change. Remote steering apparatus for outboards had not found widespread application at that time, and so to make the little boat plane with such a small motor, I had fitted my outboard with an extension handle to permit riding amidships. The new owner, quite naturally, sat well toward the stern where he could steer with his conventional motor handle. To say that this shift in center of gravity caused the porpoising would be an over-simplification, if not in downright error. Indirectly, however, it was this change that was responsible. A good general statement might be that porpoising stability for a planing hull depends upon an adequate longitudinal distribution of its supporting forces. This distribution is generally related to the dimensions and configuration of the wetted bottom area which, in turn, are influenced by the center of gravity location.

Determining Stability: Until now, most of us, at least, have not been able to predetermine, by means of a single chart or equation, the conditions under which a given hull will porpoise. It was known that wetted length had a strong influence on this type of stability, but mean wetted length alone could not be the entire answer. For one thing, there are times when a hull will porpoise while passing through a certain range of speeds, but will regain stability upon reaching higher speeds (see Fig. 1). The fact that mean wetted length never increases with higher speed indicates that some additional factors are necessarily involved.

Professional people had determined some time ago that for a given beam, load, and angle of deadrise, the porpoising limit can be defined on a plot of trim angle v. speed. Especially for application to seaplanes which are subject to external forces such as the lift of the wings and the trimming effect of control surfaces, this relationship is quite appropriate. For the free-to-trim surface craft, however, and particularly for use by the layman, this method of determining stability presents these disadvantages: it is necessary to have a curve for each angle of deadrise; the information is not generally available to laymen, and it is necessary to compute the trim angle for a number of different speeds before the curves can be used to determine stability throughout the speed range.

It happens that the parameters of load, beam, speed, trim angle, and deadrise are sufficient to define the dimensions and configuration of the wetted bottom area for hard-chine planing surface craft. The speed-trim angle relationship, therefore, could be converted to an expression in terms of wetted area dimensions.

Not long ago, I conducted a series of experiments, using models, to establish a correlation between wetted area patterns and the porpoising limit, and to evaluate any possible influence of other parameters. Basically, I was seeking a coefficient which would represent the degree of porpoising stability. Such a coefficient would necessarily have a constant value at the stability limit for all normal values of deadrise and operating conditions.

After many experimental runs and an analysis of the data, a satisfactory relationship was found which is most conveniently stated as a "stability index." This index can be used to predetermine porpoising stability under any given set of wetted area dimensions, although in the final analysis these dimensions need not be known to determine the center of gravity location required for stability throughout the speed range.

Like the speed-trim angle relationship, the mathematical expression for the stability index, SI, is strictly empirical. It is written as follows:

$$SI = 0.97 \frac{r^3}{c^2 b} \qquad \text{(Equation 1)}$$

where r is the radius of gyration of the wetted area pattern about an axis at the transom, c is the distance from the transom to the geometric centroid of the wetted area, and b is the beam. The stability limit is represented by an index value of 1.0 plus or minus about 3%. At values greater than 1.03, stable operation is practically guaranteed, while at values less than 0.97 the hull is almost certain to porpoise. (A comparison of this with the previously known speed-trim curve for a 10° deadrise surface is given in Fig. 2.) By an interesting coincidence, the stability limit for a flat plate planing at high speed (where the forces of buoyancy become negligible) is reached when the center of gravity for such a craft is located at exactly one beam forward of the transom.

Computing the stability index in terms of r and c would be arduous and would require knowing the wetted area dimensions. If there are those who are interested in determining stability for a number of specific speeds and other operating conditions, however, the task may be alleviated by preparing a plot of the index (SI) against a function of the wetted area configuration. A convenient form of this is a plot of SI b/L v. Lc/L.

Influence of Center of Gravity: But most of us wish to avoid porpoising at all speeds. We are primarily interested in knowing how far forward the center of gravity (c.g.) must be to assure stable operation throughout the entire speed range. This, fortunately, simplifies the problem. It should be understood that c.g. location, in itself, does not affect porpoising. For the free-to-trim craft, however, the location does have a direct influence on wetted lengths which, in turn, are related to the porpoising limit. Thus, indirectly, c.g. location is of utmost importance and, significantly, it is the only parameter which we can alter to assure stability for a given hull. A determination of the limiting c.g. location for stable operation at the most critical speed can be made directly from Fig. 3.

For a complete understanding of the relationship given in Fig. 3, an explanation of its derivation will be in order. A hypothetical case will illustrate some of the phenomena involved.

Assume that the boat in Fig. 1 is a 16′ hull of 5′ beam and has five degrees of deadrise. The gross load on the water is 1500 pounds and the center of gravity is located 4½′ forward of the transom. This c.g. location is far enough aft to be in the critical range from a porpoising standpoint. Under these conditions, the hull will begin to plane at about 11 mph and at this point the trim angle will be quite steep —about nine degrees. At this low speed the hull has not yet climbed out onto the surface of the water so much as it will at higher speeds, and the wetted length is still relatively long. As the hull gains speed, the trim angle is reduced and the mean wetted length is reduced—rapidly at first, not so rapidly as the higher speeds are attained.

The charts in Fig. 4 indicate how these changes occur as the craft accelerates to speeds as high as 45 mph. It should be noted that as the trim angle is reduced, the wetted length at the keel begins to increase after a minimum at about 20 mph. Moreover, as higher speeds are reached, the wetted length at the keel begins to increase considerably faster than mean wetted length is reduced, resulting in a change in the wetted area pattern and greater distribution of the supporting forces along the length of the hull. Accordingly, the stability index is high at the low speeds where mean wetted length is highest, begins to decrease as the hull accelerates, reaches a minimum value at about 23 mph, and then increases due to the longer wetted keel at the higher speeds. The boat will probably begin to porpoise at about 17 mph and is certain to do so at 20 mph. At about 34 mph where the stability index reaches a value of 1.0 again, the hull is likely to regain its stability. Stable operation is fully assured at speeds of 38 mph and faster. This characteristic dip and minimum value of the stability index at a critical speed is typical of deadrise surfaces which are loaded with the c.g. far enough aft to be close to the porpoising range. The solid and dotted lines of Fig. 3 represent the c.g. locations corresponding to minimum index values of 1.0 and 1.03 respectively.

By referring to Fig. 3 we could have predicted some instability in our hypothetical boat without using the plots given in Fig. 4. All we need to know is the distance to the center