Choose Your Own Adventure Report

Growth Pressure of Vine Robots in Pipe Elbows

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Growth Pressure of Vine Robots in Pipe Elbows is Unknown

Question:
How much pressure is required to grow an apical extension (vine) robot through pipe elbows of varying radii?

Significance: Vine robots are are promising for use in

- Minimally Invasive Surgery
- Search and Rescue
- Industrial Inspection (significantly, pipes)
- Archaeological Exploration

Fig. 1: Vine Robots can navigate cluttered and unpredictable environments. (Hawkes et. al., Coad et. al.)

Understanding growth pressure determines the required burst pressure of the robot and guides pump and motor selection.

Current Literature Outlines Models for Unconstrained Growth of Vine Robots

Blumenschein et. al.: Model for required Growth Pressure of Vine Robots

$$PA = [Path\ Independent] + [Path\ Dependent]$$

$$PA = \left[YA + \left(\frac{1}{\varphi}v\right)^{\frac{1}{n}} A\right] + \left[\mu_s wL + \sum_i C e^{\frac{\mu_C L_i}{R_i}}\right]$$

Yield Force: required to deform material at the tip.

Extensibility: associated with velocity-dependent extension of the material.

Linear Friction Force: due to the dragging of the robot tail against the wall.

Capstan Friction: due to friction between the tail and the wall at turns.

Proposal: Add a term that describes the pressure required to grow through a 90 degree elbow of diameter D. The term is hypothesized to be linear with respect to the diameter due to it’s frictional nature.

An empirical Procedure is Used to Model Growth Pressure in Elbows

Test diameters [in]: 1.61, 2.07, 3.07, 4.03
All pipes are selected to adhere to the ASME Long Elbow standard.

Sensors:
Pre-calibrated digital pressure sensor (FS: 0.5 psi, Total Error Band: 0.001 psi)

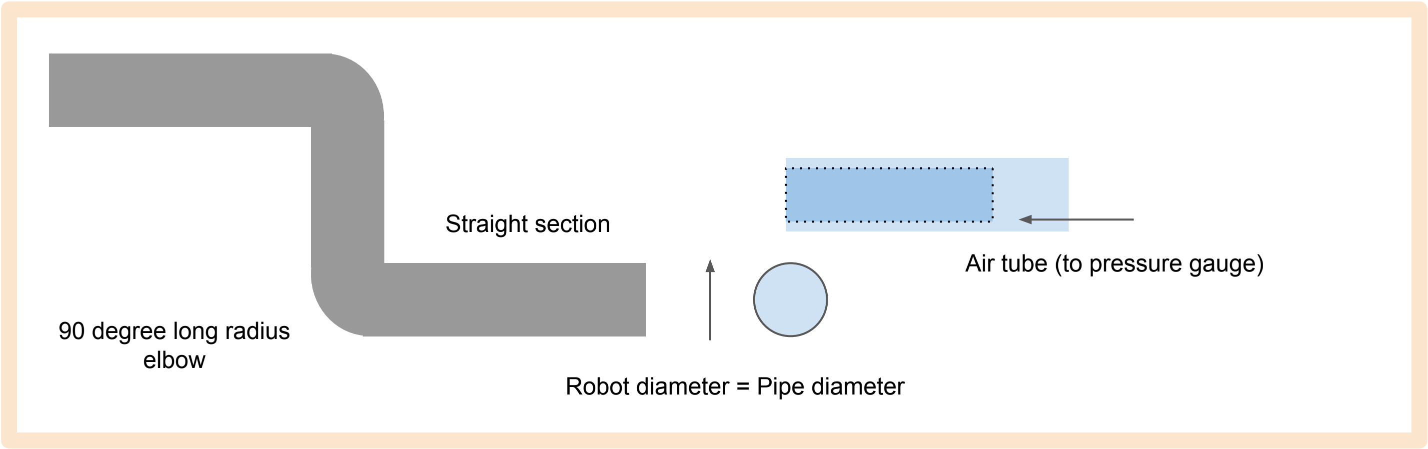

Fig. 2: Experimental setup

An empirical Procedure is Used to Model Growth Pressure in Elbows

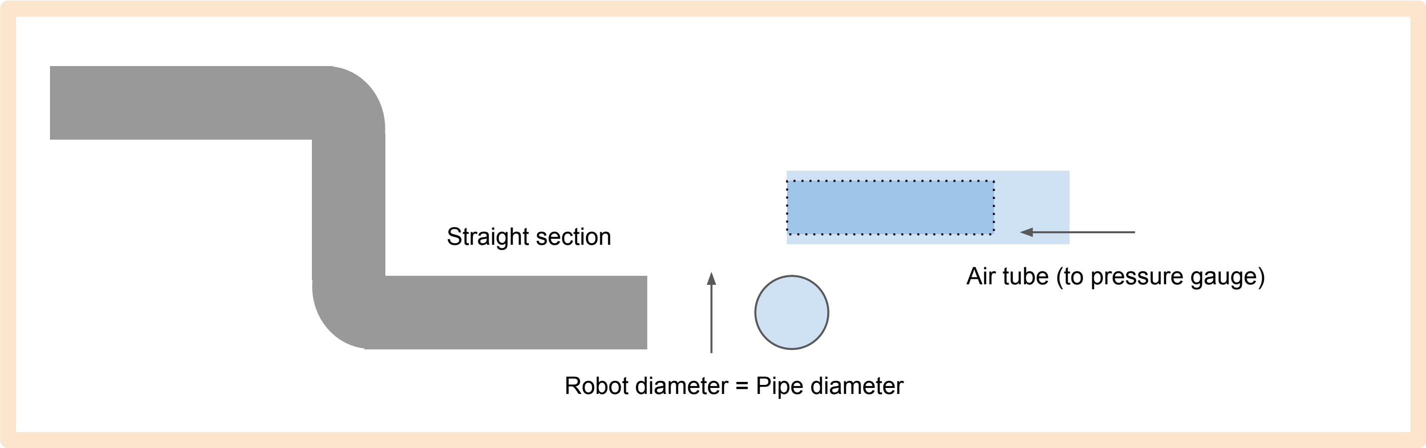

Fig. 2: Diagram of experimental setup

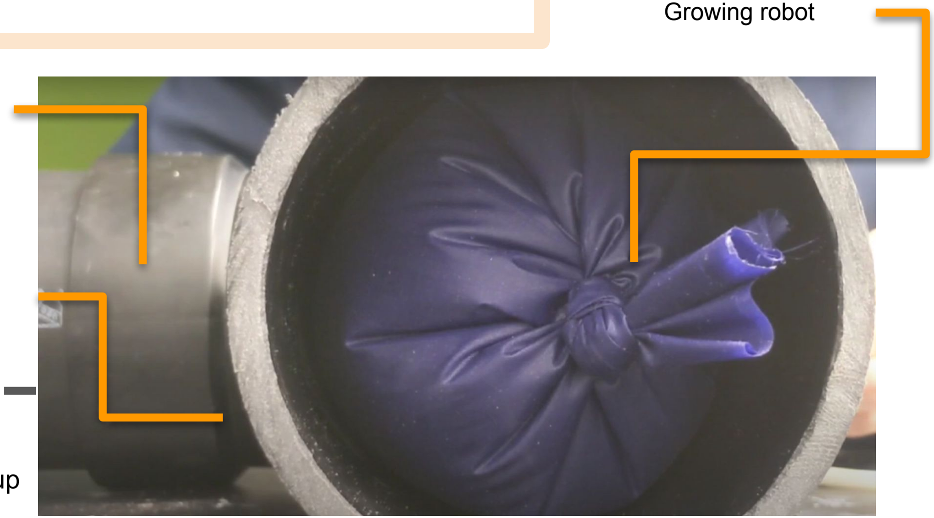

Fig. 3: Picture of physical experimental setup

Theoretical Model is Used to Analyze the Experimental Data

Pressure Rise Due to Elbow = Measured Pressure - PA

Where PA is given by

$$PA = [Path\ Independent] + [Path\ Dependent]$$

$$PA = \left[YA + \left(\frac{1}{\varphi} v \right)^{\frac{1}{n}} \mathrm{A} \right] + \left[\mu_s wL + \sum_i Ce^{\frac{\mu_c L_i}{R_i}} \right]$$

Goodness of fit:

The R-squared value of a linear regression, or the coefficient of determination, is used as a measure of goodness of fit.

Error Propagation:

For multiple samples (n = 3), standard deviation of mean is adopted to report the uncertainty of the presented figures.

$$\sigma = \sqrt{\frac{\sum (x_i - \mu)^2}{N}}$$

σ = population standard deviation

N = the size of the population

x_i = each value from the population

μ = the population mean

Raw Data Reflects a Pressure Rise at the Elbows

Diameter (in)	Growth Pressure (PSI)					
		Straight Section	Turn 1	Straight Section	Turn 2	Straight Section
1.61	Experimental Averages	0.057	0.220	0.100	0.290	0.183
	Standard Deviation	0.01	0.02	0.01	0.02	0.02
	Model Predictions	0.046	0.089	0.112	0.136	0.176
2.067	Experimental Averages	0.033	0.173	0.080	0.233	0.113
	Standard Deviation	0.01	0.03	0.01	0.03	0.01
	Model Predictions	0.029	0.054	0.069	0.083	0.103
3.068	Experimental Averages	0.030	0.113	0.047	0.143	0.050
	Standard Deviation	0.01	0.03	0.01	0.04	0.01
	Model Predictions	0.017	0.029	0.037	0.044	0.050
4.026	Experimental Averages	0.017	0.050	0.027	0.043	0.020
	Standard Deviation	0.01	0.01	0.01	0.01	0.01
	Model Predictions	0.013	0.021	0.025	0.030	0.032

Tbl. 1: Raw data collected for required growth pressure at elbows of varying diameters.

Raw Data Reflects a Pressure Rise at the Elbows

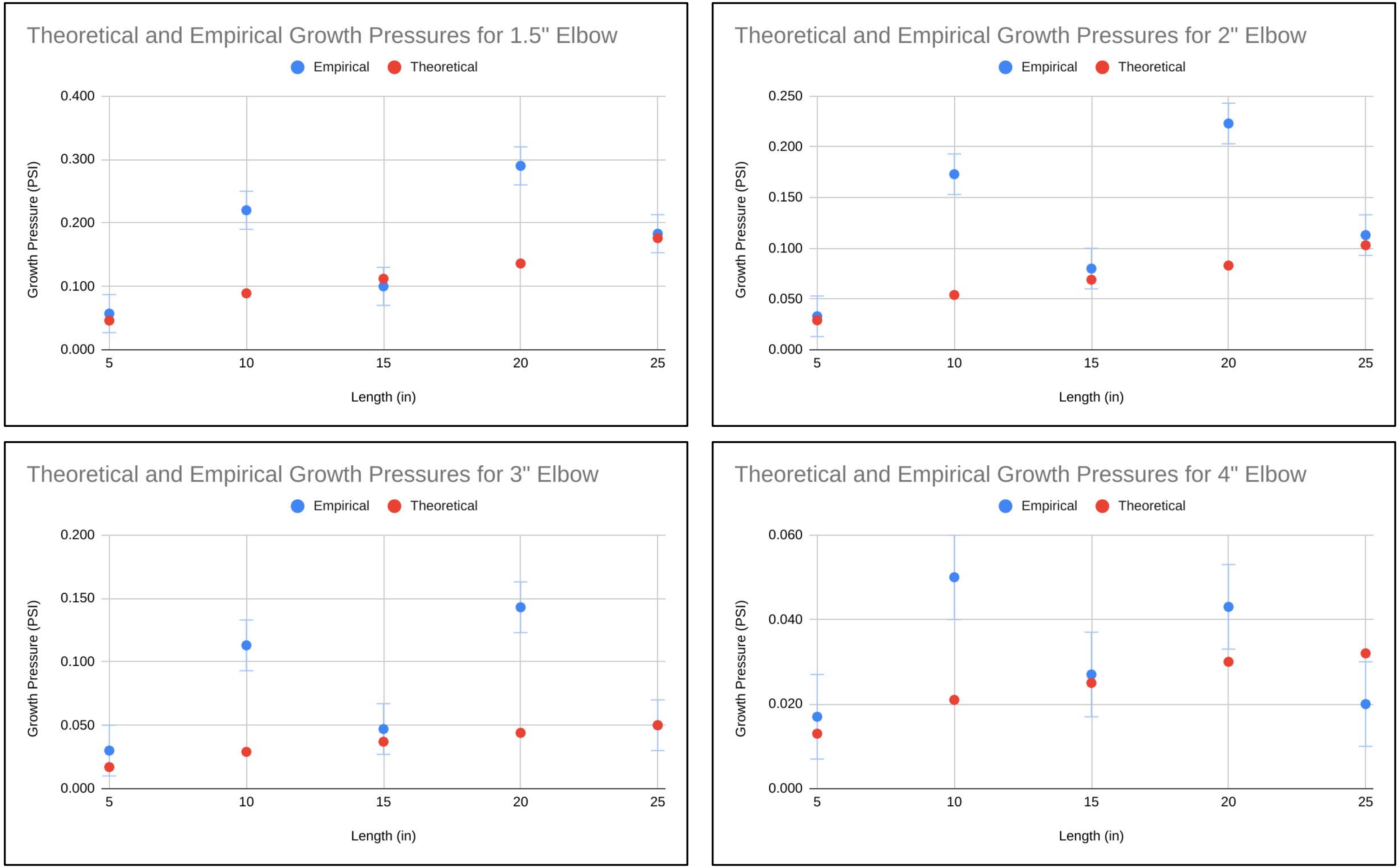

Fig. 4: Plots visualizing theoretical and experimental growth pressures. The spikes at the turns are used to augment the existing growth models.

Pressure Raisers are Extracted Using the Theoretical Model

Pressure Rise =

Mean
(

Experimental Pressure at Turns [PSI]

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Theoretical Pressure at turns (slide 5) [PSI]

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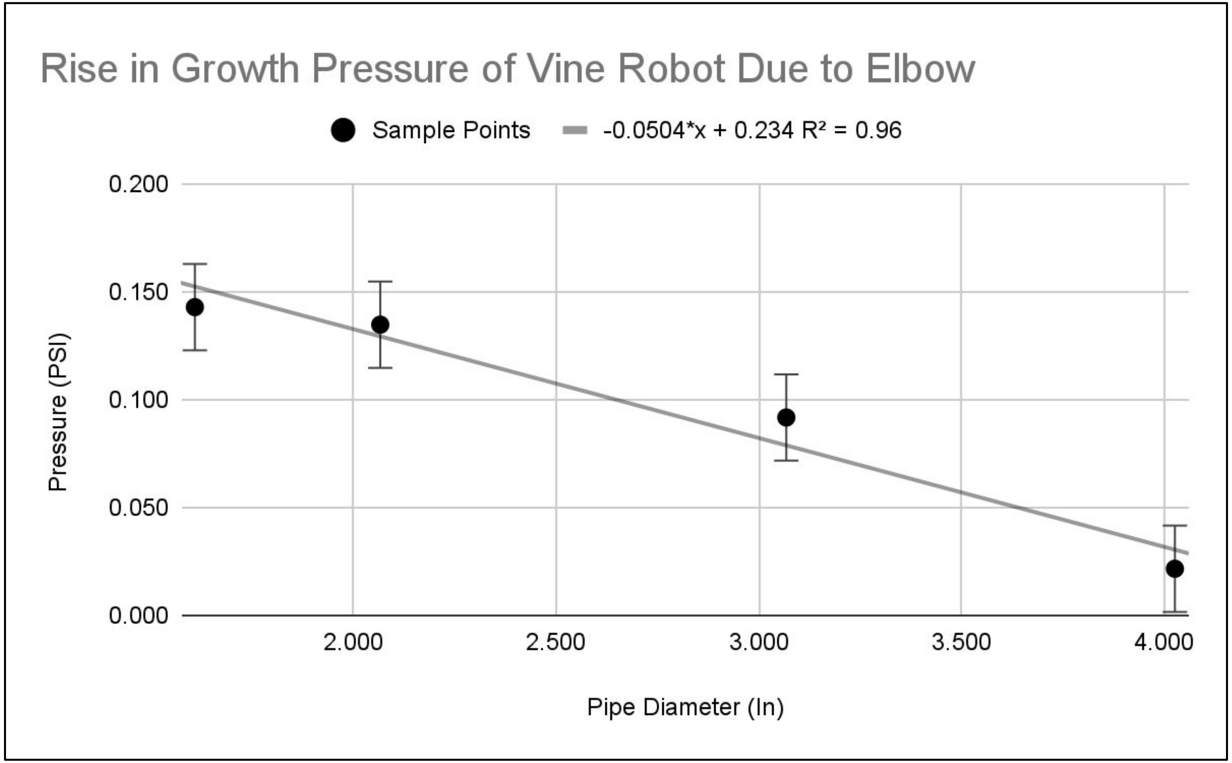

Fig. 5: Pressure rising effect of 90 degree elbows as a function of pipe diameter.

Pressure Rise at the Elbows Appears Linear With Respect to Diameter

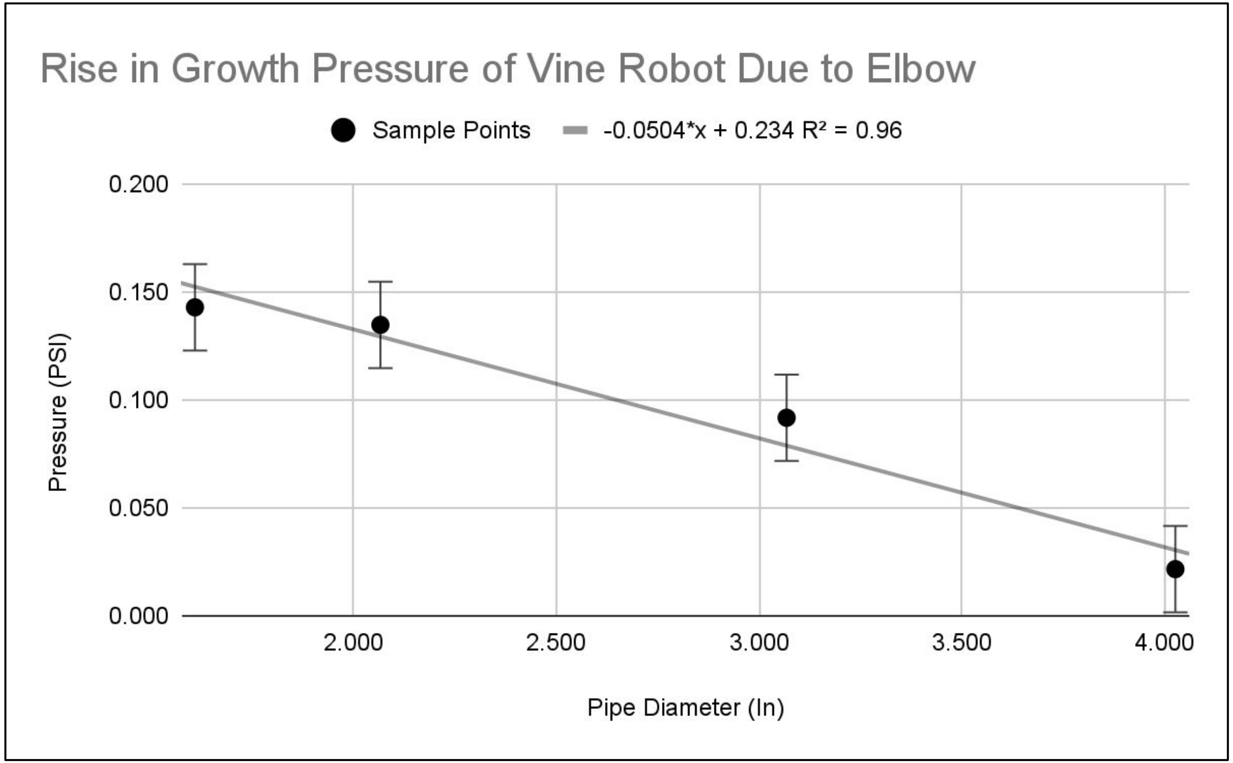

Fig. 5: Pressure rising effect of 90 degree elbows as a function of pipe diameter.

- The results do not deviate from the proposed linear trend.
- The results indicate that for larger pipes, which are commonly inspected by robots, the pressure rising effect is minimized.
- The experimental results could be applied with more certainty if larger pipes (~1ft) are included in testing.