Towards Self-Sensing Flapping-Wing UAV Development

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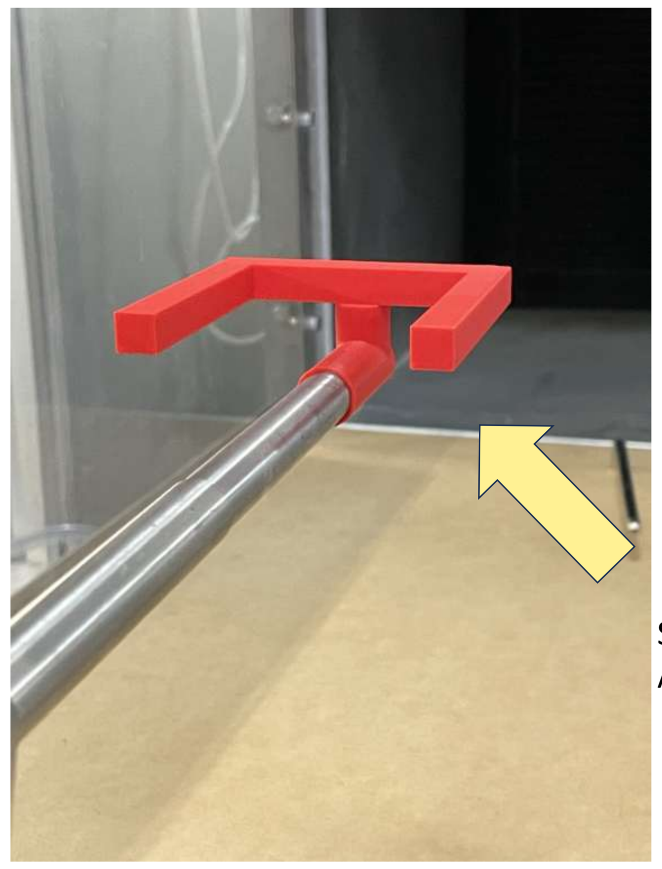
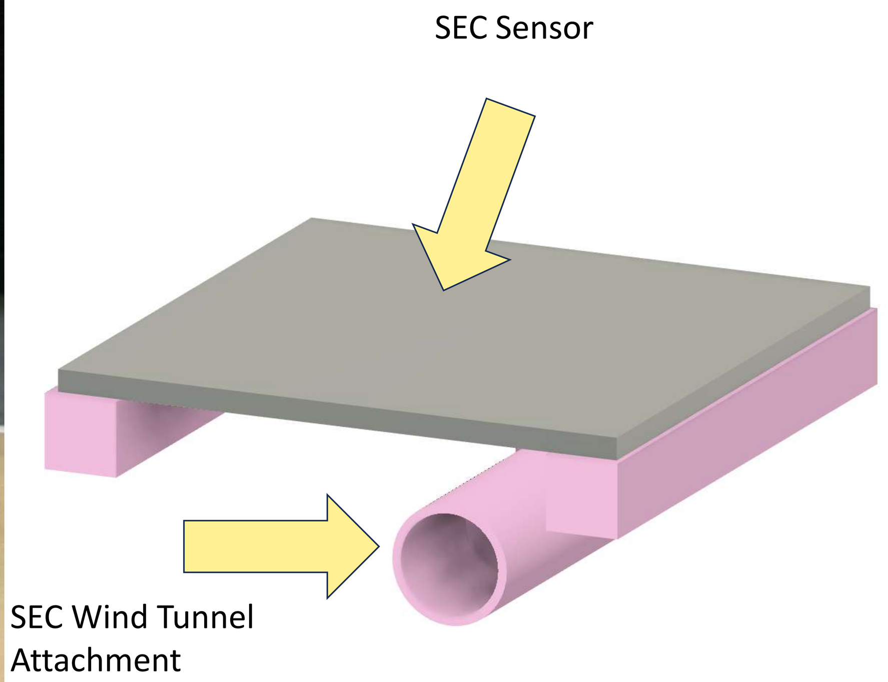
Introduction

- Soft-elastomeric capacitors (SECs) are stretchable, low-power strain sensors made by layering a flexible dielectric between compliant conductive electrodes. As they deform, their capacitance changes—enabling precise strain measurements across large, flexible surfaces ideal for integration into soft structures. However, they are susceptible to noise. This study aims to encase the SECs in silicone to reduce noise, to create sensors that will be feedback surfaces on flapping-wing drones.

The UAV draws inspiration from the dragonfly and will resemble it when completed. Vengolis, CC BY-SA 4.0 <https://creativecommons.org/licenses/by-sa/4.0>, via Wikimedia Commons



The SEC attachment in the wind tunnel. Wind will blow from the background to the fore ground across the surface of the sensor.



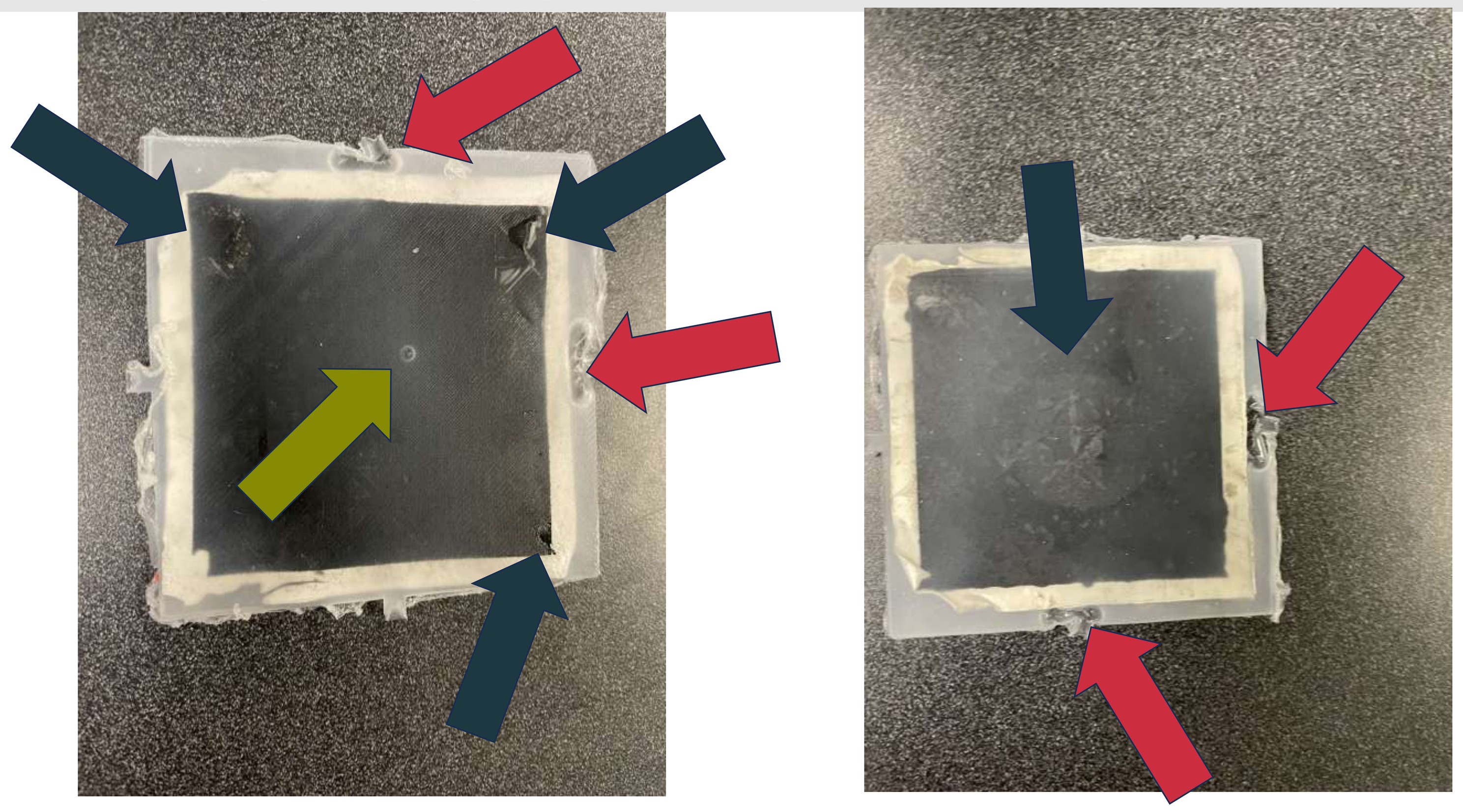
The SEC attachment and a 3D representation of the SEC sensor adhered to the attachment.

Methods

- Both molds are coated in Ease Release, a release agent, to ensure proper demolding.
- Ecoflex 00-30 is the silicone used at a 1:1 ratio by weight.
- Silicone is poured into the bottom mold, and the SEC is placed on top of that layer carefully to prevent trapped air. Then more silicone is poured on top.
- The top mold is pressed against, allowing excess silicone to escape. And using the excess to smear the overflow holes to prevent siphoning.
- After 4 hours at room temperature the sample is ready.

Results

- Without Release Agent: Silicone failed to adhere to the SEC, leading to partial sealing and air pockets.
- With Release Agent (Ease Release 200): Full encapsulation achieved with improved mold release. Minor issues remained:
  - Thin or missing silicone in spots, causing easy delamination under friction.
  - Trapped air between SEC and silicone layers led to weak bonding and peeling.
- Status: A perfect sample has yet to be produced, with uniform coverage and defect-free encapsulation still proving challenging.



The latest sample pointing out the various defects.
- Blue: To thin silicone, exposure of SEC, and surface adhesion.
- Red: Siphoning.
- Green: Air bubble.

Note: All samples to date have been made using old SEC sensors without the electrical contacts. The sensor is not functional without them

Significance

- Silicone-encapsulated SECs enhance signal clarity in soft robotics and morphing UAVs—enabling low-noise, reliable sensing in dynamic, adaptive environments. This advancement lays the foundation for integrating strain sensors into feedback-controlled, flapping-wing drones.

Conclusion

- Use of Ease Release 200 improved mold separation and enabled more complete encapsulation.
- Samples still exhibit defects such as:
  - Thin or missing silicone regions
  - Air entrapment between SEC and silicone layers
  - These defects cause peeling, friction sensitivity, and poor interlayer bonding.
- No perfect sample has been achieved—uniform coverage and defect-free encapsulation remain challenges.

Next Steps

- Refine encapsulation process to eliminate defects like bubbles, thin coverage, and bonding issues
- Begin wind tunnel testing to compare:
  - Encapsulated vs. non-encapsulated samples
  - Effectiveness of encapsulation in reducing noise and improving signal clarity

References

- Emmanuel A. Ogunniyi, Han Liu, Austin R. J. Downey, Simon Laflamme, Jian Li, Caroline Bennett, William Collins, Hongki Jo, Paul Ziehl, "Soft elastomeric capacitors with an extended polymer matrix for strain sensing on concrete," Proc. SPIE 12486, Sensors and Smart Structures Technologies for Civil, Mechanical, and Aerospace Systems 2023, 1248618 (18 April 2023); https://doi.org/10.1117/12.2658568

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