is subjected to the bending and torsion of the tangential impulse-reaction forces. The blade must withstand these stresses which are generally of a vibratory and cyclic nature while at high temperatures. The elevated temperatures at which the turbine must function produce extreme conditions for structural creep and fatigue considerations. Consequently, the engine speed and temperature operating limits demand very careful consideration. Excessive engine temperatures or speeds may produce damage which is immediately apparent. However, creep and fatigue damage is cumulative and even though damage may not be immediately apparent by visual inspection, proper inspection methods (other than visual) must be utilized and proper records kept regarding the occurrence.

Actually, the development of high temperature alloys for turbines is a critical factor in the development of high efficiency, high output aircraft gas turbines. The higher the temperature of gases entering the turbine, the higher can be the temperature and pressure of the gases at discharge from the turbine with greater exhaust jet velocity and thrust.

The function of the *tailpipe or exhaust nozzle* is to discharge the exhaust gases to the atmosphere at the highest possible velocity to produce the greatest momentum change and thrust. If a majority of the expansion occurs through the turbine section, there remains only to conduct the exhaust gases rearward with a minimum energy loss. However, if the turbine operates against a noticeable back pressure, the nozzle must convert the remaining pressure energy into exhaust gas velocity. Under ideal conditions, the nozzle would expand the flow to the ambient static pressure at the exhaust and the area distribution in the nozzle must provide these conditions. When the ratio of exhaust gas pressure to ambient pressure is relatively low and incapable of producing sonic flow, a converging nozzle provides the expansion. The exit area must be of proper size to bring about proper exit conditions. If the exit area is too large, incomplete expansion will take place; if the exit area is too small, an over expansion tendency results. The exit area can affect the upstream conditions and must be properly proportioned for overall performance.

When the ratio of exhaust gas pressure to ambient pressure is greater than some critical value, sonic flow can exist and the nozzle will be choked or limited to some maximum flow. When supersonic exhaust gas velocities are required to produce the necessary momentum change, the expansion process will require the convergent-divergent nozzle illustrated in figure 2.9. With sufficient pressure available the initial expansion in the converging portion is subsonic increasing to sonic velocity at the throat. Subsequent expansion in the divergent portion of the nozzle is supersonic and the result is the highest exit velocity for a given pressure ratio and mass flow. When the pressure ratio is very high the final exit diameter required to expand to ambient pressure may be very large but is practically limited to the fuselage or nacelle afterbody diameter. If the exhaust gases exceed sonic velocity, as is possible in a ramjet combustion chamber or afterburner section, only the divergent portion of the nozzle may be necessary.

Figure 2.9 provides illustration of the function of the various engine components and the changes in static pressure, temperature, and velocity through the engine. The conditions at the inlet provide the initial properties of the engine airflow. The compressor section furnishes the compression pressure rise with a certain unavoidable but undesirable increase in temperature. High pressure air delivered to combustion chamber receives heat from the combustion of fuel and experiences a rise in temperature. The fuel flow is limited so that the turbine inlet temperature is within limits which can be tolerated by the turbine structure. The combustion takes place at relatively constant pressure and initially low velocity. Heat addition then causes large increases in gas volume and flow velocity.