MILITARY TECHNICAL COLLEGE

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# COMPUTER AIDED SHIP DESIGN ECONOMICS

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## ABSTRACT

As the computer aided ship design (CASD) is a way to translate the owners requirements into a feasible project through a methodical treatment of ship design problems oftenly by using spirals, the computer aided ship design economics is a way to help the shipowner himself to optimize his requirements by putting the answers of the questions frequently arise to him before putting his order.
From the main economical factors which are concerned by the shipowner the design speed, the economical life, and the maximum permissible price of the proposed ship.

This paper gives an approach to the optimum predictions of the above-mentioned factors and attempts an analysing procedure for determining the economical particulars for a newly ordered ship.

A closed design model (CDM) is developed which-besides the decisions for speed, life, and price-makes the necessary analyses to investigate the sensitivity of these factors to each other and to other technical and economical factors.

The algorithm of procedure is explained, flow charts of computer programs are given, and the results of analyses are presented and discussed through the paper.

## 1. INTRODUCTION

The development of useful, computerized ship design models is established by tackling the conventional design methods in a systematic way suitable for computers. This is called the computer aided ship design (CASD).
The CASD can be defined as a scientific way of using computers to make the preliminary design of a certain ship type.

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In computer aided design (CAD),there are three design models which can be distinguished [1] :

1- The open design model (ODM),which is used both in interactive as well as in conversational CAD. All decisions are taken by the designer,while all calculations are made by the computer.
2- The partly closed design model (PDM),which is similar to ODM both in interactive as well as in conversational CAD , but it allows the designer to take a part of decisions , other parts are pre-programmed mathematically to be taken by the computer.
3- The closed design model (CDM),which is used in batch of CAD: all calculations and all decisions are programmed to be taken by the computer.

In each of the given models the shipowner's requirements are the basic input to the problem,but as the CASD takes care for the design project following to the owner's order,the computer aided ship design economics(CASDE) take care for the owner's requirements themselves and help the owner in making the proper order for his new ship.

From the main questions arise to the shipowner before putting an order for a new ship,what is the optimal speed on which the design of the ship to be based,how long is the economical life of the ship,and how much money to pay for her ? .

The answers of these questions are dependent on a lot of technical and economical factors especially if the speed,life,and price of the ship are linked in such a way that it appears difficult to determine which is the dependent and which is the independent factor.

The optimization problem which includes the optimal speed,economical life,and permissible price of a ship is solved by specifying the objective which determines these factors at a specified market condition(cost & freight) .

The optimal speed of the ship is discussed from different points of view and is mathematically derived and examined at different conditions.

The treatments concerning economical life of the ship are given and a sensitivity analysis is made.

A method for determining the maximum permissible price of the ship is given,a discussion is made about depreciation,operation life,speed,and revenues and their effects on the maximum permissibl price of a newly ordered ship.

## 2. OPTIMAL SPEED OF A CARGO SHIP

The technical success of any ship over a lengthy period depends not only upon its suitability to the average working conditions but also upon its adaptability to wide variations from these conditions. The correct choice of ships speed and consequently the power are of major importance.

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The first thing to be settled with almost any new ship are the displacement and speed desired,but the highest speed of a ship of given dimensions is restricted to a certain extent because of the likelihood of damage at sea,the extra cost of fuel and the increased size of engine required for high propelling speed which reduces the cargo tonnage of the ship. On the other hand,the lower speed-although it may increase the tonnage of the ship-may reduce the number of earning trips and reduce the revenues.

The main criteria for an optimal speed are based on :

1- Minimizing overall cost,or
2- Maximizing profit.

The optimal speeds of cargo ships have been treated analytically in[2],however,the mathematical derivations are necessary to show the mutual dependence between the speed and different design and operational elements.

### 2.1. OPTIMAL SPEED FOR MINIMUM OVERALL COST

The overall cost of a ship are formed from the operation costs (crew,provisions,maintenance &repair,insurance,stores and supplies..etc) and the voyage costs(bunkering ..etc.),besides the annual capital cost which is the product of capital recovery factor by the capital. The costs are generally divided into speed dependent and speed independent elements. The rate of escalation of cost elements is generally differing which may necessitates the life span calculations,this is shown in the analytical derivation of optimal speeds given in[2] .

The mathematical derivation of optimal speeds may assume that the escalation rates of cost elements are identical and equal to the rate of interest,this may allow the first year figures to be applied in the mathematical derivation.
The overall costs of the ship are included in a suitable measure of economical utility of the ship which is called "the specific cost",it is equal to the overall costs of the ship divided by the ton.mile performed by the ship,it can be applied for life span or year time or even trip time.

The procedure is dependent mainly on deriving the equation of sp.cost per trip which may appears as follows:

$$S_c = \frac{Y.P.(D_s + D_p) + F_t.\ E}{R_u.(Dwt - F_{t1})} \qquad \text{................(1)}$$

$$F_t = D_s.(F_o + F_d) + D_p.F_p \qquad \text{................(2)}$$

$$F_{t1} = F_t + W_{ff} \qquad \text{................(3)}$$

Where ;

$S_c$ = specific cost (\$ / ton.mile)

Y = coefficient of daily fixed cost

P = first cost of the ship

$F_t$ = total fuel and diesel consumption per trip

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$E$ = fuel price per ton (U.S.$)
$D_s$ = number of days at sea per trip
$D_p$ = number of days in ports per trip
$F_o$ = fuel consumption per day at sea
$F_d$ = diesel consumption per day at sea
$F_p$ = fuel consumption in ports per day
$Dwt$= deadweight of the ship
$R_u$ = ruote distance in sea miles
$W_{ff}$= weight of reserve fuel and fresh water

Equation no.(1) is based on the assumptions that the total trip costs are equal to the sum of fixed cost(operation costs) and voyage cost and that the weight of fuel is an element of the carrying capacity of the ship which influences on the cargo transport capacity of the ship.

The first cost of the ship is partially dependent on ships spe-ed,it may be expressed as follows:

$$P = C_o + C_1 \cdot V^n \qquad \ldots\ldots\ldots\ldots\ldots\ldots(4)$$

$C_o$ = the portion of first cost which is speed independent
$C_1$ = the coefficient of speed-dependent portion of first cost
$V$ = design speed of the ship

The fuel consumption is totally function of ships speed and may be expressed as follows:

$$F_o = K \cdot V^3 \qquad \ldots\ldots\ldots\ldots\ldots\ldots(5)$$

$K$ = coefficient which is dependent on ships type,engine type and power,and service conditions.

The number of days at sea is dependent on the route distance and ships speed,

$$D_s = \frac{R_u}{24 \cdot V} \qquad \ldots\ldots\ldots\ldots\ldots\ldots(6)$$

$$R_u = L_r \cdot (1 + C_s) \qquad \ldots\ldots\ldots\ldots\ldots\ldots(7)$$

$L_r$ = the actual route distance of round trip in sea miles
$C_s$ = a coefficient which covers the voyage uncertainities,it may be taken equal to 5%

The equation of specific cost per trip may then be rewritten as given below :

$$S_c = \frac{Y(C_o+C_1 \cdot V^n)(D_s+D_p)+E \cdot D_s \cdot (K \cdot V^3+F_d)+D_p \cdot F_p \cdot E}{R_u \cdot (Dwt-D_s \cdot (K \cdot V^3+F_d)-D_p \cdot F_p-W_{ff})} \qquad \ldots\ldots(8)$$

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The determination of optimal speed which corresponds to the least specific cost may be done by equalizing the first derivative of equation (8) relative to the speed V by zero :

$$\frac{d}{dV}(S_c) = 0.0 \qquad \text{.....................(9)}$$

Rearranging the equation after defferentiation, the optimal speed will be the root of the following equation:

$$B.V^4 - C.V^3 + G.V^2 - H.V = M \qquad \text{................(10)}$$

or ;
$$V = \sqrt[4]{\frac{M + H.V - G.V^2 + C.V^3}{B}} \qquad \text{................(11)}$$

$$B = K.D_p.(2Y.P+2E.F_p-n.Y(P-C_o))+2A.K.E \qquad \text{..............(12)}$$

$$C = R_u.K.(n.Y(P-C_o)-3Y.P)/24 \qquad \text{..............(13)}$$

$$G = 24.A.D_p.n.Y.(P-C_o)/R_u \qquad \text{..............(14)}$$

$$H = n.Y.(P-C_o)(F_d.D_p-A)+E.F_p+Y.P)(F_d.D_p-A) \qquad \text{...........(15)}$$

$$M = R_u.F_d.n.Y.(P-C_o)/24 \qquad \text{...........(16)}$$

$$A = Dwt - D_p.F_p - W_{ff} \qquad \text{...........(17)}$$

The constants $C_o$, $C_1$ ,and n can be calculated from market prices or using statistical data for similar types of ships. The following procedure may be applied:

From the available data about prices and speeds of ships of similar type and mission a group of equations of exponential form may be written as follows :

$$P_1=C_o+C_1.V_1^n \quad , \quad P_2=C_o+C_1.V_2^n \quad , \quad P_3=C_o+C_1.V_3^n \qquad \text{.......(18)}$$

From which ;

$$\frac{dP}{dV} = n.\ C_1\ .\ V^{n-1} \qquad \text{...........(19)}$$

$$dP = P_2 - P_1 \quad , \quad dV = V_2 - V_1 \quad , \quad V = (\ V_2 + V_1)/2 \qquad \text{..(20)}$$

$$dP = P_3 - P_2 \quad , \quad dV = V_3 - V_2 \quad , \quad V = (\ V_3 + V_2)/2 \qquad \text{..(21)}$$

Thus ;

$$\frac{P_2 - P_1}{V_2 - V_1} = n.C_1.\left(\frac{V_1 + V_2}{2}\right)^{n-1} \qquad \text{............(22)}$$

$$\frac{P_3 - P_2}{V_3 - V_2} = n.C_1.\left(\frac{V_2 + V_3}{2}\right)^{n-1} \qquad \text{............(23)}$$

From (22),(23) ;

$$\frac{P_2 - P_1}{V_2 - V_1} \cdot \frac{V_3 - V_2}{P_3 - P_2} = \left(\frac{V_1 + V_2}{V_2 + V_3}\right)^{n-1} \qquad \text{........(24)}$$

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$$n = 1 + \frac{Log(P_2-P_1)-Log(P_3-P_2)+Log(V_3-V_2)-Log(V_2-V_1)}{Log((V_1+V_2)/(V_2+V_3))} \quad ..(25)$$

$$C_1 = ( P_1 - P_2 )/( V_1^n - V_2^n ) \quad ............(26)$$

$$C_o = P_1 - C_1.V_1^n \quad ............(27)$$

The solution for optimal speed using the given procedure requires a trial and error process or it can be solved by successive approximation.

2.2. OPTIMAL SPEED FOR MAXIMUM PROFIT

In case if the market freight rates for cargo transport are of known levels,it will be of large interest to make a similar derivation for the optimal profitable speed of the ship and investigate the effect of freight rates on the decision of ship's speed.

In design conditions,it is rather difficult to determine the future levels of freight rates as they are varying not only with time but also due to other reasons,e.g.,economical,political and/or environmental. Thus,the design decision may become worse -if it is based on a certain level of freight rates-due to the sharp alterations joined with local or international problems.

In order to simplify the mathematical derivation of the optimal profitable speed,some assumptions may become necessary,e.g.,the freight rate has a steady level,and the average annual escalation rates of costs and freights are identical and equal to the rate of interest required to determine the present worths.

The equation of annual profit may apear in the following form:

$$P_r = V_n.F_r.(Dwt-D_s.(K.V^3+F_d)-D_p.F_p-W_{ff})-H_d.Y.(C_o+C_1.V^n)-V_n.(E.D_s.(K.V^3+F_d)-D_p.F_p.E) \quad ................(28)$$

$$V_n = H_d / ( D_s + D_p ) \quad ...............(29)$$

$P_r$ = annual profit

$V_n$ = number of earning trips per year

$F_r$ = market freight rate per ton

$H_d$ = hire days per year.

The determination of optimal speed which corresponds to maximum profit may be done by equalizing the first derivative of eq.(28) relative to the speed by zero;

$$\frac{d}{dV}( P_r ) = 0.0 \quad ...............(30)$$

Rearranging the equation after defferentiation,the optimal speed

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6 for maximum profit may have the root of the following equation:

$$W \cdot V^4 + Q \cdot V^3 + S \cdot V^2 - T \cdot V + U = 0.0 \qquad \text{......(31)}$$

$$W = 2.D_p.K.(F_r+E) \qquad \text{......(32)}$$

$$Q = 3.R_u.K.(F_r+E)/24 \qquad \text{......(33)}$$

$$S = 24.D_p^{\,2}.n.Y.(P-C_o)/R_u \qquad \text{......(34)}$$

$$T = F_r.A-D_p.(F_p.E+2.n.Y.(P-C_o)-F_d.(F_r+E)) \qquad \text{......(35)}$$

$$T = n.Y.R_u.(P-C_o)/24 \qquad \text{......(36)}$$

The solution for the optimal profitable speed in eq.(31) may be done by trial and error or by successive approximation.

### 2.3. SENSITIVITY ANALYSES OF OPTIMAL SPEEDS

The sensitivity of optimal speeds is examined after altering many technical and economical factors on which the speed may depends,these factors are:the route distance of round trip, coefficient of daily fixed cost,fuel cost,fuel consumption, and freight rate.

The flow chart of computer program which makes such anylyses is shown in figure(1). In figure(2) the optimal speed for minimum overall cost(the economical speed) and the optimal profitable speed are given in accordance to the route distance.

It can be seen that the economical speed increases due to increasing route distance,while the profitable speed decreases if the freight rate is not accordingly changed as the route distance increases. The reason for increasing economical speed is that the ratio between sea days and port days increases which means that the ship can produce more ton.mile per trip which allows for the shown increase in speed. It is also seen that the increase in economical speed is not a permanent phenomenon, i.e.,the rate of increase of economical speeds is somewhat larger for the range of short routes to medium route distances while the rate is decreased for higher routes so, it seems that there are a limit for the assymptotic increase of economical speeds after which the maximum economy is maintained at nearly a constant speed disregarding the increase of route distance.

The optimum profitable speed is decreased due to increasing route distance or increasing sea days per trip,this is clearly understood if the freight rate is not increasing accordingly. It is also seen from figure(2) that for short trade routes and relatively high freights the profitable speed is allowed to be high and the revenues are so attractive that they cover the consequent increase in operation and voyage costs and give a good sum as a profit.

From the example given in figure(2) it can be seen that the same profitable speed can be maintained at route distance 5000 sea miles with freight rate of \$25/ton and at route distance 8000 sea miles if the freight rate increases to \$30/ton.

Figure(3) illustrates the influence of increasing the coeffic-

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ient of daily fixed cost(Y) on optimal speeds,the coefficient (Y)-if multiplied by the first cost of the ship-gives the operation costs per day which determines the daily share of the costs of crew,provision,maintenance and repair,stores and supplies,insurance,administrations plus the capital recovery portion. The increase of (Y) gives the opportunity to study the influence of increasing fixed costs or any element of the above-mentioned on the optimal speeds. The economical speeds increase if the operation cost increase because this part of costs is not dependent on ship's speed and is approximately fixed or slightly increasing at higher speeds,thus,the economy philosofy dictates that the ship must operate as fast as possible if there are no appreciable increase in operation costs. The consequent increase in voyage cost is constraining the increasing speed. The profitable speed decreases if the freight rate is not increasing accordingly.

Figure(3) shows also that the same profitable speed can be maintained if for the altered value of(Y) from 0.0003 to about 0.0005 the freight is to move from $25 to $30/ton. A group of similar curves can help in deciding the reasonable freight rate at any level of operation costs.

In figure(4),the influence of fuel price on optimal speeds is illustrated,it is shown that both economical and profitable speeds are reduced due to increasing fuel price.

In figure(5),the influence of daily fuel consumption on optimal speeds is illustrated,the increased fuel consumption may arise due to increasing loading on propeller or due to additional service resistance. It is shown that both economical and profitable speeds are reduced due to increasing fuel consumption which leads to increasing voyage cost and reducing cargo transport capacity.

## 3. THE ECONOMICAL LIFE OF A SHIP

For any long-term investment,it is difficult to decide how long is the economical period for exploiting such investment.
The practical and reliable decisions may be based on a year-to-year analysis. This concept is feasible during the operation period of the investment object,but if this object is a ship, the economical utility is basically dependent on the economical life which is to be approximated from the very begining of design procedure that helps in determining the optimal technical and economical particulars of the ship.

There are originally two methods for determining the economical life of the ship,the first of which the replacement decision is taken according to year-to-year analysis,the second of which the economical life of the ship is determined during the preliminary design stages. Although the first method is the more realistic one due to use real figures of expenses and income at the right time,the second method is the suitable one for determining the economical life of the ship during the preliminary design stages as it is necessary to have a close idea about the life span of the newly ordered ship.

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### 3.1. JELEN'S - ALCHAIN'S METHOD

This method is the first one from the above-mentioned which is concerned in replacement decision by estimating the cash flows for the present year and for one year hence during which a comparison between the defender and chalenger is done for existing ships. The largest net present value(N.P.V.) of cash flow determines the decision which is either replace now or wait one more year and repeat the analysis.
In this method,it is assumed that the better costs and returns for a new chalenger ship form a loss opportunity for the old defender ship. Since this method is not applicable during the early stages of ship design it will be considered out of the scope of this paper.

### 3.2. THE AVERAGE ANNUAL COST METHOD

This method is given by Edge(a Canadian Author) in 1964,[3],he used the avarage annual cost as a criterion,this method requires the knowledge of the initial cost,annual operating costs and their escalation rates. It requires also the prediction of disposal value every year and the rate of interest .
This method may be performed through the following steps:

a. Convert the capital cost into annual cost using capital recovery factor CR ,
b. Convert the operation and voyage costs each year to their present worths,add the present worths of the previous years and convert into annual cost using CR ,
c. Convert the disposal value into negative annual cost using sinking fund factor or from its present worth using CR ,
d. The summation of elements from a,b,and c gives a figure for comparison,the number of years which gives the lowest total is the economical life of the ship.

The general equation of average annual cost at different lives may have the following form:

$$AAC_n = \left[P + \sum_{n=1}^{N} (PW-i-n)(O_c+V_c) - (PW-i-n)S_n\right](CR-i-n) \quad \ldots(37)$$

$AAC_n$ = the average annual cost at the n th year
P = the first cost of the ship
$O_c$ = the operation costs
$V_c$ = tha voyage cost
$S_n$ = the disposal value at n th year .

The average annual cost method suggests the conversion of all data to after tax basis,but the author thinks that for the reason of comparison the economical life before tax will be also the economical life after tax due to the similar figures of tax rates applied for each duration investigated. Thus it can be said that the before tax figure will be a satisfactory indicator to the choice of economical life for a newly ordered ship .

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### 3.3. SENSITIVITY ANALYSES OF ECONOMICAL LIFE

In order to investigate the sensitivity of economical life to design and operation particulars,a computer program is developed to discuss the influence of operation cost,voyage cost,and speed on the economical life of the ship. The flow chart of the program is given in figure(6),the results are shown in figures(7),(8),and(9).

In figure(7),the influence of operation costs and speeds on the economical life of the ship is shown,the coefficient(Y) is changed from 0.0003 to 0.0008,this change showed how much is the economical life sensitive to operation costs. From the figure it can be seen that the the increase of (Y) from 0.0003 to 0.0008 reduces the economical life from 19 years to only 8 years.

The economical life mentioned here is the life of the ship which is for the sake of shipowner is sufficient to keep the ship and after which he must replace her by a new ship.
The ship in this condition is not necessarily sold for demolition,she can be used for another period of operation according to the policy of the new owner.

In figure(8),the effect of daily fuel consumption on the economical life is shown. It can be seen that the economical life is decreased by increasing daily fuel consumption due to the economical deterioration of the ship which results from higher fuel cost and less cargo transport.

The influence of fuel price on the economical life is shown in figure(9),it is shown that the economical life is less affected by increasing fuel price than by increasing fuel consumption, the reason is that the increased fuel consumption is joined by a reduction of cargo transport capacity which results from the additional space required for bunkering. However,it is shown that increasing fuel price reduces the economical life.

From the results of sensitivity analyses,it can be concluded that the economical life of the ship is reduced due to increasing any of cost elements,there are also an inverse proportion between ships speed and economical life due to the corresponding increase in first cost and other voyage and operation costs.

## 4. THE PERMISSIBLE PRICE OF A SHIP

Before going on a new investment in a ship,the first cost of the ship represents a real problem to the owner. In such condition the owner have to compare between different offers from shipyards using his own criterion but in every case he believes that he must not deposit in such investment more than the money it deserves. In other words,the ship must not produce any loss throughout her employment life.

### 4.1. PREDICTION OF THE PERMISSIBLE PRICE FOR A SHIP

The maximum permissible price for a newly ordered ship is treated in this paper from the owners point of view which is practically differing from the shipyards .

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6 The owner's criterion for estimating the maximum permissible price of the ship is based on maximizing what is called "reproduction factor" which is the ratio between the owner's permissible price and the shipyard's offered price.

Satisfying this condition can be attained if the difference between total revenues and total costs becomes equal to the shipyard's offered price multiplied by a reproduction factor which must be always more than unity, [4] .

$$r \cdot P = \sum ( R - Y_t ) \qquad r > 1 \qquad .......(38)$$

- $r$ = reproduction factor
- $P$ = investment cost (shipyard's offer)
- $R$ = present worth of revenues
- $Y_t$ = total present values of operation and voyage costs

The total revenues depend on the cargo transported and the freight rate,both are differing by time,the profits are to be on the after-tax basis.

$$R = Fr_n \cdot Q_n \qquad .......(39)$$

- $Fr$ = freight rate per ton
- $Q$ = cargo transported per year

The indices of Fr and Q are denoting the year.
Accordingly,the equation no.(38) yields ;

$$r.P = \sum_{1}^{N} ( PW\text{-}i\text{-}n ) \left[ (( R - Y_t ) - Dep)(1 - T_x) + Dep \right] \qquad ......(40)$$

$n = 1 ,2 ,......, N$

The total costs $Y_t$ are considered through the life span of the ship.
It is known that both revenues and expenses may be subjected to changing their levels by time,but if the revenues may depress at any period due to some political or market crises the expenses escalate disregarding the market condition,it even may become worse due to these crises.

The freight rate in spite of depression periods,follows a mean line of escalation which may be approximated in a close figure for long-term analyses. Figure(10) shows the behaviour of freight undex during the period 1974 - 1979 .

## 4.2. SENSITIVITY ANALYSES OF THE PERMISSIBLE PRICE

The permissible price for a ship,if precisely estimated,determines the flixibility of shipowner during negotiations with shipyards and hence it is rather important for shipowner to predetermine such ranges of price over which he must not pay and at which a maximum reproduction factor is attained.

The sensitivity of permissible price of the ship is investigated under different speeds,lives,and depreciation policies.
A computer program is developed for such analyses,the flow chart is given in figures(11-a to e).

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## 4.3. THE ALGORITHM OF MAIN AND SUBPROGRAMS

The program have the ability of calculating the maximum permissible price for any cargo ship according to the given input data ,for straight line depreciation,declining balance depreciation,sum of the years digit depreciation,and free depreciation types,figure(11-a) .

a. The straight line depreciation subprogram (STRLN),fig.(11-b)

This subprogram calculates the fraction which if multiplied by the first cost gives the depreciation allowance:

$$FRAC = ( 1 - S_v ) / NE \quad ..........(41)$$

NE = ship's life

$S_v$ = scrap value

b. The declining balance depreciation subprogram(DBLNC)

This subprogram calculates the annual percentage of depreciation(R),and the fraction which determines the annual allowance, figure(11-c).

$$R = 1 - S_v^{(1/NE)} \quad ...........(42)$$

$$FRAC = R \cdot (1 - R)^{(n-1)} \quad ...........(43)$$

n = ship's age , n = 1,2,...,NE

c. The sum of the years digit subprogram(SUMDGT)

This subprogram calculates the annual fraction which determines the annual depreciation allowance,figure(11-d) .

$$XN = 1+2+3+....+NE \quad ...........(44)$$

$$FRAC = (NE - n + 1)(1-S_v)/ XN \quad ...........(45)$$

d. The free depreciation subprogram(FREE)

In this subprogram ,the difficulty was that the free depreciation method requires the knowledge of the price itself to subtract the annual profit from it until the price being consumed totally. But as the price is already unknown,the process will require a trial and error procedure which is based on the fact that the sum of profits before taxs at a certain time through the ship's life must equal to the sum of present worths of this portion of profits plus the present worths for the after taxed profits of the rest time of ship's life. Thus ,an estimation is done annualy for detecting the time at which the above-mentioned condition is satisfied.

The flow chart of the subprogram is given in figure(11-e). Following are the definitions of the quantities and abbreviations given in the subprogram:

$$P_o = REVX_{n-1} + X \cdot DIF \quad ...............(46)$$

$$X = ( RE - 1.0 + Tx )/(Tx-TERM) \quad ..............(47)$$

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6 $RE = (REVX_{n-1} - REVY_{n-1} - REVZ_{n+1}).TERM/DIF$ .....(48)

$DIF$ = the profits at the year when the price is consumed

$X.DIF$ = the portion of profit which if added to the profits of previous years completes the permissible price

$P_o$ = the permissible price of the ship

$TERM = (1 + i)^n$ ......(49)

$REVX_n$ = total profits up to the year (N)

$REVY_n$ = total present worths of profits up to year (N)

$REVZ_n$ = total present worths of after taxed profits from the year(N+1) and up to the end of operation life

$Tx$ = tax rate

$i$ = rate of interest .

### 4.4. DISCUSSION OF PROGRAM RESULTS

In figures(12),(13),and(14) the influence of economical life of the ship on the permissible price at different freight rates and depreciation policies is illustrated. The permissible price of the ship is presented in the form of a reproduction factor (r) which equals to the ratio between owner's permissible price and shipyard's price which is calculated according to equation(4).

From these figures the following can be noticed:

a - It is clear that increasing the initial freight rate causes an increase in the reproduction factor at a constant speed. It is also shown in the given example that the freight rate of $15/ton does not allow for owning a ship,while at a freight rate of $25/ton the reproduction factor becomes higher than unity at the free depreciation type starting from 10 years life and is not encourageable at other types .

b - The reproduction factor increases by increasing the operation life at higher freight rates.

c.- The reproduction factor increases by increasing ship's speed through a finite range according to ship's type and operation data

d - The free depreciation method holds better reproduction factor than all other types of depreciation policies.

In figure(15) it is shown that there is a definite relation between the speed and reproduction factor at a constant operation life,here,another indication for optimal profitable speed is given.

### 5. CONCLUSIONS

The computer aided ship design economics(CASDE) is an important tool which may help the shipowner in making his decision and put his order in a proper manner. The most important economical decisions for a newly ordered ship are the optimal speed,the economical life , and the permissible price.

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There are two basis for evaluating the optimal speeds,e.g., the maximum economy and maximumprofit. The former may be applied if for long term trends the freight rates are not predictable in a satisfactory manner,it maintains the maximum efficiency of transport at the least cost. The latter is better be used if the freight rates are well known at present and their future trends are predictable,the optimal profitable speeds are generally higher than the economical speeds especially at higher freight rates.

The increasing of operation costs have a different influence on both economical and profitable speeds,it increases the economical speed and decreases the profitable speed.

The increase of route distance at constant freight rate decreases the profitable speed while it increases slightly the economical speed.

The increase of fuel consumption which may be caused by added resistance or increasing loading on propeller reduces the economical speed as well as the profitable speed,it also reduces the cargo carrying capacity and increases the voyage cost and reduces the profits.

The economical life is determined in the preliminary stages of ship design using the AAC method,it gives an idea about the time at which the ship may be replaced.

The economical life of the ship is reduced if the fuel consumption increases due to any reason,it also decreases if the first cost,operation costs,or voyage cost increase.

The economical life is also reduced by increasing design speed of the ship.

As the economical life is dependent only on cost elements,it has no relation to the freight rates.

It is now clear that the permissible price of the ship from owners point of view is essentially depending on the economical life,design speed,freight rate,and the depreciation policy.

The higher freight rate and free depreciation type bring higher reproduction factors,while the low freight rates may not assist the decision for putting the order for a new ship,and other types of depreciation policies bring less reproduction factors.

The maximum reproduction factor may assist the criteria for the optimal profitable speeds,it may also give a new criterion for the optimal life which gives the maximum reproduction factor, but it seems that this optimal life will ba longer for higher freight rates which may add some difficulties of costs prediction and may give an optimal life which is longer than the technical life of the ship .

## 6. LITERATURES

[1] E. Deetman — How to use CAI&CAD in preliminary ship design. III - Symposium Theory and practice, F.S.B. Zagreb , Yugoslavia , 1978 .

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[2] G. Younis The computer role in controlling design and operation speeds of cargo ships.
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[3] H. Benford Optimal life and replacement analyses of ships and shipyards.
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V- Sympozium Theory and practice of shipbuilding, F.S.B. Zagreb, Split, Yugoslavia,May 1982.

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THE FIGURES

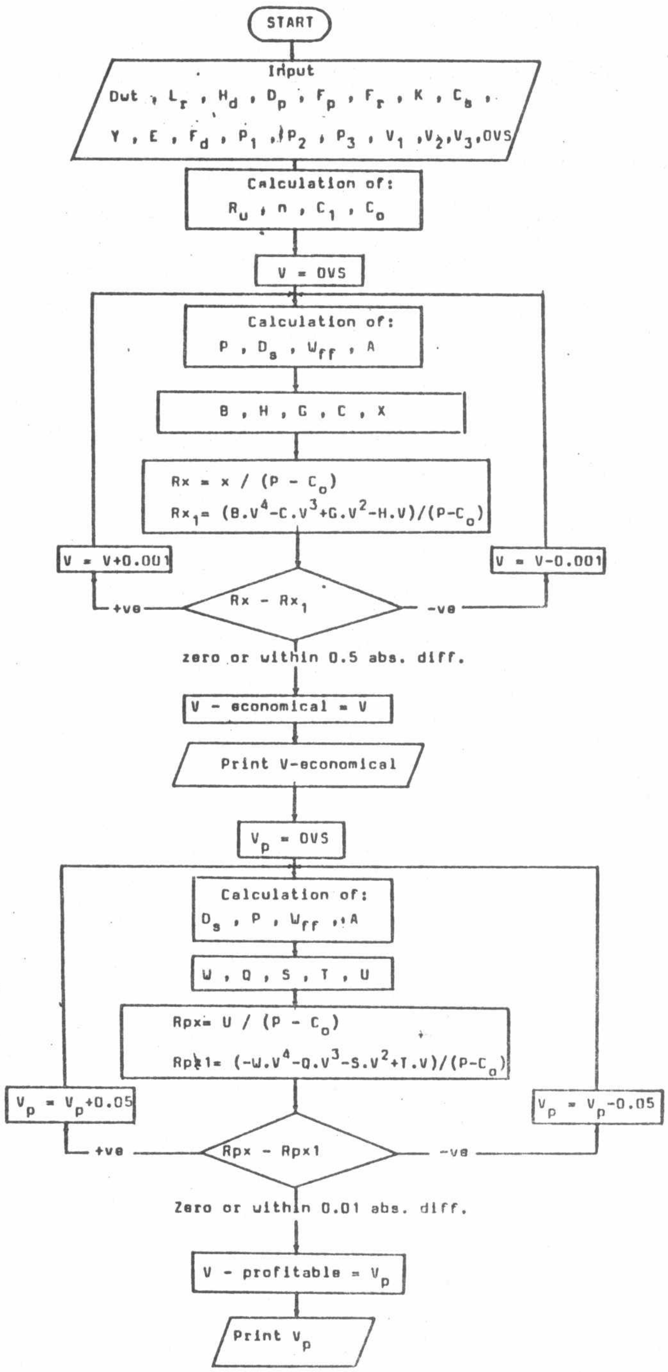


Figure (1). Flow Chart of Optimal Speeds Program .

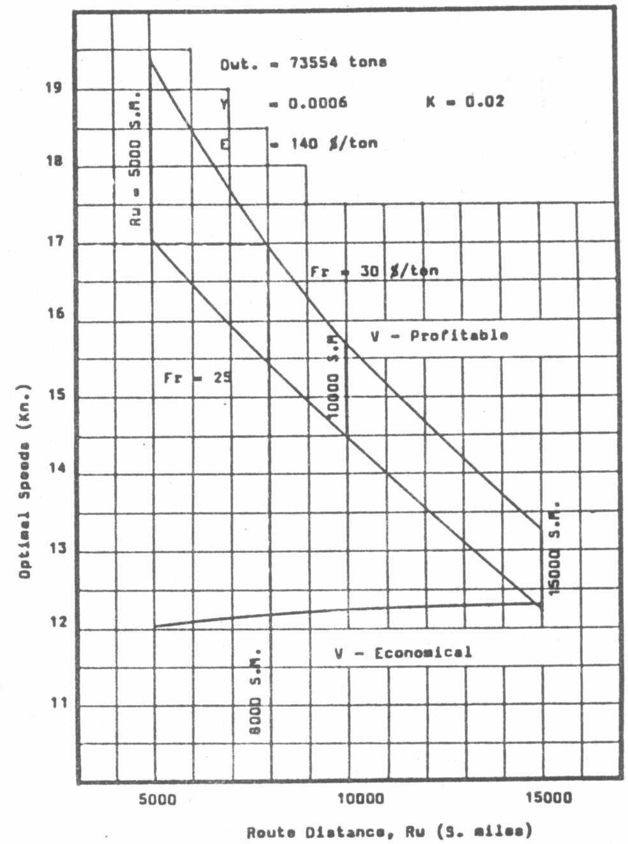


Figure (2). The Influence of Route Distance on Optimal Speeds of the Ship .

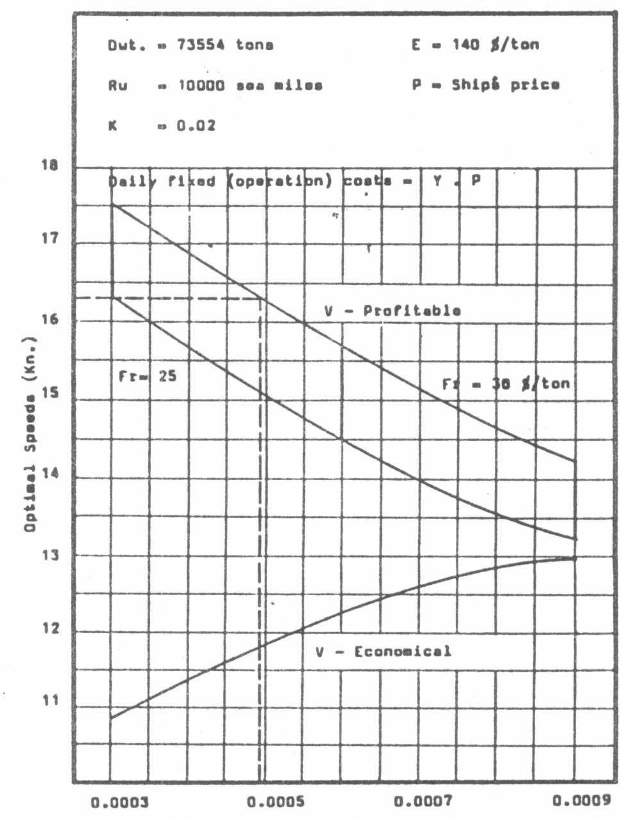


Figure (3). Influence of Operation Costs on Optimal Speeds

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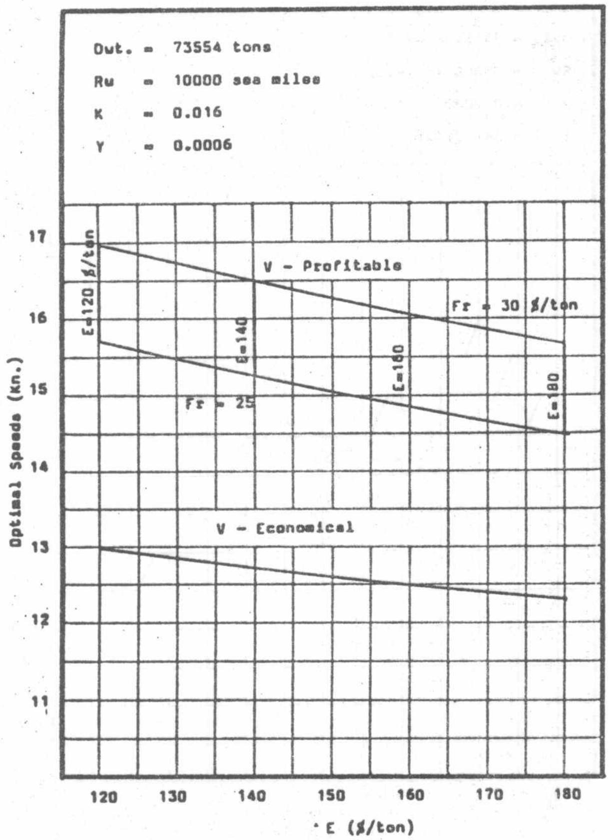



Figure (4). Influence of Fuel Price on Optimal Speeds .

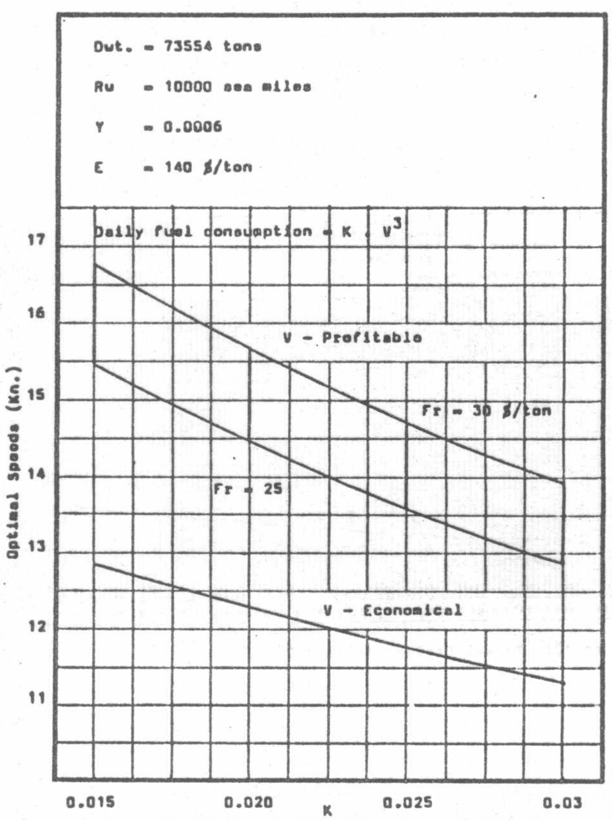
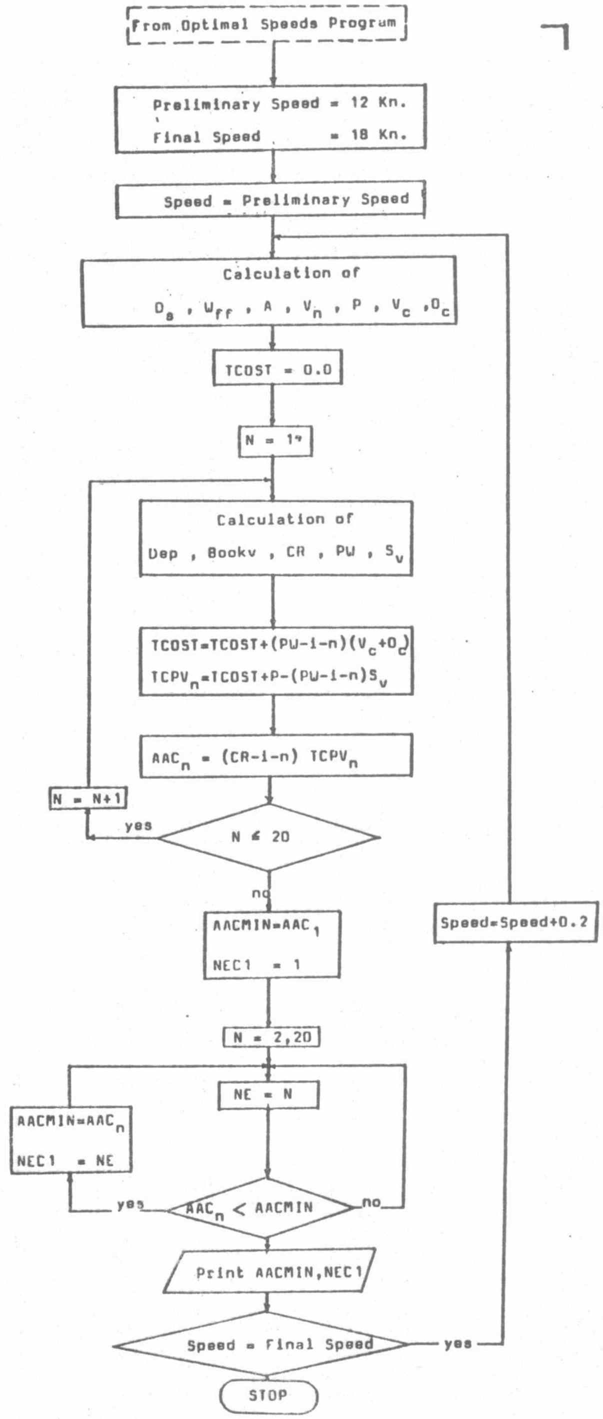



Figure (5). Influence of daily fuel consumption on optimal speeds of the ship .




Figure(6). Flow Chart of Economical Life Program .

$V_c$ = initial voyage costs

$O_c$ = initial operation costs

Dep = depreciation allowance(based on sum of the years digit depreciation)

Bookv = book value of the ship

$S_v$ = resale value,it is assumed equal to book value

CR = capital recovery factor

PW = present worth factor

i = rate of interest

TCOST = total operation and voyage costs up to year(n)

$TCPV_n$ = net present value of total costs,first cost and resale value of the ship at the year(n)

NEC1 = the economical life

$AAC_n$ = the average annual cost at the year (n)

AACMIN= the least average annual cost .

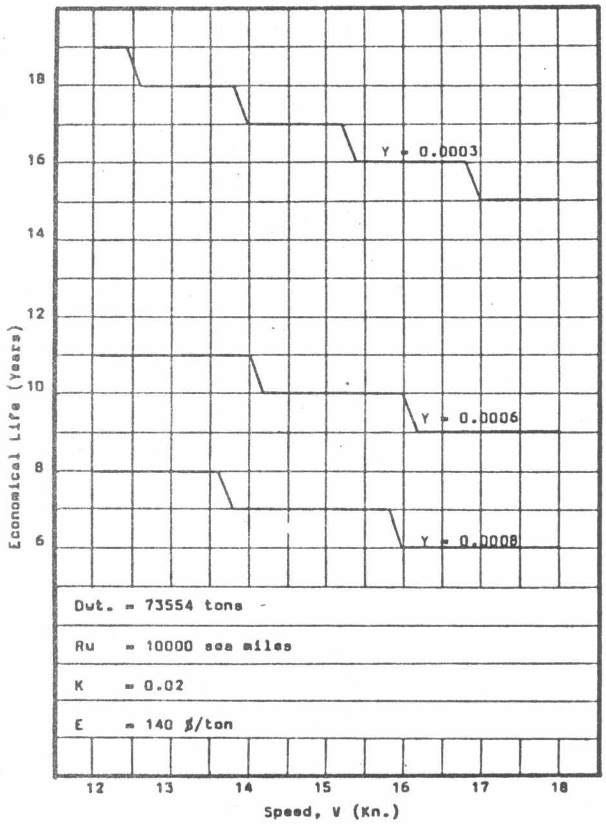



Figure (7). Influence of Speed and Operation Costs on the Economical Life of the Ship .

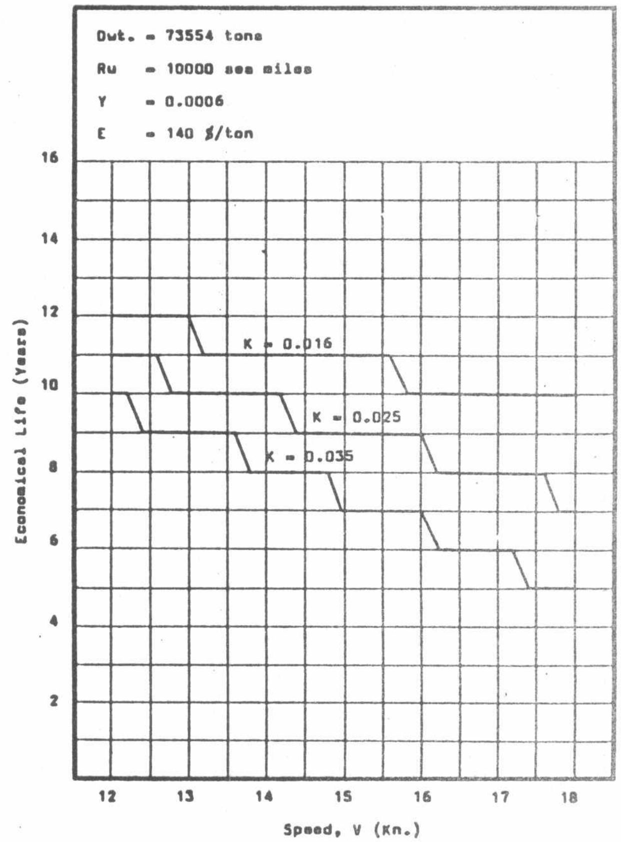



Figure (8) Influence of Speed and Daily Fuel Consumption on the Economical Life of the Ship .

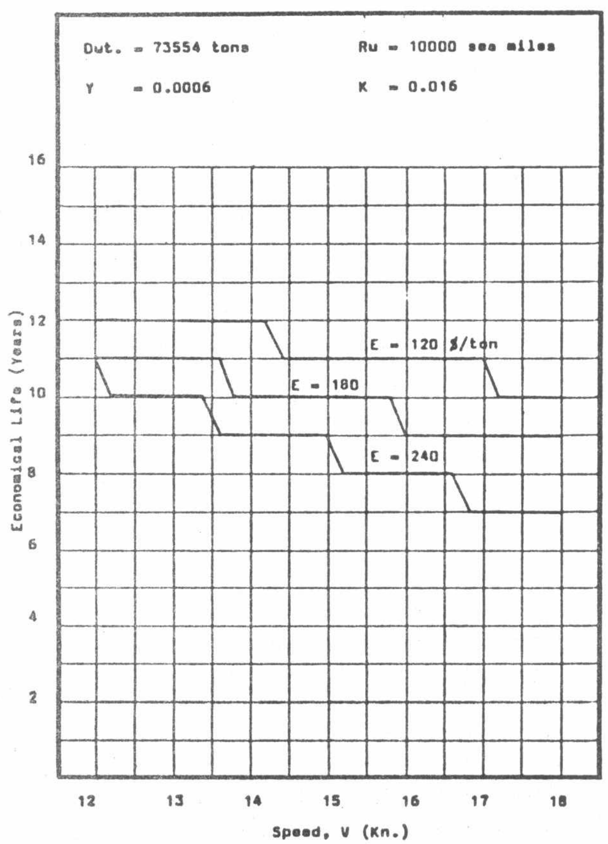
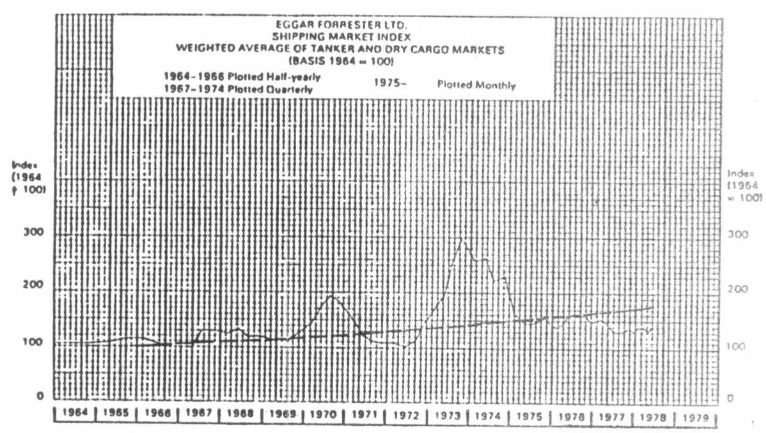



Figure (9). Influence of Speed and Fuel Price on the Economical Life of the Ship .




Figure(10). Market Freight Index 1964-1979

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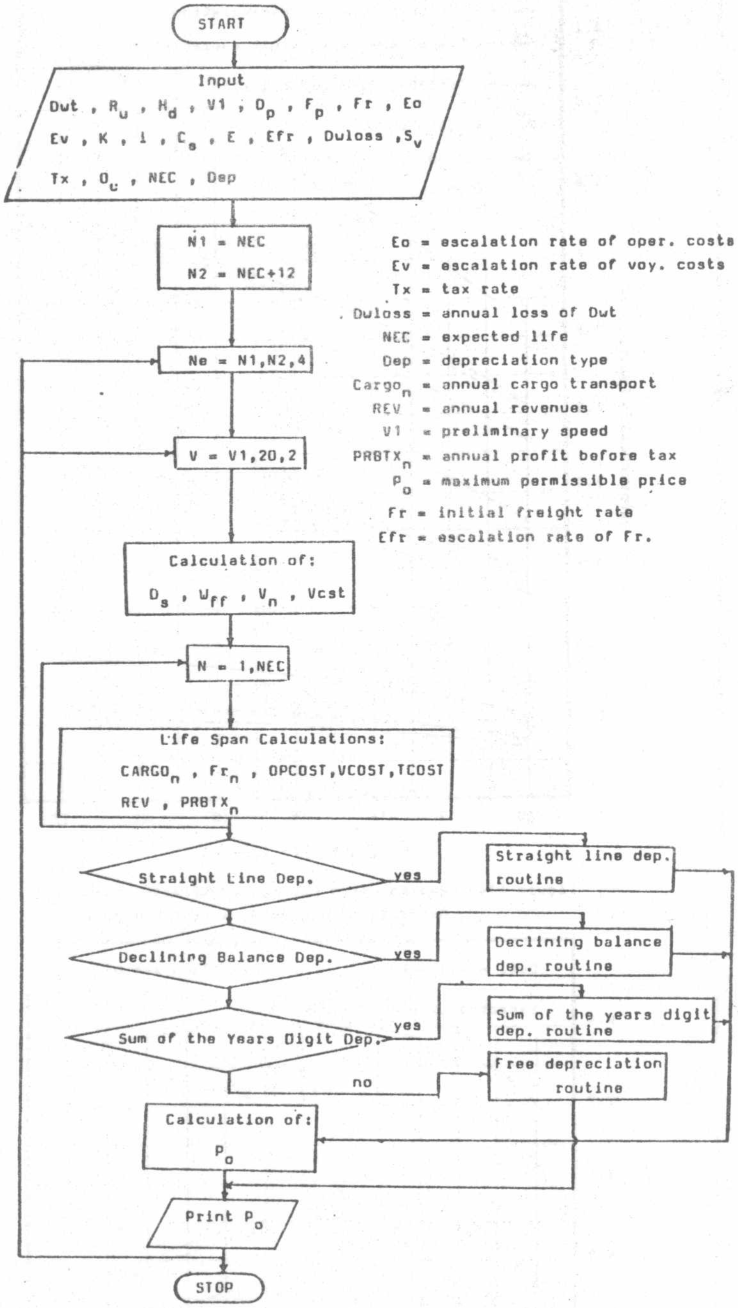
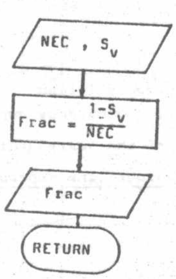
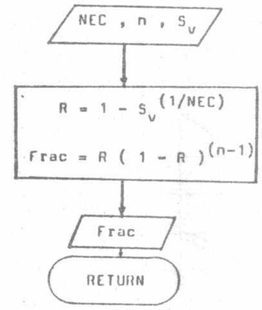


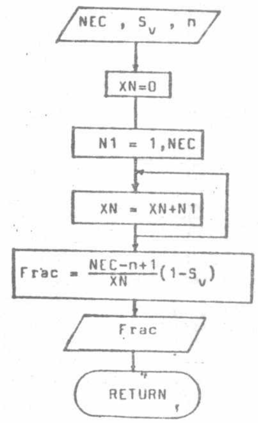

Figure(11-a) Flow Chart of Permissible Price Program.



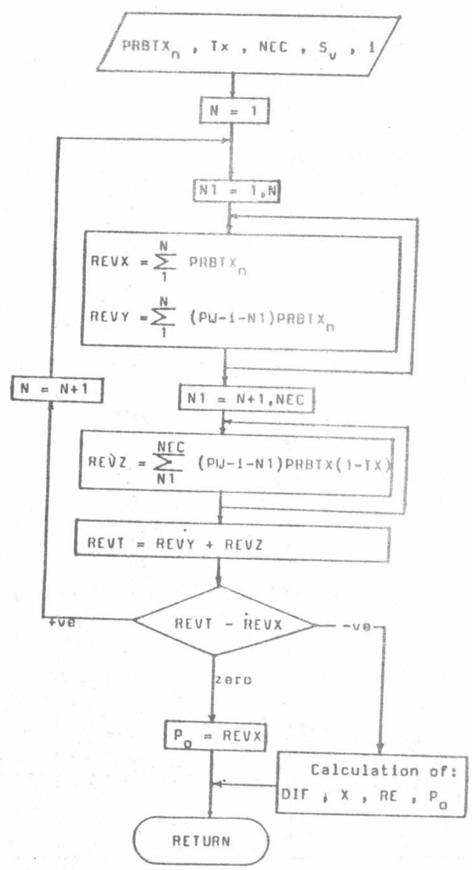

Figure(11-b). Flow Chart of Straight Line Dep. Subroutine .




Figure(11-c). Flow Chart of Declining Balance Dep. Subroutine.




Figure(11-d). Flow Chart of Sum of the Years Digit Subroutine.




Figure(11-e). Flow Chart of Free Depreciation Subroutine .

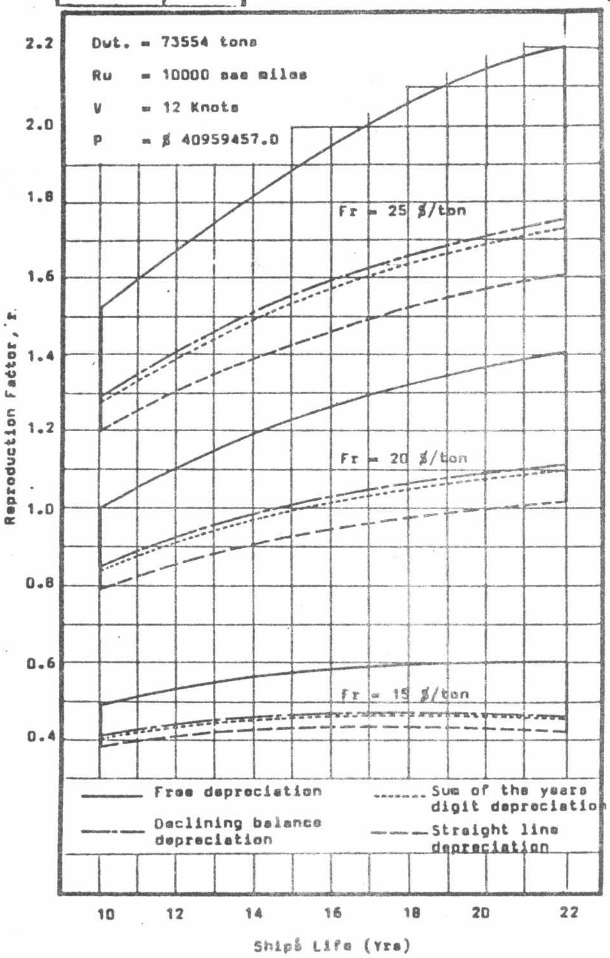



Figure (12). The Reproduction Factor at Different Lives and Depreciation Policies at speed= 12 Knots.

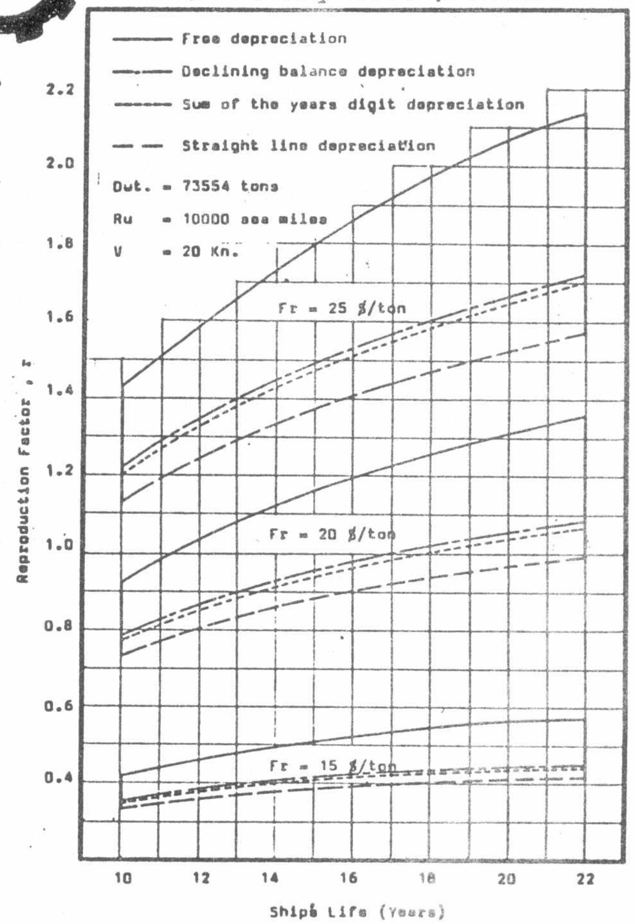



Figure (14). Reproduction Factor at Different Lives and Depreciation Policies at Speed = 20 Kn.

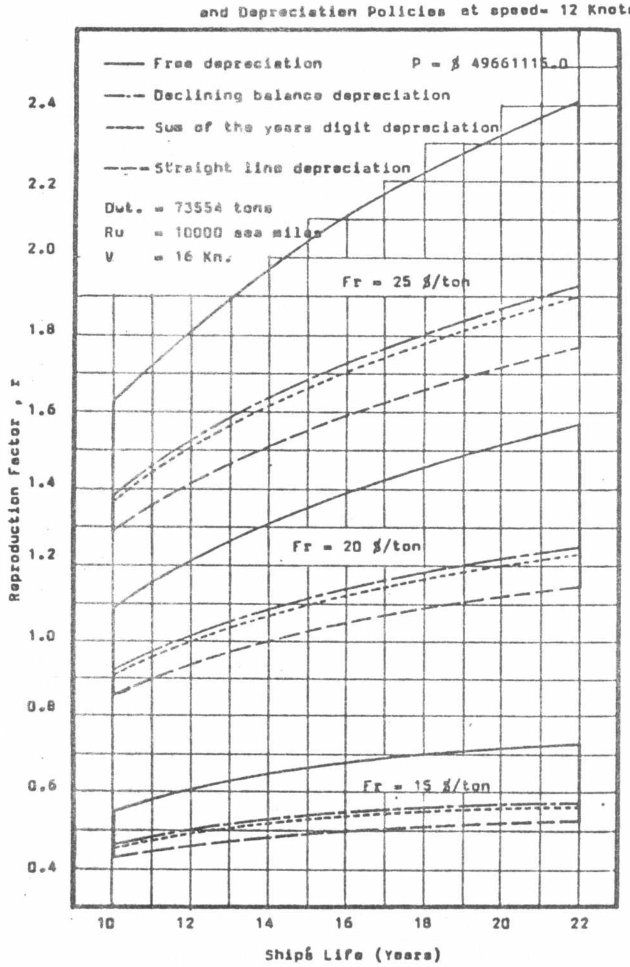



Figure (13). Reproduction Factor at Different Lives and

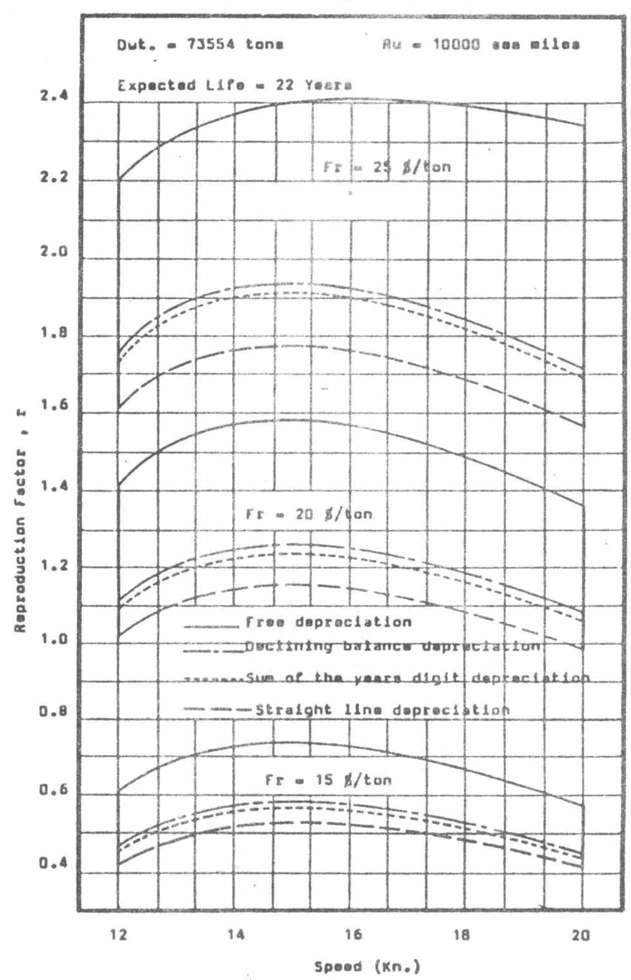



Figure (15). The Reproduction Factor at Different Speeds