AUSTRALIAN MARITIME ENGINEERING
CO-OPERATIVE RESEARCH CENTRE

SCHOOL OF MECHANICAL AND MANUFACTURING ENGINEERING
UNIVERSITY OF NEW SOUTH WALES
PO BOX 1, KENSINGTON NSW 2033

COMPUTER-AIDED PRELIMINARY DESIGN OF TUGS

PRABHAT KUMAR PAL

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PRABHAT KUMAR PAL
School of Mechanical and Manufacturing Engineering
University of New South Wales
PO Box 1, Kensington, NSW 2033, Australia

ABSTRACT

The compromise decision support problem (DSP) technique [1], [2] is used to find the solution of the problem of preliminary design of a tug which is a complex one as a tug is to perform efficiently in more than one condition of operation of conflicting nature. A tug is to operate with the maximum efficiency in the free–running condition and at the same time to meet the contractual condition of the bollard pull without overloading the engine. A general harbour tug design is chosen to demonstrate the use of the technique.

INTRODUCTION

Preliminary design of tugs is done for the last few decades using an iterative process involving trial and error, repetitive and complex analysis, and extrapolation of data of existing vessels. A feasible design only and not the best is produced using the method. The best design is desirable and this can be achieved by comparing many feasible alternatives which cannot be created in the process as sufficient time is not available. The produced feasible design is accepted and constructed, if the demand in the market is very high, otherwise, most of such designs are not accepted for construction which in turn increases the design costs and finally the management is forced to reduce the cost of management by reducing the design and associated staffs. Moreover, the design so produced is not competitive in the market as it is not the best. Many of such problems will be removed if a computer–aided method is employed using mathematical optimisation techniques. Single objective optimisation techniques were employed in the past, reviews of some of which were made by Lyon and Mistree [3] and Pal [4]. If the problem is formulated with a single objective optimisation function, only one aspect can be considered, e.g. the maximisation of profit, the minimisation of the cost of construction, the minimisation of total resistance etc. Whereas, if the problem is framed with multiple goals, then many aspects, e.g. various technical aspects, economic aspects can be considered at a time. The designer is then able to set an aspiration level for each of the goals. In many practical problems it might not be possible to achieve all goals due to the complexity of the problem. Appropriate deviation variables may be introduced to assess the magnitude of the differences between aspirations and achievements. Then the problem becomes a minimisation of these deviation variables satisfying system constraints. The interaction between goals can also be studied by introducing priorities by the designer.

The preliminary tug design is a complex one, particularly when propulsion is considered. Two conflicting demands are to be satisfied without overloading the engine, e.g. the maximum static bollard pull and free–running speed at the maximum efficiency. However, this is solved to some extent using a controllable pitch propeller which makes initial cost and maintenance cost higher. But the conflicting demands still exist with the installation of fixed pitch open or nozzle propellers. As cheaper to install and operate, fixed pitch propellers are considered in the design and the technique is applied to find solutions. The technique as developed is named as Compromise Decision Support Problem Technique [1],[2].

THE COMPROMISE DSP FOR A TUG DESIGN

Preamble

The compromise DSP and its application to solve marine vehicle design problems have been documented in references [3], [5] and [6].

A problem to design a harbour tug less than 40 m LOA is chosen to demonstrate the application of the compromise DSP technique. The design is a simplified harbour tug whose typical general arrangement is shown in Fig. 1. As propulsion machine, twin engines are chosen to drive fixed pitch twin propellers through gear drive. Fixed pitch propellers are chosen for reduction in the initial cost as well as lower maintenance cost. Also this arrangement requires the model to be formulated as a multi–objective optimisation problem, meeting the conflicting demands. Four–bladed as well as five–bladed B–series fixed pitch propellers are chosen to find solutions.

Mathematical Structure

Given: Required bollard pull in tonnes, free–running speed in knots, and sea state

Find: (a) System variables:

(System variables are selected as functions of design parameters or ratio of design parameters so that their ranges lie between 0 and 1.)

The general form of a function is

X(I) = (The value of the parameter or the ratio of parameters – its lower limit) / its range, i.e. the difference of the upper limit and the lower limit.

It is possible to keep a function between 0 and 1 with this type of formulation. The confusion regarding units and ranges of parameters is also eliminated. A set of fraction values can be used as input data.

X(1) : A function of the length overall–cube root of required bollard pull ratio (eq. 1)

X(2) : A function of length overall–beam ratio (eq. 2)

X(3) : A function of beam–mean draught ratio (eq. 3)

X(4)	:	A function of the beam–depth ratio	(eq. 4)
X(5)	:	A function of prismatic coefficient	(eq. 5)
X(6)	:	A function of the water plane area coefficient	(eq. 6)
X(7)	:	A function of the maximum section area coefficient	(eq. 7)
X(8)	:	A function of the longitudinal position of the centre of buoyancy	(eq. 8)
X(9)	:	A function of the half–angle of entrance	(eq. 9)
X(10)	:	A function of the propeller diameter–draught aft ratio	(eq. 10)
X(11)	:	A function of the pitch–propeller diameter ratio	(eq. 11)
X(12)	:	A function of the propeller revolutions per minute	(eq. 12)
X(13)	:	A function of the blade–area (expanded) ratio of the propeller This function varies with the type of propeller arrangement and number of blades, e.g. four–blade, five–blade, nozzle propeller (type of nozzle and number of blades).	(eq. 13)
X(14)	:	A function of the total installed horsepower–required bollard pull ratio	(eq. 14)

Functions and equations of related design parameters are shown below:

X(1)	=	$(LOA/RBP^{1/3} - 7.0)/4.0$	eq. 1
LOA	=	$(X(1) \times 4.0 + 7.0) \times RBP^{1/3}$	eq. 1a
X(2)	=	$(LOA/BM - 3.0)/1.00$	eq. 2
BM	=	$LOA/(X(2) \times 1.0 + 3.0)$	eq. 2a
X(3)	=	$(BM/TM - 2.25)/1.00$	eq. 3
TM	=	$BM/(X(3) \times 1.00 + 2.25)$	eq. 3a
X(4)	=	$(BM/DP - 1.90)/0.60$	eq. 4
DP	=	$BM/(X(4) \times 0.60 + 1.90)$	eq. 4a
X(5)	=	$(CP - 0.55)/0.10$	eq. 5
CP	=	$X(5) \times 0.10 + 0.55$	eq. 5a
X(6)	=	$(CWP - 0.70)/0.10$	eq. 6
CWP	=	$X(6) \times 0.10 + 0.70$	eq. 6a
X(7)	=	$(CM - 0.83)/0.10$	eq. 7
CM	=	$X(7) \times 0.10 + 0.83$	eq. 7a
X(8)	=	$(LCB - (-0.5))/(-4.0)$	eq. 8
LCB	=	$X(8) \times (-4.0) + (-0.5)$	eq. 8a
X(9)	=	$(ANGLE - 15.0)/15.0$	eq. 9
ANGLE	=	$X(9) \times 15.0 + 15.0$	eq. 9a
X(10)	=	$(DPR/TA - 0.5)/0.3$	eq. 10
DPR	=	$TA \times (X(10) \times 0.3 + 0.5)$	eq. 10a
X(11)	=	$(PCH/DPR - 0.5)/0.9$	eq. 11
PCH	=	$DPR \times (X(11) \times 0.9 + 0.5)$	eq. 11a
X(12)	=	$(RPM - 150.0)/150.0$	eq. 12
RPM	=	$X(12) \times 150.0 + 150.0$	eq. 12a
X(13)	=	$(AEAO - 0.40)/0.60$ (four–blade propeller)	eq. 13
AEAO	=	$X(13) \times 0.60 + 0.40$	eq. 13a

X(14)	=	(BHPT/RBP – 60.0)/20.0	eq. 14
BHPT	=	RBP × (X(14) × 20.0 + 60.0)	eq. 14a

The following assumptions are made for the design:

(i) The standard freeboard is calculated using a regression equation developed as a polynomial of the LP (FB).

(ii) Trim by aft as per cent of the LP (TRIM): 4 per cent

(iii) Surface area of shaft bracket in sq. m (ASB): $1.28 \times TA^2$

(iv) Surface area of the skeg in sq. m (ASG): $0.210 \times LP \times TA$

(v) Surface area of the hull bossings in sq. m (AHB): $0.1257 \times LP \times TA$

(vi) Surface area of shaft in sq. m (ASFT): $0.20 \times AHB$

(vii) Height of the water level above the centre line of the shaft (HCL): $TA - 0.55 \times DPR$

(viii) Surface area of twin screw balanced rudders (ABRTS): $0.144 \times LP \times TM$

(xi) Transverse immersed transom area in rest in sq. m (AT): $0.10 \times CM \times BM \times TM$

(xii) Coefficient of the stem shape (CST): 0.0

(xiii) Area of the bulb in sq. m (AB): 0.0

(xiv) Height of the centre of the bulb (HBC): above the keel in m: 0.0

(xv) Area of rudder behind skeg in sq. m (ARBSK): 0.0

(xvi) Area of rudder behind stem in sq. m (ARBST): 0.0

(xvii) Area of strut bossing in sq. m (ASTB): 0.0

(xviii) Area of dome in sq. m (ADM): 0.0

(xix) Area of bilge keels in sq. m (ABKL): 0.0

(xx) Diameter of bow thruster (DBTNL): 0.0

(xxi) Area of stabilizer fins in sq. m (ASTF): 0.0

(xxii) The height of the centre of gravity above the keel in per cent of depth (KGDPR): 70.00

(b) <u>Deviation variables</u>:

$$d_1^-,\ d_1^+,\ d_2^-,\ d_2^+,\ d_3^-,\ d_3^+,\ d_4^-,\ d_4^+,\ d_5^-,\ d_5^+$$

Satisfy (must):

(a) <u>System constraints</u>:

AREA30	– 0.055	≥	0.0	eq. 15
AREA40	– 0.090	≥	0.0	eq. 16

AR4030	− 0.030	≥	0.0	eq. 17
RADMX	− 0.4363	≥	0.0	eq. 18
RLEVMX	− 0.200	≥	0.0	eq. 19
RLEV30	− 0.200	≥	0.0	eq. 20
ARABHL	− 0.40 × AREA40	≥	0.0	eq. 21
ROLL	− 1.10 × TER	≥	0.0	eq. 22
PITCH	− 1.10 × TEP	≥	0.0	eq. 23
HEAVE	− 1.10 × TEH	≥	0.0	eq. 24
GMINI	− 0.15	≥	0.0	eq. 25
FB	− (DP − TM)	≥	0.0	eq. 26
TOWC	− TOWCC	≥	0.0	eq. 27
TOWBPC	− TOWCBP	≥	0.0	eq. 28

(b) Bounds (system variables):

X(1),X(2), ... X(14)	≥	0.0	eq. 29 – eq. 42
X(1),X(2), ... X(14)	≤	1.0	eq. 43 – eq. 56

Satisfy (as far as possible):

Goal constraints:

Fulfilment of the required bollard pull

$$BPC/RBP + d_1^- - d_1^+ = 1.0 \qquad \text{eq. 57}$$

Minimisation of the total resistance

$$RTOT/TRTOT + d_2^- - d_2^+ = 1.0 \qquad \text{eq. 58}$$

Maximisation of the quasi propulsive coefficient

$$QPC/TRQPC + d_3^- - d_3^+ = 1.0 \qquad \text{eq. 59}$$

Equalisation of the displacement and the total weight

$$DISPLT/WEIGHT + d_4^- - d_4^+ = 1.0 \qquad \text{eq. 60}$$

Fulfilment of the required horsepower

$$DHPC/DHP + d_5^- - d_5^+ = 1.0 \qquad \text{eq. 61}$$

Target values are selected according to the set of input data.

Minimise:

The objective function:
(a function of deviation variables)

$$Z = P_1d_1^- + P_2d_1^+ + P_3d_2^- + P_4d_2^+ + P_5d_3^- + P_6d_3^+ + P_7d_4^- + P_8d_4^+ + P_9d_5^- + P_{10}d_5^+ \quad \text{eq. 62}$$

$P_1, P_2, P_3, P_4, P_5, P_6, P_7, P_8, P_9$, and P_{10} are priorities of goal constraints.

$d_1^-, d_2^-, d_3^-, d_4^-$, and d_5^- are under–achievement deviation variables, and

$d_1^+, d_2^+, d_3^+, d_4^+$, and d_5^+ are over–achievement deviation variables.

Definitions of symbols and acronyms are shown in Appendix I.

A pre–emptive approach is adopted to select values of priorities. In this approach, P_1 is preferred to P_2 which is preferred to P_3 and so on. This approach is found convenient for application to preliminary design problems of marine vehicles. Another approach (Archimedean) is applied to problems where the characteristics of solutions are known.

Solution

The program DSIDES [2] is applied to find solution of the preliminary tug design problem. The program is suitable of solving problems [3], [5], [6] of design of marine vehicles consisting of a large number of system variables with a large number of constraints of various types (linear and non–linear as well as equality and inequality). The optimisation is achieved by linearising non–linear constraints and then solving the transformed linear programming problem at each design point. Linearisations are performed using first–order and second–order derivatives [1]. The logical structure of the controlling program, SLPCTL is documented by Lyon [3]. The logical structure of user provided subroutines (differs from problem to problem) prepared for the preliminary design of harbour tug is shown in Fig. 2.

User Provided Subroutines

The subroutine SET calls subroutines for evaluation of constraints EVALG1, EVALG2 (system constraints) and EVALG3 (goal constraints). Values of design parameters required to evaluate constraints, system – as well as goal – are calculated for a set of values of system variables through the subroutine TUGDGN called by SET. The subroutine TUGDGN calls RESPOW for estimation of total resistance and associated parameters, KTKQBSR for propeller characteristics for free–running condition and for bollard pull condition, TUGSTB for estimation of particulars of stability requirements, SEAKIP for estimation of natural periods and periods of encounter of pitching, rolling and heaving. The subroutine TUGDGN also estimates components weight of the design.

Evaluation of Constraints

Constraints are identified with respect to requirements of transverse stability, sea–keeping and cavitation. Stability constraints are due to requirements of the regulatory body [7]. It is not possible to estimate them for any design at its preliminary design stage. These can only be estimated if cross curves of stability are known. As no method for estimation of such requirements is available, in this model, form stability levers are estimated at various angles of inclination at an interval of 10° up to 80°, using regression equations developed for trawler form [15] (round bilge) on the assumption that a tug form is not much different from that of a trawler form.

The sea-keeping requirements are identified assuming the design operates in the super-critical condition, i.e. the natural periods of roll, pitch and heave are all greater than the period of encounter with respect to each of these motions for the expected sea state. In this model, a natural period is assumed to be equal to or greater than 110 per cent of the period of encounter. Natural periods and periods of encounter are estimated using equations as given in the reference [8]. The constraints regarding cavitation of propeller blade, are estimated for free-running and bollard pull conditions using a regression equation developed for the Burrill's cavitation curve (upper limit of merchant propeller of all type sections). The limiting values of ratios of the thrust per unit projected blade area to the stagnation pressure for the corresponding cavitation numbers (TOWC, TOWCBP) are estimated for the free-running as well as for the bollard pull condition, using the regression equation as stated above. Corresponding values are calculated for actual conditions of loading (TOWCC and TOWBPC).

Estimation of weights of component items of light ship is made as suggested in [16], [14]. The deadweight is assumed as 30 per cent of lightship weight.

Resistance of a design is estimated using the method suggested by Holtrop, et al. [10], [11]. Design of propeller is done using regression equations for thrust and torque coefficients of B-series propellers [12].

Lower and upper limits of system variables are chosen from data published in references [9], [18], [19], [20], [21], [22].

Output Data

An extract of a set of output data is shown in Appendix II.

RESULTS

The program is tested for a set of required bollard pull in tonnes and free running speed in knots. Due to shortage of time, many computer runs can not be completed. Only a few runs are completed, extract of results of which are shown in Table I for two sets of data with 4-bladed and 5-bladed propellers, for a bollard pull of 20 tonnes and 25 tonnes. The same priority values are assumed for all goals.

CLOSURE

Conclusion

The preliminary design of a tug is done using the compromise DSP technique considering the complex propeller design with fixed pitch blade. The model is valid for the design of a general purpose harbour tug for a pull up to 25 tonnes. This technique is definitely suitable for solving complex marine vehicle design problems.

Future Work

Separate models: Separate models may be made for the design using a controllable pitch propeller and fixed pitch propeller with various nozzles, whose characteristics are known. Using later models it is possible to find the combination of propeller and nozzle which require the minimum power for a particular pull. Another model with fixed pitch open propeller may be made considering 10 per cent overload of the engine at the bollard pull and 10 per cent increase in revolution per minute for the free running condition, as suggested in the reference [17].

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TABLE I
Extract of results of some computer runs

Required bollard pull	(tonnes)	20	20	25	25
Free running speed	(knots)	11.7	11.7	11.8	11.8
Length overall	(m)	29.86	29.86	32.16	32.16
Length between perpendiculars	(m)	26.87	26.87	28.95	28.95
Length on waterline	(m)	28.37	28.37	30.56	30.56
Beam moulded	(m)	7.50	7.50	8.12	8.12
Draught moulded (mean)	(m)	2.31	2.31	2.50	2.50
Depth moulded	(m)	2.54	2.54	2.74	2.74
Freeboard (minimum)	(m)	0.22	0.22	0.24	0.24
Block coefficient		0.465	0.465	0.466	0.474
LCB* from the midpoint of waterline length		-1.475	-1.475	-2.450	-4.450
Displacement	(tonnes)	224.19	224.19	283.36	287.28
Weight	(tonnes)	219.51	219.51	276.08	279.18
Initial metacentric height	(m)	3.289	3.289	3.586	3.620
Diameter of propeller	(m)	2.282	2.282	2.466	2.461
Blade area ratio		0.860	0.870	0.870	0.990
Pitch of propeller	(m)	1.313	1.295	1.362	1.511
Propeller revolution per minute		294.76	293.71	288.52	286.06
Number of blades		4	5	4	5
Total installed power	(kW)	1225.0	1225.0	1562.50	1937.5
Effective horsepower (free running)	(kW)	200.96	200.96	224.40	226.58
Quasi propulsive coefficient		0.408	0.398	0.392	0.519
Calculated bollard pull	(tonnes)	20.05	20.07	25.14	24.67
Required power (free running)	(kW)	566.18	581.00	657.91	502.13
TOWC* (free running)		0.146	0.146	0.137	0.139
TOWCC* (free running)		0.024	0.023	0.024	0.042
TOWCBP* (bollard pull)		0.185	0.186	0.172	0.191
TOWBPC* (bollard pull)		0.183	0.184	0.177	0.190

* See Appendix I

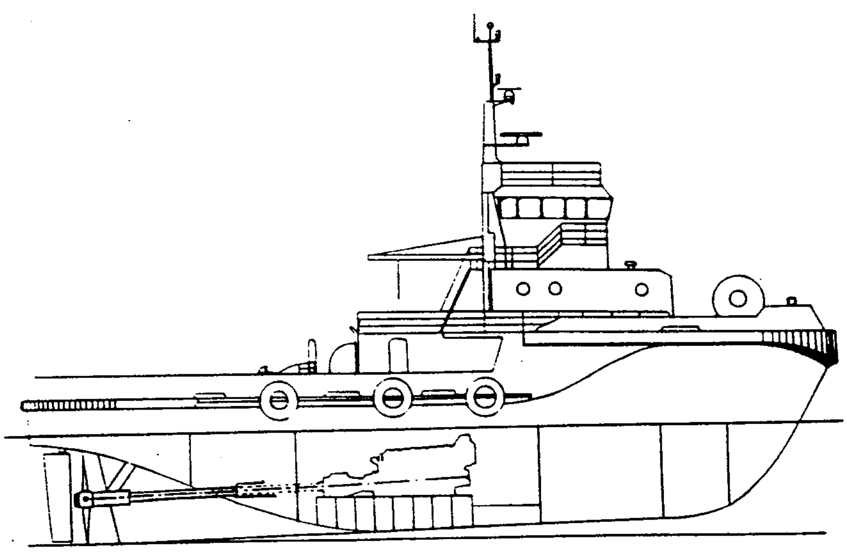
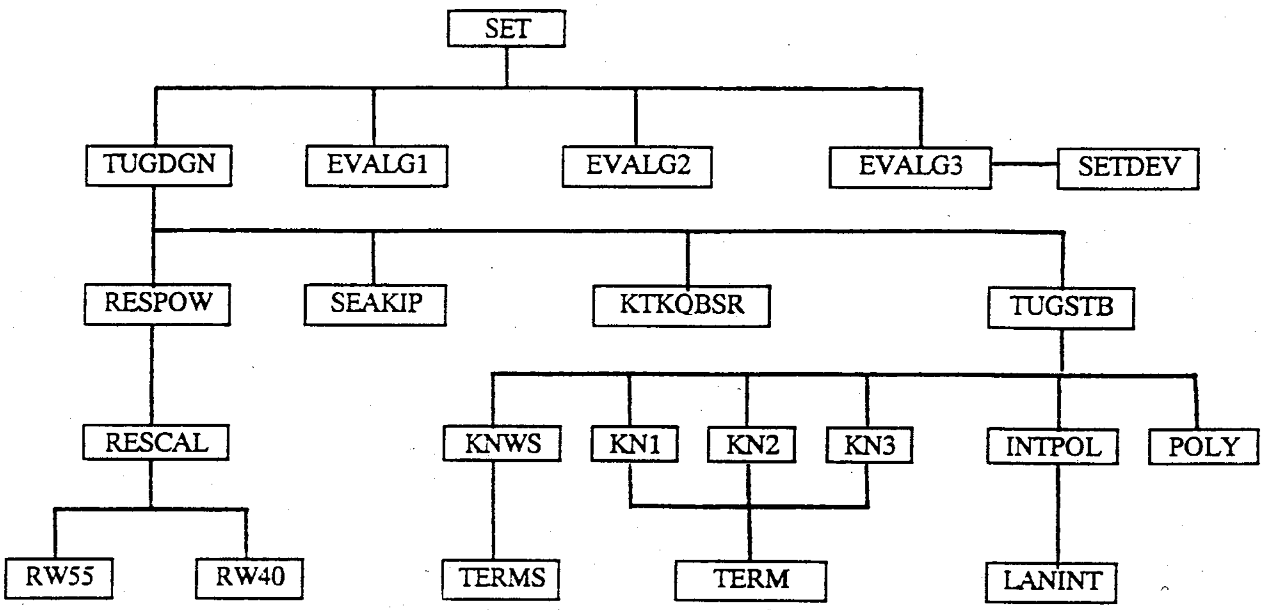


Figure 1. The design model (profile)



SUBROUTINE NAME	SUBROUTINE FUNCTION
SET	Calls constraint evaluation subroutines
EVALG1	Evaluates non–linear system constraints
EVALG2	Evaluates non–linear system constraints
EVALG3	Evaluates non–linear goal constraints
SETDEV	Sets values of deviation variables
TUGDGN	Evaluates parameters for all constraints
RESPOW	Evaluates parameters for effective horsepower
SEAKIP	Evaluates parameters for sea keeping constraints
KTKQBSR	Evaluates characteristics of B–series propellers and parameters for cavitation constraints
TUGSTB	Evaluates parameters for stability constraints
KNWS, KN1, KN2, KN3, TERM, TERMS, POLY	Evaluates form stability levers used for fitting a curve of third degree polynomial
INTPOL, LANINT	Used for interpolation purpose
RESCAL, RW40, RW55	Evaluates resistance and effective horsepower for a speed

Figure 2. User–defined subroutines logical structure

APPENDIX I
Definitions of Acronyms and Abbreviations

AB	:	Transverse area of the bulb at FP in sq. m
ABKL	:	Area of the bilge keel in sq. m
ABRTS	:	Surface area of twin screw balance rudder in sq. m
ADM	:	Area of the dome in sq. m
AEAO	:	Blade area ratio of the propeller
AHB	:	Surface area of the hull bossing in sq. m
ANGLE	:	Half angle of entrance in degrees
ARBSK	:	Area of rudder behind the skeg in sq. m
ARBST	:	Area of rudder behind the stern in sq. m
AREA30	:	Area under the stability lever curve up to 30° in m radians
AREA40	:	Area under the stability lever curve up to 40° in m radians
AR4030	:	Area under the stability lever curve between 40° and 30° in m radians
ARABHL	:	Area above heeling level curve and below stat. stab. lev. curve up to 40° in m rads
ASB	:	Surface area of the shaft bracket in sq. m
ASG	:	Area of skeg in sq. m
ASFT	:	Surface area of shaft in sq. m
ASTB	:	Area of strut bossing in sq. m
ASTF	:	Area of stabilizer fins in sq. m
AT	:	Transverse immersed transom area at rest in sq. m
BHPT	:	Total installed power in kW
BPC	:	Calculated bollard pull in tonnes
BM	:	Moulded beam in m
CP	:	Prismatic coefficient
CM	:	Maximum section area coefficient
CST	:	Coefficient of stern shape
CWP	:	Water plane area coefficient
DBTNL	:	Diameter of bow thruster tunnel in m
DHP	:	Available delivery power
DHPC	:	Required delivery power for the free running condition in kW
DISPLT	:	Displacement of the vessel in tonnes
DP	:	Depth in m
DPR	:	Propeller diameter in m
EHP	:	Effective horsepower in kW
FB	:	Freeboard in m
GMINI	:	Initial metacentric height in m
HBC	:	Height of the centre of the bulb above the keel in m
HCL	:	Height of water above the centreline of the ship in m
HEAVE	:	Time period of natural heaving in sec
KGDPR	:	Height of centre of gravity above keel to depth ratio
LCB	:	Longitudinal position of centre of buoyancy in per cent of water line length from midlength –ve means aft of midlength
LOA	:	Length overall in m
LP		Length between perpendiculars in m
PCH	:	Pitch of propeller blade in m
PITCH	:	Time period of natural pitching in secs
QPC	:	Quasi propulsive coefficient

RADMX	:	Angle at which the maximum righting lever occurs in radians
RBP	:	Required bollard pull in tonnes
RLEVMX	:	Maximum righting lever in m
RLEV30	:	Righting lever at 30° inclination in m
ROLL	:	Time period of natural roll in secs
RPM	:	Propeller revolutions per min corresponding to the rated condition
RTOT	:	Total resistance of hull in k Newtons
TA	:	Draught aft in m
TER	:	Time period of encounter of rolling in secs
TEP	:	Time period of encounter of pitching in secs
TEH	:	Time period of encounter of heaving in secs
TF	:	Draught forward in m
TM	:	Draught mean in m
TOWBPC	:	Thrust per unit projected blade area–stag. pres. ratio (bollard pull – calculated)
TOWC	:	Thrust per unit projected blade area–stag. pres. ratio (free running – limiting)
TOWCBP	:	Thrust per unit projected blade area–stag. pres. ratio (bollard pull – limiting)
TOWCC	:	Thrust per unit projected blade area–stag. pres. ratio (free running – calculated)
TRIM	:	Trim in per cent of LP by aft
TRTOT	:	Target value of the total resistance in k Newtons
TRQPC	:	Target value of the quasi propulsive coefficient
WEIGHT	:	Total weight (lightship weight + deadweight) in tonnes

APPENDIX II
An extract of an output

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TUG DESIGN BY COMPROMISE DSP
ANALYSIS SYNTHESIS CYCLE NUMBER :      1
PROBLEM NO.   0 FINAL FEASIBLE DESIGN - SYNTHESIS CYCLE NO.     4
..........................................................
VARIABLE       VALUE                  VARIABLE      VALUE
........       .....                  ........      .....
  LBPR          1.0000                  LBMR         0.98125
  BTMR         0.99000                  BDPR         0.93750E-02
  CP           0.94431E-01              CWP          0.93750E-02
  CM           0.15502E-01              LCB          0.24375
  ANGL         0.93750E-02              DPTR          1.0000
  PDR          0.84043E-01              RPM          0.96505
  AEAO         0.76900                  HPBP         0.62500E-01
  UABP         0.00000E+00              OABP         0.23767E-02
  UART         0.00000E+00              OART         0.49327
  UAQP         0.45575                  OAQP         0.00000E+00
  UAWD         0.00000E+00              OAWD         0.21289E-01
  UAHP         0.50831                  OAHP         0.00000E+00
VALUE OF ACHIEVEMENT FUNCTION (Sum of dev. vars.) =  1.4810     KW
  SERVICE SPEED                                  =11.700 KNOTS
 REQUIRED BOLLARD PULL                           =20.000TONNES
 SEA STATE                                       = 1
  LENGTH OVERALL                                  = 29.86   M
 LENGTH BETWEEN PERPENDICULARS                   = 26.87   M
 LENTGH ON WATER LINE                            = 28.37   M
 BEAM MOULDED                                    =  7.50   M
 DRAUGHT MOULDED (MEAN)                          =  2.31   M
 DRAUGHT AFT                                     =  2.85   M
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DRAUGHT FORWARD	= 1.78 M
DEPTH MOULDED	= 2.54 M
PRISMATIC COEFFICIENT	= 0.559
MAXIMUM SECTION AREA COEFFICIENT	= 0.832
WATER PLANE AREA COEFFICIENT	= 0.701
BLOCK COEFFICIENT	= 0.465
LONG. POS. OF CENT. OF BUOY. FROM MID LL IN % OF LL (+VE:FORWARD AND -VE:AFT)	=-1.475 %
HALF ANGLE OF ENTRANCE	= 15.14 DEG
FREE BOARD (MINIMUM)	= 0.22 M
DISPLACEMENT	= 224.19TONNES
WEIGHT	= 219.51TONNES
BLADE AREA RATIO	= 0.86
DIAMETER OF PROPELLER	= 2.282 M
PITCH OF PROPELLER	= 1.313 M
PROPELLER REVOLUTION PER MINUTE	= 294.76
NUMBER OF BLADE	= 4
NUMBER OF PROPELLER	= 2
PITCH OF PROPELLER FOR BOLLARD PULL COND.	= 1.313 M
INITIAL METACENTRIC HEIGHT	= 3.289 M
AREA UND. CUR. OF STAT.STAB.LEVER UP TO 30 D	= 0.227 M RAD
AREA UND. CUR. OF STAT.STAB.LEVER UP TO 40 D	= 0.322 M RAD
AREA UND.CUR.OF STAT.STAB.LEVER BET.30&40 D	= 0.095 M RAD
RIGHTING LEVER AT 30 DEG INCLINATION	= 0.554 M
ANGLE OF INCLINATION OF MAXIMUM LEVER	= 0.45 RAD
MAXIMUM RIGHTING LEVER	= 0.560 M
AREA BET. CUR.OF HEEL & RIGH.LEVRS. UP TO 40D	= 0.298 M RAD
RATIO OF HEIGHT OF C.G. TO DEPTH	= 0.700
NATURAL PERIOD OF ROLLING	= 2.904 SEC
NATURAL PERIOD OF PITCHING	= 3.494 SEC
NATURAL PERIOD OF HEAVING	= 3.756 SEC
PERIOD OF ENCOUNTER (ROLLING)	= 2.400 SEC
PERIOD OF ENCOUNTER (PITCHING)	= 0.921 SEC
PERIOD OF ENCOUNTER (HEAVING)	= 0.921 SEC
FROUDE NUMBER	= 0.433
CAVITATION NUMBER	= 0.345
RATIO OF THRUST/UNIT AREA TO STAG.PRESSURE	= 0.146
SURFACE AREA OF APPENDAGES	= 47.03 SQ.M
WETTED SURFACE AREA OF HULL	=209.80 SQ.M
WAVE RESISTANCE	= 64.11 KNEW
TOTAL RESISTANCE	= 89.60 KNEW
WAKE FRACTION	= 0.036
THRUST DEDUCTION FACTOR	= 0.048
RELATIVE ROTATIVE EFFICIENCY	= 1.003
EFFECTIVE HORSE POWER	= 200.96 KW
TOTAL BRAKE HORSE POWER INSTALLED	= 1225.00 KW
DELIVERY HORSE POWER	= 1151.50 KW
BOLLARD PULL WITHOUT OVER LOADING THE ENG.	= 20.05TONNES
REVOLUTION PER MINUTE AT BOLLARD PULL COND.	= 239.794
REQUIRED DHP FOR SERVICE CONDITION	= 566.18 KW
LIMITING VALUE OF TOWC AT FREE RUNNING COND.	= 0.146
CALCULATED VALUE OF TOWC AT FREE RUNNING COND.	= 0.024
LIMITING VALUE OF TOWC AT BOLLARD PULL COND.	= 0.185
CALCULATED VALUE OF TOWC AT BOLLARD PULL COND.	= 0.183

JOB COMPLETED ON: 24-OCT-91 AT: 10:01:41 HOURS

END OF PROBLEM SET