of gravity location from the transom in beams (distance/beam), the load coefficient, and the deadrise. The l.c.g. is 4.5/5.0 = 0.9; the load coefficient is W/b^3 or 1500/5x5x5 = 12.0; and the deadrise is 5°. The value of Cw/B to be spotted on the abscissa is 12/5 = 2.4. The solid line plotted in Fig. 3 indicates that to just reach the porpoising limit at the most critical speed, our l.c.g. should have been 0.93 instead of 0.90. To guarantee stability it should have been 0.96 as indicated by the dotted line. If the l.c.g. had been 0.93, the minimum value of the index in Fig. 4 would have been 1.0, and had the c.g. been located at 0.96 beams, the minimum value of the index would have been 1.03, thus assuring stability.

Like the stability index, the relationship given in Fig. 3 is empirical. It is, however, reliable and useful for those wishing to assure stability without the need of determining trim angle, wetted area dimensions, or critical porpoising speeds. For those who prefer equations to graphic representation, the relationship may be written as follows:

For a minimum stability index of 1.0;

$$\text{l.c.g.} = 1 - \frac{1}{3.4\left(\frac{Cw}{B}\right)^{1.28} + 4} \qquad \text{(Equation 2)}$$

(Cw is the load coefficient and B is the deadrise value as given in Figure 3.)

For a minimum stability index of 1.03;

$$\text{l.c.g.} = 1.03 - \frac{1}{3.4\left(\frac{Cw}{B}\right)^{1.28} + 4} \qquad \text{(Equation 3)}$$

It should be pointed out that Figure 3, as well as the stability index itself, has been developed on the basis of the hard-chine hull. It is probable, however, that porpoising characteristics for the round bilge hull will not be widely different except, perhaps, for some increase in stability, so that use of the relationship given here will be conservative.

Necessary Adjustments: Before using Fig. 3, there are several details with respect to propeller location and shaft angles which should be clarified. The use of the true, unadjusted center of gravity location would not be entirely accurate because of the effect of the propelling forces. Instead, we should use what might be called the "effective center of gravity."

The fact that the propeller does its pushing on a line below the bottom of the boat produces a "couple" which acts to increase the trim angle and to affect wetted lengths in exactly the same way in which these variables would be affected by shifting the c.g. slightly toward the stern. The exact amount of the effective shift may be computed by multiplying the vertical distance from the bottom of the hull to the center of the propeller by the boat's drag-lift ratio. If the drag-lift ratio is not known, it may be safely estimated at about 0.2 for this purpose. As an example, if the propeller for the hull in Fig. 1 is centered at 10″ below the bottom, the true c.g. location at 54″ should have been adjusted by 10 x 0.2 = 2″, to an effective c.g. location at 52″, provided that the shaft is horizontal.

For an inboard, however, the shaft is never horizontal. The thrust of the propeller is in the direction of the shaft, upward as well as forward. This lift component at the propeller has the same effect as moving the c.g. forward by an amount equal to the product of the horizontal distance from the propeller to the true c.g. location, times the drag-lift ratio, times the tangent of the shaft angle. The direction of this adjustment is the reverse of that for the coupling effect, so that for inboards the net adjustment may be quite small. If the intersection of the shaft with the keel happens to be directly under the true c.g. location, the two adjustments will cancel each other completely and true unadjusted c.g. location will be accurate. A general equation for the effective center of gravity location may be expressed as follows:

$$\text{e.c.g.} = \text{True c.g.} + d(D \tan A - h) \qquad \text{(Equation 4)}$$

where d is the drag-lift ratio and D is the horizontal distance from the propeller to the true c.g. location. A is the shaft angle. For this purpose, it will be sufficiently accurate to consider the Tan A for conventional shafts to be about 0.2.

Strictly speaking, an adjustment should be made to the load coefficient for inboards to account for the effect of the vertical component of propeller thrust. This would normally amount to a reduction in load of about 4%, not enough to have an important influence on the porpoising limit. Moreover, the error caused by omission of this adjustment is in a conservative direction. It may, therefore, be safely overlooked.

While we normally think of the outboard propeller shaft as being essentially horizontal, it actually changes along with the regular motor angle adjustment. When outboard hulls are loaded so that they are very close to the porpoising limit, the adjustment of the motor angle may thus spell the difference between porpoising and stable operation.

Observations: The concept of stability as a function of wetted area configuration affords an explanation of some of the things which have been previously observed about porpoising. For example, when a motorboat is loaded so that the effective c.g. is slightly aft of its limiting position, she will porpoise on smooth water, but frequently will regain stability upon entering rough water. As the hull planes over waves, the *average* wetted lengths over a period of time are undoubtedly quite close to the values experienced in calm water. The effect of the waves, however, is to distribute the area of support over a longer length of the hull since forward areas which are normally dry are momentarily wetted upon entering each wave. The effect of this is to increase the value of the stability index, thus bringing the hull into a stable range. This effect is sometimes advantageous to racers since the race course seems always to be rough, which permits the c.g. to be located further aft with a more favorable trim angle.

Some of the racing inboards have toyed with the use of convex bottom surfaces near the transom which they appropriately refer to as a "rocker." The effect of the rocker is to introduce a suction at the stern which is equivalent to the addition of a weight in that area, except that it becomes "heavier" as the boat goes faster. Effectively, this moves the e.c.g. aft with corresponding shorter wetted lengths and reduced stability. A really fast stepless racer, such as the recently introduced ski boat, already has its c.g. well to the stern. The suction caused by the rocker increases with higher speed and invariably leads the hull into an unstable range with the result of an exceptionally wild and porpoising race boat and a correspondingly dangerous race course.

On rare occasions, one may see a light outboard stepless utility racer under nearly unbelievable operating conditions. The little hull is skimming over smooth water with barely more than a foot of wetted length and, yet, is as stable as you please. The very existence of such a short wetted length provides a clue to this apparent mystery. Obviously, the combined load of the hull, driver, and motor could not possibly be centered so far aft as to correspond with any short wetted length. This light hull, therefore, is necessarily receiving a large measure of support from the air. The air-borne component of support, of course, is fairly evenly distributed over the length of the hull, resulting in longitudinal stability.

It has always been possible, and it is usually convenient, to arrange for plenty of weight forward in a conventional motorboat to avoid porpoising. This is frequently desirable for other reasons. As we have pointed out though, this does not always provide the greatest speed or efficiency, especially for light loads and high speeds. Although a precise definition of the porpoising limit might conceivably never influence the design of an inboard runabout, it will have more frequent application in outboard design.

More important, the science of planing hull design would not seem complete without it.