Name: Cherie Francis
Assignment: ME1 Design Step 3

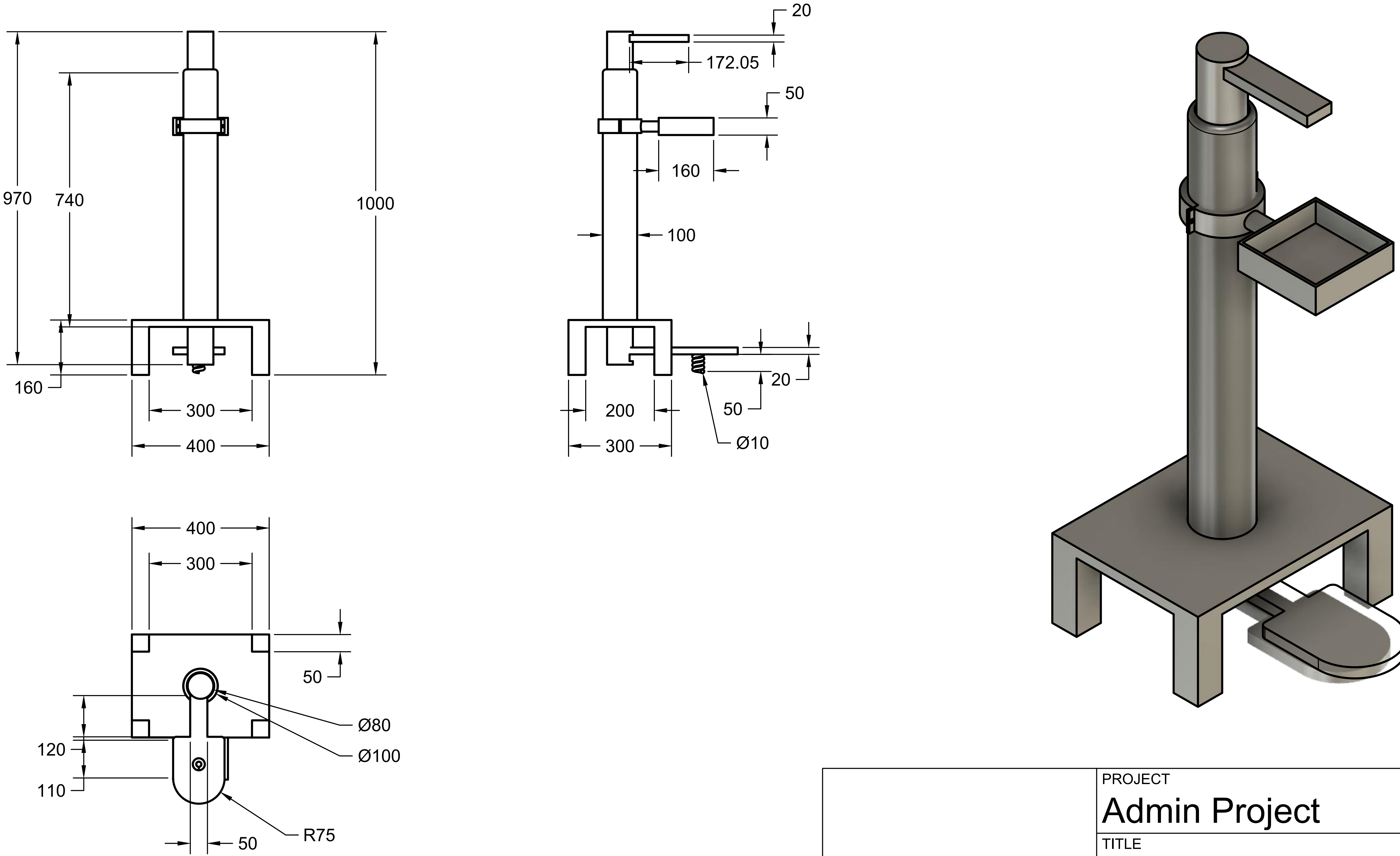
Project Choice: Hand Sanitizer Foot Pump
For this project, I chose to design the foot pump for hand sanitizer as it can be especially useful during this current pandemic.

Design Challenge:
Due to the current pandemic, it is now necessary to apply hand sanitizer upon entering majority of indoor locations, inclusive of supermarkets, offices and stores. This is done to disinfect our hands and limit the spread of COVID-19. However, other health concerns may arise from a large amount of people touching the same handle throughout each day. Therefore, it can be very useful to add a foot pump mechanism to the hand sanitizer bottles to limit contact. It's essential that this pump can operate without any hands-on contact while also having the ability to accommodate hand sanitizers of different sizes. It should also require minimal amount of force to operate so that individuals ranging from small children to seniors (ages 6+), can easily access the hand sanitizer. It also needs to be a lightweight device for ease of relocation but also sturdy enough to remain upright if people bounce into it. Additionally, the design shouldn't utilize electricity for the mechanism to work.

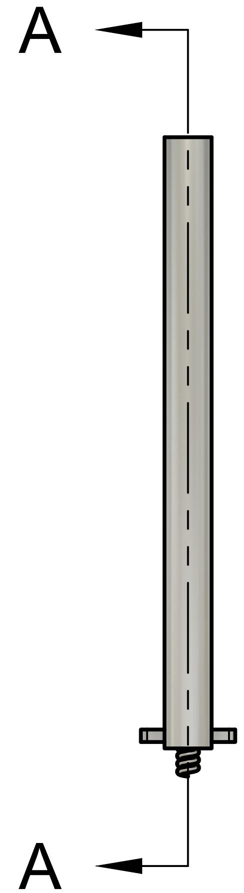
Design Criteria		
1	Ease of Use	Device should be easily manipulated by people within the range of small children to senior citizens (ages 6+). It should require a force of less than 88.5 N to operate. o Value found from people of different ages being asked to place one foot on a scale and press with a slight amount of force in order to determine the ideal force to be used for the pump's operation.
2	Safety	Shouldn't be easily knocked over and potentially fall on people within a close proximity. o Must have ability to withstand forces due to persons bouncing into the product, at least 100 N.
3	Adjustability	Must have ability to accommodate a range of hand sanitizer bottle sizes. o Will have a component to hold sanitizer in place, that's large enough for a 4.0"W x 3.5"D x 10.5"H bottle, whether circular or rectangular.
4	Accessibility	Height should be low enough so that children can receive the hand sanitizer but also high enough to allow for adults to collect the sanitizer in their hands without bending. o Device should be approximately 100 cm tall o This value is still lower than a 6-year old's average height yet high enough so that adults can place their hand under the dispenser.

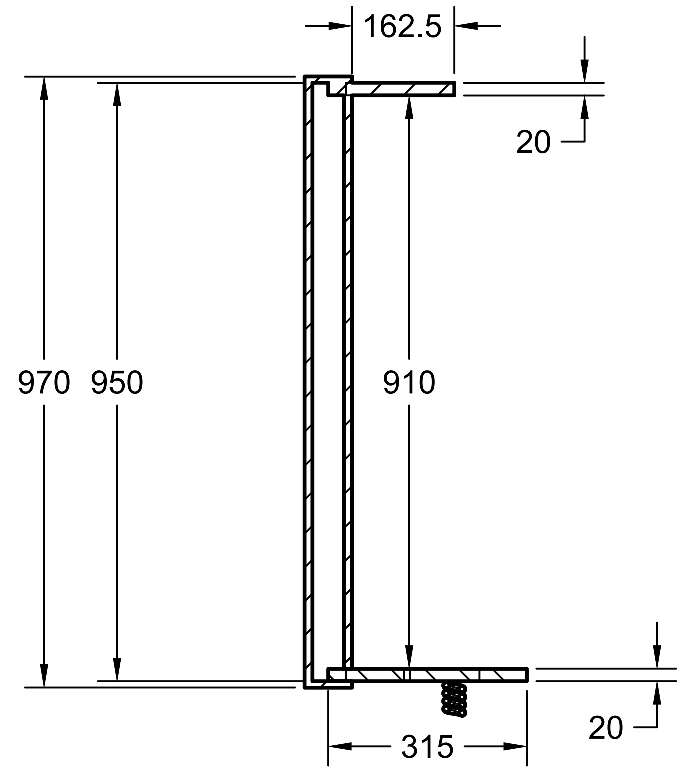
5	Portability	The pump should ideally have a weight less than 176.6 N to be moved with one hand for ease of relocation. o To find this value, different people were asked to lift suitcases containing different loads and indicate which ones they can lift with their dominant and non-dominant hands.
6	Cost	The cost for manufacturing one device should ideally be less than $100.
7	Durability	Product must be able to withstand daily use by 50+ people without damage or need for adjustments for at least 2 years.
8	Easy to Clean	Dust, mud or liquid from users' shoes or extra hand sanitizer should be easily wiped off the system. o Should be easily wiped off with a mop, rag or paper towel

Drawings of the final design and well as a critical component (the pedal-pumper component) are shown below.

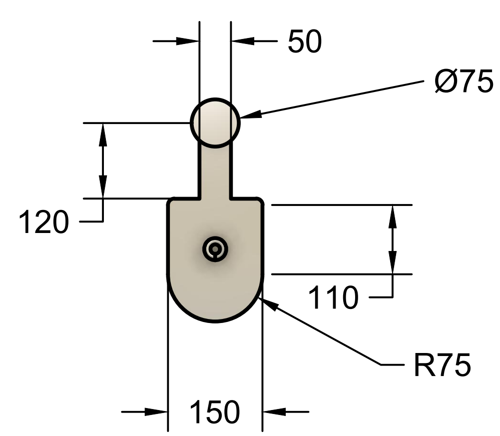


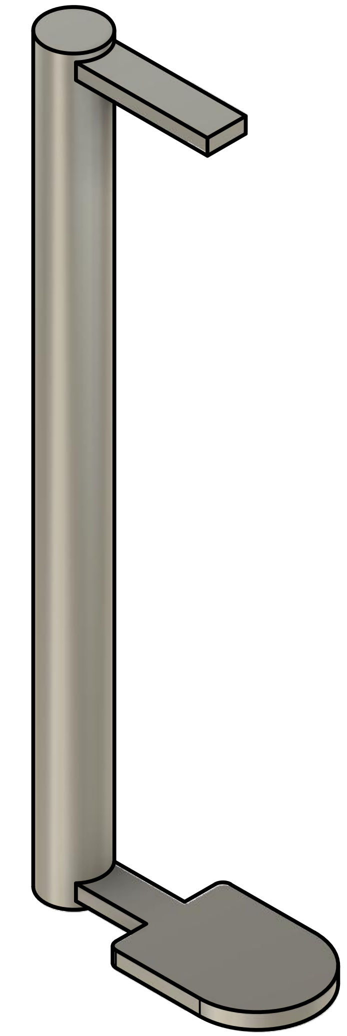
PROJECT Admin Project				
TITLE Foot Pump				
APPROVED	SIZE	CODE	DWG NO	REV
CHECKED	B			
DRAWN Cherie Francis 11/23/20	SCALE 1:12	WEIGHT 701.4 N	SHEET 1/1	





SECTION A-A
SCALE 1:12

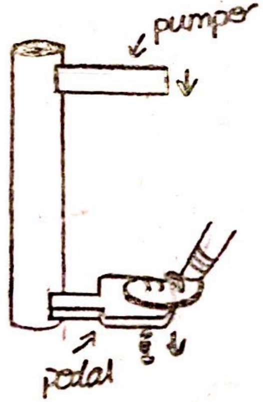




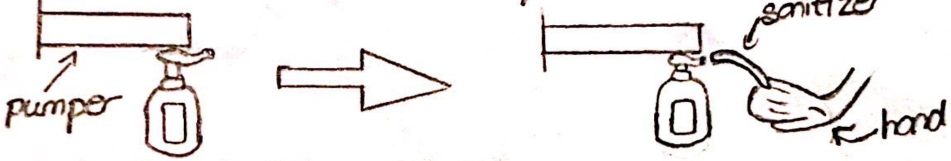
	PROJECT Design Step 3			
	TITLE Pumper			
APPROVED	SIZE	CODE	DWG NO	REV
CHECKED	B			
DRAWN Cherie Francis 11/23/20	SCALE 1:12	WEIGHT 238.9 N	SHEET 1/1	

HOW DOES IT WORK?

1. The user steps on the pedal positioned below the platform

2. 

The pedal is connected to a hollow cylindrical component to which the "pumper" is also attached to. Once the pedal is pushed, the cylindrical component, along with the pumper, moves downwords. This causes the pumper to press down on the sanitizer pump and dispense the liquid gel



3. After the user receives the sanitizer, they remove their foot and the pumper-pedal component returns to its original position due to the spring force pushing the pedal upwards.

This design was chosen because it possesses the following:

- It has a wide 0.4m x 0.3m base which allows for a sturdier design and a lighter device.
- Its height is 1.0m which allows the device to be used by a variety of age groups and individuals of varying heights. It satisfies the accessibility criteria.
- It has an adjustable clamp feature, modelled based on pipe clamps, to accommodate hand sanitizer bottles of varying heights. There are two screws to be placed in the holes on both sides of the clamp. Unscrew the screws to loosen the clamp and later the position of the hand sanitizer container. Afterwards, tighten the screws once you have the container at the desired location.

Additional Design Features:

Hand sanitizer pumps only require a force of 6 lbs. to operate, which is approximately equal to 27N. The design created has the pedal connected to a cylindrical component along with the pumper (to press down on the sanitizer). This makes the force exerted by the user's foot on the pedal be equal to the force exerted by the pumper on the sanitizer. Therefore, the foot pump only requires a small amount of force to operate, much less than the ideal value of 88.5N previously found.

From the analysis done, the weight of the device was found to be 701.4 N which is approximately equal to 157.8 lbs. This value is 524.8 N (118 lbs.) larger than the ideal value of 176.6 N (39.7 lbs.). The material chosen to construct this device was stainless steel because it's a strong material. Bamboo was initially going to be used for this product, however overall weight of the design would be too light to withstand external forces equal to or greater than 100N without tipping. Therefore, I opted for a heavier design since safety was ranked higher than portability (ease of transport) in the design criteria. With this larger weight, the design is now able to withstand forces less than or equal to 105.2N when pushed from the top of the product. However, when pushed from the base, which is more likely to happen due to the dimensions of the device, it can withstand forces up to 876.8N without tipping. This value is 776.8N higher than the target force of 100N, suggesting that the device is over 7x stronger than we hoped for in this scenario. The manufacturing cost of the product is also related to the material used along with the product's actual weight. The total cost was calculated to be $209.18, which is more than double the target price. However, the safety of the users is ranked higher than the cost criteria, and therefore more important.

The container in which the hand sanitizer is to be placed was made with the ability to accommodate bottles with the dimensions: 4.0"W x 3.5"D x 10.5"H. The square container has internal sides each of length 15cm, which are almost 6 inches long. Therefore, the design accounts for hand sanitizer bottles that could have larger dimensions from the ones previously mentioned. The design also reduces the chance of the bottle falling onto the ground because it has a 4cm tall barrier to keep the sanitizer in place.

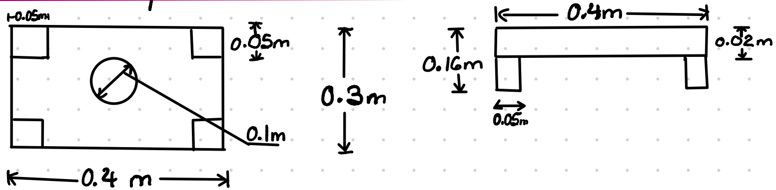
In addition to the above, the design allows for easy cleaning. The design is very smooth and doesn't consist of any abnormal shapes of rough edges, meaning that any dirt or excess sanitizer can be easily wiped from the surface. The design is also expected to last longer than 2 years without damage, provided users don't exert too large of a force on the pedal, causing either it or the pumper to break. The analysis also produced a maximum stress of 13.3 MPa for the pumper. This means that it can undergo a stress of 13.3 MPa before it breaks. Another value that was found was the spring constant of the spring, k, which was 15296 N/m, a rather large value. This implies that a very stiff spring is needed to aid in the operation of the device.

FINAL ANALYSIS

1. FINDING WEIGHT OF DEVICE

To do this, we find the weight of each component by multiplying the volume of each component by the density of titanium and gravity, then adding together each weight to find the total weight.
Let gravity, $g = 9.81\ m/s^2$ for all calculations

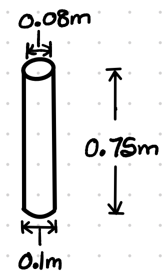
Volume of platform/base

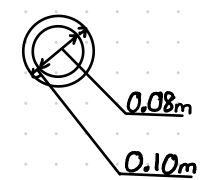


Cuboid : $V = 0.4\ m \times 0.3m \times 0.02m = 2.4 \times 10^{-3}\ m^3$
Cylinder : $V = \pi \times (0.05m)^2 \times 0.02m = 1.57 \times 10^{-4}\ m^3$
Each Peg : $V = 0.05m \times 0.05m \times 0.14m = 3.5 \times 10^{-4}\ m^3$

Base $V = (4.05 \times 10^{-3} m^3 - 1.57 \times 10^{-4} m^3) + 4(3.5 \times 10^{-4} m^3) = 3.64 \times 10^{-3}\ m^3$
Base $W = \rho V g = 7480\ kg/m^3 \times 3.64 \times 10^{-3} m^3 \times 9.81\ m/s^2 = 267\ N$

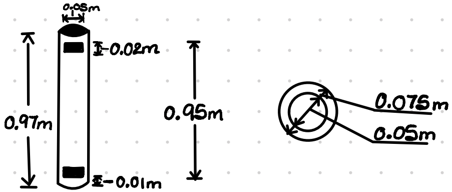
Coating



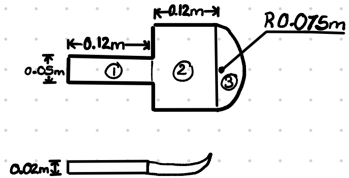


Outer $V = \pi \times (0.05\ m)^2 \times 0.75\ m = 5.89 \times 10^{-3}\ m^3$
Inner $V = \pi \times (0.04\ m)^2 \times 0.75\ m = 3.77 \times 10^{-3}\ m^3$
$V = 5.89 \times 10^{-3} m^3 - 3.77 \times 10^{-3} m^3 = 2.12 \times 10^{-3}\ m^3$
$W = \rho V g = 7480\ kg/m^3 \times 2.12 \times 10^{-3} m^3 \times 9.81\ m/s^2 = 155\ N$

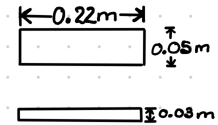
Pedal-Pump Component



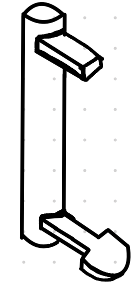
Support



Pedal



Pumper



Outer $V = \pi(0.0375m)^2 \times 0.97m = 4.29 \times 10^{-3}\ m^3$

Cutouts $V_1 = 2 \times 0.05m \times 0.02m \times 0.01m = 2 \times 10^{-5}\ m^3$

Inner $V = \pi(0.025\ m)^2 \times 0.95m = 1.87 \times 10^{-3}\ m^3$

Support $V = 4.29 \times 10^{-3} m^3 - (2 \times 10^{-5} m^3 + 1.87 \times 10^{-3} m^3) = 2.4 \times 10^{-3}\ m^3$

$W = \rho V g = 7480\ kg/m^3 \times 2.4 \times 10^{-3}\ m^3 \times 9.81\ m/s^2 = 176\ N$

Pedal

$V_1 = 0.12m \times 0.05m \times 0.02m = 1.2 \times 10^{-4}\ m^3$

$V_2 = 0.12m \times 0.15m \times 0.02m = 3.6 \times 10^{-4}\ m^3$

$V_3 = \frac{1}{2} \times \pi \times (0.075m)^2 \times 0.02m = 1.77 \times 10^{-4}\ m^3$

$V = 1.2 \times 10^{-4} m^3 + 3.6 \times 10^{-4} m^3 + 1.77 \times 10^{-4} m^3 = 6.57 \times 10^{-4}\ m^3$

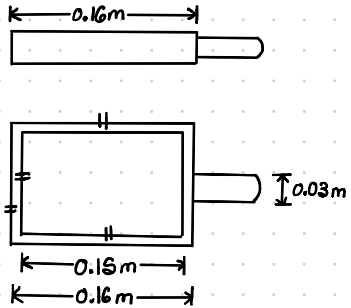
$W = \rho V g = 7480\ kg/m^3 \times 6.57 \times 10^{-4} m^3 \times 9.81\ m/s^2 = 48.2\ N$

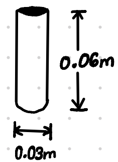
Pumper $V = 0.05m \times 0.02m \times 0.2\ m = 2 \times 10^{-4}\ m^3$

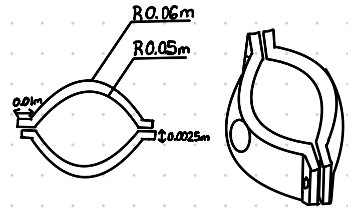
$W = \rho V g = 7480\ kg/m^3 \times 2 \times 10^{-4} m^3 \times 9.81\ m/s^2 = 14.7\ N$

Total $W = 176\,N + 48.2\,N + 14.7\ N = 238.9\ N$

Container & Clamp







$$V_{s1} = 0.16m \times 0.16m \times 0.05m = 1.28 \times 10^{-3}\, m^3$$
$$V_{s2} = 0.15m \times 0.15m \times 0.04m = 9 \times 10^{-4}\, m^3$$
$$V_{Hole} = \pi \times (0.0150m)^2 \times 0.005m = 3.53 \times 10^{-6}\, m^3$$
$$V_{cyl} = \pi \times (0.0150m)^2 \times 0.06m = 4.24 \times 10^{-5}\, m^3$$

$$V_{con} = 1.28 \times 10^{-3} m^3 - 9 \times 10^{-4} m^3 - 3.53 \times 10^{-6} m^3 + 4.24 \times 10^{-5} m^3 = 4.19 \times 10^{-4}\, m^3$$

$$V_{c1} = \pi \times (0.06m)^2 \times 0.04m = 4.52 \times 10^{-4}\, m^3$$
$$V_{c2} = \pi \times (0.05m)^2 \times 0.04m = 3.14 \times 10^{-4}\, m^3$$
$$V_{Hole} = \pi \times (0.015m)^2 \times 0.01m = 7.07 \times 10^{-6}\, m^3$$
$$V_{clip} = 0.01m \times 0.0025m \times 0.04m = 1 \times 10^{-6}\, m^3$$
$$V_{Hole_2} = \pi \times (0.007m)^2 \times 0.0025m = 3.85 \times 10^{-7}\, m^3$$

$$V_{clamp} = [4.52 \times 10^{-4} - 3.14 \times 10^{-4} - 7.07 \times 10^{-6} m^3 + 4(1 \times 10^{-6}) - 4(3.85 \times 10^{-7})]\, m^3 = 1.33 \times 10^{-4}\, m^3$$

$$W = \rho V g = 7480\, kg/m^3 \times (4.19 \times 10^{-4} m^3 + 1.33 \times 10^{-4} m^3) \times 9.81\, m/s^2 = 40.5\ N$$

$$W_T = 267\ N + 155\ N + 238.9\ N + 40.5\ N = 701.4\ N$$

$$\boxed{\therefore \text{Total weight of device} = 701.4\ N}$$

2. FINDING MAXIMUM FORCE THE PRODUCT CAN WITHSTAND

Recall: The product should be able to withstand a force of 100N at minimum.

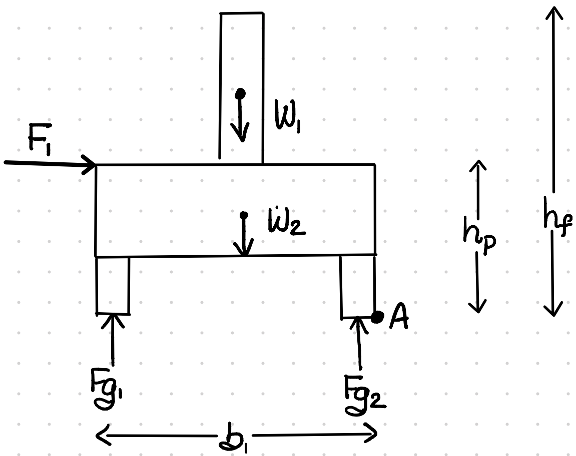
SIMPLIFIED FREE BODY DIAGRAMS (2D) + CACULATIONS

For all calculations, let gravity, $g = 9.81 \frac{m}{s^2}$

Let: $h_f = 1.0\ m$ (height of device)
$h_p = 0.16\ m$ (height of platform)
$b_1 = 0.45\ m$ (width of platform, front view)
$b_2 = 0.45\ m$ (width of platform, side view)

$W = 701.4\ N$ (weight of device)

SCENARIO #1: Device pushed from the side at the base



Assumptions: $Fg_1 = Fg_2$ and their total reaction force acts upwards towards the centre of the product

$$\Sigma F_y = 0 = Fg_1 + Fg_2 - W_1 - W_2$$

$$2Fg_1 = W_1 + W_2$$

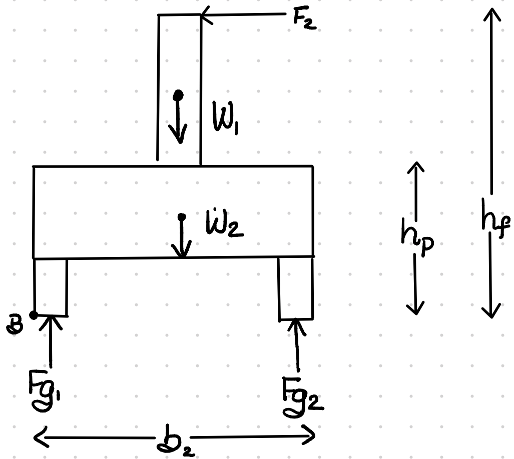
$$Fg_1 = \frac{(W_1 + W_2)}{2}$$

$$\Sigma M_A = 0 = (W_1 + W_2)\frac{b_1}{2} - F_1 h_p$$

$$\Rightarrow F_1 = \frac{b_1(W_1 + W_2)}{2h_p} = \frac{0.4\ m \times 701.4\ N}{2 \times 0.16 m}$$

$$F_1 = 876.8\ N$$

SCENARIO #2 : Device pushed from the top



Assumptions : $F_{g_1} = F_{g_2}$ and their total reaction force acts upwards towards the centre of the product

$$\Sigma F_y = 0 = F_{g_1} + F_{g_2} - W_1 - W_2$$
$$2F_{g_1} = W_1 + W_2$$
$$F_{g_1} = \frac{(W_1 + W_2)}{2}$$

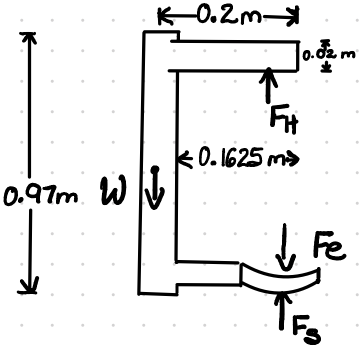
$$\Sigma M_B = 0 = F_2 h_f - (W_1 + W_2)\frac{b_2}{2}$$
$$\Rightarrow F_2 = \frac{(W_1 + W_2) b_2}{2 h_f} = \frac{701.4 \text{ N} \times 0.3 \text{ m}}{2 \times 1.0 \text{m}}$$
$$F_2 = 105.2 \text{ N}$$

∴ The foot pump can withstand a force of 876.8N applied at the top of the platform & of 105.2N applied at the top of the device.

Both values are over 100 N.

3. FINDING THE SPRING CONSTANT, k

FBD for Pumper Component



F_H : Force of hand sanitizer
F_e : External force applied by foot
F_s : Force of spring on pedal
W : Weight of component

Let $W = 238.9\,N$

$F_e = 220\ N$ Found from asking people to "stomp" on a scale then taking the largest value as the maximum F_e.
$F_{e\,max} \approx 50\text{ lbs} \approx 220\text{ N}.$

$F_H = 27\ N$ Found from pressing a hand sanitizer pump on a scale.
$F_H \approx 6\text{ lbs} \approx 27\text{ N}$

First, find F_s

$$\Sigma F_y = 0 = F_H + F_s - W - F_e$$

$$\Rightarrow F_s = W + F_e - F_H$$
$$= 238.9\,N + 220\,N - 27\,N$$
$$= 458.9\ N$$

Next, find the spring constant, k

Let $\Delta x = -0.03$ m since the spring's full length is 0.05m and it's being compressed

$$F_s = -k\Delta x$$

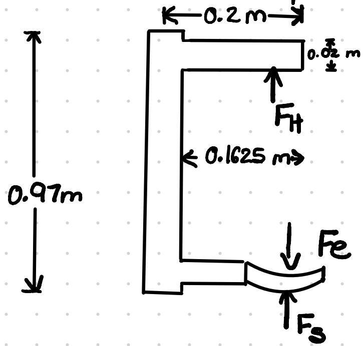
$$\Rightarrow k = -\frac{F_s}{\Delta x}$$

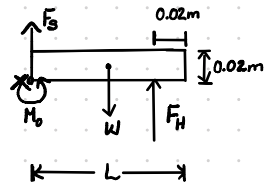
$$K = \frac{458.9\ N}{0.03 m}$$

$$\boxed{\therefore\ K = 15296\ N/m}$$

4. FINDING MAXIMUM STRESS PUMPER CAN WITHSTAND

FBD for Pumper Component





$$V = 0.1625m \times 0.02m \times 0.05m = 1.625 \times 10^{-4} m^3$$

$$W = 7480\ kg/m^3 \times 1.625 \times 10^{-4} m^3 \times 9.81\ m/s^2 = 11.9N$$

Let $L = 0.1625m$

$F_H = 27\ N$

$$\Sigma M_x = M_0 - W \cdot \frac{L}{2} + F_H (L - 0.02m)$$

$$M_0 = W \cdot \frac{L}{2} - F_H (L - 0.02m)$$

$$= \frac{11.9N \times 0.1625m}{2} - 27N(0.1625 - 0.02)m$$

$$= -2.88\ Nm$$

$$\sigma = \frac{6M_0}{bh^3} = \frac{6 \times 2.88\ Nm}{0.1625m \times (0.02m)^3} = 13.3\ MPa$$

$$\boxed{\sigma_{max} = 13.3\ MPa}$$

5. FINDING TOTAL COST TO MANUFACTURE DEVICE

Mass of product in kg $= \frac{W}{g} = \frac{701.4\ N}{9.81\ m/s^2} = 71.5\ kg$

Weight of product in lbs $= W \times 0.225 = 701.4 N \times 0.225 \frac{lbs}{N} = 157.8\ lbs$

Cost of stainless steel per lb. $= \$1.28 / lb$

cost of product $= 157.8\ lbs \times \$1.28 / lb$

$= \$201.98$

2 screws are needed for the design as well as a spring.

Cost of: 2 7mm diameter screws $= 2 \times \$0.60 = \$1.20$

1 spring $= \$6.00$

$\boxed{\therefore \text{ Total cost } \simeq \$209.18}$

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2. MetalMiner Prices: Stainless Steel Prices. (2020, November 16). Retrieved November 23, 2020, from https://agmetalminer.com/metal-prices/stainless-steel/

3. Screw and spring prices as well as hand sanitizer bottle dimensions were taken from https://www.amazon.com