# Propulsion and levitation with a large electrodynamic wheel: the effect of its pole number, radius and the track parameters.

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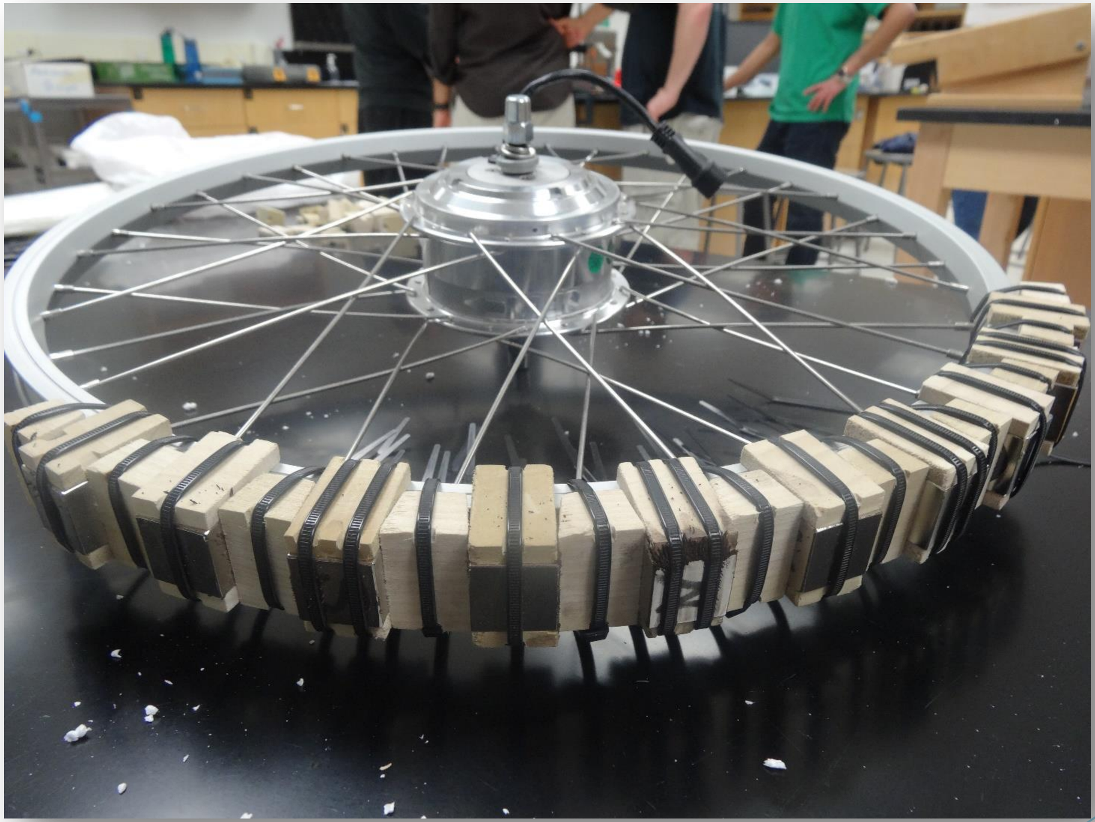
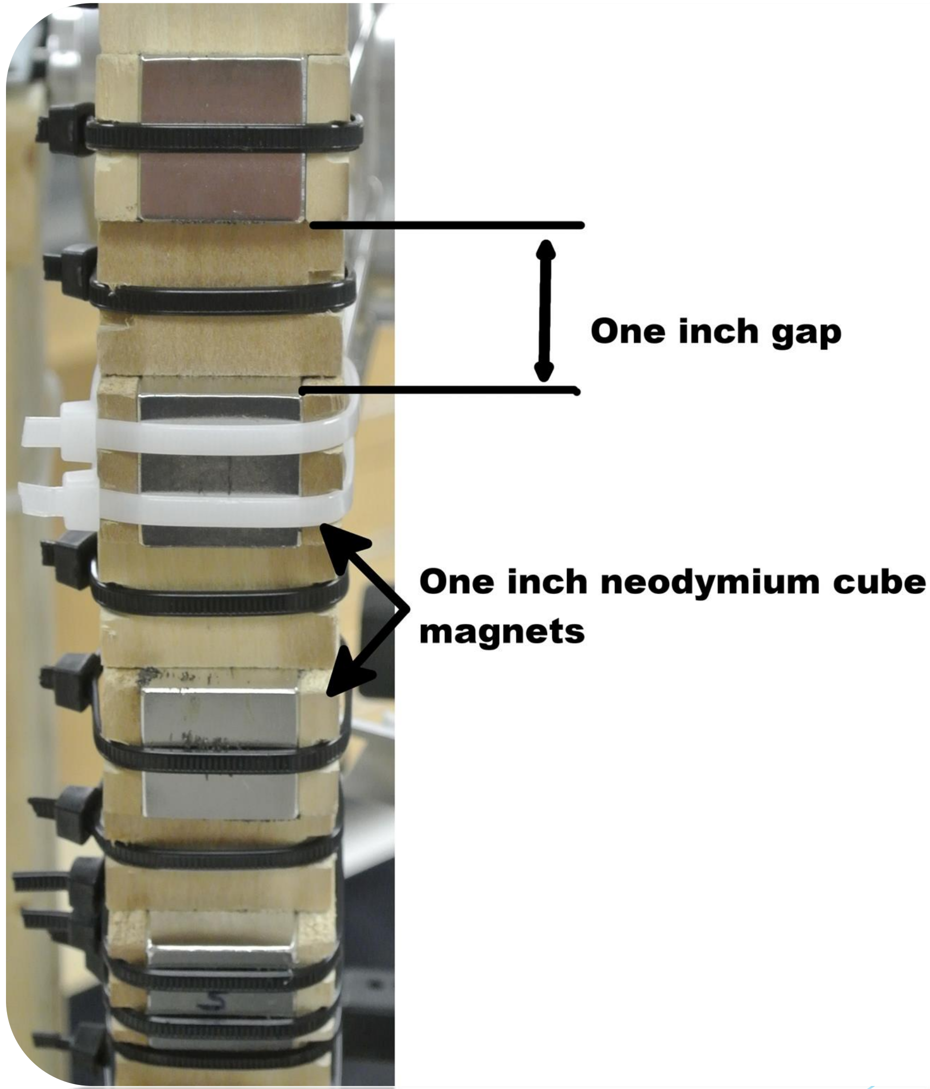
# Motorized bicycle wheel

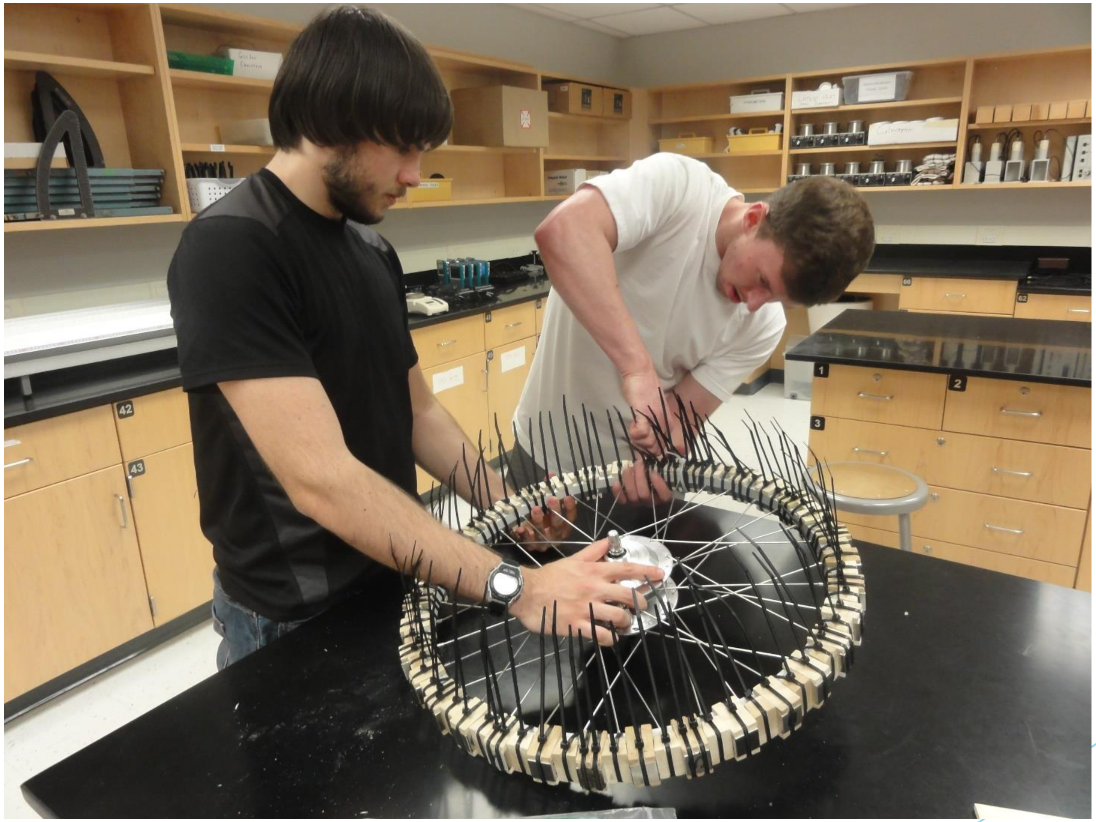
# Converted to an electrodynamic wheel…



# Close up of the wheel's rim



… by placing on the rim 36 1” cubic Nd magnets with their magnetizations oriented into a series of Halbach arrays, producing 1 Tesla variable magnetic fields



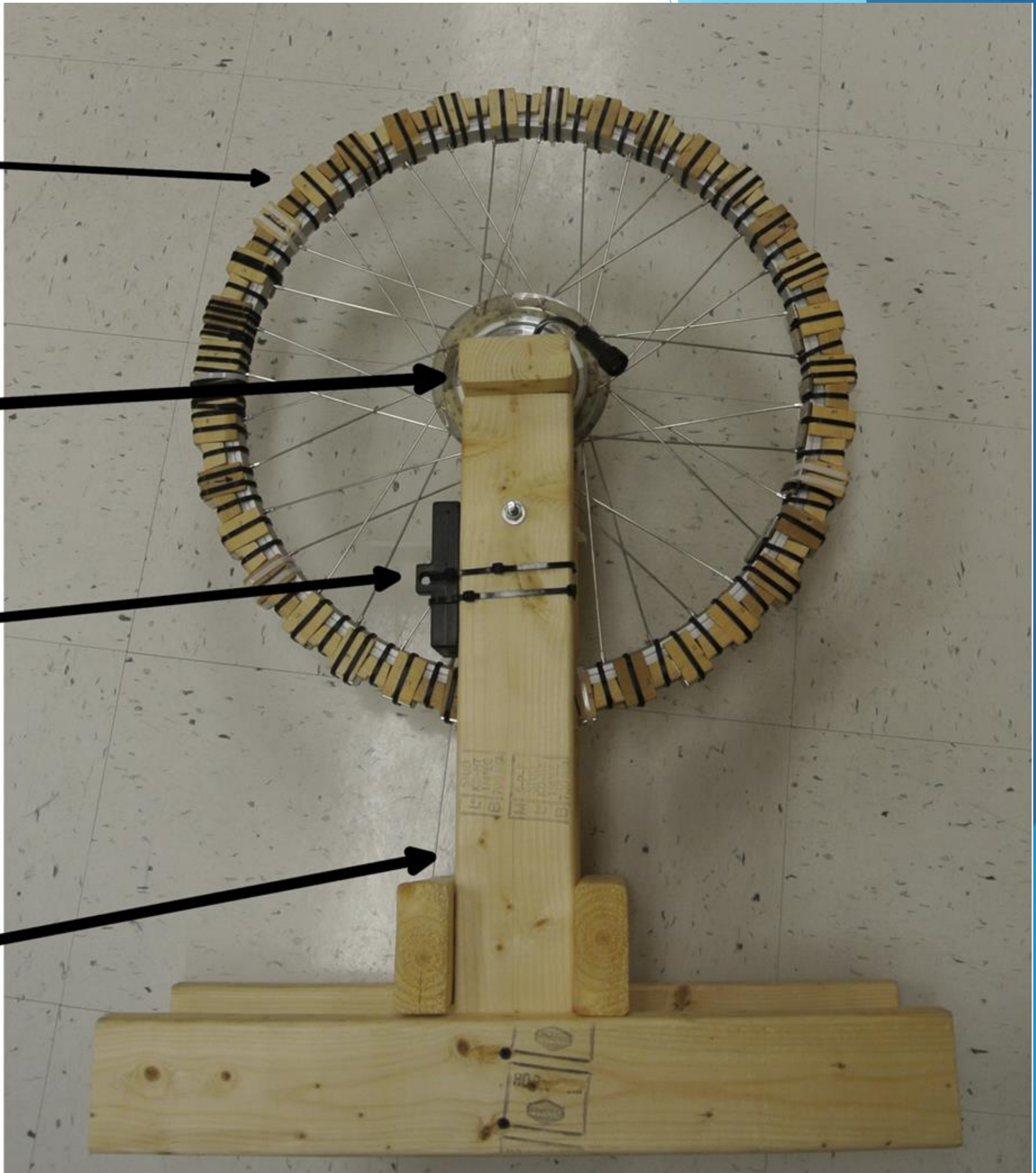
# Our group constructed a stand for the wheel

Rim composed of 36 one inch neodymium magnets arranged in 9 halbach arrays

Bicyle wheel of 11.5 inch radius with brushless hub-motor

Photogate for measuring RPM

Wood support structure

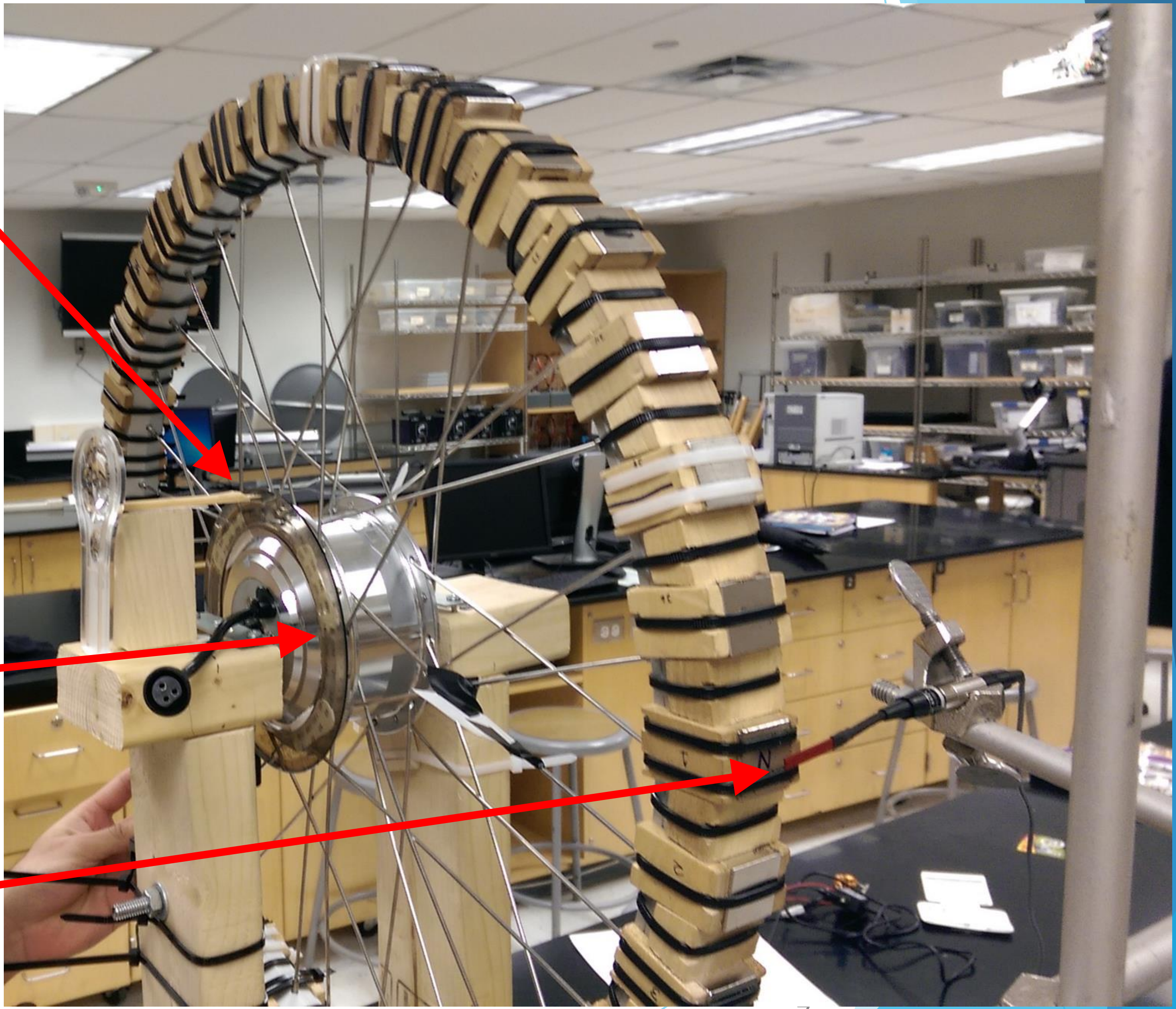


# Measuring the magnetic field around the wheel

Wooden splinter used as indicator to read protractor

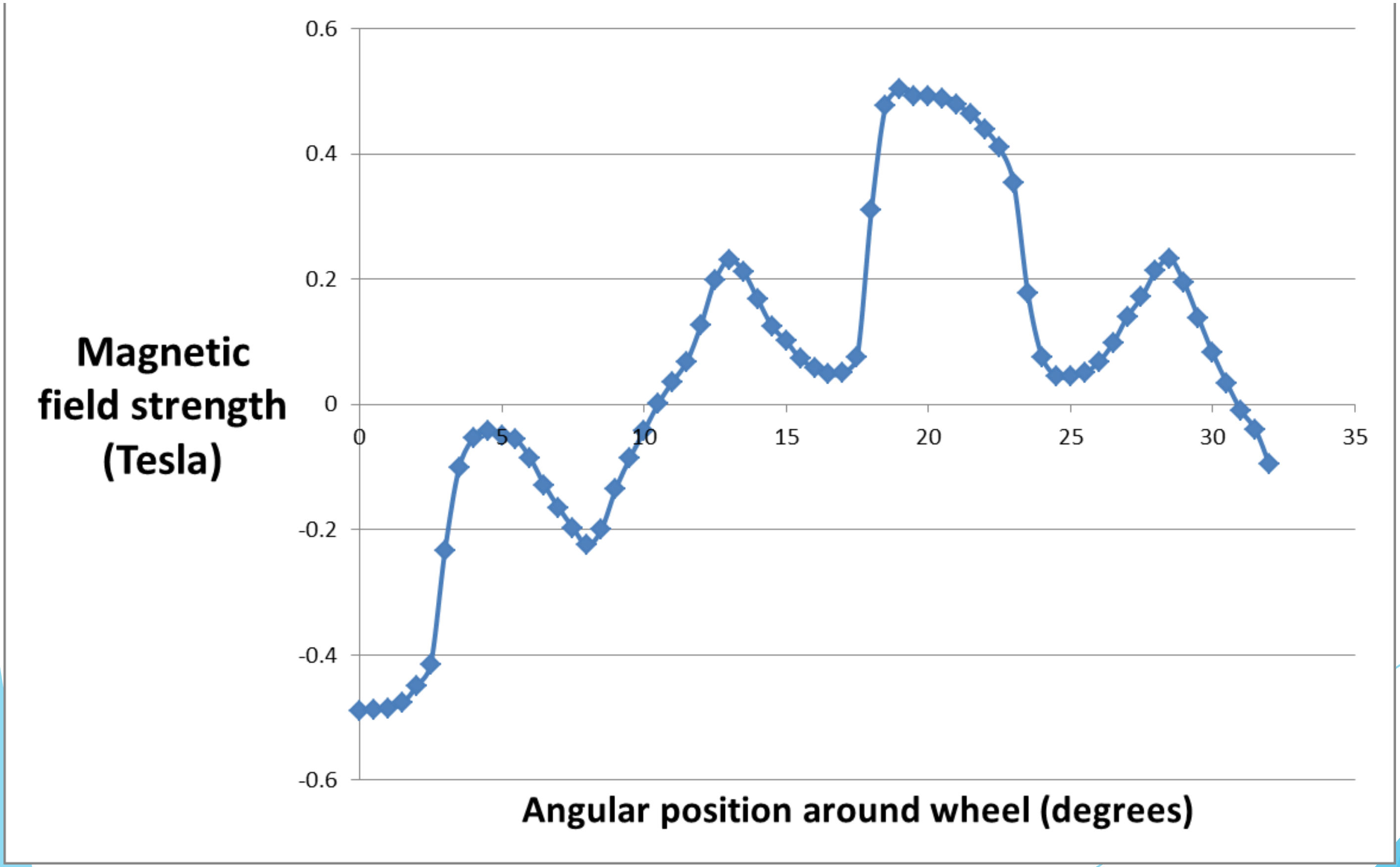
360 degree protractor to measure angular position

Magnetic field probe

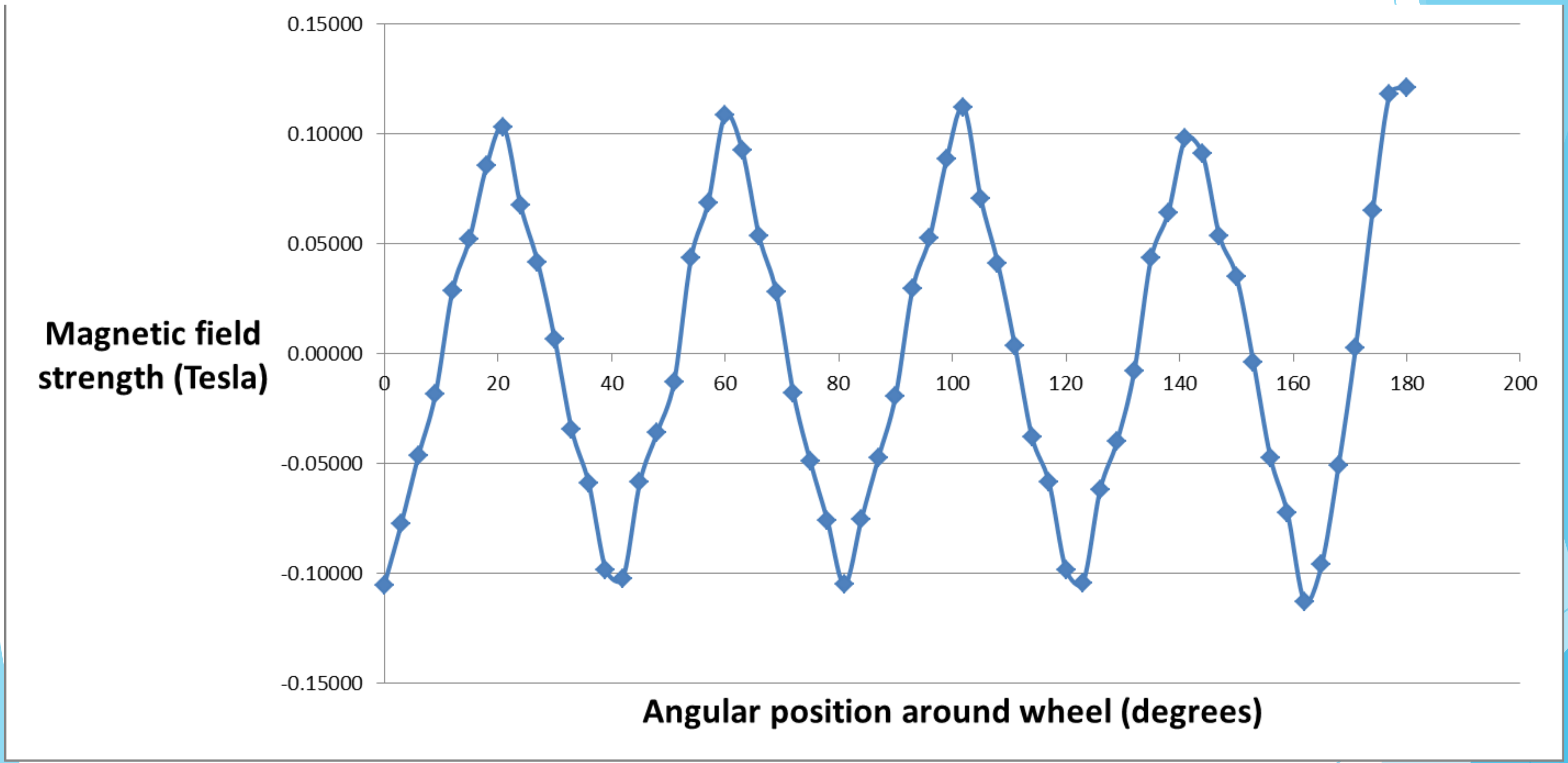


# Radial magnetic field 10 mm from the surface of the wheel

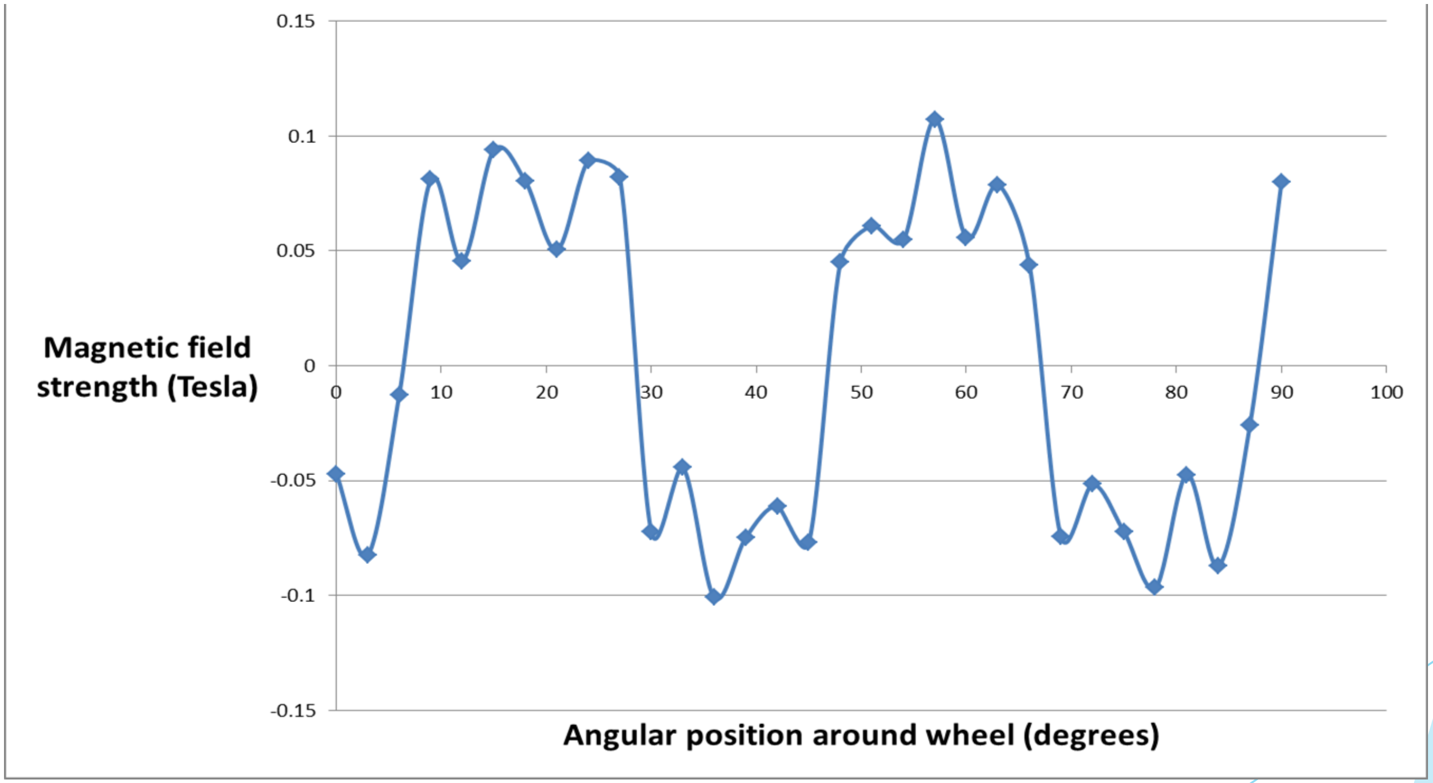
# Radial magnetic field measured over a 32 degree arc approximately 2 mm from the surface



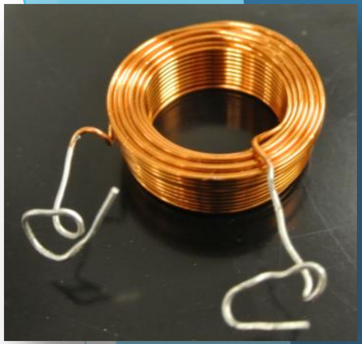
# Radial magnetic field 20 mm from the surface of the wheel

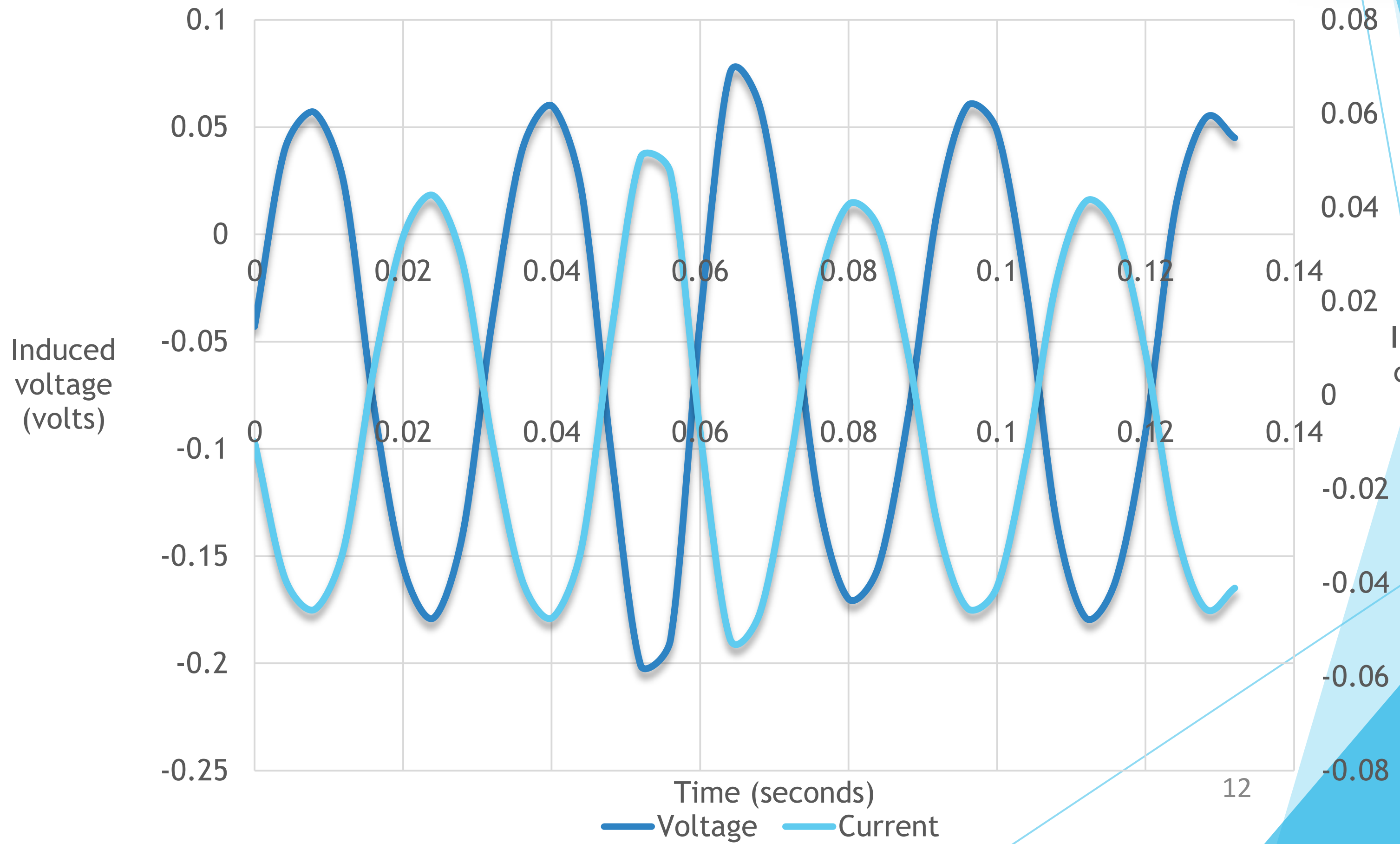


# Tangential magnetic field 10 mm from the surface of the wheel

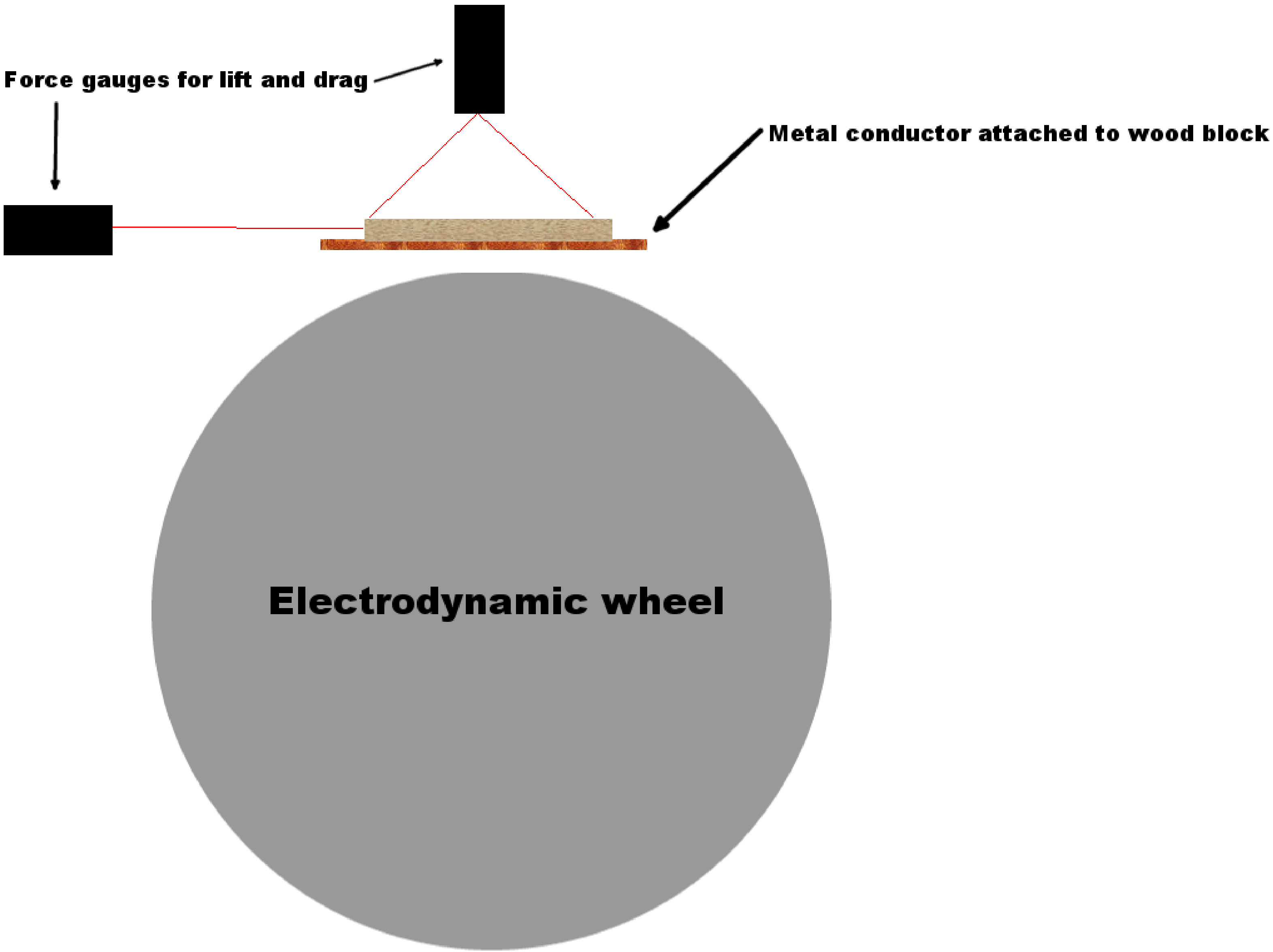


# Induced current and voltage in a 19 ohm coil as functions of time



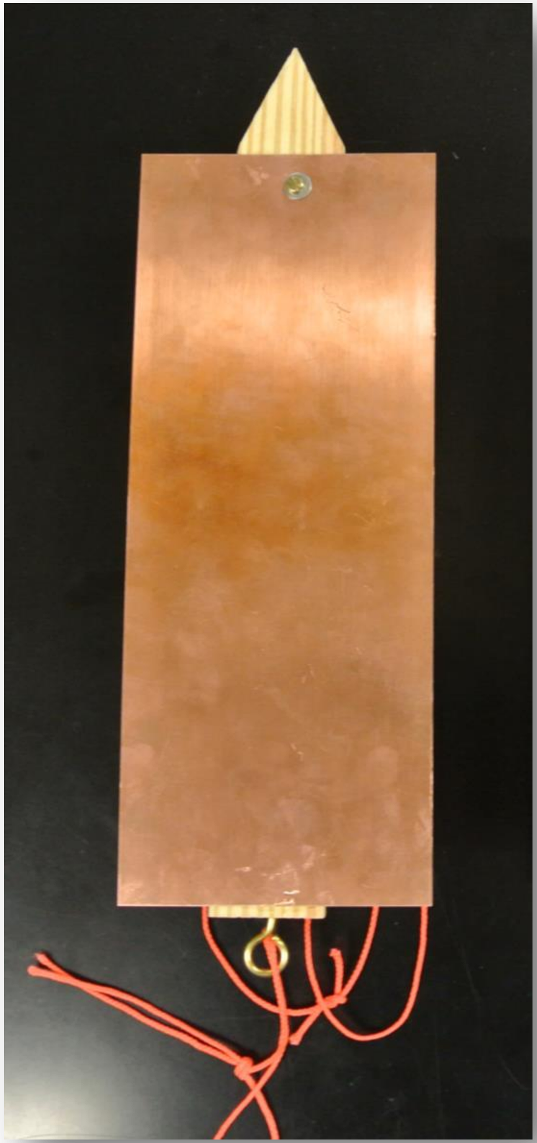


# Experimental Setup

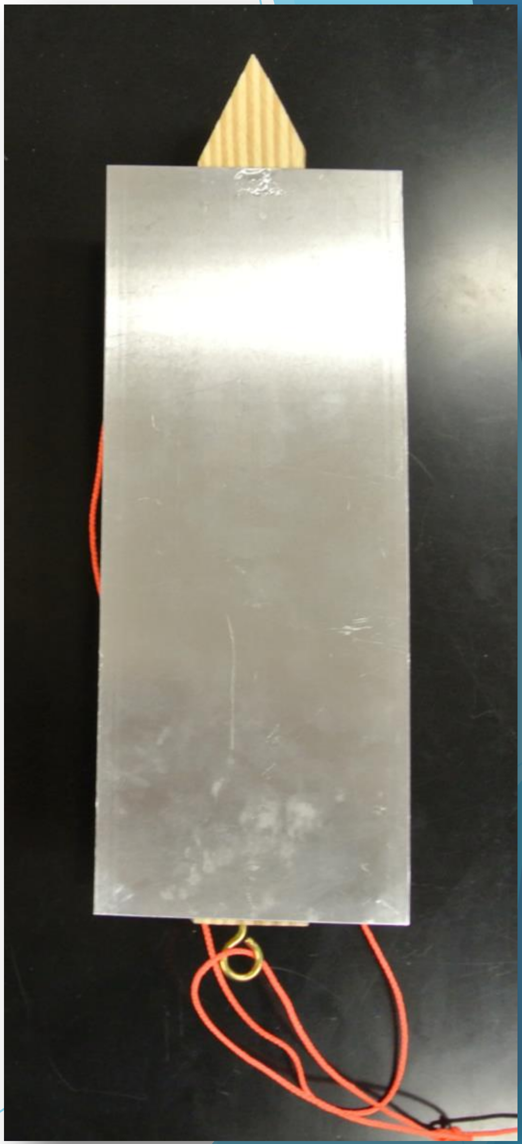


# The copper and aluminum conductors

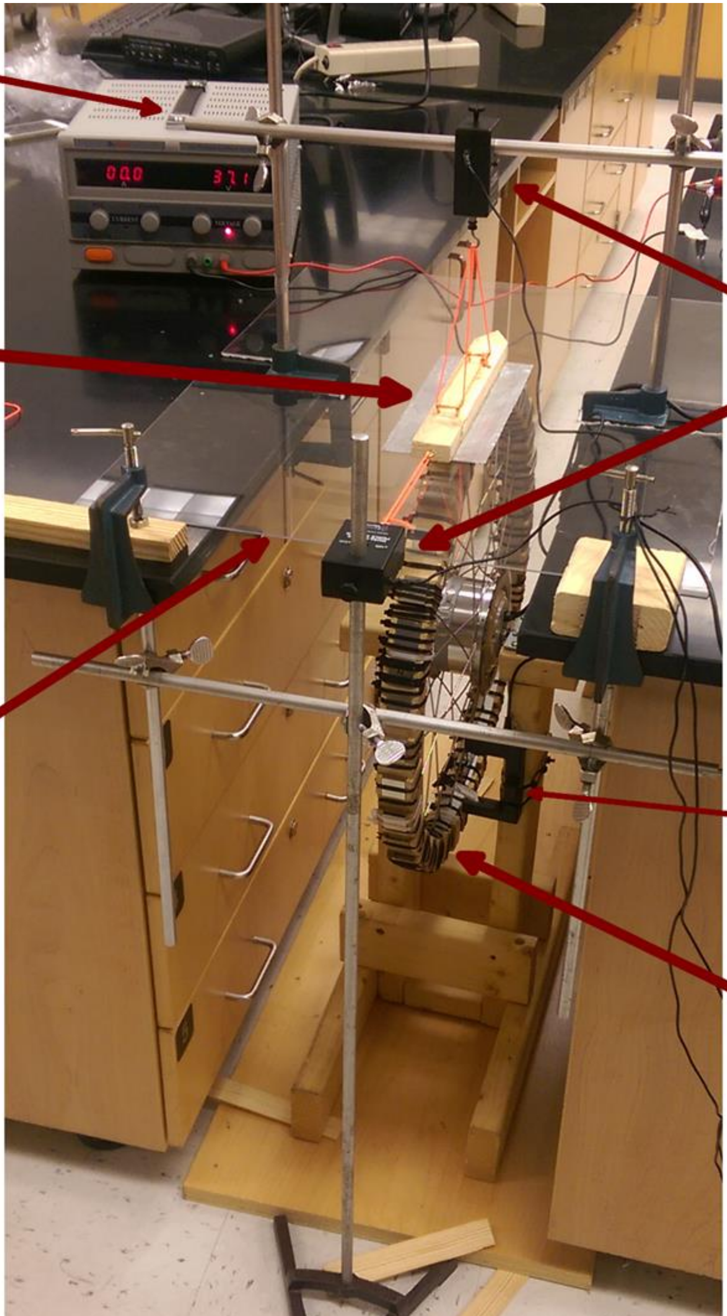
Aluminum
Weight: 1.9 N



Copper Plate
Weight: 2.3 N



# Experimental Setup



# Challenges

- Only discrete wheel speeds available from lead acid batteries
- Condensed magnet cluster throwing off wheel balance
- Air turbulence interfering with the conductor
- Weakening zip-ties

Once we solved these problems we were able to start experimenting

# Theory

Induced voltage ε and current I in the plate's eddy current circuits (of inductance L and resistance R) from variable magnetic flux of amplitude $\Phi_0$ resulting from relative motion with velocity v of the magnets with respect to a conductive plate are related by the LR circuit equation:

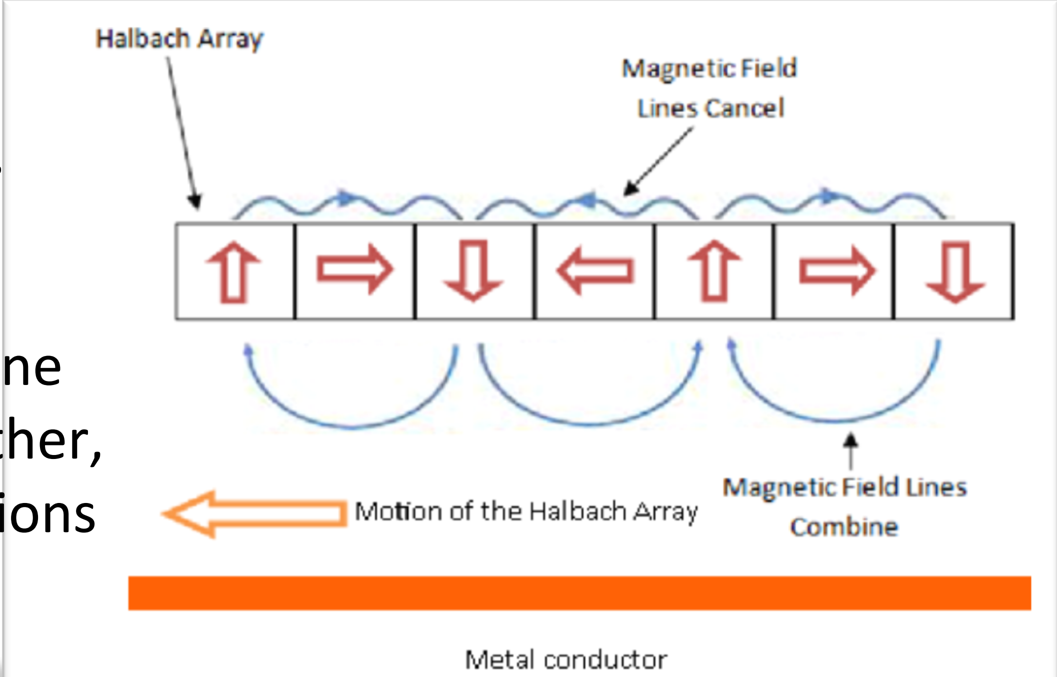
$$\varepsilon = L dI/dt + RI = \omega \Phi_0 \cos\omega t,$$

where $\omega=(2\pi/\lambda)v$, λ is the space period of the magnet, 8 inches. Solving explicitly for I and using the general magnetic force formula **F** = I **l**x**B**, **B** being the field of the magnet, we can find components of the force acting on the plate. Original calculation was done for linear motion, here we apply it for circular motion of large radius.

# Theory

- Inductional Magnetic Levitation
  - Caused by relative motion between a magnet and a conductor
  - This motion generates an opposing magnetic field which repels the conductor

    in both the tangential (drag) and normal (lift) directions.
- Halbach array of dipole permanent magnets
  - Field strengthened on one side, negligible on the other, due to the special directions of magnetizations



# Theory

$$\text{Drag} = F_x = \frac{B_o^{\,2} w^2}{2kL} * \frac{\frac{R}{\omega L}}{1+\left(\frac{R}{\omega L}\right)^2} * e^{-ky}$$

$$Lift = F_y = \frac{B_o^{\,2} w^2}{2kL} * \frac{1}{1+\left(\frac{R}{\omega L}\right)^2} * e^{-ky}$$

$$\frac{Lift}{Drag} = \frac{\omega L}{R} = \frac{2 \cdot \pi \cdot V}{\lambda} \cdot \frac{L}{R}$$


$\lambda$ =wavelength of the Halbach array;  k= $2\pi/\lambda$

R = resistance in each closed circuit

V = relative velocity between the conductor and the Halbachs

L = circuit inductance (self-inductance + inductive coupling)

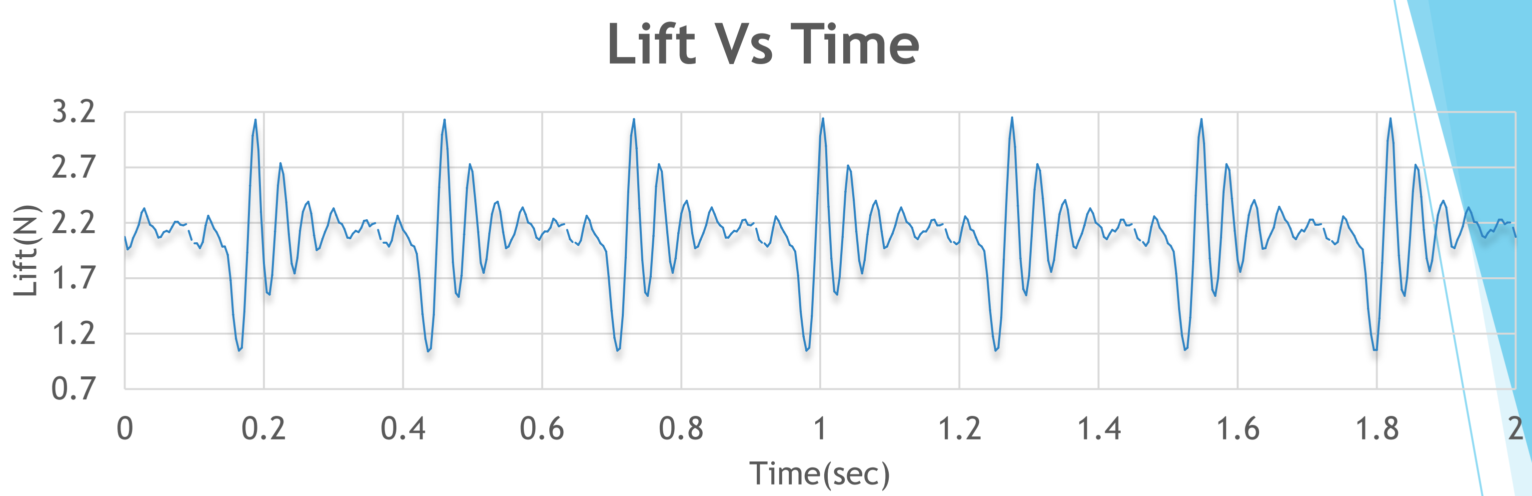
$B_0$ = peak field strength of the Halbach array

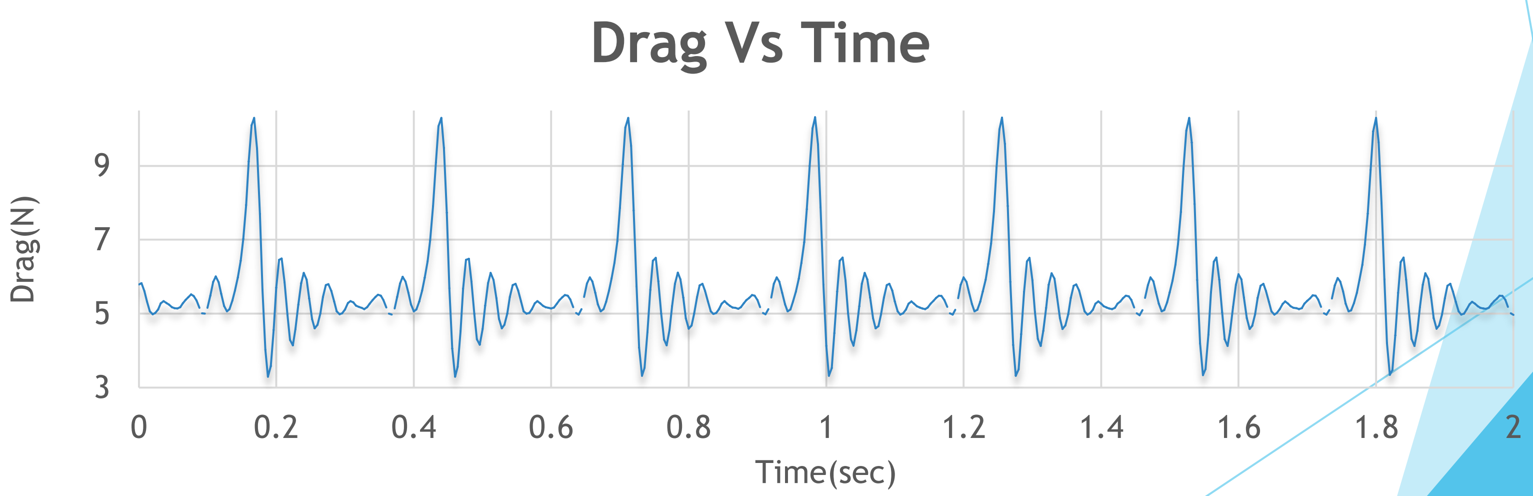
w = width of the conductor

$\omega$= angular frequency of variable flux

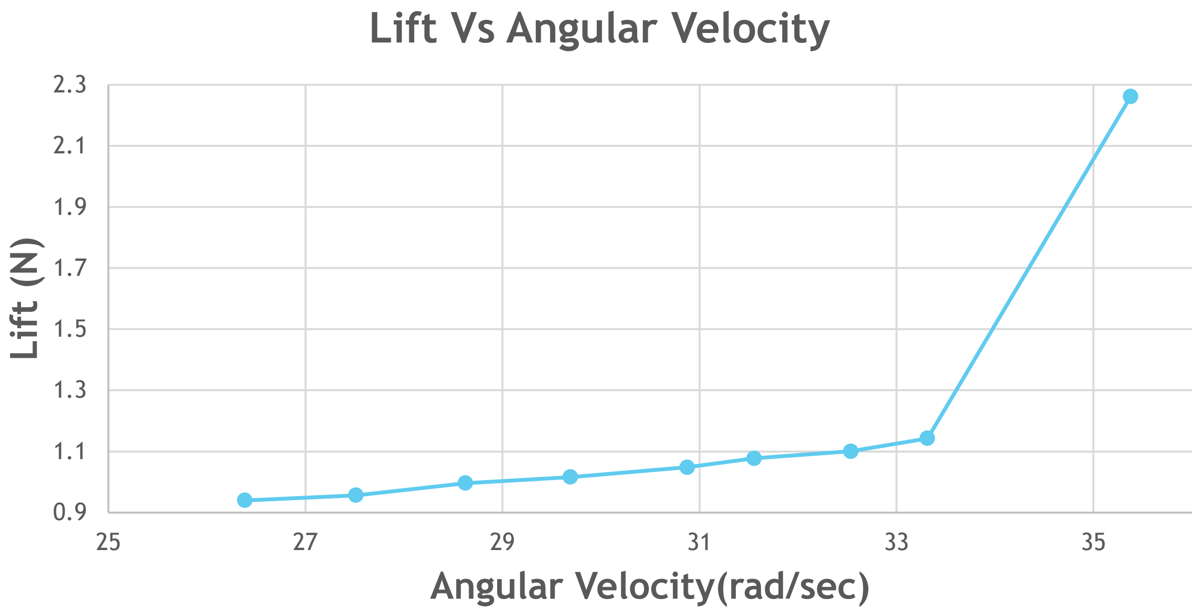
y =distance between the upper surface of the Halbachs and the inductive plate.

# Example data with conducting plate

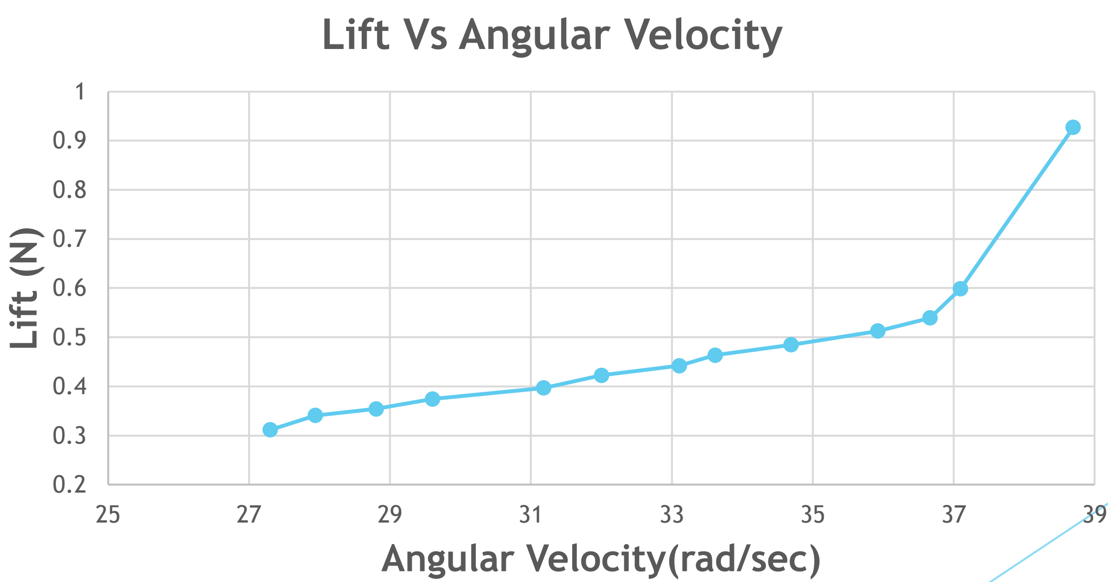


# Lift

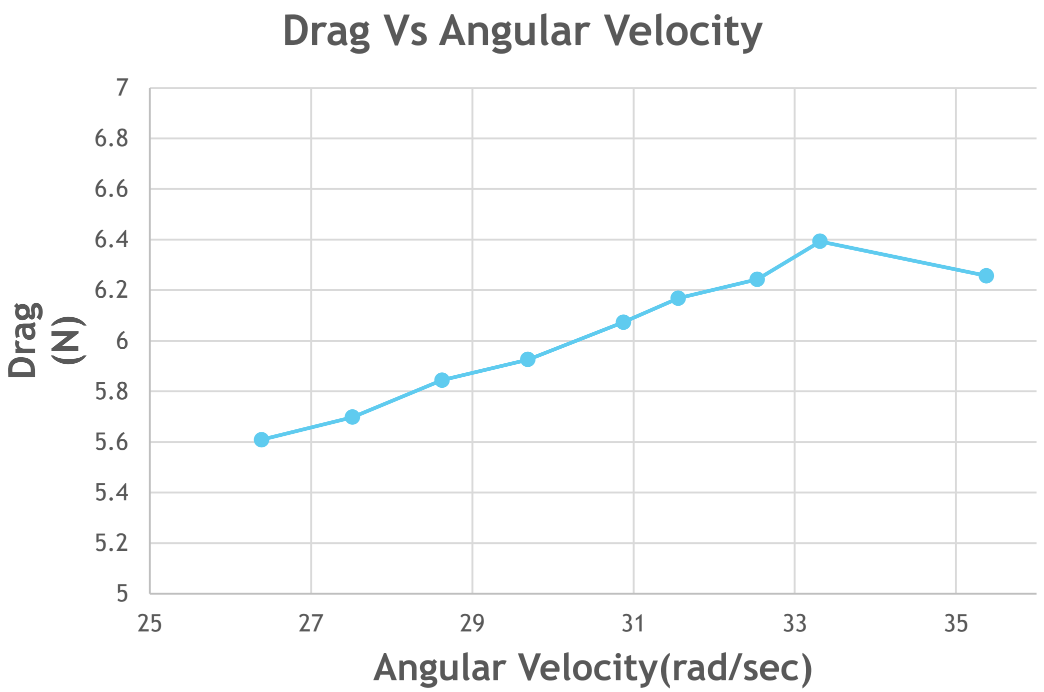



Copper

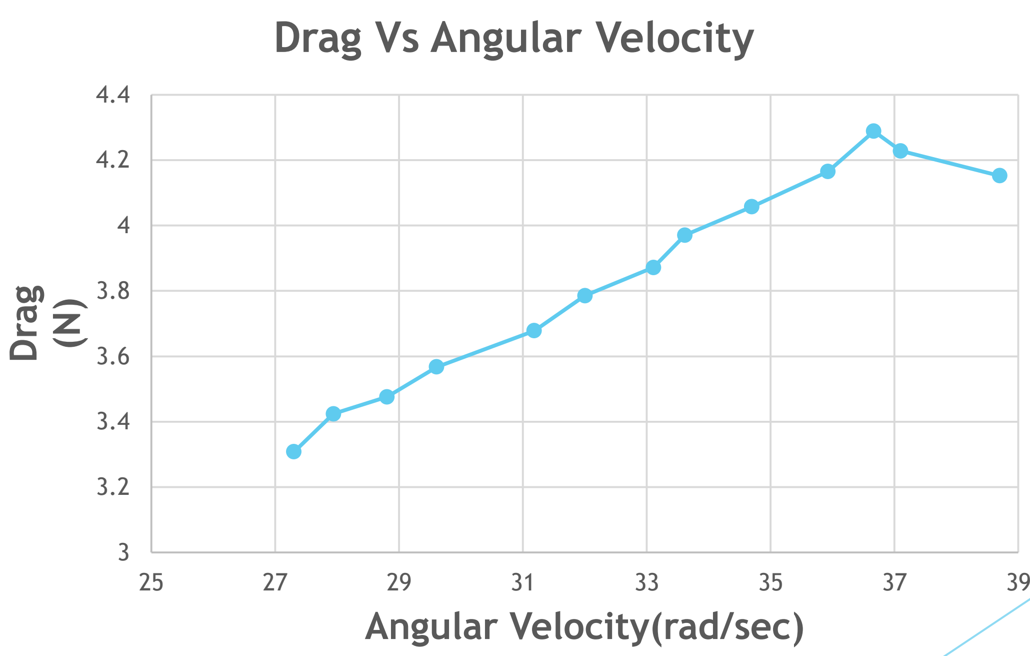



Aluminum

# Drag

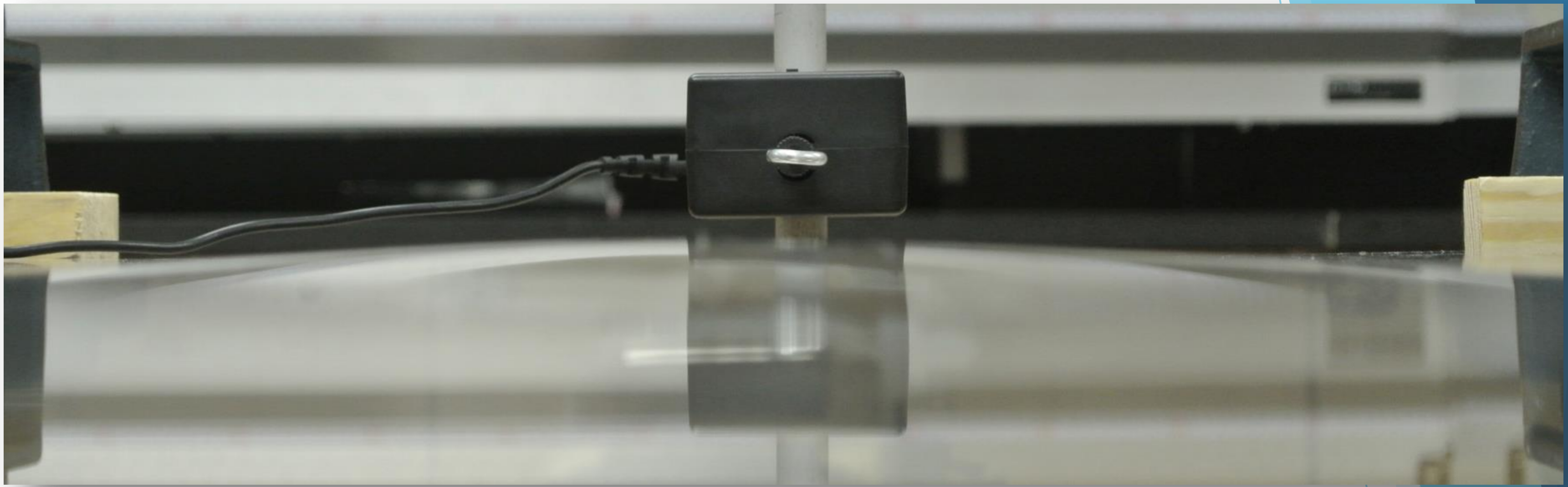


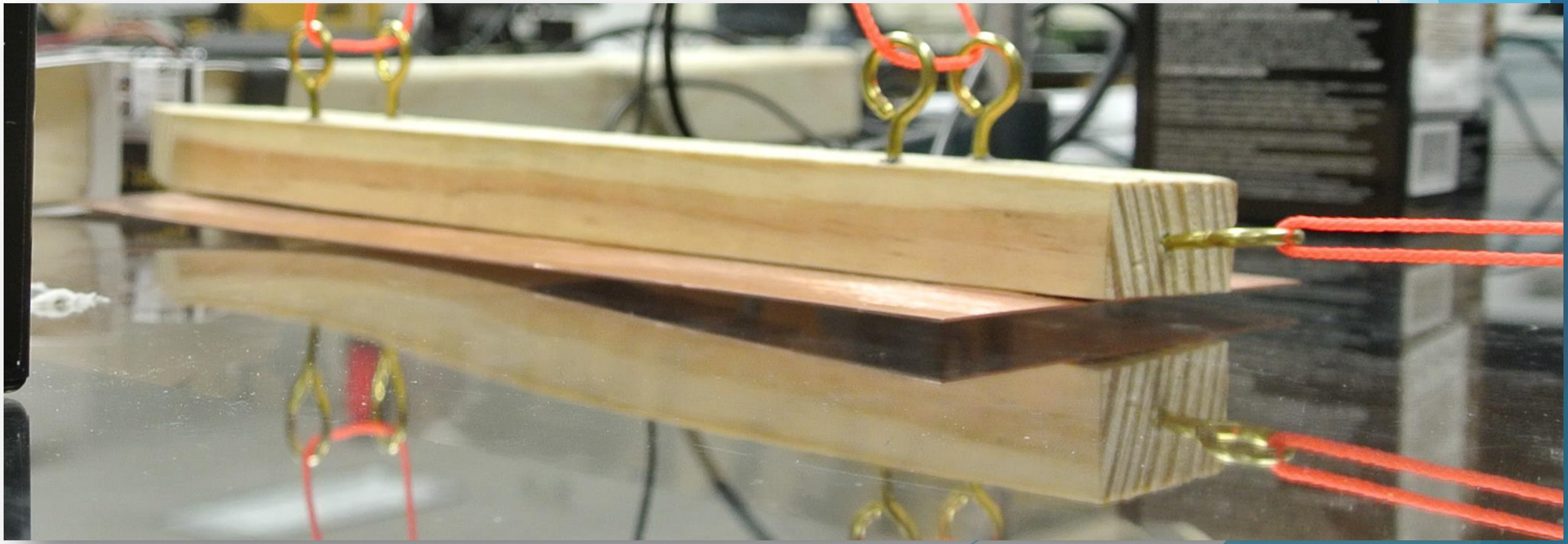

Copper



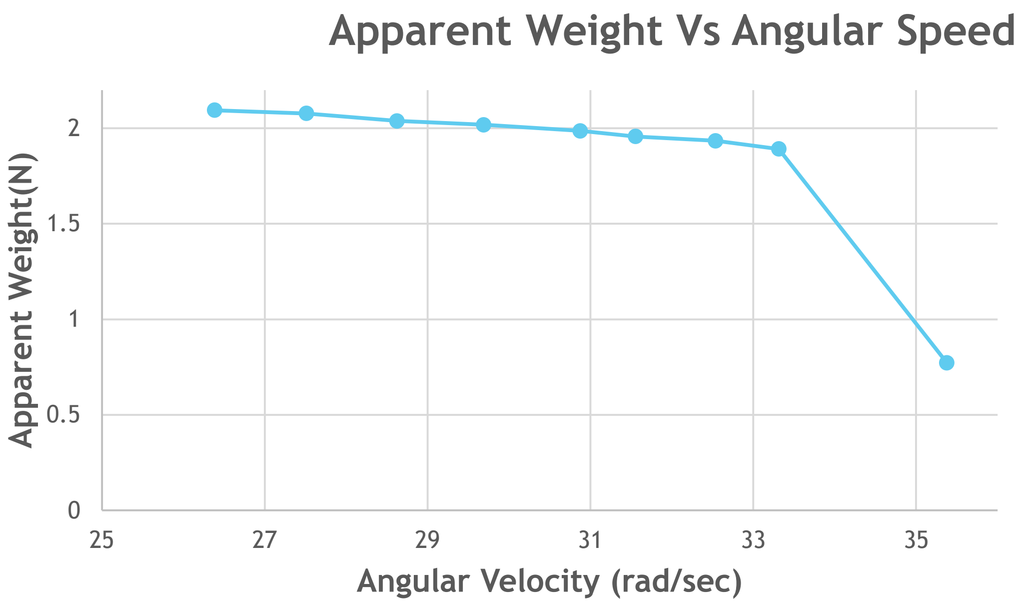

Aluminum

# The warped plastic from the heat of the conductor

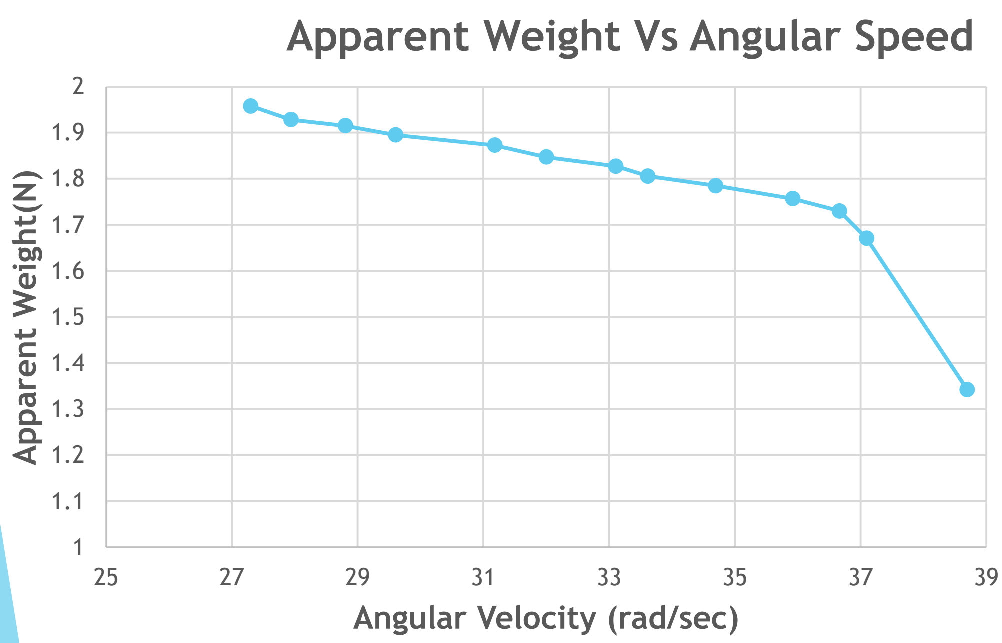




# Apparent Weight

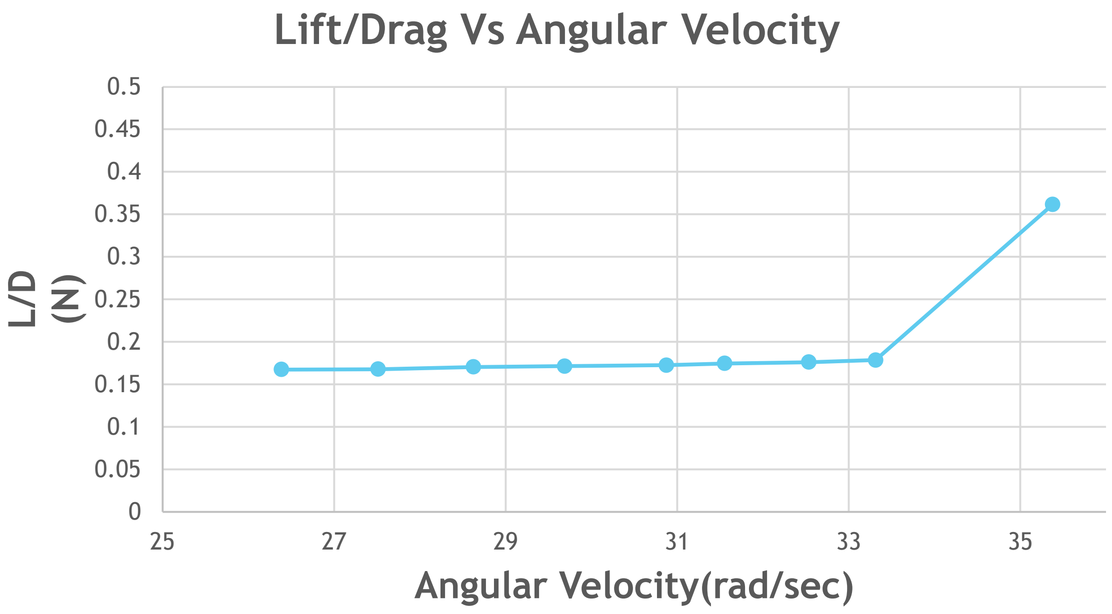



**Copper**

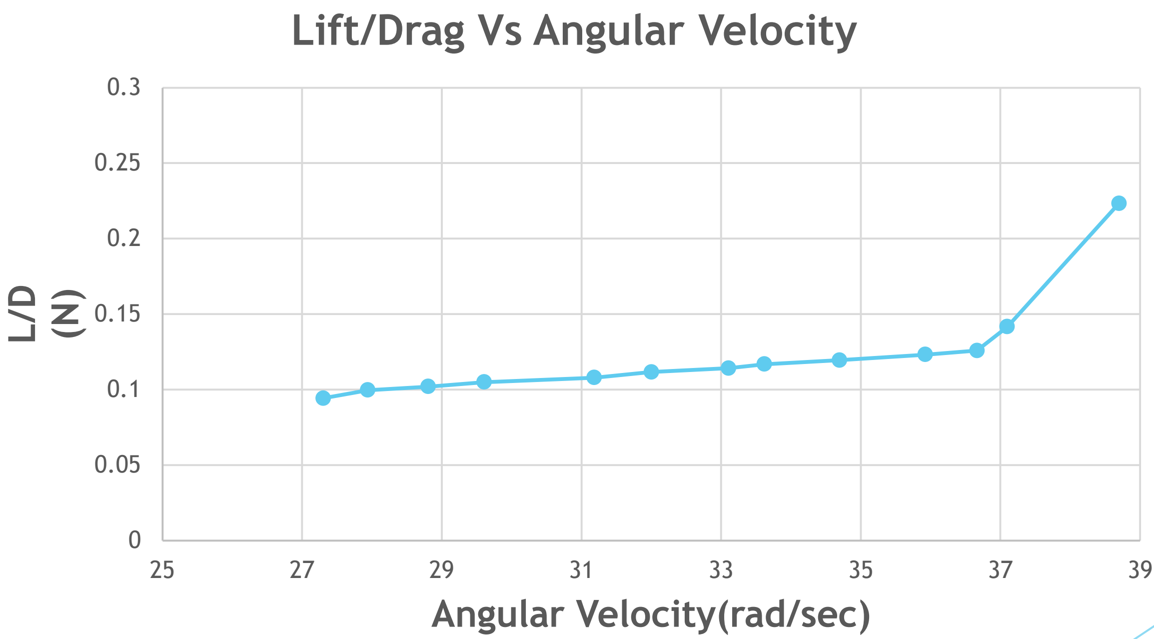



Aluminum

# L/D data




**Copper**




**Aluminum**

# Conclusion

- The faster the wheel spun the larger the lift

- In comparison to the small EDW we achieved similar lift and drag forces at relatively low rotational speeds

# Applications

- Maglev vehicles
- Frictionless bearings
- Contactless gears
- Launching systems

# Future improvements

- Rework the wheel so that it has no gaps
- Use a more powerful motor for higher rotation speeds

# References


- K. Halbach, Journal of Applied Physics, vol. 67, 109 “Applications of Permanent Magnets in Accelerators and Electron Storage Rings”, 1985.
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# Acknowledgments

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