9 Read the passage below and answer the questions that follow.

When an object is moving in a fluid such as air and water, it experiences a force known as drag force which always opposes the motion of the object. The drag force on an object is dependent on a few factors such as the velocity of the object relative to the fluid, the drag coefficient, the frontal area of the object and the density of the fluid. When taking into accounts these factors, the drag force is given by

$$D = kC\rho Av^2$$

where k is a constant;
C is the drag coefficient;
ρ is the density of the fluid;
A is the frontal area of the object;
v is the velocity of the object relative to the fluid.

The frontal area A is the cross-sectional area of the object that passes through the fluid.

The drag coefficient C is a dimensionless quantity with no unit. It is dependent largely on shape of the object and to a small extent on the velocity of the object relative to the fluid. In most cases, the drag coefficient may be considered to be independent of the speed of the object relative to the fluid.

A parachute is an inflatable device which is used to slow down the speed of an object. Parachutes come in different shapes and sizes. Parachutes are made from strong and light weight nylon that has been treated to be less porous so that it does not let as much air through especially at high speeds. This allows the open parachute to create more air resistance and to achieve a lower terminal speed just before reaching the ground.

The parachute is packed into a single backpack called the container. In a particular parachuting jumping, a parachutist with his parachute in the container leaps off from a helicopter. We may consider he falls straight down from rest when his initial horizontal speed is small and there is no wind which causes a horizontal motion.

During the first few seconds of the fall, the parachutist falls under the action of gravity with his parachute in the container. His velocity increases from zero to a constant value known as the terminal velocity. The terminal velocity is dependent on the total mass of the parachutist and the parachute, the drag coefficient, the density of the air and the frontal area of the falling parachutist with his parachute.

The parachutist may fall with his body vertical (known as feet first position) or with his body horizontal (known as spread eagle position). The frontal area of the parachutist depends on whether the parachutist is falling with feet first position or spread eagle position. In the feet first position, the frontal area is approximately 0.18 m^2 while the frontal area in the spread eagle position is about 4 times that of the feet first position.

At a suitable altitude, he triggers the parachute to open by pulling on the ripcord and the velocity decreases rapidly. The parachutist will reach a lower terminal velocity before reaching the ground.

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Fig. 9.1 shows the arrangement of the parachute with the parachute fully open.

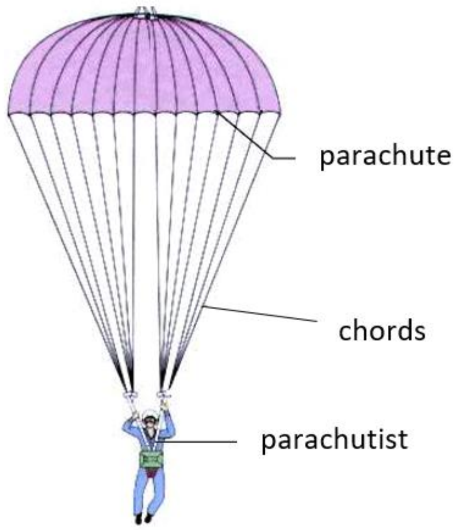

Fig. 9.1

Fig. 9.2 shows the variation with speed of the drag force per unit frontal area acting on a body with different drag coefficients.

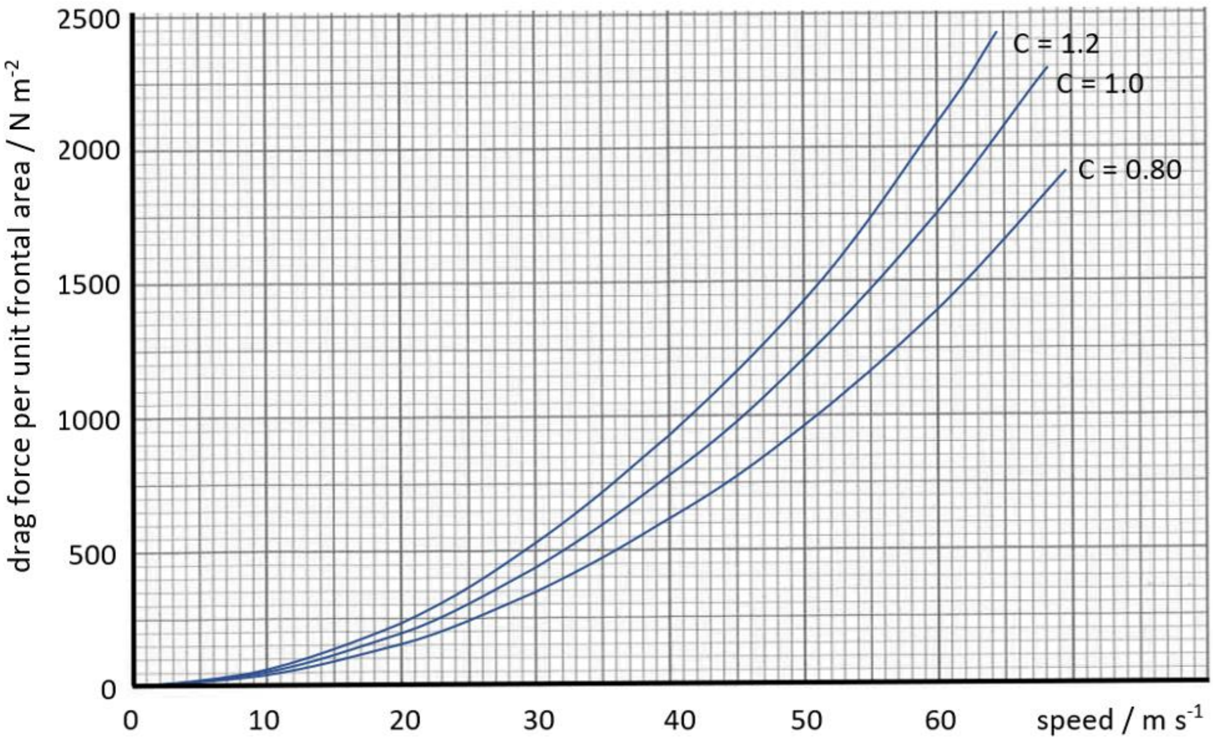

Fig. 9.2

Typical values of the drag coefficient *C* for a parachutist are as shown below:

Parachutist with parachute closed in feet first position	$C = 0.80$
Parachutist with parachute closed in spread eagle position	$C = 1.0$
Parachutist with parachute fully open	$C = 1.2$

The density of air may be assumed to be constant at 1.02 kg m^{-3} throughout the fall.

For safety reason, the terminal velocity of the parachutist must not be more than 7.5 m s^{-1} before reaching the ground. During a parachuting landing when the parachutist falls vertically, the parachutist must slightly bend his knees and clutch his body upon touching the ground, with the elbows tucked into the sides to prevent injury. The parachutist then allows his body to land on the ground before rolling his body.

Fig. 9.3 shows the variation with time of the velocity of a parachutist who falls with parachute closed in spread eagle position. The parachutist reaches a terminal velocity at time 10 s. At 19 s, the parachutist opens the parachute and reaches a new terminal velocity of 7.5 m s^{-1} at 22 s.

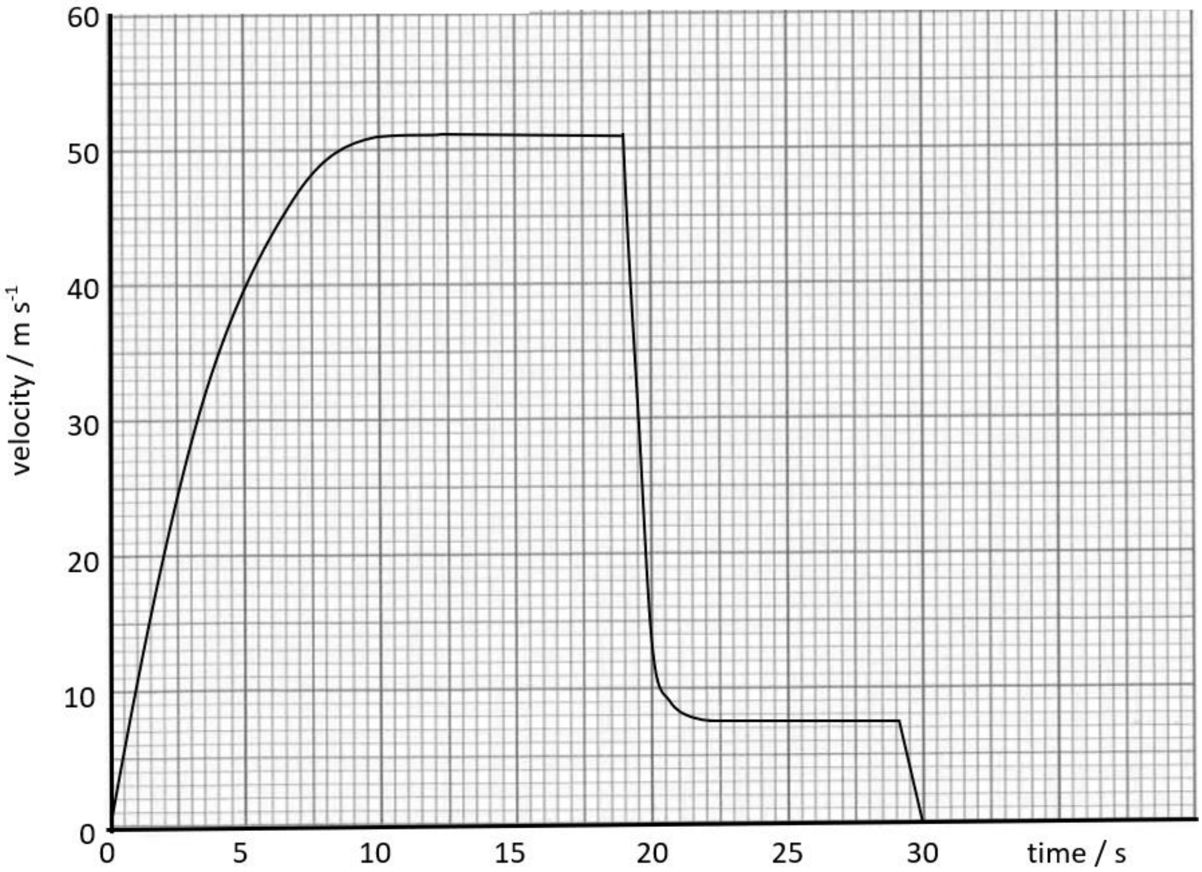

Fig. 9.3

(a) From Fig. 9.2, using the curve for the situation when the parachute is closed with the parachutist in the feet first position, show that the drag force is proportional to the square of the velocity.

[4]

(b) Explain why the acceleration of the parachutist is approximately 10 m s^{-2} when t = 0.

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(c) Explain how Fig. 9.3 shows that the drag force increases with the velocity during the first 10 s of the motion.

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(d) A parachutist falls with parachute closed from spread eagle position.

Calculate the total mass of the parachutist and the parachute.

total mass = ……………………………. kg [5]

(e) From time 19 s to 20 s, when the parachute is opened but before it is fully open, the velocity changes linearly with time and the acceleration is constant.

(i) Using Fig. 9.3, calculate the acceleration during this motion.

acceleration = ………………………… m s^{-2} [2]

(ii) Explain why drag force remains constant from 19 s to 20 s.

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(f) For safety reasons, when the parachutist falls vertically,

(i) suggest a modification to the design of the parachute if the parachutist carries a heavy load,

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.... [1]

(ii) explain why the parachutist needs to bend his knee and body upon touching the ground during landing and then roll his body.

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(g) The same parachutist with the parachute attempts to trigger the parachute to open immediately after he leaps off the hovering helicopter.

On Fig. 9.3, sketch a graph to show the expected variation with time of the velocity of the parachutist. [1]

[Total: 20]