Connections Design

Scissor Lift

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Mechanical Engineering Design - ME 4550 [Section 02]
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I. Introduction and Theory

ATV Solutions is developing a mobile, portable scissor lift for at home use. Most scissor lifts are primarily sold for commercial use and are much too large and expensive for the common consumer. However, repairs and renovations are a critical part of home ownership and are made easier through the use of a scissor lift. These tasks often involve hard-to-reach places, whether it’s a routine job such as cleaning the gutters or a more ambitious project like repainting a home’s exterior. Any job high above the ground is inherently dangerous, especially for older adults and those with physical impairments. This risk is amplified when using a ladder, which can be extremely unstable if improperly secured. This product provides the ordinary homeowner with a safer and easier way to carry out these tasks for a reasonable cost.

Since this product will be constantly raised and lowered, presumably with the consumer on it, the ATV Solutions engineering team has conducted various analyses on the critical connections identified in the design. Specifically, the weldments on the pins connecting the linkages, plates, as well as the connecting rod were analyzed. In this report, the team analyzed the critical welds for failure using weld joint analysis theory for butt and fillet welds. In addition, bolt calculations were done on the connection from the connecting to the linkages

For this analysis, it is assumed that the maximum load is 900 lbs and structural A36 steel was used in all of the welds. In addition, an E70xx electrode was used in all weld calculations and the weld size or leg length is assumed to be ¼ inch for every weld.

II. Linkage Pin Weldment

a. Connection Overview

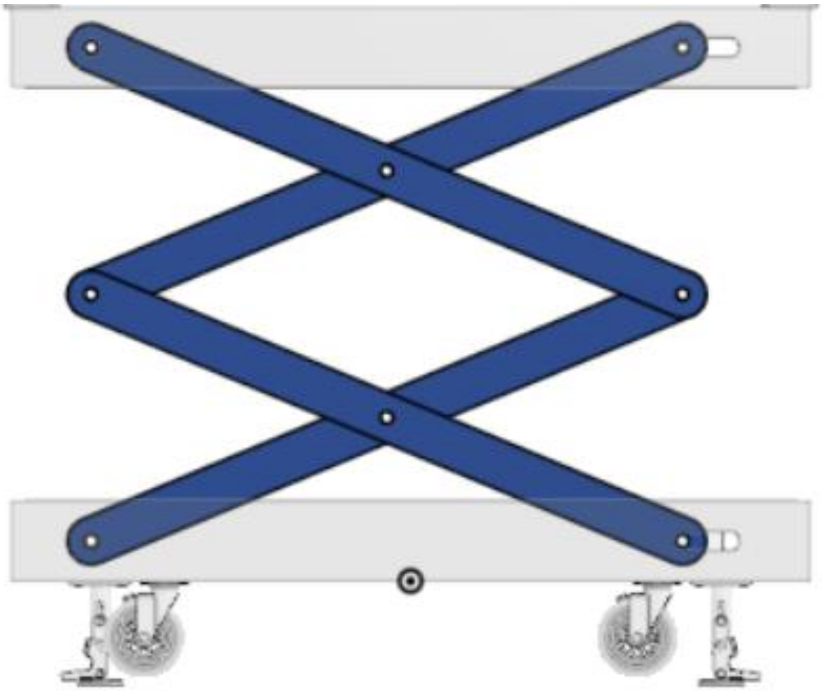


Figure II.1 - Linkage Assembly Overall

All the pins connecting the linkages to each other and to the top and bottom plates will be welded to the linkages themselves. This will save costs in manufacturing as well as simplifying the assembly process.

There are 2 separate parts involved in the linkage assembly, with two different weldment patterns. One linkage will have welded pins in all 3 holes, and the other configuration will only have 1 welded pin on an end, which will fulfill all of the motion requirements of the assembly. These configurations are not relevant to the calculation of weldment failure and thus are not pictured.

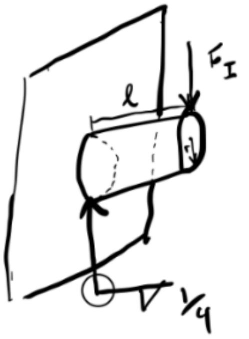
b. Assumptions

The forces acting on the assembly will be evenly distributed throughout the pin weldments in this case. This means that the pin welds can all be assumed to be the same, i.e., a circular fillet weld in direct shear in bending, with no stress from torsion. The weldments will use E70xx electrode, and the pins will be made from the same structural steel as the linkages.

The point of failure will be at the joint with the highest force, so this pin will be analyzed for failure. From the MATLAB component analysis conducted on the previous report (See Appendix B), the maximum force will be 6.36 kip at joint I.

c. Calculations

All calculations are shown in Figure II.2 and II.3 below:



From Table 9.4.1 :

$A_t = 1.414 \pi h r$, $I_u = \pi r^3$

$A_t = 0.555 \text{ in}^2$ $\quad I_u = 0.3927$

$$\tau' = \frac{V}{A_t} = \frac{6.366}{1.414\pi\left(\frac{1}{4}\right)\left(\frac{1}{2}\right)} = 12.732 \text{ ksi}$$

$F_I = 6.366$ kip

$r = \frac{1}{2}$ in

$l = \frac{1}{2}$ in

$$\tau'' = \frac{Mc}{I}$$

$I = t I_u$

$I = \left(.707 \tfrac{1}{4}\right)(0.3927)$

$I = 0.0694 \text{ in}^4$

$M = F_I l = 3.183$

$$\tau'' = 22.929 \text{ ksi}$$

$$\tau = \sqrt{(\tau')^2 + (\tau'')^2} = 26.227 \text{ ksi}$$

$$n = \frac{0.577 S_y}{\tau} = 1.254$$

Figure II.2: Static Failure Analysis

$P_{max} = 6.366 \text{ kip}$

$\tau_{min} = \frac{P_{min}}{P_{max}}(\tau) = 10.522 \text{ ksi}$

$\tau_{max} = \tau = 26.227 \text{ ksi}$

$P_{min} = 2.554 \text{ kip}$

$$\tau_a = \frac{\tau_{max} - \tau_{min}}{2} = 7.85 \text{ ksi}$$

$$\tau_m = \frac{\tau_{max} + \tau_{min}}{2} = 18.375 \text{ ksi}$$

$K_{fs} = 2.7$

$S_{ut} = 79.8 \text{ ksi}$

$k_a = 0.8206$

$S_e' = 39.9 \text{ ksi}$

$k_e = 1$

$S_{se} = 0.59 k_a k_e S_e' = 19.51 \text{ ksi}$

$S_{su} = 0.67 S_{ut} = 53.46 \text{ ksi}$

$$\eta_f = \left(\frac{K_{fs}\tau_a}{S_{se}} + \frac{\tau_m' K_{fs}}{S_{su}}\right)^{-1} = 0.5$$ → infinite life not achievable

\# cycles to failure:

$$\sigma_{ar} = \frac{\tau_a / 0.577}{1 - \frac{\tau_m}{S_{su}}} = 20.73 \text{ ksi}$$

$$a = \frac{(f \cdot S_{ut})^2}{S_{se}} \qquad b = -\frac{1}{3}\log_{10}\left(\frac{f \cdot S_{ut}}{S_{se}}\right)$$

$$a = \frac{(0.88 \cdot 79.8)^2}{19.51} = 252.76 \qquad b = -0.1855$$

$$N = \left(\frac{\sigma_{ar}}{a}\right)^{1/b} \qquad N = 720932 \text{ cycles}$$

Figure II.3 - Cyclic Failure Analysis and Number of Cycles to Failure

d. Results

As shown in the figures, the welded pins have a static safety factor of 1.25 with infinite life achieved, while the fatigue analysis shows that the weldments will last 720,932 cycles before failure. This is well within our product's anticipated lifetime and as a result is acceptable.

III. Linkage to Connecting Rod Bolt Connection

a. Connection Overview

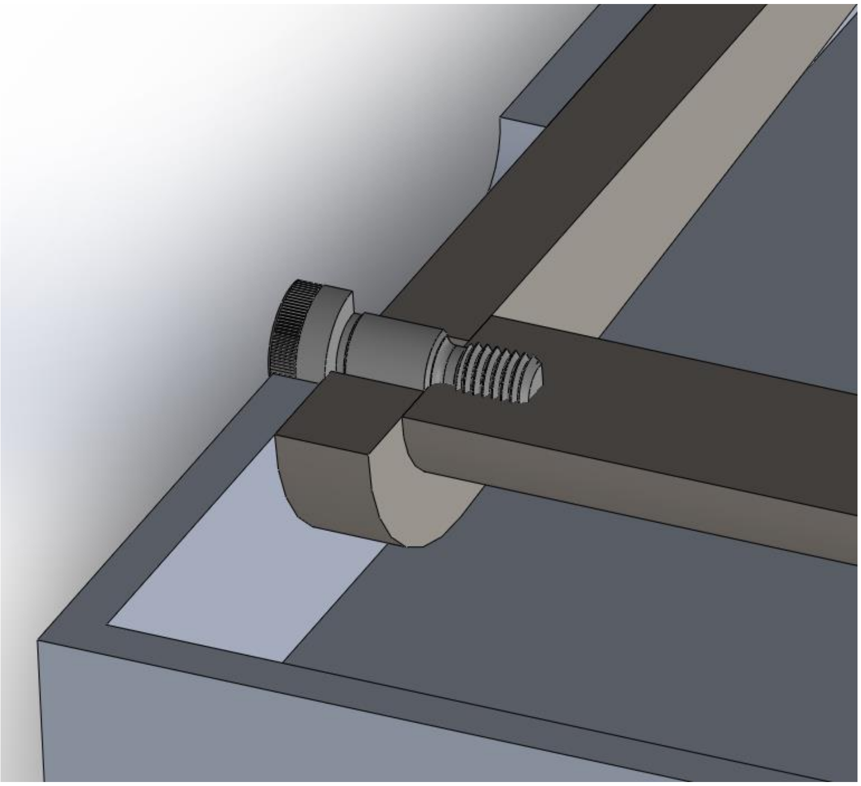


Figure III.1 – Fastener Between Linkage and Connecting Rod

Both ends of the connecting rod will be fixed into the slot and connected to the bottom linkages using a shoulder bolt. This bolt has a 1 in long unthreaded section for the linkage to rotate on and 1 in long threaded section to screw into the connecting rod.

b. Assumptions

For the connecting rod fasteners, the primary mode of failure will be due to shear given that the primary load is directed perpendicular to the bolt. Therefore, static failure and fatigue failure due to tension in the bolts will be ignored.

The Shoulder Bolt that we will use has a diameter of d = ¾ “. The bolt is subjected to a horizontal and vertical shear forces of the linkage which is taken from the component design report as FD = 9261 lb and Gy = 307 lbs. The yield strength of the bolt is equal to the yield strength of it’s material, structural steel, at 215 MPa. The calculations are shown below in section III.c.

c. Calculations

All calculations are shown the equation below.

For static loading:

$$\tau \;=\; \frac{V}{A} = \frac{\sqrt{\left(F_D^2 + G_y^2\right)}}{\frac{\pi d^2}{4}} = 36.156\,MPa$$

$$n = \frac{S_y}{2\tau} = \frac{215\,MPa}{2(31.156\,MPa)} = 2.973$$

Since there is a negligent amount of tension on this bolt setup, there is no relevant fatigue calculation. As such, the overall safety factor is that of the static loading condition (for shear).

d. Results

As shown in part C, the static safety factor for the fastener between the linkage and connecting rod is 2.973. This is a great result because it is neither unsafe nor wasteful.

IV. Connecting Rod Box Weldment

a. Connection Overview

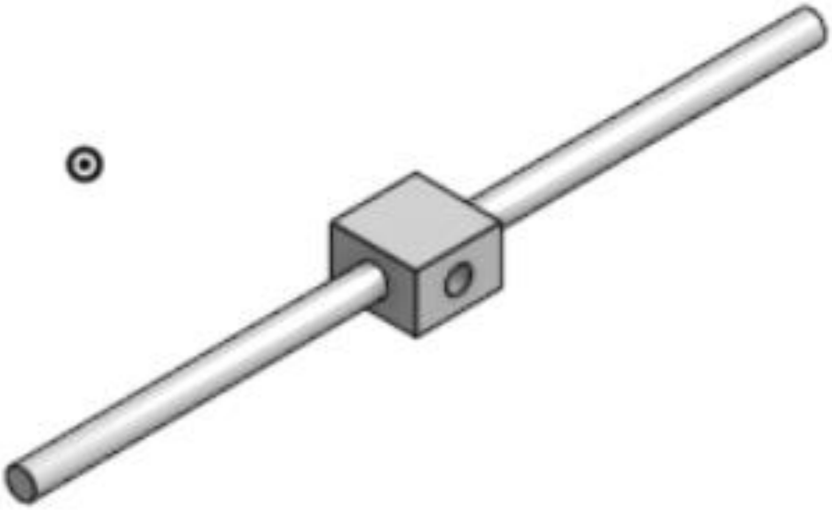


Figure IV.1 – Connecting Rod

As shown in the figure above, the connecting rod is made up of two rods welded to a bock that has a threaded hole for the power screw.

b. Assumptions

The main assumption made in the analysis of the rod to box weld is that the circumference of the rod was used for the length of the weld and the whole weld was analyzed in direct shear in bending with no stress from torsion. The shear force was also taken to be the equivalent of the horizontal drive force which was calculated to be 9.26 kip in the MATLAB force analysis from the previous report (See Appendix B).

c. Calculations

The following calculations for static failure analysis were carried out to determine the static failure safety factor. The diameter of the rods are 2 inches and the distance from the center of the rod to the center of the block was 3 inches.

Table 9.4.1:

$$A = 1.414\pi hr = (1.414) * (\pi) * (0.25) * (1) = \ 1.111\ in^2$$

$$I_u = \pi r^3 = \pi * (1^3) = \pi\ in^3$$

$$\tau' = \frac{V}{A} = \frac{9.26\ kip}{1.111\ in^2} = 8.338\ ksi$$

$$M = V * L = \ 9.26 * 3 = \ 27.78\ kip * in$$

$$(\tau")_{Bending} = \frac{M*(\frac{d}{2})}{I_u} = \frac{27.78*(\frac{1}{2})}{\pi} = 4.421\ ksi$$

$$\tau = \sqrt{(\tau')^2 + \ (\tau")^2_{Bending}} = \sqrt{8.338^2 + 4.421^2} = 9.438\ ksi$$

Table 9.3:

$$S_y = 57\ ksi$$

Von Mises Safety Factor:

$$n = \frac{0.557S_y}{\tau} = \frac{0.557 * 57}{9.438} = 3.484$$

The safety factor for static failure is 3.484.

The fatigue failure calculations were as follows, where the maximum load is the load in the lowered position and the minimum load is the load in the raised position:

$$P_{max} = 9.26\ kip$$

$$P_{min} = 3.518\ kip$$

$$\tau_{min} = \frac{P_{min}}{P_{max}} * \tau = \frac{3.518}{9.26} * 9.438 = 3.586\ ksi$$

$$\tau_{max} = \frac{P_{max}}{P_{max}} * \tau = \frac{9.26}{9.26} * 9.438 = 9.438\ ksi$$

$$\tau_a = \frac{1}{2}(\tau_{max} - \tau_{min}) = \frac{1}{2}(9.438 - 3.586) = 2.926\ ksi$$

$$\tau_m = \frac{1}{2}(\tau_{max} + \tau_{min}) = \frac{1}{2}(9.438 + 3.586) = 6.512\ ksi$$

For CD A36 Steel, assuming room temperature:

$$S'_{UT} = 79.8\ ksi$$

$$k_d = 1$$

$$S_{UT} = 79.8\ ksi$$

$$k_a = a * S_{UT}^b = (2) * (79.8)^{-.217} = 0.8286$$

$k_e = 1$

$S_e' = 0.5 * S_{UT}' = 39.9\ ksi$

$S_{Se} = 0.59 * k_a k_d k_e S_e' = 0.59 * 0.8286 * 1 * 1 * 39.9 = 19.51\ ksi$

$S_{Su} = 0.67 * S_{UT} = 0.67 * 79.8 = 53.466$

$k_{fs} = 2.7$

$$n_f = \left(\frac{k_{fs} * \tau_a}{S_{Se}} + \frac{k_{fs} * \tau_m}{S_{Su}}\right)^{-1} = \left(\frac{2.7 * 2.926}{19.51} + \frac{2.7 * 6.512}{53.466}\right) = 1.36$$

The safety factor for infinite life is 1.36.

d. Results

The factors of safety for the connecting rod welds were found to be 3.484 statically and 1.36 for fatigue cycling infinite life. These results are sufficient for the desired parameters because they are not too high where cost becomes an issue but are high enough to be within a normal operating range. The safety factor calculation for fatigue loading for the connecting rod showed that infinite life is possible, which is more than sufficient for the design of this scissor lift, considering the expected life of the product.

V. Summary

In summary, the welds and fasteners used in the design of the Scissor Lift are all well within the operating parameters. For all static loads, the lowest safety factor is 1.25 in the welded pins, which is within an acceptable margin of error. The highest safety factor is 3.484 in the connecting rod, which could be considered high but not too high to be wasteful. In terms of fatigue, the system is not rated for infinite life. This is fine, as we do not expect the Scissor Lift to endure a very high number of cycles. Instead, the limiting fatigue failure occurs at over 720,000 cycles in the linkage pin weldment, well above the amount expected of normal lifetime use (around 50,000 cycles). Because all of these safety factors and life expectancies fit within the product goals, no further iterations are required for the connection designs.

VI. Appendices

Appendix A – Group Member Contributions

This contribution distribution was agreed on by all group members.

PJ Fries: 25% Contribution: Linkage to Connecting Rod Bolt Calculations, Report Writing

Emilie Hardel: 25% Contribution: Linkage Pin Weldment Calculations, Report Writing

Lauren Kreder: 25% Contribution: Introduction, Connecting Rod Weldment Calculations, Report Writing

Justin Miller: 25% Contribution: Summary, Linkage to Connecting Rod Bolt Calculations, Report Writing

Appendix B – MATLAB Code for Reaction Force Calculations

```
clear
clc


%system force calculator


syms F_D F_P A_x A_y B_x B_y C_x C_y D_y E_x E_y G_y H_x H_y I_x I_y J_x J_y K_x K_y L L_AD L_AB theta W_link W_topPlate rho_link rho_topPlate V_link V_topPlate W_bottomPlate V_bottomPlate rho_bottomPlate L_DCentroid


g = 386.089; %in/s^2
rho_topPlate = 0.1; %lbm/in^3, density of Al
rho_bottomPlate = 0.1;
rho_link = 0.291; %structural steel
V_link = 175.777; %in^3
V_bottomPlate = 4759.928/2;
V_topPlate = 4762.243/2;
```

```
W_link = 50; %lbf
W_topPlate = 483.452;
W_bottomPlate = 483.217;

F_P = 100;
theta = 9;
L = 24;
L_AB = 37.063;
L_AD = 40;
%constants: W_link, W_topPlate, W_bottomPlate, F_P, all lengths
%variables: 15 unknowns
%Overall system- external loads and ground reactions

OS_sumFx = B_x - A_x == 0;
OS_sumFy = A_y +B_y -F_P - 4*W_link - W_topPlate/2 - W_bottomPlate/2 == 0;
OS_sumMA = B_y*L_AB - F_P*L_AD/2 -(W_link+W_topPlate+W_bottomPlate)*L_AD/2 == 0;
sol = vpasolve([OS_sumFy, OS_sumMA], [A_y, B_y]);
A_y = sol.A_y
B_y = sol.B_y

%linkage force/moment balances


%top plate
```

```
L_CCentroid = 22.76; %from onshape

L_CD = 2*L*cosd(theta);



TP_sumFy = -F_P - D_y - C_y - W_topPlate == 0;

TP_sumMC = -W_topPlate*L_CCentroid - F_P*L_CD/2 - D_y*L_CD;

topPlateSol = vpasolve([TP_sumMC,TP_sumFy],[C_y,D_y])

topPlateSol.C_y

topPlateSol.D_y



%bottom plate

L_ECentroid = 23.21;

BP_sumFy = E_y +G_y == 0;

BP_sumME = G_y*L_CD - W_bottomPlate*L_ECentroid;

BPsol = vpasolve([BP_sumME,BP_sumFy],[E_y, G_y]);

BPsol.E_y

BPsol.G_y



%link IG



IG_sumFx = I_x -H_x - F_D == 0;

IG_sumFy = I_y - H_y - G_y - W_link == 0;

IG_sumMI = -H_x*sind(theta)*L - H_y*L*sind(90-theta) - W_link*L*sind(90-theta) - F_D*2*L*sind(theta) - G_y*2*L*sind(90-theta) == 0;



%link EK



%compatibility
```

```
%comp1 = E_x == F_D;


EK_sumFx = -E_x + H_x +K_x == 0;

EK_sumFy = K_y + H_y - E_y - W_link == 0;

EK_sumMK = H_x*L*sind(theta) - H_y*L*sind(90-theta) + W_link*L*sind(90-theta) -E_x*2*L*sind(theta) + E_y*2*L*sind(90-theta);




%link CK


CK_sumFx = C_x + J_x - K_x == 0;

CK_sumFy = C_y +J_y - K_y - W_link == 0;

CK_sumMC = J_x*L*sind(theta) + J_y*L*sind(90-theta) - W_link*L*sind(90-theta) - K_x*2*L*sind(theta) - K_y*2*L*sind(90-theta);


%link DI


DI_sumFx = -J_x - I_x == 0;

DI_sumFy = D_y - J_y - I_y - W_link == 0;

DI_sumMD = -J_x*L*sind(theta) + J_y*L*sind(90-theta) + W_link*L*sind(90-theta) - I_x*2*L*sind(theta) + I_y*2*L*sind(90-theta);



solution = vpasolve([IG_sumFy,IG_sumMI,IG_sumFx,EK_sumMK,EK_sumFy,EK_sumFx,CK_sumMC,CK_sumFy,CK_sumFx,DI_sumMD,DI_sumFy,DI_sumFx,TP_sumFy, TP_sumMC],[F_D C_x C_y D_y E_x E_y G_y H_x H_y I_x I_y J_x J_y K_x K_y]);

F_D = double(solution.F_D)

C_x = double(solution.C_x)
```

```
C_y = double(solution.C_y)
D_y = double(solution.D_y)
E_x = double(solution.E_x)
E_y = double(solution.E_y)
G_y = double(solution.G_y)
H_x = double(solution.H_x)
H_y = double(solution.H_y)
I_x = double(solution.I_x)
I_y = double(solution.I_y)
J_x = double(solution.J_x)
J_y = double(solution.J_y)
K_x = double(solution.K_x)
K_y = double(solution.K_y)

F_C = sqrt(C_x^2+C_y^2)
F_E = sqrt(E_x^2+E_y^2)
F_H = sqrt(H_x^2+H_y^2)
F_I = sqrt(I_x^2+I_y^2)
F_J = sqrt(J_x^2+J_y^2)
F_K = sqrt(K_x^2+K_y^2)
```