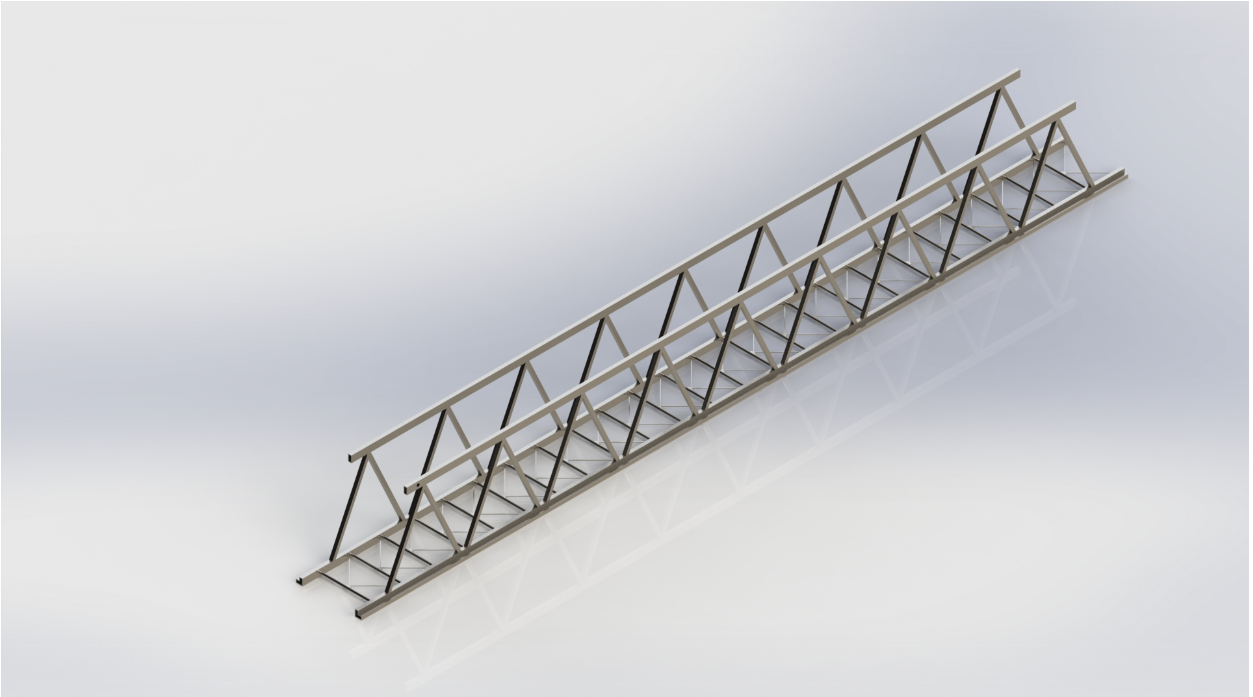


Figure C.3: Solidworks Rendering of the Fly Section of the Aerial Ladder

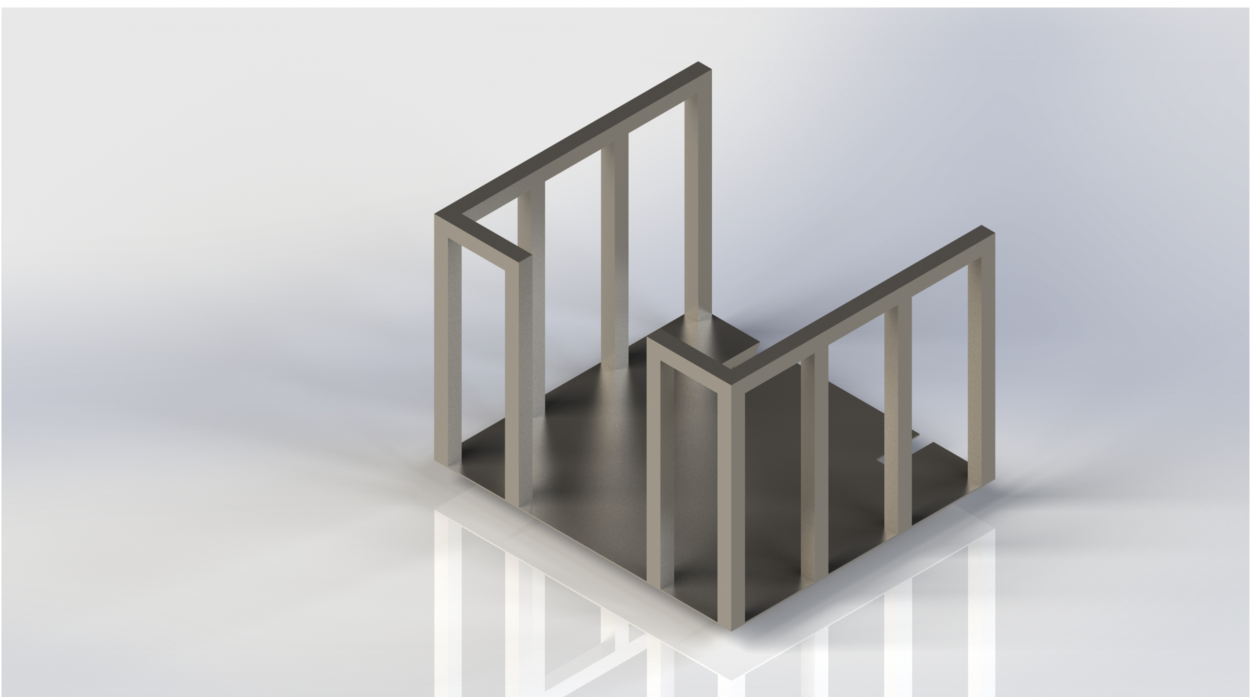


Figure C.4: Solidworks Rendering of the Basket Attached to the Aerial Apparatus

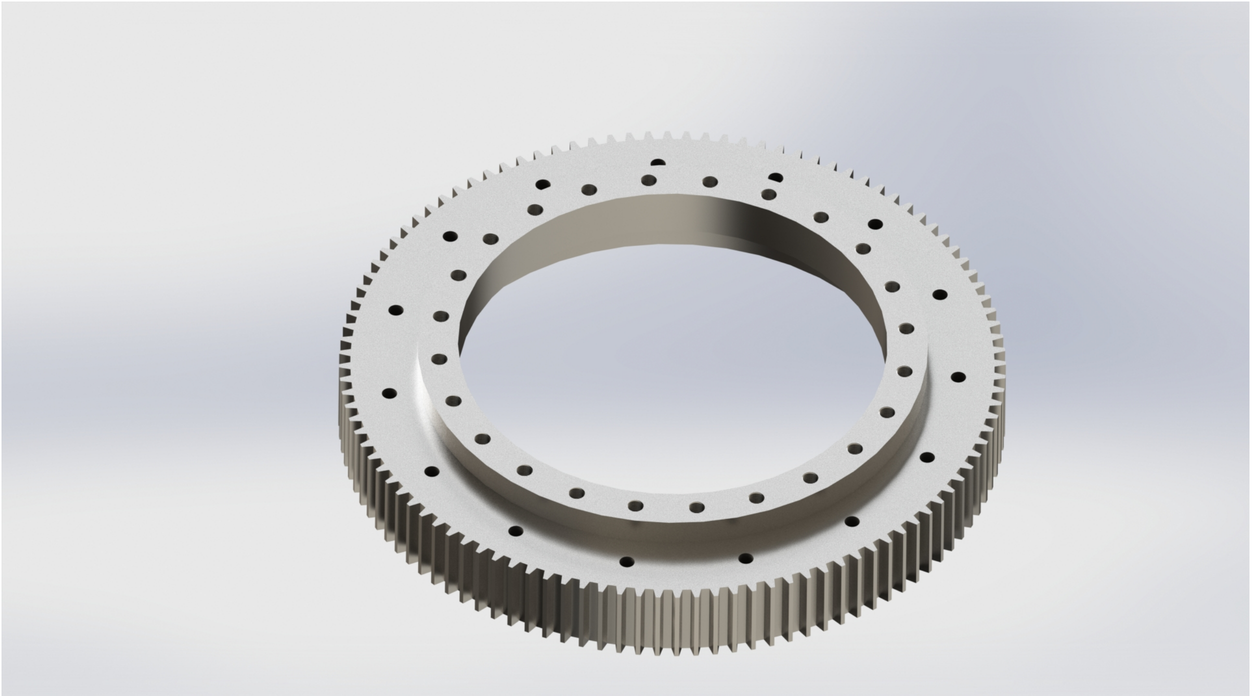


Figure C.5: Solidworks Rendering of the Customized Tiller Gear for the Rotation Mechanism of the Aerial Apparatus

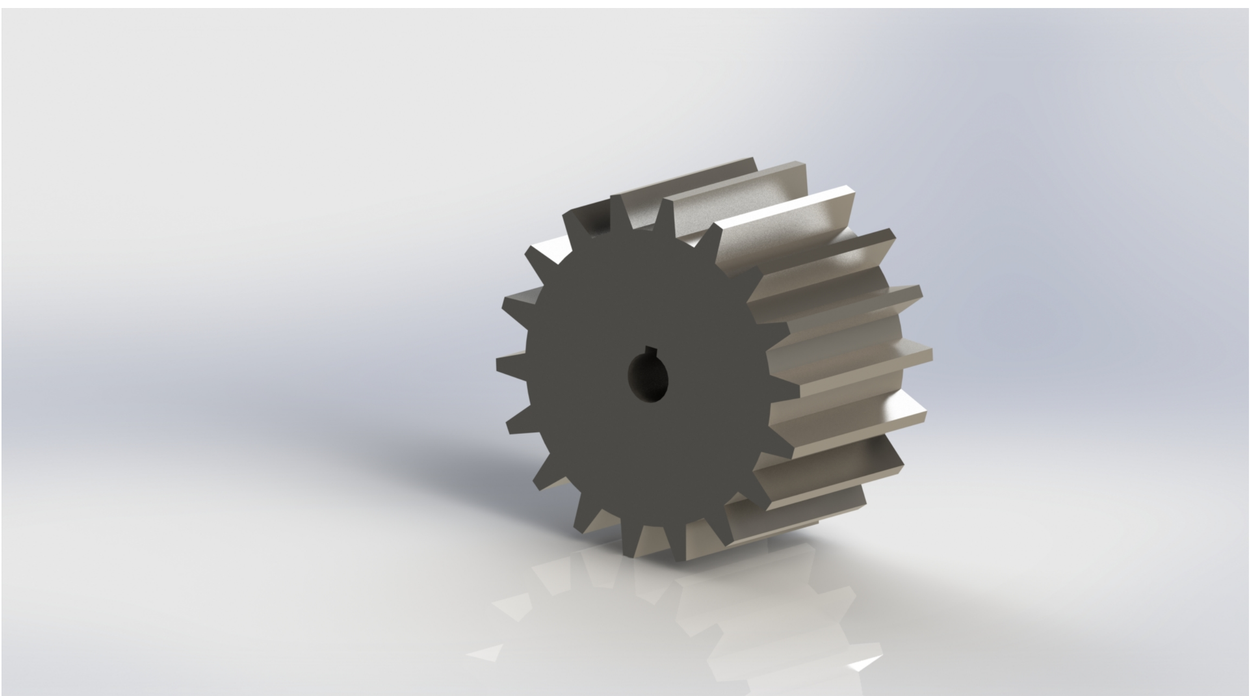


Figure C.6: Solidworks Rendering of the Customized Pinion for the Tiller Rotation Mechanism of the Aerial Apparatus

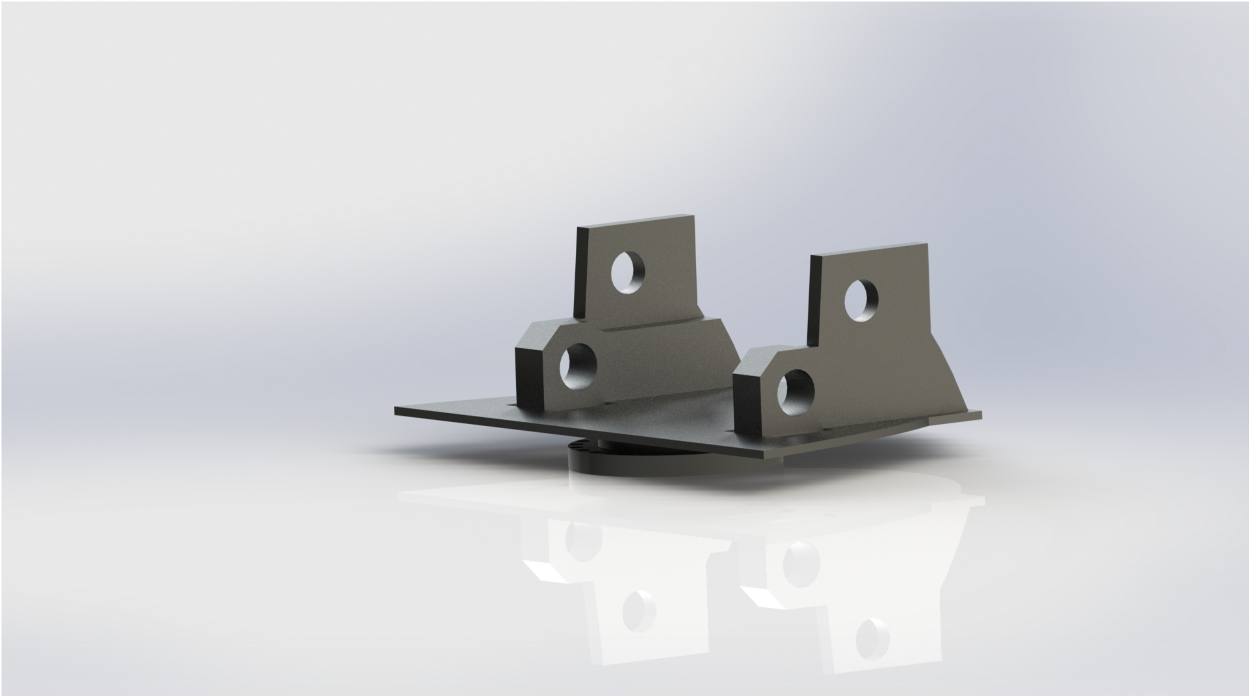


Figure C.7: Solidworks Rendering of the Custom Built Platform of the Aerial Apparatus

Figure C.8: Solidworks Rendering of the Hydraulic Motor for the Tiller Rotation Mechanism of the Aerial Apparatus

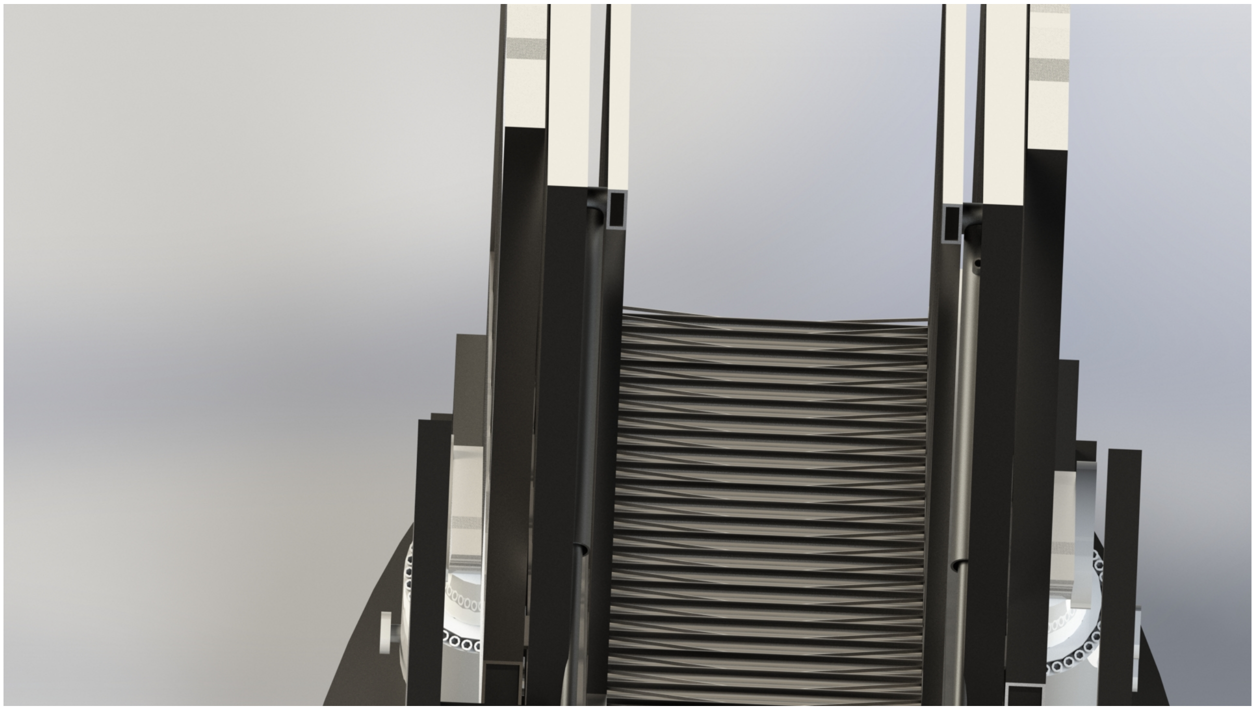


Figure C.9: Solidworks Rendering of the Aerial Apparatus with a Viewpoint from the Basket Looking Down to the Bottom

Appendix D ~ Technical Data Sheets/External Sources

Dimension Name	Specification
Alloy	**a500/a513**
Production Method	**hot rolled**
Height	**3**
Width	**5**
Wall	**0.25**
Max Length	**240**
MTR Availability	**Yes**
Material	**carbon steel**
Shape	**tube-rectangle**
Custom Cut Warehouse	**1**

Dimension Name	Specification
Alloy	**a500/a513**
Production Method	**hot rolled**
Height	**2**
Width	**3**
Wall	**0.25**
Max Length	**240**
MTR Availability	**Yes**
Full Length	**true**
Material	**carbon steel**
Shape	**tube-rectangle**
Custom Cut Warehouse	**1**

Dimension Name	Specification
Alloy	**a500/a513**
Production Method	**hot rolled**
Height	**3**
Width	**4**
Wall	**0.25**
Max Length	**240**
MTR Availability	**Yes**
Full Length	**true**
Material	**carbon steel**
Shape	**tube-rectangle**
Custom Cut Warehouse	**1**

Dimension Name	Specification
Alloy	**a500/a513**
Production Method	**hot rolled**
Height	**1.5**
Wall	**0.25**
Max Length	**240**
MTR Availability	**Yes**
Full Length	**true**
Material	**carbon steel**
Shape	**tube-square**
Custom Cut Warehouse	**1**

Figure D.1: Technical Data for Hollow Steel Beams Used in Ladder Sections Provided by OnlineMetals (From Top Left to Bottom Right: 3” x 5” x ¼”, 2” x 3” x ¼”, 3” x 4” x ¼”, 1” x 5” x ¼” Cross Sections)

TECHNICAL DATA SHEET

"NEW AND IMPROVED"

SAE 80W-90 GEAR OIL

PRODUCT # 10043, 10046, 10066, 10067, 10069

TEST	ASTM	TYPICAL
API Gravity	D-1298	25.0
Specific Gravity @ 60°F	D-1298	.9042
Density @ 60°F LBS/US Gal	D-1298	7.529
Viscosity @ 100°C cSt	D-445	15.0
Color		Clear Light Amber
Flash Point, COC °F	D-92	430
Odor		Characteristic Petroleum plus sulphur additives
AGMA Designation		4EP
FZG		12 Stage PASS
Brookfield Viscosity @ -26°C	D-2983	100,000 CPS
Pour Point, °C (°F)	D-97	-36 (-33)

EXCEEDS ALL GL CLASSIFICATIONS

API MT-1, API GL-5, MIL-PRF-2105E, MACK GO-G, PG-2 Limited Slip

Lucas SAE 80W-90 Gear Oil is a technical blend of oils and additives designed to give longer oil life and longer component life with less power draw. It is formulated with special anti-wear agents and anti-seize agents not found in common gear oils. It contains special lubricity agents for less wear, less heat, less power usage and longer bearing life. We have improved the high speed shock load and significantly improved anti-wear performance, which provides the ultimate protection to the gear components.

Lucas SAE 80W-90 Gear Oil is formulated with special "climbing additives." This action is especially important in power dividers and hypoid gears. It resists breakdown from contact with water. It will blend with other gear oils, even synthetics.

Figure D.2: Technical Data Sheet for API GL-5 80W-90 Gear Oil (Lubricant for Gear/Rotation System)

Bill of Materials Data	
Manufacturer	Cross Manufacturing, Inc.
Description	50 Series 2.32 Cubic Inch Per Revolution (in³/r) Displacement Size Gear Hydraulic Motor
Part Number	50MH23-DBCSC
Minimum Order	1
Brands	CROSS
Type	Gear
Rated Working Pressure (bar)	207
Rated Working Pressure (psi)	3000
Maximum Shock and Surge Pressure (bar)	242
Maximum Shock and Surge Pressure (psi)	3500
Mounting at Any Position	Society of Automotive Engineers (SAE) "B" Size, 2-Bolt
Body Material	Permold Aluminum Alloy
Dimension A (in)	5.96
Dimension A (mm)	151
Dimension B (in)	4.56
Dimension B (mm)	116
Maximum Input Flow Rate (gpm)	Up to 56
Maximum Input Flow Rate (L/min)	Up to 227
Maximum Continuous Speed (rpm)	Up to 3000
Maximum Power at Rated Speed and Pressure (hp)	Up to 100
Maximum Power at Rated Speed and Pressure (kW)	Up to 74.6
Approximate Weight (kg)	8.6
Approximate Weight (lb)	19
Bearings Material	Pressure Lubricated, Polytetrafluoroethylene (PTFE) Impregnated Sleeve
Shaft Seal Pressure (Special Options) (bar)	17
Shaft Seal Pressure (Special Options) (psi)	250
Displacement Size (cm³/rev)	38.0
Displacement Size (in³/r)	2.32
Rotation	Dual
Shaft Diameter (in)	7/8
Shaft Type	Woodruff Key
Shaft Size (in)	1/4
Inlet Port Size (in)	1-5/16
Outlet Port Size (in)	1-5/16
Port Type	Side
End Covers Material	Die Cast Aluminum Alloy
Gears and Shafts Material	Hardened Steel
Displacement Size (x 10)	23

Figure D.3: Technical Data Sheet for 50 Series Hydraulic Motor (Part No. 50MH38DBCSC) by Cross Manufacturing Inc.

Table	
Part Number	HS6-25P1Z
Do (in)	29.5
di (in)	21
Approx. Weight (lbs)	162
Outer Ring Lo (in)	28
Outer Ring # of Holes	15
Inner Ring Li (in)	22.5
Inner Ring # of Holes	18
Moment Rating (ft-lbs)	91800

Figure D.4: Technical Specifications for Slewing Bearing (Part No. HS6-25P1Z) Provided by Kaydon Bearing

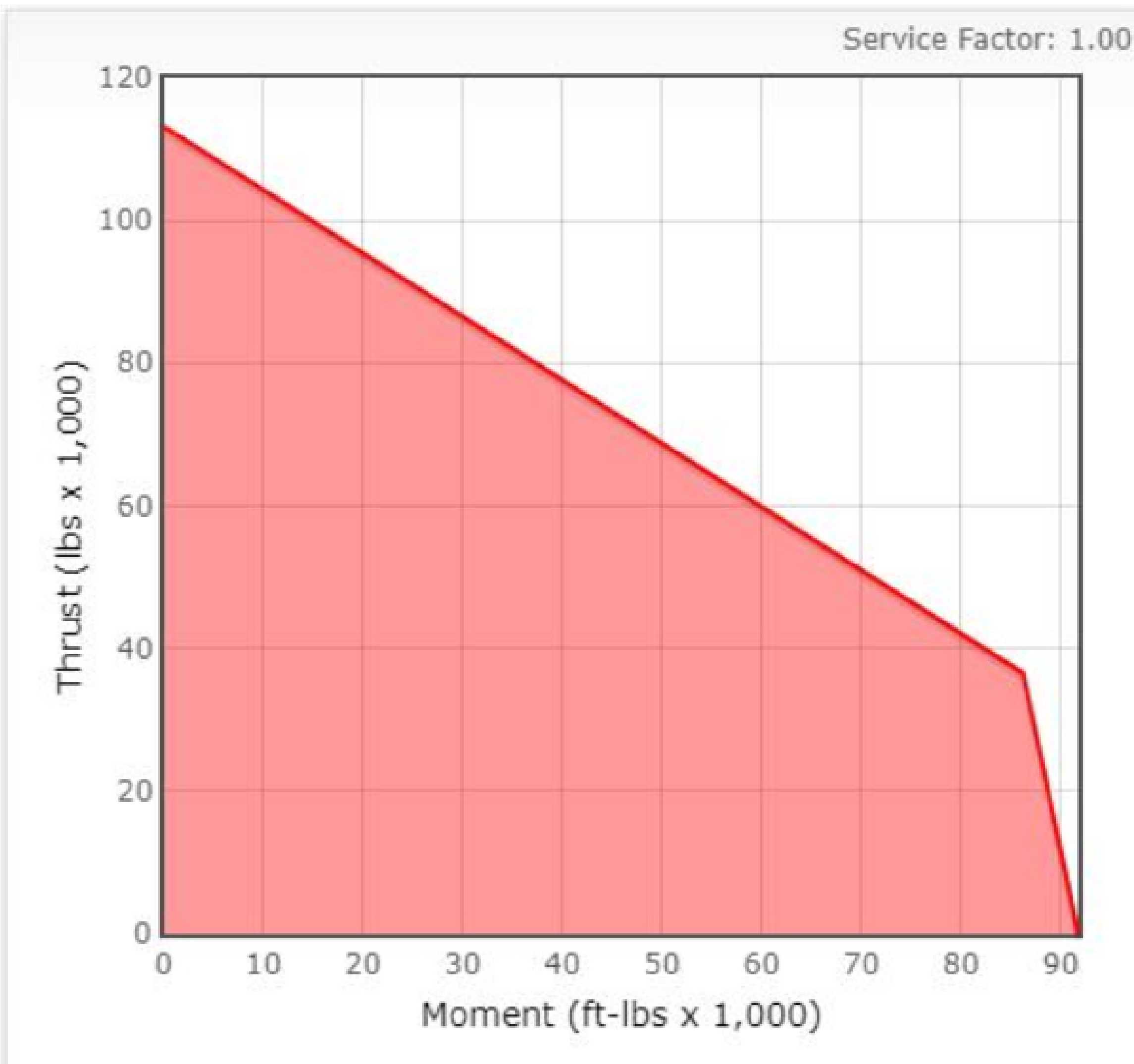


Figure D.5: Thrust-Moment Diagram of Kaydon Bearing

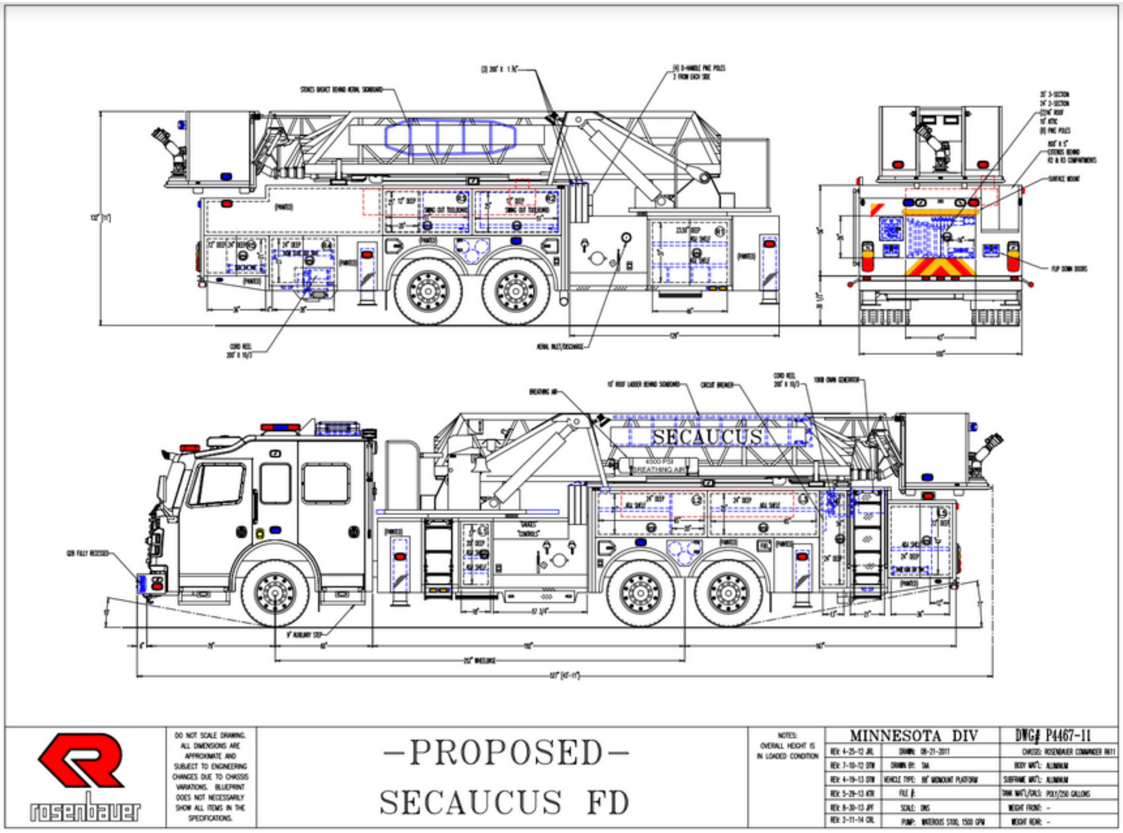


Figure D.6: Technical Data Sheet of Rosenbauer Fire Truck Provided by Secaucus Fire Department

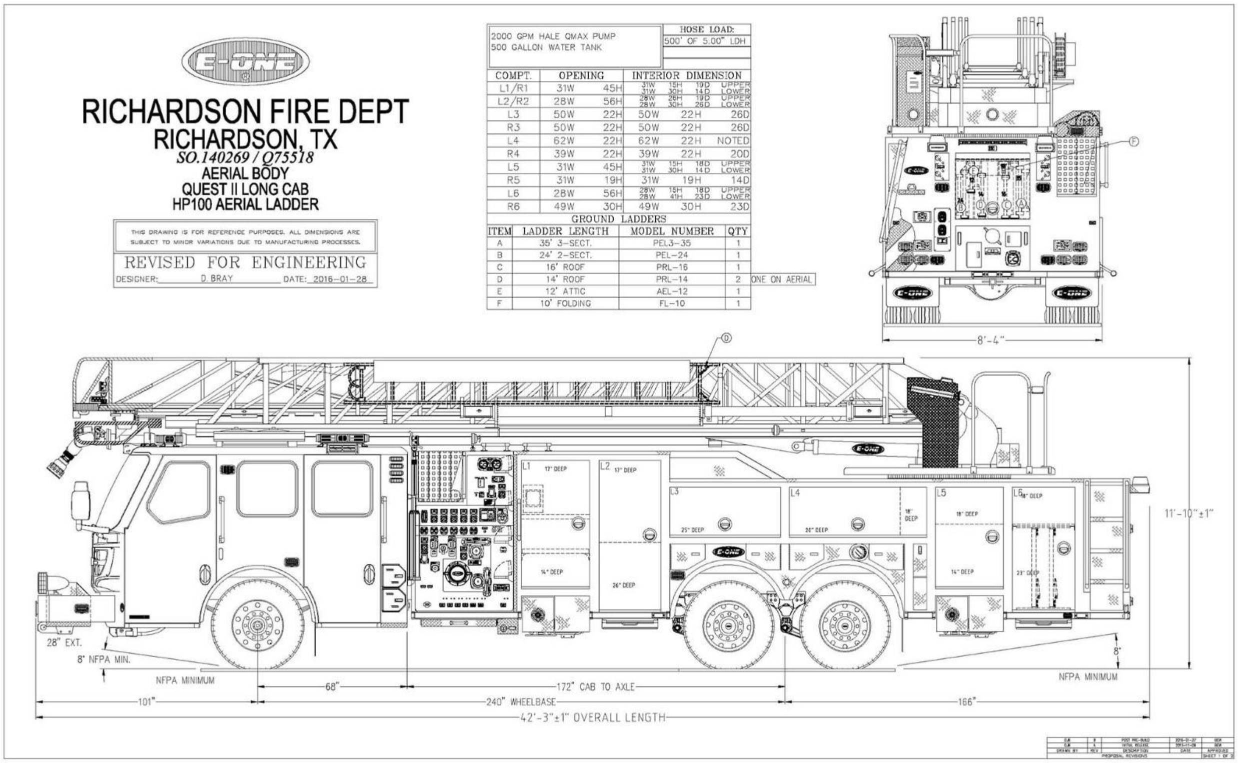


Figure D.7: Technical Drawing of E-ONE Fire Truck Provided by Richardson Fire Department

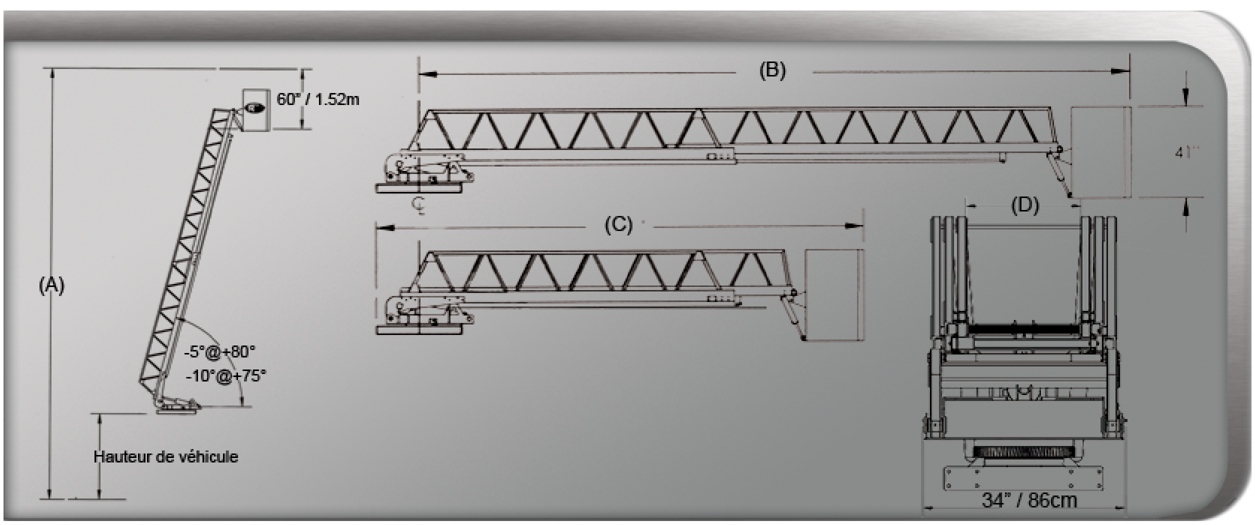
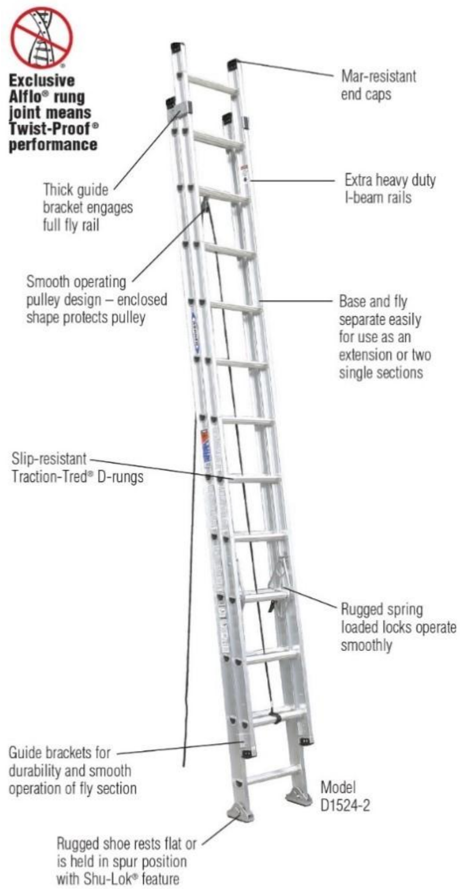


Figure D.8: Technical Drawing of Extendable Ladder (Not on Fire Truck)

D1500-2/D1500-1 SERIES

★★★★ **300**lbs. LOAD CAPACITY **TYPE IA** DUTY RATING

STYLE: D-Rung Extension/Straight Ladder



SPECIFICATIONS

Model No.	Total Length of Sections	Max. Working Length	Approx. Cu. Ft. Per Unit	Approx. Shipping Wt. Lbs.	Single Ladder Model No.	Total Length	Approx. Cu. Ft. Per Unit	Approx. Shipping Wt. Lbs.
D1516-2‡	16'	13'	6.2	30.5	D1508-1	8'	3.6	14.5
D1520-2	20'	17'	7.7	37.0	D1510-1	10'	4.5	17.5
D1524-2	24'	21'	9.2	45.0	D1512-1	12'	5.4	21.5
D1528-2	28'	25'	10.7	56.0	D1514-1	14'	6.2	27.0
D1532-2	32'	29'	12.2	67.0	D1516-1	16'	7.1	32.5
D1536-2	36'	32'	13.7	80.0	D1518-1	18'	8.0	38.5
D1540-2	40'	35'	15.2	89.5	D1520-1	20'	8.9	43.5

‡ Note: D1516-2 is not equipped with rope and pulley

DIMENSIONS

Rails:	3" wide	Rungs:	1-3/4"
Flange:	1-1/8" wide	Base Width:	18-1/8" outside rails

Figure D.9: Specifications of Extendable Ladder for Everyday Use

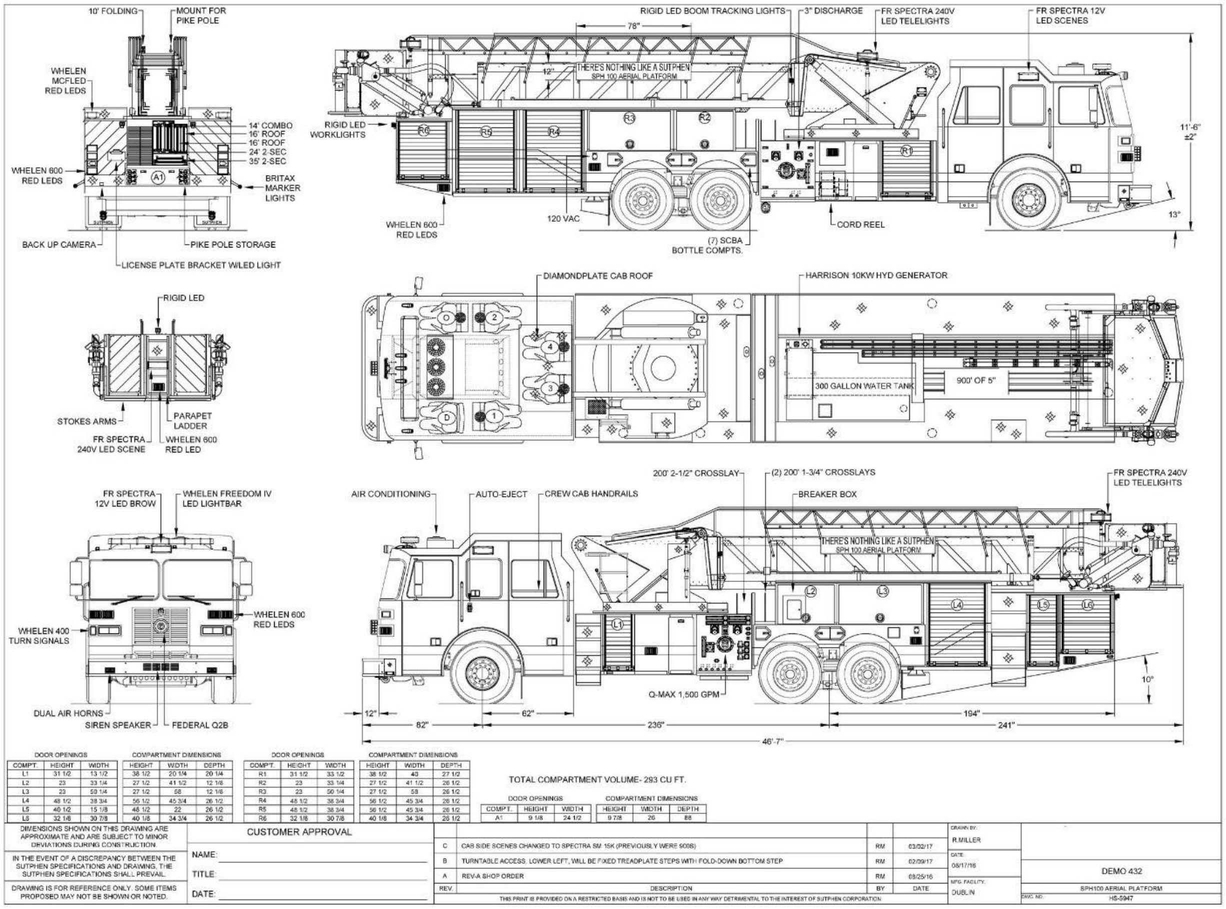


Figure D.10: Technical Drawing of Tiller Truck with Rear-Mounted Basket

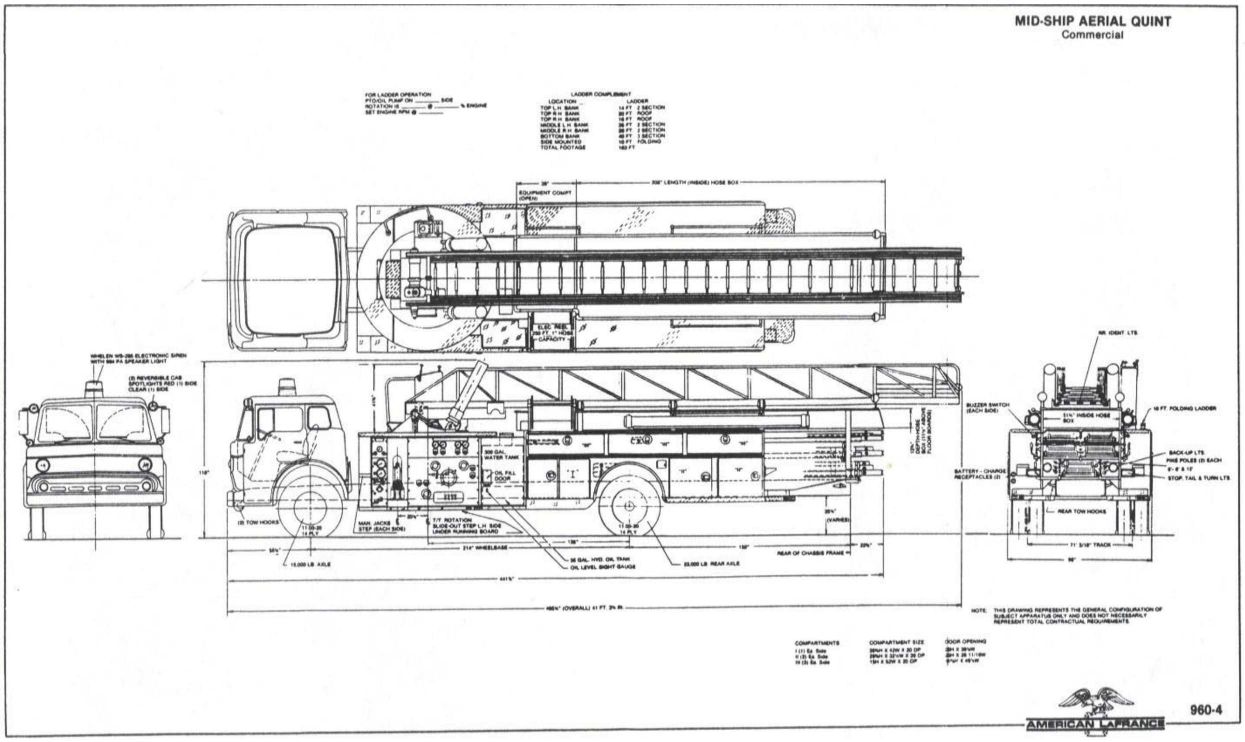


Figure D.11: Technical Drawing of Fire Truck with Rear-Mounted Aerial

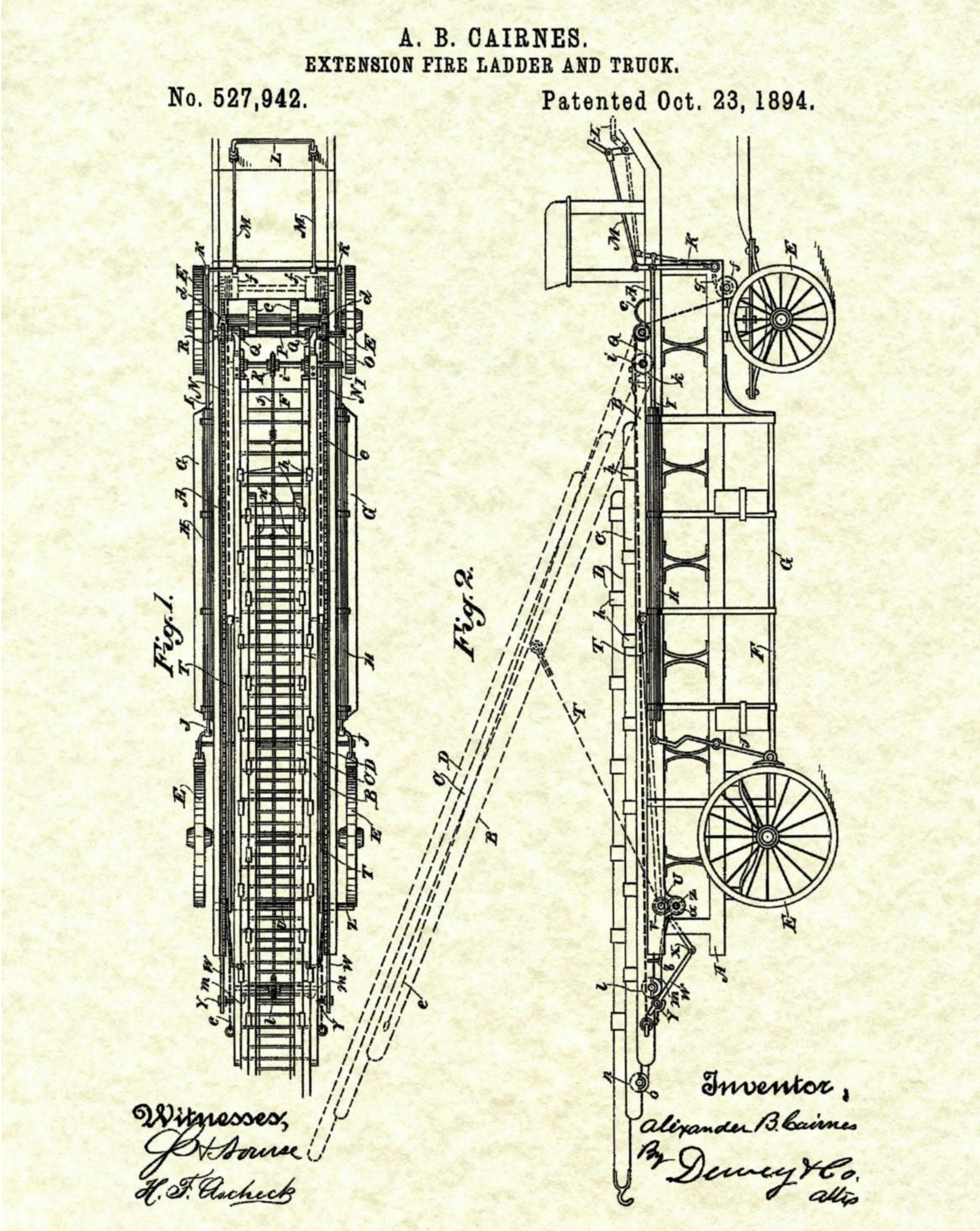


Figure D.12: Drawing of Patented Fire Truck Extendable Ladder From 1894

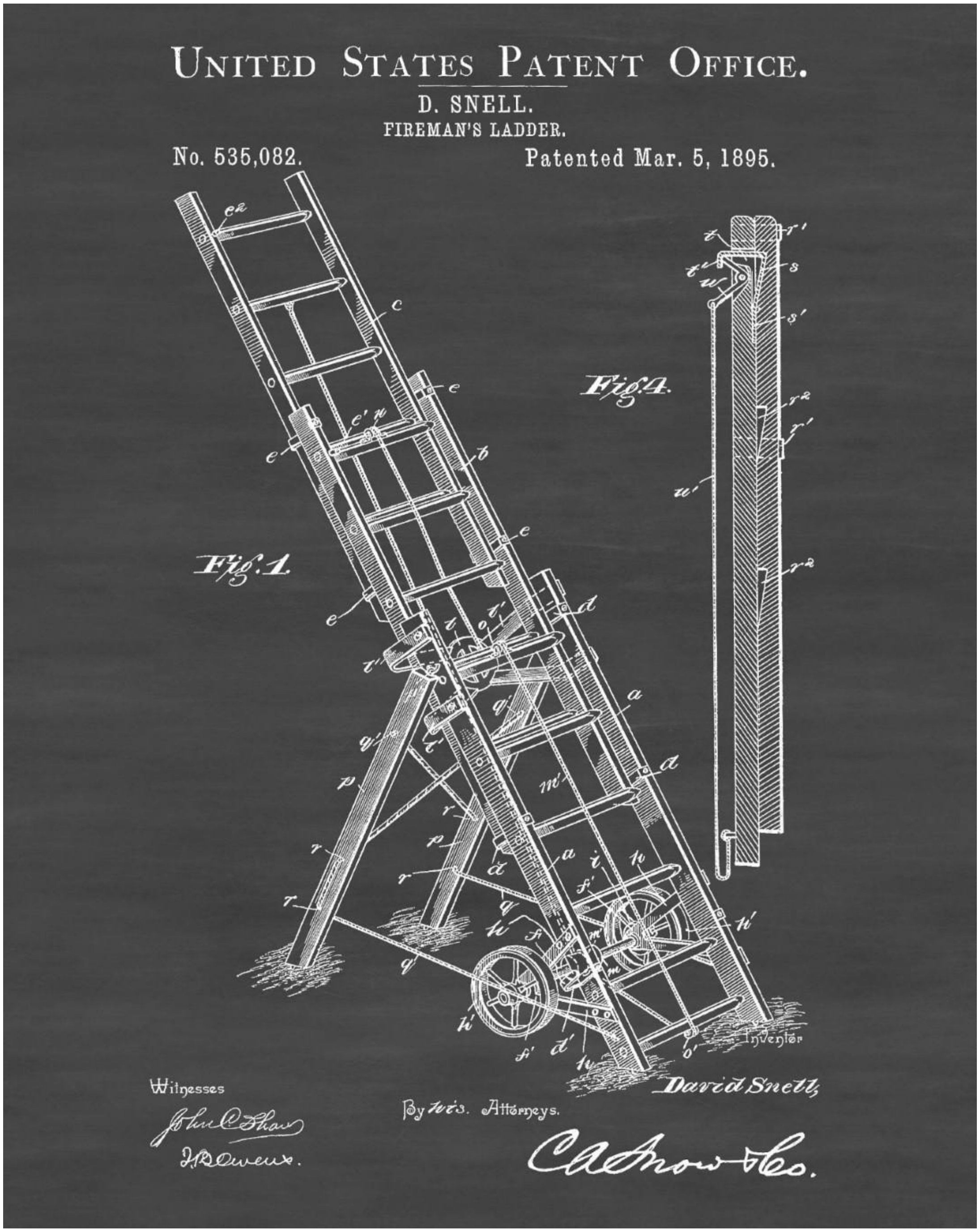


Figure D.13: Technical Drawing of Patent for Retractable and Extendable Ladder From 1895 (U.S. Patent Office)

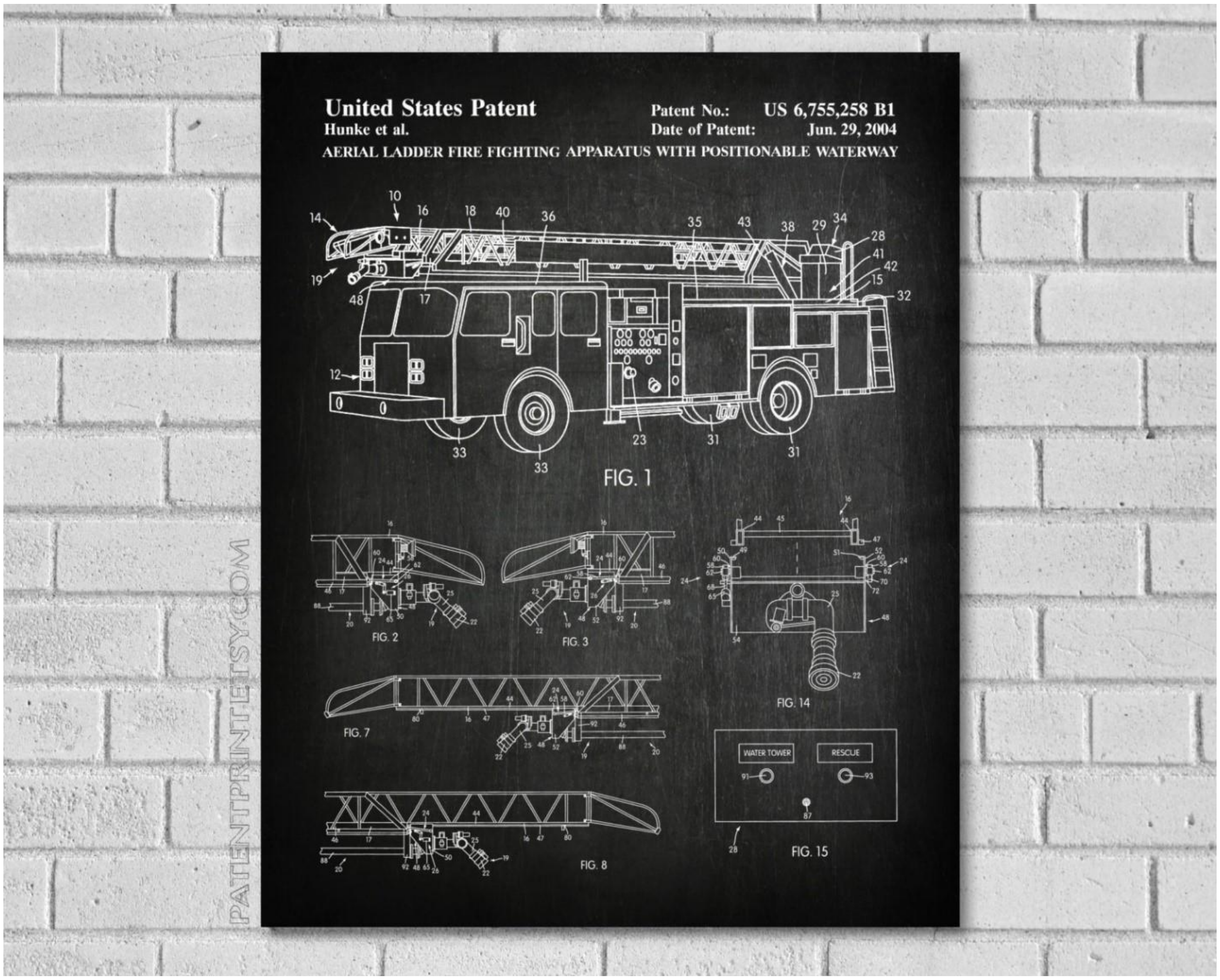
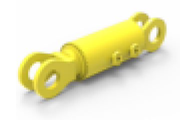
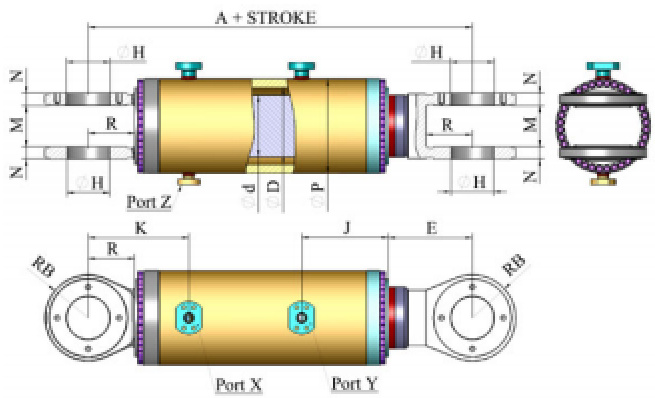


Figure D.14: Drawing of Aerial Ladder Fire Fighting Apparatus Provided by U.S. Patent Office (2004)

HydratechIndustries
Fluid Power





Part number
CM 315GG250/200x120HCX
Description
Cylinder CM 315

Product Attribute	Value
Fixing cylinder	G: Cast material fork
Fixing rod	G: Cast material fork
Rod eye type	Standard
Pressure Push (bar)	315
Pressure Pull (bar)	315
Push force (kN)	1546.3
Pull force (kN)	556.7
Bore	250
Rod	200
Stroke	120
Length mounted min (A)	1200
Material rod	HC: Hard chromium
Treatment	X: Sandblasted and primed
Connection angle (°)	0

Figure D.15: Technical Data Sheet and Drawing of Hydraulic Lift Cylinders Provided by HydratechIndustries

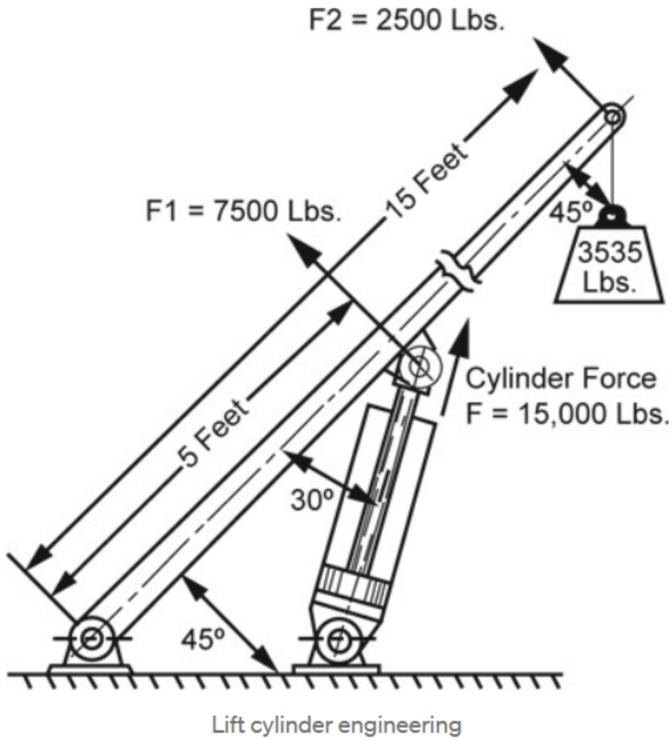


Figure D.16: Drawing of Hydraulic Lift Cylinders in Use

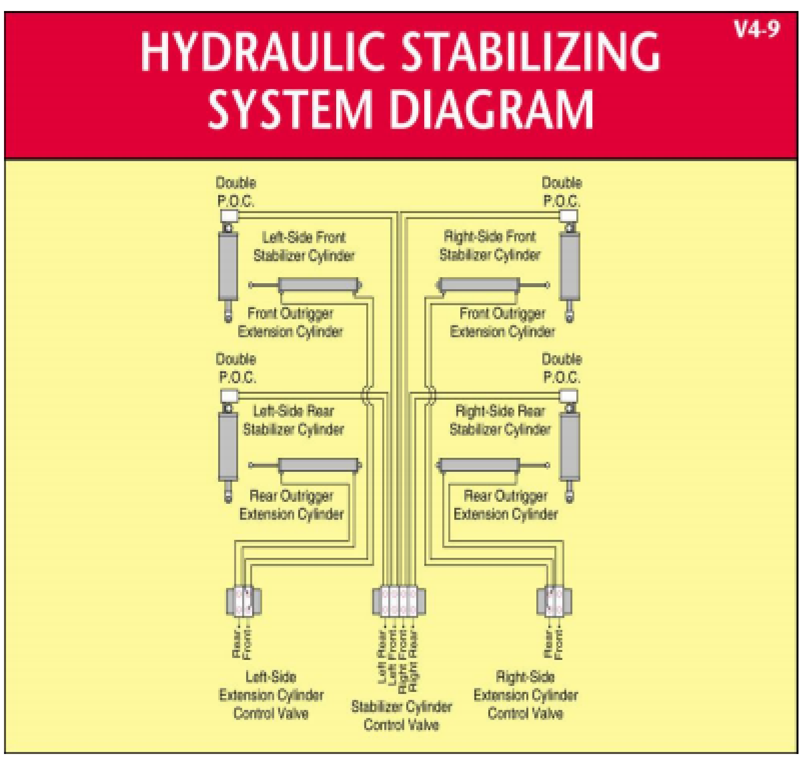


Figure D.17: Drawing of Hydraulic Lift Stabilizing System

Appendix E ~ Handwritten and Extraneous Note

Final Design Project

- Selection of Materials
- Failure Analysis
  - Static
  - Dynamic / Fatigue Loading
- Stress Analysis
  - Axial
  - Torsional
  - Bending
  - Buckling
  - Stress Concentration (K_t)
- Method of Assembly
- Modularity (Specifications)(Use Color for Solidworks)
- Mechanical Advantage
- Cost (US-Based Company)(Cite Locations)
- Safety
- Life Expectancy
- Justification of Design
  - Can include trials leading to optimal design

* Set Assembly Cost at $20/hr & Machining Costs at $65/Hr * ?

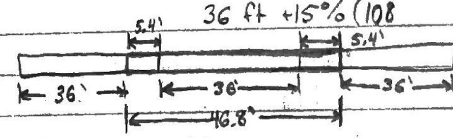
- Scenario
  - 500 Trucks
  - 90+% Buildings are 2-5 Stories
  - 30+ Lifespan
  - Profit Margin 150%
- Performance Requirements
  - Lift, Lower, Extend, Contract, Rotate
    - Rotation = 2.5-3.0 in/s
  - ~~On Top of Truck~~
  - Area = 5' x 5' x 1.5" thick AISI-1020 Steel
  - Area Under Plate = Opening is 2.5'
  - Stabilizing System is already designed
  - θ = 60° Rise

- Ask about Method of Assembly

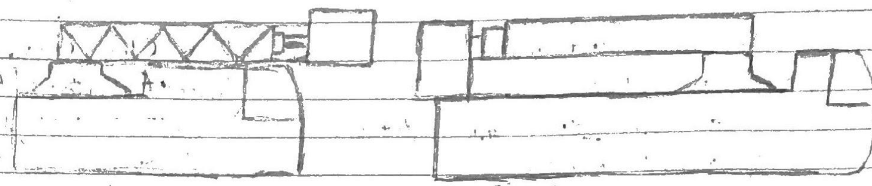
Other Considerations:
- ~~Fit under traffic lights~~
- ~~Smallest Diameter Has to be Strong Enough to Hold Basket~~
- ~~Hollow?~~

To Do For Me:
- Basket Research
- Technical Stuff
  - Selection of Materials
  - Cost
  - How to Assemble

108 ft. extend
36 ft +15% (108

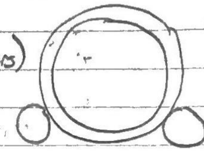


- θ = 105° CW & CCW
- Expand 75'
- Basket to House 3 Adults & Pets
  - Not Included in Extension Length
- 700 lbs in addition to dead weight
- Powered Independently by Batteries or Gas Generator



- Oil Hydraulics = Raise
- Rotation = Big Gear & 2 Smalls (w/ Servomotors)
- Extension = Winch & Pulley

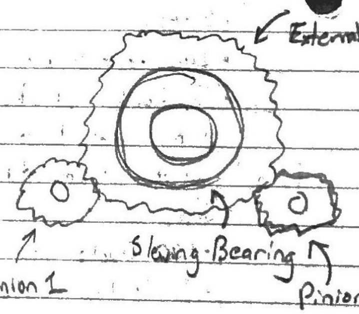
or Hydraulic Motor ?



RING GEAR + MOTOR
SLEWING UNIT/BEARING

$$\frac{3\,\text{in}}{\text{s}} = \frac{180\,\frac{\text{in}}{\text{min}}}{2\pi r} = RPM$$

- Industrial External Ring Gear
- Regarding Horsepower
  - Quasi-Static
  - Chapter 1 Juvinall & Marshek



- Parallel 4-bar (Closer to 6)
  - Chebyshev
- Kinematically can achieve, however, we can find a gyroscopic system to keep the bucket parallel to the floor

Must Stay Parallel

- Horsepower
- # of Teeth

$$\frac{180\,\frac{\text{in}}{\text{min}}}{2\pi(16\text{in})} = \boxed{1.7904\ RPM}$$

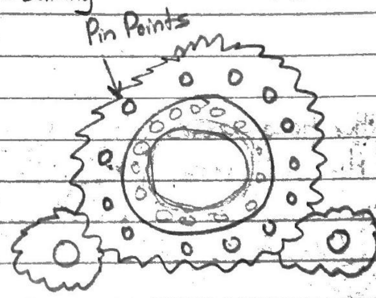
- Initial Assembly 1 cup
- For 500 units use about 1 55 Gallon drum
- For weekly maintenance, 1 cup-15 per week but that is for consumer

Live = 700 + Bucket
Dead = Weight

[redacted]

• Kaydon Bearing PN: HS6-25P1Z Outer Ring OD: 29.500in Inner Ring ID: 21.000in

swivel =

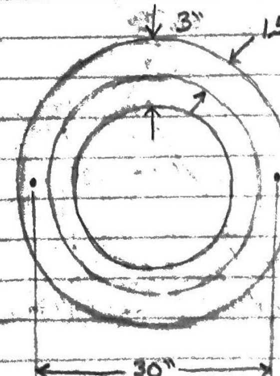


• Lubricant?
• Anchor Pins?

★ API GL5 80W90 Gear Oil ★

• Uses PTO to take power from the engine to a port on the transmission on the torque box
  • Only works when the transmission / truck is in neutral
  • Back-Up 12 volt pump in case of engine or PTO failure
• Motors work in unison for continuous 360° motion

Motor? Close
Radius?
Thickness? 3"→4"?
# of Teeth?
Height? 3.5"→4"?
Bearing? Slew + Roller?



✓ Thick: 3 in
Inner: 27 in
Outer: 33 in
✓ From Bolt Cent: 30 in
✓ Height: ~4 in

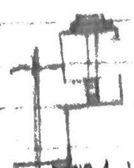
Motor

• Hydraulic Servo Motor
  • Controlled Flow of Working Fluid using by Hydraulic Circuit / Servo-Values
  • Assume Constant Pressure
• Gear will most likely be custom made

Bearing, Motor Calculations

Bolt
Motor
Pinion?

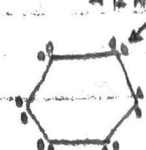
★ 36 holes ★
★ 108 teeth ★



★ 0.75" Bolt ★
★ 0.75 = 21/32 tapped hole = 0.65625
★ NC Tap

Motor ✓
Lube ✓
Base Dimensions
Gear
Pinion ✓
# of Teeth ✓
Bearing

★ 12 Anchor Pins = Hexagon



★ Washer 0.75 N Flat-H ASTM F436Z

5.5" Sheet ✓

Counterbore on Top Section

Bolts (24+24)

- High-Strength Grade 8 Steel Hex Head Screws (24) (3/4"-10 x 4in)
- High-Strength Grade 8 Steel Hex Head Screws ~~(24)~~ (3/4"-10x10in)

Washer ✓ (34) (10)

- SAE Washers (OD = 1.469 in, ID = 0.812 in) ~~(48)~~

5x10" pins
50in

Pins (1 5' Rod) ✓

- Low-Carbon Steel Rods ~~(2 6' Rods)~~ (Makes 12 10" Pins)

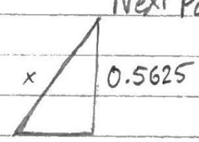
Motor

- 50 Series Gear Hydraulic Motors, 50MH38-DBCSC ✓
  - HP = Up to 100
  - T_p = 29,695.55 lb_f-ft
  - RPM = RPM_{Pin} = 10.7424

Next Page

Questions:

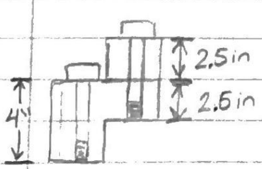
- ✓ Pitch Circle? +0.25"
- ✓ Bolt: More than 4"? 10"
- ✓ Motor: McMaster vs. Cross? (Find Cheapest)
- ✓ Torque: r = Addendum Circle?, Pitch Circle?, or Base Circle (↑ Pitch Diameter)
- ✓ Pins (↑ Use Rods)

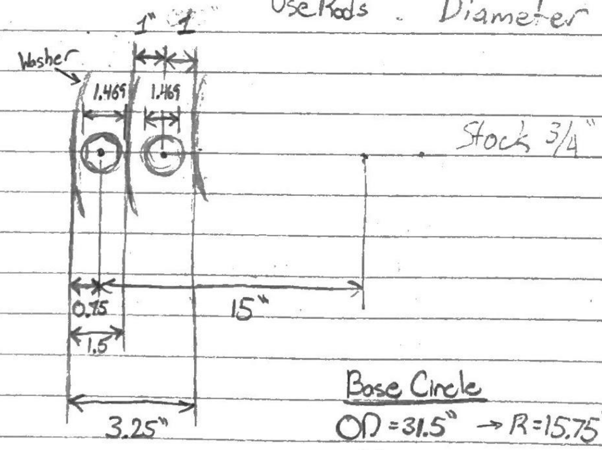


$\cos(30°) = \frac{0.5625}{x}$

$x = \frac{0.5625}{\cos(30°)} = 0.6495$ in

Bolt → Diameter = 1.30 in





Base Circle

OD = 31.5" → R = 15.75"

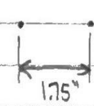
ID1 = 28.5"

ID2 = 25"

Pitch Circle = +0.25"

0.5"

20° Pressure Angle



Bolt Center to Bolt Center

From Chapter 1 Eqn

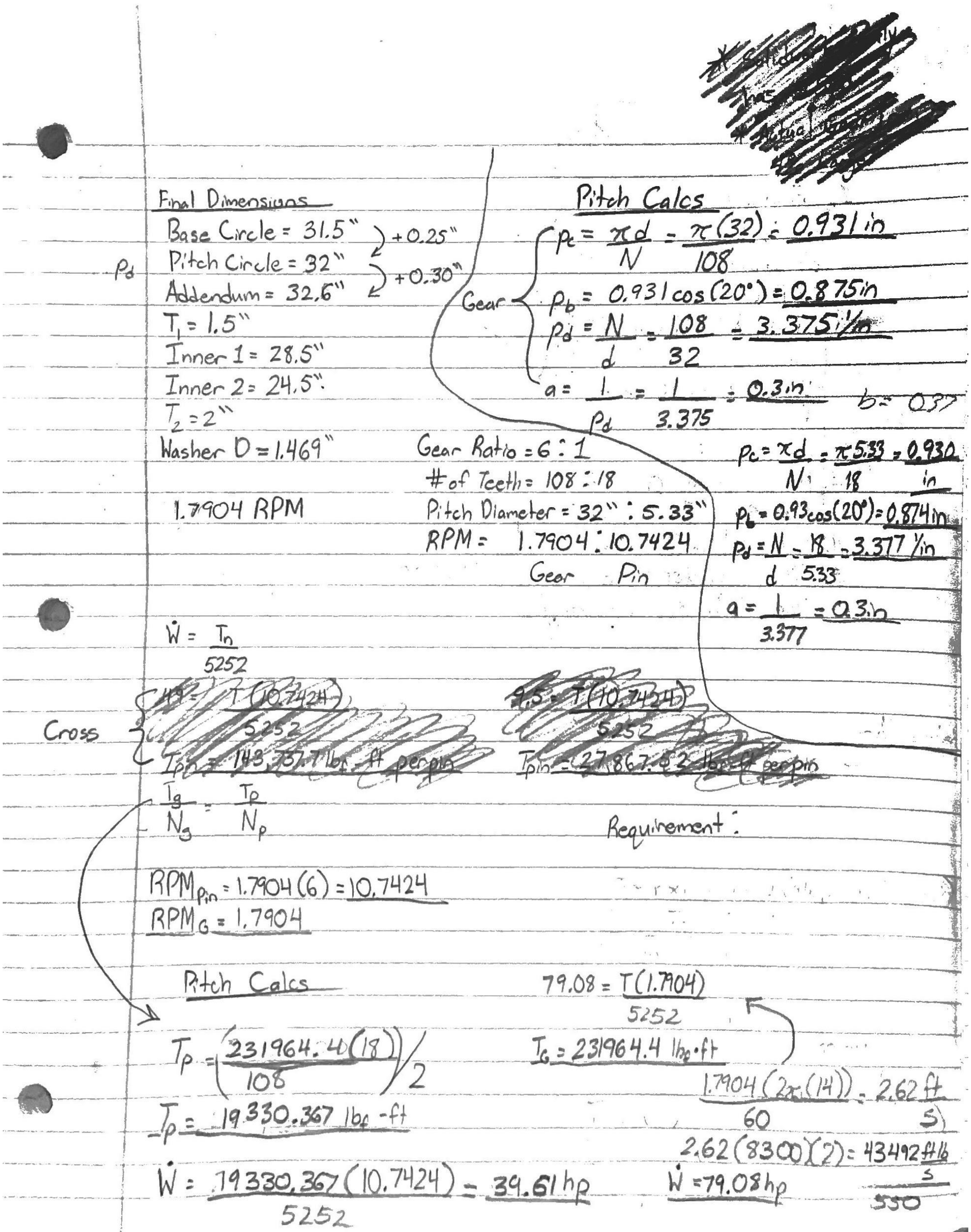
$\frac{T_{pin}}{\#_{pin}} = \frac{T_g}{\#_g}$

$[RPM(N)]_{pin} = [RPM(N)]_g$

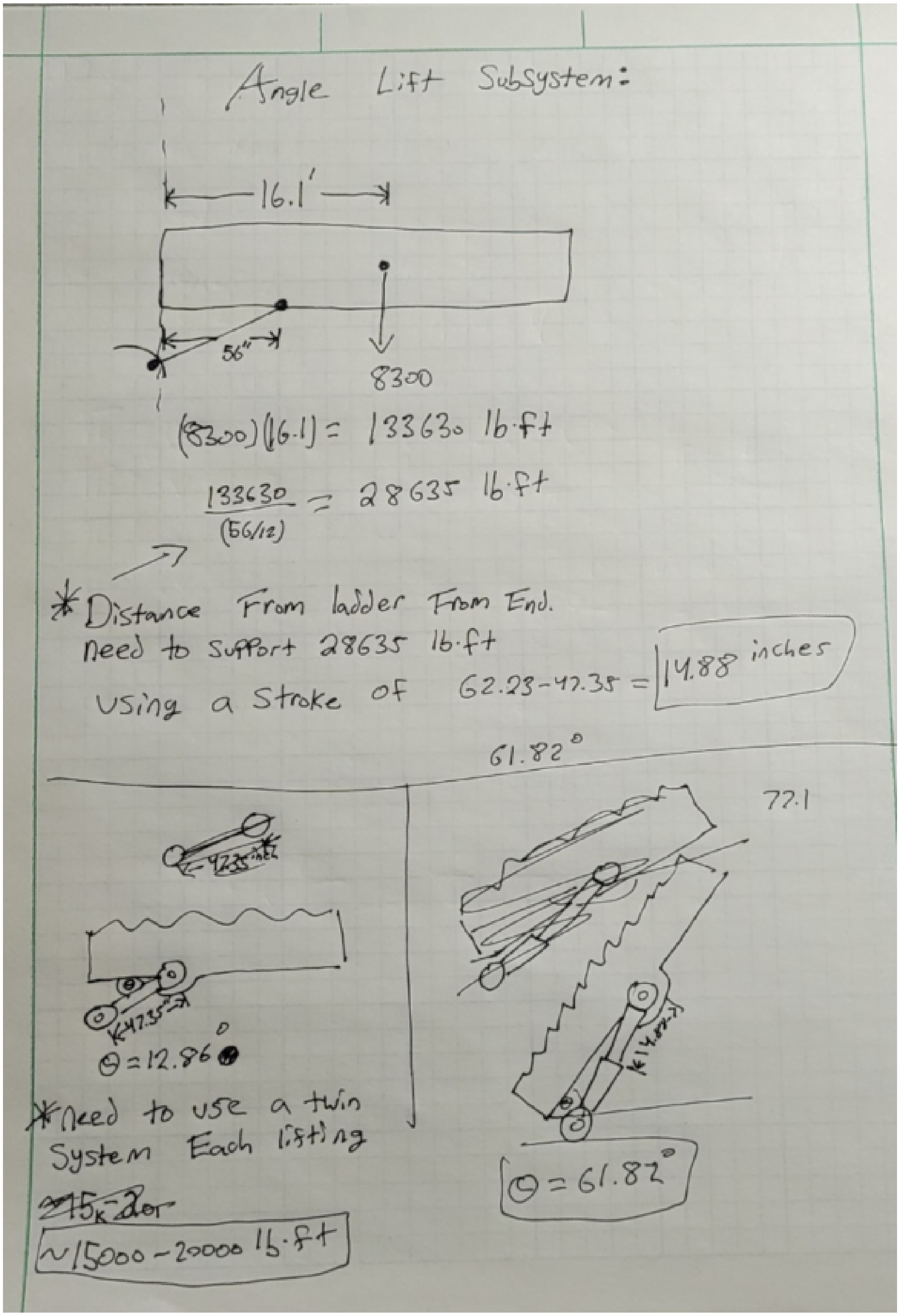
McMaster Only Allows 6 ft → 120" Steel Rod

2x6' Steel Rods

12x10"



Figures E.1: Handwritten Design Process for Gear Rotation System



Figures E.2: Handwritten Design Process for Lift Cylinder

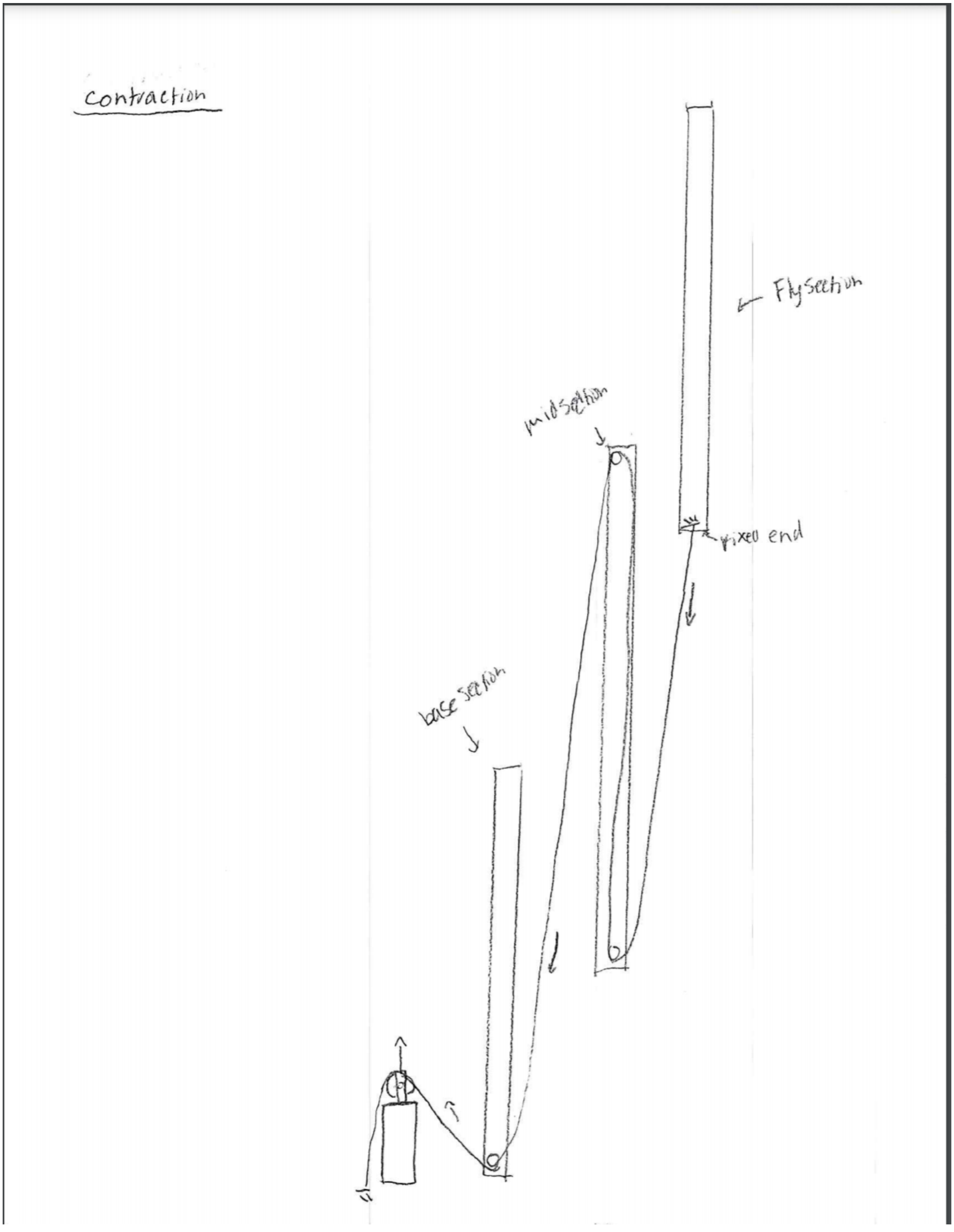


Figure E.3: Handwritten-Exploded Diagram of How the Contraction of the Ladder Pulley System Works

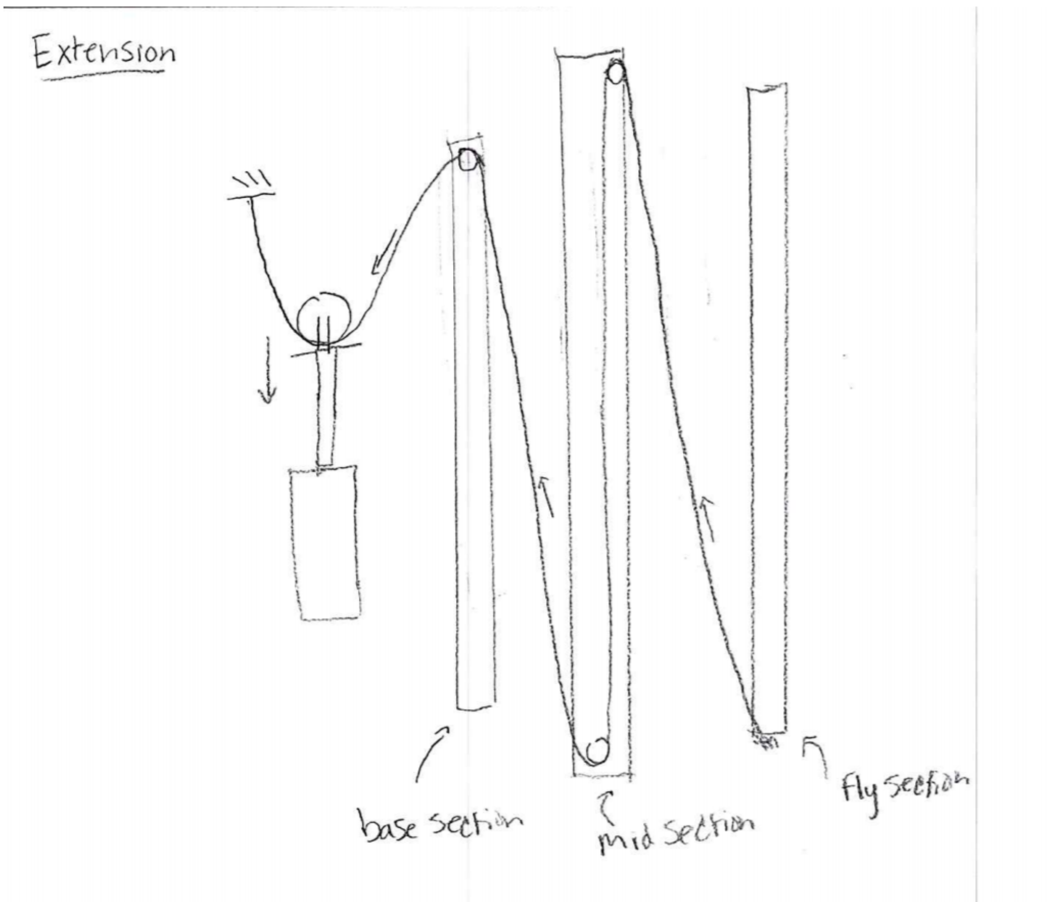


Figure E.4: Handwritten-Exploded Diagram of How the Extension of the Ladder Pulley System Works

Figure E.5: Images of the Rotation System and Ladder in Warehouse Provided by Secaucus Fire Department


End
of
Part I