Solitary Lift: Redesigning the Base and Tilter Modules to Meet Customer Needs

by

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Submitted to the Department of Mechanical Engineering
in Partial Fulfillment of the Requirements for the Degree of

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ABSTRACT

A theoretical investigation towards the redesign of the base and the tilting module of the Solitary Lift prototype improved the machine with a weight reduction of 5.73lbs. Besides lighter weight, the other criteria used to measure improvement were speed, ease of use, and durability. In these areas this iteration of the prototype increased the speed to raise the tilter by 25 seconds, replaced a complicated locking mechanism with a familiar sleeve lock found on folding tables, and considered the substitution of plastic materials for aluminum in the structure.

Thesis Supervisor: Dave Wallace

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# Chapter 1: Problem Statement

Fall of 2004 saw seventy-five Massachusetts Institute of Technology (MIT) students participate in the cornerstone course of the Mechanical Engineering Department: 2.009 – The Product Engineering Process. In this course my team designed, constructed, and tested our prototype for a drywall lift that only required one user. The name of the prototype is the Solitary Lift. Combining new innovative ideas with ones from existing models, the Solitary Lift enters into a competitive niche marketed to the do-it-yourself drywall user. It is a cable lift driven by a motor. Collapsible, mobile, and easy to setup, the Solitary Lift is a reflection of the ingenuity and creativity imbedded within the MIT student.

Although understanding the processes behind product development is essential for an engineer, knowing the process that extends from the completion of a working prototype to the final product design is even more critical. According to one source on product development, a prototype is "an approximation of the product along one or more dimensions of interest."[1] Those points of interest concern the agreement between the first design and the customer needs. This thesis attempts to address the first step on that arduous design journey: redesign of critical components.

Like most prototypes, the Solitary Lift is not without its problems. For instance, the base is too large to fit easily through some doors. The mechanism that tilts the cradle and lifter has a poor design because it is fragile. These concerns are the primary focus for the next iteration of the Solitary Lift: Beta Prototype.

[1] Ulrich, Karl T. and Steven D. Eppinger. *Product Design and Development.* Irwin McGraw-Hill: Boston, 2000. pp.275.

It order to determine whether the new design will be any better than the first a comparison will be made between the two prototypes. The criteria for comparison will be lighter weight, speed, and more user-friendly in terms of ease of use and durability. Users of the solitary lift are predicted to be most effected by these quality control characteristics. Solitary Lift was designed to meet the needs of the do-it-yourself user by providing a lightweight, portable, durable tool for lifting drywall. For exactly these reasons the base and tilter were targeted for improvement.

The base cannot simply be made smaller without taking into account how this adjustment affects the other parts of the product. Simple is better. Choosing a location that reduces the interference from other components is the goal. Finally, the tilting mechanism, as designed, is too complicated and susceptible to damage. Again, selecting a design that is simple is the solution to improvement, as we shall see.

# Chapter 2: Background

Before there were drywall lifts, contractors, do-it-yourselfers, and weekend warriors relied on manpower to fit drywall into a building. Often many people would hold a piece in place while another would drill screws in quickly to keep it in place. If fewer people were available, the use of a "T" brace would be used. The T-brace consisted of two 2"X4"s connected to each other to form a "T" shape. The pieces would be inserted under the drywall and braced against the floor to hold the drywall in place. This method, although no easier on the lifting, solved shifting problems that arose while trying to hold the drywall in place. These haphazard techniques were sufficient for contractors and subcontractors because of their manpower and speed but it became clear that a new method would be needed to fulfill the drywall lifting needs of do-it-yourselfers. A demand for a drywall lifting machine that reduced the number of people required to do the job quickly rose. Before long, engineers stepped up to the plate with tools to do just that.

## 2.1: T-Jak

The first, and simplest of these designs was the T-Jak (see Figure 1). T-Jak was just a formal design to take the place of the 2"X4"s that contractors created. It consisted of an adjustable shaft that could be locked into place at a height of 10-12ft while supporting 300-500lbs. In addition to holding drywall in place, the T-Jak could also be used for installing cabinets, shelves, and even garage doors. Its versatility makes it very popular for construction sites. However, though it made the rugged contractor invention even easier it was still not an effective tool for someone working alone. Before long, drywall lifts arrived on the market that claimed to be the answer to the do-it-yourselfers.

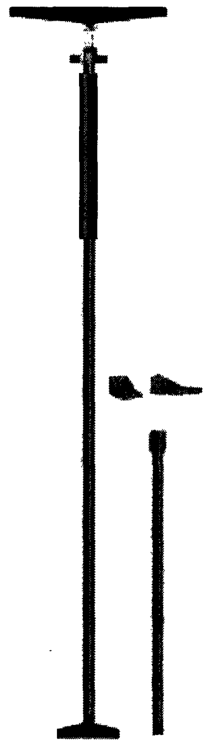


Figure 1: T-Jak Drywall tool sold by Spotnails

## 2.2 Other Drywall Lifts

The Solitary Lift was not the first drywall lift to enter the market. No, in fact, at least three other classes of designs occupy this niche. These include pneumatic lifts, hydraulic lifts, and cable driven lifts. Each is meant for a unique user with unique requirements. The pneumatic lifts are the most expensive due to their power requirements, control panel, and size. Their typical applications are towards larger lifts. They are not usually chosen to lift drywall, but they could. Hydraulic lifts (see Figure 2) require more moving parts with similar capabilities to the pneumatic design but it is much smaller and requires less power. But, it has been the cable-driven lifts that have met the most success which is why the Solitary Lift was chosen as a cable driven system. Two of the largest selling cable driven systems are the Universal Tool Systems Drywall Lift (Figure 3) and the Telpro Inc. Panel Lift (Figure 4). Each design addresses the do-it-yourself user. Universal Tool Systems Drywall Lift, the simpler of the two, encompasses a four castor base, single cable-driven shaft, with a drywall cradle with extendable arms. The winch system controls the height of the cradle. It has a loading height of 41" and a reaches a maximum height of 12'. Its competitor, the Telpro Panel Lift is the leading drywall lift on the market today. Telpro beats out Universal because not only does it have the capability to do 12' ceilings from a loading height of 30", it can also break down into five small, easily transportable pieces. Telpro Inc. Panel Lift costs about $100 less than the Universal Tool Systems design. However, both the Universal Tool Systems Drywall Lift and the Telpro Inc. Panel Lift each have their shortcomings.

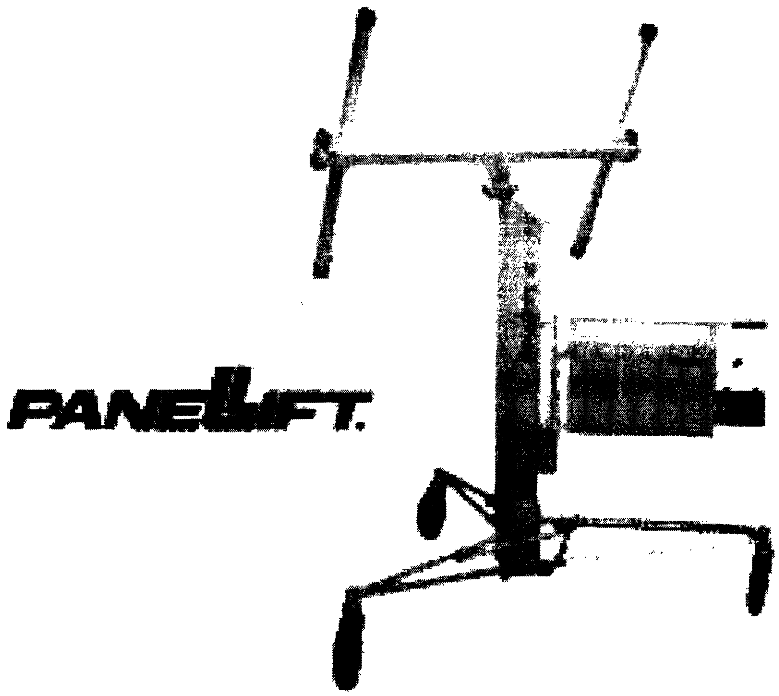



Figure 2: Hydraulic Drywall Lift from Telpro Inc. (Model 460)

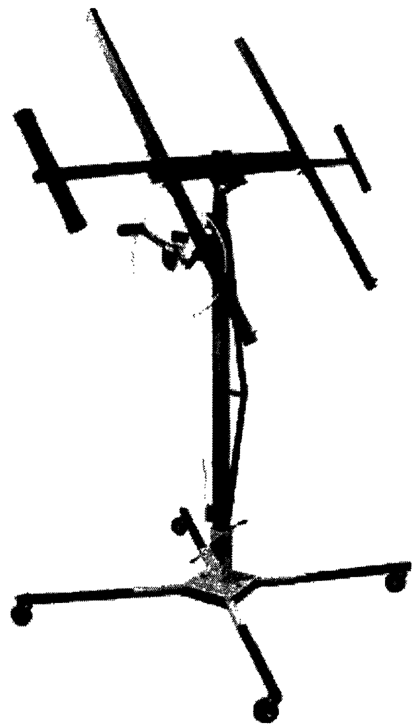


Figure 3: Cable driven drywall lift from Universal Tool Systems (Model #RPDJ100)

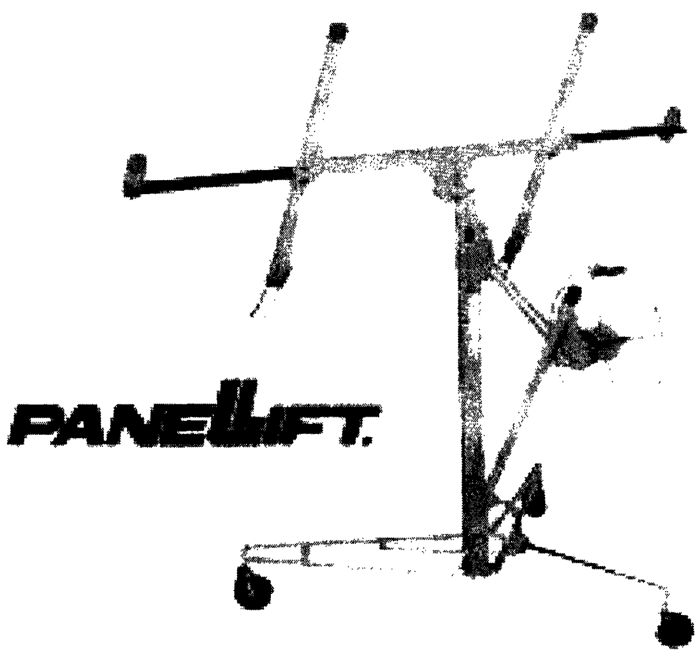



Figure 4: Cable driven drywall lift from Telpro Inc. (Model 138-2)

The Solitary Lift was the inevitable answer to the limitations of the two current designs (see Figure 5). Its versatility addresses walls, cathedral and horizontal ceilings. Though it has a cable winch system, it is driven by an electric motor through a remote control rather than manually. It resembles that of a shopping cart that can be wheeled around a room. It can handle most construction site terrains because of its big castors and, because it has a loading height of 1", can truthfully be deemed a *solitary* lift. Table 1 shows a comparison between the specifications of the models discussed in this section.

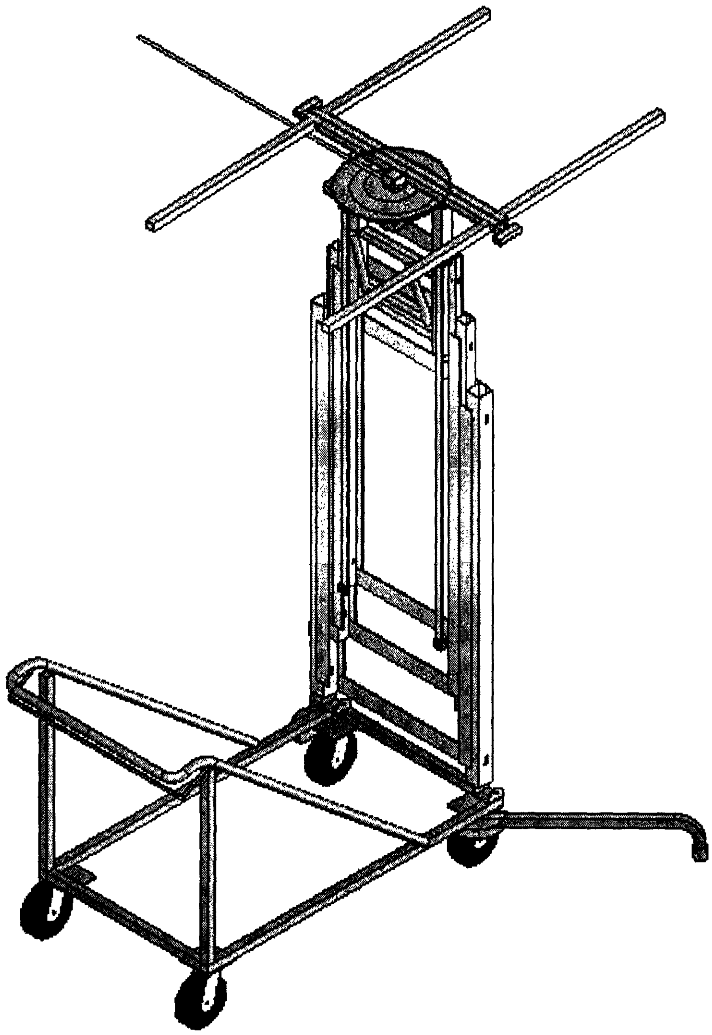
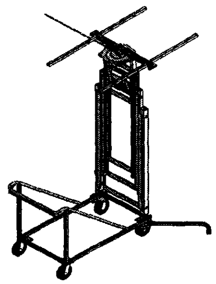
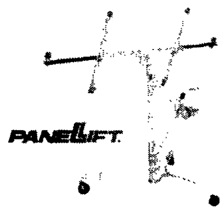
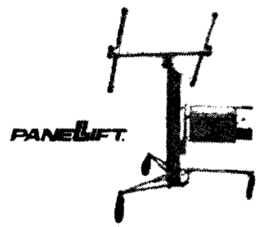
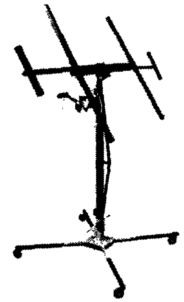
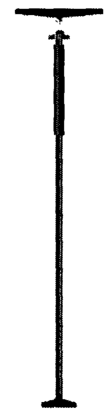


Figure 5: Solid model drawing of early Solitary Lift

Table 1: Comparison of capabilities between existing drywall lift models

| |  SOLITARY LIFT |  PANEL LIFT (Cable Winch) |  PANEL LIFT (Hydraulic) |  UNIVERSAL TOOL SYSTEMS Drywall Jack |  T-JAK |
|---|---|---|---|---|---|
| **Operation** | 1 person | 1 or 2 persons | 1 or 2 persons | 1 or 2 person | 2 or 3 persons |
| **Ceiling** | Flat & cathedral | flat | flat | Flat | flat |
| **Walls** | yes | yes | yes | Yes | no |
| **Max. Reach** | 10' | 11' | 15' | 12' | 10' |
| **Drywall Dimensions** | Up to 4x10 | Up to 4x16 | Up to 4x16 | Up to 4x16 | Up to 4x16 |
| **Max. Load Supported** | 180 lb. | 150 lbs | 150 lbs | 150 lbs | 400 lbs |
| **Loading Height** | 3" | 34" | 40" | 48" | 53" |
| **Disassembled/ Folded Volume** | 48"x27"x13" (wheelable) | 34"x20"x12" (not wheelable) | 40"x25"x16" (not wheelable) | 40"x40"x8" (not wheelable) | 10"x3"x50" (not wheelable) |
| **Assembly Req.** | No | Yes | Yes | Yes | No |
| **Net Weight** | 160 lb. | 115 lbs | 180 lbs | 78 lbs | 10 lbs |
| **Rotation Freedom** | 0 to 90 degrees | anchored | anchored | Every 45 degrees | --- |
| **Speed** | 0.5 ft/s | Depends on user | 1.25 ft/sec | Depends on user | Depends on user |
| **Maneuverable** | Wheelable (lockable) | Wheelable (no brakes) | Wheelable (no brakes) | Wheelable (lockable) | --- |

## Chapter 3: Redesign of the base

As stated earlier, the redesign of the base is nontrivial. However, the first steps are simply to identify the user requirements and then to meet those requirements. Solitary Lift will be used during the construction phase when the structure of the house or building is already in place but before the door frames are installed. Because the possibility remains that it will be used *after* the door frames are already installed, however, the width of the base can be no larger than the smallest standard door frame width: 28". In the original design, this fact was considered but it was unknown at that time the role the outriggers would play as a contribution to the overall width of the base. In truth, 28" was the target width chosen. Later, it was determined the outriggers could not be fastened below the base but must be fixed alongside its length. This complication added an inch to each side of the base totaling 30" (see Figure 6). Clearly, 30" is unacceptable for the width of the base.

### 3.1 Changes to the cradle

Changing the dimensions of the base directly affects nearly every other module in the machine. The two sides of the lift, once forced closer to each other, sacrifice stability of the

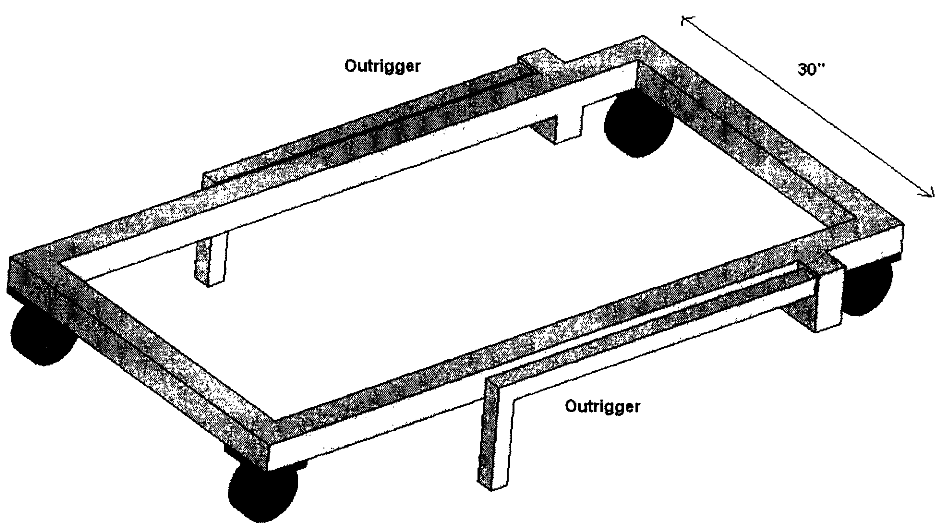



Figure 6: Model of the base of the Solitary Lift

drywall once the drywall has been mounted on the lift. To compensate for this loss in support one possible solution is to lengthen the cradle arms to better support the drywall. However, there is a limitation on the length of the cradle arms due to the base (see Figure 7). Total length of the arms combined, due to restrictions on the bending moments within the cradle, is 40" (L = 40"). On center, a 4'x16' sheet of drywall will extend six feet over the edge of the cradle arms. The Solitary Lift was specifically designed to handle, at most, sheets of drywall that were 4'x12' in size. Fortunately, this decision limits the amount of drywall extending over the edge to just over four feet. This generates a bending stress of around 460 N/m² and a bending moment of about 140 N-m (the exact value was not calculated because the Young's Modulus for drywall is not available). This value is not enough to break the drywall but an additional force of only 20 N will do just that.

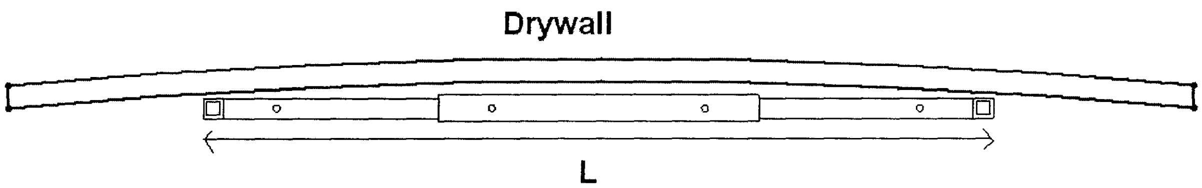



Figure 7: Diagram showing the bending of drywall over length, *L*, showing the extent of the cradle arms

To get around this problem, I determined that instead of longer arms, another contact point between the cradle and the arms is all that is needed. This is accomplished by adding another pin joint to the cradle giving each of the arms an extra two inches in length. Adjusting the length of the arms in this way regains the stability associated with the first design.

**3.2 Weight Change**

Modifications to the base led to a revision of the cradle and its arms. Changes in structure reflect changes in the total weight of the prototype. Prior to these changes the Solitary Lift maintained a resting weight of 160 lbs, far too great for a single piece. Though easy to move around it is too heavy for the average person to comfortably lift. Aluminum hollow extrusions make up 80% of the machine's weight. The two techniques I've employed were to reduce the amount of aluminum used or to substitute it for a comparable material. Table 2 compares the mechanical properties of aluminum to that of other materials. As the data shows, aluminum alloys are the common choice for machines because they offer a very good strength to weight ratio in addition to being very abundant, easy to machine, and with a relatively high Elastic Modulus. Many of the plastics offer a much lower density than aluminum and can be formed relatively easily but are expensive to machine. The prime choice of plastics as a substitute for aluminum in the cradle structure is polystyrene because it is cheap to make, strong, but it also has a low stress yield so a thick walled extrusion is required. Looking at the simple approximation of replacing the volume of the cradle and its arms entirely with polystyrene the weight is decreased by approximately ten pounds! Unfortunately, polystyrene extrusions are expensive to make and are brittle.

Polyethylene is another attractive choice for plastics. Here again, however, we face the problem of the expensive extrusions. This plastic does come in U-shaped extrusions though, making it a prime candidate for substitutions within the lift module. Compared with the aluminum already present in the lift module, the savings is about $.80 per foot. The drawbacks to the plastics are primarily attachment. They do not weld and therefore require a variety of adhesives which are subject to failure more frequently than welds.

Aluminum remains the best choice for the base because it is very strong and lightweight compared to other metals. Calculation of the mass of a structure can be done by following the simple formula,

$$M = V * \rho \tag{1}$$

where $V$ is the volume of the structure, and $\rho$ is the density of the material. Removing two inches from the width of the base equates to removing .8 lb of the total mass. Such a small reduction arises due to the thin walls of the aluminum extrusions. It is obvious that reducing the weight of the Solitary Lift will come mostly from using materials other than aluminum.

Another candidate for substitution is Delrin. However, since Delrin does cost more than aluminum its use must be optimized. Because of Delrin's low coefficient of friction, it can easily slide into the cradle. Inserting strips of Delrin onto the length of the shaft of the cradle arm inserted into the cradle (see Figure 8) completely reduces the size of the aluminum extrusion. The change in the extrusion from a 1" box to a ¾" box results in a weight change of two pounds. Reducing the size of the extrusion any greater results in a loss of the strength of the support from the aluminum cradle arm. However, it is possible to apply this method elsewhere.

Additionally, it was originally thought that by attaching Delrin to the entire surface of the interlocking extrusions of the lift would allow it to slide easier. In this case, the structure is over-constrained. Only three contacts points are needed for the lift to slide easily. Instead of using nearly five pounds (4.82lb) of Delrin, using the method describes above, we could reduce the weight to 0.85lb. So, using Delrin strategically over other materials requires that less aluminum be used for a difference of nearly six pounds (5.73lb).

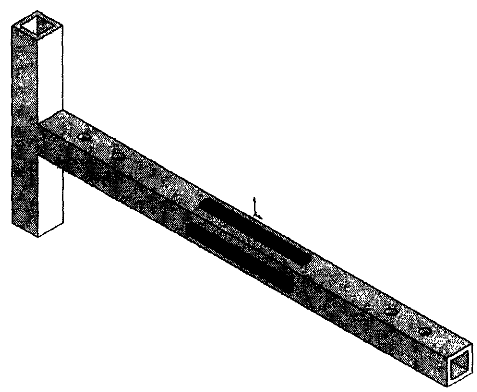


Figure 8: New cradle arm with Delrin strips

| Table 2: ELASTIC PROPERTIES FOR SELECTED ENGINEERING MATERIALS AT ROOM TEMPERATURE | | | | | | |
|---|---|---|---|---|---|---|
| **Material** | Elastic modulus, E ($10^6$psi, GPa) | | Shear modulus, G ($10^6$psi, GPa) | | Poisson's ratio n | Density g/cm3 |
| *Metals* | | | | | | |
| Aluminum alloys | 10.5 | 72.4 | 4.0 | 27.6 | 0.31 | 2.7 |
| Copper alloys | 17 | 117 | 6.4 | 44 | 0.33 | 8.9 |
| Nickel | 30 | 207 | 11.3 | 77.7 | 0.30 | 8.9 |
| Steels (low alloy) | 30.0 | 207 | 11.3 | 77.7 | 0.33 | 7.8 |
| Stainless steel (8-18) | 28.0 | 193 | 9.5 | 65.6 | 0.28 | 7.9 |
| Titanium | 16.0 | 110 | 6.5 | 44.8 | 0.31 | 4.5 |
| Tungsten | 56.0 | 386 | 22.8 | 157.3 | 0.27 | 19.3 |
| *Ceramics* | | | | | | |
| Diamond | 145 | 1000 | 3.51 | | | |
| Alumina (Al2O3) | 53 | 390 | — | — | — | 3.9 |
| Zirconia (ZrO2) | 29 | 200 | — | — | — | 5.8 |
| Silicon carbide | 65 | 450 | — | — | — | 2.9 |
| Titanium carbide | 55 | 379 | — | — | — | 7.2 |
| Tungsten carbide | 80 | 550 | 31.8 | — | 0.22 | 15.5 |
| Quartz (SiO2) | 13.6 | 94 | 4.5 | — | 0.17 | 2.6 |
| Pyrex glass | 10 | 69.0 | — | — | — | — |
| Fireclay brick | 14 | 96.6 | — | — | — | — |
| *Plastics* | | | | | | |
| Polyethylene | 0.058-0.19 | 0.4-1.3 | — | — | 0.4 | 0.91-0.97 |
| PMMA | 0.35-0.49 | 2.4-3.4 | — | — | — | 1.2 |
| Polystyrene | 0.39-0.61 | 2.7-4.2 | — | — | 0.4 | 1.1 |
| Nylon | 0.17 | 1.2 | — | — | 0.4 | 1.2 |
| *Other materials* | | | | | | |
| Concrete-cement | 6.9 | 45-50 | — | — | — | 2.5 |
| Common bricks | 1.5-2.5 | 10.4-17.2 | | — | — | |
| Rubbers | | 0.01 -0.1 | | — | 0.49 | |
| Common wood (Rgrain) | | 9-16 | | | 0.4-0.8 | |
| Common wood (Ûgrain) | | 0.6-1.0 | | | 0.4-0.8 | |

## Chapter 4: The Tilter

The responsibility of the tilter is to move the lift from 8 degree tilt to perpendicular (measured from the ground it is the same as moving from 82 to 90 degrees). Deciding to put the lift at an angle was to position the center of gravity within the footprint of the base with loaded drywall (see Figure 9). Encased within the tilter track is a ½" lead screw (with eight threads per inch) which drives the tilter. Driving the lead screw is a crank connected to a gear box which transmits rotation to the lead screw. It is expected that the user turn the crack the full length of the track: 18". Both slow and tedious, the tilter begs to be redesigned to assist the user in fast, safe work. It took 30 seconds of crank turning to complete its course.

Inspired by a common folding table, I explored the use of linkages as a feasible option for construction of the tilter. However, modifying the tilter changes the overall function of the machine. With the new design it is safer to tilt the lift unloaded. As a compromise, the new design goes between 2 and 8 degree tilts.

### 4.1 The linkages

A spring is used as the mechanism to always keep the sliding part of the tilter in tension. Figure 10 shows the spring housing combined with the lever arm that attaches to the linkages. When the spring is compressed and the sleeve is down (see Figure 11 for sleeve), the linkages have room to extend, pushing the tilter forward six degrees. Once extended, they are held in place by the sleeve, similar to the type of sleeve on a folding table. To return to the 8 degree position you simply slide the sleeve down and compress the spring so the linkages are free to move. The linkages move and the two portions of the tilter arms reconnect. When the Solitary Lift is compacted, the linkages hand below the lift, removing them from danger of being bent.

This was one of the problems with the first design. Now, by doing away with the lead screw, track, and support, there is a reduction of one pound of material.

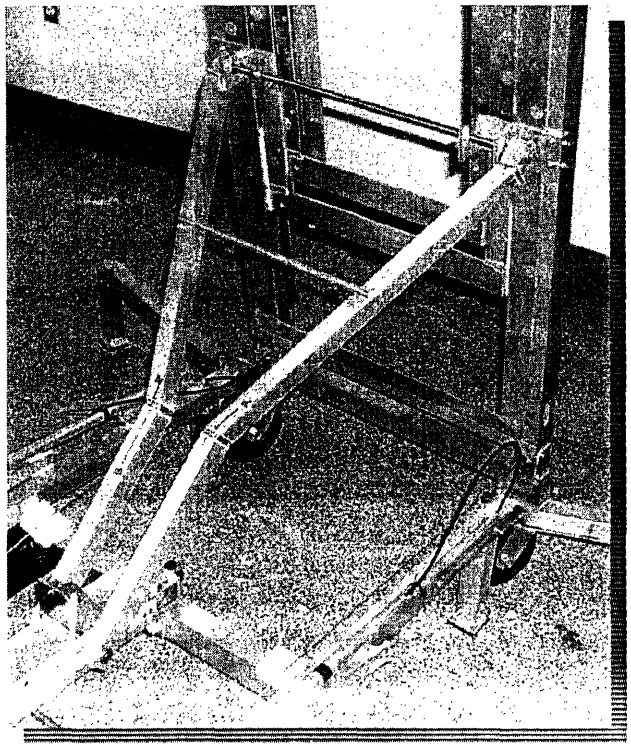


Figure 9: Picture showing the connection between the tilter, track, and base.

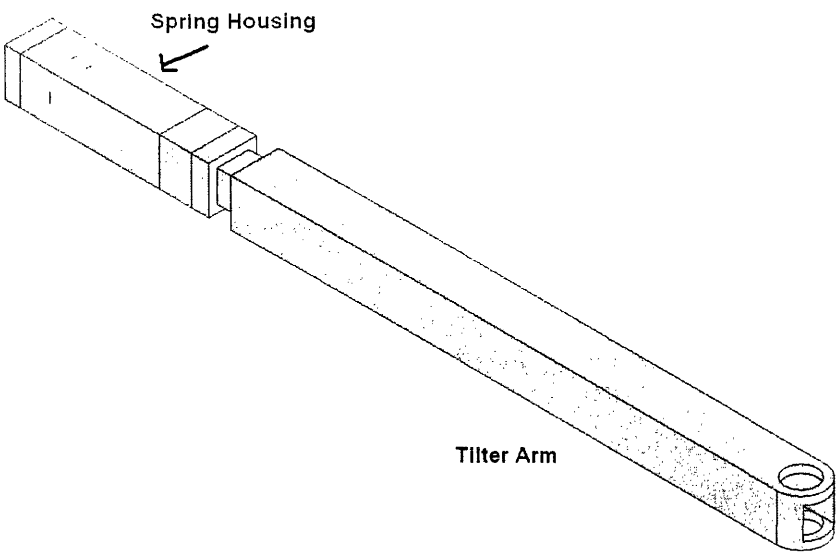



Figure 10: New tilter design.

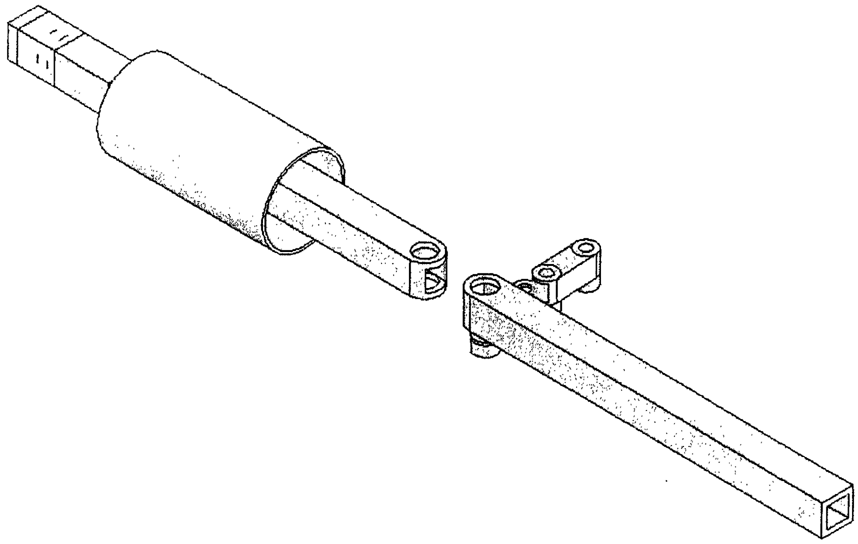


Figure 11: Linkage-tilter arm connection including sleeve for support.

Dimensions for the tilter can be found in the Appendix. Finally, we see that the base supports the load carried by the tilter (reinforcing the need to use aluminum). On the end of the base opposite the lift there is housing for the tilter to rotate about. Connecting the base housing with the spring housing enables the tilter to collapse down into a compactable size.

## 4.2 Satisfying Customer Needs

Criteria set forth to determine the effectiveness of the new design needs to be reviewed. Firstly, changing the design to make a more user-friendly model has been accomplished. Because of the familiar sleeve found on this new design users should have no trouble understanding how to operate the base. The previous design had a complicated locking and unlocking mechanism for transferring between tilt and collapse. It is estimated that the average user could fix the tilter in place from the collapsed position in under 5 seconds.

Secondly, reducing the total weight of the machine was another goal. Changing designs had the effect of about a pound lighter in weight. Insignificant as it may be, it is still progress.

Thus, I was forced to look into other materials for support. One popular choice was the plastic Delrin. Easily to machine, lighter weight than aluminum, with a low friction surface, Delrin is an appropriate choice. It does, however, cost more per foot than aluminum so its application to the tilter is minimal. The tradeoff between weight and cost cannot be afforded in this case because the Delrin does not significantly reduce the total. No other plastics were found that could offer a better alternative to aluminum in this particular portion of the machine. Delrin was used as part of the design to provide a low friction contact surface in the lift.

# **Chapter 5: Conclusion**

Seeking out to improve the needs of the customer I found my efforts to be inadequate in what I consider to be the most significant consequence of the original prototype: the large weight. My efforts towards the remodeling the base and tilter only led to a reduction of 5.73 lbs. Further work on the rest of the machine, I believe, can incorporate more weight-reducing changes. On a brighter note, the changes that I made were able to both maintain safety and make the lift more user-friendly, especially for the lift design.

In my design efforts I discovered that prototypes can go through dozens of iterations before being considered ready to enter the market as a real product. Therefore, my first steps towards reaching that goal were not in vain but were the necessary actions towards making an idea into something tangible (that could generate profit).

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# Appendices

**Appendix A:**

**Table A: Calculation of bending moment and maximum stress for drywall on cradle**

| lb | r (m) | N | L (m) | N/m | b (m) | h (m) | I ($m^4$) | max delta (m) | stress max ($N/m^2$) | bending moment (Nm) |
|---|---|---|---|---|---|---|---|---|---|---|
| 64 | 1.2192 | 0.005506 | 0.7112 | 230.9711 | 1.2192 | 0.00635 | 0.000959 | | | |
| 80 | 1.2192 | 0.013765 | 0.7112 | 288.7139 | 1.2192 | 0.015875 | 0.002397 | | | |
| 96 | 1.8288 | 0.010226 | 1.3208 | 230.9711 | 1.2192 | 0.00635 | 0.000959 | | | |
| 120 | 1.8288 | 0.025564 | 1.3208 | 288.7139 | 1.2192 | 0.015875 | 0.002397 | -1.00E-05 | 456 | 138 |

Each of the different weights corresponds to the following drywall dimensions: 4'x8' and 4'x12' sheets of thicknesses ½" and 5/8", respectfully. They are ordered from lightest to heaviest. The drywall pieces were treated like cantilever beams with a uniform distributed load over the entire surface. The table shows that drywall is very inflexible and subject to break at low stress levels. Its ductile ness makes it easy to cut.

**Appendix B:**

**Table B: Weight difference between aluminum and polystyrene**

| material | density ($lb/in^3$) | volume ($in^3$) | mass (lb) |
|---|---|---|---|
| aluminum | 0.0975 | 14.875 | 1.45 |
| polystyrene | 0.03974 | 14.875 | .23 |
| Delrin | .000191 | | |
| Aluminum with Delrin | .0975 | 5.84375 | .57 |

Table B shows the difference of weight between aluminum, polystyrene, and Delrin for the cradle module. Choosing the polystyrene saves approximately 85% in weight but is also a poor choice because it is very brittle. Inserting Delrin strips while reducing the amount of aluminum saves approximately 60% in weight while still maintaining its strength.

**Appendix C:**

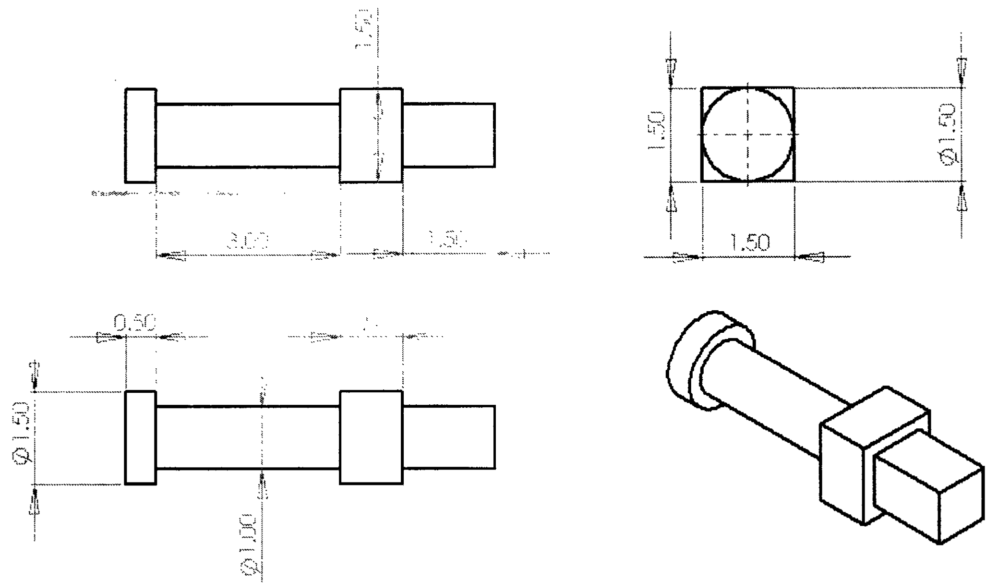


Figure C.1: Drawing and dimensions for tilter connector

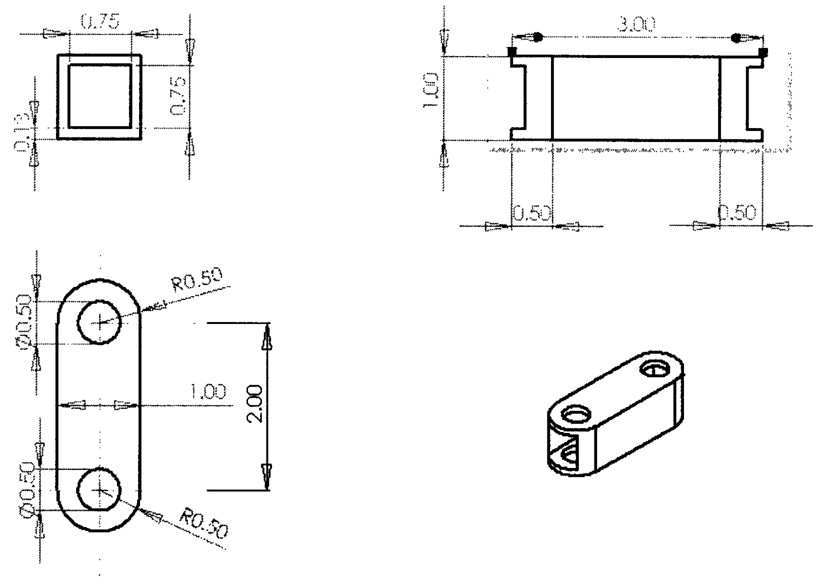


Figure C.2: Drawing and dimensions for the linkage

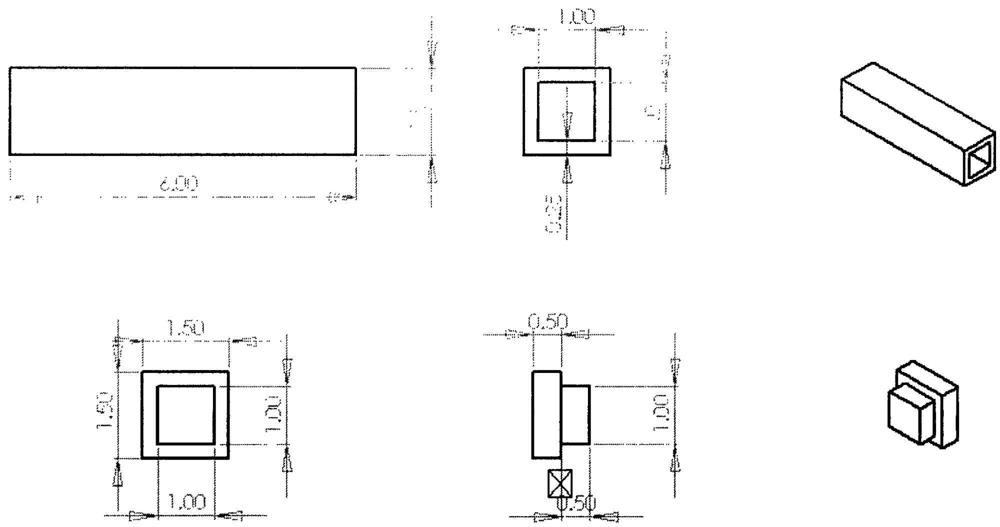


Figure C.3: Drawing and dimensions for the spring housing and spring cap

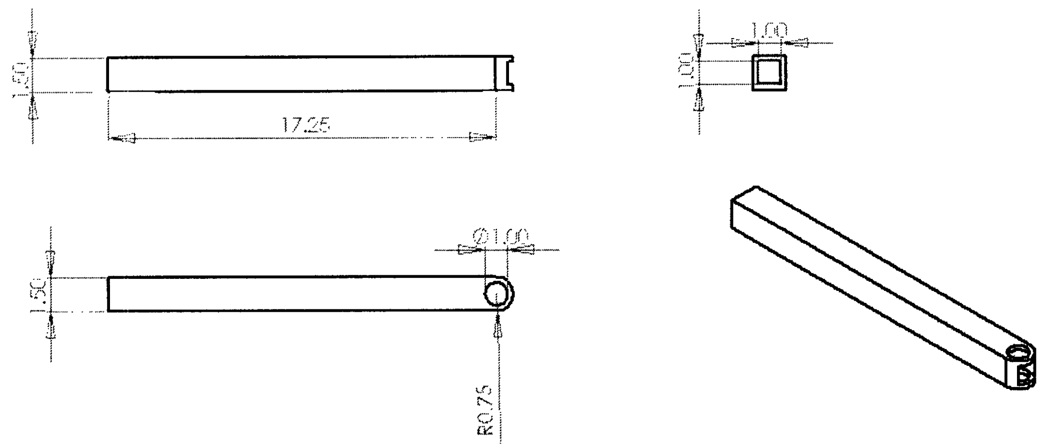


Figure C.4: Drawing and dimensions for the tilter connection

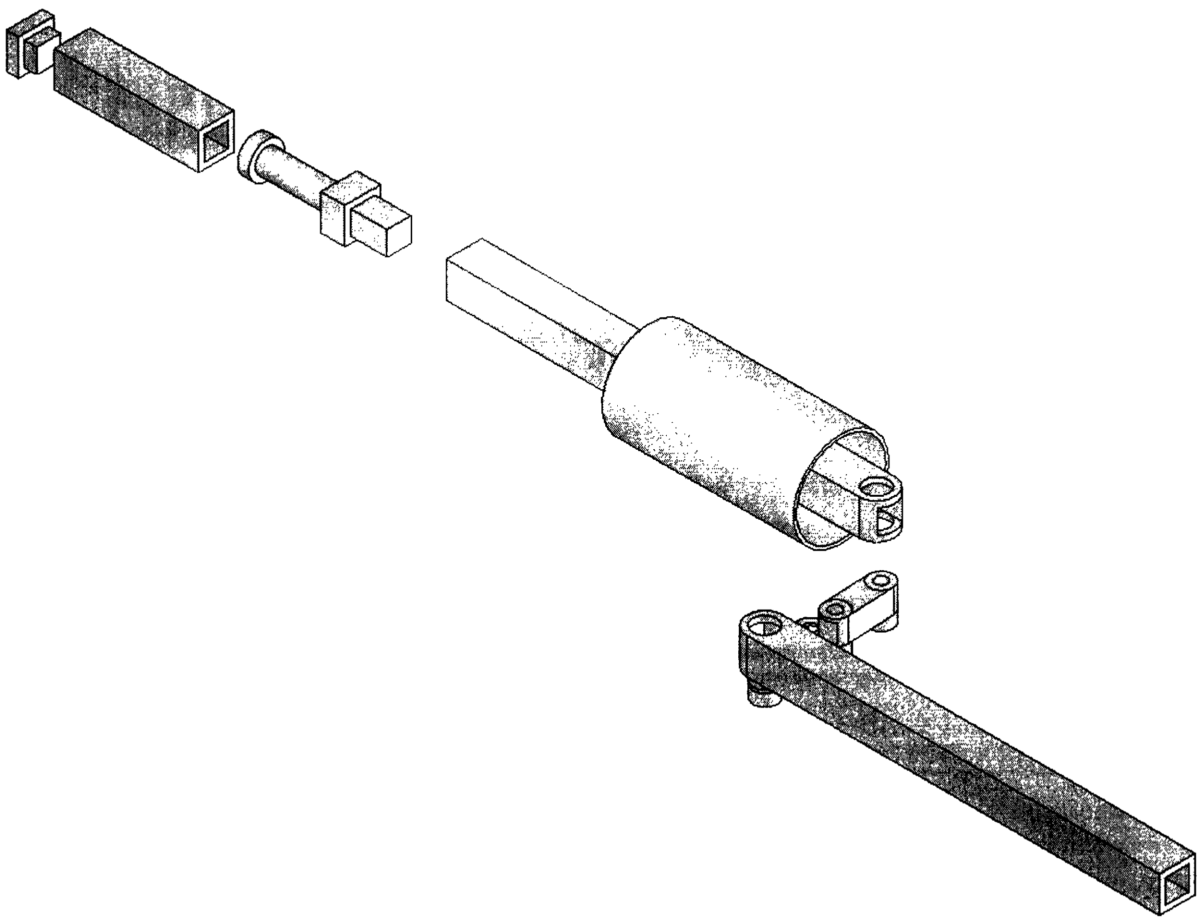

Figure C.5: Assembled drawing of new tilter including sleeve and connecting rods.