The project at hand, which is described in the project scope, is to design the components of a mechanical system that will raise and lower the roof of a simulator. The roof weighs 500 pounds and is hinged on one end. The roof is approximately 8 feet by 24 feet. Once the roof is in the horizontal direction, it is approximately 15 feet off of the ground. The following concepts are our proposals on how to solve this design problem. Table 1, which is located at the end of this document, is our design matrix and it shows how our group graded the following four concepts. 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, 2 for 5, and 1 for designs that require 6 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 a little 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, etc. 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.

Concept 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 calculations completed to discover how much force the jack is required to lift is shown below.

Lift Analysis

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

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

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

$F_r := W$

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

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

Sum of forces in y-directin yield

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

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 what 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 jack are discussed below.

Mechanical

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 1-1 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 1-1: Mechanical Lift

Figure 1-2 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 1-2: Mechanical Lift

<u>Hydraulic:</u>

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 1-3) 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 1-3: Hydraulic Jack

Table 1 shows the design matrix. 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.

Concept 2: 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 2-1. A functional schematic of such a pneumatic cylinder is pictured in Figure 2-2.

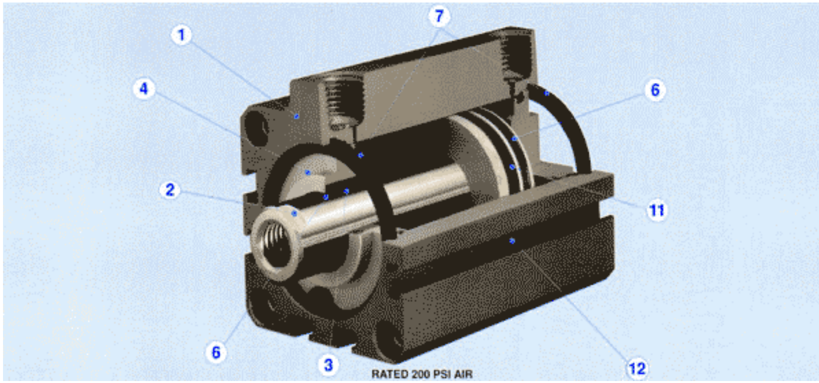


Figure 2-1: Pneumatic Cylinder

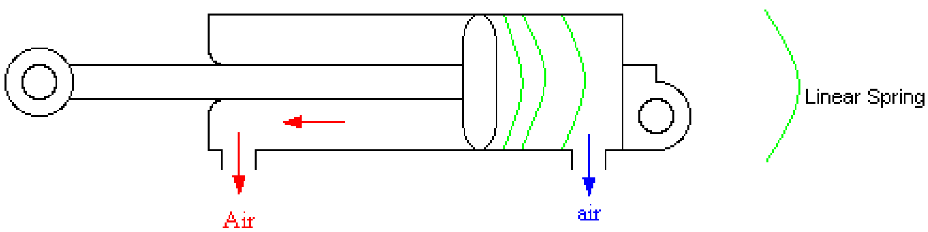


Figure 2-2: Schematic of Pneumatic Cylinder

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 2-3 shows the desired locations of the cylinders when the roof is up.

Figure 2-3: 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.

Assuming: Maximum load placed on each pneumatic cylinder is 250 lbf
Two cylinders will be pushing up on the roof at the roofs latitudinal centroid

$P_{max} := 200psi$ Based upon maximum operating load of American Cylinder LPC Series

$d_{shaft} := 1.25in$ Shaft Diameter

$$F := \frac{P_{max} \cdot \pi \cdot d_{shaft}^{2}}{4}$$

$\boxed{F = 245.437\,lbf}$ Force Applied to roof from pneumatic cylinder

$F_{summation} := 2 \cdot F$ $F_{summation} = 490.874\,lbf$

$F_{roof} := 500lbf$

$$F_{ratio} := \frac{F_{summation}}{F_{roof}}$$

$F_{ratio} = 0.982$

As designed, the pneumatic cylinders will provide 98 percent of the lifting force, leaving the roof to be liftable by one person.

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 2-4 shows a schematic of this design from the interior of the trailer.

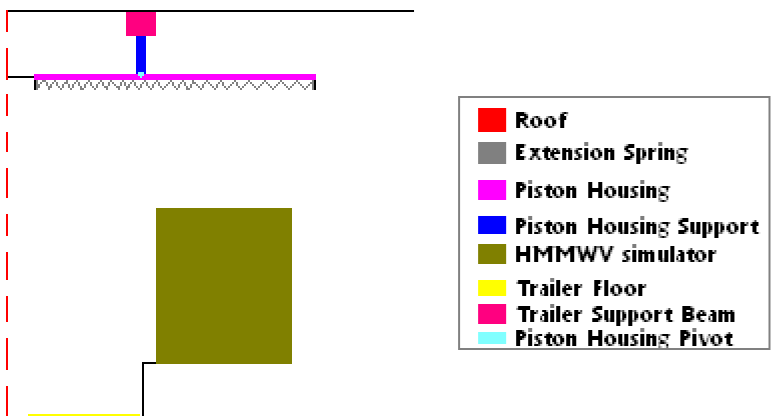


Figure 2-4: Schematic of current design

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 2-5 shows a free-body diagram of this design and will be analyzed by the following calculations.

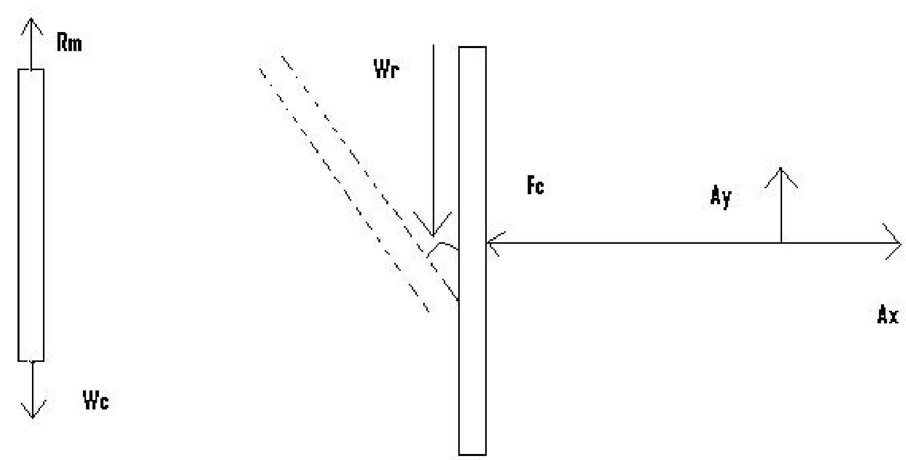


Figure 2-5: Free-Body Diagram of Concept 2

The free body diagrams in Figure 2-5 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 below show the forces due to the roof, piston, and the reactions at the pin and mounting points.

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.

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

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

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

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

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

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

$A_{Xpin}(\theta) := F_C - W_R \cdot \sin(\theta)$ $\quad A_{Xpin}(\theta) = \boxed{1.453 \cdot 10^{3}}\ \text{lbf}$ $\quad$ 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:

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

X-Direction:

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

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

$R_P := W_P$ $R_P = 15\,\mathrm{lbf}$

From the above 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.

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.

Table 1 shows the decision matrix. 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.

Concept 3: Pulley System

The third 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, that one person will crank to raise the roof. Figure 3-1 shows exactly how this process will work. The red symbols are the cables attaching the system and the ceiling.

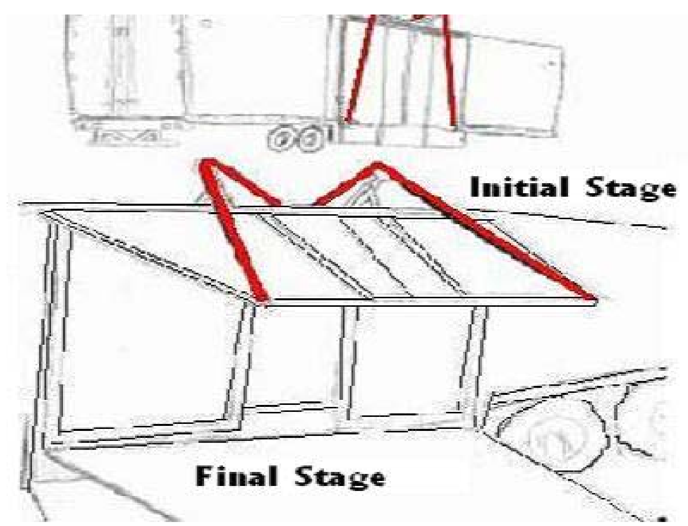


Figure 3-1- Initial and Final Stage of raising the roof

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.

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 $C := 500\,lb$

Weight of the hanging pulley $PH := 5\,lb$

Weight that each cable will experience $R := \frac{C}{2}$ $R = 250\,lb$

Force needed in each pulley to life roof $\frac{R + PH}{2} = 127.5\,lb$

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

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 3-2 shows how the Pythagorean 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.

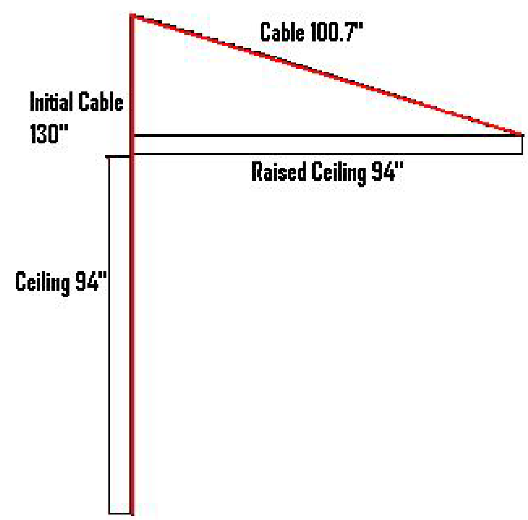


Figure 3-2- Schematic of System

After the amount of cable reeled in by the person operating the wench is determined, velocity analysis (shown below) can be performed to determine the amount of time that will be needed to lift the 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:

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

Below are the pros and cons that were used when determining the value of our third 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.

Table 1 shows where this concept ranks amongst the others in a design matrix. 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.

Concept 4: Pulley Lift System

The fourth 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 4-1 and 4-2 show examples of this type of system and Figure 4-3 shows a schematic and free body diagram of the setup.

Figure 4-1: Pulley Lift

Figure 4-2: Pulley Lift

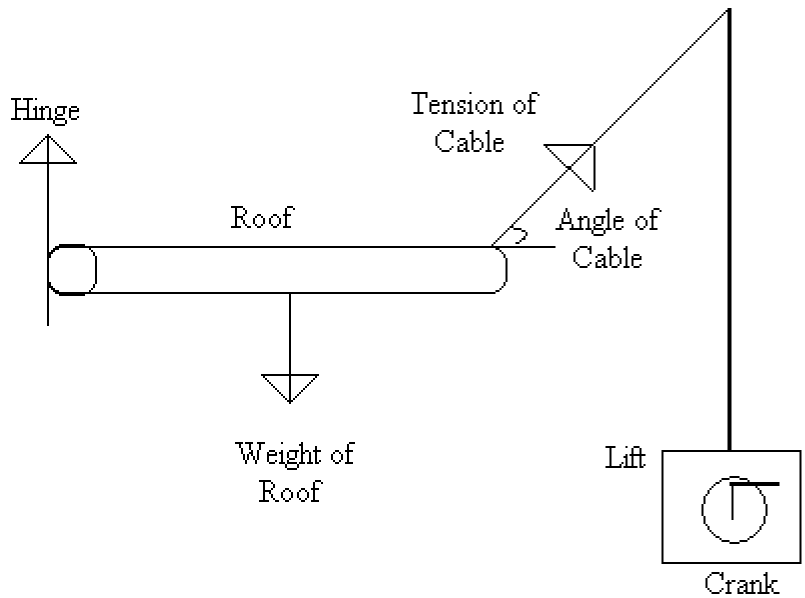


Figure 4-3: Schematic of Pulley Crank Setup

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 following analysis 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.

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

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

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

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

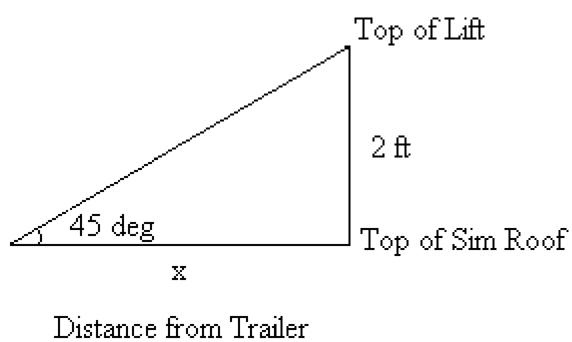
$$T\sin\theta = 250\text{lb}$$

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

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

As θ gets closer to 90 deg, sinθ 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 following calculations 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.

Calculating the Distance from the Trailer



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

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

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

Table 1 shows the design matrix for our concepts. 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.

Concept 5: 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 5-1 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 5-2 shows a diagram of when the roof is open.

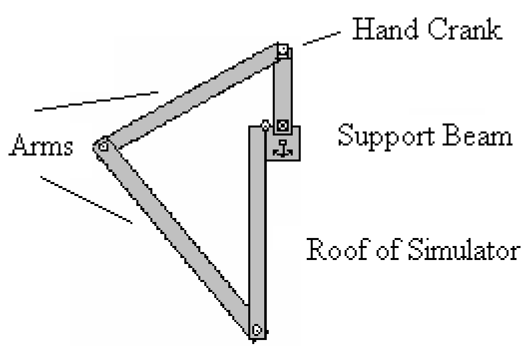


Figure 5-1: Schematic of Four-Bar Pulley System (Roof Closed)

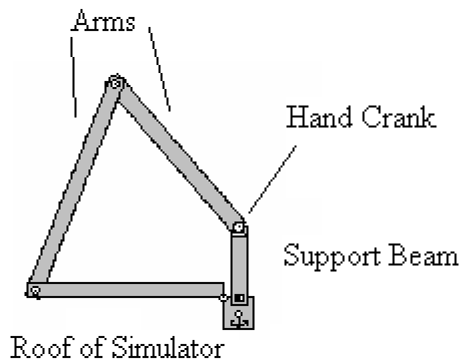


Figure 5-2: Schematic of Four-Bar Pulley System (Roof Opened)

Pros:

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

Cons:

- More expensive material
- Difficult and time consuming setup

Table 1 shows the design matrix for our concepts. 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.

Concept 6: Pneumatic cylinder utilizing external heat source as motive force

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 6-1.

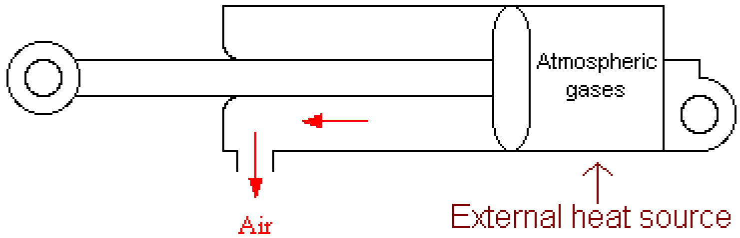


Figure 6-1: Schematic of Pneumatic Cylinder

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, the following calculations were performed to determine the maximum stroke length that could be expected from the pneumatic cylinder/trioxane interaction, under idealized conditions.

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

$C_p := 4180 \frac{J}{kg \cdot K}$ 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

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

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

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

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

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

As the initially determined required stroke length was 1.83 meters, the above 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.

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.

Concept 7: Motor Lift

Design 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 7-1 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. A more detailed analysis is currently in process.

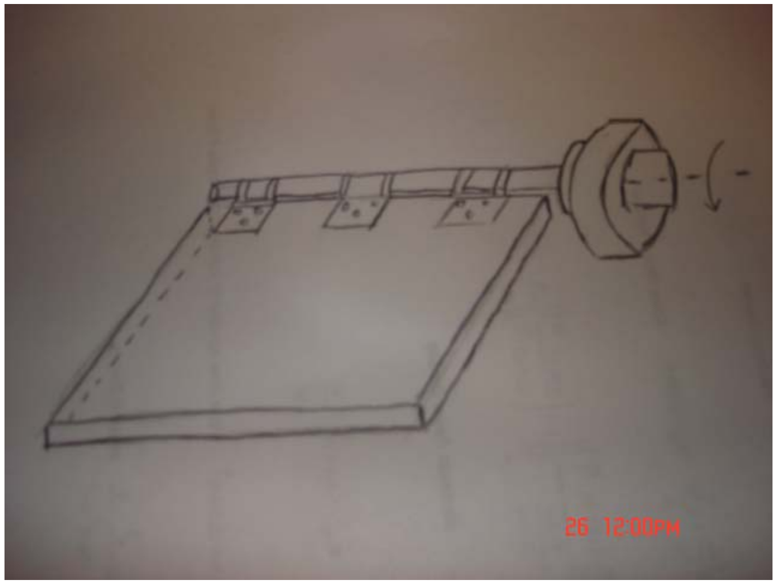


Figure 7-1: A sketch of the roof motor and supports.

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.

Concept 8: 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.

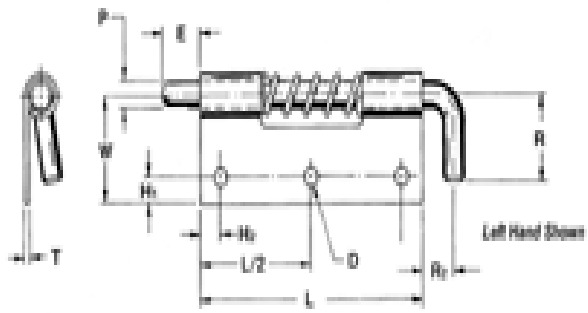


Figure 8-1: A diagram of an existing spring loaded hinge system.

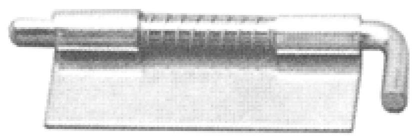


Figure 8-2: A picture of the full view of Figure 8-1

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.

Concept 9: Ground Based Pneumatic Cylinder

The final 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 9-1 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.

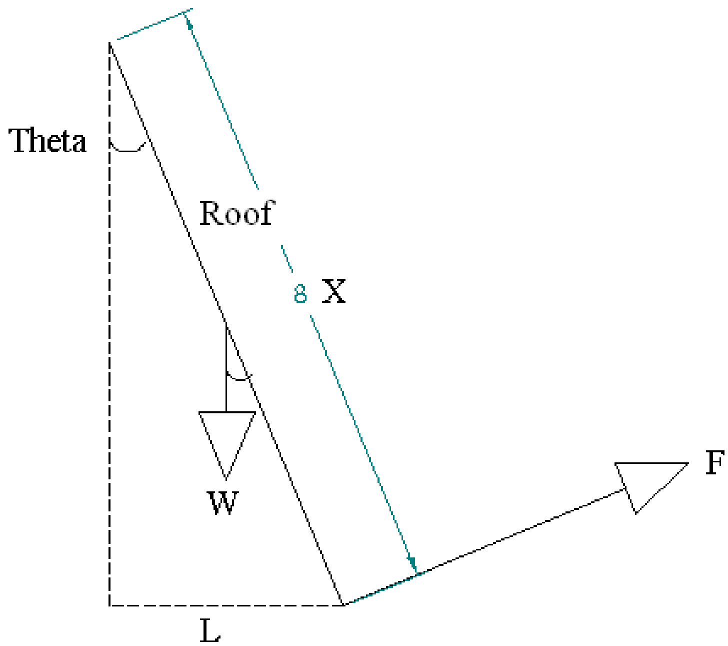


Figure 9-1: Schematic of 2 men lifting roof

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

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

$$\theta = 23.6deg$$

The 2 workers will be able to lift the roof approximately 24 degrees in the air. The following calculations show how far the bottom of the roof will be from the trailer once it is 24 degrees in the air.

$$L = x\theta$$

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

$$L = 3.3ft$$

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.

Concept	Personnel (0.3)	Safety (0.3)	Cost (0.2)	Setup (0.1)	Reliability (0.1)	Total
1A. Mechanical Lift	3	4	5	3	3	3.7
1B. Hydraulic Lift	3	3	3	4	3	3.1
2. Pneumatic Cylinder	5	3	3	4	4	3.8
3. Pulley System	4	3	3	2	4	3.3
4. Pulley Lift	5	4	4	4	4	4.3
5. Four-Bar Pulley	4	4	2	1	3	3.2
6. Pneumatic cylinder with heat source	4	3	4	4	3	3.6
7. Motor Lift	4	3	4	3	3	3.5
8. Spring Hinge	4	3	4	4	4	3.7
9. Ground Based Cylinder	4	5	3	3	4	4.0

Table 1: Decision Matrix

According to Table 1, there are 5 designs given a score of 3.8 or better. These designs were re-analyzed and matched up against one another. The 3 best designs from this group are Concepts 2, 4, and 9. 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. They told us that the pulley lift was really for lifting objects in the vertical direction, where we would have it lifting the roof from an angle. They could not assure us that the lift would not tip. A lift could be purchased, tested, and re-designed to fit our needs, however, with the budget and time constraints of this project this is really not possible for us to do. If the idea chosen does not succeed, this is a viable option for Lockheed Martin to continue to research. So both pneumatic cylinder systems will be chosen. Since they are so similar, Concept 2 will be our choice right now however, if we discover that it will not work, we can easily use the purchased equipment and try Concept 9. By making this choice, we are giving ourselves 2 viable options and hopefully one of them will prove to be successful. At the moment, however, Concept 2 will be our choice.