COMPUTER AIDED PROPULSION SYSTEM DESIGN

J. Klein Woud and C.C.P.J.M. Landa

Faculty of Mechanical Engineering and Maritime Technology, Delft University of Technology, The Netherlands

F.J.P.H.G. Verbaas
Marin, Wageningen, The Netherlands

1. INTRODUCTION

For the conceptual design of a ship's machinery plant there existed, up till recently, almost not any supportive computer program. For the detailed design of machinery systems there are of course a large number of analysis (calculation) programs and computer aided drafting systems. Examples of analysis programs are:

- pipe flow and head loss calculations
- shafting torsional, axial and whirling-vibration calculations
- design calculations for flexible mounting systems

Computer aided drafting systems are nowadays frequently used for:

- two dimensional piping diagrams
- three dimensional machinery arrangement models
- piping arrangement models complete with derived isometric sketches and bills of material for the production.

This paper gives a short description of a conceptual design system for propulsion and auxiliary systems: PROSEL.

PROSEL (propulsion installation selection) aims to support the designer with the selection of the most optimal propulsion installation and support systems for a given set of design demands.

The machinery installation of a modern ship comprises several systems, e.g. the propulsion plant, the electric power supply system, the heating system, the fuel oil, lubrication oil and cooling systems. The need for economy, both in building and operational costs, urges the naval architect to adopt an integrated design for the total installation, e.g. to use wasteheat recovery and powertakeoffs from the main propulsion system for electricity generation. This integration consequently means, that an integrated design and evaluation tool is needed. Different solutions (twin or single engine, power take of generators or separate ones, etc.) can be defined and analyzed. The results for different layouts can be compared.

The choice of the main machinery installation strongly influences the other system's design. Modern ships must be designed to perform well in different operational conditions. There can be different conditions on the hydrodynamic side, such as the weather state, towing load, operational speeds, and ship draft. On the other hand there can be different conditions concerning ship service requirements, e.g. the required electrical power, the heat demand, and mechanical power. In most cases one situation can be addressed as the' design condition. The performance of the ship in other conditions must also be analyzed. The interaction between the propulsion installation systems, considering design as well as off-design conditions, expresses the need for a complete CAD system offering an integrated design.

Design of PROSEL started in october 1988 at the Delft University of Technology in cooperation with Marin Wageningen. Also involved in the project is the dutch shipyard YsselVliet-Combinatie B.V. The PROSEL project is sponsored by the dutch organization of maritime research (CMO). The program will be available as a part of the MARDES ship design system, as well as, as a stand alone program. In this paper the main PROSEL modules for the generation of alternative propulsion systems and for the evaluation are described. The modules for design of ship's service systems and auxiliary systems are partly available and are being developed further.

For the development of PROSEL the following premises were made:

- PROSEL must offer an integrated design environment for the propulsion system Propulsion arrangement(engines, gearboxes, thrusters etc.), wasteheat-utilisation system (steam, thermal oil), integrated electric power supply and auxiliary systems. When designing one of these systems the data description of other system's components should be directly available.
- The user will be completely free in choosing his own installation layout. This means that there are no limitations to an installation configuration, as far as the components allow.
- The program will be as hardware independent as possible. Initially PROSEL will be available on an AT type personal computer with DOS operating system and on workstations with UNIX operating system.
- The user of the program is assumed to be a member of the design department of a shipyard, a shipping company or a design agent. It is expected that he has a sound judgement in composing ship propulsion installations.
- The main objective of PROSEL is to enable a fast and efficient evaluation of a large number of alternative system designs, which may lead to a technically and economically most attractive result.

2. PROSEL CHARACTERISTICS

PROSEL will consist of a number of modules:

- Propulsion system design, with which it will be possible to define a system layout and to generate a number of alternative plants, complying with this layout. Next the alternatives may be evaluated both in a technical an economical sense. Finally all relevant characteristics of the selected plant can be calculated.
- Waste-heat-utilisation for calculation of the technical and economical possibilities to use the waste-heat of exhaust gas and/or other media, for power generation and/or heating purposes
- Electric power supply system, enabling to investigate the characteristics of diesel generators, shaft generators, turbo generators and combinations of those.
- Auxiliary system design, enabling the design and evaluation of alternatives and dimensioning of cooling, lubricating and fuel oil systems.

An important aspect of PROSEL is it's fast multi alternative generation. A pre-design always aims to define a system sufficiently complete and as optimal as possible within the designer's demands. However, because only a short period of time is available, the designer frequently can make only a single or a few designs. The result will always be a compromise between time, costs and quality. PROSEL intends to shift this compromise to a higher quality, by offering the possibility to the user to generate and evaluate many alternative installation designs in a short period of time. By means of the evaluation tools the best choice, according to the user's demands, can be made from these alternatives.

Another PROSEL quality is it's integrated system design. In a propulsion installation many interrelations exist between the mentioned systems. A few examples of the interrelations are:

- the exhaust gases of a diesel engine can be used to generate steam, for a turbo generator, affecting the design of the power supply system
- the diesel engine scavenge air can be used to preheat the feedwater
- the diesel engine determines the layout and capacities of pumps, coolers and other equipment of the auxiliary systems

The connections between the different systems are represented by the components that are shared; e.g. the engine is a component in the heating system, as a heat source, and in the propulsion system as a source of mechanical energy. The amount of heat in the exhaust gases is an input value for the design of the heating system. Integration of the design of the separate systems is a.o. achieved by giving access to other system's data descriptions. In this way the required system design input data can be collected from the same database. When certain data are not available the program will ask the user or will suggest default settings.

3. PROPULSION SYSTEM DESIGN MODULE

The principle characteristics of PROSEL will be explained and illustrated for the propulsion system design. An example of the design process for a simple direct driven installation (see figure 1) is given. PROSEL is capable to generate and evaluate much more complicated plants, consisting of different thrusters in combination with multiple prime movers, through transmissions.

The PROSEL design sequence is split up into 5 parts (see figure 2):

1 specification of design demands
2 composition of installation alternatives
3 selection of interesting alternatives
4 detailed evaluation
5 final selection

These 5 parts can be run independently, of course only when the appropriate input is available, e.g. a detailed evaluation can only take place when an installation has been composed.

3.1. Specification of Design Demands

The design demands are the framework in which the installation design will take place. The user can build this framework according to his specific ideas. The design demands are split up into 3 parts:

- specification of the installation layout'
- specification of the preferences concerning the components
- definition of the operational condition and ship data

3.1.1. The Installation Layout

The layout of an installation is defined by means of the components and the links between these components. For a propulsion system only 4 types of components are being considered:

- PRIME MOVERS
diesel engines
(gasturbines, steamturbines, others);
- TRANSMISSIONS
gearboxes, shafts, couplings
(electrical transmission);
- THRUSTERS
fixed and controllable pitch screw type propellers
(ducted propellers, waterjets);
- PTO's, power-take-offs
generators, pumps, others;

The implemented components are shown, the items between brackets are being planned but are not yet implemented. When specifying the components, they can be given a name by the user for convenience in recognizing them. Such a name however has no significance for the program algorithm. The order in which the components are defined is free. The components must be linked together, completing the installation layout specification. The example is shown in sheet 1.

3.1.2. Component Preferences

For every component the user can define his preferences. For prime movers (sheet 2) it is needed to specify the type (diesel, gasturbine...). When desirable the user can also prescribe the make (SWD, Sulzer...), the series, the number of cylinders, the operating principle (2/4 stroke), minimum and maximum allowed engine margin (for explanation see paragraph 5) and preferred engine margin. When the minimum and maximum allowed engine margin are not given by the user then default values of 0.85 and 0.95 will be proposed.

For the transmission it is possible to

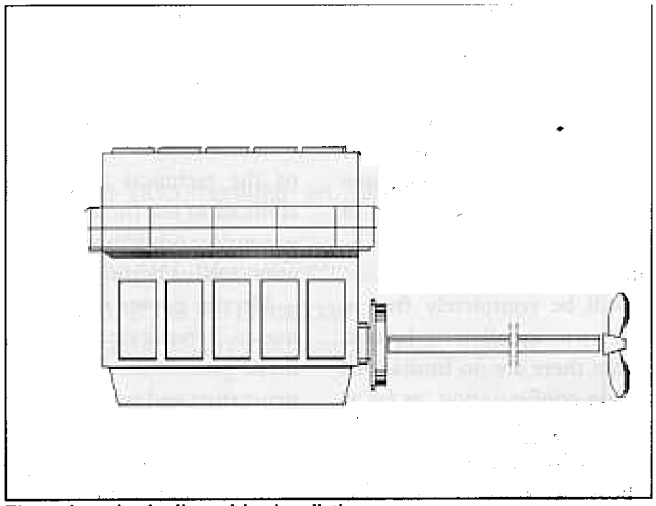

Figure 1: a simple direct drive installation

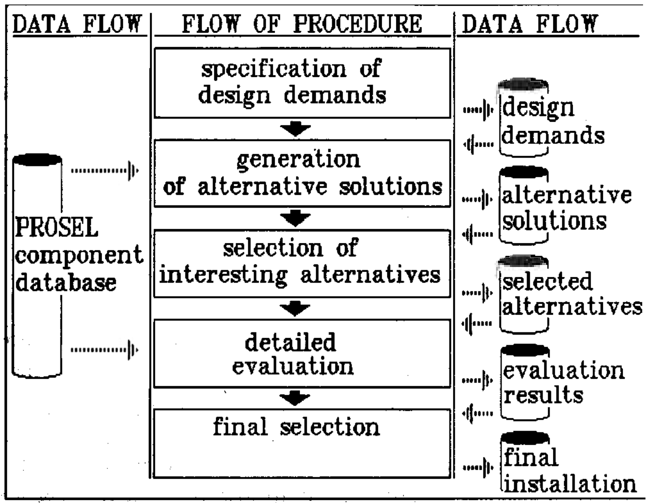

Figure 2: PROSEL design sequence

Component specification:

component 1
- *type : prime mover*
- *name : my diesel engine*

component 2
- *type : transmission*
- *name : my shaft*

component 3
- *type : thruster*
- *name : my thruster*

Link specification:

links between:

component 1	*component 2*
component 2	*component 3*

Sheet - installation layout

Prime mover preferences:

component 1
- *type : layout field diesel*
- *make : Sulzer*
- *series : RTA62*
- *# cyl. : no preference*
- *2/4 stroke : 2*
- *engine margin*
  - *minimum : 0.88*
  - *maximum : 0.93*
  - *preferred : 0.90*

Sheet 2 - prime mover preferences

Transmission preferences:

component 2

- *type : shaft*
- *make : no preference*
- *series : no preference*

normalized rpm values:
- *link to component 1 : 100*
- *link to component 2 : 100*

Sheet 3 - transmission preferences

Thruster preferences

- *type : fixed pitch propeller*
- *required thrust : -*
- *percentage of total thrust : 100 %*
- *number of blades : 4*
- *min. diameter : 4.50 m*
- *max. diameter : 8.00 m*
- *min. rpm : 70 1/min*
- *max. rpm : 130 1/min*
- *min. pitch/diameter : 0.6*
- *max. pitch/diameter : 1.4*
- *propeller clearance with the plane keel : 0.5 m*

Sheet 4 - thruster preferences

Ship data

- *ship identity : Atalante*
- *length : 180 m*
- *breadth : 25 m*
- *depth : 15 m*
- *design draft : 10 m*
- *prismatic coefficient : 0.70*
- *midship coefficient : 0.96*
- *resistance data*
  - *curve 1 : .....(up to 20 points)*
  - *curve 2 : .....(up to 20 points)*
  - *curve 3 : .....(up to 20 points)*
  - *curve 4 : .....(up to 20 points)*

Sheet 5 - ship data

Operational condition

- *ship speed : 13 knots*
- *draft : 10 m*
- *active components*
  - *my diesel engine : active*
  - *my shaft : active*
  - *my thruster : active*
- *total resistance curve =*
  - *1.25 x curve 1*
  - *+ 0.00 x curve 2*
  - *+ 0.00 x curve 3*
  - *+ 0.00 x curve 4*
- *preset power values : none*
- *preset rpm values : none*

Sheet 6 - operational condition

specify the type, the make and the series (sheet 3). For completely describing a transmission it is necessary to specify the reduction ratios between the ingoing and outgoing link(s). This is done by means of normalized rpm values. These are defining in fact the rpm ratios between the different links. When the user wants to select his own transmission without PROSEL influence, these normalized rpm values have to be specified. Otherwise they will result from automatic PROSEL action. Shafts and couplings have two links with normalized rpm values, that are always equal. Couplings have also two links, where the normalized rpm values can be chosen such that as an example also a hydraulic coupling can be described.

When the component is a thruster, it is necessary to indicate the thruster type. Further it is possible to specify the required thrust (if not specified it will be calculated from the ship's resistance curve and the design speed), the percentage of total thrust to be delivered by this thruster (default is an equal distribution among thrusters), the minimum and maximum allowed diameter, the minimum and maximum allowed rpm, the number of blades, the minimum and maximum allowed pitch/diameter ratio and the propeller clearance with the keel. (sheet 4).

3.1.3. Ship data and operational conditions

Finally the ship data (sheet 5) and operational conditions (sheet 6) have to be defined by the user. The ship identity, length, breadth, depth, design draft, prismatic and midship coefficient and the ship's resistance data have to be specified. The resistance data are given as a function of the ship speed, represented by 4 different curves (up to 20 points) for e.g. 4 loading conditions. For specifying the operational condition the user must specify the speed, draft, the components which are active, the actual resistance curve (built up from the 4 curves that were given with the ship data), incorporating the sea margin (for explanation see paragraph 5), and preset values for power and/or rpm.

3.2. Composition of Installation Alternatives

After having specified the design demands, PROSEL will start composing the installation. For complex propulsion systems it is possible that the user specified too less design demands or specified conflicting demands. The installation composition submodule therefore has been given such a structure (figure 3) that these situations are recognized and the user asked to correct his input. Depending on the component preferences it is possible that for a certain propulsion layout a (large) number of different components are acceptable. For a certain propulsion plant for instance 4 different diesel engines may be acceptable and for the gearbox transmission there may be 3 alternatives. This will lead then to 12 alternative system designs, which all will be generated by PROSEL. During installation composition 3 basic processes are performed:

– determination of link variable values and the distribution of these over the complete system
– component selection from the PROSEL component database
– combining alternative components to installation alternatives

These 3 processes are dealt with in detail in the following paragraphs.

3.2.1. Link Variable Value Determination and Distribution

The link variables are rpm and power in case of the propulsion system. When the values of these variables are known at one specific link, it is possible to distribute them over the installation to the other links.

All components have an internal description, that can be seen as a transfer function. This function translates the power and rpm values from link to link; the transfer function for rpm values is the reduction ratio, the transfer function for power values can be a power distribution and/or an efficiency.

The transfer function is not always known directly from the start of the program. It can result from database choices, e.g. dieselengine and propeller choice de-

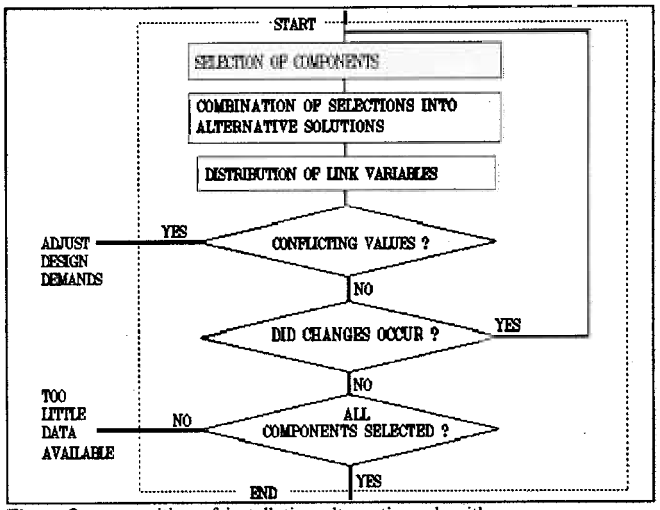

Figure 3: composition of installation alternatives algorithm

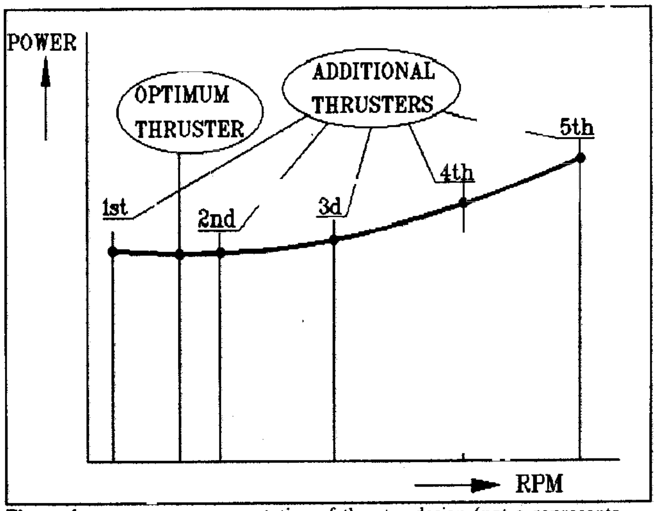

Figure 4: power-rpm representation of thruster design (not a representation of the example installation)

termining the reduction ratio of a gearbox.
Therefore the program will alternate between component selection and link variable distribution until no more changes occur. When not sufficient data were supplied by the user then execution will pause and additional data will be asked for.

3.2.2. Component Selection

For every component that is not yet selected a selection procedure will be followed. The selection procedures are depending on the type of component.

• The Component Database

Components are selected from component databases. For prime movers the database consists of a large number of entries, comprising different types of diesel engines.
For transmissions several catalogue gearboxes are present.
The thruster database involves a calculation module for Wageningen B-Series propellers. Depending on the available data the propeller dimensions and characteristics will be calculated.

• Thruster Selection

When a thruster is not yet selected a new thruster will be designed. The thruster preferences are read and the thrust to be delivered is determined by means of the ship speed, resistance and thrust deduction. The design will result in an optimum thruster (sheet 7). It is described, in the case of a Wageningen Bseries propeller, with it's diameter, pitch/diameter ratio, number of blades, blade area ratio, open water efficiency, Kt, Kq and J relations, shaft rpm and shaft power. A cavitation criterion is incorporated.
Besides this optimum thruster within the design demands, five other thruster descriptions are generated. These are thrus-

Optimum thruster design

propeller

- *type*	:	*Wageningen B*
- *diameter*	:	*8.00 m*
- *pitch/diameter*	:	*0.87*
- *blade area ratio*	:	*0.45*
- *efficiency*	:	*0.62*
- *rpm*	:	*70 1/min*

Additional thruster designs available for rpm 70 (= optimum), 85, 100, 115 and 130

Sheet 7 - thruster design results

ter designs for 5 specific design rpm values, resulting from the rpm range specified by the user. The reason for covering an rpm design range is as follows:
Imagine that there exists a fixed prescribed rpm ratio between thruster and prime mover, e.g. in a direct drive installation. After thruster design a choice is made for the prime mover from the database. The chosen engine has a specific rpm for it's design operating point. This prime mover rpm determines the thruster rpm. Because the chosen engine's rpm will seldomly comply with the optimum thruster's rpm, a different thruster than the optimum one should be selected. This thruster can be interpolated from the five thruster descriptions, that represent the rpm range.
The thruster range has the shape of a power-rpm relation represented by five points (see figure 4). The power to be delivered to the thruster can be determined in 2 ways:

– as a direct result from thruster design, in case the sea margin was added to the trial thrust before starting thruster selection (the ship owner's approach: propeller designed for service conditions)
– as the power resulting from thruster design, raised with the sea margin (the ship builder's approach: propeller designed for trial condition)

The user can make his own choice before the thruster design takes place.

• Prime Mover Selection

When a prime mover must be selected, it depends on the installation layout and the rpm and power values, that are available, which selection procedure out of 3 will be followed, or if no selection can take place yet. First it will be checked whether the power at all the prime mover's links is known. If not, then no selection can take place. The next component will be considered.
If the power to be delivered for the design operational condition is known, then it will be checked whether also the rpm is known. If not, then prime mover selection procedure 1 will be followed. This means selection with free prime mover speed. This is the case when a reduction gear is available between propeller and prime mover.
When the rpm is known and there exists a fixed reduction ratio between thruster and prime mover, selection procedure 2 will be executed. This involves an optimum thruster prime mover adjustment.
If power and rpm at the prime mover links are known, there is a fixed reduction ratio and selection procedure 2 can not be followed, then selection procedure 3 will be adopted. This will be a very rare case, when 2 or more engines are connected via a fixed ratio gearing to the same thruster.

Selection procedure 1: selection with only power prescribed; prime mover speed is free

The designer has specified the minimum and maximum allowed engine margins for the prime mover. Also the preferred engine margin is given, or can be interpolated. The power for csr (continuous

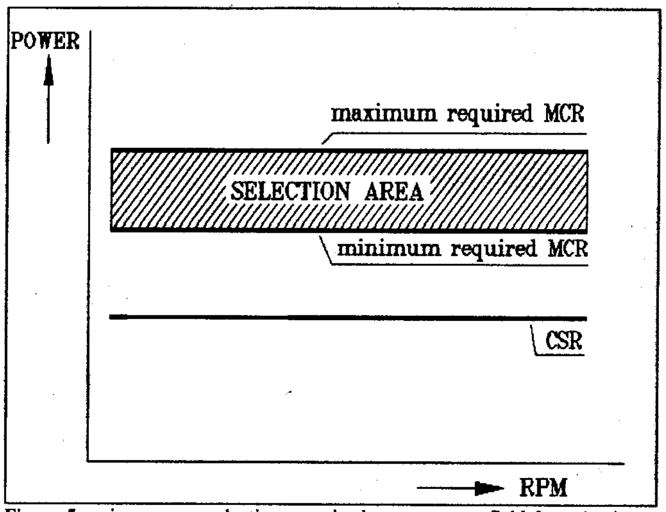

Figure 5: prime mover selection area in the power-rpm field for selection procedure 1

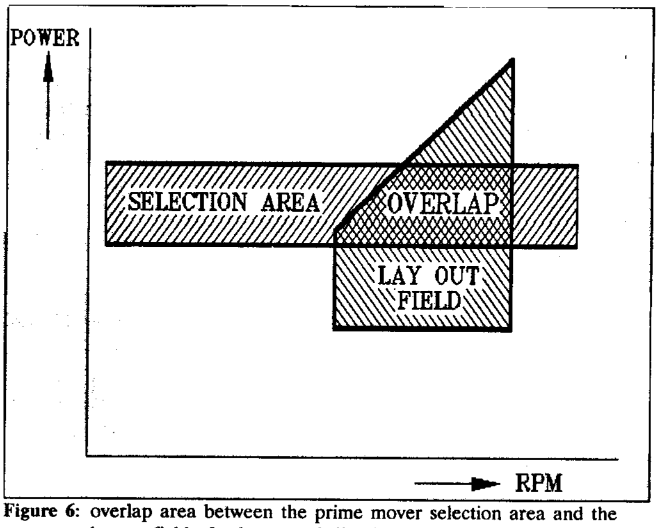

Figure 6: overlap area between the prime mover selection area and the lay-out-field of a low speed diesel engine

service rating, see paragraph 5), at the prime mover link(s), has to be converted to an mcr (maximum continuous rating, see paragraph 5) power for the database selection. The minimum required mcr power is obtained by dividing the link csr power by the maximum engine margin; the maximum mcr power is obtained similarly. In this way a prime mover selection area is created with the shape of a power band (see figure 5). All database engines with an mcr point within this band are selected.

When lay-out-field, LOF, engines (in general 2-stroke crosshead low speed dieselengines; see for explanation of LOF paragraph 5) are considered a complication is added to the selection. A LOF engine can be selected when an overlap exists between it's layoutfield and the prime mover selection area. This is illustrated in figure 6.
A specific mcr point can then be chosen, according to different criteria, that have to be specified by the user, e.g. minimum fuel oil consumption or installation weight.

If a point in the overlap area meets the preferred engine margin, then this point is selected; otherwise the point with an engine margin, that is closest to the preferred margin is chosen.

Selection procedure 2: selection with a fixed reduction ratio between thruster and prime mover
When there exists a fixed reduction ratio between prime mover and thruster, there will exist an rpm-power relation, resulting from additional thruster designs. Instead of a straight band in the selection procedure 1, a curved band will now be generated as the prime mover selection area (figure 7 shows the results for example 1).
The lower and upper limits of this band can be calculated by means of the maximum and minimum engine margins assuming a third degree propeller curve.
Every database engine with an mcr point, within this curved selection area, will be selected. For lay-out-field engines, selection is possible, when an overlap exists between the selection area and the lay-out-field. As in selection procedure 1 the mcr point will be chosen according to user's criterion.

Selection procedure 3: selection on the optimum propeller curve
When procedure 1 and 2 couldn't be applied and both the link rpm and power values at the link(s) of the prime mover are known, then procedure 3 should be followed. Assuming a third degree propeller curve the maximum and minimum required mcr power and rpm can be determined. Thus the part of the propeller curve, where an engine's mcr point should be part of, is indicated. When an engine's mcr point is lying within the rpm limits, but it's power is lying above the propeller curve, then it should also be selected. This is because it can be downrated to the power on the propeller curve (see figure 8).

- Transmission Selection

When the power and rpm at all links of an unselected transmission are known, then a selection from the database can be executed. This selection can be applied to couplings, shafts and catalogue gearbox-

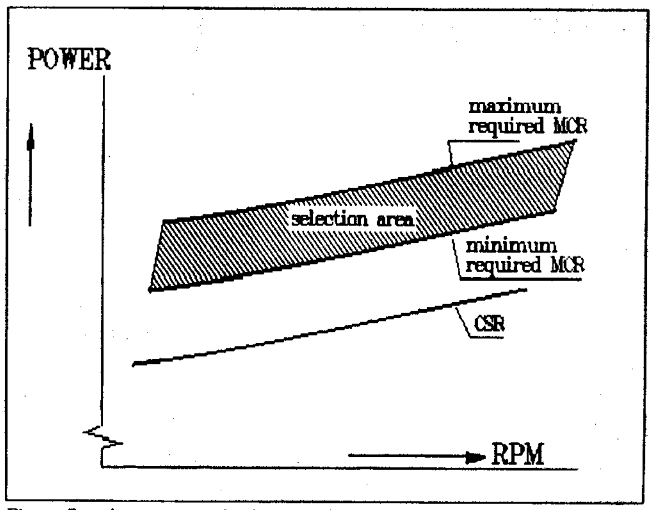

Figure 7: prime mover selection area in the power-rpm diagram for selection procedure 2

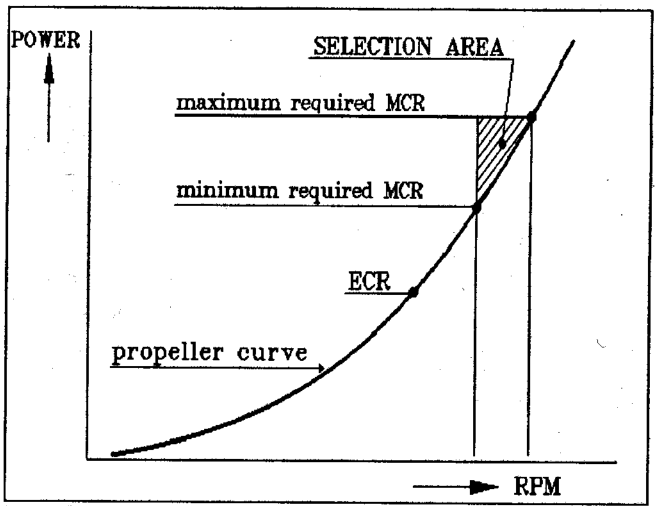

Figure 8: prime mover selection area in the power-rpm diagram for selection procedure 3

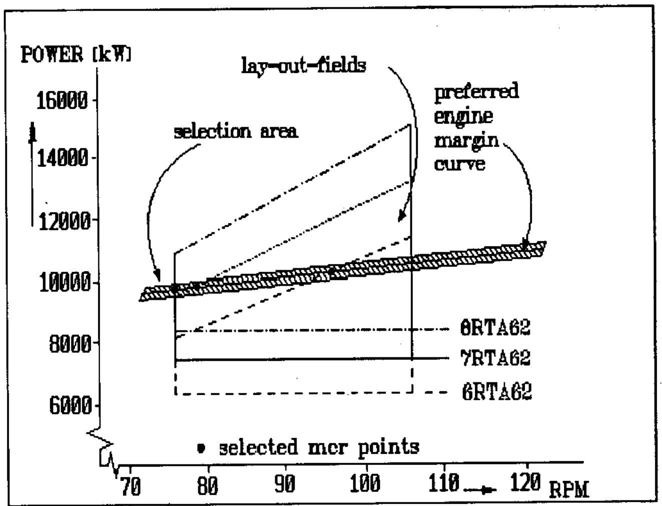

Figure 9: selection of mcr point for selected prime movers in example 1

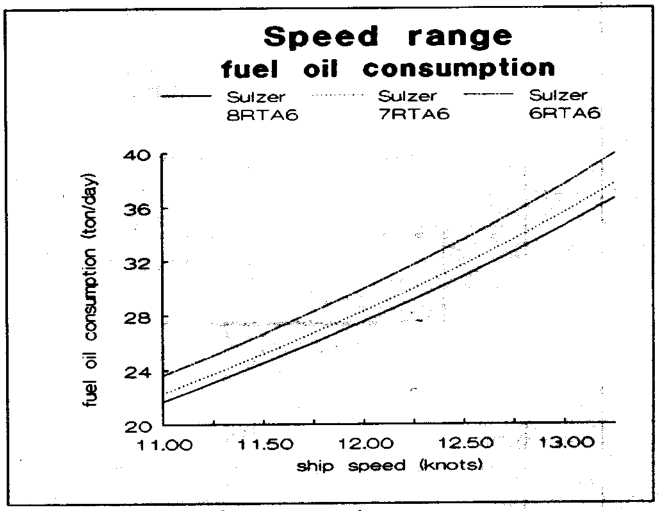

Figure 10: fuel consumption over a speed range

es. Catalogue gearboxes have one or two ingoing links and one outgoing link. In this number of links power-take-offs are not included. When a gearbox doesn't meet the catalogue, type then it is assumed to be custom made. It will be handled as if it were selected.
Shafts will be calculated according to the rules of a classification society.
The power efficiency of a transmission must be entered by the user. Suggestions are made by the program for couplings, shafting systems and gearboxes. The user can accept the suggestion or enter his own value.

- Power-take-off Selection

PTO's (power-take-offs) are not selected by PROSEL. They represent power extracted from the propulsion system.

3.2.3. Combining Component Choices Into Installation Alternatives

The choices, that are made for the components have to be combined into installation alternatives. Sheet 8 shows for example 1 that 3 suitable+ engines have been selected. Figure 9 shows the selection area and the lay-out-fields of the 3 selected engines. In this case the engine/propeller matching has been such that minimum fuel consumption resulted. As can be seen in sheet 9 the most fuel efficient propeller-prime mover combinations are different for the 3 selected engines. Consequently the 3 engine selections have led to 3 alternative propulsion systems. It will be clear that the 6cylinder solution incorporates the plant with the lowest first cost. The 7 and 8cylinder solutions might be interesting because of their 6.0% and 9.6% lower fuel consumption at csr condition.

Prime mover alternatives

* *SULZER RTA62 6 cylinders*			
mcr			
- *rpm*	:	96.3	min⁻¹
- *power*	:	10350	kW
csr			
- *rpm*	:	100.9	min⁻¹
- *power*	:	10111	kW
- *fuel oil consumption*	:	38.1	ton/d
engine margin	:	0.90	
weight	:	410	ton
length	:	8.66	m
* *SULZER RTA62 7 cylinders*			
mcr			
- *rpm*	:	78.6	min⁻¹
- *power*	:	9847	kW
csr			
- *rpm*	:	81.64	min⁻¹
- *power*	:	9539	kW
- *fuel oil consumption*	:	36.1	ton/d
engine margin	:	0.90	
weight	:	460	ton
length	:	9.76	m
* *SULZER RTA62 8 cylinders*			
mcr			
- *rpm*	:	76.0	min⁻¹
- *power*	:	9779	kW
csr			
- *rpm*		73.4	min⁻¹
- *power*		9318	kW
- *fuel oil consumption*		35.1	ton/d
engine margin		0.90	
weight		510	ton
length		10.86	m

Sheet 8 - prime mover design results

Thruster design results for selected prime movers

propeller for Sulzer 6RTA62:			
- *type*	:	Wageningen B	
- *diameter*	:	7.24	m
- *pitch/diameter*	:	0.73	
- *blade area ratio*	:	0.50	
- *efficiency*	:	0.58	
- *weight*	:	14.5	t
- *rpm*	:	93.0	1/min
propeller for Sulzer 7RTA62:			
- *type*	:	Wageningen B	
- *diameter*	:	7.83	m
- *pitch/diameter*	:	0.82	
- *blade area ratio*	:	0.46	
- *efficiency*	:	0.61	
- *weight*	:	16.8	t
- *rpm*	:	75.9	1/min
propeller for Sulzer 8RTA62:			
- *type*	:	Wageningen B	
- *diameter*	:	7.91	m
- *pitch/diameter*	:	0.84	
- *blade area ratio*	:	0.45	
- *efficiency*	:	0.61	
- *weight*	:	17.2	t
- *rpm*	:	73.4	1/min

Sheet 9 -thruster design results for selected prime movers

3.3. Selection of Interesting Alternatives

When the installation composition did result in a number of installation alternatives, then a choice can be made from these alternatives. At this stage of installation design, there is not enough data available for final selection, because a thorough investigation of the alternative's properties has not been executed yet. However, it is possible to select the most promising solutions for further evaluation. From the list with installations alternatives the user can pick out a few. He can do this by means of a merit function. For each installation a number of important characteristics can be considered, i.e. weight, first cost, fuel oil consumption and maximum attainable ship speed. Each of these characteristics can be coupled to a weight factor, and a ranking can be determined. The installations with the highest ranking are the most interesting ones. The user can make his own selection for the next program part, the evaluation.

3.4. Evaluation

An installation description resulting from the PROSEL composition part represents a chain of components, that fit together and comply with the design demands. Only a few general characteristics of the installation are known at this stage. To obtain more detailed information about the installations behaviour and properties, a more detailed evaluation must be performed. This evaluation can incorporate more detailed information for the design condition and the behaviour at other operating conditions. Both economical and technical data can be generated.

Every operational condition can be evaluated in three different ways:

– A single operating point can be defined for which all installation characteristics will be calculated.

– A given operating condition can be evaluated for a range of ship's speeds. All installation characteristics now become available as a function of speed.

– A sequence of different operating conditions, called an operating profile, can be defined together with the time being spent in each condition. Next to the information which can be calculated for a single operating point of a speed range, now also the required bunker capacity will be calculated, and the operational range.

• Single operating point

When evaluating the installation for a single operating point the user may want to obtain more information about the design operating condition but he can also choose to examine the installation's behaviour at a situation that differs from the design operating condition. The operational conditions can be changed on the hydrodynamic side as well as on the ship service side. Examples of hydrodynamic side offdesign conditions are:

– sailing at a reduced or higher speed
– sailing with different weather conditions
– sailing with an increased hull resistance
– sailing at a different draft

Ship service off-design condition examples are:

– setting the prime mover rpm to a different value
– switching off an engine in a twin engine installation
– changing the pto electrical power demand
– sailing with a trailing propeller

The user can specify any of these situations or a combination of them. The results of the calculation are:

– general installation data '
– the power and rpm values at all links between the installation's components, the ship speed
– efficiencies '
– prime mover, mechanical and propulsive
– component data

fuel and lubricating oil consumption, flows, heat rates and temperatures of auxiliary systems, information about loading condition, propeller cavitation indication etc.

• Speed range

In this evaluation mode the user will be offered the possibility to evaluate the installation's behaviour over a speed range. All the installation's characteristics, as discussed with the single operating point evaluation, will be available as a function of the ship speed. The specified speed range will therefore be divided into 10 steps. For each of these values an evaluation will take place. The results will be stored in a matrix, each row of the matrix representing a certain installation characteristic. The information from this matrix can be plotted in a 2 dimensional graph. The user can choose freely which data to be displayed on the horizontal and vertical axes. Data from different installation alternatives can be displayed in the same graph, to offer the user the possibility to make a good comparison. An example for fuel oil consumption is given in figure 10. Another example might be the operational range as a function of the ship's speed.

• Operational profile

In order to evaluate a certain route for the ship, an operating profile can be defined. A sequence of operational conditions can be specified by the user. Each condition, as defined in the single operating point evaluation, and the time that is being spent in each condition. The user can e.g. specify to sail 10 days on design draft with design speed, subsequently 2 days in the harbour, and finally 13 days in ballast condition with reduced draft and speed. PROSEL will calculate the total fuel and lubricating oil consumption or, given a certain bunker capacity, the operational range.

3.5. Final Selection

The results of the evaluation are stored for each alternative installation. This will enable to present the results of alternatives. Depending on the outcome of this comparison a final choice according to the user's desires can be made.

3.6. Interaction With Other Systems

When a propulsion system has been composed then the input data for the waste-heat-utilization system are known, e.g. eaust gas flows and temperatures. Also flows, heat rates and temperatures of the auxiliary systems have been determined. These can be used now for the design of these systems. At this moment a module for cooling system design is being developed. With this module it will be possible to define alternative layouts of the cooling systems for a given propulsion plant. These alternative systems can be dimensioned (pumps, coolers, piping) and the relevant characteristics of the system can be calculated. Both in design and offdesign conditions network flow and thermal behaviour can be investigated.

4. CONCLUSION

With PROSEL it is possible now to generate a large number of alternative propulsion systems for a given set of requirements. The evaluation tools enable to select the most optimal plant, from a technical and economical viewpoint. The modules for waste-heat-utilization, electric power supply and auxiliary systems will enable in the future an integrated system design and a thorough evaluation of system alternatives.

5. TERMINOLOGY

Continuous service rating
the powerrpm point for which the engine is chosen to operate continuously during service condition

Engine margin
the ratio between csr power and mcr power of a prime mover, specifying the design operation load

Lay-out-field
a field in the power-rpm diagram that represents the possible mcr point range. This field is found with low speed 2 stroke diesel engines.

LOF
Lay-out-field

Maximum continuous rating
the maximum power-rpm point in the rpm-power field for which a diesel engine is designed to operate continuously

Sea margin
the ratio between power to be delivered in service condition and power to be delivered during trial condition
or
the ratio between ship's resistance in service condition and that resistance in trial condition

REFERENCES

[1] E. Faber, Propulsion units directly powered by diesel engine (Sulzer publication)

[2] F. Prohaska, Matching & tuning of ship and main engine, 1986 (Sulzer publication)

[3] J. Klein Woud, Maritieme Werktuigkunde I (Delft, 1988)

[4] A.C.W.J. Oomen and P. van Oossanen, Development of a new computeraided system for the conceptual design (Marin publication)

[5] C.C.P.J.M. Landa, PROSEL propulsion installation selection, december 1990 (TU Delft publication OEMO 91/53)