The Effects of Length on the Powering of Large Slender Hull Forms

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SUMMARY

For a constant deadweight, increasing ship length is generally desirable to reduce total resistance and installed power. For large vessels where global loads dominate structural design the weight growth with length increases can be significant. Previous design studies of large slender Ro-Pax and containerships have indicated that the level of this weight increase can be of sufficient magnitude to negate any performance benefit derived from the increased ship length. As the structural weight for these types of vessels can represent 65% of the lightship weight, accurate conceptual design stage weight estimation is critical to both comparative studies between candidate designs and progression through the design cycle.

The results of a parametric study of a 6000t dwt, 40knot Pentamaran Ro-Pax are presented. The main aim of this study has been to investigate the optimum ship length to minimise the installed power demand. Conceptual design methods have been developed for assessing the impact of length driven increases in longitudinal bending moments on structural weight

AUTHORS BIOGRAPHY

James Roy graduated from the Southampton Institute with an honours degree in Yacht & Powercraft Design and then joined Nigel Gee and Associates Ltd (under contract) to undertake a joint research project with academia. Upon completion James joined Nigel Gee and Associates Ltd (full time) in 1997 as Assistant Naval Architect, promoted to Naval Architect in early 1998, and Senior Naval Architect in 2002.

Nigel Gee is Managing Director of Nigel Gee and Associates Ltd, which since 1986 has undertaken designs for over 130 built fast vessels. These vessel designs range from 10m, 30 knot crew boats, to 200m, 25 knots fast container ships. In the field of fast ferries, the company has produced designs for a number of SES and catamaran designs including two 36 knot ferries introduced into service in New York Harbour in 1997, and a 55 knot vessel which entered service in Argentina in January 1999. A number of designs have been produced for fast car and passenger ferries and fast freight vessels. Design is complete for a fast car ferry due for delivery in late 2003 and ten vessels have been constructed to the company's design for a 25 knot fast feeder container vessel. Further designs for fast freight vessels with speeds from 30-60 knots are in progress.

Before founding Nigel Gee and Associates Ltd, he spent 15 years in the fast passenger ferry design and build industry

Nigel Gee is a Fellow of the Royal Institution of Naval Architects and a Member of the Society of Naval Architects and Marine Engineers.

NOMENCLATURE

LWL	Length Waterline (m)
Δ	Displacment (tonnes)
WSA	Wetted surface area (m^2)
R_V	Viscous Resistance (kN)
R_W	Wave-making Resistance (kN)
R_T	Total Resistance (kN)
C_R	Residuary Resistance Coefficient
F_N	Froude Number
$L/\nabla^{1/3}$	Length Displacement Ratio
I_Y	2nd Moment of Area About Y-axis (m^4)
A_X	Cross-sectional Area of Longitudinal Structure (m^2)

1. INTRODUCTION

Length is perhaps the most influential dimension in ship design. It has a significant impact on economics, seakeeping and powering. This paper is concerned with the impact on the latter only.

Previous parametric studies of high speed slender vessels have shown that a longer vessel will require a lower installed power for a constant displacement due to a higher length displacement ratio and lower Froude number.

This paper presents the results of a parametric study undertaken to investigate the effects of vessel size on the powering of a 6000t dwt pentamaran RoPax.

The parametric study was undertaken to establish the likely change in displacement with changes in vessel length and hence determine if larger vessels have a significant power advantage or if the increase in weight is such that the advantage is small.

The main aim of the study was to develop a method to accurately predict changes in structural weight with changes in length at the conceptual design stage. Secondary to this a study of the effects of length on resistance was also undertaken and the two studies combined to determine the effects of length on the performance of slender hull forms, a characteristic of the pentamaran central hull.

2. VESSEL REQUIREMENTS

The primary customer specified requirements for the vessel are as listed below;

- Pentamaran hull-form.
- Medium speed diesels burning HFO.
- Total capacity 2800 lane.m.
- 6000t deadweight.
- 44 hours endurance at 85% MCR.
- 40 knots at 90% MCR, sea-state 2.

3. METHODOLOGY

The methodology for the parametric study is generally as listed below and shown in Figure 1.

- Establish likely platform size requirements.
- Determine required power for a matrix of vessel sizes.
- Investigate weight changes with changes in vessel length.
- Calculate vessel speed vs. length for a fixed installed power.

After production of an initial sketch general arrangement it was found that the minimum practical ship length compatible with the customer requirements was 290m LWL.

In order to investigate the effects of size five platforms were investigated having lengths between 280m and 300m LWL.

The hull-form selected for this base-line vessel is similar to the form developed for a pentamaran containership as described in [1]. The principal dimensions of the basis vessel are given in Table 1.

All vessels in the matrix have a constant length-beam ratio of 14.7. There is a small variation in beam-draught ratio and midship coefficient. The prismatic coefficient of all the vessels vary as the transom area must remain constant to fit the water-jets. There is consequently a small variation in LCB location for each length.

4. EFFECTS OF LENGTH FOR CONSTANT DISPLACEMENT.

Before investigating the effects of length on lightship displacement the effects on resistance were investigated for a broad matrix of vessel lengths and displacements.

Increased length for a constant speed will decrease the Froude number and increase the wetted surface area. Viscous forces will increase and wave-making resistance will fall if displacement is constant. Initially only constant displacement vessels were studied.

Initial displacement estimates were made assuming a deadweight fraction of between 25 and 30%. For a deadweight of 6000t this indicated a displacement in the range of 20000 – 24000 tonnes. This was extended to 25000 tonnes to ensure that a broad enough range of length displacement ratios were investigated. In total 15 design variants were analysed.

The matrix of design variants is presented in Table 2. Whilst in real terms the change in length between the shortest and the longest vessel is approximately 7% in Froude number terms this does not seem particularly significant with F_N ranging from 0.393 to 0.379 for 40 knots.

The change in wetted surface area between the shortest and longest vessels is approximately 5% The length displacement values range from 9.66 for the shortest heaviest vessel to 11.14 for the longest lightest vessel.

The ratio of viscous to wave making drag at this F_N is approximately 70:30 so reductions in wave making can be harder to achieve than at higher speeds where it represents a larger part of the whole. However within the F_N range already discussed the vessel is operating near hump and larger reductions in C_R are easier to achieve with increased length.

All drag predictions have been made utilising extensive model test data from the aforementioned hull-form. Power requirements presented include all aero and hydrodynamic components, i.e. they do not just relate to the central hull.

The range of installed power requirements at 40 knots is presented in Figure 2. It can be seen that this varies between 86.3MW for the highest length displacement ratio and 121MW for the lowest. This range is also plotted against length displacement ratio in Figure 3. This shows that there is a 13% drop in installed power demand for a 7% increase in length displacement ratio for the 25000t vessels and 11% for the 20000t vessels.

Analysis of the central hull drag is presented in Figure 4 which shows resistance vs. LWL for 40 knots. An increase in viscous drag of 4% occurs over the range of lengths tested whilst the wave making drag falls by 40%.

A preliminary machinery selection was made consisting of 4 x Pielstick 20V PC4.2B medium speed engines coupled to a quad waterjet installation. At the time of conducting the study this engine was the only medium speed diesel to be suitable for use with water-jets. Each engine has a rated power of 26.5MW at 100% MCR.

The predicted speed of each design variant at 100% MCR is shown in Figure 5. It can be seen that for a change in length of 7% an increase in speed of approximately 1.1 knot results. This is equivalent to a decrease in installed power demand of between 11 and 13% for the 20000 and 25000t vessels respectively at 40knots.

5. EFFECTS OF LENGTH ON STEEL & LIGHTSHIP WEIGHT.

Having investigated the effects of length for a range of vessels weights the next task was to develop a conceptual design weight prediction method to try to account accurately for changes in vessel length.

The methodology developed assumed that the longitudinal scantlings are mainly driven by longitudinal bending loads and not by local design loads.

Figure 6 presents the methodology adopted;

1. Determine the rule & design hull girder bending moment.
2. Calculate the required midship section modulus.
3. Assume the ratio of I_Y/A_X for the midship section is the same as for a suitable basis vessel.
4. Calculate the required midship cross-sectional area of longitudinal material to resist the longitudinal bending moment.
5. Make an addition for transverse structure.
6. Calculate the total mass rate per metre of ship length for the midship section.
7. Apply this to a weight distribution, integrate and hence obtain the structural weight.
8. Make additions for superstructure, sponsons, foundations and miscellaneous structure.

The procedure outlined above relies heavily on the suitability of the basis vessel;

Firstly the ratio of I_Y/A_X – for the most efficient section we want the highest value of I_Y for the lowest possible area A_X. For this ratio it is critical that the general proportions and structural arrangement of the basis vessel are similar to that of the proposed design as it is not only the amount of material but also its distribution that determines its ability to resist bending loads.

Secondly the method relies on knowing the ratio of transverse structure / longitudinal structure. It is therefore important that the basis vessel has approximately the same frame spacing as the proposed design. On a per frame basis a value of 40% was used for transverse material. Subsequent studies have shown this figure to be a bit high and 30% has been found to be more suitable for this type of vessel.

In order to convert the predicted midship mass rate into a total steel weight a longitudinal distribution must also be known for the basis vessel.

The Authors have established that a design vertical bending moment based on the calculated rule vertical bending moment +20% gives similar results to the design vertical bending moment achieved when using an LWL/20 wave. Model tests have shown this approach to be sensible [2].

Determining the correct magnitude of the hull girder moment at the conceptual design stage can be fairly critical as it has a large influence on the structural weight, which in turn represents a large proportion of the ships weight.

The procedure outlined was applied to the range of vessel lengths under consideration and the resulting steel weights found were in the range of 11880t – 15335t; a 29% increase for a 7% increase in length. Predicted structural weights are shown in Figure 7.

Having determined the effect of length on the structural weight a semi-detailed weight estimate for each ship length was developed. The predicted lightship and full load weights are presented in Table 3.

It can be seen that the range of predicted lightship weight is between approximately 18500t and 22250t corresponding to full load displacements of between approximately 24500t and 28250t. Table 3 shows that the increase in length displacement ratio between the shortest and longest ship is only about 2% which compares with a 7% increase if the displacement is constant. This would indicate that the growth in structural weight with increase in length has been fairly significant and may negate any performance benefit offered by the longer vessels.

It can be seen that the structural weight fraction varies between 65-70% whilst the deadweight fraction is slightly lower than originally anticipated and is in the range 21-25%.

It is often useful during conceptual design stages where a basis vessel is not available to have a more coarse weight estimation tool to predict changes in structural weight with changes is length. As a rule of thumb the Authors have previous assumed that for smaller craft, the displacement will typically vary with the square root of the ratio of change in length. The results of this study indicate that for these larger vessels this will under predict and that the relationship can be better expressed by the square of the ratio of the change in length.

6. EFFECTS OF LENGTH FOR VARIABLE DISPLACMENT.

Having calculated displacements for each length under consideration it was possible to make performance predictions to compare against the previously presented constant displacement data.

Figure 8 shows the predicted speed vs. length for both the constant displacement 20000t & 25000t ships and for the ships with calculated displacements. All predictions are for an installed power of 4 x 26.4MW at 100% MCR. It can be seen that the speed variation with length is so small as to effectively be negligible.

It is therefore evident that the weight increase with changes in vessel length are of sufficient magnitude to negate any performance benefit offered from the increased length.

7. SELECTED VESSEL CHARACTERISTICS AND FURTHER WORK

Following selection of the 290m LWL vessel as the candidate vessel size further work has been undertaken to verify the predicted ship weight.

A number of sections have been designed along the length using the DnV Nauticus system in order to better define the structural mass rate. These calculations formed part of a semi-detailed weight estimate for the vessels structural weight and the results show good agreement with the initial prediction. The weight predicted by the conceptual design methodology previously outlined was shown to be less than 3% different from that predicted by the semi-detailed method.

8. CONCLUSIONS

The results of a parametric study have been presented for a 6000t dwt 290m LWL RoPax. The effects of vessel length on resistance and weight have investigated.

For the designs studied it has been shown that, for a constant displacement, a 7% increase in LWL will lead to an increase in speed of approximately 1 knot for a constant power or a decrease in installed power demand of approximately 12% at 40 knots.

Methods for predicting the variation in weight with length have been presented. It has been predicted that a 29% increase in structural weight results for a 7% increase in length.

This increase in weight has been shown to be of significant magnitude to negate any performance benefit from increasing the LWL.

9. REFERENCES

[1] DUDSON, E., GEE, N., 2001. 'Optimisation of the Seakeeping and Performance of a 40 Knot Pentamaran Container Vessel.', FAST 2001.

[2] DUDSON, E., RAMBECH, H., 2001. 'Determination of Wave Bending Loads on a 40 knot, Long Slender Open Topped Containership Through Model Tests and Hydrodynamic Calculations With Particular Reference to The Effects of Hull Flexibility On Fatigue Life. ', FAST 2001.

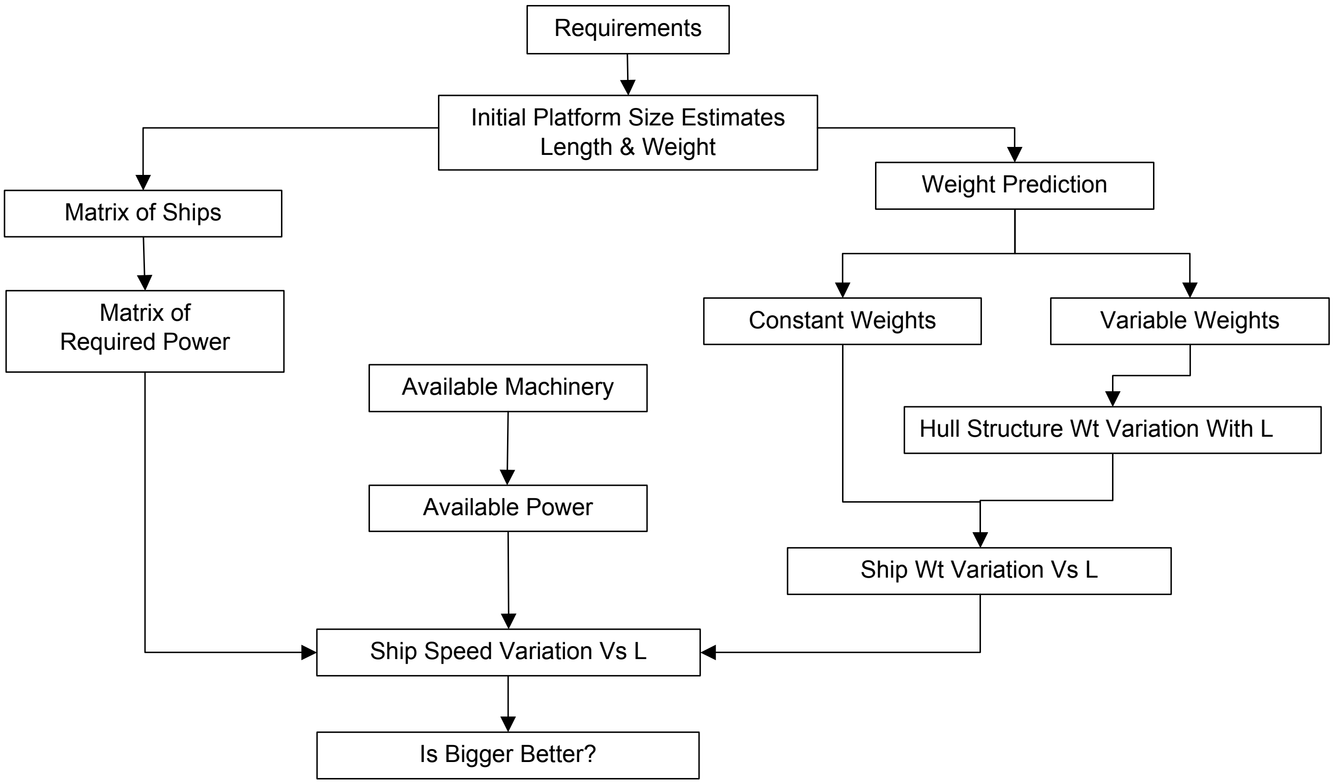
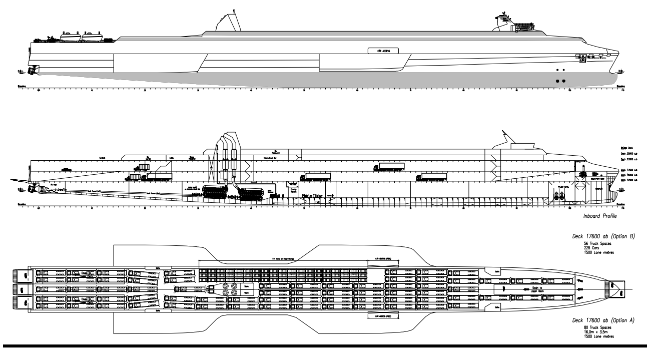


Figure 1 – Parametric Study Methodology



LOA	300.0 m
LWL	290.0 m
BWL	19.7 m
Bmax	45.0 m
Tmax	9.0 m

Table 1 – Basis Vessel Characteristics

Short & Light — Long & Light

Δ [t] / L [m]	280	285	290	295	300
	F_N = 0.393	F_N = 0.389	F_N = 0.386	F_N = 0.382	F_N = 0.379
20000	BWL = 19.05	BWL = 19.39	BWL = 19.73	BWL = 20.07	BWL = 20.41
	Tk = 7.48	Tk = 7.22	Tk = 6.97	Tk = 6.74	Tk = 6.52
	$L/\nabla^{1/3}$ = 10.40	$L/\nabla^{1/3}$ = 10.59	$L/\nabla^{1/3}$ = 10.77	$L/\nabla^{1/3}$ = 10.96	$L/\nabla^{1/3}$ = 11.14
	WSA = 6453	WSA = 6354	WSA = 6622	WSA = 6712	WSA = 6806
22500	BWL = 19.05	BWL = 19.39	BWL = 19.73	BWL = 20.07	BWL = 20.41
	Tk = 8.42	Tk = 8.12	Tk = 7.85	Tk = 7.58	Tk = 7.33
	$L/\nabla^{1/3}$ = 10.00	$L/\nabla^{1/3}$ = 10.18	$L/\nabla^{1/3}$ = 10.36	$L/\nabla^{1/3}$ = 10.54	$L/\nabla^{1/3}$ = 10.71
	WSA = 6803	WSA = 6880	WSA = 6961	WSA = 7045	WSA = 7133
25000	BWL = 19.05	BWL = 19.39	BWL = 19.73	BWL = 20.07	BWL = 20.41
	Tk = 9.35	Tk = 9.03	Tk = 8.72	Tk = 8.43	Tk = 8.15
	$L/\nabla^{1/3}$ = 9.66	$L/\nabla^{1/3}$ = 9.83	$L/\nabla^{1/3}$ = 10.00	$L/\nabla^{1/3}$ = 10.17	$L/\nabla^{1/3}$ = 10.34
	WSA = 7153	WSA = 7223	WSA = 7298	WSA = 7377	WSA = 7461

Short & Heavy — Long & Heavy

Table 2 – Matrix Of Design Variants

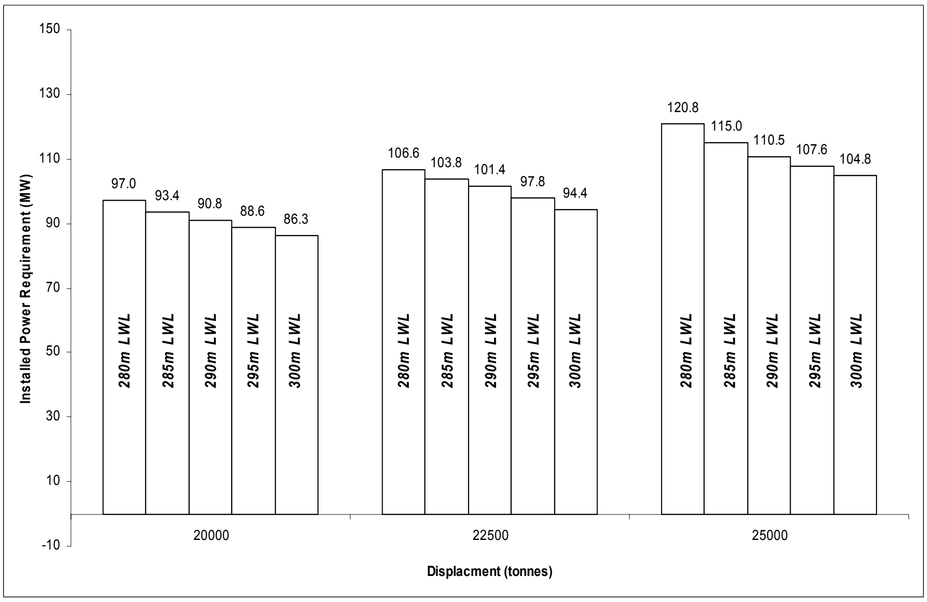


Figure 2 – Installed Power Demand Vs Displacement

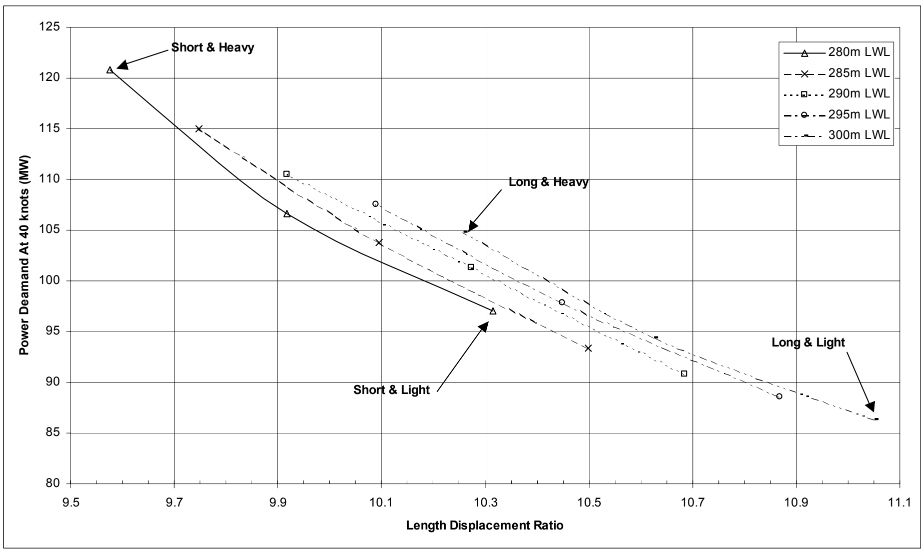


Figure 3 – Installed Power Demand Vs Length Displacement Ratio

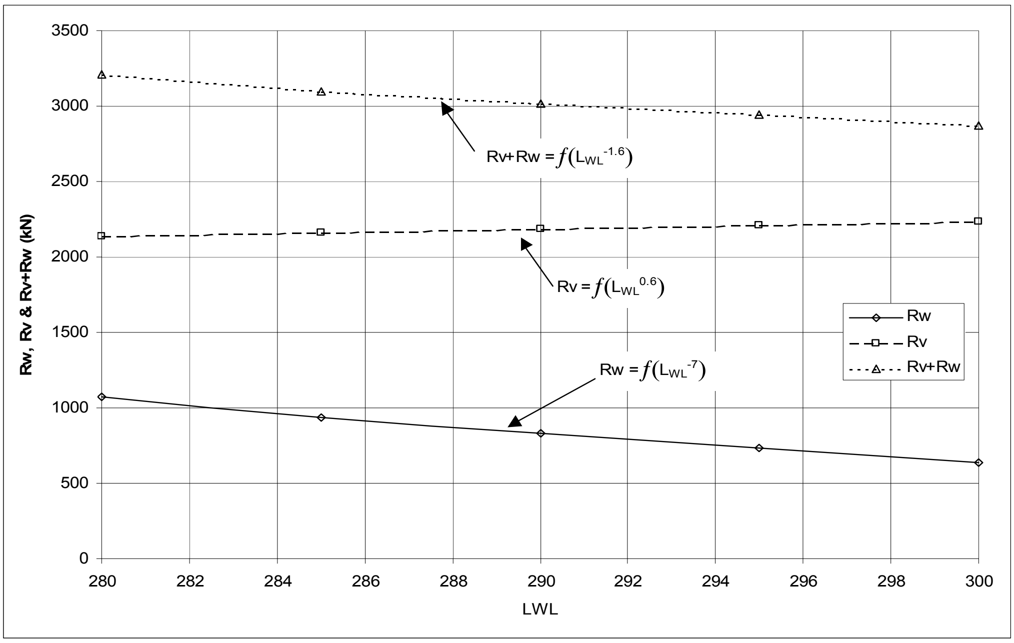


Figure 4 – Central Hull Drag Components at 40 knots Vs Length Waterline

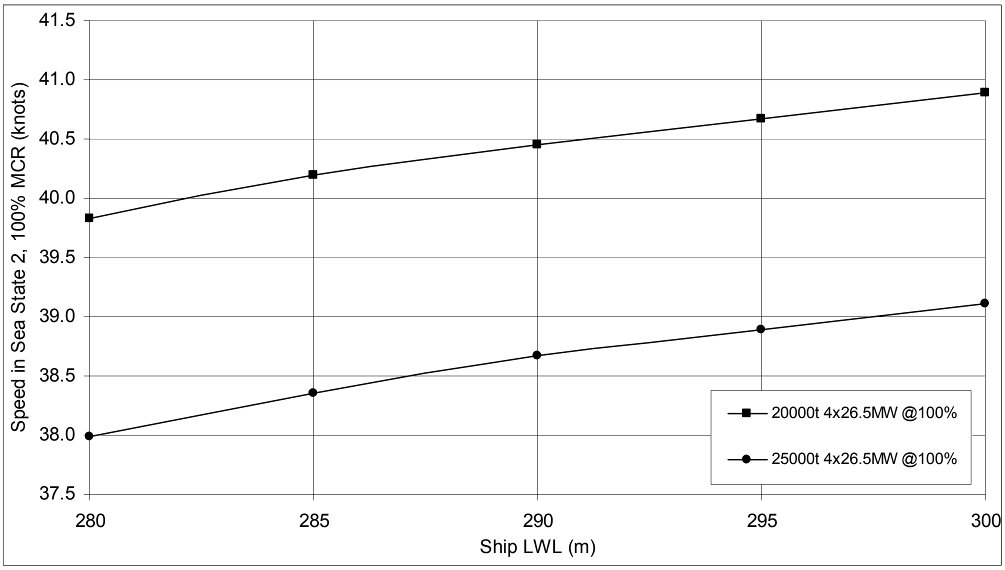


Figure 5 – Predicted Speed Vs Length Waterline

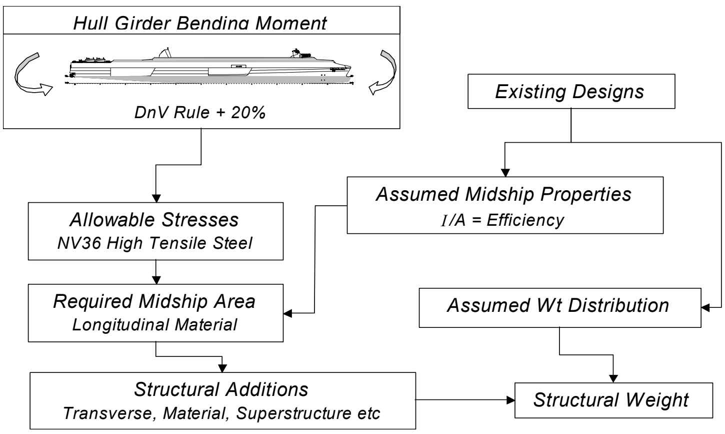


Figure 6 – Structural Weight Prediction Methodology

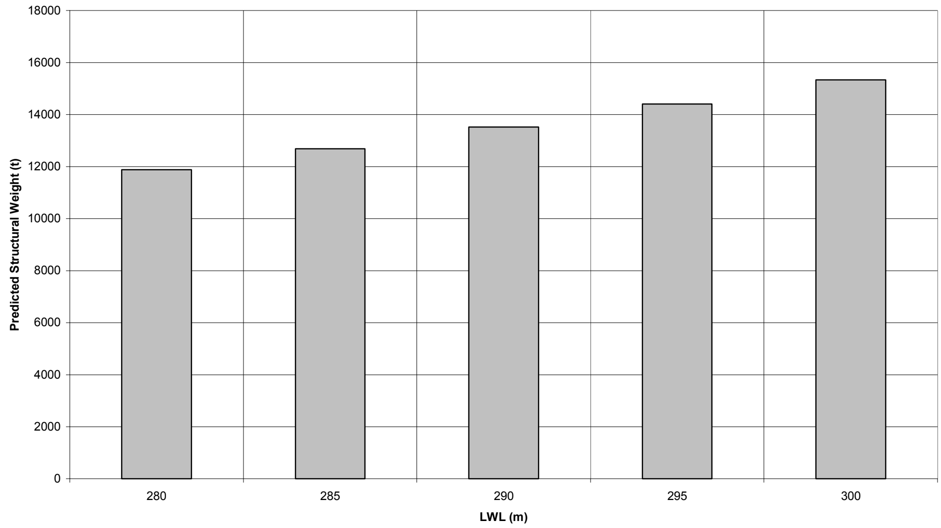


Figure 7 – Structural Weight Vs. LWL

		Non Full Breadth Vehicle Deck				
	Ship Length LWL [m]	***280***	***285***	***290***	***295***	***300***
Group No	**Weight Group**	**Weight [tonnes]**	**Weight [tonnes]**	**Weight [tonnes]**	**Weight [tonnes]**	**Weight [tonnes]**
	Lightship inc margin	18452	19333	20259	21232	22251
	Deadweight	6000	6000	6000	6000	6000
	Total Ship Weight	**24452**	**25333**	**26259**	**27232**	**28251**
	Structure as % Lightship	*64.4%*	*65.6%*	*66.8%*	*67.9%*	*68.9%*
	Displacement Length Ratio	9.73	9.78	9.84	9.89	9.93
	Deadweight Fraction	24.54%	23.68%	22.85%	22.03%	21.24%

Table 3 – Predicted Ship Weights

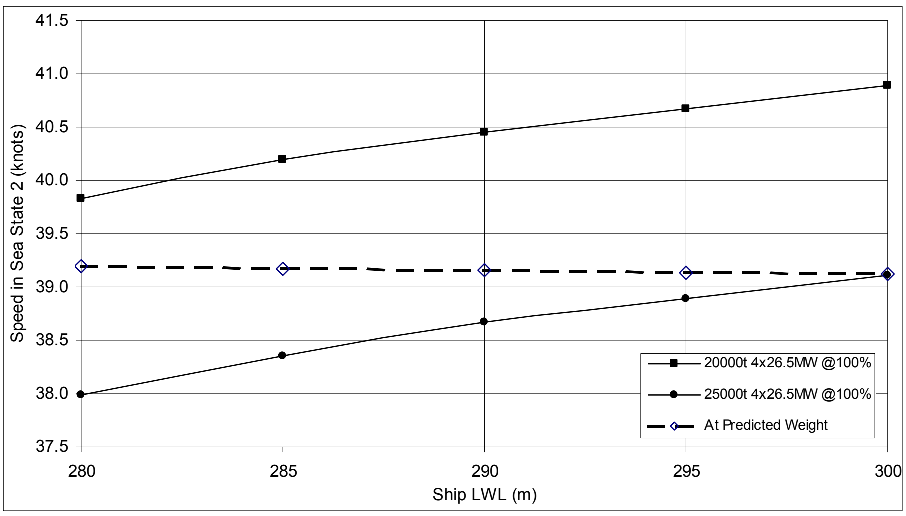


Figure 8 – Speed Vs. LWL For Constant Power