

No. 237  
May 1981

**K<sub>T</sub>, K<sub>Q</sub> and Efficiency Curves for  
the Wageningen B-Series Propellers**

by

**M.M. Bernitsas**

**D. Ray**

**P. Kinley**



Department of Naval Architecture  
and Marine Engineering  
College of Engineering  
The University of Michigan  
Ann Arbor, Michigan 48109

## ABSTRACT

The B-series propellers were designed and tested at the Netherlands Ship Model Basin in Wageningen. The open-water characteristics of 120 propeller models of the B-series were tested at N.S.M.B. and analyzed with multiple polynomial regression analysis [1]. The derived polynomials express the thrust and torque coefficients in terms of the number of blades, the blade area ratio, the pitch-diameter ratio and the advance coefficient. The Reynolds number effect and the effect of variation of blade thickness on the B-series propeller characteristics have also been evaluated at N.S.M.B. In this report the polynomials derived in [1] are used to plot the open water propeller characteristics for Reynolds number  $2.0 \times 10^6$  and for the ranges of number of blades, blade area ratio and pitch-diameter ratio recommended by N.S.M.B. The extent of applicability of the regression polynomials is also discussed.

#### ACKNOWLEDGEMENTS

This report was prepared in fulfillment of the requirements for the design project in the graduate computer-aided design course, NA 574, of the Department of Naval Architecture and Marine Engineering of the University of Michigan. Computer funds were provided by the department. Thanks are due to Professor R.F. Beck for his constructive comments and Mrs. Paula Bousley for the excellent typing and editing of this report.

TABLE OF CONTENTS

	Page
ABSTRACT.....	iii
ACKNOWLEDGEMENTS.....	v
LIST OF FIGURES.....	ix
NOMENCLATURE.....	xii
INTRODUCTION.....	1
$K_T$ , $K_Q$ POLYNOMIALS AND REYNOLDS NUMBER CORRECTIONS.....	3
LIMITATIONS OF APPLICABILITY OF THE REGRESSION POLYNOMIALS.....	6
REFERENCES.....	6
FIGURES.....	7

LIST OF FIGURES

Figure No.	Page
1. Propeller with 2 blades and $A_E/A_O = 0.30$ .....	7
2. Propeller with 2 blades and $A_E/A_O = 0.35$ .....	8
3. Propeller with 2 blades and $A_E/A_O = 0.40$ .....	9
4. Propeller with 2 blades and $A_E/A_O = 0.45$ .....	10
5. Propeller with 2 blades and $A_E/A_O = 0.50$ .....	11
6. Propeller with 2 blades and $A_E/A_O = 0.55$ .....	12
7. Propeller with 2 blades and $A_E/A_O = 0.60$ .....	13
8. Propeller with 2 blades and $A_E/A_O = 0.65$ .....	14
9. Propeller with 2 blades and $A_E/A_O = 0.70$ .....	15
10. Propeller with 2 blades and $A_E/A_O = 0.75$ .....	16
11. Propeller with 2 blades and $A_E/A_O = 0.80$ .....	17
12. Propeller with 2 blades and $A_E/A_O = 0.85$ .....	18
13. Propeller with 2 blades and $A_E/A_O = 0.90$ .....	19
14. Propeller with 2 blades and $A_E/A_O = 0.95$ .....	20
15. Propeller with 2 blades and $A_E/A_O = 1.00$ .....	21
16. Propeller with 2 blades and $A_E/A_O = 1.05$ .....	22
17. Propeller with 3 blades and $A_E/A_O = 0.30$ .....	23
18. Propeller with 3 blades and $A_E/A_O = 0.35$ .....	24
19. Propeller with 3 blades and $A_E/A_O = 0.40$ .....	25
20. Propeller with 3 blades and $A_E/A_O = 0.45$ .....	26
21. Propeller with 3 blades and $A_E/A_O = 0.50$ .....	27
22. Propeller with 3 blades and $A_E/A_O = 0.55$ .....	28
23. Propeller with 3 blades and $A_E/A_O = 0.60$ .....	29
24. Propeller with 3 blades and $A_E/A_O = 0.65$ .....	30
25. Propeller with 3 blades and $A_E/A_O = 0.70$ .....	31
26. Propeller with 3 blades and $A_E/A_O = 0.75$ .....	32
27. Propeller with 3 blades and $A_E/A_O = 0.80$ .....	33
28. Propeller with 3 blades and $A_E/A_O = 0.85$ .....	34
29. Propeller with 3 blades and $A_E/A_O = 0.90$ .....	35
30. Propeller with 3 blades and $A_E/A_O = 0.95$ .....	36
31. Propeller with 3 blades and $A_E/A_O = 1.00$ .....	37
32. Propeller with 3 blades and $A_E/A_O = 1.05$ .....	38

Figure No.		Page
33.	Propeller with 4 blades and $A_E/A_O = 0.30$ .....	39
34.	Propeller with 4 blades and $A_E/A_O = 0.35$ .....	40
35.	Propeller with 4 blades and $A_E/A_O = 0.40$ .....	41
36.	Propeller with 4 blades and $A_E/A_O = 0.45$ .....	42
37.	Propeller with 4 blades and $A_E/A_O = 0.50$ .....	43
38.	Propeller with 4 blades and $A_E/A_O = 0.55$ .....	44
39.	Propeller with 4 blades and $A_E/A_O = 0.60$ .....	45
40.	Propeller with 4 blades and $A_E/A_O = 0.65$ .....	46
41.	Propeller with 4 blades and $A_E/A_O = 0.70$ .....	47
42.	Propeller with 4 blades and $A_E/A_O = 0.75$ .....	48
43.	Propeller with 4 blades and $A_E/A_O = 0.80$ .....	49
44.	Propeller with 4 blades and $A_E/A_O = 0.85$ .....	50
45.	Propeller with 4 blades and $A_E/A_O = 0.90$ .....	51
46.	Propeller with 4 blades and $A_E/A_O = 0.95$ .....	52
47.	Propeller with 4 blades and $A_E/A_O = 1.00$ .....	53
48.	Propeller with 4 blades and $A_E/A_O = 1.05$ .....	54
49.	Propeller with 5 blades and $A_E/A_O = 0.30$ .....	55
50.	Propeller with 5 blades and $A_E/A_O = 0.35$ .....	56
51.	Propeller with 5 blades and $A_E/A_O = 0.40$ .....	57
52.	Propeller with 5 blades and $A_E/A_O = 0.45$ .....	58
53.	Propeller with 5 blades and $A_E/A_O = 0.50$ .....	59
54.	Propeller with 5 blades and $A_E/A_O = 0.55$ .....	60
55.	Propeller with 5 blades and $A_E/A_O = 0.60$ .....	61
56.	Propeller with 5 blades and $A_E/A_O = 0.65$ .....	62
57.	Propeller with 5 blades and $A_E/A_O = 0.70$ .....	63
58.	Propeller with 5 blades and $A_E/A_O = 0.75$ .....	64
59.	Propeller with 5 blades and $A_E/A_O = 0.80$ .....	65
60.	Propeller with 5 blades and $A_E/A_O = 0.85$ .....	66
61.	Propeller with 5 blades and $A_E/A_O = 0.90$ .....	67
62.	Propeller with 5 blades and $A_E/A_O = 0.95$ .....	68
63.	Propeller with 5 blades and $A_E/A_O = 1.00$ .....	69
64.	Propeller with 5 blades and $A_E/A_O = 1.05$ .....	70
65.	Propeller with 6 blades and $A_E/A_O = 0.30$ .....	71
66.	Propeller with 6 blades and $A_E/A_O = 0.35$ .....	72

Figure No.		Page
67.	Propeller with 6 blades and $A_E/A_O = 0.40$ .....	73
68.	Propeller with 6 blades and $A_E/A_O = 0.45$ .....	74
69.	Propeller with 6 blades and $A_E/A_O = 0.50$ .....	75
70.	Propeller with 6 blades and $A_E/A_O = 0.55$ .....	76
71.	Propeller with 6 blades and $A_E/A_O = 0.60$ .....	77
72.	Propeller with 6 blades and $A_E/A_O = 0.65$ .....	78
73.	Propeller with 6 blades and $A_E/A_O = 0.70$ .....	79
74.	Propeller with 6 blades and $A_E/A_O = 0.75$ .....	80
75.	Propeller with 6 blades and $A_E/A_O = 0.80$ .....	81
76.	Propeller with 6 blades and $A_E/A_O = 0.85$ .....	82
77.	Propeller with 6 blades and $A_E/A_O = 0.90$ .....	83
78.	Propeller with 6 blades and $A_E/A_O = 0.95$ .....	84
79.	Propeller with 6 blades and $A_E/A_O = 1.00$ .....	85
80.	Propeller with 6 blades and $A_E/A_O = 1.05$ .....	86
81.	Propeller with 7 blades and $A_E/A_O = 0.30$ .....	87
82.	Propeller with 7 blades and $A_E/A_O = 0.35$ .....	88
83.	Propeller with 7 blades and $A_E/A_O = 0.40$ .....	89
84.	Propeller with 7 blades and $A_E/A_O = 0.45$ .....	90
85.	Propeller with 7 blades and $A_E/A_O = 0.50$ .....	91
86.	Propeller with 7 blades and $A_E/A_O = 0.55$ .....	92
87.	Propeller with 7 blades and $A_E/A_O = 0.60$ .....	93
88.	Propeller with 7 blades and $A_E/A_O = 0.65$ .....	94
89.	Propeller with 7 blades and $A_E/A_O = 0.70$ .....	95
90.	Propeller with 7 blades and $A_E/A_O = 0.75$ .....	96
91.	Propeller with 7 blades and $A_E/A_O = 0.80$ .....	97
92.	Propeller with 7 blades and $A_E/A_O = 0.85$ .....	98
93.	Propeller with 7 blades and $A_E/A_O = 0.90$ .....	99
94.	Propeller with 7 blades and $A_E/A_O = 0.95$ .....	100
95.	Propeller with 7 blades and $A_E/A_O = 1.00$ .....	101
96.	Propeller with 7 blades and $A_E/A_O = 1.05$ .....	102

## NOMENCLATURE

$A_E/A_O$	blade area ratio
$C_s^Q, t, u, v$	coefficient in the $K_Q$ polynomial expression
$C_s^T, t, u, v$	coefficient in the $K_T$ polynomial expression
D	propeller diameter
J	advance coefficient
$K_Q$	torque coefficient
$K_T$	thrust coefficient
n	propeller revolutions per second
P/D	pitch-diameter ratio
Q	propeller torque
Re	Reynolds number
T	propeller thrust
t/c	thickness to cord ratio for propeller blades
$V_A$	speed of advance
Z	number of blades

### Greek Symbols

$\eta$	open-water propeller efficiency
$\rho$	fluid density

## INTRODUCTION

The open-water propeller characteristics conventionally are presented in the form of the thrust and torque coefficients  $K_T$  and  $K_Q$  in terms of the advance coefficient  $J$  where

$$K_T = \frac{T}{\rho n^2 D^4} \quad (1)$$

$$K_Q = \frac{Q}{\rho n^2 D^5} \quad (2)$$

$$J = \frac{V_A}{nD} \quad (3)$$

where

$T$  is the propeller thrust,

$Q$  is the propeller torque,

$\rho$  is the fluid density,

$n$  is the number of propeller revolutions per second,

$D$  is the propeller diameter and

$V_A$  is the speed of advance.

The open-water efficiency of the propeller is

$$\eta_O = \frac{J}{2\pi} \frac{K_T}{K_Q} \quad (4)$$

The thrust and torque coefficients can be written as:

$$K_T = f_T(J, \frac{P}{D}, \frac{A_E}{A_O}, Z, Re, \frac{t}{c}) \quad (5)$$

and

$$K_Q = f_Q(J, \frac{P}{D}, \frac{A_E}{A_O}, Z, Re, \frac{t}{c}) \quad (6)$$

where

$P/D$  is the pitch diameter ratio

$A_E/A_O$  is the blade area ratio

$Z$  is the number of propeller blades

$Re$  is the Reynolds number of a characteristic radius ( $0.75 R$ )

$t/c$  is the ratio of the maximum propeller blade thickness to the length of the cord at a characteristic radius ( $0.75 R$ )

$K_T$  and  $K_Q$  can be expressed in terms of polynomials of  $J$ ,  $\frac{P}{D}$ ,  $\frac{A_E}{A_O}$ , and  $Z$  (see Table 1) [1].

The Reynolds number effect on the propeller characteristics has been taken into account using Lerbs method [2]. The Reynolds number corrections for  $K_T$  and  $K_Q$  are polynomial expressions of  $Re$ ,  $P/D$ ,  $A_E/A_O$  and  $J$  (see Table 2).

Finally the effect of variation of blade thickness on propeller characteristics can be represented as a change in the Reynolds number and need not be formulated in a polynomial form [1].

### $K_T$ , $K_Q$ POLYNOMIALS AND REYNOLDS NUMBER CORRECTIONS

The polynomials for  $K_T$  and  $K_Q$  derived with multiple regression analysis are

$$K_T = \sum_{s,t,u,v} C_{s,t,u,v}^T (J)^s (P/D)^t (A_E/A_O)^u (Z)^v \quad (7)$$

$$K_Q = \sum_{s,t,u,v} C_{s,t,u,v}^Q (J)^s (P/D)^t (A_E/A_O)^u (Z)^v \quad (8)$$

The coefficients  $C_{s,t,u,v}^T$  and  $C_{s,t,u,v}^Q$  and terms  $s,t,u,v$  are given in Table 1.

For Reynolds number greater than  $2 \times 10^6$  the open water propeller characteristics should be corrected. The corrections

$$\Delta K_T(Re, J, P/D, A_E/A_O, z) \quad (9)$$

and

$$\Delta K_Q(Re, J, P/D, A_E/A_O, z) \quad (10)$$

are given in Table 2.

TABLE 1

Coefficients and terms of the  $K_T$  and  $K_Q$  polynomials for the Wageningen B-screw Series for  $R_n = 2 \times 10^6$ . Reproduced from [1]

$$K_T = \sum_{s,t,u,v} C_{s,t,u,v}^T \cdot (J)^s \cdot (P/D)^t \cdot (A_E/A_O)^u \cdot (z^v)$$

$$K_Q = \sum_{s,t,u,v} C_{s,t,u,v}^Q \cdot (J)^s \cdot (P/D)^t \cdot (A_E/A_O)^u \cdot (z^v)$$

$K_T$	$C_{s,t,u,v}^T$	$s$ (J)	$t$ (P/D)	$u$ ( $A_E/A_O$ )	$v$ (Z)	$C_{s,t,u,v}^Q$	$s$ (J)	$t$ (P/D)	$u$ ( $A_E/A_O$ )	$v$ (Z)
+0.00880496	0	0	0	0	0	+0.00379368	0	0	0	0
-0.204554	1	0	0	0	0	+0.00886523	2	0	0	0
+0.166351	0	1	0	0	0	-0.032241	1	1	0	0
+0.158114	0	2	0	0	0	+0.00344778	0	2	0	0
-0.147581	2	0	1	0	0	-0.0408811	0	1	1	0
-0.481497	1	1	1	0	0	-0.108009	1	1	1	0
+0.415437	0	2	1	0	0	-0.0885381	2	1	1	0
+0.0144043	0	0	0	1	0	+0.188561	0	2	1	0
-0.0530054	2	0	0	0	1	-0.00370871	1	0	0	1
+0.0143481	0	1	0	0	1	+0.00513696	0	1	0	1
+0.0606826	1	1	0	0	1	+0.0209449	1	1	0	1
-0.0125894	0	0	1	1	1	+0.00474319	2	1	0	1
+0.0109689	1	0	1	1	1	-0.00723408	2	0	1	1
-0.133698	0	3	0	0	0	+0.00438388	1	1	1	1
+0.00638407	0	6	0	0	0	-0.0269403	0	2	1	1
-0.00132718	2	6	0	0	0	+0.0558082	3	0	1	0
+0.168496	3	0	0	1	0	+0.0161886	0	3	1	0
-0.0507214	0	0	2	0	0	+0.00318086	1	3	1	0
+0.0854559	2	0	2	0	0	+0.015896	0	0	2	0
-0.0504475	3	0	2	0	0	+0.0471729	1	0	2	0
+0.010465	1	6	2	0	0	+0.0196283	3	0	2	0
-0.00648272	2	6	2	0	0	-0.0502782	0	1	2	0
-0.00841728	0	3	0	1	0	-0.030055	3	1	2	0
+0.0168424	1	3	0	0	1	+0.0417122	2	2	2	0
-0.00102296	3	3	0	0	1	-0.0397722	0	3	2	0
-0.0317791	0	3	1	1	1	-0.00350024	0	6	2	0
+0.018604	1	0	2	1	1	-0.0106854	3	0	0	1
-0.00410798	0	2	2	1	1	+0.00110903	3	3	0	1
-0.000606848	0	0	0	2	0	-0.000313912	0	6	0	1
-0.0049819	1	0	0	0	2	+0.0035985	3	0	1	1
+0.0025983	2	0	0	0	2	-0.00142121	0	6	1	1
-0.000560528	3	0	0	0	2	-0.00383637	1	0	2	1
-0.00163652	1	2	0	0	2	+0.0126803	0	2	2	1
-0.000328787	1	6	0	0	2	-0.00318278	2	3	2	1
+0.000116502	2	6	0	0	2	+0.00334268	0	6	2	1
+0.000690904	0	0	1	2	0	-0.00183491	1	1	0	2
+0.00421749	0	3	1	1	2	+0.000112451	3	2	0	2
+0.0000565229	3	6	1	1	2	-0.0000297228	3	6	0	2
-0.00146564	0	3	2	2	0	+0.000269551	1	6	1	2
						+0.00083265	2	0	1	2
						+0.00155334	0	2	1	2
						+0.000302683	0	6	1	2
						-0.0001843	0	0	2	2
						-0.000425399	0	3	2	2
						+0.0000869243	3	3	2	2
						-0.0004659	0	6	2	2
						+0.0000554194	1	6	2	2

$$R_n = 2 \times 10^6$$

TABLE 2

Polynomials for Reynolds number effect (above  $R_n = 2 \times 10^6$ ) on  $K_T$  and  $K_Q$

$$\Delta K_T = 0.000353485$$

$$\begin{aligned} & -0.00333758(A_E/A_O)J^2 \\ & -0.00478125(A_E/A_O)(P/D)J \\ & +0.000257792(\log R_n - 0.301)^2(A_E/A_O)J^2 \\ & +0.0000643192(\log R_n - 0.301)(P/D)^6J^2 \\ & -0.0000110636(\log R_n - 0.301)^2(P/D)^6J^2 \\ & -0.0000276305(\log R_n - 0.301)^2z(A_E/A_O)J^2 \\ & +0.0000954(\log R_n - 0.301)z(A_E/A_O)(P/D)J \\ & +0.0000032049(\log R_n - 0.301)z^2(A_E/A_O)(P/D)^3J \end{aligned}$$

$$\Delta K_Q = -0.000591412$$

$$\begin{aligned} & +0.00696898(P/D) \\ & -0.0000666654z(P/D)^6 \\ & +0.0160818(A_E/A_O)^2 \\ & -0.000938091(\log R_n - 0.301)(P/D) \\ & -0.00059593(\log R_n - 0.301)(P/D)^2 \\ & +0.0000782099(\log R_n - 0.301)^2(P/D)^2 \\ & +0.0000052199(\log R_n - 0.301)z(A_E/A_O)J^2 \\ & -0.00000088528(\log R_n - 0.301)^2z(A_E/A_O)(P/D)J \\ & +0.0000230171(\log R_n - 0.301)z(P/D)^6 \\ & -0.000000184341(\log R_n - 0.301)^2z(P/D)^6 \\ & -0.00400252(\log R_n - 0.301)(A_E/A_O)^2 \\ & +0.000220915(\log R_n - 0.301)^2(A_E/A_O)^2 \end{aligned}$$

## LIMITATIONS OF APPLICABILITY OF THE REGRESSION POLYNOMIALS

The derived regression polynomials can be used to evaluate the thrust and torque coefficients for

$$2 \leq z \leq 7 , \quad (11)$$

$$0.30 \leq A_E/A_O \leq 1.05 , \quad (12)$$

and

$$0.5 \leq P/D \leq 1.40 \quad (13)$$

However, at the extremes of the above ranges the results are not fully reliable. For instance the thrust coefficient  $K_T$  displays a local maximum for low values of  $J$ , high number of blades, low blade area ratio and high pitch-diameter ratio. This minor error is due to regression analysis.

96 open-water propeller characteristics curves are included in this report. For each set of blades between 2 and 7, sixteen graphs have been plotted for blade area ratio varying between 0.30 and 1.05 in steps of 0.05 and pitch diameter ratio varying between 0.50 and 1.40 in steps of 0.10. These graphs have been plotted with the aid of the Michigan Computer Center plotting routines which are included in the public file \*PLOTSYS [3].

## REFERENCES

1. Oosterveld, M.W.C. and P. Van Oosanen, "Further Computer-Analyzed Data of the Wageningen B-Screw Series," IV International Symposium on Ship Automation, Genova, Italy, Nov. 1974.
2. Lerbs, H.W., "On the Effect of Scale and Roughness on Free Running Propellers," Journal ASME, 1951.
3. MTS Volume 11: "Plot Description System," University of Michigan Computing Center, 1978.

FIGURE 1. WAGENINGEN B-SERIES PROPELLERS  
 FOR 2 BLADES       $A_e/A_0 = 0.300$   
 $P/D = 0.50$  TO  $1.40$

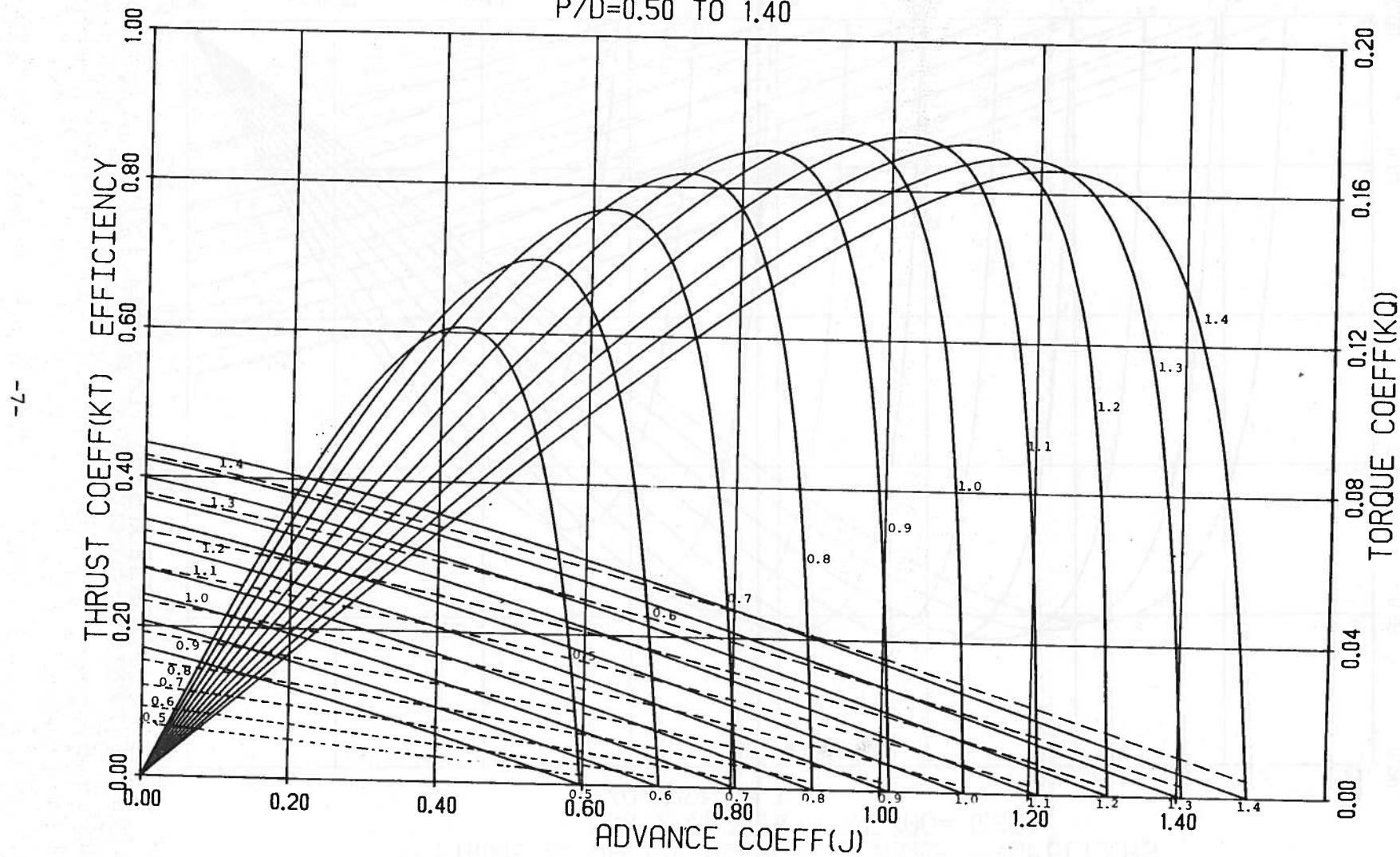


FIGURE 2. WAGENINGEN B-SERIES PROPELLERS  
FOR 2 BLADES       $A_e/A_0 = 0.350$   
 $P/D = 0.50 \text{ TO } 1.40$

-8-

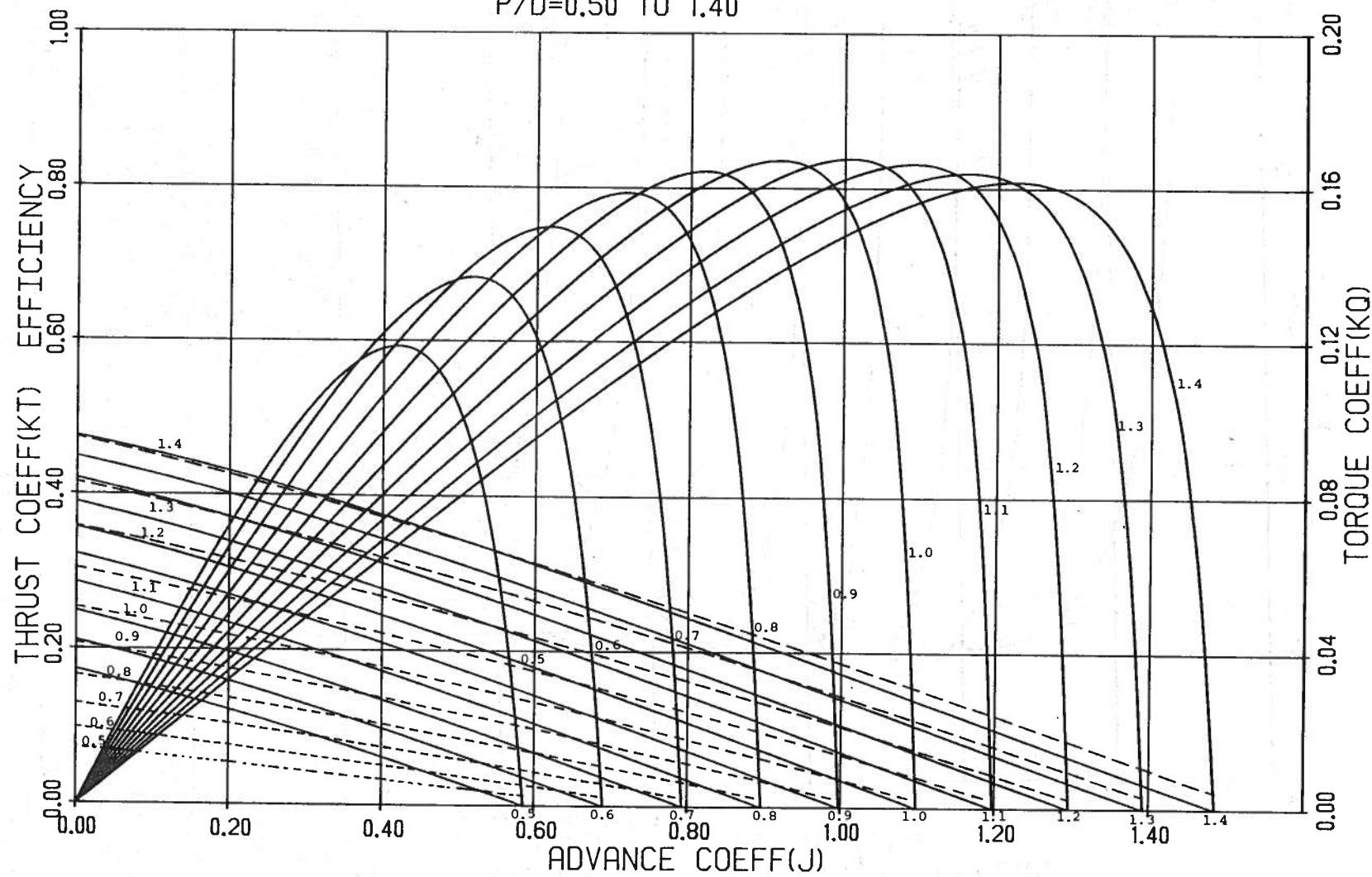


FIGURE 3. WAGENINGEN B-SERIES PROPELLERS  
FOR 2 BLADES       $A_e/A_0 = 0.400$   
 $P/D = 0.50$  TO  $1.40$

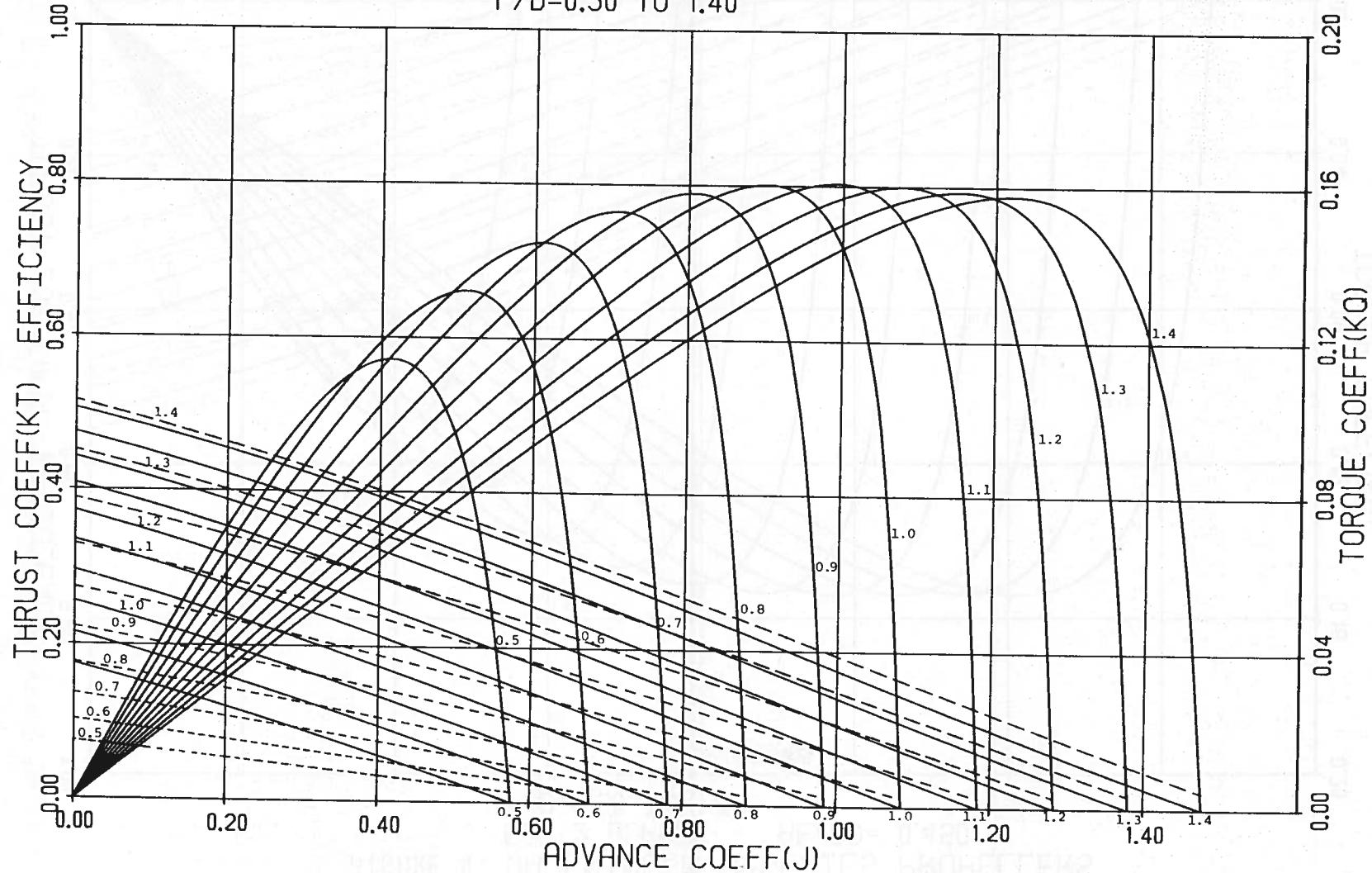


FIGURE 4. WAGENINGEN B-SERIES PROPELLERS  
FOR 2 BLADES       $A_e/A_0 = 0.450$   
 $P/D = 0.50$  TO  $1.40$

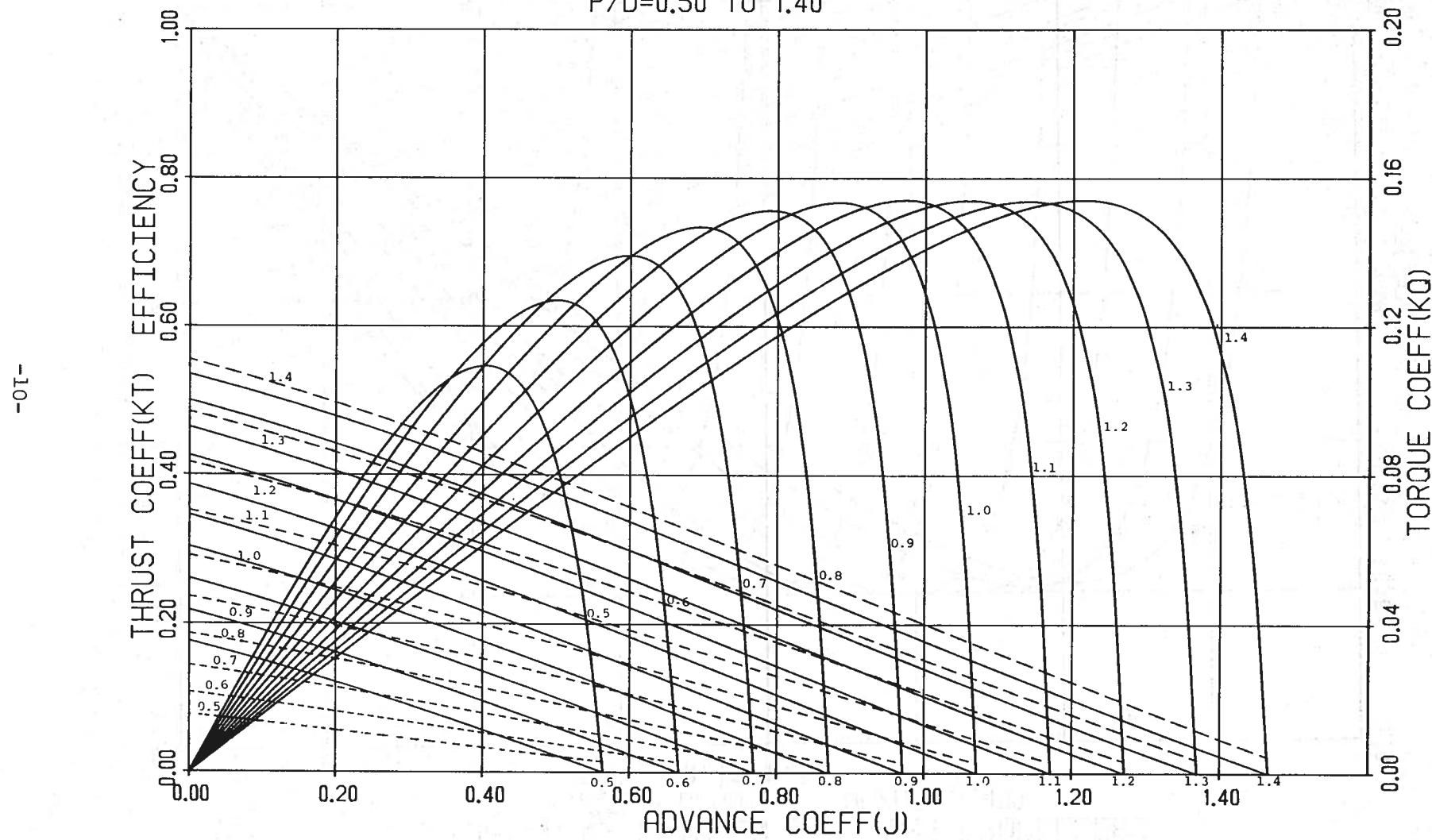


FIGURE 5. WAGENINGEN B-SERIES PROPELLERS  
FOR 2 BLADES       $A_e/A_0 = 0.500$   
 $P/D = 0.50$  TO  $1.40$

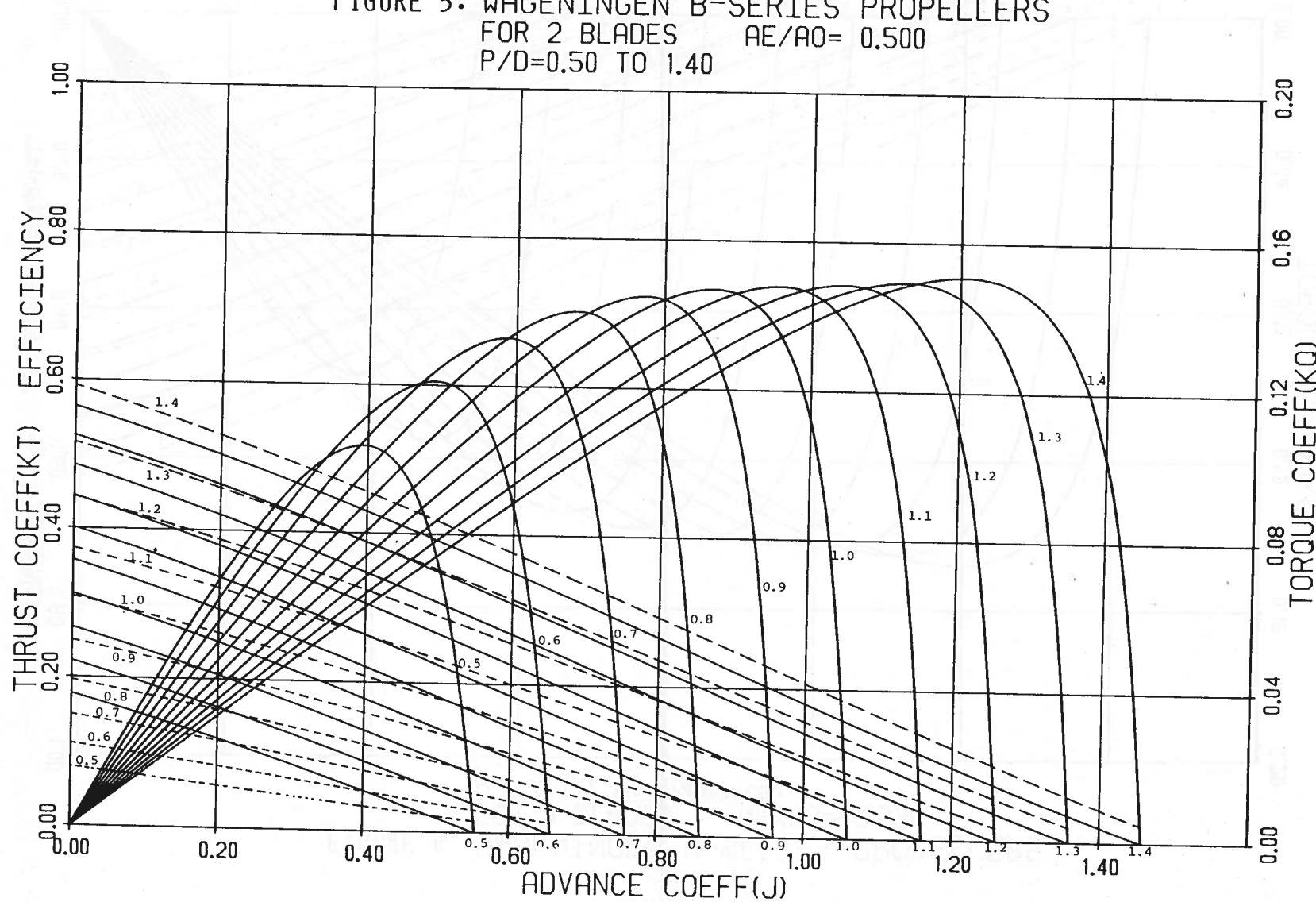


FIGURE 6. WAGENINGEN B-SERIES PROPELLERS  
FOR 2 BLADES  $A_e/A_0 = 0.550$   
 $P/D = 0.50$  TO  $1.40$

-12-

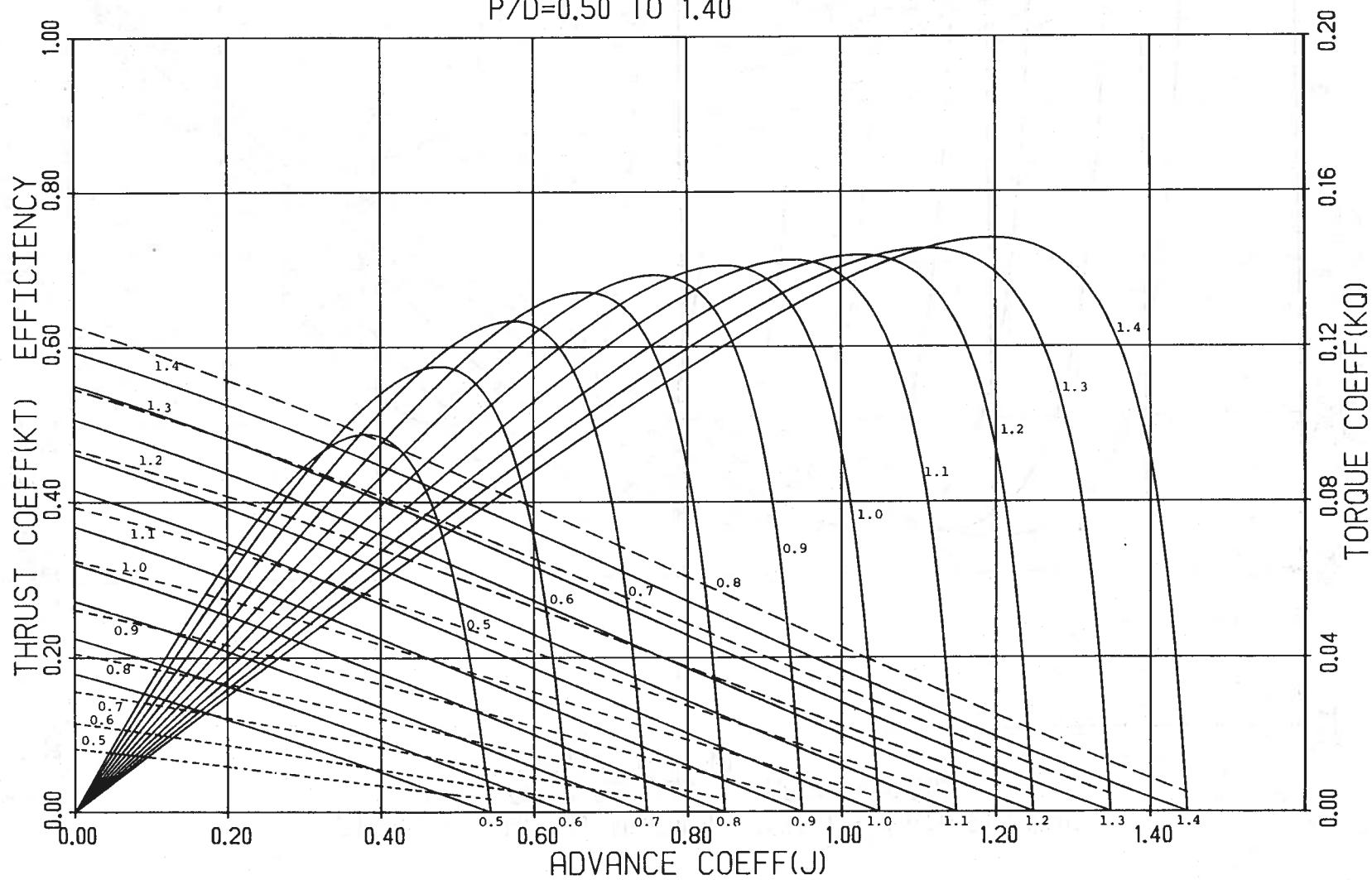


FIGURE 7. WAGENINGEN B-SERIES PROPELLERS  
 FOR 2 BLADES  $A_e/A_0 = 0.600$   
 $P/D = 0.50$  TO  $1.40$

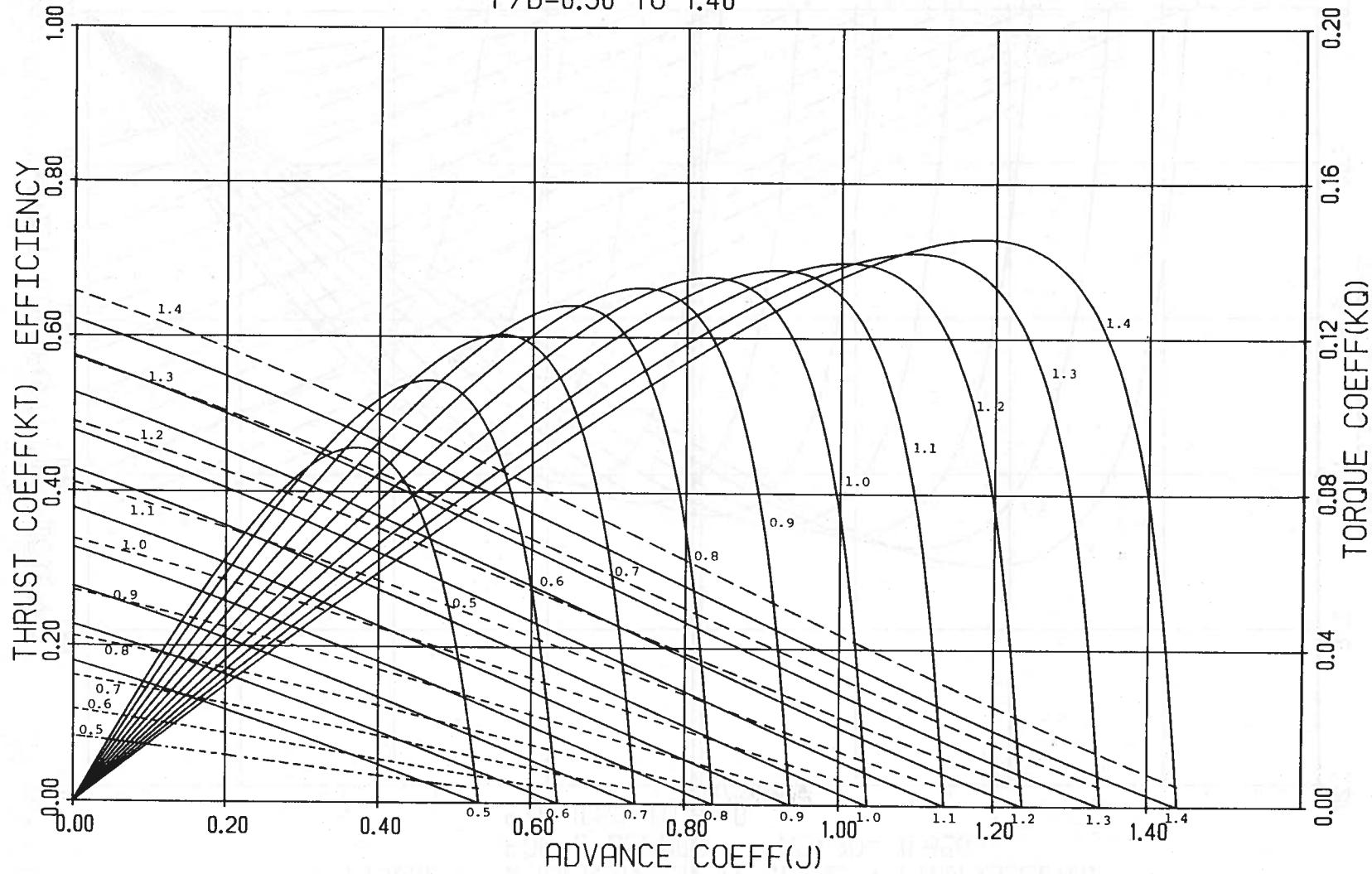


FIGURE 8. WAGENINGEN B-SERIES PROPELLERS  
 FOR 2 BLADES  $A_e/A_0 = 0.650$   
 $P/D = 0.50$  TO  $1.40$

-14-

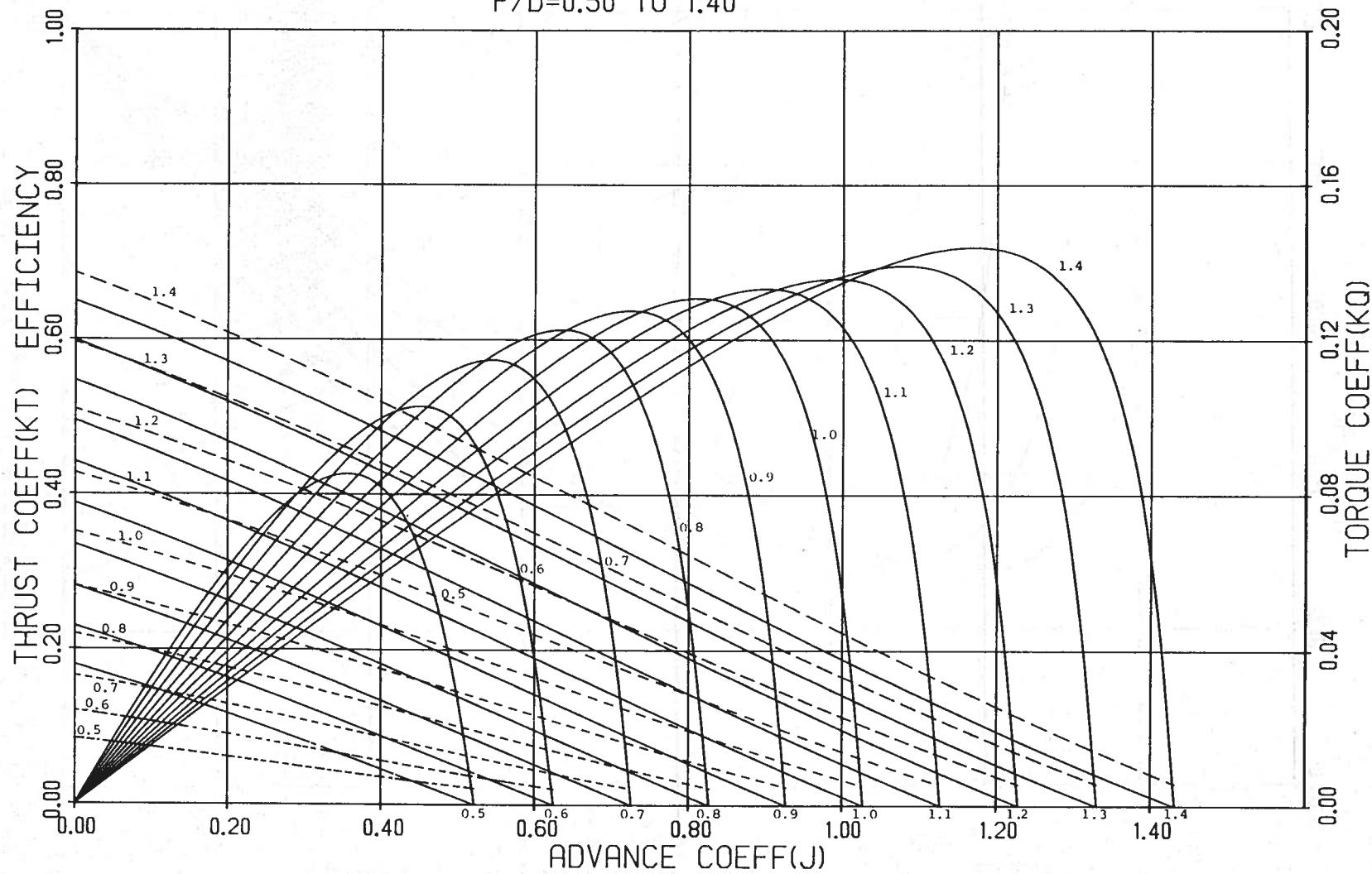


FIGURE 9. WAGENINGEN B-SERIES PROPELLERS  
FOR 2 BLADES       $A_e/A_0 = 0.700$   
 $P/D = 0.50$  TO  $1.40$

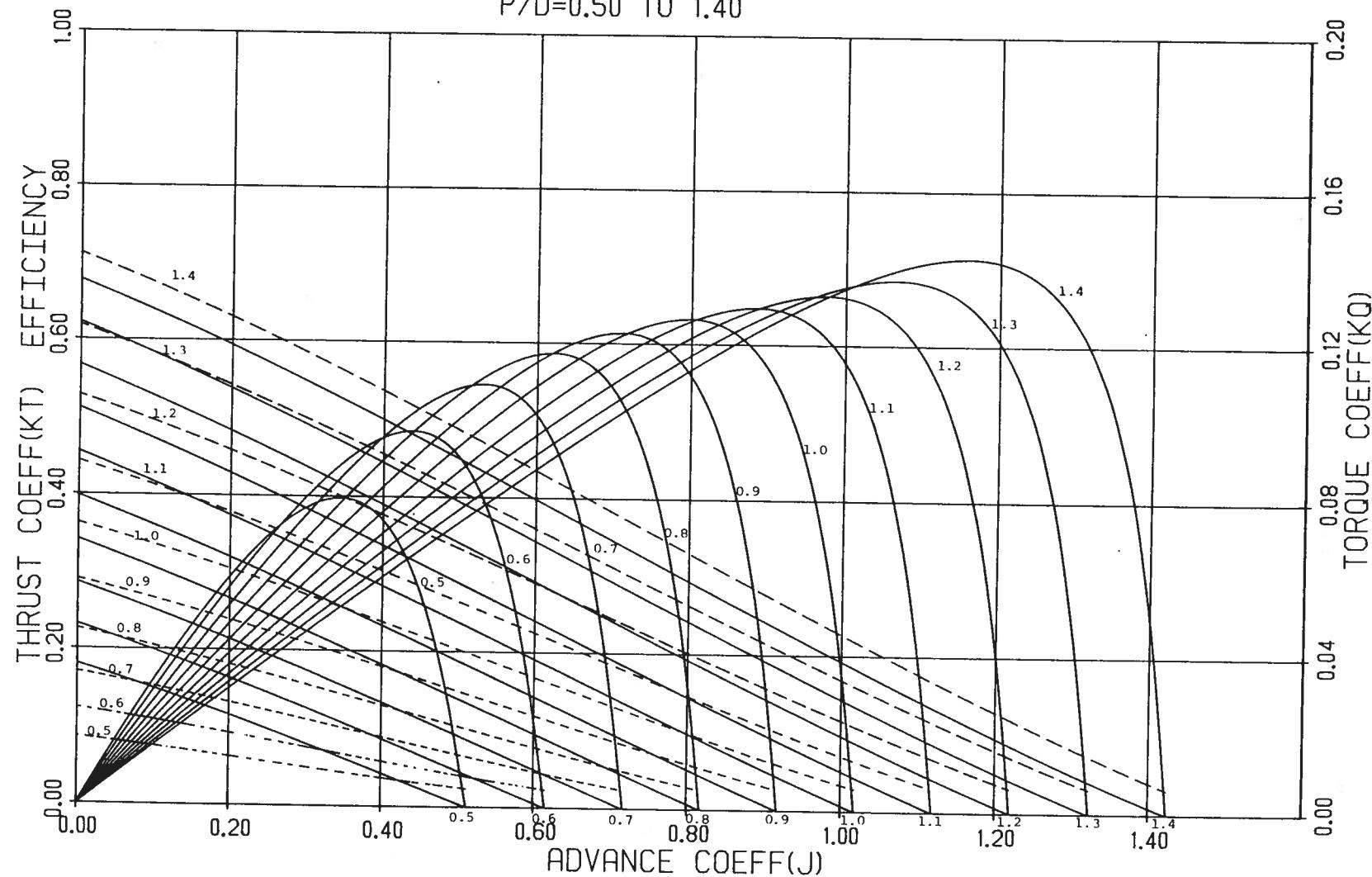


FIGURE 10. WAGENINGEN B-SERIES PROPELLERS  
FOR 2 BLADES  $A_e/A_0 = 0.750$   
 $P/D = 0.50$  TO  $1.40$

-9T-

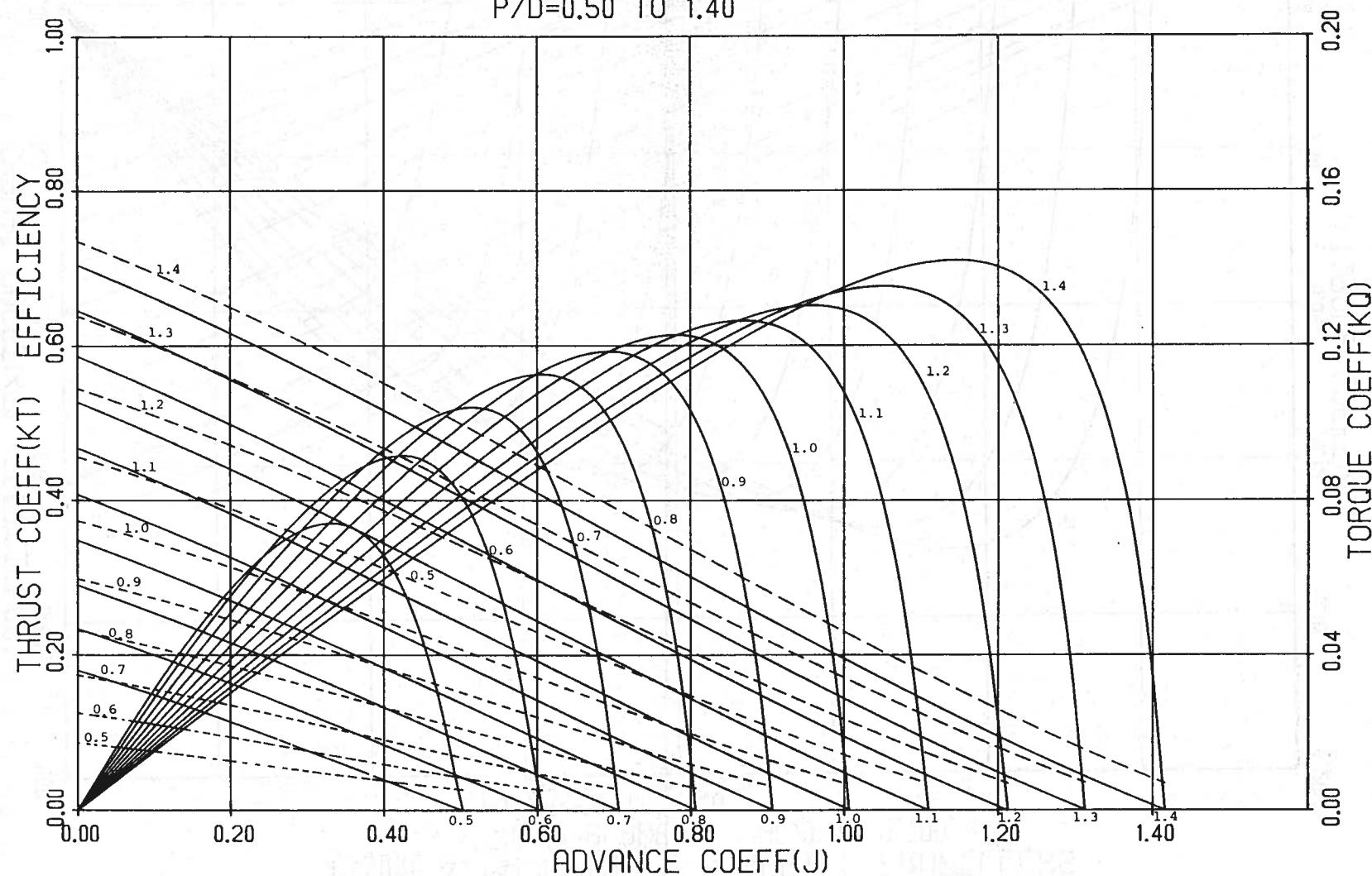


FIGURE 11. WAGENINGEN B-SERIES PROPELLERS  
FOR 2 BLADES  $A_e/A_0 = 0.800$   
 $P/D = 0.50$  TO  $1.40$

-L1-

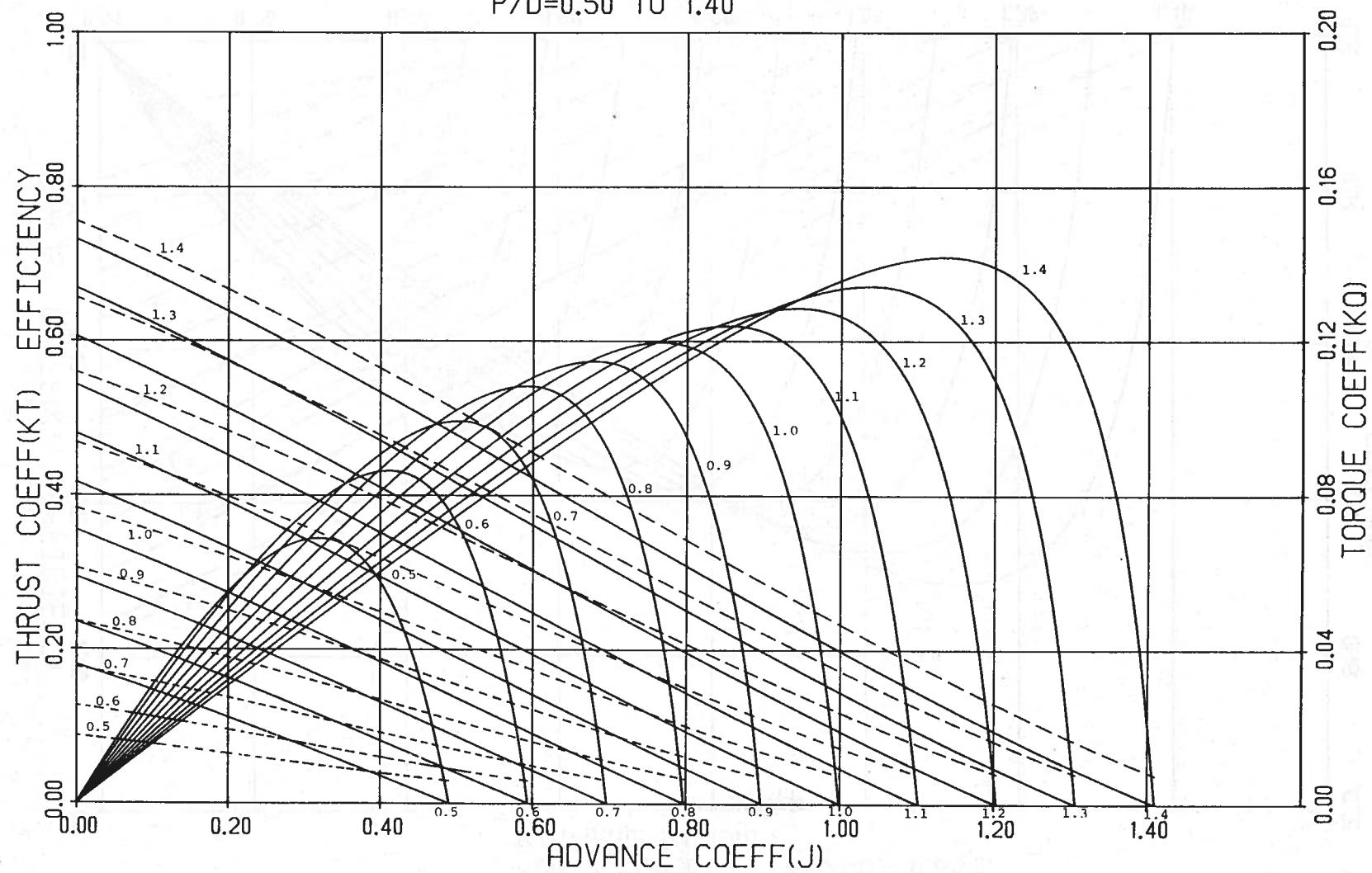


FIGURE 12. WAGENINGEN B-SERIES PROPELLERS  
FOR 2 BLADES       $A_e/A_0 = 0.850$   
 $P/D = 0.50$  TO  $1.40$

-8T-

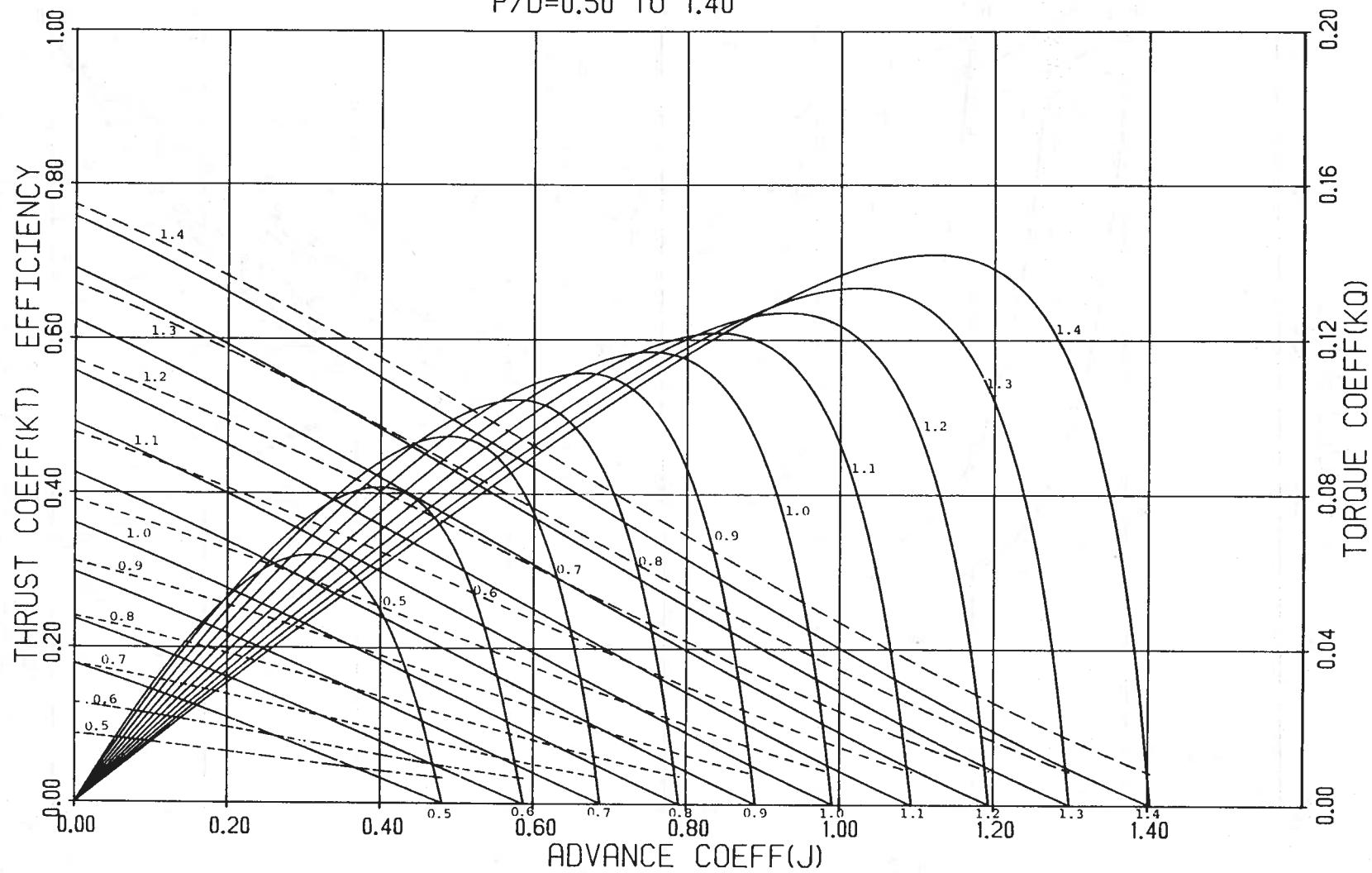


FIGURE 13. WAGENINGEN B-SERIES PROPELLERS  
FOR 2 BLADES  $A_e/A_0 = 0.900$   
 $P/D = 0.50$  TO  $1.40$

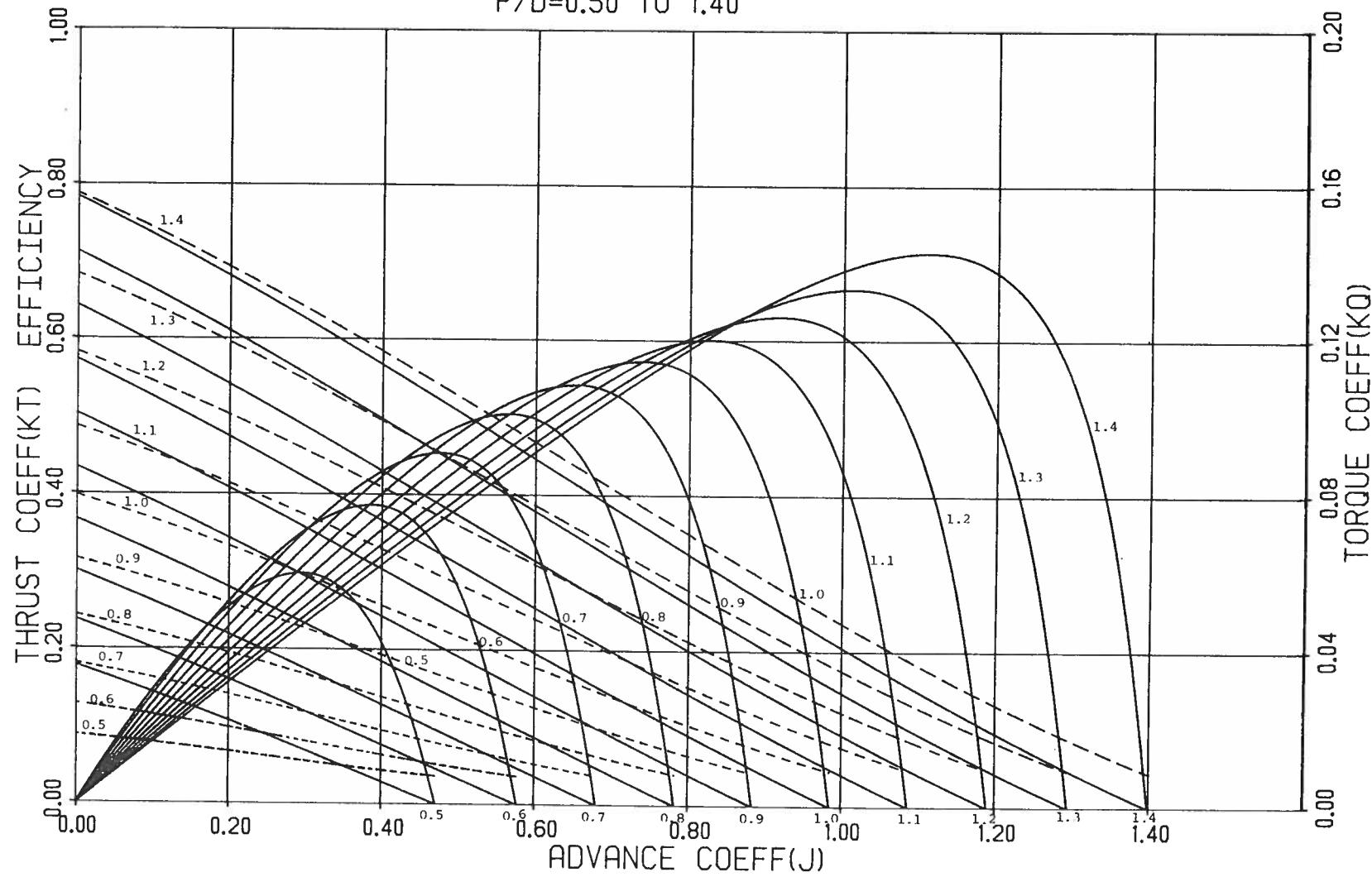


FIGURE 14. WAGENINGEN B-SERIES PROPELLERS  
 FOR 2 BLADES  $AE/A_0 = 0.950$   
 $P/D = 0.50$  TO  $1.40$

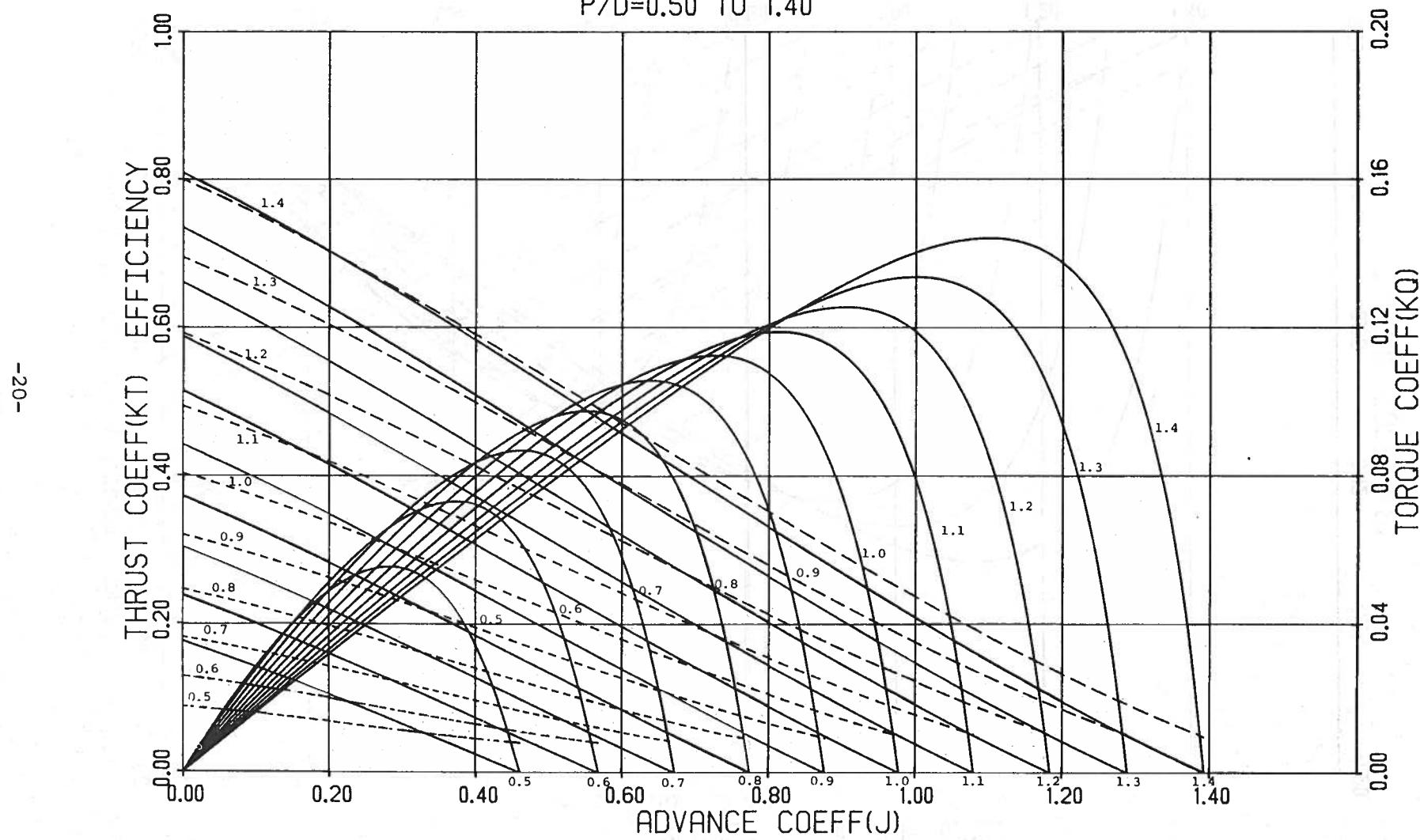


FIGURE 15. WAGENINGEN B-SERIES PROPELLERS  
FOR 2 BLADES       $A_e/A_0 = 1.000$   
 $P/D = 0.50$  TO  $1.40$

-12-

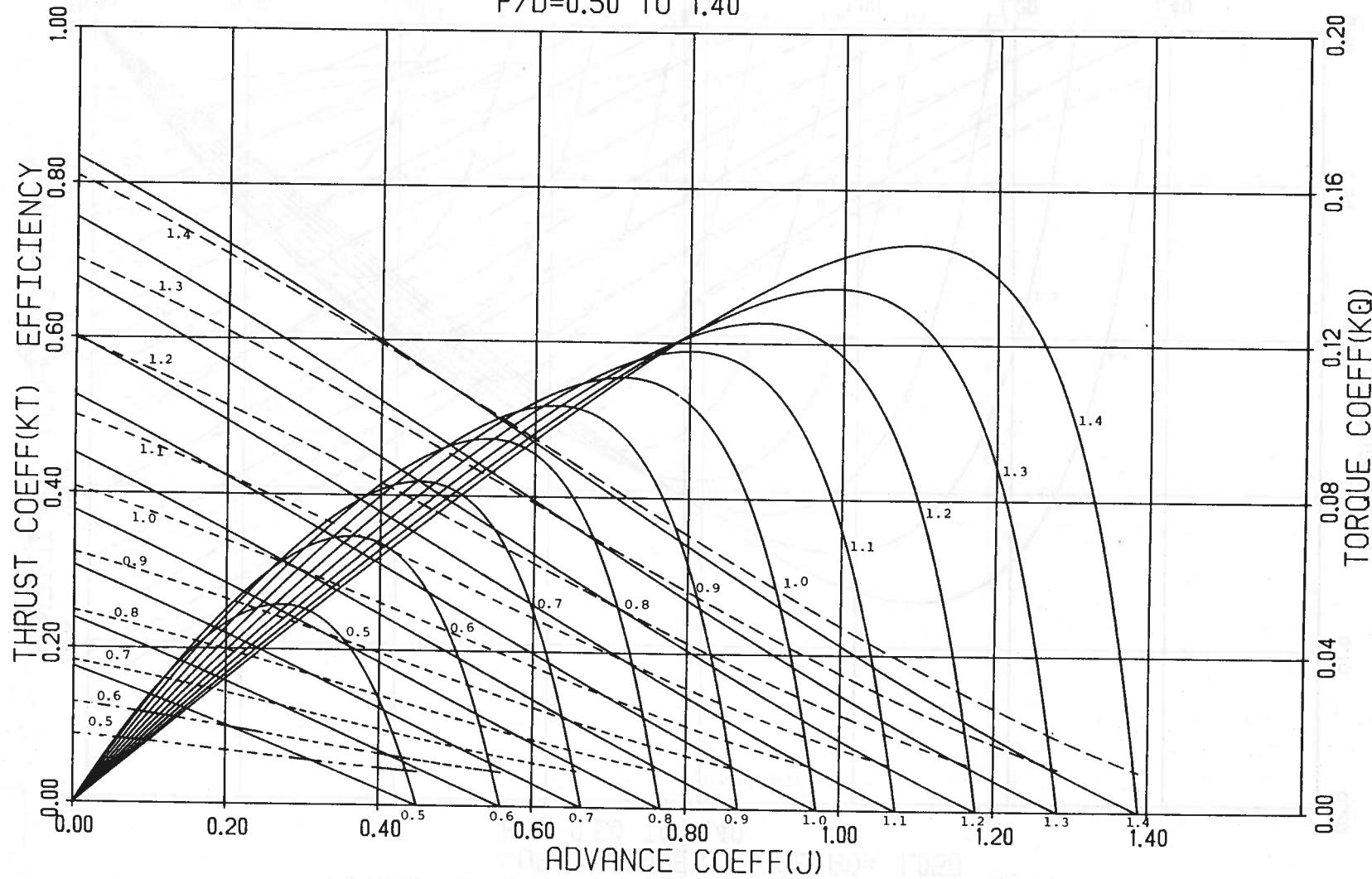


FIGURE 16. WAGENINGEN B-SERIES PROPELLERS  
FOR 2 BLADES  $A_E/A_0 = 1.050$   
 $P/D = 0.50$  TO  $1.40$

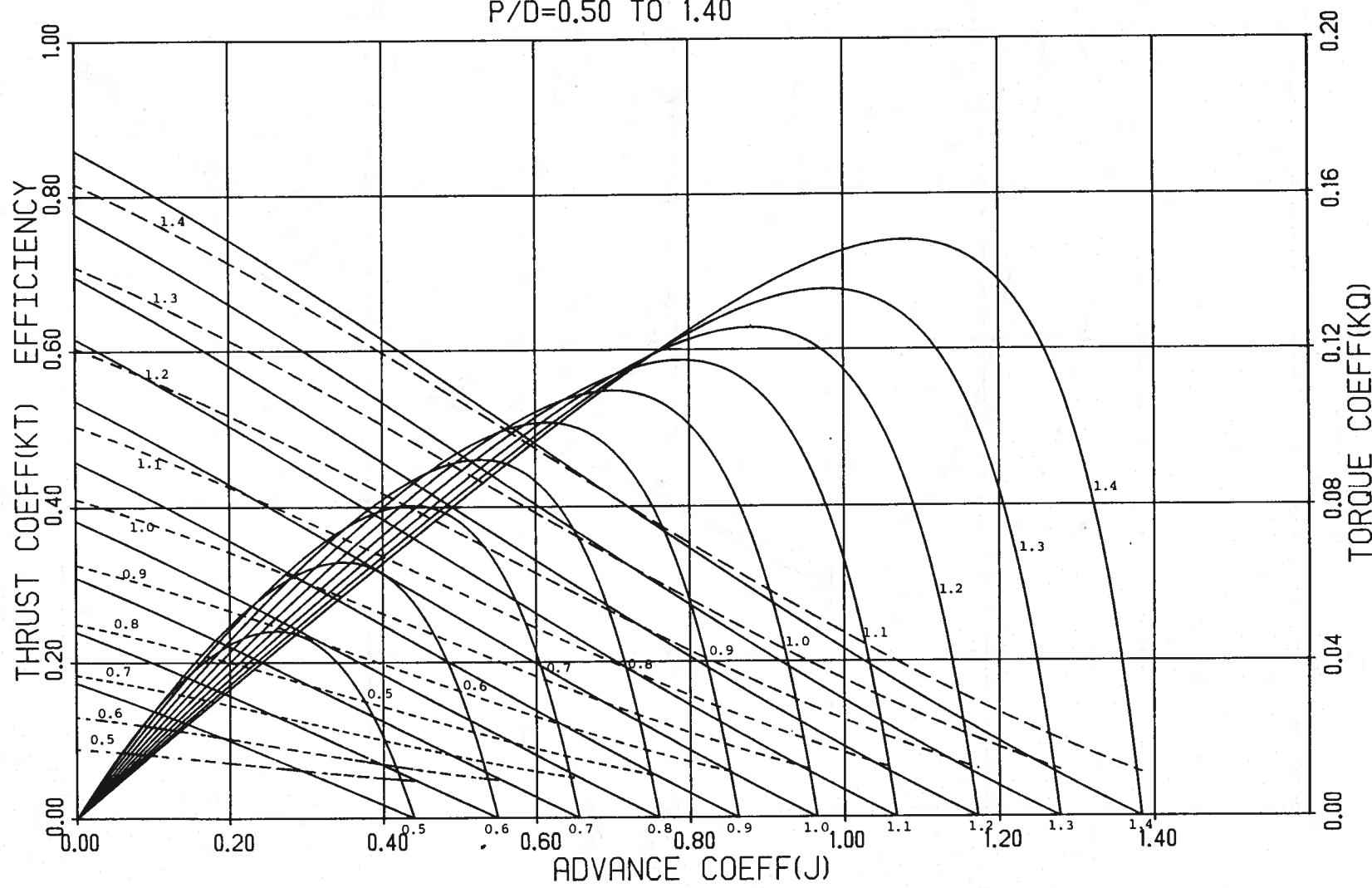


FIGURE 17. WAGENINGEN B-SERIES PROPELLERS  
FOR 3 BLADES  $A_e/A_0 = 0.300$   
 $P/D = 0.50$  TO  $1.40$

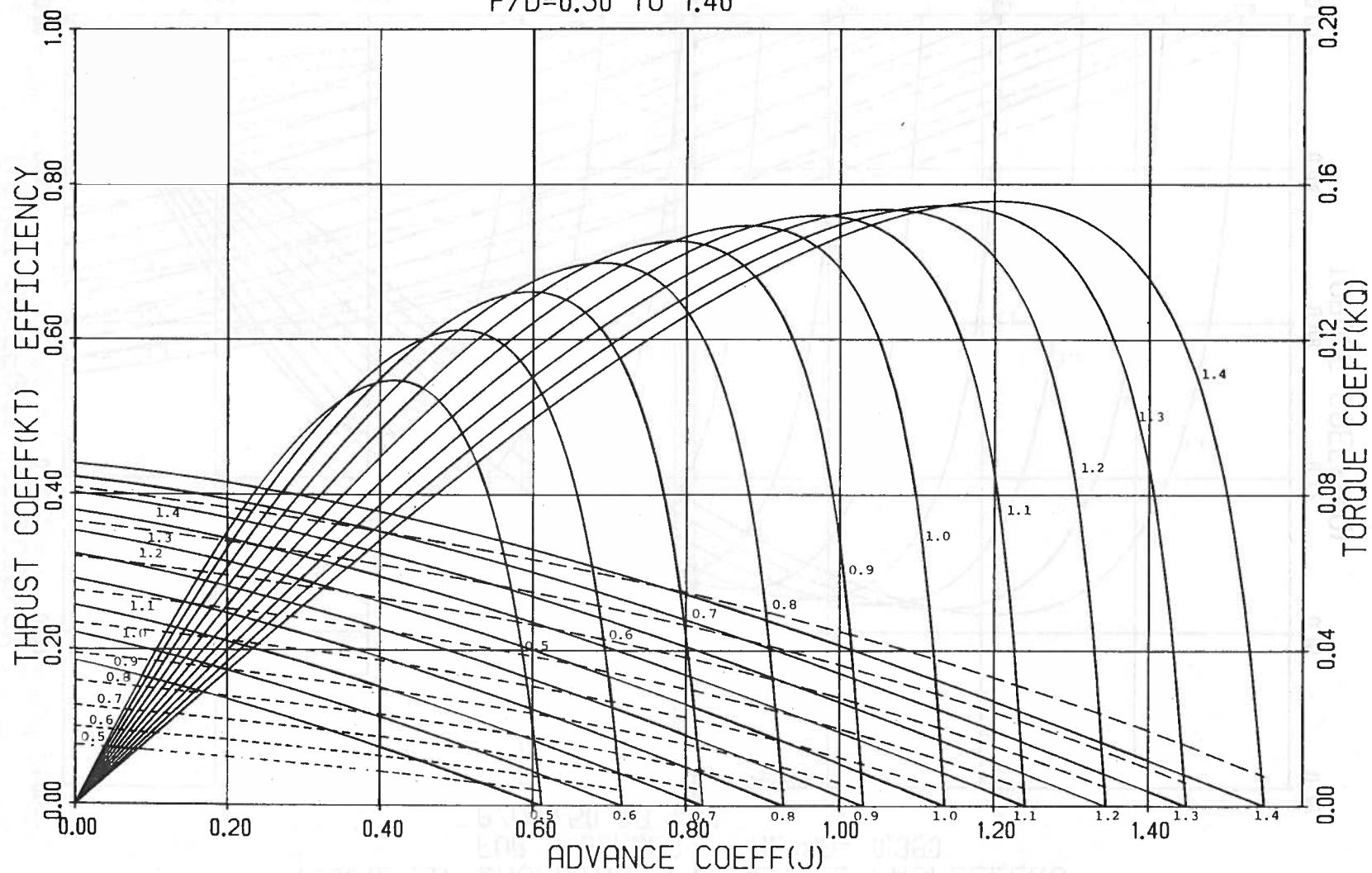


FIGURE 18. WAGENINGEN B-SERIES PROPELLERS  
 FOR 3 BLADES  $A_e/A_0 = 0.350$   
 $P/D = 0.50$  TO  $1.40$

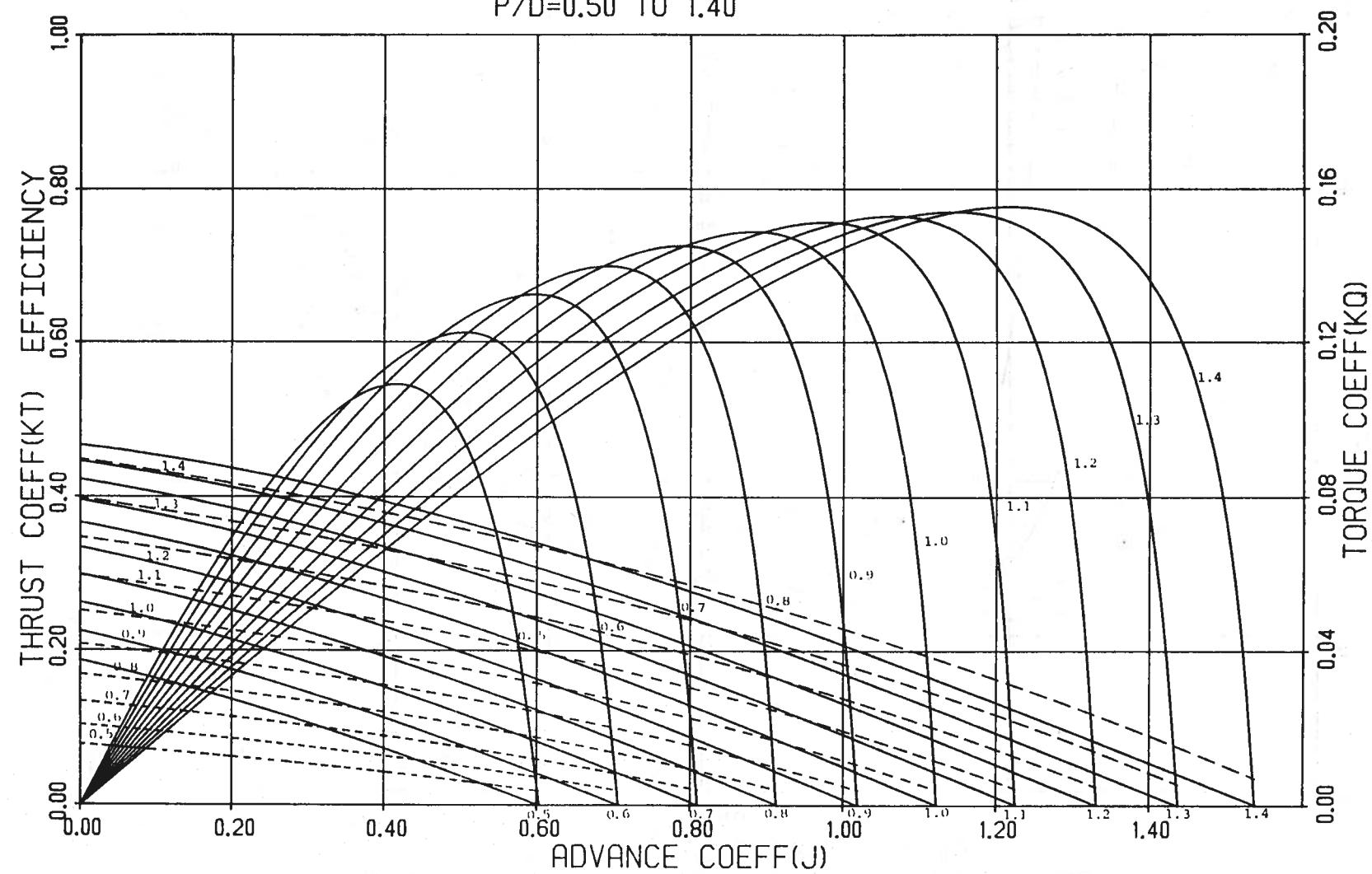


FIGURE 19. WAGENINGEN B-SERIES PROPELLERS  
FOR 3 BLADES       $A_e/A_0 = 0.400$   
 $P/D = 0.50$  TO  $1.40$

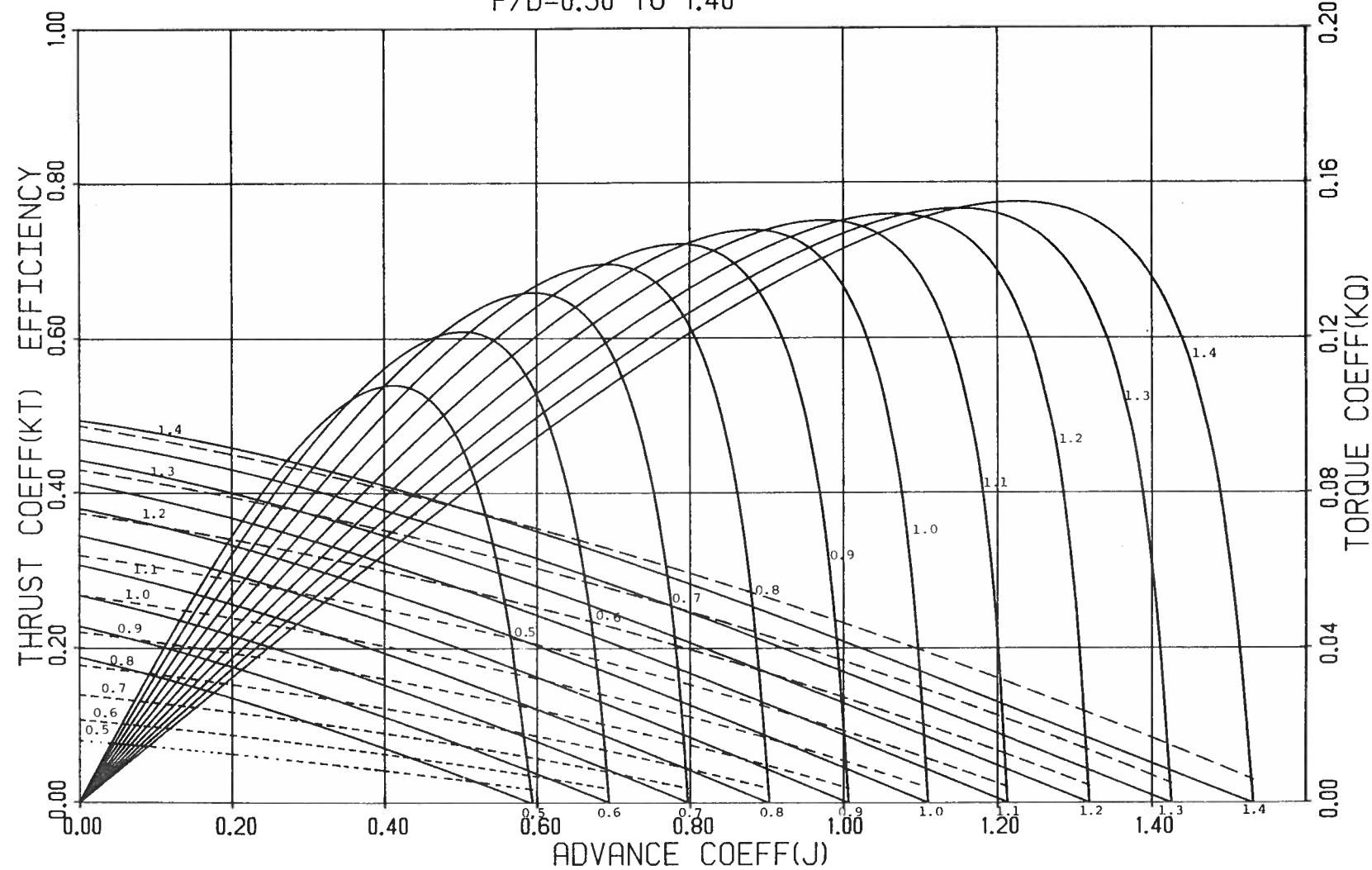


FIGURE 20. WAGENINGEN B-SERIES PROPELLERS  
FOR 3 BLADES       $A_e/A_0 = 0.450$   
 $P/D = 0.50$  TO  $1.40$

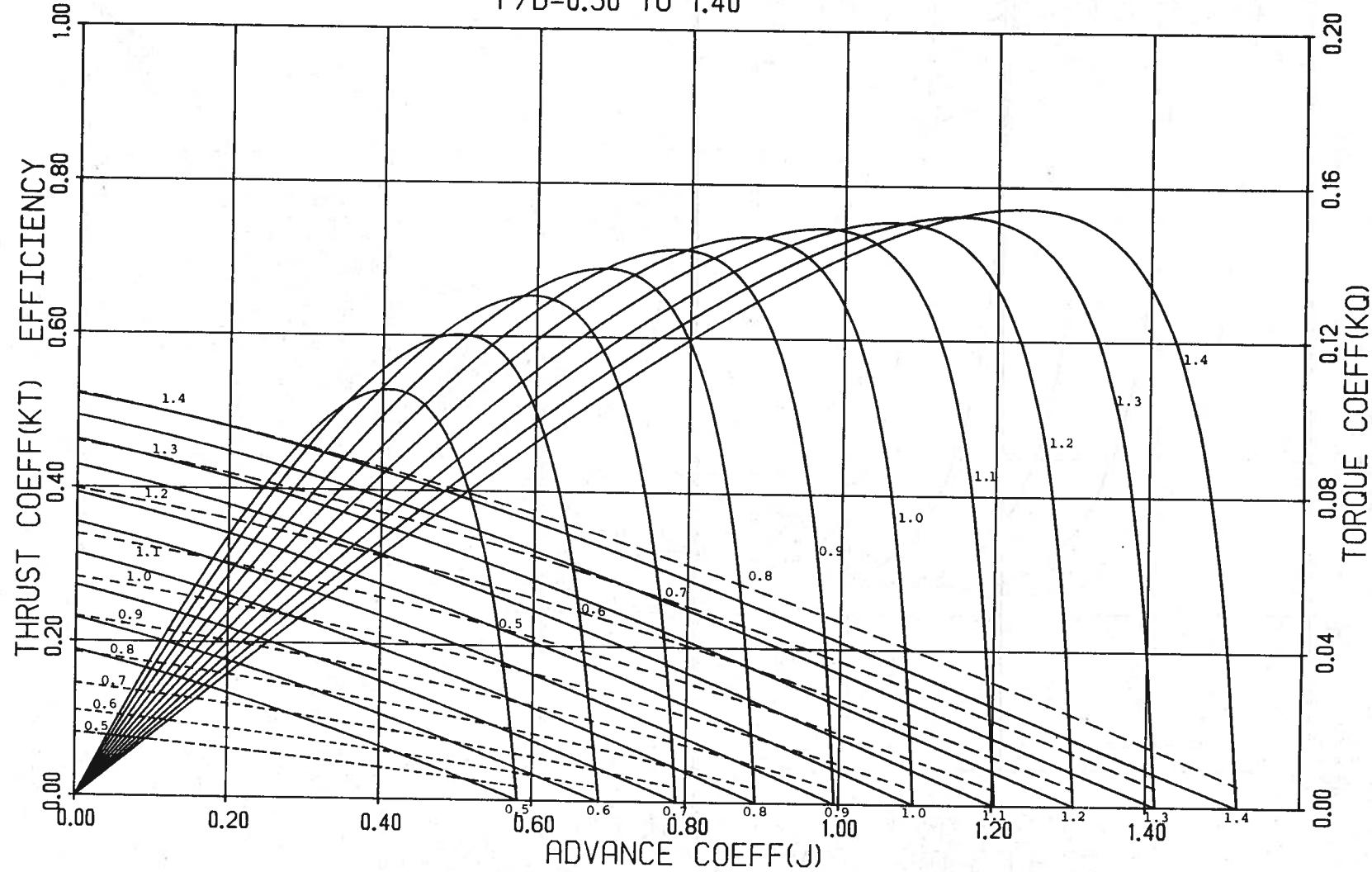


FIGURE 21. WAGENINGEN B-SERIES PROPELLERS  
FOR 3 BLADES  $A_e/A_0 = 0.500$   
 $P/D = 0.50$  TO  $1.40$

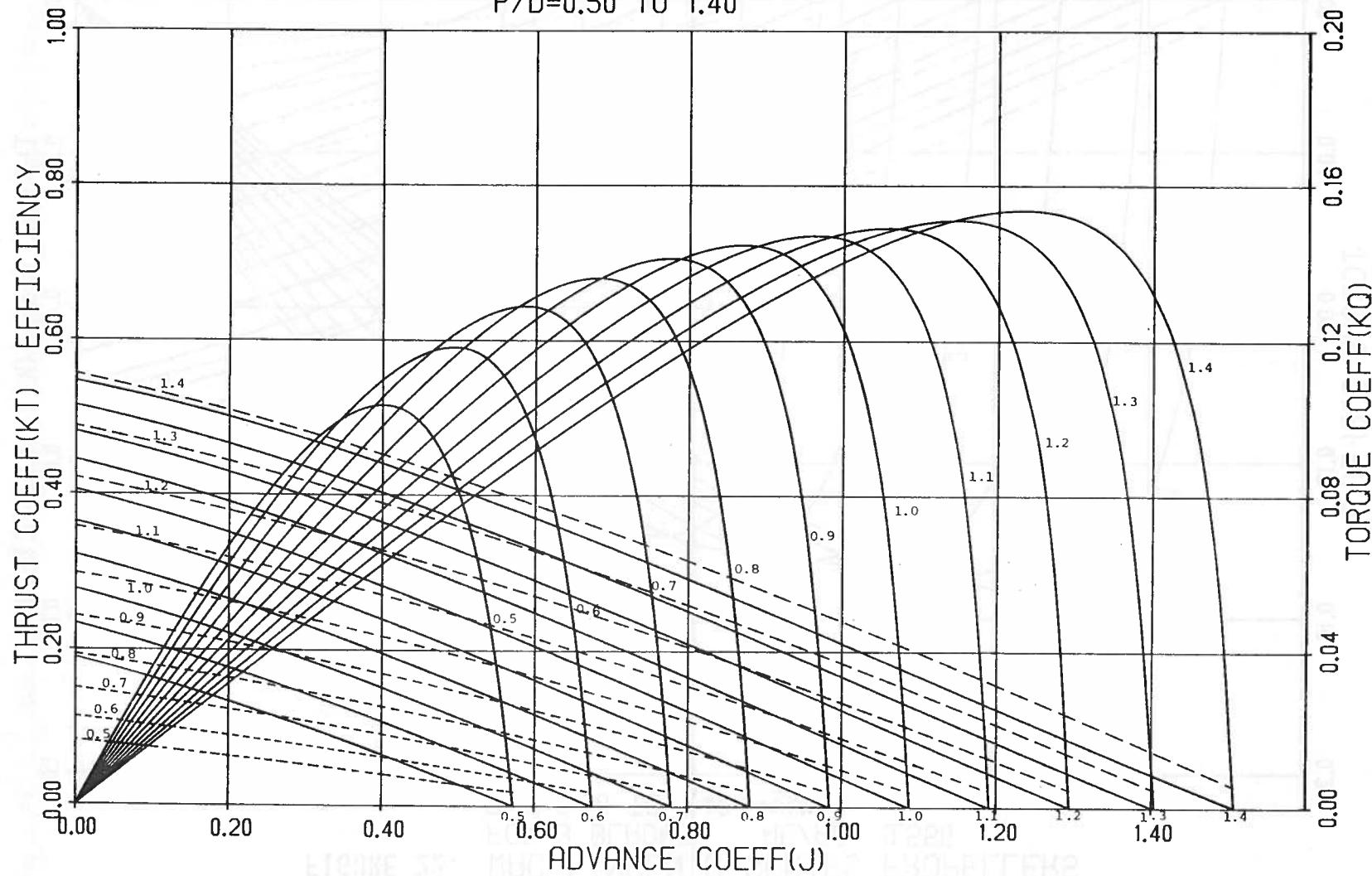


FIGURE 22. WAGENINGEN B-SERIES PROPELLERS  
FOR 3 BLADES       $A_e/A_0 = 0.550$   
 $P/D = 0.50$  TO  $1.40$

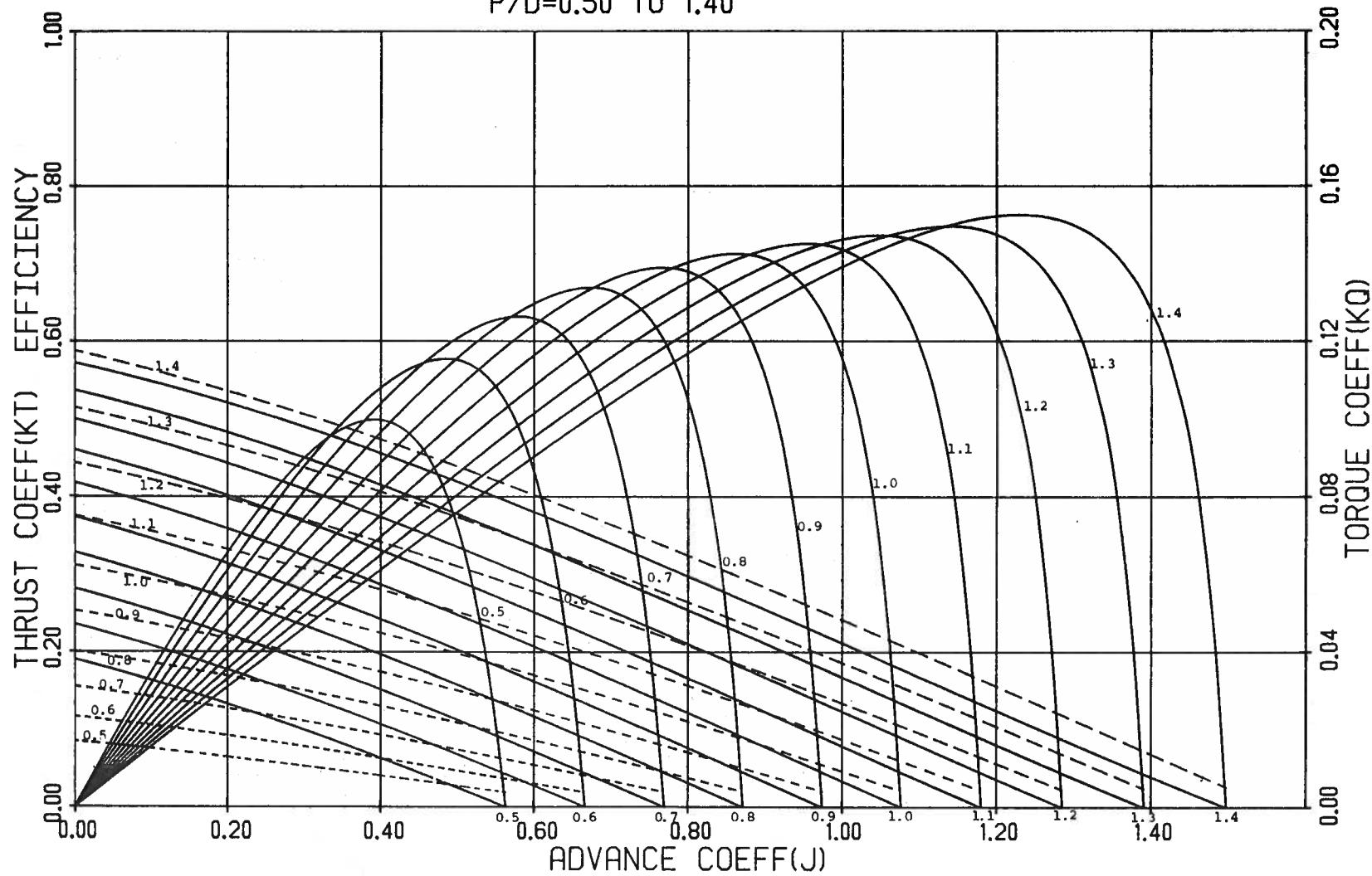


FIGURE 23. WAGENINGEN B-SERIES PROPELLERS  
FOR 3 BLADES       $A_e/A_0 = 0.600$   
 $P/D = 0.50$  TO  $1.40$

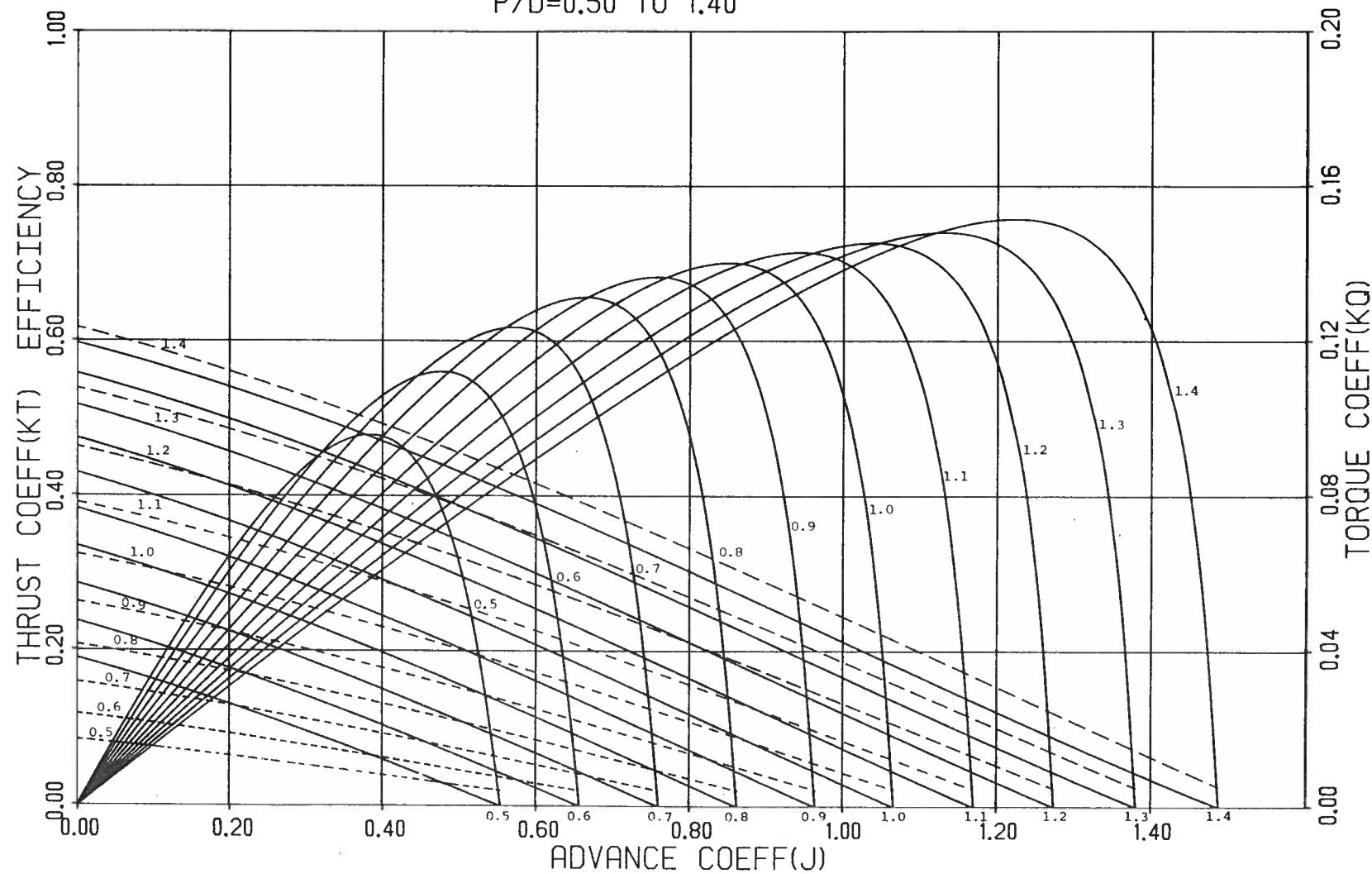


FIGURE 24. WAGENINGEN B-SERIES PROPELLERS  
 FOR 3 BLADES  $A_e/A_0 = 0.650$   
 $P/D = 0.50$  TO  $1.40$

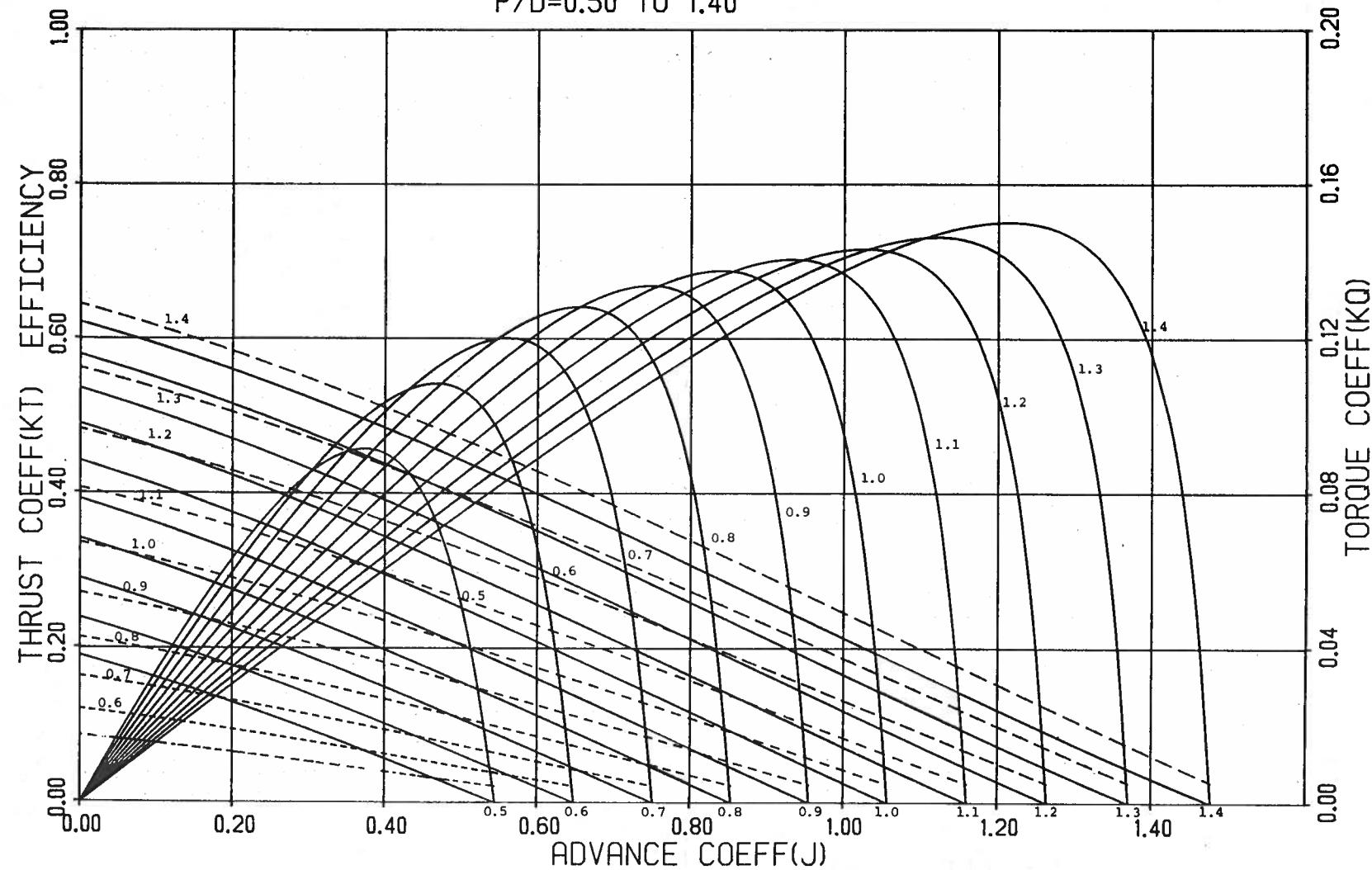


FIGURE 25. WAGENINGEN B-SERIES PROPELLERS  
FOR 3 BLADES       $A_e/A_0 = 0.700$   
 $P/D = 0.50$  TO  $1.40$

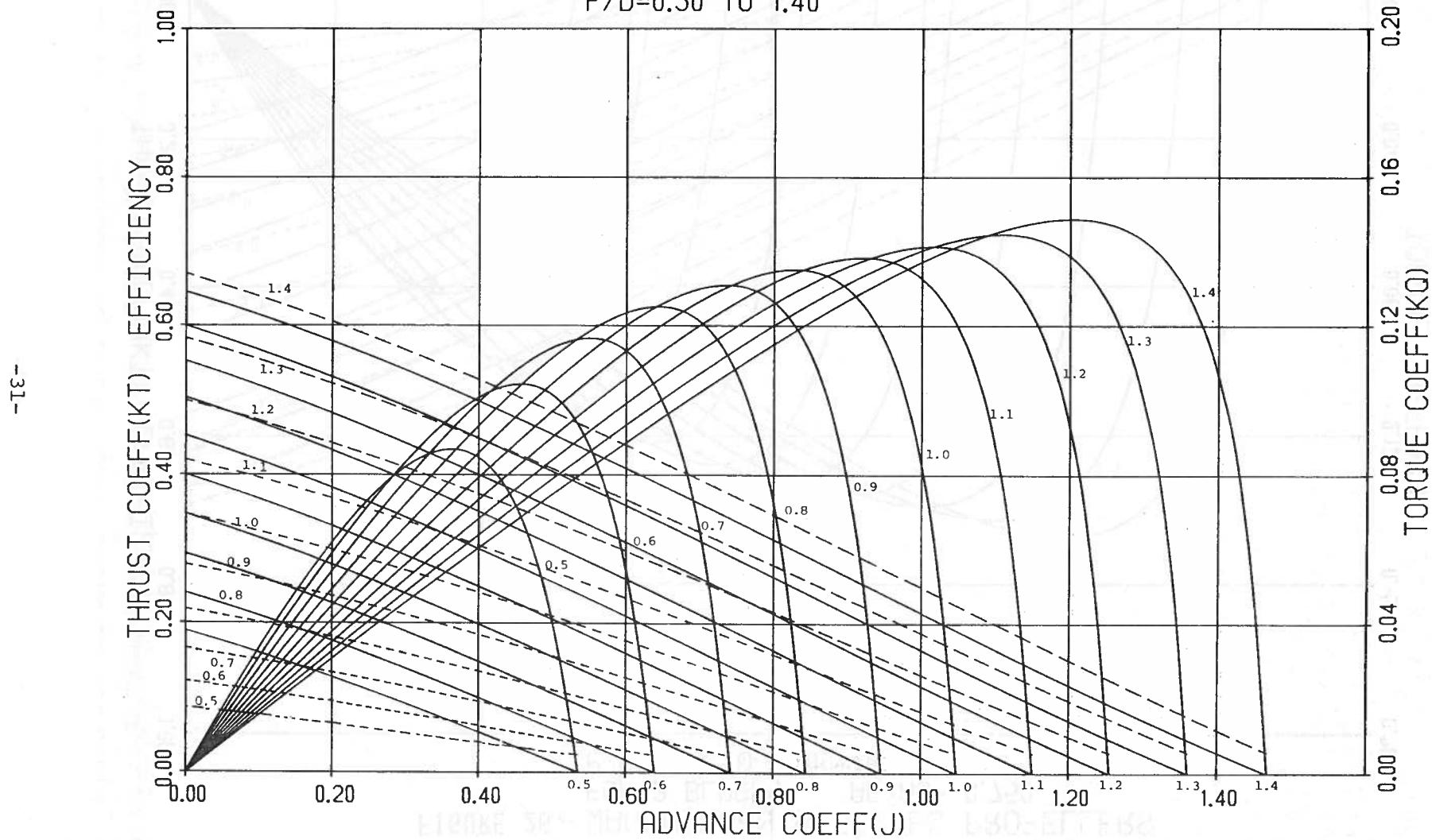


FIGURE 26. WAGENINGEN B-SERIES PROPELLERS  
FOR 3 BLADES  $A_e/A_0 = 0.750$   
 $P/D = 0.50$  TO  $1.40$

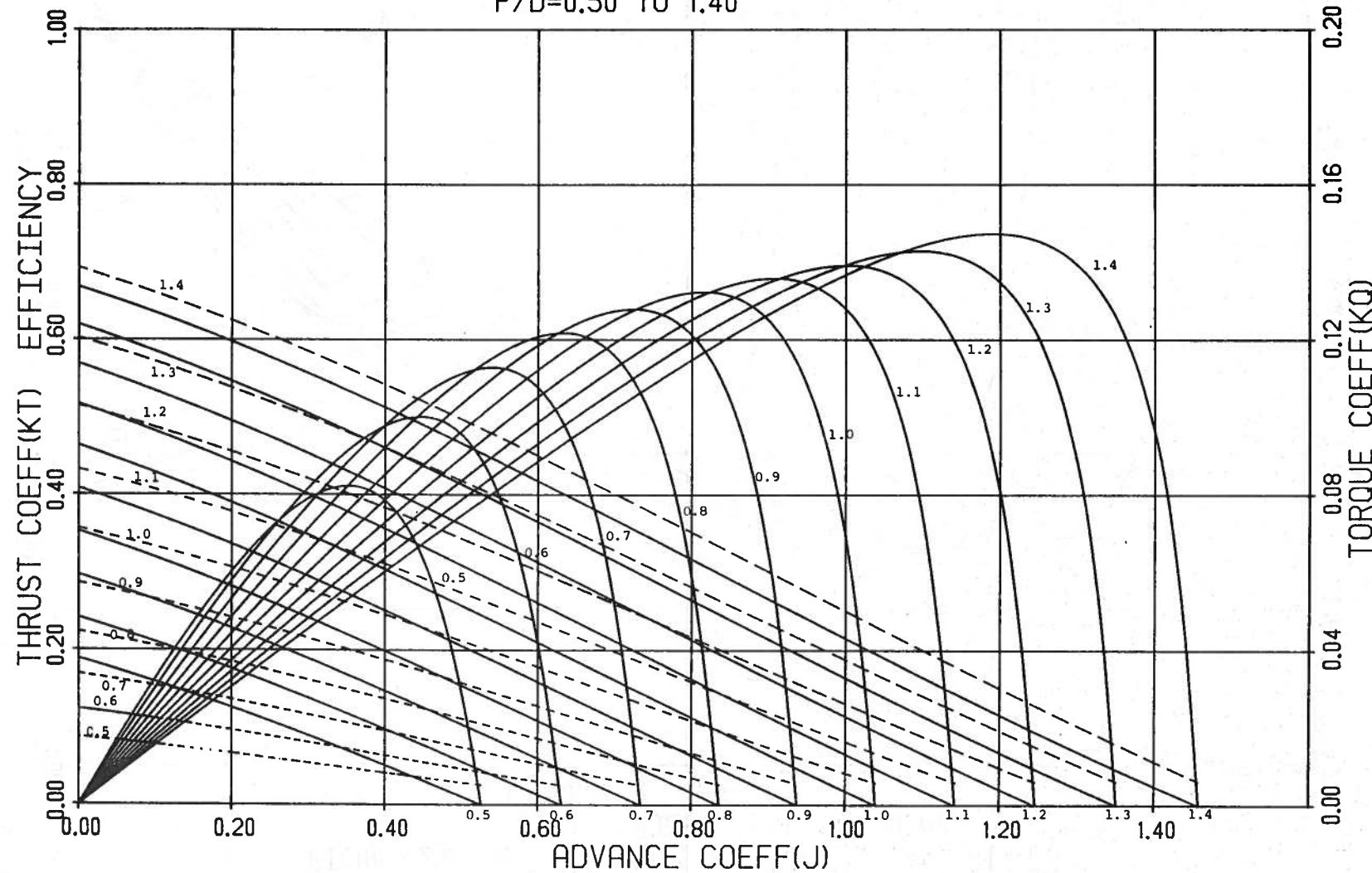


FIGURE 27. WAGENINGEN B-SERIES PROPELLERS  
 FOR 3 BLADES  
 $A_E/A_0 = 0.800$   
 $P/D = 0.50$  TO 1.40

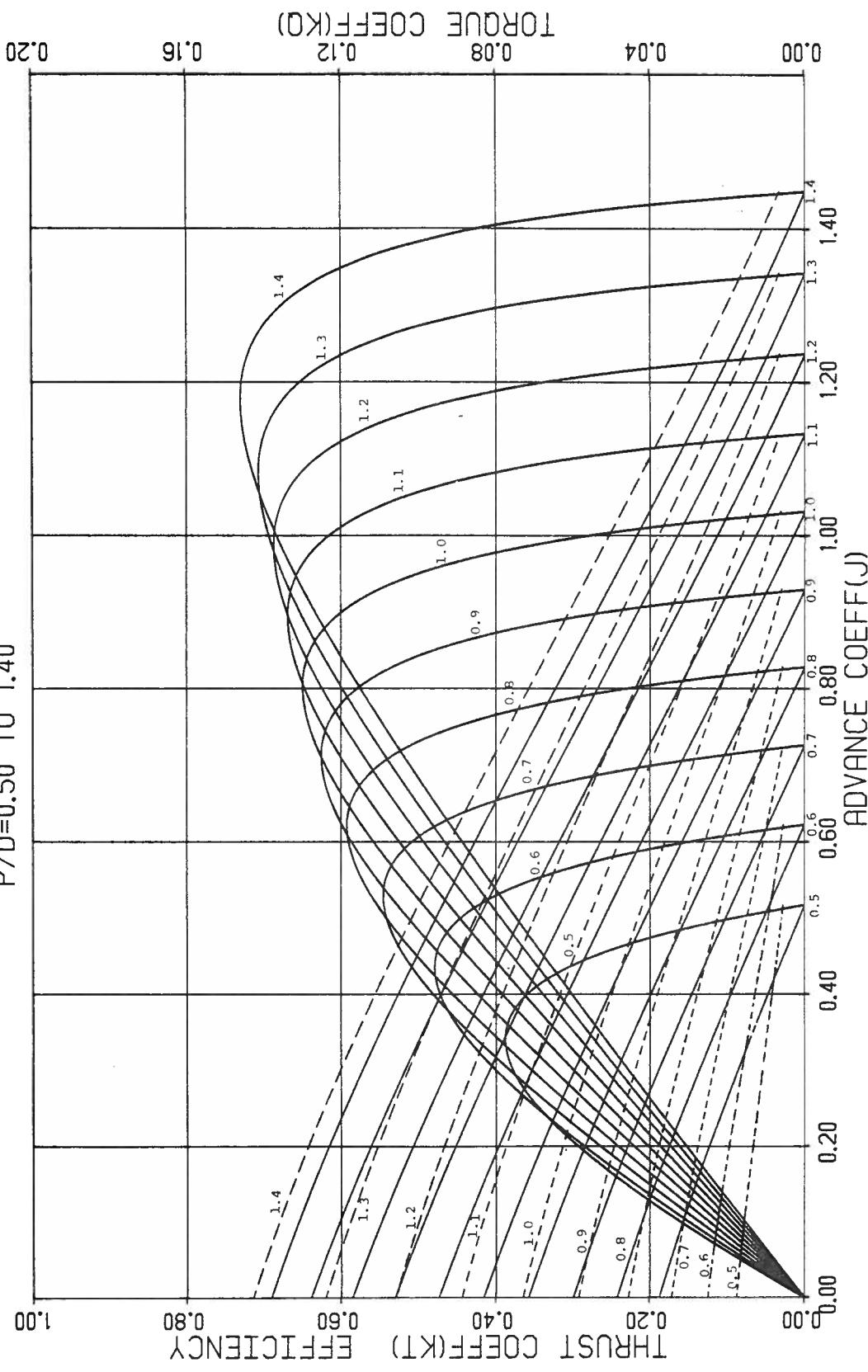


FIGURE 28. WAGENINGEN B-SERIES PROPELLERS  
FOR 3 BLADES       $A_e/A_0 = 0.850$   
 $P/D = 0.50$  TO  $1.40$

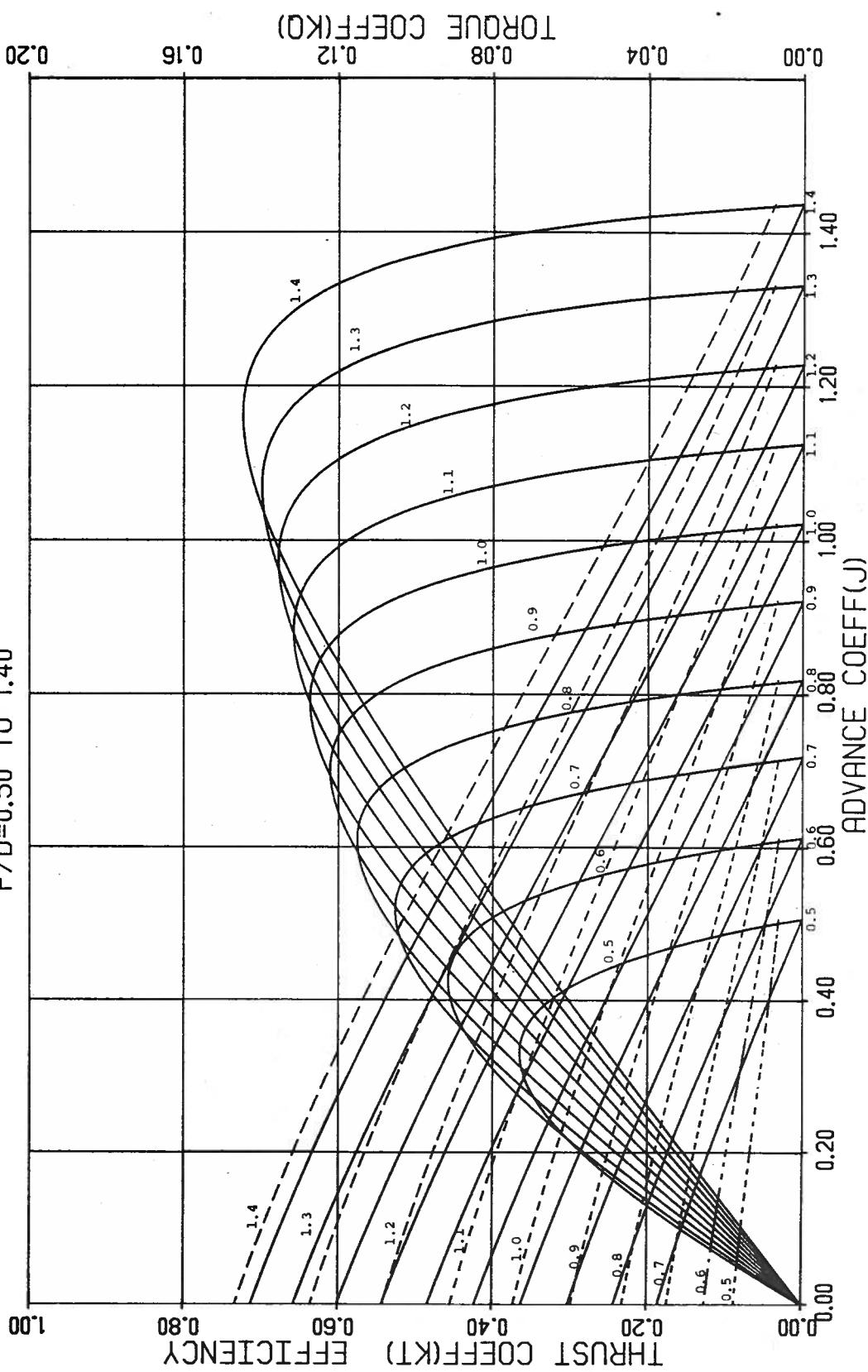


FIGURE 29. WAGENINGEN B-SERIES PROPELLERS  
 FOR 3 BLADES  $A_e/A_0 = 0.900$   
 $P/D = 0.50$  TO  $1.40$

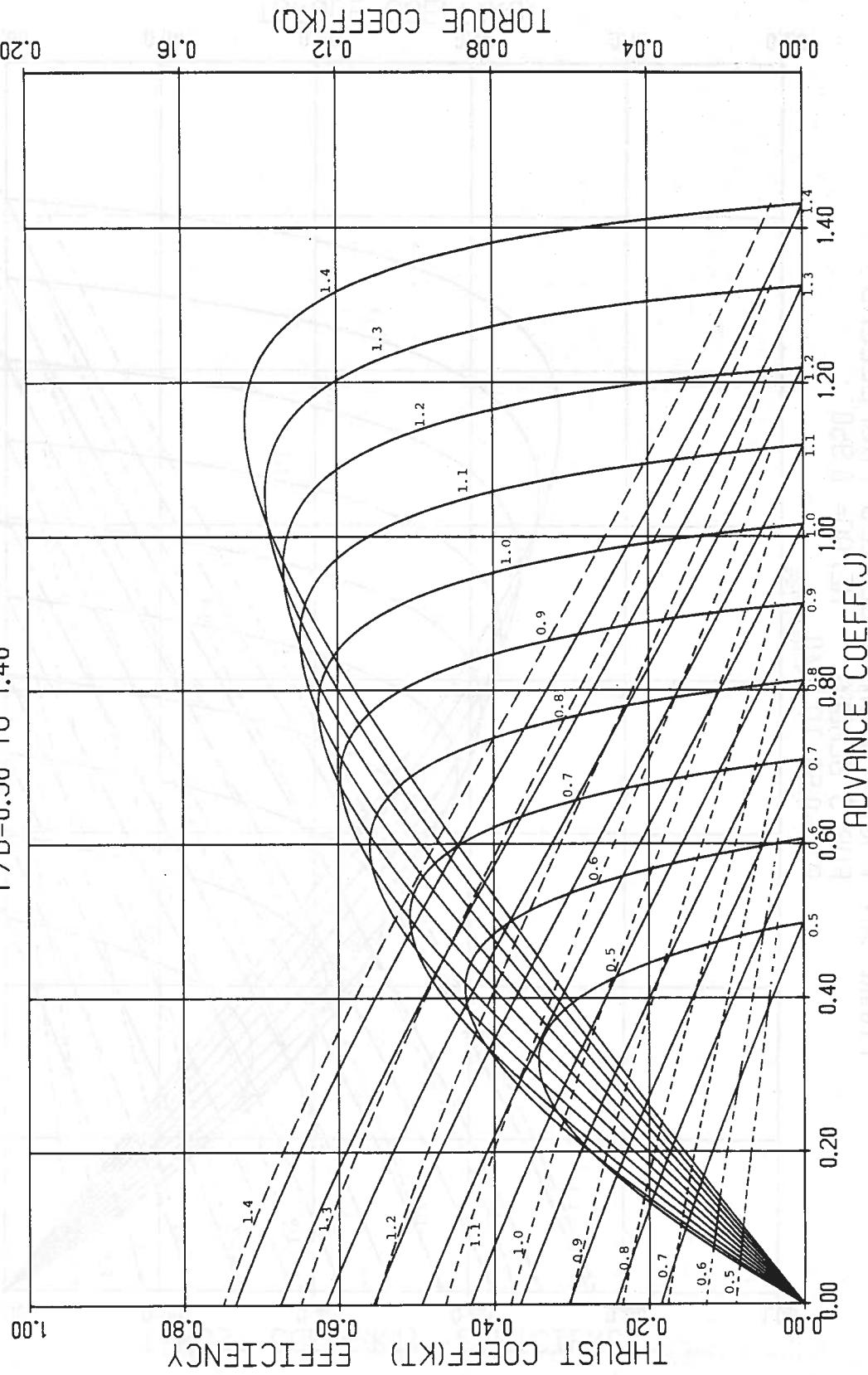


FIGURE 30. WAGENINGEN B-SERIES PROPELLERS  
 FOR 3 BLADES       $A_e/A_0 = 0.950$   
 $P/D = 0.50$  TO  $1.40$

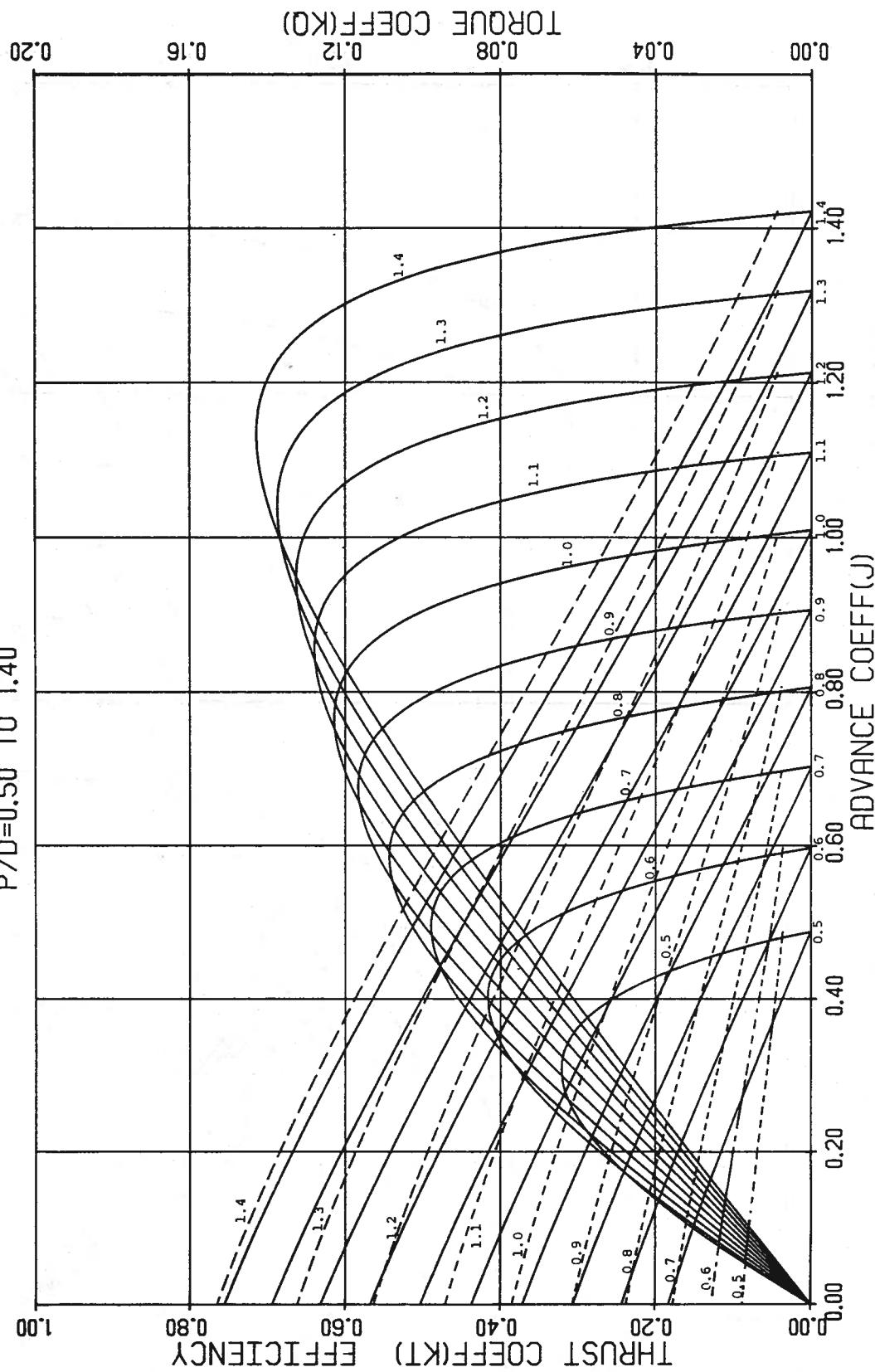


FIGURE 31. WAGENINGEN B-SERIES PROPELLERS  
 FOR 3 BLADES       $A_e/A_0 = 1.000$   
 $P/D = 0.50$  TO  $1.40$

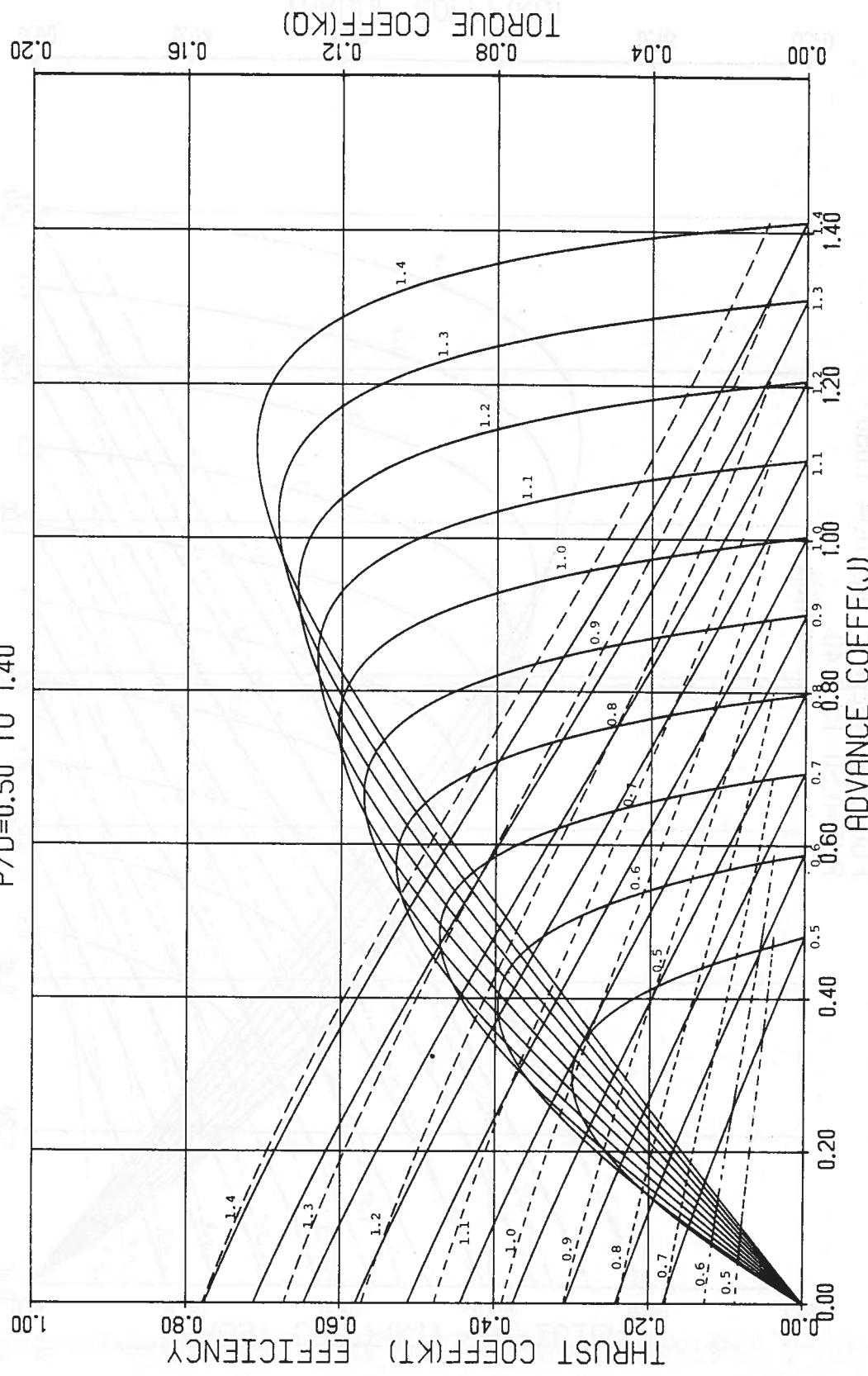


FIGURE 32. WAGENINGEN B-SERIES PROPELLERS  
 FOR 3 BLADES       $A_e/A_0 = 1.050$   
 $P/D = 0.50$  TO  $1.40$

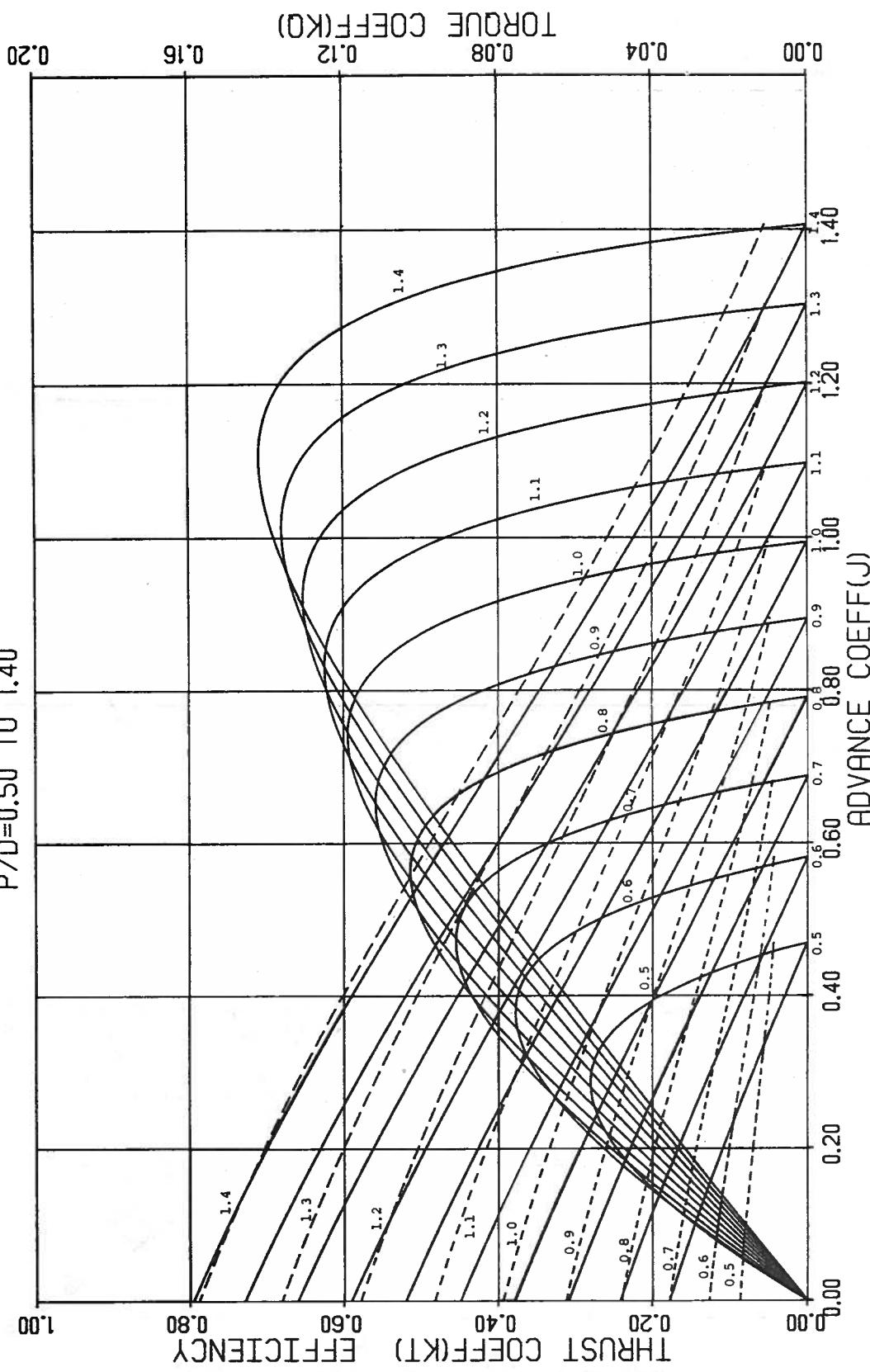


FIGURE 33. WAGENINGEN B-SERIES PROPELLERS  
 FOR 4 BLADES  $A_e/A_0 = 0.300$   
 $P/D = 0.50$  TO 1.40

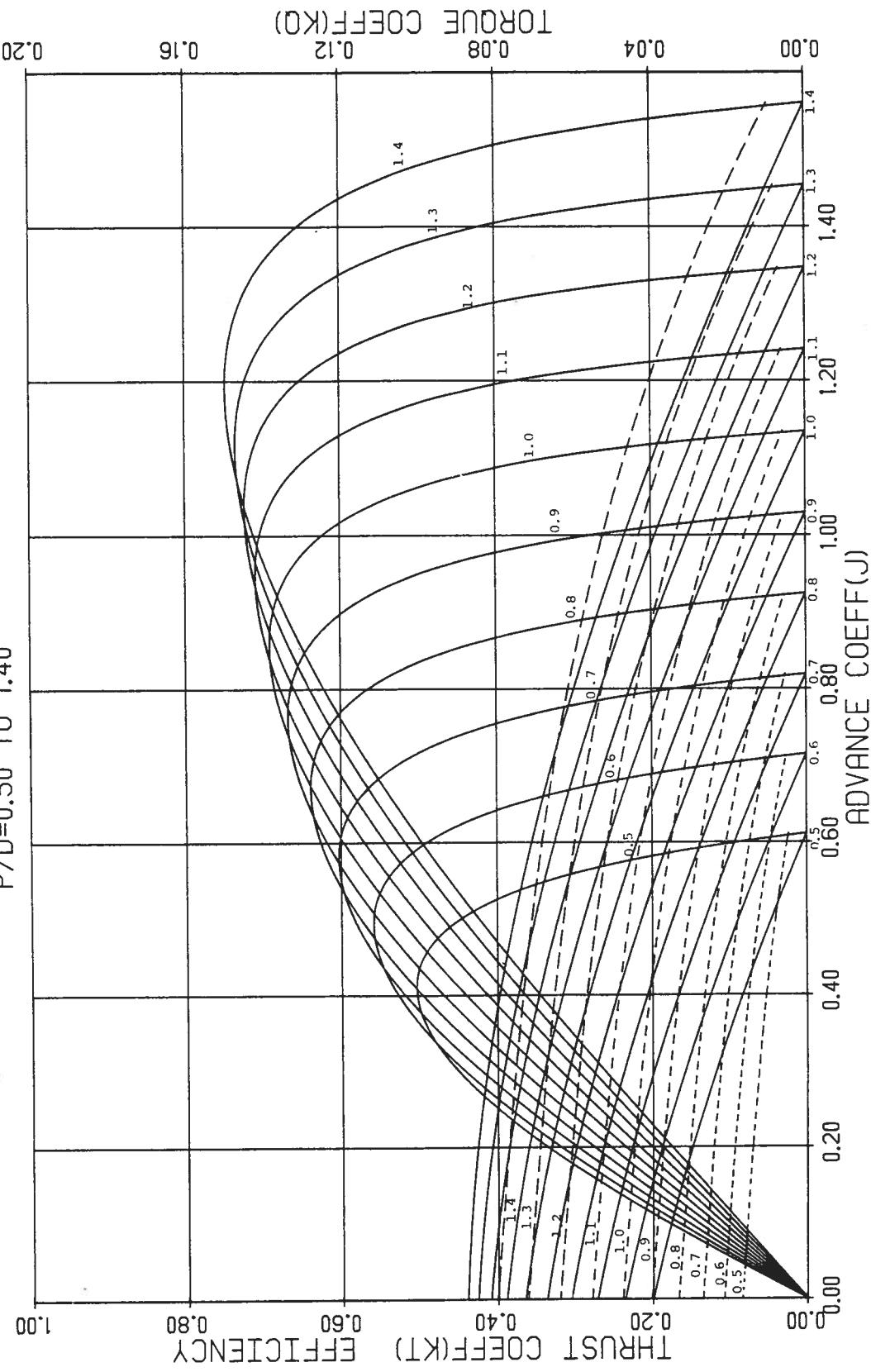


FIGURE 34. WAGENINGEN B-SERIES PROPELLERS  
 FOR 4 BLADES       $A_E/A_0 = 0.350$   
 $P/D = 0.50$  TO 1.40

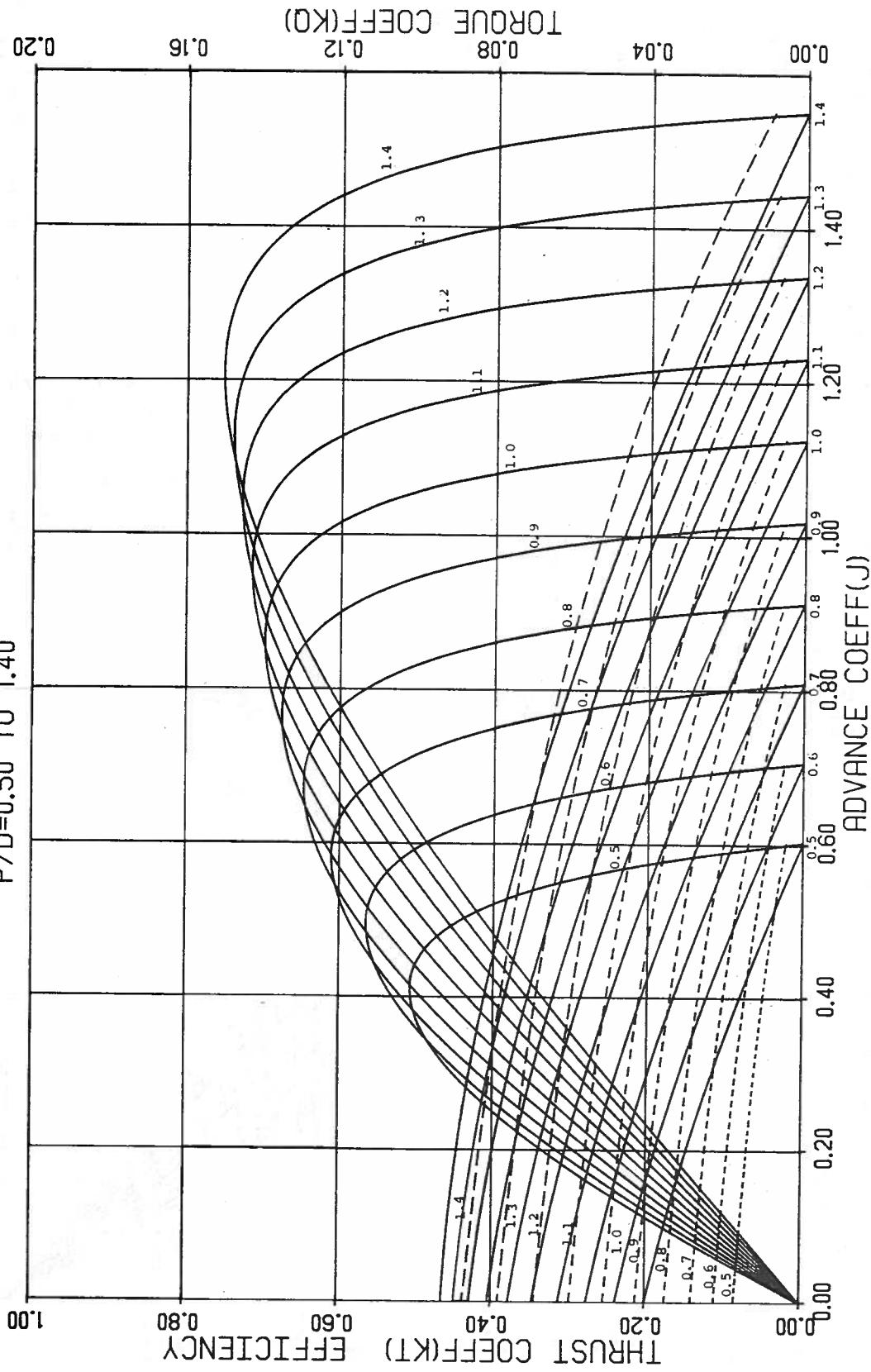


FIGURE 35. WAGENINGEN B-SERIES PROPELLERS  
 FOR 4 BLADES  
 $A_E/A_0 = 0.400$   
 $P/D = 0.50$  TO 1.40

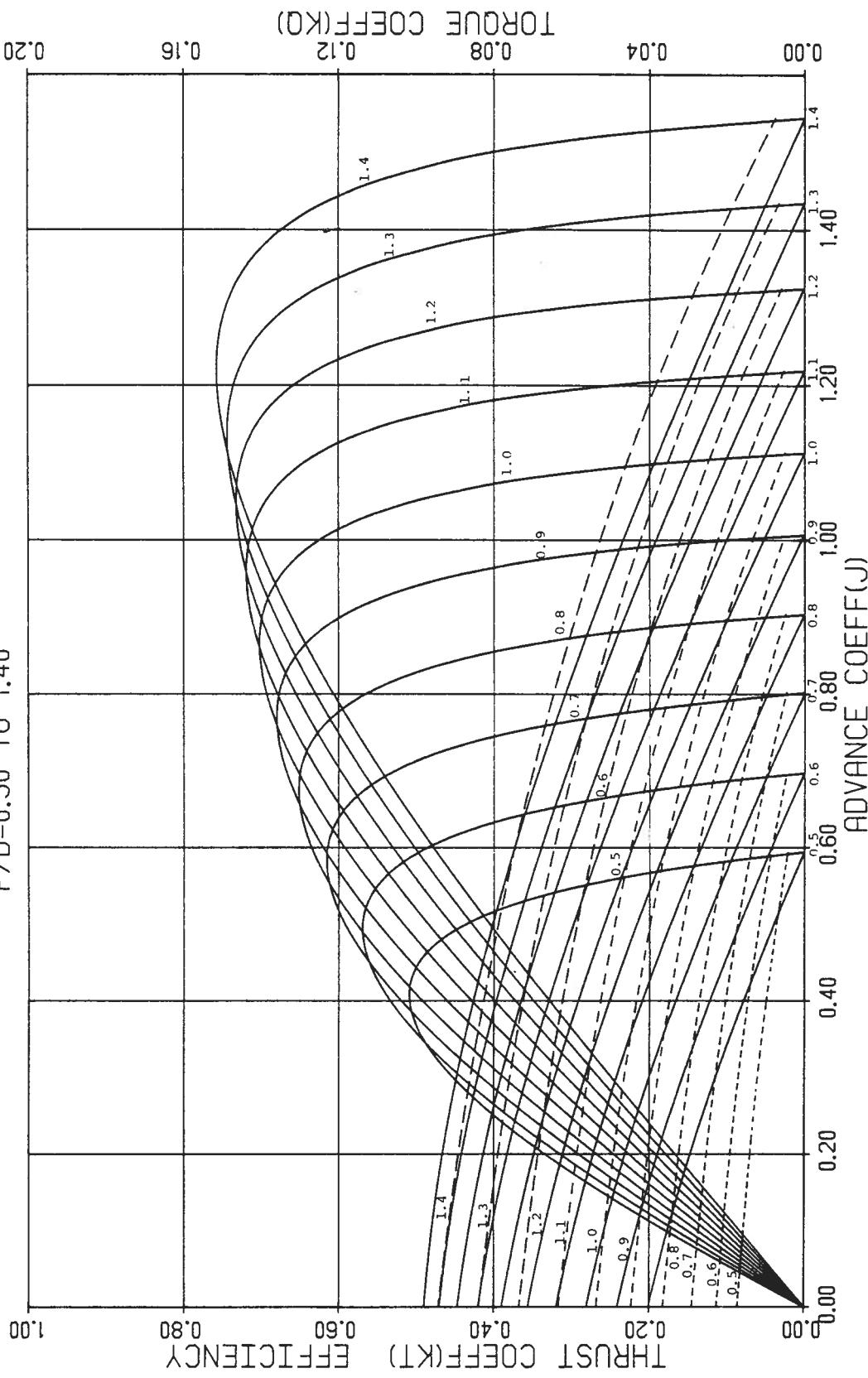


FIGURE 36. WAGENINGEN B-SERIES PROPELLERS  
 FOR 4 BLADES  $A_e/A_0 = 0.450$   
 $P/D = 0.50$  TO 1.40

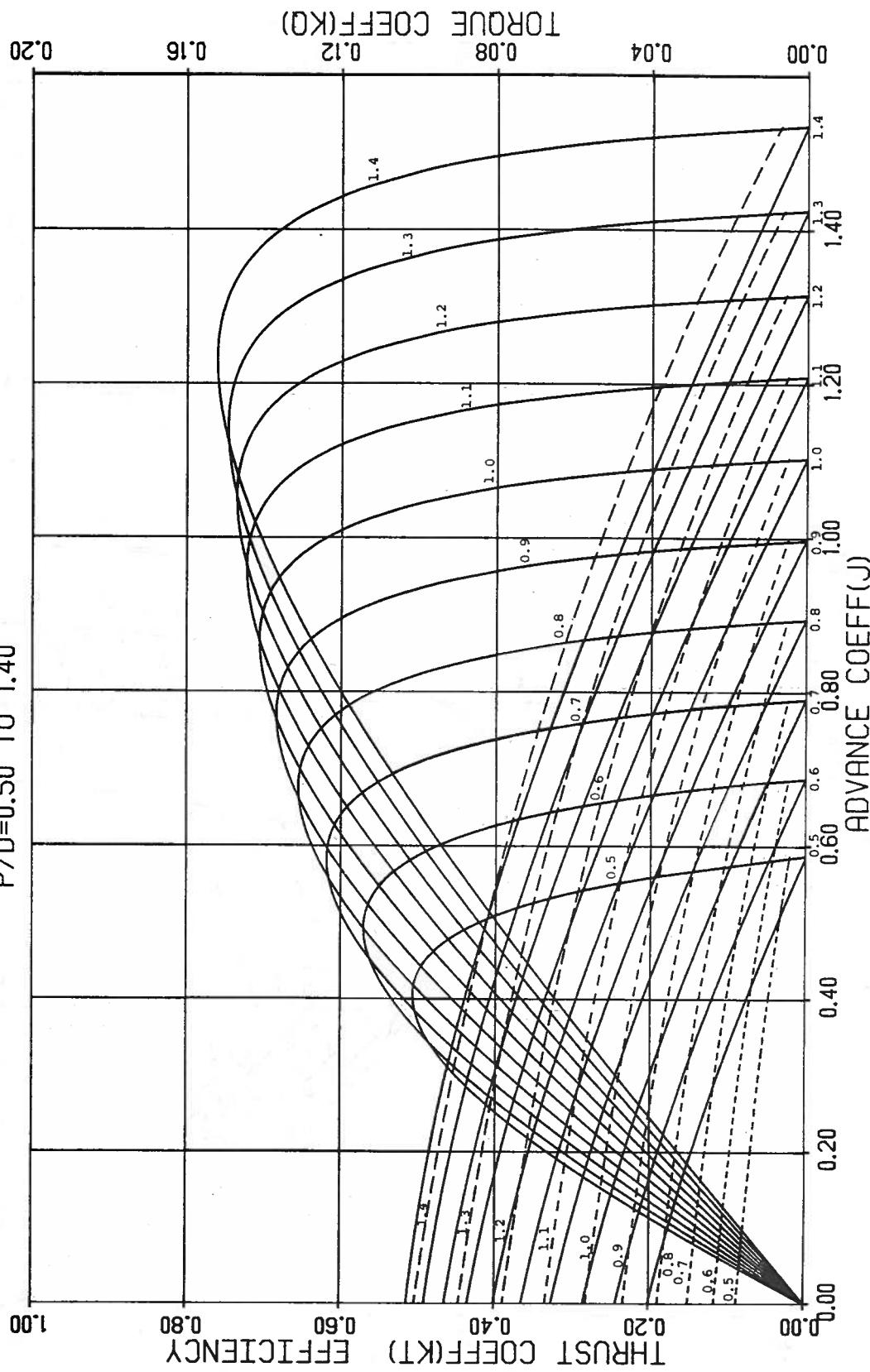


FIGURE 37. WAGENINGEN B-SERIES PROPELLERS  
 FOR 4 BLADES       $A_e/A_0 = 0.500$   
 $P/D = 0.50$  TO 1.40

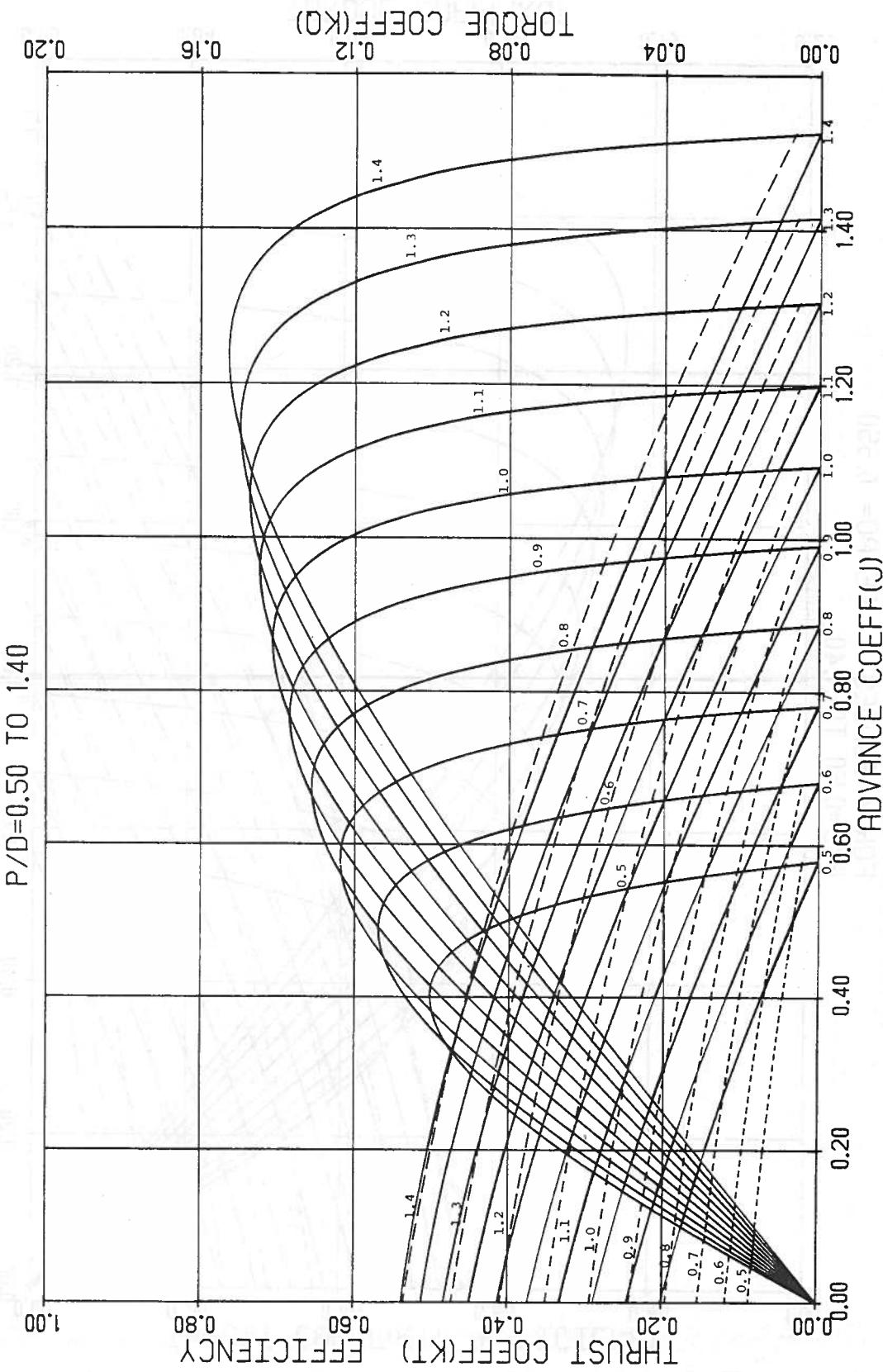


FIGURE 38. WAGENINGEN B-SERIES PROPELLERS  
FOR 4 BLADES       $A_e/A_0 = 0.550$   
 $P/D = 0.50$  TO  $1.40$

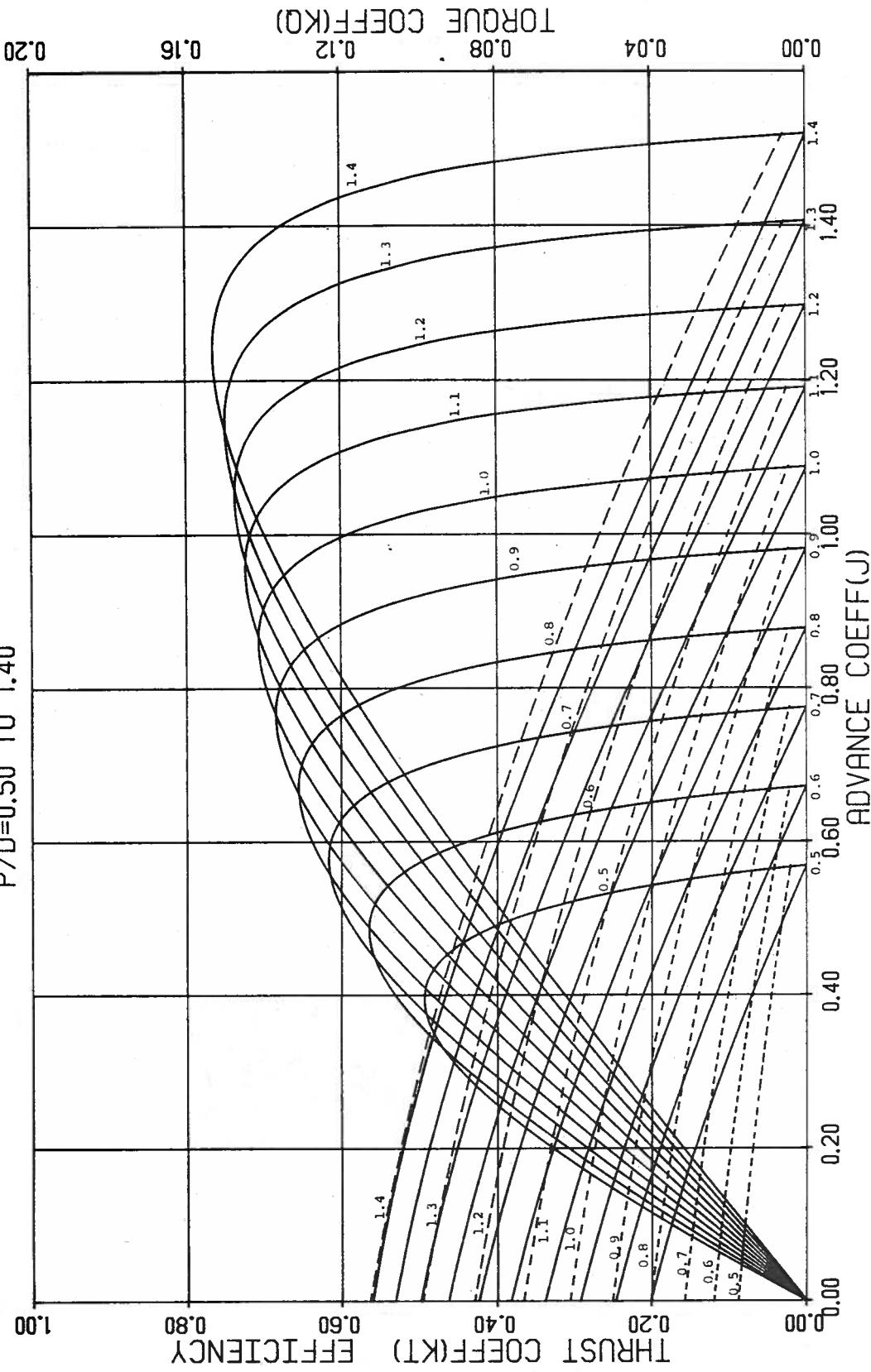


FIGURE 39. WAGENINGEN B-SERIES PROPELLERS  
 FOR 4 BLADES  
 $A_e/A_0 = 0.600$   
 $P/D = 0.50$  TO  $1.40$

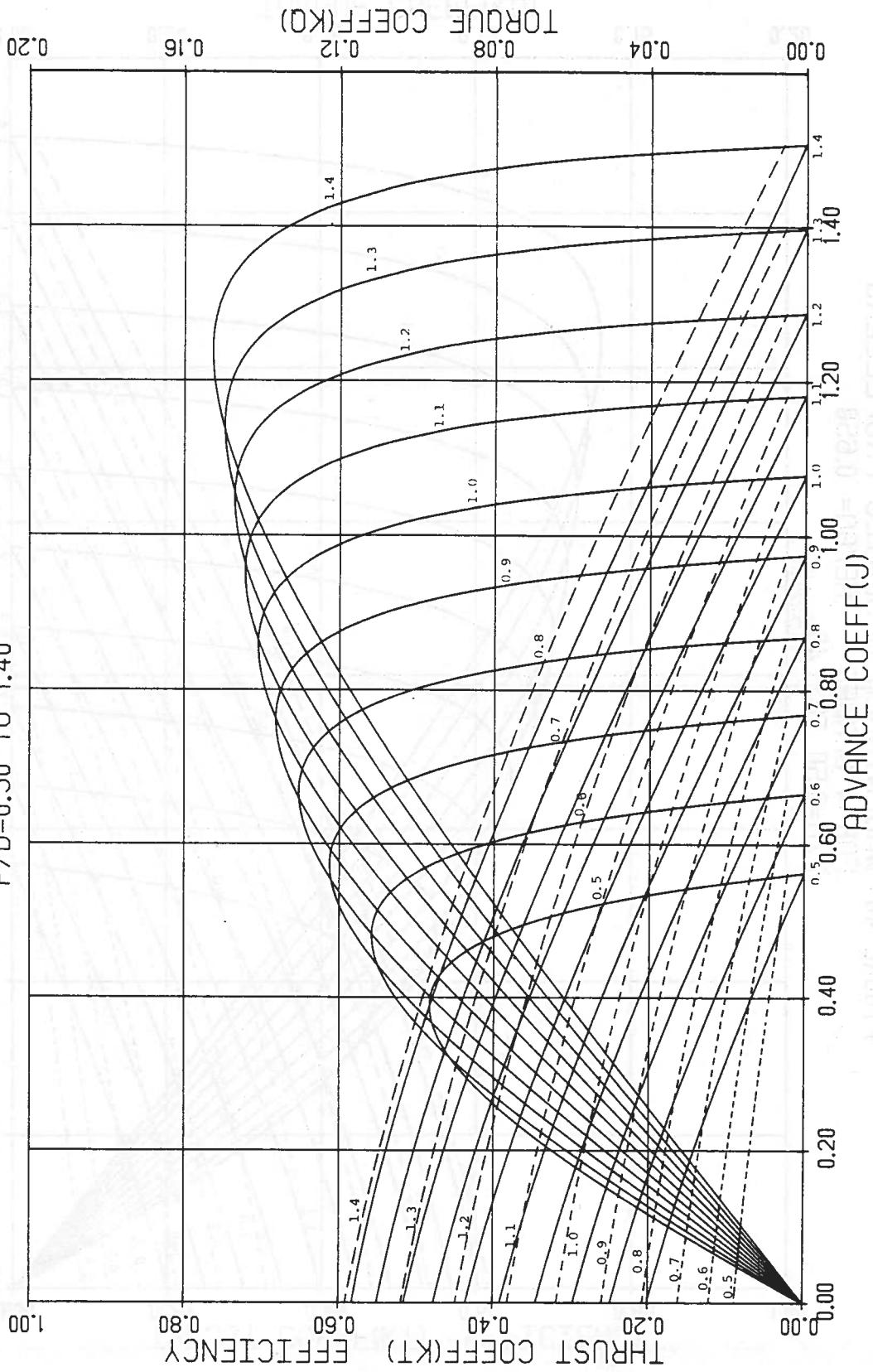


FIGURE 40. WAGENINGEN B-SERIES PROPELLERS  
 FOR 4 BLADES  
 $A_E/A_0 = 0.650$   
 $P/D = 0.50$  TO 1.40

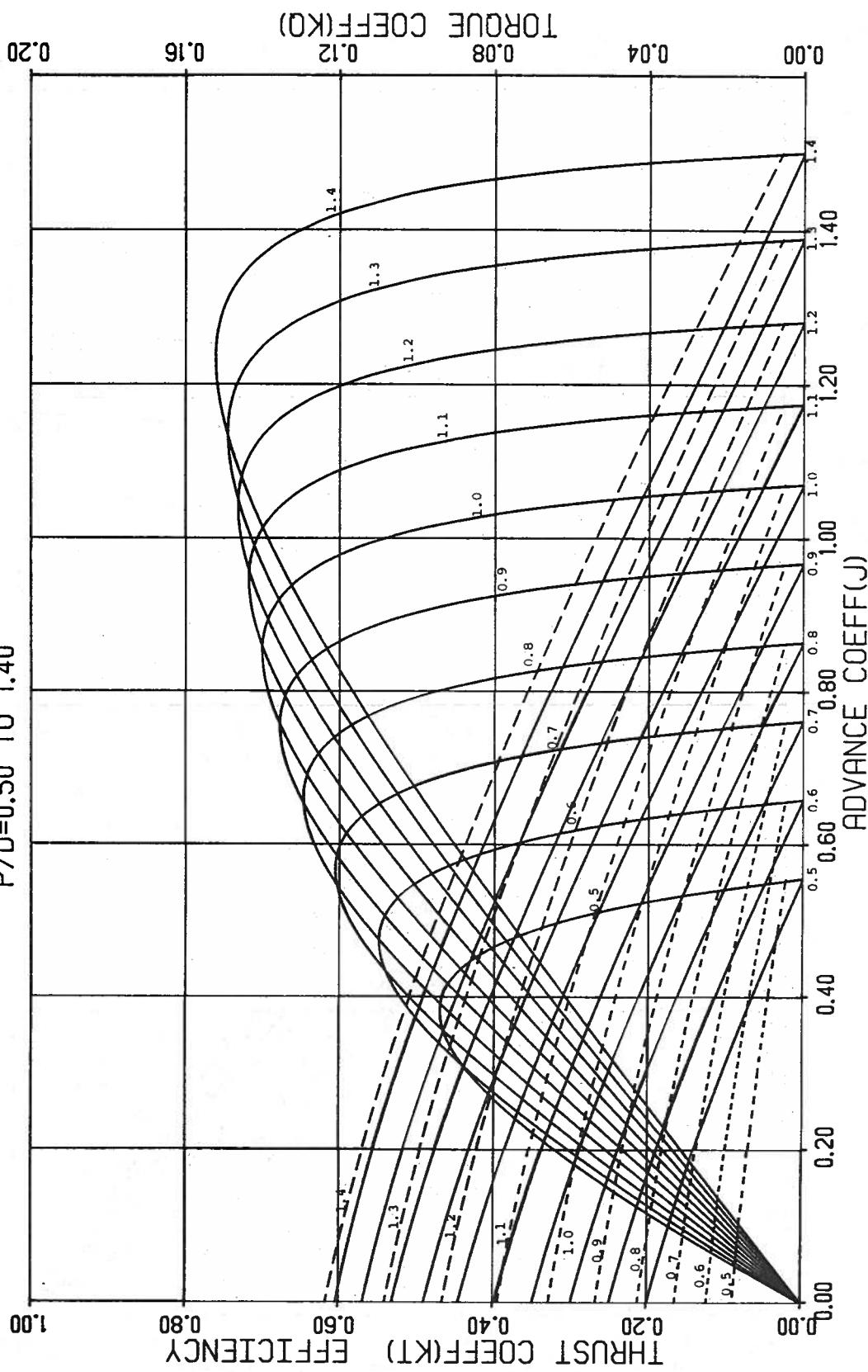


FIGURE 41. WAGENINGEN B-SERIES PROPELLERS  
 FOR 4 BLADES       $A_E/A_0 = 0.700$   
 $P/D = 0.50$  TO  $1.40$

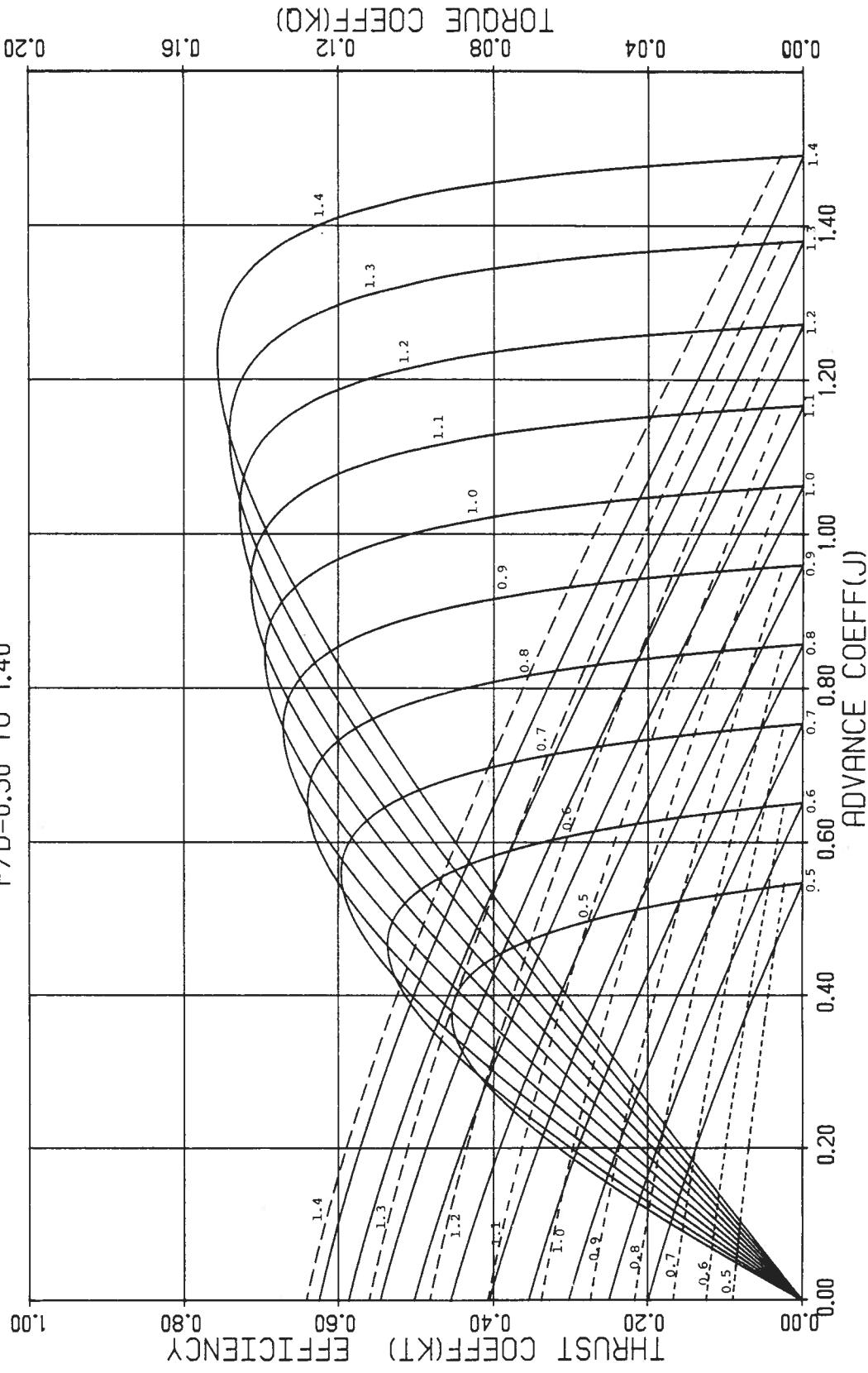


FIGURE 42. WAGENINGEN B-SERIES PROPELLERS  
 FOR 4 BLADES  $A_e/A_0 = 0.750$   
 $P/D = 0.50$  TO  $1.40$

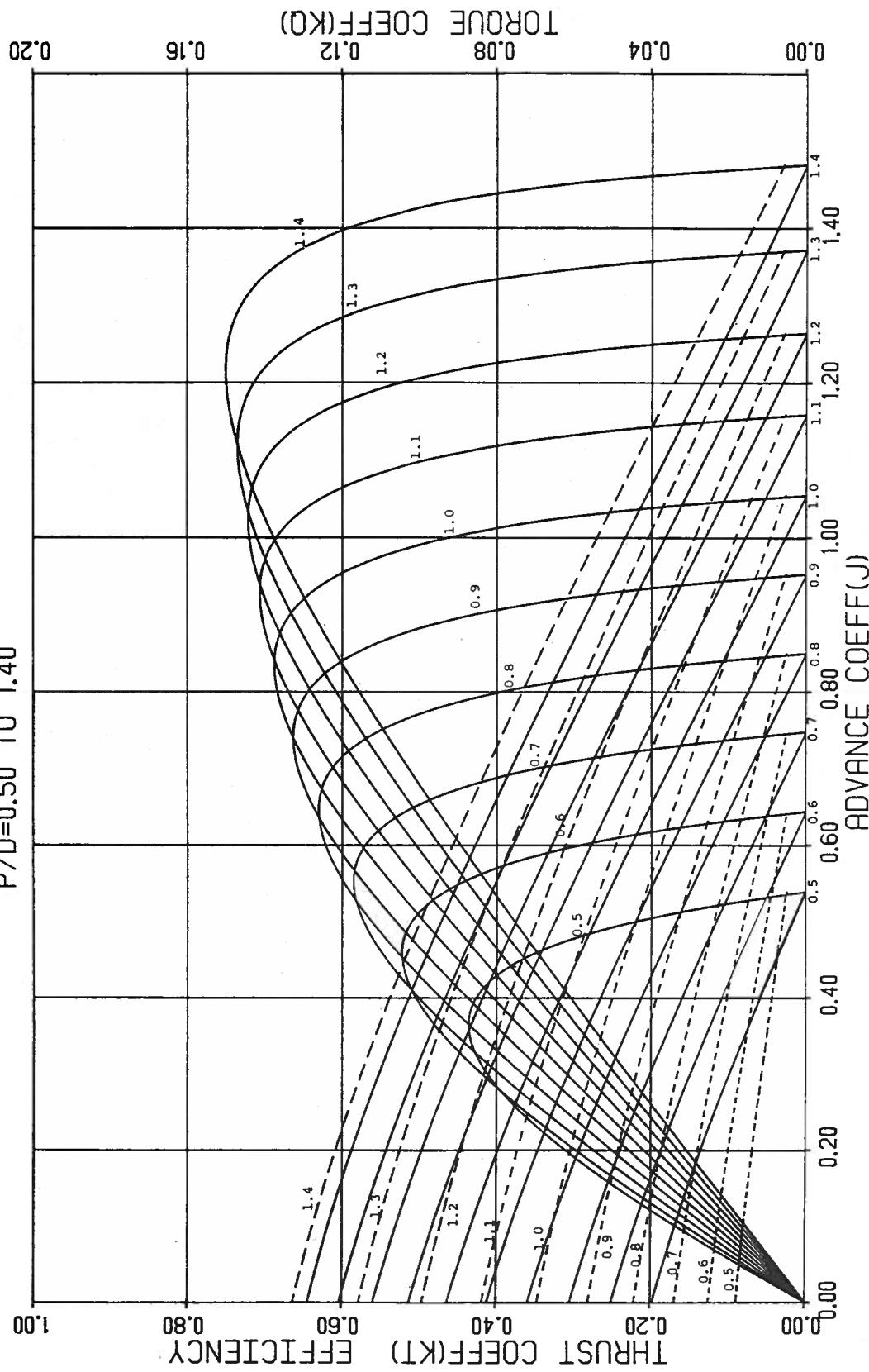


FIGURE 43. WAGENINGEN B-SERIES PROPELLERS  
 FOR 4 BLADES  $A_e/A_0 = 0.800$   
 $P/D = 0.50$  TO  $1.40$

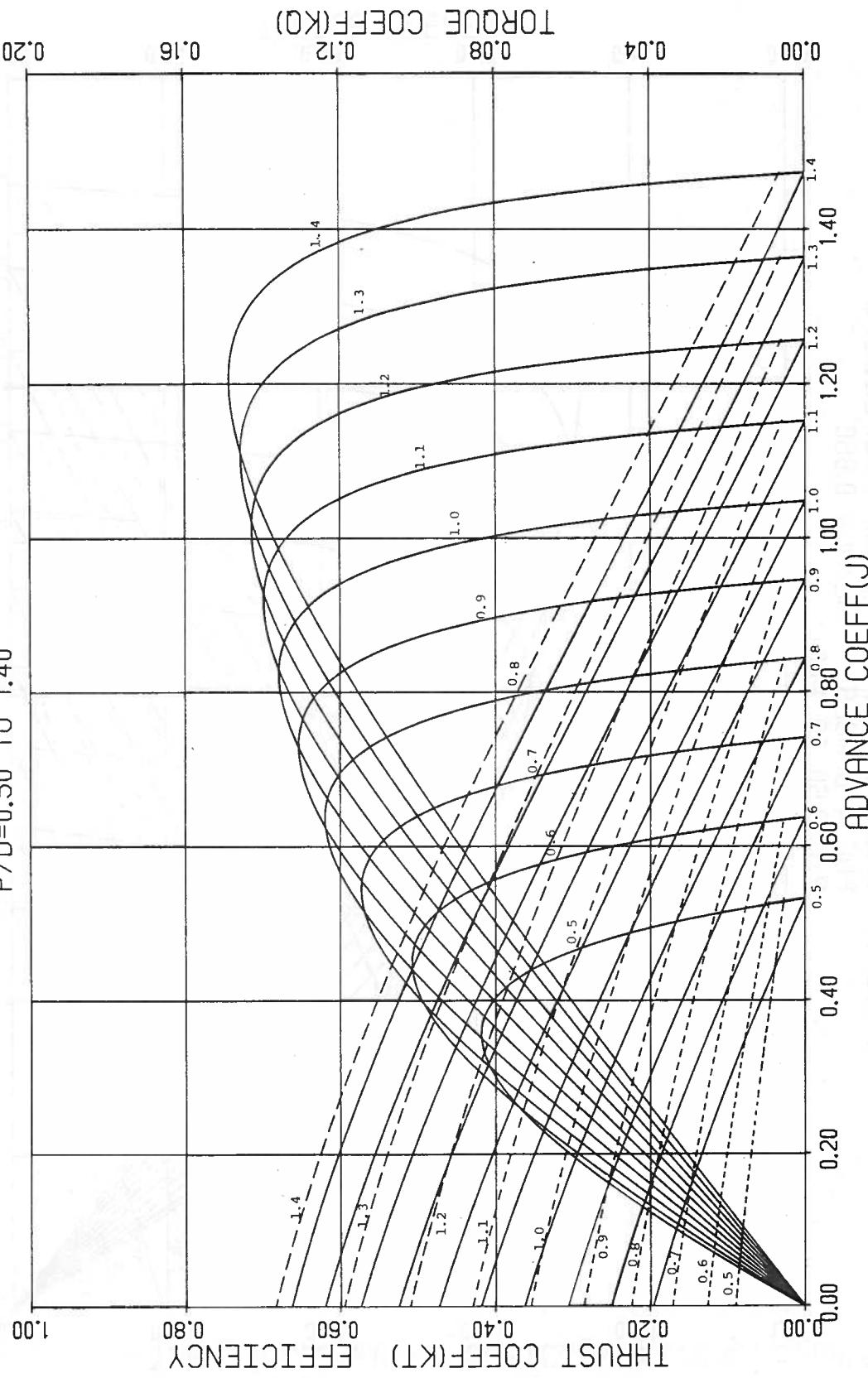


FIGURE 44. WAGENINGEN B-SERIES PROPELLERS  
FOR 4 BLADES  $A_e/A_0 = 0.850$   
 $P/D = 0.50$  TO 1.40

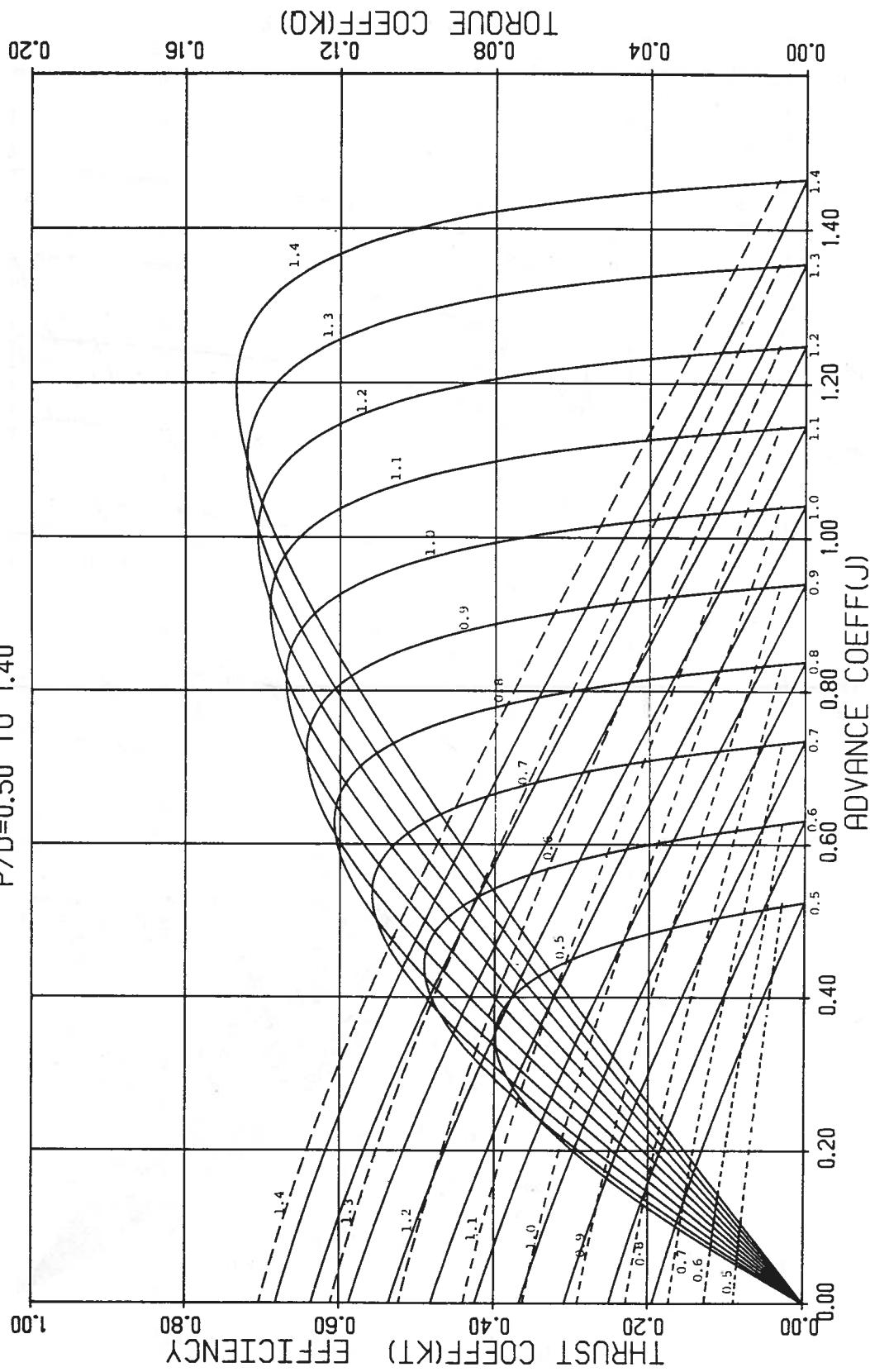


FIGURE 45. WAGENINGEN B-SERIES PROPELLERS  
 FOR 4 BLADES  
 $A_e/A_0 = 0.900$   
 $P/D = 0.50$  TO 1.40

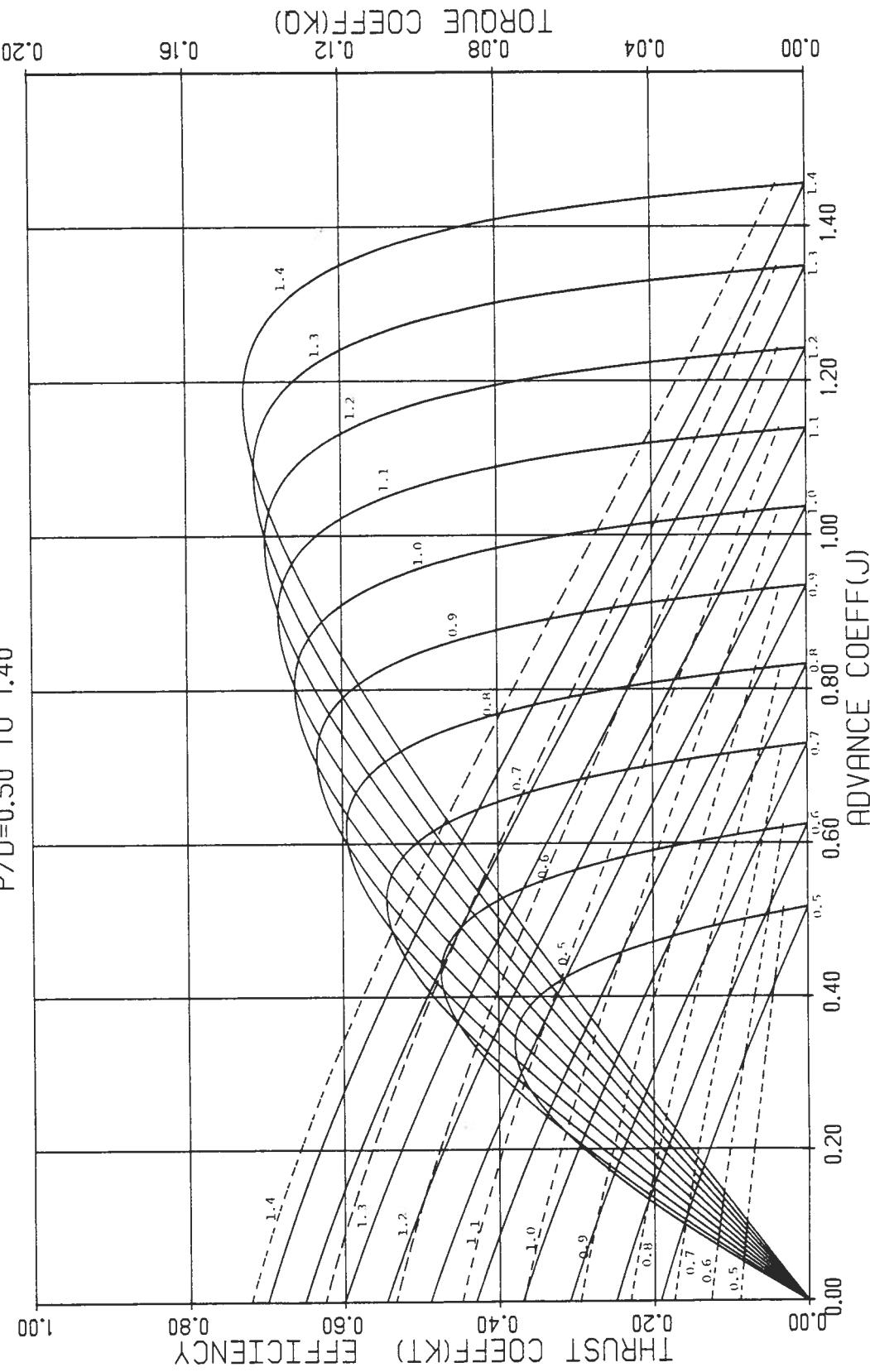


FIGURE 46. WAGENINGEN B-SERIES PROPELLERS  
 FOR 4 BLADES  
 $A_e/A_0 = 0.950$   
 $P/D = 0.50$  TO 1.40

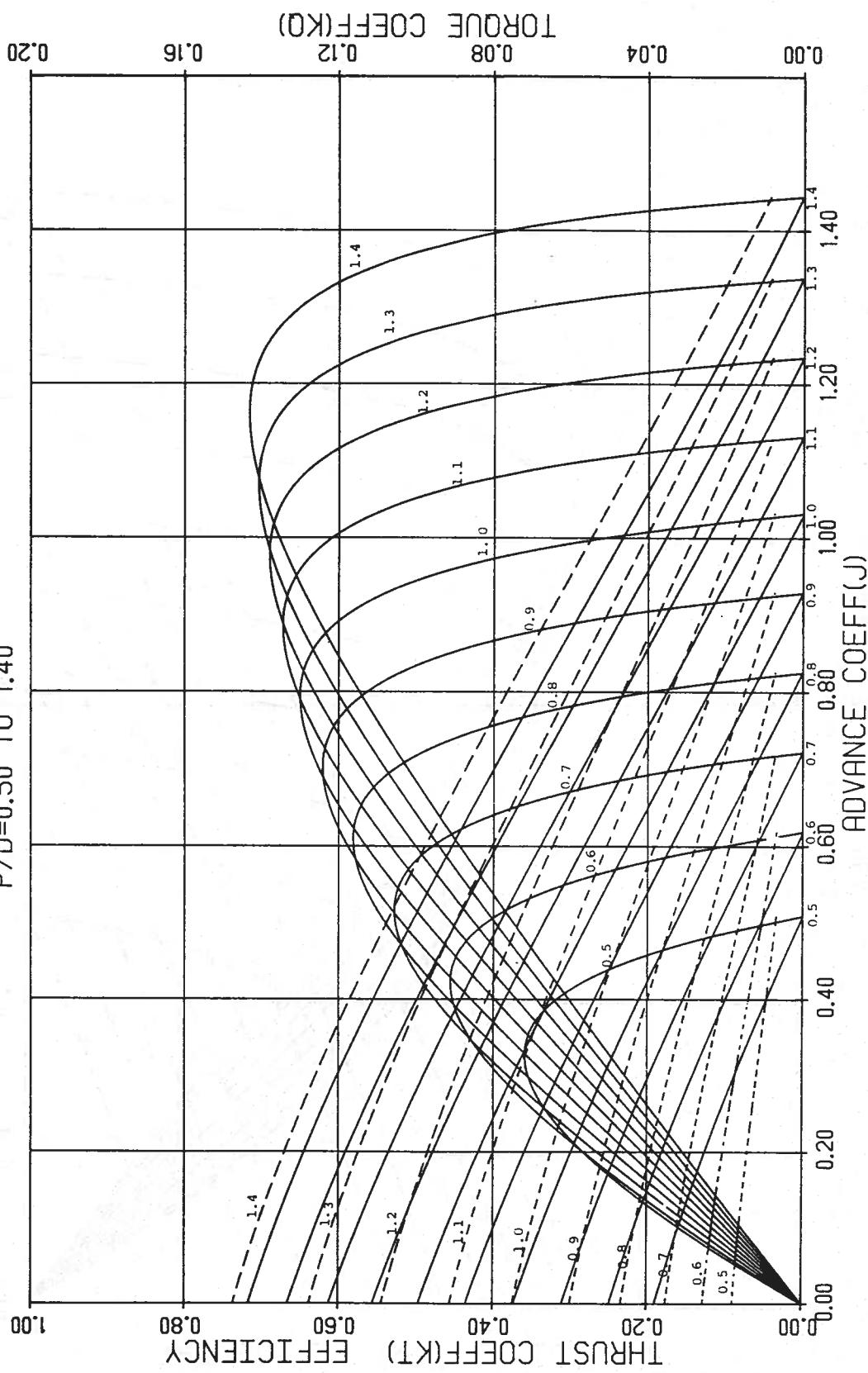


FIGURE 47. WAGENINGEN B-SERIES PROPELLERS  
 FOR 4 BLADES  
 $A_e/A_0 = 1.000$   
 $P/D = 0.50$  TO  $1.40$

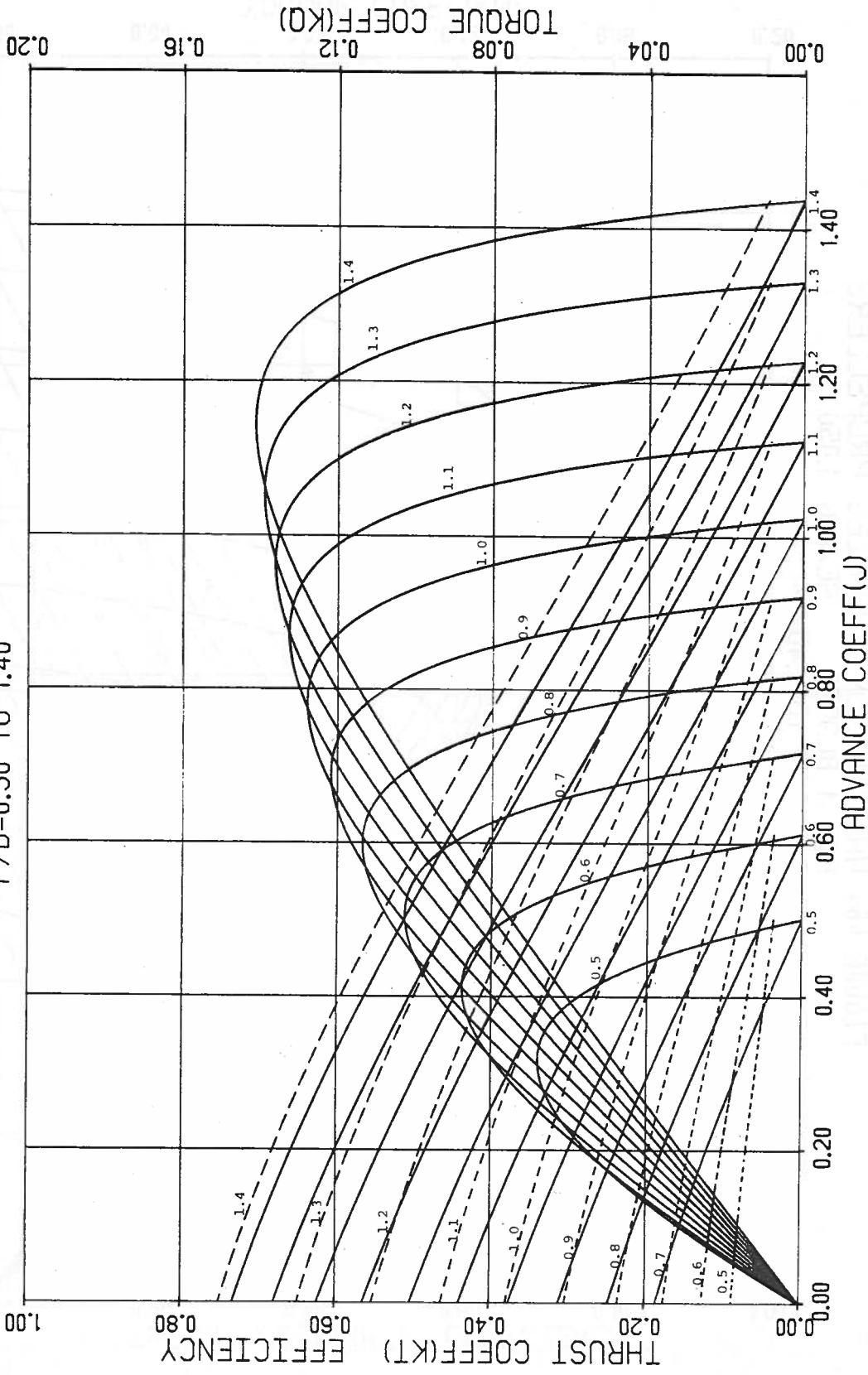


FIGURE 48. WAGENINGEN B-SERIES PROPELLERS  
 FOR 4 BLADES  
 $A_E/A_0 = 1.050$   
 $P/D = 0.50$  TO 1.40

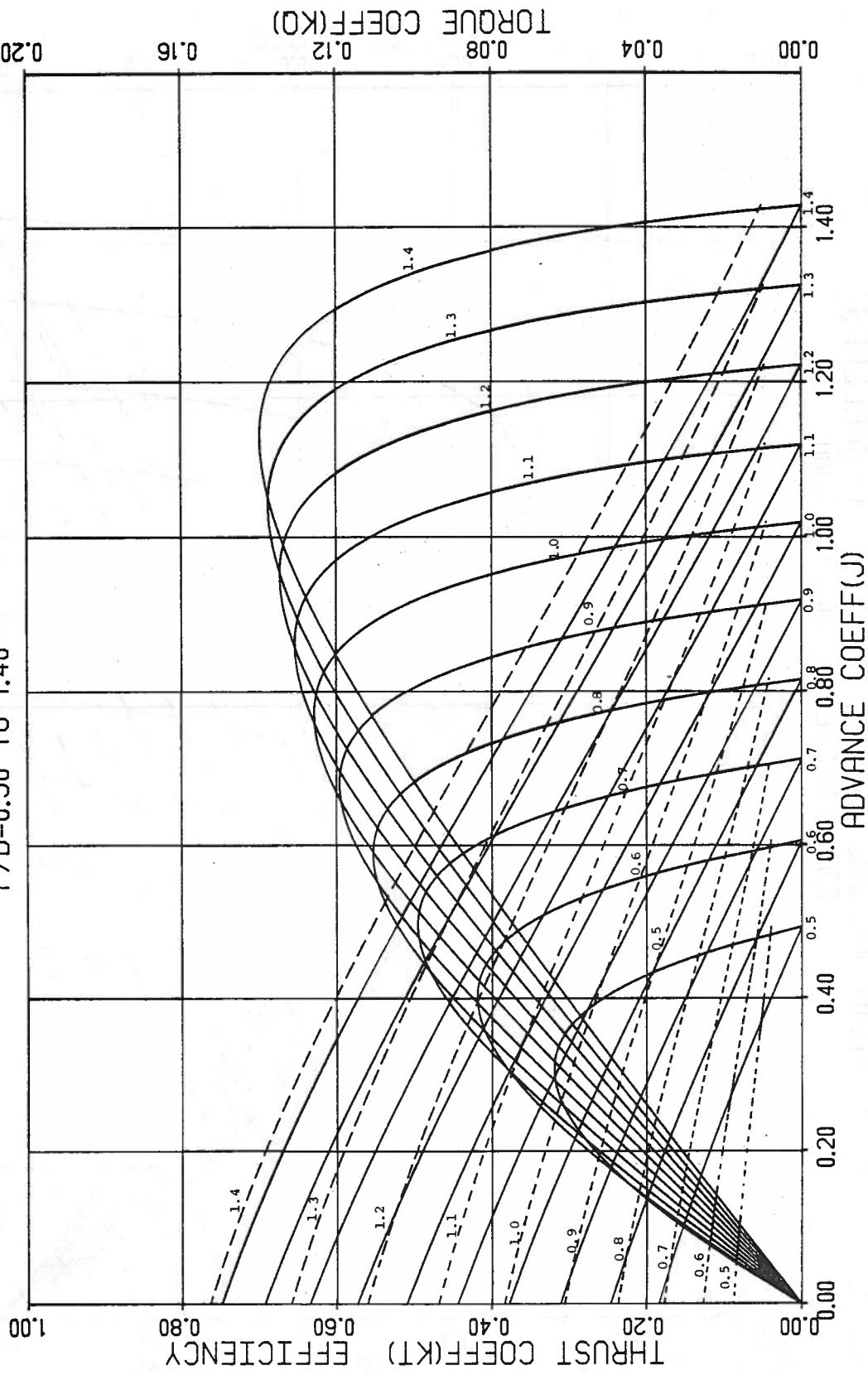


FIGURE 49. WAGENINGEN B-SERIES PROPELLERS  
 FOR 5 BLADES       $A_e/A_0 = 0.300$   
 $P/D = 0.50$  TO 1.40

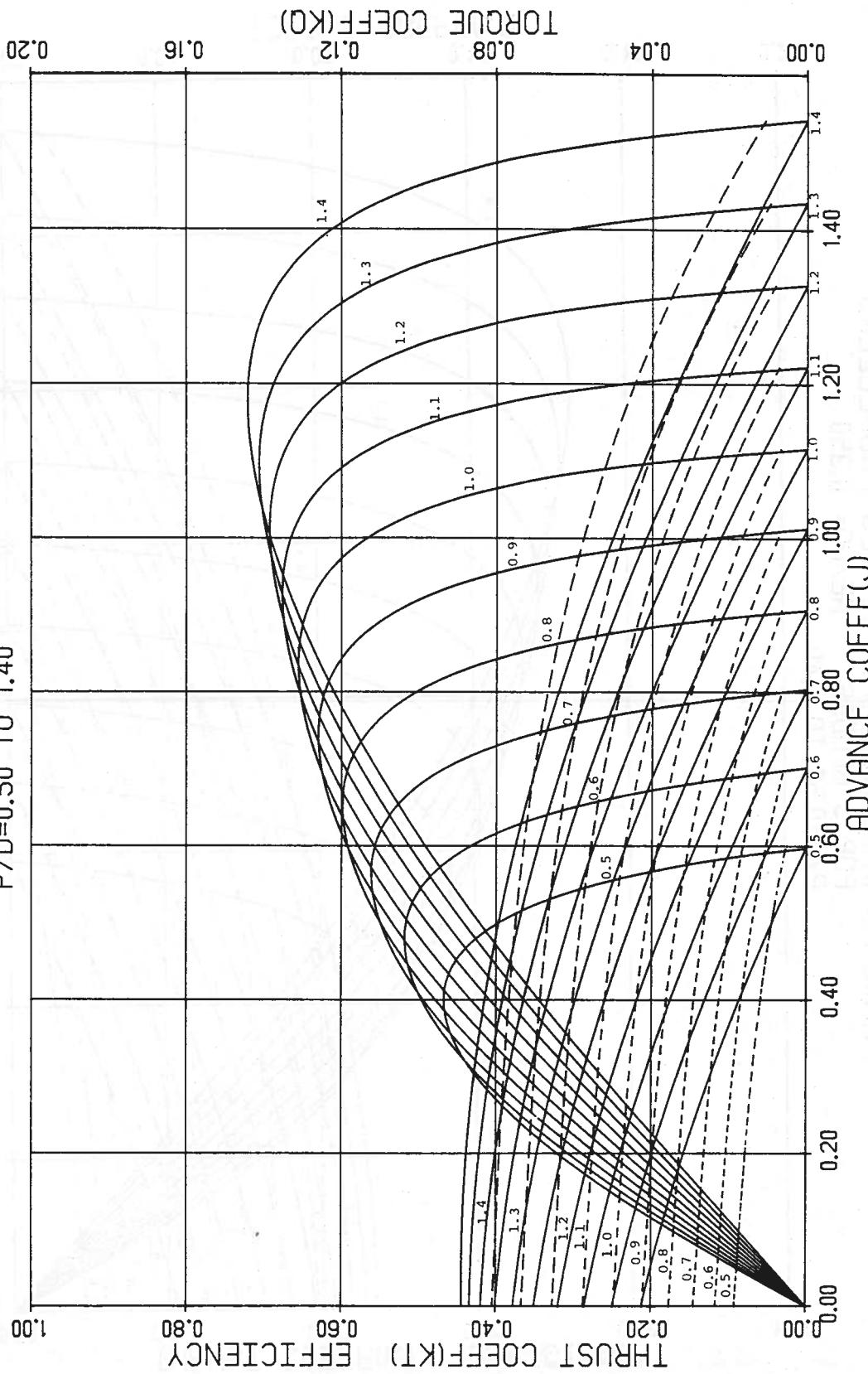


FIGURE 50. WAGENINGEN B-SERIES PROPELLERS  
 FOR 5 BLADES       $A_e/A_0 = 0.350$   
 $P/D = 0.50$  TO 1.40

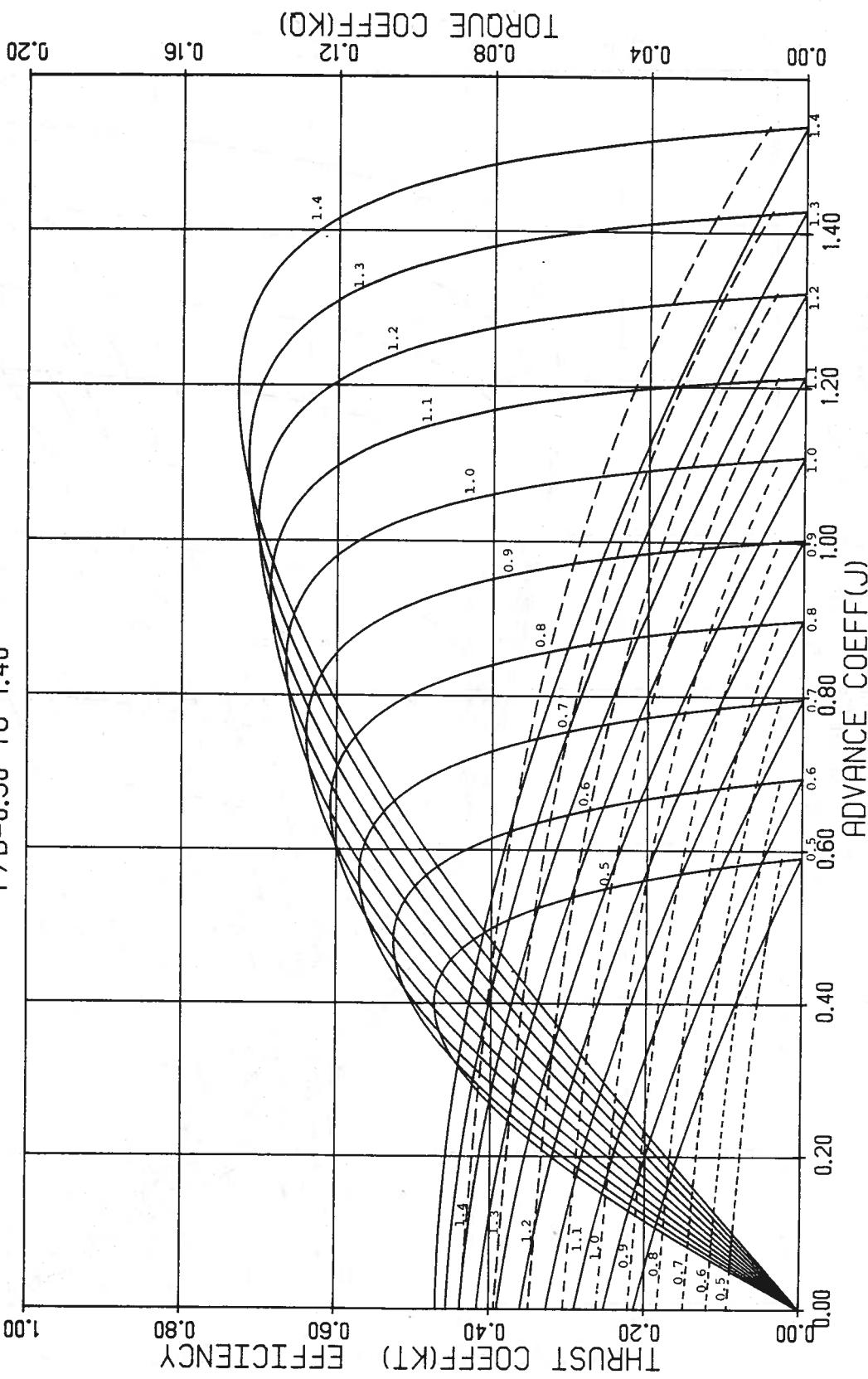


FIGURE 51. WAGENINGEN B-SERIES PROPELLERS  
 FOR 5 BLADES       $A_e/A_0 = 0.400$   
 $P/D = 0.50$  TO  $1.40$

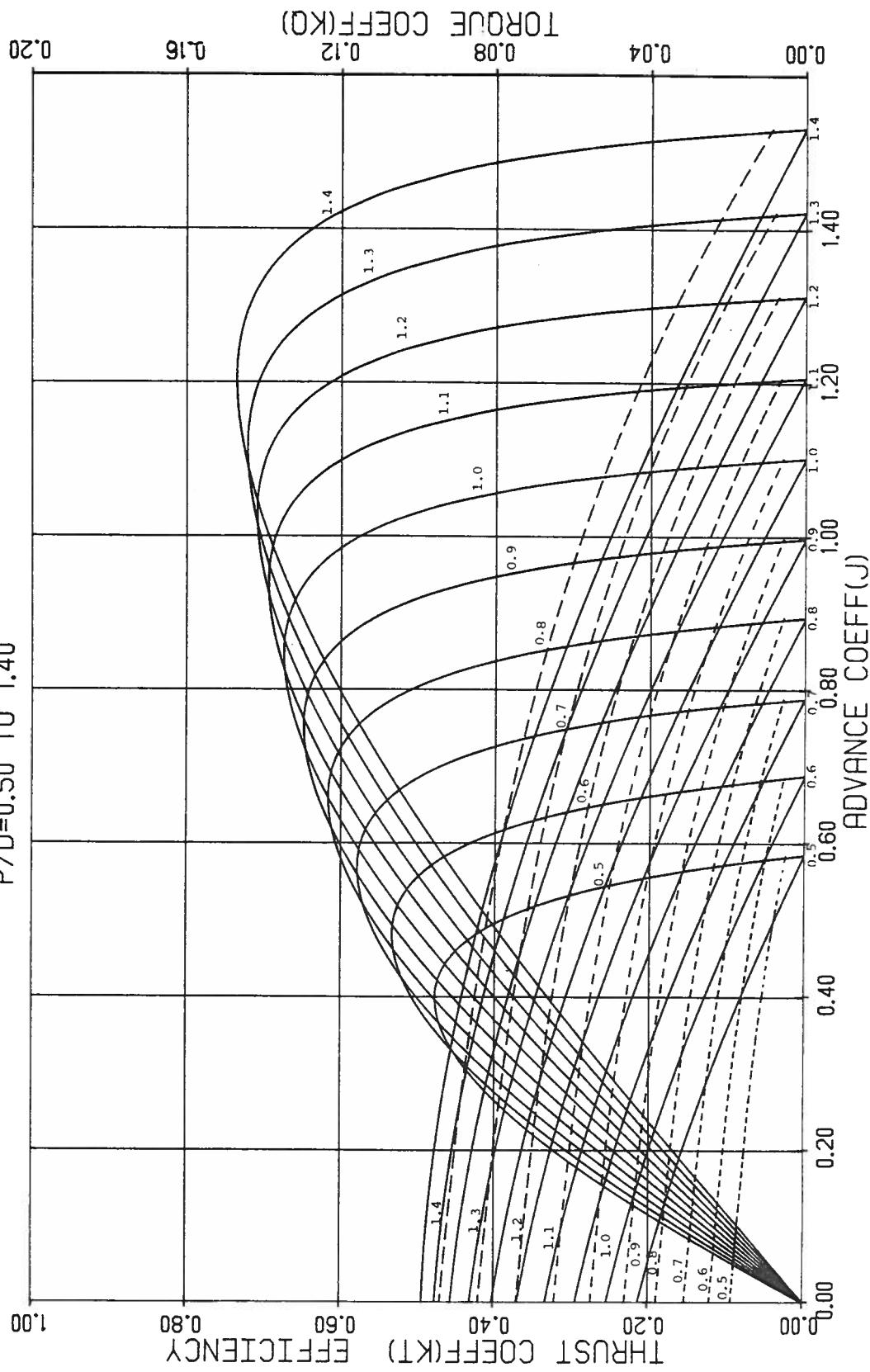


FIGURE 52. WAGENINGEN B-SERIES PROPELLERS  
 FOR 5 BLADES  
 $A_e/A_0 = 0.450$   
 $P/D = 0.50$  TO  $1.40$

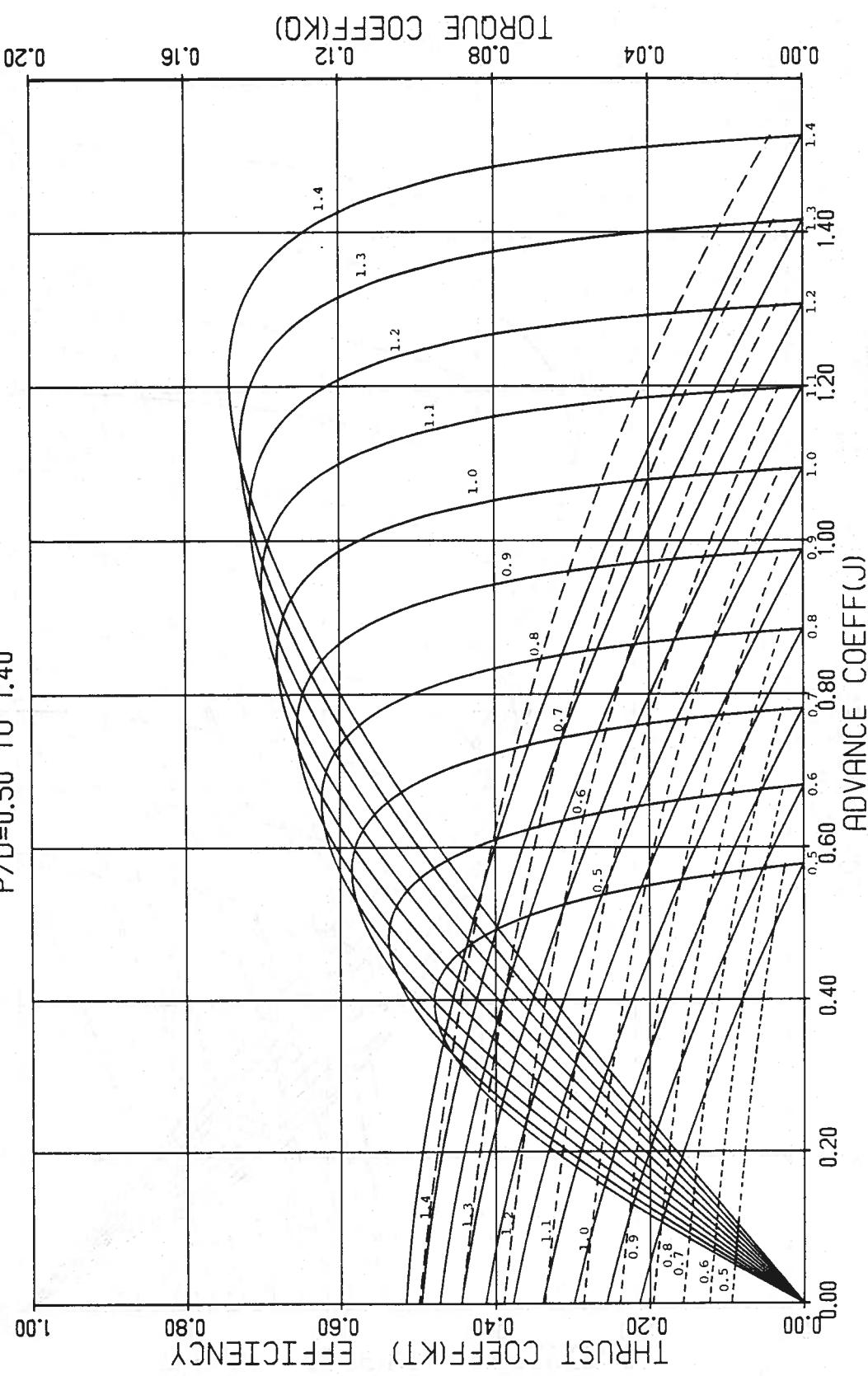


FIGURE 53. WAGENINGEN B-SERIES PROPELLERS  
 FOR 5 BLADES  
 $A_e/A_0 = 0.500$   
 $P/D = 0.50$  TO 1.40

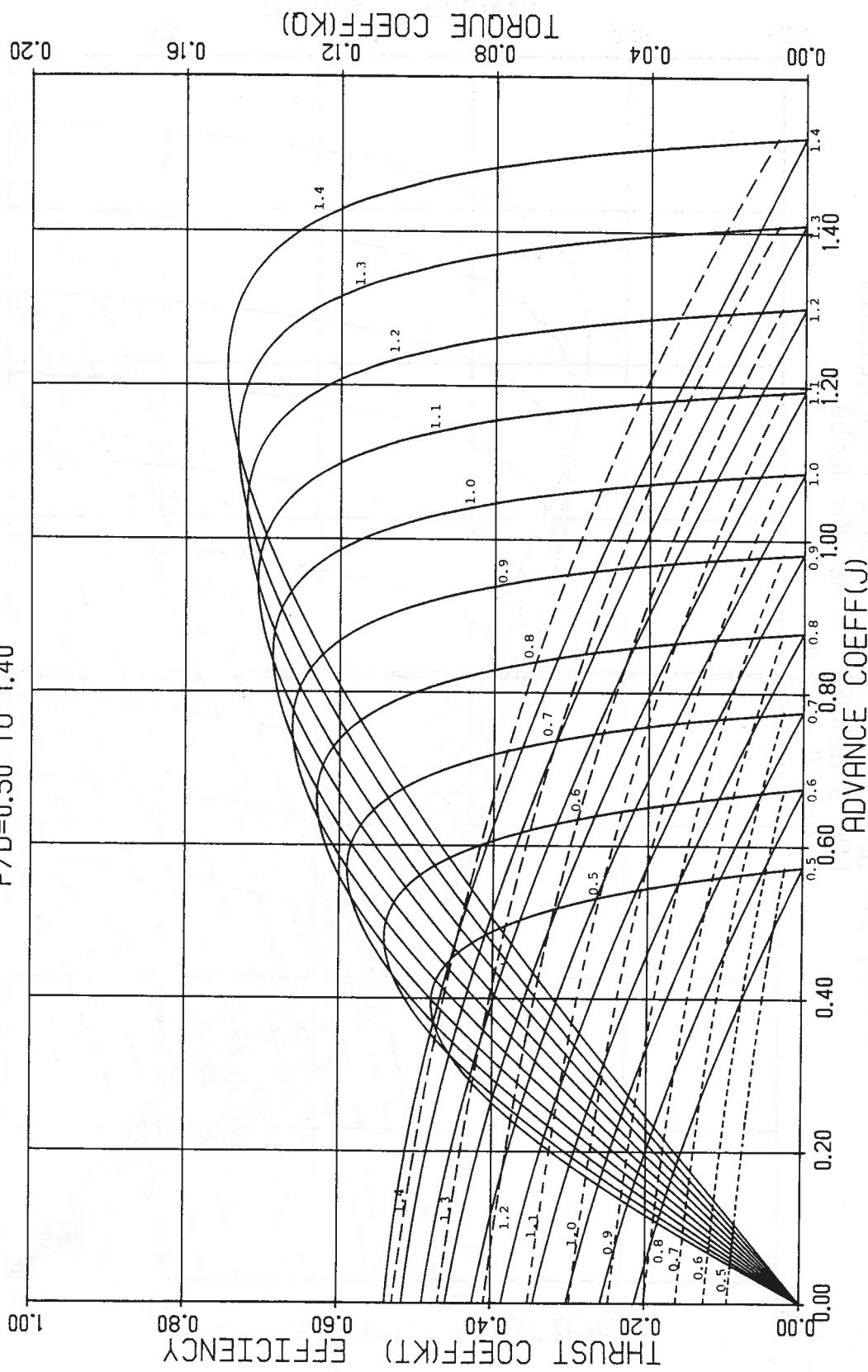


FIGURE 54. WAGENINGEN B-SERIES PROPELLERS  
FOR 5 BLADES  
 $A_e/A_0 = 0.550$   
 $P/D = 0.50$  TO 1.40

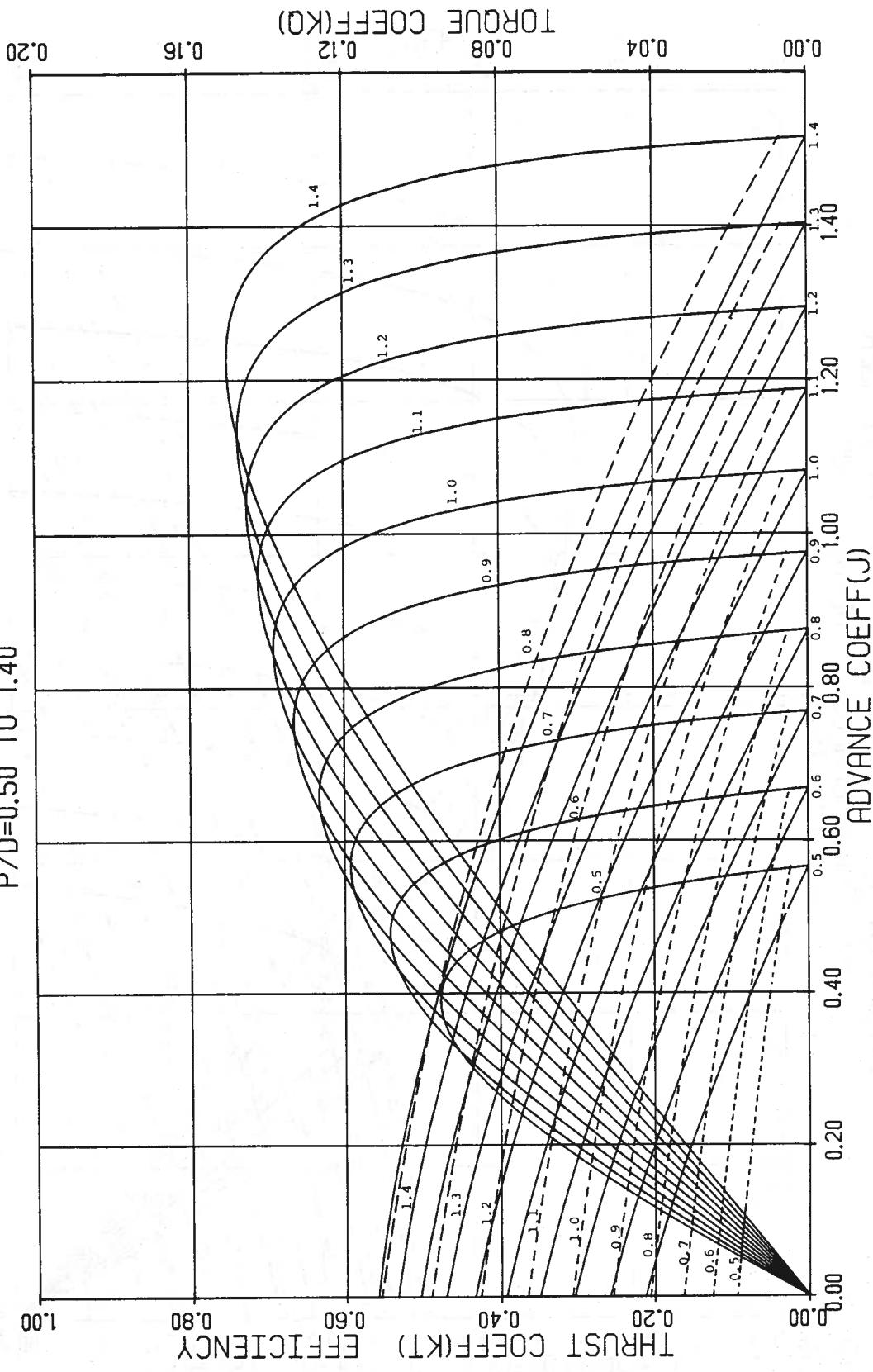


FIGURE 55. WAGENINGEN B-SERIES PROPELLERS  
 FOR 5 BLADES  
 $A_e/A_0 = 0.600$   
 $P/D = 0.50$  TO 1.40

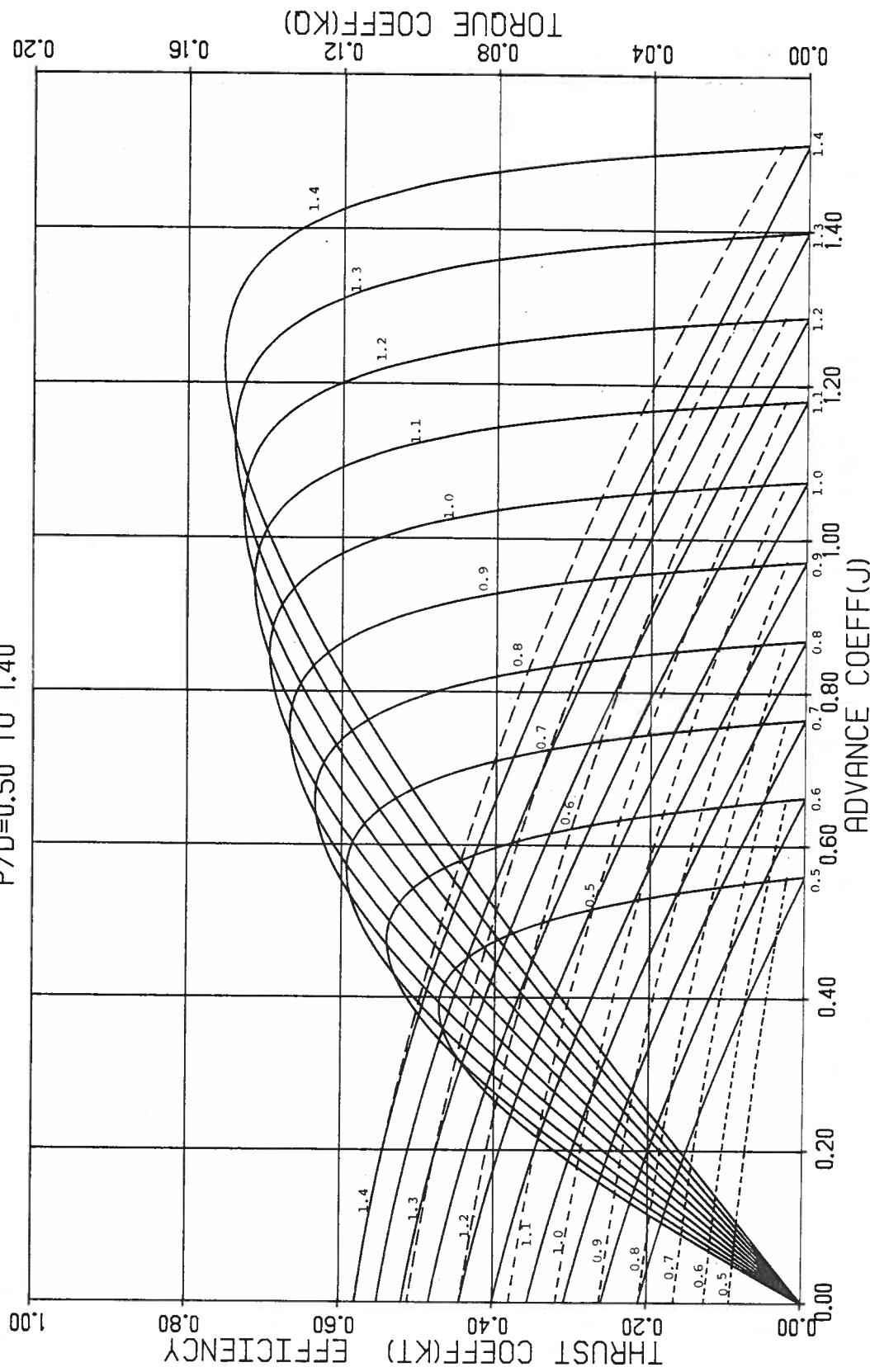


FIGURE 56. WAGENINGEN B-SERIES PROPELLERS  
FOR 5 BLADES  
 $A_e/A_0 = 0.650$   
 $P/D = 0.50$  TO 1.40

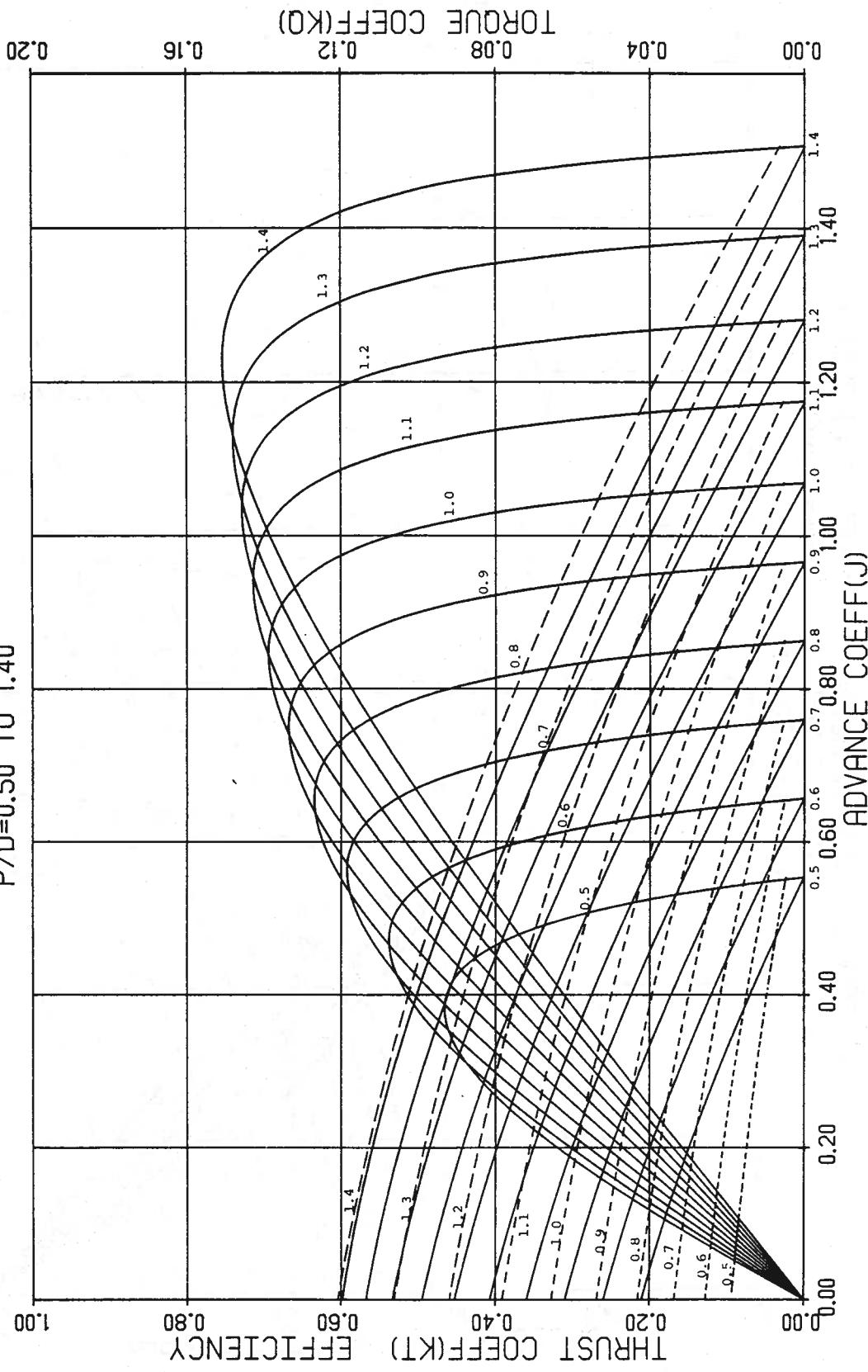


FIGURE 57. WAGENINGEN B-SERIES PROPELLERS  
 FOR 5 BLADES       $A_e/A_0 = 0.700$   
 $P/D = 0.50$  TO 1.40

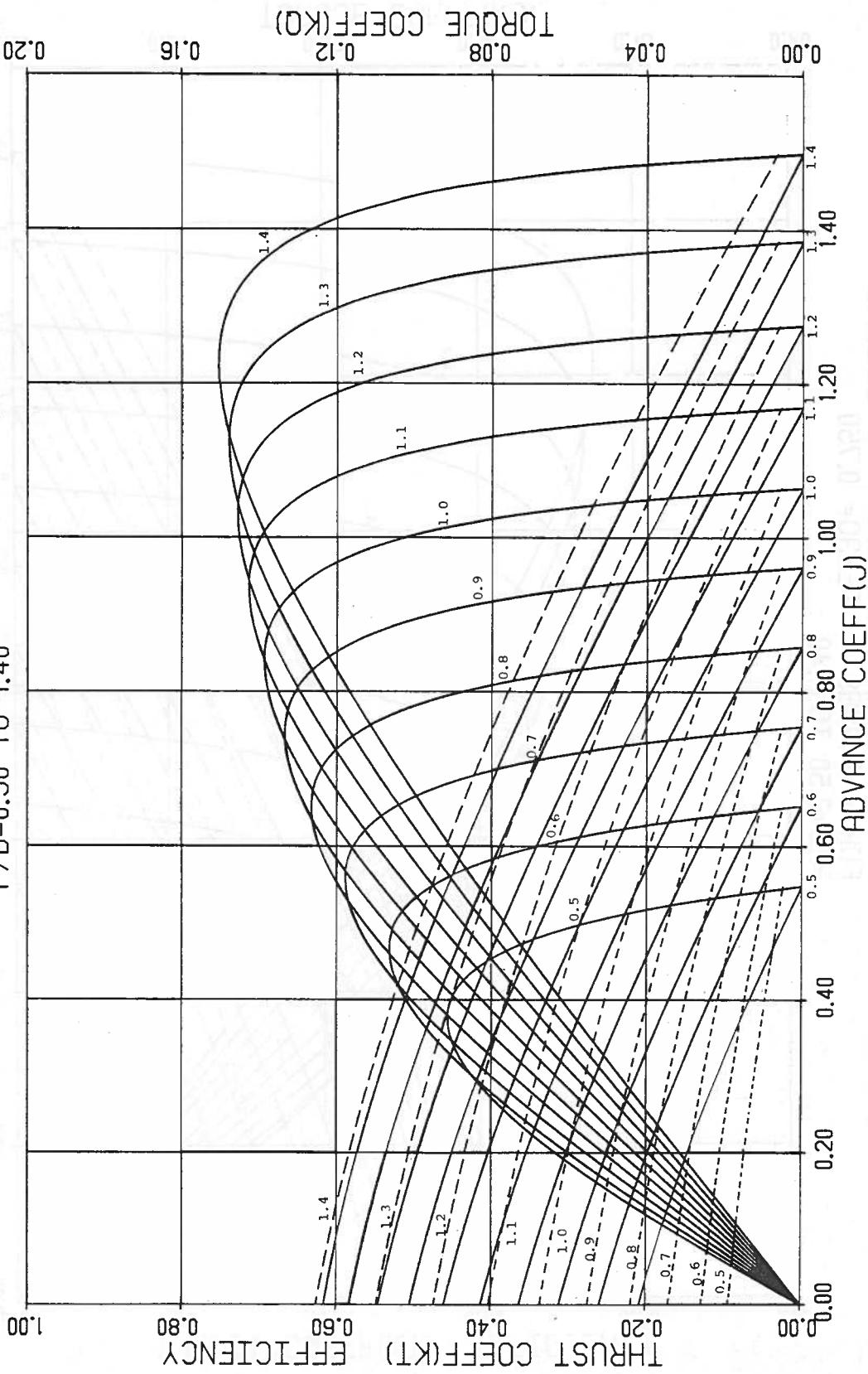


FIGURE 58. WAGENINGEN B-SERIES PROPELLERS  
 FOR 5 BLADES       $A_e/R_0 = 0.750$   
 $P/D = 0.50$  TO  $1.40$

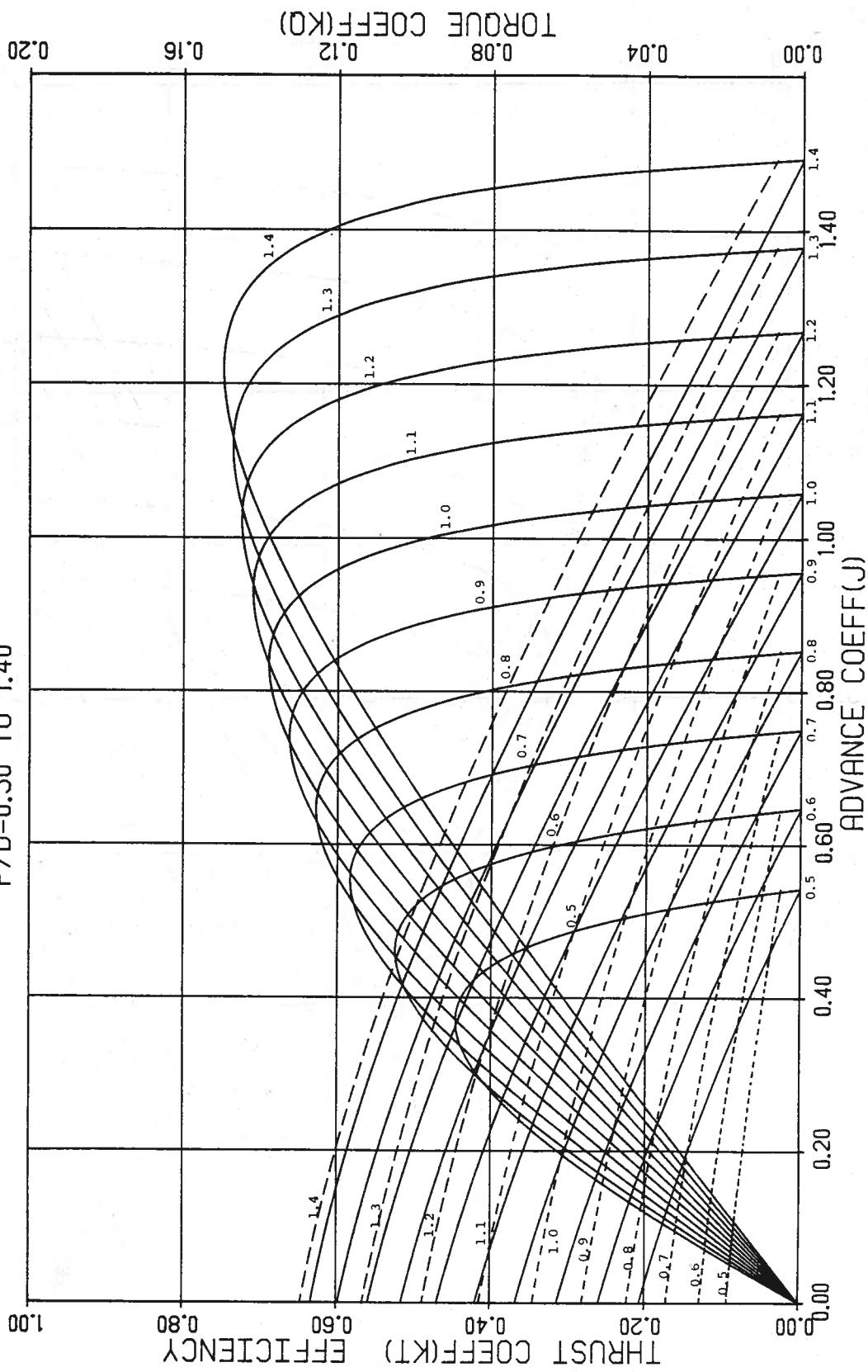


FIGURE 59. WAGENINGEN B-SERIES PROPELLERS  
 FOR 5 BLADES       $A_e/A_0 = 0.800$   
 $P/D = 0.50$  TO 1.40

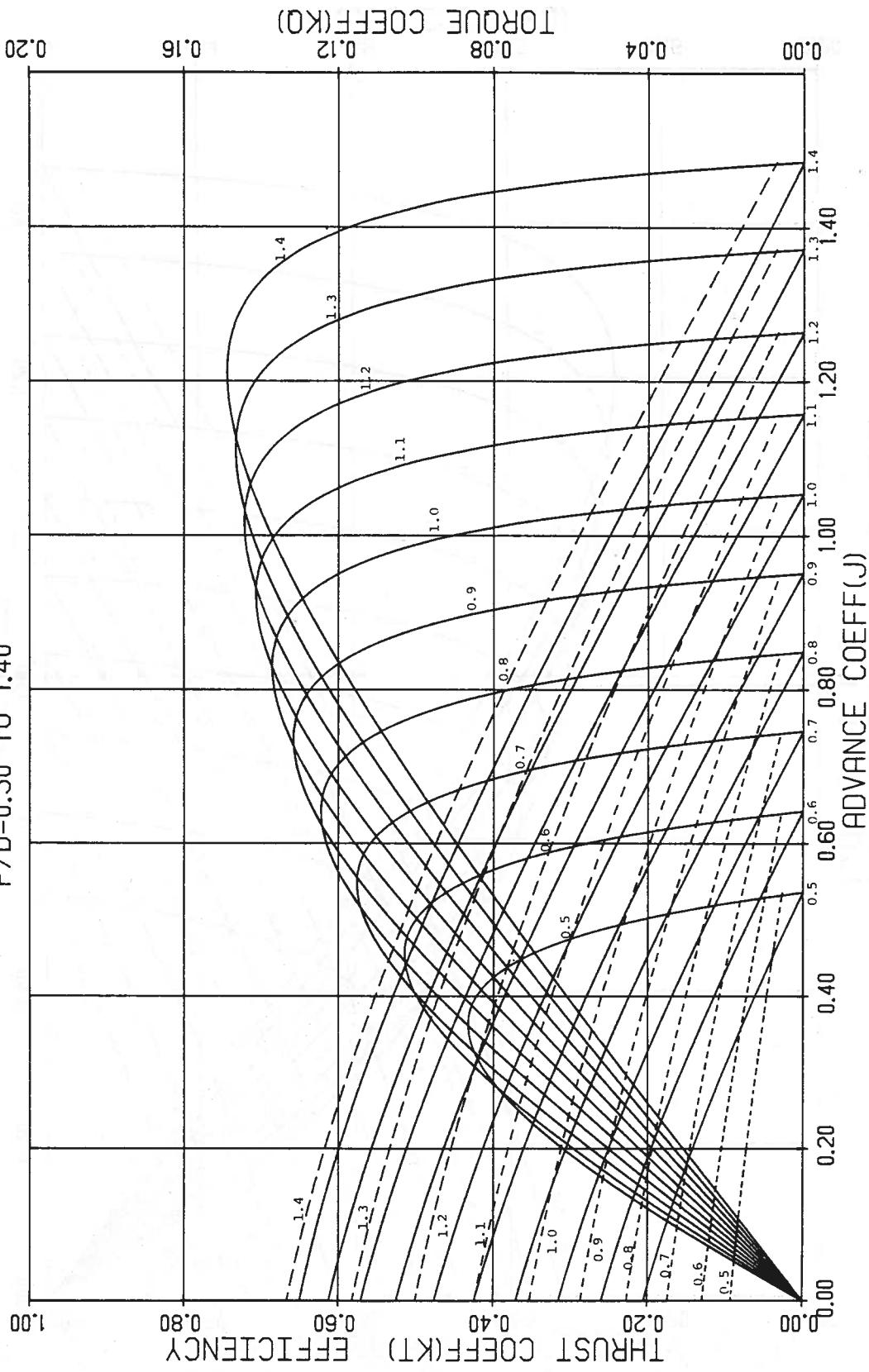


FIGURE 60. WAGENINGEN B-SERIES PROPELLERS  
FOR 5 BLADES  $A_e/A_0 = 0.850$   
 $P/D = 0.50$  TO 1.40

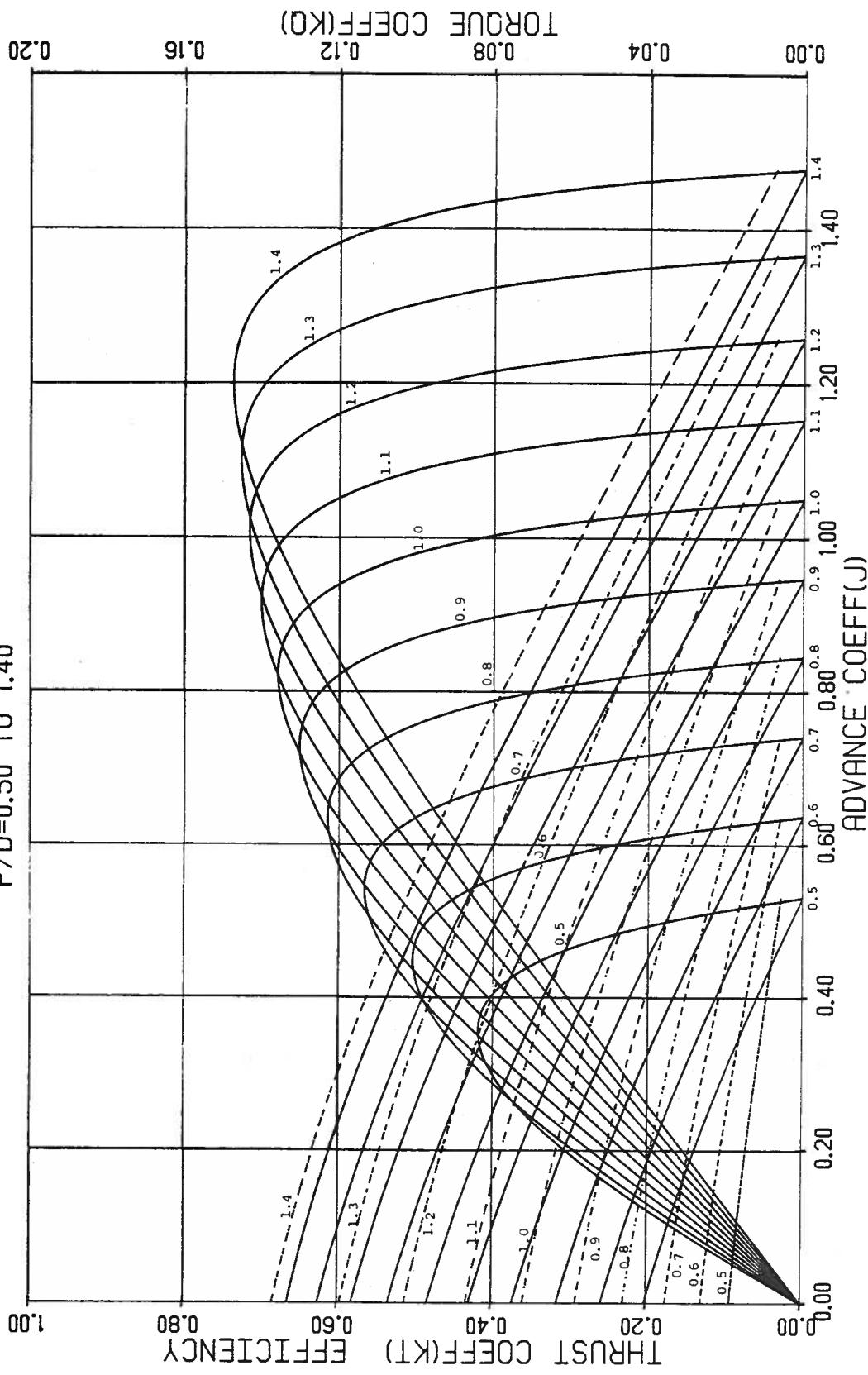


FIGURE 61. WAGENINGEN B-SERIES PROPELLERS  
FOR 5 BLADES     $A_e/A_0 = 0.900$   
 $P/D = 0.50$  TO  $1.40$

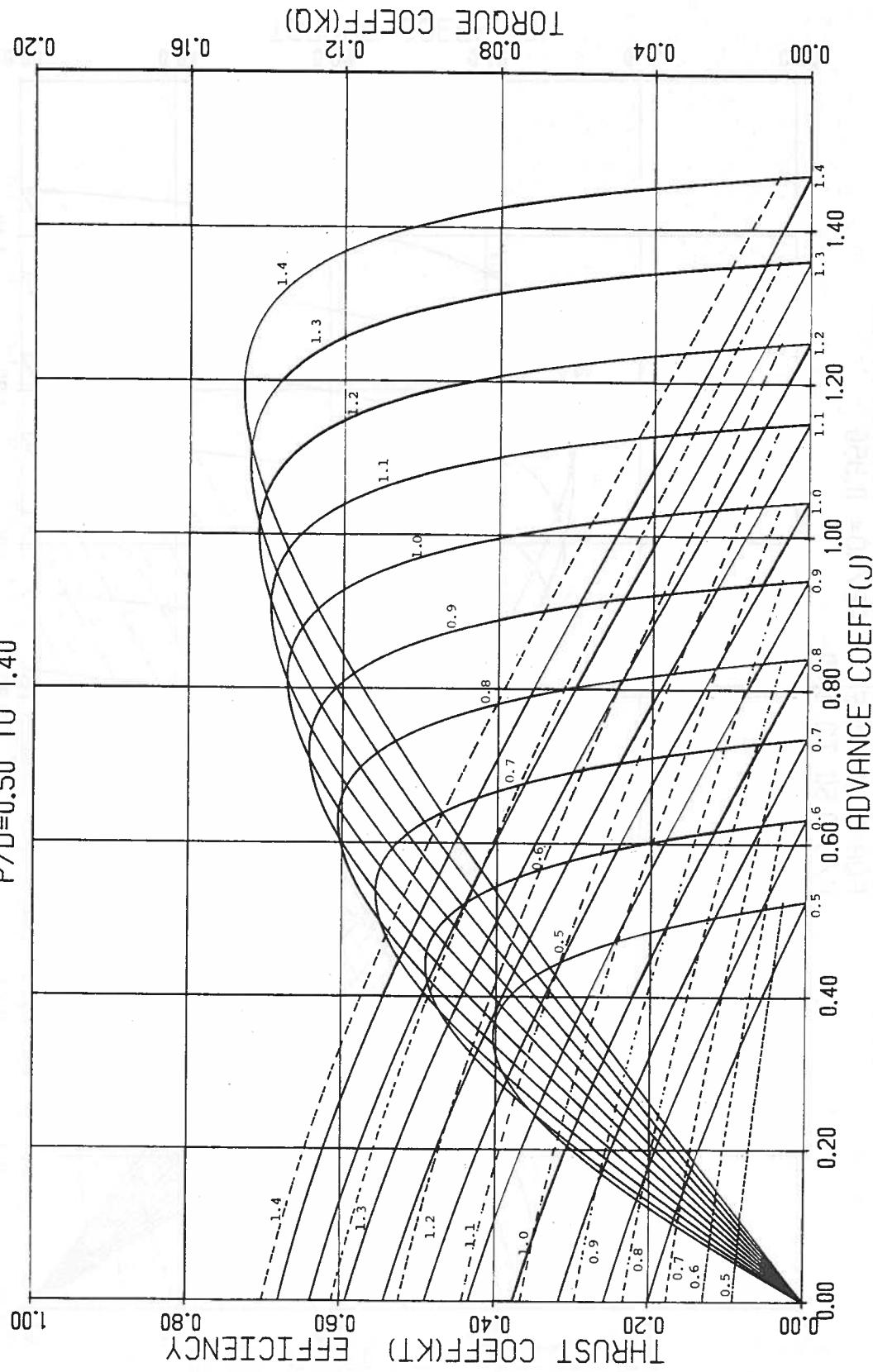


FIGURE 62. WAGENINGEN B-SERIES PROPELLERS  
 FOR 5 BLADES       $A_e/A_0 = 0.950$   
 $P/D = 0.50$  TO  $1.40$

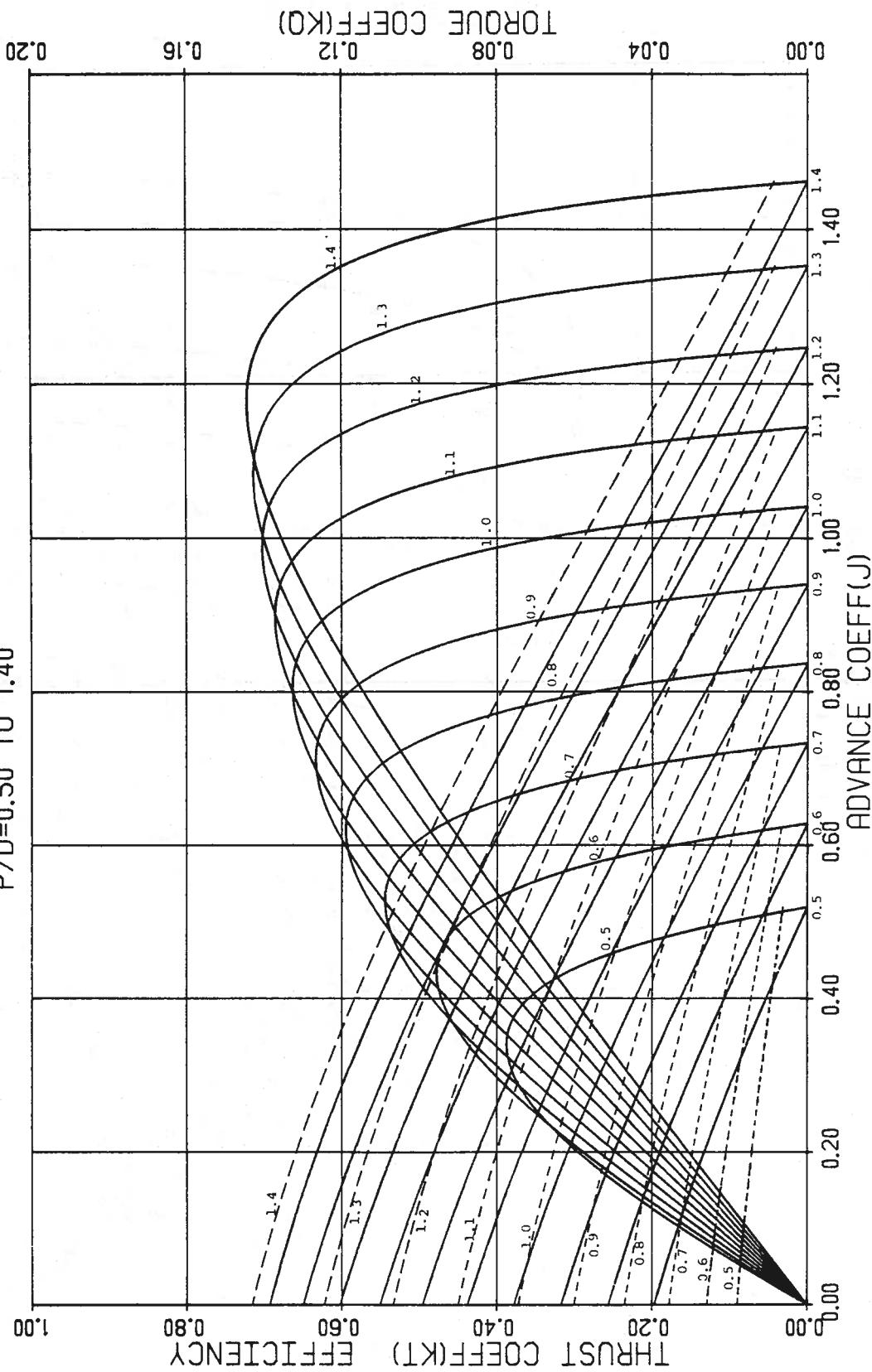


FIGURE 63. WAGENINGEN B-SERIES PROPELLERS  
 FOR 5 BLADES  
 $A_e/A_0 = 1.000$   
 $P/D = 0.50$  TO 1.40

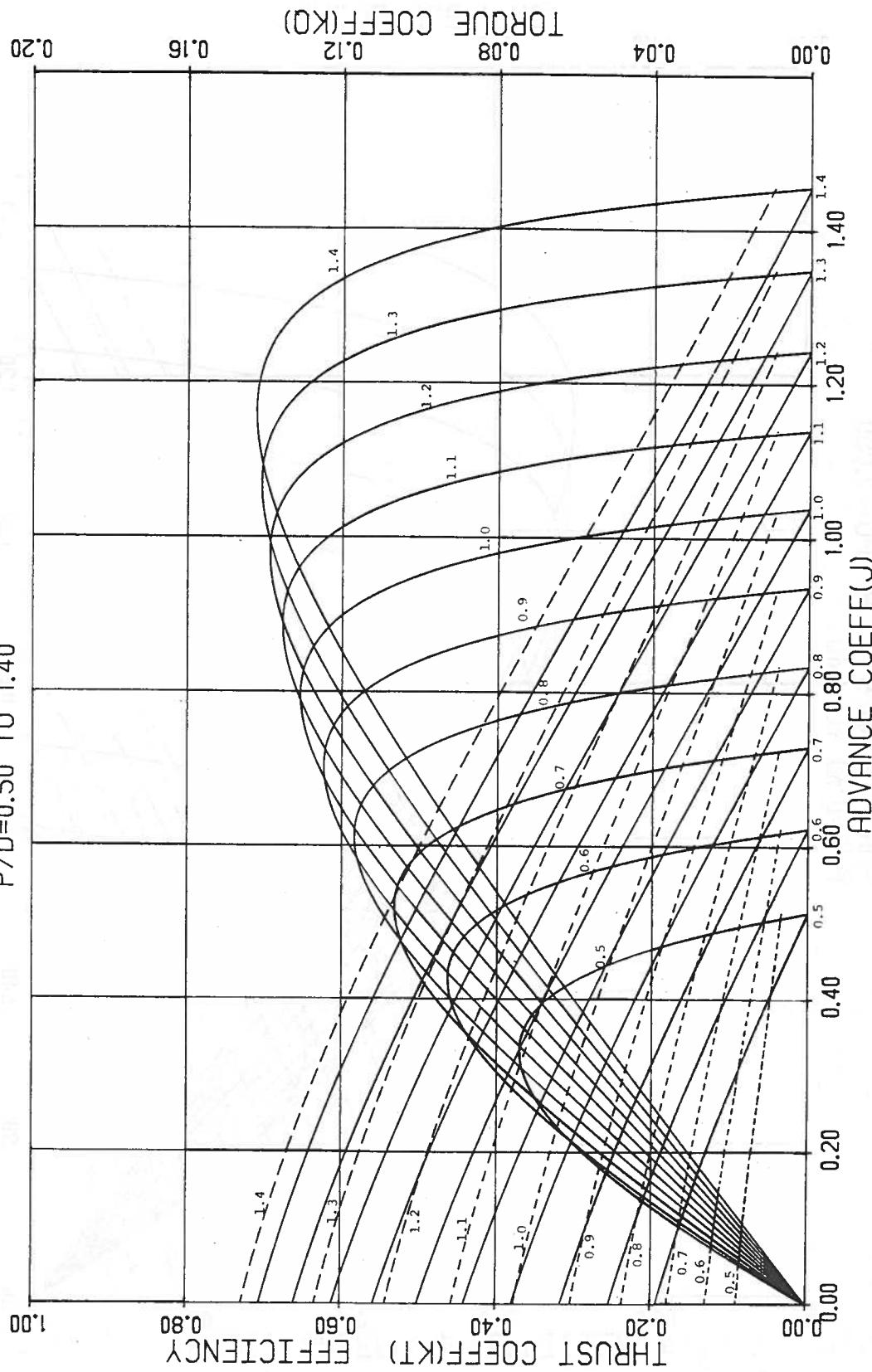


FIGURE 64. WAGENINGEN B-SERIES PROPELLERS  
FOR 5 BLADES  
 $A_e/A_0 = 1.050$   
 $P/D = 0.50$  TO  $1.40$

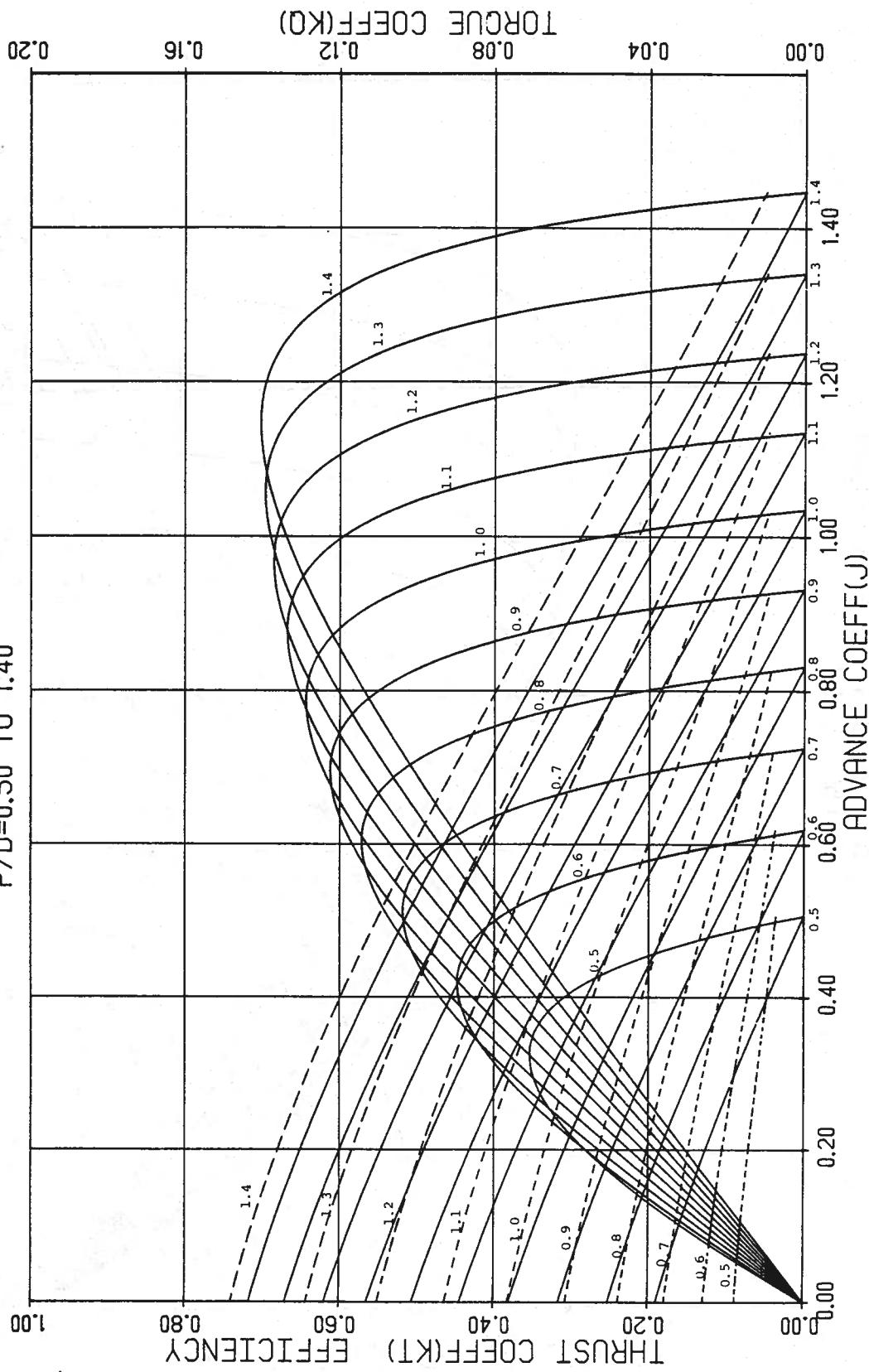


FIGURE 65. WAGENINGEN B-SERIES PROPELLERS  
 FOR 6 BLADES  
 $A_e/A_0 = 0.300$   
 $P/D = 0.50$  TO 1.40

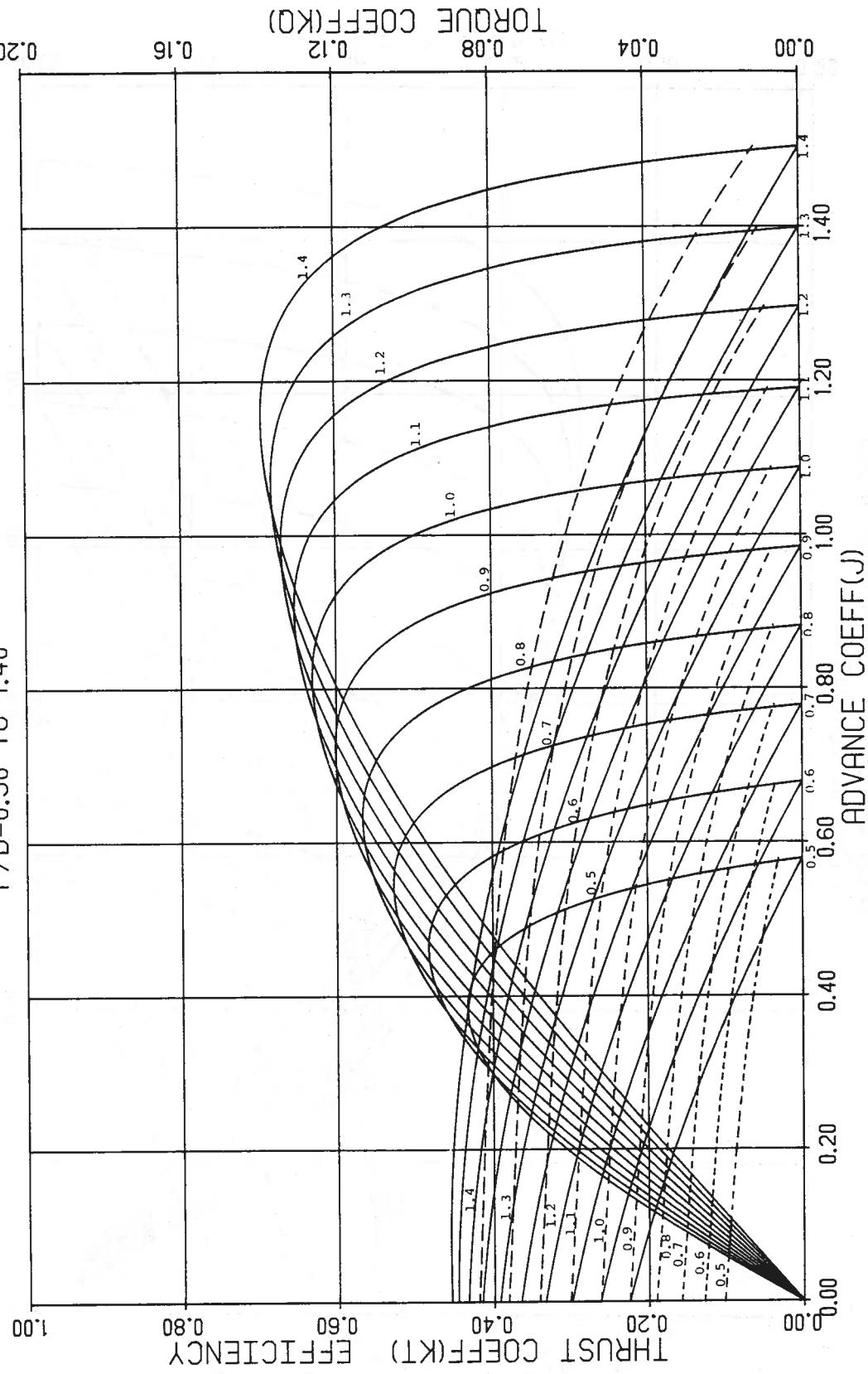


FIGURE 66. WAGENINGEN B-SERIES PROPELLERS  
 FOR 6 BLADES       $A_E/A_0 = 0.350$   
 $P/D = 0.50$  TO 1.40

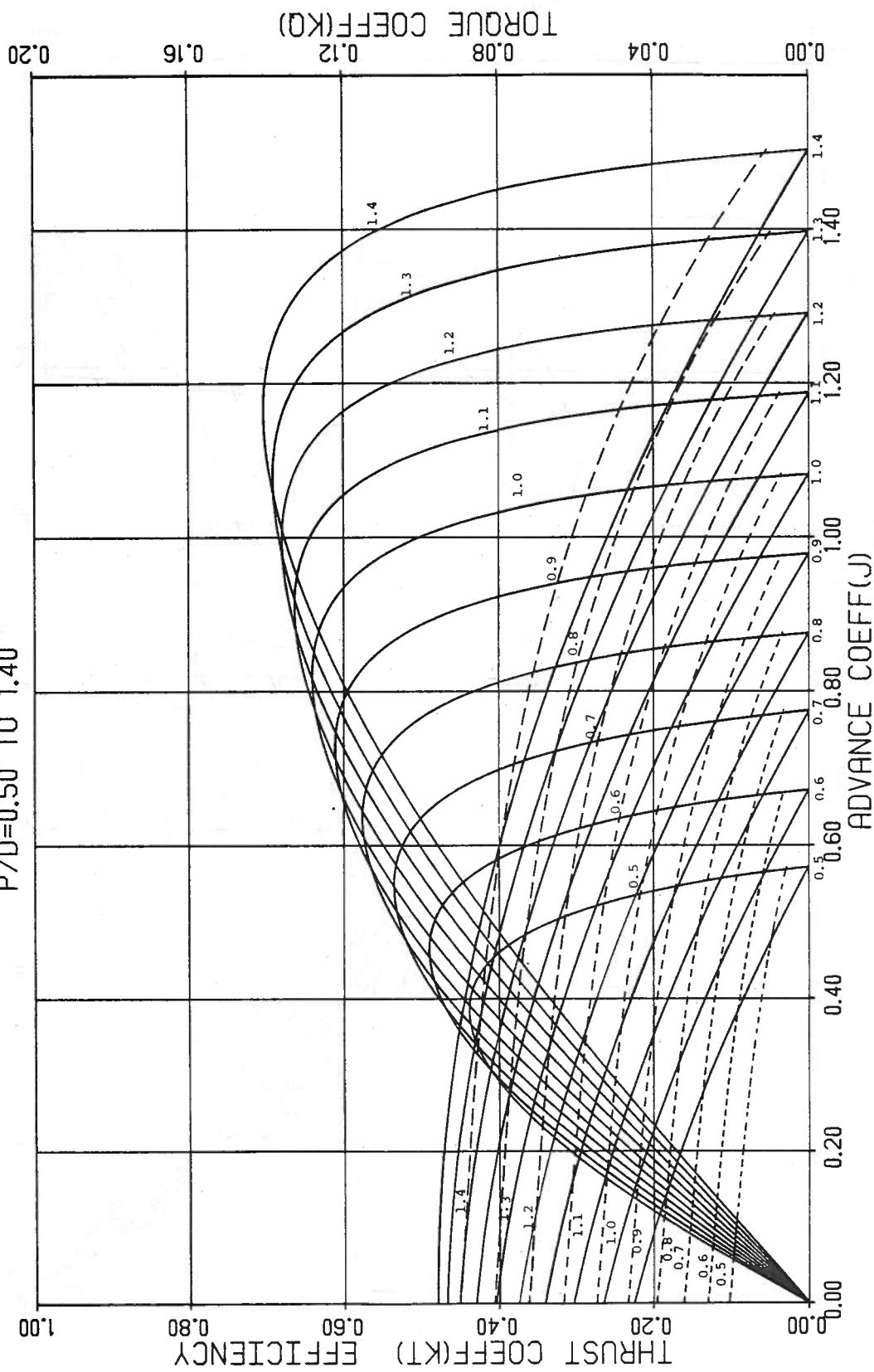


FIGURE 67. WAGENINGEN B-SERIES PROPELLERS  
FOR 6 BLADES  $A_e/A_0 = 0.400$   
 $P/D = 0.50$  TO 1.40

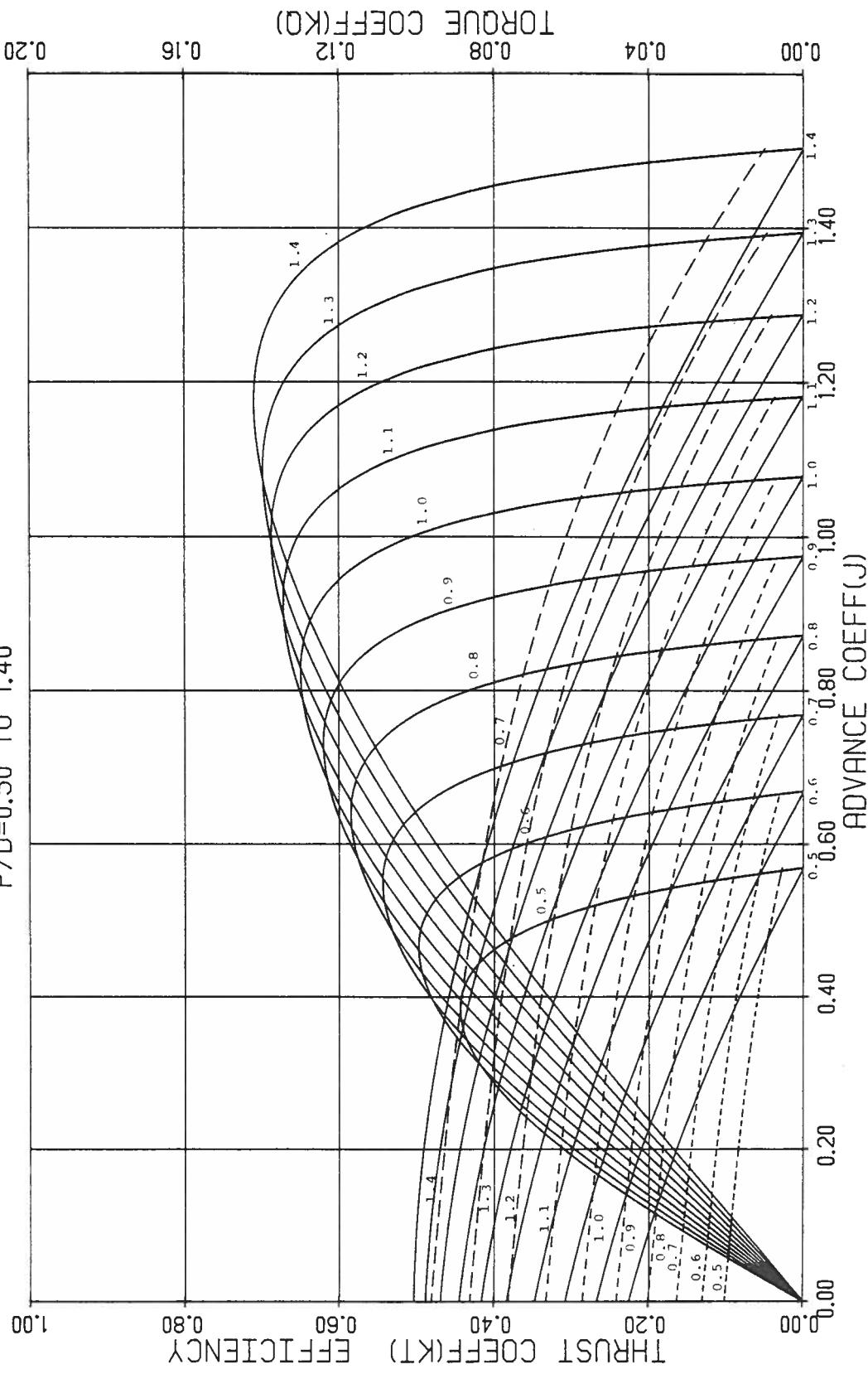


FIGURE 68. WAGENINGEN B-SERIES PROPELLERS  
 FOR 6 BLADES  $A_e/A_0 = 0.450$   
 $P/D = 0.50$  TO  $1.40$

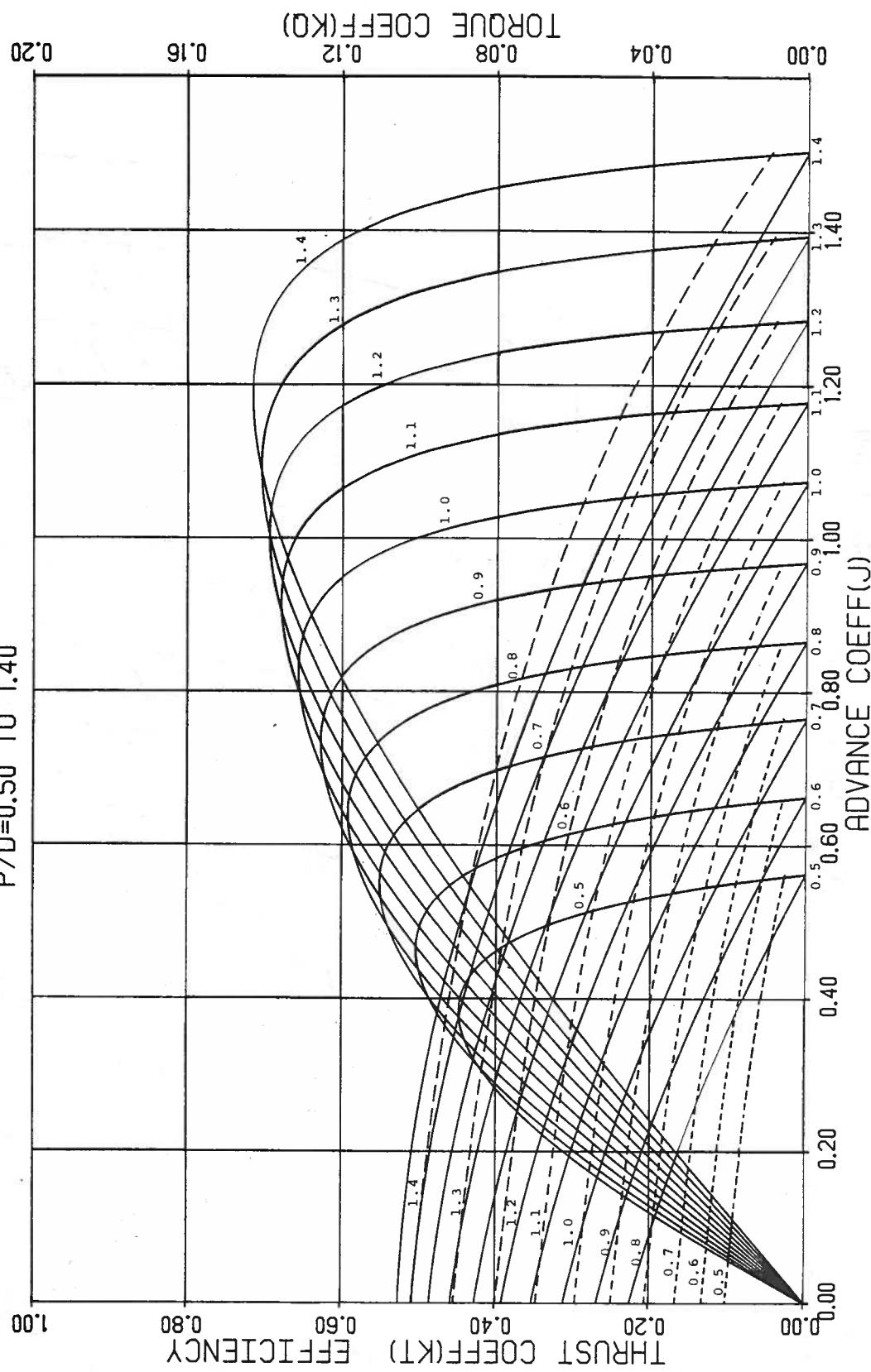


FIGURE 69. WAGENINGEN B-SERIES PROPELLERS  
 FOR 6 BLADES  
 $A_e/A_0 = 0.500$   
 $P/D = 0.50$  TO 1.40

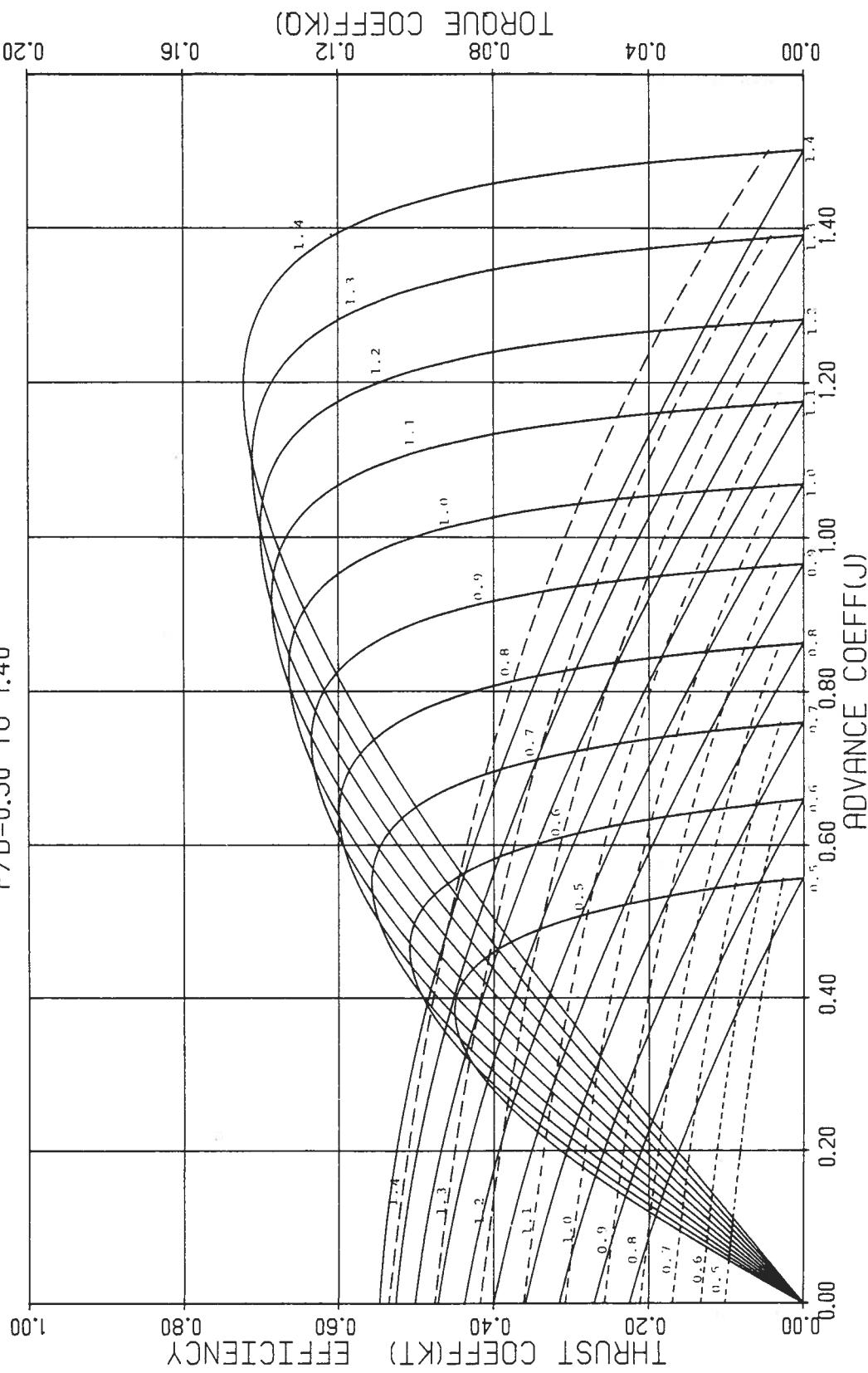


FIGURE 70. WAGENINGEN B-SERIES PROPELLERS  
 FOR 6 BLADES  $A_E/A_0 = 0.550$   
 $P/D = 0.50$  TO 1.40

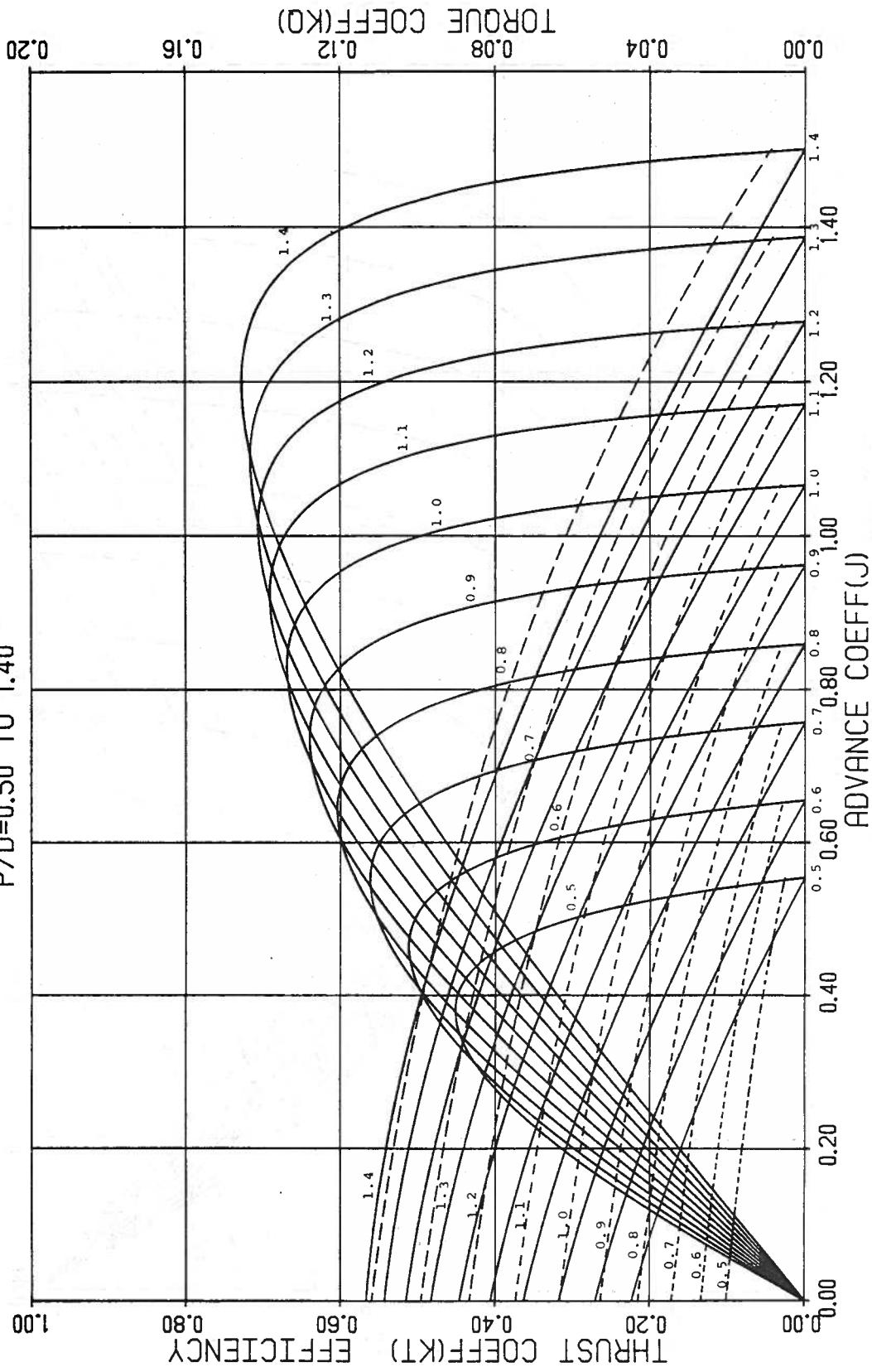


FIGURE 71. WAGENINGEN B-SERIES PROPELLERS  
 FOR 6 BLADES  
 $A_e/A_0 = 0.600$   
 $P/D = 0.50$  TO 1.40

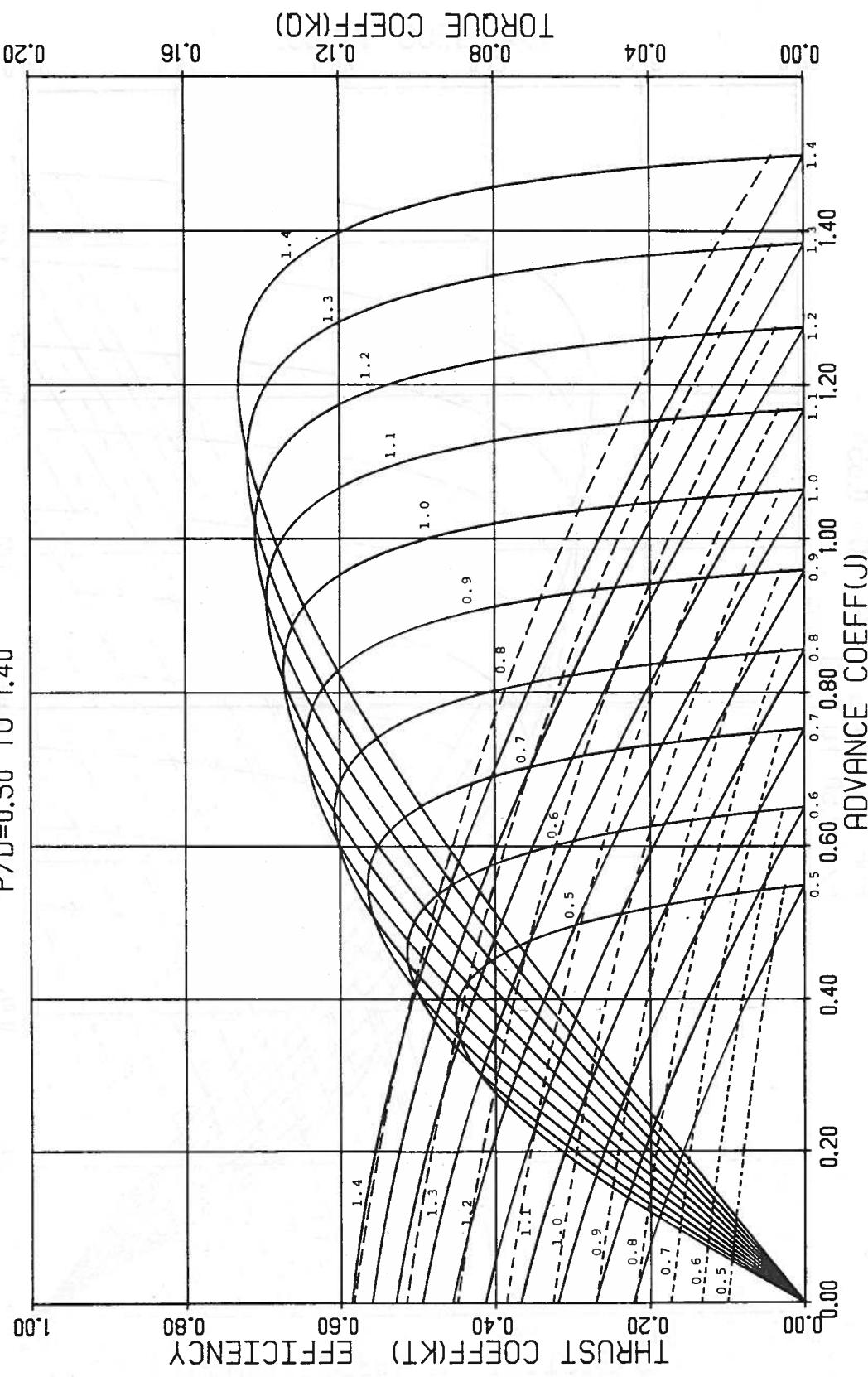


FIGURE 72. WAGENINGEN B-SERIES PROPELLERS  
 FOR 6 BLADES  $A_e/A_0 = 0.650$   
 $P/D = 0.50$  TO 1.40

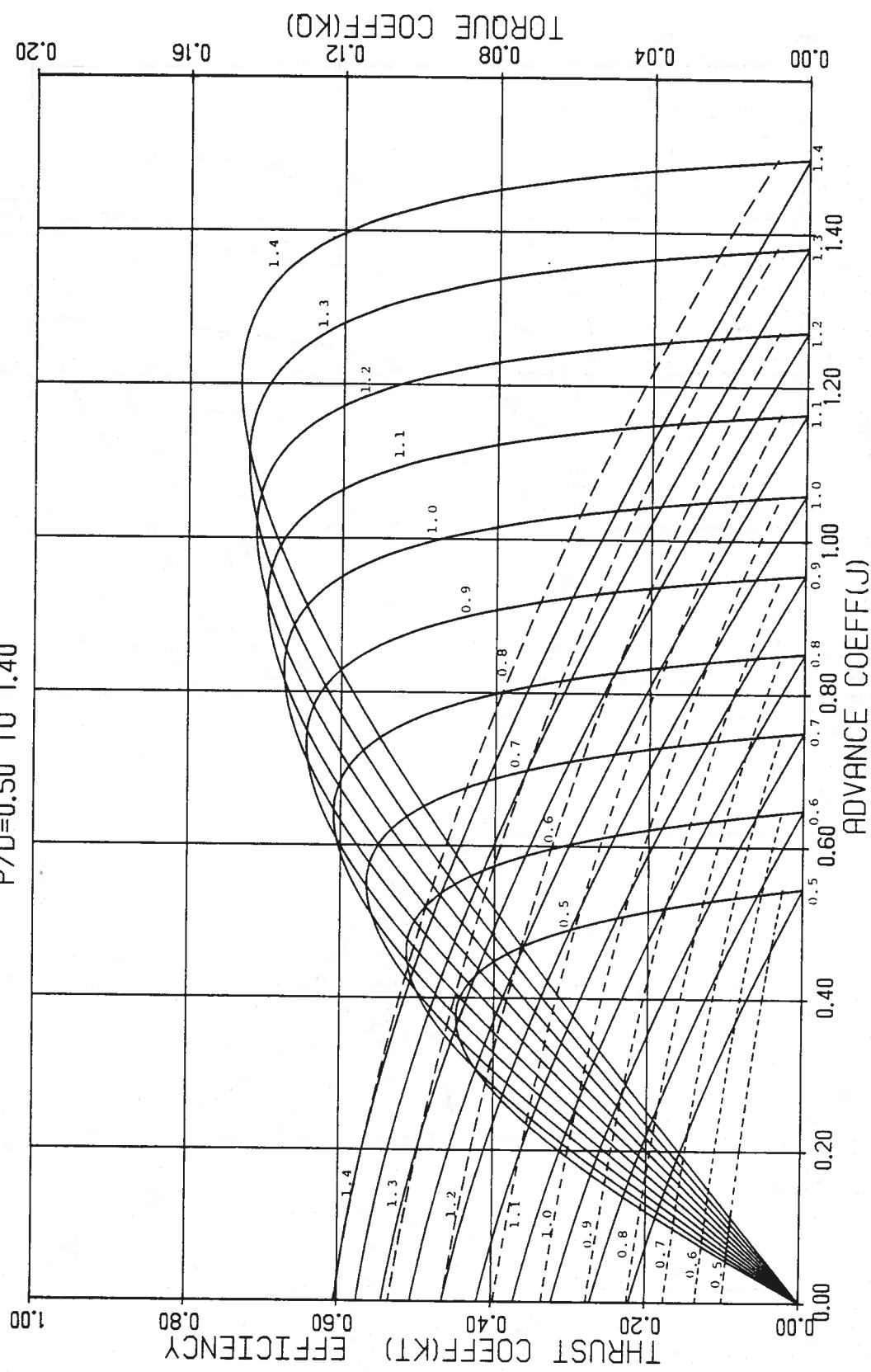


FIGURE 73. WAGENINGEN B-SERIES PROPELLERS  
 FOR 6 BLADES       $A_e/A_0 = 0.700$   
 $P/D = 0.50$  TO 1.40

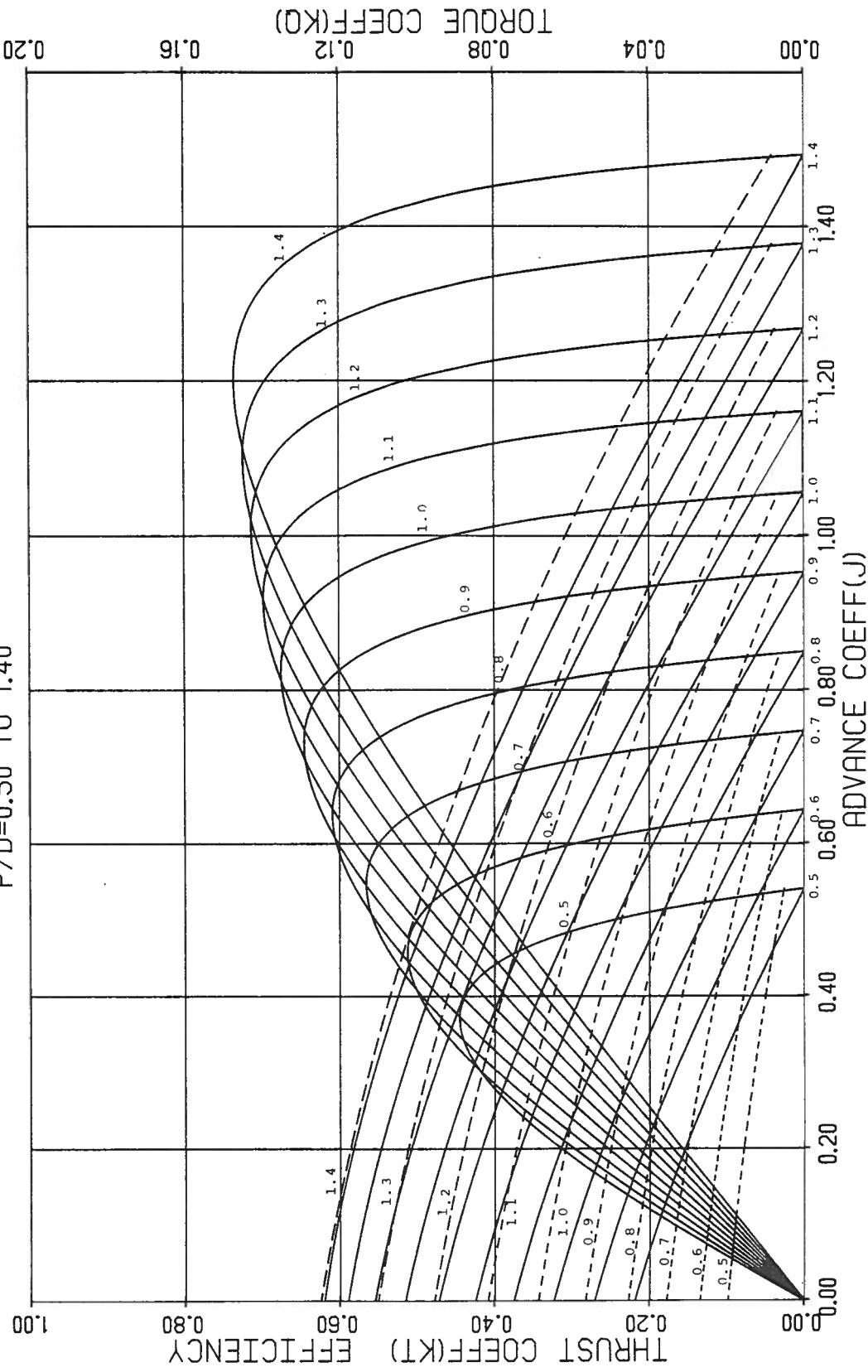


FIGURE 74. WAGENINGEN B-SERIES PROPELLERS  
 FOR 6 BLADES  
 $A_e/A_0 = 0.750$   
 $P/D = 0.50$  TO 1.40

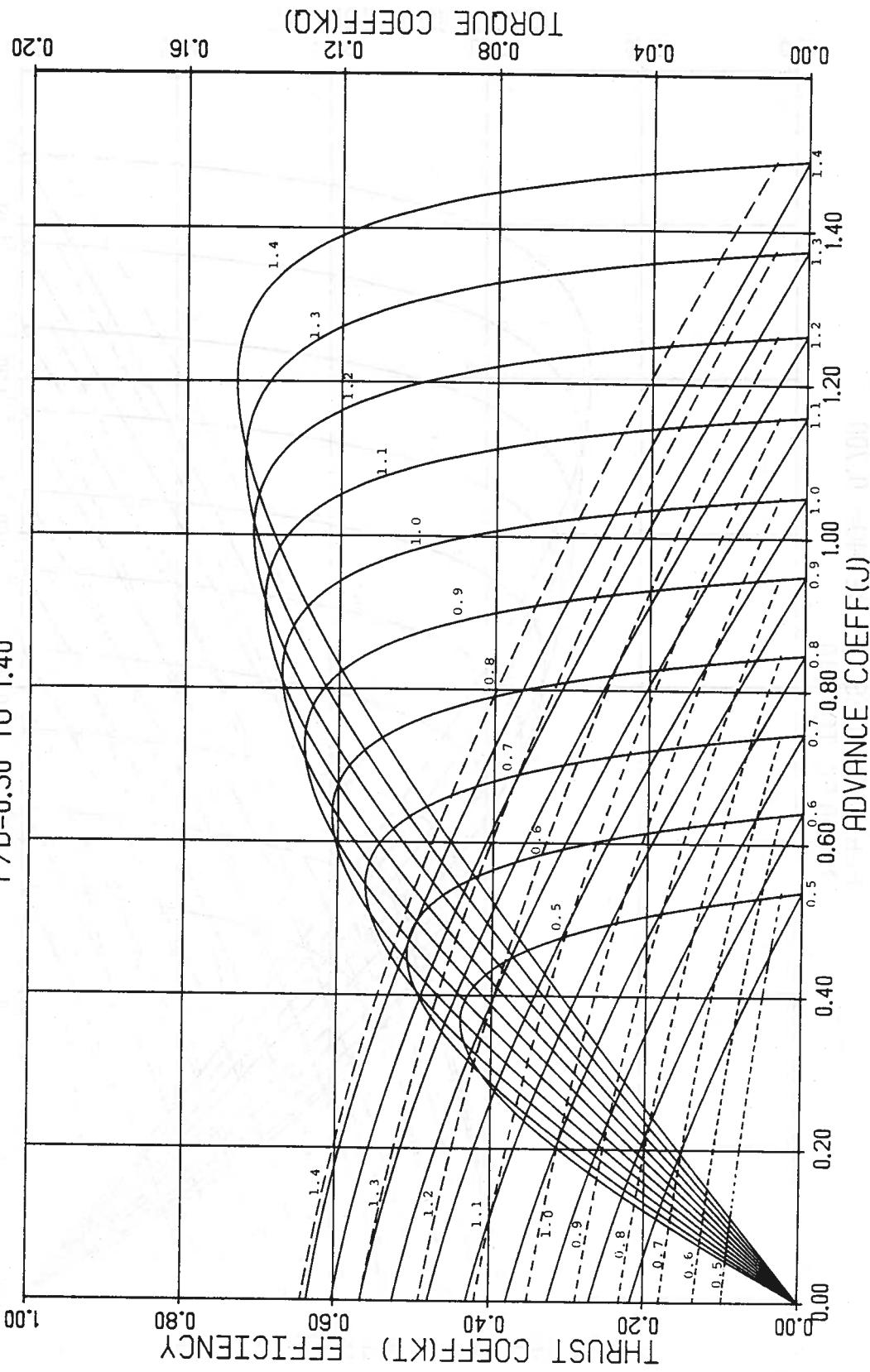


FIGURE 75. WAGENINGEN B-SERIES PROPELLERS  
 FOR 6 BLADES  
 $A_e/R_0 = 0.800$   
 $P/D = 0.50$  TO 1.40

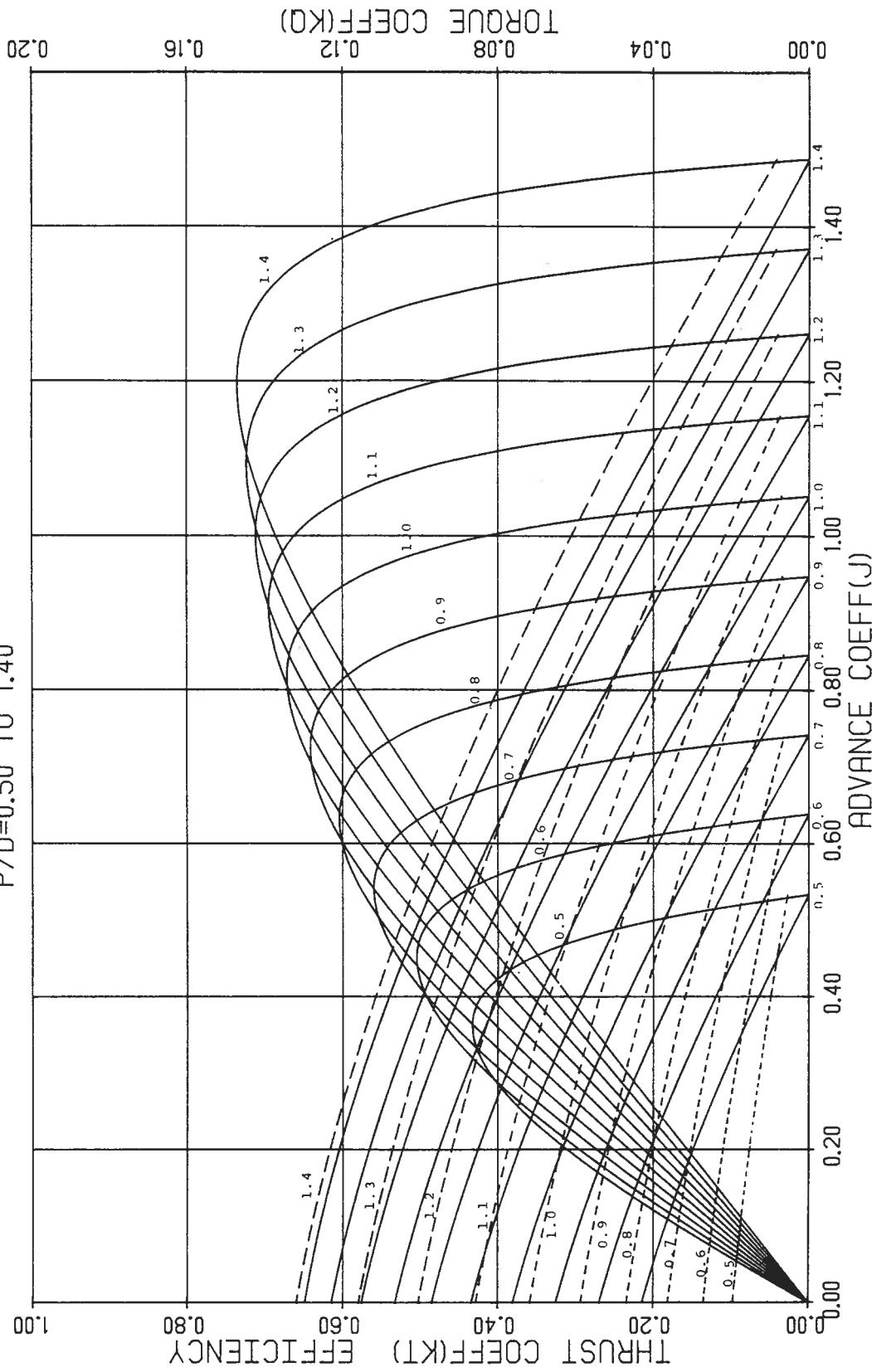


FIGURE 76. WAGENINGEN B-SERIES PROPELLERS  
 FOR 6 BLADES       $A_E/A_0 = 0.850$   
 $P/D = 0.50$  TO  $1.40$

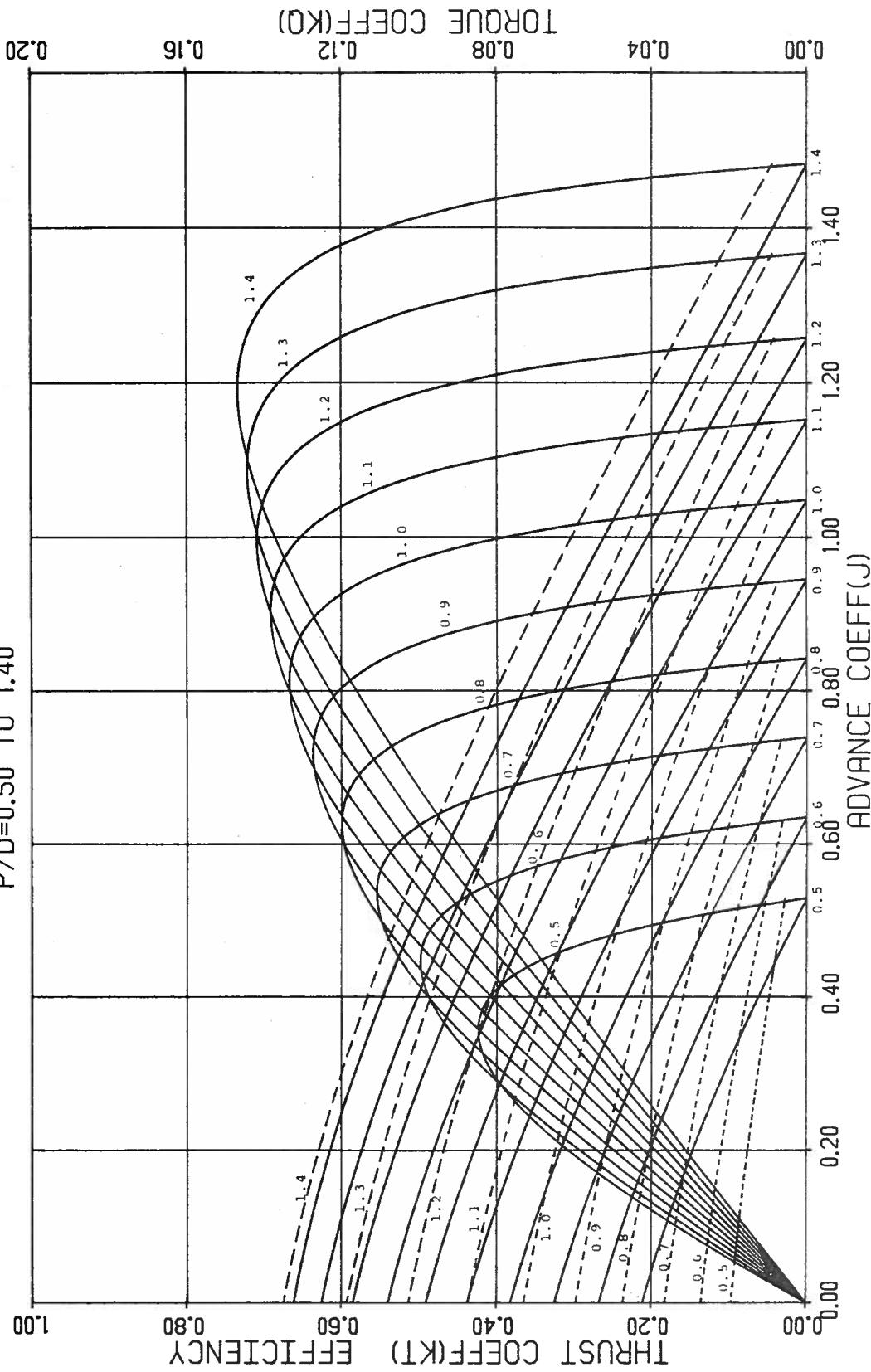


FIGURE 77. WAGENINGEN B-SERIES PROPELLERS  
 FOR 6 BLADES  
 $A_E/A_0 = 0.900$   
 $P/D = 0.50$  TO 1.40

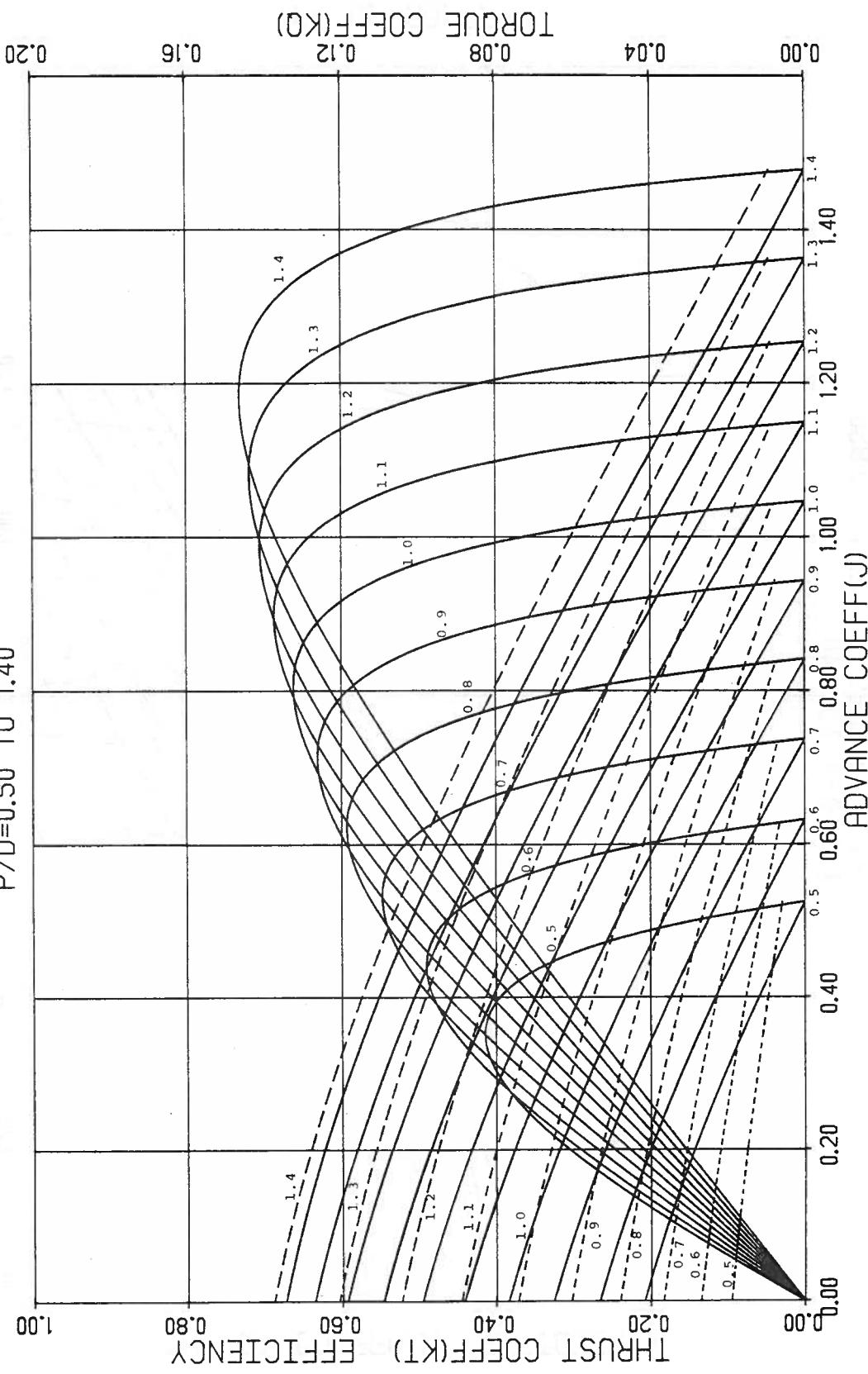


FIGURE 78. WACENTINGEN B-SERIES PROPELLERS  
 FOR 6 BLADES       $A_E/A_0 = 0.950$   
 $P/D = 0.50$  TO 1.40

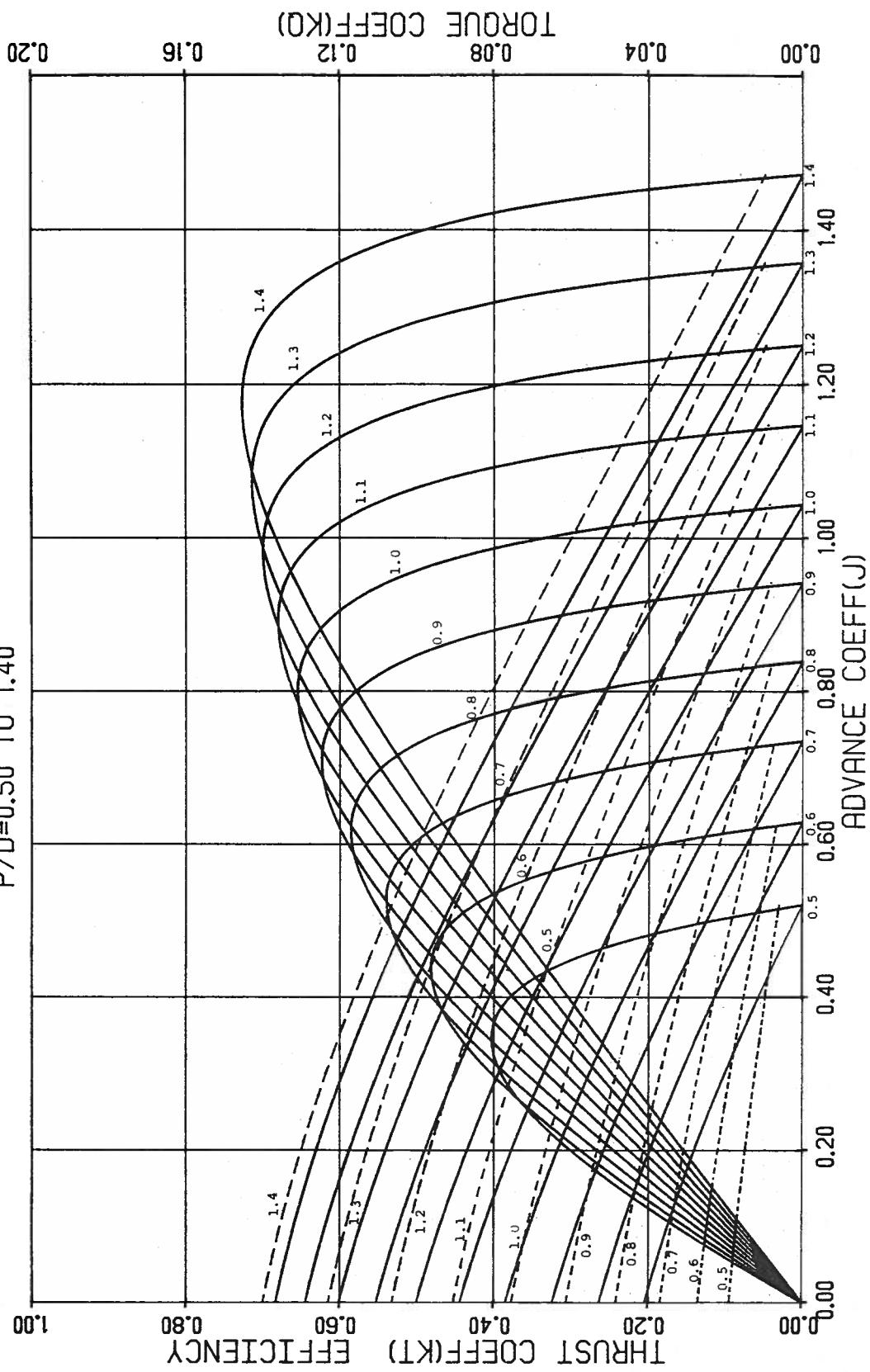


FIGURE 79. WAGENINGEN B-SERIES PROPELLERS  
 FOR 6 BLADES  
 $A_e/A_0 = 1.000$   
 $P/D = 0.50$  TO 1.40

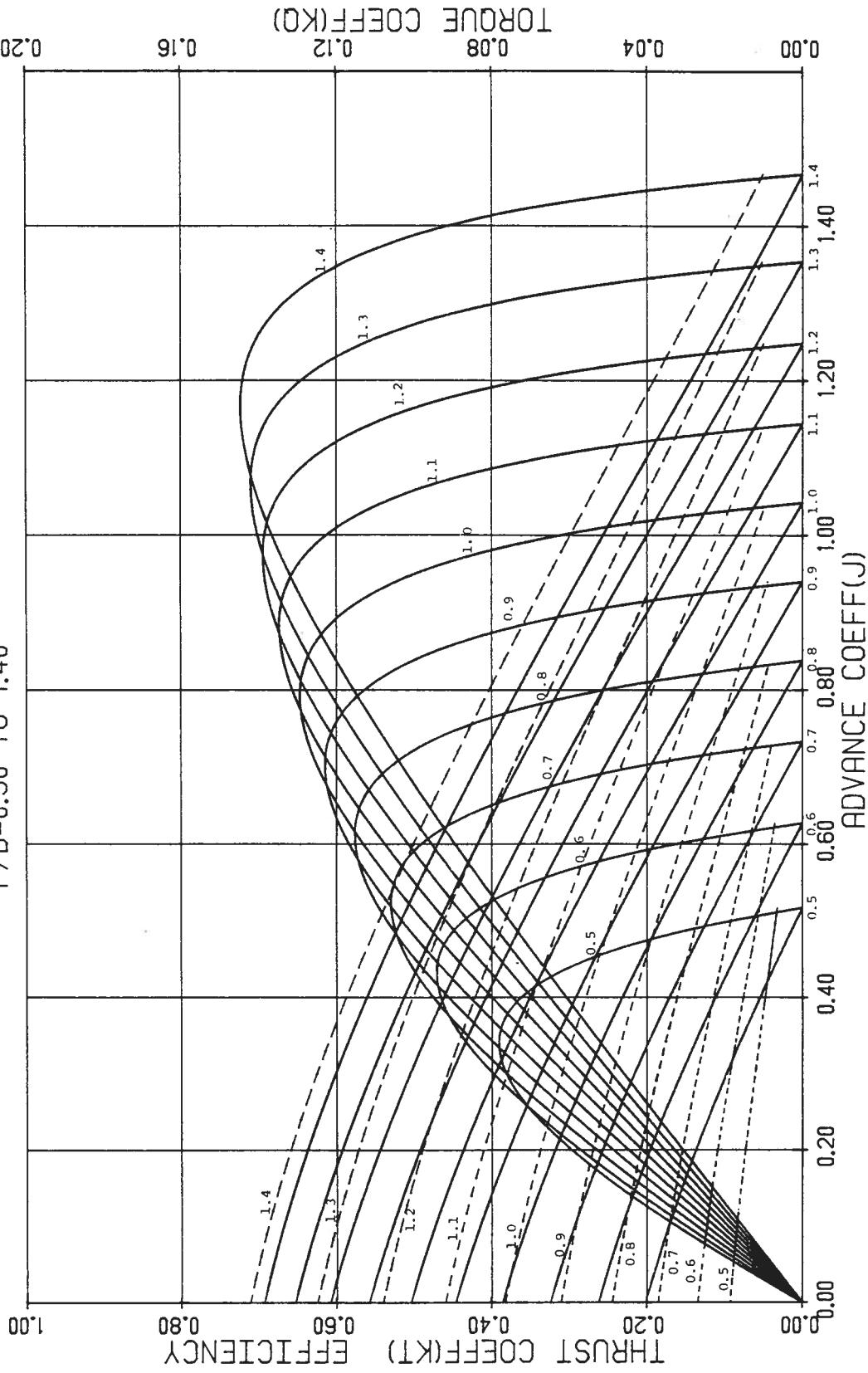


FIGURE 80. WAGENINGEN B-SERIES PROPELLERS  
 FOR 6 BLADES  $A_e/A_0 = 1.050$   
 $P/D = 0.50$  TO 1.40

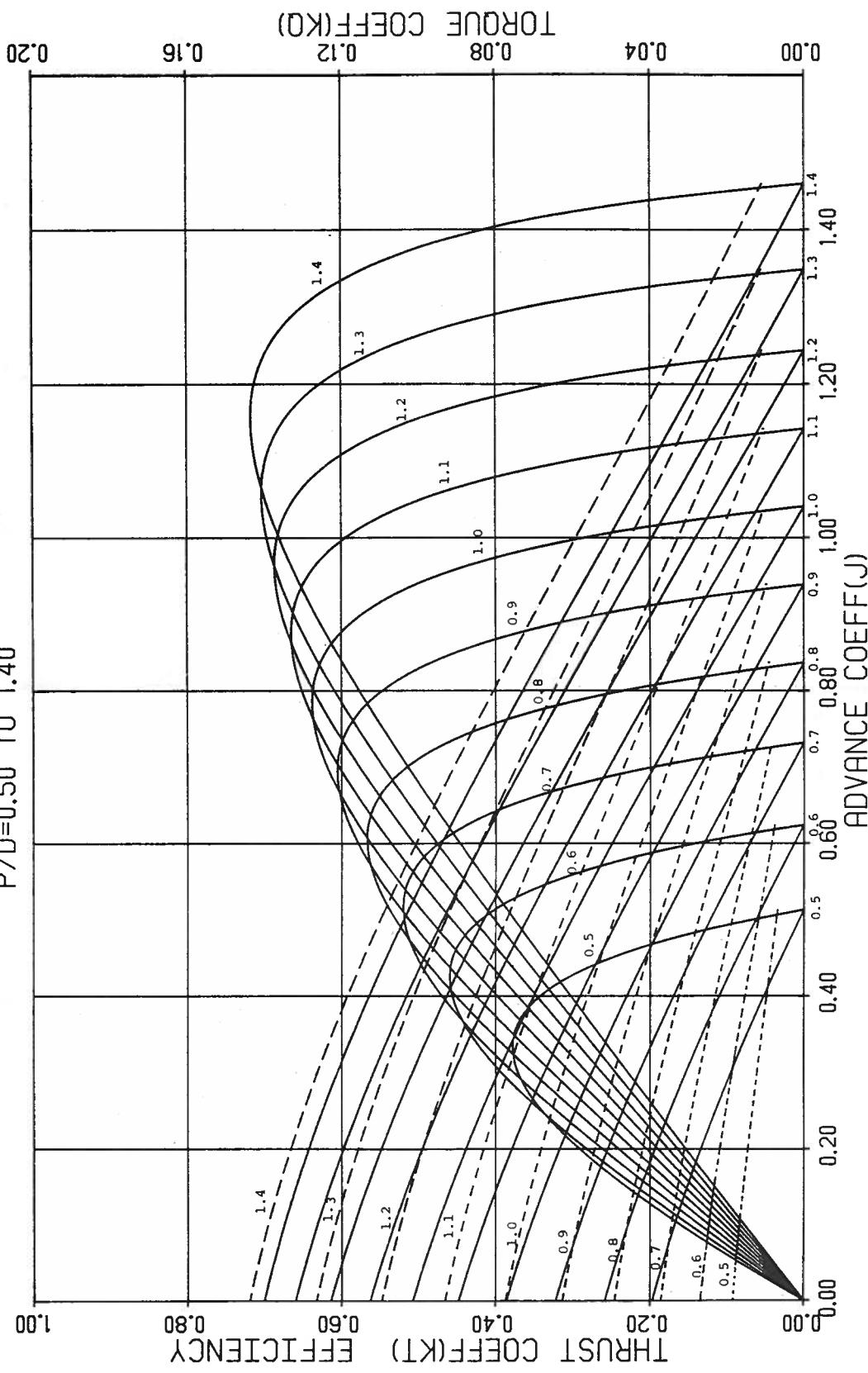


FIGURE 81. WAGENINGEN B-SERIES PROPELLERS  
 FOR 7 BLADES  
 $A_E/A_0 = 0.300$   
 $P/D = 0.50$  TO 1.40

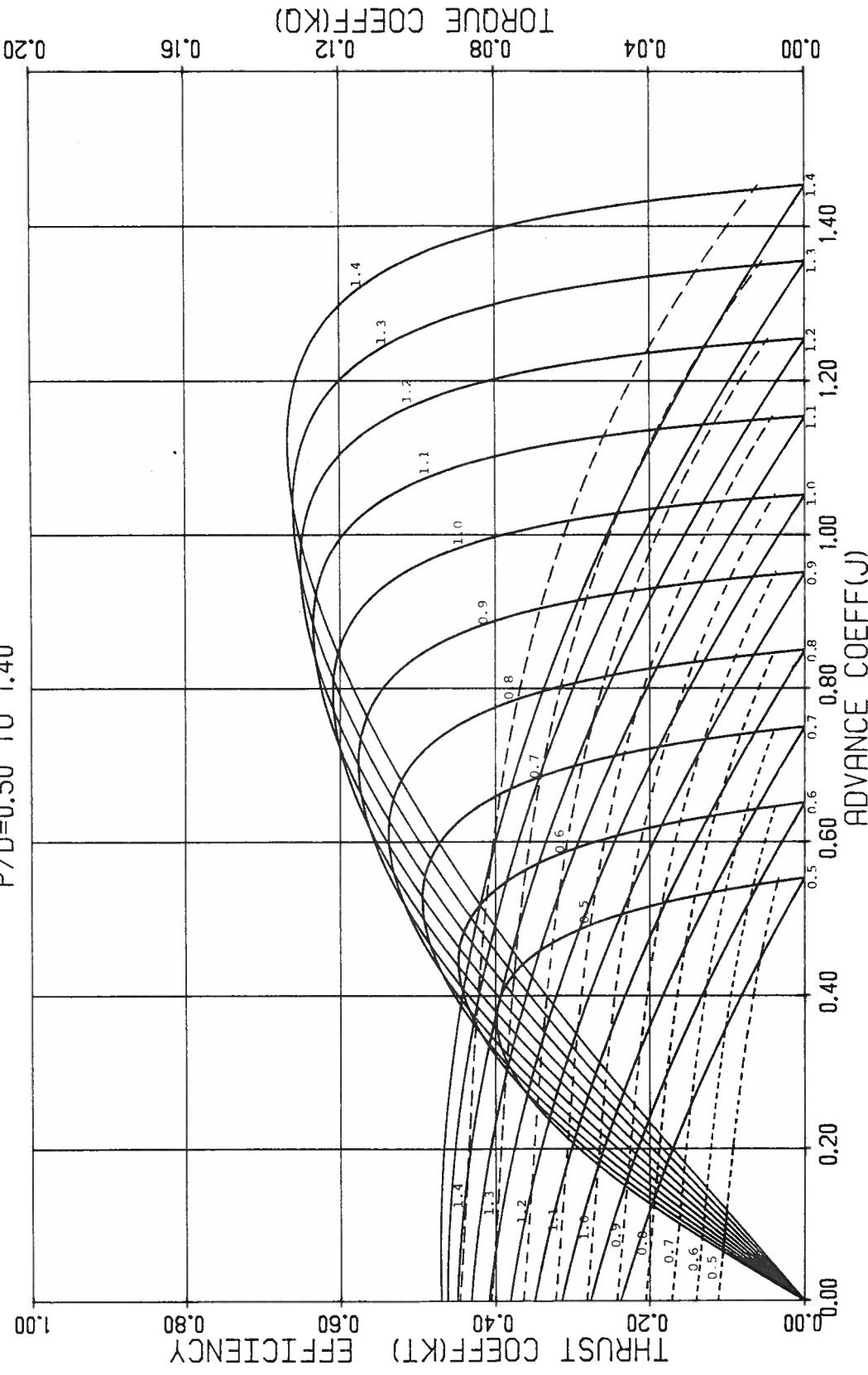


FIGURE 82. WAGENINGEN B-SERIES PROPELLERS  
 FOR 7 BLADES  $A_e/A_0 = 0.350$   
 $P/D = 0.50$  TO 1.40

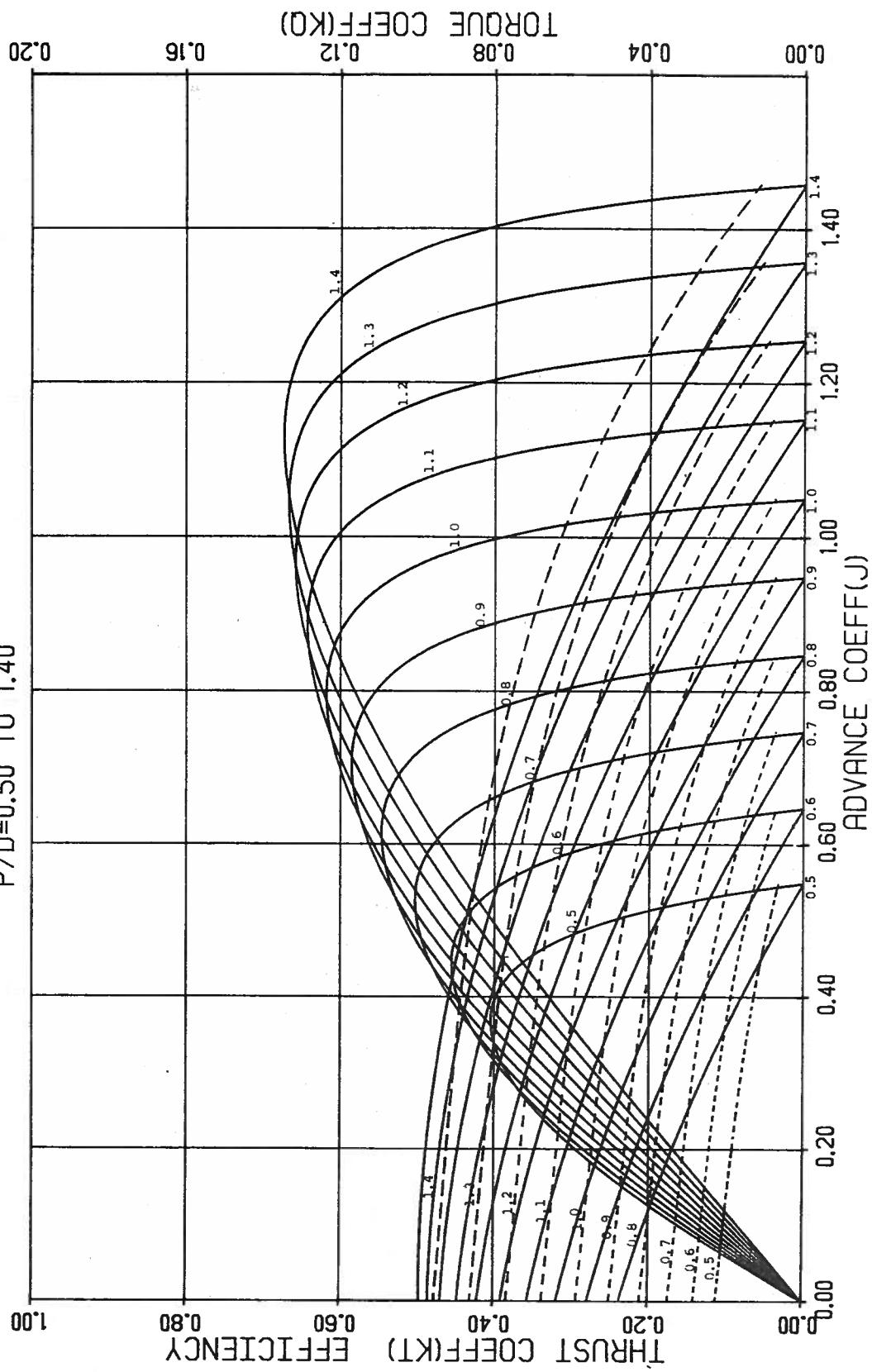


FIGURE 83. WAGENINGEN B-SERIES PROPELLERS  
FOR 7 BLADES  
 $A_E/A_0 = 0.400$   
 $P/D = 0.50$  TO  $1.40$

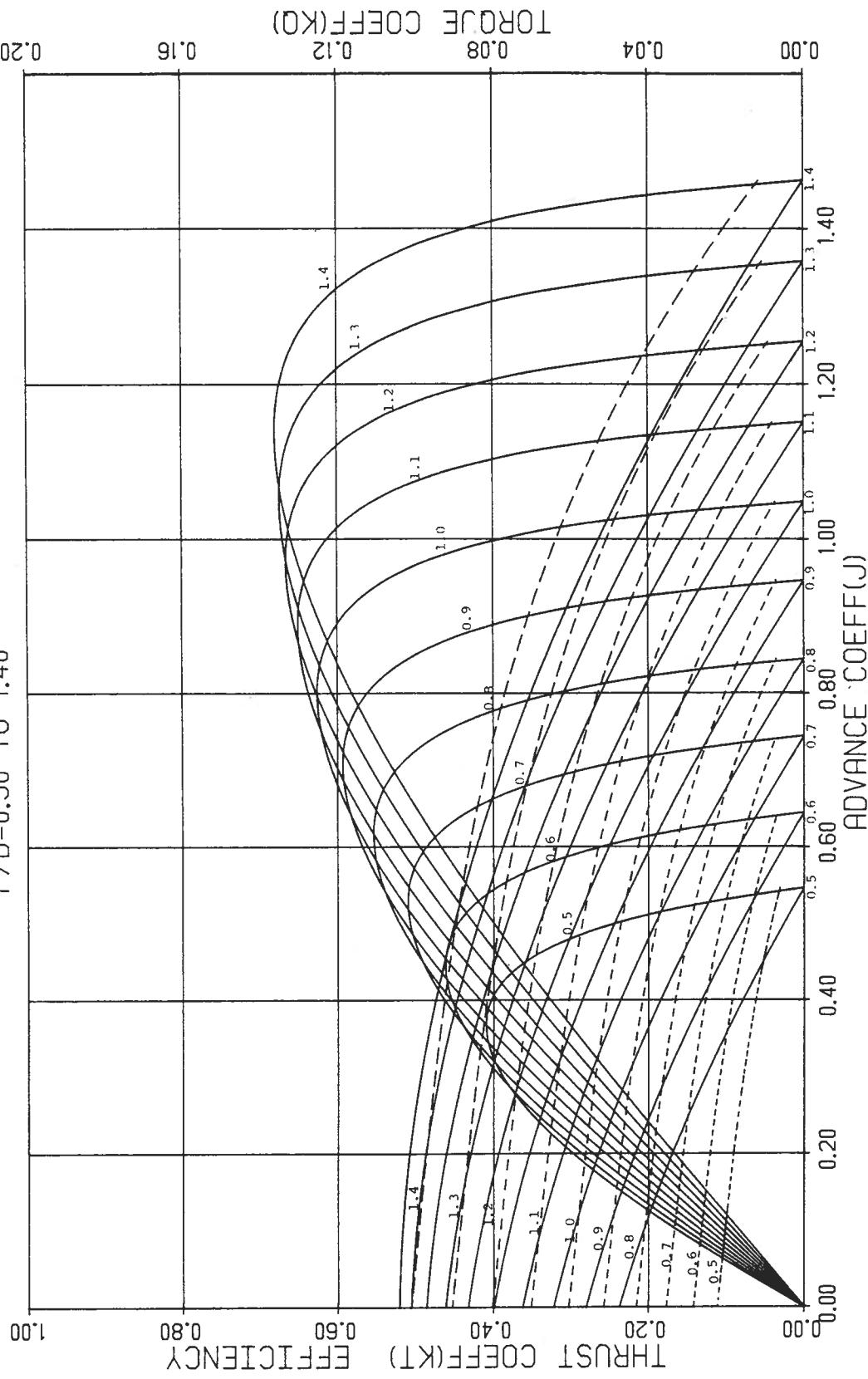


FIGURE 84. WAGENINGEN B-SERIES PROPELLERS  
 FOR 7 BLADES  
 $A_e/A_0 = 0.450$   
 $P/D = 0.50$  TO 1.40

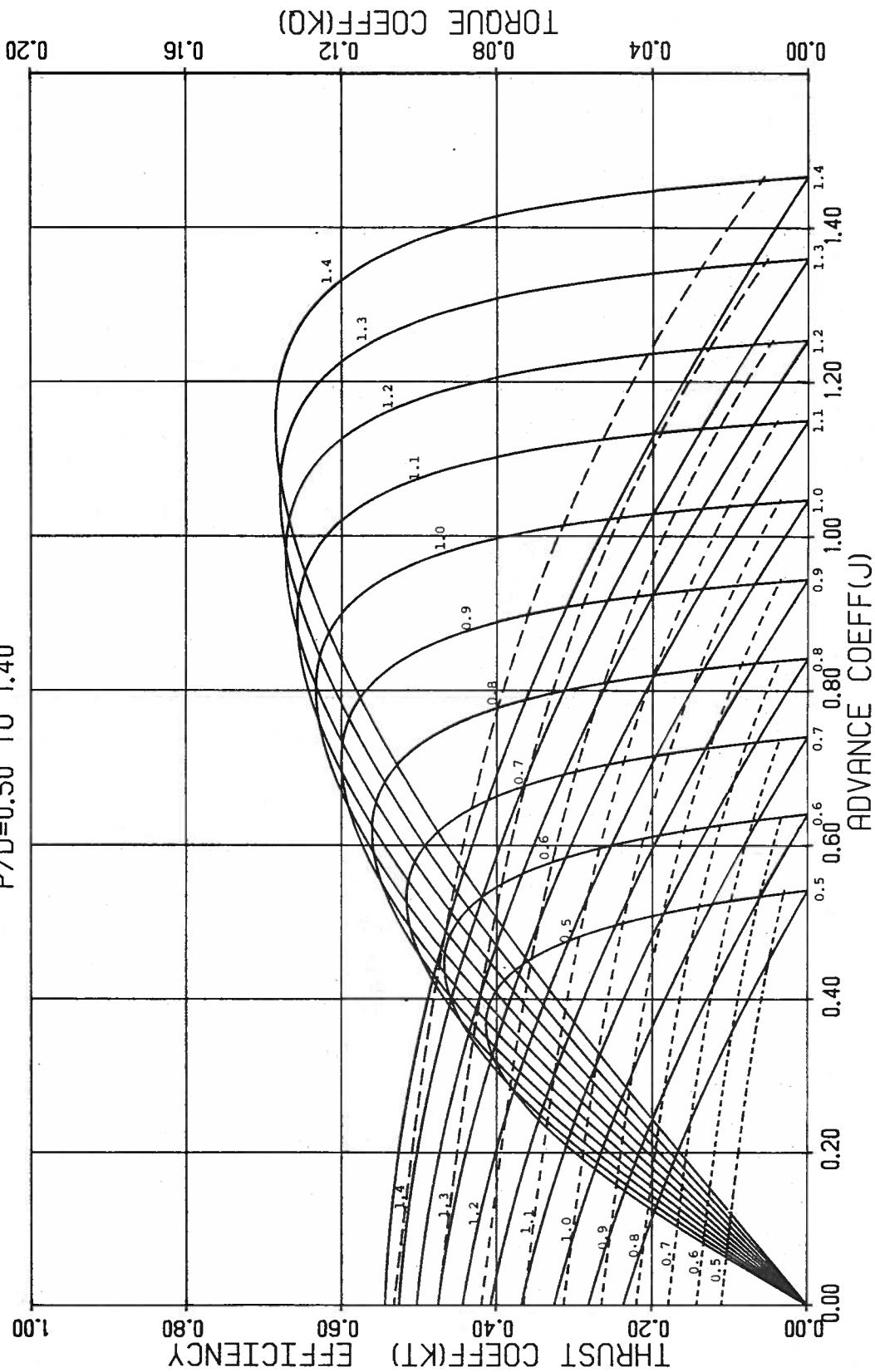


FIGURE 85. WAGENINGEN B-SERIES PROPELLERS  
 FOR 7 BLADES  $A_e/A_0 = 0.500$   
 $P/D = 0.50$  TO 1.40

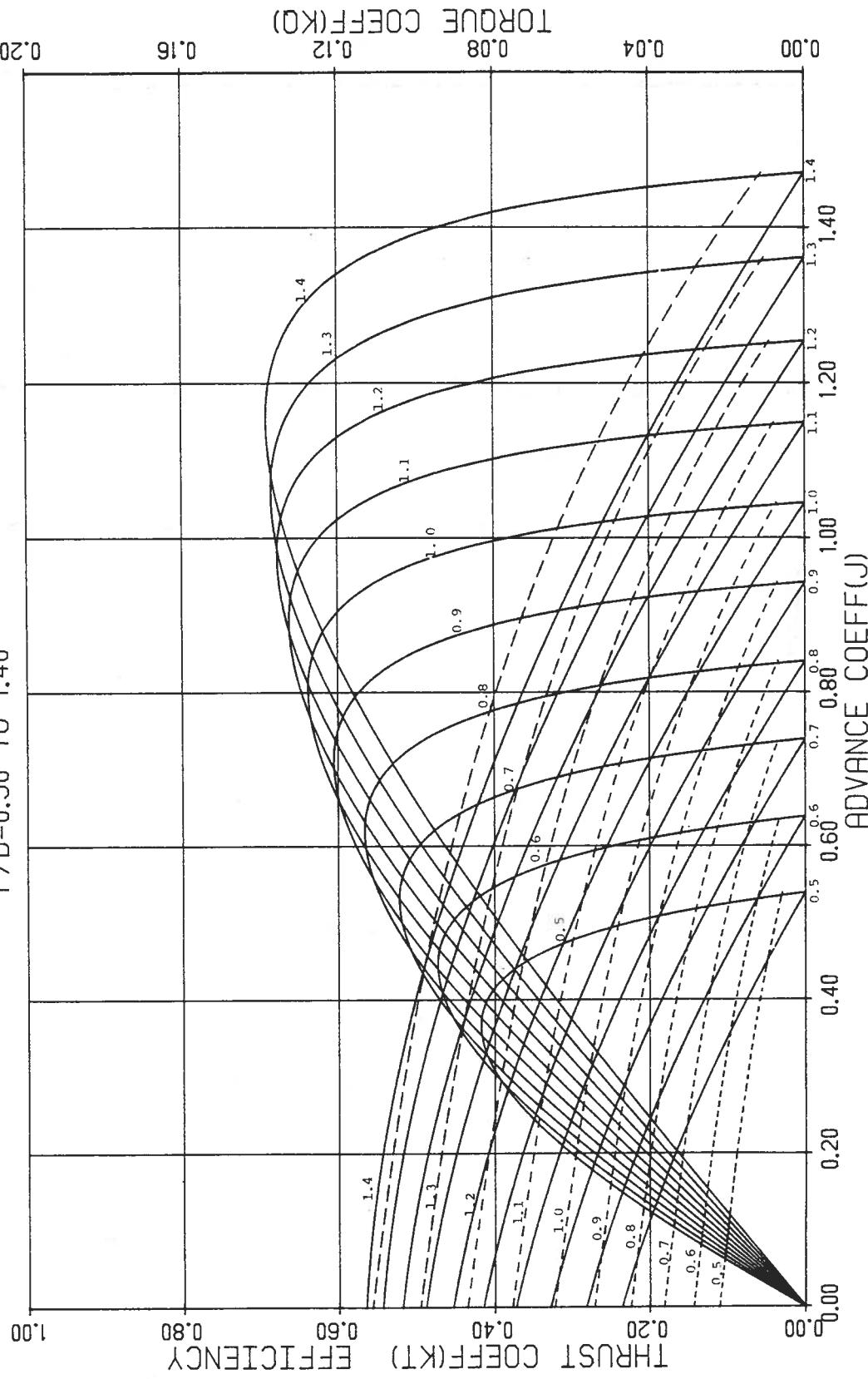


FIGURE 86. WAGENINGEN B-SERIES PROPELLERS  
 FOR 7 BLADES  $A_E/A_0 = 0.550$   
 $P/D = 0.50$  TO 1.40

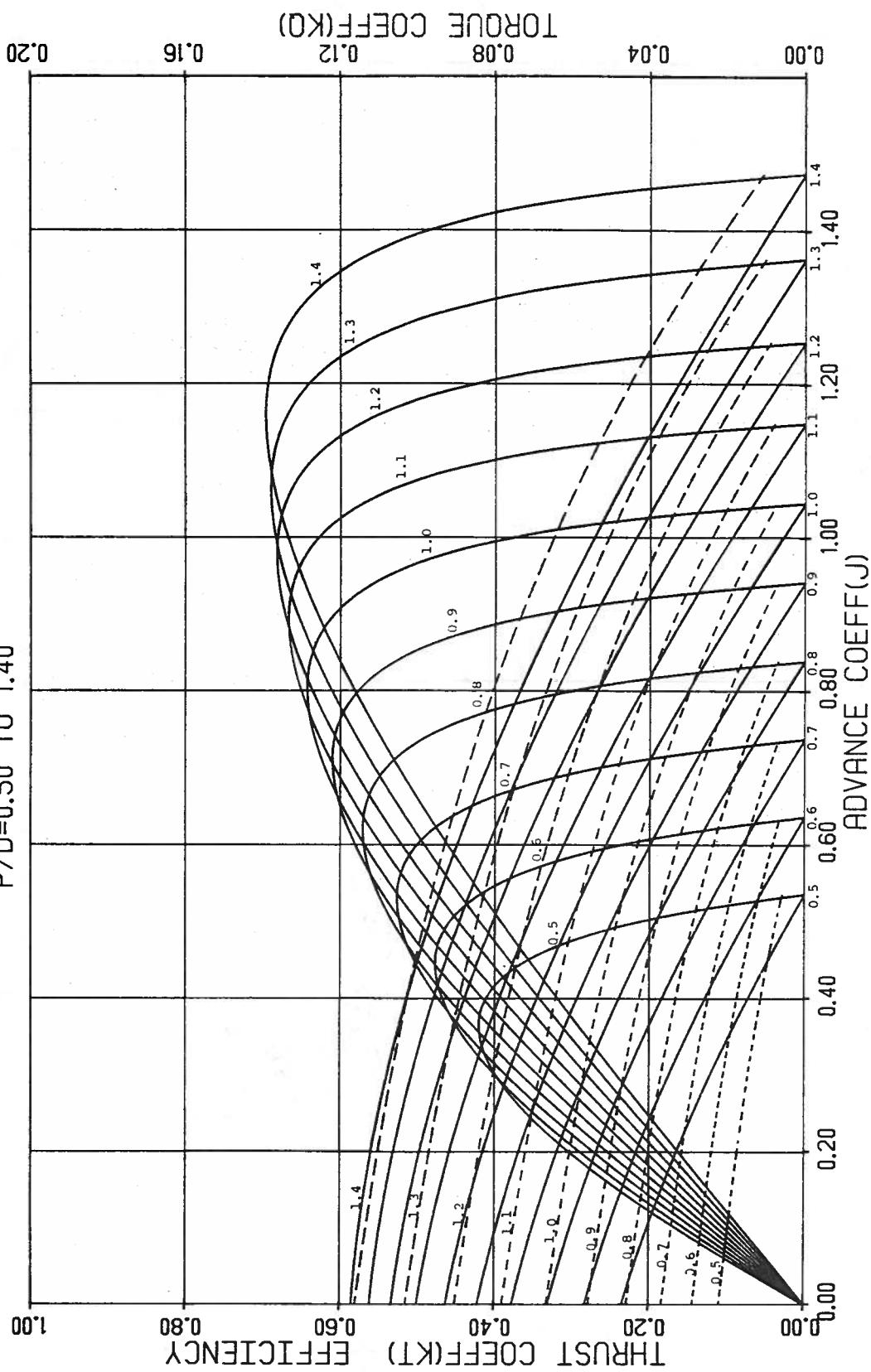


FIGURE 87. WAGENINGEN B-SERIES PROPELLERS  
 FOR 7 BLADES  
 $A_e/A_0 = 0.600$   
 $P/D = 0.50$  TO 1.40

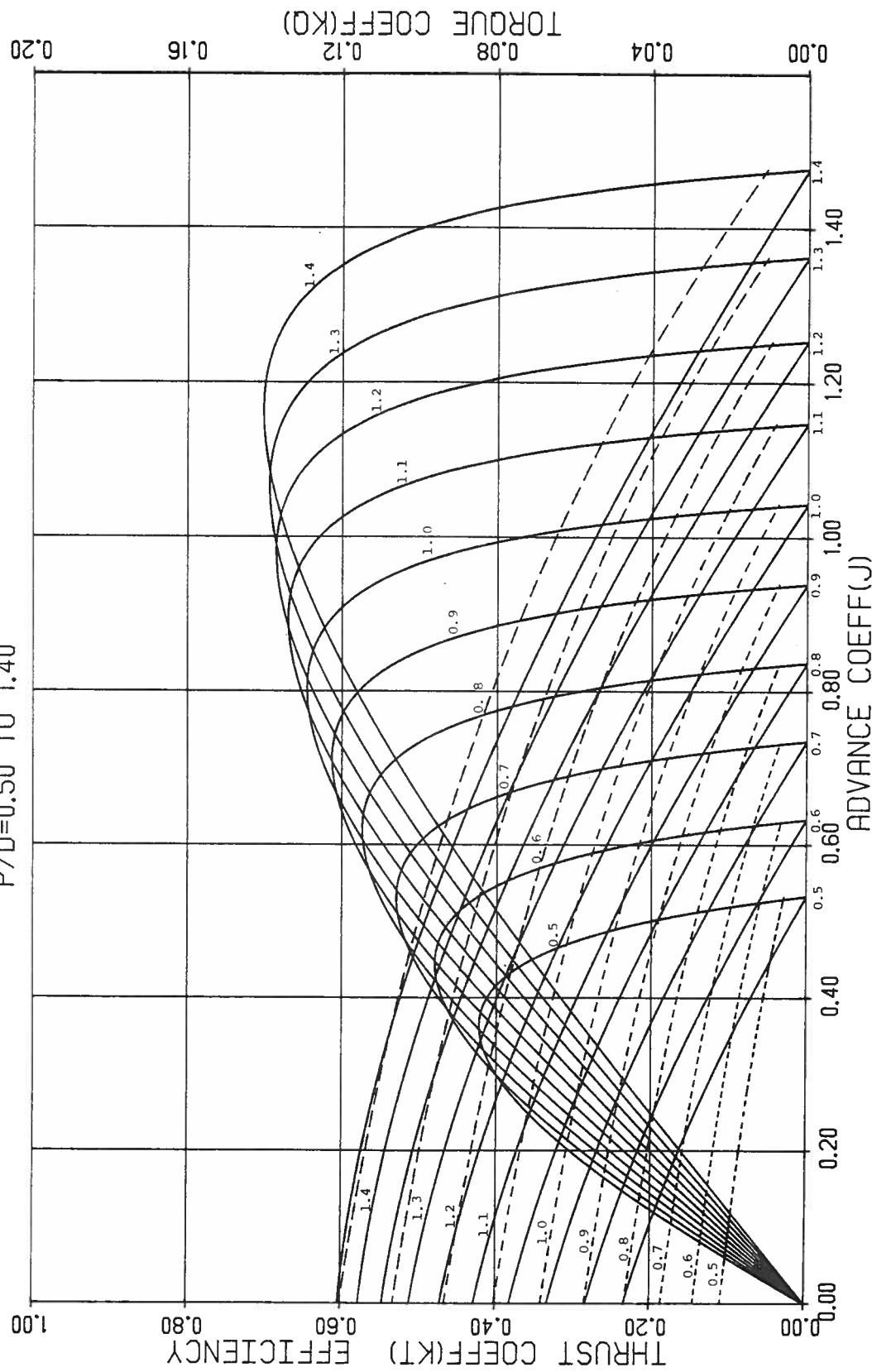


FIGURE 88. WAGENINGEN B-SERIES PROPELLERS  
 FOR 7 BLADES       $A_e/A_0 = 0.650$   
 $P/D = 0.50$  TO  $1.40$

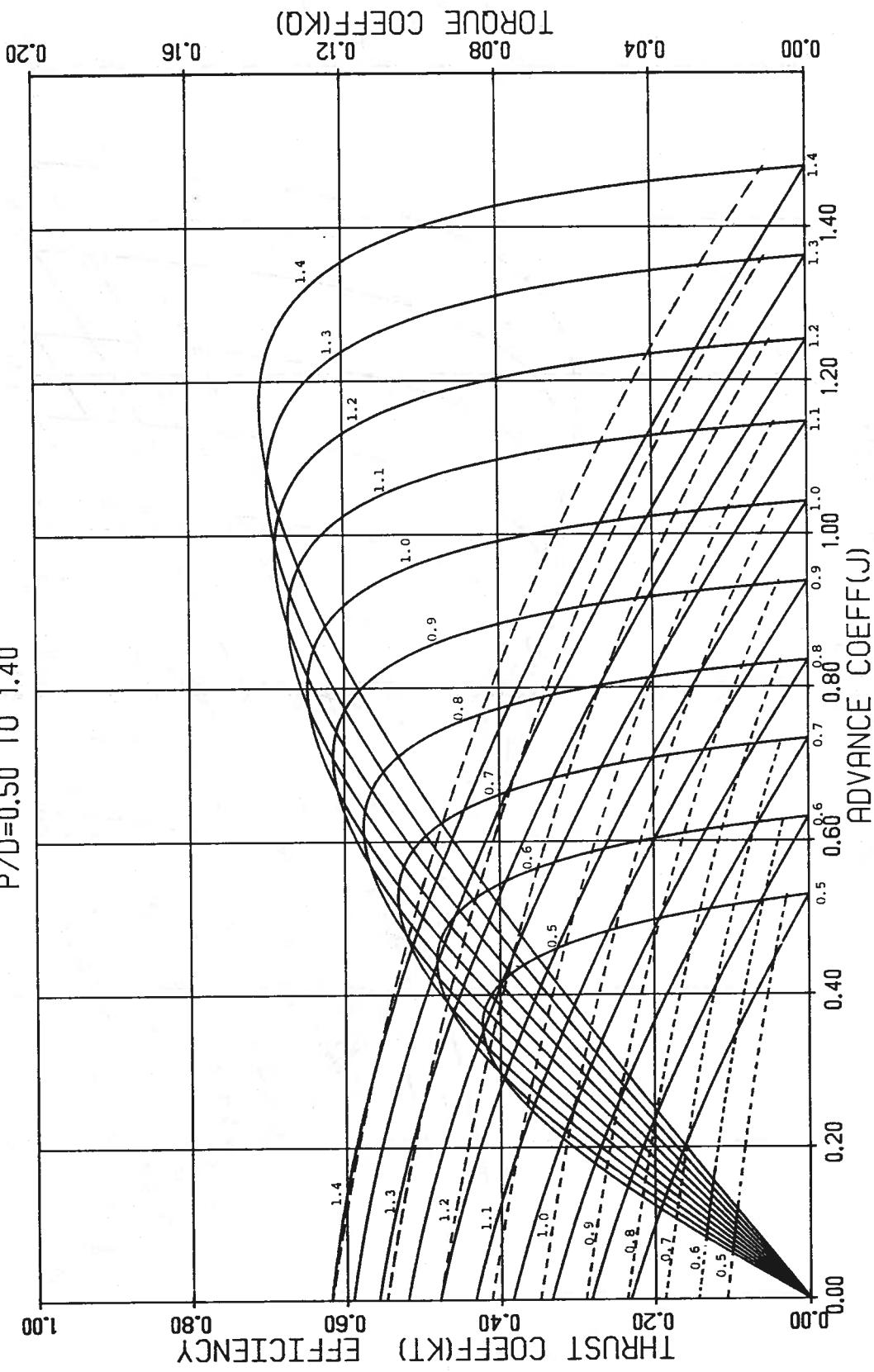


FIGURE 89. WAGENINGEN B-SERIES PROPELLERS  
 FOR 7 BLADES  
 $A_E/A_0 = 0.700$   
 $R/D = 0.50$  TO 1.40

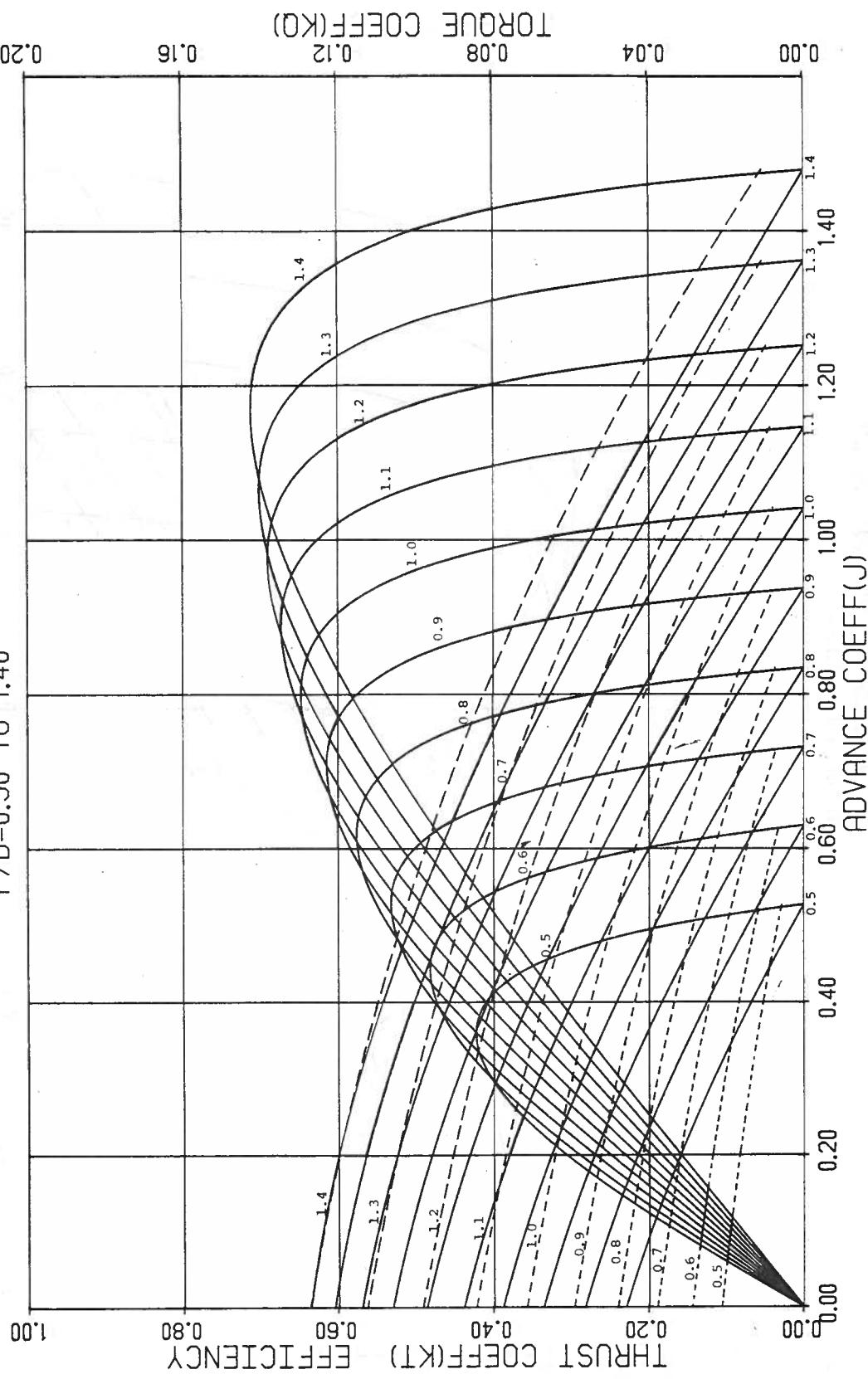


FIGURE 90. WAGENINGEN B-SERIES PROPELLERS  
 FOR 7 BLADES       $A_e/A_0 = 0.750$   
 $P/D = 0.50$  TO 1.40

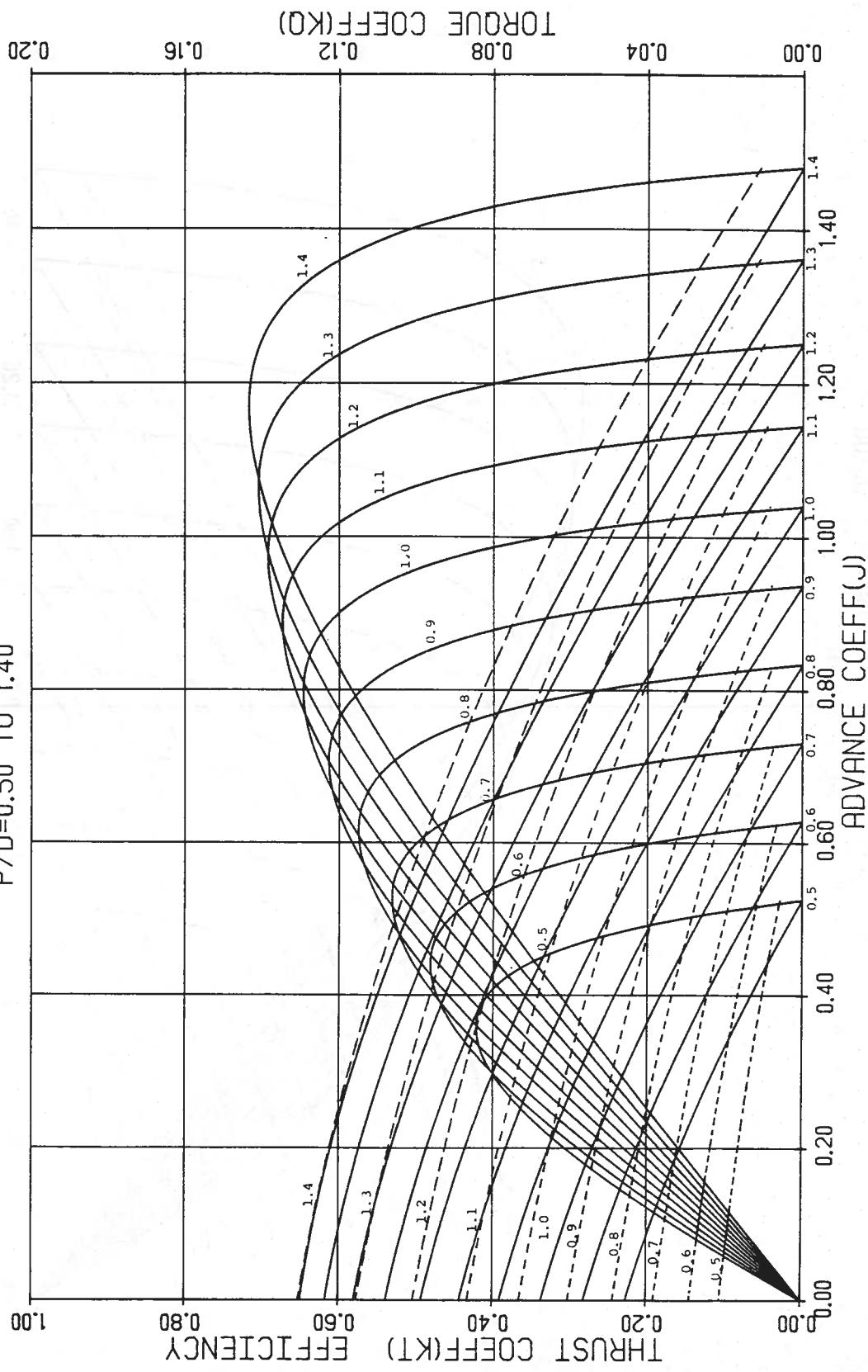


FIGURE 91. WAGENINGEN B-SERIES PROPELLERS  
 FOR 7 BLADES  
 $A_e/A_0 = 0.800$   
 $P/D = 0.50$  TO 1.40

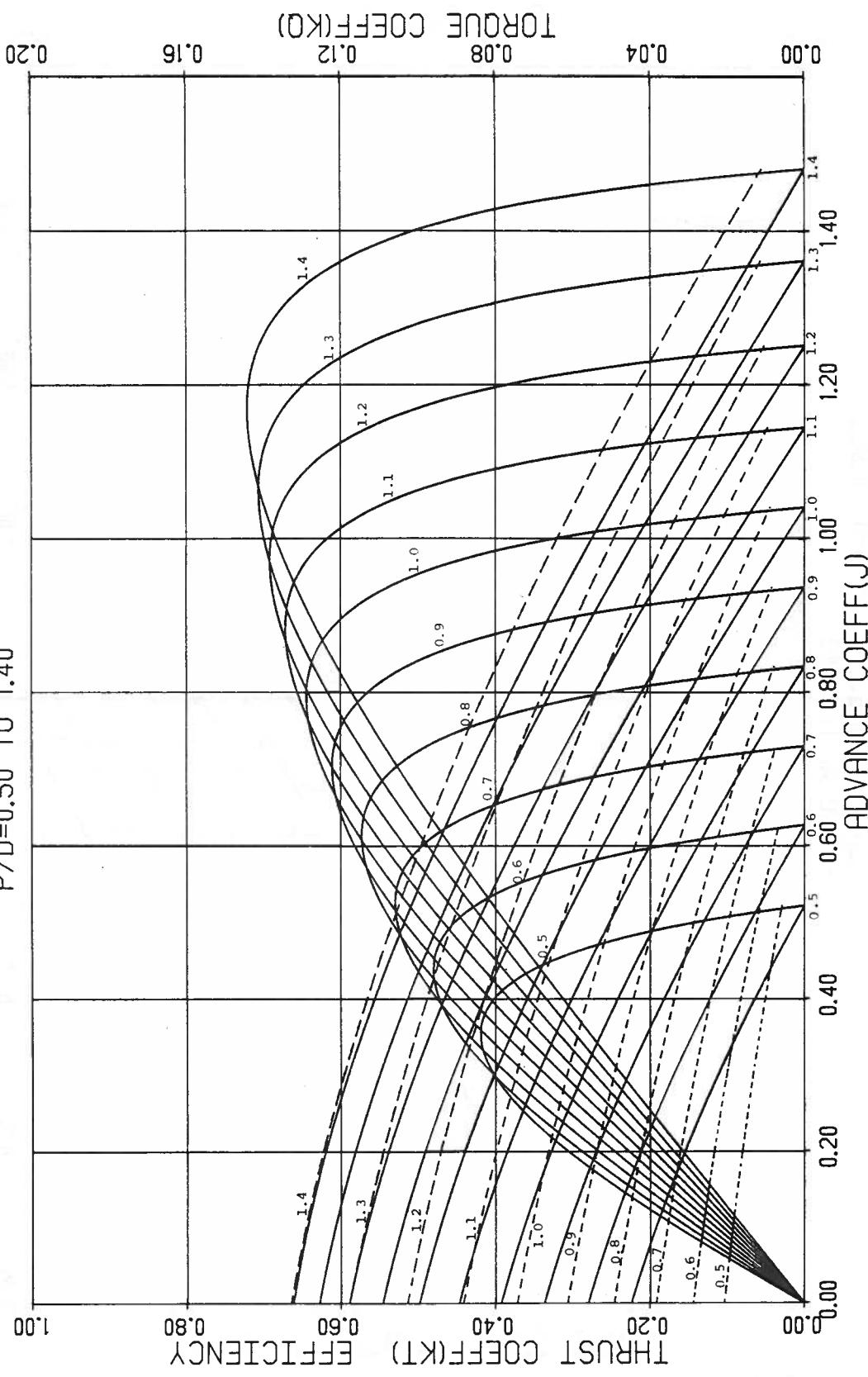


FIGURE 92. WAGENINGEN B-SERIES PROPELLERS  
 FOR 7 BLADES  
 $A_e/A_0 = 0.850$   
 $P/D = 0.50$  TO 1.40

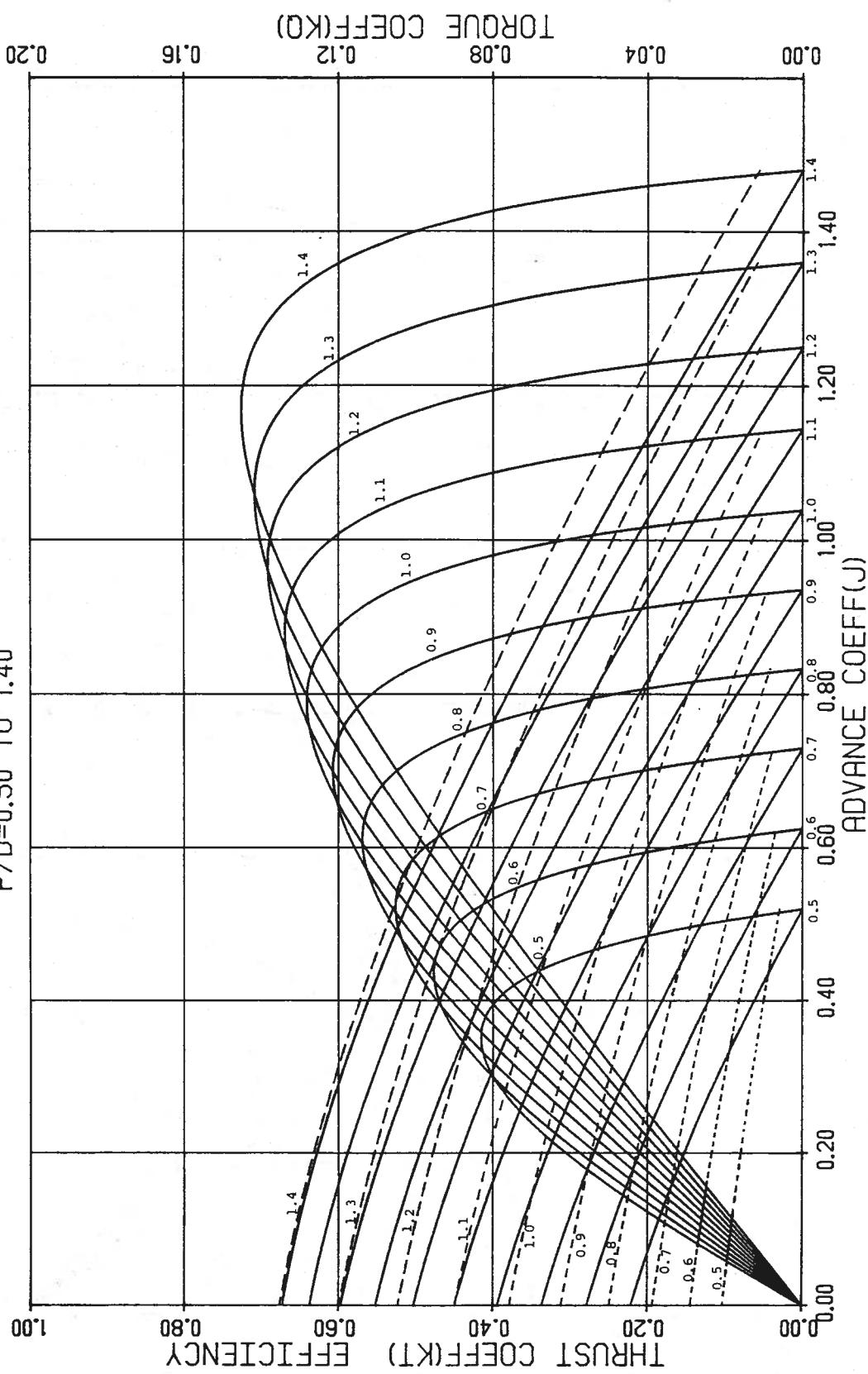


FIGURE 93. WAGENINGEN B-SERIES PROPELLERS  
FOR 7 BLADES  
 $A_e/A_0 = 0.900$   
 $P/D = 0.50$  TO 1.40

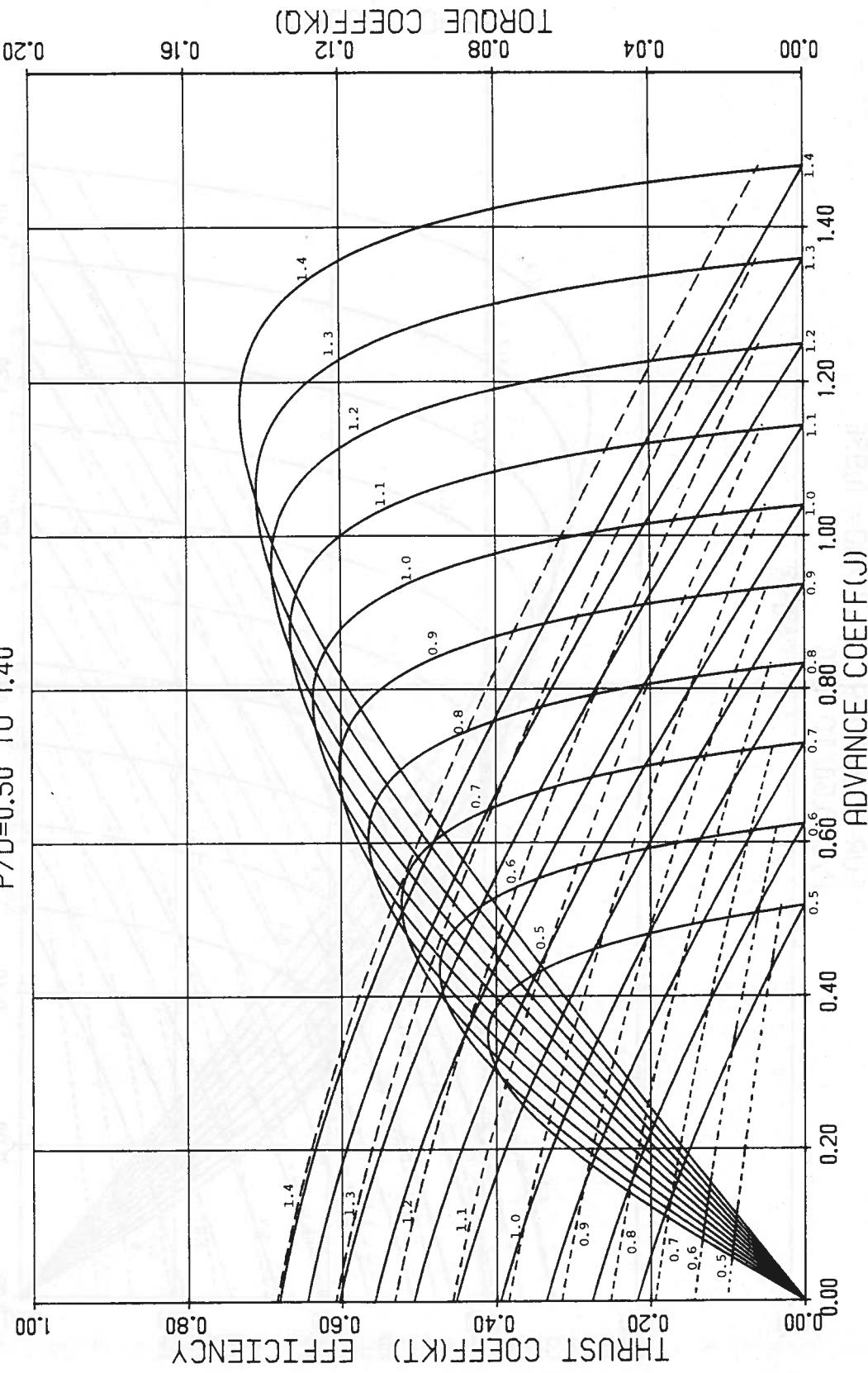


FIGURE 94. WAGENINGEN B-SERIES PROPELLERS  
 FOR 7 BLADES     $A_e/A_0 = 0.950$   
 $P/D = 0.50$  TO  $1.40$

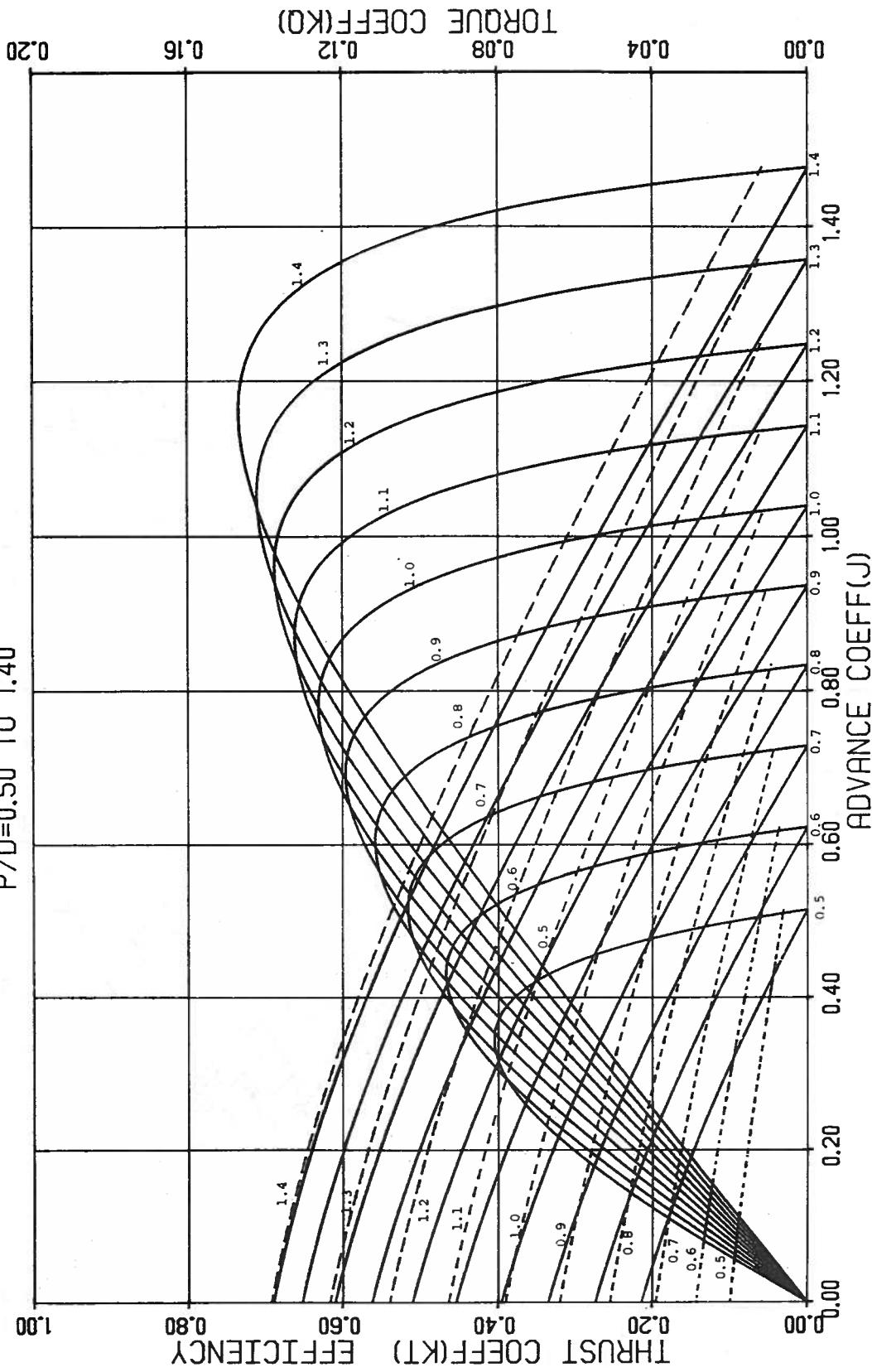


FIGURE 95. WAGENINGEN B-SERIES PROPELLERS  
 FOR 7 BLADES  
 $A_e/A_0 = 1.000$   
 $P/D = 0.50$  TO  $1.40$

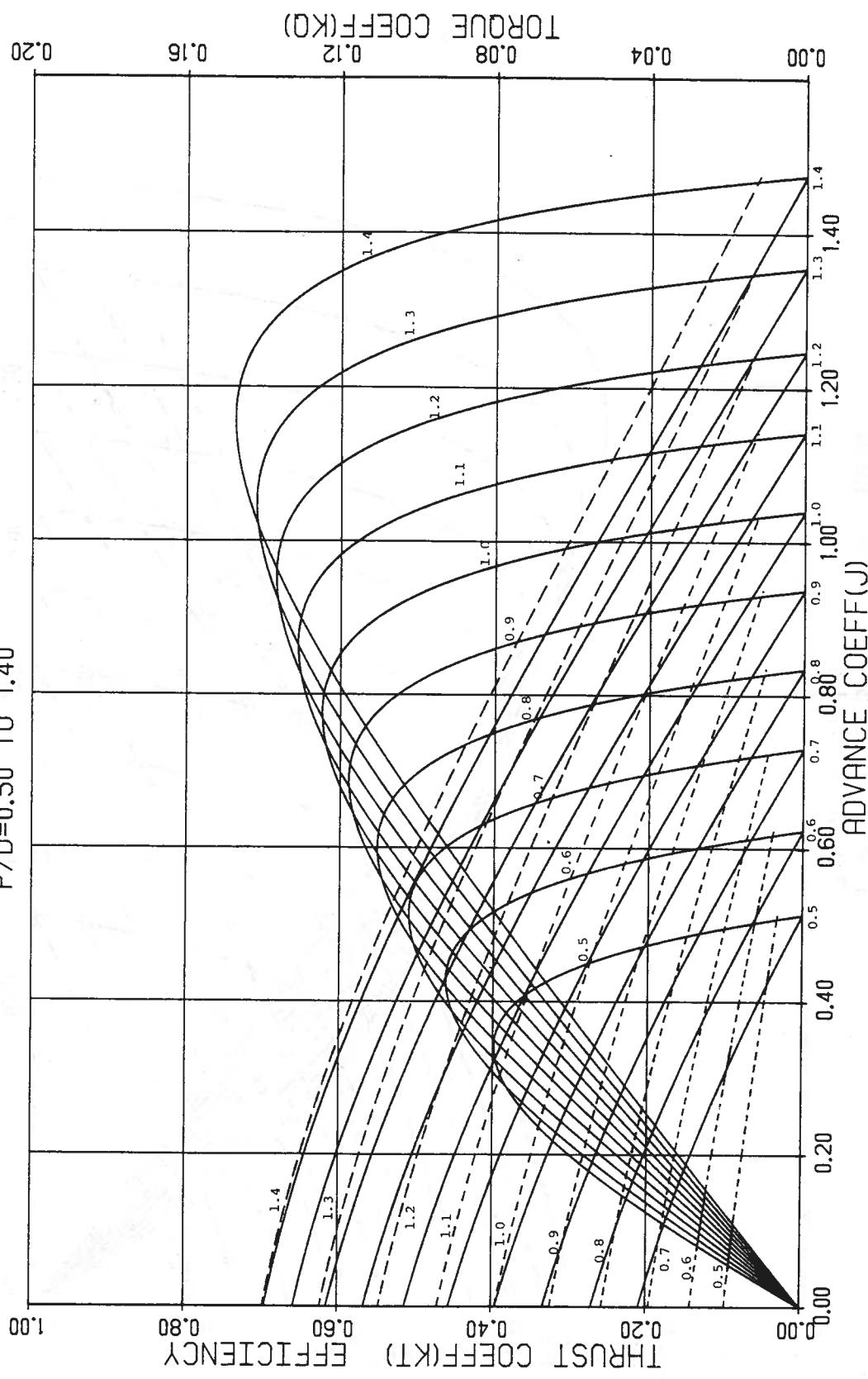
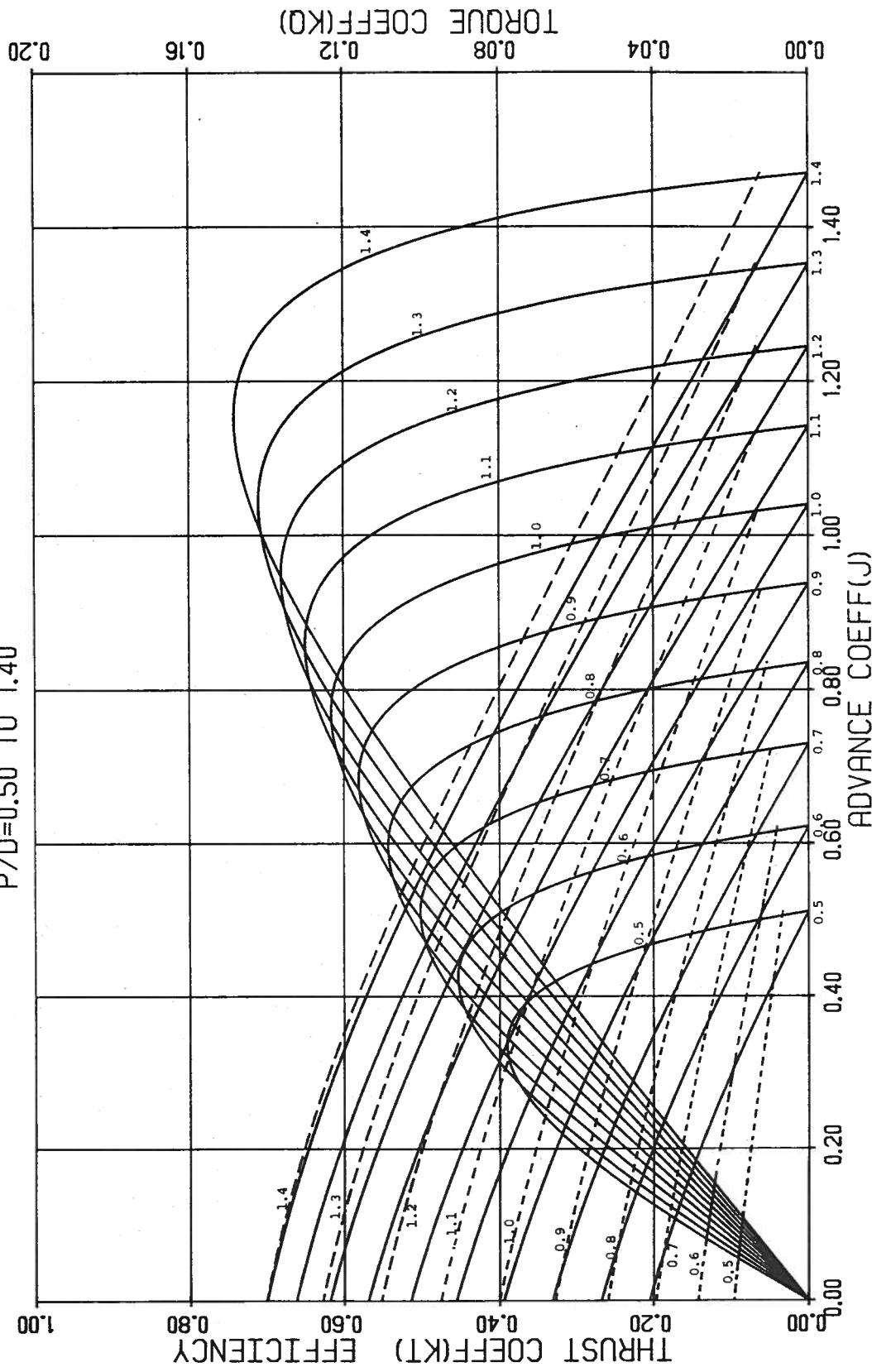


FIGURE 96. WAGENINGEN B-SERIES PROPELLERS  
 FOR 7 BLADES       $A_E/A_0 = 1.050$   
 $P/D = 0.50$  TO  $1.40$



The University of Michigan, as an equal opportunity/affirmative action employer, complies with all applicable federal and state laws regarding nondiscrimination and affirmative action, including Title IX of the Education Amendments of 1972 and Section 504 of the Rehabilitation Act of 1973. The University of Michigan is committed to a policy of nondiscrimination and equal opportunity for all persons regardless of race, sex, color, religion, creed, national origin or ancestry, age, marital status, sexual orientation, gender identity, gender expression, disability, or Vietnam-era veteran status in employment, educational programs and activities, and admissions. Inquiries or complaints may be addressed to the Senior Director for Institutional Equity and Title IX/Section 504 Coordinator, Office of Institutional Equity, 2072 Administrative Services Building, Ann Arbor, Michigan 48109-1432, 734-763-0235, TTY 734-647-1388. For other University of Michigan information call 734-764-1817.