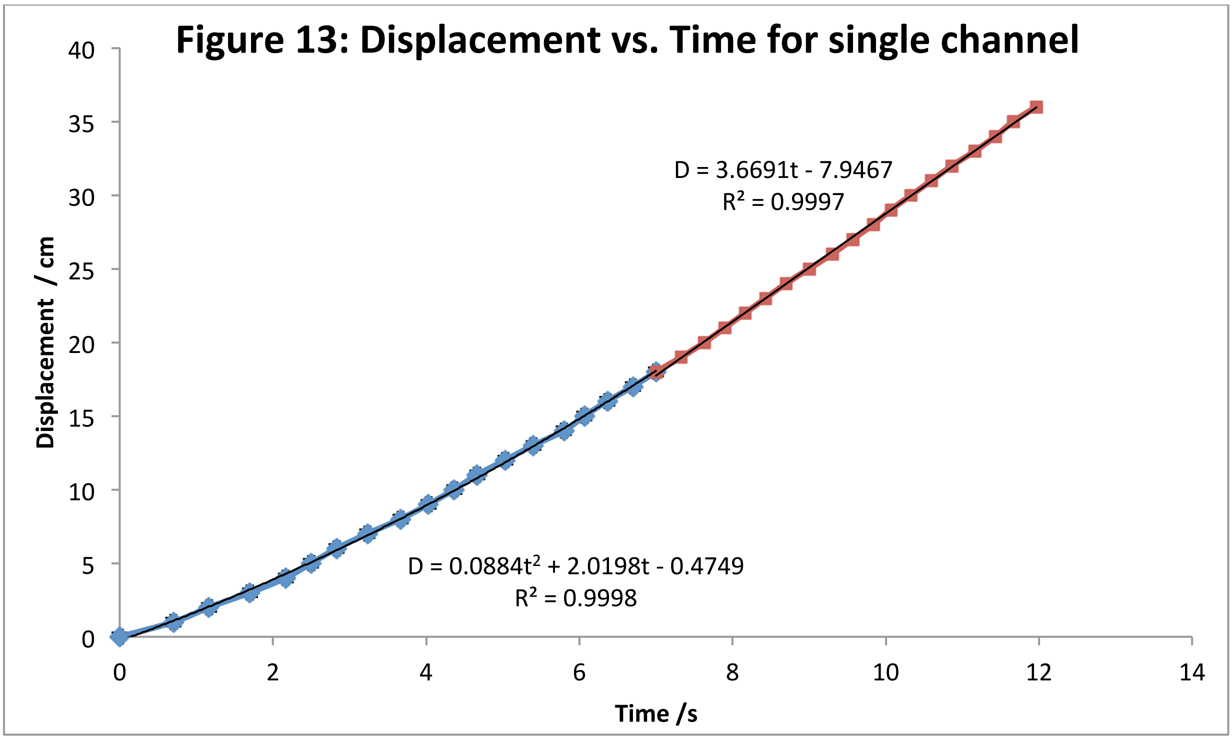
Calculating the Thrust

Using the estimate for average magnetic field it is possible to calculate the theoretical force for the single channel boat. This boat has 9 pairs of magnets along the channel giving it a channel length of $D = 13.5 \pm 0.1cm$. The width of the channel is $D = 1.6 \pm 0.1cm$. The voltage across the channel was measured to be $V = 17.92 \pm 0.005$V (error from the voltmeter). The salt water had 10% salinity and hence resistivity of $\rho = 0.07 \pm 0.01\ \Omega m$ (error in reading resistivity-salinity graph). Therefore using equation (7) the theoretical force will be F=0.1$\pm$0.02N (adding up errors in quadrature).

Displacement time graphs were plotted for different runs across the tank using the single channel boat in order to obtain an experimental estimate for the force. The data from one of the best runs is graphed in Fig. 13.



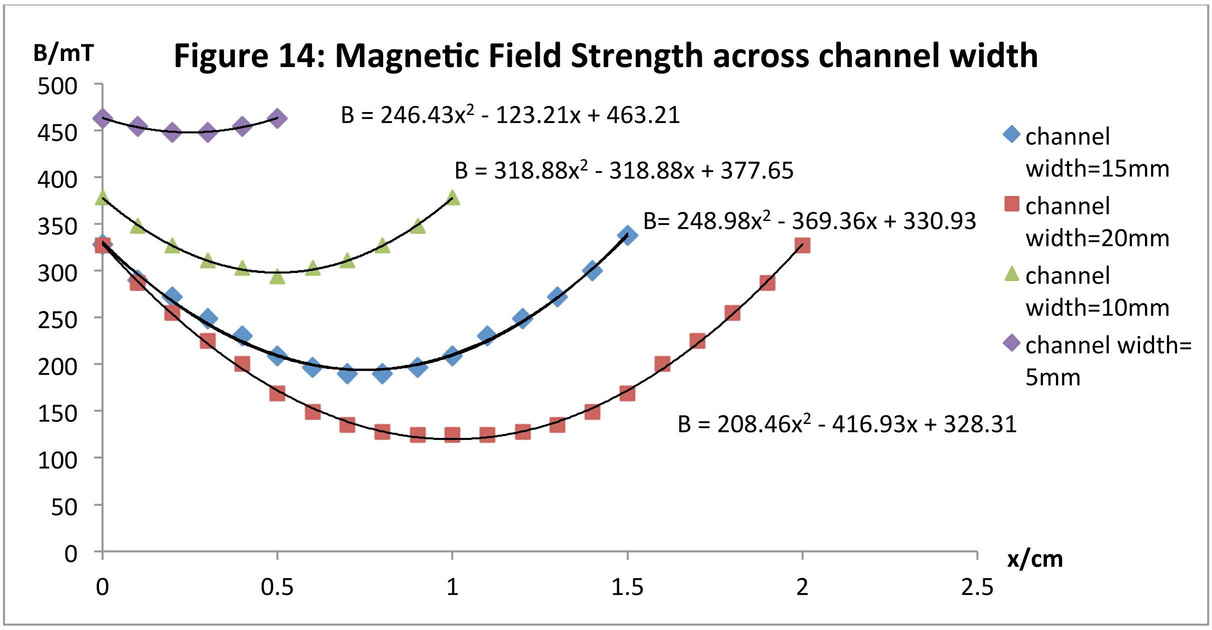
If the acceleration is assumed constant (no drag) then by comparing coefficients of the trend line with equation (8) the acceleration = 2(0.0884) = 0.177 $\pm 0.02\ cms^{-2}$. As the mass of the single channel boat was 0.33 ± 0.005kg by $F = ma$, the force will be F=$(5.9 \pm 0.3)\times 10^{-4}$N. The error on time was half the smallest time increment of the camera used $\pm$0.04s and for displacement it was $\pm$0.2cm.

This is three orders of magnitude less than the force suggesting that acceleration is not constant. This is apparent from the graph as there is a tiny acceleration initially however this decreases then after 7 seconds the boat travels at constant velocity with the x-t gradient constant. This is because of fluid drag opposing the thrust caused by the Lorentz force and thereby reducing the forward resultant force. As the boat speeds up the fluid drag against its motion increases until after 7 seconds when the fluid drag and the thrust become balanced which results in constant velocity. In this case assuming no power loss the electrical power, $P = IV$, can be equated to the mechanical power, $P = Fv$, where v is velocity. This gives the force as $F = \frac{IV}{v}$. The gradient of the straight line fit after 7s is $v = 3.67 \pm 0.02\ cms^{-1}$ (error is from the standard error of the gradient). The current measured when the boat was in the water fluctuated a lot therefore 12 measurements were taken and a mean was found $I = 0.078 \pm 0.009mA$. The standard error ($\frac{standard\ deviation}{\sqrt{number\ of\ measurements}}$) was used to calculate $\pm 0.009mA$. Hence $F = 0.04 \pm 0.01N$.

This experimental estimate is 40% of the theoretical force and the uncertainties in both values are too small for the two results to possibly overlap. It is however expected that experimental force would be less than that obtained theoretically as firstly the approximated average for B in the theoretical force is an overestimate. Also electrolysis causes bubbles and corrosion which can hinder propulsion by a large extent. Finally there will in fact be significant power losses. For instance the batteries got noticeably hot and heat will be dissipated by the current flowing through the saltwater as there is some resistance.

Channel Optimization

From background theory equation (7) the force is $|\boldsymbol{F}| = \frac{VDWB}{\rho}$. Increasing the width of the channel should proportionally increase the magnitude of force. However increasing the width of the channel decreases the average magnetic field across the width of the channel. In order to work an optimum channel width with the largest force the magnetic field from centre of one magnet was measured[7]. The data from this could then be superposed to produce magnetic field between two magnets when separated different distances, which represent different channel widths. Fig. 14 is a graph of the produced superposed magnetic fields for different channel widths.



By integrating each of the quadratic equations for the lines of best fit the average magnetic field for each different channel width can be calculated. The average magnetic field can be now plotted against channel width in Fig. 15.

[7] See Fig. 20 and Fig. 21 in Appendix 2

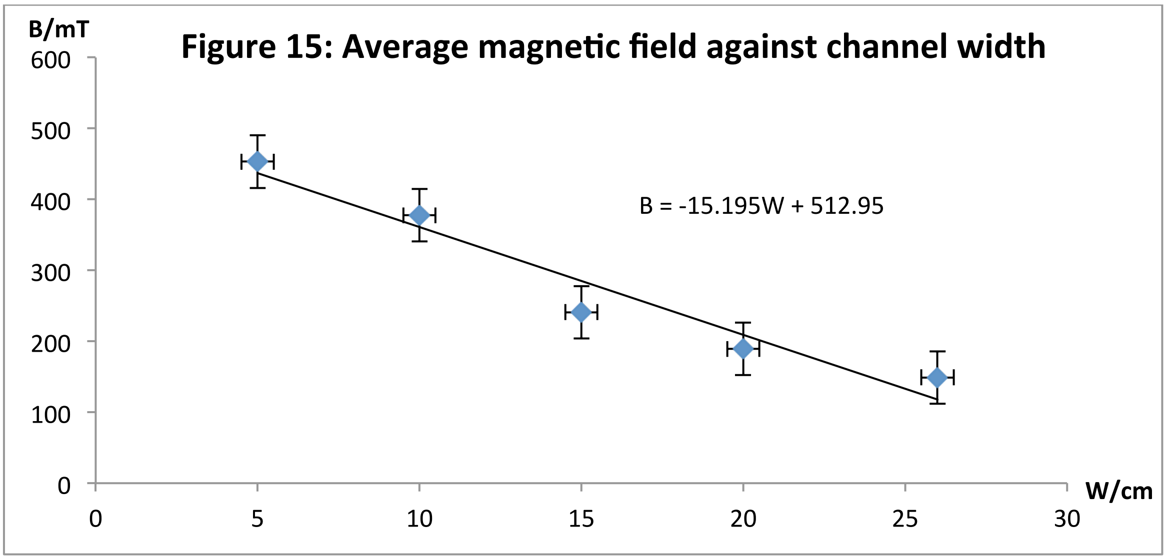


Figure 15: Average magnetic field against channel width

If you assume this equation is a suitable fit then $|\boldsymbol{F}| = \frac{VDW(-15.195W+512.95)}{\rho}$. This would give the quadratic curve shown in Fig. 16.

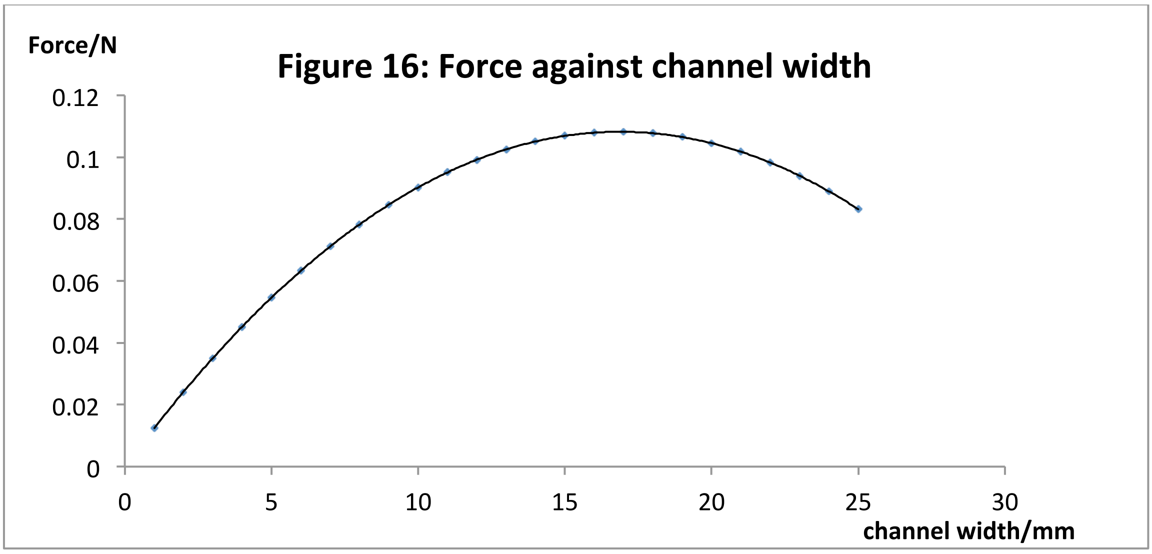


Figure 16: Force against channel width

This shows that the optimal channel width is approximately $16.0 \pm 0.5mm$.

Designing an MHD submarine

The main problem with designing a submarine utilizing MHD propulsion is the limits on portable magnets. To produce a large enough magnetic field, superconducting electromagnets are required which need a large amount of current and to be cooled down. For instance the *Yamato 1* used liquid helium cooled electromagnets which produced a magnetic field of 4 Tesla. For a 18750 tonne submarine travelling at 20 knots and with a power of 67MW an unreasonable current of 540000A would be needed if it were limited to 4T magnets. The cost and energy required to power and cool the magnets is large making conventional fossil fueled propulsion much more commercially feasible. Finally unfortunately for the Red October bubbles of chlorine and hydrogen gas produced by electrolysis of the salt water might make it easily detectable. The electrolysis also causes corrosion of the electrodes which could lead to substantial maintenance costs despite the lack of moving parts.

5. CONCLUSION Tom Neiser

As a conclusion one can state that MHD propulsion was successfully demonstrated on a small scale. A long single channel boat and a shorter twin engine boat were effectively constructed. Measurements of the resistivity, the average magnetic field strength inside the single channel boat as well as an experimental thrust value of $F = 0.04 \pm 0.01N$ enabled the optimum channel width to be computed as $16.0 \ \pm 0.5mm$, assuming ceteris paribus[8]. Several test runs illustrated, however, that these MHD engines were susceptible to a high degree of corrosion and their performance was limited by the number of batteries and the size of the magnets they could carry. Translation of these results to large scale operation will therefore need to overcome the hurdles of creating an intense magnetic field, generating large currents, defeating fast rates of corrosion and above all competing with more efficient conventional propulsion systems. Furthermore, the theoretical concept of stealthy MHD propulsion is undermined by the production of bubbles through electrolysis. Hence, large scale commercial and military implementation of MHD propulsion will remain fictional in the near future.

6. BIBLIOGRAPHY

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(Hint: search for any of the following "Imperial College First Year Project Magnetohydrodynamics MHD Propulsion boats 2009 William Sutcliffe Tom Neiser")

[8] Ceteris paribus: assuming everything else remains constant, i.e. the magnetic field strength, current and salinity of the salt water