Always keep in mind that in general, sonic velocity is a property of the fluid and varies with the state of the fluid. *Only* for gases that can be treated as perfect is the sonic velocity a function of temperature alone.

Mach Number

We define the *Mach number* as

$$\boxed{M \equiv \frac{V}{a}} \tag{4.11}$$

where

$V \equiv$ the velocity of the medium

$a \equiv$ sonic velocity through the medium

It is important to realize that both V and a are computed *locally* for conditions that actually exist at the same point. If the velocity at one point in a flow system is twice that at another point, we *cannot* say that the Mach number has doubled. We must seek further information on the sonic velocity, which has probably also changed. (What property would we be interested in if the fluid were a perfect gas?)

If the velocity is less than the local speed of sound, M is less than 1 and the flow is called *subsonic*. If the velocity is greater than the local speed of sound, M is greater than 1 and the flow is called *supersonic*. We shall soon see that the Mach number is the most important parameter in the analysis of compressible flows.

4.4 WAVE PROPAGATION

Let us examine a point disturbance that is at rest in a fluid. *Infinitesimal* pressure pulses are continually being emitted and thus they travel through the medium at *sonic* velocity in the form of spherical wave fronts. To simplify matters we shall keep track of only those pulses that are emitted every second. At the end of 3 seconds the picture will appear as shown in Figure 4.3. Note that the wave fronts are concentric.

Now consider a similar problem in which the disturbance is no longer stationary. Assume that it is moving at a speed less than sonic velocity, say $a/2$. Figure 4.4 shows such a situation at the end of 3 seconds. Note that the wave fronts are no longer concentric. Furthermore, the wave that was emitted at $t = 0$ is always in front of the disturbance itself. *Therefore, any person, object, or fluid particle located upstream will feel the wave fronts pass by and know that the disturbance is coming.*

Next, let the disturbance move at exactly sonic velocity. Figure 4.5 shows this case and you will note that all wave fronts coalesce on the left side and move along with the disturbance. After a long period of time this wave front would approximate a plane indicated by the dashed line. In this case, no region upstream is forewarned of the disturbance as the disturbance arrives at the same time as the wave front.

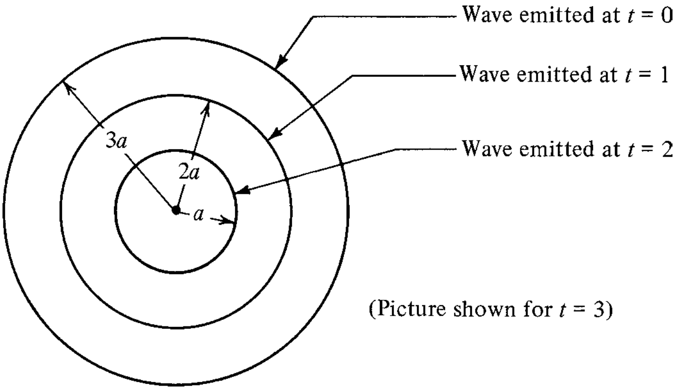

Figure 4.3 Wave fronts from a stationary disturbance.

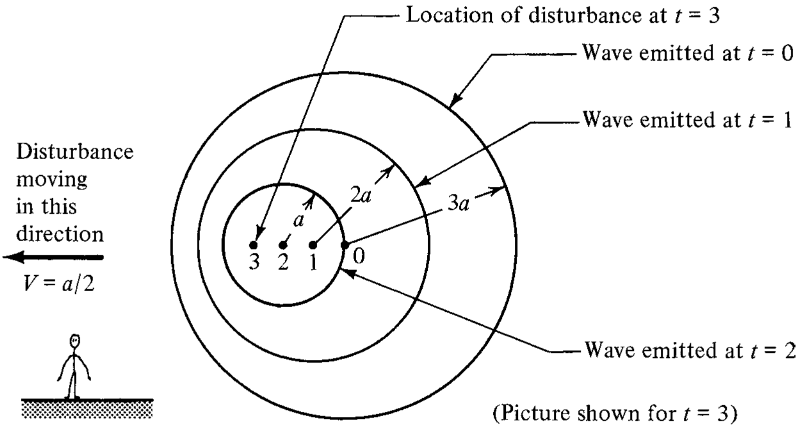

Figure 4.4 Wave fronts from subsonic disturbance.

The only other case to consider is that of a disturbance moving at velocities greater than the speed of sound. Figure 4.6 shows a point disturbance moving at Mach number = 2 (twice sonic velocity). The wave fronts have coalesced to form a cone with the disturbance at the apex. This is called a *Mach cone*. The region inside the cone is called the *zone of action* since it feels the presence of the waves. The outer region is called the *zone of silence*, as *this entire region is unaware of the disturbance*. The surface of the Mach cone is sometimes referred to as a *Mach wave*; the half-angle at the apex is called the *Mach angle* and is given the symbol μ. It should be easy to see that

$$\boxed{\sin \mu = \frac{a}{V} = \frac{1}{M}} \tag{4.12}$$

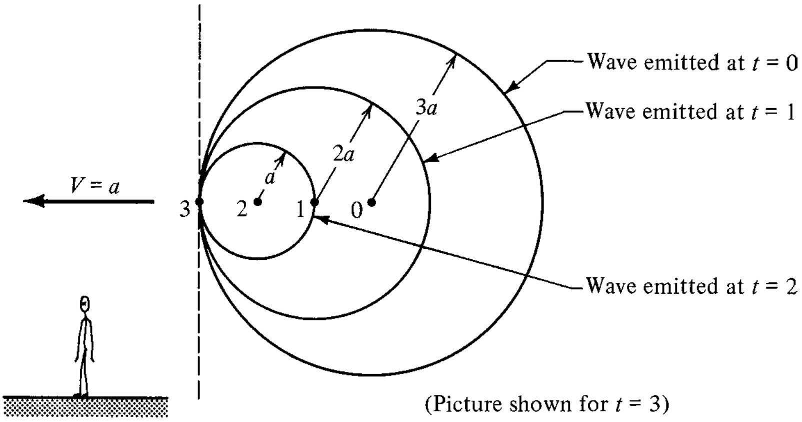

Figure 4.5 Wave fronts from sonic disturbance.

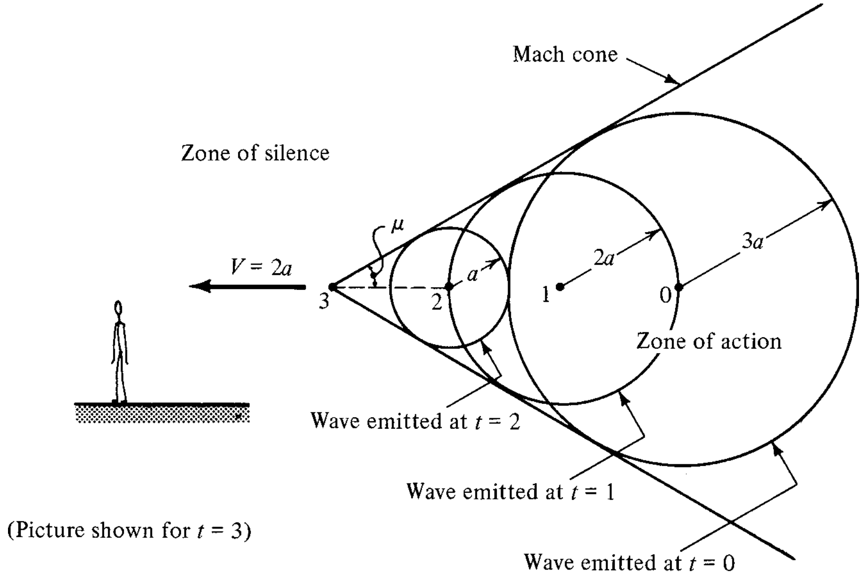

Figure 4.6 Wave fronts from supersonic disturbance.

In this section we have discovered one of the most significant differences between subsonic and supersonic flow fields. In the subsonic case the fluid can "sense" the presence of an object and smoothly adjust its flow around the object. In supersonic flow this is not possible, and thus flow adjustments occur rather abruptly in the form of shock or expansion waves. We study these in great detail in Chapters 6 through 8.