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TOW TANK RESULTS OF BULBOUS BOW RETROFITS ON NEW ENGLAND TRAWLER HULLS

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Nomenclature

a	acceleration amplitude in units of g
B	beam, waterline
C_b	block coefficient
C_f	frictional resistance coefficient
C_P	prismatic coefficient
C_r	residuary resistance coefficient
C_T	total resistance coefficient
D	diameter of bulb or propeller
EHP	effective horsepower
g	acceleration of gravity
GM	metacentric height
i_E	half-angle of entrance at LWL (degrees)
J	propeller advance coefficient, V_A/nD
k	wave number, $2\pi/\lambda$
K_T	thrust coefficient, $T/\rho n^2 D^4$
LOA	length overall
λ	wave length
L = LWL	length water line
n	propeller revolutions per second
P	propeller pitch
R = Rt	resistance
Rn	Reynolds number
RPM	propeller revolutions per minute, 60n
S	wetted surface
SHP	shaft horsepower
t	thrust deduction
T	molded draft or propeller thrust
V_A	speed of advance, propeller (ft/sec)
V_m	velocity, model (ft/sec)
V_s	velocity, full scale (ft/sec)
w	wake fraction
Δ	displacement in tons
η_h	hull efficiency, (1-t)/(1-w)
η_o	open water propeller efficiency
η_r	relative rotative efficiency
η_s	shaft & transmission efficiency
η_p	propulsive efficiency
θ	angle of pitch
ν	kinematic viscosity
ρ	mass density of water
ρ_w	added resistance ceofficient
ζ_a	wave amplitude

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Abstract:

This report describes the research conducted at MIT on bulbous bow retrofits applied to two New England type trawler hulls of 76 and 119 foot overall length. It is based, in part, on a Master's thesis by Heliotis (1). The work was initiated and sponsored by the MIT Sea Grant Center For Fisheries Engineering Research. Tests were conducted in the MIT Department of Ocean Engineering ship model towing tank. Related tests on a 164' round-bilged vessel have been reported separately (2).

The lines drawings of the two hulls were provided by John W. Gilbert Associates of Boston, Massachusetts, together with information on the propulsion and operation of the vessels in their present fisheries. A 4.5' model of each hull was constructed and a series of twelve cylindrical-type bulbous bow retrofits were prepared for each.

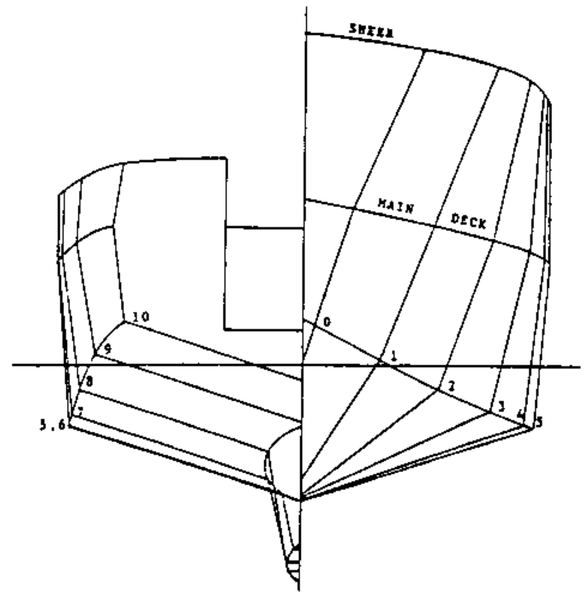
Calm water model resistance tests were conducted on the bare hull and then with each retrofitted bulb. All tests were done at constant draft, i.e., the bulb configurations were of heavier displacement than the original hull. The calm water results were compared at steaming speeds and a "best" bulb was selected for seakeeping tests. The bare and bulbous models were then tested in regular waves over a range of wave lengths at both steaming and trawling speeds. Pitch, heave, bow accelerations, and resistance were measured.

In the tests, all bulbs were fitted to the maximum limits of the forward draft and were aligned parallel to the waterlines. Variations in bulb diameter and length were studied. The results presented show the effect of these parameters on hull performance. Propeller calculations are presented to predict the effect on horsepower requirements based on the performance of the best bulb.

[1] Mr. Heliotis is currently employed by Maritech, Inc. of Arlington, Massachusetts

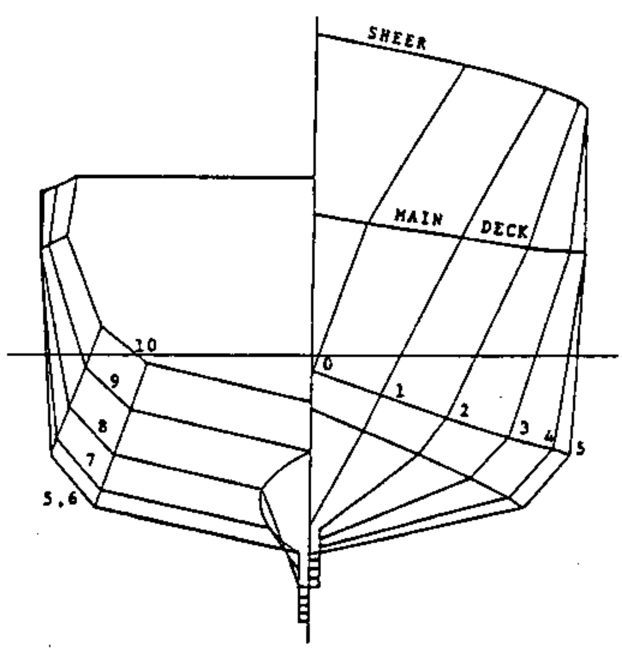
Model Construction:

The section drawings and principal dimensions of the 76' and 119' trawler hulls are presented in Figures 1 and 2.



LOA	76.6 ft
LWL	70.0 ft
B	21.1 ft
T	6.0 ft
Δ	112.3 tons
S	1390 ft^2
C	.451
C	.625
i	25.5 degrees
L/B	3.32
B/T	3.52
Vs	9.0 kts
Vt	3.0 kts

Figure 1. Section drawing of the 76' trawler.



LOA	119.4 ft
LWL	110.0 ft
B	28.0 ft
T	10.0 ft
Δ	436.3 tons
S	3391 ft^2
C	.512
C	.624
i	21.0 degrees
L/B	3.93
B/T	2.80
Vs	12.0 kts
Vt	3.5 kts

Figure 2. Section drawing of the 119' trawler.

From the section and lines drawings, glass-fiber laminated models were constructed to overall lengths of 4.5 feet. The scale ratio for the 76' hull was 17.03 to 1 and for the 119' hull it was 26.53 to 1.

The bulb retrofits studied were cylindrical with hemispherical caps. This geometry was selected due to its potential economy of full-size fabrication and reports of some success with this type of bulb on the U.S. West Coast (5). The parameters varied were diameter and length. All bulbs were positioned with their lower edge even with the intersection of the forward perpendicular and an extension of the bottom of the keel. See Figures 3 and 4.

Three bulb diameters were used to cover a range of possible sizes from approximately 10 to 30 percent of the midship section area. The same model bulb retrofits were used on both hulls. These were 2.4", 3.5", and 4.5" in diameter. For the 76' design, these sizes represented midship section percentages of 10.01, 21.29, and 35.19, respectively. For the 119' design, they represented percentages of 9.63, 20.48, and 33.86, respectively. In most cases throughout this report, they are referred to simply as 10, 20, and 30 percent bulbs.

The hemispherical caps were machined on a numerically controlled lathe from PVC round bar. Lengthening rings of 0.5, 1.0, and 1.5 diameters were prepared to allow for variation of bulb length. Fairing pieces were constructed from PVC tubing to attach the caps to the hull. These fairings extended back until they intersected with the hulls.

Each retrofit component was designed to be a press-fit with its neighbor and all bulbs, lengthening rings, and fairings were aligned with the horizontal baseline. The transition pieces were accurately fitted to the hull and a thin application of silicone caulk at each joint was all that was needed to keep the bulbs in place and watertight.

A description of each bulb is presented in Tables 1 and 2. Figures 5 through 8 are photos of some retrofitted models during the testing.

Test Facility:

The MIT Ship Model Towing Tank is 108' long, 8'-7" wide, with a normal water depth of 4' (6). The towing carriage is instrumented for resistance and motions measurements. One end of the tank is fitted with a wave generator while the other end has a wave absorbing "beach". Regular waves and various sea spectra can be developed.

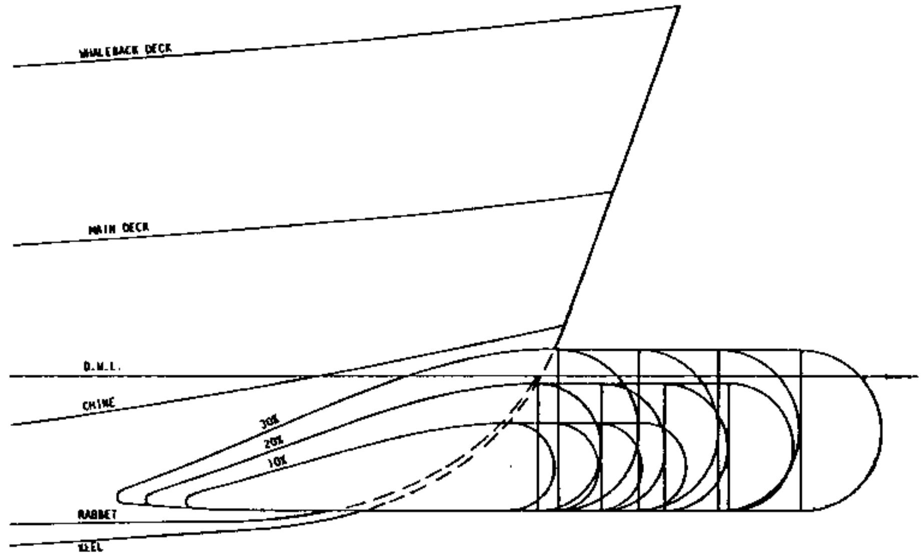


Figure 3. Profile view of the 76' design with bulb retrofits.

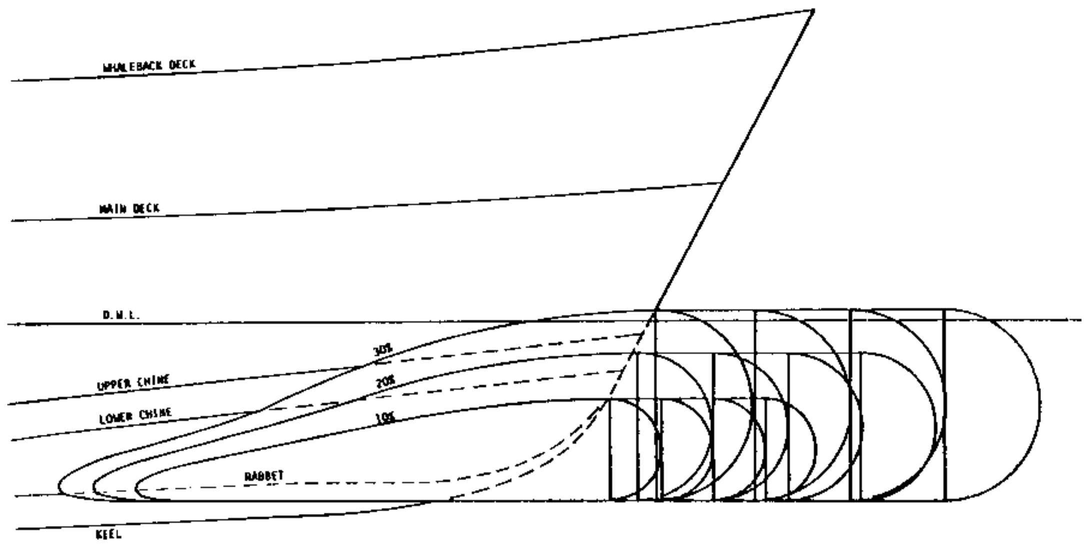


Figure 4. Profile view of the 119' design with bulb retrofits.

Bulb Description	Percent of A_M	Diameter (inches)	Length Fwd. of Stem(in)	Submergence (inches)
10%	10.01	41.0	20.5	-24.0
10% - 0.5D	10.01	41.0	41.0	-24.0
10% - 1.0D	10.01	41.0	61.5	-24.0
10% - 1.5D	10.01	41.0	82.0	-24.0
20%	21.29	60.0	30.0	-4.0
20% - 0.5D	21.29	60.0	60.0	-4.0
20% - 1.0D	21.29	60.0	90.0	-4.0
20% - 1.5D	21.29	60.0	120.0	-4.0
30%	35.19	76.6	38.3	+12.0
30% - 0.5D	35.19	76.6	76.6	+12.0
30% - 1.0D	35.19	76.6	114.9	+12.0
30% - 1.5D	35.19	76.6	153.2	+12.0

Table 1. Specifications of bulbs tested, 76' trawler.

Test Procedure:

To insure a proper transition from laminar to turbulent flow, a row of turbulence stimulators was attached to the hull 4% of the LWL behind the stem. These were made up of 0.125" diameter by 0.062" long studs spaced 0.25" apart. When the bulbs were attached, the row of studs was continued in a vertical line around the transition piece.

The bare hulls were floated in the tow tank and ballasted to their design water lines. Lead billets were used and fixed in place with clay. The correct displacement was then verified by weighing the ballasted model.

The towing carriage force block was attached to the inside of each hull at the center of flotation, on the centerline, and in a vertical position such that the force applied to the model would be approximately in line with the location of the propeller shaft. The force block is designed to pivot about the pitch axis and is attached to heave rods to allow for vertical motions. The model is restrained from roll, sway, yaw, and surge relative to the carriage.

Bulb Description	Percent of A_M	Diameter (inches)	Length Fwd. of Stem(in)	Submergence (inches)
10%	9.63	63.7	31.8	-50.0
10% - 0.5D	9.63	63.7	63.7	-50.0
10% - 1.0D	9.63	63.7	95.5	-50.0
10% - 1.5D	9.63	63.7	127.4	-50.0
20%	20.48	93.0	46.5	-21.0
20% - 0.5D	20.48	93.0	93.0	-21.0
20% - 1.0D	20.48	93.0	139.5	-21.0
20% - 1.5D	20.48	93.0	186.0	-21.0
30%	33.86	119.4	59.7	+6.0
30% - 0.5D	33.86	119.4	119.4	+6.0
30% - 1.0D	33.86	119.4	179.0	+6.0
30% - 1.5D	33.86	119.4	239.0	+6.0

Table 2. Specifications of bulbs tested, 119' trawler.

The 76' model was tested over a range of ship speeds up to 11 knots. The 119' model was tested up to 13 knots. The order of speed selection was randomized and five minutes elapsed before commencing the next run, or until all waves from the previous run dissipated. The actual speeds of each run are tabularized in Appendix A.

The procedure was repeated for each bulb retrofit. Ballast was added to the bow to counteract the buoyancy of the bulb. In some cases, the overall ballast arrangement would have to be adjusted due to the forward location of the bulbs.

As noted in Tables 1 and 2, the top surface of the 30% bulbs were above the still waterline due to their size relative to the forward drafts. At all test speeds these bulbs became submerged.

The seakeeping tests were done in a similar manner except that the placement of the ballast in the model was done to yield a longitudinal radius of gyration of 0.25 of the model length.

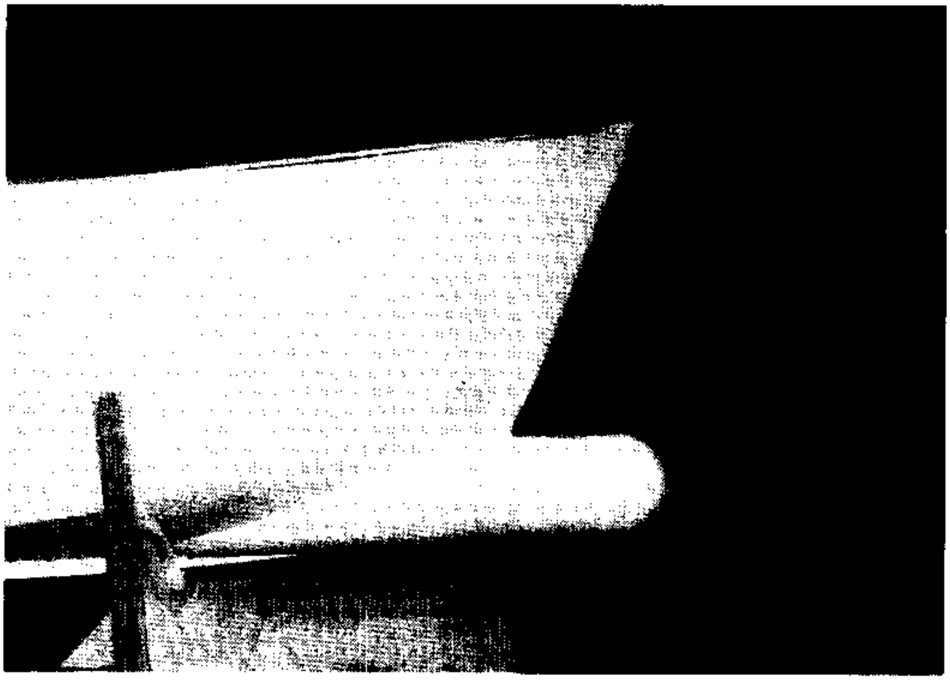


Figure 5. The 76' design with a 20% bulb and 1.0D ring.

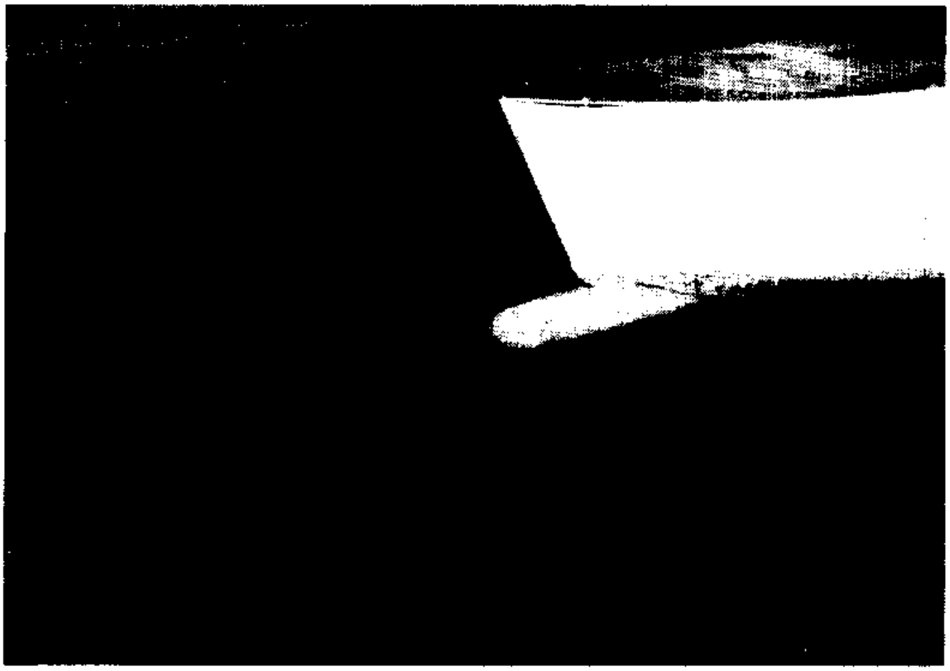


Figure 6. The above model during calm-water tests.

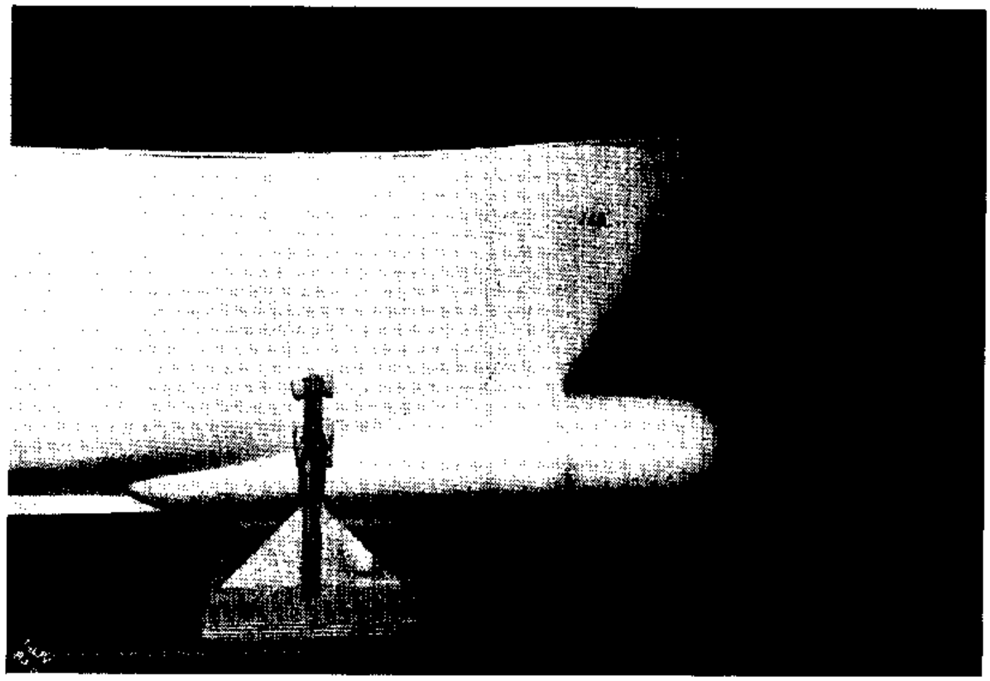


Figure 7. The 119' design with a 20% bulb and 1.0D ring.

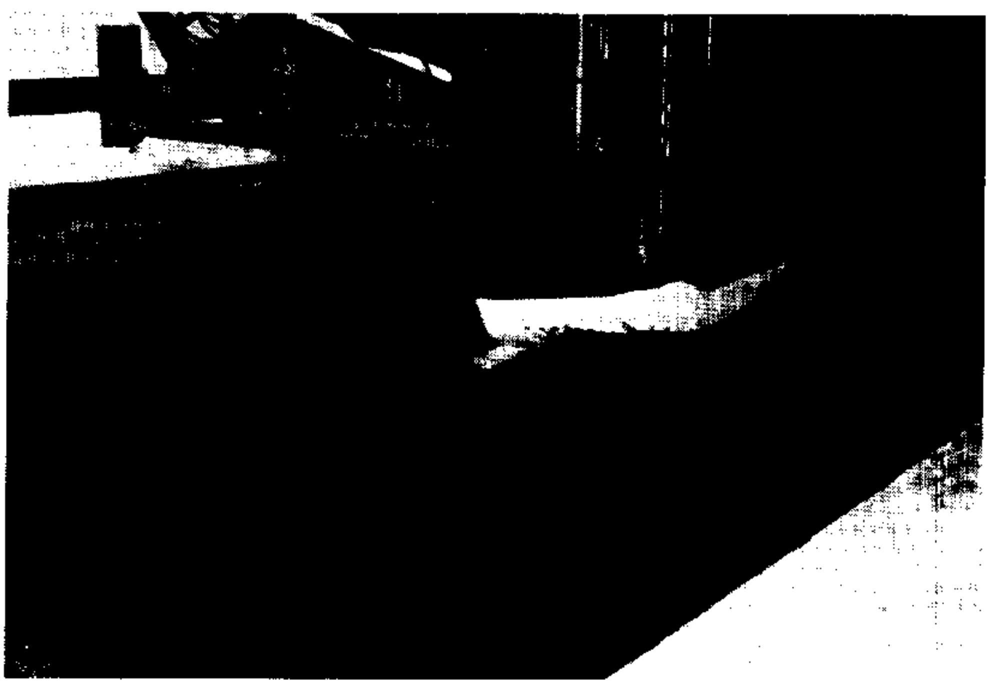


Figure 8. The above model during seakeeping tests.

Seakeeping runs were made at both steaming and trawling speeds. For the 76' design these speeds were 9.0 and 3.0 knots. For the 119' design the speeds were 12.0 and 3.5 knots. Wave lengths from 0.7 to 3.0 times LWL were generated. Wave heights were maintained at a constant 5% of the LWL.

Since the pitch and heave response of a trawler is clearly affected by the presence of the trawl gear during trawling, this effect was simulated during the seakeeping tests. A parachute-type drogue with drag characteristics appropriate for each vessel was attached to a point on the transom centerline at the main deck. This was kept submerged by a weight at the junction of the tow wire and the drogue. The weight used was equivalent to the weight of two appropriately sized trawl doors and produced a vertical warp angle of approximatety 20 degrees. The set-up is diagrammed in Figure 9.

Pitch motions, heave motions, bow accelerations, and wave height were recorded during each run. The accelerometer was located on the foredeck at station 10 1/2.

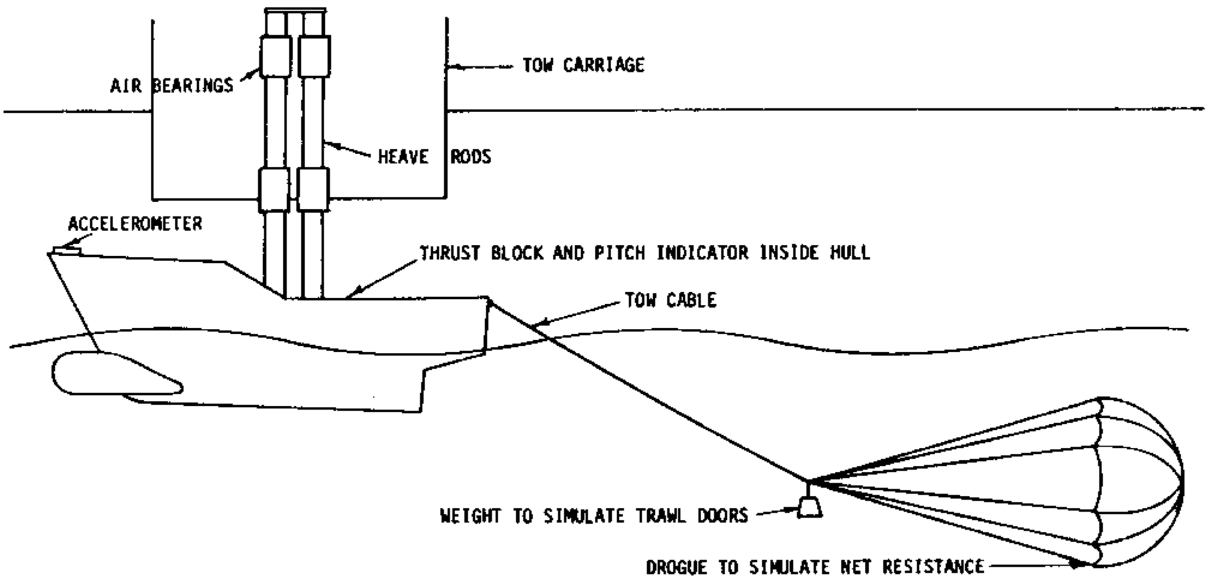


Figure 9. Rigging for the seakeeping tests at trawling speeds.

Calm-Water Results:

The model drag at each calm-water speed is presented in the tables of Appendix 1 together with the nondimensionalized drag values and the scaled-up results. These results are presented graphically in Appendix 2 where comparisons among the various bulb lengths are included.

Figure 10 is based on this data and shows the effect of bulb size on 76' effective horsepower (EHP) for speeds of 8, 9, and 10 knots. Figure 11 is a similar comparison of 119' EHP versus bulb size for speeds of 11, 12, and 13 knots. In these graphs, the bulb length producing the least total resistance has been used. The importance of bulb diameter is shown, especially on the 76' design.

To demonstrate more clearly the importance of operating speed on optimum bulb selection, the EHP changes for the three bulb diameters are presented versus speed in Figures 12 and 13.

For the 76' design, the 20% bulb is clearly superior, offering substantial EHP reductions at steaming speeds. At speeds below 7.5 knots this bulb becomes detrimental. The 10% bulb has little effect. The 30% bulb provides some advantage at higher speeds, however it is of considerable detriment at slow and moderate speeds.

For the 119' design, the 20% bulb again apears most promising at the normal steaming speed of 12 knots. The 10% bulb also offers substancial advantages with less detrimental effect at slower speeds than the 20% size. The 30% is clearly oversized offering no resistance benefits until a speed of 11 knots has been reached.

In Figures 12 and 13, the best length bulb for each diameter is used in the comparisons. It can be seen in Appendix 2 that the effect of length variations is more important with the 20 and 30 percent bulbs. We should recall however that the length increments are based on diameter and the actual length variations of these larger bulbs were quite extreme (see Tables 1 and 2).

To better visualize the effects of length, the next two figures show the results of the different length 20% bulbs in terms of EHP changes relative to the bare hull. From Figure 14 you can see that on the 76' design, the 1.0 diameter ring presents the greatest potential benefit over the speed range of interest. Only the shortest version offers no benefits over the speed range covered.

In Figure 15, the 119' design is also benefitted most by the 1.0 diameter extension. At slower speeds, however, the shorter bulbs have a less detrimental effect.

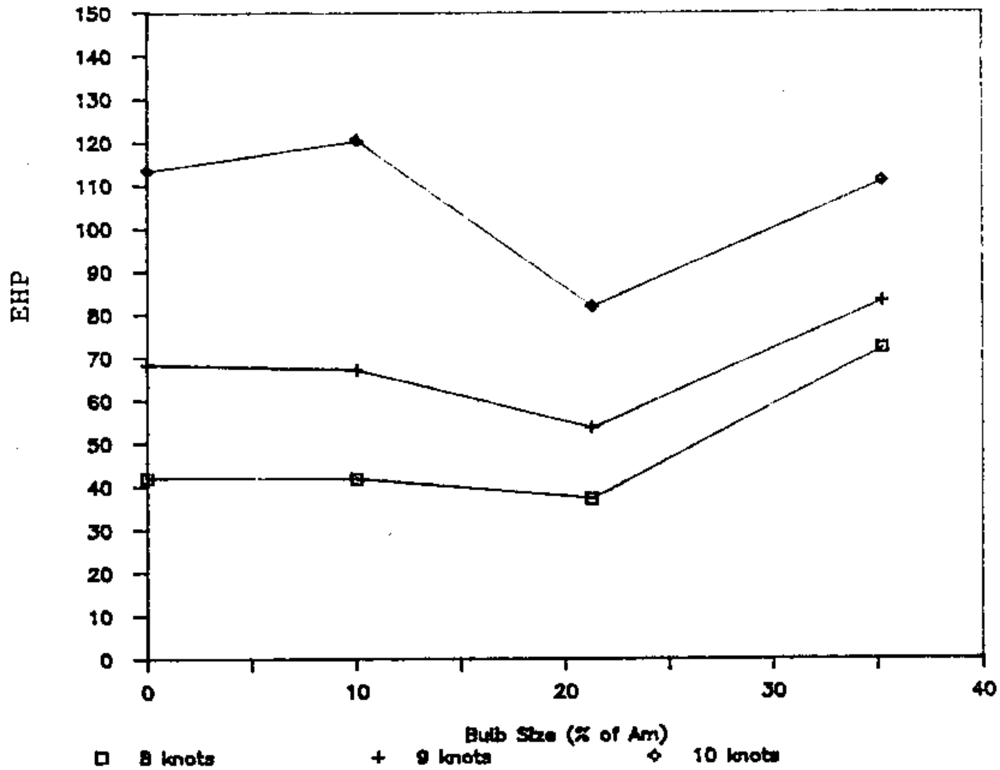


Figure 10. EHP versus bulb diameter, 76' design.

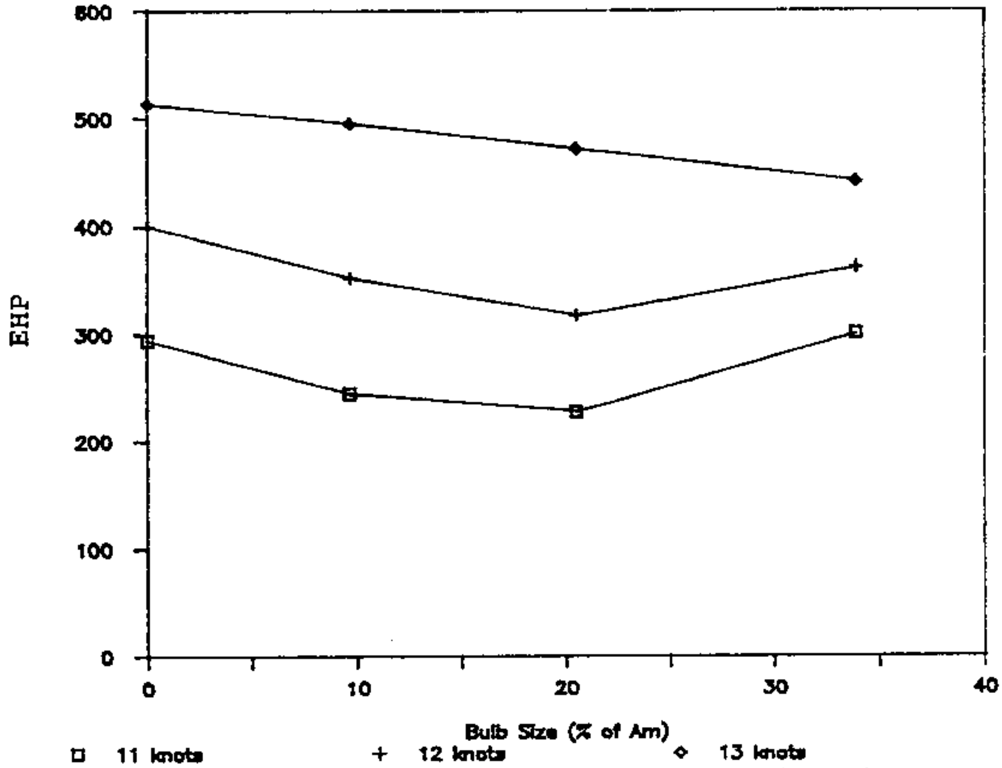


Figure 11. EHP versus bulb diameter, 119' design.

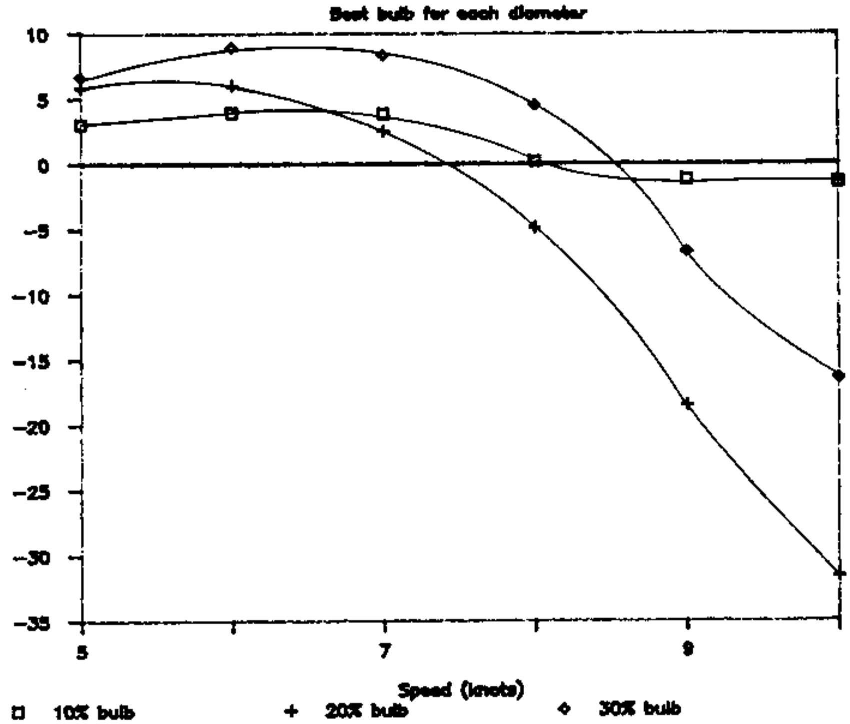


Figure 12. EHP versus speed, 76' design.

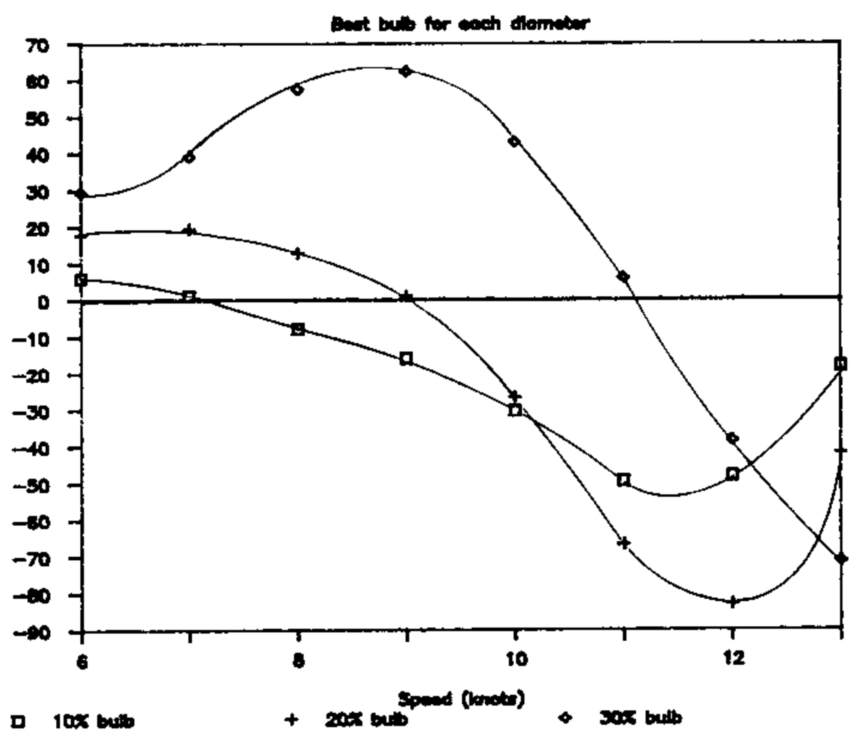


Figure 13. EHP versus speed, 119' design.

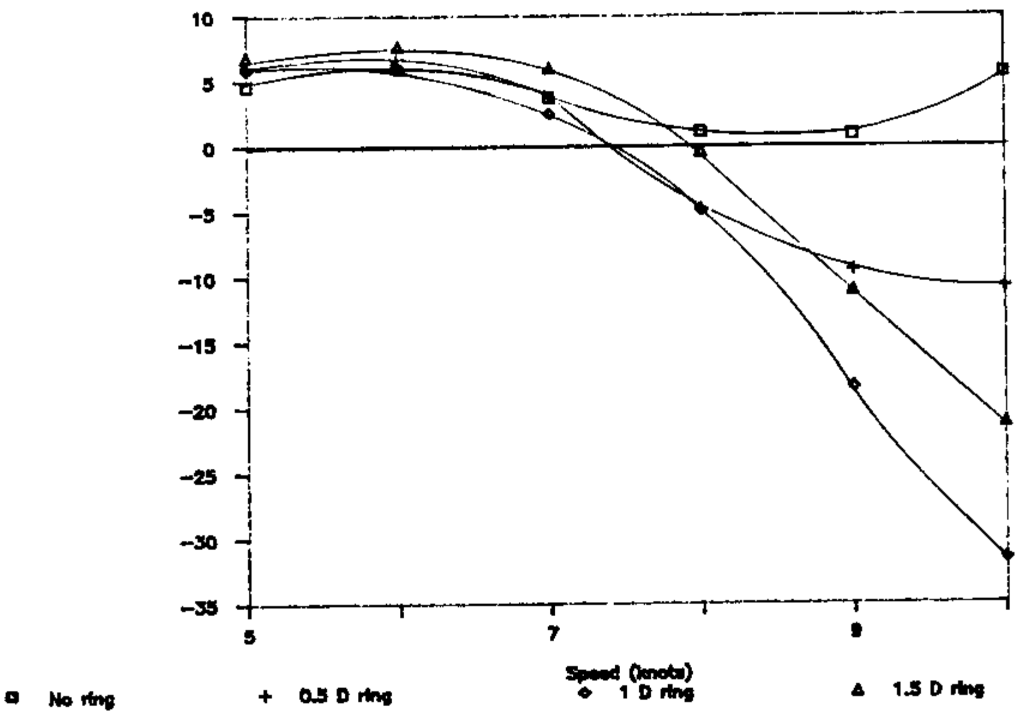


Figure 14. EHP versus bulb length, 76' design.

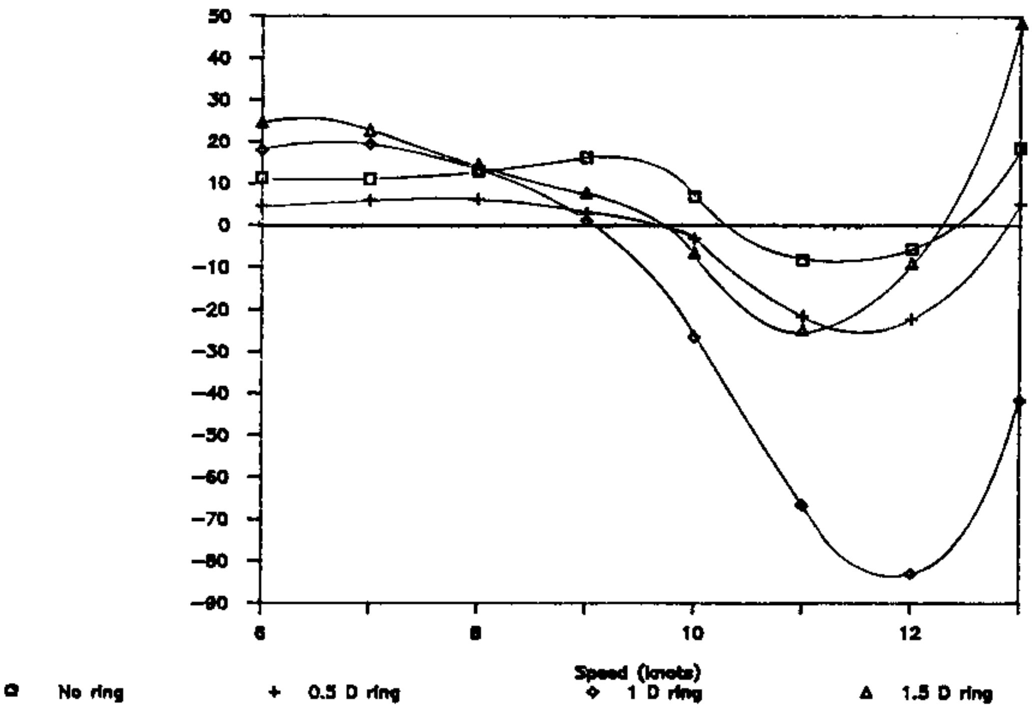


Figure 15. EHP versus bulb length, 119' design.

Regular Wave Results:

From the recorded data the average pitch and acceleration responses were determined for each regular wave length. For the steaming speed, the non-dimensionalized pitch results are shown in Figures 16 and 17.

For both vessels, the 20% bulbs appear effective at reducing pitch motions at wave lengths less than 2.0 LWL. Above this point the bulb has little effect.

Figure 18 and 19 are similar presentations of bow accelerations. Here, the advantage of the bulb is even more evident since the higher frequencies associated with the shorter wavelengths are important with respect to accelerations and crew comfort.

As would be expected, the pitch response levels off at the longer wavelengths as the vessel begins to simply follow the slope of the wave surface. The lower frequencies in this region cause the accelerations to diminish and little difference is found with the bulb.

The results at trawling speeds can be found in the thesis by Heliotis (1). The presence of the trawl-simulating drogue causes the motions to become more complicated than with the trawler alone. We were unable to determine any effect from the bulb. Frequent coincidence of bare and bulb data suggested an unusual system response which is not affected by minor changes in the hull form.

Added Resistance Results:

Since vessel motions affect powering requirements, resistance measurements were taken during the seakeeping tests. The results are presented in Figures 24 through 27 in terms of non-dimensionalized resistance ρ_w, defined by:

$$\rho_w = \frac{R - R_{calm}}{\rho g B^2 / L \, \zeta_a^2}$$

Figure 20 shows that in spite of the reduced motions, the resistance of the 76' design with the 20% bulb is more affected by head seas than the bare hull. By contrast, the results for the 119' design show a reduction in added resistance for the retrofitted hull.

At the trawling speed the results were again uninterpretable due to the complex response caused by the drogue/vessel system.

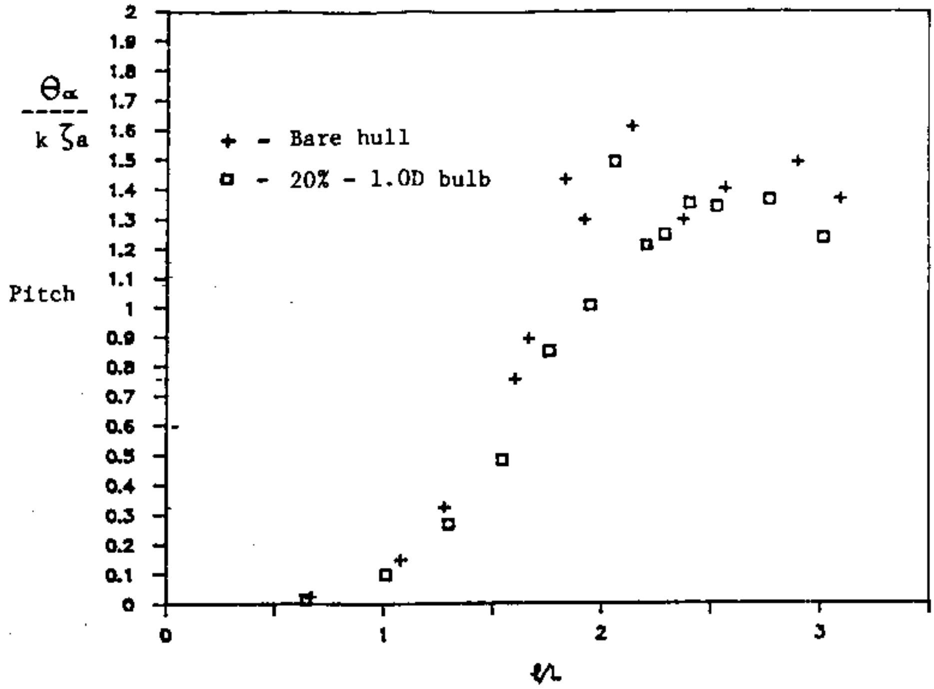


Figure 16. Nondimensionalized pitch versus wave length for the 76' design at 9 kts.

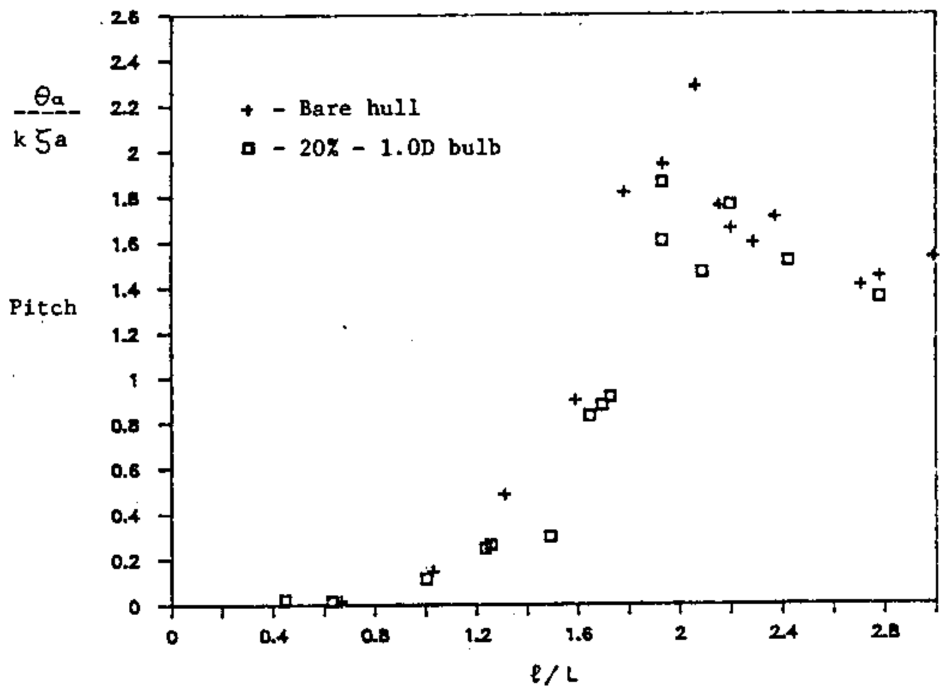


Figure 17. Nondimensionalized pitch versus wave length for the 119' design at 12 kts.

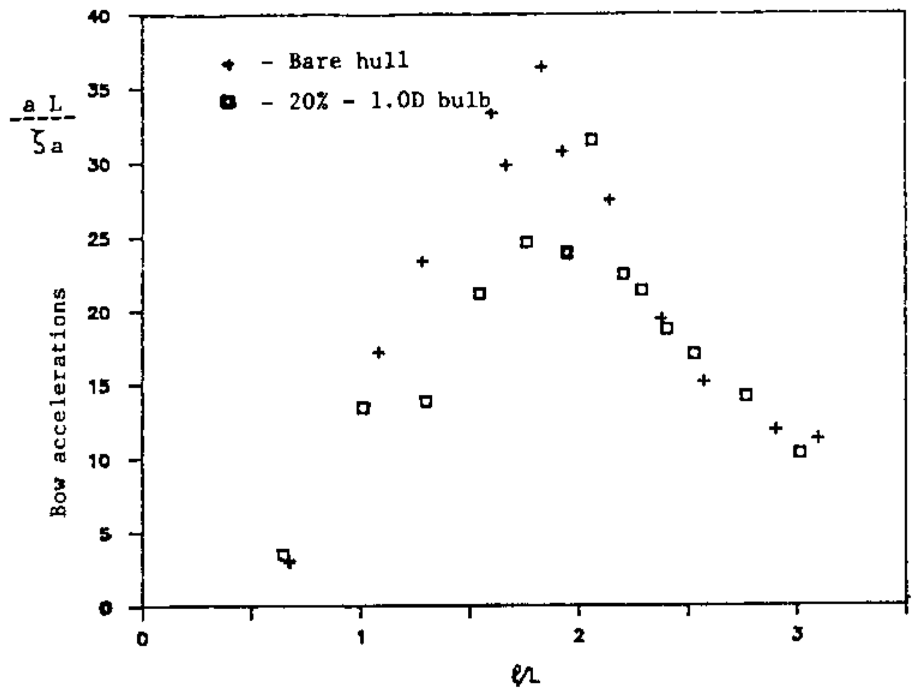


Figure 18. Normalized bow acceleration versus wave length for the 76' design at 9 kts.

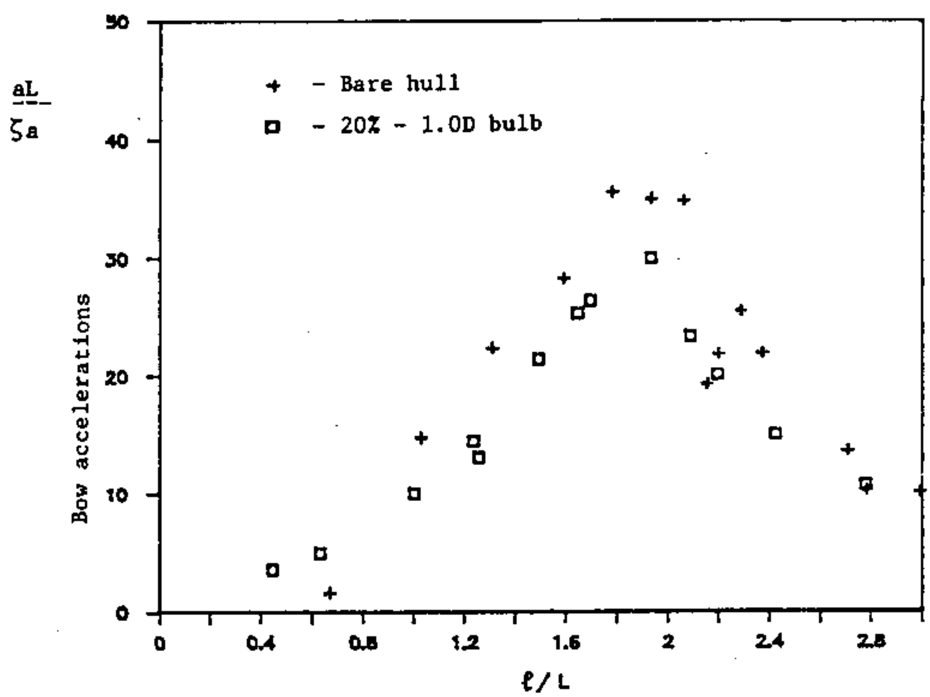


Figure 19. Normalized bow acceleration versus wave length for the 119' design at 12 kts.

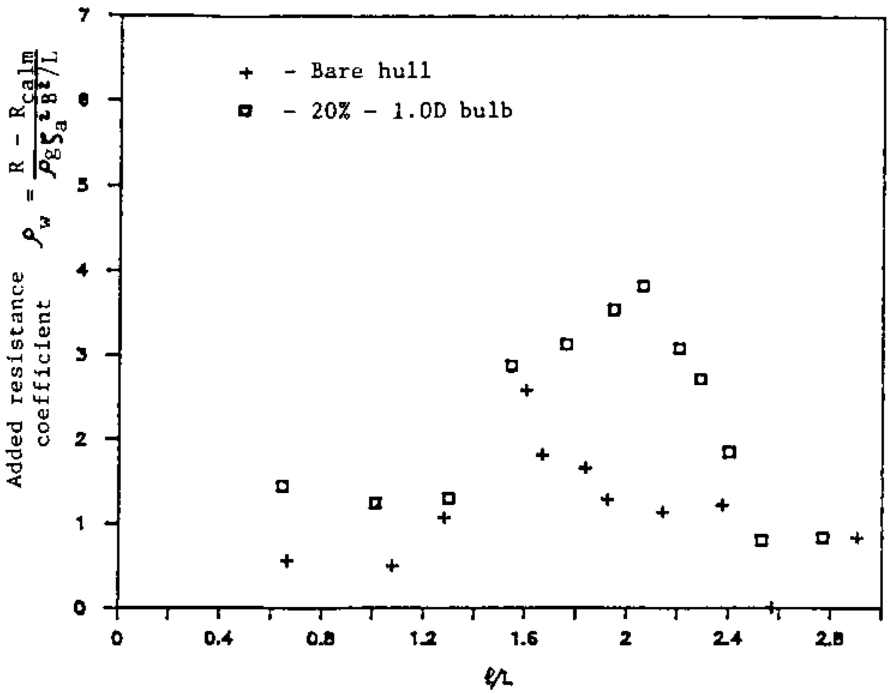


Figure 20. Added resistance versus wave length for 76' design at 9 knots.

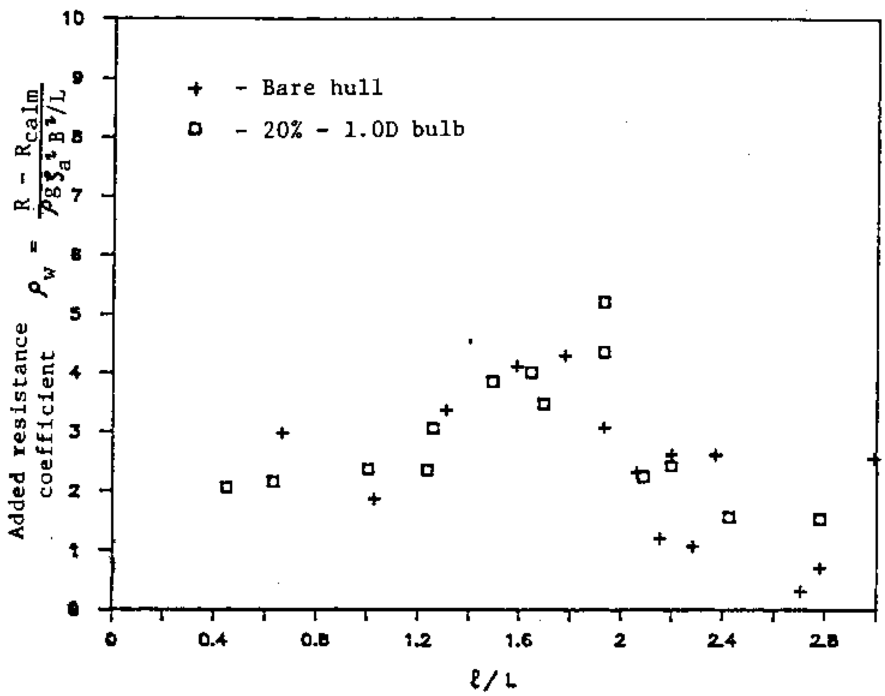


Figure 21. Added resistance versus wave length for 119' design at 2 knots.

Effect of Bulb Height:

Limitations of time and funds prevented us from exploring experimentally the effects of variations in the vertical location of the bulbs. All bulbs were located with their lower surface at the intersection of the keel line extension and the forward edge of the fairing piece.

This decision was based on the practical constraints of minimizing potential damage during grounding and dry-docking. You should note, however, that the bulbs with extension pieces do violate the extended line of the keel since they are aligned horizontally, rather than with the keel.

To gain some insight into the possible advantage of vertical locations other than those tested, a regression model was used. The model is based on a compilation of test results from the Netherlands Ship Model Basin by Holtrop (3) which has been implemented in BASIC by Sedat (4) of Webb Institute. The model includes bulb area and centroid height above the baseline as parameters. We doubt that it was intended for use on trawler-type hulls. The trends are revealing but must be used with caution.

The results of a limited series of computer runs, with and without bulbs, are presented in the thesis by Heliotis (1). Reasonable agreement was found between the regression model, which is based on the hull description, and our experimental predictions with the 10% bulbs.

The regression found the 20% and 30% bulbs to be detrimental at the steaming speed of each vessel. The important parameter of longitudinal location is not included in this regression model. As shown in Appendix 2, certain lengths of the larger-diameter bulbs tested were also detrimental.

For the 76' design at 9 knots, the regression model found the vertical location of the 10% bulb we tested nearly optimal. The 20% regression model results suggested that some improvement might be found by lowering the bulb from its tested location. Similar trends were seen with the 119' design.

Obviously, more information is needed to determine an optimum vertical location for bulbs on this type of vessel. Additional improvements may be possible, particularly if the forward-draft limitation is waived for larger diameter bulbs.

Power Requirement Calculations:

The net effect of EHP on shaft horsepower (SHP) is dependent on a variety of efficiencies and conditions related to the hull shape, propeller characteristics, and the power unit. Some of these factors would not be affected by the installation of a bulbous bow. Others would change and may have an important effect on the value of a retrofit.

In the following analysis, we have assumed that the steaming speed will remain unchanged with the retrofitted bulb. This may be a naive assumption based on some fishermen's tendency to operate at full throttle when ever possible. Based on our experimental predictions, higher steaming speeds could be achieved using an assumption of constant power, and may offer operational advantages to some operators.

Tables 3 and 4 show the sequence of calculations required to estimate SHP from EHP. In Table 3, the 76' design is considered with a propeller at a fixed pitch of 0.72, which is a compromise between the steaming and trawling condition. It is 66" in diameter, four bladed, and has an area ratio of 0.55.

Table 4 shows similar calculations for the 119' design, which is fitted with a controlable-pitch propeller in a nozzle. The propeller diameter is 78", it is four bladed, the maximum pitch is 1.0, and the blade area ratio is 0.55. With the bulb fitted we have considered two cases, one where the RPM remains the same and one where the pitch remains maximum.

In our analysis we have not considered the implications of cavitation, however the reduced thrust requirements of the retrofitted hull should be an improvement in this regard. There may also be some changes in fuel comsumption per horsepower, due to the altered engine loading.

Discussion:

The bulb shapes we have considered in this test series are purposely simple and should be economical to fabricate and install on an existing vessel. The predicted benefits in reduced resistance and motions are substancial and we have no reason to suspect that any of the configurations tested are truly optimal.

Other diameters within the range tested deserve consideration. The importance of vertical location has not been properly explored, particularly the implications of lowering the larger diameter bulbs away from the waterline. The effect of fillet fairings at the intersection of the cylinder and hull needs to be determined.

Parameter	Bare Hull	With 20% - 1.0D Bulb
EHP	68.2	53.6
V	15.2 ft/sec	15.2 ft/sec
w (7)	.25	.25
t = 0.95w	.238	.238
$\eta_H = \frac{1-t}{1-w}$	1.016	1.016
η_s (7)	0.98	0.98
η_r (7)	1.02	1.02
V = (1-w) V	11.39 ft/sec	11.39 ft/sec
D (9)	5.5 ft	5.5 ft
R	2,470 lbf	1,942 lbf
T = R/(1-t)	3,240 lbf	2,550 lbf
ρ	1.993 slugs/ft	1.993 slugs/ft
Kt/J^2	0.414	0.326
P/D (9)	0.72	0.72
J	0.539	0.572
RPM	231	217
η_o (8)	0.605	0.622
η_p	0.614	0.631
SHP	111	85

Table 3. Power Calculations, 76' design.

It is important to note that for all diameter bulbs tested, the shortest ones performed the worst. In the limited application bulbs have had on fishing vessels to date, they have generally been of minimal length. While the pitch damping of these short bulbs may be present, it is doubtful that major benefits in hull efficiency have been realized.

Parameter	Bare Hull	With 20% - 1.0D Bulb	
EHP	400	317	
V	20.25 ft/sec	20.25 ft/sec	
w (9)	.10	.10	
t = 0.95w	.095	.095	
$\eta_H = \frac{1-t}{1-w}$	1.006	1.006	
η_s (7)	0.98	0.98	
η_r (7)	1.02	1.02	
V = (1-w)V	18.23 ft/sec	18.33 ft/sec	
D (9)	6.5 ft	6.5 ft	
R	10,861 lbf	8,600 lbf	
T = R/(1-t)	12,000 lbf	9,500 lbf	
ρ	1.993 slugs/ft	1.993 slugs/ft	
Kt/J^2	0.429	0.340	
RPM	396	396	370
J	0.425	0.425	0.455
P/D (9)	1.0	0.9	1.0
η_o (10)	0.525	0.535	0.547
η_p	0.528	0.538	0.550
SHP	758	589	576

Table 4. Power Calculations, 119' design.

The fact that both hulls benefitted most from the 20% -1.0D bulb suggests that proper bulb selection may not be as design-specific as we had expected. Even though both designs were from the board of naval architect John Gilbert, the hull forms are quite different with respect to length/beam ratio, beam/draft ratio, and waterline entrance angle. We should note, however, that both vessels have sufficient draft forward to accomodate the 20% bulbs well below the design waterline.

Operating speed is an important factor in the proper size bulb and the potential benefits of an installation. Figure 14 indicates that if the 76' design had a steaming speed of 10 knots, the bulb would become even more effective. Figure 15 suggests that if the 119' design operated at 13 knots, the advantage of the 20% bulb might be diminished. If it were to operate at 10 or 11 knots, a smaller bulb might be more appropriate.

If low-speed cruising is a significant portion of the vessels operating profile, and the seakeeping advantage is not important, then there is less to be gained from a retrofit.

The reduction in vessel motions with the retrofitted bulbs is due to its damping effect during bow rise and fall. These reductions occured over the full range of wave lengths tested with the greatest effect in the region of natural pitch resonance with wave encounter frequency.

We doubt that a retrofitted bulb would have much effect on the roll response of the vessel unless it altered the GM. This could happen if the bulb was installed as an empty void, without proper means of ballasting. The retrofitted bulb would probably reduce somewhat the maneuverability of the vessel, however, course-keeping at sea would probably be improved.

The mixed results regarding the added resistance of the two retrofitted designs are puzzling. Even though both experienced less motions than the bare hulls, the head-sea resistance of the 76' hull was more, particularly at wave lengths over 1.7 times the waterline length. We offer no explanation.

The complex behavior of the vessel-drogue system indicates the important effect of the trawl gear on vessel motions. This is no surprise to anyone who has been dragging in heavy weather, but we are unaware of any previous tow tank research in which this interaction has been included for trawler seakeeping tests.

The encouraging results of the shaft horsepower calculations are to be expected since trawler propellers are typically under-pitched for steaming. The reduced thrust required with the bulb presents less of a mismatch in pitch than with the original bare hull.

Our decision to test the retrofitted hulls at the design waterline resulted in an increase in displacement equal to the added volume of the bulb. The 20% - 1.0D bulbs added nine percent to the displacement of each vessel. Reanalyzing our results on the basis of resistance/displacement would further favor the bulbs, however, this was not done since it is uncertain whether the bulb volume represents useful payload capacity. If the vessel can safely use the bulb for tankage, without severly affecting the stability when empty, then the benefits with regards to endurance could be significant.

The use of the bulb as a trim-adjusting ballast tank seems to have merit. Trim may be particularly important to bulb effectiveness however the scope of our tests did not include any variations in forward draft.

The ultimate value of a bulbous bow retrofit in terms of reduced fuel costs or increased performance due to improved habitability or passagemaking, will depend on the details of the trawling operation and the cost of retrofit. Much remains to be learned from actual installations, in this regard, and even then, the appropriateness of a bulb will vary from one boat to another. For this reason, vessel owners should enlist the services of a naval architect to properely evaluate their particular vessel and the potential value of a bulb retrofit. The implications of a bulb retrofit on stability, trim, and structural and watertight integrity should be determined before proceeding.

Conclusions:

Based on our tow tank experiments, we can conclude the following:

1. Simple bulb shapes made up of a cylinder and a hemispherical end-cap are effective at reducing the hull resistance at steaming speeds for the type of trawler hull tested.

2. Diameter and longitudinal location both have a major impact on the effectiveness of a bulb at reducing resistance.

3. Of the sizes tested, the 20% bulb, extended one diameter ahead of the stem provided the best performance on both hull designs.

4. At lower speeds all bulbs were found detrimental due to the increase in wetted surface and because the retrofitted hulls were of heavier displacement than the bare hulls.

5. At a steaming speed of 9 knots, the 76' design with the 20% - 1.0D bulb had 21.3% less resistance than the bare hull. At 12 knots, the 119' design with the 20% - 1.0D bulb had 20.7% less resistance than the bare hull.

6. Assuming constant steaming speeds, slightly improved propulsion coefficients result in shaft horsepower requirements for the 20% - 1.0D bulb to be 24% less for the 119' design and 23.4 % less for the 76' design.

7. For both vessels at steaming speeds, pitch motions in regular head seas were found to be less with the retrofitted bulbs for wave lengths up to three vessel lengths.

8. Under the same conditions, the vertical accelerations measured at the bow were less with the retrofitted bulbs.

9. Under trawling conditions, the complex interaction of the hull and the trawl-simulating drogue produced irregular pitch and acceleration responses with no meaningful difference between the bare and retrofitted hulls.

10. The increased resistance due to motions in regular head seas was found to be less for the retrofitted 119' design but more for the retrofitted 76' design. These predictions do not take into account the possible improvements in propeller efficiency due to the reduced motions of both retrofitted vessels.

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References:

1. Heliotis, A.D. 1985. The Effect of Bulbous Bow Retrofits on the Resistance and Seakeeping Performance of Fishing Vessels. Thesis, MIT Dept. of Ocean Engineering, Cambridge.

2. Goudey, C.A. and A.D. Heliotis. 1985. The Effect of Bulbous Bow Retrofits on the Resistance and Seakeeping of a 50 Meter Freshfish Stern Trawler. Center for Fisheries Engineering Research Report No. 8, MITSG 85-15.

3. Holtrop, J. and G.G.J. Mennen. 1982. An Approximate Power Prediction Method. International Shipbuilding Progress, 29:335.

4. Sedat, R. 1984. Improving Trawler Efficiency; Part 1: Matching Hull, Engine, Reduction Gear, and Propeller. New York Sea Grant Report, Webb Institute of Naval Architecture.

5. Capps, J. 1983. Scalloper Turns Midwater Trawler. National Fisherman August 1983. Camden, Maine.

6. Abkowitz, M.A. The Ship Model Towing Tank, A Description of the Laboratory. MIT Dept. of Ocean Engineering, Cambridge.

7. Comstock, J.P. 1967. Principles of Naval Architecture. SNAME, New York.

8. van Lammeren, W.P.A., J.D. van Manen, and M.W.C. Osterveld. 1969. The Wageningen B-Screw Series. SNAME Transactions.

9. Gilbert, J.W. personal communication.

10. Oosterveld, M.W.C. 1973. Ducted Propeller Characteristics. Proceedings of the Symposium on Ducted Propellers, Paper 4. RINA.

Appendix 1

Tabulated Towing Tank Results

FULL SCALE CALM WATER RESISTANCE FOR THE 76' TRAWLER

T=72°F ρf=1.9358 lbs*sec^2 /ft^4 νf=1.0245E-5 ft^2 /sec (Lwl)m=4.11 ft Sm=4.791 ft^2

ρs=1.9905 lbs*sec^2 /ft^4 νs=1.27908E-5 ft^2 /sec (Lwl)s=70 ft Ss=1389.43 ft^2

No	Vm (Knots)	Rt,m (lbs)	Ct,m (*1000)	Rn,m (*10E-6)	Cf,m (*1000)	Cr (*1000)	Vs (Knots)	Vs (ft/sec)	Rn,s (*10E-6)	Cf,s (*1000)	Ct,s (*1000)	Rt,s (lbs)	EHP
1	1.69	0.309	8.188	1.144	4.553	3.635	6.974	11.772	64.427	2.223	5.858	1122.6	24.03
2	2.277	0.734	10.714	1.542	4.276	6.438	9.397	15.861	86.805	2.127	8.565	2979.8	85.93
3	1.879	0.392	8.403	1.272	4.452	3.951	7.754	13.089	71.632	2.188	6.139	1454.4	34.61
4	1.932	0.455	9.226	1.308	4.425	4.800	7.973	13.458	73.652	2.179	6.979	1747.9	42.77
5	2.317	0.781	11.010	1.569	4.261	6.750	9.562	16.140	88.330	2.121	8.871	3195.6	93.78
6	2.55	1.016	11.825	1.727	4.177	7.648	10.523	17.763	97.212	2.092	9.740	4249.7	137.25
7	0.902	0.072	6.698	0.611	5.233	1.465	3.722	6.283	34.386	2.447	3.912	213.6	2.44
8	1.512	0.249	8.243	1.024	4.664	3.580	6.240	10.533	57.641	2.260	5.840	895.8	17.15
9	1.329	0.189	8.099	0.900	4.797	3.302	5.484	9.258	50.665	2.305	5.607	664.5	11.18
10	2.486	0.939	11.499	1.683	4.199	7.300	10.259	17.317	94.772	2.100	9.400	3898.0	122.73
11	2.068	0.534	9.450	1.400	4.363	5.088	8.534	14.406	78.837	2.157	7.244	2078.9	54.45
12	2.594	1.149	12.923	1.757	4.163	8.761	10.705	18.070	98.889	2.087	10.847	4897.8	160.91
13	1.12	0.141	8.507	0.758	4.982	3.525	4.622	7.802	42.697	2.366	5.891	495.8	7.03
14	0.498	0.038	11.596	0.337	6.026	5.571	2.055	3.469	18.985	2.692	8.262	137.5	0.87
15	2.146	0.63	10.353	1.453	4.329	6.024	8.856	14.949	81.811	2.145	8.170	2524.6	68.62
16	2.318	0.738	10.395	1.570	4.260	6.135	9.566	16.147	88.368	2.121	8.256	2976.6	87.39

10% Bulb, No Rings

T=73°F ρ f=1.9355 lbs*sec^2 /ft^4 ν f=1.01132E-5 ft^2 /sec (Lwl)m=4.11 ft Sm=4.935 ft^2

Δm=51.3 lb ρ s=1.9905 lbs*sec^2/ft^4 ν s=1.27908E-5 ft^2 /sec (Lwl)s=70 ft Ss=1431.25 ft^2

No	Vm (Knots)	Rt,m (lbs)	Ct,m (*1000)	Rn,m (*10E-6)	Cf,m (*1000)	Cr (*1000)	Vs (Knots)	Vs (ft/sec)	Rn,s (*10E-6)	Cf,s (*1000)	Ct,s (*1000)	Rt,s (lbs)	EHP
1	2.086	0.655	11.062	1.431	4.343	6.719	8.608	14.531	79.523	2.154	8.873	2668.7	70.51
2	1.871	0.424	8.901	1.284	4.443	4.457	7.721	13.033	71.327	2.189	6.646	1608.2	38.11
3	2.498	1.022	12.036	1.714	4.184	7.852	10.309	17.401	95.230	2.098	9.950	4291.6	135.78
4	2.269	0.771	11.005	1.557	4.268	6.737	9.364	15.806	86.500	2.128	8.865	3154.7	90.66
5	2.314	0.794	10.897	1.587	4.250	6.646	9.549	16.119	88.215	2.122	8.768	3245.2	95.11
6	2.541	1.161	13.214	1.743	4.169	9.045	10.486	17.700	96.869	2.093	11.138	4970.6	159.97
7	2.498	1.04	12.248	1.714	4.184	8.064	10.309	17.401	95.230	2.098	10.162	4383.0	138.67
8	1.682	0.409	10.624	1.154	4.545	6.079	6.941	11.717	64.122	2.224	8.303	1623.6	34.59
9	2.265	0.762	10.915	1.554	4.269	6.646	9.347	15.778	86.347	2.128	8.774	3111.3	89.26
10	1.46	0.257	8.860	1.002	4.686	4.174	6.025	10.170	55.659	2.272	6.446	949.7	17.56
11	2.531	1.068	12.252	1.736	4.173	8.079	10.445	17.631	96.488	2.094	10.173	4504.5	144.40
12	1.682	0.368	9.559	1.154	4.545	5.014	6.941	11.717	64.122	2.224	7.238	1415.3	30.15

10% Bulb, 0.5D Ring

T=73°F ρ f=1.9355 lbs*sec^2 /ft^4 ν f=1.01132E-5 ft^2 /sec (Lwl)m=4.11 ft Sm=4.992 ft^2

Δm=51.4 lb ρ s=1.9905 lbs*sec^2 /ft^4 νs=1.27908E-5 ft^2 /sec (Lwl)s=70 ft Ss=1447.78 ft^2

No	Vm (Knots)	Rt,m (lbs)	Ct,m (*1000)	Rn,m (*10E-6)	Cf,m (*1000)	Cr (*1000)	Vs (Knots)	Vs (ft/sec)	Rn,s (*10E-6)	Cf,s (*1000)	Ct,s (*1000)	Rt,s (lbs)	EHP
1	2.086	0.657	10.969	1.431	4.343	6.626	8.608	14.531	79.523	2.154	8.780	2671.2	70.57
2	1.871	0.456	9.463	1.284	4.443	5.020	7.721	13.033	71.327	2.189	7.209	1764.4	41.81
3	2.27	0.743	10.475	1.557	4.267	6.208	9.368	15.813	86.538	2.128	8.335	3003.1	86.34
4	2.315	0.819	11.102	1.588	4.250	6.852	9.553	16.126	88.253	2.122	8.974	3362.5	98.59
5	2.537	1.073	12.111	1.740	4.171	7.940	10.470	17.673	96.716	2.093	10.034	4515.4	145.09
6	2.498	1.029	11.980	1.714	4.184	7.796	10.309	17.401	95.230	2.098	9.894	4316.7	136.57
7	1.46	0.267	9.100	1.002	4.686	4.414	6.025	10.170	55.659	2.272	6.686	996.4	18.43
8	1.682	0.369	9.475	1.154	4.545	4.930	6.941	11.717	64.122	2.224	7.154	1415.2	30.15
9	2.315	0.795	10.777	1.588	4.250	6.527	9.553	16.126	88.253	2.122	8.648	3240.6	95.01
10	1.221	0.179	8.722	0.838	4.873	3.849	5.039	8.505	46.547	2.335	6.184	644.6	9.97

FULL SCALE CALM WATER RESISTANCE FOR THE 76' TRAWLER

10% Bulb, 1.0D Ring

T=73°F f=1.9355 lbs*sec²/ft⁴ f=1.01132E-5 ft²/sec (Lwl)m=4.11 ft Sm=5.049 ft²

Δm=51.47 1 s=1.9905 lbs*sec²/ft⁴ s=1.27908E-5 ft²/sec (Lwl)s=70 ft Ss=1464.32 ft²

No	Vm (Knots)	Rt,m (lbs)	Ct,m (*1000)	Rn,m (*10E-6)	Cf,m (*1000)	Cr (*1000)	Vs (Knots)	Vs (ft/sec)	Rn,s (*10E-6)	Cf,s (*1000)	Ct,s (*1000)	Rt,s (lbs)	EHP
1	2.086	0.625	10.317	1.431	4.343	5.974	8.608	14.531	79.523	2.154	8.128	2501.1	66.08
2	1.871	0.347	7.120	1.284	4.443	2.676	7.721	13.033	71.327	2.189	4.866	1204.5	28.54
3	2.27	0.717	9.994	1.557	4.267	5.727	9.368	15.813	86.538	2.128	7.855	2862.3	82.29
4	2.315	0.734	9.837	1.588	4.250	5.587	9.553	16.126	88.253	2.122	7.709	2921.7	85.66
5	2.537	1.04	11.606	1.740	4.171	7.435	10.470	17.673	96.716	2.093	9.529	4337.2	139.36
6	2.498	1.036	11.925	1.714	4.184	7.741	10.309	17.401	95.230	2.098	9.839	4341.9	137.37
7	1.46	0.253	8.525	1.002	4.686	3.839	6.025	10.170	55.659	2.272	6.111	921.2	17.03
8	1.682	0.376	9.546	1.154	4.545	5.001	6.941	11.717	64.122	2.224	7.225	1445.5	30.79
9	1.871	0.375	7.694	1.284	4.443	3.251	7.721	13.033	71.327	2.189	5.440	1346.7	31.91
10	2.498	1.036	11.925	1.714	4.184	7.741	10.309	17.401	95.230	2.098	9.839	4341.9	137.37
11	2.316	0.759	10.164	1.589	4.250	5.914	9.558	16.133	88.291	2.121	8.036	3048.0	89.41
12	2.537	1.045	11.662	1.740	4.171	7.491	10.470	17.673	96.716	2.093	9.585	4362.6	140.18
13	1.682	0.34	8.632	1.154	4.545	4.087	6.941	11.717	64.122	2.224	6.311	1262.6	26.90

10% Bulb, 1.5D Ring

T=73°F ρf=1.9355 lbs*sec²/ft⁴ νf=1.01132E-5 ft²/sec (Lwl)m=4.11 ft Sm=5.107 ft²

Δm=51.56 1 ρs=1.9905 lbs*sec²/ft⁴ νs=1.27908E-5 ft²/sec (Lwl)s=70 ft Ss=1481.14 ft²

No	Vm (Knots)	Rt,m (lbs)	Ct,m (*1000)	Rn,m (*10E-6)	Cf,m (*1000)	Cr (*1000)	Vs (Knots)	Vs (ft/sec)	Rn,s (*10E-6)	Cf,s (*1000)	Ct,s (*1000)	Rt,s (lbs)	EHP
1	2.086	0.648	10.575	1.431	4.343	6.232	8.608	14.531	79.523	2.154	8.386	2610.2	68.96
2	1.871	0.452	9.169	1.284	4.443	4.725	7.721	13.033	71.327	2.189	6.915	1731.4	41.03
3	2.27	0.729	10.046	1.557	4.267	5.779	9.368	15.813	86.538	2.128	7.907	2914.3	83.79
4	2.315	0.773	10.242	1.588	4.250	5.993	9.553	16.126	88.253	2.122	8.114	3110.5	91.20
5	2.537	1.034	11.408	1.740	4.171	7.237	10.470	17.673	96.716	2.093	9.331	4295.8	138.03
6	2.498	0.975	11.095	1.714	4.184	6.912	10.309	17.401	95.230	2.098	9.010	4021.5	127.23
7	1.46	0.264	8.795	1.002	4.686	4.109	6.025	10.170	55.659	2.272	6.381	972.9	17.99
8	1.682	0.28	7.028	1.154	4.545	2.483	6.941	11.717	64.122	2.224	4.707	952.5	20.29
9	2.086	0.536	8.747	1.431	4.343	4.404	8.608	14.531	79.523	2.154	6.558	2041.3	53.93
10	2.531	0.977	10.830	1.736	4.173	6.658	10.445	17.631	96.488	2.094	8.752	4010.2	128.55
11	2.498	0.996	11.334	1.714	4.184	7.151	10.309	17.401	95.230	2.098	9.249	4128.2	130.61
12	1.682	0.376	9.438	1.154	4.545	4.892	6.941	11.717	64.122	2.224	7.117	1440.2	30.68
13	2.086	0.603	9.840	1.431	4.343	5.497	8.608	14.531	79.523	2.154	7.652	2381.6	62.92

20% Bulb, 0.0D Ring

T=73°F ρf=1.9355 lbs*sec²/ft⁴ νf=1.01132E-5 ft²/sec (Lwl)m=4.11 ft Sm=5.105 ft²

Δm=53.37 1 ρs=1.9905 lbs*sec²/ft⁴ νs=1.27908E-5 ft²/sec (Lwl)s=70 ft Ss=1480.6 ft²

No	Vm (Knots)	Rt,m (lbs)	Ct,m (*1000)	Rn,m (*10E-6)	Cf,m (*1000)	Cr (*1000)	Vs (Knots)	Vs (ft/sec)	Rn,s (*10E-6)	Cf,s (*1000)	Ct,s (*1000)	Rt,s (lbs)	EHP
1	2.086	0.587	9.583	1.431	4.343	5.240	8.608	14.531	79.523	2.154	7.394	2300.7	60.78
2	1.873	0.421	8.525	1.285	4.442	4.083	7.729	13.047	71.403	2.189	6.272	1573.2	37.32
3	2.498	1.034	11.772	1.714	4.184	7.588	10.309	17.401	95.230	2.098	9.686	4321.7	136.73
4	2.316	0.86	11.390	1.589	4.250	7.140	9.558	16.133	88.291	2.121	9.262	3552.2	104.20
5	1.682	0.344	8.638	1.154	4.545	4.093	6.941	11.717	64.122	2.224	6.317	1277.8	27.22
6	2.535	1.11	12.271	1.739	4.171	8.099	10.461	17.659	96.640	2.094	10.193	4683.7	150.38
7	2.27	0.776	10.698	1.557	4.267	6.431	9.368	15.813	86.538	2.128	8.558	3153.4	90.66
8	1.46	0.286	9.531	1.002	4.686	4.845	6.025	10.170	55.659	2.272	7.117	1084.8	20.06
9	2.265	0.725	10.039	1.554	4.269	5.770	9.347	15.778	86.347	2.128	7.898	2897.3	83.12
10	2.311	0.786	10.455	1.585	4.251	6.203	9.537	16.098	88.101	2.122	8.326	3179.4	93.06
11	2.267	0.747	10.326	1.555	4.268	6.057	9.355	15.792	86.423	2.128	8.185	3007.9	86.36

FULL SCALE CALM WATER RESISTANCE FOR THE 76' TRAWLER

20% Bulb, 0.5D Ring

T=73°F, ∇m=54.45 l | ρf=1.9355 lbs*sec²/ft⁴, ρs=1.9905 lbs*sec²/ft⁴ | νf=1.01132E-5 ft²/sec, νs=1.27908E-5 ft²/sec | (Lwl)m=4.11 ft, (Lwl)s=70 ft | Sm=5.239 ft², Ss=1519.42 ft²

No	Vm (Knots)	Rt,m (lbs)	Ct,m (*1000)	Rn,m (*10E-6)	Cf,m (*1000)	Cr (*1000)	Vs (Knots)	Vs (ft/sec)	Rn,s (*10E-6)	Cf,s (*1000)	Ct,s (*1000)	Rt,s (lbs)	EHP
1	2.086	0.512	8.145	1.431	4.343	3.802	8.608	14.531	79.523	2.154	5.956	1901.8	50.25
2	1.873	0.426	8.406	1.285	4.442	3.963	7.729	13.047	71.403	2.189	6.152	1583.7	37.57
3	2.498	0.933	10.350	1.714	4.184	6.166	10.309	17.401	95.230	2.098	8.264	3784.1	119.72
4	2.316	0.64	8.259	1.589	4.250	4.010	9.558	16.133	88.291	2.121	6.131	2413.2	70.79
5	1.682	0.373	9.126	1.154	4.545	4.581	6.941	11.717	64.122	2.224	6.805	1412.8	30.10
6	2.535	0.966	10.406	1.739	4.171	6.234	10.461	17.659	96.640	2.094	8.328	3927.0	126.08
7	2.27	0.653	8.772	1.557	4.267	4.505	9.368	15.813	86.538	2.128	6.633	2507.8	72.10
8	1.46	0.279	9.060	1.002	4.686	4.374	6.025	10.170	55.659	2.272	6.646	1039.6	19.22
9	2.315	0.714	9.222	1.588	4.250	4.972	9.553	16.126	88.253	2.122	7.094	2789.7	81.79
10	1.871	0.39	7.712	1.284	4.443	3.268	7.721	13.033	71.327	2.189	5.458	1401.9	33.22
11	2.498	0.897	9.951	1.714	4.184	5.767	10.309	17.401	95.230	2.098	7.865	3601.2	113.94
12	1.46	0.278	9.028	1.002	4.686	4.342	6.025	10.170	55.659	2.272	6.614	1034.5	19.13

20% Bulb, 1 D Ring

T=73°F, ∇m=54.85 l | ρf=1.9355 lbs*sec²/ft⁴, ρs=1.9905 lbs*sec²/ft⁴ | νf=1.01132E-5 ft²/sec, νs=1.27908E-5 ft²/sec | (Lwl)m=4.11 ft, (Lwl)s=70 ft | Sm=5.373 ft², Ss=1558.17 ft²

No	Vm (Knots)	Rt,m (lbs)	Ct,m (*1000)	Rn,m (*10E-6)	Cf,m (*1000)	Cr (*1000)	Vs (Knots)	Vs (ft/sec)	Rn,s (*10E-6)	Cf,s (*1000)	Ct,s (*1000)	Rt,s (lbs)	EHP
1	2.086	0.488	7.569	1.431	4.343	3.227	8.608	14.531	79.523	2.154	5.381	1761.9	46.55
2	1.873	0.369	7.099	1.285	4.442	2.657	7.729	13.047	71.403	2.189	4.846	1279.2	30.35
3	2.498	0.875	9.465	1.714	4.184	5.281	10.309	17.401	95.230	2.098	7.379	3464.8	109.62
4	2.316	0.594	7.475	1.589	4.250	3.225	9.558	16.133	88.291	2.121	5.346	2158.0	63.30
5	1.682	0.342	8.159	1.154	4.545	3.614	6.941	11.717	64.122	2.224	5.838	1242.9	26.48
6	2.535	0.915	9.610	1.739	4.171	5.439	10.461	17.659	96.640	2.094	7.533	3642.7	116.95
7	2.27	0.643	8.422	1.557	4.267	4.155	9.368	15.813	86.538	2.128	6.283	2436.2	70.04
8	1.46	0.309	9.784	1.002	4.686	5.098	6.025	10.170	55.659	2.272	7.370	1182.2	21.86
9	2.311	0.535	6.761	1.585	4.251	2.510	9.537	16.098	88.101	2.122	4.632	1861.5	54.49
10	1.871	0.39	7.520	1.284	4.443	3.076	7.721	13.033	71.327	2.189	5.265	1387.0	32.87
11	2.498	0.897	9.702	1.714	4.184	5.519	10.309	17.401	95.230	2.098	7.617	3576.5	113.15
12	1.46	0.278	8.803	1.002	4.686	4.117	6.025	10.170	55.659	2.272	6.389	1024.8	18.95

20% Bulb, 1.5 D Ring

T=73°F, ∇m=55.13 l | ρf=1.9355 lbs*sec²/ft⁴, ρs=1.9905 lbs*sec²/ft⁴ | νf=1.01132E-5 ft²/sec, νs=1.27908E-5 ft²/sec | (Lwl)m=4.11 ft, (Lwl)s=70 ft | Sm=5.506 ft², Ss=1596.92 ft²

No	Vm (Knots)	Rt,m (lbs)	Ct,m (*1000)	Rn,m (*10E-6)	Cf,m (*1000)	Cr (*1000)	Vs (Knots)	Vs (ft/sec)	Rn,s (*10E-6)	Cf,s (*1000)	Ct,s (*1000)	Rt,s (lbs)	EHP
1	2.086	0.542	8.204	1.431	4.343	3.861	8.608	14.531	79.523	2.154	6.015	2018.6	53.33
2	1.873	0.425	7.979	1.285	4.442	3.537	7.729	13.047	71.403	2.189	5.726	1549.1	36.75
3	2.498	0.896	9.458	1.714	4.184	5.274	10.309	17.401	95.230	2.098	7.372	3547.6	112.24
4	2.265	0.644	8.268	1.554	4.269	3.999	9.347	15.778	86.347	2.128	6.127	2424.2	69.54
5	1.682	0.434	10.104	1.154	4.545	5.559	6.941	11.717	64.122	2.224	7.783	1698.1	36.18
6	2.535	0.93	9.532	1.739	4.171	5.361	10.461	17.659	96.640	2.094	7.454	3694.4	118.61
7	2.27	0.68	8.692	1.557	4.267	4.425	9.368	15.813	86.538	2.128	6.552	2603.9	74.86
8	1.46	0.305	9.424	1.002	4.686	4.738	6.025	10.170	55.659	2.272	7.010	1152.4	21.31
9	2.311	0.629	7.757	1.585	4.251	3.506	9.537	16.098	88.101	2.122	5.628	2318.0	67.85
10	1.682	0.417	9.708	1.154	4.545	5.163	6.941	11.717	64.122	2.224	7.387	1611.8	34.34
11	2.316	0.644	7.908	1.589	4.250	3.658	9.558	16.133	88.291	2.121	5.780	2390.9	70.13

FULL SCALE CALM WATER RESISTANCE FOR THE 76' TRAWLER

30% Bulb, No Ring

$T=73^{\circ}F$ $\rho f=1.9355\ lbs*sec^2/ft^4$ $\nu f=1.01132E\text{-}5\ ft^2/sec$ $(Lwl)m=4.11\ ft$ $Sm=5.283\ ft^2$

$\Delta m=53.75.0$ $\rho s=1.9905\ lbs*sec^2/ft^4$ $\nu s=1.27908E\text{-}5\ ft^2/sec$ $(Lwl)s=70\ ft$ $Ss=1532.18\ ft^2$

No	Vm (Knots)	Rt,m (lbs)	Ct,m (*1000)	Rn,m (*10E-6)	Cf,m (*1000)	Cr (*1000)	Vs (Knots)	Vs (ft/sec)	Rn,s (*10E-6)	Cf,s (*1000)	Ct,s (*1000)	Rt,s (lbs)	EHP
1	1.872	0.63	12.341	1.284	4.443	7.898	7.725	13.040	71.365	2.189	10.087	2615.6	62.01
2	2.265	0.874	11.695	1.554	4.269	7.425	9.347	15.778	86.347	2.128	9.554	3626.7	104.04
3	2.311	0.863	11.092	1.585	4.251	6.841	9.537	16.098	88.101	2.122	8.963	3542.0	103.67
4	2.086	0.79	12.463	1.431	4.343	8.120	8.608	14.531	79.523	2.154	10.274	3308.0	87.40
5	2.534	1.18	12.615	1.738	4.172	8.443	10.457	17.652	96.602	2.094	10.537	5006.5	160.68
6	2.498	1.123	12.354	1.714	4.184	8.170	10.309	17.401	95.230	2.098	10.268	4741.1	150.00
7	1.46	0.361	11.626	1.002	4.686	6.940	6.025	10.170	55.659	2.272	9.212	1452.9	26.87
8	1.682	0.441	10.700	1.154	4.545	6.155	6.941	11.717	64.122	2.224	8.379	1754.1	37.37
9	2.048	0.74	12.111	1.405	4.360	7.751	8.452	14.266	78.075	2.160	9.911	3076.1	79.79
10	1.804	0.544	11.475	1.238	4.478	6.997	7.445	12.567	68.773	2.201	9.198	2214.9	50.61
11	2.316	0.87	11.134	1.589	4.250	6.885	9.558	16.133	88.291	2.121	9.006	3574.4	104.85
12	1.682	0.494	11.986	1.154	4.545	7.441	6.941	11.717	64.122	2.224	9.665	2023.3	43.10
13	1.682	0.442	10.725	1.154	4.545	6.179	6.941	11.717	64.122	2.224	8.404	1759.2	37.48
14	2.087	0.628	9.898	1.432	4.343	5.555	8.613	14.538	79.561	2.154	7.709	2484.5	65.67
15	1.682	0.425	10.312	1.154	4.545	5.767	6.941	11.717	64.122	2.224	7.991	1672.9	35.64

30% Bulb, 0.5D Ring

$T=73^{\circ}F$ $\rho f=1.9355\ lbs*sec^2/ft^4$ $\nu f=1.01132E\text{-}5\ ft^2/sec$ $(Lwl)m=4.11\ ft$ $Sm=5.489\ ft^2$

$\Delta m=54.45\ 1$ $\rho s=1.9905\ lbs*sec^2/ft^4$ $\nu s=1.27908E\text{-}5\ ft^2/sec$ $(Lwl)s=70\ ft$ $Ss=1591.92\ ft^2$

No	Vm (Knots)	Rt,m (lbs)	Ct,m (*1000)	Rn,m (*10E-6)	Cf,m (*1000)	Cr (*1000)	Vs (Knots)	Vs (ft/sec)	Rn,s (*10E-6)	Cf,s (*1000)	Ct,s (*1000)	Rt,s (lbs)	EHP
1	1.872	0.446	8.409	1.284	4.443	3.966	7.725	13.040	71.365	2.189	6.155	1658.2	39.31
2	2.265	0.73	9.401	1.554	4.269	5.132	9.347	15.778	86.347	2.128	7.260	2863.6	82.15
3	2.31	0.735	9.100	1.585	4.252	4.849	9.533	16.091	88.063	2.122	6.971	2859.7	83.67
4	2.086	0.588	8.928	1.431	4.343	4.585	8.608	14.531	79.523	2.154	6.739	2254.5	59.56
5	2.531	0.966	9.963	1.736	4.173	5.790	10.445	17.631	96.488	2.094	7.885	3883.1	124.48
6	2.498	1.007	10.662	1.714	4.184	6.478	10.309	17.401	95.230	2.098	8.576	4114.4	130.17
7	1.46	0.331	10.259	1.002	4.686	5.573	6.025	10.170	55.659	2.272	7.845	1285.7	23.77
8	1.682	0.404	9.435	1.154	4.545	4.890	6.941	11.717	64.122	2.224	7.114	1547.2	32.96
9	2.498	0.998	10.567	1.714	4.184	6.383	10.309	17.401	95.230	2.098	8.481	4068.7	128.72
10	2.537	1.004	10.306	1.740	4.171	6.135	10.470	17.673	96.716	2.093	8.229	4071.9	130.84
11	2.27	0.768	9.847	1.557	4.267	5.580	9.368	15.813	86.538	2.128	7.708	3053.4	87.79
12	2.316	0.753	9.275	1.589	4.250	5.026	9.558	16.133	88.291	2.121	7.147	2947.2	86.45
13	1.682	0.442	10.322	1.154	4.545	5.777	6.941	11.717	64.122	2.224	8.001	1740.3	37.07
14	2.087	0.628	9.526	1.432	4.343	5.184	8.613	14.538	79.561	2.154	7.338	2457.0	64.95
15	1.682	0.425	9.925	1.154	4.545	5.380	6.941	11.717	64.122	2.224	7.604	1653.9	35.23

30% Bulb, 1.0D Ring

$T=73^{\circ}F$ $\rho f=1.9355\ lbs*sec^2/ft^4$ $\nu f=1.01132E\text{-}5\ ft^2/sec$ $(Lwl)m=4.11\ ft$ $Sm=5.695\ ft^2$

$\Delta m=55.07\ 1$ $\rho s=1.9905\ lbs*sec^2/ft^4$ $\nu s=1.27908E\text{-}5\ ft^2/sec$ $(Lwl)s=70\ ft$ $Ss=1651.67\ ft^2$

No	Vm (Knots)	Rt,m (lbs)	Ct,m (*1000)	Rn,m (*10E-6)	Cf,m (*1000)	Cr (*1000)	Vs (Knots)	Vs (ft/sec)	Rn,s (*10E-6)	Cf,s (*1000)	Ct,s (*1000)	Rt,s (lbs)	EHP
1	2.086	0.672	9.834	1.431	4.343	5.491	8.608	14.531	79.523	2.154	7.645	2653.7	70.11
2	1.871	0.508	9.241	1.284	4.443	4.797	7.721	13.033	71.327	2.189	6.987	1950.9	46.23
3	2.266	0.721	8.942	1.554	4.269	4.673	9.351	15.785	86.385	2.128	6.801	2785.5	79.94
4	2.315	0.777	9.232	1.588	4.250	4.983	9.553	16.126	88.253	2.122	7.104	3036.9	89.04
5	2.537	1.02	10.092	1.740	4.171	5.921	10.470	17.673	96.716	2.093	8.014	4114.6	132.21
6	2.498	0.965	9.848	1.714	4.184	5.664	10.309	17.401	95.230	2.098	7.762	3863.5	122.23
7	1.46	0.341	10.187	1.002	4.686	5.501	6.025	10.170	55.659	2.272	7.773	1321.6	24.44
8	1.682	0.445	10.016	1.154	4.545	5.471	6.941	11.717	64.122	2.224	7.695	1736.6	36.99
9	2.048	0.558	8.472	1.405	4.360	4.112	8.452	14.266	78.075	2.160	6.272	2098.4	54.43
10	1.221	0.232	9.910	0.838	4.873	5.036	5.039	8.505	46.547	2.335	7.371	876.5	13.56
11	2.78	1.453	11.972	1.907	4.094	7.879	11.472	19.365	105.980	2.066	9.945	6130.4	215.85
12	2.048	0.598	9.079	1.405	4.360	4.719	8.452	14.266	78.075	2.160	6.879	2301.6	59.70

FULL SCALE CALM WATER RESISTANCE FOR THE 76' TRAWLER

30% Bulb, 1.5D Ring

T=73 °F, Δ_m=55.37 lb

ρ_f=1.9355 lbs*sec²/ft⁴, ρ_s=1.9905 lbs*sec²/ft⁴

ν_f=1.01132E-5 ft²/sec, ν_s=1.27908E-5 ft²/sec

(Lwl)m=4.11 ft, (Lwl)s=70 ft

Sm=5.901 ft², Ss=1711.4 ft²

No	Vm (Knots)	Rt,m (lbs)	Ct,m (*1000)	Rn,m (*10E-6)	Cf,m (*1000)	Cr (*1000)	* Vs (Knots)	Vs (ft/sec)	Rn,s (*10E-6)	Cf,s (*1000)	Ct,s (*1000)	Rt,s (lbs)	EHP
1	2.086	0.762	10.762	1.431	4.343	6.419	8.608	14.531	79.523	2.154	8.573	3083.3	81.46
2	1.871	0.65	11.411	1.284	4.443	6.968	7.721	13.033	71.327	2.189	9.157	2649.4	62.78
3	2.266	0.772	9.240	1.554	4.269	4.971	9.351	15.785	86.385	2.128	7.099	3012.8	86.47
4	2.315	0.84	9.633	1.588	4.250	5.383	9.553	16.126	88.253	2.122	7.504	3323.9	97.46
5	2.537	1.02	9.739	1.740	4.171	5.569	10.470	17.673	96.716	2.093	7.662	4076.0	130.97
6	2.498	0.968	9.534	1.714	4.184	5.350	10.309	17.401	95.230	2.098	7.448	3841.2	121.53
7	1.46	0.395	11.388	1.002	4.686	6.702	6.025	10.170	55.659	2.272	8.974	1581.1	29.24
8	1.682	0.471	10.231	1.154	4.545	5.686	6.941	11.717	64.122	2.224	7.910	1849.7	39.40
9	1.87	0.653	11.476	1.283	4.444	7.032	7.717	13.026	71.289	2.189	9.222	2665.2	63.12
10	2.692	1.293	10.965	1.847	4.120	6.845	11.109	18.752	102.625	2.076	8.920	5342.9	182.17
11	2.086	0.796	11.242	1.431	4.343	6.899	8.608	14.531	79.523	2.154	9.053	3256.0	86.02
12	1.221	0.238	9.811	0.838	4.873	4.938	5.039	8.505	46.547	2.335	7.272	896.1	13.86
13	2.27	0.786	9.374	1.557	4.267	5.107	9.368	15.813	86.538	2.128	7.235	3081.2	88.58
14	0.675	0.068	9.172	0.463	5.582	3.590	2.786	4.702	25.733	2.562	6.152	231.7	1.98

FULL SCALE CALM WATER RESISTANCE FOR THE 119' TRAWLER

T=80°F ρ_f=1.9336 lbs*sec^2/ft^4 ν_f=0.9261E-5 ft^2/sec (Lwl)m=4.171 ft Sm=4.818 ft^2

ρ_s=1.9905 lbs*sec^2/ft^4 ν_s=1.27908E-5 ft^2/sec (Lwl)s=110.667ft Ss=3391.266ft^2

No	Vm (Knots)	Rt,m (lbs)	Ct,m (*1000)	Rn,m (*10E-6)	Cf,m (*1000)	Cr (*1000)	Vs (Knots)	Vs (ft/sec)	Rn,s (*10E-6)	Cf,s (*1000)	Ct,s (*1000)	Rt,s (lbs)	EHP
1	1.353	0.184	7.573	1.029	4.659	2.914	6.969	11.764	101.779	2.078	4.992	2331.7	49.87
2	1.916	0.463	9.503	1.457	4.327	5.176	9.869	16.659	144.131	1.977	7.153	6699.7	202.92
3	0.457	0.033	11.905	0.347	5.982	5.923	2.354	3.973	34.378	2.447	8.370	446.0	3.22
4	1.682	0.336	8.948	1.279	4.447	4.501	8.664	14.624	126.528	2.014	6.516	4703.0	125.05
5	2.124	0.591	9.870	1.615	4.235	5.635	10.940	18.467	159.778	1.949	7.584	8729.2	293.09
6	0.76	0.051	6.653	0.578	5.300	1.353	3.915	6.608	57.171	2.263	3.615	532.8	6.40
7	1.12	0.119	7.148	0.851	4.856	2.292	5.769	9.738	84.252	2.136	4.428	1417.2	25.09
8	2.27	0.646	9.446	1.726	4.178	5.268	11.692	19.736	170.760	1.931	7.199	9464.2	339.62
9	1.739	0.379	9.443	1.322	4.416	5.027	8.957	15.120	130.816	2.005	7.031	5425.3	149.14
10	0.559	0.041	9.886	0.425	5.697	4.189	2.879	4.860	42.051	2.371	6.560	523.0	4.62
11	2.315	0.734	10.319	1.760	4.161	6.158	11.924	20.128	174.146	1.926	8.084	11053.3	404.50
12	1.522	0.211	6.863	1.157	4.542	2.320	7.839	13.233	114.492	2.043	4.364	2579.0	62.05
13	0.915	0.099	8.909	0.696	5.080	3.829	4.713	7.955	68.831	2.201	6.030	1288.1	18.63
14	1.46	0.228	8.059	1.110	4.583	3.476	7.520	12.694	109.828	2.055	5.531	3008.2	69.43
15	1.871	0.36	7.748	1.422	4.348	3.400	9.637	16.267	140.746	1.984	5.384	4808.6	142.22
16	0.915	0.083	7.469	0.696	5.080	2.389	4.713	7.955	68.831	2.201	4.590	980.5	14.18
17	2.048	0.47	8.443	1.557	4.267	4.175	10.549	17.806	154.061	1.959	6.134	6564.6	212.53
18	1.887	0.438	9.268	1.435	4.341	4.927	9.719	16.406	141.949	1.982	6.909	6276.6	187.23
19	1.871	0.364	7.834	1.422	4.348	3.486	9.637	16.267	140.746	1.984	5.470	4885.5	144.50

10% Bulb, No Rings

T=72°F ρ_f=1.9358 lbs*sec^2/ft^4 ν_f=1.0245E-5 ft^2/sec (Lwl)m=4.171 ft Sm=4.818 ft^2

Δ=53.091b ρ_s=1.9905 lbs*sec^2/ft^4 ν_s=1.27908E-5 ft^2/sec (Lwl)s=110.667ft Ss=3391.266ft^2

No	Vm (Knots)	Rt,m (lbs)	Ct,m (*1000)	Rn,m (*10E-6)	Cf,m (*1000)	Cr (*1000)	Vs (Knots)	Vs (ft/sec)	Rn,s (*10E-6)	Cf,s (*1000)	Ct,s (*1000)	Rt,s (lbs)	EHP
1	2.284	0.672	9.564	1.570	4.260	5.303	11.764	19.858	171.814	1.929	7.233	9758.4	352.33
2	2.514	0.888	10.431	1.728	4.177	6.254	12.949	21.858	189.115	1.904	8.158	13335.1	529.96
3	2.168	0.573	9.051	1.490	4.307	4.744	11.167	18.850	163.088	1.943	6.687	8129.6	278.61
4	1.512	0.247	8.021	1.039	4.649	3.373	7.788	13.146	113.740	2.045	5.418	3203.3	76.56
5	2.285	0.669	9.513	1.570	4.260	5.253	11.769	19.867	171.889	1.929	7.182	9698.4	350.32
6	1.885	0.389	8.128	1.295	4.435	3.693	9.709	16.389	141.799	1.982	5.675	5215.2	155.40
7	2.196	0.636	9.791	1.509	4.295	5.496	11.311	19.093	165.194	1.940	7.436	9274.5	321.96
8	2.321	0.718	9.895	1.595	4.246	5.649	11.955	20.180	174.597	1.925	7.574	10552.6	387.18

10% Bulb, 0.5 diam. Rings

T=72°F ρ_f=1.9358 lbs*sec^2/ft^4 ν_f=1.0245E-5 ft^2/sec (Lwl)m=4.171 ft Sm=4.943 ft^2

Δ=53.141b ρ_s=1.9905 lbs*sec^2/ft^4 ν_s=1.27908E-5 ft^2/sec (Lwl)s=110.667ft Ss=3479.1 ft^2

No	Vm (Knots)	Rt,m (lbs)	Ct,m (*1000)	Rn,m (*10E-6)	Cf,m (*1000)	Cr (*1000)	Vs (Knots)	Vs (ft/sec)	Rn,s (*10E-6)	Cf,s (*1000)	Ct,s (*1000)	Rt,s (lbs)	EHP
1	2.285	0.661	9.287	1.570	4.260	5.027	11.769	19.867	171.889	1.929	6.956	9506.3	343.38
2	1.884	0.385	7.957	1.295	4.435	3.521	9.704	16.380	141.724	1.982	5.503	5113.1	152.28
3	2.515	0.869	10.078	1.728	4.177	5.902	12.954	21.866	189.191	1.904	7.805	12922.3	513.75
4	2.17	0.569	8.864	1.491	4.306	4.558	11.177	18.867	163.238	1.943	6.501	8013.0	274.88
5	1.512	0.249	7.990	1.039	4.649	3.341	7.788	13.146	113.740	2.045	5.386	3222.9	77.03
6	2.321	0.687	9.355	1.595	4.246	5.109	11.955	20.180	174.597	1.925	7.034	9917.9	363.89
7	2.285	0.675	9.483	1.570	4.260	5.224	11.769	19.867	171.889	1.929	7.153	9775.1	353.09
8	1.329	0.19	7.891	0.913	4.781	3.110	6.845	11.555	99.974	2.083	5.193	2400.9	50.44
9	1.884	0.393	8.122	1.295	4.435	3.687	9.704	16.380	141.724	1.982	5.669	5266.7	156.85
10	1.695	0.346	8.834	1.165	4.536	4.298	8.730	14.737	127.506	2.012	6.310	4745.3	127.15

FULL SCALE CALM WATER RESISTANCE FOR THE 119' TRAWLER

10% Bulb, 1 diam. Ring

T=72°F ρf=1.9358 lbs*sec²/ft⁴ νf=1.0245E-5 ft²/sec (Lwl)m=4.171 ft Sm=5.000 ft²
Δ=53.19lb ρs=1.9905 lbs*sec²/ft⁴ νs=1.27908E-5 ft²/sec (Lwl)s=110.667ft Ss=3519.2 ft²

No	Vm (Knots)	Rt,m (lbs)	Ct,m (*1000)	Rn,m (*10E-6)	Cf,m (*1000)	Cr (*1000)	Vs (Knots)	Vs (ft/sec)	Rn,s (*10E-6)	Cf,s (*1000)	Ct,s (*1000)	Rt,s (lbs)	EHP
1	2.29	0.671	9.279	1.574	4.258	5.021	11.795	19.910	172.265	1.929	6.950	9649.3	349.31
2	1.887	0.383	7.800	1.297	4.434	3.367	9.719	16.406	141.949	1.982	5.348	5042.0	150.40
3	2.516	0.865	9.909	1.729	4.176	5.733	12.959	21.875	189.266	1.903	7.637	12799.4	509.07
4	2.076	0.466	7.841	1.427	4.346	3.496	10.693	18.050	156.167	1.955	5.451	6219.6	204.11
5	1.512	0.246	7.803	1.039	4.649	3.155	7.788	13.146	113.740	2.045	5.200	3147.4	75.23
6	2.325	0.673	9.029	1.598	4.245	4.784	11.975	20.215	174.898	1.924	6.709	9601.3	352.89
7	2.195	0.592	8.911	1.508	4.295	4.615	11.306	19.084	165.119	1.940	6.555	8361.9	290.15
8	1.203	0.157	7.867	0.827	4.887	2.980	6.196	10.459	90.496	2.114	5.094	1951.7	37.12
9	1.368	0.197	7.634	0.940	4.751	2.883	7.046	11.894	102.908	2.075	4.958	2456.5	53.12
10	2.286	0.625	8.673	1.571	4.259	4.414	11.775	19.875	171.964	1.929	6.343	8775.9	317.14
11	2.196	0.566	8.512	1.509	4.295	4.216	11.311	19.093	165.194	1.940	6.156	7860.3	272.87

10% Bulb, 1.5 diam. Ring

T=72°F ρf=1.9358 lbs*sec²/ft⁴ νf=1.0245E-5 ft²/sec (Lwl)m=4.171 ft Sm=5.057 ft²
Δ=53.241b ρs=1.9905 lbs*sec²/ft⁴ νs=1.27908E-5 ft²/sec (Lwl)s=110.667ft Ss=3559.3 ft²

No	Vm (Knots)	Rt,m (lbs)	Ct,m (*1000)	Rn,m (*10E-6)	Cf,m (*1000)	Cr (*1000)	Vs (Knots)	Vs (ft/sec)	Rn,s (*10E-6)	Cf,s (*1000)	Ct,s (*1000)	Rt,s (lbs)	EHP
1	2.285	0.661	9.077	1.570	4.260	4.818	11.769	19.867	171.889	1.929	6.747	9432.8	340.72
2	1.884	0.412	8.323	1.295	4.435	3.888	9.704	16.380	141.724	1.982	5.870	5578.8	166.15
3	2.512	0.827	9.397	1.726	4.178	5.220	12.939	21.840	188.965	1.904	7.124	12036.9	477.98
4	2.074	0.513	8.551	1.425	4.347	4.205	10.683	18.032	156.016	1.955	6.160	7095.5	232.63
5	1.512	0.247	7.747	1.039	4.649	3.098	7.788	13.146	113.740	2.045	5.143	3148.6	75.26
6	2.321	0.695	9.251	1.595	4.246	5.004	11.955	20.180	174.597	1.925	6.929	9995.9	366.75
7	2.164	0.534	8.176	1.487	4.308	3.868	11.146	18.815	162.787	1.944	5.812	7288.1	249.31
8	1.329	0.19	7.713	0.913	4.781	2.932	6.845	11.555	99.974	2.083	5.015	2372.1	49.84
9	2.514	0.839	9.518	1.728	4.177	5.342	12.949	21.858	189.115	1.904	7.245	12262.0	487.31
10	1.696	0.325	8.101	1.166	4.535	3.566	8.736	14.746	127.581	2.012	5.578	4296.3	115.19
11	2.235	0.65	9.330	1.536	4.279	5.051	11.512	19.432	168.128	1.935	6.986	9344.4	330.15

20% Bulb, with no Rings

T=79°F ρf=1.9339 lbs*sec²/ft⁴ νf=0.9375E-5 ft²/sec (Lwl)m=4.171 ft Sm=5.146 ft²
Δ=55.381b ρs=1.9905 lbs*sec²/ft⁴ νs=1.27908E-5 ft²/sec (Lwl)s=110.667ft Ss=3622 ft²

No	Vm (Knots)	Rt,m (lbs)	Ct,m (*1000)	Rn,m (*10E-6)	Cf,m (*1000)	Cr (*1000)	Vs (Knots)	Vs (ft/sec)	Rn,s (*10E-6)	Cf,s (*1000)	Ct,s (*1000)	Rt,s (lbs)	EHP
1	1.934	0.5	9.428	1.452	4.329	5.099	9.962	16.815	145.485	1.975	7.074	7209.7	220.42
2	1.512	0.26	8.021	1.136	4.561	3.461	7.788	13.146	113.740	2.045	5.506	3429.9	81.98
3	2.513	0.876	9.784	1.887	4.102	5.681	12.944	21.849	189.040	1.904	7.585	13053.1	518.54
4	2.32	0.724	9.487	1.742	4.170	5.318	11.950	20.171	174.522	1.925	7.243	10622.8	389.59
5	2.07	0.521	8.576	1.555	4.269	4.307	10.662	17.997	155.715	1.956	6.263	7312.9	239.30
6	1.88	0.438	8.741	1.412	4.355	4.385	9.683	16.346	141.423	1.983	6.368	6133.1	182.27
7	1.119	0.162	9.125	0.840	4.870	4.255	5.764	9.729	84.177	2.136	6.392	2180.9	38.58
8	2.108	0.592	9.396	1.583	4.253	5.144	10.858	18.328	158.574	1.951	7.095	8590.8	286.28
9	2.147	0.606	9.272	1.612	4.237	5.036	11.059	18.667	161.508	1.946	6.982	8769.7	297.64

FULL SCALE CALM WATER RESISTANCE FOR THE 119' TRAWLER

20% Bulb, 0.5 diam. Ring

$T=79^{\circ}F$ $\rho f=1.9339$ lbs*sec²/ft⁴ — $\nu f=0.9375E\text{-}5$ ft²/sec — $(Lwl)m=4.171$ ft — $Sm=5.279$ ft²

$\Delta=55.69lb$ $\rho s=1.9905$ lbs*sec²/ft⁴ — $\nu s=1.27908E\text{-}5$ ft²/sec — $(Lwl)s=110.667ft$ — $Ss=3715.6ft^2$

No	Vm (Knots)	Rt,m (lbs)	Ct,m (*1000)	Rn,m (*10E-6)	Cf,m (*1000)	Cr (*1000)	Vs (Knots)	Vs (ft/sec)	Rn,s (*10E-6)	Cf,s (*1000)	Ct,s (*1000)	Rt,s (lbs)	EHP
1	1.987	0.508	8.846	1.492	4.305	4.541	10.234	17.276	149.472	1.967	6.508	7183.2	225.63
2	2.135	0.558	8.417	1.603	4.242	4.175	10.997	18.563	160.605	1.947	6.123	7801.4	263.30
3	2.511	0.861	9.389	1.886	4.103	5.286	12.933	21.832	188.890	1.904	7.190	12672.4	503.02
4	1.512	0.26	7.819	1.136	4.561	3.259	7.788	13.146	113.740	2.045	5.304	3389.4	81.01
5	2.285	0.696	9.165	1.716	4.183	4.982	11.769	19.867	171.889	1.929	6.912	10087.6	364.38
6	1.883	0.371	7.194	1.414	4.354	2.840	9.699	16.372	141.648	1.982	4.822	4779.8	142.28
7	1.008	0.122	8.255	0.757	4.984	3.271	5.192	8.764	75.827	2.169	5.441	1545.3	24.62
8	1.956	0.506	9.093	1.469	4.319	4.774	10.075	17.006	147.140	1.972	6.745	7214.2	223.07
9	2.365	0.717	8.814	1.776	4.153	4.660	12.181	20.562	177.907	1.920	6.580	10288.4	384.64
10	2.158	0.593	8.755	1.621	4.232	4.523	11.115	18.763	162.335	1.945	6.467	8419.2	287.21

20% Bulb, 1 diam. Ring

$T=72^{\circ}F$ $\rho f=1.9358$ lbs*sec²/ft⁴ — $\nu f=1.0245E\text{-}5$ ft²/sec — $(Lwl)m=4.171$ ft — $Sm=5.412$ ft²

$\Delta=55.87lb$ $\rho s=1.9905$ lbs*sec²/ft⁴ — $\nu s=1.27908E\text{-}5$ ft²/sec — $(Lwl)s=110.667ft$ — $Ss=3809.2ft^2$

No	Vm (Knots)	Rt,m (lbs)	Ct,m (*1000)	Rn,m (*10E-6)	Cf,m (*1000)	Cr (*1000)	Vs (Knots)	Vs (ft/sec)	Rn,s (*10E-6)	Cf,s (*1000)	Ct,s (*1000)	Rt,s (lbs)	EHP
1	2.048	0.464	7.412	1.407	4.358	3.054	10.549	17.806	154.061	1.959	5.013	6025.2	195.07
2	1.875	0.401	7.642	1.289	4.440	3.202	9.658	16.302	141.047	1.983	5.186	5224.6	154.86
3	2.309	0.58	7.289	1.587	4.251	3.038	11.893	20.075	173.694	1.926	4.964	7585.0	276.86
4	1.493	0.285	8.566	1.026	4.661	3.905	7.690	12.981	112.311	2.049	5.954	3803.2	89.76
5	2.44	0.653	7.349	1.677	4.203	3.146	12.568	21.214	183.549	1.912	5.058	8629.2	332.84
6	1.013	0.128	8.357	0.696	5.079	3.278	5.218	8.807	76.203	2.168	5.446	1601.5	25.65
7	2.138	0.553	8.105	1.469	4.319	3.786	11.012	18.589	160.831	1.947	5.733	7510.7	253.84
8	1.647	0.319	7.879	1.132	4.564	3.315	8.483	14.320	123.895	2.020	5.335	4147.5	107.98
9	2.275	0.617	7.987	1.563	4.264	3.723	11.718	19.780	171.137	1.930	5.654	8385.7	301.58
10	2.5	0.794	8.512	1.718	4.182	4.330	12.877	21.736	188.062	1.905	6.235	11167.8	441.35
11	2.478	0.769	8.391	1.703	4.189	4.201	12.764	21.545	186.407	1.907	6.109	10750.0	421.10

20% Bulb, 1.5 diam. Ring

$T=72^{\circ}F$ $\rho f=1.9358$ lbs*sec²/ft⁴ — $\nu f=1.0245E\text{-}5$ ft²/sec — $(Lwl)m=4.171$ ft — $Sm=5.545$ ft²

$\Delta=56.18lb$ $\rho s=1.9905$ lbs*sec²/ft⁴ — $\nu s=1.27908E\text{-}5$ ft²/sec — $(Lwl)s=110.667ft$ — $Ss=3902.8ft^2$

No	Vm (Knots)	Rt,m (lbs)	Ct,m (*1000)	Rn,m (*10E-6)	Cf,m (*1000)	Cr (*1000)	Vs (Knots)	Vs (ft/sec)	Rn,s (*10E-6)	Cf,s (*1000)	Ct,s (*1000)	Rt,s (lbs)	EHP
1	2.072	0.545	8.301	1.424	4.347	3.954	10.672	18.015	155.866	1.956	5.909	7449.3	244.00
2	1.882	0.418	7.717	1.293	4.436	3.281	9.694	16.363	141.573	1.982	5.263	5473.8	162.85
3	2.322	0.741	8.987	1.596	4.246	4.741	11.960	20.188	174.672	1.925	6.666	10553.3	387.37
4	1.511	0.307	8.793	1.038	4.649	4.144	7.783	13.137	113.665	2.045	6.189	4148.8	99.10
5	2.514	0.906	9.374	1.728	4.177	5.197	12.949	21.858	189.115	1.904	7.101	13177.3	523.68
6	1.085	0.175	9.721	0.746	5.001	4.720	5.589	9.433	81.619	2.146	6.866	2373.2	40.70
7	2.284	0.677	8.486	1.570	4.260	4.226	11.764	19.858	171.814	1.929	6.155	9428.3	340.41
8	2.492	0.918	9.667	1.713	4.184	5.482	12.836	21.667	187.460	1.906	7.388	13471.7	530.70
9	2.193	0.674	9.164	1.507	4.296	4.868	11.296	19.067	164.968	1.940	6.808	9614.1	333.29

FULL SCALE CALM WATER RESISTANCE FOR THE 119' TRAWLER

30% Bulb, No Rings

$T=72^\circ F$ $\rho f=1.9358$ lbs*sec^2/ft^4 $\nu f=1.0245E{-5}$ ft^2/sec (Lwl)m=4.171 ft Sm=5.476 ft^2

$\Delta=58.831b$ $\rho s=1.9905$ lbs*sec^2/ft^4 $\nu s=1.27908E{-5}$ ft^2/sec (Lwl)s=110.667ft Ss=3854.2ft^2

No	Vm (Knots)	Rt,m (lbs)	Ct,m (*1000)	Rn,m (*10E-6)	Cf,m (*1000)	Cr (*1000)	Vs (Knots)	Vs (ft/sec)	Rn,s (*10E-6)	Cf,s (*1000)	Ct,s (*1000)	Rt,s (lbs)	EHP
1	2.076	0.618	9.495	1.427	4.346	5.149	10.693	18.050	156.167	1.955	7.104	8878.4	291.37
2	1.695	0.38	8.758	1.165	4.536	4.222	8.730	14.737	127.506	2.012	6.234	5193.4	139.16
3	2.277	0.753	9.617	1.565	4.263	5.354	11.728	19.797	171.287	1.930	7.284	10950.6	394.17
4	1.512	0.318	9.211	1.039	4.649	4.562	7.788	13.146	113.740	2.045	6.607	4379.7	104.68
5	2.507	0.913	9.619	1.723	4.179	5.440	12.913	21.797	188.589	1.904	7.344	13384.2	530.43
6	1.987	0.577	9.677	1.366	4.386	5.291	10.234	17.276	149.472	1.967	7.258	8309.7	261.01
7	1.876	0.516	9.708	1.289	4.439	5.269	9.663	16.311	141.122	1.983	7.252	7401.0	219.48
8	2.468	0.884	9.610	1.696	4.193	5.417	12.712	21.458	185.655	1.909	7.326	12938.9	504.80
9	2.335	0.702	8.526	1.605	4.241	4.285	12.027	20.301	175.650	1.923	6.208	9814.7	362.28

30% Bulb, 0.5 diam. Ring

$T=72^\circ F$ $\rho f=1.9358$ lbs*sec^2/ft^4 $\nu f=1.0245E{-5}$ ft^2/sec (Lwl)m=4.171 ft Sm=5.682 ft^2

$\Delta=57.751b$ $\rho s=1.9905$ lbs*sec^2/ft^4 $\nu s=1.27908E{-5}$ ft^2/sec (Lwl)s=110.667ft Ss=3999.2ft^2

No	Vm (Knots)	Rt,m (lbs)	Ct,m (*1000)	Rn,m (*10E-6)	Cf,m (*1000)	Cr (*1000)	Vs (Knots)	Vs (ft/sec)	Rn,s (*10E-6)	Cf,s (*1000)	Ct,s (*1000)	Rt,s (lbs)	EHP
1	2.333	0.759	8.899	1.603	4.242	4.657	12.017	20.284	175.500	1.924	6.581	10777.0	397.46
2	1.511	0.351	9.811	1.038	4.649	5.161	7.783	13.137	113.665	2.045	7.207	4950.5	118.25
3	2.196	0.661	8.747	1.509	4.295	4.452	11.311	19.093	165.194	1.940	6.392	9274.1	321.95
4	1.699	0.413	9.130	1.168	4.534	4.597	8.751	14.772	127.807	2.011	6.608	5739.0	154.14
5	2.514	0.85	8.582	1.728	4.177	4.406	12.949	21.858	189.115	1.904	6.309	11997.7	476.81
6	2.078	0.558	8.246	1.428	4.345	3.902	10.703	18.067	156.317	1.955	5.856	7608.8	249.94
7	1.884	0.516	9.277	1.295	4.435	4.842	9.704	16.380	141.724	1.982	6.824	7287.5	217.04
8	2.318	0.708	8.409	1.593	4.247	4.161	11.939	20.154	174.371	1.925	6.087	9840.1	360.57
9	0.976	0.157	10.518	0.671	5.122	5.396	5.027	8.486	73.419	2.180	7.575	2171.2	33.50
10	2.489	0.819	8.436	1.711	4.185	4.251	12.820	21.640	187.235	1.906	6.157	11477.0	451.58
11	1.987	0.582	9.407	1.366	4.386	5.021	10.234	17.276	149.472	1.967	6.988	8301.6	260.76
12	2.139	0.624	8.703	1.470	4.319	4.385	11.017	18.597	160.906	1.947	6.332	8716.2	294.72

30% Bulb, 1 diam. Ring

$T=72^\circ F$ $\rho f=1.9358$ lbs*sec^2/ft^4 $\nu f=1.0245E{-5}$ ft^2/sec (Lwl)m=4.171 ft Sm=5.888 ft^2

$\Delta=59.721b$ $\rho s=1.9905$ lbs*sec^2/ft^4 $\nu s=1.27908E{-5}$ ft^2/sec (Lwl)s=110.667ft Ss=4144.2ft^2

No	Vm (Knots)	Rt,m (lbs)	Ct,m (*1000)	Rn,m (*10E-6)	Cf,m (*1000)	Cr (*1000)	Vs (Knots)	Vs (ft/sec)	Rn,s (*10E-6)	Cf,s (*1000)	Ct,s (*1000)	Rt,s (lbs)	EHP
1	2.068	0.618	8.899	1.421	4.349	4.550	10.652	17.980	155.565	1.956	6.506	8675.1	283.60
2	2.312	0.709	8.168	1.589	4.249	3.919	11.908	20.102	173.920	1.926	5.845	9740.7	356.01
3	1.69	0.461	9.940	1.161	4.539	5.401	8.705	14.694	127.130	2.013	7.414	6602.0	176.38
4	2.277	0.702	8.338	1.565	4.263	4.075	11.728	19.797	171.287	1.930	6.005	9707.6	349.42
5	1.353	0.292	9.823	0.930	4.762	5.061	6.969	11.764	101.779	2.078	7.139	4074.4	87.14
6	2.498	0.803	7.925	1.717	4.182	3.742	12.867	21.719	187.912	1.905	5.648	10988.1	433.90
7	1.929	0.542	8.970	1.326	4.413	4.557	9.936	16.772	145.109	1.975	6.532	7578.4	231.09
8	2.276	0.71	8.441	1.564	4.263	4.177	11.723	19.789	171.212	1.930	6.107	9864.0	354.90
9	2.134	0.633	8.560	1.467	4.321	4.239	10.992	18.554	160.530	1.948	6.187	8784.3	296.33

FULL SCALE CALM WATER RESISTANCE FOR THE 119' TRAWLER
30% Bulb, 1.5 diam. Ring

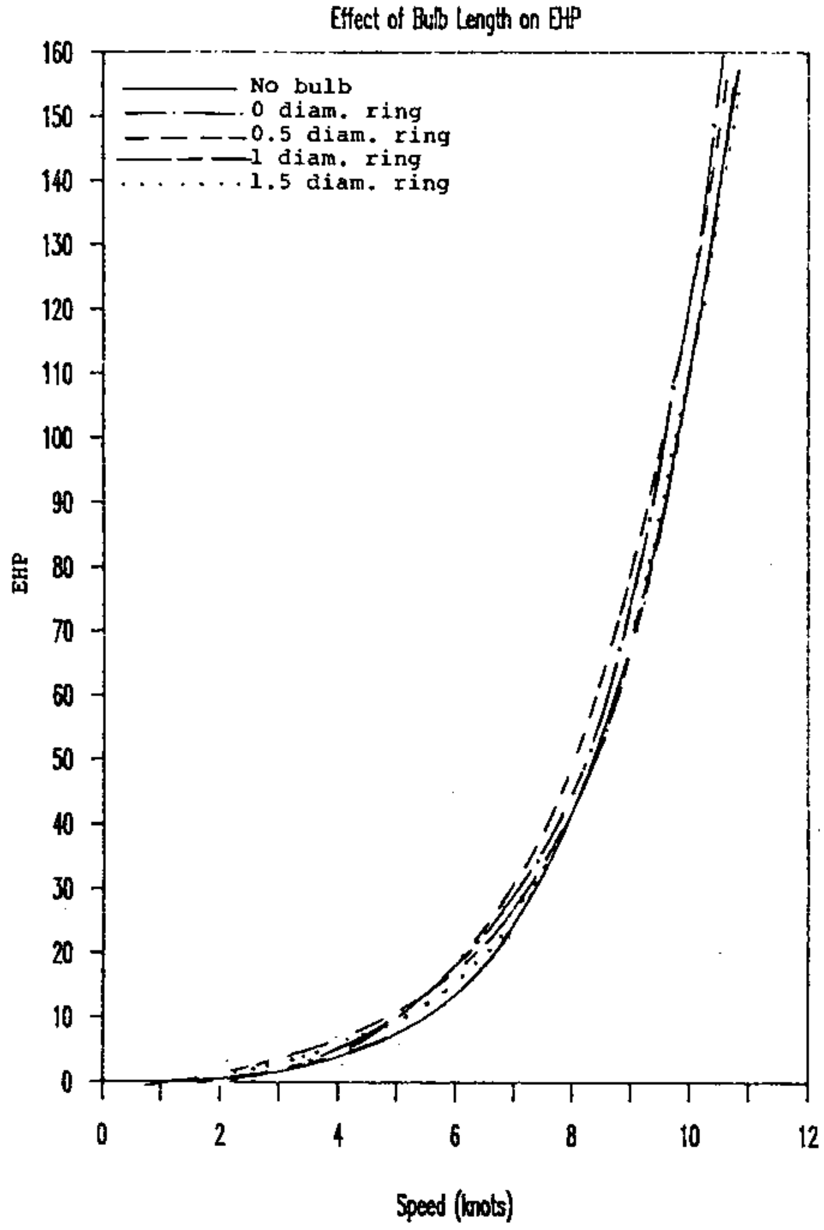
$T=72^{\circ}F$ $\rho f=1.9358$ $lbs*sec^2/ft^4$ $\nu f=1.0245E-5$ ft^2/sec $(Lwl)m=4.171$ ft $Sm=6.094$ ft^2
$\Delta=60.241b$ $\rho s=1.9905$ $lbs*sec^2/ft^4$ $\nu s=1.27908E-5$ ft^2/sec $(Lwl)s=110.667ft$ $Ss=4289.2ft^2$

No	Vm (Knots)	Rt,m (lbs)	Ct,m (*1000)	Rn,m (*10E-6)	Cf,m (*1000)	Cr (*1000)	Vs (Knots)	Vs (ft/sec)	Rn,s (*10E-6)	Cf,s (*1000)	Ct,s (*1000)	Rt,s (lbs)	EHP
1	2.07	0.65	9.026	1.423	4.348	4.678	10.662	17.997	155.715	1.956	6.634	9172.3	300.14
2	2.504	0.892	8.465	1.721	4.180	4.285	12.897	21.771	188.363	1.905	6.189	12522.8	495.69
3	2.069	0.681	9.466	1.422	4.349	5.117	10.657	17.989	155.640	1.956	7.073	9770.3	319.56
4	1.879	0.571	9.623	1.291	4.438	5.185	9.678	16.337	141.348	1.983	7.168	8166.5	242.57
5	1.393	0.314	9.628	0.957	4.732	4.896	7.175	12.111	104.788	2.069	6.965	4361.5	96.04
6	2.276	0.761	8.741	1.564	4.263	4.478	11.723	19.789	171.212	1.930	6.408	10711.4	385.39
7	2.316	0.796	8.830	1.592	4.248	4.582	11.929	20.136	174.221	1.925	6.507	11263.6	412.38
8	1.69	0.45	9.375	1.161	4.539	4.836	8.705	14.694	127.130	2.013	6.849	6312.1	168.63
9	2.503	0.878	8.339	1.720	4.181	4.158	12.892	21.762	188.288	1.905	6.063	12257.2	484.99

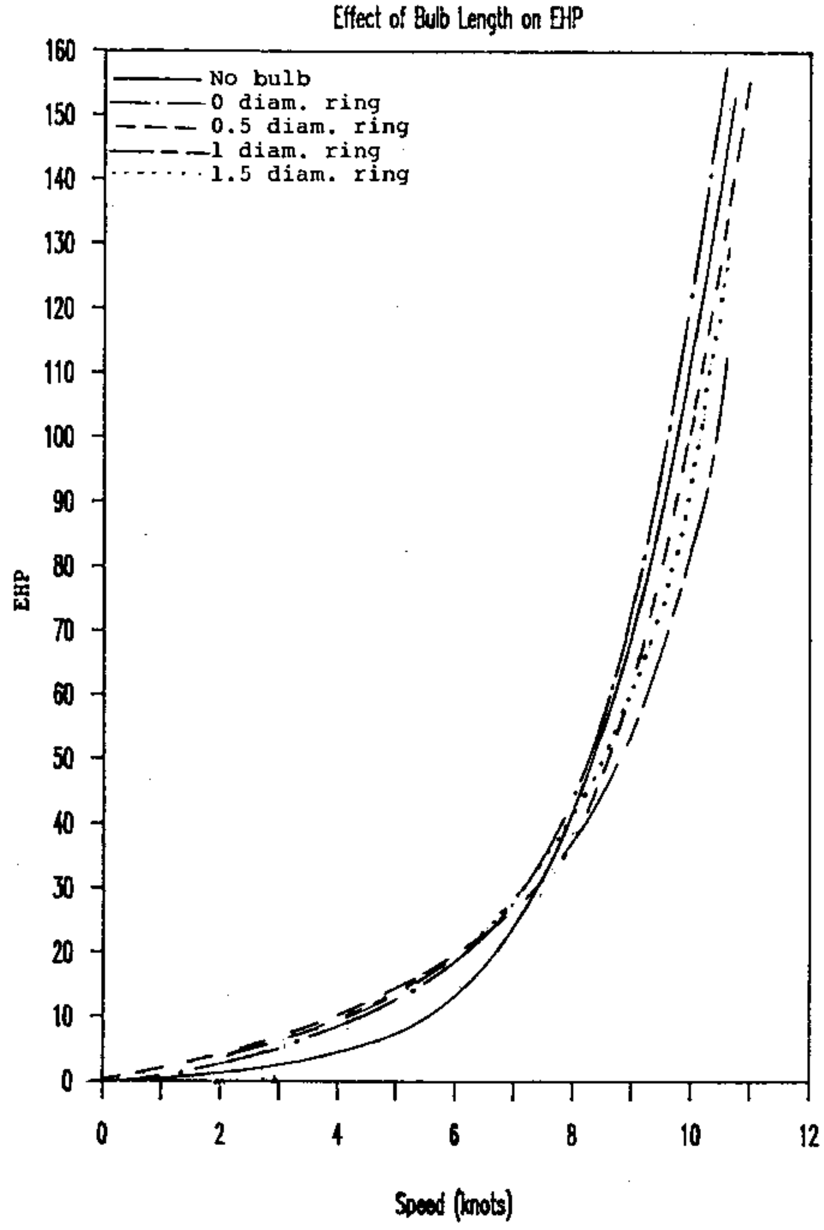
Appendix 2

Graphs of EHP versus Speed

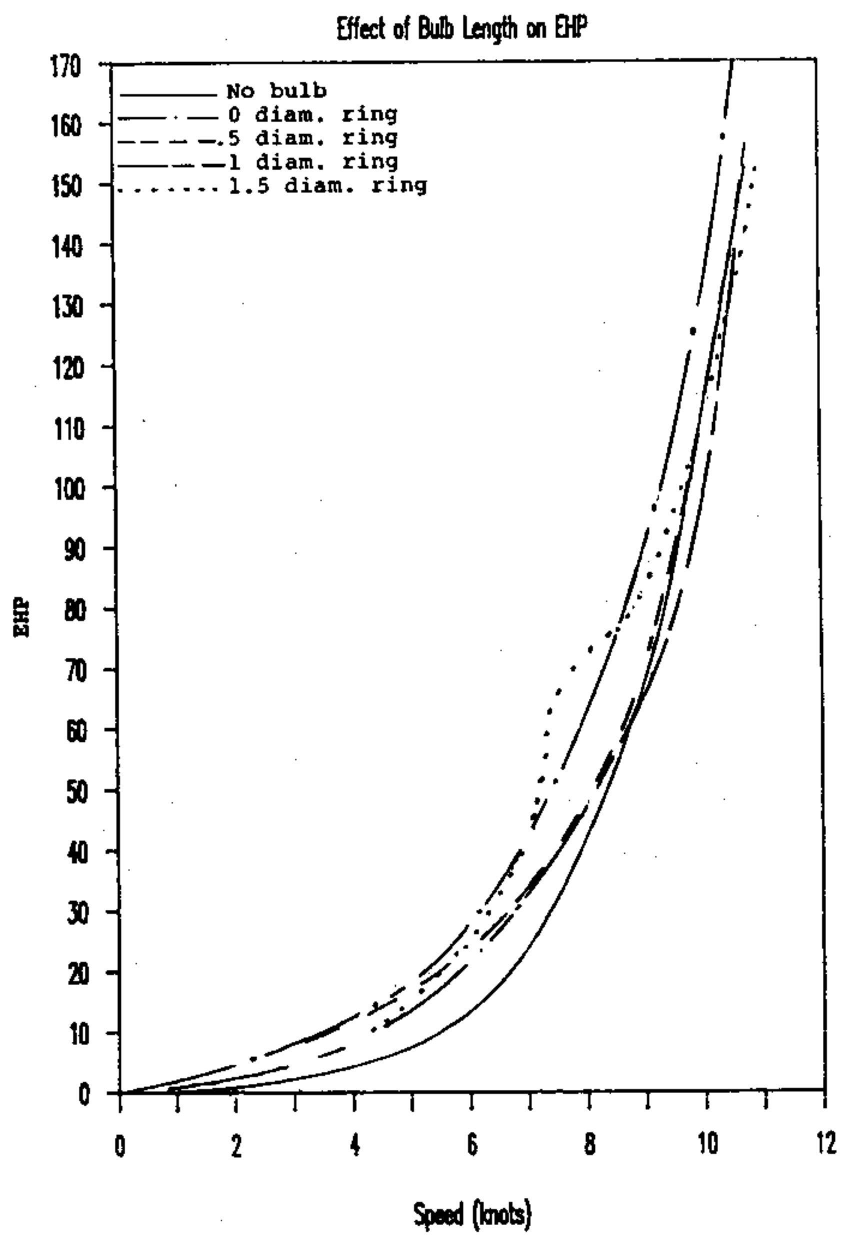
76' TRAWLER WITH 10% BULBS



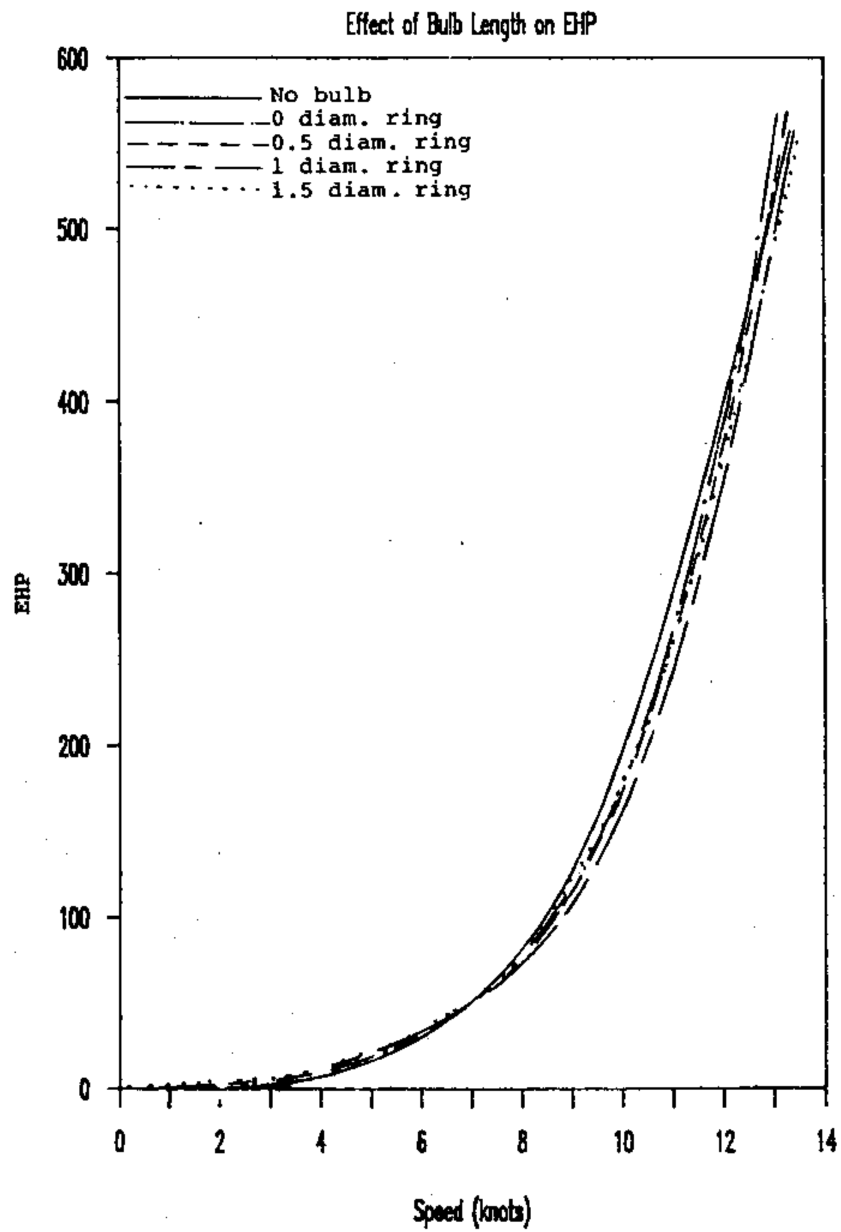
76' TRAWLER WITH 20% BULBS



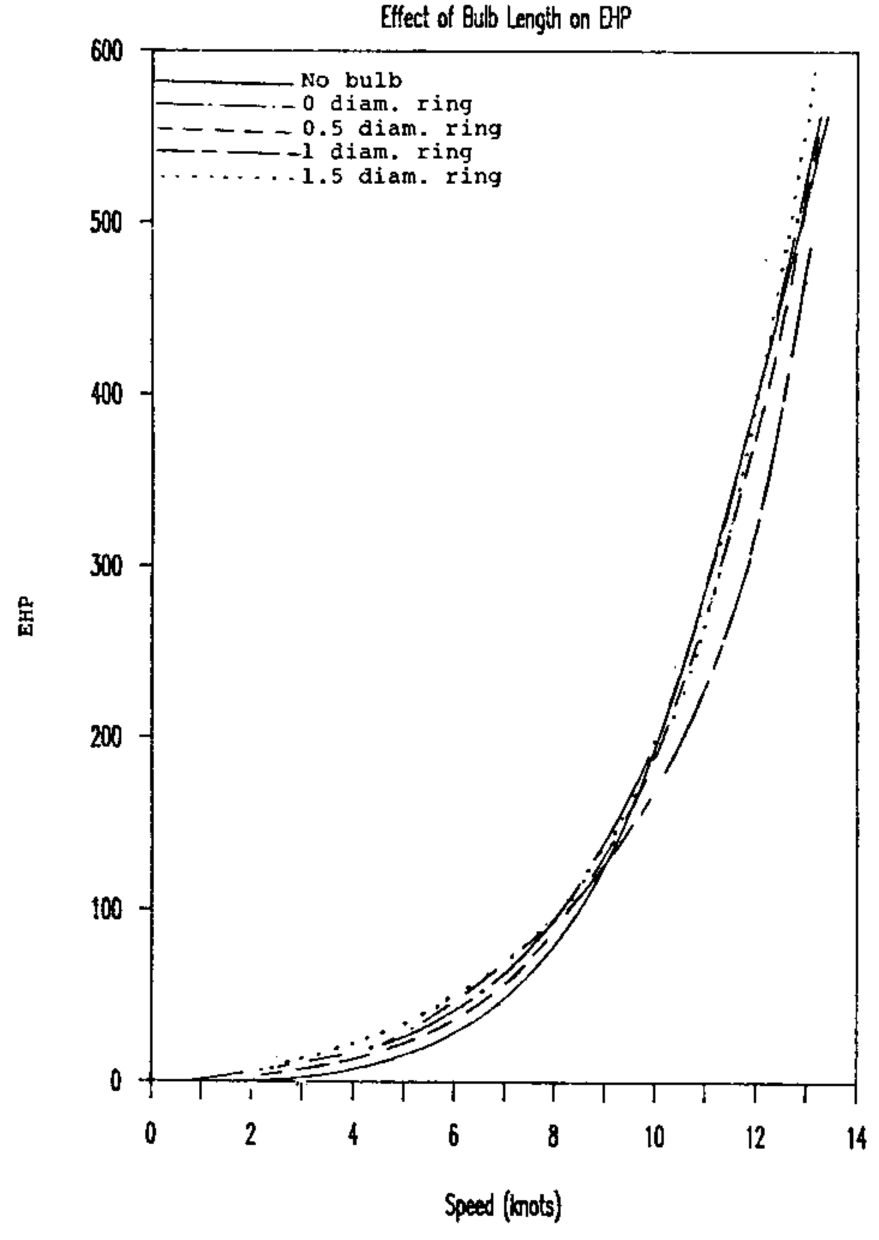
76' TRAWLER WITH 30% BULBS



119' TRAWLER WITH 10% BULBS



119' TRAWLER WITH 20% BULBS



119' TRAWLER WITH 30% BULBS