THE IZAR PENTAMARAN – Tank Testing, Speed Loss & Parametric Rolling

Nigel Gee, Nigel Gee and Associates Ltd, UK
Jose Maria Gonzalez, IZAR
Edward Dudson, Nigel Gee and Associates Ltd, UK

SUMMARY

This paper discusses the hull development of the IZAR Fast Ferry. Special attention is given to the topics of speed loss in waves and the phenomenon of parametric rolling a subject that is often thought to be of serious concern with stabilised monohulls.

AUTHORS' BIOGRAPHIES

Nigel Gee is an honours degree naval architecture graduate from Newcastle University UK and after completing a shipyard apprenticeship with Swan Hunter Shipbuilders moved to Burness Corlett and Partners as an Assistant Naval Architect in 1970 and then to manufacturing industry with Hovermarine in 1972, promoted to Engineering Manager in 1976. After four years pursuing an academic career at Southampton Institute returned to industry as Technical General Manager with the Vosper Private Group before leaving in 1986 to set up Nigel Gee and Associates Ltd to specialise in the design of high speed vessels. Since 1986, the company has undertaken designs for over 130 built fast vessels. These vessels cover a wide range of size and application. In 1995, the company patented the fast ship Pentamaran concept. Nigel Gee is a Fellow of the Royal Institution of Naval Architects and a Member of the Society of Naval Architects and Marine Engineers and has published 17 papers on the design of fast vessels.

José M. González A.-C. is the Head of Hydrodynamics of the Direction for Innovation at the Headquarters of IZAR S.A. Construcciones Navales in Madrid. He is a Naval Architect and received is PhD from the Polytechnics University of Madrid. He is as well a part-time teacher at the Naval Architecture and Marine Engineering School of the same University. Before to join IZAR, formerly Bazán, He worked at El Pardo Model Basin as well as in the Marine Insurance field.

Ed Dudson graduated from the University of Southampton in 1990 and joined Nigel Gee and Associates the same year where he has worked continuously with the exception of a year's sabbatical in MARINTEK. He is director of ship for Nigel Gee and Associates Ltd. Ed Dudson is a Chartered Engineer and Member of the Royal Institute of Naval Architects.

1. INTRODUCTION

Recent market studies carried out by IZAR have shown significant demand for fast ferries capable of speeds up to 40 knots but carrying higher deadweights than was previously possible with this type of vessel. Typically owners are asking for 1000 tonnes deadweight and in the very near future 2000 tonnes deadweight or more. It was clear to IZAR that simply scaling up existing aluminium conventional monohulls for this high speed, high deadweight role would produce designs for vessels that require very large powers and probably the use of gas turbine prime movers. The cost of such solutions would probably be unattractive to owners seeking to enter this market. Following close collaboration over a number of years, IZAR have now concluded a license arrangement with Nigel Gee and Associates Ltd for the patented Pentamaran hull form. The Pentamaran is a slender stabilised monohull, which offers the potential for a 30% reduction in power in large high speed vessels, when compared with existing monohulls or catamarans.

The Pentamaran concept was originally developed as an ocean-going ship for the carriage of containers (Reference 1). The concept was developed with the commercial backing of ADX of Fribourg, Switzerland, who are joint patent holders with Nigel Gee and Associates Ltd. The very significant advantages of this hull form, not only in terms of resistance but also in terms of seakeeping and low speed loss, were realised early in the development process.

Pentamarans developed and designed to date include ADX Express and an ultra high speed passenger vessel. The Pentamaran concept is also being studied by several of the larger world wide navies for application both as a sealift ship and multi-role combat vessel.

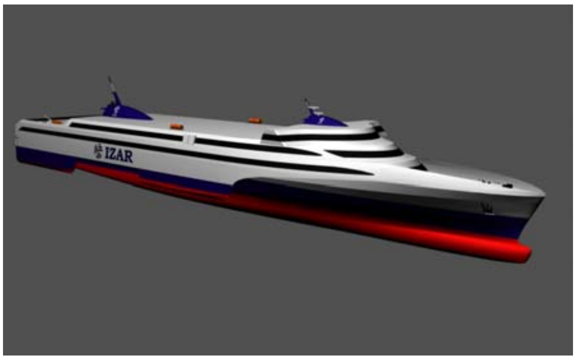

Figure 1 : Computer Rendering

Length Overall	175	m
Length Waterline	165	m
Beam Overall	32.0	m
Draught (Design)	4.05	m
Deadweight (Design)	800	tonnes
Deadweight (Max)	1000	tonnes
Main Engines	4 x MAN 16V 40/50 Medium Speed Diesels	
Waterjets	4 x Kamewa 160 SII	
Maximum Speed	38.0	knots
Service Speed	36.5	knots

Table 1 : Principal Particulars

1.1 PROJECT BACKGROUND

It was also clear from market studies that owners looking for larger vessels capable of higher deadweights would prefer to see their vessels built in steel and burning a more economical fuel than is currently possible in fast ferries using high speed diesels or gas turbines. As a consequence of this IZAR and NGA decided to trade-off the resistance and power reduction possible with a Pentamaran hull, against the weight increases required to build a robust vessel from steel, and powered by medium speed diesels burning heavy fuel oil. The resulting vessel should still be at least as good as the best state-of-the-art monohulls and catamarans in powering terms, but with the added benefit of burning fuel at a very significantly lower price. Historically IFO 380 fuel has been about half the price of marine diesel oil, and even in the current market with extraordinarily low fuel prices, is only 67% of the cost of marine diesel oil.

IZAR also argued that such a vessel should see a potentially wider market application with many owners running conventional tonnage built of steel and using medium speed diesel engines, and who are nervous of venturing into new technologies as regards prime movers and hull materials. The proposed IZAR high deadweight fast ferry is seen as the opportunity to achieve extraordinarily high speeds, but with a vessel which in engineering terms is remarkably similar to their existing conventional fleet.

2. HULL DESIGN

The hull design centres around optimising the design of the central hull, which is then stabilised by the addition of sponsons. The design of the sponsons are such as to minimise the additional resistance.

2.1 CENTRAL HULL

The central hull of the Fast Ferry has been designed for minimum wave resistance at the expected service speeds for this vessel which are between 36 and 38 knots. These speeds equate to Froude numbers between 0.46 and 0.49. The hull incorporates a slender bulbous bow to minimise wavemaking in the forebody. At this Froude number the transom resistance can be very significant, however the immersion of the transom is limited by the requirements of the waterjets.

2.2 SPONSONS

The sponsons design is dictated primarily by the stability requirements of the vessel. The waterplane area of the aft sponsons dictates the upright metacentric height of the vessel. The immersion of the aft sponsons dictates the range of displacements for which the vessel can operate without ballast, whilst the difference in keel height between the aft and forward sponsons controls the shape of the righting arm curve.

The IZAR Fast Ferry sponsons are designed to meet the requirements of the IMO HSC 2000 code and the Stockholm agreement. The aft sponsons are sufficiently immersed to ensure that no ballast is required in any loading condition.

3. MODEL TESTS

Model Tests have been performed both to confirm the calm water performance and the seakeeping of the vessel. Model Tests were conducted in Spain at the "Canal de Experiencias Hidrodinámicas de El Pardo" (cehipar) during the spring of 2002. Model tests were conducted in both regular and irregular seas at various speeds and headings. In addition special tests were devised to investigate the parametric roll excitation of the pentamaran. The model test and the results are outlined below :

3.1 MODEL TEST SET-UP

The seakeeping tests were made in the Ship Dynamics Laboratory of the CEHIPAR. The basin is 150 meters long, 30 meters wide and 5 meters deep. The towing and control of the model is made by means of a CPMC (Computerised Planar Motion Carriage) and the waves are reproduced by a hydraulic wave generator with 60 actuators of the flap type that can be moved independently from each other, this allows the generation of regular or irregular, long crested or short crested waves.

The basin depth was 5 meters, equivalent to 175 meters real scale and therefore the bottom effects are negligible.

The model was towed by the carriage on straight trajectories by means of a resistance dynamometer in such a way that the model was free to heave, roll and pitch but was restrained in yaw, sway and surge.

The co-ordinate system with reference to wave heading is such that 180 degrees represents head seas and 0 degrees following seas. The tested wave conditions are outlined in Table 2. The sea conditions have been selected to be representative of the Mediterranean area.

Wave Type	Speed (kn)	Heading (°)	Hs (m)
	30	135	3.25
Long Crested	36	0 30 135 150 180	3.25
Wall Reflected	36	135	3.25 4.00 4.40
Long Crested	30 36	135	3.25

Table 2 : Irregular Wave Tests

3.2 MOTIONS AND ACCELERATIONS

The vessel motions and accelerations in a seaway are presented in Table 3. It should be noted that all of these results are without ride control, the addition of which could further improve the motions.

		36 knots				
		0	30	135	150	180
Description	Units	3.25	3.25	3.25	3.25	3.25
Heave at COG	m	0.080	0.098	0.259	0.159	0.126
Roll	deg	-	2.323	2.002	0.737	-
Pitch	deg	0.154	0.142	0.445	0.302	0.262
Vertical acc. at FP	m/s^2	0.177	0.244	1.567	1.107	0.933
Vertical acc. at Midships	m/s^2	0.056	0.087	0.482	0.306	0.264
Vertical acc. at AP	m/s^2	0.086	0.134	0.905	0.695	0.738
Vertical acc. at windward pax	m/s^2	0.149	0.315	1.014	0.655	0.537
Vertical acc. at windward car	m/s^2	0.116	0.215	0.969	0.630	1.420
Lateral acc. at windward pax	m/s^2	-	1.701	2.051	1.518	-
Lateral acc. at windward car	m/s^2	-	0.512	0.646	0.400	-

Table 3 - Motions and Acceleration Measurements

The vertical acceleration results have been analysed against the ISO 2631-1 standard for motion sickness. The results are presented in Table 4.

			Location			
Heading (deg)	Speed (knots)	Hs (m)	Aft	Midships	Car Deck	Pax Deck
0	36	3.25	> 8 hour	> 8 hour	> 8 hour	> 8 hour
30			> 8 hour	> 8 hour	> 8 hour	> 8 hour
135	36		86 min	5 hour	96 min	112 min
150	36		190 min	> 8 hour	3h 45 min	4h 15 min
180	32	2.5	4h 30 min	> 8 hour	> 8 hour	> 8 hour
	36	1.9	> 8 hour	> 8 hour	> 8 hour	> 8 hour
		2.5	5 hour	> 8 hour	> 8 hour	> 8 hour
		3.25	78 min	> 8 hour	66 min	126 min

Table 4 - MSI According to ISO 2631-1

The most severe heading for MSI is head seas where the limiting time for 10% MSI is 66 minutes in sea state 5.

3.3 SPEED LOSS

Vessel speed loss has been estimated based on the measured added resistance in sea state 5 at different wave headings. In this design the maximum speed loss is seen in head seas, the speed loss all other wave directions is approximately 1 knot. The calculated speed loss in sea state 5 is shown in Table 4.

Wave Heading	Speed Loss knots
Head Seas	2.25
Bow Quartering	0.85
Stern Quartering	0.45
Following	1.25

Table 5 - Speed Loss in Sea State 5

3.4 PARAMETRIC & SYNCHRONOUS ROLLING MOTION

Large ships may suffer from excessive roll when sailing in head or following seas in heavy weather. This roll motion is called parametric because is not due to any external wave excitation but to the fluctuation of the restoring moment due to the cyclic change of the ship buoyancy from sagging to hogging conditions.

Therefore, longitudinal waves can activate a cyclic change of the ship's transverse stability due to her pitching and to the passing under the hull of those waves. The consequence of this fluctuation of the metacentric height (GM) may be the appearance of a sudden, unpredictable and large roll motion which can result in ship capsizing.

A simplified equation governing this parametric roll would be similar to the one depicting the free roll decaying motion:

$$I'_{\varphi\varphi}\,\phi + B_{\varphi}\,\phi + \Delta\,\overline{GM}\left(\sin\omega t\right)\varphi = 0$$

where it has been assumed that the variation in GM is approximately sinusoidal in form with a period equal to the encounter period. This is because the restoring arm which is constant when the ship is at rest in calm water has to be referred to as a time function because of the passing of the waves.

It can be seen that this equation can admit solutions giving large rolling motions for the ship.

Parametric rolling was extensively investigated in the case of the Triton trimaran build for the UK MOD, and has been the subject of a number of research projects at University College London over recent years. The pentamaran design is unique in that its transverse stability is achieved with a pair of sponsons one of which is above the free surface in the upright condition. This allows the positioning of the immersed sponsons at a very low draught, which in turn gives significant powering benefits.

One possible disadvantage of shallow sponsons is the ease at which the upright stability could reduce with a passing head or following wave. The feedback from the extensive testing on the Triton trimaran was that the sidehulls were further immersed to ensure that parametric rolling did not occur. This of course has a significant impact on the powering of the vessel. IZAR were determined to investigate all possible problem areas of the pentamaran and therefore additional model tests were performed specifically to investigate the parametric rolling of the pentamaran.

It is reported that this phenomenon is more probable when the encounter period is twice (parametric roll) or equal (synchronous roll) to the natural rolling period of the ship. It is also assumed that the ship will be more prone to this parametric rolling if the resonance conditions happen in combination with wave lengths, equal to the ship length because, in this case, the variation in GM between crest and through is larger.

Parametric roll must be thoroughly investigated when designing multihulled ships because it is known that the variations in the magnitude of the metacentric height (GM) when sailing in waves are bigger for a multihull than for a monohull vessel. The behaviour of monohull and multihull vessel also differs because, normally, the maxima of GM occur in the sagging condition for a monohull, where as these maxima appear for a multihull in hogging condition.

Therefore, an important part of the model testing programme on the IZAR Fast Ferry , has been devoted to study the ship tendency to suffer parametric or synchronous roll motions.

It is so, that several conditions trying to gather at once the worse combinations of ship speeds, wave lengths, wave slopes, wave periods and encounter frequencies were considered and four among them selected to be tested at the model basin.

First, the natural roll period for the ship in the water was obtained trough roll decay tests performed for the ship at rest, as well as for the ship at a speed of 36 knots. In order to find the resonance conditions at speed, it has been assumed a linear variation of the ship natural rolling period with the speed.

The most relevant tested conditions are summarised in Table 6:

Test condition (*)	AA	BB	CC	DD
Ship speed (kn)	6.3	6.3	16.7	1.3
Ship heading (°)	0	0	180	180
Wave period (s)	10.2	10.2	10.2	6.7
Wave length (m)	162	162	162	70
Wave height	4.1	5.4	5.4	3.5
Slope (λ/H)	40	30	30	20
Encounter period	12.5	12.5	6.25	6.25
Looking for	Synchr.	Synchr.	Param.	Param.

Table 6 - Parametric & Synchronous Roll Testing

Test conditions:

AA.- Following waves, ship speed to get an encounter period equal to the ship natural rolling period in order to check synchronous rolling inception. Regular wave length equal to the ship length.

BB.- Following waves, ship speed to get an encounter period equal to the ship natural rolling period in order to check synchronous rolling inception. Regular wave length equal to the ship length. Increased wave slope.

CC.- Head waves, ship speed to get an encounter period equal to half the ship natural rolling period in order to check parametric rolling inception. Regular wave length equal to the ship length.

DD.- Head waves, ship speed to get an encounter period equal to half the ship natural rolling period in order to check parametric rolling inception. Large wave slope.

The ship model was sailing free at the starting of each run and, later, the model was instantaneously forced to heel and released again in order to try to detect the inception of any rolling motion amplification. This instantaneously excitation was repeated several times along the tank run and, always, the ship behaved normally being the externally generated roll motion damped out similarly as observed during the standard roll decay tests previously performed.

Figures 2 and 3, depict samples of the time series of the rolling motion recorded in the tested conditions called "BB" and "DD".

The external roll excitation is clearly in the time series. The ship rolling amplitudes are always small, being of course smaller in head waves than in following waves due to a reduction of stability in following seas.

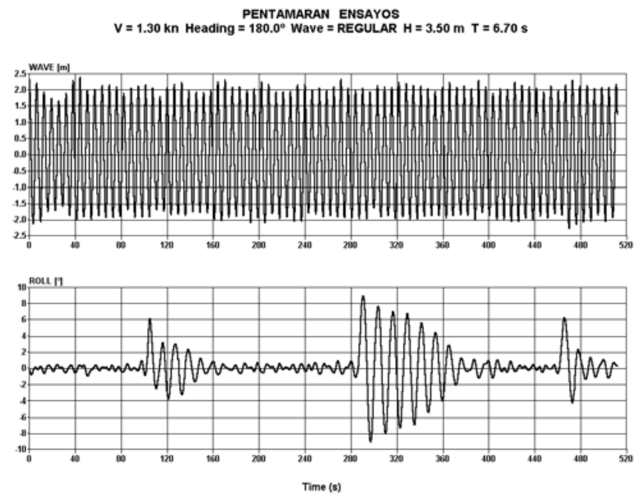

Figure 2 - Example of Time Series from tests DD

PENTAMARAN ENSAYOS
V = 6.29 kn Heading = 0.0° Wave = REGULAR H = 5.40 m T = 10.18 s