Design Project #4

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Due Date: February 15, 2019

Introduction

The purpose of this lab is to develop parameters for a car lift that does not exceed the maximum tolerances of the components used in it's construction. Each half of the lift consists of two bars, a hydraulic piston, and a spring. The spring exerts a compression force on the rigid plate and the floor. When the pistons exert a force, the rigid plate is raised.

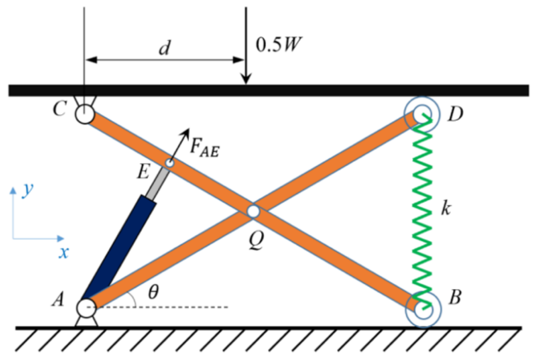


Figure 1: Figure 1 shows one half of the car lift. From the diagram, we can see all of the forces and their points of application.

<u>Constraints:</u>

1. The hydraulic cylinder is pinned to point A and to the midpoint of CQ, E.
2. The spring constant of spring BD is 0.2W N/m, it's uncompressed length is $L_0 = L$.
3. The system in the diagram above is symmetric to the other side of the lift.
4. Angle θ between AE and the x axis must be between 10˚ and 70˚.
5. The length of L is between 0.5 and 0.6 m for part 2.

Methodology

In order to determine if the hydraulic piston will be strong enough to support the car, we will use Matlab to find the force exerted on it. To accomplish this task, we first we must derive an equation for the force upon the hydraulic piston as a function of θ and L. This function can be derived from a rigorous analysis of the forces and members acting in and on the system. To find the appropriate values of L and θ within the design constraints, we will iterate solutions in Matlab to optimize.

<u>Variables</u>

Name	Meaning	Unit
θ	*The angle measure between bar AD and the horizontal axis.*	*Degrees (˚)*
L	*The length of bar AD and bar BC.*	*Meter (m)*
W	*The weight of the car*	*Newton (N)*
F_{AE}	*The force exerted by the hydraulic cylinder on bar BC*	*Newton (N)*
D	*Distance from C to the center of gravity of the car*	*Meter (m)*

Derivation of Force Equation

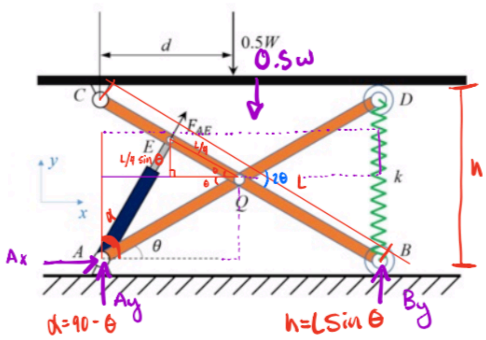


Figure 2: To establish the force in the hydraulic cylinder, we go through a rigorous analysis. Of the forces and members in the structure. Figure 2 shows the free body diagram of the overall system.

We start by observing the reactions on the entire system.

We have:

$$\sum F_x = 0 = A_x$$

$$\sum F_y = 0 = A_y + B_y$$

$$\sum M_{around\ A} = 0 = B_y * L * \cos(\theta) - 0.5 * w * d$$

We get that:

$$B_y = \frac{0.5 * w * d}{L * cos * (\theta)}$$

$$A_y = 0.5 * w - \frac{0.5 * w * d}{L * cos * (\theta)}$$

Next, we analyze the scissor mechanism and its external forces.

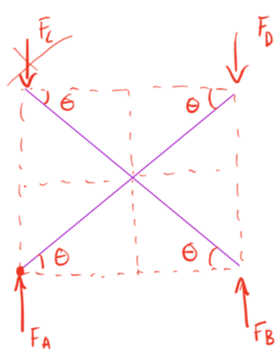


Figure 3: This figure illustrates the external forces acting on the scissor mechanism.

We now have:

$$\sum M_{around\ A} = 0 = -L * \cos(\theta) * F_b - L * \cos(\theta) * F_d$$

Solving:

$$F_b = -F_d$$

Moreover:

$$F_c = 0.5 * w - \frac{0.5 * w * d}{L * \cos(\theta)}$$

$$F_c = 0.5 * w \left(1 - \frac{d}{L * \cos(\theta)}\right)$$

Next, we analyze the bar BC

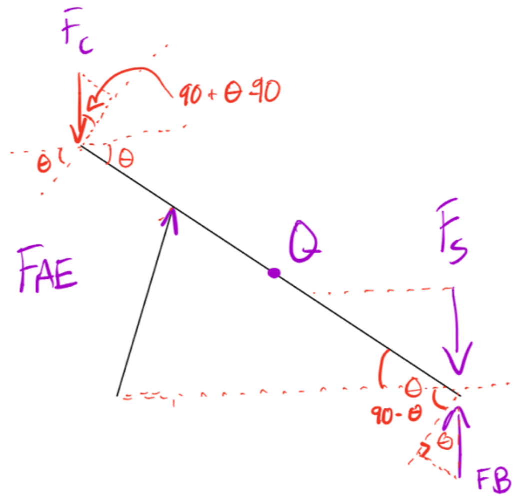


Figure 4: illustrates the forces acting on bar CB.

Using equilibrium equations, we obtain:

$$\sum M_{around\ q} = \frac{1}{2} * w * \left(1 - \frac{d}{L * \cos(\theta)}\right) * \frac{1}{2} * L * \cos(\theta)$$
$$- F_{AE} \frac{\frac{1}{4} * L^2 * \sin(\theta) * \cos(\theta)}{\frac{1}{4} * L\sqrt{1 + 8 * (\sin(\theta))^2}} = 0$$

Simplifying:

$$\frac{1}{2} * L * \cos(\theta) * w * \left[\frac{1}{2}\left(1 - \frac{d}{L * \cos(\theta)}\right) - 0.2 * L * (1 - \sin(\theta) + \frac{1}{2} * \frac{d}{L * \cos(\theta)}\right]$$
$$= F_{AE} \frac{L * \sin(\theta) * \cos(\theta)}{\sqrt{1 + 8 * (\sin(\theta))^2}}$$

$$\frac{1}{2} * w * \left[\frac{1}{2} - 0.2 * L + 0.2 * L * \sin(\theta)\right] = F_{AE} \frac{\sin(\theta)}{\sqrt{1 + 8 * (\sin(\theta))^2}}$$

$$\frac{\left[\frac{1}{4} - \frac{1}{10} * L + 0.2 * L * \sin(\theta)\right]}{\frac{\sin(\theta)}{\sqrt{1 + 8 * (\sin(\theta))^2}}} = \frac{F_{AE}}{w}$$

$$\boldsymbol{\frac{F_{AE}}{w} = \left(\frac{1}{2} - \frac{L}{10}(1 - \sin(\theta))\right) \frac{\sqrt{1 + 8 * (\sin(\theta))^2}}{\sin(\theta)}}$$

We have now derived an equation for normalized force in the hydraulic cylinder in terms of theta and L.

Results

From the Matlab script, we obtain two plots pertaining to the system in question.

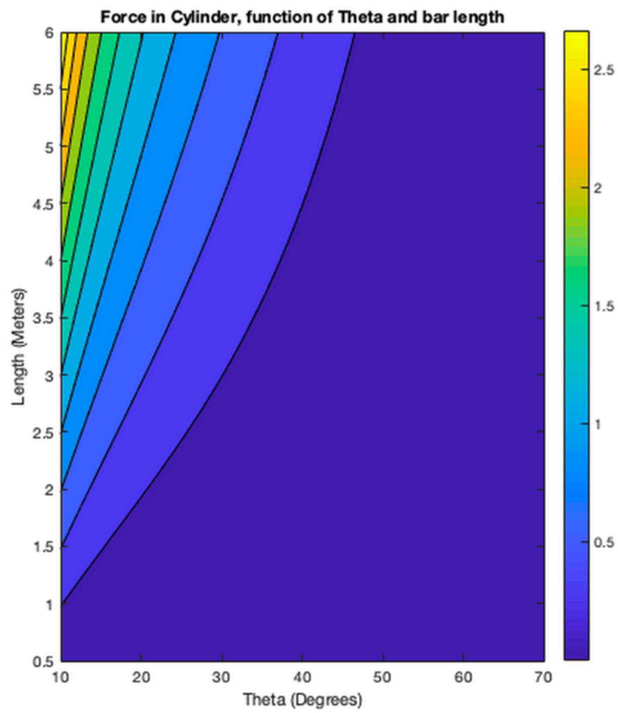
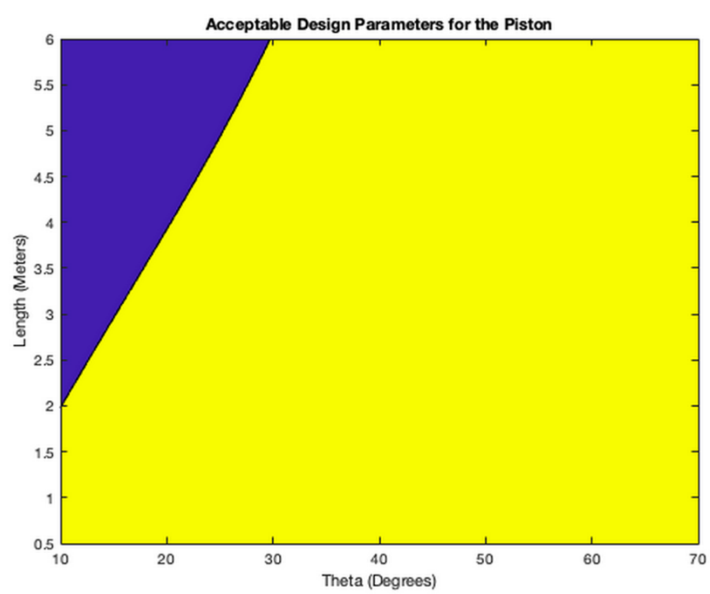


Figure 5: The first plot illustrates all solutions of the magnitude of force as a function of theta and L. Note that this plot does not discriminate solutions that exceed the max threshold for the hydraulic piston. The color scale represents the magnitude of the force applied at the hydraulic cylinder.

Figure 6: Figure 6 shows the feasible solutions to the problem. The force solutions that resulted in a magnitude larger than 0.8 N were eliminated from the feasible set. The possible solutions are represented by points in the yellow area. Solutions that would exceed the tolerances of the cylinder are blue.



Discussion

There are two critical trends that should be noted as a result of this Matlab simulation. Firstly, as theta increases, the magnitude of force required to hold the system in equilibrium decreases. This is because the vertical component increases with theta. When theta is small, a lot of the force in the hydraulic is wasted by being directed in the x direction. Pushing in this direction is the least efficient way to lift the system. When theta is large, a larger fraction of the force is directed upwards against the car's weight. The next important relationship is between L and force. Generally, as L increases, the magnitude of the force needed to hold the system increases. This trend can be proven by looking at the equation. Because L is a term in the numerator, increasing it will increase the magnitude of the force.

Due to these two trends, the upper left corner (where theta is small and L is large) is the region of infeasible solutions. In the second plot, we can simply view the possible solutions. The trends correspond with the analysis above and make construction of the car lift quite easy.

Conclusion

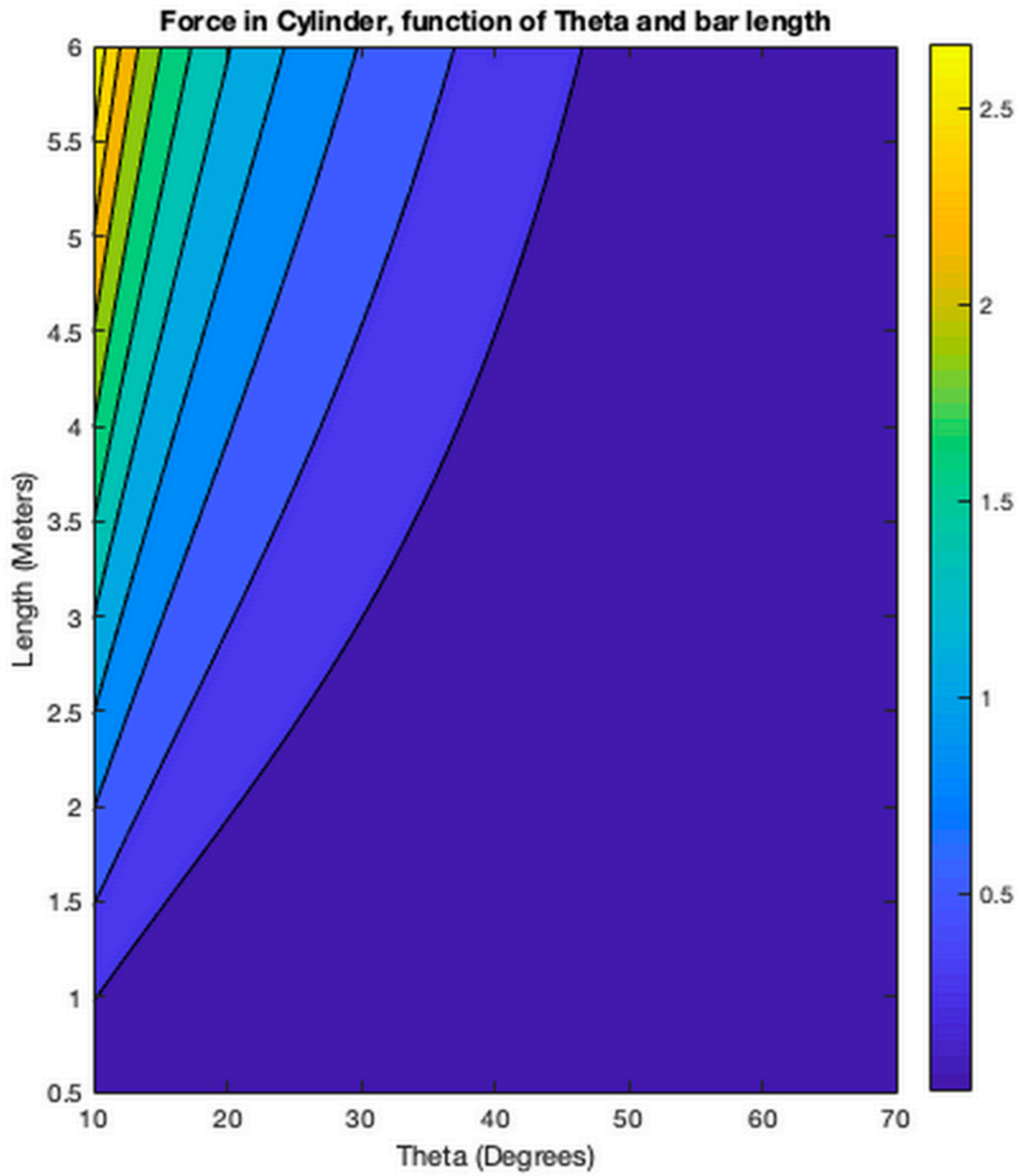
In conclusion, we have shown how to construct a system using the design parameters constrained in the problem. We derived an equation for the force in the hydraulic piston using algebra and a rigorous analysis of the forces and members in the system. Using Matlab, we were able to identify a range of possible values of theta and L. We plotted these solutions and discriminated the feasible ones in a separate chart. Making this car lift will be much easier now.

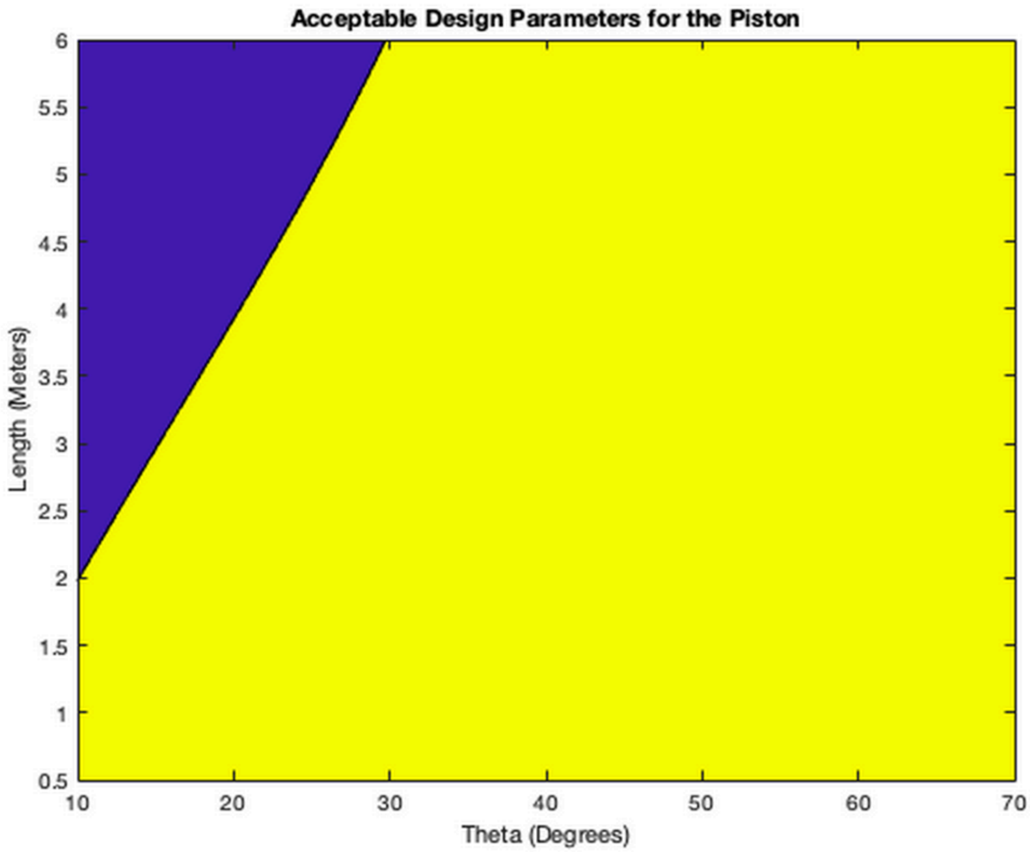
Appendix

Code:

```
res = 1000;
F=[];
theta = linspace(10,70,res);
L = linspace(0.5,6,res);
for ii = 1:length(theta)
    for jj = 1:length(L)
        F(ii,jj)=abs(1/4-(L(jj)/10*(1-sind(theta(ii))))*((sqrt(1+8*sind(theta(ii))^2))/sind(theta(ii))));
    end
end
figure(1)
clf
contourf(theta, L, F',10);
xlabel('Theta (Degrees)');
ylabel('Length (Meters)');
title('Force in Cylinder, function of Theta and bar length');
colorbar
```

```
%part 2
figure(2)
clf
Freal=F;
for ii = 1:length(theta)
    for jj = 1:length(L)
        if abs(Freal(ii,jj))<0.8 && abs(Freal(ii,jj))>0
                Freal(ii,jj)=1;
        else
               Freal(ii,jj)=0;
        end
    end
end
contourf(theta, L, Freal',10);
xlabel('Theta (Degrees)');
ylabel('Length (Meters)');
title('Acceptable Design Parameters for the Piston');
```


Force in Cylinder, function of Theta and bar length
Length (Meters)
Theta (Degrees)
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
10
20
30
40
50
60
70
2.5
2
1.5
1
0.5


Acceptable Design Parameters for the Piston
Length (Meters)
Theta (Degrees)
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
10
20
30
40
50
60
70