Element E: Application of STEM principles and practices

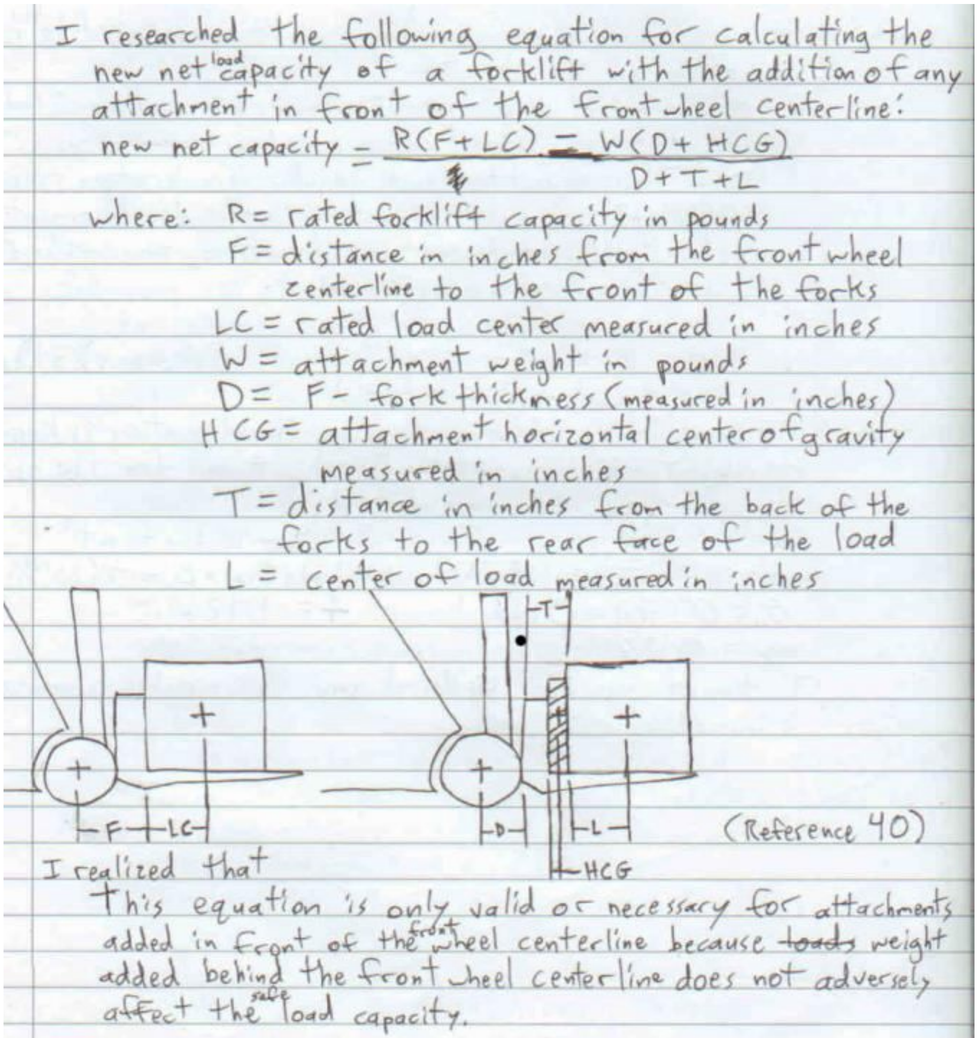
Due to the nature of the project, the application of physics, math and aspects of mechanical engineering play a key role in the development of both stability and visibility designs.

For the stability design, calculations regarding the center of gravity of an object, centripetal force calculations, and moment equations have been essential to the progress in the design of the device. Also calculations involving determining the size of a hydraulic cylinder and the size of a motor, which correlates to mechanical engineering, have been a part of the team's design determination.

As for the visibility design, calculations involving the stopping distance of a forklift and the physics behind the properties of reflected light affected the design specifications.

Forkift Attachment Calculations

As proven through the following calculations performed by the team, even relatively low weight attachments can have a significant negative impact on the safe load capacity if the attachment is located forward of the forklift's front wheel centerline. The researched equation is derived from a moment equation.


I researched the following equation for calculating the new net load capacity of a forklift with the addition of any attachment in front of the front wheel centerline:

$$\text{new net capacity} = \frac{R(F+LC) - W(D+HCG)}{D+T+L}$$

where: R = rated forklift capacity in pounds
F = distance in inches from the front wheel centerline to the front of the forks
LC = rated load center measured in inches
W = attachment weight in pounds
D = F − fork thickness (measured in inches)
HCG = attachment horizontal center of gravity measured in inches
T = distance in inches from the back of the forks to the rear face of the load
L = center of load measured in inches

(Reference 40)

I realized that this equation is only valid or necessary for attachments added in front of the front wheel centerline because ~~loads~~ weight added behind the front wheel centerline does not adversely affect the safe load capacity.

(Pictures of calculations are excerpts from the 10/31/12 entry of *[redacted student name]* Engineering Notebook.)

SUMMARY: These calculations prove that the addition of a hypothetical 25 pound attachment results in a lost capacity of 366 pounds and indicates that attachments placed forward of the front wheel centerline would have a significant negative impact on the performance and productivity of a forklift. Therefore, it was decided that a product specification would be that the solution would not have any components forward of the front wheel centerline.

Forklift Stopping Distance Calculations

The following calculations determine an approximation for the distance that it takes for a forklift to stop.

(Pictures of above calculations were copied from the 11/12/12 entry of *[redacted student name]* Engineering Notebook.)

(The picture of calculations above was copied from the 11/21/12 entry of *[redacted student names]* Engineering Notebook.)

SUMMARY: The calculated results for an approximation of the stopping distance of a forklift allowed the team to determine a value for the minimum safe distance between a forklift and an object, or person, in front of the forklift that the industrial vehicle can stop in without hitting the object or person. This became product specification 19: The minimum distance between the forklift and a hazard must be five meters at the instant that the

I researched the following values for the Toyota Model 8FGCU20 forklift which the team will primarily be testing with: (Reference 41)

$R = 4000\ lb$

$F = 16.7\ in$

$LC = 24\ in$

$D =$ ~~[illegible]~~ $16.7\ in - 4\ in = 12.7\ in$ (Gyneth and I agreed on the estimate of 4 in for the fork thickness)

$L = 24\ in$

I decided on the following values for a forklift with a front mounted attachment:

$W =$ ~~[illegible]~~ $25\ lb$

$HCG = 2\ in$

$T = 8\ in$

I calculated the new net capacity of the previously mentioned forklift with attachment using the equation researched on 10/30/12.

$$\text{new net capacity} = \frac{R(F+LC) - W(D+HCG)}{D+T+L}$$

$$\text{new net capacity} = \frac{(4{,}000\ lb)(16.7\ in + 24\ in) - (25\ lb)(12.7\ in + 2\ in)}{12.7\ in + 8\ in + 24\ in}$$

$$\text{new net capacity} = \frac{162{,}800\ lb\ in - 367.5\ lb\ in}{44.7\ in}$$

$$\text{new net capacity} = \frac{162{,}432.5\ lb\ in}{44.7\ in}$$

$$\boxed{\text{new net capacity} = 3{,}634\ lb}$$

$R - \text{new net capacity} = \text{lost capacity}$

$\text{lost capacity} = 4{,}000\ lb - 3{,}634\ lb = \boxed{366\ lb}$

I calculated the lost capacity above which I define as the difference between the previous maximum safe load weight, or rated forklift capacity, and the new maximum safe load weight, or new net capacity.

forklift operator is alerted to said hazard. (The 4.7690 meters was rounded up to 5 meters to be safe).

Physics and Newton's First Law

To analyze a possible failure in the design of the visibility solution, certain physical laws were utilized.

SUMMARY: The overwhelming majority of forklifts have lap belts, not seatbelts that extend over a shoulder. This means that when a forklift stops suddenly, the forward momentum of the operator causes the driver's head and upper body to keep moving forward, as per Newton's 1st Law: *objects in motion remain in motion unless acted upon by an unbalanced force.* In some situations, the driver's head can continue forward far enough to hit the device, especially when the device is in an angled position, as shown in Figure 4. As a result, such an occurrence is reasonably possible enough that it does represent a legitimate problem that must be addressed in order to produce a safe solution.

Physics and Properties of Reflected Light

Because of the fact that the angle of incidence is equal to the angle of reflection, as shown in the following sketch, the team was able to determine the angle of the mirrors in the

"It takes about 1.3 feet for each mile per hour for a panic stop."

(Miller, Barrett C. "Forklift Safety by Design." Safety-Engineer.com. 1998. Web. 12 Nov. 2012. <http://www.safety-engineer.com/forklift.shtml>.)

An approximation of the stopping distance was calculated based on this fact:

$$\frac{5\,mi/hr}{1}\left(\frac{1.3\,ft}{1\,mi/hr}\right)\left(\frac{12\,in}{1\,ft}\right)\left(\frac{2.54\,cm}{1\,in}\right)\left(\frac{10^{-2}\,m}{1\,cm}\right)=\boxed{1.9812\,m}$$

"It takes about 1.2m for each 5km/hr to stop a forklift under emergency conditions."

(Roads and Transport Authority. "Forklift Operators Handbook: A Guide to Safe Operation." 2008. pdf. 12 Nov. 2012. <http://www.rta.ae/wpsv5/eservices/PDF_Catalog/Forklift_Handbook_EN.pdf>.)

An approximation of the stopping distance was calculated based on this fact:

$$\frac{5\,mi/hr}{1}\left(\frac{1.60934\,km/hr}{1\,mi/hr}\right)\left(\frac{1.2\,m}{5\,km/hr}\right)=\boxed{1.9312\,m}$$

The results of the previous two calculations are accurate because the difference is less than $\frac{1}{10}$, yet the approximations were based on two different sources.

"If a load is added to the forklift, then the stopping distances will be greatly increased. Doubling the mass of the forklift will require twice the stopping distance."

(Same source as previous quote, "Forklift Operators Handbook: A Guide to Safe Operation.")

$$\left.\begin{array}{l}\text{forklift load capacity} = 4{,}000\,lb\\ \text{forklift weight w/o load} = 7{,}130\,lb\end{array}\right\}\text{Values for the forklift which the team will be testing with}$$

(Toyota Industrial Equipment 8 Series Specifications. Toyota Material Handling, USA, Inc., 2008. pdf.)

The forklift weight with load was calculated:

weight w/ load = Weight w/o load + load capacity

weight w/ load = 7,130 lb + 4,000 lb = $\boxed{11{,}130\,lb}$

visibility solution concept to be 45 degrees:

(The picture above shows the incident and reflected light at a reflective surface at a 45 degree angle, such as that of the mirror in the visibility design sketched by *[redacted student name]* on 1/20/13)

Mrs. Famoso, an Advanced Placement physics teacher and an alumni of Rensselaer Polytechnic Institute's School of Engineering confirmed the team's choice of angle of the mirrors in the device, 45 degrees.

SUMMARY: The team determined the angle of the mirrors in the visibility solution concept to be 45 degrees. See the explanation of how the 45 degree angle factors into the visibility solution at the bottom of **Element D: Design concept generation, analysis, and selection**.

Physics and Center of Mass Calculations

Regardless of whether the team decides to work with the "under mounted hydraulic cylinders" or the "under mounted counterweight with electric motor", the

Based on the fact that a direct relationship exists between a forklift's weight and its stopping distance, the following proportion was set up using calculated and researched values:

- stopping distance without load = 1.9812 m
  (The larger calculated stopping distance was used to be safe)
- weight w/o load = 7,130 lb
- weight w/ load = 11,130 lb

$$\frac{\text{weight w/o load}}{\text{weight w/ load}} = \frac{\text{stopping distance w/o load}}{\text{stopping distance w/ load}}$$

$$\frac{7{,}130\text{ lb}}{11{,}130\text{ lb}} = \frac{1.9812\text{ m}}{\text{stopping distance w/ load}}$$

stopping distance with load = $\boxed{3.0927\text{ m}}$

operator reaction time = .75 seconds
(Same source as both stopping distance conversion factors)

The distance that a forklift travels at 5 mi/hr in .75 seconds was calculated:

$$5\,\text{mi/hr}\left(\frac{1\text{ hr}}{3600\text{ s}}\right)\left(\frac{1609.34\text{ m}}{1\text{ mi}}\right) = 2.235\text{ m/s}$$

$$d = V \cdot t$$

$$d = 2.235\text{ m/s} \cdot .75\text{ s} = \boxed{1.6763\text{ m}}$$

The total stopping distance was calculated:

total stopping distance = stopping distance + reaction time distance

total stopping distance = 3.0927 m + 1.6763 m

total stopping distance = $\boxed{4.7690\text{ m}}$

I calculated the maximum and minimum stopping distances in meters of a warehouse forklift moving at 5 mi/hr ~~based~~ based on information from the meeting with Mr. Ascoli and Mr. Gorham on 11/17/12.

$$\text{max stopping distance} = 17\text{ ft}\left(\frac{12\text{ in}}{1\text{ ft}}\right)\left(\frac{2.54\text{ cm}}{1\text{ in}}\right)\left(\frac{10^{-2}\text{ m}}{1\text{ cm}}\right) = \boxed{5.1816\text{ m}}$$

$$\text{min stopping distance} = 10\text{ ft}\left(\frac{12\text{ in}}{1\text{ ft}}\right)\left(\frac{2.54\text{ cm}}{1\text{ in}}\right)\left(\frac{10^{-2}\text{ m}}{1\text{ cm}}\right) = \boxed{3.0480\text{ m}}$$

These results confirm my calculated approximate stopping distance of 4.7690 m from 11/12/12 which is between 3.0480 m and 5.1816 m.

weight of the moving counterweight needs to be determined.

The way that both solution devices stated above are designed to work is by activating when a certain type of sensor (which is yet to be determined) indicates

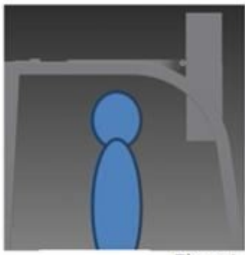


Figure 1


Figure 2

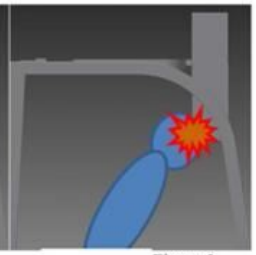
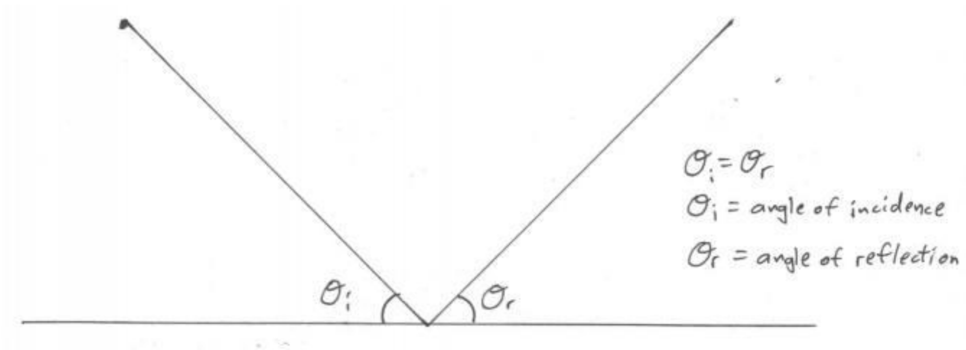


Figure 3


Figure 4



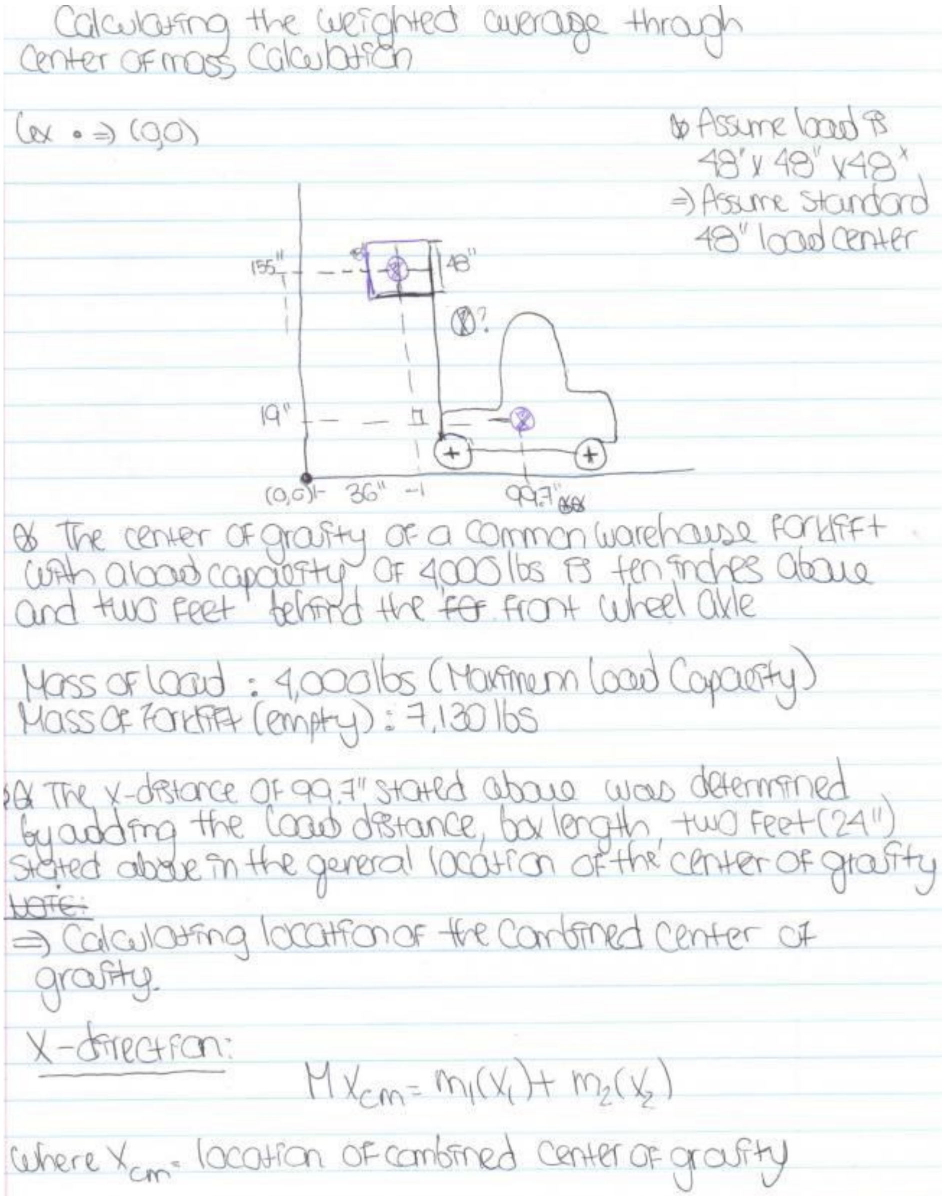
the system to do so. This causes the device to move the counterweight in the opposite direction of the tipping force, forcing the center of gravity back to its center.

The first step to these calculations is to determine the location of the combined center of mass of the empty forklift and a 4000 lb load at maximum fork height (this represents the "worst possible case scenario")

(Pictures of above calculation were copied from the 01/19/13 entry of *[redacted student name]* Engineering Notebook.)

SUMMARY: The above calculation was performed to determine what the combined center of gravity was when a forklift was at maximum fork height with a full capacity load of 4000 lbs. Now that the location has been determined it can be used to determine when the moment of the gravitational force equals the moment of the centripetal force of a forklift making a turn at seven miles an hour. A moment is defined as a force applied at a perpendicular distance. All of the measurements/dimensions were taken for the Specification Booklet of the Toyota Eight Series (“Toyota Industrial Equipment 8 Series specifications.” Toyota Material Handling, USA, Inc.2008.pdf. 19 Jan. 2013)

NOTE: Most warehouses place the speed limit of the forklifts at this speed, therefore this is the speed that will be used throughtout the calculations. Although, it is enforced that forklift drivers drive at five miles an hour.



Calculating the weighted average through
Center of mass Calculation

Lox • ⇒ (0,0)

* Assume load is
48" x 48" x 48"
⇒ Assume Standard
48" load center

155"
48"
⊗?
19"
(0,0)
36"
99.7"

* The center of gravity of a common warehouse forklift with a load capacity of 4000 lbs is ten inches above and two feet behind the ~~for~~ front wheel axle

Mass of load : 4,000 lbs (Maximum load Capacity)
Mass of Forklift (empty) : 7,130 lbs

** The x-distance of 99.7" stated above was determined by adding the load distance, box length, two feet (24") stated above in the general location of the center of gravity.

~~NOTE:~~
⇒ Calculating location of the Combined Center of gravity.

X-direction:

$$M x_{cm} = m_1(x_1) + m_2(x_2)$$

where x_{cm} = location of combined center of gravity

The statement regarding speed limits in warehouses is supported by Mr. Harford, Head Technician of Thompson & Johnson Equipment Co., Inc and Mr. Ascoli, Albany Branch Manager of Thompson and Johnson Equipment Co., Inc.

Determining Centripetal Force and Magnitude of the Center of Gravity

(Pictures of above calculations were copied from the 01/19/13 entry of *[redacted student name]* Engineering Notebook.)

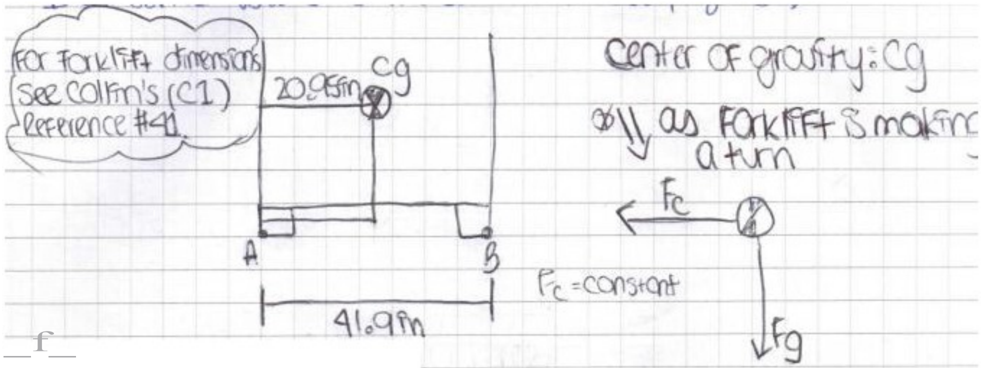
SUMMARY: To be able to calculate the moment of the centripetal force and the moment of the gravitational force, the magnitudes of each force had to be determined. The team made these calculations using the Metric system, and then converted back to Customary. The value of the radius used was the turning radius of the Toyota 8FGCU20 which was obtained from the Specification Booklet of the Toyota Eight Series (“Toyota Industrial Equipment 8 Series specifications.” Toyota Material Handling, USA, Inc.2008.pdf. 19 Jan. 2013).

$$(4{,}000\,lbs + 7{,}130\,lbs)(X_{cm}) = (4{,}000\,lbs)(36") + (7{,}130\,lbs)(99.7")$$

$$X_{cm} = \frac{144{,}000\,lbs(in) + 710{,}861\,lbs(in)}{(11{,}130\,lbs)}$$

$$\boxed{X_{cm} = 67.87691"}$$ in y-direction

location: (76.80692", 67.87691")



Weight of forklift (loaded)

7,130 lbs + 4,000 lbs = 11,130

empty — load capacity

conversions:

~~a) 20.95in (2.54cm / 1in)(1m / 100cm) =~~

G.C. Reference:

a) $20.95\,in \left(\frac{2.54\,cm}{1\,in}\right)\left(\frac{1\,m}{100\,cm}\right) = \boxed{.53213\,m}$ ⇒ location of center of gravity (laterally)

(C22)

2.54 cm = 1 in ⇒ I learned this conversion in Mrs. Villalos's AP Chemistry class.

b) $11{,}130\,lbs \left(\frac{1\,kg}{2.2\,lbs}\right)$ 5,059.09091 kg ⇒ Mass of forklift with full load

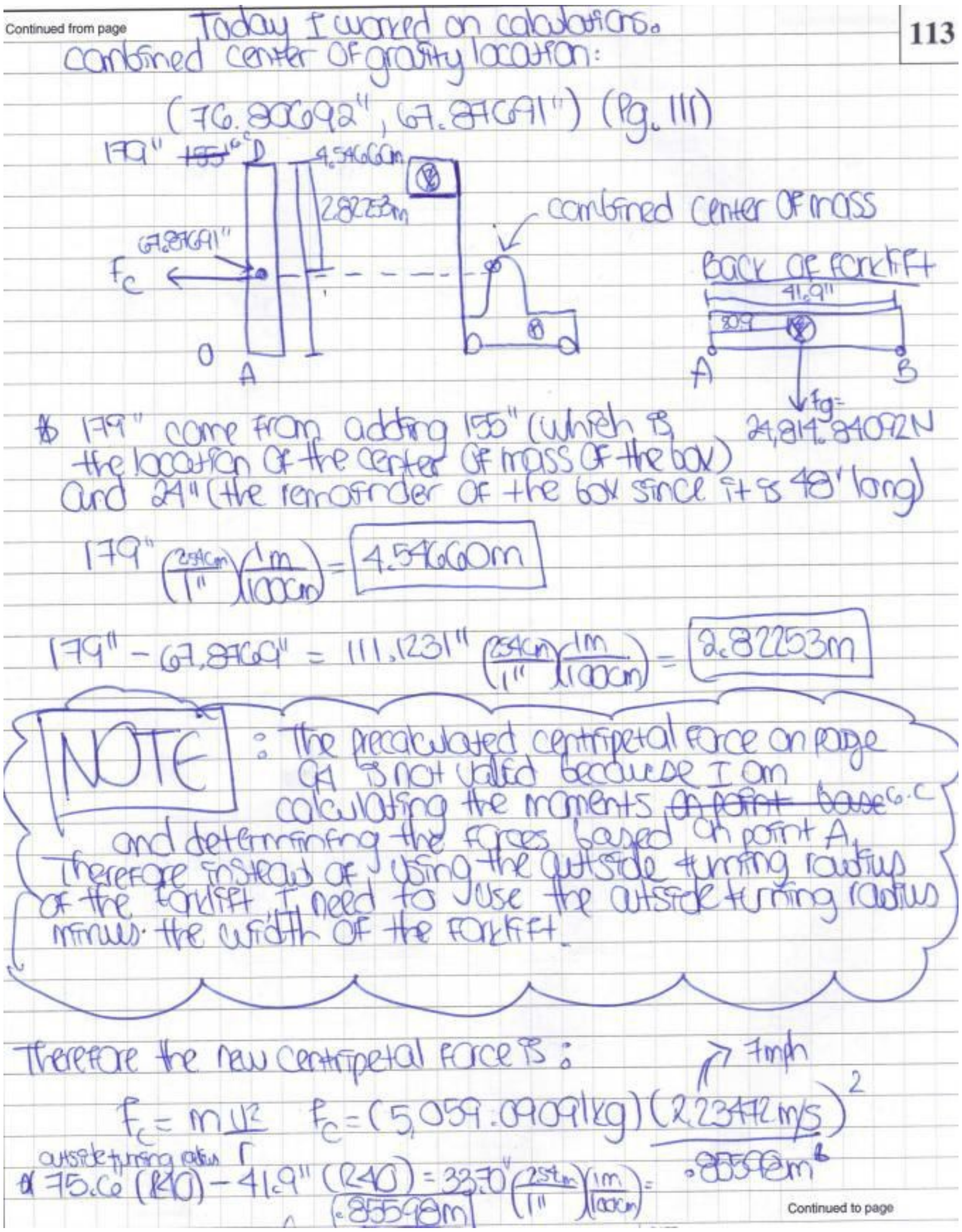
Calculations:

$$7\,mph \left(\frac{1\,hr}{3600\,s}\right)\left(\frac{1.609\,km}{1\,mi}\right)\left(\frac{1000\,m}{1\,km}\right)$$ ~~V = 3.129 m/s~~ $\boxed{V = 3.12861\,m/s}$

⇒ Fg = 49,629.68183 N (Pg 83)

The point at which the moments are equal, is the point of equilibrium. If the moment of the centripetal force at a point exceeds the moment of the gravitational force acting on that same point, the forklift will tip over.

Centripetal Force and Gravitational Force Moments: Determining the Mass of the Moving Counterweight.


Continued from page 113

Today I worked on calculations.
Combined center of gravity location:
(76.80692", 67.87691") (Pg. 111)

* 179" come from adding 155" (which is the location of the center of mass of the box) and 24" (the remainder of the box since it is 48" long)

$179'' \left(\frac{2.54cm}{1''}\right)\left(\frac{1m}{100cm}\right) = \boxed{4.54660m}$

$179'' - 67.8769'' = 111.1231'' \left(\frac{2.54cm}{1''}\right)\left(\frac{1m}{100cm}\right) = \boxed{2.82253m}$

NOTE: The precalculated centripetal force on page 91 is not valid because I am calculating the moments ~~at point base~~ C.G. and determining the forces based on point A. Therefore instead of using the outside turning radius of the forklift I need to use the outside turning radius minus the width of the forklift.

Therefore the new centripetal force is:

$F_c = \frac{mv^2}{r}$ $F_c = \frac{(5{,}059.0909kg)(2.23472\,m/s)^2}{.85598m}$ 7mph

outside turning radius r
* $75.6''(R40) - 41.9''(R40) = 33.70''\left(\frac{2.54cm}{1''}\right)\left(\frac{1m}{100cm}\right) = .85598m$

Continued to page

(Pictures of above calculations were copied from the 01/22/13 entry of *[redacted student name]* Engineering Notebook.)

SUMMARY: As stated in the summary above the moment of centripetal force and the moment of the gravitational force needed to be computed. The calculations above show the determination for the value of centripetal force at seven miles an hour. Due to the very high mass required as a result of such a high centripetal force, the values were then recalculated to determine at what speed a five hundred pound weight could be used. This is assuming all of other factors remain constant. The reason why the five hundred pounds were chosen was because this leaves two hundred pounds available for the other components

$F_C = 57,851.11374N$

So...

$+\sum M F_{CD} = 0 = (F_j \cdot 0m) + (57,851.11374N \cdot 2.82253m) - (F_A \cdot 4.54660m$

$\boxed{F_C \text{ on } F_A = 35,913.98057N}$

∴ the difference between the Fc and Fg on point A is:

~~H~~ g.c.

$35,913.98057N - 24,814.84092N =$

$\boxed{11,099.13965N}$

$\frac{11,099.13965N}{9.81 m/s^2} = \cancel{2,489}$ g.c. $1131.46747kg \left(\frac{2.2lbs}{1kg}\right) =$

$\boxed{2,489.10369 lbs}$

~~This is~~ g.c. According to the calculations 2,489.10369 lbs would be needed to counterbalance the tip over.

⇒ This is a problem because this goes ~~to~~ over the 700lb weight limit by about 1800 lbs.

⇒ This brings back the idea of using a ~~throttleback~~ g.c. a throttle back in order to slow down the forklift. (pg 97)

⇒ I need to determine when the throttle back would need to actuate ~~(and and to use and to use~~ g.c. and to what speed the forklift must slow down if the weight itself is 500 lbs. (This leaves 200lbs ~~of~~ for the rest of the parts in the system.

⇒ The tipover point or equilibrium point is when the moment of the gravitational force equals the moment of centripetal force (in this case, on point A). If the centripetal force is greater, the forklift

Continued to page

that may be in the system. If hydraulic cylinders are used then the entire system may be heavier versus using a motor. Also, the mininum size piston required was found. Eventually, the smallest size motor must be found to be able to compare which system is the most viable.

Having a 2500 pound moving counterweight may not be feasible in the amount of room available. This is why the team has considered adding a throttle back to the system. Please see **Element F: Consideration of design viability (http://innovationportal.org/portfolio/2312/element/28354)** for more details.

NOTE: Certain values pertaining to the the Toyota 8FGCU20 were obtained from the Specification Booklet of the Toyota Eight Series ("Toyota Industrial Equipment 8 Series specifications." Toyota Material Handling, USA, Inc.2008.pdf. 19 Jan. 2013).

Schematics

From taking the Principles of Engineering class at school the team learned how to draw simple schematic diagrams. The use of these made it simple to show others the way in

Continued from page will tip over.

$\sum M_{F_{C_D}} = 0 = (\cancel{F_D \cdot 0m}) + {}^{+}(F_D \cdot 2.83253m) + {}^{-}(24,814.84812N \cdot 4.54660m)$

$\cancel{f_d = 39}$ G.C

$\boxed{F_C \text{ on } D = 39,997.34953N}$

$F_C = m\frac{V^2}{r}$

$39,972.34953N = \frac{(5,059.09091kg)(V^2)}{.85598m}$

$V = 2.60061\, m/s \left(\frac{3600s}{1hr}\right)\left(\frac{1km}{1000cm}\right)\left(\frac{1mi}{1.609km}\right)$ $\boxed{V = 5.81865\, mph}$

So at the point where $mg = mF_c$ assuming ~~all~~ G.C all else is constant, the forklift would be turning at ~~5mph~~ G.C 5.81865mph.

=) If I am going to place a 500lb limit on the weight itself then

$500\, lbs \left(\frac{1kg}{2.2lbs}\right) = \boxed{227.27273\, kg}$

$F = ma$ $\quad F = \cancel{(2)}$ G.C $(227.27273kg)(9.81\, m/s^2)$

$\cancel{F = f_g}$ G.C $\boxed{F = 2,229.54546N}$

The difference between f_g and f_c if there were to be a ~~400~~ G.C 500 lbs weight would be 2,229.54546 N

$F_c - F_g = \text{difference}$

$\cancel{F_c = (2,229.54546N) + (2,229.54546N)}$

$F_c = 24,814.84812N + 1,560.68182N$

$\boxed{F_c = 27,044.38637N}$

$F_c = m\frac{V^2}{r}$ $\quad 27,044.38637N = \frac{(5,059.09091kg)V^2}{.85598m}$

Continued to page

which the stability system was designed to be wired using the limit switches. These schematics were reviewed by Bruce Campbell, an Electrical Contractor for the Chase Electric Company Inc.

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$v = 2.13911\ m/s \left(\frac{3600s}{1hr}\right)\left(\frac{1km}{1000m}\right)\left(\frac{1mi}{1.609km}\right)$

$\boxed{v = 4.78609\ mph}$

So, if the throttle back was placed it would need to slow down the forklift to 4.78609 mph immediately along with the weight to counterbalance the centripetal force and balance the forklift.

⇒ Now if I were to use the hydraulic cylinder as the solution I need to determine ~~its minimum~~ the minimum size required.

$P = \frac{Force}{Area}$ where $P = 2{,}275\ psi$ (auxiliary function pressure relief) p.40

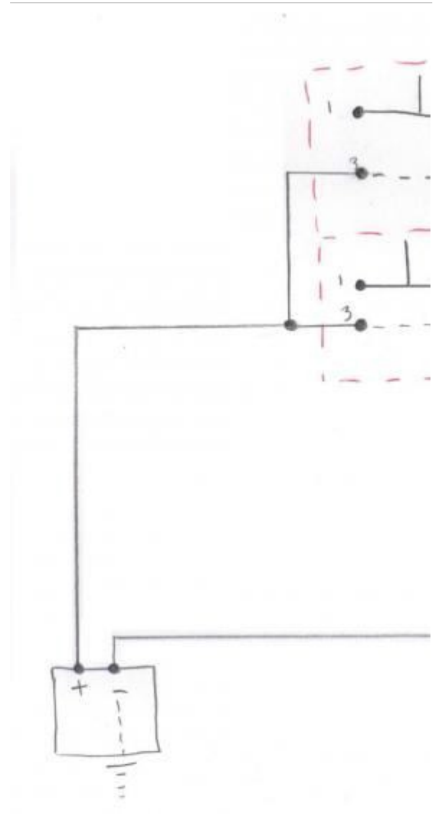
$500\ lb_m = 500\ lb_F$ (pg. 98)

$P = \frac{Force}{\pi r^2}$

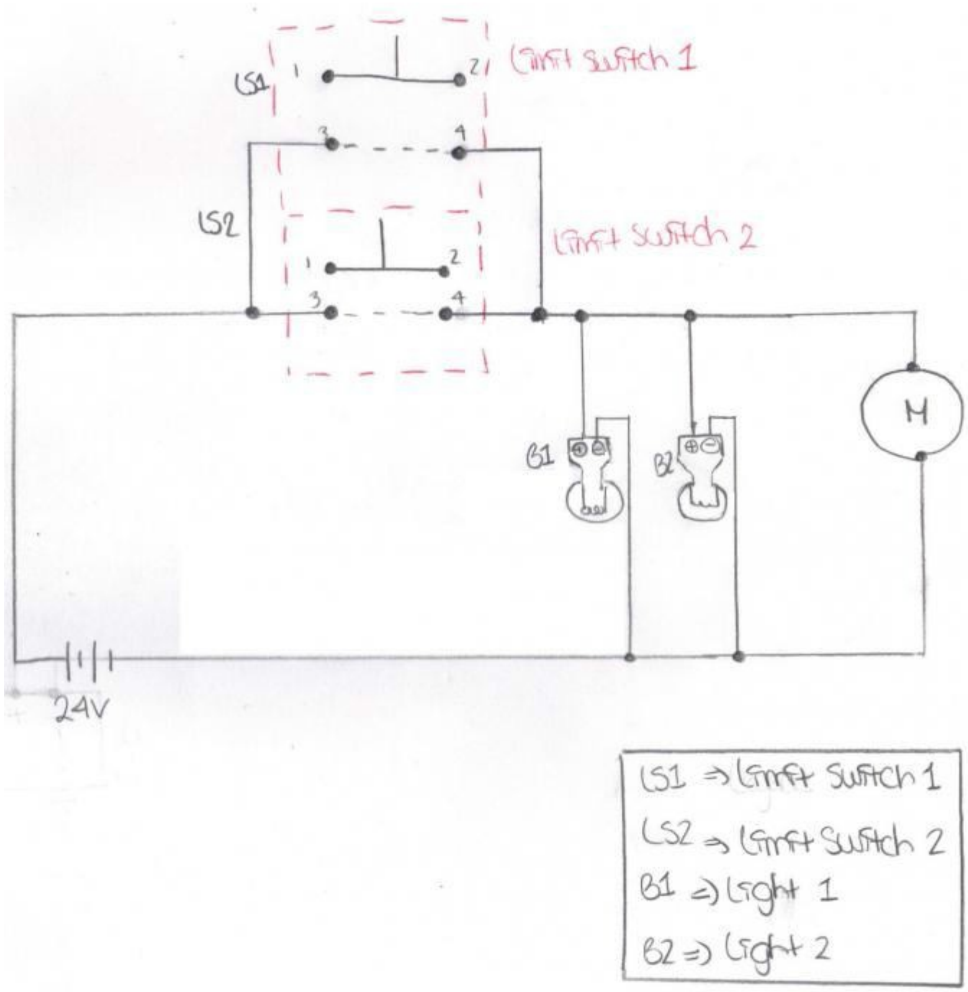
$r = \sqrt{\frac{F}{P\pi}}$ $r = \sqrt{\frac{500\ lb_F}{2{,}275\ psi(\pi)}}$

$r = (.26450\ in) \times 2 = .52899\ in\ \varnothing$

The smallest size piston for a hydraulic cylinder I know from learning hydraulics in Principles of Engineering is 1/2 ∅. This ∅ is just larger by .029.



(Picture of above schematic was copied from the 05/02/1



(Picture of above schematic was copied from the 05/02/13 entry of *[redacted student name]* Engineering Notebook.)