LIFE CYCLE COST OF MAINTAINING THE EFFECTIVENESS OF A SHIP'S STRUCTURE AND ENVIRONMENTAL IMPACT OF SHIP DESIGN PARAMETERS

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SUMMARY

In order to maintain shipping capacity to serve seaborne trade, new ships have to be built to replace those scrapped. The cost of building, manning, operating, maintaining and repairing a ship throughout its life is borne by society at large through market mechanisms. This paper investigates, through a cost/benefit analysis, how the average annual cost of ship transport varies with the corrosion additions elected at the design stage. The results of this study clearly indicate that ships built with corrosion allowances dictated by experience, adequate for the ship's design life, when all factors have been taken into account, have a lower Life Cycle cost per annum (AAC) for the maintenance of the integrity of their structure. This despite the fact that they would carry a slightly smaller quantity of cargo and therefore their income over time would be marginally less.

NOMENCLATURE

ABS: American Bureau of Shipping
CSR: Common Structural Rules
DD: Drydock
DNV: Det Norske Veritas
DRE: Daily Running Expenses (USD)
DT: Down Time
DWT, DW: Deadweight (metric tones)
GBS: Goal Based Standards
IACS: International Association of Classification Societies
IMO: International Maritime Organization
JBP: Joint Bulker Project
Life Cycle Cost per annum (AAC): is the Life Cycle cost divided by the number of years the ship is expected to be in operation. This concept represents the Average Annual Cost (ACC) for the ship's operation
LRS: Lloyd's Register of Shipping
Mt, t: Metric tones
NAABSA: Not Always Afloat But Safely Aground
NKK, Class NK: Nippon Kaiji Kyokie
PP: Purchase Price (USD)
SSY: Simpson, Spence and Young
TSCF: Tanker Structure Cooperative Forum

1. INTRODUCTION

Shipping transports over 90% of world trade. In order to maintain shipping capacity to serve this trade, new ships have to be built to replace those scrapped. The cost of building, manning, operating, maintaining and repairing a ship throughout its life is borne by society at large through market mechanisms.

This paper investigates, through a cost/benefit analysis, how the average annual cost of ship transport varies with the corrosion additions elected at the design stage.

No attempt is made to differentiate between sale and purchase decisions of various owners throughout the ship's life since, because regardless of ownership, a ship will continue to be repaired and traded until scrapped. As previously stated, through market mechanisms, these costs will be borne by society.

The results of this study clearly indicate that ships built with corrosion allowances dictated by experience, adequate for the ship's design life, when all factors have been taken into account, have a lower Life Cycle cost per annum (AAC) for the maintenance of the integrity of their structure. This despite the fact that they would carry a slightly smaller quantity of cargo and therefore their income over time would be marginally less. This appears to be a general truth regardless of the inflation environment. Furthermore these ships are more reliable performers having a lower average annual downtime.

The side benefit of such construction would be greater safety since it is accepted that steel renewals do not always restore the effectiveness of a ship's structure. In addition the increased scantlings serve as a much needed safety margin for hull strength and fatigue, especially in view of new satellite data on global wave statistics, indicating more severe spectra than previously thought. Therefore building ships that will only require the minimum steel renewals during their design life is an added safety benefit.

Furthermore ships built with corrosion allowances dictated by experience do not waste the world's resources or increase environmental pollution.

Present shipbuilding practice does not appear to share these concerns.

2. PREAMBLE

For over two decades shipyards and others have promoted the concept of "carry cargo, not steel" and have proceeded to over-optimize ship structures in an attempt to persuade shipowners that it was more beneficial to construct ships in this fashion. This paper attempts to test it.

Some classification societies have stated that steel renewal after 10 years of age was part of their design. By now adequate experience with those structures exists to be able to assess the results. Furthermore we have also seen structural problems and even the collapse of younger structures built to the above concept.

Ships are built for a specified design life. A design life is specified so that all calculations with regard to the ship's construction are focused on the exposure of the structure to the risks involved.

Classification societies state that the rules presently in force (2005) are for a ship design life of 20 years. The new IACS Common Structure Rules are said to conform to the 25 year design life set by the IMO Goal Based Standards, however they set much lower corrosion allowances than the ones set by the present 20 year lifetime rules. As IMO's GBS Tier I (Goals) paragraph .5 states: "Specified design life is the nominal period that the ship is assumed to be exposed to operating and/or environmental conditions and/or the corrosive environment and is used for selecting appropriate ship design parameters. However, the ship's actual service life may be longer or shorter depending on the actual operating conditions and maintenance of the ship throughout its life cycle".

Effective ship maintenance can only be carried out at the scheduled repair periods which occur approximately every 2.5 years plus or minus 6 months. Therefore ships must be designed and built accordingly.

It is self evident that steel renewals required because of the degradation of structural steel, despite the commercially acceptable effective maintenance carried out at scheduled repair periods, cannot be considered maintenance. Designing ships that need to have main structural elements or extensive scantlings replaced during their design life, misrepresents the concept of "Design Life".

3. SHIP OPERATION EXPERIENCE

Experience has shown that the present corrosion allowances of even the more conservative classification society are marginally adequate for a 20-year design life vessel. For certain parts of the ship they are clearly inadequate. For Cape size bulk carriers the situation is worse as it is common practice that substantial steel renewals are carried out from the time the ship is 10 years old. This is not a surprise since it has been predicted by IACS members, industry groups and research centers' studies. Papers have also been presented by IACS members analyzing actual cases.

The presently proposed corrosion allowances in the new IACS Common Structural Rules are further reduced, even though the ships are designed for a 25 year life, and thus are hugely inadequate. This can be ascertained by comparing them to the results of previously published studies by DNV, TSCF and IACS, ABS etc. (see TABLE 1), as well as recognized and respected probabilistic models and studies such as Dr. Paik's of Pusan University.

Lloyd's Register of Shipping in 1991 (1) stated inter alia "the cargoes themselves by virtue of their corrosive properties, particularly coals with a high sulphur content, can quickly diminish hold steel work". Full scale measurements were carried out on two ships belonging to British Steel (operated by Furness Withy) and P & O, companies known for their careful maintenance. One owner discovered severe wastage to the holds of a 10 year old Cape size bulk carrier. The owner estimated a wastage rate of 0.5 mm per annum except for the lower web plate where the corrosion was found to be 1.0 mm per annum. Similar cases have been presented recently by Class NK (2) where it had also been observed that corrosive sweat penetrates hard coatings and induces corrosion under the coating of the frame. Wastage of 70% and even full penetration (holes) in the lower parts of the frame had been observed on a Cape size bulk carrier. Regardless of this experience in the new IACS Common Structural Rules the corrosion allowances are based on corrosion rates of 0.1 mm per annum!

Experience with the use of epoxy coatings and their effect on corrosion rates goes back over 30 years. It is well known that a breakdown in coatings produces accelerated corrosion on the uncoated steel which acts as an anode. Such experience is documented for tanks and has been called "super accelerated corrosion". Furthermore it is well known that maintaining coatings at sea is not effective since both the preparation and the environmental conditions are improper. All available corrosion rate data, which includes coated ships, proves it. This data must be used correctly in the interest of safety.

Parts of bulk carrier structures are known not to be able to maintain coatings and thus corrode faster, the hold structure is a case in point. It makes no financial sense to replace say a 20 mm tank top when an extra 2 mm of corrosion allowance at time of build would have allowed the ship to trade to her design life of 25 years without the renewal of the tank top in question. Such a better design with regard to the tank top would cost 15 times less than the cost of the eventual repairs not including the associated down time. It would also squander fewer resources.

Similarly areas such as side shell plating in the wind/water strakes, plating of sea chests, heated fuel oil tanks, bottom plating subject to NAABSA trading as well as other locations from experience require more substantial plating. Such experience is fully confirmed by the results of the above mentioned studies.

Fatigue hot spots, which are likely to crack and need renewal, should be minimized.

Furthermore "On a bulk carrier of about 75.000 tdw, the after end, containing the engine room and associated machinery, the accommodation, electronics and navigational equipment, may cost in excess of half the price of the entire ship. Whereas the ships' machinery and accommodation is a large part of the initial cost of the ship, it is relatively cheap to maintain and will last a long time. Most ship's machinery has by now reached the limits of its development therefore substantial further economies should not be expected.

It follows that it is poor planning and design to have the hull falling apart sooner than the machinery. Either the cargo carrying part of the ship will have to be rebuilt at a high cost or the machinery will have to be scrapped together with the hull. In that case the machinery would have to be amortized in a far smaller period of time than its design life. This is not cost efficient design or construction; it is best described as planned obsolescence to give repeat work to shipyards and others" (3).

It is clear from the above that building over-optimized ships cannot produce cost effective ships with a low Life Cycle cost. Despite this some persist stating the contrary.

4. PURPOSE OF STUDY

The purpose of this paper is to estimate the Life Cycle cost of maintaining the effectiveness of a ship's steel structure. In these calculations we compare the Life Cycle cost of two Panamax bulk carriers built to two different design concepts:

Ship A: is built according to the concept of low initial cost, lighter lightship weight in order to maximize cargo carrying capacity, according to IACS's new Common Structural Rules, Draft 1, and

Ship B: is a ship of identical form and displacement to ship A but with a higher lightship weight due to greater corrosion allowances and particularly so in selected areas commensurate with present industry experience in order to minimize steel renewals. To completely eliminate them would require still greater corrosion allowances, which according to the findings of this study will further reduce the ship's Life Cycle cost. SHIP B has overall similar corrosion margins with the present rule ships (typically equivalent to 20-25% of original plate thickness) with increases in some areas where the present margins have proved inadequate (such as bulk carrier hold frames, lower transverse bulkheads, ballast tank scantlings etc.) The ships are otherwise identical having similar coatings, materials, operation and maintenance policies and are assumed to be employed in similar trading patterns. It is interesting to note, that a Panamax Bulk carrier built according to present (20 year) class rules would need only 450 tons of extra steel to reach and exceed the 25 year lifetime. But a Panamax bulker built according to the new proposed (25 year) IACS rules requires nearly 1,300 tons to conform to the advertised design life.

Greek shipping spends a lot on maintenance. It is part of our tradition. Under the circumstances it has substantial, statistically accurate, experience of how structures degrade, which co-insides with previous studies but not with the recent one put forth by IACS. This experience suggests that the corrosion rates in TABLE 1, column "proposed mm for 25year with maintenance excluding 0.5mm" are the lowest that could be considered acceptable for the intended design life of 25 years. Such corrosion margins incorporate the fact that for the ship to reach such design life, continuous good maintenance of coatings and a fair amount of steel renewals must be performed throughout its lifetime.

Steel renewal requirements are based on actual corrosion rates experienced by the Greek shipping industry, which controls approximately 27% of the world's bulk carrier fleet of all ages, from new buildings to ships of over 25 year of age, built with the present corrosion allowances.

This accumulated experience is based on 365 day a year involvement in shipping related operation and maintenance matters. This is easily 10 times greater than that accumulated by all classification societies put together. It is of course many orders of magnitude greater than the experience of shipyards who, due to present guarantee arrangements, have no experience with ship operation and maintenance at all.

It should be again pointed out that such experience closely agrees with the results of reputable published studies as stated above.

5. METHODOLOGY

In making the Life Cycle cost calculations we have separately accounted for Daily Running Expenses (DRE), Steel Renewal costs, Downtime (representing the cost of lost opportunity to trade) and Benefits from the greater deadweight capacity of the lighter ship. The calculations take account of the Purchase Price of the ship as a new building, its Sale Price as Scrap at the end of its useful life and reverse the drydocking cost element in the DRE from the time of the last drydocking to the sale of the ship for scrap. They do not take into account the financial costs as these vary between owners.

We wish to underline though that income data used in the Downtime and Benefit calculations also include estimated adjustments to the earning capacity of ships imposed through the overage insurance premiums presently required by cargo underwriters due to their experience with cargo losses from the over-optimized ships presently trading. We believe that such input will be irrelevant to the performance of ships to be built in the future if proper corrosion allowances are used in their design and construction and such "overage penalties" will be abolished.

Three series of calculations were attempted:

- The FIRST SERIES of calculations are divided in two parts. Part A is based on an inflation environment of 2% per annum with a discount rate of 5% per annum (Tables 4 and 5). This calculation, we believe, closely approximates the future. Part B is based on an inflation environment of 2% per annum with a discount rate of 10% per annum to indicate the effect of a higher discount rate that may be required by investors (Tables 6 and 7).

- The SECOND SERIES of calculations are based on an inflation environment of 7% per annum and a discount rate of 15% per annum. This calculation was made in an attempt to approximate the environment that existed in previous decades (Tables 8 and 9).

- The THIRD SERIES of calculations is based on nominal rates i.e. 0% inflation and 0% discount rate (Tables 10 and 11).

Further to the Life Cycle cost calculations and in separate tables (Tables 12 and 13) Cash Flow calculations have been carried out estimating the cash-in/cash-out of the whole project for all above series of calculations. In these calculations cash-in represents the projected 365 days/year income stream and the revenue from scrapping. Cash-out represents the purchase price, daily running expenses, repair and downtime costs (lost income). The drydock cost element in the DRE from the time of the last drydocking to the sale of the ship for scrap is also reversed.

Market statistical data are taken from SIMPSON SPENCE AND YOUNG "Monthly Shipping Review", hereafter referred to as SSY. The SSY research department has also helped with other information for which we thank them.

5.1 COST OF PURCHASE OF NEWBUILDING PANAMAX

According to data from SSY the cost of a new building Panamax of western specification has varied from about $ 20 m in 1999 to about $ 39 m during the present peak. The new building prices remained stable at between about $ 20 m and $ 24 m from January 1999 to July 2003.
We believe that after the present market normalizes and in view of the dollar depreciation, new building Panamax prices will stabilize at about $ 30 m to $ 32 m. For the sake of these calculations we use a new building price of $ 31 m for a standard western specification new building.

In view of the fact that we have chosen to use Chinese shipyard repair prices, the calculations for the extra cost for the additional steel required for SHIP B is estimated at $ 1,000/ton based on Chinese shipyard experience for the sake of consistency.

5.2 INCOME

Income is estimated at an average for one year time charter rates. According to SSY data on one year time charter rates for Panamax ships, these have fluctuated between about $ 6,000 and $ 46,000 at their peak in January 2004. For the period from January 1991 to January 2003 the average was about $ 12,000. Going forward and after the present market normalizes it could be that $ 13,000 will be a reasonable average figure. Like in the past charter rates are expected to fluctuate. We expect that they may reach a low of USD 7000 per day in the future. All charter rates used are adjusted for inflation.

The charter hire income is also adjusted for the ships' age attempting to take into account the "overage" penalties charged to ships as they grow older. Time charter income variations and assumptions are outlined in TABLE 2.

The time charter income of both ships is adjusted for the ships' different deadweight capacity maintaining the same income in dollars per deadweight ton per day for both ships.

No income is earned during the ships' repair periods. Income is used to account for the opportunity cost of Downtime during repairs (lost income).

Difference in income and the ensuing Benefits over its actual life are adjusted by the ship's deadweight capacity in the case of SHIP A.

A separate series of calculations to approximate the Cash Flow is also made. In these calculations the total income over the life of the ships and their end value is charged with the cost of acquisition, operation, repairs and downtime.

5.3 COSTS

Daily Running Expenses (DRE) are estimated at $ 4,500 per day. DRE include provisions for $ 450,000 per scheduled repair period in order to include dry docking and other maintenance costs. This represents about $ 500 per day. Drydocking costs from last drydocking to the year the ship goes for scrap are reversed and credited to the cost calculations. DRE do not include steel renewals. DRE are adjusted for inflation in the relevant series.

5.4 STEEL RENEWAL COSTS

These are charged separately. The scenarios for steel renewals for both ship types are included in TABLE 3. The corrosion rates are based on experience and are applied to the corrosion margins envisaged for each ship.

Programmed steel renewals are estimated to be carried out in China. Everywhere else would be more expensive and bias the calculations against the lighter ship. Therefore the price of steel is the average prevailing price at Chinese shipyards 2004-2005 for a mix of high tensile and mild steel. The prices are also similarly adjusted for inflation.

The repairs are deemed to be carried out at the expiration of the relevant Classification Society window, therefore at years 3,5,8,10,13, etc. The steel is renewed to original thickness.

5.5 SHIP ACTUAL SERVICE LIFE

The actual service life of both ships is dictated by the cost of Steel Renewals and downtime in order to make the ship fit for further trading.

SHIP A's actual service life of 20 years is dictated by the fact that the required steel renewals as the ship ages are excessive. According to TABLE 3 at age 18 the ship will require about 1100 tons of steel renewals which will take about 157 days to complete. Going forward at least similar amounts are envisaged. The cost of these repairs and the associated downtime will increase operating expenses by between USD 3200 and USD 4400 per day, which in addition to the ship's DRE of USD 4500 per day will necessitate income well in excess of the minimum of USD 7000 per day envisaged in a low market. Under the circumstances scrapping the ship at the age of 20 years is a very real possibility.

SHIP B on the other hand, with estimated maximum steel renewal requirements of about 300 tons necessitating 43 days downtime at the age of 28, would increase operating expenses by USD 900 to USD 1200 per day, an amount that would allow the ship to trade further. We have estimated that the ship will be scrapped at 30 years based on today's experience and the fact that it may prove difficult to find charterers willing to use ships of this age.

5.6 SCRAP

According to SSY, scrap values for Panamax ships have fluctuated between $ 110 / lightship ton in January 1999 to $ 390/ lightship ton in January 2005. Steel and scrap prices are coming down. When the market normalizes going forward we believe that an average value would be at about $ 180/lightship ton in today's dollars.

The nominal income from this sale is adjusted for inflation to the year of the sale. The sale is at the end of the 20 or 30 year period and is therefore discounted by the figures in TABLE 6 for year 21 and 31 respectively.

5.7 ADJUSTMENT TO PRESENT VALUE

As specified above all figures in the FIRST SERIES are adjusted for inflation at 2% to depict the nominal values of any year. These nominal values are then discounted at 5% per annum (Part A) and 10% per annum (Part B) so that the present value can be compared. We believe that the choice of the discount rate of 5% per annum is realistic for returns on a shipping projects going forward. The rate of 10% is an optimistic return in order to examine the effect of such a discount rate. Discount rates are used so as to account for the fact that a cost some years from now has a far lower effect on a ship owners' return on investment calculations today. Returns on equity may be different depending on leverage.

The SECOND SERIES of calculations uses an inflation rate of 7% and a discount rate of 15% to examine the effect on the environment that existed in previous decades.

In the THIRD SERIES of calculations all calculations are based on nominal values 0% inflation, 0% discount rate.

6. FINDINGS

6.1 FINANCIAL

6.1.1 LIFE CYCLE COST

The figures and the calculations used may be found in the attached TABLES 4, 5, 6, 7, 8, 9, 10 and 11.

The FIRST SERIES of calculations, Part A, for the present low interest rate environment, provide the following results:

- The Life Cycle cost of SHIP A is USD 2,916,000 per annum (AAC) while the Life Cycle cost of SHIP B is USD 2,185,000 per annum (AAC). In other words SHIP A is about 33.5% per year more expensive to operate. Even if SHIP B for some reason has to be scrapped at 20 years it still has a cheaper Life Cycle cost than SHIP A at $ 2,814,000 per annum (AAC).

The FIRST SERIES of calculations, Part B, for the present low interest rate environment but higher discount rate provide the following results:

- The Life Cycle cost of SHIP A is USD 2,432,000 per annum (AAC), while the Life Cycle cost of SHIP B is USD 1,712,000 per annum (AAC). In other words SHIP A is about 42.1% per annum more expensive to operate. Even if SHIP B for some reason has to be scrapped at 20 years it still has an identical Life Cycle cost than SHIP A at $ 2,432,000 per annum (AAC).

The SECOND SERIES of calculations, for a higher inflation environment, show equivalent results as follows:

- The Life Cycle cost of SHIP A is USD 2,373,000 per annum (AAC) while the Life Cycle cost of SHIP B is USD 1,664,000 per annum (AAC). In other words SHIP A is about 43% per year more expensive to operate. Even if SHIP B for some reason has to be scrapped at 20 years it has only a marginally more expensive Life Cycle cost than SHIP A at $ 2,387,000 per annum (AAC).

The THIRD SERIES of calculations for nominal values provide the following results:

- The Life Cycle cost of SHIP A is USD 3,388,000 per annum (AAC), while the Life Cycle cost of SHIP B is USD 2,748,000 per annum (AAC). In other words SHIP A is about 23.29% per annum more expensive to operate. Even if SHIP B for some reason has to be scrapped at 20 years it still has a lower Life Cycle cost than SHIP A at $ 3,191,000 per annum (AAC).

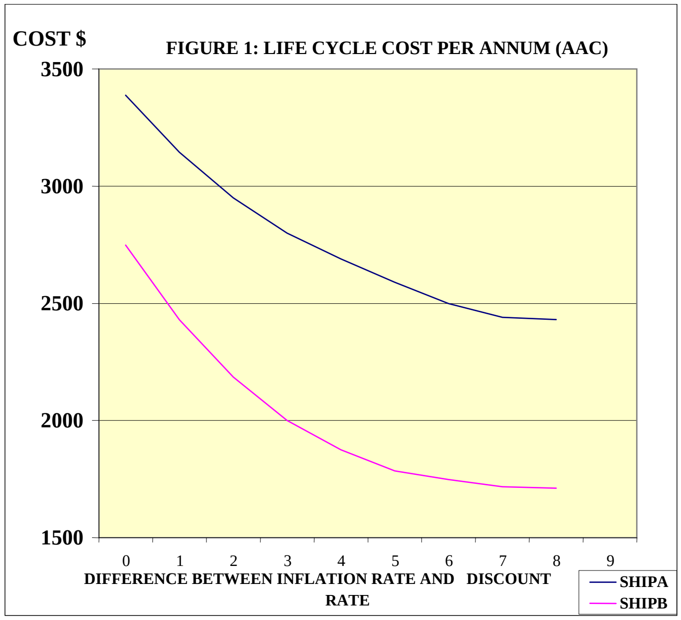
In FIGURE 1 below we show the Life Cycle cost per annum (AAC) of both ships as a function of the difference between the inflation and of the discount rate.

Under the circumstances the Life Cycle cost per annum (AAC) of SHIP A is not less, as stated by some, but unacceptably greater in all cases.

It is apparent that the percentage differences become smaller as inflation and discount rates approach zero and increase substantially when the spread between the discount rate and the inflation rate becomes greater.

It is also interesting to note that, even if a shipowner decides to scrap the ship at around 20 years of age, SHIP B is still the preferred (more economic) choice. The additional robustness, strength, safety and reduction of related accidental pollution are just side benefits to him, his crew and society.

FIGURE 1: LIFE CYCLE COST PER ANNUM (AAC)



6.1.2 CASH FLOW ANALYSIS

SHIP B consistently gives better results than SHIP A.

From the analysis of the total cash flow over the Life Cycle of all series of calculations (Tables 12 and 13) it is clear that SHIP B is superior to SHIP A. This is only to be expected in view of the results of the Life Cycle cost calculations mentioned above.

Of these results only the low inflation/low discount rate FIRST SERIES, Part A, and the THIRD SERIES of calculations give positive results which appear to be extremely marginal. In the FIRST SERIES, Part B, and the SECOND SERIES of calculations the cash flow results are negative. In all cases the lower the discount rate the better the Cash Flow.

It should be noted that no financial costs are included in these calculations. Their inclusion would make these results worse.

6.1.3 SENSITIVITY ANALYSIS

The Cash Flow results are clearly unacceptably low to cover the margins necessary for a high risk business such as shipping. Under the circumstances it appears that the chosen combination of the purchase price of the newbuilding and the estimated average time charter rate are incompatible despite having been carefully estimated. The result of this could be that through market forces either newbuilding prices will come down further or the average charter rate will increase.

To investigate the effects of such a change and since over time the time charter rates fluctuated in a predictable band, the most likely scenario is that the prices of new buildings would come down We first investigated this last scenario. To this end it was assumed that the newbuilding cost of the base ship, SHIP A, would be reduced by $ 3,000,000, all other parameters remaining the same. The results of this sensitivity analysis show that the relative values remain similar.

We also investigated the effects of a permanent quantum increase in the average annual time charter rates used for our calculations from $ 13000/day to $ 18000/day for SHIP A. This represents a 60-70% increase on the gross surplus over Daily Running Expenses and steel renewal costs. We do not consider this a realistic scenario as in all industries efficiency tends to compress margins rather than increase them. It should be noted that only a few years ago such ships were being fixed for multiyear periods at $ 9000/day. Windfall profits are short lived. When rates are good more ships will be built, the market will get overtonnaged and the rates will be compressed. This is how markets work.

Even if this situation persisted though and the rates remained high for a considerable period, then the cash flow performance of either ship, when the difference between inflation rates and discount rates remains high, is similar over a 20 year life. The advantage of SHIP B would be that she would have the added benefit of being able to trade 10 years more and under the circumstances the price she would command would have a premium over scrap.

At smaller differences between inflation and discount rates (FIRST SERIES, Part A) the results of SHIP B over 20 years are superior to those of SHIP A. At 0 inflation (THIRD SERIES) SHIP B gives better results even when averaged over 30 years.

Under the circumstances we believe that any adjustments in the purchase price of the base ship, SHIP A, or, for that matter, in the charter rates would have no material effect on the findings of this paper. SHIP B always gives better results in average market conditions that are more likely to prevail during its life and is no worse than SHIP A in extremely buoyant markets. The data for the sensitivity analysis is in Table 14.

6.2 OPERATIONAL

6.2.1 THE EFFECT OF DOWN TIME FOR REPAIRS

In all SERIES of calculations it is evident that SHIP A has 283% the average annual downtime of SHIP B, making it an unreliable performer (see Table 15).

Downtime required for repairs is a very important factor and should be considered in ship design. Ships that require long downtimes for repairs not only carry the greater opportunity cost of these delays but are also considered unreliable performers, not only because of these delays. They are also unreliable performers because of the greater possibility that substantial local wear down may materialize, be discovered and have to be repaired before the ship's programmed repair period. Sometimes this will have to happen even before the ship is allowed to sail from a port.

Such ships may lose, or may not be able to secure, profitable period employment because of their need to repair for long periods and therefore are perceived as being unreliable to perform as described.

When negotiating charters, agreeing programmed repair periods of say 60 days for a Panamax size ships is close to impossible. As per Table 3:

-SHIP A would require 50 days to complete her intermediate survey at year 13, 86 days for her special survey at year 15 and 157 days for her intermediate survey at year 18.

On the other hand:
-SHIP B would require no more than 43 days to complete her intermediate survey at year 28.

7. CONCLUSION

The steel renewal estimations in order to make the Life Cycle cost calculations are based on the expected degradation of the ship's structure using actual corrosion rates. From these estimates it seems that even the corrosion allowance margins suggested by the Greek shipping community appear to be inadequate. In order to further minimize that Life Cycle cost, larger corrosion allowances should be allowed for.

The Life Cycle cost calculation results prove that steel renewals increase the Life Cycle cost per annum (AAC) of over-optimized ships (SHIP A) regardless of the benefits from their greater deadweight and give it a greater Life

Cycle cost per annum (AAC) than a ship built with higher corrosion margins (SHIP B).

It is clear that the percentage difference in Life Cycle cost per annum (AAC) between the two ships increases as the difference between the inflation rate and the discount rate increases. Under the circumstances the concept of "carry cargo, not steel" was very much more misleading when originally stated in the early '80's, a period of high inflation when even greater differences in discount rates were anticipated.

We believe that this paper proves that the statement "carry cargo, not steel" does not stand up to scrutiny in any foreseeable economic environment.

8. RELATED ISSUES

8.1 WASTE OF RESOURCES

It has been estimated (SSY) that in 2004 about 15 million lightship tons of shipping were delivered. In other words about 15 million tons of steel was used for building new ships. This is approximately 1.6% of the world's steel demand for finished products which totaled about 950 million tons (2004). No account is made of the steel used for ship repairs. Therefore the total amount of steel to build new ships and repair old ones in any year must be larger. It could be said that ship building and ship repairing uses close to 2% of the world's steel production.

Building ships as per SHIP A not only increases average transport costs through the higher Life Cycle cost per annum (AAC) of these ships to the detriment of global growth and job creation, but is an unprecedented conscious attempt at wasting global resources.

Not only is machinery scrapped before the end of its design life but building ships with plating having inadequate corrosion allowances will require it to be renewed within the design life of the ship. It is clear that instead of, say, using the raw materials and energy to produce one plate of 22 mm, as per the example in point 3, raw materials and energy will be used to produce 2 plates of 20 mm for the life of the same ship or 80% more (120 % more if we account for the unnecessary but forced replacement of the good longitudinals attached to the tank top plate).

When taking into account the Lightship and Steel Renewal tons of steel used, SHIP A will require 13600 tons of steel to complete a 20 year cycle whereas SHIP B will require 13590 tons to work for 30 years. In other words SHIP A will require about 50% more steel per operating year from time of build to time of scrapping (see Table 15).

Therefore to maintain the same shipping capacity in service over time, one and a half times the amount of steel will have to be used if ships are constructed according to the parameters of SHIP A rather than those of SHIP B.
Other than squandering resources, one and a half times the amount of energy will also have to be used for the manufacture of this steel unnecessarily adding to global warming. The steel renewal work carried out during the ship's life also uses a lot of energy thus further adding to pollution.

According to the International Iron and Steel Institute (IISI), 1.6 tonnes of CO_2 is generated for every tonne of steel produced. If therefore about 15 million tons of steel was used to build new ships in 2004, 24 million tons of CO_2 was emitted to the world's atmosphere in order to maintain the required shipping capacity.

In view of the above and with the presently proposed reduced corrosion margins it is envisaged that the world would have to accept, as per the analysis in Table 15, a further 12 million tons of CO_2 per year in the future in order to maintain this required shipping capacity. Eliminating these additional emissions, the two major shipbuilding countries, Korea and Japan which account for about 80% of new building tankers and bulk carriers, would go a long way to help meet their criteria as per the Kyoto Protocol.

Lastly whenever SHIP A is built, over 100,000 liters (per Panamax size ship) of ecologically unfriendly extra paints and thinners must be manufactured and eventually disposed.

Such design and construction is not indicative of social responsibility. It is beyond the scope of this study to further quantify the values but the issues should be obvious to all.

8.2 SAFETY

During 1989-1992, the period of heavy bulk carrier losses, the average age of ships with collapsing side structures was between approximately 18-22 years. Recently similar accidents have happened with ships of 12 to 14 years of age despite increased maintenance efforts by owners due to stricter class and port state inspections. Recent papers as to how corrosive sweat penetrates hard coating and induces corrosion under the coatings help underline the problem. This is not an improvement in design safety.

It is also stated that steel repairs do not always restore the full original strength of the ship. Repairs also damage coatings which then proceed to accelerate corrosion by 3 – 5 times the normal rates due to the anode effect. Coating of new steel and repair of damaged coating can never be as good as in a new building shipyard, with usually short lasting results.

Under the circumstances building ships with adequate corrosion margin also benefits safety of life and property.

8.3 TRANSPARENCY

In view of the very great differences in Life Cycle cost per annum (AAC), Environmental Impact and observed safety related problems between the two different design and construction approaches, we believe that it should be mandatory that Life Cycle Data/ Corrosion Details, Costs and the associated Environmental Impact parameters be clearly shown in the main alphanumeric classification of all ships. What we propose is similar to what existed at the time of the first wrought iron sips where the alphanumeric classification expressed the envisaged economic operating life of a ship.

In the interest of transparency it cannot be that SHIP A, advertised by some as an "Asset Play" ship which would have operational problems from her 12th year onwards due to her very much increased down time, shares the same main alphanumeric classification as the environmentally friendly, rationally built SHIP B which will be a reliable performer throughout its design life.

9. FINAL REMARKS

It is clear from the above that regardless of the inflation environment, there is no benefit to society, let alone ship owners or seafarers, from the construction of over-optimized ships, purportedly stated as being more efficient because they would be capable of carrying more cargo therefore earning more freight. The exact opposite is the case.

In fact their Life Cycle cost is substantially greater and they are unreliable performers. They waste resources, increase environmental pollution and do not contribute to marine safety. The only obvious beneficiaries of such construction practices are the shipyards who, by effectively designing their ships with built-in obsolescence, look forward to repeat business whether this be from new buildings or repairs.

The world and the shipping industry have not been well served by what appear to have been self serving and unsubstantiated comments by some.

10. ACKNOWLEDGEMENTS

The authors wish to thank the research department of Simpson, Spence and Young ship brokerage firm for their valuable supply of data.

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APPENDIX (TABLES)

TABLE 1 INDICATIVE COMPARISON TABLE OF YEARLY CORROSION WASTAGE mean values (mm/year) - see notes below

CORROSION ADDITION – BALLAST TANKS	DNV[1] ProjectD mm / 10 years	DNV[1] ProjectD mm / year	Corrba[2] (reduced for 5 years to coating breakdown)	Safety at Sea Ltd[3] (submitted data)	TSCF[4] (reduced for 5 yrs to coating breakdown)	Present class rule ABS (Cape)	Present class rule ABS VLCC	Present class rule ABS Panamax BC	IACS NEW	Indicative Average of data	Propo-sed rate	Proposed mm for 25 year life w/ maintenance excluding 0.5 mm
Location												
Deck plating	2	0.20	0.23		0.24	0.36	0.20	0.21	0.12	0.22	0.22	5.5
Deck Long.Web	1.8	0.18	0.23	0.40	0.50	0.38	0.25	0.25	0.12	0.28	0.28	7
Side Plate, upper.2m	3.5	0.35	0.26			0.24	0.20	0.20	0.09	0.24	0.22	5.5
Side Plate, rest	2	0.20	0.15	0.15	0.13	0.23	0.28	0.20	0.07	0.22	0.20	5
Side Long. Web	2.4	0.24	0.23	0.27	0.48	0.25	0.20	0.15	0.076	0.24	0.24	6
Bottom Plating	1.5	0.15	0.15	0.25	0.12 one side	0.19	0.25	0.19	0.07	0.19	0.19	4.75
Bottom Long. Flange	0.8	0.08				0.15	0.25	0.15	0.076	0.16	0.20	5
Bottom Long. Web	1.4	0.14		0.25		0.15	0.16	0.15		0.15	0.22	5.5
Lon. Bkh. Plate, upper 2 m	2.3	0.23	0.19	0.38 (heated)		0.20	0.23	0.16	0.076	0.23	0.23	5.75
Lon. Bkh. Plate, remaining areas	2	0.20	0.19	0.25	0.16	0.20	0.23	0.16	0.06	0.23	0.23	5.75
Longit. Bkh. Longit. Web, upper 2 m	3	0.30	0.30	0.25	0.56	0.15	0.16	0.16		0.30	0.28	7
Longit. Bkh. Longit. Web, remaining areas	2.3	0.23	0.23	0.25		0.15	0.16	0.16		0.23	0.23	5.75
Longit. Bkh. Longit. Flange	1.6	0.16	0.15		0.32		0.23			0.22	0.22	5.5
Deck and Side Transv. Web Plating, up. 2 m	3.5	0.35	0.30	0.28	0.30(avg. deck/sides)					0.30	0.30	7.5
Transv. Web Plating, other categories	2.1	0.21	0.23	0.25	0.34	0.18	0.18	0.14	0.076	0.22	0.22	5.5
Trans. Bkh. Plate	1.9	0.19	0.19	0.25	0.32	0.20	0.22	0.31	0.076	0.25	0.25	6.25

(1) CORROSION, IMPACT ON MODERN SHIP DESIGN, DNV, PAPER SERIES No. 2000 – P008, June 2000, (2) CORRBA Project: DNV, Marintek, Norges forskningsrad ,1998, (3) Safety at Sea Ltd, Glasgow, IMO submission MSC 78/INF.6, Appendix A4, (4) Guidance Manual for Tanker Structures, Issued by TSCF in cooperation with IACS, Witherby & Co. Ltd, 1997

NOTES regarding data of Table 1.

1. Above data refers only to uniform wastage and excludes localised pitting/grooving which proceeds at much higher rates.
2. The original higher Corrba and TSCF values could be used instead of the above reduced values due to coating since, for a typical specification ship, coating breakdown at edges, welds etc develops within 1 – 2 years. However to be very conservative, since Corrba and TSCF reported rates of corrosion for uncoated (after coating breakdown), a 5 year “no corrosion period” was added and values were reduced accordingly. (Wang et al, ABS, OMAE 2003, Ref. 12, advise that ABS study data is at the high end of the original TSCF data.)
3. It must be pointed out that corrosion proceeds a lot faster in damaged areas of coating rather than in a totally non-coated tank. This is an additional reason that the above Corrba and TSCF rates of table 1 should be regarded as very conservative (low).
4. It is noteworthy that the empirical data from the shipping industry (Safety at Sea Ltd), based on class required renewals, closely agrees with Corrba and DNV projects and is more conservative (low) than the TSCF data. Furthermore the data is in agreement with reasonable probabilistic models such as Paik’s, when a reasonable COV (coefficient of variation) is chosen or when the exponential nature of corrosion rate is taken into account.
5. Corrosion wastage rates increase exponentially with the age of ship (to mean values of 0.50-0.60 mm/year from ages 20 to 25). This is not reflected in the above projects due to limited data for ships over 20 years old. Therefore for an adjustment of corrosion margin from ships of 20 year design life to 25 year design life, it is not sufficient to simply multiply the above average mean rates by 25 years (since they are mean rates of 20 year life ships). For proper corrosion additions to 25 year design life ships, the mean rates should be increased to account for the large end life increase and subsequently multiplied by 25. This was not done above in arriving at the proposed rates.
6. Considering all the conservative reductions and assumptions as per notes 1,2,3,5 above, the proposed rates should be considered as very conservative (low) resulting only if good maintenance of steel is performed throughout the ship’s life.

BULK CARRIER HOLDS		DNV mm / yr Ref. 1		Safety at Sea Ltd (submitted data)		Present class rule (cape)			IACS NEW		Proposed rate mm/year	Proposed mm for 25 year life with maint. Excluding 0.5 mm
Frames		0.30		0.27		0.16			0.10		0.28	7.0
Tanktop				0.25		0.38			0.16		0.30	7.5
Top hoppers				0.27		0.21			0.10		0.28	7.0
Bottom hoppers				0.27		0.28			0.16		0.28	7.0
Trans. Bulkheads mid				0.27		0.28			0.16		0.28	7.0

TABLE 2

DATA AND ASSUMPTIONS USED FOR THE CALCULATIONS

A. At new building stage cost of extra steel in China: 1000 kg $ 1,000

B. Scrap @ $ 180 (p.v.)/lightship ton

C. Repairs at China:
Repair cost: USD 1.7/ton of steel renewed (04/05 china)
Production rate: 6-8 tons/day say average 7 (*)
Time required for usual dd without repairs: 9 days

D. Charter hire income:
Charter rate: USD 13,000/day (p.v.) for ship a having dwt 73.000, lightship of 11.400, displ. 84.400

USD 12,770/day (p.v.) for ship B having
DWT 71.710, lightship of 12.690, displ. 84.400

Charter rate variations per ship's age:

1-15	100%
16-20	90%
21-25	85%
26-30	80%

E. Charter rates, daily running expenses and scrap price are assumed to increase at the estimated inflation rate for each series of calculations

p.v. represents present value dollars

(*) in the last few years China's popularity for repairs has resulted in large overbookings by Chinese repair shipyards resulting in delays. For the scattered nature and relatively small repair tonnages of this study, 7 mt/day is considered optimistic. However, using a smaller figure would result in Ship A being even more uneconomic.

TABLE 3

STEEL RENEWAL SCENARIOS

SHIP A: As per IACS new proposed CSR JBP rules 1st draft Lightship 11,400 MT

Max expected Lifetime 20 years (due to reduced corrosion margins necessitating expensive repairs - see write up). Specified corrosion margins are overall less than half of those required for 25 year lifetime (based on corrosion rates experience, past studies and existing class regulations). It follows that such margins will be exhausted at about 12.5 years, at which time major steel replacement will be required.

Estimated Steel Replacement

Age	Tons	
10	150+ MT	Some frames, bal. internals, hold bulkhd
13	350+ MT	Frames, hold bulkheads, internals
15	600+ MT	Various, some side shell, deck, internals
18	1.100+ MT	Various, side shell, deck, bottom
Total	2.200+ MT	(conservative estimate with very good maintenance)

Scrapping dictated by financial necessity at 20 years

SHIP B: To arrive at the lightship and performance of ship b we start with a ship built to the present rules and proceed to recalculate it to the new IACS CSR JBP net scantlings but with corrosion allowances similar to and somewhat improved than the present rules. Ship b is described in (3).

1) We start with a vessel built as per present regulations with corrosion margins of some parts upgraded for same lifetime as the rest of the ship (which with maintenance can be 27 years, scrapping at 30 years, see write up). I.E. The ship has overall similar corrosion margins with the present rule ships (typically equivalent to 20-25% of original plate thickness) with increases in some areas where the present margins have proved inadequate as follows:

Hold frames: increase corrosion allowance by 80-90% (almost double). All height of hold transverse Bulkheads, underdecks, tank internals (selected), tanktops, double bottom longitudinal bulkheads: increase allowance by about 50%. Hold hoppers top and bottom: increase by abt. 40%, and various other selected increases.

EXTRA WEIGHT DUE TO THICKNESS INCREASES:

FRAMES	(3 mm extra):	70 mt
TANKTOP	(3 mm extra):	100 mt
H.BULKHD	(2 mm extra):	35 mt
UNDERDECK	(3 mm extra):	35 mt
DECK LONG.	(3 mm extra):	25 mt
HOPPERS	(2 mm extra):	85 mt
BAL. SCANTL.	(selected):	100 mt
	TOTAL :	450 mt

Lifetime 27 years + (actual 30 years) Lightship estimated at 11,850 mt.

ESTIMATED STEEL REPLACEMENT:

Age	13	0 MT	
“	15	20 MT	
“	18	80 MT	Internals
“	20	120 MT	Some frames, various
“	23	180 MT	Frames, bulkheads, internals
“	25	200 MT	Various
“	28	300 MT	Various
	Total:	900 MT	

TABLE 3 (CONT)

Scrapping age 30+ years, if it is possible to employ the ship further. If scrapping is done at 25 years, then only 400 mt of repairs estimated will have been carried out.

2) We proceed to incorporate the IACS new proposed CSR JBP rules 1st draft scantlings but with all corrosion margins upgraded for 25 year lifetime (as per proposed margins).

Since, for many major structural areas, less than half of the proper margin is provided, this requires overall doubling of all corrosion margins and then some for certain major areas. According to DNV paper series no 2000-p008, June 2000, doubling of all corrosion margins will increase lightship by abt 7.5 % (or in our Panamax 850 mt). This DNV weight estimation is based on doubling the 10 year DNV corrosion margins (which by the way are numerically similar to the new proposed CSR margins, now advertised to be good for 25 years).

A more detailed calculation, taking into account the requirement for more than double margins in many areas, gives following extra weights:

HOLD FRAMES	(FROM NEW CSR MARGIN 2.5 MM TO 7 MM)	110 MT
TANKTOP	(FROM " " " 4.0 MM TO 7.5 MM)	115 MT
TOP HOPPERS	(FROM " " " 2.5 MM TO 7 MM)	100 MT
BOTTOM HOPPERS	(FROM " " " 4.0 MM TO 7 MM)	55 MT
LOWER BULKHEADS	(FROM " " " 4.0 MM TO 7 MM)	25 MT
STOOLS/UDECKS	(FROM " " " 4.0 MM TO 7 MM)	40 MT
SIDE SHELL	(FROM " " " 2.0 MM TO 5 MM)	175 MT
HOLD SHELL	(FROM " " " 2.0 MM TO 5 MM)	75 MT
DECK	(FROM " " " 3.0 MM TO 5.5 MM)	80 MT
BOTTOM	(FROM " " " 2.0 MM TO 5 MM)	120 MT
U/DECK LONGIT.	(FROM " " " 3.0 MM TO 6 MM)	25 MT
GIRDERS/FLOORS	(FROM " " " 2.0 MM TO 5.5 MM)	160 MT
TOP SIDE WEBS	(FROM " " " 2.0 MM TO 5.5 MM)	110 MT
OTHER BALLAST	(FROM " " " 2.0 mm to 5.5 mm)	100 MT (est)
	TOTAL	1,290 MT

Lightship at 12,690 mt

3) With the above upgrades ship b with a lightship of 12.690 becomes equivalent to the ship under (1) above in expected lifetime and future repairs.

4) For reference indicative steel weights of major parts, Panamax BC, present regulation

DECK P+S :	180M X 8.5M X 2 X 19MM X 8 =	560 MT *
CROSSDECKS :	15M X 10M X 7 X 13MM X 8 =	130 MT *
FLAT BOTTOM :	4,950 M2 X 19 X 8 =	900 MT *
SIDES :	10,650 M2 X 19 X 8 =	1,950 MT *
HOLD BULKHEADS :	42M(corr)X 13M X7X 17 X 8 =	520 MT
FLAT BULKHEADS :	25 M X 17 M X 2 X 15 X 8 =	100 MT
FRAMES :	1 MT EACH X 366 =	366 MT
TST HOPPERS :	3,060 M2 X 17 X 8 =	500 MT *
TST FLATS :	760 M2 X 17 X 8 =	120 MT *
DB HOPPERS :	2,340 M2 X 20 X 8 =	450 MT *
BULKHD STOOLS :	282 M2 X 6 X 16 X 8 =	220 MT
TANKTOP :	180 X 24 X 20 X 8 =	830 MT *
LONG. BULKHDS :	2,600 M2 X 16 X 8 =	400 MT *
FLOORS :	4,000 M2 X 16 X 8 =	620 MT *
TST WEBS :	4,000 M2 X 14 X 8 =	540 MT *
	TOTAL	8,200 MT

* INVOLVES 20% INCREASE FOR ATTACHED INTERNALS.

TABLE 4

LIFE CYCLE COST CALCULATION

FIRST SERIES/PART A - SHIP A (ALL FIGURES IN $ X1000)

YEAR	DRE (4,500)	STEEL	DOWNTIME		BENEFIT		LAST DD REVERSE	SCRAP
			D	$	D	$		
01	1643				365	84		
02	1592				365	81		
03	1548		9	110	356	78		
04	1495				365	76		
05	1448		9	103	356	72		
06	1403				365	72		
07	1360				365	70		
08	1317		9	94	356	66		
09	1277				365	65		
10	1237	192	21	206	344	60		
11	1199				365	61		
12	1162				365	59		
13	1125	408	50	445	315	50		
14	1091				365	56		
15	1057	656	86	719	279	41		
16	1024				365	47		
17	992				365	46		
18	962	1095	157	1076	208	25		
19	932				365	43		
20	903				365	41	247	
21								1093
TOTAL	24767	2351		2753		1193	247	1093

PURCHASE PRICE $ 31000 – LIGHTSHIP 11.400 T

LIFE CYCLE COST = 31000 + 24767 + 2351 + 2753 – 1193 - 247 -1093
= 58338 FOR 20 YEAR LIFE OR
$ 2916/YEAR

COMPARISON WITH SHIP B: SHIP A IS 33.5% MORE EXPENSIVE THAN SHIP B

TABLE 5

LIFE CYCLE COST CALCULATION

FIRST SERIES/PART A -SHIP B (ALL FIGURES IN $ X 1000)

YEAR	DRE (4,500)	STEEL	DOWNTIME D	DOWNTIME $	LAST DD REVERSE	SCRAP
01	1643					
02	1592					
03	1548		9	108		
04	1495					
05	1448		9	101		
06	1403					
07	1360					
08	1317		9	92		
09	1277					
10	1237		9	87		
11	1199					
12	1162					
13	1125		9	79		
14	1091					
15	1057	22	9	74		
16	1024					
17	992					
18	962	80	12	81		
19	932					
20	903	112	17	107		
21	875					
22	848					
23	821	153	26	141		
24	796					
25	771	160	29	148		
26	748					
27	724					
28	702	218	43	188		
29	680					
30	659				181	
31						889
TOTAL	32391	744		1206	181	889

PURCHASE PRICE $ 31000 + 1290 = 32290 – LIGHTSHIP 12.690 T

LIFE CYCLE COST = 32290 + 32391 + 744 + 1206 -181 – 889
= 65561 FOR 30 YEARS OR
$ 2185/YEAR

IF SHIP IS SCRAPPED AT 20 YEARS THEN LIFE CYCLE COST IS: $ 56290 OR
$ 2814/YEAR

TABLE 6

LIFE CYCLE COST CALCULATION

FIRST SERIES/PART B -SHIP A (ALL FIGURES IN $ X 1000)

YEAR	DRE (4,500)	STEEL	DOWNTIME		BENEFIT		LAST DD REVERSE	SCRAP
			D	$	D	$		
01	1643				365	84		
02	1495				365	76		
03	1384		9	99	356	69		
04	1271				365	65		
05	1167		9	83	356	58		
06	1071				365	55		
07	983				365	50		
08	902		9	64	356	45		
09	828				365	42		
10	760	118	21	126	344	37		
11	698				365	36		
12	641				365	33		
13	588	213	50	233	315	26		
14	540				365	28		
15	496	308	86	338	279	19		
16	455				365	21		
17	418				365	19		
18	384	437	157	447	208	10		
19	352				365	16		
20	323				365	15	89	
21	-	-	-	-	-	-		371
TOTAL	16399	1076		1420		804	89	371

PURCHASE PRICE $ 31000 Lightship 11400

LIFE CYCLE COST = 31000 + 16399 + 1076 + 1420 -804 – 89 - 371
= 48631 FOR 20 YEARS OR
$ 2432/YEAR

COMPARISON WITH SHIP B: SHIP A IS 42.1% MORE EXPENSIVE

TABLE 7

LIFE CYCLE COST CALCULATION

FIRST SERIES/PART B -SHIP B (ALL FIGURES IN $ X 1000)

YEAR	DRE (4,500)	STEEL	DOWNTIME D	DOWNTIME $	LAST DD REVERSE	SCRAP
01	1643					
02	1495					
03	1384		9	97		
04	1271					
05	1167		9	82		
06	1071					
07	983					
08	902		9	63		
09	828					
10	760		9	53		
11	698					
12	641					
13	588		9	41		
14	540					
15	496	10	9	35		
16	455					
17	418					
18	384	32	12	32		
19	352					
20	323	40	17	38		
21	297					
22	272					
23	250	47	26	43		
24	229					
25	211	44	29	40		
26	193					
27	178					
28	163	51	43	44		
29	149					
30	137				38	
31	-	-				175
TOTAL	18478	224		568	38	175

PURCHASE PRICE $ 31000 + 1290 = 32290 – LIGHTSHIP 12.690 T

LIFE CYCLE COST = 32290 + 18478 _ 224 + 568 – 38 – 175
= $ 51347 FOR 30 YEARS OR
$ 1712/YEAR

IF SHIP IS SCRAPPED AT 20 YEARS THEN LIFE CYCLE COST IS $ 48631 OR
$ 2432/YEAR

TABLE 8

LIFE CYCLE COST CALCULATION

SECOND SERIES - SHIP A (ALL FIGURES IN $ X 1000)

YEAR	DRE (4,500)	STEEL	DOWNTIME D	DOWNTIME $	BENEFIT D	BENEFIT $	LAST DD REVERSE	SCRAP
01	1643				365	84		
02	1494				365	76		
03	1359		9	97	356	68		
04	1236				365	63		
05	1124		9	80	356	56		
06	1022				365	52		
07	929				365	48		
08	846		9	60	356	42		
09	769				365	39		
10	699	109	21	116	344	34		
11	636				365	33		
12	578				365	30		
13	526	191	50	208	315	23		
14	478				365	24		
15	435	270	86	296	279	17		
16	396				365	18		
17	360				365	17		
18	327	373	157	366	208	9		
19	298				365	14		
20	271				365	12	74	
21								308
TOTAL	15426	943		1223		759	74	308

PURCHASE PRICE $ 31000 – LIGHTSHIP 11.400 T

LIFE CYCLE COST = 31000 + 15426 + 943 + 1223 – 759 - 74 - 308
= 47451 FOR 20 YEAR LIFE OR
$ 2373/YEAR

COMPARISON WITH SHIP B: SHIP A IS 42.6% MORE EXPENSIVE

TABLE 9

LIFE CYCLE COST CALCULATION

SECOND SERIES - SHIP B (ALL FIGURES IN $ X 1000)

YEAR	DRE (4,500)	STEEL	DOWNTIME D	DOWNTIME $	LAST DD REVERSE	SCRAP
01	1643					
02	1494					
03	1358		9	95		
04	1236					
05	1124		9	79		
06	1022					
07	929					
08	846		9	59		
09	769					
10	699		9	49		
11	636					
12	578					
13	526		9	37		
14	478					
15	435	9	9	30		
16	396					
17	360					
18	327	27	12	27		
19	298					
20	271	34	17	32		
21	247					
22	224					
23	204	38	26	35		
24	185					
25	168	35	29	32		
26	153					
27	139					
28	127	39	43	34		
29	116					
30	105				29	
31						132
TOTAL	17094	182		509	29	132

PURCHASE PRICE $ 31000 + 1290 = 32290 – LIGHTSHIP 12.690 T

LIFE CYCLE COST = 32290+17094+182+509–29–132
= $ 49914 FOR 30 YEARS OR
$ 1664/YEAR

IF SHIP IS SCRAPPED AT 20 YEARS THEN LIFE CYCLE COST IS $ 47737 OR
$ 2387/YEAR

TABLE 10

LIFE CYCLE COST CALCULATION

THIRD SERIES/NOMINAL VALUES - SHIP A (ALL FIGURES IN $ X 1000)

YEAR	DRE (4,500)	STEEL	DOWNTIME D	DOWNTIME $	BENEFIT D	BENEFIT $	LAST DD REVERSE	SCRAP
01	1643				365	84		
02	1643				365	84		
03	1643		9	117	356	82		
04	1643				365	84		
05	1643		9	117	356	82		
06	1643				365	84		
07	1643				365	84		
08	1643		9	117	356	82		
09	1643				365	84		
10	1643	255	21	273	344	79		
11	1643				365	84		
12	1643				365	84		
13	1643	595	50	650	315	72		
14	1643				365	84		
15	1643	1020	86	1118	279	64		
16	1643				365	76		
17	1643				365	76		
18	1643	1870	157	1837	208	43		
19	1643				365	76		
20	1643				365	76	450	
21	-				-	-		2052
TOTAL	32860	3740		4229		1564	450	2052

PURCHASE PRICE $ 31000

LIFE CYCLE COST = 31000 + 32860 + 3740 + 4229 – 1564 - 450 – 2052
= $ 67763 FOR 20 YEAR LIFE OR
$ 3388/YEAR

COMPARISON WITH SHIP B: SHIP A IS 23.3% MORE EXPENSIVE

TABLE 11

LIFE CYCLE COST CALCULATION

THIRD SERIES/NOMINAL VALUES - SHIP B (ALL FIGURES IN $ X 1000)

YEAR	DRE (4,500)	STEEL	DOWNTIME D	DOWNTIME $	LAST DD REVERSE	SCRAP
01	1643					
02	1643					
03	1643		9	115		
04	1643					
05	1643		9	115		
06	1643					
07	1643					
08	1643		9	115		
09	1643					
10	1643		9	115		
11	1643					
12	1643					
13	1643		9	115		
14	1643					
15	1643	34	9	115		
16	1643					
17	1643					
18	1643	136	12	138		
19	1643					
20	1643	204	17	195		
21	1643					
22	1643					
23	1643	306	26	282		
24	1643					
25	1643	340	29	315		
26	1643					
27	1643					
28	1643					
29	1643	510	43	439		
30	1643				450	
31	1643					2284
TOTAL	49290	1530		2059	450	2284

PURCHASE PRICE $ 31000 + 1290 = 32290

LIFE CYCLE COST = 32290 + 49290 + 1530 + 2059 – 450 – 2284
= $ 82435 FOR 20 YEAR LIFE OR
$ 2748/YEAR

IF SHIP IS SCRAPPED AT 20 YEARS THEN LIFE CYCLE COST IS $ 63813 OR
$ 3191/YEAR

TABLE 12

AVERAGE ANNUAL INCOME (USD X 1000)
FIRST SERIES

	PART A 2%/5%		PART B 2%/10%	
	SHIP A	SHIP B	SHIP A	SHIP B
01	4745	4661	4745	4661
02	4596	4517	4318	4242
03	4471	4392	3999	3928
04	4317	4241	3671	3606
05	4183	4109	3370	3310
06	4054	3982	3094	3039
07	3928	3859	2840	2790
08	3806	3738	2607	2561
09	3688	3623	2393	2351
10	3574	3511	2197	2158
11	3463	3402	2017	1981
12	3356	3296	1851	1819
13	3251	3194	1699	1669
14	3157	3095	1560	1533
15	3053	2999	1432	1407
16	2663	2616	1183	1162
17	2580	2535	1086	1067
18	2500	2456	998	980
19	2423	2380	916	899
20	2348	2306	840	826
21		2111		716
22		2045		657
23		1981		603
24		1920		553
25		1861		509
26		1677		439
27		1644		403
28		1593		370
29		1544		340
30		1496		312
TOTAL	70156	86784	46816	50891

CASH FLOW = INCOME–PURCHASE PRICE–DRE–STEEL–DOWNTIME+LAST DD REV+ SCRAP

PART A:
SHIP A: 70156-31000-24767-2351-2753+247+1093 = $ 10625 OVER 20 YEARS
OR $ 531/YEAR
SHIP B: 86784-32290-32391-744-1206+181+889 = $ 21233 OVER 30 YEARS
OR $ 708/YEAR
PART B:
SHIP A 46816-31000-16399-1076-1420+89+371 = $-2619 OVER 20 YEARS
OR $ - 131/YEAR
SHIP B 50891-32290-18478-224-568+38+175 = $- 456 OVER 30 YEARS
OR $ - 15/YEAR
SHIP B: 45989-32290-16399-42-403-89-415 = $ -2641 OVER 20 YEARS

TABLE 13

AVERAGE ANNUAL INCOME (USD X 1000)

	SECOND SERIES 7%/15%		THIRD SERIES 0%/0%	
	SHIP A	SHIP B	SHIP A	SHIP B
01	4745	4661	4745	4661
02	4316	4239	4745	4661
03	3925	3856	4745	4661
04	3570	3506	4745	4661
05	3247	3189	4745	4661
06	2953	2901	4745	4661
07	2685	2638	4745	4661
08	2443	2399	4745	4661
09	2222	2182	4745	4661
10	2020	1985	4745	4661
11	1838	1805	4745	4661
12	1671	1641	4745	4661
13	1520	1493	4745	4661
14	1382	1358	4745	4661
15	1258	1236	4745	4661
16	1030	1011	4271	4194
17	937	920	4271	4194
18	851	836	4271	4194
19	774	760	4271	4194
20	704	692	4271	4194
21		595		3962
22		539		3962
23		492		3962
24		447		3962
25		406		3962
26		348		3729
27		316		3729
28		287		3729
29		263		3729
30		239		3729
TOTAL	44091	47240	92530	129340

CASH FLOW = INCOME–PURCHASE PRICE–DRE–STEEL–DOWNTIME +LAST DD REV+SCRAP

SECOND SERIES:

SHIP A 44091-31000-15426-943-1223+74+308 = $-4119 OVER 20 YEARS
OR $-206/YEAR

SHIP B 47240-32290-17094-182-509+29+132 = $-2674 OVER 30 YEARS
OR $- 89/YEAR

SHIP B 43308-32290-15426-36-376+74+345 = $-4401 OVER 20 YEARS

THIRD SERIES:

SHIP A 92530-31000-32860-3740-4229+450+2052 = $ 23203 OVER 20 YEARS
OR $ 1160/YEAR

SHIP B 129340-32290-49290-1530-2059+450+2284= $ 46905 OVER 30 YEARS
OR $ 1564/YEAR

TABLE 14

SENSITIVITY ANALYSIS

THE EFFECT OF A CHANGE OF USD 3,000,000 IN THE PURCHASE PRICE OFTHE BASE SHIP A
(ALL FIGURES IN USD X 1000)

LIFE CYCLE COST

-FIRST SERIES, PART A:
SHIP A: 58338 (TABLE 4)-3000 = 55338 FOR 20 YEARS OR $ 2767/YEAR
SHIP B: 65561 (TABLE 5)-3000 = 62561 FOR 30 YEARS OR $ 2085/YEAR

-FIRST SERIES, PART B:
SHIP A: 48631 (TABLE 6)-3000 = 45631 FOR 20 YEARS OR $ 2282/YEAR
SHIP B: 51347 (TABLE 7)-3000 = 48437 FOR 30 YEARS OR $ 1612/YEAR

-SECOND SERIES:
SHIP A: 47451 (TABLE 8)-3000 = 44451 FOR 20 YEARS OR $ 2223/YEAR
SHIP B: 49914 (TABLE 9)-3000 = 46914 FOR 30 YEARS OR $ 1664/YEAR

-THIRD SERIES:
SHIP A: 67763 (TABLE 10)-3000= 64763 FOR 20 YEARS OR $ 3238/YEAR
SHIP B: 82435 (TABLE 11)-3000= 79435 FOR 30 YEARS OR $ 2648/YEAR

CASH FLOW ANALYSIS

-FIRST SERIES, PART A:
SHIP A: 10625(TABLE 12)+3000= 13625 FOR 20 YEARS OR $ 681/YEAR
SHIP B: 21233(TABLE 12)+3000= 24625 FOR 30 YEARS OR $ 821/YEAR

-FIRST SERIES, PART B:
SHIP A: 2619 (TABLE 12)+3000= 381 FOR 20 YEARS OR $ 19/YEAR
SHIP B: 456 (TABLE 12)+3000= 2544 FOR 30 YEARS OR $ 85/YEAR

-SECOND SERIES:
SHIP A: 4119 (TABLE 13)+3000= 1119 FOR 20 YEARS OR $ -56/YEAR
SHIP B: 2674 (TABLE 13)+3000= 326 F0R 30 YEARS OR $ 11/YEAR

-THIRD SERIES:
SHIP A: 23203 (TABLE 13)+3000= 26203 FOR 20 YEARS OR $ 1310/YEAR
SHIP B: 46905 (TABLE 13)+3000= 49905 FOR 30 YEARS OR $ 1663/YEAR

TABLE 14 (CONT)

THE EFFECT OF A CHANGE IN AVERAGE INCOME OF THE BASE SHIP A FROM $ 13000/DAY TO $ 18000/DAY

LIFE CYCLE COST

-FIRST SERIES, PART A:
SHIP A: 97133-31000-24767-2351-3978+247+1093 = 36377 FOR 20 YEARS OR
$ 1819/YEAR
SHIP B: 120193-32290-32391-744-1669+181+889 = $ 54169 OVER 30 YEARS OR
$ 1806/YEAR
SHIP B: 95418-32290-24767-102-860+247+1225 = $ 38871 OVER 20 YEARS OR
$ 1944/YEAR

-FIRST SERIES, PART B:
SHIP A: 64824-31000-16399-1076-1965+89+371 = $ 14844 OVER 20 YEARS OR
$ 742/YEAR
SHIP B: 70400-32290-18478-224-833+38+175 = $ 18788 OVER 30 YEARS OR
$ 626/YEAR
SHIP B: 63614-32390-16399-42-563+89+415 = $ 14824 OVER 20 YEARS OR
$ 741/YEAR

SECOND SERIES
SHIP A: 61642-31000-15426-943-1750+74+308 = $12305 OVER 20 YEARS OR
$ 615/YEAR
SHIP B: 65411-32290-17094-182-707+29+132 = $ 15299 OVER 30 YEARS OR
$ 509/PER YEAR
SHIP B: 59967-32290-15462-36-522+74+343 = $ 12074 OVER 20 YEARS OR
$ 604/YEAR

THIRD SERIES
SHIP A: 131400-31000-32860-3740-6138+450+2052 = $ 60164 OVER 20 YEARS OR
$ 3008/YEAR
SHIP B: 193618-32290-42290-1530-3200+450+2284 = $ 110042 OVER 30 YEARS OR
$ 3668/YEAR
SHIP B: 129079-32290-32860-170-1167+450+2284 = $ 65326 OVER 20 YEARS OR
$ 3266/YEAR

TABLE 15

VOLUME OF STEEL USED IN LIFETIME AND DOWNTIME

SHIP A
-LIGHTSHIP: 11.400 T
-TOTAL STEEL RENEWALS REQUIRED THROUGHOUT ITS LIFE: 2200 T
-ECONOMIC LIFE: 20 YEARS (SEE WRITE UP)
-TOTAL STEEL USED FOR BUILDING AND REPAIRING THE SHIP THROUGHOUT ITS LIFE: 13.600 T
-TOTAL DOWNTIME: 341 DAYS IN 20 YEARS
-TOTAL STEEL USED ANNUALIZED: 680 T/YEAR
-AVERAGE DOWNTIME/YEAR 17.5 DAYS/YEAR
-THE TOTAL DOWNTIME FOR THE 3 SHIPS REQUIRED TO COMPLETE A 60 YEAR CONTRACT IS: 1023 DAYS

SHIP B
-LIGHTSHIP: 12.690 T
-TOTAL STEEL RENEWALS REQUIRED THROUGHOUT ITS LIFE: 900 T
-ECONOMIC LIFE 30 YEARS (SEE WRITE UP)
-TOTAL STEEL USED FOR BUILDING AND REPAIRING THE SHIP THROUGHOUT ITS LIFE: 13.590 T
-TOTAL DOWNTIME: 181 DAYS IN 30 YEARS
-TOTAL STEEL USED ANNUALIZED: 453 T/YEAR
-AVERAGE DOWNTIME/YEAR: 6.03 DAYS/YEAR
-THE TOTAL DOWNTIME FOR THE TWO SHIPS REQUIRED TO COMPLETE A 60 YEAR CONTRACT IS: 362 DAYS

COMPARISON AT A GLANCE
SHIP A REQUIRES:

-50.1% MORE STEEL PER ANNUM
-182.6% MORE DOWNTIME PER ANNUM

TO HAVE THE SAME DWT CAPACITY TRADING AT ALL TIMES, SHIPS BUILT AS PER SHIP A WOULD REQUIRE 50% MORE STEEL TO BE USED. THE FIGURES DO NOT TAKE ACCOUNT OF THE FAR GREATER DOWNTIME OF SHIP A OR THE SLIGHTLY SMALLER (1.77%) DEADWEIGHT CAPACITY OF SHIP B