NUMERICAL AND EXPERIMENTAL STUDY OF WAVE RESISTANCE FOR TRIMARAN HULL FORMS

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SUMMARY

This paper investigates a systematic series of high-speed trimaran hull forms. Trimaran vessels are currently of interest for many new high speed ship projects due to the high levels of hydrodynamic efficiency that can be achieved compared to mono-hull and catamaran hull forms. The core of the study involves determining the wave resistance for each model in the series in conjunction with varying longitudinal side hull locations. The methods employed to determine the wave resistance of each trimaran model comprise of computational fluid dynamics (CFD) suite SHIPFLOW, theoretical slender body theory and experimental investigations.

The trimaran hull forms are transom stern high-speed displacement hull form vessels possessing moderately high L/B ratios. A wide variety of data was acquired due to the parametric space and various side hull locations. As a result, these data shows clear trend from which accurate assessments could be made. Results presented in this paper offer considerable promise and it is envisaged that further work need to be completed before further understanding can be gained.

1. INTRODUCTION

The development of the trimaran hull form originates from the general increase in slenderness ratio of a mono-hull vessel, to increase the speed of a vessel with corresponding reduction in required power. Investigations into the resistance of trimarans have proven that such hull forms have lower resistance at high speeds when compared with catamarans and mono-hulls of similar displacement. Other advantages of a trimaran over more conventional hulls are an increase in deck space, an increase in stability and passenger comfort. An example of a low resistance high speed trimaran is the *Ilian Voyager*. A 21 m trimaran built to demonstrate the efficiency of the powered trimaran hull form. The *Ilian Voyager* holds the record for the fastest circumnavigation of the British Isles without refueling.

Having three separate hulls on a trimaran creates a higher total wetted surface area compared to a similar mono-hull or catamaran. This higher wetted surface area increases the frictional resistance therefore creating comparatively higher resistance at low speeds. At high speeds the wave making resistance is relatively low due to the use of slender hulls. This is based on the widely accepted assumption that as the vessel becomes finer the wave making resistance decreases. Wave making resistance is also affected by the interference between the separate hull wakes. Optimum placement of the side hulls will result in a wake interference that reduces this resistance. The combination of a slender hull form and optimum placement of side hulls can result in a much lower resistance at high speeds when compared to both catamaran and mono-hull designs.

This paper constitutes an analysis of a systematic series of trimaran hull forms with the effects of various side hull locations on wave resistance. Comparisons are drawn between the methods, which include application of computational fluid dynamics, the slender body theory and experimental work to predict the wave resistance.

The systematic series of trimaran hull forms under analysis was based on the AMECRC systematic series of high-speed transom stern displacement hull-forms, where the outriggers are scaled versions of the main hull. The trimaran series were simulated using CFD suite SHIPFLOW and using the Slender Body Method (SBM). The data generated was then compared against experimental data. The experimental data obtained by Kiso (2001) was further complimented with additional tests to validate the original data for one trimaran model.

2. BACKGROUND

Pattison and Zhang (1995) have presented resistance characteristics of trimarans when compared against similar vessels of mono-hull or catamaran configurations.

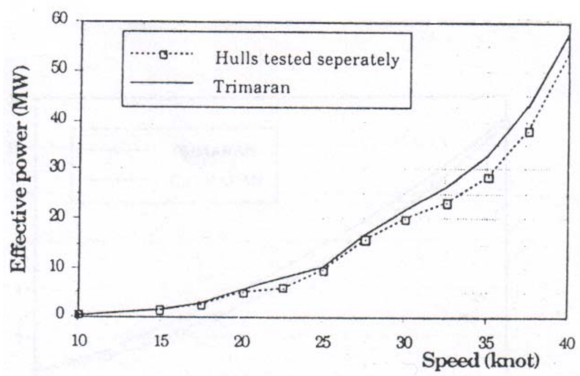


Figure 1: Influence of viscous interference on effective power, Pattison and Zhang(1995)

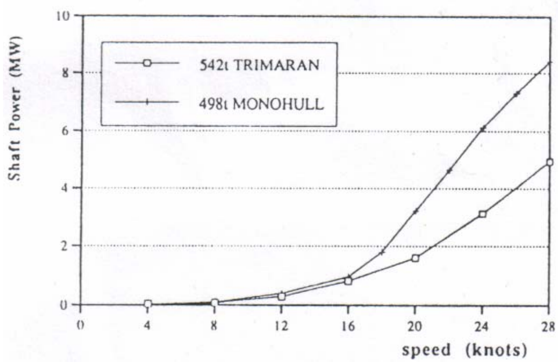


Figure 3: Shaft Power for mono-hull and trimaran offshore patrol vessels, Pattison and Zhang(1995)

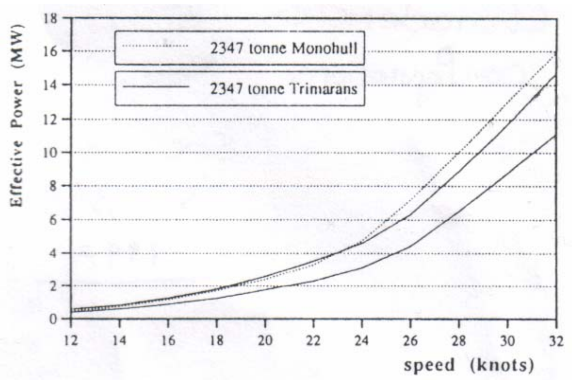


Figure 2: The effective power of a trimaran and mono-hull of the same displacement, Pattison and Zhang(1995)

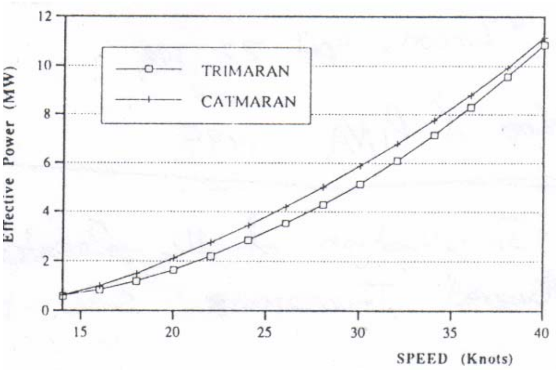


Figure 4: Effective power for a 700 tonne trimaran and catamaran, Pattison and Zhang (1995)

Figure 1 depicts the resistance of a trimaran when towed separately and as a whole, which clearly shows that interference plays as advantageous role in reducing resistance and hence effective power. Figure 2 is a comparison between a slender mono-hull frigate against a trimaran of the same displacement. The upper curve of the trimaran is at 5 % side hull displacement whereas the lower curve is the prediction for a slender monohull and suggests the lower limit for trimaran resistance. Figure 3 compares the significant difference in power between trimaran and mono-hull offshore patrol vessels of similar displacement. This comparison shows the trimaran to have lower resistance at all speeds. Figure 4 is the comparison of a geometrically similar catamaran and trimaran where the resistance is determined by use of Taylor series.

The paper by Ackers et al (1997) investigates the resistance characteristics of trimaran hull form configurations. Primarily the key areas of focus involve the interference effects between main and side hull(s). The variables for the experiments include side hull configuration, as illustrated in Figure 5, side hull locations, side hull angle of attack, ranging from -2º to 4º, and side hull displacement, corresponding to 5.8%, 8.4%, 10.9% and 13.6% total displacement of the trimaran.

In order to calculate the interference effects of each configuration both the non-interference residuary resistance and the actual residuary resistance were found. The non-interference residuary resistance was obtained by testing each hull separately over a range of speeds. Equation 1 was used to find the non-interference residuary resistance of the whole trimaran, where ratio of the wetted surfaces is employed.

$$C_{RNI} = C_{RMH}\left(\frac{S_{MH}}{S_T}\right) + C_{RSH}\left(\frac{2 \times S_{SH}}{S_T}\right) \quad (1)$$

As the side hull are smaller than the main hull the corresponding Reynolds number is much smaller and as a result, the frictional resistance must be calculated for both sides and the main hulls as shown in Equation 2.

$$C_{FT} = C_{FMH}\left(\frac{S_{MH}}{S_T}\right) + C_{FSH}\left(\frac{2 \times S_{SH}}{S_T}\right) \tag{2}$$

From this the residuary resistance, C_R, can be obtained by subtracting C_{FT} from C_F. The relative interference effects of each side hull configuration can be obtained by subtracting C_{RNI} from C_R, this value is represented as a percentage, see Equation 3. Thus, to determine the increase in residuary resistance of trimaran configurations, multiply the non-interference residuary resistance by the percent interference.

$$\Delta C_R = C_R - C_{RNI} \tag{3}$$

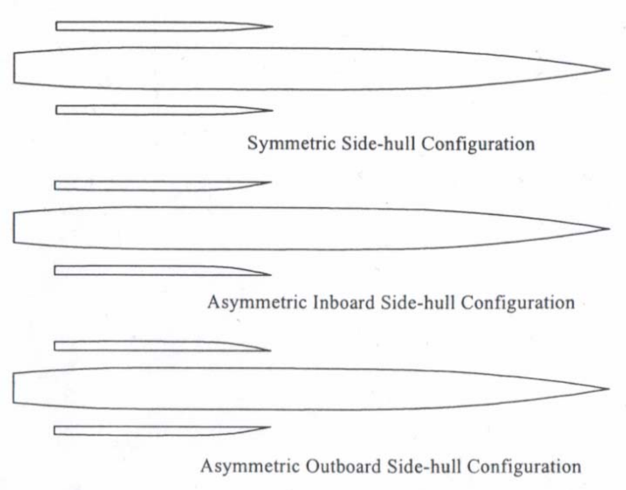


Figure 5: Model side hull configurations (Ackers et al (1997))

According to Ackers et al (1997), as a result of the investigation into the resistance characteristics of trimaran hull forms, the following conclusions can be drawn:

- A well designed trimaran could out perform a mono-hull of the same displacement at high speeds, as a 15% or greater powering advantage can be expected.

- Contour plot prove to be a useful design tool as they clearly show interference effects of both transverse and longitudinal side hull locations.

- From the data obtained within the test matrix range, it was generally found that displacement had little impact on interference.

- In relation to side hull symmetry, the interference significantly depends on the inboard face of the side hull. Generally it was found a side hull with symmetry minimizes baseline resistance.

The paper by Suzuki and Ikehata (1993) focuses on determining the optimum position of trimaran outriggers in order to minimise wave resistance. The study of the trimaran configuration involves representing the hull form mathematically, with cosine waterlines and parabolic frame lines, which then enable the resistance to be calculated mathematically. Furthermore, the study has been validated by obtaining data through model testing. For this study the configuration shown in Figures 6 and 7 were adopted by the authors.For symmetrical hull forms at the fore and aft, the main hull is mathematically represented by Equation 4 and the side hull by Equation 5.

$$y = \pm b \cos\frac{\pi}{2}x\left\{1 - \left(\frac{z}{t}\right)^4\right\} \tag{4}$$

$$y \pm y_0 = \pm b_0 \cos\frac{\pi}{2\lambda_0}(x - x_0)\left\{1 - \left(\frac{z}{t_0}\right)^4\right\} \tag{5}$$

Suzuki and Ikehata (1993) state that in the present examples, the side hull are scaled down versions of the main hull, with a scale factor of 1/3. As a result of this the displacement of the side hulls becomes 1/27 of the main hull. This displacement is much lower than the optimum value found by Seo et al (1973), which states that by satisfying the conditions below in Equation 6, maximum wave cancellation can be expected. As a result of this the side hulls required are unpractical as they are too large.

$$\nabla_0 / \nabla = 0.6 \sim 0.7$$

$$x_0 = 2\pi F_n^2 \tag{6}$$

$$y_0 = 0.4$$

Model experiments were carried in order to validate the hydrodynamic effects of the side hulls. The models were developed to allow numerous side hull configurations, providing a large database of information regarding wave, trim and sinkage analysis. The model names and side hull locations are shown in Table 1.

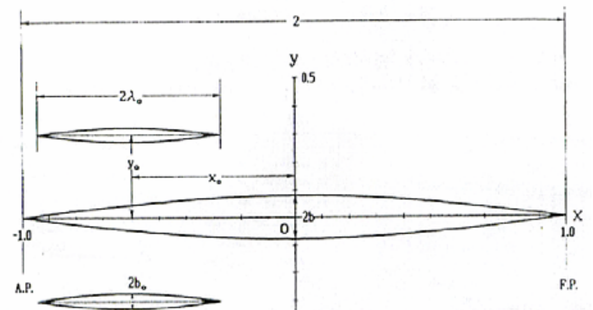


Figure 6: Trimaran Coordinate System, Suzuki & Ikehata (1993)

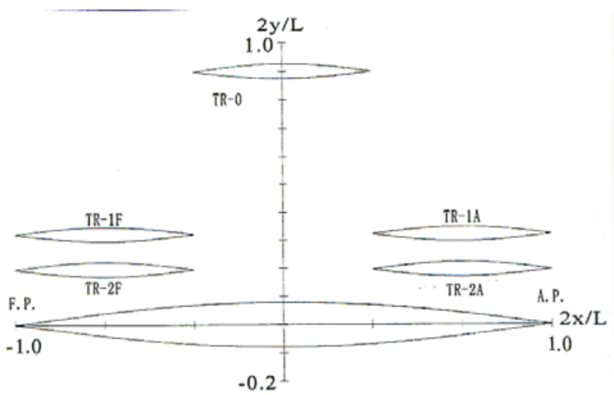


Figure 7: Model Testing Configuration, Suzuki & Ikehata (1993)

As a result of the investigation by Suzuki & Ikehata (1993) the following conclusions were established:

- Through linear superposition of amplitude functions for the main hull and side hulls the wave resistance can be minimized by optimizing the locations of the side hulls.
- Generally the residuary resistance coefficients of a trimaran are larger then the coefficients of each hull, treated as a mono-hull. However, through optimization of side hull positions at set Froude numbers, the trimaran hull form possesses lower residuary resistance coefficients.
- Changes of trim and sinkage caused by side hull locations can change the residuary resistance, as the side hull located at the stern of the main hull possesses low residuary resistance then when located at the bow.
- In order to lower the wave resistance caused by wave making interaction between the main and side hulls, optimization of side hull locations need to be analyzed.

Table 1: Model Names and Position of Side Hulls, Suzuki & Ikehata (1993)

Model Name	Design Fn	x_0	y_0
MH-0	-	without side hulls	
TR-0	-	0.0000	+-0.9000
TR-1 A	0.4	-0.6667	+-0.3220
TR-1 F		0.6667	
TR-2 A	0.5	-0.6667	+-0.1950
TR-2 F		0.6667	

The paper by Suzuki et al (1997) focuses on using the Rankine source panel method in order to numerically dictate the wave making characteristics of the trimaran hull form. This method is adopted in order to account for the hydrodynamic lifting forces on the side hull due to interference. The study is based around previous work conducted by Suzuki and Ikehata (1993), where the numerically predicted resistance coefficients are compared to results obtained through physical experiments. The numerical analysis for the study involved taking the ordinary Rankine source method and modifying it to allow for the lifting force, by applying the vortex lattice method. This method allows for a further optimized side hull configuration in relation to wave resistance. Suzuki et al (1997) concluded by stating that using the Rankine source panel method, the effects from hydrodynamic lift are accounted for. The studies undertaken prove to be quite similar to the physical experimental data, in relation to wave resistance coefficients. The importance of analyzing wave patterns caused by hull interaction for a trimaran is vital in order to dictate an accurate tool for predicting and investigating the optimum positions for the hulls.

The paper by Yeung et al (2004) emphasizes the importance and consideration of wave drag for high-speed vessels operating at Fn 0.5 and above. The study involves analyzing and expanding on the formulation for Michell's resistance for single hull forms, where the hull is considered thin, i.e., low L/B ratio. Not only is frictional resistance analyzed but the resistance caused by the interference between the hulls. From the thin-ship theory, the expression for total wave resistance is shown in Equation 7, where the second sum considers wave interference given the number of hulls.

$$R_{wT} = \sum_{i=1}^{n} R_{wi} \div \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} R_{wi\Leftrightarrow j} \qquad (7)$$

Specialized quadrature techniques are used to provide internet based 'resistance evaluator' that dictates effects of stagger and separation, in order to optimize the volumetric distribution of a trimaran. The predictions are validated through experimental data for various multi-hull configurations. Yeung et al (2004) examine and optimize the trimaran hull form using the computer based program, TRIRES. As a result, given a specific design, the optimal volumetric distribution and stagger can be determined.

The paper by Brizzolara et al. (2005) investigates the hydrodynamic behavior and inference effects for different trimaran hull form configurations, particularly fast trimaran ferries. The primary objective is to obtain the optimum hull form configuration; this is undertaken with the help of CFD tools together with modulus for automatic geometry generation and algorithms. An in depth analysis was conducted involving systematically varied configurations to the trimaran as well as numerical calculations regarding wave making resistance.

The trimaran hull design was based on a general hull form for current fast transportation vessel, possessing a round bilge main and side hulls. The models were developed with a scale of 1/50.The parameters for both the actual hull and model are given in Table 2. The test matrix for the trimaran configurations are illustrated in Table 3, where stagger (ST) values dictate the longitudinal positions of the side hulls in regards to transom location. The clearance (CL) values represent the transverse locations of the side hulls in regards to hull symmetry. The models were tested for Fn 0.35 to 0.60.

Table 2: Vessel Principal Characteristics, Brizzolara et al (2005)

	Full Scale		Model	
	Main	**Side**	**Main**	**Side**
Scale Factor	1.00	0.33	50.00	50.00
L_{WL} (m)	105.6	35.19	2.11	0.70
T (m)	4.42	0.69	0.09	0.01
B (m)	8.83	1.65	0.18	0.03
Δ (t, kg)	2318.	14.37	18.12	0.11
V_{MAX} (kn)	36.00	36.00		
C_B	0.55	0.35	0.55	0.35
L/B	11.96	21.50	11.96	21.50
B/T	2.00	2.39	2.00	2.39

Table 3: Towing Test Matrix, Brizzolara et al (2005)

	ST / L_{WL}			
CL /	0%	10%	20%	30%
9.90%	P11	P12	P13	P14
11.10%	P21	P22	P23	P24
13.40%	P31	P32	P33	P34
15.00%	P41	P42	P34	P44

The CFD method incorporated used a linear Rankine sources panel method to find the solution of the free surface potential flow. Brizzolara et al. (2005) states that to correctly predict wave resistance of high speed hulls, the dynamic attitude of the hull must be modeled; the numerical method presented in the paper satisfactorily achieves this. The automatic optimizer method is based on an algorithm coupled with a CFD solver and an intermediary program that generates the panel mesh for each hull configuration. Results of the optimizer are shown in Figure 8.

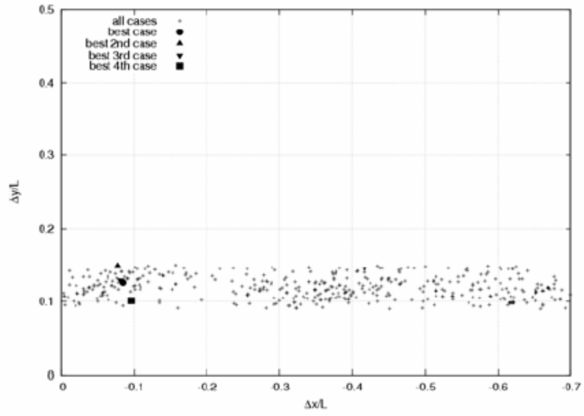


Figure 8: Plot of the evaluated individuals by optimisation algorithm, Brizzolara et al. (2005)

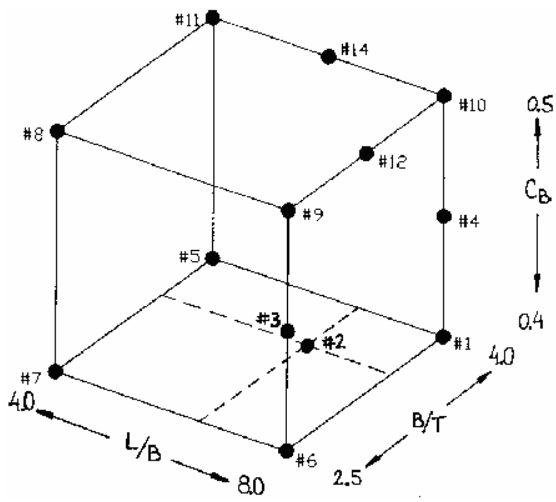


Figure 9: AMECRC Systematic Series 'Parameter Space, Bojovic (1995)

As a result of the paper an automatic optimization method has been developed in relation to side hull locations for given Fn. Effects of trim and sinkages have been discussed due to their critical effects to the wave resistance. Further investigations involve considering volumetric distribution and relative volume and dimension of side hulls.

3. HULL FORM

The trimaran hull forms under investigation have been developed from the systematic series developed by the Australian Maritime Engineering Cooperative Research Centre (AMECRC) as illustrated in Figure 9. Seven of the fourteen models were selected for computation as trimaran models, since some of the models were too wide to be considered as trimaran models. The scale factor of the side hulls are based on a previously constructed trimaran configuration involving Model 9 of the AMECRC series. The parameter space of the series is shown in Table 4.

Table 4: AMECRC Systematic Series parameters [Bojovic (1995)]

Parameters	**L/B**	**B/T**	**C_B**	**LCB aft of midship**	**C_P**	**C_{WL}**	**A_T/A_X**	**B_T/B_X**
Minimum	4	2.5	0.4	5.40%	0.626	0.796	0.296	0.964
Maximum	8	4	0.5					

Table 5: Constant Particulars

	Symbol	**Value**		**Symbol**	**Value**
L_{WL} (main)	L_1	1.6	B_{WL} (side)	B_2	0.092
L_{WL} (side)	L_2	0.7344	Block Coefficient	C_B	0.50
Scale (side)	λ	0.459	Prismatic Coefficient	C_P	0.626
B_{WL} (main)	B_1	0.2	Waterplane Coefficient	C_{WL}	0.796

The configuration of Model 9 as a trimaran model is shown in Table 5 Figure 10 and Figure 11.

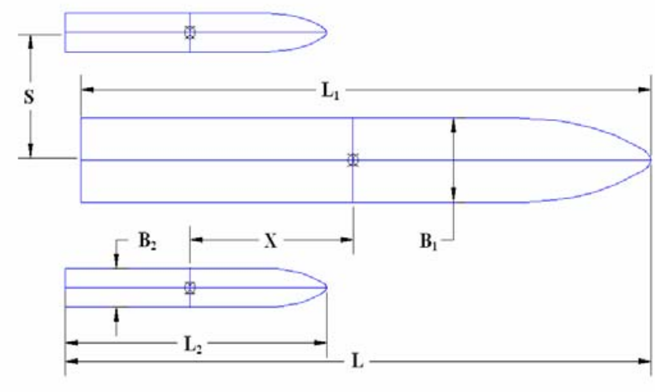


Figure 10: Typical Configuration of Trimaran model

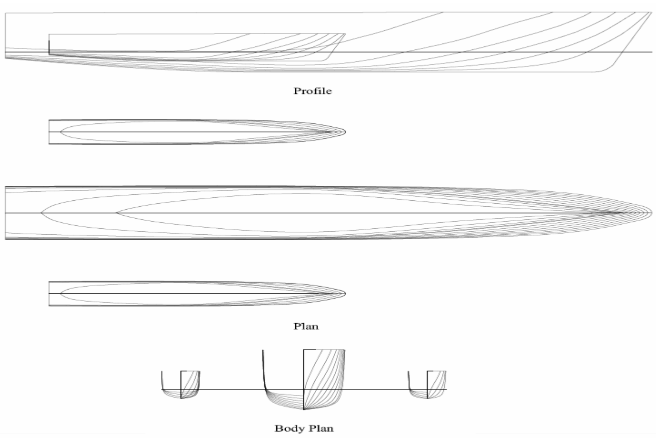


Figure 11: Configuration of Model 9 as a Trimaran

4. TEST MATRIX

The trimaran model particulars and test matrix are a major factor in the project; the development involved setting a constant transverse side hull location with different longitudinal locations, as shown in Tables 6 and 7. The speed increments employed for each method vary depending on complexity and computational time.

The variables were selected to represent practical trimaran configurations in order to produce a clear trend in the data obtained. As stated by Suzuki and Ikehata (1993) and Benjamin et al (1997), in high-speed applications the side hulls of the trimaran should be placed towards the aft end with regards to the main hull in order to reduce resistance.

Furthermore the stagger ratio (X/L_1) refers to the distance between the mid-ship of each individual hull, as resembling the longitudinal stagger employed by Suzuki and Ikehata (1993). From previous studies, such as Suzuki (1993), the maximum wave resistance coefficient is generally found to be around Fn 0.5 to 0.6, thus the corresponding speed range was selected to cover this range of Froude numbers.

Table 6: Variable Particulars

		Symbol	Values						
Trimaran Model		**TRI**	**1**	**3**	**4**	**6**	**9**	**10**	**12**
Displacement	[kg]	Δ_1	6.33	11.372	7.148	10.103	12.781	7.989	9.829
Displacement	[kg]	Δ_2	0.612	1.1	0.691	0.977	1.236	0.773	0.951
Displacement	[kg]	Δ	7.554	13.571	8.531	12.057	15.253	9.534	11.73
Draft (main)	[m]	D_1	0.05	0.08	0.05	0.08	0.08	0.05	0.062
Draft (side)	[m]	D_2	0.023	0.037	0.023	0.037	0.037	0.023	0.028
Block Coefficient		C_B	0.396	0.447	0.477	0.395	0.5	0.5	0.497
Beam-Draft Ratio		B/T	4	2.5	4	2.5	2.5	4	3.25

Table 7: Test Conditions for TRI-9

Condition	**Fn**	**Long. Location**		**Trans. Location**	
		X/L_1	(m)	S/L_1	(m)
1	0.3 to 1	-0.2	-0.32	0.2	0.32
2	0.3 to 1	-0.3	-0.48	0.2	0.32
3	0.3 to 1	-0.4	-0.64	0.2	0.32

5. COMPUTATIONAL FLUID DYNAMICS

Computational Fluid Dynamics (CFD) software, SHIPFLOW, has been employed here to determine the wave resistance of trimaran hull forms. The wave resistance coefficients are calculated by using the potential flow, boundary layer and Navier-Stokes methods implemented in SHIPFLOW. By splitting the flow into three regions an efficient approximation of the flow equations may be made and complete flow calculation may be accomplished in a few hours. The zoning configuration adopted by SHIPFLOW is represented in Figure 11.

- ZONE 1 – This is the potential flow region, where the flow is calculated using a higher order panel method, also known as the Rankin source method. The fluid flow is represented as continuous streamlines beginning forward of the bow and finishing at the stern, where the flow is assumed to be steady, incompressible and irrotational.

- ZONE 2 – This is the boundary layer region, where the flow is obtained using a 3D momentum integral method. The method begins at the stagnation point(s) at the bow and continues along the surface of the hull, incorporating flow in the corresponding laminar, laminar to turbulent transition and turbulent regions.

- ZONE 3 – The Reynolds-Average Navier-Stokes method is incorporated in this zone to calculate the energy and adverse resistance at the stern region of the hull. The majority of the wave resistance is obtained using this method, as the interference between the viscous boundary layers for the region is calculated. Due to the complexity of this method, a significant amount of computational time is consumed.

The SHIPFLOW modules executed for the analysis included XMESH and XPAN. The XMESH program is initially run to verify the panelization of the body and free-surface; it is then executed in conjunction with the XPAN module. XPAN is based on a boundary element surface singularity panel process, using Rankine sources, in order to solve the potential flow around three dimensional bodies, and consequently the wave resistance coefficients.

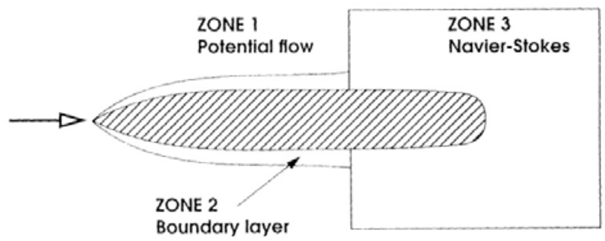


Figure 11: Schematic Diagram of SHIPFLOW Calculation Zone

6. SLENDER BODY METHOD (SBM)

The wave resistance coefficients were also calculated for the series of trimaran hulls using an analytical process known as the Slender Body Method (SBM). The process entails calculating the energy in the free surface wave pattern produced by a slender vessel and thus the vessel's wave resistance. Wave patterns can be visually represented for both mono and multi hull forms. The SBM is based on Michell's Integral where a linear first order approach is employed to predict the wave resistance. The fundamentals behind the theory involve obtaining the source strength as a function of the longitudinal deviation of the hull, where a line of sources is distributed along the centre plane. The wave resistance is acquired by integrating the forward and aft components of the pressure normal to the body over the surface of the hull; where the apparent pressure around the body that causes disturbance in the free surface is dictated from the flow around the body.

The original integral developed by Michell (1898) to predict the wave resistance of vessels is shown below:

$$R = \frac{4\rho v^4}{\pi g} \int_1^{\infty} \left(I^2 + J^2\right) \frac{\lambda^2 d\lambda}{\sqrt{\lambda^2 - 1}}, \qquad (8)$$

where

$$\lambda = mv^2 / g,$$

$$I = \int_0^{\infty} \int_{-}^{\infty} f(x,z) e^{-\lambda^2 gz / v^2} \cos \lambda gx / v^2 \, dxdz \qquad (9)$$

$$J = \int_0^{\infty} \int_{-}^{\infty} f(x,z) e^{-\lambda^2 gz / v^2} \sin \lambda gx / v^2 \, dxdz \qquad (10)$$

The SBM employed is predominantly based on the studies undertaken by Tuck, Scullen, and Lazauskas (2002). The study emphasized on efficiently and accurately computing flow fields and wave patterns both near and far of moving high-speed vessels, including conventional hulls, multi-hulls and submarines. As stated by Tuck, Scullen and Lazauskas (2002), precise wave resistance results as well as visual wave patterns with fine detail can be obtained rapidly on inexpensive computers. The calculations incorporated use distributions of Havelock sources to inherently generate flow by assuming an inviscid incompressible fluid flowing irrotationally. The Havelock sources represent point sources within the free surface. As stated by Couser, Wellicome and Molland (1998), with regards to the SBM, each individual hull must have a relatively high slenderness ratio (i.e. length: beam) in order to obtain accurate results.

7. EXPERIMENTAL TESTING

The tank testing was conducted at the Australian Maritime College Ship Hydrodynamics Centre (AMCSHC). The tank has a manned carriage containing a two post dynamometer for measuring resistance together with various instrumental and computer amenities for automatic data acquisition. The tank testing data used in this study was originally conducted by Kiso (2001) on the TRI-9 model. To ensure accuracy in the original data by Kiso (2001), one of the trimaran configurations was replicated and tested over the range of Froude numbers. Analogous results were attained in comparison to the original data, as shown in Figure 12. Thus the original data was used throughout this study.

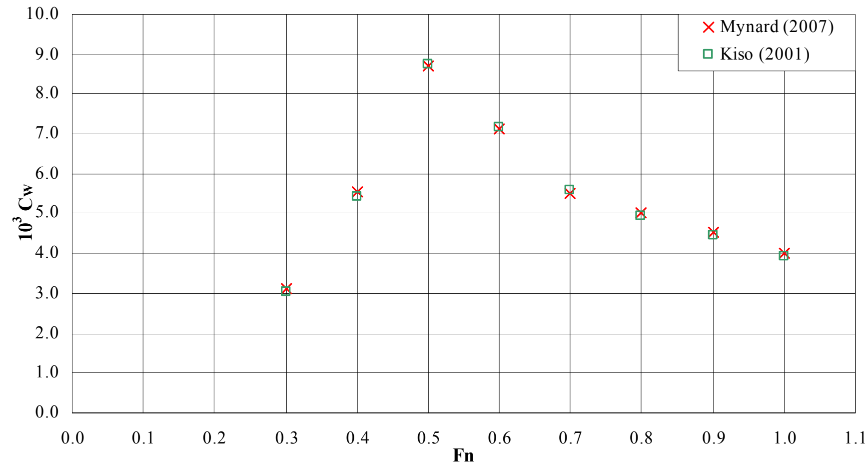


Figure 12: Comparison between Tank Testing Results, TRI-9, X/L_1 -0.2

As discussed and illustrated by Kiso (2001) and Hebblewhite (2006), due to the very low freeboard and cross members of the model, mono-film sheets are required to keep green water to a bare minimum, as shown in Figure 13. The additional forces of the mono-film sheets are not considered to significantly contribute to the overall results, as a clear trend in the data was evident.

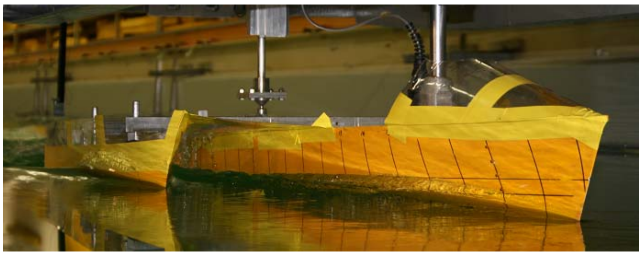


Figure 13: TRI-9, Fn 0.7, X/L_1 -0.2

8. RESULTS AND ANALYSIS

The results obtained through SHIPFLOW v3.3 were compared against side hull location for each individual trimaran and also compared against the series at each individual side hull location, over the range of Froude numbers. The following Figures 14, 15 and 16 represents the comparison between the wave resistance coefficients, for each trimaran model with longitudinal conditions X/L_1 -0.2, -0.3 and -0.4.

In each instance the maximum C_W for each trimaran is found to occur at around Fn 0.5. This is also evident for both X/L_1 -0.3 and -0.4. Furthermore there is a clear trend in the data obtained for each model over the range of Froude numbers. TRI-9 clearly has a greater C_W over the range of side hull locations; this was to be expected due to TRI-9 possessing the largest C_B and lowest B/T and $L/\nabla^{1/3}$ values. Alternatively the lowest C_W values were obtained by TRI-1 comprising of the lowest C_B and highest B/T and $L/\nabla^{1/3}$ values. The SHIPFLOW C_W results for the trimaran model TRI-9 are shown in Figure 17. As discussed by Kiso (2001), at approximately Fn = 0.3 to 0.6 the lowest C_W can be obtained with the side hulls longitudinally located at X/L_1 -0.4. Furthermore at Fn > 0.6 the minimum is found at X/L_1 -0.2.

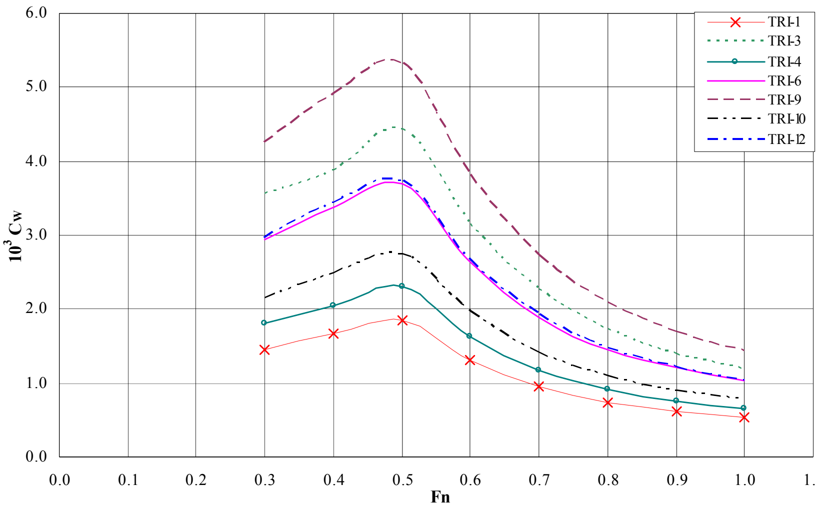


Figure 14: Wave Resistance Coefficients, SHIPFLOW, X/L_1 -0.2

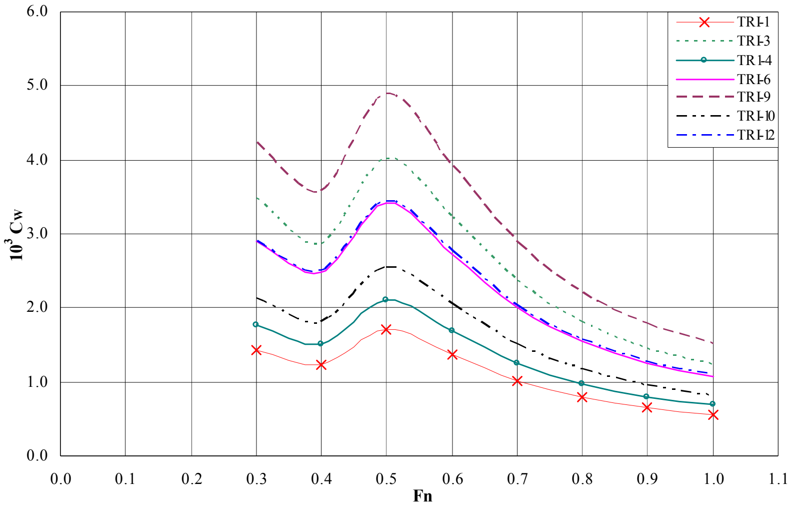


Figure 15: Wave Resistance Coefficients, SHIPFLOW, X/L_1 -0.3

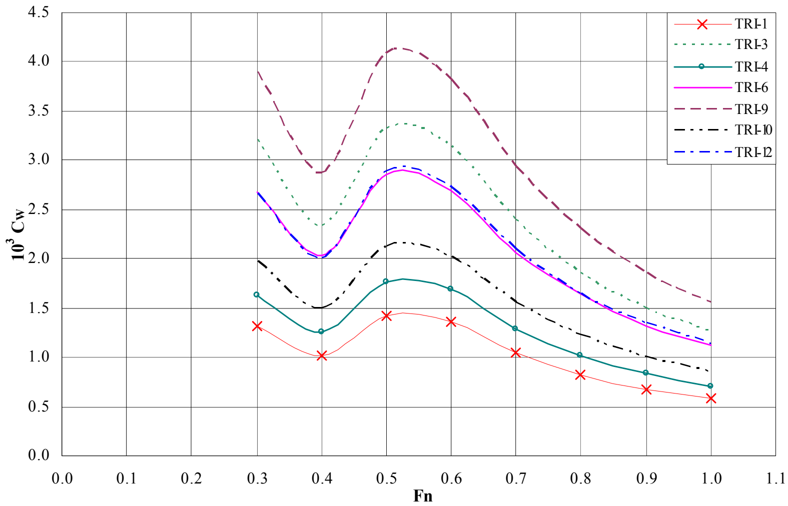


Figure 16: Wave Resistance Coefficients, SHIPFLOW, X/L_1 -0.4

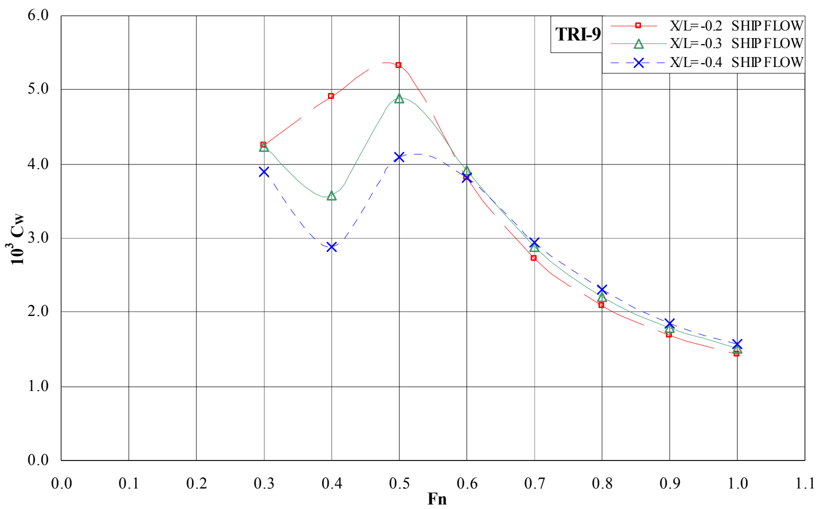
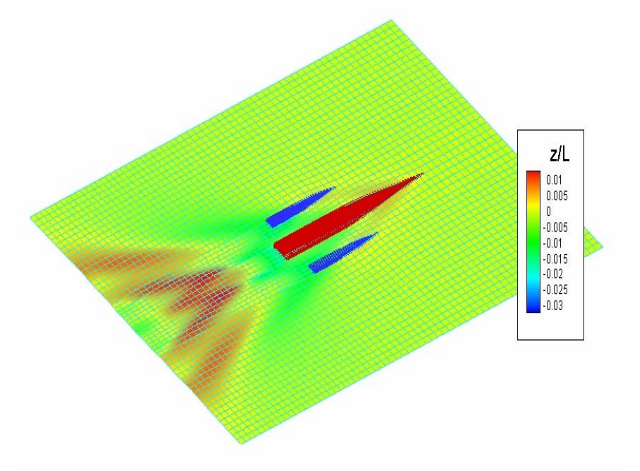
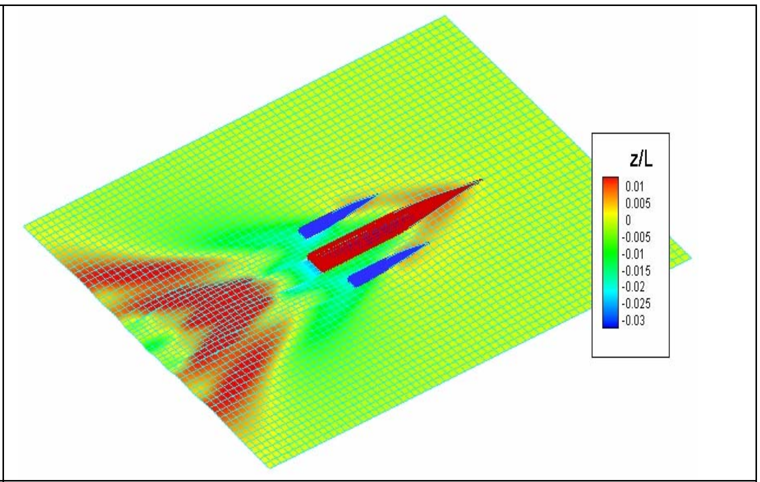


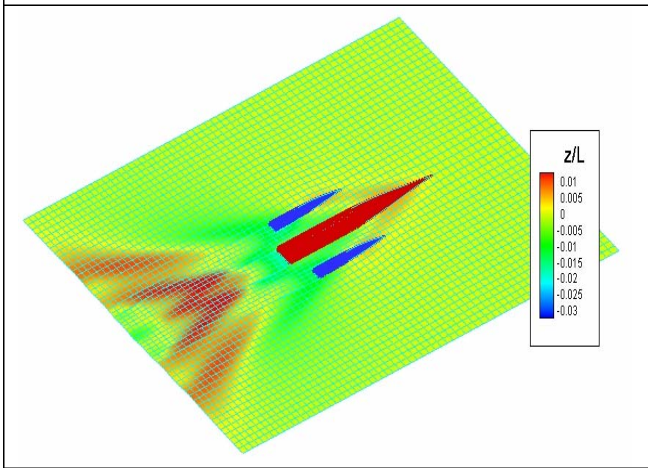
Figure 17: Wave Resistance Coefficient, SHIPFLOW, TRI-9, X/L_1 -0.2, -0.3, -0.4



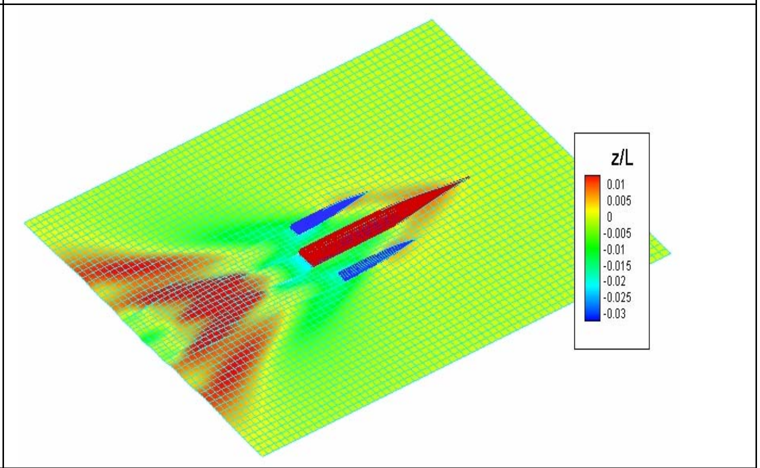
TRI-1



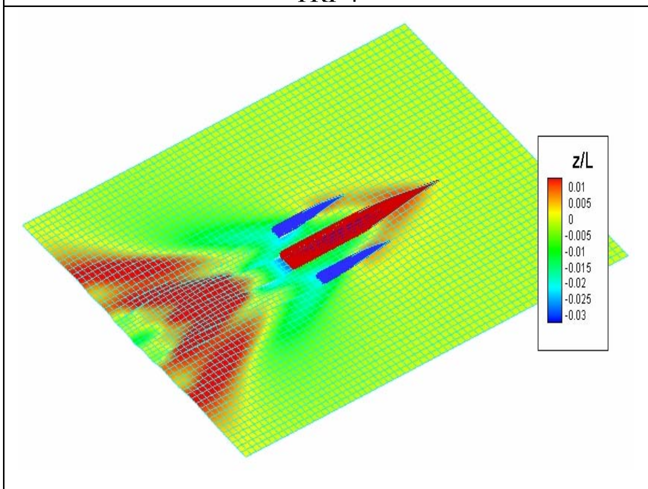
TRI-3



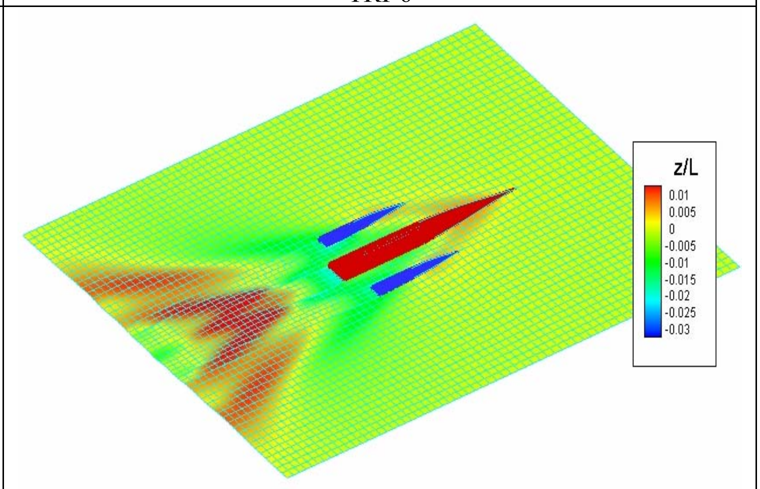
TRI-4



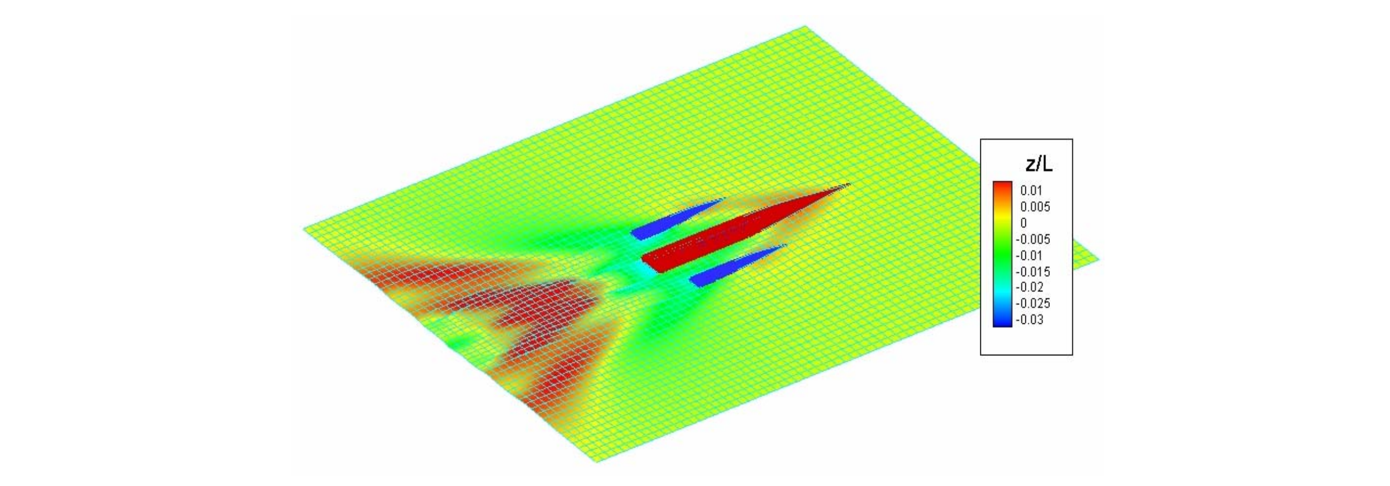
TRI-6



TRI-9



TRI-10



TRI-12

Figure 18: Wave Pattern, SHIPFLOW at Fn 0.5 and X/L_1 -0.2

The Figure 18 illustrates the wave patterns for each trimaran model at Fn 0.5 with longitudinal side hull location of X/L_1 -0.2. Clear trends in the wave elevations are evident. The images reflect the results discussed above.

In SBM each model was run over the range of Fn values corresponding to the test matrix. The wave pattern can be visualized as a solid render or by isometric elevation lines, as shown in Figure 19.

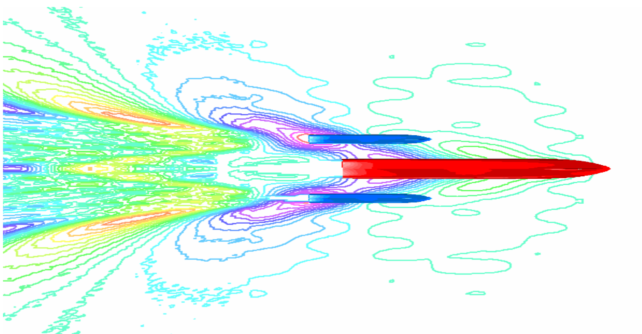


Figure 19: Sample Wave Pattern – Isometric Elevation Lines

The results obtained using the SBM are shown in Figures 20, 21 and 22 at longitudinal side hull locations of X/L_1 -0.2, -0.3 and -0.4. Due to the small increments employed over the range of speeds, clear maximum points in the data are evident. The maximum C_W values for X/L_1 -0.2 are found at Fn 0.487. The maximum C_W values for X/L_1 -0.3 are found at Fn 0.513 and at X/L_1 -0.4, the maximum is found at Fn 0.55.

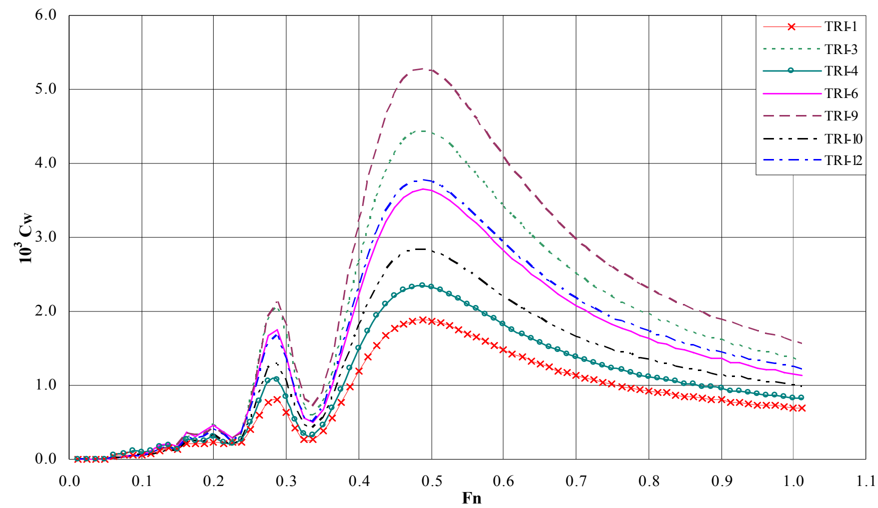


Figure 20: Wave Resistance Coefficients, SBM, X/L_1 -0.2

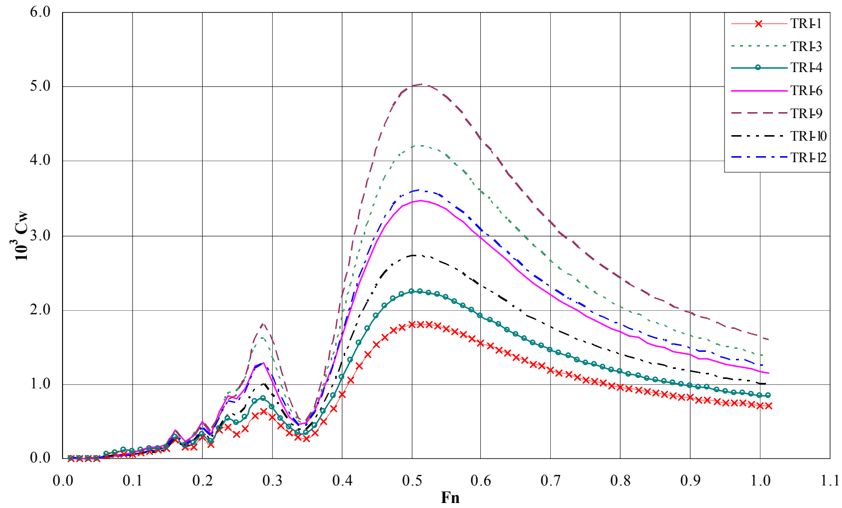


Figure 21: Wave Resistance Coefficients, SBM, X/L_1 -0.3

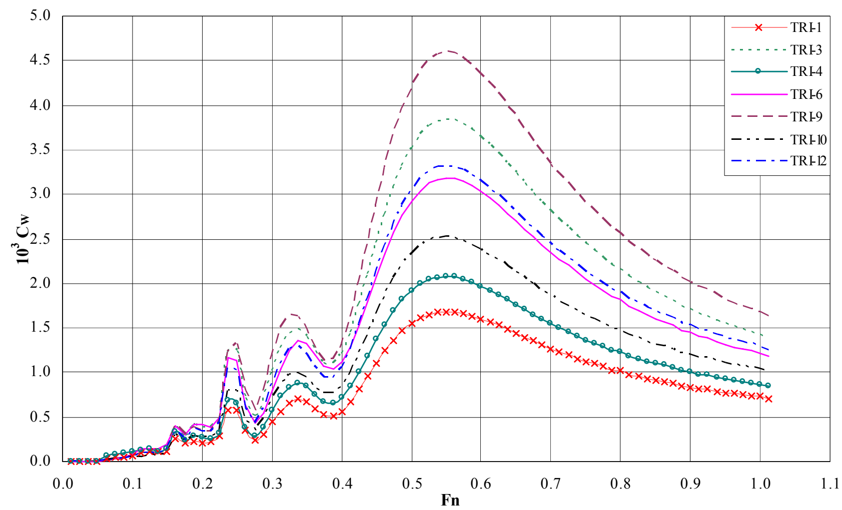


Figure 22: Wave Resistance Coefficients, SBM, X/L_1 -0.4

The effects on longitudinal side hull locations for TRI-9 are represented in Figure 23, as determined using the SBM. The optimum location to achieve minimum C_W values for Fn from 0.4 to 0.55 is X/L_1 -0.4 and for Fn > 0.55, the lowest C_W values are found with X/L_1 -0.2. The data obtained for Fn < 0.4 appears to be inconsistent, thus no conclusions have been made in relation to optimum side hull locations.

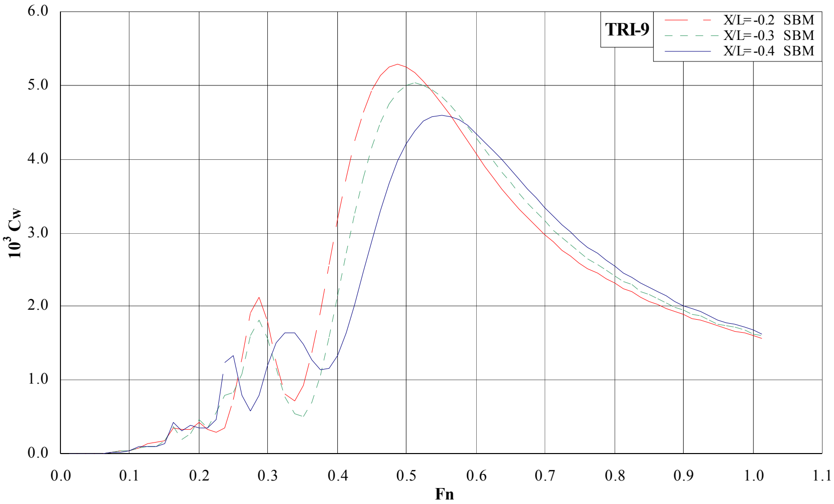


Figure 23: Wave Resistance Coefficient, Slender Body Method, TRI-9, X/L_1 -0.2, -0.3, -0.4

This section shows the comparisons between the data obtained through tank test and applying the ITTC'78 method, the SHIPFLOW data and the SBM. As shown in Figure 24, 25 and 26, the data obtained using SHIPFLOW and the slender body method are quite comparable for Fn > 0.5. Although it is quite evident that the experimental results are significantly larger, the trends in the data are quite similar for Fn > 0.5. As shown in Figure 24 for X/L=-0.2, the difference between the data is quite uniform. For X/L=-0.3 and -0.4 the difference is minimal at Fn equal to 0.5 then increase at the Fn increases.

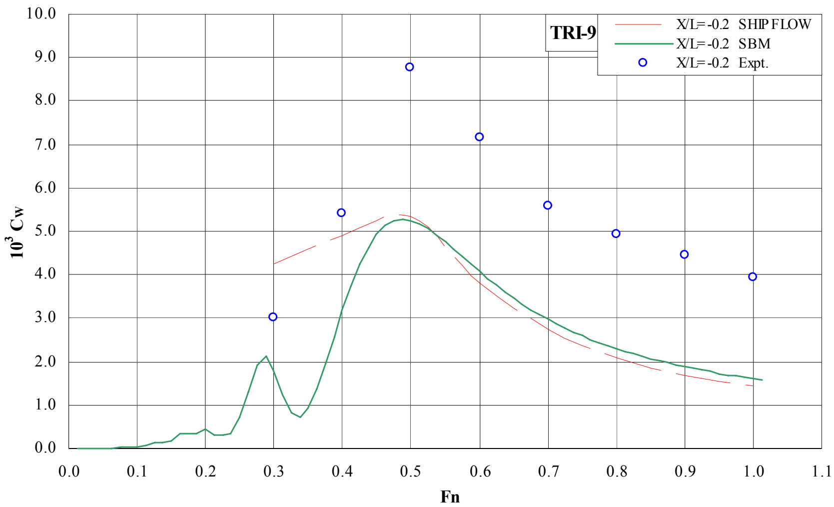


Figure 24: Wave Resistance Coefficients, Expt., SHIPFLOW and SBM, TRI-9, X/L=-0.2

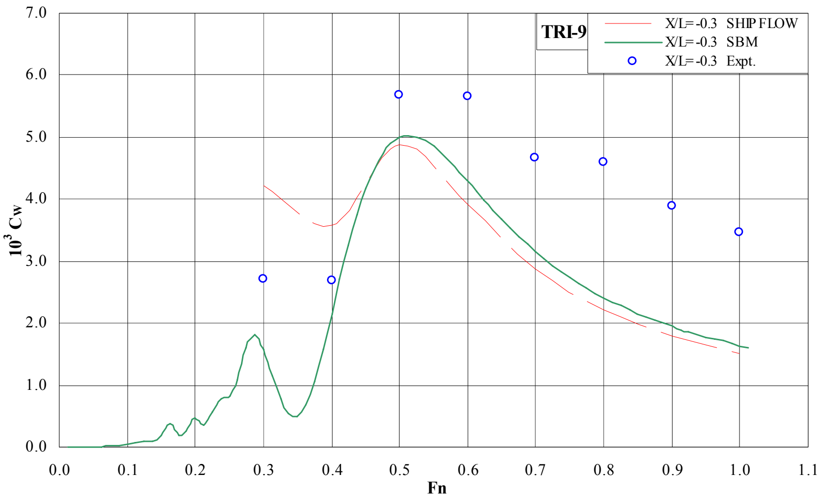


Figure 25: Wave Resistance Coefficients, Expt., SHIPFLOW and SBM, TRI-9, X/L=-0.3

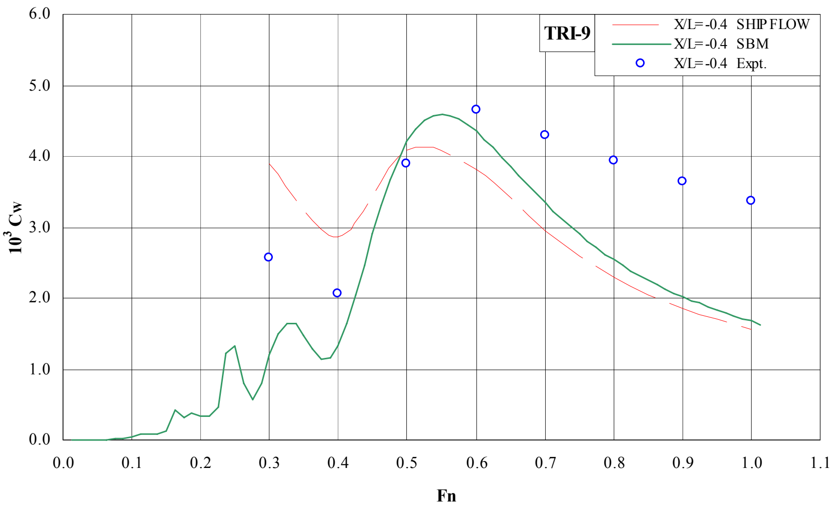


Figure 26: Wave Resistance Coefficients, Expt, SHIPFLOW and SBM, TRI-9, X/L=-04

9. CONCLUSIONS

This paper investigates through numerical and experimental work, the wave resistance characteristics of a systematic series of round bilge displacement trimaran hull forms based on the AMECRC systematic series. Although limited experimental work was carried out, mainly on TRI-9, sufficient knowledge has been gathered to conclude an appropriate location for side hulls based on operational speed requirements. It is envisaged that further experimental work need to be undertaken to validate the numerical simulations and propose a regression model for rapid resistance estimation for trimaran hull forms.

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10. REFERENCES

Lindström, J, Sirviö, J, Rantala, A, (1995): “Superslender Monohull with Outriggers”, Proc. Of Third International Conference on Fast Sea Transportation, *(FAST’95)*,pp

Mizine, I. and Amromin, E. (1999): "*Large High Speed Trimaran – Concept Optimisation*", Proc. Of Fifth International Conference on Fast Sea Transportation, (*FAST'99)*, pp 643-647

Pattison, D.R. and Zhang, J.W. (1995): "*Trimaran Ships*," Transaction of Royal Institution of Naval Architects, Vol
137, pp 143-161

Ackers, B.B. et al. (1997): "*An Investigation of the Resistance Characteristics of Powered Trimaran Side-hull Configurations",* Trans. Of Society of Naval Architects and Marine Engineers, Vol. 105, pp 349-373

Suzuki, K., Nakata, Y., Ikehata, M. and Kai, H. (1997): "*Numerical Predictions on Wave Making Resistance of High-Speed Trimaran",* Proc. Of Fourth International Conference on Fast Sea Transportation, (*FAST'97),* pp 611-617

Yang, C. (2001): "*Practical Hydrodynamic Optimisation of a Trimaran",* Trans. Of Society of Naval Architects and Marine Engineers, Vol. 109, pp. 185-196

Migali, A., Miranda, S. and Pensa, C. (2001): "*Experimental Study on the Efficiency of Trimaran Configuration for High-Speed Very Large Ships",* Proc. Of Sixth International Conference on Fast Sea Transportation, *(FAST 2001)*, pp 109-113

Suzuki, K. and Ikehata, M. (1993): "*Fundamental Study on Optimum Position of Outriggers of Trimaran from View Point of Wave Making Resistance*", Proc. Second International Conference on Fast Sea Transportation *(FAST '93),* Vol. 1, pp 1219-1230

Yeung, R. W., Poupard, G. and Toilliez, J. O. (2004): *"Interference – Resistance Prediction and Its Application to Optimal Multi-Hull Configuration Design*", Trans. Society of Naval Architects and Marine Engineers, Vol 112, pp 142-169

Brizzolara, S., Bruzzone, D. and Tincani, E. (2005): "*Automatic Optimisation of a Trimaran Hull Form Configuration*", Proc. Eighth International Conference on Fast Sea Transportation *(FAST '05)*, Vol 1, pp. 1-10

Tuck, E.O., Scullen, D.C., and Lazauskas, L. (2002): "Sea Wave Pattern Evaluation. Part 6 Report: Viscosity Factors", University of Adelaide, Department of Applied Mathematics, 14 pp