affect the pilot's opinion of the aircraft. These comments apply to aileron and rudder as well as to elevator hinge moments.

The constant part of the stick force can be shown to depend upon the stick free stability parameter $\left.\frac{dC_m}{dC_L}\right|_{Free}$. If the F/V trimmed slopes are not satisfactory, changes can be made by a gadget that gives a constant pull force to the elevator control system. The most commonly used devices are bobweights, downsprings and vee tabs. A bobweight is a mass unbalance, usually hung on the control stick, causing the stick to want to move forward. A downspring is a very long spring that also gives a constant forward pull to the stick. If such a device is used the stick force curves, F/V, are shifted upwards by a constant amount as shown in figure 2. The bobweight gives changes in the stick free maneuvering stability, since the stick force per "g" is affected. The downspring, however, being unaffected by "g's" or load factor, gives an improvement in stick free non maneuvering stability. A vee tab is a small spring loaded tab that is mounted on the trailing edge of the elevator. As the q increases this tab is pressed down and so it gives a constant trailing edge down moment. This is the same thing a downspring does.

There is another aspect to the use of bobweights and downsprings that is frequently overlooked. It has been shown, both theoretically and by experimental flight tests, that the airplane dynamics can be significantly changed by the use of bobweights and downsprings. These tests have shown that adding bobweight to correct for aft c.g. locations improves the phugoid damping. When downspring is applied however, the phugoid damping first improves and then as the downspring strength is increased further, the damping reaches a maximum and then becomes reduced. It is possible to de-stabilize the phugoid of a stable airplane by adding too much downspring. This is illustrated in figure 3. The downspring affects the parameter $N_m' - N_o'$, i.e., the difference between the stick free maneuver and neutral points. The bobweight affects the maneuver margin, $N_m' - x_{c.g.}$ In the diagram regions of instability, diverging oscillations, damped oscillations, etc., are marked off. These refer to the phugoid. Adding downspring moves aircraft down; bobweight moves right. An airplane's phugoid characteristics are determined by $N_m' - N_o'$ and $N_m - x_{c.g.}$ and this determines a point on the diagram. These boundaries depend upon the particular aircraft. You must construct a diagram for your particular aircraft. I do not propose this diagram as a design tool. Its value lies in pointing out the way that bobweights and downsprings affect the phugoid damping. Suppose the aircraft has a divergent phugoid. The diagram shows that adding downspring moves the point down into the damped oscillation and more downspring will cause undamped oscillations. Adding bobweight moves the point to the right into the region of damped oscillations again. This shows, in a rather general way, the effect of such gadgetry in the elevator control system. When bobweights are used to adjust the maneuver margin and consequently the stick force per "g," the designer must keep in mind that the stick forces predicted are for steady maneuvers and do not apply to the transient accelerations that can be produced by an abrupt deflection of the controls. The transient loads can be large and destructive.

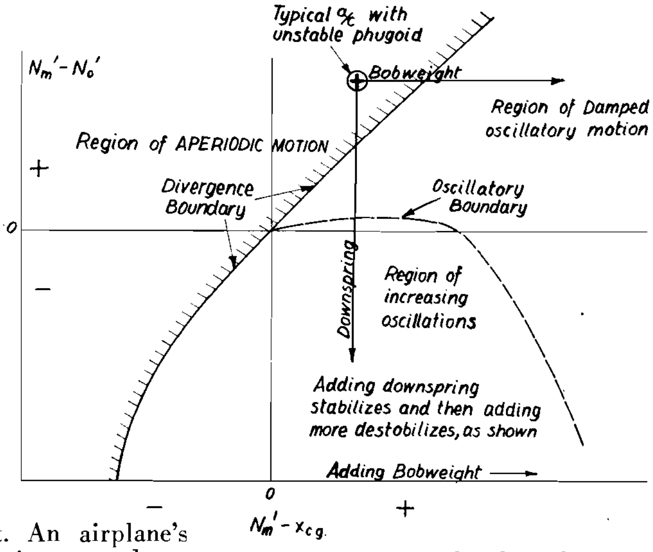

Fig. 3. Region of stable and unstable phugoid motions for a typical light aircraft.

We have spoken about the stick force gradients and their relations to the static stability. The question now arises as to the dynamic behavior of the aircraft and changes in the modes of motion as the c.g. is moved aft.

Imagine an aircraft with a sliding weight so the c.g. can be moved. Suppose the c.g. is close to the neutral point and eventually goes behind the stick fixed neutral point. It can be shown that the phugoid becomes unstable first. A mild divergence appears as c.g. goes aft. The divergent phugoid becomes apparent as the c.g. passes the N_o. The stick free neutral point is related to the force required to change speed. When the c.g. is at the stick free neutral point, no stick force is required to change speed. Whether N_o' is ahead or behind N_o depends on the floating characteristics of the tail. When the c.g. approaches and passes the maneuver points, the instability becomes very violent. This should be avoided.

It should be understood that the c.g. $- N_o$ relation can be arranged to be anything desired by shifting the c.g. with respect to N_o or changing the tail volume, i.e., tail area times moment arm. Forward c.g. limits usually depend on getting C_L max. or obtaining limit load factor.

In order to illustrate the ideas involved, suppose we examine the longitudinal stability of a typical sailplane. The stick fixed neutral point is found easily, using the standard methods shown in the references. The steps are summarized below.

1. Find the m.a.c. (mean aerodynamic chord of the wing, c)
2. Wing contribution
$$\frac{x_{c.g.} - x_{ac}}{c}$$
3. Fuselage contribution
$$\left.\frac{dC_m}{dC_L}\right|_{fus}$$
4. Tail contribution (note downwash term)
$$-\frac{a_t}{a_w}\bar{V}\frac{q_t}{q}\left(1-\frac{d\epsilon}{d\alpha}\right)$$
5. Take the sum, get
$$x_{c.g.} - N_o = \frac{dC_m}{dC_L}$$

The airplane is statically stable, stick fixed, as long as we keep the c.g. ahead of the neutral point. If the c.g. gets behind the neutral point the