CHAPTER 5: Fluid mechanics and projectile motion

Practice questions - text book pages 103 to 104

1) Which sentence best explains the flight of a projectile?
   a. the projectile travels further if air resistance is large compared with its weight.
   b. a projectile ejected at 45° to the horizontal will travel the furthest.
   c. the flight path of a projectile falls from its initial direction caused by gravity only..
   d. weight and fluid friction are the only forces acting on a projectile.

Answer: c.

2) The Bernoulli effect causes a sideways force on an object moving through a fluid because:
   a. fluids flow in a laminar pattern past a moving object.
   b. the pressure exerted by a fast moving fluid is less than that exerted by a slow moving fluid.
   c. the pressure exerted by a fast moving fluid is greater than that exerted by a slow moving fluid.
   d. an unstreamlined object will cause fluid flow to break into vortices.

Answer: b.

3) If every particle of fluid has irregular flow, then flow is said to be:
   a. laminar flow.
   b. turbulent flow.
   c fluid flow.
   d both a and b.

Answer: b.

4) A racing car has a body with:
   a. laminated design.
   b. turbulent design.
   c. flat design.
   d. streamlined design.

Answer: d.

5) Which of the following reasons explains why the best take-off angle for an elite long jumper is much closer to 22 degrees than to the predicted optimum angle from projectile motion theory of about 42 degrees?
   a. the jumper needs to generate rotation.
   b. achieving a take-off angle close to the theoretical value would drastically reduce take-off speed.
   c. the theory ignores air resistance.
   d. the jumper does not understand projectile motion theory.

Answer: b.

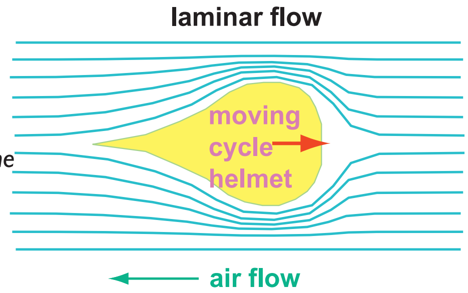
6) a) Using examples, explain how the shape of an object can alter its flight path. 4 marks

Answer:

4 marks for four of:

- *The size of the air resistance (drag) force depends on the size of the object as it is viewed from the forward direction (the technical name for this is forward cross section).*
- *The bigger this size the bigger the air resistance.*
- *Also, air resistance depends on the streamlining effect.*
- *The more the shape allows laminar flow (flow in layers without vortices) of air past the object, the less will be the air resistance (see figure Q5.1).*

figure Q5.1 – air resistance



- *The effect of air resistance is to deviate the flight path from the symmetric shape known as a parabola.*
- *Air resistance force acts in a direction opposite to the direction of motion of the object.*
- *Therefore the object would always be moving more slowly (than if there were no air resistance).*
- *The bigger the air resistance compared to the weight, the bigger the asymmetry of the flight path.*

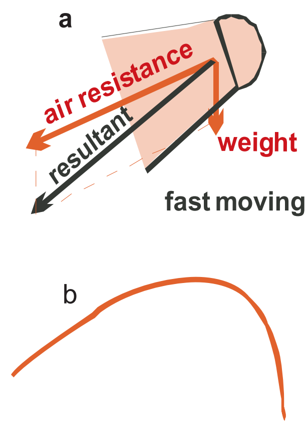
b) Explain the effect of air resistance on the flight of two badminton shuttles, one of which has been struck hard and the other gently. 10 marks

Answer:

5 marks for five of:

- *A **rapidly moving badminton shuttle** will have a very large value for air resistance at the beginning of its flight.*
- *Compared to the weight of the shuttle.*
- *Therefore the resultant force (see figure Q5.2a) is almost in the same direction as the air resistance.*
- *Later in the flight, the shuttle would have slowed considerably.*
- *Hence the air resistance value will have dropped.*
- *Until the weight is much bigger than the air resistance.*
- *Then the shuttle would fall as if under gravity only.*
- *Hence a path which differs markedly from the symmetric parabolic path which would be observed if there were zero or very little air resistance.*
- *See figure Q5.2b.*

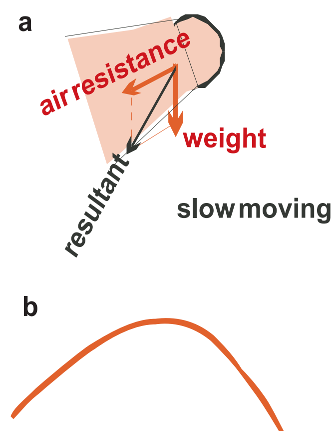
figure Q5.2 – forces acting on a badminton shuttle



5 marks for five of :

- ***Badminton shuttle struck gently** - see figure Q5.3a.*
- *Here the weight is the predominant force.*
- *Because the shuttle is moving slowly, air resistance is small.*
- *Hence resultant force is almost that of the weight only.*
- *And the flight is almost parabolic.*
- *See figure Q5.3b.*

figure Q5.3 – forces acting on a badminton shuttle



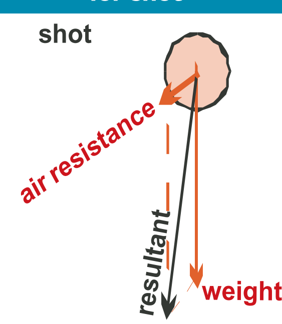
c) Briefly explain why the flight path of a shot in athletics is so different from the flight of a badminton shuttle. 4 marks

Answer:

- *Shot in flight (see figure Q5.4) - resultant force is almost in the same direction as the weight.*
- *Hence the flight of the shot is similar to gravity only.*

- *Badminton shuttle in flight - resultant force is almost in the same direction as air resistance.*
- *Opposite to the direction of motion hence marked deceleration and asymmetric path.*

figure Q5.4– air resistance for shot



7) a) Identify three physical factors (not skill factors) which govern a swimmer's speed and explain how one of these occurs. 3 marks

Answer:
- *Thrust on the water (force exerted by hands and feet on the water).*
- *Body shape (which best allows smooth flow of water past the body).*
- *Surface effects (like hair or shiny swimsuits or skullcap etc) which change the water flow past the body.*
- *Dive entry or thrust on bath side on turning.*

b) Describe the factors which determine the amount of fluid friction acting on a swimmer. 4 marks

Answer:
- *Speed of the swimmer.*
- *Forward cross section (size of the person as viewed from the forward direction).*
- *Body shape or surface effects (smooth flow).*
- *Surface area in contact with the water (big person as opposed to small person).*
- *Avoidance of water surface effects (like for example swimming underwater after a turn).*

c) Explain how you would minimise turbulent flow (high drag) of the water past the swimmer's body. 2 marks

Answer:
- *By shaving body hair.*
- *By wearing a swim cap.*
- *Swimwear surface (shiny or directionally flocked) and shape (high neck to avoid drag at neckline).*

d) Give three examples, each from a different sporting context, to show how fluid friction affects the sportsperson. 3 marks

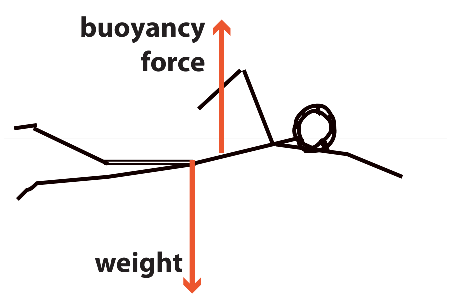
Answer:
3 marks for three of:
- *Air resistance involving performer (athlete running, skier, cyclist, parachutist).*
- *Air resistance involving sports vehicle (racing car, glider, cyclist).*
- *Air resistance involving projectile (badminton shuttle, ball).*
- *Water resistance involving performer (swimmer).*
- *Water resistance on sports vehicle (water skis, canoeing, rowing, sailing, speedboats).*

e) How would you attempt to reduce fluid friction? 3 marks

Answer:
- *Reducing forward cross sectional area by crouching. Cyclist - special bike shape to help with this, crouching when skiing.*
- *Removing resistance from surface. Special clothing (lycra), shaving head, bathing cap, removing protruding bits of cycle or boat.*
- *Reduce area of contact. Boat, windsurfer, water skis (aquaplaning).*

f) Look at figure 5.20 showing the vertical forces acting on a swimmer during a stroke. Explain why it is difficult for a swimmer to keep a horizontal floating position. 4 marks

figure 5.20 – forces acting on a swimmer



Answer:
- *The two forces (weight and buoyancy force) do not act through the same point.*
- *The forces are eccentric (are not in line).*
- *This causes a turning effect, in this case the body is turned by these forces anticlockwise.*
- *With the swimmer's feet falling downwards relative to the head.*

8) a) Fluid friction is a force which acts on a bobsleigh once it is moving. Identify the nature of the fluid friction in this case and explain how this might limit the maximum speed of the bob. 3 marks

Answer:
- *The fluid friction in this case is air resistance or drag.*
- *This increases if turbulent flow occurs, or if streamlining breaks down.*
- *This increases if the size of the bob (and its occupants) is larger than it could be (by for example a bobman putting his head out of the top of the bob).*
- *As the speed increases, the fluid friction force gets bigger, until it matches the weight component down the track, then the bob couldn't go any faster.*

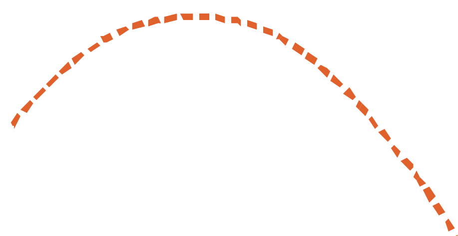
b) Explain the term 'turbulent flow', and how the bobsleigh is used to minimise this factor. 3 marks

Answer:
3 marks for three of:
- *At low speeds, air flow past a moving object is laminar, which means the air flows in layers.*
- *When this flow is interrupted either by going too fast or by a protrusion (which upsets the streamlined shape), then the air is thrown out into vortices, the layers mix up, and this is turbulent flow.*
- *When there is turbulent flow, the air resistance is greater because the bob is forcing this air to be thrown into the vortex patterns.*
- *In order to minimise turbulent flow, the bob has to be as streamlined as possible (so that flow is as laminar as possible).*
- *This is done by having a specially designed streamlined shape to the bob.*
- *And by having no protrusions from the bob while in motion - handles, heads of bobmen (this is why the bobmen crouch down once in the bob after the start).*

9) a) Sketch a diagram to show the flight path of the shot from the moment it leaves the putter's hand to the moment it lands. 2 marks

Answer:
- *See figure Q5.5. Flight path a parabola not a circle.*

figure Q5.5 – flight path of a shot



b) State and briefly explain three factors (excluding air effects) which should be used by the putter to optimise the distance thrown. 6 marks

Answer:
- *Speed of release.*
- *The faster the shot is released the further it will go.*
- *Angle of release.*
- *The optimum angle depends on height of release, but would be between 42° and 45°.*
- *Height of release above the ground.*
- *The higher the release, the further the shot will travel.*

c) Explain why the turn in a discus throw produces greater horizontal range than the standing throw. 3 marks

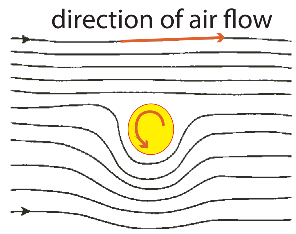
Answer:
- *Forces are applied to the discus over a larger distance.*
- *Since work = force x distance, this means that more energy is given to the discus, which therefore will have more kinetic energy on release.*
- *Or, the forces are applied over a longer time.*
- *Therefore the force x time (impulse) is bigger, and the change of momentum bigger.*
- *So the discus has a higher speed at release.*
- *Or, the discus is accelerated to some degree before the standing throw position is reached, and hence the turn produces extra velocity over and above the standing throw.*

10) a) The Magnus effect (the Bernoulli effect applied to spinning balls) states that a faster flowing liquid or gas exerts less pressure than a slower moving liquid or gas.
Using figure 5.21, show how the Magnus effect explains the swerve of a spinning ball. 4 marks

Answer:

- *The ball moving through the air causes the air flow to separate, with air flowing further past the lower half of the ball.*
- *More air is sent on the lower route, since as the air arrives at the nearest edge of the ball, it is dragged down by the downward spinning surface of the ball.*
- *In the same time as the air flow over the top of the ball (the air is a fixed entity - the ball moves through it).*
- *Therefore the air flows faster past the lower half of the ball.*
- *Therefore there is less pressure on the bottom of the ball.*
- *Hence the ball will experience a force (the Magnus effect or Bernoulli effect) downwards.*

figure 5.21 – Magnus effect on a spinning ball

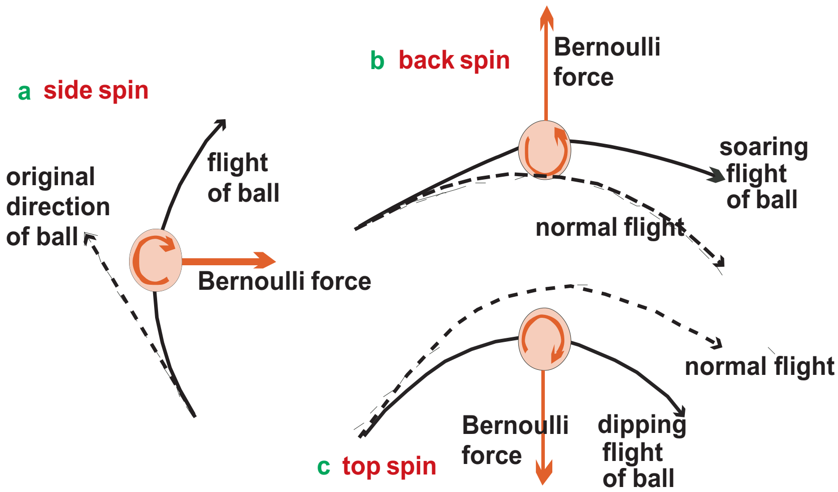


b) Use diagrams to show how your explanation relates to the flight of a table tennis ball with side, back and top spin. 3 marks

Answer:

- *Side spin, see figure Q5.6a.*
- *Back spin see figure Q5.6b.*
- *Note tendency of ball to travel straighter.*
- *Or even lift.*
- *Top spin see figure Q5.6c.*
- *Note pronounced curve downwards (dip).*

figure Q5.6 – flight path of a spinning ball

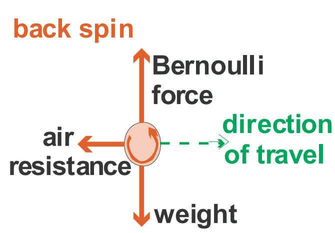


c) Sketch a vector diagram of all forces acting on a table tennis ball in flight with back spin, and explain how the resultant force on the ball predicts the actual acceleration of the ball. 4 marks

Answer:

- *See figure Q5.7.*
- *Note that the Bernoulli effect force is upwards, weight downwards, and air resistance (fluid friction) in a direction opposite to the direction of motion of the ball.*
- *Bernoulli effect force is equal or bigger than the weight.*
- *Resultant would therefore be upwards and to the left of the diagram.*
- *Acceleration of the ball (deceleration) is in the same direction as the resultant force, i.e. upwards and to the left.*
- *Hence the path upwards and to the left of original direction.*

figure Q5.7 – forces acting on a spinning ball



d) Identify one sport other than a ball game, in which the Bernoulli effect plays a part. 1 mark

Answer:

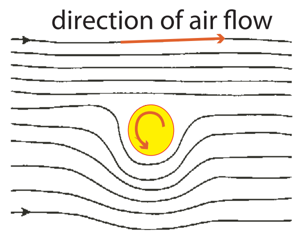
- *Ground effects in racing cars.*
- *Wing effects on gliding or flying or kites.*
- *Effects on ski jumping.*
- *Effects on hand shape in swimming (enables greater thrust on water).*

11) What do you understand by the Magnus effect?
Explain how a knowledge of Magnus forces can assist a tennis player to execute different types of spins. 10 marks

Answer:

- *The Magnus effect (the Bernoulli force on a spinning ball) is caused by a spnning ball moving through air as shown in figure Q5.8.*
- *The ball moving through the air causes the air flow to separate, with air flowing further past the lower half of the ball.*
- *More air is sent on the lower route, since as the air arrives at the nearest edge of the ball, it is dragged down by the downward spinning surface of the ball.*
- *In the same time as the air flow over the top of the ball (the air is a fixed entity - the ball moves through it).*
- *Therefore the air flows faster past the lower half of the ball.*
- *Therefore there is less pressure on the bottom of the ball.*
- *Hence the ball will experience a force downwards.*

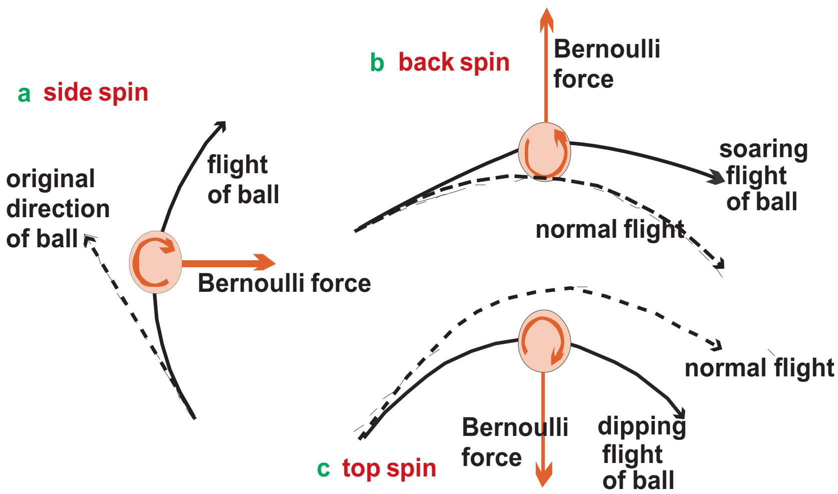
figure Q5.8 – Magnus effect on a spinning ball



- *Side spin, see figure Q5.9a.*
- *Back spin see figure Q5.9b.*
- *Note tendency of ball to travel straighter.*
- *Or even lift.*
- *Top spin see figure Q5.9c.*
- *Note pronounced curve downwards (dip).*

- *The tennis player will impart these different spins to the ball to achieve side spin, back spin, but usually top spin.*
- *And hence control the direction of the ball in flight.*

figure Q5.9 – flight path of a spinning ball



12) Compare and contrast the use of side spin in football, and the hook in golf. 4 marks

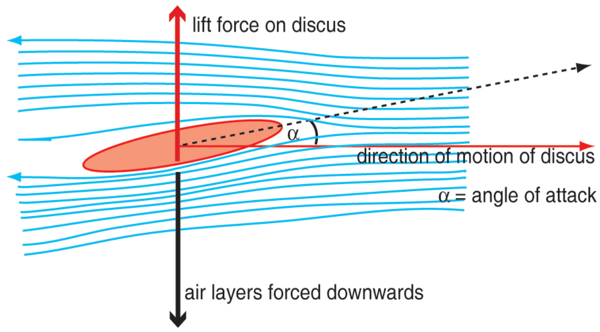
Answer:

- *Both use the Magnus effect to impart a side-spin to football or golf ball.*
- *Both apply a force to the ball to the side of its centre of mass (eccentric force).*
- *The golfing hook is caused by a force applied to the right of a ball's centre of mass which will spin anticlockwise (viewed from above).*
- *And will therefore swing to the left of a straight line defined by the initial direction of motion.*
- *The same will apply to a football struck to the side of its centre of mass.*
- *Most footballers can apply such a force on either side of the ball's centre of mass to create a leftward or a rightward swerve during flight.*

13) a) Describe how a lift force is generated by a discus in flight. 4 marks

Answer:
- *As the discus moves forward, the angle presented by the lower surface of the discus to the direction of motion (called the angle of attack).*
- *This can cause the air molecules through which the object is moving to be deflected downward.*
- *Hence would cause a downward force on the air through which the object passes (figure Q5.10).*
- *This downward force on the air would cause an upward force on the moving discus in reaction to the downward force on the air (by Newton's third law). This is the lift.*

figure Q5.10 – lift force on a discus



b) Explain how a high angle of attack will affect the distance travelled by a discus. 3 marks

Answer:
- *A low angle of attack will cause the discus to skip on the air (a bit like a flat stone on water).*
- *If the angle of attack is increased there will come a point at which the air will be forced forward.*
- *And hence the reaction force on the discus will be backward, which will slow the discus down and drastically shorten its flight distance.*