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A DESIGN ANALYSIS EXERCISE USING THE SPIRAL COMPUTER SYSTEM

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ABSTRACT

A ship design decision problem is stated and its solution is given, the solution being a combination of calculation by the SPIRAL computer system, hand calculations, and decision by a student.

The problem itself is of slight interest; the principal purpose of this report is to illustrate the use of SPIRAL: how its modules can be used in designing large-scope problems that can be done with reasonable effort by a student, yet leave essential problem elements to hand calculation and to human decision.

INTRODUCTION

This report outlines a ship design learning exercise that makes use of the SPIRAL computer system, combined with hand calculations and decisions by the student. In general, the lengthy calculations are done by the SPIRAL modules POWER, WEIGHT, BCOST, and SEAKEEP, while the calculations that can be done readily by hand are reserved for that mode. The problem is one of economic decision, that is, the student must choose the best among alternatives; the decision is based on the result of hand calculations that follow from the computer results.

The problem is of no general importance, being a special one devised especially to illustrate the use of a combination of SPIRAL modules in pursuit of a single objective. The purpose of this report is therefore NOT to make any point about ship design, engineering economics, etc, but to demonstrate to instructors in such fields how the SPIRAL system can be used.

All hand work is reproduced here, more to indicate the scope of the work than to present details. The details of the computer work are not given; the reader is asked to consult SPIRAL documentation (especially the User Manual for each module) for information on its inputs and outputs. Abstracts of the User Manuals are reproduced here in an appendix.

A virtue of the SPIRAL system is the common format followed in its library modules. The preparation by the user for running these modules is therefore minimal (the "ya seen one ya seen 'em all" principle at work!), so that the confrontations with the computer on the part of a student doing a problem such is this is a matter of only a few minutes. Don't doubt, though, that I did some grubbing to organize the problem -- to organize the magnitudes of problem variables so that the path to solution didn't wander outside the constraints found in each module. The aforesaid virtue was truly a help to me, and the computer sessions were a minor thing, but a lot of work was still required. SPIRAL makes things easier, but it doesn't replace human decison making. It doesn't replace teachers.

THE PROBLEM

A small tank ship is being designed to haul sludge to sea for dumping on a daily schedule. Its principal data are tentatively established as

LBP	300
Beam	050
Depth	022
Draft	017.5
CB	0.75
CP	0.79
SHP	4000 (medium speed diesel)
Speed loaded	14.0
Displacement	5625
Deadweight	4173

Its service requires 250 round trips per yer of a nominal 8 hours each, divided as follows:

Loading	1.5
Maneuvering	1.0
Dumping	0.5
Underway	5.0 (70 miles at 14.0 knots)

Your problem is to investigate the economic merit of building this vessel with a finer hull than that stated above. The incentive for the possible change is reduced operation costs, traded against a likely increase in building cost. Three significant factors are identified, and are to be treated in the analysis. They are

For the same deadweight, a finer hull demands a greater light ship weight, hence higher building cost.

For the same speed, less propulsive power is required by a finer hull. Alternatively, the same propulsive power will accomplish the daily voyage in less time. In either case, fuel cost is reduced.

An overtime wage penalty of $250 per hour must be paid to the crew for all time beyond 8.0 hours per day. Since bad weather occurs frequently in the area of operation, speed reductions on the passages to and from the dumping grounds are common. A finer hull may therefore save wage penalties because of higher speed capability in rough water.

Draft, beam, and L/D are to be unchanged from the tentative design.

Additional data required follows:

Price of fuel	$150/ton
Fuel rate	0.40 lb/hp-hr

Significant wave height probabilities in the operating area:

0-5	0.35
6	0.35
7	0.18
8	0.09
9	0.03
>9	negligible

SOLVING THE PROBLEM

Steps in the solution are outlined following.

Find dimensions and weights of the finer hulls by use of the module WEIGHT.

Use the module BCOST to estimate building cost of each alternative design.

Use the module POWER (series 60 option) to estimate smooth-water speeds.

Use the module SEAKEEP to estimate added resistance as a function of wave height. Translate added resistances into speed decrements, following a constant torque relationship. Latter requires hand calculation, based on the furnished propeller characteristics.

Apply the expected value criterion in a hand calculation to demonstrate whether any finer hull is justified on economic merit. "States of nature" are the wave heights to be encountered.

If you are interested in the results, note that calculations are made for block coefficients of 0.73, 0.71, and 0.69. Decreases in operating costs are compared to increases in building cost, with an arbitrarily-chosen 10 percent annual return applied to the latter. The "bottom line" shows that increases in building cost outweigh the operational savings. So stick with the tentative design!

SUMMARY OF CALCULATIONS BY POWER, WEIGHT, AND BUILDING COST MODULES

1	CB	0.75	0.73		0.71		0.69		
2	LBP	300	300	310	315	325	325	340	
3	B	50	50	50	50	50	50	50	
4	D	22	22	22.7	23.1	23.8	23.8	24.9	
5	H	17.5	17.5	17.5	17.5	17.5	17.5	17.5	
6	CM	0.95	0.95	0.95	0.95	0.95	0.95	0.95	
7	CP	0.79	0.77	0.77	0.75	0.75	0.73	0.73	①/⑥
8	Δ	5625	5475	5658	5591	5769	5606	5865	①②③⑤/35
9	W_S	500	483	535	532	565	545	596	WEIGHT MODULE
10	W_M	400	400	400	400	400	400	400	
11	W_O	552	552	565	572	584	584	602	
12	W_T	1452	1435	1500	1504	1550	1530	1599	⑨+⑩+⑪
13	DWT	4173	4040	4158	4087	4219	4076	4266	⑧ -⑫

Trial values of LBP are used above, followed by hand calculation of displacement, and calculation of weights by WEIGHT. Deadweight is then calculated by hand (displacement less total light weight). Interpolation among the columns above then gives dimensions necessary for constant deadweight. BCOST then calculates building cost, and POWER calculates smooth-water resistance (next sheet).

		0.75	0.73	0.71	0.69	Note
14	LBP	300	311.3	321.5	332.7	
15	B	50	50	50	50	
16	D	22	22.8	23.6	24.4	
17	H	17.5	17.5	17.5	17.5	
18	Δ	5625	5682	5706	5739	
19	W_S	500	542	553	571	WEIGHT MODULE
20	W_M	400	400	400	400	
21	W_O	552	566	580	593	
22	W_T	1452	1508	1533	1564	⑲+⑳+㉑
23	DWT	4173	4174	4173	4175	⑱ -㉒
24	BCOST	10.34	10.526	10.640	10.764	BCOST MODULE $\$10^6$
25	CP	0.79	0.77	0.75	0.73	
26	R	51,920	46,120	43,010	40,170	POWER MODULE
27	V	14.0	14.0	14.0	14.0	

Speed (line 27) here is the nominal speed. Smooth water speeds at 4000 shp, and speeds with several seastates, appear on the next sheet.

SUMMARY OF CALCULATIONS BY POWER AND SEAKEEPING MODULES, AND OF HAND CALCULATION OF SPEED WITH THE INCREASED RESISTANCE FOUND BY SEAKEEP

①	CB	0.75	0.73	0.71	0.69
②	LBP	300	311.3	321.5	332.7
③	B	50	50	50	50
④	D	22.0	22.8	23.6	24.4
⑤	H	17.5	17.5	17.5	17.5
⑥	Δ	5625	5682	5706	5739
⑦	R@ 14KN	51,920	46,120	43,010	40,170
⑧	SHP@ 14	3832	3404	3175	2965
⑨	V@4000SHP	14.2	14.8	15.1	15.5

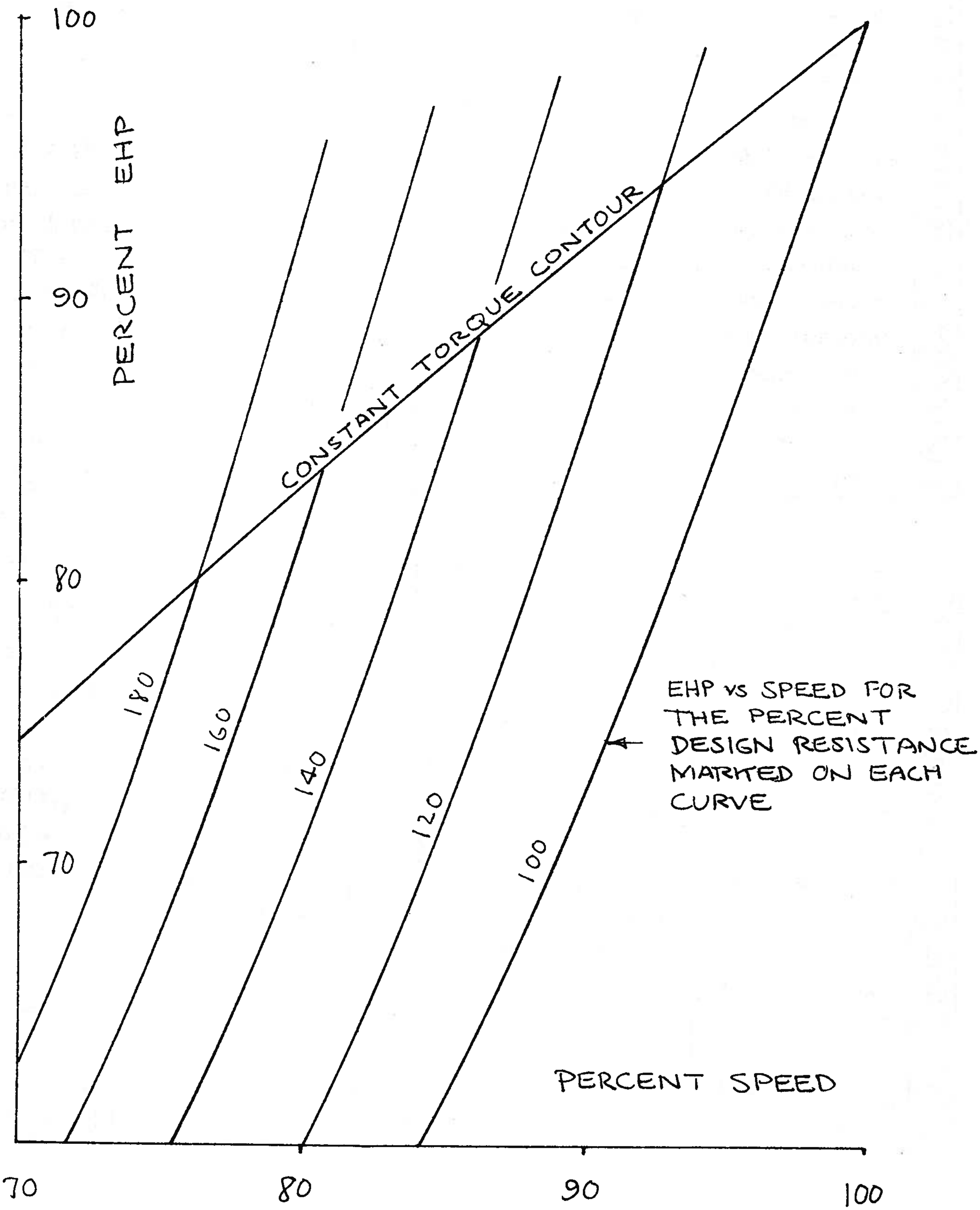
⑩	SWH	6			
⑪	R@ 14	55,900	50,250	47,200	44,400
⑫	V	13.8	14.3	14.6	14.9

⑬	SWH	7			
⑭	R@14	60,180	55,000	51,300	47,900
⑮	V	13.4	13.8	14.0	14.4

⑯	SWH	8			
⑰	R@ 14	65,200	60,400	56,800	52,700
⑱	V	12.9	13.2	13.4	13.8

⑲	SWH	9			
⑳	R@14	71,000	64,900	61,500	58,250
㉑	V	12.4	12.7	12.8	13.1

The following page contains curves of EHP vs speed, with resistance as a parameter. A contour of constant torque, calculated from the given propeller characteristics, is also plotted, and the ship is assumed to operate along this contour. The speeds above (lines 12, etc) are found by spotting the resistance on this contour.


100
90
80
70
PERCENT EHP
CONSTANT TORQUE CONTOUR
180
160
140
120
100
EHP vs SPEED FOR THE PERCENT DESIGN RESISTANCE MARKED ON EACH CURVE
PERCENT SPEED
70
80
90
100

CALCULATION OF OPERATING COSTS, EXPECTED VALUE, AND SUM OF COST DIFFERENCES

①	BLOCK COEFF.			0.75			
②	WAVE HT.	0	6	7	8	9	TRIAL VALUE
③	PROBABILITY ②	0.35	0.35	0.18	0.09	0.03	SPECIFIED
④	SPEED	14.2	13.8	13.4	12.9	12.4	PAGE 6
⑤	SEA TIME	4.93	5.07	5.22	5.43	5.65	70/④
⑥	SEA FUEL	7887	8116	8358	8682	9032	4000 x 0.4 x ⑤
⑦	FUEL COST (YR^{-1})	132,040	135,860	139,915	145,340	151,200	$\frac{250}{2240}$ x 150 x ⑥
⑧	VOYAGE HRS	7.93	8.07	8.22	8.43	8.65	⑤ + 3.0
⑨	WAGE PENALTY	—	4375	13,750	26,875	40,310	250(⑧-8.0)x 250
⑩	OPERATING COST	132,040	140,235	153,665	172,215	191,510	⑦ + ⑨
⑪	OUTCOME (YR^{-1})	46,215	49,080	27,660	15,500	5,745	③ x ⑩
⑫	EXPECTED VALUE			144,200			SUM OF ⑪
⑬	Δ EXP VALUE			BASE			DIFF FROM BASE
⑭	Δ SHIP COST			BASE			" " "
⑮	Δ SHIP COST (YR^{-1})			BASE			⑭ x 0.10
⑯	SUM			BASE			⑬ + ⑮

①	BLOCK COEFF.			0.73			
②	WAVE HT.	0	6	7	8	9	TRIAL VALUE
③	PROBABILITY ②	0.35	0.35	0.18	0.09	0.03	SPECIFIED
④	SPEED	14.8	14.3	13.8	13.2	12.7	PAGE
⑤	SEA TIME	4.730	4.895	5.070	5.303	5.512	70/④
⑥	SEA FUEL	7568	7832	8116	8485	8820	4000 x 0.4 x ⑤
⑦	FUEL COST (YR^{-1})	126,680	131,110	135,860	142,035	147,630	$\frac{250}{2240}$ x 150 x ⑥
⑧	VOYAGE HRS			8.07	8.303	8.512	⑤ + 3.0
⑨	WAGE PENALTY			4375	18,940	32,000	250(⑧-8.0)x 250
⑩	OPERATING COST	126,680	131,110	140,235	160,975	179,630	⑦ + ⑨
⑪	OUTCOME (YR^{-1})	44,340	45,890	25,240	14,490	5,390	③ x ⑩
⑫	EXPECTED VALUE			135,350			SUM OF ⑪
⑬	Δ EXP VALUE			— 8850			DIFF FROM BASE
⑭	Δ SHIP COST			186,000			" " "
⑮	Δ SHIP COST (YR^{-1})			18,600			⑭ x 0.10
⑯	SUM			9,750			⑬ + ⑮

CALCULATION OF OPERATING COSTS, EXPECTED VALUE, AND SUM OF COST DIFFERENCES

①	BLOCK COEFF.			0.71			
②	WAVE HT.	0	6	7	8	9	TRIAL VALUE
③	PROBABILITY ②	0.35	0.35	0.18	0.09	0.03	SPECIFIED
④	SPEED	15.1	14.6	14.0	13.4	12.8	PAGE 6
⑤	SEA TIME	4.636	4.795	5.0	5.224	5.468	70/④
⑥	SEA FUEL	7417	7671	8000	8358	8750	4000 x 0.4 x ⑤
⑦	FUEL COST (YR^{-1})	124,170	128,415	133,920	139,915	146,475	$\frac{250}{2240}$ x 150 x ⑥
⑧	VOYAGE HRS	7.363	7.795	8.0	8.224	8.468	⑤ + 3.0
⑨	WAGE PENALTY				14,000	29,250	250(⑧-8.0) x 250
⑩	OPERATING COST	124,170	128,415	133,920	153,915	175,725	⑦ + ⑨
⑪	OUTCOME (YR^{-1})	43,460	44,945	24,105	13,850	5,270	③ x ⑩
⑫	EXPECTED VALUE			131630			SUM OF ⑪
⑬	Δ EXP VALUE			-12570			DIFF FROM BASE
⑭	Δ SHIP COST			300,000			" " "
⑮	Δ SHIP COST (YR^{-1})			30,000			⑭ x 0.10
⑯	SUM			17,430			⑬ + ⑮

①	BLOCK COEFF.			0.69			
②	WAVE HT.	0	6	7	8	9	TRIAL VALUE
③	PROBABILITY ②	0.35	0.35	0.18	0.09	0.03	SPECIFIED
④	SPEED	15.5	14.9	14.4	13.8	13.1	PAGE
⑤	SEA TIME	4.516	4.698	4.861	5.070	5.344	70/④
⑥	SEA FUEL	7226	7517	7778	8116	8550	4000 x 0.4 x ⑤
⑦	FUEL COST (YR^{-1})	120,960	125,830	130,200	135,860	143,120	$\frac{250}{2240}$ x 150 x ⑥
⑧	VOYAGE HRS				8.070	8.344	⑤ + 3.0
⑨	WAGE PENALTY				4375	21,500	250(⑧-8.0) x 250
⑩	OPERATING COST	120,960	125,830	130,200	140,235	164,620	⑦ + ⑨
⑪	OUTCOME (YR^{-1})	42,335	44,040	23,435	12,620	4,940	③ x ⑩
⑫	EXPECTED VALUE			127,370			SUM OF ⑪
⑬	Δ EXP VALUE			-16,830			DIFF FROM BASE
⑭	Δ SHIP COST			424,000			" " "
⑮	Δ SHIP COST (YR^{-1})			42,400			⑭ x 0.10
⑯	SUM			25,570			⑬ + ⑮

CALCULATION OF THE CONSTANT TORQUE CONTOUR

①	J	0.540	0.500	0.450	0.400	CHOSEN
②	J/J_0	1.00	0.926	0.833	0.741	①/FIRST ①
③	K_Q	0.215	0.0230	0.0245	0.0260	FROM CURVE
④	K_Q/K_{Q0}	1.00	1.070	1.140	1.209	③/FIRST ③
⑤	N/N_0	1.00	0.966	0.937	0.909	$(1/④)^{1/2}$
⑥	V/V_0	1.00	0.895	0.780	0.674	② x ⑤
⑦	K_T	0.155	0.170	0.185	0.200	FROM CURVE
⑧	K_T/K_{T0}	1.00	1.097	1.193	1.290	⑦/FIRST ⑦
⑨	R/R_0	1.00	1.023	1.048	1.066	⑧ x ⑤ ^{2}
⑩	P_E/P_{E0}	1.00	0.916	0.817	0.718	⑨ x ⑥

J = advance coefficient

K_Q = torque coefficient

K_T = thrust coefficient

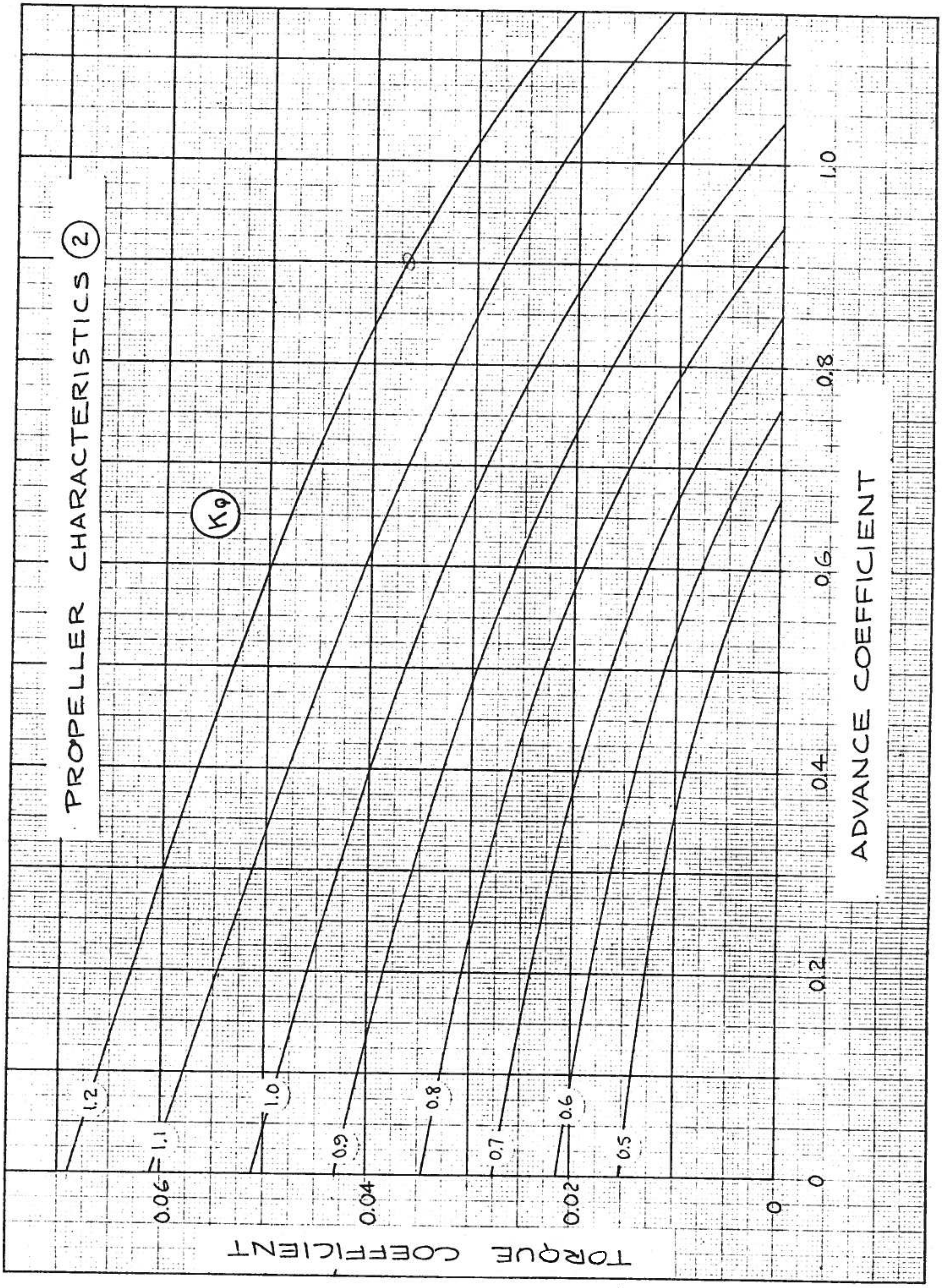
N = rpm

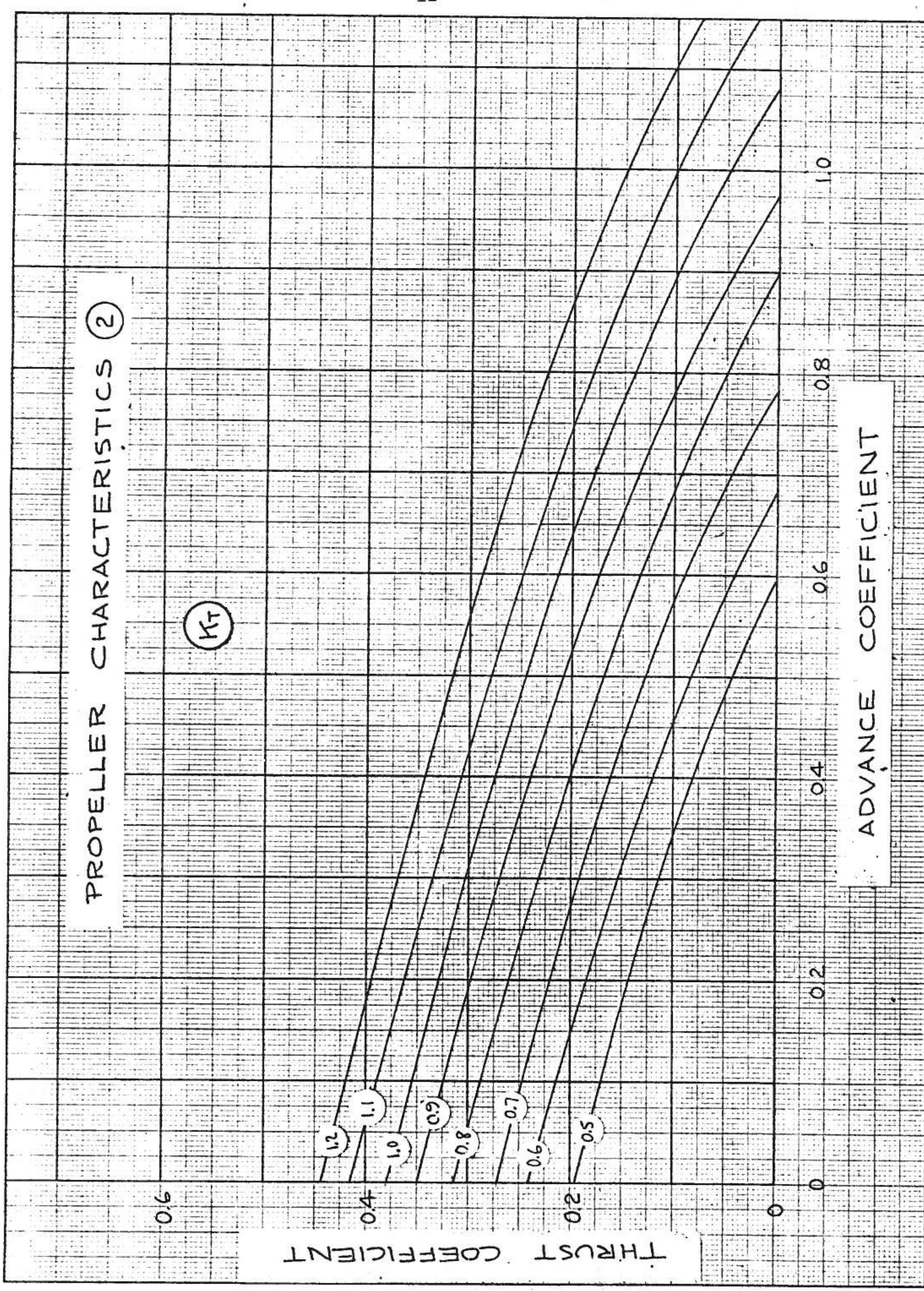
V = speed

R = resistance

P_E = effective power

Pitch ratio is 0.8, and design advance coefficient is 0.54 (first col.)


PROPELLER CHARACTERISTICS (2)
KQ
TORQUE COEFFICIENT
ADVANCE COEFFICIENT
0
0.02
0.04
0.06
0
0.2
0.4
0.6
0.8
1.0
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5


PROPELLER CHARACTERISTICS (2)
K_T
ADVANCE COEFFICIENT
0
0.2
0.4
0.6
0.8
1.0
THRUST COEFFICIENT
0
0.2
0.4
0.6
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2

APPENDIX

Abstracts of SPIRAL Modules Used Here

POWER

I. ABSTRACT

This module computes calm water resistance using Taylor A, Taylor B or Series 60 resistance data. The user must supply the ship's particulars to obtain output of speed to length ratio, Reynolds number, resistance coefficients, resistance, EHP and SHP.

WEIGHTS

I. ABSTRACT

This module computes hull steel, machinery, and outfitting weights for tankers, bulk carriers, dry cargo ships, container ships, and SEABEE vessels. In addition, it computes hull engineering weight for dry cargo ships only. The inputs are basic ship particulars, type of powerplant, and a choice of computing methods for tankers only.

BUILDING COST

I. ABSTRACT

This module computes the building cost of tankers, bulk carriers, dry cargo ships, container ships and SEABEE vessels. The inputs are the basic ship dimensions and the weights of hull steel, machinery, and outfitting. In addition, the hull engineering weight is required for Dry Cargo ships.

SEAKEEPING

I. ABSTRACT

This module calculates, dimensionally and non-dimensionally seakeeping properties of ships based on Series 60 models. (i.e. single screw merchant ships)

It is necessary to input the length between perpendiculars, beam, draft, block coefficient, significant wave height, and the speed(s) to be run. The resulting output will then be: heave at midship; pitch; bending at midship; mean added resistance; acceleration at stations 0, 5, 10, 15, and 20; the relative motion and relative velocity at stations 1, 2, 3, 4, and 20.

If the draft at station 1, the freeboard at station 1, and the propeller clearance near station 20 are inputted, then keel emergence, deck wetness, and propeller racing will also be calculated.