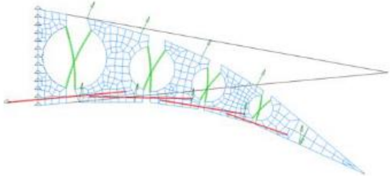
Morphing Membrane Wings Based on Tensegrity Systems

Karim Samaha

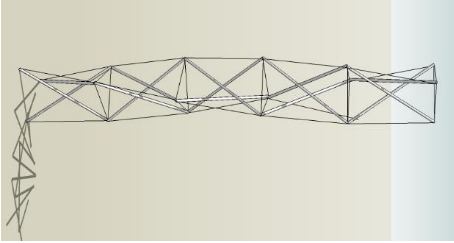
EPFL

State-of-the-art (Morphing Wings)

Greatwood, C., Waldock, A., & Richardson, T. (2017). Perched landing manoeuvres with a variable sweep wing UAV. *Aerospace Science and Technology*, *71*, 510-520.

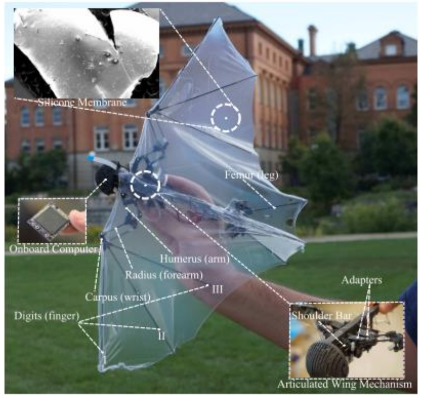


S. Barbarino, R. Pecora, L. Lecce, S. Ameduri, E. Calvi, et al. A novel sma-based concept for airfoil structural morphing. Journal of materials engineering and performance, 18(5):696–705, 2009.

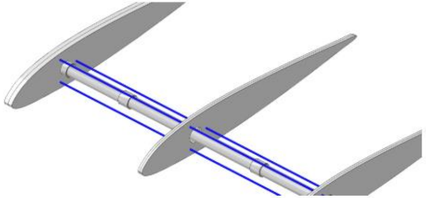


He, Y. (2020). *Modeling and Simulation of Tensegrity Structure based on SimMechanics* (Doctoral dissertation, University of Cincinnati)

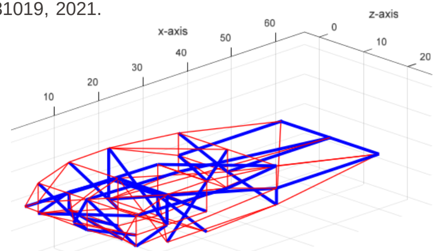
http://www.roboswift.nl/?page=design&lang=en



Ramezani, A., Shi, X., Chung, S. J., & Hutchinson, S. (2016, May). Bat Bot (B2), a biologically inspired flying machine. In *2016 IEEE International Conference on Robotics and Automation (ICRA)* (pp. 3219-3226). IEEE.

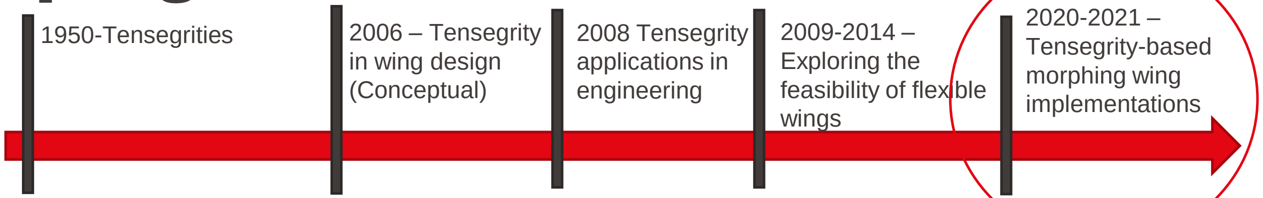


N. K. Pham and E. A. Peraza Hernandez. Modeling and design exploration of a tensegritybased twisting wing. Journal of Mechanisms and Robotics, 13(3):031019, 2021.



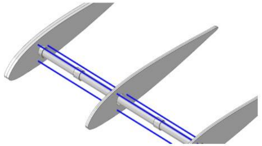
A. S. Mills, D. H. Myszka, D. C. Woods, J. J. Joo, and A. P. Murray. The structural suitability of tensegrity aircraft wings. In AIAA Scitech 2020 Forum, page 0480, 2020

State-of-the-art (Tensegrity Morphing Wings)



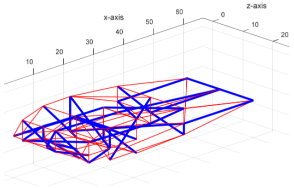
"Modeling and design exploration of tensegrity-based twisting wing," 2021 (Pham et al) Journal of Mechanisms and Robotics, 13(3):031019, 2021.

- Twisting Capabilities
- Inspired from the twisting column
- **Actuation not addressed**
- **Worked on simulation only**



"The structural suitability of tensegrity aircraft wings," 2020 (Mills et al) In AIAA Scitech 2020 Forum, page 0480, 2020

- Two design methodologies: Experimental and Optimization-based
- Structural Analysis
- **No Morphing**
- **Worked on simulation only**

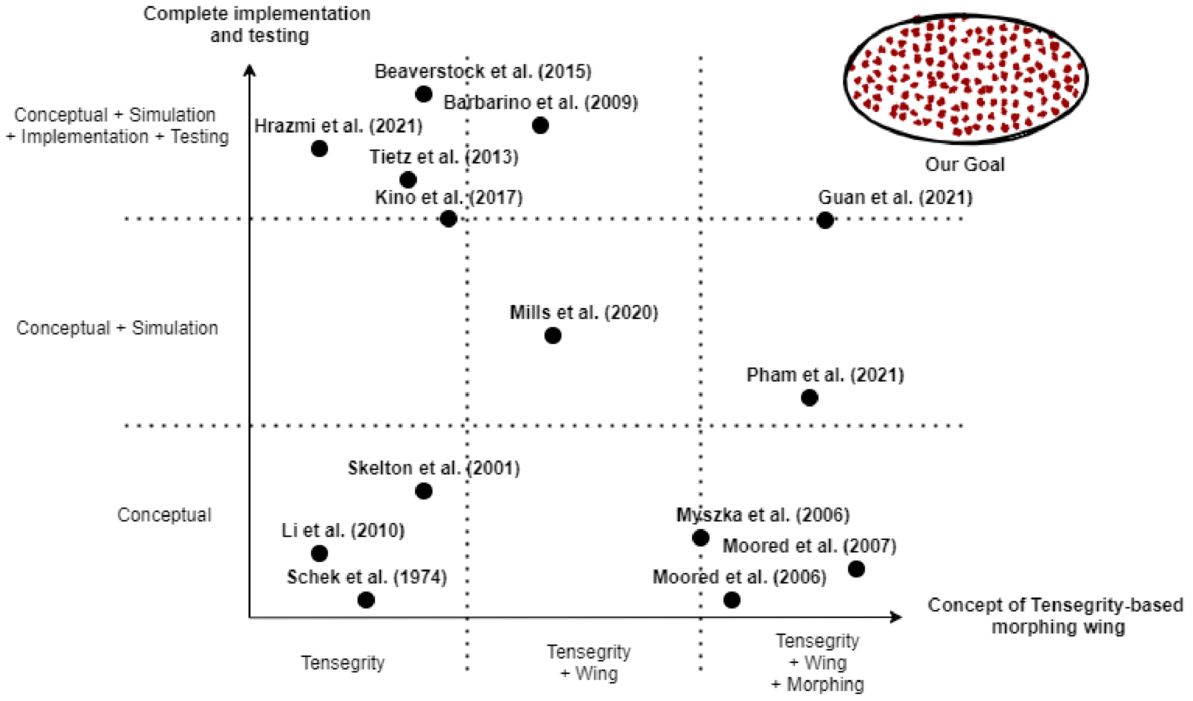


"Rolling soft membrane-driven tensegrity robots," 2020 (Baines et al) *IEEE and Automation Letters*, *5*(4), 6567-6574

- Design methodology for tensegrity membrane
- Membrane is used for actuation
- **Not related to wing morphing**

Project Objectives

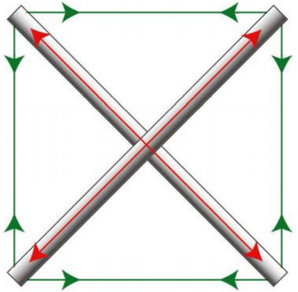
- Feasibility of tensegrity-based morphing wing
- Suitable design methodology for membrane tensegrity wing
- Design, Model and Manufacture a Morphing Wing

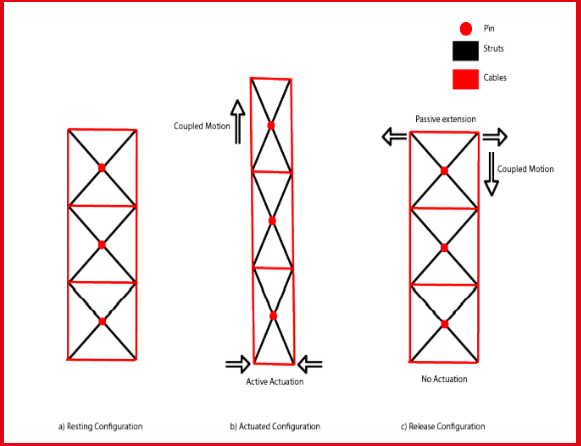


References available at the end of the presentation

Proposed Solution : Overview

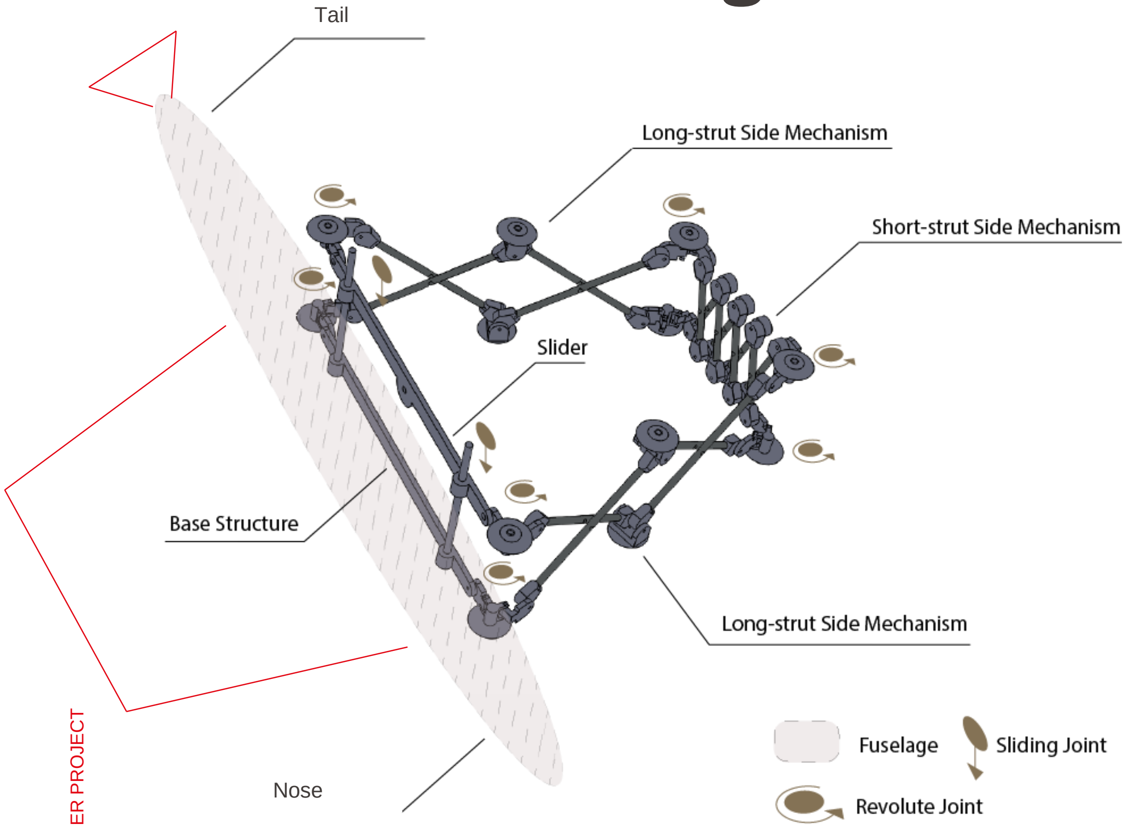
M. Seixas. Tensegrity bamboo structures. URL: https://www.researchgate.net/project/Tensegrity-bamboo-structures.





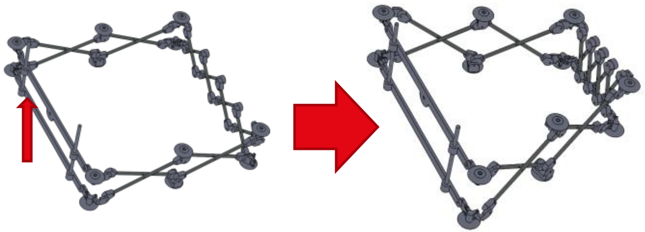
- Designed inspired from the kite-frame tensegrity module
- Struts out of carbon fiber rods + plastic
- Membrane out of silicone
- Stratified Design Methodology:
  - 1 – Mechanism Design
  - 2 – Airfoil Design
  - 3 – Membrane Design

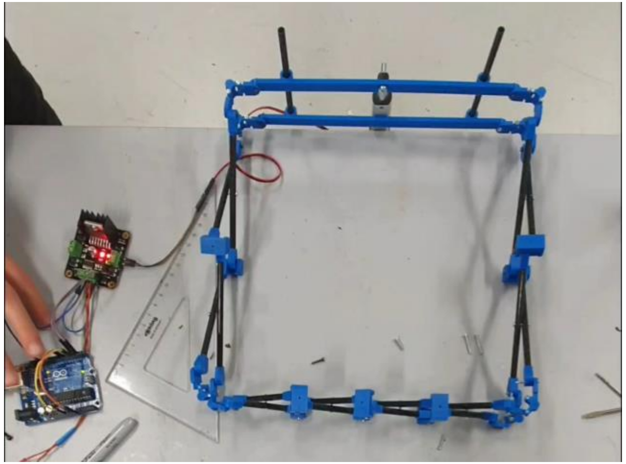
Mechanism Design



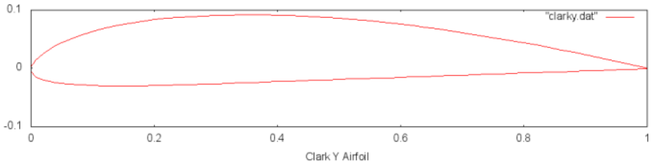
Isometric View

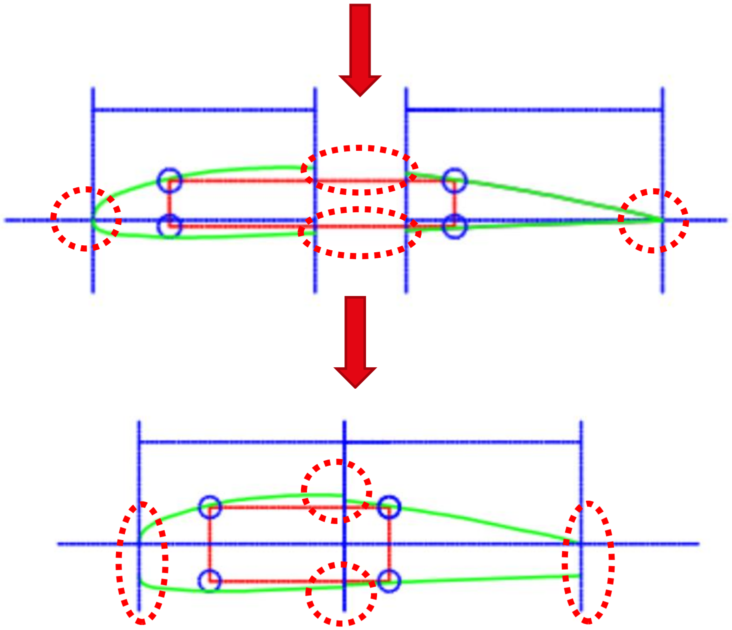
Isometric View

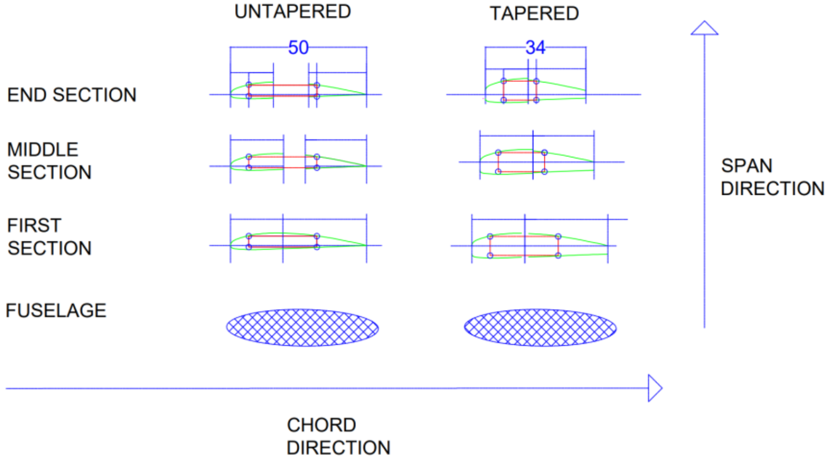


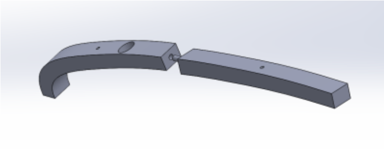


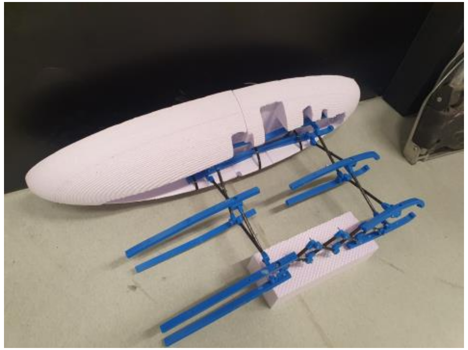
Airfoil Design



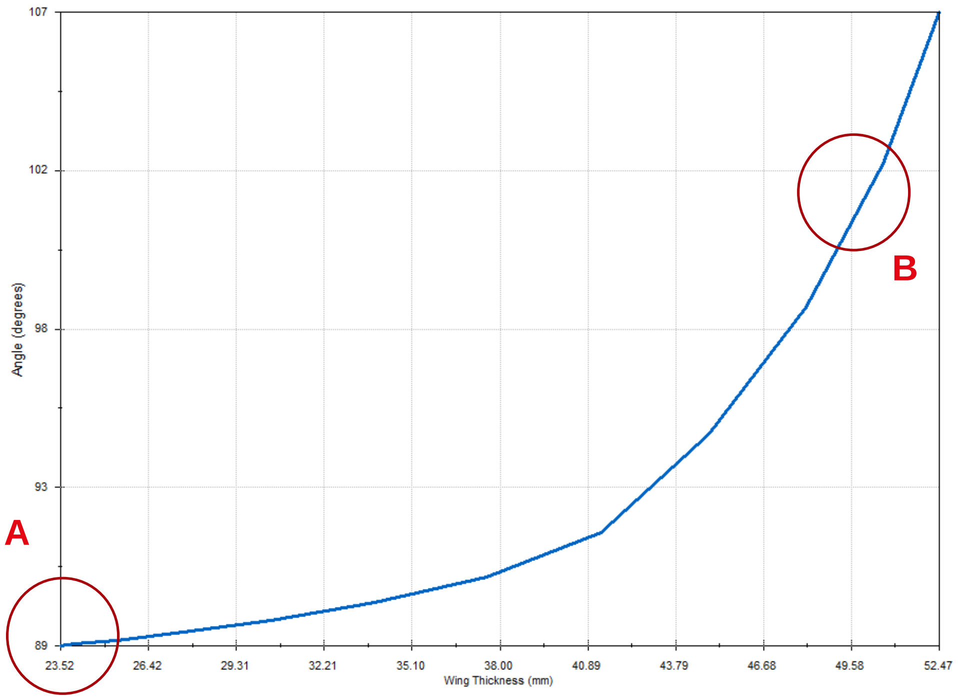


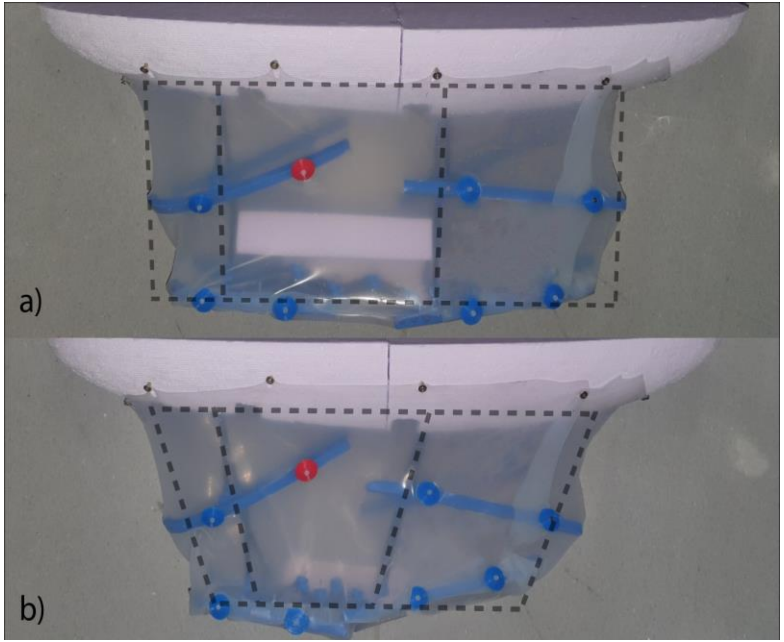






Experiments and Results – Wing Characterization



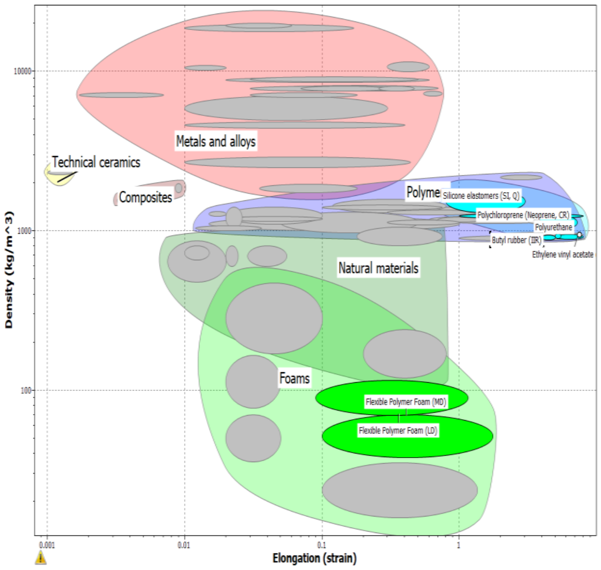


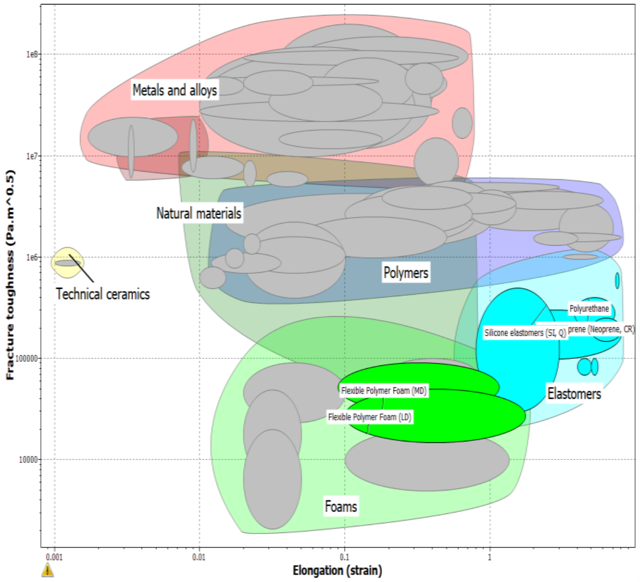
EPFL

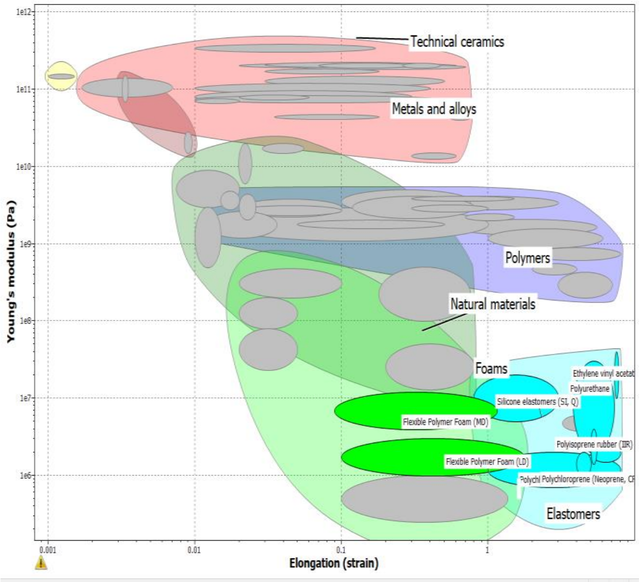
Experiments and Results – Material Exploration

- Minimum Strain 200%
- Young's Modulus Maximum 1e10^7Pa
- Minimum Fracture Toughness 1e10^4 Pa.m^0.5
- Lightweight

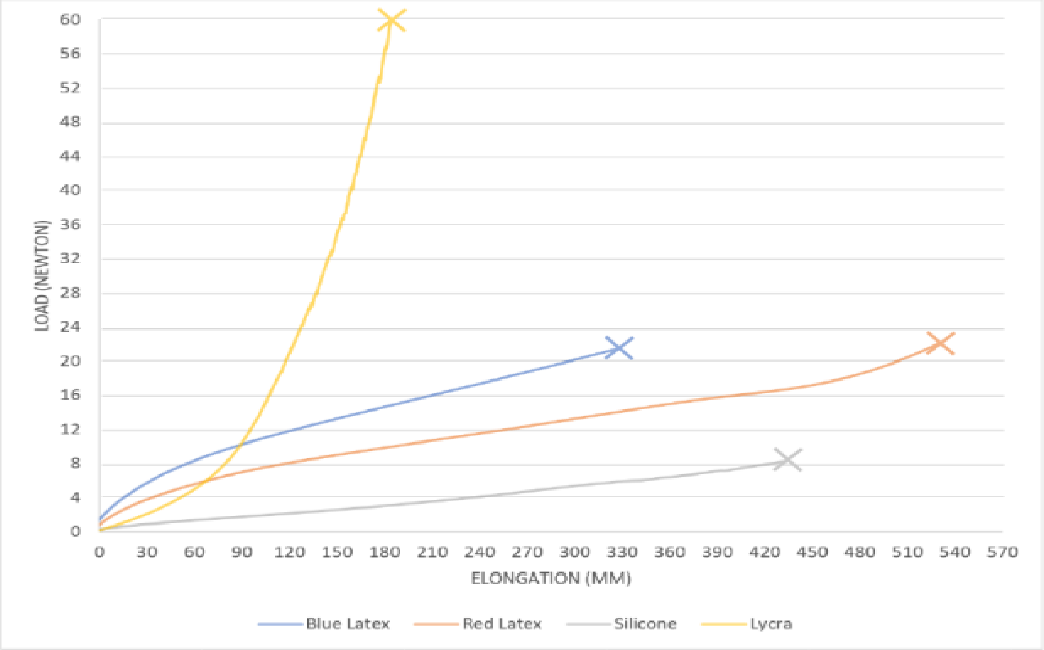
Speaker



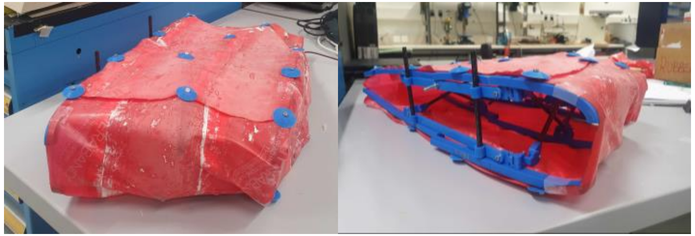




Experiments and Results – Material Exploration



(a) Unstretched (b) Stretched (a) Unstretched (b) Stretched

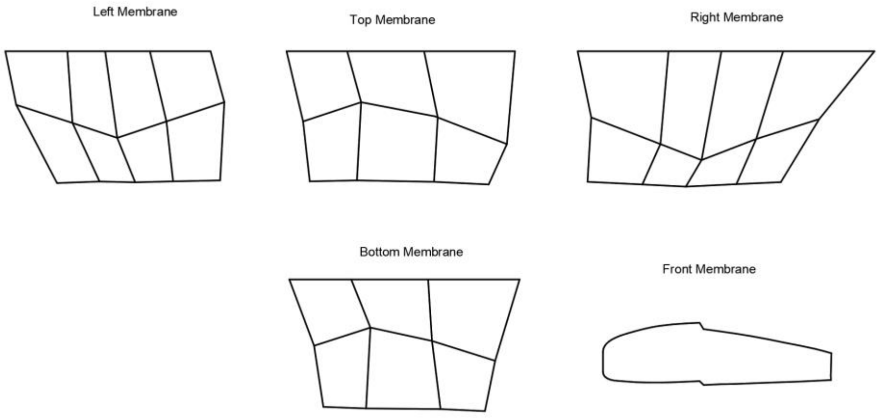


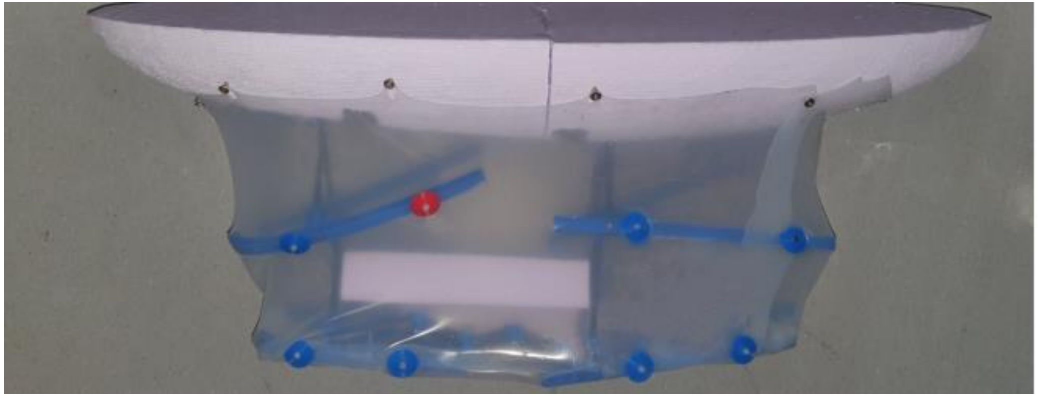
Karim

SEMESTER PROJECT

Membrane Design

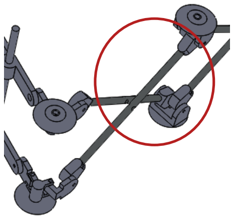
- Needs to:
  - Sustain large deformations
  - Remain always in tension
  - Be flexible
  - Be tough to resist high stress concentrations (Corners, Holes)
- Silicone portions wrapping the structure (laser-cut out of a silicone sheet 1.5mm thickness)
- Caps firmly attach the membrane to the structure

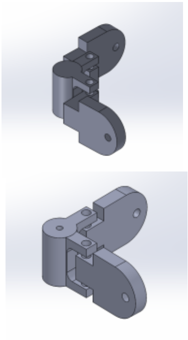




Challenges and Solutions

- **Mechanism**
  - Eccentricity
  - Number of parts
  - Simulation and Manufacturing





Solutions:

- Combine Components
- Use Compliant Mechanisms

- **Membrane Design and Attachment**
  - Manually design the 2D sheet
  - Incorporating the pre-stress

Solutions:

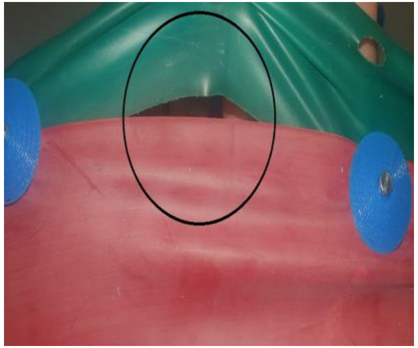
- Rely more on parametric software (Grasshopper)
- Automatically generates the 2D sheet taking the prestress into consideration

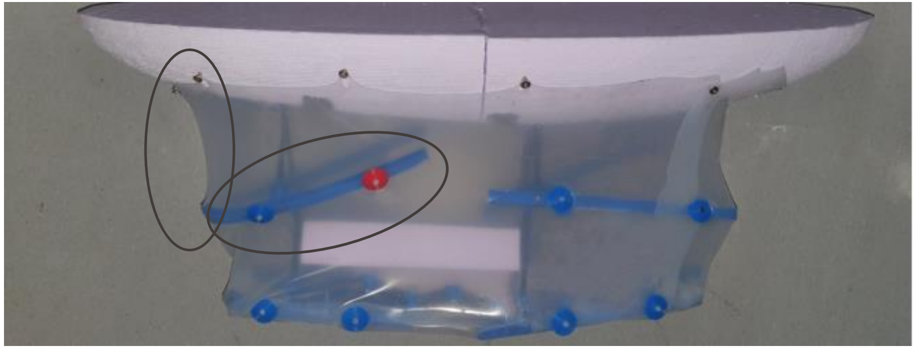
Challenges and Solutions

- **Integration**
  - Membrane/Structure interaction
  - Transient stresses generated during attachment
  - Void developments

Solutions:

- Carefully layout the membrane design as to minimize bending in the elements during attachment
- Rely on software for accurate pre-stress estimation





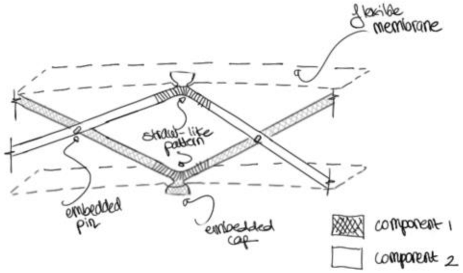
Conclusion-Future Works

- Feasibility of tensegrity-based morphing wings in practice
- Design methodology for tensegrity-based morphing wings (Membrane + Mechanism + Actuation)
- Morphing wing prototype

Future works

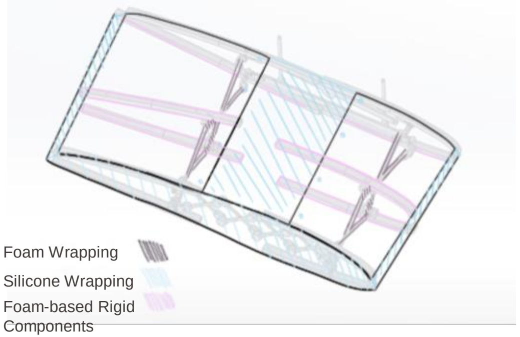
- **Topology optimization using generative algorithms** which meets all the design requirements.
- Combining tensegrities with **compliant mechanisms**





Technology for OEM Design Engineers. (n.d.). *Designfax* from http://www.designfax.net/cms/dfx/opens/article-view-dfx.php?nid=4&bid=745&aid=6748&et=featurearticle&pn=02

- **Hybrid designs**



References

1. S. Mills, D. H. Myszka, D. C. Woods, J. J. Joo, and A. P. Murray. The structural suitability of tensegrity aircraft wings. In AIAA Scitech 2020 Forum, page 0480, 2020. D. H. Myszka, J. J. Joo, D. C. Woods, and
2. A. P. Murray. Topology optimization of cableactuated, shape-changing, tensegrity systems for path generation. In International Design Engineering Technical Conferences and Computers and Information in Engineering Conference, volume 59247, page V05BT07A055. American Society of Mechanical Engineers, 2019.
3. N. K. Pham and E. A. Peraza Hernandez. Modeling and design exploration of a tensegrity-based twisting wing. Journal of Mechanisms and Robotics, 13(3):031019, 202
4. B. R. Tietz, R. W. Carnahan, R. J. Bachmann, R. D. Quinn, and V. SunSpiral. Tetraspine: Robust terrain handling on a tensegrity robot using central pattern generators. In 2013 IEEE/ASME International Conference on Advanced Intelligent Mechatronics, pages 261–267. IEEE, 2013.
5. I. Hrazmi, J. Averseng, J. Quirant, and F. Jamin. Deployable double layer tensegrity grid platforms for sea accessibility. Engineering Structures, 231:111706, 2021.
6. H. Kino, Y. Matsutani, S. Katakabe, and H. Ochi. Prototype of a tensegrity robot with nine wires for switching locomotion and calculation method of the balancing internal force. Procedia Computer Science, 105:1–6, 2017.
7. C. S. Beaverstock, B. K. S. Woods, J. H. S.-M. Fincham, and M. I. Friswell. Performance comparison between optimised camber and span for a morphing wing. Aerospace, 2(3):524– 554, 2015.
8. S. Barbarino, R. Pecora, L. Lecce, S. Ameduri, E. Calvi, et al. A novel sma-based concept for airfoil structural morphing. Journal of materials engineering and performance, 18(5):696–705, 2009.
9. Li, Y., Feng, X. Q., Cao, Y. P., & Gao, H. (2010). A Monte Carlo form-finding method for large scale regular and irregular tensegrity structures. *International Journal of Solids and Structures*, *47*(14-15), 1888-1898.
10. Guan, W., Pham, N. K., & Hernandez, E. A. P. (2021, March). Design exploration of a tensegrity twisting wing enabled by shape memory alloy wire actuation. In *Active and Passive Smart Structures and Integrated Systems XV* (Vol. 11588, p. 1158809). International Society for Optics and Photonics.
11. Skelton, R. E., & De Oliveira, M. C. (2009). *Tensegrity systems* (Vol. 1). New York: Springer.