a better known paper (this is a summary of the reference)

Optimisation Methods in Ship Design

Tanker Preliminary Design - An Optimisation Problem with Constraints

(Ref: Swift et.al. S.N.A.M.E. 1974)

1. Introduction

The task of selecting the principal design characteristics of oil tankers is formulated as a nonlinear optimisation problem with constraints. Two optimisation methods are explored; an adapted variant of the direct search by Hooke and Jeeves and a special version of the S.U.M.T. method.

2. Aims

The aim of this work is to investigate the applicability of non-linear programming methods to the ship design model. A relatively simple mathematical model of an oil tanker design is constructed and attempts are made to define an optimum vessel using non-linear methods.

3. Design Variables

These are defined as $V/\sqrt{L}$, B/T, L/B, L/D and C_B which for a fixed draught input define the free design variables as B, L, C_B and V. Certain limits are placed upon the range of the variables to comply with certain design requirements.

4. Constraints

The variables are subjected to certain limits as follows;

Variable	$V/\sqrt{L}$	B/T	L/B	L/D	C_B
Constraint	0.35 - 1.3	2.0 - 3.0	6.4 - 7.7	14	0.5 - 0.86

In addition to these explicit constraints certain implicit constraints exist because of freeboard, stability, roll period and deadweight requirements (see sect. 8).

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5. Measure of Merit

The measure of merit used to compare alternative designs in this study is Required Freight Rate (R.F.R.). The reasons for selecting the criterion and the conditions which govern its use have been well documented elsewhere. REF(1). Note:

$$RFR = \frac{F\ (CRF)\ + C}{A}$$

Where F = initial cost of vessel.

c = annual costs ince. fuel, crew, insurance etc.

A = amount of cargo carried per annum.

CRF = capital recovery factor.

6. Design Procedure

Most design and cost relationships are extracted from published work e.g. Mandel and Leopold (Ref. 2). This data is extended to cover present design practice for vessels up to 500,000 tonne deadweight and C_B's up to 0.88.

Details of the design model are as follows:

The tanker operates on a round trip of 20,000 nautical miles under conditions of unlimited cargo availability.

The power prediction data is based upon data from Silverleaf and Dawson (Ref.3).

The steelweight is calculated using the equation given by Sato (Ref. 4) and Buxton (Ref. 5).

For example, Sato's equation gave.

$$W_s = 10^{-5} \left[\frac{C_B}{0.8}\right]^{1/3} \left(5.11 \cdot \frac{3L^3B}{D} + 2.56\ L^2\ (B + D)^2\right)$$

Machinery mass is

$$W_m = 214 \left[\frac{P_s}{1000}\right]^{0.5}$$

shaft Power

Outfit weight

$$Wo = (4.7 - 0.0034L)\ L.B./100$$

Deadweight $= \Delta - W_{LS}$

Payload $= \Delta - (W_{LS} + W_{FO} + W_{Lo} + W_{MISC})$.

GM must be > 0.5
but limited

Freeboard as per 1966 load line convention.

Stability. The GM in the loaded condition is estimated as

$$GM = KB + BM - KG$$
$$= 0.515T + 0.0805 \cdot \frac{B^2}{T}\left(\left(1 - \frac{3.5 + (L/90)}{100}\right)\right) - 0.525\ D$$

These estimates were taken from(Ref. 6)

P(x) = f(x) + $\frac{1}{r_k}\sum G_j(x)$ — this is the algorithm we use as package

7. Solution Methods

The version of S.U.M.T. implemented in the paper is that which has been described in Part I (Sect. 5.6.1). In an effort to reduce the computation effort involved in minimising the successive response surfaces the authors introduced a scheme proposed by LUND Ref. (7). In this scheme an exponential extrapolation is introduced after the first two search cycles thus reducing total number of surface minimisations.

When implementing S.U.M.T. in conjunction with the direct search by Hooke and Jeeves difficulty was experienced in keeping the step width adjusted so that the search does not leave the feasible space. One course of action taken in an attempt to overcome this problem was to reduce the step size. However this did not avoid an occasional pass into the non-feasible region.

The final version tests to see if a constraint is violated. If this is the case a corrective scheme is adopted to carry the search back into the feasible space. If in the original step size a non-feasible point is reached the step width is reduced.

This means that the S.U.M.T. can be used with confidence in the neighbourhood of constraints since it is adopted automatically. With this 'in-built' check it is possible to save some r_k cycles even to the extent of letting $r_k = 0$ from the start until a constraint is contacted. The authors claim a two thirds saving of computing time

they said if starting point is feasible then assume $\frac{1}{r_k}\sum G_j(x) \simeq 0$ and min (or max) f(x) till you hit a constraint

8. Computational Experience

what is deflection?

The constraints were expressed as follows:

$0.35 \leqslant x_1 \leqslant 1.3$	where	$x_1 = V/\sqrt{L}$
$2 \leqslant x_2 \leqslant 3$		$x_2 = B/T$
$6.4 \leqslant x_3 \leqslant 7.7$		$x_3 = L/B$
$0.5 \leqslant x_4 \leqslant 0.86$		$x_4 = C_B$
$x_5 \leqslant 14$		$x_5 = L/D$

$GM_{MIN} \leq GM \leq GM_{MAX}$ Where $GM_{MIN} = 0.04B$.

$$GM_{MAX} = \frac{4\pi^2 (0.4B)^2}{g T_{LIM}^2} = 6.440855.10^{-3} B^2$$

$T_{LIM} = 10$ sec.

$Fb_{REQ} \leq Fb_{ACT}$ Fb = freeboard.

$0 \leq W_p$ Wp = payload.

The last constraint is necessary to avoid negative payload and hence negative RFR.

8.1 Step Widths & Termination Criteria.

The initial step width Δx search tolerances ε used were:

	x_1	x_2	x_3	x_4	x_5
Δx	0.1	0.1	0.1	0.05	0.1
ε	0.005	0.006	0.006	0.002	0.01

8.2 Unimodality.

An investigation was carried out using several different starting points to test for unimodality. The tests confirmed the generally held belief that economic criteria in ship design show a flat, non-oscillatory dependence on the design variables.

8.3. S.U.M.T. Versus A.D.S.

The ADS method only required about one third the number of trial points of the S.U.M.T. This result cannot be generalized too far. The relative advantage depends upon the frequency of occurence of the nesting correction at the boundary. It is probable that with more complex objective functions and constraints. ADS would be less efficient then S.U.M.T. because of too many nesting corrections.
"there are so many complex constraints that it is too difficult to pick a feasible starting point"

8.4 The Optimum Tanker

The design relationships were outlined earlier. Using a draught limit of 44ft. the resulting vessel was obtained.

(a) With Sato's weight data and $C_B \leq 0.86$

$V/\sqrt{L}$	= 0.496	V	= 14.4
B/T	= 2.99	B	= 132
L/B	= 6.41	L	= 844

C_B = 0.86		D = 64
L/D = 13.2		T = 44
Δ = 120,500		SHP = 15800
DWT = 106 100		RFR = 10.79
WP = 100 000		

(b) With Buxtons Data, CB $\leq$ 0.88

V/ L = 0.488	V = 14.5
B/T = 2.91	B = 128
L/T = 6.88	L = 881
C_B = 0.88	D = 63
L/D = 14.0	T = 44
Δ = 125,000	SHP = 17300
DW = 107,000	RFR = 11.3
W_p = 101,000	

It is interesting to note that the draught and C_B restrictions are effective in both cases. As with other studies of this nature it will be noted that the authors have expressed deadweight as the independent variable.

This is the correct design procedure for unlimited cargo availability ie to regard the deadweight as a residual value which is determined by the difference between displacement and lightweight, which in turn are derived from the optimal combination of main dimension.

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4. Sato S., "Effect of Principal Dimensions on Weight and Cost of Large Ships". S.N.A.M.E. 1967.

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6. Gilgillan A.W., "Preliminary Design by Computer". I.E.S.S. Vol 110, 1967.

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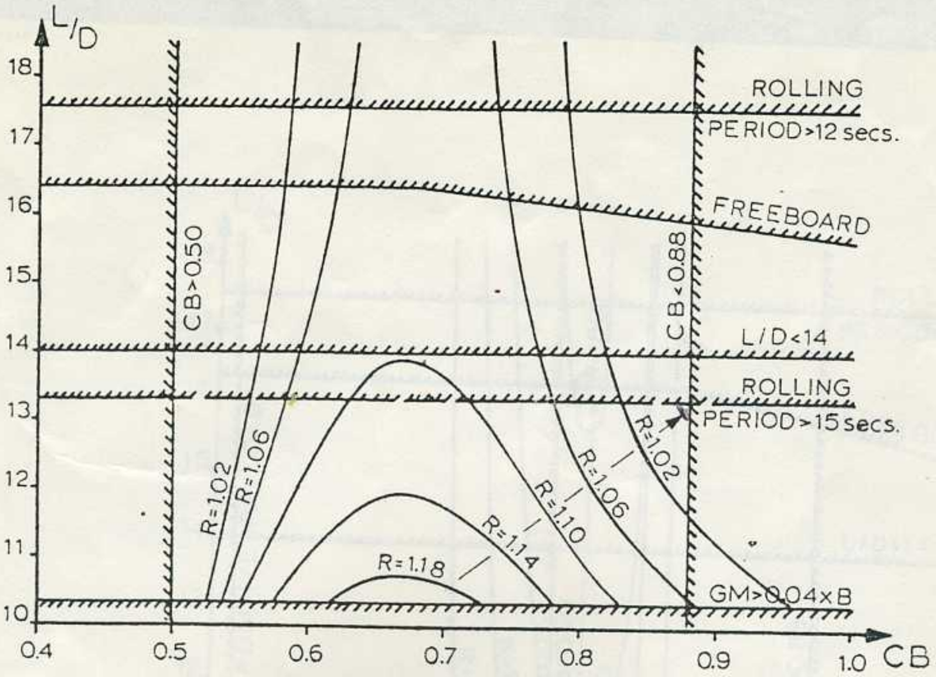

Fig. 7 Contours of the measure of merit function (R = actual/optimal required freight rate) and design constraints; $V/\sqrt{L}$ = 0.45; B/T = 2.91; L/B = 6.88

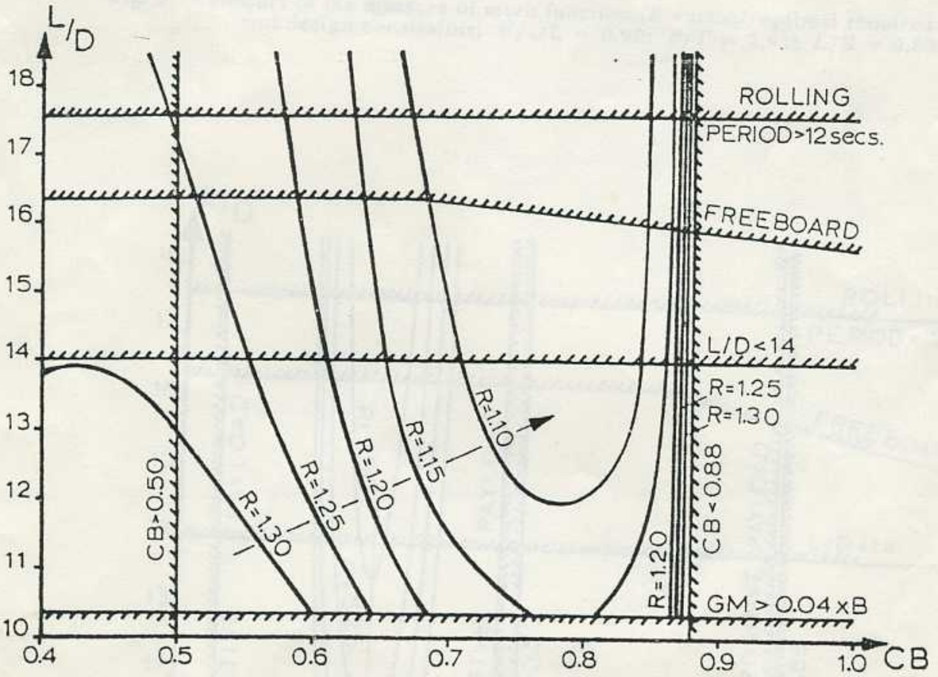

Fig. 8 Contours of the measure of merit function (R = actual/optimal required freight rate) and design constraints; $V/\sqrt{L}$ = 0.60; B/T = 2.91; L/B = 6.88

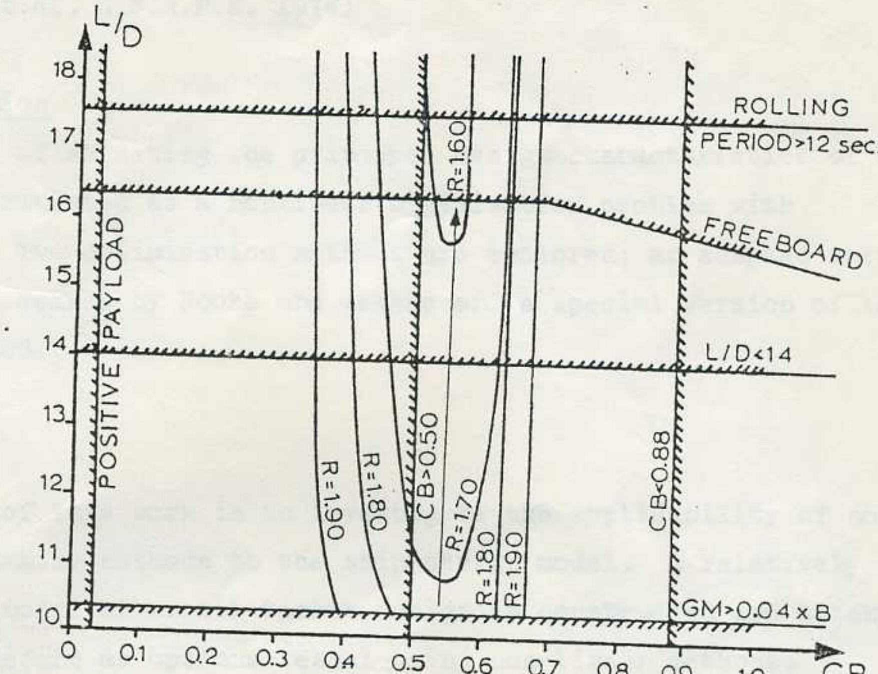

Fig. 9 Contours of the measure of merit function (R = actual/optimal required freight rate) and design constraints; $V/\sqrt{L}$ = 0.90; B/T = 2.91; L/B = 6.88

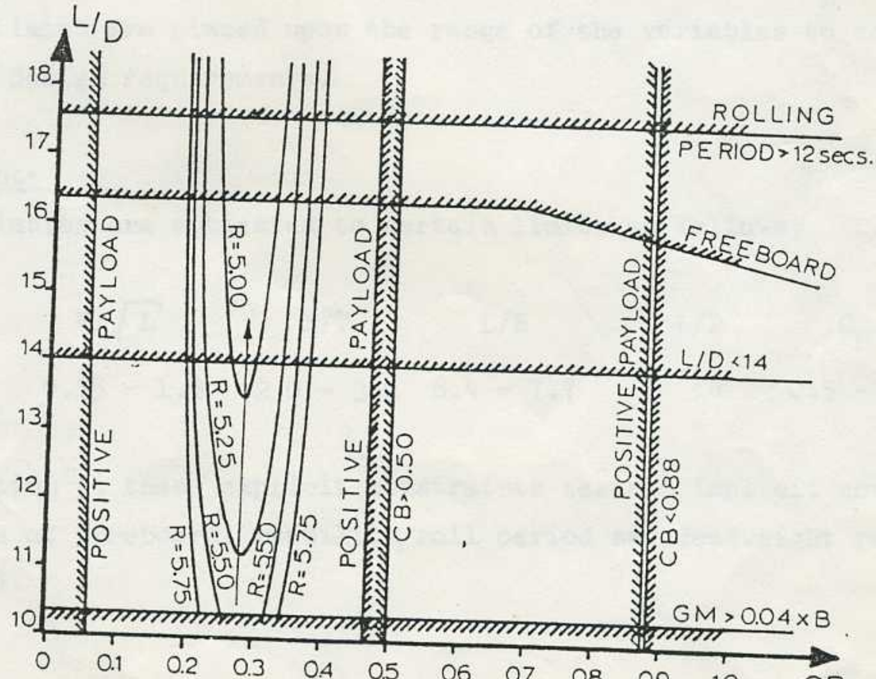

Fig. 10 Contours of the measure of merit function (R = actual/optimal required freight rate) and design constraints; $V/\sqrt{L}$ = 1.30; B/T = 2.91; L/B = 6.88