PRELIMINARY DESIGN OF TRAWLERS USING THE DECISION SUPPORT PROBLEM TECHNIQUE*

Prabhat Kumar Pal**

ABSTRACT

In this paper, the use of the Compromise Decision Support Problem, technique in the preliminary design of trawlers is described. The preliminary design of trawlers is carried out satisfying the owner's requirements, the technical requirements and the statutory requirements. Traditionally, an iterative process is involved to obtain a feasible design only. The most efficient design is obtained using a multiple objective optimisation method [1,2]. The trawler design problem is formulated as a decision support problem with four goals comprising technical and economical aspects and the solution is found.

1. INTRODUCTION

Preliminary ship design, has been carried out for more than four decades using an iterative process. This process involves repetitive and complex analysis, trial and error, and extrapolation of the data of existing ships. This approach produces a feasible design but not the best, which can only be obtained by comparing many feasible alternative designs. This method prevents the creation of alternative designs as it is very laborious and time consuming. If the demand in the market is high, the produced design is accepted and constructed. But, when the demand is low most of such deigns are not accepted for construction which in turn, increases the design costs, forces the management to reduce the design staffs. The design so produced, is not also competitive in the market. Many of these problems will be removed if a computer-aided method, using mathematical optimisation techniques is employed. The preliminary trawler design problem is solved using such a method. This approach produces a superior design quickly and economically.

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** Senior Lecturer, School of Mechanical & Industrial Engineering, University of New South Wales, Kensington, P.O. Box 1, NSW 2033 Australia.

A brief review of the traditional methods as well as the optimisation based approaches was made by Lyon and Mistree [3]. Another review was made by Pal [4]. Preliminary design of trawlers was also reviewed by Pal [4]. A brief review is made here. Sokoloski [5], conducted a study to design optimum trawlers for the Georges Bank Groundfish Fishery. He used an economic criterion, the return on investment, ROI as the criterion for optimisation. He framed the trawler design problem as a single objective function optimisation problem and no mathematical optimisation method was employed. The optimal vessel was chosen by comparing ROI values of some feasible designs. Lutkus et al. [6], studied the problem of Sokoloski [5], employing the Sequential Unconstrained Minimisation Technique, SUMT to determine the optimal vessel. The study combined considerations of trawler operations and hull form design. They treated the problem as a two stage optimisation problem. The economic optimisation determined the speed, length and displacement by maximising the ROI, and the hull form optimisation selected the remaining hull form parameters by minimising the resistance. Pal [4] solved the preliminary trawler design problem using a single objective function. The net present value index, NPVI an economic index of operation of a fishing vessel was used as the objective function. Two mathematical optimisation methods, Better Point Algorithm [4,7] and Sequential Unconstrained Minimisation Technique [4,8] were used to find solutions. In the case of a single objective optimisation, only one aspect can be considered. Whereas, if a problem is framed with multiple goals, then many aspects, e.g.,technical aspects, economic aspects, etc. can be taken into considerations. The designer is then able to set an aspiration level for each of the goals. In many practical problems it might not be possible to achieve all the goals. Appropriate deviation variables can be introduced to assess the magnitude of the differences between the aspirations and the achievements. Then the problem becomes a minimisation of these deviation variables satisfying the constraints in the system. The interaction between the goals can also be studied by the designer. Considering the reasons as stated above, the preliminary trawler design problem is framed as a multiple objective function optimisation problem known as compromise Decision Support Problem, DSP [9].

2. THE COMPROMISE DSP FOR TRAWLER DESIGN

The compromise DSP has been described by Lyon and Mistree [3]. The compromise DSP as applied to the preliminary ship design problems has also been described in the reference [10]. In this section, the compromise DSP for the preliminary design of trawlers [11], is described. The design program deals with small steel trawlers of about 50 m in length. Two types of vessels are considered in the design process. The vessels having the length on water line, LWL less than 24.5 m are treated as ice trawlers and the larger vessels having LWL from 24.5 m to 50.0 m as refrigerated trawlers. All vessels are to be constructed with only one continuous deck, accommodation being located in the extended forecastle. Only the refrigerated trawlers are equipped with the refrigerated equipment. The ice trawlers carry sufficient ice for preservation of fish in the hold. The trawlers are to be constructed with the machinery at the forward end and the fish-hold at the aft. The trawlers are to be fitted with a single screw open propeller to reduce the initial cost and the cost of maintenance. A typical general arrangement is shown in Fig.1. The engine room extends from 60 per cent of LWL forward of the aft end to 85 per cent of LWL forward. The fresh water tanks are stored at the forward of the engine room. The fuel oil is to be stored in the two wing tanks extending through the length of the engine room. The deck aft is kept free of structure for ease of handling of the net and the catch. The wheel house is situated at the forward end.

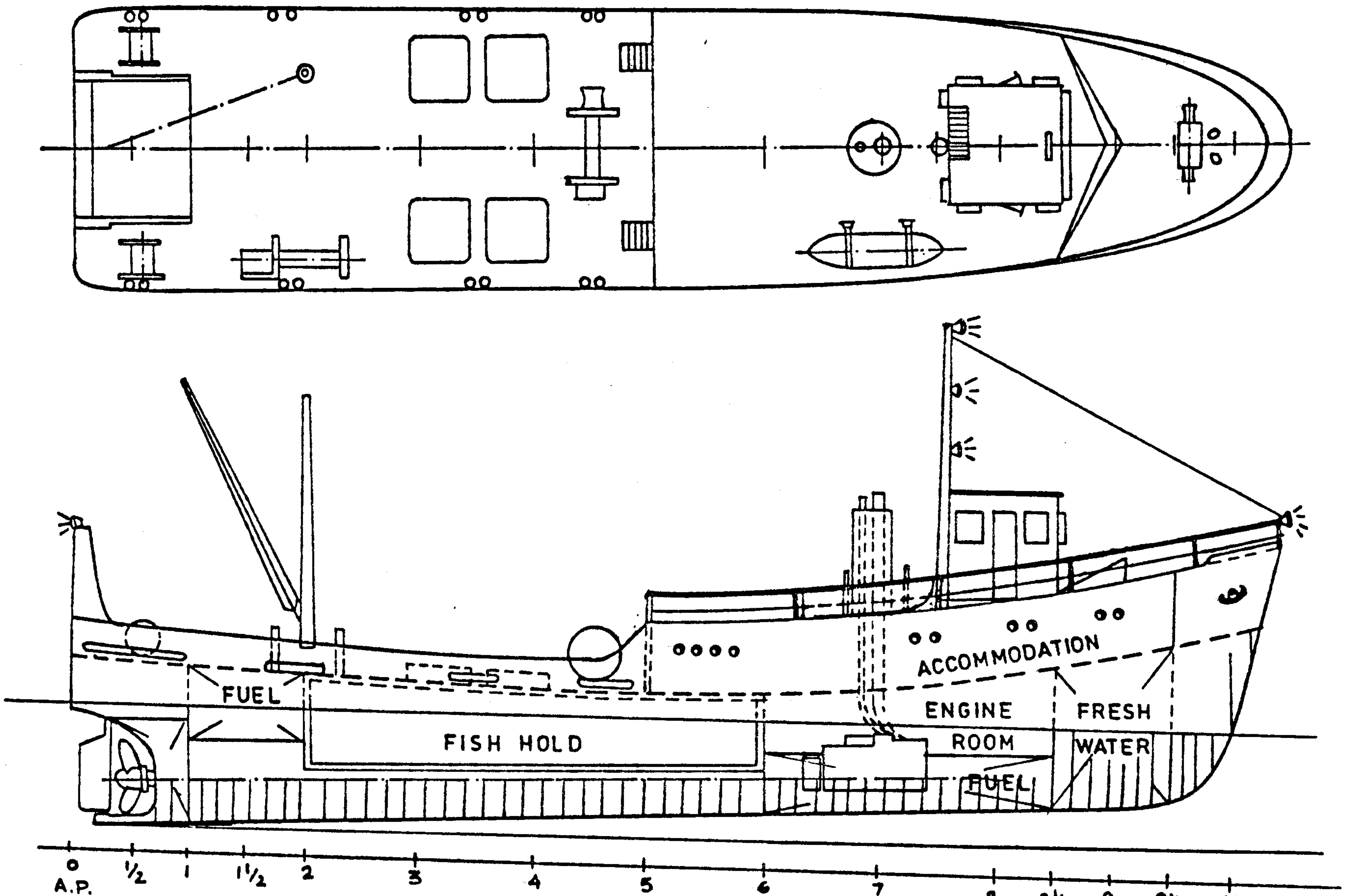


FIG. 1. A TYPICAL GENERAL ARRANGEMENT

Given

a. Owner's requirements:
fish-hold volume in m^3 (measure of earning capacity)
free running speed in knots, and
rate of return in per cent.

b. IMO requirements:
Stability particulars:

1) the area under the curve of righting levers (GZ curve) shall not be less than:
   i) 0.055 meter-radians up to an angle of 30°;
   ii) 0.090 meter-radians up to an angle of 40° or such lesser angle of heel at which the lower edges or any openings in the hull, superstructures, deckhouses or companionways, being openings which cannot be closed watertight, are immersed;
   iii) 0.030 meter-radians between the angle of heel of 30° and 40° or such lesser angle as defined in ii) above;
2) the righting lever (GZ) shall be at least 0.20 m at an angle of heel equal to greater than 30°;
3) the maximum righting lever (GZ) shall occur at an angle of heel not less than 25°;
4) in the upright position the transverse metacentric height (GM) shall not be less than 0.35 m.

c. Operation information:
data at the port, and
data at the fishing ground, (Appendix A).

Find System variables:

Functions of:

- Length on water line - beam ratio, (eq.1)
- Beam draught ratio, (eq.2), and
- Prismatic coefficient (eq.3)

(The following design parameters are calculated from the system variables:

Length on water line, LWL

Beam, B

Draught, DT

Depth, DP

Maximum section area coefficient, CM

Prismatic coefficient, CP

Longitudinal position of centre of buoyancy, LCB, (-ve if aft of LWL), and

Installed horse power, HP.)

Deviation variables:

under achievement from the owner's required cubic number

over achievement from the owner's required cubic number

under achievement from the owner's required speed

over achievement from the owner's required speed

under achievement from the required displacement

over achievement from the required displacement

under achievement from the required rate of return

over achievement from the required rate of return

Satify system constraints that:

- estimation of resistance is valid (resistance estimation is made by a regression equation [12]), (eq.4-eq.12), and
- are related to the requirements of IMO as stated above, (eq.13-eq.19).

Satisfy bounds that:

- length-beam ratio lies between 3.50 and 4.80, and the corresponding values of X(1) lie between 0.0 and 1.0 (limit of the existing data which are used to find relationship between the design parameters), (eq.20 and eq.23),
- beam-draught ratio lies within 2.00 and 4.50, and the corresponding values of X(2) lie between 0.09 and 1.0 (valid range for estimation of resistance, (eq.21 and eq.24), and

- prismatic coefficient lies between 0.549 and 0.625, and the corresponding values of X(3) lie between 0.0 and 1.0 (restriction due to the generation of hull forms which are used to estimate the stability levers), (eq. 22 and eq.25).

Satisfy goal constraints that:

- design cubic number, CUNOC (function of LOA,B and DP) plus or minus deviation is equal to owner's required cubic number CUNO (function of FHV), - LOA is the length overall in m, (eq.26),
- design speed plus or minus deviation equals owner's specified speed, (eq.27),
- displacement plus or minus deviation is equal to the sum of the components of weight, i.e., light ship weight and deadweight at the design condition, (eq.28), and
- design rate of return plus or minus deviation equals to owner's specified rate of return, (eq.29).

Minimise:

- deviation from the owner's required cubic number,
- deviation from the owner's required speed,
- deviation from the required displacement, and
- deviation from the required rate of return (eq.30)

Mathematical model

The word problem is transformed into the mathematical formulation suitable to find solution by numerical methods using a computer. The mathematical form of the DSP is shown below:

Given:

FHV-Fish-hold volume in m^3, (200 m^3)

Speed - free running speed in knots, (12.17 kn)

RI - rate of return in per cent, (20%)

IMO requirements - stability requirements asstated above, and

Operation informations - port and fishing ground data, (Appendix A).

Find System variables:

X(1), a function of length-beam ratio, (eq.1)

X(2), a function of beam - draught ratio, (eq.2), and

X(3), a function of prismatic coefficient, (eq.3).

The functions are:

$$X(1) = (LWL/B - 3.50)/1.30 \tag{1}$$

$$X(2) = (B/DT - 2.00)/2.50, \text{ and} \tag{2}$$

$$X(3) = (CP - 0.549)/0.076 \tag{3}$$

Deviation variables:

d_1^-

d_1^+

d_2^-

d_2^+

d_3^-

d_3^+

d_4^-

d_4^+

Satisfy system constraints:

$$1.325 + 1.817\ X(1) - 2.385\ (CMI-0.715)/0.265 \geq 0 \tag{4}$$

$$4.340 - 3.860\ X(1) + 4.240\ (CMI-0.715)/0.265 \geq 0 \tag{5}$$

$$5.200 + 9.100\ X(1) + 9.300\ (CPC-0.625)/0.155 \geq 0 \tag{6}$$

$$8.675 - 2.400\ X(1) - 10.075\ (CPC-0.625)/0.155 \geq 0 \tag{7}$$

$$14.700 - 9.100\ X(1) + 12.500\ (CPC-0.625)/0.155 \geq 0 \tag{8}$$

$$0.432 + 2.500\ X(2) + 1.272\ (CMI-0.715)/0.265 \geq 0 \tag{9}$$

$$0.665 - 0.750\ X(2) + 0.265\ (CMI-0.715)/0.265 \geq 0 \tag{10}$$

$$3.250 - 2.500\ X(2) + 4.650\ (CMC-0.625)/0.155 \geq 0 \tag{11}$$

$$3.250 - 2.500\ X(2) - 4.650\ (CPC-0.625)/0.155 \geq 0 \tag{12}$$

$$AREA30 - 0.055 \geq 0 \tag{13}$$

$$AREA40 - 0.090 \geq 0 \tag{14}$$

$$AR4030 - 0.030 \geq 0 \tag{15}$$

$$RADMX - 0.4363 \geq 0 \tag{16}$$

$$RLEVMX - 0.200 \geq 0 \tag{17}$$

$$RLEV30 - 0.200 \geq 0 \tag{18}$$

$$GMINI - 0.350 \geq 0 \tag{19}$$

Satisfy bounds:

$$X(1),\ X(2),\ X(3) \geq 0 \tag{20,21,22}$$

$$X(1),\ X(2),\ X(3) \leq 1.0 \tag{23,24,25}$$

Satisfy goal constraints

$$CUNOC/CUNO + d_1^- - d_1^+ = 1 \tag{26}$$

$$SPEEDC/SPEED + d_2^- - d_2^+ = 1 \tag{27}$$

$$DISPLT/WEIGHT + d_3^- - d_3^+ = 1 \tag{28}$$

$$NPVI + d_4^- - d_4^+ = 0 \tag{29}$$

Minimise

$$Z = P_1(d_1^- + d_1^+) + P_2(d_2^- + d_2^+) + P_3(d_3^- + d_3^+) + P_4(d_4^- + d_4^+) \tag{30}$$

where,

LWL = length on water line in m

B = beam in m

DT = draught in m

DP = depth in m

CP = prismatic coefficient

CPC = prismatic coefficient calculated from the generated hull form (moulded displacement/(1.026 x LWL x A_{max})), A_{max} = maximum section area in m² up to the water line)

CMI = maximum section area coefficient calculated from the generated hull form ($A/_{max}$/(B x DT))

CM = maximum section area coefficient

AREA30 = Area under the curve of righting levers up to 30° in m radian

AREA40 = Area under the curve of righting levers up to 40° in m radian

AR4030 = Area under the curve of righting levers between 30° and 40° in m radian

RADMX = Angle of inclination in radian corresponding to the maximum righting lever.

RLEV30 = Righting lever at 30° in m

RLEVM = Maximum righting lever in m

GMINI = Transverse metacentric height in the upright position in m

CUNO = Cubic number (function of FHV)

CUNOC = Cubic number (LOA x B x DP), LOA = length overall in m

SPEED = Free running speed in knots

SPEEDC = Calculated speed in knots for the installed horsepower

DISPLT = Extreme displacement (LWL x B x DT x CB x 1.033) in tonnes (1 tonne = 1000kg), CB = CP xCM

WEIGHT = Sum of the component weights (lightship weight + deadweight)

NPVI = Net present value index corresponding to the required rate of return.

d_1^-, d_2^-, d_3^-, d_4^- are under achievement deviation variables, and

d_1^+, d_2^+, d_3^+, d_4^+ are over achievement deviation variables.

P_1, P_2, P_3, P_4 are priorities of the goal constraints.

In this study, the values of priorities are taken as one, i.e.,same priority for each of the goals. Among the two approaches [3], the preemptive approach is adopted here. In the preemptive approach, P_1 is preferred to P_2 which is preferred to P_3 and so on. This approach is suitable for ship design and thus applied for the trawler design.

The design problem is described and finally reduced to a DSP with multiple objectives and non-linear constraints. The design problem is now suitable for solution by computer methods using the ALP algorithm [2]. The overall structure of the trawler design problem is described here.

Solution of a compromise DSP

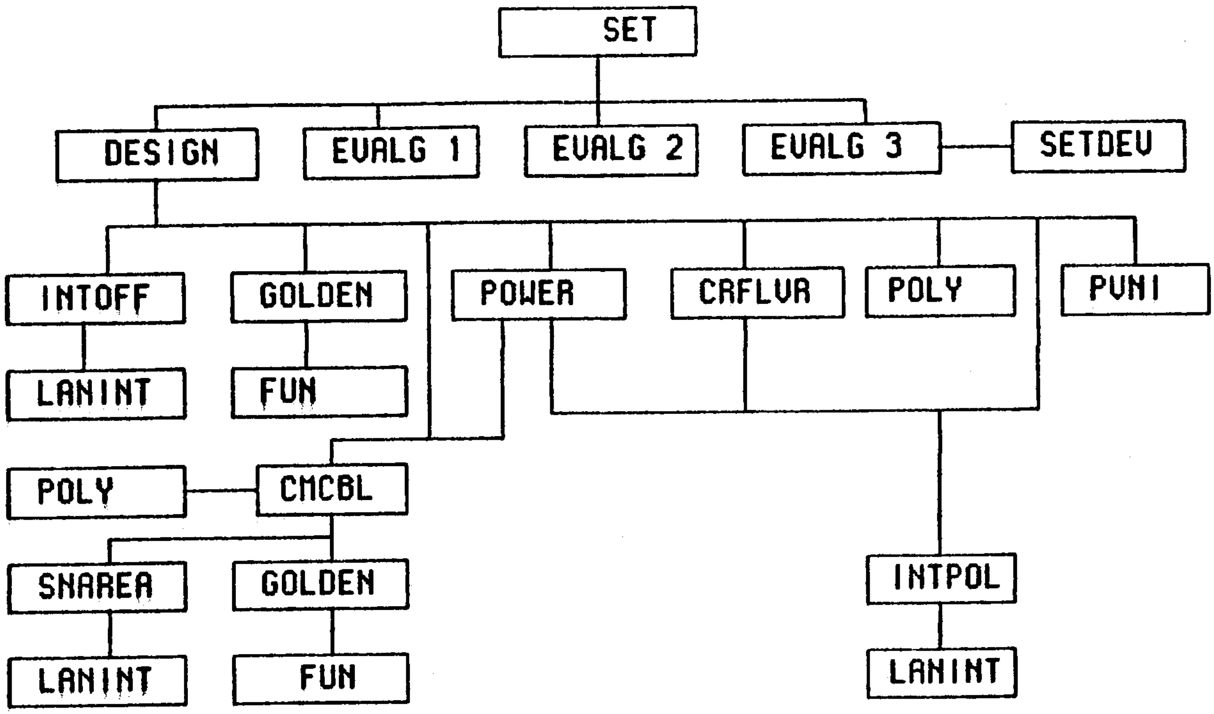
The program DSIDES, [9] is used to solve the preliminary trawler design problem. The program is capable of solving problems involving large number of constraints of various types (linear and non-linear, equality and inequality). It is claimed that the program is very fast and cost-effective and involves much less computation when compared with other methods. The optimisation is achieved by linearising the non-linear constraints and then solving the resulting linear programming problem at each design point. The linearisations are performed using first- and second- order derivative information. The logical structure of the controlling program, SLPCTL is explained by Lyon [3]. The logical structure of the user defined subroutines are shown in Figure 2.

Input Data

The input data for the program is prepared according to the reference [9]. A sample input data is shown in the Appendix A.

Design Requirements

Weight coefficients for estimating steel weight, wood and outfit weight, auxiliary machinery weight, horse power of available engines in the market, coefficients for estimating the values of CR16 for seven speed-length ratios, offset tables in per cent of the breadth for trawler form for generating any trawler form, and a set of data for the economic calculations (Appendix A) are read through data statements in various subroutines. The height of the centre of gravity above the keel is taken as 80 per cent of the depth of the vessel.



SUBROUTINE NAME	SUBROUTINE FUNCTION
SET	Calls constraint evaluation subroutines
EVALG1,EVALG2	Evaluates non-linear system constraints
EVALG3	Evaluates non-linear goal constraints
SETDEV	Sets value for deviation variables
DESIGN	Evaluates parameters for all constraints
CR16	Evaluates resistance coefficients
POWER	Evaluates horse power and selects engine
CRFLVR	Evaluates parameters for stability particulars
INTOFF	Generates offsets for a hull form
PUNI	Evaluates economic index
INTPOL,LANINT	Used for interpolation purposes
SNAREA,CMCBL	Evaluates section areas,CMI, and CPC
POLY	Used for fitting a curve of third degree polynomial
GOLDEN	Used for finding maximum ordinate of curve statical stability by golden search method

FIG. 2. User-defined subroutines -- logical structure

Bounds

The system variables are chosen as functions of the length-breadth ratio, the breadth-draught ratio, and the prismatic coefficient. The functions are so formed that the bounds lie between 0 and 1. The functions and the bounds are as follows:

$$X(1) = (ALWL/B - 3.5)/1.3, \quad 0 \leqslant X(1) \leqslant 1.0, \tag{31}$$

$$X(2) = (B/DT - 2.0)/2.5, \quad 0 \leqslant X(2) \leqslant 1.0, \text{ and} \tag{32}$$

$$X(3) = (CP - 0.549)/0.076, \quad 0 \leqslant X(3) \leqslant 1.0 \tag{33}$$

The lower bounds of all the deviation variables are taken as 0.0 and the upper bounds are taken as 1.0 except for the deviation variables associated with the net present value index, NPVI. The values are taken as 2.0 as the value of the NPVI exceeds 1.0 which in this case depends on the data of the fishing operation.

Evaluation of the constraints

In this problem, the constraints are non-linear. The non-linear constraints are evaluated in two groups, i.e., one group for the restriction imposed to estimate the resistance and the other group to satisfy the IMO requirements. The first group is evaluated through the subroutine EVALGI and the second group through the subroutine EVALG2. The relevant values of CPC, CMI and the stability particulars are estimated through the subroutine DESIGN. The parameters in the goal constraints are also estimated through the subroutine DESIGN. Specifically, the subroutine CRFLVR is used to calculate AREA30, AREA40, AR4030, RLVE30, RLEVMX, RADMX and GMINI and the subroutine PVNI calculates the net present value index, NPVI for a given value of RI, i.e., the rate of return. If the value of the NPVI is negative, then the calculated rate of return is less than the given rate of return. The details of estimation of the NPVI is discussed in the Appendix B. The details of estimation of the other constraints are discussed in the Appendix C.

Output Data

A sample output is shown in the Appendix D. In the output, the control data for running the SLPCTL, input data for the design, converging criteria data, goal priorities, and the final design data are shown.

3. RESULTS

The validity of the program is tested by solving four different cases. As an example, a set of given data, i.e., FHV=200 m^3, SPEED = 12.17 knots, and R1 = 20%, and the data (Appendix A) are chosen to find a solution. Four goal constraints are used in the program. The goal constraints, (eq. 31 and eq. 32) are connected with the requirements of the owner. The constraint, (eq. 33) is a technical goal to be achieved. The last constraint, (eq.34) is connected with the economic assessment of the design. The cases are described here and discussed in the next section.

Case 1: Convergence test

All goals are assumed to be equally important and it is felt that all of them are to be fulfilled with the same degree, simultaneously. Nineteen different starting points are selected arbitrarily in the design space. The program converges nearly to six different groups of design. The objective function values for one run of each group are plotted in Figure 3, to show convergence. The design values are shown in the Table 1.

Case 2: Sensitivity analysis - speed variation

The results for case 1, are for one speed only. To study the effect of variation of the speed, seven different values of speed in knots, e.g., 11.00, 11.50, 12.00, 12.50, 13.00, 13.50 and 14.00 are chosen. One starting point is selected arbitrarily for all the seven speeds. The convergence criteria are also kept same for all the speeds. The results are shown in Table 2.

Case 3: Variation of FHV

Keeping the problem as in the case 2, the template is tested changing the FHV value from 200 m^3 to 250 m^3, for all the seven speeds. The results are shown in the Table 3.

Case 4: Variation in the values of priorities

It is felt to study the effect of change of the values of the priorities of the goals. Three different starting points are chosen with the example in case 1 and the priorities are changed. The results are shown in the Table 4. Case A is run with the same priorities but the case B is run with different priorities as shown in the Table 4. Here, the effect of reducing the priority of the goal connected with economic evaluation is studied.

4. CLOSURE

Referring to the Table 1 and Figure 3, it is seen that the model converges well.

Variation of speed does not have a noticeable effect on the design parameters, i.e., the main dimensions are nearly the same (Fig.4). The longitudinal position of centre of buoyancy shifts forward as the speed increases (Fig.5), the maximum section area coefficient increases with the speed (Fig.6) and the prismatic coefficient also increases with the speed (Tables 2 and 3, Fig.7). A general conclusion is that the vessel becomes fuller as the required speed increases which seems to be somewhat surprising as normally, for a given size of ship lower power leads to relatively fuller lines. Here, the model is such that for the required FHV the length is fixed. So, as the speed reduces, the installed power also reduces which makes the displacement smaller as the main dimensions are nearly the same. As a result the hull becomes finer. This conclusion agrees well with the conclusion 1 of the reference [4].

TABLE 1 - RESULTS OF CONVERGENCE TEST

[Case 1]

Owner's requirements : FHV=200 m^3, SPEED = 12.17 Kn, RI = 20%

Different starting points are taken.

Reqd. speed	12.17	12.17	12.17	12.17	12.17	12.17	
Cal. speed	12.29	12.19	12.21	12.37	12.37	12.35	
Inst. power	850	750	750	850	800	880	
Reqd. CUNO	1143.88	1143.88	1143.88	1143.88	1143.88	1143.88	
Cal. CUNO	1143.92	1144.61	1144.82	1144.01	1144.00	1143.88	
Estd. displ.	432.20	429.57	429.94	430.41	429.42	429.93	
Total weight	432.21	428.96	429.03	432.23	430.41	430.37	
Displ. at fis. gr. *	429.28	426.05	426.12	429.30	427.49	427.45	
LWL	35.138	35.138	35.138	35.138	35.138	35.138	
Beam	9.210	8.849	8.817	9.145	8.879	8.898	
Draught	2.466	2.600	2.613	2.489	2.587	2.580-	
Depth	3.225	3.359	3.372	3.248	3.346	3.338	
LCB %	-4.994	-5.129	-5.133	-5.041	-5.119	-5.105	
CM	0.911	0.902	0.902	0.908	0.903	0.904	
CP	0.575	0.570	0.570	0.574	0.571	0.571	
NPVI	1.1615	1.1670	1.1682	1.1671	1.1804	1.1790	
RESULT OF	9 starting points	6 starting points	1 starting point	1 starting point	1 starting point	1 starting point	
GROUP	I	II	III	IV	V	VI	

* Displacement at the fishing ground.

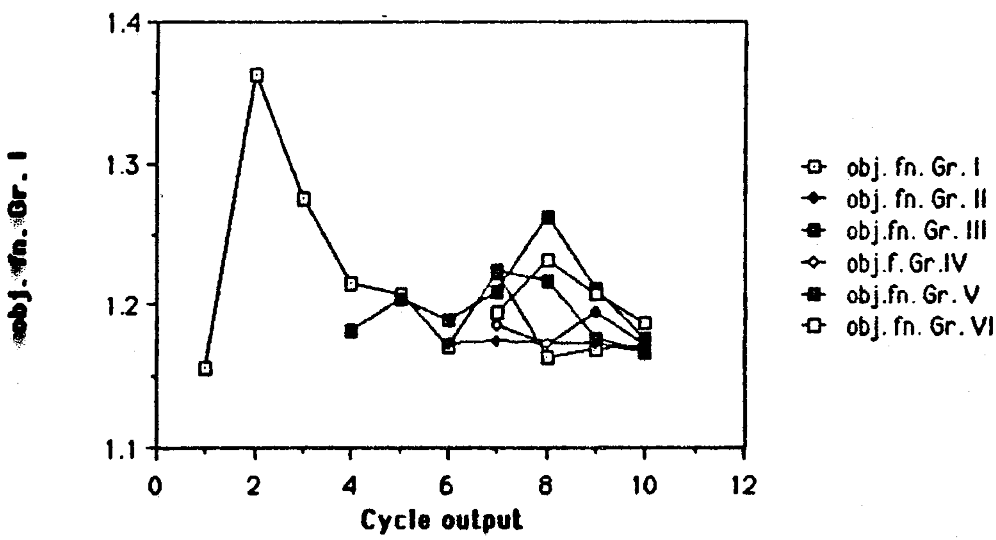


Figure 3. Convergence test

Table 2 - RESULTS OF SPEED VARIATION

[CASE - 2]

Owner's requirements : FHV = 200 m^3 , RI = 20%

The deviation variables have the same priorities as case 1.

Initial starting points are same for all the speeds.

Reqd. speed	11.00	11.50	12.00	12.50	13.00	13.50	14.00
Cal. speed	11.05	11.66	12.01	12.51	13.07	13.57	14.01
Inst. power	450	600	700	850	1000	1200	1400
Reqd. CUNO	1143.88	1143.88	1143.88	1143.88	1143.88	1143.88	1143.88
Cal. CUNO	1143.89	1143.28	1143.33	1144.27	1142.49	1144.05	1143.85
Estd. displ.	420.20	426.49	428.98	434.00	437.65	445.36	456.21
Total weight	420.11	424.15	427.01	432.32	437.97	448.53	457.18
Displ. at fis. grd. *	417.26	421.27	424.12	429.39	435.01	445.49	454.09
LWL	35.138	35.138	35.138	35.138	35.138	35.138	35.138
Beam	8.824	8.794	8.805	8.878	8.786	8.840	8.828
Draught	2.607	2.617	2.613	2.568	2.618	2.602	2.606
Depth	3.366	3.376	3.372	3.397	3.376	3.360	3.365
LCB %	-5.278	-5.182	-5.139	-5.045	-4.991	-4.851	-4.635
CM	0.891	0.898	0.902	0.908	0.911	0.919	0.927
CP	0.565	0.568	0.570	0.573	0.575	0.581	0.590
NPVI	0.7144	1.0377	1.1413	1.1774	1.1201	0.9222	0.6490

* Displacement at the fishing ground.

TABLE 3 - RESULTS OF VARIATION OF FHV

[Case 3]

Owner's requirements : FHV = 250 m^3 ,
RI = 20%

Reqd. speed	11.00	11.50	12.00	12.50	13.00	13.50	14.00
Cal. speed	11.26	11.63	12.11	12.60	13.00	13.54	14.04
Inst. power	600	700	800	1000	1150	1450	1600
Reqd. CUNO	1406.44	1406.44	1406.44	1406.44	1406.44	1406.44	1406.44
Cal. CUNO	1414.59	1420.91	1428.71	1417.59	1407.70	1407.70	1408.40
Estd. displ.	541.98	546.56	551.56	555.89	560.70	572.25	578.02
Total weight	541.51	546.42	552.14	556.57	560.90	574.55	582.42
Displ. at fi. gr. *	537.85	542.71	548.40	552.80	557.10	570.66	578.47
LWL	35.138	35.138	35.138	35.138	35.138	35.138	35.138
Beam	9.771	9.888	9.543	9.470	9.372	9.720	9.337
Draught	2.652	2.626	2.768	2.768	2.780	2.653	2.795
Depth	3.420	3.394	3.536	3.536	3.548	3.421	3.563
LCB %	-4.998	-4.953	-5.004	-4.881	-4.756	-4.324	-4.419
CM	0.911	0.914	0.910	0.917	0.923	0.917	0.925
CP	0.575	0.577	0.575	0.580	0.585	0.607	0.600
NPVI	1.0084	1.1678	1.2692	1.3159	1.2598	0.9634	0.7912

* Displacement at the fishing ground.

TABLE 4 - RESULTS OF VARIATION IN THE VALUES OF PRIORITIES

[Case 4]

Owner's requirements : FHV = 200 m^3 , SPEED =12.17 Kn

RI = 20%

Case A : Same priorities ,i.e. 1,1,1,1,1,1,1,1. Case B : Different Priorities, i.e. 2,1,2,1,2,1,3,3

Case	A	B	A	B	A	B	
Reqd. speed	12.17	12.17	12.17	12.17	12.17	12.17	
Cal. speed	12.21	12.31	12.18	12.33	12.17	12.30	
Inst. power	750	850	750	800	750	850	
Reqd. CUNO	1143.88	1143.86	1143.86	1143.88	1143.86	1143.88	
Cal. CUNO	1144.76	1146.20	1144.01	1144.69	1143.99	1144.69	
Estd. displ.	429.82	432.52	429.40	428.01	429.25	432.46	
Total weight	429.00	432.93	428.77	430.63	428.76	432.45	
Displ. at fi. gr. *	426.10	430.00	425.86	427.71	425.85	429.52	
LWL	35.138	35.138	35.138	35.138	35.138	35.138	
Beam	8.817	9.204	8.863	8.973	8.871	9.178	
Draught	2.613	2.475	2.593	2.554	2.590	2.480	
Depth	3.371	3.234	3.352	3.313	3.348	3.329	
LCB %	-5.134	-5.009	-5.123	-5.126	-5.123	-5.004	
CM	0.902	0.910	0.903	0.902	0.902	0.910	
CP	0.570	0.575	0.570	0.570	0.570	0.575	
NPVI	1.1683	1.1611	1.1667	1.1770	1.1664	1.1628	

* Displacement at the fishing ground.

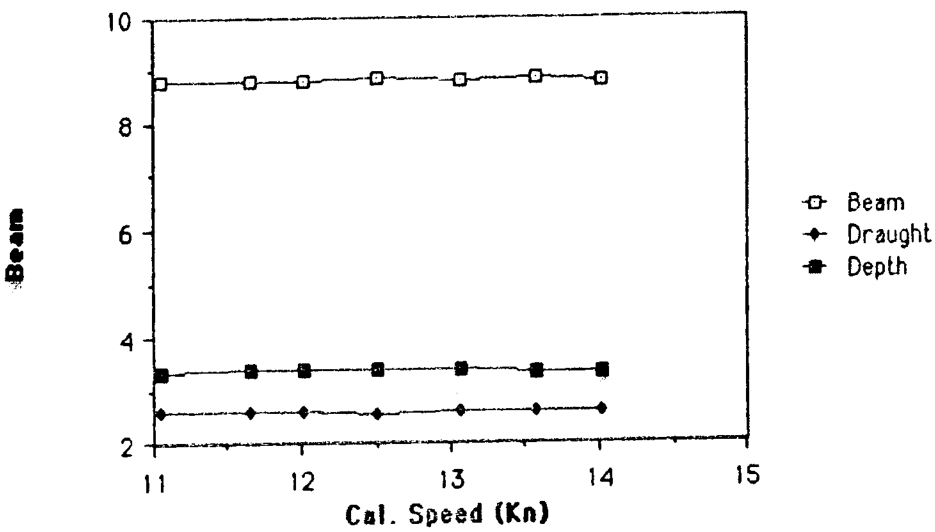


Figure 4 : Main Dimensions

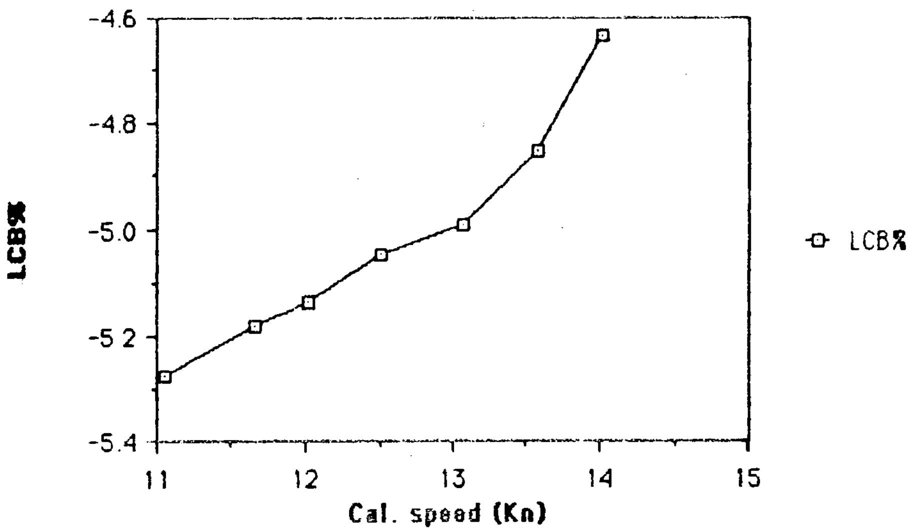


Figure 5: Logitudinal Position of Centre of Buoyancy

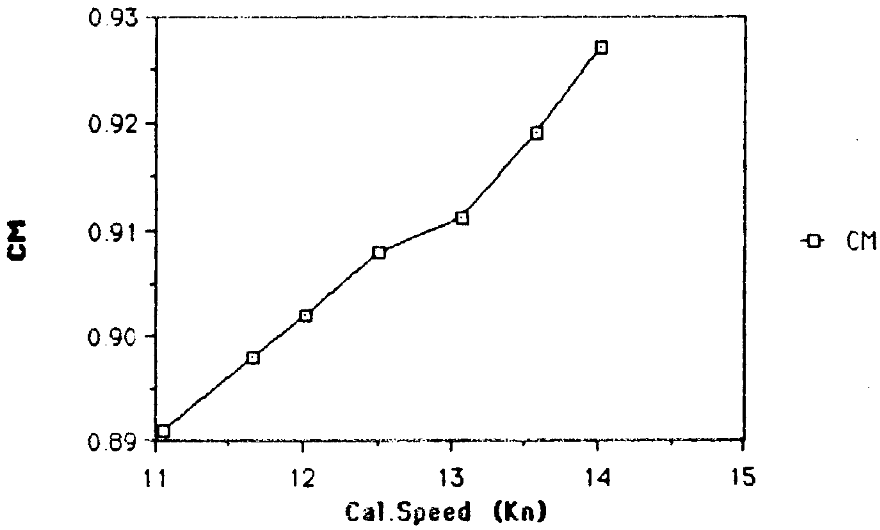


Figure 6 : Maximum Section Area Coefficient

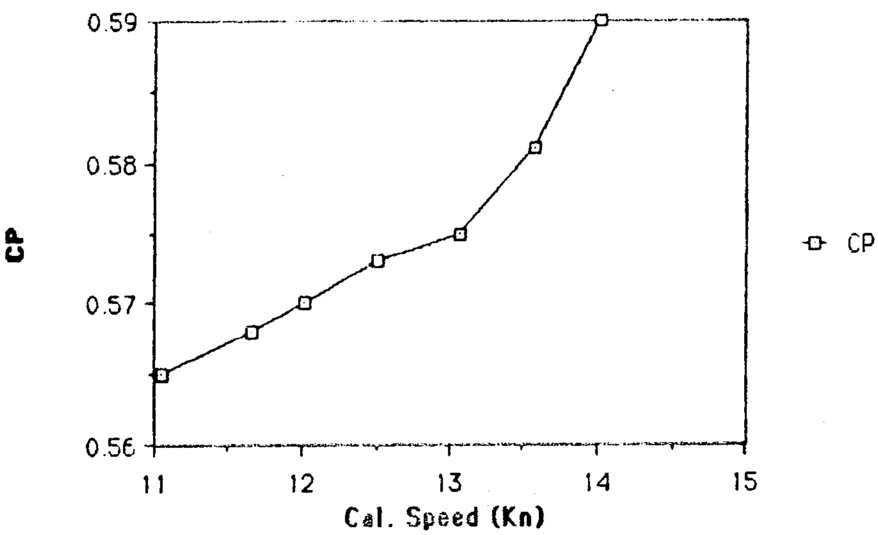


Figure 7: Prismatic Coefficient

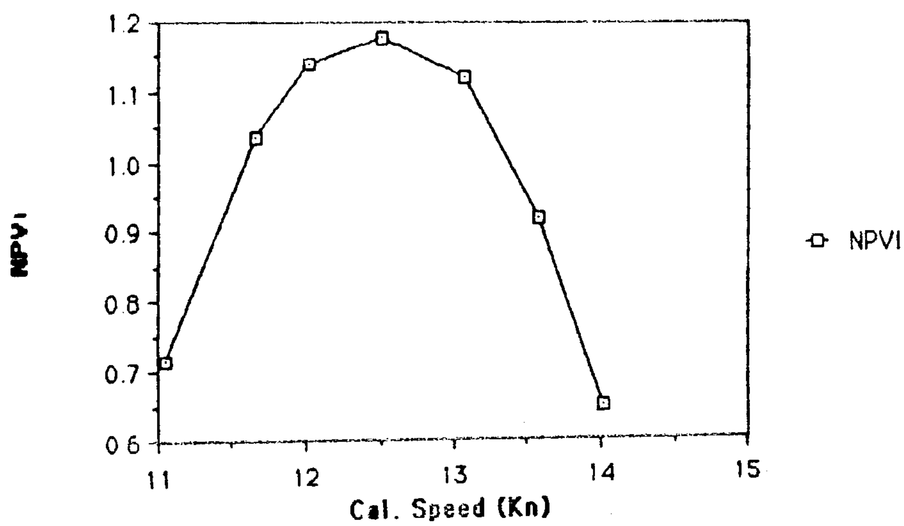


Figure 8 : Net Present Value Index

It is clearly evident that the design with a required speed of 12.50 kn for a fish-hold volume of 200 m^3 or 250 m^3 earns maximum in its life time (Fig.8). So, a design powered with an engine having the HP/CUNO ratio in the range of 0.70 and 0.75 is expected to earn maximum in its life time. This means that there is an optimal speed of operation for a design.

The model is not sensitive to the changes in the values of priority related to the economic goal constraint (Table 4).

It is concluded that the preliminary trawler design problem can be solved using the compromise DSP, efficiently and economically. It is shown that the trawler design problem can be framed as a compromise DSP using multiple goals of conflicting nature which could not be done by any methods previously mentioned. The effect of interaction between the technical and economic goals is found only by formulating the problem with multiple goals. Moreover, the change in the values of the priorities can also be studied. The traditional iterative process is eliminated to a large extent and the optimal solution is found satisfying the constraints and the goals as far as possible. A designer, now is capable of using the program to explore the design space changing the priorities of the goals, if necessary and take decision accordingly. The program has been tested for different cases which shows that this is valid for finding solutions for preliminary trawler design problems. All aspects of operation have been considered in the economic evaluation by which a designer is capable of making an economic assessment of a design also.

Suggestions for future work

The operation data and the weight estimation data are a bit old which may be replaced by latest data to obtain more realistic results.

The data of horse power of the available engines are assumed arbitrarily in this model, Actual manufacturer's data are to be used for the realistic design.

The program is made for a set of owner's requirements, i.e., a fish-hold volume, a free running speed and a rate of return. The program may be changed to find optimal solution maximising the rate of return by introducing two more variables, i.e., FHV and SPEED. thus, for a given port and fishing ground conditions, the optimal trawler can be found.

In this study, only four goals are used. Another goal minimising the resistance coefficient CR16 may be introduced to optimise the hull form by which it is possible to minimise the resistance and maximise the rate of return.

5. ACKNOWLEDGEMENTS

This work would not have been possible without the assistance of the University of New South Wales, for granting study leave, the Department of Defence (Navy), Australia, for financial assistance and the University of Houston, U.S.A. for generous use of computer and other facilities to the author. The assistance rendered by the graduate students Messrs. S. Mudali, H. Karandikar, S. Kamal, and Ms Q.J. Zhou in familiarizing the author with the DSP technique and the DSIDES is gratefully acknowledged.

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APPENDIX A.

Input data.

```
AUTOMATED RATIONAL DESIGN OF A TRAWLER
SLIP2      1     1     0     0     1     1     1
KILOGRAMS        METERS                  TONNES
SIZ.       3     8     2     1     9     7     4
VAR.   RLB  BDTR   CP
DEV.     C-    C+    S-    S+    D-    D+    E-    E+
CON.   RE1   RE2   RE3   RE4   RE5   RE6   RE7   RE8   RE9   ST1
CON.   ST2   ST3   ST4   ST5   ST6   ST7   GL1   GL2   GL3   GL4
GOAL         20          5.0   5.0   0           5.0   0     0.9
 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0
DAT 1    0               PP
1 0.0 1 1.0
DAT 1    0               PP
2 0.0 2 1.0
DAT 1    0               PP
3 0.0 3 1.0
DAT 1    0               PP
4 0.0 4 1.0
DAT 1    0               PP
5 0.0 5 1.0
DAT 1    0               PP
6 0.0 6 1.0
DAT 1    0               PP
7 0.0 7 1.0
DAT 1    0               PP
8 0.0 8 1.0
DAT 1    0               PP
9 0.0 9 1.0
DAT 1    0               PP
10 0.0 10 2.0
DAT 1    0               PP
11 0.0 11 2.0
END
STAND     1     1     0     3
PRB 1
0.65000 0.44000 0.78000 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
END
```

```
*****************************************************

              DESIGN OF FISHING VESSEL
   USING THE DECISSION SUPPORT PROBLEM TECHNIQUE

 FISH HOLD VOLUME                              200.00CUBIC METER
 FREE RUNNING SPEED                             12.17KNOTS
 RATE OF RETURN OR DISCOUNT RATE                20.00PERCENT

    CUNUM
      50.00   100.00   200.00   300.00   400.00   500.00
     600.00   700.00   800.00   900.00  1000.00
    STC
     0.2880   0.3350   0.3680   0.3700   0.3660   0.3580
     0.3500   0.3440   0.3350   0.3320   0.3250
    OTC
     0.0250   0.0500   0.0980   0.1370   0.1750   0.2060
     0.2300   0.2550   0.2700   0.2850   0.3000
    AMC
     0.0150   0.0240   0.0320   0.0400   0.0500   0.0580
     0.0660   0.0730   0.0800   0.0850   0.0880
     GDMW
       0.00     2.50     4.00     8.00    12.50
      18.50    26.00    32.50    40.00    48.00
    RBHP
       0.00   200.00   400.00   600.00   800.00
    1000.00  1200.00  1400.00  1600.00  1800.00
     NUMBER OF ENGINE AVAILABLE IN THE MARKET 50
    HORSEPOWER OF AVAILABLE ENGINES
      50.0   100.0   150.0   200.0   250.0   300.0   350.0   400.0   450.0   500.0
     550.0   600.0   650.0   700.0   750.0   800.0   850.0   900.0   950.0  1000.0
    1050.0  1100.0  1150.0  1200.0  1250.0  1300.0  1350.0  1400.0  1450.0  1500.0
    1550.0  1600.0  1650.0  1700.0  1750.0  1800.0  1850.0  1900.0  1950.0  2000.0
    2050.0  2100.0  2150.0  2200.0  2250.0  2300.0  2350.0  2400.0  2450.0  2500.0
```

VERTICAL POSITION OF CENTRE OF GRAVITY TO DEPTH RATIO	0.80
AVERAGE SELLING RATE OF FISH (LANDING VALUE):	500.00$/TONNE
PORT CHARGES :	5.00$/DAY
RATE OF CONSUMPTION OF DIESEL OIL :	180.00G/HP/HR
RATE OF CONSUMPTION OF LUBRICATING OIL :	3.00G/HP/HR
COST OF DIESEL OIL :	175.00$/TONNE
COST OF LUBRICATING OIL :	1400.00$/TONNE
FISH HANDLING CHARGES AT THE PORT :	4.00$/TONNE
COST OF ICE :	40.00$/TONNE
COST OF PROVISION :	2.00$/PS./DAY
COST OF CREW (OFFICER) :	12.00$/PS./DAY
COST OF CREW (NON-OFFICER) :	2.50$/PS./DAY
COST OF FISHING GEAR :	50.00$/HP
IMPORT DUTY ON GEAR AS PERCENT OF INITIAL COST:	50.00
OWNERS INI. EXP. AS % OF COST OF GEAR & VESSEL:	5.00
BORROWED CAPITAL AS % OF COST OF VESSEL & GEAR :	80.00
RATE OF INTEREST ON BORROWED CAPITAL :	6.00PERCENT
RATE OF INCOME TAX :	40.00PERCENT
RESALE VALUE OF VESSEL AS PERCENT OF INI. COST. :	10.00
COST OF MAINT. OF VESSEL/YEAR AS % OF INI.COST. :	5.00
COST OF MAINT. OF GEAR/YEAR AS % OF INI.COST :	40.00
COST OF INS.OF VESSEL & GEAR AS % OF INI. COST :	3.00
YEARLY ESCALATION RATE OF COST OF CREW :	4.00PERCENT
YLY. ESCAL. RATE OF COST OF MAINT. OF VESSEL:	5.00PERCENT
YLY. ESCAL. RATE OF COST OF MAINT. OF GEAR :	10.00PERCENT
YLY. ESCAL. RATE OF COST OF ADMINISTRATION :	4.00PERCENT
YLY. ESCAL. RATE OF COST OF INSURANCE :	-1.50PERCENT
YLY. ESCAL. RATE OF COST OF LUBRICATING OIL :	3.00PERCENT
YLY. ESCAL. RATE OF COST OF ICE :	3.00PERCENT
YLY. ESCAL. RATE OF COST OF DIESEL OIL :	3.00PERCENT
YLY. ESCAL. RATE OF COST OF HANDLING OF FISH:	3.00PERCENT
YLY. ESCAL. RATE OF COST OF PROVISIONS :	5.00PERCENT
YLY. ESCAL. RATE OF COST OF CHARGES AT PORT :	3.00PERCENT
YLY. ESCAL. RATE OF COST OF SEL. PR. OF FISH:	5.00PERCENT

HOUR OF OPERATION	:	20.00HR/DAY
NUMBER OF DAYS OF OPERATION	:	330.00DAYS/YR
DAYS SPENT AT PORT BETWEEN TWO TRIPS	:	3.00DAYS
COST FACTOR (CONSTANT FOR ALWL.GE.24.5M)	:	20.00
COST FACTOR (CONSTANT FOR ALWL .LT.24.5M)	:	12.00
COST FACTOR	:	0.24
GROWTH FACTOR (VESSELS COST 1970-78)	:	1.46
GROWTH FACTOR (GEARS COST 1972-78)	:	1.34
ADMINISTRATIVE COST (CONSTANT)	:	2420.00 $
ADMINISTRATIVE COST (VARIABLE)	:	2.42$/CUNO
DIST. OF FISHING GROUND FROM PORT OF OPRN.	:	300.00 SM
MAXIMUM NUMBER OF DAYS AVAILABLE FOR CATCH	:	14.00DAYS
TRAWLING SPEED	:	3.00KNOTS
DEPTH OF WATER IN FISHING GROUND	:	100.00FATHOM
FISH CONCENTRATION	:	1.50TONNE/MEGATONNE
COST OF ENGINE	:	220.00$/HP
TIME OF RECOVERY OF NET/CYCLE DURING FISHING	:	15MIN.
TIME OF HANDLING OF NET/CYCLE DURING FISHING	:	10MIN.
TIME OF OPERATION PER CYCLE OF FISHING	:	150MIN.
NUMBER OF YEARS OF REPAYMENT OF LOAN	:	8YEARS
NUMBER OF YEARS OF OPERATION	:	12YEARS
NUMBER OF INSTALMENT OF PAYMENTS	:	4
INTERVAL OF PAYMENTS	:	3MONTHS
CONTRACT PAYMENT AS % OF INITIAL COST OF VESSEL	:	10.00

DATA OF OFFSETS FOR HULL FORM OF CP=0.549

0.0	0.0	0.0	0.0	0.0	0.0	0.0	27.6	65.8	80.5	89.6	0.0	0.0	92.2
0.0	0.0	0.0	0.0	0.0	0.0	13.0	64.0	84.2	93.3	99.1	0.0	0.0	100.0
2.7	3.0	3.5	4.6	9.1	21.1	54.6	86.9	98.6	100.0	100.0	0.0	0.0	100.0
6.7	8.0	10.0	13.8	25.1	47.5	78.6	96.5	100.0	100.0	0.0	0.0	0.0	100.0
11.5	15.2	18.7	26.4	44.0	71.5	92.5	99.7	100.0	100.0	0.0	0.0	0.0	100.0
18 3	27.7	37.3	56.2	84.4	96.5	100.0	100.0	100.0	100.0	0.0	0.0	0.0	100.0
16.0	31.4	46.6	70.6	91.4	99.3	100.0	100.0	100.0	100.0	0.0	0.0	0.0	100.0
0.0	20.3	36.5	60.8	81.6	90.6	95.7	98.1	99.1	100.0	0.0	0.0	0.0	100.0
0.0	2.1	19.3	40.8	62.4	73.3	81.8	88.8	93.8	97.3	0.0	0.0	0.0	99.1
0.0	0.0	3.2	21.9	41.0	53.3	63.6	73.0	81.3	89.1	96.7	0.0	0.0	97.8
0.0	0.0	0.0	7.5	21.9	32.8	42.9	52.9	62.6	73.0	83.7	0.0	0.0	93.0
0.0	0.0	0.0	3.5	14.1	23.5	32.0	40.8	50.9	61.3	72.8	84.2	0.0	88.5
0.0	0.0	0.0	1.4	7.2	13.3	20.8	28.5	37.3	46.6	57.0	68.8	0.0	81.3
0.0	0.0	0.0	0.0	2.4	6.1	10.4	15.1	20.6	27.5	36.8	48.0	61.3	69.3
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.2	7.4	12.8	21.1	31.7	47.4

DATA OF OFFSETS FOR HULL FORM OF CP=0.579

0.0	0.0	0.0	0.0	0.0	0.0	0.0	38.7	64.8	77.0	85.4	91.7	0.0	92.2
0 0	0.0	0.0	0.0	0.0	0.0	27.2	68.7	81.1	89.1	94.6	0.0	0.0	98.0
3.5	4.4	5.2	7.0	12.2	29.1	66.7	85.4	93.7	97.8	99.8	0.0	0.0	100.0
9.6	12.0	14.8	20.2	34.6	63.0	84.4	93.5	97.8	99.8	100.0	0.0	0.0	100.0
14.8	18.9	23.5	33.3	57.0	80.0	92.6	97.4	99.4	100.0	100.0	0.0	0.0	100.0
24.6	35.9	46.5	63.7	87.0	95.4	98.7	100.0	100.0	100.0	100.0	0.0	0.0	100.0
31.7	50.0	64.8	82.4	96.5	99.8	100.0	100.0	100.0	100.0	100.0	0.0	0.0	100.0
0.0	39.3	65.2	79.8	90.7	93.9	95.7	96.7	97.6	98.5	99.6	0.0	0.0	99.6
0 0	11.5	47.4	63.3	76.3	81.7	85.2	87.6	90.0	93.3	97.4	0.0	0.0	98.3
0.0	0.0	4.8	39.6	57.2	64.1	68.9	72.4	76.5	82.2	89.4	0.0	0.0	94.6
0.0	0.0	0.0	16.5	35.2	42.2	46.5	50.0	54.4	61.1	70.2	80.9	0.0	85.7
0.0	0.0	0.0	7.8	23.3	29.8	33.9	37.4	41.3	47.6	56.5	67.2	0.0	78.7
0.0	0.0	0.0	2.2	12.6	17.6	21.3	24.4	28.3	33.5	41.1	50.9	62.0	68.3
0.0	0.0	0.0	0.0	4.8	7.8	10.0	12.2	15.2	20.0	26.1	33.9	43.0	55.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.6	6.5	11.5	17.4	23.5	35.9

DATA OF OFFSETS FOR HULL FORM OF CP=0.602

0.0	0.0	0.0	0.0	0.0	0.0	0.0	38.1	67.4	78.6	84.0	0.0	0.0	86.7
0.0	0.0	0.0	0.0	0.0	0.0	24.8	70.5	85.2	91.5	93.8	0.0	0.0	95.0
2.7	3.1	3.6	4.9	10.2	26.7	69.7	88.6	94.7	97.0	98.3	0.0	0.0	98.7
6.7	8.4	10.6	15.8	31.7	64.8	91.2	96.4	99.0	100.0	100.0	0.0	0.0	100.0
13.6	18.1	23.1	32.9	57.1	89.0	98.3	100.0	100.0	100.0	100.0	0.0	0.0	100.0
29.5	41.9	53.6	70.4	94.0	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0	100.0
28.1	48.3	66.0	87.3	99.8	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0	100.0
0.0	37.1	61.7	84.5	95.9	98.1	99.0	99.2	99.5	100.0	100.0	0.0	0.0	100.0
0.0	4.5	43.1	68.6	84.5	90.5	93.4	95.2	96.3	97.1	97.9	0.0	0.0	98.3
0.0	0.0	8.8	43.7	63.9	73.3	78.6	83.0	86.0	89.0	92.1	0.0	0.0	95.5
0.0	0.0	0.0	19.8	37.1	46.3	53.3	59.9	66.0	72.3	79.0	86.2	0.0	90.0
0.0	0.0	0.0	9.8	24.0	31.7	38.1	44.3	51.0	58.6	66.9	76.2	84.8	84.9
0 0	0.0	0.0	2.9	13.1	18.2	23.0	28.3	34.5	42.6	51.7	61.4	71.4	75.7
0.0	0.0	0.0	0.0	3.6	6.9	9.7	13.1	18.1	24.8	32.9	41.9	52.1	61.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.4	5.5	10.7	18.3	27.5	40.5

DATA OF OFFSETS FOR HULL FORM OF CP=0.625

0.0	0.0	0.0	0.0	0.0	0.0	0.0	50.0	80.0	89.0	93.3	0.0	0.0	95.9
0.0	0.0	0.0	0.0	0.0	0.0	31.3	83.1	95.2	98.5	99.1	0.0	0.0	99.1
4.1	4.7	5.3	6.7	10.4	27.0	75.1	96.4	100.0	100.0	100.0	0.0	0.0	100.0
7.5	9.3	11.5	16.0	28.4	63.6	92.9	99.5	100.0	100.0	100.0	0.0	0.0	100.0
12.4	16.7	20.9	29.0	51.3	85.7	99.1	100.0	100.0	100.0	100.0	0.0	0.0	100.0
16.9	27.8	39.0	60.9	90.9	98.4	100.0	100.0	100.0	100.0	100.0	0.0	0.0	100.0
13.3	30.5	48.7	78.7	97.2	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0	100.0
0.0	24.2	48.7	78.7	96.4	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0	100.0
0.0	6.7	37.5	67.4	84.8	92.5	95.9	97.6	98.3	98.7	99.1	0.0	0.0	99.1
0.0	0.0	17.6	48.1	65.1	72.9	77.8	82.0	85.7	89.2	92.6	0.0	0.0	94.3
0.0	0.0	0.0	26.1	40.0	47.1	51.3	55.5	60.0	65.8	73.3	82.3	0.0	84.4
0.0	0.0	0.0	15.6	27.5	33.0	36.7	40.4	45.4	51.6	60.0	70.2	0.0	77.8
0.0	0.0	0.0	5.1	15.4	19.6	22.5	26.1	30.7	36.9	45.2	55.1	67.5	68.9
0.0	0.0	0.0	0.0	4.0	6.9	9.6	12.9	17.1	22.7	30.2	38.7	48.6	55.6
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.2	7.8	13.8	20.0	26.8	36.0

HEIGHT OF DECK OF HULL FORM OF CP=0.549

168.2	164.5	161.6	159.5	156.9	153.5	151.6	151.3	154.0	163.0	177.7	187.4	198.8	211.1	225.8

HEIGHT OF DECK OF HULL FORM OF CP=0.579

181.1	177.0	173.4	170.1	167.1	162.6	160.2	160.0	162.4	172.2	188.3	198.5	210.5	224.3	238.9

HEIGHT OF DECK OF HULL FORM OF CP=0.602

178.2	173.0	168.1	164.7	162.4	160.0	158.3	160.0	166.4	177.5	192.2	199.4	208.0	216.8	226.0

HEIGHT OF DECK OF HULL FORM OF CP=0.625

179.2	174.8	171.5	169.1	166.3	162.9	160.6	160.0	162.9	170.5	183.9	192.3	[illegible]	213.4	226.2

COEFFICIENTS FOR ESTIMATION OF RESISTANCE

28.570	31.282	33.595	36 965	39.326	42.422	43.726
8.552	9.528	11.013	14 380	16.557	18.086	18.134
9.474	10.815	11.587	13.189	13.582	17.883	18.500
-6.365	-6.526	-5.749	-5.891	-6.597	-6.152	-5.872
-1.904	-1.194	0.778	1.993	5.791	4.338	1.062
-1.818	-1.010	-0.718	-0.125	-0.655	0.763	2.075
2.306	2.985	4.942	7.060	10.413	12.815	17.585
0.598	0.505	0.350	0.437	0.097	0.374	1.016
4.091	5.174	5.171	6.704	5.481	7.757	8.529
0.297	0.653	0.921	0.688	0.494	0.421	0.841
0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.665	0.711	0.953	0.720	0.159	0.416	0.147
2.177	2.225	2.557	3.540	4.224	3.566	2.505
-1.185	-2.238	-1.881	-0.905	1.877	4.670	1.547
1.703	0.232	1.777	4.916	7.625	4.381	6.128
2 307	3.307	3.821	3.891	4.658	3.703	4.116
-2.696	-2.441	-2.861	-2.215	-0.929	-1.233	-2.160
-3.317	-2.427	-1.173	-1.082	-1.624	-1.199	-1.450
-5.069	-7.023	-6.718	-5.484	-1.941	3.069	1.687
0.921	0.396	-0.344	-0.499	-0.611	-0.896	-1.604
1.220	1.546	1.226	1.594	0.206	-1.382	0.660
4.139	3.873	5.644	3.919	13.097	13.587	9.371
4.676	3.004	3.825	6.173	7.998	4.191	7.884
1.103	0.805	0.301	1.156	3.213	3.160	3.770
-3.290	-3.227	-4.681	-4.896	-6.923	-6.505	2.765
2.001	1.008	-0.169	-0.184	-0.097	-1.866	-3.359
-2.026	-2.512	-3.476	-3 864	-3.591	-6.606	-18.775
0.726	1.876	2.949	3.728	4.628	3.866	3.133
9.887	10.807	11.842	11.204	20.382	18.995	18.387
0.127	1.050	2.048	2.931	3.353	3.331	8.856
1.324	2.594	4.534	5.490	4.878	-0.716	-6.510
-7.863	-7.810	-6.821	-6.697	-7.527	-6.806	-4.271
-2.371	-2.289	-3.120	-3.851	-3.859	-5.821	-3.933
-10.511	-10.733	-14.530	-14.724	-32.762	-28.158	-13.483
0.277	0.152	-3.361	-10.159	-11.014	-11.185	-4.274
-9.512	-10.136	-12.028	-10.074	-27.758	-20.894	-9.840
-3.991	-3.127	-4.577	-15.566	-21.784	-24.728	-19.121
6.421	7.634	4.936	3.257	1.888	4.318	9.820
-0.601	-0.806	0.569	3.999	8.386	12.520	11.555
5 156	1.645	4.818	4.441	15.961	33.566	16.100
0.332	-0.663	0.815	1.374	11.698	21.602	9.909
9.252	7.048	8.893	7.351	17.359	33.967	23.857
1.516	-2.460	-0.699	-1.713	8.039	19.063	9.635
5.365	6.031	7.671	7.471	11.020	12.966	0.220
1.310	0.967	0.754	1.678	3.360	2.432	5.946
-0.628	-2.306	-3.277	-3.563	-0.026	2.140	7.502
1 575	0.982	-0.192	-1.063	-4.630	-9.855	-5.868
-3.616	-4.515	-4.418	-4.349	-4.629	-4.303	-3.173
-3 564	-4.646	-5.157	-6.226	-7.783	-8.344	-8.613
0 244	2.071	2.762	3.623	3.842	1.642	3.077
-5.293	-3.672	-3.966	-6.530	-7.951	-6.968	-8.687
0.533	3.515	2.853	-2.743	-4.162	-0.321	-4.897
-13.031	-11.918	-10.601	-11.019	-10.402	-14.066	-16.171
3.852	1.665	5.744	10.642	17.134	15.606	17.743
6.957	3.927	6.636	14.200	18.449	13.571	16.714
4.655	2.740	7.338	10.116	15.274	14.476	14.659
2.717	4.314	4.878	6.949	6.050	10.316	9.640
-9 913	-10.255	-9.050	-7.599	-8.718	-6.870	-7.419
-7.636	-6.862	-5.544	-6.856	-7.160	-6.025	-12.249
10.930	10.227	10.016	9.537	9.370	10.824	6.044
4.984	5.200	5.391	5.051	7.980	7.081	8.381
-1.861	-2.238	-2.285	-1.717	-2.719	-2.037	-1.014
-4.159	-5.673	-5.908	-8.251	-7.265	-5.178	-3.783
3.032	4.812	6.070	6.372	7.151	6.947	0.451
-4.129	-7.501	-9.539	-12.549	-11.695	-7.752	-0.850
3.591	3.625	4.203	3.615	5.533	4.817	6.009
-10.735	-7.734	-6.088	-5.306	-4.923	-5.925	-4.407
8.393	8.245	12.109	13.950	16.272	14.780	22.057
-0.521	1.379	3.077	4.524	4.312	6.178	5.999
-8 420	-9.245	-9.874	-9.986	-11.067	-10.993	-12.033
-0.136	1.614	3.576	4.167	4.700	6.431	5.515

APPENDIX B.

Details of calculation for the net present value index.

Net present value index

In this study,the net present value index, NPVI is used for the economic assessment. The value of NPVI equals to zero means the required rate of return is achieved. If it is less than zero, the rate of return is under achieved and if greater than zero, the rate of return is over achieved. The NPVI is calculated as follows:

$$NPVI = (SDCFO - SDCFB) / COSTAC \qquad \text{(B.1)}$$

where, SDCFO = discounted cash inflow of operation for the period of operation (NOP).

$$= \sum_{I=1}^{NOP} PW(\text{ yearly net earnings }) + PW(\text{ Salvage value}) \qquad \text{(B.2)}$$

SDCFB = Discounted cash outflow for building of the vessel for the periods of building (NIST) and repayment (NRP).

$$= \sum_{I=1}^{NIST} PW(\text{ instalment of payment during building})$$

$$+ \sum_{I=1}^{NRP} PW(\text{ yearly instalment of repayment}) \qquad \text{(B.3)}$$

COSTAC = Acquisition cost of the vessel

Yearly net earnings = Yearly revenue -yearly operating costs -tax rate (Yearly revenue - yearly operating costs -yearly depreciation).

PW = Present worth factor for the Ith year or the Ith instalment

$$= 1/(1+RI/100)^{I} \qquad \text{(B.4)}$$

RI = Discount rate or rate of return in per cent.

Fishing system

The functions of a fishing vessel, for the purpose of this study are assumed as follows:

1) fishing by means of trawling nets either by bottom trawling or mid-water trawling,
2) transporting the catch from the fishing ground to a landing place, and
3) preserving the catch (whole fish) between catching and landing.

These functions are expected to be carried out by :

1) catching by means of high opening bottom trawls operated from a stern trawler,
2) transportation of the catch in insulated holds, and
3) storing the fish (whole) with ice in a ice trawler or in boxes in a refrigerated trawler.

The environmental conditions at the fishing ground as well as the port of landing play important roles in the economic assessment of a vessel. Operating characteristics of a vessel are equally important. A set of data related to these items is shown as input data. The set is chosen arbitrarily, as statistical information for fishing grounds is inadequate.

Description of the mathematical model

1) Input data regarding the vessel, the fishing ground and the port of operation are read in the program as DATA statements.
2) The subroultne PVNI is called for computation of the net present value index.
3) The subroutine simulates the condition as if the vessel goes out to the specified fishing ground and does the fishing operations according to the operating schedule till the fish-hold is filled up or the permissible fuel is consumed. In the case of an ice trawler, the

maximum time allowed for fishing and return journey from the time of the first catch is also taken into considerations, for prevention of deterioration of the catch. Thus , one trip cycle is completed. The total number of trips per year is computed, knowing the number of the days of operation per year.

4) Considering the effect of escalation, the revenues and costs of operations for the subsequent years of the economic life of the trawler are calculated in the program.
5) The net cash flows are calculated for each of the years of operation of the vessel, considering the effect of taxes and depreciation.
6) The discounted cash flows are computed for each year of operation inclusive of the cash flow for salvaging the vessel at the end of the operating life.
7) The model also calculates the discounted cash flows for the building of the vessel and repayments of the loan, incurred for the acquisition of the vesse.
8) The net present value is computed by deducting the sum of the discounted cash flows for building and repayment of the loan from the sum of the discounted cash flows for operation and salvaging the vessel.
9) The net present value is divided by the acquisition cost of the vessel, which is computed at the begining of the program, to compute the net present value index.
10) The model calculates the net present values at the time of delivery of the vessel, instead of, at the time of signing the contract.

Fishing gear

It is anticipated that the trawler is equipped with the maximum size of the fishing gear capable of being handled by the main engine. The following assumptions [5] are made:

The mouth of a trawl net has the shape of an ellipse. During use, the height of the trawl-net opening (minor axis) decreases with the increase in trawing speed, unless additional bouyancy is added to the headline. The headline height is kept constant for all speeds through the use of such lifting devices (dynamic floats, kites , etc.) , as required.

Area of opening in ft^2,

$$A = 3.1426 \times l/2 \times h/2 \quad \text{.......} (B.5)$$

where, l = horizontal dimension of net opening, i.e., the major axis in ft, and h = vertical dimension of net opening, i.e., the minor axis in ft. Because of catenarity, l is assumed to be equal to 70% of the headline length and h to be equal to 12.7% of the headline length. Hence,

$$A = 3.1426 \times 0.70/2 \times HL \times 0.127/2 \times HL$$
$$= 0.055\ HL^2, \quad \text{.......} (B.6)$$

where,

HL is the headline length in ft.

From the analysis of data of trawl nets, it is found that

$$HL = SL/1.056, \quad \text{.......} (B.7)$$

where,

SL is the length of the aft end of belly in ft.

The power required to pull the net, exclusive of doors and warps for a trawl- speed, VT in knots, is estimated by the following formula :

$$TRLHP = ((0.47 \times 0.055\ HL^2 + 1.056 \times 0.0746\ HL^2) \times 2.81556\ VT^3)/550 \quad hp \quad \text{.......} (B.8).$$

Cost of vessel and gear

Owing to lack of sufficient data, the initial costs of a vessel and its gear are calculated using the results of [13,14], by correcting the cost up to 1978. The cost of a vessel is a function of the CUNO and the installed horse power of the engine, HP. The cost of a vessel is calculated by

$$COSTIV = (A_2 + A_3 \times CUNO) \times GFV \times 1000 + (HP/CUNO - 0.90) \times CUNO \times CPHP \text{ (for refrigerated trawler)} \quad \text{.......} (B.9)$$

and $COSTIV = (A_1 + A_3 \times CUNO) \times GFV \times 1000 +$
$(HP/CUNO - 0.90) \times CUNO \times CPHP$ (for ice trawler) ....(B.10)

A_1 and A_2 are the fixed components which are independent of CUNO and A_3 is the variable component which varies with CUNO. GFV is the growth factor of cost of the vessel. The vessels whose data were analysed for the estimation of cost, had HP/CUNO values in the range of 0.90. Therefore, any variation of this ratio will change the estimated cost. This is taken into consideration, in the second term of the above mentioned equations (B.9 and B.10). The values for A_2 and A_1 are taken as 20 and 12 respectively, as refrigerated vessels are equipped with costly machinery. The growth rate of 5% is assumed in this study for estimating the costs at the level of 1978. The cost data of the vessels were at the level of 1970 and for gear at 1972 level. Hence the growth factor for correcting the costs of the vessel, up to 1978 level is 1.48 and that for gear is 1.34. For correction to HP/CUNO ratios other than 0.90, the cost of machinery per HP is taken as 220 dollars at 1978 level. The method of estimating the cost of gear varies widely [15,16,17]. In one study [17], the cost of gear is shown as a function of hold capacity, while in another study [16] it is shown as a function of headline length, and in [15] the cost of gear is taken as a function of the installed horse power which seems to be logical. So, the method adopted in [15] is chosen for estimating the cost of the gear, after making necessary corrections for the growth rate. The cost at the 1978 level is taken as 40 dollars per HP.

Cost of repair and maintenance - vessel and gear

The annual cost of maintenance and repair is assumed to vary with the initial cost of the vessel. In the studies [15,16,17] it is stated that the cost of maintenance and repair in the first year of operation is about 5% of the initial cost of the vessel and this increases by 7% per year compounded. The cost of maintenance and repair of the gear is much more than that of the vessel. In the first year, it is assumed as 40% of the initial cost.

Cost of insurance - vessel and gear

According to the references [15,16], the initial costs of insurance vary between 3% and 5% of the initial cost of the veseel and gear. The combined effect of yearly escalation and depreciation is zero [15].

Economic lifetime

The economic life of a fishing vessel is shorter than its physical life. It is influenced by many factors such as :

1) productivity charges,
2) changes in the cost of maintenance and repair,
3) changes in the residual values, and
4) catch efficiency and costs of operation of new vessels introduced into the fishery at a later date.

This is a topic of separate study. In this study, the economic life of a vessel is assumed to be 12 years [15, 16 , 17].

Salvage value

It is, generally, assumed that the market value of a fishing vessel decreases by 70% to 85% over its economic lifetime of 12 years. In this study, the salvage value is assumed as 20% of the initial cost of the vessel. The salvage value of the gear is normally zero.

Preservation of fish

In the refrigerated trawlers, preservation of fish (whole) is done by keeping the fish in boxes in a refrigerated hold. In the ice trawers, it is done by keeping fish in boxes mixed with ice pieces in an insulated hold. Ice is carried in the insulated hold from the port of operation. This type of trawler operates in the fishing ground for a maximum period of 14 days minus the days required for the return journey from the fishing ground to the port of landing. This limitation is imposed as the majority of sea fish stored at 0^{0} C start deteriorating in quality and appearance in about 14 days, and reduce their landed value. For the proper preservation of fish, the fish-to-ice ratio is assumed to be 1:1, and in that condition, the ice and the fish occupy 0.80 t/m^3 of the available fish-hold volume. Within the fish-hold about 20% of the space is required to be kept free for movement, etc. Therefore, only 80% of FHV will be available for stowing fish and ice. The requirement of ice, calculated in conformity with the practice is shown below:

reserve ice - 6% of the volume available for stowage,
ice for maintaining the temperature - 20% of the volume available for stowage, and
ice for operation - 1% of the volume available for stowage per day the vessel will be out from the port, i.e., steaming and fishing days.

Fishing seasons

A sub-season is defined as a period of the fishing season during which the environment and fishing conditions are identical [15,16,17]. The whole season can be divided into a number of sub-seasons to distinguish the influential factors of the fishing activities. However, in this study, the fishing season is not divided into sub-seasons to simplify the mathematical model for the economic assessment.

Free running speed

The free running speed of the vessel on her onward journey is the speed which is attained at full power. The free running speed during the return journey is assumed to be 90% of that of the onward journey as it is expected that the displacement will be greater duirng the return journey.

Distance

There is a possibility of variations in the distance to the fishing grounds during the whole fishing season. Here, the distance for the entire season is kept constant for the sake of simplicity.

Fishing schedule

There are many activities to be carried out in the fishing grounds shch as searching for fish, trawling, gear handling, repairing of nets, rest, etc. In this study, it is assumed that one cycle of fishing, ITC consisting of shooting, trawling, recovering and manipulating is of 150 minutes duration. The recovery time, ITR is assumed to be 15 minutes and that for manipulating, ITM to be 10 minutes. The shooting time, ITS is a function of the depth of water in fathoms, WATER [5].

$$ITS = 0.05 \times WATER \text{ in minutes.} \quad \text{(B.11)}$$

Hence, the time for fishing,

$$ITF = ITC - (ITR + ITM + ITS) \quad \text{minutes} \quad \text{(B.12)}$$

Crew

The number of crew for the trawlers is taken as a function of size, i.e., CUNO. The number of crew, CREW is estimated by the following equation:

$$\text{Number of complement} = 13.20901 - 35.3959 \times CUNO/10^3 + 65.4548 \times CUNO^2/10^6 - 32.47362 \times CUNO^3/10^9 + 49.21995 \times CUNO^4/10^{13} \quad \text{(B.13)}$$

The next integer value is obtained by adding 0.5 with value so calculated. It is further assumed that 2 officers will be required for the ice trawlers and 3 officers for the refrigerated trawlers. It is expected that fishing will be carried out in two shifts round the clock for 20 hours, allowing each shift an overtime of two hours.

Number of days at sea

The number of days at sea per year varies according to the prevailing weather condition at the fishing ground. In the fishing grounds, where the weather is very bad, the days of operation per year may be taken as 250, but they may be taken as high as 350 in the fishing grounds having a good weather.

Time in port

A certain time is necessary in the port for unloading of the catch, cleaning, refueling, loading of the ice (in case of the ice trawler), maintenance, repair and rest for the crew. Accurate requirements of time for these activities are difficult to establish. In this study, the time spent at the port is taken as 3 days per trip.

Crew remuneration

In this study, the cost of an officer per day is assumed as $12.00 and that for a non-officer as $2.50. The cost of overtime is assumed as double the normal wage. Over and above the normal wages, the cost of crew benefits is taken as 20% of the normal wages per year. The program does not assume any incentive scheme.

Costs of administration

The cost of shore management is very difficult to assess. A certain part of administration costs is taken to be independent of the size of the vessel and is taken as $2420.0 per year. The variable part is dependent on CUNO. This is $2.42 per CUNO per year [15,16,17].

Rate of discount

The rate of discount is assumed as 20%. The discount factors at that rate are shown below:

Year :	1	2	3	4	5	6	7	8	9
Dis. fac.:	0.833	0.694	0.578	0.482	0.402	0.335	0.279	0.232	0.194

Year:	10	11	12
Dis. fac.:	0.162	0.138	0.112

Depreciation

The straight line depreciation is assumed in this model. The depreciated amount is the cost of investment minus the salvage value. Depreciation per year is the depreciated amount divided by the number of years of operation, i.e., the economic life of the vessel.

Taxes

No concession for taxes is assumed in this study, i.e., the tax is to be paid from the first year of operation. The interest paid on the borrowed amount is taken as an allowable deduction for the purpose of taxation:

Taxable amount = Revenue - all expenses - depreciation - interest......(B.14)

Finance

The finance required to procure a trawler can be either arranged fully from the qwner's resources or partly, the balance being obtained as a loan from financial organisations. Normally, 20% of the cost of the vessel and the gear is arranged from the owner's own fund and the remaining 80% is taken as loan on interest.

Construction

The vessel is expected to be built on order. The program assumes that at the time of signing the contract, some payment is made to the builder. This contract signing payment may be taken as some percentage of the cost of the vessel. the remaining part of the cost is assumed to be paid in a number of instalments at regular intervals. The net present value of all the transactions is calculated at the year of delivery, which is assumed as zero year. If the vessel is imported, the import duty is taken as some percentage of the cost of the vessel and the gear. The owner's initial expenses are also taken as a percentage of the cost of the vessel and the gear. The interest on the borrowed sum during the period of building of the vessel is assumed to be paid at the time of delivery. The repayment of the loan, if any, is made by equal annual instalments in a stipulated number of years. Interests are paid annually till the borrowed sum is fully paid. At the time of delivery, the owner pays the import duty, all initial expenses and the accrued interest during the building of the vessel from his own fund.

Cost of ice

This is applicable for the ice trawlers only. It is assumed that 20% of FHV is taken as handling space. The reserve ice is taken as 26% of FHV and the remaining ice is estimated as 1% of FHV per day of operation at sea. One m^3 of ice pieces weigh 0.4 tonnes. The cost of the ice can be calculated knowing the rate per tonne.

Cost of fuel and lubricating oil

The following assumptions are made to estimate the costs of fuel and lubricating oil :

1) During trawling 100% of power is used.
2) During recovery of the net 20% of power plus 100% of winch power is used.
3) Durine shooting 50% of power is used.
4) During non-shooting period, i.e., 24 hours, full power is used for searching, etc.

5) For the refrigerated trawlers. the generators are to run at full load for the fishing days plus one day in the port for clearance of the catch, and at 50% of the full load for the remaining two days in the port per trip.
6) For the ice trawlers, the generator horse power is 5% of the installed power. The generator is to run at full load for all the days of operation.

Port charges

These are divided into two categories, one for handling the catch and the other for security, port dues, etc.. The handling charges are taken as a function of the weight of the catch and the handling rate. The port charges are assumed to be a function of the days in port and the charges per day. The charges should vary with the size of the vessel. In this study, owing to lack of data, the port charges are considered as constant, irrespective of the size of the vessels.

Cost of provision

Over and above the salary paid to the crew and officers, they are expected to be paid a daily provision allowance. The cost of provision is a function of the rate per day per person and the number of the crew and officers.

Revenue

The catch per cycle of operation is a function of fish concentration per metric ton of water and the weight of water passed through the net, which is a function of the area of the mouth of the net, the fishing time and the trawling speed. The catch per day is a function of catch per cycle and the number of cycle per day. The catch per year is a function of the catch per day, the number of days per trip and the number of trips per year.
In the case of the ice trawlers, the number of actual fishing days is estimated as follows:

Let the maximum number of days available from the preservation point of view be DAYM (14 days). So, the maximum number of days available for fishing , DAYFM is equal to DAYM minus the days of returning. If the quantity of fish caught per day is CATD , and the normal fishing days to fill up the hold are DAYF, then

DAYF = FHV x 0.8 x 0.4 /CATD ....(B.15)

Let the actual days of fishing be FDAY. Now if DAYF is less than DAYFM,

FDAY = DAYF, ...(B.16)

otherwise,

FDAY = DAYFM ....(B.17)

In the case of refrigerated trawlers, this restriction of DAYM is not there but the actual fishing days will depend on the catch rate per day and the capacity of the fish-hold. But if sufficient catch is not available, the actual fishing days will depend on the availability of the fuel at the fishing ground. It is assumed that 55% of the FHV is available for fish stowage and each m^3 of such space is to stow 0.5 tonne of whole fish. Therefore, the normal days of fishing,

DAYF = FHV x 0.55 x 0.5/CATD ....(B.18)

Assuming 10% of the fuel as reserve and 15% as the consumption of the generator, the available fuel for fishing at the grounds is given by:

AFUELF = FUELC x 0.75 - (consumption of fuel for onward and retrun journey) ....(B.19)

FUELC is the capacity of the fuel tank. FUELC is a function of CUNO.

Now the consumption of fuel per day of fishing,

FUPD = consumption per cycle x number of cycle per day + consumption for the remaining part of the day. ....(B.20)

Therefore, the maximum days available for fishing,

DAYFM = AFUELF/FUPD. ....(B.21)

If DAYF is less than DAYFM,

FDAY = DAYF , ...(B.22)

otherwise,

FDAY = DAYFM. ....(B.23)

Therefore, the revenue,

REV = CATD x FDAY x TRIPN x SELLR ....(B.24)

where,

TRIPN is the number of trips per day, and SELLR is the landing price of the catch per tonne.

Escalation :

The revenue and expenses for operation will be escalated every year assuming that there will be growth and increase in cost every year.

NOTE : All formulas used in the model are not shown here. If any reader is further interested, the author will be happy to furnish them.

APPENDIX C.
The details of evaluation of the constraints

Generation of hull form

A hull form is generated for a given value of prismatic coefficient by Lagrange's interpolation formula using four basic hull forms [4]. The hull form is required to estimate the stability particulars to assess the values of the stability constraints.

Power and speed

The free running speed is given as owner's requirement. The power required for the hull form generated for a set of system variables, is computed for seven speed-length ratios, from 0.90 to 1.20, using the regression equation for CR16 , developed by Hayes and Engvall [12]. The power is estimated using the following equation:

$$EHP = (CRL \times DISPLT \times VKT^3) / (325.7 \times ALWF) \quad \text{(C.1)}$$

$$BHP = EHP \times 1.30 / 0.55 \quad \text{(QPC is assumed as 0.55)} \quad \text{(C.2)}$$

An engine having the next higher horse power is selected for installation. The speed , SPEEDC is calculated for the installed horse power, using the Lagrange's interpolation formula. If the installed power exceeds the calculated power coresponding to the speed-length ratio of 1.20, the speed is estimated on the assumption that at higher speeds the power is proportional to the n th power of the speed. Therefore,

$$Power = K \times Speed^n, \text{ and} \quad \text{(C.3)}$$
$$Speed = (Power/K)^{1/n} \quad \text{(C.4)}$$

Weight

The data, suggested by Benford in an article in the reference [13] are used to estimate the weights of the steel hull, wood and outfit, and auxiliary machinery. The coefficients of these weights vary with the cubic number in feet units, CNF. An interlopation subroutine, INTPOL, is used to estimate the weight coefficients for the CNF of the design. The steel weight coefficient thus estimated is increased by 3 per cent. The weight of the main machinery is estimated from the installed power. Finally, the light weight of any design is estimated by adding the component weights and a margin of 20 per cent.

Displacement

The deadweight to estimate the displacement, is taken as the deadweight at the fishing ground or in the port, whichever is greater. The deadweight in port is assumed to be the sum of the weight of fuel, lubricating oil, fresh water, provision, and crew and their effects plus the weight of ice (in the case of the ice trawlers only). The weight of the ice is estimated as a function of the available fish-hold volume (0.8 xFHV) and assuming a value of days at sea, DAYS as 14. The deadweight at a fishing ground is assumed as the full weight of the fish plus the weight of the crew and their effects plus the weights of 50 per cent of the fuel oil, lubricating oil, fresh water, and provision.

For the ice trawlers, the weight of fish is estimated on the assumption that 1 m^3 of available fish-hold volume stows 0.8 tonnes of fish and ice in the proportion of 1:1 by weight. Hence, the weight of fish in tonnes is equal to 0.4 times the available fish-hold volume in m^3. For the refrigerated trawlers, the weight of fish is estimated on the assumption that 55 per cent of the FHV is available for the stowage of the whole fish at a stowage rate of 0.5 t/m^3 of available space. Hence, the weight of the fish in tonnes is equal to 0.5 x 0.55 x FHV. Therefore, the maxium displacement is estimated as the sum of the light ship weight and the deadweight (maxium of that in the port and at the fishing ground) plus a margin of 10 per cent, as suggested by Benford in the reference [13].

Parameters for the stability constraints

The parameters for the stability constraints are estimated from the particulars of the curve of the statical stability levers and the free surface for the design floating condition. The particulars of the curve of the statical stability are estimated from the particulars of the cross curves of the statical stability of the design. A subroutine CRFLVR, based on a program [18], is used to calculate the stability particulars in the design model. To simplify the calculation, the righting levers are calculated up to the uppermost continuous deck. The effect of superstructure,i.e., the extended forecastle is not considered. The effect of the extended forecastle is zero till the deck touches the water and beyond the angle of inclination at which the deck touches the water, this effect increases the safety of the vessel which is assumed as safety margin.

Further, the effect of free surface is not considered, as the arrangements of the tanks vary from design to design. But as the particulars of the righting levers of the design are available from the data of the output, a designer can easily plot the curve of the righting moments; find the amounts of allowable free surface moments after satisfying the IMO requirements ; and consequently, finalise the arrangements of the tanks.

The righting levers are estimated assuming a value of the height of the vertical centre of gravity above the keel as 0.8 times the depth of the vessel. This value is read through a DATA statement. Hence, by changing this value, the effect of change of the height can be studied.

The curve of the righting levers contains nine equidistant points as shown in the Figure C-1. The abscissa represents the angles of inclination in radians and the ordinates represents the righting levers in meters (or moments in meter tonnes). Through these nine points a smooth curve is fitted. This is done through a subroutine POLY. The four points, 1,2,3, and 4 from the left hand side as shown in the Figure C-1 , are taken and a third degree polynomial is fitted through the points. The equation of the polynomial is:

$$GZ = COEF(1,1) + COEF(1,2) \times X + COEF(1,3) \times X^2 + COEF(1,4) \times X^3 \quad \text{..........(C.5)}$$

where, GZ is the righting lever and X is in radians. The equation (C.5) defines the curve between the points 1 and 2. The next four points, 2, 3, 4, and 5 are chosen and another third degree polynomial is fitted. This polynomial,

$$GZ = COEF(2,1) + COEF(2,2) \times X + COEF(2,3) \times X^2 + COEF(2,4) \times X^3 \quad \text{.............(C.6)}$$

defines the curve between the points 2 and 3. The curve between the points 8 and 9 is defined by the equation,

$$GZ = COEF(8,1) + COEF(8,2) \times X + COEF(8,3) \times X^2 + COEF(8,4) \times X^3 \quad \text{.............(C.7)}$$

Thus, the entire curve between the points 1 and 9 can be defined by changing the coefficients only. The value of the first derivative of the curve at the point 1 is the value of the initial metacentric height. Therefore, differentiating the curve between 1 and 2,

$$GMINI = [\, d/dx\,(GZ)\,]_{X=0} = COEF(1,2) \quad \text{..........(C.8)}$$

The smooth curve through the points is divided into a number of parts as shown in Fig. C-1 . Let a, b, c, and d represent the areas under the curve up to the base line between 1 and 2, 2 and 3, 3 and 4, and 4 and 5 respectively. Therefore, the sum of the areas a, b, and c is the area up to 30^0 and that of a, b, c, and d is the area up to 40^0. Integrating the relevant equations between their end points, the areas a, b, c, and d are obtained. For example, the area up to the base line under the curve between any two consecutive points I and II having coordinates on the base line XCOR(I) and XCOR(II) respectively, is:

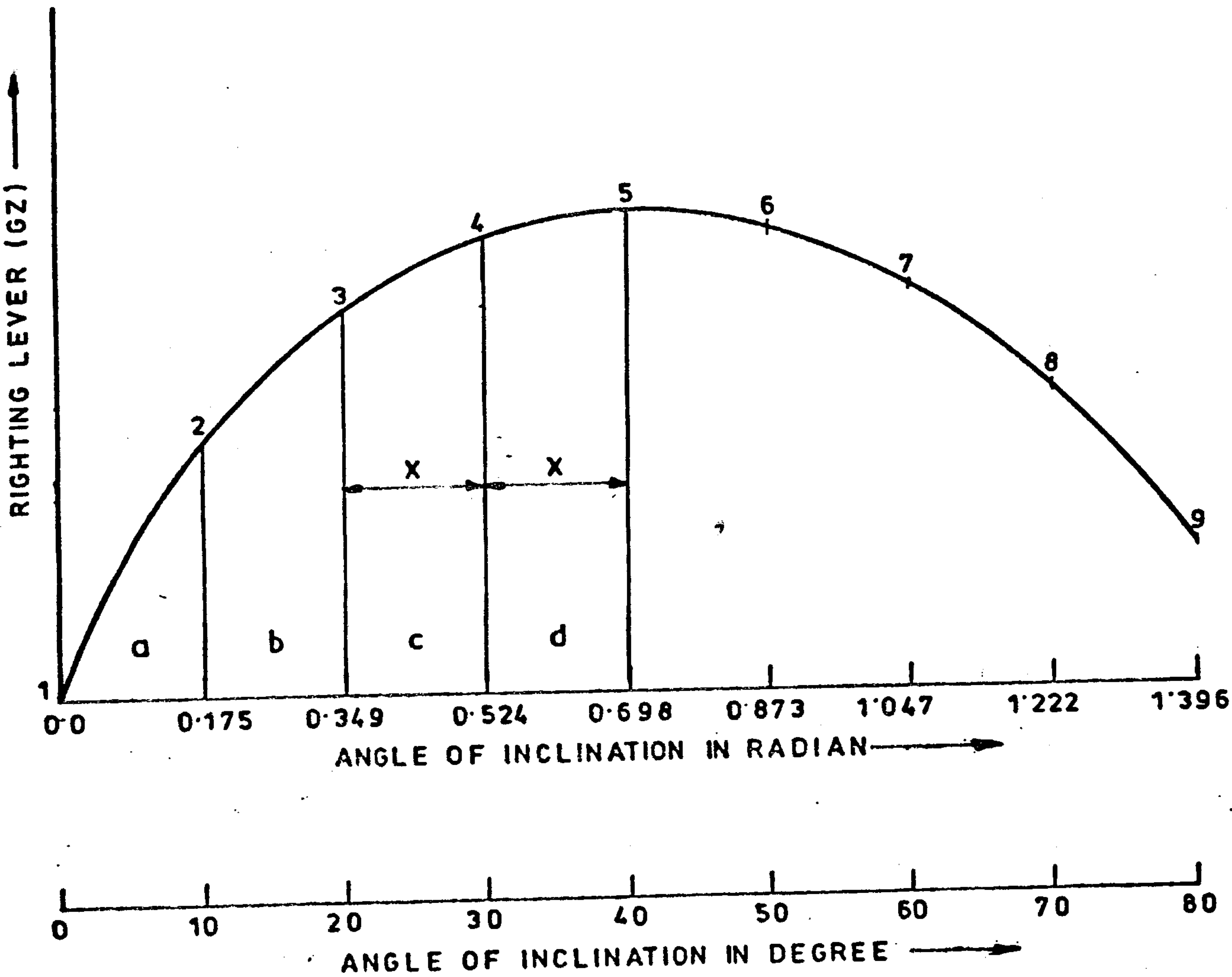

FIG. C -1. CURVE OF RIGHTING LEVERS (GZ)

$$\int_{XCOR(I)}^{XCOR(II)} [\,COEF(I,1)+COEF(I,2) \times X+COEF(I,3) \times X^2+COEF(I,4) \times X^3\,]\,dx \quad \text{....(C.9)}$$

$$= [\,COEF(I,1)(XCOR(II) - XCOR(I)) + COEF(I,2)/2(XCOR(II) - XCOR(I))^2$$

$$+ COEF(I,3)/3(XCOR(II) - XCOR(I))^3 + COEF(I,4)/4\,(XCOR(II) - XCOR(I))^4\,].$$

Thus the areas AREA30, AREA40, AR40, and AR4030 are calculated. The value of the maximum righting lever, and the angle in radians at which it occurs are deteremined through another subroutine GOLDEN. Thus the values of RLEVMX and RADMX are obtained.

Cubic number:

CUNO, being the function of FHV, is evaluated by using the equation

$$CUNO = 93.6601 + 5.2511 \times FHV \quad \text{....(C.10)}$$

CUNOC is obtained as the product of length overall, beam and depth.

$$CUNOC = LOA \times B \times DP \quad \text{....(C.11)}$$

$$LOA = 1.095 \times LWL \quad \text{....(C.12)}$$

where, LWL is the length on water line.

$$LWL = 11.9518 + 26.09953 \times CUNO/10^3 - 52.026687 \times CUNO^2/10^7 + 92.785 \times CUNO^3/10^{12} \quad \text{....(C.13)}$$

APPENDIX D

Output data

SLIPML - VERSION 4.6 - MARCH 1985

LAST UPDATE BY F. MISTREE, UNIVERSITY OF HOUSTON

DEPT. OF MECH. ENG.

MAXIMUM NUMBER OF VARIABLES PERMITTED = 50

MAXIMUM NUMBER OF LINEAR CONSTRAINTS PERMITTED = 26

MAXIMUM NUMBER OF NON-LINEAR CONSTRAINTS PERMITTED = 35

UPDATE DONE ON SEPT. 21, 1985

```
AUTOMATED RATIONAL DESIGN OF A TRAWLER
*** USER PROVIDED INPUT ROUTINE TO BE USED.
*** USER PROVIDED OUTPUT ROUTINE TO BE USED.
*** AUTOMATIC GENERATION OF DEVIATION VARIABLES
*** TIME STATISTICS PROVIDED
*** Rank ordered priorities (exact values internally      estimated.
UNITS: FORCE LENGTH MERIT OTHER  KILOGRAMS       METERS               TONNE
-----------------------------------------------------------------------------
NUMBER OF SYSTEM VARIABLES        3
NUMBER OF DEVIATION VARIABLES        8
NUMBER OF CONSTRAINT GROUPS        3
NUMBER OF NONLINEAR CONSTRAINTS     20
NUMBER OF CONSTRAINTS IN EACH GROUP       9     7     4
-----------------------------------------------------------------------------
NAMES OF SYSTEM VARIABLES
 RLB BDTR    CP
NAMES OF DEVIATIONAL VARIABLES
  C-    C+    S-    S+    D-    D+    E-    E+
NAMES OF NONLINEAR CONSTRAINTS (SYSTEM AND GOAL)
 RE1  RE2  RE3  RE4  RE5  RE6  RE7  RE8  RE9  ST1  ST2  ST3  ST4  ST5  ST6
 ST7  GL1  GL2  GL3  GL4
-----------------------------------------------------------------------------
        OPTIMIZATION CRITERIA

    TYPE OF DSP                 GOAL
    PERMITTED NO. OF ITERATIONS                    20
    FRAC1=  5.00% (OBJ. FUNC. VALUE CHANGE LIMIT(I-1,I))
    FRAC2=  5.00% (DESIGN VARIABLE STATIONARY BETWEEN LIMIT(I,I-1) - DEFAULT
    FRAC3= -5.00% (NONLINEAR CONSTRAINT SATISFIED WITHIN LIMIT- DEFAULT)
    MOVE =  0.90  (REDUCED MOVE COEFFICIENT)
    (I=SYNTHESIS CYCLE NO.)


 GOAL PRIORITIES
 0.0000000E+00  0.0000000E+00  0.0000000E+00   1.000000     1.000000
  1.000000       1.000000       1.000000       1.000000     1.000000
  1.000000
```

DESIGN IS FEASIBLE

DESIGN VARIABLES BETWEEN ITERATIONS STATIONARY

DSP OPTIMIZATION STATISTICS:

NUMBER OF ITERATIONS	=	3
NUMBER OF PROBLEM VARIABLES	=	11
NUMBER OF CONSTRAINTS	=	22

AUTOMATED RATIONAL DESIGN OF A TRAWLER
ANALYSIS SYNTHESIS CYCLE NUMBER : 1
PROBLEM NO. 0 FINAL FEASIBLE DESIGN - SYNTHESIS CYCLE NO. 2

VARIABLE	VALUE	VARIABLE	VALUE
RLB	0.24285	BDTR	0.69314
CP	0.38522	C-	0.00000E+00
C+	0.62590E-04	S-	0.00000E+00
S+	0.10235E-01	D-	0.27552E-03
D+	0.00000E+00	E-	0.00000E+00
E+	1.1621		

VALUE OF OBJECTIVE FUNCTION 1.1727

END ANALYSIS/SYNTHESIS CYCLES NUMBER 1

****

TRAWLER DESIGN PARAMETERS
USING DECISION SUPPORT PROBLEM TECHNIQUE

****

OWNENRS REQUIREMENTS

FISH-HOLD VOLUME	:	200.000CU.M
FREE RUNNING SPEED	:	12.170KNOTS
RATE OF RETURN OR DISCOUNT RATE	:	20.000%
NET PRESENT VALUE INDEX	:	1.1616
LENGTH ON WATER LINE	:	35.138M
BEAM	:	9.209M
DRAUGHT	:	2.467M
DEPTH	:	3.226M
MAXIMUM SECTION ARERA COEFFICIENT	:	0.911
PRISMATIC COEFFICIENT	:	0.575
LONG.POSN. OF CENT.OF BUOYANCY	:	-4.995

DESIGN FREE RUNNING SPEED	:	12.296KNOTS
INSTALLED HORSE POWER	:	850.00HP
CUBIC NUMBER REQUIRED	:	1143.88 CU.M
CUBIC NUMBER CALCULATED	:	1143.97 CU.M
EXTREME DISPLACEMENT IN SALT WATER	:	432.18TONNES
TOTAL WEIGHT	:	432.22TONNES
DISPLT.FOR STABILITY CALCULATION	:	429.29TONNES
WEIGHT OF STEEL	:	144.71TONNES
WEIGHT OF OUTFIT	:	57.91TONNES
WEIGHT OF MAIN MACHINERY	:	14.08TONNES
WEIGHT OF AUX. MACHINERY	:	16.63TONNES
WEIGHT OF LIGHT SHIP	:	280.00TONNES
WEIGHT OF FISH	:	55.00TONNES
WEIGHT OF FUEL	:	82.49TONNES
WEIGHT OF LUBRICATING OIL	:	1.61TONNES
WEIGHT OF FRESH WATER	:	21.86TONNES
WEIGHT OF PROVISION	:	2.70TONNES
WEIGHT OF CREW AND EFFECT	:	3.60TONNES
DEADWEIGHT AT FISHING GROUND	:	112.93TONNES
DEADWEIGHT AT PORT	:	112.26TONNES
HT.OF VER. CEN. OF GRAVITY TO DEPTH RATIO	:	0.80
INITIAL METACENTRIC HEIGHT	:	1.700 M
AREA UNDER CUR.OF STA.STY.UP TO 30 D	:	0.168M RAD
AREA UNDER CUR.OF STA.STY.UP TO 40 D	:	0.241M RAD
AREA ... BETWEEN 40 D AND 30 D	:	0.073M RAD
RIGHTING LEVER AT 30 D	:	0.459 M
MAXIMUM RIGHTING LEVER	:	0.475 M
ANGLE OF MAXIMUM LEVER	:	0.445RADIAN

HALF BREADTHS IN METERS

BASE	.05DT	.10DT	.20DT	.40DT	.60DT	.80DT	1.0DT	1.2DT	1.4DT	1.6DT	1.8DT	2.0DT	DECK
0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.78	2.98	3.55	3.94	4.26	0.00	4.26
0.00	0.00	0.00	0.00	0.00	0.00	1.25	3.16	3.73	4.10	4.36	0.00	0.00	4.52
0.16	0.20	0.24	0.32	0.56	1.34	3.06	3.93	4.32	4.51	4.60	0.00	0.00	4.60
0.45	0.56	0.69	0.93	1.59	2.89	3.88	4.30	4.50	4.59	4.60	0.00	0.00	4.60
0.68	0.87	1.08	1.53	2.62	3.67	4.26	4.48	4.58	4.60	4.60	0.00	0.00	4.60
1.12	1.64	2.12	2.92	3.99	4.39	4.54	4.60	4.60	4.60	4.60	0.00	0.00	4.60
1.46	2.29	2.97	3.78	4.44	4.59	4.60	4.60	4.60	4.60	4.60	0.00	0.00	4.60
0.00	1.80	2.99	3.66	4.17	4.32	4.40	4.45	4.49	4.53	4.55	0.00	0.00	4.59
0.00	0.54	2.18	2.90	3.50	3.75	3.91	4.02	4.14	4.29	4.45	0.00	0.00	4.53
-0.00	0.00	0.22	1.81	2.62	2.94	3.16	3.32	3.51	3.78	4.12	0.00	0.00	4.36
0.00	0.00	0.00	0.75	1.61	1.93	2.13	2.29	2.49	2.80	3.22	3.69	0.00	3.94
0.00	0.00	0.00	0.36	1.07	1.37	1.55	1.71	1.89	2.18	2.59	3.09	0.00	3.62
0.00	0.00	0.00	0.10	0.58	0.81	0.98	1.12	1.30	1.53	1.88	2.33	2.82	3.14
0.00	0.00	0.00	0.00	0.22	0.36	0.46	0.56	0.70	0.92	1.20	1.55	1.97	2.53
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.30	0.53	0.80	1.08	1.65

HEIGHT OF DECK AT SIDE IN METER

3.748 3.648 3.560 3.479 3.405 3.292 3.232 3.226 3.282 3.522 3.919 4.173 4.472 4.816 3.19

SECTION AREA IN SQUARE METER

0.485 2.355 7.386 11.718 14.798 18.971 20.697 19.354 16.096 11.457 7.258 5.034 2.975 1.294 0.00

ANGLE OF INCLINATION IN RADIANS

0.000 0.175 0.349 0.524 0.698 0.873 1.047 1.222 1.396

VALUES OF RIGHTING LEVERS IN METERS

0.000 0.260 0.445 0.459 0.365 0.212 0.031 -0.152 -0.333

ANALYSIS SYNTHESIS CYCLE STATISTICS

DESIGN CYCLE NUMBER	=	1
TIME TO CREATE MODEL	=	1.180 SECONDS
TIME FOR DESIGN EVALUATION	=	0.000 SECONDS
TIME TO OPTIMIZE	=	177.773 SECONDS