ENGINEERING ANALYSIS 2

Design Report 2

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1. Problem Statement:

Use the following diagrams and information below to solve the three problems.

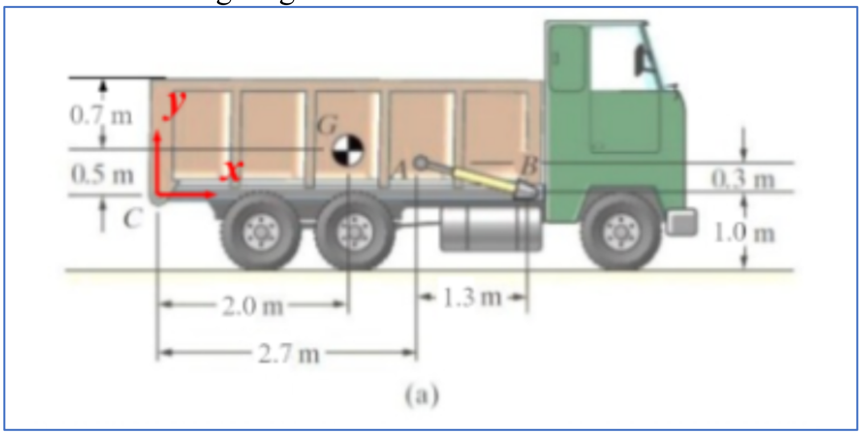

Figure 1.1: The first diagram given.

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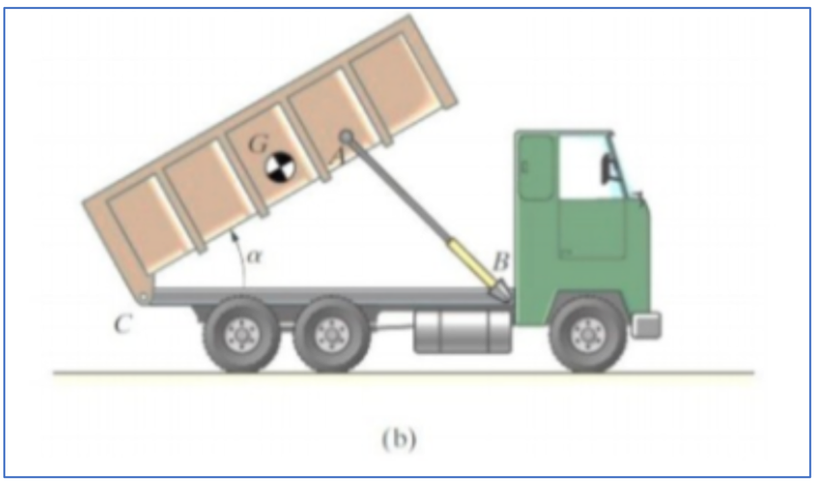

Figure 1.2: The second diagram given.

Problem 1:

Given:

- The bed of the dump truck (figure a) is raised by two hydraulic cylinders AB (figure b)
- The weight of the truck's bed and load totals to 120kN
- This weight acts at point G (doesn't change when bed is raised)
- The diagrams shown (figure 1.1 and figure 1.2)

Find:

- Calculate the force exerted from AB to the truck's bed when the angle α is 45°

Problem 2:

Given:

- The bed of the dump truck (figure a) is raised by two hydraulic cylinders AB (figure b)
- The weight of the truck's bed and load totals to 120kN
- This weight acts at point G (doesn't change when bed is raised)
- The diagrams shown (figure 1.1 and figure 1.2)

Find:

- Draw a graph of the magnitude of the hydraulic cylinders force versus the angle α from 0 to 45° by MATLAB (using a step size of 1°)

Problem 3:

Given:

- The bed of the dump truck (figure a) is raised by two hydraulic cylinders AB (figure b)
- The weight of the truck's bed and load totals to 120kN
- This weight acts at point G (doesn't change when bed is raised)
- The diagrams shown (figure 1.1 and figure 1.2)
- Suppose the location of attachment point B is fixed and the location of point A is varied in the x-y plane (within the truck bed).
- The initial length of the hydraulic cylinders should be at least 0.8 m.

Find:

- Find the maximum magnitude of force required for the hydraulic cylinders to move the truck bed through angle α from 0 to 45° for each valid location of point A.
- Present the results in a surface plot by MATLAB (step size of coordinates for A as 0.05m)

2. Theory Manual:

Free-body Diagram:

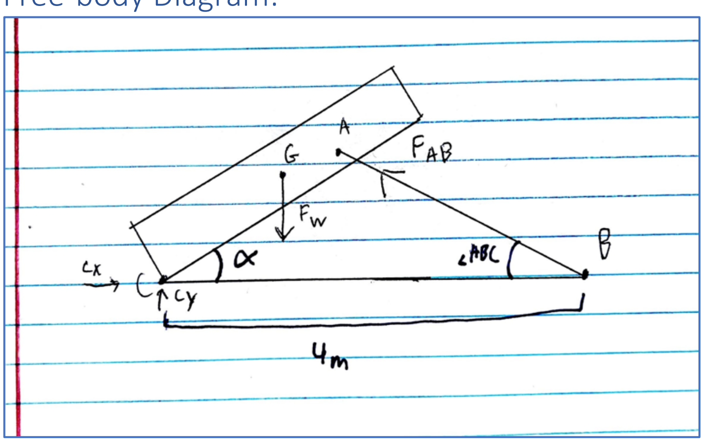

Figure 2.1: Free-body diagram for the problems

Equations & Processes:

Problem 1:

The first step is to calculate the length of AC, CG, and BC respectively. For AC (1) and CG (2), this is done by getting the difference in the x and y components of the points, then taking the magnitude of that. For BC (3), this is just done by taking difference between the points.

$$(1.)\ L_{AC} = \sqrt{(2.7-0)^2+(0.3-0)^2} = 2.7166\ m$$

$$(2.)\ L_{CG} = \sqrt{(2-0)^2+(0.5-0)^2} = 2.0616\ m$$

$$(3.)\ L_{BC} = ((2.7+1.3)-0) = 4\ m$$

The next step is to calculate the angles of AC (4) and CG (5). They will be treated as theta one and theta two. This is done by dividing the difference in the y coordinates of the points by the difference in the x coordinates of the components, and then taking the arctangent of that value.

$$(4.)\ \theta_1 = \tan^{-1}\frac{0.3}{2.7} = 6.3402°$$

$$(5.)\ \theta_2 = \tan^{-1}\frac{0.5}{2} = 14.0362°$$

The next step requires use of the cosine rule (6-7).

$$(6.)\ L_{AB} = \sqrt{(L_{AC})^2+(L_{BC})^2 - 2(L_{AC})(L_{BC})\cos(\alpha+\theta_1)}$$

$$(7.)\ L_{AB} = \sqrt{(2.7166)^2+(4)^2 - 2(2.7166)(4)\cos(45+6.3402)} = 3.131\ m$$

The next step is to get the x (8-9) and y (10-11) components of AC.

$$(8.)\ AC_x = L_{AC} * \cos(\alpha+\theta_1)$$

$$(9.)\ AC_x = 2.7166\cos(45+6.3402) = 1.697\ m$$

$$(10.)\ AC_y = L_{AC} * \sin(\alpha+\theta_1)$$

$$(11.)\ AC_y = 2.7166\sin(45+6.3402) = 2.121\ m$$

The next step is to calculate angle ABC (12-13).

$$(12.)\ \angle ABC = \tan^{-1}\left(\frac{AC_y}{4 - AC_x}\right)$$

$$(13.)\ \angle ABC = \tan^{-1}\frac{2.121}{4 - 1.697} = 42.64°$$

The next step is to calculate the force AB. This is done by calculating the moment around C (14-16). This includes the forces from W, the x component of force AB, and the y component of the force AB. There is one unknown of force AB, therefore it is possible to solve for its value.

$$(14.)\ \sum_{about\ C} M: -|W|\, L_{CG}\cos(\alpha+\theta_2) + F_{AB}\cos(\angle \mathrm{ABC})(AC_y) + F_{AB}\sin(\angle \mathrm{ABC})(AC_x) = 0$$

$$(15.)\ (-120)\cdot 2.0616\cdot\cos(45+14.036) + F_{AB}\cos(42.64)(2.121) + F_{AB}\sin(42.64)(1.697) = 0$$

$$(16.)\ F_{AB} = \frac{120\cdot 2.0616\cdot\cos(45+14.036)}{\cos(42.64)(2.121)+\sin(42.64)(1.697)} = 46.97\ kN$$

These equations and process can be conducted using MATLAB to reach the same solution.

Problem 2:

For the next question, the same method is used to calculate the force AB (17). The same setup of taking the forces from W, the x component of force AB, and the y component of the force AB.

$$(17.)\ \sum_{about\ C} M:\ -|W|\, L_{CG}\cos(\alpha+\theta_2) + F_{AB}\cos(\angle \mathrm{ABC})(AC_y) + F_{AB}\sin(\angle \mathrm{ABC})(AC_x) = 0$$

In this problem, the value of angle Alpha is being changed. Therefore, the equations for the variables in the moments equation need to be rewritten in order to fit a changing alpha. These include the x component of AC (18), the y component of AC (19), and the angle ABC (20-21).

$$(18.)\ AC_x = 2.7166\cdot\cos(\alpha+6.34)$$

$$(19.)\ AC_y = 2.7166\cdot\sin(\alpha+6.34)$$

$$(20.)\ \angle \mathrm{ABC} = \tan^{-1}\left(\frac{AC_y}{4-CA_x}\right)$$

$$(21.)\ \angle \mathrm{ABC} = \frac{2.7166\cdot\cos(\alpha+6.34)}{4-(2.7166\cdot\sin(\alpha+6.34))}$$

Then, plugging in the fixed variables for the equation gets this equation (22). This equation can be manipulated in order to solve for force AB (23).

$$(22.)\ (-120)\cdot 2.0616\cdot\cos(\alpha+14.036) + F_{AB}\cos(\angle \mathrm{ABC})(AC_y) + F_{AB}\sin(\angle \mathrm{ABC})(AC_x) = 0$$

$$(23.)\ F_{AB} = \frac{120\cdot 2.0616\cdot\cos(\alpha+14.036)}{\cos(\angle \mathrm{ABC})(AC_y)+\sin(\angle \mathrm{ABC})(AC_x)}$$

Then by using equations 18-21, the value of force AB can be calculated based on any value of angle Alpha.

Problem 3:

For the next question since the x and y coordinates of A are changing, it is necessary to assign variables to their values. A_x and A_y (24).

$$(24.)\ A(A_x, A_y)$$

$$(25.)\ L_{AC} = \sqrt{(A_x - 0)^2 + (A_y - 0)^2}$$

Then using the coordinates of A, the same process (26) needs to be done to calculate the length of AC and the angle of AC and the bed of the truck(4).

$$(26.)\ \theta_1 = \tan^{-1}\frac{A_y}{A_x}$$

Then, the length of AB needs to be calculated using the values A_x and A_y for the values of the x and y coordinates of A (27). For this problem, there is a minimum length requirement of the length of AB, as it can not be below 0.8 meters (28).

$$(27)\ L_{AB} = \sqrt{(4 - A_x)^2 + (A_y)^2}$$

$$(28)\ L_{AB} \geq 0.8\, m$$

Using the value of L_{AC} , the values of AC_y (8-9) and AC_x (10-11) can be calculated using the same process from problem 1. These components allow for the calculation of angle ABC (12-13). All of these values will allow for the calculation of the moment about C (29). This is done using the same setup from before (14,17).

$$(29)\ \sum_{about\ C} M: (-120) \cdot 2.0616 \cdot \cos(\alpha + 14.036) + F_{AB}\cos(\angle \mathrm{ABC})(AC_y) + F_{AB}\sin(\angle \mathrm{ABC})(AC_x) = 0$$

Then, by using these equations the values for the force AB can be calculated at each value for the coordinates of A.

3. Programmer Manual:

Flowchart & Stepwise Explanation:

Problem 1:

4. Use the given points from the diagrams to find the lengths and angles for AC and CG.
5. Use the given angle Alpha of 45 degrees to get the y and x coordinates for A.
6. Calculate angle ABC.
7. Use the length of CG, the angle of CG, angle Alpha, angle ABC, the x coordinate of A, and the y coordinate of A to calculate the force of AB.

*See figure 3.1

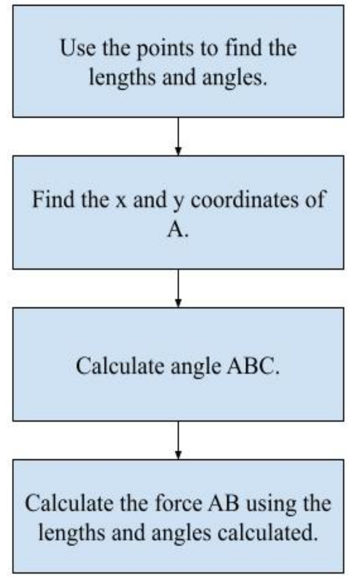

Figure 3.1: Flowchart for problem 1

Problem 2:

1. Use the given points from the diagrams to find the lengths and angles for AC and CG.
2. Use the given angle Alpha of 45 degrees to get the y and x coordinates for A.
3. Initialize an array to hold the force AB values.
4. Loop through all the possible angle Alpha values in increments of one and calculate the forces of AB at each angle.
5. Plot the data of the angles of the force AB versus the angle Alpha.

*See figure 3.2

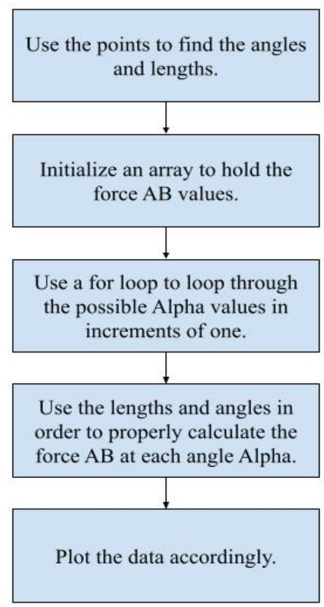

Figure 3.2: Flowchart for problem

Problem 3:

1. Use the given points from the diagram to calculate the angle and length for CG.
2. Initialize the matrix to hold the forces for AB
3. Create the values in order to properly increment the x and y coordinates for A.
4. Use a for loop to increment through the coordinates of x and y for A and the angle Alpha value.
5. At each different coordinate and angle, calculate the necessary lengths and angles.
6. Check to see if the length of AB meets the minimum value of 0.8m.
7. If it does meet the minimum, then calculate the value of force AB.
8. Find the max force of AB at each x and y value.
9. Plot the data of the x coordinate, y coordinate, and the max force of AB.

*See figure 3.3

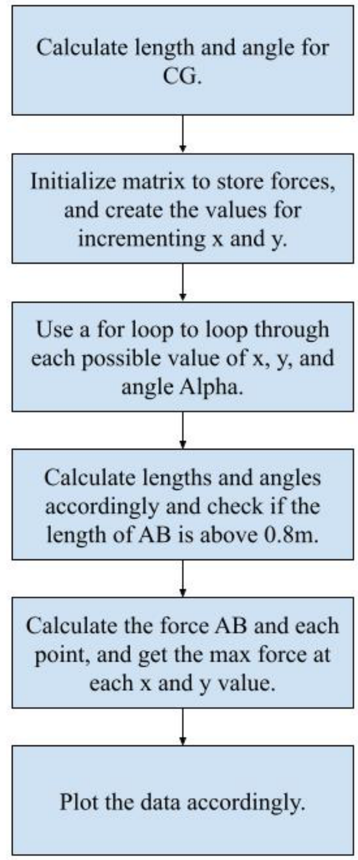

Figure 3.3: Flowchart for problem 3

Variables Used

The table (figure 3.4) shows the variables used in the MATLAB program.

Variable	Description of Variable
pt_A	Stores the coordinates of point A.
pt_C	Stores the coordinates of point C.
pt_G	Stores the coordinates of point G.
r_AC	Stores the vector for AC.
r_CG	Stores the vector for CG.
len_AC	Stores the distance of AC.
len_CG	Stores the distance of CG.
ang_AC	Stores the angle of AC and the truck bed.
ang_CG	Stores the angle of CG and the truck bed.
ang_Alpha	Stores the angle of Alpha.

y_A	The y coordinate of point a for problem 2.
x_A	The x coordinate of point a for problem 2.
ang_ABC	Stores the angle of ABC.
force_AB_final	Stores the force of AB for the solution to problem 1.
force_AB	A matrix that will store the values of the force AB for problem 2.
force_current_AB	The current value of the force AB at the given Alpha for problem 2.
force_AB_max	A matrix of dimension of 81x25 that starts filled with zeros.
a_Y	The y coordinate of point a for problem 3.
a_X	The x coordinate of point b for problem 3.
a_X_increment	The increments for the x coordinate for problem 3.
a_Y_increment	The increments for the y coordinate for problem 3.
force_AB_xy	A matrix of dimension 1x46 that starts filled with zeros that stores the forces for AB at the given alpha in problem 3.

Figure 3.4: Programming Variables and their descriptions

Functions Used

The table (figure 3.5) shows the functions used in the MATLAB program.

Function	Description of Function
norm	Takes a vector and returns the vector magnitude.
atand	Calculates the arctan in degrees.
cosd	Calculates the cosine in degrees.
sind	Calculates the sine in degrees.
fprintf	Outputs chosen texts and variable values to the user.
figure	Creates a new figure window.
plot	Plots the inputted data.
xlabel	Creates the label for the x-axis of a graph.
ylabel	Creates the label for the y-axis of a graph.
title	Creates the label for the title of a graph.
zeros	Creates a matrix of zeroes with the given dimensions
sqrt	Square root operator
surf	Creates a three-dimensional surface plot
zlabel	Creates the label for the z-axis of a graph.
*	Multiplication operator
+	Addition operator
-	Subtraction operator
/	Division operator
=	Assigns a value
‘	Transposes a matrix

Figure 3.5: Programming Functions and their descriptions

4. Results and Analysis:

Problem 1:

```
>> project2q1
The force exerted from AB to the truck's bed when the angle Alpha is 45 degrees is 46.965931 kN.>>
```

Figure 4.1: MATLAB output of program 1

Figure 4.1 Analysis:

The output (figure 4.1) shows that the force exerted from AB to the truck's bed when the angle Alpha is 45 degrees, is equal to about 46.966 kN.

Problem 1 Results:

A force of 46.966kN is exerted from AB to the truck's bed.

Problem 1 Overall Analysis:

Through calculating the resulting angles and distances from the angle Alpha being 45 degrees, the force that is being exerted from AB to the truck's bed is able to be calculated. Due to the angle Alpha affecting these other variables of the other angles and distances, changing the Alpha value would result in a different force to be calculated.

Problem 2:

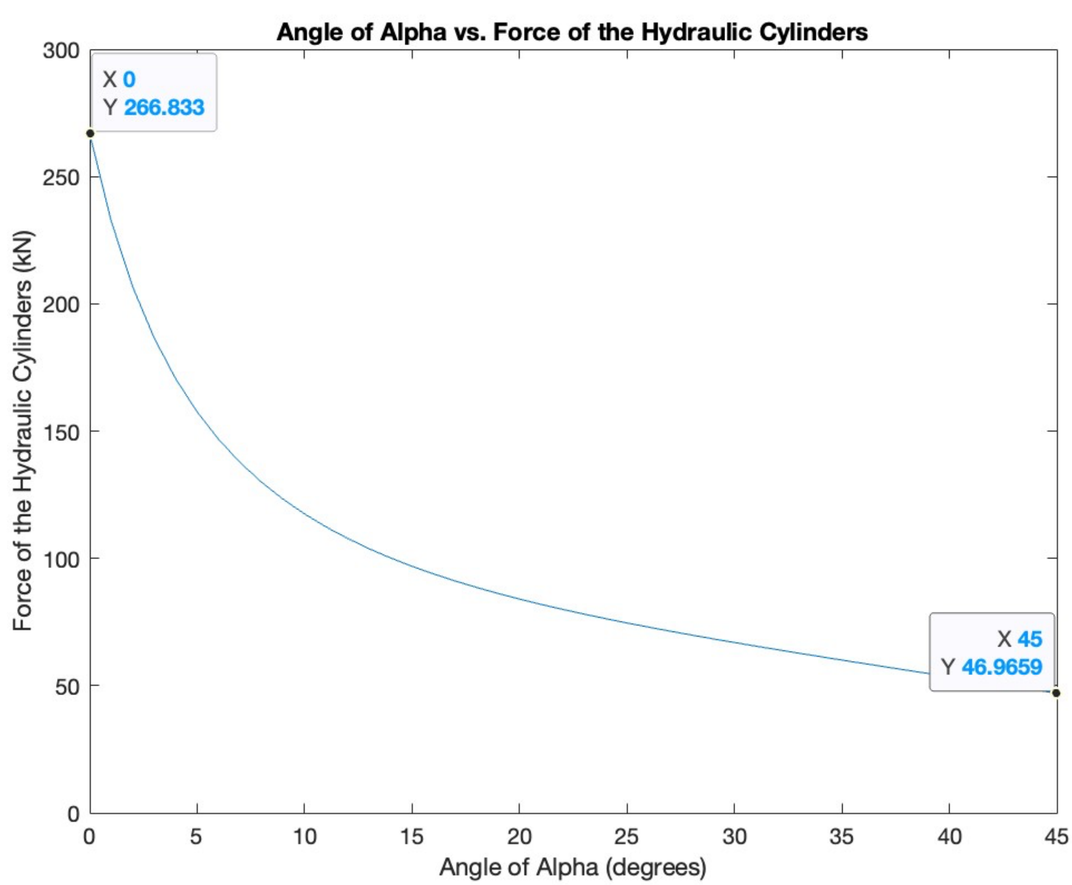

Figure 4.2: MATLAB plot of program 2

Figure 4.2 Analysis:
As the angle of Alpha increases, the force of the hydraulic cylinders decreases. As the force of the hydraulic cylinders increases, the angle of Alpha decrease. The most force of the hydraulic cylinders shown occurs at 0 degrees with the force being about 266 kN, while the least force shown occurs at 45 degrees with the force being about 47 kN.

Problem 2 Results:
The graph shown in figure 4.2.

Problem 2 Overall Analysis:
The plot shows an inverse relationship between the force of the hydraulic cylinders and the angle of Alpha. As the angle of Alpha decreases, the truck load gets closer and closer to being parallel with the truck bed. This results in more force needing to be exerted by the hydraulic cylinders to match the force from the load. When the angle is 0 degrees and the load is directly parallel with the truck bed, that is where the most force is needed from the hydraulic cylinders. . This relationship exists due to the system being in equilibrium. The force at AB needs to decrease as the angle Alpha increases in order to keep the moment at C at equilibrium. As the angle Alpha is increasing, the force that needs to be exerted by AB is less.

Problem 3:

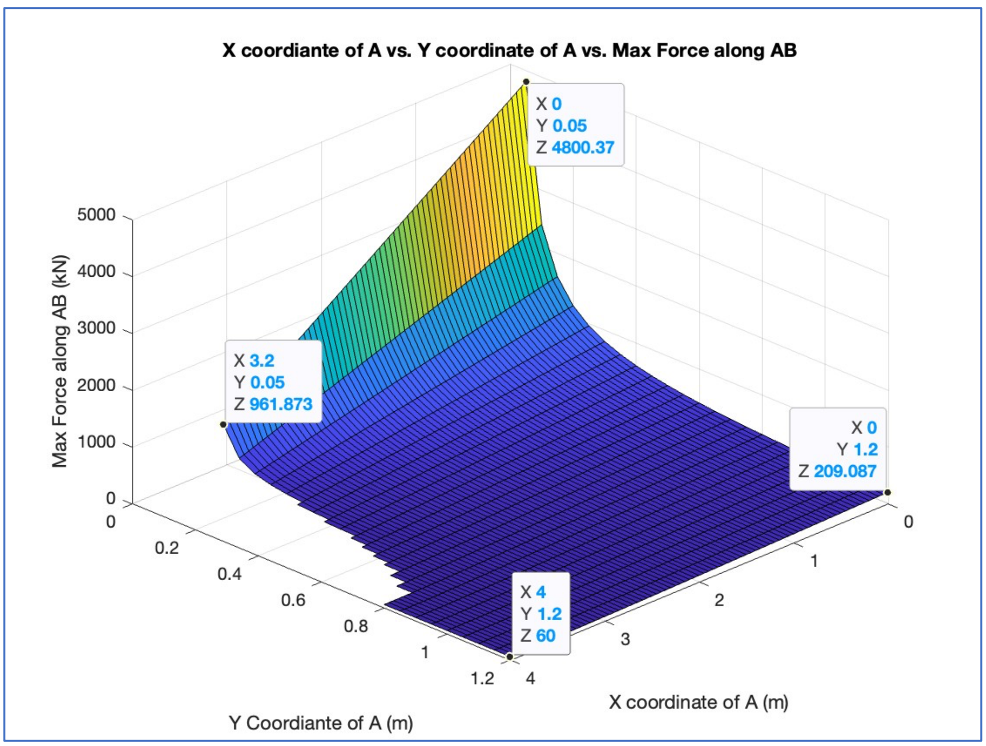

Figure 4.3: MATLAB 3D plot of program 3

Figure 4.3 Analysis:
The plot shows that as the x and y coordinates increase, the max force decreases. As the x and y coordinates decrease, the max force increases. When x is 4m and y is 1.2m, the max force is 60 kN. When x is 0m and y is 0.05m, the max force is about 4800 kN.

Problem 3 Results:
The plot shown in figure 4.3.

Problem 3 Overall Analysis:
The plot shows an inverse relationship between the x and y coordinate versus the max force along AB. This connects back to the results shown in problem 2. In problem 2, it was established that the greatest force along the hydraulic cylinders and AB occurs when the angle Alpha is the lowest. This occurs when the coordinates of A are close to (0,0). Therefore, it makes sense that the max force along AB occurs when the coordinates are close to (0,0) as the angle Alpha is low at this point. Though directly at (0,0), an infinite force is calculated. That is why the max force is found at (0,0.5) instead. Then inversely, the greatest value of angle Alpha would occur when the x and y coordinates are at their max. This is why the lowest max force along AB occurs when the x and y coordinates are at their greatest values. This reasoning connects back to problem 2 in regard to the need to keep the system at equilibrium specifically moment about C. This relationship between the force that is being exerted versus the force that needs to counter that force in order to keep the system at equilibrium is consistent throughout these problems. For this graph, there exists a portion that does not have calculated forces, and this is due to the limitation built into the problem regarding a minimum length of 0.8m for the length of AB.

5. Appendix:

MATLAB Code:

Problem 1:

```
% The points of A (2.7,0.3), C (0.0,0.0), and G (2.0,0.5) are initialized.
% Their locations can be found through examining the given diagram.
pt_A = [2.7,0.3];
pt_C = [0.0,0.0];
pt_G = [2.0,0.5];

% The vectors for AC and CG are calculated. Then the magntiude of those
% vectors are found in order to get the length of AC and the length of CG.
r_AC = (pt_C-pt_A);
r_CG = (pt_G-pt_C);
len_AC = norm(r_AC);
len_CG = norm(r_CG);

% Using the vectors of AC and CG, the angles in degrees are found between
% AC and the truck bed and CG and the truck bed respectively.
ang_AC = atand(r_AC(2)/r_AC(1));
ang_CG = atand(r_CG(2)/r_CG(1));
```

```
% The angle of alpha is given in the problem and declared as such.  Then
% the x and y coordinates are declared for A through adding the alpha angle
% with the angle for AC and the truck bed from before, and then taking the
% sine and cosine to then multiply by the length of AC to get
% the y and x coordinates respectively.
ang_Alpha = 45;
y_A = len_AC*sind(ang_Alpha+ang_AC);
x_A = len_AC*cosd(ang_Alpha+ang_AC);

% the angle of ABC is then calculated using the known y and x coordinates
% of A
ang_ABC = atand(y_A/(4-x_A));

% The force exerted from AB onto the truck bed is then calculated using the
% variables from before including the angle alpha, angle CG, length CG,
% angle ABC, y coordinate of A, and x coordinate of A.
force_AB_final = (120*cosd(angAlpha+ang_CG)*len_CG)/(cosd(ang_ABC)*y_A+sind(ang_ABC)*x_A);

% The resulting force that is exerted is then printed.
fprintf('The force exerted from AB to the truck\"s bed when the angle Alpha is 45 degrees is %f kN.',
force_AB_final)
```

Problem 2:

```
% The points of A (2.7,0.3), C (0.0,0.0), and G (2.0,0.5) are initialized.
% Their locations can be found through examining the given diagram.
pt_A = [2.7,0.3];
pt_C = [0,0];
pt_G = [2,0.5];

% The vectors for AC and CG are calculated.  Then the magntiude of those
% vectors are found in order to get the length of AC and the length of CG.
r_AC = (pt_C-pt_A);
r_CG = (pt_G-pt_C);
len_AC = norm(r_AC);
len_CG = norm(r_CG);

% Using the vectors of AC and CG, the angles in degrees are found between
% AC and the truck bed and CG and the truck bed respectively.
ang_AC = atand(r_AC(2)/r_AC(1));
ang_CG = atand(r_CG(2)/r_CG(1));

% An array force_AB is created that will store the forces needed at each
% angle
force_AB = [];

% A for loop will iterate from 0 to 45 degrees in increments of 1.  Each
% time, the y and x coordinates of the current angle is calculate as well
% as the angle of ABC.  Then, the force at that current angle is calculated
% and stored in the the force_AB vector that was created before.
for ang_Alpha = 0:1:45
  y_A = len_AC*sind(ang_Alpha+ang_AC);
  x_A = len_AC*cosd(ang_Alpha+ang_AC);
```

```
    ang_ABC = atand(y_A/(4-x_A));
    force_current_AB =
(120*cosd(ang_Alpha+ang_CG)*len_CG)/(cosd(ang_ABC)*y_A+sind(ang_ABC)*x_A) ;
    force_AB(end+1) = force_current_AB;
end

% The data is then plotted on a graph where it compares the angle of Alpha
% and the force from the hydraulic cylinders.
figure;
plot(0:1:45, force_AB)
xlabel('Angle of Alpha (degrees)');
ylabel('Force of the Hydraulic Cylinders (kN)');
title('Angle of Alpha vs. Force of the Hydraulic Cylinders');
```

Problem 3:

```
% length from point C to point G. This is initialized and stored in variable
% lenCG
% Using the points of C and G, the vector of CG, the length of CG, and the
% angle of CG and the truck bed is calculated.
pt_C = [0,0];
pt_G = [2,0.5];
r_CG = (pt_G-pt_C);
len_CG = norm(r_CG);
ang_CG = atand(r_CG(2)/r_CG(1));

% The max force matrix of 81x25 is created that will store the matx forces
% along AB.  It is initialized with zeros as placeholder values.
force_AB_max = zeros(81,25);

% The x and y values for a are initialized as zero as a placeholder.  The
% incremenets are initialized for both x and y as well with the increment
% being 0.05m.
a_Y = 0;
a_X = 0;
a_X_increment = 0:0.05:4;
a_Y_increment = 0:0.05:1.2;

% A for loop through loops through the values of the x coordinate and y
% coordinates of A.  Each time it is looped through, the coordinate is
% increased by the increment.  The force_AB_xy matrix is declared each time,
% which will store the force values at the given x and y coordinates.
for x_increment = 1:81
    a_X = 0.05*(x_increment-1);
    for y_increment = 1:25
        a_Y = (y_increment-1) * 0.05;
        force_AB_xy = zeros(1,46);

% A for loop that iterates through the angle of A with increments of 1.
% Each time the length of AC, the angle of AC and the truck bed, and the
% length of AB is calculated.
        for ang_Alpha = 0:45
            len_AC = sqrt(a_X^2+a_Y^2);
            ang_AC = atan2d(a_Y,a_X);
```

```
        len_AB = norm([a_X,a_Y]-[4,0]);

% The length of AB is then checked to atleast meet the 0.8 meter minimum.
% If it is met then the force is calculated and stored at that angle and
% coordinates point.  If not, then the force for that angle and coordinates
% location is stored as not a number.
        if len_AB >= 0.8

          % Then the x and y coordinates of point A are calcualted
          % along with the% angle ABC.
          y_A = len_AC*sind(ang_Alpha+ang_AC);
          x_A = len_AC*cosd(ang_Alpha+ang_AC);
          ang_ABC = atan2d(y_A,4-x_A);

          % The force at the current coordinates and angle are then
          % calculated and then stored in the force_AB matrix, which
          % is specific to these x and y coordinates.
          force_current_AB =
(120*cosd(ang_Alpha+ang_CG)*len_CG)/(cosd(ang_ABC)*y_A+sind(ang_ABC)*x_A);
          force_AB_xy(ang_Alpha+1) = force_current_AB;
        else
          force_AB_xy(ang_Alpha+1) = NaN;
        end
      end

% The max force at that x and y coordinate is then stored in the
% force_AB_max matrix
      force_AB_max(x_increment,y_increment) = max(force_AB_xy);
   end
end

% The max force along AB is then plotted along with the x and y coordinate
% for that force.
force_AB_max = force_AB_max';
figure;
surf(a_X_increment, a_Y_increment, force_AB_max);
xlabel('X coordinate of A (m)');
ylabel('Y Coordiante of A (m)');
zlabel('Max Force along AB (kN)');
title('X coordiante of A vs. Y coordinate of A vs. Max Force along AB');
```