can be assumed to take place with negligible changes in velocity. The second mode consists of a pitching oscillation during which the airplane is being restored to equilibrium by the static stability and the amplitude of oscillation decreased by pitch damping. The typical motion is of relatively high frequency with a period of oscillation on the order of 0.5 to 5 seconds.

For the conventional subsonic airplane, the second mode stick-fixed is characterized by heavy damping with a time to damp to half amplitude of approximately 0.5 seconds. Usually, if the airplane has static stability stick-fixed, the pitch damping contributed by the horizontal tail will assume sufficient dynamic stability for the short period oscillation. However, the second mode *stick-free* has the possibility of weak damping or unstable oscillations. This is the case where static stability does not automatically imply adequate dynamic stability. The second mode stick-free is essentially a coupling of motion between the airplane short period pitching motion and elevator in rotation about the hinge line. Extreme care must be taken in the design of the control surfaces to ensure dynamic stability for this mode. The elevators must be statically balanced about the hinge line and aerodynamic balance must be within certain limits. Control system friction must be minimized as it contributes to the oscillatory tendency. If instability were to exist in the second mode, "porpoising" of the airplane would result with possibility of structural damage. An oscillation at high dynamic pressures with large changes in angle of attack could produce severe flight loads.

The second mode has relatively short periods that correspond closely with the normal pilot response lag time, e.g., 1 or 2 seconds or less. There is the possibility that an attempt to forceably damp an oscillation may actually reinforce the oscillation and produce instability. This is particularly true in the case of powered controls where a small input energy into the control system is greatly magnified. In addition, response lag of the controls may add to the problem of attempting to forceably damp the oscillation. In this case, should an oscillation appear, the best rule is to release the controls as the airplane stick-free will demonstrate the necessary damping. Even an attempt to fix the controls when the airplane is oscillating may result in a small unstable input into the control system which can reinforce the oscillation to produce failing flight loads. Because of the very short period of the oscillation, the amplitude of an unstable oscillation can reach dangerous proportions in an extremely short period of time.

The *third mode* occurs in the elevator free case and is usually a very short period oscillation. The motion is essentially one of the elevator flapping about the hinge line and, in most cases, the oscillation has very heavy damping. A typical flapping mode may have a period of 0.3 to 1.5 seconds and a time to damp to half-amplitude of approximately 0.1 second.

Of all the modes of longitudinal dynamic stability, the second mode or porpoising oscillation is of greatest importance. The porpoising oscillation has the possibility of damaging flight loads and can be adversely affected by pilot response lag. It should be remembered that when stick-free the airplane will demonstrate the necessary damping.

The problems of dynamic stability are acute under certain conditions of flight. Low static stability generally increases the period (decreases frequency) of the short period oscillations and increases the time to damp to half-amplitude. High altitude—and consequently low density—reduces the aerodynamic damping. Also, high Mach numbers of supersonic flight produce a decay of aerodynamic damping.

MODERN CONTROL SYSTEMS

In order to accomplish the stability and control objectives, various configurations of control systems are necessary. Generally, the