DEPARTMENT OF MECHANICAL ENGINEERING
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VENTRICLE VISCOELASTICITY BIAXIAL TESTER

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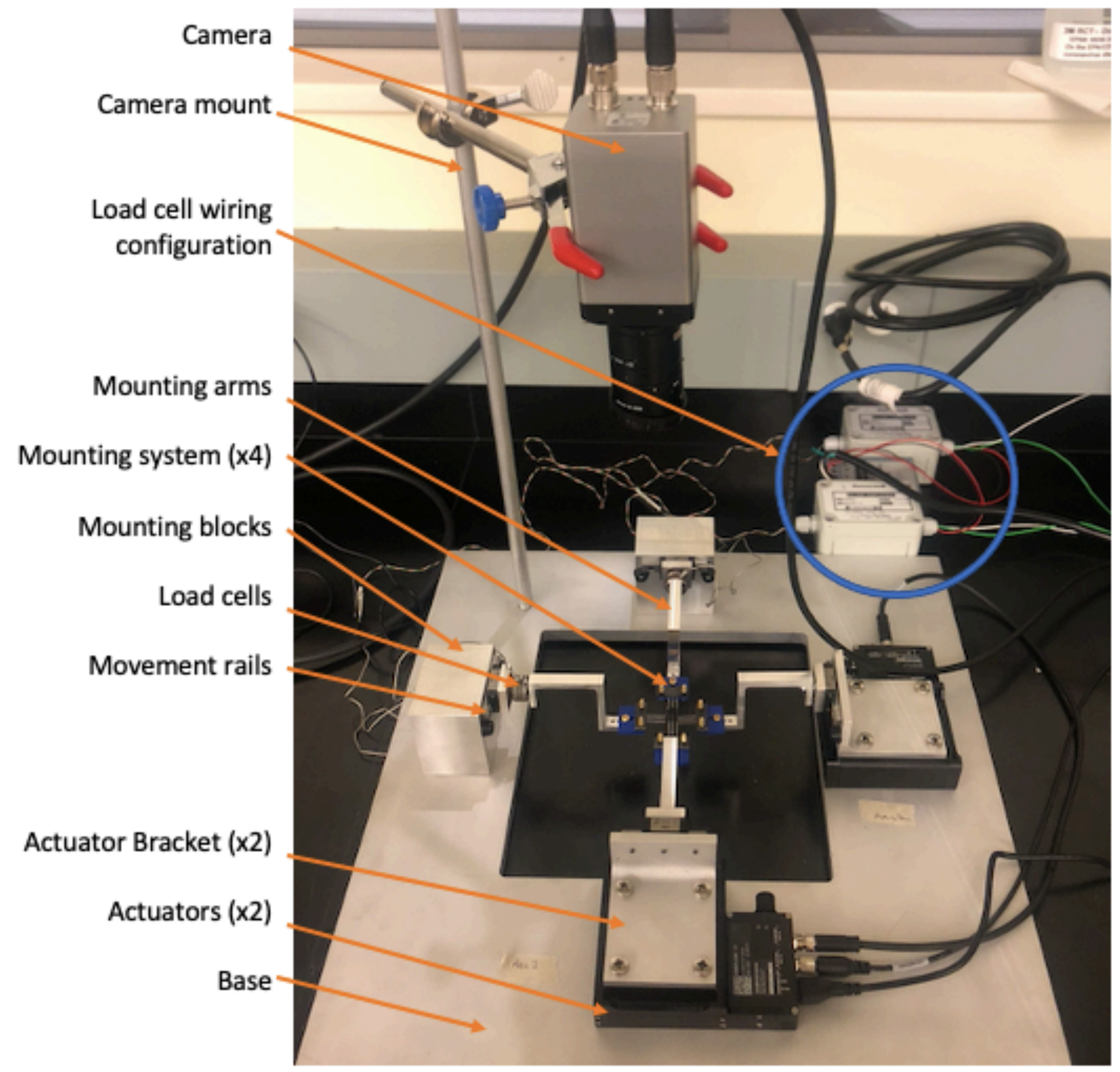
Abstract

An estimated 6.2 million adult Americans have heart failure (HF) [1]. The mechanical behavior of cardiac tissues is known to change during HF development, and it contributes to the function of myocardium (the muscular tissues in the ventricles). Currently there are limitations in the understanding of the viscoelastic behavior of myocardium and its alteration during HF progression. To fill these gaps in knowledge, it is critical to measure the tissue's viscoelasticity. Because viscoelasticity is a time- and strain-dependent mechanical behavior, the full characterization of myocardial viscoelasticity at physiological rates & non-linear deformation is critical. Therefore, the objective of this work is to establish a biaxial testing system that cyclically deforms myocardium sinusoidally at various frequencies up to 15Hz. The system development will enable viscoelastic measurement of cardiac tissue under physiological conditions across small and large animal species.

Specific Aims

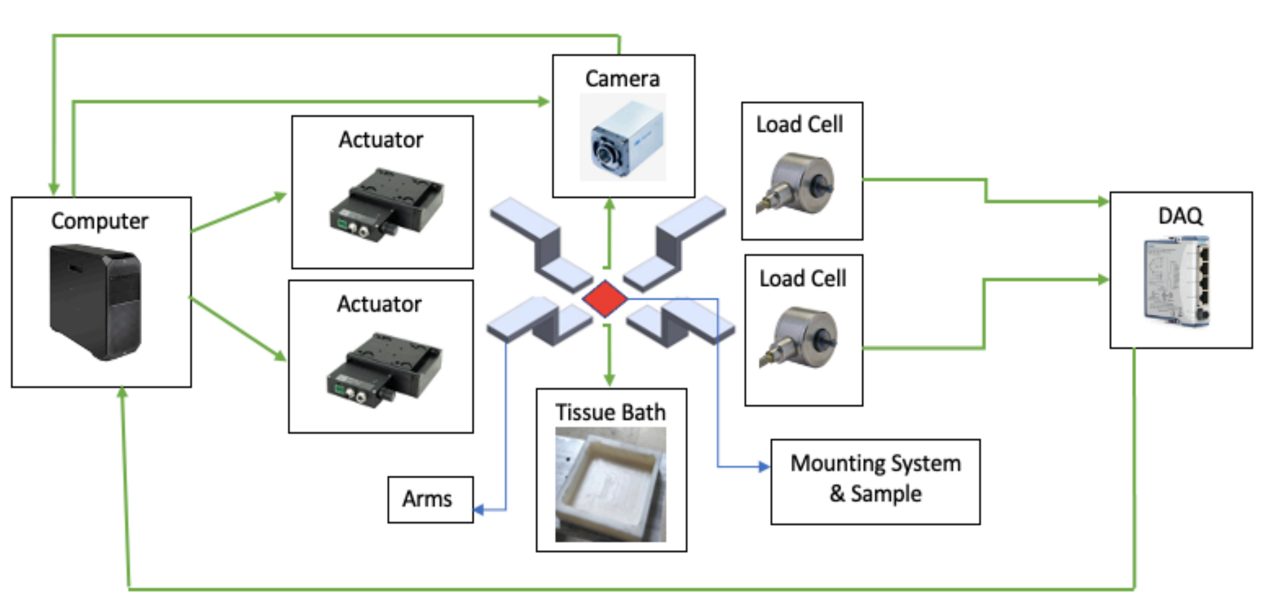
Aim 1: Build a biaxial testing system to measure myocardial viscoelasticity in physiologically relevant deformations

Aim 2: Validate the testing system with synthetic material.

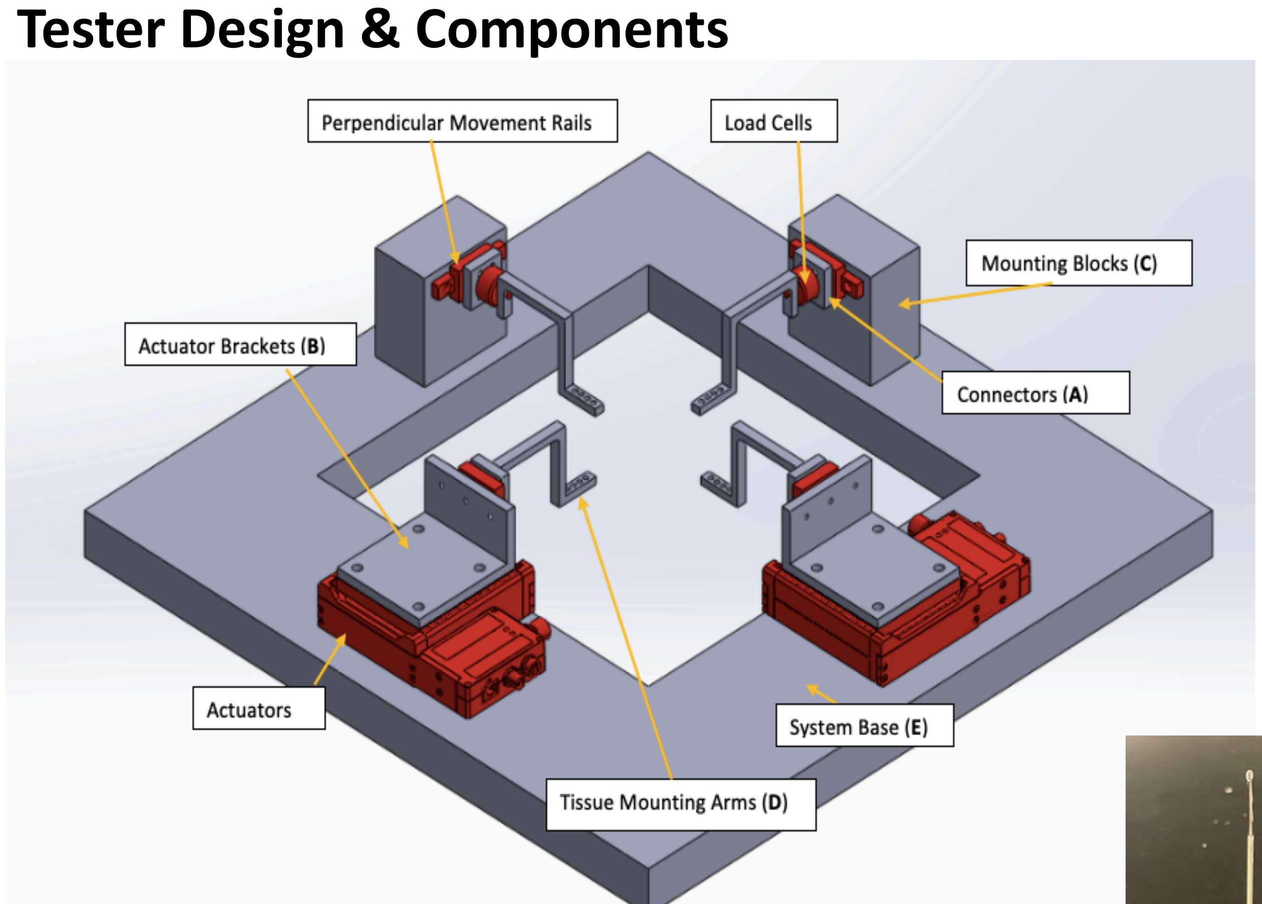


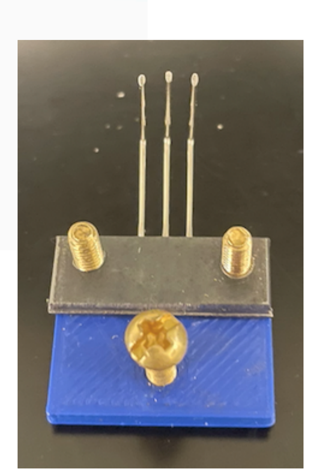
Biaxial Tester Construction

Diagram of the biaxial tester



Tester Design & Components





Desired specifications for high-speed (15 Hz) cyclic stretch:

- The maximum required sinusoidal velocity is 117.8mm/s
- The maximum image acquisition is 600 frames per second (FPS) (40 frames per cycle)

Parts Purchased:

- Zaber actuators (model XDMQ-DE) capable of the maximal velocity of 1400mm/s
- 5 lb. Honeywell load cells (model 31)
- Baumer camera (model BLXT-17M.I) capable of 660 FPS and 1100x1600 resolution.

Designing and fabricating the tester parts

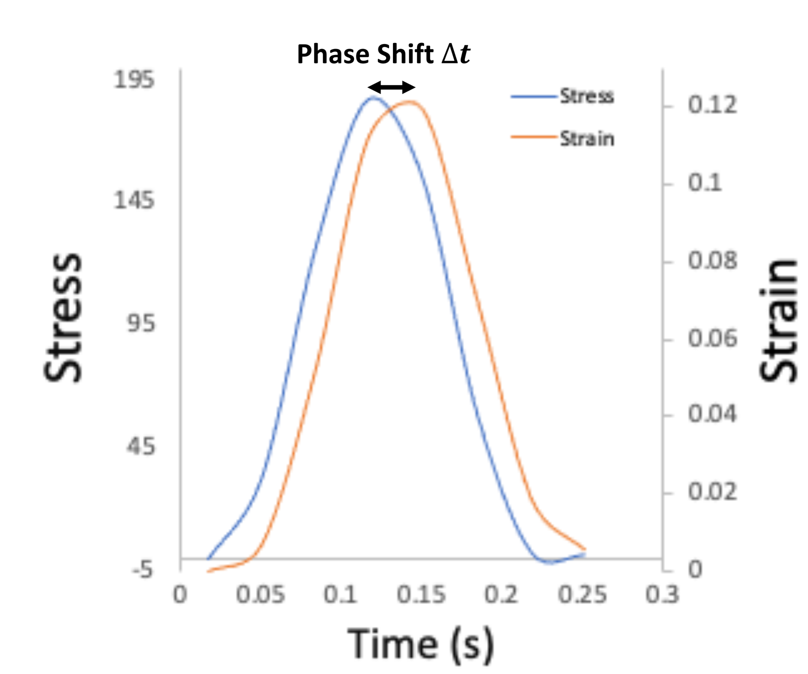
- Each non-industrial part is designed to induce planar biaxial deformation of small samples (10 mm x 10 mm – 20 mm x 20 mm).
- Aluminum was used as the primary material due to its light weight, mechanical strength, inability to form rust, and machinability.
- Parts were manufactured using hand milling and lathing, CNC milling, and 3D printing processes.

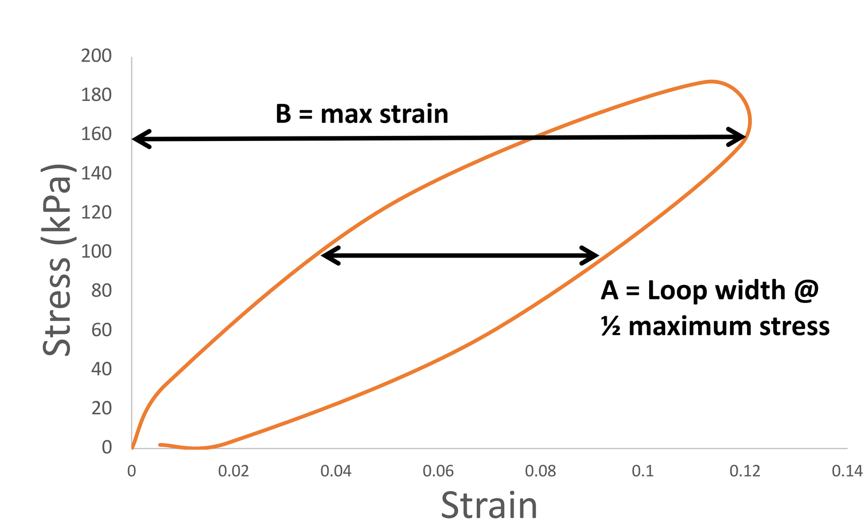
Data Acquisition in LabVIEW

- LabVIEW programming was used for the control of the actuators and the collection of force and camera data.
- Due to the delay in Baumer camera shipping, the LabVIEW code for camera data is still in the process to ensure synchronized force and camera data.

Analysis Methods

Dynamic mechanical analysis (DMA) is a viscoelastic measurement method where a material is subjected to a sinusoidal stress or strain. If there is a phase difference (see figure below) between the input and output stress and strain oscillations, the material is viscoelastic [2]. The viscoelastic behavior can be further analyzed from the hysteresis loop.





Calculation:

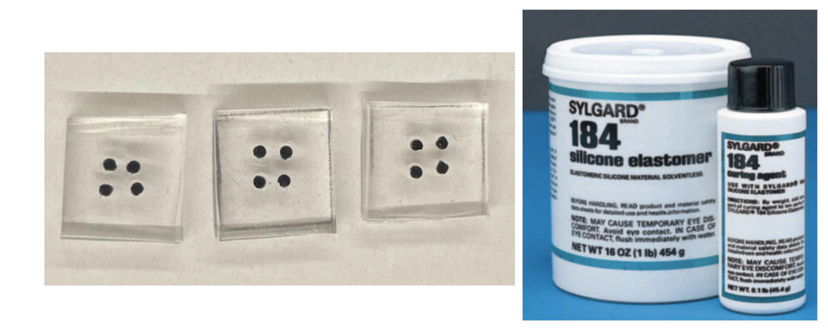
$Tangent\ delta = \tan(\operatorname{asin}\left(\frac{A}{B}\right))$ or tan (Δt * 2πf)

Elastic modulus (EM) = slope of entire hysteresis loop

Results

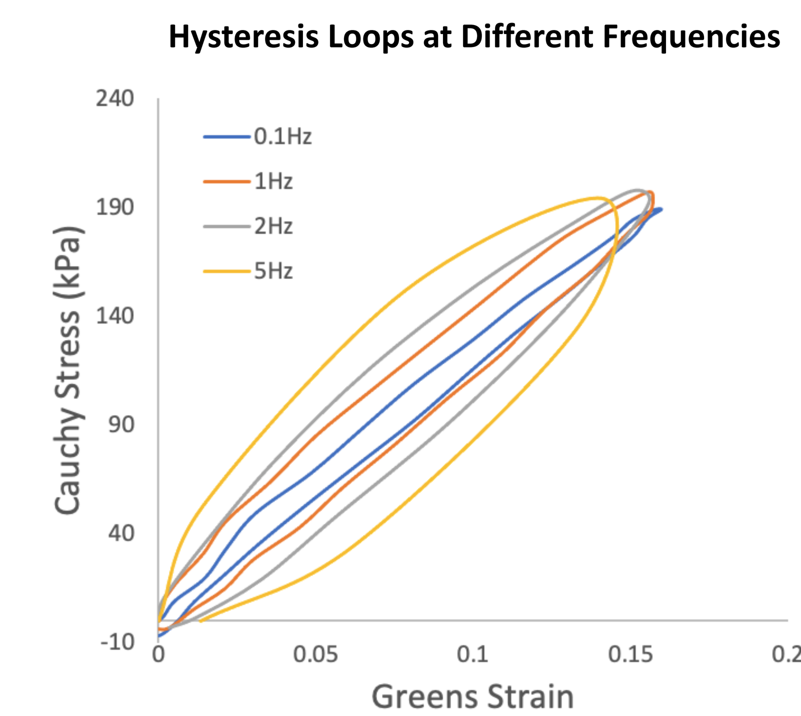
Validation Material

- Silicone (PDMS) sheet (Sylgard 184, Dow Corning) with reported viscoelastic properties was used.
- The silicone (10:1 curing ratio) was prepared in a stainless-steel container and cured in room temperature in a Vacuum oven at -25inHg for 48 hrs.



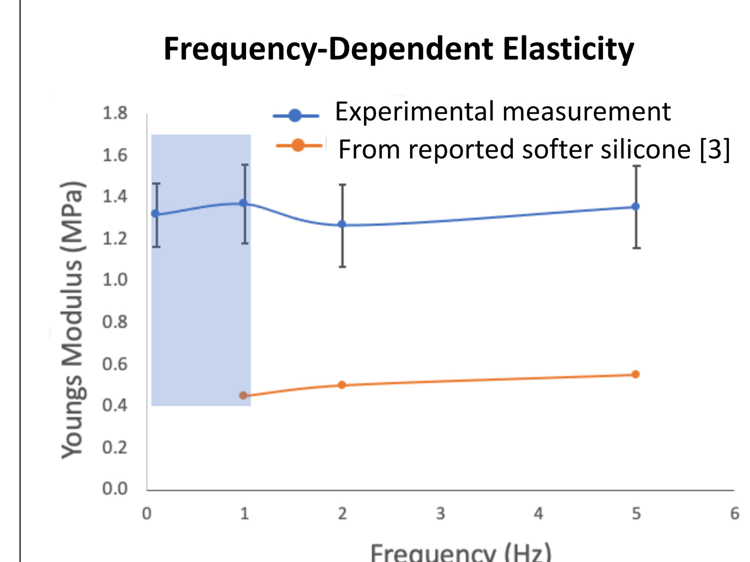
Uniaxial cyclic tensile test

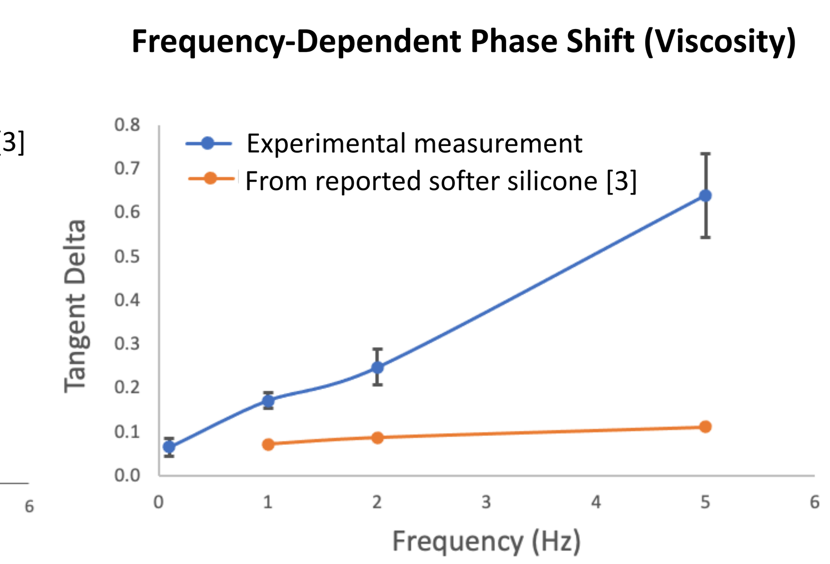
- **A temporary camera** (frame rate of 30Hz) was used for validation
- Isotropic property of silicone sheet was confirmed (data not shown)
- Preloaded by approximately 0.1N
- Cyclic stretched at 0.1, 1, 2, and 5 Hz, at 30% of maximal stretch in room temperature.



Outcomes

- Elasticity of silicone is within the literature reported range [3,4].
- The trend of frequency-dependent viscosity is correct. But the viscosity at higher frequencies is larger than reported in literature (in asilicone sheet with a smaller EM than ours) [3,4].





Shaded zone denotes the range of reported values from literature [3,4]

Conclusions

- The biaxial tester is functioning properly for measurement of elastic soft tissue properties.
- More work is needed to complete validation and confirm accurate measurement of viscoelasticity using the Baumer camera.
- Further improvement of the tester's software and post processing will enable myocardium viscoelasticity measurements across large and small animal species.

Acknowledgements

I would like to express my gratitude to Dr. Wang, Wenqiang (Eric) Liu, Michael Nguyen-Truong, Matt Ahern, Ethan Barron and the entire CVB lab for their feedback and guidance throughout my research effort.

References

[1] C. Yancy et al. *Journal of the American College of Cardiology*, 62(16), 1495–1539. (2013).
[2] R. S. Lakes. Viscoelastic Materials. *Cambridge University Press. (2009)*
[3] A. Goyal et al. *MACROMOLECULAR RAPID COMMUNICATIONS*, 30(13), 1116-1122. (2009)
[4] Deguchi et al. Viscoelastic and optical properties of four different PDMS polymers. *Journal of Micromechanics and Microengineering*, 25. 2015