EXPLORATION OF A TRIMARAN BASED CONCEPT FOR A FAST SEA LIFT LOGISTICS SHIP

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This is an edited version of the paper first presented at the RINA Warship 2000 International Symposium on Warships for Amphibious Operations and Mine Warfare, *held in London in June 2000.*

ABSTRACT

The Strategic Defence Review of 1998 identified a requirement to deliver the Joint Rapid Reaction Force equipment into an operational area. This requirement is currently planned to be met by up to 6 commercially standard Ro-Ro ferries, typically capable of speeds up to 22kt.

This article explores the benefit of a trimaran based concept (the pentamaran configuration as pioneered by Nigel Gee & Associates Ltd.) with a high power water jet propulsion system to replace such vessels in the future, and was carried out as a joint group project for the UCL Naval Architecture and Marine Engineering MSc programmes.

The study initially explores the trade-off between ship numbers, payload in lane metres and speed, for various operational ranges. By utilizing a speed of 35kt with a payload of 3,500 lane metres, the number of vessels has been reduced while at the same time achieving a faster initial response time. It is shown that the high slenderness hull form is extremely efficient at achieving high speed for modest power requirements, and for generating high quantities of useful deck space. Vehicles can be loaded onto two internal decks as well as the upper deck of the vessel, including a provision for containerised cargo. Alternatively for commercial use, a mix of Ro-Ro and containers (up to a maximum of 1200 TEU approx.) can be carried.

Although unit initial cost is shown significantly higher than equivalent displacement, but slower monohulls, the final squadron costs are similar.

Introduction

The Strategic Defence Review of 1998 created a defence requirement for a large capacity of military sealift vessels. The purpose of the vessels is to transport the 15000 Lane metre (LIM) Joint Rapid Reaction Force (JRRF). The cargo consists of a mix of wheeled and tracked vehicles, helicopters, 20ft ISO containers and palletised freight. At the time of writing, two ships (of 2500 LIM approx) are in service (*Sea Crusader* and *Sea Centurion*) to provide support for British operations in Kosovo as well as undertaking general military freight for UK Forces worldwide.

The UK MoD is seeking to meet the long term JRRF requirement, by contracting commercial shipowners/operators to provide a sealift service through a PFI* arrangement. The ships offered by the service provider will be conventional Ro-

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*Private Finance Initiative

Ro vessels, which must also be suitable for commercial use to generate third party revenue.

Over the last 10 years, there has been a growing trend in marine trade for increased transit speeds. Current Ocean going Ro-Ro designs operate up to 26kts and projected speed over the next 20 years is more than 30kts. Current large monohull vessels (>15000T) require excessive power to reach these speeds and alternative hullforms must be considered to reduce power requirements and maintain economic viability.

In the past decade, University College London (UCL) has been exploring the application of the trimaran concept to various naval and commercial applications.[1,2,3,4] This indicates that significant power savings are achievable over equivalent monohull designs at relatively high speeds. More recently, Nigel Gee and Associates Ltd (NGA) have conducted studies into a variant of the trimaran called the 'pentamaran' which involves a trimaran configuration with very shallow sidehulls and two additional flying side-hulls forward to provide a stability reserve. These studies have identified excellent potential applications for fast ferries and fast container ships.[5,6] This suggested that there might be mutual benefit in the pentamaran form for a hybrid military/commercial high speed application.

This article describes a feasibility study carried out as a joint group project as part of the UCL MSc's in Naval Architecture and Marine Engineering to examine the viability of a pentamaran Fast Sea Lift Logistics sealift requirement. In order to assess the benefits of the pentamaran design it was decided to compare lift capacity and delivery schedules using fewer ships transiting at higher speeds with a higher number of standard vessels travelling at slower speeds. It was also assumed for the purposes of the study that the design solution must be able to fill a commercial market niche and be suitable for a PFI type service arrangement.

Operational analysis

For this exercise, a hypothetical user requirement for the vessels was established and formed the basis for the subsequent operational analysis. The key elements are shown below:

- To transport at high speed, world-wide, the vehicles equipment and stores necessary to support the JRRF.
- To carry and handle a mixed load of wheeled and tracked vehicles, helicopters, containerised and palletised freight including ammunition. Total lift not less than 2,500 LIM and dead weight of the order of 10,000Te. Provide facilities for embarkation by means of a Ro-Ro arrangement.
- Minimum higher transit speed 30kts, minimum range 5,000nm at 20kts.
- LOA not greater than 250m, Draught less than 10m, Suez capable – but not Panama.

The first issue to be resolved was the trade-off between speed, number and capacity of vessels. Initial studies centred on the delivery schedules with all ships in the squadron operating at full capacity over transit distances between 1,000nm to 8,000nm and in the speed range 26-40kts. It was assumed that the JRRF might operate in North Africa as the closest (1,500nm) and the Persian Gulf as the furthest (6,000nm) locations. Round trip times were calculated based on two transits, 8 hour load and 8 hour unload. Current vessels are meeting these load times and it is reasonable to expect future vessels to achieve the times.

Below the minimum transit distance considered, the proportion of the round trip time spent in the load and unload state is significant and the required speed for fewer numbers of vessels becomes excessive. The results of this analysis are summarized at Table 1. The results show the optimum operating points, using whole ships, required to match the same LIM delivery schedule as a typical baseline 6 x 2,500 LIM 22kt solution.

TABLE 1 – *Initial operational analysis*

Capacity (LIM)	Speed (kt)	No. Vessels
2500	22	6
2500	28	5
2500	36	4
3000	30	4
3000	39	3
3500	34	3

Given that a PFI solution is assumed for the operation of the vessels, the notice of availability to the MoD has an important influence on delivery rate during the early stages of building a force in theatre. The options considered are shown in Table 2.

TABLE 2. – NOTICE PERIODS EXAMINED UNDER PFI SOLUTIONS

	Option A	Option B	Option C
Baseline 6 Ships	Baseline Assumption		
5 Ships	2 at immediate 1 at 10 day 2 at 20 day	2 at immediate 2 at 10 day 1 at 20 day	1 at immediate 2 at 10 day 2 at 20 day
4 Ships	1 at immediate 2 at 10 day 1 at 20 day	2 at immediate 1 at 10 day 1 at 20 day	2 at immediate 2 at immediate
3 Ships	1 at immediate 1 at 10 day 1 at 20 day	2 at immediate 1 at 10 day	2 at immediate 1 at 20 day

Using the options at Table 1, the speed and capacity of the vessels under each regime was examined. In order to compare the results to the current solution the delivery time for the 15,000 LIM of the JRRF over 1,500, 3,000 and 6,000nm (e.g. North Africa, Eastern Mediterranean, Gulf) was examined. In addition, consideration was given to a protracted re-supply regime with 30 and 90 day achieved LIM delivery in theatre over each transit distance being examined.

A summary of the results from this operational analysis is at Table 3. All alternative solutions are better than the baseline solution except scenario 4 and 14 in all JRRF delivery scenarios. Equally all solutions are better over a 30 day period. However, in the longer 90 day protracted support scenario, the alternative solutions fell marginally short of the baseline. The results are broadly comparable however (within 10% of the baseline) and by the time that these levels of LIM have been delivered to theatre the requirement should be diminishing.

Current blue water Ro-Ro vessels have a capacity of between 2,000 and 2,750LIM. Based on this it was decided to take forward a 2,500LIM solution for analysis. It would be expected that the pentamaran would be more expensive to build than an equivalent capacity monohull. Only when the transit speeds rise and the powering of the monohull becomes unacceptable does the low powering of the pentamaran become an overriding factor. This issue had been identified by the user requirement by introducing a minimum transit speed of 30kts. The four ship solution at 35kts with a capacity of 2,500 LIM was therefore chosen. Further studies showed that the number of ships could be reduced to three if the lane meterage could be raised to 3,500 LIM, for the same operational speed.

TABLE 3 – *Comparison of PFI option to Baseline solution*

					JRRF build time (days)			**LIM delivered in timescale**					
	Scenario	**No. of Ships**	**Speed (Kts)**	**Capacity (LIM)**	**1,500nm JRRF**	**3,000nm JRRF**	**6,000nm JRRF**	**1,500nm 30 days**	**1,500nm 90 days**	**3,000nm 30 days**	**3,000nm 90 days**	**6,000nm 30 days**	**6,000nm 90 days**
1	Baseline	6	22	2,500	15	20	28	42,500	212,500	25,000	115,000	15,000	62,500
2	A	5	28	2,500	12	19	26	52,500	200,000	3,000	110,000	17,500	60,000
3	B	5	28	2,500	12	16	23	57,500	205,000	32,500	112,500	20,000	60,000
4	**C**	**5**	**28**	**2,500**	**15**	**21**	**27**	**47,500**	**195,000**	**27,500**	**105,000**	**17,500**	**57,500**
5	A	4	35	2,500	14	19	26	50,000	192,500	30,000	105,000	17,500	57,500
6	B	4	35	2,500	11	16	24	55,000	197,500	32,500	110,000	17,500	57,500
7	C	4	35	2,500	11	20	27	50,000	192,500	30,000	105,000	17,500	57,500
8	A	4	29	3,000	13	18	25	51,000	198,000	30,000	108,000	18,000	57,000
9	B	4	29	3,000	11	15	23	57,000	204,000	33,000	111,000	18,000	60,000
10	C	4	29	3,000	11	19	26	51,000	198,000	30,000	108,000	18,000	57,000
11	A	3	39	3,000	14	20	27	48,000	189,000	27,000	105,000	15,000	57,000
12	B	3	39	3,000	9	13	20	63,000	204,000	36,000	114,000	21,000	60,000
13	C	3	39	3,000	9	15	24	57,000	195,000	33,000	108,000	18,000	57,000
14	**A**	**3**	**33**	**3,500**	**15**	**21**	**29**	**49,000**	**192,500**	**28,000**	**105,000**	**17,500**	**56,000**
15	B	3	33	3,500	10	14	23	65,500	206,500	38,500	112,000	21,000	59,500
16	C	3	33	3,500	10	18	27	56,000	199,500	35,000	108,500	17,500	59,500

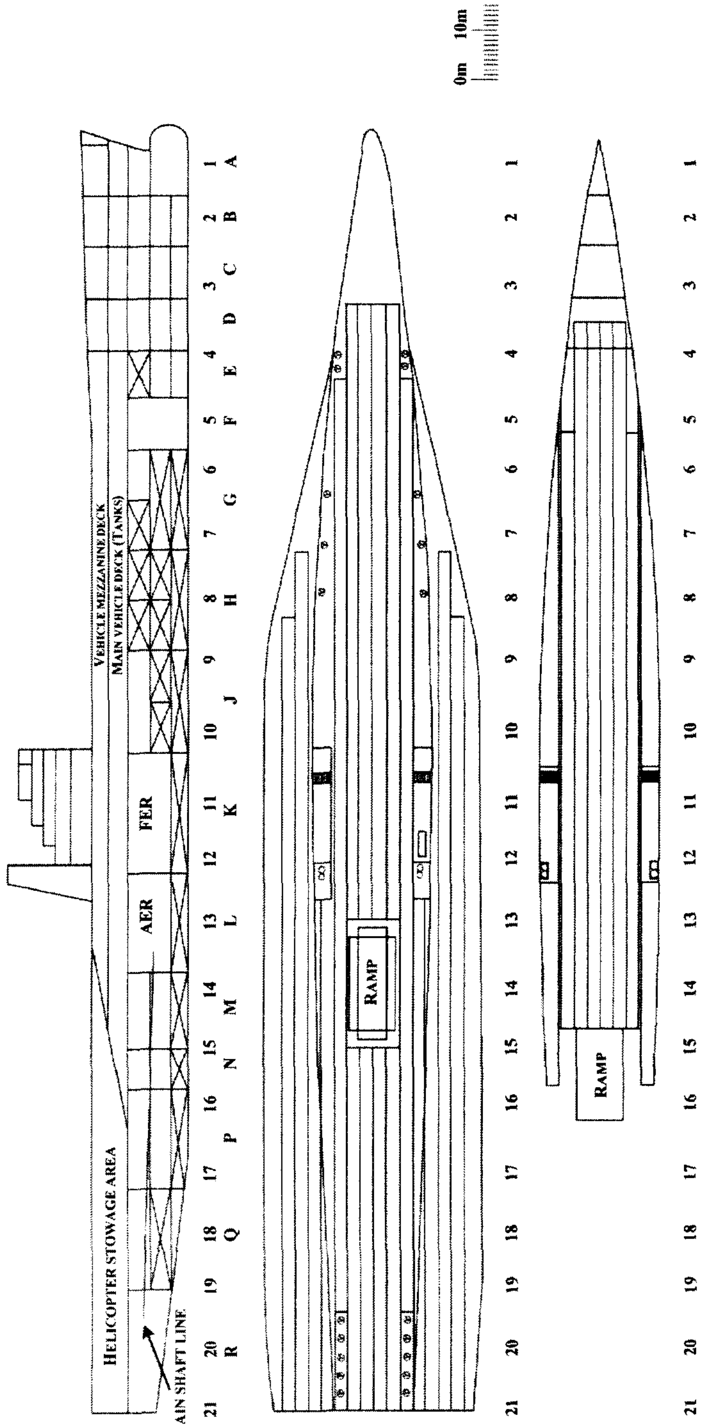

FIG. 1 – GENERAL ARRANGEMENT OF FAST SEA LIFT LOGISTICS SHIP

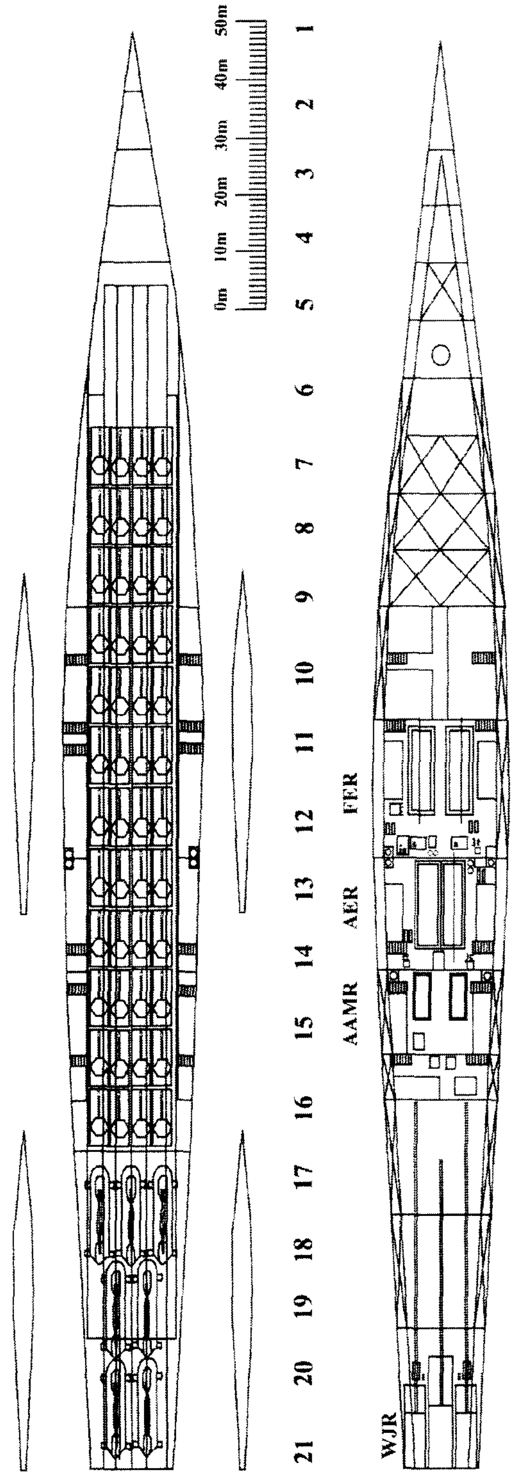

FIG. 1 – GENERAL ARRANGEMENT OF FAST SEA LIFT LOGISTIC SHIP

Summary of design solution

The configuration of the ship is shown in (FIG.1). A summary of the characteristics of the final design solution is given below in Table 4. This was developed initially using parametric methods, and updated as the machinery solution and general arrangement was progressed.

TABLE.4 – *Single Sheet Characteristics*

Payload	2500 LIM with surge capacity of 3500 LIM 10000 te. Military: Variable mix of JRRF Equipment/Ro-Ro and Containers Commercial Variable mix Ro-Ro and Containers (max 1200 approx.)
Speed	35kts
Endurance	5,000nm @ 35kts
Complement	Total of 17 plus accommodation for 12 passengers
Volume & Weight	Total Volume 98,000m^3 Displacement 25,500te

Dimensions and Geometry

Main Hull (at waterline)		**Side Hulls**		**Box Platform**	
∇mh//∇	99.5%	∇sh//∇	0.5% (2 hulls)		
L mh	250.0m	L sh	60.0m	L box	157.5
B mh	26.3m	B sh	3.0m	Wet Deck	9.6m
T mh	8.5m	T sh	1.0m (aft pair)		
D mh	19.6m	T sh	-1.0m (front pair)		
B overall (incl side hulls	43.4m	D sh	10.5m		
L/B mh	9.5	L/B sh	20		
L/$\nabla^{1/3}$ mh	8.5	L/$\nabla^{1/3}$ sh	15.5		

PROPULSION

Installed Power	80MW (including 10% margin)
Main Engines	4 x 20 MW Medium Speed Diesels (e.g. Wartsila 64 range)
Propulsors	2x 20 MW Steerable/ReversibleWaterjet (up to 27 kt) 1 x 40 MW Boost Water Jet (up to 35 kt.)
Auxiliaries	2 x Shaft driven alternators 2 x HS Diesel Generators (back-up and harbour load)
Cost	Indicative £80M @ 1999 price levels

Development of overall design

Pentamaran hullform concept

The pentamaran concept utilizes a long slender main-hull with two stabilizing sponsors aft and two flying sponsors forward. The aim of the concept is to minimize residuary resistance of the main-hull, keep the powering requirements of the side-hulls to a minimum whilst providing an acceptably stable platform. The purpose of the flying side-hulls is to provide a reserve of stability. They are positioned so that as an aft side-hull emerges, due to heel, the opposite forward side-hull becomes immersed replacing the lost waterplane area. In order to reduce the powering of the main-hull the length to beam ratio used is generally higher than the normal upper value for monohulls. The block coefficient is also low (<0.5) to further reduce powering.

Some initial sizing issues

Layout Assumptions

The vast majority of the items required by the JRRF for transport are under 3.5m in height; of those only the helicopters are over 4.0m high. It became clear that there would be a large volume of void space above nearly all vehicles if the main deck were designed to carry helicopters for the full length. A mezzanine deck was provisionally placed for 50% of the ship length within the main vehicle deck. To maximize its usefulness it was designed for 3.5m vehicles with a scantling allowance of 0.5m. This increased the height of the main vehicle deck from 7m to 8m and also provided a useful staging point for ramps to the upper deck.

Ballast

A feature of the pentamaran concept, which has major implications for the overall design, is that the stabilizing side-hulls have shallow draught and the vessel must be kept at constant trim and draught to maintain stability and minimize resistance. This means that the ship must replace the dead weight – cargo and fuel – by an equivalent amount of ballast; which in the case of this design amounts to 12,000 te. approximately of ballast.

Stability

In comparison to a conventional trimaran with single side-hulls, the pentamaran concept addresses some of the concerns about trimaran damaged stability. Under normal circumstances the trimaran must be able to withstand flooding of a side-hull and survive. This leads to rather long side-hulls. By judicious spacing of the shorter side-hulls in the pentamaran format (separation greater than 0.15L) the MoD standard transverse damage scenario will only ever involve one side-hull. The loss of any one side-hull always leaves a 'spare' on the same side to maintain waterplane area, assuming some parallel sinkage. A pentamaran may also offer survivability benefits against longitudinal raking damage at higher speeds and has good resistance against the effects of vehicle deck flooding provided the side-hulls are flared. Initial stability (GM) was set to a value of 2m. This proved adequate to meet the MoD stability standards.

Resistance predictions

For initial design the most convenient method for estimating resistance was found to be the Holtrop and Mennen statistical power prediction formulas.[7,8] This method is suitable for the hull form shape and Froude numbers ranges considered for the pentamaran, and crucially also allows the effect of bulbous bow and transom shape to be included. Although, the results produced by these algorithms were found in some cases to be some 10-15% lower than the simpler Taylor Gertlei predictions (mainly due to the ability to model bulbous bows), their accuracy has been validated against frigate resistance data and tank testing data of pentamaran models. The aft side-hulls were located as far aft as possible to gain hydrodynamic advantage and at a position from the centreline to provide adequate transverse stability.

Shaft powers were ultimately predicted using a propulsive coefficient of 0.7 based on a final waterjet solution. Despite having a marginally poorer propulsive coefficient than a propeller solution, the waterjet resulted in lower powers due to lower appendage drag. Of interest is the breakdown in resistance between main and the aft side-hulls as shown in Table 5

TABLE 5 – *Breakdown of resistance at maximum speed*

	Main Hull	**Side-Hulls**
Relative % of Total Resistance	95	5
of which		
Residual	40	15
Viscous	60	85

General arrangement

Arrangement of Cargo and Vehicle decks

Bulkheads and decks were arranged to meet IMO SOLAS regulations. With a double bottom height of 2m and a main machinery compartment depth of 9m the bulkhead deck was set at a freeboard of approximately 3m, forming the lowest vehicle deck. Bulkheads were arranged to achieve a two compartment standard. The main deck was set 8.5m above this level with an intermediate mezzanine vehicle deck (see FIG.1). In total 65% of the target LIM of 2500 were available on internal decks, and the remainder on the upper deck. Additional space on the sides of the upper-deck would allow an additional 40% capacity to 3500 LIM.

Initial concepts considered the use of a bow door to allow a true Ro-Ro configuration. Though causing slower load times, the lack of bow door allows collision bulkheads to be placed forward and reduce the vulnerability of the deck to flooding. The bow door design was dismissed as unacceptable for a high speed application and a stern exit was assumed. The width of the internal decks was constrained to provide a full turning circle for the majority of vehicles.

The position of the ramps and hence the extent of the mezzanine deck is governed by the requirement for full height stowage. Upper deck access was designed for vehicles of up to 4.5m in height. A full height area of up to 8.5m was positioned at the stern next to the main vehicle access ramp. This means that helicopters only require the full height area though the deck must be designed for the stowage and transit of all other vehicles. Ramp angles of 13° were used to calculate ramp lengths. The maximum vehicle width for transit to the upper and mezzanine deck is less than 4m therefore two 5m wide ramps side by side could be employed per deck allowing redundancy in case of ramp breakdown and allowing loading of more than one deck at any one time.

In a similar configuration to the internal ramps, the real ramp has been allocated a width of 10m allowing the use of two units. If two 5m wide ramps were used then both would need to be functional for the on and off load of helicopters. The ramp is required to be partially self-supporting to allow unload to 'mexeflotes' and avoid damage to non Ro-Ro capable docksides. The aft ramps also form a watertight seal to the transom above the vehicle deck.

Superstructure

The superstructure is positioned so that the main diesel uptakes run vertically through the vessel and through a funnel at the aft end of the structure. To allow maximum use of the upper deck, for vehicles, a bridge style superstructure was used with passage underneath to the forecastle being permitted, (see FIG.1). The first deck of the superstructure is located at 7m from the main deck to allow passage of all required vehicles. The superstructure is supported on two full length, 4m wide piers. Below 01 deck these piers function as machinery spaces for the salvage generator, ACP and refrigeration machinery. Access to the higher decks from the upper deck is via these structures.

Tankage

As noted above there is a requirement of over 12000 te. of water ballast. Main fuel tanks were positioned in 4J tanks, allowing all other major spaces to be filled by ballast. Large tanks were subdivided so that the largest ballast tanks were in the region of 500m^3. All double bottom and the majority of wing tanks are dedicated to ballast. Minor tanks such as fresh water, lub-oil and sludge are accommodated within machinery spaces. Internal tanks are used at the 3 and 4 deck positions for ballast water. There are no tanks forward of D section.

Although the volume required was evidently substantial, it was not a critical factor in determining the size of the vessel. Much of this volume was available in any case due to the fact that the dimensions were governed by the length demand of the vehicle decks and the need to reduce resistance, whilst the freeboard and beam were dictated by stability requirements.

Machinery

Operating profile and machinery drivers

The vessel's operating profile, propulsive power and service load requirements, mainly drove the selection of the machinery plant.

A typical deployment could involve embarking equipment at Marchwood and then running at maximum speed to the final destination where the vessel could be offloaded prior to an empty return trip to Marchwood. This procedure could be repeated until the JRRF was fully deployed. Good manoeuvrability whilst entering and leaving port may be beneficial and it was felt that an ability to operate the vessel at a 'loiter' speed needed to be seriously considered. For example, if the vessel was required to remain on station in the vicinity of the destination port while a final political decision was taken to deploy the JRRF. The derived operating profile is shown in (FIG.2).

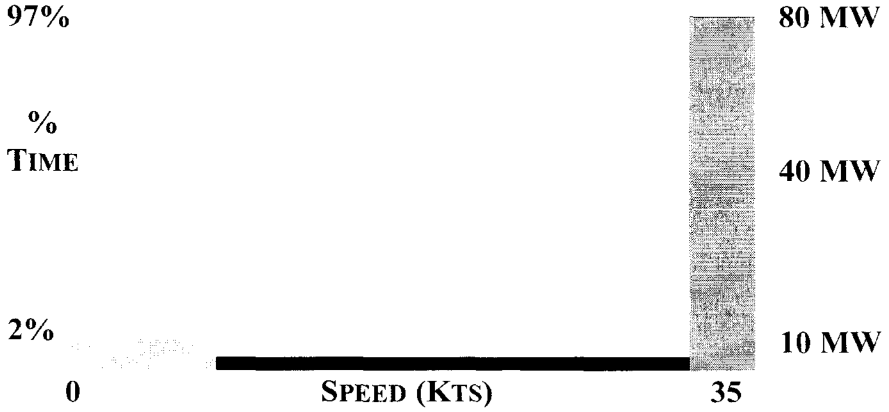

FIG.2 – OPERATING PROFILE

Initial sizing of the vessel yielded a total installed power requirement of 60MW with the main factors influencing the design of the machinery plant being:

- Optimization of the propulsion plant for the designed operating speed.
- Low through life costs.
- Attractive for commercial PFI use.
- High reliability and availability, with ease of maintenance.
- Minimum impact on cargo carrying capability.
- Low Unit Production Cost (UPC) and compliance with civilian classifications.
- A degree of flexibility and redundancy.
- Ability to meet increasingly stringent exhaust gas emissions regulations.
- Ability to meet the power demands of the cargo.

A study of comparable vessels with similar operating profiles suggested a trend towards direct mechanical propulsion system utilizing medium or high-speed diesels as the prime movers and Contollable Pitch Propellers (CPPs) as the propulsors whilst separate diesel driven generators or shaft generators provide electrical power.

Prime Mover selection

The large propulsive power requirements for this vessel required careful consideration as to the choice of prime movers. All options were considered but diesel and gas turbine engines emerged as the most viable options at an early stage in the design.

High-speed diesels and slow speed diesels were not viable. High speed diesels could not deliver the amount of power required with a reasonable number of engines and large slow-speed diesels could not fit into the slender centre-hull.

Prime-mover selection was thereby reduced to a choice between gas turbines and medium speed diesels. As this vessel needed to be attractive to the PFI contractors so the prime considerations were operating cost, UPC, and Through Life Cost (TLC). Analysis was carried to compare prime-mover fuel requirement using the fuel costs per tonne of payload for a 5,000 mile trip. Costs were compared for medium speed diesels and gas turbines and the results are summarized in Table 6.

TABLE 6 – *Comparison of fuel; costs*

	Medium Speed Diesels	**Gas Turbines**
Power (MW)	60	60
Total dead-weight (Tonne)	12,760	11,860
Fuel (Tonne)	1,457	1,765
Payload (Tonne)	10,925	11,517
Fuel cost per tonne per trip (US$)	10.27	21
Fuel costs:		
Heavy Fuel Oil (US$)	77	
Diesel Oil (US$)	137	

The decision matrix shown in Table 7 was also used to help finalize the choice with the emphasis being placed on the importance of UPC and TLC. Medium speed diesel engines emerged as the first choice for this vessel.

TABLE.7 – *Comparison of Gas Turbines versus Medium Speed Diesels*

Attribute	Diesel Engine	Gas Turbine	Comment
UPC	***	*	
TLC	***	**	Due to cost of fuel
Time to overhaul	***	*	Diesel – 12,000 GT Can change – 1,500
LIFEX of engine	***	*	Diesel main components – 24,000 GT – 6-8,000
Size of exhaust	***	*	Possible interference with cargo deck
Max height	*	***	
IMO compliance	**	***	
Maintenance	**	***	
Engine availability	***	*	
Risk	***	*	
Proven technology	***	**	
Start time to load	***	**	
Daily maintenance	***	*	GT requires daily water wash
Key: ***** = Good ** = Fair * = Poor**			

Having selected medium speed diesels the key specifications for the engines were established as being:

- Compatibility with required power.
- Low UPC.
- Low TLC.
- Extremely long intervals between overhauls.
- Currently IMO compliant with options for further emission control methods.
- Engine size falls within deck limitations.
- Powering of engine easily increased if deemed necessary.
- Low risk design solution.
- Established maintenance pool.

There are several engines from various manufacturers that meet these criteria available on the market today.

Propulsor selection

The propulsor selection was between waterjets and CPPs both being competitive at the design operating speed of 35 knots.

The efficiency of a waterjet at 35 knots was established as being marginally better than that of the CPP. A propeller solution established the need for two 8m diameter propellers with the maximum CPP blade area ratio (BAR) of 0.8. Given the final draught of 8.5m the propeller diameter is large in comparison to the vessel though this enhances efficiencies and gives a slower shaft speed. The propeller solution allowed the use of an optimal transom area ($30m^2$).

Although the largest waterjet available within today's market place is 22 MW, development is underway to design a range of higher power waterjets to meet the needs of the new breed of fast ferries and high-speed cargo ships. For example, it is understood that six 50 MW wateriets are being planned for the 'Fast Ship Atlantic' project – a vessel expected to be in service by 2002. This predicted growth in the high-powered waterjet market allowed a high degree of flexibility when selecting the waterjet configuration for the FSLL(P). Several options were considered from 4 x 20 MW units to 2 x 40 MW units along with various combinations of 2 outboard steering and reversible units with a central boost unit.

Due consideration was given to each solution supported by a decision matrix to finalize propulsor selection. The total installed power was calculated giving an installed power requirements of 79.6 MW and 83.4 MW for the waterjet and propeller solution respectively. Notwithstanding the reduction in the number of hydraulic systems and exposed machinery provided by the waterjet solution, this represents a 4.7% overall advantage in terms of power for the waterjet.

The result was the selection of a single large boost waterjet flanked by two steerable/reversible waterjets with this arrangement giving the following advantages:

- Flexible manoeuvring over entire speed range.
- Maximum ship control down to zero speed.
- Increased acceleration and stopping capability.
- Less vibration and hydro-acoustic noise than propellers – at speeds over 20 knots, the vibrations and noise can be decreased by more than 50%.
- At constant rpm the waterjets absorb approximately the same power regardless of the ship's speed.
- The independence of speed makes it easy to combine different size waterjet units.

The central boost waterjet was rated at 40 MW whilst the steerable/reversible waterjets were rated at 20MW each. Such an arrangement gave inherent flexibility with operation. For example the central boost unit can be turned off providing power to operate efficiently at a lower cruise speed such as during loiter and manoeuvring operations. This configuration of waterjets also matched to the selected medium speed diesel engine prime-movers easily.

Machinery configuration

A baseline option for propulsion, employing integrated mechanical propulsion within a pentamaran hull form had now been established to meet the system requirements. Revised power estimates were found to be somewhat higher than first estimated, with the final installed power requirement being 80 MW including a 10% margin. The basic configuration remained the same however with only minor adjustments being made to provide the additional power.

The final propulsion train arrangement is shown in (FIG-3). It consists of two outboard 20MW reversible and steerable waterjets each connected via a single reduction gearbox to a 20MW medium speed diesel. A central 40 MW boost waterjet is connected via a two into one single reduction gearbox to two more 20 MW medium speed diesels. Two shaft driven alternators are connected to the two outboard engines.

The propulsion configuration selected, as well as optimizing the efficiency at the designed operating speed, allowed a degree of flexibility in the operation of the machinery plant. As stated earlier, although the operating profile suggested a very high percentage time at the design speed over the total life of the vessel, the additional operating requirement of a 'loiter' speed encourages a more flexible machinery plant.

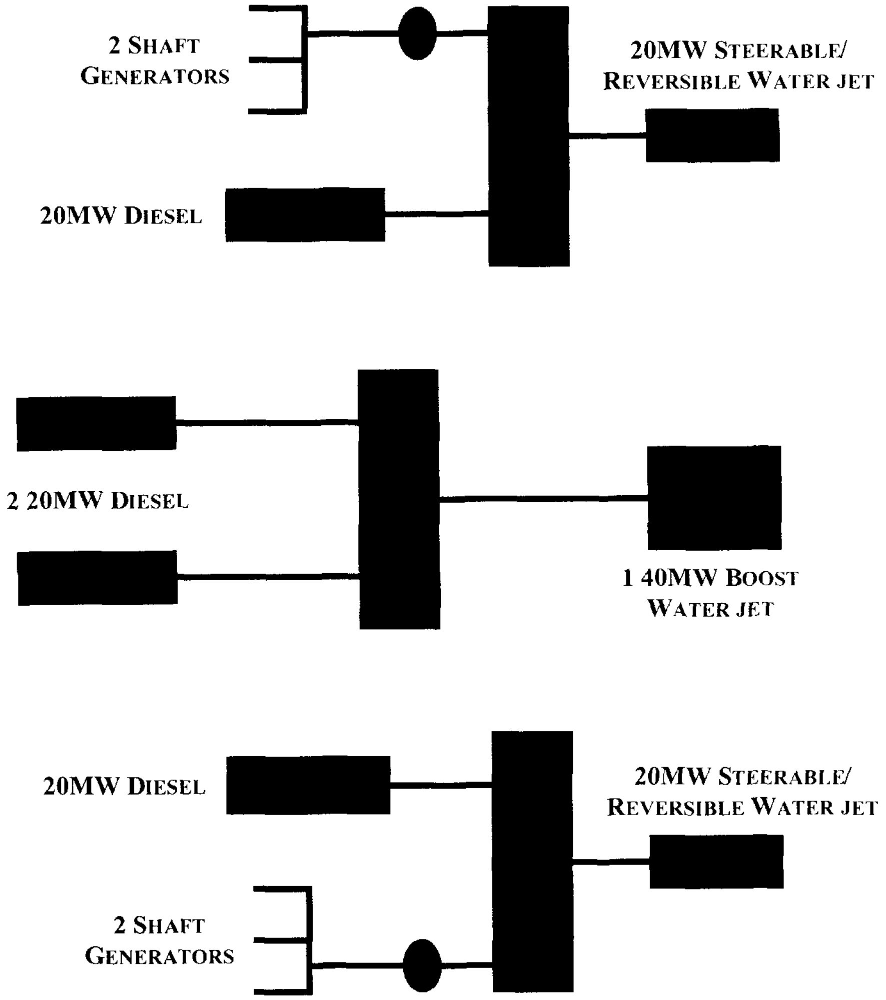

FIG.3 - SELECTED MACHINERY LAYOUT

Steering at medium and cruise speeds is achieved by the use of the two smaller steerable waterjets. The system allows direction of the jet from the nozzle up to 40° port and starboard. The moments applied to the ship are therefore full jet thrust at the required angle. This represents a major improvement over foil section rudders and tests by manufacturers and on full size vessels bear out this improvement. For berthing and slow speed operation a bow thruster was considered. A pump jet solution was chosen as giving minimum drag at high speeds whilst providing sufficient turning moment. Reversing is achieved by the use of buckets.

Power speed curve

With the selection of the propulsion arrangement fixed, a power-speed curve was produced as shown in (FIG.4). The curve was calculated using efficiencies provided by waterjet manufacturers and it illustrates the power absorbed by the pair of outboard waterjets, the central waterjet and the combined power of all three units. It can be seen that with the central waterjet idling, a lower cruise speed of 25 knots could be achieved, thus giving a very flexible propulsion arrangement.

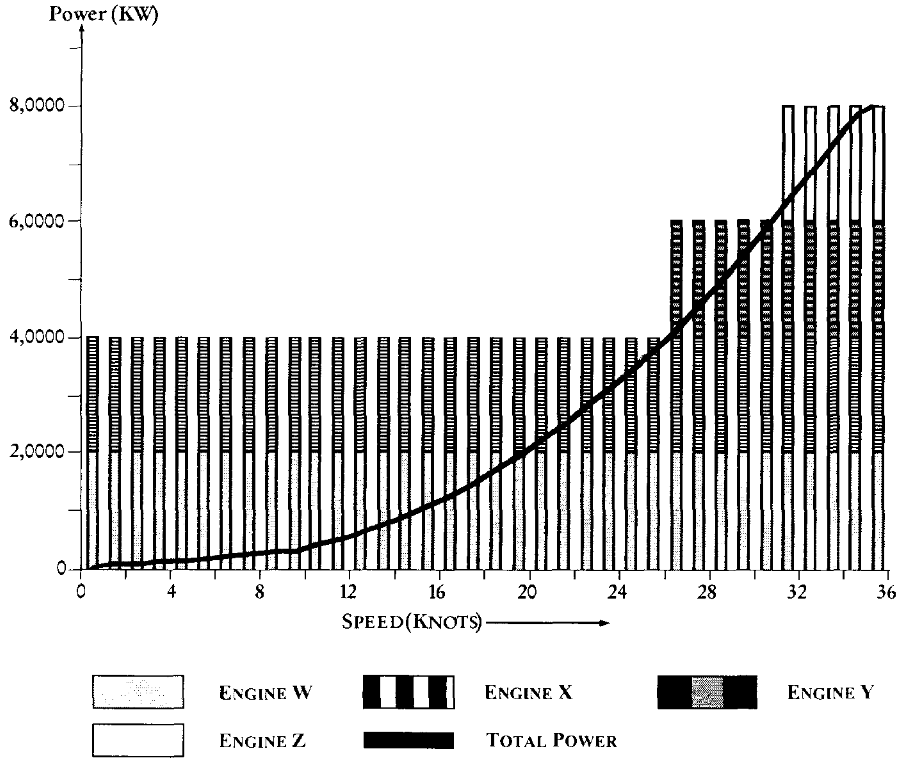

FIG.4 – POWER SPEED CURVE

Low speed manoeuvrability was initially of some concern because large prime-movers had been selected however it was established that such engines can operate as low as 5% of their normal operating power for considerable periods. This corresponded to a speed of 3 knots whereas speeds below 3 knots can be achieved by changing the vectored thrust of the waterjet. Such a configuration provides the lower power flexibility required for manoeuvring. Table 8 summarizes the operating philosophy. Figure 4 illustrates the Power/speed curve with the engine utilization superimposed to illustrate four, three and two engine operation.

TABLE 8 – *Operating philosophy*

Speed Range (kt)	Propulsion Control
0-3	2 waterjet operation with vectored thrust of waterjet to control speed.
3-12	2 waterjet operation with restrictions on operation up to 100 hrs.
12-25	2 waterjet operation with no restrictions.
25-31	3 waterjet operation with 3 diesels on line.
31-35	3 waterjet operation with 4 diesels on line (90% MCR)

Electrical generation and distribution

An electrical load chart was constructed which detailed every load within the vessel to reflect the worldwide area of operations. This enabled the calculation of electrical loading for sub-Arctic, tropical and temperate climates. Within each environmental area utilization and diversity factors were applied to harbour and cruise loads. This yielded a total loading figure to which a growth and life margin was applied. In the event of a total electrical failure the essential loads in each state were calculated which determined the size of the emergency generator.

The vessels operating profile indicated long periods at constant speed, in line with many commercial vessels, the FSLL(P) design had two shaft driven alternators to provide power whilst at sea. In addition to these, two highspeed diesel generators were provided as back up generators and to provide power whilst at anchor.

To make the vessel more attractive to PFI it was decided that it be fitted with 30 reefer points, which could be extended to 300. In order that the generators were not over sized for this occasional load a facility for a mobile generator was designed in. This would allow a generator to be driven onto the upper deck and connected directly to a reefer switchboard situated within the superstructure.

Machinery arrangement

With main decks and wing tanks in place it was possible to position the main propulsion diesels. Given the maintenance envelopes they were placed as far aft as possible to minimize the shaft line lengths. Original plans had been to place the diesels within 20m of the waterjets. However, as the deck plans were developed it became clear that the double bottom deck became extremely narrow at fore and after ends only allowing the diesels to be fitted just aft of amidships. The bow pump jet was placed as far forward as possible given the restriction of the wing tanks at the double bottom deck.

Access and removal routes

At sea, the mezzanine and main vehicle decks are sealed off with passage from the superstructure to the MMS being via wing compartments. This has the added effect of reducing the width of the vehicle decks and the vulnerability to free surface effects following fire fighting. The main diesel engines are designed to be fitted for the life of the vessel with major overhauls being conducted in situ. Soft patches are to be fitted from the machinery mezzanine deck to the main vehicle deck to allow removal of smaller diesels and machinery. Deckhead clearances are sufficient to allow machinery to be taken along the main deck and off the stern ramp. Machinery in the superstructure can be taken out sideways and shipped down the vehicle ramps for off load.

Fire-fightinq and zoning

The ship is split into six fire-fighting zones. Each MMS is supplied by a CO_2 drench and sprinkler system with coverage and flow rates designed in accordance with IMO regulations. Though Hi fog, CO_2 and other gas systems were considered, the main and mezzanine vehicle deck are equipped with a standard water drench system. This is configured to operate in zones so that a small incident on the vehicle deck does not trigger all the sprays. It is common practice in vessels of this nature to employ a lightweight rolling flooding barrier and fire curtain at each zone of the spray system to prevent spreading of water and fire.

Capital cost

Costing a new style of design is always difficult without previous build data and the parametric approach proposed by CARREYETTE was used.[9] This was modified for structural fabrication based on guidance from NGA Ltd and directly estimated machinery costs. This resulted in an indicative overall capital cost estimate of £80M at 1999 price level, when calibrated against a similar estimate of a conventional 22 kt Ro-Ro ferry of around £40M.

With a 4 ship fleet, as originally envisaged, this would yield a much higher overall fleet capital cost than the estimated baseline 6 ship solution. However, given the surge capacity 3500 LIM, it would be possible to operate successfully with only 3 ships at 35kt (see Table 1). This would then give a nominal fleet cost of £240M, which is equivalent to the estimated six ship fleet cost of conventional ferries. This figure is very tentative and could be significantly affected by any shipyard perceived risk in taking on the project. The formula used gives only rough estimates of cost and more detailed design work would be necessary to refine the figure. Through life personnel and support costs should be significantly reduced by the use of three vessels. However, a final conclusion on the suitability of the vessels for a PPI service type contract would require analysis of the total ownership costs, which was outside the scope of this short study.

Conclusions

The study has demonstrated the potential of a trimaran based concept as a Fast Sea Lift Logistics ship with a good capability for alternative commercial use.

The concept allows the achievement of significantly higher speeds at modest powers than a monohull, through optimization of main hull geometry for powering, whilst providing large deck spaces for the stowage of Ro-Ro and container freight. At the displacements considered in this exercise, the concept is well adapted for speeds in the range 30-40kts. Below these speeds conventional monohulls are more suitable.

However for this size of vessel the dimensions of a pentamaran solution (and equally so for a conventional trimaran) are significant in terms of both length and beam and this could be a constraint on use of ports and dry docking facilities.

The pentamaran form appears to offer a number of specific advantages over conventional (single side-hull) trimarans. The split side-hull configuration overcomes some of the reservations about trimarans in terms of damaged stability (both transverse and raking damage) whilst the low length and shallow draught allows minimization of side-hull resistance. The style of vessel also shows the potential to have very good intact and damaged stability, particularly for damage cases involving symmetric main hull deck flooding. However, further studies are necessary to identify seakeeping behaviour in high sea states. In this particular design the need to provide ballast compensation for dead-weight variation, was not found to be a major design driver.

A machinery plant has been designed to be flexible providing good fuel economy at high transit speeds, good manoeuvrability and cruise and loiter modes of operation. For the derived operational profile full load efficiency is the overriding factor and the use of waterjets is more suitable than a conventional CPP plant at these speeds. The pentamaran form combined with the propulsion plant also provides good manoeuvrability using steerable waterjets and pump jet thruster and flexible operating profile using twin or three shaft operation.

The capital cost of an individual FSSL pentamaran ship (LIM 3500, 35kts) has been shown to be approximately twice that of a conventional monohull ferry (LIM

2500, 22kts). For the military logistics requirement this results in the need for a smaller number of ships with a comparable (or possibly slightly higher) overall capital cost but with reduced through life costs due to the smaller squadron number. The alternative commercial use of the concept depends on the market viability of a high speed 5,000nm container service. Although this has not been examined in any detail, for a speed around 35-40kts and a payload of 10,000 te. a trimaran/pentamaran solution would appear to require significantly lower installed power than monohull solutions.

Acknowledgements

The authors would like to acknowledge the contributions by the following individuals and organizations who helped the team during the exercise: NGA Ltd. – in particular Nigel GEE and James ROY, and to the various equipment manufacturers, particularly: Kamewa; LIPS; MacGregor and Wartsilla who provided data and advice.

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