changes due to control deflection do not appear immediately. The time it takes for the air speed to reach its new value after the elevator has been deflected depends on the time characteristics of the phugoid.

Static Stability

The static stability criteria can be expressed by the requirements

$$\Sigma C_m = 0$$

$$\frac{dC_m}{dC_L} < 0$$

i.e., the aircraft is trimmed and a change in angle of attack or C_L produces a restoring pitching moment. The term dC_m/dC_L can be broken up into the contributions of the component parts and their mutual interactions, i.e., wing-body and tail.

The tail contributes a stabilizing term of the form

$$\frac{a_t}{a_w}\overline{V}\left(1-\frac{d\epsilon}{d\alpha}\right)\frac{q_T}{q}$$

$\overline{V}$ is the tail volume coefficient defined by $\overline{V} = \frac{l_t}{c}\frac{S_t}{S_w}$ and $1 - d\epsilon/d\alpha$ reflects the difference between tail angle of attack and wing angle of attack due to the downwash changes behind the wing. The static stability is a very sensitive function of the c.g. location. The c.g. location for which $\frac{dC_m}{dC_L} = 0$ is called the neutral point, N_o.

It can be easily shown that with the stick fixed

$$\frac{dC_m}{dC_L} = X_{c.g.} - N_o$$

(measured in percent m.a.c.).
The stick fixed neutral point, N_o, is the aerodynamic center of the wing-body-tail combination with the controls locked in place. The neutral point must lie behind the c.g. if the aircraft is to be statically stable. The neutral point, N_o, may be thought of as the place where the resultant of all aerodynamic forces acts on the airplane. To obtain stability, the neutral point can be moved aft by increasing the tail volume, or the c.g. can be brought forward.

With the controls free the neutral point is denoted by N_o' and can be ahead or behind N_o depending upon the floating characteristics of the tail surfaces. The maneuvering stability is concerned with the elevator angle per "g" (stick fixed) and stick force per "g" (stick free). The maneuver points are defined by the c.g. location for which these gradients

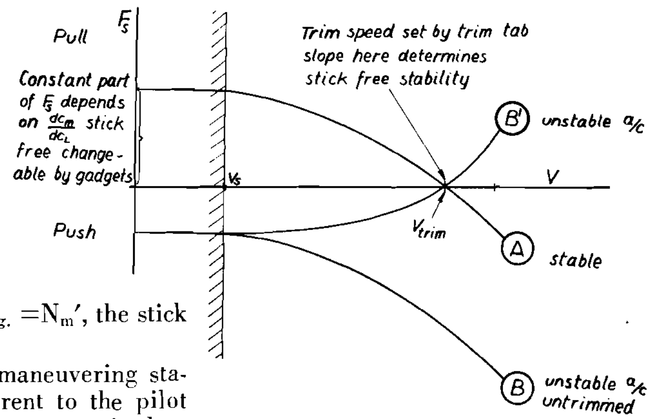

Fig. 2. Stick force variation with speed.

vanish, i.e., when $x_{c.g.} = N_m'$, the stick force per "g" = 0.

The control free maneuvering stability is made apparent to the pilot through the stick forces required to "pull g's" at nearly constant speed. The quantity stick force per "g" or F per "g" refers to the stick force required in a steady pull up or turn and does not indicate anything about the maximum "g's" arising from an abrupt application of a stick force of magnitude F. The stick free stability in non-maneuvering flight influences the stick force change per speed change.

If we look at figure 2 showing F vs. V we note that there is a constant force at V = 0 and the F drops off as V^2. The point at which F = 0 is the speed at which the aircraft is trimmed. We speak of stability only with respect to disturbances from a trim point. For the aircraft shown here it takes a pull force on the stick to decrease speed and a push force to increase speed. This is a stable aircraft. If the aircraft were unstable with the stick free then the F vs. V curve would look like the one in part B of the figure. The curves look alike and the slopes are similar, however, there is no trim point shown. If a trim tab is used to trim the aircraft out at the same speed as in part A, we see that the slopes are reversed. It now takes a steady *pull* force to keep the aircraft at a *higher* speed and a steady *push* force to keep the aircraft at the *lower*. These are steady forces. A *pull* force is needed to *start* the velocity *decreasing* but a force reversal is necessary to keep the aircraft from slowing up too much. The same thing applies to an attempt to increase speed.

Freeing the controls adds another degree of freedom to the problem. The elevator motion must now be coupled to the aircraft motion. In many cases the free elevator does not affect the phugoid. This is not always true and there are important exceptions. It may couple with the short period mode to give a motion known as porpoising. This is usually the worst for close aerodynamic balancing and mass unbalance. The stick forces form the basis of the pilot's opinion. If they are too light the aircraft seems too sensitive. If they are heavy and cannot be trimmed out the pilot will be fatigued.

In order to reduce hinge moments, designers often use aerodynamic balance in control surfaces. If we look at a simple flapped surface mounted in a wind tunnel, we notice that the control flap floats up or down as the angle of attack of the stabilizer is changed. The floating angle depends on the ratio of the derivatives C_{h_α} and C_{h_δ}. If we put a torque measuring instrument at the hinge line we can find the change in hinge moment coefficient due to changes in angle of attack of the tail and due to deflection of the control surface. These derivatives reflect the changes in the pressure distribution over the surface as the angle of attack or angle of flap deflection is changed.

Let us now look at the stability of an aircraft with the elevator free to float. It is clear that if the elevator floating angle is equal to $-\frac{1}{\tau}\alpha$ then the stabilizing effect of the tail is lost.* If the angle of attack of the aircraft increases then the lift on the tail should increase causing a restoring or nose down pitching moment. If the elevator floats up with the wind then the stability is reduced. If the floating angle change $\delta = -\frac{\alpha}{\tau}$ than a change in aircraft angle of attack will not cause enough change in tail lift. We must therefore try to design the control surfaces so that they float against the wind.

The hinge moments directly affect the control forces and these directly

*Note: τ = control surface effectiveness parameter $\frac{C_{L_\delta}}{C_{L_{\alpha_{Tail}}}}$