Mechanics Revision and Applications

A.C. Norman

Bishop Heber High School

12 April 2011

First, an exam problem

Time allowed: 11 minutes
The problem is about terminal velocity.

REMINDER: Office Hours are Tuesday (tonight) 3.45–5.0 p.m. in Room 20A (the science office).

Exam problem

Time allowed: 11 minutes
[Question 3 June 2009]

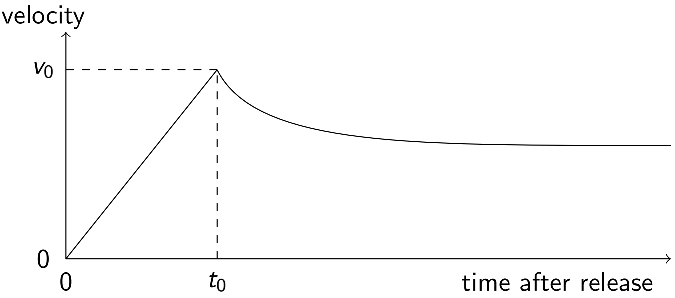
A steel ball is released from rest above a cylinder of liquid.The ball descends vertically in the air then in the liquid until it reaches the bottom of the cylinder.

3 (a) The vertical distance from the bottom of the ball at the point where it is released to the liquid surface is 0.16 m.

(i) Calculate the time taken, t_0, by the ball to fall to the liquid surface from the point where it is released. Give your answer to an appropriate number of significant figures. (3 marks)

(ii) Calculate the velocity, v_0, of the ball on reaching the liquid. (2 marks)

3 (b) Figure 4 below shows how the velocity of the ball changed after it was released.



Describe and explain how the acceleration of the ball changed after it entered the liquid until it reached the bottom of the cylinder.
The quality of your written answer will be assessed in this question. (6 marks)

Lesson Objectives

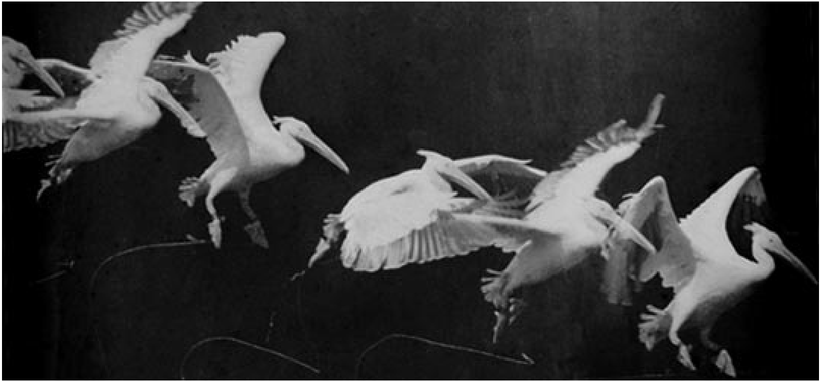
1. To solve exam problems in Newton's laws and free fall confidently.
2. To analyse some common exam-type situations so that we can recognize them.
3. To learn how to apply the physics we learnt in the last few lessons to the real world.

Terminal Velocity: A quick recap

- Last time, we saw that in high speed flows, $F_D \sim \rho A v^2$.
- The drag force increases with velocity, and in free fall will eventually equal the weight force mg.
- This means a maximum speed will be reached, which we call the **terminal velocity**.
- Terminal velocity is reached when $mg = F_D$.
- This means that (if we take out terms which don't depend on the object) $v^2 \sim \frac{m}{A}$.
- $\frac{m}{A}$ is the ratio of the object's mass to the area it presents to the fluid.

Cats: do they always land on their feet?

- 1890: Étienne-Jules Marey



Consider a moving vehicle (Boeing-747 or family car). It needs energy to keep it moving, and this is mainly because it has to do work against the drag force.[1]
The work done is the product of the drag force and the distance travelled, so for a given distance, the fuel consumption is proportional to the drag force.
We can use our knowledge of physics to answer some everyday questions now!

Question 1 Is is true that it's more efficient to drive at 50 mph rather than 70 mph? If so, how much?

[1] A car's top speed is limited by its terminal velocity, which is why lots of time is spent designing streamlined cars, which turns out to have a much bigger effect on top speed than increasing the power of the engine.

Driving your petrol-guzzling car more efficiently

Question 1 Is is true that it's more efficient to drive at 50 mph rather than 70 mph? If so, how much? In fact, when oil became expensive in Western countries in the 1970s, the United States attempted to reduce its oil consumption by mandating a speed limit of 55 mph on highways.

We know that $F_D \sim \rho A v^2$. Let us presume that the speed limit does not affect how far people drive. It may be a dubious assumption, since people regulate their commuting by total time rather than distance, but we need to make it to get anywhere fast in this problem.
The fuel consumption is directly proportional to the drag force, so fuel consumption $\sim v^2$. This gives us $(50\text{ mph}/70\text{ mph})^2$, which is roughly half of the fuel used at the higher speed (51.0%).

Question 2: What's the fuel efficiency of a Boeing-747?

Let's work out now how a plane's fuel consumption compares to that of a car. We already know that the fuel consumption is proportional to the drag force:

$$\text{fuel consumption} \sim \text{area} \times \text{density} \times \text{speed}^2$$

So to work out the ratio of fuel consumptions, we need to know three corresponding factors:

$$\frac{\text{plane consumption}}{\text{car consumption}} \sim \frac{\text{area}_{\text{plane}}}{\text{area}_{\text{car}}} \times \frac{\text{air density}_{\text{plane}}}{\text{air density}_{\text{car}}} \times \frac{\text{speed}^2_{\text{plane}}}{\text{speed}^2_{\text{car}}}$$