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 feasibility 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-field. → Where to find it?
→ Book "Large Space structures: Dynamics and control"
→ Convince the library to get it?

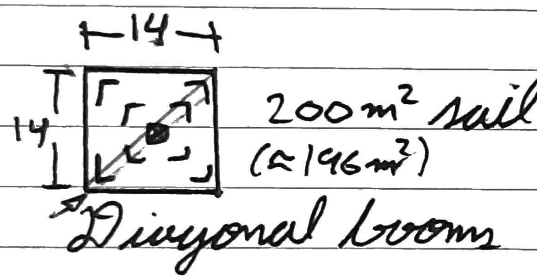
* There is a proposal due on the 1st of november. Does it have to be independent?

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

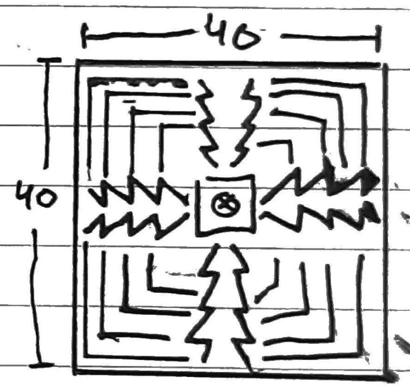
1st literature review:

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

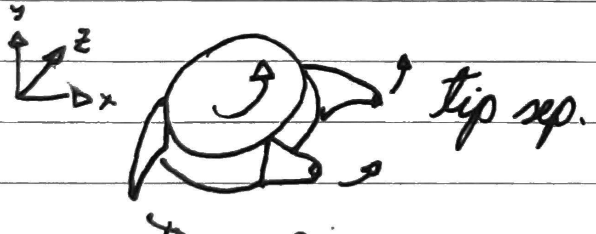
- The first mission to use sail technology was the IKAROS in 2010 by JAXA. Sail probe is in Venus.
- IKAROS used a boom-supported sail to deploy its sail.
- For larger sails, booms and their mechanism become to heavy to be useful, so a centrifugal approach is taken.

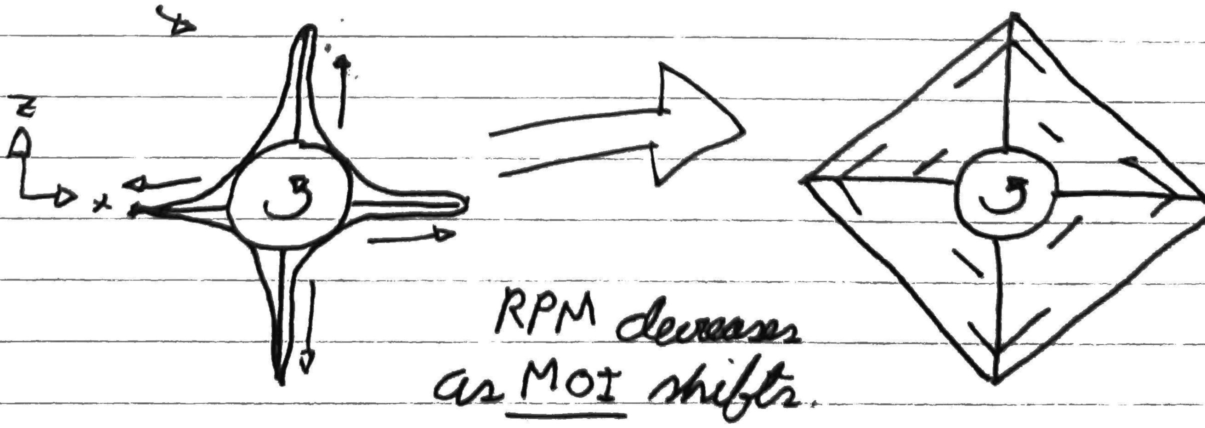


IKAROS



オケアノス
OKEANOS

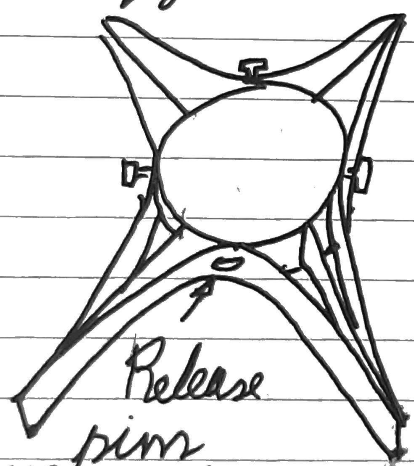


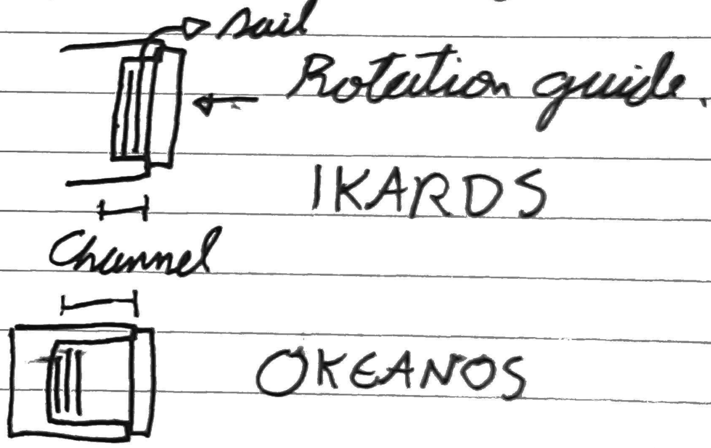


RPM decreases as MOI shifts.

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."

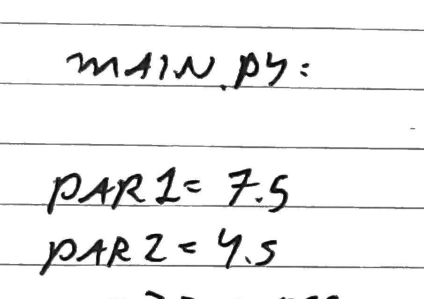
MAIN.py:

PAR1 = 7.5
PAR2 = 4.5
PAR3 = 0.055

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 = PAR3
distance = 0.1
number of NODES = 10.

* Triple FOR loop = 11 elements "NODES" = $11^3 = 1331$



cycles

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

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 parameter" 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... maneoveres 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 torque from scratch to de-orbiting

→ Sam and Jack 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

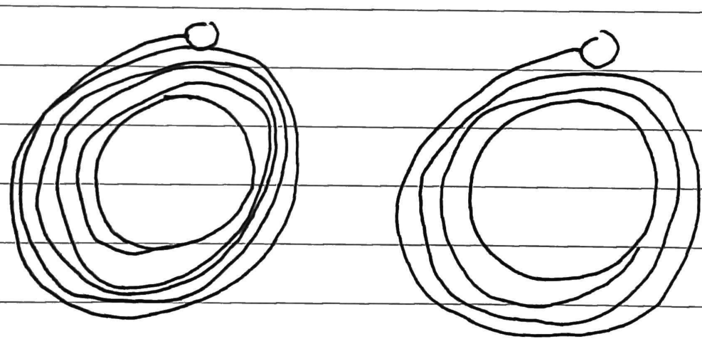
- Introduction
  - Background:

① Satellite story, first uses and sizes.

→ Sputnik

→ Vanguard I

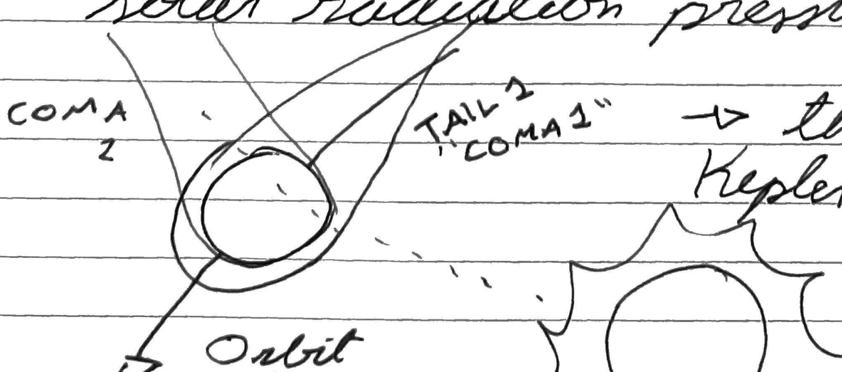
→ First use of solar energy, 1958



Expected: 2,000 years

Got: 240 years (Est)

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



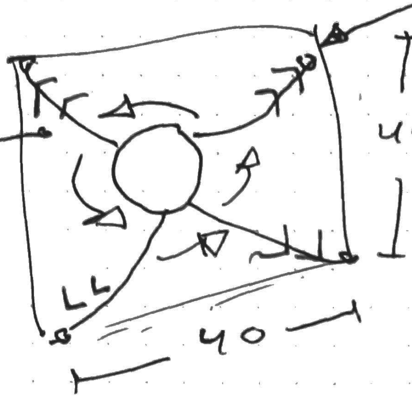
→ the coma

Kepler theory.

IKAROS EXPERIMENT by JAXA.

centrifugal mass
500g

$W = 2kg$



$p \approx \frac{2kg}{196 m^2} =$

$= 10 g/m^2$

$t = 7.5$ MM
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?

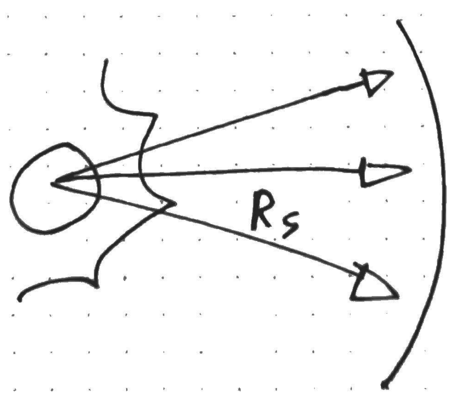
$\boxed{\rightarrow 0.72 AU}$

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

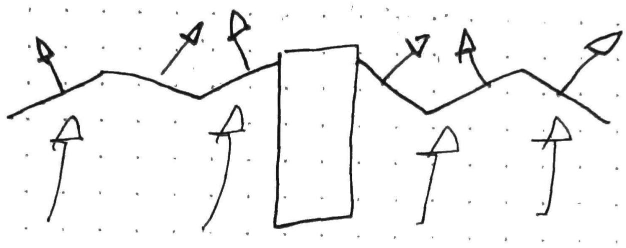
$P = 4.58 \cdot 10^{-6} \left(\frac{1AU}{0.72AU}\right)^2$

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

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

?

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 uses the "cannon ball" model mode?

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. c/m
→ identity M.
→ mass.

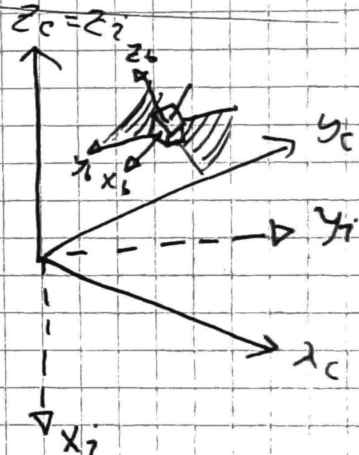
Euler eq. → rotational

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

→ speed
→ MOI   body ref.
→ acc.

Curtis Howard 2007 Orbital mech 4 Eng stud

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



Eq. motion

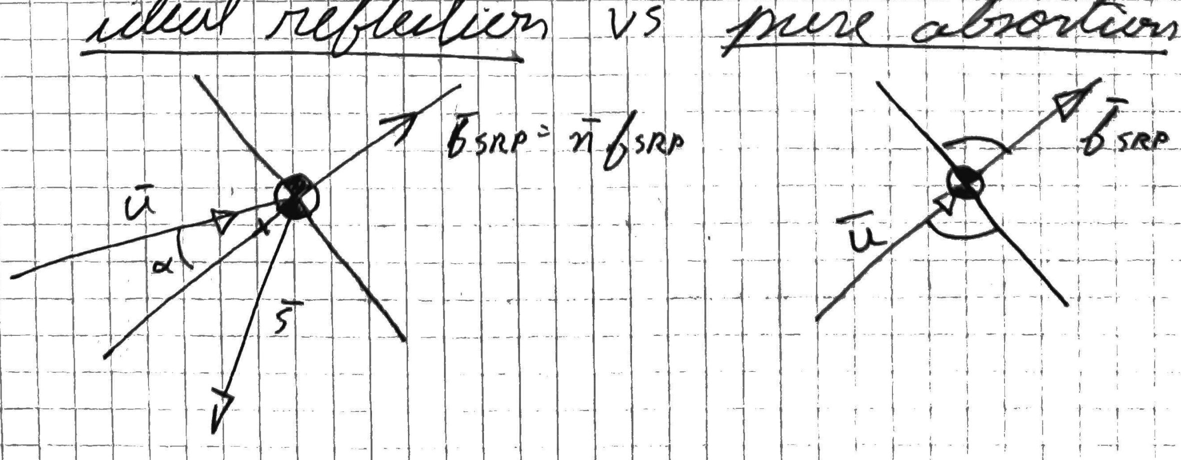
$\ddot{x} = \frac{\partial U}{\partial x} + 2\dot{y}$

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

$\ddot{z} = \frac{\partial U}{\partial z}$

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.

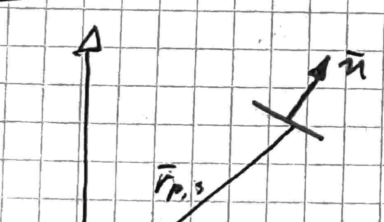
$$\frac{\bar{F}_{SRP}}{|F_{SRP}|} = \frac{\bar{F}_a}{F_a} = \hat{u} \text{ normalised.}$$

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

I.R

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

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



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

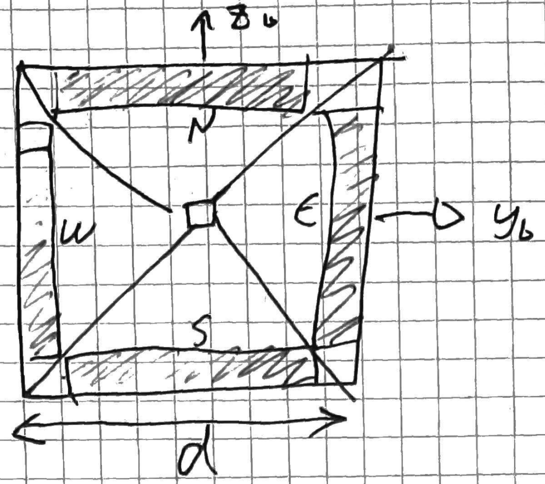
$$\hat{u} = \frac{\bar{r}_{pS}}{\|\bar{r}_{p,S}\|}$$

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

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

2

let:



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

$$\bar{q} = [\bar{q}_{3\times1}^T \;\; q_4]^T = \vdots = (\vdots) \quad 2\times3.$$

$\bar{q}$ = attitude quaternion $= (\cdots)^T = \vdots = \begin{pmatrix} \bar{q}_1 \\ \bar{q}_2 \\ \bar{q}_3 \\ q_4 \end{pmatrix}$

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

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

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

Using quaternions prevents singularities

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

$$\begin{cases} \dfrac{d\omega_x}{dt} = \dfrac{M_{x_{NET}}}{A} - \dfrac{C-B}{A}\,\omega_z\omega_y \\[2ex] \dfrac{\partial \omega_y}{\partial t} = \dfrac{M_{y_{NET}}}{B} - \dfrac{A-C}{B}\,\omega_x\omega_z \\[2ex] \dfrac{\partial \omega_z}{dt} = \dfrac{M_{z_{NET}}}{C} - \dfrac{B-A}{C}\,\omega_y\omega_x \end{cases}$$

MOI along
A x_b
B y_b
C z_b

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

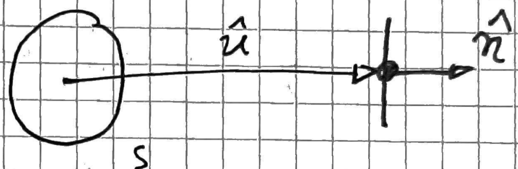
the state of the reflectors is assumed to be binary. Heaviside step funct

$$H(t) = \dots$$

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

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

$\hat{x}, \hat{y}, \hat{z} \rightarrow$ 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 ~~$\hat{x}$~~ $\hat{y}$ 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

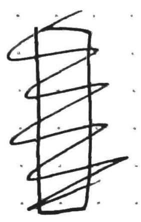
start from here Soldini will send me the presentation !!

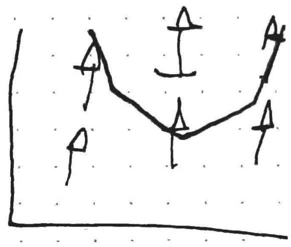
meeting 12/11/20

→ 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: Aleksander's reports w/ "Gimball Lock"

- First start with transformation matrices

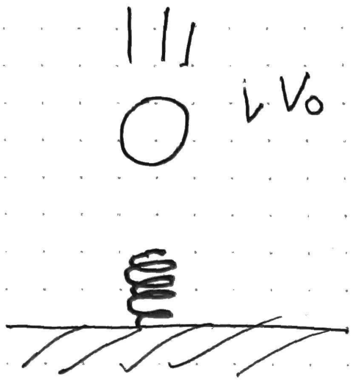
meeting 11/12/20

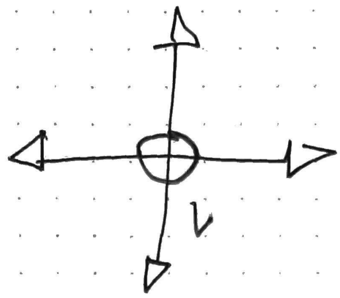
1-on-1 w/ Soldini.

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

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

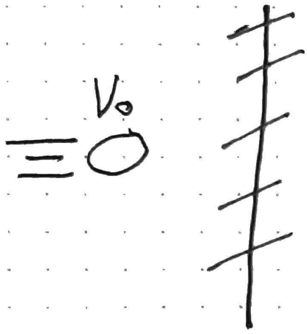
→ check ref 1. for SRP formulae.





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

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



time-to-stop: Kinectical energy is drained.

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

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

$\cancel{M_s}$ $\qquad \alpha_s T_s = \omega_{\cancel{RA}SRP}$

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

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

$0 \to -0.1$ rad is achieved in 300 s, therefore $\quad M_{SRP} = -\frac{\omega_{SRP}I}{\cancel{I}T_s} + \frac{M_{SRP}I}{I}$

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

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

$M = I\alpha$

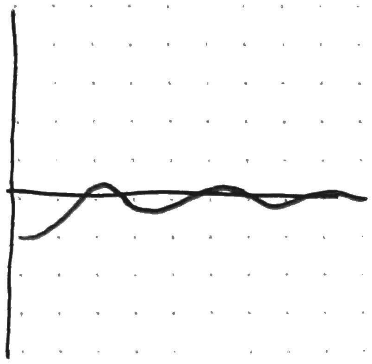
$\alpha = \frac{\omega}{300} =$

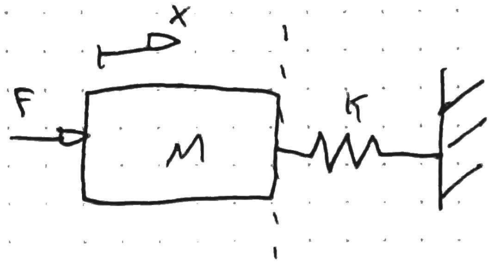
$C(\theta) = M_{SRP(\theta)} - \frac{\omega_{SRP(\theta)}I}{T_s}$

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

$C_\theta = -\infty$

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





$am = F - Kx$

$am = F - Kx$

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

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

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

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

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

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

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

$ma'' -$

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

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

at $u = 0$ $x = 0$

at $u = 5N$

$-5N = Kx$

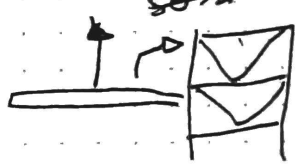
$x = 1.67$

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

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

$v = 0$

~~sent~~ 0.10 rad/s



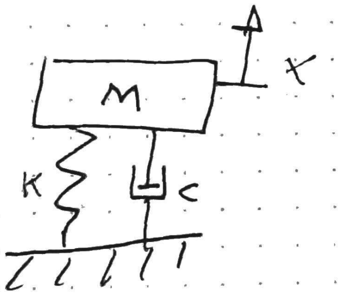
$a = 0.10°/s^2$

$t = 0.01s.$

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

$\theta = 1.10^{-3} - 5.10^{-6}$

$\theta = 9.95.10^{-4}.$



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

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

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

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

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

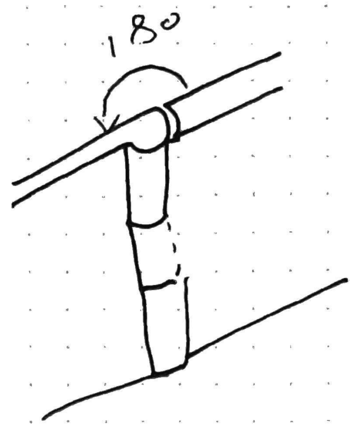
$m\ddot{x} + Kx + 0\dot{x} - F_{xt} = 0$

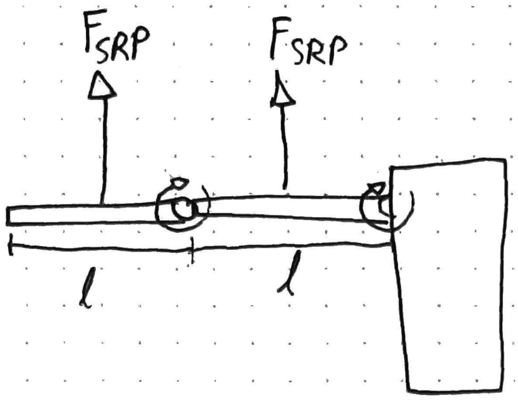
$\ddot{x} + 0\dot{x} + \frac{K}{m}x = \frac{F_{xt}}{m}$

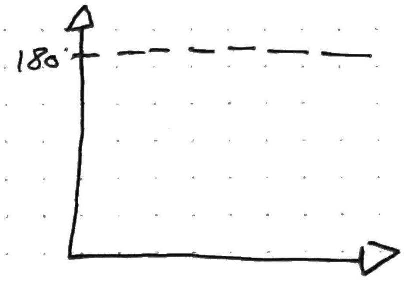
$\omega = \sqrt{\frac{K}{I}}$

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

$\xi = 0$ Ever oscillating



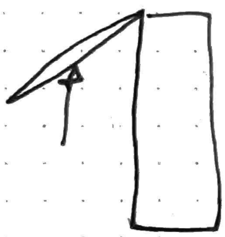




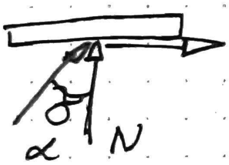
atn = 1

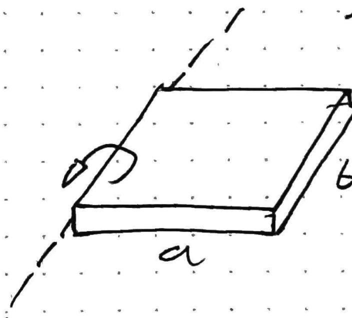
$F_{SRP} \cdot \frac{l}{2} = M_R$ $\qquad M = I\alpha$

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



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



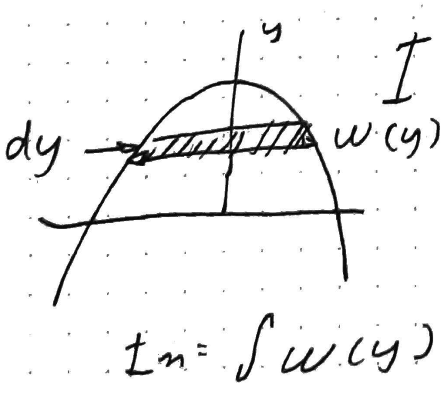


$\boxed{I = \frac{1}{3} M a^2}$

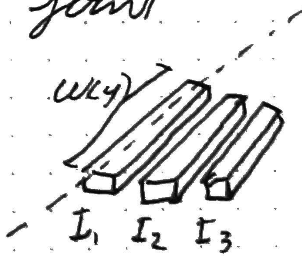
$\cos\alpha = \frac{A}{H}$

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

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



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

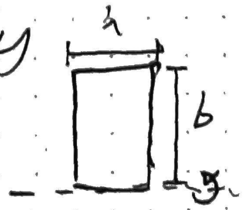


$I = \sum I_N$

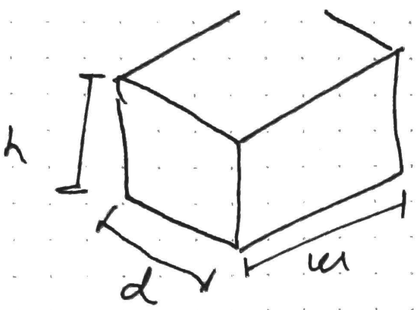
$I_1 = \underbrace{\underbrace{\underbrace{w(y)dy}_{\text{area}}\, \rho}_{\text{mass at point}}\, y}_{\text{Inertia}}$

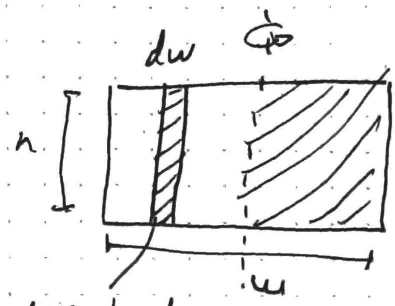
$I_n = \int w(y) y^2 \rho\, dy$

For a rectangle slab



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





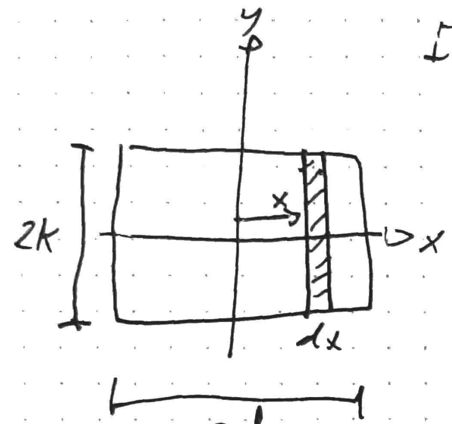
$dw \cdot h \cdot d \cdot \rho$

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

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

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

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



$\Delta m x^2$

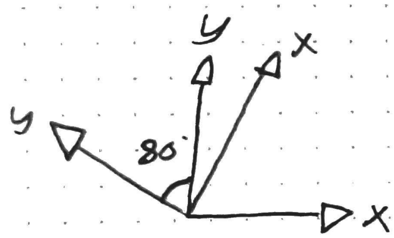
$\rho = t\rho$

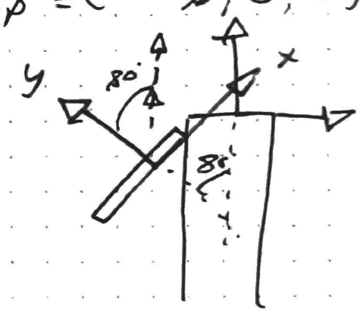
$\Delta m = dx \cdot 2K \cdot t \cdot \rho x^2$

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

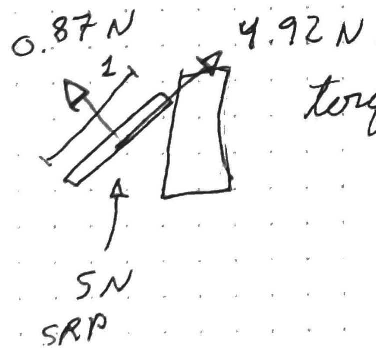
$\cancel{F_{SRP}}$

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





$\tau = ds$



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

$[\alpha] = \left[\frac{NM}{Kg\,M^2}\right] = \frac{N}{Kg\,M} = \frac{\cancel{Kg}\,\cancel{M}}{\cancel{Kg}\,M\,S^2} = \frac{1}{S^2}$

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

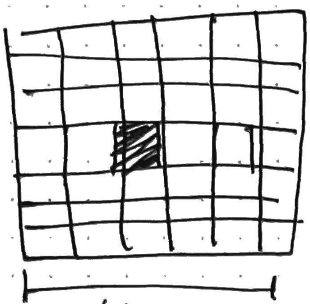
$\omega = \alpha t$

$\omega =$

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

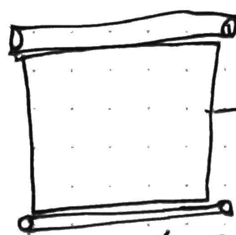
$\theta = \omega_0 t + \frac{\alpha t^2}{2}$ $\quad \omega_{B_2} = \omega + \alpha T$

0.70



4.24

$1.8\, m^2$



$\boxed{15\, kg/m^2}$

→ $A = 0.49$
$m = 7.35\, kg$

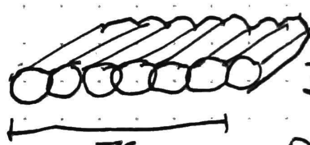
Foil: $2.71\, g/cm^3$

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

$7.5\,\mu m$ thick

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

$V = 2.45 \cdot 10^{-5}\, m^3$
$V\ \cancel{m} = 24.5\, cm^3$
$m\ \cancel{V} = 30.38\, g$



$50\,\mu m$

70cm

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

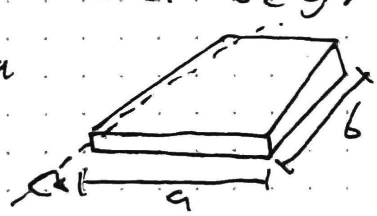
$\rho = 6.2 \cdot 10^{-5}\, \frac{gm}{cm^3} \cdot \frac{1 \cdot 10^6\, cm^3}{m^3}$

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

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

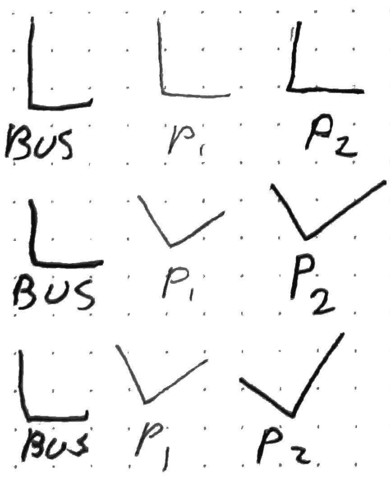
$\rho_{panel} = 0.062\, kg/m^2$
$= 62\, g/m^3$ //

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



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

$[Nm] = [kg\, m][\frac{m}{s^2}]$
$= [kg \frac{m^2}{s^2}] = [Nm]$



turn P_1 0.52^c

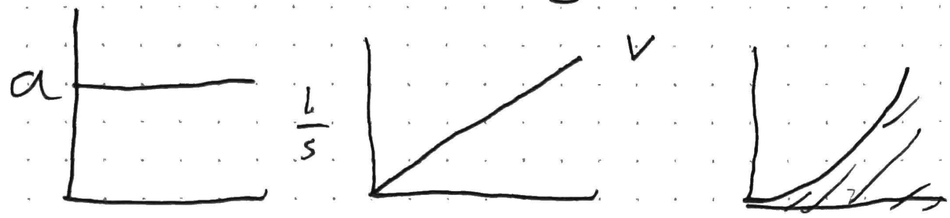
turn P_2 0.52^c

P_c should be 1.047^c ccw from Bus

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

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

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



$\theta = W_0 t + \frac{\alpha t^2}{2}$

$\underline{2\theta} = 2W$

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

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

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

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

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

$d = at^2$

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

$t =$

$\theta = W_0 t + \frac{\alpha t^2}{2}$

$\therefore$ $2\theta = 2W_0 t + \alpha t^2$ $\quad \alpha t^2 + 2W_0 t - 2\theta$

$2\theta = (2W_0 + \alpha t) t$ $\quad \frac{-2W_0 \pm \sqrt{4W_0^2 + 4\alpha.2\theta}}{2\alpha}$

$\cancel{t = 2\theta}$

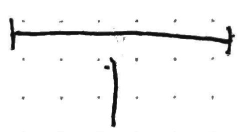
$\alpha = 2\,rad/s^2$

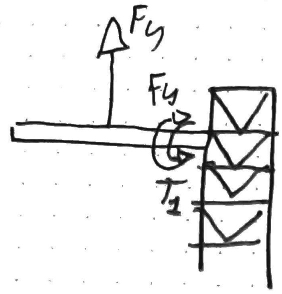
$\theta = 0,349^c$

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

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

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



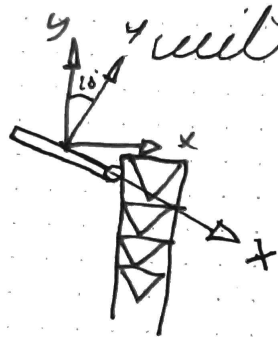


a torsional spring acts at the root, as such:

$M = T_R - F_{My} = 0$

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

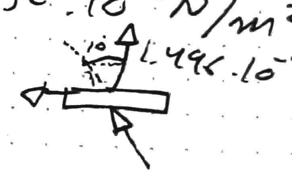
C is the spring constant ~~at which~~ with units $\left[\frac{N}{rad}\right]$,

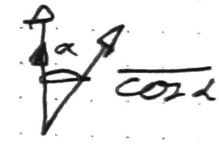


with a sun-bus angle of 30° and distance 1.5 AU,

state = θ

$p = 1.92 \cdot 10^{-6} N/m^2$





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

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

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

$M_C = M_{SRP}$

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

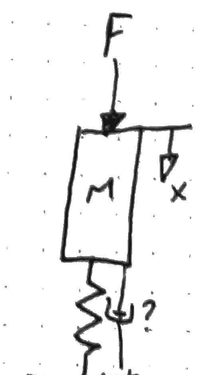
$C(0.1745 - \theta_r) = 7.48 \cdot 10^{-7} NM$

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

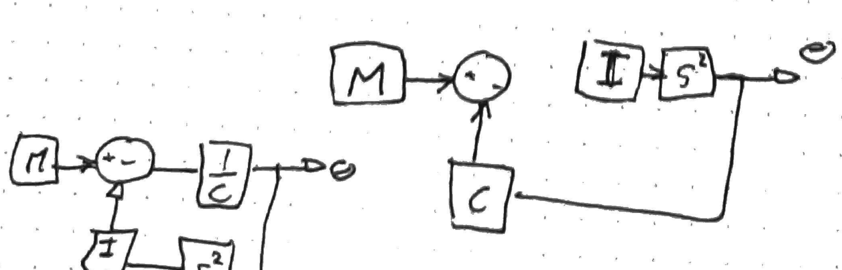
BUS is 30° ACW, SUN

FRAME IS 10° CW, BUS

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



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



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

$I\alpha = M - C\theta$

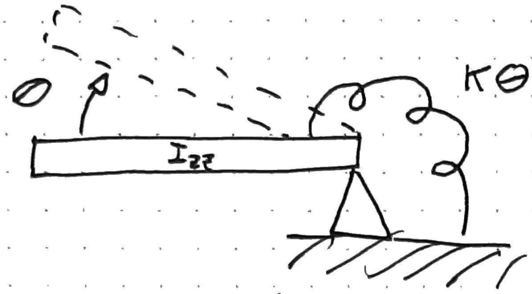
$I\ddot{\theta} = M - C\theta$

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

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

Meeting with Aloisa 29/1/21

→ In regards to the dynamic system I found:



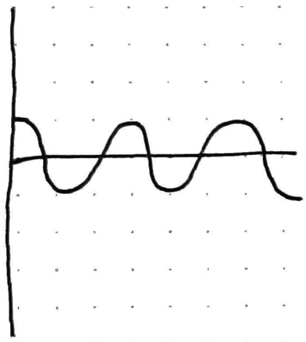
$M = I\alpha = I\ddot{\theta}$

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

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

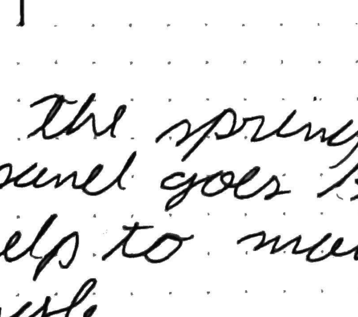
$\therefore \quad I\alpha = \underbrace{I\alpha_{SRP}}_{M_{SRP}} + (-K)\theta$

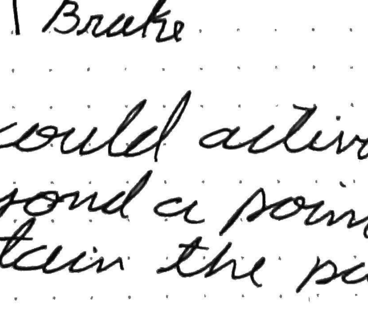
$I\ddot{\theta} = F_{eq}(\theta)\frac{l_z}{2} - K\theta$ where $F_{eq\,SRP} = P_{SRP} A\cos\theta$



← no dampening?

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



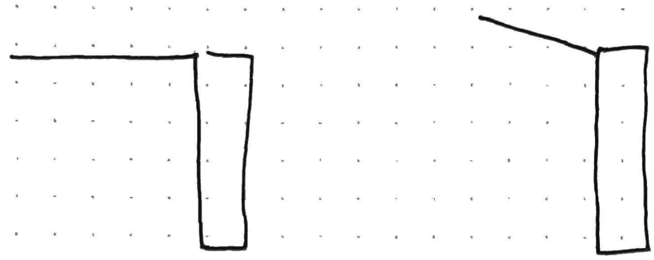


→ maintain normal to the sun.

→ Bring to 0°

↓ Brake

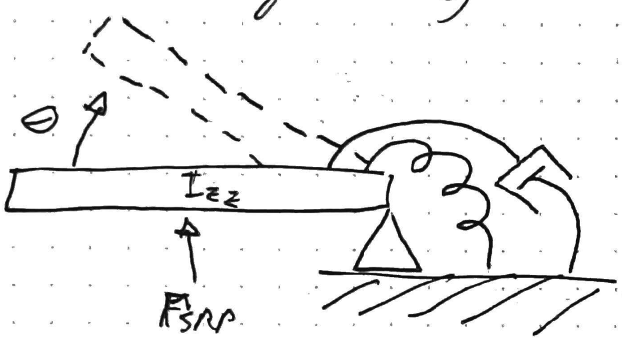
The spring could activate when the panel goes beyond a point, and should help to maintain the panel at an optimum angle.



0° → maximum force

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

→ Passive dampening



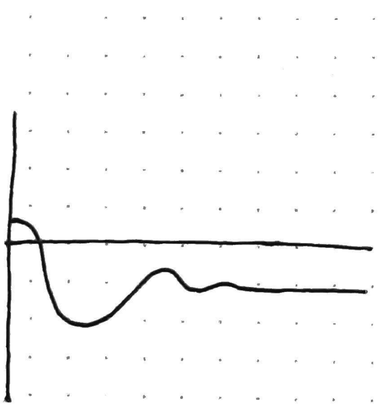
$$I\alpha = M_{SRP}(\theta) - K\theta - C\omega$$

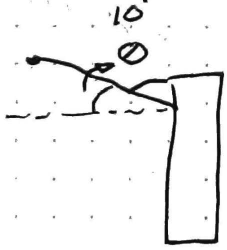
$$I\ddot{\theta} + C\dot{\theta} + K\theta = M_{SRP}(\theta)$$

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

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

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



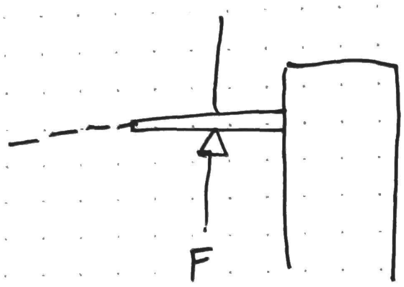


Will converge in a less-than-optimal angle.

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

EQUILIBRIUM

ADJUST M_{SPRING}?



$a_x = 0.5 m$

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

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

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

$M_S = C(\theta)$

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

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

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

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

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

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

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

$M_T = M_P + M_S$

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

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

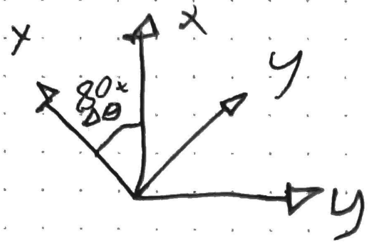
$a^S = \beta \frac{M_{SUN}}{r^2}$

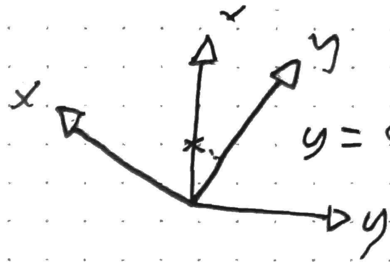
#15 reference.

IKAROS → travelled with normal engines

an

→ get angle between panel to bus
→ re-orient frame $\Delta\theta$ per iteration

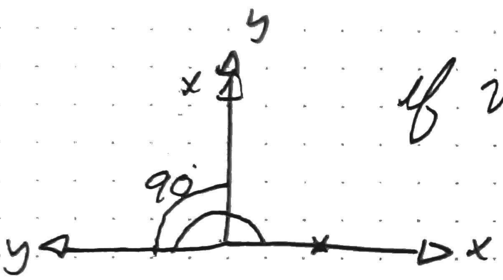




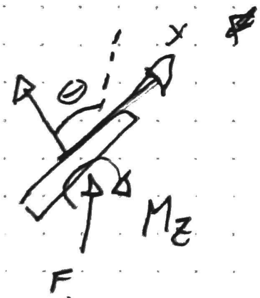
$y = \cos(90-\theta)P$
$x = \cos(\theta)P$

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

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



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



F.express(PANEL FRME)

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

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

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

$M_z = l_x . F_y$

$M = F . l_F = \begin{pmatrix}F_x\\ F_y\\ F_z\end{pmatrix}\begin{pmatrix}0\\ 0\\ 0\end{pmatrix}$ → moments

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

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

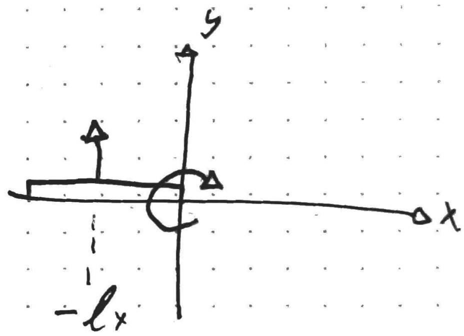
M must be -ve.

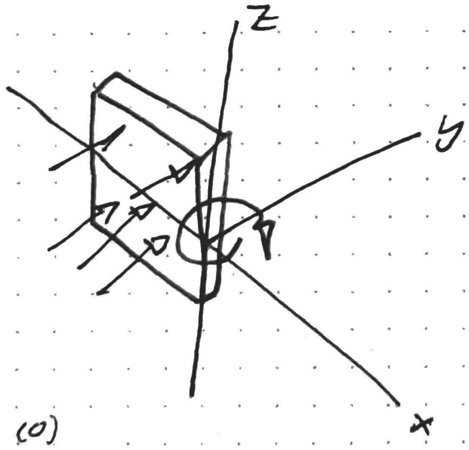
$$\alpha = \frac{M}{I}$$

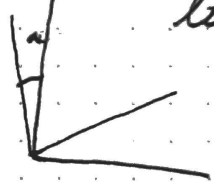
$$M = F.dl \qquad \begin{pmatrix}\tau_x\\ \\ \end{pmatrix}\Bigg($$

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

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







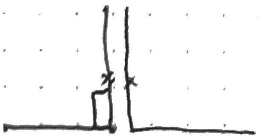
tan

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

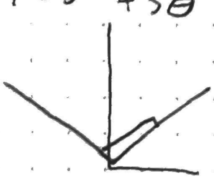
$$\underline{a} \cdot \underline{b} = |a||b|\cos\theta$$

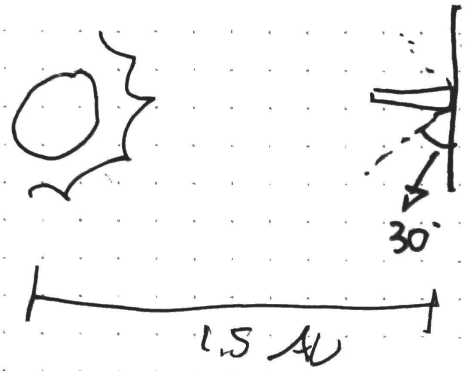
(0)

+cX +sx



+cθ +sθ ct-sθ





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

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

$A = 0.49\ m^2$

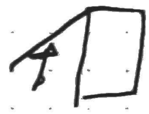
State : 1 $\quad F_T = 1.99 \cdot 10^{-6}\ N$

$M_{SPR} = -k\theta$

$= -4.29 \cdot 10^{-6} \cdot 30°$ $\cancel{NM/deg}$ 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 $= \cancel{8.28} \cdot 10^{-6}$

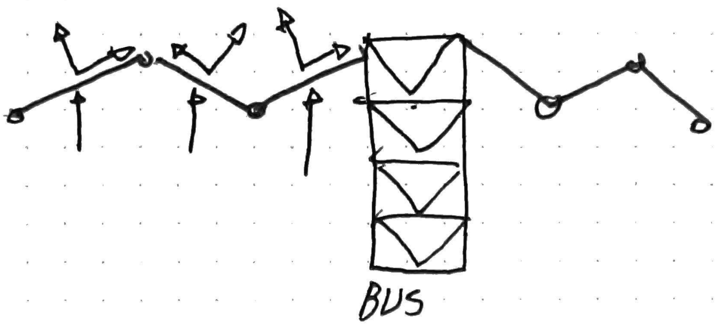
$I = 7.09 \cdot 10^{-3}$; $\alpha = \cancel{-2.32 \cdot 10^{-4}}$ $\frac{rad}{s^2}$ $\quad \alpha = -4.02$

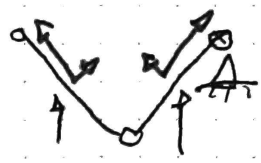
$\theta = \frac{\alpha T^2}{2} = 2.607 \cdot 10^{-3}$

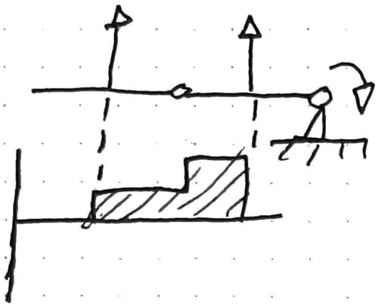
(I) NO FINAL RESULT

(II) SPRING ACTUATED
$F_T =$

(III) DAMPENED at $\xi = 0.45$
$F_T = 3.92$ mN



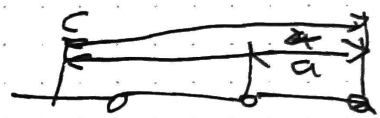




$F_{SRP_1} \cdot \frac{d_1}{2} + F_{SRP} \cdot \frac{d_2}{2}$

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

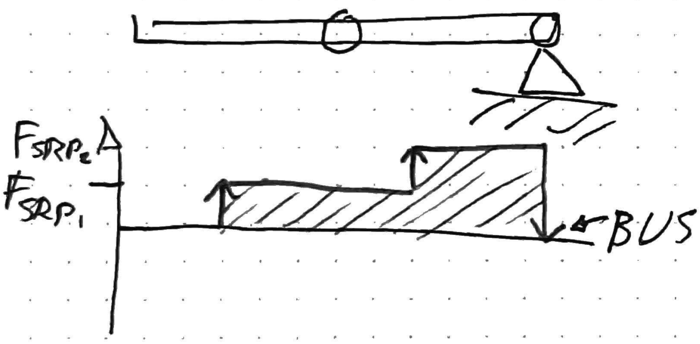
where $d_n = 2\cancel{a}^{n} - \frac{a}{2}$

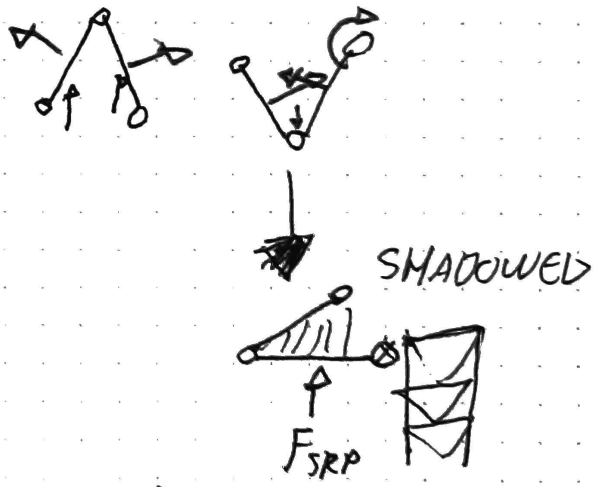


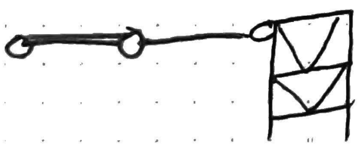
$na - \frac{a}{2}$

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

$= 2.5$







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

$R_{S,0}$

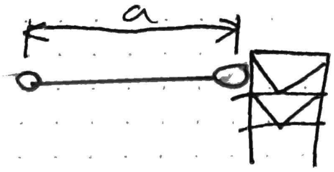
$\cancel{R_{S,0}} = 4.56 \cdot 10^{-6} \frac{N}{m^2}$ → SRP at 1au.

$P_0 =$

at $R_S = 2$ AU and $\alpha = 45°$

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

attitude control of large gossamer spacecraft



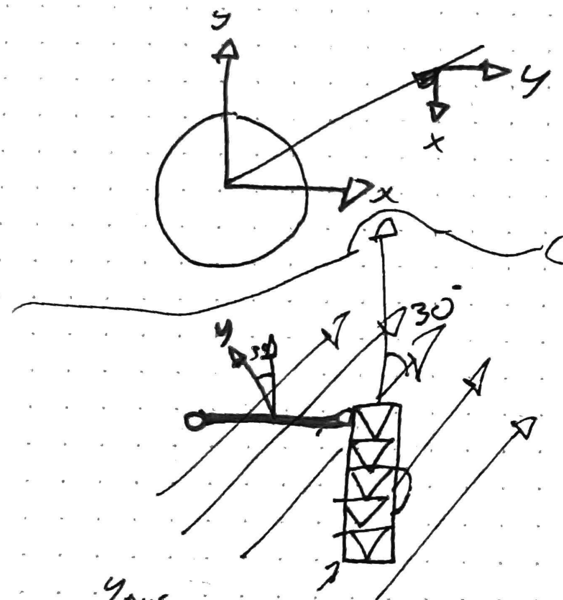
let a = 1m
and a panel area is a^2
at a distance of 1.5 AU,
~~45~~ 0° (Normal to the sun)
state = 1 (on, reflection)

$$P_{SRP} = P_0(1+\rho)\left(\frac{R_{S_0}}{R_S}\right)^2 \cos^2\theta$$

$$P_{SRP} = 4.56\cdot10^{-6}\cdot 2\cdot(0.444)\cdot 1 = 4.05\cdot10^{-6}\ \frac{N}{m}$$

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

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



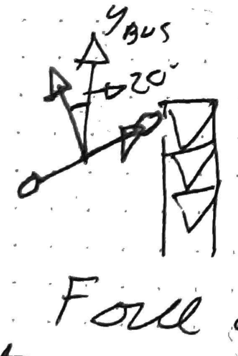
let $\vec{d}$ be a position vector as such,

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

$$P_{SRP} = 4.56\cdot10^{-6}(1+0)\left(\frac{R_{S_0}}{R_S}\right)^2\cos 30°$$

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

$\longrightarrow$ normal to bus.



$P_{SRP}\cdot$ panel = force

$\vec{\ } = 1.52\cdot10^{-6}$ 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

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

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

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