'THE APPLICATION OF SLENDER HULL TECHNOLOGY IN POWERED YACHTS AND SMALL COMMERCIAL CRAFT'.

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PREAMBLE

This paper sets out to examine the role of slender-hull forms in the current powerboat market (both leisure and commercial), and suggests how that role might change in the future.

The first section will consider slender single-hulled semi-planing vessels and the second section will deal with slender hulls as applied to multihulls.

Although fuel prices are currently on the increase fuel is still a relatively cheap and available commodity but that the availability of suitable berthing facilities (mainly marina berths) is not. This has encouraged the development of short planing-hulled vessels. Whilst these are usually fuel-efficient at high speed in reality they may often be operating at low to medium speed - often because of adverse sea conditions. At these lower speeds their performance is often unsatisfactory and inefficient.

As a general rule, vessels that spend longer at sea - travelling greater distances, and less time in port (e.g. working patrol boats) will enjoy the economic and sea keeping benefits that longer length offers whilst living with those less harbour-friendly dimensions when not.

At the other end of the scale a leisure powerboat that is seldom away from its home berth for more than a few hours at a time and does not log many sea miles in a season will be happy to keep berthing charges as low as possible and accept higher fuel costs.

1. SINGLE-HULLED VESSELS

1.1 'SLENDER HULL' DEFINITION

In the context of single-hulled vessels the term 'slender-hulled' is used here in the absence of a more accurate generic term to describe any vessel that reaches its design speed with little or no dependence on dynamic lift. The following parameters describe the nature of these hulls:

a. Design speed would normally be in the region of up to 2.0 **x** √dwl(ft) although 2.5 **x √dwl(ft)** would still be realistic as a maximum cruise speed – at which point there would a degree of dynamic lift would be present. There is, therefore, no pretence that slender single-hulled vessels can be as suitable for high speed operation as dynamically lifted hulls

b. Favorable displacement/length ratios are at the heart of a successful non-dynamically lifted vessel. Typically they will need be less than 100. [where DL = Displ. (long tons) /(0.01 x dwl $)^3$].

c. Slenderness ratios (W.L.beam/length) of better than 4.5 would be typical for this kind of vessel – which is achievable without loss of stability as a simple consequence of the low centre of gravity associated with low a displacement/length ratios.

N.B. The above parameters become progressively unreliable as bigger craft are considered.

1.2 SLENDER HULL QUALITIES

Mankind has been building more easily-driven hulls by making them long and narrow since he learned how to hollow out half a tree trunk, and it is only during the 20th century that the search for higher speeds has lead to the inevitable use of some kind of dynamic lifting technology to break free from the clutches of excess wave-making drag and, ultimately, skin friction – the Achilles heal of the slender hull.

As operating speed/length ratio increases it is well established that there comes a point where at least some degree of dynamic lift is necessary to avoid the need to apply exponential amounts of power.

The point at which this dynamic lift becomes essential depends very much on the configuration of the vessel in question; if it has a favourable displacement/length ratio, for example, then a non-planing or semi-planing hull form can be driven faster without incurring excessive drag penalties but with only modest amounts of dynamic lift being generated.

To some extent favourable (low) displacement/length ratios may be achieved simply by using lightweight building technology but it is more likely to be the result of a fundamental design decision to cut down on both the living volume and complexity of its on-board systems (referred to as ‘diminished (or enhanced) living facilities’ hereafter).

It is obvious therefore that to provide comparable living facilities on a vessel that has a favourable displacement/length ratio that vessel must be longer than its high displacement/length ratio counterpart. As a result that non-planing or semi-planing performance potential is being enhanced not only as a consequence of a more favourable displacement/length ratio but also simply as a result of a longer waterline length.

As displacement/length ratios become more favourable it is also likely that the centre of gravity of a vessel will also be lowered. This allows the hull to be designed with a narrower waterline than the more voluminous vessel and yet still meet the same stability criteria. That narrow waterline will, in turn, further add to the efficiency of the already- efficient low displacement/length hull.

If a case can be made for a slender hulled vessel purely on grounds of low-medium speed efficiency then it should be added that good seakeeping qualities are usually available as a bonus. There are several areas in which slender- hulled vessels excel:

a) The dilemma with any planing-hulled vessel is to choose a dead-rise angle that is low enough to allow planing to occur at relatively low speeds (and reasonable power) and high enough to limit the hull’s propensity to slam when powering to windward. The sections of a slender-hulled vessel can be as deep as necessary to promote a more gentle upwind ride as the hull is not being asked to provide dynamic lift. The most sea-kindly planing hulls usually have high dead-rise angles but, in consequence, high installed power requirements. If they are designed to be able to make way fast upwind in almost any conditions (e.g. lifeboats) then they will also be heavy – which will again call for more power.

b) A relatively slender-hulled vessel can provide a good quality of ride upwind as a result of being long enough to span wave crests, but it should be noted that if the rate of wave encounter of such a vessel when making way upwind happens to coincide with the natural pitch frequency of that vessel then ride quality will rapidly deteriorate – to the point where it will be necessary to change that rate of encounter - either by slowing down or speeding up the vessel, or by changing heading.

c) Planing-hulled vessels can be difficult to manage in following seas; by their nature the half-angle of entry of their waterlines is often very high – especially above the chine. If powering downwind in strong conditions there is a danger that such a vessel will plane into the back of a wave where it will decelerate very rapidly. As the mass of the engines is often well aft on a planing-hulled vessel there can be a tendency for the stern to try to overtake the bow. This is aggravated by the fact that the rudders - which are usually designed to operate in the back-wash of the propellers – will lack area when the power is suddenly taken off . The result is that directional stability is difficult to achieve and progress can be slow and laborious at best - and dangerous at worst.

1.3 SLENDER HULL DRAWBACKS

Whilst on paper more and more extreme displacement/length ratios generally yield ever-greater efficiency it is clear that in practical considerations usually set limits on the dimensioning of any new vessel. The inescapable truth is that harbour dues and mooring charges are usually levied on a per-unit-length basis – many marinas charging an increased tariff ***per metre*** for vessels over certain threshold lengths.

There are also other financial burdens to be born by the owner of the longer vessel: In the following comparison between a standard planing-hulled and a slender-hulled a common nominal displacement of 5.5 tonnes results in the planing-hulled vessel having a length of 10.20 metres against 12.00 metres for slender-hulled model – an increase of 18%.

As it happened in the case of the featured example RANGEBOAT the slender-hulled model was required to be about 12 metres long so it fell neatly under the RCD 12 metre threshold, but had the client wanted a ‘true’ 12 metre boat the slender-hulled vessel would have been some 14.16 metres long (applying the same 18% differential), so the certification process would not have benefited from the exemptions available to vessels under 12 metres.

In general terms the planing powerboat has a shape that is ideal from an accommodation point of view, the topsides usually being near-vertical and the higher beam/length ratios compared to the slender-hulled equivalent model which can result cabin shapes that have proportionally more space lost to corridors and passages.

2. MULTI-HULLED VESSELS

2.1 GENERAL PRINCIPLE

Placing two or more slender hulls next to each other to form a catamaran, trimaran or proa is in essence a way of separating the function of stability from the other hydrostatic hull functions. Doing so enormously increases the non-planing performance available from each of the hulls.

Freed from the need to provide stability from width each hull can so slender that it attracts minimal wave-making resistance. As can be seen in the 'Performance Comparison' graph data for the 21.30m trimaran iLAN VOYAGER shows a barely detectable 'hump' speed at around 15 knots.

It will be seen that above 15 knots the growth of drag – now almost entirely the result of skin-friction – is (as would be expected) a slowly steepening curve. In the case of iLAN VOYAGER the curve finally crosses the curve of the planing- hulled BAVARIA at about 29 knots (in reality just above the maximum speed of the vessel and therefore only deduced by extrapolation of curve.)

It is important to note that whilst the performance of a slender-hulled vessel (along with all full displacement vessels) is very much tied to waterline length, a planing–hull of any size will go on increasing speed as power is applied (until drag even from a small wetted-surface becomes eventually steepens the drag curve once again)

In the case of the slender hull (as the power comparison below shows) the best way to push up speed is to build a bigger boat. Doing so obviously stretches the entire curve out down the speed axis of the graph. (Equally obviously it may or may not be economical to do so).

2.2 NOTES ABOUT THE EXPERIMENTAL TRIMARAN iLAN VOYAGER and CATAMARANS IN GENERAL:

The experimental 'iLAN VOYAGER' was designed and built in 1988 using as its basis a 21.30 metre centre hull which was of broadly similar design to those used in sailing yachts of similar size at that time. These hulls are characterized by their extremely high slenderness ratios and equally extreme displacement/length ratios.

In the case of 'iLAN VOYAGER' the figures were:

L/B ratio = 20
D/L ratio = 17 $(\text{Displ.T}/(0.01\text{xWL})^3$ where Displ.T = long tons and WL = ft.

In consequence the vessel was capable of reaching its maximum speed of 27.5 knots with virtually no dependence on dynamic lift. In reality this speed – being about 3.3 x $\sqrt{\text{WL}}$ (ft) - is about the highest sustained service speed/length ratio that should be contemplated for this type of hull.

Extrapolation of powering data lifted from the 'iLAN VOYAGER' shows that whereas 176kw (236 HP) of installed power achieved a very creditable speed of 27.5 kts, more than double that figure (365kw (491 HP)) would be required to achieve 35 knots.

As speed requirements increase the wetted surface of a pure slender hull form - which remains virtually constant throughout the speed range – will ultimately result in an excess of skin-friction. At that point the efficiency advantage can only pass to a dynamically supported vessel.

2.1.a Lateral stability considerations:

When evaluating the suitability of a trimaran platform for different tasks it is important to consider the effects of scale; The lateral stability of a trimaran - in common with a single-hulled vessel – is more easily achieved in the case of a larger vessel than in a small one.

The righting moment being applied as a trimaran takes up an angle of heel is a function of the immersed volume of the outside hull multiplied by the distance from the centre of that volume to the centreline of the vessel. This fourth power progression is to be compared with a growth in displacement which will be progressing at only something approaching a cube law with length.

The effect of this is that the smaller the vessel the more dominant become the outside hulls and the higher the beam/length ratio. Add to this the fact that on a vessel of less than, say, 50 metres LOA it will be unlikely that either the outside hulls or even the wing structure between the hulls can be put to any good use and it becomes clear that the advantage lies with the bigger vessel.

Put another way the cost and encumbrance of the outside hull/ wing structure of a smaller vessel is a more onerous consideration than it is on a bigger one.

In the case of a bigger vessel the outside hulls can be designed and placed in such a way that resonant roll frequency and amplitude can be predetermined to suit the application.

The desired roll characteristics of a small vessel are, it appears, more difficult to determine. Any resonant roll frequency that is slow enough to be tolerated by the passengers on board is likely to produce *either* insufficient total righting moment to be safe in severe sea conditions *or* to result in the need to build very big outside hulls. This may well call into question the whole economic justification for building a trimaran (as opposed to, for example, a catamaran – in which most of what is built is usable for accommodation).

In consequence the approach used to address the lateral stability issue in the case of both ‘iLAN VOYAGER’ is based on a different line of thought. Conventional wisdom suggests that a vessel which has a high frequency, low amplitude roll characteristic will probably provide passengers with an uncomfortable ride, but this assumes that they are positioned sufficiently far above the role axis to allow gyratory motion to translate into lateral acceleration.

In the case of a catamaran bridge-deck clearance considerations mean that passengers are by definition situated well above that roll axis – resulting in the familiar - and often unpleasant - ‘snap-roll’ associated with these vessels.

By contrast the passengers riding in a trimaran can be situated at any height within the vessel – even exactly on the roll axis if the sea conditions in which the vessel is required to operate are severe enough to make that a desirable objective.

Practical experience with the two vessels tested so far has lead to the conclusion that a good compromise between ride comfort, visibility from the cabin/pilot house, and habitable volume per unit length of vessel is to arrange the accommodation so that the height of eye of passengers/crew subtends an angle of declination down to the centre of the waterplane of the outside hull of no more than 25˚.

In the case of ‘iLAN VOYAGER’ the original underwater bodies of the outside hulls were actually fitted with planing surfaces. Although this produced the ultimate in ‘snap-roll’ movement, but in reality the lack of lateral acceleration associated with it meant that this low amplitude roll was very acceptable to passengers – partly, perhaps, because the hulls only responding to wave profiles so that no resonant rolling motion was present.

For other reasons these original hulls were eventually replaced by more conventional slender canoe-bodied hulls. Whilst these were an improvement in some respects it is generally felt that the vessel's ride quality was less inclined to produce sea-sickness with the original 'bumpy' hulls fitted.

2.1.b. Pitch considerations:

The ability to progress upwind in severe conditions is an inherent quality of the trimaran configuration. As no need exists to create low-deadrise dynamic lifting surfaces underwater the hull sections can be as 'pointed' as desired – with only a small penalty when compared to low wetted surface semi-circular sections. Such sections (depending how 'pointed' they are) are effective in virtually eliminating slamming loads in pitch.

Nonetheless the most effective way ensure a smooth and comfortable ride upwind has always been to build a bigger vessel – irrespective of its configuration, so there are natural limits to the speed at which a small (i.e. 5.5 tonne) vessel like 'ilAN VOYAGER' can be pushed in severe conditions.

Generally it has been found that whilst the extreme length of these centre hulls is a great advantage in limiting pitch amplitude it is very important to avoid rates of wave encounter excite the natural resonant pitch frequency of the trimaran in question.

In practice this can mean altering course, slowing down or (often in the case of 'iLAN VOYAGER') speeding up to break the synchrony between rate of encounter and resonant pitch frequency of the vessel. Sometimes sea conditions on a regular route contemplated by a slender-hulled vessel may unluckily provoke a resonant response in the vessel at the speeds required.

If that happens then the extreme length of the hull opens the possibility of using relatively small quantities of water (or fuel) ballast in the ends of the hull to modify that frequency until it is out of phase with the rate of encounter.

One word of warning should be sounded about the pitch characteristic of a true 'canoe' style slender hull such as was used for 'iLAN VOYAGER'': In the interests of reducing both wetted surface and transom drag this vessel has a fairly narrow waterline aft.

As, like any other vessel, iLAN VOYAGER tends to pitch about an axis that is roughly at the centroid of the waterplane area there is a tendency for her to suffer from negative gravity at the aft end of the accommodation when pitching (i.e. the pitch action has the characteristic oscillation similar to a seesaw). Whilst the human body can cope with reasonable decelerations as the forward part pf any vessel pitches into a sea, it is ill equipped to handle the rigors of becoming 'airborne' when positioned at the aft end – which is both an unpleasant and dangerous phenomenon.

It is also true that by pitching around an axis that is too far forward the effective length of the vessel is reduced in pitch (i.e. the vessel is not making as much use of all its length to decrease pitch frequency).

Any future vessel designed by us will be likely to have a waterplane that is more like a very high aspect 'delta' in shape – even though a wetted surface penalty will have to be accepted.

2.1.c Conclusions:

16 years experience with small offshore power trimarans has lead to the following conclusions :

1. In the size range considered (up to 35 metres LOA) it needs to be accepted that whilst a trimaran can display truly remarkable properties its use must be well matched to a narrow and very specific range of tasks at which it truly excels. There are no miracles.

2. If a trimaran is allowed to become too voluminous (often as a result of client pressure to create more accommodation space) it is unlikely to live up to its promises. Whilst more volume means more weight the real problem is that it also means a higher centre of gravity. That has the effect of making the outside hulls work too hard – so they will need to be very big, cumbersome and expensive. The passengers will also be riding too far above the roll axis (as described above) so they will not be comfortable.

3. For as given number of passenger seats a trimaran is expensive to build and should not be contemplated if a catamaran (whose accommodation is more accommodation-friendly) will do the job.

4. The corollary argument of 3 above is that if a small catamaran is chosen (by the company accountant?) to carry passengers on a route where sea conditions are severe then the choice may turn out to be a false economy because passengers will avoid travelling on it.

5. Ideal applications for a small trimaran would be as follows:

   - As a patrol or surveillance boat in which a small crew need to be able to cover large distances at speeds of between 15 and 25 knots – depending on size of vessel. (The very small 'iLAN VOYGER' has routinely made trips between Northern Europe and the Cape Verde Islands (where she is based) - which is unusual for a vessel of only 5.5 tonnes displacement.)

   - As a fast ferry for a small number of passengers (eg 25 – 50) who need to cross a stretch of water on which a conventional catamaran or single-hulled vessel would be too uncomfortable

   - As a transporter of fairly small volume/high value goods (such as medication, fresh produce etc) in areas of the world where air transport may be considered too expensive or air-strips do not exist. The slender hull non-dynamically lifted platform is not especially sensitive to weight so heavier goods could be contemplated provided they were of low volume so that their weight could be carried relatively low down in the vessel.

6. Catamarans can be thought of as being less extreme than trimarans. They offer cost-effective solutions as fast ferries, but are generally poor performers in open sea conditions (unless very large). As has been repeatedly mentioned the non-planing or semi-planing hull is dependent on length if higher speeds are needed. For a given displacement the central hull of a trimaran will be longer than each of the two hulls of a catamaran and so it will be operating at a more favourable (lower) speed/length ratio for a given speed. There will almost certainly be a sea-keeping benefit resulting from the additional length of the trimaran.

3. COMPARITIVE DATA:

Some comparative data follows that is intended to complement and corroborate the above qualitative information. It should be used with great caution because numerical information does not tell the whole story.

The powering curves are shown below for three contrasting generic vessel types.

The first test vessel – the BAVARIA BMB 32DC built by Bavaria Yachtbau GmbH – represents a typical mainstream planing-hulled power yacht.

The second is the RANGEBOAT built by Seatech SARL which represents a fairly moderate departure towards the 'slender-hull' semi-displacement philosophy.

A third vessel, iLAN VOYAGER, is a proof-of-concept vessel that has been included for the purposes of illustration only. This very extreme trimaran (which happens to share a displacement the other two vessels) was built to explore the possibilities offered by carrying the slender hull philosophy to its logical conclusion. (see 2.2 above)

BAVARIA BMB 32 DC

Designed by J&J Design

LOA: 10.20
BOA: 3.20m
Displacement: 5000 kgs
Power: 2 x 260 HP

RANGEBOAT

Designed by Nigel Irens Design

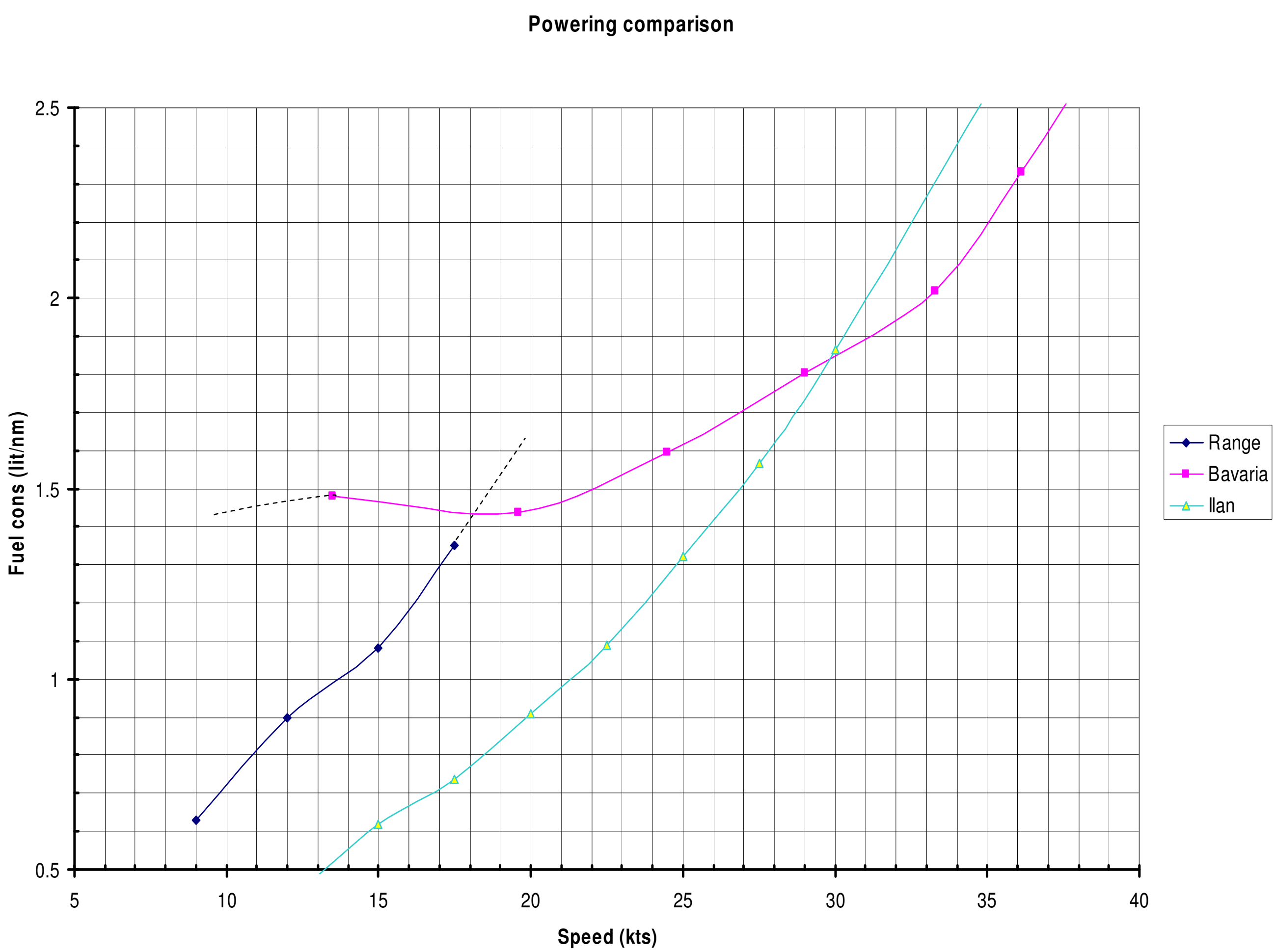
LOA: 12.00m
BOA: 3.30m
Displacement 5500 kgs
Power: 1 x 130 HP

<u>iLAN VOYAGER</u>

Designed by Nigel Irens Design

LOA: 21.30m
BOA: 10.00m
Displacement 5500 kgs
Power: 1 x 237 HP

The graph compares the power requirement for each of the three vessels concerned. As the arguments are largely economic ones applied power has been expressed in terms of fuel consumption for convenience . The 'Y' axis is therefore graduated in litres per nautical mile.



3.1 CONCLUSIONS

3.1.a The first and most obvious conclusion that can be drawn from this chart is that high speed is an expensive option – no matter what hull-form is chosen.

3.1.b Non-planing or semi-planing RANGEBOAT-type hulls are very dependent on waterline length if they are to produce really convincing performance figures. One could imagine that the curve for a 17 m LWL version of the RANGEBOAT hull would produce a curve that lay about half way between the RANGEBOAT curve in the chart above and that of the iLAN VOYAGER. That vessel would be as relaxed and relatively frugal at 18 knots as the RANGEBOAT is at 14 knots. Once again, as a bonus sea-keeping qualities would be even better than those of the RANGEBOAT.

3.1.c The reality of the experience with operating the RANGEBOAT is that the vessel settles to a comfortable and sustainable speed of between 13 and 15 knots. The chart shows that fuel economy at those speeds is satisfactory. No tests have been carried out yet to explore how transom flaps could improve top-end performance. The above photograph shows the vessel squatting at her maximum speed, but the picture was taken on first trials and when fully fitted her trim does not suggest the need for transom flaps unless a subsequent boat was to be fitted with more powerful machinery.

Every effort has been made to reduce noise levels and the objective is to make it possible to use the vessel in much the same way as a sailing yacht is used, so that passages of 100-200 miles could be realistically undertaken .

3.1.d The issue of fuel cost differentials does not appear to be a significant one – except perhaps in the case of a power yacht that is subject to very heavy annual usage and whose owner cannot purchase fuel at duty-free prices. (The exemption from duty enjoyed by UK leisure boat owners is likely to be cancelled or severely cut before the end of 2005).

The owner of non-exempt planing – hulled vessel such as the BAVARIA will be paying some 1500€ for fuel for each 1,000 miles traveled in a season at 22 knots - roughly 500 € more than the owner of a RANGEBOAT type of vessel covering the same distance at 14 knots.

Future trends in fuel cost are unpredictable but likely to be more volatile than they have been in the past.
Another 1972-style price increase would appear to hold more serious consequences for a commercial operator than for a leisure-boat owner: Increases in the barrel price of oil are likely to be passed directly on to a commercial operator, whereas the average leisure boat owner may only use a fraction of that fuel quantity in a season he or she will see its cost rise less in percentage terms because a high proportion of his or her fuel bill will already be paid as duty.

A working boat operator who logs 15000 miles per year, for example, will be paying typically 8,300 € per year in fuel costs to travel at 22 knots in a planing-hulled vessel., whereas an owner operating a RANGEBOAT–type boat will spend 5,250 € to complete the same distance at 14 knots – probably not enough to make a big difference to a global operating budget, especially as the slower boat will spend 390 hrs longer at sea per year to cover the same mileage.

3.1.e The real question – the answer to which cannot be found in the above chart – is : what proportion of the time spent underway in the average planing-hulled leisure powerboat is spent at the high speeds for which the hull was really designed ? Figures may not exist to

answer that question, but realistically it appears that high speed operation is very often limited by sea state.

The strongest argument to support the use of slender-hulled power vessels must surely be that they offer a pragmatic solution to this problem. Like their planing counterparts reality will dictate that even their lower cruising speed will often be further reduced as a result of adverse sea conditions, but they are fundamentally well adapted to performing in a seaworthy and safe way at *any* chosen speed.

As vessel size increases then the arguments in favour of the slender-hulled vessel become more persuasive. On the one hand it is easier to obtain higher operating speeds from a scaled-up slender-hull, and on the other hand the technical difficulty and cost of building a planing-hulled vessel increase rapidly with size.

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