School Van Access in Nepal

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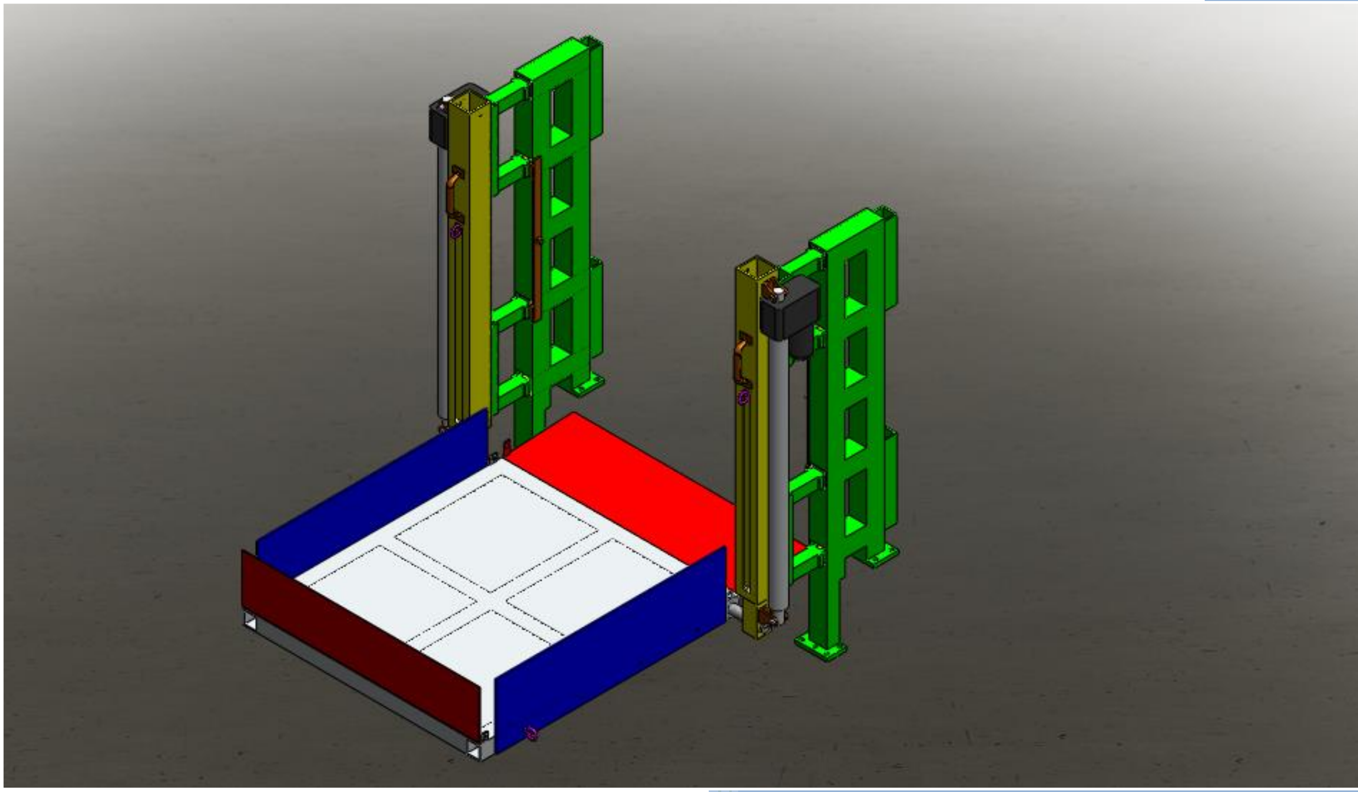

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School Van Access in Nepal Final Design Report

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Abstract

A need has been identified by a school in Nepal intended for children with Cerebral Palsy, called Sathi Sansar, to develop a more effective solution to loading and unloading students onto the school's Toyota HiAce van. Currently, a combination of the driver, parents and teachers manually help the students on and off the van. However, this task has proven to be both laborious and time consuming for all parties involved. A solution to this problem needs to be designed and one is currently being developed by a team of engineering students from California Polytechnic State University-San Luis Obispo and Katmandu University. The project intends to develop a solution that both eases the labor and reduces the time required to load and unload students while also creating a more independent environment for the children. The final design presented is a wheelchair lift using linear actuators to lift passengers to the height of the floor of the van. Analyses completed verify the ability for the design to function properly while the cost analysis accurately shows a relatively inexpensive solution.

Chapter 1: Introduction

Introduction

This project is intended to create a more accessible environment for students with cerebral palsy attending Sathi Sansar, a school located in Pokhara, Nepal. Currently, the process of going to and from school for these students involves the driver having to assist the students with entering and exiting the van upon arrival to a location. This process is time-consuming and requires considerable effort from the driver, teachers, and parents of the students attending the school. The students are also very dependent on those helping them as they board on and off the van. While ensuring that some of the effort is alleviated from the driver, teachers, and parents, it is equally important to create a more independent environment for the students as they go to and from school. The goal of this project is to create a setting where both of these are accomplished with the help of engineering students from Katmandu University. While staying within a minimal budget, this will be done by modifying the van currently used at the school so that it is more accessible for any student with cerebral palsy while also securing them in the seats of the van.

Background

Cerebral palsy is the loss or impairment of motor function caused by brain damage resulting from a brain injury or abnormal development of the brain before birth, during birth, or after birth. Physical impairment will vary from person to person having cerebral palsy. Because cerebral palsy affects the muscles and the ability to control them, the affected person's limbs may tremble, shake, or be at a painfully awkward position. As a result, the students from Nepal may have a hard time getting on and off the van unassisted depending on the severity of their condition.

Currently, the school has a Toyota HiAce H200 that has 3 rows of bench seats that are split in the middle of the van to allow for passage, similar to a school bus. The students board the van through the side door but may also have access via a rear door if the rear bench seat is replaced

with 2 regular seats. The side door is primarily used because a built-in step in the body makes it easy to get into the vehicle. Other pertinent information about the van that is noteworthy is that it's forward-wheel drive. Additionally, pictures that were taken show that the gas tank might be located somewhere near the middle of the underbody.

The engineering students from Kathmandu recorded a video that show how the students with cerebral palsy were boarded onto the van after school. From the video, it can be observed that there were about 4-5 adults (possibly the driver, teachers, and parents) helping students get onto the van and into their respective seats. The smaller children were easily carried into the van and placed on a seat. However, the older, larger, and less capable children were carried into the van with the help of two people. According to the engineering students, the older students were the most difficult to get in the van due to their weight and size. Also, it's a challenge to get into the van using the van step since it's hard for two people to carry a child while also trying to get into the van themselves. It is necessary to develop a solution that requires less effort from the driver, teachers, and/or parents while also adding accessibility for the student.

As of today, there is no seat belt design specifically for people with cerebral palsy. Since physical impairment will vary from person to person, an automatic seat belt would more than likely need to be designed. Automatic seat belts implemented in cars during 1980-1995 were a hassle and inconvenience when getting in and out of a car because a person would have to be in a certain position in order for the seat belt to retract safely and correctly. Further experimenting with this design could prove a successful candidate for safely securing students with cerebral palsy. However, a simple lap belt could do the job of restraining the students without the inconvenience of additional alterations to the vehicle. Furthermore, the issue of securing students in the seats with some type of restraint will be considered pending the overall cost of the wheelchair lift design.

Objective

Team V.A.N. has been formed to create an independent and safe place for the children of Sathi Sansar with cerebral palsy, as well as for the people interacting with them. Our accessible van

project will assist all the children in improving their education experience by providing them a safe form of transportation to and from school.

Based on the information obtained from professors at both Cal Poly and Katmandu University, we understand that our main users of the product will be the children. It has also been determined that the people interacting with them such as the van driver, parents, and teachers are also part of the customer selection since they are involved in the lives of these children. In order to determine what is needed to satisfy the need of our customers, we employed the Quality Function Deployment method (QFD) (see Appendix A.1).

As a first step of the QFD method, we identified our principal customers, which include the children, the parents, the van driver, and the teachers. Next, we identified and prioritized the customers' expectations and requirements. We also conducted research on products that are currently in the market to see if these products can satisfy the customers' need. Then, we derived a list of engineering specifications related to the customers' requirements. The next step included finding correlations between the customers' requirements and engineering requirements. Three main types of correlations were established as follows: strong, medium, and small correlation. An engineering requirement that was found to have the strongest correlation to the children's requirements was time. Time has a strong correlation since the ability to get into the van and onto a specific seat within a reasonable amount of time is important. We believe that the device should allow the children to get into the van as quickly as possible because there are so many students who need to be transported. This is opposed to the overall weight of the device, which has no correlation at all with getting into the van. The complete QFD table is attached in the appendix section for reference (see Appendix A.1).

The engineering requirements identified are shown below in Table 1. We used the "compliance" method to show how each design requirement is to be met. The following four methods will be used during the design process: Analysis (A), Test (T), Similarity to Existing Designs (S), and Inspection (I). We also evaluated the risk of meeting each of the engineering targets and specifications. We set three different levels of risk: High (H), Medium (M), or Low (L).

Table 1. Van Accessibility in Nepal Project: Formal Engineering Requirements

Spec. #	Parameter Description	Requirement or Target (units)	Risk	Compliance
1	Height From Ground	23 in	H	T, I, S
2	Height inside van	13 in	H	T, S, I
3	Load Capacity	400 lbf	H	A, T, I
4	Time	5 min	M	T, S
5	Size (width)	50 in	M	A, T, I
6	Weight	100 lb	M	A, T, S, I
7	Life Cycle	10 yrs.	H	A, T,
8	Cost	\$1,000$^{\underline{00}}$	M	S

As an example, the device installation height from the ground is one of the main factors because the designed device will be mostly used by the children that have movement limitations. It is also important that the children be able to operate the system with minimal effort. The size and weight of the final product are important since they will be limited by the capacity of the vehicle being modified. The stability of the vehicle is also important to avoid rollover during operation. The risk of meeting these requirements is therefore crucial. It is essential to design a device capable of supporting a minimum of 400 pounds and being able to last at least 10 years based on daily operation.

Chapter 2: Background

Existing Products

There are a few products on the market that can be retrofitted to a van to allow access for people with impairments. One example is the assistive seating, which is a seat that swivels and lowers so that a person can get on a vehicle (see Appendix A.2). The price of this product varies based on the number of options chosen. For example, the basic model only swivels from side to side and costs around $3,000. The medium model swivels and tilts the seat so that it's easier for a person to get on the seat but costs $4,000. The deluxe model does what the previous ones do but also lowers and raises the seat to make it even easier for a person to get on but costs approximately $8,000. All three options are extremely out of range for our budget.

Another example is a wheelchair lift, which essentially consists of a platform that lifts a person on wheelchair (see Appendix A.3). There are a few different designs for wheelchair lifts that could be possibly used. The first one is a lift with a single arm that lifts all the weight. Generally, these can handle less weight but they provide more passenger space to allow for entry. Also, it enables the handicap lift to move out of the way of a non-wheelchair user when it is not in use. Dual arm lifts take considerably more space but can handle heavier loads due to increased stability. Specific prices for each model are not listed, but they vary from $1,000 to $4,000 according to VCI Mobility. A lift like this could possibly be an option, but it would require use of the entire budget.

A relatively inexpensive way to give access to a van for the disabled is by using a ramp. Measurements need to be taken in order to determine the best length so that it doesn't require much effort to ascend the ramp. Myportableramp.com suggests a ratio of 1:12 when building a ramp. Therefore, if a ramp needs to be installed onto a 23-inch height, the length of the ramp needs to be around 276 inches for the ramp angle to be 5 degrees. Discountramp.com offers various ramp designs and lengths that meet the needs for the disabled (see Appendix A.4). One of the ramps on this website weighs about 50 pounds, can handle a load of 600 pounds, is 9-feet long, and has a price listed around $400, which would leave plenty on the budget for other

modifications. One thing that also needs to be considered is that the ramp needs to be able to fold so that it can be stored away when not in use. Lastly, the most suitable materials for a ramp that meets specifications include steel, aluminum, carbon fiber, and fiber glass, among others. The metallic ramps are heavy but can withstand excessive forces and wear. The composite ramps are lightweight but can be less safe since they can shatter with a powerful enough force.

In comparing the best wheelchair lifts for vans, several factors must be taken into account. Those factors include:

- Load capacity
- Actuation time
- Reliability
- Footprint Size (In and out of Van)

The larger the load capacity of a lift, the less likely of a chance there will be at overloading it. However, load capacity is directly related to speed. A compromise of modest speed and decent load capacity needs to be met in order to have a great lift. Our specific scenario involves a predicted load of approximately 400 pounds and a 23 inch height (from the ground to the van floor), so a powerful, long stroke lift would be the required. Also, the lift has to be very reliable because it will be used multiple times a day and 5 days a week. The footprint size of the lift is one of the major factors that will determine the best lift. Braunability.com is a website that prides itself on its wheelchair lifts. Two specific lifts are designed to take minimal space inside and outside the van. The lifts are either retrofitted to the underbody of the van (under vehicle lift) or the wheelchair platform is folded into several pieces to minimize space taken in the van. Also, the products have built in safety features like manual operation of a lift in case of vehicle electric failure. A second safety feature is a threshold sensor mat that is placed in the working envelope of the lift that prevents injury by stopping motion when it is triggered.

Specific Technical Data

The Under Vehicle Wheelchair Lift has a lifting capacity of 750 lb, weighs 356lb, and has platform dimensions of 31 inches by 53 inches. Actuation time for the lift to lower to ground

level is between 10 and 15 seconds. One important safety feature is a hydraulic power pack that is used in case of a vehicle electric failure. The Folding Platform Wheelchair & Scooter Lift – Vangater Series has a lifting capacity of 600 pounds, weighs 345 pounds, and has platform dimensions of 30 inches by 47 inches. The time taken by the lift to lower to ground level is between 10 and 15 seconds.

List of Applicable Standards

There are a few standards that need to be followed when building devices that aid people with disabilities. For wheelchair ramps, a 1:12 slope standard is required to ease access up the ramp. For wheelchair lifts, a wide and long enough platform is required to be able to fit a wheelchair. Also, power-sized actuators are required to lift predicted max load. A standard wheel chair weighs around 30 to 40 pounds, an average 14 year old boy weighs between 100 to 130 lb, and average weight for an adult is approximately 130 to 160 pounds. At worst case scenario, a lifting force of 330 pounds (40+130+160) is required without even considering the actual lift. It is estimated that a 400 pound load will be seen by the actuating mechanism.

Chapter 3: Design Development

Introduction

The design development for this process can be separated into two separate phases due to the scope of this project. The initial phase of this project involves the first design solution, the foldable ramp, while the second phase involves the chosen solution, a wheelchair lift. This first phase involving the foldable ramp was carried through the conceptual design process where it was eventually determined to be a less feasible idea and other options were then explored. The second phase involves the decision to use a wheelchair lift design which would result in more usability for the school. The first phase is presented below with the following phase presented second.

Design Development: Phase 1

Design Process

The design development process for this project is unique because it pertains to a problem that that doesn't appear to be difficult. However, the scope and magnitude of the logistics associated with solving this problem are great in size and are ultimately where the difficulties come in. Utilizing an inexpensive budget and working with a team of engineers in a separate country and culture along with various intangibles shaped the design development process. The main factors that were considered in the design selection process were the price to manufacture or purchase the design, how well it would complete the task, and how simple the assembly and maintenance would be for the Sathi Sansar Nepal school. For instance, a design with multiple gears and motors was not highly considered because long-life reliability in this design is not very high. The repair and maintenance of broken parts within this design would also not be easy to accomplish once given to the school. Furthermore, the ability for the design to work continuously with a long life span was important since ensuring that the design did not create any extra troubles for the school was crucial.

Brainstorming

Our team conducted brainstorming sessions in order to generate different design ideas that could possibly meet the need of the customers. We made sketches of possible solutions that came to

mind and wrote down a list of materials that could be used in the manufacturing process. Also, we conducted meetings with the students from Katmandu University to discuss and compare ideas that both teams generated. Our team came out with five different concept designs that could satisfy the engineering requirements established at the beginning. The design ideas included a ramp, a wheelchair lift, a person lift, sliding seats, and a pulley lift. The decision matrix for these design ideas can be found in Appendix G.1. Utilizing the score found in the decision matrix and engineering judgment, we concluded that a ramp would be the best solution for this problem. Furthermore, we conducted another set of decision matrices in order to decide on a style of ramp that should be used (also found in Appendix G.1). The simplified results of our main decision matrix are shown below.

Table 2. Decision Matrix for Moving Kids from the Ground to the Height of the Van

Idea	**Score**
Ramp	150
Wheelchair Lift	100
Person Lift	96
Pulley Lift	89
Sliding Seats	74

Description of Top Concepts

There were three main types of ramps that we considered as our top concept designs. There was a simple ramp extending from the door opening, a ramp extending out from the bottom of the van, and a foldable/collapsible ramp. Our first model consists of a one-piece ramp attached to the van, which can be lowered manually or automatically. The length of this ramp was limited by the space opening of the door, which resulted in a shorter ramp (see Appendix G.2). The second model is a ramp stored under the body of the van. This ramp consists of two pieces attached together with hinges, which allows for a longer ramp. As with the first model, this ramp could be extended manually or automatically. However, this ramp would only need to be ejected and extended out from the slot whenever it needs to be used. Therefore, there is no need to move it out of the way every time a person gets in and out of the van since it is not in the way. Our third

and final model is a foldable ramp consisting of four pieces attached together. This ramp is attached to the van in the same manner as the first model. The hinges on the platform allow this ramp to be folded, thus requiring less storage space. Also, it eliminates the necessity to lower the ramp when it is not needed. See Appendix G.3 for SolidWorks models of each of these concept designs.

Design and Price Analysis

The initial steps of this process involved researching current solutions that are widely available in the United States as well as associated prices. Following this, the price to manufacture our own solution was analyzed to use in comparison to the solutions already present. We determined the cost with price analyses and calculations. The calculations for the stress and deflection associated with our own solutions made from either aluminum or steel are shown in Appendix E.1. From these calculations, we found the size and shape of each material that we would need in order to manufacture our design. An initial analysis was performed on our selected concept design, the ramp. The initial analysis was conducted primarily to determine the overall dimensions of the platform. The analysis consisted of calculating bending moments and shear forces as well as the maximum deflection of the platform.

We modeled the platform as a beam simply supported at both ends with an applied load at the center. The applied load represents the weight of a person standing on the platform. The thickness of the platform was determined based on this model. We used bending moment and shear force theory to find the maximum bending moment and maximum stresses within the platform. We transferred the equations into Excel in order to compute those values for a 9-foot-long, 3-foot-wide platform with a concentrated load of 400 pounds-force. Based on these results and using data for maximum allowable stress for different materials we calculated the required thickness. Table 3 shows the calculated required thickness for aluminum and steel. We then proceeded to calculate the maximum deflection based on the calculated thickness to see if the platform will withstand the applied load without deflecting too much.

Table 3. Required thickness of platform based on material properties, L=9 ft and an applied load of 400 lbf

Material	Yield Strength (ksi)	Required Thickness (in)
Aluminum	21	0.296
Steel (ASTM A514 T1)	30	0.248

After finding this information, the price to purchase and manufacture these materials was analyzed using metal manufacturers on the Internet. As shown in the following price analysis, we determined the rough minimum cost to purchase, deliver, and manufacture our ramp (prices from www.discountsteel.com):

Table 4. Price and Weight Analysis of Aluminum and Steel

Material	Total Price	Weight
Aluminum	$535	120 pounds
Steel (ASTM A514 T1)	$550	280 pounds

Description of Final Design

Team V.A.N.'s top concept is a prebuilt ramp, sold by discountramps.com, that will be permanently fixed to the van (see Figure 1). The ramp is 9 feet long and 30 inches wide when unfolded and 6 inches long, 15 inches wide, and 9 inches thick when folded. The ramp weighs approximately 52 pounds and is rated for a maximum load of 600 pounds. Also, the ramp costs $370 with free shipping and leaves additional space on the budget.

Figure 1. Prebuilt ramp by discountramps.com

As seen in Figures 2 and 3, the ramp will be fixed to a rail so that it can be folded out of the way when not needed. Note that the designed hinge and rail are only for visual purposes in order to see how the mechanism will work. A more adequate hinge and rail will be designed after closer examination of the ramp.

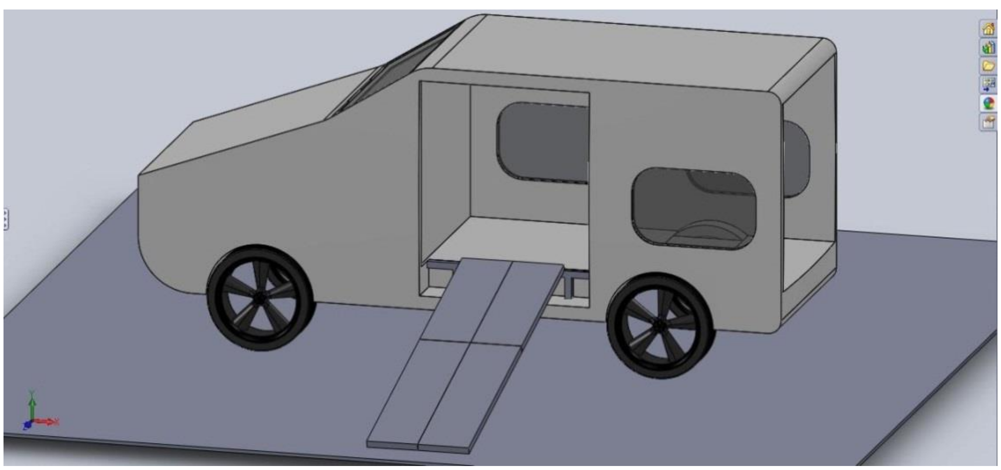


Figure 2. Toyota HiAce H200 retrofitted with prebuilt ramp

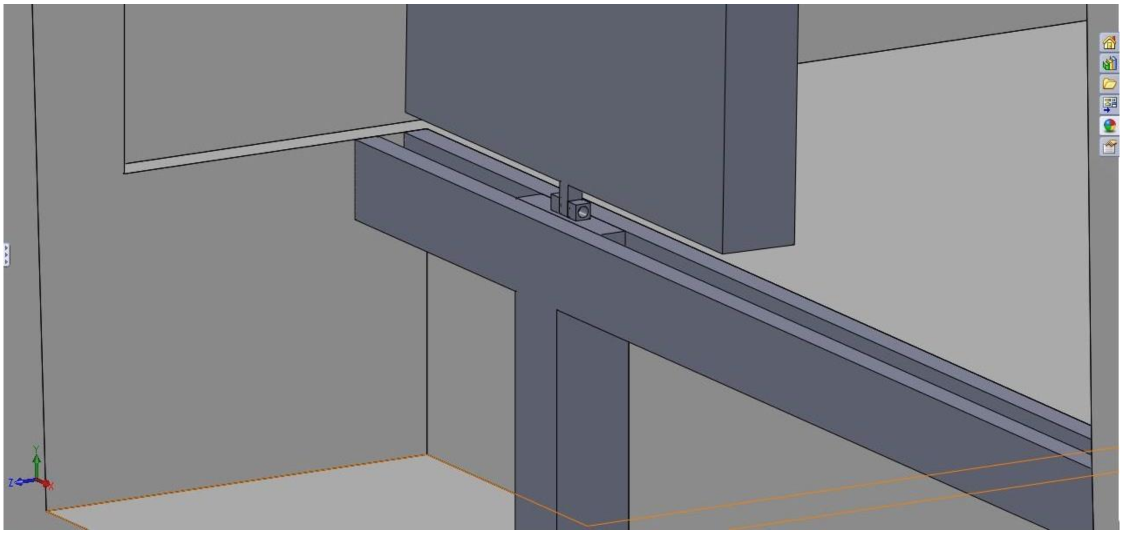


Figure 3. Rail system designed in order to slide ramp out of the way
(Design is only for visual purposes)

Figures 4 through 7 demonstrate how the ramp will fold and stow away when not needed. After the ramp is folded to its minimum size, the ramp will slide on the rail in order to move out of the way.

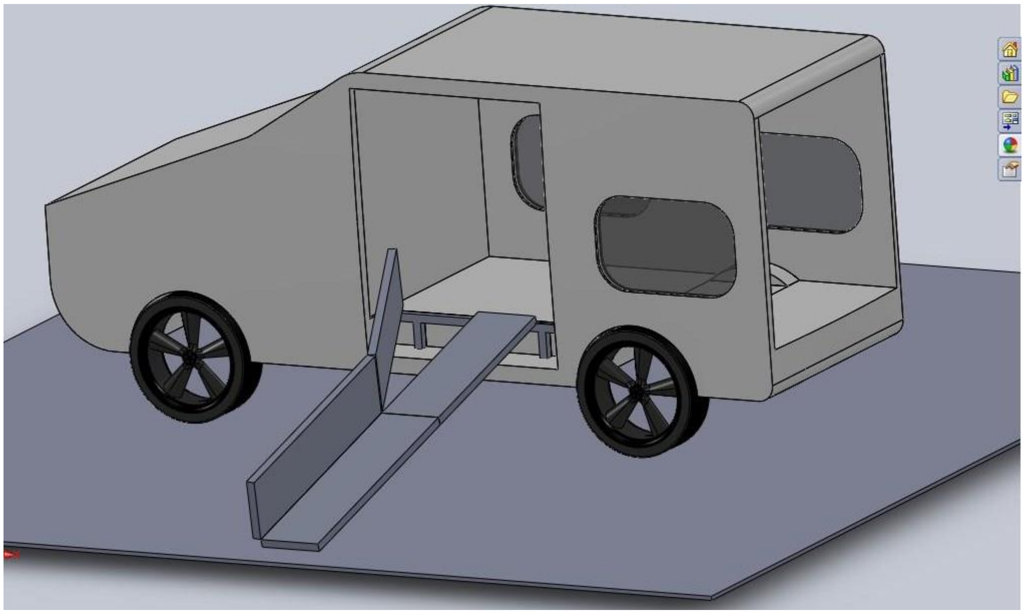


Figure 4. Prebuilt ramp folding away

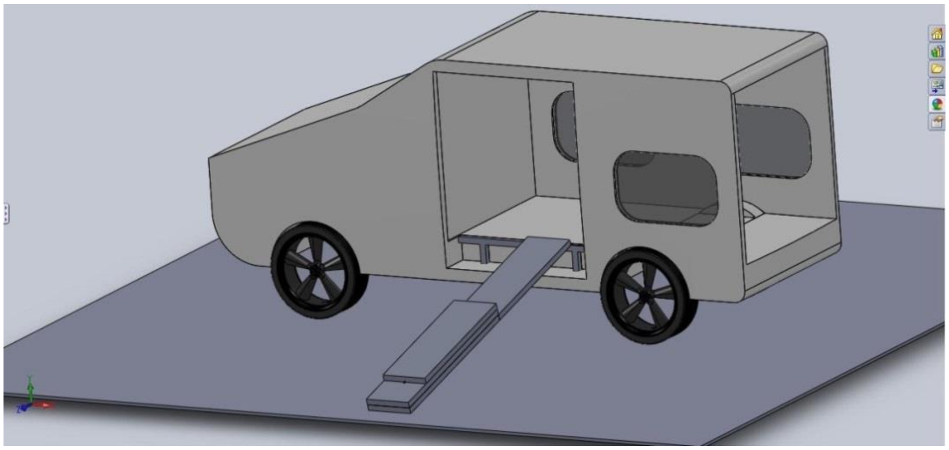


Figure 5. Prebuilt ramp folded ¾ of the way

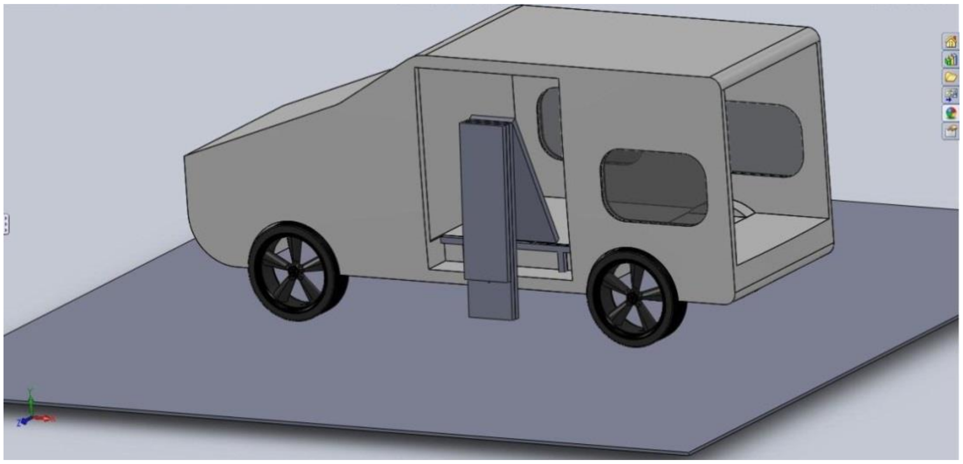


Figure 6. Prebuilt ramp fully folded

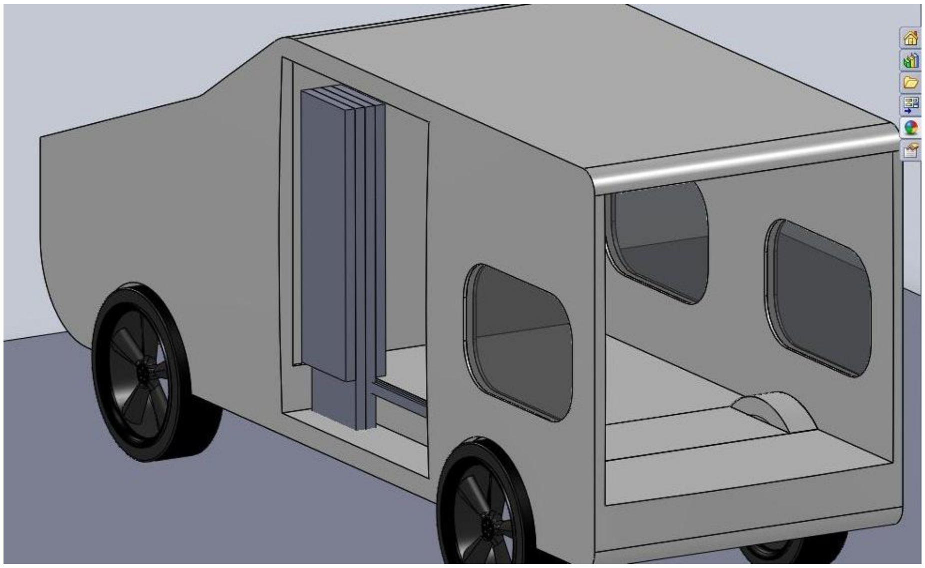


Figure 7. Prebuilt ramp fully folded and out of the way

Due to the time constraint, a seat belt or restraint system has not yet been formulated but will be discussed in the future to determine if it can also be designed, time permitting. However, the early design ideas for a restraint system include either a lap belt or an automatic seat belt. The automatic seat belt is an adequate solution because it requires no effort from the student and/or helper; however, it could prove dangerous with the automatic moving parts. Therefore, from preliminary discussions, the lap belt appears to be a better solution due to lower cost and ease of use.

Specification Requirements

Designing and creating an idea for a solution to a problem can prove to be completely useless if the problem specified is not actually addressed within the solution. To ensure that this was not an issue for our team, we decided that solving the exact problem specified by Sathi Sansar Nepal was a high priority. We found that the most crucial element that needed to be addressed was helping alleviate the labor needed to move the students from the ground to the height of the van. We also discovered that the most laborious task was moving the eldest students in wheelchairs since they are not only the tallest and biggest but may also be the least mobile. Correspondingly, creating the most independent environment for the students with limited mobility was also important. The use of a wheelchair ramp will satisfy both of these specifications because it allows for the students in wheelchairs to be moved to the height of the van while also helping other students by alleviating the need to climb up the step at the side door.

Furthermore, utilizing a tri-foldable ramp takes away extra stress from the driver and teachers since the ramp can be easily stowed while driving. The tri-foldable ramp can also be kept within the van when not needed at each individual's house. A large ramp that needs to be unfolded at each stop would quickly become a nuisance and the tri-fold ramp design specified takes away this issue.

Design Development: Phase 2

Design Process

Although the foldable ramp conceptual design had lots of advantages, it also had lots of disadvantages and questions that went unanswered. Two main problems associated with the first design solution were found including the inability to extend a nine foot long ramp at all locations that the van would be traveling. Due to the tight streets and spaces found in Nepal, there was a significant chance that the ramp would not be able to be properly used at all locations. Additionally at each pick-up or drop-off location the driver of the van would have to manually open and extend the ramp, wasting valuable time. The second main problem found was the inability to stow the ramp when not in use. After considerable thought, no solution was found as to how the ramp should be stored away in the van to ensure both the safety of the passengers and an easily accessible ramp. As a result of these problems, a second design idea was explored that resulted in a much more suitable design solution, a wheelchair lift.

Brainstorming

As seen again in Table 5 below, the weighted decision matrix involving the five initial ideas resulted in a wheelchair lift as the second highest score. Due to the price variable being given a significant weight, it was a main factor resulting in a lower total score for the wheelchair lift. However, after discussions with Professor James Widmann of Cal Poly, it was determined that the price factor should not be as heavily weighted; and if the wheelchair was the best overall solution it should be the final design.

Table 5. Decision Matrix for Moving Kids from the Ground to the Height of the Van

Idea	Score
Ramp	150
Wheelchair Lift	100
Person Lift	96
Pulley Lift	89
Sliding Seats	74

From this, a second brainstorming process was conducted utilizing the wheelchair lift design. Multiple ideas were generated including using as the lifting mechanism either linear actuators, hydraulic pumps or a combination of gears and pulleys with manual force.

Description of Top Concepts

From the design process two main concepts were chosen both utilizing linear actuators but in different forms. The first design concept involved a track actuator which lifts the desired payload using a carriage that follows along a track as seen below in Figure 8.

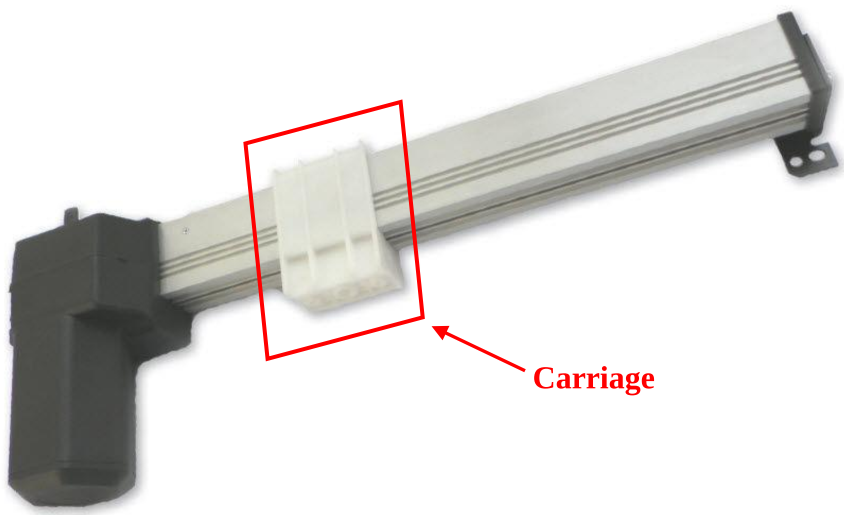


Figure 8. Progressive Automations Track Actuator

The track actuator analyzed in the conceptual design can lift a desired payload of 1300 pounds and the track is comprised of aluminum alloy. In the first design (Figure 9) two track actuators are utilized on opposite sides of the platform and synchronized to lift the platform and passengers to the required height. The platform and track actuators are supported by two “Tower Supports” and slide along these supports, enabling the platform to be stored inside of the van when not in use.

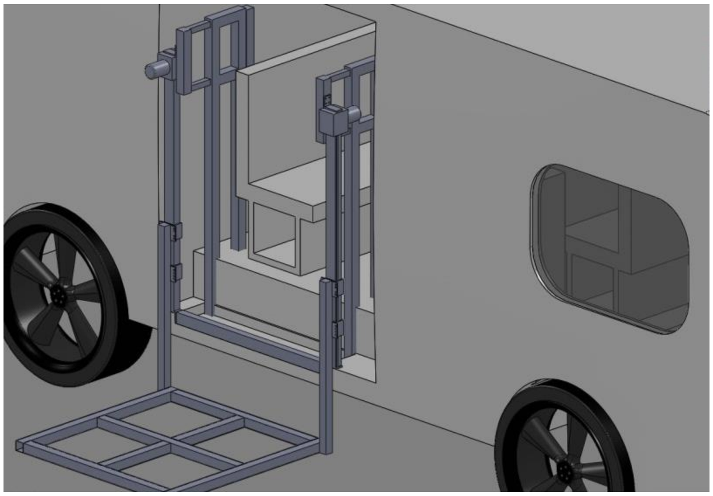


Figure 9. Conceptual Design Utilizing Track Actuators

The second conceptual design featured a standard linear actuator (Figure 10) which includes a piston with the desired stroke length that carries the desired payload. Although linear actuators are generally able to lift a higher payload, because the piston is comprised of a thin aluminum rod, they are not able to take much bending which is what the wheelchair lift will be exposed to. There reason for so much bending is because the actuator can only be fixed to the van in one location where as the track actuator had 2 locations to fix to the van. This conceptual design is found below in Figure 11 and utilizes the same features as the conceptual design with the track actuators, with the only difference being linear actuators used instead.

Figure 10. ServoCity Linear Actuator

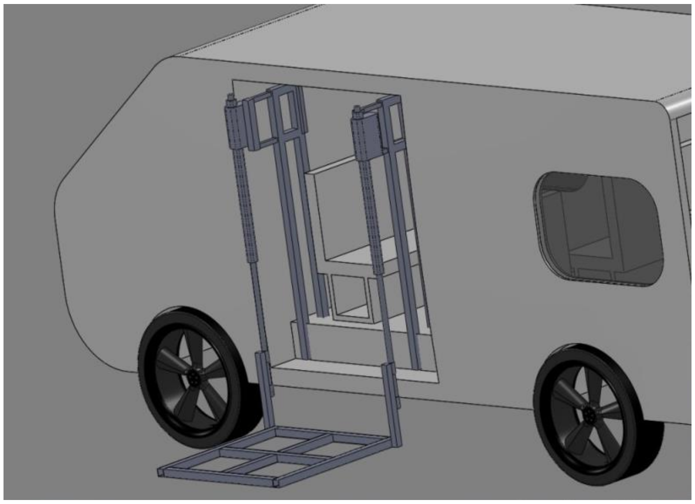


Figure 11. Conceptual Design Utilizing Linear Actuators

Design and Price Analysis

The generalized conceptual designs require the same basic components regardless of the type of actuator used. These components are designed to be comprised of steel with the platform being made out of aluminum to reduce the weight. Using generalized prices from the supplier *DiscountSteel.com*, the estimated total cost to purchase the materials needed for the platform and supports is around $300. Because the main components of the design do not vary greatly between the two conceptual designs, the main decision to be made was the option of either choosing either the track actuator or the linear actuator.

The track actuator chosen from *Progressive Automations* would only cost $130 and could lift a desired payload of up to 1,300 pounds, using two of these track actuators would allow for the wheelchair lift assembly to raise up to 2,600 pounds to the desired height. However, the slow lifting speed resulted in a run-time of nearly one and a half minutes to raise the platform from the ground to the desired height of 23 inches. Additionally, a duty cycle of only 10 percent ensued a rest time of nearly 10 minutes for every one minute of use to ensure that the motor in the actuator was not overheating. As a result, each time that a passenger was raised to the height of the van, the track actuator could not be used again for over 15 minutes. These factors created problems with the track actuator that could not be overcome so the linear actuator was the following design to be analyzed.

Using a linear actuator chosen from the manufacturer *ServoCity* costing $400 ($800 for two) was found to be able to lift a total force of 560 pounds. As stated above with the track actuator, using a wheelchair lift comprised of two linear actuators would result in a total force of nearly 1,120 pounds allowing to be raised. This linear actuator also has an increased lifting speed and higher duty cycle compared to the track actuator. Assuming that the total payload needed to be raised is 400 pounds at the maximum (150 pounds for the student, 150 pounds for the helper, 25 pounds for the wheelchair and 75 pounds for the material of the platform); each linear actuator would be required to lift 200 pounds. Using the linear actuator specified above from *ServoCity*, the linear actuator has a lifting speed of over two inches per second meaning that the passenger and helper can be lifted the 24 inch height in only 12 seconds. Additionally, a specified duty cycle of 25 percent means that for every one minute of use, only two and a half minutes of rest time are required. All of these specifications result in meeting the needed requirements of raising the student in a small amount of time with little outside labor.

Description of Final Design

The linear actuator was determined to be the best option to raise the platform and students to the height of the floor in the van. However, a main issue faced was diverting the bending moment seen by the piston in the linear actuator. The piston will receive both a high axial load but it will also receive a high bending moment resulting in a large bending stress. To resolve this issue, a support was created to be attached to the top and bottom of the linear actuator to take the large bending moments. The inner and outer supports for these actuators as seen below in Figure 12 are comprised of steel which enables the axial load to be taken by the actuator and the bending moment to be taken by the steel supports. The platform is hinged to the bottom of the supports and connected to a cable (not seen in the picture) which enables the platform to both hold the weight and fold into a stowed away position. Mechanisms attached to the actuator slide through holes in the tower supports which allow for the wheelchair lift to be moved into a stowed away position inside the van while it’s moving.

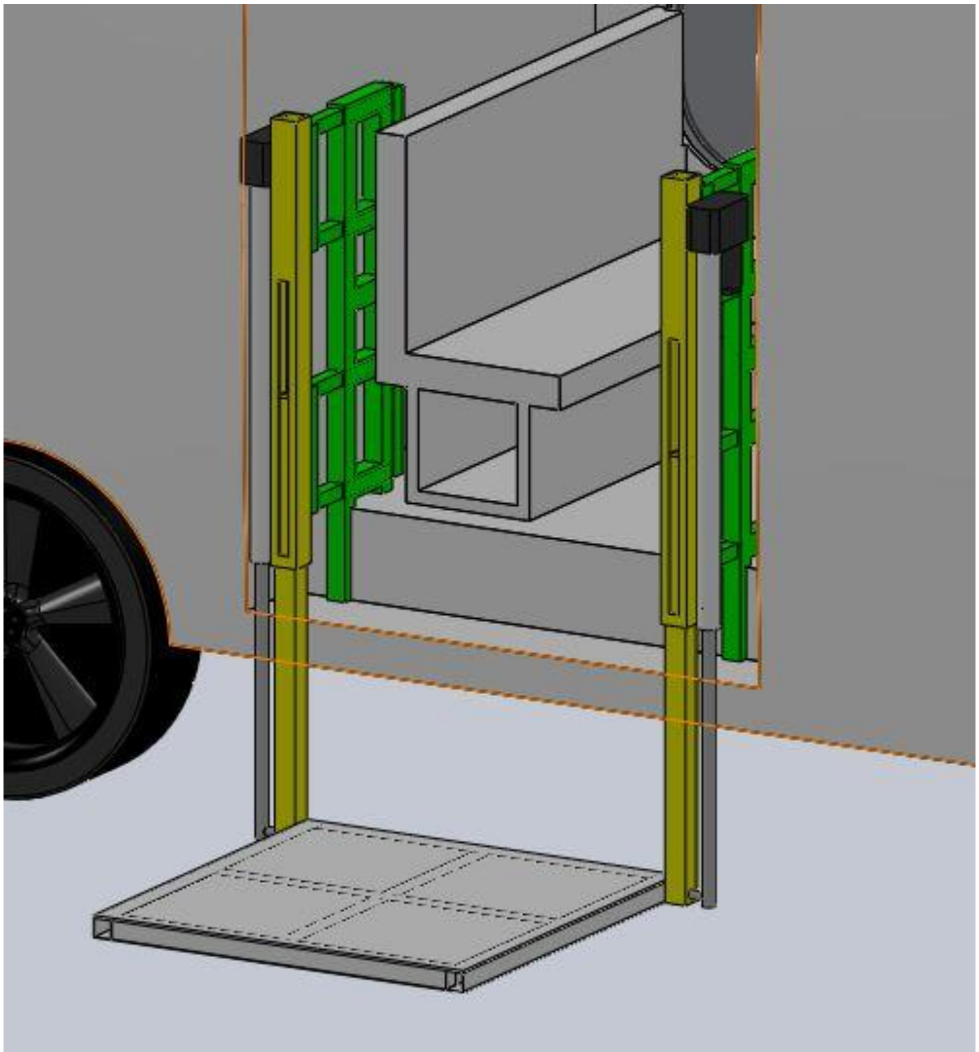


Figure 12. Final Conceptual Design

Chapter 4: Final Design

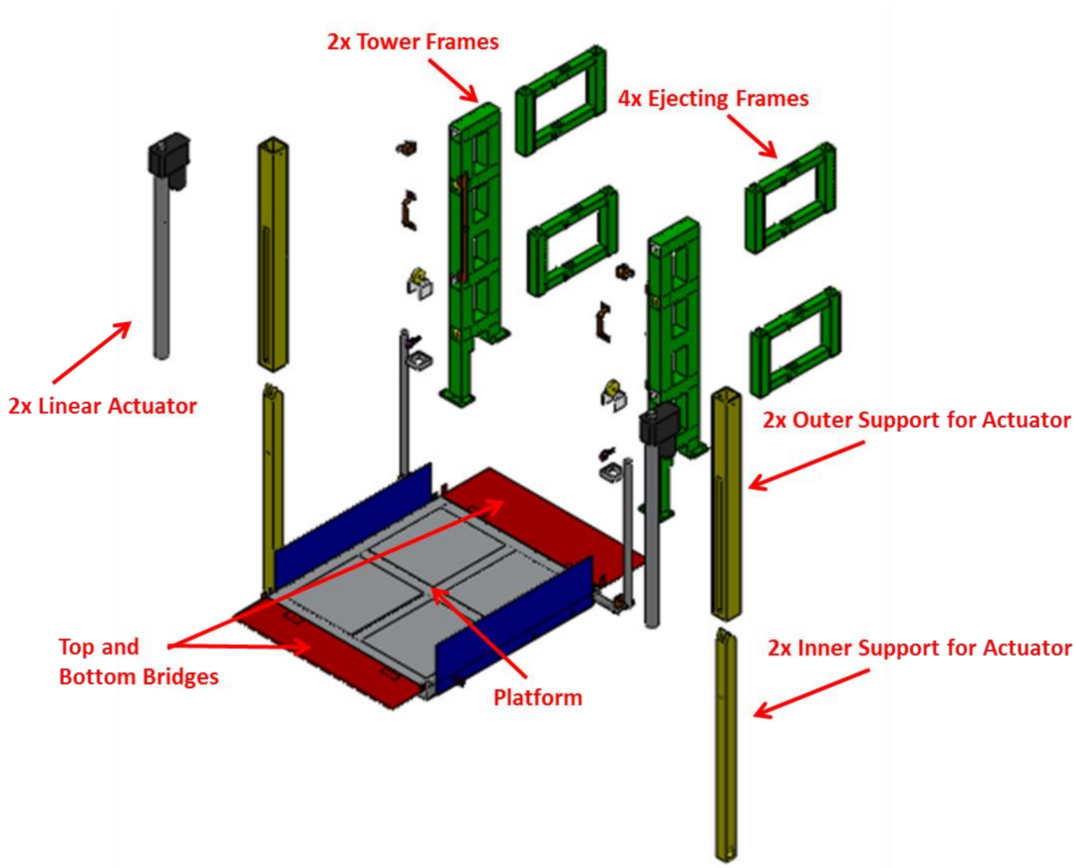


Figure 13. Exploded View of Lift Design

Detailed Description of Lift Design

The final design for Team V.A.N. involves 8 major parts which make up a lift, as seen in Figure 13 as an exploded view. These major parts are on the main components of the lift and the essential parts to completing the overall function of the lift (raising and lower students). The first part is composed of two linear actuators that have a 24 inch stroke and 560 pound thrust force. The actuator has the main role of raising and lowering the lift assembly. The second and third parts are the inner and outer supports for the actuator, which are steel square tubing, designed to take the entire bending moment caused by a load on the platform so that the linear actuators aren't exposed to any bending (see Figure 14). Note that the outer support for the actuator has a cut out slot. This slot is cut out so that a cable can be attached the platform and protruding inner

support for actuator to hold up the platform (see Figure 15). The fourth portion of the design is the ejecting frames which are steel square tubing designed to eject and retract the lift mechanism into and out of the van. The fifth part is the tower frames made of steel square tubing and designed to secure the lift to the van via the tower frame flanges bolted to the frame of the van (see Figure 16). The sixth part is the platform which is a square tubing frame with a thin sheet of aluminum to provide a walking surface. Parts seven and eight are bridges designed to ease getting on platform from ground (Bottom Bridge) and getting on van from platform (Top Bridge). Note that the platform and bridges have pin slot flanges which are designed to hold the bridges vertically with a pin (see Figure 17).

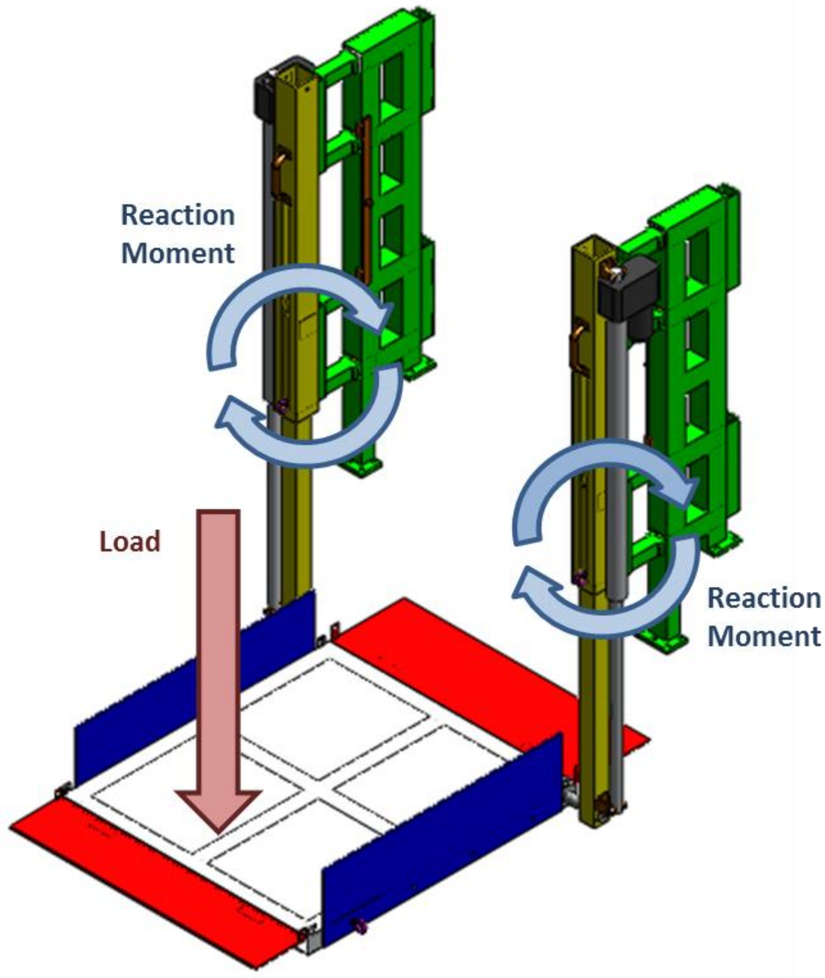


Figure 14. Lift Assembly with load and moment reactions

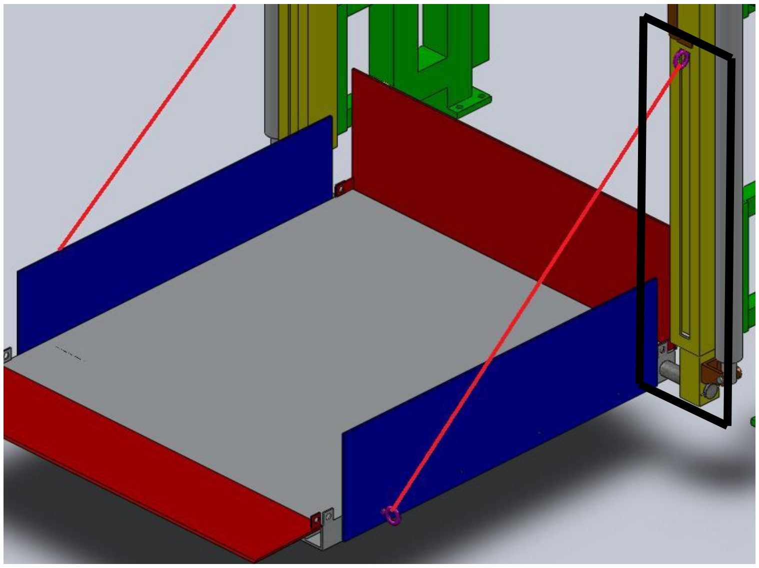


Figure 15. Slots on Outer Support for Actuator with Cable Shown in Red

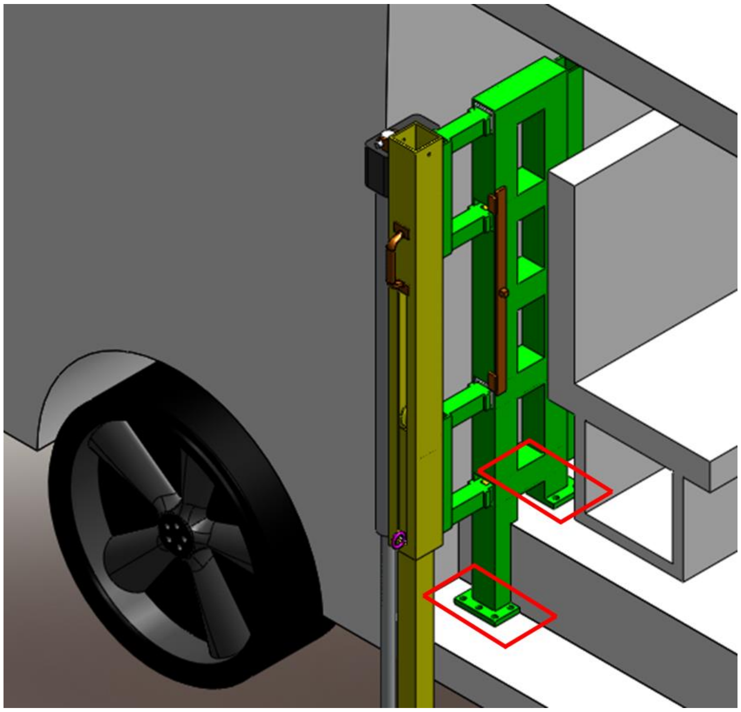


Figure 16. Tower Frame Flanges

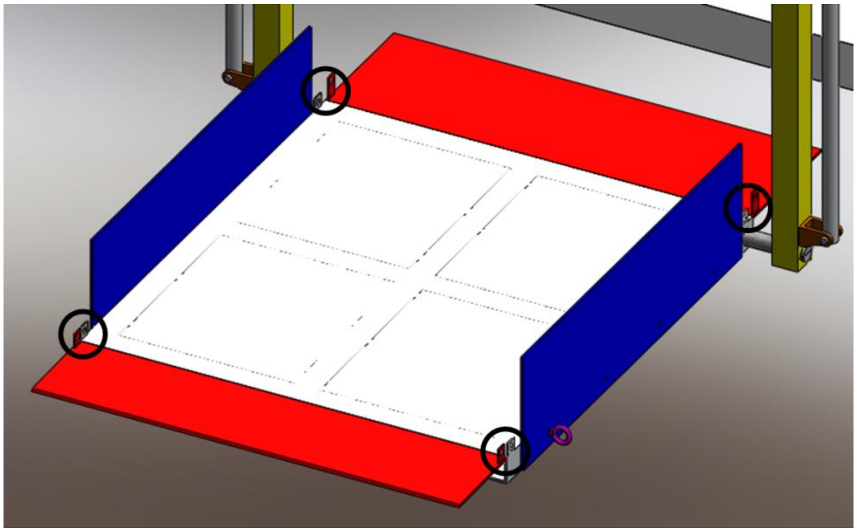


Figure 17. Pin slot flanges to hold bridges up

Some of the minor portions of the lift include the hinges which connect the top and bottom bridges to the platform and allow the bridges to raise and lower as well (seen in Figure 18). Additionally, handles located on the outer support will be attached to ease the process of ejecting the lift from the tower supports while also moving the lift back into the stowed away position. The handles will be affixed to outer support directly above the slot that is going to be cut out, the left handle can be found below in Figure 19. Also included in the minor components of this design are the side walls located on the platform. These walls made of plastic can be seen above in Figure 17 as the blue pieces. These side walls will aid in ensuring that no one boards the lift from the side and will also be used as a safety precaution to provide a barrier for people falling off the side of the platform. The last minor component to the final design will be the use of steel cable that holds the platform in place when it is unfolded. The steel cable will be connected to both the inner support and the platform via eyebolts seen in Figure 20.

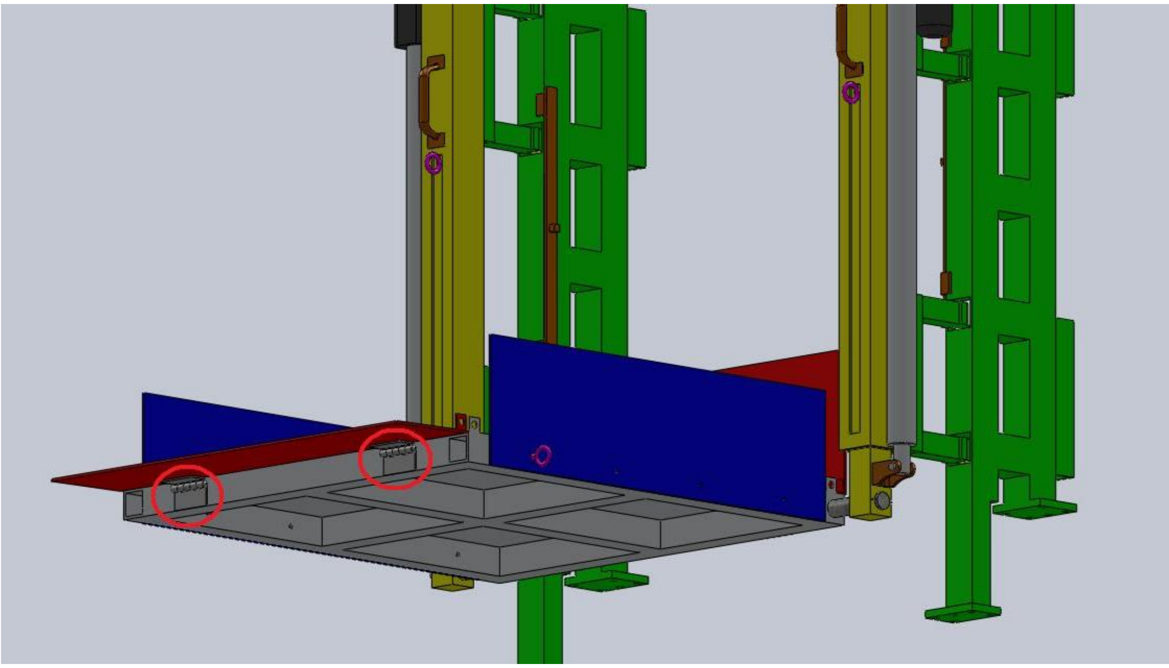


Figure 18. Hinges that Connect Bottom Bridge to Platform

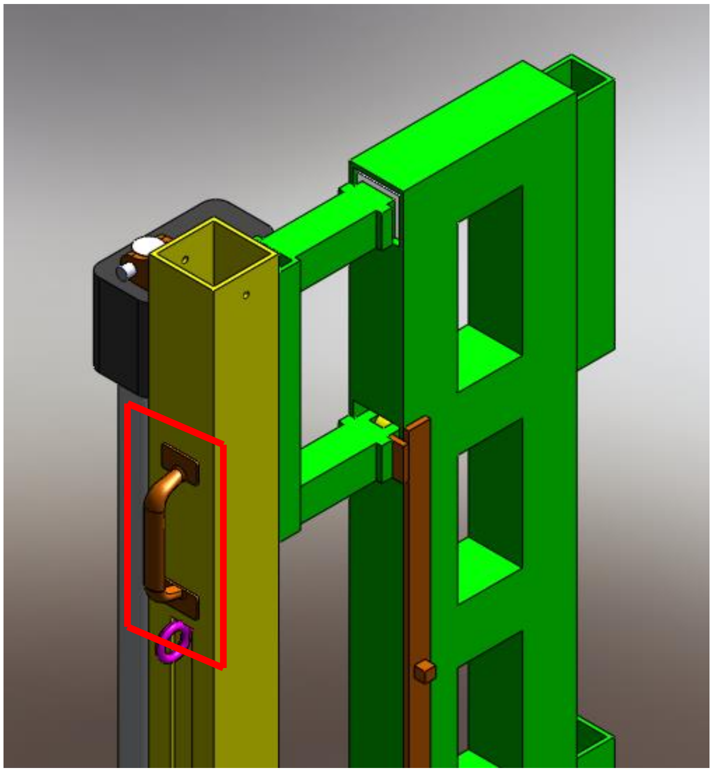


Figure 19. Left Handle Attached to Outer Support

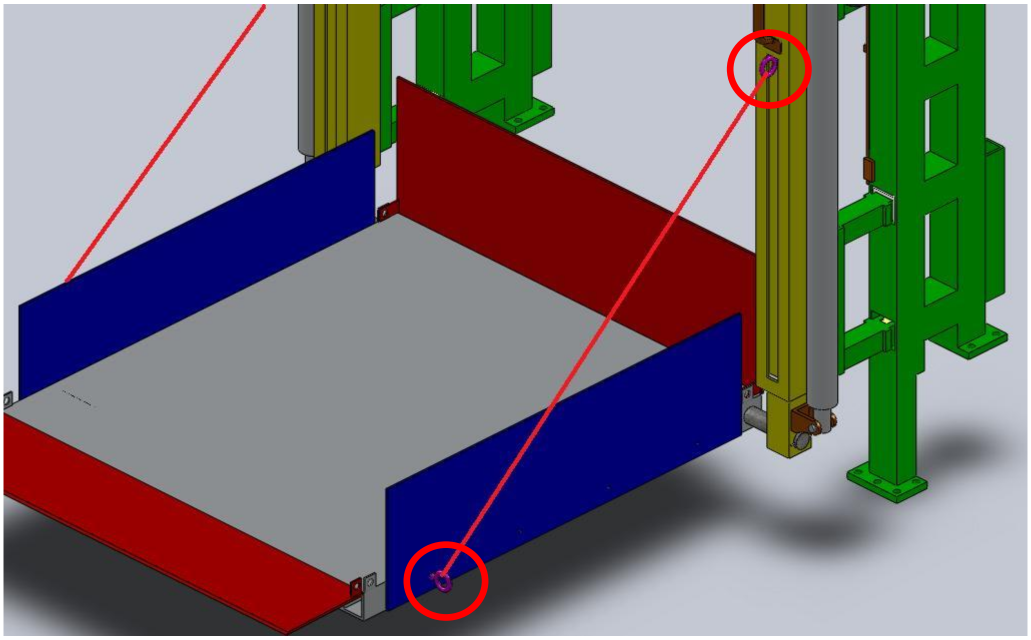


Figure 20. The Two Eyebolts on the Right Side of the Lift

The wiring diagram for the wiring of the linear actuators that will be raising and lowering the lift is shown in Figure 21. Each actuator is rated for a maximum current of 20 Amps, so a fuse will be wired inline of the power wire for each actuator to prevent failure. 10 gauge wires should be sufficient for 12 Volts and 20 Amps needed for the actuators. A switch (momentary-on off momentary-on) known as SPDT will be placed in line on the ground wire (negative terminal) that will control ejection and retraction of the actuators.

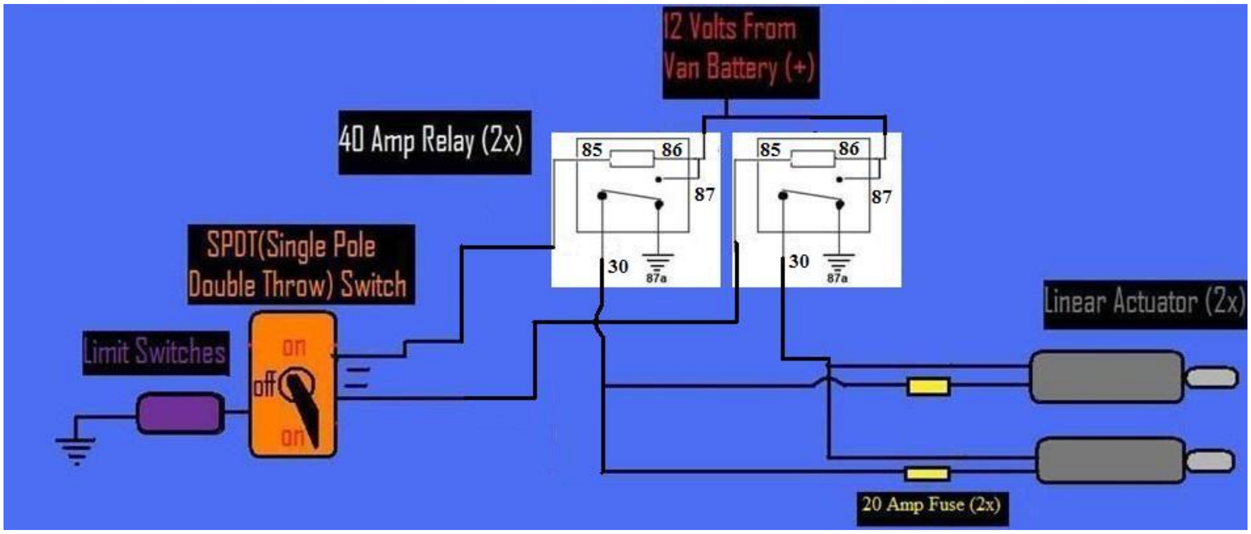


Figure 21. Wiring Diagram for Actuators

Detailed Predicted Operation of Lift Design

Before operating the lift (seen below in Figure 22), it is required to have the van in park to ensure that the van cannot be driven while the lift is in use, the van will also have to be on (engine running) in order to avoid draining the battery, the door will have to be open (where lift is located), the lift will have to be manually ejected (ejecting frames will slide through tower frame slots), and the platform will have to be lowered (from vertical to horizontal position); otherwise, the lift will be inoperable. After these conditions are met, the lift can be lowered via a switch connected to the battery and linear actuators. Once the lift has reached ground floor, the pins on the bottom bridge can be removed in order to drop the bridge to gain access to platform. After a person is fully secured on the platform, the pins on the bottom bridge can be replaced and the lift can be raised. Once the actuators have fully retracted, the top bridge pins can be removed in order to drop the bridge to be able to walk into the van. Once person is off the platform, the top bridge pins can be replaced in order to be able to lower van. Then, the process can be repeated if needed. Finally, with the lift at the highest position, the lift can be pushed into the van (ejecting frames will slide though tower frame slots), the bridges will have to be secured to the platform via the pins, the platform will have to be raised (from horizontal to vertical position), and then the door can be closed.

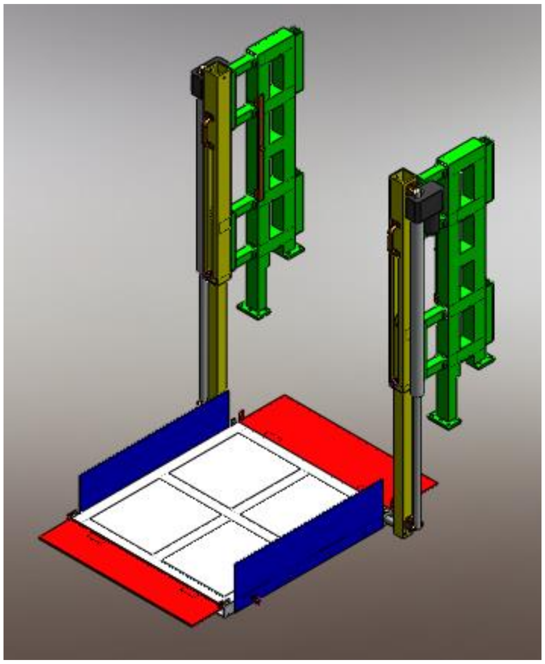


Figure 22. The Final Design

Analysis

Each main component of our final design was analyzed to verify and find all critical dimensions of the components. The components that were analyzed are: sliding (ejecting) mechanism, tower (frame) support, platform support, and actuator (inner and outer) supports. The sliding mechanism was analyzed to find how much they would deflect while in use. The other components were also analyzed for bending. The platform support was analyzed to ensure that it will be able to handle the expected loading. The actuator supports were analyzed to make sure they will not deflect too much when the load is applied at the center of the platform. Life-stress analysis was also performed on the sliding mechanism and actuator supports. Additionally, a cost analysis was performed to estimate the total cost of materials for this project. This total cost was found to be around $1,800 and can be found in detail in Appendix C.

Sliding (Ejecting) Mechanism Analysis

A bending stress analysis of the sliding mechanism (mechanical drawing in Appendix B.2) was performed to see if it would yield when a load is applied at the center of the platform. The chosen size of the material was 1 inch x 1 inch square solid bars for the sliding mechanism. The sliding mechanism was modeled as a cantilever beam with an applied load of 300 pounds at one end as shown in the Figure 23. Based on the dimensions the maximum bending stress occurs at point B, so a bending stress analysis was conducted at this point. A bending stress analysis based off a 400 pound load showed that the bending stresses were small compared to the allowable stress. The yield factor of safety was 4 for an applied load of 300 pounds and 3 for 400 pound load. A completed deflection analysis resulted in a maximum deflection of approximately 0.02 inches. The complete analysis is shown in Appendix E.2.

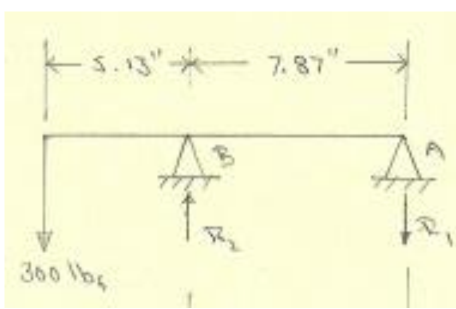


Figure 23. Model diagram of sliding mechanism used for analysis.

Tower (Frame) Support Analysis

Multiple engineering analyses were performed on the tower support (mechanical drawing in Appendix B.3). Initially, a buckling analysis was completed to ensure that the structure will not buckle when the platform is in use. The tower support was modeled as a structural member fixed at one end under compression as shown in Figure 24. As described before, the tower support consists of 2 inch x 2 inch x 3/16 inch square hollow bars. Based on this dimension, the critical concentric load that will cause the member to buckle was calculated. The result showed that a load of approximately 32.5 kips will cause buckling on the structure. Following this, a bending stress analysis was performed to ensure that no yielding will occur. As with the sliding mechanism, the tower support was modeled as a cantilever beam (see Appendix E.3). Based on the results, the maximum bending stress was approximately 3.63 kpsi which is smaller when compared to the yield strength of the material (A36 Carbon Steel: S_y= 36, 300 psi). Finally, a stress-life analysis was calculated to determine the life cycle of the tower support. Based on Modified Goodman Criterion, the life cycle of the tower support is $7x10^{12}$ cycles which essentially means infinite life. See Appendix E.3 for complete calculations.

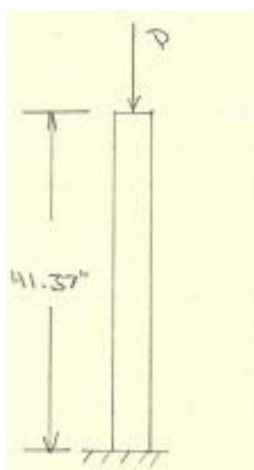


Figure 24. Structural member of tower support under compression.

Platform Support Analysis

It is critical that the platform support be able to handle the weight of a person on a wheelchair, and a second person assisting. In order to find the critical dimension of the structural members for the platform support (mechanical drawing in Appendix B.6) and plate a bending stress and

deflection analysis was completed on both the platform support and plate located on top. The stress analysis was based on a load of 600 pounds applied at the center of the platform, assuming that a maximum load of 600 pounds the platform will see during usage. Assuming a factor of safety of two (n=2) it was found that the maximum bending stress on one member is 12.5 kpsi. Based on this result and a maximum allowable deflection of 0.1 inches, the required dimensions for the square hollow structural members were analyzed. The results showed that 2 inch x 2 inch x 3/16 inch aluminum members will meet the requirements for both maximum deflection and bending stress. Additionally, it was confirmed that when using 6063 Aluminum that the strength wouldn't be reduced less than a safety factor of two at points near the weld. This was determined with prior knowledge that 6063 Aluminum has a loss in strength of only 20 percent as compared to 80 percent with 6061 Aluminum. For the deflection analysis on the plate, the plate was modeled as a cantilever beam supported at both ends with a load of 150 pounds at the center. The thickness of the plate was calculated based on a maximum deflection of 0.1 inches. The result showed that the plate must have a minimum thickness of approximately 0.16 inches. The complete analysis on the platform support and plate is shown in Appendix E.4.

Actuator (Inner & Outer) Support Analysis

The actuator support consists of a 2 inch x 2 inch x ¼ inch structural member (inner support) that slides inside of another square-hollow member (mechanical drawings in Appendix B.4 and Appendix B.5). Since the inner support will handle most of the loading, this component was initially analyzed. As with the other components, a bending stress analysis on this member was calculated. Based on calculated bending stress and material (steel) yield strength, the yield factor of safety was approximately 2. A stress-life analysis to make sure that the inner support will not fail under constant use was also conducted. Based on the Modified Goodman Criterion, the cycle life for inner support is 29×10^6 cycles. A complete analysis on the actuator support can be found in Appendix E.5.

Safety Considerations

As with any mechanical design, it is important to note any safety considerations that need to be taken into account. When working with a wheelchair lift that raises and lowers students with cerebral palsy it is quickly apparent that many safety issues need to be addressed. Some of the

main issues that could be faced include, but are not limited to: incorrect operations of the lift, overloading the lift, passengers falling off the lift, pinching points, and moving the lift horizontally while in vertical motion, among others. To address these concerns, bridges are connected to the platform to prevent the wheelchair from rolling off of the platform when in use. Additionally, extra flanges intend to be welded onto the sides of the platform to prevent side loading of the platform. Pins and slots for pins will be added on the sliding mechanism to prevent the lift sliding mechanism from being used to move the entire lift when it is in vertical motion. In regards to this issue, additional linear actuators may be placed on the lift sliding mechanism (pending the overall cost and budget) to automatically eject the entire platform, instead of having a manual ejection. Lastly, detailed instructions will be given to the school to ensure that no incorrect assumptions are made or questions left unanswered in regards to the operation of the lift.

Chapter 5: Manufacturing

Manufacturing Plan

Since the overall design of the solution has been done with the collaboration between the group of students from Kathmandu University and those from Cal Poly, it is only fitting that the manufacturing of the lift be a collaborative effort as well. The two teams of engineering students decided that the assembly of the lift would be divided into two portions and that these two portions would be assembled by the Kathmandu University team on-site in Nepal. It was decided that the manufacturing would be broken up into the two portions seen below in Figure 25 with the Kathmandu University team building the portion on the left while the Cal Poly team will be building what is seen on the right.

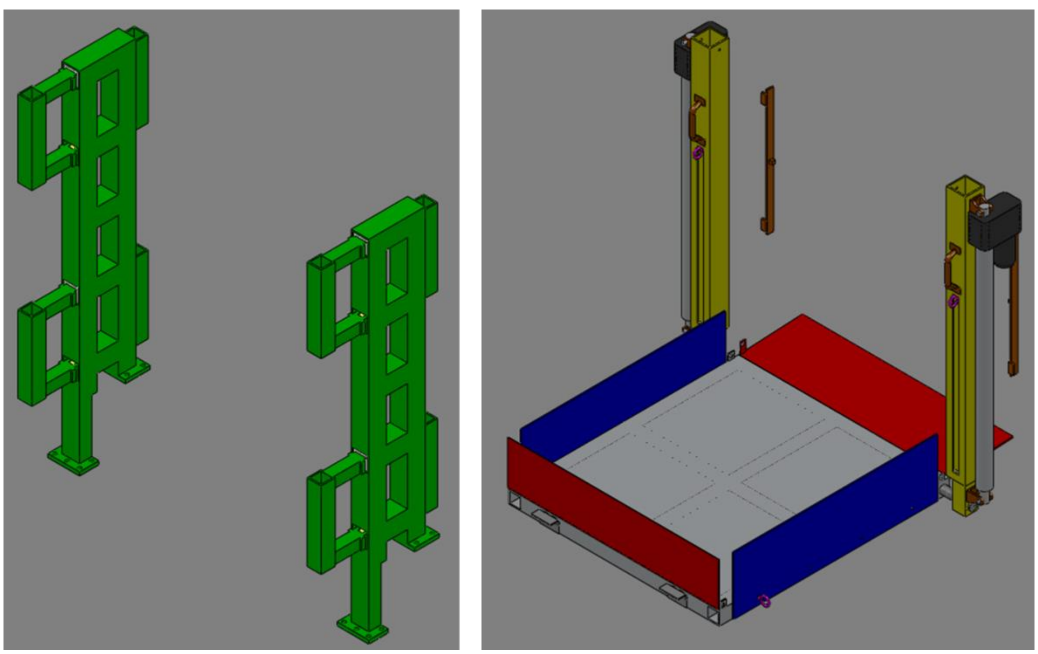


Figure 25. Manufacturing Division of Labor (Left: Kathmandu University; Right: Cal Poly

As noted above, when both sets of teams complete their respective portions the Cal Poly team will ship what they have completed to Nepal to be assembled with the Kathmandu University team's portion. Both teams will find and purchase the materials needed in their respective country with an exception coming if the Kathmandu University team cannot find the materials needed in Nepal. In this scenario, the Cal Poly team will purchase the required materials and ship

them to Nepal so that the Kathmandu University team can finish their portion of the lift. All mechanical drawings for all parts of the lift can be found in Appendix B. Included with each drawing are the necessary dimensions along with where the welds will need to be placed to ensure that the parts are manufactured correctly.

Manufacturing

Manufacturing of the lift was commenced by purchasing the steel tubing for the outer supports and the steel bars for the inner supports from a local steel manufacturer (McCarthy Steel). The outer supports (x2) had slots milled out in order to allow clearance for an eye bolt and were then lined with UHMW at the bottom of the tube. The UHMW was attached to the steel by scoring a surface of the UHMW with course sand paper and then applying Loctite epoxy. The UHMW was clamped down to secure adhesion to the steel. See Figures 26 and 27.

Figure 256. UHMW being epoxied to steel tube

Figure 27. Outer Support with milled slot and UHMW lining

Then, manufacturing was carried on to working on the inner supports. The mill was used to create the slot for the roller. Then, a hole was made for the rod that will be placed in order to be able to rotate the platform and to be held-in-place. One small mistake was made when milling out the hole for the rod; the hole was milled on the wrong plane. Due to insufficient time and money to purchase and manufacture a new inner support, it was determined that the mistake did not affect the design and so a new hole on the correct plane was made. Last minute holes were made on the inner support to bolt down the brackets for the actuators. This was done to make the lift easier to be taken apart once built. After completing the machining on the inner supports, the rollers and UHMW lining were installed. Again, the UHMW was scored, epoxied with Loctite, and finally clamped down to create adhesion to the steel. See figures 28 and 29.

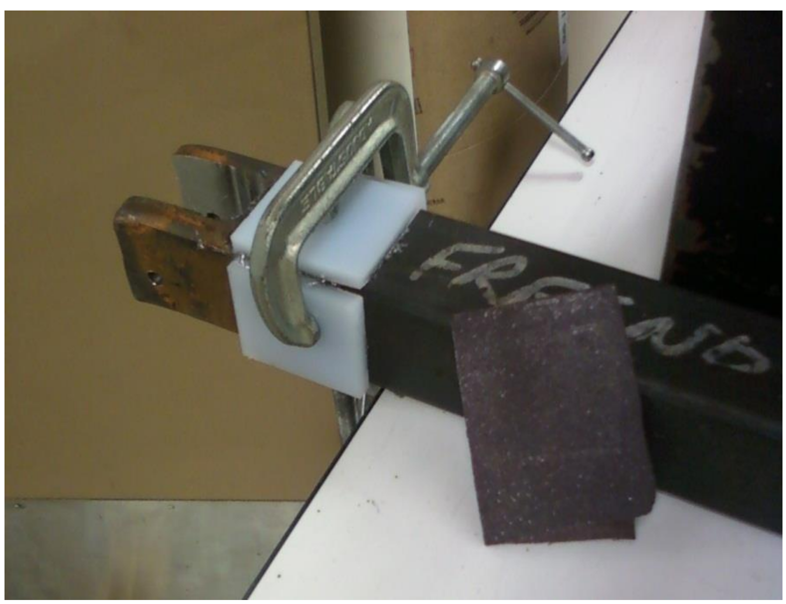


Figure 28. UHMW being epoxied to inner support

Figure 29. Inner Support with Roller and UHMW lining

After completing 2 inner supports and 2 outer supports, the completed support design was put together to test the “smoothness” of the roller and UHMW combination. See figure 30. It is worthy to note that re-application of UHMW will be a time consuming and bothersome task. Also, it is a bit tough to initially pull the inner support through the outer support due to the lack of clearance between the semi-bent end of the inner supports and the UHMW.

Figure 260. Inner Support slid through the Outer Support

The next component that was worked on was the platform. Two side tubes had holes drilled on them in order to install PVC sidewalls. Then, all the tubing was clamped and put together in order to be welded together. See figure 31. After the welding, the platform sheet was epoxied on. Then, the sidewalls were installed and bolted on. See figure 32.

Figure 31. Tubing clamped together to be welded to create the frame of the platform

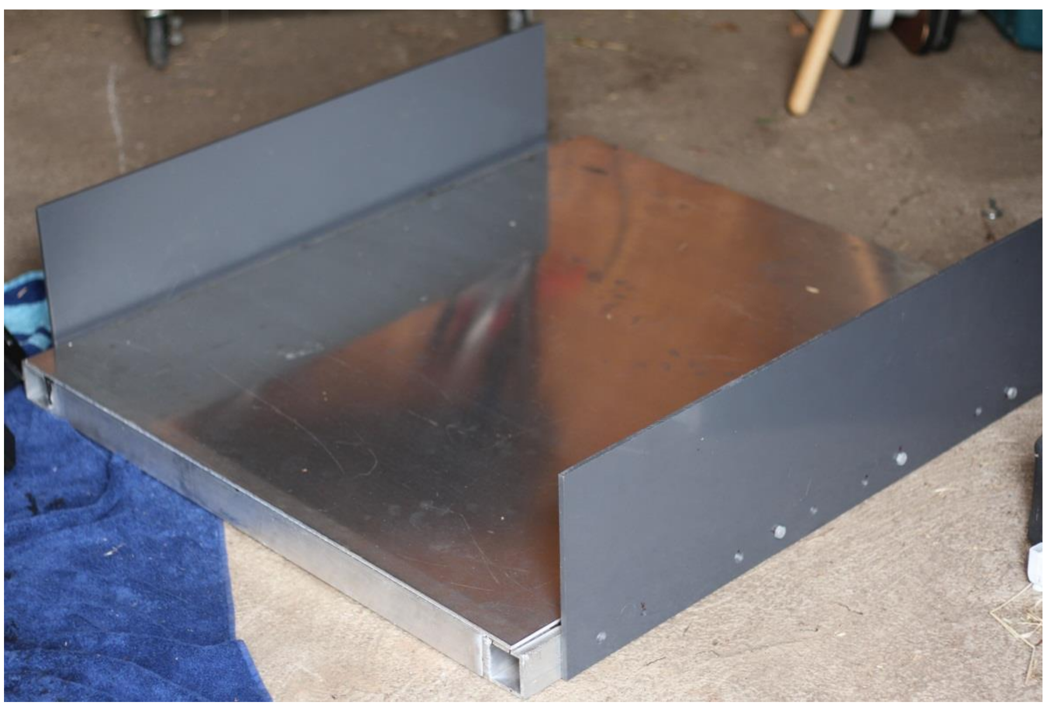


Figure 32. Platform sheet epoxied to frame and PVC sidewalls bolted

The next components are the top and bottom bridges which are installed on the platform. Hinges were welded to the bridges to be bolted onto the platform.

The next components are the brackets that fix the actuators to the supports. Tubing was used in order to manufacture the brackets. Because the piston can rotate 360 degrees, the brackets can be easily turned to face any direction. See figure 34. However, the top portion of the actuator that supports the brackets was initially facing the wrong direction. See figure 35. The actuators had to be opened and the pins had to be rotated to face the correct direction. See figure 36. After that, the brackets were successfully installed. See figure 37.

Figure 34. Bottom Brackets installed on Actuators

Figure 35. Pins and bolts facing the wrong direction

Figure 36. Cap is removed to rotate direction of pin

Figure 37. Pins and bolts facing the correct direction with brackets installed

Shipping Manufacturer Parts

It is important to note that nothing has been fully assembly in order to keep weight and size down. This is being done in order to keep shipping prices from Cal Poly San Luis Obispo to Kathmandu Nepal relatively low. Keeping weight and size down will make a huge difference in shipping costs as a difference in 10 pounds accounts for hundreds in dollars more. Also, because nothing has been fully assembled, it will be impossible to conduct testing of the wheelchair lift.

Kathmandu Team Manufacturing

The construction of the sliding mechanisms with rollers installed is seen in figure 38. In figure 39, the manufacturing of the tower frame is displayed. Finally, in figure 39 the assembly of the sliding mechanisms and tower frame is seen.

Figure 38. Welding of Sliding Mechanism

Figure 39. Construction of Tower Frame

Figure 270. Assembly of Tower Frame and Sliding Mechanisms

Comparing the SolidWorks Model to the Actual lift

The Solidworks model was closely followed when machining the different components of the lift; however, accurate and precise locations for holes, slots, cuts, etc made a bit challenging to follow it exactly. If all the small machining errors are ignored, then there is virtually no difference between the Solidworks prototype and the planed design.

Recommendations

There were a few errors we encountered that could have been avoided if more thinking and planning were done. For example, the slots on the outer supports could have been offset to each side so that the rollers would be able to roll more smoothly. However, UHMW was used to line the inner and outer support to aid with the smoothness.

While working on one of the inner supports, a large hole was made on the wrong plane of the tube which caused a huge waste in time and it also doesn’t look esthetically pleasing. If more time would have been taken to properly label where the hole was to be drilled, the error would have been avoided.

Other than those two main concerns, everything else was machined and put together without any hiccups.

Chapter 6: Assembly Instructions

Assembly Plan

As it was mentioned before, the wheelchair lift components manufactured by the Cal Poly team will be shipped to Nepal where the final assembly will take place. Both teams have agreed that the group from Kathmandu University will be responsible for the assembly of the wheelchair lift. The final assembly of the wheelchair lift will take place at the school location. General instructions for the assembly of the wheelchair lift are provided below to assist the Kathmandu team.

The assembly procedure of the wheelchair lift is broken into different subassembly categories which allow working on different parts at the same time. It is worth mentioning that components are heavy; therefore precautionary measures must be taken while working with them. The first step of the assembly procedure involves the attachment of the outer support to the sliding mechanism. The two outer supports are to be welded to each of the sliding mechanisms (see Appendix B.1 –Drawing #24). The next step is to couple the inner supports and outer supports. The components manufactured by the Cal Poly team have been labeled as follows: inner supports are labeled with an "I" and outer supports labeled with an "O" (i.e. I1, I2, O1 and O2) to ensure proper coupling. The inner support is slid inside the outer support making sure that the offset side of the roller is on the side of the slot on the outer support. Also, the UHMW plastics should remain in their place to ensure proper sliding of the inner support. Next, the bracket supports for the linear actuator are welded to the top of the outer support and to the bottom of the inner support. The locations of where the brackets will be placed have also been labeled with the top brackets being labeled O1 and O2, and the bottom brackets being labeled I1 and I2.

The tower supports will be bolted to the van floor near the left side door of the van. The exact location of the tower support will be determined by the Kathmandu team based on available space. Once the tower supports have been bolted, the sliding mechanisms will be joined to them. Note that the sliding mechanism at this point consists of the outer and inner supports as well. The ejecting frame, member A, of the sliding mechanism should slide through the tower frame slots. Then the second piece, B, is bolted (see Appendix B.2). The next step is to attach the

linear actuators to the brackets. The linear actuators are attached to the actuator supports as shown in Appendix B.1 as well.

The last major component to be assembled is the platform. Both the top and bottom bridges are bolted to the platform (see Figure 17). The platform is then raised to the level of the bottom end of the inners supports. The holes for the steel rod on both the platform and inner supports must coincide so the steel rod can slide through. Once the steel rod has been placed, a pin is placed at the other end to secure it. Eyebolts are placed on both the actuator supports and the platform as shown in Figure 20. Finally, steel cables are attached to the eyebolts to hold the platform in the horizontal position.

Procedure

The following is a set of procedures of how to assemble all parts of the wheelchair lift:

Assembly of Inner Supports to Outer Support

Note: Each inner support weighs about 45 lbs.

1. Weld the outer support to the sliding mechanism. See Appendix B.1 –Drawing #24 for correct dimensions.

2. Slide the inner support inside the outer support making sure the UHMW plastic remains on place as shown in Figure 41. The offset side of the roller should face the side where the slot is on the outer support.

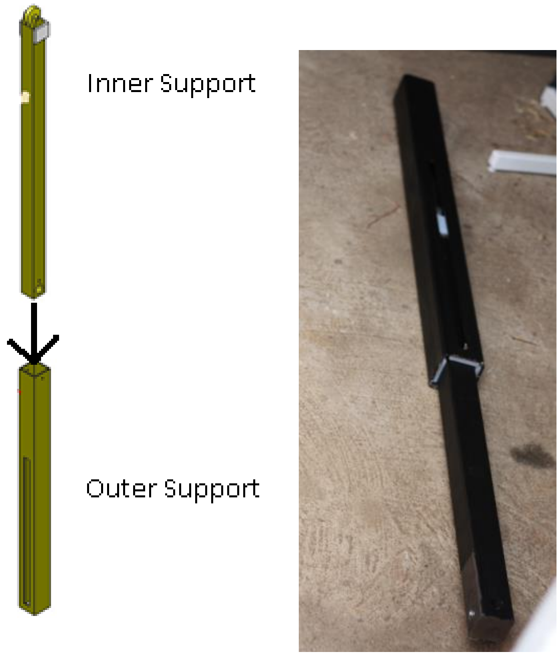


Figure 41. a) Schematic assembly of inner support and outer support and b) actual inner support inside the outer support.

3. Weld the top (smaller) brackets for the linear actuators to the top of outer supports. Locations for the top brackets are label as O1 and O2 (O stands for outer support).

4. Bolt the bottom (bigger) brackets for the actuator to bottom of the inner supports. Locations for the bottom brackets are label as I1 and I2 (I stands for inner support).

Assembly of Tower Supports to the Van

Note: The correct dimensions of the platform should be used to ensure proper locations as to where the tower supports will be bolted.

1. Drill holes on the interior of the van where the tower supports will be attached to. The holes should match the holes on the flanges of the tower supports. See Appendix B.3-Drawing #22 for correct dimensions.

2. Bolt the tower supports to the van.

3. Attach the sliding mechanism consisting of the outer support and inner support to the tower supports as shown in Figure 42.

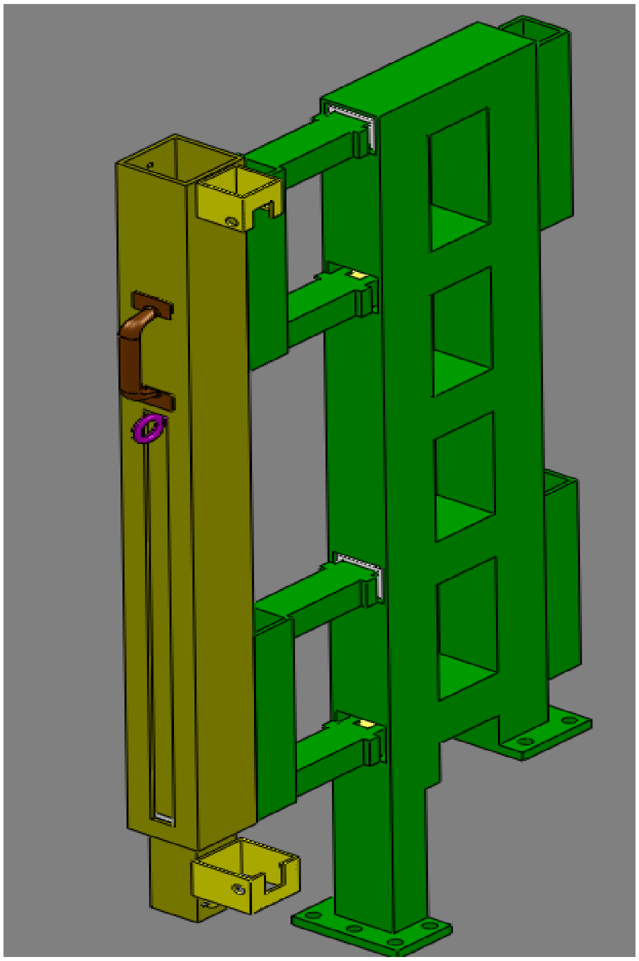


Figure 42. Assembly of actuator support to the tower support (van is not shown for clarity).

5. Bolt the second piece of the sliding mechanism after the sliding mechanism has been placed on the tower support. See Appendix B.2, Drawing #21 for reference.

6. Bolt the linear actuators to the brackets

Assembly of Platform

1. Bolt the top (bigger) bridge to the platform.

2. Bolt the bottom (smaller) bridge to the platform.

3. Raise and hold the platform to the level of the bottom of the inner support already attached to tower support. The bigger holes on the platform should coincide with the holes at the bottom of the inner supports.

4. Slide the steel rod through the hole located at the bottom of one inner support passing thru the platform and thru the second inner support.

5. Secure the steel rod with a pin.

6. Attach the smaller eyebolts to the actuator (inner) supports and the bigger eyebolts to the platform. See Figure 20 for reference.

7. Attach the steel cables to the eyebolts as shown in Figure 20. The steel cables are used to hold the platform in horizontal position.

Chapter 7: Design Verification Plan

Design Verification Plan (DVP)

During the process of any design, tests must be performed to verify that the design meets all the engineering specifications and requirements. This project is unique because each team will be required to test their portions of the lift in different and distinct ways to ensure that when assembled together the lift will work smoothly. As a result of this, the Kathmandu University team will be responsible for testing their portion of the lift that they will be building as described in Chapter 5. Similarly, the Cal Poly team will be responsible for testing their portion of the lift which is also outlined under Chapter 5.

Cal Poly's Design Verification

The scope of the testing outlined in this section will only include the testing needed for the Cal Poly team. The Cal Poly team identified three major components within their portion of the design that needed to be tested. The components include: the platform, the basic wiring and linear actuators and lastly the inner and outer supports.

Once the platform was completely manufactured it was tested to ensure its strength is more than adequate and verify its ability to hold the estimated payload without yielding or bending. The test was kept simple and cheap to create as cost-effective of a test as possible. The test consisted of raising the platform off the ground with some risers (in this case wood) and then loading the platform with 450 pounds of force (three adult males) to confirm the ability of the platform to hold this estimated weight. During the test, no bending was observed and there were no physical signs of wear or stress that would be a cause of concern. Due to the scope of this project and the limited budget provided it was not possible to test any component to failure to completely verify its integrity. As a result of this, only preliminary tests could be conducted on the platform at a weight of double that which the platform would see during daily usage in Nepal.

The basic wiring and linear actuators were tested by wiring the relays and switch to the linear actuators as seen in Figure 21 of Chapter 4. From the test it was confirmed that the wiring could

be used as designed and that the two linear actuators could be run simultaneously as needed for the lift. During the test, the actuators were capable of running in both directions, as expected, using the single-pole double-throw switch provided. It has additionally been determined that testing will also be conducted on the linear actuators once in Nepal which implements the use of either fuses or breakers into the wiring. These will be included as a fail-safe mechanism in the event that either linear actuator sees more current than what it can handle (i.e. the lift is overloaded). These tests will be conducted by supplying more current through the actuators than what they are rated for to see if the fuses or the breaker switches blow as predicted.

The last component testing included the inner and outer supports. In order to test this part it was initially planned that the linear actuators would be bolted to the inner and outer supports and then turned on. However, since the final design solution was switched to having the Kathmandu University team weld the brackets onto outer supports; this testing could not be conducted with the actuators connected to the inner and outer supports together. Instead of this, an inner support was placed inside of the outer support, a load was placed onto the inner support to simulate the bending which the supports would see, and then the inner support was slid back and forth to see if the friction force was reduced. The objective of this test was to determine if the rollers and UHMW placed between the inner and outer supports worked as designed, which is reducing the friction between the two materials and thus reducing the overall load the actuators will see. From this test it was clearly evident that the friction force was greatly reduced as planned. Additionally, a point of concern in the manufacturing process was whether or not the UHMW epoxied onto the inner and outer supports would stay in place during use. During this testing the UHMW stayed securely in place, this testing adequately showed the capability of the epoxy to join the steel and UHMW together as required. As an additional point of assurance, the UHMW was subjected to a 50 pound force to ensure that the epoxy would hold. This 50 pound force simulated the calculated friction force which the inner and outer supports would see.

Final Design Verification

As a result of the both the Cal Poly team and the Kathmandu University team building separate parts of the project, the final testing cannot occur until both team's components are together in Nepal. The sponsor of this project indicated that it was not necessary for the Cal Poly team to fully test their components because the price to do this would be exorbitantly high since the

Kathmandu University team was building one half of the project as well, which is required for testing. Therefore, the final testing of the project will occur once the Cal Poly team's components are shipped to Nepal and can be assembled by the team in Nepal. Once both team's parts that they manufactured are together in Nepal, a rigorous design verification plan will be completely essential since children will be using the design on a day-to-day basis. This design verification plan will ensure that the design is capable of meeting all of the engineering requirements relating to lifting the predicted payload, running continuously and rising in a specific time among other things. However, the design will need to be ensured for safety above all else due to the customers and the nature of those using the product.

The design verification plan that the Kathmandu team will complete will be broken down into sections. The first section of verification will involve ensuring the integrity of the actuators and wiring once connected to the van's battery. The wiring on the actuators will be connected to the van's battery and then the switch will be activated so that the actuators run smoothly in both the forward and reverse direction. This preliminary step will be conducted so that the Kathmandu team can verify that they understand how the wiring is to be complete before anything is assembled. This will allow for time to adjust anything in the van that needs to be changed to accommodate the wiring setup. Additionally, if any questions arise from this verification, the Kathmandu team will be able to contact the Cal Poly team to troubleshoot any electrical issues that they are having. After the wiring has been verified to work correctly, the exact same process will occur but this time the linear actuators will also be connected to the inner and outer supports via the manufactured brackets. This part of the verification will prove that the linear actuators can still move easily even after being mounted to the inner and outer supports with the inner support telescoping in and out of the outer support. It is essential to note though, that at this point in the design verification all testing conducted is done outside of the van preferably on the ground. The second section of testing will involve the actual process of testing components assembled inside of the van.

Following the testing and confirmation of the wiring portion to be working correctly, the second section will commence which begins after the outer supports are welded to the sliding mechanisms. The sliding mechanisms will then be used with the outer supports to check that the

mechanisms move back and forth easily without any interference while the outer supports are attached. Following this step, the linear actuators along with the inner supports can be attached to the outer support using the Cal Poly team's brackets. Once these are installed the wiring along the wiring harness connecting the actuators to the car battery will be set up. Subsequently, the entire system will be tested similar to when the actuators and wiring were tested in the first section. The switch will be activated and the linear actuators will run in both the forward and reverse directions while mounted to both inner and outer supports in the van.

The third section in the design verification will involve the preliminary testing of the platform. Before the platform can be attached to the inner support using the steel rod, the aluminum bridges need to be tested to ensure their strength and integrity. The aluminum bridges will be mounted and then the bottom bridge will be placed at an angle on the ground to simulate someone loading the platform. The Kathmandu team will then load the bridge with the estimated weight that it will be seeing to verify the strength. Following this step, the top bridge will be tested by mounting it to the platform and then folding it down flat so that it can rest on a riser to simulate it touching the van floor when the lift is raised. Again, the bride will be loaded with the estimated weight and again confirm its ability.

The fourth section of testing includes the overall testing of the platform, the steel cables, the steel rod and the eyebolts. All of these components will be assembled on the ground and then attached to the inner and outer supports (which are already assembled in the van). The actuators will then be raised up and down with all of the components assembled together. This will be completed in at least three cycles. During each of these cycles the Kathmandu team will extensively look for any flaws in the design or for any areas of concern. If the three cycles are completed and while using engineering judgment, the Kathmandu team verifies this preliminary step, then the final section of design verification can begin.

The fifth and final section in the design verification plan will be comprised of testing all of the components assembled together with a payload on the platform. This payload will not consist of any people but rather with weights that measure to the estimated load which the device will see. With the platform on the ground, the Kathmandu team will run the lift using the switch

connected to the linear actuators. The lift will be raised two inches off the ground and then lowered back to the starting position. This process will continue with the height that the lift is being raised increasing incrementally by two inches until the final run where the lift is raised all the way to the height of the van. During this process, continual observations will be made by the Kathmandu team to determine if the lift can be tested with a person on it. If the Kathmandu team can reach a consensus that the lift can be safely tested with a person on it then one of the members of the team will stand on the lift and the previous process will be repeated with the team member on it.

After these sections of design verification are complete, the Kathmandu team will recheck that all of the previous tests were valid and that they are confident in the results. Once this is complete, the team will conduct a safety phase of the design verification to search for any components or areas that may be unsafe. The Kathmandu team will validate the safety of the device and confirm with the Sathi Sansar School that the lift can operate safely with the students and any helpers on board.

Chapter 8: Project Management Plan

Management Plan

This team is comprised of two groups of students from Katmandu University in Nepal and California Polytechnic State University (Cal Poly) in California. Collaboration from both teams will be crucial to the completion of this project. The students from Katmandu University will be responsible for direct contact with Sathi Sansar in Nepal and will also be the primary group for assembly and installation of the final product on location. The students from Cal Poly will be responsible for any materials needed to complete the project that are not available in Nepal. Anything needed by the students from Katmandu University will be shipped from the students at Cal Poly. The two teams will be equally responsible in the design process to ensure that the final design meets all required specifications and pre-determined goals.

The design, manufacturing, and testing of this project can be loosely divided based on each academic quarter. Fall quarter of 2012 is the primary design quarter where conceptual designs and ideas will be developed and considered. The two groups of students from Cal Poly and Katmandu University will work closely to ensure that the best designs are being considered. Winter quarter 2013 will serve as the manufacturing and building quarter where the design ideas are built and implemented. At the end of this quarter, the primary goal is to have a functioning project that is ready to be shipped to Nepal. Lastly, spring quarter will consist of ensuring that the project is functional in Nepal and allows for time to improve the idea and ship any extra needed materials. Included in Appendix F are the Gantt charts for each academic quarter. Note that this chart is not intended to cover all specifics and is intended to allow for improvement in modification based on ever-changing scenarios.

Within the team of students from Cal Poly, the following general responsibilities will be given to ensure that the team is always running smoothly. Humberto is responsible for all finances and ensuring that the budget is always up to date and accounted for. Josh is responsible for all contact with the students from Katmandu University and will serve as the main point of contact between the two groups of students. Lastly, Edgar is in charge of the coordination of meetings and

verifying that the meetings are held on time and everything is completed as scheduled within each meeting.

Chapter 9: Conclusions and Recommendations

The next steps for completing this project involve the shipment of the Cal Poly team's material to Nepal and the continued fabrication of the Kathmandu team's components. Once these two steps are complete the Kathmandu team will begin the assembly and testing of both team's components. Collaboration between the teams of engineering students at Katmandu University and Cal Poly will continue past the Cal Poly team's graduation date to offer assistance and help where the Kathmandu team needs it.

Insight from Professor James Widmann of Cal Poly will also be taken to determine the best solution to the issue of shipping the parts to Nepal. Recommendations for the Kathmandu team are to follow the assembly instructions and design verification plan as closely as possible. The assembly and design verification are to be done utilizing engineering judgment with the Kathmandu team seeking collaboration between both teams when needed.

Appendix A

Background

Appendix A.1

Van Accessibility in Nepal

Engineering Requirements (HOWS)

Customer Requirements (Whats)	Weighting (Total 100)	Height from Ground	Height inside van	Force	Time	Size	Weight	Life cycle	Ergonomics	Strength	Cost			Lift-Up® Seat (VCI Mobility)	Wheelchair Lift (VCI Mobility)	Automatic Seatbelt
Disabled Student																
Get on Van		●		●	●	Δ		●	◊					5	4	1
Get on Seat			●	◊	●	Δ		◊	●					5	1	1
Strapped down (seat belt)			●	◊	◊			◊	●	●	◊			1	1	5
Safety		◊	◊			◊	●	●	◊	●	◊			3	3	3
Ease of Use		Δ	◊	●	●	◊	◊		◊		●			4	3	5
Students Can use by themselves (or limited help)		●	●	●	●	Δ	Δ							3	3	2
Comfortability			Δ			◊			●		Δ			5	5	3
Effort		◊	◊	●	●	◊			Δ					4	4	5
Student Age Range (varying)		◊	Δ	◊	◊	Δ								5	5	5
Space			◊			●	◊		◊		●			1	1	5
Driver																
Limited Help		Δ	Δ	●	◊	◊	◊				◊			4	4	2
Time (loading)		Δ	◊	Δ		Δ			Δ					1	2	4
Effort		◊	◊	◊	Δ	◊	◊		Δ					4	4	4
Ease of Use		Δ	◊	◊	◊	◊	◊		◊		●			4	4	5
Safety		◊	Δ	Δ	Δ	Δ	●	●	◊	●	◊			5	3	5
Teachers																
Time (unloading)		◊	◊	Δ		◊			Δ					1	1	4
Effort		◊	◊	◊	Δ	◊	◊		Δ					4	4	4
Ease of Use		Δ	Δ	◊	●	Δ	◊		Δ		●			4	4	5
Safety		◊	Δ	Δ	Δ	Δ	●	●	◊	●	◊			5	3	5
General Operation (maintenance)			Δ			●	●	◊		Δ	●			1	2	4
Must Retrofit current Van		Δ	Δ			●	●			◊	●			1	2	3
Stability				◊		●	●	◊		●	●			5	4	4
Parents																
Safety		◊	Δ	◊	◊		●	●	◊	●	◊			5	4	5
Units		ft	ft	lbf	min	ft^3	lb	years	TBD	psi	Dollars					
Targets		2	1.5	250	5	TBD	100	10	TBD	TBD	2000					
Lift-Up® Seat (VCI Mobility)		5	5	5	5	1	2	3			2					
Wheelchair Lift (VCI Mobility)		5	5	5	5	4	3	3			3					
Automatic Seatbelt			5	5	5	5	5	4			5					

Customer Requirements

●	Srong Correlation
◊	Medium Correlation
Δ	Small Correlation
Blank	No Correlation

Appendix A.2

Lift-Up® Seat (VCI Mobility)

http://vanconinc.com/equipment/assistive-seating/turning-automotive-seating/

Model TAS-5001/5201

Appendix A.3

Wheelchair Lift (VCI Mobility)

http://vanconinc.com/equipment/wheelchair-lifts/

Appendix A.4

Wheelchair Ramp

DWR-8 (8' LONG) ON A FULL-SIZE VAN

DWR-7 (7' LONG) ON A MINI VAN

http://www.discountramps.com/portable-wheelchair-ramps.htm

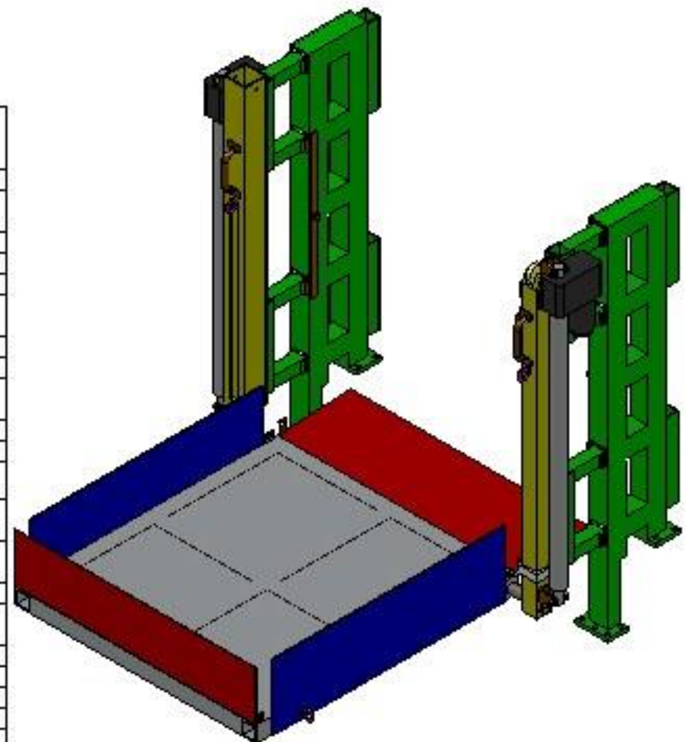
Appendix B

Drawings

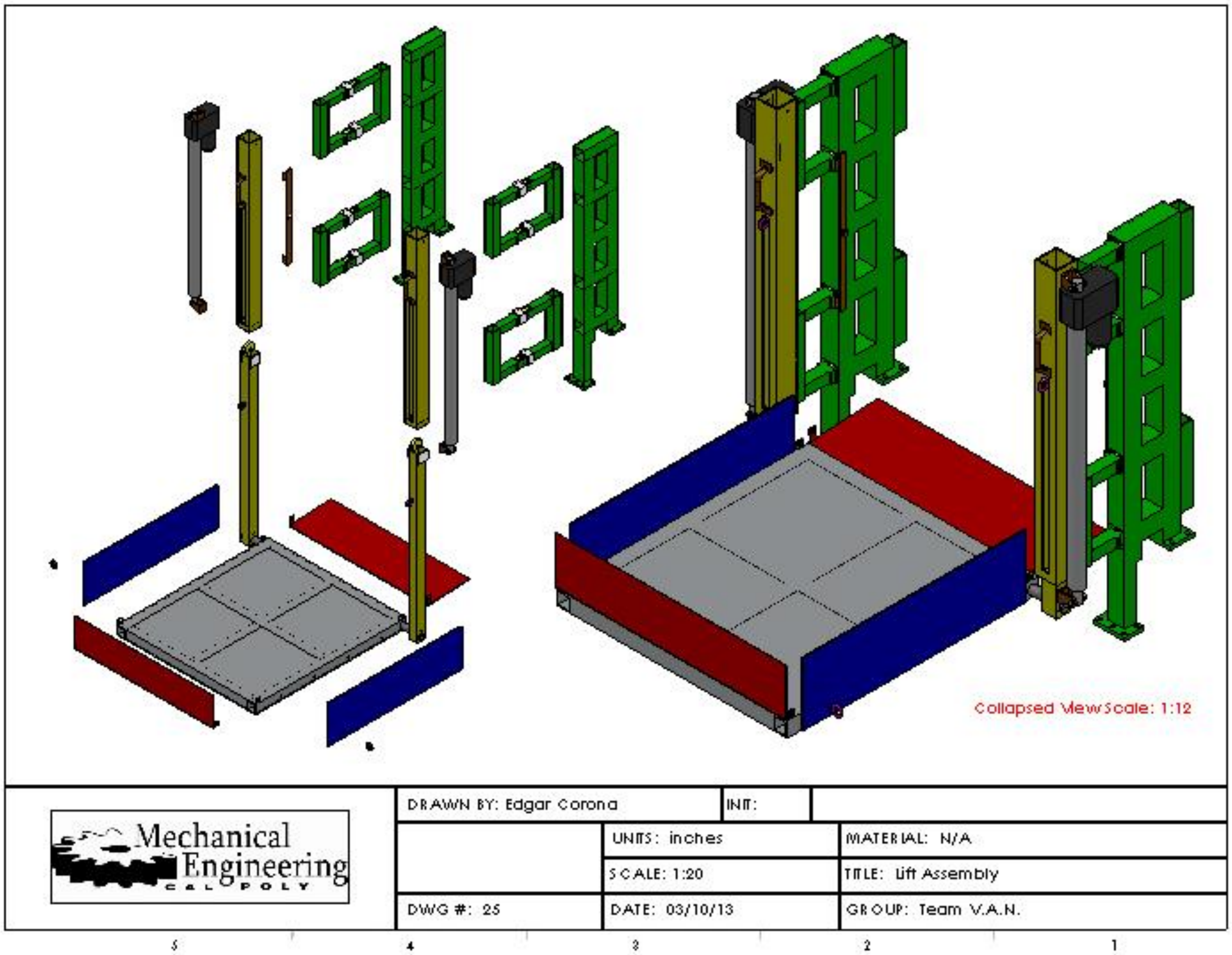
Appendix B.1

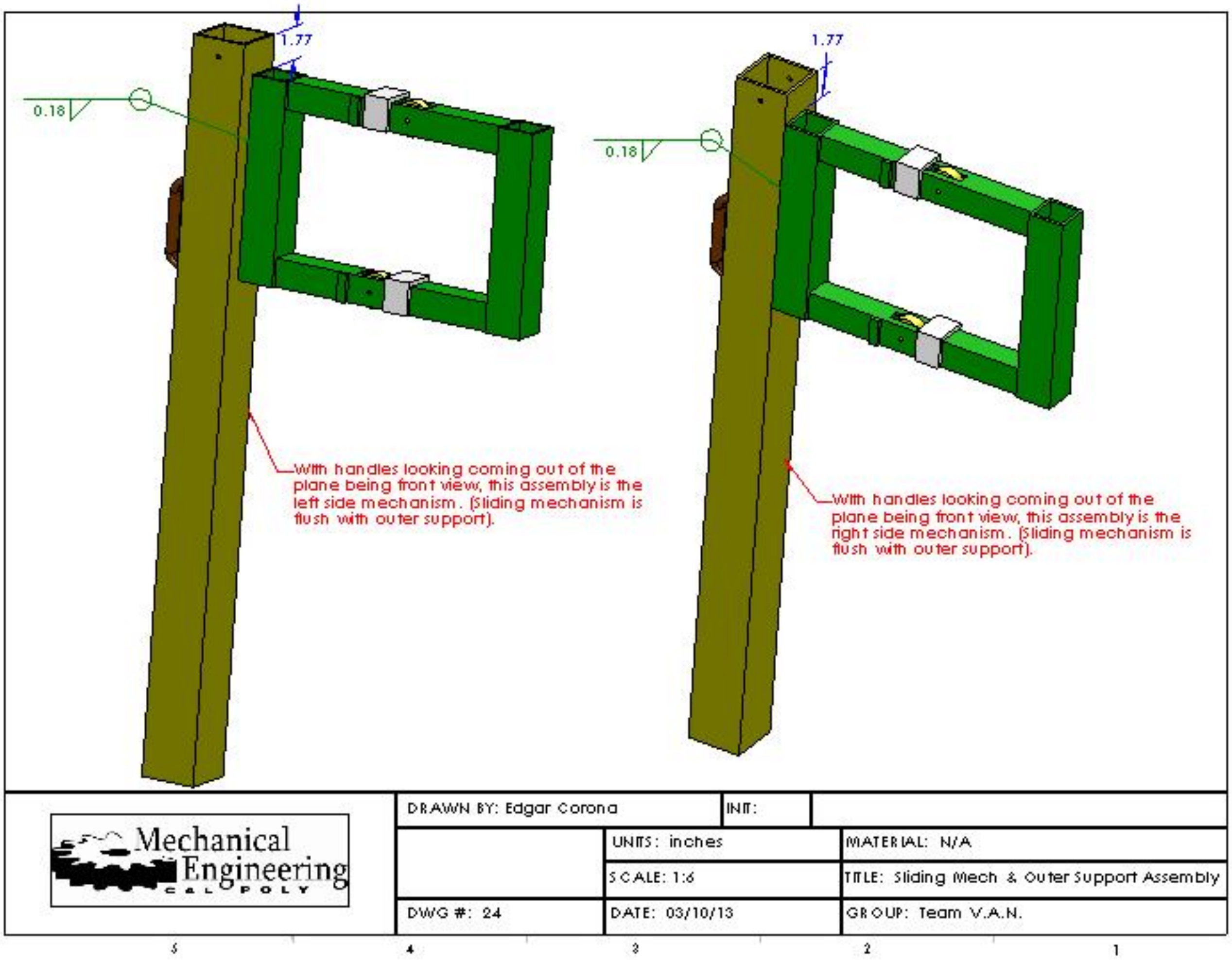
Lift Assemblies and Bill of Materials

ITEM NO.	PART NUMBER	Description	QTY.
1	Tower Frame	Green Tower	2
2	Sliding Mechanism	Green Rectangular Shape	4
3	Outer Support for the Actuator	Outer Yellow Square Tube	2
4	Roller (Sliding Mechanism)	See Drwg# 21	8
5	Plastic Lining (Sliding Mechanism)	See Drwg# 21	8
6	Plastic Lining (Outer Support Lining)	See Drwg#19	2
7	Inner Support for the Actuator	Inner Yellow Square Tube	2
8	Roller (Inner Support)	See Drwg# 15	2
9	Plastic Lining (Inner Support Lining)	See Drwg# 15	2
10	Linear Actuator	$400	2
11	Mounting Bracket (Top)	Connects to Motor End	2
12	Mounting Bracket (Bottom)	Connects to Piston End	2
13	Pin (Bracket)	Connects Actuator to Bracket	4
14	Handle	McMaster: 1650A2	2
15	Eye Bolt (Short)	McMaster: 3014T862	2
16	Rod Support	Rod Supporting the Platform	1
17	Platform	See Drwgs# 1-5	1
18	Top Bridge	Red Sheet	1
19	Bottom Bridge	Red Sheet	1
20	Sidewall	Blue sidewall	2
21	Eye Bolt (Long)	McMaster: 3014T904	2
22	Locking Mechanism (Sliding Mechanism)	To Be Determined	2
23	Hinge	To Be Determined	4
24	Locking Mechanism (Platform)	To Be Determined	1



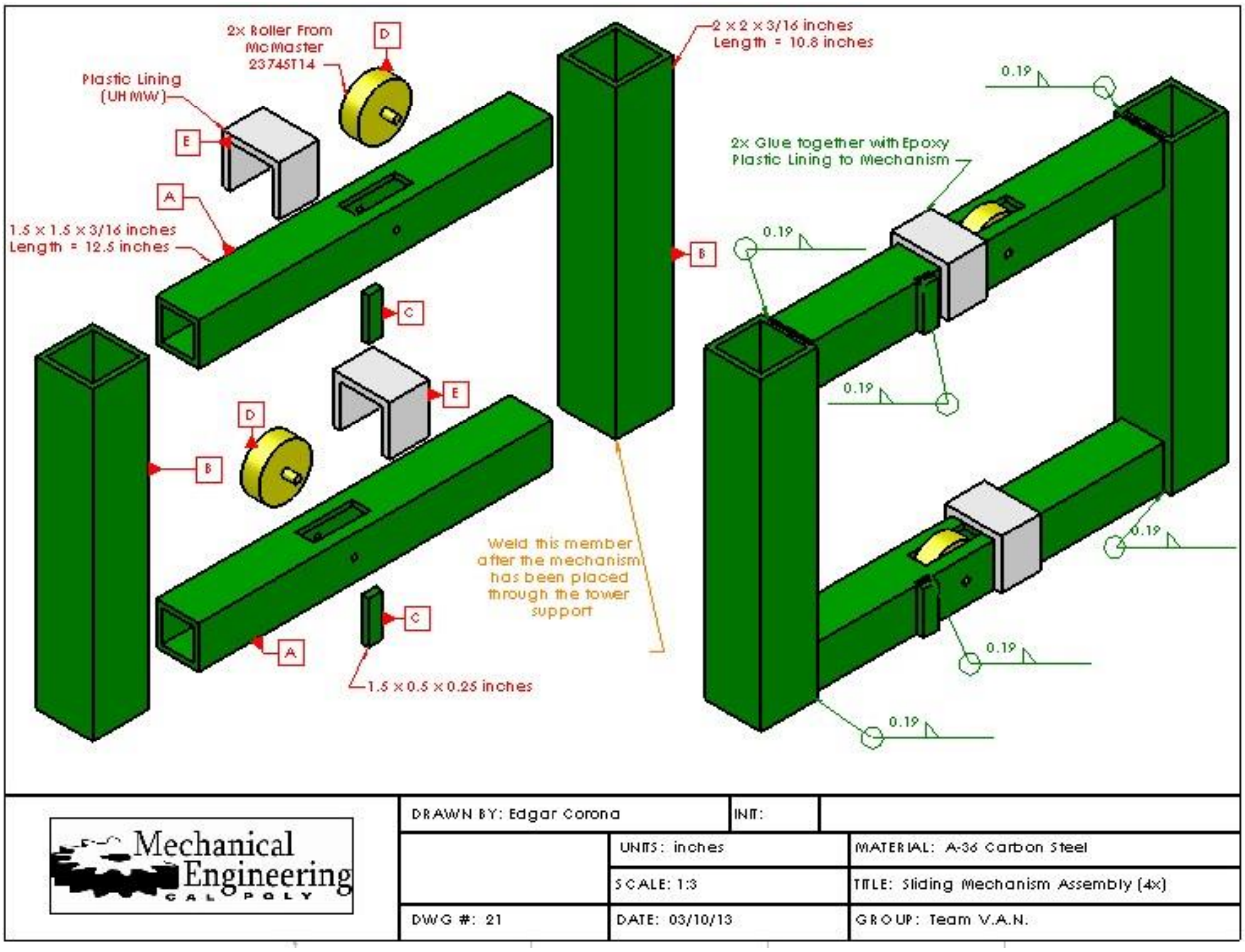
DRAWN BY: Edgar Corona		
	UNITS: inches	MATERIAL: N/A
	SCALE: 1:12	TITLE: Bill of Materials
DWG #: 25	DATE: 03/10/13	GROUP: Team V.A.N.

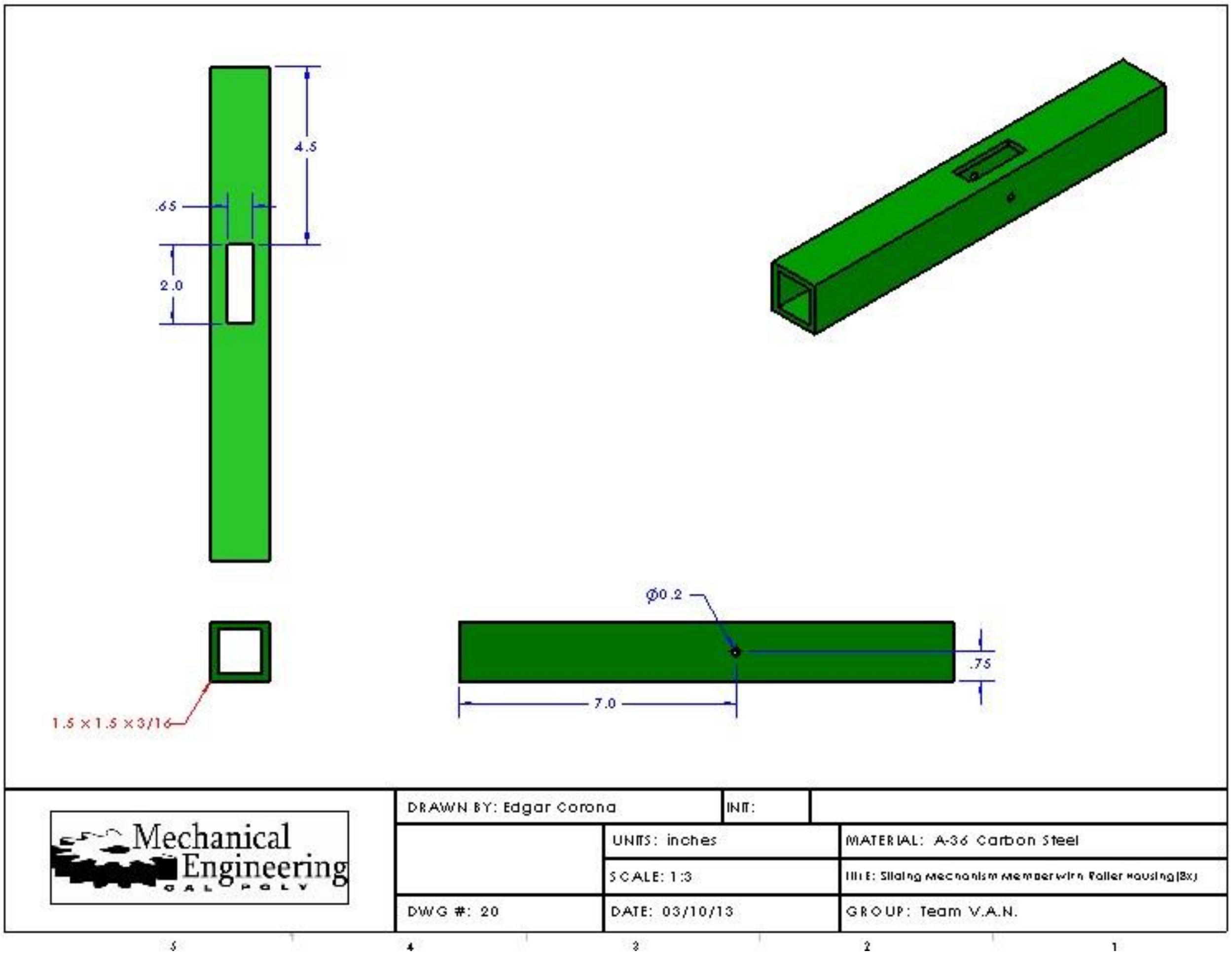

Collapsed View Scale: 1:12
Mechanical Engineering
CAL POLY
DRAWN BY: Edgar Corona
INIT:
UNITS: inches
MATERIAL: N/A
SCALE: 1:20
TITLE: Lift Assembly
DWG #: 25
DATE: 03/10/13
GROUP: Team V.A.N.
5
4
3
2
1


1.77
0.18
1.77
0.18
With handles looking coming out of the plane being front view, this assembly is the left side mechanism. (Sliding mechanism is flush with outer support).
With handles looking coming out of the plane being front view, this assembly is the right side mechanism. (Sliding mechanism is flush with outer support).
Mechanical Engineering CAL POLY
DRAWN BY: Edgar Corona
INIT:
UNITS: inches
MATERIAL: N/A
SCALE: 1:6
TITLE: Sliding Mech & Outer Support Assembly
DWG #: 24
DATE: 03/10/13
GROUP: Team V.A.N.

Appendix B.2

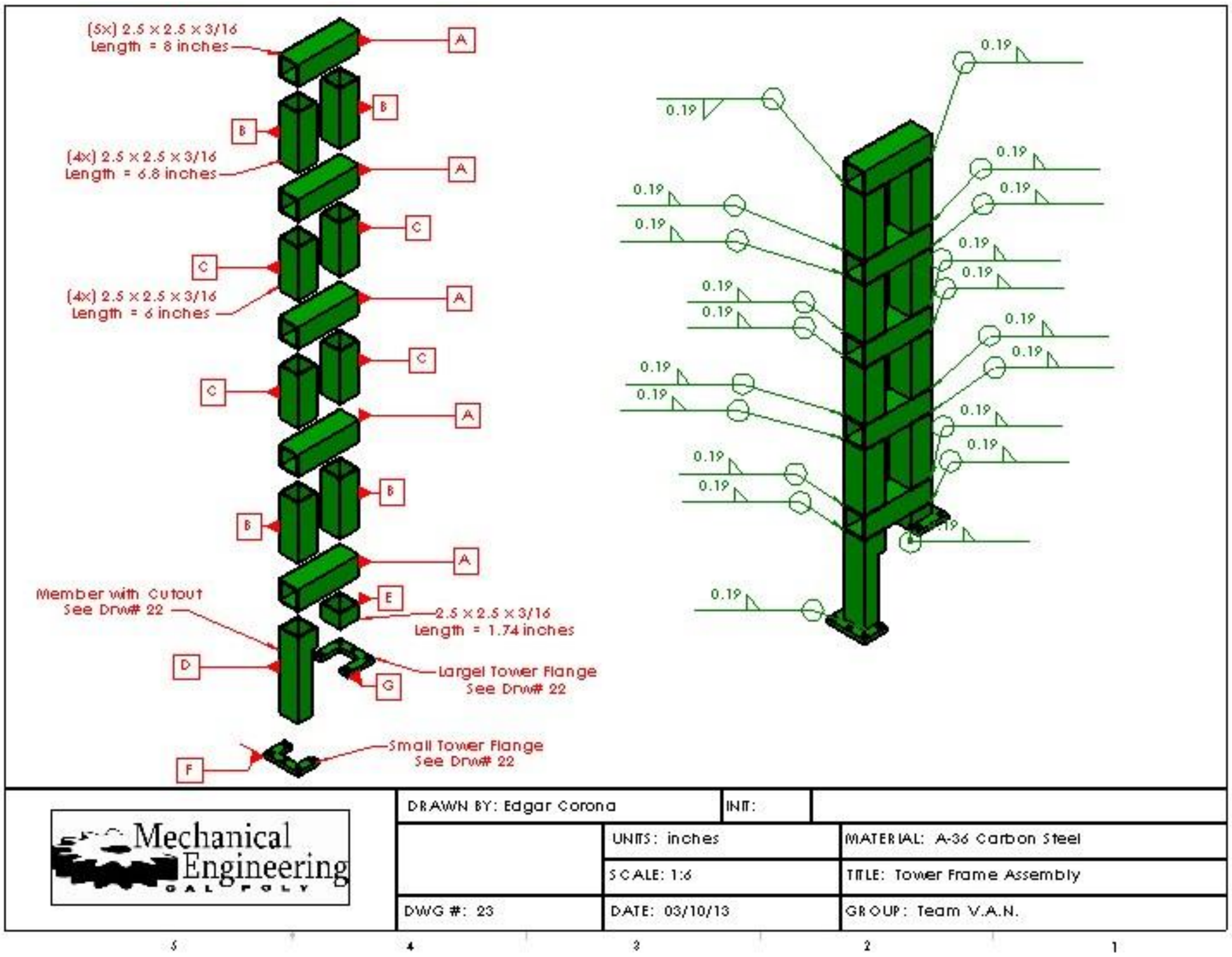
Lift Sliding (Ejecting) Mechanism

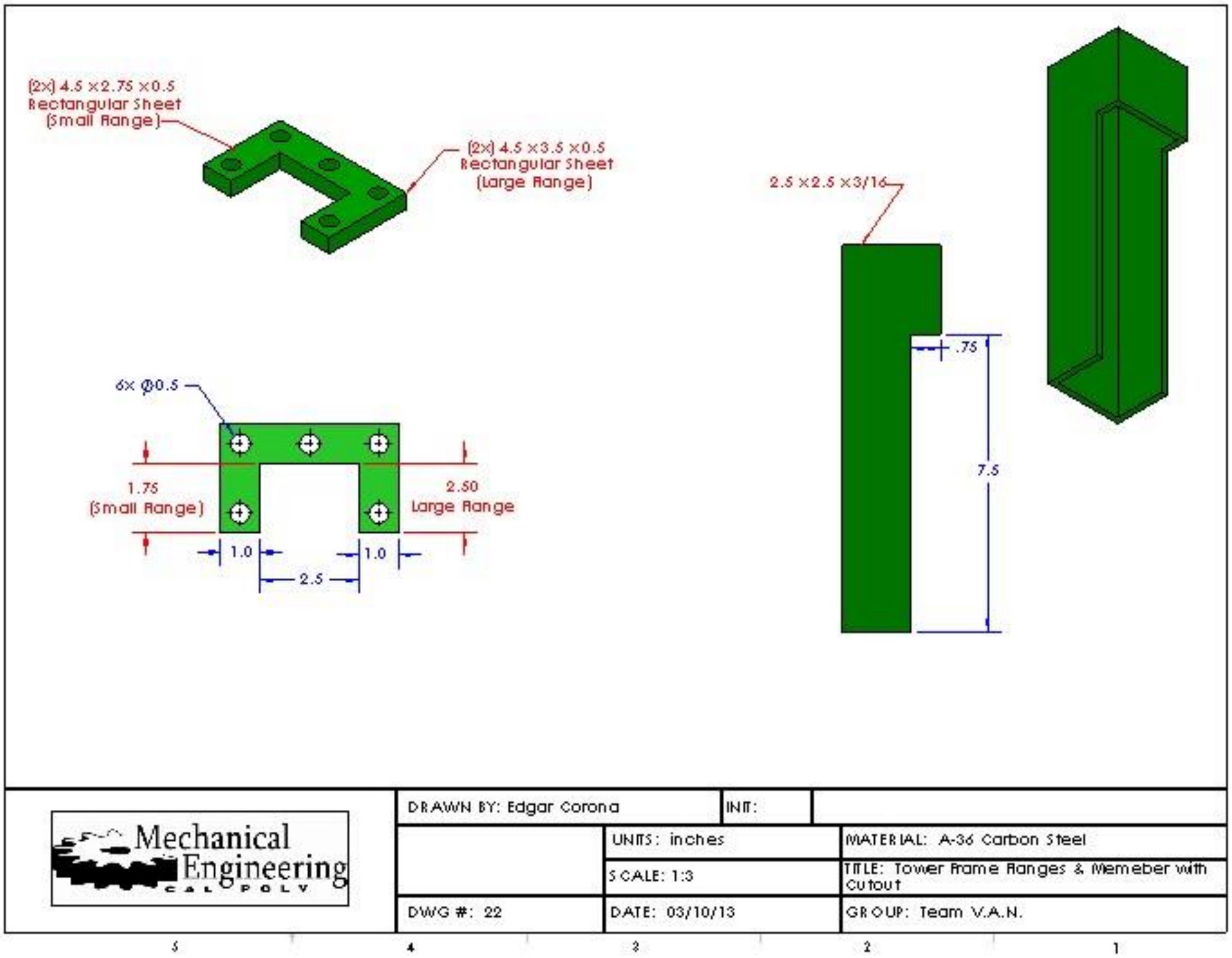



4.5
.65
2.0
Ø0.2
.75
7.0
1.5 × 1.5 × 3/16
Mechanical Engineering
CAL POLY
DRAWN BY: Edgar Corona
INIT:
UNITS: inches
MATERIAL: A-36 Carbon Steel
SCALE: 1:3
TITLE: Sliding Mechanism Member with Roller Housing (8x)
DWG #: 20
DATE: 03/10/13
GROUP: Team V.A.N.

Appendix B.3

Tower (Frame) Support

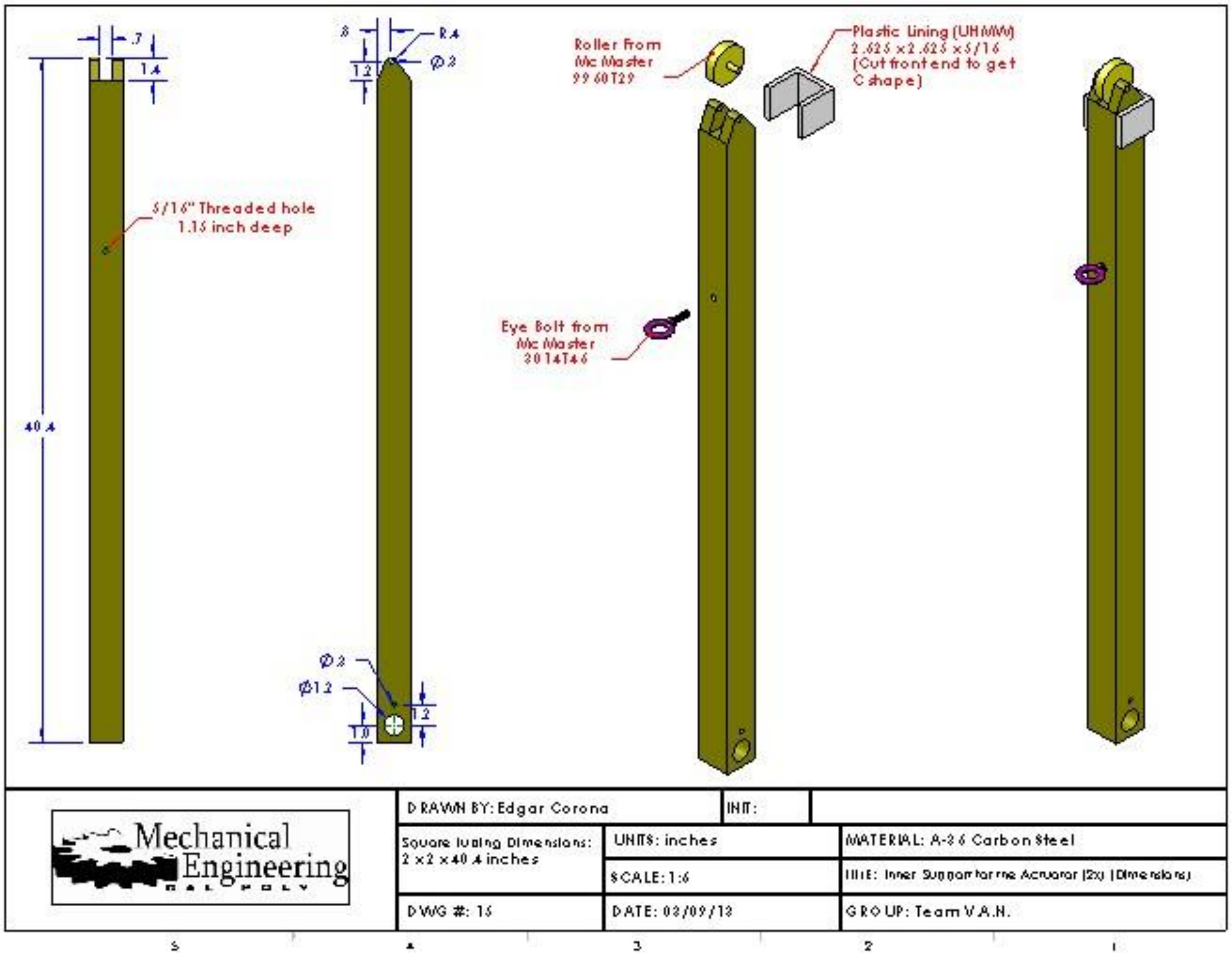




(2x) 4.5 x 2.75 x 0.5
Rectangular Sheet
(Small Flange)
(2x) 4.5 x 3.5 x 0.5
Rectangular Sheet
(Large Flange)
2.5 x 2.5 x 3/16
6x Ø0.5
1.75
(Small Flange)
2.50
Large Flange
1.0
2.5
1.0
.75
7.5
Mechanical Engineering
CAL POLY
DRAWN BY: Edgar Corona
INIT:
UNITS: inches
MATERIAL: A-36 Carbon Steel
SCALE: 1:3
TITLE: Tower Frame Flanges & Memeber with Cutout
DWG #: 22
DATE: 03/10/13
GROUP: Team V.A.N.
5
4
3
2
1

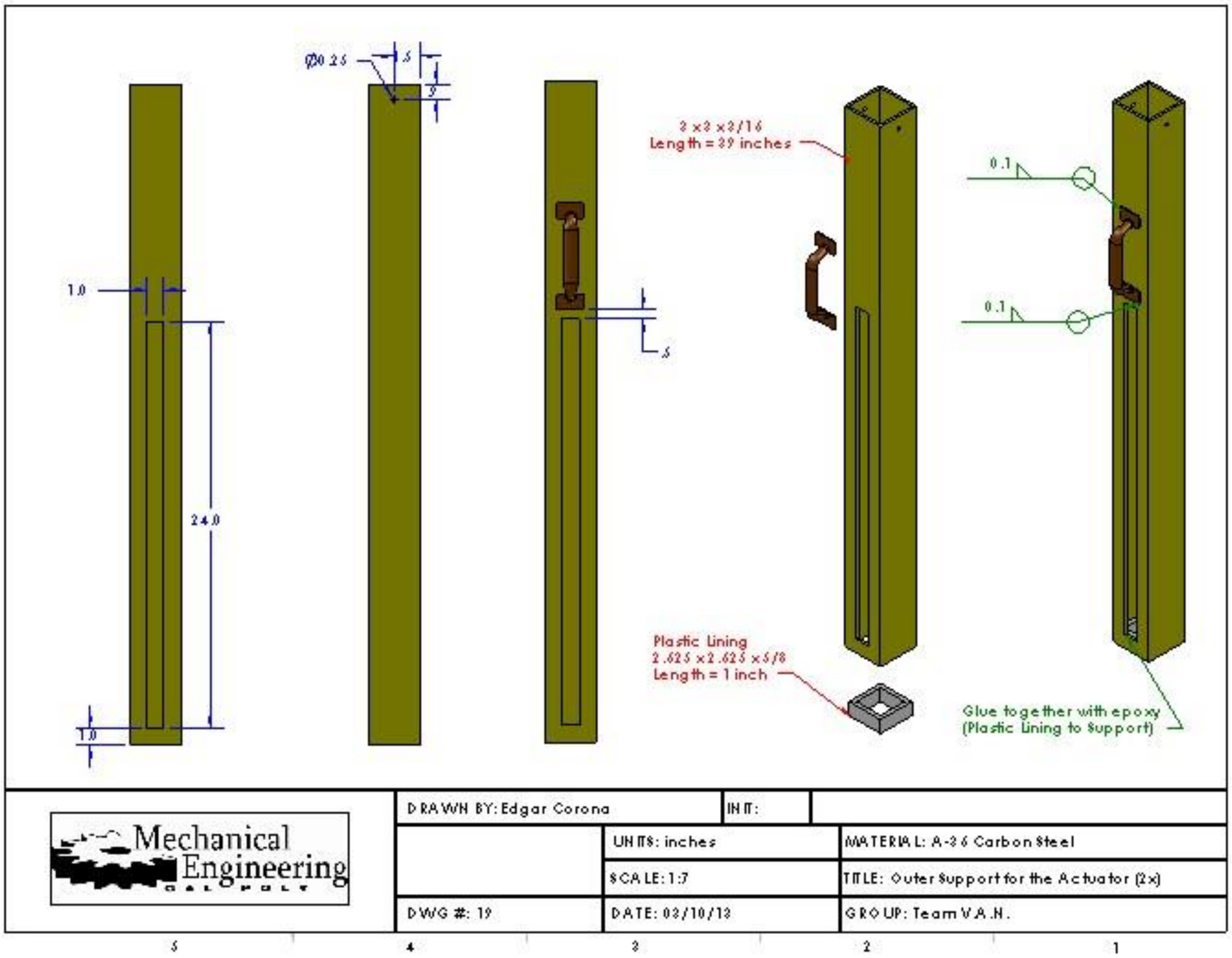
Appendix B.4

Inner Support for Actuator



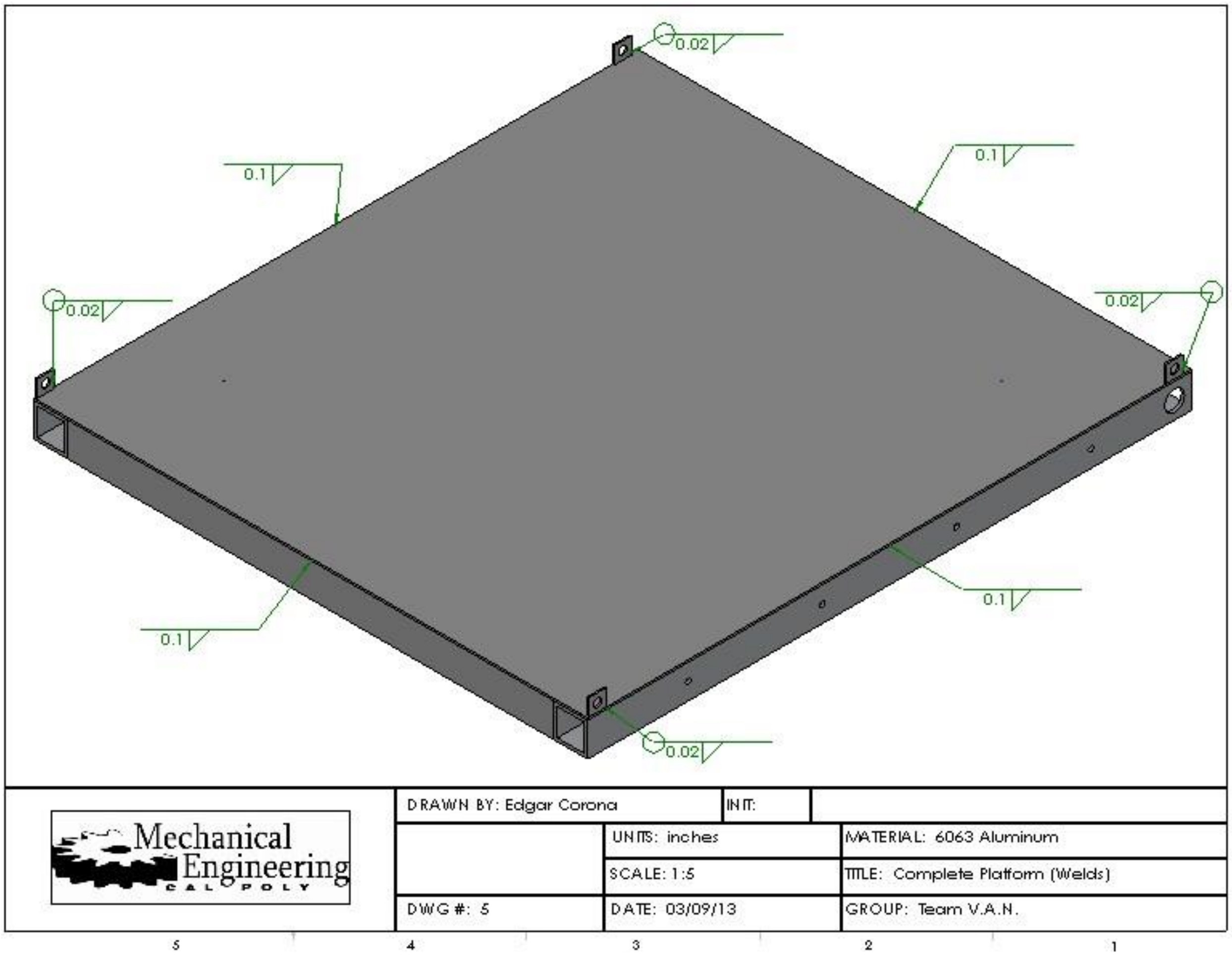
Appendix B.5

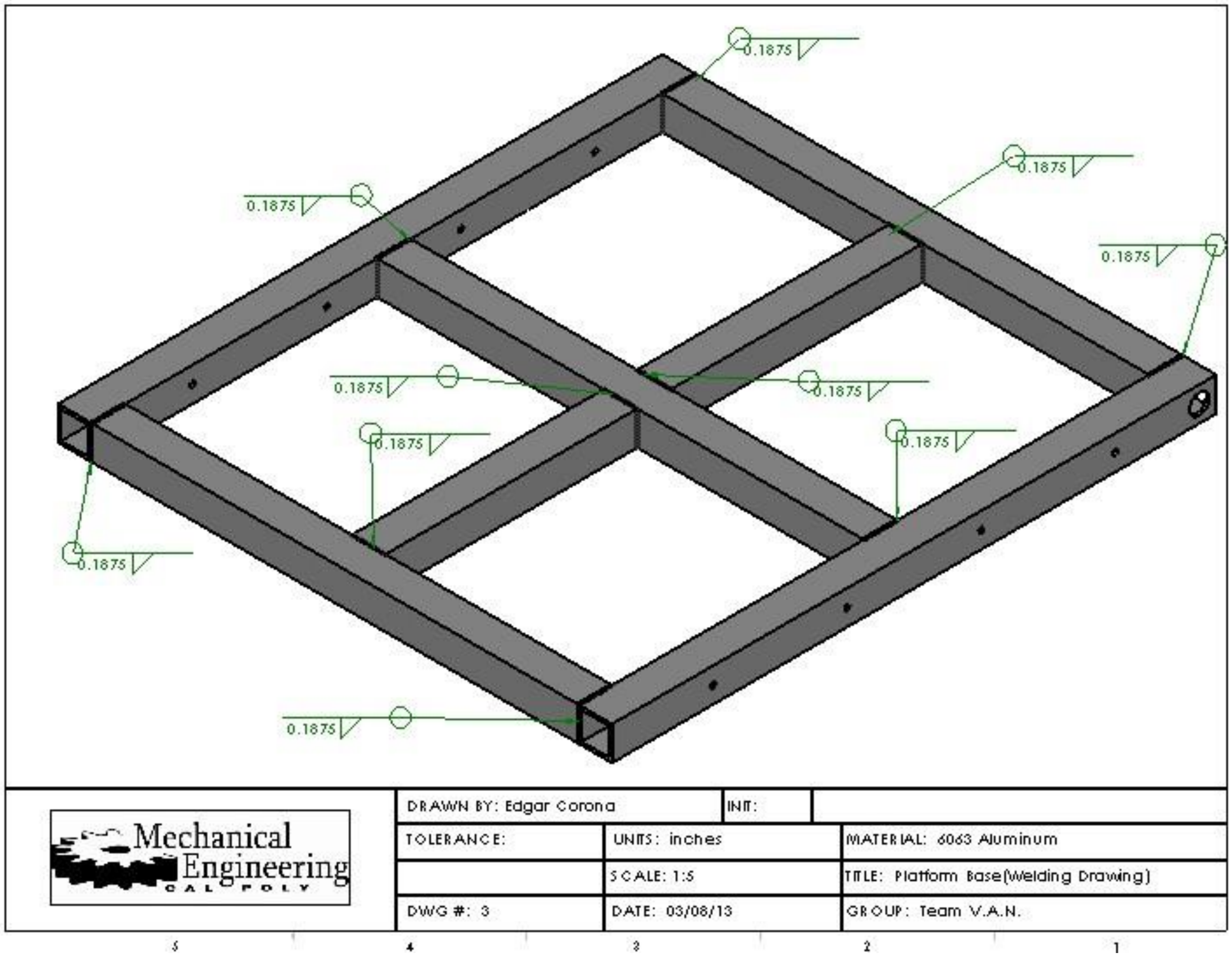
Outer Support for Actuator

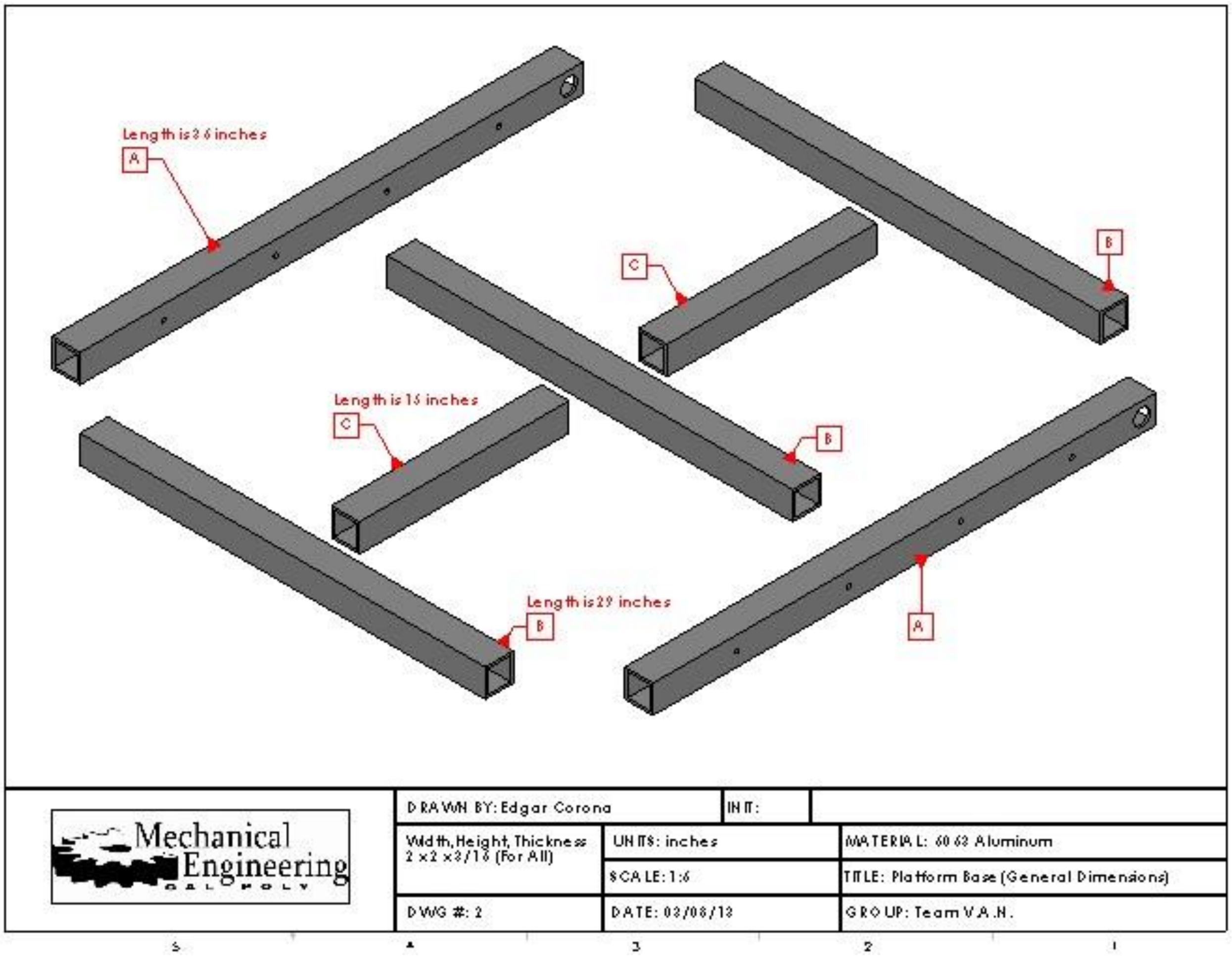


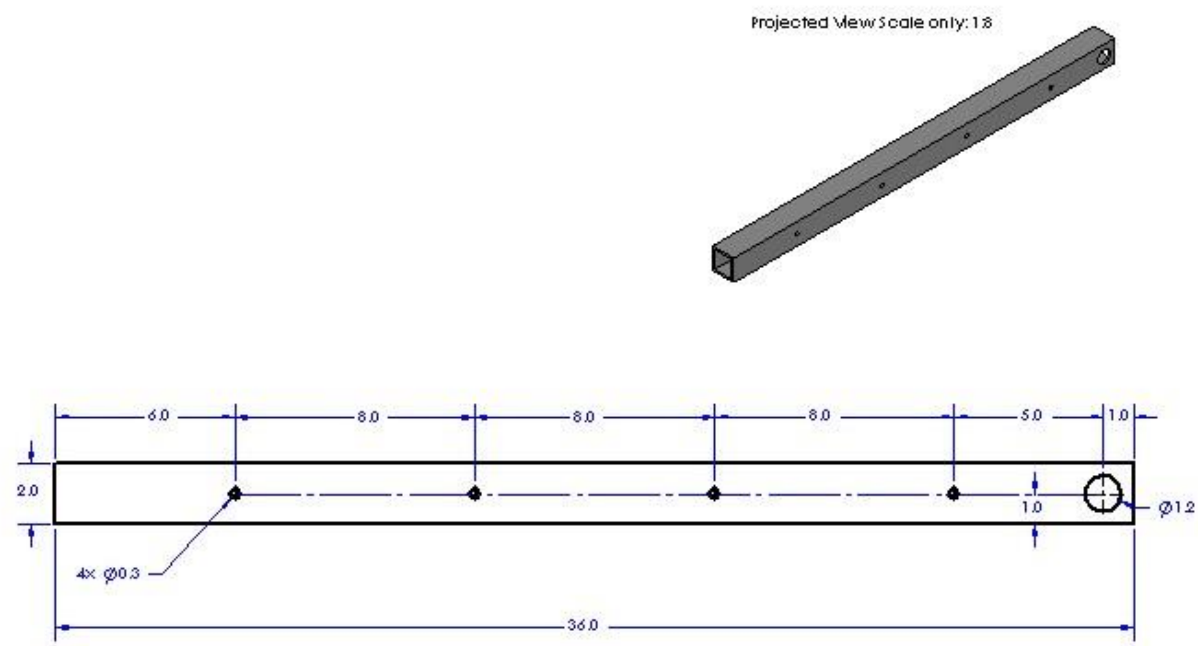
Appendix B.6

Platform




0.1875
DRAWN BY: Edgar Corona
INIT:
Mechanical Engineering
CAL POLY
TOLERANCE:
UNITS: inches
MATERIAL: 6063 Aluminum
SCALE: 1:5
TITLE: Platform Base(Welding Drawing)
DWG #: 3
DATE: 03/08/13
GROUP: Team V.A.N.
5
4
3
2
1


Length is 36 inches
A
Length is 15 inches
C
C
B
B
B
Length is 29 inches
A
DRAWN BY: Edgar Corona
INIT:
Width, Height, Thickness 2 x 2 x 3/16 (For All)
UNITS: inches
MATERIAL: 6063 Aluminum
SCALE: 1:6
TITLE: Platform Base (General Dimensions)
DWG #: 2
DATE: 03/08/13
GROUP: Team V.A.N.

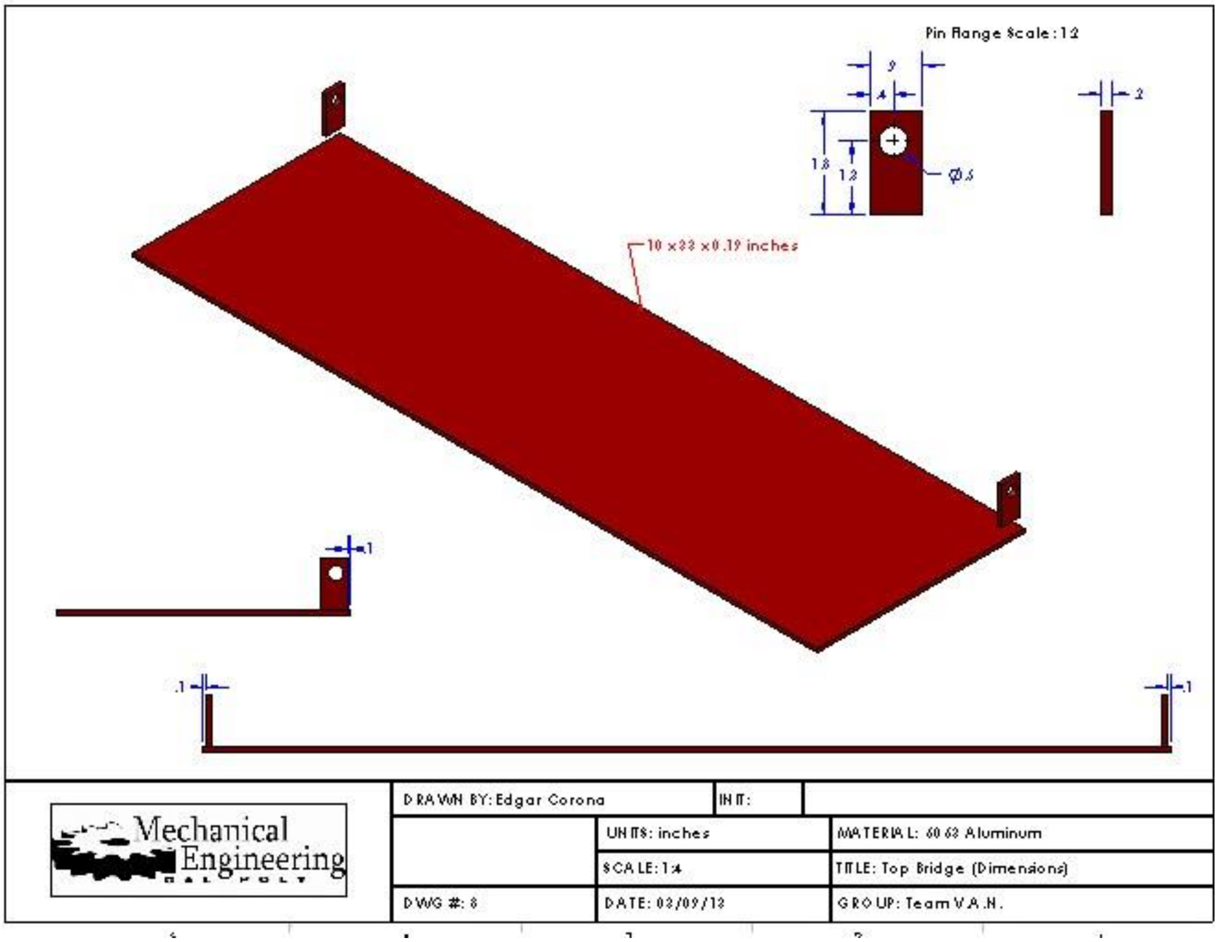


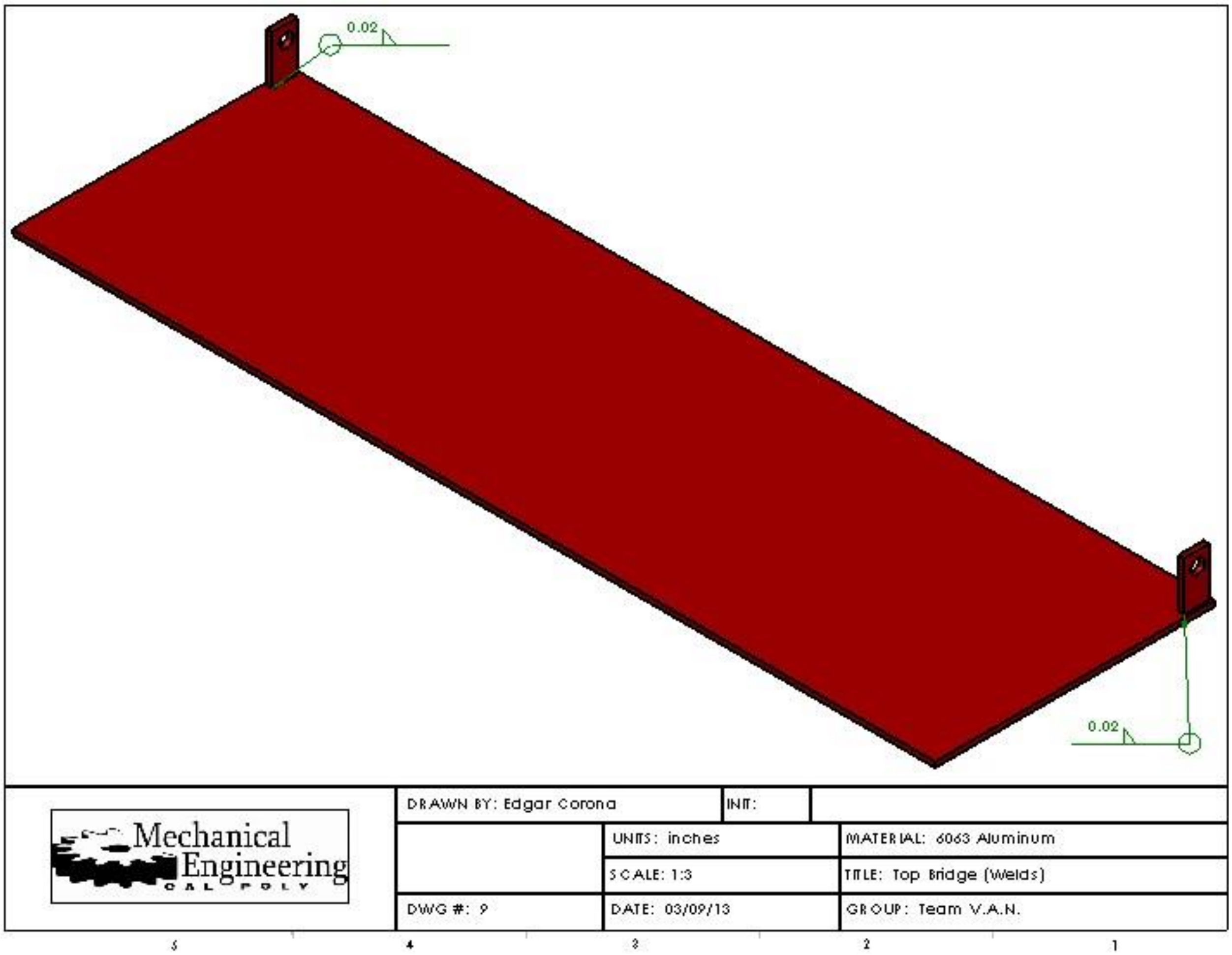
Mechanical Engineering CAL POLY	DRAWN BY: Edgar Corona	INIT:	
	Width, Height, Thickness: 2×2×3/16	UNITS: inches	MATERIAL: 6063 Aluminum
		SCALE: 1:4	TITLE: Platform Main Side Member (x2)
	DWG #: 1	DATE: 03/08/13	GROUP: Team V.A.N.

5 4 3 2 1

Appendix B.7

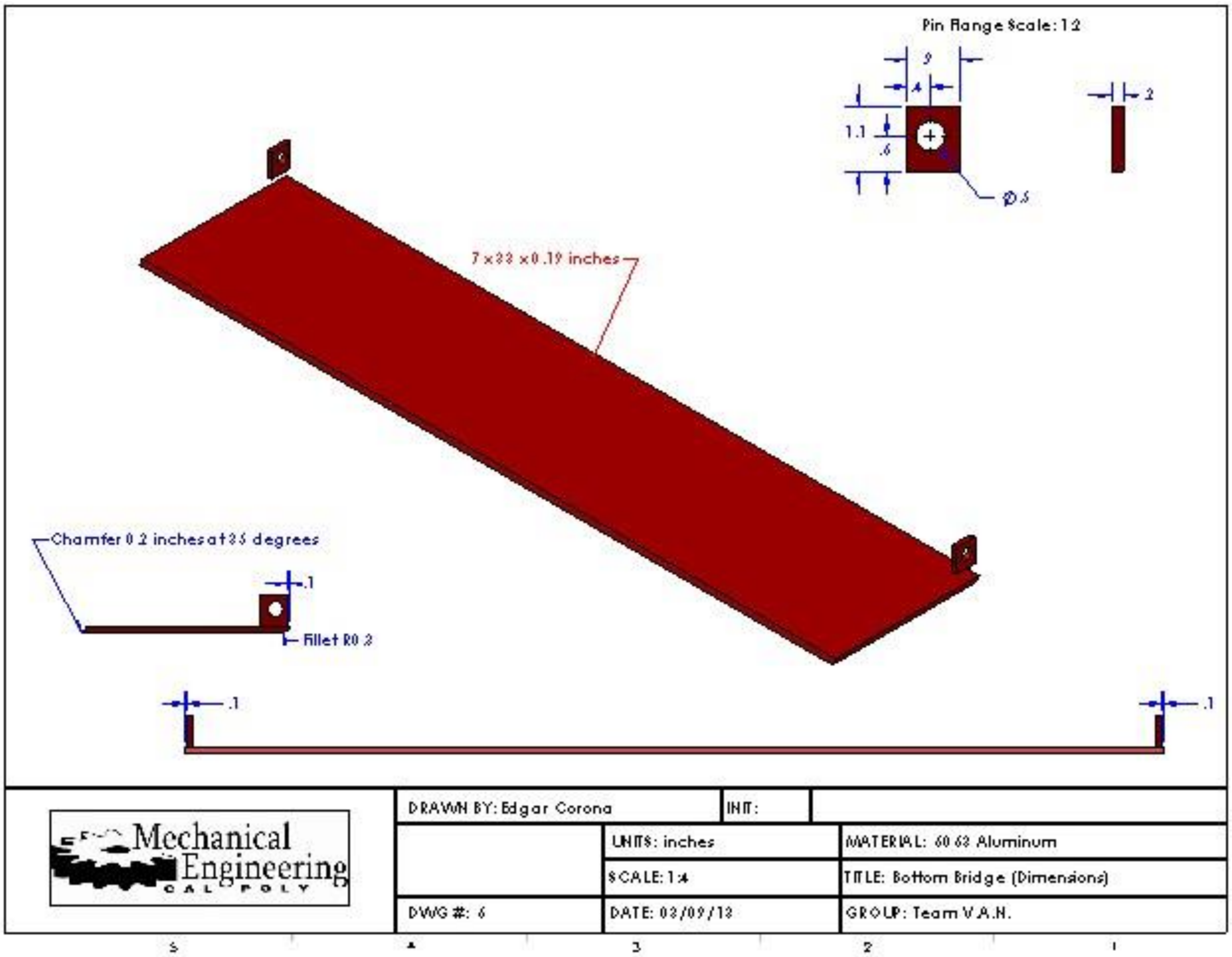
Top Bridge

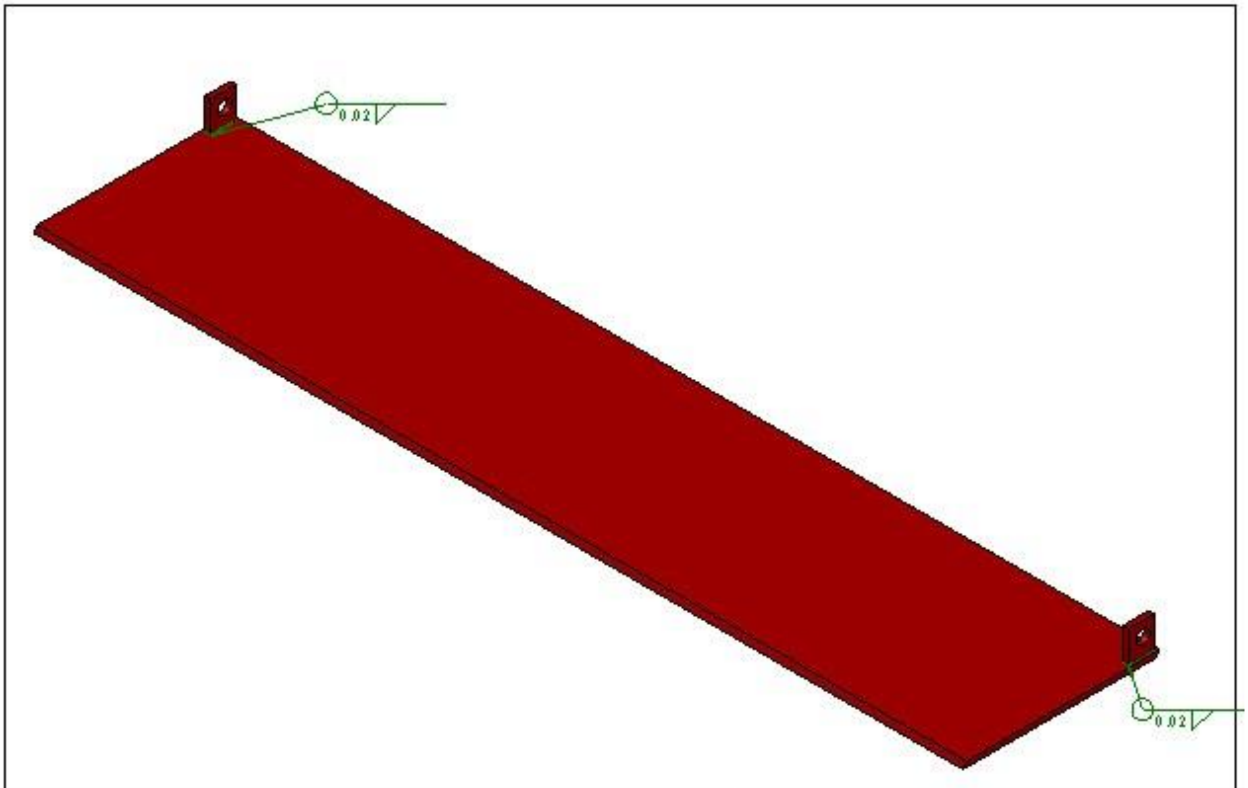



0.02
0.02
Mechanical Engineering CAL POLY
DRAWN BY: Edgar Corona
INIT:
UNITS: inches
MATERIAL: 6063 Aluminum
SCALE: 1:3
TITLE: Top Bridge (Welds)
DWG #: 9
DATE: 03/09/13
GROUP: Team V.A.N.

Appendix B.8

Bottom Bridge

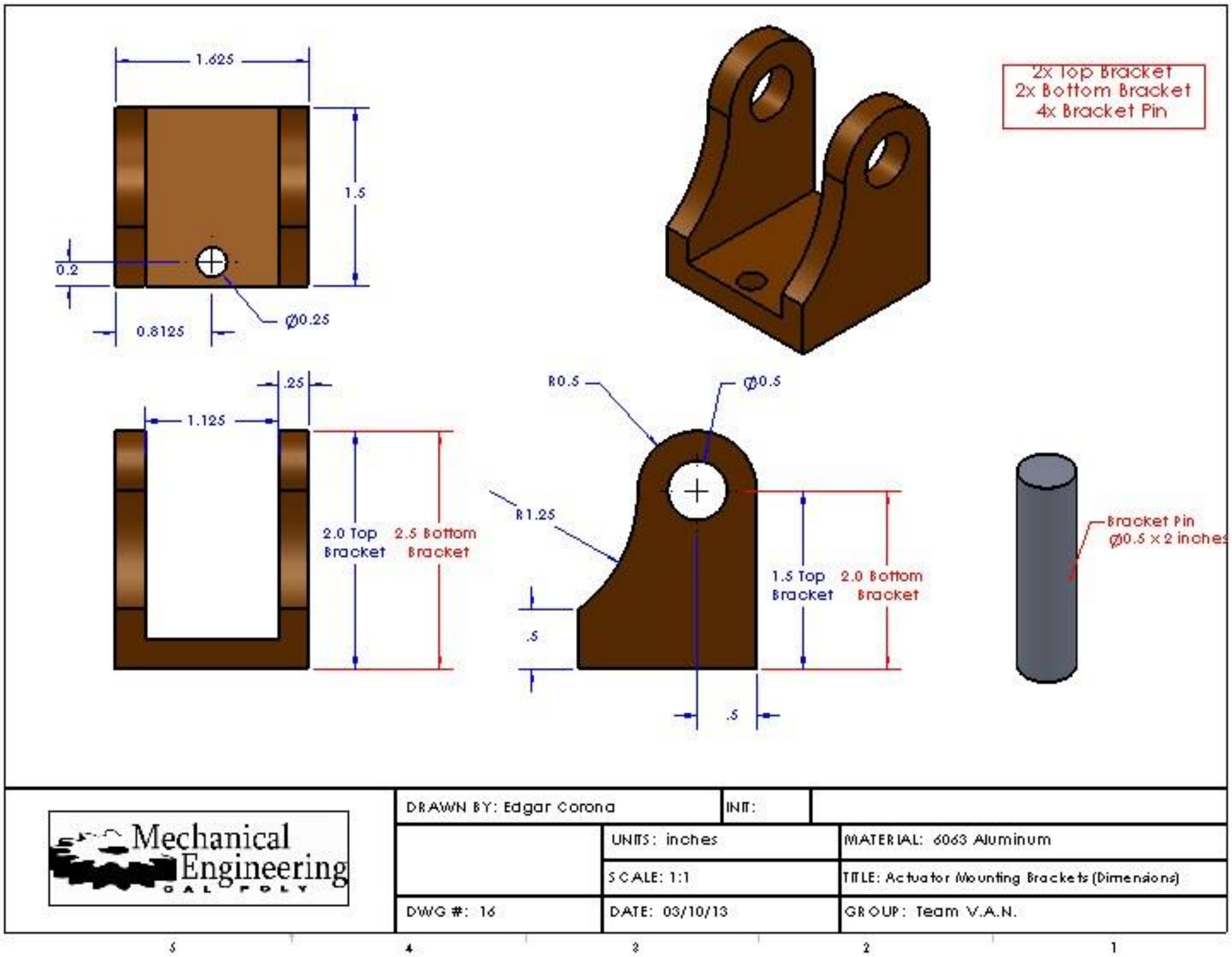




Mechanical Engineering CAL POLY	DRAWN BY: Edgar Corona	INIT:	
		UNITS: inches	MATERIAL: 6063 Aluminum
		SCALE:13	TITLE: Bottom Bridge (Welds)
	DWG #: 7	DATE: 03/09/13	GROUP: Team V.A.N.

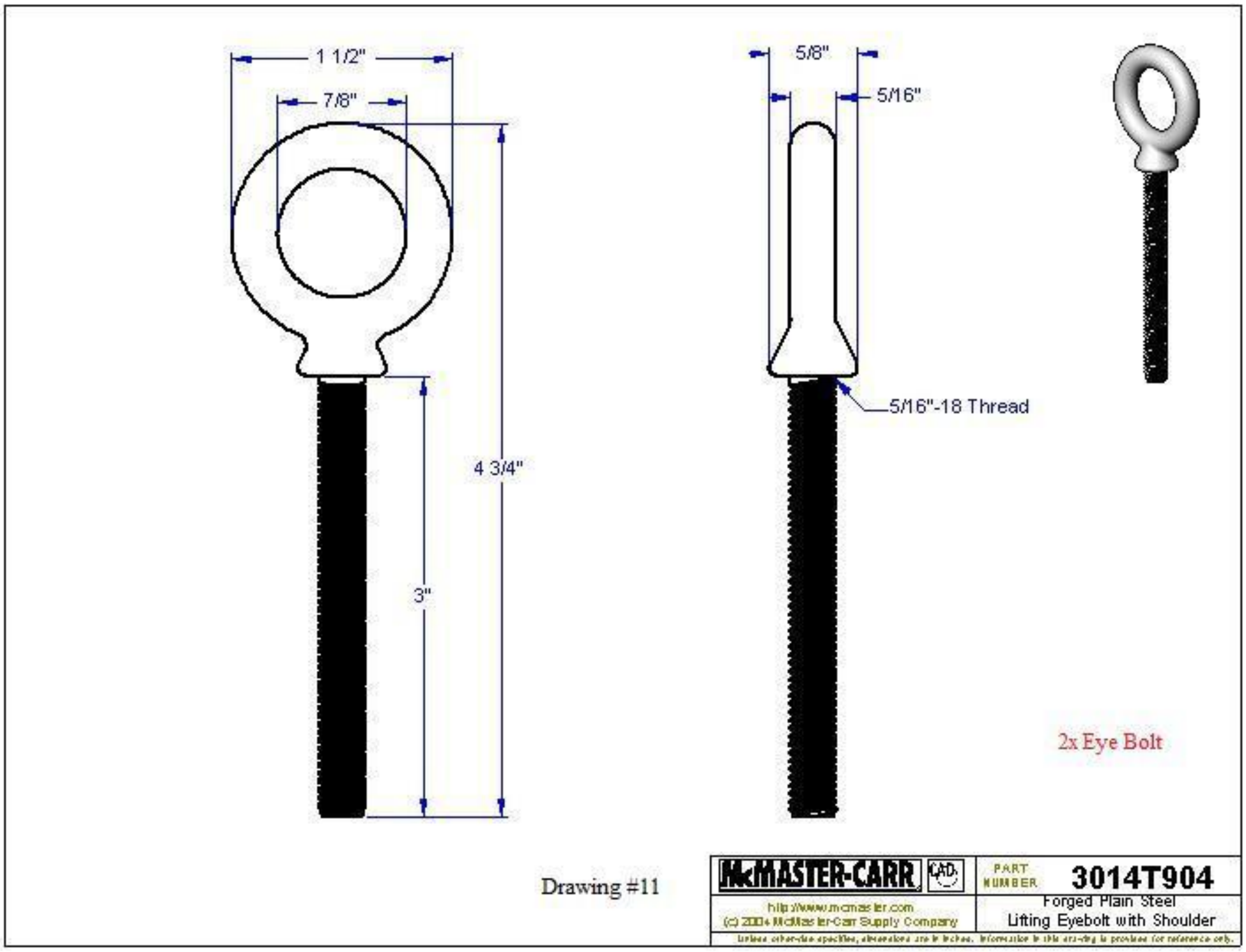
Appendix B.9

Linear Actuator


1.625
1.5
0.2
0.8125
Ø0.25
2x Top Bracket
2x Bottom Bracket
4x Bracket Pin
.25
1.125
2.0 Top Bracket
2.5 Bottom Bracket
R0.5
Ø0.5
R1.25
1.5 Top Bracket
2.0 Bottom Bracket
.5
.5
Bracket Pin
Ø0.5 x 2 inches
Mechanical Engineering
CAL POLY
DRAWN BY: Edgar Corona
INIT:
UNITS: inches
MATERIAL: 6063 Aluminum
SCALE: 1:1
TITLE: Actuator Mounting Brackets (Dimensions)
DWG #: 16
DATE: 03/10/13
GROUP: Team V.A.N.

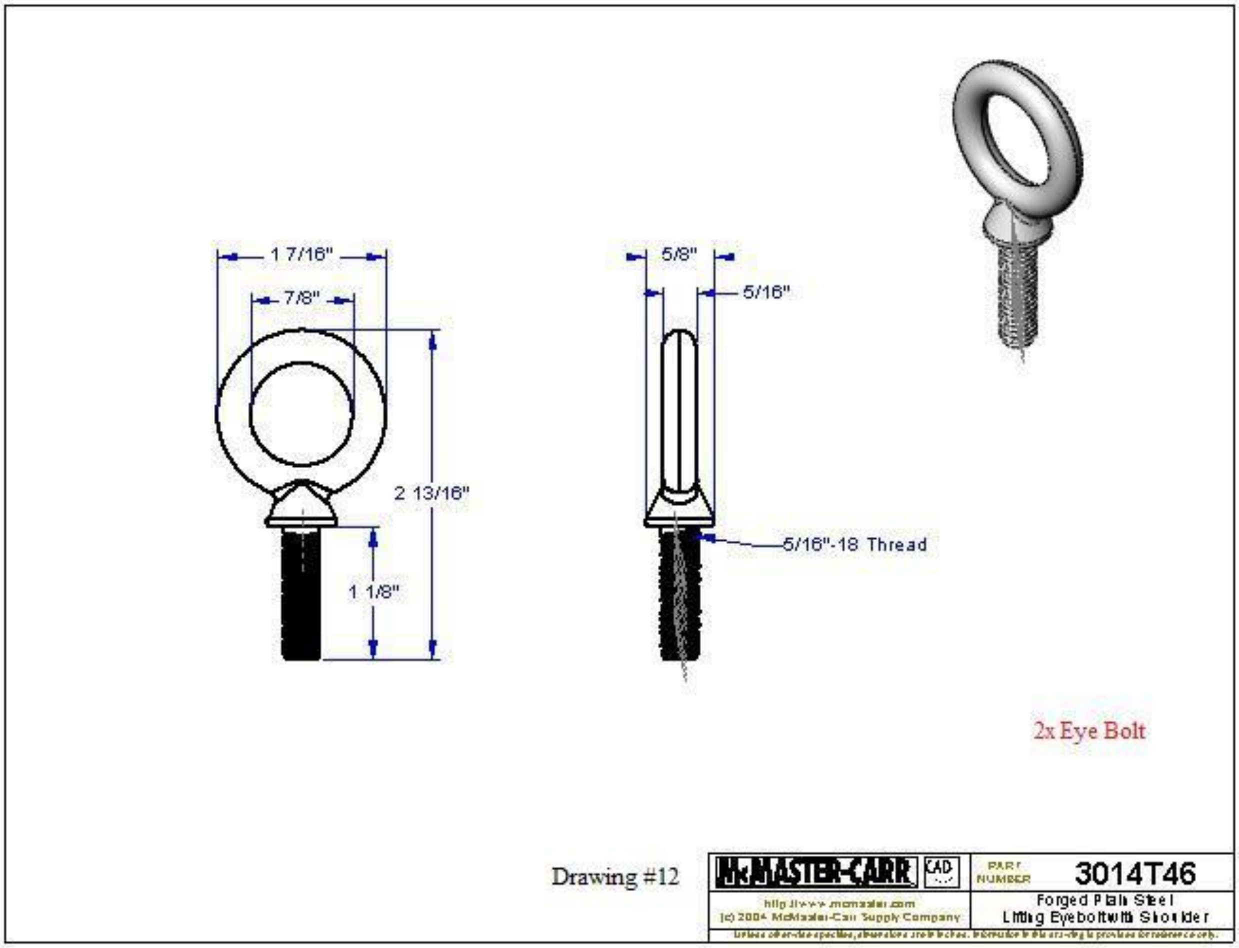
Appendix B.10

Eye Bolts for Platform



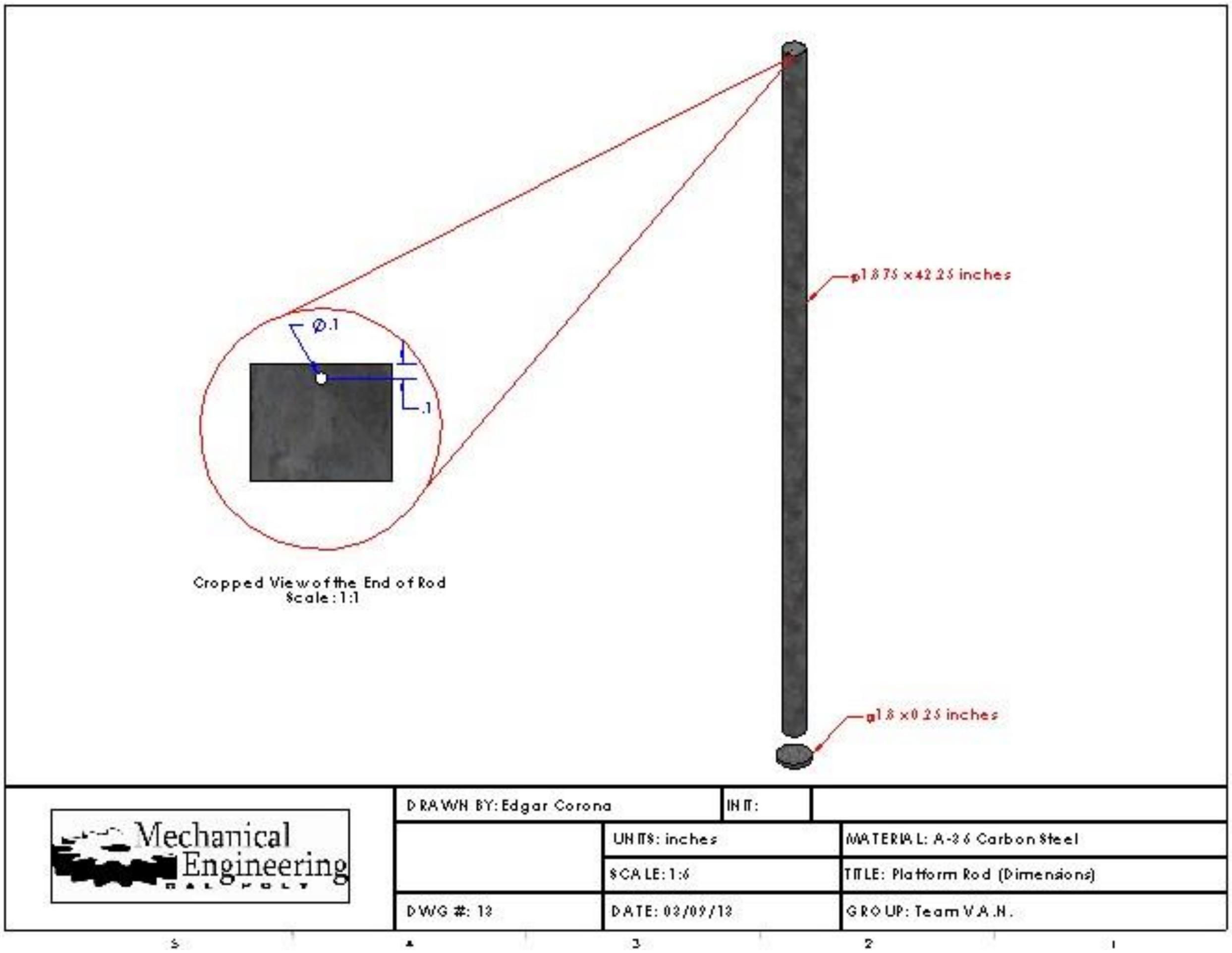
Appendix B.11

Eye Bolts for Inner Support



Appendix B.12

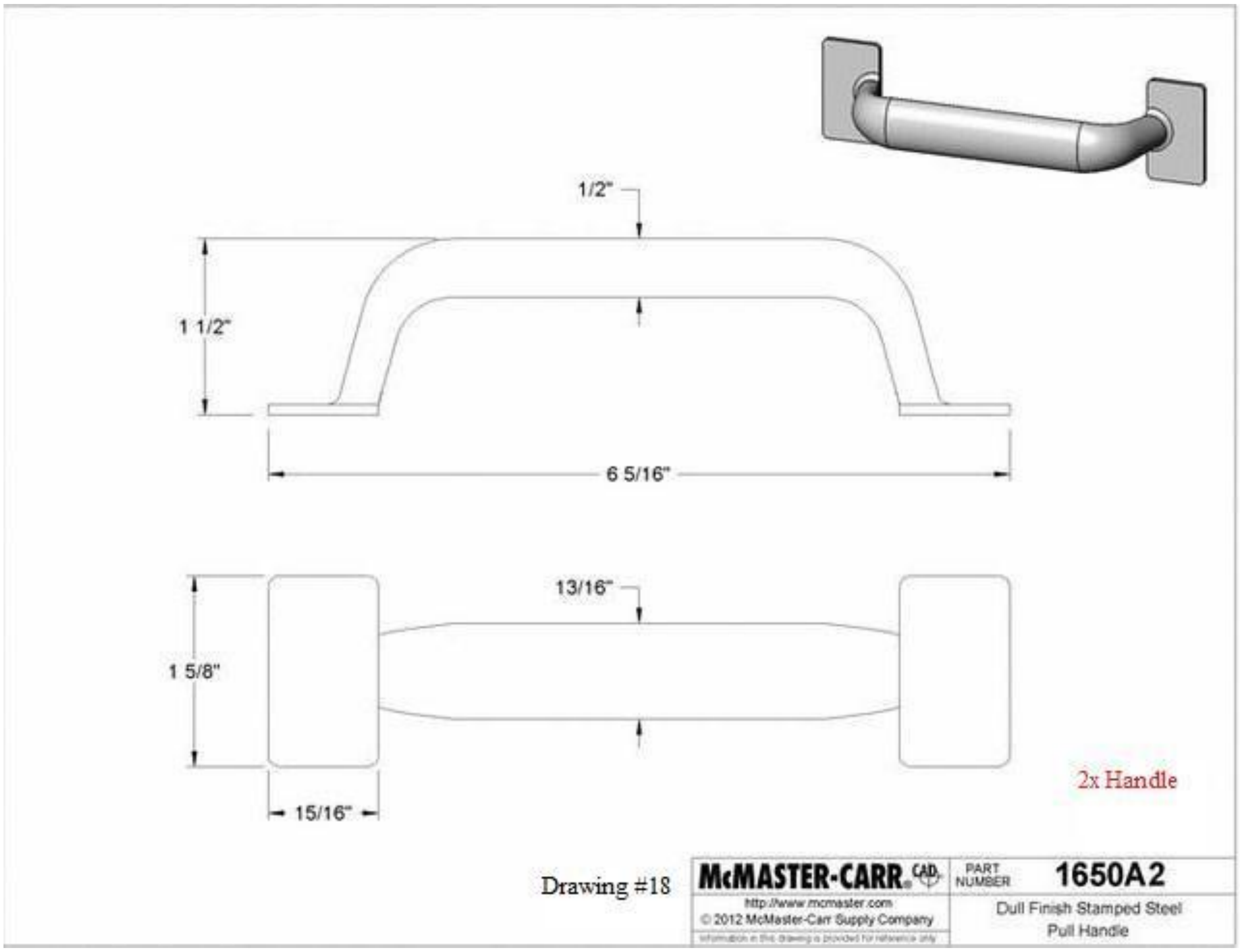
Rod through Inner Supports



Mechanical Engineering CAL POLY	DRAWN BY: Edgar Corona		INIT:	
		UNITS: inches		MATERIAL: A-36 Carbon Steel
		SCALE: 1:6		TITLE: Platform Rod (Welds)
	DWG #: 14	DATE: 03/09/13		GROUP: Team V.A.N.

Appendix B.12

Handles for Outer Supports



Appendix C

Vendors and Pricing

Appendix C.1

Estimated Total Cost

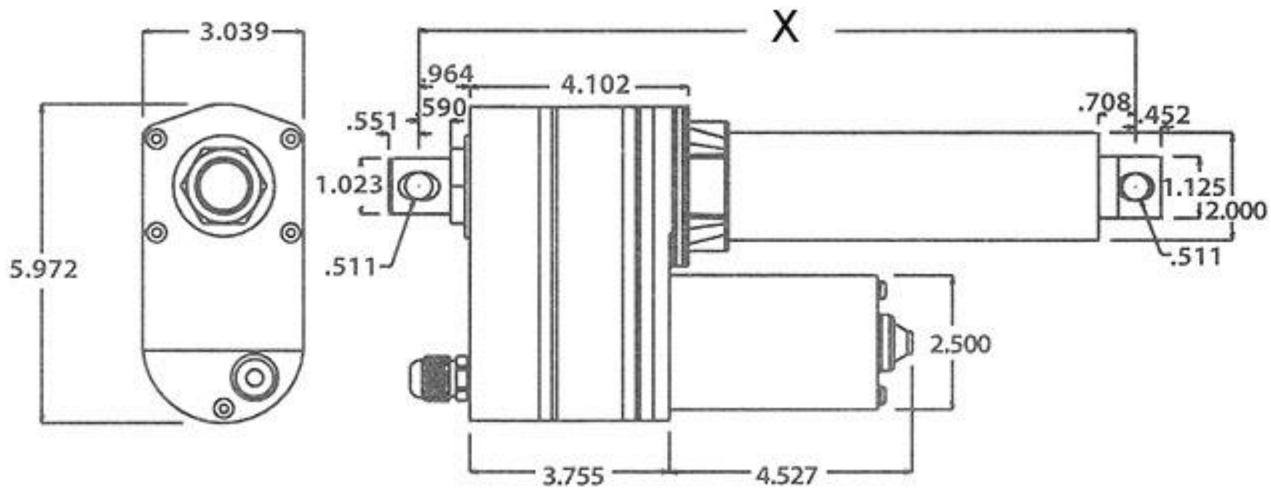
Supplier	*Model*	*Price*	*Quantity*	*Total Cost*
Servocity	560 lbs. Linear Thrust Actuator	$400.00	2	$800.00
	Super-Duty Mounting Bracket	$25.00	4	$100.00
Discount Steel	ASTM B221-08 6063-T52 Aluminum Square Tube	$57	2	$114.32
	ASTM B209-10 6061-T6 Aluminum Sheet	$120	1	$120.00
	ASTM A108 1045 Cold Rolled Round Bar	$50	1	$50.00
	ASTM A36 Hot Rolled Steel Square Bar	$54	2	$108.00
	Mechanical/Structural A36 Steel Square Tube	$25	2	$50.00
	Mechanical/Structural A36 Steel Square Tube	$35	2	$70.00
	Mechanical/Structural A36 Steel Square Tube	$25	2	$50.00
	ASTM A36 Hot Rolled Steel Square Bar	$40	2	$80.00
	Mechanical/Structural A36 Steel Square Tube	$15	2	$30.00
McMaster-Carr	Skate Wheel Steel	$4.42	2	$8.84
	Heavy Duty Skate Steel Wheel	$6.40	8	$51.20
	Unfinished Aluminum Surface-Mount Hinges	$7.00	4	$28.00
	Steel Eyebolt	$12.23	2	$24.46
	Steel Eyebolt	$3.08	2	$6.16
	Commercial Grade Rope 7 x 19 Strand Core Plastic Coated	$10.00	1	$10.00
	Tin-Plated Copper Sleeves for Stainless Steel Wire Rope	$12.30	1	$12.30
	Supermax (Grade 100) Sling Hook with Latch	$30.54	1	$30.54
Plastics International	UHMW Sheet	$15.00	1	$15.00
Tap Plastics	High-Impact Strength PVC Sheet	$20.00	1	$20.00
Amazon	AGT (5 Pack) 30/40 AMP Relay Harness SPDT 12V Bosch Style	$4.99	1	$4.99
Ebay	50’ 8 Gauge 25' BLACK 25' RED Power Ground Wire	$20.00	1	$20.00
	Carling DP DT Momentary Toggle Switch	$6.99	1	$6.99
			Total:	**$1,810.80**

Appendix D

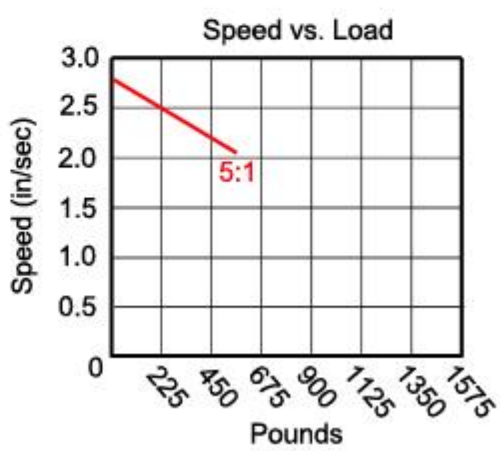
Vendor Supplied Component Specifications

Appendix D.1

ServoCity 560 lb. Linear Actuator Specifications



Drawing



Speed vs. Load Graph

Appendix E

Analysis

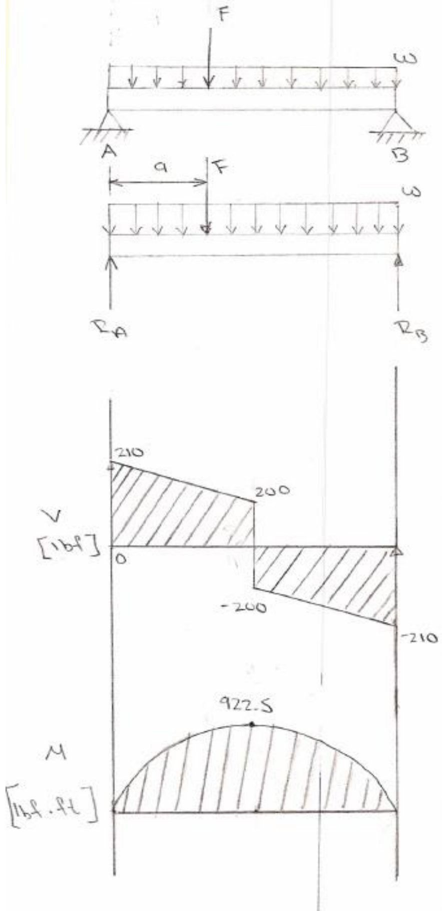
Appendix E.1

Initial Ramp Design Calculations

ANALYSIS ON RAMP

- ASSUME WEIGHT OF PLATE IS 20 lb AND F= 400 lb
- L = 9 FT
- ALUMINUM

$$\omega = \frac{20\ lbf}{9\ FT} = 2.22\ lbf/FT$$



WIDTH $b = 36\ in$ $h = 1/8\ in$

$$\circlearrowleft + \Sigma M_A = 0 \Rightarrow R_B L - Fa - \omega L(L/2) = 0$$

$$R_B = \frac{Fa + \omega(L^2/2)}{L}$$

$$\Sigma F_y = 0 \Rightarrow R_A - F - \omega L + R_B = 0$$

$$R_A = F + \omega L - R_B$$

- ASSUMING CONCENTRATED LOAD P ACTS AT THE CENTER OF THE BEAM (a = 4.5 FT)

$$\Rightarrow R_B = \frac{400\ lb\ (4.5\ FT) + 20\ lb\ \left(\frac{9\ FT}{2}\right)}{9\ FT} = 210\ lb$$

$$\Rightarrow R_A = 210\ lb$$

- MAXIMUM BENDING MOMENT OCCURS UNDER THE CONCENTRATED LOAD

$$M_{MAX} = 922.5\ lbf \cdot ft$$

- SECTION MODULUS S

$$S = \frac{bh^2}{6} = \frac{1}{6}(36\ in)(1/8\ in)^2 = 0.09375\ in^3$$

MAXIMUM STRESS σ_t

$$\sigma_t = \frac{M_{MAX}}{S} = \frac{(922.5\ lbf \cdot FT)\left(\frac{12\ in}{1\ FT}\right)}{0.09375\ in^3} = 118080\ lbf/in^2 = 118.1\ kpsi$$

- SOLVE FOR h BASED ON ALLOWABLE STRESS

$$S = \frac{M_{MAX}}{\sigma_{ALLOW}} \qquad \sigma_{ALLOW} = 21{,}000\ psi \text{ FOR ALUMINUM}$$

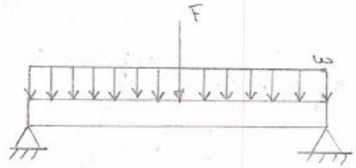
$$S = \frac{922.5\ lbf \cdot ft \left(\frac{12\ in}{1\ FT}\right)}{21000\ lbf/in^2} = 0.527\ in^3 \Rightarrow \frac{bh^2}{6} = 0.527\ in^2$$

$$\Rightarrow h^2 = \frac{6\ (0.527\ in^3)}{36\ in} = 0.0879\ in^2 \Rightarrow h = 0.30\ in$$

MAXIMUM DEFLECTION ON RAMP

- ASSUME WEIGHT OF PLATE IS 20 lbf AND F = 400 lb
- L = 9 FT

$$w = \frac{20\ \text{lbf}}{9\ \text{FT}} = 2.22\ \text{lbf/ft}$$

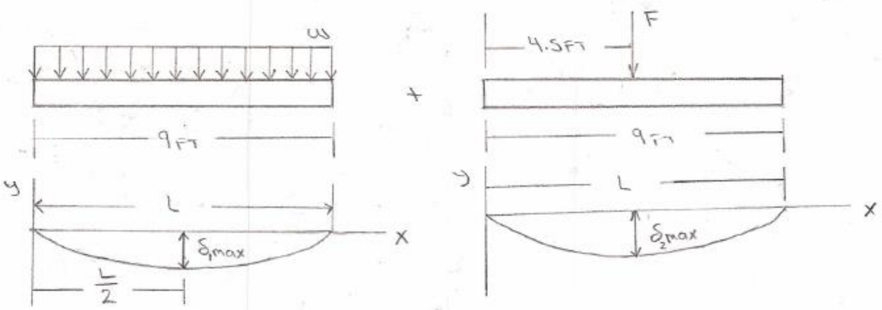


- CROSS-SECTION

b = 36 in

h = 0.30 in

- USING SUPERPOSITION



$$\delta_{1MAX} = -\frac{5wL^4}{384EI}$$

- FOR ALUMINUM

$E = 10 \times 10^6$ psi

$$I = \frac{1}{12} bh^3 = \frac{1}{12}(36\text{in})(0.30\text{in})^3$$

$$I = 0.081\ \text{in}^4$$

$$\delta_{1MAX} = -\frac{5\left(\frac{20\ \text{lbf}}{108\ \text{in}}\right)(108\ \text{in})^4}{384\,(10\times10^6\ \text{lbf/in}^2)\,(0.081\ \text{in}^4)}$$

$$\delta_{1MAX} = -0.405\ \text{in}$$

$$\delta_{2MAX} = -\frac{PL^3}{48EI}$$

$$\delta_{2MAX} = -\frac{(400\ \text{lbf})(108\ \text{in})^3}{48\,(10\times10^6\ \text{lbf/in}^2)(0.081\ \text{in}^4)}$$

$$\delta_{2MAX} = -12.96\ \text{in}$$

$$|\delta_{TOTAL}| = 0.405\ \text{in} + 12.96\ \text{in}$$

$$|\delta_{TOTAL}| = 13.365\ \text{in}$$

$$|\delta_{TOTAL}| = 13.4\ \text{in}$$

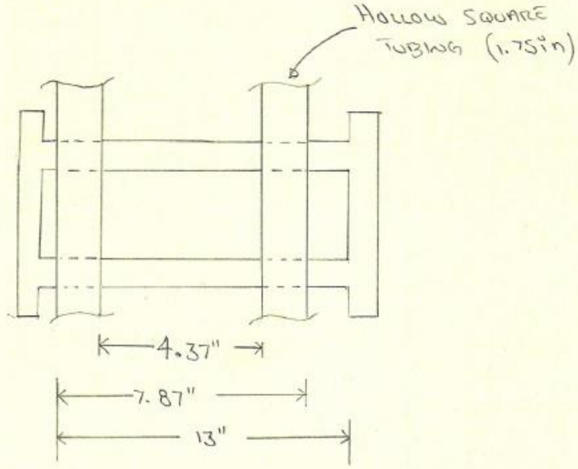
- DEFLECTION IS TO LARGE

Appendix E.2

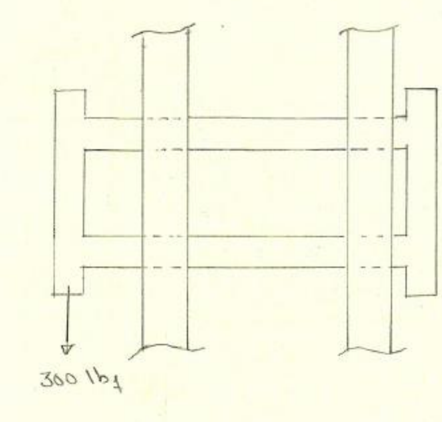
Sliding (Ejecting) Mechanism Calculations

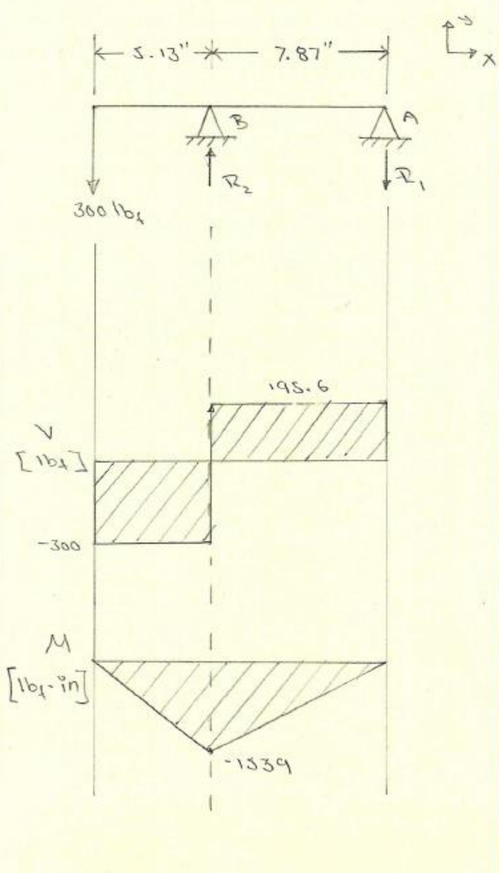
LIFT MECHANISM ANALYSIS

SUPPORT FOR LIFT:



DEFLECTION:





ΣM_A:

$$R_1 = \frac{(300\ lb)(5.13")}{7.87"} = 195.6\ lb_f$$

ΣF_y:

$$R_2 = (300 + 195.6)\ lb = 495.6\ lb_f$$

DEFLECTION (CONT')

$$y_c = \frac{Fa^2}{3EI}(l + a)$$

$l = 15$ in
$a = 5.13$ in

• ASSUME 1" SQUARE BAR STOCK (STEEL)

$$I = \frac{1}{12} bh^3$$

$$y_c = \frac{(300\text{ lb})(5.13\text{ in})^2}{3\left(30\times10^6 \frac{\text{lb}}{\text{in}^2}\right)\left(\frac{1}{12}\right)(1\text{ in}^4)}(13\text{ in})$$

$$y_c = \boxed{0.0137\text{ in}}$$

- NOW ASSUME 400 lb (ACCOUNT FOR EXTRA WEIGHT)

$$y = \frac{(400\text{ lb})(5.13\text{ in})^2}{3\left(30\times10^6 \frac{\text{lb}}{\text{in}^2}\right)\left(\frac{1}{12}\right)(1\text{ in}^4)}(13\text{ in}) = \boxed{0.0182\text{ in}}$$

STRESS ANALYSIS:

FOR $F = 300\ \text{lb}_f$

$$\sigma = \frac{Mc}{I}$$

$$\sigma = \frac{(1539\text{ lb}\cdot\text{in})(0.5\text{ in})}{\frac{1}{12}(1\text{ in}^4)}$$

$$\sigma = \boxed{9234\text{ psi}}$$

SAFETY FACTOR:

$$n = \frac{S_y}{\sigma}$$

$$n = \frac{36\text{ ksi}}{9.23\text{ ksi}}$$

$$n = 3.9$$

FOR $F = 400\ \text{lb}_f$

$$\sigma = \frac{Mc}{I}$$

$$\sigma = \frac{(2052\text{ lb}\cdot\text{in})(0.5\text{ in})}{\frac{1}{12}(1\text{ in}^4)}$$

$$\sigma = \boxed{12312\text{ psi}}$$

SAFETY FACTOR:

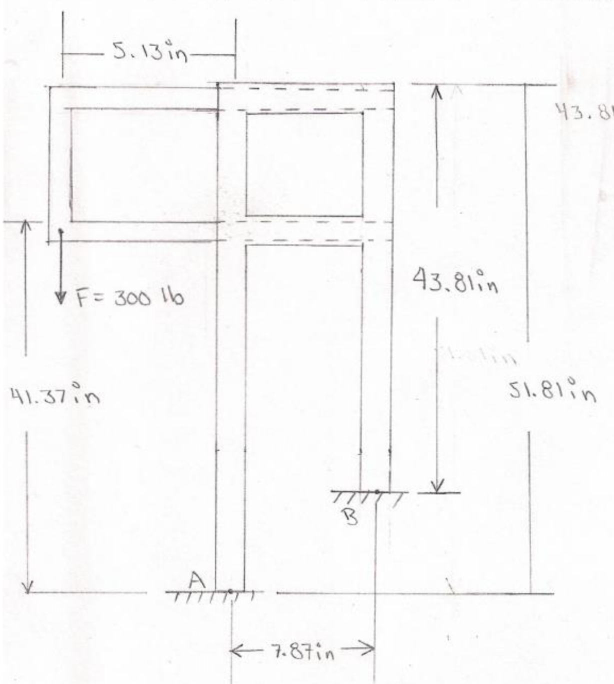
$$n = \frac{S_y}{\sigma} = \frac{36\text{ ksi}}{12.3\text{ ksi}}$$

$$n = 2.92$$

Appendix E.3

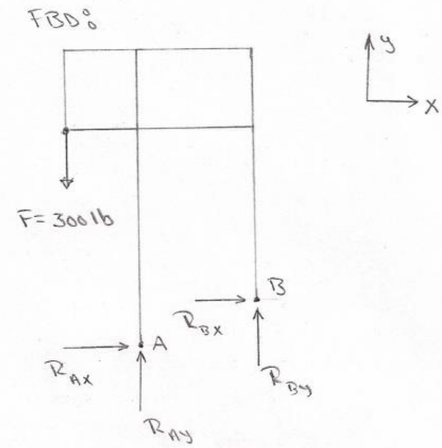
Tower (Frame) Support Calculations

LIFT MECHANISM ANALYSIS : SUPPORT FOR LIFT



FIND : REACTION FORCES AT POINT A & B

FBD:



POINT A :

$\circlearrowleft + \sum M_A = 0 \Rightarrow 300\,lb\,(5.13\,in) + (7.87\,in)R_{By} + 8\,in\,(R_{Bx}) = 0$

POINT B :

$\circlearrowleft + \sum M_B = 0 \Rightarrow 300\,lb\,(13\,in) - (7.87\,in)R_{Ay} + 8\,in\,(R_{Ax}) = 0$

$\sum F_x = 0 \Rightarrow R_{Ax} + R_{Bx} = 0 \Rightarrow R_{Ax} = -R_{Bx}$

$\sum F_y = 0 \Rightarrow R_{Ay} + R_{By} - 300\,lb = 0 \Rightarrow R_{Ay} = 300 - R_{By}$

$1539\,lb \cdot in + 7.87\,R_{By}\,lb\,in + 8\,R_{Bx}\,lb \cdot in = 0$

$3900\,lb \cdot in - 7.87\,R_{Ay} + 8(-R_{Bx})\,lb \cdot in = 0$

$\Big\}\; 5439 + 7.87\,R_{By} - 7.87\,R_{Ay} = 0$

$\Rightarrow 5439 + 7.87\,R_{By} - 7.87(300 - R_{By}) = 0$

$5439 + 7.87\,R_{By} - 2361 + 7.87\,R_{By} = 0$

$15.74\,R_{By} + 3078 = 0$

$*\; R_{By} = -195.6\,lb$

$R_{Ay} = 300 - (-195.6\,lb)$

$*\; R_{Ay} = 495.6\,lb$

$1539 + 7.87(-195.6) + 8R_{Bx} = 0$

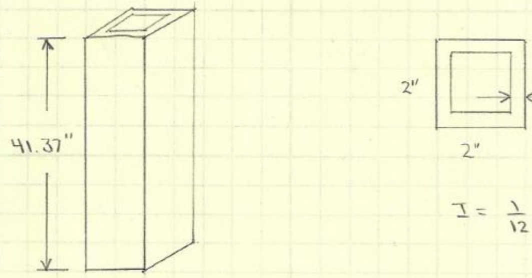
$1539 - 1539 + 8R_{Bx} = 0$

$*\; R_{Bx} = 0$

$*\; R_{Ax} = 0$

BUCKLING ANALYSIS ON SUPPORT OF LIFT
(TOWER SUPPORT STRUCTURAL MEMBER)

CROSS-SECTIONAL AREA OF STRUCTURAL MEMBER

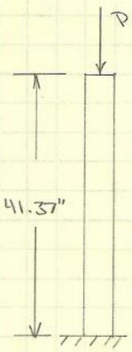


MATERIAL: STEEL

$E = 30.0 \times 10^6$ psi
OR 69 GPa

$$I = \frac{1}{12}\left(bh^3 - b_i h_i^3\right)$$

• CALCULATE THE MAXIMUM FORCE TO BE APPLIED ON THE MEMBER WITHOUT CAUSING BUCKLING



$$P_{cr} = \frac{c\pi^2 EI}{\ell^2}$$ WHERE $c = 1/4$ (ONE END FREE & ONE END FIXED)

$$I = \frac{1}{12}\left((2)(2)^3 - (1.75)(1.75)^3\right) = 0.5518 \text{ in}^4$$

$$P_{cr} = \frac{(0.25)\pi^2 (30 \times 10^6 \text{ lb/in}^2)(0.5518 \text{ in}^4)}{(41.37 \text{ in})^2} = \boxed{23860 \text{ lb}_f}$$

$= 23.8$ kips

• IF $t = 3/16$ in

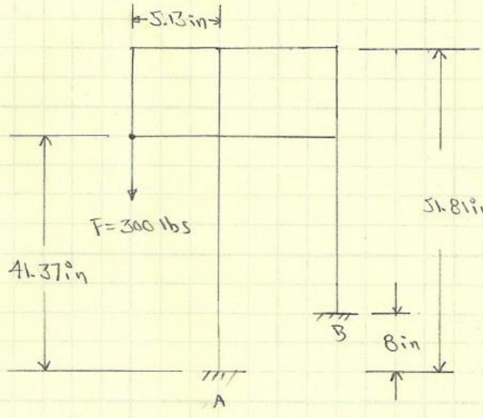
$$I = \frac{1}{12}\left((2)(2)^3 - (1.625)(1.625)^3\right) = 0.752 \text{ in}^4$$

$$P_{cr} = \frac{(0.25)\pi^2 (30 \times 10^6 \text{ lb/in}^2)(0.752 \text{ in}^4)}{(41.37 \text{ in})^2} = \boxed{32530 \text{ lb}_f} = 32.5 \text{ kips}$$

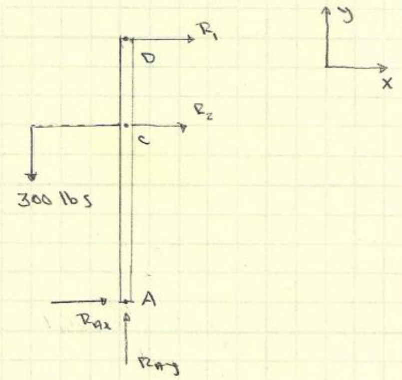
• ACCORDING TO RESULTS, BUCKLING SHOULD NOT BE A PROBLEM IF THE APPLIED FORCE DOES NOT EXCEED

23.8 kips FOR 2" × 2" × 1/8"
AND
32.5 kips FOR 2" × 2" × 3/16"

BENDING STRESS ANALYSIS: TOWER SUPPOR



FBD: STRUCTURAL MEMBER A



FROM PREVIOUS CALCULATIONS: $R_{Ax} = 0$ lbs $\quad R_{Ay} = 496$ lbs

• SOLVE FOR R_1 & R_2

$(+)\ \Sigma M_A = 0 \qquad -R_2(41.37in) - R_1(51.81in) + 300lbs(5.13in) = 0$

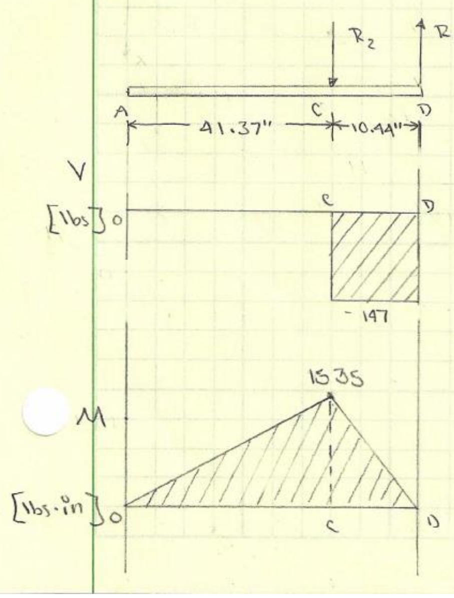
$\Rightarrow \quad 41.37R_2 + 51.81R_1 = 1539$

$\Sigma F_x = 0 \qquad R_1 + R_2 + R_{Ax} = 0$ ($R_{Ax} \to 0$)

$R_1 = -R_2$

$\Rightarrow \quad 41.37R_2 + 51.81(-R_2) = 1539$

$-10.44R_2 = 1539 \qquad \Rightarrow R_2 = -147.4$ lbs $\quad$ & $\quad R_1 = 147.4$ lbs



* MAXIMUM BENDING AT POINT C

$\sigma = \dfrac{M_c}{I}$ $\qquad$ 2" x 2" $\quad$ t = 0.091in

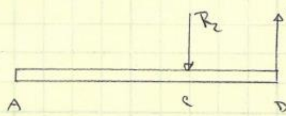
$\sigma = \dfrac{(1535\ lbs \cdot in)(1in)}{\frac{1}{12}(2^4 - 1.818^4)in^4}$

$\sigma = \underline{3630\ psi}$

STRESS-LIFE ANALYSIS ON TOWER SUPPORT

- FROM PREVIOUS CALCULATIONS THE MAXIMUM BENDING STRESS OCCURS AT POINT C OF TOWER SUPPORT MEMBER A:

MEMBER A:



$\sigma_m = 3630$ psi

$\therefore \sigma_{max} = 3630$ psi ; $\sigma_{min} = 0$

- USING STRESS-LIFE METHOD

1. DETERMINE S_e' (MATERIAL: A36 CARBON STEEL $S_{ut} = 58000 - 79800$ psi)

Use $S_{ut} = 58.0$ kpsi

$\Rightarrow S_e' = 0.5\,(58.0 \text{ kpsi}) = 29$ kpsi

2. MODIFY S_e' TO DETERMINE S_e

$S_e = k_a k_b k_c k_d k_e k_f S_e'$

- $k_a = a S_{ut}^b$ (HOT ROLLED $\Rightarrow a = 14.4$ and $b = -0.718$)

$k_a = 14.4\,(58.0 \text{ kpsi})^{-0.718} = \underline{0.780}$

- SIZE FACTOR k_b

Find effective diameter for nonrotating hollow square member

$d_e = 0.808\,(hb)^{1/2} = 0.808\,(2 \cdot 2)^{1/2} = 1.616$ in $\quad 0.11 \le d_e \le 2$ in

$\Rightarrow k_b = 0.879\,(d_e)^{-0.107} = 0.879\,(1.62)^{-0.107} = \underline{0.835}$

- LOADING FACTOR k_c

$\underline{k_c = 1}$ (FOR BENDING)

- TEMPERATURE FACTOR k_d

$k_d = 1$ (AT ROOM TEMP.)

- RELIABILITY FACTOR k_e

$k_e = 0.814$ (FOR 99% RELIABILITY)

- MISCELLANEOUS-EFFECTS FACTOR k_f (USE $k_f = 1$)

$\Rightarrow S_e = (0.780)(0.835)(1)(1)(0.814)(1)(29 \text{ kpsi}) = 15.38$ kpsi

STRESS-LIFE ANALYSIS
(TOWER SUPPOR)

FLUCTUATING SIMPLE LOADING

3. CALCULATE σ_m and σ_a

$$\sigma_m = \frac{\sigma_{max} + \sigma_{min}}{2} = \frac{3630 + 0}{2} = 1815 \text{ psi} = 1.815 \text{ kpsi}$$

$$\sigma_a = \frac{|\sigma_{max} - \sigma_{min}|}{2} = \frac{3630}{2} = 1815 \text{ psi} = 1.815 \text{ kpsi}$$

USING MODIFIED GOODMAN CRITERION

$$\frac{\sigma_a}{S_e} + \frac{\sigma_m}{S_{ut}} = \frac{1}{n}$$

SOLVE FOR n

$$n = \frac{1}{\frac{\sigma_a}{S_e} + \frac{\sigma_m}{S_{ut}}} = \frac{1}{\frac{1.815}{15.38} + \frac{1.815}{58.0}} = 6.7 \sim 7$$

∘ FATIGUE FACTOR OF SAFETY BASED ON INFINITE LIFE

4. CHECK FOR LOCAL YIELDING

FOR A36 CARBON STEEL $S_y = 36,300$ psi

$$\sigma_a + \sigma_m = \frac{S_y}{n} \Rightarrow n = \frac{S_y}{\sigma_a + \sigma_m}$$

$$n = \frac{36.3 \text{ kpsi}}{3.63 \text{ kpsi}} = 10$$

∘ YIELD FACTOR OF SAFETY

5. FOR FINITE-LIFE FATIGUE STRENGTH, EQUIVALENT COMPLETELY REVERSED STRESS

MOD-GOODMAN

$$\sigma_{rev} = \frac{\sigma_a}{1 - \frac{\sigma_m}{S_{ut}}}$$

$$\sigma_{rev} = \frac{1.815}{1 - \frac{1.815}{58.0}} = 1.87 \text{ kpsi}$$

$$N = \left(\frac{\sigma_{rev}/n}{a}\right)^{1/b}$$

$$a = \frac{(f S_{ut})^2}{S_e} = \frac{[0.9\,(58.0)]^2}{15.38} = 177.2$$

$$b = -\frac{1}{3}\log\left(\frac{f S_{ut}}{S_e}\right) = -\frac{1}{3}\log\left[\frac{0.9\,(58.0)}{15.38}\right] = -0.177$$

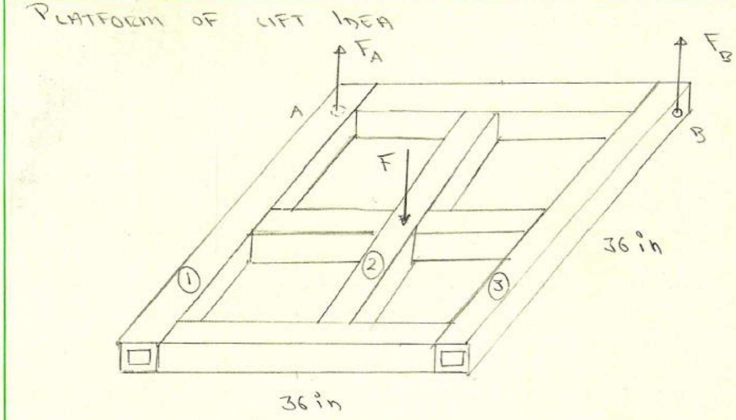
ASSUME SAFETY OF FACTOR $n = 2$

$$N = \left(\frac{1.87/2}{177}\right)^{-1/0.177} = 7 \times 10^{12} \text{ CYCLES}$$

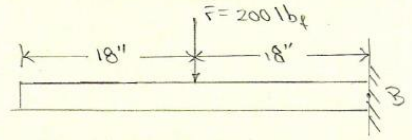
Appendix E.4

Platform Support Calculations

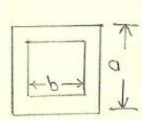
PLATFORM OF LIFT IDEA

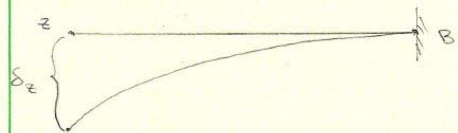


- ASSUME SUPPORT MECHANISMS AT A & B THAT HANDLE LOAD AT CENTER OF $F = 600\ lb_f$
- ASSUME THE 3 BEAMS NUMBERED EACH HAVE $200\ lb_f$ DISTRIBUTED TO THEM AT CENTER



CROSS-SECTIONAL AREA





$\sigma \le \frac{M_c}{I}$ and $n = \frac{S_y}{\sigma}$

ASSUME $n = 2$

$\Rightarrow 2 = \frac{S_y}{\sigma} \Rightarrow \sigma = \frac{S_y}{2} = \frac{25\ kpsi}{2} = 12.5\ kpsi$

- NEED TO FIND STRUCTURAL SQUARE TUBING WITH $\frac{I}{c}$ RATIO OF $0.216\ in^3$

SOLVE FOR $\frac{I}{c}$ RATIO

$12500 \frac{lb}{in^2} \le \frac{(200\ lbf)(18 in) \cdot c}{I} \Rightarrow \frac{I}{c} \le 0.288\ in$

$\frac{I}{c} = \frac{\frac{1}{12}\left[a^4 - b^4\right]}{\frac{a}{2}} = 0.288\ in^3 \Rightarrow \frac{1}{6a}\left(a^4 - b^4\right) \le 0.288\ in^3$

USING STANDARD CHART, ITERATE TO FIND SMALLEST TUBING THAT MEET REQUIREMENT

* 1" X 1" X 18 ga SQUARE STEEL TUBING MEETS REQUIREMENT

PLATFORM SUPPORT (CONT'.)

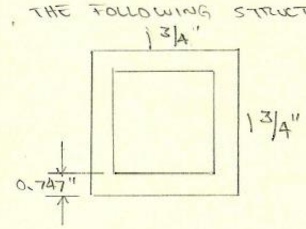
USING VALUES JUST FOUND, SOLVE FOR DEFLECTION AND SLOPE AT POINT (2)

$$\delta_2 = \frac{Pa^2}{6EI}(3L-a)$$

- FIND SMALLEST VALUE OF a and b THAT RESULT IN DEFLECTION OF AROUND 0.1 in

  - PREVIOUS SELECTION RESULTS IN TOO HIGH OF DEFLECTION
  - USING ITERATION PROCESS (EXCEL), THE FOLLOWING STRUCTURAL MEMBER WAS CHOOSEN

$1\,3/4" \times 1\,3/4" \times 14$ ga



BASED ON DIMENSION OF SUPPORT FOR SHEET METAL

TOTAL LENGTH NEEDED = 200.25" ⇒ $34.84

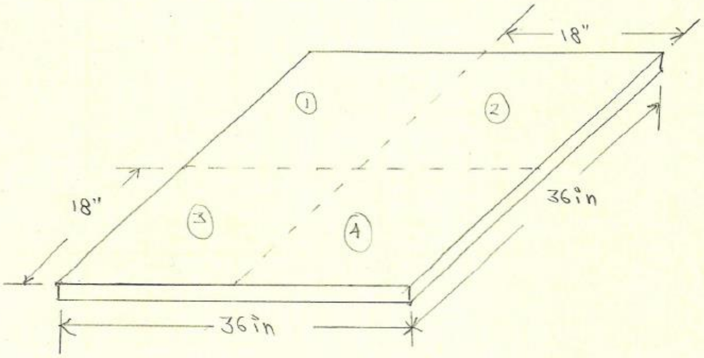
DEFLECTION BASED ON CHOOSEN STRUCTURAL TUBING

$\delta_2 = 0.138"$

$\frac{I}{c} = 0.268\ in^3$

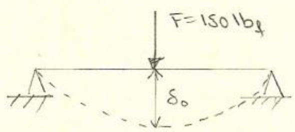
} MEETS BOTH DESIGN REQUIREMENTS OUTLINED

STEEL PLATE ON TOP OF STRUCTURE



- ASSUME THAT THE 600 lb LOAD IS DISTRIBUTED EVENLY TO EACH OF THE 4 SECTIONS NUMBERED OFF.

- FIND THICKNESS OF STEEL REQUIRED FOR MINIMUM DEFLECTION (≈ 0.005 in)



$$I = \frac{1}{12} b h^3 = \frac{1}{12} (18\text{in})(h^3)$$

$$\delta_o = \frac{PL^3}{48EI} \Rightarrow 0.005\text{ in} = \frac{(150\text{ lb})(18\text{ in})^3}{48\left(30\times10^6 \frac{\text{lb}}{\text{in}^2}\right)\left(\frac{1}{12}\right)(18\text{ in})(h^3)}$$

$\Rightarrow h = 0.433$ in

- TOO LARGE, LOWER DEFLECTION TO 0.05 in

$$\Rightarrow 0.05\text{ in} = \frac{(150\text{ lb})(18\text{ in})^3}{48\left(30\times10^6 \frac{\text{lb}}{\text{in}^2}\right)\left(\frac{1}{12}\right)(18\text{in})(h^3)} \Rightarrow h = 0.2\text{ in}$$

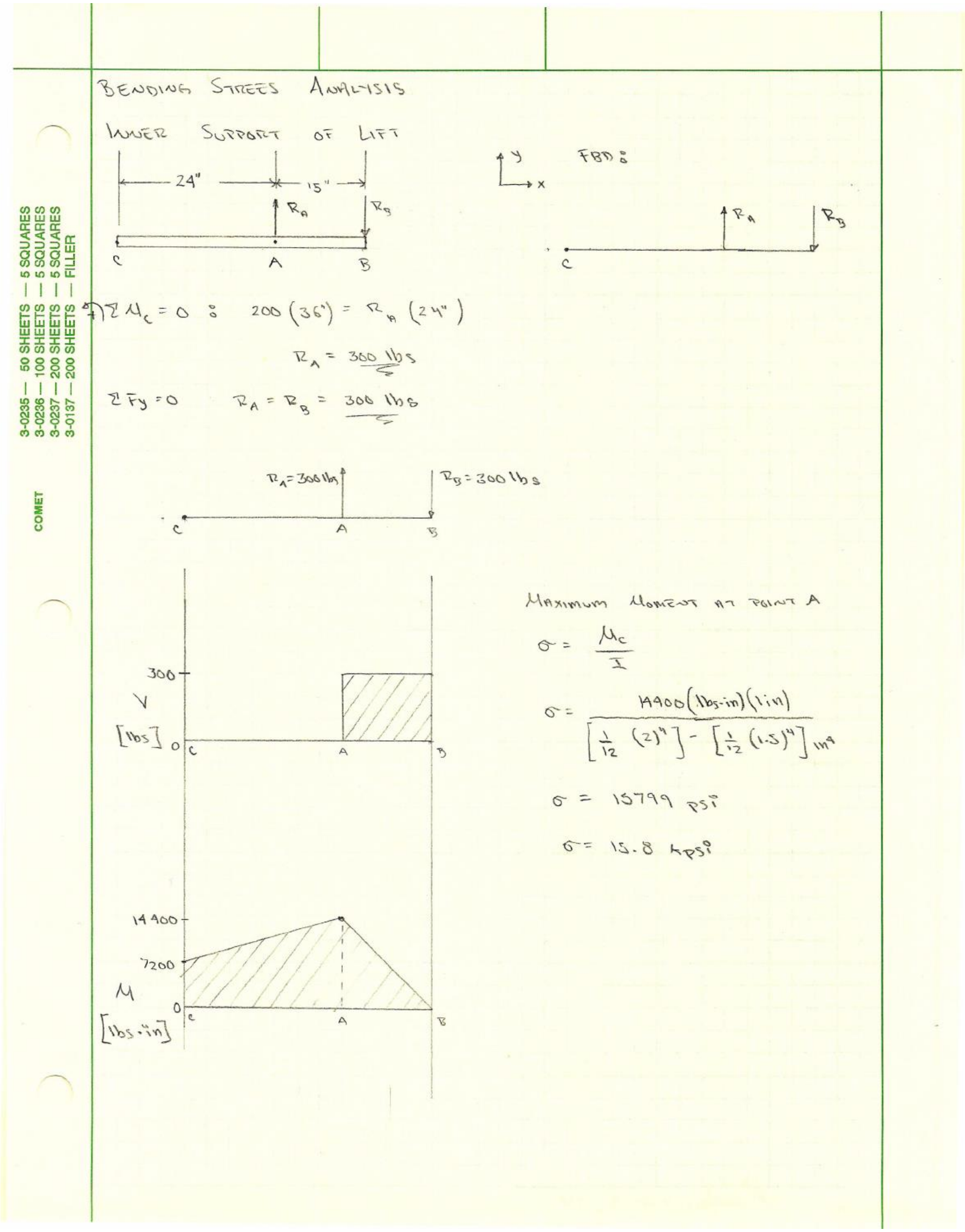
- TRY DEFLECTION OF 0.1 in

  $\Rightarrow h = 0.159$ in

- TOTAL PRICE FOR SHEET IS AROUND \$60.00

Appendix E.5

Actuator (Inner & Outer) Support Calculations



$\Sigma M_C = 0$: $200(36") = R_A(24")$

$R_A = 300$ lbs

$\Sigma F_y = 0$ $\quad R_A = R_B = 300$ lbs

$R_A = 300$ lbs $\quad R_B = 300$ lbs

Maximum Moment at Point A

$$\sigma = \frac{Mc}{I}$$

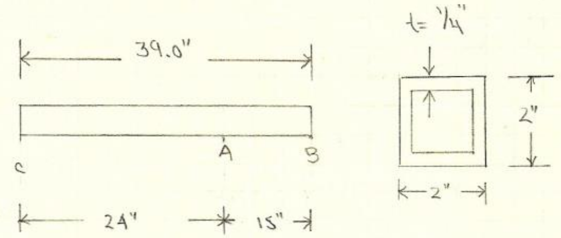
$$\sigma = \frac{14400(\text{lbs-in})(1\text{ in})}{\left[\frac{1}{12}(2)^4\right] - \left[\frac{1}{12}(1.5)^4\right]\text{in}^4}$$

$\sigma = 15799$ psi

$\sigma = 15.8$ kpsi

STRESS-LIFE CALCULATION

INNER SUPPORT FOR ACTUATOR



A36 CARBON STEEL

$S_{ut} = 58\,000 - 79\,800$ psi

$S_y = 36,300$ psi

(HOT-ROLLED)

- DETERMINE S_e': $S_{ut} < 200$ kpsi USE $S_{ut} = 71.9$ kpsi

$S_e' = 0.5\, S_{ut} = 0.5\,(71.9 \text{ kpsi}) = \underline{35.95 \text{ kpsi}}$

- SURFACE FACTOR: $k_a = a S_{ut}^{\,b} = 14.4\,(71.9)^{-0.718} = 0.669$
- SIZE FACTOR: k_b

FOR RECTANGULAR SECTION $d_e = 0.808\,(hb)^{1/2} = 0.808\,((2)(2))^{1/2} = 1.616$ in

$\Rightarrow k_b = 0.879\, d_e^{-0.107} = 0.879\,(1.616)^{-0.107} = \underline{0.835}$

- LOADING FACTOR: k_c

$k_c = 1$ (BENDING)

- TEMPERATURE FACTOR: $k_d = 1$ (ROOM TEMPERATURE)
- RELIABILITY FACTOR: $k_e = 0.868$ (95% RELIABILITY)

▶ CALCULATE ENDURANCE LIMIT S_e

$S_e = k_a k_b k_c k_d k_e k_f S_e'$

$S_e = (0.669)(0.835)(1)(1)(0.868)(1)(35.95 \text{ kpsi}) = 17.43$ kpsi

▶ STEEL BAR UNDERGOES CYCLIC LOADING SUCH THAT:

$\sigma_{max} = 15.8$ kpsi and $\sigma_{min} = 0$ (FROM BENDING STRESS CALCULATIONS)

$$\sigma_m = \frac{\sigma_{max} + \sigma_{min}}{2} = \frac{15.8 + 0}{2} = 7.9 \text{ kpsi}$$

$$\sigma_a = \left| \frac{\sigma_{max} - \sigma_{min}}{2} \right| = \left| \frac{15.8 - 0}{2} \right| = 7.9 \text{ kpsi}$$

- USING MODIFIED GOODMAN CRITERION

$$n_f = \frac{1}{\dfrac{\sigma_a}{S_e} + \dfrac{\sigma_m}{S_{ut}}} = \frac{1}{\dfrac{7.9}{17.43} + \dfrac{7.9}{71.9}} = 1.8$$

- FATIGUE FACTOR OF SAFETY BASED ON INFINITE LIFE

STRESS-LIFE CONT.
(INNER SUPPORT)

3-0235 — 50 SHEETS — 5 SQUARES
3-0236 — 100 SHEETS — 5 SQUARES
3-0237 — 200 SHEETS — 5 SQUARES
3-0137 — 200 SHEETS — FILLER
COMET

- FIND AN EQUIVALENT COMPLETELY REVERSED STRESS

$$\sigma_{rev} = \frac{\sigma_a}{1 - \frac{\sigma_m}{S_{ut}}} = \frac{7.9}{1 - \frac{7.9}{71.9}} = 8.87 \text{ kpsi}$$

- CALCULATE NUMBER OF CYCLES

$$N = \left(\frac{\sigma_{rev}}{a}\right)^{1/b}$$

$$a = \frac{(f S_{ut})^2}{S_e} = \frac{[.897\,(71.9)]^2}{17.43} = 229.2 \text{ kpsi}$$

$$b = -\frac{1}{3}\log\left(\frac{f S_{ut}}{S_e}\right) = -\frac{1}{3}\log\left[\frac{(.897)(71.9)}{17.43}\right] = -0.189$$

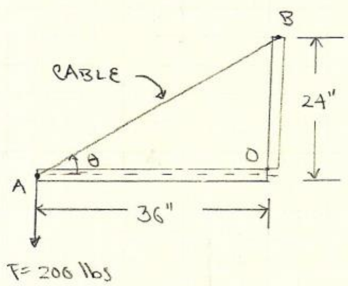
$$N = \left(\frac{\sigma_{rev}}{229.2}\right)^{-1/0.189} = \left(\frac{8.87}{229.2}\right)^{-1/0.189} = \underline{\underline{29 \times 10^6}} \text{ cycles}$$

Appendix E.6

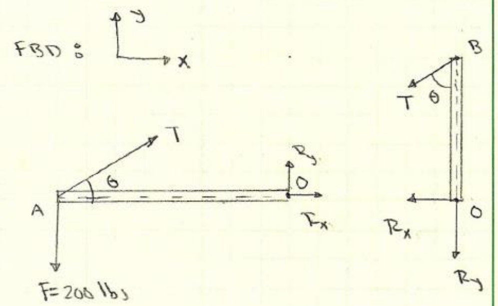
Cable Calculations

ANALYSIS ON CABLE

PLATFORM STRUCTURE:



FBD:



FIND ANGLE θ:

$\tan\theta = \left(\frac{24''}{36''}\right) \Rightarrow \theta = \tan^{-1}\left(24/36\right) = 33.7°$

MEMBER A:

$\Sigma F_y = 0 \Rightarrow -200 + R_y + T\sin\theta = 0$

$\Sigma F_x = 0 \quad T\cos\theta + R_x = 0$

$\circlearrowleft^{+} \Sigma M_o = 0 \Rightarrow 200\text{ lbs}\,(36\text{ in}) - T\sin\theta\,(36\text{ in}) = 0$

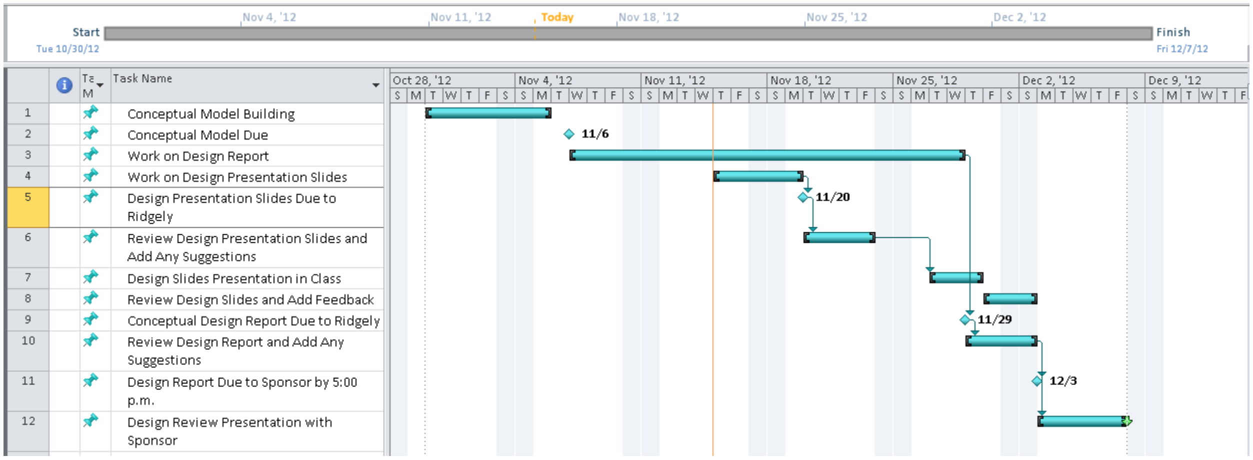
$36\,T\sin\theta = 7200$

$$T = \frac{7200}{36\sin\theta} = \frac{7200}{36\sin(33.7°)} = \boxed{360\text{ lbs}}$$

Appendix F

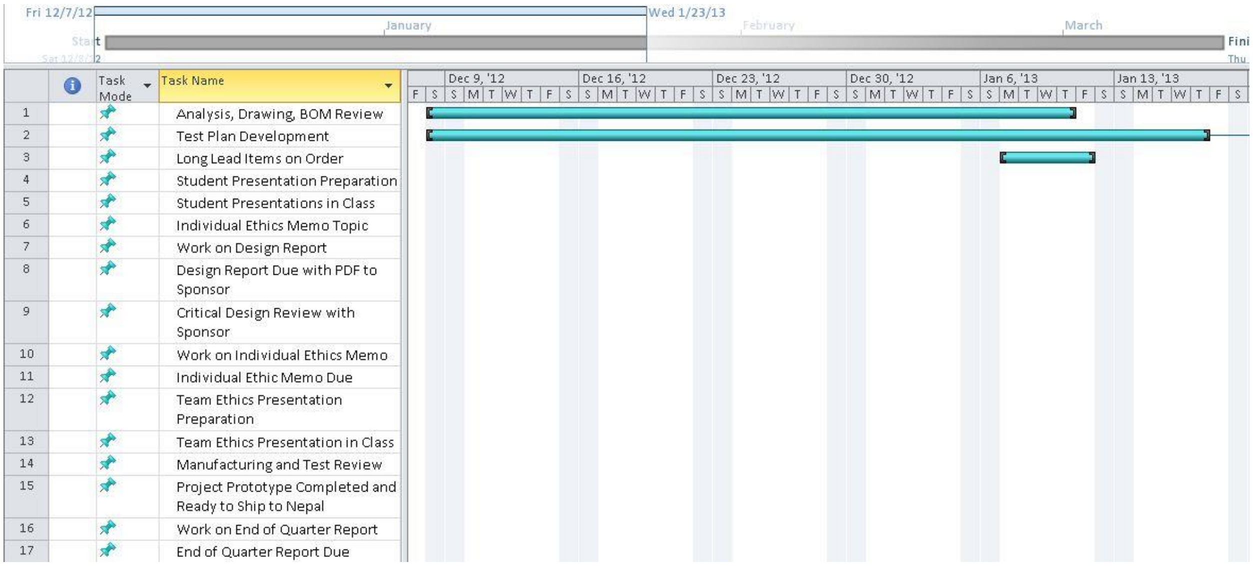
Gantt Charts

Appendix F.1

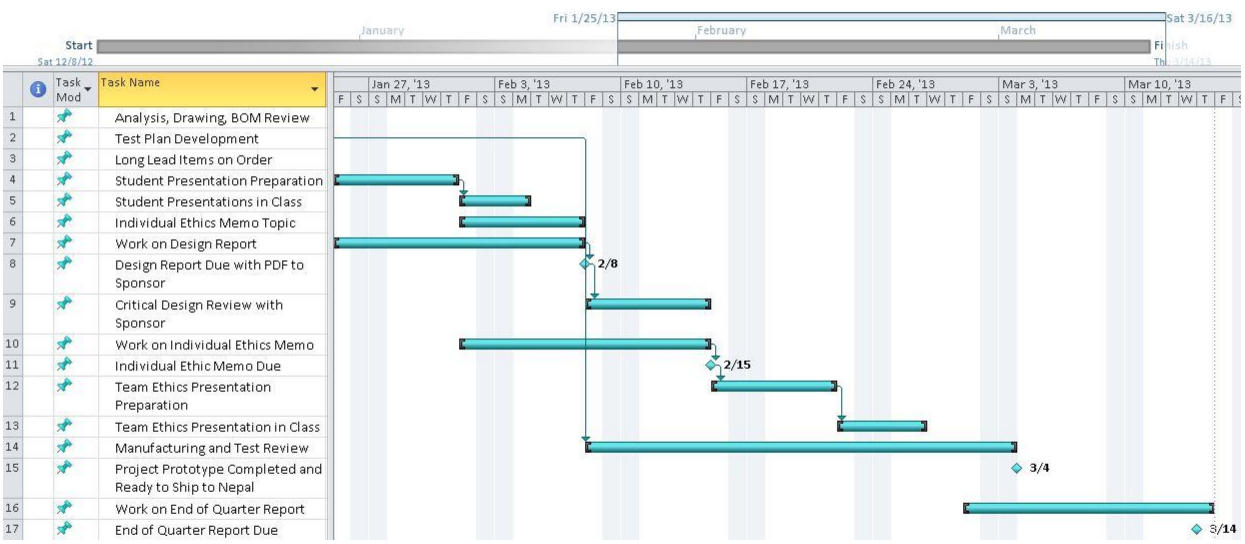


Fall Quarter Schedule

Appendix F.2

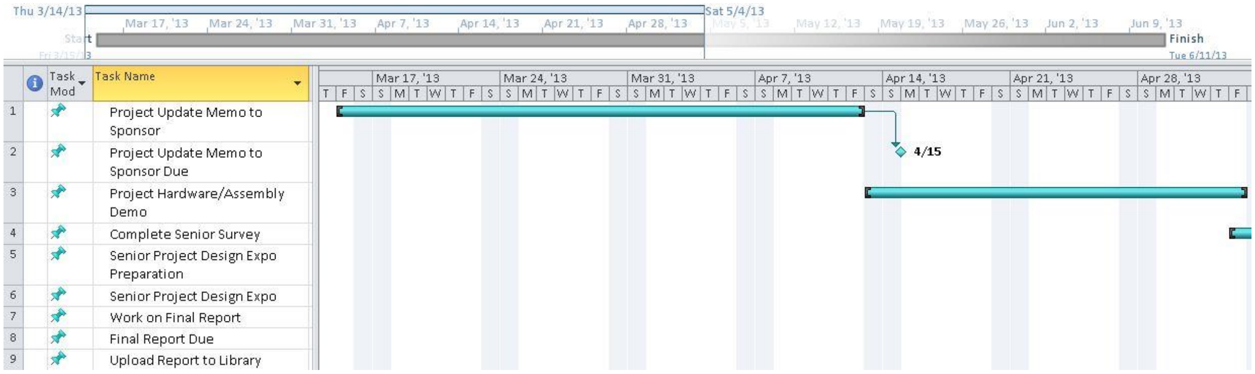


Winter Quarter Schedule 1

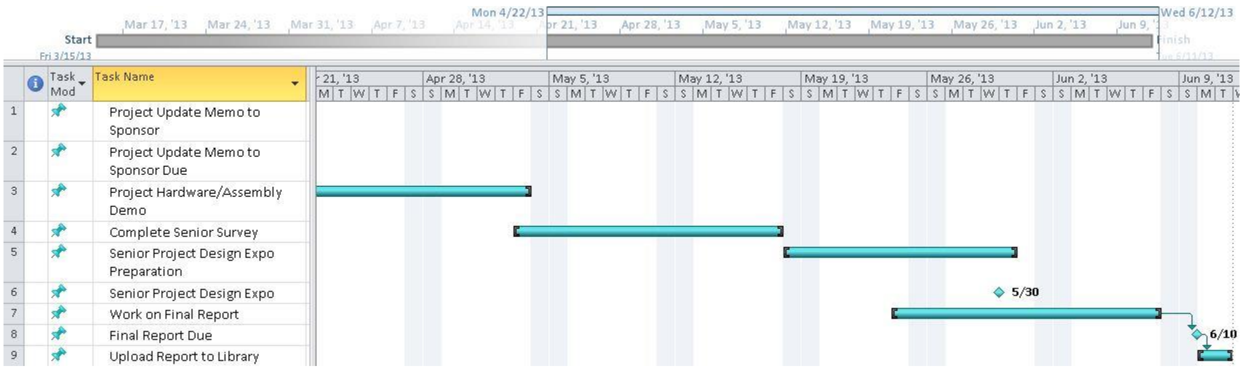


Winter Quarter Schedule 2

Appendix F.3



Spring Quarter Schedule 1



Spring Quarter Schedule 2

Appendix G

Design Development

Appendix G.1

Decision Matrix for Moving Kids from the Ground to the Height of the Van

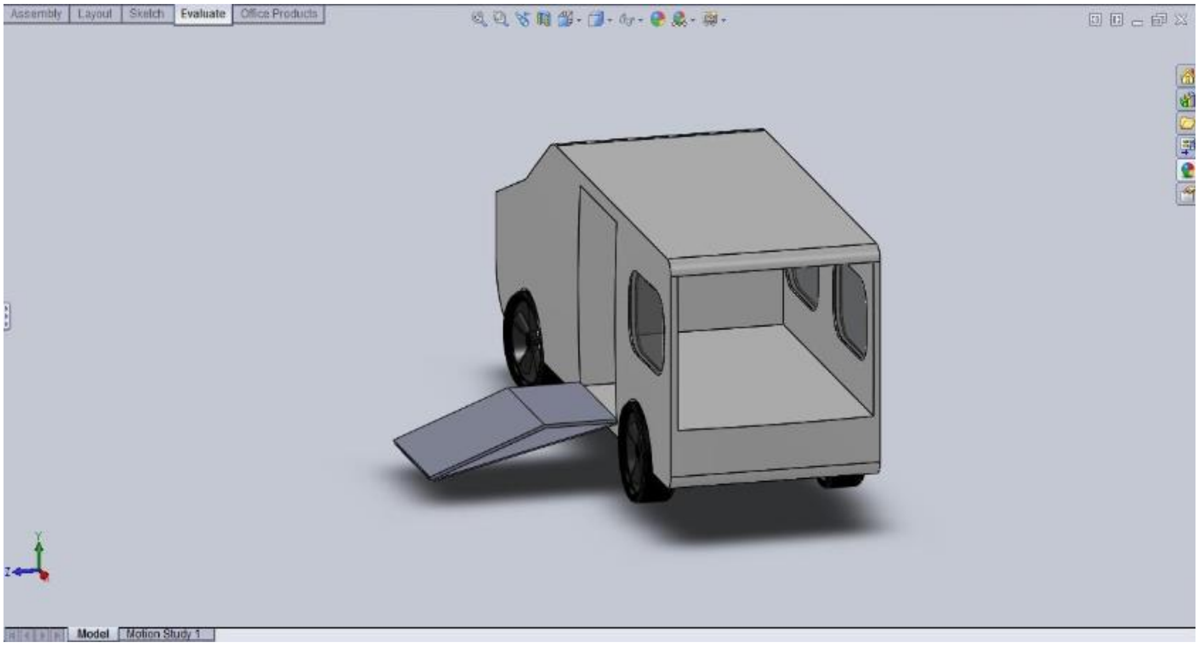
	Weight Factor	Ramp		Wheelchair Lift		Person Lift		Sliding Seats		Pulley Lift	
Reliability	5	5	25	3	15	3	15	1	5	1	5
Storage	3	3	9	2	6	2	6	4	12	4	12
Weight	3	4	12	3	9	3	9	1	3	4	12
Time	4	5	20	4	16	4	16	1	4	1	4
Ease of Use/Labor	4	4	16	5	20	4	16	2	8	2	8
Cost	5	4	20	1	5	2	10	3	15	3	15
Location	2	3	6	3	6	3	6	4	8	4	8
Size	3	4	12	2	6	2	6	1	3	4	12
Safety	5	5	25	3	15	2	10	3	15	2	10
Maintenance	1	5	5	2	2	2	2	1	1	3	3
		Total:	**150**	Total:	**100**	Total:	**96**	Total:	**74**	Total:	**89**

Decision Matrices for Different Ramp Designs

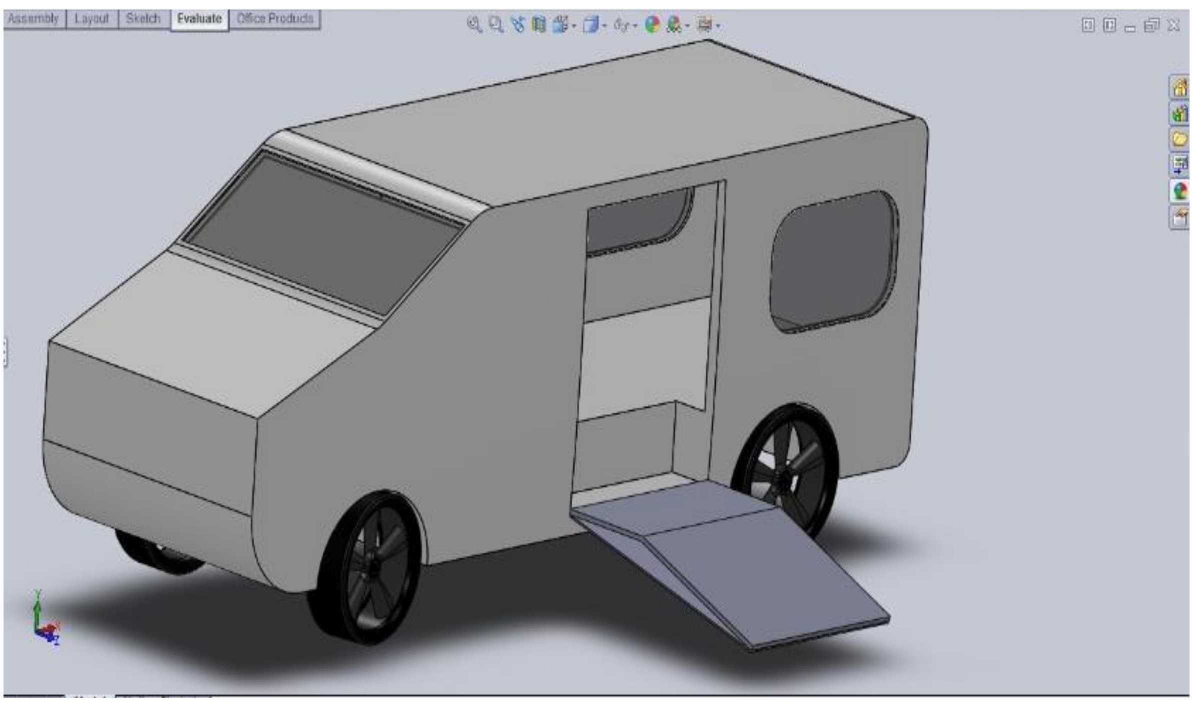
		Ramp Placement			
	Weight Factor	**Ramp Extending from Side**		**Ramp Extending Along Side**	
Reliability	5	5	25	4	20
Storage	3	4	12	2	6
Weight	3	4	12	4	12
Time	4	5	20	4	16
Manufacturing	4	4	16	3	12
Assembly	4	4	16	3	12
Ease of Use/Labor	4	4	16	4	16
Cost	5	4	20	4	20
Location	2	3	6	2	4
Size	2	4	8	3	6
Safety	5	5	25	5	25
Maintenance	1	4	4	3	3
		Total:	**180**	Total:	**152**

	Ramp Operation				Ramp Miscellaneous				Ramp Storage			
	Automatic Ramp		**Maunal Ramp**		**Detachable Ramp**		**Fixed Ramp**		**Foldable Ramp**		**Sliding Ramp**	
Reliability	3	15	5	25	4	20	5	25	5	25	3	15
Storage	3	9	4	12	5	15	4	12	3	9	3	9
Weight	3	9	5	15	3	9	3	9	3	9	3	9
Time	3	12	3	12	3	12	5	20	3	12	4	16
Manufacturing	2	8	4	16	4	16	4	16	5	20	3	12
Assembly	2	8	4	16	5	20	4	16	5	20	3	12
Ease of Use/Labor	5	20	2	8	4	16	5	20	3	12	4	16
Cost	2	10	5	25	3	15	3	15	5	25	4	20
Location	2	4	3	6	4	8	2	4	3	6	3	6
Size	4	8	5	10	3	6	3	6	3	6	3	6
Safety	3	15	5	25	3	15	4	20	5	25	5	25
Maintenance	2	2	5	5	5	5	4	4	4	4	3	3
	Total:	**120**	Total:	**175**	Total:	**157**	Total:	**167**	Total:	**173**	Total:	**149**

Appendix G.2

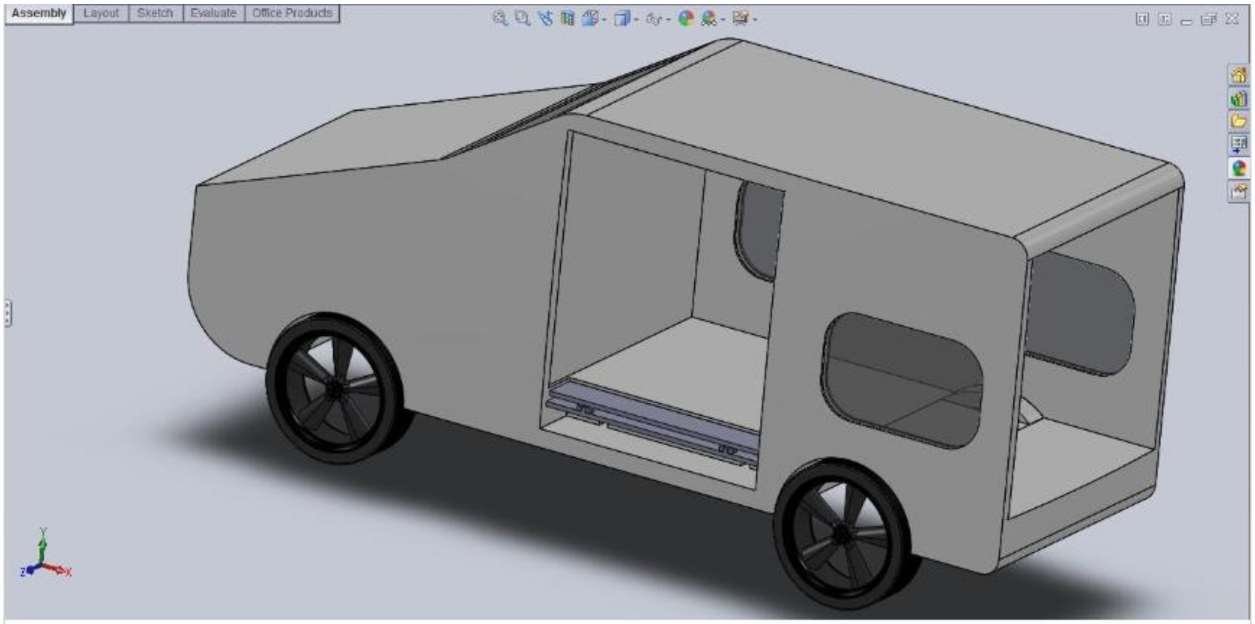


Simple-piece ramp model

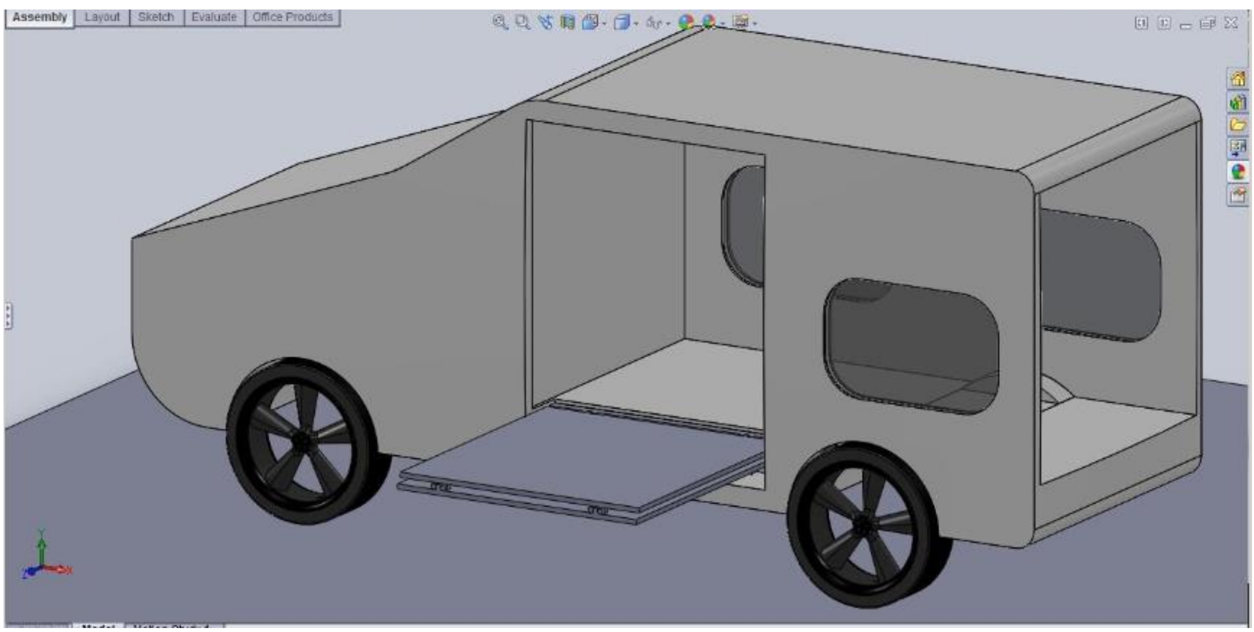


Simple-piece ramp model

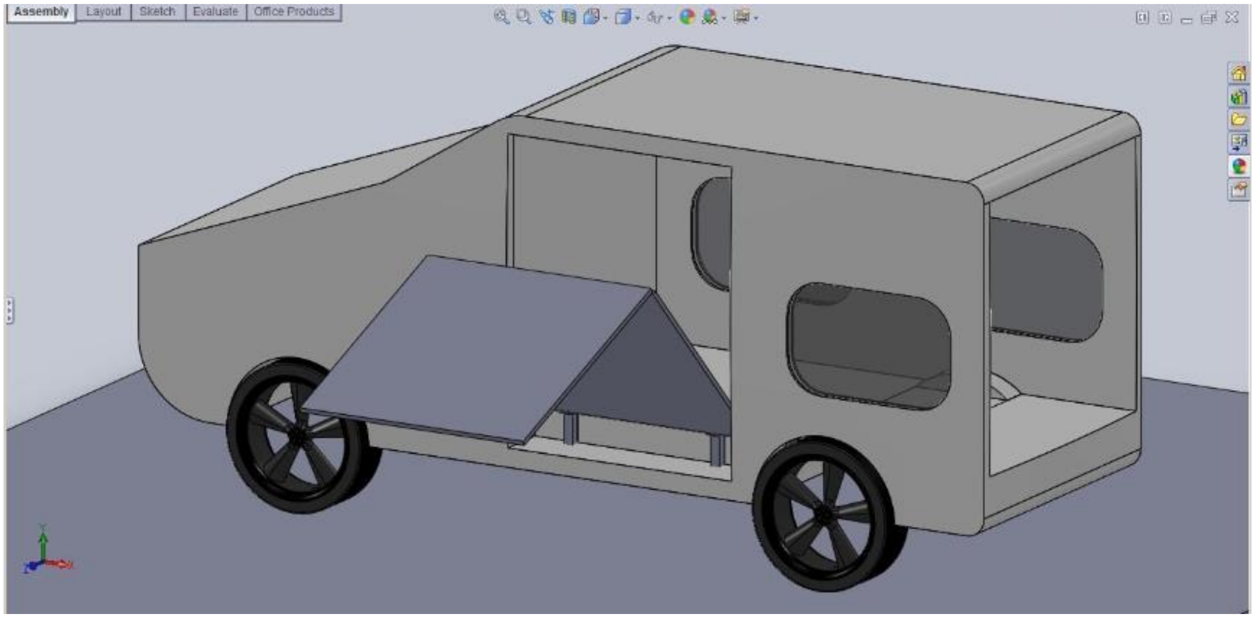
Appendix G.3



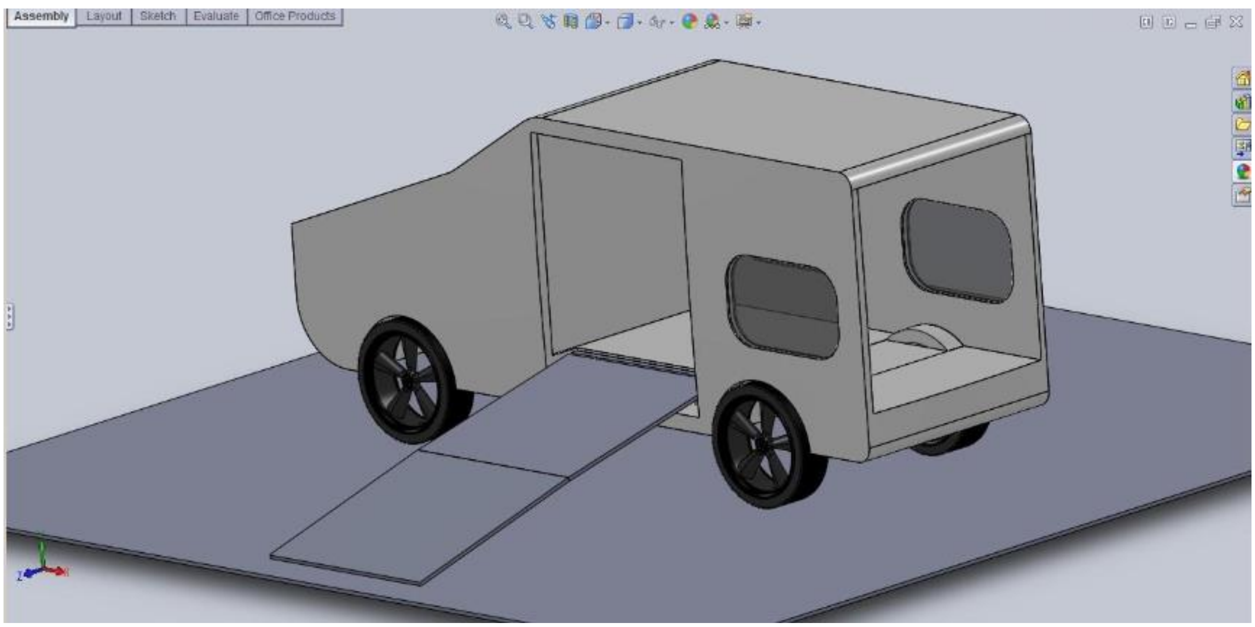
Ramp tucked away underneath van floor



Ramp extending out from the bottom of the van



Two-piece ramp Design



Full extended foldable ramp

References

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