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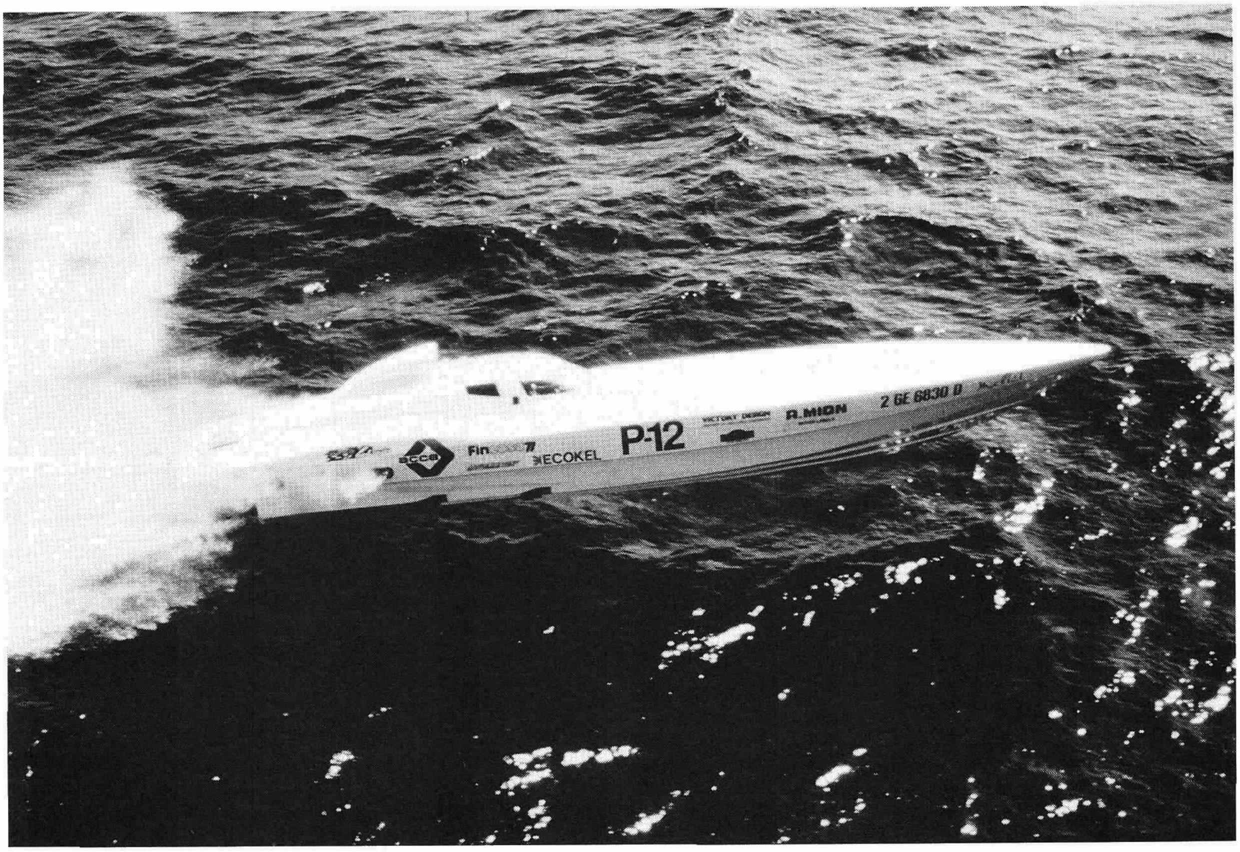

SM Racer wins the Cowes Classic Powerboat Race in 1993 at the record speed of 91.76 mph

SM Racer: Design and Operation of One of the World's Fastest Monohulls

Brunello Acampora[1]

Powerboat racing goes back to the beginning of the century, but offshore racing as we know it today started in the 1950's. The natural evolution of the sport led in 1990 to the birth of the Endurance class, intended for extended races on long offshore routes. This paper introduces Endurance racing and describes the design and practical operation of a powerboat, the *SM Racer,* expressly built for this kind of competition.

Introduction

POWERBOAT racing is often considered a hobby for rich men trying to show off with little or no interest paid to the sport from a purely scientific viewpoint. Racing is the obvious instrument by which to measure the technical innovations of the sport and to compare the different ideas and solutions for the quest for speed at sea.

While there is a purely sportive side of the game of powerboat racing, which not everyone might like or enjoy, which is true for any kind of racing, the author is mainly interested in the technological advancement connected to the sport.

A winning raceboat is one which is faster than last year's winner, even if by only a fraction of a percent, but still faster. This is the guarantee for the constant development of the sport. The technological feedback from the racing scene into the production of pleasure, military and commercial vessels could be, and often is, tremendous.

The Endurance races, born to promote long open sea races on monohull vessels, could be a discipline with almost immediate innovative feedback to the military and commercial industry.

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This paper describes the design of a 48 ft racing monohull, the *SM Racer*, specifically intended for the Endurance type of competition, outlining all the main design stages, the technical problems and the solutions adopted. The vessel was then tested and raced, often with the designer on board, providing a unique opportunity to verify, in actual operating conditions, all the ideas incorporated into the design.

1. Evolution of offshore racing

The history of powerboat racing goes back to the beginning of the century, both in Europe and in America, with races such as the Algeria-Mahon-Toulon in 1905 (395 n.m.), the London-Cowes in 1906 (180 n.m.), the New York-Bermuda from 1907 to 1913 (665 n.m.) and the Miami-Gun Cay in 1907 and 1917 (50 n.m.). Still, offshore racing as we know it today was probably born in 1956, with the first edition of the Miami-Nassau race, won by the legendary Sam Griffith. From that moment onwards, it was clearly understood that these kinds of races required and promoted better designed and built boats, able to sustain high speed in rough conditions. Up to that moment, most of the planing hull developments were due to the military requirements during the First and Second World Wars.

In 1958 Raymond Hunt's first "deep-V" hull made its appearance in Newport, USA, while in India another brilliant aeronautical engineer, Renato "Sonny" Levi, was experimenting with similar hull configurations.

The "deep-V" hull design was probably the single most important advancement in high speed travel at sea on planing crafts. This new configuration, characterized by high deadrise values at the transom (20 to 25 deg approx.) and longitudinal "spray strakes" or "risers," was the logical evolution of the early flat-bottomed warped planing hulls.

It was therefore during the sixties that the design of planing craft advanced more than any other time in its history, basically because of the competition requirements for faster, safer, smoother boats.

Once the first "deep-V" hulls were introduced, they were refined for a period of about ten years with tremendous improvement in top speed potential and sea keeping properties. Undoubtedly part of the credit for this must go to the availability of lighter and more powerful machinery but, until the seventies, the naval architecture side was probably the driving force behind this advancement. Two of the most significant boats of that period were *Surfury* (1965), Levi's first *Delta* (". . . an elongated triangle when seen both in plan view and profile . . ." Levi (1971)) and later the Don Aronow built *The Cigarette* (1970).

From that moment onwards, say in the last 20–25 years, very little has changed in high speed planing monohull design, and the golden rules discovered through racing in the Sixties, are basically still applied today.

Regardless of that, top speed increased from about 65 knots in 1970 to about 85 knots towards the end of the eighties; this time the increase in performance was only possible because of the constant developments on the mechanical and propulsive side, with the introduction of more efficient power units, the stern drive and the surface piercing propeller. As a matter of fact, monohulls were now approaching their physiological limit, and several accidents seemed to prove that, at speeds approaching 85 knots, the "deep-V" configuration became unstable both transversely (chine walking), longitudinally (porpoising) and directionally (spin-out).

In a matter of three or four years the entire offshore racing fleet converted to the catamaran configuration which, originally developed by the Italian Molinari family for circuit racing, had been promoted for offshore racing by the British James Beard and Clive Curtis, founders of Cougar Marine (UK).

Nowadays there is not a single monohull into offshore racing, except for the American Superboat "V" class, and the new so called "Endurance" racing in Europe: in these two categories, only monohulls can be entered.

Very briefly, the Americans decided to split the monohulls from the catamarans, in the Superboat category (no limit of power or capacity), so that who wanted to race with monohulls could keep doing it, without having to measure against catamarans.

Endurance racing is something different in as much as it is based on the philosophy of promoting the development of faster and safer production powerboats which, anyway, the rules assume to be only monohulls. Apart from the declared objectives, the impression is that the people who conceived and organized the first real contemporary endurance race, the "Venice-Monte Carlo 1990," wanted to bring offshore racing back to the original concept, i.e., long routes in open seas on powerboats which had to be seaworthy even if with some compromise on pure speed. They synthesized all this in one word: monohulls.

If one has to compare powerboat racing to car racing, it could be said that offshore stays to Endurance roughly as Formula 1 stays to rallies.

Endurance is therefore an evolution in the history of powerboat racing in an attempt to recover the original meaning of the sport. It is a new kind of racing which obviously needs new and different rules and regulations, which are always a matter of discussion. As usual, one of the major conflicts is on how to compare diesel and petrol powered boats, and some politics and commercial interests are always involved. Enough to say that so far the rules have undergone substantial changes every year, and the recognition of Endurance racing from the Italian Powerboating Association (F.I.M.) in 1992 actually seemed to aggravate the situation.

At present, the new 1994 set of rules give a net advantage to diesel boats, and it is easy to prove that, from a technical viewpoint, it would be almost impossible now to design a competitive boat for endurance racing using supercharged production petrol engines. As a direct consequence of this, the steering committee of the "Venice-Monte Carlo," in strong disagreement with the new rules, decided that the race should be run in 1994 with its own set of rules, which doesn't penalize petrol engines.

The steering committee for the "Venice-Monte Carlo" has decided that should the International Powerboating Association (UIM) or F.I.M. not allow the race to be run with an independent set of rules, then the race will not be run, leaving the Endurance racing calendar without its most significant event.

2. Design objectives

The *SM Racer* was specifically designed around the 1993 Endurance rules to be raced in the "P" (prototype) "2" (length between 12 and 15 m) class. These rules for the first year introduced a new formula which, for each class, determined the maximum allowable power for a given length.

It was clear from the beginning that the owner, who was going to throttle the boat himself, wanted an extreme vessel capable of an overall win. The objective was therefore to produce the fastest possible boat within the given rules, capable of sustaining very high speeds even in rough conditions, with a high degree of reliability, and capable of finishing a race even with part of the propulsive plant out of order. As if this was not difficult enough, the rules called for the vessel to be approved by a recognized classification society, and there were limits on the available project budget, as there was no commercial sponsor at the time construction began.

A crew of three had to be carried: the throttle man (the owner, playing the engines), the helmsman and the navigator. Since from the beginning one could imagine that we were talking of a boat capable of top speeds very close, if not above, the 100 knots barrier in open sea; this called for some kind of crew passive safety device, in case of an accident.

The vessel's range had to be of approximately 230 nautical miles at a cruising speed of 80 knots.

3. Power package selection

The choice of the number of engines to be fitted into the boat was to be based on reliability considerations, the requirement of the boat having to finish a race even with part of the propulsive package out of order and last but not least, rules restrictions. The rules fixed the number of engines, in the prototype class, to a maximum of four; it was therefore possible to consider a triple or twin engine installation. The engines had to be of standard production and approved by the register of classification, with no modification whatsoever permitted.

The triple installation was discarded on the basis of the negative influence that three propellers would have on vessel lateral stability at speed. Twin engines, which would seem to be the simplest and easiest choice, would not guarantee the required margin of power to complete a race, should an engine break down; also, as the designer was looking at a total installed power of about 3000 shp, both in the case of petrol or diesel machinery, a lightweight unit delivering 1500 shp was not available on the market.

Four engines seemed to be logical choice. The vessel, driven by four counter-rotating propellers would be totally balanced; in case of one engine breaking down, 75% of the total installed power would still be available to finish the race, and lightweight units capable of delivering around 750 shp were readily available.

As far as petrol or diesel was concerned, the owner already had very clear ideas, based on his previous experience in endurance racing with both engine types. He came to the conclusion that petrol engines would be the best possible choice and he didn't want a diesel boat. The designer and owner agreement on this point was total, so that the boat was basically designed around a four-engine petrol installation.

It must be said that if designer and owner both liked the petrol option, they arrived at this conclusion following different routes. The owner is basically a true sportsman who doesn't just want to win, but enjoys racing against other pilots with different boats and technical choices; it is rather like horse racing, where some people just want to put their money on a known winning horse, while others are ready to bet on an outsider which they believe to have great potential. In this particular case, the last two editions of the Venice to Monte Carlo were won by diesel powered boats, both with the same engines and from the same drawing board: the owner wanted to win with different engines, and with a different boat.

The designer surely enjoyed this kind of philosophy (true sportsman are extremely rare nowadays, at least in offshore racing), but above all felt absolutely sure that the project was feasible and that from a technical viewpoint, following that route, a winner could be produced.

The Italian boating community doesn't generally like petrol engines and looks at them as a cheap option to diesel machinery; "for the money you save, you get an unreliable and dangerous package full of electronics." The least one could say is that there is some misinformation and prejudice. Several factors are responsible for this and one should remember that there is virtually just one big manufacturer of marine inboard petrol engines in Europe and one in the States, while so many companies all over the world commercialize marine diesels which are derived from industrial and automotive blocks. Also, the boatyards are responsible for the construction of fuel tanks and systems, design of engine room vents and so forth: it is therefore much safer for them to sell diesel engine boats, where their mistakes will not have severe consequences. It is in the author's opinion that, in Europe, the use of petrol engines on small planing pleasure crafts (say up to approx. 15 m, 50 ft) needs to be promoted, as these units are lighter, smaller, cheaper and just as safe as their diesel equivalent, provided the installation is properly carried out. Also they generally have much better power and torque curves than turbocharged diesel, while the arguments of higher specific fuel consumption and fuel price are both directly linked to hours of use per year and generally insignificant when compared to the initial cost savings.

While not everyone may agree with these ideas with reference to the pleasure market, in this specific case the objective was a race boat, so that the advantages of having a lighter and smaller engine for the same power already were very significant; a lighter installation also meant lighter hull scantlings to deal with the high inertial forces involved. But, perhaps more important than anything else, the use of mechanically supercharged petrol engines would allow for a response on the throttles unknown to any diesel turbocharged engine.

It is necessary to explain here in more detail the driving technique involved with this kind of vessel. The most important man on board is the throttle man; he is not just setting the pace of the race, but also trimming the boat in what he believes to be the best trim for the sea conditions, with the aid of transom tabs and a bow tank. Still, his main job is to play the throttles in such a way that, as the boat flies out of the water and the propellers become airborne, he reduces the revs on the engines, lessening the strain on all mechanical components; but it is vital that, as the propellers are reentering the water surface, full throttle is applied again so that the hull cuts through the water surface without any loss of forward speed, much lessening the vertical impact forces. It is an extremely demanding technique, originally developed by American Sam Griffith in the 1950's, which requires extreme sensitivity and total concentration. The procedure can be repeated, especially on short choppy sea conditions, virtually continuously, and it is vital that the engines should have great response to the throttle. Petrol engines are generally better than diesels in this respect, because of the smaller rotational masses; but, above all, the mechanical supercharging system doesn't suffer from the typical discontinuous torque curve of diesel turbocharged engines.

The engine chosen was the Mercruiser HP 800 SC, a high performance production unit with full manufacturer warranty, and an impressive reliability record mainly due to its generous displacement (9.4 LT) and low supercharging pressures. The unit delivers 750 shp/560 kW at 5000 rpm, the maximum torque range is between 3500 and 4000 rpm and the fuel consumption is 264 L/hr (70 U.S. gal/hr) at Wide Open Throttles (WOT).

4. Engine room layout

The installation of four engines driving four drive units faces the designer with several options. In this particular case, the goal was to get the shortest and narrowest engine room layout, trying to keep the engine crankshafts symmetrical and as close as possible to the vessel centerline.

A short engine room is required because the optimum location of LCG on these high speed monohulls, for maximum speed on flat waters, is as far aft as possible, and this largely depends on machinery location. Also, internal drive shafts need to be kept as short as possible with much to be gained in terms of reliability and weight of the components.

In plan view, it is essential to keep the installation as close as possible to the vessel centerline, because the vessel beam will be mostly determined by the space required in the engine room.

Symmetry of the engines about their crankshaft centerline is required both for lateral balance of weights and for the need to connect the engines to drives which will obviously need to be symmetrical port and starboard; these drives, again, will need to be as close as possible to the keel so that the propellers are the last thing to leave the water and the first to reenter.

The chosen layout was a double staggered one, which satisfies all the above listed requirements, while leaving optimum space in the engine room for ordinary engine maintenance.

5. Propeller design

For really high speed planing boats, the only feasible propulsion system available today is one based on partially submerged surface-piercing propellers.

This system involves that only part of the propeller disk area is immersed (roughly 50%), so that shaft and bracket drag, often a high percentage of the total resistance, is eliminated. The propellers used are almost invariably of wedge type section, with the number of blades generally varying from three up to nine. Not much published data is available on the design of these propellers and in the offshore racing field the two main manufacturers of such propellers are Rolla SP (Swiss) and Mercury (USA); both produce investment cast high tensile steel propellers, but while Mercury only produces them for its own range of stern drives, Rolla SP will custom design propellers for any kind of application. For the *SM Racer,* Philip Rolla designed four four-bladed surface propellers, of which he gives the following description:

"The propellers for the *SM Racer* were four-bladed, 1.85 *PD* (pitch/diameter ratio), 15 deg blade rake with skew to give a straight trailing edge profile, popularly known as 'cleaver' profile. The propellers were investment cast in ARMCO 17-4-PH steel, and had complete heat treatment cycle in vacuum atmosphere.

The Geometry is exactly as had been tested at the High Speed Free-Surface Cavitation Tunnel at the Technische Universitat Berlin with Dr. Kuppa and the results in full scale running of the *SM Racer* were exactly as predicted from the testing. Efficiency of the propellers from the KT, KQ, ETO curves was 0.745 running at 40% submergence.

The vertical force of the propeller, as predicted from the testing on the six component dynamometer, were also calculated and balanced with the hydrodynamic forces of the hull for an optimum running angle of attack at high speeds.

No modification was necessary to the propellers as machined and mounted on the *SM Racer,* this being the best demonstration of the validity and accuracy of the cavitation tunnel tests, and the absence of any scale effect. The model test propellers were done in the same steel and machined with the same program as the actual propellers so as to be as accurate as the real propeller and the steel used insured no deformation in running on the extremely thin models" (Philip Rolla).

6. VDD 3000 drive system

The required vessel reliability, plus the need of completing a race even with part of the machinery out of order, immediately ruled out the idea of coupling two engines to a single drive unit: from a purely efficiency viewpoint, this would have been no doubt the best possible choice.

As far as the actual drive system is concerned, several standard units are available on the market, the two most important ones being the Mercruiser model VI stern-drive and the Arneson system, both manufactured in the U.S.

The Mercruiser system is basically a "Z" stern-drive mounted at such a height that the propeller works in a surface condition as described above; as on any other stern-drive, craft directional control is accomplished by steering the actual unit, which has a fin rudder incorporated ahead of the propeller; the thrust angle can be adjusted while underway by trimming the entire drive up or down. Propeller counter-rotation and shaft speed reduction are accomplished in the stern-drive gearing and a very acceptable 7% drive train power loss has been recorded on dynamometer tests. While this system has proven its qualities in racing, for this particular installation the designer felt that it was not leaving enough freedom as far as propeller location, with relation to the vessel's centerline, was concerned: the mechanical layout of the stern-drive implies that, in plan view, the propeller should be in line with the engine, while in this case it was desirable to close the propellers as much as possible to the vessel's centerline. Also, it was felt that the weight of four such units would be quite high, and the drag of four steering fins excessive when compared to two bigger rudders which, if located further aft in the propeller stream, could be even more effective. Finally, it must be said that in economical terms these drives were rather expensive when compared to other options.

The Arneson is a patented drive system which employs a propeller shaft tube connected to the drive train via a mechanical joint contained in a transom mounted watertight spherical thrust-bearing assembly, about which the drive can be steered and trimmed. The unit is available both in direct drive or with a transom bolted drop-down chain gearbox, which permits propeller shaft speed reduction; also, and this was of particular interest to the designer, this drop box can be mounted onto the transom in such a position that the upper input side can be aligned with the engine in plan view, while the lower propeller shaft side can be closer to the vessel's centerline, so that the propellers can be located in a more favorable position. Vessel directional control is achieved basically in the same way as on the Mercruiser stern drive, as this unit also incorporates a steering fin ahead of the propeller, so that the same considerations about drag apply; moreover, the actual hydraulics and tie-bar assembly required to steer four of such units would be rather complicated and heavy.

It was decided to custom design a drive system that, based on the Arneson principle, would be incorporated into the aft part of the vessel with the shaft lines fixed both in the vertical and horizontal planes. Steering would be accomplished by means of two spade rudders located well astern, aft of the propellers, while the thrust line angle could only be adjusted during testing, or before each race, by shimmying the special "A" brackets supporting the shaft tubes. The designer felt that this system would be much simpler, lighter and more reliable, while the aft rudders would allow for a drag reduction compared to the standard steering fins plus better directional stability and steering action, as their center of pressure would be located further aft of the vessel's pivoting point. Also, the structural drives and rudders support could be used to accommodate items which otherwise would have to go into the engine room (batteries, holding tanks etc.) and there was even space for two additional small fuel tanks, so that LCG could be shifted further aft for optimum flat water performance. Finally, this layout allowed the design of special rudders which incorporate the engine cooling water pick-ups, which are so placed in the lowest possible point of the boat. This custom drive layout was named Victory Design Drive 3000 (VDD 3000).

The actual drive train, while using the original Arneson's spherical thrust-bearing unit, was completely redesigned and manufactured by Italian BPM. The main differences between the original Arneson components and the BPM manufactured ones were the length and material of the shaft stern tubes, which were lengthened so as to locate the propellers further aft, and machine milled out of solid aluminum-magnesium alloy, with three inner needle roller bearings supporting the propeller shaft, instead of the original two; also, the transom mounted gear boxes employed a full gear system, doing away with the original chain system and allowing for propeller shaft counter-rotation. These units proved to be a real masterpiece of engineering, being extremely light and totally reliable.

On the possible benefits of the VDD 3000 configuration, it was realized that the lower face of the drives supporting structure could be shaped in such a way that not only would it help the vessel getting onto the plane, but also act as a trim control surface that is normally well clear of the water but, on a sudden bow wave encounter, comes in contact with the surface, providing a bow down balancing moment which makes the vessel fly with a level attitude.

The VDD 3000 Drive System is a direct development of the 70's Renato "Sonny" Levi patented "Step Drive," incorporating basically all the concepts originally developed by this undisputed master.

7. Hull design

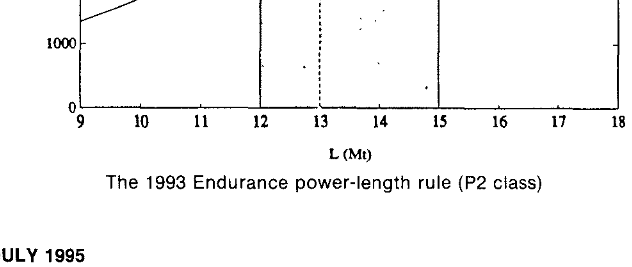
The 1993 Endurance rules, for the first time introduced into this kind of racing a parameter correlating hull length to the maximum power which could be installed. For the Prototype class, this relationship was given by the following formula:

$$P = [(L - 9) \times 20 + 150] \times L$$

where P is power, shp, and L the hull length in meters.

This is the equation of a parabola, which basically allows more power per meter as length increases, trying to account for the nonlinear increase in structural weight with length.

Already at a preliminary design stage, the designer and the owner were looking at an approximate hull length of over 40 ft as this was considered to be the minimum acceptable for handling rough seas at the speeds under consideration. After a final decision on machinery selection was made, it was possible to solve for L in the equation; 3000 shp therefore required a minimum hull length of 13.02 m. As the objective was for the fastest possible boat it made sense to fix the length at a value of 13.07 m, just stretching the vessel 0.05 m to allow a margin which would avoid discussions with the race official measurers.



The 1993 Endurance power-length rule (P2 class)

It should be stressed that this is the effective hull length, from the actual transom, where the drive units are attached, to the foremost part of the hull, excluding any bow pulpit or s-shaped bow. This appears to be a sound rule, which avoids cheater-bows while at the same time promoting a cutaway forefoot which, if proper deadrise values are maintained is ideal for very high speeds. The final hull overall length of the *SM Racer* was 14.67 m (48.1 ft), including the aft drive supporting overhang.

A preliminary estimate showed that the vessel design weight should be between 5500 kg (dry) and 7500 kg (with full fuel tanks). A simple Barnaby-Levi approach indicated that the expected $V/\sqrt{L}$ would be on the order of 17, which is equivalent to a beam based Froude number of about 10. The first consideration was how to retain equilibrium at these speeds.

8. Chine beam

Chine beam is one of those parameters where the designer must really seek an optimum compromise between conflicting requirements. From a hydrodynamic viewpoint, considering the lifting area required at the speeds and loading under consideration, it is clearly evident that chine beam should be minimal for optimum performance. This is demonstrated in practice by the high performance of racing catamarans which employ extremely narrow hulls. As the top speed is largely dependent on power to weight ratio and weight is to be minimized, from a structural viewpoint, again chine beam should be as little as possible. In practice, the designer is fighting against the most obscure area in ultra-high speed monohull design which is transverse dynamic stability (chine-walking). While several theories have been formulated, nothing seemed to give sensible results at the speeds under consideration. Chine beam is obviously one of the main factors in the transverse stability equation, together with the deadrise angle and resulting location of the vertical center of hydrodynamic lift, vertical location of the center of gravity and transverse weight distribution.

Another limit towards chine beam reduction comes from the space required to physically install the propulsive machinery. All these conflicting requirements led the designer towards a L/B ratio of approximately 5. While it cannot be said that beam selection was operated on a purely empirical basis, it must be stressed that, as in many other areas of naval architecture, the designer could not derive a simple equation taking into account all the different aspects of the problem; this is therefore an area which would ideally require some scientific investigation, involving an experimental rig where variables could be systematically changed and the resultant behaviors recorded and analyzed.

9. Deadrise

Deadrise selection on a "deep-V" hull is again connected to several factors, the governing ones in this case being design speed and prevalent sea conditions.

A collection of data from existing vessels will show how deadrise (measured at the transom) is normally gradually increased with speed, with values ranging from about 15 deg for the heavier, slower boats up to 25 deg or more for the light, fast ones. Levi, who is probably the single most experienced and influential designer in the field, in ref. 1 deals with the possibility that at very high speeds a deadrise reduction over the recommended values might be desirable in terms of pure efficiency. Again, this seems to be confirmed by the relatively low deadrise values found on offshore racing catamarans, but in this case the vertical impact forces are cushioned by the considerably high tunnel aerodynamic pressures.

For the *SM Racer,* while the mean deadrise value was slightly below the typical 25 deg, the designer adopted convex transverse sections which effectively reduced deadrise towards the keel and increased it towards the chines. This shaping of the running surface also affects the flow pattern so that the center of hydrodynamic lift is shifted forward (compared to straight sections), while helping flow separation of the spray rails.

10. Stepped hull form

For a given deadrise, lift is a function of speed, planing area and angle of attack so that, as speed increases, either planing area or the angle of attack, or both, will have to decrease to produce the same amount of lift (approximately equivalent to the vessel weight, at very high speeds).

On a prismatic deep deadrise hull, because of its shape, a substantial reduction in planing area is possible as the vessel lifts bodily out of the water; this allows for a lower rate of angle of attack reduction with speed, when compared to a flat bottomed hull, and consequent better *L/D* ratios. Nevertheless, for equilibrium, as speed increases the waterplane will still need to lengthen so that the longitudinal center of pressure (LCP) is always vertically in line with the longitudinal center of gravity (LCG); therefore, the tendency is for the waterplane area to get narrower (until a point where even the chine is dry) and longer. This shape is both inefficient in terms of resistance (low aspect ratio and shallow angle of attack, with consequent high wetted area and frictional drag) and dangerous in terms of directional stability (forward location of the center of lateral pressure, CLP), while the wetted beam reduction has a negative effect on lateral stability.

Furthermore, as the steeper bow buttock lines touch the water's surface, a sudden shift forward of LCP will cause a bow up moment which will almost instantaneously lift the bow well clear of the water, while simultaneously increasing the angle of attack of the aft planing surfaces: this, in turn will violently shift LCP aft of LCG, starting a rhythmic pitching action (porpoising). Moving LCG as far aft as possible, while improving things both in terms of resistance and stability on completely flat waters, will also produce excessive bow response to external forces, so that the sudden encounter with a wave will make the craft airborne and, in the best case, initiate the porpoising action. While trim tabs and bow tanks are essential, they do not solve the basic problem of such a hull configuration; the most effective system is a variable thrust line system, where it is possible, within some extent, to balance the hull longitudinally into the most desirable trim for the particular sea conditions; this must involve a loss in propulsive efficiency, as the thrust vector is not used purely to propel the vessel. It is interesting to note that virtually all American racing or fast pleasure monohulls, which generally employ an unstepped "deep-V" hull, use some kind of variable thrust line drive system.

To solve the problem, two transverse steps were incorporated into the *SM Racer* hull. The basic concept was to have a middle surface close to the LCG, with the forward and aft portions of the hull stabilizing the craft longitudinally; also, the hull is running on three areas of contact which can be set at a more favorable angle of attack and have a higher aspect-ratio, while a wetted area reduction is possible because of the flow detachment at the step. Some "rocker" is usually built into the aft planing step, i.e. this surface is set at a lower angle of attack with reference to the base line; this is mostly done for top speed considerations, to reduce the lift aft and therefore mitigate the tendency to a flat running trim, but also helps in following seas where bow response is required. On the negative side, "rocker" will almost invariably introduce, again, a slight porpoising motion at a well defined speed; this time the problem, caused by a slight unbalance of the forward and aft lifting forces, is of minor concern and is easily cured by the application of a small angle of attack on the trim tabs, effectively increasing the lift of the aft section and balancing the system.

Step geometry is a highly complicated area of the design which is based on semi-empirical basis, where the designer's experience and personal feelings have a lot of influence. The designer found the most interesting reading about the subject to be some pre-war books dealing with the design of flying boat hulls and floats; the problems there were slightly different, but the basic line of reasoning could still be useful.

Generally speaking, it is felt that steps will increase the vessel's average resistance in rough conditions, when the boat is often airborne and, on water re-entry, the aft vertical face will not be ventilated, causing a peak of resistance due to the low pressures generated in that area of the hull. Ducting air to the vertical face of the step is in theory an excellent idea, but somehow difficult to arrange, especially on composite boats where cutting holes in the hull shell is structurally very undesirable.

A configuration employing a great number of very short steps would probably be extremely fast on flat waters, but inefficient in rough conditions. Conversely, a single step is a feasible proposition, except that it is a less forgiving layout, where the surfaces angle of attack and longitudinal step location with reference to LCG need to be absolutely right, the risk being that the vessel will be bouncing from one step to the other if the system is unbalanced; also, as two points of contact are the minimum required for maintaining equilibrium, should the forward step become dry, the sudden shift of LCP aft would cause a powerful bow down moment which again might promote porpoising.

Three points of contact, and therefore two steps, seemed to be a good compromise between balance of forces, drag experienced in both flat and rough conditions and above all it allowed, when compared to a single step geometry, more freedom in trimming the hull while underway by shifting LCG and/or LCP.

While trim tabs and bow ballast tank are essential for getting maximum performance on different sea conditions, such a hull shape does not necessarily require, unlike its unstepped counterpart, a variable thrust drive system. This does not mean that such a system would be of no use at all, but simply that if other considerations discourage its adoption, the basic performance and stability of a properly designed stepped hull will not be compromised by a fixed drive configuration.

11. Spray rails

Spray rails are vital to both performance and handling properties, exactly as on an unstepped deep-V hull; as it is now well known, these longitudinal strakes, of triangular cross section and generally horizontal lower face, basically provide lift and promote flow separation reducing wetted surface area and hence frictional drag. While everybody generally agrees that in the aft body they should run parallel to the keel, several different contours have been tried in the forebody, from along the waterlines to the diagonals and the buttocks. In the first case, the excessively low angle of attack will produce poor lift (bow response), while the exposed vertical faces promote directional instability (risk of broaching). Following the buttocks places the rails at an excessive angle of attack with high drag, poor lift and little spray suppressing effect. There seems to be plenty of theory and practical applications to say that the best solution is to run them roughly parallel to the chine, carefully considering both the widths (taper) and deadrise angles needed towards the bows. Apart from resistance considerations, spray rails will improve vessel dynamic roll stability, as the bottom faces on the depressed side will have a greater angle of incidence.

Contrary to general principles, the designer decided not to have spray rails in the aft body, other than the chine rail, in an attempt to keep the chine wet aft for transversal stability considerations. The *SM Racer* had two spray rails per side in the forward part of the hull, one on the middle surface and one aft.

12. Deck design

At the speeds these vessels operate, aerodynamic lift and drag are of considerable significance. Drag reduction possibilities are limited by other requirements but clearly attention should be paid to producing the cleanest possible upper works, and in this case, care was taken to make changes in cross sectional areas as smooth as possible in accordance with an "area rule" approach to minimizing pressure drag. Aerodynamic lift and, in particular, the longitudinal center of lift are of greater significance, especially on those occasions when the craft becomes airborne. It is highly desirable that the boat "flies" in as level an attitude as possible, but with a small tendency to pitch bow up. To achieve this, the center of aerodynamic lift should be close to, and forward of, the longitudinal center of gravity. A simple flat deck profile will not achieve this result since the center of lift for such a configuration will be about 35% of length aft the stem. The desired outcome is produced by incorporating convex curvature in the profile towards the after part of the deck. This will lower pressure over this area and then move the center of lift aft.

Attempts have been made to influence transverse stability by the use of aerodynamic aids in the form of wings set at a dihedral angle. Such devices may have a beneficial effect on longitudinal aerodynamic stability but do not help transverse stability except perhaps by increasing roll inertia and thus period. Wings set at a dihedral angle only promote roll stability when side slip velocities are relatively large, a situation that should not arise for a surface vessel. Apart from the additional drag created, a wing system will raise the center of gravity and it is a measure of their lack of effectiveness that those boats that are fitted for them usually remove them for races that are to be run in other than flat sea conditions.

Aerodynamic effects may influence transverse stability, especially in cross winds, if the deck to topside joint is incorrectly treated. If this joint is given a radius which is structurally (and aesthetically) attractive, then it is possible that transverse airflow will remain attached as the boat rolls. Since the center of lift will be closer to the windward edge, this will produce a substantial roll moment leading to a serious risk of capsize especially if the boat is airborne. Similar effects may arise with attached water flows were the boat to land on its topsides rather than bottom panels. Clearly it is desirable to ensure that both air and water flows will separate at the lowest possible angles of attack and this is best achieved by keeping the deck edge to topside joint as sharp as possible. Excessive deck camber should also be avoided and it may be worthwhile incorporating a topside spray rail or knuckle to encourage flow separation should the boat be heavily rolled. This feature was incorporated in the design of the *SM Racer*.

13. Safety

The sport of power boating, as all disciplines involving humans travelling at high speed, from skiing to Formula Indy racing, does involve a component of risk, almost always connected to a loss of control of the vehicle employed. It is not intended here to try to understand what a good pilot should do to prevent an accident, especially as the racing environment introduces several variables difficult to evaluate.

The measures one can take at a design stage are fundamentally based on active and passive safety criteria.

Given for granted that the designer is making an effort to produce a vehicle which is as stable as possible, one must always consider the situation when the system will not be able to self-restore itself to a balanced situation, so that pilot action is required in order to reestablish equilibrium. Further than that, the unfortunate event of a "nonreturn" situation where nothing else can be done to prevent the accident must also be considered.

Therefore, the design of the *SM Racer* required the investigation of three levels of safety:

1. Vessel primary behavior (passive safety)
2. Vessel reaction to crew corrective action (active safety)
3. Crew protection in case of accident (passive safety)

The vessel primary behavior and its reaction to crew corrective actions are connected to hull shape, control surfaces size and design, c.g. location, weight distribution, free surface effects and so forth; these points are discussed elsewhere in this paper, so that here we will concentrate on the third point.

Passive safety in case of an accident is an involved matter which would in theory require the consultantcy of specialists in the field. Still, these people are often so specialized in their own field, for example the car industry, that they have problems in switching to an environment with totally different problems and mechanics of the accident. Also, it must be said that successful passive safety design would require a lot of extremely expensive full size testing, plus a lot of R&D work: the budget and time allowed for the complete design of a racing powerboat such as the one described in this paper, does not leave enough freedom for proper exploitation of the subject.

Still, since from the first proposal drawing, the *SM Racer* made use of an enclosed safety canopy with two roof mounted access hatches. This system involves that the crew should be seated into car racing style bucket seats and well strapped in, with a five-point quick release harness system. Seating the crew and restraining their movement allows the reduction of the volume of the canopy and its transparent area to the minimum required; this obviously increases its overall strength.

The canopy was shaped around a molded polycarbonate optical screen available on the market. This screen is manufactured in Texas, and is basically a polycarbonate shell with an outer acrylic ply, for scratch resistance, bonded by a urethane film, for a final thickness of approximately 18 mm. Its compound shape further increases the impact resistance, and the general building technique is basically the same employed on F-16 fighter plane canopies (same manufacturer).

The non-transparent part of the canopy was built in composite materials, as was the rest of the boat, with carbon for overall rigidity and Kevlar for impact resistance. The lower perimeter of this enclosed "bubble" was bonded onto the deck in way of substantial below-deck secondary structure; the aft side rests on the engine room bulkhead while half way through, between the two front pilots and the aft one, an internal stiffening composite frame was inserted.

Two more transparent fixed windows were cut in the aft sides of the cell, one port one starboard, for the aft seated pilot side visibility; these two side windows were made of 19 mm Plexiglas, on account of their smaller area and, in theory, less exposed position.

Normally, on all other offshore racing powerboats employing similar protection systems, the transparent surfaces are fastened to the rest of the canopy by through bolting onto a resting flange. The designer did not believe that, on impact loading, this would be a satisfactory solution, as it is very likely that cracking would propagate from the actual fastening holes because of excessively rigid local restraint, where the polycarbonate or the composite bolting flange would have to give away before the actual bolt. Also, already during the screen installation, it was more than possible that over tightening of one or more bolts could damage the screen; large washers would improve, but not altogether solve, the problem.

It was therefore decided that no drilling of the screen and the flange should take place, and bonding would rely on modern elastic adhesive technology, using a polyurethane based product. The adoption of such a system seemed to bring the following benefits:

- Total elimination of stress peaks, typical of mechanical joining techniques
- Great tolerances allowance (up to 5 mm) in screen to flange connection, with virtually no loss in tensile shear strength of the adhesive layer
- Perfect joint water tightness
- Flush screen installation
- Reduction of structural vibrations transmission to the screen
- Much simplified installation

Also, the decision took into account that, in case of an accident, the system would only have to deal with an externally applied load, putting the adhesive layer almost entirely in shear, which is the most favorable loading condition for these polyurethane bonding adhesives.

An enclosed cell of the type developed for the *SM Racer* is mainly intended to protect the crew from the impact with water, should the deck come in direct contact with the surface at speed; this can happen as a consequence of nose-diving, barrel-rolling due to a sudden loss of directional instability, some kind of pitch-poling, or simply rolling over because of a resonance between the vessel rolling motion and the encounter with a train of waves, not properly handled by the pilots: in all cases one can imagine that the deck could touch the water's surface with the vessel still retaining its full original speed; and it is unlikely that, at the speeds involved here, a human being could survive such an impact.

There are some people who still are against enclosed safety cockpits, as they fear that the crew might be trapped inside after the accident, should the boat remain in a capsized position. In this case, the only thing one can do is to provide each crew member in the cockpit with a personal air bottle, so that they can either wait for some external help (there is often helicopter assistance with frogmen ready to help in these races), or try to get out themselves; the real enemy, obviously, is panic. Things are further complicated if the crew is in an unconscious condition, but it is likely that at least one of them will be able to help the others. Careful design of the hatches and their locking system is required to be able to exit the vessel in a capsized position in the easiest possible way. As far as the hatches are concerned, they obviously need to be as big as possible, without weakening the actual canopy, and they can only open outward: this raises the problem that outside water pressure will fight against the crew or a frogman trying to open it; this is why the cockpit has to be floodable, even if at a slow rate. The problem of the hatch locking system is more involved, as a system is required which should be extremely easy to operate both from inside and outside, while at the same time being able to keep the hatch securely closed under normal conditions.

After some research, it was decided to design a custom made latch, based on a spring operated bolt, which could be opened by pulling a wire running along the entire length of the hatch inner surface, which could be easily grabbed even in a panic situation; the spring action of a thick rubber seal around the edge would then avoid the hatch locking again once tension from the wire was released. From the outside, a red handle would be connected to the same latch through a small hole, so that all one has to do is to pull it. In normal conditions, to close the hatch there is a small handle from the inside, so as to apply enough pressure to squeeze the perimetrical rubber seal.

14. Structural design

A successful structural design, while always of the utmost importance, was absolutely vital for this particular project, as hull weight and position of the actual vessel's center of gravity had to be located exactly where it was decided at the preliminary design stage. On top of that, while researching maximum lightness, the structure had to be approved by a classification society (in this case the Registro Italiano Navale) and if local minor failures under particularly demanding conditions are somehow acceptable in a racing environment, the nature of the project clearly faced the designers with an extremely high "consequences factor." In other words, at the speeds under consideration, any serious structural failure might immediately progress to a catastrophic state potentially leading to a loss of human lives.

When dealing with advanced composite materials under extremely demanding conditions, it is essential that specialists in the field are involved in the structural design. Victory Design s.r.l., in assembling the design team for this specific project, choose Mr. Luca Olivari, one of the world's leading experts in the field, to be responsible for the structural design of *SM Racer*. Mr. Olivari had large previous practical experience in the structural design and analysis of composite ultra-high speed powerboats, mainly Class 1 Offshore racing catamarans.

The *SM Racer* was entirely built in sandwich panels with unidirectional glass, Kevlar and carbon skins around foam cores of varying densities and properties.

The project budget did not allow for the use of pre-pregs and large quantities of carbon fiber, so an epoxy resin wet lay-up technique with vacuum bagging and thermal post cure was adopted. The decision not to use a full carbon structure was not only based on budget restrictions, but also on overall impact resistance considerations, keeping in mind that it was more than possible that the vessel might hit some floating object when at full speed. This last consideration also led to the introduction of specially designed core crack propagation barriers.

The successful operation of the *SM Racer* proved that the laminate analysis was absolutely right in showing that it was possible to have three widely different materials as glass, Kevlar and carbon all working together. The final result was an extremely light, strong and stiff structure produced at a very competitive price when compared to "traditional" high-tech composites construction.

As far as the bottom core selection was concerned, theoretically it was possible to use an aluminum honeycomb which could easily take the predicted shear stresses, but fatigue resistance consideration in way of skin bonding and especially the required material "memory," i.e., the capacity of taking locally applied loads higher than those predicted without going into the plastic state and starting a delamination process, suggested the use of an expanded PVC core. In particular, a new high density cross-linked ductile type PVC had been developed, initially for application on mine hunters, with noticeably good fatigue resistance properties and an excellent 48% elongation at breakage.

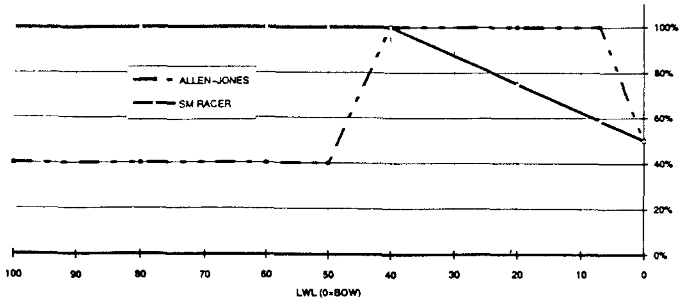
Impact pressures were calculated using the Allen-Jones method, but employing different impact acceleration values derived both from previous experience (full scale recordings with accelerometers on similar vessels) and checking the results against the deformation of the bottom plating of an aluminum Offshore Class 1 racing monohull of some years ago. Finally, the total bottom structure was analyzed with finite elements at the design pressures.

Considering that the average bottom panel size between stiffeners was about 0.7 to 0.8 square meters, based on the design pressures derived, the loading on each panel was approximately 12 000 to 15 000 kg (120 to 150 knots), i.e., a factor of 2 on the vessel weight. As the minimal impact area is going to be greater than at least two panels, it can be deduced that this loading included a high dynamic factor, as one would expect on this kind of vessel.

The Factor of Safety on the *SM Racer* structures was higher than normally found on other racing boats. For example, if composite racing catamarans have a factor of safety from 2 to 3, here, with the *SM Racer,* it went from a minimum of 3 to 3.5. One of the Register requirements which had to be met was that each structural element should have a maximum deflection under its maximum design load not greater than 1/200 of its span. It might be of interest to know, that as a measure of the hull stiffness, finite element analysis showed the maximum deflection measured at the keel to be approximately 5 mm with the full bottom design load applied.

Preliminary estimates showed that, should the boat be built on male molds, up to 200 kg of filler would be required to finish the hull outer surface, as one must remember that, unlike many sailing or displacement vessels, here the shell thickness varies a lot in different areas, and the aft planing surfaces can be three times thicker than the topside thickness. It was therefore decided to build a direct plywood female mold and this technique proved to be feasible and very successful.

Spray rails were not molded into the hull in order to keep the shell laminate continuous and with minimal change of orientation of the unidirectional fibers. The final bare hull weight of the *SM Racer,* painted and with the canopy and all hatches, was around 2500 kg. This must be regarded as a very good result considering that the vessel proved capable of handling force 4 sea states at speeds of around 75 knots, without any major structural failure.



15. Trials

The *SM Racer* was rigged in Belgium and went on trials on the 2nd of June 1993 on the river Schelde. The vessel was loaded with about 800 liters of fuel and in a very light condition as some components (life raft, fire extinguishers and the like) were not on board for these first runs. She floated exactly on her DWL when at rest and this already showed that our efforts in keeping LCG in a well determined position had been successful.

A series of runs at very low speed (up to 40 knots) demonstrated the vessel's capability of getting very easily on to the plane, with no help at all being required from the trim tabs. These preliminary runs were also necessary in order to check all on-board installations and for a minimal running-in of the machinery.

Finally, the *SM Racer* was brought, through some channels, to the broadest section of the river in the area, and there the throttles were opened to the maximum. The GPS recorded a maximum continuous top speed of 103.5 knots equivalent to over 119 mph, the boat being totally stable both longitudinally and transversally. At a speed of about 85 knots a slight porpoising motion was recorded, but a small positive angle of attack on the trim tabs, which did not seem to affect the speed, dampened the motion out completely. This moment officially concluded the design stage, with the vessel living up to the most optimistic predictions. The complete absence of the chine walking phenomena on mirror-flat waters and in a very light condition were, from a design viewpoint, probably the most noticeable result.

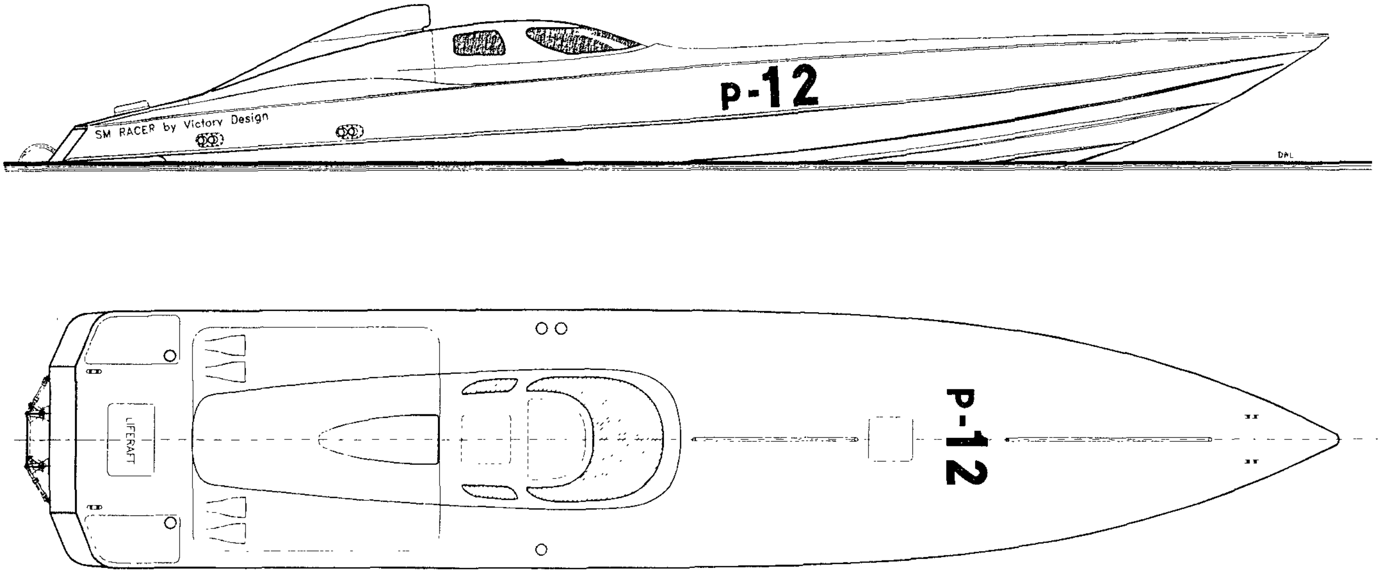
16. Venice to Monte Carlo, 1993

The boat was moved from Belgium to Italy about thirty days before the race start. During this period a lot of further work was carried out, basically fixing part of the on-board systems which, during trials, showed signs of weakness or did not work as expected. Also, some porosity in the fuel tanks caused a leakage which, while not worrying at all from a purely technical viewpoint, involved re-opening the tanks, losing precious time for proper sea-trials which are essential for tuning up such an extreme and innovative prototype as the *SM Racer*.

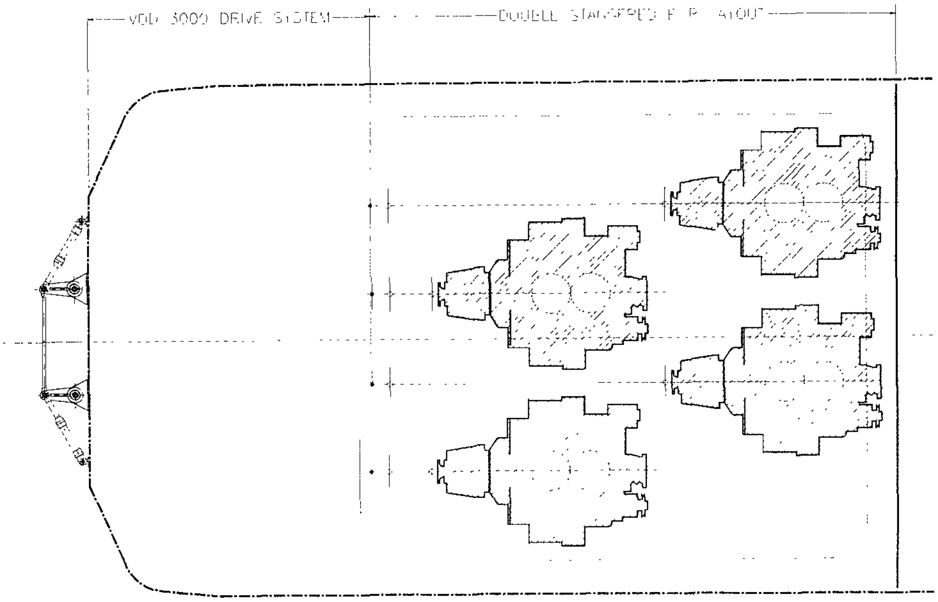
But above all, the entire team, from the owner to the designer, were extremely busy fighting in court against the organizers of the 1993 Endurance championship: the steering committee, apparently with the support of the Italian Power Boating Association (FIM), had decided to change the rules about twenty days before the start of the season, ruling out the *SM Racer* from the competition. Only the strong team reaction finally solved the situation as the application of the new rules was postponed.

The day before the start of the race, another important test was done as the vessel was run on three engines only, and a very promising top speed of approximately 75 knots was achieved in this condition.

Finally, on July 21st the race started, in extremely rough weather conditions. The owner asked the designer to be on board as the navigator, a chance at which he jumped immediately, more for the opportunity of checking personally the results of his work than for the pure pleasure of racing. The *SM Racer* led the pack until, after about twenty minutes, the warning light from a bilge pump forced the crew to stop and check what was going on in the engine room. Here it was discovered that the immersion type plastic pumps were



Profile and plan view



Engine layout

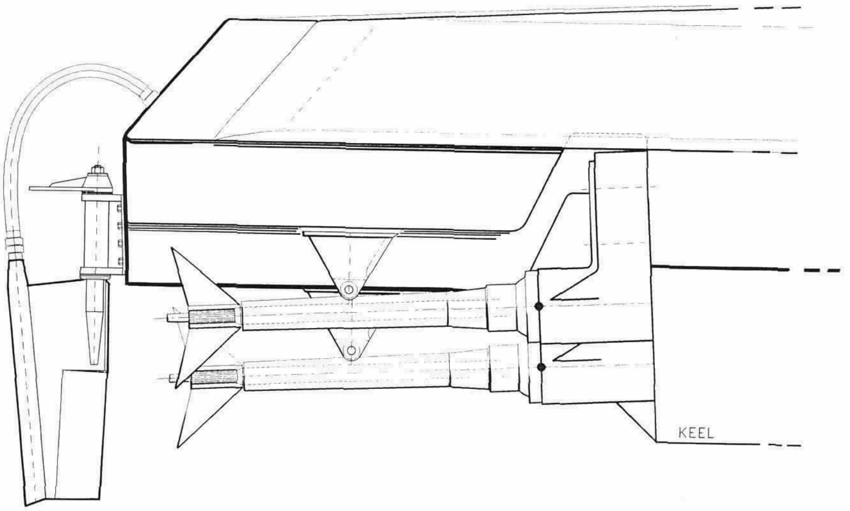
smashed in bits and pieces because of the extremely high impacts. Apart from that, everything else was okay. The *SM Racer* had lost some time but the race could be continued. After about another thirty minutes, one of the hydraulic steering system connections started leaking and at each impact some oil was lost. The crew decided to slow down so as to be able to finish the leg. Once in Giulianova, after about 185 nautical miles of race in a sea state of force 4 to 5, the *SM Racer* was second overall, at twelve minutes from the first boat. Considering all the troubles incurred and the fact of having slowed down so much for the second half of the race, the result was encouraging for a brand new race boat.

This, and the following legs were, for the *SM Racer,* more than an actual race—the first real open sea trials which in theory should have taken place before the actual competition.

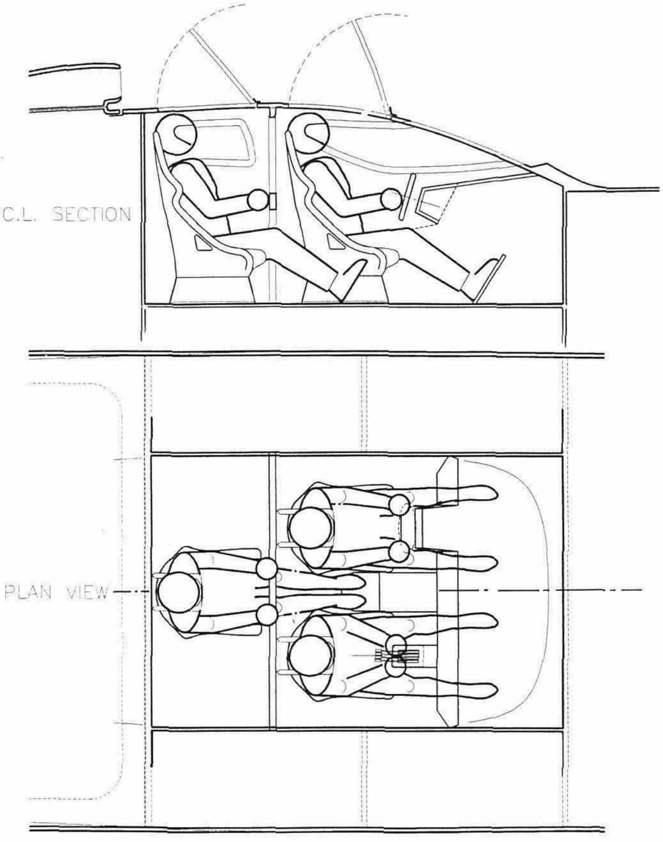
While in general the vessel's behavior was always and by everybody, both crew and competitors, considered excellent in any sea state, a series of minor problems plagued this first race. In particular, a structural weakness of the gunwale in way of the engine room deck opening was discovered and the cast aluminum trim tabs proved to be unexpectedly too weak, cracking in several places and also damaging the actual transom. While these weaknesses obviously were something which in theory should have been predicted at a design stage, it is important to point out that this was by far the toughest "Venice–Monte Carlo" to date, and the crew always pushed the vessel to, and possibly above, its limits. It is probably a good indication of the toughness of the race that the throttle man suffered a spine injury during a particularly hard water reentry.

Another area which showed some weakness was the bonding of the wooden spray rails to the hull shell, and possibly not enough attention was given to this detail, from a purely craftsmanship viewpoint, during construction.

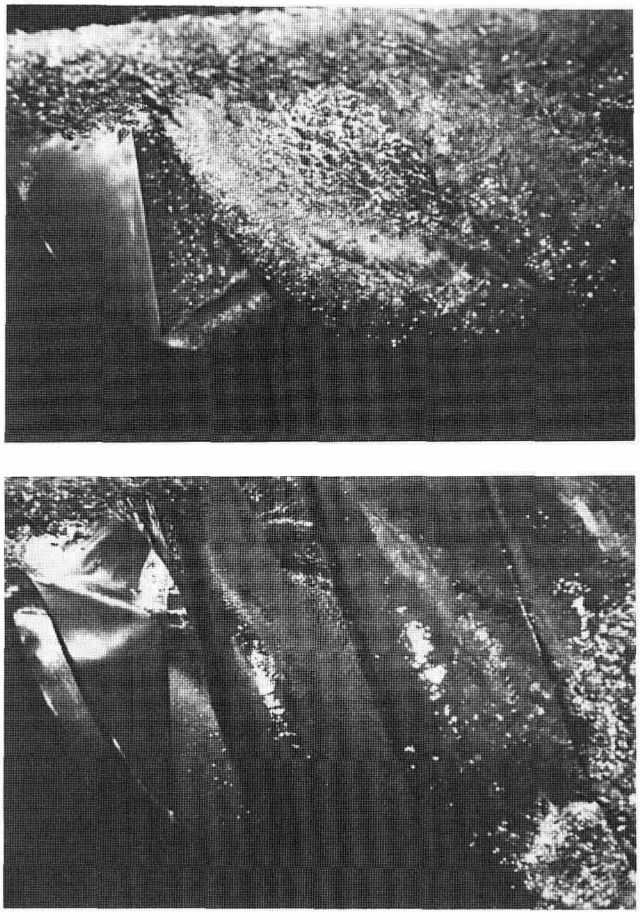
Regardless of this, working overnight to start the next leg



Victory Design Drive 3000



Cockpit layout



Views of propeller tests: (top) 40% immersion; (bottom) 50% immersion

the morning after, the *SM Racer* was basically always in the lead when some problem cropped up, and always managed to finish the race at least in second place.

Finally, the *SM Racer* very convincingly won the Vibo Valentia-Ischia leg, establishing the new record for Endurance racing at over 78 knots of average speed. During the night in Ischia, the *SM Racer* underwent an act of sabotage, as unknown perpetrators damaged the inspection hatch gaskets to the fuel tanks. While the team decided to bring the vessel to Monte Carlo anyway, the *SM Racer* was practically ruled out of the race.

Apart from the final sabotage, which is something very difficult to accept or understand, this first race must be considered very positive from a technical viewpoint, as the design proved to be absolutely capable of fulfilling its initial objectives and the problems were of a minor nature.

Soon after the race the team started working on the trim tabs and reinforced the gunwale aft and the spray rails bonding, getting the vessel ready for the next race, the "Cowes Classic '93."

17. Cowes Classic '93

This 33-year-old race is a milestone in the history of power boating, and its previous winners include some of the most influential personalities of the sport like "Sonny" Levi, Dick Bertram, Jim Wynne, Don Aronow, Don Shead, James Beard and many others.

Pre-race tests showed that the *SM Racer* was in perfect condition and a top speed of about 120 mph was recorded in the Solent waters.

This was basically the first time Endurance boats entered the race, while its previous editions were dominated by Offshore Class 1 raceboats. The record for the race was held by a petrol powered Class 1 catamaran at 90.98 mph set in 1990.

The morning of the 29th of August, the race started from the Isle of Wight, in ideal weather conditions. As usual the *SM Racer* took the lead, but almost immediately, for unknown reasons, the GPS signal was lost. The crew decided to keep side-by-side with the next fastest boat in order to be sure not to jump any race mark and stayed in this position for about three-quarters of the race. Also, the throttle man noticed a loss of power from two engines but, regardless of that fact, he was still capable of controlling the race. When the last buoy was turned, the throttles were opened to the maximum and the *SM Racer* crew was easily first in Cowes, with a twelve minute advantage over the second boat. The 184 nautical miles course had been covered in 2 hours 18 minutes and 14 seconds at an average speed of about 80 knots (91.76 mph) which was also the new record both for the Cowes Classic and for Endurance racing. The loss of power was confirmed after the race by the two forward engines having lost, apparently early in the race, the supercharger driving belts; in this condition, the *SM Racer* had lost about 500 hp in total.

18. Conclusions

Practical operation results placed the *SM Racer* among the world's fastest monohulls at the time this paper was written. The most impressive side of this result is that the *SM Racer*'s basic ingredients are not extreme components born for pure racing, but simply high performance items which could be incorporated in any production boat, as the vessel carries full register classification and is regarded by the authorities as a normal pleasure boat. This proves that today it would be possible to build a pleasure, military or commercial vessel capable of averaging speeds close to 80 knots on relatively long (200 nm) offshore routes.

It is feared that Endurance racing might not develop at the expected rate mainly because of the shortsightedness of the rules imposed by the Italian Powerboating Association (F.I.M.), which are not, as one would expect, the result of discussions with designers, builders, pilots and engine builders. The excessive advantage given to diesel boats can be qualified by saying that the *SM Racer* would now need to be 19 m long (62 ft) to be allowed to use its current power package, while the same hull could be retained if, for example, four turbo diesel engines, giving about 850 shp each, were to be installed.

It is hoped that in the future the nautical industry will somehow support powerboat racing as a logical extension of scientific research and development activities.

Acknowledgments

This paper has been written mainly thanks to the strong encouragement and the valuable help of Wayne Thomas and Rik van Hemmen, to whom the author is extremely grateful.

The *SM Racer* would not have been built without the enthusiastic determination of an exceptional owner, Sergio Mion, who never lost faith in the designer's work, even when some problems cropped up. Both him and his driver and co-owner, Giuseppe Amati, jumped into this project determined to build a new and innovative vessel, taking all the risks involved. Thank you for the faith you showed in me.

The author is also in debt to all the people which, in one way or the other, contributed to the design and the construction of this rather exceptional vehicle. The final result proved that people fighting together for a common objective is very powerful.

Finally, I would like to thank all the people who tried to stop, several times and in several ways, the *SM Racer;* they only managed to make our motivation stronger and give us more confidence in the vessel's potential.

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