NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

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THRUST AND BLADE SPINDLE TORQUE MEASUREMENTS OF FIVE CONTROLLABLE-PITCH PROPELLER DESIGNS FOR MSO 421

by

E. Orm Hansen

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S-F013 07 10
Task 3741

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NOTATION

D	Propeller diameter
D.A.	Propeller-disk area
E.A.	Expanded-blade area
E.A.R.	Expanded-blade area ratio
J	Advance coefficient
K_{BC}	Centrifugal component of blade spindle-torque coefficient, $\frac{Q_{BC}}{\rho_B n^2 D^5}$
K_{BH}	Hydrodynamic component of blade spindle-torque coefficient, $\frac{Q_{BH}}{\rho n^2 D^5}$
K_t	Propeller-thrust coefficient, $\frac{T}{\rho n^2 D^4}$
n	Revolutions per unit time
P	Propeller pitch at 0.7R and at the spindle axis
Q_{BC}	Centrifugal component of spindle torque for one blade
Q_{BH}	Hydrodynamic component of spindle torque for one blade
R	Propeller radius
T	Propeller thrust
V	Speed of advance
γ	Angular location of propeller blade with respect to design location
ρ	Mass density of water
ρ_B	Mass density of propeller-blade material

ABSTRACT

An experimental study is presented of the blade spindle torque of five controllable-pitch propeller models, representing five different designs for MSO-421. The study covers a range of both positive and negative advance coefficients at both ahead and astern pitch settings. It was found that the blade with spindle axis located 40 percent of blade width from the leading edge and with uncambered National Advisory Council for Aeronautics Series 66 (NACA 66) airfoil blade sections modified by the Bureau of Ships required the least extreme value of spindle torque.

ADMINISTRATIVE INFORMATION

The David Taylor Model Basin was requested by Naval Ship Engineering Center to carry out the work described herein. The work was performed under Subproject S-F013 07 10, Task 3741, TMB Problem 526-038.

INTRODUCTION

As a continuation of the work presented in Reference 1* concerning performance evaluation of propeller designs for MSO-421, Naval Ship Engineering Center (NAVSEC) requested the Model Basin (TMB) to extend the tests described in Reference 1 to include tests of the propellers at positive and negative pitch ratios over a range of positive and negative advance coefficients. The Model Basin was also requested to manufacture and test three new propeller-blade modifications of the basic design. As in Reference 1, the chief objective of the tests was to determine the effect of spindle-axis location and blade-section shape on the blade-turning effort.

The tests were carried out in the 24-inch water tunnel, and, in addition to the water tunnel tests, thrust characteristics of the propellers were obtained in open water. It was found that the design with uncambered NACABS blade sections and spindle-axis located 40 percent of blade width from leading edge required the least extreme spindle-torque values of the blades tested.

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*References are listed on page 57.

DESCRIPTION OF TESTS

DEFINITION OF TERMS

The following definitions and sign conventions will be used:

Positive and negative propeller pitch is ahead and astern pitch, respectively.

Positive and negative speed of advance V is ahead and astern speed, respectively.

Propeller revolutions n are always positive and therefore advance coefficients J = V/nD have the same signs as the water speeds on which they are based.

Steady and "transient" propulsive conditions are defined as conditions where the propeller pitch and advance coefficient have the same or opposite signs, respectively.

Propeller thrust is defined as positive when tending to move the ship ahead.

Blade spindle torque, defined as the spindle torque exerted on the blade by the fluid, is positive for torque tending to increase the ahead pitch, and is the torque for one blade only.

PROPELLER GEOMETRY AND STRAIN GAGING

The drawings of the five propellers are shown in Figures 1 through 5. The principal characteristics of the propellers are listed in Table 1. The NACABS blade section is a Bureau of Ships modification of the NACA-66-series airfoil, and the Zero-X-blade section was derived from elliptical arcs.

Each of the propellers has four blades, and each blade can be manually rotated to obtain the desired pitch setting, after which the blades are clamped in the hub. In the tests described in Reference 1, the pitch could be set and adjusted with an external pitch changing mechanism while the propeller was running. However, this pitch changing system had a low degree of precision, and the propeller blades could rotate slightly in the hub during the tests.

The pitch reference used is the nose-to-tail line at the 0.7-radius section when the propeller is set at the designed pitch. Any other nominal

TABLE 1

Main Design Characteristics of Propellers 3728, 3371, and 4120 through 4122

Propeller	$\frac{E.A.}{D.A.}$ = E.A.R.	Blade Section	Spindle Axis Location in Percent of Blade Width from Leading Edge
3728	0.540	NACABS	40
3771	0.540	Zero-X	40
4120	0.540	NACABS	50
4121	0.540	NACABS (no camber)	40
4122	1.013	NACABS	40

value of pitch was obtained by rotating the blade about the spindle through the angle γ from the designed pitch setting so that

$$\gamma = \arctan \frac{P_{set}}{0.7\pi D} - \arctan \frac{P_{des}}{0.7\pi D}$$

where P_{set} is the pitch to be set, and P_{des} is the designed pitch; in this case, 14.027 inches.

For the water tunnel tests, one of the blades of each propeller had a strain-gaged torque element between it and its attachment in the hub in order to measure the spindle torque required to restrain the blade from moving from its set pitch angle. Wires from the gages passed through a hollow shaft to sliprings outside of the tunnel. During calibration, it was found that the strain-gaged torque element not only registered spindle-torque load, but also gave an output when the gage was loaded with forces normal to the spindle-torque axis. This interference effect was further investigated, and it was found that the output from the element varied sinusoidally as a function of the angular position of the force applied normal to the torque axis of the measuring element. By estimating the magnitude of the propeller thrust and torque, it was possible to orient the strain-gaged element with respect to the propeller blade mounted on it in such a way that only an insignificant part of the output of the gage was due to propeller thrust and torque interactions. For each test, the selected orientation of the strain-gaged element for minimum interaction was checked on the basis of the measured propeller thrust and torque. The torque element used in the present tests is the same that was used in the tests described in Reference 1 but for these tests, the torque element was not thoroughly calibrated with respect to nonspindle-torque forces.

WATER TUNNEL TESTS

Tests were carried out in the 24-inch variable-pressure water tunnel. Measurements of propeller thrust, rpm, and tunnel water speed and pressure were made using the usual TMB 24-inch water tunnel instrumentation. The propellers were tested at atmospheric pressure over a range of both positive and negative pitch settings and for both positive and negative advance coefficients J, covering steady and "transient" propulsion conditions. Propellers 3728, 3771, 4120, and 4121 were tested at pitch angles corresponding to nominal pitch ratios of -0.9, -0.6, -0.3, 0.0, 0.3, 0.6, 0.9, and 1.2 at 0.7R. Propellers 3771 and 4120 were also tested at pitch ratios of -1.2. Propeller 4122 was tested only at nominal pitch ratios of 0.3 and 0.9. A Reynolds number greater than 5×10^5 was obtained for the entire range of test conditions.

Thrust and blade-spindle torque were in most cases repeatable both for the steady ahead and the steady astern propulsive conditions. For the "transient" propulsive conditions, much of the data obtained was not repeatable due to lack of control of and/or ability to measure water speed. Several ways of obtaining water speed were tried, including an attempt to calculate the water speed from the tunnel-impeller characteristics. None of the methods of obtaining water speed in the tunnel were satisfactory when the propellers were operating in the "transient" conditions.

At the "transient" conditions a cavitating ring vortex was almost always visible in the vicinity of the propeller when tested at numerical small advance coefficients. The diameter of the vortex ring was approximately 18 inches. The ring thickness for constant J was a function of the water speed and had an approximate diameter of 1/2 inch for a water speed from 1 to 2 fps and 4 inches for a water speed of 15 fps. The longitudinal location of the vortex ring depended on J and was, for low values of J, in the plane of the propeller. For numerically higher values of J, the ring was located downstream from the propeller at a distance that depended on the propeller pitch ratio. As the advance coefficient was increased, it was possible to push the vortex ring downstream to the point where it disappeared. The disappearance always caused a discontinuity and some hysteresis in the thrust and blade spindle-torque measurements. An attempt was made to eliminate the cavitating vortex ring by increasing the tunnel pressure, but a pressure increase to 1.65 atmospheres, which corresponded to 65-percent increase in the propeller cavitation number, did not have any visible effect on the cavitating vortex ring nor on the thrust and spindle-torque measurements.

To separate the centrifugal and the hydrodynamic components of spindle torque, air-spin tests were run. These were also carried out in the 24-inch water tunnel. The spindle-torque measurements obtained without water in the tunnel are due only to centrifugal forces. This centrifugal spindle torque must be subtracted from the total spindle torque measured with water in the tunnel in order to get the hydrodynamic spindle-torque component.

OPEN-WATER TESTS

In addition to the water tunnel tests, the propellers were tested in open water, using the 35-horsepower dynamometer on Carriage 2 to determine their thrust characteristics. The propellers were tested at both positive and negative advance coefficients and at the same pitch settings as in the water tunnel tests. Most of the data obtained was repeatable; however, some scatter was observed with the propellers operating at numerically low values of advance coefficient and with high pitch ratios in the "transient" propulsive conditions.

DATA ANALYSIS AND PRESENTATION OF RESULTS

The open-water propeller-thrust coefficients K_t obtained in the towing basin are presented in Figures 6 through 41. There is some scatter in the data obtained with the propellers working in the "transient" conditions.

A typical example of the thrust characteristics obtained in the water tunnel is presented in Figure 42. The curve drawn in the figure is the K_t curve from the open-water tests of Propeller 4120 at a pitch setting P/D = 0.9, and the data points shown in the figure are thrust-coefficient data from the water tunnel tests of the same propeller at the same pitch setting. The figure shows that thrust coefficients obtained in the basin and in the water tunnel are in good agreement for advance coefficients J higher than 0.4 but differ for all other advance coefficients. The water tunnel thrust-coefficient data show much scatter in the "transient" propulsion conditions both with and without the cavitating vortex ring in the flow. Moreover, the thrust-coefficient data presented in Figure 42 show both the discontinuity and hysteresis effect at the vortex-ring diaappearance. It is believed that the scatter in the thrust-coefficient data obtained in the water tunnel is a combination of wall effect and the influence of the propeller on the velocities measured with the pitot tube.

Blade spindle torque was measured only in the water tunnel. The hydrodynamic spindle-torque coefficients are presented in Figures 43 through 78, and minimum and maximum values of advance coefficients for each propeller condition are presented in Table 2. The spindle torque coefficients show just as much scatter and discontinuity as the water tunnel obtained K_t data. In the figures the spindle torque data are plotted against advance coefficients from open-water K_t identity. Open-water K_t identity means that all water tunnel data are plotted against advance coefficients, corrected so that water tunnel K_t curves are identical with corresponding open-water K_t curves.

In some cases it was not possible to correct the advance coefficients uniquely due to humps in the smooth open-water K_t curves. These humps resulted in triple values of the advance coefficient for some data and resulted in plotting other data at such advance coefficients as would mean a change from "transient" to steady propulsion condition. In these cases an attempt was made to correct the advance coefficients by correlating the open-water thrust characteristics with the rate of rotation of the water-tunnel impeller. This correlation was not successful. Data corresponding to the conditions mentioned are shown in Figures 43 through 78 as uncorrected water tunnel data.

The centrifugal propeller-blade spindle torque from the air-spin tests is presented in Figure 79. The centrifugal spindle-torque measurements were subtracted from the spindle torque measured with water in the 24-inch water tunnel in order to get the hydrodynamic component of the propeller-blade spindle torque. The hydrodynamic and centrifugal components of the spindle torque must be separated in order to nondimensionalize the components with respect to the densities upon which they depend.

DISCUSSION OF RESULTS

The thrust and hydrodynamic blade spindle-torque characteristics of Propellers 3728 and 3771 for steady forward propulsion are not in agreement with the curves given in Reference 1. The thrust data presented in Reference 1 were obtained in the 24-inch water tunnel, and the thrust data presented in this report were obtained in the towing basin. Both the spindle-torque coefficients presented in Reference 1 and in this report were obtained in the 24-inch water tunnel.

The lack of thrust and spindle-torque agreement between the present tests and the test of Reference 1 could partly be due to the lack of precise pitch control described in Reference 1. The spindle-torque disagreements may also be due to errors in Reference 1 since the strain-gaged torque-measuring element used in these tests was not thoroughly calibrated with respect to nonspindle forces.

The curves shown in Figure 80 represent centrifugal spindle torque of Propeller 3771, obtained in different ways. Two of the curves are obtained experimentally; one of the curves, from the tests described in

Reference 1; and the other, from the present tests. The third curve is calculated using the method presented in Reference 2. All three curves are in good agreement.

Of the propellers tested, Propeller 4121 with uncambered NACABS blade sections and 40-percent spindle-axis location* requires the least extreme value of turning effort for all steady conditions, except for the conditions with pitch settings P/D = 1.2 and -0.9. Propeller 3771 with Zero-X-blade sections and 40-percent spindle-axis location requires less extreme value of spindle torque than Propeller 4121 for conditions with pitch settings P/D = 1.2 and -0.9. For all other pitch settings, higher values of spindle torque were measured with Propeller 3771 than with Propeller 4121. Higher values of spindle torque were measured with Propeller 3728, NACABS blade sections and 40-percent spindle-axis location; and still higher values were measured with Propeller 4120, which has NACABS blade sections and 50-percent spindle-axis location. Propeller 4122 with NACABS blade sections, 40-percent spindle-axis location, and wide blades required the largest blade turning effort of all the propellers tested at steady propulsion conditions.

CONCLUSIONS AND RECOMMENDATIONS

The conclusions based on the extreme values of spindle torque for steady propulsion are:

1. For the 40-percent spindle-axis location, the uncambered NACABS sections require less turning effort than either the cambered-NACABS sections or the Zero-X sections, except for extreme pitch settings.

2. The designs with cambered-NACABS blade sections require lower spindle torque for the 40-percent spindle-axis location than for the 50-percent location but more spindle torque than with the Zero-X section with spindle axis at 40 percent.

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*Spindle-axis location is given in percent of blade width from leading edge.

3. A substantial increase of the propeller blade-area ratio of the design with the 40-percent NACABS sections gives a substantial increase in required spindle torque. However, the range of propulsion conditions tested with the wide-bladed propeller was small.

For the "transient" propulsive conditions, the data are very scattered and are to be used with considerable reservation. However, it appears that also for these conditions the lowest extreme values of spindle torque were measured with Propeller 4121, and the highest were measured with Propeller 4122.

It must be noted that these conclusions for both the steady and "transient" conditions are based only on the measured extreme values of spindle torque and that it is possible that the advance coefficients at which these extreme spindle-torque values were measured may be avoided when maneuvering with variable-pitch propellers.

For further study of the characteristics of the propellers operating in the "transient" propulsive conditions, the following is recommended:

1. It is recommended that additional tests be carried out in the 24-inch water tunnel and in the towing basin in order to determine the ratio of propeller to tunnel diameters for which accurate data can be obtained with the propellers working in the "transient" conditions. This recommendation is also based on the investigation described in Reference 3, where it is concluded that the ratio of tunnel to screw diameters required to give a true picture of the free flow, increases rapidly as the advance coefficients for the "transient" propulsive conditions diminish.

2. It is recommended that a new spindle-torque gage be designed to eliminate the interaction problems.

3. It is recommended to study the characteristics of the propellers rotating in the reverse direction. This recommendation is based on the discussion in Reference 4, where it is stated that the best performance astern may generally be obtained with adjustable-pitch propellers rotating in the reverse direction.

PROPELLER 3728

Number of Blades 4	Diameter . . . . . . 16.390 in.
Exp. Area Ratio 0.540	Pitch at 0.7R . . . 14.027 in.
MWR 0.280	Rotation . . . . . R. H.
BTF 0.038	Designed by Bureau of Ships
P/D at 0.7R 0.857	Reference: BuShips Drawing No. MSO 421 S 4400-1737504A

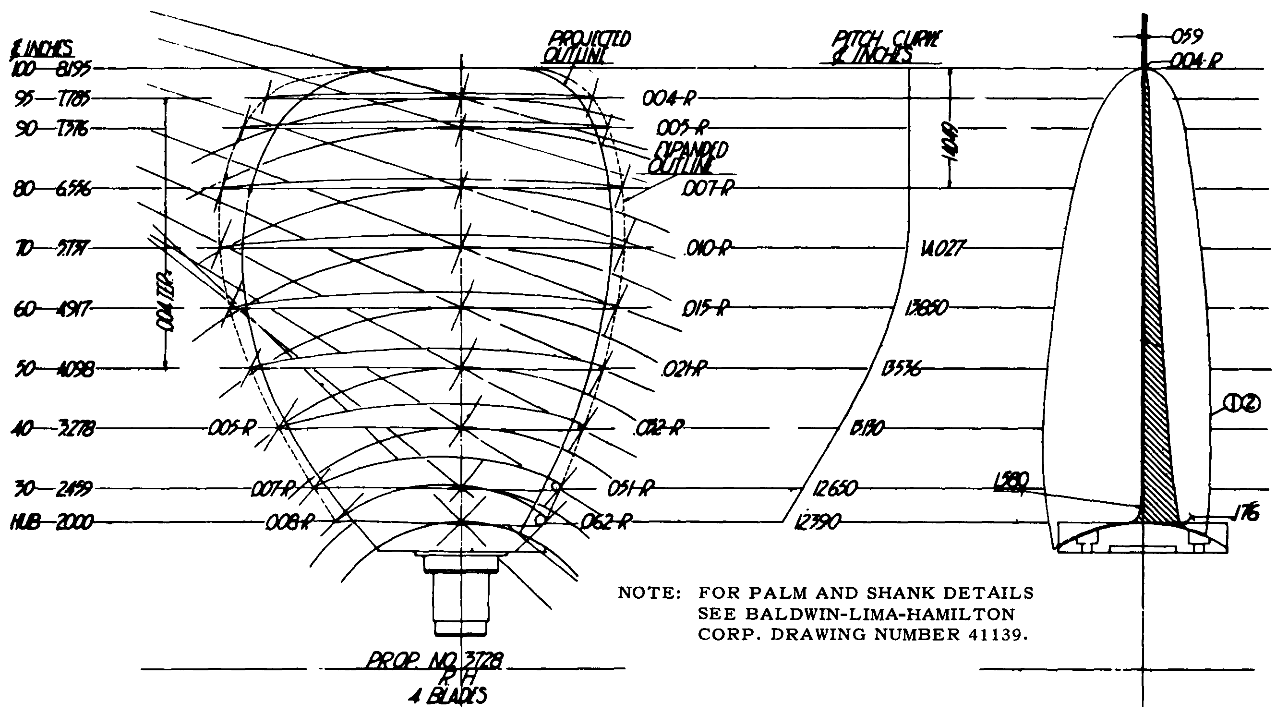


Figure 1 - Blade for Model Propeller 3728

PROPELLER 3771

Number of Blades	4	Diameter	16.390 in.
Exp. Area Ratio	0.540	Pitch at 0.7R . . .	14.027 in.
MWR	0.280	Rotation	R. H.
BTF	0.039	Designed by Bureau of Ships	
P/D at 0.7R	0.857	Reference: BuShips Drawing No. AM 421-S 4400-H-1022135	

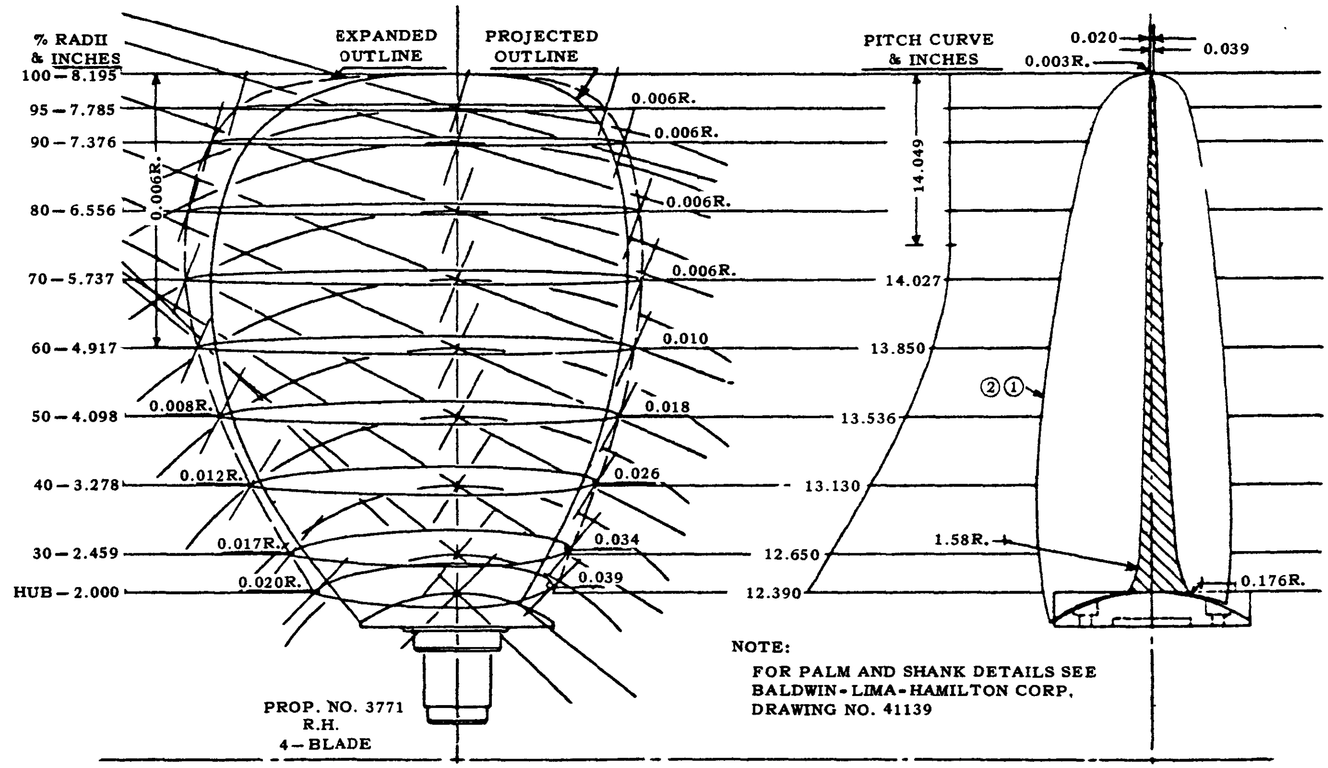


Figure 2 - Blade for Model Propeller 3771

PROPELLER 4120

Number of Blades	4	Diameter	16.39 in.
Exp. Area Ratio	0.540	Pitch at 0.7R . . .	14.027 in.
MWR	0.281	Rotation	R. H.
BTF	0.039	Designed by Bureau of Ships	
P/D at 0.7R	0.857	Reference: DTMB Prop. No. 3727	

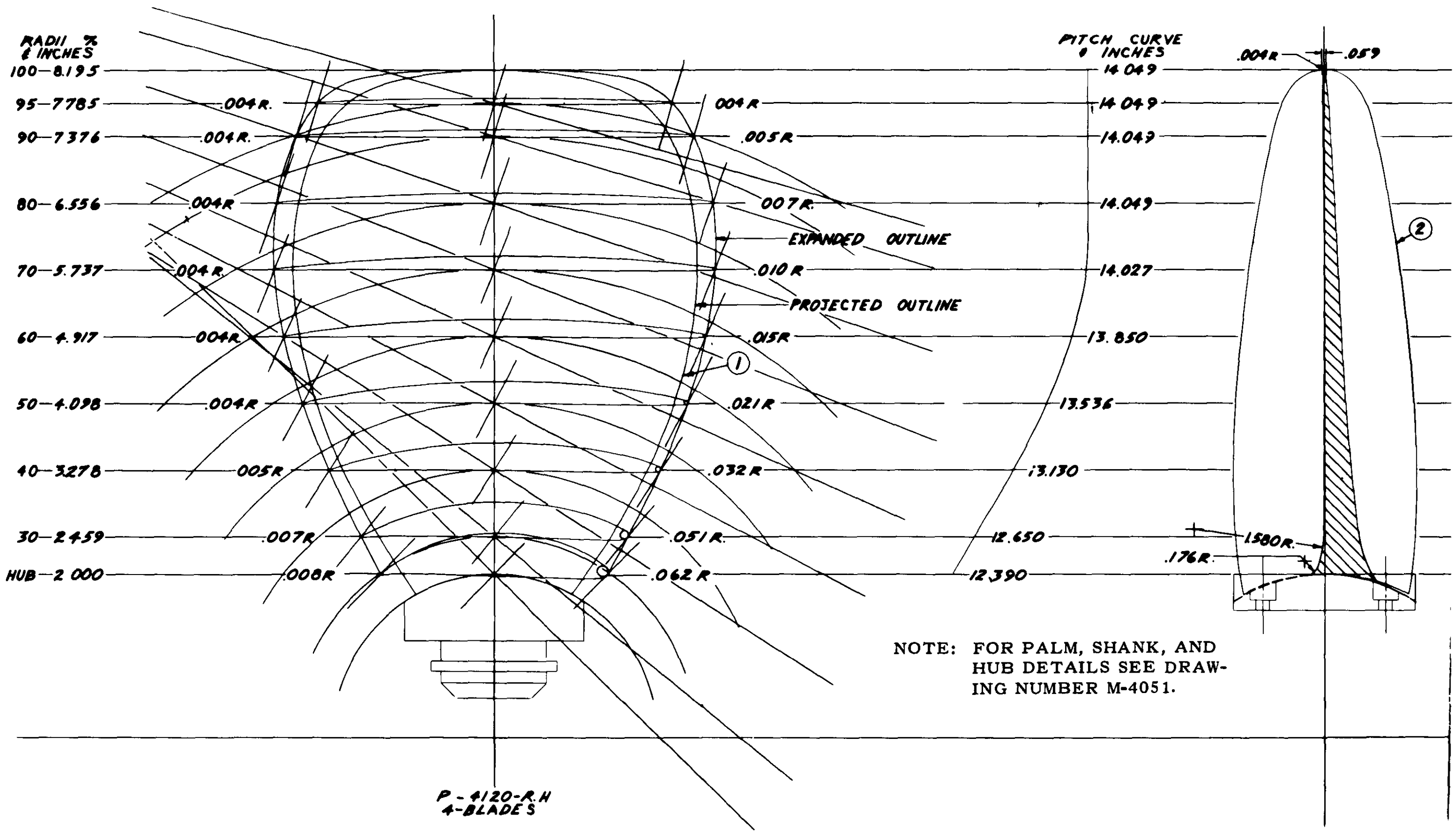


Figure 3 - Blade for Model Propeller 4120

PROPELLER 4121

Number of Blades	4	Diameter	16.390 in.
Exp. Area Ratio	0.540	Pitch at 0.7R . . .	14.027 in.
MWR	0.281	Rotation	R. H.
BTF	0.038	Designed by Bureau of Ships	
P/D at 0.7R	0.857	Reference: DTMB Prop. No. 3727	

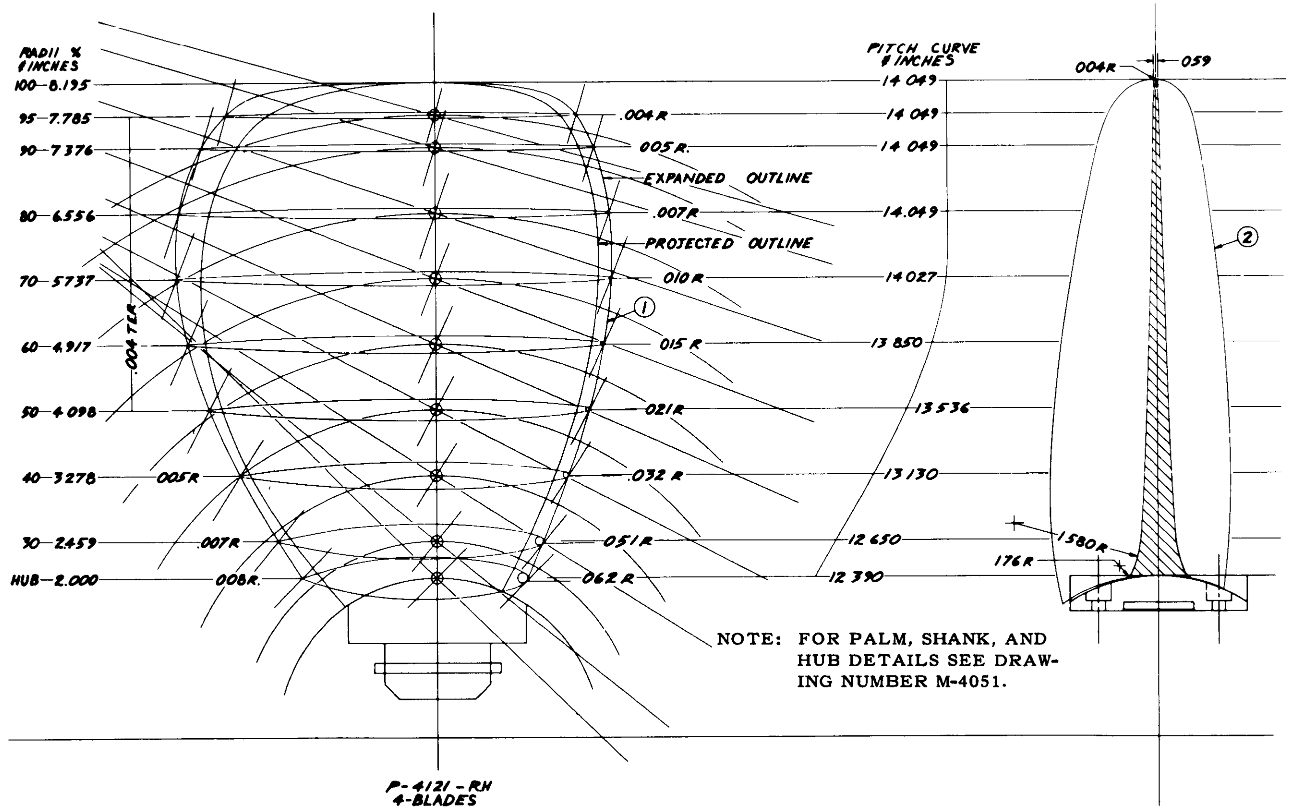


Figure 4 - Blade for Model Propeller 4121

PROPELLER 4122

Number of Blades	4	Diameter	16.390 in.
Exp. Area Ratio	1.013	Pitch at 0.7R . . .	14.027 in.
MWR	0.526	Rotation	R. H.
BTF	0.039	Designed by Bureau of Ships	
P/D at 0.7R	0.857	Reference: DTMB Prop. No. 3727	

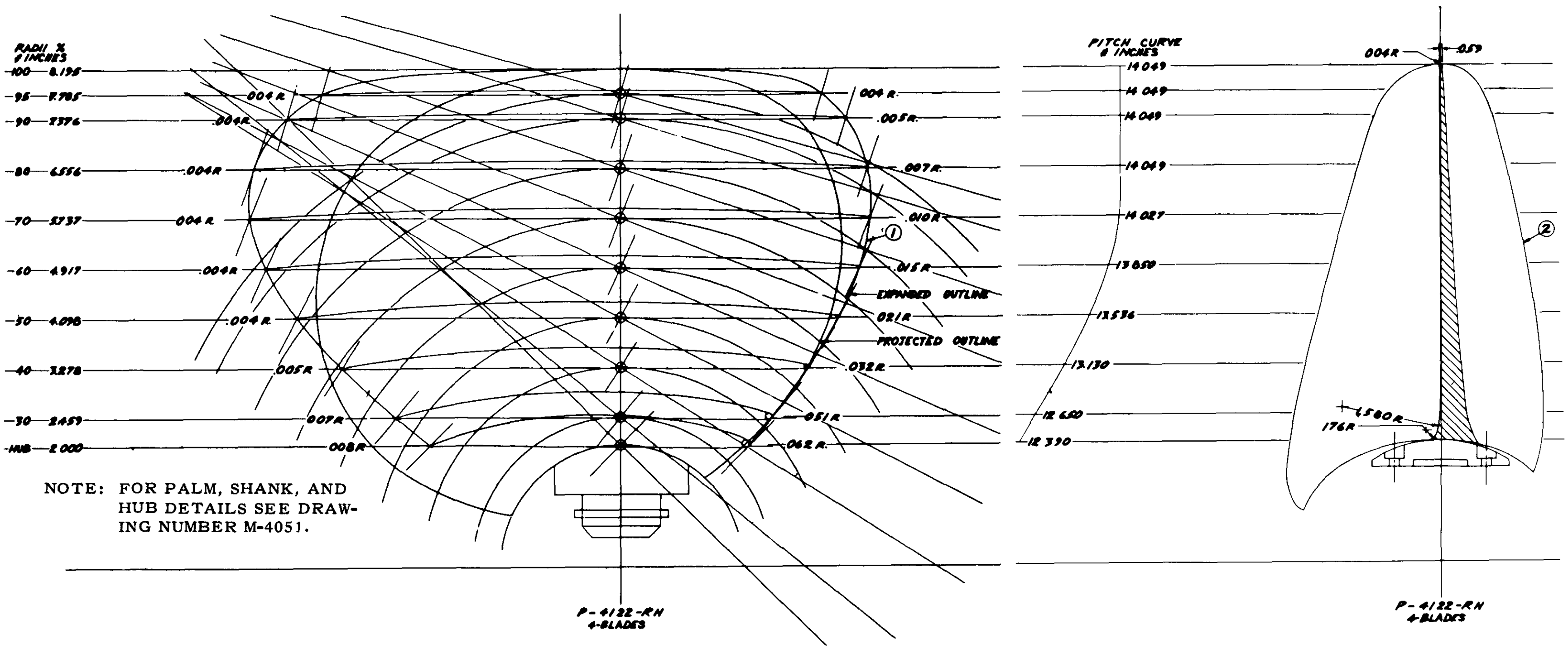


Figure 5 - Blade for Model Propeller 4122

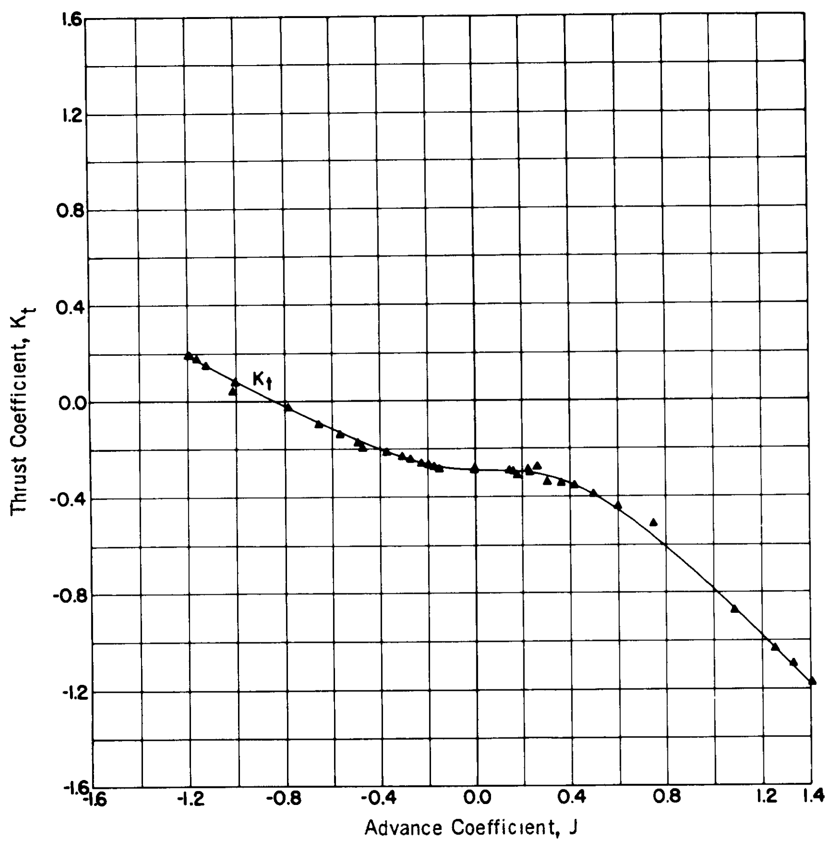


Figure 6 - Thrust Characteristic for Propeller 3728 at P/D = -0.9

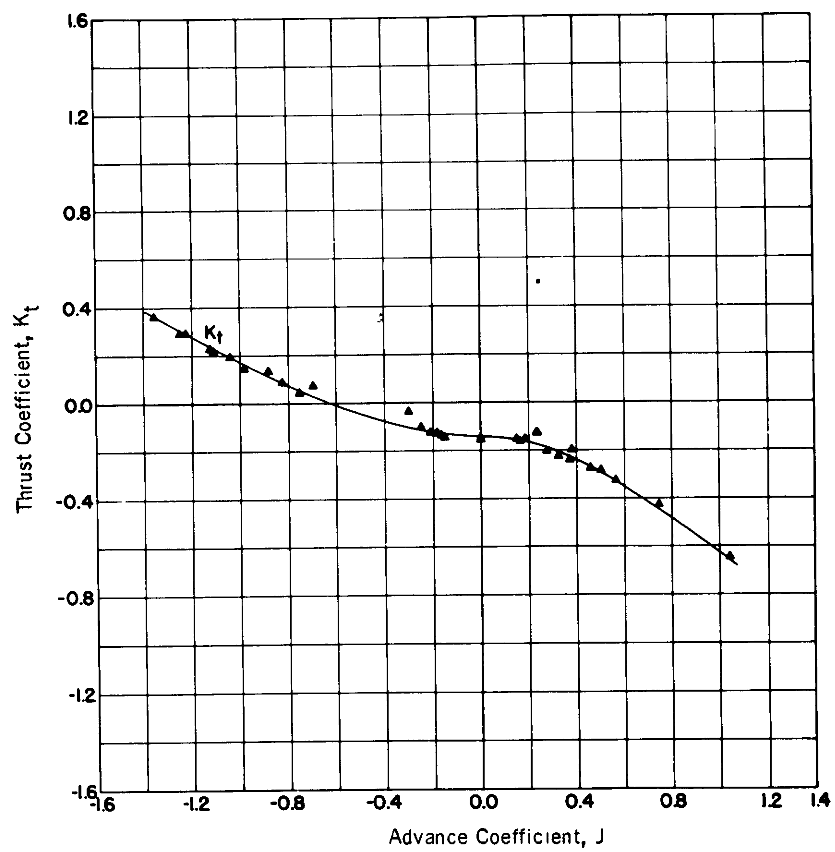


Figure 7 - Thrust Characteristic for Propeller 3728 at P/D = -0.6

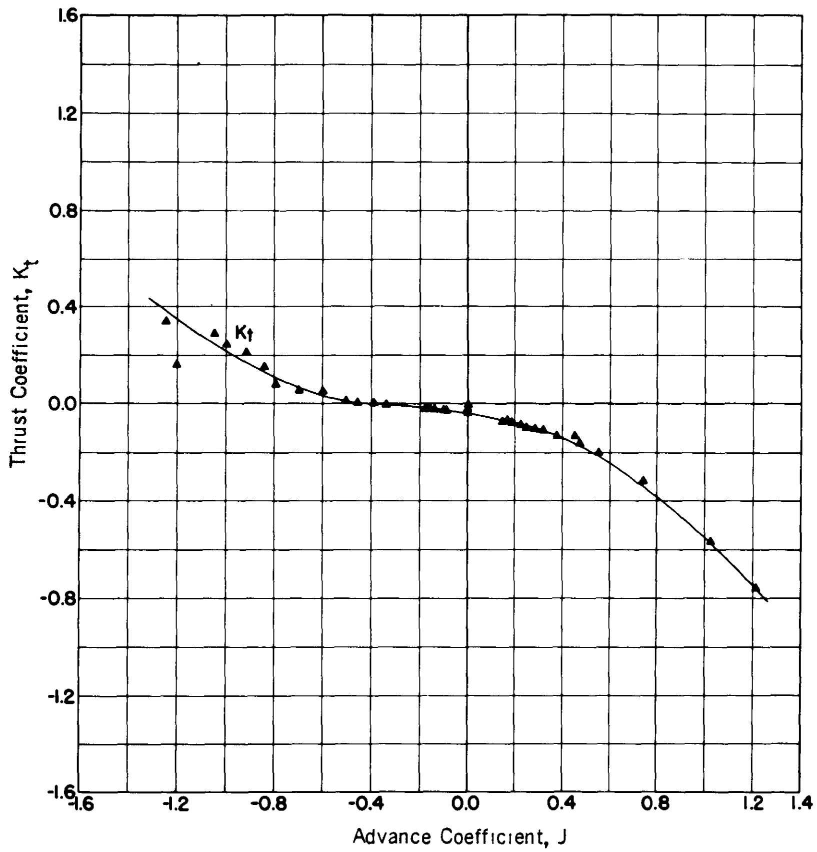


Figure 8 - Thrust Characteristic for Propeller 3728 at P/D = -0.3

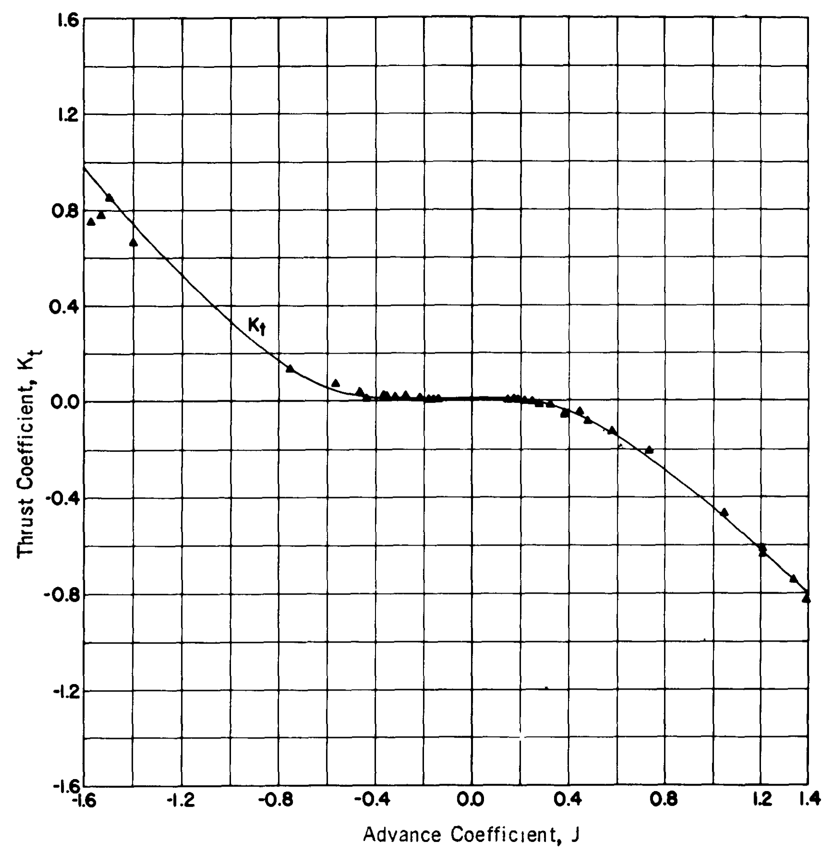


Figure 9 - Thrust Characteristic for Propeller 3728 at P/D = 0.0

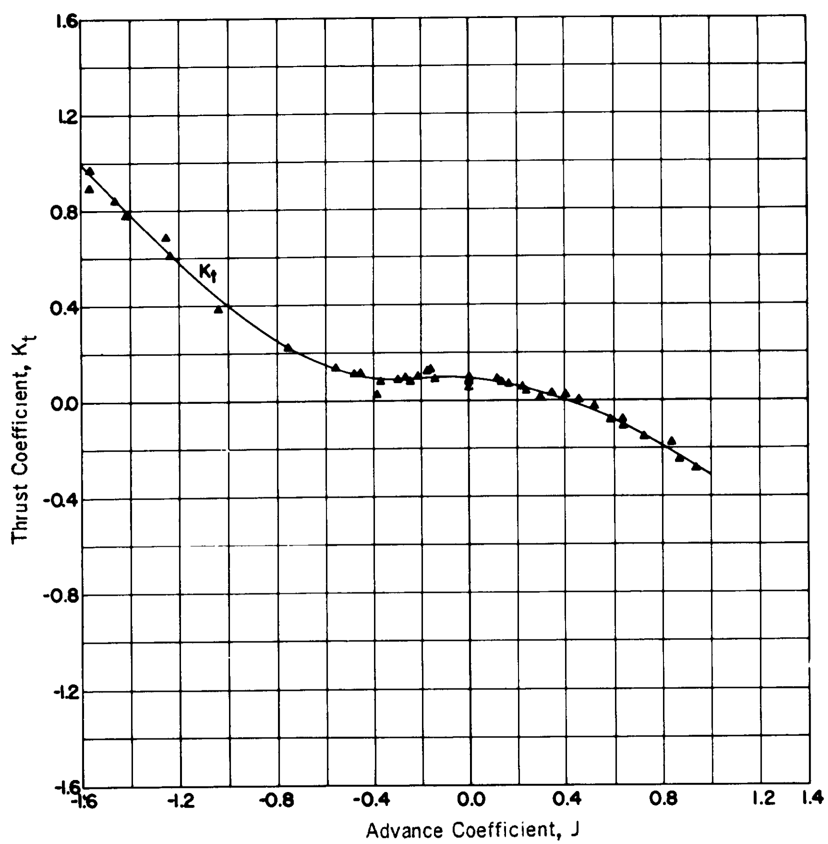


Figure 10 - Thrust Characteristic for Propeller 3728 at P/D = 0.3

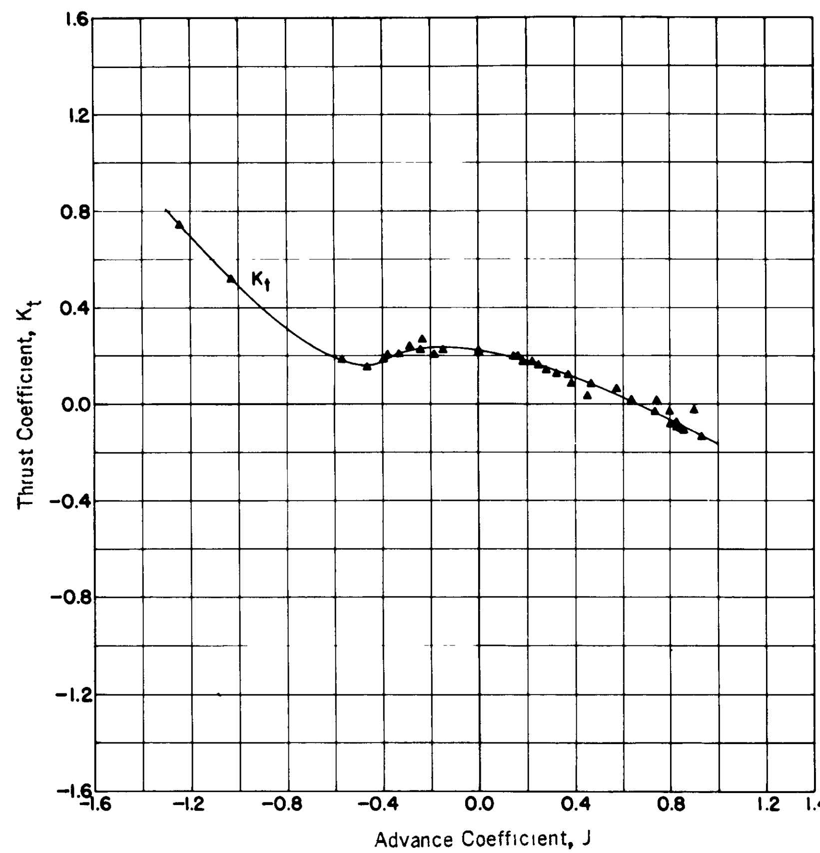


Figure 11 - Thrust Characteristic for Propeller 3728 at P/D = 0.6

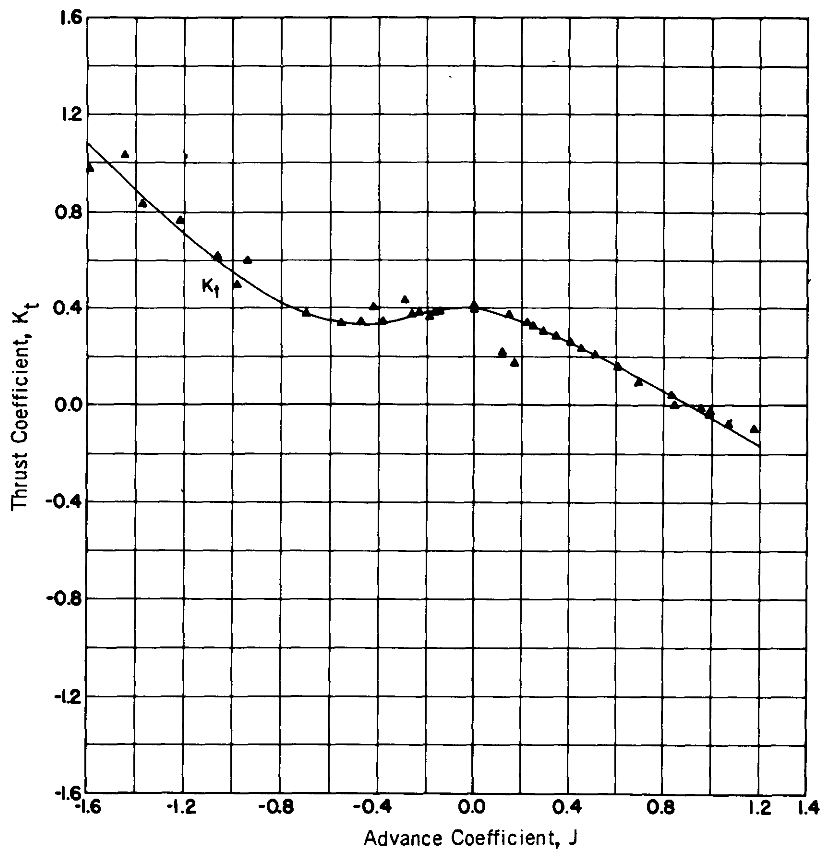


Figure 12 - Thrust Characteristic for Propeller 3728 at P/D = 0.9

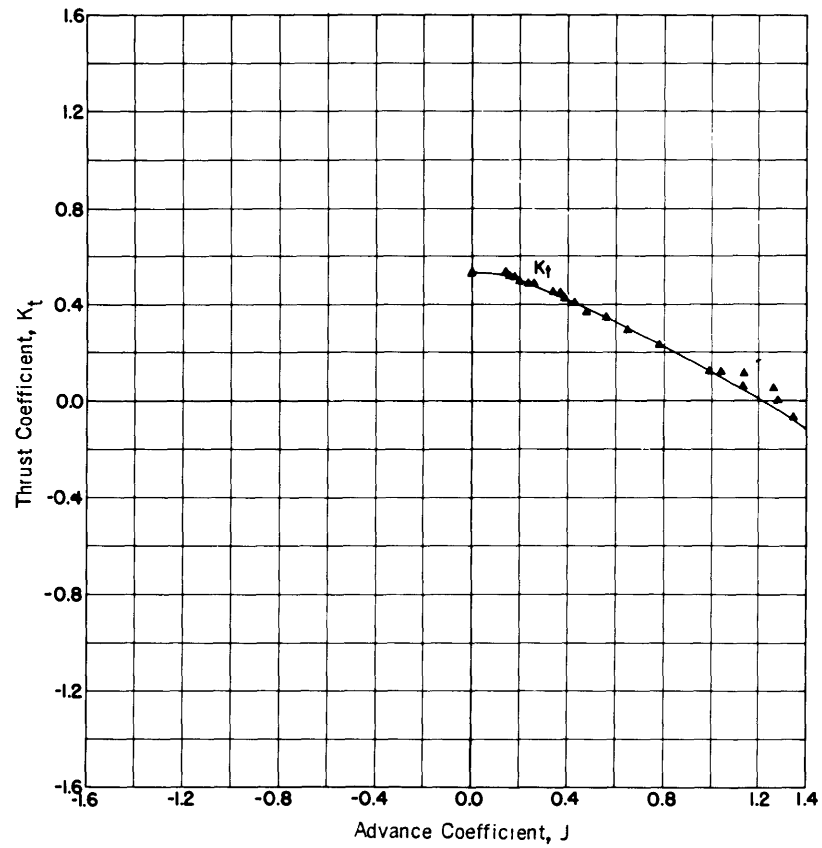


Figure 13 - Thrust Characteristic for Propeller 3728 at P/D = 1.2

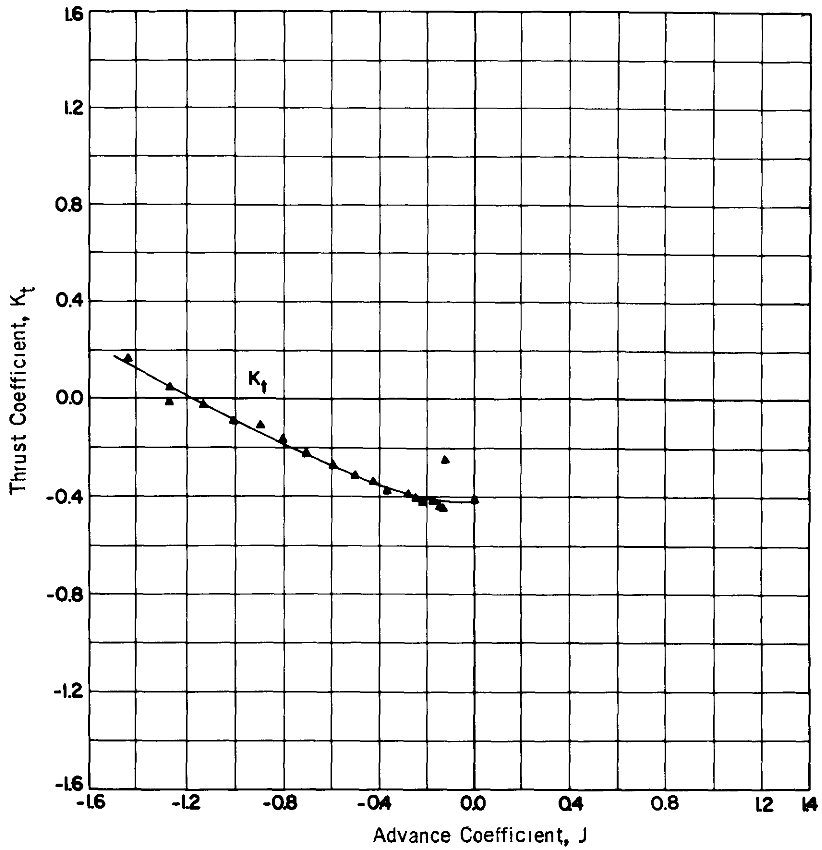


Figure 14 - Thrust Characteristic for Propeller 3771 at P/D = -1.2

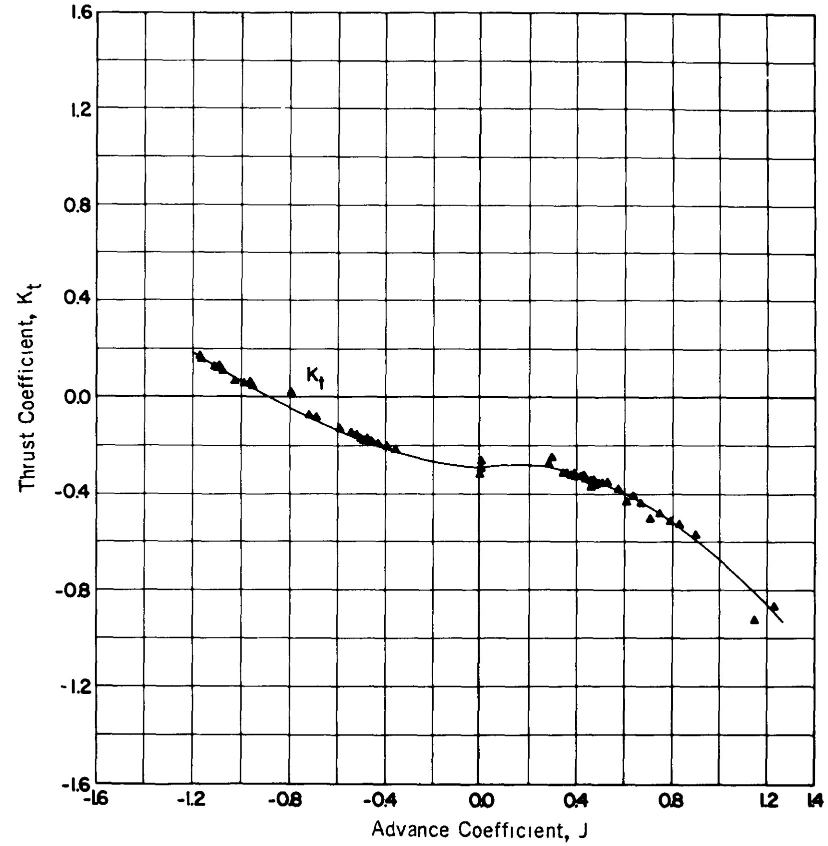


Figure 15 - Thrust Characteristic for Propeller 3771 at P/D = -0.9

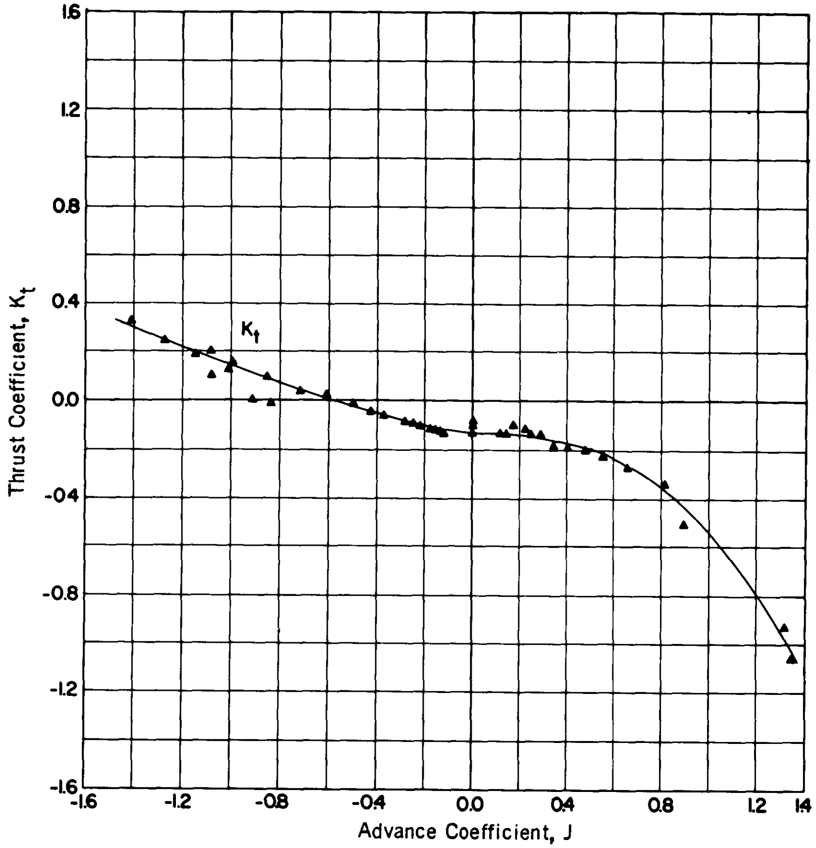


Figure 16 - Thrust Characteristic for Propeller 3771 at P/D = -0.6

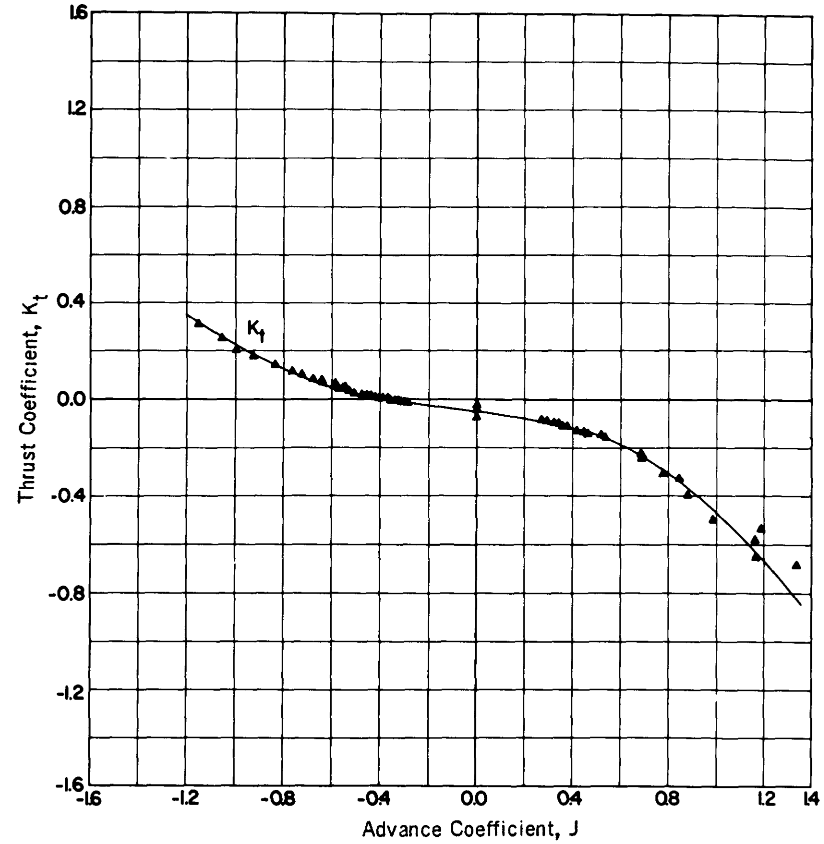


Figure 17 - Thrust Characteristic for Propeller 3771 at P/D = -0.3

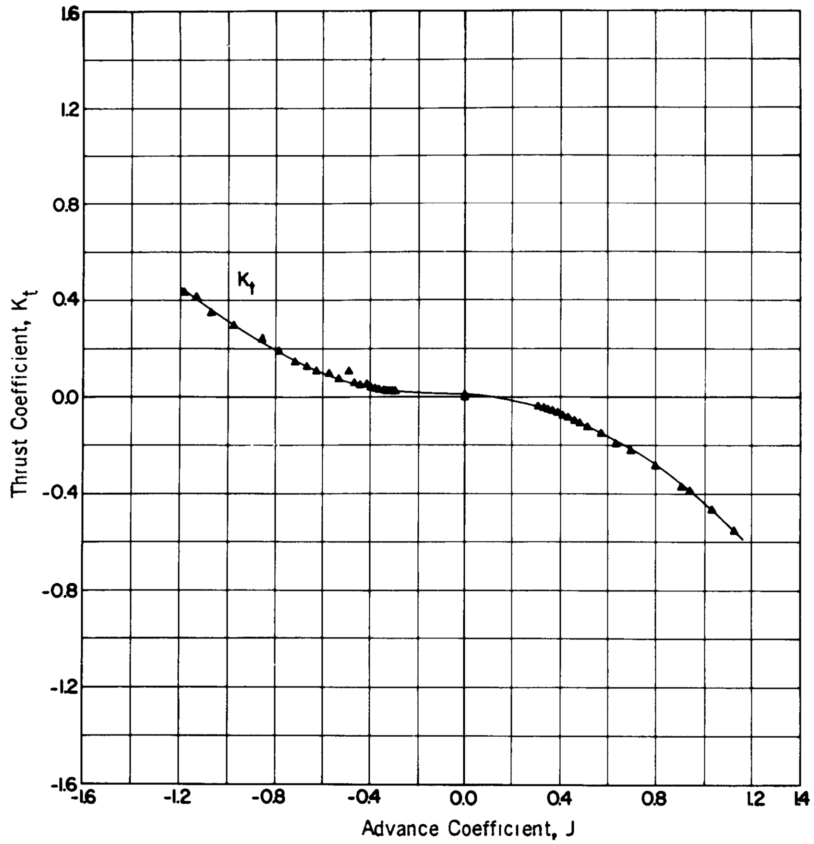


Figure 18 - Thrust Characteristic for Propeller 3771 at P/D = 0.0

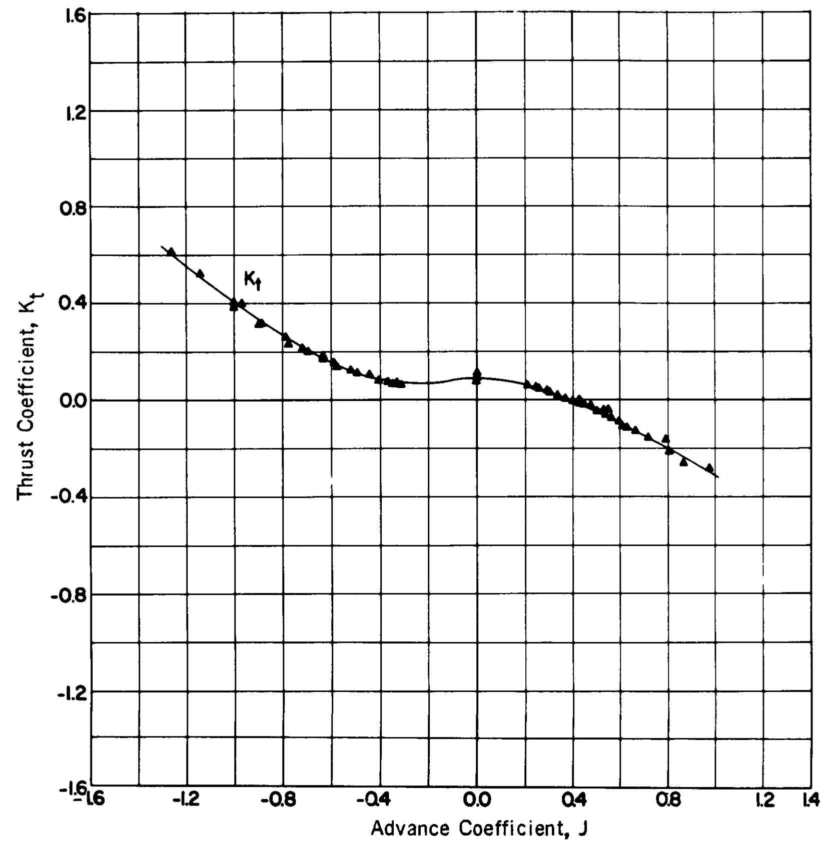


Figure 19 - Thrust Characteristic for Propeller 3771 at P/D = 0.3

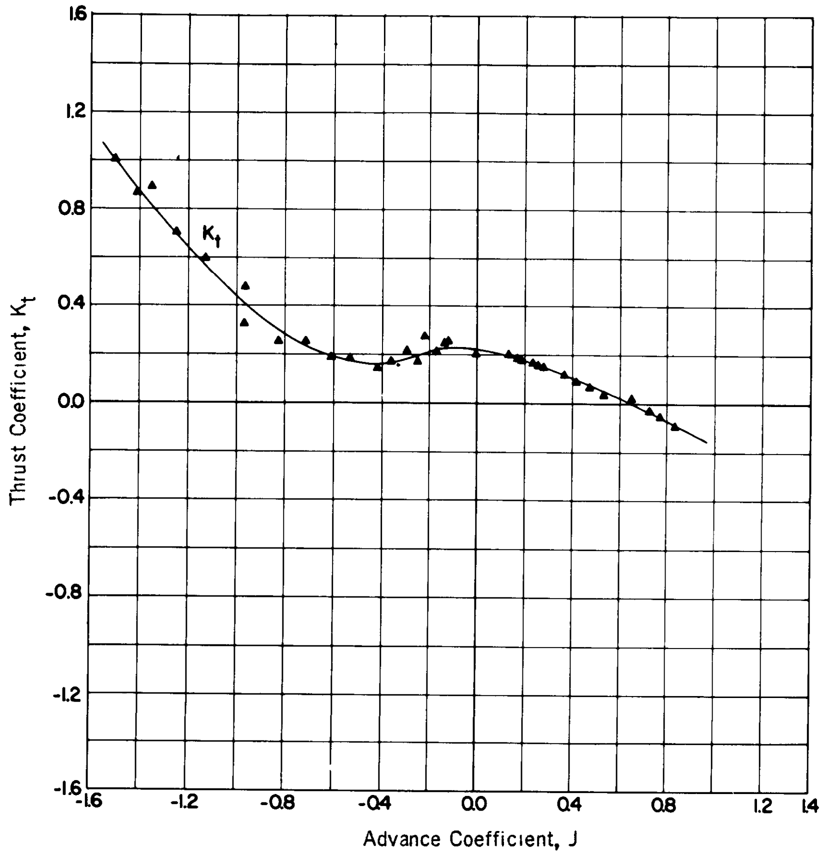


Figure 20 - Thrust Characteristic for Propeller 3771 at P/D = 0.6

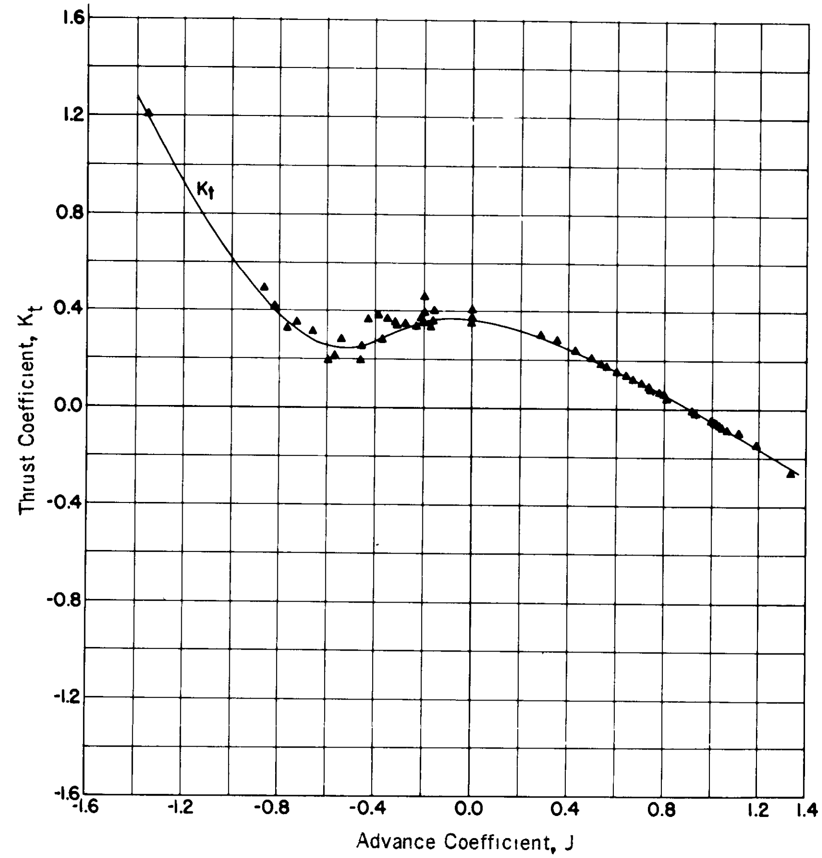


Figure 21 - Thrust Characteristic for Propeller 3771 at P/D = 0.9

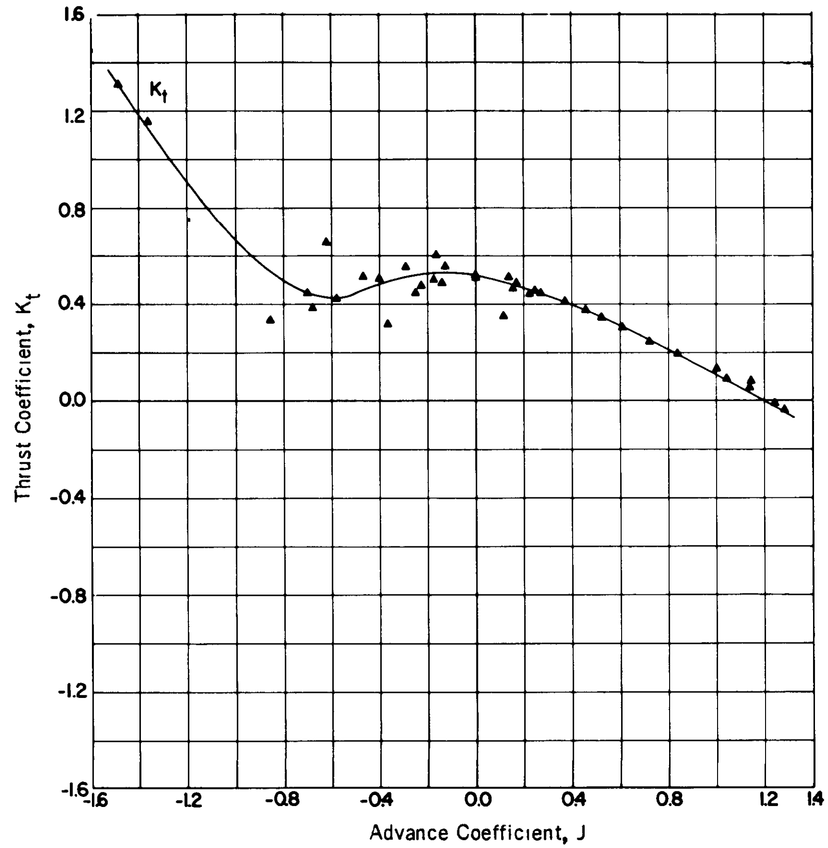


Figure 22 - Thrust Characteristic for Propeller 3771 at P/D = 1.2

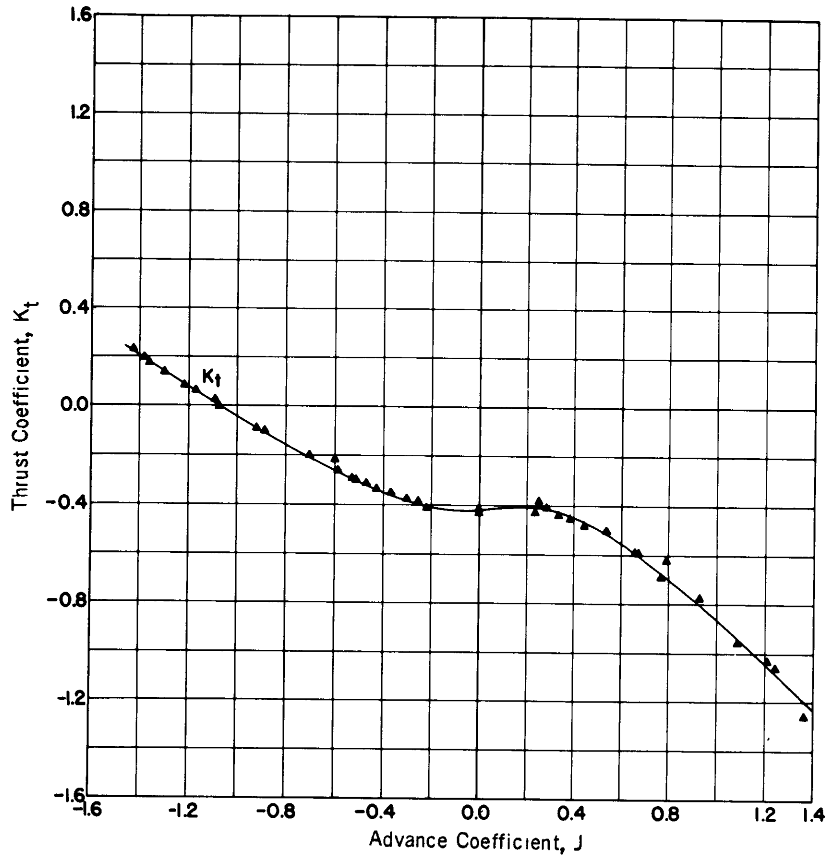


Figure 23 - Thrust Characteristic for Propeller 4120 at P/D = -1.2

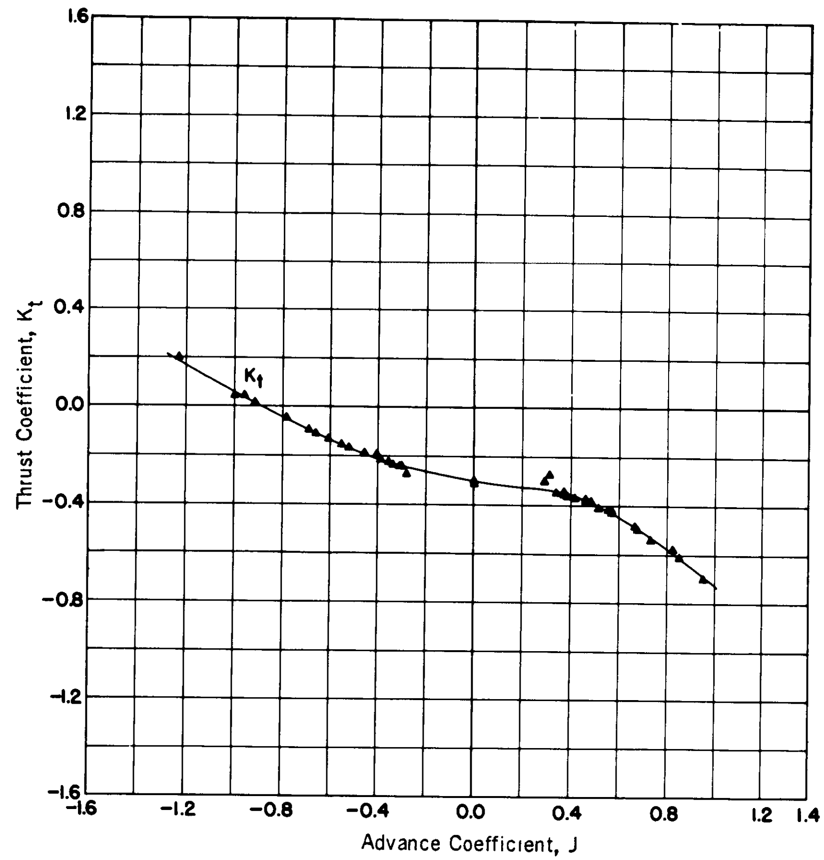


Figure 24 - Thrust Characteristic for Propeller 4120 at P/D = -0.9

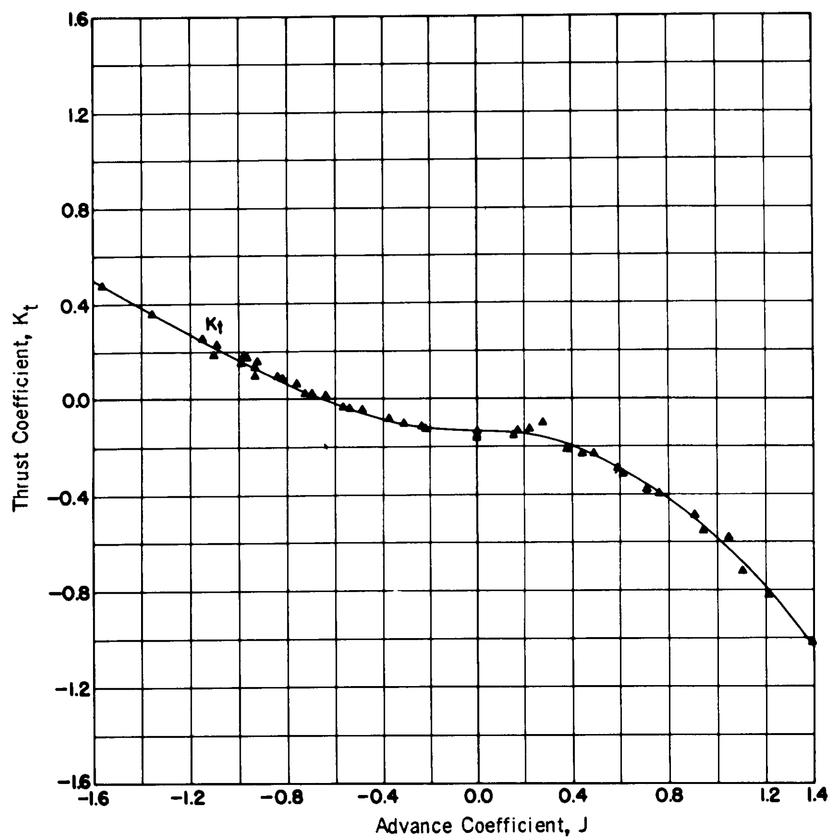


Figure 25 - Thrust Characteristic for Propeller 4120 at P/D = -0.6

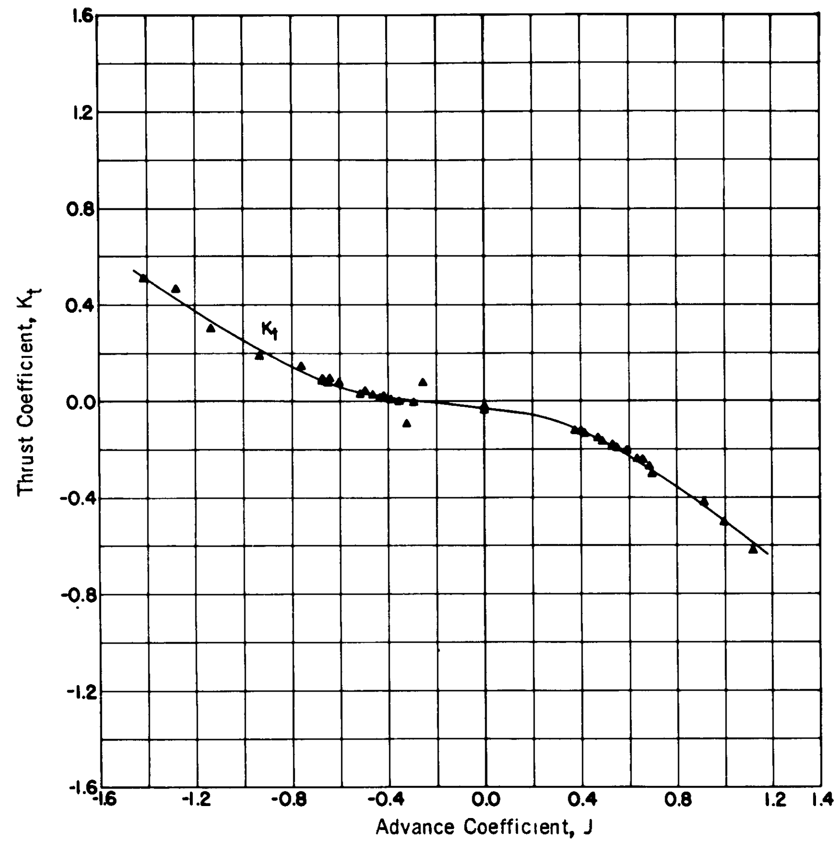


Figure 26 - Thrust Characteristic for Propeller 4120 at P/D = -0.3

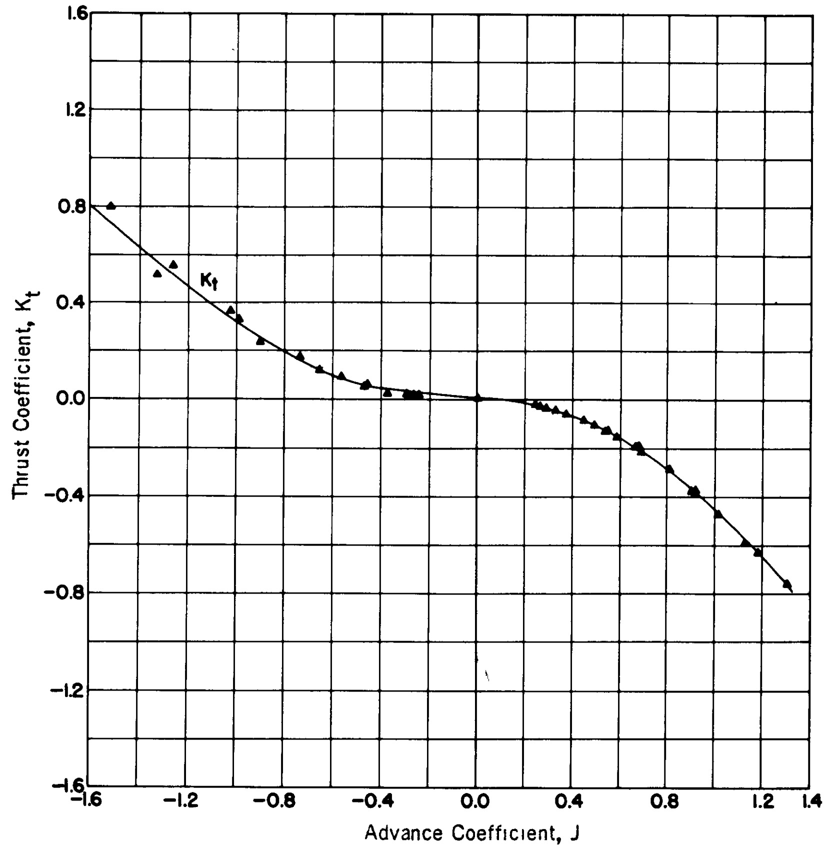


Figure 27 - Thrust Characteristic for Propeller 4120 at P/D = 0.0

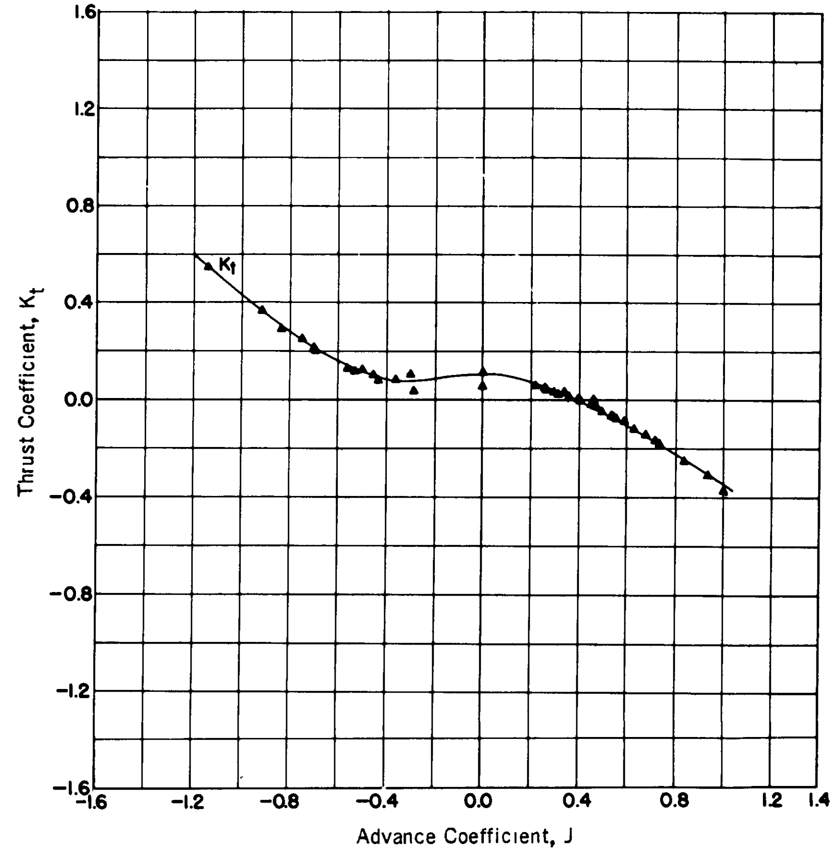


Figure 28 - Thrust Characteristic for Propeller 4120 at P/D = 0.3

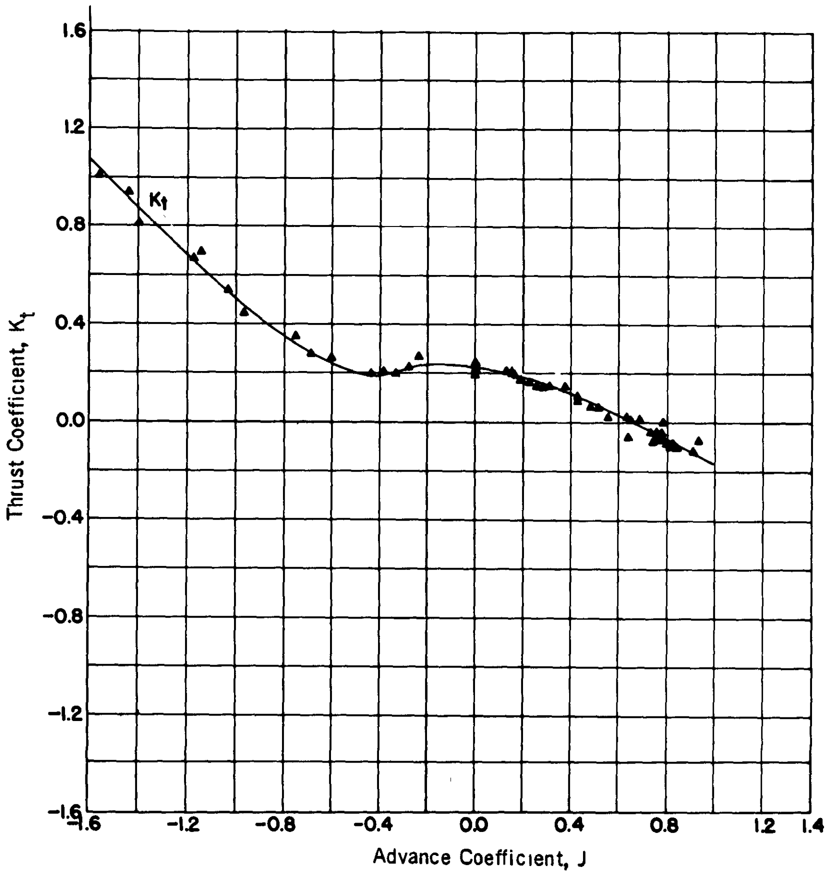


Figure 29 - Thrust Characteristic for Propeller 4120 at P/D = 0.6

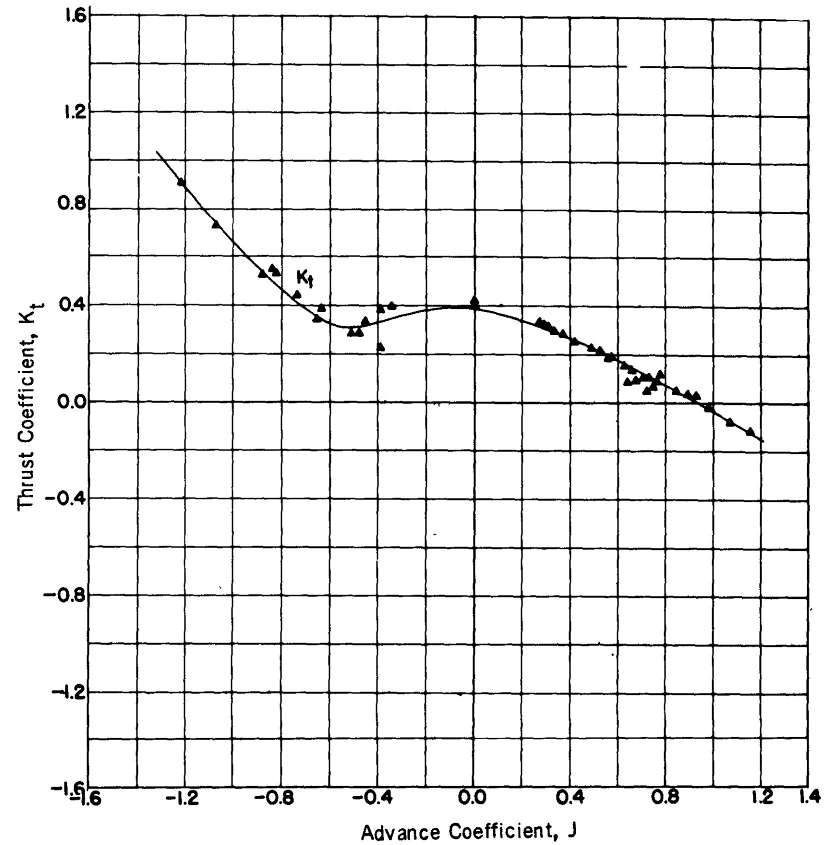


Figure 30 - Thrust Characteristic for Propeller 4120 at P/D = 0.9

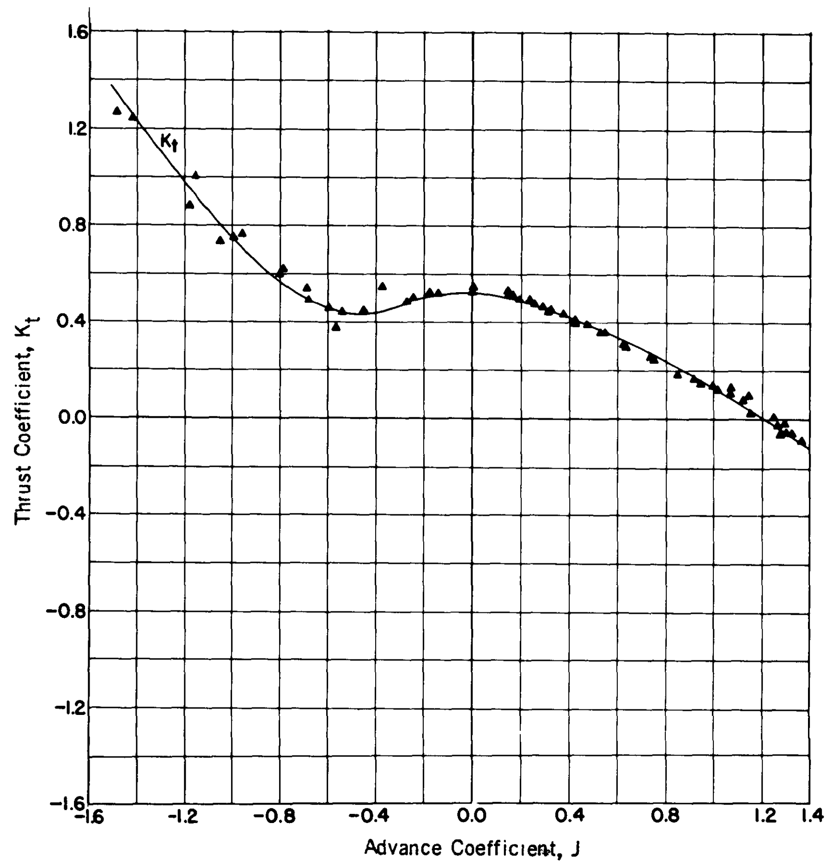


Figure 31 - Thrust Characteristic for Propeller 4120
at P/D = 1.2

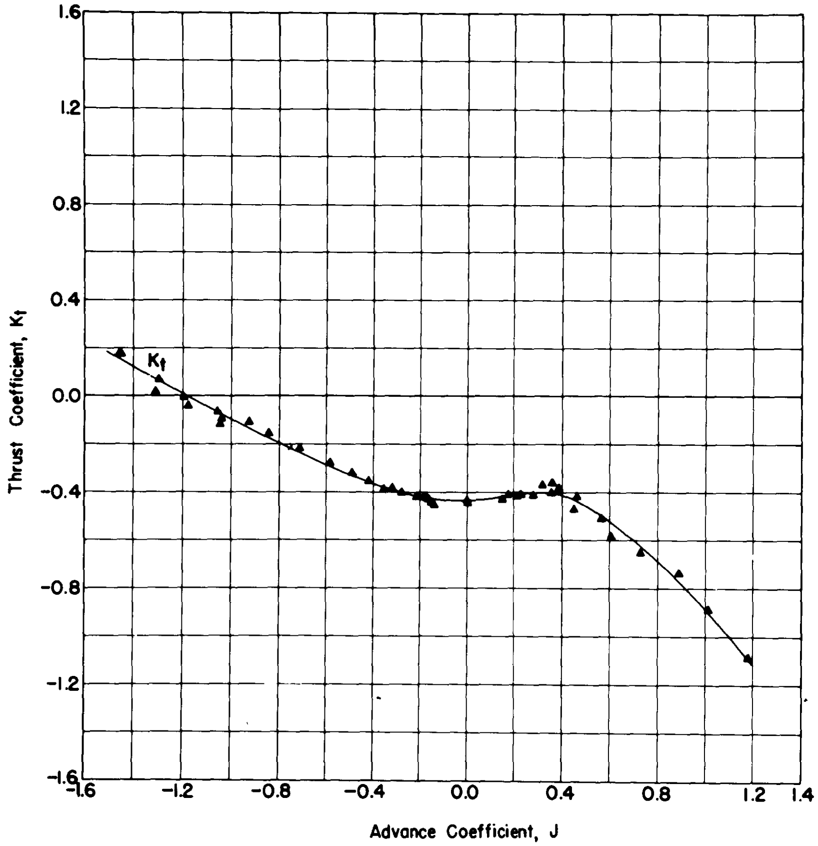


Figure 32 - Thrust Characteristic for Propeller 4121 at P/D = -0.9

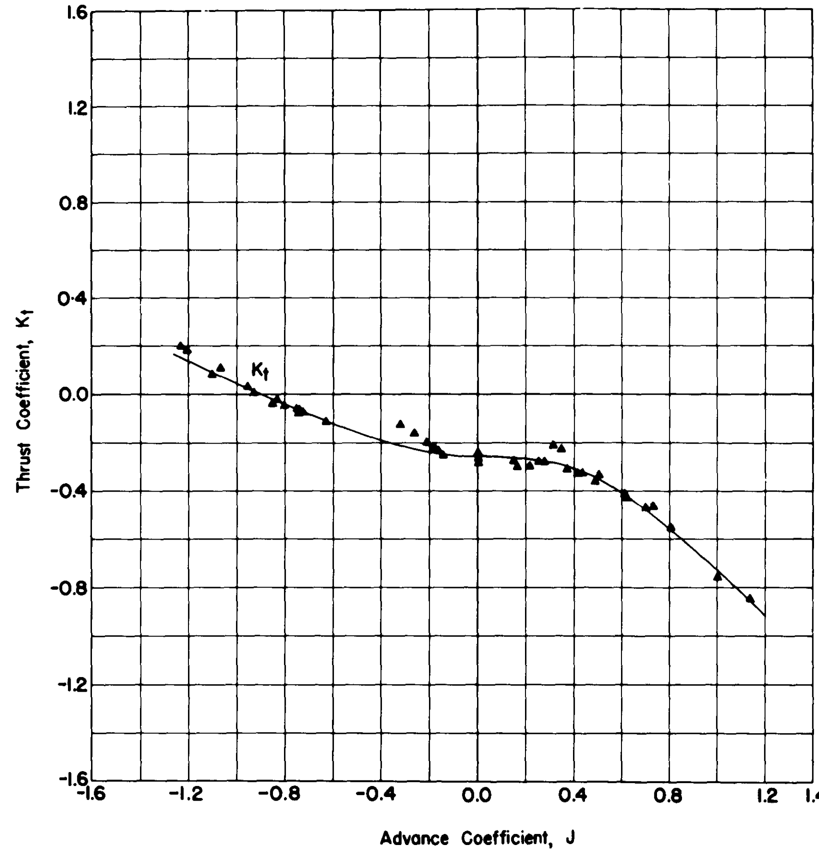
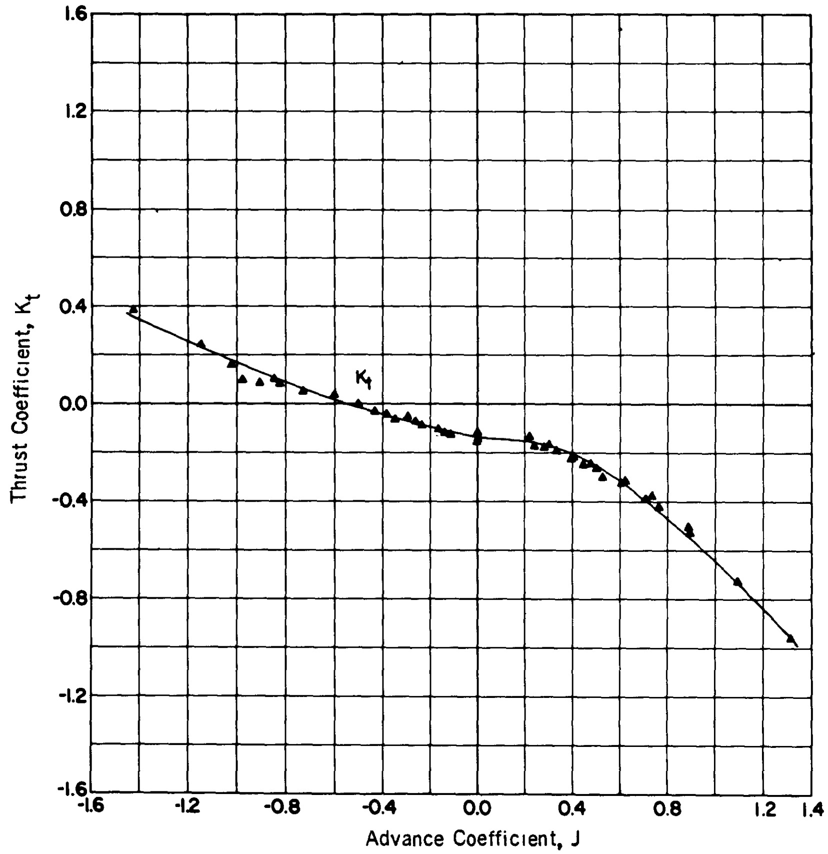


Figure 33 - Thrust Characteristic for Propeller 4121 at P/D = -0.6



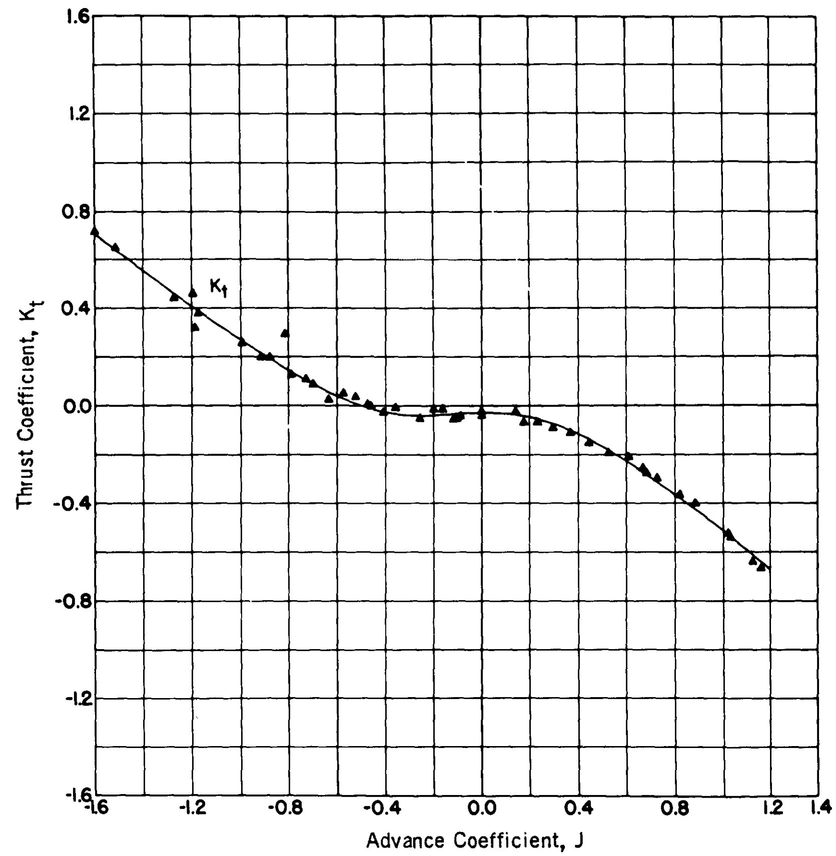


Figure 34 - Thrust Characteristic for Propeller 4121 at P/D = -0.3

Figure 35 - Thrust Characteristic for Propeller 4121 at P/D = 0.0

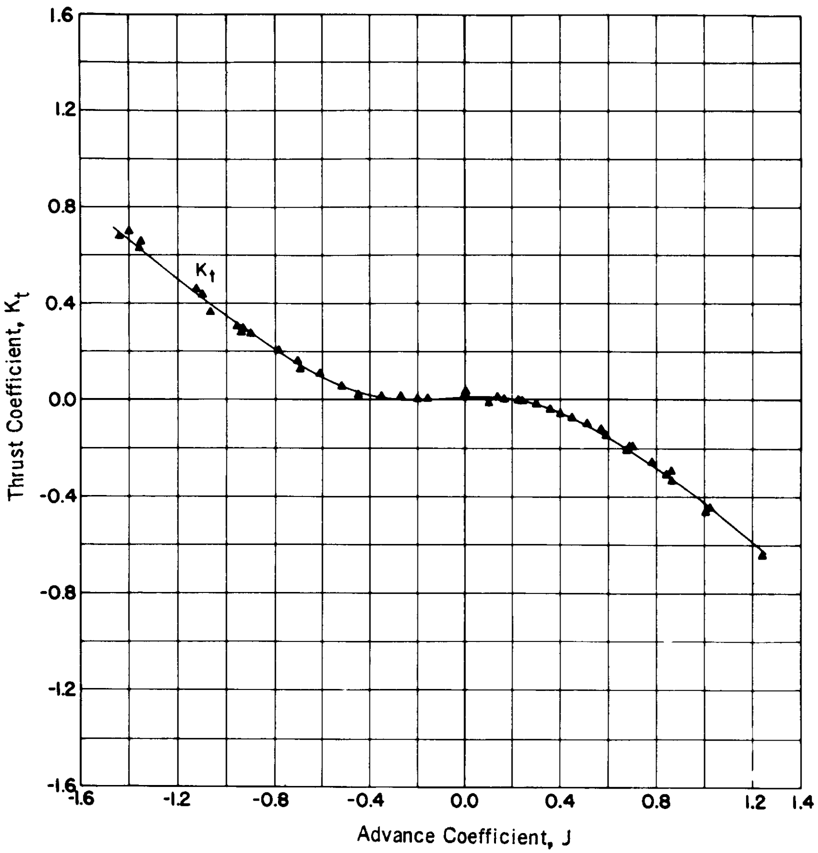


Figure 36 - Thrust Characteristic for Propeller 4121 at P/D = 0.3

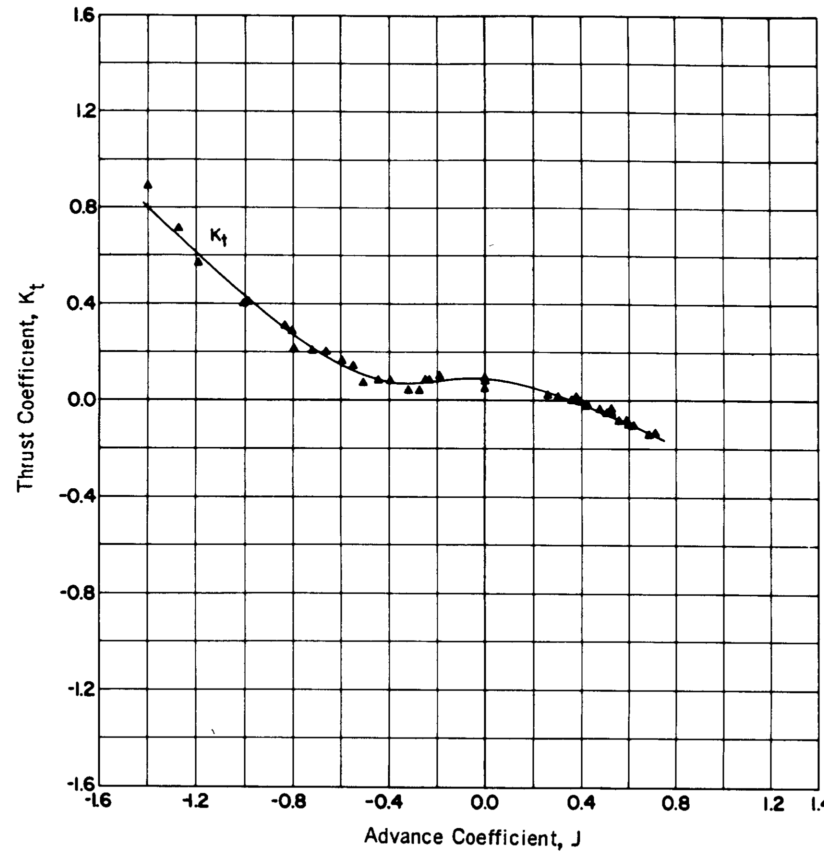


Figure 37 - Thrust Characteristic for Propeller 4121 at P/D = 0.6

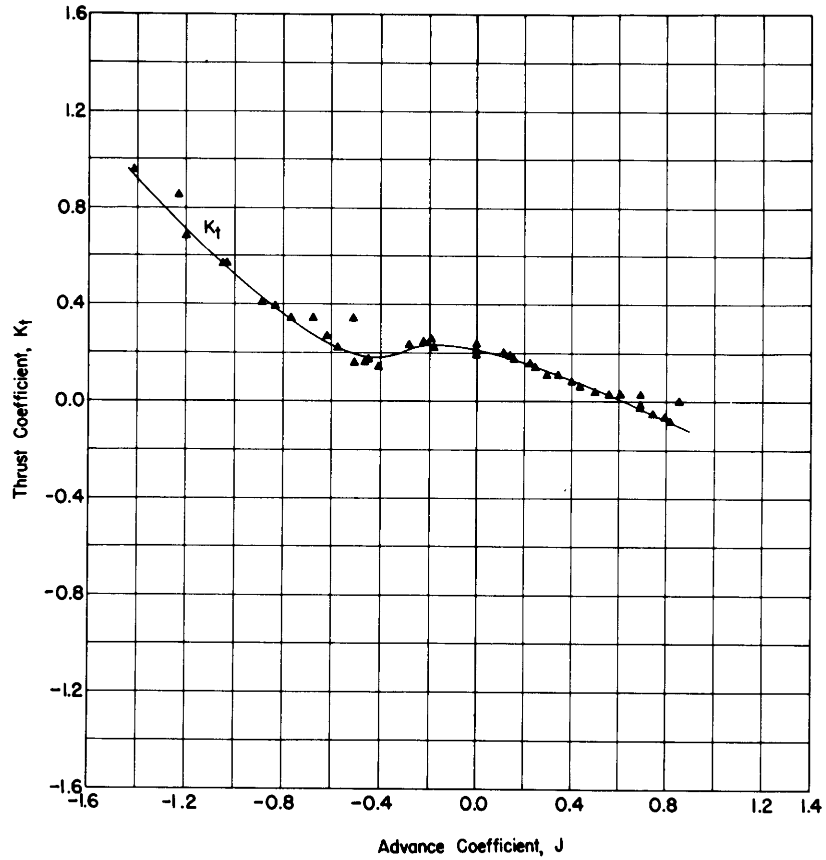


Figure 38 - Thrust Characteristic for Propeller 4121 at P/D = 0.9

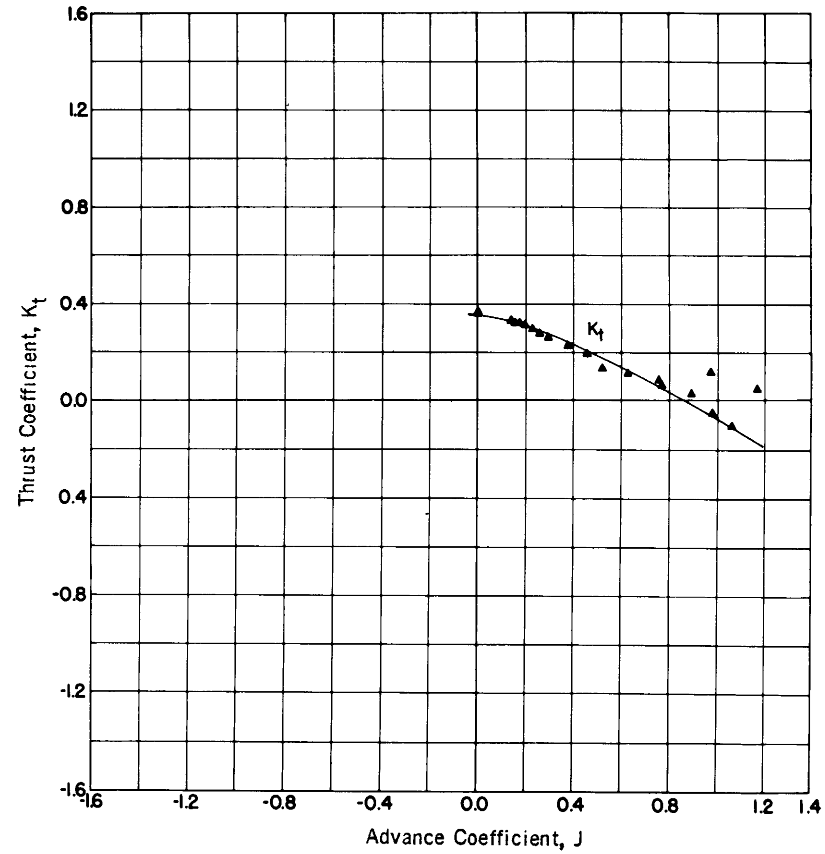


Figure 39 - Thrust Characteristic for Propeller 4121 at P/D = 1.2

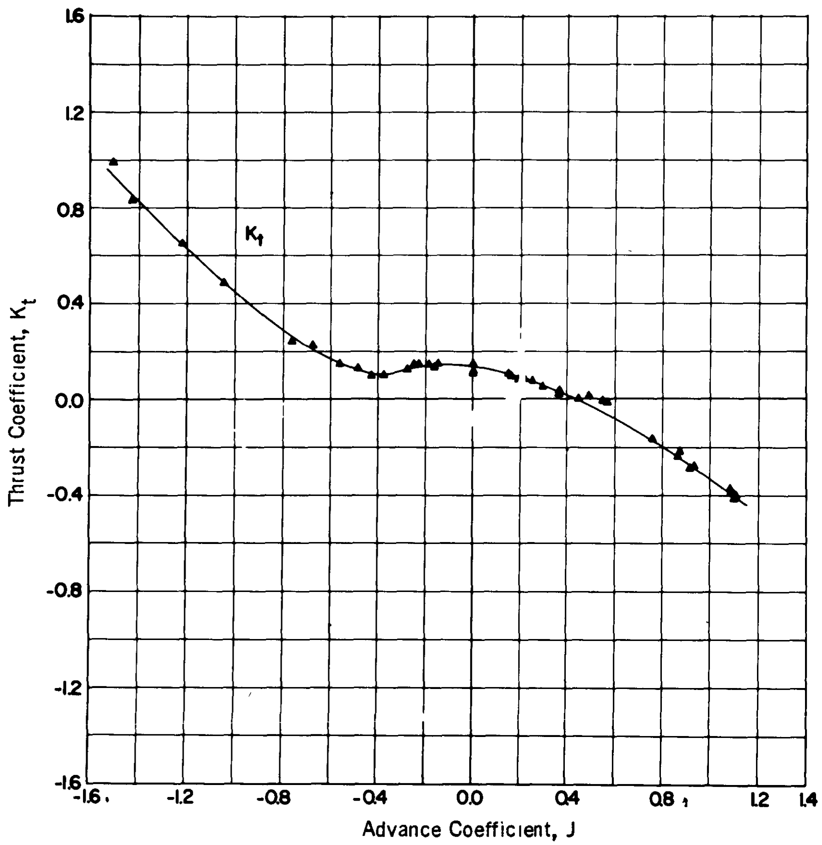


Figure 40 - Thrust Characteristic for Propeller 4122 at P/D = 0.3

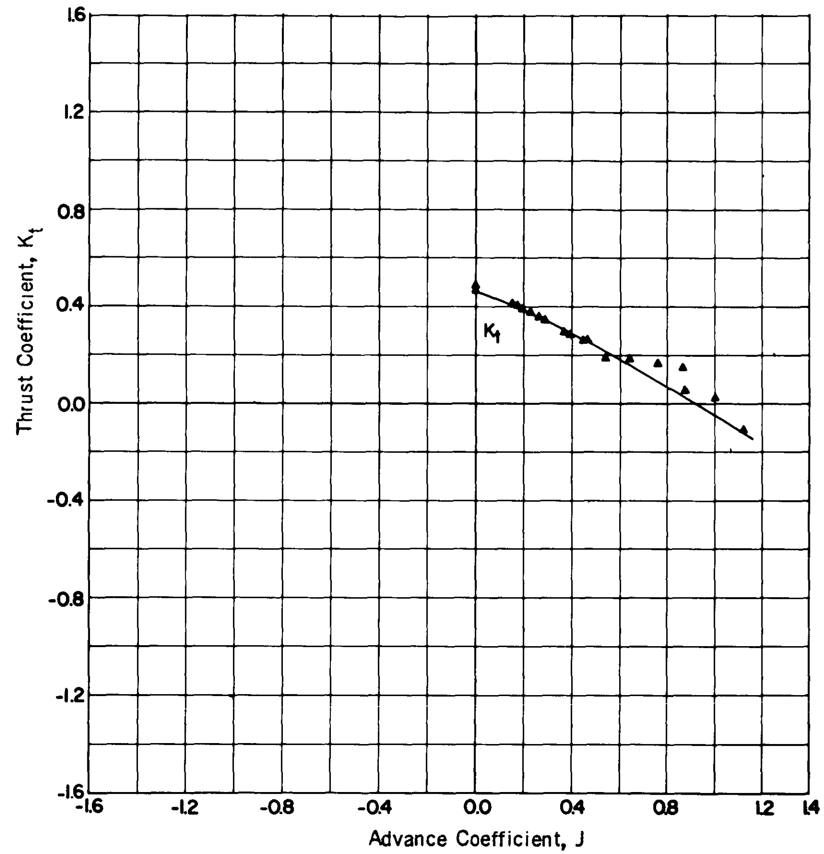


Figure 41 - Thrust Characteristic for Propeller 4122 at P/D = 0.9

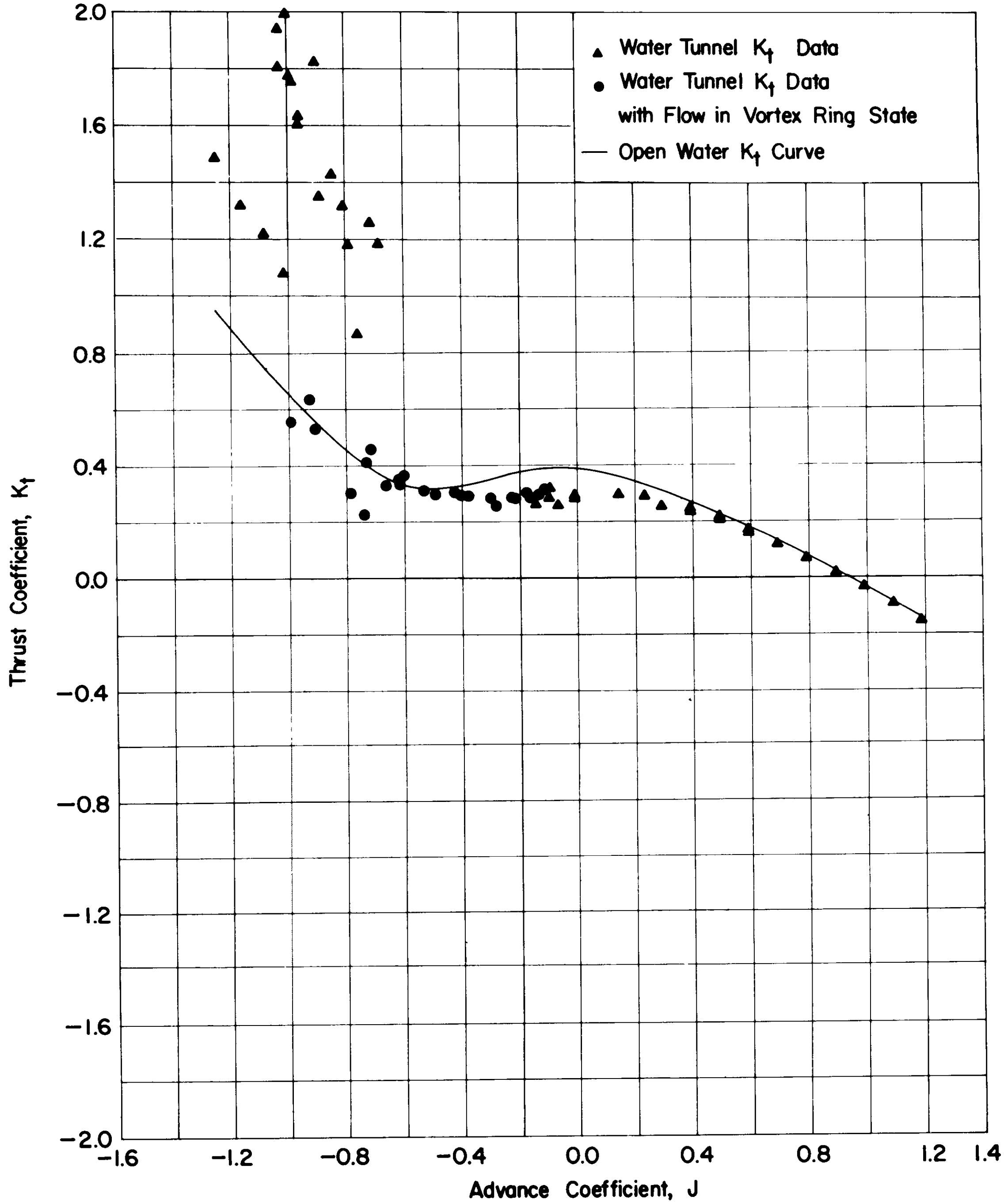


Figure 42 - Water Tunnel Thrust Coefficient Data for Propeller 4120 at P/D = 0.9

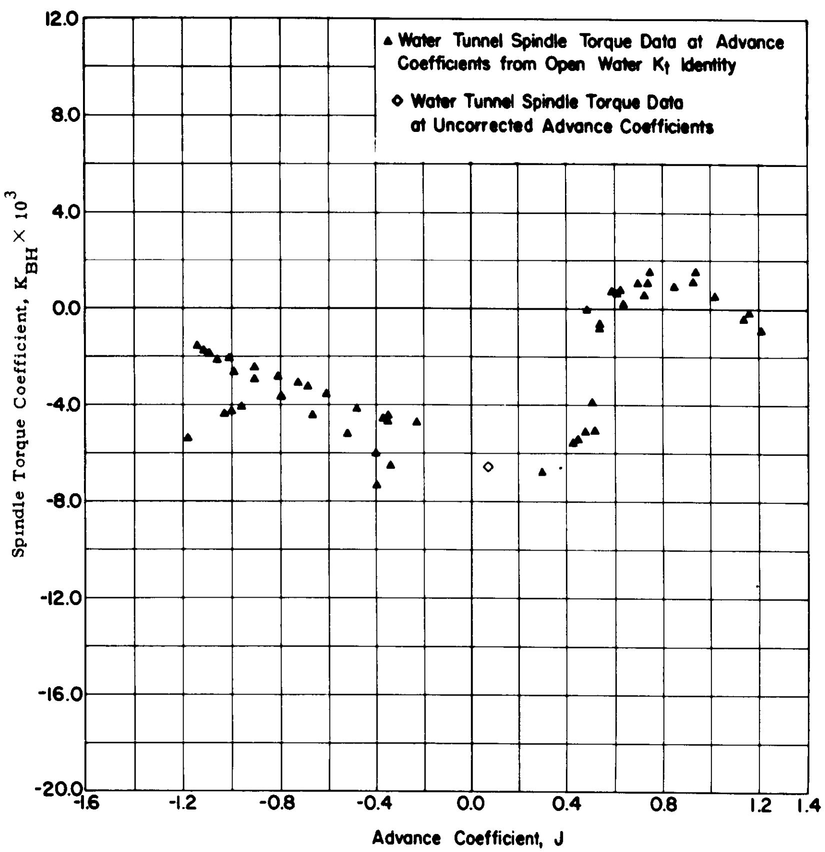


Figure 43 - Hydrodynamic Blade Spindle Torque Characteristic for Propeller 3728 at P/D = -0.9

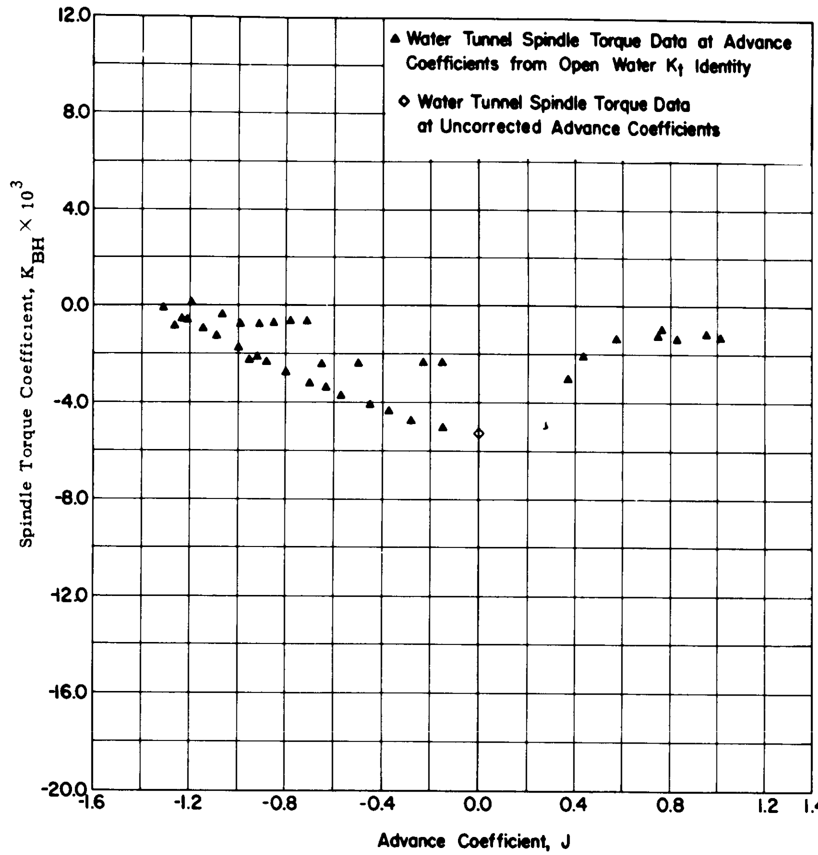


Figure 44 - Hydrodynamic Blade Spindle Torque Characteristic for Propeller 3728 at P/D = -0.6

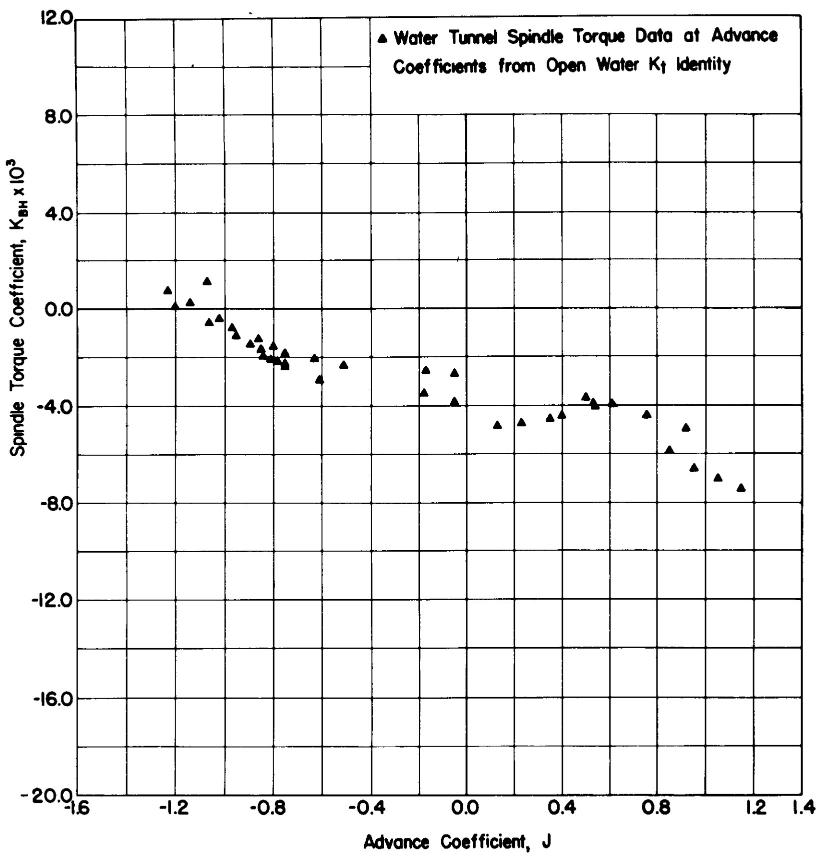


Figure 45 - Hydrodynamic Blade Spindle Torque Characteristic for Propeller 3728 at P/D = -0.3

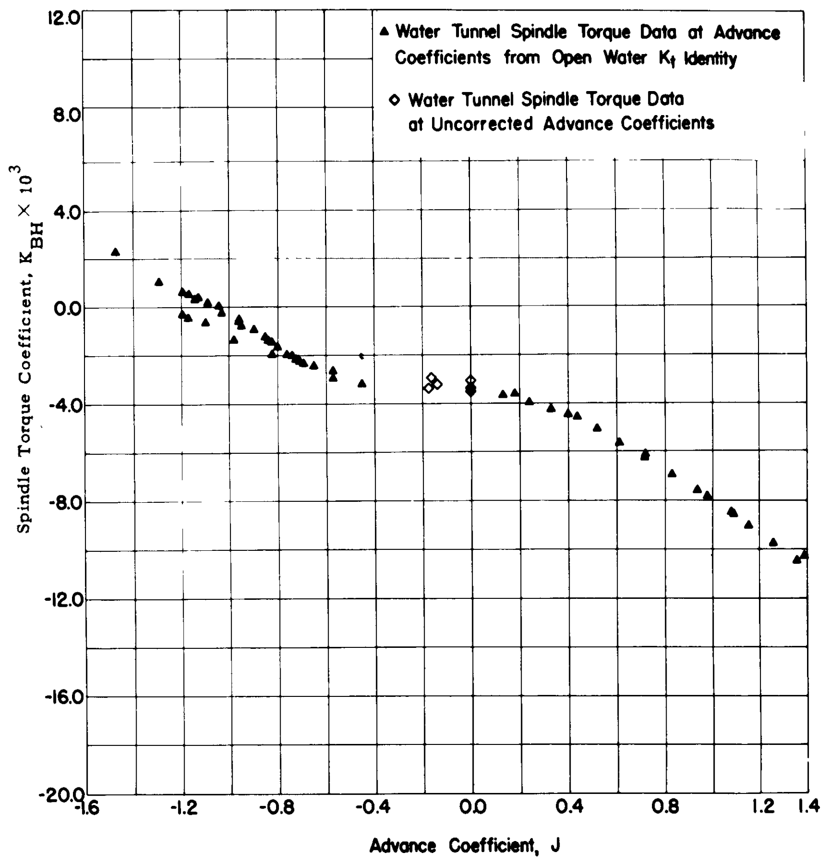


Figure 46 - Hydrodynamic Blade Spindle Torque Characteristic for Propeller 3728 at P/D = 0.0

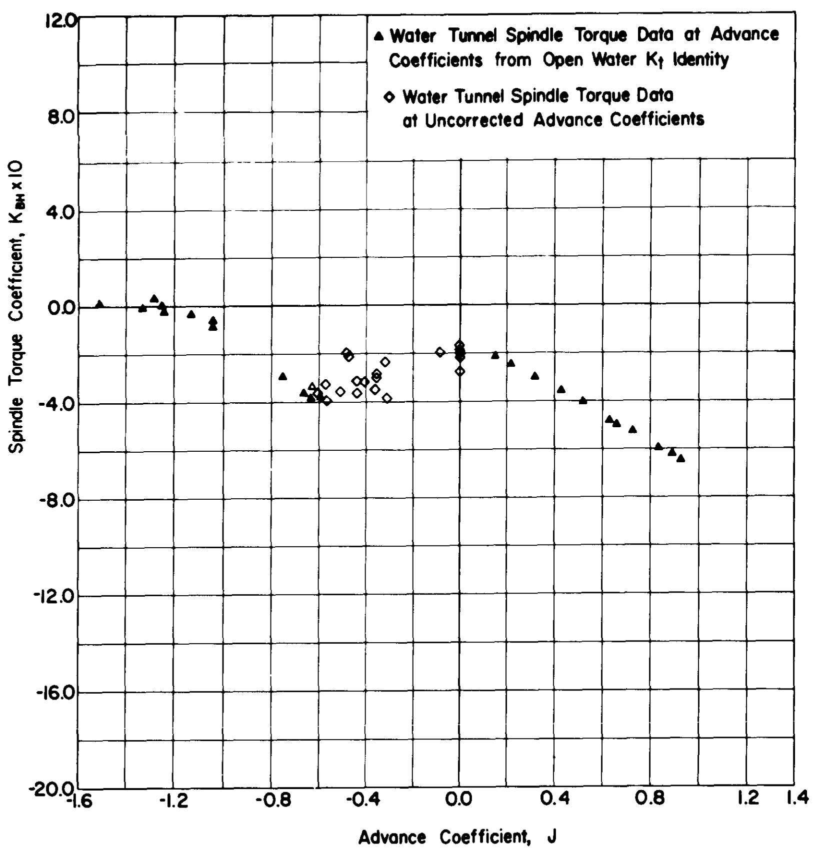


Figure 47 - Hydrodynamic Blade Spindle Torque Characteristic for Propeller 3728 at P/D = 0.3

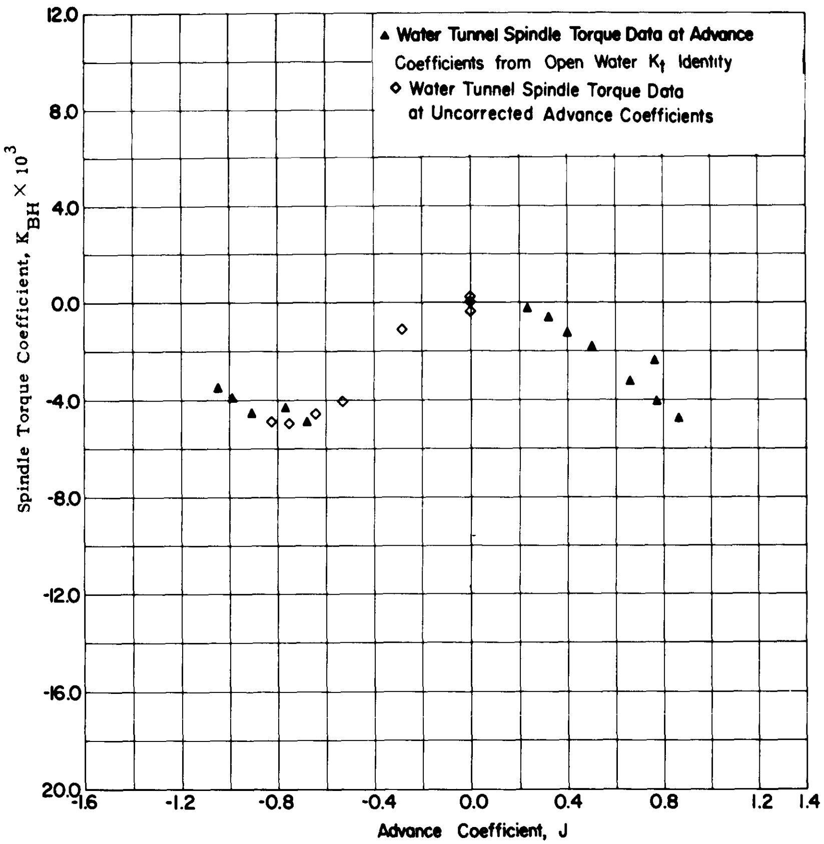


Figure 48 - Hydrodynamic Blade Spindle Torque Characteristic for Propeller 3728 at P/D = 0.6

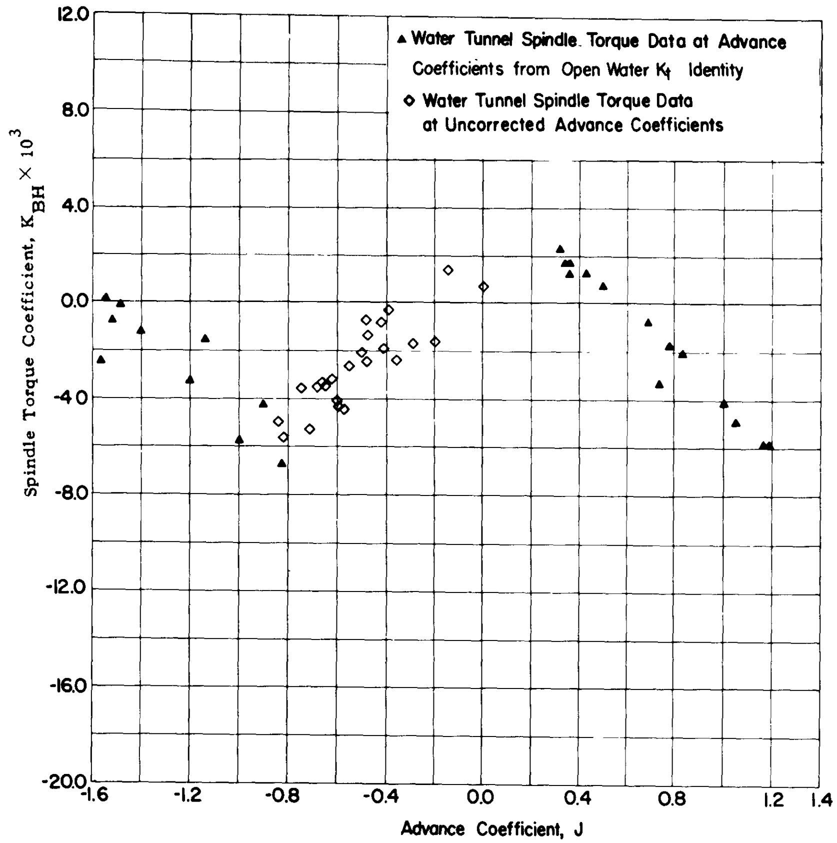


Figure 49 - Hydrodynamic Blade Spindle Torque Characteristic for Propeller 3728 at P/D = 0.9

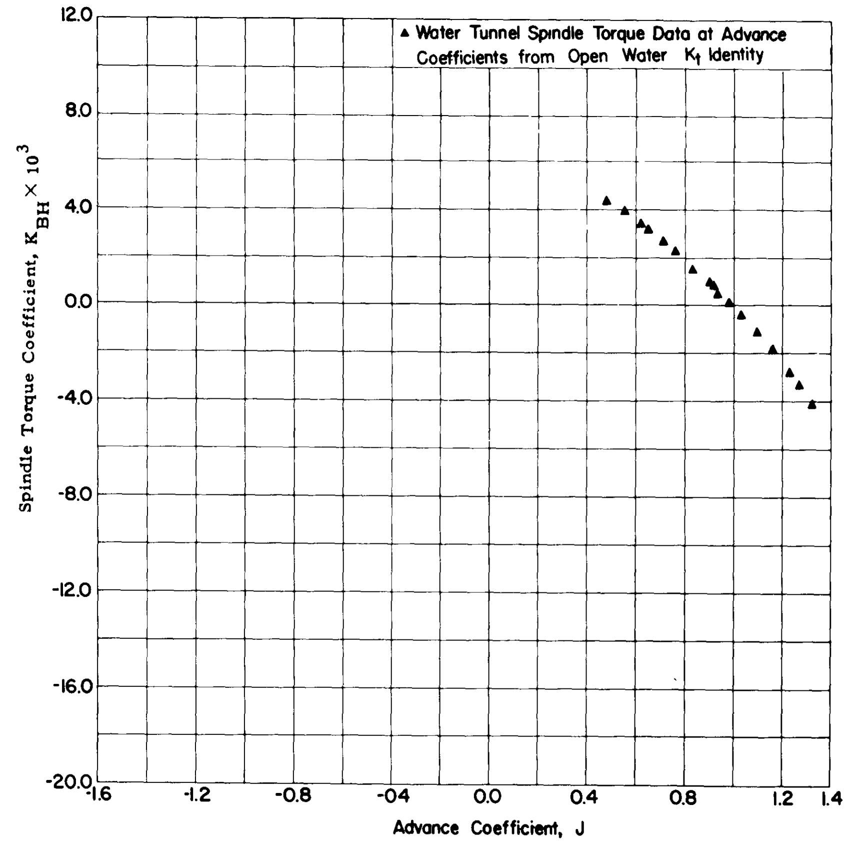


Figure 50 - Hydrodynamic Blade Spindle Torque Characteristic for Propeller 3728 at P/D = 1.2

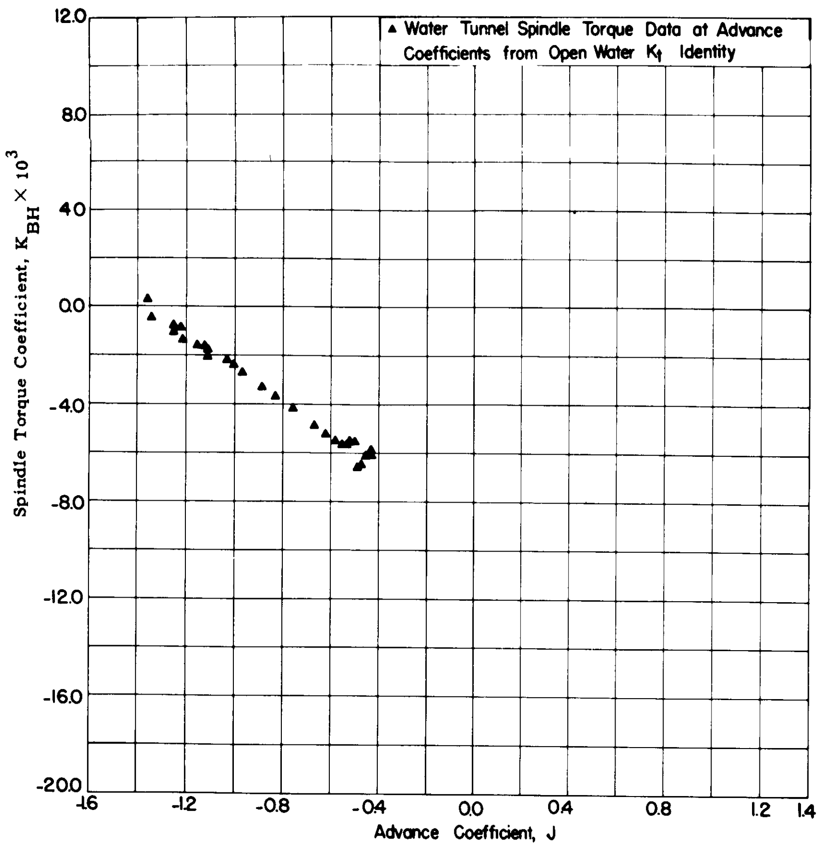


Figure 51 - Hydrodynamic Blade Spindle Torque Characteristic for Propeller 3771 at P/D = -1.2

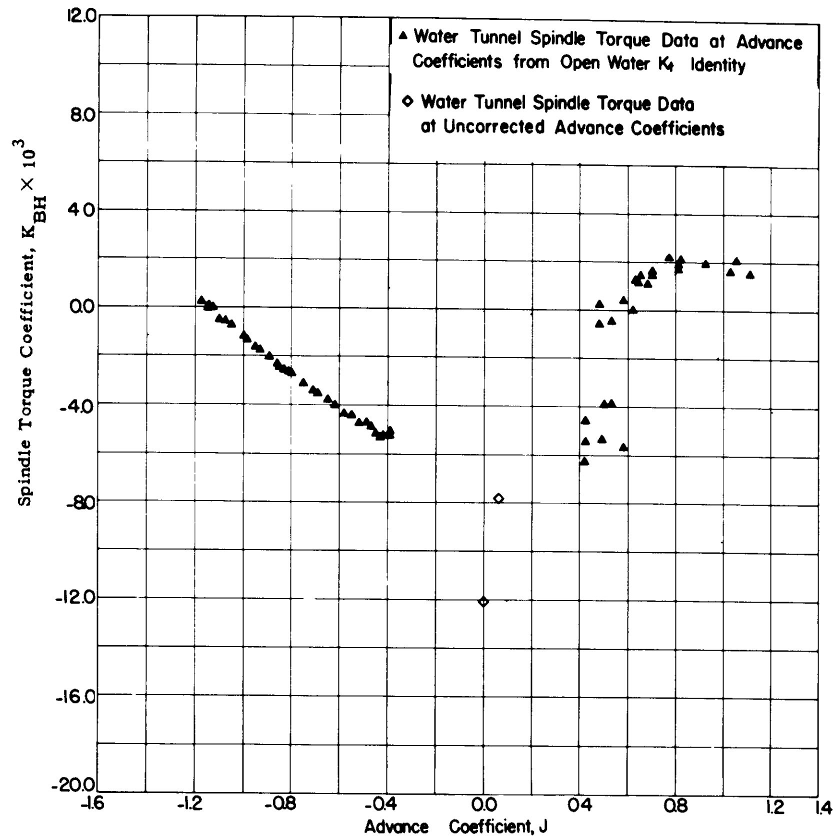


Figure 52 - Hydrodynamic Blade Spindle Torque Characteristic for Propeller 3771 at P/D = -0.9

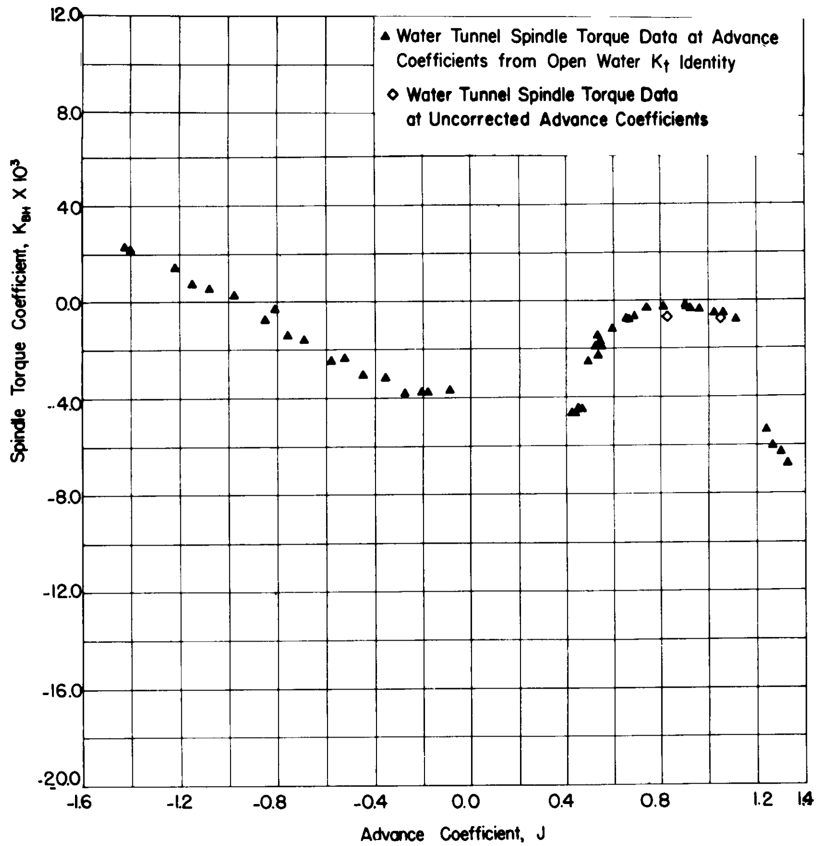


Figure 53 - Hydrodynamic Blade Spindle Torque Characteristic for Propeller 3771 at P/D = -0.6

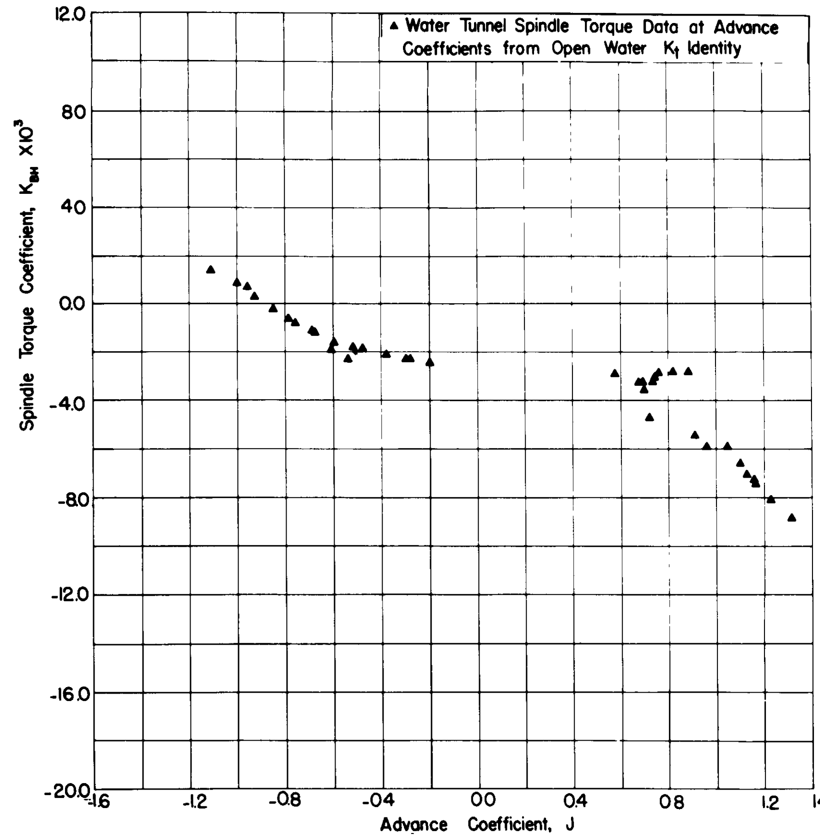


Figure 54 - Hydrodynamic Blade Spindle Torque Characteristic for Propeller 3771 at P/D = -0.3

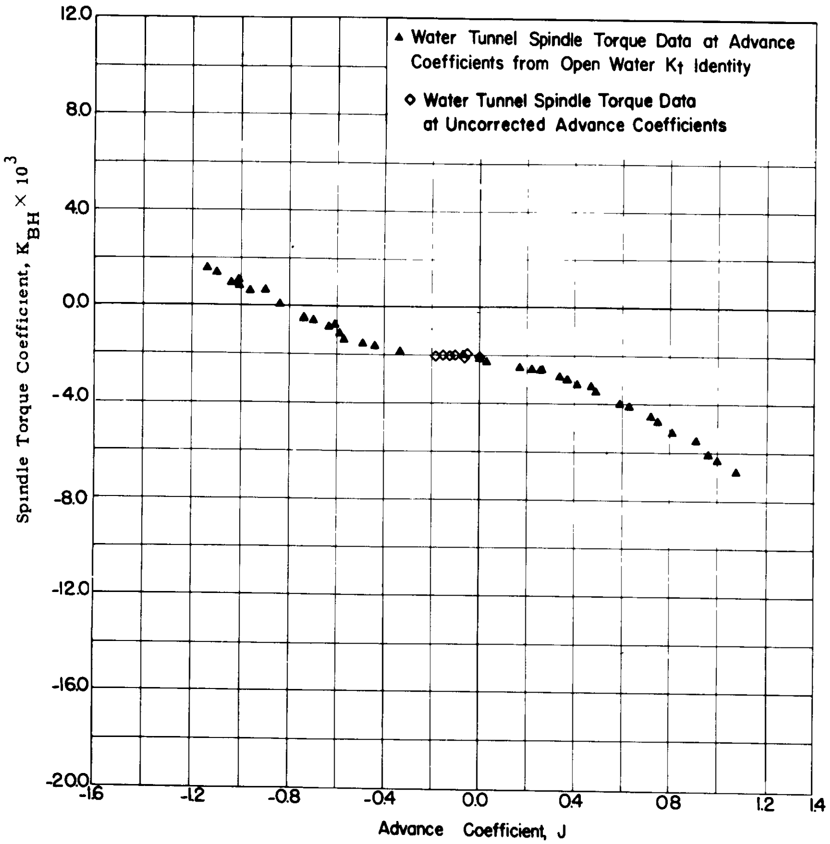


Figure 55 - Hydrodynamic Blade Spindle Torque Characteristic for Propeller 3771 at P/D = 0.0

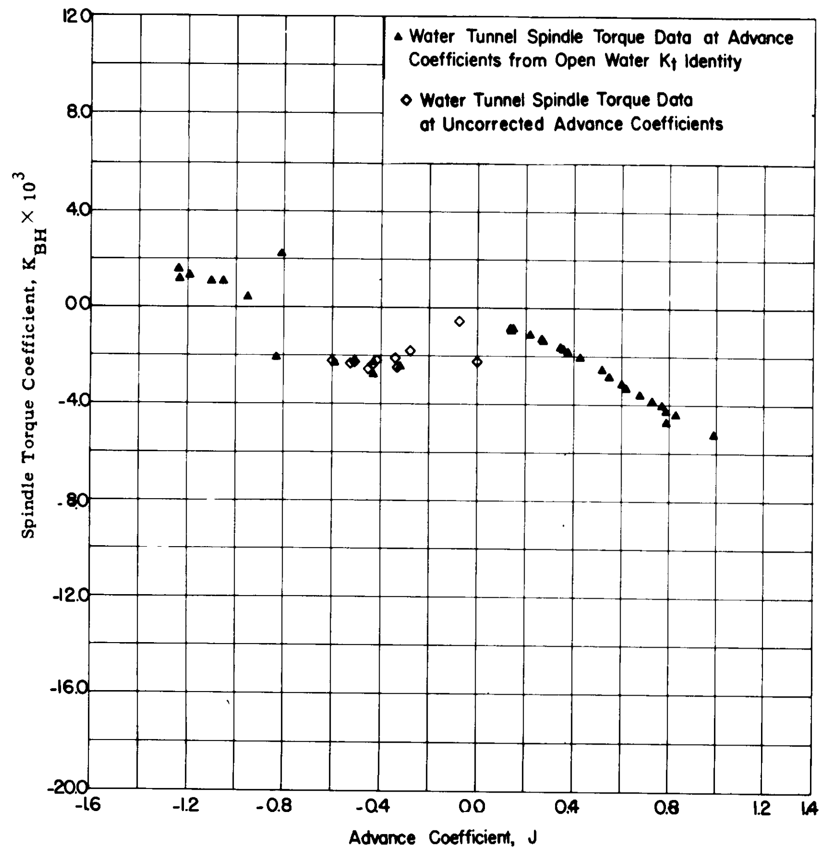


Figure 56 - Hydrodynamic Blade Spindle Torque Characteristic for Propeller 3771 at P/D = 0.3

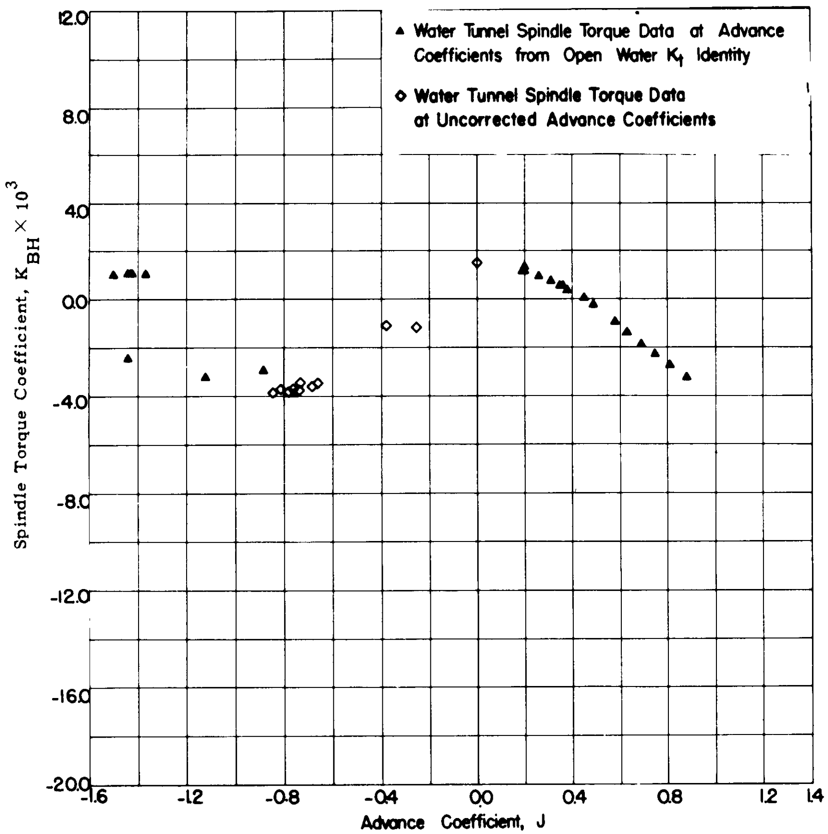


Figure 57 - Hydrodynamic Blade Spindle Torque Characteristic for Propeller 3771 at P/D = 0.6

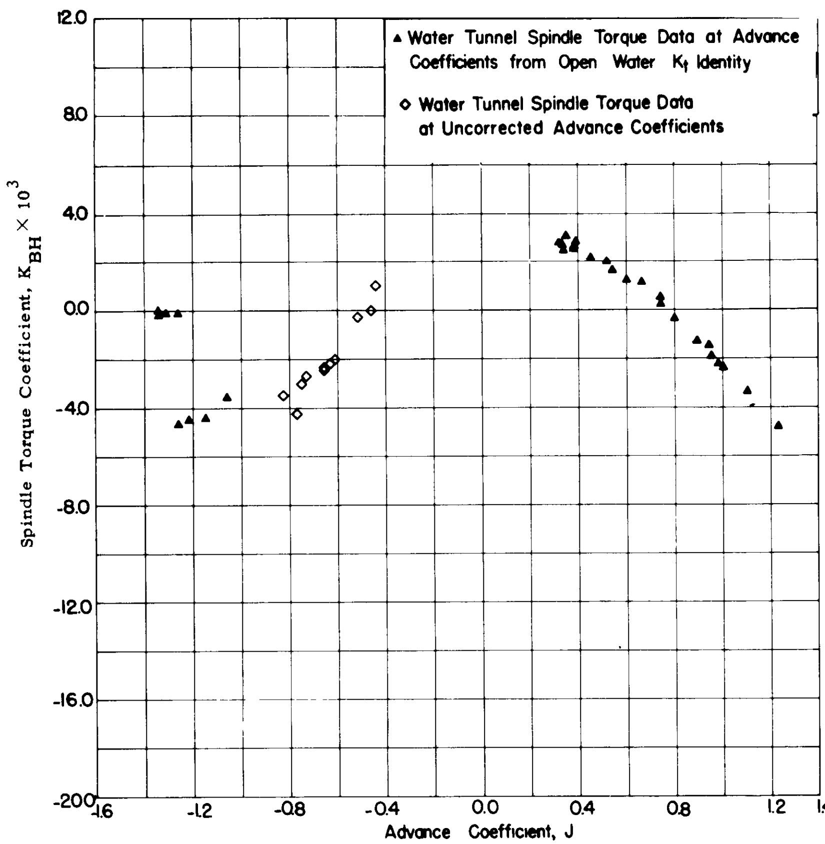


Figure 58 - Hydrodynamic Blade Spindle Torque Characteristic for Propeller 3771 at P/D = 0.9

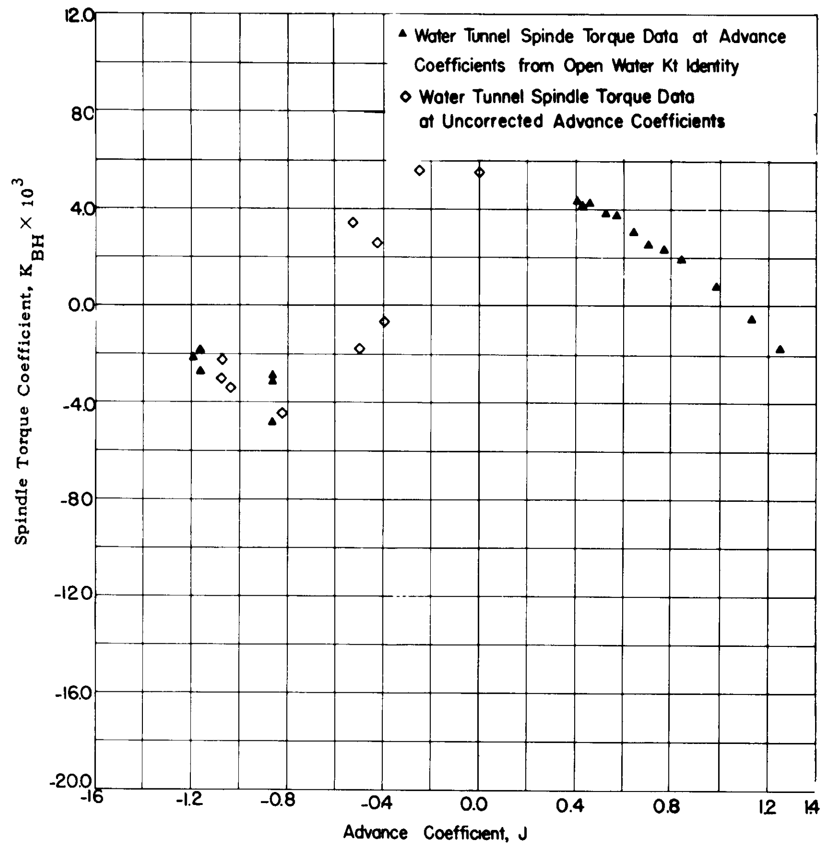


Figure 59 - Hydrodynamic Blade Spindle Torque Characteristic for Propeller 3771 at P/D = 1.2

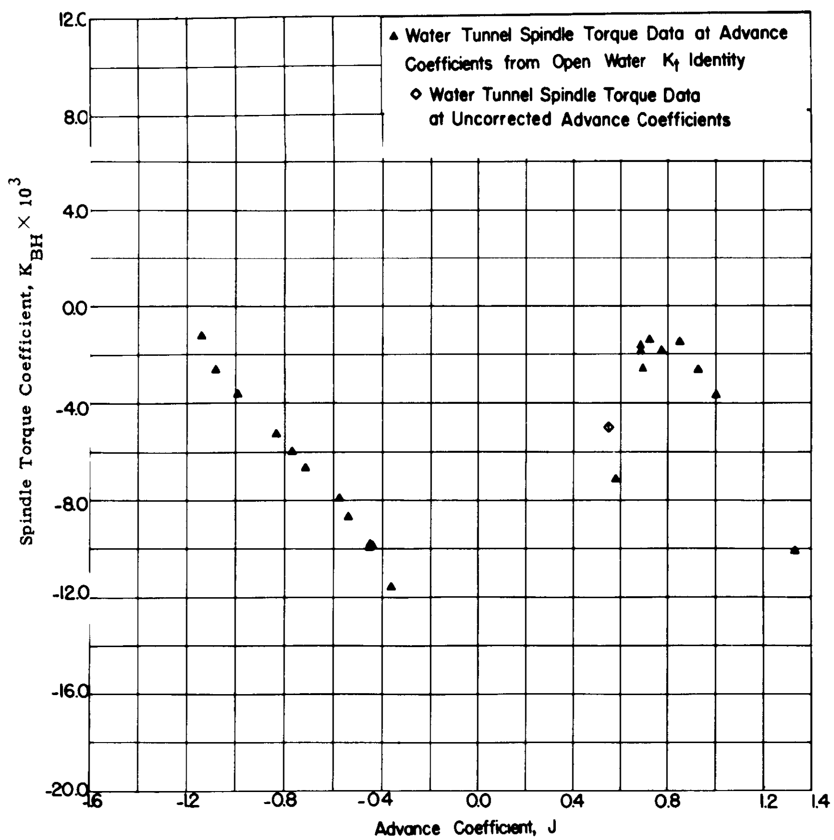


Figure 60 - Hydrodynamic Blade Spindle Torque Characteristic for Propeller 4120 at P/D = -1.2

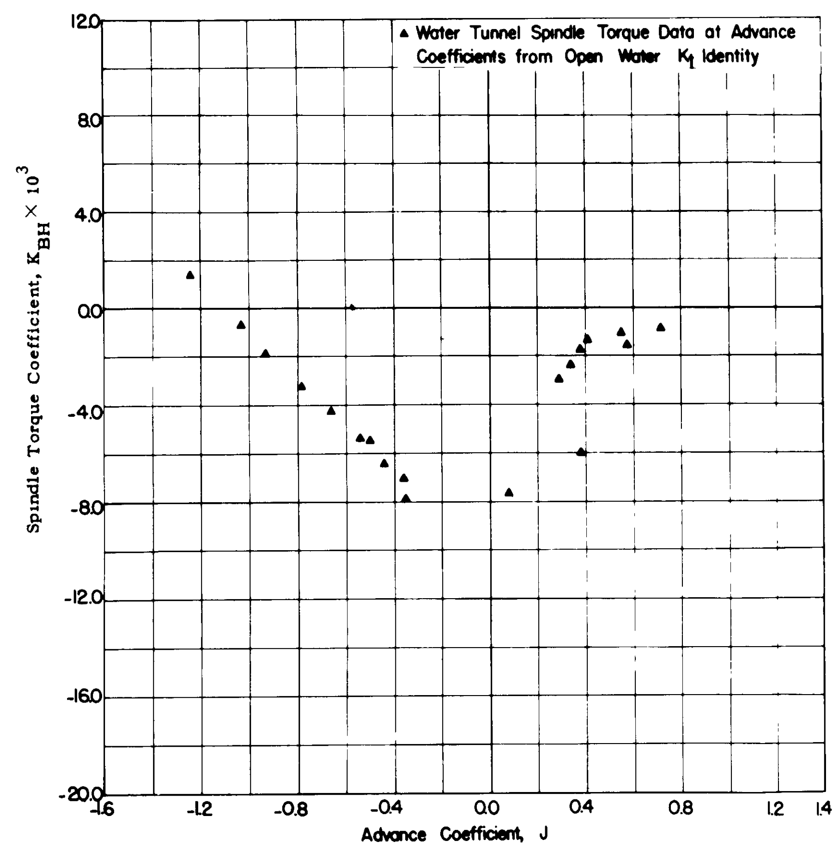


Figure 61 - Hydrodynamic Blade Spindle Torque Characteristic for Propeller 4120 at P/D = -0.9

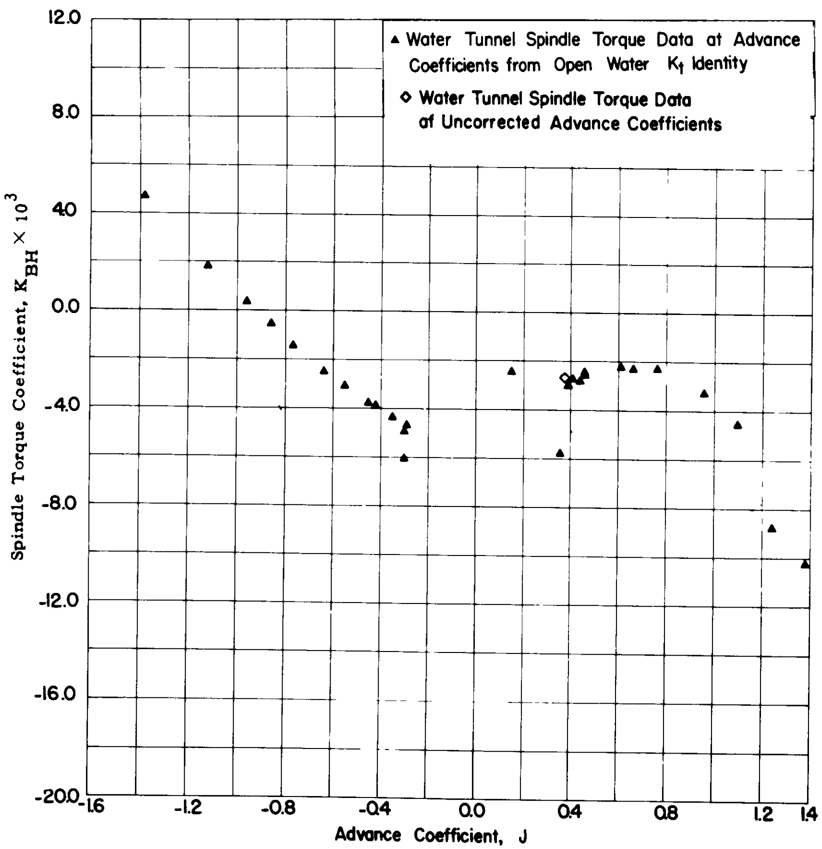


Figure 62 - Hydrodynamic Blade Spindle Torque Characteristic for Propeller 4120 at P/D = -0.6

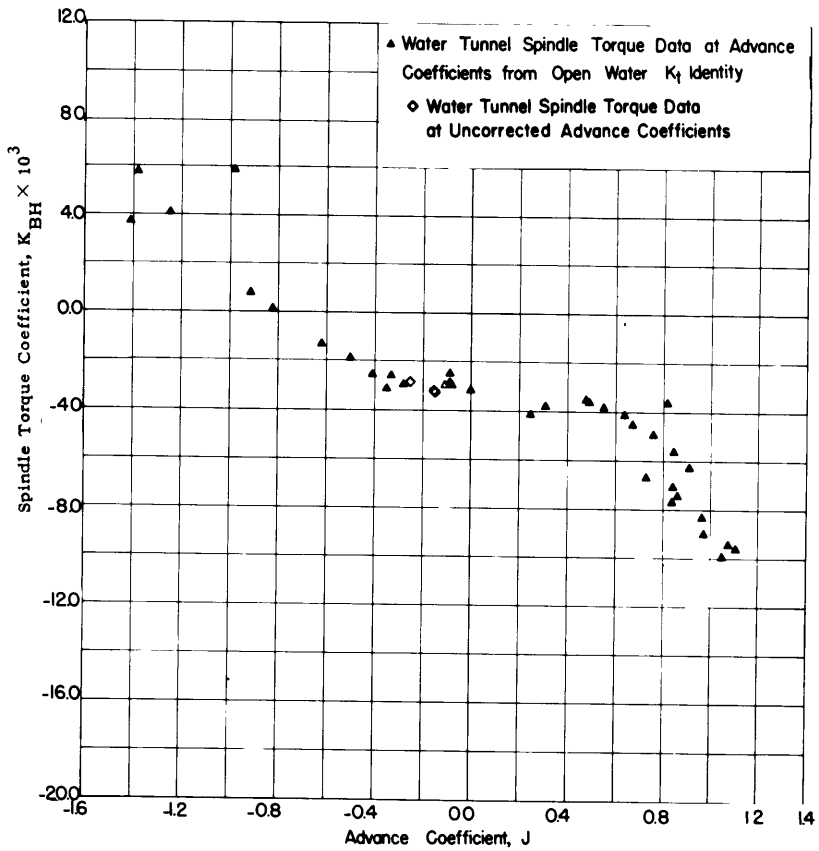


Figure 63 - Hydrodynamic Blade Spindle Torque Characteristic for Propeller 4120 at P/D = -0.3

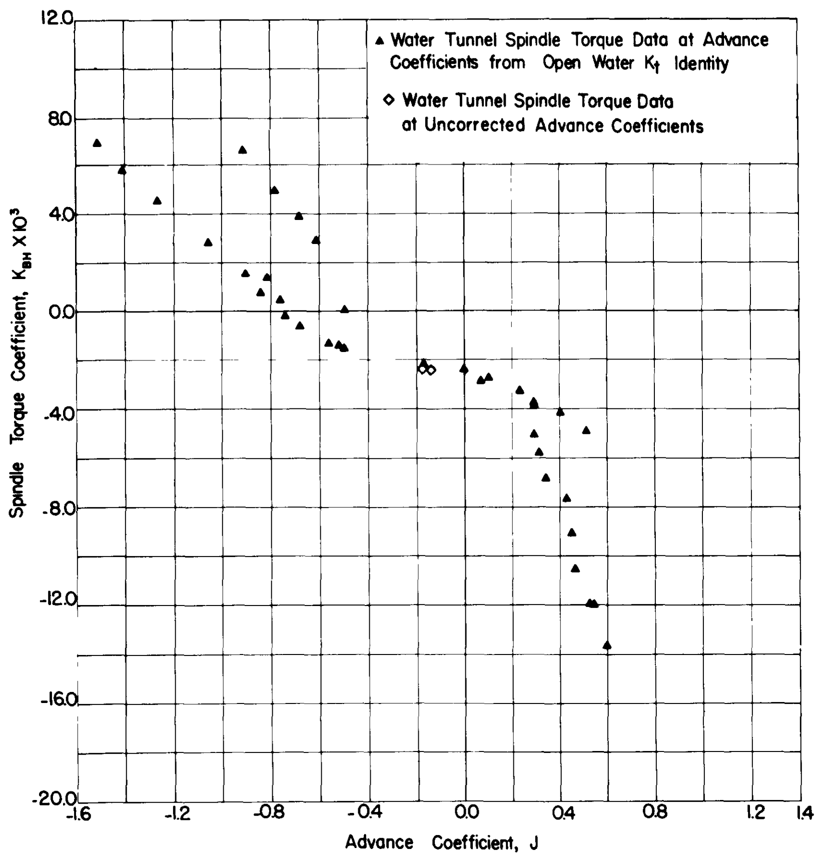


Figure 64 - Hydrodynamic Blade Spindle Torque Characteristic for Propeller 4120 at P/D = 0.0

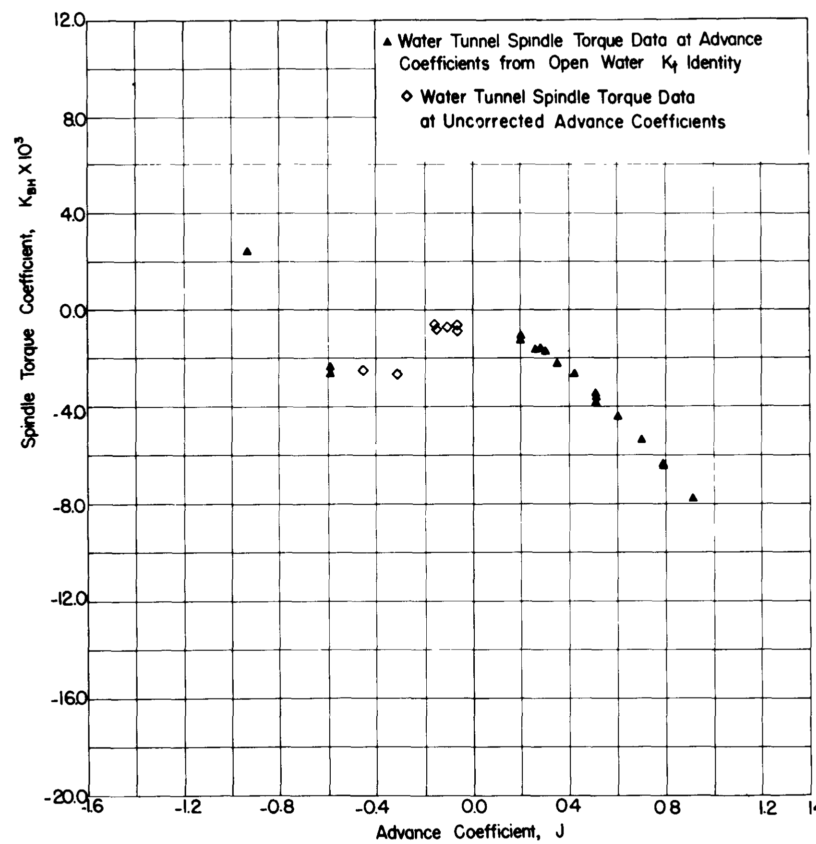


Figure 65 - Hydrodynamic Blade Spindle Torque Characteristic for Propeller 4120 at P/D = 0.3

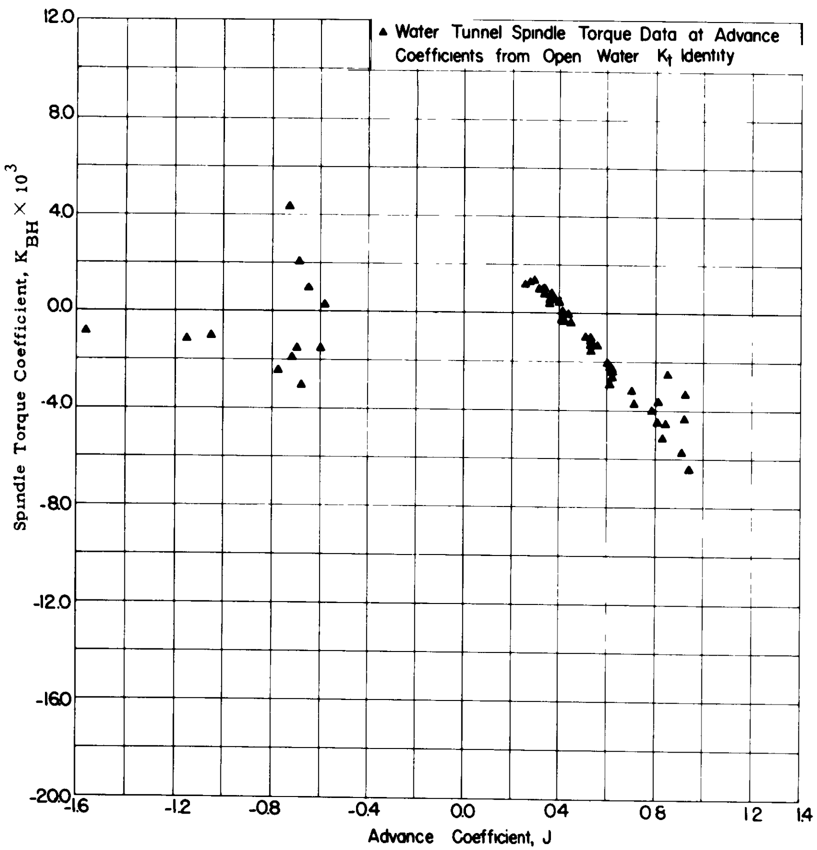


Figure 66 - Hydrodynamic Blade Spindle Torque Characteristic for Propeller 4120 at P/D = 0.6

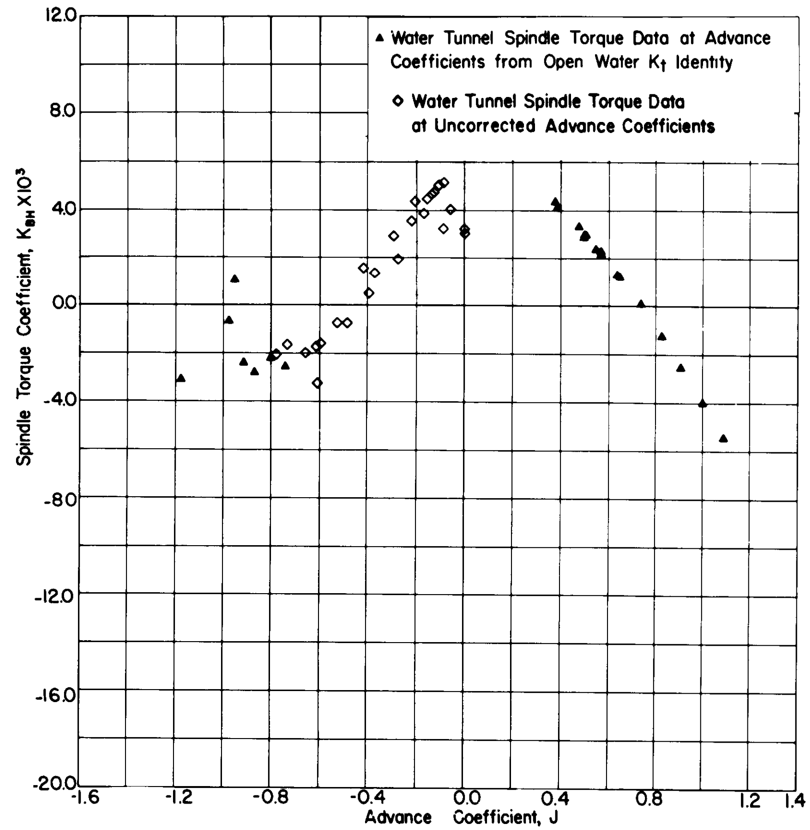


Figure 67 - Hydrodynamic Blade Spindle Torque Characteristic for Propeller 4120 at P/D = 0.9

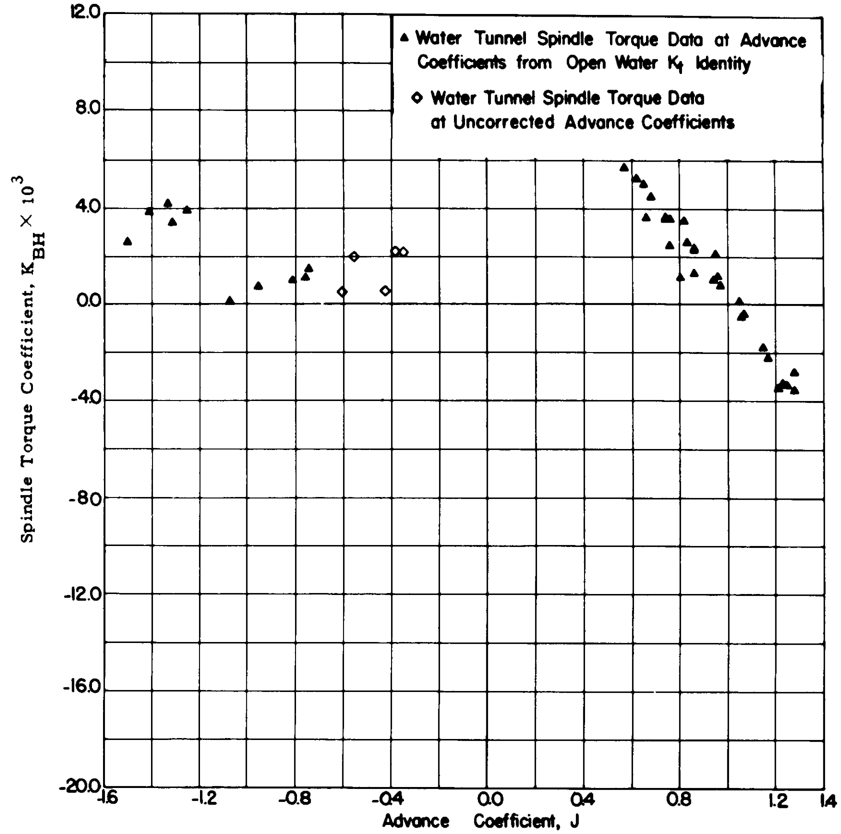


Figure 68 - Hydrodynamic Blade Spindle Torque Characteristic for Propeller 4120 at P/D = 1.2

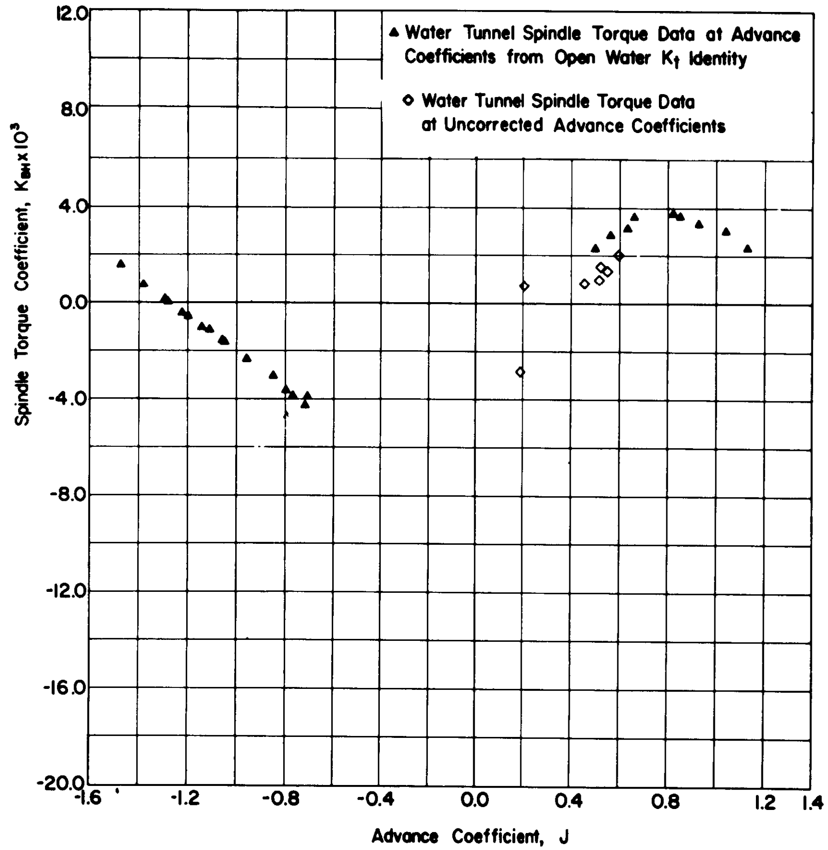


Figure 69 - Hydrodynamic Blade Spindle Torque Characteristic for Propeller 4121 at P/D = -0.9

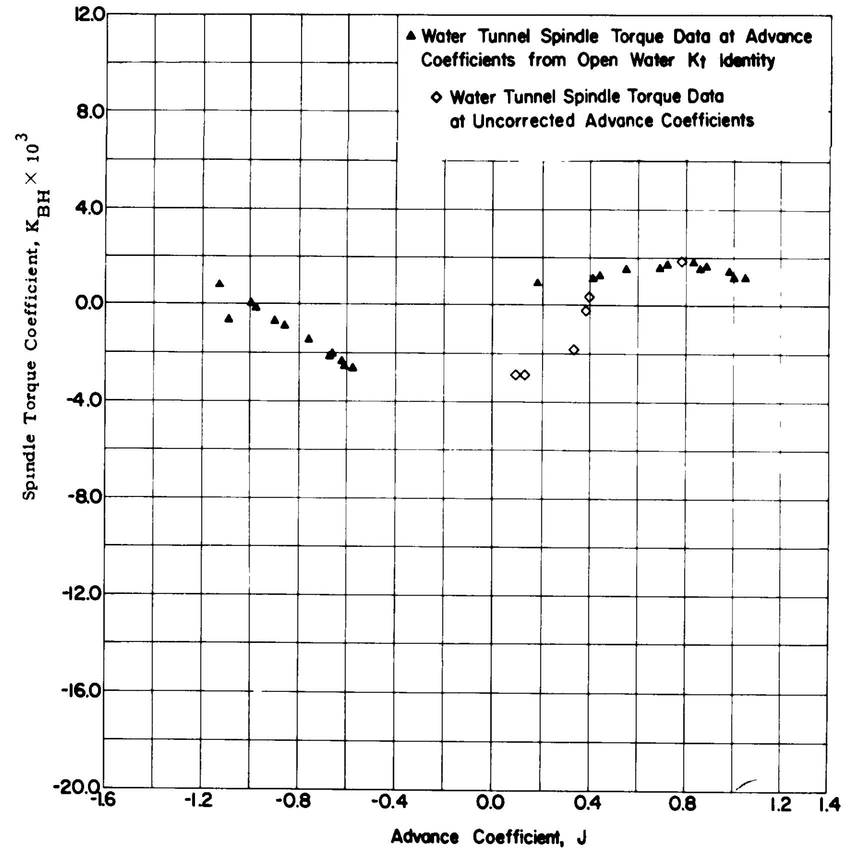


Figure 70 - Hydrodynamic Blade Spindle Torque Characteristic for Propeller 4121 at P/D = -0.6

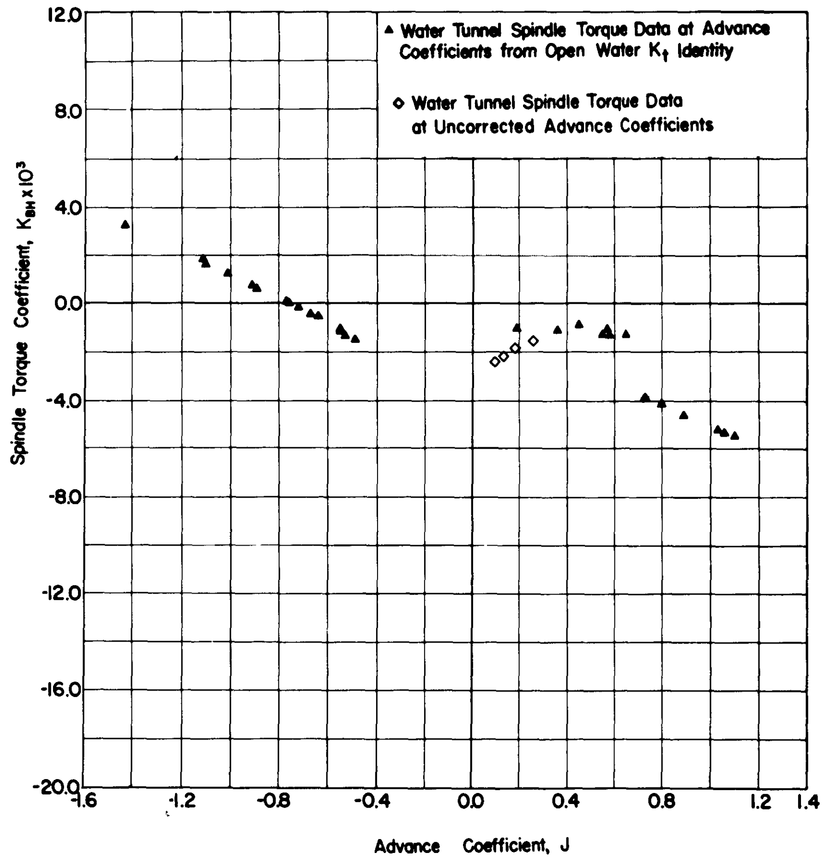


Figure 71 - Hydrodynamic Blade Spindle Torque Characteristic for Propeller 4121 at P/D = -0.3

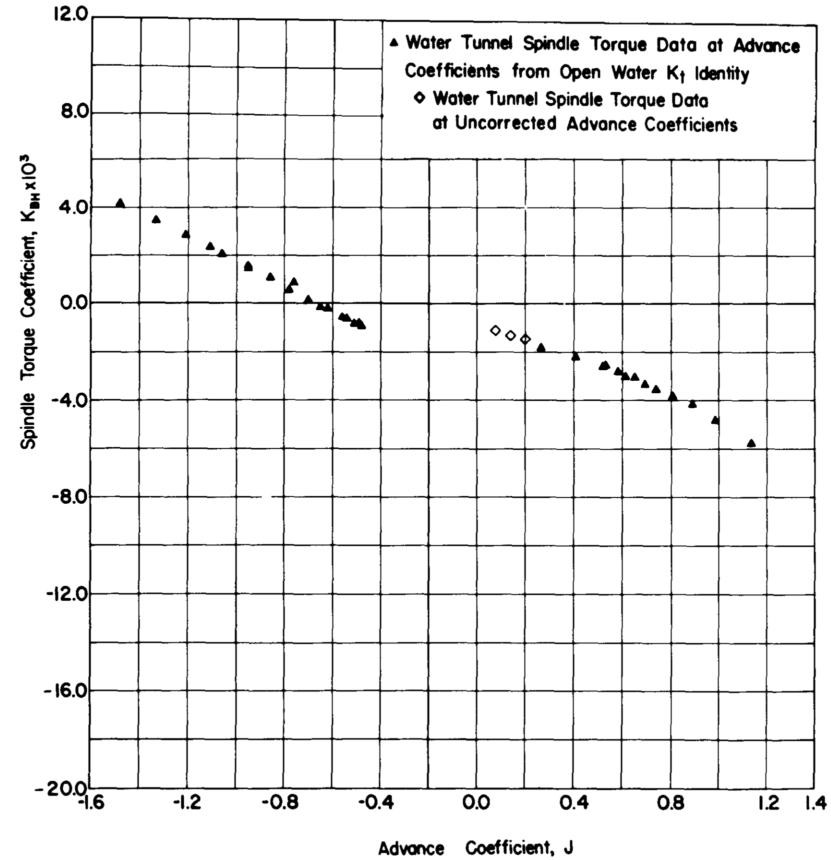


Figure 72 - Hydrodynamic Blade Spindle Torque Characteristic for Propeller 4121 at P/D = 0.0

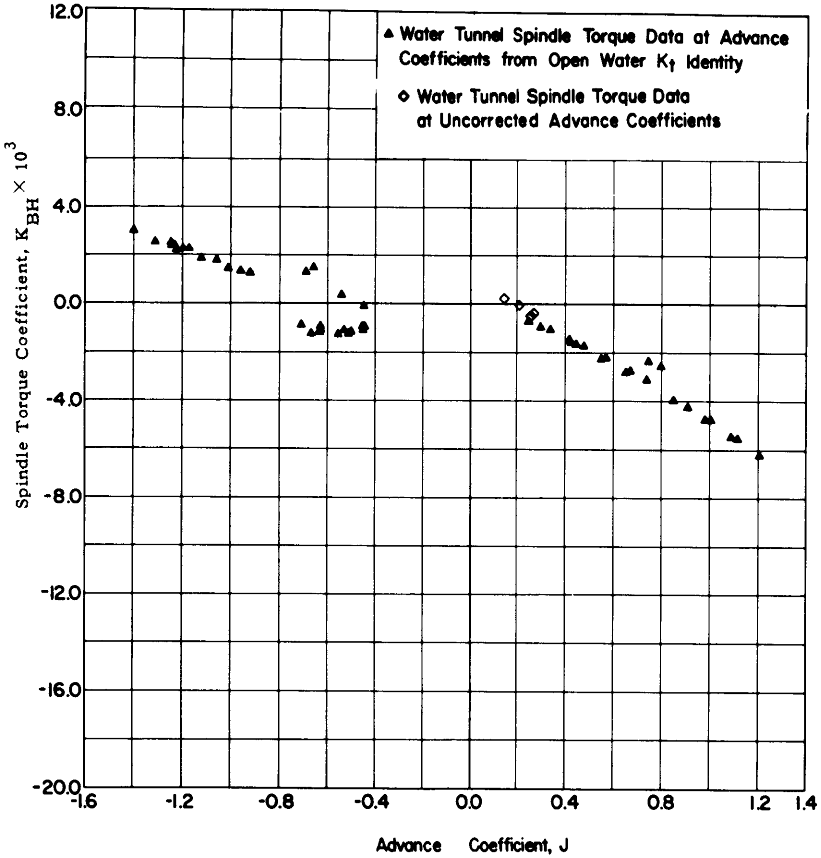


Figure 73 - Hydrodynamic Blade Spindle Torque Characteristic for Propeller 4121 at P/D = 0.3

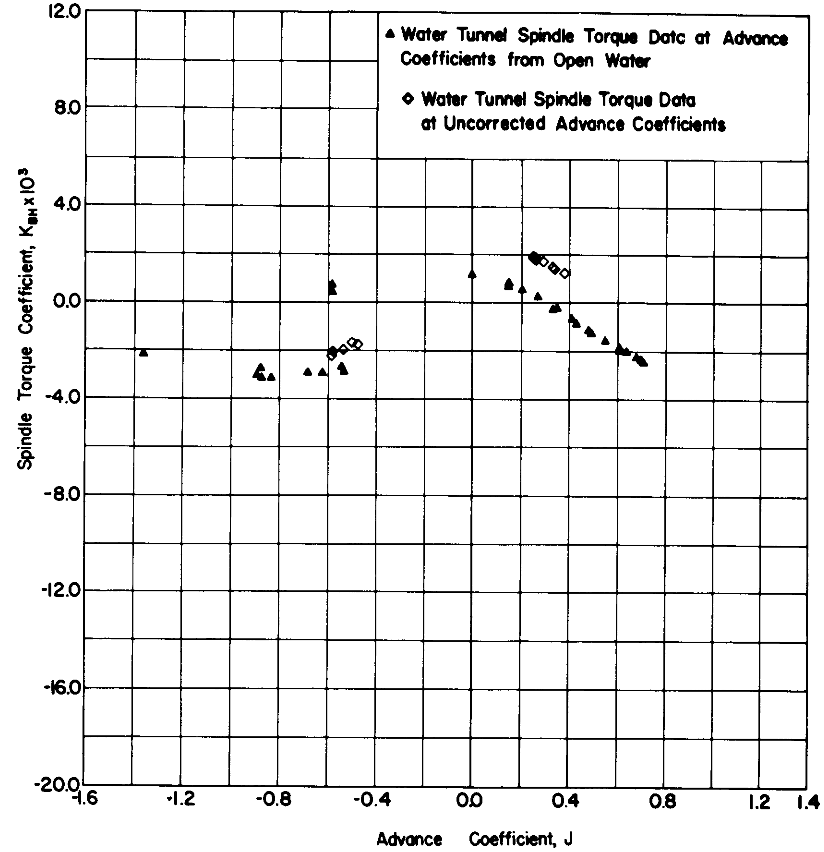


Figure 74 - Hydrodynamic Blade Spindle Torque Characteristic for Propeller 4121 at P/D = 0.6

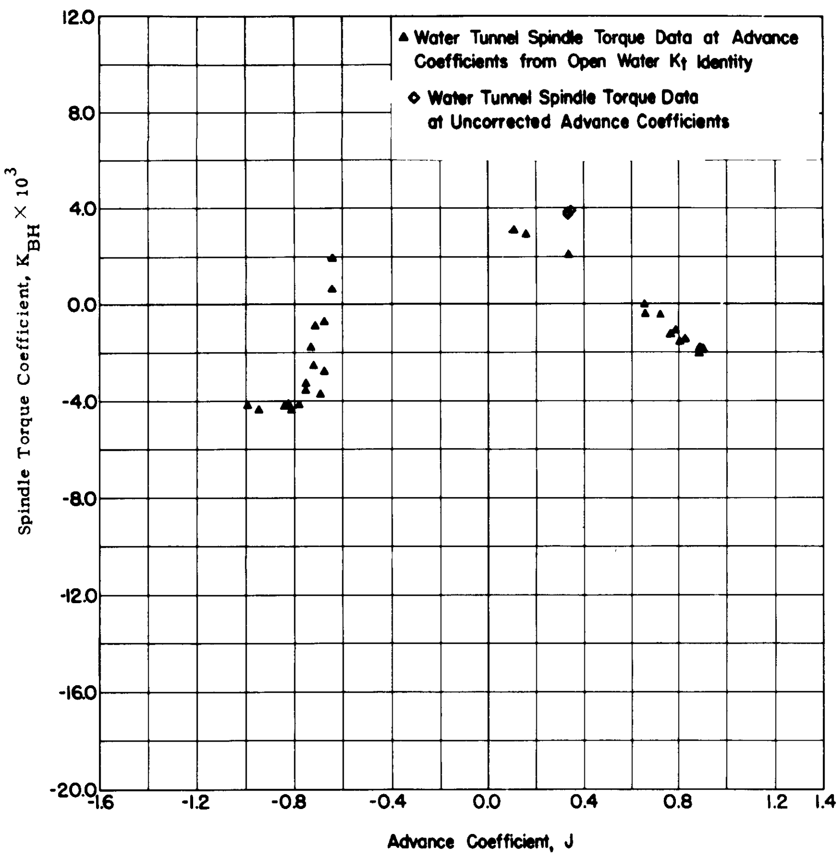


Figure 75 - Hydrodynamic Blade Spindle Torque Characteristic for Propeller 4121 at P/D = 0.9

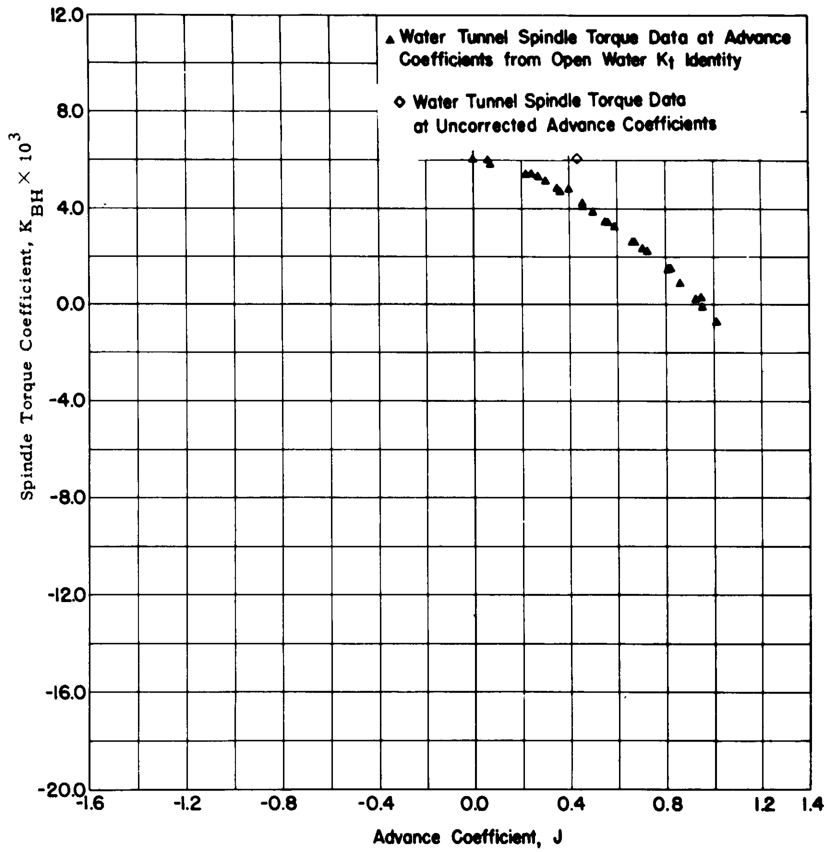


Figure 76 - Hydrodynamic Blade Spindle Torque Characteristic for Propeller 4121 at P/D = 1.2

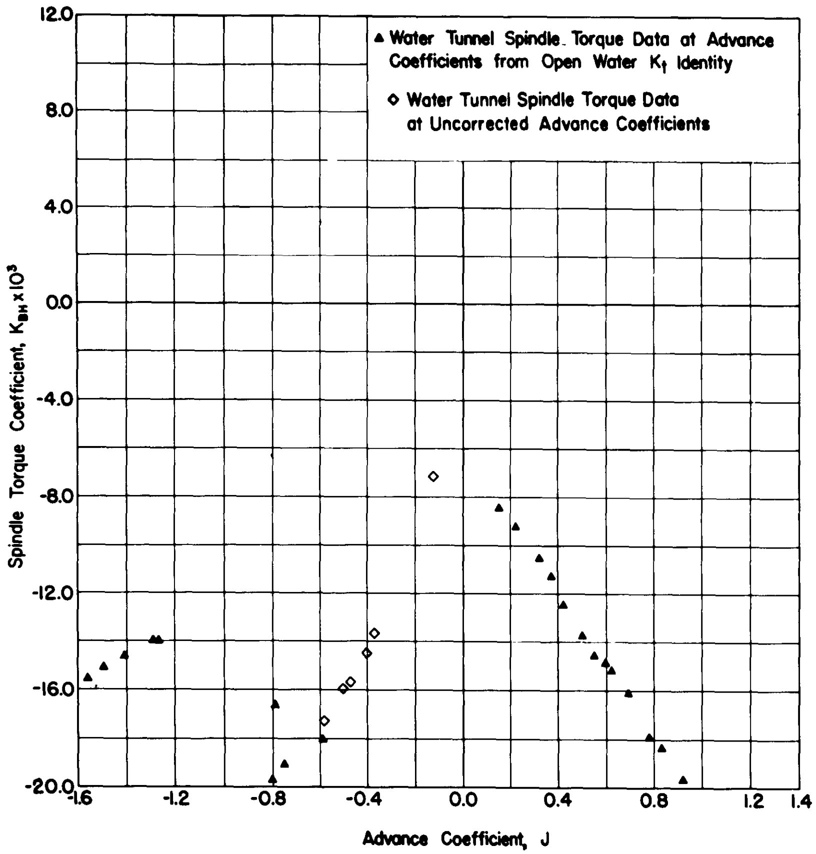


Figure 77 - Hydrodynamic Blade Spindle Torque Characteristic for Propeller 4122 at P/D = 0.3

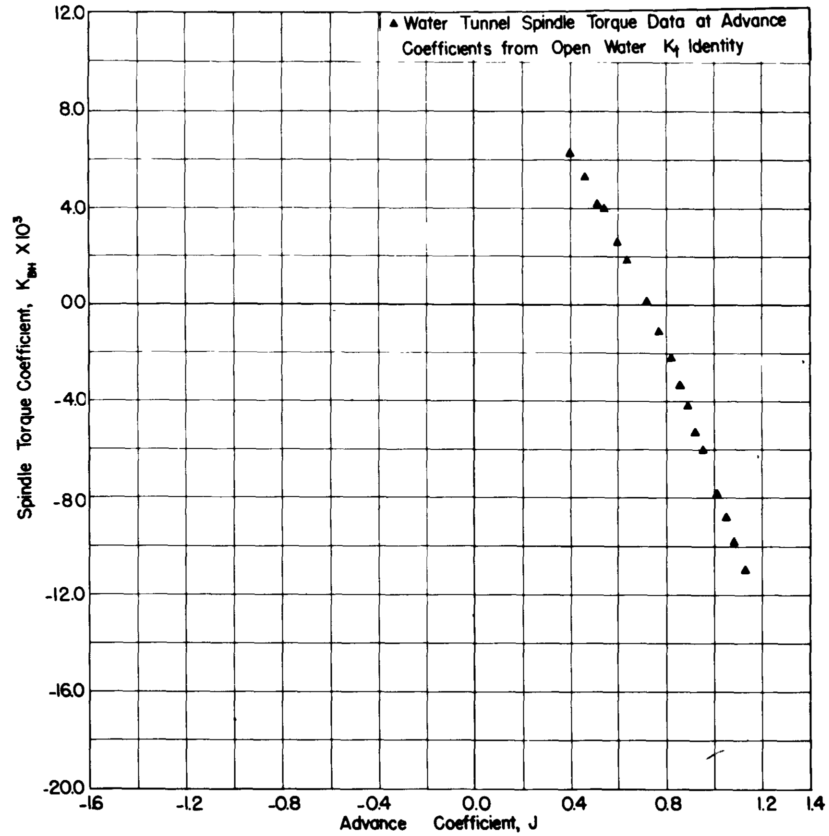


Figure 78 - Hydrodynamic Blade Spindle Torque Characteristic for Propeller 4122 at P/D = 0.9

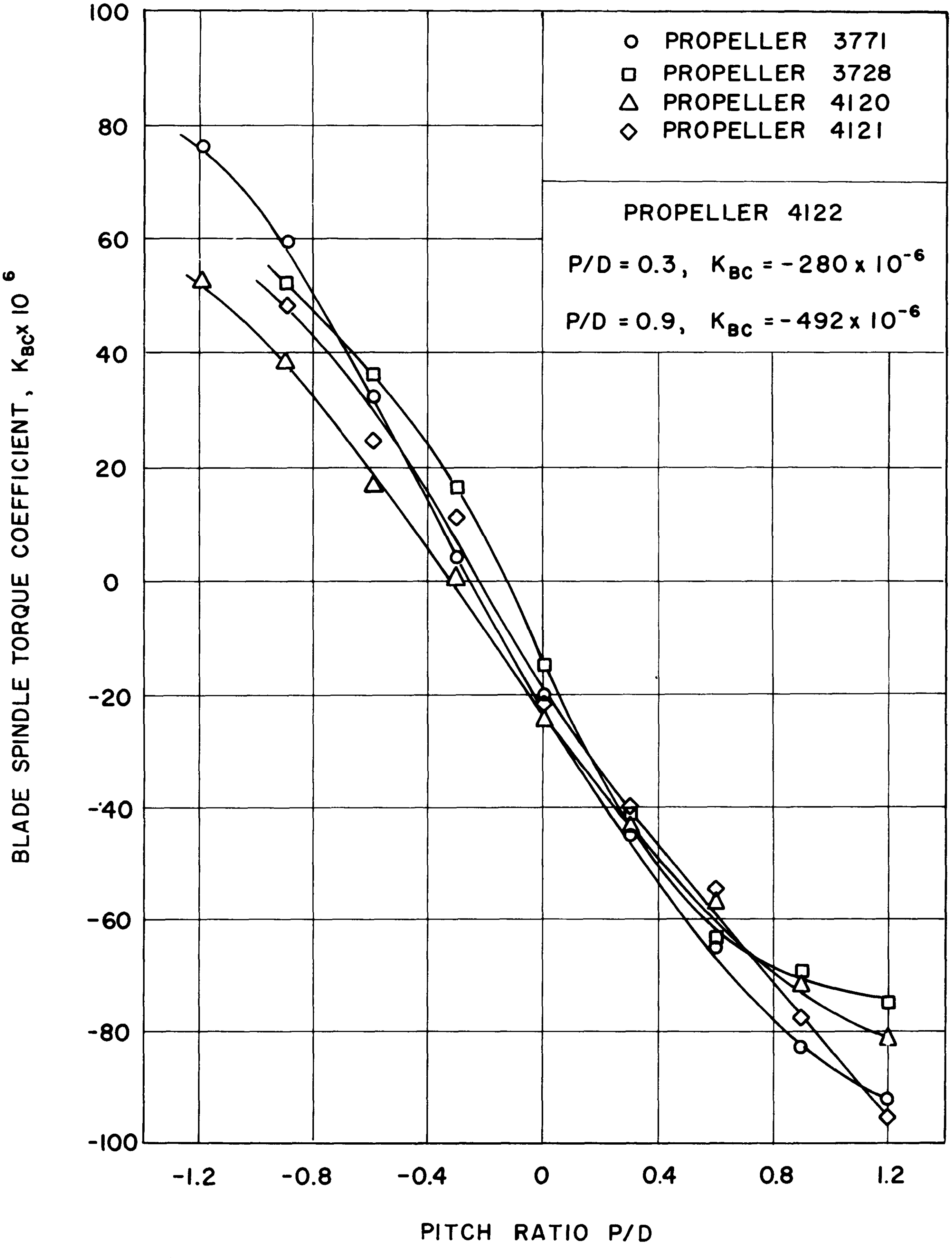


Figure 79 - Experimental Centrifugal Blade Spindle Torque for Propellers 3728, 3771, 4120, 4121, and 4122

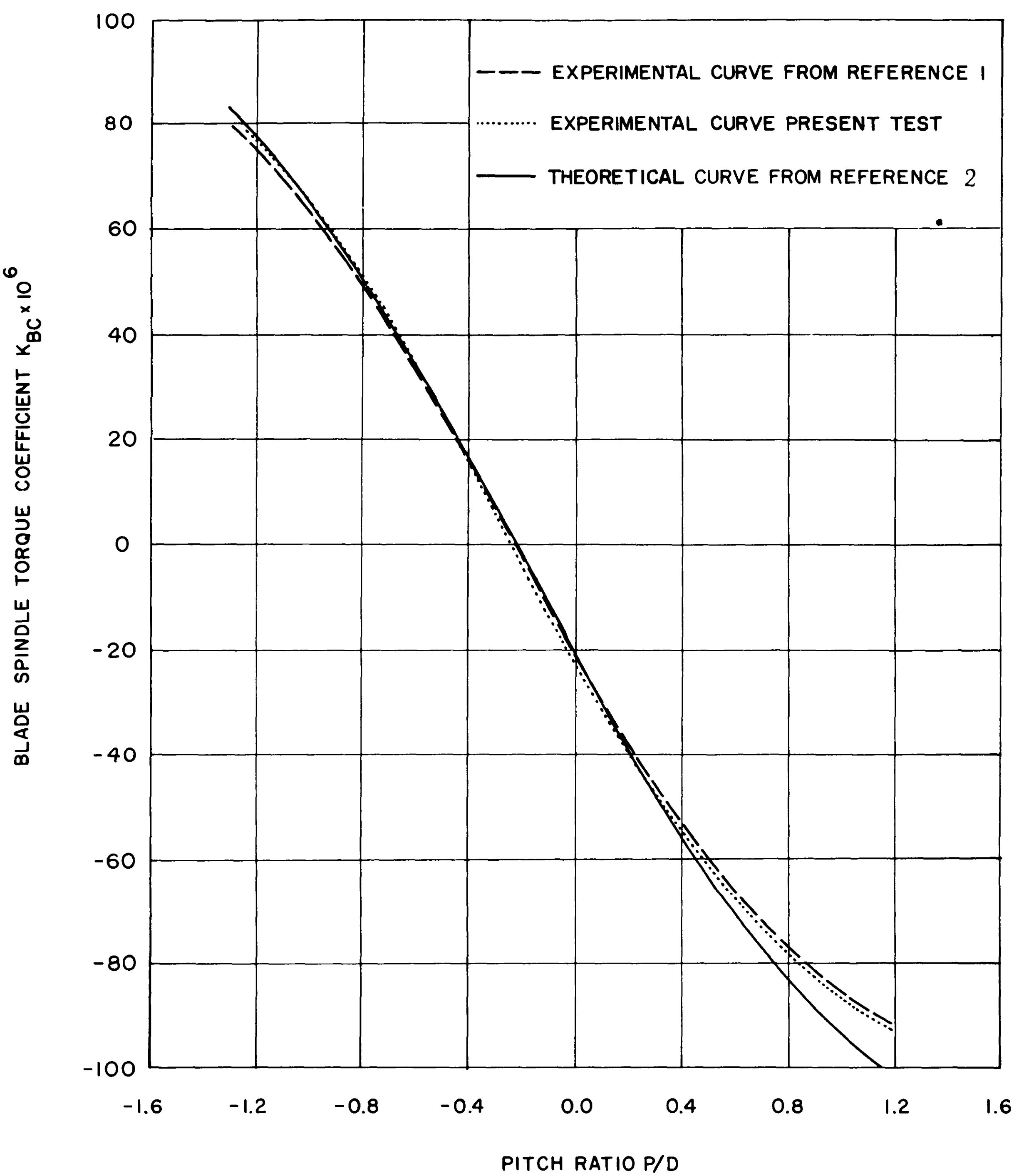


Figure 80 - Centrifugal Blade Spindle Torque for Propeller 3771

TABLE 2

Maximum and Minimum Values of Advance Coefficients and Hydrodynamic Spindle-Torque Coefficients

Propeller 3728

P/D	J_{min}	J_{max}	$K_{BH_{max}} \times 10^3$	$J_{K_{BH_{max}}}$	$K_{BH_{min}} \times 10^3$	$J_{K_{BH_{min}}}$
-0.9	-1.18	1.21	1.55	0.75	-7.35	-0.40
-0.6	-1.31	1.01	0.10	-1.19	-5.25	0.00*
-0.3	-1.23	1.15	1.10	-1.07	-7.45	1.15
0.0	-1.47	1.39	2.30	-1.47	-10.45	1.36
0.3	-1.51	0.93	0.35	-1.28	- 6.45	0.93
0.6	-1.05	0.86	0.25	0.00*	-5.00	-0.75*
0.9	-1.56	1.19	2.30	0.32	-6.75	-0.83
1.2	0.48	1.32	4.30	0.48	-4.15	1.32

Propeller 4120

P/D	J_{min}	J_{max}	$K_{BH_{max}} \times 10^3$	$J_{K_{BH_{max}}}$	$K_{BH_{min}} \times 10^3$	$J_{K_{BH_{min}}}$
-1.2	-1.14	1.33	-1.25	-1.14	-11.60	-0.36
-0.9	-1.24	0.72	1.40	-1.24	- 7.90	-0.35*
-0.6	-1.38	1.38	4.70	-1.38	-10.25	1.38
-0.3	-1.41	1.11	5.85	-0.98	-10.00	1.05
0.0	-1.51	0.59	6.90	-1.51	-13.65	0.59
0.3	-0.93	0.91	2.40	-0.93	- 7.80	0.91
0.6	-1.56	0.94	4.30	-0.73	- 6.40	0.94
0.9	-1.18	1.09	5.20	-0.09*	- 5.50	1.09
1.2	-1.50	1.28	7.15	0.43	- 3.50	1.28

Propeller 3771

P/D	J_{min}	J_{max}	$K_{BH_{max}} \times 10^3$	$J_{K_{BH_{max}}}$	$K_{BH_{min}} \times 10^3$	$J_{K_{BH_{min}}}$
-1.2	-1.36	-0.43	0.30	-1.36	-6.60	-0.49
-0.9	-1.18	1.11	2.20	0.77	-12.10	0.00*
-0.6	-1.43	1.33	2.35	-1.43	-6.70	1.33
-0.3	-1.11	1.31	1.35	-1.11	-8.80	1.31
0.0	-1.14	1.08	1.50	-1.14	-6.75	1.08
0.3	-1.24	0.99	2.20	-0.81	-5.25	0.99
0.6	-1.50	0.88	1.45	0.00*	-3.90	-0.76
0.9	-1.34	1.23	3.10	0.35	-4.80	1.23
1.2	-1.19	1.25	5.60	-0.25*	-4.85	-0.86*

Propeller 4121

P/D	J_{min}	J_{max}	$K_{BH_{max}} \times 10^3$	$J_{K_{BH_{max}}}$	$K_{BH_{min}} \times 10^3$	$J_{K_{BH_{min}}}$
-0.9	-1.47	1.13	3.75	0.82	-4.30	-0.72
-0.6	-1.13	1.05	1.85	0.78*	-2.90	0.09
-0.3	-1.43	1.10	3.25	-1.43	-5.50	1.10
0.0	-1.48	1.14	4.15	-1.48	-5.75	1.14
0.3	-1.40	1.20	3.05	-1.40	-6.25	1.20
0.6	-1.36	0.71	1.95	0.25*	-3.15	-0.87
0.9	-0.99	0.90	3.90	0.35*	-4.35	-0.81
1.2	0.00	1.01	6.05	0.00	-0.75	1.01

Propeller 4122

P/D	J_{min}	J_{max}	$K_{BH_{max}} \times 10^3$	$J_{K_{BH_{max}}}$	$K_{BH_{min}} \times 10^3$	$J_{K_{BH_{min}}}$
0.3	-1.56	0.92	-7.20	-0.13*	-19.70	0.92
0.9	0.40	1.13	6.25	0.40	-11.00	1.13

*At uncorrected water tunnel advance coefficient.

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13 ABSTRACT

An experimental study is presented of the blade spindle torque of five controllable-pitch propeller models, representing five different designs for MSO-421. The study covers a range of both positive and negative advance coefficients at both ahead and astern pitch settings. It was found that the blade with spindle axis located 40 percent of blade width from the leading edge and with uncambered National Advisory Council for Aeronautics Series 66 (NACA 66) airfoil blade sections modified by the Bureau of Ships required the least extreme value of spindle torque.

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Spindle torque						
Controllable-pitch						
MSO (Mine Sweeper Oceangoing)						