pounded a relationship which applied reasonably well to ship forms of the displacement type, advancing at speeds which, had he known it, were below the Reynolds number of turbulence. This is a tremendous limitation and involves not only flow patterns but the shapes and streamlines of the bodies around which the flow takes place. At low speeds, the viscosity of water is such that reasonably clean laminar flow can take place around a body floating at the surface. But this laminar flow becomes generally turbulent as speed exceeds the viscous resurgent capacity of the water.

Thus, it has become apparent that it is possible to drive displacement hulls only up to speed-length ratios as high as perhaps 2. Beyond this general range, displacement hulls cannot go. And for very substantial reasons, no amount of power can drive the displacement hull faster. In fact, the speed-length relationship itself ceases to exist as a comparative value at any ratio above an approximate 2.0.

Limiting Factors

The observed fact is that at a speed-length ratio of approximately 2, a hull must have begun to show either one of two possible tendencies, according to its shape. Canoe-shaped sterns will have begun to settle, and the application of increased power will only increase the draft, even to the point of outright sinkage. Sterns with slightly more bearing aft resist the squatting tendency a fraction longer. But the tendency to swamp exists in all hulls where the buttocks, or running lines, curve upward to the water surface.

The other possible tendency is for the hull to lift and skim the surface. Flat buttocks ending at a broad stern form the characteristic hull shape fostering the tendency to lift and plane. Therefore, in that critical range of speed-length ratios between, say, 1.6 and 2.0, the hull with straight running lines and wide bearing aft will resist sinkage. Instead, it will lift and the flow beneath the hull will continue its laminar pattern for some distance aft of the hull.

This persistence of the flow pattern beyond the last point of hull contact is the first indication of new conditions beyond the scope of the Froude relationship Instead of water from below rising immediately to the surface and tumbling against the transom clear to the boot topping, the new planing tendency has ironed out the wake for some considerable distance. The flow pattern existing beneath the hull has extended itself beyond the direct influence of the hull. When this phenomenon occurs, the shape of the transom is plainly discernible in the depressed water surface for some distance aft. The water has broken clean from the transom and the resulting flow pattern is formed as if by an imaginary extension of the hull itself.

Herein is the key to the flow pattern as it now exists. It is the same as if the hull were longer and did exist over the depressed wake surface visible aft. Were it possible to say just how much added length of hull would exactly fill the wake where the flow is still coming up to the surface, this "induced length" might be added to the tangible hull length and the total used as a factor for the speed-length relationship.

However, there are two insurmountable reasons against the use of even this corrected length factor. First, there is the practical difficulty of measuring the true extent of induced length. Unfortunately, the wash from the sides quickly rolls in and covers the perfectly formed depression. Further aft, the slipstream boils up to obliterate any last trace of the true flow pattern. It is therefore impossible to observe to just what distance aft exact induced length does extend.

The second reason against using a corrected length figure is that it is no longer comparative. That is, the speed-length ratio of all clean planing hulls is 2. In other words, a correct estimate of the true induced length would always be sufficient to return the speed-length relationship to 2.0. For example, from observation together with a Reynolds number check, the induced length of a 36-foot waterline Chris-Craft moving at 18 knots, was 44 feet, making a total of 80 feet of flow length. The speed-length ratio thus becomes 2.0. Upon increasing the speed to 22 knots, the induced length has become 84 feet, making the theoretical corrected length about 120 feet. Again the speed-length ratio is 2.0. Obviously, any value as a comparative relationship has been lost.

One further difficulty remains to be pointed out in the way of any practical use of speed-length ratios for planing hulls. That is another practical impossibility in measuring the length, not only as induced aft, but also as existing forward under a hull which may have lifted half of its length clear of the water. Clearly, any workable figure of length is not to be obtained for the planing hull.

The underlying principle upon which the Froude relationship is based, applies only to the hydraulics of floating bodies surrounded by lines of flow which are too slow, relatively, to have acquired any velocity head. But since the modern, fast hull is designed with a shape which fosters lift, its dynamics more nearly approach that of the plane.

Instead of a hydraulic limitation, the properly designed hull benefits from a lifting tendency theoretically proportionate to the square of the speed. This does not necessarily presume any reduction or "hump" in the power expended for attainment of the higher speed. Rather, the planing tendency indicates that the hull has been so shaped as to have an inherent ability to receive and absorb higher powers without succumbing to the hydraulic laws which would cause a sucking under of hulls of finer waterplane.

Conversely, the broad-sterned hull *must* receive and expend greater horsepower, not only above the speeds at which submerged bodies can operate, but also within the submerged body range. Thus, at low speed-length ratios, even the planing hull is actually operating as a displacement craft and is therefore subject to the laws of bodies submerged at the surface. As such, its lines of flow are, at best, poorly shaped for low resistance at low speeds. However, some inefficiency at low speeds is a necessary corollary of any hull operating outside the scope of its fundamental design. In other words, the hydraulics of bodies submerged at the surface is a field apart from the dynamics of planing.

General Effect of Gravity

Consideration of these phenomena occurring within the range of speed-length ratios between 1.6 and 2, leads to the inescapable conclusion that for boat speeds involving any tendency toward lift, the flow characteristics surrounding the plane, and not those of purely submerged bodies, must be employed. This necessity has been fully recognized in aeronautical practice, and such a speed ratio has been developed by the National Advisory Committee on Aeronautics, which will be discussed later.

When a body moves at the surface of separation between water and air, waves are created. The densities of water and air are so different that for all practical purposes the effect of the air on the waves is negligible, the density of sea water being 1.99 and that of average air at sea level being .0024 per cubic foot. Therefore, wave surfaces are apparently acted upon from above by uniform hydrostatic pressure. But since the fact is that waves actually are created, the elevated water particles must be acted upon by pressures less than ordinary hydrostatic pressures. Similarly, the particles which are depressed must be acted upon by greater hydrostatic pressures. The significant fact in