twisting deformation will be great enough to nullify the effect on aileron deflection and the aileron effectiveness will be zero. Since speeds above this point create rolling moments opposite to the direction controlled, this point is termed the "aileron reversal speed." Operation beyond the reversal speed would create an obvious control difficulty. Also, the extremely large twisting moments which produce loss of aileron effectiveness create large twisting moments capable of structural damage.

In order to prevent loss of aileron effectiveness at high airspeeds, the wing must have high torsional stiffness. This may be a feature difficult to accomplish in a wing of very thin section and may favor the use of inboard ailerons to reduce the twisted span length and effectively increase torsional stiffness. The use of spoilers for lateral control minimizes the twisting moments and alleviates the reversal problem.

Divergence is another phenomenon common to flight at high dynamic pressures. Like aileron reversal, it is an effect due to the interaction of aerodynamic forces and elastic deflections of the structure. However, it differs from aileron reversal in that it is a violent instability which produces immediate failure. Figure 5.5 illustrates the process of instability. If the surface is above the divergence speed, any disturbance precipitates this sequence. Any change in lift takes place at the aerodynamic center of the section. The change in lift ahead of the elastic axis produces a twisting moment and a consequent twisting deflection. The change in angle of attack creates greater lift at the a.c., greater twisting deflection, more lift, etc., until failure occurs.

At low flight speeds where the dynamic pressure is low, the relationship between aerodynamic force buildup and torsional deflection is stable. However, the change in lift per angle of attack is proportional to V^2 but the structural torsional stiffness of the wing remains constant. This relationship implies that at some high speed, the aerodynamic force buildup may overpower the resisting torsional stiffness and "divergence" will occur. The divergence speed of the surfaces must be sufficiently high that the airplane does not encounter this phenomenon within the normal operating envelope. Sweepback, short span, and high taper help raise the divergence speed.

Flutter involves aerodynamic forces, inertia forces and the elastic properties of a surface. The distribution of mass and stiffness in a structure determine certain natural frequencies and modes of vibration. If the structure is subject to a forcing frequency near these natural frequencies, a resonant condition can result with an unstable oscillation. The aircraft is subject to many aerodynamic excitations while in operation and the aerodynamic forces at various speeds have characteristic properties for rate of change of force and moment. The aerodynamic forces may interact with the structure in a fashion which may excite or negatively damp the natural modes of the structure and allow flutter. Flutter must not occur within the normal flight operating envelope and the natural modes must be damped if possible or designed to occur beyond the limit speed. A typical flutter mode is illustrated in figure 5.5.

Since the problem is one of high speed flight, it is generally desirable to have very high natural frequencies and flutter speeds well above the normal operating speeds. Any change of stiffness or mass distribution will alter the modes and frequencies and thus allow a change in the flutter speeds. If the aircraft is not properly maintained and excessive play and flexibility exist, flutter could occur at flight speeds below the limit airspeed.

Compressibility problems may define the limit airspeed for an airplane in terms of Mach number. The supersonic airplane may experience a great decay of stability at some high Mach number or encounter critical structural or engine inlet temperatures due to aerodynamic heating. The transonic airplane at an excessive