Chronic ankle instability (CAI) is a long-term disability that arises due to recurrent ankle sprains which can cause permanent deformation to the tendons surrounding the ankle joint [1, 2]. Current common solutions for rehabilitation are rigid ankle-foot orthoses (AFOs) made of lightweight plastics that lend their stiffness to the ankle joint [3, 4]. This AFO affects the user’s gait and can result in gait abnormalities and inability to achieve the full ankle motion which can result in further injury or discomfort to the individual, such as back, hip and knee problems, and increased probability of tripping and falling [6–8].

A soft robotic AFO is a solution to the traditional rigid AFO because it is a dynamic and adaptable solution to support the ankle.

Based on the model of a simply supported cantilever beam with a single point load at the free end and using Timoshenko’s theory, the deflection of an inflatable beam can be modeled [12]–14 using the following equation for calculating deflection:

\[ \delta = \frac{P}{E \cdot I} \left( \frac{a^3}{3} + \frac{a}{2} \right) \]

where:

- \( P \) is the shear coefficient of a thin-walled box section from Cowper’s formulation [15]:

\[ k = \frac{10}{(1 + v)(1 + 3v)} \left( \frac{12 + 125v + 300v^2}{1 + 6v + 300v^2} \right) + 10v(1 + 3v) \]

Where \( m = \frac{E}{1 + v} \) and \( n = \frac{E}{1 - v} \)

- The maximum deflection can be calculated using \( k \) is [14], which reduces Eq. (1) to:

\[ \delta = \frac{P}{E \cdot I} \left( \frac{a^3}{3} + \frac{a}{2} \right) \]

- The total length \( l \) of the actuator is calculated as:

\[ l = 2a + N(L_v + L_h) + L_h \]

For an actuator with \( N \) segments of different materials, the total deflection \( \delta \) of the MAVS is then calculated by:

\[ \delta = N(V_{V, AFO} + V_{V, 0}) \]

**Final Design**

- Soft actuator with combined compliant and rigid materials would be a novel and effective solution to the research question at hand.
- The final design was inspired by Jiang and Gravish’s sliding-layer laminate concept which observed different stiffness levels with various orientations of rigid pieces [16].
- Rigid retainers limit vertical expansion, reducing volume and therefore, reducing inflation time [17].

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**References**


**Figures**

- Figure 1: The original actuator for IE support incorporated into the SR-AFO as proposed in previous work [9].
- Figure 2: (a) Side profile inflated, (b) Side Profile Deflated, (c) Right Cross-Section, (d) Left Cross-Section.
- Figure 3: Side view of the MAVS when (a) inflated, (b) deflated, and (c) the top view.
- Figure 4: (a)–(h) Fabrication process for the MAVs for the soft actuator (a)–(g) and the rigid retainers (d)–(f) and how the layers are fixed together [17].
- Figure 5: (a) MAVs fixed in the custom clamp while being subjected to a vertical, transverse load from the UTm [17]. (b) The dual-axis platform with a user positioned for testing while wearing the SR-AFO [18].
- Figure 6: The force required to deflect 20mm for each iteration of the MAVS, comparing the iterations with the same \( L_v \) and different \( L_h \) [17].
- Figure 7: The ankle angles for each condition (active, passive, or no exosuit) for each of the platform conditions (rigid, 100 Nm/rad, or 50 Nm/rad) with deviation between each participant shown by the error bars [17].

**Methods**

- To evaluate the stiffness of the MAVS iterations, a universal testing machine (UTM) was used for deflection testing with a custom clamp to fix one end of the MAVS while the other end was kept free in a cantilever beam setup (Fig. 5a).
- The MAVS were evaluated on the bench when passive, active, and at varied pressures, 0 kPa to 100 kPa in increments of 10 kPa.
- Three healthy participants (n = 3) were asked to walk across a dual-axis robotic platform [18] to characterize stiffness behavior of MAWs while embedded in the SR-AFO while the stiffness of the platform in the frontal plane is varied randomly for three haptic conditions:
  - Rigid (No compliance)
  - 100 Nm/rad
  - 50 Nm/rad

**Results**

- Analytical model predicted that lower the values of \( L_v \) and \( L_h \) produced higher resulting stiffness and was validated using the UTM.
- A1 saw the highest passive and active stiffness, but since the MAVS will be integrated in a wearable exosuit, the high passive stiffness is not ideal.
- The final MAVS design determined to be the best suited for the SR-AFO is the A2 MAVS, with a rigid retainer of \( L_h = 1 \) cm and a gap of exposed soft actuator at \( L_v = 1 \) cm.