Dual Use Short Sea Shipping Trimaran Trailership HSTT-180

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ABSTRACT

This paper describes the concept design of a high-speed trimaran Ro-Ro designed for commercial cargo but readily convertible to military use. It is designed for a coastal express service such as Port Canaveral to Wilmington Delaware, so the emphasis is on speed, simplicity and reliability. All the Ro-Ro cargo is carried on the main deck, and there is room for a limited number of passengers to accompany their cargos.

Figure 1 – HSTT-180 – Commercial Mode

INTRODUCTION

Truck traffic along the I-95 corridor is a major source of air, noise and water pollution on the US East Coast. As traffic volume continues to increase, road congestion becomes a major concern for local governments because of increased pollution and accident rates. Accident rates are of particular interest because a truck accident can easily close an entire highway with a major impact on the surrounding area. Reducing congestion will require a major infusion of federal highway tax dollars and will not address pollution issues.

While there are now several water alternatives to this truck traffic, none offer sufficient speed, reliability and economy of operation to effectively compete with the highway. Water transportation offers greater fuel efficiency, reduced total air and water pollution, emission abatement in air-quality control districts, reduced total noise pollution, and relocation of the noise and pollution offshore.

The military services have a similar need for high-speed coastal shipment of military cargo. This paper examines the feasibility of using a high-speed trimaran with SWATH side hulls to provide a service with enough speed, reliablity, and economy to draw truck traffic away from the coastal highway, and also provide capability to move future military cargoes quickly and efficiently both to a war theater and within a theater.

HIGH SPEED TRIMARAN SHIPS

High Speed Trimaran Hull forms offer the following advantages:

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- Multi-Speed Mode - Economical and Very High Speeds (25-40kts). Improved propulsion efficiency and reduced fuel consumption at both moderate and maximum speeds
- Improved Wave loads, Maneuverability and Stability
- Interoperability – Can handle a wide variety of cargo such as tractor-trailers, containers, palletized cargo, large tracked or wheeled vehicles, military modular cargo, etc.
- High schedule reliability due to redundancy and insensitivity to weather.

They also present the following technology development issues:

- Non conventional multi hull propulsion systems and ship arrangement
- Multihull / Trimaran sea structural loading
- Special hydrodynamic effects - wave interaction and scale correlation factors for slender transom hull forms
- Hull-waterjet interaction factors–Axial Flow waterjets for large ships
- Efficient Cargo handling systems to maximize benefit of large open cargo deck.

PRINCIPAL CHARACTERISTICS

The commercial Short Sea Shipping trade includes both domestic road trailers and sea containers on chassis between US East Coast ports. The goal is to offer a profitable coastwise shipping service which would take tractor trailers off the Route 95 corridor, thereby relieving highway congestion and delivering the trailers in less time than driving over the congested road system. As with any high speed ship, the cargo loading and stowage arrangement must be designed so that the vessel spends a minimum time in port. Considering cargo availability issues along with these factors results in a desirable payload of about 2000 metric tons. To be an effective premium cargo carrier the top service speed should be about 40 knots, while the ship should operate very efficiently at speeds in the middle twenty knot range.

Short Sea Shipping includes slow, medium and high speed service. This design is to offer high speed service between Canaveral, Florida and Wilmington, Delaware, with other ports optional. This route is 985 highway miles or 784 nautical miles. The keys to the success of this service include a tight integration with trucking and rail service on each end of the ocean route, and the ability to operate efficiently over a wide range of at sea speeds to provide schedule flexibility and reliability.

At the same time that this commercial opportunity is evolving, a high speed military sealift ship requirement has been defined by the army for its Theater Support Vessel (TSV) logistics ship mission. This military mission requires a similar payload and a speed of about 40 knots “in theater” with the ability to cross oceans at slower speeds. Like the Short Sea Shipping commercial service, the TSV also requires a large deck area and the ability to load and unload quickly spending a minimum time in port.

High Speed Trimaran technology is well suited to both of these ocean shipping requirements.

To properly serve the US East Cost trade the ship must have the ability to carry a full load of 90 trailers (about 200 TEU equivalent) at 40 knots even in the high seas off Cape Hatteras, to achieve one day delivery times from port pairs such as Canaveral to Wilmington. Alternatively, this 40 knot speed capability can be used to make up for lost time in port or due to weather delays to maintain reliable on time service between these ports on a twice or even three times a week round trip schedule. Fuel cost would be minimized by spending most of the time at sea traveling at 25 or 26 knots, providing slower service with two round trips per week per ship. The efficient dual speed capability of High Speed Trimaran ships supports this requirement for flexible scheduling service and the ability to add or substitute ports for seasonal or occasional cargos.

Length overall	181 meters
Beam total	32.2 meters
Draft center hull	5.7 meters
Draft side hull	8 meters
Displacement	8,700 tonnes
Machinery Weight	900 tonnes
Steel Weight	4,700 tonnes
Total Installed Power	104 MW
Diesels Power	32MW
Waterjets	2xKamewa 250 VLWJ 2xKamewa 140SII
Economy Speed – diesels only	26 knots
Service high speed	40 knots
Fuel oil / tank capacity	500 t / 1500 t
Total cargo payload in commercial / military modes	2000 t / 1640 t
Cargo area in com/mil modes	2680 m^2 / 3850 m^2
Lanes in com/mil modes	1190 m / 1870 m
Passenger cabins (VIP type)	6
Four berths staterooms	8
Crew cabins	22

Table 1 – HSTT-180 Principal Characteristics

A Panamax beam was selected to maximize deck area and hull separation while remaining within the limitations of anticipated ports and repair facilities. The center hull propulsion is a CODAG (Combined Diesel and Gas Turbine arrangement but further development of alternative arrangements is very desirable. Each weight includes 10% margin. Additional lines refinement is needed to suit machinery arrangements. This refinement will increase displacement, providing more margin with little impact on propulsion power.

SPEED AND POWER PREDICTION

The relationship between speed and power was predicted using a modified form of the Quasi-Linear Theory (QLT) method (Amromin, Ivanov, Mizine, Timoshin 1984). The Modified QLT (MQLT) is a numerical technique for high-speed trimaran resistance calculations. The technique is based on the modified viscous-inviscid interaction concept and quasi-linear theory of wave resistance. The key element of the technique is how to account for the influence of Froude number on the ship trim, transom drag and wetted surface. This influence leads to appearance of a significant drag component that depends on both Reynolds number and Froude number. The MQLT calculations of residuary drag of a trimaran take into account the following drag components:

- wave resistance at its dynamic trim and sinkage
- form resistance (including the transom's contribution)
- variation of friction due to the dynamic variations of the wetted surface.

The MQLT resistance results for High Speed Trimarans were verified in the course of sets of model tests in David Taylor Model Basin during 1999-2003 studies for the Very High Speed Sealift Trimaran (VHSST) designs. The MQLT computations of boundary layers were also compared with the RANS calculations (one-equation turbulence model by Spalart and Allmaras, 1992) at model and ship scale Reynolds numbers. An analysis of the model–ship scale correlation factor for VHSST-50's high-speed slender hulls with transom sterns and diverse relative position of the trimaran hulls was also done (Mizine, Amromin, Crook, Day, Korpus 2004).

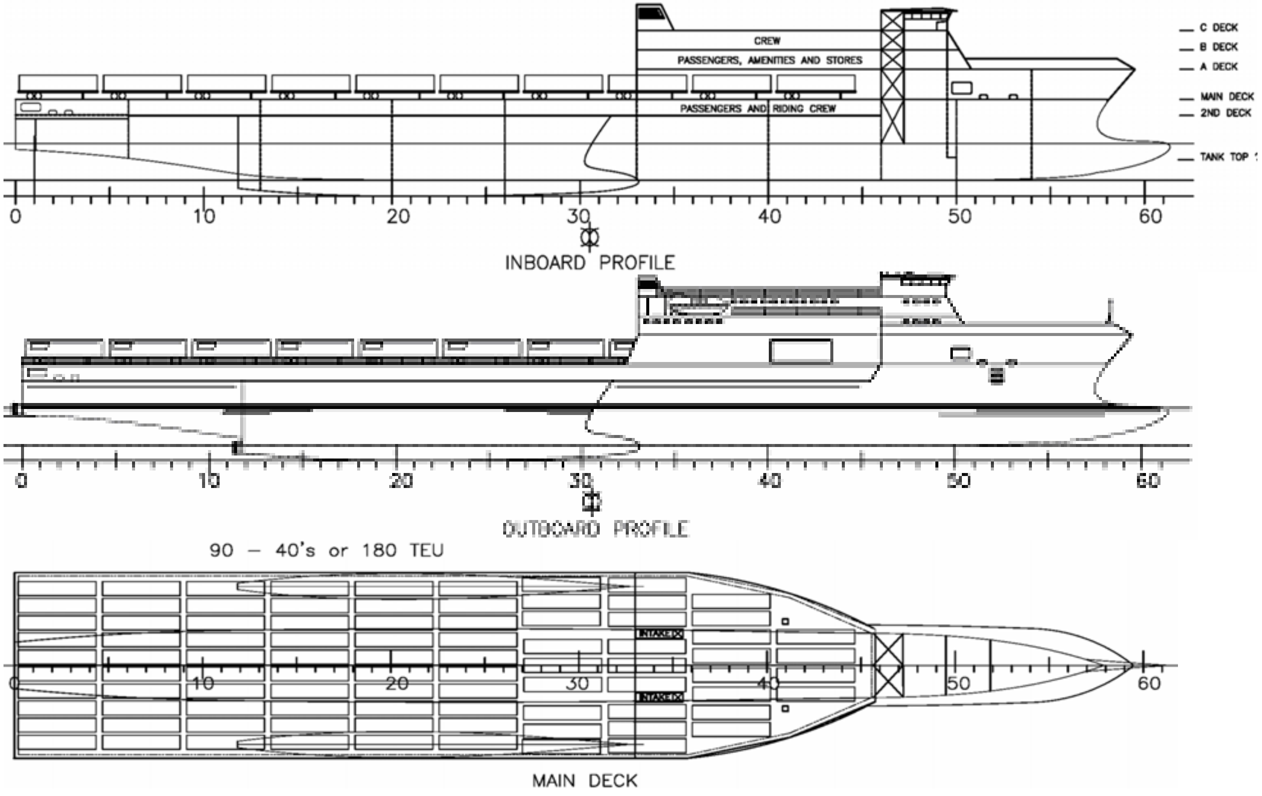


Figure 2 – HSTT-180 Commercial Cargo Arrangement

This method of applying MQLT predicts the following speed / power curve for the HSTT-180:

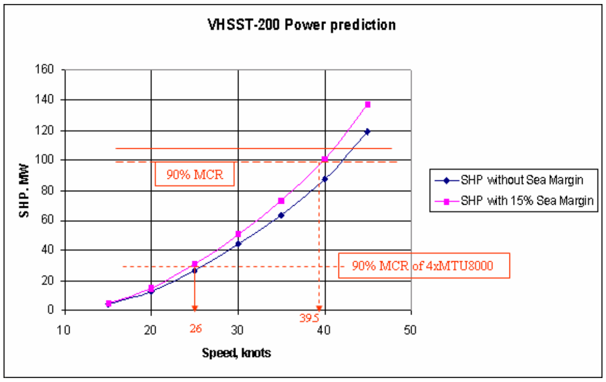


Figure 3 – HSTT-180 Speed vs Power Curve

With a payload weight of 2,000 tonnes, this predicts a range of at least 800 nautical miles at a speed of 39.5 knots with 15% Sea Margin, or 1800 nautical miles at the economical speed of 26 knots (Diesel engines only). The fuel capacity permits about 3 times these ranges with a payload of 1,000 tonnes

CARGO ARRANGEMENTS

Commercial Version

Two configurations were considered: commercial and military. The commercial mode, shown in Figure 1, stows all vehicles on the main deck, with access provided by a shoreside ramp over the stern. The deckhouse, passenger spaces and navigating bridge are forward. The narrow bow is partially surface-piercing, but has been modified to accommodate the anchor & mooring winches. The main propulsion air intakes are shown above the deckhouse; the exhaust is between hulls to maximize cargo loading efficiency. The mooring flat aft is below the cargo deck.

This arrangement offers a clean deck with natural ventilation through large ventilation openings at the forward end of the trailer deck. There is no mechanical ventilation of trailer spaces as with conventional designs, since they are are on an open deck protected from seas and spray. This offers simplicity and economy of design, construction and operation compared to conventional RO-RO designs. The arrangement provides 3886 Sq. Meters of Cargo Deck Area, accommodating at least 180 TEU, e.g. 90 Forty Foot Trailers or Containers on Chassis. Mixed sizes can be more efficiently stowed, e.g. 60 x 53-ft trailers plus 10 x 48' trailers = 183 TEU.

Trailers are loaded and unloaded (Last In First Out) over a shore-based stern ramp. They must back into slots starting at the forward end of the trailer deck. Drivers either drive the tractor back off, or exit forward past parked trailers as they are being lashed. A stair tower at the forward end of the trailer deck provides a safe route for drivers to exit to accommodations, or to the lower deck passage for safe egress (aft). This arrangement is functional but may not be optimal – additional studies should include the costs and benefits of more automated loading and unloading systems, and alternative main engine intake and exhaust systems discussed later.

The modified surface-piercing bow & SWATH pontoon hulls will minimize sea loads and speed reduction in a seaway. The ship should be able to operate in sea state 5 with about 2-knot speed reduction. The CODAG arrangement is not optimal for center hull – separate waterjets for diesels and Gas Turbines would be preferred but is not possible with present state of the art waterjets. Further development of axial-flow technology will hopefully permit a simpler arrangement with improved efficiency for both Normal and Maximum speeds. The CODAG arrangement would be clutched with simple clutches, not designed for engagement under power. Maneuvering would be done with only the side hull diesels (2x8 MW); the normal 26kt operating speed would utilize the two center- hull diesels as well as the side hulls, total 4x8 = 32 MW.

Military Version

The HSTT-180 is designed for a commercial short sea shipping coastal trade with flexible scheduling capability. This feature is very applicable to military needs in two separate valuable ways:

1) To support the US Army as a future, larger, follow on intra-theater logistics support ship, and

2) To support the Navy, Marines and Army as an operational test bed for future high speed strategic sea lift ships.

The U.S. Army is considering a Theater Support Vessel (TSV) ship acquisition program. This program is to design and build an intra-theater logistics support ship to transport a minimum payload of 680 metric tons of Army troops, military vehicles, supplies in containers and pallets which are not on trailers and other equipment at a minimum average speed of 36 knots for a round trip distance of 625 nautical miles each way operating within military theaters of operation. They also require a 4726 nautical mile self-deployment range carrying no cargo at a minimum average speed of 24 knots

These are the threshold requirements. They also have Objective values of carrying 1140 tonnes at average speeds of 50 knots over a round trip with each leg being 1250 nm. Other anticipated requirements include: 361 passengers; 1870 square meters (threshold) to 2760 square meters (objective) of effective rolling stock deck area; 31 crew and Panamax beam (32.2 m).

With space available to provide extra crew and troop accommodations the commercial version of HSTT-180 easily meets the threshold requirements, and a slightly longer version could meet the Objective values.

They also require a draft of 5.5 meters (threshold) to 4.57 meters (objective). This preliminary requirement is not met by the present design of HSTT-180, but could conceivably be met by changing the hull lines. However, the military version of HSTT-180 has two and a half times the objective RO/RO deck area (6871 square meters), almost 50% more payload (over 1600 metric tons) than the TSV objective, and most importantly, a very seaworthy and stable platform for transoceanic passage and helicopter operation in Sea State 5 wave conditions. This makes the HSTT-180 an excellent intra-theater logistics ship for the Army beyond flight 0.

Military vehicles have a relatively low weight density, so the military version has a spar deck added to provide more deck area, with less payload tonnage due

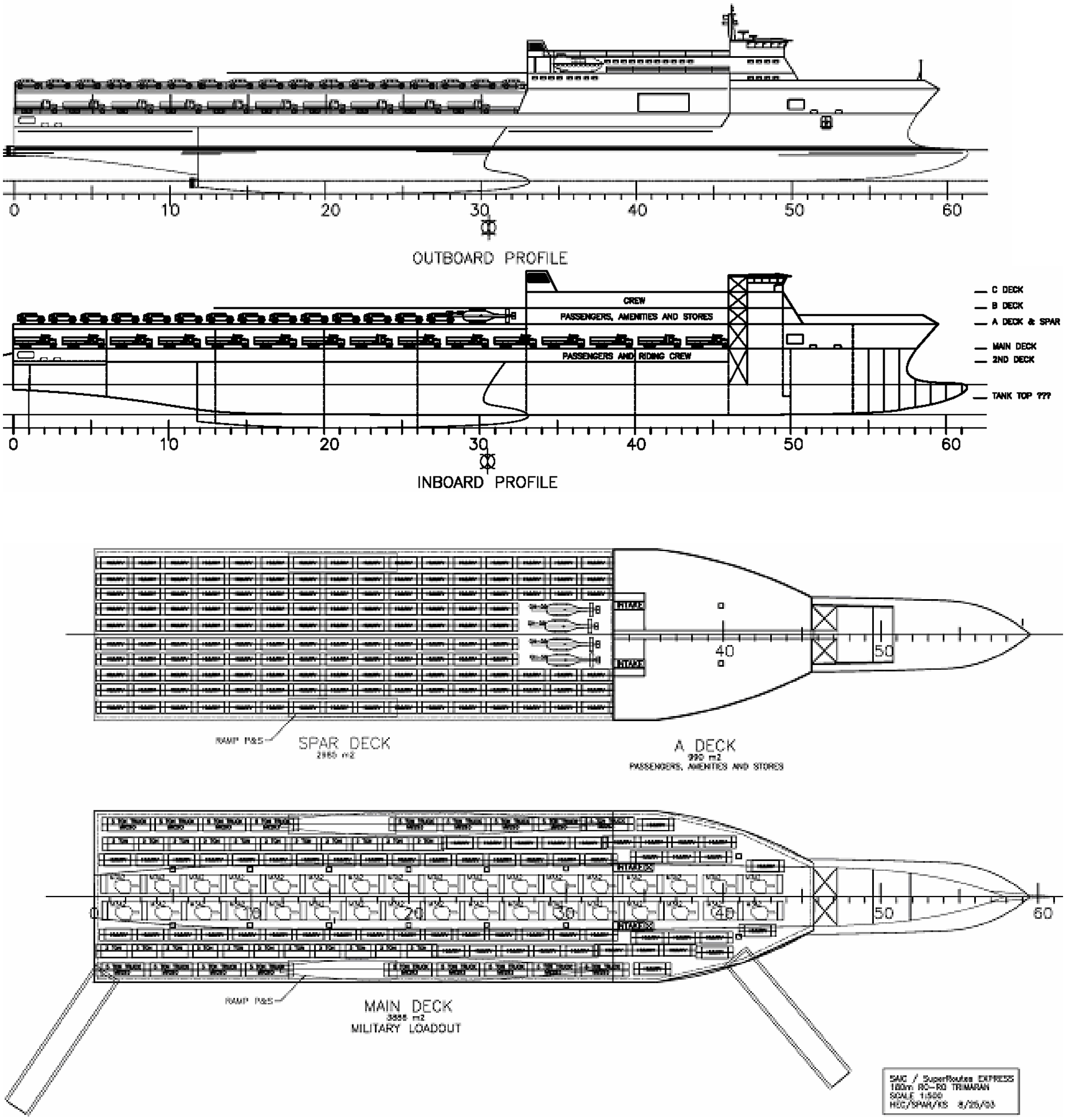


Figure 4 – HSTT-180 Military Cargo Arrangement

to the added weight of the deck. A second spar deck could be added forward for more area and enclosure of helicopters or other weather-sensitive cargo.

Fixed ramps are shown between the Main Deck and the Spar Deck, to reduce the acquisition and maintenance cost. Liftable ramps may be preferred to maximize cargo area and improve traffic flow on the main deck once the spar deck is full. Another way to increase cargo area is to add a 2nd partial spar deck fwd which would also shelter helicopters from weather. The forward trailerdeck vent opening can be used for a loading / discharge ramp to reduce the time to load and unload cargo.

Gross tonnage is approximately 8700 tonnes and Net tonnage is approximately 4000 tonnes. The spar deck and cargo deck under the house do not add to the tonnage measurement because they are considered open spaces by the tonnage rules.

The design of the loading ramps is a very important consideration but was not part of this project. The design assumes that for a point-to-point operation, shoreside ramps will be more economical than shipboard ramps, so no provision is made to handle ramps. Kingposts could be added but would incur a large weight and cost penalty. Preliminary discussions with potential users indicate that ramp stowage & handling is not desired even for the military version.

The ship should provide an extremely stable platform for helicopter operations. Helicopter operations would require local reinforcement of the Spar Deck, as well as lights and firefighting equipment, depending on the level of operations desired. Underdeck storage space has limited headroom, but this could be improved by increasing the depth which would also improve longitudinal strength so the weight penalty should be minimal and could easily be compensated by refinements in hull form. Depth is limited primarily by port facilities, which have also only been designed to the concept level. Detailed tradeoff studies to optimize total depth, balancing wet-deck wetness against loading and stowage considerations, were beyond the scope of this project.

There is a large unassigned underdeck volume which could be used for troop accommodations or dry cargo / stores.

MACHINERY AND OUTFIT

Gas Turbine Intake & Exhaust Paths

Machinery arrangement profiles and plans are shown on the next page, with a section on the following page. Gas turbine air intake and exhaust ducting is a major design consideration which was only examined at the feasibility level. Two possible intake configurations and 3 exhaust configurations are shown. The cleanest cargo deck arrangement is obtained by exhausting through the wet deck, but raises concerns of exhaust backpressure from waves contacting the exhaust openings. Two dry-exhaust options are also shown, one exhausting through a center island and one through the side shell above the second deck. The center island option also provides and easy route for removal of gas turbine rotors for maintenance.

Similarly, two options are shown for air intakes. The forward position provide excellent support for the aft end of the deckhouse with minimal vehicle interference, but the long intake interferes with the below-deck passage and stores spaces and raises concerns about intake noise and pressure drop. It may therefore be more practical to use a center island for intake & exhaust, as also shown above, accepting some reduction in ease of loading and unloading. This island causes some rearrangement of trailers, but does not affect the total available stowage. Alternative support for the aft end of the deckhouse should improve traffic flow at the forward end.

Navigating Lights

If the upper deck is kept clear as shown above, a stern kingpost is required for the stern range light required by the international ColRegs. The kingpost could be reinforced to handle ramps, but there would be a significant penalty in weight and cost. This kingpost can be moved forward to the dry exhaust / intake island if that option proves more practical. The location shown for the intake/exhaust island is still within the requirements of the ColRegs.

Anchor Handling and Mooring

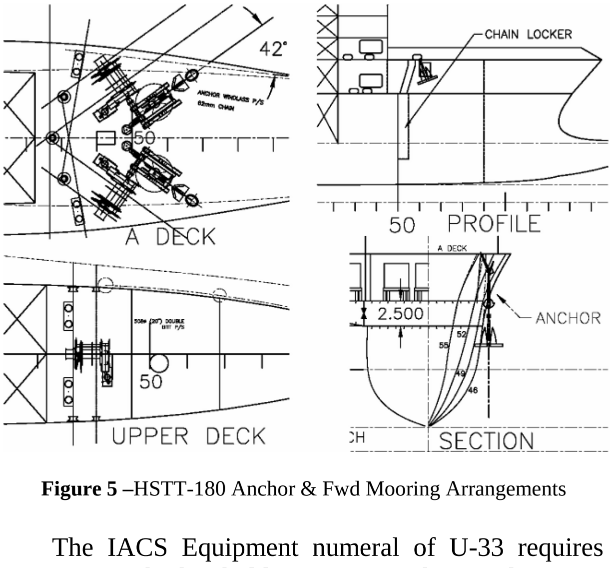


Figure 5 –HSTT-180 Anchor & Fwd Mooring Arrangements

The IACS Equipment numeral of U-33 requires two 4500Kg higher-holding power anchors and 577.5m of grade U3 chain, plus 7 mooring wires of 41t breaking strength. Surface-piercing bows generally have only minimal deck area forward and do not provide much room for anchor handling and mooring. The lines forward were modified slightly to accommodate the system shown below. No changes were made below the design waterline, but enough flare was added to stow the anchor. The change should have only a minimal effect on power, wave bending loads and seakeeping.

Aft mooring gear is located on the second deck, frames 0-6. The flat extends the full Panamax beam, and is 500mm deeper than the forward part of the 2nd Deck to improve headroom above the stiffeners in the

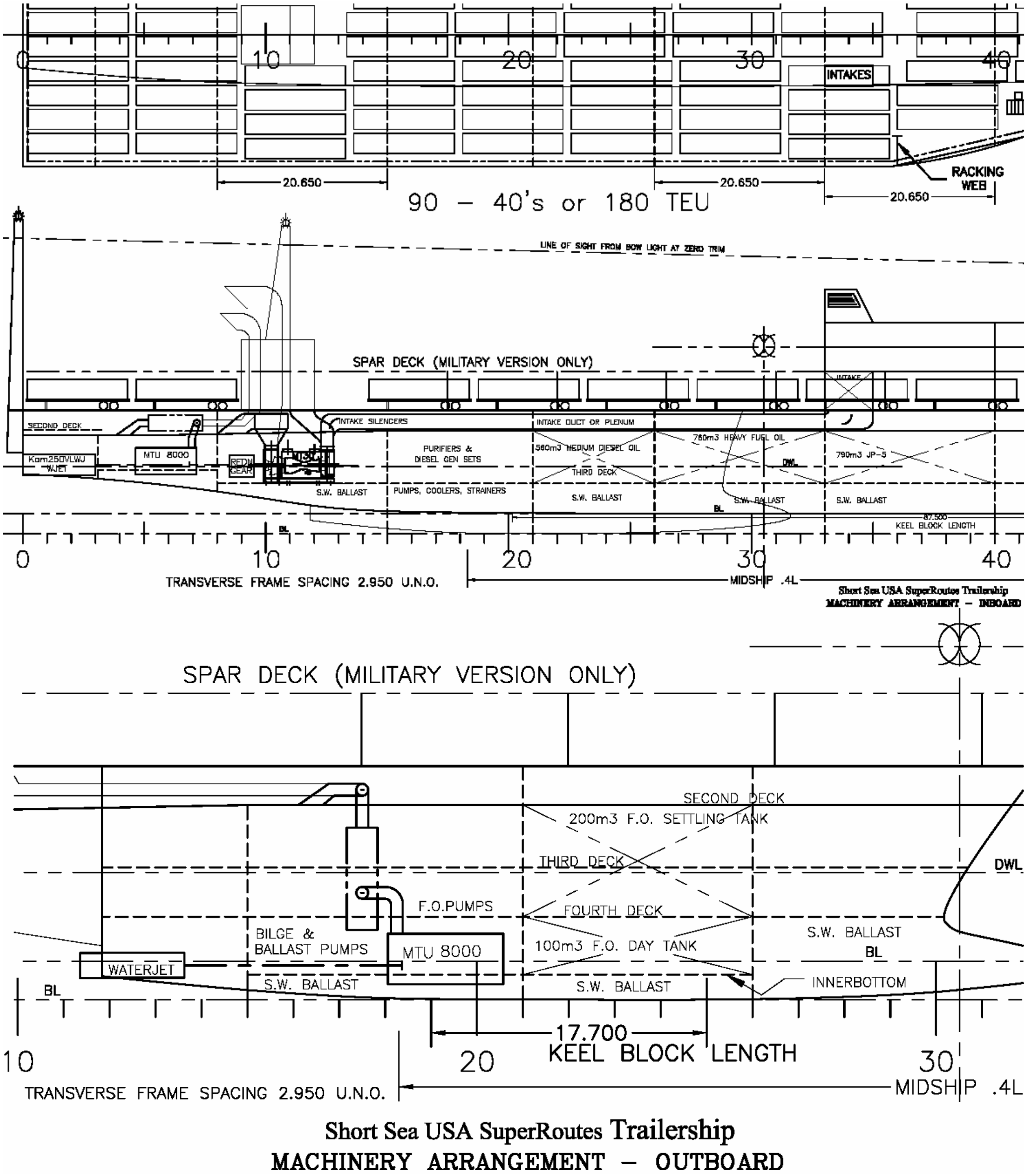


Figure 6 – HSTT-180 Machinery & Outfit Arrangements – Plan & Profiles

crossover. Passengers would enter and exit through the transom at this level, near the centerline. Mooring wires crossing the centerline go under the passenger walkway, which is separated from the (P&S) mooring equipment by handrails.

Machinery Arrangement

The center hull lines were originally developed for 4 direct-driven axial-flow waterjets, one for each prime mover, eliminating gears and clutches, as shown in figure 7 To avoid interference between the gas turbine waterjet and the diesel waterjet, the gas turbine waterjet is mounted at bulkhead 3 and a tube connects the waterjet to the transom. This arrangement offers great simplicity and economy, but discussions with vendors indicated that axial-flow technology is not yet sufficiently mature to form the basis of a viable design. For these reasons, the center hull uses a CODAG (Combined Diesel And Gas Turbine) arrangement with a single large waterjet (P&S) powered through a reduction gear by an MTU 8000 Diesel and a Rolls Royce 36mw Gas Turbine, as shown in figures 5 and 8. The side hull propulsion power is provided by a Kamewa 140SII waterjet directly connected to an MTU 8000 diesel engine. The potentially favorable submerged waterjet - hull interaction of the deep-draft side hull waterjets has to be further investigated.

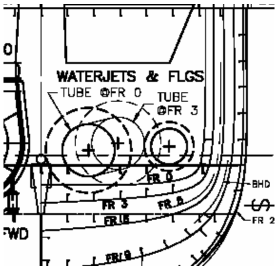


Figure 7 –HSTT-200 Machinery Arrangement with 4 Center-hull Waterjets

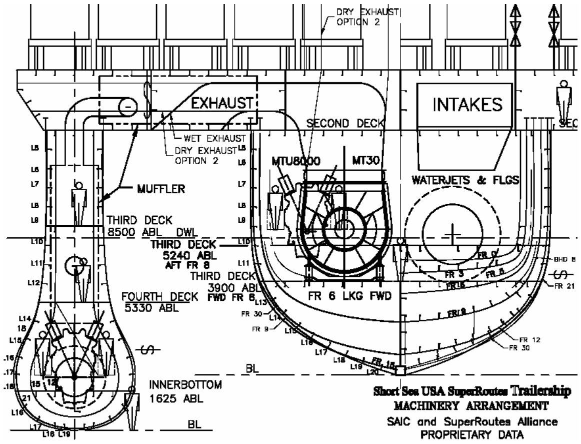


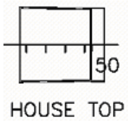
Figure 8 –HSTT-180 Machinery Arrangement - sections

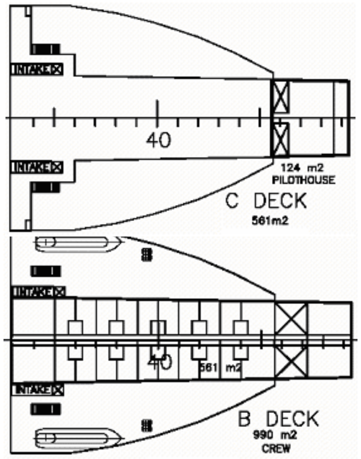
Diesel engine intake air is taken from the engine rooms, exhaust can be either wet or dry similar to the gas turbine exhaust options shown. The side hull diesel engine muffler is shown vertical in figures 5 and 8, but could be horizontal as shown in Figure 8. The mufflers shown are the largest mufflers which are commercially available, and leave little room for insulation and maintenance. Actual muffler sizes would require a noise study which is beyond the scope of this project.

The side hull lines need to be filled out slightly at the fourth deck to provide better access to the engine for maintenance and repair – this refinement also should have only minimal impact on power and will provide additional margin for weight growth.

Forward of the main engine room is an auxiliary machinery space for purifiers & generators above the third deck, with pumps, coolers and strainers below. Only ballast is stored in the double bottoms and forward – all fuel can be stored in protected locations. 540m3 MDO, 780m3 HFO and 780m3 JP-5 for the gas turbines are stored in center hull tanks above the third deck. There is about 600m3 of unassigned space forward for military stores & personnel. Bilge & Ballast Pumps are aft of the engine where the hulls are narrower. Fuel Oil Pumps are above the engine. The 200m3 Fuel Oil Settling Tank and 100m3 Fuel Oil Day Tank in the side hulls are too big and would actually be subdivided differently or used for more ballast. They are shown only to demonstrate sufficient capacity, even with a double-skinned day tank as shown in Figure 10. S.W. Ballast is carried below the Inner bottom aft and for the full height forward.

Deckhouse





Accommodations are provided for at least 38 passengers and 22 crew. Cabins for officers and crew are shown on B Deck. Single staterooms with shared heads are provided for the crew. Officers have private staterooms and heads, with quick access to the pilothouse on C Deck. The galley, mess, stores and lounges are on the

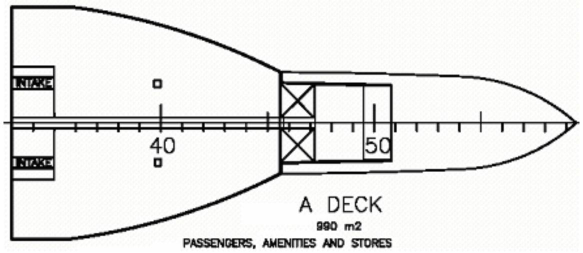


Figure 9 – VHSST-200 Deckhouse

A Deck. Passenger staterooms are on the A deck and double as riding crew berthing for overnight trips. There is room for six single cabins (VIP types) and eight four-berth staterooms for truck drivers or riding crew. Day seating and lounge space is provided on the A Deck for day trips.

The Main Deck house area is used for passage, mechanical spaces including emergency generator, and stores. Riding crew spaces are provided on the second deck immediately below the accommodations on the Main Deck. Drivers accompanying commercial or military Ro/Ro cargo will use the riding crew spaces on overnight routes. Space on the second deck may be converted to additional berthing for passengers, riding crew or military personnel as commercial routes or military missions require.

Lifeboats and inflatable liferafts are located on B deck aft at the maximum beam to avoid entrapment between hulls. Bridge wings are provided to assist docking and undocking, and also provide access to the lifeboats. The pilot house access to the bridge wings could be improved by moving it up and aft or by moving the bridge wings forward.

STRUCTURAL DESIGN

Hullform Considerations

The side hulls are carried below the center hull to maintain constant separation between hulls with a SWATH configuration while providing sufficient clearance for maintenance around the diesel engine. While this increases the cost of construction and maintenance, preliminary discussions with facilities have indicated that this increase is not a serious cost factor.

The longitudinal location of the side hulls has very little impact on the hydrodynamics. The location shown is the furthest forward practical location which was assumed required for proper trim. Preliminary studies indicate a need for about 250m3 of S.W. ballast forward to control trim, so the optimum location is probably slightly aft of that shown. Final location would be determined after the lines are finalized.

The shapes of both center and side hulls are best suited for longitudinal stiffening over their full length except for about 5m at each bow. The bows would be stiffened by breast hooks bracketed to the longitudinal stiffener ends except in the bulb area. The bulb area preliminary lines have an entry half-angle of less than 5° in the bulbs, which must be rounded to prevent cavitation vibration and facilitate construction. This refinement is beyond the scope of this project.

The HSTT-180 hull form presents a number of unique design and operational challenges:

The side hulls end at approximately midship, making them ineffective for longitudinal strength. The deckhouse also ends at approximately midship. This appears to leave a notch at midship. The notch effect is reduced by the flexibility of the connection between the side hulls and the deckhouse, but clearly a large bulwark of higher-strength steel will be required to bridge this gap.

The small keel and large stern overhang complicate blocking for both construction and periodic overhauls.

The large unsupported deck area is cantilevered off the main hull for much of its length.

Design Criteria

ABS Rules for Passenger vessels have only been applied to a relatively small number of vessels, none approaching the HSTT-180 in size and speed. For this reason, Lloyd's Rules were selected because of their extensive experience with high-speed ferries of a variety of sizes and materials. Lloyd's Rules have also been found to result in slightly lighter structures than ABS in many more traditional designs, and are more theoretically based than ABS Rules which tend to be experience based. The past experience with relative weights, plus the uncertainties of applying any Rules to a ship with this unusual hull form (for example, what values to use for length, beam and draft, and how to calculate block coefficient), has indicated a larger margin on weight estimates than is common for a design for which Rule scantlings have been calculated. No Classification Society will class the The HSTT-180 without extensive finite-element analysis – the Rule calculations described below are only an estimate of initial scantlings.

To reduce some of these uncertainties, the LR scantlings were compared with values estimated by NSWC Carderock Division (David Taylor Model Basin) based on earlier model tests. This comparison is given in Table 2.

	DTMB Predictions for		Lloyd's Rule values	Units
	Unrestricted Operations	US East Coast		
Wave BM, Hog	1,366,066	1,040,486	639,289	Kn-m
Wave BM, Sag	1,382,738	1,061,080	-1,077,550	Kn-m
Sqz/Pry Force*	4,060	2,440	2,374 *	tonnes
Scantlgs - Fwd tunnel sides	15.7	15.2	est 15 *	mm thick PL
	414.8	390.4	est 600 *	cm^3 stiffeners
Scantlgs - Mid tunnel sides	13.7	11.1	12.5	mm thick PL
	316.1	206.7	494.0	cm^3 stiffeners
Scantlgs - Mid wet deck	17.8	14.2	12.5	mm thick PL
	535.8	341.0	494.0	cm^3 stiffeners

*not directly from LR Rules - see text below.

Table 2 – Comparison of Lloyd's Rule Loads to Loads Predicted by DTMB (NSWCCD) for HSTT-180

The “tunnel” refers to the structure under the cross-structure connecting the outriggers to the center hull, with the wet deck forming the top of the tunnel and the center hull and outrigger shells forming the sides. Forward refers to the area about the leading edge of the outrigger and mid refers to the region around the longitudinal middle of the outrigger.

The LR scantlings for midbody plate thickness and minimum stiffener section modulus are for side shell plating below the sheerstrake; the NSWCCD values are obtained from LR Rules for WT bulkheads using design pressures estimated by NSWCCD. The LR forward tunnel side scantlings would be Rule bow scantlings which were not calculated but are estimated from midship values based on past experience.

Wave-induced side forces on the outrigger hulls cause them to squeeze inward and pry outward from the center hull. This “Sqz/Pry Force” in Table 2 is more fully discussed under “Transverse Strength” below.

Longitudinal Strength

Maximum still water bending moments were estimated to be 500,000 kN-m hogging and 220,000 kN-m hogging, reflecting the actual lightship weight distribution and sectional areas with the cargo weight uniformly distributed over the main deck. Longitudinal strength requirements were based on these plus Rule wave bending moments. The Rule wave loads (ABS is the same as Lloyd’s) are for a Rule length L=175.2m = .97LWL. This is probably conservative due to the narrow wave-piercing bow, but compares well to the NSWCCD predictions. Unlike most monohull designs, longitudinal strength governs only the center-hull bottom shell scantlings. Main deck scantlings are governed by vehicle loads, second deck by transverse strength and local hydrostatic loads, and side hull scantlings are governed by local hydrostatic loads.

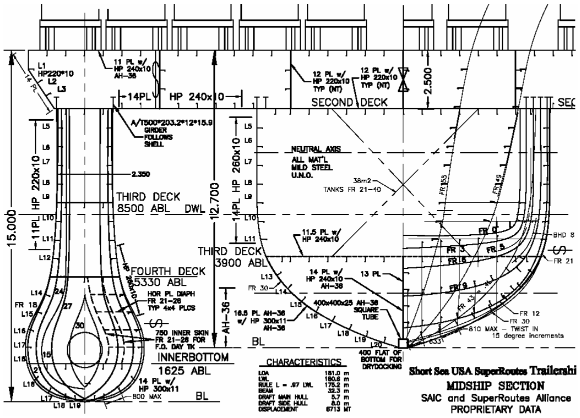


Figure 10 –HSTT-180 Longitudinal Sections

All material is steel. Mild steel is used for most of the hull – grade AH-36 higher-strength steel is used for the trailerdeck (for vehicle loads) and bottom shell (for longitudinal strength. Each location gave at least a 15% weight reduction from mild steel, giving a net reduction in cost as well as weight. Only the keel is thick enough to require higher toughness than AH-36 or grade A. Reinforcement is provided for keel blocks in both the center and side hulls.

Transverse Strength

There are three considerations for transverse strength – transverse web frames supporting shell and longitudinal bulkhead stiffeners, squeeze-pry forces, and transverse bulkheads. Transverse web frame scantlings and the number, spacing and scantlings of transverse bulkheads were calculated from LR Rules and are shown in figures 12 and 13. Squeeze-pry forces were estimated two ways, compared in the “Sqz / Pry” column of Table 2. Squeeze / Pry force is not directly

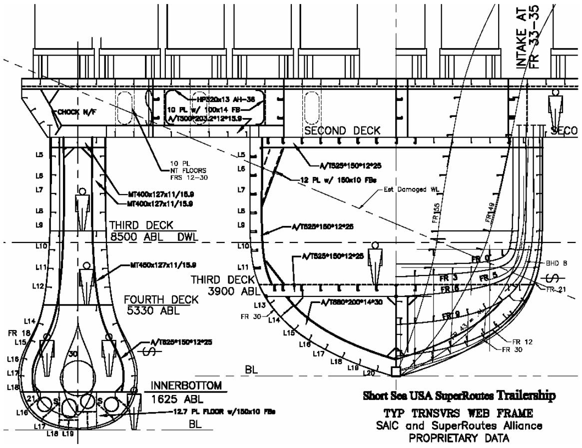


Figure 11 – Typical Transverse Web Frame

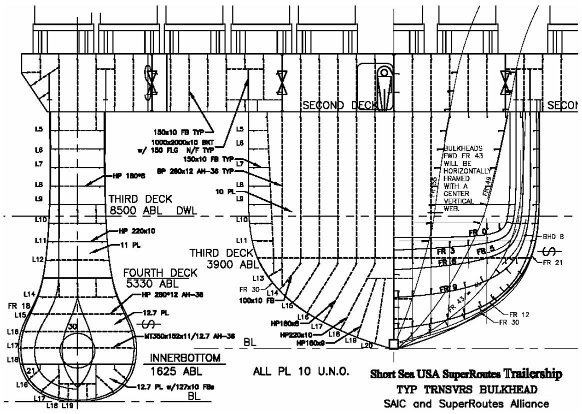


Figure 12 – Typical Transverse Bulkhead

given by Lloyd's – the Lloyd's value in Table 2 is the buoyancy force of the side hull at full load draft at the widest section, less the weight of both decks with no cargo. These forces are to be applied as a line load along the length of the outrigger at the mid-draft level.

Web frames are shown open with a web below the trailerdeck and another above the wet deck, with spans broken by longitudinal bulkheads. Several frames in way of the side hulls (frames 12-30) would be Non-Tight plate floors to better support the side hulls. These scantlings, shown in Figure 11, were calculated from LR Rule allowable stresses using beam theory.

Structural optimization was beyond the scope of this study. Scantlings were used only to better estimate weights and structural complexity for cost estimating.

ECONOMIC VIABIITY IN SSS TRADE

The United States Maritime Administration (MARAD) estimates that truck traffic on U.S. highways will at least double by 2020. Expanding highways is no longer a viable option. New highways cost $32-million per lane mile, and new highway interchanges cost over $100-million apiece.

Short sea shipping systems show excellent promise as an economical alternative to land-based trucking. High speed ships can provide a service at a competitive required freight rate, particularly considering the support that taxpayers spend building and maintaining the national highways.

The required freight rate (RFR or cost per trailer per equivalent highway mile) is influenced by a number of cost factors: capital costs; the ship's cargo carrying capacity; the shipping route and frequency of service; and the operating characteristics of the ship over these routes. Figure 13 shows the RFR for Port Canaveral to Wilmington Delaware at two design speeds.

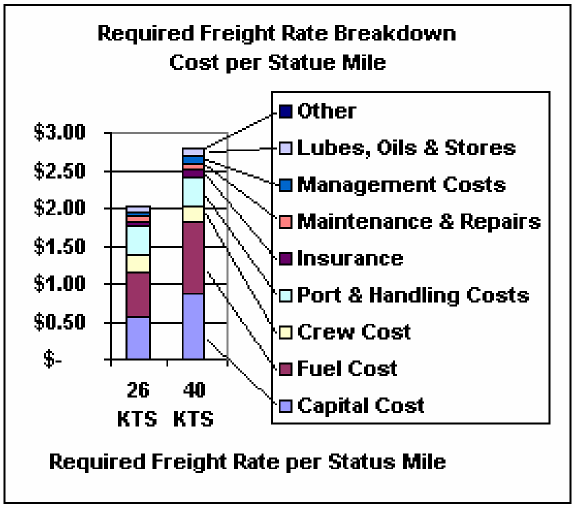


Figure 13 – Required Freight Rate

Capital costs include the design and construction costs and the equity and financing costs incurred by the ship owner. Construction costs were estimated using the ESTI-MATE program and the following light-ship weight distribution:

Structure-Ctr Hull	1,523 (1/4 AH-36)	Propulsion	598
2 Side Hulls	440	Electrical	60
Bridge Deck	1,656	Electronics & Navigation	20
Superstructure	351	Auxillary Systems	134
Foundations	150	Outfit & Furnishings	380
Bulwarks	75	Margin	672
Total Structure:	4,194	Light Ship	6,058 Metric Tons

Table 3 – HSTT-180 light-ship weight distribution

Estimated construction costs (Figure 14) were based upon ships being built at a mid-size commercial shipyard. The effects of design speed are further discussed in Figure 19.

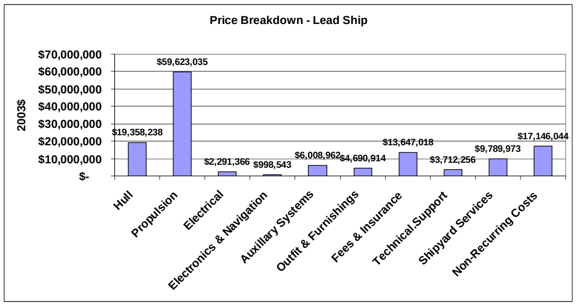


Figure 14 – Estimated Construction Costs

Construction costs can vary depending on the shipyard. Yards that historically do government work typically add considerably to the cost of construction (Figure 15). The cost variation is typically more affected by the manhours than by the cost per manhour.

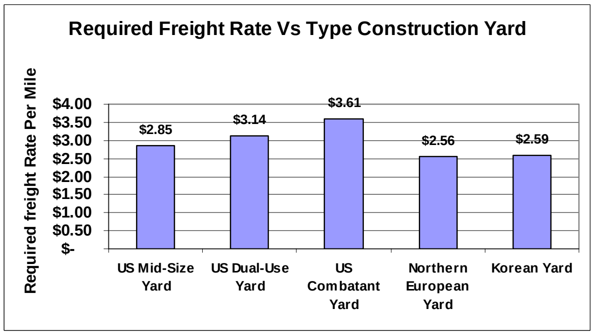


Figure 15 – RFR versus Type of Construction Yard

Multiple ship construction programs can reduce the capital costs per ship. Not only can series production reduce costs through appropriate learning processes, but the initial non-recurring design and engineering costs can be spread across more ships (Figure 16).

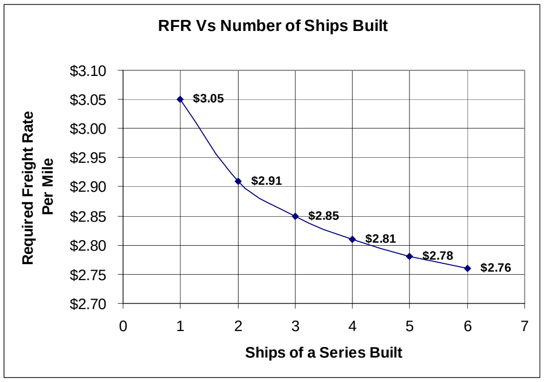


Figure 15– RFR versus Number of Ships Built

The choice of construction materials also impacts construction costs (Figure 17). The higher construction and maintenance costs of more exotic materials are not always offset by their potential benefits such as weight savings, unless there are positive benefits in increased payload and/or speed capabilities.

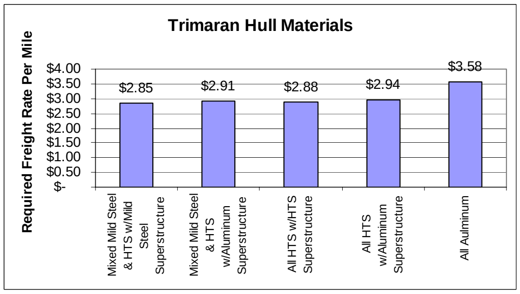


Figure 17 – RFR versus Construction Materials

Required freight rate is heavily influenced by the amount of cargo that can be transported over a given period of time. Generally, the more that can be carried in a single transit, the lower the RFR (Figure 18).

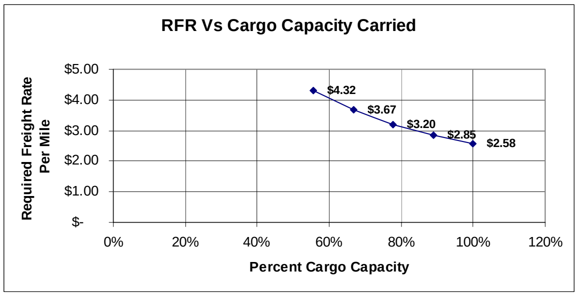


Figure 18 – RFR versus Cargo Carrying Capacity

Operating costs are significantly driven by the rate of fuel consumption. Higher speed allows more cargo to be transported over a given period of time, reducing the RFR. But at higher speeds, RFR will begin to increase as the escalating cost for fuel from increased consumption counters these savings (Figure 19).

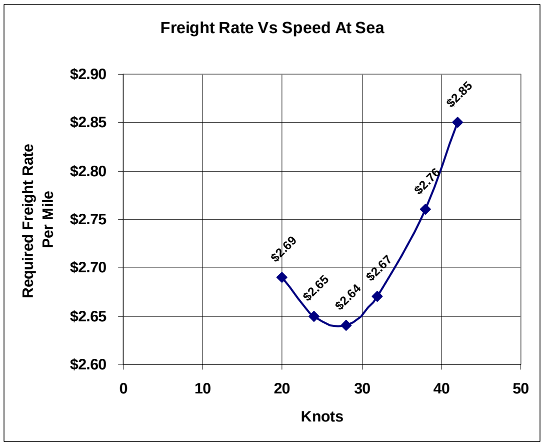


Figure 19 – RFR versus Speed At Sea

Figure 19 shows the cost sensitivity to speed of operation for the ship with a 40kt design speed. As shown in Figure 13, a dramatic reduction in cost can be achieved by reducing the design speed to 26 kts and eliminating the gas turbines and associated machinery. The gas turbines were included in the baseline design for two reasons – desirability for the military variant, and the need to have margin to assure schedule reliability in the event of port delays, a diversion, or mechanical breakdown.

Finally, as we all are painfully aware today, the cost of fuel has a direct influence on RFR (Figure 20). Highway trucking costs are also heavily impacted by fuel costs. The baseline price of fuel was $300 per metric ton.

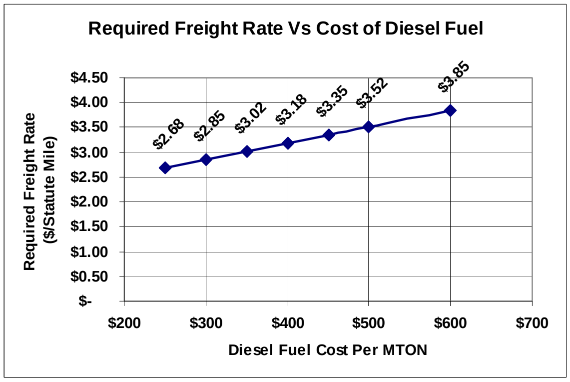


Figure 20 – RFR versus Cost of Fuel

Other variables in the operating route scenario that affect RFR are the port costs, time-in-port, number of days out of service, etc. Since the present design is only to the level of a feasibility study, the construction costs are also only roughly estimated.

To compare short sea transportation RFR fairly with land-based transportation RFR, the added costs of future road construction should be included, as well as the annual subsidy of these systems by the tax paying public. As a rough comparison, an unpublished study in November 2000 cited road trucking costs over $4.00 / trailer mile in the northeastern United States, indicating that water transportation is a viable alternative.

All considered, the short sea transportation alternative is very attractive from a cost point of view, for its capacity to relieve traffic congestion and air pollution, and for its contributions towards increasing passenger car safety on the highways. These public benefits appear to justify diverting public investment in highways to investment in improved port facilities and alternative transportation systems.

CONCLUSIONS AND FUTURE WORK

This paper has demonstrated that a coastal express service using a high-speed trimaran Ro-Ro could provide a viable alternative to coastal highways. Developing the optimum configuration of hull and machinery is a preliminary and contract design process challenge. Development of axial-flow waterjet technology could reduce waterjet diameters and increase the range of efficient operation, significantly improving the economics of multi-speed operation and simplifying the design.

The vessel is a multi-speed trimaran with a CODAG propulsion system in the center hull and medium-speed diesels in the side hulls. Multiple prime movers deliver optimum fuel economy throughout the full power range. This arrangement also provides outstanding maneuverability.

Development of axial-flow waterjet technology could permit the center hull CODAG arrangement to be replaced with a simple connection of each prime mover to its own waterjet, further improving simplicity and reliability.

The HSTT-180 is designed for dual operations: Roll on – Roll off cargo vessel (“Commercial mode”) and theater support /military sealift (“Military mode”). The vessel is designed for Short Sea Shipping operations with enhanced endurance at economical speed and high-speed capability to assure schedule reliability and flexibility.

In commercial operation, all Ro-Ro cargo (about 180 TEU) is carried on a single open deck, eliminating the need for mechanical ventilation and maximizing cargo mix flexibility. For sealift operations, wheeled, tracked and containerized cargo is carried on this deck and a second spar deck which is also open.

The least-cost structural design is primarily mild steel, with higher-strength (ABS grade AH-36) used in strategic locations (about ¼ of the total) to reduce weight and cost. Aluminum was generally found to be more expensive despite its lighter weight, due to the higher cost of material and fabrication.

Future work involves refining the concepts presented here to reduce hull weight and cost, improve access for maintenance, and design port facilities.

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The ideas expressed in this paper are those of the authors and do not necessarily reflect opinions of any of these companies or associates.

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