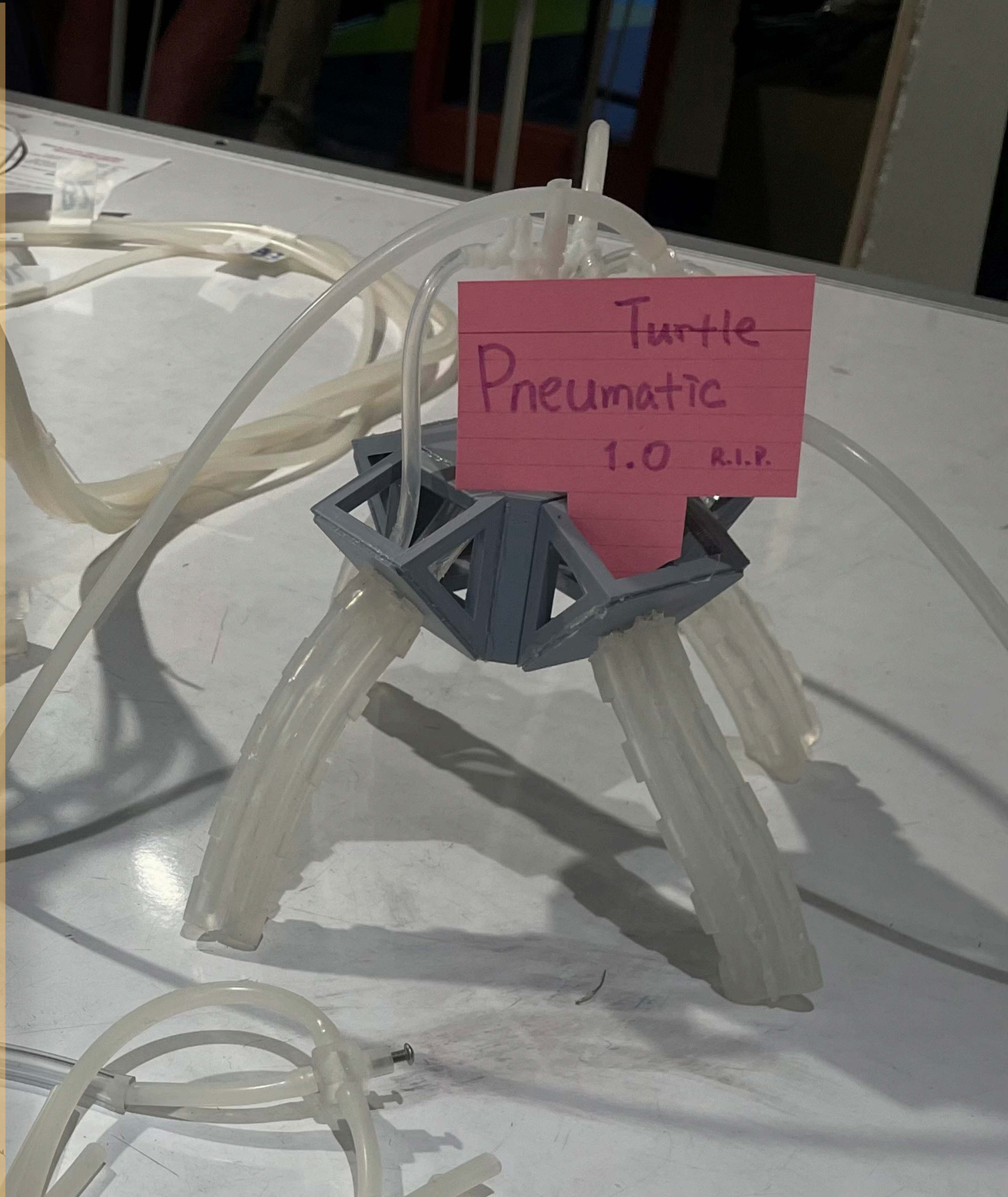
Pneumatic Soft-legged Turtle Robotic

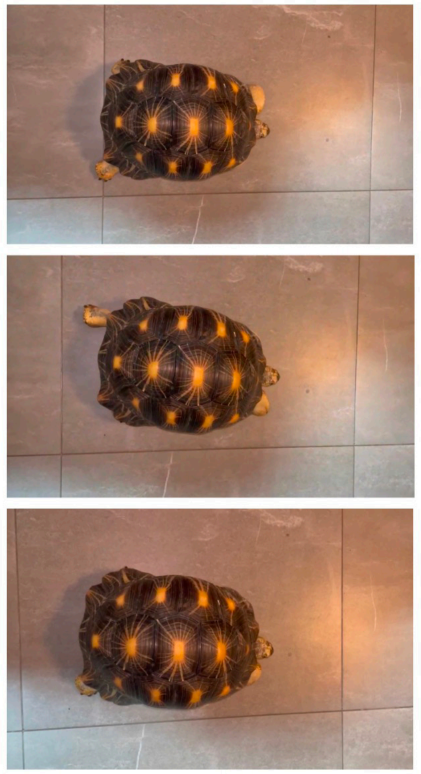
2023 Course Project

The Pneumatic Soft-legged Turtle Robotic project, developed as part of a 2023 course, 16480 - Creative Soft Robotic, focuses on creating a soft robotic system that mimics the gait and movement of a turtle. Using pneumatic actuators and flexible silicone components, the robot is designed for smooth, controlled motion across different terrains. The project combines soft robotics principles with biomimicry to achieve stability and adaptability, making it an innovative example of how soft materials and air-driven systems can replicate complex biological movements. This project aims to advance soft robotics in environments where flexibility and safety are paramount.



BACKGROUND

Tortoises Walking Style



Tortoises possess a distinctive walking style that offers numerous advantages, allowing them to move with remarkable efficiency and balance. Their slow, deliberate pace is key to their stability, symmetry, low center of gravity, and enduring stamina.

- Stability: Tortoises move with slow, small steps, maintaining a stable center of gravity, and their shell adds extra support for balance on uneven terrain.

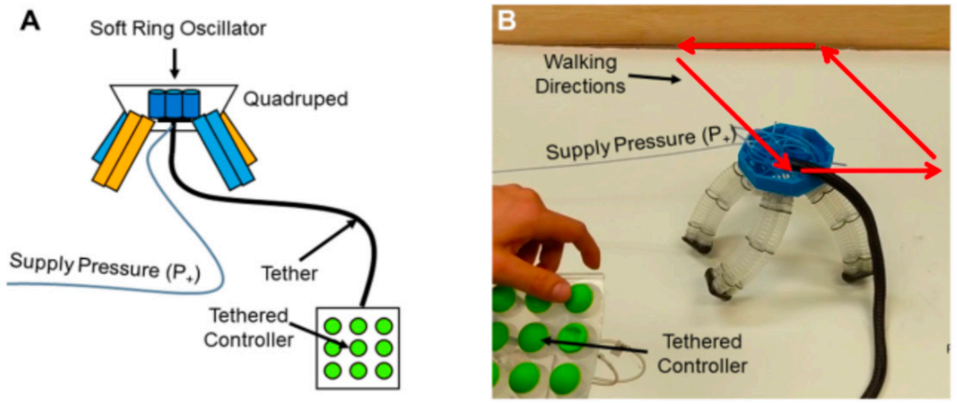
- Symmetry: Their symmetrical, alternating leg movement ensures balance and conserves energy, making walking efficient.

- Low Center of Gravity:A low center of gravity keeps them close to the ground, providing stability and resistance to external forces.

- Endurance:Their slow, energy-efficient gait allows for long-distance walking with minimal strain on muscles and joints.

Relative Research

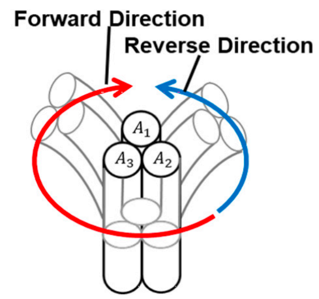
Drotman et. al(2021). Electronics-free pneumatic circuits for controlling soft-legged robots. Science Robotics, 6(52), eabf0839.



Electronics-Free Gait Control System

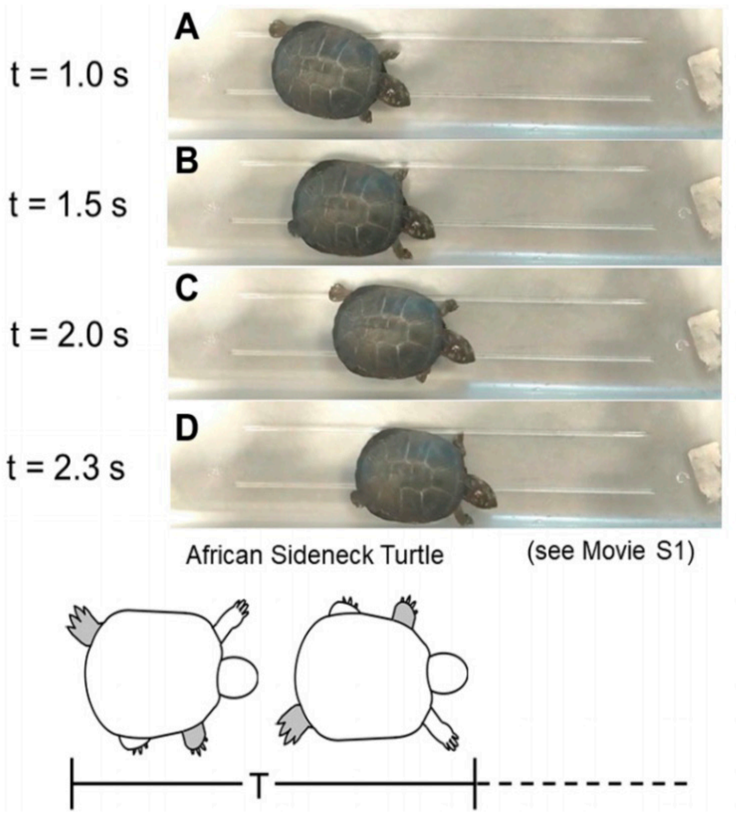
The system operates using a CO2 canister that powers pneumatic oscillators, controlling the robot's legs in diagonal pairs for coordinated walking. By alternating high-pressure states through a pneumatic circuit, the robot mimics biological gait patterns, allowing it to walk smoothly. This setup enables the robot to change direction, either forward or reverse, by adjusting the sequence of leg movements. Notably, the entire process is electronics-free, relying purely on pneumatic components, making it simple and effective for various terrains.

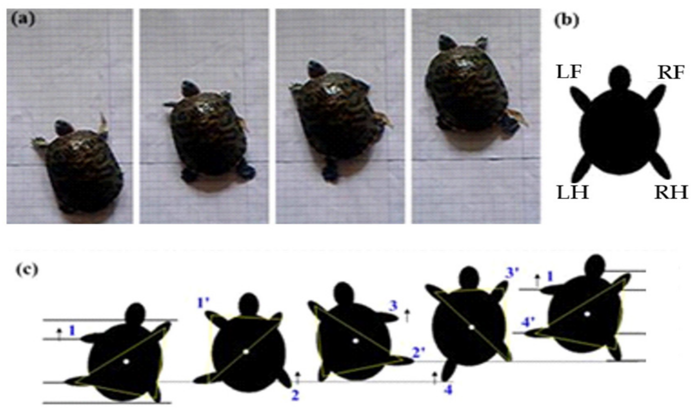
The pneumatic legs are powered by a CO2 canister, which inflates and deflates the legs using pressurized air. Each leg moves in a coordinated sequence controlled by pneumatic oscillators, mimicking natural walking patterns. This system enables the robot to walk and

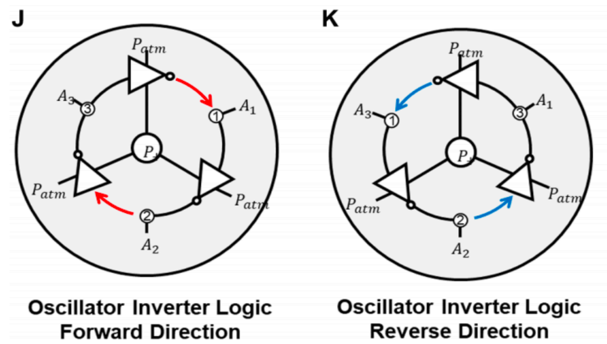


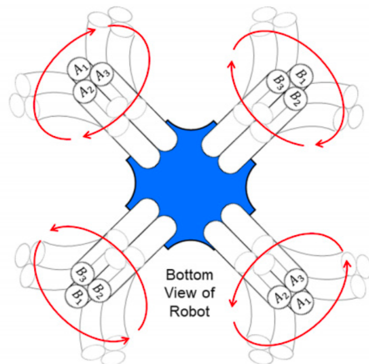
DIAGONAL COUPLET GAIT SEQUENCE

The Diagonal Couplet Gait Sequence refers to the walking pattern observed in animals like the African sideneck turtle, where the movement of the legs occurs in diagonal pairs. As shown in the image (A to D), the turtle alternates its front-left and back-right limbs, followed by its front-right and back-left limbs. This rhythmic and coordinated motion allows the turtle to maintain stability while moving forward. In robotics, such a gait pattern can be replicated to enhance balance and energy efficiency in quadruped robots, making it ideal for navigating uneven terrains.









DESIGN PATTERN

I plan to design a soft-legged animal (turtle) robot that relies on pneumatic control.

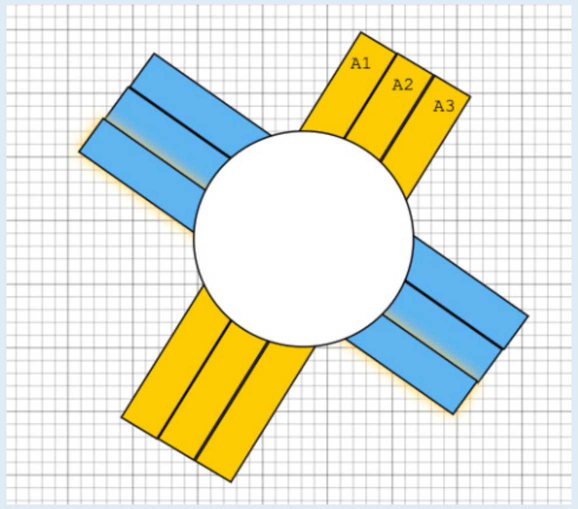
- Each leg has three chambers and controls the bipedal legs in a diagonal fashion, switching between gaits to control the direction of movement.
- During progression, turtles use their limbs to push forward alternately. Typically, they move using the limbs on opposite corners (left front limb and right hind limb, right front limb and left hind limb) simultaneously, such a gait helps in maintaining body stability and distributing weight.

Using three pneumatic chambers per leg allows for more complex and controlled movements. This design likely enables multi-axis bending and rotation, essential for achieving a more natural and versatile walking motion.

Diagonal couplet gait control

The chambers labeled A1, A2, and A3 for one diagonal pair of legs and B1, B2, B3 for the opposite diagonal pair are inflated in sequence.

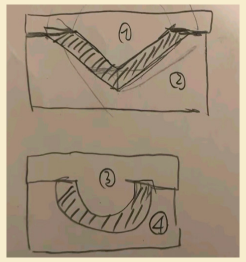
The inflation sequence for one pair (e.g., A1, then A2, then A3) causes the robot to rotate its legs in one direction, enabling it to take a step diagonally. Similarly, inflating B1, then B2, then B3 propels the robot in a perpendicular direction. By reversing the inflation sequence (e.g., inflating A1, A3, and then A2), the robot moves in the opposite direction.



In the Carnegie Mellon A5 lab, silicone casting is used as a key process in soft robotics to create flexible, adaptive components. The principle involves pouring liquid silicone into custom molds, . These silicone components are ideal for soft robots because they can bend, twist, and stretch in response to pneumatic or hydraulic pressure, mimicking biological movements. This process enables the design of robots that are lightweight, flexible, and capable of interacting safely with complex environments.

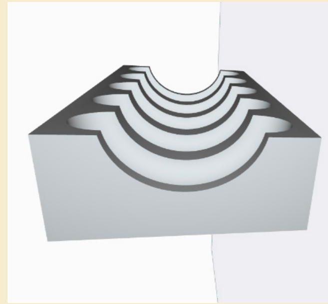
THE LEGS

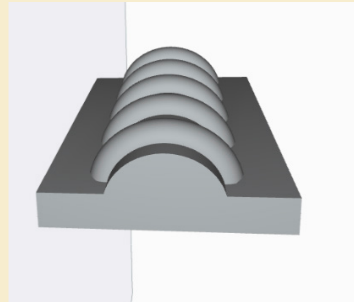
Iteration 1.0



The model will be divided into two parts:
Piece 1: curved part
Piece 2: Triangular part (120°)
1 part will be made up of Part1+Part2 and each pneumatic leg will be made up of 3 parts

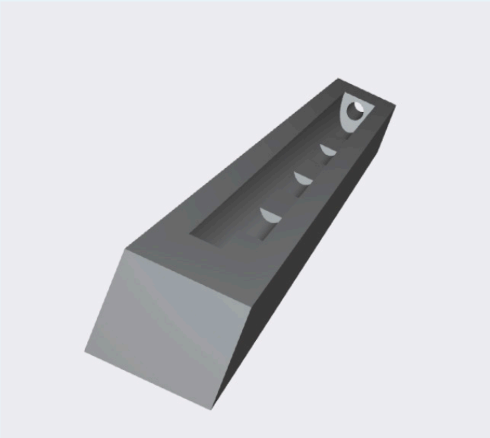
3D CAD





The drawbacks of this iteration include having too many bonding points, which increases the risk of air leakage. Additionally, the wall thickness may pose an issue, not only increasing material costs but also potentially affecting the flexibility and expandability of the pneumatic leg. These issues should be addressed in the next iteration by reducing the number of bonding points and optimizing structural strength.

ITERATION 2.0



Single-side punch

Based on the experience of the first time, this time I designed one leg for the entire airlock, while running a steel cylinder through the center to keep the airlock center control. This ensures the airtightness of the chamber

The center section is a three-pronged column. A pneumatic leg consists of a core + 3 chambers. The parts to be glued are the three faces of the triangular prism. I used a special glue for rubber for this step.

1core + 3 chambers

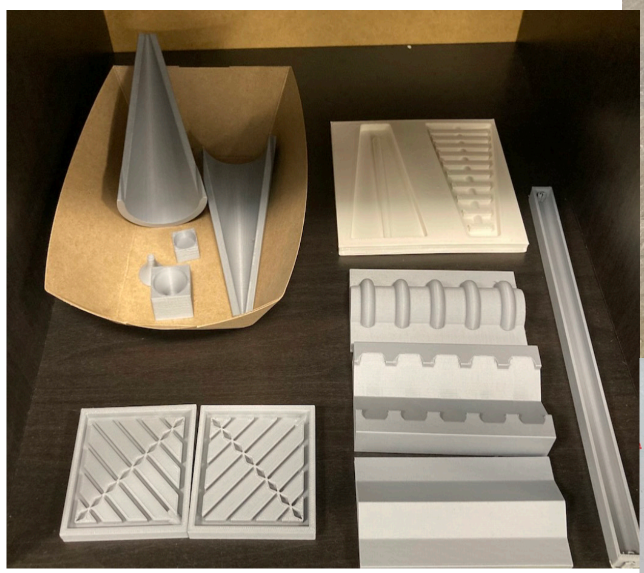
Curve Test

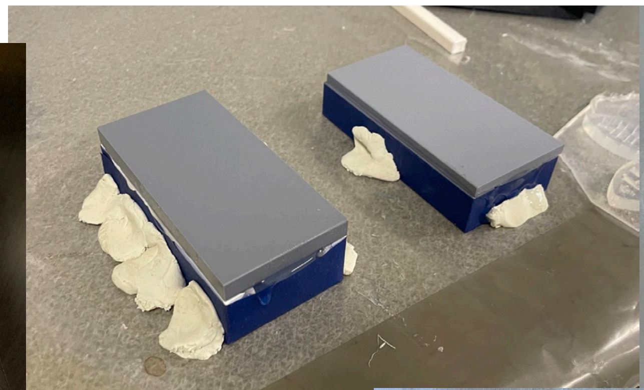
The iterative process used a simple pneumatic actuator to check the bending pressure of the chamber, which proved to be very successful.

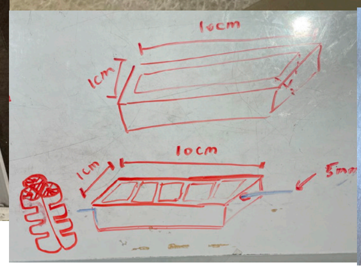
Optimized Design

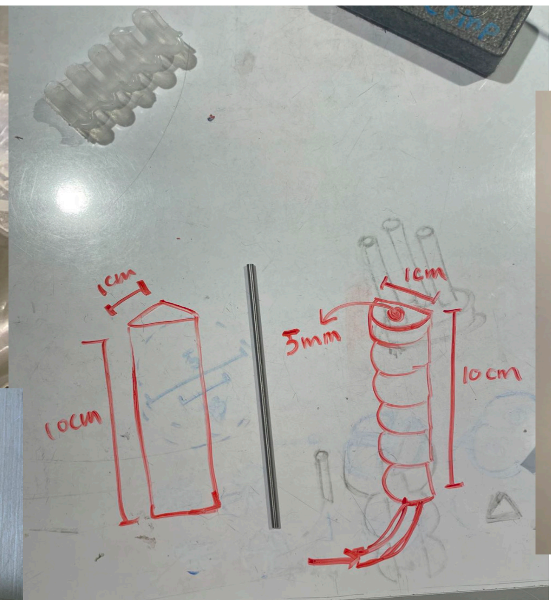
The design focused on enhancing the airtightness of the pneumatic chambers by implementing a single-side punch technique and maintaining center control with a steel cylinder. The use of a three-pronged core with three chambers, glued with specialized rubber adhesive, ensured reliable performance. The curve test confirmed the system's success by effectively measuring the bending pressure, showcasing the improved control and airtight construction. These optimizations resulted in more precise movement and increased durability of the soft pneumatic leg.

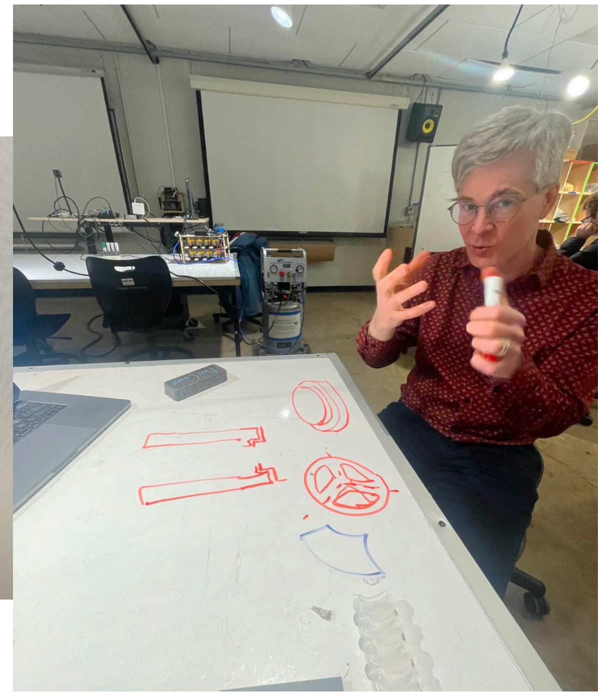
SOME OF THE PRODUCTION PROCESS





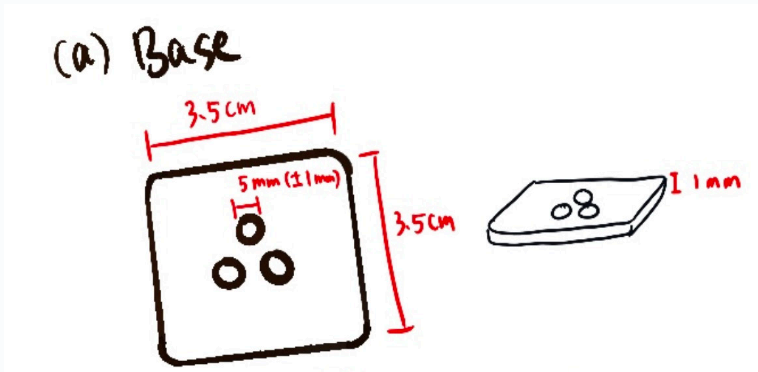




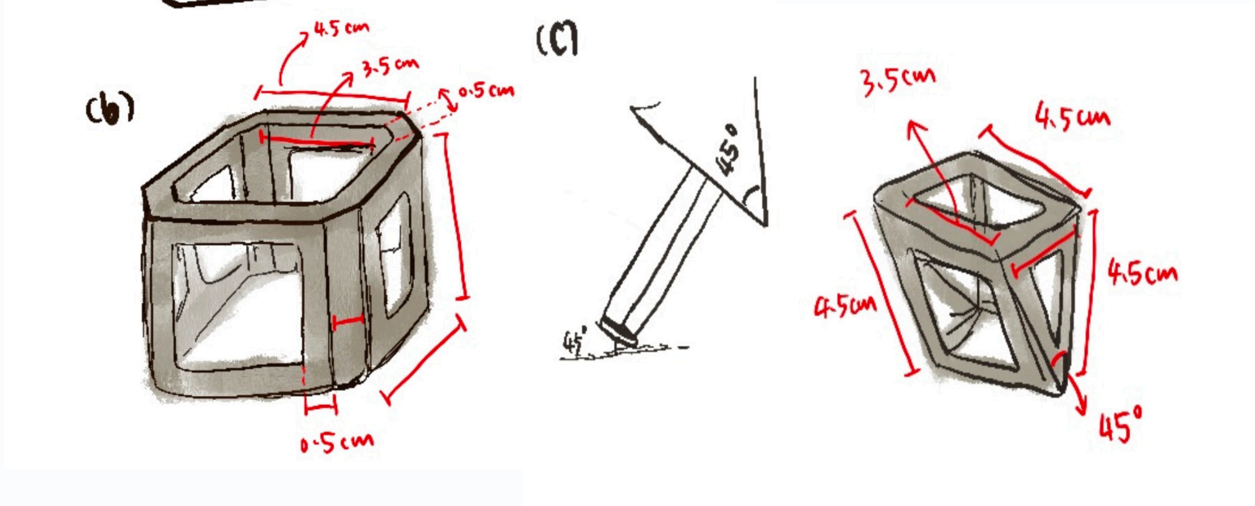


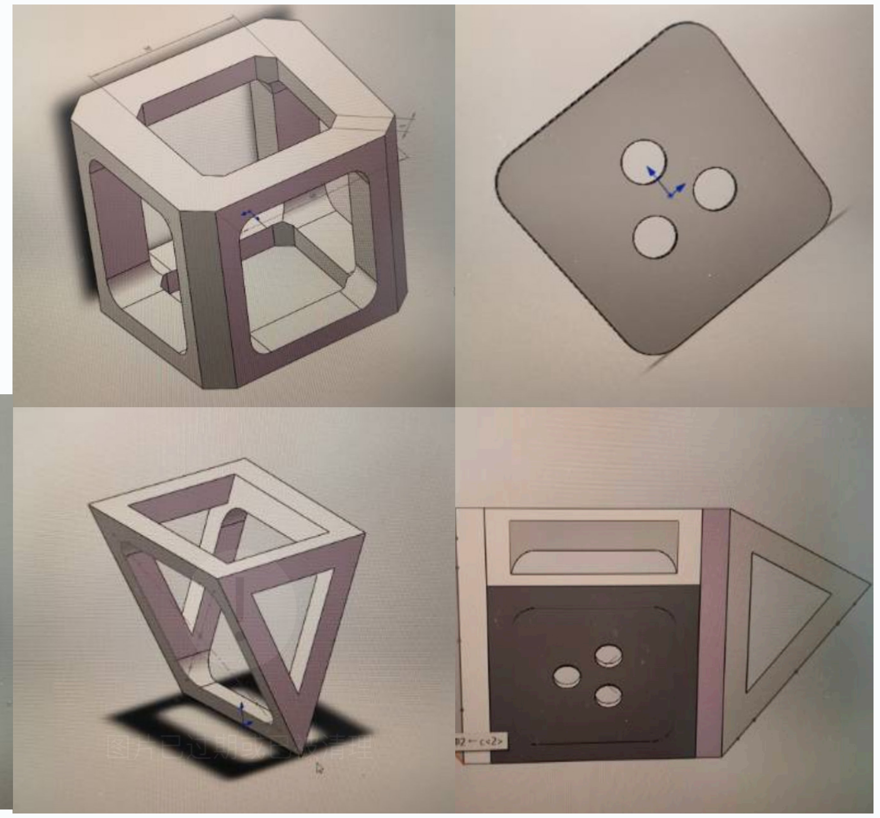
Garth is offering advice :)

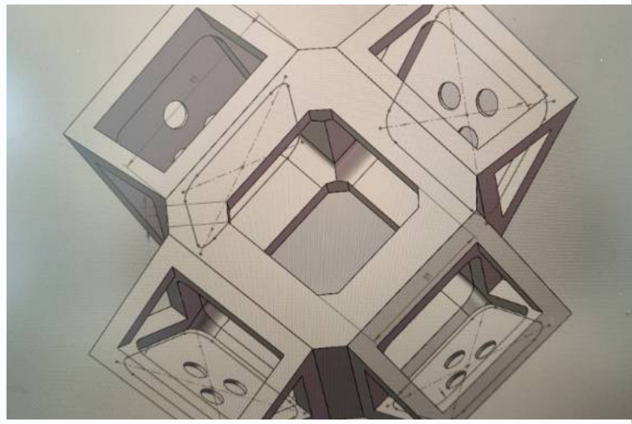
THE SHELL

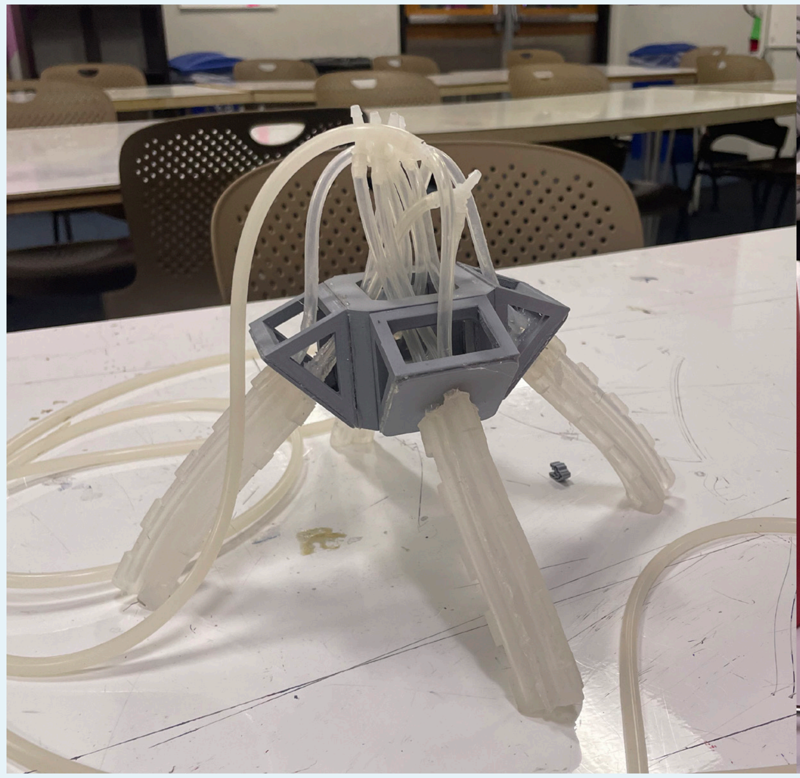


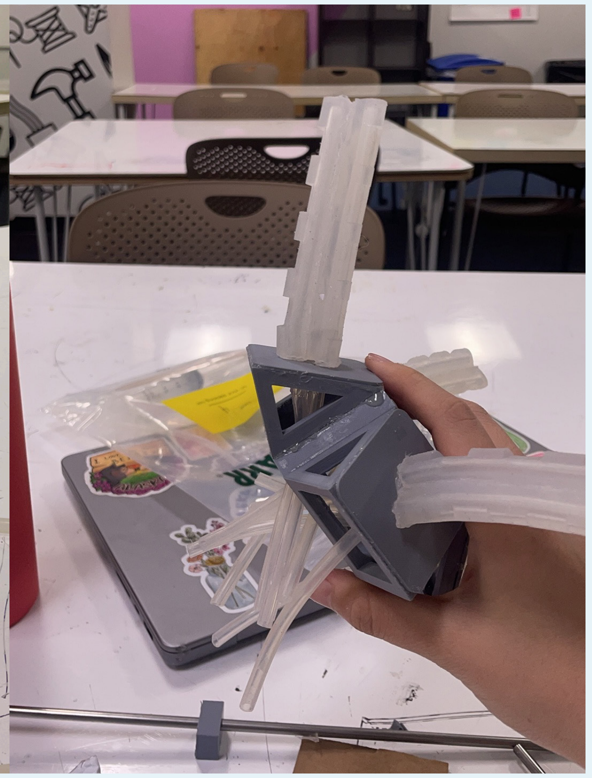
For the design of the turtle shell, there was only one goal: light weight and the need to integrate all the tubes and chambers, so I chose a shell structure that is as hollow as possible: a cubic frame + 4 triangular frames + 4 sections with integrated 3 tubes. The use of PLA (Polylactic Acid) provides strong support for the pneumatic system due to its ease of 3D printing and rigid structure. Its lightweight and durable properties help maintain the form of the airlock chambers, making it ideal for soft robotics applications.







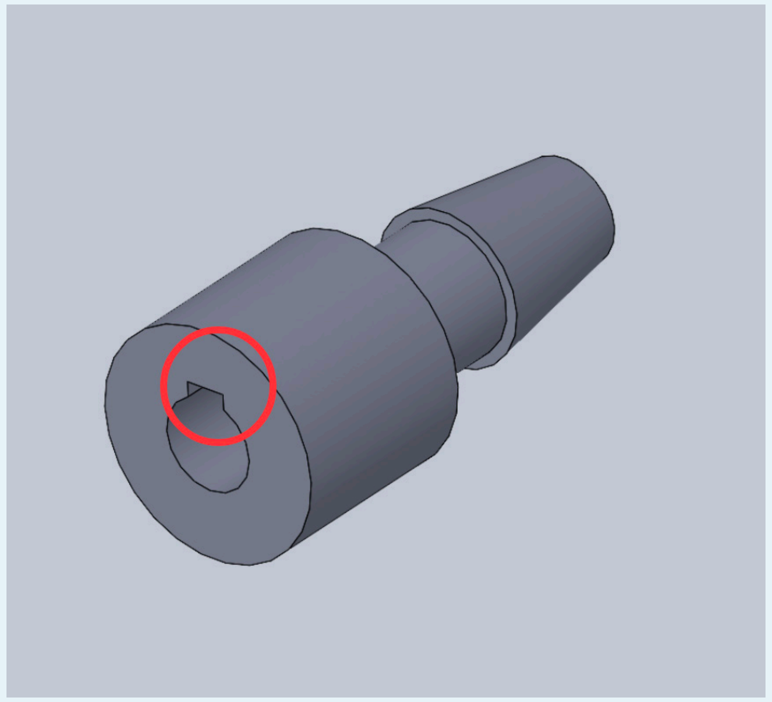


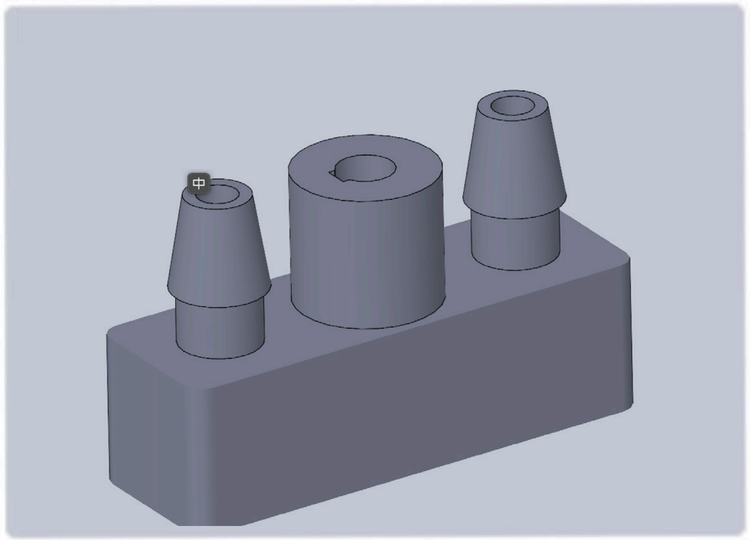


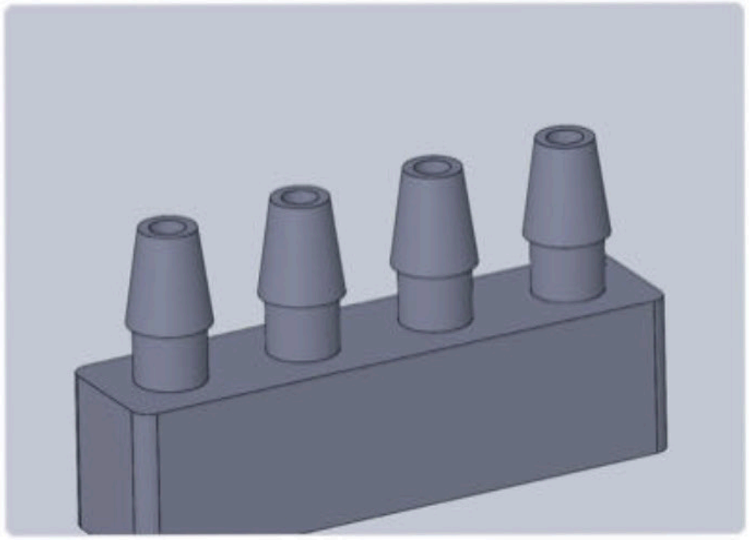
THE CONNECTOR

Under Garth's leadership, we developed new valves, done by 3D printing. The 3D-printed air tubing manifold is designed with internal chambers that connect various ports, allowing for streamlined air flow.

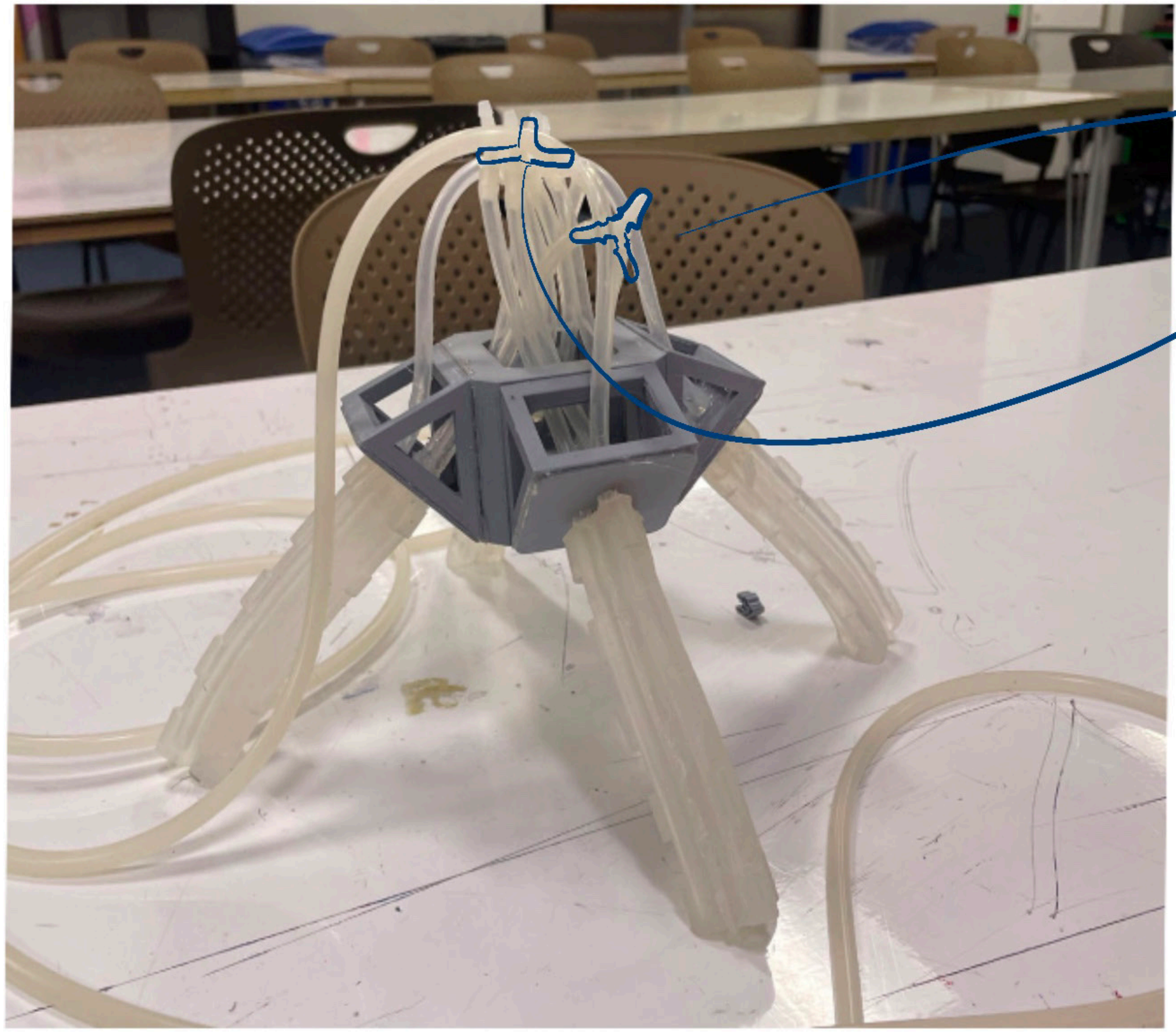
A key feature is the adjustable bleed valve, controlled by a screw, which enables fine-tuning of air venting. The modular design of these components allows for easy customization, making it adaptable for different air plumbing setups.

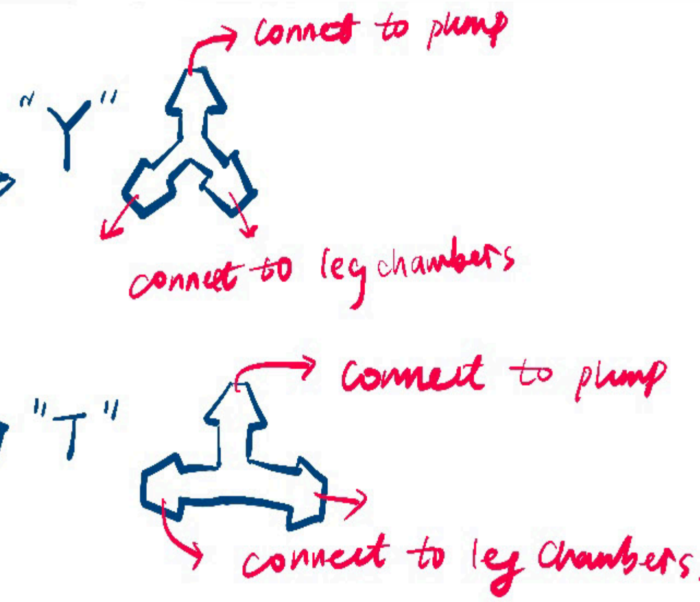


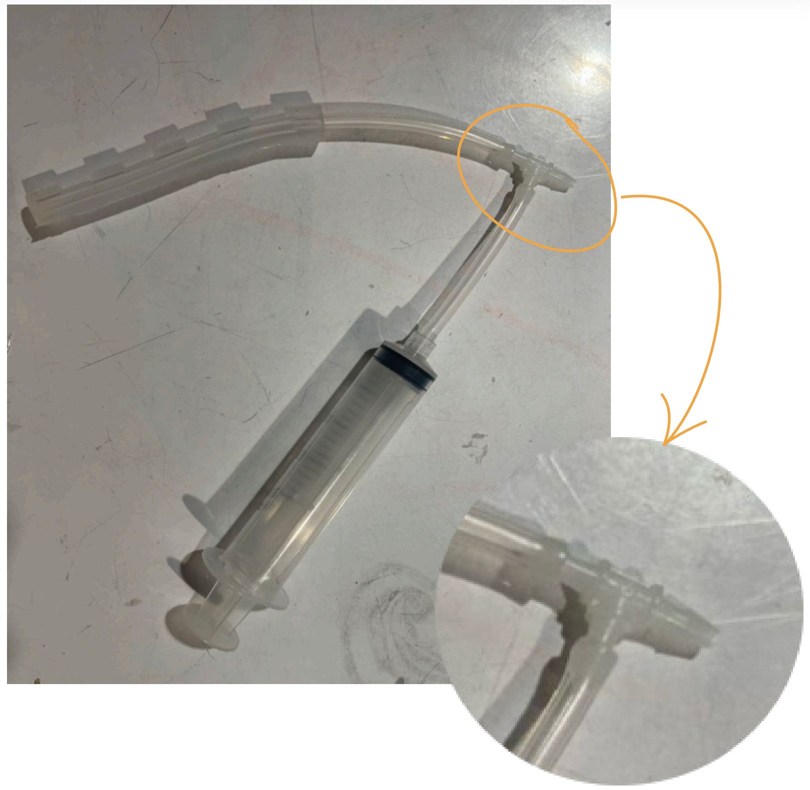


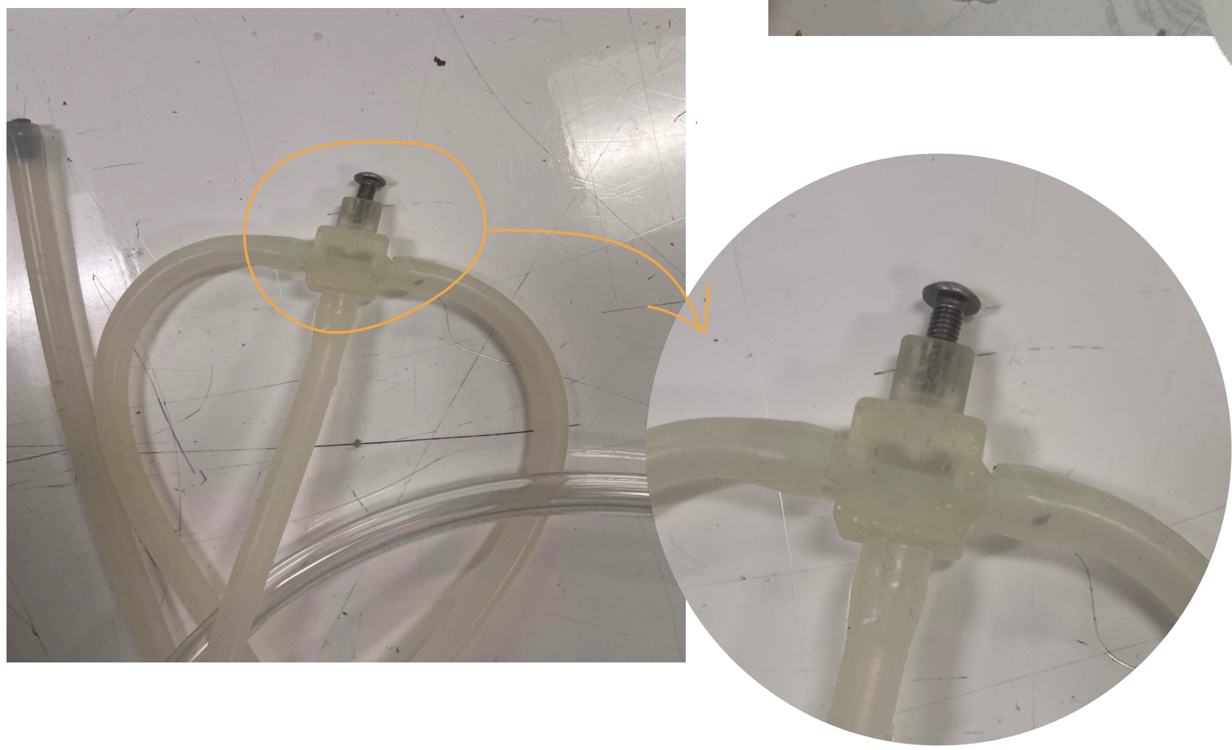


We ultimately chose a T-shaped connector with a screw-based mechanism to control the air valve, allowing fine adjustments based on the screw's insertion depth. The screw acts as an adjustable valve: as the screw is turned, it either increases or decreases the depth of insertion into the connector, which controls the size of the air opening. The tighter the screw is turned in, the smaller the air passage becomes, limiting the airflow, and conversely, loosening the screw opens the passage more, allowing increased airflow. This setup allows for precise manual control over air pressure, contributing to both the robot's stability and more efficient pneumatic operation compared to earlier methods.
Additionally, the connector was produced using resin printing, which ensured the final product's strength and durability, making it well-suited for handling pneumatic pressures.









FINAL SHOW