Quantifying Impedance Defined Flow

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This project investigates impedance defined flow, a new phenomenon in which periodic mechanical compression of an asymmetric loop of tubing with different hardnesses produces one-way flow. The goal of this project was to develop a testbench for measuring impedance defined flow and to conduct pilot experiments on the effects of several system properties on flow rate. A circular loop of tubes with two distinct material properties, one rigid and one flexible, was fabricated. An analysis of hand-applied compressions that were successful in producing flow informed the design and implementation of an automatic compressor, which used a high force linear solenoid to apply compressions. To quantify flow, optical tracking was used to measure the velocity of a neutrally buoyant tracking particle, which allowed for calculation of volumetric flow rate. An optical tracking program was developed with MATLAB for more robust tracking than available software could provide, and allowed for tuning to testbench lighting conditions. Experiments were conducted varying the position of compressions, and with tubing materials of different hardnesses and flexibility. Results substantiate previous lab findings under different testing conditions, demonstrating that impedance defined flow is a repeatable phenomena. This project presents a robust testbench for continued experimentation with impedance defined flow and gives recommendations for material selection and compression type based on these results.

PROBLEM DEFINITION & BACKGROUND

Impedance defined flow is a phenomenon in which mechanical compressions of vessels produce one-way flow in the absence of valves due to a difference in upstream and downstream impedance [1].

Impedance pumps have yet to be widely implemented but are being studied for their various applications. The main advantage impedance pumps offer over traditional methods of pumping is the production of one-way flow without the need for valves. Impedence pumps are studied for applications in microfluidics and energy harvesting, and for the potential to restore or aid flow to biological vessels noninvasively. This phenomenon is also thought to contribute to the effectiveness of CPR and to circulation during the early stages of cardiac development [2].

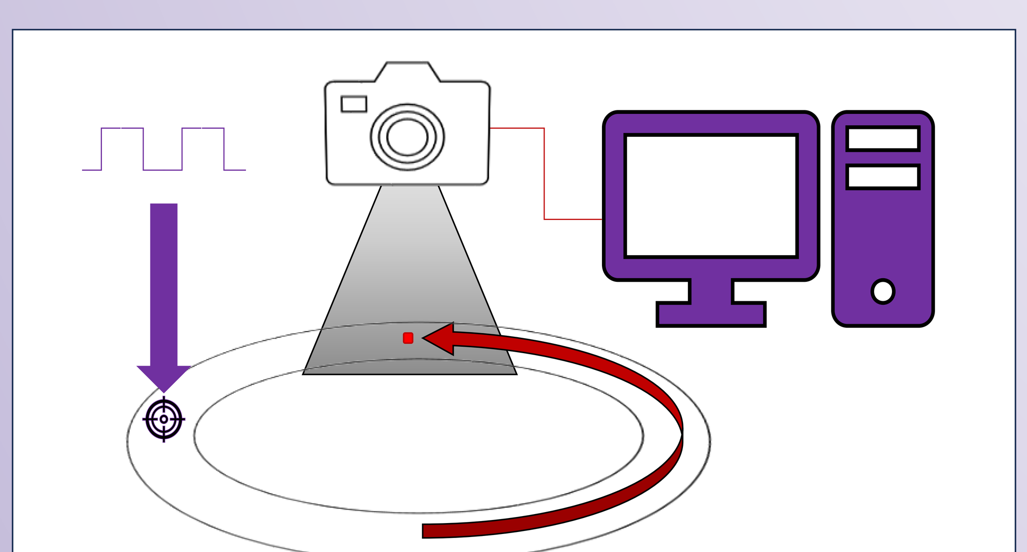
While some preliminary work has been done on the topic and its applications, the need for a reliable testbench to explore the various factors is apparent. The objective of this project is to develop a testbench to facilitate future research work and to inform future directions. To achieve this, this projects goals are to build a test rig with controllable compression, to capture and interpret the flow of the system using particle tracking, and to explore the relationship between tubing properties and induced flow.

DESIGN REQUIREMENTS

This project requires three major components:

1. A circular loop of two different tubing types, to act as our mechanically asymmetrical system. At least one of the tubes must be transparent to allow motion capture of a particle in the flow.
2. A way to quantify flow within the system. This will be done with an optical tracking system, consisting of a neutrally buoyant particle, a camera, and a computer vision program.
3. An automatic compression mechanism, to apply repeatable force to the system.

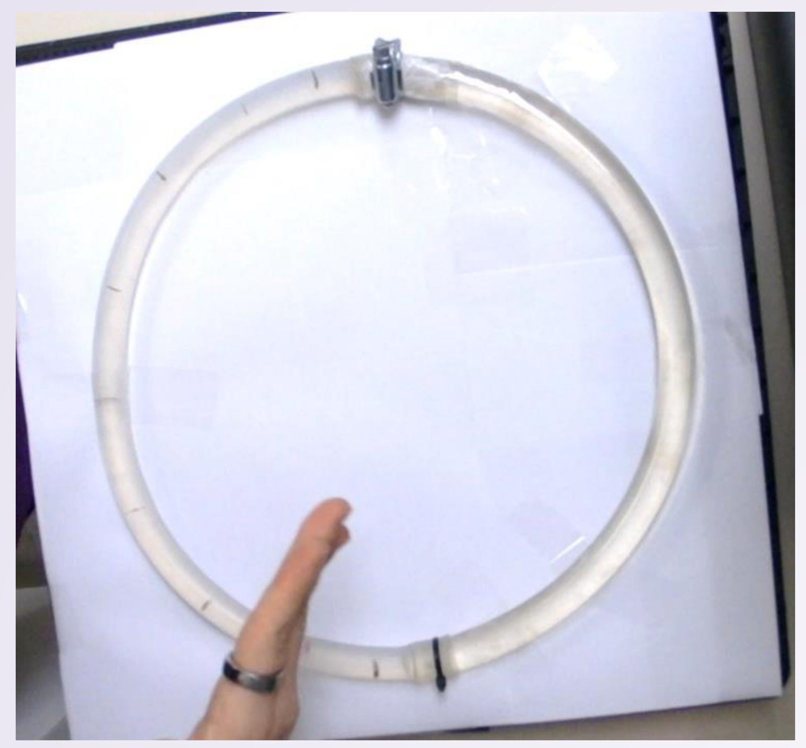
In addition to these requirements, this project must also be completed within the timeframe of one academic year, and within a budget of $400.



Above: Diagram of testbench design, showing tubing loop, optical tracking system, and compression waveform input.

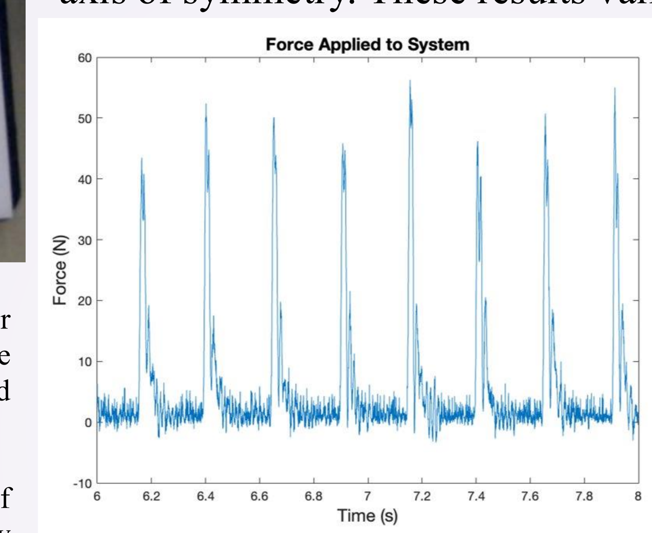
DESIGN PROCESS, ALTERNATIVES, & EVALUATION

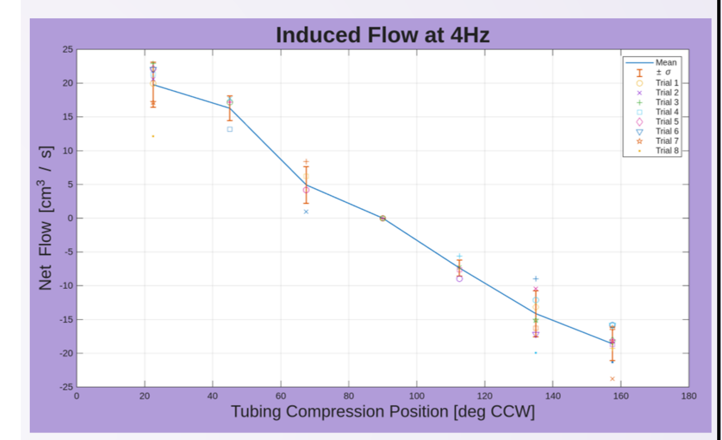
PROTOTYPE DESIGN



In the initial testing and design stage, compressions were applied by hand. To quantify the types compressions that were effective, a force plate was used to measure the force applied to the system. The figure below shows an example of a force profile that successfully generated flow, averaging 40 Newtons of force.

Using this setup, we investigated the effect of compression placement on flow. The figure below shows that both the magnitude and direction of flow are dependent on where the flexible tubing is compressed relative to the axis of symmetry. These results validate previous work in this lab.





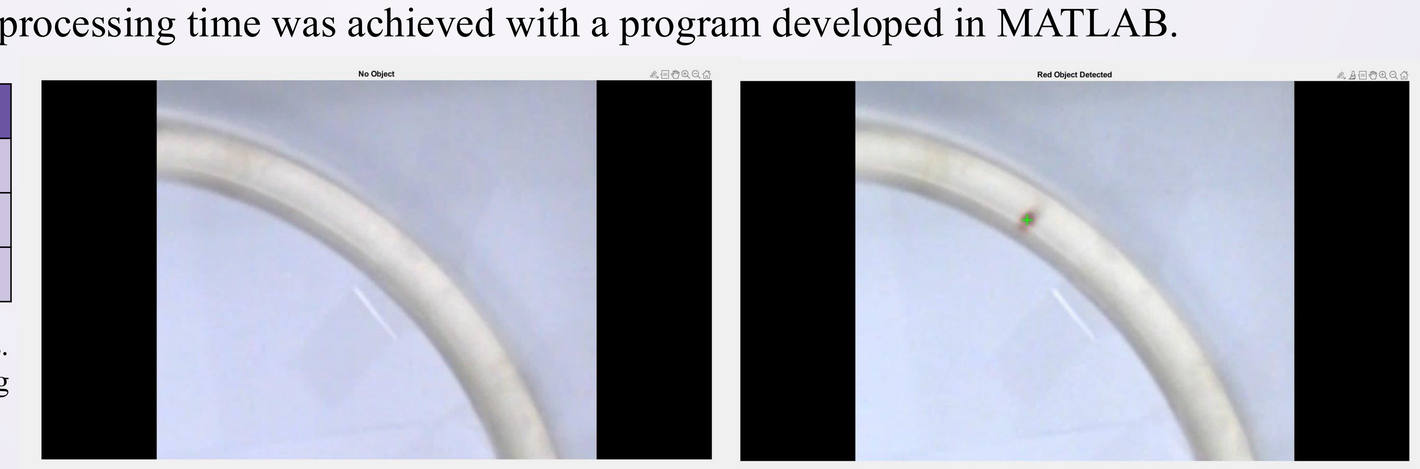
Above: First iteration of our test setup. Two ½" inner diameter Tygon tubes, one more rigid and one flexible, are joined in an 11" diameter loop. Compressions are applied manually by hand as pictured.
Right: Force profile of successful compressions.
Far right: Relationship between the distance from the axis of symmetry that compressions are applied and the flow generated in the system.

OPTICAL TRACKING SYSTEM

Particle tracking was done using a camera and a red neutrally buoyant particle in the flow. Several methods of particle tracking were explored, and the fastest processing time was achieved with a program developed in MATLAB.

	Processing Time
Manual Collection	30 min
PASCO Vision	15 min
MATLAB	2.5 min

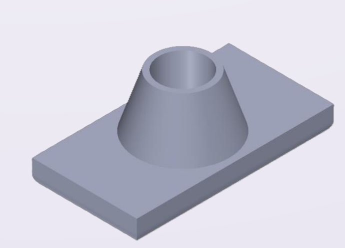
Above: Processing time of various tracking methods.
Right: MATLAB program detection of red tracking particle in frame.



AUTOMATIC COMPRESSION MECHANISM

Design of an automatic compression mechanism (right) was informed by early investigation of compression waveforms. Based on the force profile results shown above, a high-force linear solenoid was chosen over linear actuators for its ability to quickly apply a large force (up to 29 Newtons) to the tubing.

Initial testing demonstrated that an important factor in producing flow was compression of the entire cross section of the tube. The solenoid was fitted with an endcap that compressed the entire cross section of the tube, such as the one shown in the image at right.



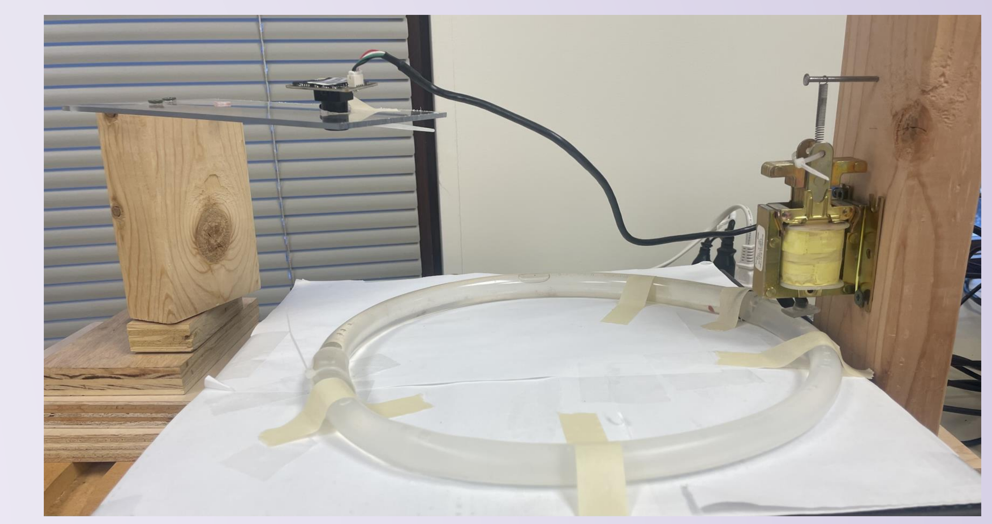
Resin printed striker end.

FINAL DESIGN & IMPLEMENTATION

Vision System: Mounted web cam feeds video into MATLAB Image Processing Toolbox. The program extracts particle position and uses a window in/window out method to determine particle flow.

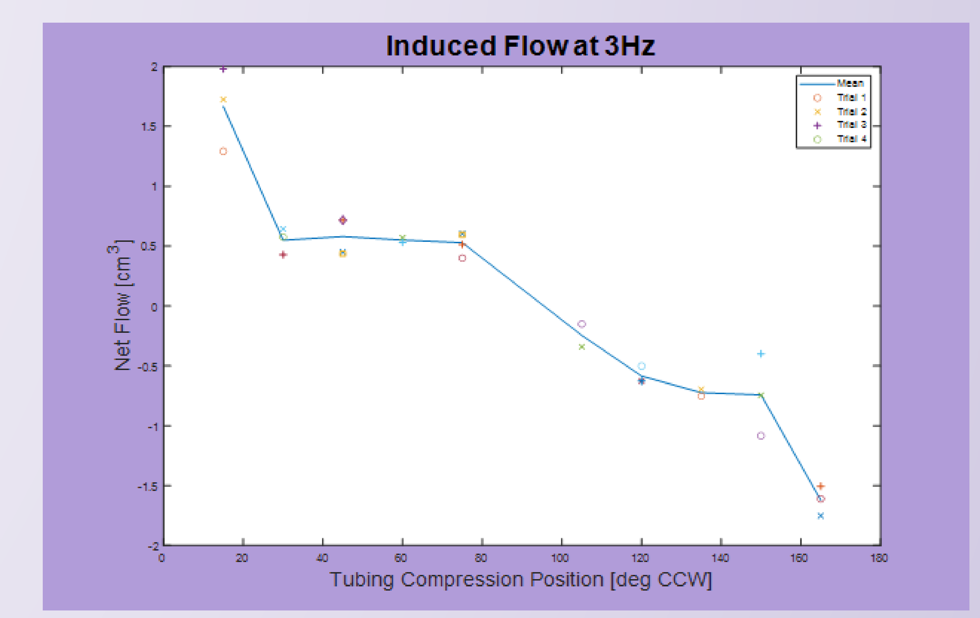
Tubing: Two circular configurations with different tubing characteristics. Degassed water.

Compression Mechanism: High force AC solenoid controlled via solid state relay and DC waveform generator at desired testing frequencies.



Above: Picture of final testbench setup, with camera, automatic compression mechanism, and circular test loop.

Demonstration of impedance defined flow as a reproducible phenomena and validation of our testing system: results obtained with this testbench compare well with both the results from hand compressing the tubing and with those presented in Bovard et. al, 2004 [3].



Above: Reproduced results of flow rate as a function of compression location.

CONCLUSIONS & RECOMMENDATIONS

This project was successful in developing a testbench for experiments in impedance defined flow, enabling standardized and easily repeatable testing of impedance defined flow systems. Future work should utilize this system to look at how system variables impact the flow rate of the system, such as tubing material properties, system size, and compression frequency.

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