ME 254: Compliant Mechanisms		
Assigned: Jan. 30, 2024	Homework 2	Due: Feb. 6, 2024

Question 1 (10 points)

a. For the compliant mechanism you had chosen for HW 1, please compute the degrees of freedom and interpret them.
b. Using your COMSOL model (linear analysis is enough), apply a force corresponding to each degree of freedom and record your comments.

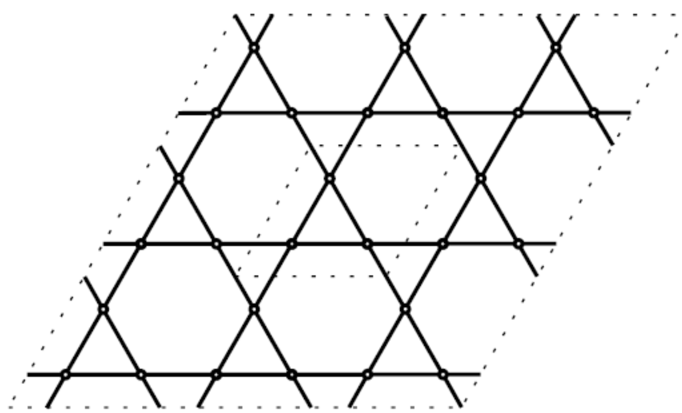
Question 2 (10 points)

Choose a compliant suspension from https://mecheng.iisc.ac.in/m2d2/CMcollection/ and inform others in the class by sending an email to ME254_2024@iisc.ac.in (so that nobody else choose yours).

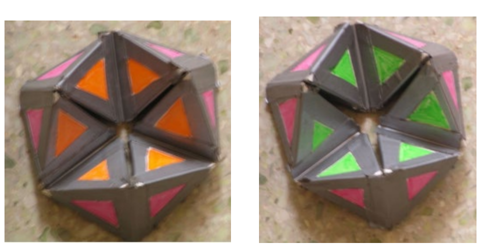
a. Compute the 3D multiaxial stiffness matrix analytically using the Myosotis method.
b. Obtain the stiffness matrix using Matlab beam modeling. Compare these values with what you found analytically. Mention the reasons for any discrepancy.
c. Extra 5 points for 3D-printing it (small size, please) with TA's help.

Question 3 (10 points)

For the repetitive truss whose basic building block is shown in the figure on the right, obtain degrees of freedom (DoF) and states of self-stress (SoSS) by counting and then using the Matlab code that computes them using the force equilibrium or compatibility matrix. Show also the modes of rigid-body freedom and states of self-stress, if applicable.



Question 4 (10 points)



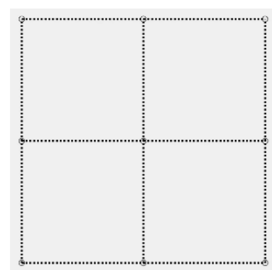
A kaleidoscopic mechanism (which is based on a Bricard linkage), shown on the left, consists of six tetrahedrons connected to one another with a revolute joint in a specific way. The four faces of each tetrahedron have different colors. This can be rotated continuously exposing two colors at a time. To illustrate this, two instances are shown next.

- For this mechanism, use Maxwell-Calladine formula to compute DoF and SoSS, first by counting and then using the truss-mobility code in Matlab. Observe the mode shape and write your comment.
- Extra five points if you make a card-board design of this mechanism.

What you need to submit:

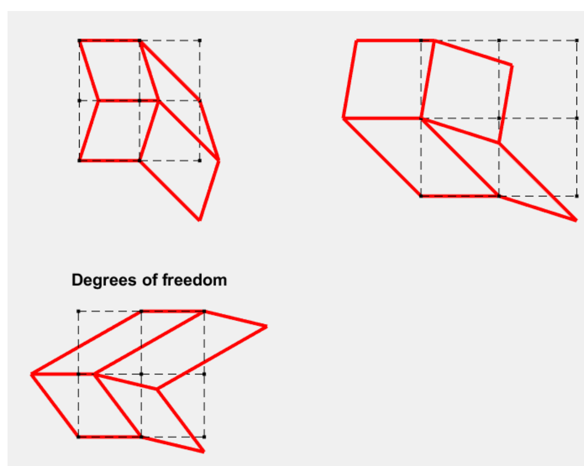
1. Paper copy of your results clearly written down with all details
2. Graphs and pictures of your results with proper annotation (paper copy)
3. Four data files for FEA beam code in Matlab of your chosen compliant mechanism.
4. Your 3D-printed compliant suspension (optional for extra points)
5. Kaleidoscopic mechanism (optional for extra points)

A sample solution for question 3 (guidance to solve)

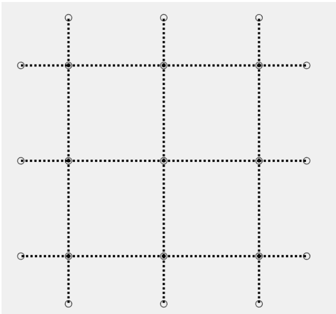


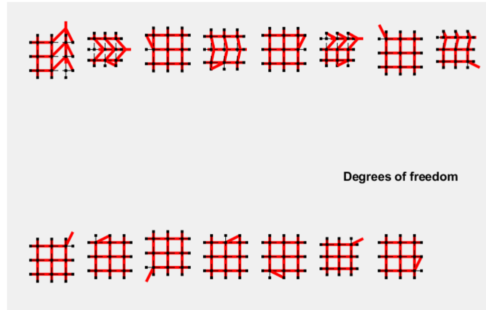
First, take the non-repetitive samples truss shown on the right. Its data files are shown in the table and the three rigid-body modes of motion are also indicated. Maxwell-Calladine formula gives (with $v = 9$ and $b = 12$, DoF - SoSS = $2(9) - 12 - 3 = 3 = 3 - 0$ (because there are no states of self-stress.

1	0	0	1 1 2 1e-4 1e11
2	1	0	2 2 3 1e-4 1e11
3	2	0	3 1 4 1e-4 1e11
4	0	1	4 2 5 1e-4 1e11
5	1	1	5 3 6 1e-4 1e11
6	2	1	6 4 5 1e-4 1e11
7	0	2	7 5 6 1e-4 1e11
8	1	2	8 4 7 1e-4 1e11
9	2	2	9 5 8 1e-4 1e11
			10 6 9 1e-4 1e11
			11 7 8 1e-4 1e11
			12 8 9 1e-4 1e11



Now, to analyze it for repetitive structure, add half edges for each of the eight outer vertices. Maxwell-Calladine formula gives (with $v = 9 + 12 = 21$ and $b = 12 + 12 = 24$, DoF - SoSS = $2(21) - 24 - 3 = 15 = 15 - 0$. The data files and 15 rigid-body modes of motion, shown ahead, may please be examined.





2	1	0	1 1 2 1e-4 1e11
3	2	0	2 2 3 1e-4 1e11
4	0	1	3 1 4 1e-4 1e11
5	1	1	4 2 5 1e-4 1e11
6	2	1	5 3 6 1e-4 1e11
7	0	2	6 4 5 1e-4 1e11
8	1	2	7 5 6 1e-4 1e11
9	2	2	8 4 7 1e-4 1e11
10	-0.5	0	9 5 8 1e-4 1e11
11	0	-0.5	10 6 9 1e-4 1e11
12	1	-0.5	11 7 8 1e-4 1e11
13	2	-0.5	12 8 9 1e-4 1e11
14	2.5	0	13 1 10 1e-4 1e11
15	-0.5	1	14 1 11 1e-4 1e11
16	2.5	1	15 2 12 1e-4 1e11
17	-0.5	2	16 3 13 1e-4 1e11
18	2.5	2	17 3 14 1e-4 1e11
19	0	2.5	18 15 4 1e-4 1e11
20	1	2.5	19 6 16 1e-4 1e11
21	2	2.5	20 17 7 1e-4 1e11
			21 9 18 1e-4 1e11
			22 7 19 1e-4 1e11
			23 8 20 1e-4 1e11
			24 9 21 1e-4 1e11

The additional 15 DoF are simply the rotations of the 15 extensions at the outer vertices. For repetitive arrangement, we must impose further conditions on the outer nodes. Thise conditions are as follows:

- Top vertices and bottom vertices should be constrained to have the same displacements.
- Left vertices and right vertices should be constrained to have the same displacements.

This can be done by adding additional rows to the $\mathbf{C}$ matrix. By doing so, we get the augmented matrix for repetitive truss.

$\mathbf{C}^{Aug}\mathbf{u} = \mathbf{e} = \mathbf{0}$ (we need to relate some pairs of components of $\mathbf{u}$ to have the same slope when they move. By studying the vertex coordinates (and thus figuring out the displacement indices shown in blue), one can see how we are relating them.

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AugC = C;
AugC(25,:) = zeros(1,42); AugC(25,21) = 1; AugC(25,37) = 1;
AugC(26,:) = zeros(1,42); AugC(26,22) = 1; AugC(26,38) = 1;
AugC(27,:) = zeros(1,42); AugC(27,23) = 1; AugC(27,39) = 1;
AugC(28,:) = zeros(1,42); AugC(28,24) = 1; AugC(28,40) = 1;
AugC(29,:) = zeros(1,42); AugC(29,25) = 1; AugC(29,41) = 1;
AugC(30,:) = zeros(1,42); AugC(30,26) = 1; AugC(30,42) = 1;
AugC(31,:) = zeros(1,42); AugC(31,19) = 1; AugC(31,27) = 1;
AugC(32,:) = zeros(1,42); AugC(32,20) = 1; AugC(32,28) = 1;
AugC(33,:) = zeros(1,42); AugC(33,29) = 1; AugC(33,31) = 1;
AugC(34,:) = zeros(1,42); AugC(34,30) = 1; AugC(34,32) = 1;
AugC(35,:) = zeros(1,42); AugC(35,33) = 1; AugC(35,35) = 1;
AugC(36,:) = zeros(1,42); AugC(36,34) = 1; AugC(36,36) = 1;
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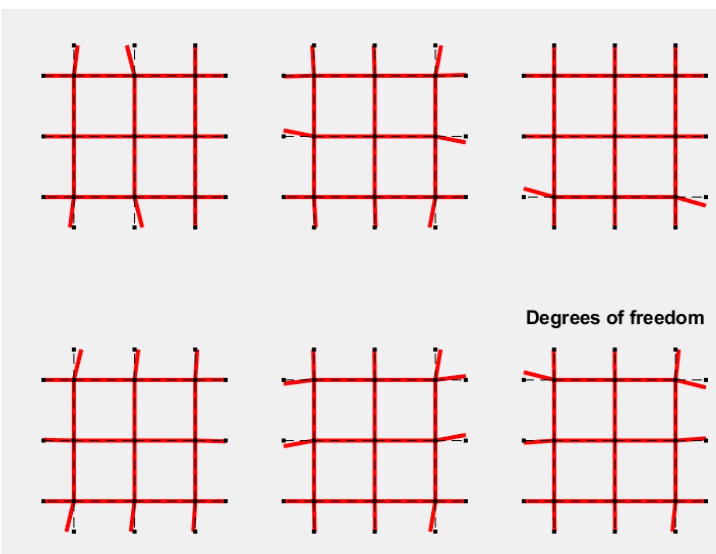
The abovementioned conditions impose the repetitive nature of the building block. With this, we get only six DoF as shown next. Now, you can see counting formula of Maxwell-Calladine is not enough for repetitive truss grids.



Is this fine? Or do we need to do more? Think about it further.