CHAPTER 12

Supersonic Flight

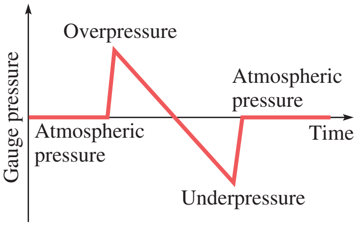


Figure 12.20 The variation in pressure at a point on the ground as a supersonic plane flies overhead.

The pressure variation shown in Fig. 12.20 is the sonic boom caused by an airplane flying at a constant velocity faster than sound. The variation is called an *N*-wave (because the pressure graph is shaped like the letter N). The initial, sudden rise in pressure is the shock wave formed at the nose of the plane. Then the pressure decreases linearly, becoming less than atmospheric, until it abruptly returns to atmospheric as the tail wave passes. The duration of the sonic boom ranges from about 0.1 s for small military planes up to about 0.5 s for the Space Shuttle.

The shock cone spreads out as it moves away from the plane; the higher the plane, the lower the intensity of the sonic boom. The largest intensity boom occurs directly under the flight path, but the boom is heard throughout the cone area. The sudden onset and release of pressure can even do physical damage to something under its path, breaking a window or shaking a building. It is not that the magnitude of the pressure change is so large, but the change happens in a very short time interval. The overpressure for supersonic planes flying in normal conditions ranges from 50 to 500 Pa.

The speed of a supersonic plane is often given as a *Mach number,* named for Austrian physicist Ernst Mach (1838–1916). The Mach number is the ratio of the speed of the plane to the speed of sound. A plane flying at Mach 3.3 where the air temperature is 11°C is moving at 3.3×338 m/s = 1100 m/s with respect to the air.

When the Space Shuttle lands, two "crack" sounds can easily be heard, due to the two shock waves created by the nose and tail. The pressure variation for the Space Shuttle is 60 Pa above and below atmospheric pressure at Mach 1.5 when it is making a landing approach at a height of 18 km. With small fighter planes, the two booms are usually heard as a single boom; there is not enough time between them for two separate sounds to be distinguished by the ear.

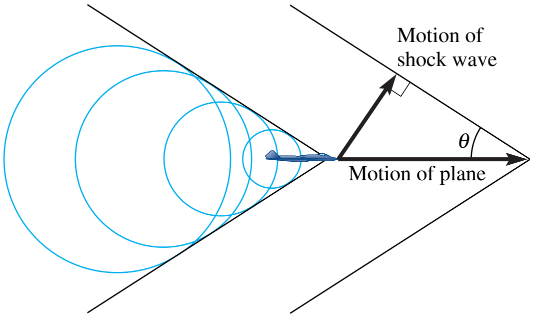
Problems

70. A supersonic plane moves at speed v_{plane}; the speed of sound is v_{sound}. The conical shock wave makes an angle θ with the direction of motion of the plane. Show that $\sin\theta = v_{\text{sound}}/v_{\text{plane}}$. [*Hint:* Consider how far and in what direction the plane and the shock wave move during a time interval Δt.]

71. A plane is flying at supersonic speed at an elevation where the speed of sound is 322 m/s. The shock wave cone forms with an angle $\theta = 22.0°$ with the direction of motion of the plane (see Problem 70). (a) What is the Mach number for this plane? (b) How fast is the plane traveling?

✦72. An airplane is flying 1.0 km directly over your position on the ground at Mach 2.0. How far from that overhead position will the airplane have moved along its horizontal flight path when you hear the sonic boom? [*Hint:* See Problem 70.]

73. A wind tunnel is used to simulate the flight of a plane. Air at 20°C is blown past the model plane at very high speeds. If a shock cone angle of $\theta = 40.0°$ develops, how fast is the air moving? [*Hint:* See Problem 70.]



Problems 70–73