
Hydrofoil system of the "Monitor."

The Flying Sailboat

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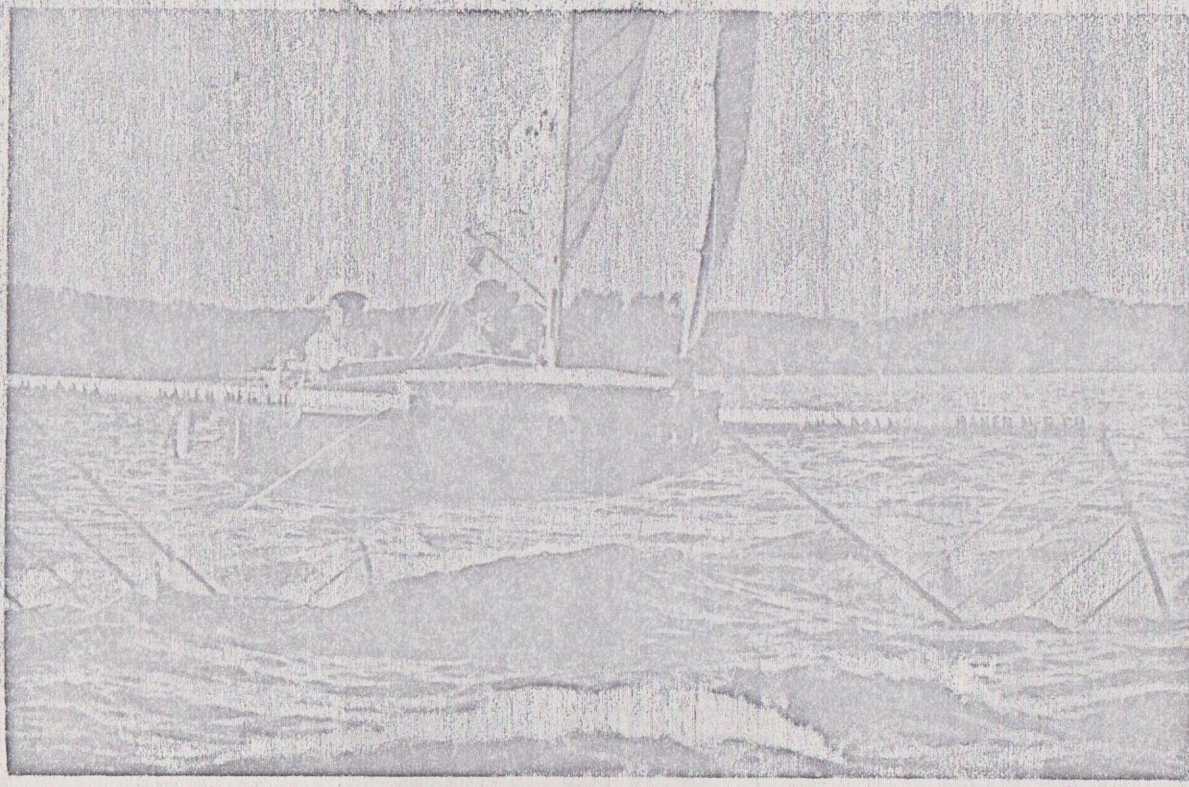
The combination of the wind as a source of propulsive power and hydrofoils for sustentation promises exciting new horizons for the sailing enthusiast.

Hydrofoils are something like waterskis on a boat, but with the important difference that they run submerged so that lift is produced on both the upper and lower surfaces, just as it is on an airplane wing. This lift causes the hull to rise entirely clear of the water, thus greatly reducing the forward resistance and avoiding the pounding forces experienced by a planing or displacement hull at high speed. The sensation of riding in and operating a hydrofoil sailboat is unique, particularly when climbing free of the water's surface and when accelerating during flight as the result of a change in course or trimming the sheets. The obvious magnitude of the elemental forces that are brought to play with so little noise is equally impressive.

Much of the recent progress in the development of hydrofoil sailboats has been made possible through the interest of the Office of Naval Research in obtaining hydrodynamic data on hydrofoil configurations in a relatively inexpensive way and without the complication of separating out the effects of propellers, struts, and propulsion plants. In this article, however, only those aspects that are of particular interest in the application of hydrofoils to sailboats will be emphasized.

Most experiments with hydrofoils have been carried out with power boats, but sailboat applications have been investigated by A. Locke, R. Gilruth, and W. P. Carl, Jr., and by the Baker Manufacturing Company,



The "Monitor" in flight.

which has built two different hydrofoil sailboats, a 16 footer and the 26-foot "Monitor." The latter boat, which was built as a company project and equipped with foils fabricated under a contract with the Office of Naval Research, has sailed at a speed of 30 knots.

Hydrofoils offer more of an advantage to a sailboat than they do to a motorboat. The reason they do is that the propulsion thrust of a sail increases with speed while the maximum obtainable thrust from a given engine decreases with an increase in speed through the water. In a beam wind of a given velocity an increase in sail speed by a factor of four increases the maximum obtainable thrust about 1.5 times. (This holds as long as the sail speed is not over four times the wind speed.) By contrast, an increase in speed of a motorboat by a factor of four with the same engine means a reduction in the maximum obtainable thrust to about one-quarter.

The increase in propulsion thrust of a sail with speed is well demonstrated by iceboats. In a 10-knot breeze, for instance, it may be necessary to push an iceboat to get it started, but once underway it may skim over the frozen surface at 40 knots. It is for this reason that the ratio of potential gain in speed due to reducing forward resistance by the use of hydrofoils is much greater for the sailboat than for the motorboat.

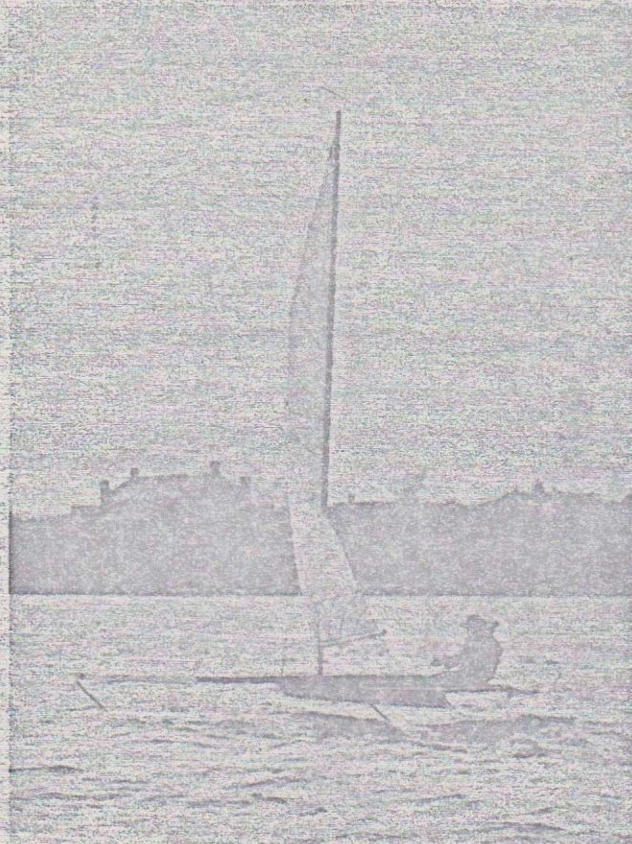
Unfortunately, if the maximum propulsion thrust is obtained, the sail side force—the component of the resultant force on the sail perpendicular to the course—increases by a much larger factor than that by which the forward thrust increases. At high speed the side force and resulting rolling moment under the condition of maximum propulsion thrust become so large that the lateral spacing and area of the hydrofoils needed to counteract them would be too great to be practical.

Fortunately, once a hydrofoil sailboat has attained enough speed to become foil-borne, she no longer needs the maximum thrust of her sail to keep her flying. By using a flat sail, trimmed to spill some of the wind, a skipper can fly his boat without rolling the lee foils under. Even with this reduction the forces on the sail are enormous, becaues during flying the relative wind reaches gale velocities. With a canvas sail it is difficult to maintain a proper sail shape, and considerable effort is required to trim the sheets. For these reasons a rigid sail appears desirable, if the problem of cost and transportation over land could be overcome.

In addition to supporting the boat, the hydrofoil system of a flying sailboat must, of course, sustain all reactions of the sail not supplied by the weight and the weight distribution of the boat. The ability of the hydrofoil system to counteract the high side force of the sail depends (1) on the projected area of the hydrofoils in a vertical plane parallel to the keel and (2) on the type of hydrofoil configuration.

The rolling moment produced by the side force acting at the center of area of the sail can be balanced partly by shifting weight to windward, but the main reliance must be on the difference in submergence and angle of attack between the windward and leeward hydrofoils. The

The 16-foot flying sailboat.



magnitudes of these differences depend on the lateral spacing and the type of hydrofoil.

The V-foil configurations of the 16-foot flying sailboat (see photograph above) and of the model hydrofoil system (see photograph on page 4) require wider lateral spacing of the hydrofoils for the same rolling moment than does the ladder-foil configuration of the "Monitor." With adequate projected area and lateral spacing of the hydrofoils, the necessary side force and rolling moment reactions can be sustained without difficulty.

The forward thrust acting at the center of area of the sail causes a pitching moment tending to bury the bow, but this is balanced by the greater lift of the forward foils and the distribution of weight aft. A slowly changing thrust can be offset by either a longitudinal weight shift or manual adjustment of the foil-angle settings to vary their lift. However, with a quick change in thrust as occurs with a gust of wind or an alteration in course, the errors in such adjustments are apt to result in either a sharp climb or drive of the boat. In case of a climb the foils lose their lift through ventilation (entry of air along the upper, low pressure surface), and the boat drops onto the surface of the water. In case of a dive the boat plunges into the water, stopping suddenly.

The rate of climb or dive due to variation in pitching moment can be reduced by increasing the fore and aft spacing of the hydrofoils. The amount of pitching-moment variation which can be tolerated increases about as the square of this spacing. Where adequate spacing means too long a boat, automatic regulation of trim under the varying pitching moment is needed.

In the case of the "Monitor," automatic trim regulation is accomplished by continuously determining the pitching moment of the sail on the hull with a mechanical computer and using a motion proportional to the pitching moment to vary the angle setting of the rear foil. This produces an opposite pitching moment on the hull. When the thrust increases, some over-compensation is made so that moderate climb is introduced. No power is required to operate the regulator other than that derived from the sail.

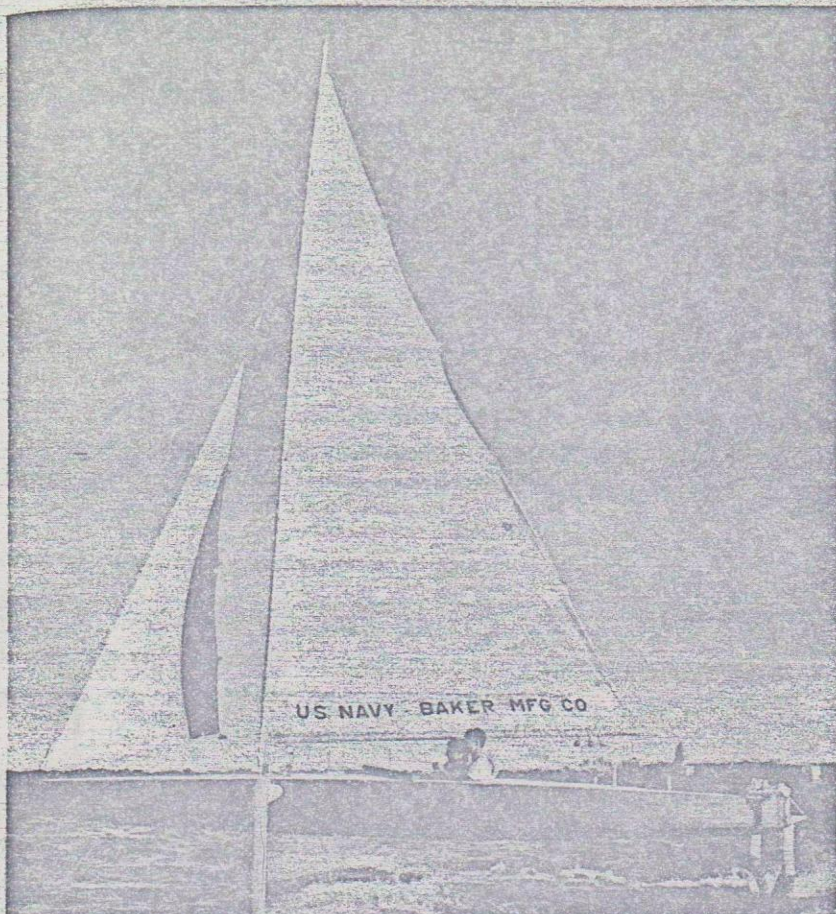
In order to steer either the V-foil or the ladder-foil system, the rear foil unit is rotated about an upright axis. A semicircular tiller is attached directly to the foil structure of the 16-foot flying sailboat. The "Monitor" is steered from the cockpit with a wheel mechanically connected through a suitable reduction to the rear foil.

The photograph below shows a model hydrofoil system designed for use on a flying sailboat undergoing a towing test. The side force and rolling moment of the sail are simulated on the rig by attaching the tow line over the deck on a post and by guiding the model with respect to the towing boat in such a way as to make the line of tow coincide with the line of action of the resultant force of a sail if one were used.

The specifications for the 16-foot flying sailboat are as follows:

- Sail area - 115 square feet.
- Length of hull - 16 feet.
- Overall width - 22 feet.
- Approximate maximum elevation above the water of the hull bottom in flight - 2 feet.
- Top speed - About 20 knots.

Tow test of a hydrofoil system for a flying sailboat.



The "Monitor" in flight.

- Wind velocity required to fly - About 13 knots.
- Number in crew - 1.
- Pitching moment partly compensated by fore and aft movement of operator.
- Rolling moment partly compensated by lateral movement of operator.
- No adjustment of the angle setting of the foils with respect to the hull in flight.
- Steering - By rotation of rear hydrofoil unit.

The 16-foot flying sailboat operates well in steady flight on a reach or a beat. It will point about as high as a conventional sailboat—an Inland Lakes Scow, for example. Acceleration or deceleration must be limited in order to avoid either diving or excessive climbing with consequent ventilation and dropping. The boat can be jibed without the hull touching the water. In coming about, the hull does touch down. When stationary the boat has a strong tendency to remain in stays.

The following specifications are for the "Monitor":

- Sail area - 230 square feet.
- Length of hull - 26 feet.
- Overall width - 21 feet.
- Approximate maximum elevation above the water of the hull bottom in flight - 2 feet, 6 inches.
- Top speed - About 30.4 knots.
- Wind velocity required to fly - About 13 knots.
- Number in crew - 2.
- Automatic trim regulation with varying thrust.
- Rolling moment partly compensated by differential adjustment of foil angles.
- All foil incidence angles adjustable in flight.
- Steering - By rotation of the rear foil.

The trim regulation on the "Monitor" eliminates the pitching-moment difficulties associated with acceleration on the 16-foot boat. The "Monitor" does not point as high as the 16-foot boat due partly to compromises for high speed. There is no difficulty in getting out of stays because of the jib. The roll resistance when the hull is in the water needs to be increased.

SPEED COMPARISONS

Type of Boat	Name	Knots	Date	Source of Information
American Cup Boat	Yankee	13.5	1931	Communication from Yachting Publishing Corp., N. Y., N. Y., Sept. 19, 1955.
Clipper Ship	Sovereign of the Seas	17.7	About 1854	"Clipper Ship Days," by John Jennings, published by Random House, N. Y., N. Y., 1952.
Catamaran	—	25.0	1952	"World's Fastest," Life Magazine, Aug. 25, 1952, Vol. 33, Pg. 55.
16-foot Flying Sailboat	—	20.0	Before 1952	Comparison with a motorboat with a known speed-tachometer relationship.
Flying Sailboat	Monitor	26.1	Sept. 1955	Comparison with two different motorboats with known speed-tachometer relationships.
		30.4	1956	Comparison with Univ. of Wisconsin motor lifeboat, which has a known speed-tachometer relationship.

Although the results achieved thus far in flying sailboat development are encouraging, there remains considerable room for improvement in the sail rig, the hydrofoil system, and in the structure. The main need is to lower the wind velocities required for flying in order to increase the opportunities for high speed travel. It is expected that eventually flight will be possible in about a 10-knot wind instead of the 13-knot wind required at present.