List of Figures, Tables, and Charts.

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(2) Taylor, D. W., "Tests of Model Propellers of Various Blade Sections", Transactions of The Society of Naval Architects and Marine Engineers, 1930.

(3) Troost, L., "Open-Water Test Series with Modern Propeller Forms, Part I: Four-Bladed," North East Coast Institution of Engineers and Shipbuilders, 1937-1938.
Troost, L., "Open-Water Test Series with Modern Propeller Forms, Part 2: Three-Bladed," North East Coast Institution of Engineers and Shipbuilders, 1939-1940.

(4) Principles of Naval Architecture, Vol. 2, P. 160-167.

(5) Ackerson, James Lee, "Test Results of a Series of Fifteen Models", Transactions of The Society of Naval Architects and Marine Engineers, 1930.

(6) Bragg, E. M., "The Quasi-Wake Factor", Transactions of The Society of Naval Architects and Marine Engineers, 1944, Pages 57, 58.

(7) Ibid. Fig. 13.

(8) Ibid. Fig. 19.

(9) F. H. Todd, "The Effect of Stream-line Fin upon the Efficiency of Ship Propulsion", Liverpool Engineering Society, Inc., 1934.

SYMBOLS

a = pitch-ratio of propeller, in wake.

a_b = pitch-ratio of propeller, in open.

$B_u = \frac{N\sqrt{U}}{V_a^{2.5}} = \frac{N\sqrt{EHP(1-w)}}{V_g^{2.5}(1-w)^{2.5}} = \frac{N\sqrt{EHP}}{V_g^{2.5}(1-w)^{2}}$

D = diameter of propeller, in ft..

e_o = efficiency of propeller in open test.

e_b = basic efficiency in open for condition determined by $\frac{v_g}{n\ D}$ and K_T.

EHP = towrope horsepower = $\frac{R x V_g}{325.7}$

In Open Test - $K_T = \frac{T}{\frac{\rho}{2} n^2 D^4}$

In Self-Propelled Test - $K_T = \frac{R}{\frac{\rho}{2} n^2 D^4}$ in the determination of <u>qwf</u>,

$K_T = \frac{\frac{R}{1-t}}{\frac{\rho}{2} n^2 D^4}$, in the determination of <u>w</u>.

N = RPM = revolutions per minute.

n = revolutions per second.

qpc = quasi-propulsive coefficient, $= \frac{EHP}{SHP}$

R = towrope resistance in lbs..

SYMBOLS

(Cont.)

ρ = mass-density of water.

SHP = shaft horsepower delivered to propeller.

T = thrust in lbs. registered on thrust block in self-propelled test.

T_o = thrust in lbs. registered on thrust block in open test.

t $= 1 - \frac{R}{T}$

$V_a = V_g(1-w)$

V_g = speed over ground in knots.

v_g = speed over ground in feet per second.

w = wake factor determined by use of $\frac{R}{I-t}$.

(1-w) = pitch-ratio factor.

qwf = wake factor determined by use of R.

(1-qwf) = pitch-ratio factor.

J_g = advance ratio $= \frac{v_g}{nD}$

$= a(1-s) = \frac{101.33}{\delta}$

s = slip ratio

$\delta = \frac{ND}{V_g}$

THE EFFECT OF WAKE UPON PITCH-RATIO.

The propeller data which is at the disposal of propeller designers was obtained from the tests of model propellers in the open condition where the water was, nominally, at rest. These open tests were carried out systematically upon certain types of propellers; some with ogival shaped blade sections, some with airfoil shaped blade sections. Adm. Taylor[1] has published the results of tests upon 3 bladed and 4 bladed propellers of the ogival type, and a certain amount upon 4 bladed propellers of different airfoil types.[2] Dr. Troost[3] has published results of tests upon 3 bladed and 4 bladed propellers of certain airfoil types, and there are other data available.[4]

While these results were obtained under open conditions, the propellers that we design are to operate in the behind condition where the water has a follow-up velocity. It would be an unending task to test all the propellers for which we have open data behind all the different forms commonly used in practise, each propeller having a variety of transverse and vertical locations in the wake. Each self-propelled test determines a few points in this vast area. The propeller designer is constantly endeavoring to work out a system that will correlate these scattered points and determine design factors that will enable him to predict from the open test data the action of the behind propeller at intermediate points not covered by self-propelled tests.

The self-propelled test gives the designer all the information that he needs for the one particular condition tested. It gives him the shaft horsepower that will be needed to propel the ship at the desired speed, and the R.P.M. at which the propeller will deliver the needed thrust when working in the wake created by the model. The designer is not interested in the qpc or the wake-factor unless he wishes to use the results of this self-propelled test as a guide in some other design where the same type of propeller is to be used and no self-propelled test is to be made.

In order that the results obtained from the self-propelled test may be of use in this latter case, it is necessary to correlate the qpc obtained in the self-propelled test with some open efficiency given in Taylor's or Troost's charts, and to determine to what extent the wake developed behind the model supplants pitch-ratio in these same open charts. The wake-factor is a measure of the extent to which wake in the self-propelled test supplants pitch-ratio in the open test, where no wake is present.

The attributes of the water in which the open tests were made usually differ from the attributes of the water in which the behind propeller is to operate in three main particulars, temperature, degree of salinity, and motion. The open tests are usually conducted in fresh water which is at rest and whose temperature is around 70 degrees, F. The behind propeller, more often, is to operate in salt water whose temperature is around 50 degrees, F., and this water has a follow-up velocity.

If we make use of the non-dimensional quantities -

$$\frac{v_g}{n\ D} = J_g \quad \text{and} \quad K_T = \frac{T_o}{\rho\ n^2\ D^4}$$

for propeller design, differences of temperature and degree of salinity can be taken care of by means of the factor ρ ; difference in the motion attribute is taken care of by means of the wake-factor. The use of this factor to determine the extent to which wake supplants pitch-ratio can be illustrated by means of Fig. I.

The curves of efficiency and pitch-ratio in this figure are taken from Chart I for Taylor's ogival, 4 bladed propellers. The points a, a', b, b', and c, represent the results of Ackerson's tests (5) upon propeller 928 behind Model 2933. Assuming the full-sized ship to be 400 ft. long, the propeller was 16.75 ft. in diameter and 13.50 ft. in pitch. It was 4 bladed and without rake, the sections were ogival, the mean-width-ratio was 0.25 and the blade-thickness-ratio was 0.05. The tip was 4.35 ft. below the surface. At 14 knots the R.P.M. were 99.2, E.H.P. = 2135, and S.H.P. = 2930. The test showed a thrust-deduction factor of 0.190 and a qpc value of 0.730.

Hence, $J_g = 0.855$, $\dfrac{R}{\rho n^2 D^4} = 0.12$ (point a)

$$\frac{\frac{R}{I-t}}{\rho n^2 D^4} = 0.148 \text{ (point a')}$$

In a previous paper (6) I have advocated the use of R in determining K_T. Present practise is to determine it by the use of $\dfrac{R}{I-t}$. The use of $\dfrac{R}{I-t}$ is inconsistent with our practise in determining the values of qpc and B_U. In both of these cases we use the EHP based upon R. $qpc = \dfrac{EHP}{SHP}$, $B_U = \dfrac{N\sqrt{EHP}}{V_g^{2.5}(I-qwf)^2}$

Why should we change to $\dfrac{R}{I-t}$ in determining the wake factor?

In Fig. I the J_g value of 0.855 and the K_T value of 0.12 determine the point a, and the K_T value of 0.12 and the pitch-ratio value of .806 determine the point b. At b the J_g value is 0.683. The ratio of these two values of J_g establish the value of (I-qwf). (I-qwf) = $\dfrac{0.683}{}$ = 0.799 or qwf = 0.201.

If one prefers to use $\frac{R}{I-t}$ and determine **w**, instead of using R to determine <u>qwf</u>, the same Figure can be used. The J_g value of 0.855 and the K_T value of 0.148 determine the point <u>a'</u>, and the K_T value of 0.148 and the pitch-ratio value of 0.806 determine <u>b'</u>. At <u>b'</u> the J_g value is 0.62. $\therefore (I-w) = \frac{0.62}{0.855} = 0.725$, or $\underline{w} = 0.275$.

I consider the qwf value of 0.201 to be the more consistent value to use in determining the extent to which wake supplants pitch-ratio since it is determined from R, as are also the values of qpc and B_U.

Fig. I can be used to illustrate another method of determining to what extent wake supplants pitch-ratio in the self-propelled test. When the propeller of .806 pitch-ratio was tested in the open, the K_T value developed at $J_g = 0.855$ was 0.045, as shown at point c, and it took a pitch-ratio of .955 to develop a K_T value of 0.12 (point a), and a pitch-ratio of 1.015 (point a') to develop a K_T value of 0.148. If we work on the assumption that $K_T = \frac{R}{\rho \, n^2 D^4}$, the follow-up velocity of the water behind the model during the self-propelled test increased the K_T value from 0.045 to 0.12. If we are working on the assumption that $K_T = \frac{\frac{R}{I - t}}{\rho \, n^2 D^4}$, the follow-up velocity plus the augmented thrust due to the existence of a region of low pressure between the model and the propeller, increased the K_T value from 0.045 to 0.148.

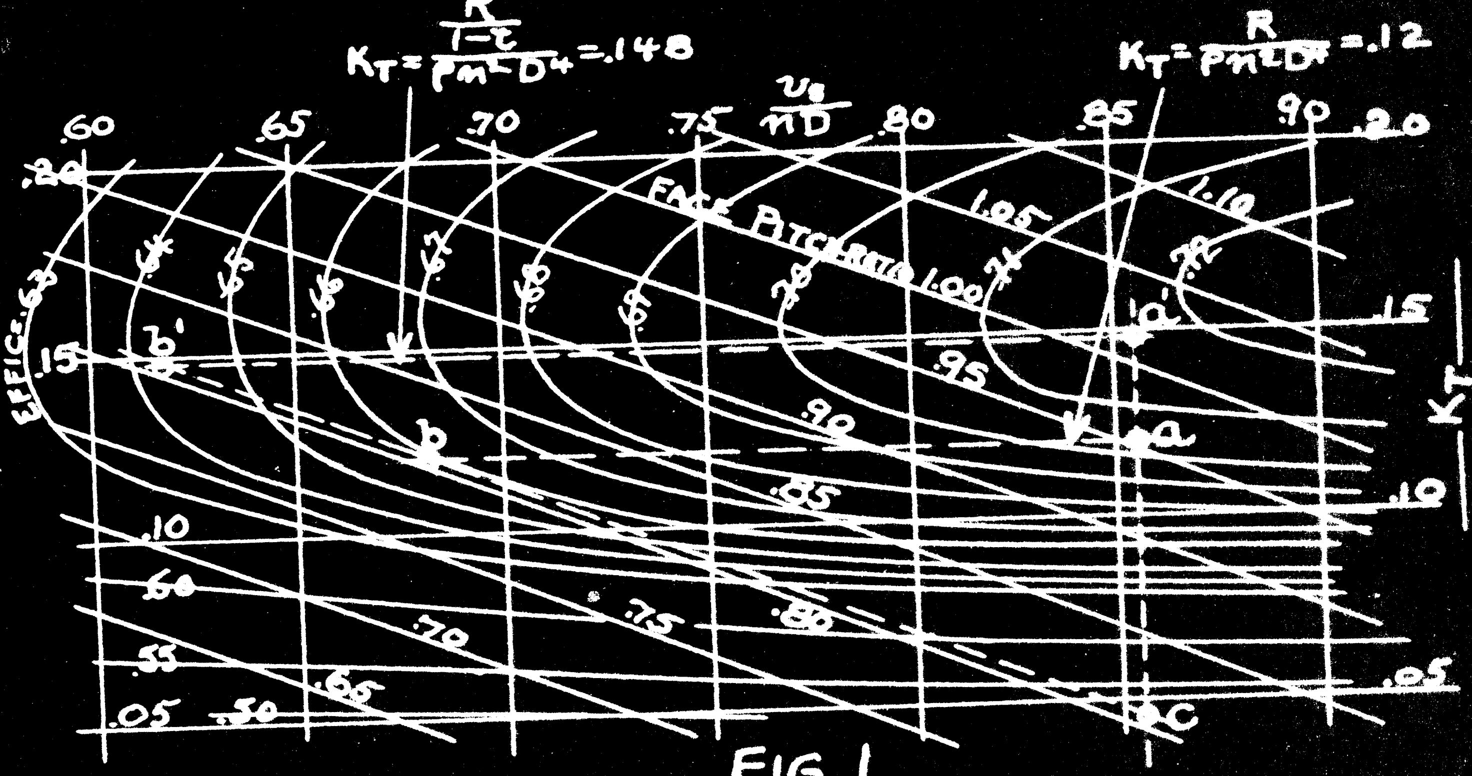
The factor for this third method, using constant J_g instead of constant K_T as in the two methods above, might be called the quasi-thrust factor, (qtf), and the augmented quasi-thrust factor, (aqtf). The qtf in this case would be determined from the ratio $\frac{0.045}{0.12} = (I\text{-qtf}) = 0.375$, or qtf = 0.625. The aqtf would be determined from

$\frac{0.045}{0.148} = (I-aqtf) = 0.304$ or $\underline{aqtf} = 0.696$.

I am not advocating the use of this third method but merely call attention to it to emphasize the fact that the end served by any such factor is to determine to what extent the motion of the water in the self-propelled test supplants pitch-ratio in the open test.

When the propeller operates in the open, a K_T value of 0.12 can be obtained with a pitch-ratio value of .955 when $J_g = 0.855$. This gives a slip angle value of 2^o-33' since $\varphi = \tan^{-1}\frac{a}{\pi} - \tan^{-1}\left(\frac{1}{\pi}J_g\right)$. When the propeller has a pitch-ratio of .806, the slip angle is 0^o-52' at a J_g value of 0.855. When this propeller operates in the wake of Model 2933 the follow-up velocity of the water increases the slip angle from 0^o-52' to 2^o-33' and the K_T value from 0.045 to 0.12.

It is more logical to use a K_T value derived from R than to use, as at present, the value of K_T derived from $\frac{R}{I-t}$. In the open test of the model propeller, increase of K_T at constant J_g value is obtained by increasing the slip angle through the agency of increased pitch-ratio. The flow of the water to the propeller is not impeded by the presence of a hull and there is not the column of water at reduced pressure ahead of the open propeller that there is in the self-propelled test.



$K_T = \frac{\frac{R}{1-t}}{\rho n^2 D^4} = .148$
$K_T = \frac{R}{\rho n^2 D^4} = .12$
$\frac{v_a}{nD}$
.60
.65
.70
.75
.80
.85
.90
.20
.15
.10
.05
K_T
FACE PITCH RATIO 1.00
1.05
1.10
.95
.90
.85
.80
.75
.70
.65
.60
.55
.50
EFFIC. .63
.64
.65
.66
.67
.68
.69
.70
.71
.72
b'
b
a'
a
c

FIG. 1

Designers who use $\frac{R}{I-t}$ to determine K_T virtually claim that increase of K_T by means of such a column of water at reduced pressure has the same effect upon efficiency as increase of K_T through increased slip angle. They have no valid basis for such an assumption. No doubt, the net propelling force in theself-propelled test is somewhat larger than R, the tow-rope resistance of the model, but it certainly is not as large as $\frac{R}{I - t}$. If designers believe that the net propelling thrust is really $\frac{R}{I - t}$, then they should have the courage of their convictions and use qpc values obtained from the expression qpc $= \frac{\left(\frac{EHP}{I - t}\right)}{SHP}$.

The non-dimensional quantities J_g and $K_T = \frac{R}{\rho\, n^2 D^4}$ orient us in the particular chart that we elect to use and establish the basic efficiency that should accompany the operation of the propeller under those conditions, (see efficiency at a or a', Fig. I). This efficiency holds whether the propeller operates in soft water or hard water, in fresh water or salt water, at one depth or another depth, in water at rest or in moving water. Such differences make it necessary to change the pitch-ratio which obtained in the open in order that the desired values of J_g and K_T may be attained in wake. The conditions that exist in the wake of a ship form are not as ideal as in the open test and the efficiency in wake will be less than the basic efficiency in the open.

It is the purpose of the wake factor to determine to what extent the basic pitch-ratio at a or a' must be changed to allow for the motion of the water behind the model. The efficiency will be determined by J_g and $K_T = \frac{R}{n D}$ but the pitch-ratio will be determined by J_g (I-qwf) and $K_T = \frac{R}{n D}$. If $\frac{R}{I-t}$ is used instead of R, then the efficiency is determined by J_g and $K_T = \frac{\left(\frac{R}{I-t}\right)}{n D}$ and the pitch-ratio by J_g (I-w) and $K_T = \frac{\left(\frac{R}{I-t}\right)}{n D}$, (see Fig. I).

The necessity for determining the efficiency and the pitch-ratio at different points is illustrated by Fig. 2 which gives the results of tests upon two airfoil propellers, one for a single screw Lake Freighter (7) and one for the twin screw "America" (8). The curves marked e_o and K_T (open) are plotted from data obtained from the open tests of the propellers. The curves of K_T (behind) and qpc are plotted from the self-propelled tests. In both cases two sets of curves are given, one based upon the use of R and one upon the use of $\frac{R}{I-t}$. The self-propelled results cover speeds from 8 to 14 knots in the case of the single screw Freighter, and from 12 to 24 knots in the case of the "America".

The value of (I-qwf) is the ratio of the values of J_g at b and a, while the value of (I-w) is the ratio at b' and a'. The qpc values should be compared with efficiencies related to a or a' and not with the efficiencies e and e' which are given by b and b! The open efficiencies corresponding to conditions at a and a'are obtained under open conditions that parallel as closely as possible the self-propelled conditions for which we wish to know the qpc values. The J_g values are the same, the thrust values are the same; the only difference is that in the open tests, where there is no wake, the slip angle is obtained by using a larger pitch-ratio than in the self-propelled tests where the same slip angle is obtained by means of a smaller pitch-ratio combined with wake.

It is true that the K_T value is the same at a as it is at b, and is the same at a' that it is at b'. However, since $K_T = \frac{R}{\rho n^2 D^4}$ the K_T value may be constant with wide variations in the values of n and R. In the case of the single screw vessel whose tests are shown in Fig. 2, let us assume that V_g = 12k., RPM = 88, the needed thrust, R,= 59700 lbs., D= 16.5', and a = 0.939 . Then v_g = 20.27' and n = 1.467. . . $J_g = \frac{20.27}{1.467 \times 16.5} = 0.838$, $K_T = \frac{59,700}{1.94 \times (1.467)^2 \times (16.5)^4}$ =0.193.

A K_T value of 0.193 intersects the K_T(open) curve at a J_g value of 0.61. Since v_g and D have not changed, this means that n has increased from 1.467 at a to 2.015 at b, and T_o, or R, has increased from 59,700 lbs. to 112,700 lbs.. If we are using $\frac{R}{1-t}$, then K_T=0.239, since t = 0.194. A K_T value of 0.239 intersects the K_T(open) curve at a J_g value of 0.493, which means that n has increased from 1.467 at a' to 2.492 at b'. This would cause T_o, or R, to inrease from 59,700 lbs. at a' to 172,500 lbs. at b'.

The design condition which we have established and for which we wish to know the efficiency calls for the following quantities:

T_o = R = 59,700 lbs., RPM = 88, J_g = 0.838, K_T = 0.193

Pitch-ratio=0.939 with wake present.

These conditions are met in the open test of B-4-55, Chart III, in every particular except one. The slip angle necessary to produce a K_T value of 0.193 is produced by a pitch-ratio of 1.14 alone without the help of any wake, instead of by a pitch-ratio of 0.939 and whatever wake the model produced.

These conditions are not met to the same extent at line b e since:

T_o = R = 112,700 lbs., RPM = 120.1 J_g = 0.61, K_T = 0.193,

Pitch-ratio 0.939 with no wake present.

The conditions at <u>b' e'</u> are still further afield:-

T_0 = R = 172,500 lbs., RPM = 149.5, J_g = 0.493, K_T = 0.193, Pitch-ratio = 0.939 with no wake present.

It is obviously absurd to take the efficiency which prevails at <u>e</u> (Fig. 2), where J_g = 0.61 and the thrust is 112,700 lbs., or at e' where J_g = 0.493 and the thrust is 172,500 lbs., as applying in any way to the condition where J_g = 0.838 and the thrust is 59,700 lbs..

It might seem as if the efficiency which prevails at <u>d</u> (Fig. 2) might be used, but that would be equivalent to using the efficiency at <u>c</u> (Fig. 1). The efficiency at <u>d</u> was obtained when the K_T value was 0.096 in Fig. 2 and does not apply to the condition where the K_T value is 0.193 or 0.239.

The open test of the propeller that is to be used in the self-propelled test does not supply information that can be used to determine the efficiency in wake. Tests of the propeller at larger pitch-ratios are needed since the behind propeller working in the wake of the model generates thrust at a slip angle that can be duplicated in the open only by a larger pitch-ratio. If the propeller belongs to a family for which we do not have a chart similar to those that accompany this paper, we may make use of the chart for the family that seems to come nearest to the propeller in question. In Fig. 2 are shown portions of the K_T curves taken from the different charts for a pitch-ratio of 0.939 for the single screw, and for a pitch-ratio of 1.00 for the twin screw. The propeller B-4-55 seems to come nearest for the single screw, so portions of the efficiency curves for that propeller for constant K_T values of 0.193 and 0.239 are shown. The basic efficiency values, e_b, should be determined by the intersection of these curves with the line a a'. In the case of the twin screw, Taylor's "D" propeller seems to come nearest to the propeller of the "America" and portions of the efficiency curves of the "D" propeller at constant K_T values of 0.125 and 0.139 are shown.

The disturbed and turbulent condition of the wake accounts for the fact that the qpc values of twin screws are lower than the e_b values by 4% or so. The same would be true for single screws if we had any open tests of propellers with rudders and vanes back of them. These devices increase the efficiency of propulsion by 8% or so. (9) We find, therefore, that the qpc values of single screws, after making allowance for about 4% wake loss, are about 4% greater than the e_b values of open propellers tested without rudders and fins.

While most of our propeller design is concerned with single screws,

TABLE I.

	CHART No	MEAN WIDTH RATIO	BLADE THICK. RATIO	HUB DIAM. RATIO	DEV. AREA RATIO	RAKE	SKEW	PITCH RATIO VARIATION.
GROUP I-OGIVAL								
TAYLOR	I	.25	.05	.20	.509	NONE	NONE	NONE
TAYLOR-A	VII	.25	.05	.20	.509	"	"	"
GROUP 2-AIRFOIL								
TAYLOR-C	VI	.25	.05	.20	.509	"	"	"
TAYLOR-D	V	.25	.05	.20	.509	"	"	SOME
GROUP 3-AIRFOIL								
TROOST-A-4-40	IV	.19	.05	.167	.40	15°	SOME	20%
" B-4-55	III	.26	.045	.167	.55	15°	"	20%
" B-4-40	II	.19	.045	.167	.40	15°	"	20%

TABLE II.

	CHART No	$\frac{v_s}{nD} = .85$ $K_T = .15$		$\frac{v_s}{nD} = .70$ $K_T = .175$		$\frac{v_s}{nD} = .55$ $K_T = .20$	
		a	e_o	a	e_o	a	e_o
GROUP I - OGIVAL							
TAYLOR	I	1.015	.716	.935	.676	.865	.60
TAYLOR-A	VII	1.023	.709	.94	.674	.865	.597
GROUP 2 - AIRFOIL							
TAYLOR-C	VI	1.06	.737	.975	.687	.89	.606
TAYLOR-D	V	1.05	.742	.965	.69	.88	.607
GROUP 3 - AIRFOIL							
TROOST-A-4-40	IV	1.065	.732	.98	.682	.915	.604
" B-4-55	III	1.075	.717	.985	.662	.90	.579
" B-4-40	II	1.075	.735	.985	.687	.91	.605

all of our open data applies, strictly, to twin screws and we have to design single screws on a "shoe string" of data, as far as open data is concerned.

The characteristics of the chart propellers are shown in Table I and fall, in general, into three groups. Group I differs from most modern ogival section propellers in having no rake and no variation of pitch-ratio. Group II differs from most modern airfoil propellers in having no rake, no skew, no pitch-ratio variation, and a rather large hub. Group III differs from most modern propellers in the large amount of pitch-ratio variation near the hub, and the "wash back" of the blade section at the following edge.

Table II shows the pitch-ratio necessary to deliver a given K_T value at a certain value of J_g. Ogival section propellers are the best thrust producers, i.e., will produce a given thrust with a lower pitch-ratio, but at the expense of efficiency. The type of section used in Group III is inferior in thrust and efficiency* to the type used in Group II, but would probably be more efficient when backing.

* The efficiency given for Troost's propellers is the blade efficiency, i.e., the drag of the hub has been subtracted. The efficiencies given on the charts should be reduced by about 0.01 in comparing them with efficiencies given on Taylor's charts.

It should be kept clearly in mind that in adopting a particular chart for reference purposes we are not adopting that particular type of propeller. We are merely using the numerals on that particular pitch-ratio grid to give us the pitch-ratio numeral for our type of propeller. The results of the self-propelled test locate the point a in Fig. I, and point b is determined by the numeral that we have used to designate the pitch-ratio of the propeller tested.

The effective pitch-ratio of any propeller is an unknown quantity and does not need to be known. All that pitch-ratio does is to identify a particular propeller for which we have test data, and enables a reproduction to be made. There may be five propellers used in the tests that give us the data from which such charts as I to VII are constructed. The results of such tests may be plotted under the head of-

A---B---C---D---E,

or I---2---3---4---5,

or face pitch-ratio, 0.6--0.8--I.00--1.2--1.4,

or experimental pitch-ratio, 0.685--0.888--1.095--1.316--1.532 .

Since the object of the identification is to enable one to have a full scale propeller made that will have certain non-dimensional characteristics exhibited by the 8" model, a system of identification that is related to the process of manufacture seems desirable. Since the face pitch-ratio gives definite information to this end, it would seem to be the logical choice.

In Fig. I, the relation between efficiency, K_T, and J_g, remains fixed for variations in specific gravity and motion of the fluid. The compensating element is pitch-ratio, and the pitch-ratio grid slides to the right or to the left to compensate for these variations. In the case of the single-screw Lake Freighter model in Fig. 2, the wake, or motion condition, of the water, was such that the pitch-ratio grid moved to the right a considerable distance until point b coincided with point a. In the case of the twin-screw "America", the lesser wake called for a smaller displacement of the pitch-ratio grid. In the case of a propeller working up stream against a current strong enough to produce negative wake, the grid movement would have been to the left and a larger pitch-ratio than that at a would have to be used.

The parameter (I-qwf), or (I-w), makes allowance for a number of differences between the open and the self-propelled conditions. In the open test the water is solid, with practically uniform velocity of approach in all parts of the supply stream, and the direction of flow is parallel to the centerline of the shaft. The water, which was originally at rest, is given a sternward velocity. In the behind condition, the water has a follow-up velocity which is reduced or entirely eliminated by the action of the propeller. The water in the supply stream is under reduced pressure and permeated with eddies and vapor pockets. The direction of flow has inward and upward components and the velocity of flow varies in different parts of the supply stream. The parameter (I-qwf) cannot be interpreted in terms of velocity alone, and the product of V_g and (I-qwf) is not the velocity of the propeller relative to the surrounding water. In the expression

$$Bu = \frac{N\sqrt{EHP}}{V_g^{2.5}(I-qwf)^2}$$

the two quantities in the denominator have just as distinct and corporate identities as the two quantities in the numerator and can no more be merged than can N and $\sqrt{EHP}$.

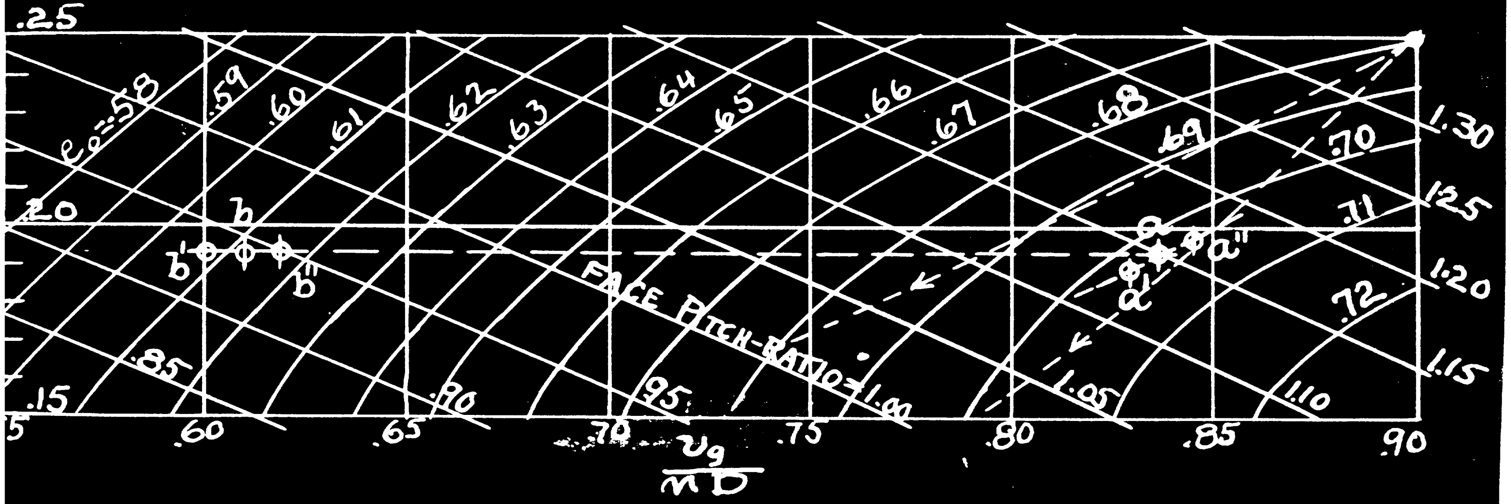
The above expression can be put into the form -

$$Bu_{(open)} = \frac{1}{(I-qwf)^2}\left(\frac{N\sqrt{EHP}}{V_g^{2.5}}\right)(behind) \qquad (1)$$

$$\therefore (I-qwf)^2 = \frac{Bu(behind)}{Bu(open)} \qquad (2)$$

In the self-propelled test, where wake is present, a given EHP will be developed at a certain speed, V_g, by a propeller of a given pitch-ratio

FIG. 3.



.25
.20
.15
e_0 = .58
.59
.60
.61
.62
.63
.64
.65
.66
.67
.68
.69
.70
.71
.72
1.30
1.25
1.20
1.15
b
b'
b''
a
a'
a''
FACE PITCH-RATIO = 1.00
.85
.90
.95
1.05
1.10
.60
.65
.70
.75
.80
.85
.90
$\frac{v_g}{nD}$

at a smaller number of revolutions than that same propeller can develop that EHP in the open condition where no wake is present. The parameter $(I-qwf)^2$ expresses the effect of all the differences mentioned above upon the quantities that go to make up the B_u expressions derived from open and self-propelled tests.

In the same way, the expression -

$$\delta = \frac{N\ D}{V_g(I-qwf)} = \delta_{open} = \frac{1}{(I-qwf)} \left(\frac{N\ D}{V_g}\right)_{behind}, \qquad (3)$$

$$\therefore (I-qwf) = \frac{\delta\ behind}{\delta\ open} \qquad (4)$$

The wake factor cannot be interpreted in terms of velocity alone; it makes allowance for numerous differences not directly connected with velocity. Therefore, the propriety of using $V_a = V_g(I-w)$ in the expression for useful horsepower, U, is questionable. The only logical form for B_u is the one given above, - $B_u = \frac{N\sqrt{EHP}}{V_g^{2.5}(I-qwf)^2}$.

<u>Pitch Ratio Factor</u>

It is unfortunate that the factor derived from the relation between $B_{u(behind)}$ and $B_{u(open)}$ in Eq. 2, or between $\delta_{(behind)}$ and $\delta_{(open)}$ in Eq. 4, has taken the form (I-qwf) or (I-w). The quantities <u>qwf</u>, or <u>w</u>, are never used by themselves but always in the form (I-qwf) or (I-w). The emphasis placed upon <u>qwf</u> or <u>w</u> makes it seem that in going from a value of 0.20 to a value of 0.21 there is a variation of 5%, whereas, in reality, this variation in the value of the wake factor makes a variation of only 1.25% in the values of (I-qwf) or (1-w). Since this is the factor which determines the extent to which the open pitch-ratio must be reduced to accomodate the propeller to the wake conditions and give the desired values of J_g and K_T, the factor (I-qwf) or (I-w) will be referred to as the pitch-ratio factor. Since this factor covers a variety of differences not directly connected with the velocity of the wake created by the model when towed, it is unwise to try to tie it up with that wake value.

Attention should be called to the lines on the Charts that show the effects of changes in revolutions and diameter. In most cases it desirable to use as large a diameter of propeller as possible, but if, with the number of revolutions fixed, the resulting value of K_T is less than 0.125 for airfoil propellers, or less than 0.15 for ogival sections, the efficiency will be improved by using a smaller diameter of propeller.

While a low number of revolutions usually gives a higher efficiency than a high number, there are cases in the higher range of K_T values where it is better to use the higher number. The effect upon efficiency of increasing the number of revolutions is shown on the Charts by the lines marked "Effect of Increasing n". The tendency of these curves to run parallel with the efficiency curves at certain combinations of J_g and K_T shows that there are certain areas in which there may be wide variations in revolutions, and less wide variation in diameter, without an appreciable change in the efficiency. This, in turn, indicates that in those areas the wake-factor, or quasi-wake-factor, does not have to be selected with meticulous care where it is a question of efficiency only. If one is dealing with "revolution conscious" machinery and it is considered necessary to hit a certain number of revolutions "on the nose", a more painstaking selection of wake values has to be made.

If a mistake is made in estimating the wake effect and a quasi-wake factor of 0.11 or 0.09 is used instead of 0.10 for twin screws, the propeller efficiency will be only slightly affected, in the regions mentioned above. In the case of single screws, it will make little difference whether a quasi-wake factor value of 0.19 or 0.21 is used instead of 0.20 .

Let us take the case of the single-screw propeller for the Lake-Freighter[8] shown in Fig. 2. That propeller had a pitch-ratio of 0.939, and the results of the self-propelled test at 12 knots showed a J_g value of 0.838 and a K_T value of 0.193. If we use a portion of Chart III, as shown in Fig. 3, for Troost propeller B-4-55, these co-ordinates locate a point a; the K_T value and the pitch-ratio value of 0.939 locate point b at a J_g value of 0.61. The (I-qwf) value, when this Chart is used, will be 0.728, since (I-qwf) = $\frac{0.61}{0.838}$ = 0.728.

Let us suppose that we did not have the benefit of the self-propelled test at our disposal and that we overestimated the wake effect, taking it as 0.282 instead of 0.272. Then (I-qwf) = 0.718, and 0.838 x 0.718 = 0.602. This value of J_g gives point b' in Fig. 3, and the pitch-ratio of 0.93 would be indicated instead of 0.939 which went with the qwf value of 0.272. This lower pitch-ratio would cause the rpm to increase from 88 to about 88.8 . This increase in rpm would cause J_g to have a value of 0.83 instead of 0.838, and K_T to have a value of 0.1896 instead of 0.193 . These co-ordinates locate point a' in Fig. 3.

If we had underestimated the wake effect and used a qwf value of 0.262, then (I-qwf) = 0.738, and the J_g value that locates point b" would be 0.838 x 0.738 = 0.618. This would cause us to choose a pitch-ratio of 0.948, and the rpm would be about 87.2. With these revolutions the value of J_g would be 0.846 and the value of K_T would be 0.1967, locating point a" . The basic efficiency of all of these three points is practically the same. Any machinery suitable for ship propulsion should be able to accommodate itself to revolutions of the order of 88.8 or 87.2 instead of 88.0 without appreciable loss of engine efficiency, or without introducing operational difficulties.

The Charts show that high values of J_g are, in general, desirable and that the K_T value of 0.125 is a minimum for air-foil propellers and that 0.15 is a minimum for ogival section propellers. As a matter of fact, the combined efficiency of ship form, machinery, and propeller, will probably be a maximum when K_T is somewhat larger.

Whatever change is made in <u>n D</u> to increase or decrease the value of J_g will also increase or decrease the value of K_T, resulting in a diagonal path across the Chart, as shown by Line <u>a' a"</u> in Fig. 3. The Charts show in what areas changes in revolutions and diameter can be made to advantage, and in what areas the basic efficiency is unaffected by such changes.

It has been stated above that the wake factor was a measure of the extent to which wake in the self-propelled test supplanted pitch-ratio in the open test. We are not concerned with the actual value of the pitch-ratio which obtained in the open test. What we are concerned with is the relation between the J_g value at which the desired K_T was

TABLE III

ACKERSON'S TEST Nº 6 — STREAMLINE RUDDER									
MODEL Nº 2933					PROPELLER Nº 928				
b=.658 m=98					a=806 OGIVAL				
l=.671 $\frac{B}{H}$=2.5					m.w.r.=.25 b.t.f.=05				
TRIAL CONDITIONS: $\frac{V}{\sqrt{L}}=0.7$, $\frac{v_a}{nD}=.855$, $K_T=12$, $t=0.19$, Q.P.C.=.73									
	1 CHART Nº	2 a_b FOR $\frac{v_a}{nD}=.855$ $K_T=.12$	3 $\frac{v_a}{nD}$ WHEN $a=.806$ $K_T=.12$	4 $(1-q w_f)=\frac{③}{.855}$	5 $\frac{a}{a_b}$	6 e_b	7 $\frac{Q.P.C.}{e_b}$	8 e_o	9 $\frac{Q.P.C.}{e_o}$
GROUP I – OGIVAL									
TAYLOR	I	.955	.683	.799	.843	.703	1.038	.659	1.106
TAYLOR A	VII	.965	.680	.796	.836	.700	1.042	.660	1.105
GROUP 2 – AIRFOIL									
TAYLOR C	VI	.995	.670	.783	.810	.739	.988	.689	1.058
TAYLOR D	V	1.00	.660	.772	.806	.751	.973	.705	1.035
GROUP 3 – AIRFOIL									
TROOST-A-4-40	IV	1.003	.635	.743	.804	.730*	1.00	.672*	1.086
" B-4-55	III	1.023	.630	.737	.788	.715*	1.021	.637*	1.146
" B-4-40	II	1.007	.645	.754	.800	.737*	.990	.686*	1.064

* SEE NOTE REGARDING TROOST EFFICIENCIES.

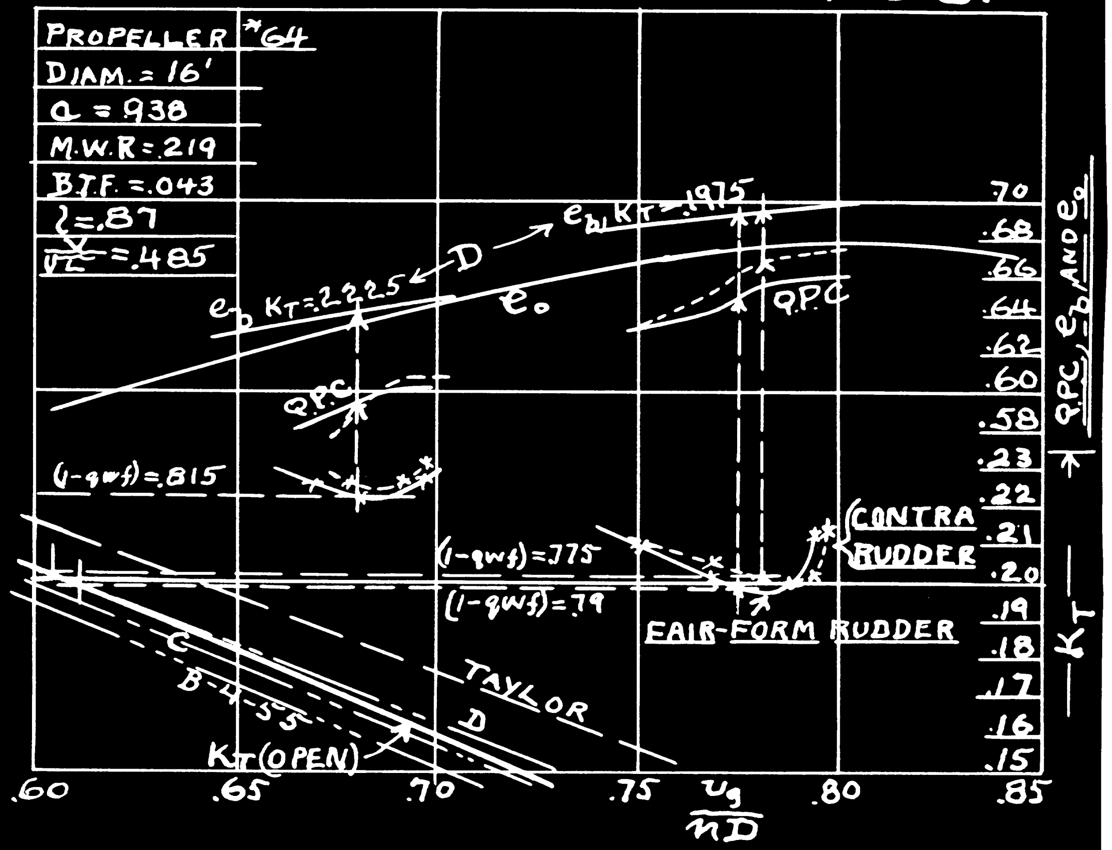
attained in the self-propelled test, i.e., 0.855 at a in Fig. I, and the J_g value on any Chart at which the same K_T was attained and the pitch-ratio label attached to the propeller ~~is~~ was identical with that attached to the propeller tested behind the model, i.e., 0.68 at b in Fig. I. In Fig. I the results of tests upon an ogival type propeller were plotted upon a portion of Chart I. If the same results had been plotted upon the other Charts, the values of the pitch-ratio factor would be as given in Table III and would have varied from 0.799 to 0.737, dependent upon the chart used. The values of e_b and e_o would also vary, but the ratio of qpc to e_b, as given in Column 7, varies through a smaller range than does the ratio of qpc to e_o, as given in Column 9.

The value of the pitch-ratio factor for any given propeller is affected by the characteristics of the model in front of it, the speed-length ratio, the wake condition, the position of the propeller in the wake, the thrust per sq. in. of effective blade area, and the appendages in front of, and behind the propeller. The pitch-ratio factor can be determined by plotting the results of self-propelled tests in the manner shown in Figs. 5 - 11.

Self Propelled Tests

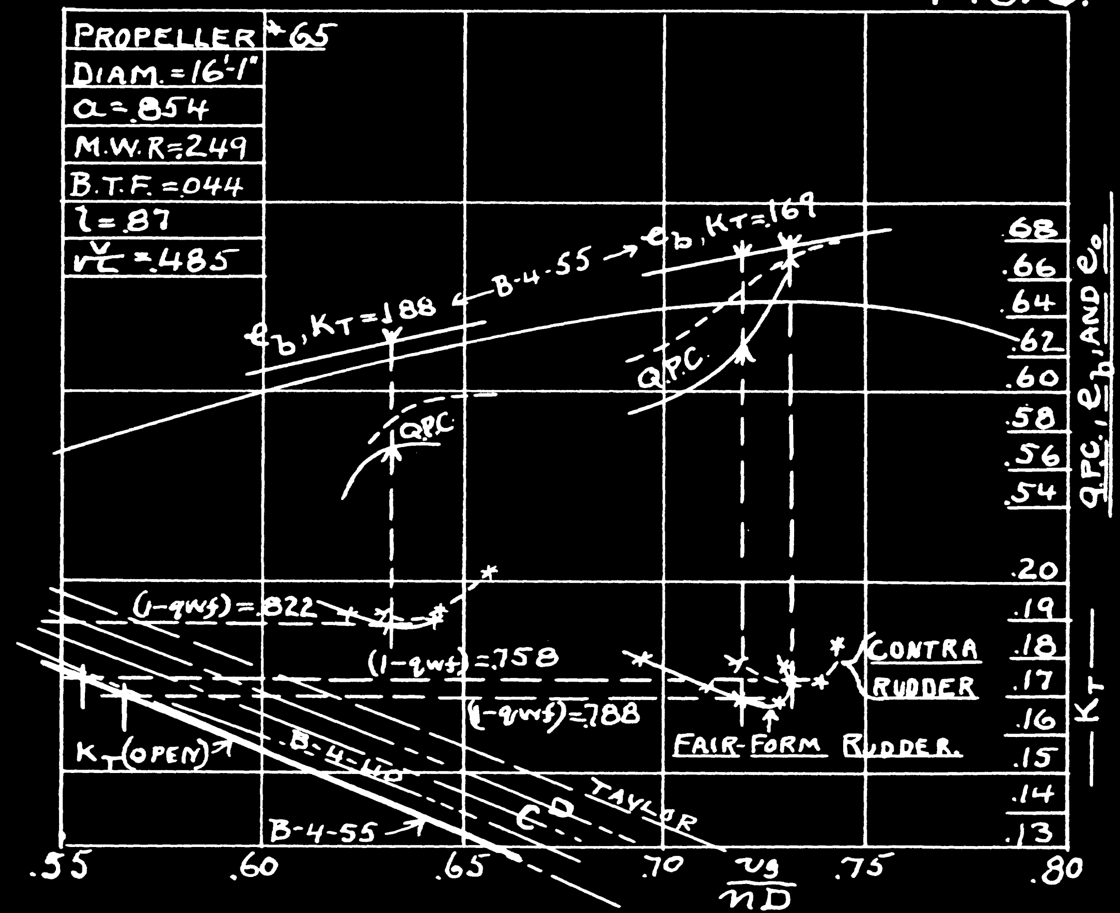
If the curve of R.P.M. were a straight line and the curve of E.H.P.

FIG. 5.



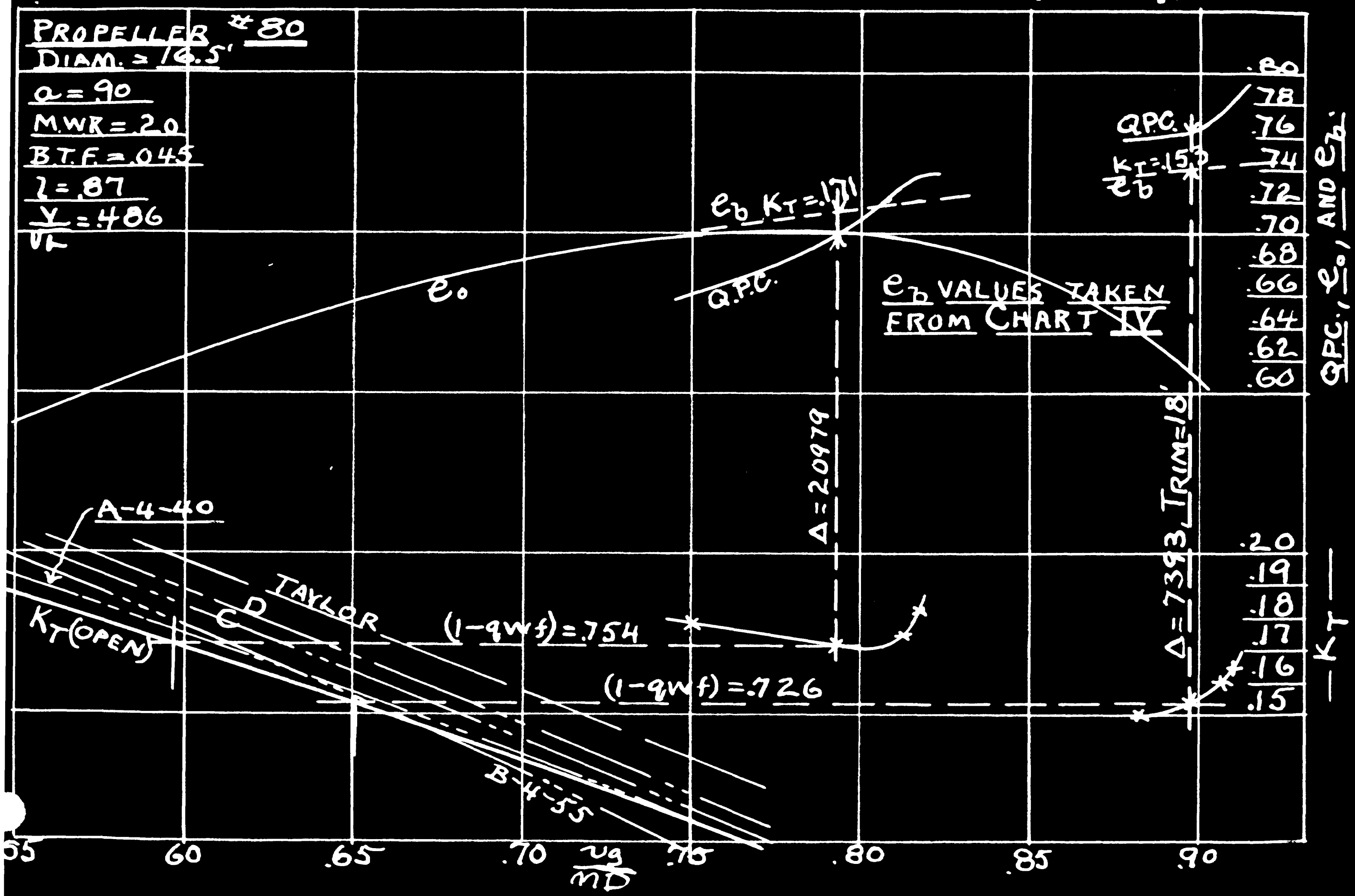
PROPELLER #64
DIAM. = 16'
a = .938
M.W.R = .219
B.T.F. = .043
ξ = .87
V/√L = .485
e_b K_T = .2225
D
e_b K_T = .1975
e_o
Q.P.C
Q.P.C
(1-qwf) = .815
(1-qwf) = .775
(1-qwf) = .79
CONTRA RUDDER
FAIR-FORM RUDDER
C
B-4-55
TAYLOR
D
K_T (OPEN)
.60
.65
.70
.75
.80
.85
$\frac{u_g}{nD}$
.70
.68
.66
.64
.62
.60
.58
.23
.22
.21
.20
.19
.18
.17
.16
.15
Q.P.C., e_b AND e_o
K_T

FIG. 6.



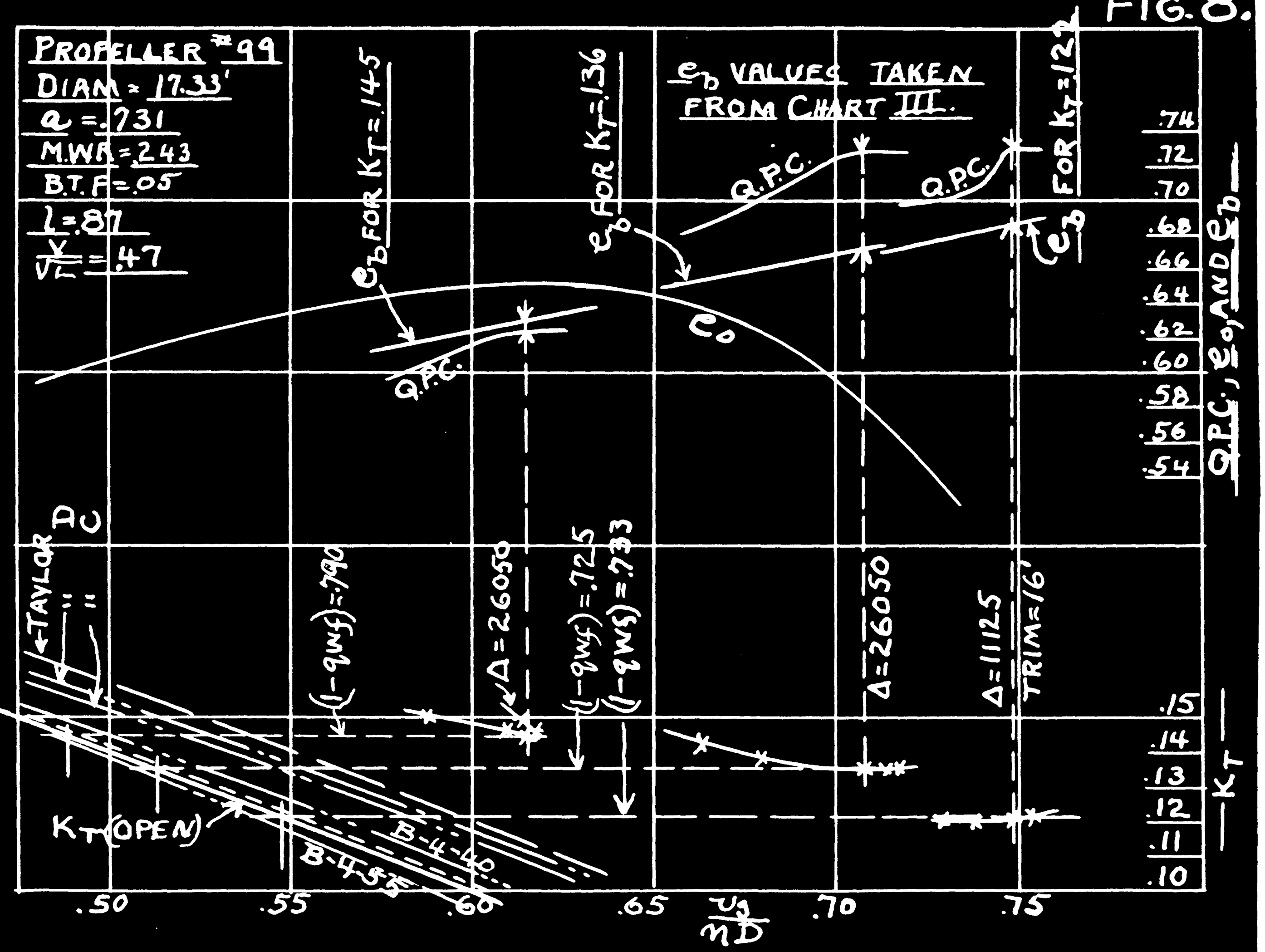
PROPELLER #65
DIAM. = 16'-1"
a = .854
M.W.R = .249
B.T.F. = .044
l = .87
v/L = .485
e_b, K_T = .188 ← B-4-55 → e_b, K_T = .169
Q.P.C.
Q.P.C.
(1-qwf) = .822
(1-qwf) = .758
(1-qwf) = .788
CONTRA RUDDER
FAIR-FORM RUDDER.
K_T (OPEN)
B-4-40
B-4-55
C
D
TAYLOR
.55
.60
.65
.70
.75
.80
vs/nD
.68
.66
.64
.62
.60
.58
.56
.54
.20
.19
.18
.17
.16
.15
.14
.13
Q.P.C., e_b, AND e_0
K_T

FIG. 7.



PROPELLER #80
DIAM. = 16.5'
a = .90
M.W.R. = 2.0
B.T.F. = .045
η = .87
V/√L = .486
e_o
e_b K_T = .171
Q.P.C.
e_b VALUES TAKEN FROM CHART IV
Q.P.C.
K_T = .153 / e_b
Δ = 20979
Δ = 7393 TRIM = 18'
A-4-40
TAYLOR
D
C
K_T (OPEN)
(1-qwf) = .754
(1-qwf) = .726
B-4-55
.80
.78
.76
.74
.72
.70
.68
.66
.64
.62
.60
Q.P.C., e_o, AND e_b
.20
.19
.18
.17
.16
.15
K_T
.55
.60
.65
.70
.75
.80
.85
.90
v_g/nD

FIG. 8.



PROPELLER # 99
DIAM = 17.33'
a = .731
M.W.R. = 243
B.T.F. = .05
L = 87
V/√L = .47
e_D VALUES TAKEN FROM CHART III.
e_D FOR K_T = .145
e_D FOR K_T = .136
e_D FOR K_T = .122
Q.P.C.
e_D
e_o
TAYLOR
K_T (OPEN)
B-4-40
B-4-55
(1-qwf) = .790
Δ = 26050
(1-qwf) = .725
(1-qws) = .733
Δ = 26050
Δ = 11125
TRIM = 16'
.50
.55
.60
.65
.70
.75
$\frac{V_a}{nD}$
.74
.72
.70
.68
.66
.64
.62
.60
.58
.56
.54
Q.P.C., e_o, AND e_D
.15
.14
.13
.12
.11
.10
K_T

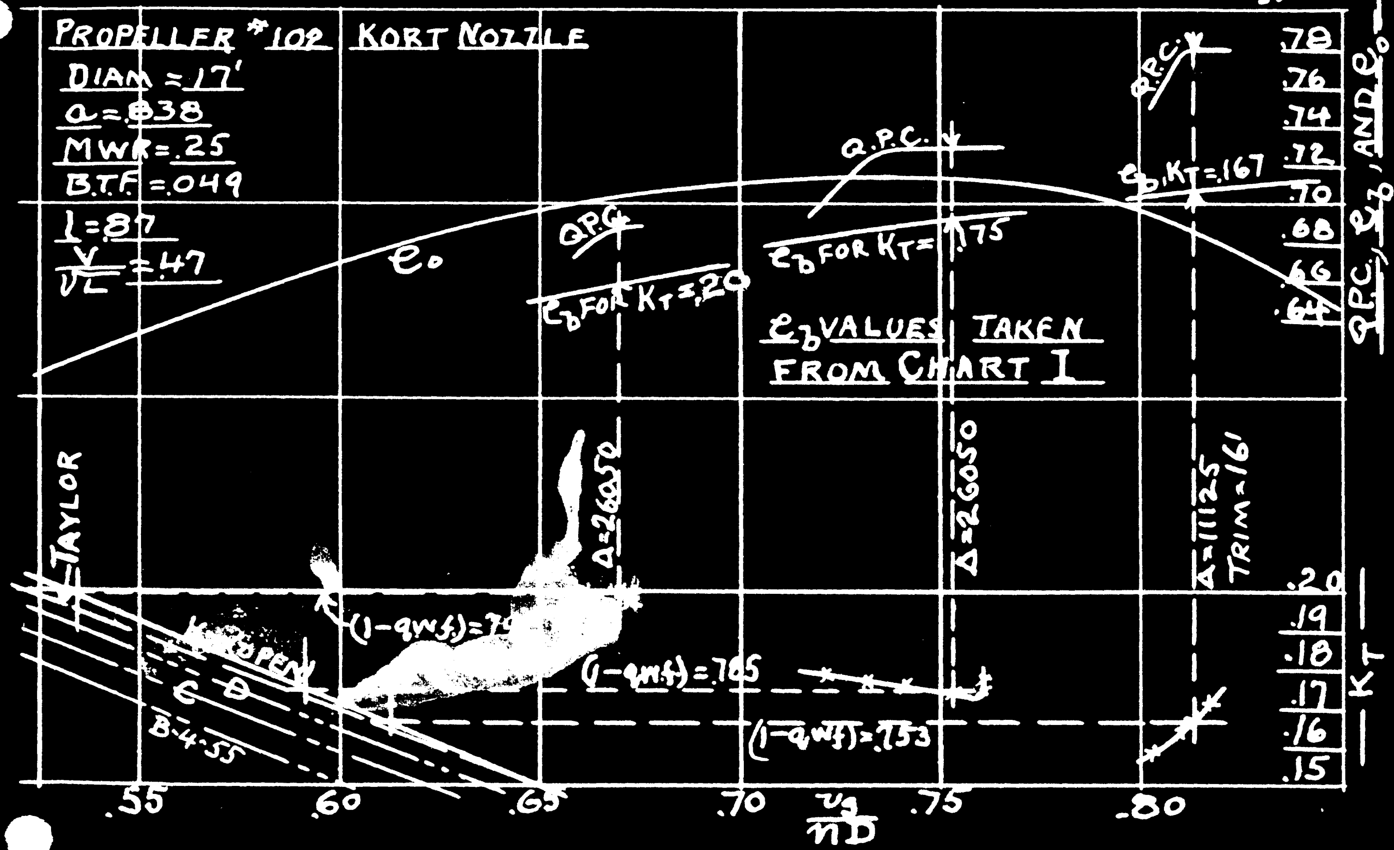
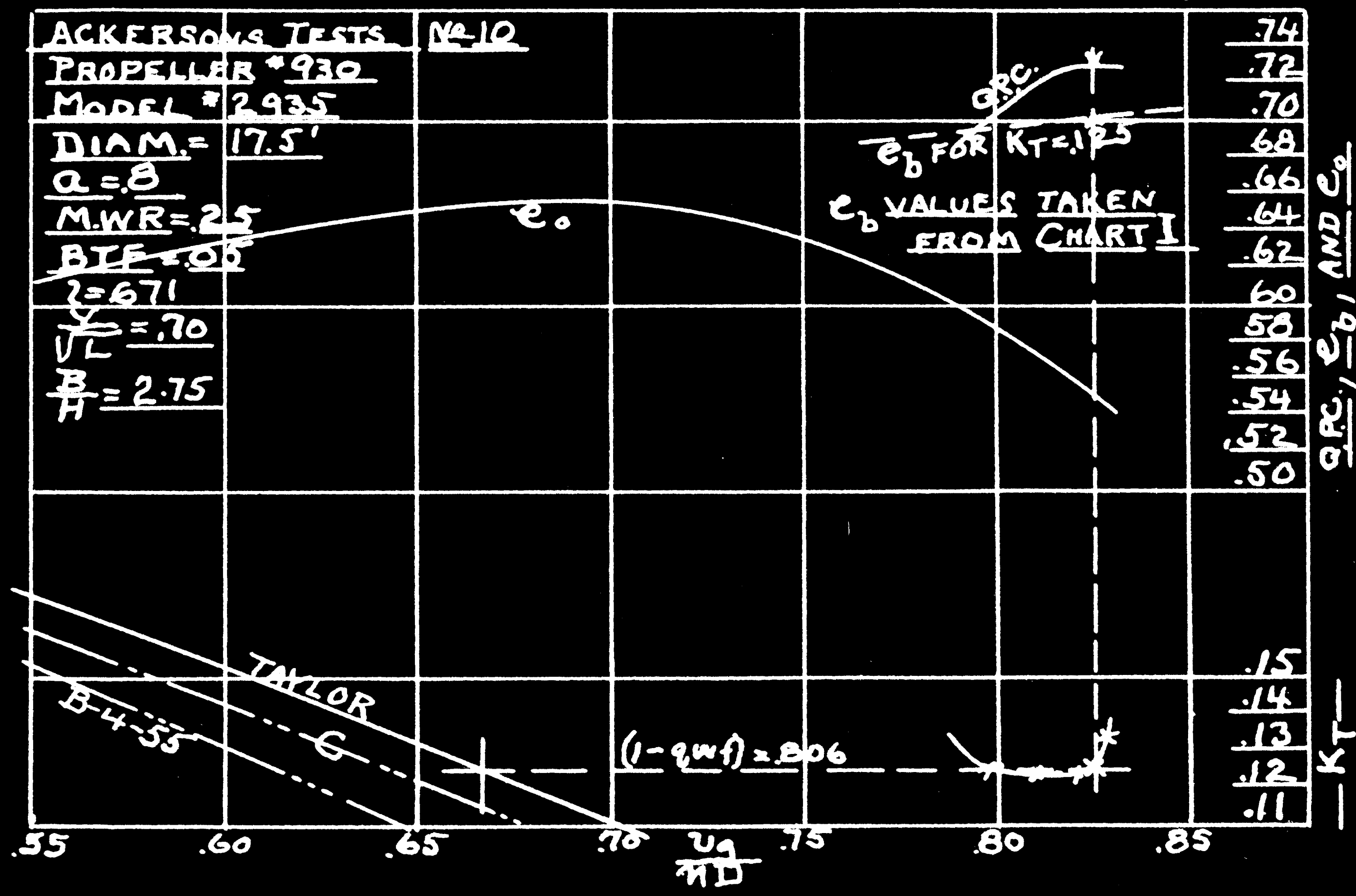

PROPELLER #102 KORT NOZZLE
DIAM = 17'
a = .838
MWR = .25
B.T.F. = .049
l = .87
V/√L = .47
e_o
Q.P.C.
e_b FOR K_T = .20
Q.P.C.
e_b FOR K_T = .175
Q.P.C.
e_b, K_T = .167
e_b VALUES TAKEN FROM CHART I
Δ = 26050
Δ = 26050
Δ = 11125
TRIM = .161
TAYLOR
KORT OPEN
(1-w_f) = .79
(1-w_f) = .765
(1-w_f) = .753
C
D
B-4-55
.55
.60
.65
.70
.75
.80
v_a/nD
.78
.76
.74
.72
.70
.68
.66
.64
Q.P.C., e_b, AND e_o
.20
.19
.18
.17
.16
.15
K_T

FIG. 9.

FIG. 10.


ACKERSONS TESTS No 10
PROPELLER #930
MODEL #2935
DIAM.= 17.5'
a = .8
M.W.R = .25
B.T.F = .05
ℓ = .671
V/√L = .70
B/H = 2.75
Q.P.C.
e_b FOR K_T = .125
e_b VALUES TAKEN FROM CHART I
e_o
TAYLOR
G
B-4-55
(1-qwf) = .806
.55
.60
.65
.70
.75
.80
.85
U_a/nD
.74
.72
.70
.68
.66
.64
.62
.60
.58
.56
.54
.52
.50
Q.P.C., e_b, AND e_o
.15
.14
.13
.12
.11
K_T

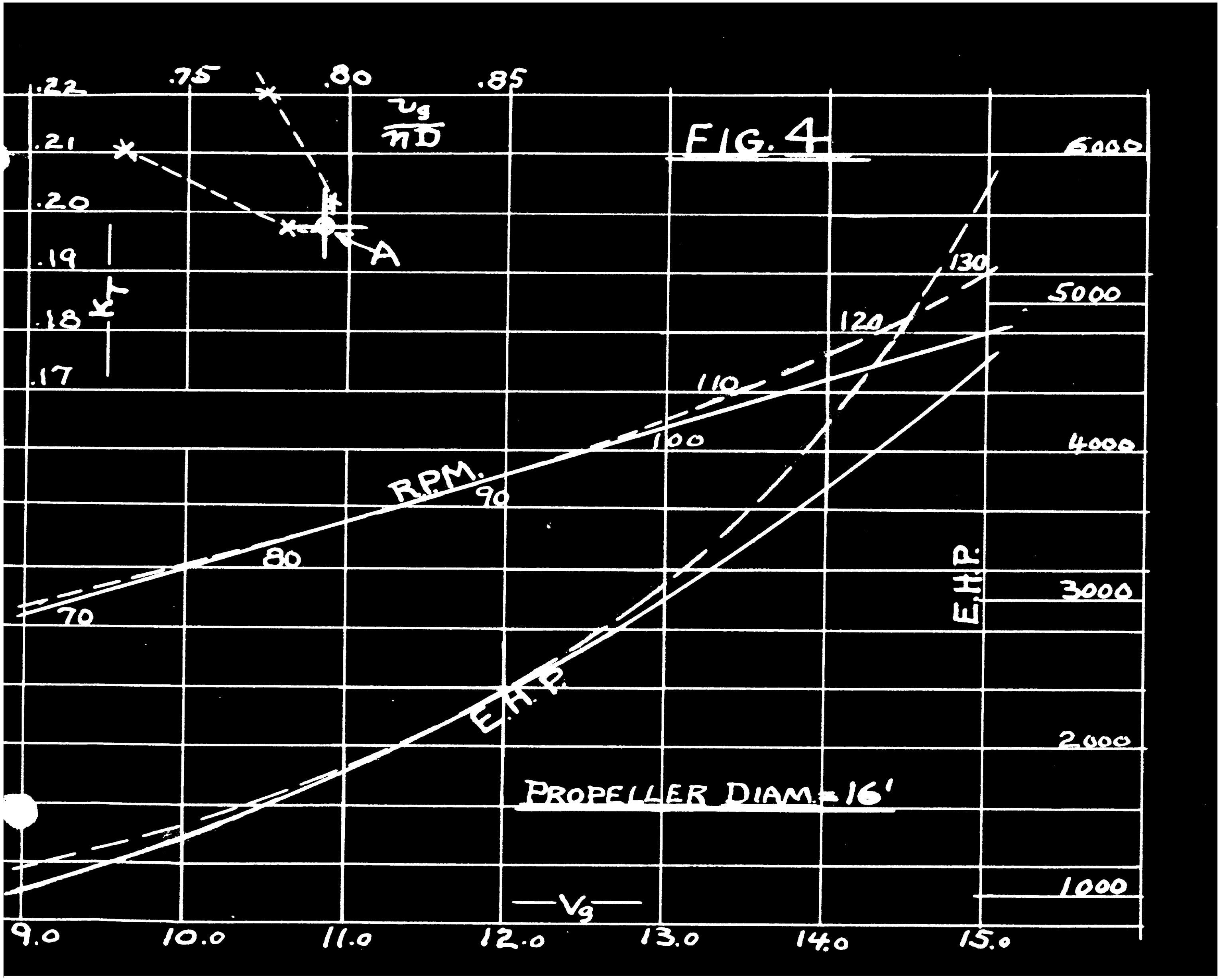


FIG. 4
$\frac{v_g}{nD}$
.75
.80
.85
.22
.21
.20
.19
.18
.17
K_T
A
R.P.M.
70
80
90
100
110
120
130
E.H.P.
E.H.P.
6000
5000
4000
3000
2000
1000
PROPELLER DIAM.=16'
V_g
9.0
10.0
11.0
12.0
13.0
14.0
15.0

varied as the cube of the speed, as shown in full lines in Fig. 4, the results of the entire test would plot in one point, A, as shown in the upper part of that figure. Any deviation from that "ideal" condition, such as is shown by the dotted lines, causes the results to plot in the form of a loop. Different combinations of deviations from the "ideal" condition result in the different loops shown in the Figures. If the R.P.M. curve were straight and the E.H.P. curve deviated from the "ideal", the loop would become a vertical line. If the E.H.P. curve varied as $(\text{speed})^3$ and the R.P.M. curve deviated from the "ideal", the loop would become a horizontal line. It is considered by some designers that the upper economic limit of speed for any given commercial form is the speed at which the power varies as $(\text{speed})^3$. This would be the speed at which the loop becomes tangent to the horizontal.

Single Screws

Each self-propelled test, then, gives data for only one significant point. These points have been taken from Figures 5 to 11 and plotted in Fig. 12. The lower part of Figure 12 gives the pitch-ratio factor determined by referring the self-propelled data to the propeller's own $K_{T(\text{open})}$ curve, which is usually given as a part of the data obtained in the open test of the propeller. The middle portion of the figure gives the K_T

TABLE IV

TEST No	DIAM. FT.	a	K_T FOR $\frac{v_a}{nD} = 0.7$	QPC	$(1-q_{ws})$ USING OWN K_T CURVE	$\frac{i}{D}$	DISP. WHEN LENGTH = 400 FT	$\frac{B}{H}$
1	14.75	1.00	.1615	.764	.798	.661	6400	2.25
3	14.75	1.00	.1712	.764	.772	.556	6400	2.75
5	15.25	1.00	.1784	.754	.801	.835	9600	2.50
7	16.0	1.00	.188	.75	.802	1.083	12800	2.25
9	16.0	1.00	.187	.745	.807	.917	12800	2.75
2	16.0	.813	.1113	.737	.784	.61	6400	2.25
4	16.0	.813	.1153	.736	.777	.503	6400	2.75
6	16.75	.806	.12	.73	.799	.76	9600	2.50
8	17.5	.80	.1267	.729	.802	.99	12800	2.25
10	17.5	.80	.125	.729	.806	.838	12800	2.75

values at which the propeller operated and shows the relation of that value to the K_T value for maximum propeller efficiency.

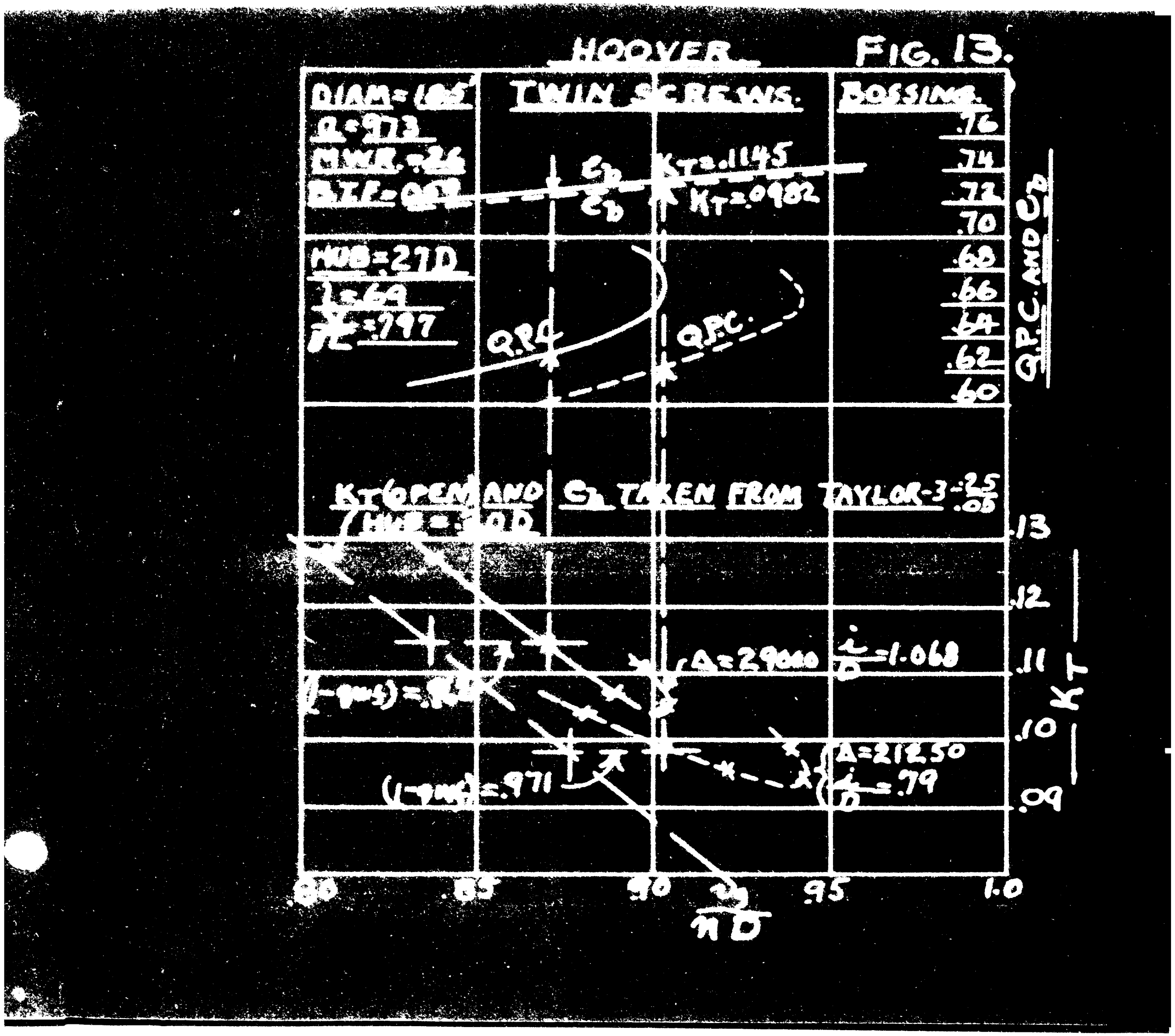
Since at the outset of any design we do not have the $K_{T(open)}$ curve for that propeller, it is convenient to have the pitch-ratio factor referred to one of the standard Charts in which the complete family history of a propeller is given. This has been done in the upper part of Fig. 12 and shows the pitch-ratio factor in terms of Type D propeller, Chart V.

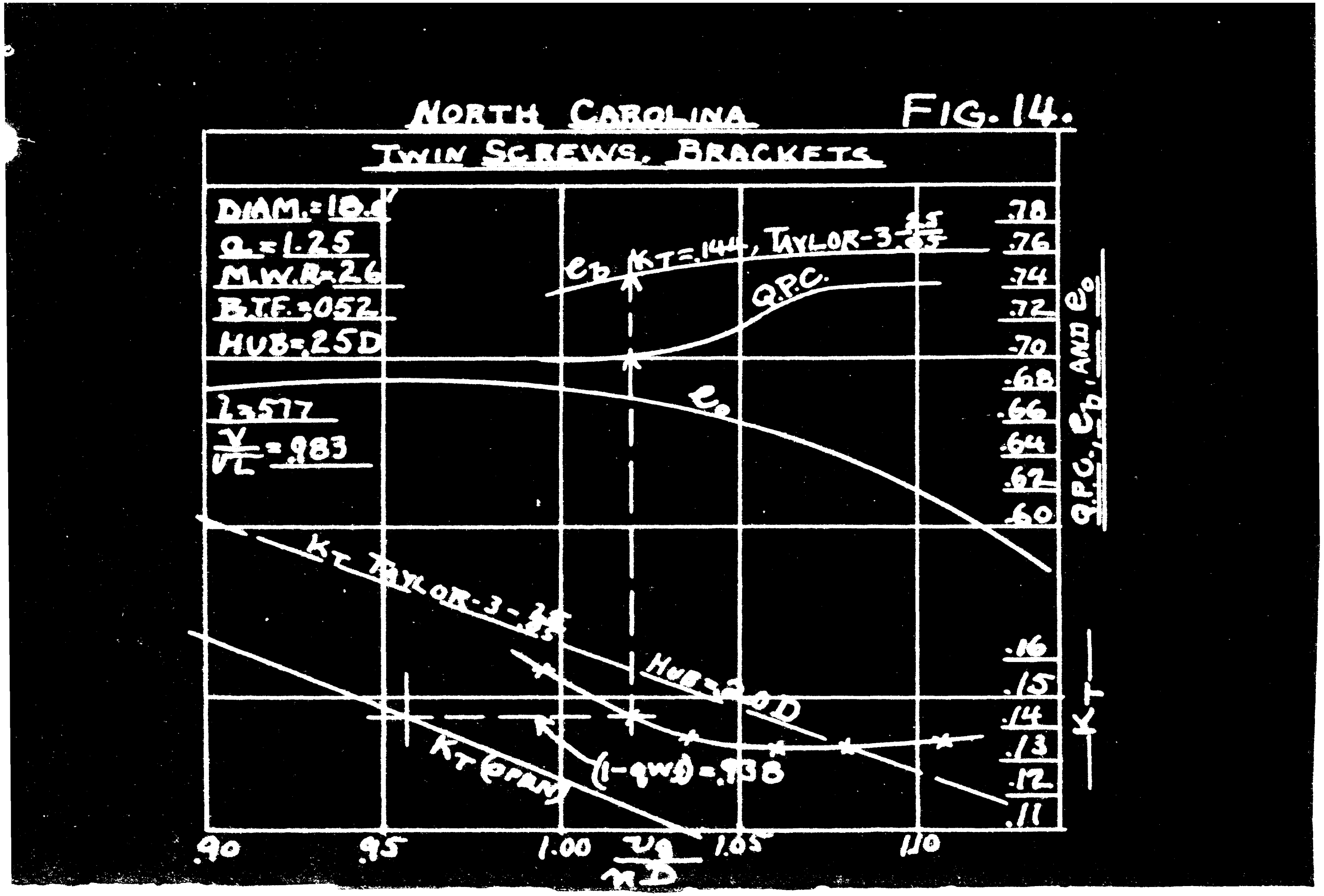
In Ackerson's tests the rudder used was of the simplified fair-form type and the tests upon Propellers 64 and 65 show that the pitch-ratio factor decreases as we go from the fair-form type to the Contra-rudder with its contra fin. If a modern rudder had been used in the Ackerson tests the factors would have been lower in value. Propellers 99 and 102, had in addition, a contra-propeller post ahead of the propeller and this would cause the pitch-ratio factor to have a lower value.

Presumably, propellers 64 and 65 had sufficient surface for the normal condition but were overloaded when the resistance was increased 45%. The result of overloading a propeller, or of providing insufficient effective surface, is to increase the value of the pitch-ratio factor.

In the Ackerson tests the propellers and models had the characteristics shown in Table IV. The propellers of 1.00 pitch ratio were of the right size and were operating at K_T values which caused them to have a qpc value about 0.02 larger than the propellers in the other group, which were too large. If the tests had been made with contra-fins and rudders in place of the simplified fair-form rudders, the qpc values would have been higher and the pitch-ratio factors somewhat lower. The model ahead of these propellers had a longitudinal coefficient of 0.671 in all the tests and the resistance was increased about 65% by increasing the displacement from 6400 tons to 12800 tons and changing the $\frac{B}{H}$ ratio. It seems likely that the pitch-ratio factor in the lower part of Fig. 12 would have been about 0.79 for the propellers of 1.00 pitch-ratio with modern appendages.

In the case of the other tests shown in the lower part of Fig. 12, the models had the Lake Freighter characteristics, the longitudinal prismatic coefficient being about 0.87. The speed-length ratio appropriate for this fullness is from 0.45 to 0.50. When the propeller surface was adequate, the pitch-ratio factor averaged about 0.74. When the load upon the propeller was augmented 45% artificially, and the blade surface became inadequate, the pitch-ratio factor had a value of about 0.81. Presumably for prismatic coefficients between 0.67 and 0.87 the pitch-ratio factor, for normal loading, would vary between 0.79 and 0.74. As pointed


HOOVER
FIG. 13.
TWIN SCREWS.
BOSSING.
DIAM = 10.5'
Q = 973
MWF = .26
BTF = .062
HUB = .27D
KT = .1145
KT = .0982
Q.P.C.
Q.P.C.
Q.P.C. AND e_D
KT (OPEN) AND e_D TAKEN FROM TAYLOR 3 - .25/.06
(HUB = .20D)
Δ = 29000
i/D = 1.068
Δ = 21250
i/D = .79
(1 - W) = .971
KT
.76
.74
.72
.70
.68
.66
.64
.62
.60
.13
.12
.11
.10
.09
.80
.85
.90
.95
1.0
V/nD



NORTH CAROLINA
FIG. 14.
TWIN SCREWS, BRACKETS
DIAM.=18.5'
Q=1.25
M.W.R.=.26
B.T.F.=.052
HUB=.25D
Z=577
V/√L=.983
e_b K_T=.144, TAYLOR-3-.25/.85
Q.P.C.
e_0
K_T TAYLOR-3-.25/.85
HUB=.20D
K_T (OPEN)
(1-w_Q)=.938
.78
.76
.74
.72
.70
.68
.66
.64
.62
.60
.16
.15
.14
.13
.12
.11
Q.P.C., e_b, AND e_0
K_T
.90
.95
1.00
1.05
1.10
V_a/nD

TABLE V TWIN SCREWS.

	DIAM. OF PROPEL D	a	HUB DIAM.	MEAN WIDTH RATIO	TYPE OF PROPEL	BRACKET OR BOSSING	No. OF BLADES	BLADE THICK. RATIO
AMERICA	19.5	.998	.184D	.24	D	BOSS.	4	.0535
HOOVER	18.5	.973	.27 D	.26	OGIVAL	BOSS.	3	.059
No. CAROLINA	18.0	1.25	.25 D	.26	OGIVAL	BRACK.	3	.052

out above, when operating with K_T values suitable for best over-all economy, the pitch-ratio factor can be varied by 0.01 or 0.02 without producing any appreciable effect upon the efficiency, and the revolutions will be affected to the extent of 1% or 2%. If the machinery is suitable for marine propulsion and has been conservatively rated as to power, this variation in revolutions will not be of any consequence.

If the pitch-ratio factor is obtained by the use of Chart V, for Type D propeller, the pitch-ratio factor will vary from about 0.75 for prismatic coefficients of 0.67, to 0.80 for prismatic coefficients of 0.87.

TWIN SCREWS.

The three examples of twin screws given in Figs. 11, 13, & 14, are rather heterogeneous in character, as shown by Table V but serve to bring out certain points that may be of interest.

In the case of the "Hoover", the $K_{T\ (open)}$ curve was not available, so the K_T curve for Taylor's 3 bladed propeller with a hub ratio of 0.20 was used for comparison. If results were available for such propellers with a hub ratio of 0.27 instead of 0.20, the K_T curve would probably be lower and the value of the pitch-ratio factor would be nearer 0.93 than 0.96. In the case of the "North Carolina" the $K_{T\ (open)}$ curve was available and the pitch-ratio factor was 0.938. Here again, if the Taylor propeller had been tested with a hub ratio of 0.25 D, the Taylor K_T curve would have been lower and the K_T curve of the "North Carolina" when self-propelled would have coincided more nearly with the Taylor K_T curve, which in Fig. 14 lies almost entirely above it. Using the Taylor curve for comparison in both cases we would have a pitch-ratio factor of 0.93 for bossing and a factor of about 1.00 for brackets.

This difference in factors with and without bossing is due to the difference in direction of flow of water to the propellers with and without bossing. Propellers will have a higher efficiency and lower pitch-ratio factor if the flow of water in the supply stream is directed against the direction of motion of the propeller blade. With outward turning propellers, the blade is rising when working in the water nearest the hull. The presence of bossing directs the water horizontally in its approach to the blade. If the end of the bossing is shaped to form a contra-fin, the efficiency will be improved and the pitch-ratio factor decreased. If the bossing is removed, the flow of the water is upward, parallel to the direction of the buttock lines, and the propeller blade has to overtake the water. The resultant direction of motion imposed upon the water leaving the blades has a large upward component which is

TABLE VI

PROPELLER Nº	PITCH-RATIO FACTOR: NORMAL RESIST.	PITCH-RATIO FACTOR: RESIST. AUGMENT 45%	GROUP	PRESSURE # D.A.: NORMAL RESIST.	PRESSURE # D.A.: RESIST. AUGMENT. 45%	$J_g = \frac{v_g}{nD}$: NORMAL RESIST.	$J_g = \frac{v_g}{nD}$: RESIST. AUGMENT. 45%
64C	.775	.80	2	7.05 LBS	10.01 LBS	.782	.684
65C	.758	.812	3	6.08	8.72	.732	.635
99	.725	.790	3	4.9	7.12	.708	.612
102-KORT	.785	.792	1	4.69	6.8	.753	.672

useless for propulsion. When the direction of motion of the water supplied to the propeller is opposed to the direction of motion of the propeller blade, as would be the case if the propeller were inturning, the resultant direction imposed upon the water is more nearly horizontal. Where brackets are used, the brackets adjacent to the propeller should have a contra-vane shape, directing the water against the motion of the blade. The higher qpc values that appear in the figure for the "North Carolina" are due largely to the fact that the propellers are operating at a J_g value of 1.02, while the "Hoover" propellers are acting at a value of 0.87. The apparent poor performance of the "Hoover" propellers is due partly to the fact that the qpc values are compared with the performance of $\frac{.25}{.05}$ blades with a hub ratio of 0.20, while the "Hoover" had $\frac{.26}{.059}$ blades with a hub ratio of 0.27.

CLASSIFICATION OF PROPELLERS.

The actual performance of a propeller in the self-propelled test, compared with the performance of propellers in Charts I to VII is the best means of classification. Factors such as rake and skew, which bulk large on the drawing board, may be of minor importance in actual performance. A study of Fig.s. 5-11 will show that the propellers fall into the three classes mentioned above and have thrust capacities that compare favorably with the Chart propellers, except in a few cases. Propeller #80 was undersurfaced for its particular job and showed a low qpc value at normal load. Propeller #65, though apparently of ample surface, had characteristics that affected its thrust capacity at lower values of J_g As stated above, "washing back" the after edge of the blade causes a reduction in effective surface, as does excessive reduction of pitch-ratio near the hub.

IMMERSION OF PROPELLERS.

The single screw works in the way of a wave crest where the direction of rotation of the water adds to the wake effect. When the immersion is less than 0.75D, the pitch-ratio factor will be affected and will decrease in value (see Ackerson test points #1, #2, #3, & #4, and test points when trim is 16 ft. and 18 ft., Fig. 12). The propellers in Ackerson test #3 and #4, were overcoming the same resistance as were the propellers in test #1 and #2, but the latter propellers had an immersion factor of 0.661 and 0.61, respectively.

Twin screws are working in the way of a wave hollow and the effect of the rotation of the water particle is to counteract the wake produced by the form. As the propeller comes nearer the surface, the pitch-ratio factor increases, as is shown by Fig. 15 which gives results for the

"America" at four drafts, on an even keel. The propellers of the "America" were more like C in sectional shape but were more like D in thrust capacity. The effect of decreased immersion commenced to be felt when the immersion ratio was 0.97.

The difference in the effect of propeller immersion upon single screws and twin screws is shown in Fig. II. While the pitch-ratio factor for twin screws reverses its trend when the immersion factor is less than 0.97, in the case of the "America", it can go as low as 0.54 in the case of single screws before reversal takes place.

APPENDAGES.

Placing contra-fins and rudders back of the propellers slows them down and causes the pitch-ratio factor to be smaller. This is shown by the tests made upon propellers #64 and #65, Figs. 5 & 6. Eliminating shaft bossings in the case of twin screws, makes it necessary to increase the pitch if the same revolutions are to be maintained. In other words, the pitch-ratio factor is increased. The pitch-ratio factor should be decreased if use is to be made of any of the contra devices in front of, or behind the propeller.

SIZE OF PROPELLER.

A small propeller works in the worst part of the wake, where the water is most turbulent, and where it has to struggle hard to get its supply of water. Consequently, the thrust deduction factor increases and the propeller is nearer the cavitating point than a larger propeller would be. It is conceivable that a propeller might be so small and its supply stream so permeated with water vapor voids that it would produce no more thrust with wake than the open propeller, with a solid supply stream, would produce without wake. In this case the pitch-ratio factor would increase to 1.00. In the tests of propellers #64, #65, #99, #102, where the resistance was increased 45% by artificial means, the pitch-ratio factor increased as shown in Table VI. The nozzle in the case of #102 protects the supply stream from the demoralizing effects experienced by the others, and the pitch-ratio factor was practically unaffected.

MEAN WIDTH RATIO

Increase in mean-width ratio is one of the ways of counteracting the harmful effects of a turbulent wake, permeated with water vapor voids. However, there is a virtual reduction of area when the edges of the blade are "washed back", as in the Troost wheels; when the pitch-ratio is unduly reduced at the hub; and when a large hub is used. There is stream line flow around the hub which neutralizes a certain protion of the wake effect, and this effect increases with increase in the size of hub. If the pitch-ratio is unduly reduced in the neighborhood of the large hub, this portion of the surface becomes ineffective and the thrust is concentrated upon the outer portions of the blades.

LIMITED RANGE OF VALUE OF PITCH-RATIO FACTOR

The pitch-ratio factor cannot be tied up too closely with the form wake produced by the model. The very qualitites in a model which produce a large wake and would naturally call for a small value of pitch-ratio factor, give rise to turbulence, cross flow, and cavitation, and make access of water to the propeller difficult. All these, in their turn, would call for an increase in the value of the pitch-ratio factor in order that the desired thrust may be produced. As a consequence of these conflicting conditions, we find that the pitch-ratio factor has the rather narrow limits of variation shown in Fig. 12.

The ratio of qpc to e_b is, in general, higher as the K_T value at which the propeller operates is nearer to the K_T value for maximum efficiency. In Fig. 12, Propeller #64 operates at a K_T value of about 0.20, while the K_T value for maximum efficiency of Group 2 propellers is 0.125. Propeller #65 operates at a K_T value of 0.17, while the value for maximum efficiency of Group 3 propellers, at a J_g value of 0.77, is about 0.13. Propeller #99 is operating at the K_T value which gives maximum propeller efficiency. A study of Figures 5, 6, & 8 will show that the ratio of qpc to e_b is highest in the case of Propeller #99 and lowest in the case of #64. However, the fact that the propeller is achieving a high efficiency does not imply that the design of which it is a part would not have a higher economic efficiency if the K_T value were higher than that called for from the point of view of propeller efficiency alone.