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Methodical Series Experiments on Cylindrical Bows

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SUMMARY: This report describes experiments carried out with models of 0·800, 0·825 and 0·850 block coefficient, for which three cylindrical bow variations of a parent conventional bow form were made for each block coefficient and their effect on resistance and propulsion factors determined.

These experiments were conducted at 100% displacement level trim and at 50% displacement with 10 ft./700 ft. trim by the stern.

The results show that for a 600 ft. ship of 0·800 block coefficient operating at speeds up to 15 knots loaded a cylindrical bow has little to be recommended. At 0·825 block for ships of 600 ft., a reduction of about 10% in required power can be expected from a cylindrical bow at 15 knots loaded and of about 6% in ballast at a corresponding speed of 16 knots.

For 800 ft. ships operating at 16 knots loaded and at 17·5 knots in ballast the reductions are 9 and 10% in the loaded condition for 0·825 and 0·850 block coefficients respectively. The reductions in ballast for these ships are very small for the 0·825 block coefficient and for the 0·850 block ships even a slight increase in required power is found with the cylindrical bow.

The highest reductions in required power with a cylindrical bow are thus obtained with ships of 0·825 to 0·850 block coefficients in the loaded condition. For these blocks a cylindrical bow can definitely be recommended, since ships so fitted have already proved that no adverse effects are to be expected with regard to seakeeping or course stability.

1. INTRODUCTION

In 1964 in Ref. 1 a tanker was shown with a cylindrical bow, which it was claimed, would make possible a reduction in the overall length of the ship without sacrificing displacement and speed. This statement was substantiated in Ref. 2 by the following remarks: 'Model tests in calm water had given poorer results for conical (or cylindrical) type bows, despite which, vessels so fitted subsequently gave better performance in service compared with their conventional sister ships. Further extensive model tests were therefore made in simulated wave conditions which clearly showed that the advantages of the conical form were in wave conditions'.

Results given in Ref. 3, however, suggested that possibly also in still water improvements in speed could be expected with cylindrical bows. The modifications were unfortunately not systematically varied so that trends could not be deduced from the test results published.

In 1965 at the N.S.M.B. several sponsored tests were carried out with cylindrical bow modifications.

In the beginning these were not successful, since in an effort to obtain as simplified lines in the forebody as possible, section shapes and a stem profile as indicated by Fig. 1 were adopted. These sections proved to have too small bilge radii and the circular stem profile at the bottom caused separation and thereby considerable extra drag. It was not until large bilge radii in the forebody and smooth transitions of the stem profile into the bottom were used, that reductions in required power in still water could be obtained. Much experience was then obtained from routine test programmes, confirming that both in calm water and in waves cylindrical bows could have a favourable effect on the required power.

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The available information, however, was too limited to determine systematic trends as a function of block coefficient and speed.

A research program was therefore initiated under the auspices of the Netherlands Ship Research Centre T.N.O. to determine these trends. The results of this research are described below.

2. RANGE OF INVESTIGATIONS

The object of the research was to obtain, with as limited a number of model modifications as possible, design information for the selection of a cylindrical bow for high-block tankers and bulk carriers.

It was soon realised that a truly systematic approach of the problem would mean an enormous number of variations to be tested, since it was found that the optimum size of the cylindrical bow would be a function of speed, C_B, LCB, L/B and B/T. Discussions were therefore held with the shipowners interested in the programme to find a compromise basic ship for this research which would suit both the interests of the bulk carrier and the tanker owners.

It was finally agreed to use the following parameters for the basic form:

C_B = 0·825

L/B = 6·5

B/T = 2·65

LCB = 2% of LBP forward of midship

For the bulk carrier a length of 600 ft. was considered to be representative and at the same time 800 ft. for the tanker.

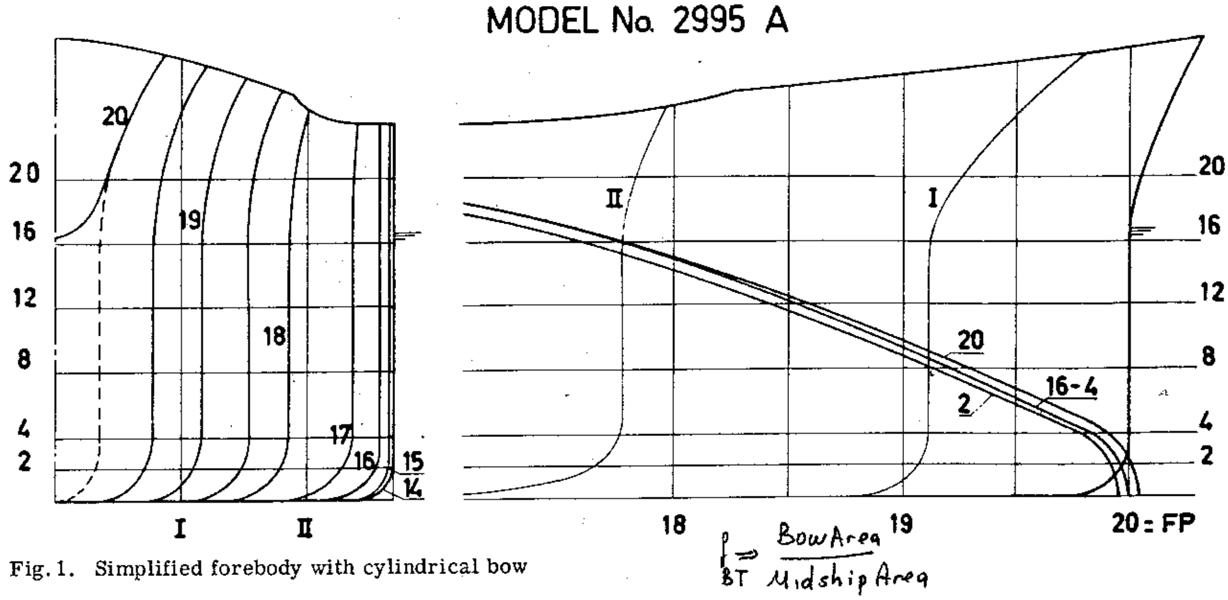

Fig. 1. Simplified forebody with cylindrical bow

The lines of the basic model without cylindrical bow were to be designed according to the best available knowledge gained from routine test programmes carried out at the N.S.M.B.

For the cylindrical bow modifications it was considered to be of most interest to reduce the fullness of the fore-shoulder by shifting displacement out of the shoulder into the cylindrical bow. This could be achieved in many ways, viz. by taking the displacement away from the load waterline area, from the bilges or uniformly over the whole height of the stations in the fore shoulder.

In order to change the shape of the sections in the forebody as little as possible it was finally decided to choose the last possibility, so that the cylindrical bow modifications in effect reflect as purely as possible a change in the curve of sectional areas in the forebody, keeping C_B, L/B, B/T and section shape constant at constant displacement.

To characterise the shape of the curve of sectional areas of a forebody with cylindrical bow the Taylor coefficients for characterising a bulbous bow, f_{BT} and t, will be used in the following. For the sectional area coefficient f_{BT} the fictitious area at station 20 of the section formed by the waterlines continued through to station 20 is used here.

To keep the number of modifications to the minimum and to change as little as possible the curve of sectional areas in the forebody and the forebody section shapes, it was decided to ignore the influence of the coefficient t for the present investigation and to vary f_{BT} by accepting a slight change in the value of t for each f_{BT}.

Thus for a given block the basic model without cylindrical bow and three f_{BT} modifications would be sufficient for determining the optimum f_{BT} for that block.

Due to the many simplifications it was found impossible to relate the ship lines of the different modifications by means of mathematical transformations, so personal judgement had to be used extensively in laying out the lines plans for the cylindrical bow modifications.

The final parameter field for the test programme, which satisfied both the bulk carrier and the tanker operator's interests, is given in Table I.

For the parent models with $f_{BT} = 0$ (conventional bow) it was decided to choose optimum conventional lines and LCB positions to ensure the best possible performance with the conventional models for each block coefficient. These lines were determined from statistical experience obtained from routine test programmes and again cannot be related by mathematical transformations, each block having its own parent form.

The tanker owners were mainly interested in the 0·850 block models. Since resistance tests as well as propulsion tests were contemplated, it was requested by the sponsors to extrapolate and carry out the propulsion tests for the 0·850 block models to represent an 800 ft. ship and for the 0·800 block to represent a 600 ft. ship.

TABLE I. Parameter field chosen for the test programme

L/B	6·5											
B/T	2·65											
C_B	0·800				0·825				0·850			
f_{BT}	0	0·07	0·11	0·15	0	0·07	0·11	0·15	0	0·07	0·11	0·15
LCB	1·6% F				2·1% F				2·8% F			
Model No.	3332	3332 A	3332 B	3332 C	2991	2991 A	2991 B	2991 C	3343	3343 A	3343 B	3343 C

The stock propellers used for the tests were then selected to suit this wish and for the 0·825 block models it was decided to run the propulsion tests with both stock propellers and to extrapolate the results for a 600 ft. ship as well as for an 800 ft. ship. By this procedure it was at the same time possible to check the consistency of the measurements with different stock propellers.

The tests were carried out for 100% displacement on even keel and for 50% displacement at 10 ft./700 ft. trim by the stern.

3. MAIN PARTICULARS OF MODELS

All the tests were carried out with models of 7·03 m. length between perpendiculars, representing a 600 ft. bulk carrier to scale 1/26 or an 800 ft. tanker to scale 1/34½. For the basic ship of 0·825 block, the loaded displacement amounts to approx. 45,000 m.^{3} for the 600 ft. ship and 105,000 m.^{3} for the 800 ft. ship.

The main particulars of the models are given in Table II. The sectional area coefficients are given in Table III and the fore-body sectional area curves are represented in Figs. 2, 3 and 4.

The lines plans of the respective models are shown in Figs. 5, 6 and 7.

The stock propellers used for the tests are shown in Fig. 8 for the 600 ft. ships (propeller No. 3502) and in Fig. 9 for the 800 ft. ships (propeller No. 3708). Their main characteristics are mentioned in these figures.

The ship models were made of paraffin wax.

Turbulence stimulation was obtained by studs in accordance with I.T.T.C. recommendations.

There were no bilge keels fitted to the models.

During the resistance tests the rudder was not fitted to the model.

4. METHOD OF EXTRAPOLATION

The model test results were extrapolated according to the I.T.T.C.-Froude method, using the I.T.T.C.-57 coefficients with a correlation allowance $C_A = 0{\cdot}00035$ for the 600 ft. ships and $C_A = 0{\cdot}00020$ for the 800 ft. ships. The data were corrected to 15° Centigrade salt water..

The results of the self-propulsion tests refer to the self-propulsion point of the ship.

These results were directly calculated from measured model values without any allowance for appendages not present on the model nor for wind and sea.

The tow-rope force applied to the self-propelled model was equal to the friction correction force according to the I.T.T.C.-57 coefficients including the above correlation allowances, reduced to model scale.

The number of revolutions of the ship's screw are given without correction for differences between the wakes of ship and model and without any allowance.

5. PRESENTATION

In this report the results of the tests have been presented in graphical form. The results of the resistance tests are presented in Fig. 10 through 13. In Figs. 17 through 24 the results are given of the propulsion tests.

The open water propeller characteristics of the stock propellers are shown in Fig. 16.

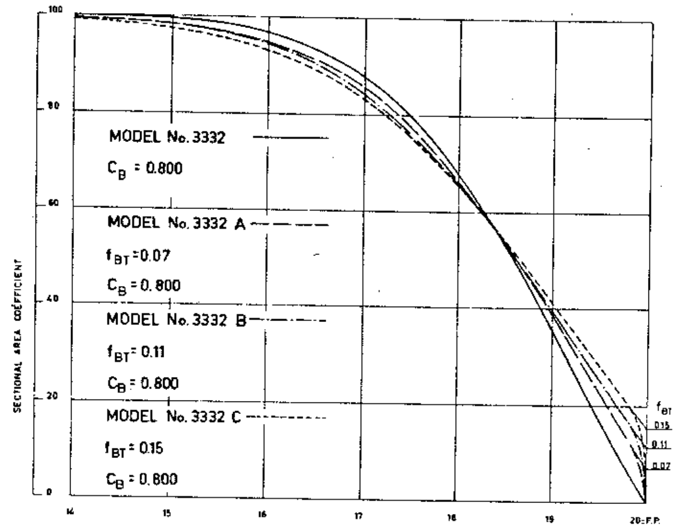

Fig. 2. Sectional area coefficients 0·800 block models

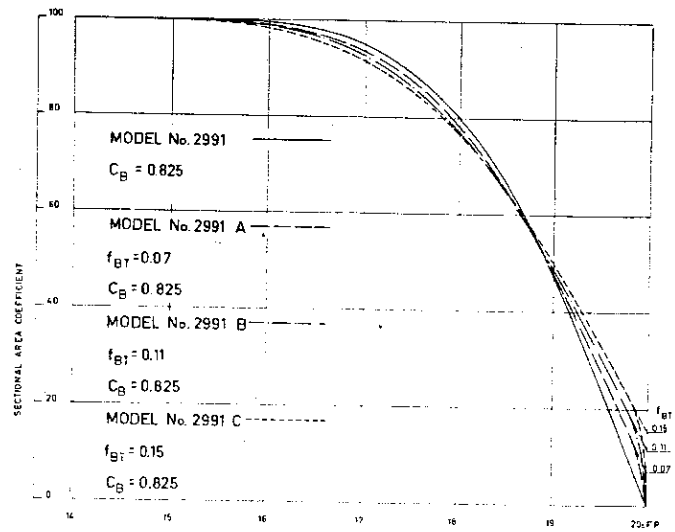

Fig. 3. Sectional area coefficients 0·825 block models

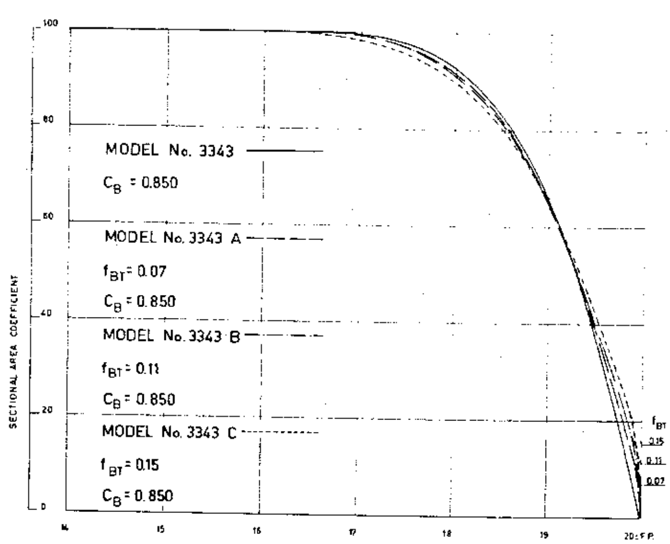

Fig. 4. Sectional area coefficients 0·850 block models

Bow Area

0 20.794 32.676 44.558

0 36.598 57.511 78.424

TABLE II. Geometrical particulars

Model No.	3332	3332 A	3332 B	3332 C	2991	2991 A	2991 B	2991 C	2991	2991 A	2991 B	2991 C	3343	3343 A	3343 B	3343 C
C_B	0·800	0·800	0·800	0·800	0·825	0·825	0·825	0·825	0·825	0·825	0·825	0·825	0·850	0·850	0·850	0·850
f_{BT}	0	0·07	0·11	0·15	0	0·07	0·11	0·15	0	0·07	0·11	0·15	0	0·07	0·11	0·15
	600 ft. LBP 100% Displacement								800 ft. LBP 100% Displacement							
L (m)	182·88								242·67							
Wetted length (m)	188·03								249·50							
B (m)	28·14								37·33							
T (level trim) (m)	10·62								14·09							
L/B	6·5								6·5							
B/T	2·65								2·65							
C_M	0·994								0·994							
Rise of floor (m)	0·075								0·10							
Bilge radius (m)	1·507								2·00							
∇ (m^3)	43717				45125				105306				108522			
$L/\nabla^{1/3}$	5·192				5·139				5·139				5·088			
C_P	0·805				0·830				0·830				0·855			
C_{PA}	0·770				0·785				0·785				0·796			
C_{PF}	0·841				0·875				0·875				0·915			
Wetted surface (m^2)	7527	7544	7524	7537	7732	7734	7734	7739	13614	13617	13618	13623	13876	13889	13893	13883
LCB, % LBP from ½ LBP	1·60 F	1·63 F	1·66 F	1·70 F	2·10 F	2·10 F	2·11 F	2·14 F	2·10 F	2·10 F	2·11 F	2·14 F	2·80 F	2·80 F	2·82 F	2·83 F
i_E (deg)	34	32	30	28	43	40	38	36	43	40	38	36	59	53	50	46
	600 ft. LBP 50% Displacement								800 ft. LBP 50% Displacement							
T Forward (m)	4·31				4·28				5·68				5·69			
T Aft (m)	6·92				6·89				9·14				9·16			
Wetted length (m)	179·17	179·66	179·66	179·66	179·13	179·63	179·63	179·63	237·69	238·36	238·36	238·36	237·71	238·46	238·46	238·46
∇ (m^3)	21858	21858	21858	21858	22563	22488	22499	22510	52714	52540	52565	52590	54261	54261	54267	54271
Wetted surface (m^2)	5628	5625	5626	5639	5792	5788	5789	5782	10199	10191	10193	10181	10450	10445	10445	10447

TABLE III. Section areas expressed as a percentage of maximum section area

	$C_B = 0{\cdot}800$				$C_B = 0{\cdot}825$				$C_B = 0{\cdot}850$			
	Model no.				Model no.				Model no.			
Station	3332	3332 A	3332 B	3332 C	2991	2991 A	2991 B	2991 C	3343	3343 A	3343 B	3343 C
0	2·4				2·5				2·5			
½	9·0				9·2				9·9			
1	22·8				23·6				24·8			
1½	36·0				37·5				39·6			
2	48·5				50·7				53·1			
3	70·0				73·5				76·3			
4	85·1				89·4				91·8			
5	93·8				97·2				98·3			
6	98·3				99·6				99·8			
7	99·7				100				100			
8	100				100				100			
9	100				100				100			
10	100				100				100			
11	100				100				100			
12	100				100				100			
13	100	100	100	100	100				100			
14	100	99·5	99·5	99·3	100	100	100	100	100			
15	99·4	98·2	98·2	97·2	99·9	99·9	99·8	99·7	100			
16	96·8	94·9	94·4	93·0	99·2	99·2	98·9	98·3	100	100	100	100
17	87·9	85·7	84·4	83·2	94·8	93·7	92·6	91·4	99·7	99·2	99·2	98·2
18	68·0	66·4	65·5	65·8	79·7	77·7	76·6	76·4	92·8	91·8	91·2	89·8
18½	53·1	53·3	53·1	54·2	66·1	64·5	64·2	64·4	82·7	81·5	81·3	79·7
19	35·7	38·5	39·6	41·2	47·5	48·0	48·7	49·8	65·6	64·1	64·2	64·5
19½	17·3	22·7	25·3	28·2	24·1	28·4	30·8	33·2	37·9	39·1	40·2	42·5
20	0	7·0	11·1	15·1	0	7·0	11·1	15·1	0	7·0	10·9	15·1

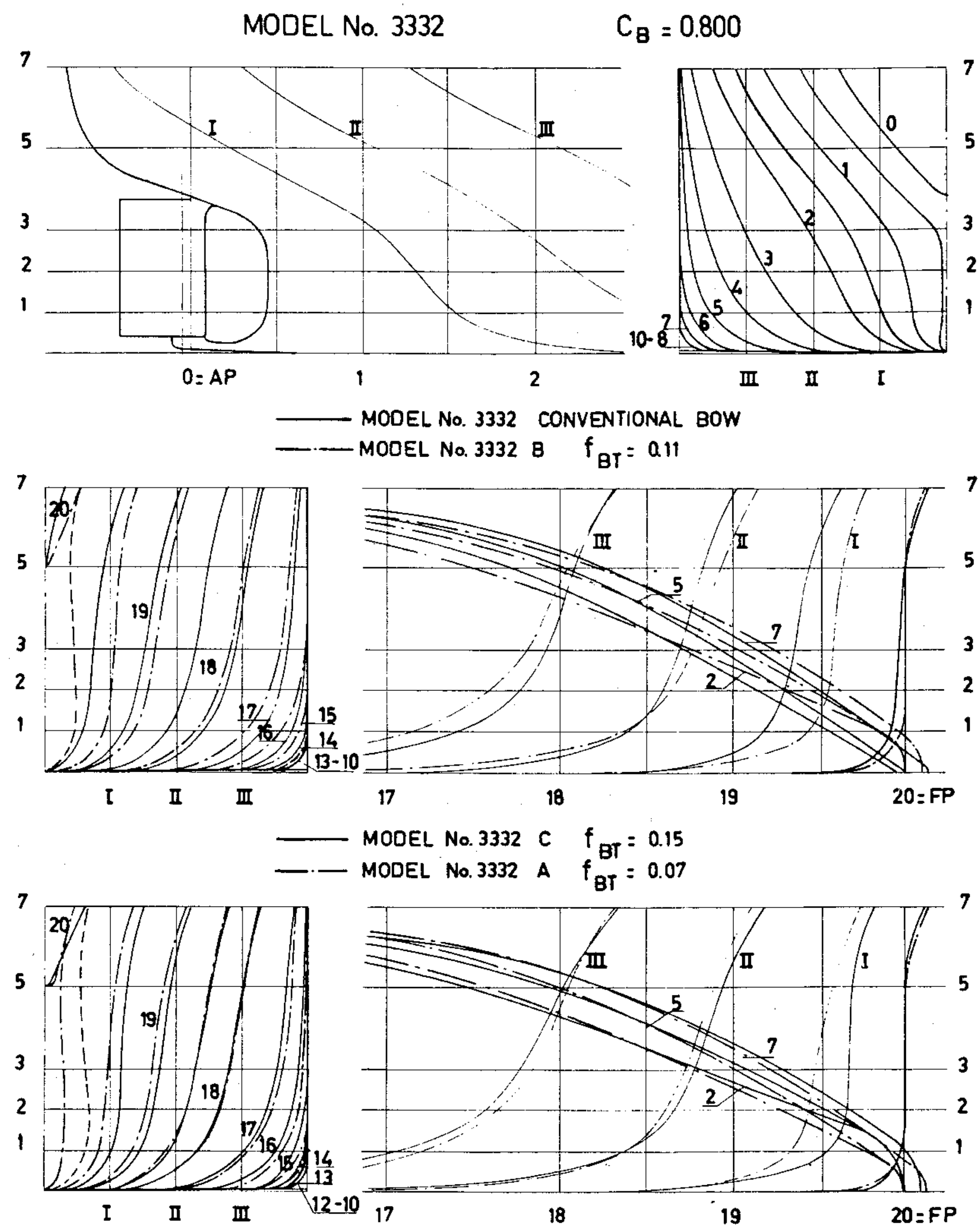

Fig. 5. Body plans 0·800 block models

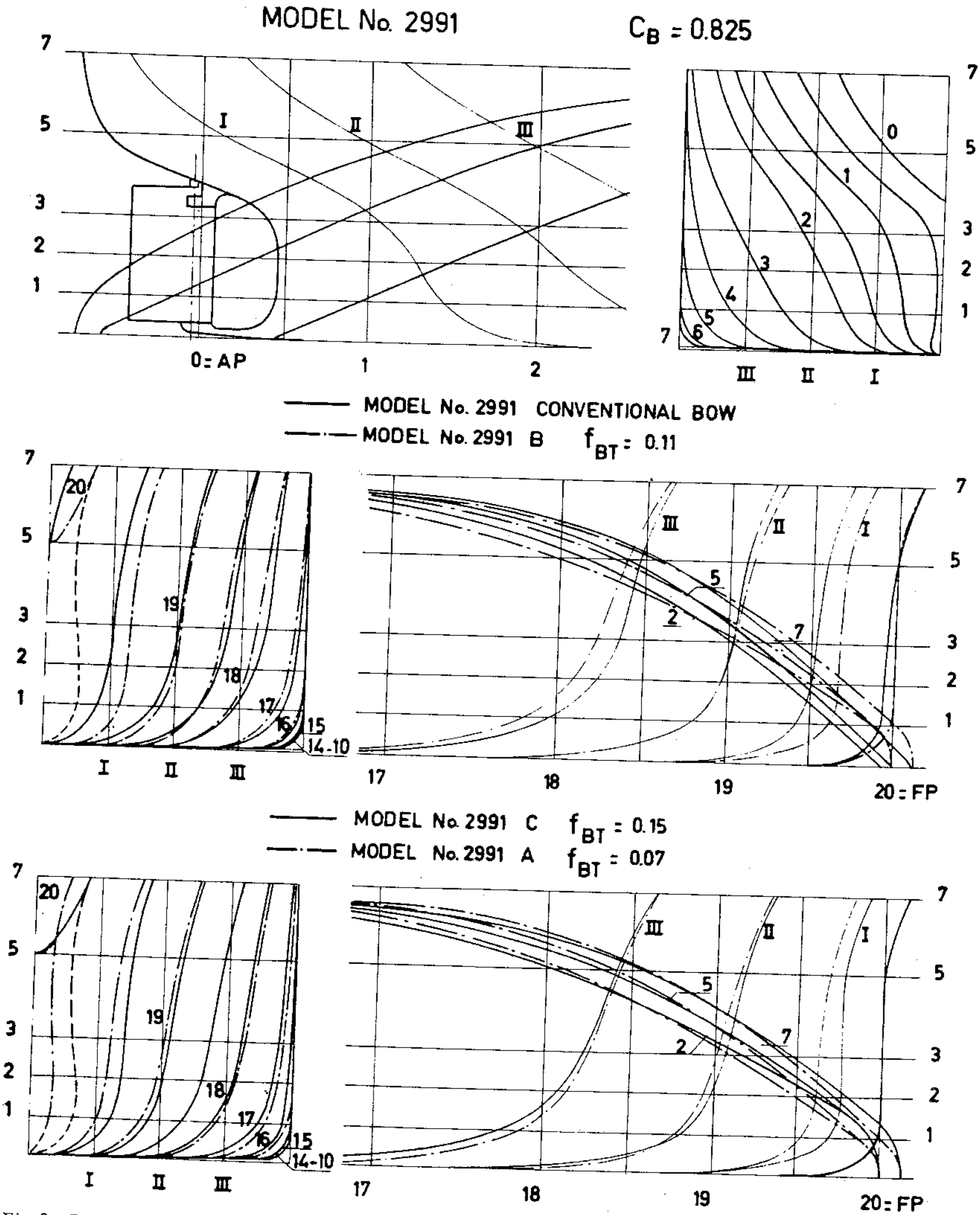

Fig. 6. Body plans 0·825 block models

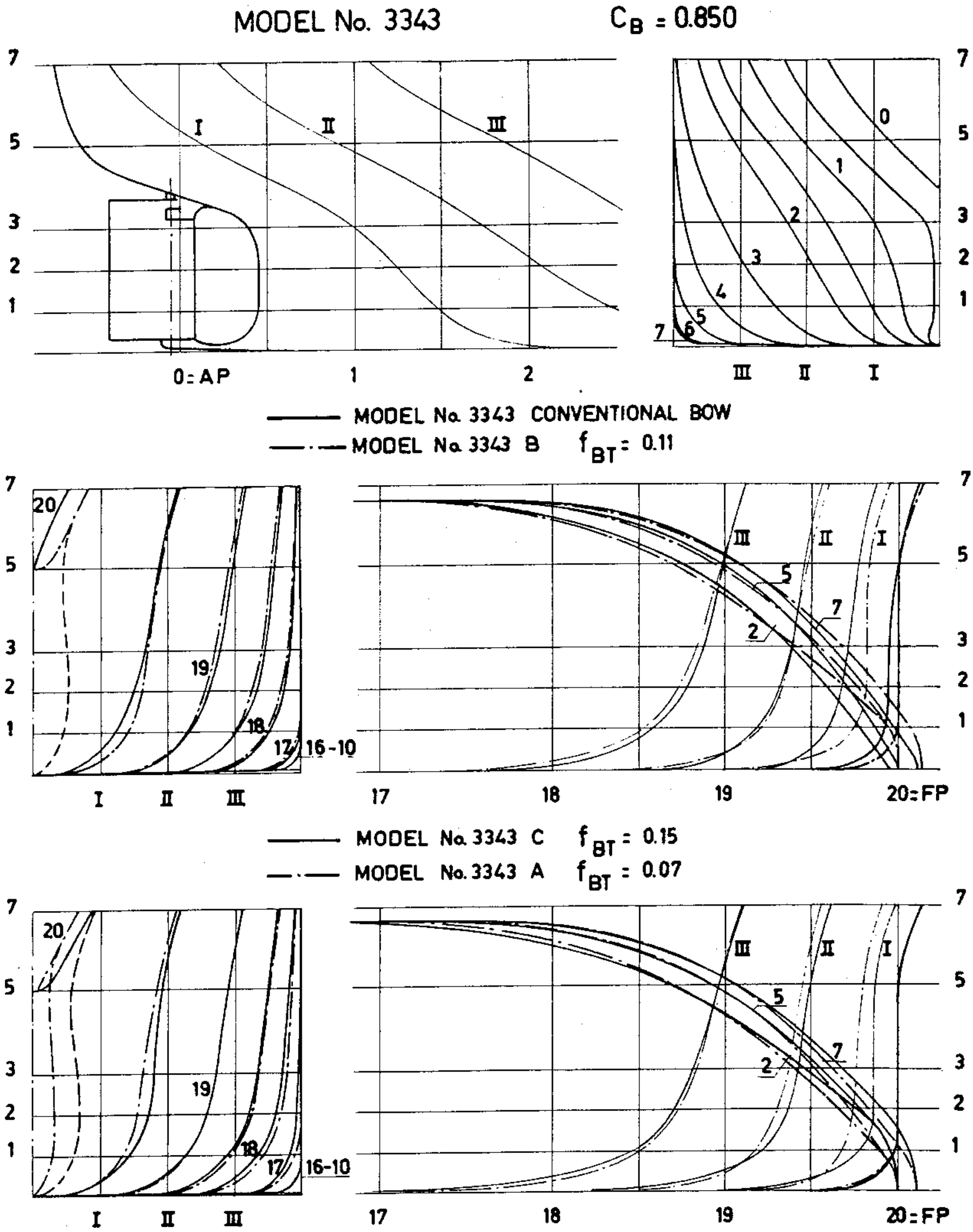

Fig. 7. Body plans 0·850 block models

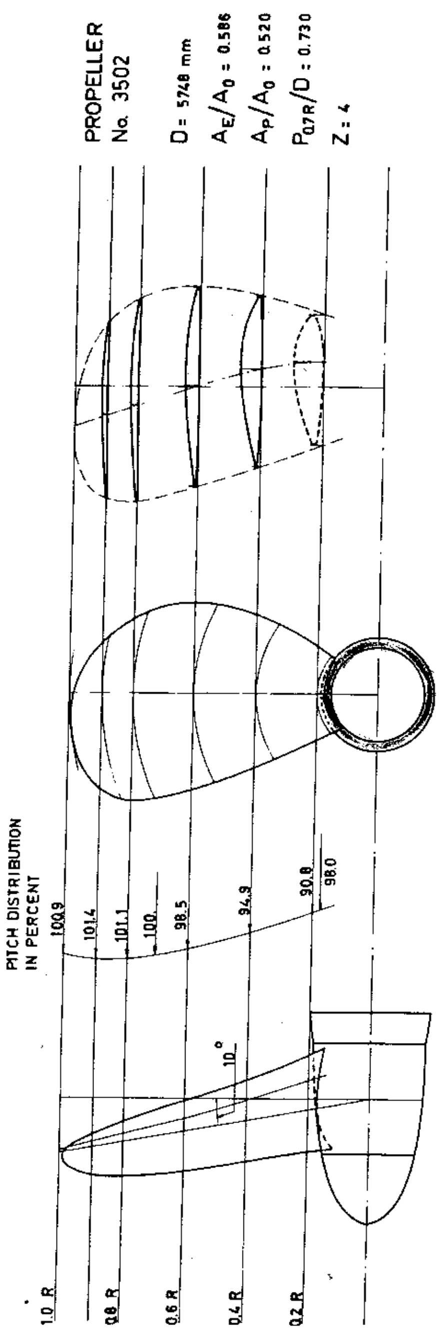

Fig. 8. Stock propeller No. 3502 used for the 600 ft. ships

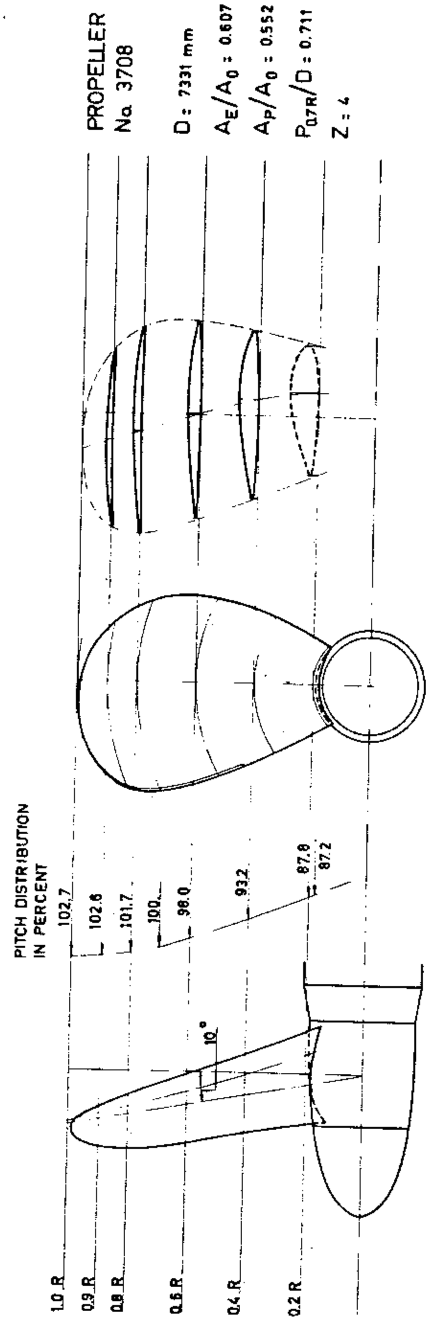

Fig. 9. Stock propeller No. 3708 used for the 800 ft. ships

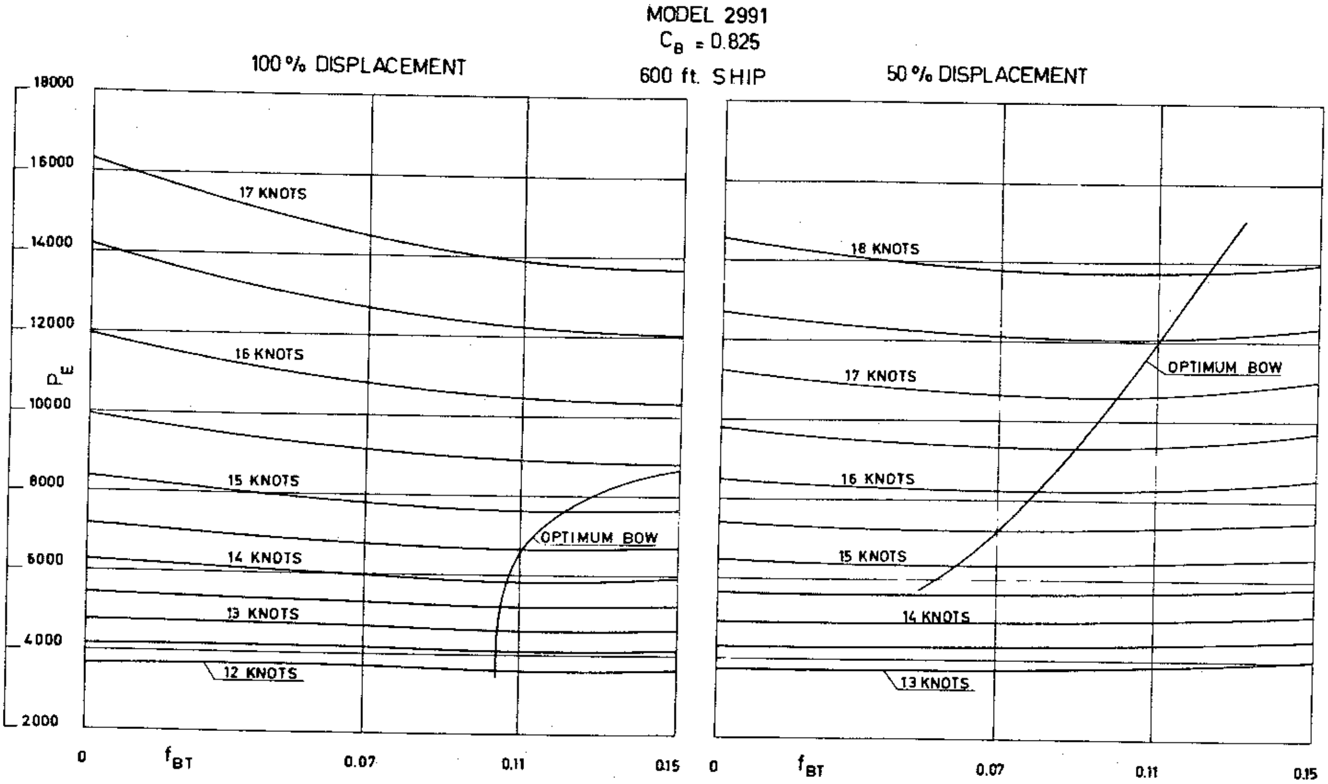

Fig. 11. Effective power as a function of cylindrical bow size for 600 ft. ships of 0·825 block

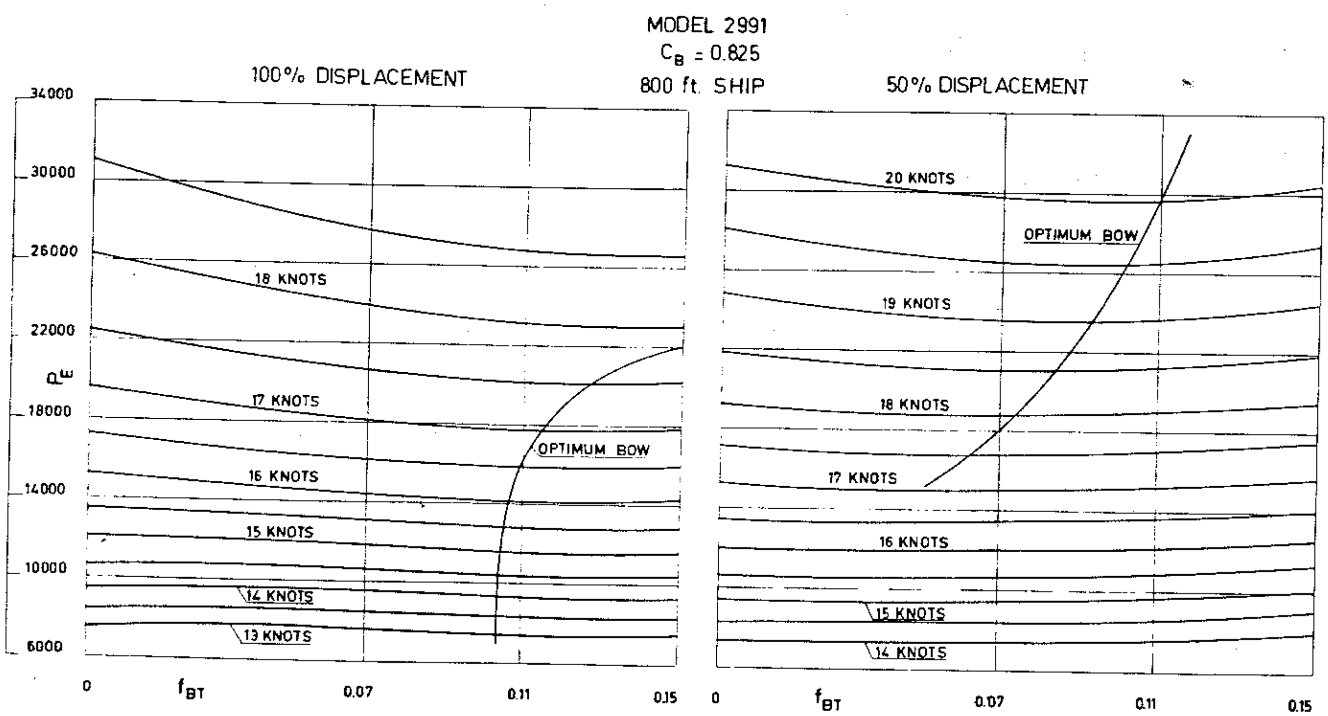

Fig. 12. Effective power as a function of cylindrical bow size for 800 ft. ships of 0·825 block

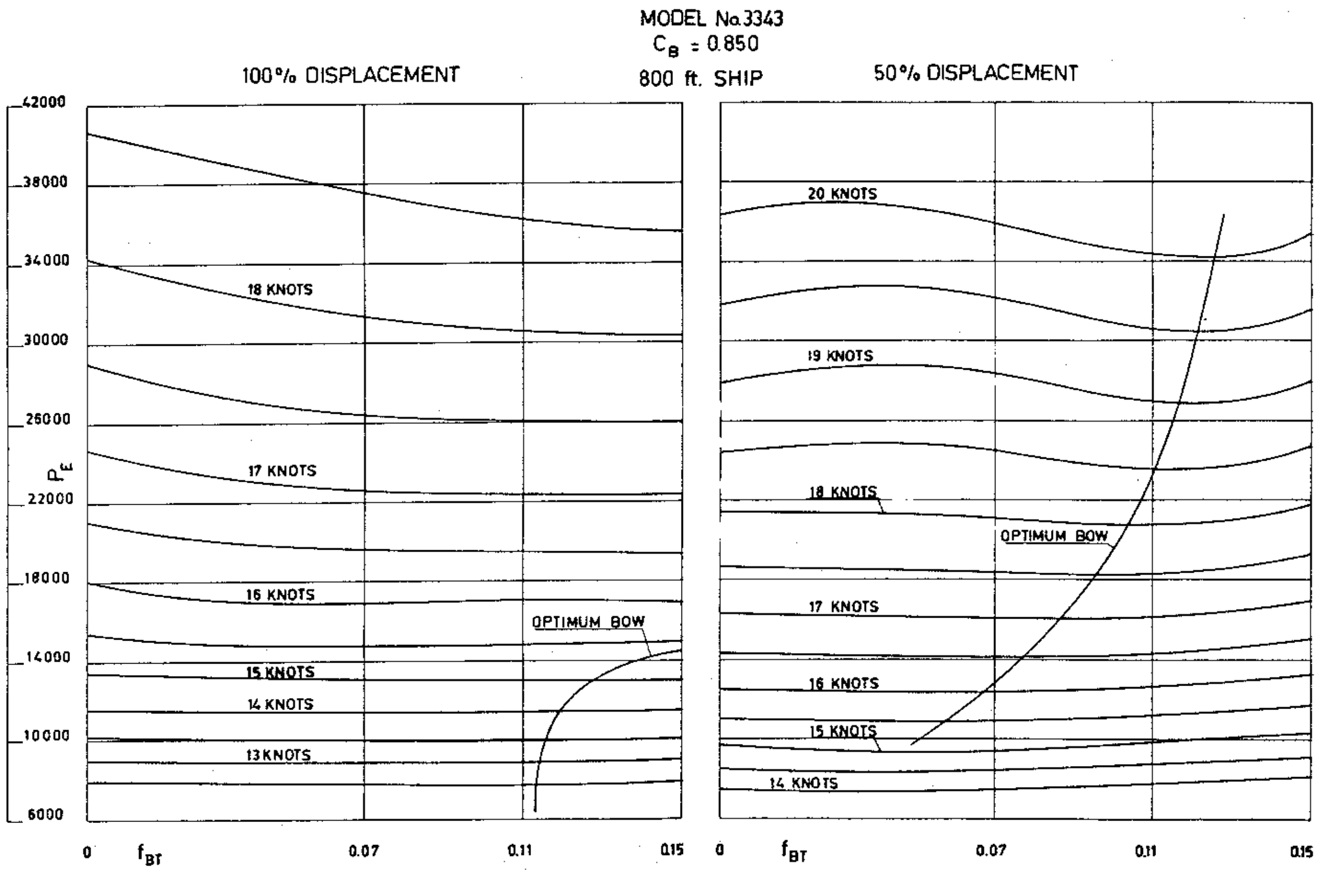

Fig. 13. Effective power as a function of cylindrical bow size for 800 ft. ships of 0·850 block

6. DISCUSSION OF RESULTS

With each model, resistance tests were carried out at 100% and at 50% displacement. Since for each block the displacement and the length of each modification were kept constant, the results can be compared directly on base of P_E as a function of ship speed.

Cross-fairing of the P_E values at constant speeds on base of cylindrical bow size f_{BT} shows the patterns found in Figs. 10, 11, 12 and 13. In these figures the points of minimum P_E at each speed were connected by the curves marked 'optimum bow', indicating for the respective blocks the optimum bow size f_{BT} for each speed.

From these 'optimum bow' curves Figs. 14 and 15 were derived. Fig. 14 shows the optimum bow size as a function of block coefficient on a base of speed-length ratio $V/\sqrt{L}$. From this figure, it follows that the optimum bow size increases with increasing speeds both in the loaded as well as in the ballast condition. Further, it shows that the higher the block coefficient the larger the cylindrical bow should be for a given speed-length ratio. There is a marked difference between the optimum bow size at 100% displacement and that at 50% displacement, the latter being considerably smaller than the former. This can be an unfavourable effect, as will be demonstrated later. Fig. 14 finally indicates that cylindrical bows for 0·800 block ships are only worth consideration at fairly high speed-length ratios, which are well above present operating conditions.

In Fig. 15 the percentages reduction in P_E for 600 to 800 ft. ships with an optimum cylindrical bow are given as a function of speed-length ratio on base of block coefficient. This figure clearly shows that the advantages of a cylindrical bow are most pronounced at 100% displacement. The highest reductions are obtained in the range of block coefficients between 0·825 and 0·850.

The order of magnitude of the reduction in P_E that can be obtained by adopting a cylindrical bow is illustrated for a ship having the following particulars:

LBP = 800 ft.

$C_B = 0{\cdot}825$

Service speed loaded = 16 knots

$V/\sqrt{L} = 0{\cdot}565$

From Fig. 14 it is found that the optimum f_{BT} will be about 0·105 and from Fig. 15 it then follows that the reduction in P_E will be about 7·5% at 100% displacement. For the 50% displacement the service speed will be around 17·5 knots or $V/\sqrt{L} = 0{\cdot}62$, so that the optimum f_{BT} at 50% displacement is about 0·05 and the reduction in P_E only about 1%. Therefore the f_{BT} for this ship will be chosen for optimum performance at 100% displacement, or $f_{BT} = 0{\cdot}105$. With $f_{BT} = 0{\cdot}105$ from Fig. 12 (or from the P_E curves of Fig. 22) it can be deduced that at 50% displacement the reduction in P_E at 17·5 knots will be zero and at lower speeds even a slight increase in P_E is found over the conventional bow.

For the 50% displacement the above findings are in general valid over the whole range of block coefficients for the speed range normally considered for practical use, so that a cylindrical bow may very often have a slight negative effect in ballast especially at lower speeds.

To economise on the costs of the programme, it was not considered necessary to carry out propulsion tests with all model modifications used for the resistance tests and it was decided to use for the propulsion tests only the models coming closest to the optimum performance in resistance in the loaded condition at speeds of 15 to 16 knots. For the 600 ft. ships

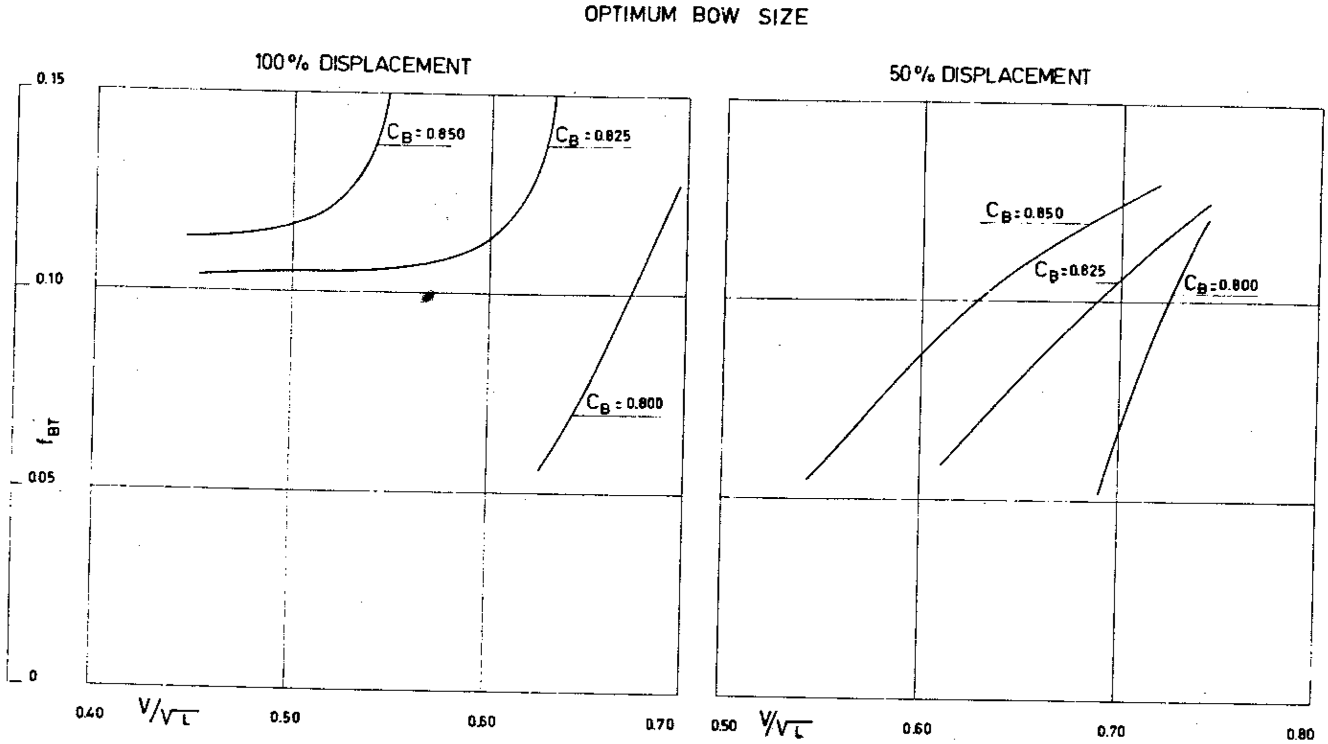

Fig. 14. Optimum bow size as a function of speed-length ratio for different block coefficients

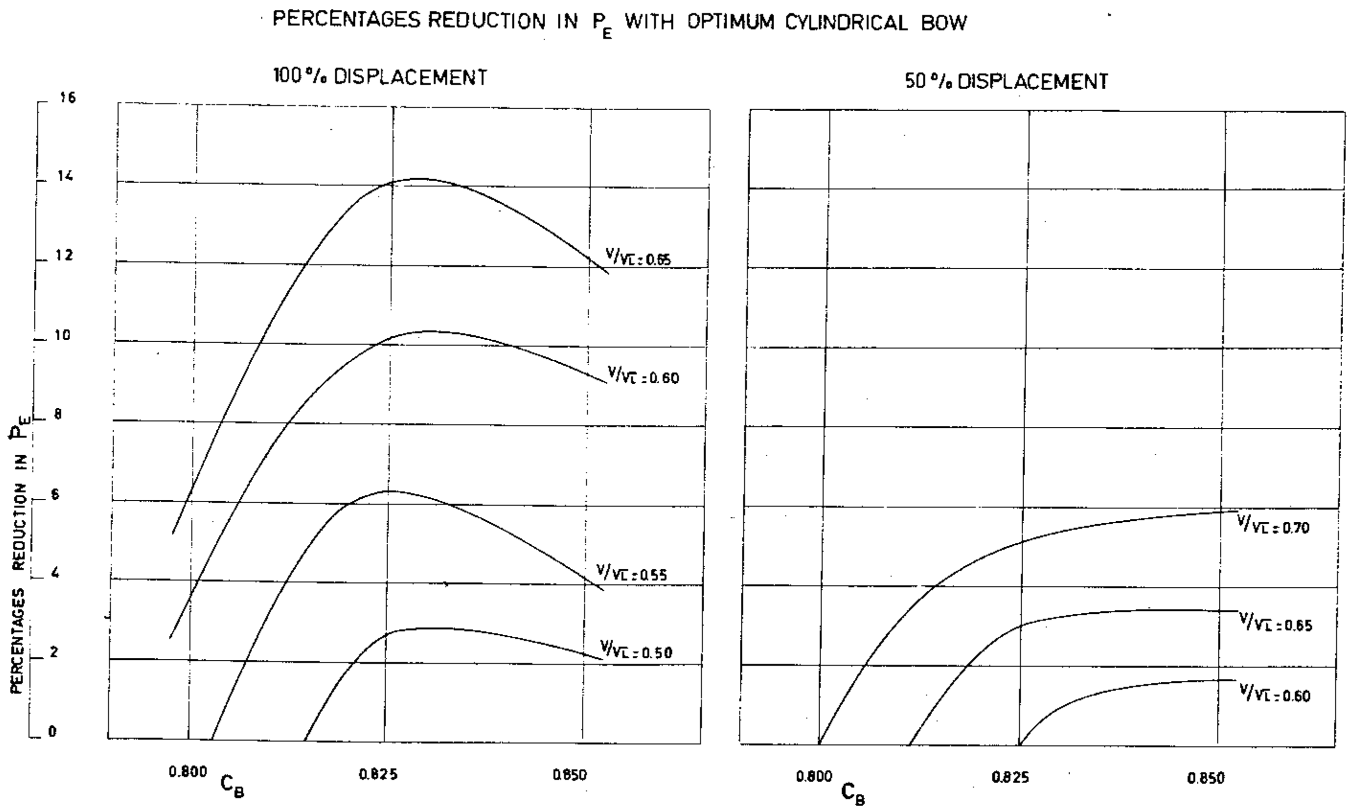

Fig. 15. Percentages reduction in effective power with optimum cylindrical bow