Shadow Bot Calculations

The governing equations are :

Let the Thrust supplied by the EDF be T,

and the Weight off the bot be W, then

for **No Sliding**,

$$T \geq \frac{W}{\mu}$$

and for **No Toppling**,

$$W \leq T * \frac{x}{c}$$

where,

x is the point of application of thrust from the rear wheel of the bot,

c is the clearance of the bot with the ground.

For the bot to move ,

Motor torque,**M** required is ,

$$M \geq \frac{W * R}{2}$$

where,

R = radius of the wheel.

And also the bot should satisfy these conditions while running,

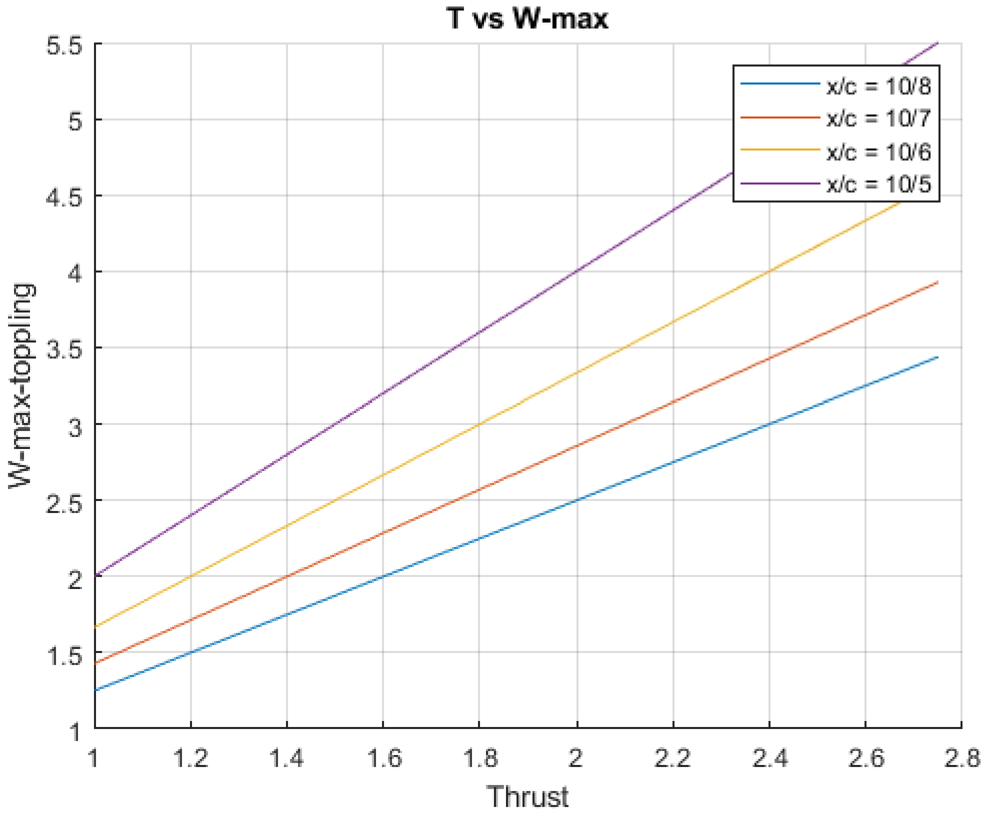
$$T \geq W * \frac{c}{x} - \frac{M}{x}$$

$$M \geq \frac{\left(\mu \frac{T}{2} - \frac{\mu W}{4} + m_0 \frac{W}{\left(\frac{W}{g} + 2m_0\right)}\right)}{\left(\frac{m_0}{\left(Rm_0 + \frac{W}{g}\right)} - \frac{\mu}{2L}\right)}$$

which has to ensured.

Thrust vs W_max of the bot calculation for different Thrust_distance(x)/clearance of bot ratios keeping other parameters fixed :

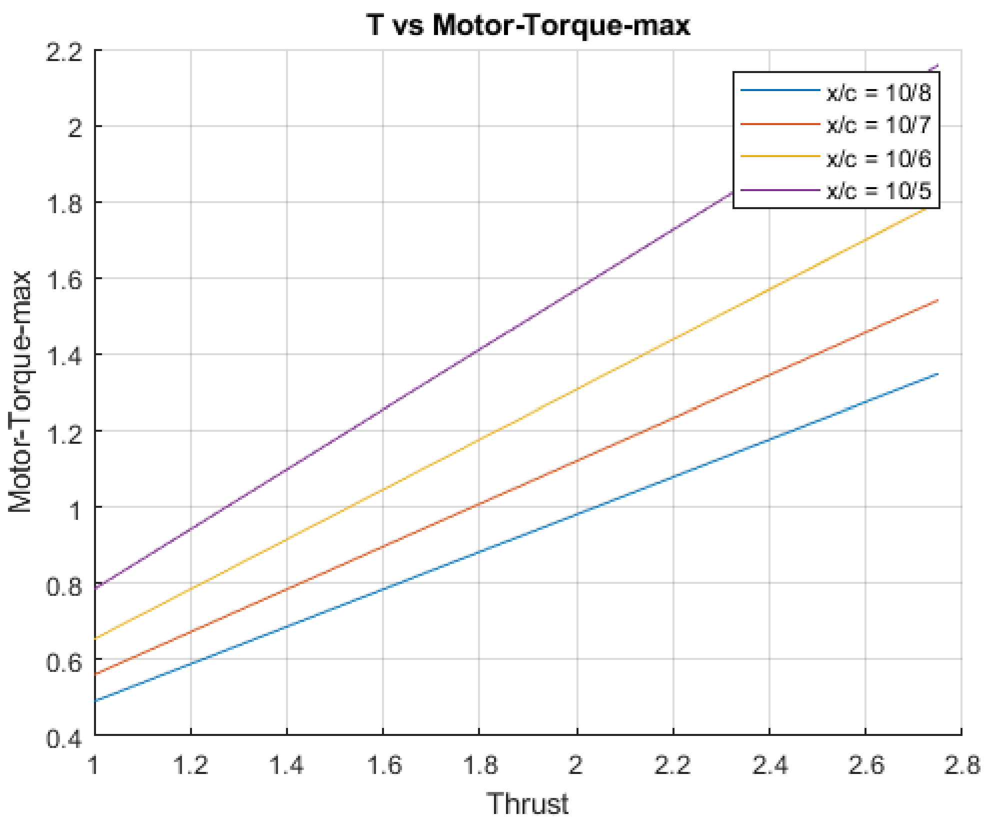
```
% Thrust vs W_max of the bot calculation for different
% Thrust_distance(x)/clearance of bot ratios keeping
% other parameters fixed
x = table2array(TvsM(13:27,2));
y = table2array(TvsM(13:27,10));
x1 = table2array(TvsM(28:42,2));
y1 = table2array(TvsM(28:42,10));
x2 = table2array(TvsM(43:57,2));
y2 = table2array(TvsM(43:57,10));
x3 = table2array(TvsM(58:72,2));
y3 = table2array(TvsM(58:72,10));
figure;
hold on;
xlabel('Thrust');
ylabel('W-max-toppling');
title('T vs W-max');
plot(x,y,x1,y1,x2,y2,x3,y3);
legend('x/c = 10/8','x/c = 10/7','x/c = 10/6','x/c = 10/5');
grid on;
hold off;
```



Motor Torque vs Thrust for the same above conditions :

```
% Motor Torque vs Thrust for the same above conditions
z = table2array(TvsM(13:27,12));
```

```
z1 = table2array(TvsM(28:42,12));
z2 = table2array(TvsM(43:57,12));
z3 = table2array(TvsM(58:72,12));
figure;
hold on;
xlabel('Thrust');
ylabel('Motor-Torque-max');
title('T vs Motor-Torque-max');
plot(x,z,x1,z1,x2,z2,x3,z3);
legend('x/c = 10/8','x/c = 10/7','x/c = 10/6','x/c = 10/5');
grid on;
hold off;
```

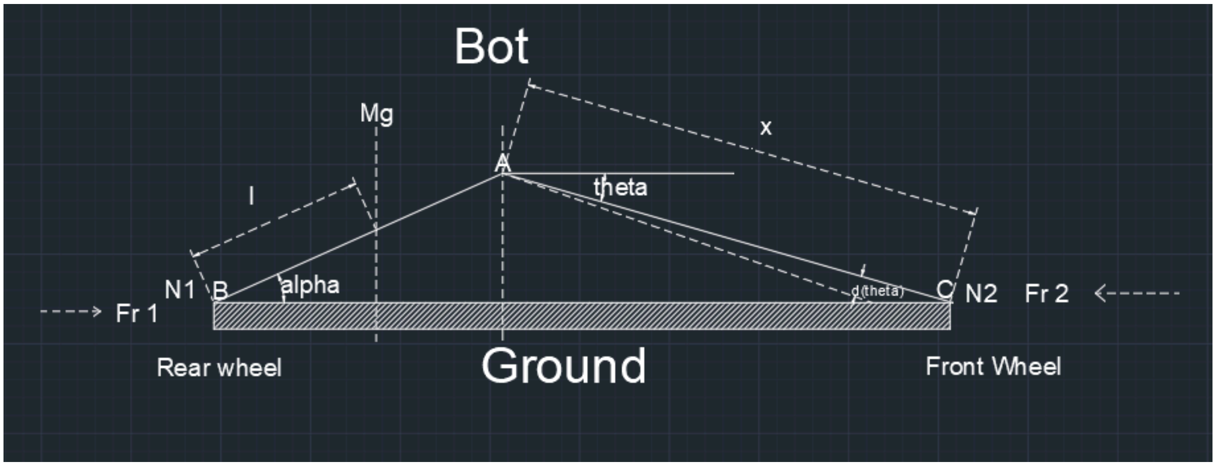


The Min Motor Torque $,M_{\min} \geq \dfrac{W_{\min} * R}{2}$

and $W_{\min}$ **=** $\mu * T$ **and hence depends on** μ **and T only. It does not depend on other parameters.**

Front Wheel Motor Torque:

Calculations for the minimum motor torque required to actuate the front links :



Analysing the bot using the method of **virtual work** to obtain the min Motor torque required we get,

Le the distance of the center of mass of the bot from the rear wheels be l,

the length of the front links be x.

Let's say that the motor produces a torque, M_f to actuate the front wheels,

the **Work done** by the **motor** to rotate the link by an angle $d\theta$ = $M_f * d\theta$

To find Work done by gravity :

Using sine rule in the triangle ABC we get,

$$\frac{\sin(\theta)}{L} = \frac{\sin(\alpha)}{x} \qquad \rightarrow (1)$$

let the height of the centre of mass of the bot from the ground be h,

$h = l * \sin(\alpha)$

but from (1) we get $L * \sin(\alpha) = x * \sin(\theta)$

but $L = l + y$, where

$l =$distance of COM from the back link along the back link

Removing the unknown variable y and relating l and L with the height we get ,

$h = \frac{(l * \sin(\theta) * x)}{L}$ and therefore,

so $\mathrm{dh} = \frac{l * d\theta * \cos(\theta) * x}{L}$

Work done by **gravity** during this time = - $M * g * x * \cos(\theta) * d\theta$,

the minus sign indicates that the gravity does negative work.

Work done by the **normal reactions** $N_1, N_2 = 0$, since there is not net displacement in the vertical direction.

But , frictional force Fr_2 does some work

let the distance of the front wheel from the point of connection of the front links be y then,

$$y = x * \cos(\theta)$$
$$\mathrm{dy} = -x * \sin(\theta) * d\theta$$

Work done by **frictional force** Fr_2 = $\mathrm{Fr}_2 * x * \sin(\theta) * d\theta$

Now using work energy theorem we get ,

Work done by net forces , $W_{\mathrm{net}} = \Delta\, \mathrm{KE}_{\mathrm{system}}$ but since the system is at rest ,

$\Delta\, \mathrm{KE}_{\mathrm{system}}$ = 0

and we get ,

- $M * g * x * \cos(\theta) * d\theta$ + ($\mathrm{Fr}_2 * x * \sin(\theta) * d\theta$) + $M_f * d\theta$ = 0

M_f = $M * g * x * \cos(\theta)$ - $\mathrm{Fr}_2 * x * \sin(\theta)$

and at $\theta = 0^o$ we get ,

$$M_f = \frac{M * g * x * l}{L}$$

which is the minimum Motor Torque required by the front wheels to be actuated.

Wheel Design :

Euler characteristic (χ) of Wheel (Disc) is 1.

But,

$\chi = V - E + F$ where,

V is the number of vertices,

E is the number of edges,

F is the number of faces.

Let the disc contain P number of Pentagons,

H number of Hexagons,

then,

$$V = \frac{5 * P + 6 * H}{3}$$

$$E = \frac{5 * P + 6 * H}{2}$$

$F = P + H$

Substituting these values we get,

$P = 6$

But we need to find the number of Hexagons,

The number of Hexagons can be arbitrary to fill the remaining space,

Here I neededed 5 hexagons to cover the fill the disk.

So for our case,

$H = 5.$