Final Design Review

Lockheed #2
Sponsor: Sara Delk

John Ervin
Andre Neal
Mackinson Renard
Tom Vito

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Abstract

The objective of this project was to design a device that will assist in the raising and lowering of the roof of the Virtual Combat Convoy Trainer simulator. The current process of raising and lowering the roof costs Lockheed Martin $60,000 each time the trailer is transported and several safety violations had been investigated during an operational period of one year. The device designed needed to follow several parameters, however, its main goal was to decrease the number of personnel required to raise and lower the roof and decrease the risks associates with these tasks. Addressing these requirements, nine major concepts were researched and one was chosen using a decision matrix to evaluate the most acceptable design approach. The concept decided upon utilized a pneumatic cylinder that employed compressed air as the working fluid. The scope of the project was defined in the first semester of the design process, but after further review, it was redefined in the final semester to include the construction of a 1:5 scale model of the design, to include scaled models of the frame structure of the VCCT trailer and the HMMWV vehicle which is housed within it. The model of the roof-lifting mechanism and supporting models were fabricated for $750 and demonstrated during testing the potential for meeting the requirements for decreased personnel and increased margins of safety associated with raising and lowering the roof of the extension section of the VCCT trailer. Several safety tests were conducted with the scaled model and the design has been proven to meet operational requirements for simplicity, safety and cost effectiveness.

1.0 Team Lockheed Martin #2

1.1 Team Building

On Thursday, September 1st Team Lockheed Martin #2 was formed. The members included John Ervin, Andre Neal, Mackinson Renard and Tom Vito. The team knew that teamwork requires mutual respect and patience and that it was important to know and support each member of the team. To begin this process, the team went to out to lunch on Monday, September 5th. This time was used to learn about each other and to begin to understand each others strengths and weaknesses. This was when initial reactions to the project were discussed, as well as initial ideas for solving the problems associated with the design requirements.

1.2 Code of Conduct

During the teams initial meeting, a Code of Conduct was drafted. This document stated when the team would meet and what the expectations of the team members were. The most important section of the Code of Conduct dealt with communication, especially when it came to meeting times. It was understood that an occasional absence could occur with each member, however, if such a contingency arose, it was very important that each member communicated their absence with the remainder of the team. Communication was very important to Team Lockheed #2 and it was something that each member took pride in. The Code of Conduct also discussed our meeting times. For the majority of the semester, the team met Monday, Wednesday, and Friday from 1PM to 3PM and Tuesday and Thursday from 2:45PM to 5PM. We held weekly teleconferences with our sponsor on Tuesday from 3:30PM to 4PM. The Code of Conduct may be seen in its entirety in Appendix A. At the completion of the Code of Conduct, each team member agreed to the terms and signed their names proving their commitment to the team.

2.0 Background Information

For more than 75 years, Lockheed Martin has helped revolutionize the aerospace industry with a passion for invention that is unparalleled in the industry. Lockheed Martin is one of the leading providers of systems and solutions that support the United States military. In fact, about 60% of their business is from the United States Department of Defense. As the defense and homeland security customers turn their attention to integrated, networked capabilities to fight the war on terrorism, Lockheed offers an invaluable resource to help them define and deliver that future. The war on terrorism exposed the warfighter to a form of battle that many say the US military was not prepared for. Unfamiliarity with the current theatres of operation caused the soldiers to be very vulnerable to attack from the insurgents. To help alleviate this problem, and the accompanying dangers posed to convoying soldiers and Marines, Lockheed Martin created a training system, known as the Virtual Convoy Combat Trainer (VCCT), which simulates the close-quarters combat common to vehicular counter-ambush situations and provides participating personnel with immediate after-action feedback on their tactical performance during the simulation (Figures 2-1 and 2-2).

Figure 2-1: Undeployed VCCT

The Lockheed Martin VCCT is a three level trainer system designed to improve soldiers' ability to identify and react to threats in an asymmetrical combat environment. The VCCT provides training for drivers, shooters, communicators, and decision makers, encompassing all aspects of soldiering. The VCCT requires soldiers to coordinate actions on a single vehicle, between multiple vehicles and with higher headquarters. This system incorporates precision weapons effect simulation along with driving skill assessment for a variety of vehicles. Soldiers are placed in Shoot/Don't Shoot situations requiring a transition from perceived threat to re-act to contact in a split second. Actions on contact are oriented towards countering threats from Improvised Explosive Devices and ambush scenarios. The VCCT is a training system designed to constantly test soldiers' ability to maintain vigilance, identify and assess the threat, and take the appropriate action.

Figure 2-2: Deployed VCCT

The original VCCT development program was conducted as a very fast response to an urgent need to deliver a convoy trainer to the troops. Since then, more VCCT trailers have been produced. As a result of multiple set-ups and teardowns, some safety concerns have arisen due to the personnel-intensive methods of setup and teardown. This project was conducted to improve the current operational characteristics of the VCCT extension section roof lowering and raising procedure.

3.0 Project Scope

Many safety concerns have arose from the setup and teardown process for the training system. Within the teardown process, the “roof collapsing” portion is the most difficult and hazardous event. Below is a description of the teardown and setup processes and related hazards within them. This information was provided by the VCCT Safety Study, which is located in Appendix B, and the VCCT Procedure, which is located in Appendix C.

3.1 Teardown process

During the process of lowering the roof, several people (4-6) are holding up the roof with the vertical support poles and two personnel are under the roof facing away from the trailer. The personnel on the support poles walk away from the trailer while supporting the roof with the attached poles. As they back away, the two people under the roof, equipped with 2x4s approximately 4 ft long, try to catch the roof and engage the channel located toward the free end and support the roof as it collapses onto them. As the pole handlers move away, the roof reaches a “tipping point” after which time they have little control over its descent. The two people under the roof are trying to control the roof’s fall with the 2x4s while backing up and ducking so as not to get trapped between the roof and the side of the trailer. All of this effort requires teamwork, which is coordinated by one assigned person who counts and provides orders to the others on when to lift, move, etc.

During two of the four times this procedure was witnessed, at least one of the two people under the roof slipped while backing up. During two of the four times, the 2x4s have slipped off the surface contributing to the roof coming down faster than expected. On one occasion the teardown was being conducted in the rain causing the wood and the roof to be wet, which made a difficult situation even worse. Fortunately, in all cases all personnel were able to duck and hold the roof up long enough to keep from getting smashed by it. In two of the four cases, the vast majority of the weight has ended up borne by one person, while at the same time that person was ducking so not to be struck by the collapsing roof. One of the biggest problems with this process is that the current 2x4s are only roughly 4 ft long, which is too short; the personnel cannot engage the roof/channel due to its height and therefore are trying to “catch” it as it comes down. This entire process is extremely dangerous and poses many concerns regarding worker health and safety.

3.2 Setup process

While the setup of the roof on the VCCT trailer is a more controlled operation than the teardown, many observations similar to those on teardown were noted. The critical, and most difficult, part of the operation is the effort needed to move the roof from its resting position hanging on the side of the trailer into a horizontal position supported by the support poles. Similar to the teardown operation, this part of the setup uses four to six people on the support poles and two personnel facing out from the trailer using 2x4s to push up on the roof while the personnel on the roof support poles lift and walk backwards pulling the roof away from the trailer. When they reach the critical "tipping point", they reverse directions and transfer the force they are exerting into a pushing force to raise the roof while walking forward. All of this effort, as with the teardown, requires teamwork, which is coordinated by one assigned person who counts and provides orders to keep the group working together.

The setup and teardown processes are both broken down into 3 main phases. Phase 1 (Figure 2-1) is when the roof is in "transit" mode, which means it is pinned to the side of the trailer and ready to travel. Phase 2 is the intermediate phase (Figure 3-1). Once the roof is unpinned the workers will lift it up and place the support poles on the ground. At this point the floor is folded down and moved into position. Phase 3 (Figure 3-2) is the final setup. Once the floor is in position, the support poles are lifted onto the floor and pinned into place. At this point, the roof is up and the remainder of the procedure can be completed.

Figure 3-1: Intermediate Step

Figure 3-2: Final Step

While the roof setup does appear to be easier and less hazardous than teardown, it does present hazards to the personnel involved. The most critical hazard is to the personnel with the 2x4s who are under the roof pushing on it while the roof is being placed into the horizontal position. While no incidents were observed or reported, it would not be hard to envision a situation where the personnel on the roof support poles “miss” the tipping point and the roof falls back down to its vertical hanging position against the trailer wall, possibly crushing the two personnel with the 2x4s as it collapses. This risk is real since there are several people on the support poles, all of whom must act in concert to raise the roof while changing both their direction of travel and the forces they are using from pulling to pushing. A slip that occurs at the tipping point may result in injury to the two personnel who are under the roof during this operation.

Another potential for injury during this operation is the possibility of a lifting injury to the backs of the people who are assigned to the roof support poles. Changing directions of movement while simultaneously changing directions of force, as well as lifting considerable weight (~225 lbs) contributes to the potential for back injury. Currently six employees are needed to raise and lower the wing roof of a Virtual Combat Convoy Trainer. Economically funding six people to perform this task at different locations has proven to be an unnecessary burden on the customer.

3.3 Possible Solutions

A mechanism was needed to raise and lower the roof with the help of 2 to 3 people. Initial conceptual designs were developed and design specifications were created with the help of the customer. Some initial potential solutions included a hydraulic lift, pneumatic cylinder, or a mechanical crank. Upon design completion, fewer employees were to be needed for the setup and teardown process. The new design was also to reduce the safety hazards encountered during the setup and teardown process. Less workers and reduced safety risks will save the customer in terms of capital expended and liability obligations.

4.0 Product Details

4.1 Needs Assessment

Once the problem was determined and the schedule was completed, the constraints of the problem were addressed. The following constraints were provided by the customer and are in the order of importance. These constraints were assessed and a better understanding of some potential solutions was then formed.

1) The device must keep the roof level.

2) The parts of the device (if it needs to be disassembled) must only need 2 men (2 persons preferred) to lift.

3) The device cannot be permanently attached to the trailer if it increases the height or width of the trailer.

4) The device must be able to be stored in and transported with the trailers.

5) The device must work on pavement, asphalt, dirt, or gravel.

6) If the device is separate from the trailer, it must be put together and taken apart using standard tools.

7) Disassembly of the device should only be required for storage.

8) The device must be able to handle being in extreme weather conditions (heat, rain, snow).

9) The design may require modifications to the existing trailer.

4.2 Product Specifications

Once the needs of the project were completed, the specifications of the product were determined. These specifications provided a more analytical description of the constraints and helped quantify what needed to be completed. They are listed below in order of decreasing importance.

1) The device should be able to hold 500lbs for some time during the setup and teardown.

2) MIL-STD-1472 recommends that men lift a maximum of 56lbs and females lift a maximum of 37lbs. So 2-3 males (preferably) or 2 males and 1 female should be able to operate the device.

3) Nothing can disturb the actual simulation (i.e., projector, screens, users, etc).

4) The design cannot add to the height or width of the trailer.

5) The device should be able to operate under any environmental conditions (i.e., rain, snow, heat, etc).

6) Transfer of the device should take no longer than 20 minutes.

7) Cost for design and manufacture should be less than $2000.

8) Electric motors cannot be used because electricity is not always available.

5.0 Concept Generation and Selection

5.1 Design Matrix Categories

The project at hand, which is described in the project scope, was to design the components of a mechanical system that can raise and lower the roof of the extension section of the simulator. The roof weighs 500 pounds and is hinged on one end. The roof measures approximately 24 feet wide by 8 feet tall. Once the roof is in the horizontal position, it is approximately 15 feet off of the ground. The following concepts were our proposals as to how to solve this design problem. Table 5-1 is our design matrix and it shows how our group graded our nine concepts (which are described in Appendix E). Each concept includes a detailed description, force analysis, pros and cons, and how it was graded for each category in the design matrix. The matrix categories are as follows (in order of importance): personnel required, safety, cost, ease of setup, and reliability.

Each category will be ranked from 1 to 5 with 1 being the worst possible situation and 5 being the best. For the category of personnel required a score of 5 will be given for designs that only require 1 to 2 people, a score of 4 for 3 people, 3 for 4 people, 2 for 5 people, and 1 for designs that require 6 people or more. The category of cost was ranked in the following manner: 5: $0-$500, 4: $500-$1000, 3: $1500-$2000, 2: $2000-$4000, and 1: $4000 or more. For reliability, no maintenance got a score of 5, yearly maintenance got a score of 4, monthly maintenance got a score of 3, weekly maintenance got a score of 2, and daily maintenance got a score of 1. The category of safety was scored differently. The following five statement were used to score each design: 1) Safe for teardown, 2) Meets all worker lift requirements, 3) OSHA approved (meets all standards), 4) No environmental hazards, and 5) No additional safety requirements are needed. If a design passed all of these, it would receive a score of 5. If it only passed 4 of these, it would receive a score of 4, and so forth. Finally, the setup score was based on how long the setup of the device and the lifting of the roof would take and whether or not extra tools would be required: 5: 20 minutes or less with no extra tools, 4: 20 minutes or less with the use of extra tools, 3: 30 minutes with or without tools, 2: 45 minutes with or without tools, and 1: 1 hour or more with or without tools.

5.2 Decision Matrix

Concept	Personnel (0.3)	Safety (0.3)	Cost (0.2)	Setup (0.1)	Reliability (0.1)	Total (1.0)
Mechanical Lift	3	4	5	3	3	3.7
Hydraulic Lift	3	3	3	4	3	3.1
Interior Pneumatic Cylinder	5	3	3	4	4	3.8
Pulley System	4	3	3	2	4	3.3
Pulley Lift	5	4	4	4	4	4.3
Four-Bar Pulley	4	4	2	1	3	3.2
Pneumatic Cylinder w/ heat source	4	3	4	4	3	3.6
Motor Lift	4	3	4	3	3	3.5
Spring Hinge	4	3	4	4	4	3.7
Exterior Pneumatic Cylinder	4	5	3	3	4	4.0

Table 5-1: Decision Matrix

5.3 Concept Selection

According to Table 5-1, there are five designs given a score of 3.8 or better. These designs were re-analyzed and matched up against one another. The three best designs from this group were Concepts two, four, and nine. The pulley-lift system, which graded with the highest score, was researched more and the vendor was consulted to see if they believed their product would accomplish the task at hand. Unfortunately, they could not give us a guarantee that their design would accomplish our task. We were told that the pulley lift was for lifting objects in the vertical direction, where we would have it lifting the roof from an angle. It could not be assured us that the lift would not tip while lifting the roof. A lift could have been purchased, tested, and re-designed to fit our needs, however, with the budget and time constraints of this project this was not possible. If the idea chosen did not succeed, this was considered a viable option for Lockheed Martin to continue to research.

As such, the remaining two acceptable approaches, the pneumatic cylinder systems, were chosen for further evaluation. Due to the similarity of the mechanisms, Concept two was our initial choice, however, if it is discovered that this approach will not work, the equipment organic to this concept may be reused to pursue Concept nine. As a result, we were giving ourselves two viable options in case one of them would prove to be unsuccessful.

6.0 Analysis

6.1 Design Improvements

Concept two was our initial choice, however, after further review some things have changed. Firstly, the cylinder would not be mounted onto the roof of the trailer. The roof was not designed to handle the kind of forces that would be applied, so the front support beam was chosen for use. Two support poles are to descend from the support beam. A pin connection would not be used to connect the cylinder housing to the support beams. A rigid pin connection would be used so the cylinder cannot rotate. This was different from our original idea in that the cylinder would be stationary, however, to allow the cylinder to properly open the roof, it would be positioned at a 30-degree angle from the horizontal. Instead of using an extension spring to provide the force needed to lift the roof, a compression spring was chosen for use. This decision was made due to its reduced cost and greater availability than the extension spring application. Instead of being outside of the housing, the compression spring will be located inside the housing.

6.2 Product Procedure

The procedure will be the same as mentioned in the concept selection section. The roof will start in the "transit" position (Figure 6-1).

Figure 6-1: Starting ("Transit Position")

The spring will only be able to lift 95% of the weight of the roof, so the cylinders will need help to lift the roof. Once the roof is unpinned from the trailer, two workers will pull on the support poles and lift the roof to its intermediate position (Figure 6-2).

Figure 6-2: Intermediate Position

At this point the floor is extended and finally the support poles are lifted onto the floor, lifting the roof to its final position (Figure 6-3). Here the support poles are locked into place and the rest of the setup procedure is completed. The same procedure is used to bring the roof down. A small hole will be cut into the cylinder housing to dampen the fall, so the roof doesn't slam down. The reason that only 95% of the roof will be lifted by the spring is because if the spring could lift the roof entirely by itself, then it would be very difficult to close it. Since the spring will only lift 95% of the roof, the closing procedure is made much easier.

Figure 6-3: Final Position

6.3 Product Description

Figures 6-4 and 6-5 show schematics of the system when the roof is open and closed, respectively. Figure 6-6 shows a schematic of the inside of the housing. When the roof is closed, the piston arm, piston, and spring will all be enclosed in the housing. The spring will be welded to the housing. The spring will be "wrapped" around a rod, which will give it support. The main reason for this is so the spring does not oscillate. A small hole will be cut in the piston for the support rod. The piston arm, which is hollow, will move out as the spring extends and open the roof. There will be a small hole cut into the housing to create a damping when the spring begins to recompress. This will help the roof from slamming down when it is closing.

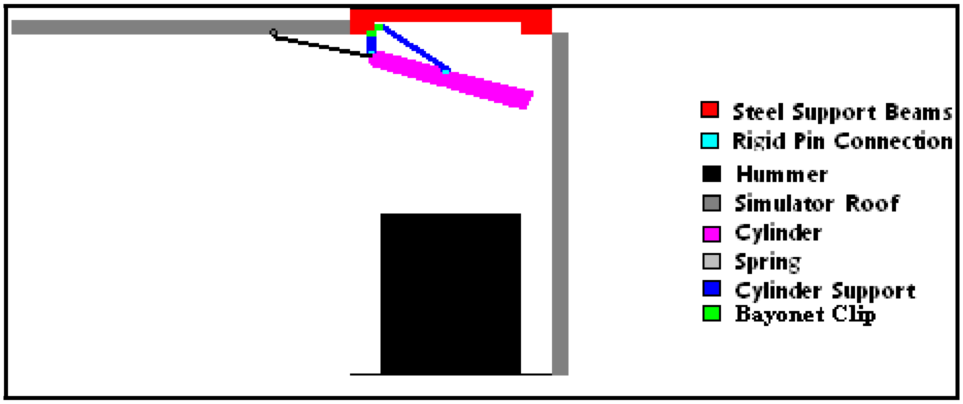

Figure 6-4: Schematic of System (Open)

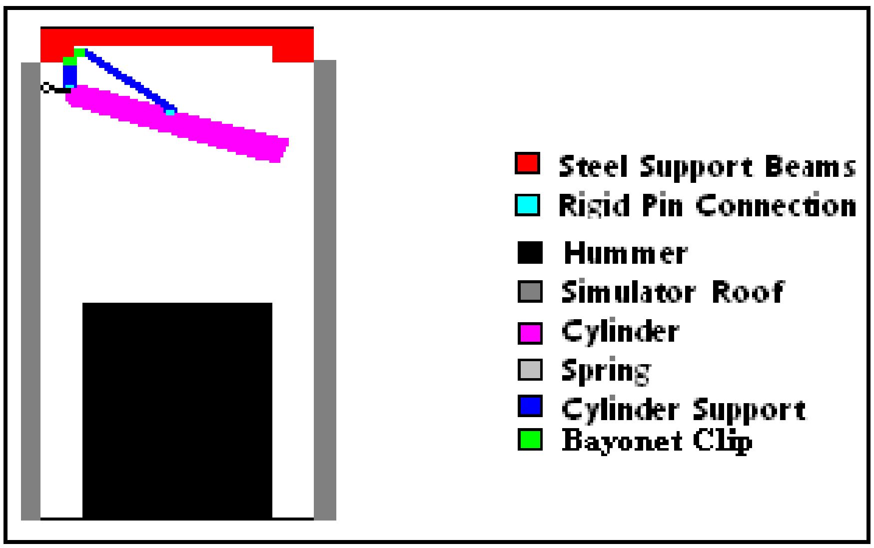

Figure 6-5: Schematic of System (Closed)

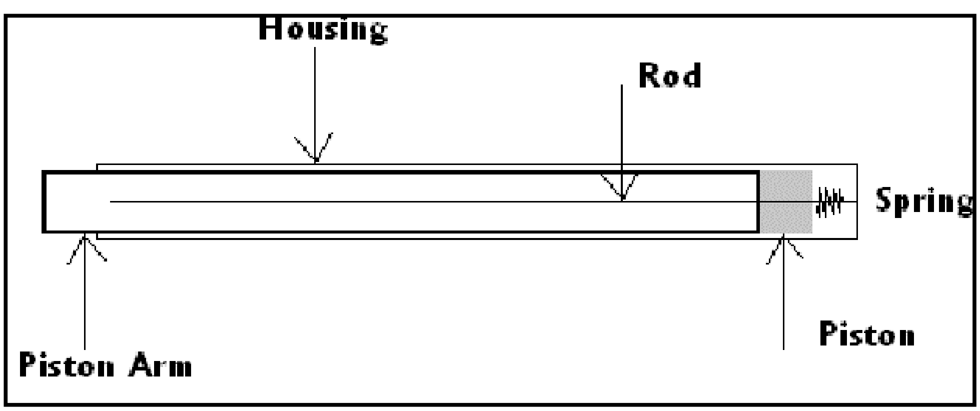

Figure 6-6: Schematic of Interior of Housing

The design consists of a hollow housing made of aluminum 6061 that will hold the piston and piston arm. These two components will also be made of aluminum 6061, a material that was chosen to handle the load and stress factors during extensive operation of this design. A rigid pin connection will be used to mount the housing to two support poles that will hang from the steel support beam. The housing will be hung at an angle of 30 degrees to provide a greater vertical force to open the roof. The use of a compressed spring will provide the force as seen in needed to move the piston arm and lift the roof. The piston arm will be subjected to forces that may cause bending or buckling of the arm during the lift process as the arm expands out of the piston housing. To briefly summarize the design's operation; the piston and piston arm is inside the housing under compression from the spring, and once released the spring exerts a force on the piston arm large enough to achieve the required lift height of the roof. A wheel connected to the piston arm will be the point of contact between the roof and the piston arm to allow ease in motion as it expands. Two support beams will connect to the trailers main support beam to sustain the cylinder. The cylinder will be pinned connected to these support beams and the support beams will be mounted to the trailer's main support beam.

6.4 Position of System

It was a very delicate process to determine the position of the two cylinders on the trailer. Since the trailer wings fold in when the trailer is in transit, there are several panels that block the roof from the interior of the trailer. There is a small space, however, that can be used. Figure 6- 7 shows a picture of where this space is on the trailer.

Figure 6-7: Useable Space on Trailer

The white square represents the area that can be used. Figure 6-7 shows a picture of when the panels are in their "transit" position. In this picture the floor is lowered, but the floor is folded up when in "transit" position and covers the panels up to the top of the doors. The roof folds down on everything to create the side of the trailer. So the white square is the only available space that connects the roof to the inside of the trailer. The space is 28.75 inches in height and 69.5 inches in length. Figure 6-8 shows a side view schematic of the roof and where the cylinders will be connected to the roof. The four squares represent the cylinders and the drawing is to scale with the thickness of the housing considered.

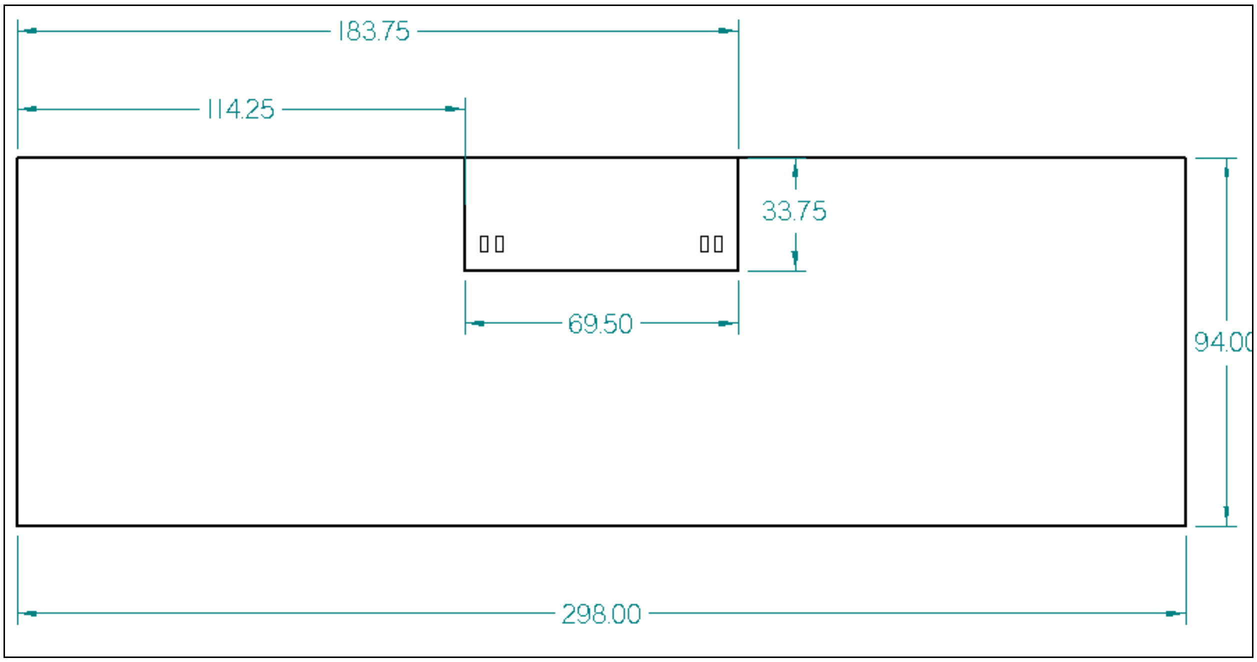

Figure 6-8: Positioning of Cylinders on Roof

Figure 6-9 shows a more detailed view of the usable space of the roof. The square is the part of the roof that can be used to mount the cylinders. This region represents the region in the white box in Figure 6-7. As can be seen, the roof is 298 inches by 94 inches. The cylinders will be placed as low as possible to lessen the force needed to raise the roof and as far apart as possible to reduce the bending moment that the roof will feel. So the cylinder will be placed at the following locations if the top, left corner of the roof is considered the origin: (118.25", 23.75") and (179.75", 23.75").

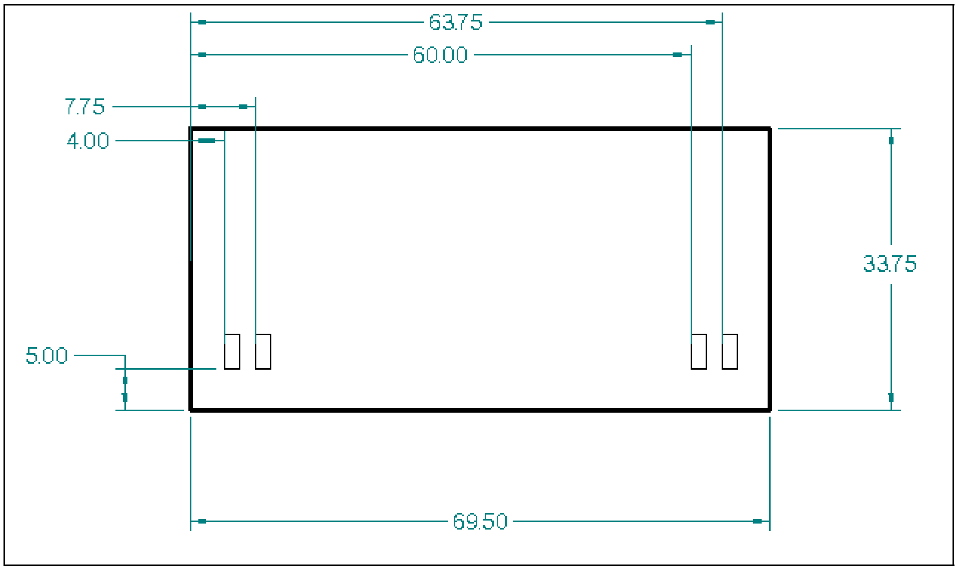

Figure 6-9: Usable Space for Cylinders

6.5 Force Analysis

Now that the positioning of the cylinder is known, the next step is to determine how much force the cylinder will have to exert on the roof to open it. Figure 6-10 and 6-11 show free-body diagrams of the system when the cylinder is at 90 and 45 degrees, respectively. The red rectangle is the roof and the blue arrow is the force exerted by the cylinder. The actual calculations can be found on page C-6. To calculate the force exerted by the cylinder (Fc), the moment about the hinge (H) was completed. As the roof opens, the angle theta will decrease from 90 to 0 degrees. Table 6-1 shows what the force exerted by the cylinder is in intervals of 10 degrees. Figure 6-12 shows a graph that relates the force exerted by the cylinder as a function of the angle theta. It can be concluded that the force is minimum when the angle is 90 degrees, which is when the roof is closed, and maximum when the angle is 0 degrees or when the roof is open. Since two cylinders will be used, the maximum force that each cylinder must exert is 925 lbf.

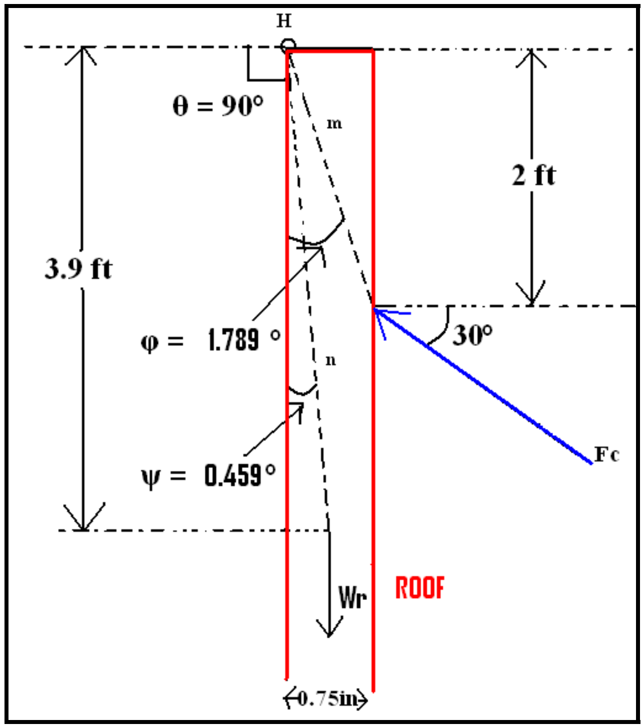

Figure 6-10: Free-Body Diagram When Roof is Closed (90 Degrees)

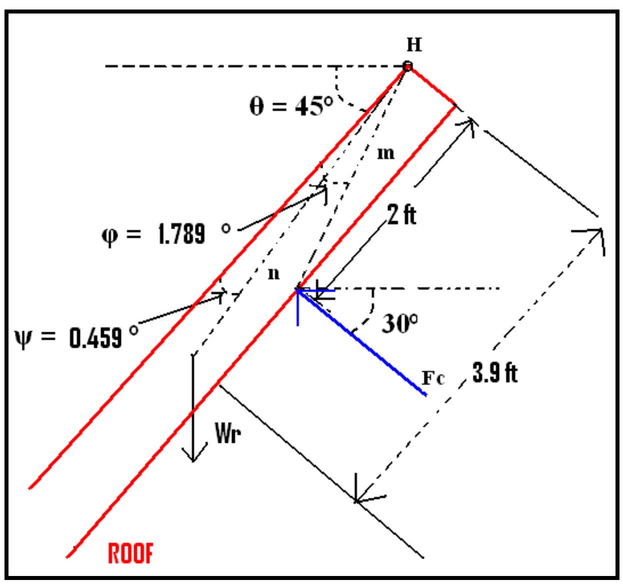

Figure 6-11: Free-Body Diagram When Roof is at 45 Degrees

Angle (deg)	Force (lbf)
0	925
10	719
20	581
30	477
40	390
50	313
60	240
70	167
80	87
90	5

Table 6-2: Force of Cylinder at Different Roof Angles

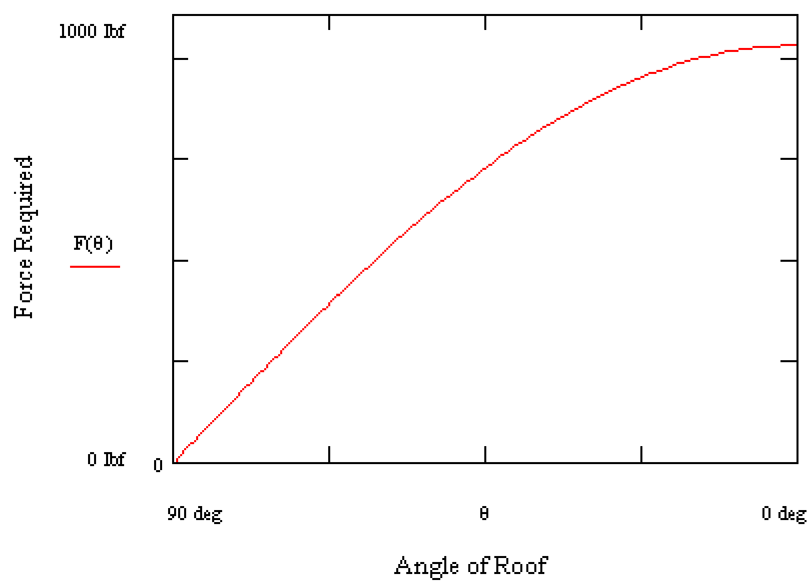

Figure 6-12: Angle of Roof vs. Force Exerted by Cylinder

The pins that connect the housing of the pneumatic cylinder and the beam connectors will experience a considerable amount of force from the roof pushing back on the cylinder. Pin selection is dependant on these forces and the pins chosen must be able to withstand the maximum force calculated. It must also be able to handle the force fluctuation as the force changes when the roof is raised or lowered. Figure 6-13 shows the free-body diagram of the cylinder with pins A and B shown. As noticed, Pin B experiences a resultant force from forces acting in the x and y-direction while Pin A only experiences a force in the y-direction. The force Fc is located in the base of the housing because while the piston is pushing out on the roof on one side it is experiencing an equal but opposite force acting on the other end where the spring is located. For the calculations (on page C-11 the moment about Pin B is taken since there are two unknowns located there. From there, static equilibrium equations are used to determine the remaining unknowns. The maximum forces on the pins are experienced when the roof is completely raised. Pin A experiences a maximum force of 631 lb and Pin B experiences 1629 lbf.

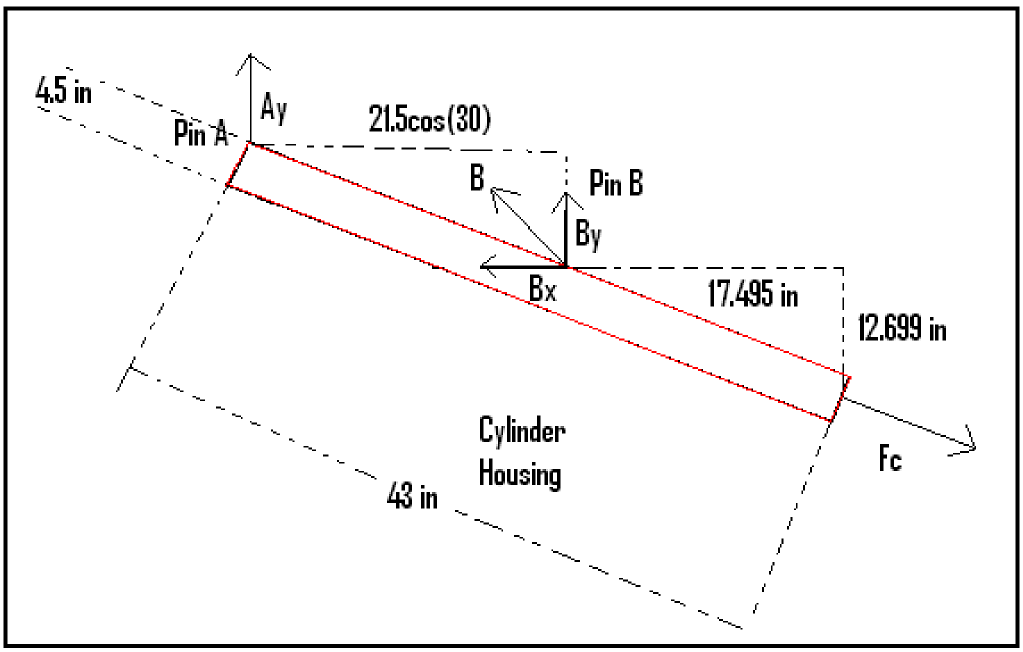

Figure 6-13: Free-Body Diagram of Cylinder

6.6 Stress Analysis

The R.C. Hibbler Statics and Mechanics of Materials textbook was used to formulate and analyze the stresses at the pins, hinges, and on the roof with the maximum loads determined in the force analysis. The area and force for each member was determined and the force per unit area (stress) was calculated. Where A is the cross sectional area and F is the max force the components will be subjected to, respectively. The stress for each member was then determined as a function of the applied load and the area of each member respectively. The buckling analysis for the piston arm was determined from analyzing the maximum critical load that the arm would be subjected to axially and the use of the material properties and shape factors such as; internal moment of the member, the perpendicular distance from the neutral axis to the point farthest away, the moment of inertia, and the modulus of elasticity. All of these calculations can be seen on page C-12. The stress on the piston was calculated to determine how much the piston will bend under the maximum force. Equation 6-1 was used to calculate the bending due to the stress.

$$\sigma_{bend} := \frac{\left(M_{pistonarm} \cdot c\right)}{(I)}$$

Equation 6-1

Since the maximum moment will not change, the only variables that will cause the bending stress to vary is the size, shape, and material of the piston. Several different materials, sizes and shapes will be used to determine which combination will have the lowest bending stress and deflection. The piston arm will be hollow because the weight needs to be as low as possible. The materials studied will be steel and aluminum, specifically; A36 Steel, Al6061, Al6063T52, and Al6063T52. The materials beginning with "Al" are different types of aluminum, while the other material is steel. Two different shapes will be studied; rectangular and circular cross-sections. The different size rectangular cross-sections are as follows with the height and width in inches, respectively: 3 x 2 (A36 steel), 3 x 2 (Al6061), 4 x 2 (Al6061), 3 x 1 (Al6063T52), and 4 x 1.75 (Al6063T52). The circular beam has an outer diameter of 3.5 inches and an inner diameter of 2.5 inches. All of these beams are available at McMaster Carr and that is why certain materials have certain specifications. The equation for the moment of inertia for the rectangular shaped beams can be seen in Equation 6-2 and the equation for the circular beam in Equation 6-3.

$$I := 2\cdot\left[\left(\frac{1}{12}\right)\cdot\left(\frac{W}{12\cdot\frac{in}{ft}}\right)\cdot\left(\frac{t}{12\cdot\frac{in}{ft}}\right)^3 + \left(\frac{W}{12\cdot\frac{in}{ft}}\right)\cdot\left(\frac{t}{12\cdot\frac{in}{ft}}\right)\cdot\left[\frac{\left[\frac{H}{2} - (.5\cdot t)\right]}{12\cdot\frac{in}{ft}}\right]^2\right] + 2\left(\frac{1}{12}\right)\cdot\left(\frac{t}{12\cdot\frac{in}{ft}}\right)\cdot\left[\frac{(H - 2\cdot t)}{12\,\frac{in}{ft}}\right]^3$$

Equation 6-2

$$I := \frac{\pi}{64}\cdot\left(D_o^{\,4} - D_i^{\,4}\right)$$

Equation 6-3

Once the bending stress was known the deflection of the piston arm was calculated using Equation 6-4. Finally the factor of safety was calculated by using Equation 6-5.

$$piston\_arm\_deflection := \frac{-\left(F_{ry}\cdot L^3\right)}{(3\cdot E\cdot I)}$$

Equation 6-4

$$FS := \frac{\sigma_{A36YIELD}}{\sigma_{bend}}$$

Figure 6-5

The factor of safety and deflection calculations can be seen on page C-12. The process in the appendix shows the calculations for Al6061 (4 x 2); however, it is the same for all of the different sizes and materials. The Young's Modulus was given to be 10 x 10^6 psi for aluminum and 30 x 10^6 psi for steel. The yield strength for aluminum was given to be 35000 psi for aluminum and 34000 psi for steel. The weight of these materials was also calculated and can be seen on page C-15.

The stress on the support beam was also calculated. Once this stress was determined, the thickness of the support beams could be determined. The stress analysis on the support system is a critical part to this design. The calculations (page C-18 through C-20) will prove the safety of the device by eliminating safety hazards from failure of the components. The first analysis was done on the vertical mounting component which will be subjected to only an axial load therefore buckling was only considered in this case. The critical load was taken from the pin analysis, and the critical stress was determined from the ratio of the critical load and the area of the component. The final calculation done for this part was the factor of safety that is given by the ratio of the theoretical yield stress of the material, and the actual stress determined from the calculations. The second part of the mounting system needed a little more analysis due to it having two component forces acting on it. The buckling analysis was done using the same equation as the first component. The bending analysis was done using the maximum moment the component would be subjected to and some material properties. The maximum bending stress was determined as the ratio of the materials theoretical stress divided by the actual stress calculated. From this analysis the factor of safety that is given by the ratio of the theoretical yield stress of the material, and the actual stress was determined. The factor of safety values obtained from the analysis done shows that the design is both safe and reliable.

6.7 Material Analysis

Once those calculations were completed, the materials were analyzed and the best material available for the piston arm was determined. Table 6-3 shows the results for the rectangular tubing and Table 6-4 shows the results for the circular tubing.

Material	Height (in)	Width (in)	Thickness (in)	Cost ($)	Weight (lbf)	Factor of Safety (bending)	Deflection (in)
A36 steel	3	2	0.188	$38.00	23.5	2.2	0.3
Al6061	3	2	0.25	$102.00	10.5	2.7	0.7
Al6061	4	2	0.25	$125.00	12.8	2.2	0.3
Al6063T52	3	1	0.125	$43.10	4.4	1.0	1.8
Al6063T52	4	1.75	0.125	$57.49	6.4	2.2	0.6

Table 6-3: Rectangular Tubing

Material	Outer Diameter (in)	Inner Diameter (in)	Wall Thickness (in)	Cost ($)	Weight (lbf)	Factor of Safety (bending)	Deflection (in)
Al6061T65	3.5	2.5	0.5	$214.00	22	4.9	0.3

Table 6-4: Round Tubing

Several factors will determine which material and size will be chosen for the piston arm. Obviously the factor of safety and the deflection are very important, however, the cost and the weight will also be important factors. After much debate, the Al6063T52 (4 x 1.75) will be used because it is cheap and light compared to the other materials and sizes. It has a factor of safety of over 2 and a deflection of under 0.6 in. Several other materials and sizes have better factor of safety or smaller deflection, however, it was determined that a factor of safety of over 2 and a deflection of less than 0.6 in is acceptable.

The next major piece of equipment is the spring. Earlier it was calculated that the force needed to be exerted by the spring is 925 lbf. Since only 95% of the work will be completed by the spring, the force needed to be exerted by the spring is actually 879 lbf. Equation 6-6 will be used to calculate what the spring constant is.

$$F = kx$$

Equation 6-6

The "x" term in the equation is the distance the spring will stretch. This distance is equal to the distance the piston arm must travel to open the roof. Figure 6-14 shows a more detailed diagram of the piston and the roof.

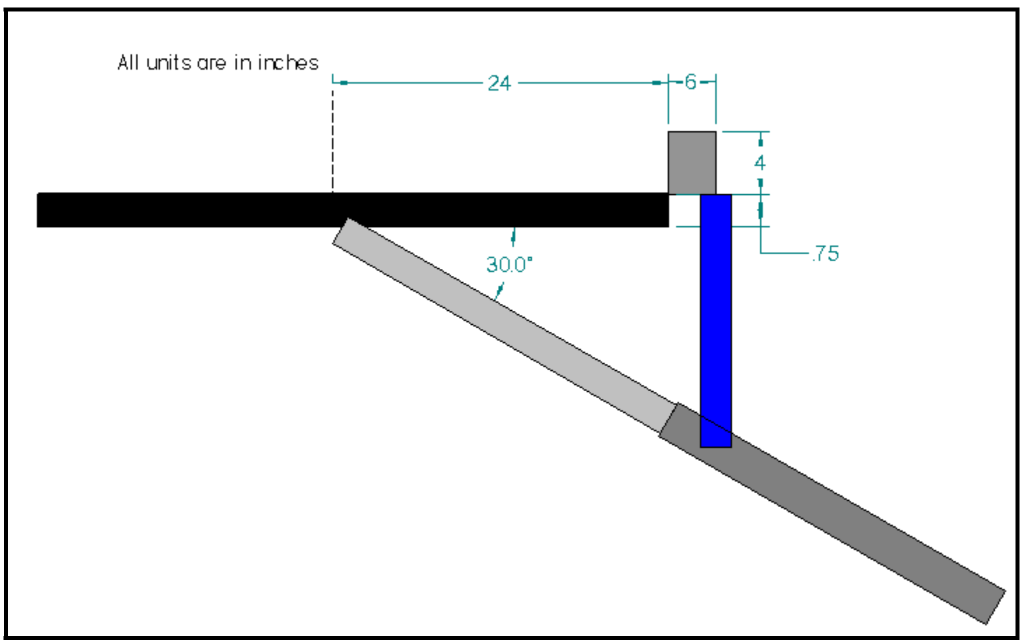

Figure 6-14: Piston Arm Schematic

In Figure 6-14, the roof is the black rectangle, the piston arm and housing are light gray and gray, respectively, and the blue vertical beam is one of the support beams. The other support beam is not shown in this diagram because it is not important for this exercise. Figure 6-15 is the triangle that was used to calculate how far the piston arm must travel to open the roof. The top line in the triangle is the distance from the connection of the piston arm to the support beam. This distance is 30 inches, which can be seen in the figure. It is known that the cylinder will be mounted at a 30-degree angle from the horizontal, so the distance the pin must travel and the length of the support beam can be determined.

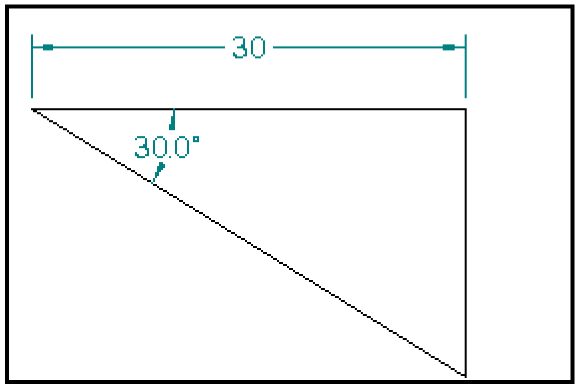

Figure 6-15: Geometric Representation of Piston Arm and Roof

Since this is a right triangle, the hypotenuse, which is the piston arm, can be calculated by using Pythagorean's Theorem. This distance was calculated be 34.5 inches, so the piston arm must travel at least this distance to fully open the roof. This value can be used in Equation 6-6 to determine what the spring constant needs to be. The spring constant must be 25.5 lbf/in for the spring to raise 95% of the roof. The length of the support beam can also be determined. This length was calculated to be 18.1 inches. Both of these calculations can be seen on page C-17 and C-18, respectively.

6.8 Cost Analysis

Part	Company	Part Number	Cost ($)	
Piston Arm	McMaster Carr	88935K84	$57.49	
Piston	ThumperStuff	NA	$101.00	
Spring	McMaster Carr	9662K15	$12.50	
Vertical Support Beam	McMaster Carr	88935K66	$58.73	
Angular Support Beam	McMaster Carr	88935K66	$58.73	
Cylinder Housing	Online Metals	6566K563	$47.10	
Wheel	McMaster Carr	2315T527	$6.57	
Pin	McMaster Carr	92735A510	$4.20	
Rod	McMaster Carr	9061K123	$23.10	**$369**

Table 6-5: Parts Analysis

6.9 Final Fall Design

Once the final parts and their sizes were known, the design was modeled using Pro-E. Figures 6-16 through 6-25 show the different components of the design. Figure 6-15 shows the entire exterior view of the design. The cylinder housing is shown in gray, the piston arm in green, and the support beams are also in gray. Figure 6-16 shows the interior of the design. The components can be seen in the following order and color: piston arm (green), piston (gray), and spring (light green). Figure 6-17 shows just the piston and the spring, Figure 6-18 shows the spring alone, and Figure 6-19 shows the piston arm alone. Figures 6-20 and 6-21 show both views of the piston. Finally, Figures 6-22 and 6-23 show the support beams connected to the cylinder housing. The part drawings and dimensions can be seen in Appendix D.

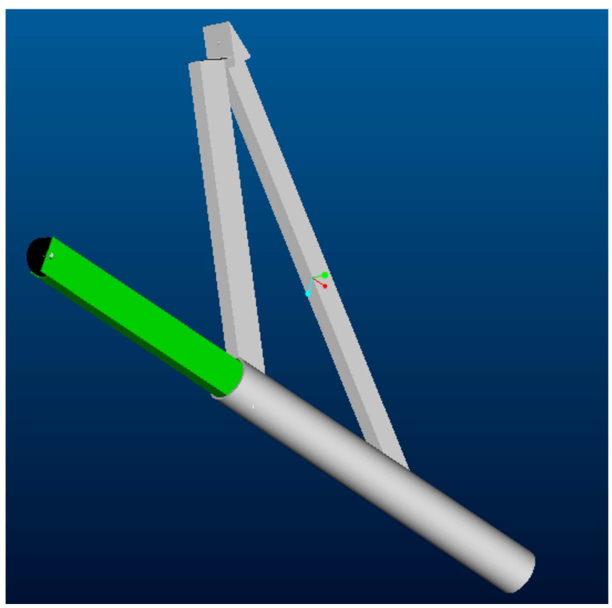

Figure 6-16: Exterior View of Design

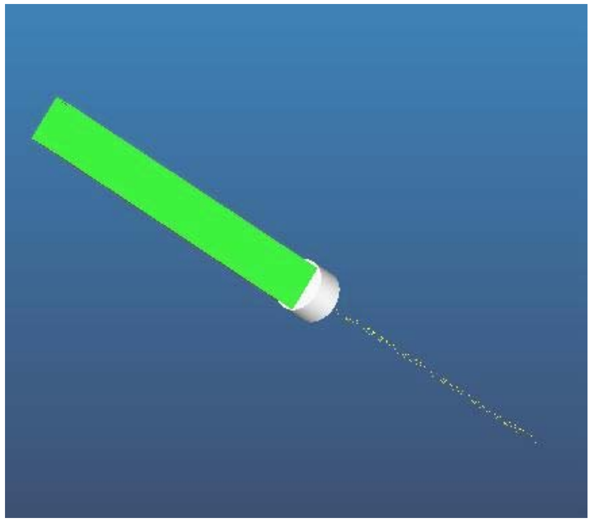

Figure 6-17: Interior View of Design

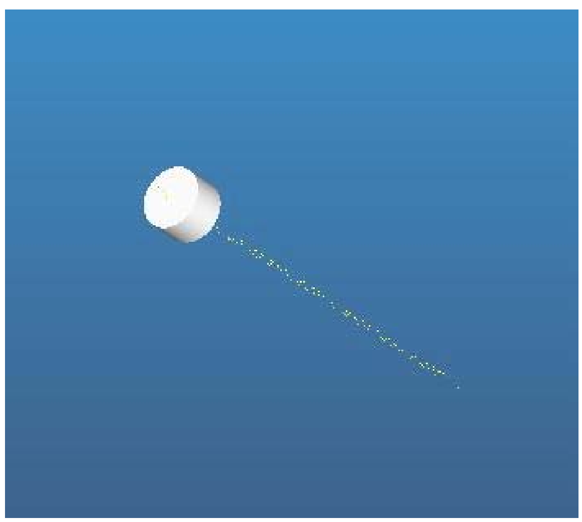

Figure 6-18: Spring and Piston

Figure 6-19: Spring

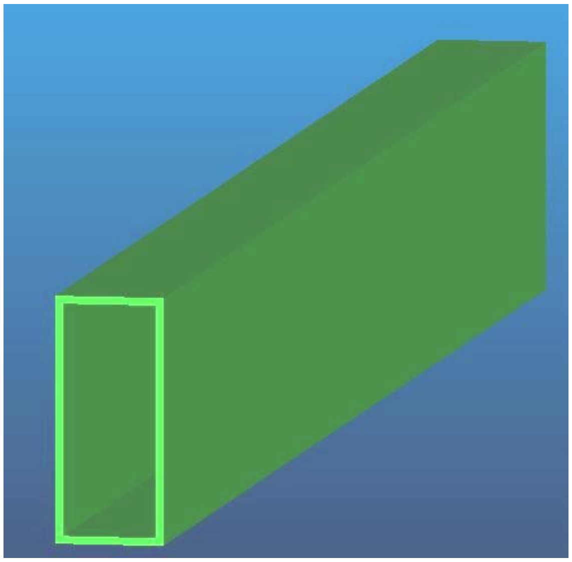

Figure 6-20: Piston Arm

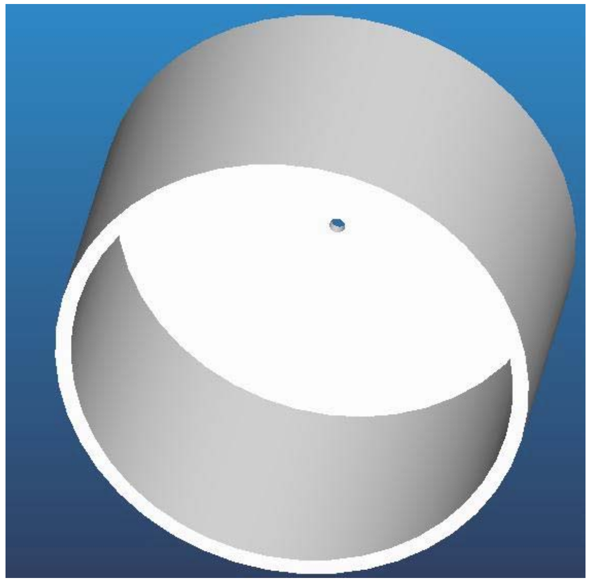
Figure 6-21: Piston (Bottom View)

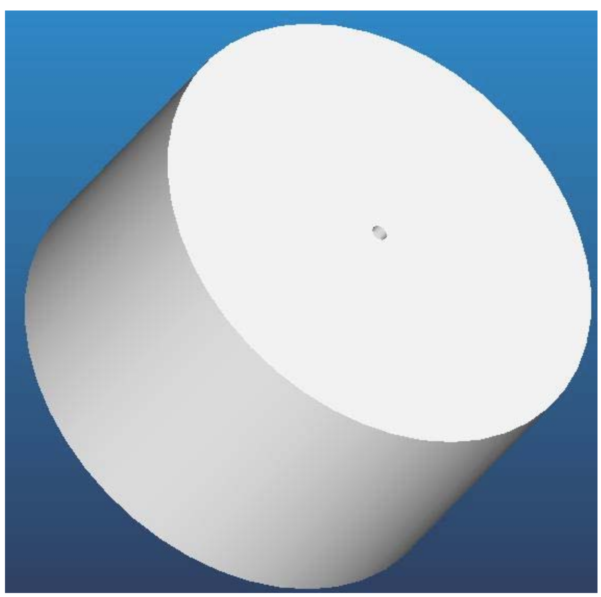
Figure 6-22: Piston (Top View)

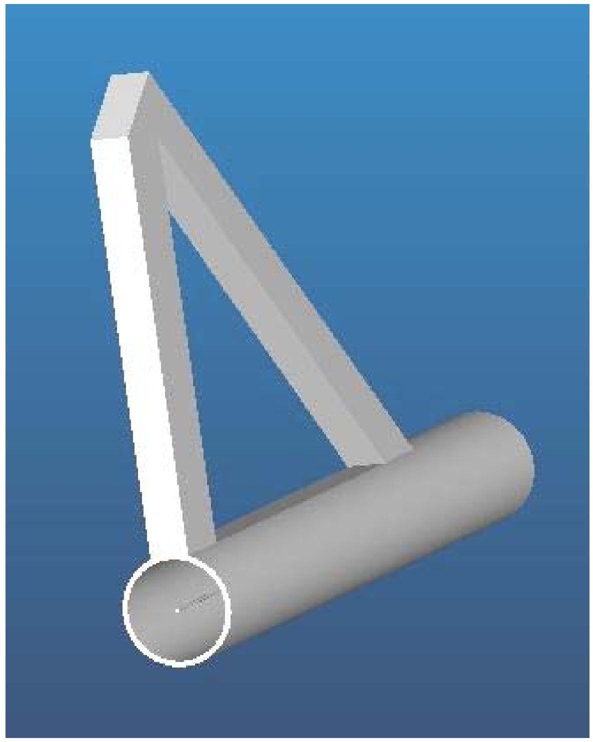

Figure 6-23: Support Beams Connected to Cylinder (Front View)

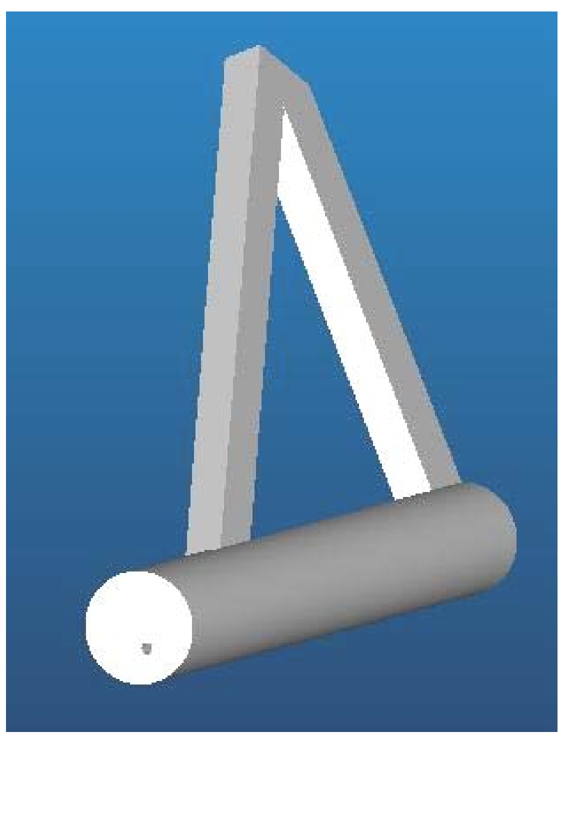

Figure 6-24: Support Beams Connected to Cylinder (Back View)

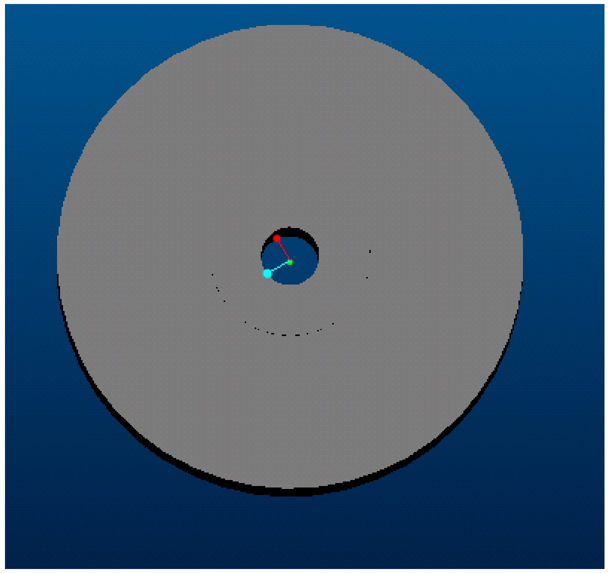

Figure 6-25: Roller Wheel

7.0 Spring Redesign

7.1 Modified Cylinder

Once our design was complete, it came to our attention by Dr. Cesar Luongo that there were some design flaws. Primarily, the spring will produce its maximum force when the least amount of force is needed and its minimum force when the most force is needed. The spring would rapidly swing the roof open at first, slow down to a halt, and then provide scarcely any support to the workers as they lift the roof the remaining distance. Since the object of this design is to assist the workers, forcing them to lift the entire roof at all, even a short distance, is not acceptable. Additional forms of power were discussed and researched and one of the constraints was lifted to help make a final decision.

It was decided that the design shown in Figure 6-6 is still adequate for what we need, however, it will be modified slightly. The spring will not be used because of the reasons stated above. Compressed air will be utilized to cause the motion of the piston, which will move the piston arm. Originally this approach was not considered because Lockheed Martin did not want to use compressed air, however, late in the design process they changed this constraint and this method became available. The air will come from an air container that can produce a maximum pressure of 160 psi. Figure 7-1 shows the new interior of the cylinder.

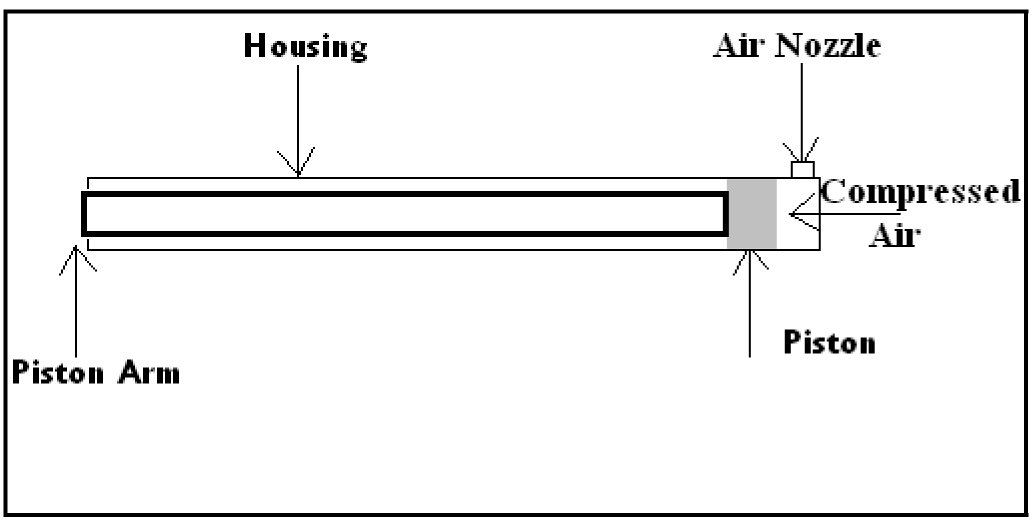

Figure 7-1: Schematic of Interior of Pneumatic Cylinder

A new calculation needed to be completed to determine how much pressure will be needed to open the roof. The forces needed to open the roof were calculated earlier, so to determine the pressure the force is divided by the area of the piston. Table 7-1 and Figure 7-2 show the pressure verses the angle of the roof.

Angle (deg)	Pressure (psi)
90	0
80	10.1
70	20.0
60	29.2
50	37.6
40	44.8
30	50.6
20	54.9
10	55.7
0	58.4

Table 7-1: Air Pressure Needed at Different Roof Angles

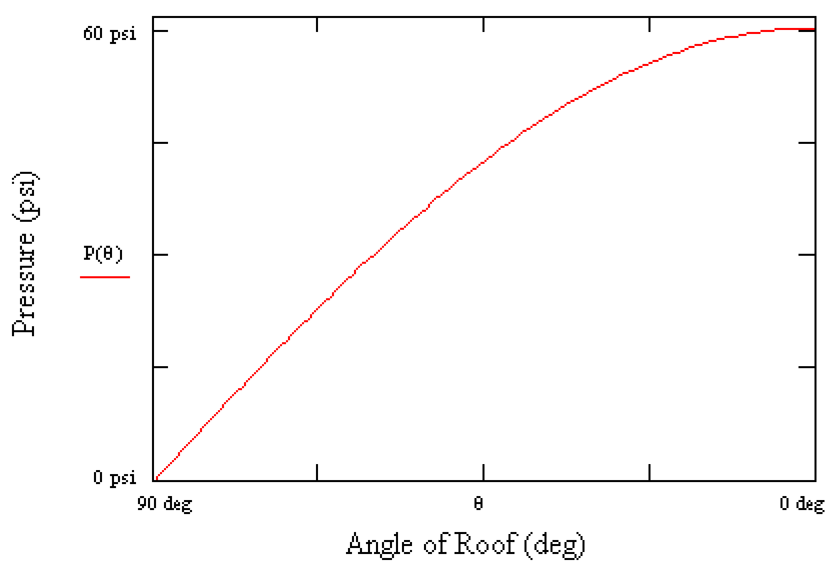

Figure 7-2: Angle of Roof vs. Pressure

Table 7-1 shows that the maximum pressure that will be needed to open the roof is 58.4 psi. The available air tank can exert a maximum pressure of 160 psi, so this tank can be used in our design. Figure 7-2 shows that as the angle of the roof increases, the pressure needed to open it also increases. Another reason why this approach is improved over the spring idea is that it can be controlled. Once the spring was unlocked, it could not be controlled. The air canister, however, has a valve that a worker can open and close and it has a pressure gauge, so the pressure can be monitored. The worker can start with a small pressure when the roof is closed and increase it as it is needed.

Once the pneumatic cylinder idea was reviewed and accepted by the team, the question of whether to build or buy one came up. Originally the idea was to build a pneumatic cylinder and test it within our design. We eventually decided against this because of the complexity of designing and building a pneumatic cylinder. We agreed that it would be very difficult to machine a perfect pneumatic cylinder that did not leak without the proper tools and machinery. Because of this, we decided to purchase one from McMaster Carr. Our main concern was that if we built a pneumatic cylinder and our design failed to work, there would be two possibly reasons. The device could have been poorly designed or the pneumatic cylinder could have been poorly constructed. Since our concern is to build a device that can lift the roof of the VCCT and not whether or not we can construct a pneumatic cylinder, we decided to purchase one that we could have confidence in. So if the device did not work, we would know that it was designed poorly. This will allow us to spend all of our time testing and improving our design.

7.2 Redefined Scope

At the beginning of the spring semester all involved with our project decided to redefine the scope of the project. It was agreed upon to build a scaled down model of our design. Several reasons caused this change in the scope. First of all, since the actual VCCT trailers are located in Orlando and Army bases around the world, testing any device would be extremely tedious because a 4-hour drive would be required. Even if a VCCT trailer were somewhere local, there would still be issues. Since the program is a Department of Defense contract, any modification to the trailer would require months of safety inspections. Finally, once the safety inspections are complete, Lockheed Martin would require approval from their engineers before any modifications to the VCCT trailer could be conducted. This too could possibly take several months to complete. So even if our design passed all of the safety inspections and the lead engineers assigned to the VCCT signed off on it, we would not be around to test our design. To solve these issues, a 1/5 scaled down version of the VCCT trailer and our design will be fabricated and tested. This will allow us to build our design, test it, and fix any problems that may occur. This approach will assist in designing the best possible device for Lockheed Martin. Once our model is complete, it will be up to Lockheed Martin to decide if they want to build and test a full-scale version.

7.3 New Design Setups and Concerns

Now that the main design is complete, three different support designs will be modeled and tested to see which one is the best possibly solution. The cylinder will be supported by the trailer's main support beam shown in Figure 7-3 (in blue) and Figure 7-4 and the piston arm will be connected to the roof. These two supports will be varied to determine the best possible connections for our design. The main questions are whether or not the cylinder should be free to rotate as the roof rises or stationary and whether or not a rigid or non-rigid connection should connect the roof to the piston arm. Three support designs described below will be constructed and tested.

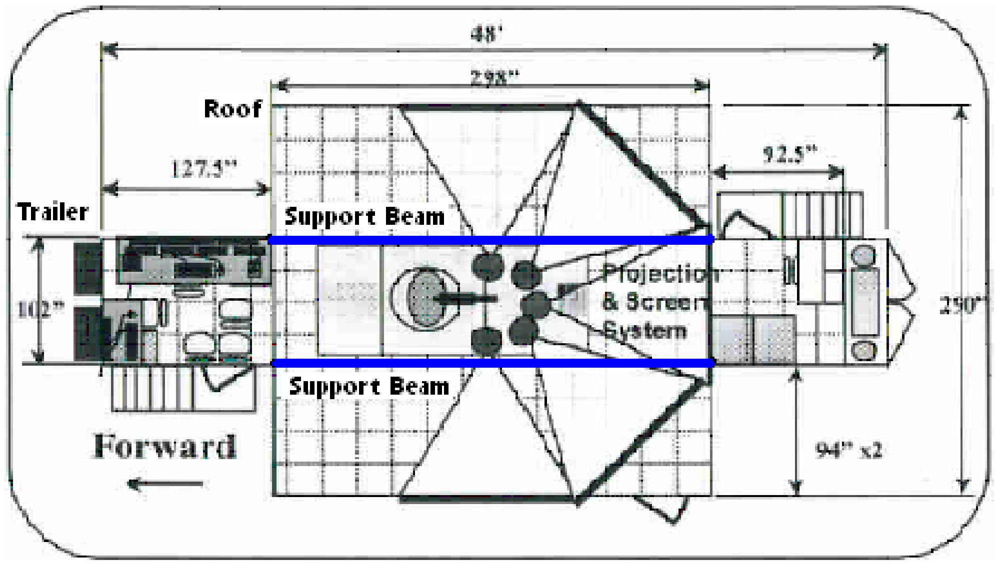

Figure 7-3: Schematic of VCCT

Figure 7-4: Picture of Trailer's Main Support Beam

Support Option 1: 30 degree, non-rigid connection to roof

Other than the switch from a spring-loaded cylinder to a pneumatic cylinder, the design completed at the end of the fall semester will be constructed and tested. The cylinder in this design will be mounted onto the trailer's main support beam at a 30-degree angle and will be connected to the roof by a free rotating wheel. The 30-degree angle was calculated to be the best position for the cylinder to overcome the weight of the roof. These calculations can be seen on page C-6. The wheel will be connected to the piston arm and provide a non-rigid connection to the roof. As the roof opens, the wheel will be free to move. There are several possible pitfalls of this design. As the roof opens, the piston arms may move too far down the roof, which could leave the roof less than 90 degrees. Also, the fabrication of the main support beams will be difficult to complete because they need to be at a certain angle. It is very difficult to manufacture something that has such strict requirements. It certainly would be possible for Lockheed Martin however we want to design something that can be made in common machine shops. Figures 7-5 and 7-6 show what these two connections will look.

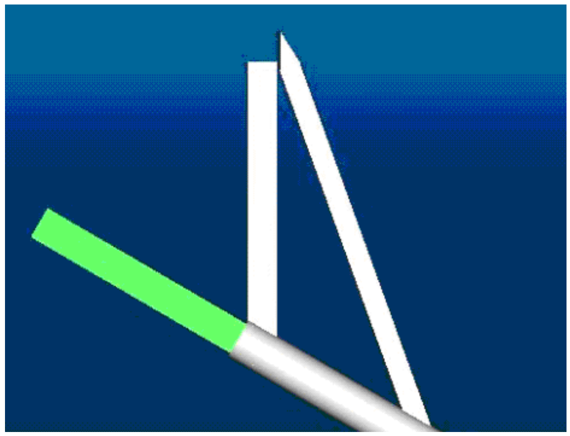

Figure 7-5: 30-Degree Support

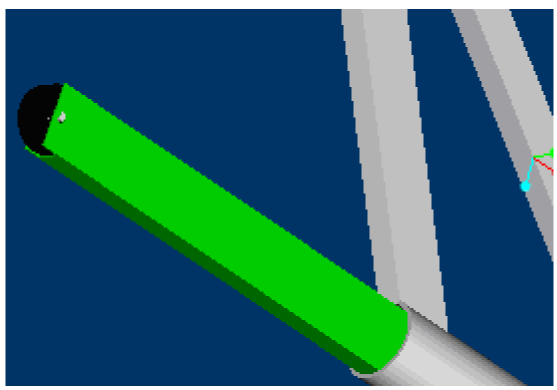

Figure 7-6: Piston Arm to Roof Connection: Wheel

Support Option 2: Hinge connections on cylinder and roof (L-support)

This design differs slightly to the above one in that the support beams will allow the cylinder to freely rotate. The cylinder support beam will be an L-shaped bracket. This bracket will be connected to the cylinder by a hinge, which will allow the cylinder to rotate. The connection of the piston arm to the roof will also be a hinge, which will allow that connection to rotate as well. The cylinder will be allowed to rotate as the roof swings open. The main problem with this support structure is that as the roof swings up, the back of the cylinder will swing down. In the actual design a Hummer is in the trailer, so the cylinder can only swing down so low. Also, it may be impractical to use a hinge connection on the roof in the actual design.

Support Option 3: Hinge connection on cylinder and clevis connection on roof (Horizontal L-support)

This design is different from the above two in that the cylinder will have a much smaller angle and will not be allowed to rotate as much. A horizontal L-shaped support will be used to connect the main support beam to the cylinder. This bracket will be hinge connected to the foot bracket of the cylinder, which will allow slight movement by the cylinder. The piston arm will be connected to a triangular connection by a clevis rod. This will allow the piston arm to rotate as the roof opens, causing the cylinder to rotate less. The triangular connection will be connected to the roof. This should keep the back of the cylinder high enough from hitting the Hummer. One possible problem with this design is that the cylinder will need to be at a slight inclined angle to start the motion. The back of the cylinder may hit the top of the trailer as the roof starts to open. This idea is the best use of the force of the cylinder because when the roof is fully open and requires the most force, the piston arm is perpendicular to the triangular support, so its mechanical advantage is highest at this point. The free body diagram of this setup can be seen on page C-23. Figure 7-8 shows the support structure and the colors represent the following: horizontal L-bracket is red, hinge is green, and foot bracket is orange.

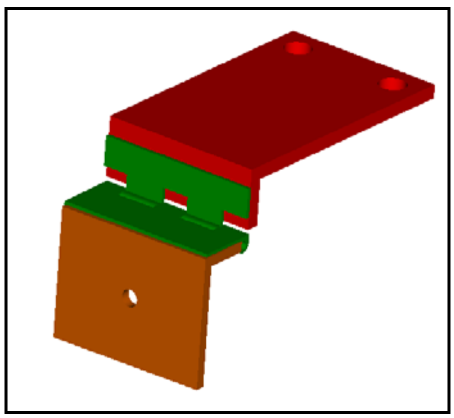

Figure 7-8: Horizontal L-Support Beam and Hinge

7.4 Final Design

Once the final part sizes were known, the design was modeled using Pro-E. Figures 7-9 and 7-10 show the final design. Support Option 3 was determined to be our best option and that one was completely modeled. The other two options will be fabricated and tested just to exhaust all of our options and to make sure that we chose the best one. The colors in the pictures are as follows: the frame is blue, the roof is white, the floor of the trailer is black, the Hummer is tan, the triangular support piece is yellow, the cylinder is red and the support beam is also red. The support beam can be seen in more detail in Figure 7-8. Figure 7-11 shows a zoned in picture of the piston arm to roof support structure. The part drawings and dimensions can be seen in Appendix D.

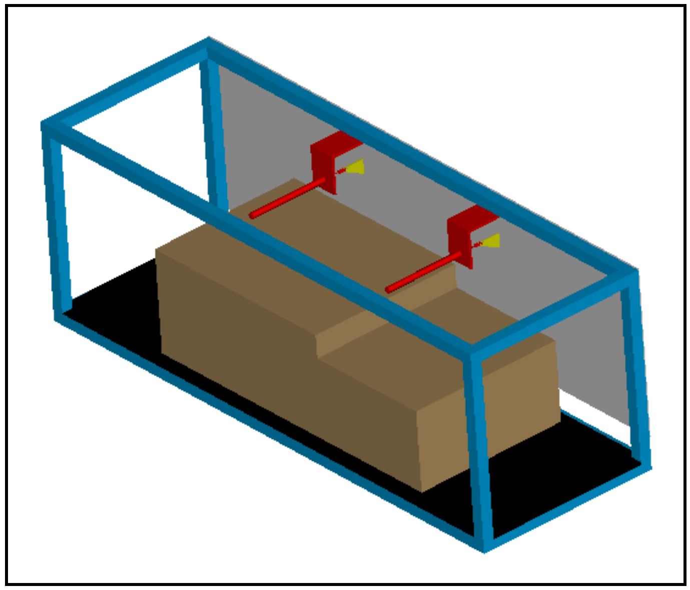

Figure 7-9: Final Design

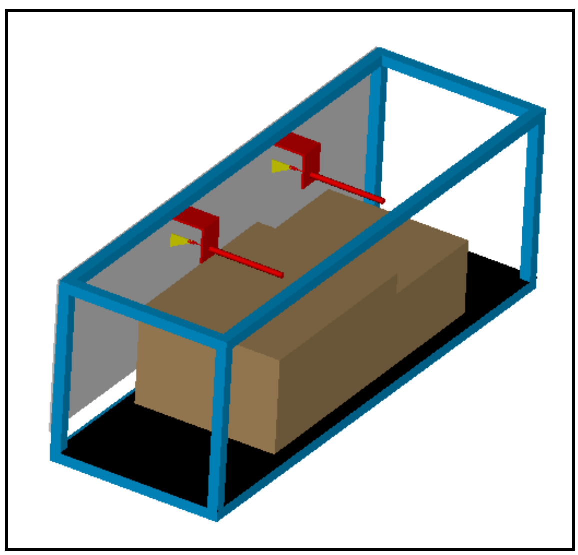

Figure 7-10: Final Design

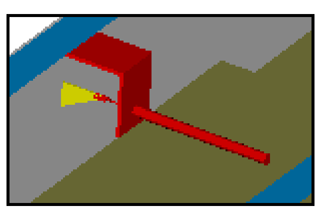

Figure 7-11: Piston Arm to Roof Connection

7.5 Finite Element Analysis of Support Beams

A finite element analysis was performed on Support Options 2 and 3 to reassure us that they will not bend under the current load. Figures 7-12 through 7-14 are for Support Option 2. The two red lines in all of the figures represent where the beam will be bolted into the main trailer support beam. Figure 7-12 shows the maximum principle stresses, which is also known as the normal axial stress. For the most part, very little stress will be felt, approximately 5 psi. Figure 7-13 shows the von Mises stress, which is used to estimate the yield criteria. It is calculated by combining stresses in two or three dimensions, with the result compared to the tensile strength of the material. As can be seen, the von Mises stress will be high where the bracket is bolted to the support beam, but it is very low where the cylinder will be connected and this is the area that concerns us. Figure 7-14 shows the displacement of the beam and, as seen in the figure, the maximum the beam should deflect is only 0.0013 inches, which is not a problem.

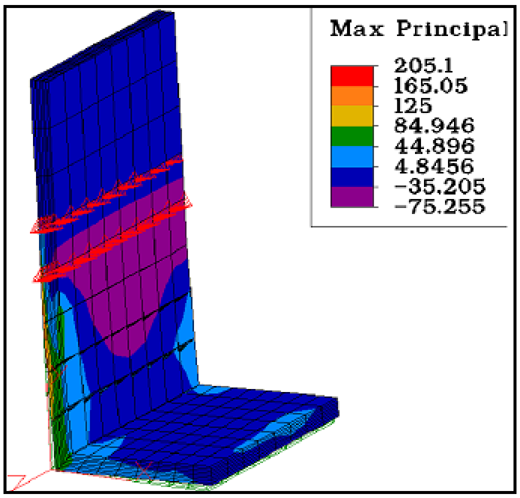

Figure 7-12: Maximum Principal Stress of Support Option 2 (in psi)

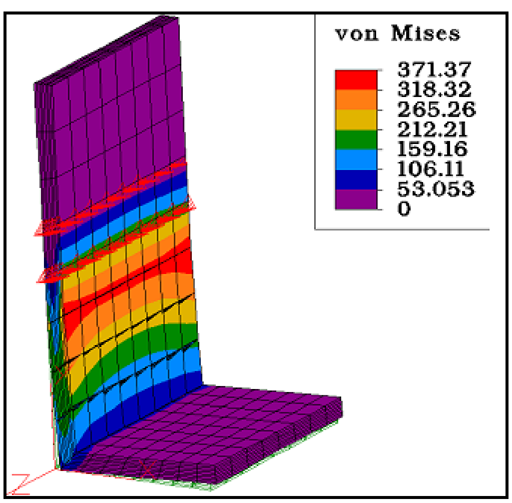

Figure 7-13: von Mises Stress of Support Option 2 (in psi)

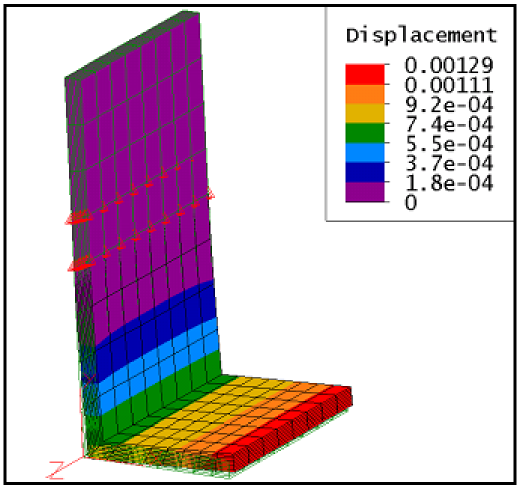

Figure 7-14: Maximum Displacement of Support Option 2 (in inches)

Figures 7-15 through 7-17 show the FEA of Support Option 3. These figures, however, are for the actual size bracket and not for the model and it was assuming a factor of safety of 1.5. Since we were adamant that this option was the best, we decided to make sure that this bracket could work for the actual trailer. Figure 7-15 shows the maximum principal stress, Figure 7-16 shows the von Mises stress and Figure 7-18 shows the maximum displacement. The bracket will feel a large amount of force because the roof weighs 500 pounds. Figure 7-18 is the important picture to look at because it tells us how much the bracket will bend. The maximum displacement is approximately 0.025 inches, which is reasonable.

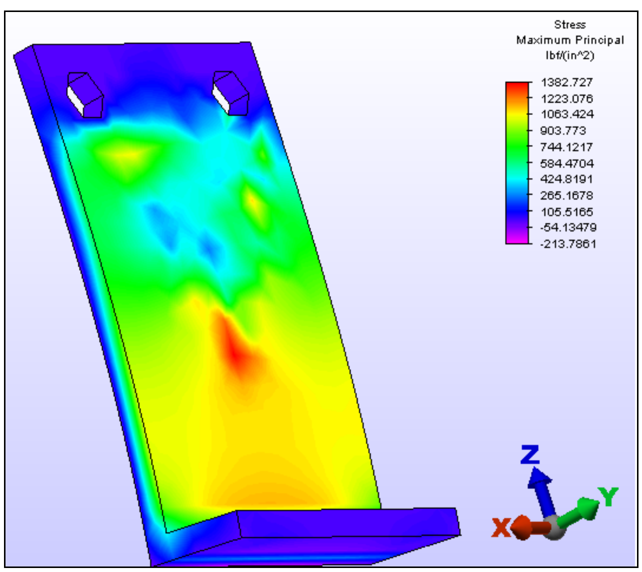

Figure 7-15: Maximum Principal Stress of Support Option 3 (in psi)

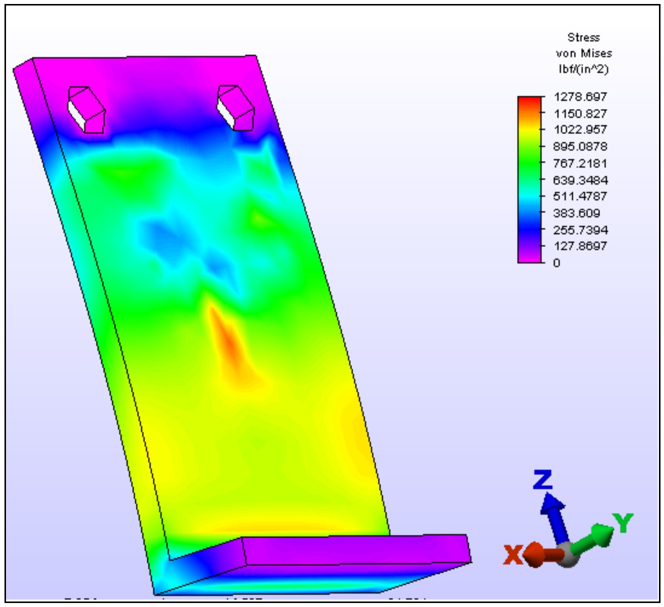

Figure 7-16: von Mises Stress of Support Option 3 (in psi)

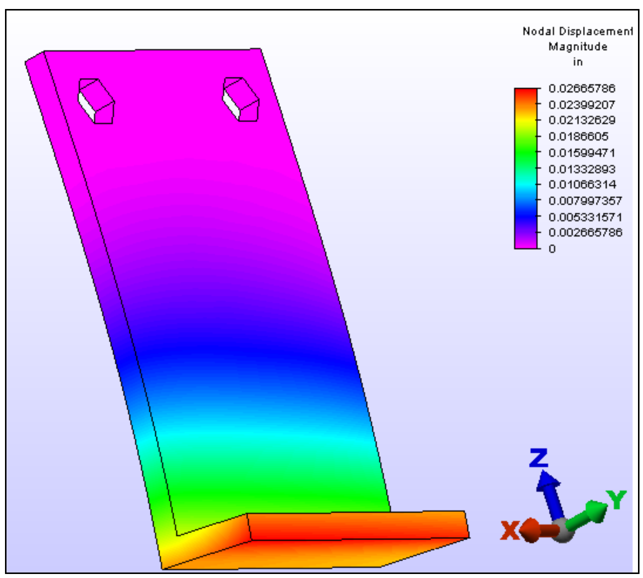

Figure 7-17: Maximum Displacement of Support Option 3 (in inches)

8.0 Fabrication

8.1 Construction of Frame and Roof

Once the needed materials were purchased, the frame was ready to be built. It was agreed upon to first construct the frame because this is essentially the base of the design. The measurements of the frame were taken from the schematic in Figure 7-3 and reduced by 1/5 to provide the dimensions for our scaled down frame. Our frame was approximately 5 feet long, 1.6 feet high, and 1.7 feet width. Steel square tubing at 1.2 inches per side was used to construct the frame. These pieces were cut and welded together to form the frame. The process of constructing the frame was as follows: 1) Cut the pieces into the desired lengths, 2) Weld the pieces together, and 3) Grind the welds to create a smooth surface. Figures 8-1 through 8-3 show this process.

Figure 8-1: Welding the Frame Together

Figure 8-2: Grinding the Welds

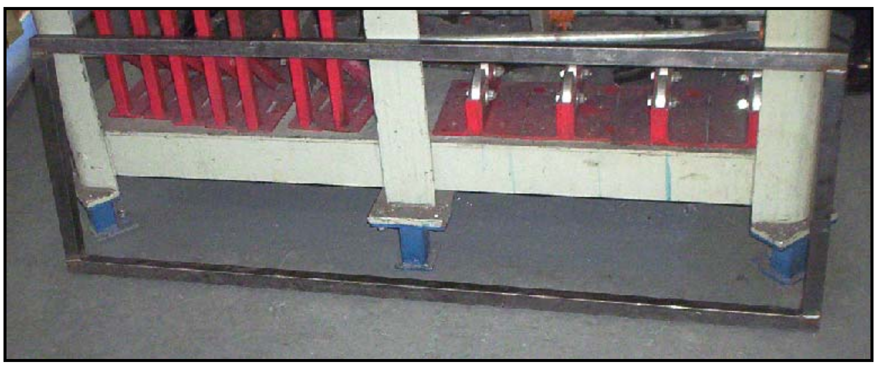

Figure 8-3: One of the Completed Sides of the Frame

Once the frame was completed, the roof of the simulator was our next project. The dimensions of the roof were taken from the schematic in Figure 7-3 and scaled down just as the frame was. The dimensions of the roof are 5 feet long, 1.5 feet high and 0.25 inches thick. The most important dimension of the roof is the weight, which is actually 500 pounds, so for our scale model it will need to be 100 pounds. The material of the actual roof could not be used because it is a special composite that Lockheed Martin has specially designed. Our first idea was steel, but the problem with using steel is that it has a lower density than the composite material used. A piece of black iron steel at the dimensions needed was only 50 pounds. Since the weight is our main concern, we decided to double the thickness of the roof to 0.5 inches so it weighed 100 pounds. We originally purchased a piece of black iron steel at quarter thickness, so all we did was buy an exact replica and welded the two pieces together. This gave us a roof that was 1.5 high, 5 feet long and 0.5 inches thick, but with a weight of approximately 100 pounds. The actual roof is connected the main trailer support beam by a hinge. We looked into several different types of hinges and settled on simple door hinges. We welded 4 door hinges to the frame and to the roof to connect the two pieces. Figure 8-4 shows a picture of the final roof and frame structure.

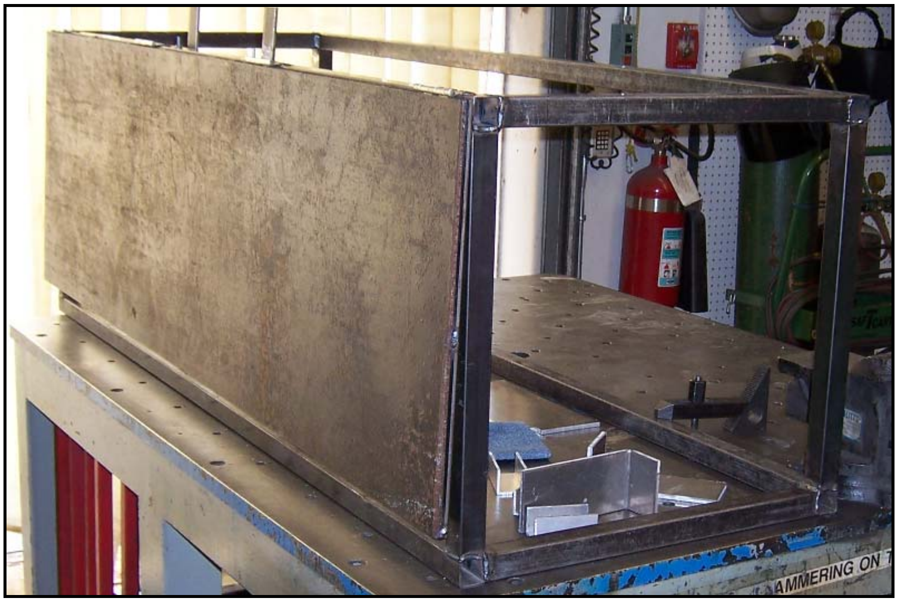

Figure 8-4: Frame and Roof Structure

8.2 Pneumatic Cylinder

The pneumatic cylinder was purchased from McMaster Carr. Figure 8-5 shows a picture of the pneumatic cylinder and Figure 8-6 shows a schematic of it.

Figure 8-5: Pneumatic Cylinder

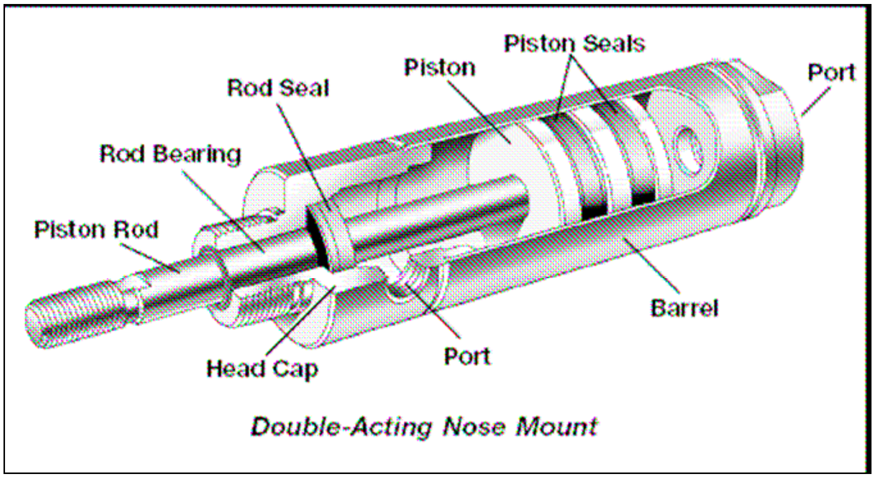

Figure 8-6: Schematic of Pneumatic Cylinder

The important dimensions of the cylinder selected can be seen in Table 8-1.

Stroke	8 in
Bore	2 in
Total Retracted Length	13.5 in
Weight	6 pounds
Port and Piston Rod	¼ inch threads
Maximum Pressure	250 psi
Force Exerted at 130 psi	400 lbf

Table 8-1: Important Cylinder Information

The important information to get out of Table 8-1 is that the stroke length is 8 in and the force exerted at 130 psi is 400 lbf. The stroke length is important because the minimum stroke required, which was calculated on page C-16, is 35 inches. When scaled down, the stroke should be 7 inches, but we went to 8 just to be safe. The compressor that was purchased has a maximum pressure of 130 psi, so that is why it is important to know how much force is exerted at 250 psi.

8.3 Construction of Support Beams

As mentioned earlier, three different support beams will be tested to determine the best one. The consensus of the group is that Support Option 3 will be the best however we want to look at different types. The support beams that will connect the cylinder to the trailer's main support beam and the connection of the piston arm to the roof will be discussed in the following sections. All of the support beams will be made out of aluminum because we want the weight of these to be as minimal as possible.

8.3.1 Support Option 1

This support beam was the most difficult to manufacture. The reason for this is because it needed to be fabricated at a 30-degree angle. Figure 8-7 shows a picture of this support beam. It is a very basic design consisting of two ¼ inch aluminum plates welded together at a 30-degree angle. A block was wedged in between the two plates to ensure that the angle would remain at 30. Two rectangular pieces were cut out of a ¼ inch aluminum plate to create the support posts, which were welded onto the 30-degree support. One support post was vertical and one was angular. The support posts were welded to an elbow bracket, which connected the whole piece to the trailer's main support beam. Two screws were used to connect this piece; one in the vertical direction and one in the horizontal direction. Figure 8-8 shows it connected to the main support beam

Figure 8-7: 30-Degree Support

Figure 8-8: 30-Degree Support Connected to Main Support Beam

The cylinder was bolted to the bottom of these supports with the help of a foot bracket. Figure 8-9 shows a picture of the cylinder bolted to a foot bracket. Bolts were now used to connect the foot bracket to the support beam. This setup kept the cylinder at a 30-degree angle as the roof swung open. The piston arm, which had a wheel screwed on the end, had a free connection to the roof. This allowed the wheel to freely move up and down the surface of the roof.

Figure 8-9: Cylinder Connected to Foot Bracket

8.3.2 Support Option 2

Our second option is different from the first, in that, it will allow the cylinder to rotate and the piston arm to remain stationary. An L-bracket support will be used to connect the main support beam to the cylinder. This beam will be made out of aluminum to reduce weight and a rough version can be seen in Figure 8-10.

Figure 8-10: L-Bracket Support

This support will be bolted to the main support beam with two screws; one in the vertical direction and one in the horizontal direction. This bracket will be connected to the cylinder by a hinge. This will allow the cylinder to rotate freely as the roof swings open. The hinge will be bolted to the foot bracket, which will be bolted to the cylinder. Figure 8-11 shows a picture of the cylinder and hinge setup.

Figure 8-11: Cylinder and Hinge Setup

Another hinge will be connected to the roof to provide a connection for the piston arm. The piston arm will be screwed into a nut, which will be welded onto this second hinge. Figure 8-12 shows a picture of the entire L-bracket support system.

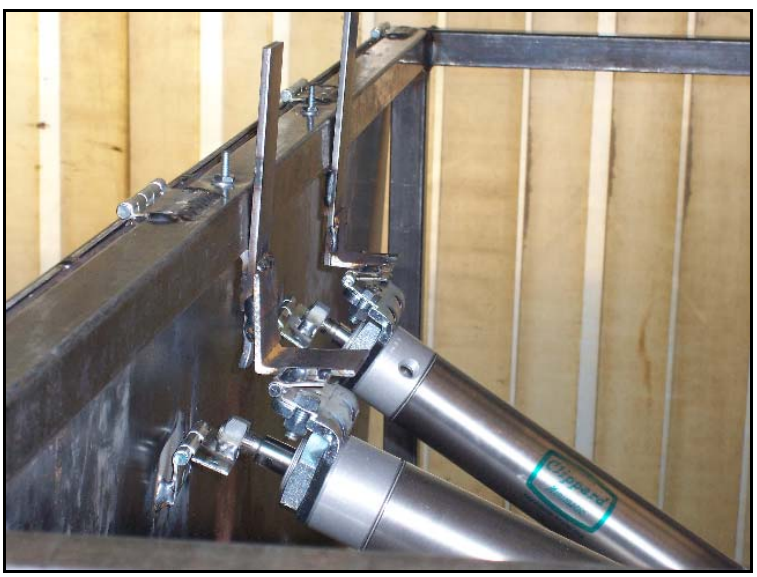

Figure 8-12: Final Setup of Support Option 2

8.3.3 Support Option 3

Our third option differs from the first two, in that the cylinders will not start at a 30-degree angle. The cylinder will actually be angled slightly down. A horizontal L-bracket will be used to connect the cylinder to the main support beam. As in Support Option 2, the cylinder will be bolted to the foot bracket, which will be bolted to the hinge. The hinge will be bolted to the horizontal L-bracket. This setup can be seen in Figure 8-13. Two vertical screws will bolt the horizontal L-bracket to the trailer's main support beam.

Figure 8-13: Horizontal L-Bracket Support

The connection of the piston arm to the roof is also unique from the first two options. A triangular piece of steel will be connected to the roof. Figure 8-14 shows this piece welded to the roof. This triangular piece will act as a lever arm and will increase the mechanical advantage of the piston arm.

Figure 8-14: Triangular Connector Attached to the Roof

A clevis rod will be screwed on the piston arm (Figure 8-15), and pin connected to the triangular connector (Figure 8-16). The clevis rod will allow the piston to rotate as the roof swings open. Figure 8-17 shows a picture of the entire setup.

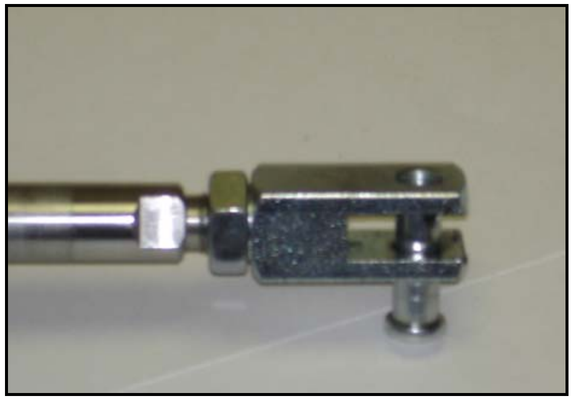

Figure 8-15: Clevis Rod Connected to Piston Arm

Figure 8-16: Clevis Rod Connected to Triangular Connector

Figure 8-17: Final Setup of Support Option 3

8.4 Air Connections

Once the cylinders are attached to the trailer, hose connections are needed to provide the air pressure. A Husky compressor was purchased at Home Depot that has a maximum pressure of 130 psi and a 6-gallon tank (Figure 8-18). This provides us with more than enough pressure and enough air to keep the compressor turned off during test runs. Since we will have 2 cylinders running off of one compressor, a splitter will be needed to distribute the air (Figure 8-19).

Figure 8-18: Compressor

Figure 8-19: Air Splitter

Three hose connections will be needed; two to connect the hose to the cylinders and one to connect the hose to the compressor. We decided to go with quick connect hose connections (Figure 8-20). These are beneficial because we won't have to screw/unscrew the connectors every time we want to install/uninstall the cylinders.

Figure 8-20: Quick Connect Hose Connectors

The quick connect hose connectors will connect to the cylinders by a hose fitting (Figure 8-21). These are not normal hose fittings however. These fittings are safety fittings. They act as a one-way damping valve. The air can pass through in one direction unscathed, but is dampen when it tries to pass through the other direction. This occurs because a small ball bearing, located inside of the fitting, is "pushed" out of the way when the air is moving from the female side to the male side and "clogs" up the hole when the air tries moving in the opposite direction. In our design, these fittings will allow the air through unscathed when the roof is lifting and dampen the air when it is closing. This will add to safety of the design because if there is a sudden loss of pressure, i.e., a hose is punctured or the compressor is damaged, the roof will slowly fall to its initial position instead of slam down as it currently does. A 90-degree fitting allows the hose to come into the cylinder from any direction. Figure 8-22 shows the entire hose setup.

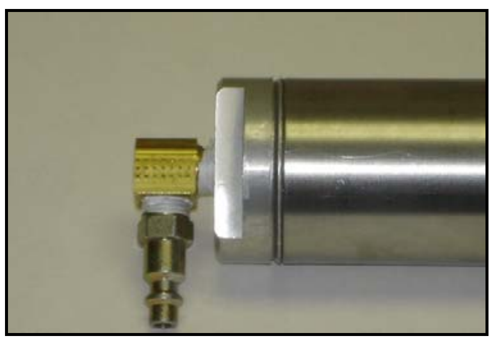

Figure 8-21: Safety Hose Fittings

Figure 8-22: Final Hose Setup

8.5 Quick Release Ball Pins

One of the main goals of this design is to decrease the number of personnel setting up and tearing down the roof of the trailer. To expedite this process, quick connect ball pins (Figure 8-23) will be used. These pins will be used instead of bolts because they will reduce most of the setup and teardown time of screwing in bolts. These pins are safety pins, in that they have a cone that protects the push button from inadvertently being pushed. To make this setup possible, two small steel rods (Figure 8-24) will be needed to "act" as bolts for the horizontal L-bracket to connect to. The ball pins will then be inserted underneath the horizontal L-bracket to support them. Another ball pin will be used to connect the clevis rod to the triangular piece. The final setup can be seen in Figure 8-25.

Figure 8-23: Quick Release Ball Pins

Figure 8-24: Steel Rod Setup

Figure 8-25: Final Quick Release Setup

8.6 Cost Analysis

Table 8-2 shows the cost analysis of the final design. This does not account for material not used, but only for the material that will be used in the final design. The total amount spend was $766.53, which is well below our budget of $2,000.

Part	Company	Cost ($)	
Steel Tubing	McMaster Carr	$18.69 (x7)	
¼ in. Steel Plate	Kelly's Steel	$130.00	
Hinges	Home Depot	$3.50 (x2)	
Pneumatic Cylinder	McMaster Carr	$68.78 (x2)	
Cylinder Foot Brackets	McMaster Carr	$5.35 (x2)	
Clevis Rods	McMaster Carr	$4.47 (x2)	
Air Tank	Home Depot	$130	
Roof Support	Kelly's Steel	$10.00	
Cylinder Support: Rod	Tallahassee Welding	$1.00	
Cylinder Support: Beam	Metal Fabrication	$20.00	
¼ in. Quick Release Pin	McMaster Carr	31.50 (x2)	
3/8 in. Quick Release Pin	McMaster Carr	$31.50 (x2)	
Balsa Wood	Home Depot	$30.00	
Safety Tube Connector	Capital Rubber	$9.50	
Spray Paint	Home Depot	$15.00	**$766.53**

Table 8-2: Final Cost Analysis

9.0 Testing

9.1 Support Beam Test

Once our design was fabricated, the three support beam options needed to be tested. The following test questions were asked and determined for each option:

1. Does the cylinder hit the Hummer?
2. Does the roof open to at least 90-degrees?
3. Is there any yielding on the support beams?

When Support Option 1 was tested, two of the three answers to the test questions were negative. In this case, the cylinder was held at a 30-degree angle, so it did not come into contact with the Hummer. The most noticeable problem, however, was that the roof only raised approximately 75-degrees. It was observed that as the roof swung open, the wheel began to slide too far down the roof and the piston arm became fully extended. A solution to this problem would have been to purchase a pneumatic cylinder with a longer stroke length, however, this would add to the overall length of the cylinder. We are trying to keep the cylinder as small as possible, so this was really not an option. Also, the vertical and angular support beams were clearly yielded. This was a problem because we want to design something that can work for a long period of time. Not something that will need maintenance or repairs. For these reasons Support Option 1 was not considered for the final design.

When Support Option 2 was tested, only one test question was negative. In this case, the cylinder was free to rotate and the roof to piston arm connection was rigid. This allowed the cylinder to raise the full 90-degrees with still some stroke length to spare. The support beams also showed no signs of yielding or strain at all, so they were absolutely strong enough. The problem with this setup was that the back of the cylinder came too low as the roof was swinging open. At that particular height, it would come into contact with the Hummer. For these reasons, Support Option 2 was not considered for the final design.

Support Option 3 was theorized to be the best option and the testing supported that. The beams handled the load fine and the roof lifted over 90-degrees. Also, since this setup causes the cylinder to rotate less and start higher, it will not come into contact with the Hummer. It only required 7.5 inches of stroke, so a smaller cylinder could have actually accomplished the job. This idea is also the best use of the force of the cylinder because when the roof is fully open and requires the most force, the piston arm is perpendicular to the triangular support, so its mechanical advantage is highest at this point. So at the moment the trailer requires the most force, the cylinder can provide the highest mechanical advantage. For all of these reasons, Support Option 3 was used for the final design.

9.2 Safety Test

One of the two most important goals for this design was to increase the safety of setting up and tearing down the roof. To accomplish this, the safety hose fitting (Figure 8-21) will be used. This fitting will allow the air to flow from the compressor into the cylinders to raise the roof. However, it will dampen the flow from the cylinder back into the compressor. This will cause the roof to fall slowly whether or not it is connected to the compressor. Once the final design was complete, several different tests were conducted to make sure that the roof would never fall uncontrollably. For example, one test entailed us lifting the roof to its maximum height and then simultaneously unplugging both quick connect hose connectors (Figure 8-20) from the cylinders. This simulated if the compressor unexpectedly shut down or if the hoses were somehow damaged. The roof stayed at 90-degrees for a few moments, and then slowly closed. The closing process took 1-2 minutes to complete, so if anyone were in the way, they would have plenty of time to reach safety. Another test conducted was to increase the pressure at a very fast rate and then decrease it at a very fast rate. The cylinder responded well by lifting the roof to its maximum position and then slowing dropping it to its rest position. The cylinders responded well for all of the tests, so they were all considered successful.

10.0 Final Design

10.1 Scale Model

Figures 10-1 through 10-5 show pictures of the final scale model .As mentioned above, Support Option 3 was considered the best option and will be used on the final design.

Figure 10-1: Final Scale Model

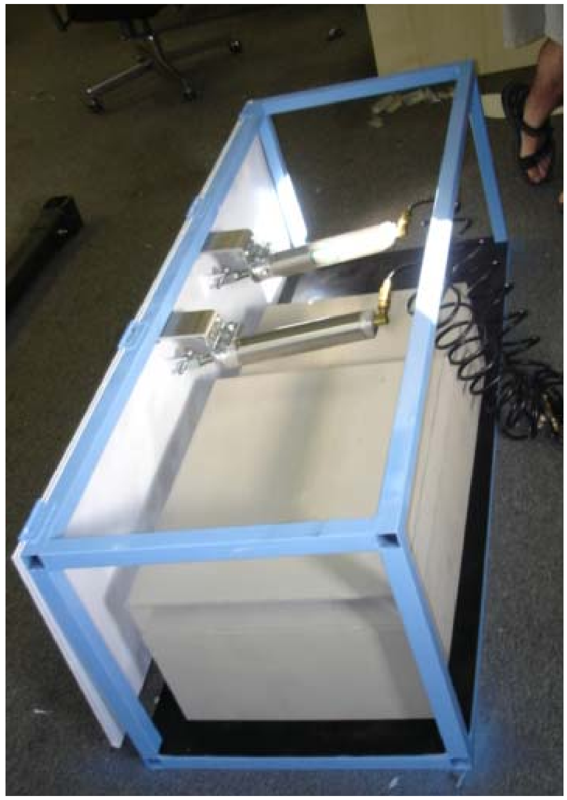

Figure 10-2: Final Scale Model

Figure 10-3: Final Scale Model

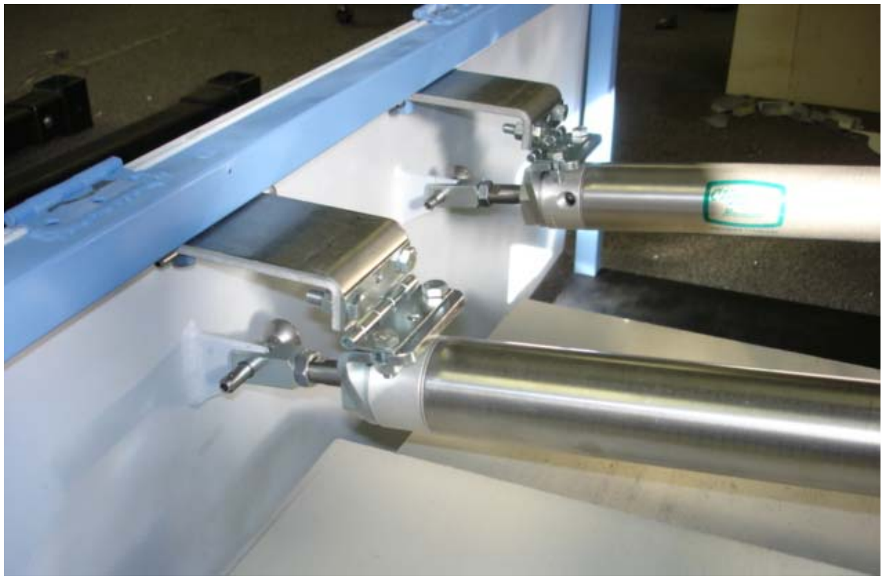

Figure 10-4: Final Scale Model

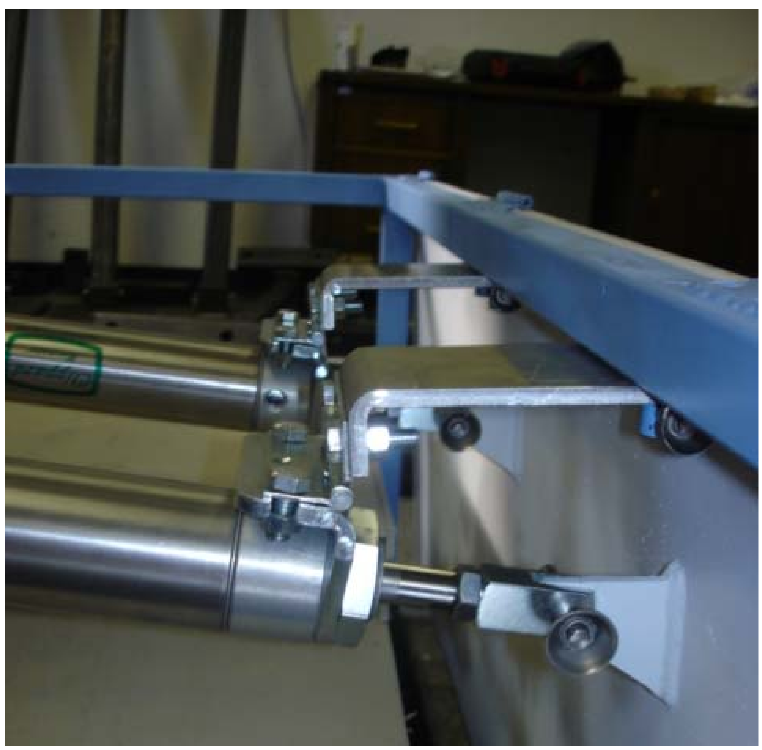

Figure 10-5: Final Scale Model

10.2 Actual Model

The scaling of this design is very simple and Lockheed Martin should have no trouble scaling up our design. The following parts can just be scaled up by 5 (Engineering Drawings are in Appendix D): triangular support, horizontal L-bracket, and steel rods. These are the only parts in the design that are independent of the size of the cylinder. Now the actual cylinder will be much smaller than our current cylinder scaled up by 5. The only part of the cylinder that needs to be scaled up exactly is the stroke length. The actual cylinder that could be used is seen in Figure 10-6. This cylinder has a bore of 3 inches, stroke of 40 inches, and a total length of 49.5 inches. The significant thing to see here is that this cylinder is not 5 times the size of the one used in the model. If that one were scaled up by 5, its dimensions would be as follows: 10 inch bore, 40 inch stroke, and 67.5 inch total length. This one is obviously much smaller in size. This is why there is no concern that the cylinder in the model seems very bulky because the actual cylinder will be thinner, shorter, and will fit inside of the trailer much nicer. Figure 10-7 shows a comparison of this cylinder to the one used in the model scaled up by 5. The black cylinder is the actual one that can be used and the gray one is the cylinder used on the model scaled up by 5. Once you have the cylinder, the clevis rod, tube connectors and ball pins can be purchased at a size relative to the cylinder. This shows how much of a difference in size this cylinder will make. The weight of this cylinder is approximately 30 pounds and that added to weight of the support beam (~15 pounds) will give a total weight of 45 pounds. The MIL-SPEC of the amount of weight a man can lift is 56 pounds. Since the operating manual states that two men will lift the cylinder as it is installed and uninstalled, this is a very reasonable weight. Two men should have no problem lifting a 45-pound device. The cost of this cylinder is approximately $350. This is just one option that Lockheed Martin can look into because there are many companies that can design and build custom pneumatic cylinders.

Figure 10-6: Actual Pneumatic Cylinder

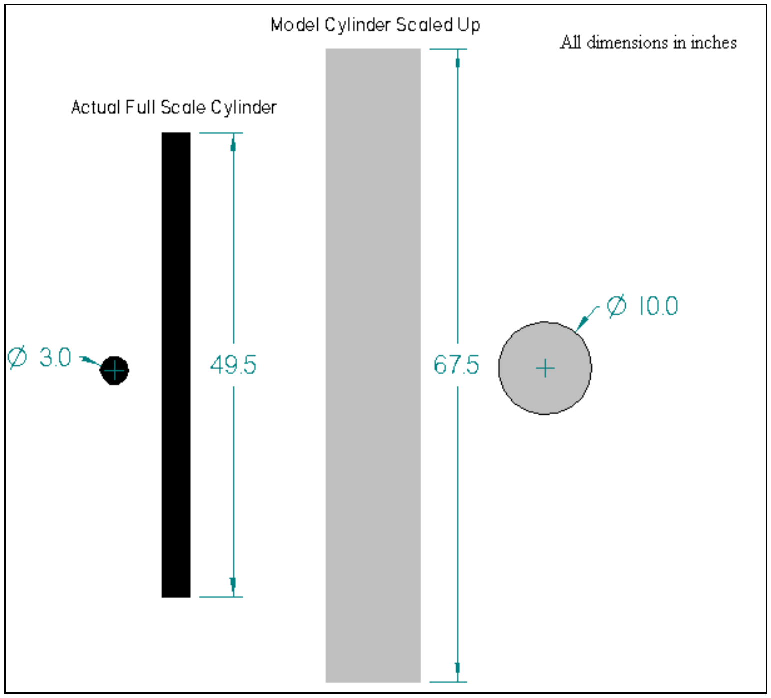

Figure 10-7: Cylinder Comparison

11.0 Conclusion

At the onset of this project, several different concepts were researched and several of them were considered very worthy. Our final decision was to attempt to design and build a pneumatic cylinder that should provide increased safety and decrease the personnel required to setup and teardown the roof of the VCCT. These are the main objectives of this project and it seems that this design will improve the current situation. We propose to add two pneumatic cylinders to the VCCT that will assist in the raising and lowering of the simulator roof. These cylinders will be hooked up to a compressor that is currently in the trailer. As the air pressure to the cylinders increases, the roof will slowly swing open. The person controlling the air compressor will have full control of the entire situation. They can raise or lower the roof at any moment. When the roof is above 90-degrees, another worker can setup the floor of the simulator and remove the panels. At this point, the roof will be slowly lowered onto the side panels and the cylinders can be removed. When the roof is ready to be closed, they can be quickly installed and the roof will slowly lower back into its rest position.

At first it was proposed to the team to design and build an actual device that could be used on the existing trailers. After further consideration, however, it was decided that a scale model would be a more appropriate approach. To recap the design, the cylinder will be mounted onto the trailer's main support beam by an aluminum "L-bracket". This bracket will be inserted into two steel rods that will be connected to the trailer's main support beam. Once inserted, a quick connect ball pin will keep the bracket in place. A triangular piece of steel will be connected to the roof and will provide a contact point for the piston arm. A clevis rod will connect the piston arm to the triangular piece, which will allow the arm to rotate.

Several calculations were conducted to complete this design. The most important one was the amount of force the cylinder must exert to raise the roof of the scale model. This force was calculated to be 150lbf. It was calculated that a stroke of 7.5 inches would be needed to fully raise the roof. The pressure needed will depend upon the bore of the cylinder. For our scale model, a bore size of 2 inches requires 70 psi. All of these calculations can be seen in Appendix C. For the full scale model, the following was calculated: 750 lbf required to lift the actual roof, 37.5 inches of stroke, and a bore of 3 inches which would require 160 psi. As the bore size increases, the pressure required would decreases, but so would the size and weight of the cylinder. Also, the above numbers were assuming a factor of safety of 1.5. The factor of safety required would increase or decrease the bore size and the pressure needed.

The goals of this design were to decrease personnel and increase safety. The setup designed will weigh approximately 45 pounds. The military standard lifting requirements for a male is 56 pounds. So one man could handle this weight, but it is proposed that two men lift the cylinder into position. The quick connect pins will help decrease the setup and teardown time. The safety hose connectors will increase the safety because at no time will the roof ever be uncontrollable. The main goals of the design were all accomplished.

There are a couple of improvements that Lockheed Martin could consider to make this design even better. The piston arm is made of solid steel and accounts for most of the weight of the design. It could be possible to fabricate a carbon fiber rod that would be just as strong as the steel rod, but significantly lighter. Another way to lighten the design would be to skeletonize the support beams. A finite element analysis could be completed on the beams and areas where no or little force is felt could be removed from the support beams. This could significantly reduce the weight of the design. A system of only one cylinder could also be used. For this system to be successful, however, a cylinder with a larger bore would be required to lift the roof and this would add to the weight of the system. All of these options could be weighed by Lockheed Martin and a perfect system for them could be designed. If simplicity and setup speed is more important, a one-cylinder system could be used. If personnel safety is more important, a two-cylinder system could be used. Also, if cost is not an issue, then a lighter cylinder could be fabricated. This design is considered a success and it is hoped that Lockheed Martin will take it into serious consideration when determining how to improve the Virtual Combat Convoy Trainer.

References

1) McMaster Carr. "Parts List/Information." http://www.mcmaster.com.

2) "VCCT 2005-008 Mobile Trailer Operation Procedures." Lockheed Martin.

3) "VCCT Human Factors Safety Repost." Lockheed Martin Information Studies. 10 June 2005.

4) Online Metals. "Parts List/Information." http://www.onlinemetals.com/

5) Callister, William. "Materials Science and Engineering." Wiley. August 2002

Appendix A

Deliverables

Team Photo

Contact Information

Tom Vito
Phone: 850-980-2580
Email: Address-tav9168@fsu.edu

John Ervin
Phone: 904-614-6632
Email: Address-ervinjo@eng.fsu.edu

Andre Neal
Phone: 850-294-0224
Email: Address-nealan@eng.fsu.edu

Mackinson Renard
Phone: 850-284-9264
Email: Address-mjr02f@fsu.edu

Sara Delk
Phone: 407-306-4080
Email: sara.e.delk@lmco.com

Code of Conduct

1. We plan to meet every Tuesday and Thursday during our usual class time and on Monday after Senior Seminar.

2. If you are going to miss a scheduled meeting or be late, call a team member before we are scheduled to meet.

3. The entire team must approve anything being turned in.

4. Assignments must be completed at least two days before the actual due date.

5. There will be bi-weekly team evaluations.

6. One weekend per month must be left open for unscheduled meetings.

7. Amendments of this Constitution can be made with approval of the entire team.

8. Make sure to have fun and not get too stressed out.

Thomas A Vito Mackinson Renard

Andre Neal John Ervin

Fall Project Calendar

ID	Indicators	Task Name	Duration
1		Team Meeting, Teleconference	1 day?
2		Lecture: Reports and Technical	1 day?
3		Due: Needs Assessment and Pr	1 day?
4		Trip to Orlando (Meet Sara/See	1 day?
5		Team Meeting, Teleconference (	1 day?
6		Staff Meeting (Concepts, Produc	1 day?
7		Due: Product Specs and Proje	1 day?
8		Lecture: Presentations, Telecon	1 day?
9		Due: Presentation: Conceptua	1 day?
10		Team Meeting, Teleconference (	1 day?
11		Staff Meeting (Concept Generat	1 day?
12		Due: Concept Generation and	1 day?
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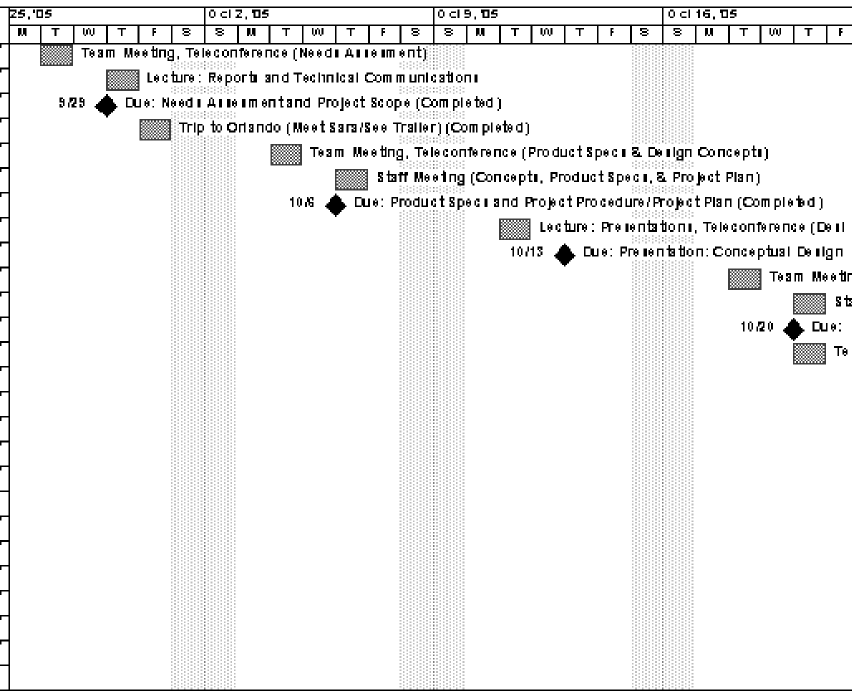
15		Staff Meeting (Concept Selectio	1 day?
16		Team Meeting, Teleconference (	1 day?
17		Team Meeting (Concept Selecti	1 day?
18		Lecture: Presentations, Telecon	1 day?
19		Due: Presentation: Interim De	1 day?
20		Team Meeting, Teleconference (	1 day?
21		Staff Meeting (Continue Detailed	1 day?
22		Team Meeting, Teleconference	1 day?
23		Team Meeting, Teleconference (	1 day?
24		Staff Meeting (Final Design Rev	1 day?
25		Lecture: Presentations	1 day?
26		Due: Presentation: Final Desig	1 day?



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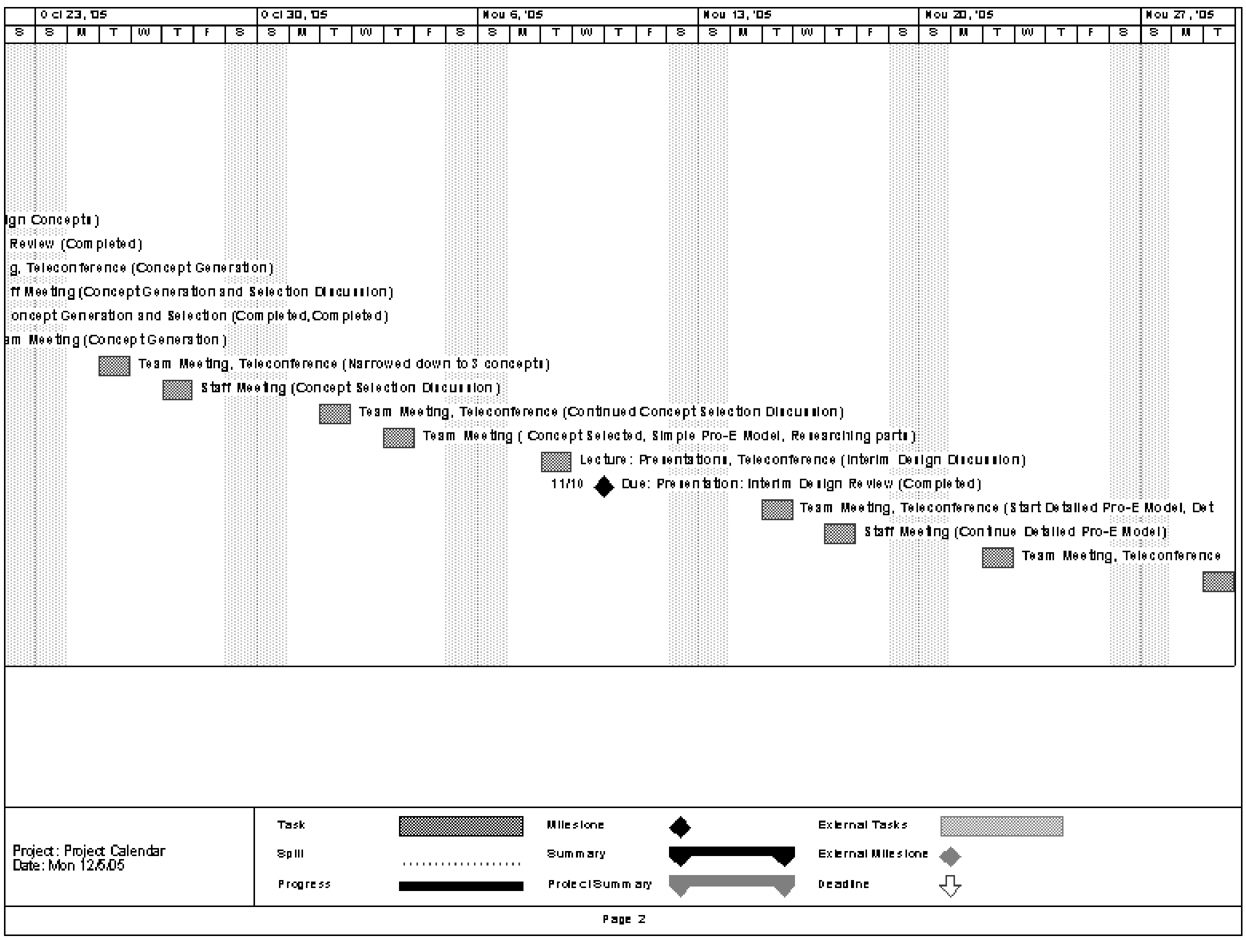
Progress		Project Summary		Deadline	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am Meeting (Concept Generation)
Team Meeting, Teleconference (Narrowed down to 3 concepts)
Staff Meeting (Concept Selection Discussion)
Team Meeting, Teleconference (Continued Concept Selection Discussion)
Team Meeting (Concept Selected, Simple Pro-E Model, Researching parts)
Lecture: Presentations, Teleconference (Interim Design Discussion)
11/10
Due: Presentation: Interim Design Review (Completed)
Team Meeting, Teleconference (Start Detailed Pro-E Model, Det
Staff Meeting (Continue Detailed Pro-E Model)
Team Meeting, Teleconference
Project: Project Calendar
Date: Mon 12/5/05
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External Milestone
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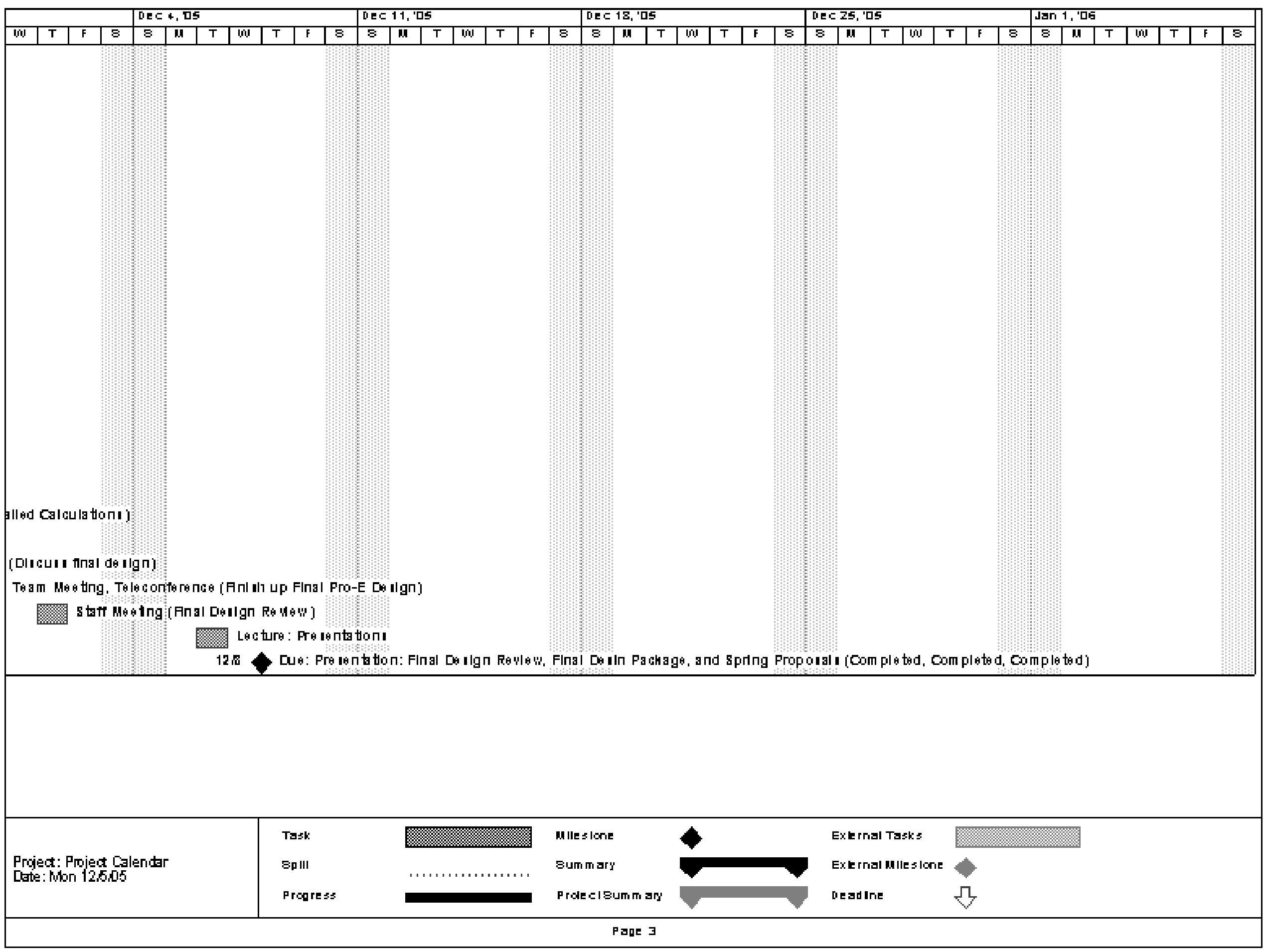

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Dec 11, '05
Dec 18, '05
Dec 25, '05
Jan 1, '06
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(Discuss final design)
Team Meeting, Teleconference (Finish up Final Pro-E Design)
Staff Meeting (Final Design Review)
Lecture: Presentations
12/8
Due: Presentation: Final Design Review, Final Desin Package, and Spring Proposals (Completed, Completed, Completed)
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Date: Mon 12/5/05
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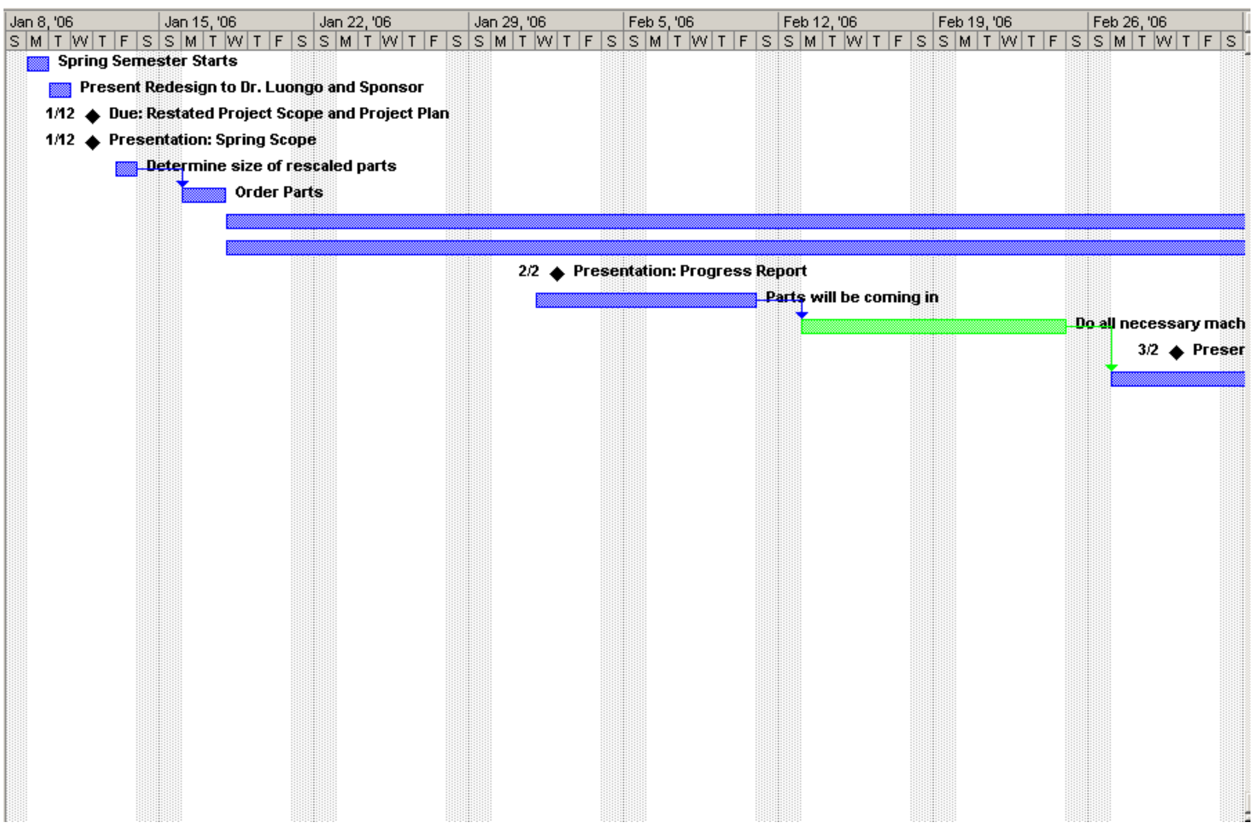
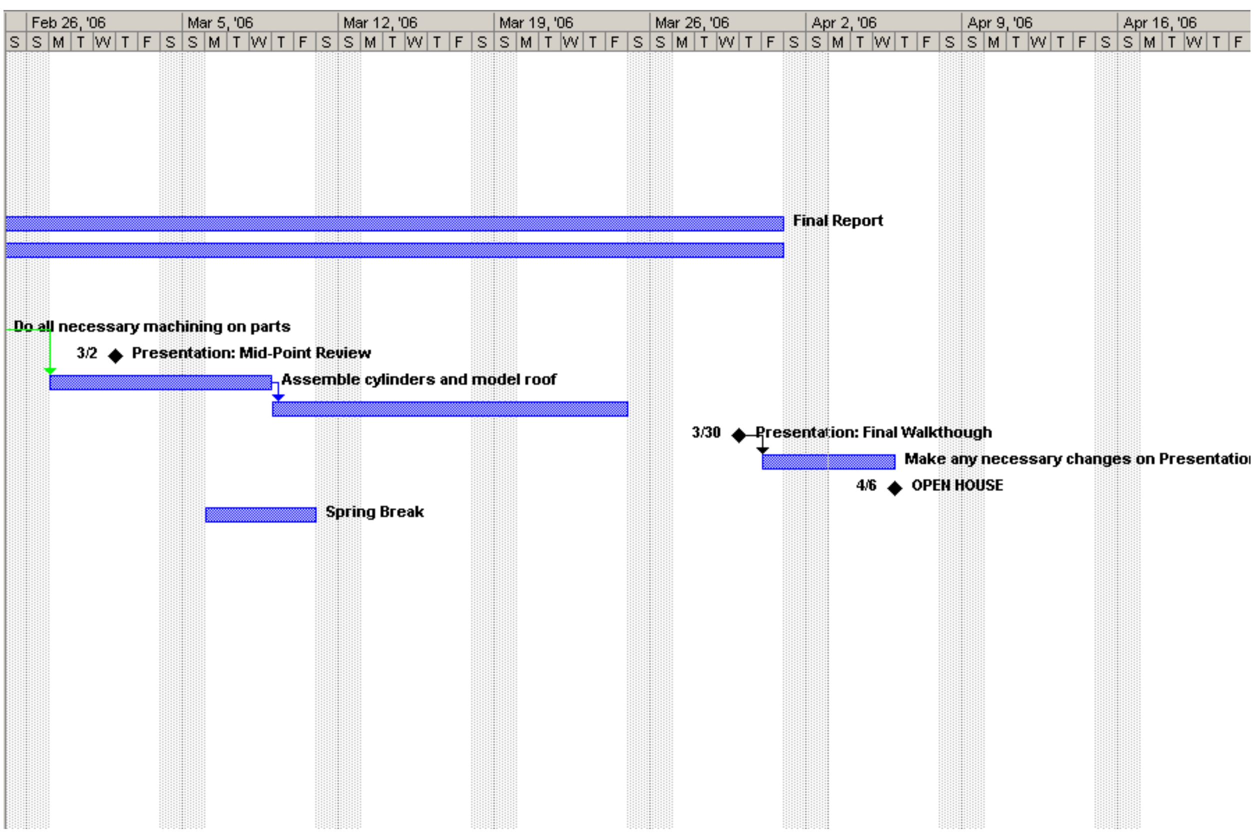
Spring Project Calendar





Feb 26, '06
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Mar 12, '06
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Apr 2, '06
Apr 9, '06
Apr 16, '06
Final Report
Do all necessary machining on parts
3/2
Presentation: Mid-Point Review
Assemble cylinders and model roof
3/30
Presentation: Final Walkthough
Make any necessary changes on Presentatio
4/6
OPEN HOUSE
Spring Break

Appendix B:

Virtual Combat Convoy Trainer Safety Study

1.0 Purpose

The purpose of this study is to assess the VCCT setup and teardown processes from a human factors and safety standpoint.

2.0 Background

The original Virtual Combat Convoy Trainer (VCCT) development program was conducted as a very quick response to an urgent need to deliver a convoy trainer to the troops. Since then, more VCCT's have been produced. As a result of multiple set-ups and teardowns, some safety concerns have arisen due to the personnel-intensive methods of setup and teardown. Therefore, this study was conducted to assess the safety of the VCCT setup and teardown processes.

3.0 References

MIL-STD-1472	Department Of Defense Design Criteria Standard -- Human Engineering
Mobilized Systems, Inc.	Operators, Maintenance, and Service Manual for the Vehicle Close Combat Trainer (VCCT) Model 53042 Rev. A – 2/15/05
MCTM04-059	Operator's and Maintenance Manual -- Virtual Combat Convoy Trainer (VCCT) -- Appendix C -- Mobile Trailer Operation Procedures – 25 April 2005

4.0 Approach

The approach used for this study was to observe the setup and teardown processes multiple times under various conditions with different teams being used to do the setup and teardowns. Interviews were also conducted with various personnel involved in VCCT including engineers, the LM STS Product Safety Council, manufacturing, and the setup/teardown personnel. The gathered data was then analyzed to identify and assess hazards, to synthesize options, and to make recommendations.

Personnel interviewed for this study included:

- Scott Crawford – Production Program Manager
- John Quarti – Manufacturing Lead
- Jody Parker – Manufacturing Technician
- Shane Carty -- Manufacturing Technician
- Shane Bailes -- Manufacturing Technician
- Gio Beam -- Manufacturing Technician
- Tom Moran – Hardware Architect
- Vic Poteat – Subcontracts Program Manager
- Bill Hays -- Manufacturing Technician

- Vic Tisdel -- Engineer
- Scott Courier – Safety Engineer / LM STS Product Safety Coucil Chairman

5.0 Data Gathered

The following paragraphs summarize the basic data gathered during this study.

5.1 Setup Process

Based on the observations made during several setups of the VCCT Trailer, the setup process is summarized in the following steps:

- Level trailer
- Unload equipment from rear room
- Lay out parts on ground in convenient locations for assembly
- Unpin support poles
- Attach second half of support poles
- Insert lift bars into support poles
- Lift roof away from trailer and support roof on ground on extended support poles
- Lower flap revealing support joists
- Two personnel stand in position with back toward trailer with 2x4's (wood 2" x 4" x 4')
- Four or more personnel grasp the lift bars
- On the count of "3", the lift bar is walked back while the 2 personnel with 2x4's push up on roof. The lift personnel articulate the support poles and push up the roof. The support poles are rested on the ground, holding up the roof.
- Floor joists are installed
- Unlatch and lower floor sections
- Install perimeter support joists and pin in place
- Unpin support poles.
- Lift to extend poles and pin in place
- Lift support poles into position on support joist
- Open walls up
- Install jack stands
- Level using hydraulic jack
- Insert wall into channels
- Install center wall sections
- Lower roof into channels and pin

5.2 Teardown Process

Based on the observations made during teardowns of the VCCT trailer, the teardown process is summarized in the following steps:

- Lift roof and pin
- Remove center sections
- Using hydraulic jack, jack up floor at end to relieve pressure; floor drops.
- Fold in side panels
- Unpin roof supports
- Lift/drop support pole to ground
- Remove pins from floor
- Remove perimeter support joists
- Fold up floor panels
- Slide in support bars
- Stow perimeter supports, etc. under bed
- Remove pins from support poles
- Lower to ground (~3 ft.)
- Two personnel standing with back to trailer, push up on roof with 2x4's
- Four personnel support roof with support poles
- These four personnel pull out on supports and step backwards to lower roof
- Roof drops as roof passes tipping point. The two personnel with 2x4's hold roof section up while walking backwards towards trailer while roof is lowering. They must duck in order to not be crushed as the roof collapses. The other four personnel pull on the support poles to slow the roof's collapse.
- Fold up lower section
- Drop roof and secure

5.3 Weights

The weights of the various VCCT panels are not known precisely. In discussions with MSI, the following weight estimates and personnel requirements were provided:

Panel	Estimated Total Weight (lbs.)	Estimated Weight at Lift Point (lbs.)	Number of Personnel Required (MSI Recommendations)
Roof	~450 - 500	~225	4 Men
Floor Panels	~60 - 70	~35	1 Person
Center Filler Panels	~80	~80	2 Men

5.4 Incidents

During discussions with the various personnel involved, the following anecdotal evidence was gathered indicating that there have been a number of minor injuries sustained during the setup or teardown of the VCCT trailers:

- One MSI person was injured when he was "clipped" by the collapsing roof. The extent of injuries is unknown.

- At least three LM personnel have had strained backs as a result of the setup or teardown process.

6.0 Observations and Assessment

By observing the setup and teardown operations a number of times, reviewing the manual, and by talking with the various personnel involved, the following observations were made. An assessment of each of the observations is included, and recommendations were synthesized.

6.1 Observations on the Roof Collapsing During Teardown

The "roof collapsing" portion of the process is obviously the most difficult and the most hazardous portion of the setup and teardown process. It is unfortunately an accident waiting to happen. As the teardown process is currently done, during the process of dropping the roof, several people are holding up the roof with the vertical support poles (4-6) and two personnel are under the roof facing away from the trailer. The personnel on the support poles walk away from the trailer while supporting the roof with the attached poles. As they back away, the two people under the roof, equipped with 2" x 4" boards about 4 ft. long try to catch the roof and engage the channel located toward the free end and support the roof as it collapses onto them. As the pole handlers move away, the roof reaches a "tipping point" after which time they have little control over its descent. The two people under the roof are trying to control the roof's fall with the 2x4's while backing up and ducking so as not to get trapped between the roof and the side of the trailer. All of this effort requires teamwork, which is coordinated by one assigned person who counts and provides orders to the others on when to lift, etc. In two of the four times this procedure was witnessed, at least one of the two people under the roof slipped while backing up. In two of the four times, the 2x4's have slipped off the surface contributing to the roof coming down faster than expected. One time the teardown was being accomplished in the rain and the wood and the roof was wet making a difficult situation even worse. Fortunately, in all cases they were able to duck and hold the roof up enough to keep from getting smashed by it. In two of the four cases, the vast majority of the weight has ended up on one person at the same time that person was ducking so as not to be struck by the collapsing roof. The current 2x4's are only about 4 ft. long which is too short; the personnel can't engage the roof/channel due to its height and therefore are trying to "catch" it as it comes down.

6.2 Recommendations on the Roof Collapsing During Teardown

Since the current design requires this process to continue to be performed, it is recommended that the process be improved. The personnel indicate that they had created a supporting device, to be used in lieu of the wood 2x4's, which was described as a pole like a "broomstick". The "broomstick" has a flat surface perpendicular to the pole that provides a surface to engage the roof. This surface is also covered with rubber to make it “stickier” so it will not slip on the under surface of the roof panel. None of these push poles have been available to see, or see in operation, nor are there any drawings of them. These devices would be better than the 2x4’s that are currently being used to “catch” the roof. More of these push-poles should be made ASAP to replace the 2x4’s. The use of 2x4’s should be discontinued. A set of the “broomstick” devices should accompany each trailer, and the manual should be updated to reflect their use. The device should be made at least 6 ft. long to allow the personnel to engage the roof before the roof is collapsed.

Due to the apparent weight of the roof and awkwardness of the handling of the roof, it is also suggested that three (3) people be used, equipped with devices as described above, instead of the two that are currently used. Using three people rather than two people to catch the roof would improve the safety of the operation. It was twice observed that one of people lost his balance as roof collapsed. The other person had to catch the whole weight with his hands. Both were almost hit by collapsing roof. If three were used, if one slipped other two have better chance of catching and holding the weight (~225 lbs) rather than the one remaining person.

It was also observed that on those occasions where the roof was lowered to a lower starting position first, it made it significantly easier for the two personnel with 2x4’s to take on the weight of roof without the necessity of “catching” it when it is falling on them. When the roof was lowered from a higher position, they were in the position of “catching” it while it is falling vs. having the weight shifted from support poles to 2x4s. It is recommended that the roof lowering procedure be modified to always start from the lowest position possible. This additional step should be indicated in the manual.

It is further recommended that six (6) people be used on support poles rather than the four (4) that are indicated by MSI due to the weight alone. This seems to have developed as “standard practice” and, like using three instead of two for roofing catching, reduces the weight distribution per person and provides backup in the event that someone slips, or is for some other reason, unable to lift their share of the weight. Training should be provided to all personnel assigned to support the setup or teardown of the VCCT. Emphasis should be placed on the importance of having one lead person to coordinate the operation.

It is recommended that these improvements be implemented as soon as possible before going through too many more setup/teardown cycles to protect the people doing the job and to make the operation easier.

There is not a drawing to which the “broomstick” push-poles can be manufactured. A drawing should be created and these devices should be added to the VCCT Bill of Materials (BOM). (Note: a PDF sketch has subsequently been created and will become a released drawing when the design is finalized.)

The use of additional Personnel Protective Equipment (PPE) should be considered. The use of gloves, hard hats, back support belts, safety glasses, and safety shoes are discussed in a later paragraph.

6.3 Observations on Roof Setup

While the setup of the roof on the VCCT trailer is a more controlled operation than the teardown, many observations similar to those on teardown were noted. The critical, and most difficult, part of the operation is the effort needed to move the roof from its resting position hanging on the side of the trailer into a horizontal position supported by the support poles. Like the teardown operation, this part of the setup uses four to six people on the support poles and two personnel facing out from the trailer using 2x4's to push up on the roof while the personnel on the roof support poles lift and walk backwards pulling the roof away from the trailer. When they reach the critical "tipping point", they reverse directions and transfer the force they are exerting into a pushing force to raise the roof while walking forward. All of this effort, as with the teardown, requires teamwork, which is coordinated by one assigned person who counts and provides orders to the others coordinating when to lift, etc.

While the roof setup does appear to be easier and less hazardous than teardown, it does present hazards to the personnel involved. The most critical hazard is to the personnel with the 2x4's who are under the roof pushing on it with 2x4's while the roof is being hoisted into the horizontal position. While no incidents were observed or reported, it would not be hard to envision a situation where the personnel on the roof support poles "miss" the tipping point and the roof falls back down to its vertical hanging position against the trailer wall, possibly crushing the two personnel with 2x4's as it collapses. This risk is real since there are several people on the support poles all of whom must act in concert to raise the roof while changing both their direction of travel and the forces they are using from pulling to pushing. A slip that occurs at the tipping point may result in injury to the two personnel who are under the roof during this operation.

Another potential for injury during this operation is the possibility of a lifting injury to the backs of the people who are assigned to the roof support poles. Again, changing directions of movement while simultaneously changing directions of force while lifting considerable weight (~225 lbs.) contributes to the potential for back injury.

6.4 Recommendation on Roof Setup

As with the teardown operation recommendations, the use of the "broomstick" device, the increase of personnel from two to three manning the "broomstick" devices, and the increase from four to six personnel to man the roof support poles would minimize the risk of injury to all, either from accidental collapsing of the roof or from back injuries caused by lifting.

The use of additional Personnel Protective Equipment (PPE) should be considered. The use of gloves, hard hats, back support belts, safety glasses, and safety shoes are discussed in a later paragraph.

6.5 Observations on the Use of Females

It was noted that at least one female was used in at least one of the teardown operations observed. Other females have apparently been used although not observed for this study. According to the MSI recommendations based on weight, the roof setup and teardown operations are a 4-man lift operation. This 4-man recommendation was based on the guidelines of MIL-STD-1472, which allows a men-only population to lift 56 lbs, but a mixed population (male and female) to lift only 37 lbs.

6.6 Recommendations on the Use of Females

Because of the weight of the roof and the MIL-STD-1472 guidelines, it is recommended that females not be used in that part of the operation involving setup and collapsing of the roof. Even if the recommendation to use six (6) people on the lifting of the roof is implemented, the weight per person still exceeds the 37 lbs., and therefore females should not be used for the roof operations.

6.7 Observations on the Use of Pins

Many pins are used on the VCCT trailer to pin the roof support posts, the joists, the panels, etc. It was observed that the pinning and/or unpinning operations were quite often difficult to accomplish. Personnel experienced the most difficulty with pins on joists and in support poles. Pins on the floor joists are hard to grasp and pull out when disassembling. Pin tethers and rings are very lightweight/weak; they break and/or pull apart easily. This could allow pins to fly (as has been reported) and/or be lost. Several of the pin rings have been replaced with wire loops, which were rusting and weak.

6.8 Recommendations on the Use of Pins

It is recommended that improvements to the pins be considered. It may be possible to loosen the tolerances of the holes in order to make the pins easier to insert without sacrificing setup accuracy since most of the uses of pins appeared to be to secure something and not to pin it accurately in place. The pins that were used on the support poles were bent at an angle. This helped the personnel grip the pins enabling easier removal. Therefore, consideration should be given to the use of similar pins bent at an angle to improve personnel’s ability to grip the pins, especially for those associated with the assembly of floor joists.

Pin tethers and rings should be made of stronger parts and rust-resistant materials to prevent breakage and corrosion.

6.9 Observations on the Number of Parts and Pieces

Closely related to the problems observed with pins is the observation that the VCCT trailer requires the assembly and disassembly of many parts and pieces. Besides requiring considerable time and effort, the large number of parts and pieces provide many opportunities for finger pinching injuries.

6.10 Recommendations on the Number of Parts and Pieces

Consideration should be given to simplifying the VCCT design in the areas that would streamline setup and teardown while simultaneously reducing finger-pinching opportunities.   An area where this may be particularly helpful would be to make floor joists a one-piece unit that slides in and out.

Appendix C:

Calculations

Lift Analysis

Force and Speed analysis using kinematics of a rigid body, Newton's Laws and initial bounc
conditions supplied by our sponsor

$W := 500\,lb$ $\quad g := 32.2\frac{ft}{s^2}$ $\quad v_o := 0$ $\quad y := 13.5\,ft$

$m := \frac{W}{g}$ $\quad m = 23.108\frac{kg\,s^2}{m}$ $\quad y_o := 0$ $\quad t := 300\,s$

$F_r := W$

$$a := \frac{2 \cdot y}{t^2} \qquad a = 9.144\times 10^{-5}\,\frac{m}{s^2}$$

$$v := \int_0^{300} a\,dt \qquad v = 0.027\frac{m}{s^2}$$

Sum of forces in y-directin yield

$F_l := F_r + m \cdot a$ $\quad F_l = 226.798\,kg$

Based on the geometry of the system we have determined that if the piston is placed at a distance of 10.5 ft from the base of the roof a displacement of 3ft by the piston would achieve a lift of 8ft. The analysis below shows the Forces due to the roof, piston, and the reactions at the pin and mounting points.

$W_C := 10\text{lbf}$ $W_R := 500\text{lbf}$ $F_C := 1000\text{lbf}$

$L := 13.5\text{ft}$ $d := 6\text{ft}$ $W_P := 15\text{lbf}$

$\theta := 24, 25 .. 90$

The sum of the forces in the y-direction for the vertical load applied at the pin connection.

$A_{Ypin}(\theta) := W_C + W_R \cdot \cos(\theta)$ $A_{Ypin}(\theta) = \boxed{509.922}\ \text{lbf}$ Max Force at 44 deg

The sum of the forces in the x-direction for the horizontal load applied at the pin connection

$A_{Xpin}(\theta) := F_C - W_R \cdot \sin(\theta)$ $A_{Xpin}(\theta) = \boxed{1.453 \cdot 10^3}\ \text{lbf}$ Max Force at 80 deg

The ball and socket joint connected to the end of the piston will be a function of the weight of the roof as the angle theta changes during the lift process.

Y-Direction:

$R_{BSy}(\theta) := W_R \cdot \sin(\theta)$ $R_{BSy}(\theta) = \boxed{499.956}\ \text{lbf}$ Max Force at 33 deg

X-Direction:

$R_{BSx}(\theta) := W_R \cdot \cos(\theta)$ $R_{BSx}(\theta) = \boxed{499.922}\ \text{lbf}$ Max Force at 44 deg

The support holding the piston will proportinal to only the wieght of the piston device.

$R_P := W_P$ $R_P = 15\text{lbf}$

Distance 2 men can "pull out" roof:

$$Fx = W\sin\theta\cdot\frac{x}{2}$$

$$(100lb)(8ft) = (500lb)\sin\theta\cdot\left(\frac{8ft}{2}\right)$$

$$\theta = 23.6deg$$

$$L = x\theta$$

$$L = (8ft)(23.6deg)\left(\frac{\pi}{180deg}\right)$$

$$L = 3.3ft$$

Calculations based upon cylinder with 2.54cm diameter bore

$a := \pi\cdot .0127\cdot m\cdot .0127\cdot m$ $\quad a = 5.067\times 10^{-4}\,m^2$ Area of piston face

$C_p := 4180\dfrac{J}{kg\cdot K}$ Specific heat of water at given conditions

$m_{water} := 1\cdot kg$ Mass of water boiled

$T_{amb} := 298\cdot K$ Starting water temperature

$T_{final} := 373\cdot K$ Boiling temperature of water

$W_{available} := C_p\cdot m_{water}\cdot\left(T_{final} - T_{amb}\right)$ $\quad W_{available} = 3.135\times 10^{5}\,J$ Available work to push piston

Making the assumption that piston terminus is mounted at centroid of roof:

$F_{applied} := 500lbf$ $\quad F_{applied} = 2.224\times 10^{3}\,N$ Force applied to lift roof

$$Piston_{travelavailable} := \frac{W_{available}}{F_{applied}}$$

$Piston_{travelavailable} = 140.955m$ Maximum ideal length of piston travel

Optimal Number of Pulleys

Force required to lift anything witha pulley is proportional to the amount of pulleys being used.

Assuming that only two puleys will be used and the hanging pulley will weigh more or less 5 lbs.

Weight of the ceiling	$C := 500lb$	
Weight of the hanging pulley	$PH := 5lb$	
Weight that each cable will experience	$R := \frac{C}{2}$	$R = 250lb$
Force needed in each pulley to life roof	$\frac{R + PH}{2} = 127.5lb$	

The mechanical advantage of a pulley system would be 2 because it is equal to the amount of pulleys in the pulley system.

Time Needed for Pulley to Open Roof

The distance needed to be moved: $D := 29.3in$

Using a constant velocity of 1 in/min the time needed to lift one side will be:

$$t := \frac{D}{2\frac{in}{min}} \qquad t = 14.65\,min$$

Force of Pulley System

$$\sum F_y = F + T\sin\theta - W = 0.$$

$$F + T\sin\theta = 500\text{lb}$$

The centroid of the roof is approximately 4 feet from the e

$$\sum M_F = -W(4\text{ft}) + T\sin\theta(8\text{ft}) = 0$$

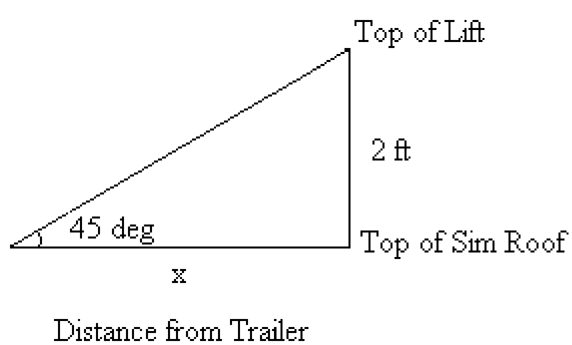
$$T\sin\theta = 250\text{lb}$$

By substitution, the force of the hinge is equal to 250 lbs.

$$F = 250\text{lb}$$

Distance of Pulley Lift From Trailer

Calculating the Distance from the Trailer



$$\tan(45) = \frac{2}{x}$$

$$x = 2\text{ft}$$

The force exerted by the cylinder on the roof. We are planning on using 2 cylinders to open and close the roof.

$W_r := 250\,lbf$ Weight of Roof is 500 lbs but 2 cylinders will be used so each cylinder will only "feel" 250 lbs

$d := 2ft$ Distance cylinder will be from hinge and support beam

$x := 3.9ft$ Vertical distance centroid of roof is from hinge and support beam

$y := 0.375in$ Horizontal distance from the centroid of the roof to the cylinder

$z := 0.75in$ Thickness of roof

$\theta := 90deg, 89deg .. 0deg$ angle of roof

$\upsilon := 30deg$ angle of cylinder

The following equations are used to see what the force the cylinder exerts at all angles from 0 to 90 deg:

$$m := \sqrt{(2ft)^2 + \left(\frac{0.75}{12}ft\right)^2}$$

$m = 2.001ft$ Resultant distance from hinge to cylinder

$$\phi := \operatorname{atan}\left(\frac{\frac{0.75}{12}ft}{m}\right)$$

$\phi = 1.789deg$ angle of hinge with point of contanct ofcylinder

$$n := \sqrt{(3.9ft)^2 + \left(\frac{.375}{12}ft\right)^2}$$

$n = 3.9ft$ Resultant distance from hinge to centroid

$$\psi := \operatorname{atan}\left(\frac{\frac{.375}{12}ft}{n}\right)$$

$\psi = 0.459deg$ angle of hinge with centroid

3 equations must be used because as the roof opens, the signs of each component of the moment will change, so the 3 equations below takes this into account.

All moments are about hinge (Counterclockwise is positive):

Roof is 90 to 88.67 deg (roof is slightly open):

$$\theta := 90deg, 89.99deg .. 88.67deg$$

$$-W_r \cdot (n \cdot \cos(180 - \theta - \psi)) - F_c \cdot \cos(\upsilon) \cdot (m \cdot \sin(180 - \theta - \phi)) + F_c \cdot \sin(\upsilon) \cdot (m \cdot \cos(180 - \theta - \phi)) = 0$$

$$F_c(\theta) := \left| \frac{W_r \cdot (n \cdot \cos(\theta - \psi))}{-\cos(\upsilon) \cdot (m \cdot \sin(\theta - \phi)) + \sin(\upsilon) \cdot (m \cdot \cos(\theta - \phi))} \right|$$

Roof is 88.67 to 88.21 deg (roof is slightly open):

$\theta := 88.67deg, 88.66deg .. 88.21deg$

$$W_r \cdot (n \cdot \cos(\theta + \psi)) - F_c \cdot \cos(\upsilon) \cdot (m \cdot \sin(180 - \theta - \phi)) + F_c \cdot \sin(\upsilon) \cdot (m \cdot \cos(180 - \theta - \phi)) = 0$$

$$F_c(\theta) := \left| \frac{W_r \cdot (n \cdot \cos(\theta + \psi))}{-\cos(\upsilon) \cdot (m \cdot \sin(\theta - \phi)) + \sin(\upsilon) \cdot (m \cdot \cos(\theta - \phi))} \right|$$

Roof is 88.21 deg to 0 deg:

$\theta := 88.21deg, 88.20deg .. 0deg$

$$-W_r \cdot (n \cdot \cos(\theta + \psi)) + F_c(\theta) \cdot \cos(\upsilon) \cdot (m \cdot \sin(\theta + \phi)) + F_c(\theta) \cdot \sin(\upsilon) \cdot (m \cdot \cos(\theta + \phi) = 0)$$

$$F_c(\theta) := \frac{W_r \cdot (n \cdot \cos(\theta + \psi))}{\cos(\upsilon) \cdot (m \cdot \sin(\theta + \phi)) + \sin(\upsilon) \cdot (m \cdot \cos(\theta + \phi))}$$

These 3 equations will all be taken into account to calculate the force exerted by the cylinder at all roof angles.

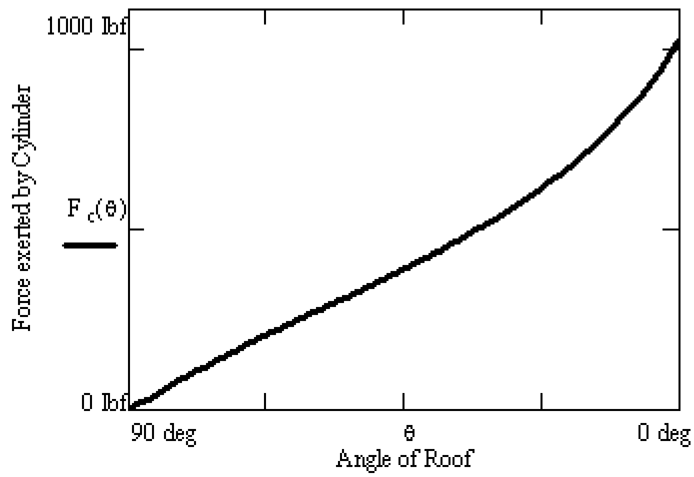
$\theta := 90deg, 88.99deg .. 0deg$

$$F_c(\theta) := \begin{cases} \left| \frac{W_r \cdot (n \cdot \cos(\theta - \psi))}{-\cos(\upsilon) \cdot (m \cdot \sin(\theta - \phi)) + \sin(\upsilon) \cdot (m \cdot \cos(\theta - \phi))} \right| & \text{if } 90deg \ge \theta > 88.67deg \\ \left| \frac{W_r \cdot (n \cdot \cos(\theta + \psi))}{-\cos(\upsilon) \cdot (m \cdot \sin(\theta - \phi)) + \sin(\upsilon) \cdot (m \cdot \cos(\theta - \phi))} \right| & \text{if } 88.67deg \ge \theta > 88.21deg \\ \left| \frac{W_r \cdot (n \cdot \cos(\theta + \psi))}{\cos(\upsilon) \cdot (m \cdot \sin(\theta + \phi)) + \sin(\upsilon) \cdot (m \cdot \cos(\theta + \phi))} \right| & \text{if } 88.21deg \ge \theta \ge 0deg \end{cases}$$

$F_c(\theta) =$

640.84
654.765
669.172
684.096
699.575
715.65
732.367
749.776
767.933
786.899
806.742
827.538
849.37
872.334
896.533
922.088

lbf



The force exerted by each cylinder will be maximum (922 lbf) at 0 deg or when the roof is fully open. The graph shows that as the roof opens (90 deg to 0 deg), the force the cylinder exerts increases.

The following equations will be used as a check. These equations were completed just by looking at the 90 deg and 0 deg situations and completing the moments about the hinge with cclockwise being positive.

When the roof is at 90 deg:

$$-F_c \cdot \cos(\upsilon) \cdot (d) + F_c \cdot \sin(\upsilon) \cdot (z) - W_r \cdot (y) = 0$$

$$F_c := \left| \frac{W_r \cdot y}{-\cos(\upsilon) \cdot d + \sin(\upsilon) \cdot z} \right|$$

$F_c = 4.593\,lbf$ Force exerted by cylinder at 90 deg (roof is closed)

When the roof is at 0 deg:

Moment about the hinge with counterclockwise being positive:

$$-F_c \cdot \cos(\upsilon) \cdot (z) - F_c \cdot \sin(\upsilon) \cdot (d) + W_r \cdot (x) = 0$$

$$F_c := \frac{-W_r \cdot x}{-\cos(\upsilon) \cdot z - \sin(\upsilon) \cdot d}$$

$F_c = 924.936\,lbf$ Force exerted by cylinder at 0 deg (roof is open)

According to the above calculations, the force exerted by the cylinder is 4.9 lbf at 90 deg and 925 lbf at 0 deg. These are similar to the values calculated in the equations completed earlier, so those values and the graph is considered correct.

Pin Analysis

$\theta := 0deg, 10deg .. 90deg$

Moment about B

$-Ay \cdot 21.5in \cdot \cos(30deg) - Fc \cdot \sin(30deg) \cdot 17.495in + Fc \cdot \cos(30deg) \cdot 12.699in = 0$

$$Ay(\theta) := \frac{F_c(\theta) \cdot [(\cos(deg) \cdot 12.699in) - (\sin(30deg) \cdot 12.699in)]}{21.5in \cdot \cos(30deg)}$$

Sum of the forces in the y-direction

$Ay + By - Fc \cdot \sin(30deg) = 0$

$$By(\theta) := F_c(\theta) \cdot \sin(30deg) - Ay(\theta)$$

Sum of the forces in the x-direction

$-Bx + Fc \cdot \cos(30deg) = 0$

$$Bx(\theta) := F_c(\theta) \cdot \cos(30deg)$$

$$B(\theta) := \sqrt{Bx(\theta)^2 + By(\theta)^2}$$

$Ay(\theta) =$ (lbf)

630.653
490.275
396.16
324.988
266.116
213.701
163.886
113.52
59.306
3.132

$B(\theta) =$ (lbf)

$1.629 \cdot 10^3$
$1.266 \cdot 10^3$
$1.023 \cdot 10^3$
839.395
687.339
551.958
423.295
293.206
153.177
8.089

Stress Analysis of Piston Arm

$L := 48 \cdot in$ Piston arm stroke length

$t := .25 \cdot in$ Wall thickness

$H := 4 \cdot in$ Height of rectangular tubing

$W := 2 \cdot in$ Width of rectangular tubing

Applied vertical force as a function of roof angle with respect to the vertical plane

Positive sign denotes 'skyward' sense of vertical force vector

$w_r := 250 \cdot lbf$ Weight of roof borne by one pneumatic cylinder

$d_{centroid} := 3.9 \cdot ft$ Distance to latitudinal centroid of roof

$\theta := 30 \cdot deg$ Angle of roof with respect to the vertical plane

$d_{application} := 2 \cdot ft$ Latitudinal distance from roof hinge to point of pneumatic cylinder force application

$F_{cyl} := 925 \cdot lbf$ Vertical component of cylinder force on roof, calculated above

$F_{hinge} := w_r - F_{cyl}$ $F_{hinge} = -675 lbf$ Force exerted by roof hinge to prevent roof rotation about roof center-of-mass

Perpendicular force on piston arm by roof

Applied at junction of piston and roof

$F_{ry} := F_{cyl} \cdot \sin(\theta)$ $F_{ry} = 462.5 lbf$ Force on piston arm by roof

$M_{pistonarm} := L \cdot F_{ry}$ $M_{pistonarm} = 1.85 \times 10^{3} ft \cdot lbf$ Internal moment on piston arm present at junction of piston arm and piston housing

Area moment of inertia (Rectangular)

$$I := 2\cdot\left[\left(\frac{1}{12}\right)\cdot\left(\frac{W}{12\cdot\frac{in}{ft}}\right)\cdot\left(\frac{t}{12\cdot\frac{in}{ft}}\right)^{3} + \left(\frac{W}{12\cdot\frac{in}{ft}}\right)\cdot\left(\frac{t}{12\cdot\frac{in}{ft}}\right)\cdot\left[\frac{\left[\frac{H}{2} - (.5\cdot t)\right]}{12\cdot\frac{in}{ft}}\right]^{2}\right] + 2\left(\frac{1}{12}\right)\cdot\left(\frac{t}{12\cdot\frac{in}{ft}}\right)\cdot\left[\frac{(H - 2\cdot t)}{12\cdot\frac{in}{ft}}\right]^{3}$$

$I = 2.559\times 10^{-4}\,ft^{4}$ Area moment of inertia about neutral axis

Beam bending moment and deflection

$c := 2in$ Distance from neutral axis to outermost surface of rectangular tubing

$E := 10\cdot 10^{6}\cdot psi$ Youngs Modulus of Al6061

$$\sigma_{bend} := \frac{(M_{pistonarm}\cdot c)}{(I)} \qquad \sigma_{bend} = 8.366\times 10^{3}\,psi$$

$$piston\_arm\_deflection := \frac{-\left(F_{ry}\cdot L^{3}\right)}{(3\cdot E\cdot I)} \qquad piston\_arm\_deflection = -0.321in$$

$\sigma_{A36YIELD} := 35000\,psi$ Yield strength of A6061

$$FS := \frac{\sigma_{A36YIELD}}{\sigma_{bend}} \qquad FS = 4.184$$ Factor of Safety

Area moment of inertia (Circular)

$D_o := 3.5in$ $D_i := 2.5in$

$$I := \frac{\pi}{64}\cdot\left(D_o^{\,4} - D_i^{\,4}\right)$$

$$I = 2.628\times 10^{-4}\,ft^4$$

Beam bending moment and deflection

$c := 1.75in$ Distance from neutral axis to outermost surface of rectangular tubing

$E := 10\cdot 10^6\cdot psi$ Youngs Modulus of Al6061

$$\sigma_{bend} := \frac{\left(M_{pistonarm}\cdot c\right)}{(I)} \qquad \sigma_{bend} = 7.13\times 10^3\,psi$$

$$piston\_arm\_deflection := \frac{-\left(F_{ry}\cdot L^3\right)}{(3\cdot E\cdot I)} \qquad piston\_arm\_deflection = -0.313in$$

$\sigma_{A36YIELD} := 35000\,psi$ Yield strength of A6061

$$FS := \frac{\sigma_{A36YIELD}}{\sigma_{bend}} \qquad FS = 4.909$$ Factor of Safety

Weights of Beams and Pneumatic cylinder parts

Piston Arm (rectangular and square tubing)

$\rho_{Al6061} := 2700 \cdot \frac{kg}{m^3}$ Density of Aluminum 6061

$L := 48 \cdot in$ $L = 1.219m$ Piston arm stroke length

$H := 1 \cdot in$ $H = 0.025m$ Height of piston arm

$W := 1 \cdot in$ $W = 0.025m$ Width of piston arm

$t := .125 \cdot in$ $t = 3.175 \times 10^{-3} m$ Wall thickness of tube

$v := (L \cdot H \cdot W) - [L \cdot (H - 2 \cdot t) \cdot (W - 2 \cdot t)]$ $v = 3.441 \times 10^{-4} m^3$ Volume of aluminum of tube

$m := \rho_{Al6061} \cdot v$ $m = 0.929kg$ Mass of aluminum of tube

Piston Arm (round tubing)

$D_o := 3.5 \cdot in$

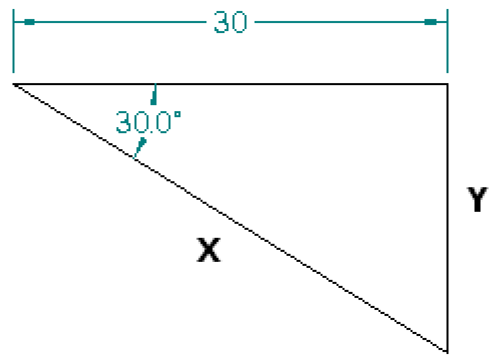
$D_i := 2.5 \cdot in$

$v := \left[\pi \cdot \left(\frac{D_o}{2}\right)^2 \cdot L\right] - \left[\pi \cdot \left(\frac{D_i}{2}\right)^2 \cdot L\right]$ $v = 3.707 \times 10^{-3} m^3$

$m := \rho_{Al6061} \cdot v$

$m = 10.008kg$

Distance Piston Must travel



$$X := \frac{30}{\cos(30deg)}$$

$X = 34.5in$ Minimum distance piston arm must travel

$Y := 30 \cdot \tan(30deg)$

$Y = 17.3in$

$Length\_SupportBeam = 17.3in + 0.75in$

$Length\_SupportBeam = 18.1in$

Spring Analysis

$F := 879 lbf$ Force spring needs to exert (95% of 925 lbf)

$x := 34.5 in$ Distance Piston needs to travel to raise roof

$F = kx$

$k := \frac{F}{x}$

$k = 25.478 \frac{lbf}{in}$ Spring Constant needed by spring

The spring needs a spring constant of at least 25.5 lbf/in and an equilibrium to maximum compression distance of at least 34.5 in.

Mounting Arms

The stress analysis on the two rectangular mounting arms made of aluminum 6061. Using data obtained from the pin force analysis above, a max bending and buckling stress was calculated for the vertical mount and the angled mount.

Vertical Mount

$E_{6061} := 59 \times 10^{9} \cdot Pa$

Since this mount will only be subjected to an axial load it will not feel any bending. Therefore only a buckling analysis is needed.

$L_1 := 17.75in$ Where L1 is the length of the vertical mount.

$t_1 := 1.75in$ Where t1 is the thickness of the vertical mount.

$A_1 := L_1 \cdot t_1 \qquad A_1 = 0.02m^2$ Where A1 is the area of the vertical mount.

$F_{ymax} := 631lbf$ From Appendix

$P_{cr} := F_{ymax}$ Pcr is the critical load which corresponds to the maximum axial force (Fymax) the vertical member will be subjected to during operation.

$$\sigma_{cr} := \frac{P_{cr}}{A_1}$$

Sigma critical is the max stress due to the critical load on the vertical member.

$\sigma_{cr} = 1.401 \times 10^{5} Pa \qquad \sigma_{y6061} := 48 \cdot 10^{5} \cdot Pa$ Where sigma sub y 6061 is the theoretical stress of the material.

The critical stress must be less than the yield stress and the factor of safety is given as the ratio of the theoretical stress divided by the actual stress.

$$n := \frac{\sigma_{y6061}}{\sigma_{cr}} \qquad n = 34.271$$

Angled Mount

$L_2 := 39.25in$ Where L2 is the length of the mount.

$t_2 := 1.75in$ Where T2 is the thickness of the mount

$A_2 := t_2 \cdot L_2$ Where A.2 is the area of the mount

$A_2 = 0.044m^2$

This mount is at an anlge and is subjected to two force components thus it will feel both bending and buckling.

Bending

$c := \frac{1.72}{2} in$ c is the perpendicular distance from the neutral axis to the point farthest away.

The maximum moment can be determined from multiplying the max horizontal and vertical force by the total length of the mount and adding the two.

$F_{xmax} := 1629lbf$ Where Fxmax is the max horizontal force the mount will feel during operation

$F_{ymax} := 294lbf$ Where Fymax is the max vertical force the mount will feel during operation

$M_{max2} := F_{xmax} \cdot L_2 + F_{ymax} \cdot L_2$ Where Mmax is the max moment the mount is subjected to

$M_{max2} = 8.528 \times 10^3 kg\, m^2 s^{-2}$

$I_2 := \frac{t_2 \cdot L_2^3}{12}$ $I_2 = 3.67 \times 10^{-3} m^4$ Where I is the moment of inertia of the mounts' cross section

$\sigma_{maxbend2} := \frac{M_{max2} \cdot c}{I_2}$ Sigma max is the maximum bending stress for the mount

$\sigma_{maxbend2} = 5.075 \times 10^4 Pa$

The bending factor of safety is given as the ratio of the theoretical stress and the actual bending stress.

$n_2 := \frac{\sigma_{y6061}}{\sigma_{maxbend2}}$ $n_2 = 94.576$

Buckling

$F_{2y} := 294 lbf$

The max vertical force the mount will feel

$P_{cr2} := F_{2y}$

Pcr is the critical load which corresponds to the maximum axial force (Fymax) the vertical member will be subjected to during operation.

$$\sigma_{2cr} := \frac{P_{cr2}}{A_2}$$

Sigma critical is the max stress due to the critical load on the vertical member.

$\sigma_{2cr} = 2.951 \times 10^4 Pa$

The critical stress must be less than the yield stress and the factor of safety is given as:

$$n := \frac{\sigma_{y6061}}{\sigma_{2cr}}$$

$n = 162.649$

The Forces the cylinder must exert on the roof to open it (Check)

$L := 7.8\text{ft}$ Height of roof

$h := 1.5\text{ft}$ Height of vertical support to cylinder

$d := 6\text{in}$ Length of hinge to vertical support

$\theta := 0\text{deg}, 1\text{deg}..90\text{deg}$

$W := 250\text{lbf}$ Weight of Roof

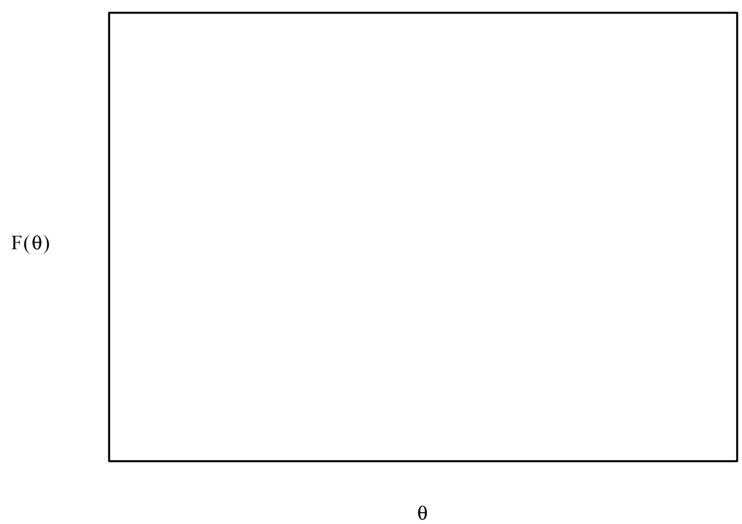
$$F(\theta) := W \cdot \frac{L}{2 \cdot (h - d \cdot \tan(30 \cdot \text{deg}))} \cdot \frac{\cos(\theta)}{\cos(60 \cdot \text{deg} - \theta)} \cdot \frac{\sin(30 \cdot \text{deg} + \theta)}{\sin(60 \cdot \text{deg})}$$

$F(\theta) =$

▮ lbf

$F(90\text{deg}) =$ ▮ lbf

$F(0\text{deg}) =$ ▮ lbf

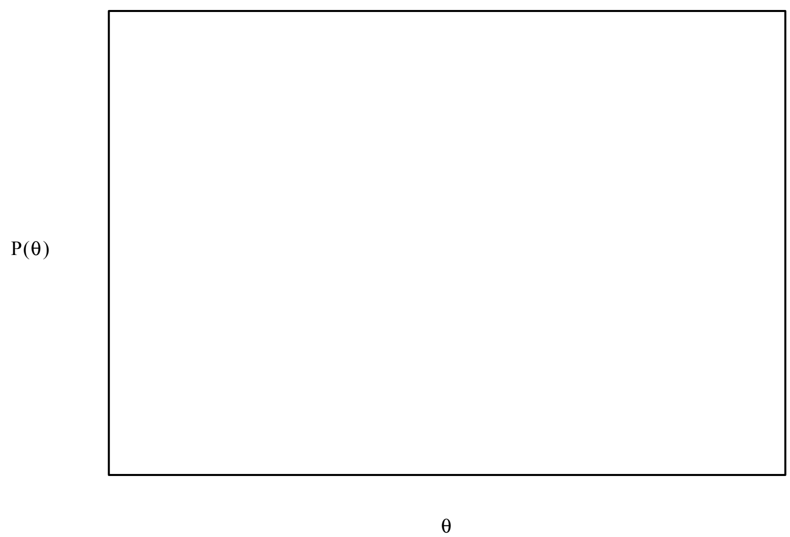


Pressure needed to raise the roof

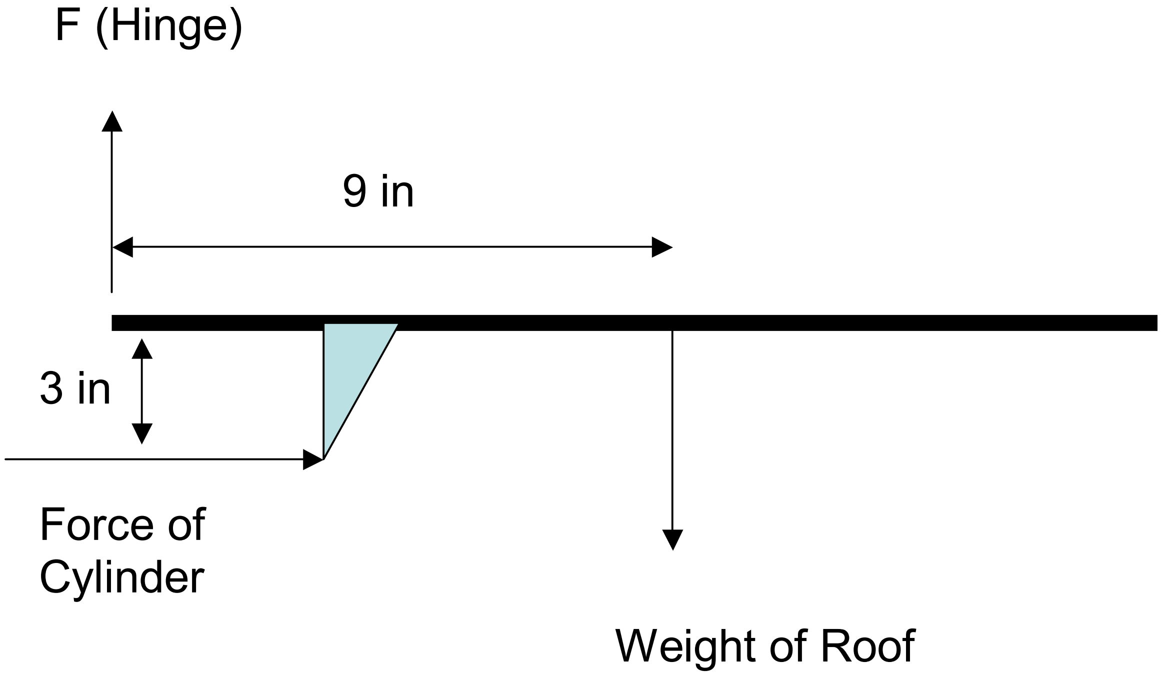
$r := 2.25in$ Radius of piston

$$P(\theta) := \frac{F(\theta)}{\pi \cdot r^2}$$

$P(\theta) =$
$\blacksquare$ psi



Spring Calculations



$\sum M_H = F_c \cdot (3 \cdot in) - 50 \cdot (9 \cdot in) = 0$ Moment about the hinge

$F_c = 150 lbs$ Force required by each cylinder to lift the roof on mode

$F_c = 750 lbs$ Force required by each cylinder to lift the actual roof

$F_c = 1125 lbs$ Assuming a factor of safety of 1.5

$$P = \frac{F}{A}$$

$$A = \frac{F}{P}$$

$$\pi \cdot \left(\frac{d}{2}\right)^2 = \frac{1125\text{lbs}}{160\text{psi}}$$

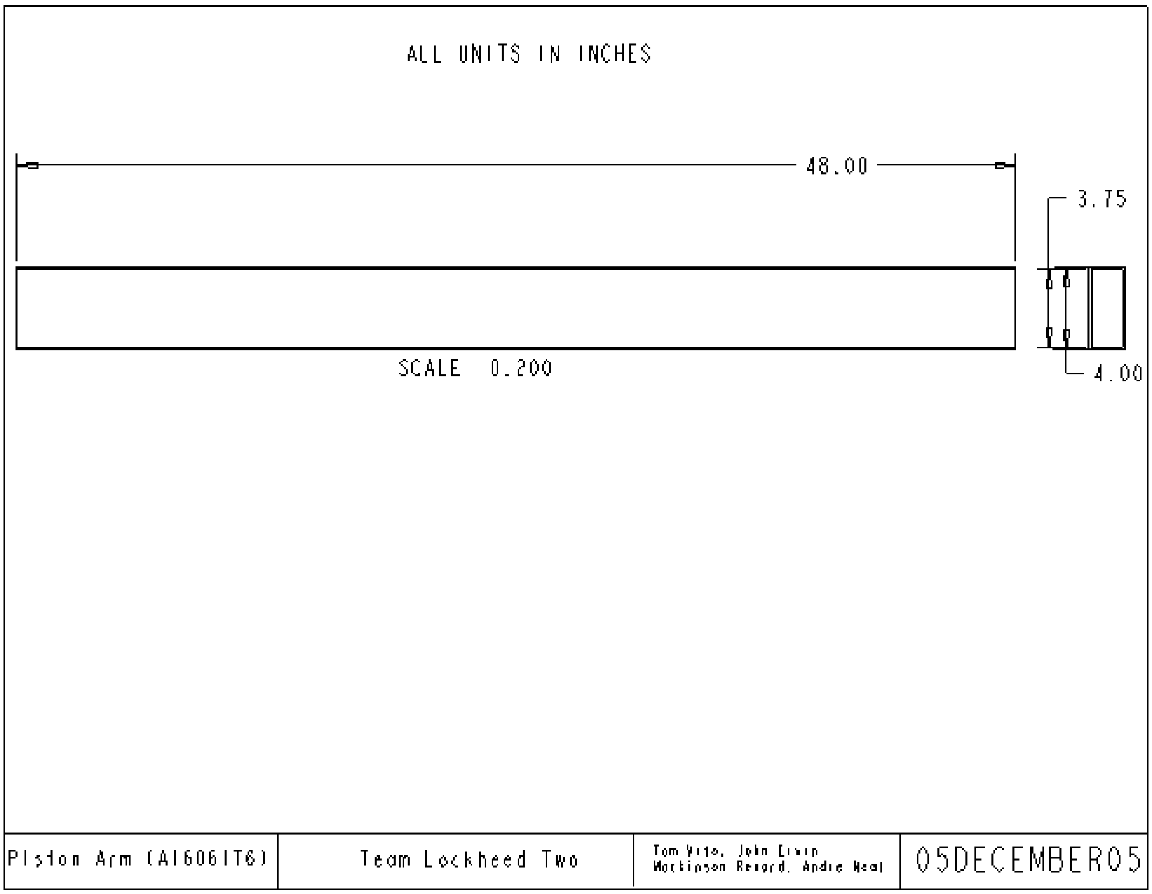
$$d = 3\text{in}$$

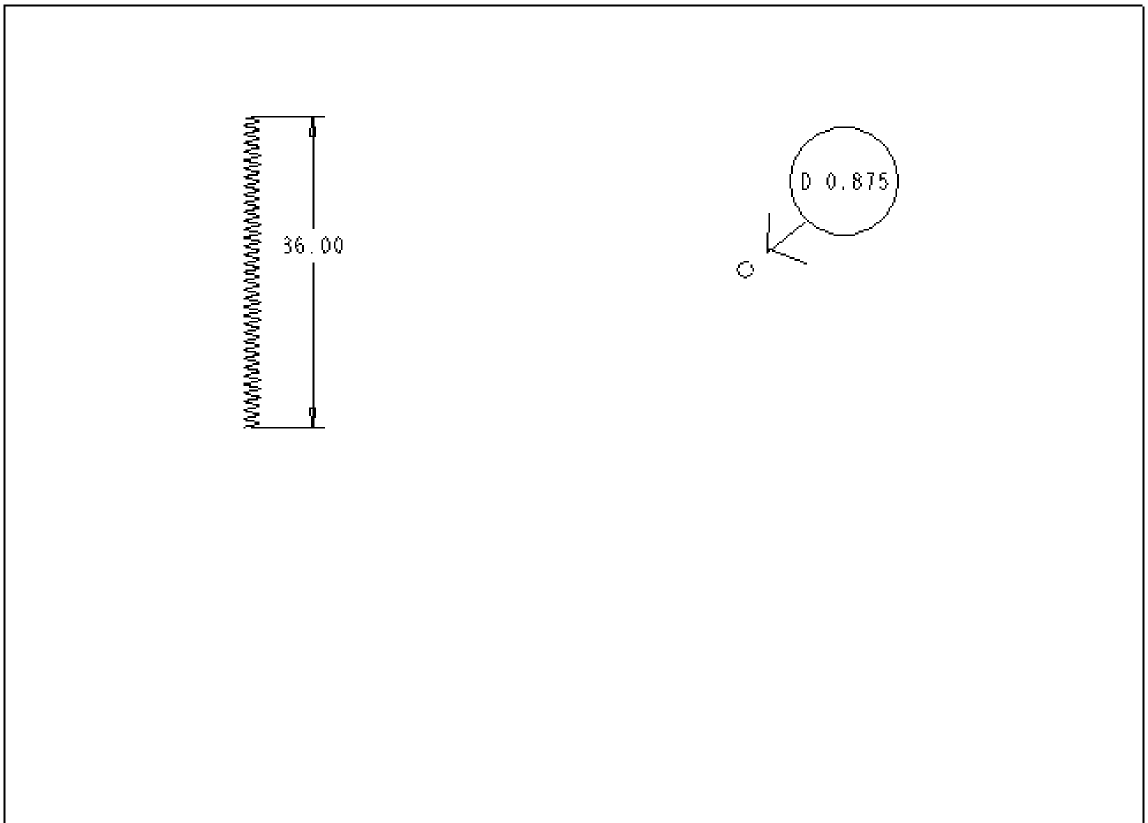
A cylinder with a 3 inch bore will suffice in this situation. This is considering factor of safety of 1.5 and utilizing the maximum available pressure.

Appendix D:

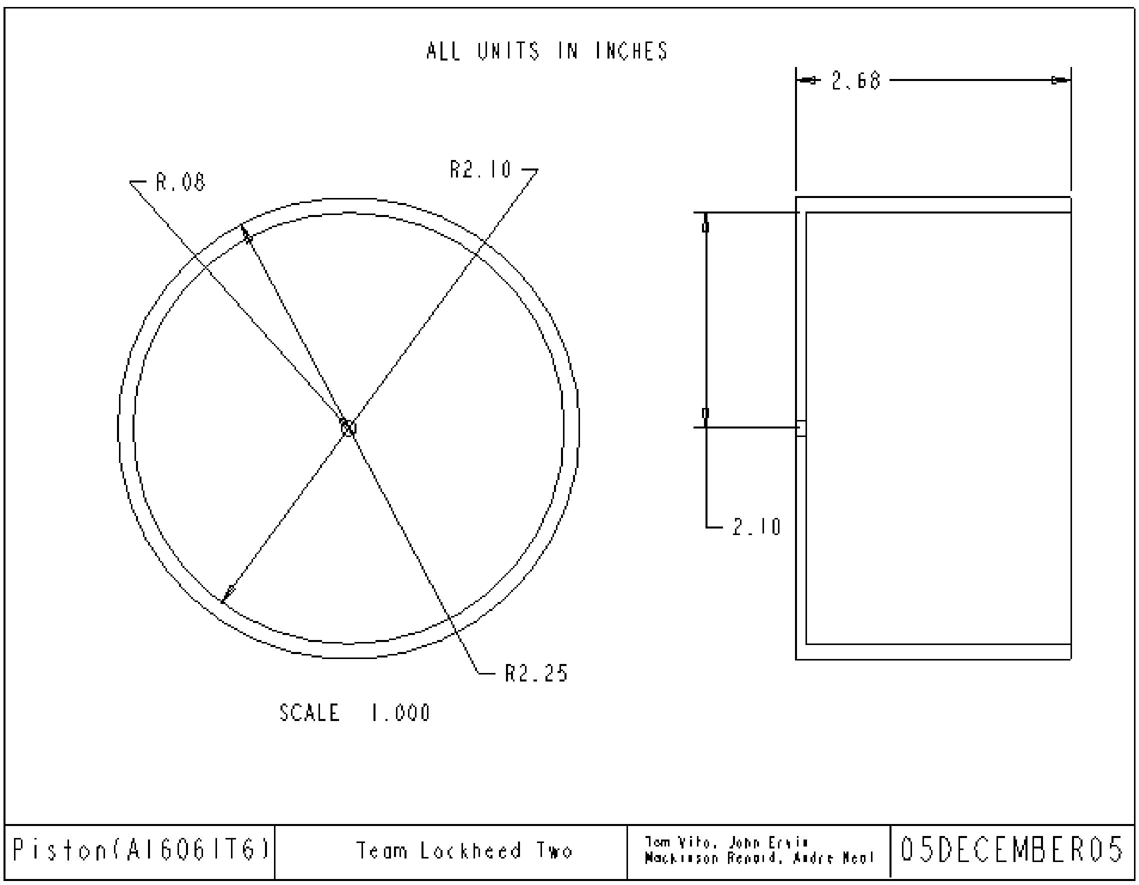
Engineering Drawings

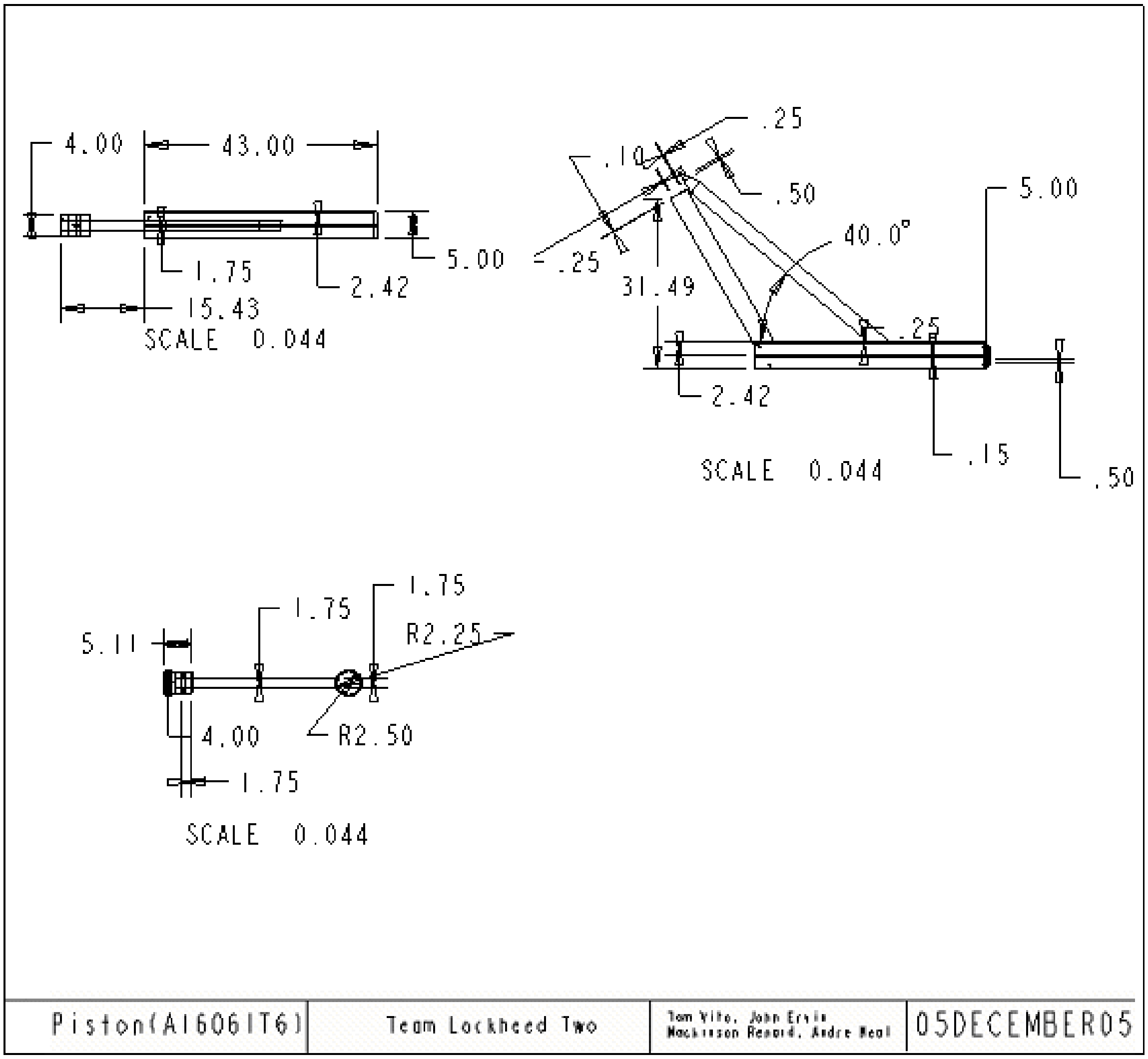
Fall Engineering Drawings

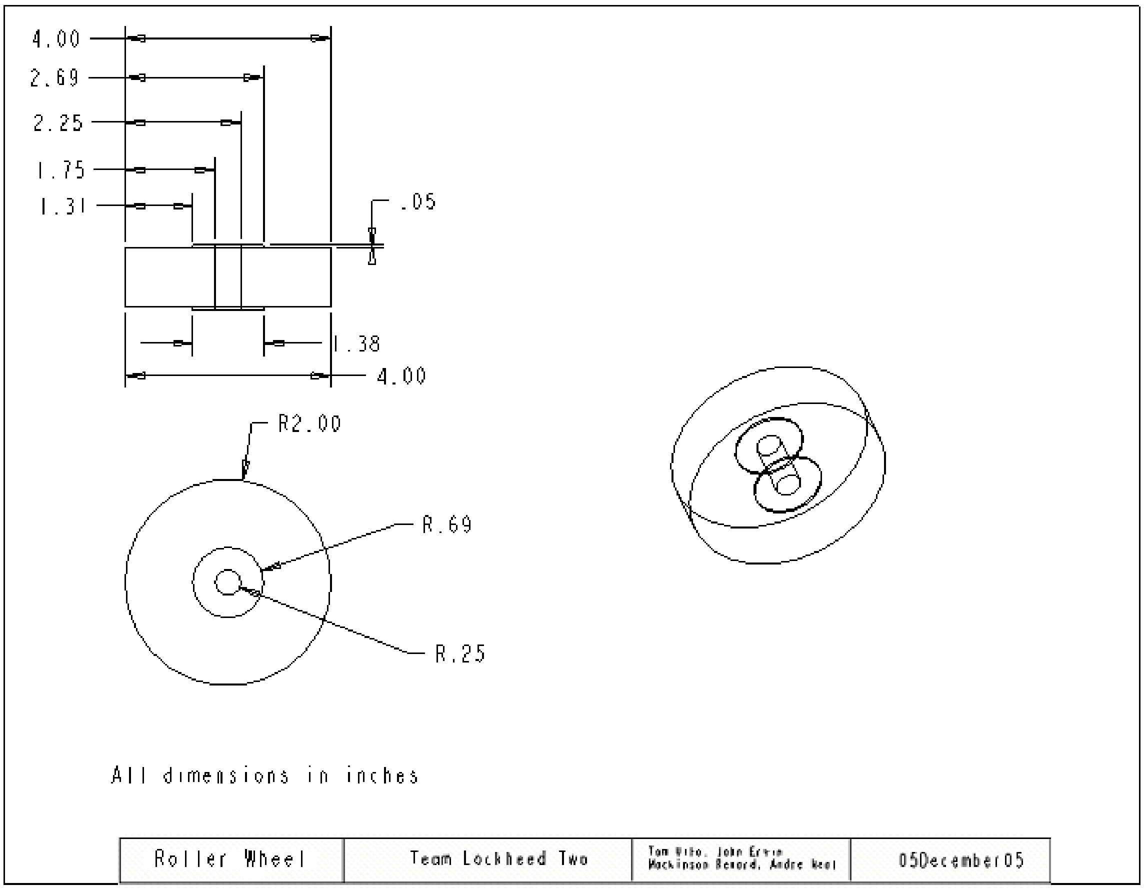




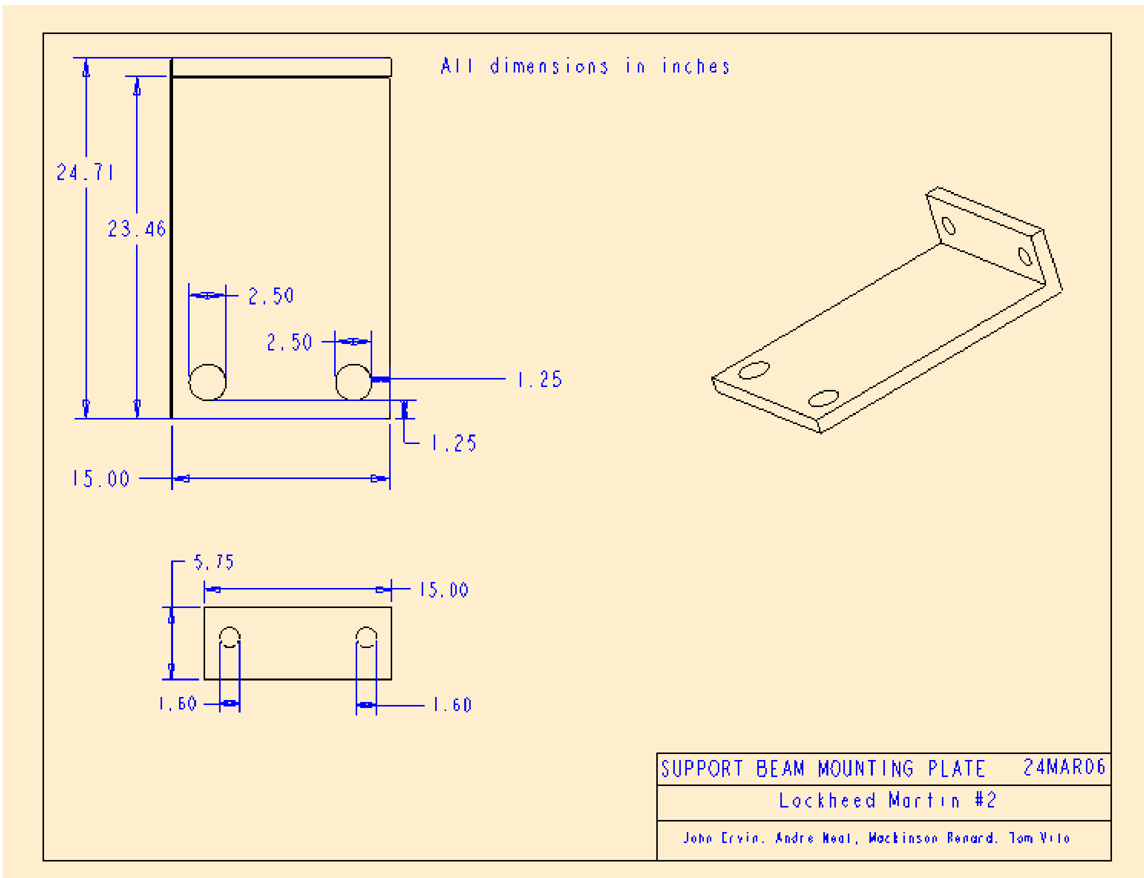
Spring	Team Lockheed Two	Tom Vito, John Ervin Mockinson Renord, Andre Neal	05December05

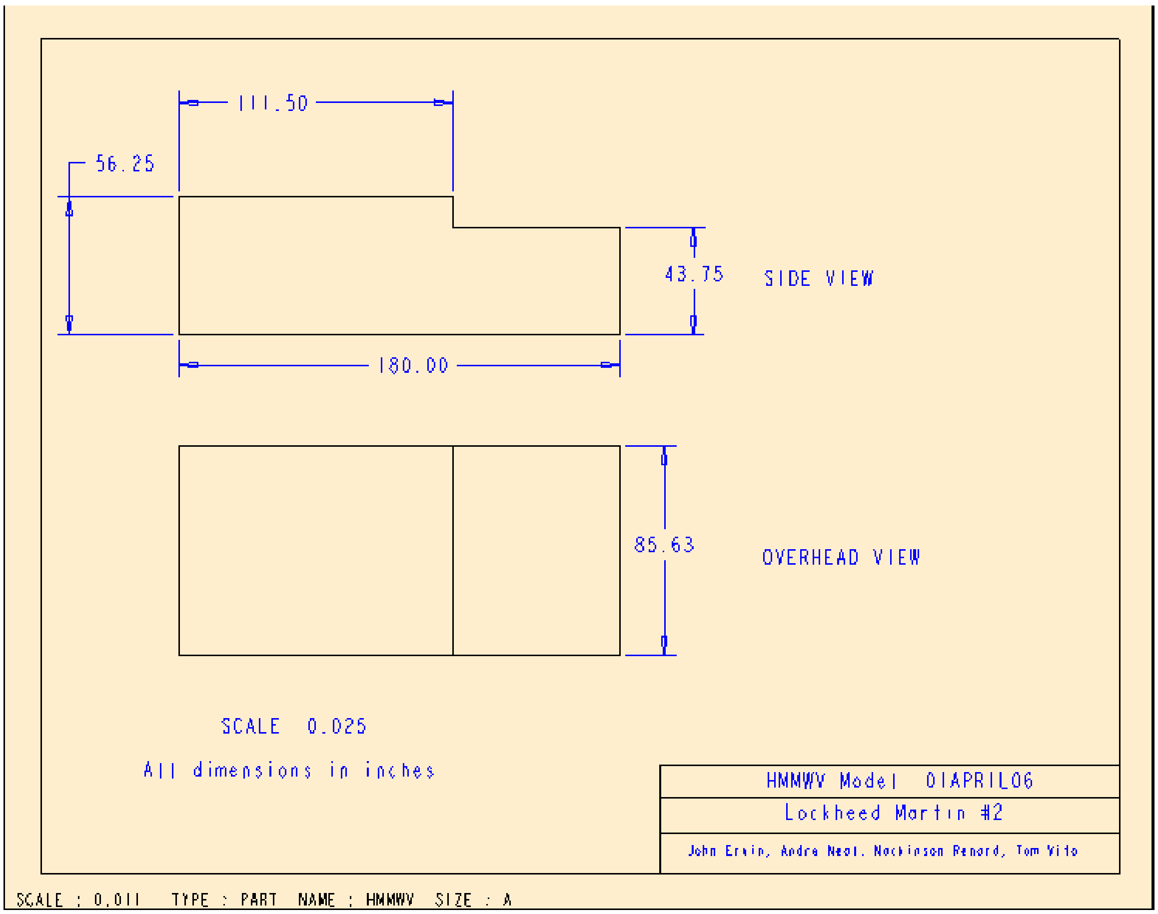

ALL UNITS IN INCHES
R.08
R2.10
2.68
2.10
R2.25
SCALE 1.000
Piston(Al6061T6)
Team Lockheed Two
Tom Vito, John Ervin
Mackinson Renaud, Andre Neal
05DECEMBER05


4.00
43.00
5.00
1.75
2.42
15.43
SCALE 0.044
.25
.10
.50
5.00
40.0°
.25
31.49
.25
2.42
.15
.50
SCALE 0.044
1.75
1.75
R2.25
5.11
4.00
R2.50
1.75
SCALE 0.044
Piston(Al6061T6)
Team Lockheed Two
Tom Vito, John Ervin
05DECEMBER05


4.00
2.69
2.25
1.75
1.31
.05
1.38
4.00
R2.00
R.69
R.25
All dimensions in inches
Roller Wheel
Team Lockheed Two
05December05

Spring Engineering Drawings




111.50
56.25
43.75
SIDE VIEW
180.00
85.63
OVERHEAD VIEW
SCALE 0.025
All dimensions in inches
HMMWV Model 01APRIL06
Lockheed Martin #2
SCALE : 0.011 TYPE : PART NAME : HMMWV SIZE : A

Appendix E:

Concept Generation

Design Concepts

E.1 Lift

Industrialists' have been using lifting devices for many years. There are several types of lifting devices in the world today. The most commonly used lifting systems are: Pulley Cable, Hydraulic, Linkage, and Magnetic. The pulley cable system is the use of pulleys in a system of cables designed to balance a force while providing a generated motion. A great example of such would be the automobile engine. The hydraulic system has improved over the years and is now being used on machines, such as aircraft. The use of fluids under pressure creating desired motion makes this design operable. Linkage systems are also being operated widely around the world in such devices as the rear suspension in automobiles, exercise equipment, and utility tractors. In this system links and joints are used to provide a desired motion. The magnetic lifting system uses the electric field of a magnet to attach and hold an object of both large and small size, while transporting it over a given distance within a given time. The amount of force the jack is required to lift was calculated to be 227 kg (Calculations shown on page C-1).

The use of a hydraulic or mechanical jack would seem to be a very feasible alternative to meeting our customer's need. It is a very simple design and would be cheap to manufacture. The main problem expected from using this style design would be the time in which it would take to lift the roof 15 feet. The roof's material would have to be considered (i.e., modulus, toughness fatigue, failure, etc) due to the static contact or surface force between the jack and the 500-pound roof. The pros and cons of both the mechanical and hydraulic jacks are discussed below.

<u>Mechanical</u>

Pros:

- Long service life; roller chains last a long time
- Stops accurately, which allows multi-level use
- Synchronized chains permit extra wide carriages
- Faster speeds, typically 30 FPM
- High cycle rate. Great for automation applications

Cons:

- Higher initial cost
- Higher installation cost, due to the additional wiring

Here are two examples of possible mechanical lifts that could be used in our design. The ten-ton capacity jack shown in Figure E-1 is an ideal method for heavy lifting. This would create a problem, however, with location of contact point with the roof due to the floor having to be pulled all the way out before the wall panels are in put in place.

Figure E-1: Mechanical Lift

Figure E-2 shows a high lift that is a light and easy to maneuver jack and is versatile enough to be used for lifting or winching 4,660 lbs of rated lift capacity.

Figure E-2: Mechanical Lift

Hydraulic:

Pros:

- Lower initial cost
- Dual cylinder lifting systems provide redundancy
- Velocity fuses avoid Over-speeds

Cons:

- Greater maintenance, due to nature of hydraulics

- Units may begin to drift with wear
- Limited duty cycle rates of approximately 20 operations per hour
- Ground plus one stop service only

Rack and pinion steel jacks (Figure E-3) provide safe, smooth lifting operations. The safety crank has a double acting brake for secure load holding and heat-treated gears for low cranking effort. Configurations include adjustable toe, fixed toe, and cable reel styles in lifting capacities from 3,300 to 22,000 lbs.

Figure E-3: Hydraulic Jack

The numerical values assigned to the mechanical and hydraulic lifts are as follows: the mechanical jack has a much longer service life which makes it very reliable; the hydraulic lift does not last as long but has a lower initial cost. The hydraulic jack price ranges from $60-$1500 and the mechanical lift ranges from $30-500. The safety was determined from evaluating the operational hazards of both lifts. The mechanical lift stops accurately allowing for multi- level operation of the device where as the hydraulic lift units may begin to drift with wear. Both jacks are similar in personnel needed to operate the devices with the hydraulic jack getting the slight edge due to not having to operate a cranking mechanism to achieve the desired height.

E.2 Interior Pneumatic Cylinder

In order to provide roof-lifting personnel a decisive mechanical advantage while raising or lowering the roof, the integration of quick-detachable pneumatic cylinders to the frame of the trailer and the roof of the VCCT trailer is proposed. Initially the pneumatic cylinder in question was a double-acting type, in that the device consists of a sealed piston-cylinder system forming two physically separate volumes. These volumes each have one radially drilled pressure inlet or outlet and one volume will contain a metallic linear spring. A picture of a possible pneumatic cylinder is shown in Figure E-4. A functional schematic of such a pneumatic cylinder is pictured in Figure E-5.

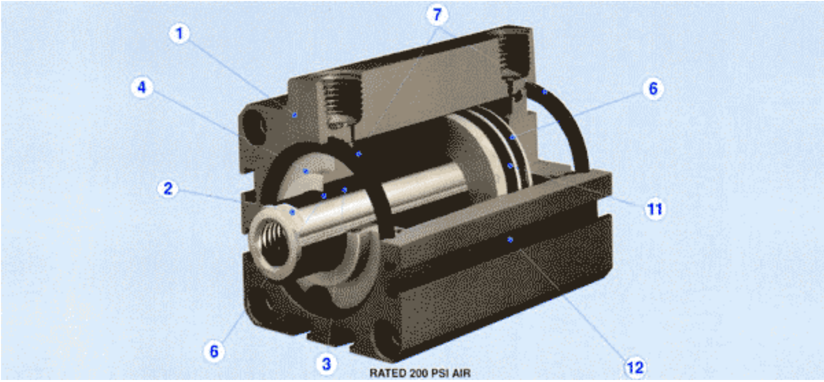


Figure E-4: Pneumatic Cylinder

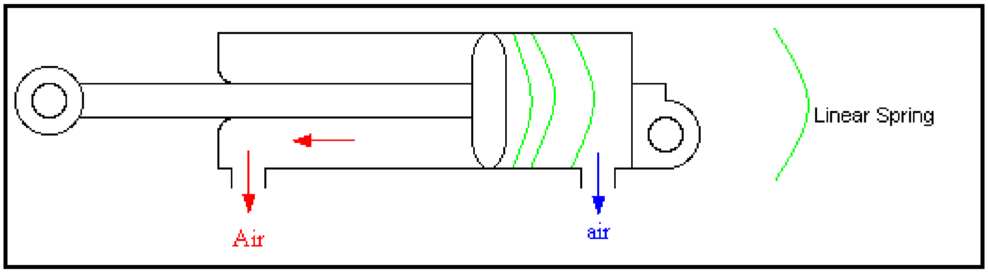


Figure E-5: Schematic of Pneumatic Cylinder

The termini of the cylinders on the roof will be as close to the roof's latitudinal centroid so as to minimize the rotational moment of the roof. Figure E-6 shows the desired locations of the cylinders when the roof is up.

Figure E-6: Pneumatic Cylinder Locations

When it is desired to lift the roof, the linear spring will become extended, exerting force on the piston/shaft system. It is the desire of the design team to specify the spring rate and force response such that the roof will be provided with a constant lifting force in the range of ninety percent the force of gravity. The end result of this approach will be to allow the roof to be lifted by one man, while preventing unintended activation and the potential safety hazards that accompany such an action. While the piston is being pushed along the cylinder axis, the system speed will be moderated by virtue of the gas outlet hole present in the compressing volume. The diameter of this outlet hole will be dimensioned such that the gas stream escaping out of the cylinder will be subjected to head loss of the appropriate magnitude, thus damping the motion of the system.

Given the imposing exterior physical dimensions of such a system and the requirement that the images produced by the projector system will not be interfered with by the team's modifications, it is anticipated that the pneumatic cylinder system will have to be removed prior to further preparation of the trailer for usage. To this end, it is intended by the team to utilize a 'bayonet lug' type of attachment method in the interests of facilitating rapid installation and removal of the pneumatic cylinder system. The bayonet lug attachment method can be found on most rifles in the United States military inventory and is intended to provide a secure and fast method of attaching bayonet knives to military firearms. It is currently believed by the team that this method may be scaled-up and safely employed for usage on the intended load bearing assemblies.

For lowering the roof, the spring action of the pushing spring will be supplemented by the head loss of the pressure outlet found in the chamber containing the spring, which will effectively dampen and slow the descent of the roof back to its original position. This setup will completely alleviate the manpower requirement necessary to lower the roof. The following calculations were completed to discover what force the cylinder would have to overcome to lift the roof and the percentage at which it would overcome it. So this setup up would lift 98 percent of the weight, which means that a person would have to lift the other 2 percent to lift up the roof. We did this so the roof would not uncontrollably swing open and hurt someone.

In order to integrate seamlessly with the pre-existing structures of the interior of the trailer, and by so doing maximize ease of installation and removal, it was decided by the team to make efforts to minimize the overall physical dimensions of the pneumatic cylinder and supporting structures. So a new type of pneumatic cylinder will be used, however, the overall concept and design will remain the same as mentioned above.

Primary among the considerations faced by the team was keeping the length of the piston housing to a minimum because of the constraint to rotation imposed by the presence and non-removeability of the simulator vehicle. It was determined that the aforementioned linear compression spring, constrained to move axially through the piston housing, could be replaced by a linear spring mounted on the immediate exterior of the piston housing. The benefit of this approach is that it eliminates the unused space behind the piston occupied by the compressed linear spring. Additionally, should it be discovered further on in the project that it is desirable to provide a spring rate that is not physically producible by the singular spring at a given deflection, the incorporation of an externally-mounted spring will allow the team greater design flexibility with regard to the incorporation of a double spring or another extension spring that works in series with the primary spring to provide the additional force required at some position of the roof.

This approach necessitated the consideration of the rotating linkage upon which the cylinder housing sits and rotates as the linkage would restrict the range of extension/compression of a spring mounted externally to the cylinder in an equal-radial fashion. As such, it was decided that an eccentric location at a 180 degree offset from the point of attachment would provide the maximum range of spring motion while minimizing the overall length required for the piston housing. To allow the externally mounted spring to impart force to the piston/shaft system, it was found necessary to machine a slot through the wall of the piston housing, facing the spring. Through this slot is to protrude an extension of the piston itself, such that the piston may still be in direct contact with the spring. The dimensions of the slot will be determined by the team such that a balance is found between the head loss experienced by the air being forced out of or drawn into the cylinder through the slot and the strength of materials consideration associated with the thickness of the material used to construct the piston extension. Figure E-7 shows a schematic of this design from the interior of the trailer.

Figure E-7: Schematic of Pneumatic Cylinder Setup

The only potential drawback of this system is that there are no inherent failsafe mechanisms in the case of catastrophic failure of the piston sealing ring or rings. In such a case, only the raising spring could be counted on to decrease the speed of roof descent, albeit in the presence of an oscillatory as opposed to damped motion. The pros and cons of the pneumatic cylinder are stated below. Figure E-8 shows a free-body diagram of this design and will be analyzed by the following calculations.

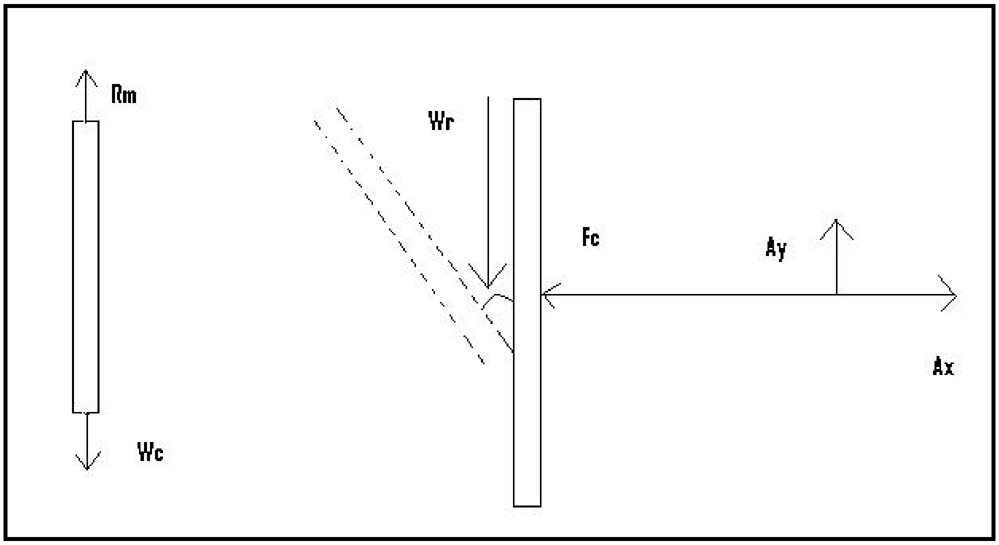


Figure E-8: Free-Body Diagram of Pneumatic Cylinder Setup

The free body diagrams in Figure E-8 show the forces and reactions at the supports for the pneumatic cylinder design. The variables used are as follows: Wc is the weight of the cylinder, Rm is the reaction support for the mount, Ay and Ax are the pin support reaction forces where the mounting device connects to the cylinder, Fc is the force exerted by the cylinders piston, and Wr the weight of the roof will change as a function of the angle shown in the second diagram. The force calculations on page C-2 show the forces due to the roof, piston, and the reactions at the pin and mounting points. From these calculations, the pin connections that will be used need to be able to handle 1500 pounds of force. The ball and socket joint that will connect the cylinder to the roof of the cylinder needs to be able to handle 500 pounds of force. The pros and cons of this setup are shown below.

Pros:

- Reduces manpower requirements on the lift sequence to one person
- Provides damped rotational motion on both lift and collapse sequence
- System is easily removable and installable with hand tools

Cons:

- System damping performance is largely dependant upon physical condition of piston and the corresponding air tightness of the compressing and expanding volumes. This focuses reliability concerns on one part.
- No failsafe mechanism is integral to pneumatic cylinder to provide controlled damped motion, should a part failure be experienced.
- Physical dimensions of trailer and sequence of trailer setup disallow attachment and positioning of pneumatic cylinders with respect to the trailer roof in an optimum location for force transmission.

A weight of 5 was given to the area of reducing personnel numbers and time required to setup and break down the roof section of the trailer, due to Lockheed's requirement that the labor and costs associated with setup be significantly reduced from the current magnitude of $60,000.

The issue of worker safety during setup of the roof was assigned a weight of 3. The reason for this is that, were one worker to become injured during setup or break down of the trailer by a perceived design defect in the roof section, Lockheed could presumably be held liable for the damages perceived and incurred.

Physically constructing this concept in a way that reliability could be maximized was given a weight of 4. This was based on the simple assumption that any machine must work before it can provide a benefit to the user and that any failure of the roof raising or lowering mechanism could have catastrophic effects on worker safety.

The setup of this design could be complex because it would have to be setup and disassembled each time the simulator would need to be run. The use of the bayonet clips, however, will greatly reduce the setup time. A weight of 4 was given to the ease of setup.

The remaining concern was the overall cost of the modifications and this was given a weight of 3. Lockheed Martin has earmarked two thousand dollars for Team 13 to utilize in the redesign of the VCCT roof section, with contingency funding assured should costs run over budget. In any case, a primary goal of the team is to reduce the cost to Lockheed of operating this trailer and that is reflected in the weight given to the importance of producing a cost-effective solution.

E.3 Exterior Pneumatic Cylinder

The next concept proposed was for a ground based pneumatic cylinder. This concept would use the same principles and ideas as Concept 2, except instead of being located inside the trailer it would be located on the ground. Two workers could use the currently used poles to "pull" the roof open slightly. A third person could place 1 or 2 pneumatic cylinders into a support structure on the ground connecting them to the roof. These cylinders will then take over the work and open the roof. The same cylinders will be used as in Concept 2. The following calculations were conducted to estimate how far 2 workers (who can lift 50 pounds each) could pull the roof open. Figure E-9 shows a schematic of this situation. In the drawing, F is the force that 2 men can lift (100 pounds), W is the weight of the trailer (500 pounds), X is the length of the roof (8 feet) and L is the distance from the side of the trailer.

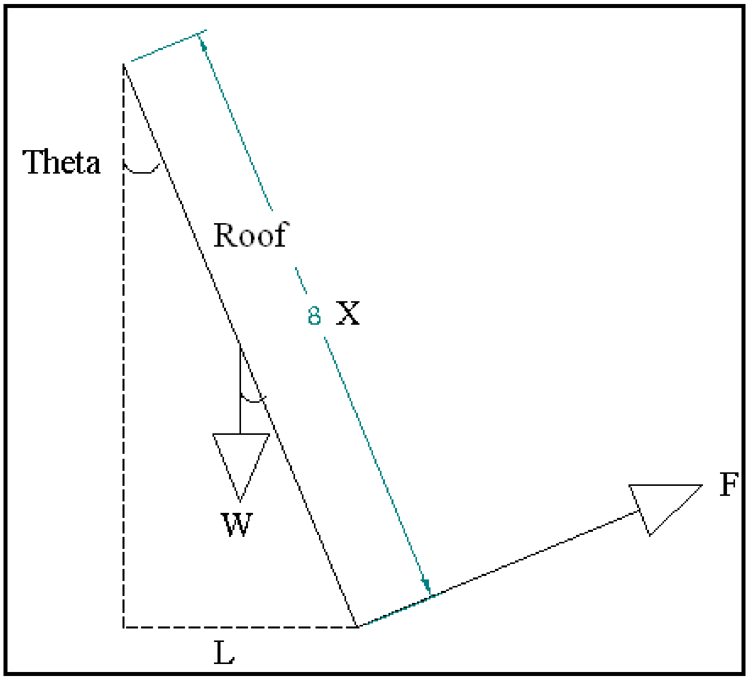


Figure E-9: Schematic of 2 Men Lifting Roof

The 2 workers will be able to lift the roof approximately 24 degrees in the air (Calculations seen on page C-3). So the workers can lift the roof approximately 3.5 feet from the trailer. At this point a third worker will setup the two cylinders that will be used to raise the roof

Pros:

- Simple setup
- System is easily removable and installable with hand tools

Cons:

- May get in the way of the floor
- Will require 2 workers to "open" roof initially and a 3rd to position cylinders

This design is very similar to Concept 2. The personnel required would be 3 people, so that corresponds to a rating of 4. So it will pass all of the safety requirements, this design will receive a safety rating of 5. Since the same equipment will be used as Concept 2, it will receive the same cost grading as Concept 2, which was a 3. The set-up will take some time because as 2 workers hold the simulator roof at 24 degrees, a third will have to setup the cylinders. Because of this, a setup rating of 3 was given. Finally, the reliability again goes hand and hand with Concept 2, so a rating of 4 was given.

E.4 Pneumatic Cylinder with Heat Source

This design utilizes the same operating principles as the pneumatic cylinder approach (Concept 2) to raising the VCCT roof, with the exception that the pushing force is provided by a fixed mass of air placed under pressure through an increase in temperature imparted by an external source; whereas the former method utilized a linear spring of appropriate magnitude and rate to impart motion to the roof.

In order to facilitate the implementation of this approach, a modification to the cylinder body was undertaken by eliminating the inlet/outlet hole on the cylinder side of the piston that formerly contained a spring, as depicted in Figure E-10.

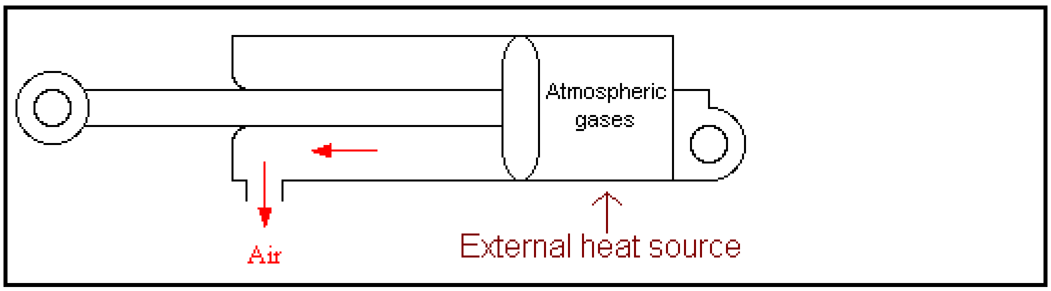


Figure E-10: Schematic of Pneumatic Cylinder with Heat Source

As proposed, when the roof is in the stowed-for-transport condition, the piston will be compressing the atmospheric gas cavity to full pressure. When the time comes to raise the roof, an external heat source is to be activated at a location directly beneath the cylinder at an axial and a radial distance to be determined based on the fuel source designed for and optimization studies thereof. With respect to the fuel type, it was determined by the team that the fuel to be specified by readily obtainable on military bases, be inexpensive and be safe to work with and around. The agreed-upon fuel was the trioxane fuel tablet (National Stock Number NSN 9110-00-263-9865); utilized by soldiers to heat food and boil water due to its availability and suitable lower heating value.

It was realized that the reaction of the atmospheric gases within the sealed volume could be broadly analyzed, thereby assessing the feasibility of the approach, by determining the lower heating value of an individual trioxane fuel bar. This was done by boiling one liter of water, burning under wind-still conditions (sea level atmospheric pressure and 25˚C bulk ambient temperature) without a specialized enclosure, and making note of the time required to accomplish the task. During the course of evaluation, which encompassed five separate runs, it was found that one trioxane tablet could boil one liter of water during the course of its 10-minute burning duration. As such, calculations (page C-3) were performed to determine the maximum stroke length that could be expected from the pneumatic cylinder/trioxane interaction, under idealized conditions. This number was calculated to be 141 meters. As the initially determined required stroke length was 1.83 meters, this figure is clearly acceptable. However, the drawbacks to utilizing an open flame have been determined to negate the benefits of this approach. In particular, it was feared that the utilization of a high-temperature source could lead to fires and thermal injuries in the event of a system malfunction. Additional concerns deal with the military procurement process and the turbulation therein that can cause supply shortages and necessitate design of military equipment, thus rendering a physical setup optimized for the trioxane bar in a state of questionable future serviceability. The pros and cons for this system are shown below.

Pros:

- Elimination of driving spring
- Ability to raise the roof will limited user interaction
- Reduction of parts in cylinder
- Slight increase in reliability

Cons:

- Could cause a fire
- No failsafe mechanism is integral to pneumatic cylinder to provide controlled damped motion, should a part failure be experienced.
- System damping performance is largely dependant upon physical condition of piston and the corresponding air tightness of the compressing and expanding volumes. This focuses reliability concerns on one part.

With regard to the decision matrix for this approach, the personnel requirement for setup was given a 4 weight, in that once all roof tie-down equipment is removed and the trioxane bar is ignited, no personnel are required to lift the roof until the final stages when the side panels are swung under the roof to support it. Similarly, the safety of workers is increased by this device because no workers are required to be in the vicinity of the roof until the roof is almost parallel with the plane of the ground. As such, the safety was given a weight of 3 on the Decision Matrix.

Because this approach does not utilize a linear spring, which would likely have to be custom-made to meet the dynamic requirements of the system, and utilizes a singular compressed fuel tablet at a cost of one dollar per unit, cost associated with the system is minimal. Therefore, the weight given this system for cost reduction is a 4.

The setup of the device only requires the removal of the equipment securing the roof and the placement and ignition of a solid fuel bar underneath the pneumatic cylinders sealed volume. From that point onward, standard operating procedures for readying the trailer are followed. The ease of setup of this approach is given a 4.

Due to the complex nature of a free stream flow of thermal energy produced by the tablet, and the inherent unpredictability of such a supply of heat in field usage, the power source of the system is subject to external interference such as colder-than-expected weather, wind and rain. A shielding enclosure would have to be utilized to increase the odds of successful operation during foul weather. For this reason, reliability is weighted at 3.

E.5 Pulley System

The next concept uses a pulley system and it’s the first attempt at attacking the problem externally as opposed to trying to push out the ceiling internally. Set-up for this pulley system will take place on top of the trailer. Multiple pulleys will be arranged on the roof of the trailer with the two to three cables connecting the ceiling that needs to be deployed. This system is to be powered by a wench that is similar to a boat wench, which one person will crank to raise the roof. Figure E-11 shows exactly how this process will work. The red symbols are the cables attaching the system and the ceiling.

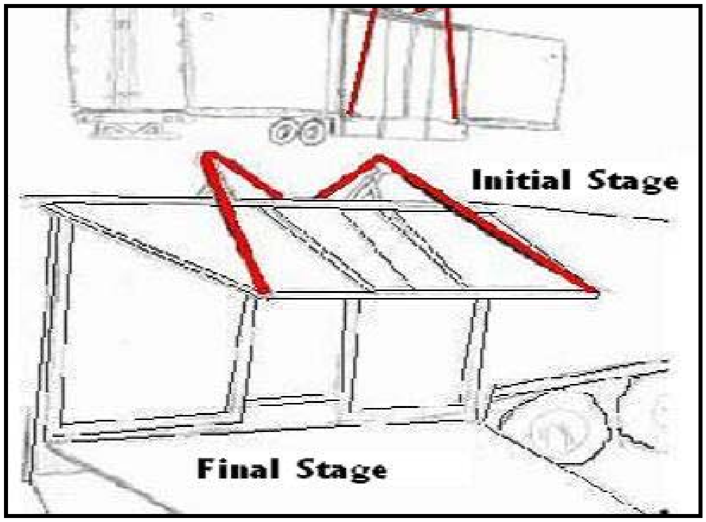


Figure E-11: Initial and Final Stage of Pulley System

The best thing about this method is that the system would be able to simultaneously raise both sides of the trailer. The more pulleys that are in a system the less work that will need to be done to raise the roof, so, ideally, analysis is done to see how many pulleys would be needed to complete the task. We do not want to use more than necessary since more pulleys would increase the cost. According to the calculations completed on page C-4, 2 pulleys would be ideal.

The total length of the ceiling that needs to be raised is 94 inches. Since the cables are attached to the ceiling when it is still in its downward position, the person powering the wench will only need to crank in a small amount of the cable since the length of the ceiling isn't changing. The only thing that will need to be considered is the change in height of the ceilings edge. Figure E-12 shows how Pythagorean's Theorem is used to determine how much of the cable will need to be reeled in so the roof could be fully raised to its max point.

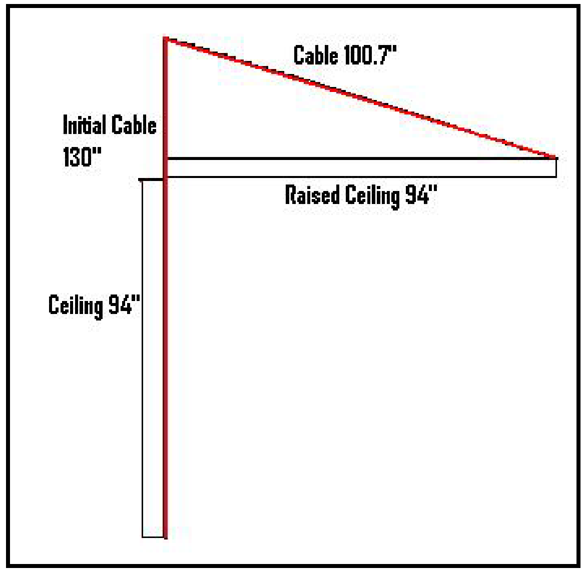


Figure E-12: Schematic of Pulley System

After the amount of cable reeled in by the person operating the wench is determined, velocity analysis (page C-5) can be performed to determine the amount of time that will be needed to lift the roof. This value was calculated to approximately 14.5 minutes. Below are the pros and cons that were used when determining the values of this concept.

Pros:

- Enables both sides of the trailer to be raised simultaneously
- Adding more pulleys to the systems sequence drastically cuts down the weight of the ceiling
- Parts are fairly cheap

Cons:

- The system is not fail safe due to the fact that the system relies on cables to raise the roof. Extra means are needed to assure that the roof will not slam shut if the cables were to snap.
- Set-up will prove to be very difficult since multiple small pieces will need to be set up on top of the trailer for the system to perform. The time to simply set up the system could probably last longer then the actual process we are attempting to improve.

The one thing that really stands out for this concept is the personnel required to the set-up and teardown of the trailer. Only three people will be needed max and really only one person does most of the work and that is the person operating the wench. For the personnel requirement this concept receives a 4. Because the cable could snap causing the roof to slam shut, safety becomes a major issue and another device will be needed to make this fail safe, so a 3 was given. The cost and reliability received a 3 and 4, respectively because while they are minimal, they aren't the best. The reliability goes hand and hand with the safety of the design. Lastly, the design received a 2 for set up because while set up isn't extremely difficult, the amount of time that will be needed for set up could prove to be lengthy.

E.6 Pulley Lift System

The next concept considered was a pulley lift system. This concept will combine the pulley and lift systems. Basically, a cable and pulley will be attached to a lift. A hook will connect the pulley to the front of the roof. The lift will be placed at the optimum distance from the roof. This distance will have to be around 10 feet because it needs to be at least 8 feet to clear the roof once it is totally horizontally in the air and an additional 2 feet will give the operators some extra room to work with. Once the pulley is connected to the roof, the lift, which will have the pulley attached to its top, will be lifted vertically, thus moving the pulley and the cable vertically in the air. This movement will raise the roof as the cable increases in tension. A crank will allow a single person to operate this device. Figures E-13 and E-14 show examples of this type of system and Figure E-15 shows a schematic and free body diagram of the setup.

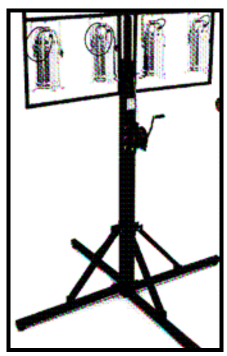


Figure E-13: Pulley Lift

Figure E-14: Pulley Lift

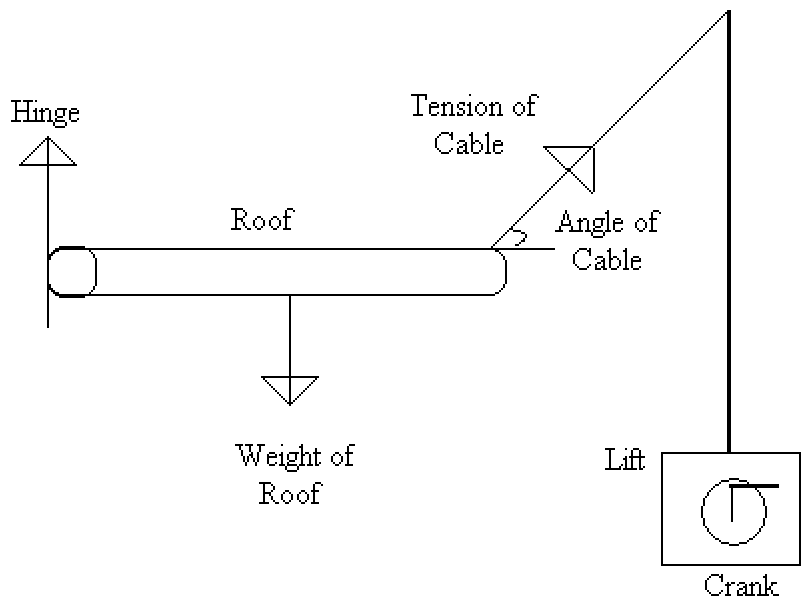


Figure E-15: Schematic of Pulley Lift Setup

Both of the pulley lifts shown can lift a maximum weight of 500 pounds and both can lift to a maximum height of 16 feet. They both can be collapsed into objects that will easily be able to fit in the trailer's storage area. The analysis (page C-5) shows how much force that will be on the cable when the roof is lifted horizontally. This force will depend on the angle of the cable. As the angle approaches zero, the force felt by the lift will be 250 pounds. At 45 degrees, the force will be 354 pounds and at 30 degrees, the force will be 500 pounds. Since the lift can handle a maximum of 500 pounds, the pulley would have to be positioned in such a way that the smallest angle every seen is greater than 30 degrees.

As θ gets closer to 90 deg, $\sin\theta$ gets closer to 1. This is the point where the cable will be lifting the least amount of weight, which is 250 lbs. Even at 45 deg, the cable will only be lifting approximately 354 lbs. The calculations on page C-5 show where the lift should be place, in relation to the trailer, for the cable to be at a 45-degree angle. The top of the roof of the simulator is 13.5 feet and the maximum height of the lift is 16 feet. It will be assumed that the lift will be lifted to a height of 15.5 feet or 2 feet higher than the top of the trailer. According to the calculations below, the lift should be placed 2 feet away from the trailer if the cable is to be at a 45-degree angle. If the tension of the cable is too high, the lift can be moved closer to the trailer to reduce the tension on the cable.

Pros:

- Simple design
- User friendly
- Reduces manpower requirements on the lift sequence to one person
- Within budget

Cons:

- Needs a failsafe mechanism in case cable snaps
- Needs a steady base to keep from tipping over

This device will be extremely easy to setup and teardown and once the pulley is hooked to the roof, the roof should open with just one person rotating the crank. So only one person is needed, but two could be used because the lift would weight approximately 100 pounds. This is below the design specifications set out for this project, so this system gets a 5 for personnel. Safety should really not be a concern with this design, but it is possible the cable could snap and the roof would slam into the trailer. This could injure someone if they were struck by the roof. Because of this possibility, some type of safety device would be needed. So this design gets a 4 for safety. Both lifts shown above are well under our budget. Figure 7 costs roughly $1,139 and Figure 8 costs roughly $1,520. Figure 8 is a little more powerful, but either lift is possible. The cable only costs about $0.50 per foot, so that is negliable in the total scheme of things. At these prices, however, only one lift could be purchased and testing several different lifts would not be an option. For cost, this design gets a 4. The setup of this design could not be easier. Once the optimal spot is discovered and logged in the procedure, anyone should be able to carry this out of the trailer and setup up. For setup, this design gets a 4. Finally, for reliability this design gets a 4. Since it is possible for the cable to snap, the reliability is a small issue.

E.7 Four-Bar Pulley System

The four-bar pulley system is an idea that was spurned from the pulley system. This design would be very similar to the pulley system however instead of a pulley and cable it would have 2 arms that would open the door. Figure E-16 shows a diagram of what this system would look like. This system would be braced by the support beam via the roof. A small beam would extend from the support beam, which is located inside of the trailer, approximately 1 foot from the ceiling, out of the roof. Two arms would extend from this beam and connect to the roof of the simulator. A hand crank would be connected to the beam and when rotated, it would rotate the first arm, which would open the roof. Figure E-17 shows a diagram of when the roof is open.

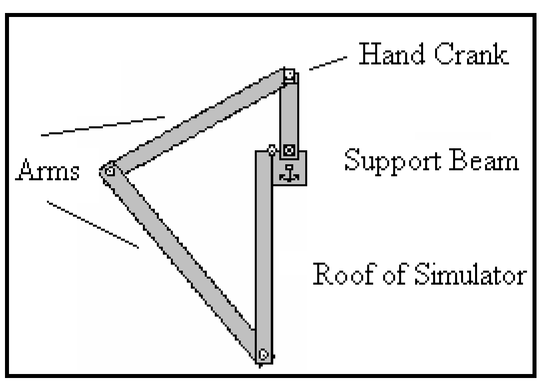


Figure E-16: Schematic of Four-Bar Pulley System (Roof Closed)

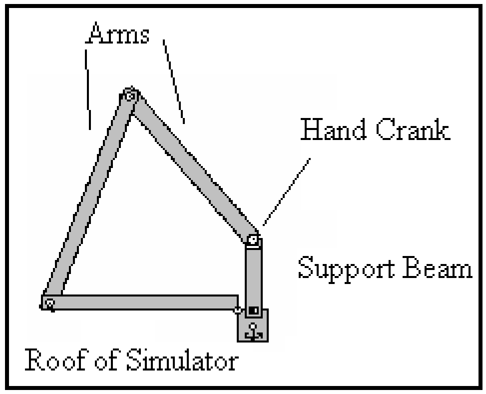


Figure E-17: Schematic of Four-Bar Pulley System (Roof Opened)

Pros:

- User friendly
- Reduces manpower requirements on the lift sequence to one person

Cons:

- More expensive material
- Difficult and time consuming setup

This design received a 4 for personnel requirements because only 1 man would be needed to turn the crank. The other 2 men could be using the rods to give support to the roof as it was moving up or down. It got a 4 for safety because, since no cables are involved, there is no chance for a cable to snap. Steel would be used on all the arms, so it will easily be able to support the roof. Also, since the guy rotating the crank is on the roof of the trailer, he cannot get injured if the roof of the simulator were to fall. The cost of this design received a 2 because we will be using steel beams and steel can get very expensive. The setup received a 1 because the arms would need to be added and removed every time the trailer is in transit. Also, it may be difficult to setup up the beams because they will be heavy. This design got a reliability rating of 3 because there is a very small chance the beams would break or bend because they will be able to handle a large amount of weight.

E.8 Motor Lift

The next design is a detachable gear driven motor that would drive a shaft connected through the hinges of the roof connection, rotating with enough force to raise the 20 by 10 ft roof 14 feet vertically. The analysis of the gear systems will come from using previous knowledge gained in mechanical systems. The gear ratios, size, shaft size, torque, and material will come from this analysis. The power supplied to the shaft and also force and stress analysis of the shaft can be determined using spur gear transmitted load and torque equations. Figure E-18 shows a sketch of the roof with the hinge supports and shaft extended slightly to allow a detachable motor to be placed on the shaft that will provide 7000 lb-ft of torque determined from T=Fr, where F is the force and r is the distance.

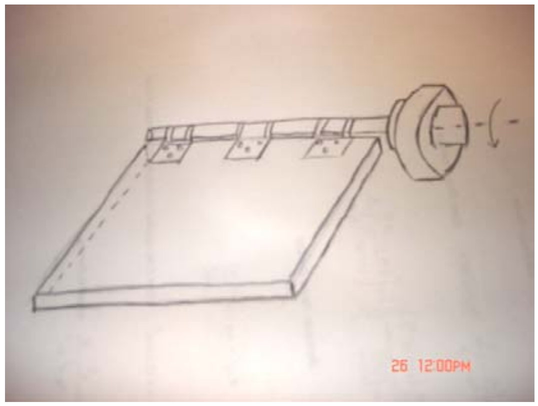


Figure E-18: Sketch of the Motor and Supports

Pros:

- Simplifies setup and teardown
- It should raise the roof in a very short amount of time

Cons:

- Power supply could fail
- Gears could wear

The motor was given an economical rating of four based on the low price range for a motor that will handle the 500 lb load over the 13.5 ft. distance. The personnel operation rating of 4 is due to only needing a max of two people to operate the device. Reliability rating at 3 comes from the tendency for the electrical components and gears to wear out. The set-up rating of 3 comes from having to climb to mount and detach the motor. The safety rating of 3 deals with the possible failure of the power sources, motor locks, and gears.

E.9 Spring Hinge

The use of a spring loaded dampening system attached to the hinges that will lower the force of the 500-pound roof from the 14 ft vertical position. The use of dynamic systems analysis will help to achieve the desired spring stiffness for this type of design concept. Springs exert a restoring force that opposes an extension or compression. The equation below shows the force applied (F) with respect to the spring stiffness (k), and the displacement (X). F=kx. This system is what you would call a 1-degree of freedom problem due to the motion constraints that the hinge system allows. The spring would exert a force on the shaft that connects the hinge and the roof creating a damping effect to the clockwise rotation of the roof. Figures E-19 and E-20 show a diagram and a picture, respectively of a spring loaded hinge system.

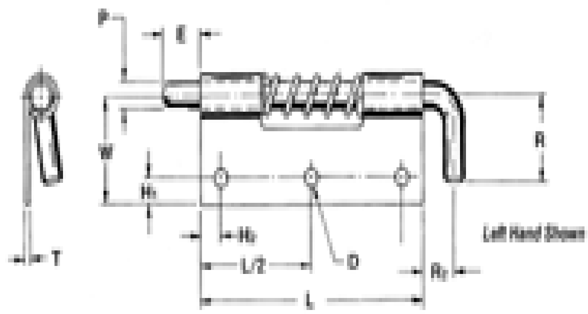


Figure E-19: Diagram of Spring Loaded Hinge System

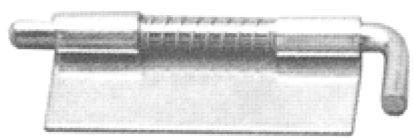


Figure E-20: Picture of Spring Loaded Hinge System

Pros:
- Only would have to setup hinges once
- Could be used as a failsafe

Cons:
- Spring will wear after certain amount cycles
- Does not help raise the roof

This concept is to help mainly with the teardown process that is unsafe. The option to combine this concept with another seems to be a more feasible solution to the entire problem. The spring hinge received a 4 economical rating due to low cost of the hinges. The personnel operation rating of 4 was given due to the hinges only needing to be mounted once. The reliability rating of 4 is based on the spring stiffness and its ability to withstand the loading situation. The setup rating of 4 also deals with only having to install the hinges once. The safety of 3 is due to spring wear over a certain number of operation cycles.

<u>Appendix F:</u>

Purchase Orders

ORDER CONFIRMATION

Includes Shipping Charges

Order Date	01/15/2006
Confirmation Number	0115TVITO
Order Placed By	Tom Vito (tav9168@fsu.edu)

Products

Line	Quantity	Part Number	Description	Unit Price	Total Price	Ships
1	1 Each	1681T27	Alloy 6060 Aluminum Metric Rod 12mm Diameter, 1 Meter Length	$17.63	$17.63	Monday morning
2	1 Each	8199K17	Alloy 5052 Aluminum Sheet W/#4 Satin Finish .187" Thick, 12" X 12"	$28.13	$28.13	Monday morning
3	1 Each	88835K81	Alloy 2024 Aluminum Sheet .100" Thick, 12" X 12"	$37.88	$37.88	Monday morning
4	1 Each	1968T19	Alloy 2024 Aluminum Tube .50" OD, .43" ID, .035" Wall Thick, 6' Length	$29.19	$29.19	Monday morning
5	2 Each	2473K14	Press-Fit Drive Roller 1/2" Diameter X 5/8" Width, 1/4" Bore ID	$22.33	$44.66	Monday morning (from our Chicago warehouse)
				Merchandise	$157.49	
				Shipping	$17.75	
				Your credit card will be charged	$175.24	

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Order Date 01/27/2006

ORDER CONFIRMATION

Includes Shipping Charges

Confirmation Number 0127TVITO

Order Placed By Tom Vito (tav9168@fsu.edu)

Products

Line	Quantity	Part Number	Description	Unit Price	Total Price	Ships
1	1 Each	15665A213	Unfinished Steel Piano Hinge W/O Holes .025" Thick, 1" Open Width, 6' Length	$2.42	$2.42	today
2	2 Each	6498K413	Stainless Steel Air Cylinder Double-Acting, Nose-Mount, 2" Bore, 8" Stroke	$68.78	$137.56	today
3	2 Each	6498K574	Foot Bracket for 2" & 2-1/2" Bore Stainless Steel Air Cylinder	$5.35	$10.70	today
4	1 Each	5865T51	Alloy 5086 Aluminum Sheet .249" Thick, 12" X 12"	$23.05	$23.05	today
				Merchandise	$173.73	
				Shipping	$14.75	
				Your credit card will be charged	$188.48	

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ORDER CONFIRMATION

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Products

Line	Quantity	Part Number	Description	Unit Price	Total Price	Ships
1	7 Each	6527K14	Low-Carbon Steel Square Tube 1-1/4" X 1-1/4", .060" Wall Thickness, 6' Length	$18.69	$130.83	today
				Merchandise	$130.83	
				Shipping	$17.50	
				Your credit card will be charged	$148.33	

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Order Date	03/03/2006	**ORDER CONFIRMATION**
Confirmation Number	0303TVITO	**Includes Shipping Charges**
Order Placed By	Tom Vito (tav9168@fsu.edu)	

Products

Line	Quantity	Part Number	Description	Unit Price	Total Price	Ships
1	2 Each	6498K187	Stainless Steel Air Cylinder Double-Acting, Nose-Mount, 1-1/16" Bore, 8" Stroke (Same as 6498K62)	$31.02	$62.04	today
2	2 Each	6498K33	Foot Bracket for 3/4" Dbl & 1-1/16" Spring/Dbl Stainless Steel Air Cylinder (Same as 6498K39)	$2.08	$4.16	today
				Merchandise	$66.20	
				Shipping	$4.25	
				Your credit card will be charged	$70.45	

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Includes Shipping Charges

Order Date	03/09/2006
Confirmation Number	0309TVITO
Order Placed By	Tom Vito (tav9168@fsu.edu)

Products

Line	Quantity	Part Number	Description	Unit Price	Total Price	Ships
1	2 Each	6498K554	Rod Clevis with Pin for 2" & 2-1/2" Bore Stainless Steel Air Cylinder	$4.47	$8.94	today
2	2 Each	6498K43	Rod Clevis with Pin for 1-1/16" Bore Stainless Steel Air Cylinder	$3.08	$6.16	today
				Merchandise	$15.10	
				Shipping	$4.25	
				Your credit card will be charged	$19.35	

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Appendix G:

Operations Manual

Safety Precautions

Ensure by verbal confirmation that all personnel in the area of the VCCT are aware that the expansion roof will be raised or lowered. Inform them of the danger area around the expansion roofs travel. All pneumatic lines are to be disconnected from the cylinders until the time that the roof is to be either raised or lowered. Immediately after the roof is either in the fully up or fully down position, the pneumatic lines are to be disconnected from the cylinders. Before use, visually inspect all hardware for cracks or other signs of damage. Halt all roof lifting operations and notify your supervisor if any signs of non-serviceability are found. Ensure that all pins connecting the lifting mechanism to the trailer are lubricated with wheel bearing grease – CLP may be substituted if no grease is available. Make visual confirmation that the expansion roof is clear of foreign objects such as snow or debris before lowering or raising the roof. Failure to follow these instructions can result in death or severe injury.

Lowering the roof (two persons required):

1. One person is to attach the lifting device to the VCCT overhead support beam, by using a stepladder, while their partner is to stand a short distance away from them, so that they can help the person on the ladder avoid falling, in case of a loss of balance.
2. The person on the ladder should climb to a comfortable height on the ladder and slowly take control of the lifting device from the hands of the person assisting them. Placing one hand on the red painted circle on the lifting device cylinder and the other on the lifting device mount, orient the assembly such that the tabs protruding from the roof are lined up with the holes in the lifting device mount and the piston rod is pointing towards the expansion roof section.
3. Raise the cylinder mount such that the protrusions fit through the holes in the cylinder mount and place the mount as flush with the roof support beam as possible. Slide the quick-detach safety pin (hanging from a lanyard on the support beam) through the holes drilled into the sides of the protrusions. The cylinder should now be fully supported on the support beam of the trailer. Visually and physically inspect that both protrusions are through both holes and that the safety pin is securely fastened into the holes drilled in the sides of both protrusions.
4. Step down from the stepladder and move it under the hinged pin connection (painted green) on the expansion roof. While this is being done, the other partner is to place their stepladder under the roof-lifting device. This partner is to slowly pull the piston rod of the roof-lifting device towards the hinged pin connection, so that you can attach the end of the piston rod to the expansion roof hinged pin connection.
5. Once you are in possession of the end of the piston rod, align the holes of the hinged pin connection with the holes found in the end of the piston rod. Using the same procedure as before, locate the quick-detach safety pin (hanging from a lanyard in the vicinity of the hinge) and slide it through all of the holes. Insure both by feel and sight that all holes are aligned and that the pin is inserted fully. Step down from the ladder and clear the work area of all non-essential objects.

6. Visually confirm that the pressure in the air compressor lines is set to '**0 psi**'. If it is not, adjust it to read '**0 psi**'. Request that your partner attach the pneumatic line to the rear of the roof-lifting device. This is done by placing the end of the air hose on the connection found at the rear of the cylinder and compressing (by hand) a spring-loaded ring found on the outside of the air hose fitting, while pushing the fitting onto the air hose. Once the fitting is in place on the rear of the cylinder, let go of the fitting and gently tug the fitting in the direction opposite that you were just pushing. Once you are certain that the air hose is correctly installed, get down off of the ladder and repeat steps 1–6 to install the other roof-lifting device.
7. Once the two cylinders are installed and you and your partner are certain of the correct installation of your roof lifting devices, loudly give warning that the roof is about to be lowered.
8. Assign your partner to operate the air compressor to increase/decrease the air pressure in the air hoses. Position yourself in an area clear of the roof lifting devices such that you can visually verify that the roof has lifted off of the side doors. Ensure that the electricity supply to the air compressor is turned on and connected.
9. Give a 'come-on' hand signal to indicate to your partner to increase the air pressure. It is critical that the air pressure be increased slowly (**no more than 10 psi per second**) or severe damage to the trailer and personnel can result. Once it is observed that the roof has been lifted off of the side doors (this is visible by a hand-sized gap between the bottom edge of the roof and the top of the side doors), give the 'stop' hand signal to your partner to advise them to **stop increasing** the air pressure. Under no circumstance is pressure to be released at this time. Ensure ahead of time that you and your partner agree on what hand signal means what action.
10. Initiate your normal procedure for folding the side doors and floor panels. Secure these panels in the normal fashion.
11. Making sure that both you and your partner are clear of the swing of the roof, slowly decrease the air compressor pressure at a rate of no more than **1 psi per second**, until the roof is touching the side of the trailer. Assign one partner to stand outside of the trailer to inform passersby of the dangerous nature of the operation.

Raising the roof (two persons required):

1. One person is to be attaching the lifting device to the VCCT overhead support beam, by using a stepladder, while their partner is to stand a short distance away from them, so that they can help the person on the ladder avoid falling, in case of a loss of balance.
2. The person on the ladder should climb to a comfortable height on the ladder and slowly take control of the lifting device from the hands of the person assisting them. Placing one hand on the red painted circle on the lifting device cylinder and the other on the lifting device mount, orient the assembly such that the tabs protruding from the roof are lined up with the holes in the lifting device mount and the piston rod is pointing towards the expansion roof section.

3. Raise the cylinder mount such that the protrusions fit through the holes in the cylinder mount and place the mount as flush with the roof support beam as possible. Slide the quick-detach safety pin (hanging from a lanyard on the support beam) through the holes drilled into the sides of the protrusions. The cylinder should now be fully supported on the support beam of the trailer. Visually and physically inspect that both protrusions are through both holes and that the safety pin is securely fastened into the holes drilled in the sides of both protrusions.
4. Attach the end of the piston rod to the extension roof by aligning the holes of the hinged pin connection with the holes found in the end of the piston rod. Using the same procedure as before, locate the quick-detach safety pin (hanging from a lanyard in the vicinity of the hinge) and slide it through all of the holes. Insure both by feel and sight that all holes are aligned and that the pin is inserted fully. Step down from the ladder and clear the work area of all non-essential objects.
5. Visually confirm that the pressure in the air compressor lines is set to '**0 psi**'. If it is not, adjust it to read '**0 psi**'. Request that your partner attach the pneumatic line to the rear of the roof-lifting device. This is done by placing the end of the air hose on the connection found at the rear of the cylinder and compressing (by hand) a spring-loaded ring found on the outside of the air hose fitting, while pushing the fitting onto the air hose. Once the fitting is in place on the rear of the cylinder, let go of the fitting and gently tug the fitting in the direction opposite that you were just pushing. Once you are certain that the air hose is correctly installed, get down off of the ladder and repeat steps 1–5 to install the other roof-lifting device.
6. Once the two cylinders are installed and you and your partner are certain of the correct installation of your roof lifting devices, loudly give warning that the roof is about to be raised.
7. Assign your partner to operate the air compressor to increase/decrease the air pressure in the air hoses. Ensure that the electricity supply to the air compressor is turned on and connected. Position yourself such that your partner can see you and that you can see the angle that the roof is making with the ground, preferably outside of the trailer.
8. Give a 'come-on' hand signal to indicate to your partner to increase the air pressure. It is critical that the air pressure be increased slowly (**no more than 10 psi per second**) or severe damage to the trailer and personnel can result. Once the roof has visually been raised above 95 degrees, give the 'stop' hand signal to your partner to indicate that the pressure is not to be increased. **At no time is the pressure to be decreased on this step.**
9. Initiate your normal procedure for folding the side doors and floor panels.
10. Slowly decrease the air compressor pressure at a rate of no more than **1 psi per second**, until the roof is sitting on the top of the trailer doors.

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