Water-Based Microgravity Simulator

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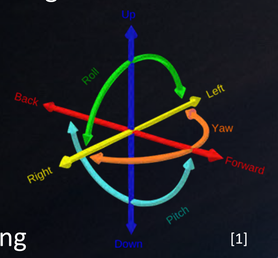
Project Overview

Dr. Abbott is developing a magnetic system for use in space debris removal. He needs a proper testing setup that will allow him to test moving a conductive metal object in 6 Degrees of Freedom (DOF). This is accomplished by designing a system that gets as close to neutral buoyancy as possible.



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Requirements

- Minimal restoring torques and forces
- Flat faces for QR Code tracking stickers
- Watertight
- Floats underwater without sinking or rising

Background

What is Neutral Buoyancy?

- Buoyancy force balances weight of an object.

Buoyancy Force = Gravitational Force

Microgravity Experiment

- Omnimagnets are used to induce an eddy current in a nonmagnetic, electrically conductive metal object.
- Forces and torques are induced on the metal object due to the eddy currents.

Omnimagnet Forces

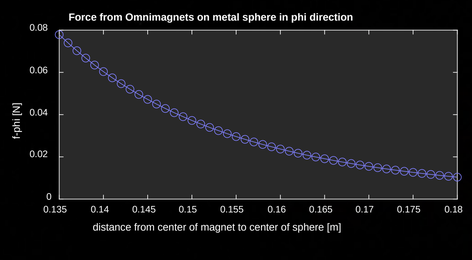
- Force to raise or lower the metal sphere, fϕ, calculation:

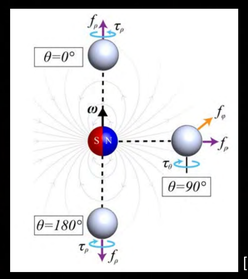
$$f, \tau = \frac{(c_0 \sigma \mu_0 \omega r^2)^{c_1 (\sigma \mu_0 \omega r^2)^{c_2}} 10^{c_3} (\mu_0 m^2)}{\left(\frac{\rho}{r}\right)^{c_4} r^{c_5}}$$

Parameter	Description
σ	Electrical conductivity of conductive sphere
μ_0	Permeability of free space
ω	Angular velocity
r	Radius of conductive sphere
m	Dipole strength
ρ	Distance from center of dipole to center of conductive sphere
$c_0, c_1, c_2, c_3, c_4, c_5$	Coefficients for force/torque model

[2]

- Increased distance from the center of the magnet to the center of the metal sphere results in decreased force that the omnimagnets can produce on the metal sphere.





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Primary Vessel Design

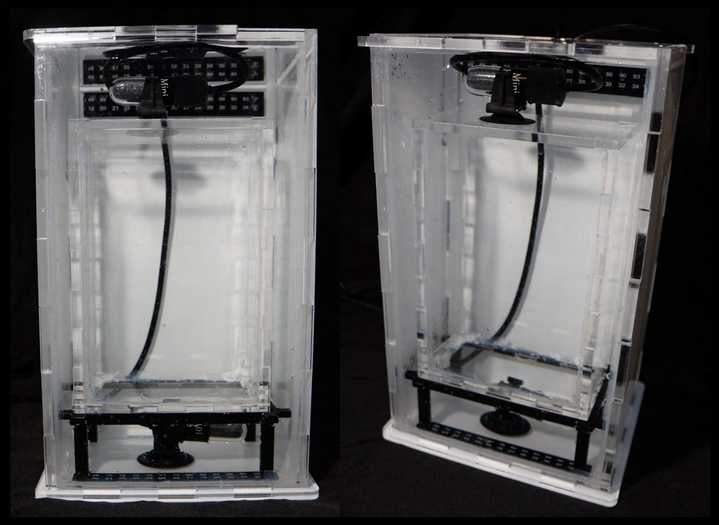
Dodecahedron

- Geometry is a platonic solid, so the center of buoyancy and center of mass coincide.
- Faces are flat so QR code stickers are visible for tracking.
- Mass of the vessel is exactly equal to the mass of water displaced by the vessel.

Tank Design

6-DOF (Double Boiler)

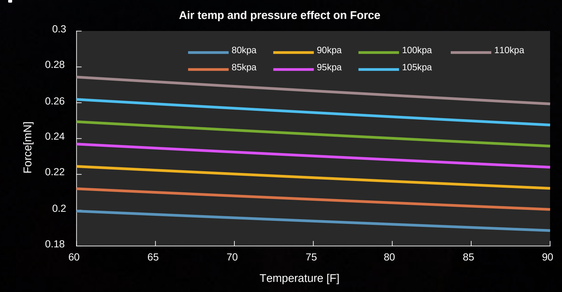
- Exterior tank is thermally regulated and surrounds the inner tank on five sides.
- Inner tank holds the vessel for experiments.
- Separation prevents water currents from the heater affecting the vessel.



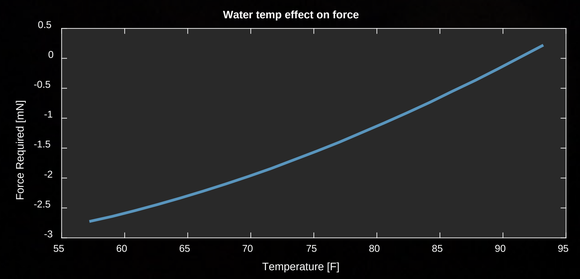
Force Diagrams

Each plot demonstrates the effect of various environmental factors that influence the overall force required to manipulate the dodecahedron vessel.

Air Temperature and Pressure

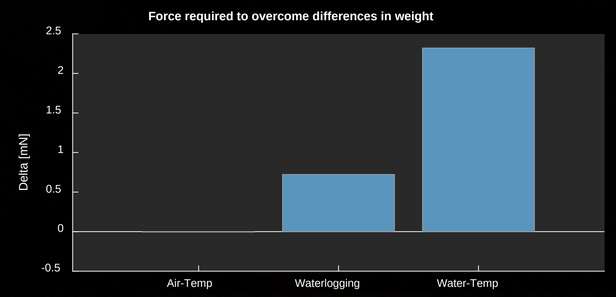


Water Temperature



Impact of Environmental Factors

- Contribution of each environmental factor on the force to manipulate the dodecahedron vessel are shown in terms of total force required to overcome additional weight.



Conclusion

- Neutral buoyancy is not possible without a control system.
- The environmental factors that have the greatest effect on neutral buoyancy are temperature and the vessel waterlogging.
- By adding a heater and cooler to the water tank, we can create a density gradient in the water.

Sources:
[1] B. Lang, “An introduction to positional tracking and degrees of freedom (DOF),” Road to VR, https://www.roadtovr.com/introduction-positional-tracking-degrees-freedom-dof/.
[2] J. Abbott, “Attracting Conductive Nonmagnetic Objects With Rotating Magnetic Dipole Fields,” IEEE ROBOTICS AND AUTOMATION LETTERS, https://mmrobotics.mech.utah.edu/wp-content/uploads/2023/01/Dalton_RAL22_Attracting.pdf.