Modeling Pneumatic Inflatable Actuators (PIA)

By Zachary R. Shuler

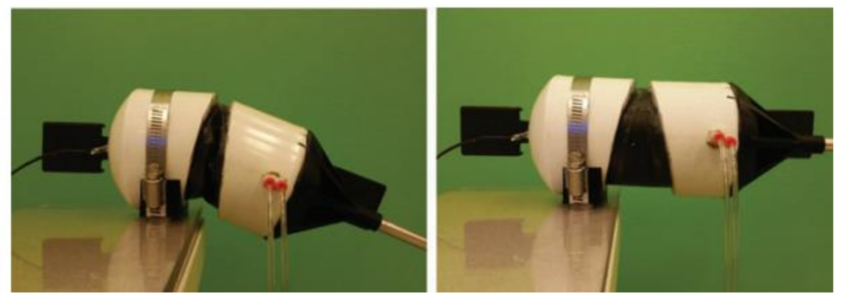
Principal Investigator Dr. Donal Holland

University College Dublin, Dublin Ireland

Introduction

Pneumatic Inflatable Actuators (PIA) are devices that can be used in soft robotic actuators. These actuators buckle at an angle when inflated. These buckling action causes a reduction in the volume of the actuator as it starts to self-intersect. The actuator generates a force, which in turn creates a torque. The torque generated by these actuators can simulate joint or muscle movement. Such actuators can be used in exoskeletons or restore movement to people suffering from paralysis.

A group of researchers led by Christopher Nesler proposed a design for such an actuator. Then, another group of researchers led by Allan Veale built on this research to design an actuator to aid in going from sitting to standing. Meanwhile, Dr. Holland worked on a proposal for a similar actuator during this time but paused work after the Nesler paper was published. The goal for the project is to compare these results to determine if Dr. Holland can publish



An actuator Designed by Nesler

Methodology

1.Read the papers by Nesler, Veale and related work on pneumatic inflatable actuators.

2.Examine Nesler's torque equation, its proof, then try to replicate it.

3.Examine Dr. Holland's force equation and its derivation. Then try to replicate its derivation.

4. Convert Dr. Holland's force equation to a torque equation and compare it to Nesler's torque equation.

5. Put the volume change equations by Nesler and Holland into the same terms and compare them

6. Create a given set of parameters to plug into the volume change and torque equations. Then plot the equations over a range of angles from 0 to 80 degrees. Compare the results

7. Also examine previous comparisons of these equations with experimental data.

Nesler's Model

Nesler's original equation for volume change

$$V(\theta) = \pi r^2(L - 2rtan(\frac{\theta}{2}))$$

After being rewritten in the terms used by Holland:

$$\Delta V = \frac{\pi D^3 \tan(\theta)}{4}$$

Torque equations for Nesler accounting for volume and pressure changes

$$\tau = (P_1 - P_{atm}) * (\frac{dV(\theta)}{d\theta})$$

If P_0 is the undeformed pressure:

$$\tau = -\pi r^3(\frac{P_0 L}{L - 2rtan\left(\frac{\theta}{2}\right)} - P_{atm})((tan(\frac{\theta}{2}))^2 + 1)$$

After Being rewritten in terms used by Holland:

$$\tau = \frac{\pi D^3 P}{8}(tan^2(\theta) + 1)$$

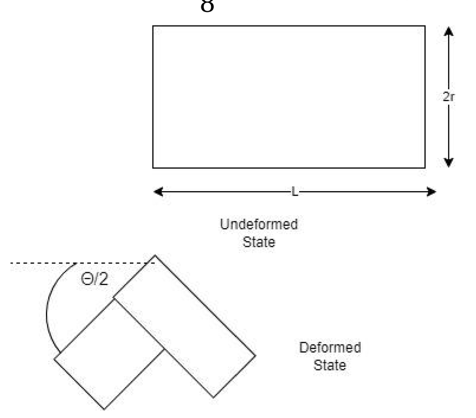
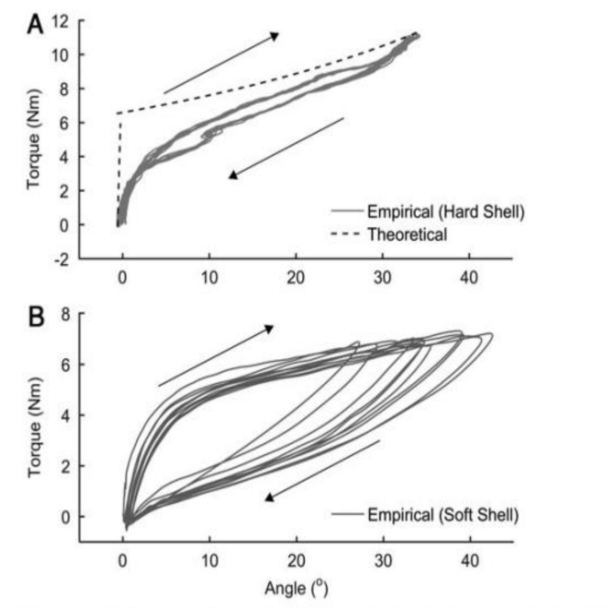
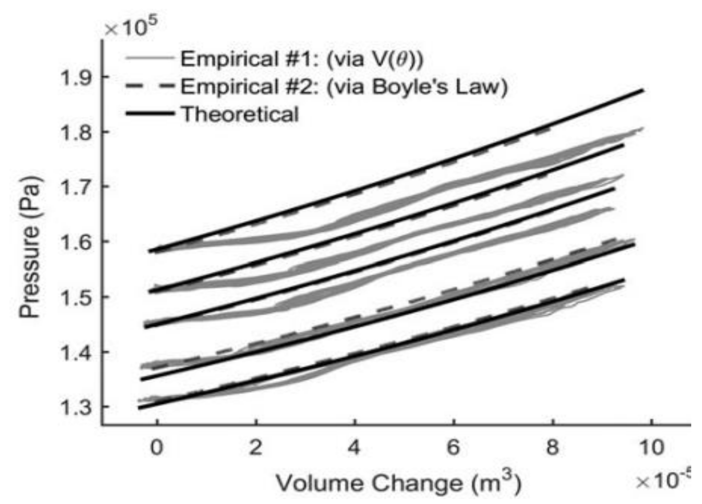


Diagram for Nesler's Actuator



This Plot compares Nesler's Torque Equations with their experimental data.



This plot compares Experimental Data with Nesler's equations for Volume as a function of pressure.

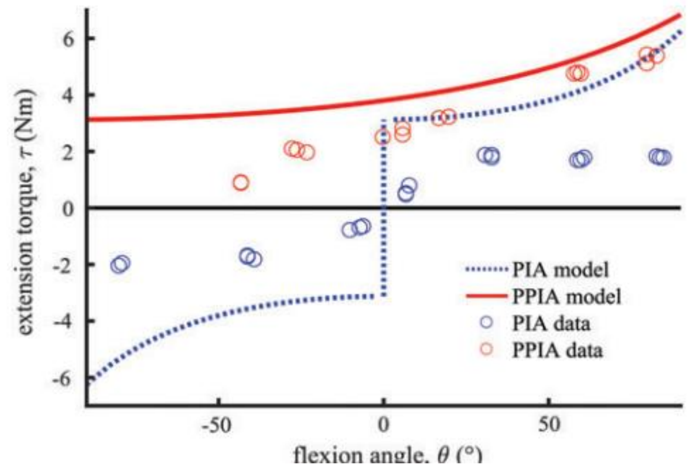
Veale's Model

Volume equation used by Veale

$$V_{PIA}(\theta_{PIA}) = \frac{\pi D^3 \tan(\frac{\theta_{PIA}}{2})}{4}$$

Torque Equation used by Veale

$$\tau(\theta_{PIA}, P) = \frac{\pi D^3}{8} * \frac{P}{cos^2(\frac{\theta_{PIA}}{2})}$$



This plot shows the results of Veale's torque equations. It shows how closely they predicted the experimental results. Veale's theoretical results were consistently higher than the experimental results and also higher than Holland's theoretical results.

Holland's Model

Dr Holland's Equation for volume change

$$\Delta V = \frac{\pi D^3 tan\theta}{12}$$

Dr. Holland's Equation for Actuator Force

$$F_{act} = \frac{P\pi D^3}{12} * \frac{tan\theta}{\frac{L}{2}sin\theta + \sqrt{\frac{L^2}{4}sin^2\theta + D^2cos^2\theta} - D}$$

Holland's Torque Equation

$$\tau = \frac{P\pi D^3 L}{48cos\theta} * \frac{tan\theta}{\frac{L}{2}sin\theta + \sqrt{\frac{L^2}{4}sin^2\theta + D^2cos^2\theta} - D}$$

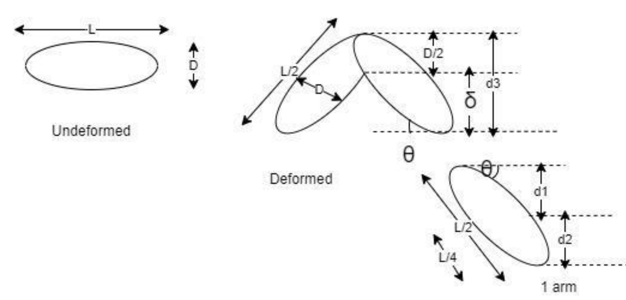
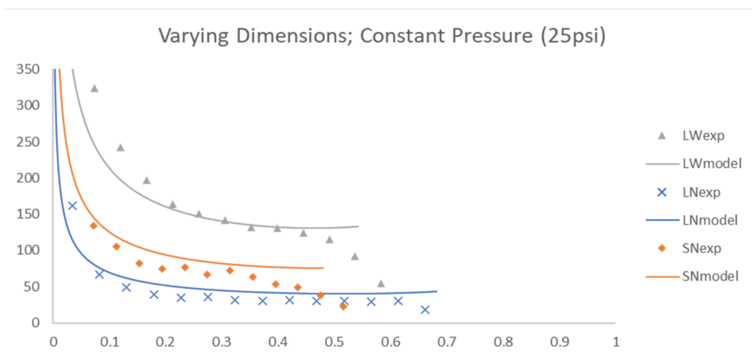


Diagram for Dr. Holland's Actuator Design

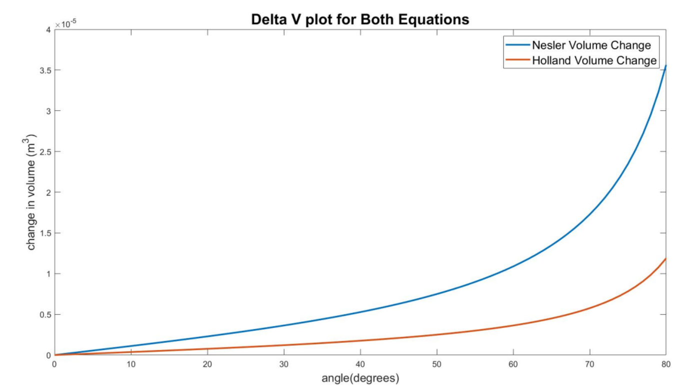


This plot shows a comparison between Dr. Holland's force values predicted by the equations and the experimental results.

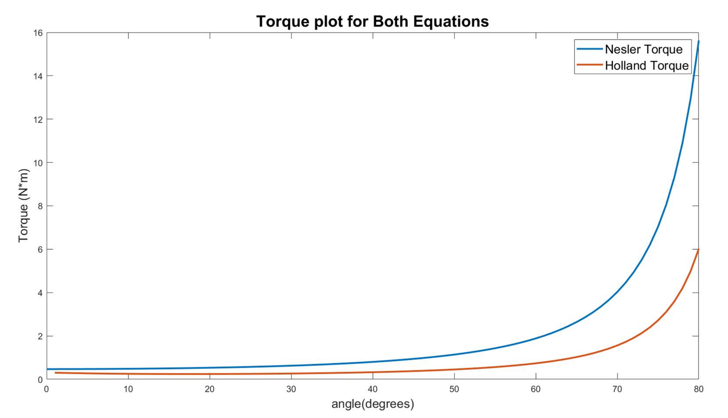
Results

To compare the results of Nesler's equations and Holland's equations, the change in pressure was fixed at a value of 150 kPa. The length of the actuator was fixed at 0.15 m ,and its diameter at 0.02 m. These values assumed the actuator had a circular cross section when undeformed. However, Holland's proof for the actuator force equations made the assumption that the buckling region would not have a circular cross section. Nesler made a similar assumption in his proof as well.

Having established these values, the volume change and torque equations were each plotted together. This enabled us to easily observe differences between the volume change and torque equations derived by Holland and Nesler. They were plotted against the buckling angle, which ranged from 0 to 80 degrees. In the volume change equations, both versions had a similar shape, as they increased more rapidly at higher angles. As expected, Nesler's value was triple Holland's value at a given angle. A similar pattern was observed for the equations showing torque changes, but this time, the magnitude of the torque from Nesler's equation was much greater than the torque magnitude from Holland's equation.



This plot shows both Volume Change Equations. Holland's equation always has a value that is 1/3 of Nesler's equation, but both plots have similar shapes.



This plot shows the Torque Equations together. Again, the values for Nesler's Torque equations are much larger, but the plots do appear to have a somewhat similar pattern.

Conclusion:

The derivations and plots for Nesler's and Holland's torque and volume change equations show some common patterns. The concepts leading to each set of derivations were quite similar. The plots for each set of volume change and torque equations often had a similar shape. However, the magnitude of Volume Change and Torque for Nesler's equations were always much more than the equivalent values in Holland's equations.

This would suggest that while the derivations seem similar, there may be enough differences for Holland to publish this work independently. Both sets of equations appeared to be quite close to the experimental results from each lab. Another area to explore would be to determine if there are situations in which one equation set is more accurate than the other.

References

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