WEEK 1

Article: Wang *et.al.*, Insect-scale jumping robots enabled by a dynamic buckling cascade, *PNAS*, 2023.

QUESTIONS (Group 1a)

1. Numerical solutions of laterally constrained buckled beams have been available since the nineties [1,2]. Creating a numerical solver for buckled beams that imposes a maximum deflection on one side should be relatively simple as shown for bilateral constraints by Jiao et al. [3]. Why do such solutions not apply in this case?

[1] Holmes, Philip & Domokos, Gabor & Schmitt, John & Szeberényi, Imre. (1999). Constrained Euler buckling: An interplay of computation and analysis. Computer Methods in Applied Mechanics and Engineering 170:175-207. 10.1016/S0045-7825(98)00194-7.

[2] Domokos, Gabor & Holmes, P. & Royce, B. (1997). Constrained Euler Buckling. Journal of Nonlinear Science. 7:281-314. 10.1007/BF02678090.

[3] Jiao, Pengcheo & Alavi, Amir H & Borchani, Wassim & Lajnef Nizar. (2019) Small and large Deformation models of post-buckled beams under lateral constraints. Mathematics and Mechanics of Solids. 24:386-405. 10.1177/1081286517741341.

2. Is the jumping direction primarily influenced by the asymmetry of the beam or the robot's weight distribution? Considering Figure 2b, SyP jumps vertically and has the highest jumping capacity—could this be attributed to its more balanced weight distribution compared to other designs? How does the mass distribution of the robot affect its jumping dynamics? Specifically, where is the center of mass located, and could an uneven weight distribution explain variations in jumping direction across different phenotypes? For instance, if additional weight is placed on the front side, would the robot be more likely to land on its back?

3. It is mentioned, as well as illustrated in Figure 2A, that a rotational block and a protrusion to push the bulking beam have been added during the iterative design procedure. How did each of these components improve the overall performance of the initial designs (i.e. the initial seed)? What role did they play in increasing the performance of a controlled snap-through?

4. Instead of solely focusing on achieving maximum height, could the robot's design be adjusted to enable proper landing, self-righting, and directional control? As seen in Figure 3A, the robots translate vertically like predicted by the mathematical model depicted in Figure 6A, but also translate horizontal during the jump. How might the principles of dynamic buckling cascading be adapted to enable steering? Given the asymmetrical beam likely produces a non-uniform force distribution during snap-through, how might this inherent asymmetry be tuned to achieve directional control during takeoff?

5. The symmetric and asymmetric configurations in the article can be considered to be the first and second harmonic buckling modes of a beam respectively. Theoretically, higher harmonics require more energy to make a beam buckle but consequently allow to store more energy. Could higher harmonics be exploited through this design in order to achieve higher jumps? The SyP configuration performs better than the AsP one, despite seemingly storing less energy (cf. Force-displacement curves). How does the symmetry, or lack thereof, impact the jumping performance?

6. Considering the lumped model shown in Figure 6A, what are the parameter conditions and inequality constraints (especially on the acceleration of m_b) required to initiate ghost jumping?

7. The high-speed footage (Figure 5A) reveals that symmetrical and asymmetrical beam robots interact differently with the ground during takeoff. Given that surface interactions (such as friction and compliance) influence snap-through dynamics, how do these differences impact jumping consistency and landing stability? Additionally, considering that surface properties may not always be controllable, what design adaptations or control strategies could improve performance across various terrains? How does the ground contact time during the snap-through phase affect the jump height?