

# LIMIT-TERMINAL VELOCITY



## AIM OF THE CHAPTER:

To comprehend limit velocity  
Define air friction  
To define friction.



## KEYWORDS

Limit velocity  
Terminal velocity  
Drag force

### AIR FRICTION: Another Type of Frictional Force

The equation for the frictional force  $F = \mu N$  does not work in all cases. This form of the frictional force works well for solid surfaces in contact. It does not describe the frictional forces acting on the object in air. When an object in air falls down, the air molecules apply a force in the opposite direction of its motion. This force is called air resistance, friction, or drag force ( $F_R$ ). The air resistance for objects moving at relatively high velocities has been determined by experiment to be:

$$F_R = k A V^2$$

Where;  $k$ : coefficient and it depends on the density of the medium =  $\text{kg} / \text{m}^3$

$A$ : cross-sectional area of the object =  $\text{m}^2$

$V$ : the object's velocity =  $\text{m} / \text{s}$

$F_R$ : Air friction = Newtons

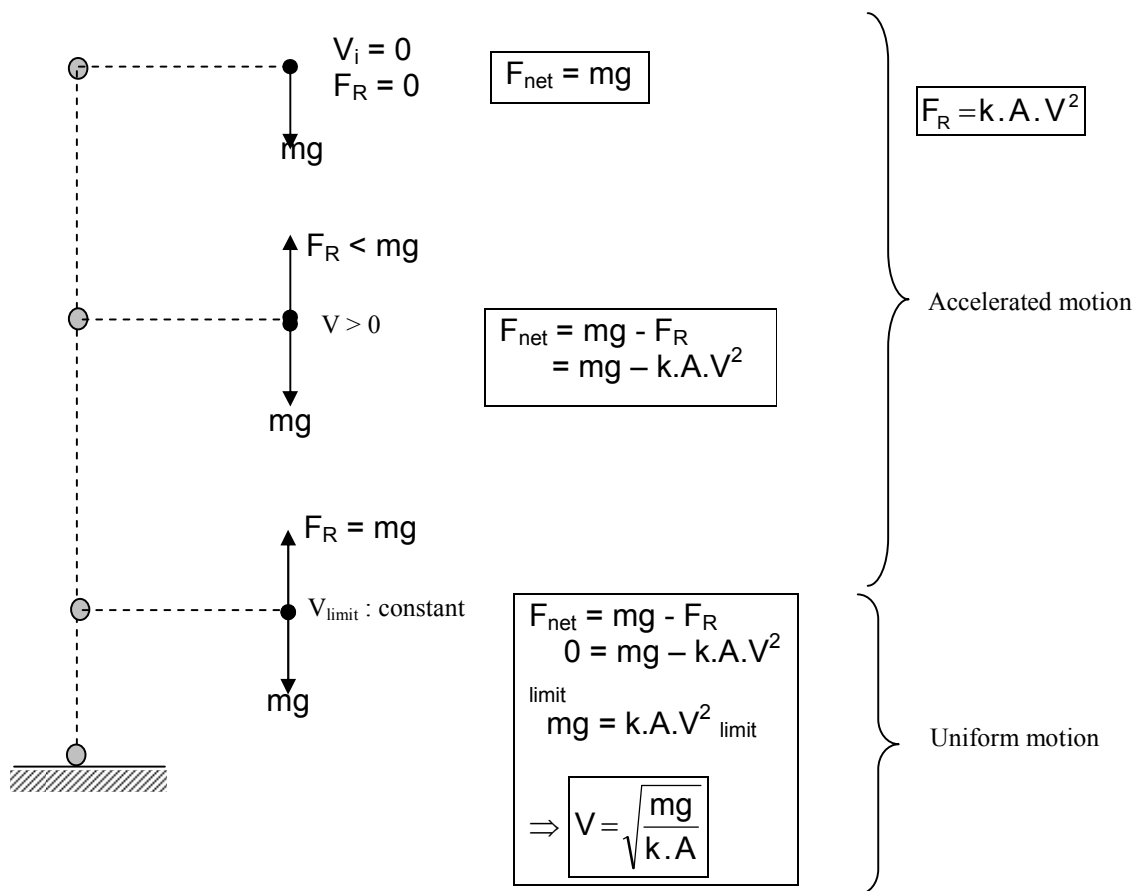
The air resistance is an example of a velocity dependent force. If an object is dropped, it begins to accelerate under the gravitational force. Since the initial velocity is small, the air friction doesn't have a large effect on the motion. As the speed of the object increases, so does the air friction. At some point, the air friction will become as large as the gravitational force. At this point, the net force is zero and the object continues its descent at a constant velocity (Newton's first law). This velocity where the air friction is equal to the gravitational force is called the **terminal velocity**.

From Newton's second law, we can determine the terminal velocity,  $v_t$ , for an object falling in a fluid. Since the acceleration is zero, we know that:

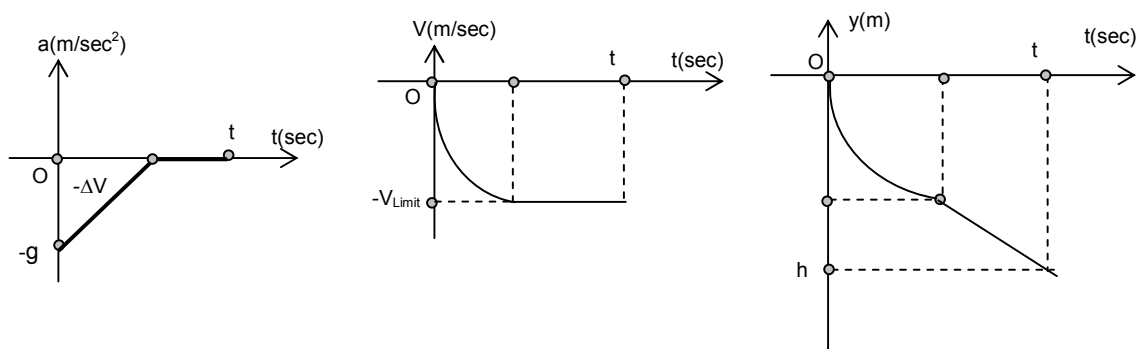
$$\begin{aligned} mg &= F_R \\ \text{or} \\ mg &= k A v^2 \end{aligned}$$

We can solve for  $V$  (Terminal velocity)

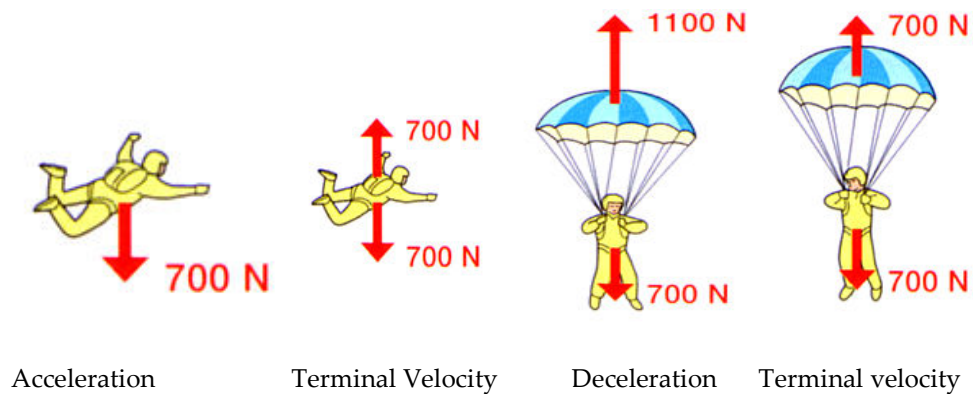
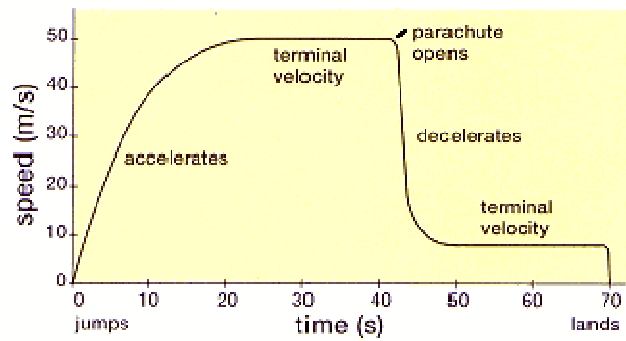
$$V = \sqrt{\frac{mg}{kA}} \quad \text{Terminal Velocity}$$



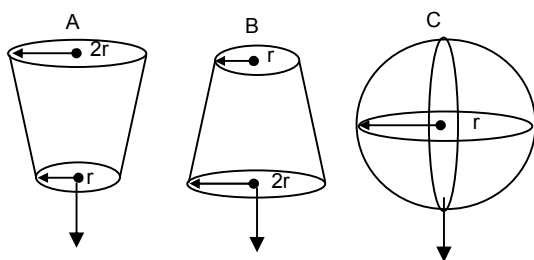
The a-t, v-t and x-t graphs of an object falling down under the effect of air resistance are shown below ;



For a free-fall parachutist, before the parachute opens, terminal velocity is around 50 m/s. When the parachute opens, the terminal velocity decreases to only a few m / s for a much better way to hit the ground!

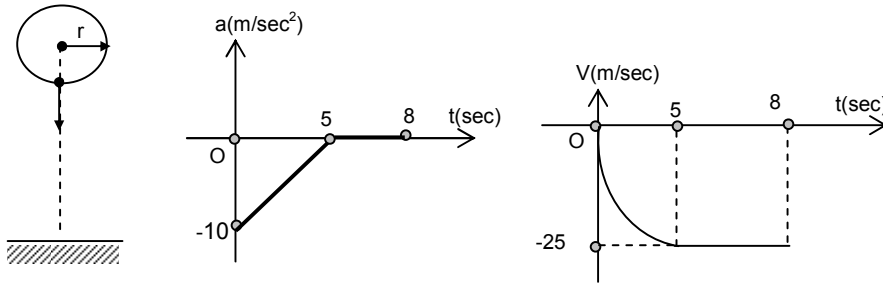


**Example 1**



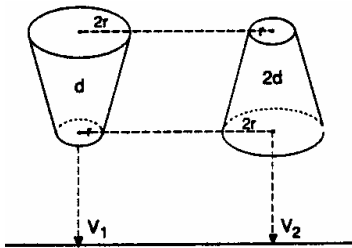
The radii of the objects A , B and C are given in the figure. The coefficients of air resistance acting on them are  $k$  ,  $3 k$  and  $2 k$  respectively . Their masses are  $m$  ,  $m$  and  $2 m$  respectively . Compare their limit velocities .

### Example 2



The mass and radius of a spherical ball are  $1200 \text{ kg}$  and  $20 \text{ cm}$  respectively. It is dropped from a certain height above the ground. Its acceleration decreases uniformly until it becomes zero in  $5$  seconds. It strikes the ground in  $8$  seconds. What is the coefficient of air resistance?

### Example 3



The objects shown in the figure above strike the ground at the limit velocities  $V_1$  and  $V_2$  respectively as shown.

What is the ratio  $V_1 / V_2$  if the objects move in the same medium?

- a)  $2^{1/2} / 2$
- b)  $2^{1/2}$
- c)  $1$
- d)  $2$
- e)  $4$

**Example 5** A  $70 \text{ kg}$  skydiver with an approximately area of  $0.7 \text{ m}^2$  jumps out of the plane and after a certain time reaches to a limit velocity. If the drag coefficient is  $0.29 \text{ kg/m}^3$  ( $k=0.29 \text{ kg/m}^3$ ) find the limit velocity of the skydiver.

