2 A drone is a battery powered flying machine that can carry small loads.

Drones have rotors with each consisting of two rotor blades rotating around a central axis. The rotors exert a force downwards on the air.
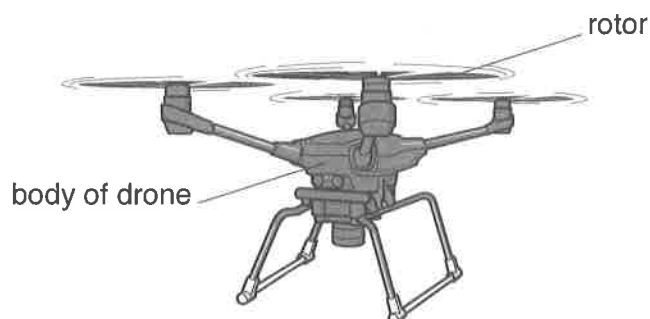


Fig. 2.1

**(a)** There are balanced forces acting on the drone in Fig. 2.1 when it is hovering stationary in the air.

**(i)** On Fig. 2.1, draw and label arrows to show these forces. [2]

**(ii)** State what causes each of these forces.

...................................................................................................................................

...................................................................................................................................

...................................................................................................................................

.......................................................................................................................... [2]

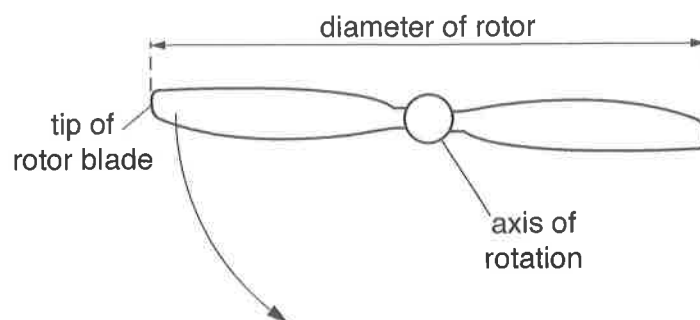**(b)** Fig. 2.2 shows one rotor viewed from above.



**Fig. 2.2**

Table 2.1 shows information about the rotors on three different types of drone when operating at maximum power. Each drone has four rotors.

**Table 2.1**

| type of drone | diameter of rotor /cm | velocity of tip of rotor blade /m s$^{-1}$ | angular velocity of rotor blades /rad s$^{-1}$ | velocity of air displaced downwards /m s$^{-1}$ |
|---|---|---|---|---|
| Nile | 18.0 | | 200 | 25.0 |
| Thames | 22.0 | 20.9 | 190 | 20.0 |
| Yangtze | 25.0 | 26.3 | | 30.0 |

Complete Table 2.1. [2]

**(c)** The Nile drone is hovering stationary, it accelerates the air from rest to the velocity shown in the right-most column of Table 2.1.

The density of air is $1.2\,kg\,m^{-3}$.

**(i)** Calculate the mass of air that passes through one rotor in 1.0 s. Assume that the air moves downward in a cylindrical shape with the same diameter as the rotor.

$$density,\ \rho = \frac{mass,\ m}{volume,\ V}$$

mass = ................................................... kg [1]

**(ii)** Calculate the downward force produced by the Nile drone from all four rotors.

force = ................................................... N [2]

**(iii)** Calculate the total work done on the air by all four rotors of the Nile drone in 1.0 s.

work done = ................................................... J [1]

**(iv)** The Nile drone has a flying time of 30 minutes when operating at maximum power.

The overall efficiency of the drone is 74%.

Calculate the energy stored in the battery when fully charged.

energy = ................................................... J [2]

**(v)** State which drone can lift the heaviest package.

Without further calculation, give reasons for your answer and state any assumptions you have made.

..................................................................................................................................

..................................................................................................................................

..................................................................................................................................

.......................................................................................................................... [2]

[Total: 14]