# DESIGN AND CONSTRUCTION OF A COMPACT, PORTABLE, ALL-ELECTRIC, 185-KG SCISSOR LIFT

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***ABSTRACT****: An all-electric, cart-mounted, single-stage scissor lift with a capacity of 185 kg has been designed and fabricated with ASTM A36 steel. The lift's platform measures 508 mm by 813 mm and elevates the load 811 mm from the floor. The lift is optimized in terms of mobility, stability, rigidity, safety, and versatility. An 8897-N screw-drive, electric actuator is mounted horizontally at the lift's base. Operation is by 12VDC battery with an optional 120VAC plug-in power supply. Both two- and three-dimensional finite element analyses were employed to evaluate structural material choices and thicknesses based on a safety factor of two. This effort was conducted as part of a university-level capstone manufacturing engineering technology student project.*

***KEYWORDS****: ANSYS, electric actuator, scissor lift.*

## 1 THE SCISSOR LIFT MECHANISM

Even rather compact loads may be too heavy for one worker, and some form of mechanical assistance is necessary. Historically, the scissor lift mechanism has been utilized because of its ease of use in many and varying applications. The applications can be domestic, commercial, industrial, or institutional. A properly-chosen lift will raise and lower loads, increasing efficiency while reducing the risk of injury. Furthermore, a desirable feature is portability, the ability to cart the load from one location to another. The majority of lifts use hydraulics, powered by an electric motor, to raise and lower the load.

The first scissor lift was patented just over fifty years ago (Larson, 1966), and while a multitude of variations now exist, the basic design and operation remain the same. One useful variation is the scissor lift table/cart combination as shown in Figure 1 and is the type of design reported on here. The wheels give mobility to the table. Most designs consist of five basic components:

- platform: the top of the lift table upon which the load is situated;
- base: bottom of the lift and supporting the structure of scissor legs and platform;
- scissor legs: the vertical members that join the base and platform, and their motion allows the platform to change elevation;
- actuator: a power cylinder (pneumatic, hydraulic, electric), lead screw, or rack and pinion drive with controllable length of travel and limits the scissoring motion; and
- power source: manual, electric motor, or air motor providing the actuator's power stroke.

The platform size and lifting capacity vary greatly but many smaller devices consist of 1.22 m by 1.83 m (4 ft. by 6 ft.) platforms with a capacity to 2268 kg (5000 lbm). A hydraulic cylinder powered by an electric motor comprises the most common scissor lifts and is suitable for numerous

**Figure 1. Schematic view of the subject scissor lift table/cart**

industrial and commercial applications. However, hydraulic systems tend to be heavy and require the maintenance of hydraulic fluid. Pneumatic systems are limited in lifting capacity and cannot be positioned as precisely due to the compressive nature of the working fluid - air. In recent years electric actuators have been replacing hydraulic and pneumatic units in many systems, including lifts. Although electrical components can be expensive, relative to other types, their costs are constantly decreasing and all-electrical actuation will continue to gain market share. The goals of this lift project were to provide a small footprint, portability, and ease of maintenance and operation. Thus all-electric power and actuation was selected. Here, an electric motor forces the power stroke; this ensures smoother and more precise lifting and positioning and relies only on electrical power, directly from a battery or wall receptacle.

The mechanism of a scissor lift is apparent from Figure 1 which features a lift with a single set of scissoring legs joined at a hinge. The angle of the legs from the horizontal (scissor angle, $\Theta$) is directly related to the lifting force required. The smaller this initial angle is, the greater the force to initiate the lift. As the load rises, this angle increases and the platform is elevated by a translation of linear motion to elevation change. Simultaneously, the angle with respect to the vertical direction of the legs decreases. This is the principle of a pantograph, where a set of parallelograms are connected with hinges that allow for the structure's elongation in the vertical direction while maintaining its basic geometry (Stancek & Bulej, 2015). For higher lifts, more sets of scissor legs are stacked by hinging the top of the legs from the first stage to the bottom of the legs of the next one; the process repeats for as many stages (levels) as are structurally feasible.

## 2 DESIGN, OPERATIONAL, AND SAFETY FEATURES

This project was originated and conducted by a student team as part of their one-year capstone course requirement for the Manufacturing Engineering Technology degree from the College of Engineering and Engineering Technology at Northern Illinois University, DeKalb, Illinois, USA. The goal is to implement knowledge from all coursework - in statics, mechanical stress analysis, engineering materials, computer-aided design, project management, electronic controls, and safety - during their final year of study. Scissor lifts is a topic very suitable for student-centered projects (Manuel, et al., 2004, Smith, 1995). The idea came from discussions with university mailroom workers. They expressed a need for assistance in lifting mail bags and packages. The items could then be moved from station to station and sorted. Furthermore, due to space constraints, a small footprint was called for. In any case, simple, quiet operation was also a design specification.

Based on this application, Figure 2 is the resulting design. It consists of bottom and top frames coupled by one set of four supporting scissoring legs. The bottom end of a leg pair is fixed while the other pair is wheeled to slide within a track. The actuator is located at the bottom frame and positioned horizontally. The platform measures 508 mm by 813 mm (20 in. by 32 in.). The base is mounted on four castors, each rated at 91 kg (200 lbm), providing a safety factor somewhat under two based on the combined weight of the lift and its capacity. Two of the castors are fixed in direction and two are locking and swiveling. This combination allows the lift to move in a straight line or be pivoted easily by one worker with the aid of the cart's handle. The castor floor locks can be engaged when loading and unloading items. When fully extended, the platform height is 811 mm (31.9 in.) and is 414 mm (16.3 in.) when fully collapsed (Figure 3) with an initial scissor angle of $13.65^{o}$.

Proper design includes safety considerations, and there are standards that apply to lift devices. Safety is particularly important when using these devices as they are specifically built to interact with workers, encounter heavy loads, and feature moving parts. For the present scissor lift cart, the structural components are designed with a safety factor of two. Although this is less than that of published standards, a safety factor of two was deemed adequate for the mailroom application where the exact usage of the device is known and carefully controlled. (This also serves to minimize weight and ensure portability.) This safety factor was used in the stress analyses leading to the materials and component thicknesses chosen.

Operational safety issues, such as pinch points and edge gaps between the legs and platform or base, involve the movement of the lift as it cycles from fully closed to open (raised). A proper design significantly reduces the risk of injury to the worker, or it offers a short but sufficient amount of time to clear fingers, hands, etc., before an accident. Pinch point gaps and clearances were set per the British Standards Institute (2014). Although not used here, another option is to employ a table skirt that completely closes off the interior components of the lift. Such a skirt has a bellows action which expands and contracts as the scissor lift raises and lowers. A separate safety concern is failure of the electrical power source. The lift cannot be allowed to suddenly collapse at loss of power. One fix is to incorporate some mechanical safety device that locks in place when the lift is fully extended. In our device, the actuator features a screw type of drive and utilizes a threaded nut that is self-locking when the screw stops. Therefore, if the electrical supply fails, the load on the platform will remain secured in any extended position. Moreover, the actuator has a built-in limit switch that may be set to help prevent accidents. When transporting loads, the cart must be in the fully collapsed position to minimize the center of gravity and to avoid tipping. Tipping potential is increased by carting speed and/or unfavorable ground conditions, including slope and terrain (Dong, et. al., 2012).

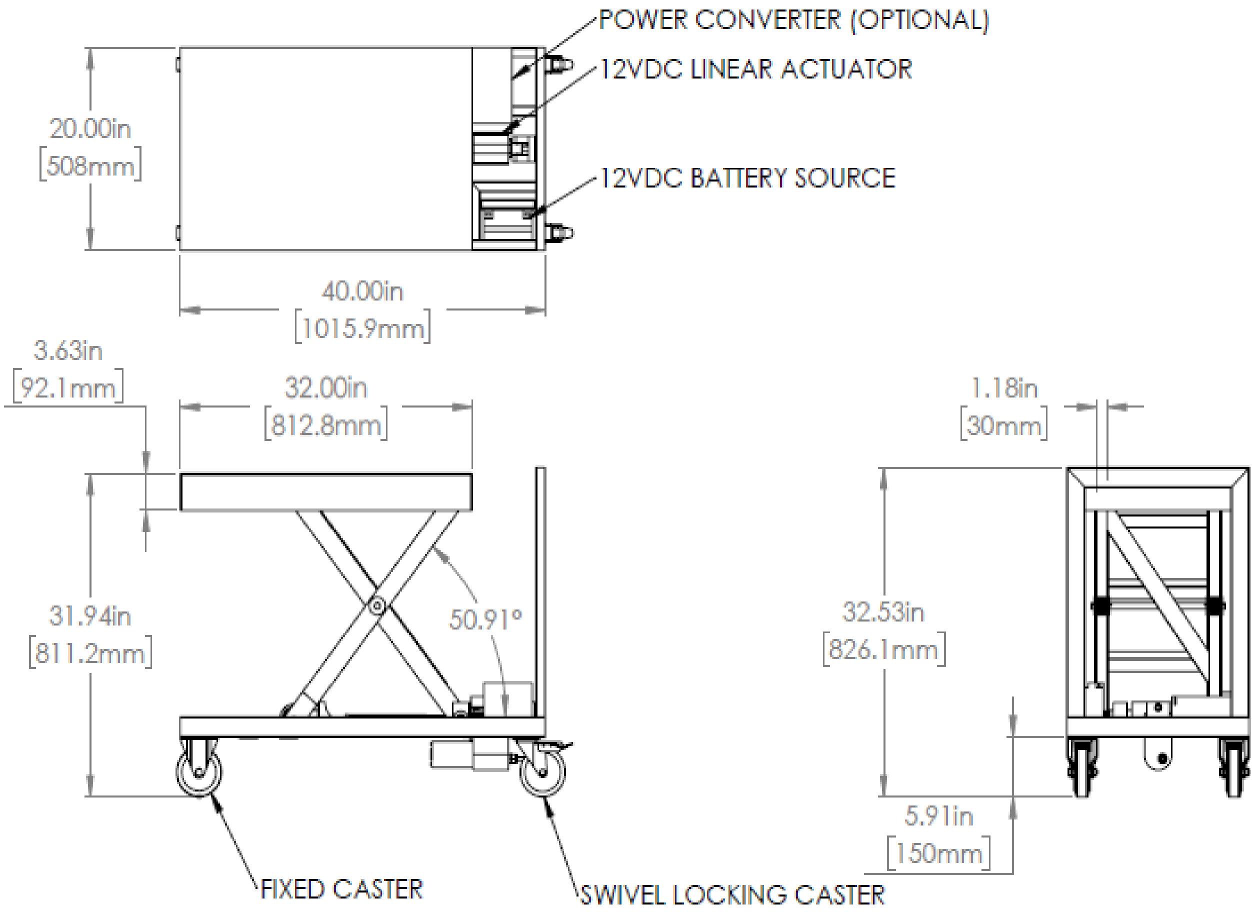


**Figure 2. Component drawing of the all-electric scissor lift**

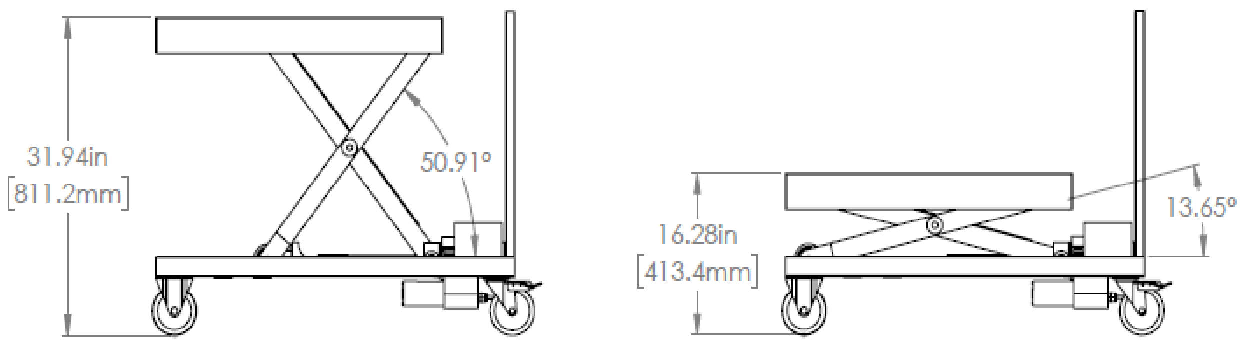


**Figure 3. Side-view of scissor lift in the fully closed and open states**

## 3 ANALYSIS OF MECHANICAL COMPONENTS

After the overall conceptual design, it became necessary to size the lift components, including the actuator force, and to choose materials and thicknesses. For a single-stage lift with a horizontally-mounted actuator, the relationship between the required force, $F$, scissor angle, $\Theta$, and the loads is well known (Saxena, 2016):

$$F = \frac{L + w/2}{\tan\theta} \quad (1)$$

Here $L$ is the load to be lifted on the platform and $w$ is the weight of the scissoring structure, primarily the legs, upper frame, and the platform. This equation has inherent assumptions such as neglecting lift joint friction, and it distributes the structure's weight evenly throughout the three-dimensional space as it is opening (lifting). Equation 1 points out that the lift force will be at a maximum when the structure is collapsed and the force decreases as the lift progresses (increasing $\Theta$). With the structural components estimated to weigh 300 N (67 lbf), and with the design capacity of the unit chosen as 185 kg (408 lbm) or 1815 N (408 lbf), this allows the sizing of the actuator: $F$=8091 N (1819 lbf) at $\Theta$=13.65$^{o}$. Thus, a 12VDC, screw-drive, linear actuator with a maximum force of 8897 N (2000 lbf) was selected. It has a stroking length and rate, at maximum force, of 1016 mm (40 in.) and 6.9 mm (0.27 in.) per second, respectively. The mechanism is all-electric, and an optional 120VAC power supply is included, where the power supply plugs directly into a 120VAC receptacle. Operation is controlled by a simple rocker switch to change the direction of the actuator. The current draw is 18.2 amps at 8091 N (1819 lbf).

The remaining analyses involved calculation of mechanical stresses and strains of the structural elements, mainly the legs, based on the design lifting capacity. The material selection and component thickness analyses were conducted with a commercial finite element (FEA) software package (ANSYS Mechanical APDL 17, Ansys, Inc., Canonsburg, PA, USA). Runs quickly showed, as expected, the maximum stress and deflection occurs at the scissoring pivot junction of each pair of legs. Modeling the placement of the load on the platform ranged from the center of the platform to distributing it along the platform's entire edge.

The analyses began with a two-dimensional frame model using 11,600 to 60,000 beam finite elements to examine buckling issues. The solution became element-number independent at 45,000 elements. Then 230,000 three-dimensional, eight-node brick elements focused on all the high-stress regions, especially the pivot joint that pinned the legs together as well as at the bracket transmitting the actuator force to the legs. Both ASTM A36 steel and ASTM 7075 alloy aluminum were material options and modeled. In terms of buckling, the fully-open frame yields higher stress values three times greater than the collapsed position; thus, the majority of modeling was in the fully-open state. Generally, aluminum displayed adequate strength but experienced larger deflections, consistent with the findings of Murthy, et. al. (2014).

From the FEA work, even though aluminum was acceptable, the A36 steel was chosen due to the fact that it is stiffer. Although adding to the structure's weight ($w$ in Equation 1), thus slightly decreasing the lift's capacity, steel certainly welds easier and costs far less. Per the analyses, structural components of 3.2 mm to 4.8 mm (1/8 in. to 3/16 in.) thicknesses were sufficient and provided the safety factor of two. Figure 4 is a drawing of the major structural parts of the lift. The legs are 51 mm by 737 mm (2 in. by 29 in.) and 4.8 mm (3/16 in.) thick and attached together with 15.9-mm- (5/8-inch-) diameter pins. The platform is made of 3.2-mm- (1/8-inch-) thick sheet metal, 508 mm by 813 mm (20 in. by 32 in.). There is an 88.9 mm (3.5 in.) wide, 3.2 mm (1/8 in.) thick side-skirt running around the platform's edge. Welding was the preferred method of assembly unless the joint needed to be bolted.

Special attention was given to the actuator/legs interface. For this, a bracket was designed to hold a 25.4-mm- (1-inch-) diameter solid steel cylinder that spans the lift and attaches to the bottom ends of a leg pair. This is a critical structural item as it directs the full force of the actuator to the lift members. Figure 5 features this component subject to the maximum 8897 N (2000 lbf) pulling (opening) force; a slight deflection in the bracket is seen which serves to relieve some stressing.

## 4 CONCLUDING REMARKS

A simple, all-electric, cart-mounted scissor lift with a capacity of 185 kg (408 lbm) has been designed and constructed using steel. It is optimized in terms of mobility, stability, rigidity, safety, and versatility. An 8897-N (2000-lbf) actuator translates its purely horizontal force into a vertical lift.

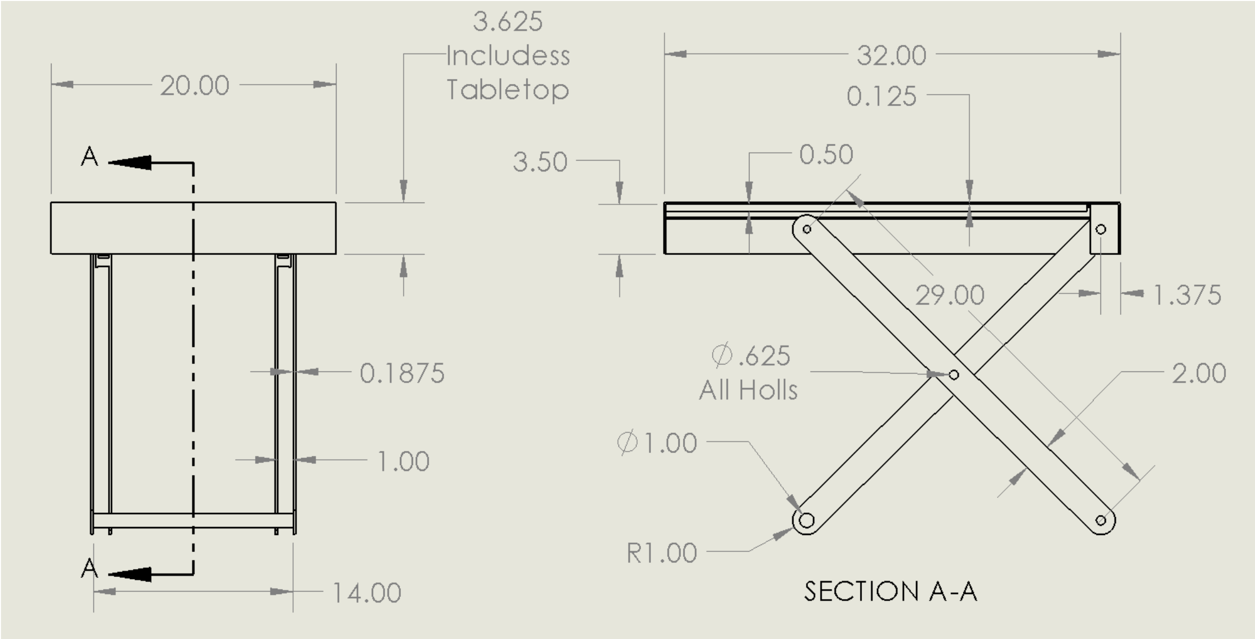


**Figure 4. Drawing of the main structural components of the lift (dimensions = inches)**

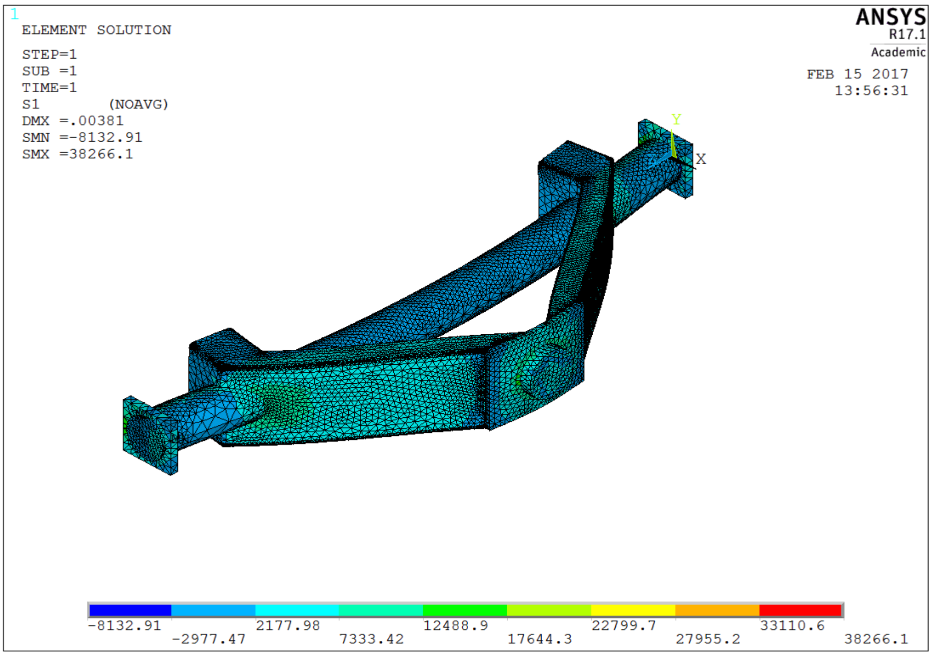


**Figure 5. FEA analysis of the deflection of the bracket connecting the actuator to the scissor legs (deflection = inches, stress = psi)**

Finite element analyses yielded mechanical stress and strain profiles that resulted in the choice of the common ASTM A36 steel for the structural components. The process proved quite suitable for a university-level capstone student project. Now built, the lift may be the subject of work efficiency studies during mailroom use. The studies would lead to design changes and improvements.

## 5 ACKNOWLEDGEMENTS

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## 6 REFERENCES

►British Standards Institute. (2014). Safety Requirements for Lifting Tables. Lifting Tables Serving up to Two Fixed Landings, BS EN 1570-1:2011+A1:2014.

►Dong, R. G., Pan, C. S., Hartsell, J. J., Welcome, D. E., Lutz, T., Brumfield, A., Harris, J. R., Wu, J. Z., Wimer, B., Mucino, V., Means, K. (2012). *An Investigation on the Dynamic Stability of Scissor Lift*, Open Journal of Safety Science and Technology 2, pp. 8-15.

►Larson, C. L. (1966). *Scissor-lift Mechanism*, U.S. Patent 3,246,876, filed Dec. 26, 1963.

►Manuel, J., Clement, P., Pakulski, E., Godiciu, R., Hefzy, M. S., Nemunaitis, G. (2004). *Development of a Compact and Mobile Scissor Lift to Transfer a Wheelchair User to and from the Deck of a Pool*, ASME International Mechanical Engineering Congress and Exposition, Nov. 13-20, Anaheim, CA, pp. 171-172.

►Murthy, P. S. K. N., Rao, D. V. P., Vinay, C. H. S., Kumar, S. R., Narayan, K. S. (2014). *Modeling and Analysis (Linear Static) on a Scissor Lift*, International Journal of Mechanical Engineering and Information Technology 2(9), pp. 754-759.

►Saxena, A. (2016). Deriving a Generalized, Actuator Position-Independent Expression for the Force Output of a Scissor Lift, Cornell University Library, arXiv:1611.10182, pp. 1-18.

►Smith, S. L. (1995). *Design of a Low-cost Wheelchair Lift*, ASME International Mechanical Engineering Congress and Exposition, Nov. 12-17, San Francisco, CA, pp. 1-10.

►Stancek J., Bulej, V. (2015). *Design of Driving System for Scissor Lifting Mechanism*, Academic Journal of Manufacturing Engineering 13(4), pp. 38-43.