The Boat That Almost Was

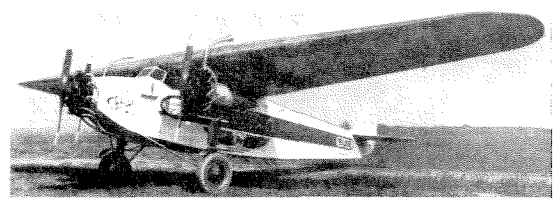
by Francis H. Clauser

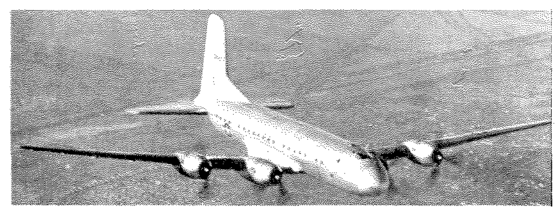
Above: Eagle, *currently competing among the America's Cup challengers in the waters off Perth, was built by the Newport Harbor Yacht Club as their conventional 12-meter yacht.*

In the late summer of 1984 Chuck Newton approached me at lunch in the Athenaeum and asked if I would be willing to meet a man who wanted to talk to me about the America's Cup. That man turned out to be George Tooby, BS '35 — almost a classmate of mine — who proposed that I sign on with the Newport Harbor Yacht Club to bring aeronautical science into the design of its America's Cup challenger.

I had never designed boats before, but my interest had already been piqued by the 1983 America's Cup race of 12-meter yachts. Before that race a number of my sailor friends had assured me that the United States was sure to win the cup again, as it had consistently for the past 132 years. These friends said that we had the finest crews in the world and that furthermore, the art of 12-meter yacht design had reached a pinnacle of perfection in this country. When the Australians won with their winged keel, the question naturally arose in my mind: Is the design of these yachts as advanced as I had been led to believe? The Australian keel wasn't that radical. If this was really supposed to be the state of high technology in yacht design, I thought it might be interesting to see how it looked from an insider's point of view.

So I began to study the various America's Cup contenders over the years, particularly the 12-meter yachts that had been racing since the competition was resumed in 1958 following the hiatus of World War II. I was immediately struck by a parallel with my early experience in aeronautics. In the 1920s airplanes were designed mostly by intuition. When scientific knowledge was applied to air-





The Fokker Trimotor 10-passenger transport (top) was typical of the intuitive designs of the 1920s. The Douglas Globemaster (bottom) was designed during World War II. It typifies the changes brought about by the revolution in aeronautical science during the 30s and 40s. The author designed the wing and tail sections on this airplane, and he holds the patents on the ailerons and flaps.

Figure 1: The 12-meter yacht Intrepid *was typical of the America's Cup contenders of the 1960s and 70s. These yachts experienced the same type of stability and control problems that airplanes of the 1920s did.*

plane design in the 1930s, earlier intuition frequently turned out to have been grossly wrong. For example, pilots often complained that the early airplanes had problems with stability and control. Science in the 1930s showed that the tail surfaces (elevators and rudders) had been much too small.

As I looked at the America's Cup yachts, my immediate reaction was that they must have had stability and control problems with their very small rudders located in the wake of both the hull and the keel. And it turned out that indeed a previous America's Cup skipper, Bill Ficker of *Intrepid* in 1970, claimed that "the present breed of 12 meters is very difficult to steer and keep 'in the groove.' *Intrepid's* biggest difficulties were experienced when tacking in light weather. It was not easy at all to get her moving again on the wind and to regain the speed of the previous tack." Other helmsmen said the yachts needed constant control to keep from yawing in moderate weather. Comments from the designers of these yachts make it clear that they didn't know how to solve this serious problem. It was at this point that I concluded that the design of 12-meter yachts probably had not reached the peak of scientific perfection that everyone seemed to think.

Ever since a group of New York millionaires first challenged the British yacht clubs in 1851, the America's Cup has been a race not between nations but between yacht clubs. It was set up as a series of match races every three years between a single defender and a single challenger. The defenders and the challengers would hold their own series of eliminations to choose one boat to represent them. But there are different rules for each side. The winner of the challengers' elimination races would represent its home yacht club, while the defender must sail under the colors of the yacht club that holds the cup — until 1983 the New York Yacht Club. This had been a galling experience for all the other American yacht clubs, particularly since the New York Yacht Club had grown almost insolent about its superior position in the race. Australia's winning of the cup made it possible for other American yacht clubs to dream of winning the cup. At present a total of 13 yachts are vying for the opportunity to challenge Australia in the waters off Perth — one each from England, Canada, and New Zealand, two each from France and Italy, and six from the United States.

When George Tooby decided that it would be appropriate for the Newport Harbor Yacht Club to enter a challenger in the next America's Cup race, he formed the money-raising *Eagle* syndicate and hired Johan Valentijn as Newport Harbor's chief designer. Valentijn, a young, Dutch naval architect, had designed *Liberty*, the unsuccessful American defender that had lost to the Australians in the 1983 cup race, as well as an earlier contender, *Magic*, for the New York Yacht Club. In the fall of 1984 I (as chief scientist) joined forces with Valentijn to build one-third size models of *Liberty* and *Magic* (the latter having been purchased by the *Eagle* syndicate) — to be tested in the large towing tank in Escondido. This was to establish a database of known characteristics of these two yachts so that we could compare future models with these two well-known quantities.

The *Eagle* syndicate had laid out a program to build two yachts, for which their fund raising goal was $8-10 million. The first of these was to be a conventional yacht, incorporating whatever improvements could be made on *Magic* and *Liberty*. The second was to be as radical and innovative as we were capable of making it. Valentijn and I agreed that he would spend almost all of his time on the conventional yacht, and I would devote most of my effort to the more radical second yacht.

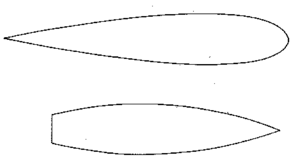


Figure 2: The airfoil or airship (top) is the aerodynamicist's concept of a well-streamlined shape. In contrast, the typical boat shape (bottom) is designed to travel the other way around.

Early in my work with Valentijn I was struck by the great difference in our perceptions of what constitutes a good streamlined shape. Both theory and experiment long ago led aerodynamicists to conclude that the typical airfoil or airship shape shown in Figure 2 has the least resistance. Also shown in the figure is the typical shape associated with boats. Any tendency to see a similarity between them is dispelled when one realizes that in one case the pointed end is forward and in the other it is backward. When we tested the model of *Magic*, I persuaded Valentijn to tow it backward as well as forward. The results, shown in Figure 3, were a shocking revelation to Valentijn. I kidded him by saying the reason we lost the cup was that we were sailing the wrong way around.

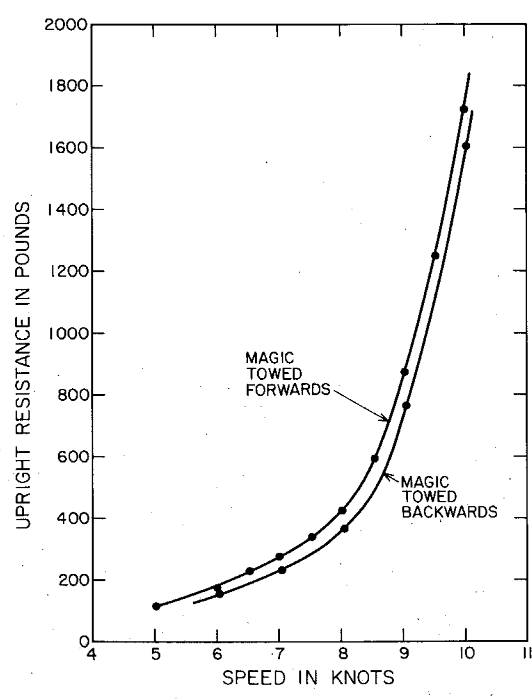


Figure 3: Towing tank tests on Magic's *hull (without keel and rudder) showed that it had less resistance when towed backwards rather than forwards.*

Unfortunately, his conventional boat ended up still sailing the wrong way around in my opinion.

What *is* a 12-meter yacht? For an America's Cup designer, this always looms as a key question, since it defines the limits to his innovation and creativity. As originally laid down, the rules were intended to be sharply and clearly defined. As the rules are written, two quite different lengths are involved. One of these lengths, LWL, is the length on the waterline from the bow to the stern (or to the rudder post if this is farther aft), when the yacht is afloat without a crew. This length has nothing to do with the 12-meter rating but serves to limit the yacht's displacement and draft. The displacement must not be less than the volume given by

$$\left(\frac{LWL + 0.75}{5}\right)^3$$

all in meters. Otherwise the yacht is penalized in its rating by double the deficiency. The draft must not exceed 16 percent of the LWL plus 0.5 meters. Here the penalty is three times the excess. The second length, L, is directly involved in the 12-meter rating. It enters the all-important formula

$$\text{Rated length} = 12 \text{ meters} = \frac{L + 2d - F + \sqrt{S}}{2.37}$$

Here d is the girth difference, F is the freeboard, and S is the sail area, all in meters. (I do not know the origin of the factor 2.37; without it, these would be 28.44-meter yachts.)

The definition of L is a study in complexity. Imagine a plane 0.18 meters (7 in.) above the waterplane. This defines new bow and stern points, and the first part of L is the distance between these points. The second is a girth measurement from a point on one side of the bow 0.6 meters above the original waterline, around and under the bow, and up to the corresponding point on the other side. From this is subtracted 1.2 meters, and the result is multiplied by 1.5 to give the second part of L. The third is a corresponding measurement at the stern, except that here the multiplying factor is 0.33. The forward girth measurement (when multiplied by 1.5) has a minimum value of 0.54 meters, and if the actual value is less than this, the minimum value must be used. The aft girth measurement similarly has a minimum value of 0.4 meters. In practice most yachts have measurements close to these minimums.

The girth difference measurement, d in the formula, is taken at the keel. It's the difference in length between a chain following along the hull from a point "a" above the waterline down along the keel to a point 1.5 meters below the waterline, and the length of a chain stretched tight between these same two points (Figure 4). The freeboard, F, is an average distance from the deck to the water plane. Since it is subtracted in the formula, it encourages the designer to build high decks. There is a maximum value of 1.21 meters permitted for F, however, and most designers use this maximum value. When L, d, and F have been determined, the sail area must then be chosen so as to give the yacht a 12-meter rating, that is, to fit the formula. If we add the requirements that the beam must be at least 3.6 meters, the height of the mast must not exceed 25 meters, and the height of the jib must not exceed 18.75 meters, we have the basic answer to the question: What is a 12-meter yacht?

There are other subtle but important restrictions, however. One is that there be no hollows in the hull between the waterline and the deckline except in the region near the rudder — a rule that excludes catamarans and other multi-hull craft. A second restriction states that below 1.7 meters under the water plane, no width can exceed 3.6 meters. This was adopted to limit the span of the wings on Australian-type keels.

A third restriction requires construction in accordance with the "scantlings" established by Lloyd's Register of Shipping. These are an archaic set of construction specifications that almost completely rule out significant structural innovations. In effect they require that, regardless of a 12-meter yacht's total displacement, the hull minus its keel must weigh approximately 17,000 lbs.

And finally, for 12 meters competing in the America's Cup races, there is an additional rule that requires the length of the yacht at a plane 50 mm (2 in.) above the water plane to be at least 44 ft. long.

Given all the variations that are possible, why is it that almost all 12-meter yachts weigh close to 57,000 lbs. and have an overall length of 66 ft. and a waterline length of 46 ft.? To figure out why, we must first explore some of the fundamental facts of hydrodynamics so that we can understand why a good yacht goes fast. When a ship travels at low speeds, the principal resistance it encounters is from the skin friction of the water as it moves along the wetted surface and from the eddies off the stern that are created when the streamlines fail to close in behind the ship. These resistances increase roughly as the square of the ship's speed.

At higher speeds wave resistance also comes strongly into play. At first many small waves form; as the speed increases, the waves increase in both length and height, and the pattern becomes less complex. Finally there comes a speed for which there is simply a wave crest at the bow, a trough along the midship and a final crest at the stern. Spreading out from this wave pattern at the ship itself is a great train of waves extending out in a chevron to the rear. At higher speeds this wave train carries off large amounts of energy, resulting in a large increase in resistance of the ship. This wave resistance can become so great that it overshadows the frictional resistance (Figure 5).

It was an Englishman, William Froude, who in the last century showed that the wave pattern of a ship is governed by the dimensionless ratio $V/\sqrt{gL}$, that is, velocity divided by the square root of the acceleration of gravity times length. This important result enables us to predict the wave resistance of large ships from tests on smaller scale models. Another Englishman, Osborne Reynolds, also working in the last century, showed that fluid frictional resistance is governed by the dimensionless ratio VL/ν, that is, velocity times length divided by kinematic viscosity. Using

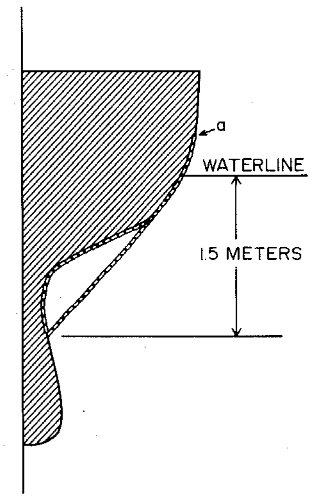


Figure 4: The chain midgirth measurement is the difference in length between a chain running from point "a" along the hull to a point 1.5 meters below the waterline and a chain stretched tight between those points.

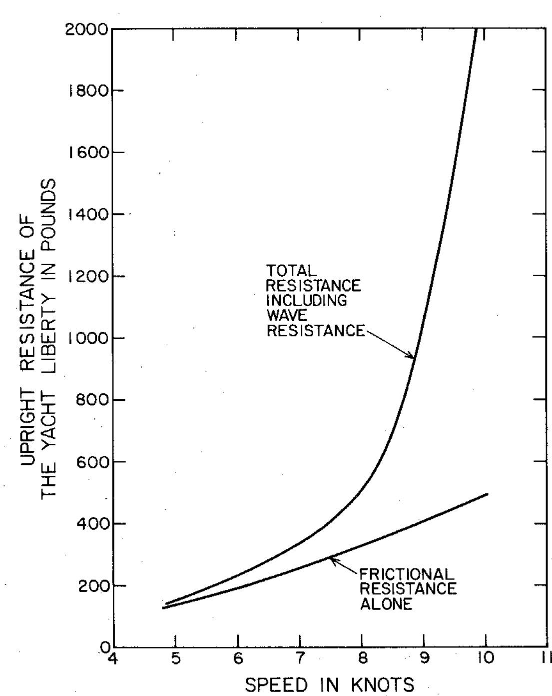


Figure 5 shows results from towing tank tests on a one-third-scale model of the 12-meter yacht Liberty. *Note how wave formation causes the total resistance to rise rapidly at higher speeds.*

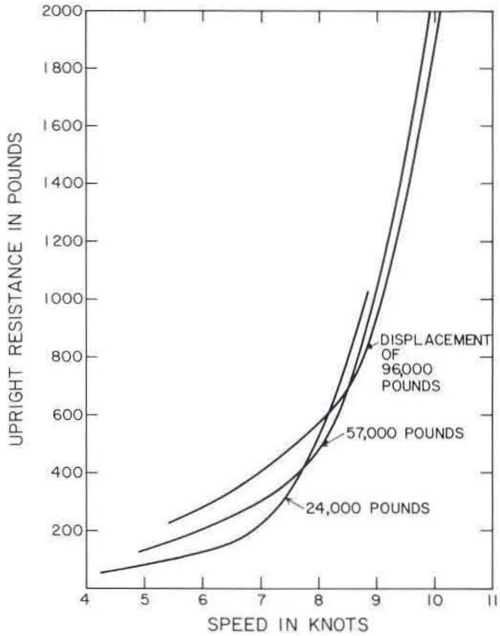


Figure 6: Towing tank data have been scaled up to show the effect of size on the resistance of typical 12-meter yachts.

this result we can scale up the fluid friction of a model to that of the full-sized ship.

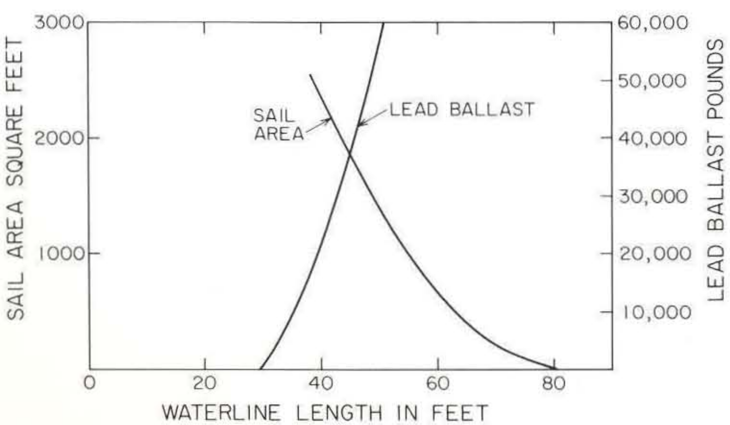
The first question that faces the 12-meter designer is: How heavy should the boat be? If *Liberty* were to be built in three sizes, 24,000, 57,000, and 96,000 lbs., with waterline lengths of 33.6, 45.6 and 54.8 ft. respectively, how would their resistances compare? Using our towing tank data and the scaling laws described above, we can calculate the resistance curves for these three yachts (Figure 6). At low speeds the lightest boat, being smaller, naturally has the least resistance. But at higher speeds the picture changes. For the longer boats the rapid rise in wave resistance does not begin until proportionally higher speeds are reached. Consequently their total resistance is lower at high speeds, where they enjoy a superiority that progressively gets better with length.

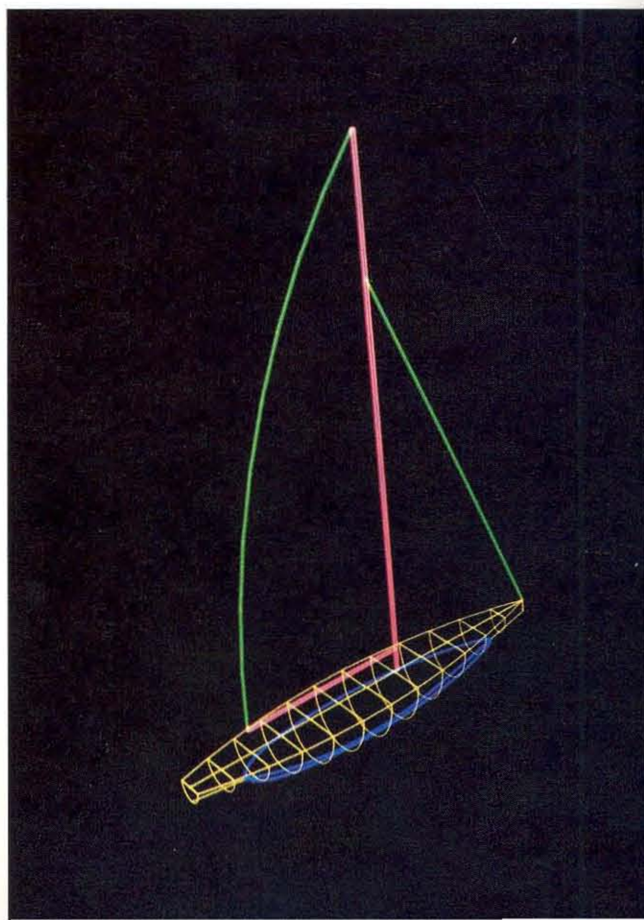
In Perth the winds are expected to be strong, and in most of the races the yachts will be pushed right up into this high speed range. So it would seem that designers of 1986-87 America's Cup yachts should strive for the greatest length they can get. And indeed, the first models that Valentijn and I built after our benchmark tests were larger, heavier versions of *Liberty*.

But if we look back at the 12-meter rules, we see that as the size of the hull (length, girth, and freeboard) goes up, the area of the sail must come down. For a typically proportioned hull, this leads to the relationship of sail area to length shown in Figure 7. Clearly, under the 12-meter rule the 96,000-lb. yacht with its 54.8 ft. of length would be required to have a much smaller sail. This result seems to indicate that, instead of a longer, larger hull to gain the advantage of high speed, the designer should be aiming for the smallest boat possible to have the greatest amount of sail area.

The hull must, however, be constructed in accordance with Lloyd's scantlings, which specify that the hull structure (minus keel) shall weigh no less than approximately 17,000 lbs. regardless of the displacement of the yacht. The 57,000-lb. yacht will thus be able to have 40,000 lbs. of lead in her keel, while the 24,000-lb. boat can have only 7,000 lbs. In a 12 meter the principal factor that enables the yacht to stand up in heavy winds is the enormous amount of lead ballast down in the

Figure 7: Under 12-meter rules, as the hull of a conventional yacht increases in size, the sail area must be decreased. The lead ballast permitted for upright stability goes up with length, leading to a design dilemma.

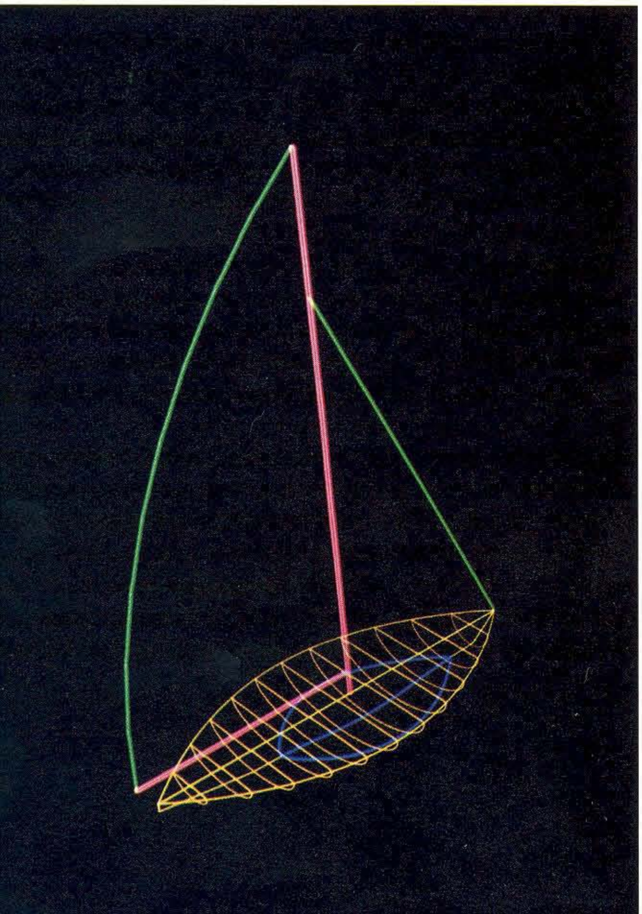




keel. In fact, all 12 meters have keels much larger than hydrodynamics alone would dictate, simply to house the lead. Our tank tests showed that the great advantage of the Australian winged keel lay not in the hydrodynamic properties of the wings themselves, but in the fact that the shape of the keel and the wings permitted the center of gravity of the lead to be significantly lower.

Figure 7 also shows the amount of lead ballast permitted in 12-meter yachts of various sizes. This now puts the designer's task in sharp focus. If he designs a small hull, it can have large sails, but even light winds will blow the boat over because of its small righting moment. In contrast, a large hull will have a very large upright stability, but it will be permitted to use only small sails. These opposing constraints dictate that most 12-meter yachts end up with waterline lengths of 43 to 48 ft. and with gross weights of 50,000 to 65,000 lbs.

It was in the fall of 1985 that the design of Valentijn's conventional yacht *Eagle*, was completed, and my ideas about a radically new boat began to crystallize. In international offshore racing a new class of fast ultra-light boats has been sweeping the field. How do they do it? There are several ways of gaining upright stability other than by placing lead in the keel, and ultra-lights do it by using broad beams with shallow-draft hulls. In spite of the success of this idea, it doesn't seem to have occurred to 12-meter designers to explore this avenue.



What would a 12 meter look like as an ultra-light? The conventional 12 meter with a gross weight of 57,000 lbs. has a righting moment of about 160,000 ft.-lbs. when it is heeled 30°. The keel with its 40,000 lbs. of lead provides about 145,000 ft.-lbs. of this. The remainder is made up of an unstable moment of about 38,000 ft.-lbs. from the hull, mast, rigging, and sails, and a stable hydrostatic moment of about 53,000 ft.-lbs. provided by a waterline beam of approximately 11 ft.

An ultra-light with a gross weight of 24,000 lbs. (less than half that of the conventional 12 meter) would have a length of 33.6 ft. compared to the 45.6 ft. of the conventional hull. To comply with the America's Cup rule, it would have to have a length of 44 ft. at a height 2 inches above the waterline. So it would have long, nearly horizontal overhangs both fore and aft.

One purpose of designing an ultra-light is to be able to use much greater sail area. My calculations indicated that to be able to stand up in the wind, it would need 40 percent more righting moment, that is 160,000 × 1.40, or 224,000 ft.-lbs. when it heels 30°. Here the righting moment is to come from a broader beam, rather than from a heavy keel. This will require a waterline beam of 20 ft. rather than the conventional 11 ft. Being much lighter and broader of beam, the draft of the lightweight hull at 1.5 ft. will be much shallower than the usual 4.5 ft. Entering the dimensions of such an ultra-light hull into the 12-meter formula gives a sail area of approximately 2,450 sq. ft., which is much greater than the typical 1,750 sq. ft. for 12 meters. Referring back to Figure 6, we see that the lightweight hull has the advantage of significantly less resistance at low speeds, and the larger sail area would much more than make up for its greater resistance at higher speeds.

It has been found that lightweight, broad-beamed boats can readily get up and plane like a surfboard on the forward face of a wave. They frequently reach speeds of 14 to 18 knots. The reason for this is simple. For a planing hull the resistance, instead of rising sharply at high speeds as shown in earlier

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Figure 8 (far left) shows a conventional 12 meter in computer graphics created by Bob Bolender. Figure 9 (to its right) depicts a broad-beamed, lightweight hull, which is permitted to carry a much larger sail. It can plane like a surfboard.

America's Cup contenders in 1983, Liberty *(top) and* Australia II, *illustrate the running room that they require when both have mainsails and spinnakers out.*

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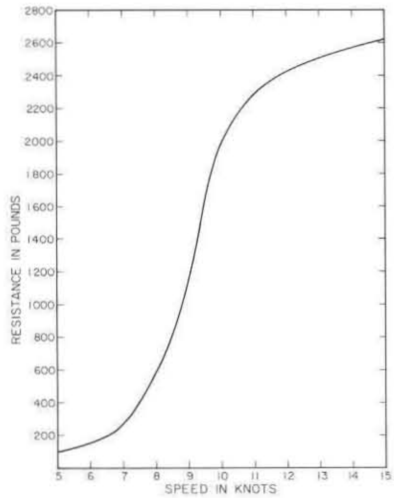
Figure 10 indicates that the upright resistance of a planing hull (with a gross weight of 24,000 lbs.) levels off at high speeds. This will permit it to surf on larger waves.



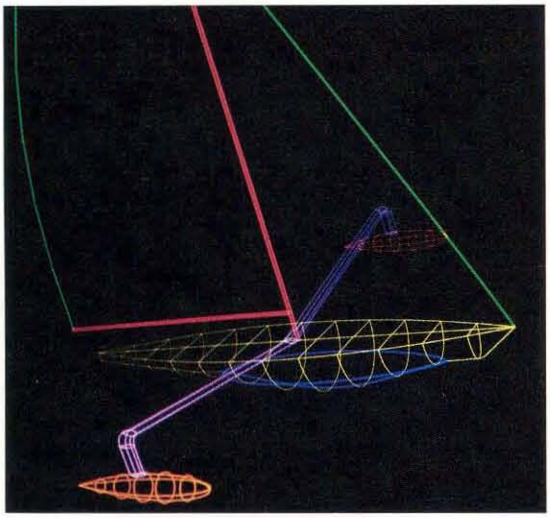
figures, levels off as indicated in Figure 10. Although sails cannot provide the several thousand pounds of thrust to cause a hull to plane, ocean waves frequently have slopes of 20 percent or more, and for a 24,000-lb. yacht, this gives a forward thrust of 4,800 lbs. or more — quite enough to cause it to plane.

Besides a wide beam, there are other ways to provide upright stability for an ultra-light hull. When a sailboat is running before the wind, it has the mainsail out on one side and the spinnaker out on the other. On a 12 meter each of these sweeps out to a distance of about 35 ft. on each side of the boat. This establishes the "running room" that must be permitted under the rules.

This suggests the possibility of deploying pontoons on outriggers within this running room in order to obtain upright stability instead of using lead ballast. If the pontoons are out of the water when the boat is in the upright position (all 12-meter measurements are taken in the upright position), they would not be classed as extra "hulls." In fact, they can be lying on the deck when the yacht is measured. And if the outriggers are deployed above the deck level, they would be classed as "booms" and thus not in violation of the "hollows in the hull" rule.

If the pontoons take the place of lead ballast, the wetted area of the keel can be reduced by about 140 sq. ft. If one of the pontoons has this much wetted area, then using an airship shape, such a pontoon could have a buoyancy of 6,000 lbs. When deployed on a boom 35 ft. long, such a pontoon would give a righting moment of 230,000 ft.-lbs., an even greater moment than provided by the wide beam of our earlier lightweight hull (and far greater than provided by the conventional lead keel). Perhaps even more important, the pontoons would prevent the yacht from heeling more than about 15°. This would be a significant advantage, since a great deal of sail power of a conventional yacht is lost when it's heeled as much as 30°. Pontoons could also be changed just as sails are changed. When light winds are anticipated, small pontoons with less resistance could be used, and extra-large pontoons could be substituted in heavy winds.

The required upright stability for ultra-lights can also be provided by "ailerons" extending out 35 ft. on each side of the boat. Each of these long thin wings could be rotated about its axis so as to provide hydrodynamic heeling moments when the yacht is under way, acting in the same way as ailerons on an airplane. Since almost all of the 12-meter measurements are



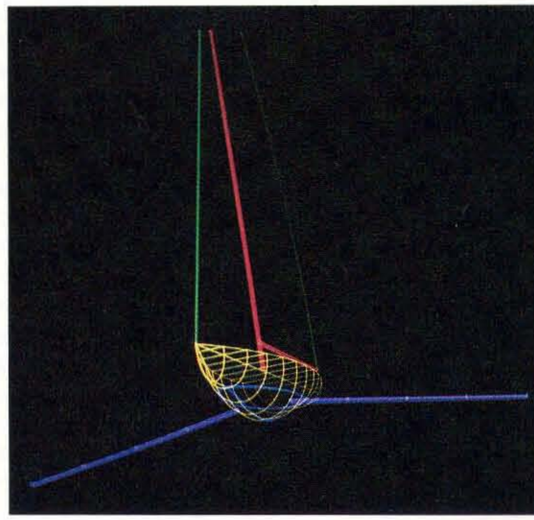


Figure 11: Pontoons on outriggers (far left) can provide upright stability and also keep the yacht from heeling more than 15°. The underwater "ailerons" in Figure 12 (to the immediate left) can also provide upright stability. Such solutions as broad beams, pontoons, and ailerons render a heavy keel unnecessary and make an ultra-light hull feasible.

Below: Later this last summer the author had this 40-percent-scale model built and tested to explore further the potentialities of the underwater proboscis.

taken at or above the waterline, there is nothing to prevent this. In fact, an official interpretation of the rule says that the hull may be of any shape below 150 mm (6 in.) below the waterline as long as it does not exceed the length between the fore and aft points 180 mm above the waterline.

If these wings, made of carbon fiber composites, have chords of 12 in. and thicknesses of 2.5 in., they can support the loads that are required to keep the yacht from heeling under the force of the sail. Such wings would have about 140 sq. ft. of wetted area, about the same amount that would be saved if the lead were removed from the keel. So the fluid friction would be approximately the same as that of the larger keel, but with the very great savings in weight that would make the ultra-light hull possible.

Ailerons would have a significant advantage in heavy winds. As wind strength increases, the forces go up as the square of the speed. With a conventional keel, the heeling of the yacht increases rapidly with increasing winds, and once it has reached 30°, the sail area must be decreased (reefed) to prevent the yacht from heeling farther. As a result of the decreased sail area, the yacht's speed no longer increases with increasing wind speed. In contrast, the power of the ailerons goes up with the square of the boat's speed, enabling the yacht to stand up straight even in the strongest of winds. So the yacht could take full advantage of higher winds without sacrificing sail area and thus speed, as shown in Figure 13 on the next page.

The fact that the 12-meter rules give the designer great freedom in shaping the portion of the hull that is 6 in. or more below the waterline suggests still another avenue to explore: Is there a way of making a boat with a small waterline length have a much larger wavemaking length?

We often see supertankers and other commercial vessels with bulbous bows that are designed to reduce their wave resistance at a specific speed. The reasoning that leads to the bulbous bow concept is relatively simple. The bow of a ship cutting through the water creates a wave crest, which initiates the train of waves that spread out behind. It is known that if a sphere is towed just under the surface of the water, there is a slight upwelling ahead of the sphere, but a large trough is created immediately behind it. This also initiates a train of waves that spread out behind it. But where the ship's waves start off with a large crest, the waves from the sphere start off with a large trough. If this trough could be positioned to counteract the crest, they would cancel each other, and the wave resistance would be nearly eliminated. It turned out indeed that by placing a bulb underwater out ahead of the ship's bow and joining it smoothly into the hull lines, the bow waves could be dramatically reduced.

One problem was that the interaction of the two wave systems was altered by a change in the ship's speed. A bulb that would produce a favorable interaction at one speed could produce unfavorable interactions at other speeds. For commercial vessels that spend their time traveling at one speed, this was an acceptable restriction. But for sailboats, which travel at a wide variety of speeds, bulbous bows have appeared in the past to have little chance of success.

Earlier we have seen that it is the Froude number, $V/\sqrt{gL}$, that governs the wave patterns of ships. Commercial vessels typically travel at Froude numbers between 0.25 and 0.30. In contrast, 12-meter yachts in moderate to heavy winds travel at Froude numbers of 0.37 to 0.45. At these higher values the wave pattern is simpler. This should make the design of a 12-meter bulbous bow simpler and should permit it, if properly designed, to be effective over a wider range of speeds.

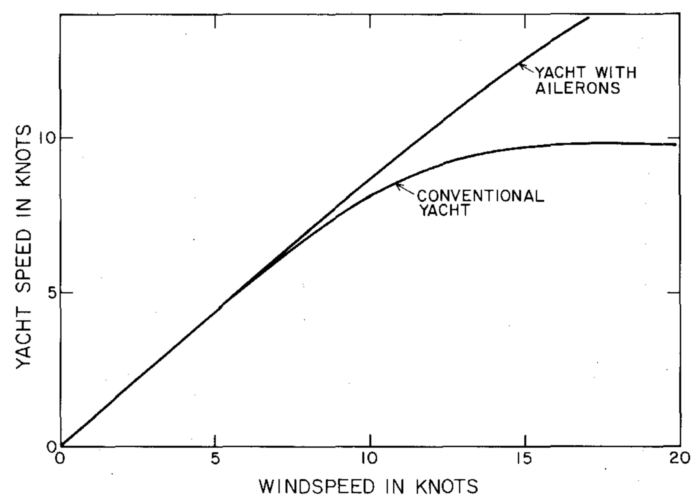
The concept of a bulb producing a beneficial interaction with the bow is a useful one, but it misses an important point. The wave resistance of a hull is proportional to the fourth power of the slenderness ratio of the hull. The bulbous bows on tankers are merely small add-ons. However, the 12-meter rule gives the designer great freedom to make the bulbous bow almost any shape he desires as long as it is at least 6 in. under the waterline. Such an underwater proboscis can thus extend far out ahead of the bow without increasing the measured length. And it can provide a significant addition to the displacement so that the hull itself can be greatly slenderized.

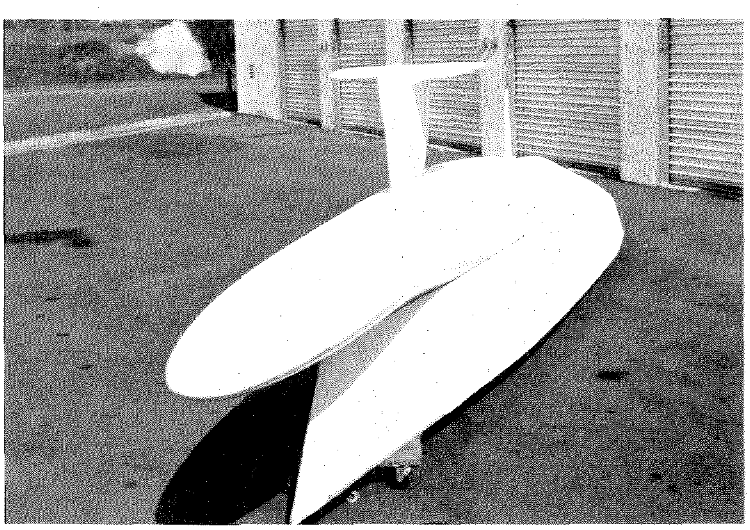
Let us consider again an ultra-light with a gross weight of 24,000 lbs. and a waterline length of 33.6 ft. Again, using nearly horizontal bow and stern overhangs, we can meet the America's Cup rule for a minimum length of 44 ft. at a plane 2 in. above the waterplane. And with proper shaping of the bow and stern we can have a measured length which will again allow a sail area of 2,450 sq. ft. Further, the 12-meter rule will permit a total underwater length of 44 ft. Hence the proboscis can extend 44 minus 33.6 ft., or 10.4 ft. out ahead of the bow.

All of this accomplishes two important things. First, the wavemaking length of 44 ft. is now nearly equal to the 45.6 ft. of conventional 12 meters. But more importantly, the light weight (24,000 lbs. vs. 57,000 lbs.) and the long underwater proboscis lead to a hull whose slenderness ratio is about half that of the conventional hull. This implies that the wave resistance will be reduced to a small fraction of that of the conventional hull. So much for theory and computer calculations. How will such a hull really perform?

When all of this was coming into focus in my mind in November 1985, construction was just beginning on Valentijn's conventional yacht *Eagle*. Unfortunately, the *Eagle* syndicate was a half-million dollars in debt. The construction costs for *Eagle* began to mount rapidly, and ahead still lay the need for sails, masts, booms, and so on.

Under these circumstances the board of directors of the *Eagle* syndicate became deeply divided on the question of planning for the second, more radical boat. Tooby, chairman of the board, and Gary Thomson, syn-





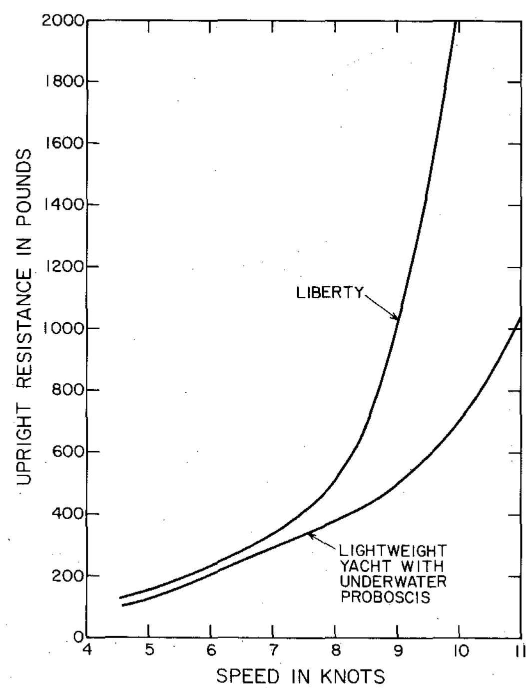


Figure 13 (above left): Since the power of the ailerons goes up with the square of the boat's speed, a yacht with ailerons could take full advantage of high winds. A conventional yacht would have to reef its sail, thus leveling off its speed, to keep from heeling too far.

Figure 14 (above): Towing tank tests showed the slender, lightweight model with an underwater proboscis with the same resistance at 11 knots as Liberty *had at 9 knots. The* Eagle *syndicate insisted that these tests on the model at the left be conducted with* Eagle's *keel rather than with pontoons or ailerons.*

dicate president, were enthusiastic about building and testing a model of my proposed hull with the underwater proboscis. But Valentijn and other members of the syndicate were opposed on the grounds that this would take away funds needed for *Eagle*.

It was not until March 1986 that a decision was made to make funds available to build a 40-percent scale model of the lightweight boat with the underwater proboscis. Even though this boat was designed to be used with either pontoons or ailerons, members of the syndicate insisted that it be tested with the keel and rudder used on *Eagle*, ostensibly to have a direct comparison.

Early in April we were able to test this model, and the results were little short of spectacular. They are shown in Figure 14 in comparison with *Liberty*. At low speeds the resistance is lower because of the smaller size of the lightweight hull. At higher speeds, instead of the usual disadvantage that a smaller boat has, the underwater proboscis, combined with the slenderness that it makes possible, gives the ultra-light the truly remarkable advantage in decreased resistance that theory had predicted. The ultra-light has the same resistance at 11 knots that the conventional hull has at 9 knots. And on top of this, the ultra-light can carry 40 percent more sail area. Advantages such as this usually occur only in a yachtsman's wildest dreams.

These results created quite a commotion within the *Eagle* syndicate. Tooby and Thomson (who had witnessed the towing tank tests) were highly enthusiastic. Others were less so. Because of an ever-increasing dearth of funds, there was now the danger that if a new hull were to be built, work on the original hull might have to be stopped. But perhaps the most critical factor facing us all was the question of time. To compete in the America's Cup, all yachts had to be measured and certificated by September 1, 1986. In order to meet this date, construction on the new hull would have to begin by May 1, and it would have to be flown to Perth by air cargo.

During the last two weeks in April, Thomson and Tooby made a heroic effort to raise an extra million dollars to build the new boat. But by May 1 it was clear that there was no chance of meeting this goal, and the syndicate decided to focus its efforts on the conventional boat.

At this point Tooby and I decided to resign from the *Eagle* syndicate and approach the New York Yacht Club (of which Tooby was a member) to see if at this late date they would have any interest in undertaking the design and construction of such a radical hull. The members of the New York Yacht Club syndicate expressed enthusiastic interest, but the boat-building firm that had constructed all of the NYYC's 12-meter yachts (as well as *Eagle*) told them that it was too late to design and build a new hull, particularly such a radical one.

By this time the New York Yacht Club had already built two versions of its yacht *America II* and was in the process of launching a third, since the first of these had proven to be a poor contender. Although it was too late to design and build a new boat, the boat builders said that it might be possible to take the first boat, cut the entire bottom out of it, and put in a new bottom. They thought they could do that by September 1.

Tooby and I went back East for a lengthy meeting with representatives of the New York Yacht Club and their designer. We laid all our cards on the table, describing in detail the design of the hull and the towing tank tests on it. The NYYC members were at first skeptical but then admitted that in all their computer studies they had never uncovered the great potential that our tests had demonstrated. They said they would have to confer with their various committees. Tooby and I came away buoyed up.

A week later we received a letter from the chief operating officer of the *America II* syndicate full of praise for what we had done but then saying that they had decided not to go ahead with such a radical project. It thus became clear that the current America's Cup races would be run without any of the ideas that I have described here.

As I look back on my two years' initiation into the design of America's Cup yachts, I am amazed at the great difference between the hyperbolic claims of "high tech" innovation that appear in the press and the design of the actual yachts now contending in the waters off Perth. The designers of most of these yachts are outspoken proponents of the "2 percent school," that is, that what it takes to win the America's Cup race is a 2 percent advantage. This is being borne out in Perth. In a four-hour race, the difference between the winner and the loser is usually less than five minutes.

Still, I am convinced by our tests that improvements of tens of percent are possible. What lies behind this difference in point of view? Almost certainly it can be traced to the secrecy that surrounds the design of 12-meter yachts. There is almost no scientific literature on the subject. Each designer jealously guards his store of information. The usual intellectual discipline that exists when scientific ideas are published and subjected to the examination of others is almost entirely lacking. I have become aware of a long list of intuitive ideas that sailors and designers alike cling to that I am convinced are nonsense. Perhaps with this article I can convince others to publish their ideas and, in the process, to see how well these ideas stand up under scientific scrutiny.

One risk I run in doing this is that publishing this article may cause the rules to be changed. Although the rules as originally written were intended to be well defined, the keepers of the rule book, being human, couldn't quite let go of the strings of control. Not in the rules themselves but in the instructions to the measurers, they inserted the following paragraph:

"If from any peculiarity . . . the National Yacht Racing Union . . . is in doubt as to the application of the rules or instructions . . . it shall report the case to the International Yacht Racing Union, who . . . shall award such certificate of rating as it may deem equitable; and the measurement shall be deemed incomplete until this has been done."

As a result, almost every innovation is challenged on the basis of this "peculiarity" instruction. The IYRU has maneuvered so that it can make quite subjective judgments as to what it will permit. The New York Yacht Club people told me that a number of decisions have been made solely on the basis of what the IYRU deemed "good for the sport." It remains to be seen whether broad beams, pontoons, ailerons, or underwater proboscises will be good for the sport. □