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Michigan Conceptual Ship Design Software Environment – User's Manuals

by

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ABSTRACT

This report provides the User's Manuals for a set of programs developed to support the teaching of conceptual ship design within the University of Michigan's Department of Naval Architecture and Marine Engineering. These programs were initially created and adapted by Professor Michael G. Parsons for use in undergraduate teaching within the senior-level course NA470 Ship Design. The software is also extensively used within the subsequent, team design project course NA475 Ship Design Project. These programs were initially developed during the 1983-1995 period as FORTRAN applications compiled for use on the Macintosh computers. The programs were occasionally recompiled without change for use on PC DOS and Windows machines.

During 1987-1988, these programs were all converted to Windows NT as part of the department's participation in the DARPA sponsored COMPASS project. This effort was undertaken in conjunction with the transition of the department's design teaching to a fully Windows NT environment in the new Undergraduate Marine Design Laboratory. Dr. Jun Li developed Visual C++ Windows Graphical User Interfaces for each of the programs and adapted and recompiled the legacy code for use on Window machines. These programs and the corresponding User's Manual sections will be made available on the World Wide Web.

This series includes five programs in similar format. They are developed for use primarily in the early conceptual design stage of displacement ships when only dimensions and parameters define the vessel; i.e., before the hull form is developed and detailed section offsets are available for analysis. The series includes the following:

- Power Prediction Program (PPP1.8)
- Propeller Optimization Program (POP1.5)
- Maneuvering Prediction Program (MPP1.3)
- Seakeeping Prediction Program (SPP1.5)
- Gear Sizing Program (GSP1.0)

The Seakeeping Prediction Program utilizes Active X utilities not usually available on Windows 95. The remaining programs operate on Windows 95 as well.

Early versions of three of the programs were created as individual study projects developed by students at the University of Michigan. Volker Elste created a precursor to the Propeller Optimization Program, Louise Durand programmed the initial code for the Power Prediction Program, and Bennie Glasner programmed the initial version of the Gear Sizing Program.

M. G. P., 7/13/98

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University of Michigan
Department of Naval Architecture and Marine Engineering
Conceptual Ship Design Software Environment

Welcome to the University of Michigan software environment for the conceptual design of displacement type ships. This collection of software has been developed over the years to support the teaching of conceptual ship design within the undergraduate curriculum of the Department of Naval Architecture and Marine Engineering. The emphasis has primarily been on analysis methods which can be utilized at the parameter stage of design before a detailed hull design is developed and offsets are available. The legacy FORTRAN programs were developed by and under the supervision of Professor Michael G. Parsons over the period 1983-1995 and used as Macintosh applications in the senior design courses NA470 Ship Design and NA475 Ship Design Project. During 1997-1998, Dr. Jun Li developed Visual C++ Windows Graphical User Interfaces for the programs as part of the DARPA sponsored COMPASS project. These Windows programs are now available through the World Wide Web. The individuals involved, the department, and the university can, however, accept no responsibility for problems resulting from the use of these programs.

OVERVIEW. The following programs are available:

- Power Prediction Program (PPP) calculates the resistance and hull/propeller interaction of a displacement hull using the regression-based method of Haltrop and Mennon. This uses a modified Hughes Method. An explicit air drag model has been added.

- Propeller Optimization Program (POP) calculates the optimum open water efficiency Wageningen B-Screw Series propeller subject to user-specified diameter and cavitation constraints. The nonlinear programming Nelder and Mead Simplex Search method is used with an External Penalty Function. The program will also calculate the operating conditions and efficiency for a specified operating point.

- Maneuvering Prediction Program (MPP) uses (1) methods presented by Clarke et al to assess the course stability, turnability, and controllability by a helmsman, and (2) the regression results of Lyster and Knights to estimate the turning circle characteristics of a displacement vessel.

- Seakeeping Prediction Program (SPP) is an adaptation of the five degree-of-freedom SCORES program to provide estimates of heave, pitch, roll, vertical wave bending moment, horizontal wave bending moment, and hull torsional moment in a random, long-crested seaway. It can be used at the parameter stage for initial estimates or, with greater accuracy, after the specific Section Area Curve and Design Waterline Curves are available. Hull offsets are not required.

- Gear Sizing Program (GSP) adapts the method presented by Balukjian to provide initial estimates of the size and arrangement of a marine reduction gear for a given input, output, and K-factor gear tooth contact stress loading.

The methods, input, and output of each of these programs will be described in succession.

Note that for these programs to run successfully, the entire program folder as provided must be located in a region of the computer to which the user has write privileges.

POWER PREDICTION PROGRAM (PPP1.8)
M. G. Parsons, January, 1996

REFERENCES:

1. Holtrop, J., and Mennen, G. G. J., "An Approximate Power Prediction Method," *International Shipbuilding Progress*, Vol. 29, No. 335, July, 1982.
2. Holtrop, J., "A Statistical Re-Analysis of Resistance and Propulsion Data," *International Shipbuilding Progress*, Vol. 31, No. 363, November, 1984.

METHODS:

This program implements the statistical ship power estimation method presented by Holtrop and Mennen and Holtrop (1, 2). This model is based upon hydrodynamic theory with coefficients obtained from the regression analysis of the results of 334 ship model tests conducted at MARIN. The user should consult copies of these papers prior to using the program. An explicit air drag estimate has been added. The range of applicability of this estimation method is stated to be the following:

$$0.55 \le C_P \le 0.85$$
$$3.90 \le L/B \le 14.9$$
$$2.10 \le B/T \le 4.00$$
$$0.05 \le F_n \le 1.00$$

The program requires the completion of all of the **Input** menu windows and then it can be run from either the **Analysis** menu or the **RunPPP** button.

For simplicity, the program automatically calculates all the output for eight user-specified speeds. The user inputs an initial speed V_0 in knots and a speed increment V_{INC} in knots. These are used to determine the eight speeds as follows:

$$V_i = V_0 + (i - 1) * V_{INC} \ , \ i = 1,2,...,8.$$

The output from the calculations consists of three tables of information for the eight speeds V_i. The first table gives the speeds in various units, the Froude number, the speed-length ratio, and the traditional resistance coefficients C_F, C_R, and C_A. The components of resistance listed below are then presented in Newtons. The third table gives the total resistance, effective power, and the total required thrust (each including the design margin) and the propulsion factors. The resistance model is Haltrop and Mennen's modified Hughes Method with an explicit air drag estimate and design margin added as follows:

$$R_T = [R_F\,(1 + K_1) + R_W + R_{APP} + R_B + R_{TR} + R_A + R_{AIR}]\ (1.0 + DMAR/100)$$

R_F 1957 ITTC frictional resistance
R_F*K_1 viscous form resistance
R_{APP} appendage resistance (1)
R_W wave-making and wave-breaking resistance
R_B additional pressure resistance of bulbous bow near surface (1)
R_{TR} additional pressure resistance of immersed transom (1)
R_A model-ship correlation resistance
R_{AIR} air drag assuming C_D=0.4 for the hull and CD=0.8 for the deck house/deck cargo

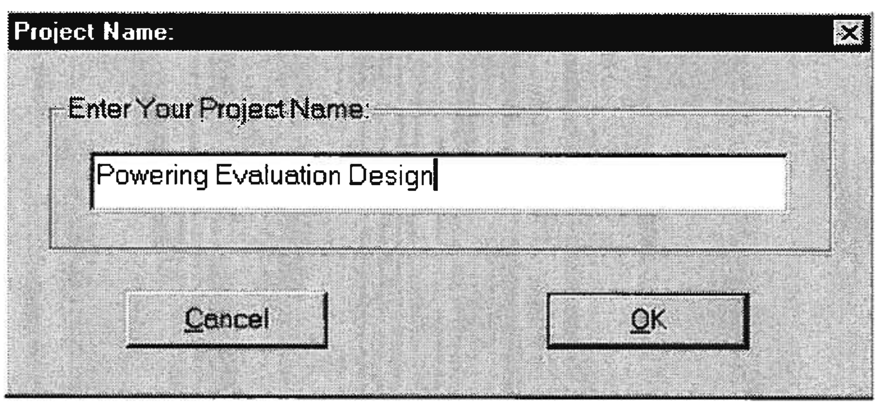
INPUT:

The input to PPP is through a series of eight windows within the menu **Input** as follows:

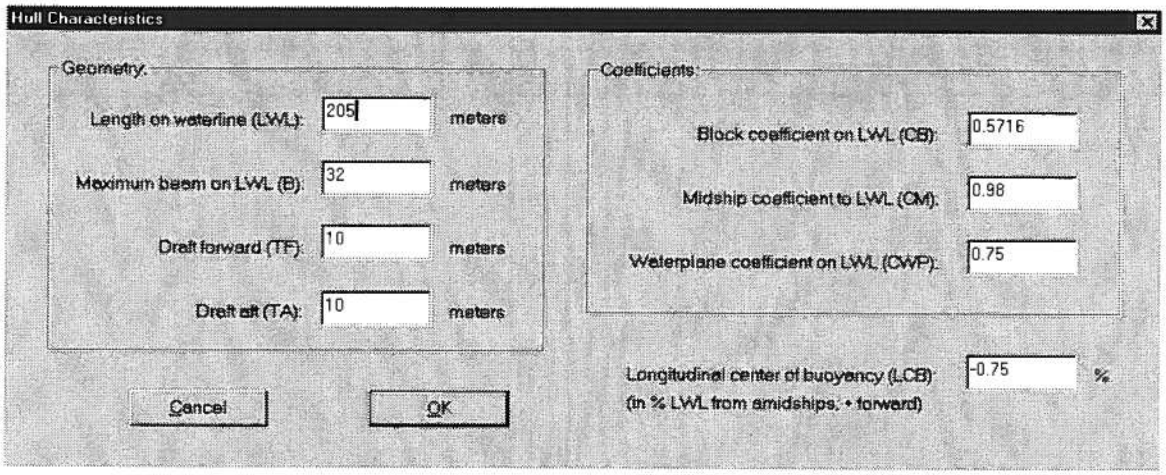
Input
- **Project Name**
- **Hull Characteristics**
- **Hull Features**
- **Propulsion Factors Model**
- **Appendages**
- **Modeling**
- **Design Margin**
- **Water Properties**

Each of these windows must be completed before an analysis can be performed. The completed input data can be saved using the **Save** button for later re-use.

Project Name provides a location for the general identification of the project being analyzed.

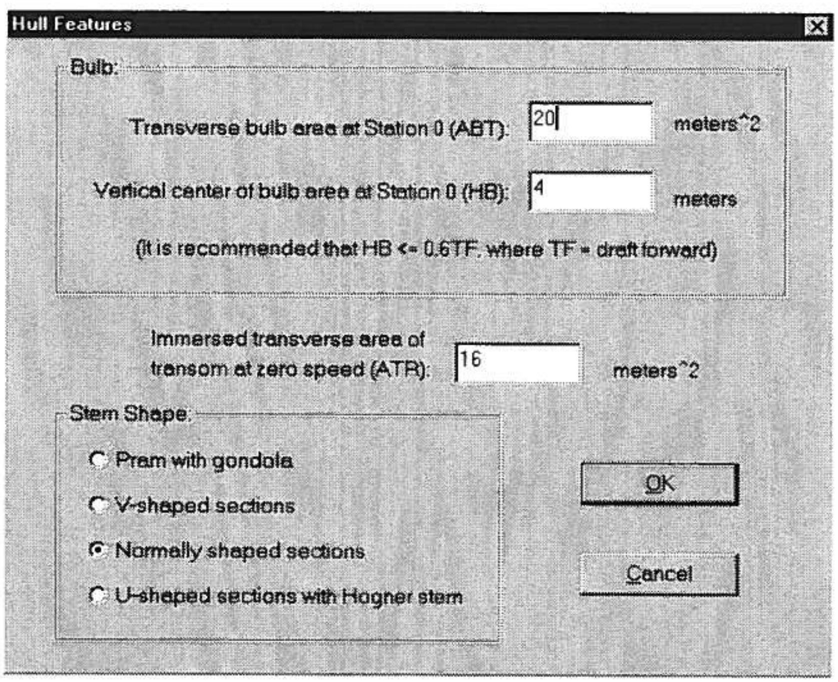


Hull Characteristics obtains the basic dimensions and form coefficients for the hull.



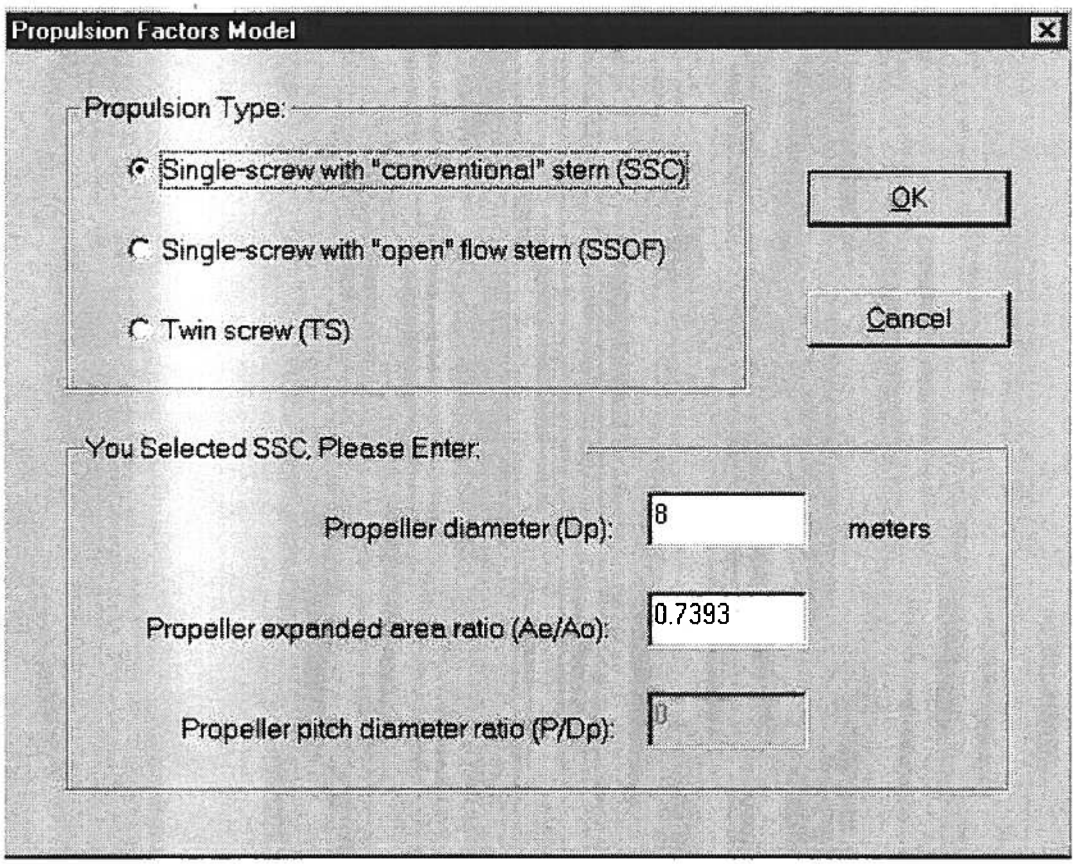
LWL	length on waterline in meters
B	maximum beam on waterline in meters
T_F	draft forward in meters
T_A	draft aft in meters
C_B	block coefficient on LWL
C_M	midship coefficient to LWL
C_{WP}	waterplane coefficient on LWL
LCB	longitudinal center of buoyancy in %LWL from amidships; positive forward

Hull Features obtains information on the bulbous bow, immersed transom, and the shape of the stern.



ABT	transverse bulb area at Station 0 in meters^2
HB	height of centroid of ABT above baseline in meters (It is recommended that HB not be allowed to exceed 0.6*TF)
ATR	immersed transverse area of transom at zero speed in meters^2
CSTERN	after body shape selected from among: • pram with gondola (barge type buttock flow stern with wide skeg) • V-shaped sections • normal shaped sections • bulbous U-shaped sections; e.g., Hogner stern

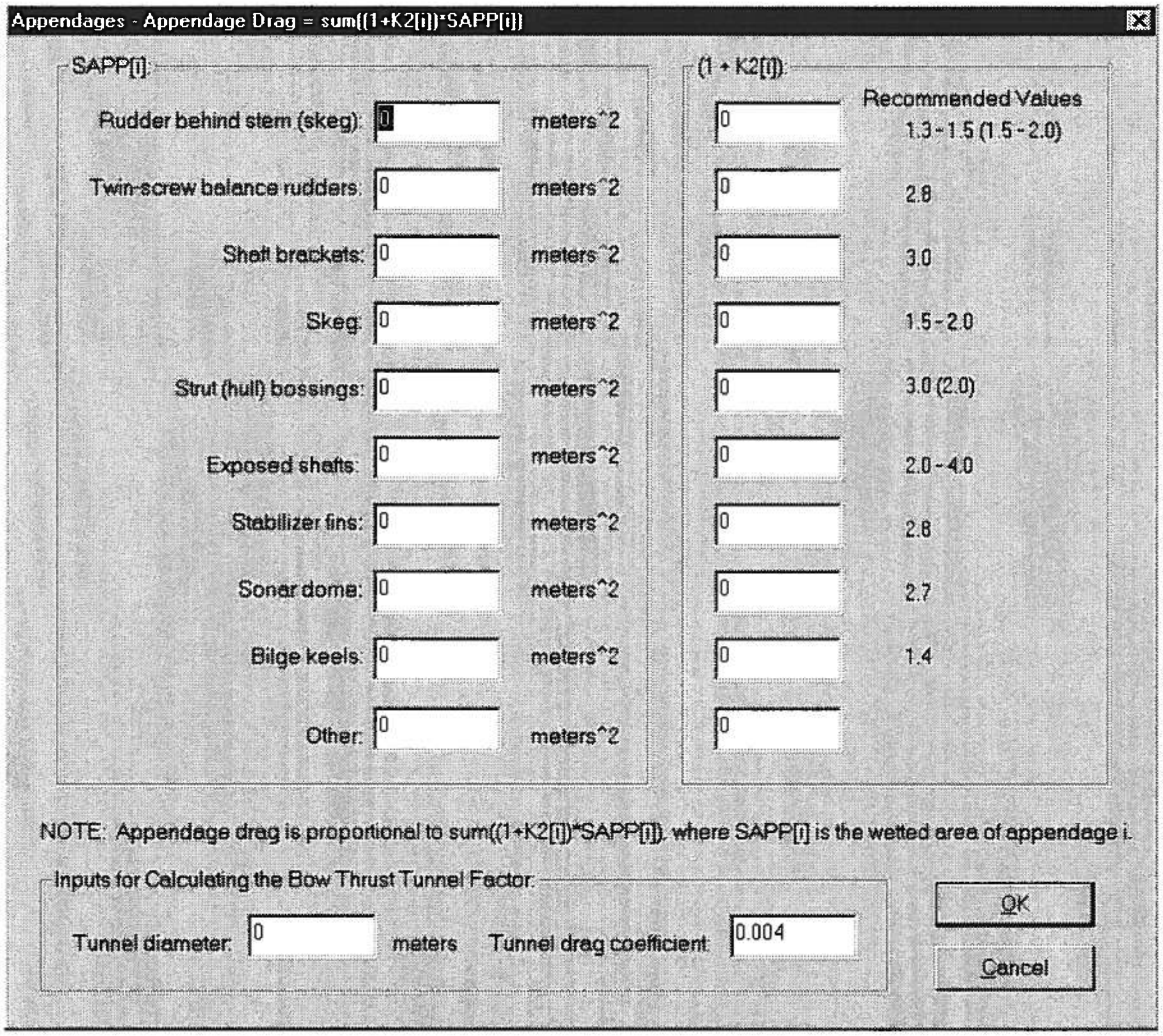
Propulsion Factors Model allows the choice from among three models for the estimation of the hull/propeller interaction based upon the propulsion type:



The inputs then vary based upon the model selected and these may include:

D	propeller diameter in meters; needed only if conventional single screw or twin screw
A_e/A_o	propeller expanded area ratio A_e/A_o; needed only if conventional single screw
PD	propeller pitch diameter ratio P/D_p; needed only if twin screw

Appendages allows the selection between two appendage drag models: a simple percent of bare hull resistance or a rational method requiring the wetted area $SAPP_i$ (e.g., both sides of foils) and factor $(1 + K_{2i})$ for each appendage included in the design. The window for the latter case appears as follows:

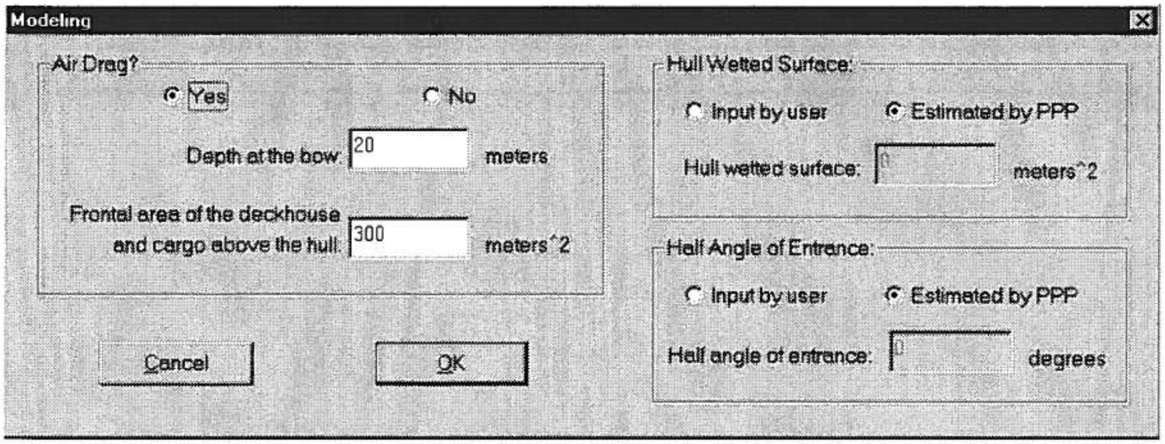


$SAPP_i$ is the wetted area of appendage i in meters^2

$(1 + K_{2i})$ reflects the local drag coefficient of and the local velocity at the appendage

When an option is in parentheses such as (skeg) with the recommended (1.5 - 2.0) also in parenthesis, that pair is an alternative to stern and 1.3 - 1.5.

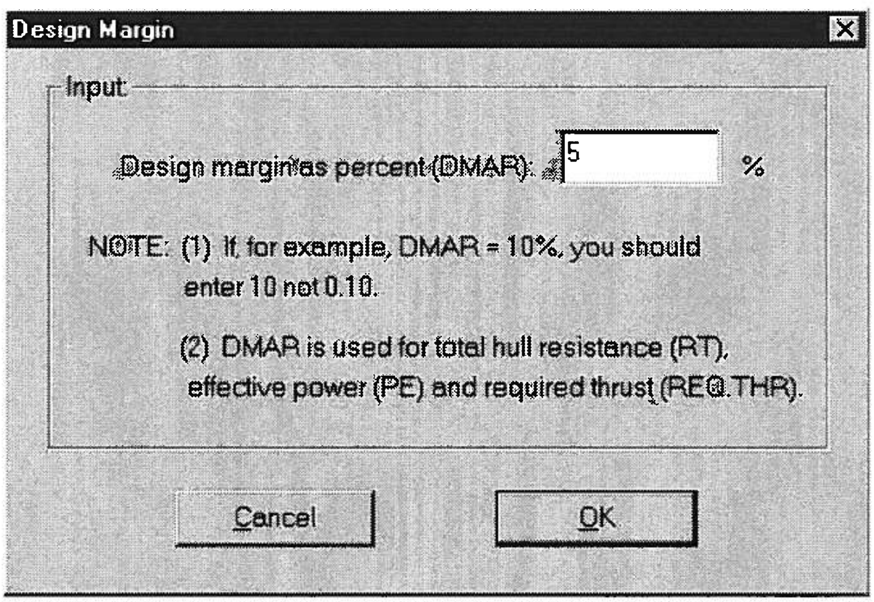
Modeling allows a choice of including an explicit air drag estimate and the use of the internal regression models for the estimation of the wetted surface and the half angle of entrance if these are not yet know in early design.



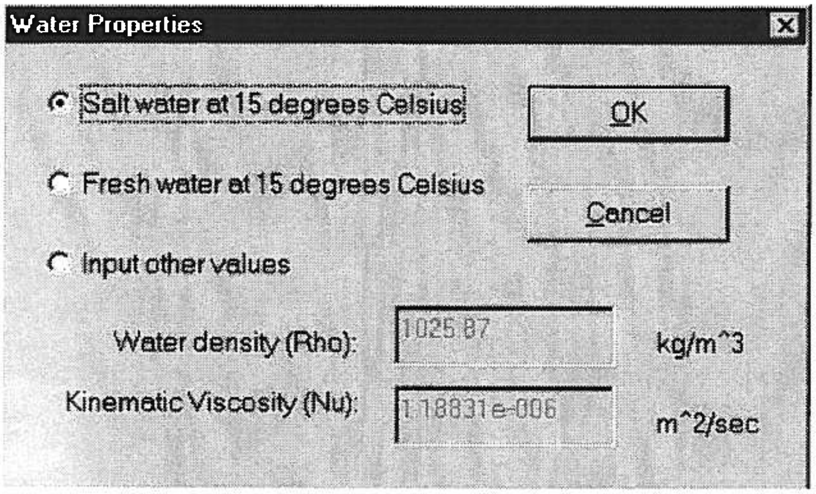
When air drag is selected, the first two definitions apply:

DBOW — depth at the bow in meters
AF — frontal area of the deckhouse and cargo above the hull in meters^2
S — hull wetted surface in meters^2; or calculated by program using regression model S(LWL,B,TF,TA,CB,CM,CWP,ABT)
EANGL — half angle of entrance of the design waterline in degrees; or calculated by program using regression model EANGL(LWL,B,TF,TA,CB,CM,CWP,LCB)

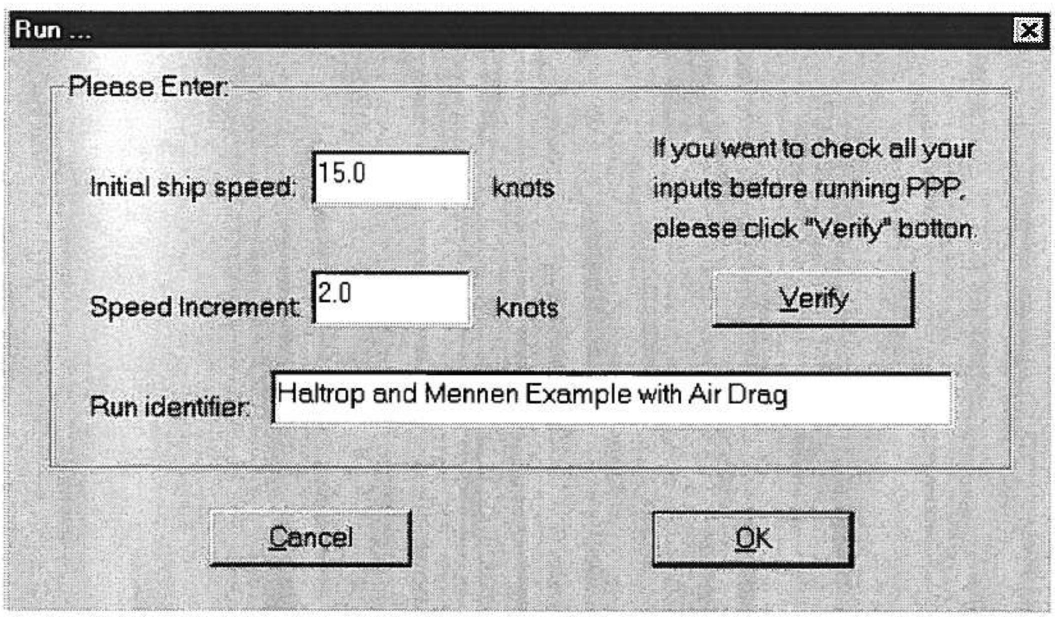
Design Margin allows the input of the design margin that is applied to the total resistance, effective power, and required propeller thrust as a percent.



Water Properties allows the choice of fresh water @ 15C, salt water @ 15C or user-specified water properties.



When the input process is completed, the program can be run through the **Analysis** menu or by selecting the **RunPPP** button. This will produce a final run input window where the initial speed Vo and speed increment Vi are entered in knots. The user can also enter a run specific identifier at this point, if desired.



OUTPUT:

A sample output report resulting from the input from the above windows follows. Notice that the added pressure resistance due to the bulb plowing the free surface is negligible in this example. Also, note that the transom clears (the streamlines leave the lower edge of the transom which becomes dry) at just over 23 knots causing the added pressure resistance due to the immersed transom to become zero. The Required Thrust and wake fraction are used in the propeller design requirements.

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Project Name: Powering Evaluation Design          Thu Jul 09 12:39:03 1998
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                 University of Michigan
Department of Naval Architecture and Marine Engineering

 Power Prediction Program (PPP-1.8) by M. G. Parsons

 Source:1. Holtrop,J., & Mennen, G.G.J., "An Approximate
            Power Prediction Method," International Shipbuilding
             Progress, Vol.29, No.335, July, 1982.
        2. Holtrop,J., "A Statistical Reanalysis of
            Resistance and Propulsion Data," International
            Shipbuilding Progress, Vol.31, No.363, Nov., 1984.

Run Identification: Haltrop and Mennen Example with Air Drag

Input Verification:

     Length of Waterline LWL (m)                =    205.00
     Maximum Beam on LWL (m)                    =     32.00
     Depth at the Bow (m)                       =     20.00

     Mean Draft (m)                             =     10.00
     Draft Forward (m)                          =     10.00
     Draft Aft (m)                              =     10.00

     Block Coefficient on LWL CB                =    0.5716
     Prismatic Coefficient on LWL CP            =    0.5833
     Midship Coefficient to LWL CM=CX           =    0.9800
     Waterplane Coefficient on LWL CWP          =    0.7500

     Center of Buoyancy LCB (% LWL; + Fwd)      =   -0.7500
     Center of Buoyancy LCB (m from FP)         =    104.04
     Molded Volume (m^3)                        =   37497.0
     Deck House/Cargo Frontal Area (m^2)        =    300.00

     Water Type                                 =  Salt@15C
     Water Density (kg/m^3)                     =   1025.87
     Kinematic Viscosity (m^2/s)                =   0.118831E-05

     Appen. Drag (% Bare Hull Resistance)       =      5.00

     Bulb Section Area at Station 0 (m^2)       =     20.00
     Vertical Center of Bulb Area (m)           =      4.00

     Transom Immersed Area (m^2)                =     16.00
     Stern Type                                 = Normally Shaped
     Design Margin on RT,PE,REQ.THR (%)         =      5.00
     Propulsion Type                            =  SS, Conv.

     Propeller Diameter (m)                     =      8.00
     Propeller Expanded Area Ratio Ae/Ao        =    0.7393

     Wetted Surface (m^2)                       =   7381.24
     Half Angle of Entrance (deg)               =     12.11
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Source:1. Holtrop,J., & Mennen, G.G.J., "An Approximate Power Prediction Method," International Shipbuilding Progress, Vol.29, No.335, July, 1982.
2. Holtrop,J., "A Statistical Reanalysis of Resistance and Propulsion Data," International Shipbuilding Progress, Vol.31, No.363, Nov., 1984.

Run Identification: Haltrop and Mennen Example with Air Drag

Speed, Resistance Coefficients and Frictional Resistance RF(N):

V(kts)	V(m/s)	FN	SLRATIO	CF	CR	CA	RF
15.00	7.72	0.1721	0.5784	0.001478	0.000441	0.000352	333139.8
17.00	8.75	0.1951	0.6555	0.001455	0.000472	0.000352	421443.8
19.00	9.77	0.2180	0.7326	0.001436	0.000549	0.000352	519426.3
21.00	10.80	0.2409	0.8097	0.001419	0.000674	0.000352	626970.3
23.00	11.83	0.2639	0.8869	0.001404	0.000878	0.000352	743972.3
25.00	12.86	0.2868	0.9640	0.001390	0.001108	0.000352	870339.8
27.00	13.89	0.3098	1.0411	0.001377	0.001260	0.000352	1005989.3
29.00	14.92	0.3327	1.1182	0.001366	0.001465	0.000352	1150844.6

Remaining Resistance Components (N):

V(kts)	Form RF*K1	Appendage RAPP	Wave RW	Bulb RB	Transom RTR	Correlation RA	Air Drag RAIR
15.00	53277.7	21627.6	12091.4	24.6	34017.7	79469.8	13476.4
17.00	67399.9	27907.1	36487.5	30.0	32781.2	102074.5	17309.7
19.00	83069.8	35893.0	88011.8	35.3	27316.6	127504.8	21622.2
21.00	100268.9	46238.6	180775.2	40.2	16717.9	155760.8	26413.8
23.00	118980.5	60471.7	346357.5	44.9	78.7	186842.3	31684.6
25.00	139190.0	78214.1	554702.9	49.2	0.0	220749.4	37434.5
27.00	160883.9	96303.5	759144.4	53.2	0.0	257482.1	43663.6
29.00	184050.0	119248.5	1050018.4	57.0	0.0	297040.4	50371.9

Resistance, Effective Power, Propulsion Factors and Required Thrust

V(kts)	RT(N)	PE(kW)	w	t	REQ.THR(N)	etaH	etaRR
15.00	574481.3	4433.04	0.2402	0.1834	703483.2	1.0748	0.9931
17.00	740705.4	6477.82	0.2397	0.1834	907033.5	1.0741	0.9931
19.00	948023.8	9266.33	0.2393	0.1834	1160906.0	1.0736	0.9931
21.00	1210844.9	13081.05	0.2390	0.1834	1482744.5	1.0731	0.9931
23.00	1562854.0	18491.88	0.2387	0.1834	1913798.5	1.0726	0.9931
25.00	1995714.0	25666.88	0.2384	0.1834	2443858.8	1.0722	0.9931
27.00	2439696.3	33887.09	0.2381	0.1834	2987538.8	1.0718	0.9931
29.00	2994212.3	44669.94	0.2379	0.1834	3666573.5	1.0715	0.9931

Design Margin Has Been Included in RT, PE, and REQ.THR = RT/(1-t).

PROPELLER OPTIMIZATION PROGRAM (POP.1.5)
M. G. Parsons, December, 1994

REFERENCES:

1. Oosterveld, M. W. C., and van Oossanen, P., "Further Computer-Analyzed Data of the Wageningen B-Screw Series," *International Shipbuilding Progress*, Vol. 22, No. 251, July, 1975.
2. Parsons, M. G., "Optimization Methods for Use in Computer-Aided Ship Design," *Proceedings* of the First SNAME STAR Symposium, 1975.
3. Comstock, J. P. (Ed.), *Principles of Naval Architecture*, Vol. II, 1988 Edition, SNAME, New York, p. 182.

METHODS:

This program implements the Wageningen B-Screw Series regression equations presented by Oosterveld and van Oossanen (1). The user can either evaluate a given propeller or use mathematical programming from Parsons (2) to obtain the optimum open water efficiency propeller for a given application.

In the optimization mode, the user specifies the required thrust and speed of advance. The program then uses the Nelder and Mead Simplex Search method with an External Penalty Function (2) to determine the optimum propeller. Wageningen B-Screw Series 3- through 7-bladed propellers with Reynolds number corrections are available. Optimization among blade number must be handled with separate runs for each blade number and then simple comparison. For controllable-reversible-pitch propeller estimates, the program reduces the B-Screw Series open water efficiency by 2 percent. The program includes either the Burrill five or ten percent back cavitation criterion (3). The optimization independent variables are the expanded area ratio A_e/A_o, the pitch-diameter ratio P/D_p, and the propeller diameter D_p. The propeller RPM needed to produce the specified thrust (within about 1 lbf.) is determined at each step of the search in an internal loop. Thus, instead of having RPM as a fourth independent variable, it is established by the equality constraint that the produced thrust must equal the required thrust. This is an implicit constraint so the required RPM is found by an iteration. The constraints on the variables are as follows:

$3 \le NBLADE \le 7$	(integer, from model)
$0.3 \le A_e/A_o \le 1.05$	(from model)
$0.5 \le P/D_p \le 1.40$	(from model)
$D_{MIN} \le D_p \le D_{MAX}$	(user-specified)
$0.0 \le J \le 1.60$	(from physics and model)
$0.0 \le$ thrust loading $\le$ Burrill 5% or 10% limit	(physics and user-selected)

The optimization is for the maximum open water efficiency propeller that will produce the required thrust at the specified speed of advance. The Burrill 5% back cavitation criterion is recommended. The program does not check to see that the resulting design is "slightly to the left" of the peak of the efficiency versus J diagram as is usually recommended as margin if the design misses the predicted operating point RPM. The user should check this on the graphical output.

An error message will be printed if the determination of the RPM needed to produce the required thrust does not converge within 400 iterations within the computations.

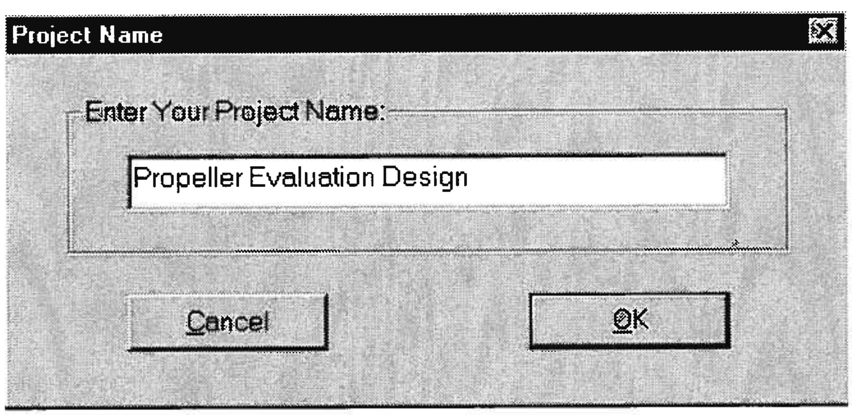
INPUT:

The input to POP is through a series of five windows within the menu **Input** as follows:

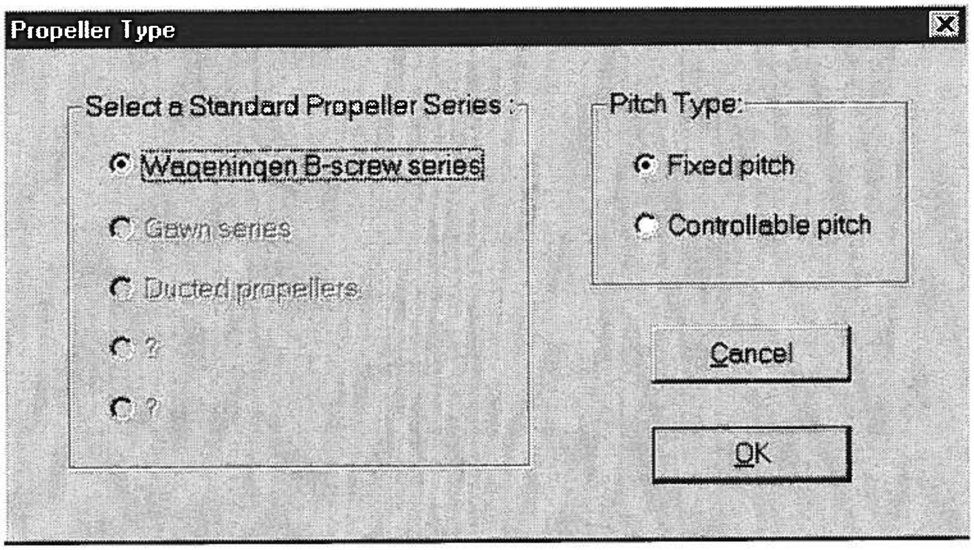
Input
- **Project Name**
- **Propeller Type**
- **Propeller Characteristics**
- **Operating Conditions**
- **Water Properties**

Each of these windows must be completed before an analysis can be performed. The completed input data can be saved using the **Save** button for later re-use.

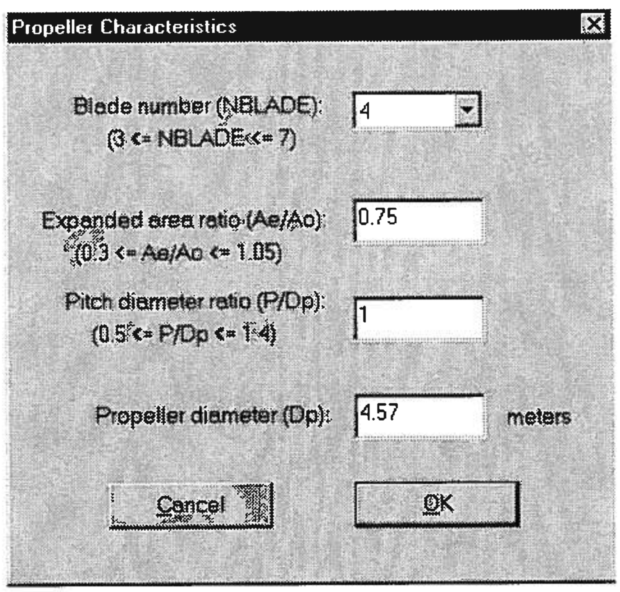
Project Name provides a location for the general identification of the project being analyzed.



Propeller Type allows the selection of a fixed-pitch or controllable-pitch propeller. At this time, only the Wageningen B-Screw Series is supported and the open water efficiency is reduced by 2 percent for the controllable-pitch propeller option to reflect the larger hub.

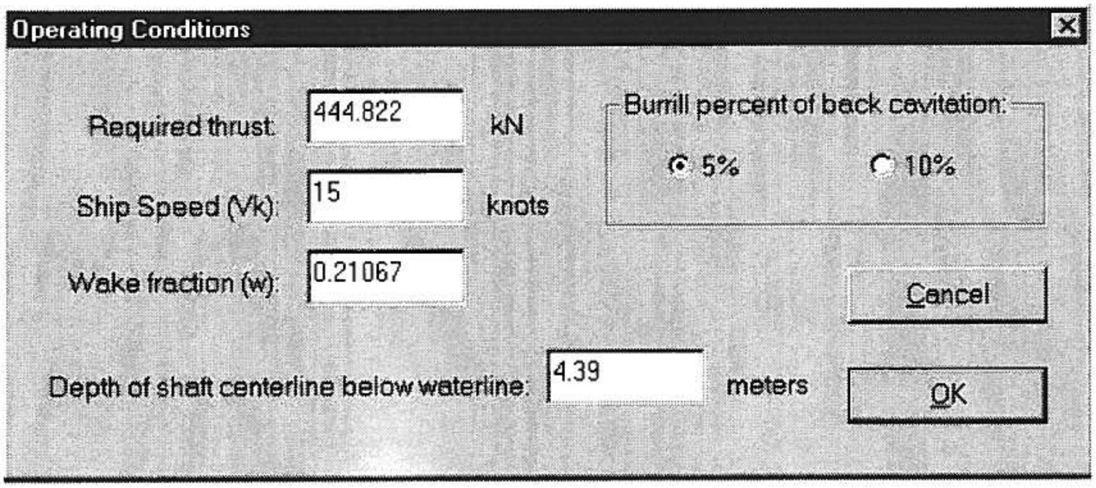


Propeller Characteristics obtains the blade number and the basic parameters for the propeller. If the optimization option is being used, the parameters are the initial values used by the search algorithm. If the evaluation option is being used, the parameters are those evaluated by the program.



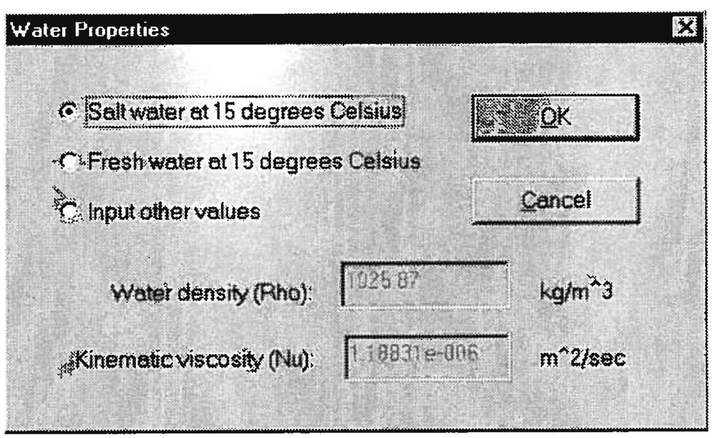
NBLADE	number of blades on propeller, 3 through 7 supported
A_e/A_o	initial point for search or evaluated expanded area ratio
P/D_p	initial point for search or evaluated pitch diameter ratio
D_p	initial point for search or evaluated propeller diameter in meters

Operating Conditions obtains the ship speed, wake fraction, and thrust required from the propeller. It also allows the selection of the 5% or 10% Burrill back cavitation constraint and obtains the submergence of the shaft centerline needed to calculate the Cavitation Number at the blade tip.

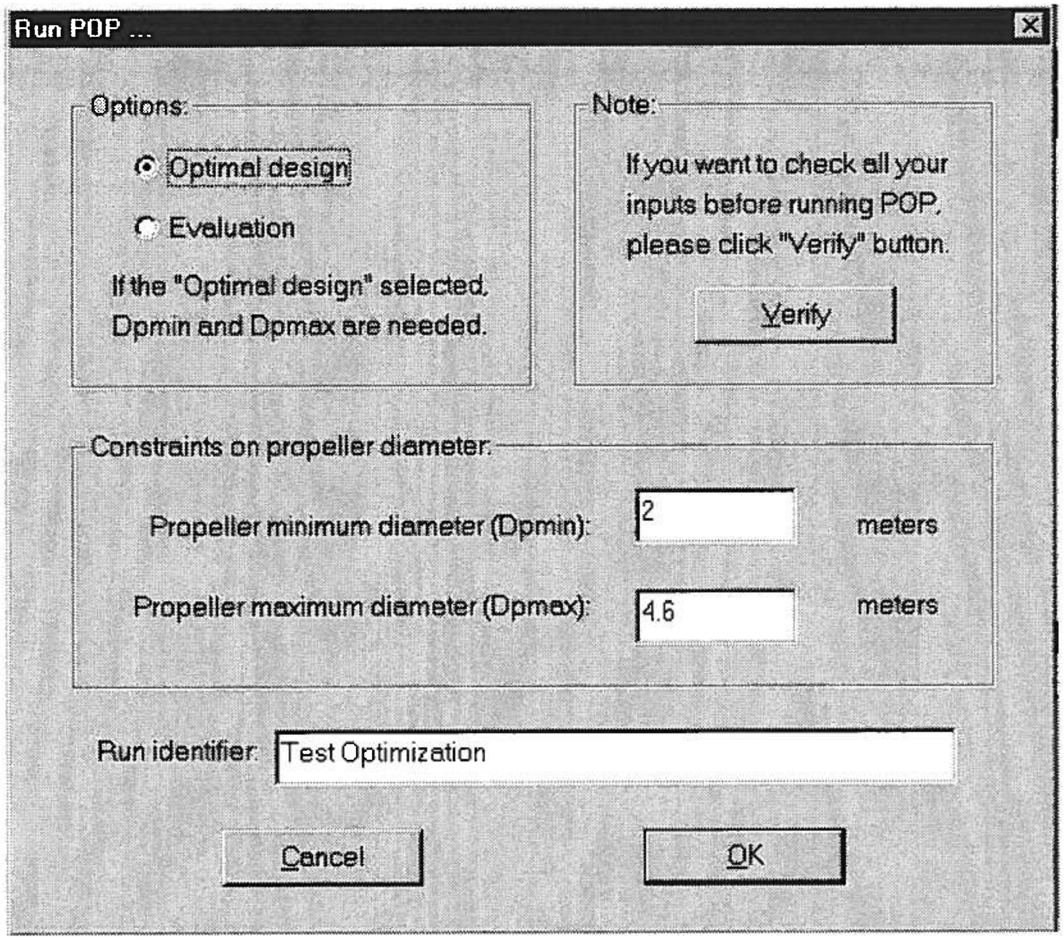


THR	required thrust per propeller in kilonewtons; $R_T/(1 - t)$
Vk	ship speed in knots
w	average longitudinal wake fraction
HWLM	depth of shaft centerline below waterline in meters

Water Properties allows the choice of fresh water @ 15C, salt water @ 15C or user-specified water properties.



When the input process is completed, the program can be run through the **Analysis** menu or by selecting the **RunPOP** button. This will produce a final run input window where the selection is made for design optimization or the evaluation of the specified operating condition. When the optimization is selected, a minimum and maximum propeller diameter must be specified. The user can also enter a run specific identifier at this point, if desired.



Dpmin Minimum propeller diameter in meters. Typically this is about 25% of Dpmax for fixed-pitch propellers and about 35% of Dpmax for controllable-pitch propellers.

Dpmax Maximum propeller diameter permitted by hull and required clearances, in meters.

When the analysis process is completed, the program can be produce an open water efficiency, KT, and KQ versus J plot through the **Plot** option in the **Analysis** menu or by selecting the **Plot KT, KQ, Eta0 versus J** button.

OUTPUT:

A sample output report and plot resulting from the input from the above windows is shown next. Note that the operating point is indicated on the plot by a vertical line drawn at the operating advance coefficient J. This output is followed by an example evaluation run.

University of Michigan
Department of Naval Architecture and Marine Engineering

Propeller Optimization Program (POP-1.5) by M.G. Parsons

Source:1. Oosterveld, M. W. C., and Van Oossanen, P., "Further Computer-Analyzed Data of the Wageningen B-Screw Series", International Shipbuilding Progress, Vol. 22, No. 251, July, 1975.
2. Parsons, M. G., "Optimiztion Methods for Use in Computer-Aided Ship Design", Proceedings of the First SNAME STAR Symposium, 1975

Wageningen B-Screw Series Propeller Preliminary Design

*** Eta 0 Reduced by 2% When Controllable Pitch ***

Run Identification: Test Optimization

Input Data:

Optimization Run

Fixed-Pitch Propeller

Number of Propeller Blades	=	4
Required Propeller Thrust (kN)	=	444.8
Ship Speed Vk (knots)	=	15.00
Wake Fraction w	=	0.211
Depth of Shaft below Waterline (m)	=	4.39
Water Type	=	salt@15C
Water Density Rho (kg/m^3)	=	1025.87
Kinematic Viscosity Nu (m^2/sec)	=	0.118831E-05
Burrill Back Cavitation Constraint	=	5%
Initial Expanded Area Ratio Ae/Ao	=	0.750
Initial Pitch Diameter Ratio P/Dp	=	1.000
Initial Propeller Diameter Dp (m)	=	4.57
Minimum Diameter Constraint Dpmin (m)	=	2.00
Maximum Diameter Constraint Dpmax (m)	=	4.60

Optimal Design Results:

Propeller Diameter Dp (m)	=	4.60
Propeller Pitch P (m)	=	3.76
Pitch Diameter Ratio P/Dp	=	0.8171
Expanded Area Ratio Ae/Ao	=	0.6293
Propeller Revolutions per Minute (rpm)	=	147.07
Advance Coefficient J	=	0.5408
Thrust Coefficient KT	=	0.1615
Torque Coefficient KQ	=	0.02205
Propeller Open Water Efficiency Eta 0	=	0.631
Propeller Thrust (kN)	=	444.8
Reynolds Number RN	=	0.368E+08
Cavitation Number Sigma	=	0.4339
Optimization Search Evaluation Count	=	73

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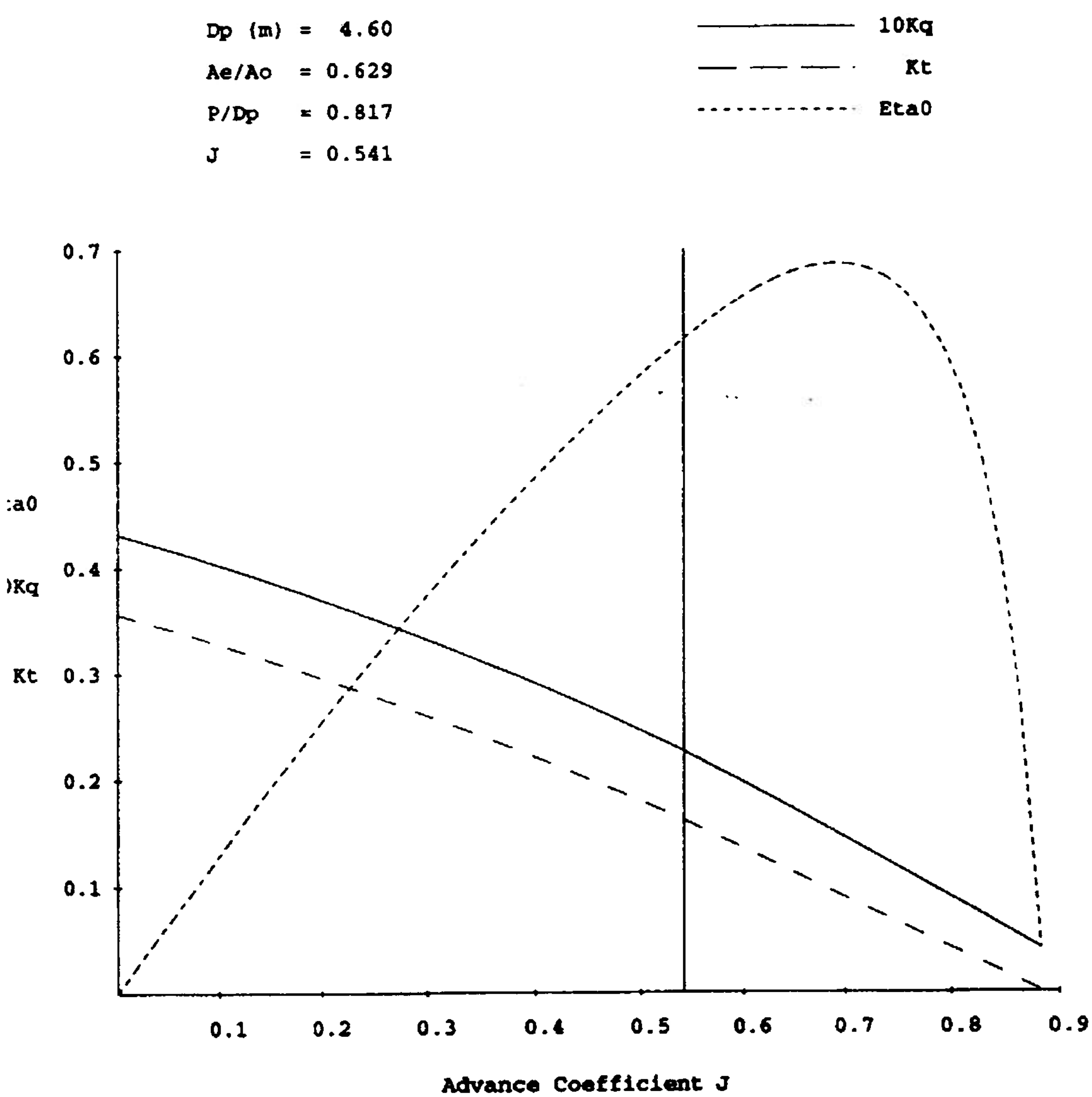
Department of Naval Architecture and Marine Engineering

Propeller Optimization Program (POP-1.5) by M. G. Parsons

Wageningen B-Screw Series Propeller Characteristics

Run Identification: Test Optimization

Dp (m) = 4.60
Ae/Ao = 0.629
P/Dp = 0.817
J = 0.541



University of Michigan
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Propeller Optimization Program (POP-1.5) by M.G. Parsons

Source:1. Oosterveld, M. W. C., and Van Oossanen, P., "Further Computer-Analyzed Data of the Wageningen B-Screw Series", International Shipbuilding Progress, Vol. 22, No. 251, July, 1975.
2. Parsons, M. G., "Optimiztion Methods for Use in Computer-Aided Ship Design", Proceedings of the First SNAME STAR Symposium, 1975

Wageningen B-Screw Series Propeller Preliminary Design

*** Eta 0 Reduced by 2% When Controllable Pitch ***

Run Identification: Test Evaluation

Input Data:

Evaluation Run

Fixed-Pitch Propeller

Number of Propeller Blades	=	4
Required Propeller Thrust (kN)	=	594.0
Ship Speed Vk (knots)	=	14.00
Wake Fraction w	=	0.166
Depth of Shaft below Waterline (m)	=	4.39
Water Type	=	salt@15C
Water Density Rho (kg/m^3)	=	1025.87
Kinematic Viscosity Nu (m^2/sec)	=	0.118831E-05
Burrill Back Cavitation Constraint	=	5%
Expanded Area Ratio Ae/Ao	=	0.850
Pitch Diameter Ratio P/Dp	=	1.000
Propeller Diameter Dp (m)	=	4.57

Output Results:

Propeller Diameter Dp (m)	=	4.57
Propeller Pitch P (m)	=	4.57
Pitch Diameter Ratio P/Dp	=	1.0000
Expanded Area Ratio Ae/Ao	=	0.8500
Propeller Revolutions per Minute (rpm)	=	139.86
Advance Coefficient J	=	0.5645
Thrust Coefficient KT	=	0.2445
Torque Coefficient KQ	=	0.03857
Propeller Open Water Efficiency Eta 0	=	0.569
Propeller Thrust (kN)	=	594.0
Reynolds Number RN	=	0.468E+08
Cavitation Number Sigma	=	0.4832

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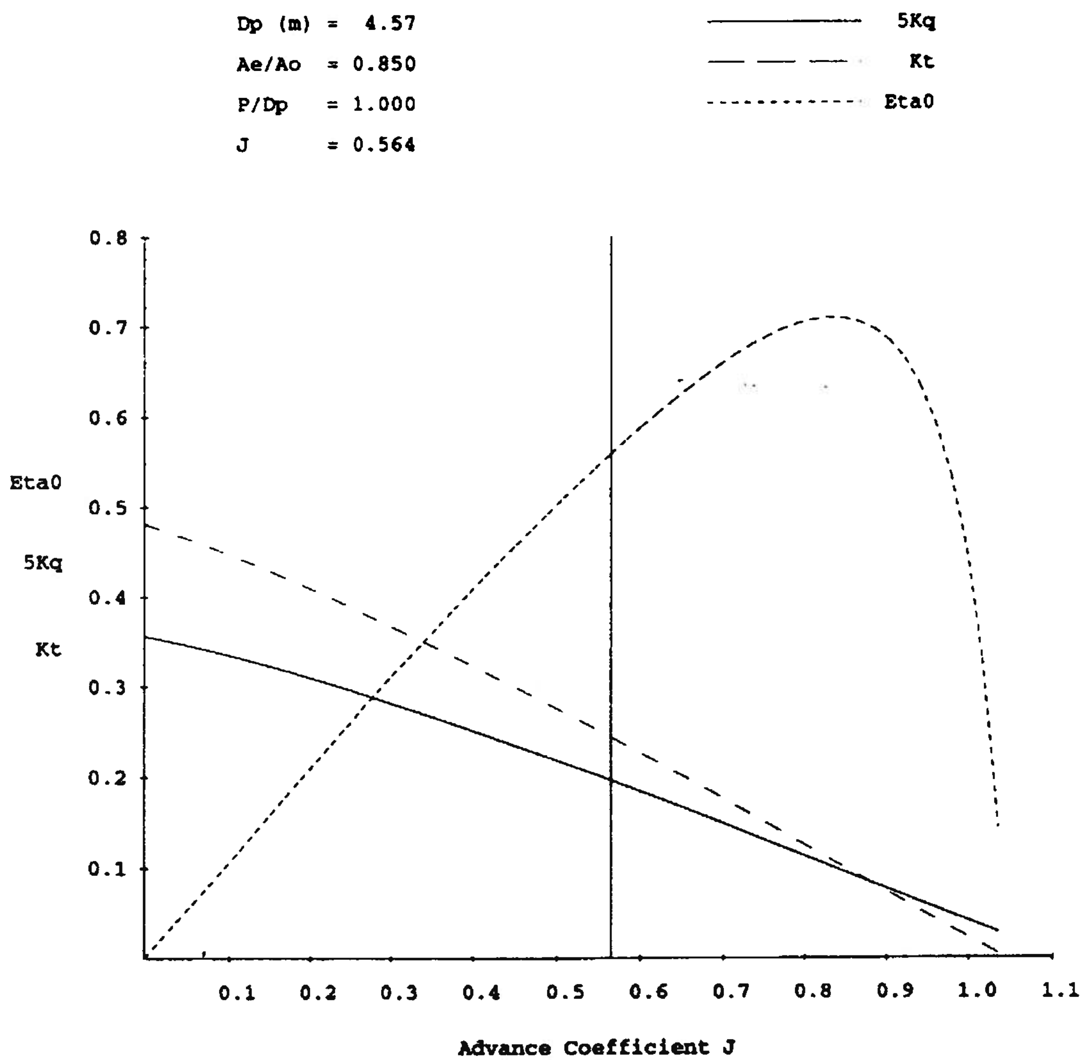
Propeller Optimization Program (POP-1.5) by M. G. Parsons

Wageningen B-Screw Series Propeller Characteristics

Run Identification: Test Evaluation

Dp (m) = 4.57
Ae/Ao = 0.850
P/Dp = 1.000
J = 0.564



MANEUVERING PREDICTION PROGRAM (MPP1.3)
M. G. Parsons, December, 1994

REFERENCES:

1. Clarke, D., Gedling, P., and Hine, G., "The Application of Manoevring Criteria in Hull Design Using Linear Theory, " *Transactions* RINA, Vol. 124, 1982.
2. Lyster, C. A., and Knights, H. L., "Prediction Equations for Ships' Turning Circles," *Transactions* NECIES 1978-1979.
3. Parsons, M. G., "Informal Notes for NA530 Automatic Control in Naval Architecture and Marine Engineering," Vol. I, "Classical Control," and Vol. II "Modern Control."
4. Fugino, M., "Maneuverability in Restricted Waters: State of the Art," The University of Michigan NAME Report No. 184, Aug., 1976.
5. Inoue, S., Hirano, M., and Kijima, K., "Hydrodynamic Derivatives on Ship Manoevring, " *International Shipbuilding Progress*, Vol. 28, No. 321, 1981.

METHODS:

This program offers two main options: **Linear Evaluation** which implements the methods proposed by Clarke, Gedling, and Hine (1) for the assessment of course stability, turning ability, and controllability by a helmsman; and **Turning Prediction** which implements the multiple linear regression equations presented by Lyster and Knights (2) for the estimation of turning circle characteristics. The user should consult the Clarke paper prior to using the program. If the **Linear Evaluation** option is used, the user can also obtain the linearized maneuvering equations of motion in state variable form (3).

In the **Linear Evaluation** option, the linear derivatives are estimated using the multiple linear regression equations presented by Clarke et al (1). The velocity derivatives were obtained from 72 sets of data from rotating arm and planar motion tests. Acceleration derivatives were obtained from planar motion test data. The independent variables include T/LWL, $C_B * B/T$, B/LWL, and B/T. Clarke feels that these results are at least as effective as the semi-empirical equations developed by Wagner Smitt, Norrbin, or Inoue. Water depth corrections were added by regressing the data presented by Fugino (4) for the *Tokyo Maru* ($C_B = 0.805$) and the *Mariner* ($C_B = 0.589$). Independent variables in these analyses were C_B and inverse powers of $F = (H/T) - 1$. These can be used for water depths down to H/T= 1.3, but are considered unreliable below this value. The trim corrections presented by Inoue (5) are used for the velocity derivatives. The independent variable in these corrections is the trim to mean draft ratio. The various time constants and gains in the first- and second-order Nomoto's equations are calculated from the linear derivatives.

The quantities calculated to allow evaluation of the maneuvering performance of the vessels are as follows:

- Inverse time constant (1/T') and inverse gain (1/K'). Turning ability increases with decreasing 1/K' while course stability and quickness of response to helm increases with 1/T'.
- Clarke's turning index P. This quantity is derived from the linear equations as the amount of turn achieved in one ship length using a unit step rudder. A minimum value of 0.3 (equivalent to about 10 degrees for a 35 degree step rudder, within the limits of the linearized equations of motion) is recommended with values as low as 0.2 considered acceptable for large tankers.
- Bare hull dynamic stability criterion C. This must be positive for open-loop, controls-fixed course stability of the bare hull.
- Phase margin applicable to the closed-loop steering system. The phase margin of the ship transfer function, including the steering gear, is calculated. Nomoto notes that by anticipating the ship's turning, a typical helmsman can apply between 20 and 30 degrees of phase advance. Thus, the ship with steering gear cannot have more than this amount of negative phase margin for the combination of the ship and helmsman to be closed-loop stable on course. Thus, a phase margin greater than about -20 degrees is recommended for reasonable human control.

All output is nondimensional following Clarke (1) except the phase margin which is expressed in degrees.

In the completely independent **Turning Prediction** option, the regression equations developed by Lyster and Knights (2) from sea trial results are used to estimate turning characteristics for a user-input rudder angle and approach speed. The dependence of the turns of single screw ships on the direction of propeller rotation and the ratio of the mean draft to the design draft were not implemented. The option produces estimates of the following:

steady turning diameter (meters)
tactical diameter (meters)
advance (meters)
transfer (meters)
steady speed in the turn (knots)

This model is for deep water and includes no dependence on water depth. The range of the ship parameters included in the Lyster and Knights' regression data set is as follows:

single screw			twin screw		
54.9 ≤	LBP	≤ 329.2 m	76.2 ≤	LBP	≤ 225.6 m
0.56 ≤	C_B	≤ 0.87	0.42 ≤	C_B	≤ 0.62
10.0 ≤	rudder angle	≤ 45 degrees	10.0 ≤	rudder angle	≤ 35 degrees
5.56 ≤	L/B	≤ 9.09	5.00 ≤	L/B	≤ 16.67
0.00 ≤	trim/LBP	≤ 0.05	-0.01 ≤	trim/LBP	≤ 0.03
0.01 ≤	A_R	≤ 0.04	0.01 ≤	A_R	≤ 0.02 per rudder
-0.11 ≤	A_B	≤ 0.04	-0.10 ≤	A_B	≤ 0.0
0.060 ≤	F_n	≤ 0.298	0.074 ≤	F_n	≤ 0.655

This model should be used with CAUTION outside this range.

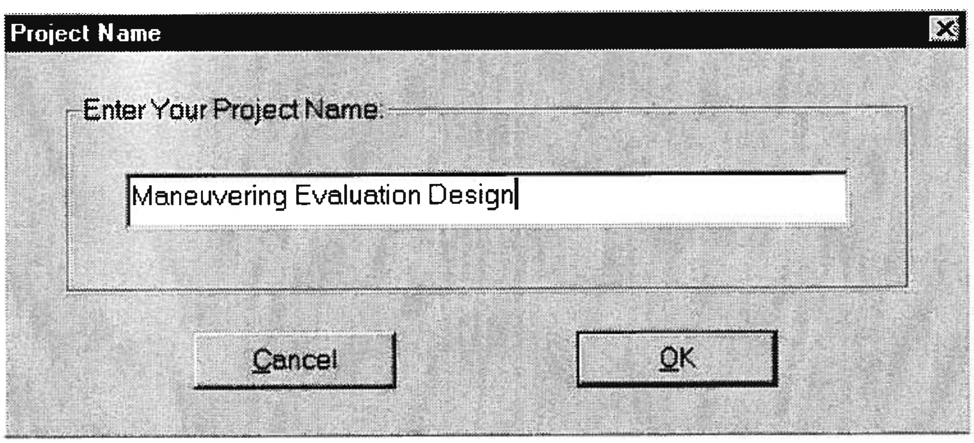
INPUT:

The input to MPP is through a series of five windows within the menu **Input** as follows:

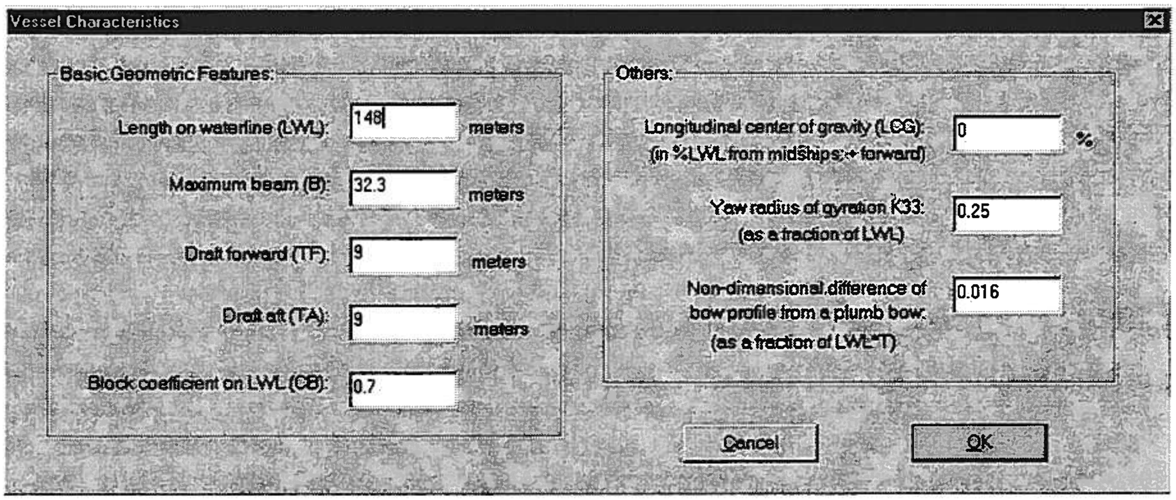
Input
- **Project Name**
- **Vessel Characteristics**
- **Steering Characteristics**
- **Operating Conditions**
- **Water Properties**

Each of these windows must be completed before an analysis can be performed. The completed input data can be saved using the **Save** button for later re-use.

Project Name provides a location for the general identification of the project being analyzed.

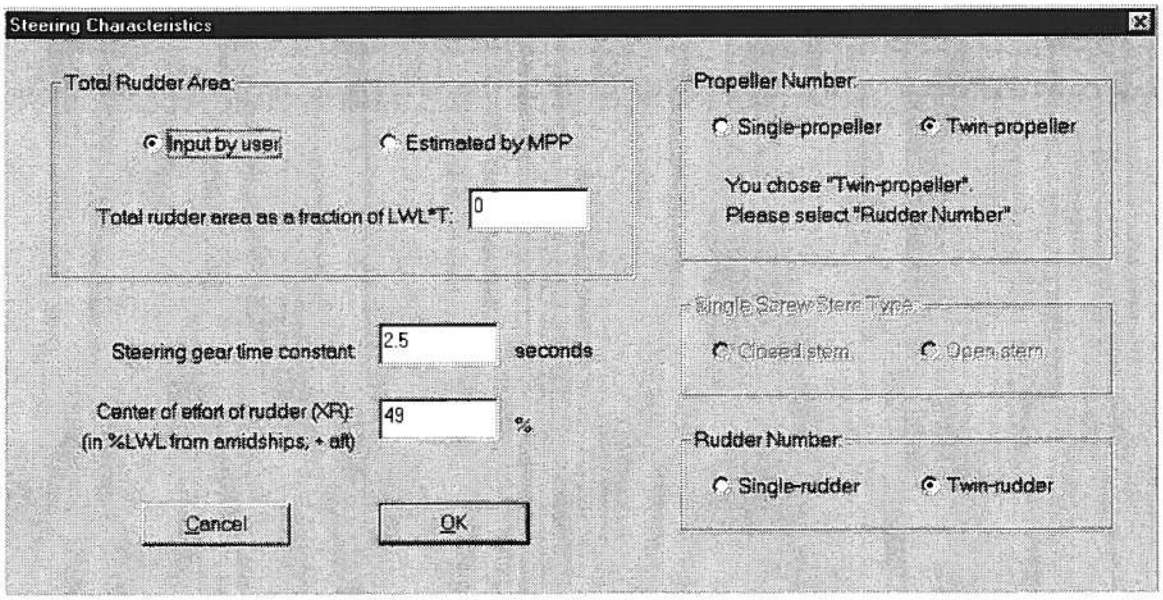


Vessel Characteristics obtains the basic dimensions, form coefficients, LCG, yaw radius of gyration, and bow profile information for the hull.



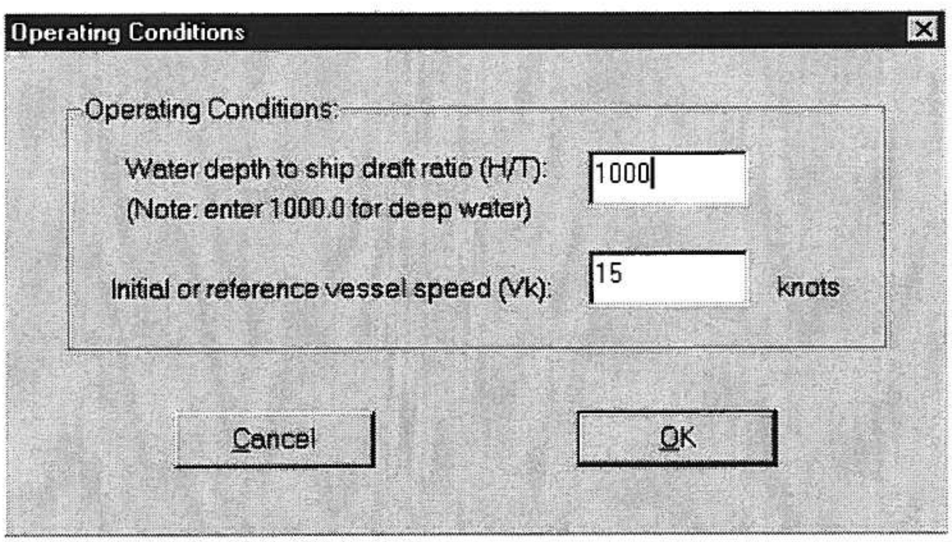
LWL	length on waterline in meters
B	maximum beam on waterline in meters
TF	draft forward in meters
TA	draft aft in meters
CB	block coefficient on LWL
LCG	longitudinal center of gravity in %LWL from amidships; + forward
GYRAD	yaw radius of gyration k_{33} as a fraction of LWL; default value 0.25
AB	difference between the submerged bow **profile** area on the centerplane and that of a plumb bow as fraction of LWL*T; i.e., AB = area forward of STA0/(LWL∗T), positive when a bulbous bow projects forward of the forward perpendicular, or AB = cutaway area aft of STA0/(LWL∗T), negative with a raked stem or cutaway forefoot

Steering Characteristics obtains the rudder area, steering gear time constant, position of the rudder center of effort (typically the 1/4 chord point from the leading edge), and selection of single or twin screw. The rudder area can be input either as a fraction of LWL*T or automatically as the minumum rudder area specified by Det Norske Veritas for commercial vessels. For single screw, the sterm type must be designated as a closed or open stern. For twin screw, the number of rudders must be designated as one or two.



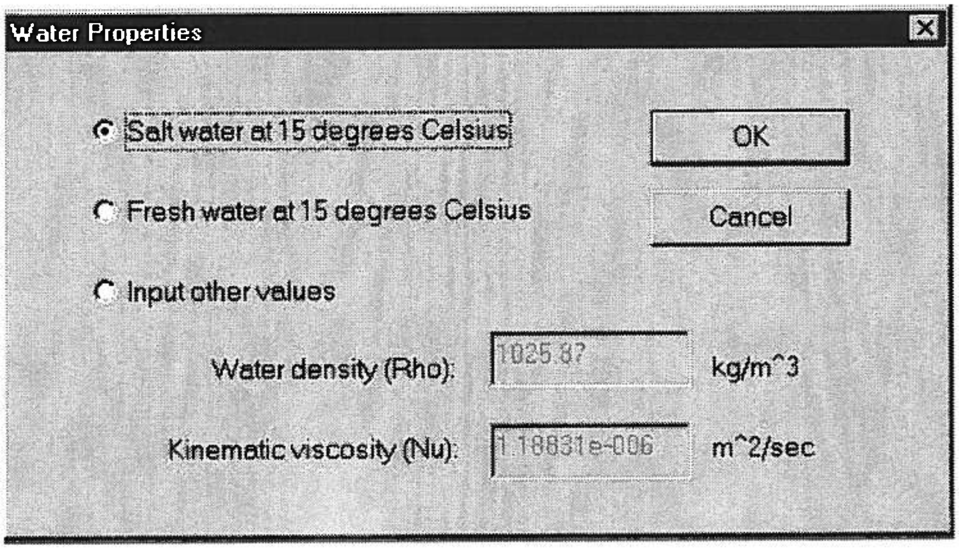
A_R	<u>total</u> rudder area as fraction of LWL∗T; i.e., A_R = A/(LWL∗T); option is calculated from the Det Norske Veritas **minimum** rudder area
T_E	steering gear time constant in seconds; default value is 2.5 s
X_R	center of effort of rudder in %LWL from amidships; + aft; i.e., about 49.0

Operating Conditions obtains the water depth and the initial vessel speed.

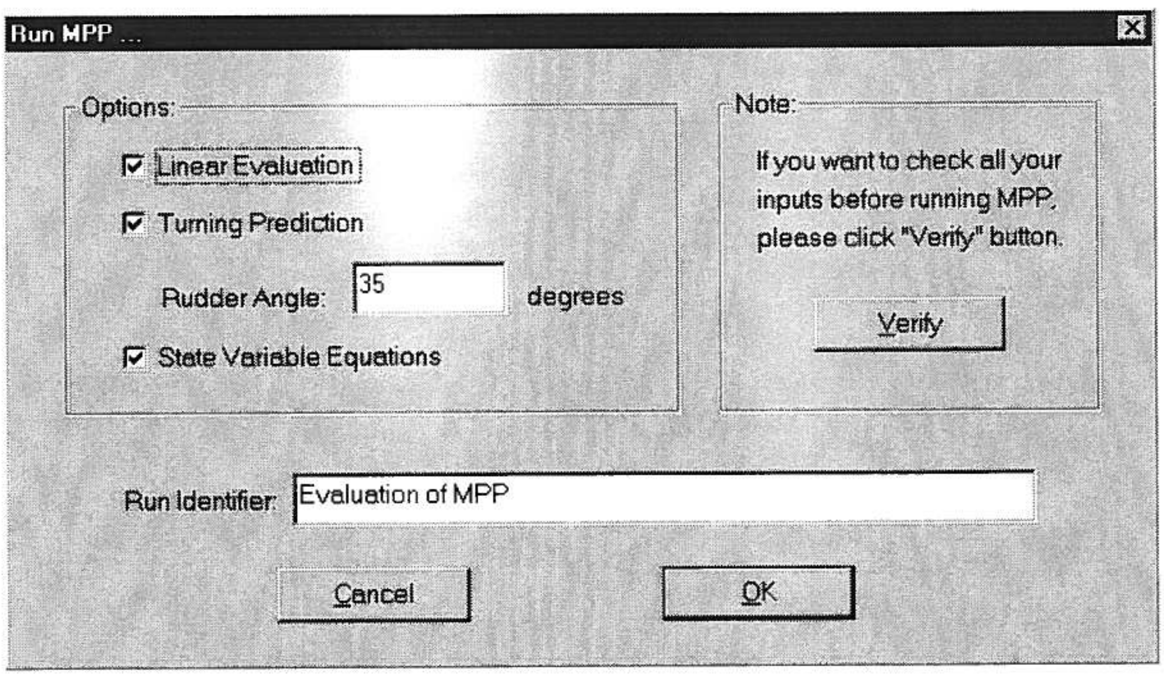


H/T	water depth to ship draft ratio (H/T); input 1000 for deep water
V_K	initial or reference ship speed in knots

Water Properties allows the choice of fresh water @ 15C, salt water @ 15C or user-specified water properties.



When the input process is completed, the program can be run through the **Analysis** menu or by selecting the **RunMPP** button. This will produce a final run input window where the selection is made for the **Linear Evaluation**, **Turning Prediction**, and **State Variable Equations** options. With selection of the **Turning Prediction** option, a rudder angle is specified. The user can also enter a run specific identifier at this point, if desired.



OUTPUT:

A sample output report resulting from the input from the above windows follows

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Department of Naval Architecture and Marine Engineering

Maneuvering Prediction Program (MPP-1.3) by M.G. Parsons

References: Clarke,D., Gedling,P., and Hine,G.,
"The Application of Manoeuvring Criteria in Hull Design using Linear Theory," Trans. RINA, 1983
Lyster, C., and Knights, H. L.,
"Prediction Equations for Ships' Turning Circles," Trans. NECIES, 1978-1979

Run Identification: Evaluation of MPP

Input Verification:

Length of Waterline LWL (m)	=	148.00
Maximum Beam on LWL (m)	=	32.30
Mean Draft (m)	=	9.00
Draft Forward (m)	=	9.00
Draft Aft (m)	=	9.00
Block Coefficient on LWL CB	=	0.7000
Molded Volume (m^3)	=	30116.52
Center of Gravity LCG (%LWL; + Fwd)	=	0.0000
Center of Gravity LCG (m from FP)	=	74.00
Midships to Rudder CE XR (%LWL; + Aft)	=	49.0000
Rudder Center of Effort XR (m from FP)	=	146.52
Initial Ship Speed (knots)	=	15.00
Initial Ship Speed (m/s)	=	7.7166
Water Type	=	Salt@15C
Water Density (kg/m^3)	=	1025.87
Kinematic Viscosity (m^2/s)	=	0.118831E-05
Yaw Radius of Gyration K33/LWL	=	0.2500
Water Depth to Ship Draft Ratio H/T	=	1000.00
Steering Gear Time Constant (s)	=	2.50
Total Rudder Area - Fraction of LWL*T	=	0.0219
Number of Propellers	=	2
Number of Rudders	=	2
Submerged Bow Area - Fraction of LWL*T	=	0.0160

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Maneuvering Prediction Program (MPP-1.3) by M.G. Parsons

*** Linear Maneuvering Criteria Option ***

Reference: Clarke, D., Gedling, P., and Hine, G., "The Application of Manoeuvring Criteria in Hull Design using Linear Theory," Trans. RINA, 1983

Run Identification: Evaluation of MPP

Linear Maneuvering Derivatives

Nondimensional Mass	M prime	=	0.018580
Nondimensional Mass Moment	I sub zz	=	0.001161
Sway Velocity Derivative	Y sub v	=	-0.024491
Sway Acceleration Derivative	Y sub v dot	=	-0.013465
Yaw Velocity Derivative	N sub v	=	-0.006917
Yaw Acceleration Derivative	N sub v dot	=	-0.001080
Sway Velocity Derivative	Y sub r	=	0.004154
Sway Acceleration Derivative	Y sub r dot	=	-0.001205
Yaw Velocity Derivative	N sub r	=	-0.003398
Yaw Acceleration Derivative	N sub r dot	=	-0.000628
Sway Rudder Derivative	Y sub delta	=	0.003997
Yaw Rudder Derivative	N sub delta	=	-0.001958

Time Constants and Gains for Nomoto's Equation

Dominant Ship Time Constant	T1 prime	=	-8.1946
Ship Time Constant	T2 prime	=	0.4130
Numerator Time Constant	T3 prime	=	0.8871
Numerator Time Constant	T4 prime	=	0.2273
1st Order Eqn. Time Constant	T prime	=	-8.6686
Rudder Gain Factor	K prime	=	4.5675
Rudder Gain Factor	K sub v prime	=	-2.5273
Steering Gear Time Constant	TE prime	=	0.1303

Evaluation of Turning Ability and Stability

Inverse Time Constant	1/|T prime|	=	0.1154
Inverse Gain Factor	1/|K prime|	=	0.2189
Clarke's Turning Index	P	=	0.4633
Linear Dynamic, Stability Criterion	C	=	-0.0000166

Vessel is hydrodynamically open loop course unstable

Closed Loop Phase Margin with Steering Engine = 2.4258 degrees

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Maneuvering Prediction Program (MPP-1.3) by M.G. Parsons

*** Turning Prediction Option ***

Reference: Lyster, C., and Knights, H. L.,
"Prediction Equations for Ships' Turning Circle",
Trans. NECIES, 1978-1979

Run Identification: Evaluation of MPP

Approach Speed	=	15.00 knots
Rudder Angle	=	35.00 degrees
Steady Turning Diameter	=	489.71 meters
Tactical Diameter	=	510.02 meters
Advance	=	421.76 meters
Transfer	=	219.02 meters
Steady Speed in Turn	=	9.62 knots

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***State Variable Equations Option ***

Run Identification: Evaluation of MPP

```
      [psi]     [ 0  1    0  ][psi]    [0 ]
d/dt[ r ]  = [ 0 a22 a23 ][ r ]  + [b2] delta
      [ v ]     [ 0 a32 a33 ][ v ]    [b3]

              [      0            0    ]
            + [gamma 21   gamma 22][Y external]
              [gamma 31   gamma 32][N external]
```

```
Open Loop Dynamics Matrix Coeff.          a22 =     -1.66593
Open Loop Dynamics Matrix Coeff.          a23 =      3.48446
Open Loop Dynamics Matrix Coeff.          a32 =      0.44714
Open Loop Dynamics Matrix Coeff.          a33 =     -0.63323

Control Distribution Matrix Coeff.         b2 =     -1.19719
Control Distribution Matrix Coeff.         b3 =     -0.16973

Ext. Force Distr. Matrix Coeff.     gamma 21 =    -19.26932
Ext. Force Distr. Matrix Coeff.     gamma 22 =    571.99927
Ext. Force Distr. Matrix Coeff.     gamma 31 =    -31.93038
Ext. Force Distr. Matrix Coeff.     gamma 32 =     21.50796
```

SEAKEEPING PREDICTION PROGRAM (SPP1.5)
M. G. Parsons, March, 1997

REFERENCES:

1. Raff, A. I., "Program SCORES - Ship Structural Response in Waves," Ship Structures Committee Report SSC-230, 1972.
2. Price, W. G. and Bishop, R. E. D., *Probabilistic Theory of Ship Dynamics*, Halsted Press, 1974.
3. Troesch, A. W., "Naval Architecture NA440 Ship Dynamics II," Course Notes.

METHODS:

This program implements a version of the five degree-of-freedom SCORES Program written by Raff and Kaplan while at Oceanics, Inc. in the early 1970's (1). This probabilistic analysis (2,3) involves the use of strip theory and models long-crested seas. Each hull section is represented by a Lewis Form transformation which makes it possible to run the program when only the Section Area, Design Waterline, and drafts are known. An input option also allows the approximate development of this data from early ship parameters only. The hydrodynamic calculations utilize ideal fluid theory which seriously underpredicts the roll damping, which is mostly viscous. To produce acceptable roll results, the user can input an effective roll damping ratio (zeta) to account for the viscous effects in roll.

The program calculates the motion response in heave, pitch, and roll and the vertical wave bending moment, lateral wave bending moment, and hull torsional moment in a specified case of sea spectrum, ship speed, and ship heading relative to the waves. The natural frequencies and period in heave, pitch, and roll are calculated. The Root Mean Square (RMS), average, average of the 1/3 highest or significant, and average of the 1/10 highest values are calculated for the input wave spectrum and each of the six response spectra. A design value is also produced for each of the bending moments M_i using a long-term extreme prediction due to Ochi,

design value M_i = RMS_i*SQRT(2*ln(N/alpha)),

with N = 1000, roughly the number of waves encountered in 3+ hour peak exposure in a severe storm; and alpha = 0.01, giving an approximate probability of exceedance of one percent. The Pierson-Moskowitz spectrum, ISSC two parameter spectrum, and the JONSWAP fetch-limited spectrum are available as wave inputs.

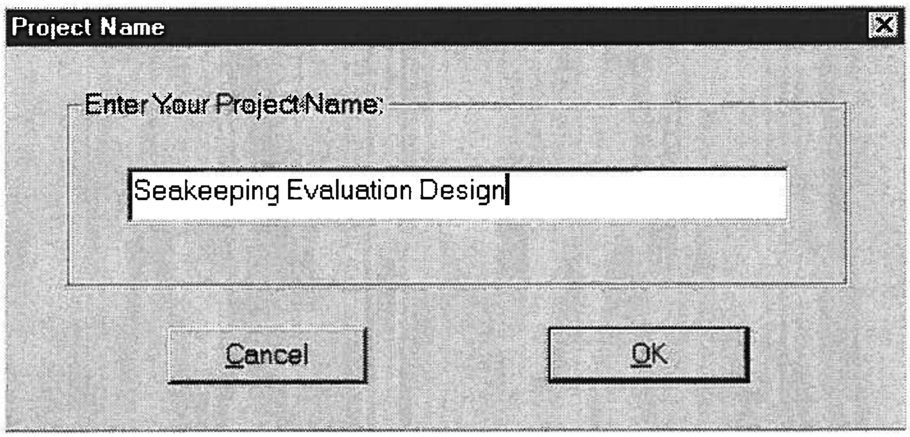
INPUT:

The input to SPP is through a series of four windows within the menu **Input** as follows:

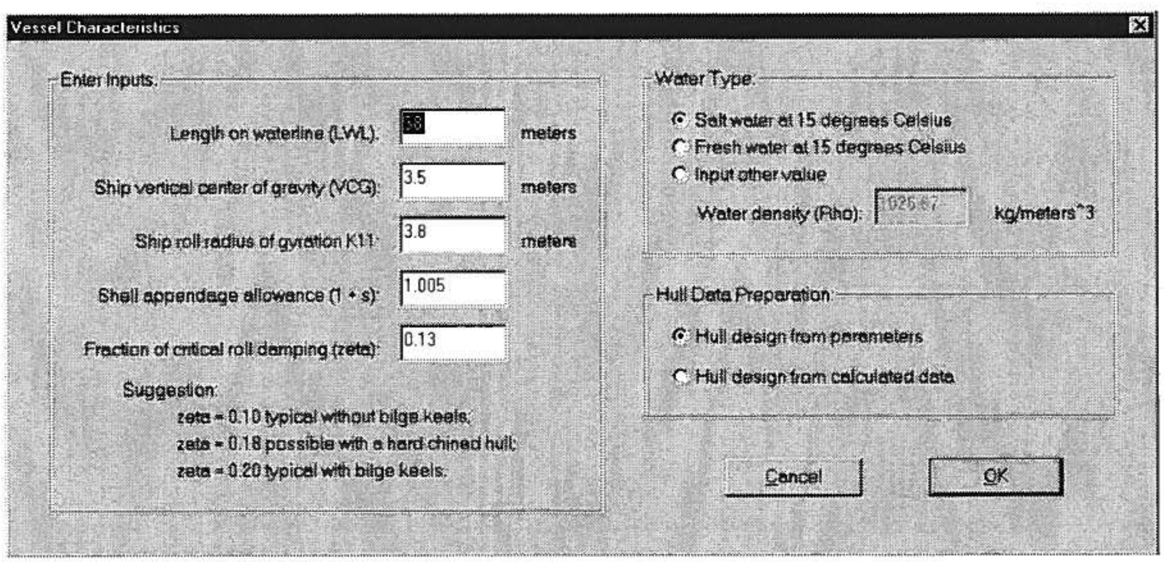
Input
- **Project Name**
- **Vessel Characteristics**
- **Operating Conditions**
- **Seaway Characteristics**

Each of these windows must be completed before an analysis can be performed. The completed input data can be saved using the **Save** button for later re-use.

Project Name provides a location for the identification of the project being analyzed.



Vessel Characteristics obtains the basic dimensions and characteristics of the hull. It also includes the selection of the water properties from among fresh water @15C, salt water @15C, or user-specified properties.



LWL	length on waterline in meters
VCG	ship vertical center of gravity in meters
GYRAD	ship roll radius of gyration k_{11} in meters; for typical commercial hulls this can be estimated as $k_{11} = 0.5*0.79*B$
(1 + s)	shell appendage allowance on molded displacement; typically 1.005 for large ships
zeta	decimal fraction of critical roll damping (zeta = 0.10 is typical without bilge keels; zeta = 0.18 is possible with a hard chined hull; zeta = 0.20 is typical with bilge keels)

This input window also includes the choice of two ways to enter the hull definition for the analysis with options for **Hull design from parameters** and **Hull design from calculated data**. The first option approximates the Sectional Area Curve and Design Waterline Curve from parameters using 6th-order (degree 5) polynomials which depend upon the hull parameters. The second option is for use after the hull form has been developed and the Sectional Area Curve and Design Waterline Curve are available from hydrostatic analysis of the hull surface or offsets.

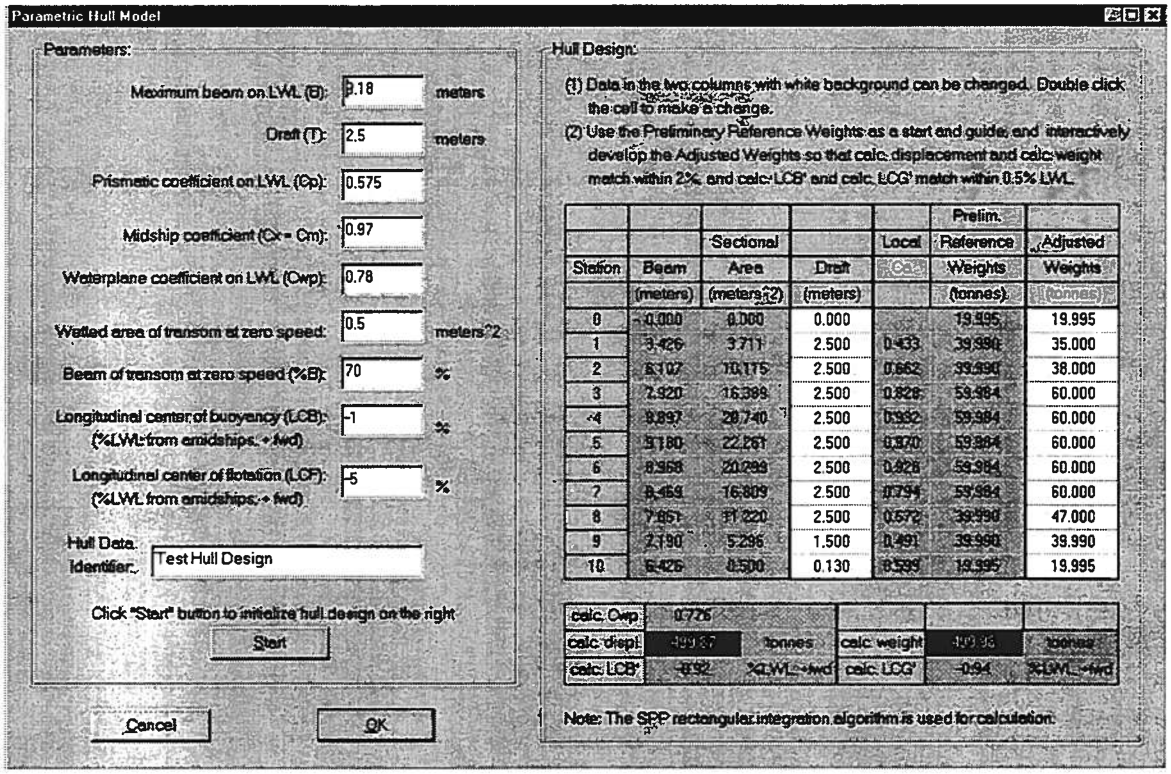
The input window for the option selected either generates or requires input of the following hull data provided at eleven stations (I = 0 to 10 from the FP):

BEAM(I)	station waterline full breadth (local beam) in meters
AREA(I)	station (local) submerged area in meters^2
DRAFT(I)	station draft in meters (**NOTE**: if the BEAM is zero, the corresponding DRAFT must also be zero.)
DWEIGHT(I)	<u>discrete</u> weight of the portion of ship centered at each station in tonnes. (**NOTE**: there is only half a station spacing, plus any overhang, associated with stations 0 and 10.)

The station spacing is assumed to be LWL/10. The area and the weight must agree within 2% and the area LCB and the weight LCG must agree within 0.5% of the LWL. The input process checks these limits. The discrete weight distribution is used only to estimate the pitch mass moment of inertia and can be somewhat approximate provided it produces the correct total weight and LCG. The spreadsheet input window aids the user in developing an acceptable discrete weight distribution.

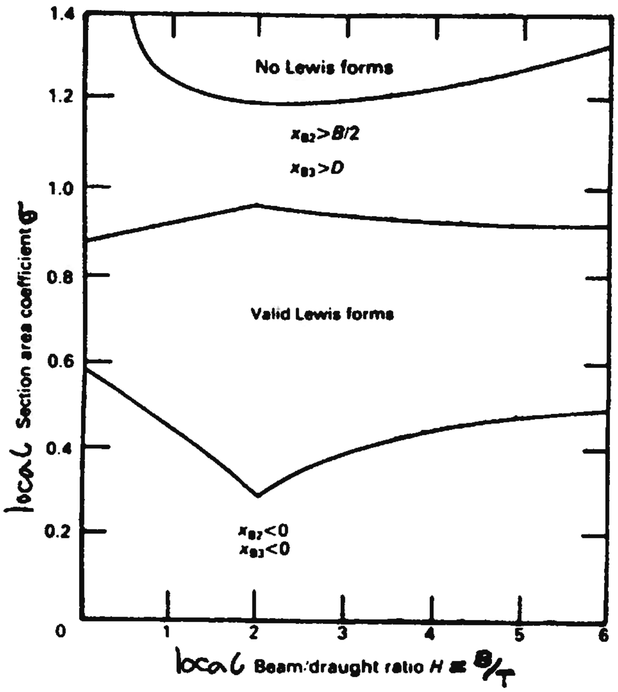
1. **Hull design from parameters** option:

In this first option, a spreadsheet appears which allows the development of an approximate Design Waterline Curve and Section Area Curve from ship parameters using 6-th order (degree 5) polynomials for each curve. This model neglects a bulbous bow, but allows a transom stern since this has significant impact on the design waterplane and, thus, seakeeping. The model is not effective in modeling hulls with significant parallel midbody. The user inputs maximum beam, Cp, Cwp, Cx, draft, wetted area of the transom at zero speed in m^2, transom beam at zero speed as a percent of maximum beam, and LCB and LCF from amidships as a percent of LWL, positive forward.



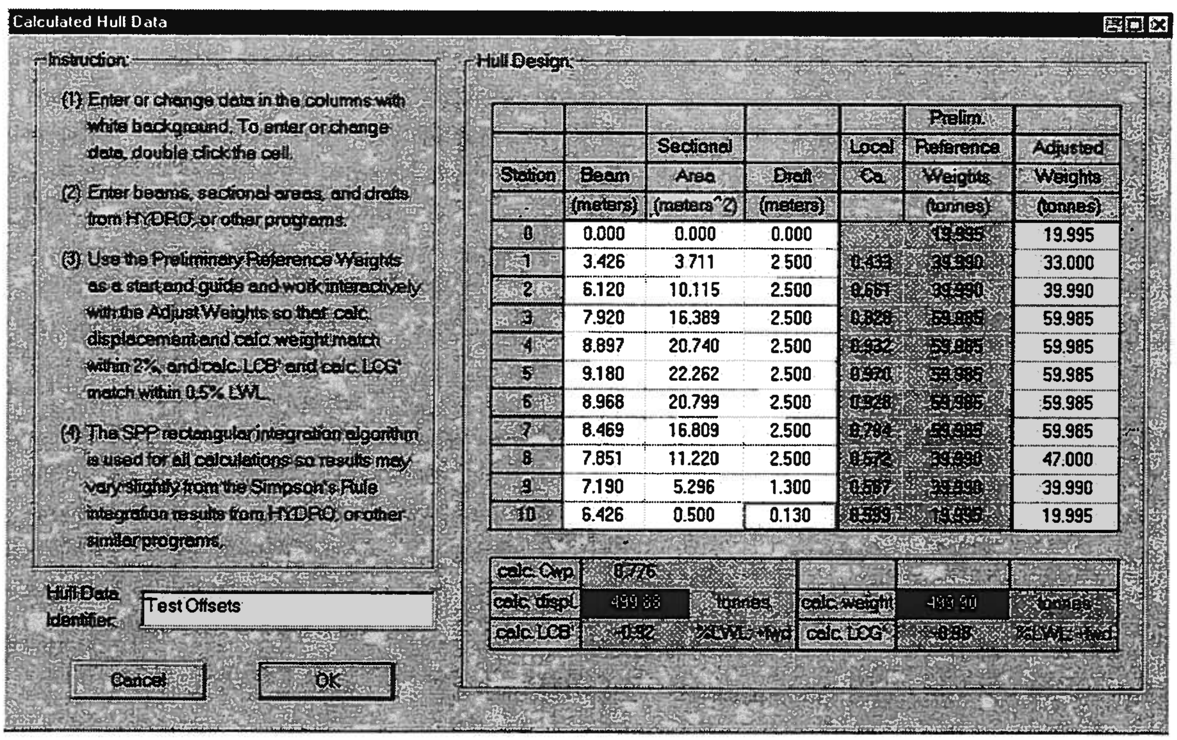
Since SPP uses the Lewis Form complex variable transformation to model the hull sections, the user needs to be cognizant of the limits of this transformation. The hull section is transformed to a half circle based upon the local section area coefficient and the local beam-draft ratio. The spreadsheet shows the local section area coefficient for reference. This should vary smoothly along the length and provide a valid Lewis Form as shown in the central band in the figure below. There is not limit to the permissible local beam-draft ratio but only a limited range of the local section area coefficient is possible.

The spreadsheet also assists the user in developing a discrete weight distribution which provides the required weight~displacement and LCG~LCB. The spreadsheet shows a preliminary discrete weight distribution with the correct weight, but LCG = 0, which can be used for reference in interactively developing the final weight distribution in the next column. The user can use the reference distribution and the calculated LCB to develop a final discrete weight distribution which reflects the details of the particular ship design and provides both the required total weight and LCG. The white cells in the spreadsheet can have data entered or edited by the user by double clicking on the call to be changed.



2. **Hull design from calculated data** option:

In this second option, a spreadsheet appears which allows the user to input the Design Waterline Curve and the Sectional Area Curve using data obtained from the Hydrostatics analysis of the detailed hull NURB surface or the resulting hull offsets. The development of the discrete weight distribution is the same as in the Hull design from parameters option above.


Calculated Hull Data

Instruction:

(1) Enter or change data in the columns with white background. To enter or change data, double click the cell.

(2) Enter beams, sectional areas, and drafts from HYDRO, or other programs.

(3) Use the Preliminary Reference Weights as a start and guide and work interactively with the Adjust Weights so that calc. displacement and calc weight match within 2%, and calc. LCB' and calc. LCG' match within 0.5% LWL.

(4) The SPP rectangular integration algorithm is used for all calculations so results may vary slightly from the Simpson's Rule integration results from HYDRO, or other similar programs.

Hull Data Identifier: Test Offsets

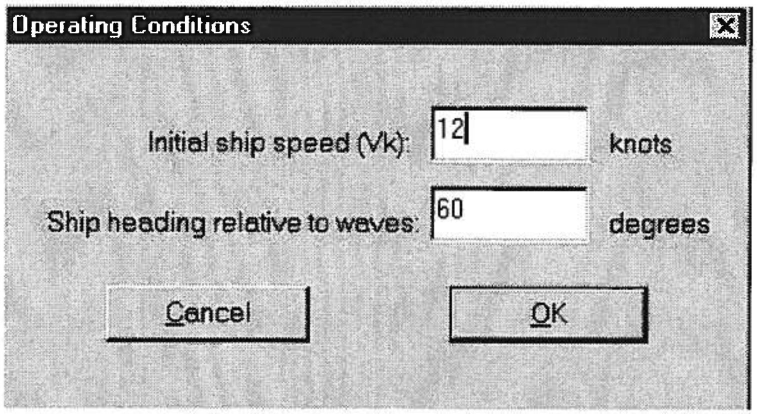
Hull Design:

					Prelim.	
		Sectional		Local	Reference	Adjusted
Station	Beam	Area	Draft	Ca	Weights	Weights
-	(meters)	(meters^2)	(meters)		(tonnes)	(tonnes)
0	0.000	0.000	0.000		19.995	19.995
1	3.426	3.711	2.500	0.433	39.990	33.000
2	6.120	10.115	2.500	0.661	39.990	39.990
3	7.920	16.389	2.500	0.828	59.985	59.985
4	8.897	20.740	2.500	0.932	59.985	59.985
5	9.180	22.262	2.500	0.970	59.985	59.985
6	8.968	20.799	2.500	0.928	59.985	59.985
7	8.469	16.809	2.500	0.784	59.985	59.985
8	7.851	11.220	2.500	0.572	39.990	47.000
9	7.190	5.296	1.300	0.567	39.990	39.990
10	6.426	0.500	0.130	0.599	19.995	19.995

calc. Cwp	0.776				
calc. displ.	499.88	tonnes	calc. weight	499.90	tonnes
calc. LCB'	-0.92	%LWL +fwd	calc. LCG'	-0.88	%LWL +fwd

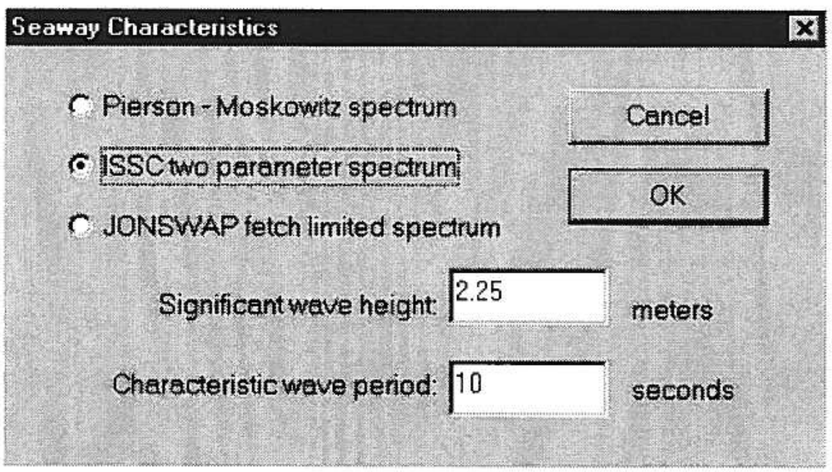
Cancel OK

Operating Conditions obtains the vessel speed and the ship heading angle relative to the wave heading.



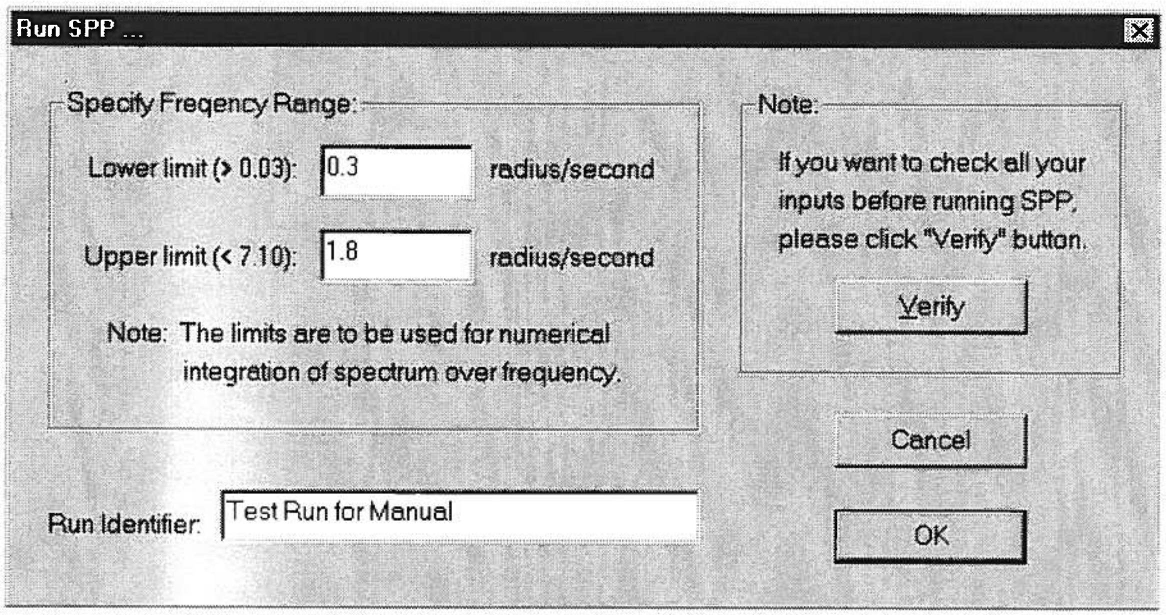
V_K	ship speed in knots
$THETA_W$	ship heading relative to waves in degrees (following seas 0, beam seas 90, head seas 180)

Seaway Characteristics provides the selection from among the three available seaway spectra models: Pierson-Moskowitz spectrum, ISSC two parameter spectrum, or JONSWAP fetch-limited spectrum. It then obtains the parameters needed to define the selected spectrum.



V_W	wind speed in knots, for Pierson-Moskowitz spectrum or JONSWAP fetch-limited spectrum
FETCH	wind fetch in kilometers, for JONSWAP fetch-limited spectrum
H_S	significant wave height in meters, for ISSC two parameter spectrum
T_1	characteristic wave period in seconds, for ISSC two parameter spectrum

When the input process is completed, the program can be run through the **Analysis** menu or by selecting the **RunSPP** button. This will produce a final run input window where the user must specify a lower limit and an upper limit for the truncation of the numerical integrations of the input and output spectra needed to obtain the RMS values. The user can also enter a run specific identifier at this point, if desired.



SWL lower limit of frequency range to be considered in rad/s (>0.03; about 0.3 recommended, but verify this for output of interest)

BWL upper limit of frequency range to be considered in rad/s (<7.10; about 1.5 recommended, but verify this for output of interest)

The numerical integrals of the input and output spectra are approximated by rectangular integration with a fixed number of ordinates (19) evenly spaced from SWL to BWL. For acceptable numerical accuracy, therefore, it is desirable to have BWL - SWL as small a possible to obtain good resolution of the spectral peak, provided the errors introduced by the truncation of the tails (below SWL and above BWL) are negligible.

CAUTIONS:

1. The program may have problems with extremely flat, transom stern sections. In some cases it has been necessary to artificially increase the area of Station 10 up to a local area coefficient of about 0.6 to obtain numerical results. These small changes should have little effect on the overall, total ship results.

2. The SCORES documentation (1) states the following: "Errors in the calculation of the two-dimensional properties will be self explanatory. However, if an error is found in the energy balance check on the results of the two-

dimensional lateral motion calculation the message is printed, but the computations proceed. It has usually been found that such errors in the energy balance check have little influence on the calculated two-dimensional properties." This is not a fatal error so the computations are allowed to proceed and the results are considered to have engineering validity.

3. Hydrodynamic coefficients used in the heave, pitch, and vertical bending moment computations involve division by the encounter frequency which is shown on the program output for reference. In some circumstances in following seas, the encounter frequency passes through zero at a specific value of wave frequency. At these frequencies, the output spectrum ordinates may have very large, physically meaningless values which produce very large response values. This is usually recognizable when the response at a specific value of $theta_w$ *is clearly inconsistent with the values at adjacent wave angles. The results at these wave angles should be ignored as numerically unreliable.*

OUTPUT:

A sample output report resulting from the input from the above windows using the **Hull design from parameters** option follows.

Univeristy of Michigan
Department of Naval Architecture and Marine Engineering

Seakeeping Prediction Program (SPP-1.5) by M.G. Parsons

Reference: Raff, A. I., "Program SCORES - Ship Structural Response in Waves", Ship Structures Committee Report SSC-230, 1972

Hull Data Identification: Test Hull Design

Run Identification: Test Run for Manual

Input Verification:

Length of Waterline LWL (m)	=	38.00
Vessel Displacement (tonnes)	=	499.9
Vertical Center of Gravity VCG (m)	=	3.50
Roll Radius of Gyration k11 (m)	=	3.80
Fraction of Critical Roll Damping	=	0.1300
Ship Speed (knots)	=	12.00
Ship Heading Relative to Waves (deg)	=	60.00
Water Type	=	Salt@15C
Water Density Rho (kg/m^3)	=	1025.87
ISSC Two Parameter Spectrum Excitation		
Significant Wave Height (m)	=	2.25
Characteristic Wave Period (s)	=	10.00
Lower Freq. Integration Limit (rad/s)	=	0.30
Upper Freq. Integration Limit (rad/s)	=	1.80

Sta.	Beam[m]	Area[m^2]	Draft[m]	Weight[t]
0	0.00	0.00	0.00	20.0
1	3.43	3.71	2.50	35.0
2	6.11	10.11	2.50	38.0
3	7.92	16.39	2.50	60.0
4	8.90	20.74	2.50	60.0
5	9.18	22.26	2.50	60.0
6	8.97	20.80	2.50	60.0
7	8.47	16.81	2.50	60.0
8	7.85	11.22	2.50	47.0
9	7.19	5.30	1.50	40.0
10	6.43	0.50	0.13	20.0

Univeristy of Michigan
Department of Naval Architecture and Marine Engineering

Seakeeping Prediction Program (SPP-1.5) by M.G. Parsons

Reference: Raff, A. I., "Program SCORES - Ship Structural Response in Waves", Ship Structures Committee Report SSC-230, 1972

Hull Data Identification: Test Hull Design

Run Identification: Test Run for Manual

Motion Natural Frequencies and Periods:

Heave Natural Frequency = 1.551 rad/s Heave Natural Period = 4.05 sec.

Pitch Natural Frequency = 1.563 rad/s Pitch Natural Period = 4.02 sec.

Roll Natural Frequency = 0.704 rad/s Roll Natural Period = 8.93 sec.

Roll Damping Results:

Roll Wave Damping = 0.910E+01

Added Viscous Roll Damping = 0.154E+03

Seakeeping Response Results:

Ship Speed = 12.0 knots = 6.17 m/s

Wave Angle (with Head Seas 180 deg.) = 60.0 deg.

ISSC Two Parameter Spectrum - Sign.Height = 2.25 m Char. Period = 10.00 s

Nondimensional Motion Response Amplitude Operators:

Wave Freq. r/s	Encount. Freq. r/s	Wave Length m	Heave Ampl. n.d.	Heave Phase deg.	Pitch Ampl. n.d.	Pitch Phase deg.	Roll Ampl. n.d.	Roll Phase deg.
0.300	0.272	684.6	0.997E+00	179.9	0.514E+00	-89.5	0.972E+00	-92.5
0.383	0.337	419.3	0.993E+00	179.8	0.512E+00	-88.8	0.104E+01	-92.7
0.467	0.398	282.9	0.987E+00	179.6	0.509E+00	-87.9	0.112E+01	-93.1
0.550	0.455	203.7	0.977E+00	179.3	0.504E+00	-86.8	0.124E+01	-93.8
0.633	0.507	153.6	0.963E+00	179.0	0.497E+00	-85.4	0.138E+01	-95.0
0.717	0.555	120.0	0.943E+00	178.6	0.487E+00	-83.8	0.156E+01	-97.2
0.800	0.599	96.3	0.918E+00	178.1	0.474E+00	-81.9	0.179E+01	-101.0
0.883	0.638	79.0	0.886E+00	177.5	0.458E+00	-79.7	0.203E+01	-107.2
0.967	0.673	65.9	0.846E+00	176.9	0.438E+00	-77.2	0.224E+01	-116.2
1.050	0.703	55.9	0.799E+00	176.1	0.414E+00	-74.4	0.231E+01	-127.2
1.133	0.729	48.0	0.744E+00	175.3	0.386E+00	-71.2	0.217E+01	-137.5
1.217	0.751	41.6	0.682E+00	174.3	0.354E+00	-67.6	0.190E+01	-144.3
1.300	0.768	36.5	0.614E+00	173.1	0.318E+00	-63.7	0.161E+01	-147.2
1.383	0.781	32.2	0.539E+00	171.6	0.279E+00	-59.4	0.135E+01	-146.5
1.467	0.790	28.6	0.459E+00	169.7	0.236E+00	-54.6	0.112E+01	-142.6
1.550	0.794	25.6	0.376E+00	167.0	0.192E+00	-49.3	0.928E+00	-135.7
1.633	0.794	23.1	0.293E+00	162.6	0.147E+00	-43.3	0.759E+00	-125.3
1.717	0.789	20.9	0.214E+00	154.8	0.103E+00	-36.4	0.610E+00	-110.4
1.800	0.780	19.0	0.148E+00	139.6	0.613E-01	-27.6	0.485E+00	-88.7

Seakeeping Prediction Program (SPP-1.5) by M.G. Parsons

Run Identification: Test Run for Manual

Nondimensional Moment Response Amplitude Operators:

Wave Freq. r/s	Encount. Freq. r/s	Wave Length m	Vertical Moment Ampl. n.d.	Vertical Moment Phase deg.	Trans. Moment Ampl. n.d.	Trans. Moment Phase deg.	Tors. Moment Ampl. n.d.	Tors. Moment Phase deg.
0.300	0.272	684.6	0.308E-03	173.7	0.399E-03	88.3	0.195E-04	-138.2
0.383	0.337	419.3	0.449E-03	171.3	0.645E-03	87.9	0.473E-04	-135.3
0.467	0.398	282.9	0.580E-03	166.7	0.938E-03	87.4	0.990E-04	-133.2
0.550	0.455	203.7	0.695E-03	158.5	0.127E-02	86.9	0.188E-03	-131.6
0.633	0.507	153.6	0.813E-03	145.3	0.164E-02	86.3	0.333E-03	-130.9
0.717	0.555	120.0	0.101E-02	127.7	0.205E-02	85.5	0.563E-03	-131.1
0.800	0.599	96.3	0.139E-02	110.3	0.249E-02	84.5	0.913E-03	-132.9
0.883	0.638	79.0	0.204E-02	97.8	0.294E-02	83.4	0.142E-02	-137.0
0.967	0.673	65.9	0.300E-02	90.3	0.341E-02	82.4	0.208E-02	-143.8
1.050	0.703	55.9	0.425E-02	86.6	0.392E-02	82.0	0.276E-02	-152.4
1.133	0.729	48.0	0.581E-02	85.2	0.450E-02	82.0	0.330E-02	-160.4
1.217	0.751	41.6	0.762E-02	85.4	0.523E-02	81.8	0.363E-02	-165.0
1.300	0.768	36.5	0.961E-02	86.7	0.604E-02	81.1	0.383E-02	-166.0
1.383	0.781	32.2	0.117E-01	88.8	0.694E-02	80.2	0.396E-02	-164.2
1.467	0.790	28.6	0.137E-01	91.4	0.788E-02	79.2	0.405E-02	-160.3
1.550	0.794	25.6	0.154E-01	94.5	0.879E-02	78.2	0.409E-02	-154.9
1.633	0.794	23.1	0.167E-01	98.1	0.963E-02	77.5	0.405E-02	-148.2
1.717	0.789	20.9	0.173E-01	102.0	0.103E-01	77.1	0.389E-02	-140.4
1.800	0.780	19.0	0.170E-01	106.5	0.107E-01	77.1	0.352E-02	-131.1

Wave Input and Response Amplitude Spectra:

Freq. r/s	Wave Amp. m^2s	Heave m^2s	Pitch deg.^2s	Roll deg.^2s	Vert. Mom. (t-m)^2s	Lat. Mom. (t-m)^2s	Tors. Mom. (t-m)^2s
0.300	0.007	0.007	0.000	0.002	0.120E+00	0.201E+00	0.481E-03
0.383	0.426	0.420	0.082	0.338	0.159E+02	0.328E+02	0.176E+00
0.467	0.918	0.894	0.385	1.878	0.572E+02	0.149E+03	0.166E+01
0.550	0.818	0.780	0.648	3.900	0.730E+02	0.245E+03	0.533E+01
0.633	0.560	0.519	0.759	5.861	0.685E+02	0.280E+03	0.115E+02
0.717	0.357	0.318	0.762	7.861	0.672E+02	0.278E+03	0.209E+02
0.800	0.226	0.191	0.711	10.101	0.807E+02	0.259E+03	0.349E+02
0.883	0.146	0.114	0.635	12.548	0.112E+03	0.233E+03	0.545E+02
0.967	0.096	0.069	0.550	14.437	0.160E+03	0.207E+03	0.766E+02
1.050	0.065	0.042	0.463	14.373	0.217E+03	0.184E+03	0.917E+02
1.133	0.045	0.025	0.379	11.955	0.281E+03	0.169E+03	0.908E+02
1.217	0.032	0.015	0.300	8.645	0.343E+03	0.162E+03	0.778E+02
1.300	0.023	0.009	0.228	5.856	0.395E+03	0.156E+03	0.625E+02
1.383	0.017	0.005	0.165	3.870	0.430E+03	0.152E+03	0.493E+02
1.467	0.013	0.003	0.112	2.536	0.442E+03	0.146E+03	0.387E+02
1.550	0.010	0.001	0.070	1.646	0.427E+03	0.139E+03	0.301E+02
1.633	0.007	0.001	0.039	1.047	0.387E+03	0.128E+03	0.228E+02
1.717	0.006	0.000	0.018	0.646	0.324E+03	0.115E+03	0.163E+02
1.800	0.005	0.000	0.006	0.390	0.247E+03	0.980E+02	0.106E+02

Wave Input and Response Amplitude Statistics:

	m	m	deg.	deg.	t-m	t-m	t-m
R.M.S.	0.561	0.533	0.725	2.996	0.183E+02	0.160E+02	0.759E+01
Ave.	0.701	0.666	0.906	3.745	0.228E+02	0.200E+02	0.948E+01
Signif.	1.121	1.066	1.450	5.991	0.365E+02	0.321E+02	0.152E+02
Ave 1/10	1.430	1.359	1.849	7.639	0.466E+02	0.409E+02	0.193E+02
Design Value with N=1000 and alpha=0.01					0.877E+02	0.770E+02	0.364E+02

GEAR SIZING PROGRAM (GSP1.0)
M. G. Parsons, January, 1991

REFERENCES:

1. Balukjian, H., "A Computerized Method for the Preliminary Design of Main Reduction Gears," *Naval Engineers Journal*, February, 1972.
2. Mowers, G. P., "Reduction Gears," Ch. IX in *Marine Engineering*, Harrington, R. L., (Ed.), SNAME, Jersey City, N. J., 1992.
3. Parsons, M. G., "NA330 Class Notes for Ship Power Systems I," September, 1977.

METHODS:

This program implements the gear sizing and arrangement method presented by Balukjian (1), Mowers (2) and Parsons (3). The user should consult Balukjian and Mowers prior to using the program.

Based on the input, the program calculates the following gear characteristics:

- total reduction ratio.
- first reduction ratio, if a double reduction gear.
- diameter of the pinion for the first reduction.
- diameter of the gear for the first reduction.
- diameter of the pinion for the second reduction, if a double reduction gear.
- diameter of the gear for the second reduction, if a double reduction gear.
- estimate of the total gear weight.
- estimate of the overall gear box length.
- shaft separation (vertical or horizontal or both, depending on the case analyzed).
- estimate of the overall breadth of the gear box.
- estimate of the overall height of the gear box.

The user should compare the dimensions with the appropriate drawing in the Appendix. For example, if the user has input data for two engines, one power path per engine, and a single reduction gear, then the appropriate drawing is Case 5. Note that in this case the only available offset is horizontal.

INPUT:

The input to GSP is through a series of three windows within the menu **Input** as follows:

Input

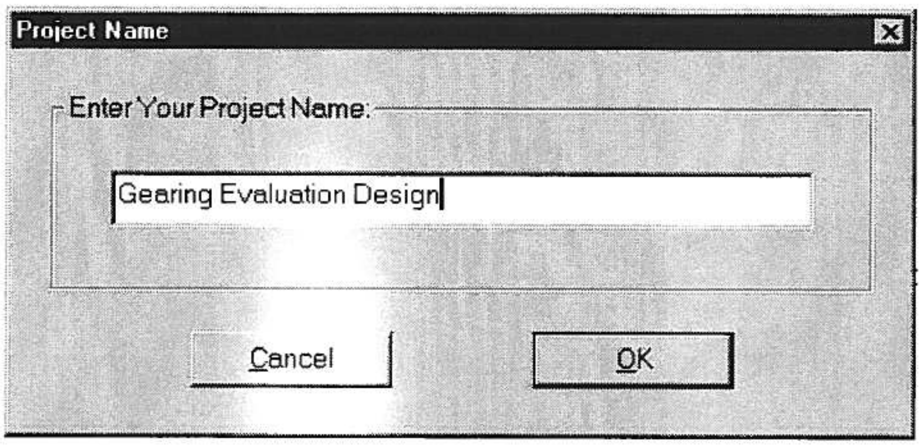
Project Name

Gear Functions

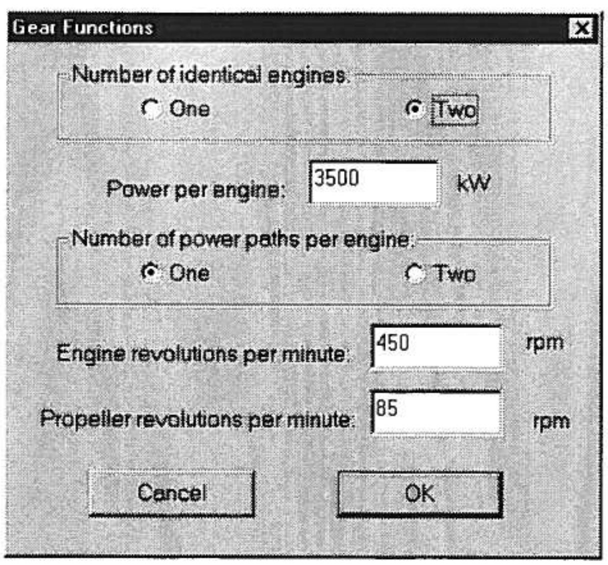
Gear Details

Each of these windows must be completed before an analysis can be performed. The completed input data can be saved using the **Save** button for later re-use.

Project Name provides a location for the general identification of the project being analyzed.

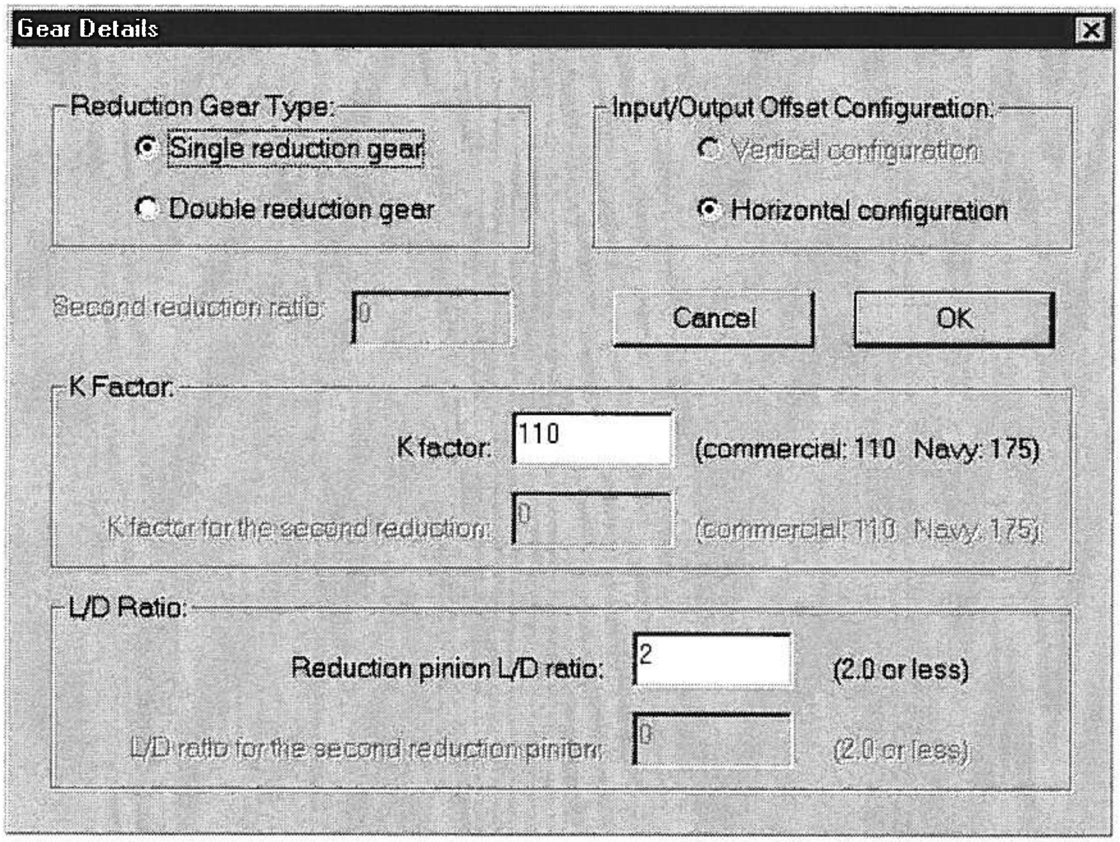


Gear Functions obtains the basic functionality of the reduction gear including number of identical input engines (1 or 2), number of power paths per engine (1 or 2), input power per engine, engine input RPM, and propeller output RPM.



kW	input power per engine in kilowatts
RPME	engine input revolutions per minute
RPMP	propeller output revolutions per minute

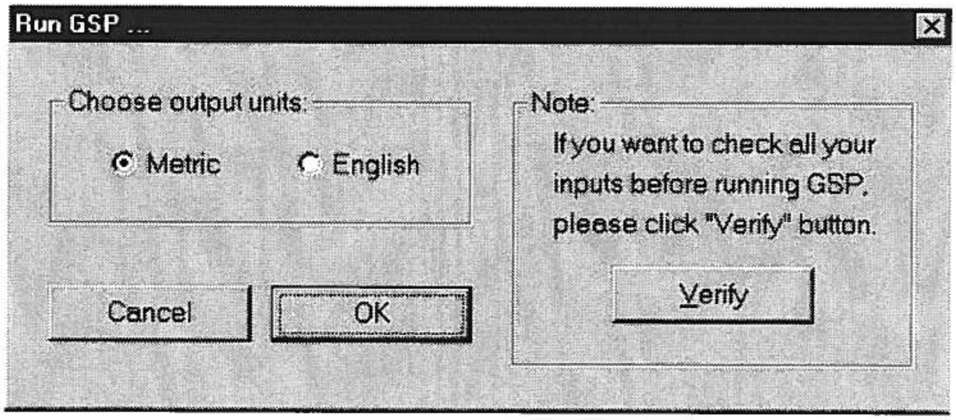
Gear Details obtains the requirement for a single or double reduction gear and then the appropriate parameters for the gear design selected.



R2	second reduction ratio if double reduction gear; a first approximation for R2 can be taken as R2 = 0.2*(ROA)+1, where ROA = RPME/RPMP
IVH	vertical or horizontal input/output offset configuration when a choice; two engine, double reduction gears have a default 45 degree offset
K1	K-factor for the first (high speed) reduction - a dimensional variable with units lbf/in-in; recommended values: • 140 commercial, 225 Navy for the first reduction of double reduction gears • 110 commercial, 175 Navy for single reduction gears
K2	K-factor for the second reduction of double reduction gears recommended values: • 110 commercial, 175 Navy
RLD1	length-diameter L/D ratio for the first reduction pinion recommended value 2.0 or less

RLD2 length-diameter L/D ratio for the second reduction pinion of double reduction gears recommended value 2.0 or less

When the input process is completed, the program can be run through the **Analysis** menu or by selecting the **RunGSP** button. This will produce a final run input window where the user must specify the output units in metric or English.



OUTPUT:

A sample output report resulting from the input from the above windows follows:

The University of Michigan
Department of Naval Architecture and Marine Engineering

Gear Sizing Program (GSP1.0) by M. G. Parsons - January, 1991

Source: Balukjian, H.,"A Computerized Method for the Preliminary Design of Main Reduction Gears," Naval Engineers Journal, February,1972.

Input Verification:

Power per Engine (kW)	=	3500.00
Number of Identical Engines	=	2
Total Power (kW)	=	7000.00
Total Horsepower (BrHP)	=	9387.15
Number of Power Paths per Engine	=	1
Engine Revolutions per Minute (rpm)	=	450.00
Propeller Revolutions per Minute (rpm)	=	85.00
Reduction Gear Type	=	single reduction
Input/Output Offset Configuration	=	horizontal
K-Factor	=	110.00
Pinion L/D Ratio	=	2.00
Results units	=	metric

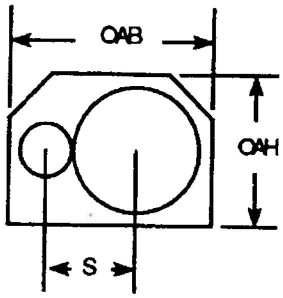
Calculations Results:

Total Reduction Ratio	=	5.29
Pinion Diameter (m)	=	0.49
Gear Diameter (m)	=	2.59
Total Gear Weight (tonnes)	=	35.26
Overall Gear Length (m)	=	2.69
Shaft Separation (Horizontal) (m)	=	3.07
Overall Breadth of the Gear Box (m)	=	4.27
Overall Height of the Gear Box (m)	=	3.10

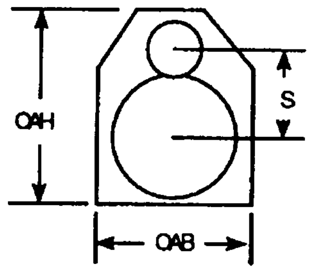
Appendix: Reduction Gear Geometries

OAB=overall breadth; OAH=overall height;
S, HS, and VS=input/output or input/input shaft (horizontal/vertical) separation

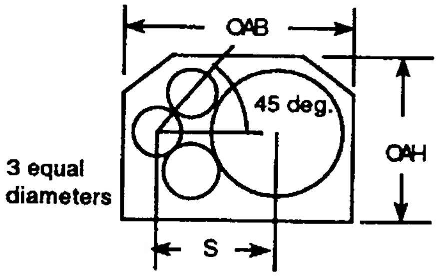
Case 1: one engine, single reduction, horizontal offset, one power path



Case 2: one engine, single reduction, vertical offset, one power path



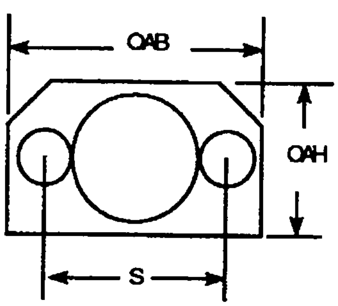
Case 3: one engine, single reduction, horizontal offset, two power paths



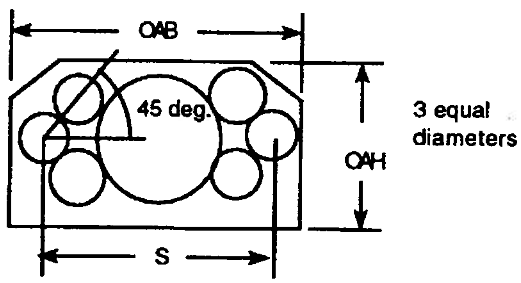
Case 4: one engine, single reduction, vertical offset, two power paths

As in Case 3, but rotated. Dimensions as in Case 2.

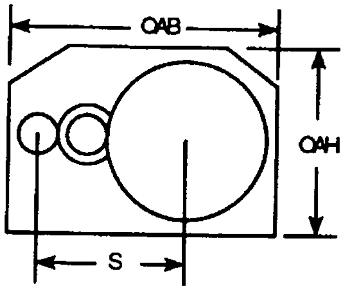
Case 5: two engines, single reduction, horizontal offset, one power path



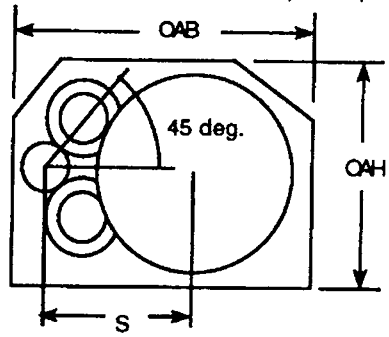
Case 6: two engines, single reduction, horizontal offset, two power paths



Case 7: one engine, double reduction, horizontal offset, one power path



Case 8: one engine, double reduction, horizontal offset, two power paths



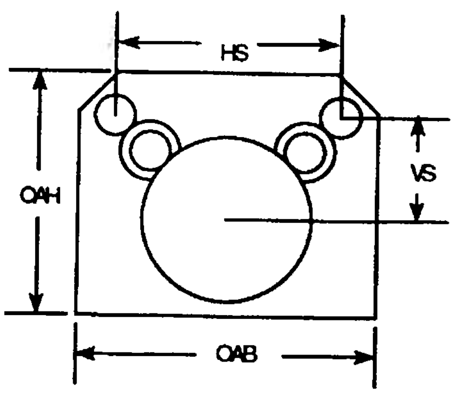
Case 9: one engine, double reduction, vertical offset, one power path

As in Case 7, but rotated. Dimensions as in Case 2.

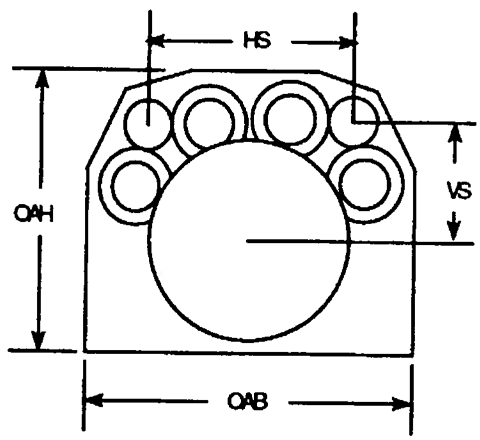
Case 10: one engine, double reduction, vertical offset, two power paths

As in Case 8, but rotated. Dimensions as in Case 2.

Case 11: two engines, double reduction, 45 degree offset, one power path



Case 12: two engines, double reduction, 45 degree offset, two power paths



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