PRELIMINARY DESIGN OF CRUISING SAILING YACHTS AS A DECISION SUPPORT PROBLEM

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SUMMARY

Currently, sailing yachts are used for two principal purposes – cruising and racing. Throughout the world a large number of sailing yachts are designed and constructed. Traditional design procedures are usually employed to determine a technically feasible design. Some designers use a parametric study approach to find an optimal design. This method takes considerable time and the cost of design becomes high. Therefore, it is necessary to find an optimal solution quickly using a mathematical optimisation technique at a lower cost. The primary objective of a racing yacht is to win the race, so the design process is dominated by the performance of the yacht under sail without considering the cost of construction. Whereas, the design process for a cruising sailing yacht is dominated by the consideration of the cost, internal space, aspect of aesthetics, etc.

This study records the development of a mathematical model for rapid prototyping to determine the principal design parameters of a cruising sailing yacht at the preliminary design (pre-lines plan) stage minimising resistance, heel angle, lightship weight, cost and maximising the velocity made good (VMG). Space requirement makes the yacht fuller whereas, the resistance requirement makes it finer. The conflicting demands require a compromise solution that is obtained by formulating the problem as a compromise decision support problem (DSP) and applying the decision support problem technique (DSPT).

The model is tested for a set of owner’s requirements, i.e. number of cabins, number of berths, number of days at sea, true wind velocity and a restriction on draft. A sensitivity analysis is also carried out varying the true wind velocity, number of cabins, number of berths, number of days at sea as well as the restriction of draft . Results are shown and their implications discussed.

NOMENCLATURE

CBC	Calculated block coefficient
CE	Centre of effort above deck (m)
CLR	Centre of lat. resistance below deck (m)
DISPTL	Displacement (tonnes)
HEELMV	Heel angle at VMGMAX (degrees)
MASSTL	Total mass (kg)
ROHBL	Density of ballast material (kg/m^3)
ROHLD	Density of lead (kg/m^3)
RTOTMV	Total resistance at VMGMAX (kN)

SLM	Factor to limit the mast height
TMAX	Maximum draught (m)
TRES	Restriction of draught (m)
TRMSTL	Target total mass (kg)
TRHLAN	Target heel angle (degrees)
TRTOTR	Target resistance (kN)
TRVMG	Target VMGMAX (kn)
TRYTCS	Target cost of yacht (Euros)
VOLBL	Volume of ballast (m^3)
VOLK	Volume of keel (m^3)
VOLR	Volume of rudder (m^3)
VMGMAX	Maximum velocity made good (kn)
VOLCB	Volume of canoe body (m^3)
YATCST	Cost of yacht (Euros)

1. INTRODUCTION

Sailing yacht designers use the traditional iterative method through the steps of the "design spiral" to find only one technically feasible design. Sometimes the parametric study method is also used to determine an optimal solution that normally takes considerable time and thus the cost of design becomes high. Artificial neural networks have been applied to the problem for sailing yachts e.g.[1], and other vessels e.g. [2] to generate main dimensions of the vessel for given performance targets. They provide a quick estimation of preliminary design characteristics, the quality of the information depending on the strength of the training data set used. They must be trained for each combination of inputs separately. Artana and Ishida [3] take a similar approach for the preliminary design of a tanker for minimum economic cost of transport, though they use a spreadsheet for analysis rather than an executable code. Most of the yacht applications have focused on aero-and hydro-dynamic characteristics of the yachts, as distinct from interior design and cost. Van Oosanen [4] developed a "Concept Exploration Model" for the design of cruising yachts. This model is limited by a fixed hull and rig configurations and a material of construction. No mathematical optimisation is used.The current approach is to develop a model using a mathematical optimisation method. Genetic algorithms have also been used to good effect as they can deal with nonlinear holistic design problems and discrete variables, though they demand high computing power. Gradient search methods, on the other hand can be very fast but require discrete variables to be converted to continuous approximations [5].

The considerations for the design of cruising yachts are quite different from that of racing yachts. The performance under sail dominates the design of a racing yacht and the cost factor does not influence the process. However, for the design of a cruising yacht, the cost, internal space and aesthetics influence the design process and the performance under sail plays secondary role. The vessel becomes fuller to provide more internal space but to attain larger VMG for a particular wind speed, the vessel must be finer. These are conflicting demands. Therefore, the design problem may be formulated as a compromise decision support problem and the solution may be obtained using the Decision Support Problem Technique (DSPT) [6]. One such model for the design of a racing yacht was developed by Pal [8]. Some of the works of the author and his associates on the successful application of this technique to design various types of marine vehicles at the preliminary design stage are for trawlers [9,10], tugs [11], hatchcoverless container ships [12,13], river catamarans [14], catamaran ferries [15,16], monohull ferries [17.18] and SWATH ferries [19].

2 HULL GEOMETRY

The model in the study is of a simplified hull configuration with keel fin (not fitted with bulb) and a rudder freely hinged at the after end of the yacht. The keel volume is such that the required mass of ballast is fully contained in it. The sail configuration consists of a masthead rig with mainsail and genoa only. This is assumed to reduce the cost. The yacht is constructed of single skin fibreglass.

3 MATHEMATICAL MODEL

A mathematical model is developed to solve the complicated design problem as a compromise decision support problem (DSP). This problem is solved by decision support problem technique (DSPT) [6,7].

The cruising sailing yacht design model is described as shown below:

Given:

a) A set of owner's requirements (Table1):

- Number of cabins
- Number of berths
- Number of days at sea
- Restriction of draught
- True wind speed

b) A set of five goals

- minimisation of resistance
- minimisation of heel angle
- minimisation of cost yacht
- maximisation of velocity made good
- minimisation of total mass

Find:

a) System variables (twenty nine) defined in Table 2:

System variables are free variables that are chosen as non-dimensional functions of design parameters, or ratios of design parameters, that are used for defining the geometry of the vessel and rig configuration. The values of the variables vary between zero and one. The lower and upper limits of the design parameters are chosen from the data of about 250 recently built cruising sailing yachts (data obtained from the web pages of various yacht builders in 2003).

b) Deviation variables (ten):

Deviation variables are due to under-achievements (d_i^-) and over-achievements (d_i^+) of the five goals, and equalisation of displacement and total mass. These deviation variables are:

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

Satisfy:

a) Six system constraints:

- maximum draught is less than restriction on draught
- Density of ballast material is less than that of lead
- Volume of keel and rudder is less than 20 per cent of canoe body volume
- Block coefficient is greater than 0.3
- Displacement and mass must be very close within a tolerance (0.1%) This is transformed into two inequality constraints to cover exceedance and shortfall.

b) Upper and lower bounds on the 29 system variables must be satisfied:
$1.0 > X_i > 0.0$ for i = 1:29

(c) Five goals to be achieved as far as possible:
Goals (1) = 1.0 – TRTOTR/RTOTMV (minimisation of resistance)
Goals (2) = 1.0 – TRHLAN/HEELMV (minimisation of heel angle)
Goals (3) = 1.0 – TRYTCS/YATCST (minimisation of construction cost)
Goals (4) = VMGMAX/TRVMG – 1.0 (maximisation of velocity made good)
Goals (5) = 1.0 – TRMSTL/MASSTL (minimisation of total mass)

The aim is to minimise the objective function i.e. to reach a solution for which the goals are as close to zero as possible

The general Archimedean formulation of the objective function (deviation variables only) is:

$$Z\,(d_i^-, d_i^+) = [P_1\,(d_1^-, d_1^+) + P_2\,(d_2^-, d_2^+) + P_3\,(d_3^-, d_3^+) + P_4\,(d_4^-, d_4^+) + P_5\,(d_5^-, d_5^+)]$$

where, P is the priority level of each deviation – a subjectively chosen weighting.

The Archimedean formulation of the objective function is the weighted sum of d_i^-, d_i^+ deviation variables. For the present five-goal problem, the weight of each deviation is chosen arbitrarily as 0.01.

4 TECHNICAL ANALYSIS

The main program calls the subroutines prepared for the design of the yacht. These subroutines are combined to create a template. It consists of some structured subroutines for input, output, definition of constraints and subroutines prepared for calculation of design parameters and constraints (design analysis).

The design analysis subroutine starts with a set of input data of the twenty-nine system variables in Table 2 and a set of owner’s requirements.

It then estimates the necessary parameters to define the geometry of hull, keel, rudder and sail particulars.
The masses of rig and sails, deck gear, machinery, interior fittings and respective KGs (height of centre of gravity above the bottom of keel) are estimated by the method as suggested in [4]. The ballast material is chosen so that the entire volume of keel is filled in and its specific gravity is not to be greater than that of lead. The keel mass and its KG are estimated as suggested in [20]. The masses of deck and equipment, interior fittings and machinery are assumed as the mean of lower and upper limits as suggested in [4]. An inboard engine is assumed for the 2 cabin and 3 cabin yachts. For the 1 cabin yacht it is assumed that an outboard motor weighing 40 kg is fitted and the mass of fuel is 20 kg.

As the cost data are difficult to obtain, the approximate cost (Euro) of the yacht is estimated using the formula suggested in [5]. As these cost data are for 2003, the cost was adjusted using an escalation factor of 1.05 per year. The resulting estimated costs shown are for 2009 values.

The program next estimates the velocity made good (VMG) for each of seven Froude numbers selected within the range of data available for the estimation of resistance and sail forces using a subroutine for the prediction of velocity as suggested in [4]. The maximum of the seven VMGs is estimated by a routine that uses search technique by Golden Section Method [21]. The other particulars at the maximum VMG are estimated by an interpolation subroutine.

There is an option for the STability IndeX (STIX) – (part of the ISO Stability and Buoyancy standard) to be estimated. For the European market, it is mandatory to include the calculation for STIX. The particulars required for the STIX can only be calculated accurately the if the lines plan of the vessel is available. As lines plan is not developed at this preliminary design stage, the righting levers are estimated as suggested in [4], and the approximate method as suggested in [22] is adopted to calculate a value of STIX.

As the general arrangement is not defined at the preliminary design stage, the down flooding angle is assumed to be one degree greater than the angle of the vanishing stability.

5 RESULTS AND DISCUSSION

Two important considerations must be borne in mind when interpreting the results. Firstly, the output is intended only to be an example of what can be achieved, rather than offering an optimal design solution to the problem posed. Secondly, a designer may, and most probably will select different goals, weightings and constraints to those used here, based on their own experience and using their own databases. For example, the model selected here fixes the main hull shape and stability once the length has been determined, which in turn is governed largely by internal layout. This results in a model that optimises for comfort and cost rather than performance. The effect can be seen when true wind velocity is varied, revealing little change in displacement, GM or sail area.

The model is applied to the 3 sets of owner's requirements shown in Table 1. The resulting principal design parameters are shown in Figure 1. It shows that the main dimensions increase as the number of required cabins increases, as expected. The dimensionless ratios also change, as shown in Figure 2. This illustrates the effect of using such an optimisation technique. Figure 3 shows mass, cost, velocity made good and length overall, for yachts of all three configurations.

A sensitivity analysis is carried out varying true wind speed between 10 and 20 knots. Performance and cost as a function of wind speed are plotted in Figure 4, Figure 5 and Figure 6 for 3 Cabin, 2 Cabin and 1 Cabin configurations respectively. The cost of the yacht is independent of wind speed because it is determined largely by vessel length, which in turn is governed more by interior volume than sailing performance for the way the model has been set up here.

A sensitivity analysis to loading condition is conducted for the 2 Cabin configurations by varying the number of cruising days from 2 to 16. The results are shown in Figure 7. The results are again as expected; the longer passage time requiring more stores and a heavier boat to accommodate them, with a consequent increase in construction costs.

The models of all configurations converge at the upper limit of mast height so another sensitivity analysis is conducted for the effect of mast height on cost. Mast height is not an input, so this was explored by altering the limit values for mast height. The results, shown in Figure 8, show how cost and mass increase with mast height.

A similar investigation was carried out to see the effect of constraining the draft. The draft limit is steadily reduced from 2.8m to 1.23m. The results, shown in Table 3, yield what might at first reading be a surprising result – the sail area, displacement and GM do not change significantly as draught is decreased. This is because, again, the model is driven by usable interior volume rather than performance and stability. For a cruising yacht, the need to optimise performance is less strong than that for a racing yacht, therefore the model accepts hydrodynamically non-optimal shapes as a trade-off for space and cost optimisation.

All the model results up to this point have been for the 5 goals listed in section 3 above. Curiosity led us to investigate the effect of reducing the goals incrementally from 5 down to 1 (the one being cost). The results, in Table 5 show that the design features for the 1-goal problem are fairly similar in most respects to the results for the 5-goal problem. This reinforces the point made previously, that the hull shape is driven by cost rather than performance. It would be quite feasible to change this if a more performance-orientated design was sought, by for example changing the weightings given to the goals.

6 CONCLUSIONS

A multiple-objective optimisation technique is employed to develop a mathematical model for the preliminary design of sailing cruising yachts configuration. The model is applied to a set of owner's requirements for 3 cabins, 2 cabins and 1 cabin configurations.

The use of the model demonstrates that principal design parameters could be quickly determined using the decision support problem technique.

7 FUTURE WORK

Work is necessary to develop subroutines for the preparation of the lines plan from the known principal design parameters, which would enable accurate calculations for the coefficients and stability particulars. Subroutines are required for the calculation of the structural weight of the hull and detailed costing of construction and other items to develop a better realistic model. Replacement of the present velocity prediction routine may be made by developing a better method using detailed analysis.

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FIGURES

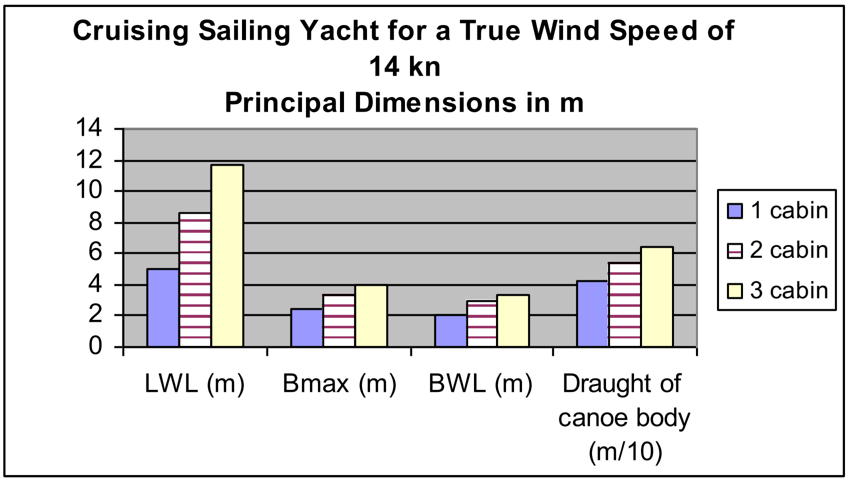

Figure 1 Effect of cabins on principal dimensions

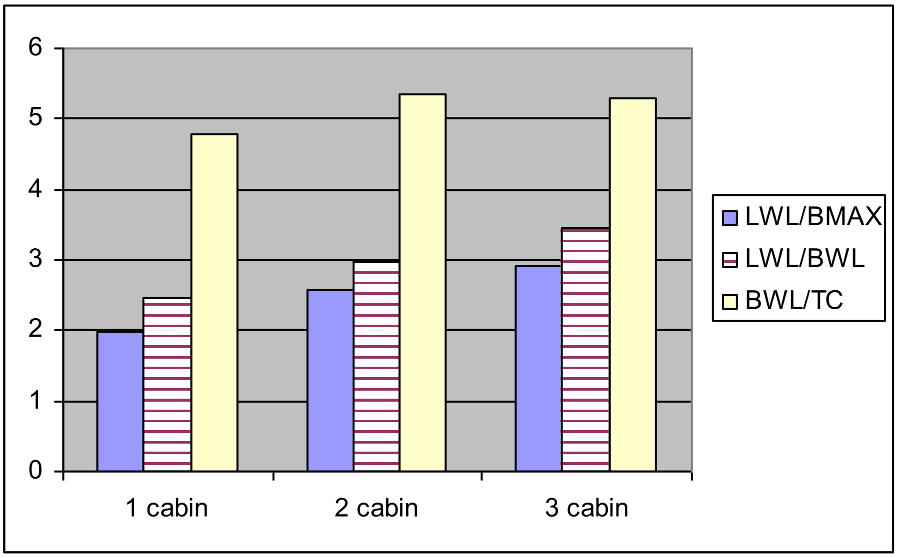

Figure 2 Effect of cabins on dimensionless hull characteristics

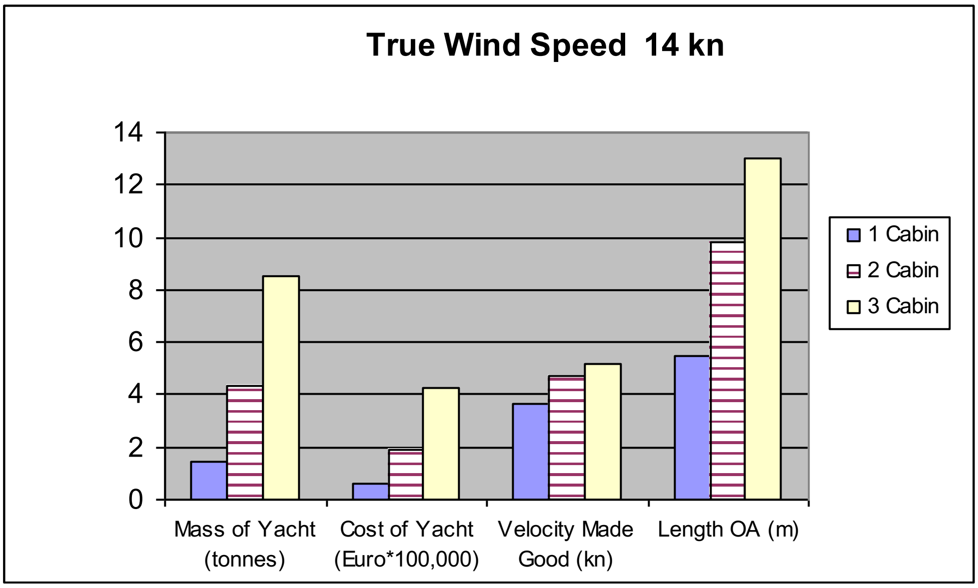

Figure 3 Effect of cabins on dimensions and performance

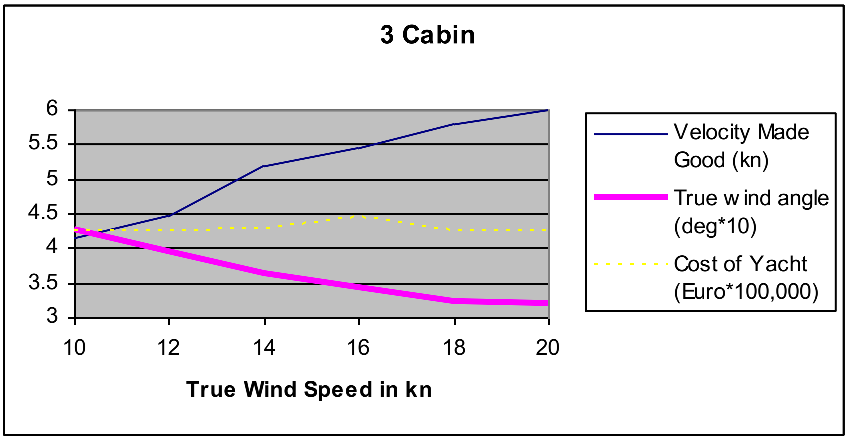

Figure 4 Effect of wind speed – 3 cabins

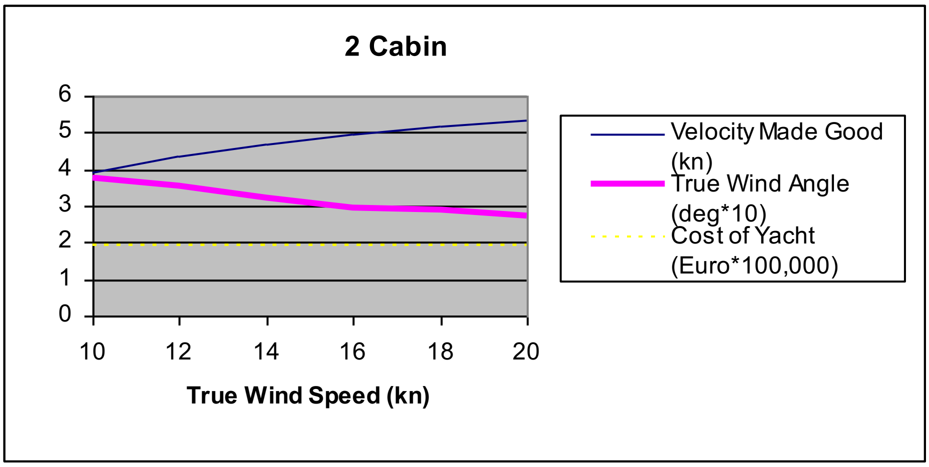

Figure 5 Effect of wind speed – 2 cabins

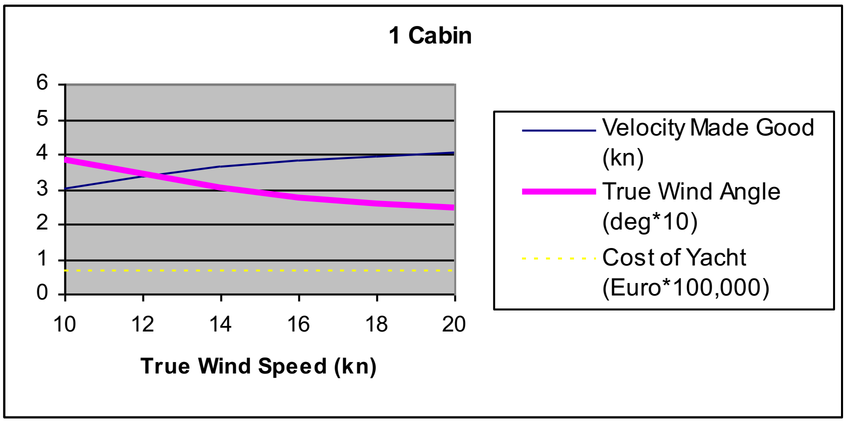

Figure 6 Effect of wind speed – 1 cabin

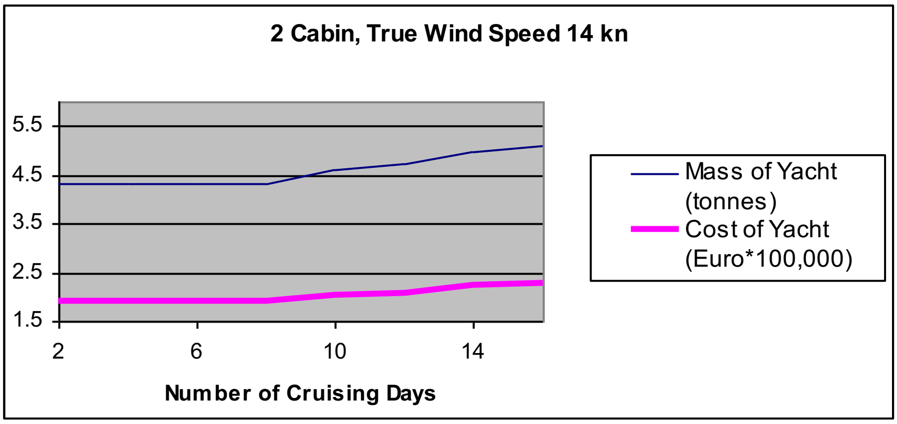

Figure 7 Effect of loading condition

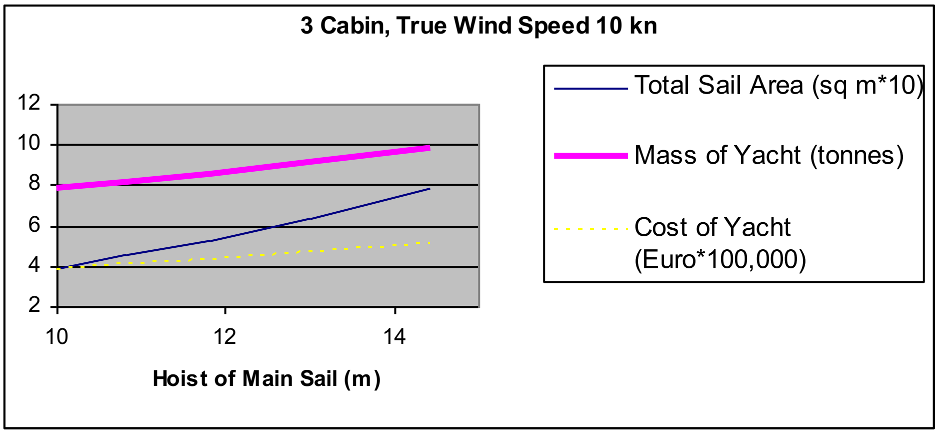

Figure 8 Effect of rig height

TABLES

number of cabins:	3	2	1
number of berths:	6	4	2
number of days at sea:	8	8	8
maximum draught in m:	3.0	3.0	3.0
true wind speed in knots:	14	14	14
a starting Froude number:	0.2	0.2	0.2

Table 1 Owner's requirements

X(1): Function of length overall (LOA) that depends on cabins (CABIN)	LOA=X(1)*2.50+5.50 (CABIN=1) LOA=X(1)*5.00+9.85 (CABIN=2) LOA=X(1)*5.3+13.00 (CABIN=3)
X(2): Function of length overall to length on waterline (LWL)	LWL=LOA/(X(2)*0.10+1.05)
X(3): Function of LWL to maximum breadth (BMAX)	BMAX=LWL/(X(3)*2.05+1.85)
X(4): Function of waterline beam (BWL) to BMAX	BWL= BMAX*(X(4)*0.089+0.783)
X(5): Function of BWL to canoe body draught (TC)	TC=BWL/(X(5)*2.35+3.00)
X(6): Function of LWL to maximum draught (TMAX)	TMAX=LWL/(X(6)*3.0+4.0)
X(7): Function of longitudinal position of centre of buoyancy (LCB); - ve aft and + ve forward of LWL/2.0	LCB=X(7)*-2.0-2.0
X(8): Function of prismatic coefficient (CP)	CP=X(8)*0.13+0.48
X(9): Function of water plane area coefficient (CWP)	CWP=X(9)*0.10+0.65
X(10): Function of LOA to hoist of main sail (HOISTM)	HOISTM=LOA/(X(10)*0.20+SLM)
X(11): Function of HOISTM to base of mail sail (FOOTM)	FOOTM=HOISTM/(X(11)*1.06+2.00)
X(12): Function of CLEAR	CLEAR=X(12)*1.0+1.0
X(13): Function of (HOISTM +CLEAR) to HOISTG	HOISTG=(HOISTM+CLEAR)/(X(13)*3.00+0.70)
X(14): Function of HOISTG to Base of Fore Triangle (BASEF)	BASEF=HOISTG/(X(14)*1.00+2.50)
X(15): Function of overlap of fore sail (OVRLAP)	OVRLAP=X(15)*3.50+0.0
X(16): Function of root chord of keel (CHRK)	CHRK=X(16)*5.5+1.0
X(17): Function of tip chord of keel (CHTK)	CHTK=X(17)*3.3+1.0
X(18): Function of thickness-chord ratio of keel sec. (ATCRK)	ATCRK=X(18)*0.12+0.08
X(19): Function of root chord of rudder (CHRR)	CHRR=X(19)*1.00+0.50
X(20): Function of tip chord of rudder (CHTR)	CHTR=X(20)*0.50+0.25
X(21): Function of sweep angle of qr.ch. of keel (SWANKD)	SWANKD=X(21)*30.0+0.0
X(22): Function of sweep angle of qr.ch. of rudder (SWANRD)	SWANRD=X(22)*30.0+0.0
X(23): Function of vertical span of rudder (VSPANR)	VSPANR=X(23)*4.0+5.0
X(24): Function of rudder angle (RANGLD)	RANGLD=X(24)*6.0+0.0
X(25): Function of half trailing edge angle of av. keel section (HTANKD)	HTANKD=X(25)*2.0+5.0
X(26): Function of half trailing edge angle of av. rudder section (HTANRD)	HTANRD=X(26)*2.5+5.0
X(27): Function of LWL/total volume (VOLTL)**0.333	VOLTL=(LWL/(X(27)*1.45+3.75))**3.00 (Cabin=1) VOLTL=(LWL/(X(27)*1.30+4.00))**3.00 (Cabin=2) VOLTL=(LWL/(X(27)*1.00+4.50))**3.00 (Cabin=3)
X(28): Function of mass of ballast (MASSBL) to total displacement (DISPTL)	DISPTL=VOLTL*1.025 MASSBL=DISPTL*(X(28)*0.24+0.24)
X(29): Function of freeboard that depends on length up to 15m	FREEBD=X(29)*1.0+0.5 (Cabin=1) FREEBD=X(29)*1.0+0.5 (Cabin=2) FREEBD=X(29)*0.75+1.0 (Cabin=3)

Table 2 Definition of system variables

Restriction of draught in m	2.8	2.4	2.0	1.5	1.4	1.25	1.23
Length overall in m	9.85	9.85	9.85	9.85	9.85	9.85	9.85
Length on waterline in m	8.57	8.57	8.57	8.57	8.57	8.57	8.57
Breadth maximum in m	3.32	3.32	3.32	3.32	3.51	3.40	3.53
Breadth on waterline in m	2.89	2.89	2.89	2.89	2.94	2.91	2.93
Draught canoe body in m	0.54	0.54	0.54	0.54	0.55	0.55	0.55
Draught maximum in m	1.48	1.48	1.48	1.48	1.25	1.23	1.23
Canoe body CB (block coefficient)	0.303	0.303	0.303	0.303	0.302	0.302	0.299
Canoe body volume of displ. in cu m	4.07	4.07	4.07	4.08	4.12	4.12	4.14
Vertical span of keel in m	0.93	0.93	0.93	0.93	0.70	0.68	0.67
Root chord of keel in m	2.06	2.06	2.06	2.06	1.90	2.31	2.34
Tip chord of keel in m	0.70	0.70	0.70	0.70	0.73	0.91	0.90
Keel volume in cu m	0.14	0.14	0.14	0.14	0.12	0.11	0.11
Vertical span of rudder in m	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Root chord of rudder in m	0.50	0.50	0.50	0.50	0.52	0.56	0.76
Tip chord of rudder in m	0.25	0.25	0.25	0.25	0.25	0.50	0.35
Rudder volume in cu m	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Displacement of yacht in kg	4326.3	4326.3	4326.2	4326.9	4395.3	4343.5	4365.2
Mass of yacht in kg	4322.2	4322.2	4322.2	4322.6	4390.5	4339.2	4360.4
Maximum VMG in knots	4.713	4.713	4.713	4.713	4.706	4.691	4.689
Froude number at max. VMG	0.328	0.328	0.328	0.328	0.328	0.328	0.328
Mass of crew and effect in kg	340.0	340.0	340.0	340.0	340.0	340.0	340.0
Mass of provision in kg	160.0	160.0	160.0	160.0	160.0	160.0	160.0
Mass fresh water in kg	384.0	384.0	384.0	384.0	384.0	384.0	384.0
Mass fuel oil in kg	48.98	48.98	48.98	48.98	48.98	48.98	48.98
Mass of ballast in kg	1041.7	1041.7	1041.7	1042.1	1083.6	1046.7	1049.4

Table 3 Extract of results of variation of restriction in draught for cabins: 2, berths: 4, cruising days: 8, for a wind velocity of 14 knots

Cruising days	2	4	8	10	12	14	16
Length overall in m	9.85	9.85	9.85	9.85	9.85	9.85	9.85
Length on waterline in m	8.57	8.57	8.57	8.70	8.57	8.58	8.58
Breadth maximum in m	3.41	3.41	3.32	3.47	3.47	3.74	3.60
Breadth on waterline in m	2.90	2.93	2.89	2.98	3.02	3.10	3.11
Draught canoe body in m	0.54	0.55	0.54	0.56	0.57	0.59	0.61
Draught maximum in m	1.86	2.14	1.48	1.34	1.33	1.27	2.14
Canoe body CB (block coefficient)	0.297	0.297	0.303	0.304	0.305	0.299	0.301
Displacement of yacht in kg	4326.3	4326.3	4327.0	4616.6	4719.3	4974.3	5124.5
Mass of yacht in kg	4321.0	4321.3	4322.5	4612.7	47152	4968.3	5119.3
Maximum VMG in knots	4.687	4.662	4.713	4.677	4.632	4.582	4.529
Froude number at max. VMG	0.327	0.326	0.328	0.326	0.326	0.324	0.319
Mass of crew and effect in kg	340.0	340.0	340.0	340.0	340.0	340.0	340.0
Mass of provision in kg	40.0	80.0	160.0	200.0	240.0	280.0	320.0
Mass fresh water in kg	96.0	192.0	384.0	480.0	576.0	672.0	768.0
Mass fuel oil in kg	48.98	48.98	48.98	48.98	48.98	48.98	48.98
Mass of ballast in kg	1435.1	1207.8	1042.2	1108.0	1132.6	1194.3	1229.9

Table 4 Extract of results of variation of cruising days for cabins: 2, berths: 4, and maximum draught in m : 3 for a true wind velocity of 14 knots

Number of Goals*	5	4	3	2	1
Length overall in m	9.85	9.85	9.85	9.85	9.85
Length on waterline in m	8.57	8.57	8.57	8.57	8.57
Breadth maximum in m	3.17	2.62	2.60	2.70	2.40
Breadth on waterline in m	2.76	2.20	2.25	2.31	2.09
Draught canoe body in m	0.57	0.69	0.65	0.69	0.70
Draught maximum in m	1.41	1.49	1.43	1.32	1.68
Canoe body CP	0.520	0.521	0.52	0.520	0.520
Canoe body CM (max. sec. area coeff.)	0.582	0.598	0.625	0.577	0.606
Canoe body CB (block coefficient)	0.303	0.312	0.325	0.300	0.315
Canoe body CWP	0.731	0.688	0.683	0.749	0.650
Canoe body LCB (-ve aft and +ve fd) % of LWL of LWL/2.0	-3.891	-2.764	-2.518	-2.300	-2.000
Freeboard in m	0.500	0.557	0.553	0.500	0.500
Metacentric height in m	1.321	0.513	0.532	0.618	0.518
Height of CE above CLR in m	4.619	4.737	4.759	4.728	4.844
Clearance bet. deck and boom in m	1.000	1.000	1.000	1.009	1.000
Hoist of main sail in m	8.95	8.95	8.95	8.96	8.95
Foot of main sail in m	2.93	3.42	3.71	4.02	2.93
Hoist of genoa in m	9.955	9.955	10.409	10.691	9.955
Base of genoa in m	3.091	3.002	3.436	3.562	2.844
Area of main sail in sq. m	17.03	19.90	21.62	23.41	17.03
Area of fore triangle in sq. m	15.38	14.94	17.88	19.28	14.16
Total sail area in sq. m	32.42	34.84	39.50	42.68	31.19
Displacement of yacht in kg	4326.4	4326.3	4334.4	4345.8	4326.3
Mass of yacht in kg	4322.8	4322.9	4330.9	4342.3	4304.9
Vertical span of keel in m	0.84	0.80	0.77	0.62	1.17
Root chord of keel in m	2.53	2.33	2.39	2.33	1.95
Tip chord of keel in m	0.52	0.79	0.67	0.87	1.15
Vertical span of rudder in m	0.50	0.69	0.50	0.53	1.60
Root chord of rudder in m	0.62	0.50	0.51	0.58	1.50
Tip chord of rudder in m	0.25	0.25	0.25	0.34	1.15
Rudder angle in degree	0.00	0.00	0.01	0.00	0.00
Maximum VMG in knots	3.933	4.052	4.163	4.276	3.783
Froude number at max. VMG	0.292	0.301	0.304	0.309	0.287
Heel angle at max. VMG in degree	4.99	13.92	14.89	14.19	12.44
Leeway angle at max. VMG in degree	3.22	3.07	3.82	4.54	1.52
App. wind angle at max. VMG in deg.	23.96	23.85	22.27	20.83	26.74
True wind angle at max. VMG in deg.	37.72	37.91	36.08	34.47	40.74
Sail driving force at max VMG in N	325.97	315.76	337.21	352.57	306.28
Total resistance at max. VMG in N	326.00	315.92	336.86	352.44	306.23
Cost of yacht in A$ M	0.2459	0.2418	0.2438	0.2470	0.2353
Angle of vanishing stability in degree	125.62	114.84	111.88	115.79	120.86
Angle of down flooding in degree	126.62	115.84	112.88	116.79	121.86
Area up to vanishing stabil. in m. deg.	55.98	30.14	26.55	3294	31.78
Righting lever at 90 degree in m	0.51	0.25	0.21	0.28	0.28
Value of STIX	32.65	29.73	28.73	29.77	31.86

* 5 Goals: Min. of Resistance, Min. of Heel angle, Min. of Cost, Max. of VMG, and Min. of Mass
4 Goals: Min. of Resistance, Min of Heel angle, Min. of Cost, and Max. of VMG
3 Goals: Min. of Resistance, Max.of VMG, and Min. of Mass
2 Goals: Min. of Cost and Max.of VMG, and 1Goal: Min. of Cost

Table 5 Extract of results of variation of Goals for cabins: 2, berths: 4, cruising