The Development of a Hydrofoil-Supported-Rigid-Inflatable Boat

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1. INTRODUCTION

High-speed power catamarans have been strongly developed in recent years and present a well-accepted hull principle with good rough water high-speed characteristics. One of the major draw-backs of the high speed power catamaran is the high propulsion power requirement, which is about 35% higher than for a comparable deep-V-monohull and which had retarded it's development.

Nowadays powerful outboard engines easily compensate for this handicap but the fuel consumption remains high. By use of the hydrofoil supported systems the propulsion power can be reduced by nearly 50% and make the so-called Hysucats more efficient than comparable deep-V-monohulls. Together with the new generations of four-stroke Outboard engines the Hysucats are also considerably more fuel-efficient and this way become environment friendly.

The author developed hydrofoil assistance for catamarans for two decades after initial model tests in the towing tank at the University of Stellenbosch had shown that resistance improvements of over 40% against the same catamaran without foils are possible.

Considerable research effort was applied to first prove and explain the enormous gains due to a relatively small hydrofoil installed inside the tunnel of the catamaran where it did not obstruct the design and operation. Later research efforts were directed to optimize the hydrofoil supporting systems by use of systematical model test series and the development of the theory which later resulted in a computer model which allowed further design optimization. Aside the catamaran hull tests systematical hydrofoil towing tank tests were conducted to establish the required hydrodynamic design parameter. At the end many application designs of Hysucats were tested in the towing tank and in the high-speed water circulation tank.

Applications of Hysucats or in many cases only the foil system design for existing catamarans, so called Hysucat conversions, were applied to craft of 5m to 45m, over 200 units are on the sea now. The Hysucat principle offers advantages for special high-speed ship types such as ferries, yachts, patrol boats, game fishing boats and police and custom patrol craft for which large deck areas are required.

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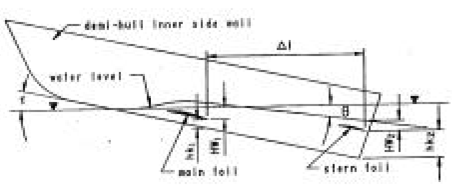
Ferries were developed for craft of 17m to 22m in Germany and in South Africa (Rheinjet, Nordblitz, Sea Princess) as well as Navy and patrol boats from 10m to 19m in South Africa, Germany and Thailand. Hysucat yachts from 8,5m to 36m (Chief Flying Sun), Prout Panther 64 in the U.K. and the 21m Kingcat in France. The largest Hysucat on the water is the 45m E-Cat developed by Halter Marine in New Orleans, USA with a so-called Hysuwac foil system which improved the speed from 33 knots to a maximum of 44 knots.

The smallest Hysucat is a 6,5m Semi-Rigid-Inflatable boat designed by the author in collaboration with Malan Conradie of Aqua Fun in Gordon's Bay. Hull and foil systems were optimized in combination for a seagoing rough water craft.

The Hysucat principle and its configuration becomes clear from Fig. 1, Typical Hysucat Arrangement. More detailed explanations can be found in the publications of Hoppe (1991, 1991a, 1992 and 1995). Foil systems for larger ferries which mostly have semi-displacement type demi-hulls can look considerably different. See Hoppe (1998), Hoppe (1999) and Migeotte, Hoppe (1999).



Hysucat Principle

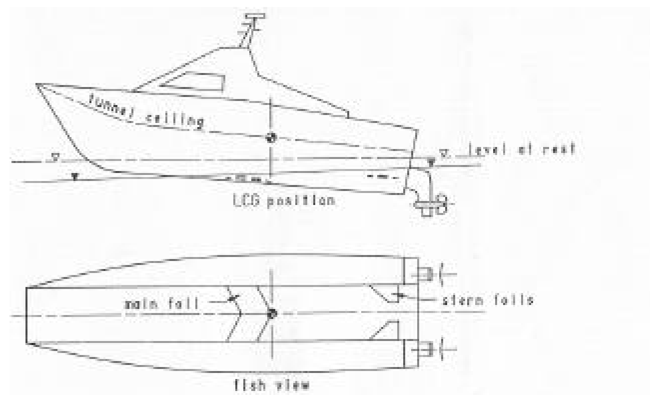


Figure 1: Typical Hysucat Arrangement

Aside of the hydrofoil system the special hull design features shall be explained in the following and which contribute to the excellent rough water performance of this smallest application of the Hysucat principle which has already established several records at sea, as for example a "First" in the 1998 Trans Agullhas Inflatable race of over 1000 km along the southern coast of South Africa from Plettenberg Bay to the Strand Beach in which only two RIB's finished from over 70 entrees (mainly Inflatables). The rest had to give up due to extremely rough seas on the fifth leg at the end of the race. The joy of the winning teams did not last long as the Racing Committee cancelled the fifth day because of the disastrous weather which necessitated a large rescue operation by three helicopters and rescue boats.

The performance improvement due to the Hysucat principle will be explained by use of dimesionless performance parameters with proper comparison to other crafts.

2. RIB DEVELOPMENT

The smallest Hysucat development is a so-called Semi-Rigid Inflatable Hysucat (RIB) designed by Prof. K.G. Hoppe and built in collaboration with Malan Conradie of Aqua-Fun in Gordon's Bay, RSA in 1997. The craft was in mass production by Hysucat Marine (Pty) Ltd, Cape Town with export outlets to the UK and Australia and which recently was taken over by Magson Marine in Strand, RSA.

Figure 2: Hysucat Prototype in rough water test

To date, over 120 boats have been produced and are popular because of the unparalleled sea-friendly behavior at high speed in rough water. With twin 50hp outboard engines the prototype reached 50 knots+ in open sea conditions. This is possible due to the improved sea-keeping and soft riding in waves due to the specially developed catamaran hull and damping effect of the hydrofoil system.

The demi-hulls incorporate a patented tapered spray rail system and the tunnel between the demi-hulls has a double arc shaped ceiling for soft wave impacting. A wave spoiler system prevents excessive bow dipping which would offset the required foil attack angle when running in following seas. The double arc tunnel ceiling has self-stabilizing qualities. Figure 2. shows the 6.5m Hysucat RIB prototype at full speed in rough water during the original trial runs at Theewaters Kloof Dam in the Western Cape, RSA.

3. RIB HULL DESIGN

The demi-hulls of the catamaran are main contributors to the seakeeping of the craft. The 6.5m Hysucat RIB has been designed as a rough water craft which necessitated extreme slender demi-hulls of the fully asymmetrical type with so-called Deep-V-planing craft characteristics (high dead rise) sharp entry, prismatic shape in rear part and well defined chine.

Fig. 3 shows the body plan of the initial design with a single engine installation, which necessitates an additional deflector in front of the outboard leg. The craft has a full wet deck connecting both inflatable pontoons. The tunnel features a so-called double arc vortex shape which allows a soft ride at lower speeds when the tunnel ceiling is partly submerged. At higher speeds the tunnel is free of solid water contact, but, occasional wave passages run off with little impact.

In model tests of the isolated tunnel section it was found that the double arc tunnel creates efficient dynamic lift forces at speed without destabilizing the craft transversewise as it appears for single arc tunnels. The double arc tunnel is self-stabilizing. A so-called wave spoiler is fitted at the tunnel center foreward to prevent large negative dipping-trim-angles in waves in order to maintain the required attack angles on the hydrofoils at all speeds. Later designs incorporate a symmetrical bow entrance section (not shown in this figure) which gives further stabilization in following waves and for extreme shifts of the LCG position.

The two standard sprayrails shown in Fig. 3 were later replaced by the patented sprayrail which has a tapered shape with growing cross-sectional area towards the transom. These sprayrails allow the vortex created by water impact towards the rails to extend from the stagnation point foreward to the end at the transom. This way the impact forces due to encountered waves are reduced significantly and a soft ride is achieved which is not possible otherwise with a Deep-V-planing surface. The foil system additionally introduces a damping effect when running in rough water.

Several hydrofoil designs are applied for various service conditions. The very fast racing version has an extremely thin mainfoil, for cavitation free speeds above 50 knots, arranged to be slightly below the keel lines by use of a slight dihedral angle.
The standard foil is thicker for higher lift creation already at the lower and medium speeds. It functions cavitation free up to speeds of about 44 knots.

A middle strut connects the hydrofoil to the center of the tunnel ceiling which is the lowest point due to the double arcs and which gives a short and efficient middle strut which can easily take up the heavy pounding forces in waves.
The inflatable pontoons have four watertight compartments. The hulls are also watertight from below and above and separated from each other. This makes the craft very safe against sinking and capsizing.

Different deck layouts are offered with a standing console or a sitting arrangement. All seats and the console are fixed to two longitudinal stainless steel rails inserted into the deck which allows length-wise shifting in order to compensate for LCG shifts and to make the craft easily adaptable to different load conditions or engine arrangements.

In the twin outboard engine arrangement the engines are mounted behind the transom of the demi-hulls which gives better flow conditions to the engine legs which are in the flow-shade of the hulls. The engines are fitted with a slight outward inclination of the lower legs. Seeing it from behind it looks like an X-arrangement.

It was found that the craft banks inwards with this arrangement when running into a turning circle because a moment is set up by the engine legs and skegs which tend to incline the craft towards the center of the turning circle. This gives a more stable run similar to a motorbike and not the destabilizing feel of the usually outwards banking catamarans. In waves the craft runs more stable with the twin outboards arrangement which is the preferred system for open sea operation as the chances of two engines failing at the same time is low.

More details about the 6,5m Hysucat-RIB can be found in the article of Du Plessis (2000).

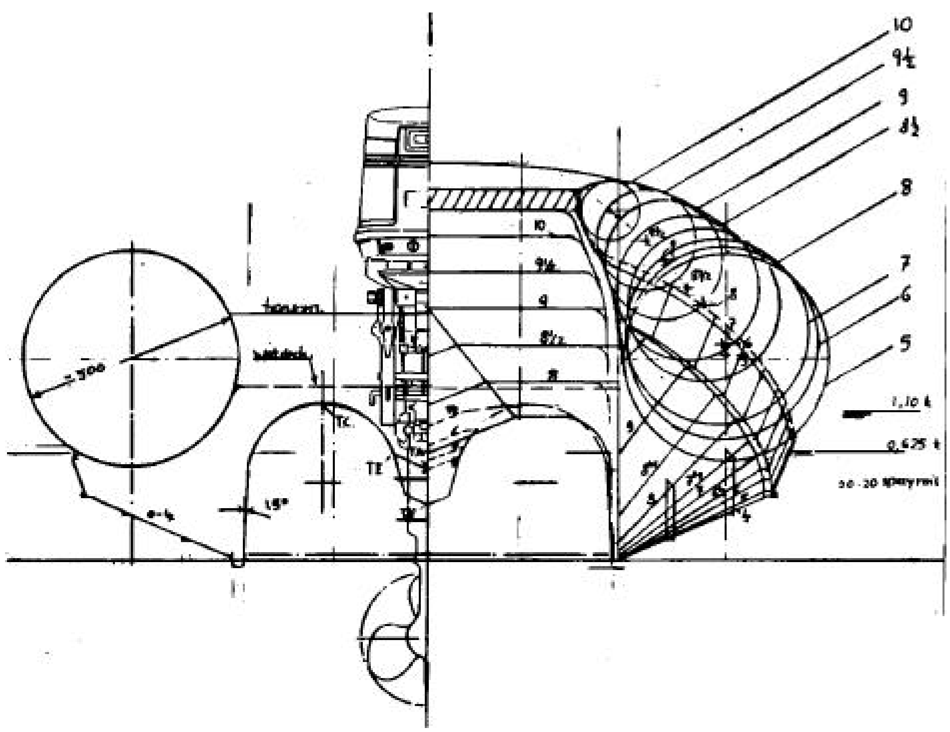


Figure 3: Initial Bodyplan of 6m Hysucat RIB

Figure 4: A standard RIB

4. RIB – PERFORMANCE EVALUATION

The two main advantages gained by use of the Hysucat principle are:

i) a lower ship resistance which means that smaller engine powers are able to do the same job with considerably lower fuel consumption and,

ii) a more sea friendly seakeeping with considerably lower accelerations and smoother operation in waves and rough water.

Other advantages which become clear in the operation of the first Hysucat RIB prototype are the considerable course stability of the RIB which allows high speeds in following waves (and even breaking waves) without broaching tendencies, complete dry run in rough water, no porpoising tendencies and high speed turning circles without capsizing danger.

Outboard engines with automatic trim are preferred as they allow to adjust the optimum trim of the craft and adapt it to the prevailing load and speed conditions by the helmsman (push button control!). Running in following seas requires higher trim angles than facing head waves.

The prototype Hysucat RIB with an operational mass (4 crew!) of 1050 kg and two 50hp two-stroke outboard engines reached top speeds of over 50 knots. The standard production RIB with the thicker and stronger mainfoil (which allows beaching!) has top speeds between 36 knots and 40 knots and can carry up to 10 persons. With four-stroke 50hp outboard engines the fuel consumption at medium and high speed is only about ½ to ? of the one of comparable Deep-V-planing craft.

The overall propulsion efficiency of outboard engines is lower than on large craft propulsion systems due to the parasitic drag of the skeg and gearbox in the high speed water stream and reaches best values of only 50% to 55% and much lower efficiency at very high speeds.

For the extreme speeds in races (over 50 knots!) the outboards are lifted higher up to allow ventilated surface propellers with a minimum of skeg and gearbox submerged.
Under those conditions a waterjet or Arneson Surface drive could bring considerable improvements.

To give an idea about the Hysucat performance improvement a method to compare different craft performances to the Hysucats was developed and is presented in diagram form in Figure 5., as developed by Hoppe (1991). Which contains tendency curves and specific data points of various different craft to allow comparisons to any candidate hull.

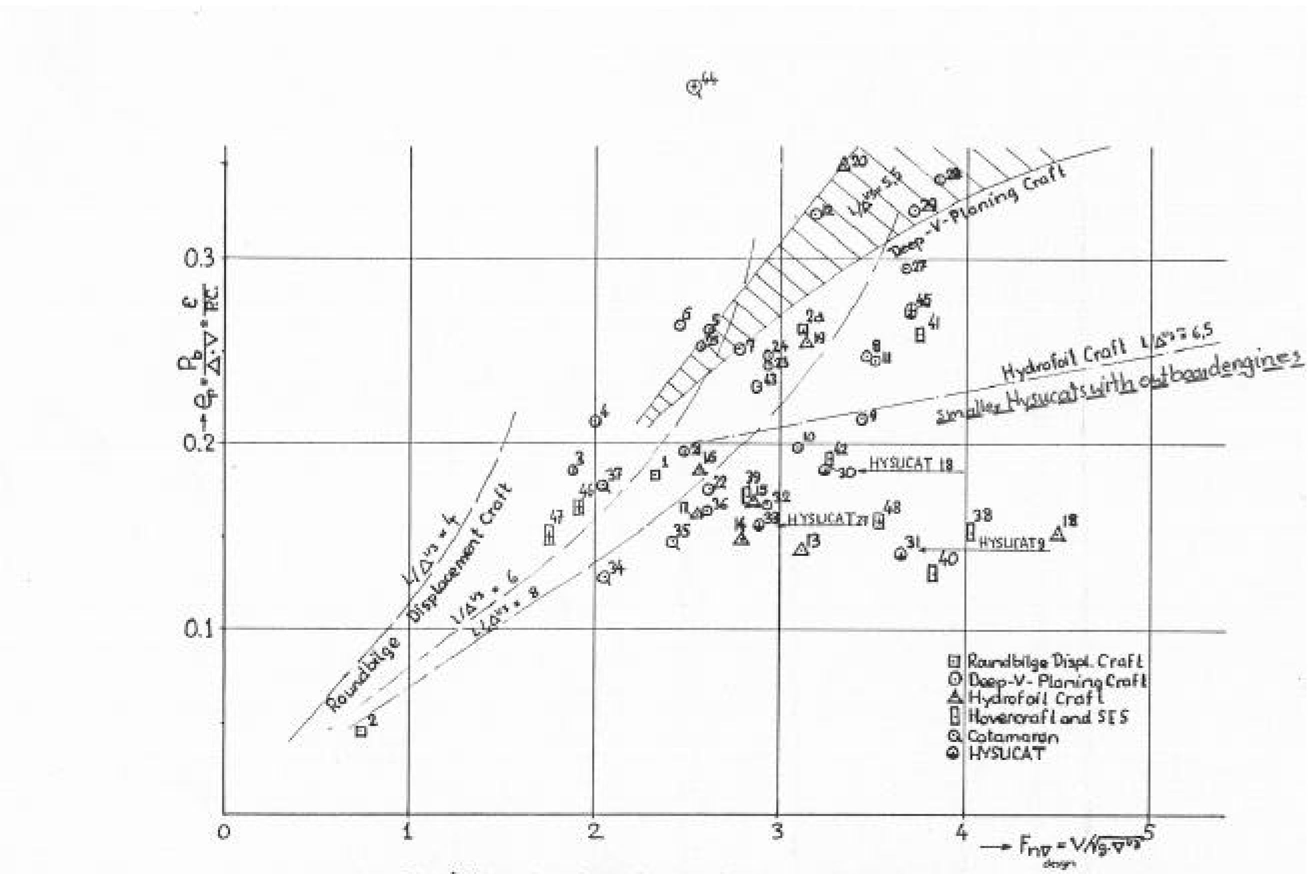


Figure 5: High Speed Surface Craft Power ratio

Table 1

Hydrodynamic Performance Comparison of High-Speed-Small-Craft

(Code for Figure. 5)

Sym.	Nr	Name of Craft	Builder	Δ[t]	V[knot]	P[kw]	Fn∇	ε	H.P.R.
		Round bilge Displacement and Semi-Desplacement Craft							
⊡	1	Type S 143	Lürssen	375	38	13235	2,33	0,184	12,54
m	2	PB	Italy	1361	15	4706	0.74	0,046	16,11
⊡	2a	Shergar, Lürssens,	Bremen - Germany	188	45,5	11290	3.13	0,262	11,92
		Deep - V - Planning Craft							
⊙	3	PT	Damen	85	24	1847	1,88	0,186	10,12
⊙	4	Cohete	Lewi Dsgn	60	24	1544	2,00	0,213	9,38
⊙	5	SAR 33	Abekg&Rasm	250	40	13235	2,62	0,262	10,08
⊙	6	Zarcos 16	Lewi Dsgn	22	25	735	2,46	0,265	9,27
⊙	7	Zarcos 12	Lewi Dsgn	8	24	243	2,79	0,251	11,12
⊙	8	Nasty Class	Norway	83	44	4559	3,47	0,248	14,00
⊙	9	P2 000	G.B.	49	40	2118	3,44	0,214	16,00
⊙	10	P2 000	Dheeb AL Behar	49	36	1765	3,10	0,198	15,60
⊙	11	Intermar. Mk 55		165	50	10294	3,51	0,247	14,19
⊙	12	Ilikai	Lewi Dsgn	9	28	412	3,19	0,324	9,84
		Hydrofoil Craft							
A	13	PT 20	Supramar	33	34	810	3,12	0,143	21,82
A	14	PT 50	Supramar	63	34	1620	2,80	0,149	18,81
A	15	PT 75	Supramar	78,5	36	2420	2,86	0,170	16,83
A	16	PT 150	Supramar	150	36	5058	2,57	0,186	13,81
A	16a	PT 150	Supramar	150	36	with start.power boosting			
A	17	High PointPCH1	USA	120	48	4706	3,56	0,162	21,94
A	18	Tuccumcari	USA	58	53	2353	4,50	0,152	29,62
A	19	Plainview AGEH-1	USA	320	50	20588	3,15	0,255	12,32
A	20	PHM Nato Hydr.	Boeing	218	50	19265	3,35	0,350	9,52
		Recently built Craft and Catamarans							
⊙	21	Sea Link Cat. Ferry		50	29	1430	2,49	0,196	12,68
⊙	22	Jet Cat Ferry Jc-1		73	32,5	2100	2,62	0,176	14,86
⊙	23	EM1 , China Sh. Tradg		78	37	3529	2,94	0,243	12,12
⊙	24	Dvora, Israel Airc. Ind.		47	34	2000	2,94	0,248	11,87
⊙	25	Olympic 76	Greece	50	30	1912	2,57	0,253	10,16
⊙	26	Span. Cust: Craft (with Ri.CaL Jets)		15	55	1470	5,76	0,353	16,31
⊙	27	Indonesian Wat.jet.,	PT Kodja	4,09	28,3	172	3,68	0,295	12,47
⊙	28	P 1200	G.B.	13	36	810	3,86	0,343	11,25
⊙	29	Precision Offshore 17,	Australia	22	38	1375	3,73	0,326	11,45
⊙	30	HYSUCAT 18	Tech.Thaild.	36,5	36	1240	3,25	0,187	17,5
⊙	31	HYSUCAT 9	Tank predict.	33,5	40	950	3,66	0,141	26,0
⊙	32	PT 14,5, Singap. S. + E.		23	30	934	2,93	0,268	10,0
⊙	33	HYSUCAT 27, Lürss.,Dsgn-Tank pred.		140	40	4412	2,89	0,157	18,4
⊙	34	Tropic Sunbird Cat.,SFB-Eng. Austr.		127	28	2320	2,05	0,129	15,89
⊙	35	Tassie DeviL 2001	Int.Cat.Tasmania	72	26	1660	2,42	0,148	16,35
⊙	36	AZ60	Azimut Italy	30	28	1118	2,61	0,264	9,88
⊙	37	Norsul Cat.,Fjelstrd.	Norway	84	26	1956	2,04	0,178	11,50
⊟	38	Hovercraft API. 88	G.B.	38,5	45	1338	4,03	0,153	26,30
⊟	39	SES Norcat	Norway	85	36	2650	2,82	0,172	16,42
⊟	40	SAH 2200, Slingsby Aviat,	G.B.	6,8	32	140	3,83	0,131	30,20
⊟	41	4000TD, Griffon	G.B.	12,8	38	588	3,76	0,260	15,67
⊟	42	SES Jet Rider, Karlskronavarvef,	Sweden	88,3	42	(90%)3582	3,27	0,192	17,07
⊙	43	Westcruiser	Norway	30,5	31	1103	2,88	0,231	12,47
⊙	44	Lady K, Wat.jet, T-Craft Cape Town		8,3	22	368	2,54	0,399	6,36
⊙	45	Lady K, Wat.Jet, T-Craft Cape Town		8,3	32	368	3,70	0,275	13,48
⊟	46	Mark I, Shanghai Zhonghua SES China		95	25	1968	1,93	0,166	11,63
⊟	47	Mark II, Shanghai Zhonghua SES China		124	24	2265	1,77	0,151	11,70
⊟	48	Corsair, Blohm+Voss ,	Germany	160	50*	6320	3,53	0,157	22,54
⊟	48a	Corsair, reported max. performance		170	52*	6320	3.63	0,142	25,63

* Trial Speed confirmation not available to date.

Figure 5. shows the power ratio e_p versus the Froude Displacement Number Fn_V diagram, which allows a proper physical evaluation of a candidate hull and which shall be used here to give a quantitative preliminary result of the improvements due to foil systems on catamarans as predicted in the test series. The power ratio was developed by Hoppe (1991) to establish a tool for fast craft evaluation and comparisons and is defined as:

$$e_p = P_b / (?\cdot 9.81\cdot V) = ?_{total} / P.C.$$

With P_b =total brake power in kW, ?=displacement mass in metric tons, V=ship speed in m/s, $?_{total}$ =total resistance to displacement ratio and P.C.=propulsive coefficient.

It turned out that the e_p ratio is the inverse of the well known transport efficiency $?_T$. The e_p diagram in Figure 5 contains tendency curves for displacement, planing, semi-displacement (mono-hulls and twin hulls) and hydrofoil craft.

Some e_p data of catamarans and Hysucats are plotted on the diagram. The lower the e_p value of a candidate hull is for a given Froude number, which is a dimensionless speed parameter, the more efficient the craft will be. The planing hull Hysucats are well below the tendency curve for planing craft showing that the efficiencies of the Hysucats are much higher.

The broken and pointed line indicates performance efficiencies of the outboard driven craft which are usually smaller than the inboard versions of work boats. The resistance of the smaller craft is relatively higher than for large craft due to the higher frictional resistance. The tendency curves for the smaller Deep-V-planing craft is higher than the indicated top line in the diagram. The overall propulsion efficiency, called Propulsive Coefficient (P.C.) is lower for outboard propulsion which results in the slightly higher e_p values.

The improvement due to the Hysucat principle is about 35% to 40% in the Froude number range of 3.5 to 4.0. At lower speeds and much higher speeds the improvements are less. The racing craft operate at Froude numbers near to 10 which range is not included in this diagram as it needs special consideration and special foil arrangements. The selection of the right propulsion system is of utmost importance for these crafts.

5. DEVELOPMENT OF THE 12m HYSUCAT RIB

During the promotion of the 6,5m RIB, marketing agent in the U.K. Paul Lemmer, who holds several world record titles in international RIB racing [2], initiated the interest of the client Mark Phillips (nickname = Dog) who is a trainer for professional RIB teams, in larger RIB's of a similar type which lead to contacts made in South Africa with Prof. Hoppe of Foil-Assisted-Ship-Technologies cc (FASTcc) and Mr Malan Conradie of Stealth Marine (Pty) Ltd, both developers of the 6,5m Hysucat RIB, to discuss the development of a 12m Hysucat RIB which lead to a combined venture project with Panthercats.com, U.K., in October 1999 and in 2002 to the creation of the new company "Hydrofoil Boats International (Pty) Ltd" which builds the 6,5m Hysucat RIB, an 8,5m Hysucat and a 12m Hysucat.

FASTcc developed the efficient concept and hull shape with a Hysucat foil system corresponding to the Hysucat design philosophy as outlined for the 6,5m RIB under point 3 of this publication.

Malan Conradie was involved in the detail and styling design in order to achieve a pleasant and beautiful end product as shown in the 6,5 design. He also is employed as the main contractor for the construction of the hull and deck moulds and the building of the first prototype in South Africa. Future mass-production is planned through the company "Hydrofoil Boats International (Pty) Ltd" near Gordon's Bay in the Western Cape, RSA.

The 12m Hysucat RIB is developed as a fast pleasure yacht with variants as fast workboats for sea rescue or policing duties. Contrary to usual RIB's the Hysucat offers wide deck and cabin area (about 4,5m) at efficient performance due to the foil assist catamaran principle and the use of inflatable D-tubes which do not reduce deck area as in usual RIB's.

For the anticipated high speed operation the craft has a relatively low profile and streamlined superstructure allowing all round vision from the steering position in the cabin. Designed for European sea conditions an open cockpit version was not followed up but a yacht version with a fly-bridge (refer to artist impression) is included. The craft can also be delivered without D-tubes as a Game Fishing Boat.

The initial craft design was intended to use twin Yanmar 6LP-STZE Diesels with 221 kW at 3800 rpm combined with Bravo III sterndrive units which are equipped with Duo-Propellers which give higher efficiency than the standard fixed pitch propellers. The design weight in the fully loaded condition for extended range at high speed resulted in a total weight of 10,2 t for which the performance calculations indicate a top speed of 37 knots.

During the design phase the client decided to go for the faster variant of the same craft with twin Yanmar 6LY2M-STZE delivering 308 kW at 3300rpm and twin Hamilton Waterjets HJ 292 as the first prototype. Design recalculation resulted in a fully laden weight of 11,5 t.

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[2] For further details contact Paul Lemmer at Paul.lemmer@btinternet.com.

The hull and foil-assisted-system were optimized by the Mathematical Hysucat computer model which was developed by Prof Hoppe, and which has given excellent results in many applications, see Hoppe K-G, 1991.

The performance characteristics of the 12m RIB and Hamilton Waterjets are shown in the accompanying Figure and indicate a top speed for the fully laden craft at 11,5 t of about 44 knots. At lighter loads speeds above 50 knots are possible. The foil system is designed to allow speeds of up to 55 knots.

At the time of writing the hull plug and mould are finalized including the deck and cabin mould and two products, one for a propeller on inclined shafts version and another with Sea Fury surface propeller propulsion, are nearing completion. Trial runs are envisaged for end of August 2002.

The accompanying artist impressions show the 12m Hysucat RIB as a high speed version and a yacht with the fly-bridge version (D-tubes not shown!). Other propulsion systems are possible for clients with special wishes as for example units as high speed versions with surface drives, as Arnison or Seafury Systems or with the trimable Pulse Drive.

6. CONCLUSION

The hybrid of a catamaran hull in combination with lifting hydrofoils improves the hull efficiency considerably and this has now been proven in many applications. The lift carrying capability of hydrofoils when designed for optimum condition is so much better than the one of the standard fast ship hulls that still further improvements seem feasible.

The development of the Hysucat-RIB and many seatrials gave a lot of new design data to be used as input to future designs in many other projects.

However, not only the resistance improvement alone is important but all other performance parameters of a craft as the dynamic trim, course-holding, transverse and longitudinal stability at all speeds, broaching and porposing behaviour, seakeeping etc. must not be negatively off-set by the addition of a foil system. This makes the design of a Hysucat a formidable and sophisticated task which very few designers are able to tackle without extensive use of model- or prototype testing.

The smaller craft can easier be tested under extreme sea conditions and return a wealth of data to the designer. The development of larger craft can profit enormously as the smaller boats can be used as so called manned models.

Originally the Hysucat principle was intended for the smaller craft of up to 20m. However, the request for larger applications initiated research efforts in foil development for craft of up to 80m/650t and speeds of 60 knots for which a foil design has been completed and is under construction.

Optimized new designs have to consider the hybrid as a unit with the hull design also adapted to the new craft from the beginning on as an integrated entiety, which should also include the propulsion system. Then, considerable improvements seem feasible in the near future.

All Hysucat and Hysuwac foil systems have been designed by Foil-Assisted-Ship-Technologies c.c. (FASTcc).

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Figure 6: Hysucat RIB in the Agullhas Race

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