The speed of sound is the distance travelled during a unit of time by a sound wave propagating through an elastic medium. In dry air at 20 °C (68 °F), the speed of sound is 343.2 metres per second (1,126 ft/s). This is 1,236 kilometres per hour (768 mph), or about one kilometer in three seconds or approximately one mile in five seconds.

In fluid dynamics, the speed of sound in a fluid medium (gas or liquid) is used as a relative measure of speed itself. The speed (in distance per time) divided by the speed of sound in the fluid is called the Mach number. Objects moving at speeds greater than Mach1 are traveling at supersonic speeds.

The speed of sound varies from substance to substance. Sound travels faster in liquids and non-porous solids than it does in air. It travels about 4.3 times faster in water (1,484 m/s), and nearly 15 times as fast in iron (5,120 m/s), than in air at 20 degrees Celsius.

The speed of sound is variable and depends on the properties of the substance through which the wave is travelling. In solids, the speed of longitudinal waves depend on the stiffness to tensile stress, and the density of the medium. In fluids, the medium's compressibility and density are the important factors.

In gases, compressibility and density are related, making other compositional effects and properties important, such as temperature and molecular composition. For a given ideal gas the sound speed depends only on its temperature. At a constant temperature, the ideal gas pressure has no effect on the speed of sound, because pressure and density (also proportional to pressure) have equal but opposite effects on the speed of sound, and the two contributions cancel out exactly.

**Converting Mach to TAS:**

\[ \text{TAS} = 39M\sqrt{T} \]

**Converting TAS to Mach:**

\[ M = \frac{TAS}{39\sqrt{T}} \]

**Transonic Flight**

Transport aircraft fly below M1.0 but at speeds which are high enough to cause the development of local supersonic flows. This is the transonic regime.

In transonic flight, both subsonic and supersonic speeds exist in the flow around the aeroplane, whereas in supersonic flight the airflow everywhere around the aircraft is supersonic.
First effect of increasing the Mach number is the increase in the upwash angle thus increasing CL.

Near M1.0 this effect reverses and CL reduces.

The development of shockwaves from MCRIT to MDET affects the flow pattern around the wing, in turn affecting lift and drag.

Above MCRIT there is a sudden rise in drag.

The speed at which this occurs is the "Drag Divergence Mach No".

It is caused by Interference drag, Trim drag and the Wave drag.

Wave drag cannot be eliminated because it is intrinsic to the formation of shockwaves.

Wave drag is composed of two parts.

1) Energy Drag: Energy lost in the temperature rise through the shockwaves.

2) Boundary Layer Separation: Which occurs while the shockwaves are attached to the wing surface. Above M0.98 when shockwaves move to the trailing edge, this factor reduces.

The point at which MDET occurs depends on the shape of the aeroplane.

For most aircraft (designed for supersonic flights) this occurs at around M1.3

Above MDET in the supersonic regime the bow shock wave will be attached and oblique.

**Transonic Lateral Stability**

Lateral stability in sideslip and roll authority decrease in transonic flight.

In a sideslip the down going or inside wing gets extra lift from dihedral or sweepback.

Both these effects produce increased flow over the upper surface of the wing and an increase in ML which may give a decrease in lift.

Thus design features promoting lateral stability in sideslip may have the opposite effect in the transonic regime.

**Transonic Longitudinal Stability**

As speed is increased towards M1.0 in transonic flight, a nose down pitching moment occurs (Mach Tuck or Tuck Under).

It is due to rearward shift of the CP and reduction of downwash over the tailplane.

The rearward movement of CP in the high transonic range increases static longitudinal stability.

Mach Trim feature in aircraft automatically adjusts for Mach Tuck or Tuck Under.

Failure of the Mach trim function will limit the Mach number to a lower value for the flight.
**Vortex Generators in Transonic Flight**

They increase the energy of the boundary layer.

A high energy layer can punch through the shockwave foot (attached to the airfoil surface).

This reduces the boundary layer separation.

Thus reducing the severity of the separation drag.

Vortex generators installed for this purpose are usually found further aft on the wing than those used for stall control.

**Compressive Corner**

A compressive corner is a term used for a convergent corner.

In subsonic flow the air will accelerate and the pressure will decrease.

In supersonic flow a shockwave will form at the corner. The speed will reduce and the pressure will increase.

Wing leading edge acts like a compressive corner.

As aircraft passes M1.0, the bow Mach wave becomes a normal shockwave.

Air hitting the wing leading edge comes to rest.

Pressure rises.

Compressibility takes place.

Compression raises the temperature.

Temperature rise means the speed of sound just ahead of the wing leading edge is higher than in the free stream.

So Mach waves propagates forward faster than the M1.0 free stream.

When Mach waves moves out from the warm area (into the cold) their speed reduces.

Thus the shock wave stays detached from the leading edge.

Bow shockwave will attach to the leading edge when Free Stream Mach (MFS) is equal to the forward speed of Mach waves.

This will not happen for a blunt and rounded leading edge as increase in MFS will further increase the temperature at the stagnation point and push the shockwave ahead. So the bow shock wave will remain detached.

However if the leading edge is sharp and angled then the shockwave will attach when MFS is equal to Mach wave speed.
The MFS at which the shockwave attaches is called the detachment Mach number (MDET).

\textit{Mdet gets its perverse name from the early days of supersonic research when the only way to get a supersonic wind tunnel was to pump up a huge tank of air then suddenly pull the plug, letting the air past the model at high M. As the air slowed down, the bow shock would straighten up and then detach itself from the model. Hence Mdet and not Matt... Source: (http://www.pprune.org/tech-log/72694-when-does-bow-wave-appear.html)}

If MFS > MDET, the attached shockwave will become oblique.

These are oblique shock waves and are at an angle of less than 90 degrees to the relative airflow.

Airflow in front and behind the shockwave will now be supersonic.

After an oblique shockwave there is an increase in the following:

- Temperature.
- The local speed of sound due to temperature increase (thus the Mach number decreases).
- Static pressure (but the total pressure decreases).
- Density.

Air behind a normal shockwave is more compressed than that behind an oblique shockwave.

\textbf{Expansive Corner}

An expansive corner is the name given to a divergent corner.

In subsonic flow the air speed will reduce and the pressure will increase.

In supersonic flow the speed will increase and the pressure will decrease.

\textbf{Swept Wing and Sweep Angle}

The sweep angle can be defined as the angle between the 25% chord line and the lateral axis.
The airflow for the swept wing is \( V \).

Airflow for a straight wing would be \( V_1 \) (right angles to the 25% chord line as shown in the figure).

Difference of angle is the sweep angle.

By the knowledge of trigonometry we know that:

\[ \cos (\text{angle}) = \frac{\text{Adjacent}}{\text{Hypotenuse}} \]

\[ \cos \text{ of sweep angle} = \frac{V_1}{V} \]

or

\[ V = \frac{V_1}{\cos \text{ of sweep angle}} \]

If \( V_1 \) is MCRIT for the wing when straight.

Then \( V \) is MCRIT for the wing when swept.

Therefore:

\[ \text{MCRIT (swept)} = \frac{\text{MCRIT (straight)}}{\cos \text{ine of sweep angle}} \]

From the above formula it can be calculated and confirmed that MCRIT is at higher MFS on swept wings than on straight wings of the same Thickness/Chord ratio.
This also applies to MCDR.

Swept wings have a very low drag at high speed, and this is a bigger advantage than the disadvantages that swept wings have.

The disadvantages are:

Tip stalling.

Pitching up at low speed stall.

High angles of attack on approach at low speed results in high drag values.

**Supercritical Airfoil**

As an aircraft approaches the speed of sound, it reaches a point where the air flowing over the wings reaches supersonic speeds though the plane itself is still moving slower than Mach 1, causing a dramatic increase in drag. The airspeed at which this occurs is called the critical Mach number for the wing. For example, if the air flowing over a wing reaches Mach 1 when the wing is only moving at Mach 0.8, the wing’s critical Mach number is 0.8. The spot where this happens on the wing is usually about halfway between the leading edge and the trailing edge of the wing.

Designers deal with this dramatic increase in drag by angling the wings back from the fuselage, making them thinner, and using other features designed to reduce drag. But all of these solutions increase structural weight, decreasing range and fuel economy, and making them unattractive for commercial use. In addition, thinner wings cannot be used to store fuel, a common location for fuel tanks on passenger planes.

In the early 1960s, Whitcomb sought to develop a new airfoil shape that would allow the wing to reach a higher speed before the airflow over it reached the speed of sound. He proposed a new airfoil shape featuring a well-rounded leading edge, relatively flatter upper surface (not as curved or cambered as other wings) that pushed the critical Mach point farther back on the wings, and a sharply down-curving trailing edge that increased lift. He called this the "supercritical" airfoil.

Wind tunnel tests suggested that the supercritical wing might allow planes to travel up to 10 percent faster. Alternatively, a plane with the new wing could fly more efficiently at the same speed (for example, a plane that normally cruised at Mach 0.7 could be equipped with a supercritical wing and achieve better fuel economy).

Flight tests proved that wind tunnel results were correct. The supercritical airfoil would allow planes to cruise at higher speeds. Passenger jets could be equipped with wings that would allow them to fly at Mach 0.9 or 0.95 instead of Mach 0.7 or Mach 0.8, and still be relatively fuel efficient.

In addition to being more fuel efficient, the blunt leading edge of a supercritical wing improved take-off and landing performance, as well as manoeuvrability.
When an object passes through the air it creates a series of pressure waves in front of it and behind it, similar to the bow and stern waves created by a boat. These waves travel at the speed of sound, and as the speed of the object increases, the waves are forced together, or compressed, because they cannot get out of the way of each other, eventually merging into a single shock wave at the speed of sound. This critical speed is known as Mach 1 and is approximately 1,225 km/h (761 mph) at sea level and 20 °C (68 °F). In smooth flight, the shock wave starts at the nose of the aircraft and ends at the tail. Because radial directions around the aircraft’s direction of travel are equivalent, the shock forms a Mach cone with the aircraft at its tip. The faster it goes, the finer, (more pointed) the cone.

Pressure waves from an aircraft will propagate at the speed of sound.

After M0.4 compressibility starts.

Large pressure changes takes place which change the air density.

Approaching M1.0, individual pressure waves pile up into a single pressure wave (Mach wave) ahead of the aircraft.

Mach waves (away from the aircraft) are relatively low intensity pressure changes.

Mach waves that form near the aircraft, on the wings and other parts are more intense, and are called shockwaves.

Through the shockwave the air is compressed, the pressure, density and temperature rise and the speed reduces.

Some of the dynamic pressure is converted into heat and total pressure falls (Bernoulli’s theory invalid here).

Through a normal shockwave (shockwave at right angles to the airflow) speed will reduce to be subsonic.
At subsonic speed (below M1.0) the energy accounted for by the rise in temperature is lost, meaning extra drag.

This is wave drag which is associated with shockwaves.