aircraft is statically unstable, stick fixed. Suppose that the aircraft has a stable static margin of, say .05. This, of course, is with the elevator locked so that it cannot float. In practice the pilot cannot provide an infinitely rigid constraint on the elevator and so we must consider the stick free stability. In order to look at the stick free stability we have to know something about the type of elevator so that we can determine the floating characteristics. Let's not fool ourselves. Hinge moments are very hard to estimate accurately, especially if there is a peculiar nose shape on the flap. The best thing to do is to try to get reliable full scale data, i.e., NACA tests. The simplest configuration is the plain flap with no aerodynamic balance, and we will look at this case first.

Some assumptions are necessary before we can proceed. Assume that a sailplane has the following characteristics.

$S_T = 20$ ft.^{2} $\quad l_t = 15$ ft.
$S_w = 150$ ft.^{2} $\quad c = 4$ ft.
$a_t = .06$/deg. $\quad a_w = .1$/deg.

Thus, $\bar{V} = .50$. Assume that $x_{c.g.} - N_o = -.05$. The change in neutral point $N_o - N_o'$ due to freeing the elevators can be shown to be:

$$N_o - N_o' = -\frac{Cm_\delta}{a_w}\frac{C_{h_\alpha}}{C_{h_\delta}}\left(1 - \frac{d\epsilon}{d\alpha}\right)$$

$$\text{Assume} \quad 1 - \frac{d\epsilon}{d\alpha} = .5$$

Assume a plain flapped tail with flap/chord ratio = .2, $\tau = .4$.

$$C_{h_\alpha} = -.004$$
$$C_{h_\delta} = -.0115$$

$N_o - N_o' = .021$ or 2.1 percent m.a.c.
Case II plain flapped tail F/C = .4, $\tau = .6$

$$C_{h_\alpha} = -.01, C_{h_\delta} = -.015$$
$$N_o - N_o' = .06$$

Since $N_o - x_{c.g.} = .05$, the aircraft is now slightly unstable stick free. Thus we see that an airplane that is statically stable stick fixed may become unstable stick free. The overhanging balance or setback hinge is a very common type of control surface aerodynamic balance. This type of balance affects both C_{h_α} and C_{h_δ}. These derivatives are also very sensitive to changes in the shape of the flap nose. The setback hinge can be made to give positive values of C_{h_α} but the designer must watch out for positive vales of C_{h_δ} as this gives an unstable short period oscillation. The horn balance can make C_{h_α} less negative or even positive without too much change in C_{h_δ}. A beveled trailing edge on a *SEALED* flap can get C_{h_α} close to 0 for 10° or 15° trailing edge angle.

Geared tabs and spring tabs are trailing edge tabs linked by gearing or springs to the tail. The spring tab acts like a geared tab with variable gearing. It assumes more of the load as the speed increases. The geared tabs change C_{h_δ} without changing C_{h_α}. The designer can change C_{h_α} and C_{h_δ} almost independently by suitable choice of balance combinations.

All moving tails require very close attention and can be very dangerous if not designed properly. Since $C_{h_\alpha} = C_{h_\delta}$ and $\tau = 1$, there is no stick free stability if an all moving tail is used alone, no matter where the hinge is. Maneuvering stability is greatly reduced unless anti-balance tabs are used. If the hinge is at the tail a.c., then there is no stick force at all. The use of springs for control feel will be disastrous unless "q" sensitive spring is used. Otherwise, you can get full deflection at all speeds with the same stick force so F_s/g *falls off* as $1/V^2$. This is very dangerous. An all moving tail with geared anti-balance tab is all right. You set C_{h_α} with the hinge location and C_{h_δ} is adjusted by the anti-balance tab.

One method of illustrating the effects of balancing devices on hinge moments and changes in stability uses a plot of C_{h_α} vs. C_{h_δ} with a stability boundary drawn in. There is linear relation between C_{h_α} and C_{h_δ} such that the phugoid is neutrally stable. This is shown in the figure.

The slope of this boundary depends on the static margin, stick fixed. Suppose the aircraft stick fixed static margin is known to be .05 as in our example. If we use a plain flap with C_{h_α} and C_{h_δ} as estimated before in Case II, we see that the aircraft is unstable. We can combine this chart with another showing the changes in C_{h_α} and C_{h_δ} as the aerodynamic balance is changed. If we add horn balance we can move (C_{h_α}, C_{h_δ}) into the stable region. The effects of geared tabs, internal balance, trailing edge bevel, etc. can also be shown. It is possible to trace the result of combinations of balance on this chart.

The short period frequency and damping can be estimated during the preliminary design stage. It is clear that any analysis of the dynamic stability requires estimated values of the moments of inertia. Once the aircraft has been built it is possible to measure the moments of inertia but this is often not a practical thing to do. The moment of inertia can be measured by swinging the aircraft and solving the compound pendulum problem, or by constructing a shaking machine and measuring responses at different applied frequencies. Neither of these schemes seem very attractive. The moments of inertia can usually be estimated theoretically with enough accuracy for an estimate of the short period mode.

The question now arises as to what values of period and damping we should try to provide for these longitudinal modes. The best that can be said at this date is that pilots seem to like short period mode frequencies between .4 and .6 cps and damping ratios between .5 and 1.0. Another criterion requires the short period to damp to ½ amplitude in one cycle and have a period less than one second. Flight tests and simulator studies at Cornell Aero Lab, Princeton, and NACA Ames indicate that pilot opinion can be correlated with short period and damping. These results were obtained for fighter type configurations. Usually mildly divergent phugoids with long periods are considered acceptable. It seems to me that pilots of sailplanes with high L/D and circling at high C_L's would find it annoying to have difficulty keeping the speed constant. It would be desirable to have a damped phugoid stick free even if you have to move the c.g. forward with ballast or use bobweight or downspring.

It would be very desirable to perform some studies of sailplane handling qualities to obtain some design criteria. A means for accomplishing this by flight test would require the modification of a sailplane to have:

1. Variable gear ratios at stick
2. Variable bobweights and downsprings
3. Variable geared balance and anti-balance tabs on elevator and ailerons
4. Spring tabs on elevators and aileron.

By adjusting these devices and using ballast if necessary, we could simulate a wide variety of stick free characteristics. A systematic flight test program would provide very useful information as to what characteristics are required of the sailplane's handling qualities.

(Part 2 of this paper will appear in the next issue of "Soaring." It covers "Lateral Directional Modes," "The Roll Response to Aileron Deflection" and lists 15 references.)