Super Fuel Efficient Long Range Motoryachts

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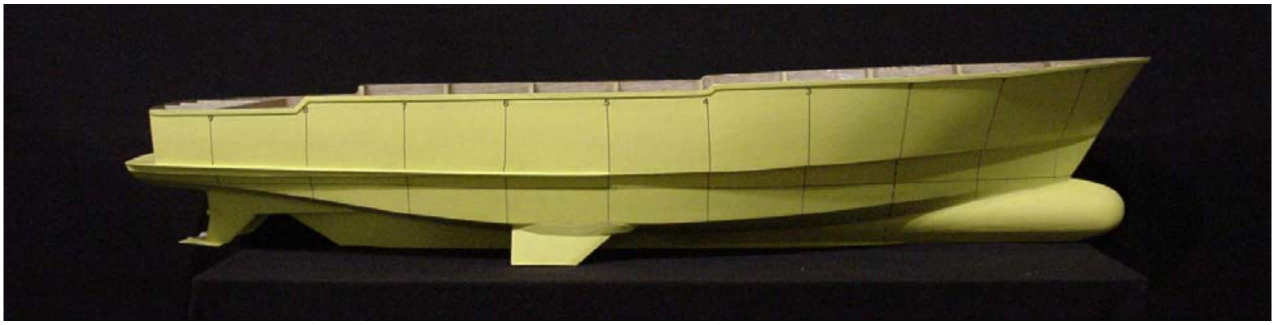


Fox 86 model with appendages

Abstract

With the continually rising cost of fuel, the demand for more fuel-efficient vessels seems only logical. This paper outlines the author's significant gains in this area over 14 years of research and development in appendage design with application to long-range displacement and semi-displacement vessels.

KEY WORDS: fuel-efficient, bulbous bows, long-range, displacement, semi-displacement, trawlers, passagemakers, motoryachts.

INTRODUCTION

This paper is a follow-up to the work published in the **SNAME 2000** paper "***Development of a 47-foot Modern Trawler Yacht***". That paper discussed the work done to date and its application in a small ocean-going yacht. Since that time the volume of work has expand considerably as well as being applied to larger vessels both in retrofit and new build construction. For those who have not had the opportunity to read that paper and/or are not familiar with this work, here is a brief recap.

Over 14 years ago, the author initiated an in-house research project with the goal of increasing the efficiency of long-range motoryachts. The intent was to achieve a hull form that was efficient over a wide range of displacement and high semi-displacement speeds. The basic scenario was for a long-range vessel capable of serious ocean passages such as trans-Atlantic or better, at displacement speed, with a comfortable motion, good stability characteristics and with very good fuel economy. Once over to the Mediterranean or other long distance cruising waters, the vessel could power around at higher semi-displacement speeds in order to keep up with faster local yachts, while still maintaining the same high degree of comfort and fuel efficiency, and then return across the Atlantic in a displacement mode. This would be achieved not by re-inventing Naval Architecture, but instead refining it by utilizing and enhancing the current technology. A comparable analogy would be the progression of the internal combustion engine, from the first inefficient version to its modern-day efficiency. One of the first engines (1890) was a 1.1 litre motor capable of 4 hp @ 900 rpm (Daimler/Maybach). Today that same size production motor with today's efficient carburetors, turbo chargers, header exhaust, fuel injection, and careful intake and exhaust porting can develop over 100 bhp @ 6000 rpm while still being lighter and more fuel efficient than the original model. The basic principles of combustion and even the general design of these motors have not changed greatly from the initial concept but fine-tuning the design has brought huge gains. Much of this has been brought about by bolting on better carburetors, tuned air intake and exhaust systems, etc. In that same spirit the principles of a good basic hull design were evaluated and then methods looked at to increase efficiency by utilizing enhanced "bolt-on" appendages.

Market Response:

The main reason any of this work is even made possible is the huge and still-growing interest in long-range motoryachts, also known as passagemakers. As aging baby-boomers retire with a record amount of wealth, in good health and with a thirst for adventure, they look to the capabilities of the fishing trawlers and crabbers and ask if it is possible to achieve that seaworthiness in a motoryacht. The commercial fleets, the majority at 60-90 ft. (18 – 28 m), head out to sea off the coasts of Alaska and Canada in some of the worst weather imaginable. These single-screw displacement vessels venture many miles out into open ocean year after year. Many have been converted to pleasure craft, some with more success than others. The baby-boomers with their high-tech interests are intrigued by, and look for, innovation - as long as it is backed up by solid engineering. Many have earned their retirement funds from the technology and dot-com industries and see innovation as a part of their everyday life.

Hull Design:

This hull design work started with a paper study on various published hull forms, their relative efficiencies and seaworthiness. Standard resistance curves for a wide variety of displacement, semi-displacement, and planing hulls were studied to establish their "sweet spots" and how this applied to the speed/length ratios that had been targeted. Out of this analysis came the decision to use a lobster boat type of hull, as it was considered to be the most efficient over this range of speed ($\sqrt{LWL} * 0.9 – 2.3$).

From here various features were added to further enhance performance; a finer bow for low resistance and low bow wave, but high, wide spray knockers to add significant volume when pitching into a seaway; low transom immersion to reduce drag at low speeds, and wide spray chines above the waterline to give trim control at higher speeds. (Fig. 1)

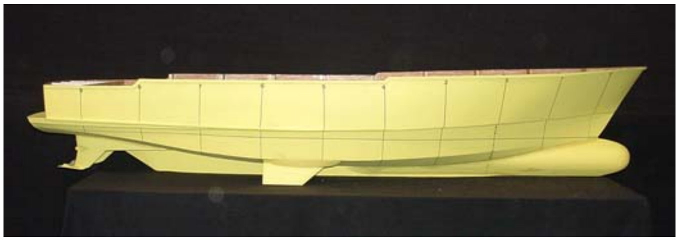


Fig. 1 Fox 86, Config. A

With the addition of performance enhancing appendages this work saw gains of up to 30% in efficiency and has been incorporated into vessels without having to resort to unattractive styling or stealth-style lines. In fact, this contemporary styling makes these boats real sleepers, disguising their efficiency to the point that their abilities are often disbelieved even with reality floating right there at the dock.

At 6 knots with this hull shape and appendage combination, there is no noticeable wave train. At 15 knots there is considerably less wave than most moderate-displacement trawlers. (Fig. 2) At 20 knots, this form is equal to chined, fully planing forms for resistance and wave profile.

Fig. 2 Cape Scott 86 at 15 knots

APPENDAGES

Bulbous Bow:

The bulb design work was inspired by the work of Dr. Calisal of the University of British Columbia who did extensive studies on the application of bulbous bows on fish boats in the early ninteen-eighties. From his published work with the fishing vessel "Kynok" a refined concept has been developing that results in a bulb design that is effective from 8-20 knots and produces a drop in resistance of over 11% at its maximum efficiency. In retrofitting bulbs to over 36 existing vessels, over the past six years, it was found that the attachment of a bulb would produce an immediate ¾ knot increase in speed, or a minimum 10% fuel savings.

A quote from a recent model-test program for the Fox 86-footer states *"From the Resistance and EHP plots it is evident that the bulb reduces the required power throughout the range of speeds from 9 to 19 knots, with crossover at 20 knots. The reduction is accomplished through wave cancellation and by reduction of the running trim due to the hydrodynamic forces acting on the bulb."* In addition to these fuel savings there is close to 50% reduction in pitching motion - but more on that once the other appendages have been discussed.

Bi-foil Skeg:

Another piece of technology inspired by work developed for the fishing fleets is the "Bi-foil Skeg" (Fig.3). It's evolution is a paper in itself but suffice it to say that it came about through drag reduction technology applied to the pipe frame net guard, typically called a "Beaver Tail", fitted under the propeller on fishing seiners. By optimizing the plan form and utilising a proper hydrodynamic foil section it is possible to reduce drag and increase propeller thrust. This is done by driving water to the prop and loading it up with clean, turbulence free water. The foil shape also acts as an automatic trim device. As the stern-down trim increases the angle of attack on the foil increases creating more lift. This lift then reduces the running trim and dampens out the pitching motions at the stern as well. At the same time the prop is more protected from logs and lines. This work is still in the initial stages of development and shows great promise. A 10% increase in thrust has been achieved in most cases so far.

Fig. 3 Bi-foil Skeg

Midship Blisters:

One of the most recent advancements comes through the use of significant appendage fairings. Having reduced the bow wave with a fine entrance angle and the use of a bow bulb, attention was turned to reducing the midship hollow. It was reasoned that this would help reduce drag by reducing the overall wave train and increase stability underway by reducing the midship hollow. Essentially, the goal was to duplicate the success of the bow bulb with a midship bulb or bilge blister. By adding a large fairing at the root of the stabilizer fin a midship wave would be created cancelling out the hollow (Fig. 4). Although this technology is still very new a maximum reduction of 6% in resistance has been achieved over a range of speed from 8-16 knots with no resistance penalty all the way up to 20 knots (Fig. 5).

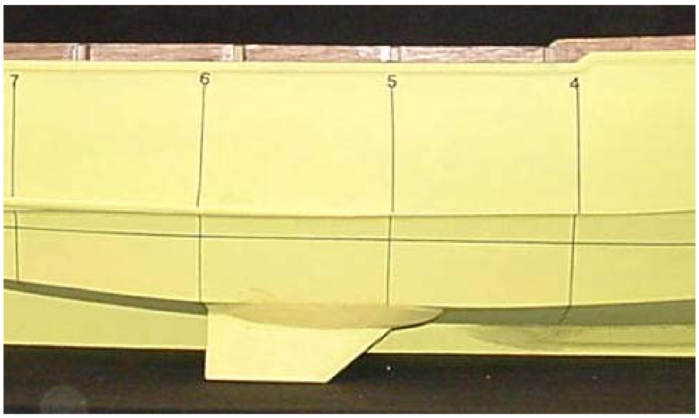
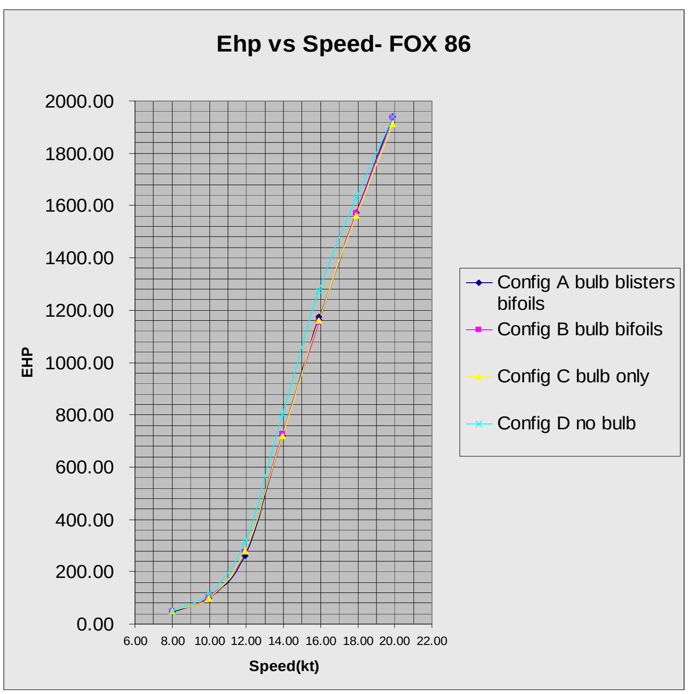


Fig. 4 Midship Blisters



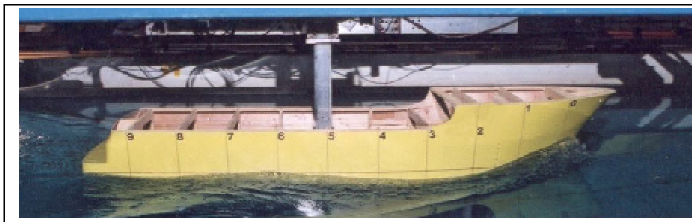
To determine shaft horsepower (SHP) divide EHP by the appropriate overall propulsive coefficient (OPC).
For open propellers a conservative value would be 0.55.

Fig. 5 Powering Predictions

A separate program at the University of British Columbia has seen reductions of up to 10%. In this program they have experimented with midship bulbs. The rationale is the same but the execution appears to produce better results. A joint research program is planned to explore this in greater depth.

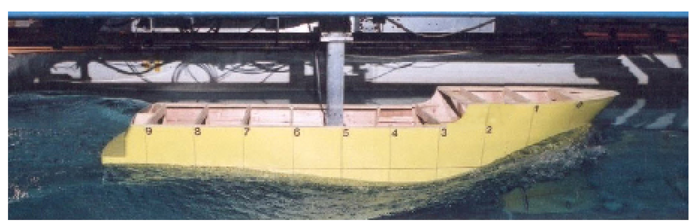
Comparison to a typical trawler:

On comparing powering estimates to other existing vessels without this technology it is found that the author's tested designs proved to be 30% more efficient and can operate over a wider range of speed (Fig 6). This has been ocean-proven in full size vessels on long offshore passages. Lower fuel consumption means less fuel to carry to achieve long range. Less fuel means less weight to carry. Less weight means a smaller engine required and less structural weight to carry it. Which means less overall weight that requires less power to move and lower fuel consumption, etc. The usually vicious circle of increasing penalties, (more fuel for greater range requiring more power that consumes the extra fuel), has become a spiral of benefits (Fig. 7).



Typical trawler at 10 knots

Fox 86 at 10 knots



Typical trawler at 13 knots

Fox 86 at 13 knots

Fig. 6 Typical trawler vs. Fox 86

PERFORMANCE FIGURES OF A TYPICAL TRAWLER COMPARED TO THE FOX 86

Speed (knots)	SHP		GPH (US Gal)		Range (nautical miles)		Gal/mile (USG/NM)		% Difference
	Typical	**Fox 86**	**Typical**	**Fox 86**	**Typical**	**Fox 86**	**Typical**	**Fox 86**	
8	100	108	4.0	4.2	13905	13568	0.50	0.52	-92.6
10	316	238	13.3	9.6	5279	7696	1.33	0.91	132.8
12	808	615	33.9	24.7	2476	3546	2.83	1.97	131.4
14	2266	1725	95.2	69.2	956	1476	7.4	4.74	131.3

	Typical		**Fox 86**	
LOA	85.35'	(26.0m)	85.75'	(26.14m)
LWL	77.5'	(23.62m)	77.5'	(23.62m)
Beam O.A.	23.38'	(6.52m)	24.5'	(7.47m)
Beam WL	21.2'	(6.46m)	21.17'	(6.45m)
Draft Hull	6.83'	(2.1m)	4.92'	(1.5m)
Draft	7.28'	(2.22m)	6.5'	(1.98m)
Displacement	150 Tons	(136.11 Tonnes)	125 Tons	(113.66 tonnes)

Fig. 7 Performance Comparison

Table 1 Superior Seakeeping – Fox 86 seakeeping data, bulb vs. no bulb

Seastate	**Speed (kt)**	**Bow Accelerations (g - rms)**	**CG Accelerations (g- rms)**	**Stern Accelerations (g-rms)**
Config D no bulb, no bi-foil				
SS 3	8	0.247	0.091	0.124
SS 3	10	0.275	0.109	0.145
SS 3	12	0.273	0.115	0.159
SS 5	6	0.281	0.106	0.148
SS 5	8	0.349	0.138	0.185
SS 5	10	0.374	0.159	0.210
Config A **bulb and bi-foil**				
SS 3	10	0.254	0.109	0.138
SS 3	12	0.256	0.122	0.154
SS 5	8	0.298	0.127	0.164
SS 5	10	0.352	0.160	0.200

Seakeeping:

The added appendages (bow bulb, midship blisters, and bi-foil) and slick hull form also give superior seakeeping characteristics. Not only can the vessel operate economically at a higher speed, but also there is no loss in the degree of comfort. The reduced bow wave height means that when the bow enters a wave there is less water being pushed aside so there is less water to come on deck. In fact, clients have confirmed that this form produces a very dry boat overall. A recent article in Showboats Magazine (March 2006) says *"He (the Owner) wanted the efficiency and seaworthiness that a bulbous bow provides by reducing pitching. Bray Yacht Design organized tank tests, which showed that the bulb and a redesign of the cutwater would provide a 12 percent reduction in resistance, allowing **Impetus** to make 9 knots (instead of 7 knots) into a 9 foot sea."*

Of all the boats that we have retrofitted with bulbs, it is the reduction in pitching that is noticed the most by the owners.

It can be seen from this table (Table 1) that with the addition of the appendages the vessel has virtually the same degree of comfort at 10 knots in Seastate 3 as it does at 8 knots in the same sea without the appendages. In fact, an increase in speed to 12 knots causes very little increase in pitching motions. This 2 knot speed advantage continues to be true at Seastate 5 as well. The addition of the appendages allows a 2 knot increase in speed with no real increase in motions for the vessel. (Seastate 3 is defined as having a scale significant wave height of 3.5 - 4.0 ft. (1 – 1.2 m) with a scale significant wave period of 5.8 seconds. Seastate 5 is defined as having a scale significant wave height of 8.0 – 12.0 ft. (2.4 – 3.65 m) with a scale significant wave period of 8.25 seconds.)

Stability:

In addition to all of these other features the hull form produced has excellent stability characteristics in keeping with a good roll period in a seaway and with sufficient range of stability to make the vessel safe for long range ocean cruising. This hull not only exceeds the minimum requirements of International Authorities, it has a good, healthy range of stability even in steep seas (Fig. 8).

Extensive studies were done on stability parameters and the effects of hull and superstructure forms on the range of positive righting arm. Every effort is made to keep weight low in the vessel as the design develops. During the design process as features are incorporated into the overall form they are placed and planned to produce a good overall movement of the center of buoyancy in relation to the center of gravity. The resultant vessel has excellent stability parameters without having to resort to anything more than minor amounts of trimming ballast.

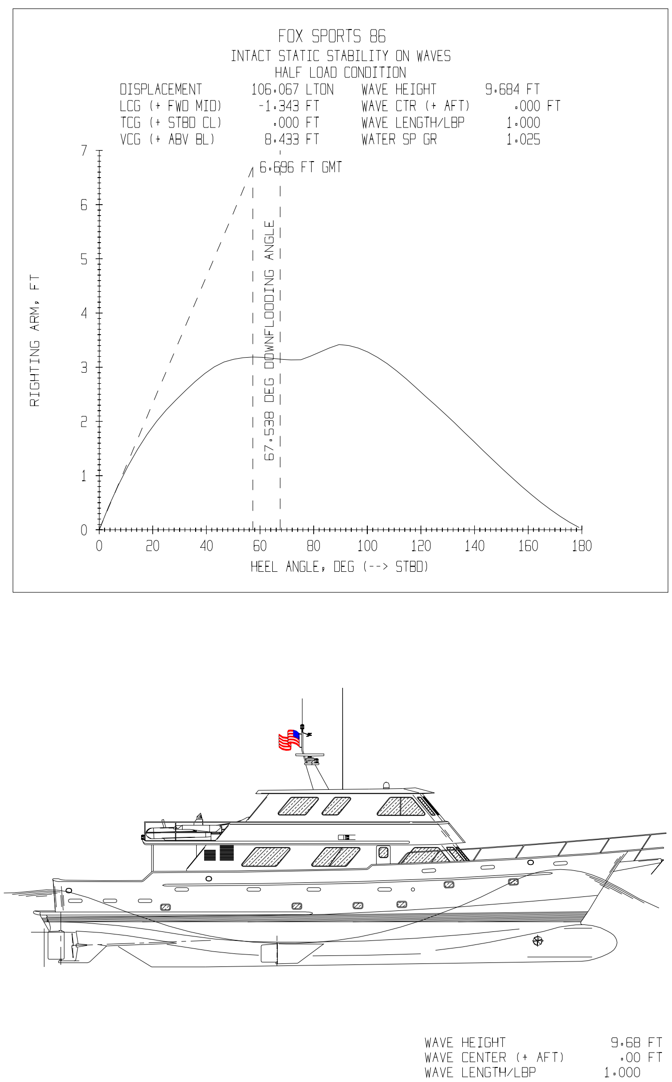


Fig. 8. Fox 86 - Stability on waves

EXAMPLES:

"Amnesia IV"

This is one of the first large fiberglass motoryachts to take advantage of some of this technology. The vessel is 86 ft. (26.2 m) long with a 23 ft. (7 m) beam and 6 ft. (1.83 m) draft. With a single 1300 hp MAN diesel a top speed of 15 knots has been attained. At 210,000 lbs. (95.3 tonnes) displacement (half load) it is considered to be a medium weight vessel. It has a 7000 mile range at 9 knots on 6000 US gallons (22,680 litres) of fuel. As reported by the Captain, on a trip from Vancouver, B.C. to San Diego, CA the vessel easily averaged 9 knots in big seas and high winds burning less than a gallon per nautical mile, (including generator run time), in comfort.

"Kookaburra"

This vessel is an all-steel 76 ft. (23 m) ocean trawler with a 22 ft. (6.7 m) beam and a 6.5 ft. (2 m) draft. Fitted with twin 330 hp diesels the vessel has a top speed of 12 knots. At 225,000 lbs. (102 tonnes) displacement (half loaded) it is considered moderately heavy. It has a 3500 mile range at 9 knots on 3300 US gallons (12,500 litres) of fuel. The Owner reported that on her first trip from Vancouver, B.C. to Mexico she easily averaged 9 knots in reasonable weather. Although the initial intention was not to cruise that fast, they started out at that pace, found it comfortable and just never throttled back. They burned about 1 US gallon of fuel per nautical mile including running the generator 3 hours per day.

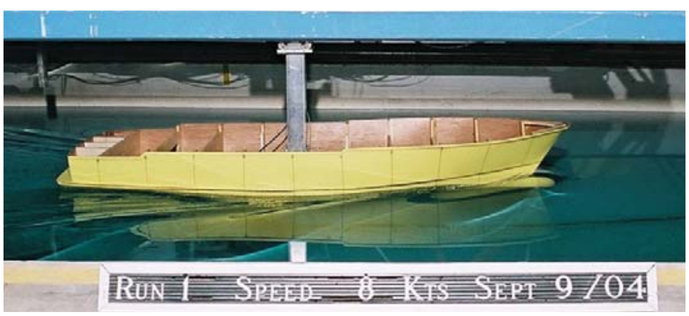
"Fox" Project

The latest project, to be launched in the summer of 2006, was extensively tank tested at Vizon Scitec Ocean Engineering at the University of British Columbia. Much of the data in this paper is taken from that test report. The Fox Sports 86 is an 85.75 ft. (26.14 m) long-range sportfish with a 24.5 ft. (7.47 m) beam and 6.5 ft. (1.98 m) draft. Built with a steel hull and fibreglass superstructure the vessel displaces 250,000 lbs. (113.66 tonnes) half loaded. Twin 550 hp. diesels will push it up to 15 knots with a range of 7000 miles on 5500 US gallons (20,790 litres) of fuel.

Model runs for Fox 86

Both the wave train and resistance numbers were very good for this hull and typical of this technology. Seakeeping showed no water coming on deck and the bulb never completely emerged from the water despite the shorter than typical wave train tested.

Config. A: with bulb, stabilizers, blisters, bi-foils - see Table 2

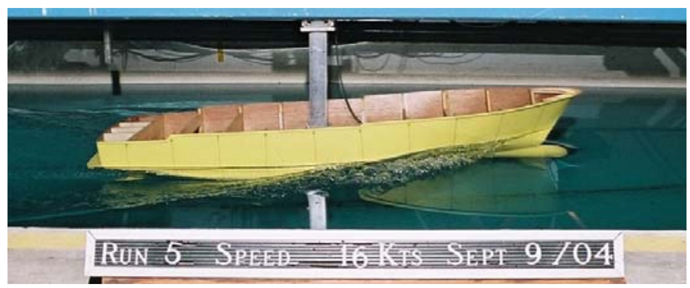


Very little wave train with significant hollow after the bulb.

Typical long range cruise speed. Shallow wave train with little disturbance.

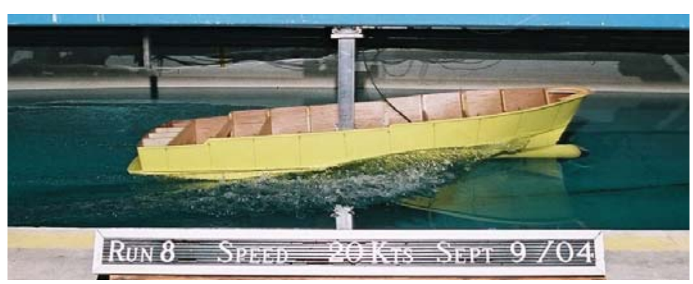
Fast long range cruise with appendages working at their maximum efficiency. The bow wave has just reached the spray knocker.

Positive bow trim for the first time.



Trim only 2.6 degrees

This is the maximum practical limit to this hull form and appendage combination.



The resistance advantage of the appendages has zeroed out and there is no benefit to this technology beyond this speed/length ratio.

CONCLUSION

The bow bulb work has been retrofitted to over 3 dozen vessels from 40 ft. to 95 ft. (12 – 30 m) and model tested on designs up to 160 ft. (48.8 m). It has gone through only one revision to date and currently shows no signs of slamming and in fact seldom comes clear of the water. The design parameters and real-time results have been well established by feedback from numerous clients and their Captains and crew. These results from the bow bulb are a minimum ¾ knot increase in speed or minimum 10% drop in fuel consumption as well as a very significant reduction in pitching motions.

The midship blisters, which show an initial result of a 6% drop in resistance, need further study to bring out their full potential and determine the exact proportions necessary to create the maximum benefits. The goal is to achieve a significant reduction in the midship wave hollow in combination with the wave reduction of a bulbous bow, which will bring a reduction in the stern wave through an overall shallower wave train. This will also contribute to increased stability underway as there is less midship trough for the vessel to heel into.

With the reduction in bow and midship waves it is only natural to next look aft to the transom. The large reduction in bow wave needs to be matched by a similar reduction in the stern wave. How this will be accomplished is yet to be determined but there are some areas of work that hold promise, including the stern bi-foil mentioned earlier. As well, there has been some very promising, but limited work done on stern bulbs. If a successful stern type bulb appendage could produce results similar to that of the bow or midship bulbs then there would be some phenomenal gains in economy of propulsion.

For the future, a joint program with Dr. Calisal and his team at the University of British Columbia is planned. This continued look at improvements in hull resistance will focus on enhancement and optimization of appendages. By combining these separate programs a 15%-20% reduction is expected beyond what has already been achieved based on an initial assessment of each group's past work. Both CFD and model testing will be required to cover the many combinations possible with so many different parts, locations, and sizes.

Once a combination of optimized appendages has been established a new hull form will need to be developed to take maximum advantage of all the benefits. The added displacement of the appendages alone will allow finer beam/length and draft/length ratios all of which will contribute to lower resistance numbers through their own reduced hull volume.

The ultimate goal is to have a vessel that will slip through the water without any disturbance to mark its passing, the ultimate interface vehicle. This work is continuing on many of our new projects, particularly focusing on 100 ft. plus long-range motoryachts.

ACKNOWLEDGEMENTS

George Roddan of Roddan Engineering has been an invaluable consultant and contributor to this technology from the start.

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TABLE 2 – FOX 86

ANALYSIS OF TANK TEST CONDUCTED AT BCRI OCEAN ENGINEERING CENTRE

Full Size Ship Constants

Length Overall (ship).	85.75 ft	26.135m
Length Waterline (ship)	77.5 ft.	23.621m
Beam Overall (ship)	24.5 ft.	7.467m
Draught (ship)	6.49 ft.	1.978m
Displacement (ship)	109.62 L.Tons	111.41 Tonnes
Block Coefficient	0.36	
Prismatic Coefficient	0.62	

Config. A: with Bulb, Stabilizers, Blisters, Bi-foils, Level Trim

SPEED (knots)	V/L1/2 (kts/ft1/2)	HEAVE CHANGE (ft)	TRIM CHANGE (deg)	EHP
8.0	0.91	-0.25	-0.29	46.4
10.0	1.13	-0.39	-0.52	100.1
11.9	1.36	-0.70	-0.32	259.6
13.9	1.58	-0.98	1.40	720.9
15.9	1.81	-0.87	2.57	1169.8
17.9	2.03	-0.69	3.30	1574.4
19.9	2.26	-0.53	3.56	1939.2

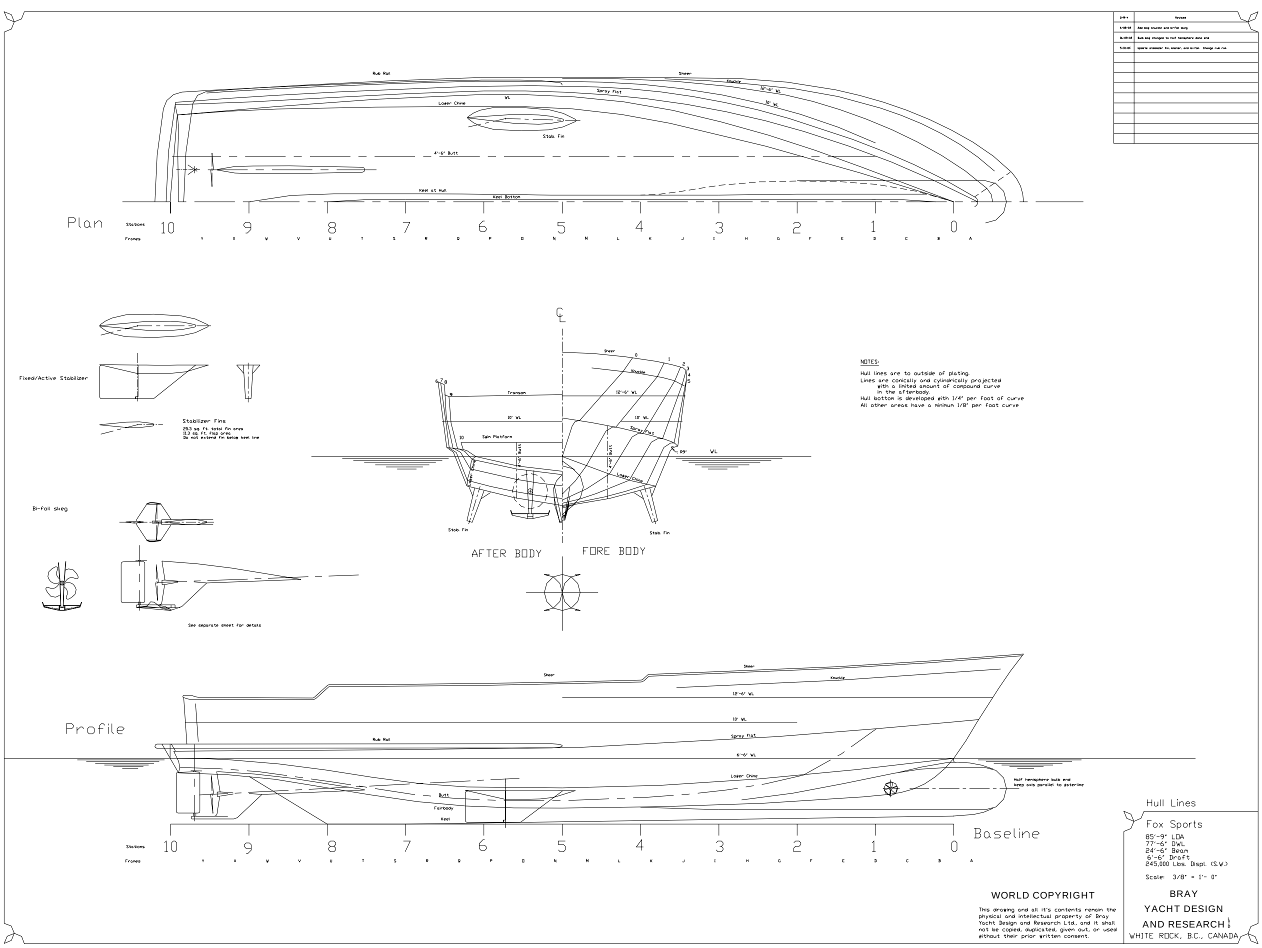

TABLE 3 – FOX 86

Config. D: without Bulb, Stabilizer Blisters, or Bi-foils, Level Trim

SPEED (knots)	V/L1/2 (kts/ft1/2)	HEAVE CHANGE (ft)	TRIM CHANGE (deg)	EHP
8.0	0.91	-0.21	-0.14	47.7
10.0	1.13	-0.38	-0.23	115.6
11.9	1.36	-0.65	0.23	312.5
13.9	1.58	-0.77	2.13	800.7
15.9	1.81	-0.66	3.56	1273.1
17.9	2.03	-0.38	4.24	1628.1
19.9	2.26	-0.16	4.42	1940.8