Simulation of an Electrostatically Driven Microinjector Pump

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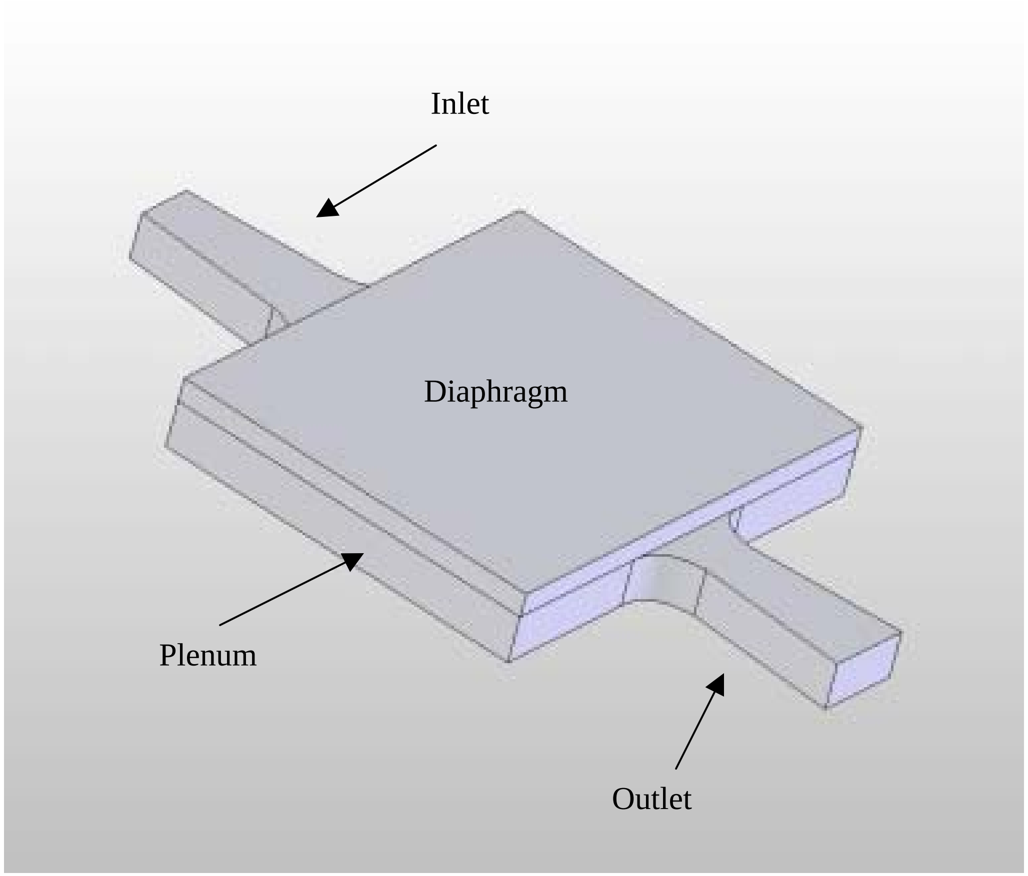
- (Design details proprietary, so don’t ask! Have injector will sell!)

Motivation

- Goal is to develop fuel injection suitable for Pulsed Detonation Engine (PDE).
- Very small droplet sizes required to initiate detonation $< 3\ \mu$m.
- Exploring use of micro and meso scale technology based on inkjet experience.
- Have developed designs and fabrication methods and are about to start testing.

Model Pump with Passive Valves



Works because flow resistance is less in outlet direction

Previous Work

- Numerous workers have studied micro pumps because of plethora of applications:
  - Woias P., "Micropumps – summarizing the first two decades, Microfluidics and BioMEMS," Proc. Of SPIE Vol. 4560, 39-52 (2001).
- Of particular interest to us is the work of Olsson:
  - Olsson A., G. Stemme and E. Stemme, "A valve-less planar fluid pump with two pump chambers," *Sensors Actuators* A**47,** 549–556 (1995) (And more …)

Simple Relationships

- Electrostatic Force

$$P = \frac{\varepsilon_0 V_{app}^2}{g^2}$$

- Static Deflection

$$y_{\max} = \frac{3P(m^2 - 1)L^4}{16\pi E m^2 t}$$

- Natural Frequency

$$f_1 = \frac{13.49}{2\pi L^2}\sqrt{\frac{D}{\rho t}} \qquad D = \frac{Et^3}{12(1-\nu^2)} \qquad \frac{f_{1\,fluid}}{f_{1vac}} = \frac{1}{\left(1 + \frac{A_p}{M_p}\right)^{1/2}}$$

Simple Relations

- Pressure Drop (Nozzle/Diffuser)

$$\Delta p_{N,D} = K_{N,D} \rho \frac{V^2}{2} \qquad \eta = \frac{K_N}{K_D}$$

- Net Flow Rate

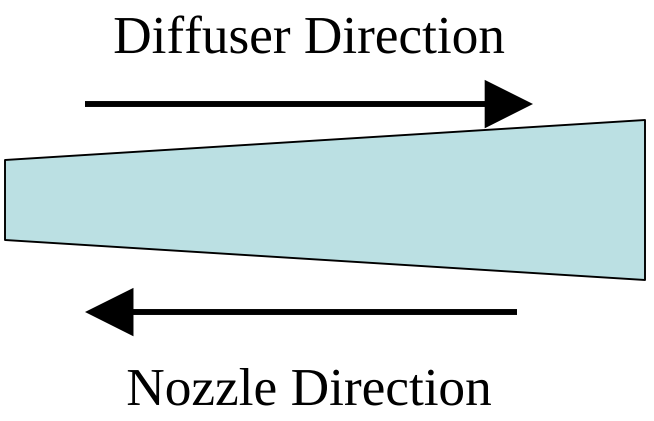
$$Q_p = \frac{V_0 \omega}{\pi} \left(\frac{\eta^{1/2} - 1}{\eta^{1/2} + 1} \right)$$

- Question: How well do these work?

Numerical Methods

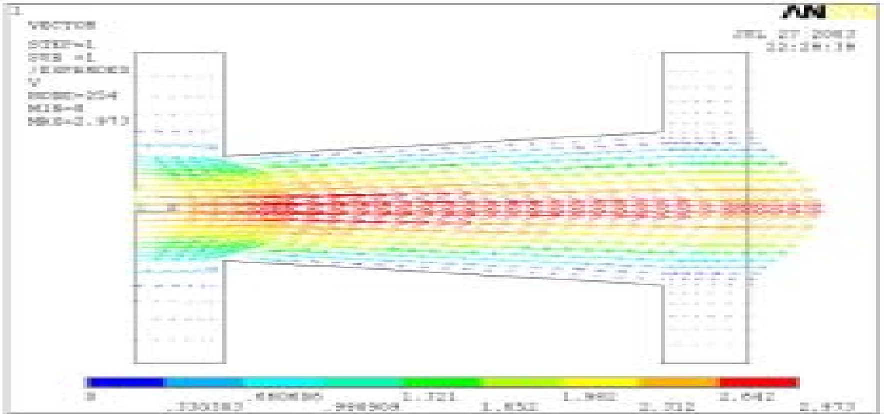
- ANSYS Multi-physics finite element code is used to carry out simulation:
  - Weak sequential algorithm to couple structural and fluid dynamics,
  - Arbitrary Langrangian-Eulerian formulation solves for the fluid flow with moving boundaries,
  - Fluid dynamics is solved using ANSYS FLOTRAN (Flow treated as incompressible.)

Modeled Passive Valve Geometry (Steady-state 2-D Simulation)



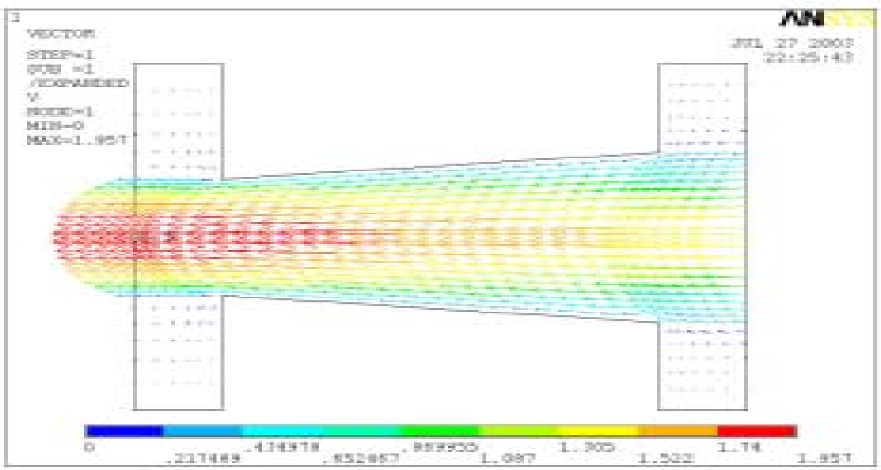
L = 1 μm w_{outlet} = 250 mm α = 5 degrees

Passive Valve Results



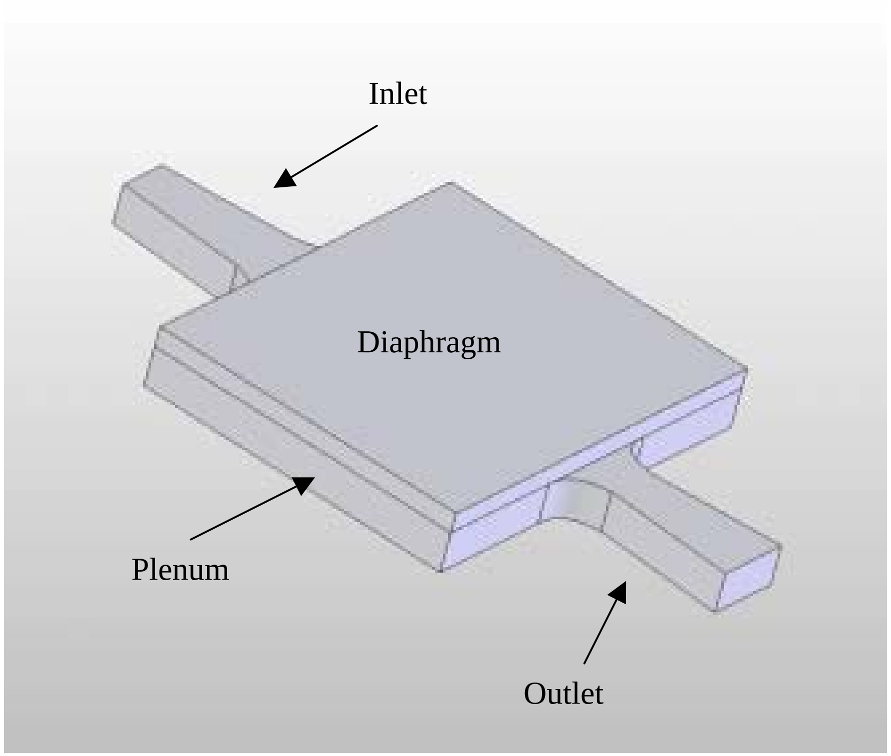
Diffuser Direction

$Q_D/Q_N \sim 2.2$



Nozzle Direction

Modeled Pump Geometry
Time Dependent 3-D Simulation



L_{diaph} = 1 mm

t_{diaph} = 50 μm

t_{plenum} = 100 μm

$t_{passages}$ = 100 μm

$L_{passages}$ = 0.33 mm

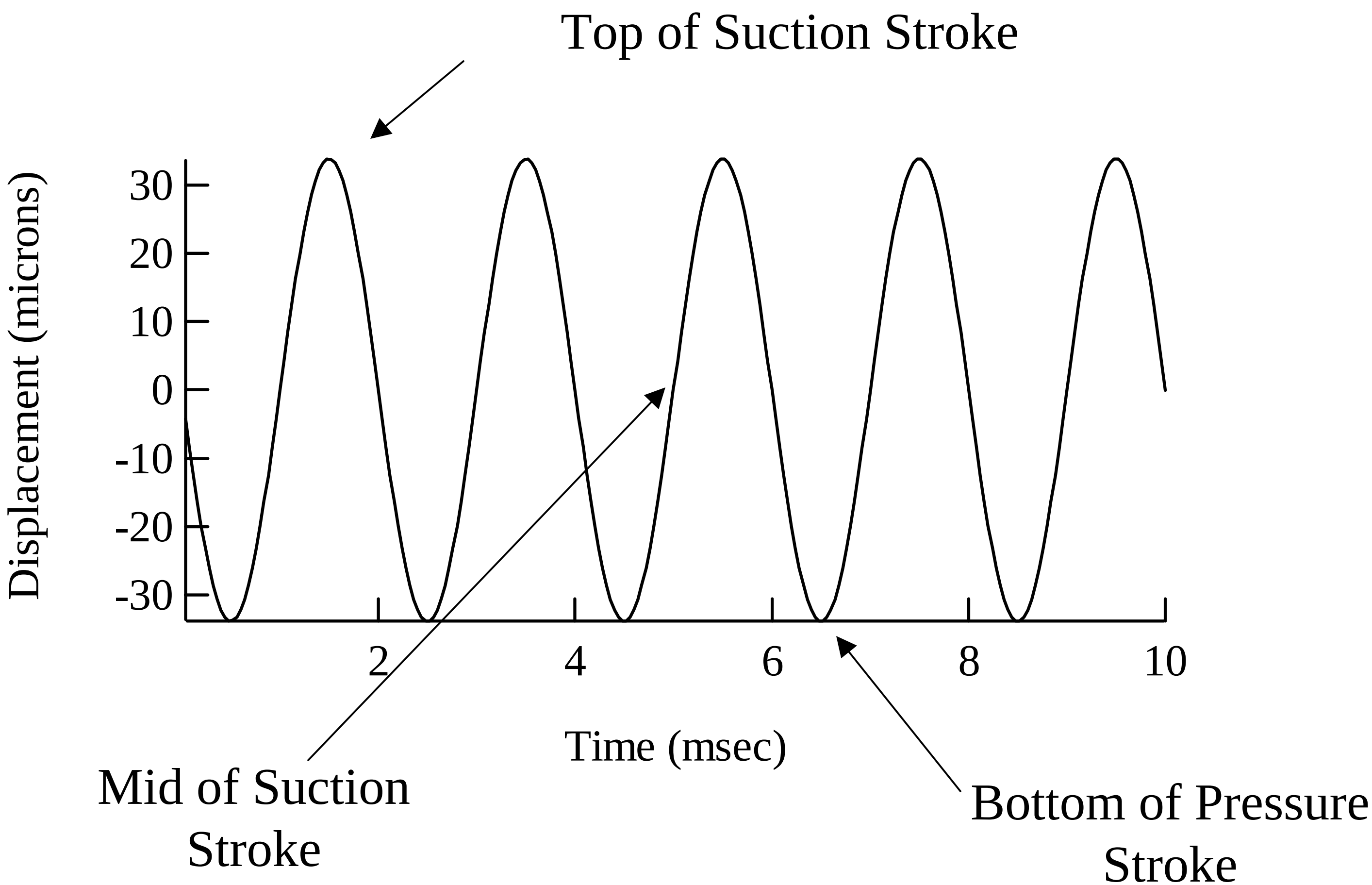
$W_{inpassages}$ = 66.7 μm

α_{valve} = 5 degrees

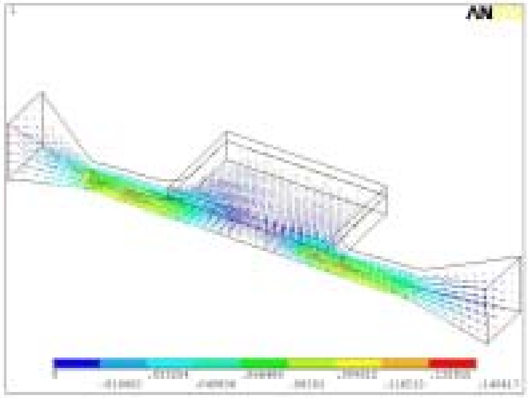
Simulation uses vertical symmetry plane

Calculations for 100-900 Hz

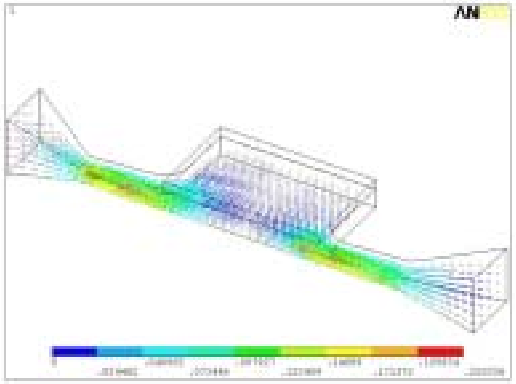
Displacement
500 Hz



Flow Field

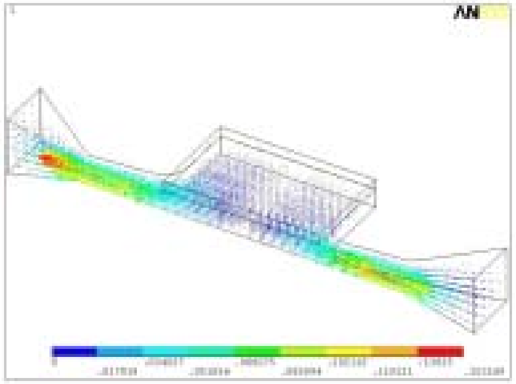


Top of Suction Stroke

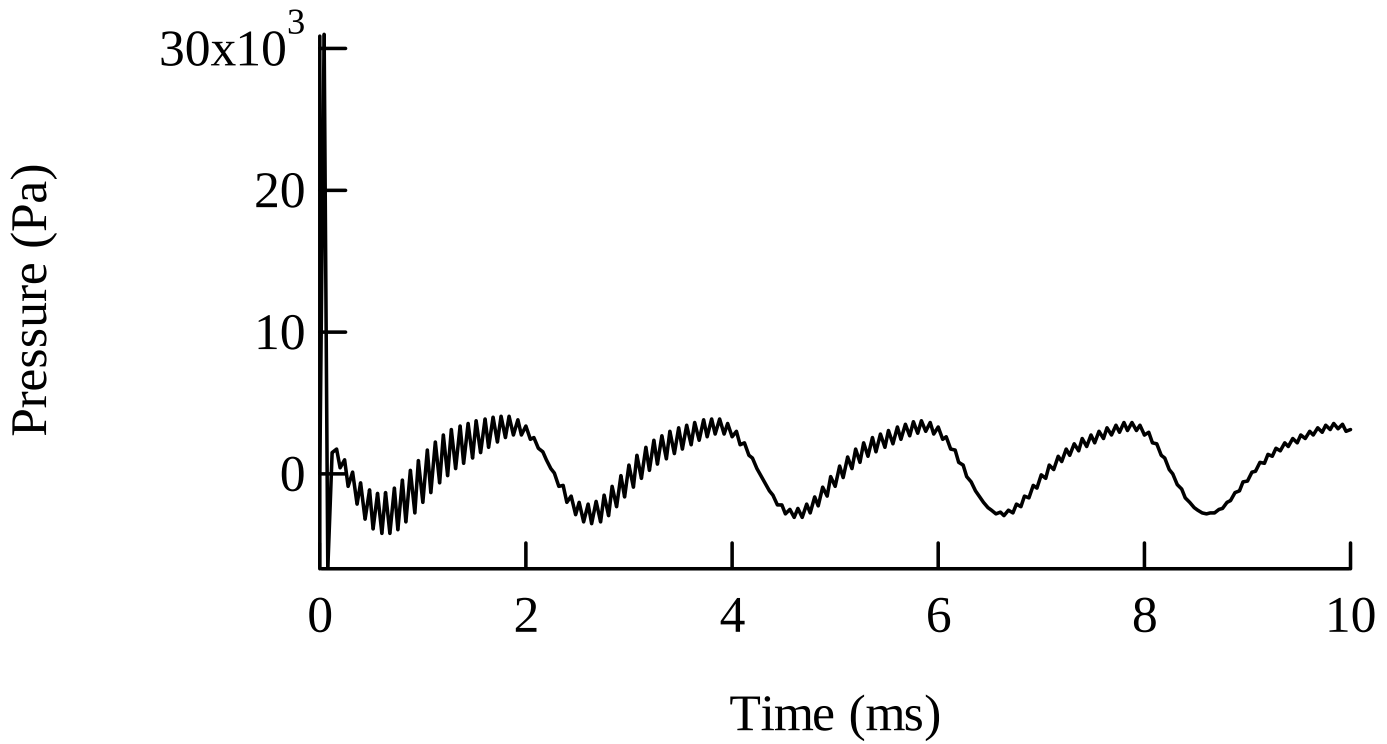


Mid of Suction Stroke

Bottom of Pressure Stroke

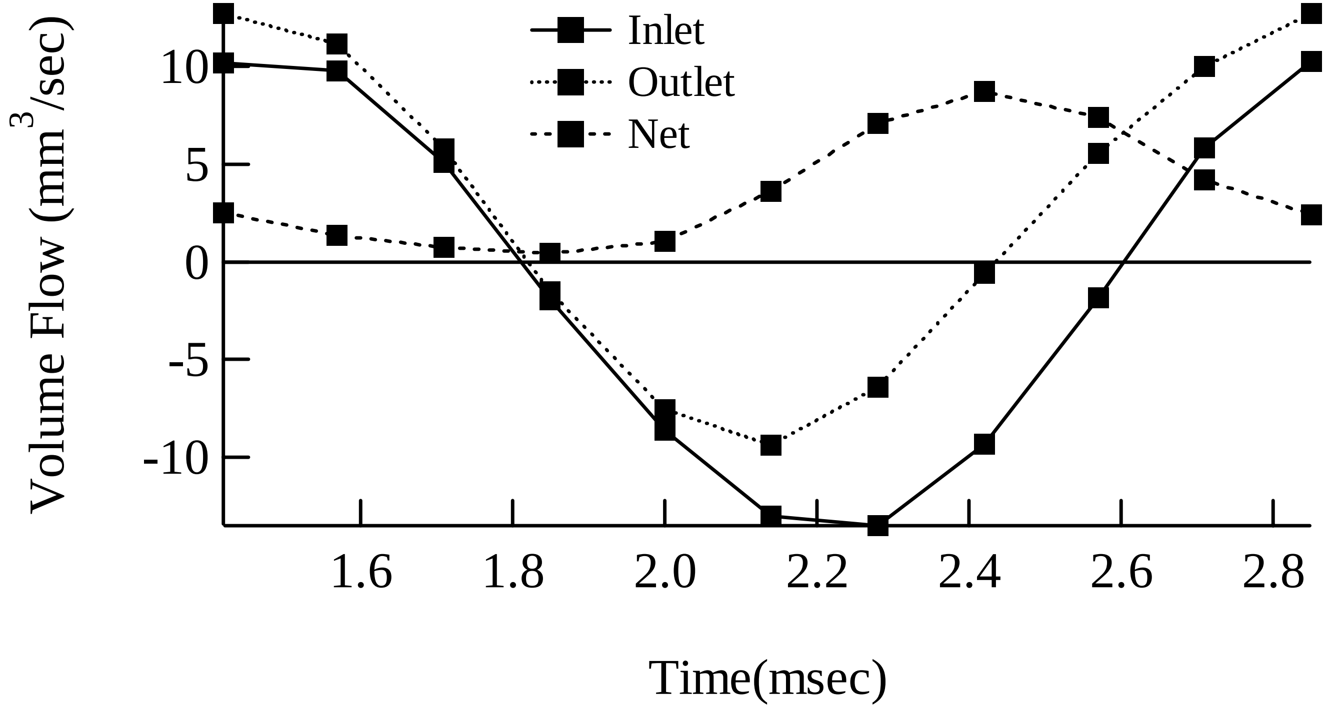


Pressure at Diaphragm Center
500 Hz

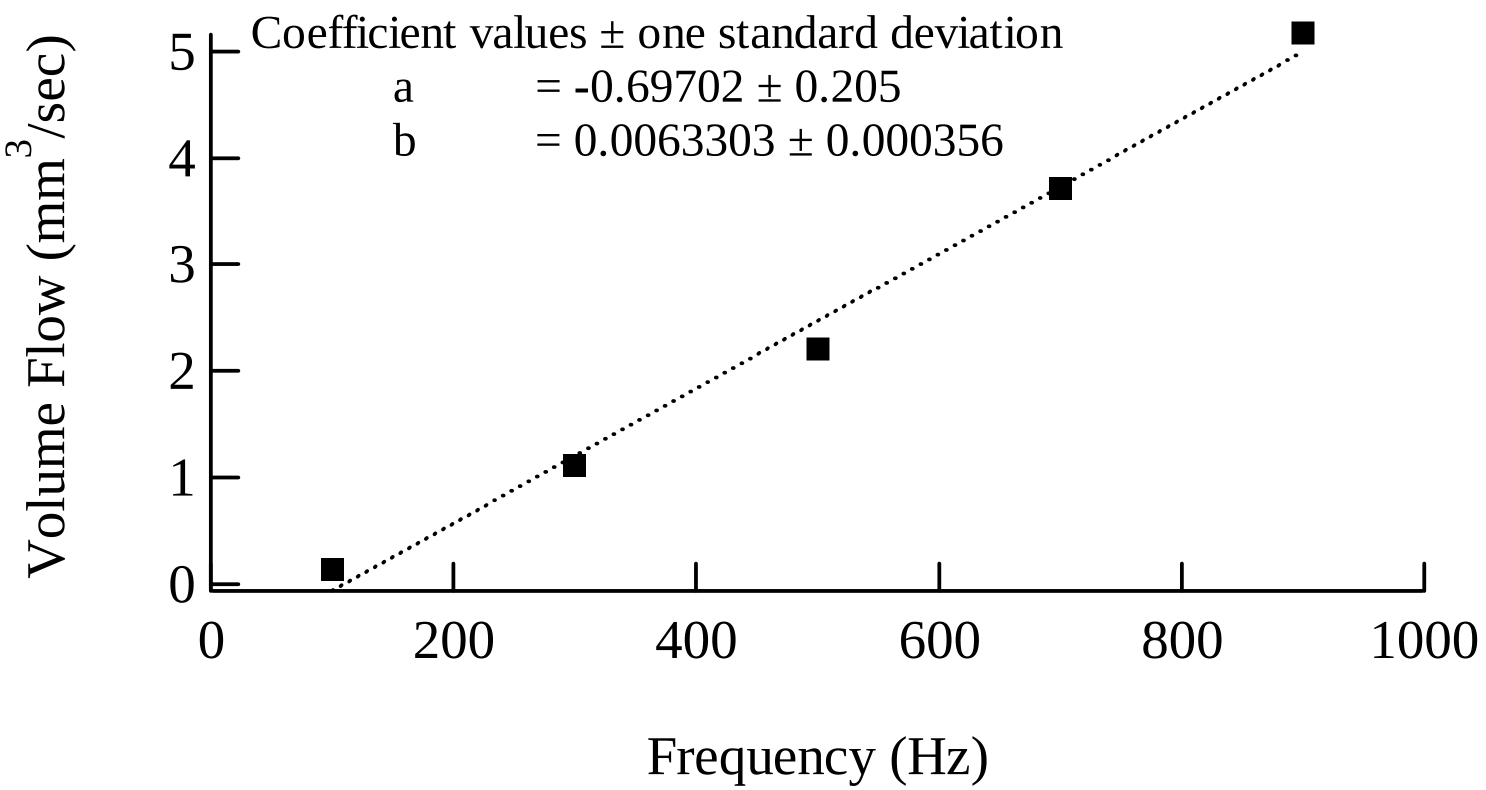


(Compare to ~30 MPa applied pressure)

Flow Rates
700 Hz



Net Flow Rate



Discussion

- Net flow generated!
- Olsson relationship predicts linear flow rate increase with frequency when V_0 constant as we observe.
- Olsson relationship does not predict offset observed in their experiments and our simulation.

Discussion

- Fitting Olsson relationship suggests effective $\eta \simeq 1.36$ which is smaller than steady calculations predict.
- Differences likely due to complexity of unsteady fluid dynamics.
- Work is needed to optimize passive valving.

Conclusions

- ANSYS code seems to have successfully to simulated valves and pump. (Proof will be in pudding of testing.)
- Flow is somewhat complex, but simple relations can guide design efforts.
- Future work on valve optimization, wider range of operating conditions, exploring designs where diaphragm resonance is approached (meso-scale), and simulating full injector.