Thursday 22/10/20 * First Meeting

Meeting with Soldini and the other research assistants involved.

Break-down between 4 tasks:

1. Mission Analysis: The need, the feasability and the planning. Jack, Sam, Benedict.

2. Origami Robotics: self-descriptive. Robert.

3. Multi-body folding dynamics: The programmatical approach to simulation. Raymond.

Soldini introduced us to the tasks and research assistants like Aleksander, who has developed a PYTHON-based tool for the analysis and simulations of unfolding panels. However, this is not fully developed as it only does 2d simulations, it is expected of me to further develope this to be used for the design.

4. Reflective Control devices: How the reflectivity of the panels may be controlled to thus control momentum gained from solar exposure

It was deemed that meeting once a week on thursdays is the best option for everyone

For next meeting, I will have familiarised myself with the subject, and read useful resources:

→ PhD thesis by Takao Yuki: "Improvement of sail storage and deployment mechanism for spin-type solar power sail"

→ PhD glasgow thesis "Multi body Dynamics" but with magnetic fields → Where to find it?

→ Book "Large Space Structures: Dynamics and control"
→ Convince the library to get it?

* There is a proposal due on the 1st of november. Does it have to be independent?

To do:

→ Read and summarise Takao's thesis
→ Find the Glasgow PhD project?
→ Find way to get book through the library

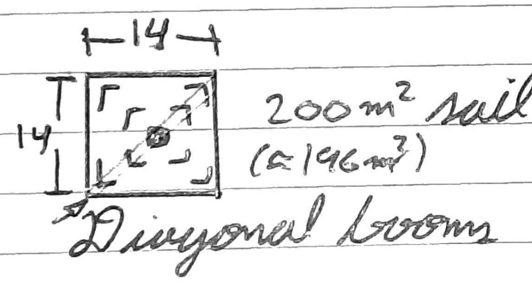
1st literature review:

O. Mori et al: "Improvement of sail storage..."

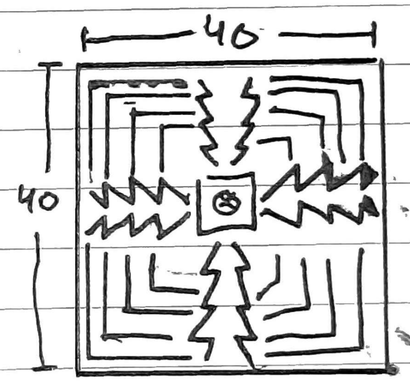
▷ The first mission to use sail technology was the IKAROS in 2010 by JAXA. Said probe is in Venus.

• IKAROS used a boom-supported sail to deploy its sail.

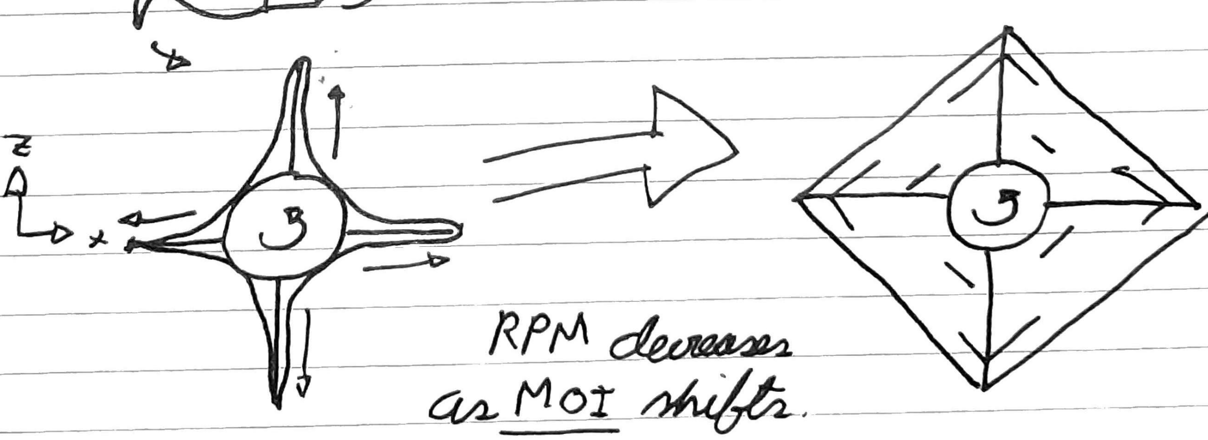
▷ For larger sails, booms and their mechanism become to heavy to be useful, so a centrifugal approach is taken.



IKAROS



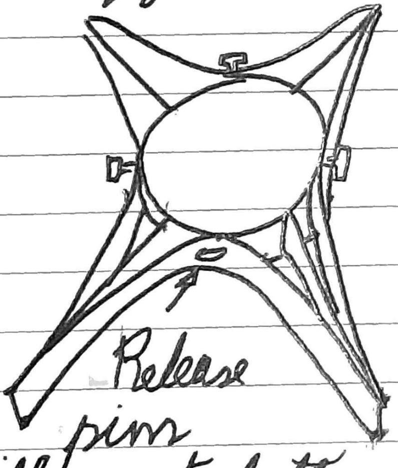
オケアノス
OKEANOS

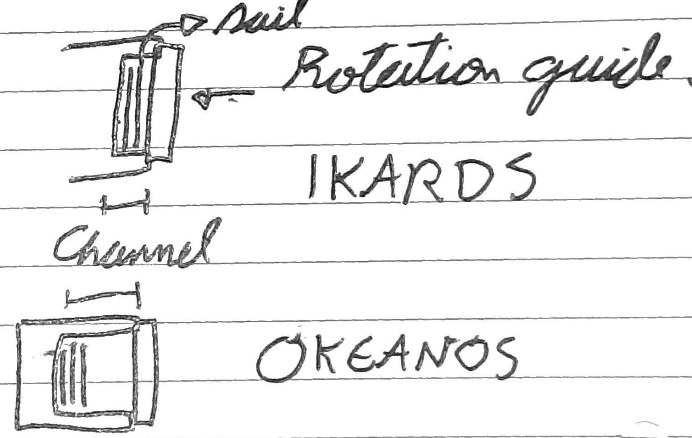


RPM decreases
as MOI shifts.

A problem in the deployment ensued when one of the sails petals did not roll out enough due to tape attachment / retainer not coming off. This retainer was ill-designed due to time and mass constraints, adding to the fact that IKAROS was a "piggyback" mission.

This problem could happen again with a bigger sail, so changes to the design were made to suit a more effective centrifugal deployment system including a 10x bigger sail.





will work better for synchronous deployment.

Due to the small channel in IKAROS, tape was used to avoid the sail from "Dropping Out"

A deeper channel in OKEANOS already prevents said dropout and thus the use of the unreliable tape / retainer is phased out.

Pre-meeting 29/10/20

→ Discuss content for proposal, clearly outline and describe my deliverables.

→ Have Aleksander explain to me the above and possibly give me an introductory to the code.

✓ Get access to the online repository and give the code a skim to "orientate myself."

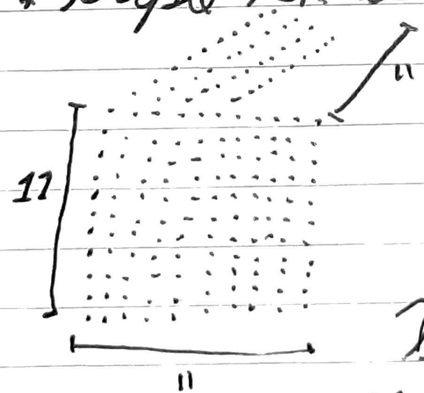
MAIN.py:

PAR1 = 7.5
PAR2 = 4.5
PAR3 = 0.055

$$\text{CONTROpt} = \begin{pmatrix} -7.5, -4.5, 0 \\ 7.5, -4.5, 0 \\ 7.5, 4.5, 0 \\ -7.5, 4.5, 0 \end{pmatrix}$$

PAROpt = PAR~~1~~3
distance = 0.1
number of NODES = 10.

* Triple FOR loop = 11 elements "NODES" = ~~10~~^{3} $11^3 = 1331$ cycles



CONTROLSRP $\left(-7.5\left(1+\left[n^{N}\times d\right]-\frac{d}{2}\right), [J], [k]\ldots \right.$
⋮

This seems to resemble an FEA operation wherein each one of the 1331 nodes receive a CONTROLSRP matrix.

For each matrix, an instance of ad. PROBLEM is called with pre-determined initial states and orientation.

PROPAGATE() → number the time-steps.
linspace (0, prop time, proptime * 100)

For each of these time instances, a solution is calculated depending on the "control parameters" which in these cases seem to be "SOLARSAILS"

Proposal stage report (for sunday 1st Nov)

→ It is individual
→ It is going to be similar among group members.

Structure planned:

Intro. { → Front page.
→ 2-3 pages for background, aim and Obj.

Project Plan ← { → 2-3 pages textually laying out the work packages and tasks
→ Gantt Chart.

1. Introduction
1.1 Background
→ Satellites as a scientific instrument
→ Common hardships of geocentric orbits
→ Deep space exploration and constraints
→ Sails as energy collector
→ Sails as thrust mechanism
→ Packing methods, folding techniques

→ How origami is used and how it can be used in this field.

? → The importance of having a reliable system to numerically simulate multi-body dynamics (several panels)

1.2 Aim and Objectives (4 of them!)

~~2.~~

Review Euler equations and ?

* Robert is making simulations too active... maneovres ref 13

* Aleksander is to write a report on his code.

2. Project Plan.

Literature Review

Code review → Code development

Liaise w/ mission specs to highlight needs.

Prove suitability through numerical simulation

Meeting 29/10/20

Foley Benedict:

→ Design a mission [illegible] from scratch to de-orbiting

→ Sam and [illegible] will also work in the above.

→ Robert has been working on potential shapes for the origami sail.

→ aleksander will be making his internship report soon which will help me develope the first part.

→ Stefania will be able to give me feedback for my proposal project on friday 30TH.

Proposal Writting

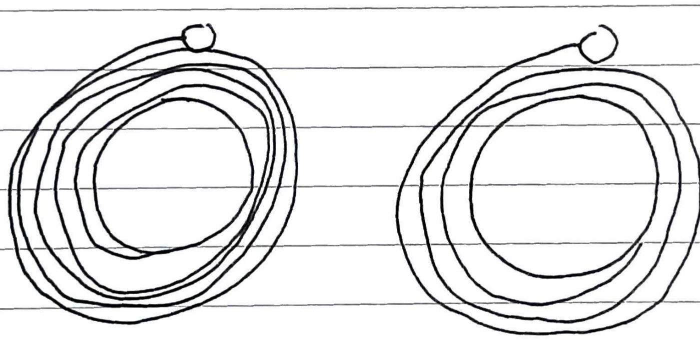
- Introduction
  - Background:

② Satellite story, first uses and sizes.

→ Sputnik

→ Vanguard I

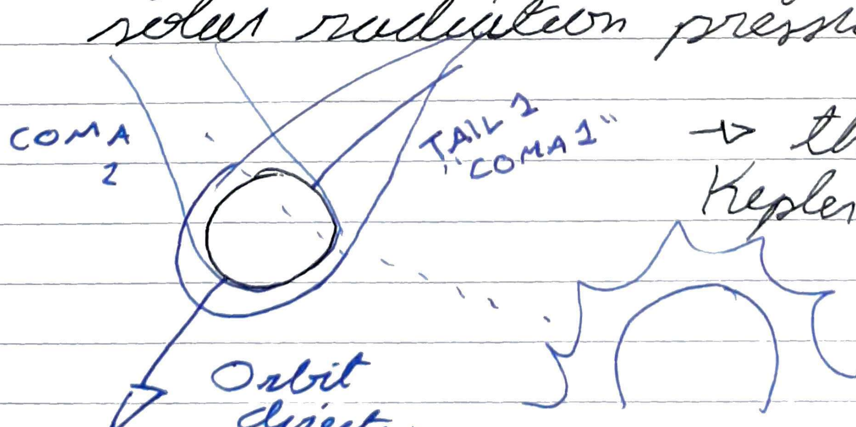
↳ First use of solar energy, 1958



Expected: 2,000 years

Got: 240 years (Est)

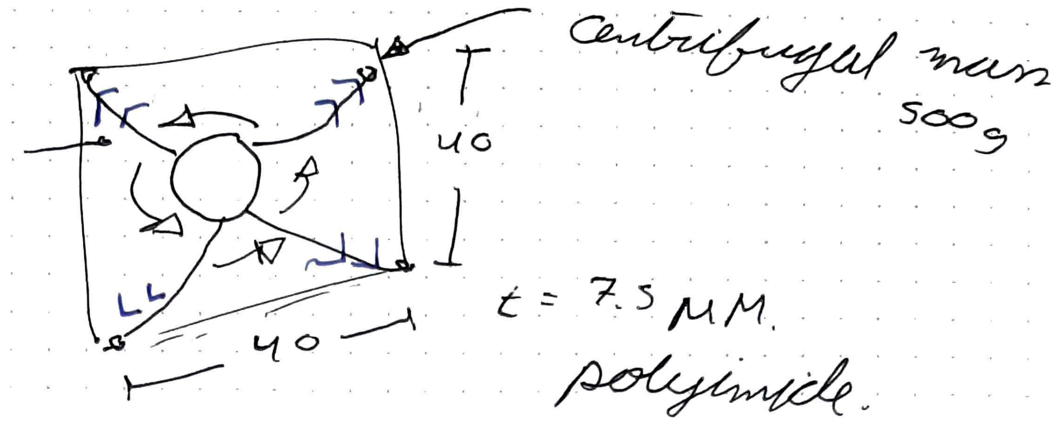
→ First scientific measurement of momentum change due to solar radiation pressure.



→ the coma

Kepler theory.

IKAROS EXPERIMENT by JAXA



$p \approx \frac{2\,kg}{196\,m^2} = 10\,g/m^2$

$t = 7.5\,\mu M$
polyimide.

$P_{POLYAMIDE} = 10\,g/m^2$

$F_{SRP_{MEASURED}} = 1.12 \cdot 10^{-3}\,N$

$\therefore \boxed{P_{SRP,eq} = 5.71 \cdot 10^{-6}\,N/m^2}$

at a distance of: Venus?

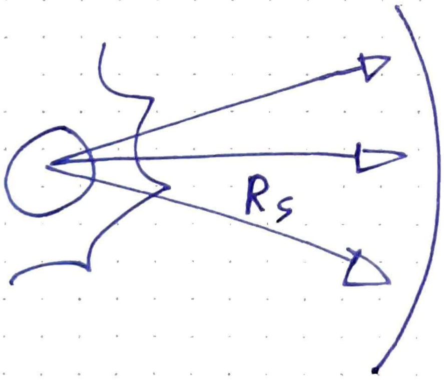
$\boxed{\rightarrow 0.72\,AU}$

Can I expect this?

→ Solar constant: $1361\,\frac{W}{M^2}$

→ Pressure due to G_{SC}: $\boxed{\frac{G_{SC}}{c} = 4.58 \cdot 10^{-6}\,N/m^2}$

$d = 1\,AU$



Reverse inverse law

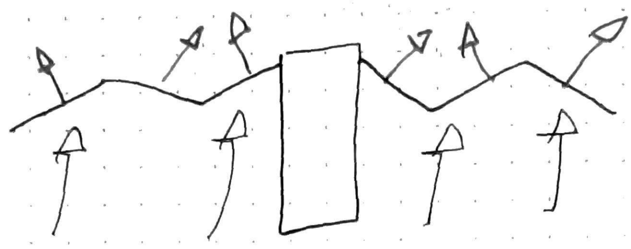
$P = 4.58 \cdot 10^{-6} \left(\frac{1\,AU}{0.72\,AU}\right)^2$

$P_{EXPECTED,\,VENUS} = 8.84 \cdot 10^{-6}\,N$

$\frac{5.71}{8.84} = 0.65 \approx \boxed{64.6\%}$

?

Simulation idea:



Study how much force, and time to deploy for these shapes.

- → multidynamics, use simscale?
- → SyPy (Python?)
- → WBS (see Gantt chart)

training needed? none that I can't do.

technical needed? my computer.
Financial need? none for the foreseeable future + Free open software solutions.

Feedback: Describe the apparatus used for controlling attitude

When was the "cannon ball" model made?

Submission date:

1st of november

circular restricted
- three body problem CR3BP

newton's equation in inertial space:
→ traslatory

$$F = (m I_3)\,\bar{a}_{cm}$$

→ acc. cm
→ identity M.
→ mass.

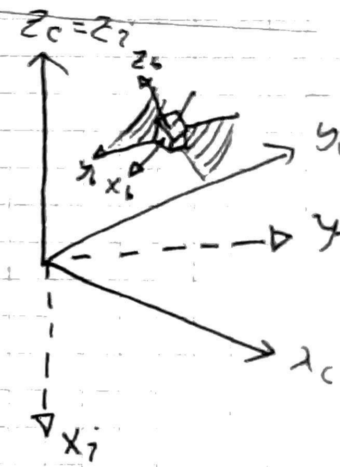
Euler eq. → rotational

$$\tau = I_{cm}\,\bar{\alpha} + \bar{\omega} \times I_{cm}\,\bar{\omega}$$

→ speed body ref.
→ MOI
→ acc.

Curtis Howard 2007 Orbital mech 4 Eng stud.

b → body ref
c → CR3BP ref
i → Fixed inertial ref.

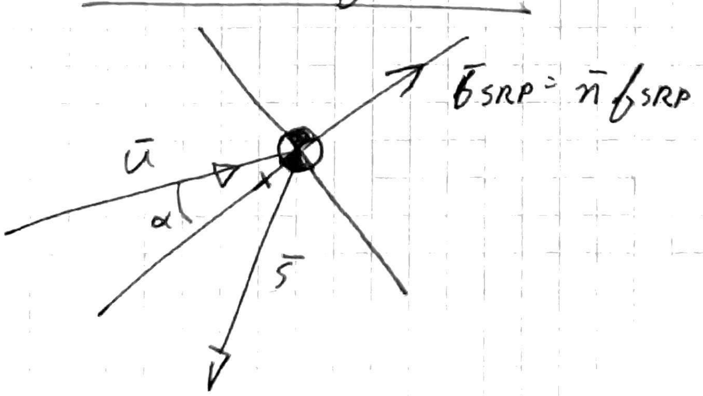


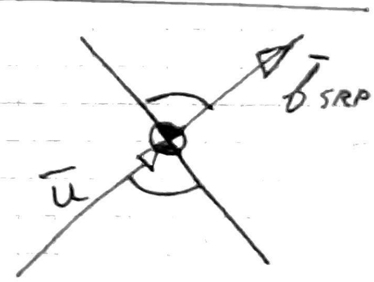
Eq. motion

$$\ddot{x} = \frac{\partial U}{\partial x} + 2\dot{y}$$
$$\ddot{y} = \frac{\partial U}{\partial y} - 2\dot{x}$$
$$\ddot{z} = \frac{\partial U}{\partial z}$$

U → gravity field potential

ideal reflection vs pure absortion





P. A

$$\bar{F}_{SRP} = \bar{F}_a = PA(\hat{u}\cdot\hat{n})\hat{u} = F_a\hat{u}$$

$\hat{u}$ normalised radiation rays direction
$\hat{n}$ dir. normal to sail.

Refresher: the dot product symbolises the amount of (vector magnitudes) projected in the direction of another vector

$\hat{u}\cdot\hat{n}$ → ratio of rays gone in direction of (normal to the sail) $\hat{n}$

P → pressure

A → area.

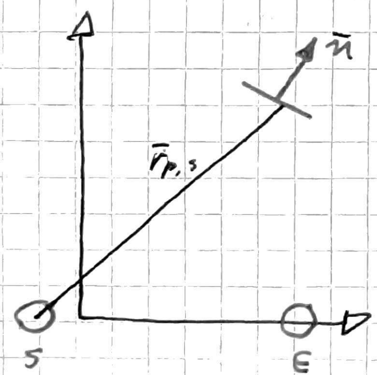
$$\frac{\bar{F}_{SRP}}{|\bar{F}_{SRP}|} = \frac{\bar{F}_a}{F_a} = \hat{u} \text{ normalised.}$$

$$\therefore \bar{F}_a = F_a\hat{u}$$

I. R

$$\bar{F}_{SRP} = \bar{F}_R = 2PA(\hat{u}\,\hat{n})^2\hat{n} = F_R\hat{n}$$

→ mc Innes Colin 1999 Solar sailing tech... Dynamics and Mission appli...



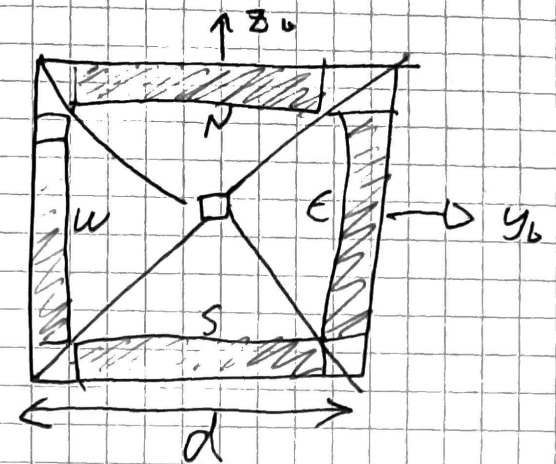
$\hat{u}$ unit vector passing through the S position vect OS

$$\hat{u} = \frac{\bar{r}_{pS}}{\|\bar{r}_{p,S}\|}$$

$$\bar{r}_{p,S} = \bar{r}_p - \bar{r}_S$$

$\hat{n} = -\hat{x}$ → body frame axis ⊥ to sail $\hat{x} = \begin{bmatrix}1\\0\\0\end{bmatrix}_b$

let:



let state vector $\bar{x} = [\bar{r}, \dot{\bar{r}}, \bar{q}, \bar{\omega}]$

$$\bar{q} = [\bar{q}^T_{3\times1} \quad q_4]^T$$

$\bar{q}$ = attitude quaternion $= \begin{pmatrix} \bar{q}_1 \\ \bar{q}_2 \\ \bar{q}_3 \\ q_4 \end{pmatrix}$

$= [q_3^T \quad q_4]^T \quad \bar{\omega} = \bar{\omega}_b$

$$\dot{\bar{x}} = [\dot{\bar{r}} \quad \ddot{\bar{r}} \quad \dot{\bar{q}} \quad \dot{\bar{\omega}}]$$

$$\frac{d}{dt}\begin{bmatrix} \bar{r} \\ \dot{\bar{r}} \end{bmatrix} = \begin{bmatrix} \dot{\bar{r}} \\ \begin{bmatrix} \ddot{x} \\ \ddot{y} \\ \ddot{z} \end{bmatrix} \end{bmatrix} = \begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{z} \\ \ddot{x} \\ \ddot{y} \\ \ddot{z} \end{bmatrix}$$

Using quaternions prevents singularities

to find $\dot{\bar{x}}$ → algorithm Ex. 9.23
Curtis Howard (2009) Orbital mech. for engineering stud.

$$\begin{cases} \dfrac{d\omega_x}{dt} = \dfrac{M_{x_{NET}}}{A} - \dfrac{C-B}{A}\omega_x\omega_y \\ \dfrac{\partial\omega_y}{\partial t} = \dfrac{M_{y_{NET}}}{B} - \dfrac{A-C}{B}\omega_x\omega_y \\ \dfrac{\partial\omega_z}{dt} = \dfrac{M_{z_{NET}}}{C} - \dfrac{B-A}{C}\omega_y\omega_x \end{cases}$$

MOI along	
A	x_b
B	y_b
C	z_b

$$\bar{M} = \begin{bmatrix} M_{x_{NET}} \\ M_{y_{NET}} \\ M_{z_{NET}} \end{bmatrix}$$

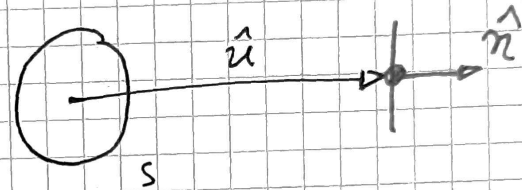
the state of the reflectors is assumed to be binary. Heaviside step funct

$$H(t) = \ldots$$

Condition: the sail forms a normal plane against the direction of the sun:

$$\hat{u} \cdot \hat{x} = -1$$

$\hat{x}, \hat{y}, \hat{z} \to$ body axes directions



$\hat{n} = -\hat{x}$

$-\hat{n} = \hat{x}$

$\hat{u} \cdot \hat{x} = -1$

$\hat{u} \cdot (-\hat{n}) = -1$

$\hat{u} \cdot \hat{n} = 1$

As dot product was defined, $\hat{u}$ is 1 times the size of $\hat{x}$ in the -1 direction (opposites) or 1 in the $\hat{n}$ (vessel heading, solar sail normal plane)

Further:

$\hat{u} \cdot \hat{y} = 0$

$\hat{u} \cdot \hat{z} = 0$

$\hat{u}$ projects itself 0 times on $\cancel{\hat{x}}$ $\hat{y}$ and $\hat{z}$.

Assuming reaction wheels are ideal they can reach $\alpha_{RW} = \infty$ and $|T_{RW}| = \infty$

sail is released around $\hat{n}$ because it wouldn't affect the orientation of the sail.

Glasgow PhD student → deals with attitude control but with EMF

mass & size

torque is located at the edges.

2D → 3D

start from soldini will send me

next

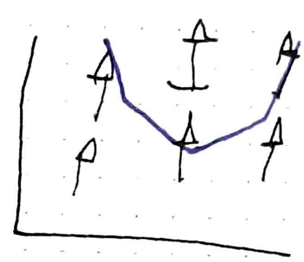
The presentation !!

meeting 12/11/20

→ Robert has made a simulation to show folds required.

→ Benedict wasn't in the meeting.

→ the student in Glasgow, although he hasn't published it. I can use it to guide myself.



→ Some panels have values of 1 or 0 and reflect more or less respect...

- momentum
- momentum

meeting 18/11/20

- Clarifying the need for quaternions
aleksandar's reports w/ "Gimbal Lock"
- First start with transformation matrices

*

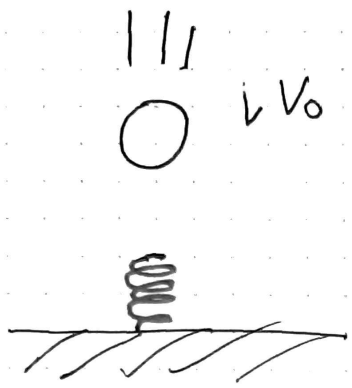
meeting 11/12/20

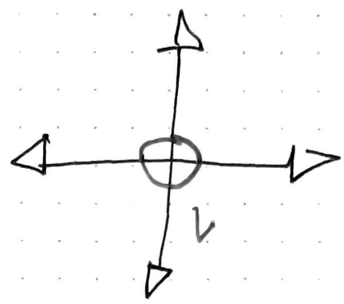
1-on-1 w/ Soldini.

→ Explication of the influence of the LCD's on the panels' reflection.

→ Deliverable for interim report: MBD simulation of panels on SRP.

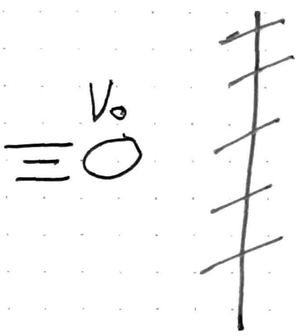
→ check ref 1. for SRP formulae.





$K_e = mv\frac{1}{2} \equiv K_e = I\omega\frac{1}{2}$

$F=ma \equiv M=I\alpha$



time-to-stop: kinectical energy is drained.

$$\frac{K_e}{s} = \frac{I\omega\frac{1}{2}}{s} \equiv -I\alpha\frac{1}{2} = \frac{M}{s}$$

$$s = \frac{M}{-I\alpha\frac{1}{2}} \;?$$

$\cancel{M_s}$ $\quad \alpha_s T_s = W_{\cancel{A}SRP}$

$$\alpha_s = \frac{M_{SRP}-M_{SPR}}{I} \qquad \left(\frac{M_{SRP}-M_{SPR}}{I}\right)T_s = W_{SRP}$$

On default model $\quad -\frac{M_{SPR}T_s}{I} = W_{SRP} - \frac{M_{SRP}T_s}{I}$

0 -> -0.1rad is achieved in 300s, therefore:

$$M_{SRP} = -\frac{W_{SRP}I}{\cancel{2}T_s} + \frac{M_{SRP}I}{I}$$

$$T_s = C(\theta) = \frac{-\alpha I}{300s}$$

$$M_{\cancel{SRP}\,SPR} = M_{SRP} - \frac{W_{SRP}I}{T_s}$$

$M = I\alpha$

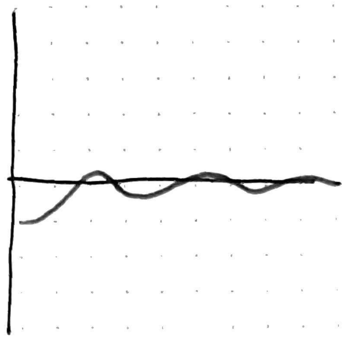
$\alpha = \frac{W}{300} =$

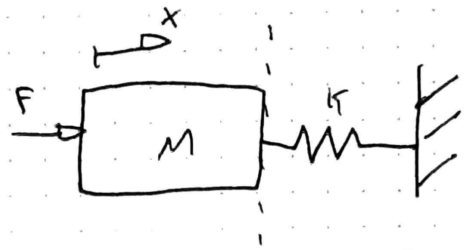
$$C(\theta) = M_{SRP(\theta)} - \frac{W_{SRP(\theta)}I}{T_s}$$

$$\lim_{T_s\to 0} C_\theta = \frac{-W_{SRP}I}{T_s}$$

$$C_\theta = -\infty$$

$$\lim_{T_s\to\infty} C_\theta = M_{SRP}$$





$a m = F - Kx$

$a m = F - Kx$

$\ddot{x} m = F - Kx$

$\ddot{x} m = u - Kx$

$\ddot{x} m + Kx - u$

$\frac{dx}{dt} = v = \dot{x}$

$\frac{dv}{dt} = \dot{v} = a$

$a = \dot{v} = \ddot{x}$

at $u = 0$ $x = 0$

at $u = 5N$

$-5N = Kx$

$x = 1.67$

$x = F_{(t)} - \ddot{x} m$

$m\ddot{x} - F_{(t)} + x = 0$

$ma'' -$

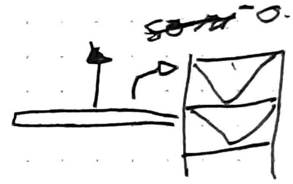
$\ddot{a} - F_{(t)} + m$

$\ddot{x} m = 5N - 0$

$\ddot{x} = 0.025 \cancel{Kg}\ M/s^2$

$v = 0$

~~sen~~ 0.10 rad/s



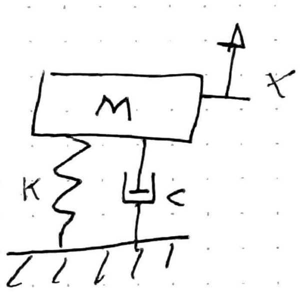
$a = 0.10 °/s^2$

$t = 0.01s.$

$\theta = \omega t + \frac{a t^2}{2}$

$\theta = 1 \cdot 10^{-3} - 5 \cdot 10^{-6}$

$\theta = 9.95 \cdot 10^{-4}.$



$m\ddot{x} = -Kx - C\dot{x} + F_{ext}$

$m\ddot{x} + Kx + C\dot{x} - F_{xt} = 0 \Rightarrow \ddot{x} + \frac{K}{m}x + \frac{C}{m}\dot{x} - \frac{F_{xt}}{m} = 0$

$2\xi\omega_n = \frac{C}{m}$ $\omega_n = \sqrt{\frac{K}{m}}$

$\xi = \frac{C}{2m\sqrt{\frac{K}{m}}}$

$\xi = \frac{C}{2\sqrt{Km}}$

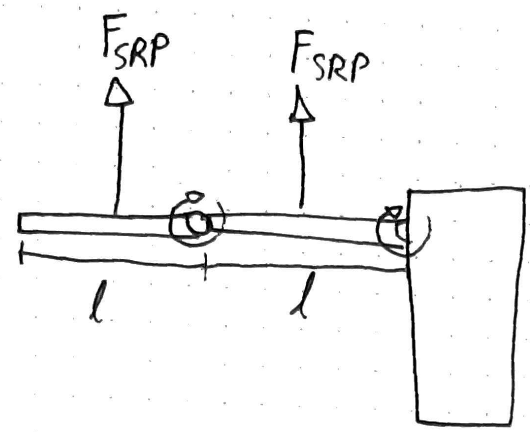
$m\ddot{x} + Kx + 0\dot{x} - F_{xt} = 0$

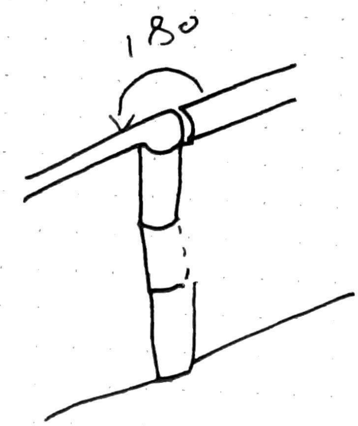
$\ddot{x} + 0\dot{x} + \frac{K}{m}x = \frac{F_{xt}}{m}$

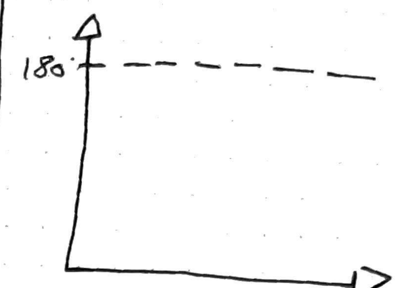
$\omega = \sqrt{\frac{K}{I}}$

$2\xi\omega_n = 0$; $\omega_n = \sqrt{\frac{K}{m}}$

$\xi = 0$ ← Ever oscillating

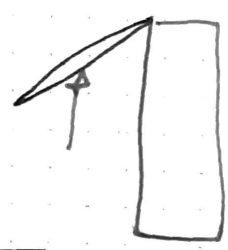






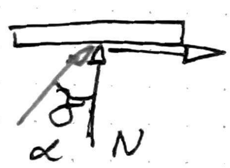
atn = 1

$F_{SRP} \cdot \frac{l}{2} = M_R$ $\qquad M = I\alpha$

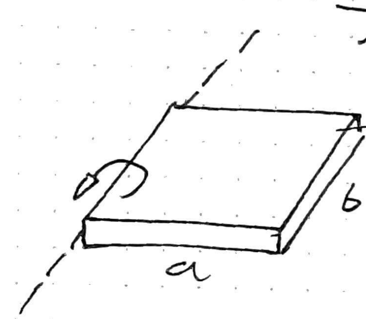


$[NM] = [?\ \frac{rad}{s}]$

$\left[\frac{NMS}{rad}\right] = \left[\frac{kg\frac{m}{s^2}\,8}{rad}\right] = \left[\frac{kg\,m}{s\,rad}\right]$



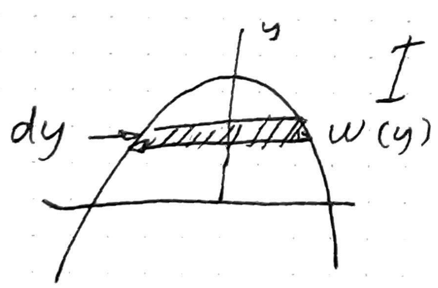
$\cos = \frac{A}{H}$



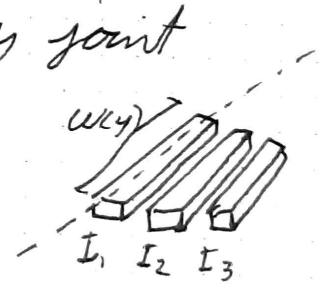
$\boxed{I = \frac{1}{3} M a^2}$

$F_{SRP} \cos\alpha = F_{SRP_N}$.

$F_{SRP} \sin\alpha = F_{SRP_T}$ ← Resisted by joint



$I = \int \rho y^2 w(y)\, dy$

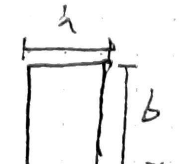


$I = \sum I_N$

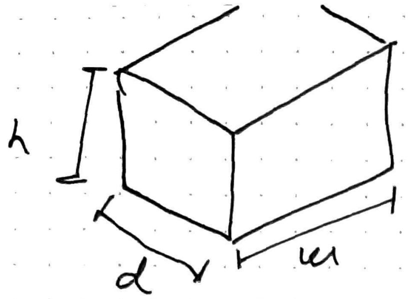
$I_1 = \underbrace{\underbrace{\underbrace{w(y)\,dy}_{\text{area}}\ \rho}_{\text{mass at point}}\ y}_{\text{inertia}}$

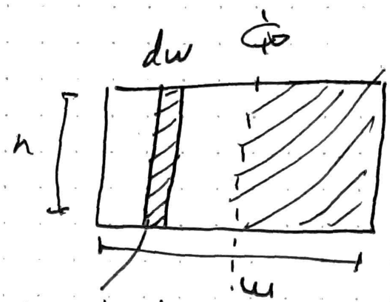
$I_n = \int w(y)\, y^2 \rho\, dy$

For a rectangle slab



$\rho h b \cdot b/2 = \frac{1}{2} \rho b^2 h$





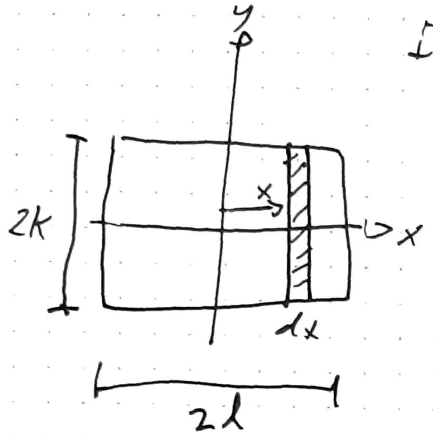
$dw.\,h.d.\rho.$

$M = \frac{w}{2} h d \rho$

$I = \frac{w}{2} h d \rho \cdot \frac{w}{4}$

$I = \frac{w^2}{8} h d \rho$

$I_n = \frac{1}{12} \rho h d w^3 + \frac{1}{12} \rho h d^3 w$



$\Delta m x^2$

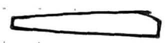
$P = t\rho$

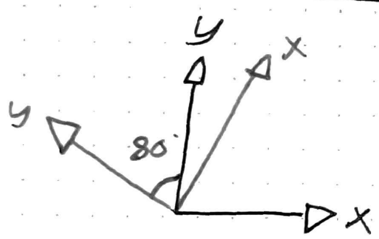
$\Delta m = dx\, 2k\, t.\rho x^2$

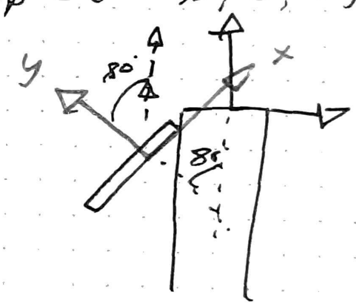
$I_y = \cancel{\Sigma 2k\rho}$

$\cancel{F_{SRP}}$

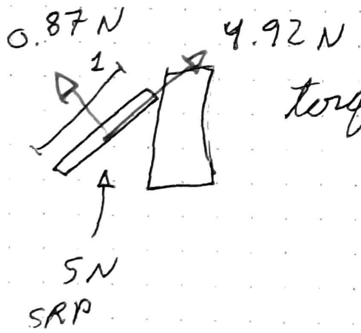
$F_{SRP} = (\cancel{S}, 0, 0)$







$\tau = ds$



torque $= 0.87 \times 0.5 = 0.435$ Nm

$M = I\alpha$

$\alpha = \frac{M}{I}$

$I = \frac{1}{3} \rho a^2 \cdot 2$

$\alpha = 0.2175$ rads $/s^2$

$[\alpha] = \left[\frac{Nm}{kg\, m^2}\right] = \frac{N}{kg\, m} = \frac{\cancel{kg}\,\cancel{m}}{\cancel{kg}\, m s^2} = \frac{1}{s^2}$

$\alpha = \ddot{\theta}(t)$

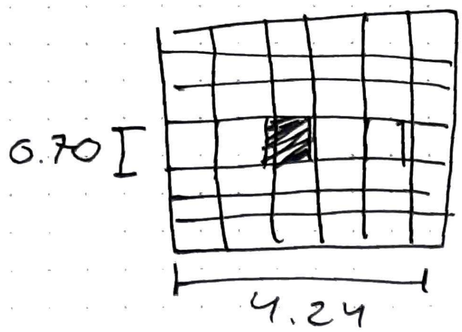
$\omega = \alpha t$

$\omega =$

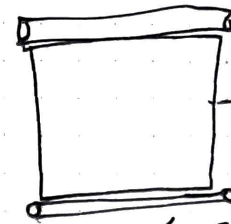
$X = V_0.t + \frac{a.t^2}{2}$ $\quad V_F = V_0 + a.t$

$\theta = \omega_0 t + \frac{\alpha t^2}{2}$ $\quad \omega_{\theta_2} = \omega + \alpha T$

*



$1.8\ m^2$



$\rightarrow A = 0.49$

$m = 7.35\ kg$

Foil: $2.71\ g/cm^3$

IKAROS: $\dfrac{2\ kg}{196\ m^2} = \boxed{10.2 \cdot 10^{-3}\ \dfrac{kg}{m^2}}$

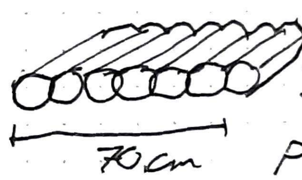
$7.5\ \mu m$ thick

For a PLA panel, $50\ \mu m$ thick, $\rho = 1.24\ g/cm^3$

$V = 2.45 \cdot 10^{-5}\ m^3$

$V\ \cancel{m} = 24.5\ cm^3$

$m\ \cancel{V} = 30.38\ g$



$\rho = 6.2 \cdot 10^{-3}\ g/cm^3$

$\rho = 6.2 \cdot 10^{-3}\ \dfrac{g}{cm^3} \cdot \dfrac{1 \cdot 10^{6}\ cm^3}{m^3}$

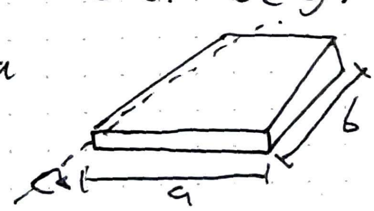
$\rho = 62\ g/m^2$

$\rho = 1.24\ g/cm^3 = 1240\ kg/m^3$

$\rho_{PANEL} = 0.062\ kg/m^2$

$= \cancel{62}\ 62\ g/m^3$ //

$I = \dfrac{1}{3} Ma$



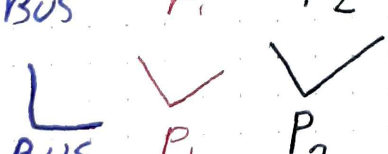
$\therefore I = \dfrac{1}{3} \underset{kg}{0.03} \cdot \underset{m}{0.7} = 7 \cdot 10^{-3}\ kg\,m$

$[Nm] = [kg\,m]\left[\dfrac{m}{s^2}\right]$

$= \left[kg \dfrac{m^2}{s^2}\right] = [Nm]$

turn P_1 0.52^c

turn P_2 0.52^c

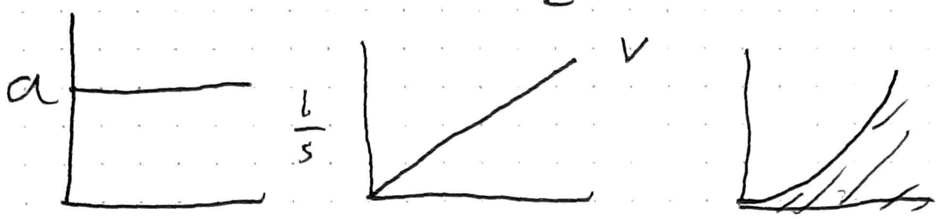


P_c should be 1.047^c ccw from Bus

$\alpha = \dot{\omega} = \ddot{\theta}$

$V_F = V_0 t + \frac{a.t^2}{2}$ $\quad V.t$

$d_F = V_0 t^2 + \frac{a.t^3}{2}$



$V_F = V_0 .t + \frac{a.t^2}{2}$ $\quad V_F = \frac{d}{t}$

$\theta = \omega_0 t + \frac{\alpha t^2}{2}$

$2\theta = 2\omega$

$d = V_0 t^2 + \frac{a t^3}{2}$

$2d - 2V_0 t^2 - \frac{a t^3}{2}$

$t = 5$
$d = 50$
$a = 2$

$d = Vt$ $\quad \sqrt{\frac{d}{a}} = t$ $\quad V_F = 10\ m/s$

$d = at^2$

$10\ m/s = 0 + \frac{a.t^2}{2}$

$t =$

$\theta = \omega_0 t + \frac{\alpha t^2}{2}$

$\therefore\ 2\theta = 2\omega_0 t + \alpha t^2$ $\quad \alpha t^2 + 2\omega_0 t - 2\theta$

$2\theta = (2\omega_0 + \alpha t) t$ $\quad \frac{-2\omega_0 \pm \sqrt{4\omega_0^2 + 4\alpha.2\theta}}{2\alpha}$

$\cancel{t = 2\theta}$

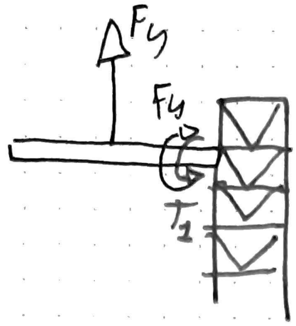
$\alpha = 2\ rad/s^2$

$\theta = 0.349^c$

$t = \cancel{1.18s}\ 0.59\ s$

$t = \frac{\sqrt{4\alpha 2}}{2a} = \frac{\sqrt{8\alpha\theta}}{2\alpha}$

$t = \cancel{2s}\ 1.18s$

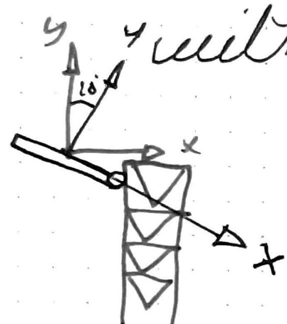


a torsional spring acts at the root, as such:

$M = T_R - F l_y = 0$

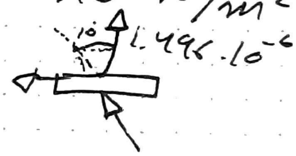
$T_R = C(\theta - \theta_r)$ where θ_r is the reference at which the spring will not deliver moment

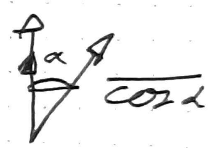
C is the spring constant ~~at which~~ with units $\left[\frac{N}{rad}\right]$,,



with a sun-bus angle of 30° and distance 1.5 AU, state = θ

$P = 1.52 \cdot 10^{-5}\ N/m^2$





$M = F_{SRP} \cdot 0.5m$

$= 7.4846 \cdot 10^{-7}\ NM$

$M_T = M_{SRP} - M_C = 0$

$M_C = M_{SRP}$

$C(\theta - \theta_r) = M_C = +7.48 \cdot 10^{-7}\ NM$

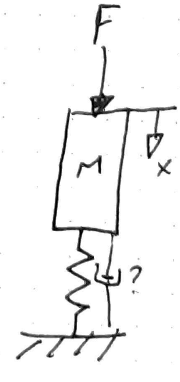
$C(0.1745 - \theta_r) = 7.48 \cdot 10^{-7}\ NM$

assuming $\theta_r = 0°, 0^c \rightarrow C = +4.29 \cdot 10^{-6}\ \frac{NM}{rad}$

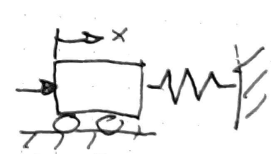
BUS is 30° ACW, SUN

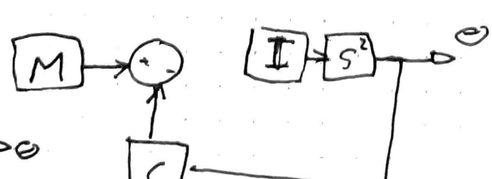
FRAME is 10° CW, BUS

$P_{SRP} = 1.995 \cdot 10^{-6}\ N/m^2$



$m\ddot{x} = F - cx$





$m\ddot{x} = F - xC$

$I\alpha = M - C\theta$

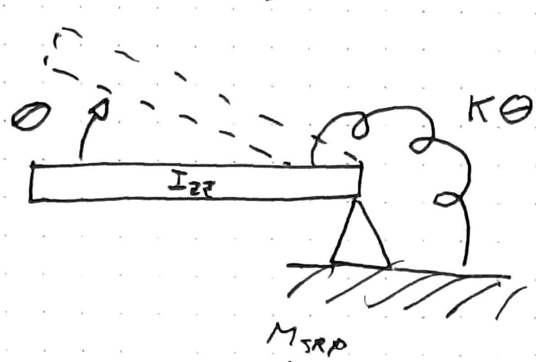
$I\ddot{\theta} = M - C\theta$

~~$I\ddot{\theta} - M$~~

$\theta = \frac{M - I\ddot{\theta}}{C}$

Meeting with Aloisa 29/1/21

→ In regards to the dynamic system I found:



$$M = I\alpha = I\ddot{\theta}$$

$$\therefore \ddot{\theta} = \frac{M}{I}$$

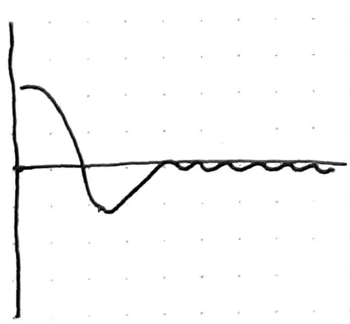
$$M = F_{eq,SRP} \cdot \frac{l_z}{2}$$

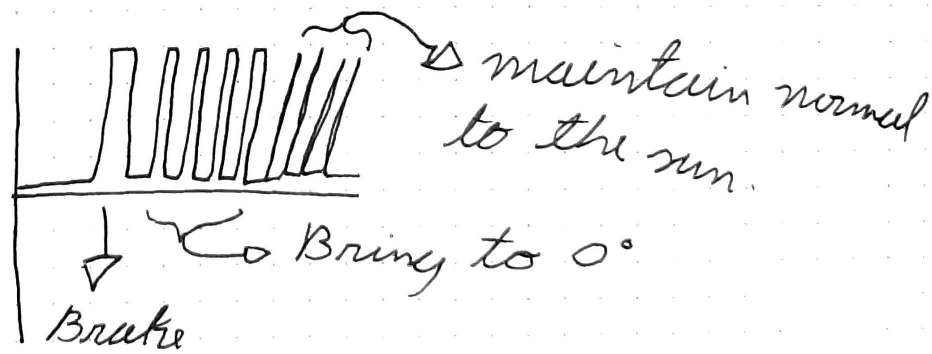
$$\therefore \quad I\alpha = \overbrace{I\alpha_{SRP}}^{M_{SRP}} + (-K)\theta$$

$$I\ddot{\theta} = F_{eq}(\theta)\,\frac{l_z}{2} - K\theta \qquad \text{where } F_{eq\,SRP} = P_{SRP} A\cos\theta$$

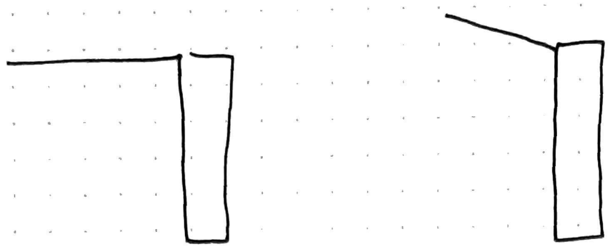
← no dampening?

→ Aloisa says this doesn't have to be permanently on, spring can be electrically activated.





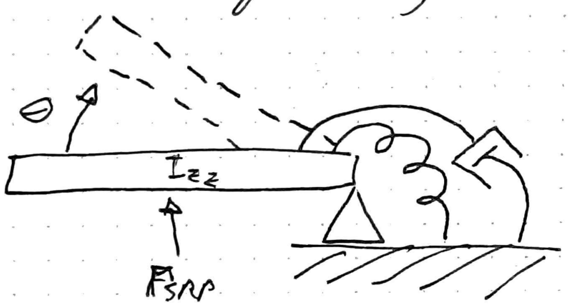
The spring could activate when the panel goes beyond a point, and should help to maintain the panel at an optimum angle.



0° → maximum force

~10° Equilibrium point, less energy used on spring.

→ Passive dampening



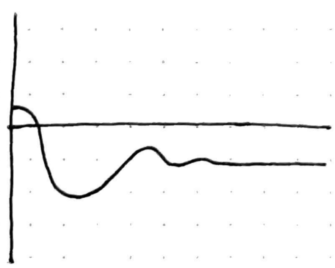
$$I\alpha = F_{SRP}(\theta) - K\theta - C\omega$$

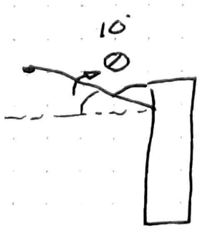
$$I\ddot{\theta} + C\dot{\theta} + K\theta = M_{SRP}(\theta)$$

$$\ddot{\theta} + \frac{C\dot{\theta}}{I} + \frac{K\theta}{I} = M_{SRP}(\theta)$$

where $\omega_n = \sqrt{\frac{K}{I}}$ and $\xi = \frac{C}{I 2\omega_n}$

$$\xi = \frac{C}{2I\sqrt{\frac{K}{I}}} = \frac{C}{2\sqrt{KI}}$$



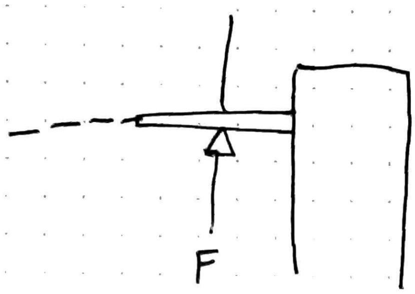


Will converge in a less-than-optimal angle.

$\theta_{con.} = M_{SPRING}(\theta) + M_{SRP}(\theta) = 0$

EQUILIBRIUM

ADJUST M_{SPRING}?



$a_x = 0.5m$

$F_{SRP} = 4.56 \cdot 10^{-6}$

$F_{SRP_{LOCAL}} = 1.52 \cdot 10^{-6} N$

$M = F \cos\theta \, a_x$

$M_S = C(\theta)$

$\cancel{\theta} = M_S = 4.29 \cdot 10^{-6} \frac{NM}{rad}, \theta$

$M_T = M_{SRP} + M_{SPR}$

$I\alpha = F\cos\theta \, a_x + C\theta$

$I\ddot{\theta} = F\cos\theta \, a_x + C\theta$

$\theta = \frac{I\ddot{\theta} - F\cos\theta}{C}$

$x = \frac{I\ddot{x} - F_{SRP}\cos(x)}{C}$

$x = \frac{\ddot{x} I - \cos(x) F_{SRP}}{C}$

$M_T = M_P + M_S$

$I_T \ddot{\alpha}_T = F_{SRP} \cos\theta \, a_x + C\theta$

$\frac{I_T \alpha_T - F_{SRP} \cos\theta \, x}{C} = \theta$

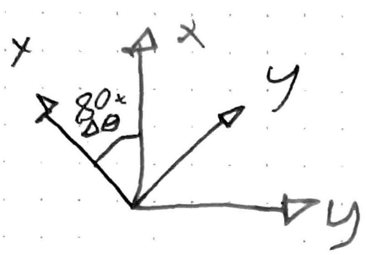
$a^s = \beta \frac{M_{SUN}}{r^2}$

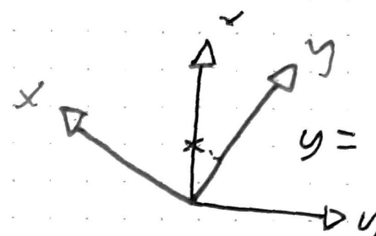
#15 reference.

IKAROS → travelled with normal engines

ar

→ get angle between panel to bus
→ re-orient frame Δθ per iteration

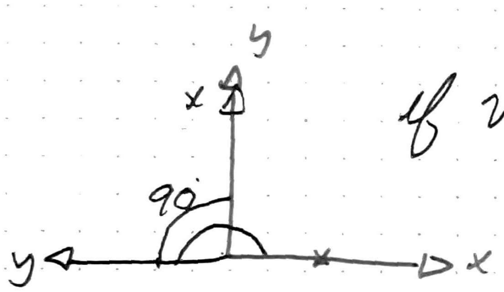




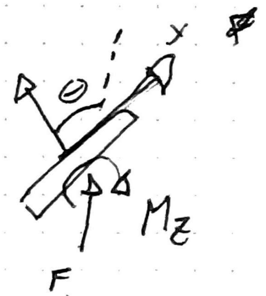
$y = \cos(90-\theta)R$
$x = \cos(\theta)P$

$$\begin{pmatrix}1&0&0\\0&0&1\\0&-1&0\end{pmatrix}(1,0,0) = \begin{pmatrix}1&0&0\\0&0&1\\0&-1&0\end{pmatrix}\begin{pmatrix}1\\0\\0\end{pmatrix}\begin{pmatrix}1\\0\\0\end{pmatrix}$$

$$= (1,0,0)\begin{pmatrix}1&0&0\\0&0&1\\0&-1&0\end{pmatrix}(1\ 0\ 0)$$



if $v = \boxed{\begin{matrix}\hat{v} = (1,0,0)_N \\ \hat{v} = (0,-1,0)_A\end{matrix}}$ when $A_\theta = 90°$



F.express(PANEL FRME)

$(5\sin(0.444\pi) + 0.x,\ 5\cos(0.444\pi),\ 0)$
$(0.12,\ 4.97)$

$\alpha = \dfrac{M}{I}$ $\qquad \alpha = MI^{-1}$

$M = I\alpha$ $\qquad \begin{pmatrix}\cancel{-0.217}\\0\\-0.217\end{pmatrix} = \begin{pmatrix}L\\M\\N\end{pmatrix}\begin{pmatrix}1/I_{xx}\\1/I_{yy}\\1/I_{zz}\end{pmatrix}$

$M_z = l_x \cdot F_y$

$M = F \cdot l_F = \begin{pmatrix}F_x\\F_y\\F_z\end{pmatrix}\begin{pmatrix}\cancel{l_x}\ 0\\0\\0\end{pmatrix}$ ← moments

$$\begin{pmatrix} \tau_x \\ \tau_y \\ \tau_z \end{pmatrix} = \begin{pmatrix} I_{xx} & I_{xy} & I_{xz} \\ I_{yx} & I_{yy} & I_{yz} \\ I_{zx} & I_{zy} & I_{zz} \end{pmatrix} \begin{pmatrix} \alpha_x \\ \alpha_y \\ \alpha_z \end{pmatrix}$$

$$\begin{pmatrix} \alpha_x \\ \alpha_y \\ \alpha_z \end{pmatrix} = \begin{pmatrix} I_{xx} & I_{xy} & I_{xz} \\ I_{yx} & I_{yy} & I_{yz} \\ I_{zx} & I_{zy} & I_{zz} \end{pmatrix}^{-1} \begin{pmatrix} \tau_x \\ \tau_y \\ \tau_z \end{pmatrix}$$

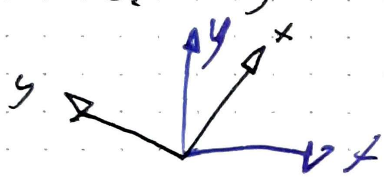
M must be -ve.

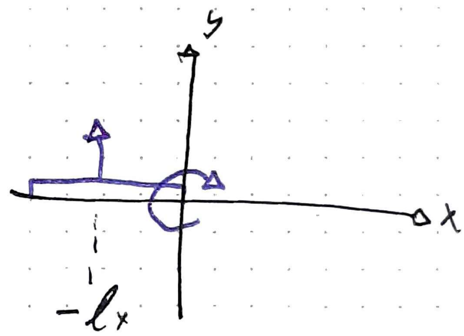
$$\alpha = \frac{M}{I}$$

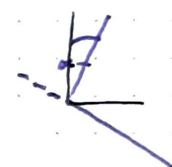
$$M = F.dl \qquad \begin{pmatrix} \tau_x \\ \\ \end{pmatrix} \Big($$

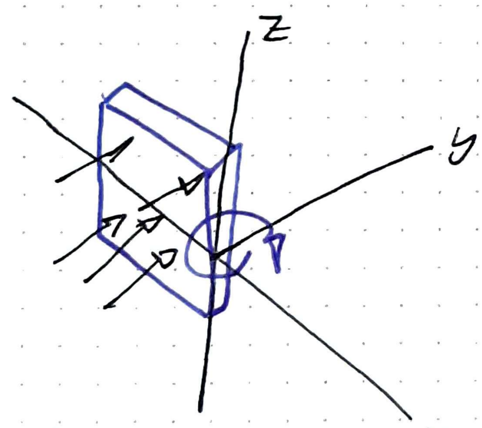
$$\tau_x = F_y . l_x + 0$$
$$\tau_y = F_x . l_y + 0$$
$$\tau_z = F_y$$

$$\tau_z = \alpha_x I_{zx} + \alpha_y I_{zy} + \alpha_z I_{zz}$$









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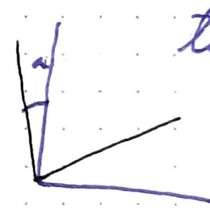
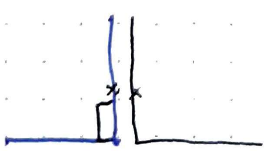


$$A^2 = A^2 + B^2 + 2ac \cos c$$

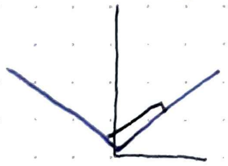
$$\underline{a} \cdot \underline{b} = |a||b| \cos \theta$$

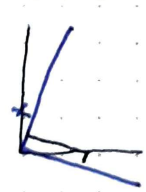
(0)

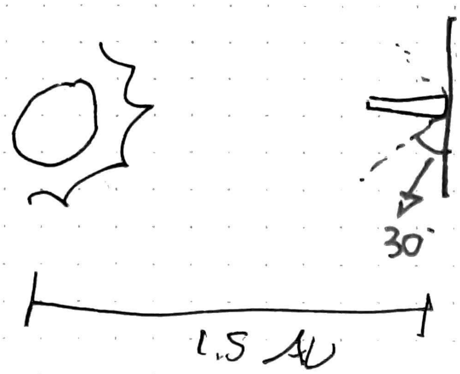
$+cX$ $+sx$



$+c\theta$ $+s\theta$ $c\theta - s\theta$







$P = 4.56 \cdot 10^{-6} \cdot \frac{1}{1.5^2} \cos(\text{SUN-BUS})$

$P = 2.03 \cdot 10^{-6}\ N/m^2$

$A = 0.49\ m^2$

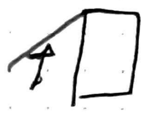
State : 1 $\quad F_T = 1.99 \cdot 10^{-6}\ N$

$M_{SPR} = -k\theta$

$= -4.29 \cdot 10^{-6} \cdot 30°$ $NM/\cancel{deg}$ rad

$= -2.25 \cdot 10^{-6}\ NM$

$F_{PANEL} = 1.72 \cdot 10^{-6}\ N$



$M_{SRP} = 6.03 \cdot 10^{-7}\ NM \quad 2.85 \cdot 10^{-6}$

$M_T = -\cancel{1.64 \cdot 10^{-6}}\ NM = \cancel{8.78} \cdot 10^{-6}$

$I = 7.09 \cdot 10^{-3}$; $\alpha = \cancel{-2.32 \cdot 10^{-4}}\ rad/s^2$

$\theta = \frac{\alpha T^2}{2} = 2.607 \cdot 10^{-3} \qquad \alpha = -4.02$

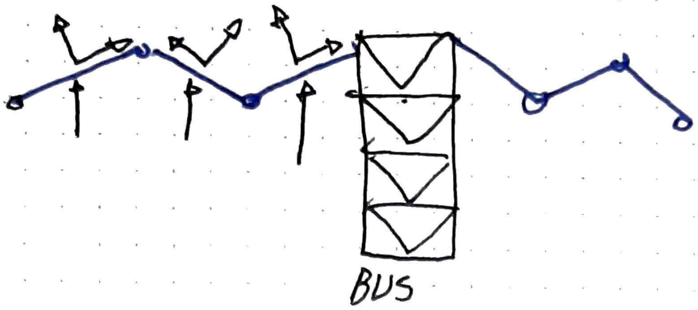
(I) NO FINAL RESULT

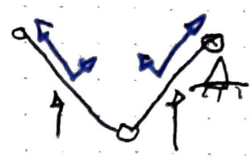
(II) SPRING ACTUATED

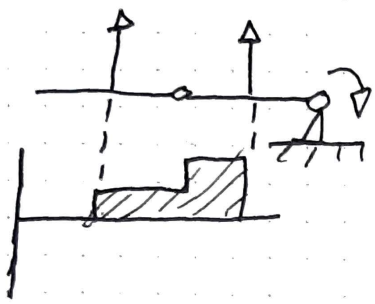
$F_T =$

(III) DAMPENED at $\xi = 0.45$

$F_T = 3.92\ \mu N$



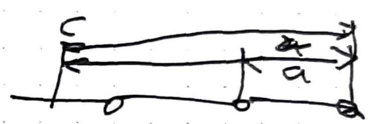




$F_{SRP_1} \cdot \frac{d_1}{2} + F_{SRP} \cdot \frac{d_2}{2}$

When $\theta_2 = 0°$, joint transmits moment.

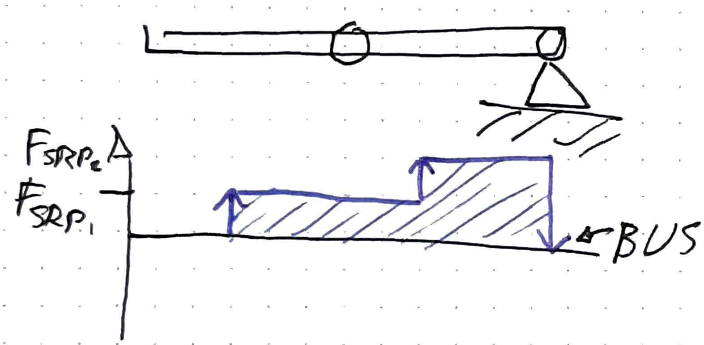
where $d_n = 2^{n} a - \frac{a}{2}$

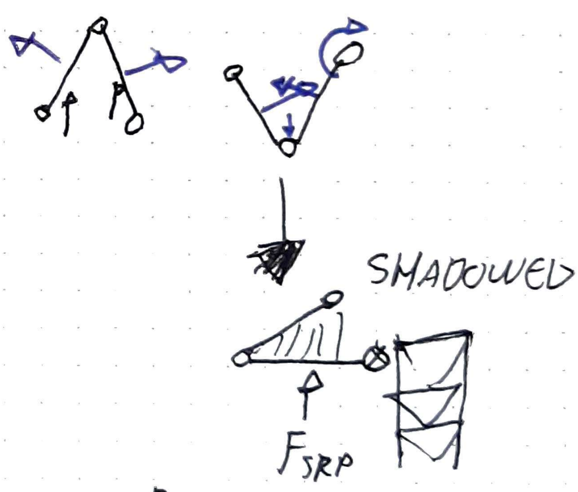


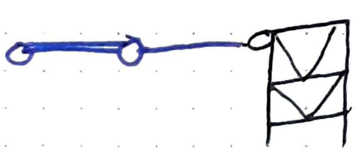
$na - \frac{a}{2}$

$3 \cdot 1 - \frac{1}{2} = 3 - \frac{1}{2}$

$= 2.5$



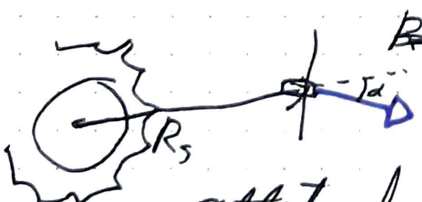




$p_{SRP} = P_0 [1+\rho] \left(\frac{R_{S0}}{R_s}\right)^2 \cos\alpha$

$R_{S,0}$

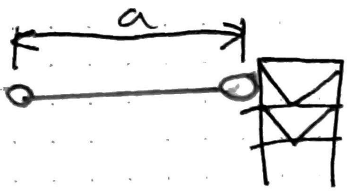
$\cancel{R_{S,0}} = 4.56 \cdot 10^{-6} \frac{N}{m^2}$ → SRP at 1au.



At $R_s = 2AU$ and $\alpha = 45°$

$p_{SRP} = \frac{1}{8} P_0$

attitude control of large gossamer spacecraft



let a = 1m

and a panel area is a^2

at a distance of 1.5 AU

~~[illegible]~~ 0° (Normal to the sun)

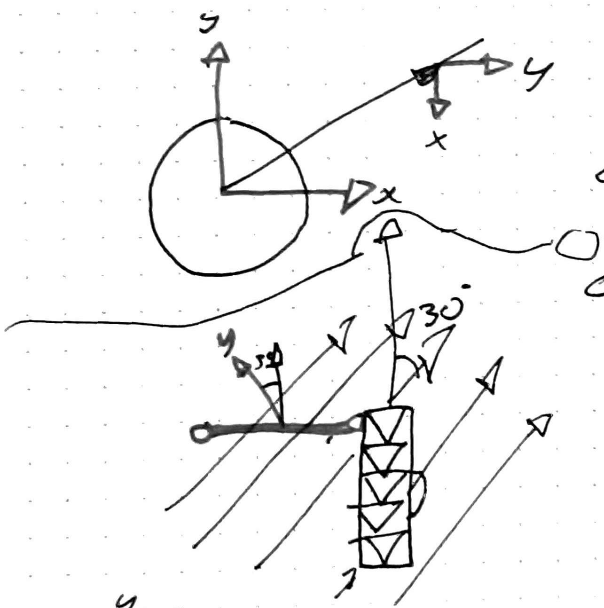
state = 1 (on, reflection)

$$P_{SRP} = P_0(1+\rho)\left(\frac{R_{S,e}}{R_S}\right)^2 \cos^2\theta$$

$$P_{SRP} = 4.56\cdot10^{-6}\cdot 2\cdot(0.44\bar{4})\cdot 1 = 4.05\cdot10^{-6}\,\frac{N}{m}$$

$$F_{SRP} = 4.05\cdot10^{-6}\ N\ //$$

$$M = I_{zz}\,\alpha \quad \therefore \quad \alpha = \frac{M}{I_{zz}} = \ddot{\theta}$$



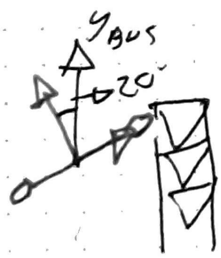
let $\vec{d}$ be a position vector as such,

$$\cos^{-1}\left(\frac{\hat{\vec{d}}\cdot\hat{y}}{1}\right)$$

$$P_{SRP} = 4.56\cdot10^{-6}\,(1+0)\left(\frac{R_{Se}}{R_S}\right)^2\cos 30°$$

$$P_{SRP} = 1.52\cdot10^{-6}\,\frac{N}{m^2}$$

$\longrightarrow$ normal to bus.



$P_{SRP}\cdot$ panel = force

$\rightarrow = 1.52\cdot10^{-6}\,N$ ✓

angled force:

$y = 1.43\cdot10^{-6}$ $x = 5.199\cdot10^{-7}$

Force acting normal to surface: $F_y = 1.428\cdot10^{-6}\,N$

$$M = F_y\cdot d_y = 1.43\cdot10^{-6}\cdot 0.5M$$

$$M = 7.15\cdot10^{-7}\,NM$$

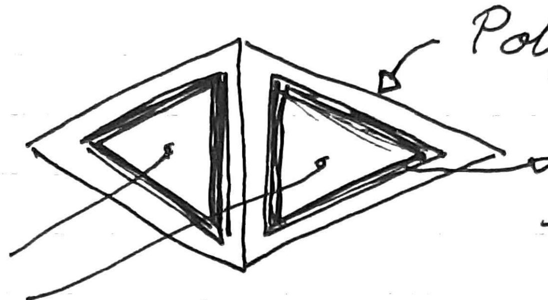
$$\alpha = \frac{M}{I} = \frac{7.15\cdot10^{-9}\,NM}{2.0} = 3.58\cdot10^{-7}\ \text{rads}/s^2$$

Meeting Thursday 4/03/21

→ Everyone present + Aloisia

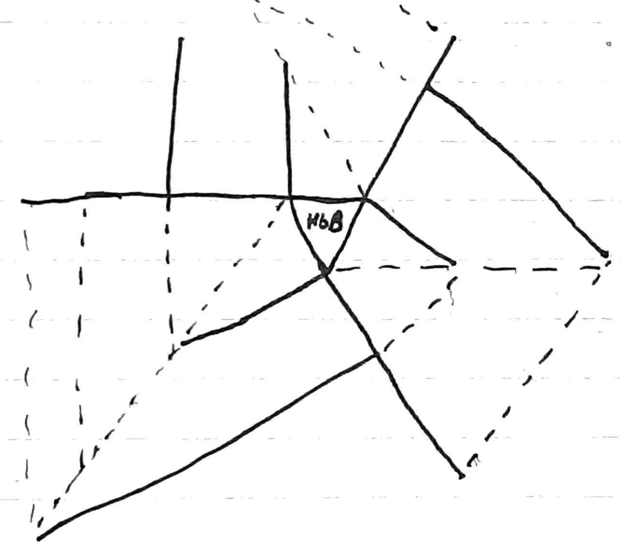
Aloisia made a presentation on the shapes she has worked with.

Polyamide membrane



3D printed skeleton
PLA, NYLON, ABS

alternable between PDLCs and solar generators



Aloisia's shape.

Robert is also working on this.

→ Mission analysis should come up with some parameters for weight and thrust needed, SRP. (Foley Benedict)

→ What ~~pla~~ panels can be turned on/off to achieve what shapes.

meeting 10/03/21

→ Aloisia, Stefania, Robert and I.

→ Lots of testing and iterations is a good way to get marks.

→ the material is printed in "scientific" grade machines, highest quality

→ technology readiness level.

CAD DESIGN OF THE FINAL SHAPE

Major folds n=3

folding lines from central figure edges

They are mounts

Intermediate folds

dashed folding lines which are valleys

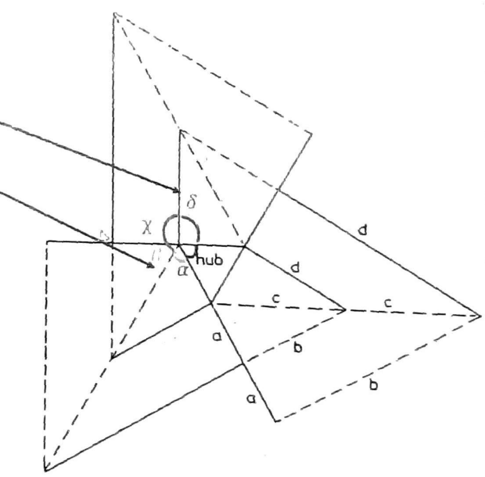
Hub angle $\alpha = (1 - \frac{2}{n})\pi$

$$\alpha + \beta + \delta + \chi = 2\pi$$

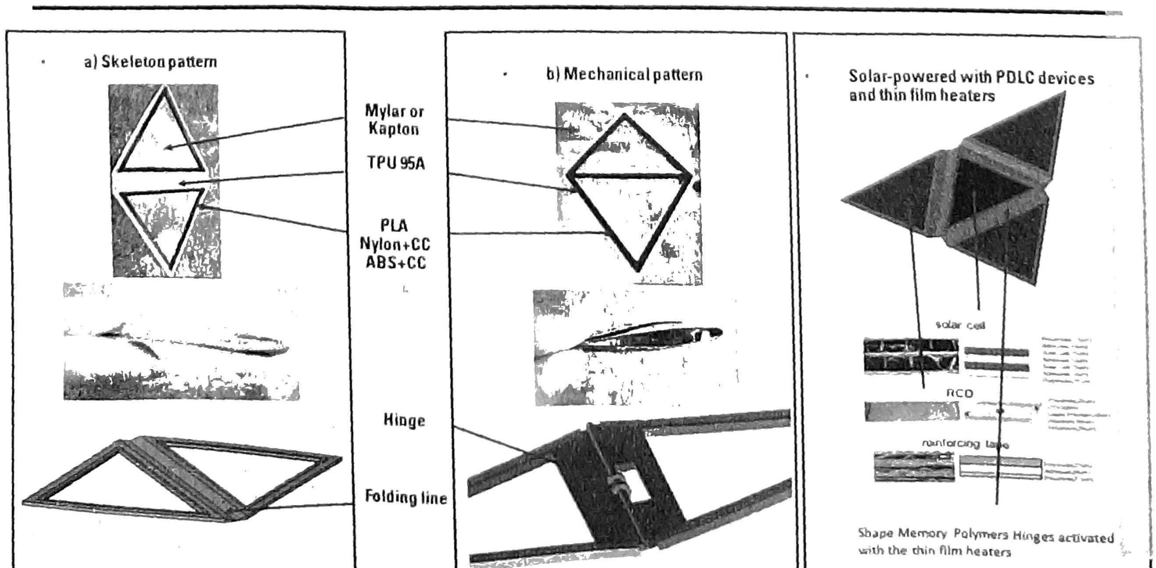
$$\beta = \frac{\pi}{n}, \chi = \left(\frac{1}{2} + \frac{1}{n}\right)\pi$$

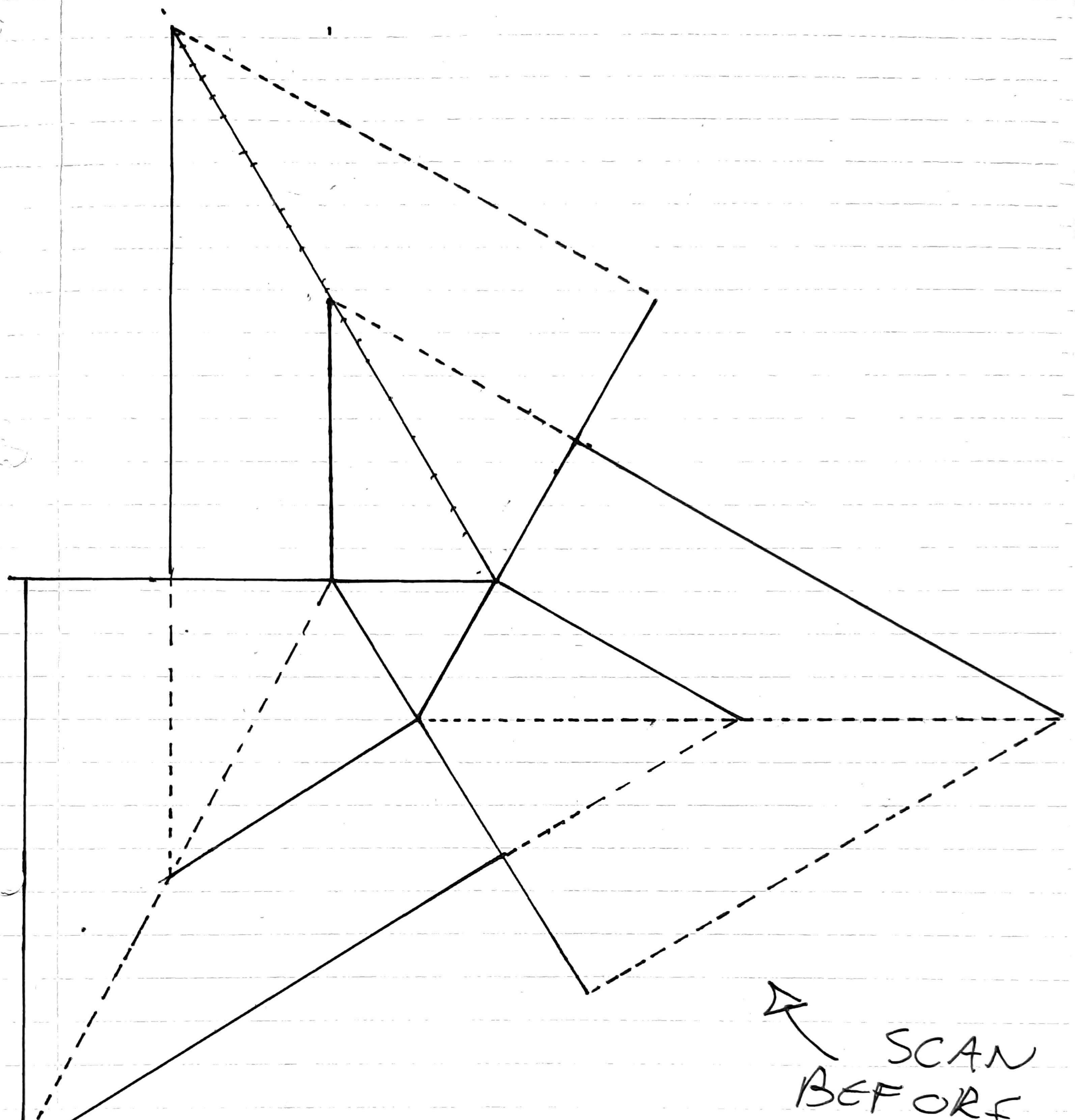
$$\alpha = \frac{\pi}{3}, \beta = \frac{\pi}{3}, \delta = \frac{\pi}{2}, \chi = \frac{5}{6}\pi$$

a = 3 cm, b =5.2 cm, c = 6 cm

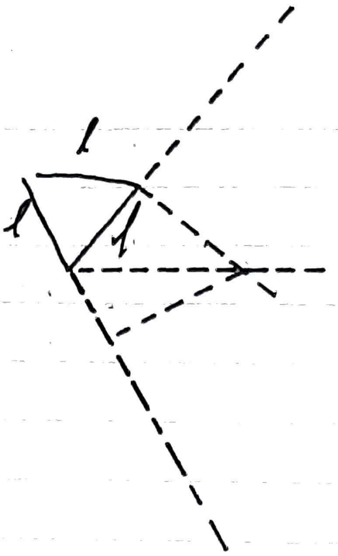


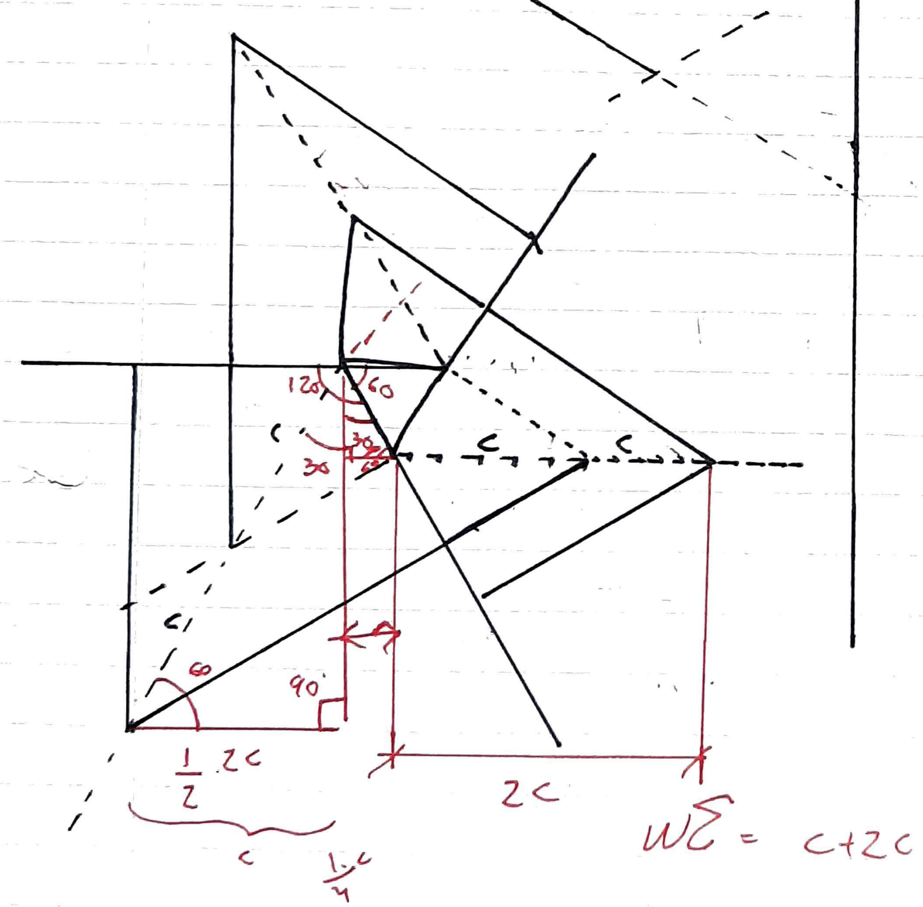
TRADE-OFF ANALYSIS

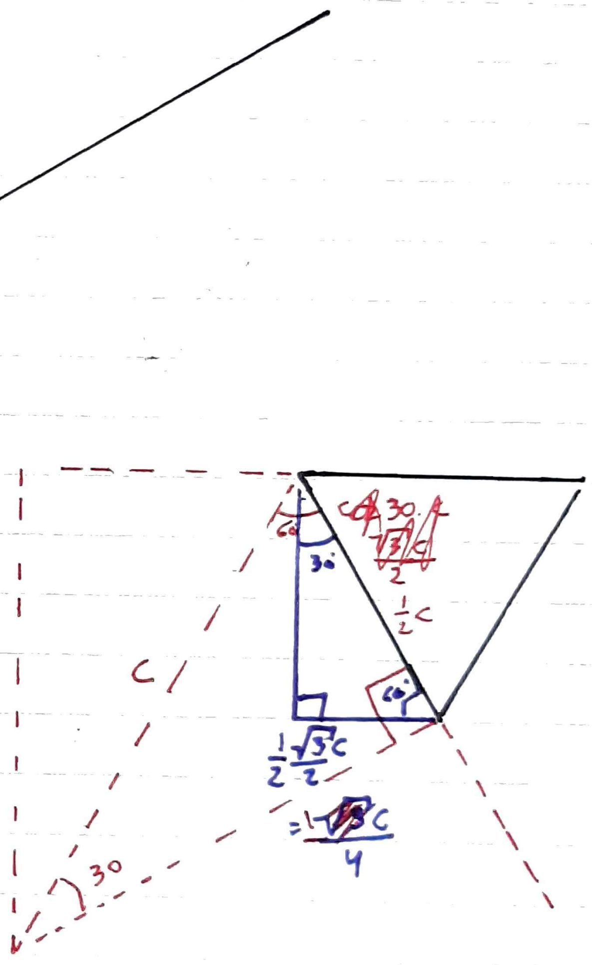




SCAN
BEFORE
CUTTING
OUT



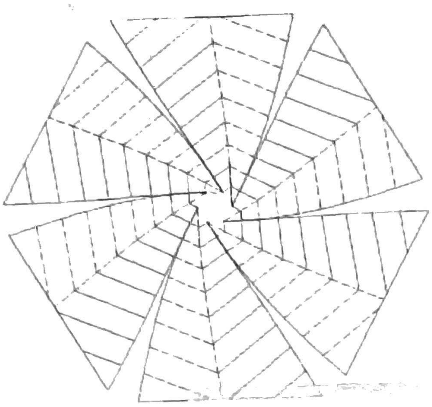


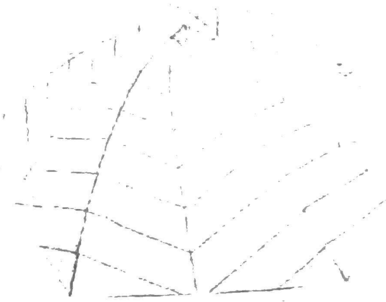


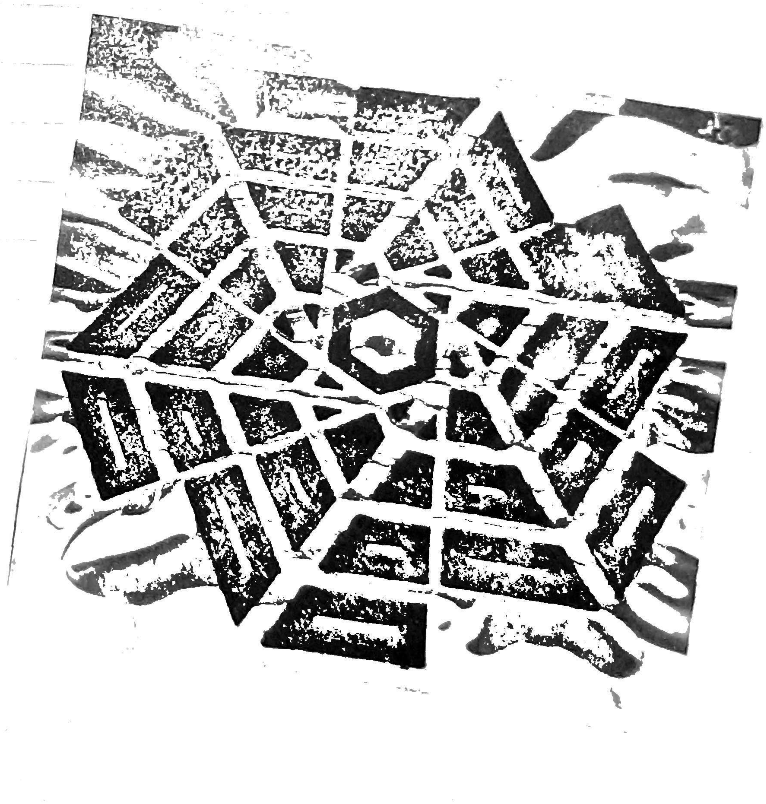
$$W\Sigma = c + 2c + \frac{1}{4}c = \frac{4c + 8c + c}{4} = \frac{13}{4}c.$$

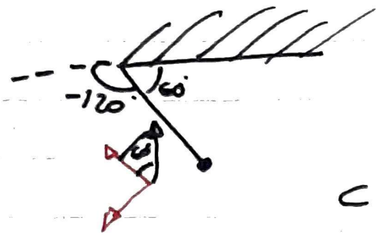
Possible CONCENTRIC AND RADIAL SHAPES

(g)









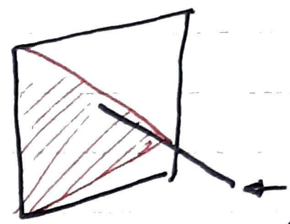
~~8.77~~

$$F_{SRP} = 2.03 \cdot 10^{-6} \frac{N}{m^2} \cdot 43.3\,m^2 = 8.8 \cdot 10^{-5}\,N$$

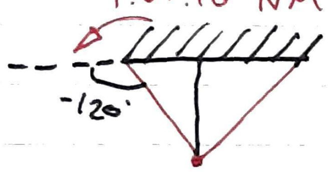
$$c = \frac{\sqrt{3}\,l}{6} = 2.87\,m$$

$$T_{SRP} = \cancel{2.54 \cdot 10^{-4}\,NM} = -1.2614 \cdot 10^{-4}\,NM \checkmark$$

Finding minimum "C" spring coefficient for opening pyramid at a distance of 0.39 AU from the sun (Mercury orbit, worst/strongest SRP escenario)

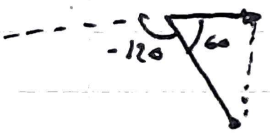


simulator body to stop panel from folding.



$$T_{S_{\theta=-120}} > T_{SRP_{\theta=120}}$$

~~co~~ cos 60 · 10 =



$$T_s > |T_{SRP}|$$

$$T_s > 1.87 \cdot 10^{-3}\,NM \quad (CW)$$

$$T_s = -C(\theta - \theta_{ref}) > \cancel{1.87} \cdot 10^{-3}$$

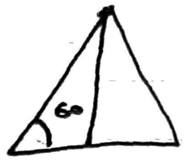
$$T_s = -C(-120° - 0) > \cancel{1.87} \cdot 10^{-3}$$

$$C \cdot 120° > \cancel{1.87} \cdot 10^{-3}$$

$$C > \cancel{8.9286 \cdot 10^{-4}}\,NM/rad$$

$$C > 1.542 \cdot 10^{-4}\,NM/rad$$

$2h + l = 18$



$\sqrt{3}h + L = \cancel{18}\ 16$

$\therefore L = \dfrac{\cancel{18}\ 16}{\sqrt{3}+1} = \cancel{6.6}\ 5.86$

$\therefore h = \cancel{8.71}\ 5.0$ 5.0 $5.$

$lm =$

$\tan 60 = \dfrac{h}{\frac{L}{2}}$

$\therefore h = \dfrac{\tan 60^\circ L}{2}$

$h = \dfrac{\sqrt{3}}{2} L$

$y(x) = 2 \ldots$
$\quad 2\tan \ldots$

$lm = \rho z\, d(2\tan \ldots$

$dm = \rho z\, d(\dfrac{2\sqrt{3}}{3} . (h \ldots$

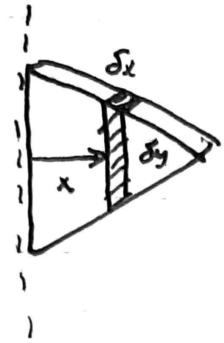
$m = \rho z\, \cancel{d} \dfrac{2\sqrt{3}}{3} d(hx - x^2)$

$\cancel{\int x^2 dm = \int x^2 \rho z}$

T

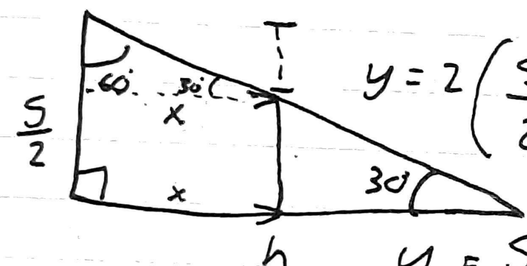
$y = 2\left(\dfrac{5}{2} - \tan(30^\circ).x\right)$

$= 5 - \dfrac{2\sqrt{3}}{3}$



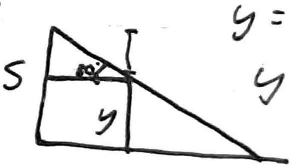
$$I = \Sigma m_i r_i^2$$
$$dm = d(p.y.x.z)$$

$$y(x) = \cancel{2\sin(30°)}$$
$$2\tan(30°).(h-x)$$
$$dm = pz\, d(2\tan(30°).(h-x).x)$$
$$dm = pz\, d\left(\frac{2\sqrt{3}}{3}.(h-x)x\right)$$
$$dm = pz\, \cancel{d}\, \frac{2\sqrt{3}}{3}\, d(hx - x^2)$$
$$\cancel{I = \int r^2 dm = \int x^2 pz}$$



$$y = 2\left(\frac{S}{2} - \tan(30°).x\right)$$
$$y = S - \frac{2\sqrt{3}}{3}x$$

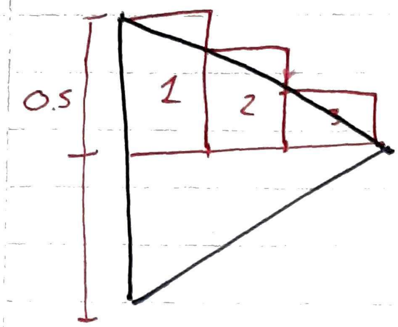
$$S = \sqrt{h^2 + \left(\frac{S}{2}\right)^2}$$
$$S^2 = h^2 + \frac{S^2}{4}$$
$$S^2 - \frac{S^2}{4} = h^2 = \frac{3S^2}{4} = h^2$$



$$y = S - \tan(30°).x$$
$$y = S - \frac{\sqrt{3}}{3}x$$

$$dm = d(p.y.x.z)$$
$$dm = d(yx)\, p.z$$
$$dm = d\left(Sx - \frac{\sqrt{3}}{3}x^2\right)pz.$$

$\delta x = \frac{0.5.3}{\sqrt{3}.3} = \frac{0.5}{\sqrt{3}} =$



$0.\cancel{33}$ 5

① $m_1 = \rho . \delta x . y(x) . 2$

$m_1 = \cancel{8.9484 \cdot 10^{-3}}\ Kg$ 0.017897

$I_1 = m_1 x_1^2 = 0$

0.33

② $m_2 = \rho \delta x\ y(x) . 2$

$m_2 = 0.01281$

$I_2 = 9.8438$

③ $m_3 = 5.9671 . 10^{-3}$

$I = \cancel{4.97 . 10^{-4}}\ 1.989 . 10^{-3}$ $T = \frac{0}{A}$ $A = \frac{0}{1}$

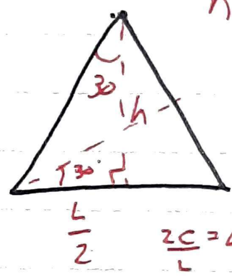
$I = 1.48 . 10^{-3}$

$3 \rightarrow 2.97 . 10^{-3}$

$30 \rightarrow 3.35 . 10^{-3}$

$300 \rightarrow 3.36 . 10^{-3}$

$3000 \rightarrow 3.36 . 10^{-3}$

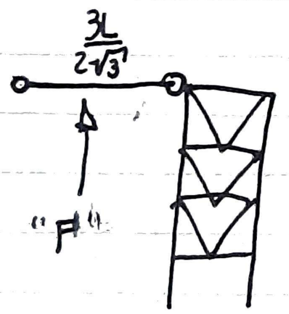


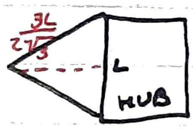
$h = \frac{L}{2 \tan(30)}$

$h = \frac{L.3}{2\sqrt{3}}$

$\frac{2c}{L} = \tan 30$

$c = \frac{\sqrt{3}L}{6}$





$A = 43.30\ m^2$

$I = 33.56\ Kg m^2$

$F = A\, P_{SRP} . (1 + S_{TATE})$

$P_{SRP} = 2.03 . 10^{-6}\ N/m^2$

$\therefore F = 1.76 . 10^{-4}\ N$

$C = 2.89\ M$

$\therefore T = 5.08\ NM\ (.10^{-4})$

$\therefore \alpha = 1.5137 . 10^{-5}\ rad/s^2$

$\delta\theta = \omega . \delta t + \frac{\alpha \delta t^2}{2} = 9.78 . 10^{-5}\ rad$

$c = \frac{\sqrt{3}L}{5}$

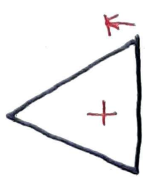
$\Sigma m r^2 = [Kg\, M^2]$

$[N] = [Kg \frac{M^2}{S^2}]$

$\cancel{[N S] = [Kg M]}$

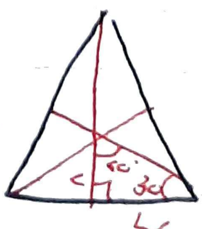
$\cancel{[\frac{Kg M^2}{S}] = [Kg M^2]}$

$[N S^2 M] = [Kg\, M^2]$



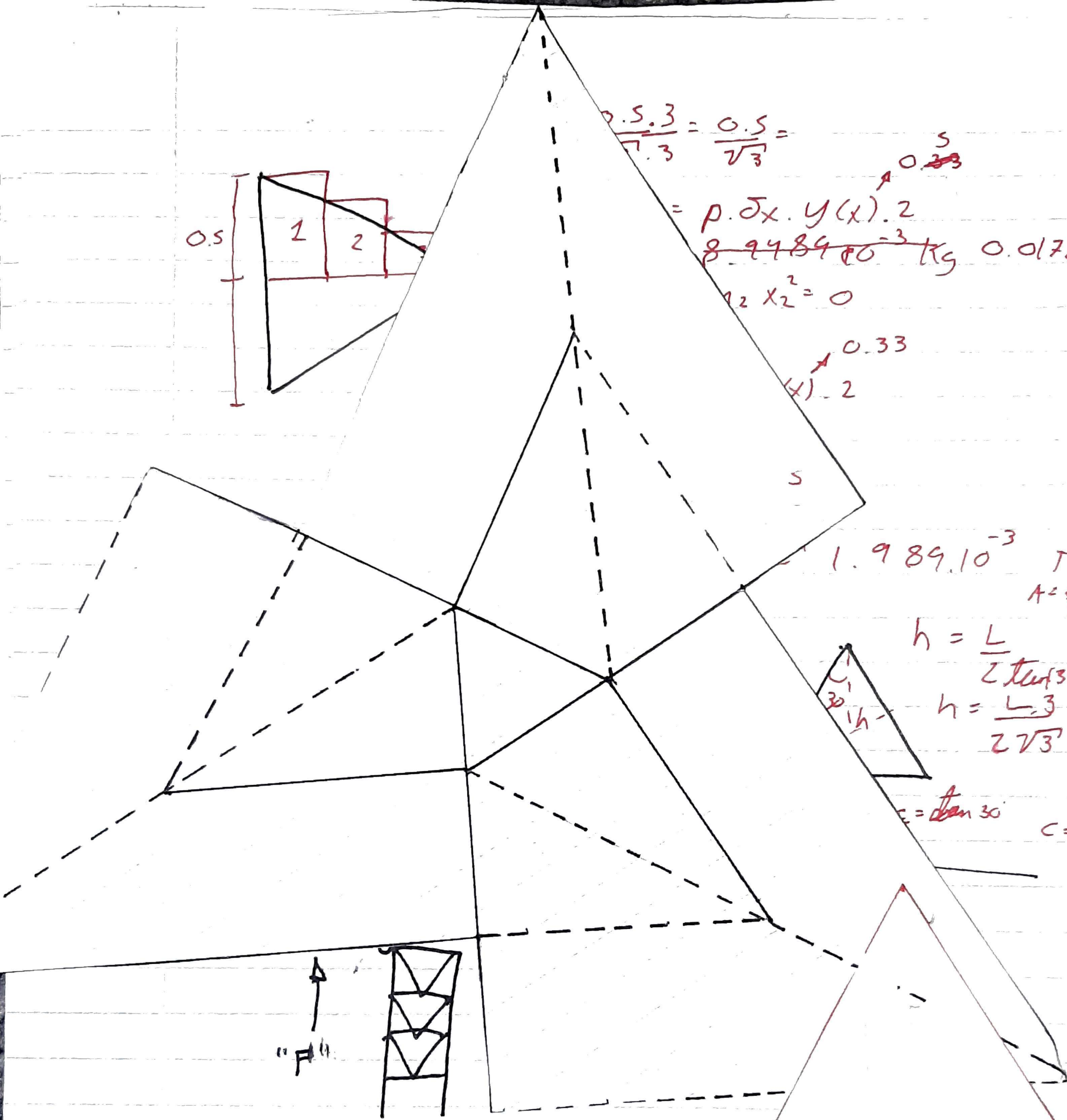
$T = I \alpha$

$\therefore I\ [\frac{NM}{rad/s^2}]$



$\frac{c}{L/2} = \tan(30)$

$2c = \frac{\sqrt{3}}{3} L$



$\frac{0.5.3}{\sqrt{}.3} = \frac{0.5}{\sqrt{3}} =$

$0.\cancel{33}$ 5

$= \rho.\delta x.y(x).2$

$\cancel{8.9484.10^{-3}}$ Kg 0.017897

$x_2 \; x_2^2 = 0$

0.33

$(x).2$

S

$1.989.10^{-3}$

$T = \frac{0}{4}$

$A = \frac{0}{1}$

$h = \frac{L}{2\tan(30)}$

$h = \frac{L.3}{2\sqrt{3}}$

$c = \tan 30$

$c = \frac{\sqrt{3}L}{6.}$

$A = 43.30\,m^2$

$I = 33.56\ kgm^2$

$F = A\,p_{SRP}.(1 + S_{TATE})$

$P_{SRP} = 2.03.10^{-6}\ N/$

$\therefore F = 1.76.10^{-4}\ N$

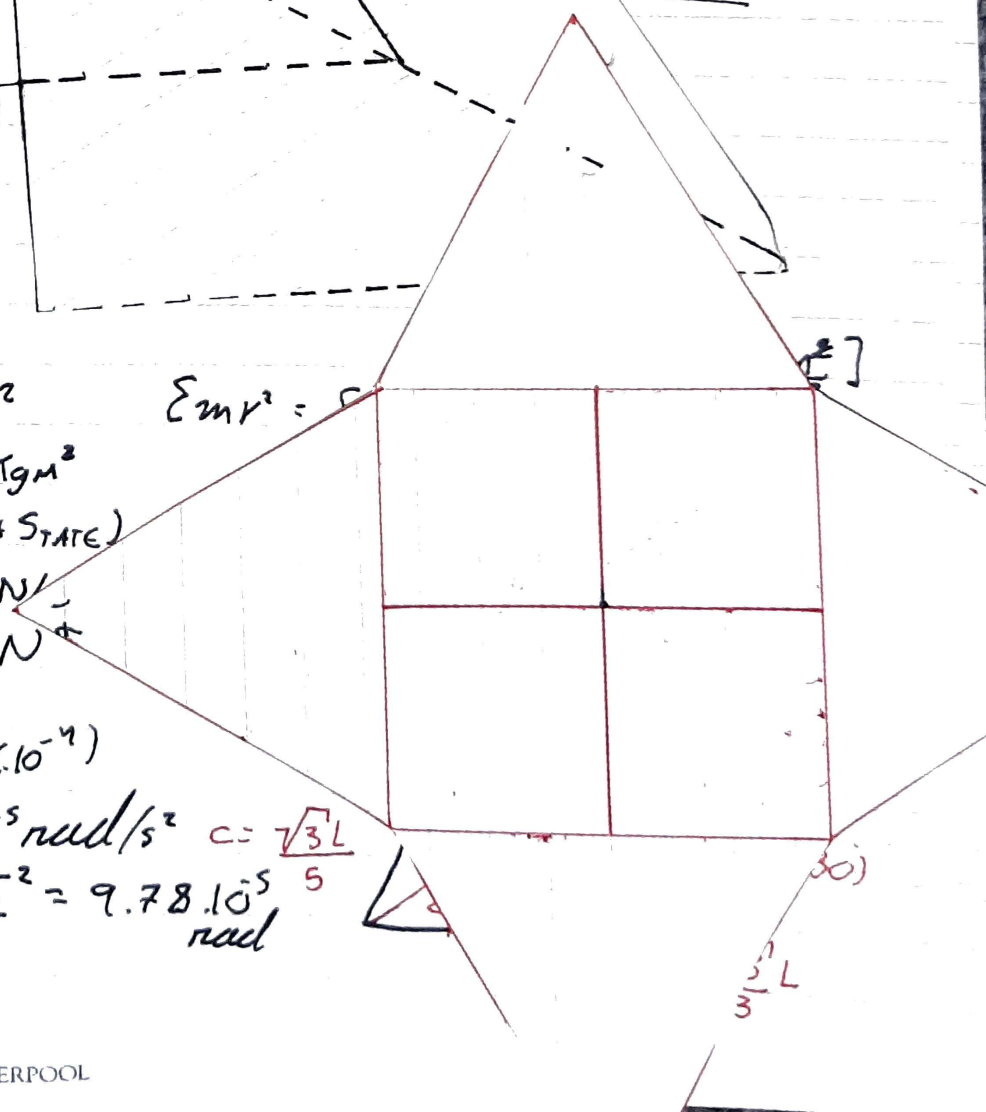
$C = 2.89\ M$

$\therefore T = 5.08\ NM\ (.10^{-4})$

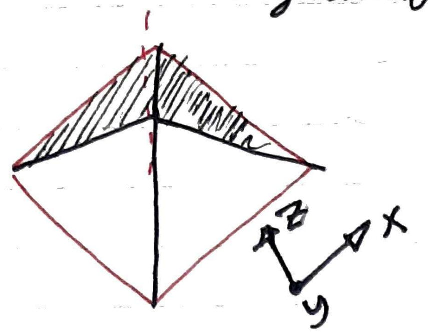
$\therefore \alpha = 1.5137.10^{-5}\ rad/s^2$ $\quad c = \frac{\sqrt{3}L}{5}$

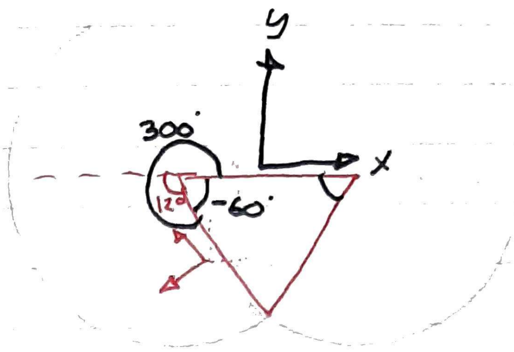
$\delta\theta = \omega.\delta t + \frac{\alpha\delta t^2}{2} = 9.78.10^{-5}$ rad

$\Sigma m r^2 =$



Pyramid deployment





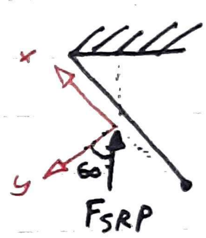
Use electrically controlled spring to make angle

When as a pyramid, $\theta = -120° = -2.09^c$

$T_s = C(\theta - \theta_{ref})$

$T_s = -C(-2.09 - 0)$

$T_s = 2.09C$



$T_s > T$

$\therefore\ 2.09^c C_{SR} > +\cos 1.05^c F_{SRP}$

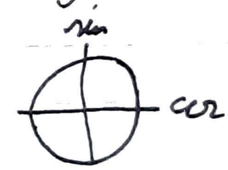
$2.09^c C_{SPR} > \frac{1}{2} F_{SRP}$

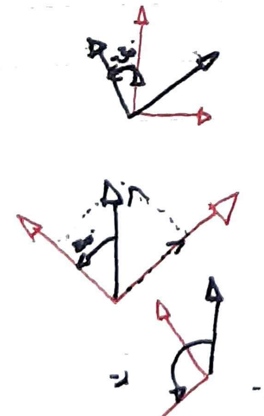
$C_{SPR} > \frac{1\ F_{SRP_T}}{2 \cdot 2.09}$

$y: -\cos 60°\ F_{SRP}$

$x: \sin 60°\ F_{SRP}$

$\therefore T = F_{SRP}\ y.C$

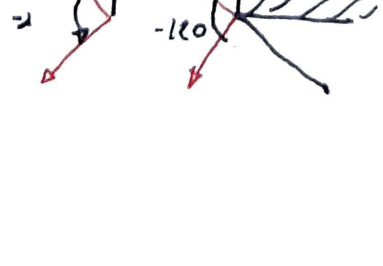




$y: \cos(30°) F_{SRP}$

$y: \cos(-120°) F_{SRP}$

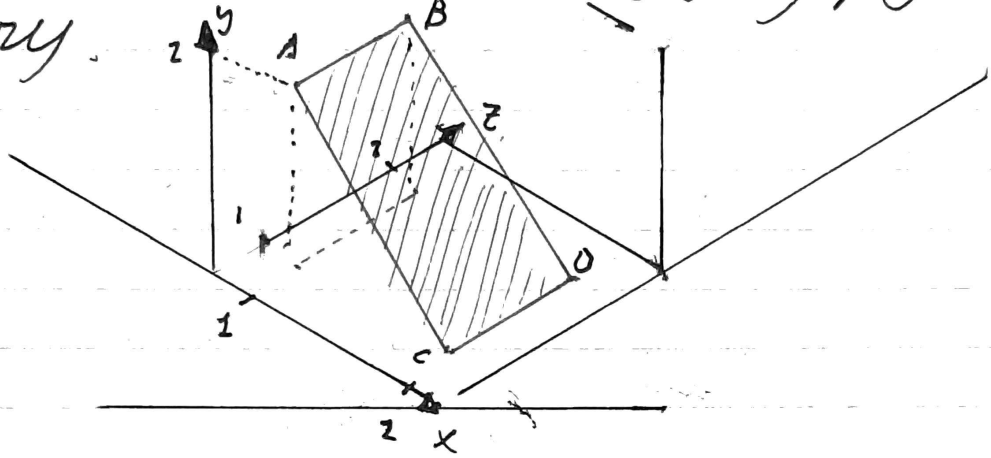
$= \frac{-1}{2} F_{SRP}$



$x: \sin(-120) F_{SRP}$

3D Rendering tests

→ At the proposal stage, the rendering method was a simple matplotlib vector plot based on the coordinates calculated in the simulation; a way to make it 3D is using Pylab's library.



A(1, 2, 1); B(1, 2, 2); C(2, 0, 1); D(2, 0, 2)

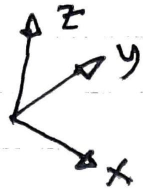
Correction: change frame from y z x to z y x as such:

A(1, 1, 2); B(1, 2, 2); C(2, 1, 0); D(2, 2, 0)

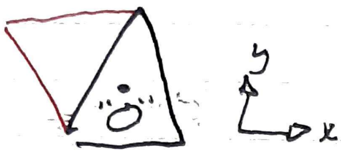
→ Movement may also be simulated by using matplotlib's animation library.

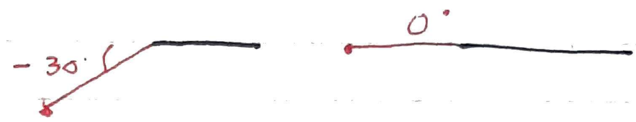
→ the test animating this is succesful. it will iterate through frame "n" where n is the time-jump at which convergence was detected.

- animation test: "Flappy" triangle with:

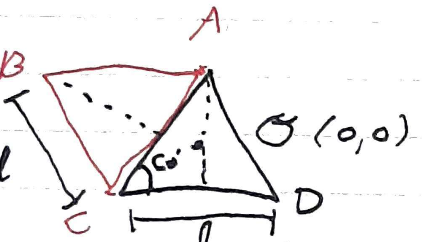


Frame 1. Frame 2.





Frame 3.



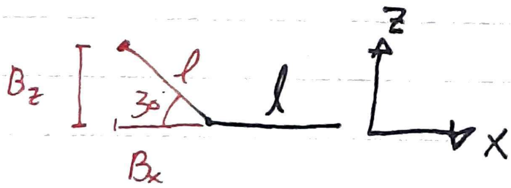
$A = (0, \frac{\sqrt{3}}{3} l)$ $C = (-\frac{l}{2}, -\frac{3-\sqrt{3}}{3} l)$

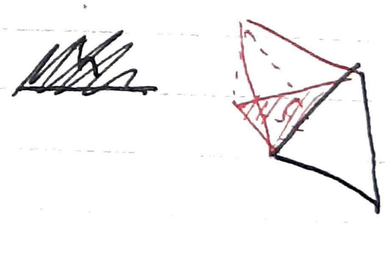
$B = (-l, \frac{\sqrt{3}}{3} l)$

$D = (\frac{l}{2}, -\frac{3-\sqrt{3}}{3} l)$

$$\frac{\sin 120°}{l} = \frac{\sin 30}{A_y}$$

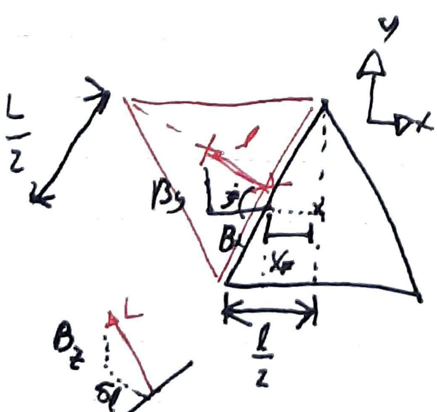
$$A_y = \frac{\sin 30}{\sin 120} \cdot l = \frac{\sqrt{3}}{3} l.$$





$B_z = \cancel{\cos}\ (30) . l = \cancel{\frac{\sqrt{3}}{2}} l$

sin α



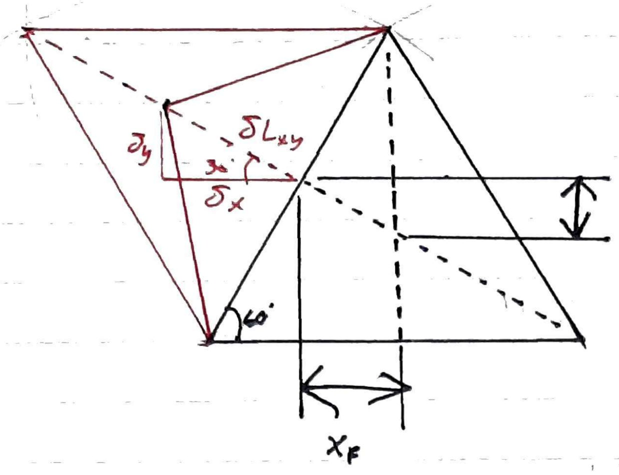
$X_F = -\frac{l}{2} - \cos(60°) . \frac{l}{2} = -\frac{l}{2} - \frac{1}{2}\frac{l}{2} = -\frac{3}{4} l.$

$l^2 = B_z^2 + (\partial L)^2$ & $\partial L^2 = B_x^2 + B_y^2$

$l^2 = B_z^2 + B_x^2 + B_y^2$

$\tan 30° = \left(\frac{B_y}{B_x}\right) = \frac{\sqrt{3}}{3}$ $\therefore l^2 = B_z^2 + B_x^2 + \frac{-}{9} 3 x^2$

$B_y = \cancel{\frac{\sqrt{3}}{3}} B_x$ $l^2 = B_z^2 + \frac{4}{3} B_x^2$



$$X_F : -\frac{l}{2} + \cos 60° \, \frac{L}{2} = -\frac{1}{4} l.$$

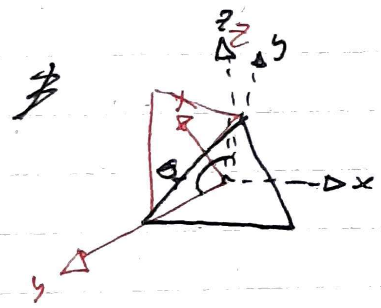
$$y_F : \frac{X_F}{\tan 60°} = \frac{-1}{4} l \cdot \frac{\sqrt{3}}{4} = \frac{\sqrt{3}}{12} l$$

$$\therefore h = \sin 60° \, l = \frac{\sqrt{3}}{2} l.$$

at ①, the point B should be at:

$$h_{cl} = \cos 30° \cdot h = \frac{\sqrt{3}}{2} \frac{\sqrt{3}}{2} l = \frac{3}{4} l.$$

$B(-0.\cancel{0}8495, 0.5193, 0.433)$
$\theta = 30°$



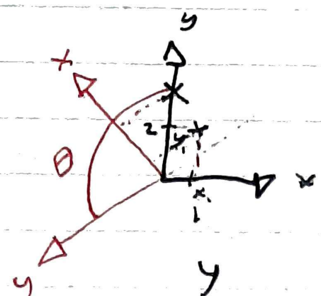
$$B_2 = B \cdot T_{0,2}$$

cloned triangle

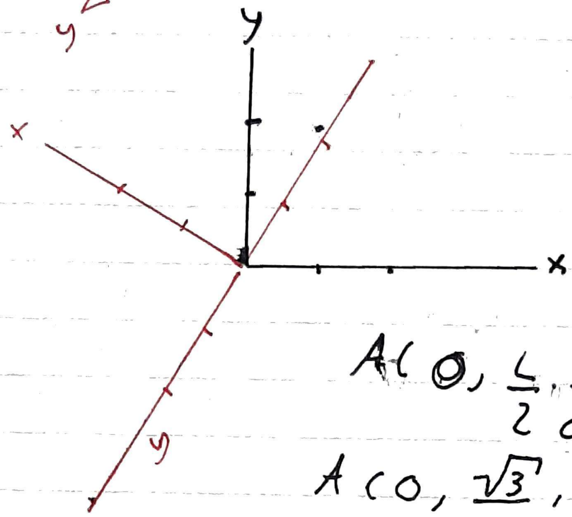
$$T_{02} = \begin{pmatrix} \cos\theta & -\sin\theta & 0 \\ \sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

let $\theta = 120°$

$$B_2 = \begin{pmatrix} -0.\cancel{0}8495 \\ 0.5193 \\ 0.433 \end{pmatrix} \begin{pmatrix} -0.5 & -0.866 & 0 \\ 0.866 & -0.5 & 0 \\ 0 & 0 & 1 \end{pmatrix} = \begin{pmatrix} 0.899 \\ 0.5193 \\ 0.433 \end{pmatrix}$$



$$\cancel{y_r} = \begin{pmatrix} \cos\theta & -\sin\theta & 0 \\ \sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} 1 \\ 2 \\ 0 \end{pmatrix} = \begin{pmatrix} -2.23 \\ -0.134 \\ 0 \end{pmatrix}$$



$$A\left(0, \frac{1}{2} \cdot \frac{1}{\cos 30}, 0\right)$$

$$A\left(0, \frac{\sqrt{3}}{3}, 0\right)$$

$$\begin{pmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{pmatrix} \begin{pmatrix} 0 \\ \sqrt{3}/3 \end{pmatrix} = \begin{pmatrix} -1/2 \\ \cancel{0.5} \end{pmatrix}$$

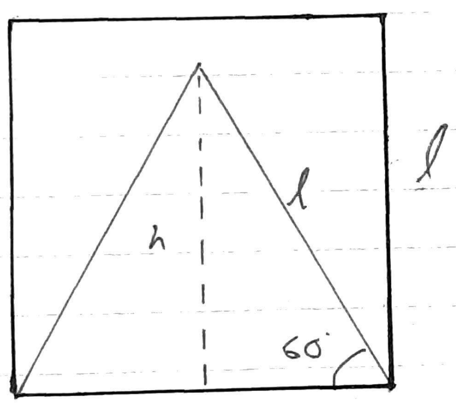
-0.289

Animation of multiple triangular components was a success.

→ Load up coordinate data per frame from interim report simulation

Future goal: make slider for selecting frame, display timestamp?

- Draw initial "Pyramid" shape:



$h = \sin 60° \, l = \frac{\sqrt{3}}{2} l$

at this position and $P_{SRP} = 2.998 \cdot 10^{-5}$ N/m²

$\therefore T = \cancel{1.87} \, 1 - 9.37 \cdot 10^{-4}$ NM

$T_s \geq T$

$T_s > -K(\theta - \theta_{ref}) \cdot \quad T_s > -K(2.09° - 0)$

$4.48 \cdot 10^{-4} \geq K$ NM/rad.

* After these tests, the program failed; there was no balance convergence due to the spring not being equilibrated.

M_{SRP} MAX: $7.495 \cdot 10^{-3}$ NM $= -T_{SRING}$

$T_{SPRING} = -K(\theta - \theta_{ref})$ let $\theta = 0$

$T_{SPRING} = +K\theta_{ref}$ let $\theta_{ref} = \frac{30\pi}{180}$

$\therefore K = 0.0143$

$P_{SRP} = 2.998 \cdot 10^{-5}\ N/m^2$ $A = 43.3\ m^2$

$\theta = 0.016^c$

$F_{SRP} = A \cdot \cos\theta \cdot P_{SRP} = 1.298 \cdot 10^{-3}\ N$

$F_{SRP} = 1.298 \cdot 10^{-3}\ N$ $s = 1$

$F_{SRP_{x,STATE}} = 2.598 \cdot 10^{-3}\ N$

$M_{SRP} = -7.49 \cdot 10^{-3}\ N$

$I = 33.56$

$M_{SPR} = -7.26 \cdot 10^{-3}\ NM$

$M_p = -14.75 \cdot 10^{-3}\ NM$

$M_p = I\alpha$ $\alpha = -4.\cancel{395}\,53 \cdot 10^{-4}\ rad/s^2$

$\Delta\omega = 3.\cancel{6} \cdot \alpha = -1.\cancel{58} \cdot 10^{-3}\ rad/s$

$\Delta\theta = -\cancel{2.85} \cdot 10^{-3}\ rad$ 63

$2.93 \cdot 10$

$\therefore \rightarrow \theta = 0.01288$

$\alpha_2 = -4.52 \cdot 10^{-4}\ rad/s^2$ $\omega = \cancel{0.0}$

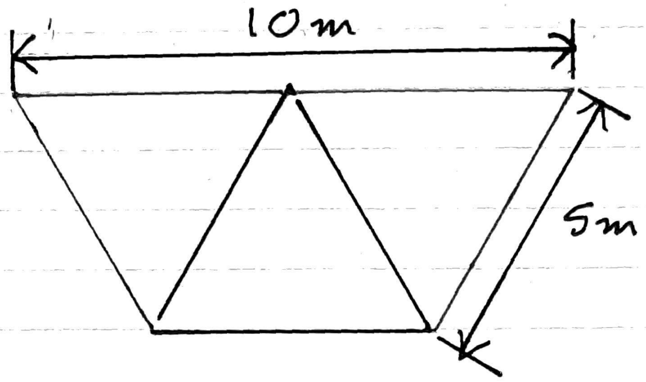
$\Delta\theta = 8.8 \cdot 10^{-3}\ rad$ $-4.87 \cdot 10^{-3}$

$\rightarrow \theta = 0.003971\ rad.$

$\alpha_3 = -4.48 \cdot 10^{-4}\ rad/s^2$

$\Delta\theta = -0.02$

Test: 10M base for whole sail.



Meeting 22/04 12:00

attendants:
- Stefania Soldini
- Aloisia Russo
- Ma'an Nazeer

Meeting is only for multi-body dynamics people.

Ma'an is joining the project as a MEng.

My tests and 3D presentations are useful and will suffice to show the concept, just a few changes:

- make suits of different filled in colours to denote the state,
- different states to denote asymmetry reachable
- if pressure in central hub is higher make it so it goes forth and drags other panels with them

- Lagrangian?

- Stefania asks if I can make renders of these for her presentation, yes I can. → before 28th

- synchronise my GIT with Stefania's bitbucket → Can Ma'an acces this?

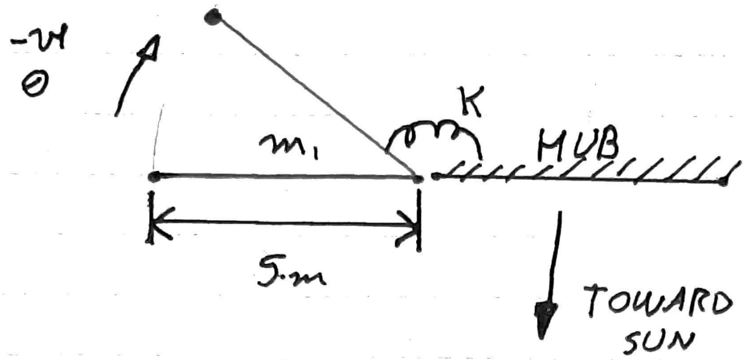
- For next meeting 29/04/21, I should have an index for ~~a~~ my final report.

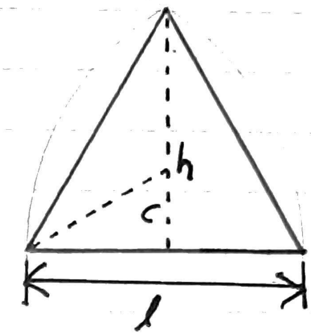
- Ma'am will do some more reading about the bibliography and get back to ~~us~~ us if there is any other questions

- Derive an equation for the minimum value of "K" needed as function

- Stefania may send us a lecture from Glasgow for a better understanding the name is Bonart.

Calculation: general spring behavior





$$h \cdot \sin 60^\circ = l$$
$$h = \frac{2l}{\sqrt{3}}$$

$$A = \frac{l \cdot h}{2}$$

$$\frac{c}{\frac{l}{2}} = \tan 30^\circ \qquad c = \frac{l\sqrt{3}}{6}$$

$$M_{SRP} = P_{SRP} \cdot \cos^2(\theta) \cdot A\,c$$

$$M_{SPR} = -K \cdot (\theta - \theta_{ref}) = K\,(\theta_{ref} - \theta)$$

* θ_{ref} may not be configurable, as it (the material) is manufactured flat as a roll, it would be impossible to control

∴ assuming $\theta_{ref} = 0^\circ$ [NM/deg]

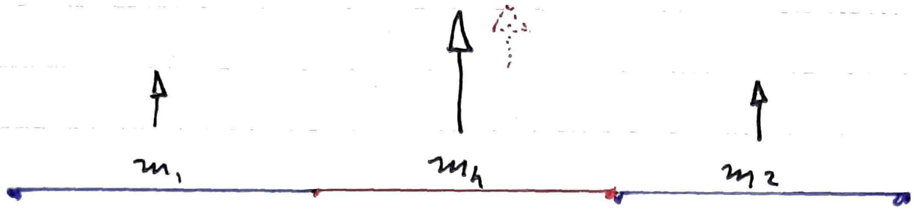
$M_{SRP} = M_{SPR}$ → Point of balance (convergeance)

$$P_{SRP} \cos^2(\theta)\, A.C = K(-\theta)$$
$$-\frac{P_{SRP} \cos^2(\theta)\, A.c}{\theta} = K \Rightarrow K(\theta, P_{SRP}, A, c)$$

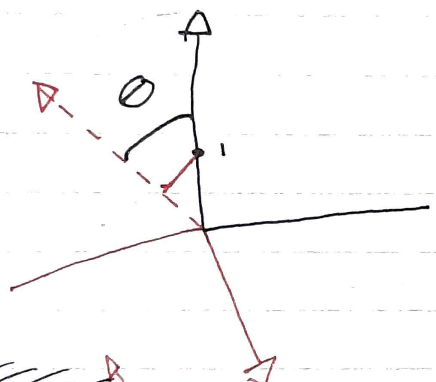
a function for K as a function of θ, P_{SRP}, A, c is derived.

At the limit, $\theta = -\frac{\pi}{2}$ rads, $M_{SRP} = 0$

Differential push - to use inertia to close form:

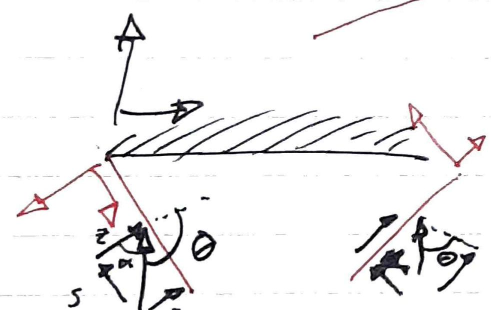


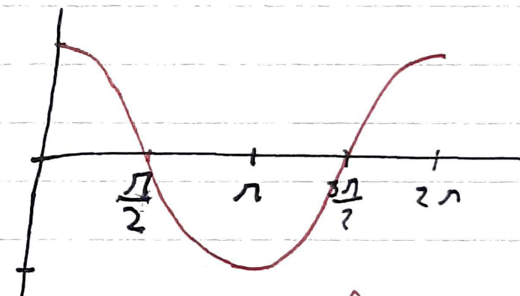
assuming $m_1 = m_2 = m_h$ then $F = ma$
and $F_1 = F_2$ and $F_1 << F_h$



$\theta = 0 \quad y \cdot y = 1 \quad x \cdot x = 1$

$\theta = 1.57 \quad y \cdot y = \cancel{0}\,{-1} \quad x \cdot x = -1$



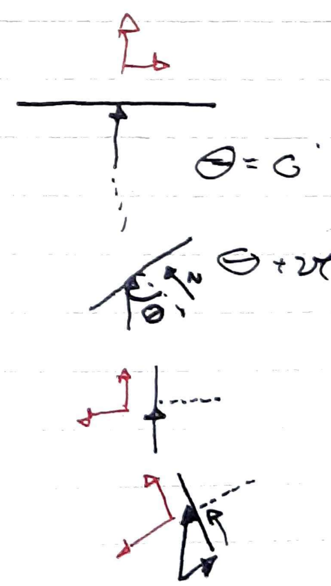


$z = -\cos(\alpha)\, F \qquad \alpha = 180 - \theta$

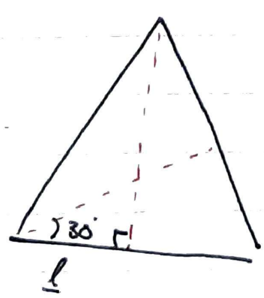
$s = -\sin(\alpha)\, O \qquad \sin(\theta) F = F_y$

$z = -\cos(180 - \theta)\, F$

$s = -\sin(180 - \theta)\, F$



$N = \cos\theta \, . \, F$

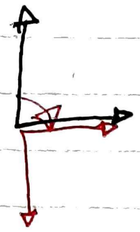
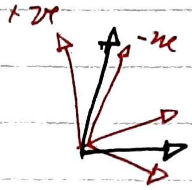


a positive SRP
gives more $+\Delta\theta$

$\frac{l}{2}$

~~sin~~ $\tan(30) = \frac{c}{\frac{l}{2}}$

$\frac{\sqrt{3}}{3} = \frac{2c}{l} = c = \frac{\sqrt{3}\, l}{6}$

02/05 → Review of Aloisia's and Bonar Rodd's presentations at CE II Workshop.

→ Based on manufacturing of the actual sail.

→ Materials constraint because of Ultimaker ABS and PLA? TPU 95A.

→ Membrane based rather than mechanical due to sizes being ~~too~~ small when working with mechanical hinges

→ Aluminized membrane.
→ Kapton → Polyimide film.
→ mylar

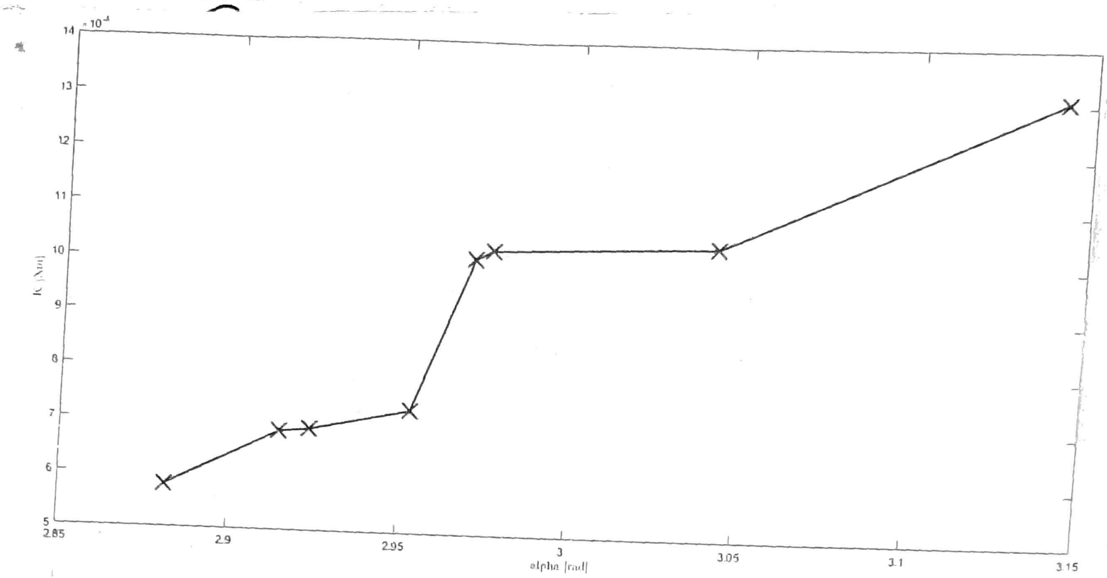
Some glues reacted badly when drying, and even corroded the material.

When temperature was normalised, the membrane developed wrinkles which could impact efficiency. These went away when put on the heating fan.

Aloisias' testing revealed that the spring K value can be between $6 \cdot 10^{-4}$ NM and $12.8 \cdot 10^{-4}$ NM.

This spring action can be achieved by thermal action → like a wire running electricity.

could the thermal behaviours be different in outer space?



Questions:

- How can the environment attack the materials? <u>High energy particles.</u>

- Heat radiation? How easy could it be to "cool-down"
  - temp is around <u>50°C</u>

Bonar Robb's Glasgow James Watt Dept.

→ Bonar used a Ray-tracing technique.

→ all modes have one body attach? to the hub, non-concentrical structures.

Uses an external frame so the system can be seen moving.

→ Considers the hub as moveable, so the hub can be ~~in the~~ enclosed by the advancing panel.

→ Discussion on how this may be tested on Earth at 0g, vacuum with a lamp. Compare and discuss this?

Good points for discussion.

Jade's Final Report guidance video:
03/05/21

- Proposal was 5% (100/100)
- interim was 10% (98/100)
- Final report 50%
- Underlying Project work 20%
- Logbook 10%
- Poster day? 20%

85%

- Cover sheet
- Summary
- table of contents
- table of notations

Table of contents:

" " of notations

P	pressure	$\frac{kg\,m}{s^2 m^2}$

1. Introduction
   - 1.1. Background
   - 2.2. Aim and Objectives
   - 1.3. Project approach.

Background:

- Describe the field of eng. at which the project pertains.
- Why is it important
- Practical usage.
- Specifics of your project

Give context.

Aim and Objectives
Quantify, measureable
4-6 items
they should justify the WBS.

to be analysed in the conclusion of the final report.

- Project approach: tools, techniques
People, Partners, Industry, facilities

$\boxed{2}$ Literature review.

$\boxed{3}$ - Presentation "of" Results
- Conclusion.

There must be evidence of good project management. (Gantt chart.

x. References HARVARD/ APA

x+1. appendices

MAX 30 PAGES

→ Big data, tables.

Technical writing guidance:

→ target audience.

→ Be self-critical

→ third person past tense

Supervisor and assesor: Engineers with no specific knowledge of this subject.

Precise, unambiguous

Have somebody to proofread.

Label figures and tables.

→ Refer to DBT

Remember to use references on fig labels if not yours.

→ Use subheadings for better story telling