Handheld Unilateral Magnet for Flow Measurements Using a Large Constant Gradient

Devin Morin

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Introduction

- Aim to measure flow velocity using a small handheld unilateral magnet. The magnet contains a large constant gradient perpendicular to the surface.

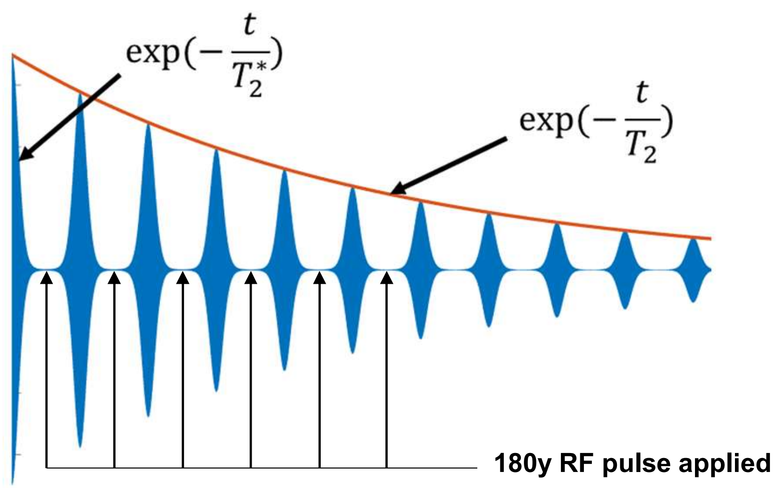
- Variable magnet orientation to change our effective probe coil length and vertical gradient.

- Magnetic resonance is employed throughout many fields (biomedicine, material characterization, food science, agriculture), and it could be of great benefit to have a device that preserves a non-invasive technique, while being portable and low hazard.

- These methods are based on the work done by Osàn T.M. *et al* and Sebastian Richard. Sebastian had done similar measurements of flow velocity using the GARField magnet.

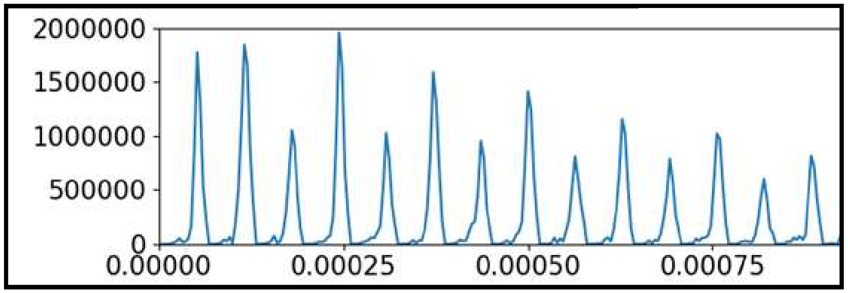
Theory

- A CPMG sequence will be used, as it will correct for pulse length errors. The CPMG sequence consists of a initial 90 degree pulse that tips magnetization into the transverse plane, which is then followed by multiple 180 degree pulse that refocus magnetization.
- The intensity of echoes will fit the form of: $I_n = e^{-2n\tau/T_2}$



Theory

- A characteristic of flow in a CPMG is the decrease signal on odd peaks. A relationship between the gradient and velocity of the water causes complete rephasing of spins on even peaks, and therefore an increased signal.
- We use even peaks only, as the odd peaks have decreased magnitude.
- The means by which we gather flow data, is due to the polarized spins, leaving the sensitive region of the probe.



Theory

- If we neglect diffusion and assume T_1 complete polarization, then a stationary sample will have a signal intensity of :

$$I(t) = I_0 e^{-2n\ /T_2}$$

where *n* is the nth spin echo of the CPMG.

- Intensity of signal will of course depend on the volume of excited sample within the sensitive region of the RF coil.

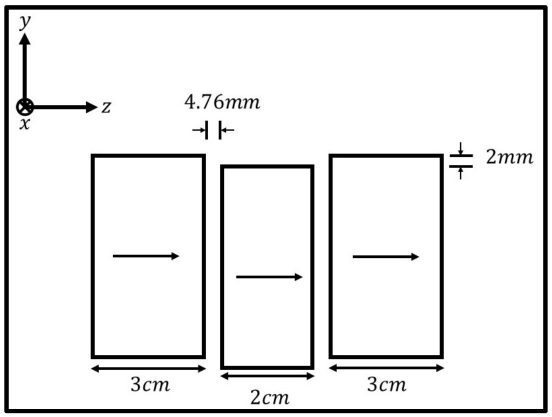
$$V(t) = V(0)(1 - \frac{v_{avg}}{L} t)$$

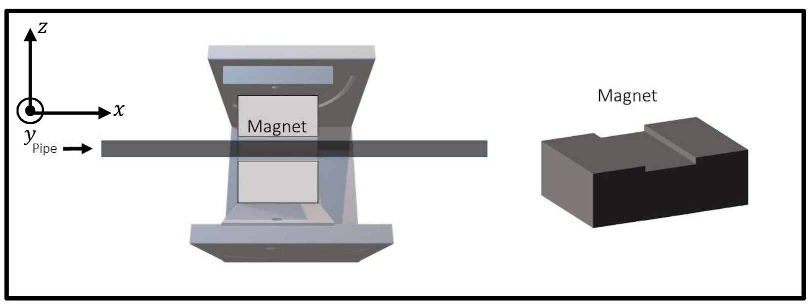
- v_{avg} is the average velocity, and *L* is the length of the probe coil.
- Intensity is proportional to volume (when t<<T2). Since V(t) has the form of a line, we can set V(t) = A+Bt and arrange to find:

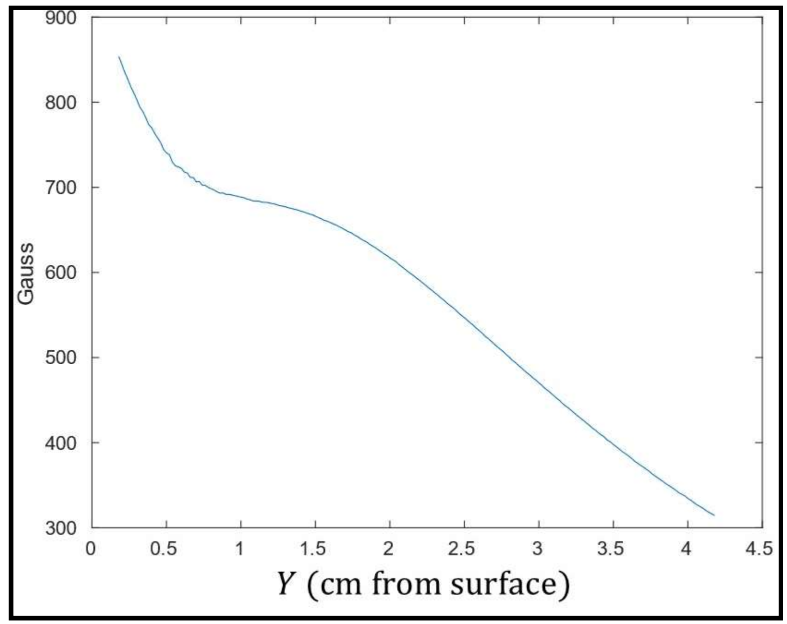
$$v_{avg} = \left(-\frac{B}{A}\right) L_{eff}$$

Materials

- Using a small handheld unilateral magnet with a constant gradient region perpendicular to the surface. A cradle system was used to suspend the magnet at different angles.

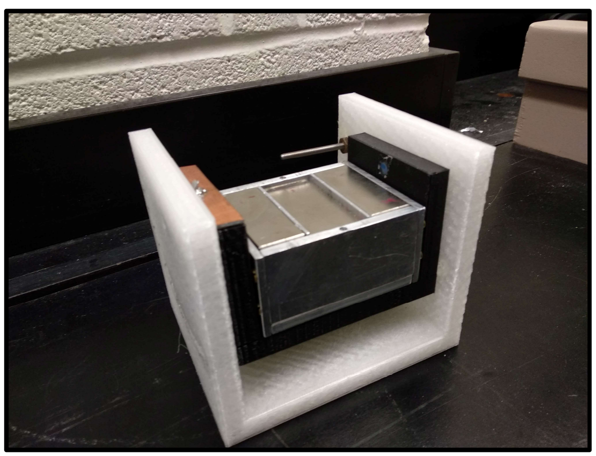


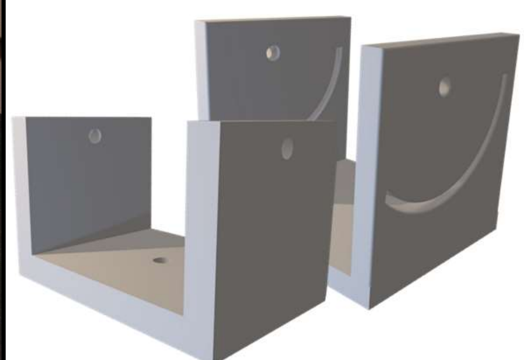


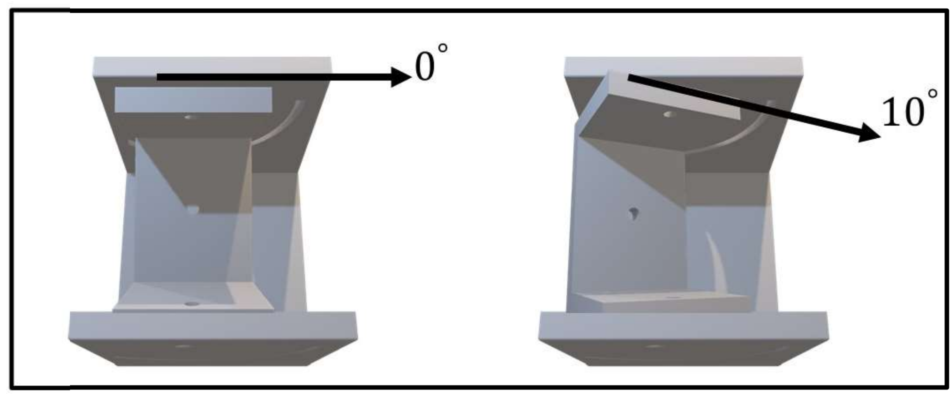


Materials

- A cradle was 3D printed to allow for the magnet to be suspended at different angles.
- This was a quick and effective solution to securely suspending the magnet.

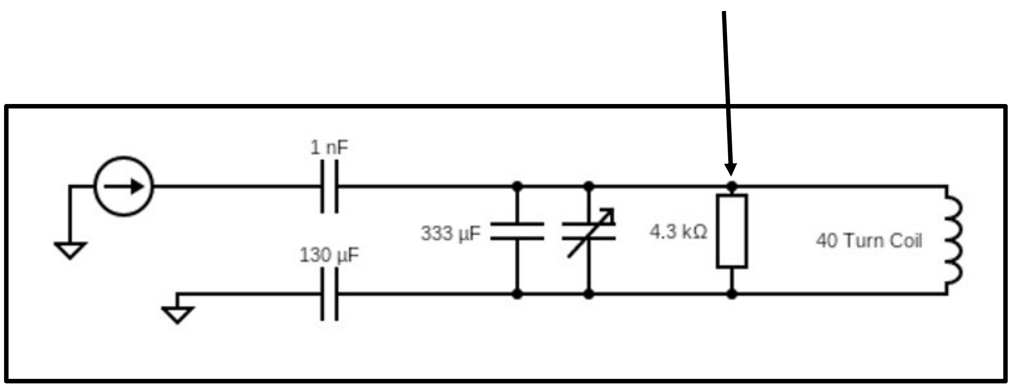


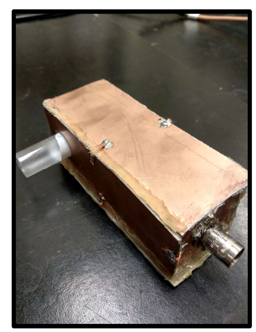




Materials

- The RF probe was tuned to 2.26MHz and matched to 50 ohms.
- 40 turn coil, wrapped about a plexiglass former.
- To reduce noise, a Faraday cage was constructed out of PCB circuit board to surround the circuitry.
- Problems with probe dead time required a resistor to be added in parallel with the coil.



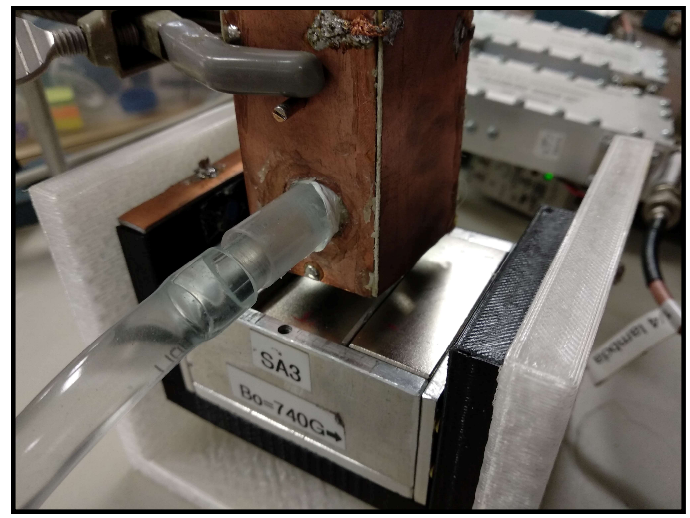


Methods

- A doped water sample was pumped through a hose that feeds into the RF coil. Flow rate can be adjusted by the pump. This flow rate is taken as the true flow rate, which will be used on the final plot.

- Pump outputs flow in CCM to an oscilloscope. Uncertainty in flow rate given by the pump is +/- 22.5 CCM.

- Pulse length was determined by considering the probe geometry, and power supplied to the coil.



Results

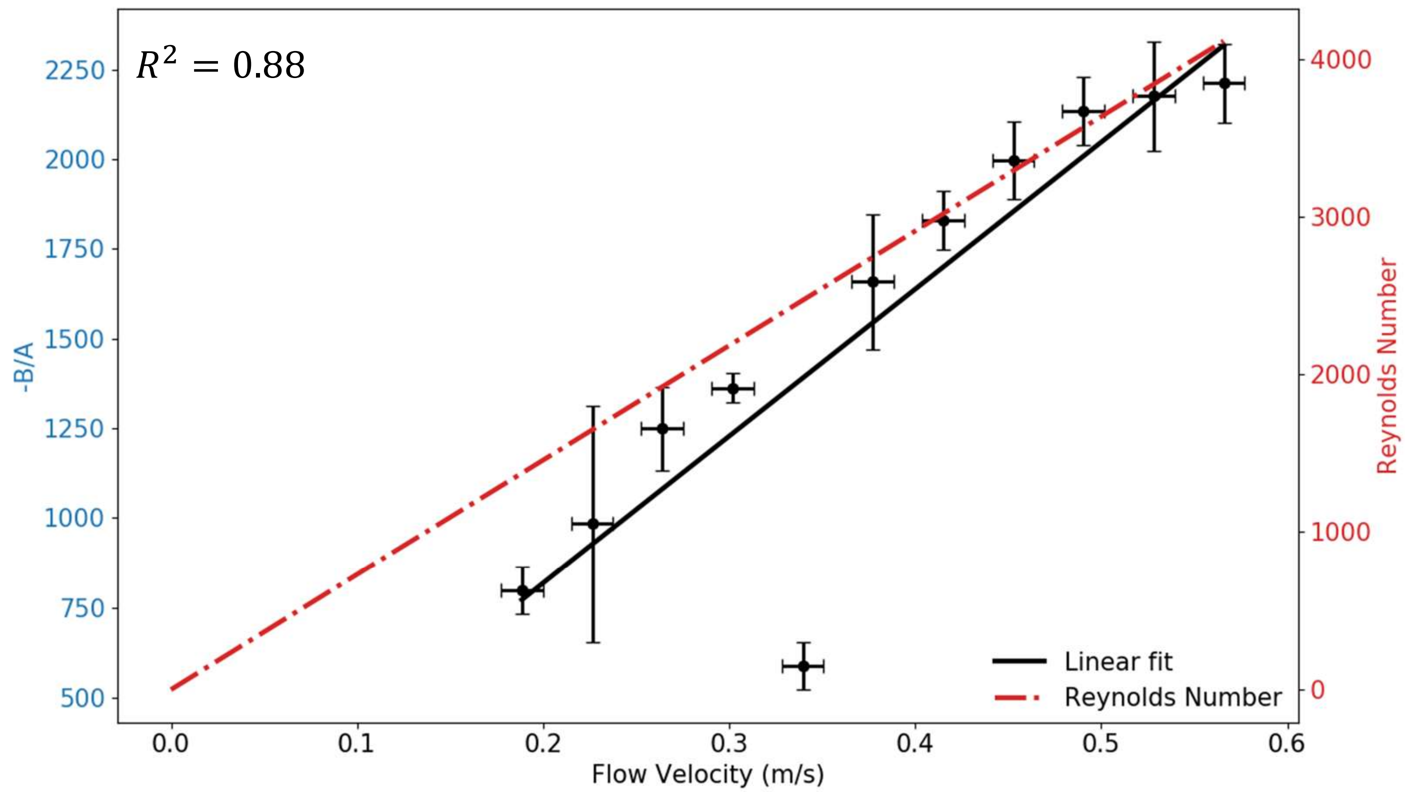
- Data was collected for 0, 5, and 10 degrees. Only the 0 degree data will contain error bars, as these measurements can take quite a long time.

- The vertical slice thickness given the vertical gradient is calculated to be 8.7 mm with:

$$\text{Slice Thickness} = \frac{1}{pw \times G \times \gamma}$$

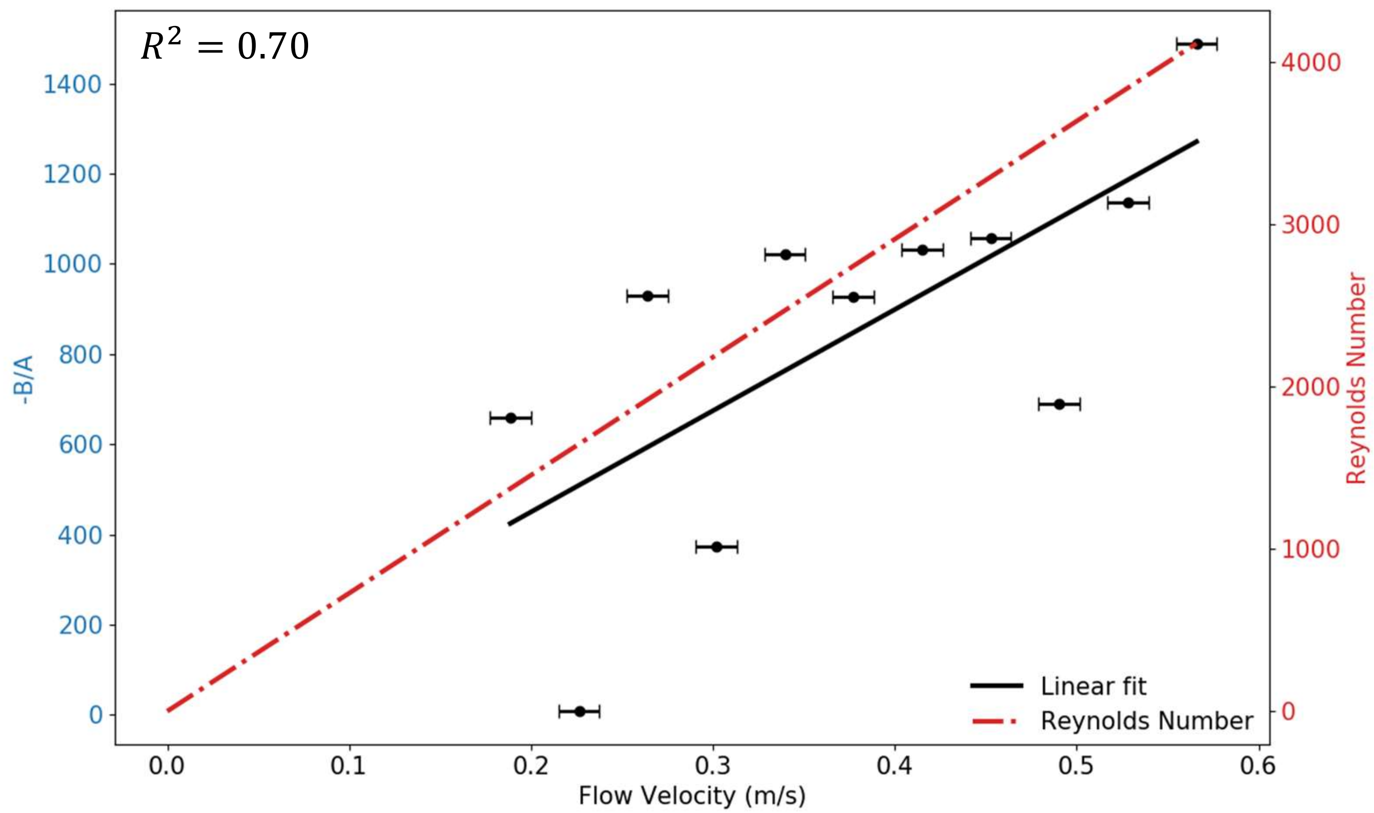
- Where *pw* is the pulse width (1.8us), *G* is the gradient (150gauss/cm), and γ is the gyromagnetic ratio.

0 degree



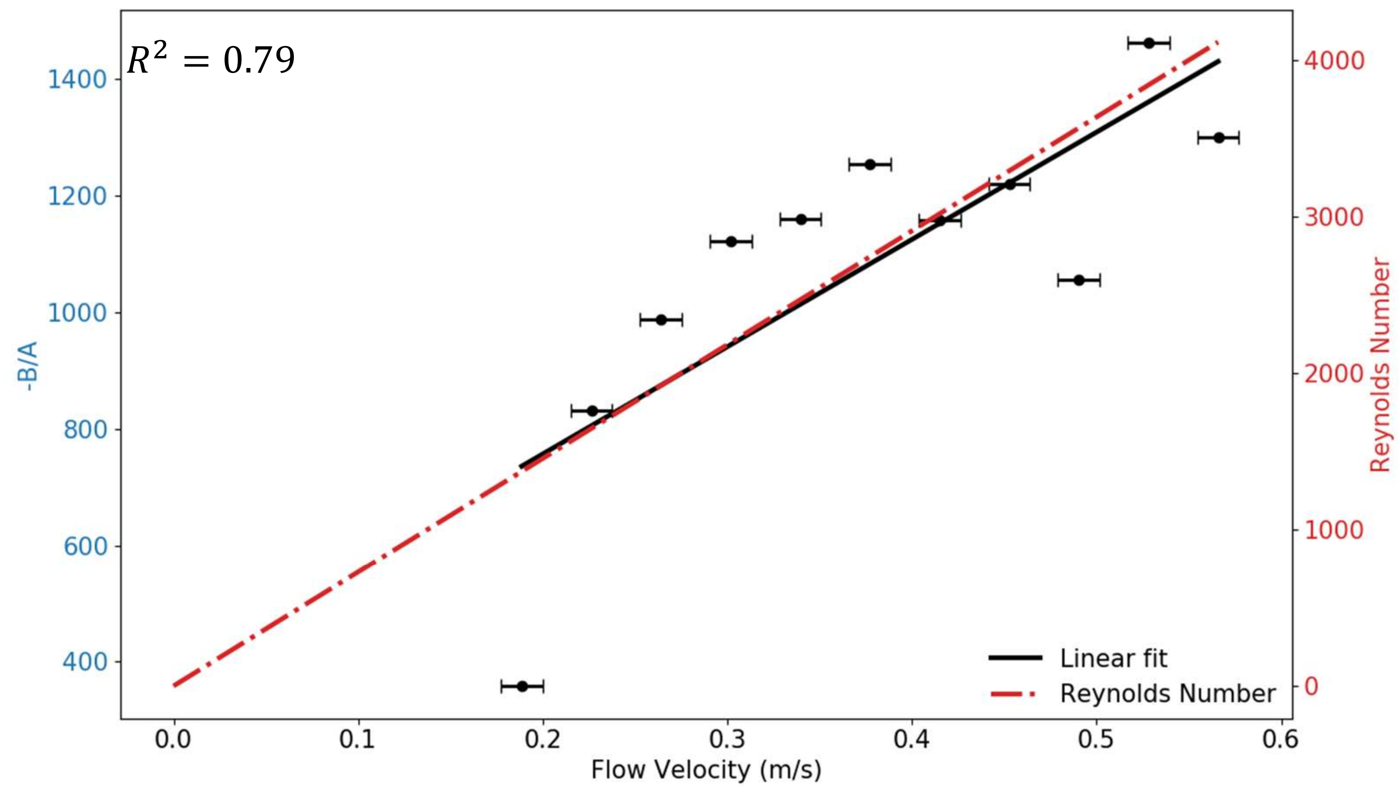
$R^2 = 0.88$
-B/A
Reynolds Number
Flow Velocity (m/s)
Linear fit
Reynolds Number
2250
2000
1750
1500
1250
1000
750
500
4000
3000
2000
1000
0
0.0
0.1
0.2
0.3
0.4
0.5
0.6

5 degree



$R^2 = 0.70$
1400
1200
1000
800
600
400
200
0
-B/A
4000
3000
2000
1000
0
Reynolds Number
0.0
0.1
0.2
0.3
0.4
0.5
0.6
Flow Velocity (m/s)
Linear fit
Reynolds Number

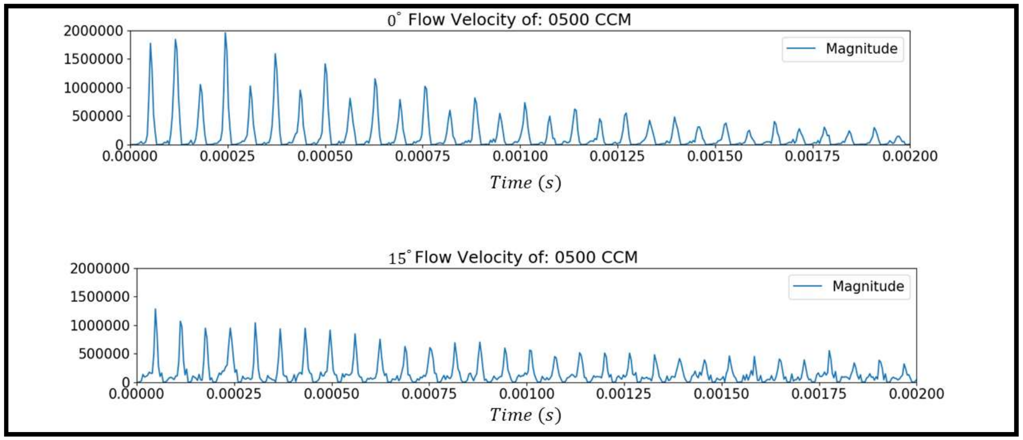
10 degree



$R^2 = 0.79$
1400
1200
1000
800
600
400
-B/A
4000
3000
2000
1000
0
Reynolds Number
0.0
0.1
0.2
0.3
0.4
0.5
0.6
Flow Velocity (m/s)
Linear fit
Reynolds Number

Discussion

- 0 degree data appears to be the best result. It contains an artifact where the data point deviates greatly from the trend.
- SNR decreases as the angle increases.
- SNR for 0 degrees is 22.9, 5 degrees is 9.2, and 10 degrees is 8.2.

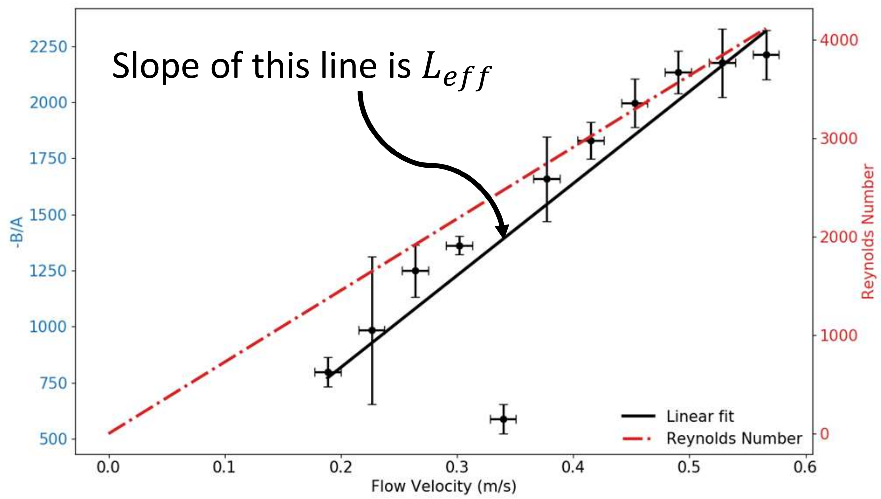


Discussion

- Effective slice thickness is calculated with :

$$v_{avg} = \left(-\frac{B}{A}\right) L_{eff}$$

- $L_{eff} = 4.9\ mm$ given 0 degree data.
- Effective probe coil length will change with a change in magnet orientation.
- We would expect L_{eff} to be different for 0, 5, and 10 degrees.



Conclusion

- We’ve been able to show that with these methods, flow measurements can be made with a small unilateral magnet.
- The method works best at 0 degrees, as SNR decreases with an increase in magnet angle.
- Overall, the project is encouraging of unilateral magnetic resonance, and shows that there is potential for a device like this to be one day used in the field.

Acknowledgements

I would like to thank Ben and Bruce for their guidance throughout the project.