THE ECONOMIC CHALLENGES OF HIGH-SPEED, LONG RANGE SEA TRANSPORTATION

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ABSTRACT

This paper examines the underlying economic considerations affecting the ability to provide higher speed service at trans-oceanic ranges. The High-Speed Sealift Technology Workshop sponsored by the U.S. government in October 1997 established technology projections affecting the transport performance of high-speed commercial and military sealift ships. The workshop attracted international participation and resulted in a report that provides basic parametric relationships between ship characteristics and mission requirements including speed, range and payload. The Transport Factor approach proposed by Kennel was refined by the Workshop. The state-of-the-art of current technology was quantified and projections were made. The present paper translates these technology projections into the economic domain in order to define the economic basis for commercially motivated advances in this field. It is shown that the three components of the transport factor, i.e. lightship, fuel and cargo, can be related to the Required Freight Rate (RFR) for a given speed and range. The paper quantifies the nominal premium to the RFR that must be charged as speed and range increase. The paper discusses the underlying reasons for these increases. Significant increases in the RFR are indicated as speed and range increase. It is noted that the RFR is not a sufficient measure of merit and an approach considering all logistic costs is used. The effect on the total logistic cost of cargo value, cargo density, transit time, and loss of product value in transit are examined to help understand the conditions where increased ship speed may be economical. Several scenarios involving the future cost and performance characteristics of high-speed, long-range ships are examined to identify possible economic limits on speed and range. The analysis shows that under some conditions speeds up to 45 knots may be economic for trans-Atlantic operation. These conditions strongly depend on the initial cost of the ship and the ability to retain a low lightship weight as speed increases. While not ruling out the possibility of ship speed trans-Atlantic service, the analysis casts doubt on the concept of relying primarily on commercial factors to significantly advance the state-of-the-art for future high-speed sealift.

INTRODUCTION

Twice during the summer of 1998 high-speed ferries being delivered to Europe broke the record for the fastest Atlantic crossing by a commercial vessel. The results of a recent workshop on High-Speed Sealift Technology, Reference 1, indicate that substantial additional improvement in speed, payload and range are technically feasible. It was the consensus of a panel of international experts at this workshop that in the near term it is *scientifically* possible to carry a 5000 ton payload at 50 knots over 10,000 nm. These developments combined with the preliminary marketing and technology development of commercial interests promoting higher speed trans-oceanic service, References 2 and 3, have led some military transportation analysts to believe that high-speed trans-oceanic commercial transport will be available in the next 10 years and provide the foundation for future military sealift capability. While these developments are encouraging, the tendency has been to focus on performance and not economics. For instance, the trans-Atlantic records broken in 1998 by the two 91m INCAT vessels is an impressive example of speed and range; however, these records were set with virtually no payload. Significant values of all three parameters (speed, payload, and range) must be achieved simultaneously to demonstrate commercial or military utility in trans-Atlantic service.

The High-Speed Sealift Technology Workshop did not address *economic* feasibility. This paper investigates the underlying challenges of high-speed, long-range sea transportation from primarily an economic viewpoint building on the technology assessment of Reference 1. The factors, which affect the total logistic cost, are defined to establish the relationship between the major factors. The key factors are the time-value of the cargo and the cost of transportation. The Transport Factor approach used in References 1 and 4 is translated into an economic parametric relationship to indicate how speed and range influence the transportation cost. The total logistic cost is analyzed in order to determine under what circumstances increased speed and range can be economically justified.

ECONOMIC COST OF TRANSPORT CONSIDERATIONS

In order to determine how shipping economics are affected by increased speed and range, a comprehensive view is needed. In the most general sense there are five factors that affect total logistic costs. They are:

1. Interest charges on goods awaiting shipment
2. Interest charges on goods in transit
3. Interest charges on goods held in safety stock
4. Loss, damage or decay of goods between manufacture and sale
5. Cost of transportation

The first three factors are directly related to the value of the goods to be shipped. The fourth factor depends on the product's perishability. Perishability can be due to either the physical life of the product, e.g. fresh flowers, or to marketable life, e.g. designer clothes. Clearly as the transit time approaches the product life, this factor becomes very important. The fifth factor is the cost of the actual transportation service. Intuitively the cost of transport must increase as speed and range increase. The fundamental question is: as speed increases under what circumstances can the reduced time in transit (the first four factors) offset the increased cost of transportation (the fifth factor)? Before addressing this question these five factors will be discussed in greater detail.

1. Interest Charges on Goods Awaiting Shipment – As goods are produced, inventory is accumulated until a sufficient quantity has been produced to justify shipment. After each shipment the process repeats. If the quantity shipped is x, the average amount of goods on hand is x/2 and the cost of holding this quantity is:

$$\text{Origin Interest Cost} = i * v * x/2 \qquad \text{Equation 1}$$

Where: i = annual interest rate
v = value of each unit produced
x = the number of units accumulated for each shipment

2. Interest Charged on Goods In Transit – During the time goods are in transit they are in effect moving inventory and experience an inventory cost.

$$\text{In Transit Inventory Cost} = x * v * i * \frac{T}{365} \qquad \text{Equation 2}$$

Where: $x * v$ = the value of each shipment
$T/365$ = fraction of the year that goods are in transit

3. Interest Charges on Goods Held as Safety Stock – To account for variations in the delivery time of a shipment and to prevent running out of inventory a shipper may hold a reserve, called a safety stock. Assuming the variation follows a normal distribution, the shipper can choose a level of protection proportional to the standard deviation of the transit time.

$$\text{Safety Stock Cost} = \frac{i * v * x * (k * \text{sigma})}{365} \qquad \text{Equation 3}$$

Where: $(i * v * x)/365$ = the interest cost for one day of a shipment
Sigma = the standard deviation of the transit time
k = a multiplier corresponding to the degree of out of stock protection desired. 90% confidence corresponds to a k value of 1.28, 95% confidence factor corresponds to a value of 1.64.

4. Perishability or Decay Cost – Unlike the three above costs, the cost due to loss of product value is not related to the inventory cost. The key factor is the change in demand or product condition associated with the portion of the product's life that has passed since manufacture. As the time in transit approaches the life of the product the loss of product value increases.

$$\text{Perish or Decay Cost} = (1-\text{Sal}) * (v * x) * [T/L]^{d} \qquad \text{Equation 4}$$

Where: Sal = the product salvage value in percent
T = time spent in transit in days
L = product life in days
d = a commodity or industry specific decay parameter

Equations 1 through 4 are adapted from Reference 5.

5. The transportation cost is defined as the freight rate per unit being shipped times the number of units shipped. For a container ship the freight rate is typically the rate per Twenty-foot Equivalent Unit (TEU). The Required Freight Rate (RFR) is the rate a ship owner must charge the customer in order to return a reasonable return on investment. The Required Freight Rate is defined as:

$$RFR = [P*CR + Y]/C + f \qquad \text{Equation 5}$$

Where: P*CR is the single invested amount at year zero.
Y is the annual operating cost, and
C is the annual amount of cargo carried
f is a fixed cost associated with the containers.

The single invested amount, P, is equal to the first cost (price) of the ship times the Capital Recovery Factor, CR. The Capital Recovery Factor, sometimes denoted as (CR-i-N), is a function of the prevailing interest rate, i, useful life of the ship, N, and the tax rate, t. The annual operating costs, Y, includes fuel, crew, maintenance and administration. The dimensions of C are units of cargo revenue such as tons or TEUs. The fixed cost of the container, f, includes the initial cost of the container, its maintenance and repair, storage when empty, insurance and terminal fees. Values of RFR calculated in dollars per ton can be converted to dollars per TEU by multiplying by the nominal weight per TEU. The dimensions of RFR for a containership are therefore dollars per TEU.

Table 1 shows a spreadsheet that was developed to estimate the Total Logistic Cost using the above formulas.

The freight rate is based on a number of considerations including the cost of operation and supply and demand on a given route. The cost of operation is clearly influenced by the ship speed, capacity and route length. To understand how these factors relate to the cost of operation a related parametric model was developed. The following section describes how the Required Freight Rate can be approximated by translating the Transport Factor of Reference 2 into the economic domain.

INTRODUCTION TO TRANSPORT FACTOR ANALYSIS

The Transport Factor (TF) is a non-dimensional empirical measure of transportation utility developed by Kennel, Reference 4. The TF compares the utility of competing designs when performing a specific transport task. The transport factor is defined as:

$$TF = (K \bullet W)/(SHP_{TI}/V_K) \qquad \text{Equation 6}$$

Where:
K = non-dimensionalizing constant (= 6.87 for the units shown below)
W = weight (full load displacement, cargo weight, etc.), long tons
SHP_{TI} = total installed power (lift power + propulsion power for dynamically supported concepts), horsepower

V_K = average ship speed for a voyage (i.e., sustained or service speed), knots

INPUT			
PARAMETER	SYMBOL	UNITS	VALUE
Annual Interest Rate	i	percent	10.0%
Range	R	nautical miles	3000
Value Per Unit	v	dollars/unit	500
Number of Units	x	number	1000
Standard deviation of transit speed	Sigma	percent	5%
Salvage Value	SAL	percent	50%
Product Life	L	days	670
Decay Parameter	d	none	1
Value Density		$/pound	10
Density of Stowage		pound/ft^3	10
Cubic Value Density		$/ft^3	100
Value in shipment		dollars	500,000
Weight of shipment		tons	25.0
TEUs per shipment		TEUs	5

OUTPUT			
PARAMETER	Units	Baseline	Variable
Speed	knots	22	25
Time in Transit	days	5.7	5.0
Origin Interest Cost	dollars	25000	25000
In Transit Inventory Cost	dollars	778	685
Safety Stock Cost	dollars	1340	1179
Perish or Decay Cost	dollars	2120	1866
Interest and Perish Cost	dollars	29239	28730
Interest & Perish Savings	percent	0%	-2%
RFR	$/TEU	1455	1506
Transportation Cost	$	7273	7531
Total Logistic Cost	$	36512	36261
Change in Total Logistic Cost	percent		-1%

Table 1
SPREADSHEET FOR CALCULATING TOTAL LOGISTIC COST

In Reference 1 the Transport Factor was calculated for a large number of high-speed craft and ships and plotted as a function of speed. This plot is reproduced as Figure 1. Note that the data set used to generate Figure 1 included both “actual” ships and “designs”. The term “designs” refer to “…mature design concepts whose performance claims …were deemed plausible at the workshop by the Hullform and Propulsors working group”. It was considered necessary to include “designs” in order to establish the practical range for the Transportation Factor. The curve in Figure 1 defines the limit of realizable transport performance and corresponds to the limit line of demonstrated capabilities of the ships and mature designs. The plot also includes the results of point designs produced using a Design Synthesis Model (DSM), Reference 6. The DSM is a parametric analysis tool based on first-principle physics developed by Band, Lavis and Associates for the Office of Naval Research. The DSM designs were produced specifically to define the upper limits of realizable performance for this analysis. This limit is shown in Figure 1 and an empirical relationship was proposed by Reference 1:

$$TF = -7x10^{-5}(speed)^3 + 0.0238(speed)^2 - 2.6962(speed) + 108.22 \qquad \text{Equation 7}$$

with speed in knots

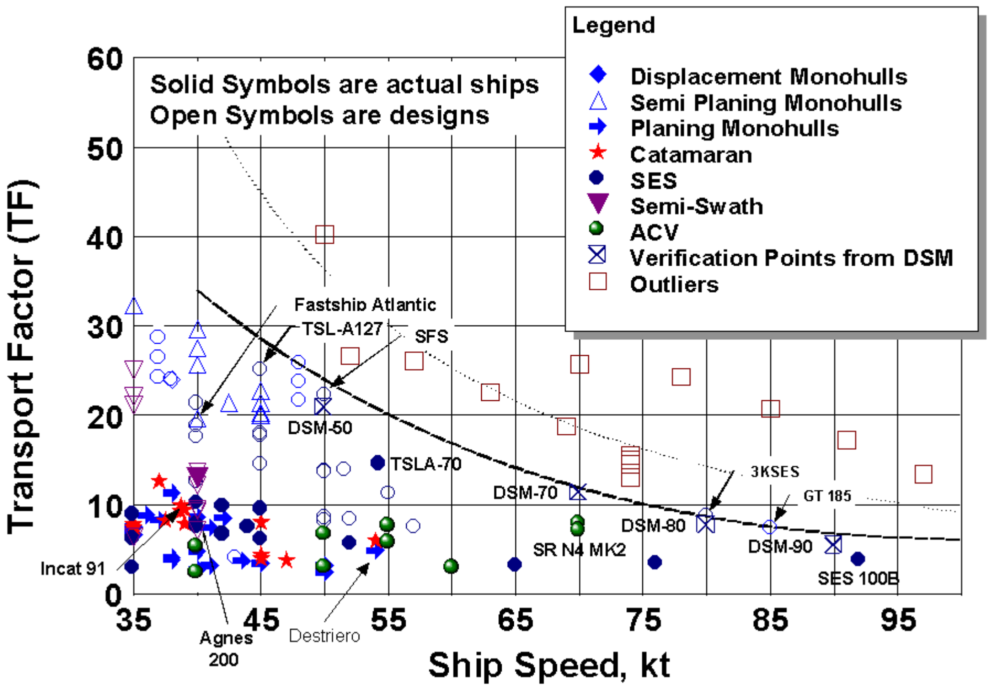

FIGURE 1
VEHICLE TRANSPORT FACTOR

The TF limit line represents the technical “edge of the envelope” for sealift transport. Reference 1 points out that, “The limit line does not imply ‘edge of the envelope’ performance can be achieved with all hullforms at all speeds. Instead, it implies that designs can be produced with at least one hullform that approaches this upper TF limit. The specific hullform(s) providing ‘edge of the envelope’ performance is expected to vary for different design requirements.” Reference 1 also points out that, ”… existing ships and mature designs in Figure 1 fall well below the ‘edge of the envelope’ limit line. This implies that commercially viable ships need not be designed for maximum scientifically achievable TF performance. To the contrary, designs with extreme TF performance are expected to require heavy investment in technology development to support successful design and production.” In fact, if a similar limit line were to be drawn through just the data points corresponding to existing vessels in financially successful service a much lower limit line would be established.

The key to relating the Transport Factor to the economic domain is to follow the approach used in References 1 and 4 of breaking TF into three elements corresponding to weight of cargo, fuel and lightship. Specifically:

$$TF = TF_{cargo} + TF_{fuel} + TF_{ship} \qquad \text{Equation 8}$$

where: TF_{cargo} = TF based on weight of cargo

TF_{fuel} = TF based on weight of fuel

TF_{ship} = TF based on weight of empty (lightship) ship

Equation (8) can be normalized by TF to yield:

$$1 = TF_{cargo}/TF + TF_{fuel}/TF + TF_{ship}/TF \qquad \text{Equation 9}$$

The terms TF_{cargo}/TF, TF_{fuel}/TF, TF_{ship}/TF are called transport fractions for the purposes of this paper. Note that a similar identity can be achieved by normalizing the individual weight components by the full load weight, W:

$$1 = W_{cargo}/W + W_{fuel}/W + W_{ship}/W \qquad \text{Equation 10}$$

The terms W_{cargo}/W, W_{fuel}/W, W_{ship}/W are generally known as weight fractions. We are interested in understanding how the weight and transport fractions relate to the economics of high-speed ships as speed and range increase. The key element is the weight fraction of cargo carried. It can be shown that the transport fractions are equal to the corresponding weight fractions. Therefore,

$$W_{cargo}/W = TF_{cargo}/TF = 1 - TF_{fuel}/TF - TF_{ship}/TF = 1 - W_{fuel}/W - W_{ship}/W \qquad \text{Equation 11}$$

Equation (11) mathematically states the obvious: as the fraction of the full load weight for fuel and empty ship increase, the fraction remaining for cargo has to decrease. As the cargo fraction approaches zero economic infeasibility is approached. These considerations are important as the range (and therefore the fuel load) increases and as the speed (and therefore the structural loads) increase. But what is this relationship?

The first step is to consider the fuel term. When the weight of fuel is non-dimensionalized in the same manner as the full load weight we find:

$$TF_{fuel} = \frac{W_{fuel}}{(SHP/\ V_K)} = 0.00307 * R * sfc \qquad \text{Equation 12}$$

where: R = Range in nautical miles, and sfc = Specific Fuel Consumption at corresponding speed, in pounds per HP-hour.

Equation (12) is linear when the ratio of fuel load to full load weight is small. For long ranges the fuel weight fraction will not be small and the effects of fuel burn-off, the Breguet range effect, has to be considered. The Breguet range effect reduces the amount of fuel required for a given range and introduces a non-linearity. The Breguet effect is approximated by the relationships shown in Figure 2, which is also taken directly from Reference 1.

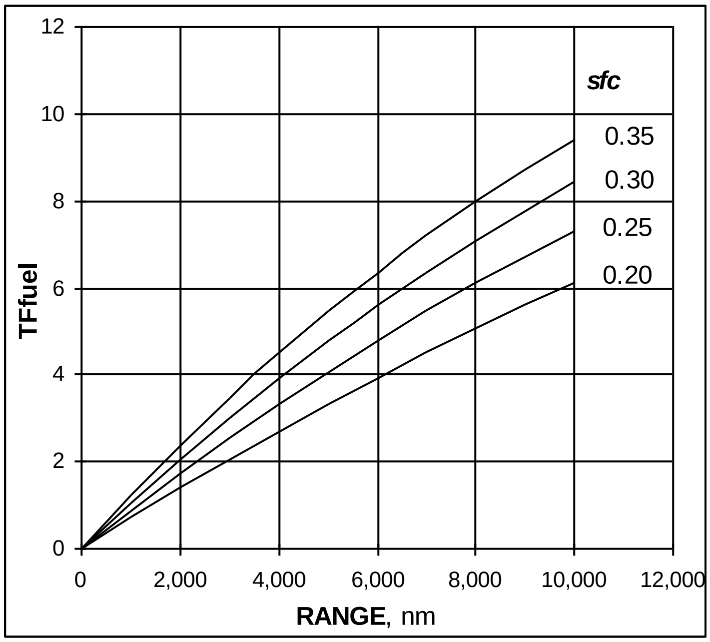

FIGURE 2
THE BEHAVIOR OF TF_{fuel}

The next term to consider is the empty ship or lightship term. As discussed above, the transport fraction for the empty ship is the same as the empty ship weight fraction. Representative empty ship weight fractions are shown in Figure 3, which is also taken from Reference 1. Figure 3 shows that representative empty ship weight fractions are between 0.55 and 0.75. The relationship with respect to speed is not evident. However, it is intuitive that this weight fraction should increase with speed.

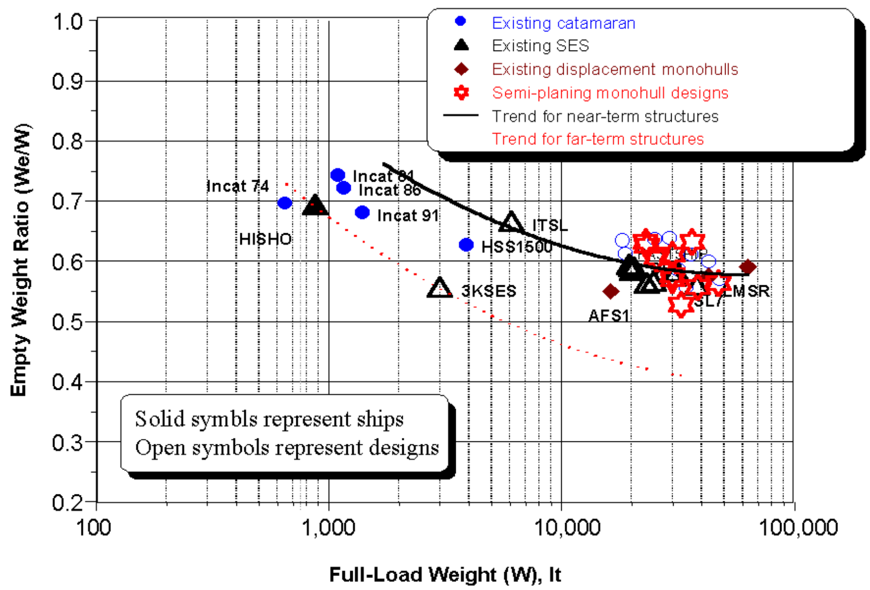

FIGURE 3
EMPTY WEIGHT TREND

Review of the original data used to develop Figure 3 indicates that, since there are no actual high-speed ships with full load displacements over about 4000 tons, the right hand side of the chart is dominated by design studies and large, relatively high speed ships like the SL-7. This tends to obscure the tendency for the empty weight fraction to increase with speed. Plotting the empty ship weight fraction, which is identical to TF_{ship}/TF, as a function of speed is arguably a better approach because SHP_{TI} in Equation 6 is approximately linear with respect to weight, but increases to approximately the third power with respect to speed. This captures the fact that as speed increases, installed power and therefore propulsion weight must increase. The higher machinery weight combined with higher structural weight associated with increased hydrodynamic loads causes the empty ship weight fraction to increase with speed. Figure 4 shows this effect for a number of existing containerships and fast ferries.

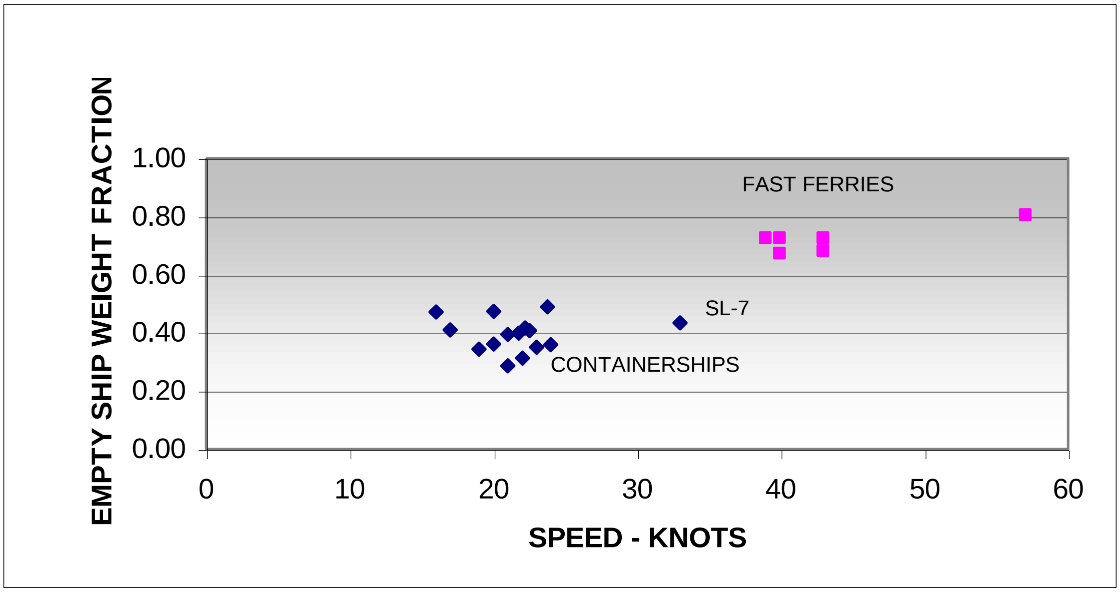

FIGURE 4
EFFECT OF SPEED ON EMPTY WEIGHT FRACTION

RELATING THE REQUIRED FREIGHT RATE TO THE TRANSPORT FACTOR

In order to understand how the Required Freight Rate is influenced by increases in speed and range it is necessary to develop the parametric relationship between the RFR and the transport factor fractions and weight fractions described above. The precise value of RFR can not be established with the very limited information in these parameters. However, fundamental trends and relative differences can be established with these parameters by introducing a few additional simplifying assumptions. Since the simplifying assumptions are relatively gross it is important to distinguish the resulting parameter from the actual Required Freight Rate. Therefore, approximate RFR based on the transport factor is noted as $\underline{RFR}$.

$$\underline{RFR} = F(TF_{cargo}/TF,\ TF_{fuel}/TF,\ TF_{ship}/TF,\ R,\ V_K) + f \qquad \text{Equation 13}$$

$$= F(W_{cargo}/W,\ W_{fuel}/W,\ W_{ship}/W,\ R,\ V_K) + f$$

To calculate the $\underline{RFR}$ we need to find expressions for P, Y and C using speed and range and the weight fractions or transport fractions.

For generally similar ships, the single invested amount P is, to a first approximation, directly proportional to the empty weight of the ship multiplied by the appropriate capital recovery factor.

$$P = k_1 * W_{ship} * CR \qquad \text{Equation 14}$$

k_1 is the slope of the plot of price as a function of empty weight. It is a constant that has dimensions of dollars per ton. The value of k_1 greatly depends on the type of ship as shown in Figure 5. The values of k_1 are bounded by containerships on the low side and fast ferries on the high side. For containerships the value of k_1 is about 2200 dollars per ton. For current fast ferries the value is about 39,000 dollars per ton. The data shown in Figure 5 are all existing ships. The large difference in the values of k_1 represents one of the biggest challenges for high-speed sea transportation.

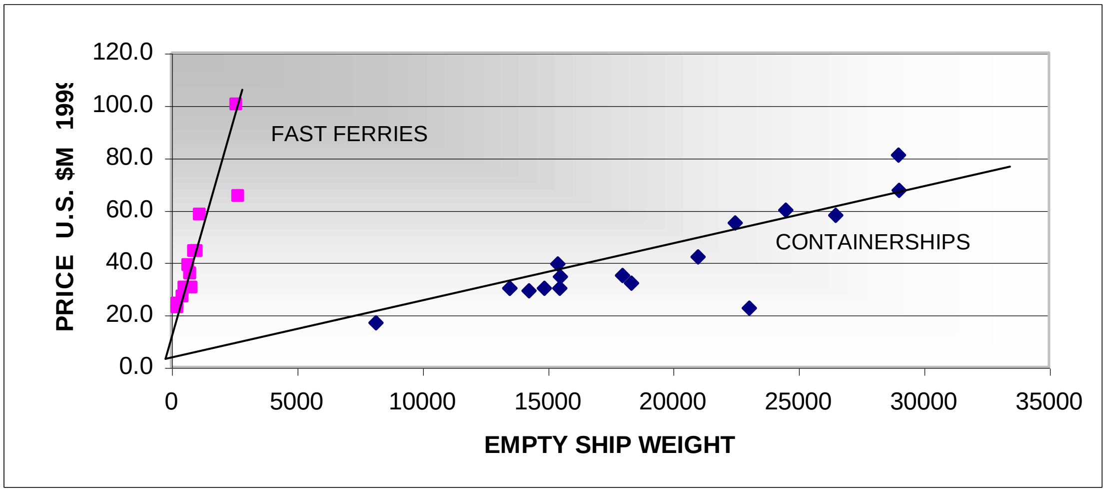

FIGURE 5
PRICE vs EMPTY WEIGHT

The annual operating cost is proportional to the amount of fuel burned per year plus the annual crew and maintenance cost. Assuming the ship burns half of its fuel on each trip, the cost of fuel burned per year, Y_{fuel}, is:

$$Y_{fuel} = k_2 * W_{fuel} * \frac{N_{trips}}{2} \qquad \text{Equation 15}$$

Where: k_2 is essentially the cost of fuel in dollars per ton. Current values of this parameter are about 150 dollars per ton for MDO.

The number of trips per year is simply:

$$N_{trips} = \frac{365 - T_{in\ maintenance}}{(R/(24 * V_K) + T_{in\ port}} \qquad \text{Equation 16}$$

Where: $T_{in\ port}$ is the average time in days spent in port between trips and $T_{in\ maintenance}$ is the number of days per year the ship is out of service for maintenance; in this analysis the value is assumed to be 10.

The annual cost of manning, maintenance and administration involves a number of factors, but to a first order is proportional to the empty ship weight.

$$Y_{m\&m} = k_3 * W_{ship} \qquad \text{Equation 17}$$

Here k_3 is by definition the annual manning, maintenance and administration cost divided by the empty ship weight. It has the dimensions of dollars per ton.

The final component is the annual amount of cargo delivered. This amount is clearly a function of the capacity of the ship, the utilization of the capacity and the number of trips per year.

$$C = k_4 * W_{cargo} * N_{trips} \qquad \text{Equation 18}$$

k_4 is effectively the utilization rate of the available cargo capacity. It is non-dimensional.

Using Equations (14) through (18), an expression for the ***RFR*** can be developed:

$$\underline{RFR} = \frac{k_1 * W_{ship} * CR + k_2 * W_{fuel} * N_{trips} + k_3 * W_{ship}}{k_4 * W_{cargo} * N_{trips}} + f \qquad \text{Equation 19}$$

Equation (19) can be expressed in terms of weight fractions by dividing the numerator and denominator by the full load weight, W.

$$\underline{RFR} = \frac{k_1 * W_{ship}/W * CR + k_2 * W_{fuel}/W * N_{trips} + k_3 * W_{ship}/W}{k_4 * W_{cargo}/W * N_{trips}} + f \qquad \text{Equation 20}$$

To make Equation (20) responsive to changes to speed and range, the fuel weight fraction (W_{fuel}/W) can be replaced by the fuel transport fraction TF_{fuel}/TF. TF_{fuel}/TF can be calculated by finding TF_{fuel} from Equation (12) and dividing by the transport factor given by Equation (7). It is also insightful to replace the cargo weight fraction by the identity expressed in Equation (11).

The final expression for ***RFR*** is:

$$\frac{1}{(1 - 2*TF_{fuel}/TF - W_{ship}/W)} * \frac{k_1 * W_{ship}/W * CR + k_2 * TF_{fuel}/TF * N_{trips} + k_3 W_{ship}/W}{k_4 * N_{trips}}$$

Equation 21

The factor of 2 introduced in the denominator of Equation 21 accounts for the assumption that the ship carries sufficient fuel for a round trip. A number of factors are neglected in the above derivation including: (1) the increased research and development costs associated with developing a higher speed ship, and (2) increased cargo handling infrastructure that may be needed to minimize in port time.

The simplifying assumptions made in order to arrive at Equation (21) are clearly rather simplistic. In order to minimize the effect of these simplifications and the neglected costs noted above, the notion of a ***RFR*** premium is introduced. Basically, the ***RFR*** premium is the percent change from some arbitrary baseline value that occurs due to a change from the baseline value of one or more of the variables used to calculate ***RFR***.

$$\underline{RFR}_{\text{premium}} = \frac{\underline{RFR} - \underline{RFR}_{\text{baseline}}}{\underline{RFR}_{\text{baseline}}} - 1 \qquad \text{Equation 22}$$

Using Equation 22 the behavior of the premium on ***RFR*** should reasonably approximate the premium on the actual RFR. In this manner key trends and approximate magnitudes of changes to the RFR can be studied. The spreadsheet, which calculates RFR and RFR premium, is shown in Table 2.

PARAMETER	VALUE	UNITS	DEFINITION
N	20	YEARS	USEFUL LIFE OF SHIP
I	10%	%/YEAR	INTEREST RATE
t	40%	%/YEAR	TAX RATE
k1	2200	$/TON	COST OF SHIP PER TON OF LIGHTSHIP DISPLACEMENT.
k2	150	$/TON	COST OF FUEL PER TON
k3	260	$/TON	AVERAGE ANNUAL MANNING AND MAINTENANCE COST PER TON OF LIGHTSHIP
k4	0.70	NONE	AVERAGE UTILIZATION OF AVAILABLE CARGO CAPACITY IN PERCENT
d	0.40	% TRIP	AVERAGE LOADING/UNLOADING TIME (DELAY)
f	1200	$/TEU	INCLUDES CONTAINER MAINTENANCE, CARGO INSURANCE, EMPTY STORAGE, ETC.
TFship/TF	VARIOUS	NONE	RATIO OF LIGHTSHIP TO FULL LOAD FROM FIGURE 4
Vk	VARIOUS	KNOTS	AVERAGE VOYAGE SPEED
R	3000	nm	DISTANCE BETWEEN PORTS

CALCULATIONS			
TFfuel @ Range	3.16	NONE	TRANSPORT FACTOR FOR FUEL FROM FIGURE 2
CR AFTER TAX	0.12		CAPITAL RECOVERY FACTOR AFTER TAX
CR	0.16		CAPITAL RECOVERY FACTOR

ITEM	22	25	30	35	40	45	50	55	60	65
TF	59.68	54.60	46.86	40.01	33.97	28.71	24.16	20.28	17.01	14.30
TFfuel/TF	0.11	0.12	0.14	0.16	0.19	0.22	0.26	0.31	0.37	0.44
TFship/TF	0.42	0.47	0.54	0.60	0.65	0.70	0.74	0.77	0.81	0.84
TFcargo/TF	0.47	0.42	0.33	0.24	0.16	0.08	0.00	-0.09	-0.18	-0.28
P ($/TON)	150	167	193	214	233	249	263	277	289	300
Y_{FUEL}	334	409	567	771	1020	1339	1748	2247	2902	3684
$Y_{M\&M}$	109	122	140	156	169	181	192	201	210	218
Y ($/TON)	443	530	707	927	1189	1520	1940	2448	3112	3902
NUMBER OF TRIPS	42	47	56	65	73	81	89	96	104	111
C (EFFECTIVE # OF TRIPS)	29	33	39	46	51	57	62	67	73	78
1/(TFcargo/TF) (=1/W_{CARGO}/W)	2.1	2.4	3.1	4.1	6.1	12.0	1117.2	NA	NA	NA
<u>RFR</u> ($/TEU)	1455	1506	1623	1819	2224	3449	238261	NA	NA	NA
<u>RFR</u> premium		4%	12%	25%	53%	137%	16279%	NA	NA	NA

TABLE 2
SPREADSHEET FOR CALCULATING ***RFR***

A study was performed to determine the sensitivity of ***RFR*** $_{\text{premium}}$ to variation in the input parameters. Table 3 shows how the ***RFR*** $_{\text{premium}}$ changes when each input parameter is varied by 20 percent. The table shows that ***RFR*** $_{\text{premium}}$ is insensitive to variation in most of the input parameters. The only input parameters that cause significant variation in ***RFR*** $_{\text{premium}}$ are k_3, the operating cost per ton, and f, the container fixed cost. In both cases where these parameters are increased by 20 percent the ***RFR*** $_{\text{premium}}$ decreases by 14 percent relative to its baseline value. This is because when these costs increase the change in ***RFR*** $_{\text{premium}}$ due to other factors is reduced.

PARAMETER	UNITS	BASELINE VALUE	BASELINE PLUS 20%	*RFR* premium % CHANGE FROM BASELINE					
				Vk = 25	Vk = 30	Vk = 35	Vk = 40	Vk = 45	Vk = 50
N - USEFUL LIFE OF SHIP	YEARS	20	24	0.0%	0.0%	0.0%	0.0%	0.0%	
I - INTEREST RATE	%/YEAR	10%	12%	2.2%	1.9%	1.6%	1.5%	1.4%	1.3%
t - TAX RATE	%/YEAR	40%	48%	1.4%	1.2%	1.0%	1.0%	0.9%	0.8%
k1 - SHIP PRICE PER TON	$/TON	2200	2640	2.6%	2.2%	1.9%	1.8%	1.6%	1.5%
k2 - PRICE OF FUEL PER TON	$/TON	150	180	1.9%	1.6%	1.4%	1.3%	1.2%	1.1%
k3 - OPERATING COST PER TON	$/TON	260	312	-14.2%	-14.2%	-14.2%	-14.2%	-14.2%	-14.2%
k4 - CELL UTILIZATION RATE	NONE	0.70	0.84	-0.2%	1.6%	1.7%	1.1%	0.8%	0.6%
d - LOAD/UNLOAD TIME	% TRIP	0.40	0.48	-0.2%	1.6%	1.7%	1.1%	0.8%	0.6%
f - CONTAINER FIXED COST	$/TEU	1200	1440	-14.2%	-14.2%	-14.2%	-14.2%	-14.2%	-14.2%

TABLE 3
INPUT PARAMETER SENSITIVITY STUDY RESULTS

TRANSPORTATION COST OF INCREASING SPEED AND RANGE

The preceding derivations and the spreadsheets shown in Tables 1 and 2 provide the basis for a parametric evaluation of the major factors affecting the economics of high-speed, long-range sea transportation. Two scenarios will be studied. The “optimistic” scenario assumes that: (1) containership-like prices can be maintained as speed and range are increased, (2) containership-like empty weight fractions can be maintained as speed and range increased and (3) the limit line for the Transport Factor shown in Figure 1 is achievable. The “pessimistic” scenario assumes that: (1) prices similar to existing fast ferry will be needed as speed and range increase, (2) empty ship weight fractions will increase with speed following the trend of demonstrated ships, and (3) the limit line for the Transport Factor shown in Figure 1 is achievable. These two scenarios bracket the problem.

Figure 6 shows how $\underline{RFR}_{\text{premium}}$ changes as a function of speed and range for the optimistic scenario. The $\underline{RFR}_{\text{premium}}$ uses a baseline speed of 22 knots which is representative of current trans-ocean containerships. Figure 6 shows that under these assumptions, the premium on required freight rate is modest (less than a 20 percent increase) up to about 40 knots. The rapid increase in $\underline{RFR}_{\text{premium}}$ at a range of 5000 nm

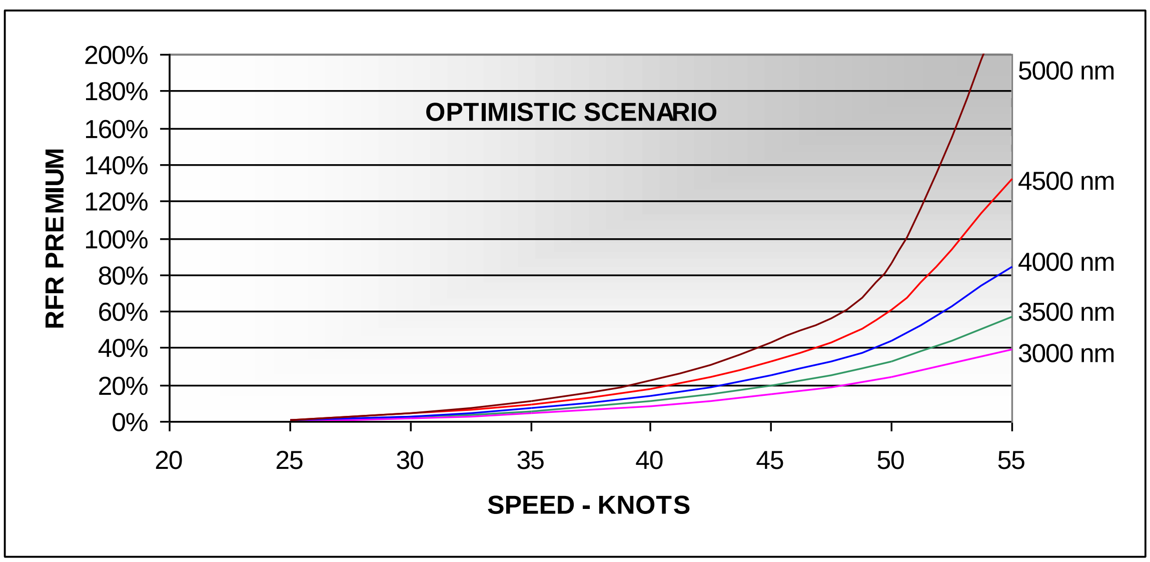

FIGURE 6
EFFECT OF SPEED AND RANGE ON RFR PREMIUM - OPTIMISTIC SCENARIO

and 50 knots casts doubt on the economic ability to achieve the scientifically achievable value of 10,000 nm at 50 knots with a 5000 ton payload.

The results of using the assumptions of the pessimistic scenario are shown in Figure 7. In this figure the $\underline{RFR}_{premium}$ is taken relative to the value of a 22 knot containership. The premiums represent the nominal increases over current required freight rates for equivalent distances. The $\underline{RFR}_{premium}$ is very large even at relatively modest increases in speed and range.

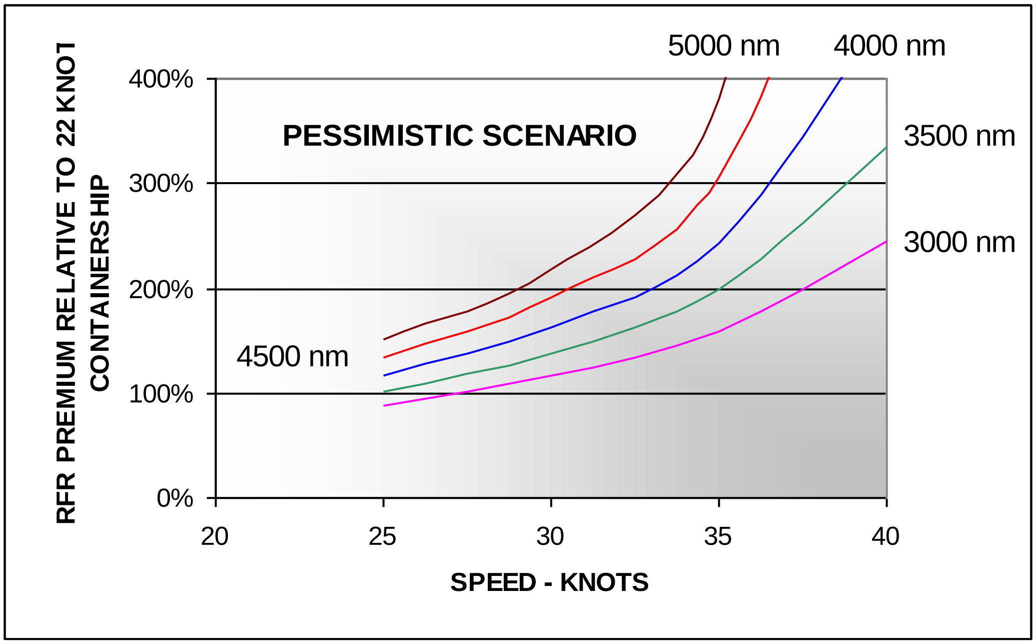

FIGURE 7
EFFECT OF SPEED AND RANGE ON RFR PREMIUM
PESIMISTIC SCENARIO

A large part of the $\underline{RFR}_{premium}$ increase is due to the significantly higher price per ton of empty ship that is indicative of fast ferries. Figure 5 shows that this difference is about an order of magnitude. To study the effect of ship price on the $\underline{RFR}_{premium}$, the pessimistic scenario was used, but with a ship price 50 percent greater than current containerships. The results are shown in Figure 8. This figure shows that modest increases in the RFR are achievable for speeds up to 40 knots and trans-Atlantic range if the price per ton of ship is on the order of 50 percent more than current containerships. For longer ranges the $\underline{RFR}_{premium}$ increases rapidly.

The RFR premium is indicative of the trend in transportation cost, but it is only one element of the Total Logistic Cost. It is important to consider the effect of increased speed on the reduction of inventory and perishable costs. This evaluation is done in the next section.

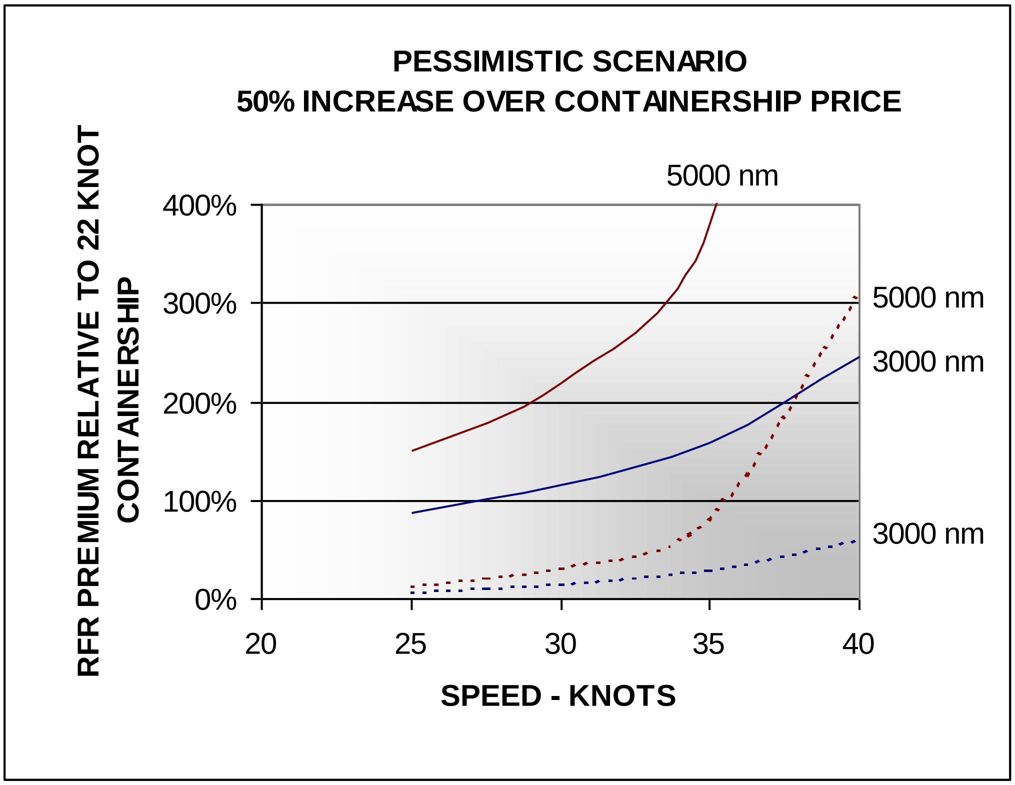

FIGURE 8
EFFECT OF SPEED AND RANGE ON RFR PREMIUM
PESIMISTIC SCENARIO WITH CONTAINERSHIP PRICES

TOTAL LOGISTIC COST OF INCREASED SPEED AND RANGE

Transportation costs are only part of the total logistic cost and therefore the higher freight rates discussed above should not be used as the primary factor for determining the economic viability of increased speed and range.

The evaluation of the effect of speed and range on the total logistic cost is more complicated than the preceding look at transportation cost because consideration must be given to the nature of the cargo including its cost, density and perishability.

The Total Logistic Cost spreadsheet was used to determine under what conditions the transportation cost of increased speed was compensated by (1) the reduction of in transit inventory cost, (2) safety stock cost and (3) perish or decay cost. The model was run for a range of value density ($/cubic foot) and storage density (pounds per cubic foot) that generated values of cubic value density (CVD) between 20 and 2000 dollars per cubic foot. Cubic Value Density is a key parameter because it drives the number of containers required for a given value of cargo. For instance, if the value of a certain cargo is $500,000 and it has a CDV of $60 per cubic foot, 8333 cubic feet of space will be needed. Assuming an 85% stowage factor inside the container, eight TEUs will be needed for the shipment. The lower the CVD, the more containers will be required and the higher the transportation cost.

The speed at which there was no difference in Total Logistic Cost relative to the 22 knot baseline was found for a range of CVD. Above this speed, the cost of transportation exceeds the savings due to in transit inventory, safety stock and decay cost. There is no economic reason to use a faster service – the shipper would be better off economically to use a slower service at a lower transportation cost.

Figure 9 shows this nominal boundary for the optimistic scenario and ranges of 3000 and 5000 nautical miles. The figure shows that if the required freight rates of the optimistic scenario can be achieved, speed increases of up to about 45 knots are justified for cargoes with a cubic value density of around 100 $ per cubic foot. Cargoes currently shipped at a CVD of 100 dollars per cubic foot could be shipped at up to 45 knots with no increase – and perhaps some saving - in the Total Logistic Cost. The transportation cost above 45

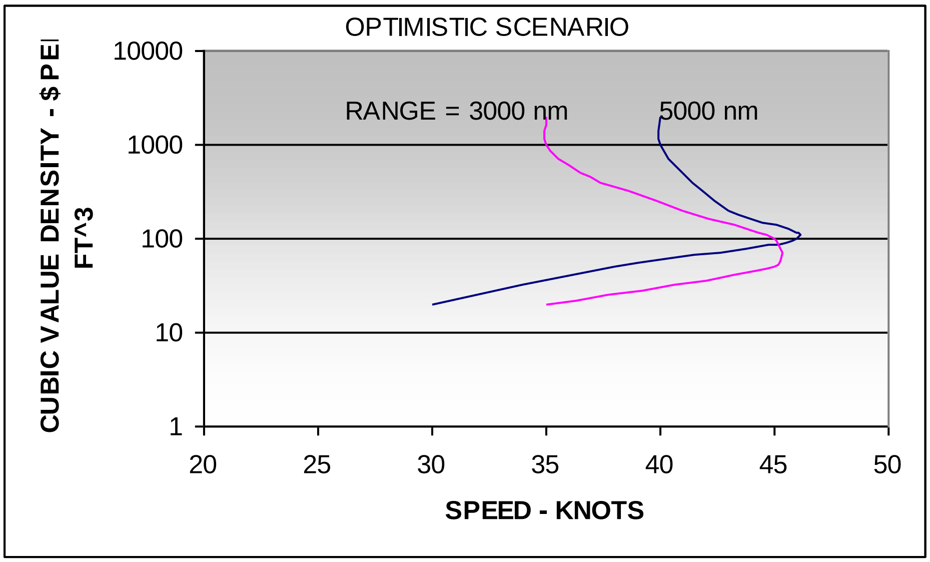

FIGURE 9
ECONOMIC BOUNDARY FOR HIGH SPEED SEA TRANSPORT

knots exceeds the reduction of the other logistic costs. Since this is the optimistic case, which is unlikely to be achieved, 45 knots represents a nominal economic speed limit. In other words, making the most optimistic assumptions reasonable, it appears unlikely that speeds over 45 knots for long range transportation are justified. The above example is for a cargo with low perishability, namely a two year shelf life and 50 percent salvage value.

Figure 10 shows a comparison between the economic boundaries of the optimistic and pessimistic scenarios for a range of 3000 nautical miles. For the pessimistic scenario the figure shows that an increase in speed from 22 knots is only justified for high cargo value densities, i.e. CVD greater than 200 dollars per cubic foot. High CVD values are indicative of air freight cargoes.

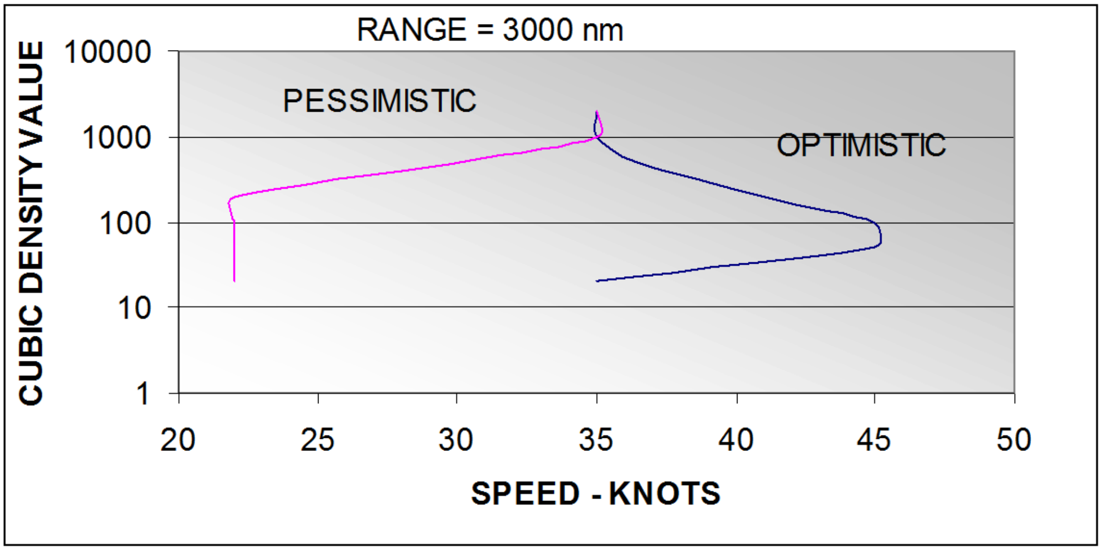

FIGURE 10
ECONOMIC BOUNDARIES FOR OPTIMISTIC AND PESIMISTIC SCENARIOS

CONCLUSIONS

The conclusions of Reference 1 that "…designs with 5000 ston payload capability are scientifically feasible, using near term technology, for speeds well in excess of existing ships" should be tempered with the understanding that the commercial viability of such ships is questionable. While the growth in fast ferry size and speed over the last 10 years has been impressive and continued improvements are likely, projecting these improvements to trans-oceanic distances is hazardous. Even with the most optimistic assumptions reasonable and taking into consideration the total logistic cost and benefits of the increased speed, it appears that speeds greater than 45 knots are not economic unless the cargo is perishable. This is due to the inherent physics of the problem which causes disproportionate increases in installed power as speed increases – regardless of the hull type. This is evidenced by the dramatic reduction in the Transport Factor as speed increases.

There are economic advantages to increased speed under some conditions up to about 45 knots. Significant reductions in the first cost of future high-speed, long-range ships are essential for their commercial viability. They face very tough competition from highly efficient conventional ships. While holding the initial price down their useful payload fractions must be competitive with existing conventional ships. These are significant challenges that militate against commercial development. The economic challenges of high speed ships for trans-oceanic operations stems from their very high price relative to conventional containership of equivalent payload capacity as well as their relatively large structure and machinery weight relative to containerships. Improvements in technology will tend to improve *both* high-speed and conventional ships. For instance, if a high-speed ship uses a new gas turbine with a ten percent improvement in specific fuel consumption, that same engine could likely be used on a conventional ship with the economic advantage still belonging to the conventional ship. Therefore, technology improvements should not be relied upon to erase the economic differences between high-speed and conventional ships.

The assumption made by some defense planners, that high-speed, trans-oceanic commercial ships will be available in the 2010 time frame to transport military cargo, has not been disproved by this analysis. However, if the U.S. military truly needs higher speed trans-oceanic logistic ships, the only sure way to obtain them is at tax-payer expense.

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