been made available for engineering applications but are not all described in detail in this article. The format of the burst correction tables facilitates the selection of a particular code or the evaluation of several codes in that codes are listed in increasing order of burst correction capability, increasing order of the irreducible polynomial exponent, and increasing magnitude of the check symbols. The capabilities of very long codes are retained or even increased after shortening the codes to mechanize them. This property should be noted. A simple mechanization is available if shift registers are used and the hardware is minimized if the first or minimal non-zero coefficient irreducible polynomial in Marsh's or Peterson's tables is used.

A special-purpose computer has been developed at the Applied Physics Laboratory to perform multiplication and division of polynomials in the binary number system and in the required algebra when it is desirable to use a shortened code, thus eliminating the need for hand computation of residues. The same device doubles as an encoder or decoder simulator for generator polynomials of degree 36 and less.

J. R. Apel

Ways and Means of BOAT DESIGN

The two most beautiful forms in creation belong to a well-designed sailboat and a well-shaped woman. A categorical statement such as this would ordinarily bring a flood of abuse upon the person who made it, but among judges of boats and women, the statement goes virtually uncontested. Though both subjects would make an interesting discussion, this paper will concern itself only with boats.

To those who know and understand them, there is real beauty in the lines of a hull or the set of the rigging of a boat, be it an 8-foot dinghy or an 80-foot diesel yacht. To those who are untrained in things nautical but who respond keenly to the visual arts, it is apparent that ships and boats have a high degree of functional styling about them. It takes only a bit of study and observation by the novice to become educated to some of the niceties of the business and to become convinced that the old saw about boats being called "she" has more truth to it than would appear at first glance.

This article will discuss the design of pleasure boats and the designers; it will also discuss the considerations that enter into designing different types of boats. Examples of a few designs will be shown with the emphasis on speed boats and hydroplanes; and an examination, in a bit of detail, will be made of a 150-mph Gold Cup hydroplane. The presentation of this article will be given from the standpoint of one whose vocation (in more fortunate times, perhaps) encompassed much of this subject matter, but who is now reduced to boating and boat design as an avocation only. So this will be a "hobby" article.

Few of the technicalities of the trade will be presented and virtually no connection will be made with its mother-science, fluid dynamics. This is because first, the technicalities are not too interesting and second, yacht design is much more nearly an art than a science. With the exception of a few craft such as the 12-meter racing sailboats of recent years, orderly research effort in pleasure

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J. R. Apel, a physicist in the Plasma Dynamics Group, co-authored a paper entitled "Beam-Plasma Interactions" in the May-June 1964 *Digest*. Coming from a boatbuilding family, Mr. Apel studied boat design at the Westlawn School of Yacht Design and practiced this profession for several years.

boat design (such as aircraft are subjected to) has not been great.

Naval Architecture

The fundamental problem in naval architecture is to design a boat or ship that is seaworthy, safe, and speedy, and that serves some specialized purpose—cargo carrying, fishing, racing and so forth. The success with which the problem is solved for small craft is chiefly a function of the skill and experience of the architect, since the analytical rules of the game are few and flexible. One result of this lack of hard criteria is that the small boat designer is usually trained less formally and more practically than his colleague who designs ships. If properly undertaken, the practical training is often as good or better for the purposes at hand, again because of the large empirical factor involved.

However, anyone, trained or not, can produce a workable boat. In fact, with no other type of vehicle does one find so many nonprofessionals audacious enough to design and build their own platform and courageous enough to set foot in the thing when it is done. Witness the native with his log dugout canoe, the coastal fisherman with his ungainly but stout 50-foot vessel built without benefit of a single blueprint, and the basement builder struggling to loft, or lay out full size, the lines of his 16-foot outboard from plans bought for $5.00 from the hobby magazine. These people are sometimes indecently successful. Witness also the degree of refinement exhibited by Messrs. Sparkman and Stevens in the design and testing of their exquisite series of 12-meter America's Cup defenders, or the engineering and skill displayed by an aircraft designer, Ted Jones, in concocting the first 200-mph hydroplane, *Slo-Mo-Shun IV*. These latter are professionals, of course, and specialized ones at that. Amateurs embarking on this level of activity are likely to meet with disaster.

For the most part, the boats one sees in the yachting magazines are designed by people who have learned their trade by observing boats, building boats, running boats, and loving boats. They may calculate their load waterline on the hull using Simpson's rule (but not know integral calculus from vichyssoise) or they may take the experimental approach and paint the waterline on the finished boat only after floating it in grimy water and letting the line define itself in dirt on the hull. Either way is workable and, for boats the size of many pleasure craft, entails comparable amounts of effort and expense. One might not trust the practitioner of the second method with any design more complex than a coal barge, but he will make a living nevertheless.

Four Pleasure Boats

As an example of the end products of a designer's efforts, four distinct types of pleasure boats are discussed in the following paragraphs. They are graduated according to hull type, starting with a pure displacement hull wherein virtually all the lifting force derives from Archimedes' ancient law, and ending with a racing hydroplane that planes on the surface and is nearly airborne at top speed.

A Sailboat

Let us return to the statement at the beginning of this article. What is it that makes the sailboat hull such an object of beauty? It is functionalism, a design perfectly attuned to the element in which it must live. In a sailboat, the requirement of harmony has ideally resulted in an object of sweeping, graceful lines that eases the water around it with minimal effort, that reacts to heavy seas with rapidly increasing buoyancy as it plunges in, and that sails almost as well halfway over on its side as it does upright. In many respects, the problems facing the sailboat designer in providing for these ideals are more complex than in any other marine design task. His product must make efficient use of wind with a speed varying from dead calm to greater than whole gale and whose direction will range from some 30 to 40° off the bow to dead astern, using a sail that acts much like a very limber airplane wing. It will be required to sail under 45° heel, perhaps, with a large reserve righting moment remaining for safety's sake. Its masts and rigging must take the strain of a spread of canvas whose area amounts to several times the lateral area of the hull supporting them. It must remain watertight, buoyant, and amenable to control under these conditions and preserve some degree of creature comfort at the same time. It is easy, for example, to design ample righting moment into a boat and make her almost impossible to capsize; without care, however, the resultant response will be so quick that under the influence of a rolling sea she will pitch crew and crockery athwartships with such force that the breakage factor for both will be intolerable. That all these requirements are not always met is obvious

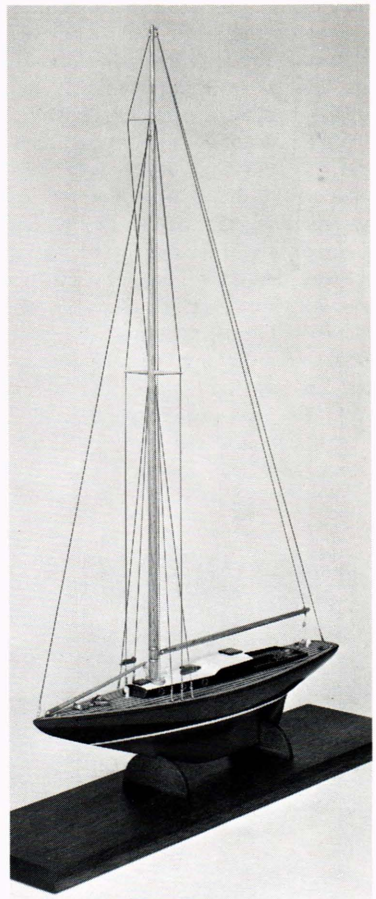

Fig. 1—Model of a 43-foot sloop designed for racing in shoal waters. Note the long, graceful lines of the hull and the height of the mast.

enough and the result is sometimes less than pleasant for boat and crew.

During the long evolution of sailing vessels, the shapes of hulls and sailing rigs have been developed to a high state of refinement and they are still evolving. There is a consensus that the general type of arrangement exhibited by the sailing sloop of Fig. 1 is one of the most efficient devised to date for smaller seagoing boats, say less than 65 feet overall. The illustration shows a model of a 43-foot fast racing sloop designed by the author, but never built (fortunately, perhaps, since sailboat design is not his forte). She is rather keen, her beam being only 8-1/2 feet, and of somewhat shallow draft for a boat of her size—5 feet. Her large Marconi-rigged mainsail and jib present about 900 square feet of area to the wind and are counterbalanced by some 8500 pounds of lead on her keel. The hull cross-sections are of the typical wine-glass shape. She is designed for racing in rather shoal waters like the Chesapeake Bay; as such, she is rather specialized, in somewhat the same sense as an Indianapolis racing car is specialized. Although beautifully shaped, the boat would probably not be too comfortable for long cruises since her fine lines do not yield the interior space or easy motion that cruising comfort demands. On the whole, it is a boat for a racing owner and not general purpose usage.

A Power Cruiser

Proceeding on from sailboats, the next hull type on our list is the semi-displacement power cruiser, probably the most familiar species of pleasure boat. This hull partially lifts itself out of the water as its speed increases but in the main remains buoyed statically rather than supported dynamically.

It is here that the feminine influence on yacht design has made itself felt most strongly, for while a sailboat is pretty much what her environment demands she be, the power cruiser in the last few years has become more what the skipper's wife demands *it* be, at least from the standpoint of styling and cabin appointments. Fortunately, hulls suffer little in this process—although there is the story about the yacht designer who gave his wife free rein in the interior arrangement of his personal high-speed planing cruiser. Such hulls are very sensitive to weight—and the inclusion of items like plate glass mirrors in the owner's quarters and an organ in the main salon proved more than the good boat could bear. She failed to plane because of the extra weight and it cost the designer the price of two larger engines and a major reworking of the hull to correct it.

Fig. 2—A 35-foot Jersey sea skiff, *Cap's Baby*. This cruising boat is comfortable and stable, though not as highly styled as some.

The important considerations in a cruiser are seaworthiness, comfort, and maneuverability. In normal use, the typical cruiser will serve as fishing boat, a 2-week vacation retreat, a floating cocktail lounge, and an important part of the customer-relations department of the owner's business. She does all these things well. In addition, she must be a seagoer, for ocean sport fishing beckons. The kind of vehicle that results may look much like the yacht shown in Fig. 2. This is a highly seaworthy, 35-foot round-bottom Jersey skiff that the author has skippered, built for breaking the rough shoal inlets found along the Eastern seaboard. Her cabin lines are somewhat severe and her grace is not increased by the flying bridge used for control while sports fishing. This type of boat tends to have a narrow stern, and the keel has a fair amount of rocker, or fore-and-aft curvature, to allow the seas to slip under her. They are usually clinker-built, with one plank overlapping another, but this one is smooth-planked. She is extremely able as cruisers go; twin 125-hp engines make her very maneuverable and permit a normal operating speed of about 12 knots. Sleeping accommodations are for six and she is equipped for extended cruising. She was designed and built by Van Sant in Atlantic City, where she summers; winters are spent in Florida in the company of her better-looking sisters built by Chris-Craft, Owens, or the like.

All in all, the design of a power cruiser is a much simpler undertaking than is the design of a sailboat of similar size, and the consequences of mistakes are not so drastic.

An Outboard Speedboat

My own speciality has been the design of speedboats and hydroplanes. These terms are used in the generic sense since a hydroplane *is* a speedboat, by necessity. "Speedboat" or "runabout" is usually reserved for the nautical equivalent of a sports car; that is, a peppy, open boat that planes on top of the water, is capable of speeds between 25 and 45 mph, is safe for skimming around in protected waters, skiing, fishing, and general waterborne random motion.

With the advent of high-power,

reliable outboard engines, the small outboard speedboat has come into its own. It has been an appreciable factor in making pleasure boating the over-two-billion-dollars-a-year business it has become in recent years. It is a boat that even families of modest income can aspire to and it can be trailed behind the car to a variety of watering places, thus circumventing dockage fees and adding variety to the owner's boating vistas.

An example of the hull design of a runabout is shown in Fig. 3. This is a set of line drawings arranged in the traditional fashion of naval architects, and shows the top and free of bumps and hollows and are self-consistent from one view in the drawing to the other.

There are good reasons for the hull shape shown in the drawing. For example, the large amount of vee bottom up forward acts as a wedge that enters the water and cushions the shock of traversing waves at high speed. Also, vee in the aft sections causes the boat to bank in a turn, thus providing a centripetal force and improved turning. However, a flat bottom is the most desirable configuration for efficient planing and hence the bottom lines must transform from vee forward to flat drag, of course. If improperly designed, the hull does not lift efficiently; a large wave is generated astern from the downward velocity imparted to the water and a forward "splash" occurs under the hull where it first contacts the surface. All this costs in power. A more proper design minimizes these effects; its propriety will become apparent from the small wake left in the water and the increased boat speed. A boat having the weight and surface area of the boat in Fig. 3 should plane at speeds above 25 mph.

The remaining hull characteristics are chiefly determined by considera-

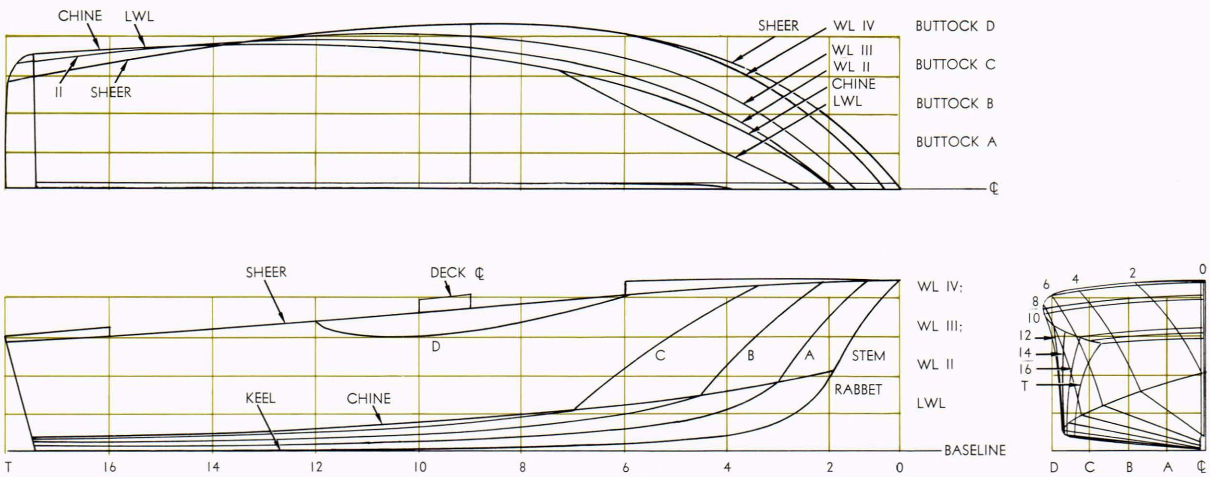

Fig. 3—A typical lines drawing showing a 17½-foot, wood runabout suitable for either outboard or inboard-outboard engines.

side views (plan and profile) plus transverse sections, of a 17-1/2-foot vee-bottom boat designed by the author for personal use. The welter of lines becomes clearer when we examine them one-by-one. The *sheer* is the line where the side and deck surfaces meet; the *chine* results from side and bottom intersections; the *rabbet* is where the bottom and side planking terminate and butt into the stem and keel. The remaining lines are waterlines, buttocks, and sections, all of which result from intersections of various sets of orthogonal planes with the hull. These lines are useful in *fairing* the hull, that is, in making sure the various complex curves are aft where the boat actually planes on the water. This evolution is displayed graphically by the buttock lines. In addition, the keel line has *rocker,* or curvature, so as to minimize the amount of nonlifting bottom in contact with the water, by elevating the forward part above the flow. As with a wing, the hull's angle of attack is determined by a balance between weight and the normal component of dynamic pressure integrated over the area in contact with the water, at a given speed. Usually this angle turns out to be about 3-1/2° as measured with respect to the straight buttock lines. The tangential component of pressure leads to tions of seakeeping. Breadth, or beam, is required for stability; freeboard or height above the water is needed to keep water out of the boat; similarly, the flare to the sides in the forward sections is to provide for increased buoyancy as the boat plunges into large waves, as well as to throw spray away from its occupants. The inward curvature of the sides at the after end is termed *tumble-home,* its origin probably being the need for the captain of a large sailing vessel to have a clear view upwards from the windows of his quarters at the stern of the ship. Tradition has retained it in small boats.

All in all, the craft in Fig. 3 should

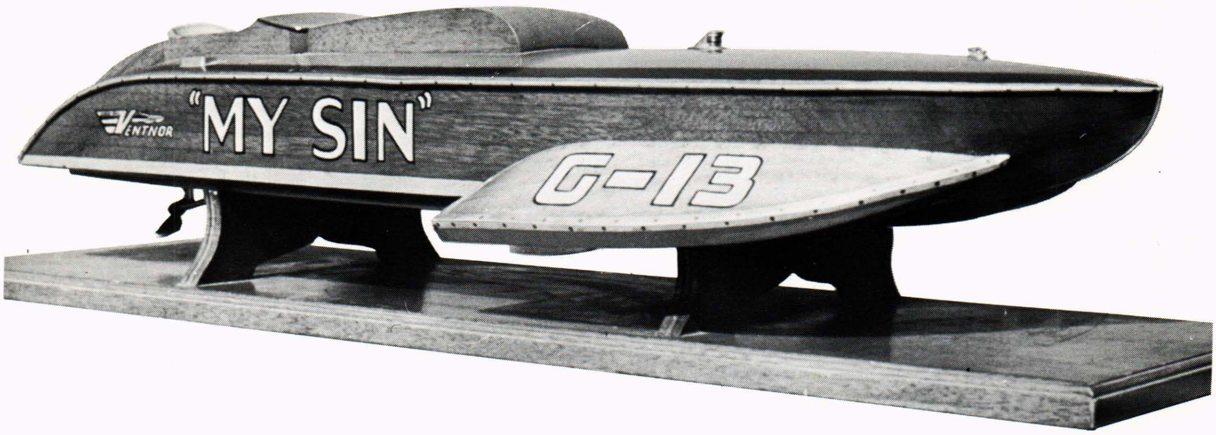

Fig. 4—Model of the 1940 three-point suspension hydroplane *My Sin.* A Gold Cup class boat, she exceeded 100 mph.

be a good-looking, dry, relatively smooth-riding boat for family use, capable of some 28 to 30 mph with a 45-hp outboard. Her framework will be built of oak and sitka spruce, and planked with mahogany. The bottom will be sheathed with fiberglass cloth and resin. This construction, coupled with her size and power, will be enough to give some comfort to her owner if he should be caught in the short, steep seas that the wind raises in a shallow body of water. I consider her a happy compromise between speed and seaworthiness and hope to demonstrate this when she is completed next summer, provided I can get her out of my basement.

A Hydroplane

At the opposite end of the spectrum from blue-water sailboats are racing hydroplanes. These craft are more nearly aircraft than boats, and if the American Power Boat Association rules did not require that they derive their thrust from action upon the water, or prohibit movable control surfaces acting against the airflow, Gold Cup and Unlimited hydroplanes would surely be jet-powered low-flying airplanes by now.

These are class boats, each class being determined by engine and boat size, among other things. They range from tiny outboards with 9-foot hulls to the smallest inboard with a 48-cubic-inch engine, up through the 266-cubic-inch displacement, 100-mph 15 footers, to the imperious Allison- or Rolls-Royce-powered Gold Cup boats. The classes are usually built around a readily available engine type—expensive specific racing engines being prohibited as beyond the pocketbook of most owners. The Gold Cup-Unlimited classes are the most interesting of all and we shall concentrate on them for the remainder of the article.

Almost to a boat, the big machines are three-point suspension hydroplanes, which means they ride skimming across the water on two forward protruding surfaces called sponsons or stabilizers, and on their sterns. This type of hull was invented in the early 1930's and was used in the first boat to achieve a mile-a-minute speed. By 1940, the design had progressed to the state shown in Fig. 4; this photograph illustrates a model of the *My Sin,* later to become Guy Lombardo's *Tempo VI.* Only 24 feet long, she was not designed for the horsepower installed in her after World War II and she flipped at 105 mph while racing in the Detroit River, breaking Lombardo's arm in the process. The sponsons are prominent in the photograph and carry the identification "G-13." One familiar with all the superstitions in racing might wonder at the wisdom of having 13 as a registry number.

Figure 5 is a schematic view of a typical 28-foot Gold Cup boat of 1960 vintage, capable of some 150 mph when powered by a 1710-cubic-inch, 2000-hp Allison aircraft engine. The view is from the water level and shows the boat in planing position; the stern is out of the water by a good fraction of a foot, lifting support being derived from the propeller, of which only one blade at a time is submerged. The engine turns the propeller near 9000 rpm through a step-up gear box whose ratio varies from perhaps 2.8 to 3.2 to one. The propeller pitch and diameter are both about 24 inches, and the boat makes good a distance of about 80% of this per propeller revolution. Supercharging is used on the engines; often the "straightway" boats—ones attempting speed records on a straight course -burn alcohol for increased power. It was under these conditions that *Slo-Mo-Shun,* a Seattle boat, exceeded 200 mph average speed on Lake Washington in a two-way run over a measured mile; it took several times this distance to accelerate and decelerate, of course.

The characteristic roostertail thrown by the propeller flies some 60 to 80 feet into the air as shown in Fig. 6, and this jet of water is often responsible for wetting down and drowning out any boat foolish

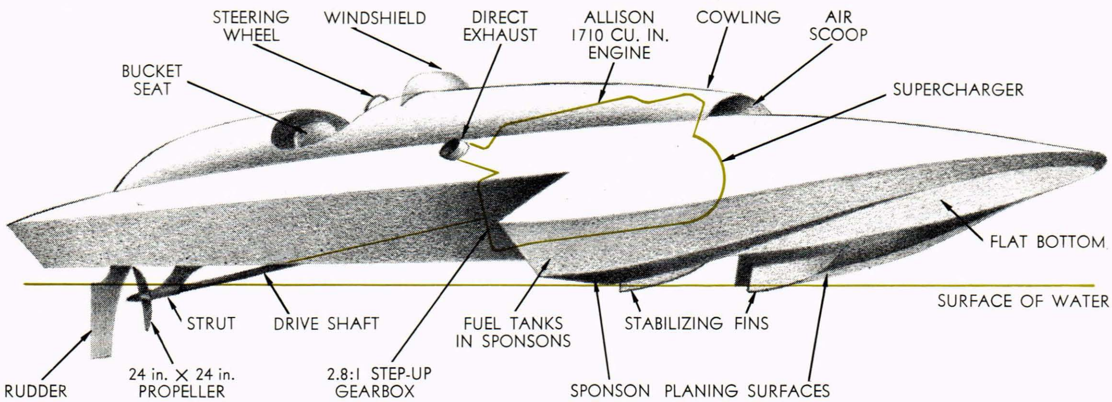

Fig. 5—Schematic of an Allison-powered, 150-mph hydroplane in running position, as seen from the water level. Only the edges of the sponsons and one blade of the propeller are in the water when proceeding at this speed.

enough to follow in the wake of the first within a few hundred feet. This last photograph shows the two-seat hydroplane *Dee-Jay IV* underway at about 125 mph in slightly choppy water. Light is clearly visible under the hull and often the boat is completely out of the water. Her general configuration is quite similar to that shown in Fig. 5 and her riding position is about the same. She was one of several big racers that the author assisted in designing, building, and testing—in this case not an altogether satisfactory experience, since the boat never overcame her bad luck and troubles. That amount of bad luck is unusual, however, and she was even an exception to the rule-of-thumb that it takes a new hydroplane at least two racing seasons before she begins to appear on the winner's list in the regatta circuit.

The initial ride in one of these monsters is a thrilling experience, especially because speed in a boat is magnified by the action and the very closeness of the water and spray. They are steered from the stern cockpit, the seat being located behind the engine and the twin 6-inch exhaust pipes. At the beginning, the starter is wound up, engaged, and the big engine catches and bleats loudly. One is set back in the seat from the acceleration, for there is no flywheel, no clutch, no gears to ease the jolt. Underway at 60 mph, the boat is riding well up on the water's surface and the wind brings tears unless goggles are used. At speeds between 80 and 90 mph, the stern lifts free under the influence of the propeller, the roostertail develops, and the boat walks crab-like to starboard from the torque at an alarming rate. One realizes that steering the thing is only an approximate maneuver and negotiating the racecourse is partly a matter of pointing it in the general direction and hoping. Over 100 mph, the driver is buffeted by hard, sharp accelerations from wave impact and reaction to the rudder movement. The boat is permeated by exhaust noise, gearbox scream, and high-frequency vibration from the propeller. At 150 mph, one's senses are nearly saturated, the remaining contact with externals being barely sufficient to warn that the course markers have flashed by and deceleration must begin, gently now, to avoid pitching stern-over-bow because the foot came off the throttle too fast.

Fig. 6—A Gold Cup hydroplane underway at 125 mph. Light may be seen under the hull. The propeller throws a roostertail 60 feet in the air and several hundred feet behind the boat.

In competition, with several other similar rigs adding to the congestion, and turns to negotiate and roostertails to avoid, the situation becomes even more confused; and it is time for the designer to abandon driving to the race driver and to sit on the shore, palms sweating, hoping his man can extract from his boat all that had been put into it, and worrying lest the 20 pounds weight saved by shaving the thickness of the main trusswork might cost a broken boat or worse yet, a broken driver. If she takes the heat, or better, the race, the inevitable pride of having created a winner is the reward; if not, more art work may be needed, and musings about balance, trim, power, and the like take over.