Physics Club Problem Sheet - Drag, air resistance, and lift

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1 Introduction

Last time, we learned about the behaviour of fluids. This problem sheet discusses the forces of resistance and lift that fluids put up when objects move through them. When thinking of most everyday scenarios, forces like air resistance can be considered to have negligible effect. However, in certain scenarios, such as aeroplanes or F1 cars, air resistance and lift forces **must** be taken into account. This week at Physics Club, we will be exploring the behaviour of air resistance, fluid drag, and lift forces. Listed below are some formulae that you may find helpful:

$$F = 6\pi r \eta v$$

This is Stoke's law, which applies to a spherical body moving through a medium of viscosity η with speed v, and where r is the radius of the body.

$$F = \frac{1}{2}\rho v^2 C_D A$$

This is the formula for the **drag** force, the force of resistance on a body of cross-sectional area A and **drag coefficient** C_D, moving at speed v through a medium of density ρ.

$$F = \frac{1}{2}\rho v^2 C_L A$$

The formula for the force of **lift** is almost identical to that of drag, except that the drag coefficient has been replaced by the **lift coefficient**, C_L.

2 Questions

Question 1 (created by Physics Club) Derive an expression for (a) the terminal velocity of a spherical object falling through a viscous liquid, accounting only for viscous drag and (b) the terminal velocity of an object falling through a fluid, taking viscous drag to be negligible.

Question 2 (Isaac Physics) Draw a force diagram of all of the forces acting on an object of mass m in free fall through air. Write down an expression for the acceleration of the object.

Question 3 (Physics Club) A sphere of volume V and density ρ is falling through honey of viscosity η at terminal velocity. What is the momentum of the ball?

3   Additional Problems

Question 4* (Physics Club) A body of mass m, cross-sectional area, A, and drag coefficient C_D is falling through air of density ρ, starting at a height $h = 0$, and taking downwards to be positive, derive a function $h(t)$ that returns the height of the body at any given time, t.

N.B. this question requires knowledge of differential equations, and some tricky integration.

Question 5 Why does having flaps on aeroplanes help with take-off and landing? Why do F1 cars have rear wings? How does this help them to gather speed? Why is it important for F1 cars and fighter jets to have a shape that minimises drag coefficient? Why might they choose not to use the most theoretically perfect shape? Discuss qualitatively.

4   Additional Resources

Introduction to the Physics of F1 cars

https://www.youtube.com/watch?v=JuEvK-zCqio

How is lift generated on a plane wing?

https://www1.grc.nasa.gov/beginners-guide-to-aeronautics/what-is-lift/
#:~:text=Lift%20is%20a%20mechanical%20force,without%20being%20in%20physical%
20contact.

Differential equations in Physics

https://isaacphysics.org/concepts/cm_differential_equations

Thank you all for coming!