APPLICATION OF AN EXPERT SYSTEM SHELL IN THE PRELIMINARY DESIGN OF OFFSHORE SUPPLY VESSELS

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Abstract

This paper presents the application of expert system programming in preliminary ship design with particular emphasis on offshore supply vessels. Instead of using one of the conventional programming expert system languages, the system is developed using an expert system shell, Leonardo. The design program is written in such a way that it is user friendly as well as giving the user full control over the progress of the design. The algorithms developed in this system are based on extensive research on existing offshore supply vessels.

1. Introduction

One of the most promising developments in the use of computers in recent years has been the work on expert systems. Its significance is that it addresses itself to providing computer systems which are able to make a 'knowledgeable' contribution to complex problems in a specific domain or field of interest such as preliminary ship design, that is, to act as an expert. In this respect, the expert system can be developed in four different modes such as :

a. the user as a client where the system acts as a consultant from whom the user wishes to get answers to problems,

b. the user as a tutor where the system accepts instructions from a domain specialist to improve or refine its knowledge,

c. the user as a pupil where the system uses its expert knowledge to instruct users in certain approaches, and

d. the user as an assistant where the system interacts with the user to encourage the user to find a solution to a problem with guidance, advice and stimulation from the system.

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It is the last mode which is most relevant to the ship design situation. The work described in this paper is based on the contention that the approaches being taken in expert systems provide a key to realising the potential of computer-aided design. For many years, we have been building complex computer-aided design systems which contain increasing amounts of knowledge. However, that knowledge has been highly constrained to particular methods, and has been implicitly rather than explicitly available. Systems based on ideas of explicit knowledge representation and reasoning, offer the possibility of greater productivity in the contribution they make to man-machine communication.

2. Selection Of An Expert System Shell

Instead of using one of the artificial intelligence languages such as Lisp or Prolog, and developing the whole system from basic principles through predicate logic as was done in some other marine applications [3], [8], [10] it was decided to use an expert system shell to write an extensive preliminary design program for offshore supply vessels.

Advantages of using such shells is the time saving in the development of the system, as work has already been done in the form of the user interface and inference engine does not have to be repeated, and no knowledge of artificial intelligence is required. However, in selecting the appropriate shell to be used in preliminary ship design, certain factors must be available in such a shell :

a. The ability to incorporate a knowledge representation language which allows the user to create a knowledge base using pseudo-english. The structure and syntax of the language allows non-expert programmers to construct different knowledge bases.

b. The facility to allow direct access to external analysis procedures written in procedural languages such as Fortran, Pascal, and C, together with the facility to access many applications programs.

c. The knowledge representation language is able to represent the type of heuristic knowledge associated with ship design.

d. The capability of graphical visualisation.

At present, there are numerous shell programs available in the market which are capable of working in microcomputers with prices ranging from a few hundreds to a few thousands of Pounds Sterling. In this paper, an expert system shell called *Leonardo* version 4.0 is used to produce a program for the preliminary design of offshore supply vessels. *Leonardo* uses rules and an object-oriented frame system. It also contains a procedural language and includes support for Bayesian statistics, fuzzy logic, and certainty factors. It runs on *IBM XT* or *AT* compatibles with 512 K, and *MS* or *PC Dos 2.00* or above. Details on the other main features and working procedure of the Leonardo is given in Reference 9.

3. Structure And Content Of The Knowledge Base

The preliminary design knowledge base for offshore supply vessel developed for the expert system contains a considerable amount of information gathered through extensive studies on the characteristics of 20 pure supply vessels and 20 anchor handling/tug/supply vessel built since 1980. This information, or domain knowledge, is expressed in the knowledge base in terms of empiricisms, factual declarations and user-supplied design parameters. Typical examples of knowledge used in the design of offshore supply vessels are given in Fig. 1. The knowledge base invoked by the system comprises of a number of elements which allow the determination of the vessel's main dimension, weight groups, capacity, freeboard, initial stability, powering, propulsion characteristics, seakeeping.and manoeuvring characteristics, and economic analysis.

The main steps followed by the system during development of the design process of an offshore supply vessel proposal in shown in Fig. 2. The user will starts the system by selecting the required type of vessel to be designed, either a pure supply vessel or an anchor handling/tug/supply vessel. On determining the type of vessel, the user will be presented with guidance on the typical functions available for each type of vessel. Having selected the type of vessel, the user will then be prompted with the requirements menu where he will define the requirement for the proposed vessel in terms of deadweight, capacity, stability, and/or speed. As for the anchor handling/tug/supply vessel, an additional requirement , that is, the bollard pull is supplied. The user may skip any design requirement which is not essential for the proposed vessel. Once the design requirement is obtained, the user will be asked for any limitation or restriction to be imposed to the main parameters of the proposed vessel. Again, the user may insert values for the length, breadth, depth and/or draught or skip all the limitations.

Once the design requirements and limitations on the main dimension are known, the program will proceed to estimate the main parameters such as length, beam, depth, draught, block coefficient and deadweight (if any of these values are not entered as input). The system will continue to evaluate the steel weight, outfit weight and the machinery weight of the vessel. The deadweight calculated in this procedure is checked with the user requirement's deadweight (if input) or the initial deadweight estimated. If the calculated deadweight is within the tolerance limit, the program will proceed to estimate the capacity of the vessel. If the calculated deadweight is not within the tolerance limit, then the process of calculating the main dimension will be repeated until the calculated deadweight is within the tolerance limit. The same procedure applies to the calculation of capacity and initial stability of the vessel.

After evaluating the above parameters, the system will proceed to generate the hull form of the vessel. The hull form is developed from an initial sketch of the vessel profile with the combination of four sectional curves. The curves are generated by incorporating several curve fitting methods such as B-spline, parabolic blending, cubic spline and tangential arc. Details of the procedure is given in Reference [17].

Once the hull form is generated and the offset data are known, the system will calculate the effective horsepower of the vessel. For both the pure supply vessel and anchor handling/tug/supply vessel, the design speed will be used to estimate the power. The total brake horsepower of the anchor handling/tug/ supply vessel will be estimated based on the assumption that the vessel's towing speed is 0.6 of the free running design speed together with the required bollard pull. Before the system proceeds with the evaluation of

```
/*      Rules to Obtain Main Dimensions of Vessel

        if input_data is known
        and main_dimension is obtained
        then dimension_of_vessel is available

/*      Rules to Generate Hullform

        if dimension_of_vessel is available
        and hull_form is generated
        then vessel_shape is obtained


/*      Rules to Calculate Propeller Characteristics

        if vessel_effective_power is obtained
        and type_of_vessel is pure_supply
        and rpm_of_engine > 0.0
        then use screen7;
        blade_number is known

        if blade_number is known
        then run propeller_characteristics (length, beam, depth, draught, ehp,
                block_coefficient, speed, displacement, dia_propeller,
                pitch, bhp);
        propeller_characteristics is obtainable


/*      Rules to Calculate Shipbuilding Costs

        if ask_cost is done
        and cost_estimation is yes
        and wage_rate > 0.0
        and material_cost > 0.0
        and type_of_vessel is pure_supply
        then run building_costs ( steelweight, outfitweight, machineryweight,
                 length, beam, depth, block_coefficient, material_costs,
                 wage_rate, material_cost, shipbuilding_costs);
        building_costs is known
```

Fig. 1 Examples of the Rules used in the Preliminary Design of Offshore Supply Vessels

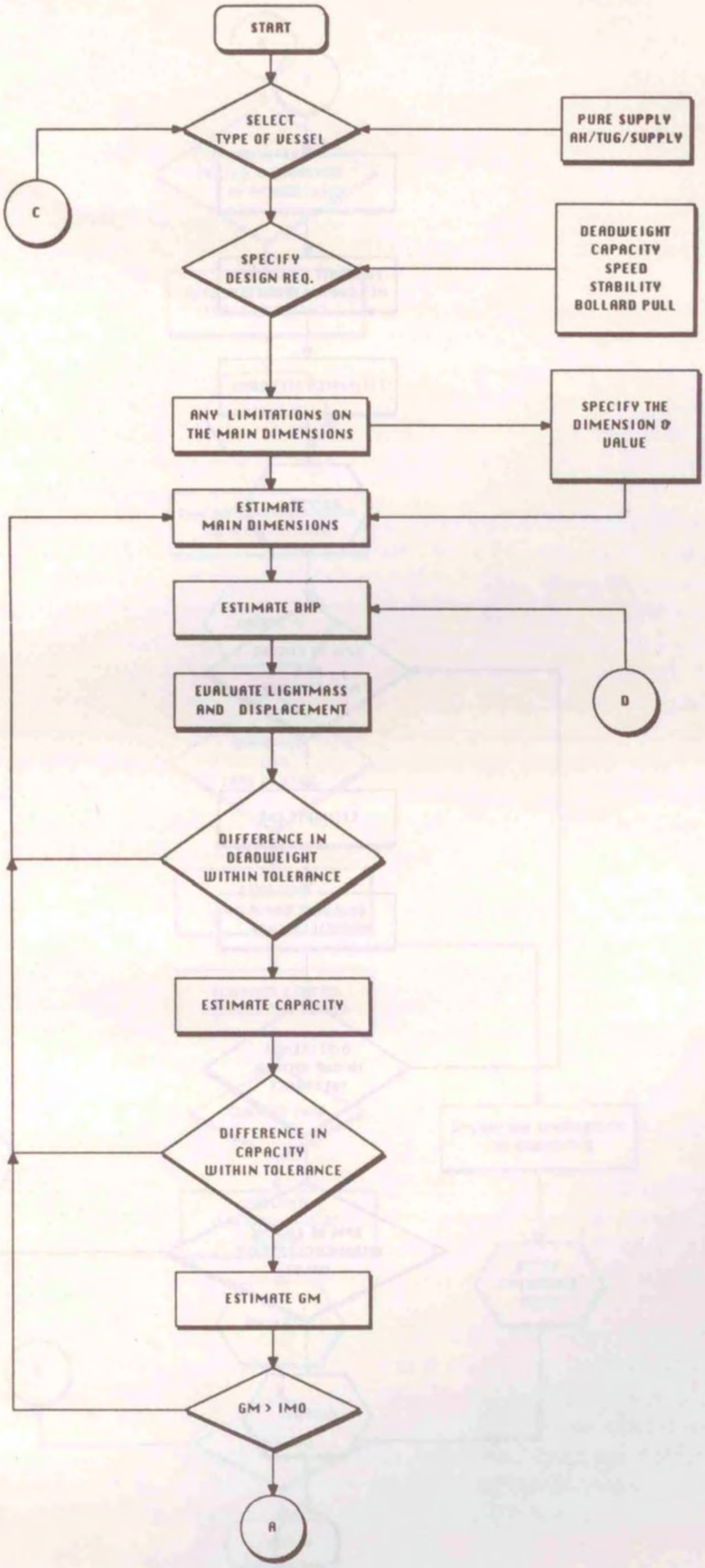

Fig. 2 Computer Algorithm Flowchart

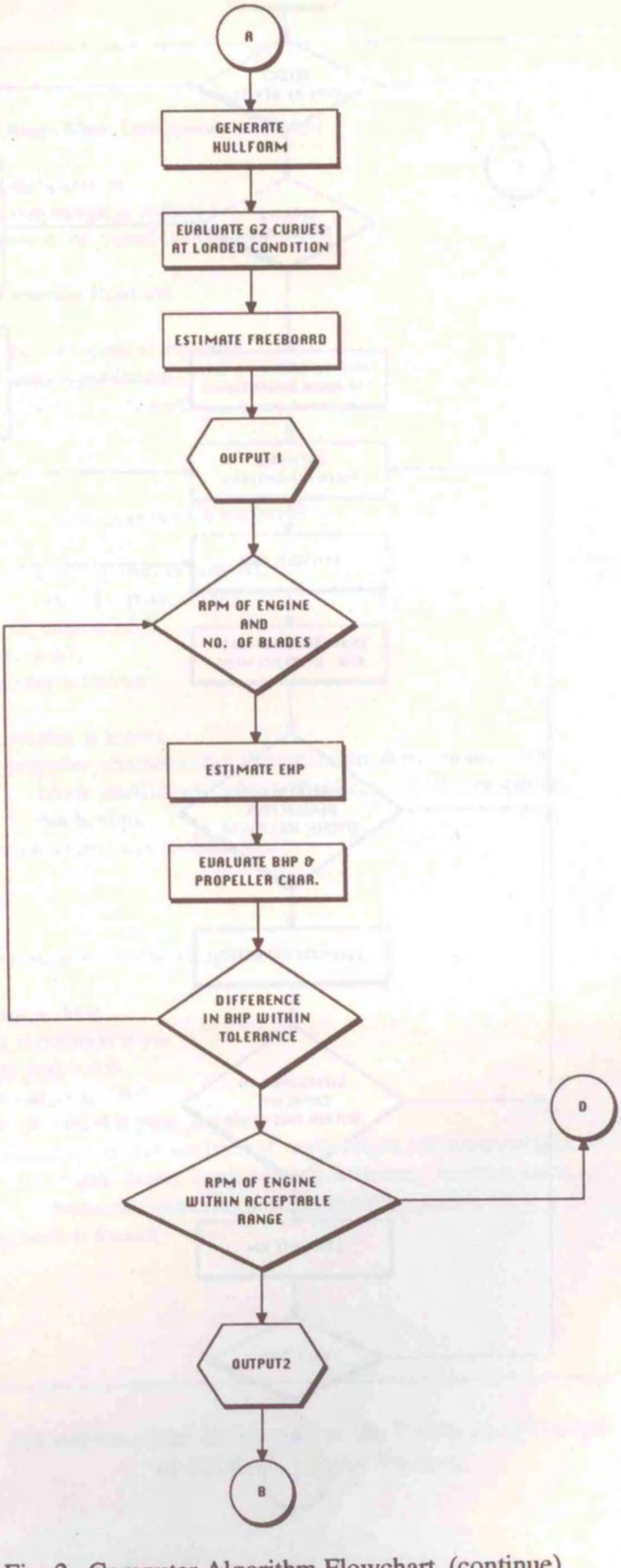

Fig. 2 Computer Algorithm Flowchart (continue)

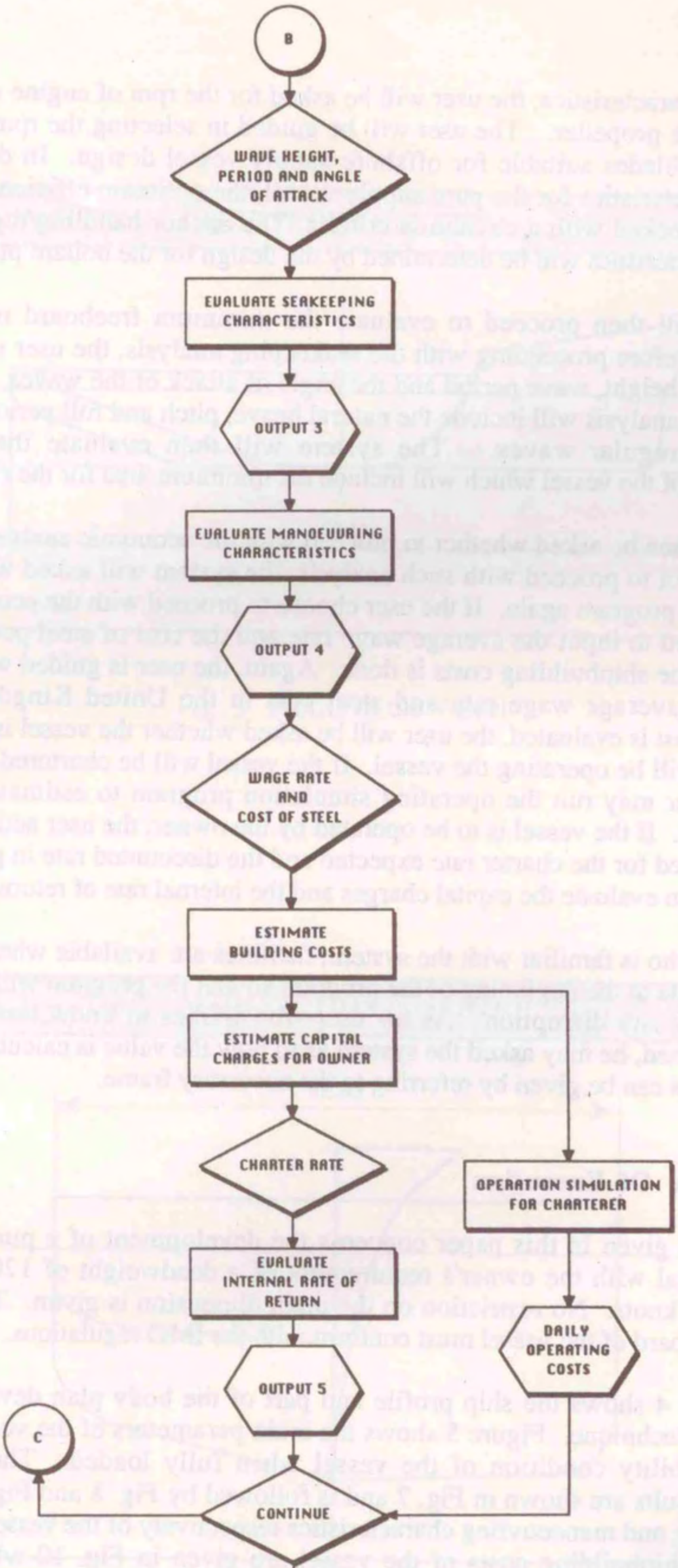

Fig. 2 Computer Algorithm Flowchart (continue)

the propeller characteristics, the user will be asked for the rpm of engine and the number of blades for the propeller. The user will be guided in selecting the rpm of engine and the number of blades suitable for offshore supply vessel design. In determining the propeller characteristics for the pure supply vessel, the optimum efficiency method will be used and checked with a cavitation criteria. The anchor handling/tug/supply vessel propeller characteristics will be determined by the design for the bollard pull requirement.

The system will then proceed to evaluate the minimum freeboard required by the regulations. Before proceeding with the seakeeping analysis, the user will be asked to input the wave height, wave period and the angle of attack of the waves. The output of the seakeeping analysis will include the natural heave, pitch and roll period as well as the response to irregular waves. The system will then evaluate the manoeuvring characteristics of the vessel which will include the minimum area for the rudders.

The user will then be asked whether to proceed with the economic analysis or not. If the user chooses not to proceed with such analysis, the system will asked whether, he may wish to run the program again. If the user choose to proceed with the economic analysis, he will be asked to input the average wage rate and the cost of steel per ton before the evaluation of the shipbuilding costs is done. Again, the user is guided with the updated values of the average wage rate and steel cost in the United Kingdom. Once the shipbuilding cost is evaluated, the user will be asked whether the vessel is to be chartered or the owner will be operating the vessel. If the vessel will be chartered, the user acting as the charterer may run the operating simulation program to estimate the minimum operating costs. If the vessel is to be operated by the owner, the user acting as the owner will be prompted for the charter rate expected and the discounted rate in percentage. The system will then evaluate the capital charges and the internal rate of return.

For any user who is familiar with the system, facilities are available where he may insert all the input data at the beginning of the program so that the program will evaluate all the output without any disruption. As for user who wishes to know how each value of output is obtained, he may asked the system as to how the value is calculated. Access to any evaluations can be given by referring to the necessary frame.

4. Example Of Execution

The example given in this paper concerns the development of a pure supply vessel design proposal with the owner's requirement of a deadweight of 1200 tonnes and v speed of 13.5 knots. No restriction on the main dimension is given. The stability and minimal freeboard of the vessel must conform with the IMO regulations.

Figures 3 and 4 shows the ship profile and part of the body plan developed from the initial sketch technique. Figure 5 shows the main parameters of the vessel while Fig. 6 gives the stability condition of the vessel when fully loaded. The powering and propulsion results are shown in Fig. 7 and is followed by Fig. 8 and Fig. 9 which gives the seakeeping and manoeuvring characteristics respectively of the vessel to be designed. Finally, the shipbuilding costs of the vessel are given in Fig. 10 which reflects the building costs if the vessel is to be built in United Kingdom.

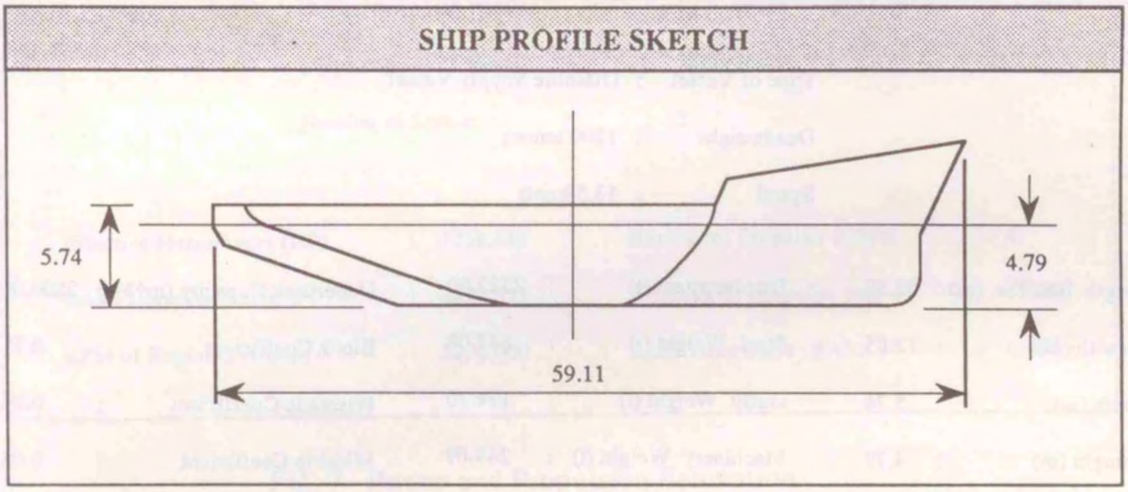

Fig. 3 Profile of the Vessel

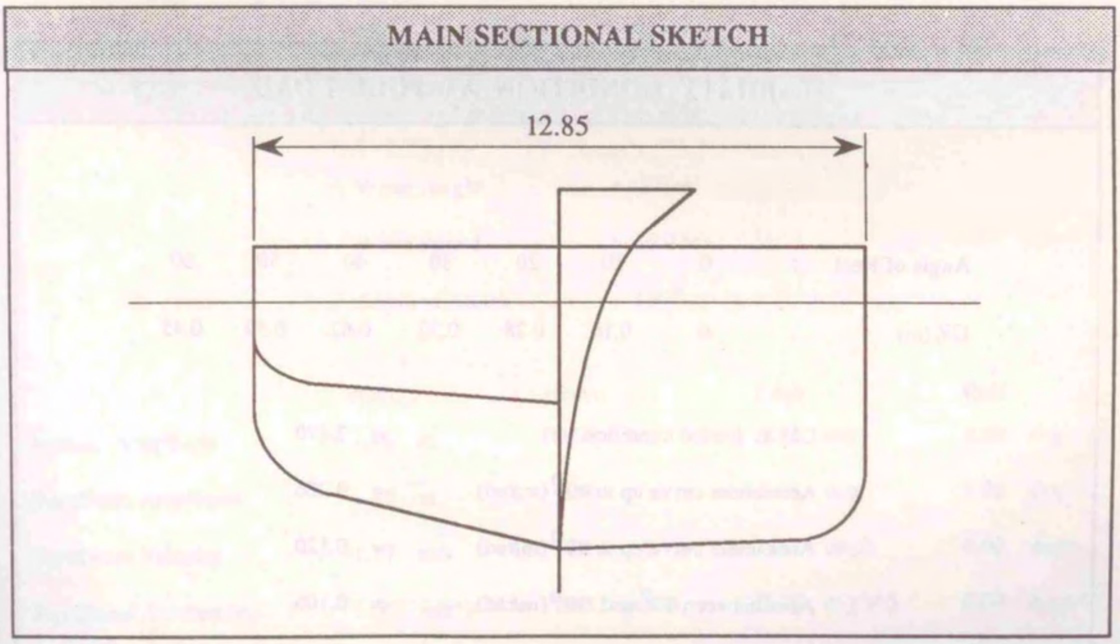

Fig. 4 Main Sections of the Vessel

MAIN PARAMETERS OF VESSEL								
			Type of Vessel	:	Offshore Supply Vessel			
			Deadweight	:	1200 tonnes			
			Speed	:	13.5 knots			
Length Bet. Per. (m)	:	52.58	Displacement (t)	:	2322.00	Underdeck Capacity (m^3)	:	2806.66
Breadth (m)	:	12.85	Steel Weight (t)	:	688.08	Block Coefficient	:	0.71
Depth (m)	:	5.74	Outfit Weight (t)	:	174.70	Prismatic Coefficient	:	0.76
Draught (m)	:	4.79	Machinery Weight (t)	:	249.09	Midship Coefficient	:	0.94
Min. Freeboard (m)	:	0.90	Margin Weight (t)	:	10.13	Waterplane Area Coeff.	:	0.78

Fig. 5 Main Parameters of Vessel

STABILITY CONDITION AT FULL LOAD								
Angle of Heel	:	0	10	20	30	40	50	60
GZ (m)	:	0	0.16	0.28	0.52	0.62	0.59	0.45

GM at loaded condition (m)	=	2.470
Area under curve up to 40^{o} (m/rad)	=	0.226
Area under curve up to 30^{o} (m/rad)	=	0.120
Area between 40^{o} and 30^{o} (m/rad)	=	0.106

Fig. 6 Stability at Full Load Condition

POWERING AND PROPULSION

Design Speed of Vessel	: 13.5 knots
Displacement of Vessel	: 2322 tonnes
Number of Screws	: 2

Effective HorsePower (HP)	: 1758.648	Number of Propeller Blades	: 4
Brake HorsePower (HP)	: 3278.337	Diameter of Propeller (m)	: 1.803
RPM of Engine (rev/min)	: 1200.000	Blade Area Ratio (BAR)	: 0.400

Fig. 7 Power and Propulsion Estimation

SEAKEEPING CHARACTERISTICS

Natural Heave Period	: 5.19 sec.
Natural Pitch Period	: 4.52 sec.
Natural Roll Period	: 6.51 sec.

Results for Seakeeping Characteristics in Irregular Sea Conditions

Wave Height	: 5.0 m
Wave Period	: 10.0 sec.
Angle of Attack	: 180^o

		Wave	Heave	Pitch	Roll
Average Amplitude	:	1.16 m	2.60 m	2.31 deg.	0.00 deg.
Significant Amplitude	:	1.85 m	4.16 m	3.69 deg.	0.00 deg.
Significant Velocity	:	1.17 m/s	3.21 m/s	2.95 deg/s	0.00 deg/s
Significant Acceleration	:	1.00 m/s^2	2.63 m/s^2	2.70 deg/s^2	0.00 deg/s^2

Fig. 8 Seakeeping Characteristics of Vessel

MANOEUVRING ANALYSIS RESULTS

LINEAR MANOEUVRING DERIVATIVES

Non-Dimensional Mass (m')	: 0.02140	Sway Velocity Derivative (Y_r)	: 0.00465
Non-Dimensional Mass Moment (I_{zz})	: 0.00134	Sway Acceleration Derivative (Y_r)	: -0.0022
Sway Velocity Derivative (Y_v)	: -0.03273	Yaw Velocity Derivative (N_r)	: -0.00450
Sway Acceleration Derivative (Y_v)	: -0.01989	Yaw Acceleration Derivative (N_r)	: -0.00081
Yaw Velocity Derivative (N_v)	: -0.01300	Sway Rudder Derivative (Y_δ)	: 0.00513
Yaw Acceleration Derivative (N_v)	: -0.00235	Yaw Rudder Derivative (N_δ)	: -0.00256

TIME CONSTANTS AND GAIN FOR NOMOTO'S EQUATION

Dominant Ship Time Constant (T1')	: 4.54117	1st Order Eqn. Time Constant (T')	: 4.10583
Ship Time Constant (T2')	: 0.37270	Rudder Gain Factor (K')	: 3.21215
Numerator Time Constant (T3')	: 0.80804	Rudder Gain Facotr (K_v')	: 1.48745
Numerator Time Constant (T4')	: 0.27241		

Clarke's Turning Index (P) : 0.39117

Linear Dynamic Stability Criterion (C) : -0.08546

TURNING PREDICTION OPTIONS

Minimum Rudder Area (m^2)	: 5.969	Advance (m)	: 207.777
Steady Turning Diameter (m)	: 269.461	Transfer (m)	: 126.376
Tactical Diameter (m)	: 277.737	Steady Speed in Turn (knot)	: 9.107

Fig. 9 Manoeuvring Characteristics of Vessel

SHIPBUILDING COSTS

Average Wage Rate : £6.05 per hour

Cost of Steel : £300 per tonne

Steel Material Costs (£)	249808.60	Steel Labour Costs (£)	1442229.00
Outfit Material Costs (£)	607275.40	Outfit Labour Costs (£)	1143657.00
Mach. Material Costs (£)	1936165.00	Mach. Labour Costs (£)	1224079.00
Miscellaneous Costs (£)	336801.10		

Total Shipbuilding Costs (£) : 6940015.10

Fig. 10 Shipbuilding Costs of the Vessel

5. Conclusion

This paper has been concerned with presenting an overall knowledge-based approach to handling numerical relationships in the preliminary design of offshore supply vessels. A number of features of the system were not presented since the aim was simply to convey the flavour of the system and to illustrate the overall concept involved. However, it is worth emphasising a number of points with respect to the usage of expert system shell in preliminary ship design :

a. the user of the system has a large degree of control over the process of the design especially in terms of the rate of progress,

b. the more the user is involved in the design process, the more he understands the design methodology,

c. the system uses built-in expertise to look for suitable relationships, thus only a part of the total model definition is active at one time.

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Nomenclature

B	breadth
BAR	blade area ratio
BHP	brake horsepower
BM	height of metacentre above the centre of buoyancy
C_B	block coefficient
C_{IT}	transverse inertia coefficient
C_R	camber
C_W	coefficient of waterplane area
D	depth
D	diameter of propeller (powering)
D_{ER}	height of engine room
D_{TT}	height of double bottom
EHP	effective horsepower
GM	metacentric height
KB	height of centre of buoyancy above keel
KG	height of centre of gravity above keel
L	length
L_P	length between perpendicular
P	propeller pitch
rpm	revolutions per minute
T	draught
R_F	frictional resistance
R_{APP}	appendage resistance
R_W	wavemaking resistance
R_{TR}	transom resistance
R_A	model-ship correlation resistance
S_A	sheer aft
S_F	sheer forward
SHP	shaft horsepower
V	velocity
W_M	machinery weight
W_O	outfit weight
W_S	steel weight
∇_{DB}	volume of double bottom
∇_{ER}	volume of engine room
∇_H	volume of hull
∇_P	volume of peaks

Appendix

A.1 Weight Estimation

$$W_S = KE^{1.36}\ \{1 + 0.5(C_{B'} - 0.70)\}$$

where

$$E = L(B + T) + 0.85L(D - T), \qquad K = 0.041 \text{ to } 0.051 \text{ for } 800 < E < 1300,$$

and $$C_{B'} = C_B + (1 - C_B)\,\frac{(0.8D - T)}{3T}$$

$$W_O = 0.23LB$$

$$W_M = 0.16(SHP)^{0.89}$$

A.2 Capacity Estimation

$$\nabla_H = 1.050 \times LB\left[D + \frac{S_F + S_A}{6} + \frac{2C_R}{3}\right]C_B$$

$$\nabla_P = 0.370 \times L_P B\left[D + \frac{S_F + S_A}{2}\right]C_B$$

$$\nabla_{DB} = 0.975 \times (L - L_P)BD_{TT}C_B$$

$$\nabla_{ER} = 0.850 \times L_{ER}B(D_{ER} - D_{TT})C_B$$

A.3 Stability Evaluation

$$GM = BM + KB - KG$$

where

$$BM = \frac{C_{IT}}{C_B} \cdot \frac{B^2}{T} \qquad \text{where} \quad C_{IT} = 0.06C_W$$

$$KB = T\left[\frac{5}{6} - \frac{C_B}{3C_W}\right] \qquad \text{and} \qquad KG = 0.8D$$

with $C_W = 1.28C_B$ for C_B between 0.60 to 0.75

A.4 Powering and Propulsion Estimation

The total resistance of the offshore supply vessel is subdivided into various components such as [21]:

$$R_T = R_F(1+k) + R_{APP} + R_W + R_{TR} + R_A$$

Once the total resistance is known, the effective horsepower of the offshore supply vessel can be calculated from

$$EHP = (R_T \times V \times 1.36) \times k2$$

where k2 is the factor incorporating wind resistance.

The propeller design is based on the 'Optimum Efficiency Equations of the NSMB Propeller Series' [20], in which the Wageningen B-Series propeller were equationed using regression analysis. For predetermined values of blade area ratio and Bp,the optimum efficiency equation is

$$\begin{aligned}\delta, P/D, \eta_{opt} = {} & A_0 + A_1(\ln B_p) + A_2(\ln B_p)^2 + A_3(\ln B_p)^3 + \\ & A_4(BAR) + A_5(BAR)^2 + A_6(BAR)^3 + A_7(\ln B_p)(BAR) + \\ & A_8(\ln B_p)(BAR)^2 + A_9(\ln B_p)^2(BAR)\end{aligned}$$

where A0, A1, ...A9 are the regression coefficients given by Sabit [20] and BAR is blade area ratio of propeller.

As for the anchor handling/tug/supply vessel, the installed power and propulsion is determined using the bollard-pull design estimation [22].

A.5 Seakeeping and Manoeuvring Characteristics

The seakeeping characteristics of the vessel are calculated using two dimensional strip theory [23], [24] while the manoeuvring characteristics are calculated based on the linear theory developed by Clarke et al [25].