Session 2 - Problem Statement

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1 Objectives

The objectives of this session are:

1. Enlist typical satellite sizes for CubeSats
2. Find mechanisms for folding solar panels used on satellites
3. Find coatings used for radiation protection in space
4. Put pictures and copy paste brief explanations of the mechanisms in the report
5. Add references to mechanisms, coatings, and solar panels searched in the bibliography
6. Write code for sizing folded solar panels for given equations
7. Write code for sizing outer cover solar panels for given equations

2 Search pointers

For the sizes of the CubeSats, use the following information:

- NASA Cubesats
- Nanosats Cubesats
- Wikipedia Cubesats

Just write a list of LxWxH that are available for various sizes listed here.

I only give some starting points of where to begin the search for the folding mechanisms and coatings here. More concrete examples will be put in the solution for this session.

Some solar folding mechanisms include:

- Origami folded panels from physics.org
- Radially folded solar panels research paper
- Sparkwing solar panels meant for satellites
- Commercial ground based simple hinge folded system. This is what we actually use bdw.

Note, find creative ways to put prompts in search engines and AI chatbots to hone in to more details about a specific mechanism you want to explore or know more about, such that you can find concrete information about the dimensions, mass, or other properties if available. Do the same for radiation protection coatings.

Remember to specifically state that you are looking for coatings used on satellites in space. Mechanisms can work anywhere but coatings need to be specifically made for space.

Some radiation protection coatings include:

- Schott glass coatings used for satellites
- This paper by Materion called Coatings Used in Space Requirements and Solutions by Samuel Pellicori published in Materion Coating Materials News.[1]

3 Fundamentals of the code

3.1 Inputs to the code from text files

The things that this code would need to begin would be in 3 main categories:

1. Cell characteristics input
2. Panel and mechanism dimensions input
3. Body dimensions input

Let's look at each in turn.

3.1.1 Cell characteristics input

- lcell = length of solar cell (in mm)
- wcell = width (less than length) of solar cell (in mm)
- powcell = power output of each cell in Watts (W)
- rho = density of the material of the panel (not the cell)

Note: the density of the material is taken as 3 mg/mm^3.

3.1.2 Panel and mechanism dimensions input

- tf = Frame thickness for each panel
- clf = Clearance for the cell frame on all sides
- clmside = Clearance for mechanism on either side of an assembly
- clhi = Clearance for the hinge on the inner side for mounting
- clho = Clearance for the hinge on the outer side for smooth movement
- clmcen = Clearance for mechanism between assemblies on either side for folded configuration
- clcell = Clearance between cells in the outer cover configuration

3.1.3 Body dimensions input

This only consists of length width and height (L, W, H) for each standard size of cubesats. L,W,H are arranged in order from longest to shortest to make the code easier.

3.2 Intermediate values to be calculated

These are the things that may not be put in the final output file but are required for calculations and to be put in separate intermediate output files.

- dhinge = Diameter of the hinge (same for both configs)
- h2hdist = hinge to hinge distance (to get total length after opening) (different for both configs)
- lframe = length of the frame when stowed (to get total volume taken up by the assembly) (different for both configs). For the outer cover lframe is a 3 element array.
- wframe = width of the frame holding the cells (the dimension from one side mechanism to the other) (different for both configs). For the outer cover wframe is a 3 element array.
- numassembs = number of assemblies for folded arrangement arranged on one side
- nstack = number of cells in each stack/ assembly for folded arrangement

- tf = frame thickness for outer cover configuration
- nxl[1,2,3] and nxw[1,2,3] = number of cells along lframe[1,2,3] for outer cover arrangement. nxl is when the cells are arranged lengthwise and nxw is when they are arranged widthwise. Thus, $nxw > nxl$
- nyl[1,2,3] and nyw[1,2,3] = number of cells along wframe[1,2,3] for outer cover arrangement. Note that nxl pairs with nyw since if the cells are arranged lengthwise along x, they are widthwise along y automatically and vis-versa.
- ncellspanel[1,2,3] = number of cells on each panel for outer cover arrangement. 1 for LxW, 2 for LxH and 3 for WxH

  Note that nx and ny each have 2 values for each of the 3 kinds of faces available in the outer cover configurations. However, only the values that lead to a higher ncellspanel are chosen.

3.3 Outputs to be written in text files

The things that this code would need to begin would be:

- ncells = Total number of cells
- ptot = Total power of the assembly
- vtot = total volume taken by the whole assembly
- lenopen = length of fully opened assembly
- widopen = width of fully opened assembly
- mtot = rough mass estimate of full solar assembly

Note that for the outer cover configuration, there are 2 different lenopen[1,2] and widopen[1,2] values. Given all the differences in the different configurations, it is advisable to use completely different programs in different folders for both configurations such that there is no confusion with functions and variable names.

4 Diagrams and Equations

4.1 Figures and Variables Labelled

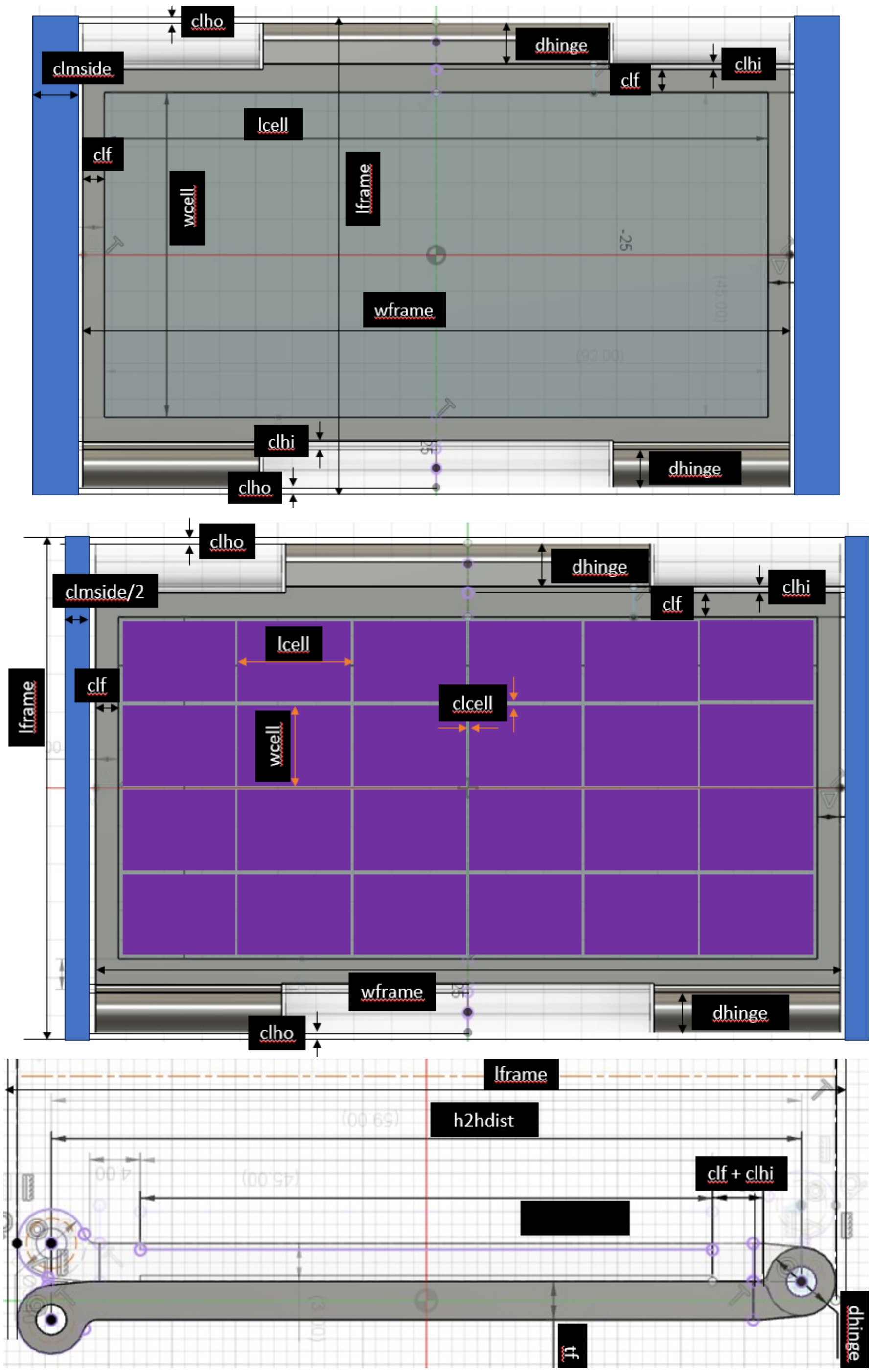

Figure 1: Front and side views for both configurations to compare: (a) Folded configuration front view (b) Outer cover configuration front view (c) Both configurations side view

This shows the dimensions that are used as inputs and the intermediate values to be calculated for both configurations.

Surprisingly, the diagram for the side view of each frame is the same for both configurations. There are advantages to standardization it seems!

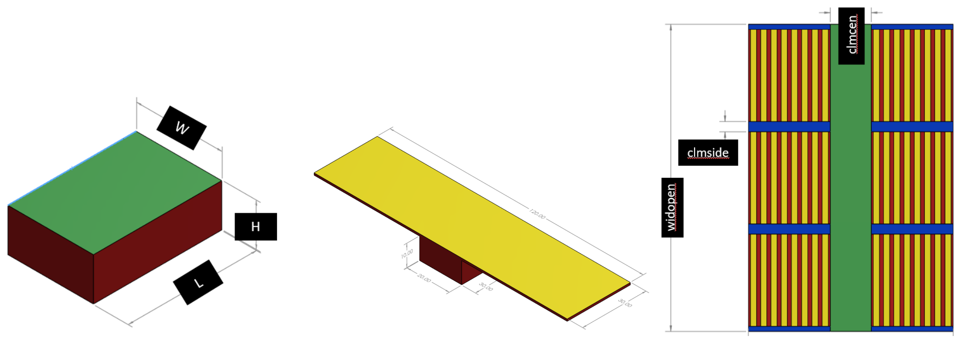

Figure 2: (a) The green face LxW chosen to put the panels on (b) Folded configuration opened (c) Dimensions in the stowed state

The surface LxW is chosen for the folded configuration to place the frame stacks. This is because the LxW has the most surface area. There are only 2 faces with the LxW cross-section. 1 faces the sun so the other can face the communication station on the ground. The ground face needs to have the max area available so the other LxW face is the only option for the folded configuration.

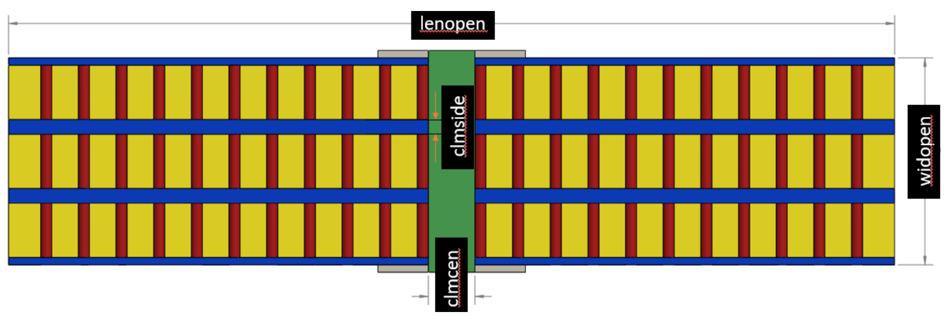

Figure 3: The folded configuration fully opened showing lenopen and widopen

We also want to minimize the lenopen for this configuration to reduce the overall moment of inertia, so we get that by aligning widopen with L and lenopen with W. This gives further clarity to the values of lenopen and widopen for the folded configuration and allows us to see how the hinges (red), cells (yellow), clmcen (green), and clmside (blue) come together in the assembly. This will make the equations in the next section clearer.

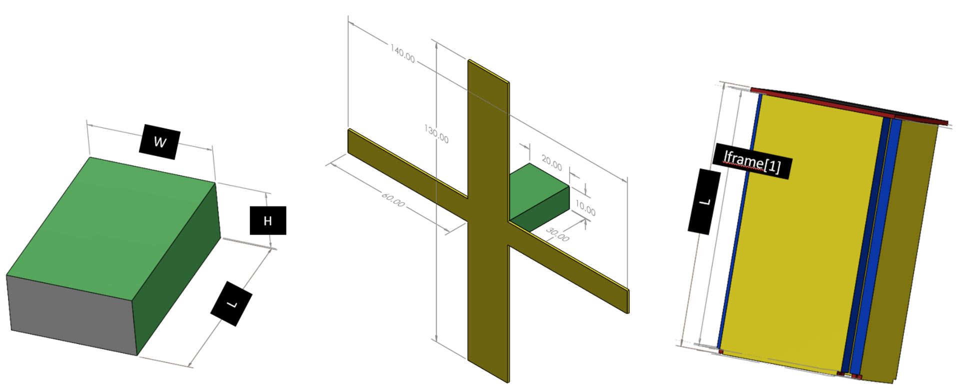

Figure 4: Outer cover configuration (a) Showing choosing LxW and LxH faces marked in green (b) Opened up state (c) Need to account for top face thickness in lframe[1]

Note that the top face is not shown here as it hides the mechanism for the panels unfolded below. The critical thing is that to fit panels on the outer body, we need to leave space for the thickness of

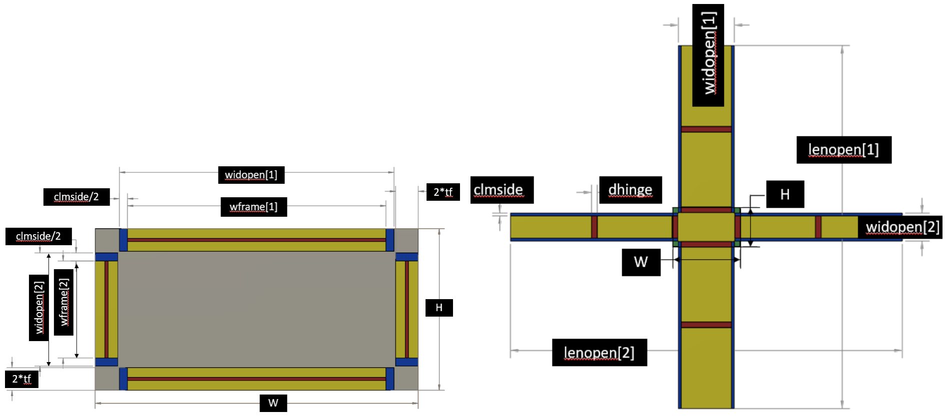

Figure 5: (a) Dimensions in stowed state (b) Dimensions in open state

the folded sheets on the sides which reduces the overall length available. Thus, this configuration is better suited for larger sized satellites.

These images show how the solar panels shall be arranged in the 2 configurations.

4.2 Equations for intermediate values

4.2.1 Both Configurations

Calculating dhinge:

$$dhinge = 2 \times (tf - clhi) \tag{1}$$

Calculating h2hdist:

$$h2hdist = lframe - 2 \cdot clho - dhinge \tag{2}$$

Note that lframe is different for both configurations but used the same way in each case.

4.2.2 Folded Configuration

Calculating lframe:

$$lframe = wcell + 2 \times (clf + clhi + dhinge + clho) \tag{3}$$

Note that we always try to minimize lframe to minimize the height taken up by the solar mechanism, thus lframe is always along wcell.

Calculating wframe:

$$wframe = lcell + 2 \times clf \tag{4}$$

Calculating nstack:

$$nstack = floor\left(\frac{W - clmcen - dhinge}{2 \cdot tf}\right) \tag{5}$$

Note: dhinge is subtracted here to leave room for the hinge on the inner side that connects to the central mechanism. Half of the hinge sticks out on either side of clmcen so one full dhinge is subtracted. The floor() function in Python rounds down to the nearest integer less than this value.

Calculating numassembs:

$$numassembs = floor\left(\frac{L}{wframe + clmside}\right) \tag{6}$$

Note: clmside/2 is on either side of each stack of width wframe. So, the effective width taken up by 1 stack is wframe + clmside.

4.2.3 Outer Cover Configuration

Calculating tf:

$$tf = 0.01 \times L \tag{7}$$

The minimum value of tf is 3mm. If it gets any lower (i.e. if $L < 300mm$) just use 3mm.

Calculating nxl[1], nxw[1] for LxW walls:

$$nxw[1] = floor\left(\frac{L - (tf + clcell) - 2 \times (dhinge + clho + clhi + clf)}{wcell + clcell}\right) \tag{8}$$

$$nxl[1] = floor\left(\frac{L - (tf + clcell) - 2 \times (dhinge + clho + clhi + clf)}{lcell + clcell}\right) \tag{9}$$

note that tf is subtracted since the top surface needs to be accounted for.

Note: $nxw > nxl$ Because $lcell > wcell$. When arranging by wcell along x, arrange by lcell along y and visversa. We try both $nxl \times nyw$ and $nxw \times nyl$ to find the combination that gives the max ncellspanel.

Calculating nyl[1], nyw[1] for LxW walls:

$$nyl[1] = floor\left(\frac{W - (clcell + clmside) - 2 \cdot clf - 4 \cdot tf}{lcell + clcell}\right) \tag{10}$$

$$nyw[1] = floor\left(\frac{W - (clcell + clmside) - 2 \cdot clf - 4 \cdot tf}{wcell + clcell}\right) \tag{11}$$

Note that clmside/2 is removed from either side so overall one full clmside is removed from W. In addition, 2 x tf is removed since it is the thickness of the mechanism that needs to fit within the walls as it is folded.

Calculating nx[2] for LxH walls:

$$nxw[2] = floor\left(\frac{L - clcell - 2 \times (dhinge + clho + clhi + clf)}{wcell + clcell}\right) \tag{12}$$

$$nxl[2] = floor\left(\frac{L - clcell - 2 \times (dhinge + clho + clhi + clf)}{lcell + clcell}\right) \tag{13}$$

Calculating ny[2] for LxH walls:

$$nyl[2] = floor\left(\frac{H - (clcell + clmside) - 2 \cdot clf - 4 \cdot tf}{lcell + clcell}\right) \tag{14}$$

$$nyw[2] = floor\left(\frac{H - (clcell + clmside) - 2 \cdot clf - 4 \cdot tf}{wcell + clcell}\right) \tag{15}$$

Only W is changed to H as the arrangement is fundamentally the same.

Calculating nx[3] for WxH walls:

$$nxw[3] = floor\left(\frac{W - clcell - 2 \cdot clf}{wcell + clcell}\right) \tag{16}$$

$$nxl[3] = floor\left(\frac{W - clcell - 2 \cdot clf}{lcell + clcell}\right) \tag{17}$$

Here, nx is arranged along W and ny arranged along H. Again try both $nxl \times nyw$ and $nxw \times nyl$ to see which gives higher ncellspanel.

Calculating ny[3] for WxH walls:

$$nyl[3] = floor\left(\frac{H - clcell - 2 \cdot clf}{lcell + clcell}\right) \tag{18}$$

$$nyw[3] = floor\left(\frac{H - clcell - 2 \cdot clf}{wcell + clcell}\right) \tag{19}$$

The product of nx and ny gives ncellspanel. Once ncellspanel is chosen, record the nx[i] ny[i] value used in the intermediate values output file. State whether it is nxw, nyl or nxl,nyw for each as well.

Calculating ncellspanel[1,2,3]:

$$ncellspanel[i] = nxw[i] \times nyl[i] \tag{20}$$

OR

$$ncellspanel[i] = nxl[i] \times nyw[i] \tag{21}$$

Calculating lframe[1,2,3]:

Even though lframe[1] and lframe[2] are both along L, their nx ny can be different so the lframe values can be different.

$$lframe[i] = nxw[i] \times (wcell + clcell) + clcell + 2 \cdot (dhinge + clho + clhi + clf) \tag{22}$$

OR

$$lframe[i] = nxl[i] \times (lcell + clcell) + clcell + 2 \cdot (dhinge + clho + clhi + clf) \tag{23}$$

As the case may be.

lframe[3] is along W so the calculation is different.

$$lframe[3] = nxw[3] \times (wcell + clcell) + 2 \cdot clf + clcell \tag{24}$$

OR

$$lframe[3] = nxl[3] \times (lcell + clcell) + 2 \cdot clf + clcell \tag{25}$$

As the case may be.

Calculating wframe[1,2,3]:

$$wframe[i] = nyw[i] \times (wcell + clcell) + 2 \cdot clf + clcell \tag{26}$$

OR

$$wframe[i] = nyl[i] \times (lcell + clcell) + 2 \cdot clf + clcell \tag{27}$$

As the case may be for each of the 3 faces.

4.3 Equations for output values

Calculating ptot:

$$ptot = powcell \times ncells \tag{28}$$

Apart from ptot, final outputs have different equations for each output for the 2 kinds of systems here. There is no overlap.

4.3.1 Folded Panels Configuration

Calculating ncells:

$$ncells = 2 \times nstack \times numassembs \tag{29}$$

Calculating lenopen:

$$lenopen = clmcen + dhinge + 2 \cdot nstack \cdot h2hdist \tag{30}$$

Half a dhinge is added on the inside of each outstretched stack. So in total, it is 1 full dhinge.

Calculating widopen:

$$widopen = numassembs \times (wframe + clmside) \tag{31}$$

Note that this width remains the same when it is open vs closed, so we can use this widopen in the stored volume (vtot) calculation.

Calculating vtot:

$$vtot = lframe \times widopen \times (2 \cdot nstack \cdot tf + clmcen) \tag{32}$$

Calculating mtot:

$$mtot = lenopen \times widopen \times tf \times rho \tag{33}$$

This total mass will come out in mg if all dimensions are used in mm. This is a rough estimate, thus the density of the densest material in the assembly is used to deliberately overestimate the value. This is to ensure that we can fit more than what is necessary.

Later, we convert this mass to kg and convert lenopen and widopen to meters instead of mm for use in the next lesson.

4.3.2 Outer Cover Configuration

Calculating ncells:

$$ncells = 4 \cdot (ncellspanel[1] + ncellspanel[2]) + ncellspanel[3] \tag{34}$$

There are 2 sheets of LxW and LxH on each side so 2 sides gives 4 each of LxW and LxH. There is only one of the WxH face. Total 9 faces.

Calculating lenopen[1,2]:

$$lenopen[1] = W + 4 \cdot h2hdist - 4 \cdot tf - dhinge \tag{35}$$

2 tf on either side is subtracted as it is accounted for in W as the folded mechanism sits inside the LWH box. The dhinge is subtracted to account for the thickness of the hinge that's on the inner side.

$$lenopen[2] = H + 4 \cdot h2hdist - 4 \cdot tf - dhinge \tag{36}$$

This is the thinner side.

There is no lenopen[3] since there are only 2 dimensions to the solar array.

Calculating widopen[1,2]:

$$widopen[i] = wframe[i] + clmside \tag{37}$$

Note that this width remains the same when it is open vs closed, so we can use this widopen in the stored volume (vtot) calculation.

Calculating vtot:

$$vtot = tf \times (4 \cdot (lframe[1] \times widopen[1] + lframe[2] \times widopen[2]) + lframe[3] \times wframe[3]) \tag{38}$$

Each sheet takes tf thickness. [1] and [2] are along the length and have 2 sheets on either side so 4 sheets each but the top surface [3] has only 1 sheet.

Calculating mtot:

$$mtot = rho \cdot tf \times (lenopen[1] \times widopen[1] + lenopen[2] \times widopen[2] - widopen[1] \times widopen[2]) \tag{39}$$

The center rectangle of widopen[1] x widopen[2] is subtracted to prevent double counting. We know that this is not precisely the area of this setup, however, it makes the approx calculations for the moment of inertia (MOI) in the next session much easier, so we use this simplified approximation. This exercise is to get initial estimates so we can start the design. Once the design is made in CAD software, the actual values of MOI will be taken from there and plugged directly into the MOI input of upcoming code. It is an iterative process so we do some hand calculation, then some code, then some sophisticated software as we refine our values.

The mass we get here will be in milligrams and the lengths are in mm. We convert these to SI units (kg and meters) to calculate MOI in the next session.

5 Tips for making the code

Make functions for things that are to be done more frequently. Isolate complicated calculations broken down into smaller steps so that it is easier to understand and debug the code.

Copy paste the functions and code that is common between the 2 types and edit that, but do not attempt to make one code that works for both configurations. The variable types for the 2 configurations are different.

Input values to use:

1. lcell: 92 mm
2. wcell: 45 mm
3. powcell: 1.2 W / cell
4. $rho : 3mg/mm^3$
5. tf: 3 mm
6. clf: 4 mm
7. clmside: 6.4 mm
8. clhi: 0.2 mm
9. clho: 0.3 mm
10. clmcen: 12 mm
11. clcell: 1 mm
12. L: 450 mm
13. W: 240 mm
14. H: 200 mm

You are encouraged to use your own values for lcell, wcell, and powecell from the datasheets of the cells found online.

6 After you have made the codes

Play around with the input values and see if you can see any patterns in the outputs you get. Save at least 3 different output values derived from 3 different input values using the same python code in each type of mechanism (folded and outer wall). Use different values for LWH, especially the one used for 16U as that's the one we are planning to use. If you can, run the code for all LWH configurations from 1U to 27U that you can find. Once you have the code, it is just a matter of running it many times.

References

[1] S. Pellicori. Coatings used in space requirements and solutions. *Materion Coating Materials News.*