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REPORT No. 64

EXPERIMENTAL RESEARCH ON AIR PROPELLERS, III

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

PREPRINT FROM FIFTH ANNUAL REPORT

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EXPERIMENTAL RESEARCH ON AIR PROPELLERS, III.

By W. F. Durand and E. P. Lesley.

SCOPE OF THE INVESTIGATION COVERED BY PRESENT TESTS.

The investigation described in this report was conducted for the National Advisory Committee for Aeronautics at Leland Stanford Junior University, Palo Alto, Calif.

The investigation on air propellers carried on during the two years 1917–18 and forming the subject of reports Nos. 14 and 30[1] of the National Advisory Committee for Aeronautics covered the following general characteristics of form and design:

Four nominal pitch ratios, viz, 0.5, 0.7, 0.9, and 1.1.

Two forms of blade contour, (1) with approximately parallel sides and slightly rounded tip and (2) curved and tapering in accordance with the common saber form.

Two mean width ratios, viz, 15 per cent and 20 per cent of the radius of the propeller.

Two forms on the driving face, viz, plane and cambered or hollowed.

Two forms of distribution of geometrical pitch, (1) uniform and (2) increasing radially as determined by the assignment of a constant theoretical angle of attack.

In the study of the hollowed or cambered driving face, all combinations of characteristics otherwise with a degree of camber measured by one-third the thickness of the corresponding straight-face section were tested, while six with a degree of camber one-half the preceding were tried.

In the study of propellers with radially increasing pitch, this feature had not been extended to those of nominal pitch ratio 1.1.

In addition to propellers with combinations of characteristics as indicated above, a considerable number of tests were carried out, as recorded in report No. 30, covering a variety of forms of blade contour combined with one or more combinations of other characteristics.

In continuation of this general program of investigation, it seemed desirable to examine in particular the influence of the following characteristics:

(1) Nominal pitch ratio 1.3 combined with a certain number of the more common or standard forms and proportions.

(2) Driving face slightly rounded or convex.

(3) Change in the location of the maximum thickness ordinate of the blade section.

(4) Pushing forward the leading edge of the blade, thus giving a rounded convex surface on the leading side of the driving face.

(5) A series of values for the constant "angle of attack" in forming propellers with radially increasing pitch.

In accordance with these purposes tests have been carried out on some 28 propellers, figure 1, having characteristics as follows

Four propellers of nominal pitch ratio 1.3, uniform pitch, straight face, and with four combinations of form of blade and area as shown in Table I.

Five propellers of nominal pitch ratios 0.5, 0.7, 0.9, 1.1, and 1.3, all of uniform pitch, one area and one blade form, and with the driving face made slightly convex by adding a crown of one-sixth the normal thickness of the corresponding straight-face sections, as shown in Table I and in sections, figure 2.

[1] See Third Annual Report, 1917, and Fourth Annual Report, 1918.

TABLE I.—*Characteristics of model propellers.*

No.	Diameter.	Nominal pitch ratio.	Nominal pitch.	Mean blade width.	Form or contour No.	Section No.	Dynamic pitch ratio.	Dynamic pitch.
	Inches.		*Inches.*					*Inches.*
111	36	1.3	46.8	0.15r	F_1	S_1	1.637	58.97
112	36	1.3	46.8	.20r	F_1	S_1	1.518	54.64
113	36	1.3	46.8	.15r	F_2	S_1	1.623	58.41
114	36	1.3	46.8	.20r	F_2	S_1	1.52	54.72
115	36	.5	18.0	.15r	F_2	S_4	.735	26.47
116	36	.7	25.2	.15r	F_2	S_4	.934	33.62
117	36	.9	32.4	.15r	F_2	S_4	1.139	41.00
118	36	1.1	39.6	.15r	F_2	S_4	1.371	49.37
119	36	1.3	46.8	.15r	F_2	S_4	1.55	55.8
120	36	.7	25.2	.15r	F_2	S_5	.865	31.14
121	36	.7	25.2	.15r	F_2	S_6	.903	32.5
122	36	.7	25.2	.15r	F_2	S_7	.961	34.6
123	36	.7	25.2	.15r	F_2	S_8	.997	35.9
124	36	.7	25.2	.15r	F_2	S_9	.965	34.74
125	36	.7	25.2	.15r	F_2	S_{10}	.991	35.68
126	36	.7	25.2	.15r	F_2	S_{11}	1.013	36.47
127	36	.5	12.32–21.29	.15r	F_2	S_1	.675	24.30
128	36	.5	9.16–23.00	.15r	F_2	S_1	.656	23.62
129	36	.7	20.1 –28.45	.15r	F_2	S_1	.912	32.83
130	36	.7	16.31–30.13	.15r	F_2	S_1	.885	31.87
131	36	.9	28.29–35.57	.15r	F_2	S_1	1.126	40.55
132	36	.9	25.24–37.23	.15r	F_2	S_1	1.099	39.57
133	36	1.1	33.5 –41.1	.15r	F_2	S_1	1.394	50.20
134	36	1.1	36.71–42.6	.15r	F_2	S_1	1.377	49.60
135	36	1.1	34.09–44.2	.15r	F_2	S_1	1.351	48.65
136	36	1.3	46.6 –48.18	.15r	F_2	S_1	1.67	60.13
137	36	1.3	45.52–49.6	.15r	F_2	S_1	1.637	58.97
138	36	1.3	43.55–51.2	.15r	F_2	S_1	1.606	57.82

Four propellers of nominal pitch ratio 0.7, uniform pitch, one blade form and area, and four locations of the maximum thickness ordinate of the blade section, as shown in Table I and in sections, figures 3, 4, 5, and 6.

Three propellers of nominal pitch ratio 0.7, uniform pitch, one blade form and area, and with three degrees of deformation of the leading edge by pushing forward, as shown in Table I and in sections, figures 7, 8, and 9.

Twelve propellers distributed over the five pitch ratios 0.5, 0.7, 0.9, 1.1, 1.3, all with one blade form and area and with radially expanding pitch derived from the assumption of varying theoretical "angles of attack," as shown in Table I.

The four propellers 111, 112, 113, and 114, of nominal pitch ratio 1.3, fall in as the last members of four series formed by the propellers having corresponding combinations of form and area and with the other pitch ratios as tested in previous years.

The five propellers 115, 116, 117, 118, and 119, with the slightly rounded driving face, give a series representing a single blade form and area carried through the five nominal pitch ratios as shown in Table I.

The four propellers 120, 121, 122, and 123, with four different positions of the maximum thickness ordinate of the blade section, all of one pitch ratio, blade form and area, form with the corresponding propeller (No. 7) tested in 1917,[1] a series of five propellers with five positions of the maximum thickness ordinate, viz, 33 per cent, from the leading edge for No. 7 (which closely represents standard practice) and positions on either side as follows:

No. 120, maximum thickness of section 0.17 per cent of width from leading edge; No. 121, 25 per cent; No. 122, 41 per cent; No. 123, 49 per cent. The combination of characteristics otherwise (pitch ratio, form and area) selected for this series was intended to represent an average or typical case.

The three propellers, 124, 125, and 126, with leading edge pushed forward, give with No. 7 a single series with three successive amounts of such deformation, all of a single-type combination otherwise. In No. 7 the driving face is straight; in Nos. 124, 125, and 126 the leading edges are moved forward 25 per cent, 50 per cent, and 75 per cent of the maximum thickness of section, respectively.

The 12 propellers, 127 to 138, show in Table I a single value for nominal pitch ratio and two values for nominal pitch. The former is the pitch ratio of the driving face at 13-inch radius

[1] See Third Annual Report, 1917.

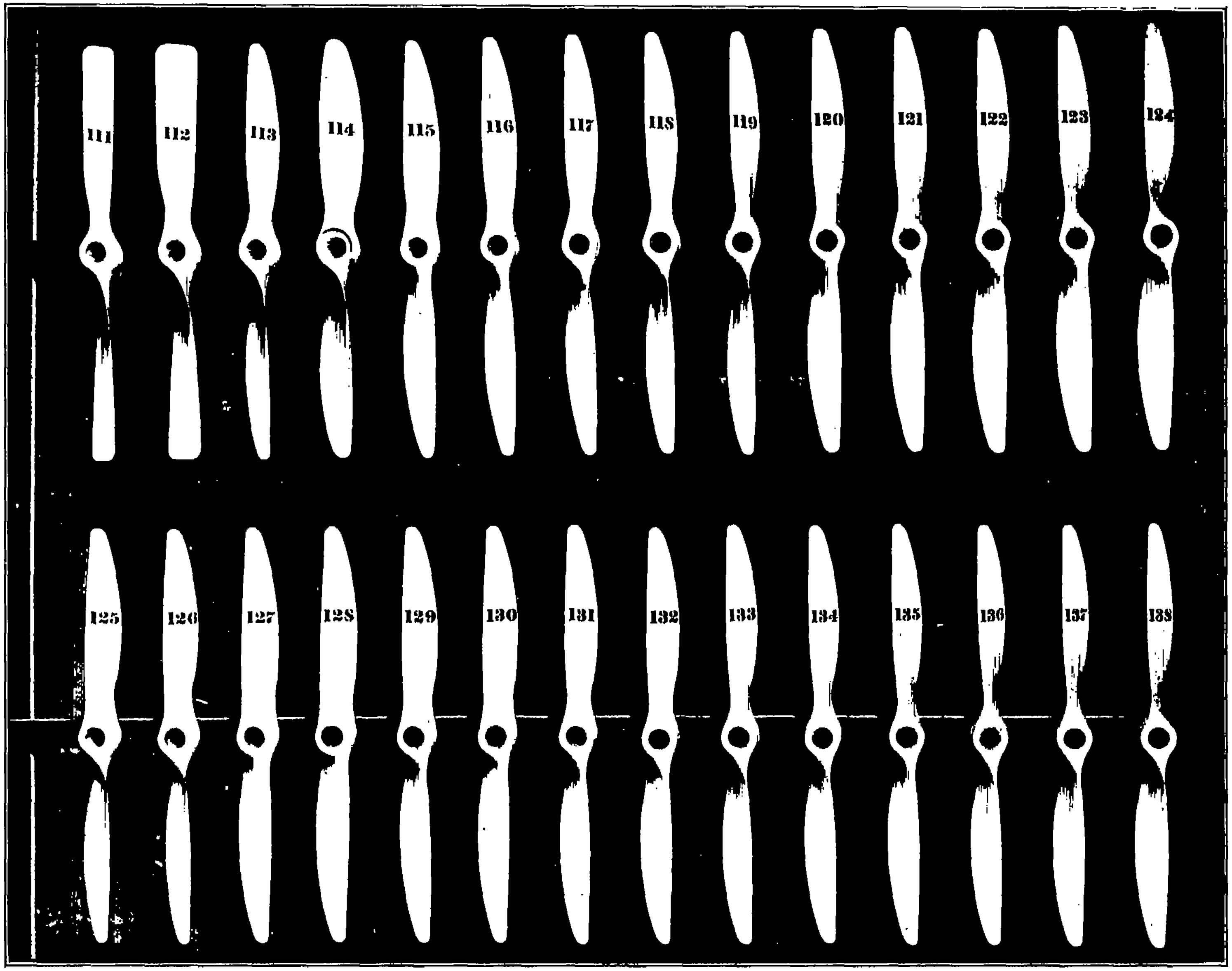


FIG. 1.—MODEL PROPELLERS.

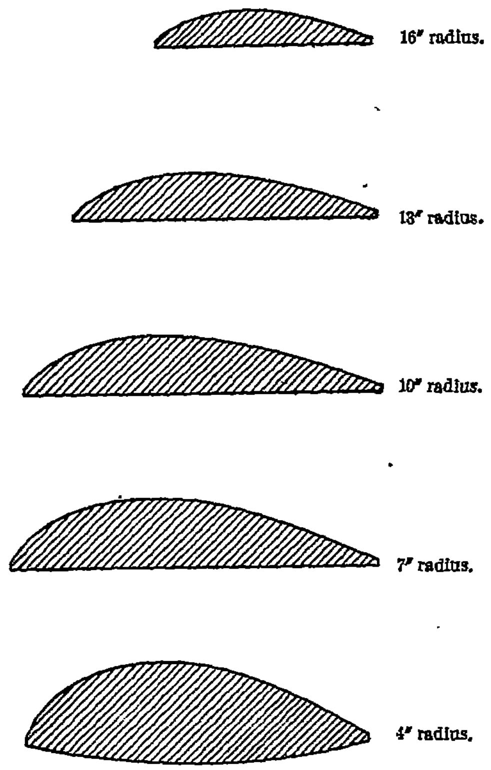


FIG. 2—Sec. 4. Prop. Nos. 115, 116, 117, 118, 119.

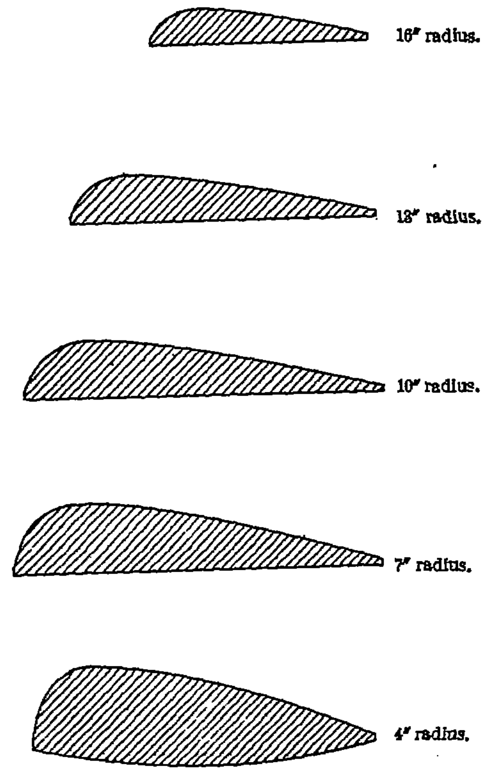


FIG. 3—Sec. 5. Prop. No. 120.

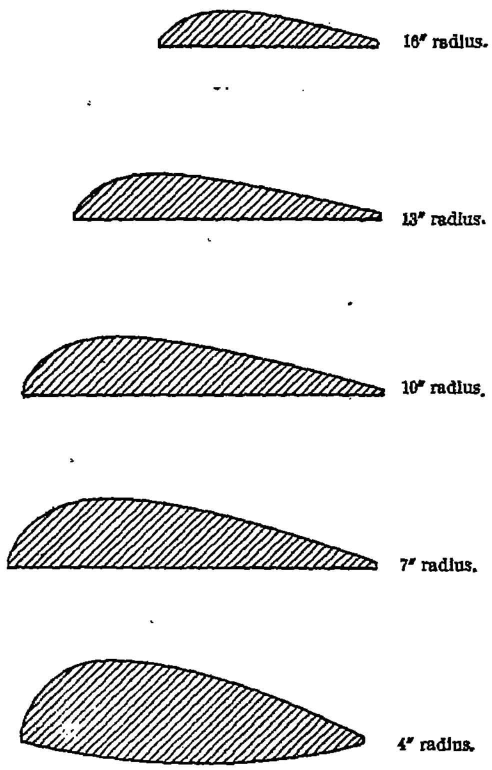


FIG. 4—Sec. 6. Prop. No. 121

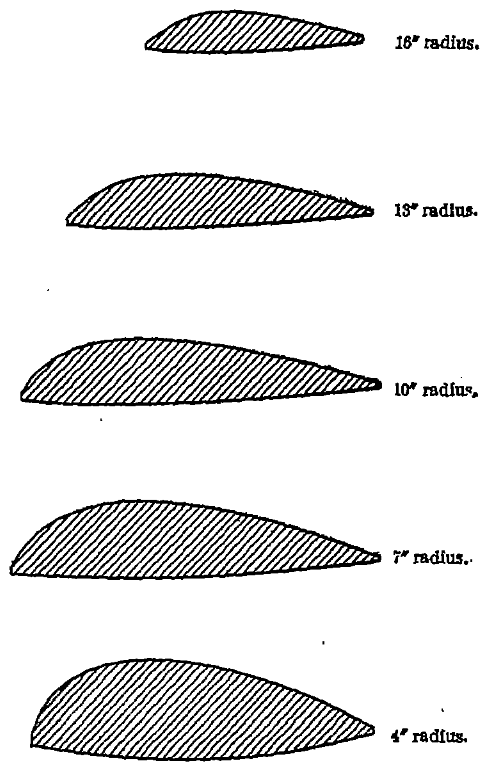


FIG. 5—Sec. 7. Prop. No. 122.

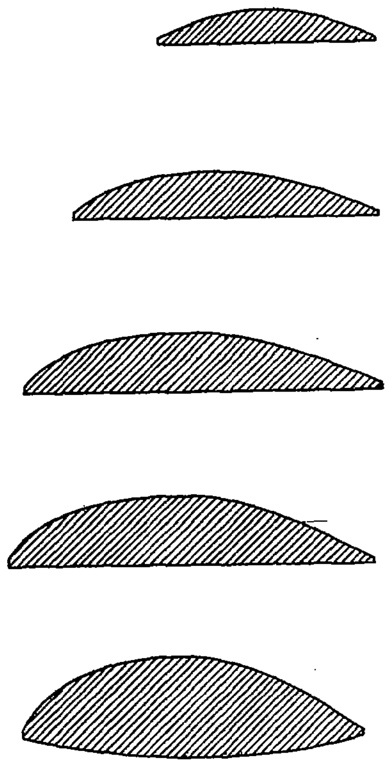


FIG. 6—Sec. 8. Prop. No. 123.

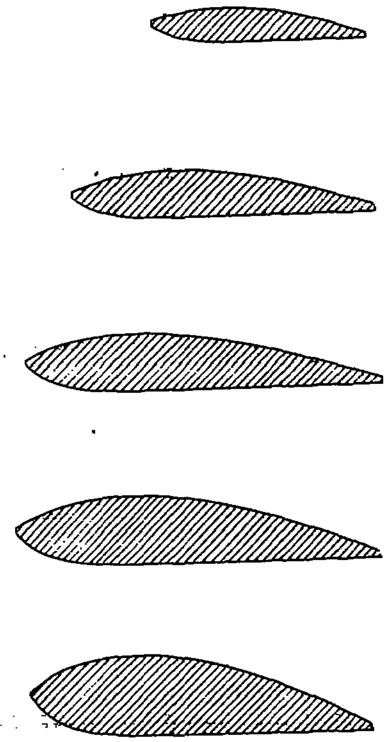


FIG. 7—Sec. 9. Prop. No. 124.

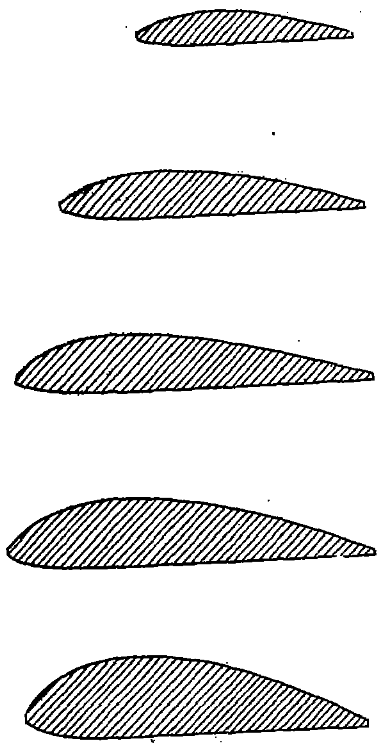


FIG. 8—Sec. 10. Prop. No. 125.

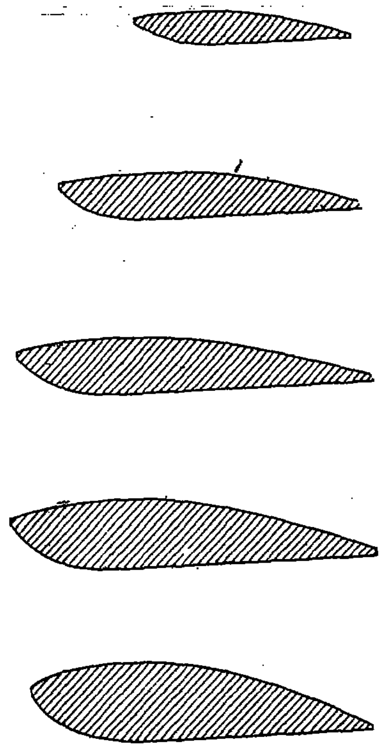


FIG. 9—Sec. 11. Prop. No. 126.

and the latter are the pitches of the driving face at the 4 and 18 inch radii, respectively. These propellers were given a radially increasing pitch according to the Drzewiecki method. For all blades showing the same value of nominal pitch ratio the pitch of the driving face at the 13-inch radius equals the diameter multiplied by the value of pitch ratio given. The following table shows the assumed constant "angle of attack" which gives rise to the variation in nominal pitch tabulated:

TABLE II.—*Assumed constant "angle of attack."*

Propeller No.	Nominal pitch ratio.	Assumed constant "angle of attack."
		Degrees.
127	0.5	6
128	.5	9
129	.7	6
130	.7	9
131	.9	6
132	.9	9
133	1.1	3
134	1.1	6
135	1.1	9
136	1.3	3
137	1.3	6
138	1.3	9

The contour, area, and section of propellers 127 to 138 are the same as for 3, 7, 11, 15, 19, and 23 of the 1917 report; 82 of the 1918 report; and 113 of the present investigation. The 20 may then be arranged in the following five series:

	Nos.
0.5 nominal pitch ratio	11, 23, 127, 128
.7 nominal pitch ratio	7, 19, 129, 130
.9 nominal pitch ratio	3, 15, 131, 132
1.1 nominal pitch ratio	82, 133, 134, 135
1.3 nominal pitch ratio	113, 136, 137, 138

The first of each series has a uniform pitch; the second has a radially expanding pitch produced by the assumption of a 3° "angle of attack"; the third one for a 6° "angle of attack"; the fourth one for a 9° "angle of attack."

All propellers in one series have the same geometrical pitch at the 13-inch radius. It should be noted that the effect of an assumed constant "angle of attack" varies inversely with the nominal pitch ratio. For instance, with propeller No. 127 (6°, 0.5 pitch ratio) the pitch changes from 12.32 to 21.29 inches, a variation of about 43 per cent of the maximum, while for propeller 137 (6°, 1.3 pitch ratio) the change is from 45.52 to 49.60 inches, a variation of less than 9 per cent of the maximum.

CONSTRUCTION OF MODELS.

The model propellers were carved from single sticks of well-seasoned Pacific coast sugar pine (*Pinus Lambertiana*) in the manner previously described. A departure was made from previous practice in the method of finish. After carving and sandpapering, the smooth bare wood was given one coat of orange shellac. This was rubbed with fine sandpaper and the surface given three to four coats of flat gray paint, put on very thin with a camel's-hair brush. Each coat was thoroughly dried and rubbed smooth, small surface defects being corrected with a filler. The propellers were then given two coats of rubbing varnish, the first being rubbed to surface with pumice and water and the second left glossy. The resultant finish is smooth, thin, and hard. For photographing, a single coat of flat gray was applied after tests were completed.

AERODYNAMIC LABORATORY.

Tests on the present series of model propellers were conducted in the aerodynamic laboratory at Stanford University, California, during the month of September, 1919. The wind tunnel is of similar form and proportions to that previously described,[1] but considerably larger,

[1] See Third Annual Report, 1917.

having a throat diameter of 7.5 feet. It is of somewhat more substantial construction, being solidly framed, and planked with ⅝-inch thick tongue-and-groove flooring.

The wind fan is 15 feet diameter, with eight blades of 12-foot pitch. It is driven by a 100-horsepower, 220-volt, variable-speed, direct-current motor, with which, at 25 per cent overload, a wind velocity of 80 miles per hour may be realized.

TESTS.

The tests were conducted in a similar manner to those described in the 1918 annual report. Somewhat greater wind velocities were used, it being the practice to start the test with a wind velocity of about 45 miles per hour. After the safe limit of thrust (about 50 pounds) or the power limit of the driving motor (12 horsepower) was reached with this velocity, observations were made at higher slips by reducing the wind velocity until the useful range of slip had been covered.

The thrust-torque dynamometer and other devices used in 1917 and 1918 were employed in these present tests. The thrust balance, torque springs, and wind-speed meter were subjected to frequent careful calibrations as previously.

REDUCTION OF DATA.

The observations of thrust, torque, revolutions, velocity, and density were combined and reduced to the coefficients

$$\frac{V}{ND},$$

$$T_c=\frac{100\times\text{thrust}}{\Delta V^2D^2},$$

$$\rho=\text{efficiency},$$

$$Q_c=\frac{1000\times\text{torque}}{\Delta V^2D^3},$$

$$\frac{P_u}{\Delta N^3D^5}=\frac{T_c}{100}\left(\frac{V}{ND}\right)^3,$$

$$\text{and } \frac{P_e}{\Delta N^3D^5}=\frac{Q_c}{1000}\left(\frac{V}{ND}\right)^2\times 2\pi.$$

Coefficients T_c, Q_c, and ρ were plotted on abscissæ of $\frac{V}{ND}$ for each observation and fair curves drawn through the points determined. The curves were checked for consistency at each 0.1 of $\frac{V}{ND}$.

Likewise log $\frac{P_u}{\Delta N^3D^5}$ and log $\frac{P_e}{\Delta N^3D^5}$ were plotted for each observation on log $\frac{V}{ND}$, and fair curves drawn and checked for consistency with T_c, Q_c, and ρ for each 0.1 of $\frac{V}{ND}$.

While English units were used in making observations, the results as presented are in metric units.

V = velocity meters per second.
N = revolutions per second.
D = diameter in meters.
T = thrust in kilograms.
Q = torque in kilogram meters.
Δ = density in kilograms per cubic meter.
P_u = useful work in kilogram meters per second.
P_e = effective work in kilogram meters per second.
1 metric horsepower = 75 kilogram meters per second.

All the coefficients are thus the same as those used in the 1918 report. Coefficients T_c, Q_c, $\frac{P_u}{\triangle N^3 D^5}$, and $\frac{P_e}{\triangle N^3 D^5}$ of the 1917 report are comparable to those of this investigation when multiplied by 3.28.

The results are presented in the form of curves of T_c, Q_c, and ρ, plotted on $\frac{V}{ND}$ (Pls. I to XVI) and of log $\frac{P_e}{\triangle N^3 D^5}$ and log $\frac{P_u}{\triangle N^3 D^5}$ plotted on log $\frac{V}{ND}$ (Pls. XVII to XXIV). The use of these diagrams has been described.[1] About one-half the observations actually made are plotted on the curves of T_c and Q_c, it being thought desirable to avoid confusion of the diagrams by multiplicity of points. Those shown are typical.

DISCUSSION OF RESULTS.

THRUST.

THRUST IN RELATION TO PITCH RATIO.

The curves of T_c for propellers 111, 112, 113, and 114 compared with those for propellers with similar characteristics except pitch show that in general for a given value of $\frac{V}{ND}$ thrust increases with pitch ratio. At the lower values of $\frac{V}{ND}$, however (below 0.5), it appears that the increment of thrust is less than that of pitch ratio and that the limit of thrust is soon reached. This is shown most clearly by curves of $\frac{P_u}{\triangle N^3 D^5}$ on Plates XIX, XXIII, and XXIV.

THRUST IN RELATION TO BLADE SECTION.

(*a*) *Rounded face.*—The thrust of propellers 115, 116, 117, 118, and 119 for the same value of $\frac{V}{ND}$ is less than that for the same form, area, and nominal pitch, straight-face blades 11, 7, and 3 of the 1917 report, 82 of the 1918 report, and 113 of the present series. A part of this reduction of thrust may be accounted for by the smaller dynamic pitch.

(*b*) *Position of maximum ordinate.*—Propellers 120, 121, 7 of 1917, 122, and 123 show that for a given value of $\frac{V}{ND}$ the thrust increases with the movement of the maximum ordinate of section away from the leading edge, until about 33 per cent of the width is reached. Beyond this there appears to be little change in thrust, No. 122 showing slightly less than No. 7 and No. 123 nearly the same. The variation in thrust is perhaps not greater than would be expected from the variation in dynamic pitch.

(*c*) *Leading one-third of face rounded by moving leading edge forward.*—Pushing the leading edge forward decreases thrust for a given value of $\frac{V}{ND}$ except at low slip, where 125 gives somewhat greater thrust than 124 and 126 greater than 125. The thrust of No. 7 (1917) is greater than any of above.

THRUST IN RELATION TO RADIALLY INCREASING PITCH.

For propellers 11, and 23 of 1917 and 127 and 128 of the present series, at a given value of $\frac{V}{ND}$, the thrust varies inversely with the "angle of attack." The variation is not greater than would be expected from the variation of dynamic pitch.

The same is true of series 7, 19, 129, and 130.

For series 3, 15, 131, 132; 82, 133, 134, 135; 113, 136, 137, 138; the differences are less marked. In some cases it is in one direction and in some in the other. This is accounted for by the fact that with the larger pitch ratios the variation of pitch is less than with the smaller pitch ratios for the same "angles of attack."

[1] Report 14, Third Annual Report 1917.

POWER.

POWER IN RELATION TO PITCH RATIOS.

As would be expected, the larger the pitch ratio, the greater the power absorbed at a given value of $\frac{V}{ND}$.

POWER IN RELATION TO BLADE SECTION.

(*a*) *Rounded face.*—The rounded-face blades 115, 116, 117, 118, and 119 absorb less power at a given value of $\frac{V}{ND}$ than the corresponding straight-face blades Nos. 11, 7, 3, 82, and 113.

(*b*) *Position of maximum ordinate of blade section.*—At a given value of $\frac{V}{ND}$ power increases as the maximum ordinate of the section is moved away from the leading edge until about 33 per cent of the width has been traversed. Beyond this point there is comparatively little difference in the models tested.

(*c*) *Leading one-third of face rounded by moving leading edge forward.*—Power absorbed for a given value of $\frac{V}{ND}$ increases as the leading edge of the propeller blade is pushed forward. An exception to this appears in propeller 126 where for values of $\frac{V}{ND}$ between 0.55 and 0.75 the power absorbed by No. 126 is slightly less than that for No. 125.

POWER IN RELATION TO RADIALLY INCREASING PITCH.

The two series 11, 23, 127, 128, and 7, 19, 129, 130 show the same general relations of power absorbed as of thrust developed; that is, power varying inversely with the "angle of attack." Also, as with thrust, the differences in the larger pitch ratios are small. In the case of series 113, 136, 137, 138 there is little difference between the torque curves. It is sometimes in one direction and sometimes in the other.

EFFICIENCY.

EFFICIENCY IN RELATION TO PITCH RATIO.

The 1.3 pitch ratio propellers show a larger range of efficiency and a slightly higher maximum than similar forms tested in 1918 (1.1 pitch ratio). There is a marked decrease in efficiency at the higher slips, some blades showing an efficiency curve which is slightly concave upward at the lower value of $\frac{V}{ND}$. This was not unexpected from tests on the variable pitch propeller No. 96 in 1918.

EFFICIENCY IN RELATION TO BLADE SECTION.

(*a*) *Rounded face.*—Propellers 115, 116, 117, 118, and 119 have practically the same efficiency curves as Nos. 11, 7, 3, 82, and 113 (straight face). Although the thrust developed is less for the former, the power absorbed is proportionally less, so that the efficiency is little affected. Having slightly less dynamic pitch, a slightly less maximum efficiency for the rounded-face series is to be expected. It appears, however, that the strength of blades may be considerably increased by slightly rounding the face, and with little or no corresponding loss in efficiency.

(*b*) Position of maximum ordinate.—Cross curves of efficiency for propellers 120, 121, 7 of 1917, 122, and 123 show highest efficiency for No. 7, whose maximum ordinate of section is one-third of the width from the leading edge. No. 121 appears superior to No. 120. There is little difference between Nos. 122 and 123, but both are distinctly less efficient than No. 7.

(*c*) *Leading one-third of face rounded by pushing leading edge forward.*—Pushing the leading edge forward increases the maximum efficiency attained but decreases the efficiency over the working range. The increase in maximum efficiency is not more than would be expected from the increase in dynamic pitch.

EFFICIENCY IN RELATION TO RADIALLY EXPANDING PITCH.

The five series of propellers, 11, 23, 127, 128; 7, 19, 129, 130; 3, 15, 131, 132; 82, 133, 134, 135; 113, 136, 137, 138, seem to indicate that no advantage in efficiency is to be gained from a radially expanding pitch produced by the method of design followed. Although these series show with increasing "angle of attack" slight increases in efficiency over the usual working range, there is an accompanying reduction in maximum efficiency, both of which results are to be expected from the decrease in dynamic pitch.

As with thrust and power, the differences for the small pitch ratios are more marked than those for the larger ones.

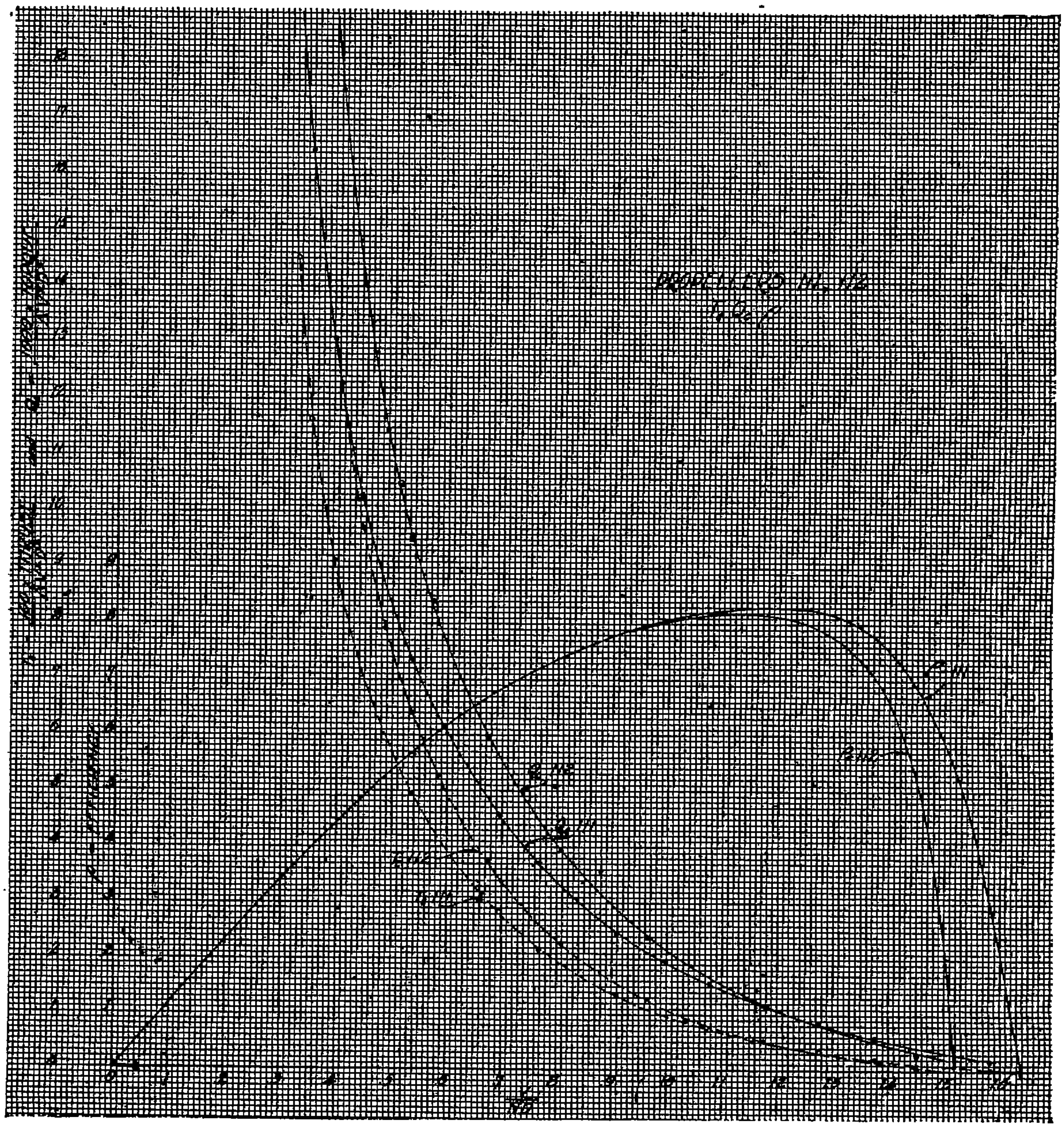


Plate I.

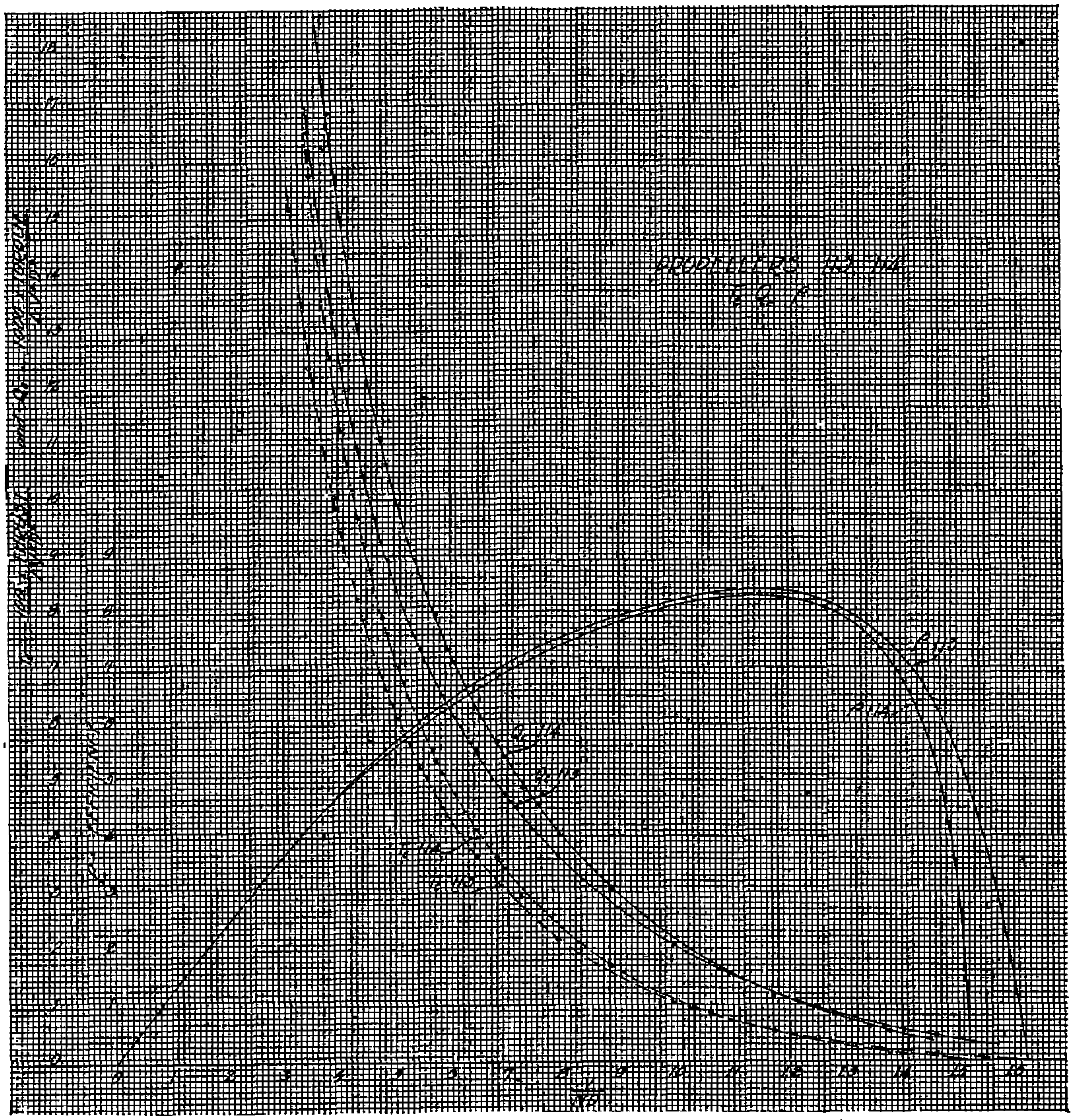


PLATE II.

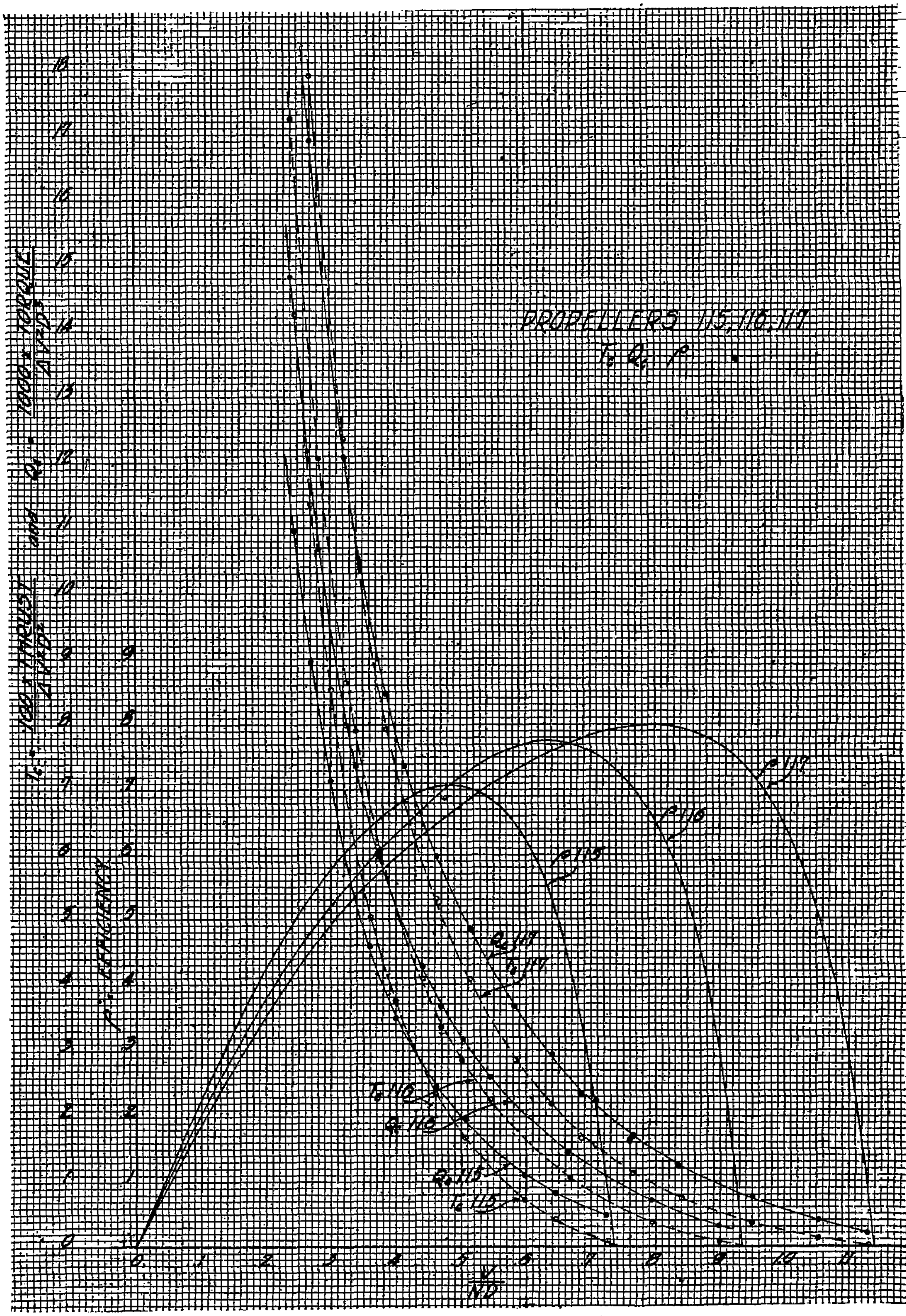

PROPELLERS 115, 116, 117
T_c, Q_c, ρ
$T_c = \frac{1000 \times THRUST}{\Delta V^2 D^2}$ and $Q_c = \frac{1000 \times TORQUE}{\Delta V^2 D^3}$
ρ = EFFICIENCY
$\frac{V}{ND}$
ρ 117
ρ 116
ρ 115
Q_c 117
T_c 117
T_c 116
Q_c 116
Q_c 115
T_c 115

PLATE III.

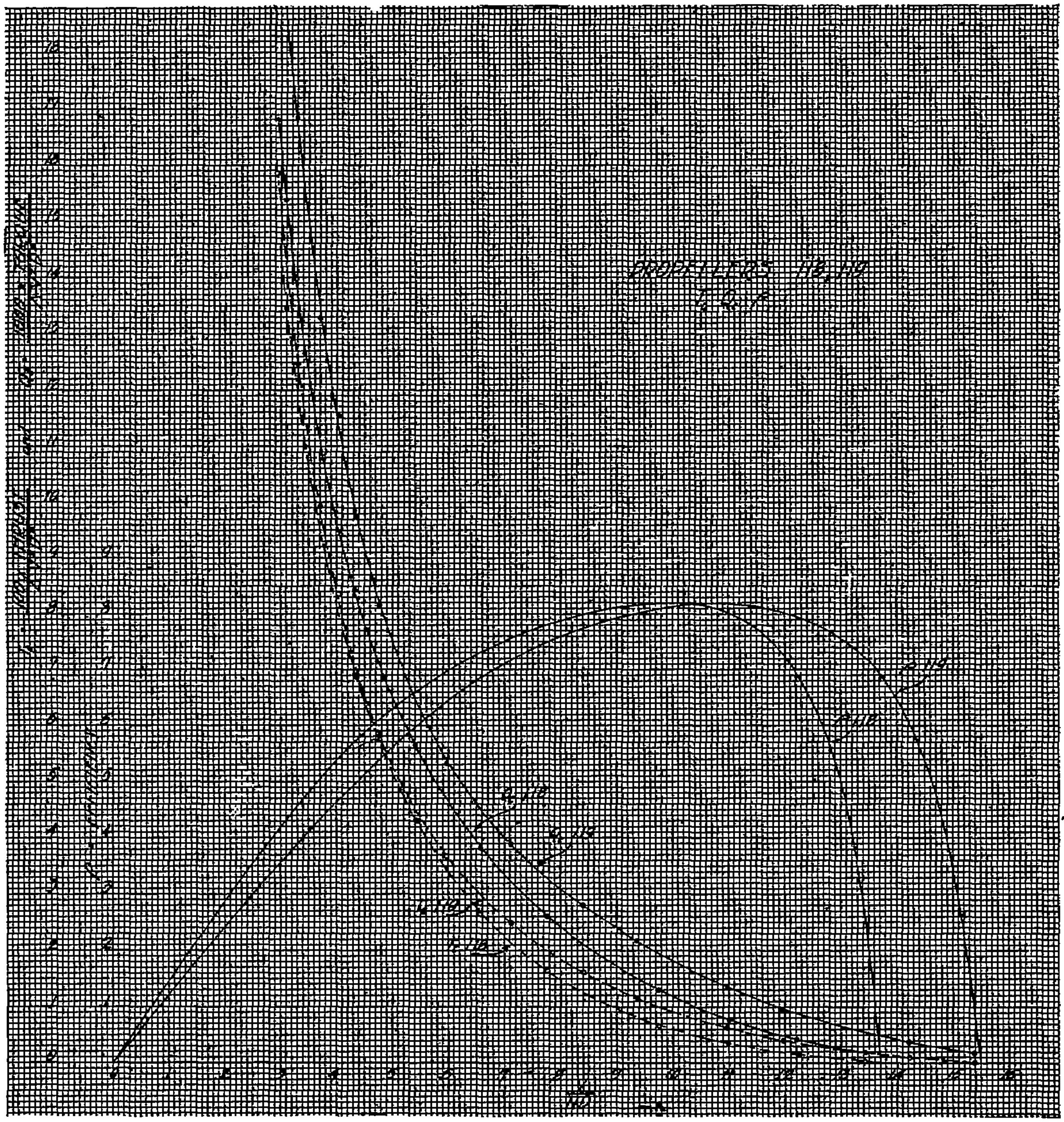


PLATE IV.

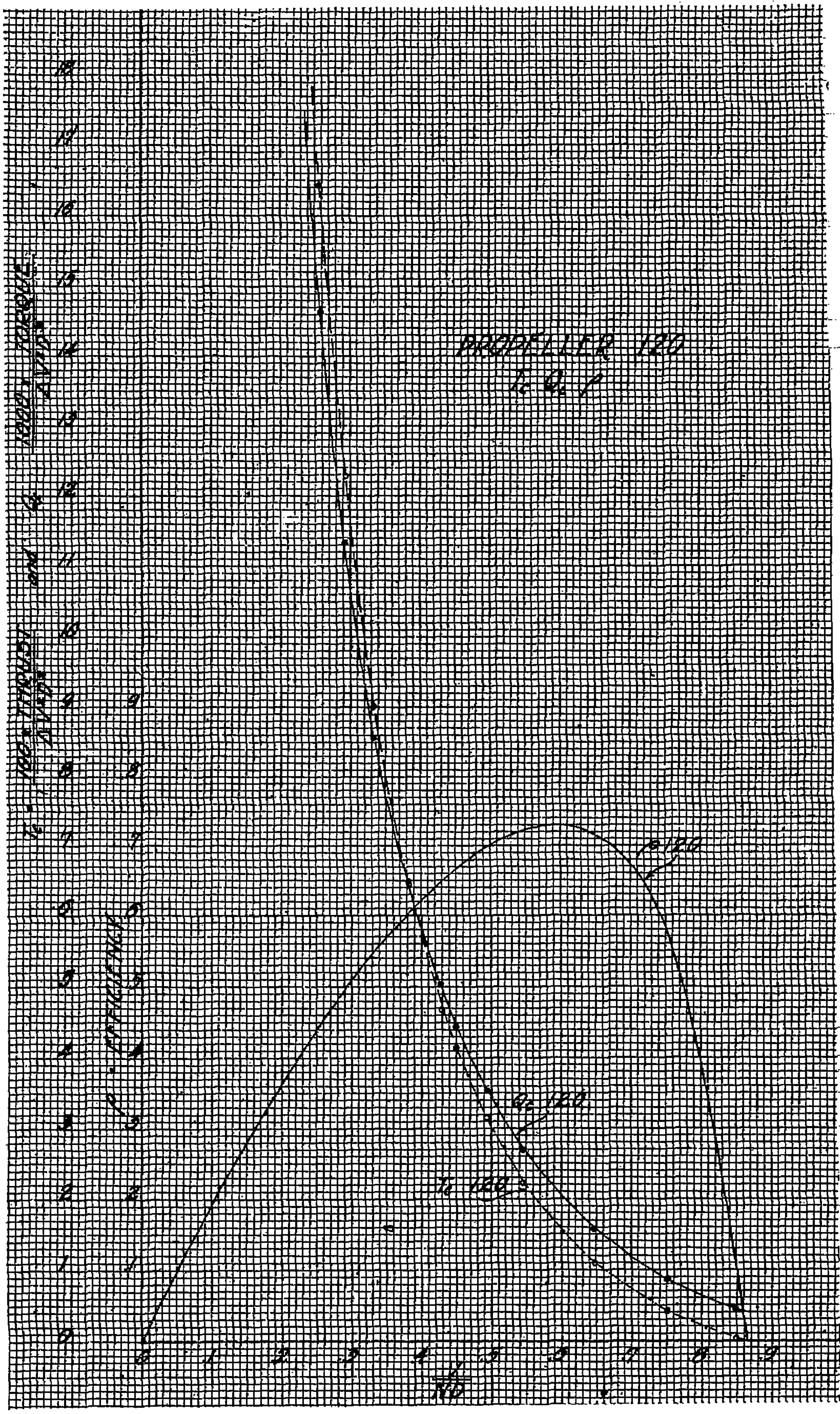


PLATE V.

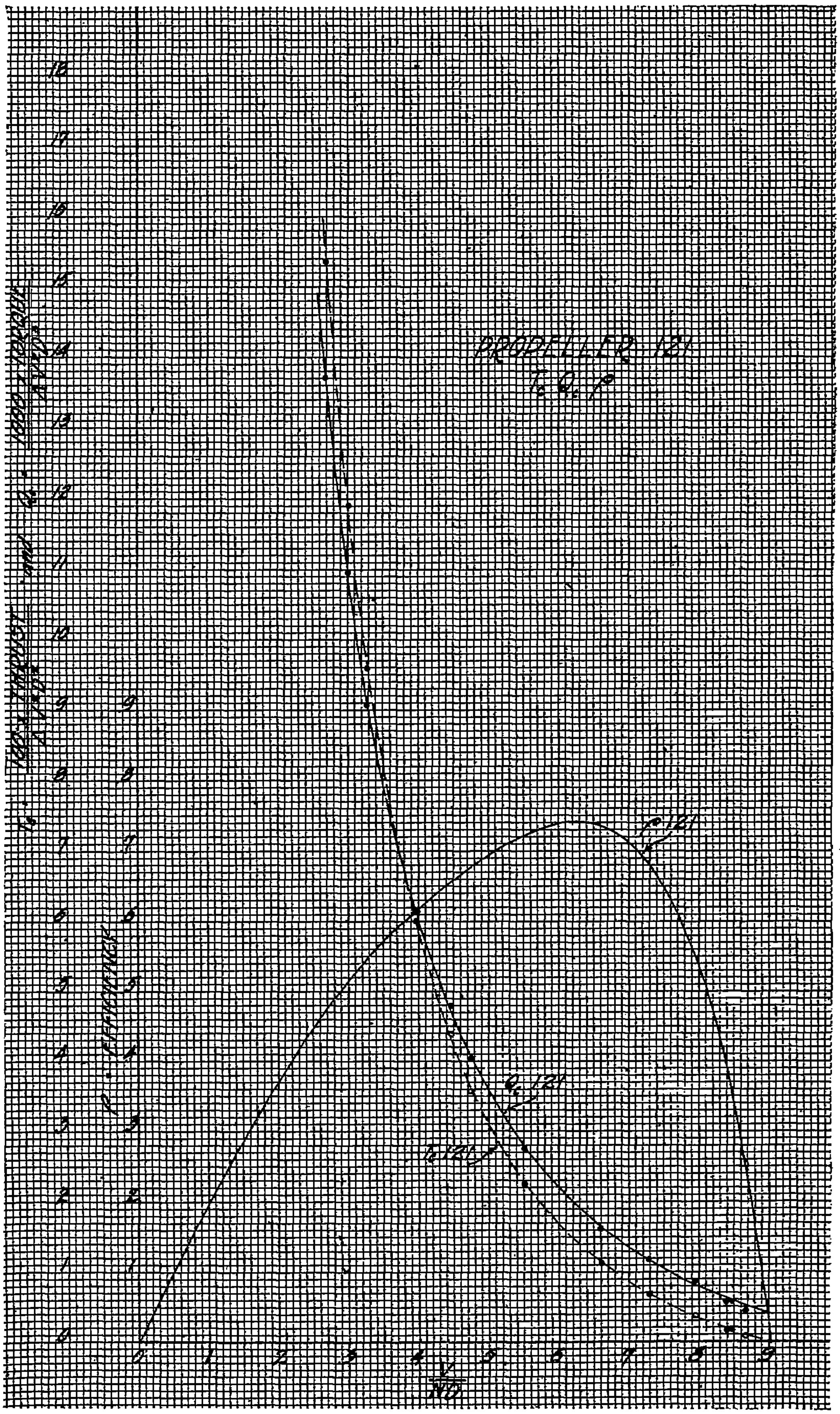


PLATE VI.

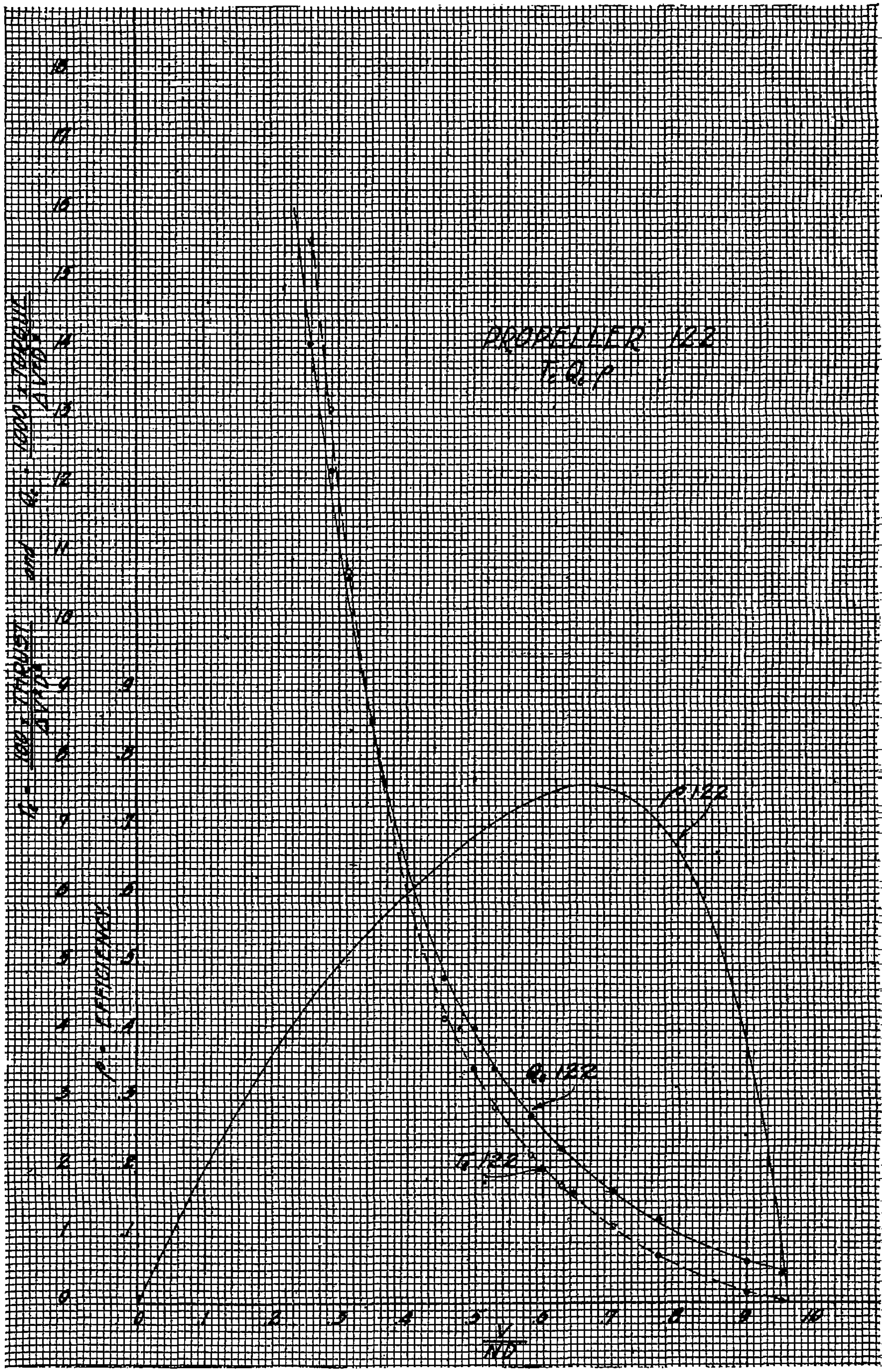


PLATE VII.

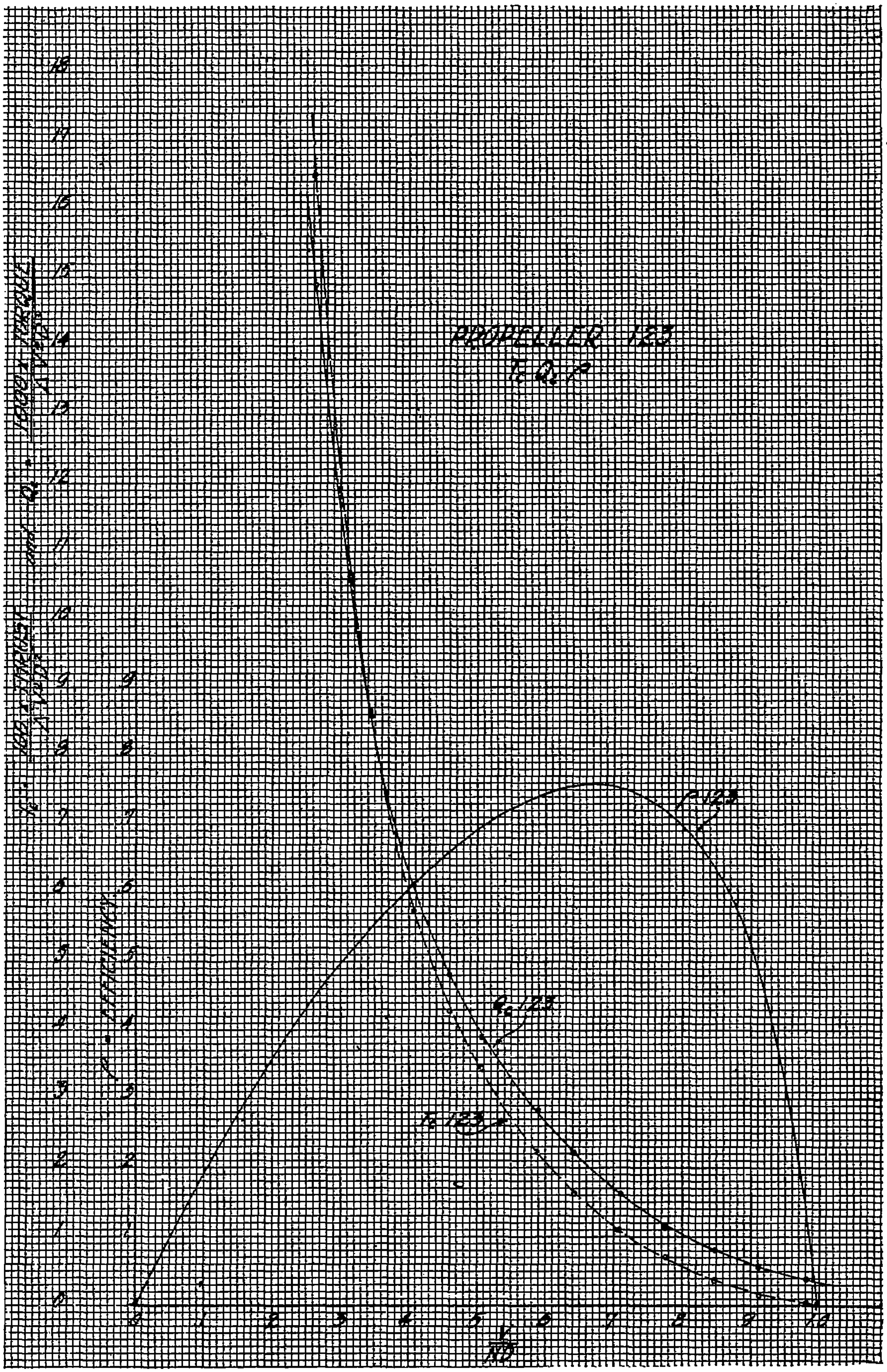


PLATE VIII.

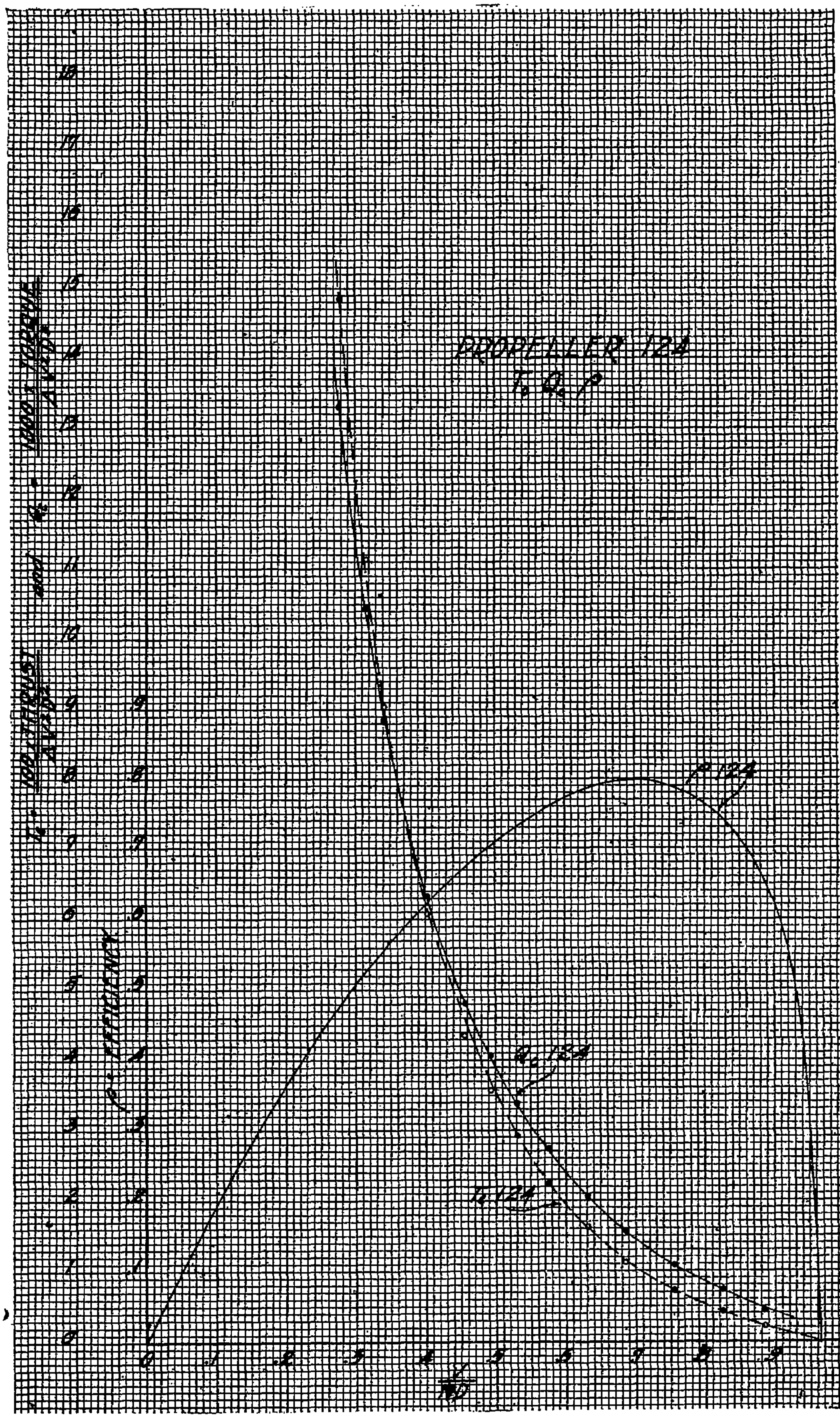

PROPELLER 124
T_c Q_c ρ
ρ 124
Q_c 124
T_c 124
ρ = EFFICIENCY
$\frac{V}{ND}$

PLATE IX.

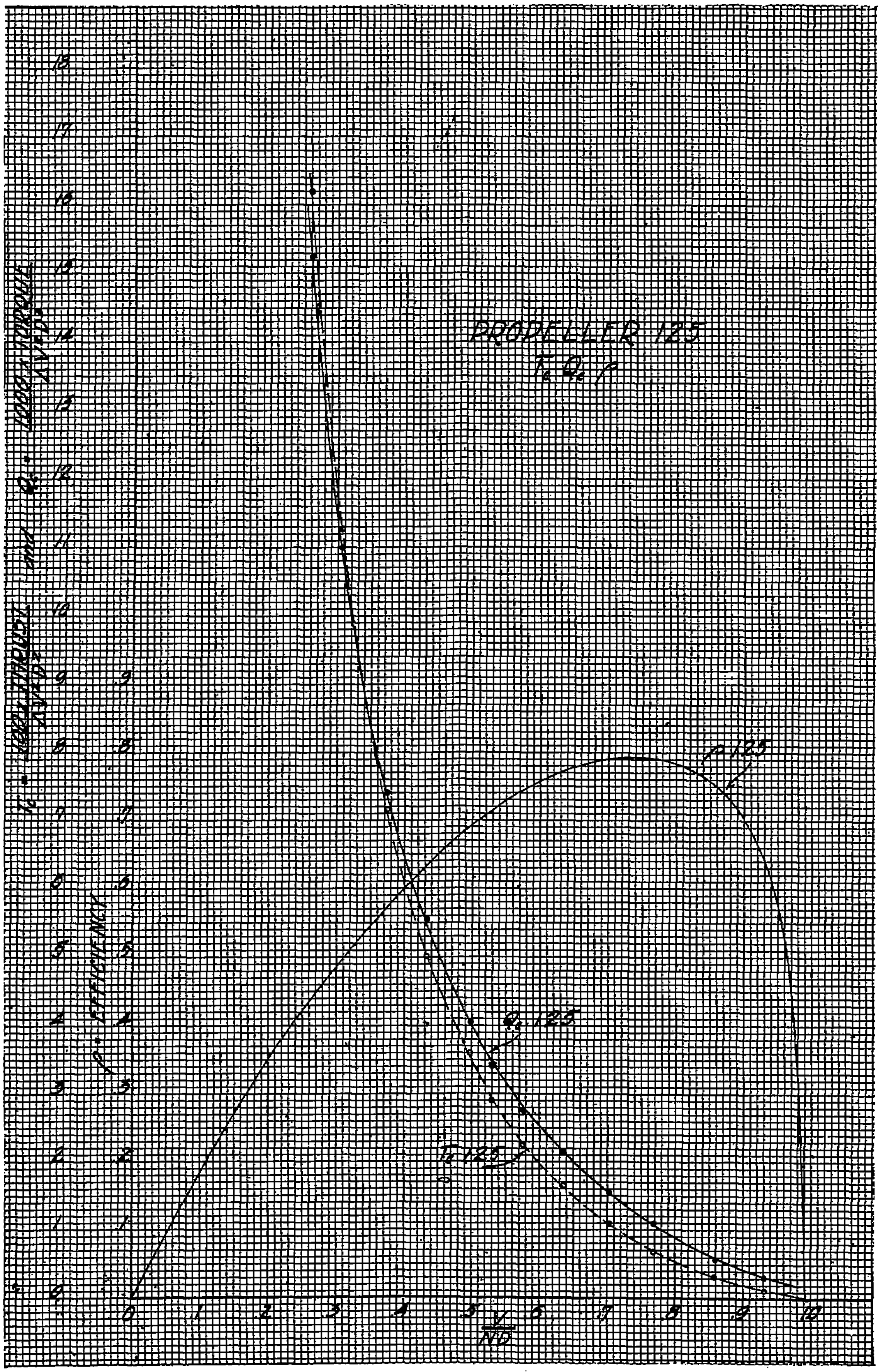

PROPELLER 125
T_c Q_c ρ
$T_c = \frac{1000 \times THRUST}{N^2 D^4}$ and $Q_c = \frac{1000 \times TORQUE}{N^2 D^5}$
ρ = EFFICIENCY
ρ 125
Q_c 125
T_c 125
$\frac{V}{ND}$

PLATE X.

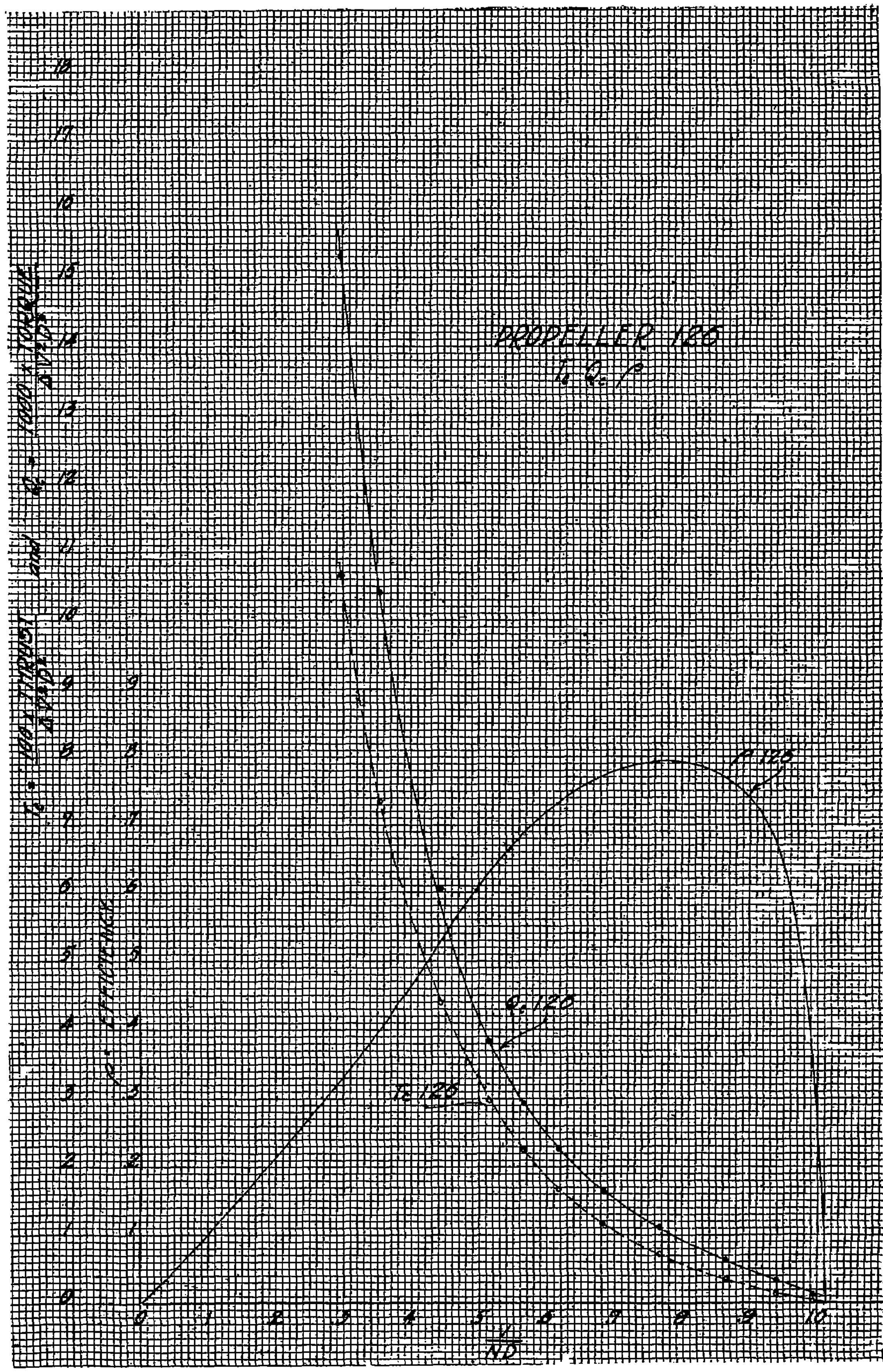
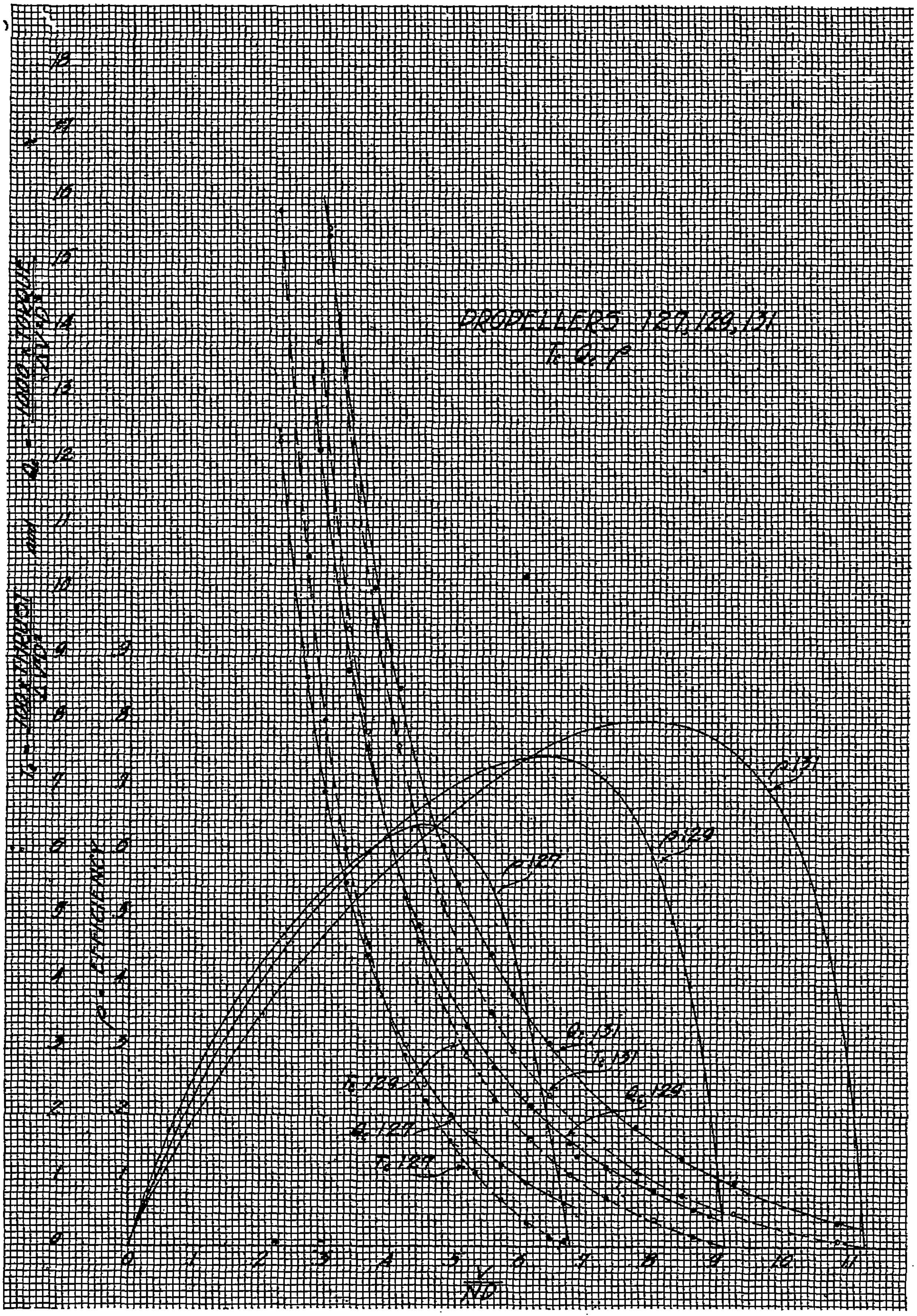

PROPELLER 125
T_c Q_c ρ
$T_c = \frac{1000 \times THRUST}{\Delta V^2 D^2}$ and $Q_c = \frac{1000 \times TORQUE}{\Delta V^2 D^3}$
ρ = EFFICIENCY
ρ 125
Q_c 125
T_c 125
$\frac{V}{ND}$

Plate XI.



PROPELLERS 127,129,131
ρ 131
ρ 129
ρ 127
Q 131
T 131
Q 129
T 129
Q 127
T 127
ρ - EFFICIENCY
V/ND

PLATE XII.

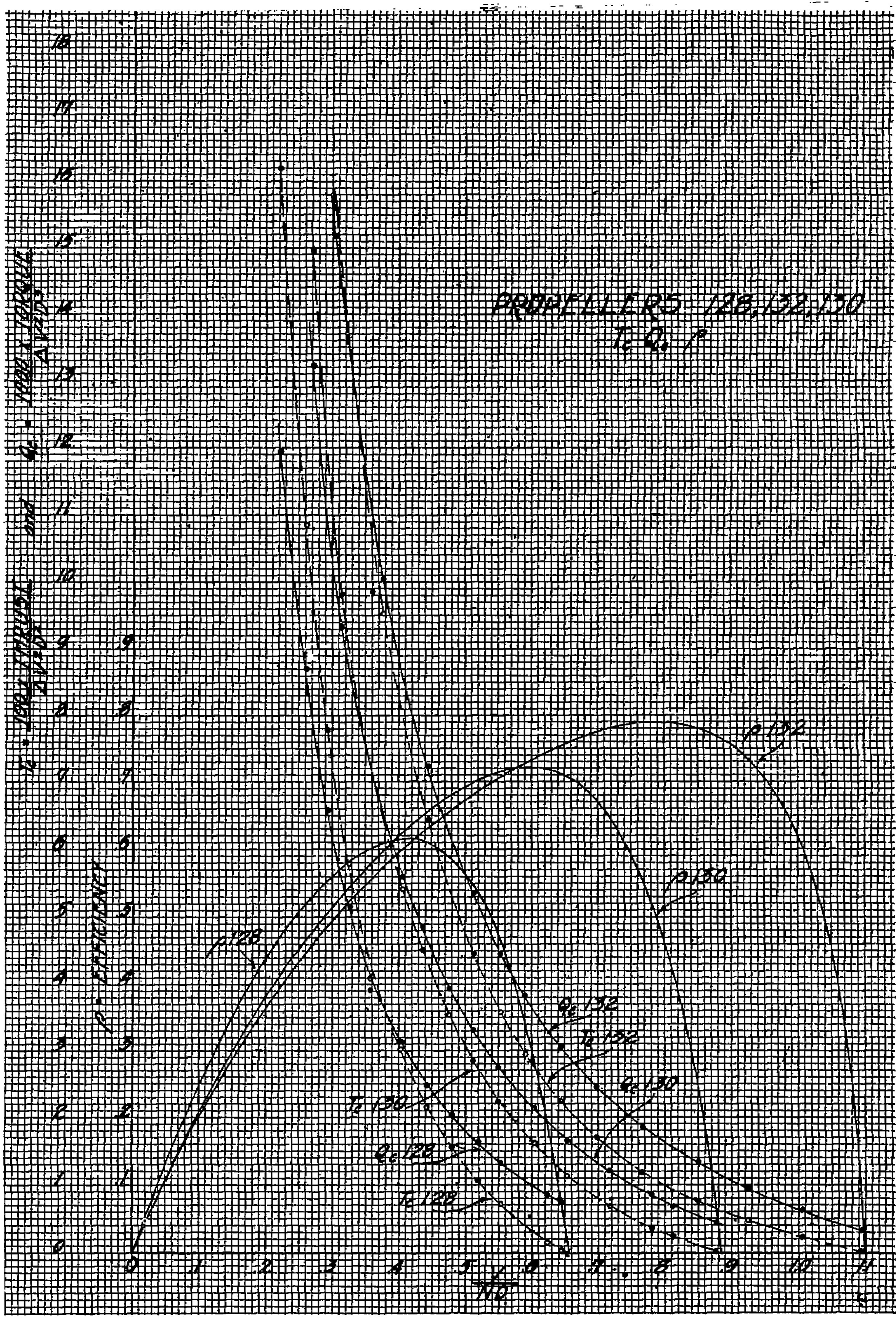
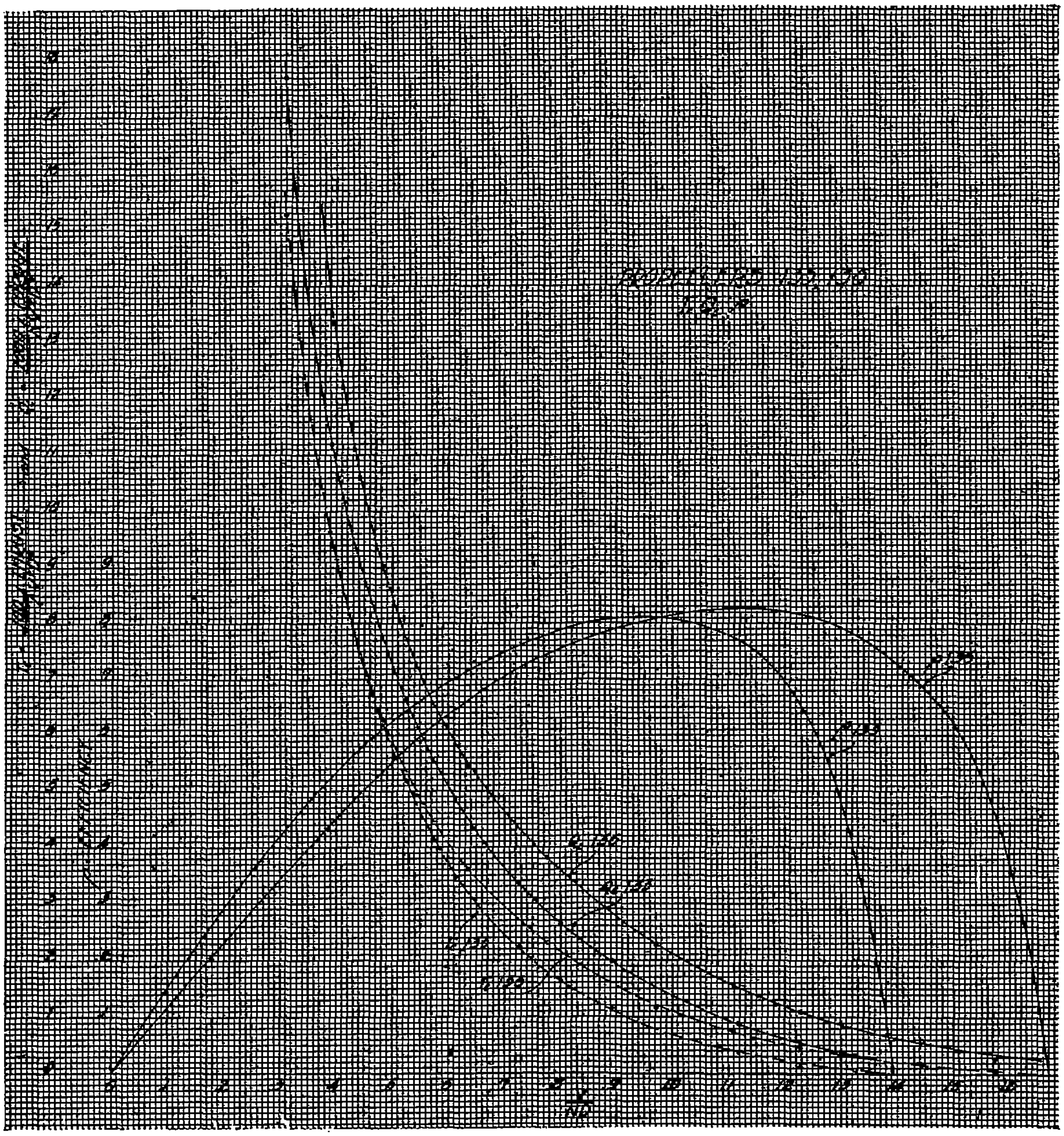

PROPELLERS 128, 132, 130
Tc Qc ρ
ρ 132
ρ 130
ρ 128
Qc 132
Tc 132
Qc 130
Tc 130
Qc 128
Tc 128
ρ = EFFICIENCY
V/ND

PLATE XIII.



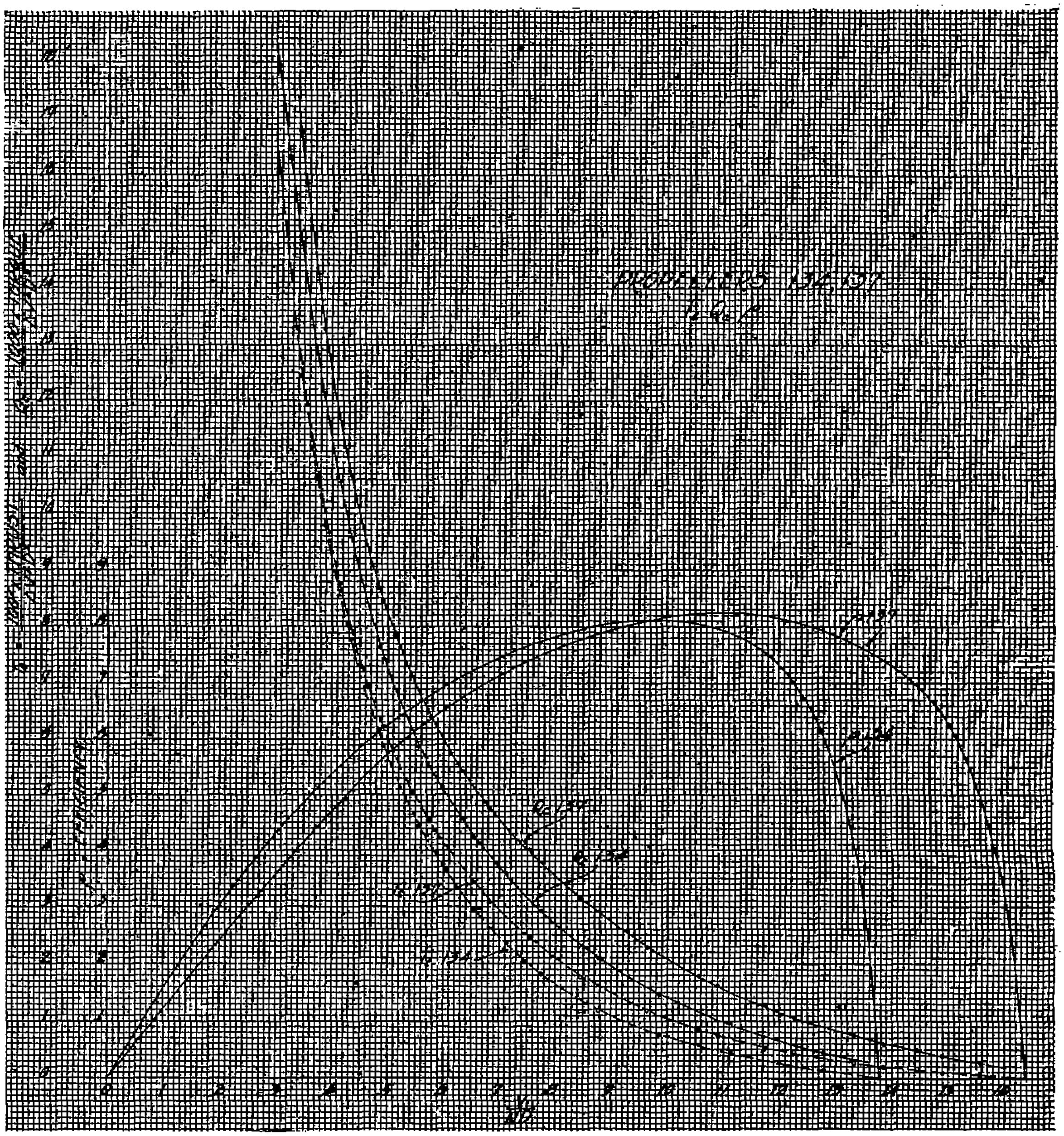


PLATE XV.

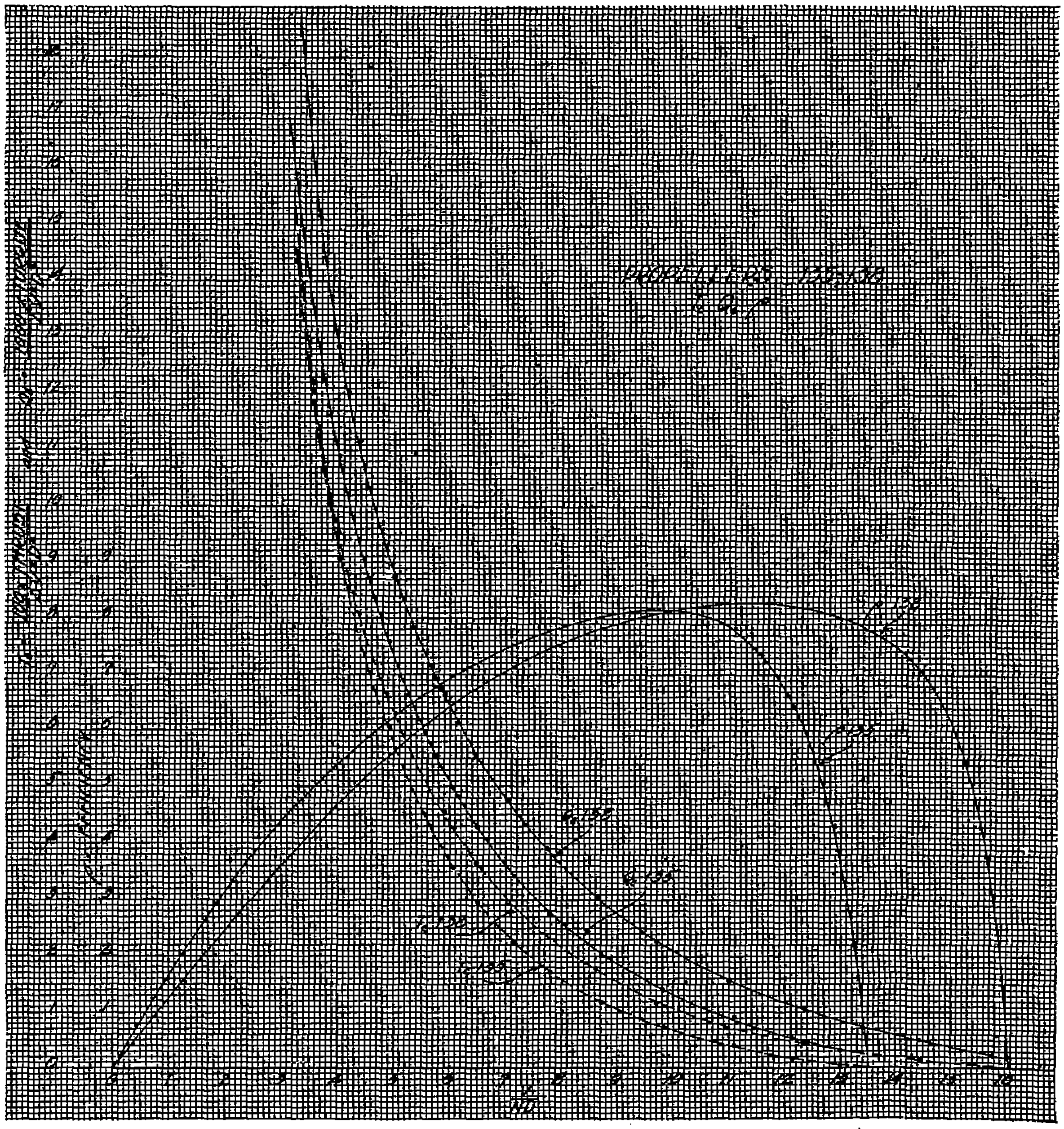
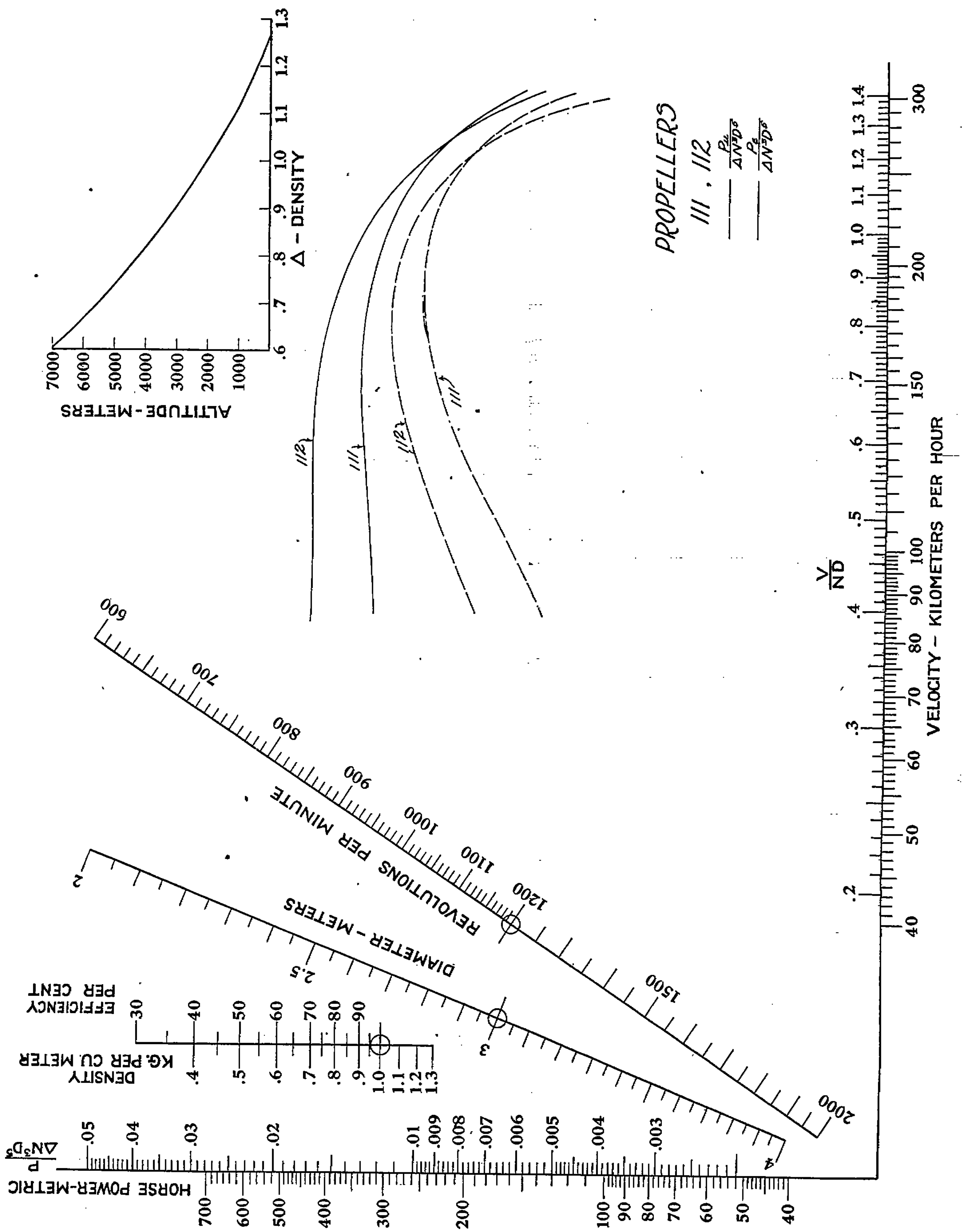


PLATE XVI.


PROPELLERS
111, 112
HORSE POWER-METRIC
P / ΔN³D⁵
DENSITY KG. PER CU. METER
EFFICIENCY PER CENT
DIAMETER - METERS
REVOLUTIONS PER MINUTE
ALTITUDE - METERS
Δ - DENSITY
V / ND
VELOCITY - KILOMETERS PER HOUR

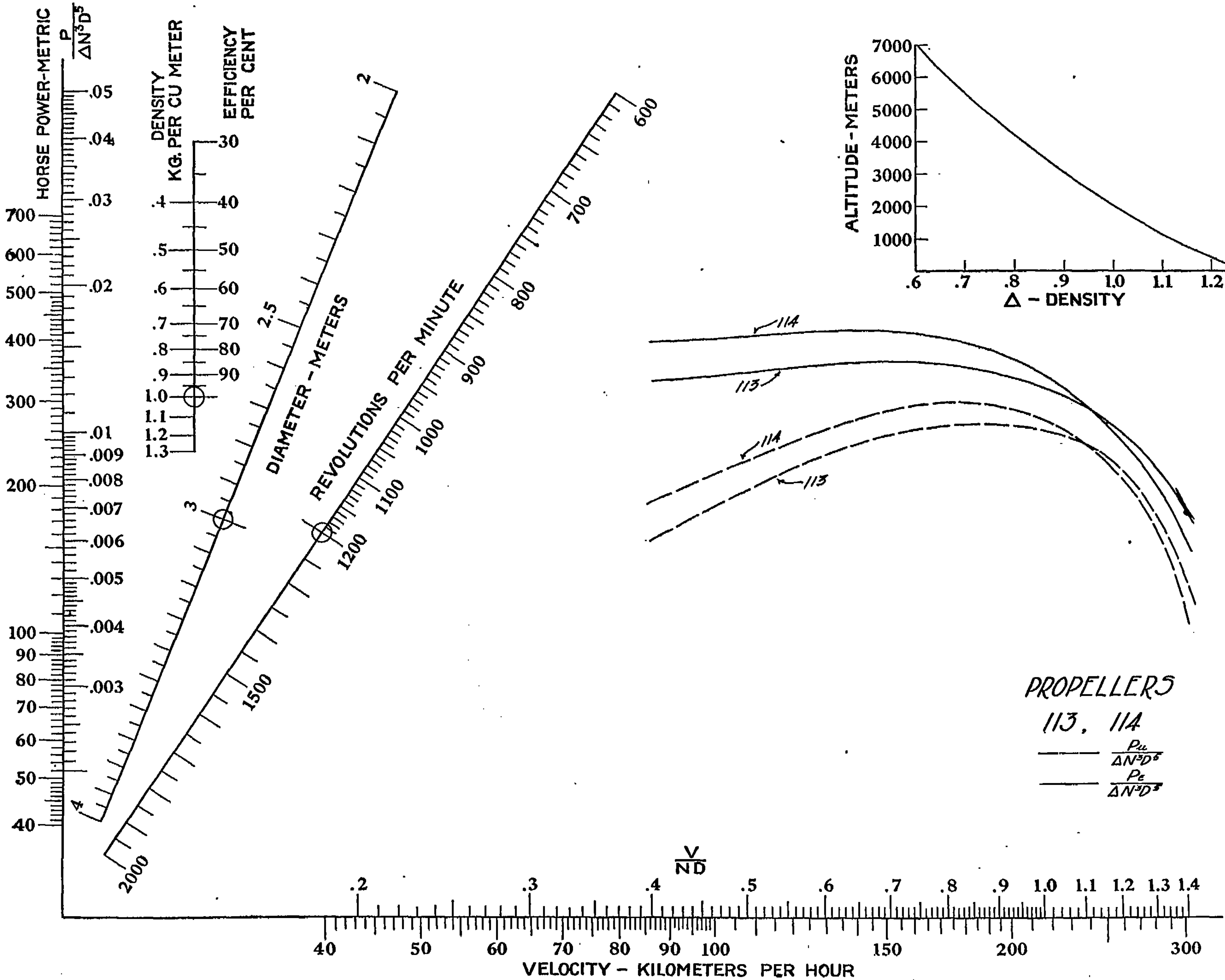

HORSE POWER-METRIC
$\frac{P}{\Delta N^3 D^5}$
DENSITY KG. PER CU METER
EFFICIENCY PER CENT
DIAMETER - METERS
REVOLUTIONS PER MINUTE
ALTITUDE - METERS
Δ - DENSITY
PROPELLERS
113, 114
$\frac{P_u}{\Delta N^3 D^5}$
$\frac{P_e}{\Delta N^3 D^5}$
$\frac{V}{ND}$
VELOCITY - KILOMETERS PER HOUR

PLATE XVIII.

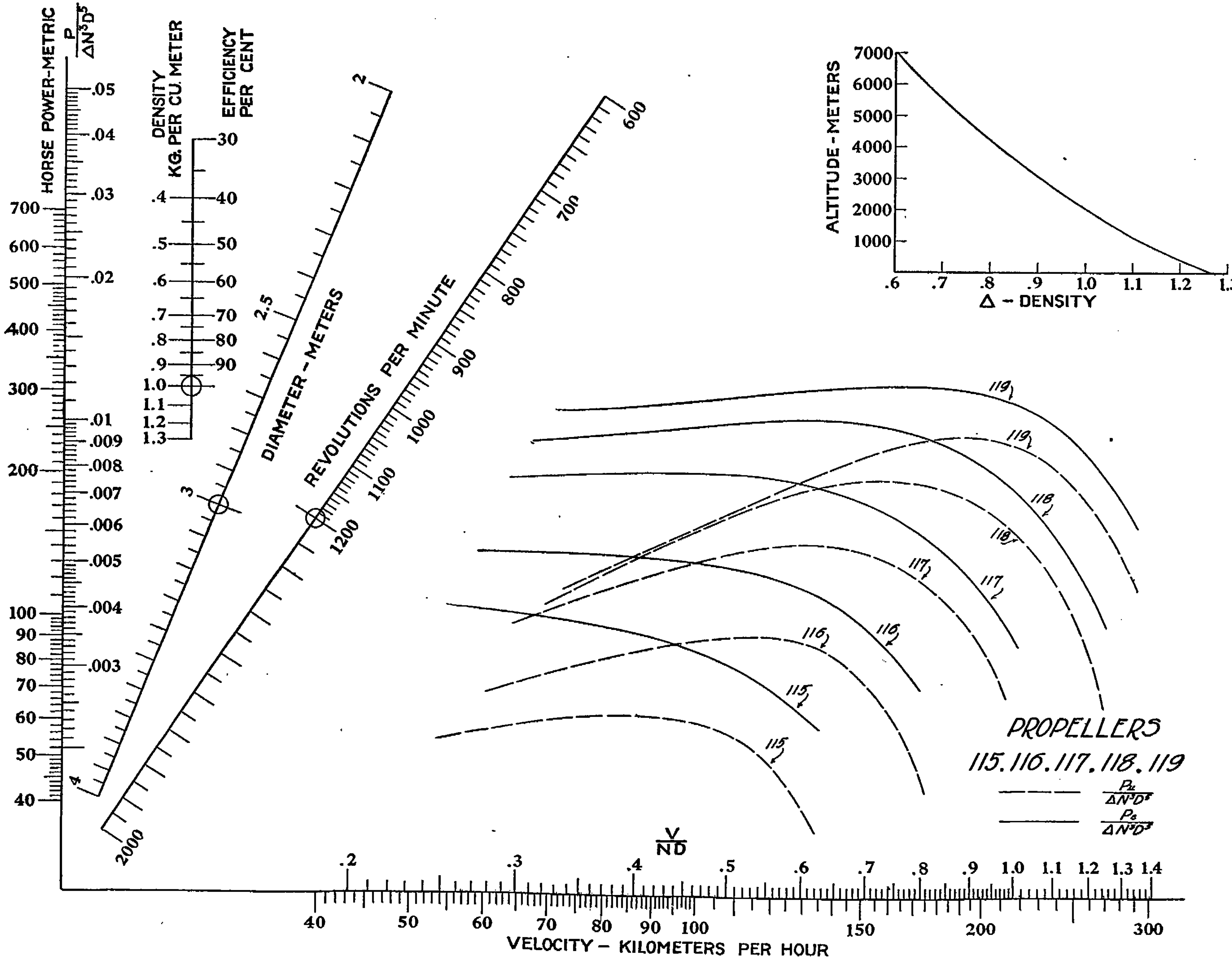

HORSE POWER-METRIC
$\frac{P}{\Delta N^3 D^5}$
DENSITY KG. PER CU. METER
EFFICIENCY PER CENT
DIAMETER - METERS
REVOLUTIONS PER MINUTE
ALTITUDE - METERS
Δ - DENSITY
PROPELLERS
115. 116. 117. 118. 119
$\frac{P_u}{\Delta N^3 D^5}$
$\frac{P_s}{\Delta N^3 D^5}$
$\frac{V}{ND}$
VELOCITY - KILOMETERS PER HOUR

Plate XIX.

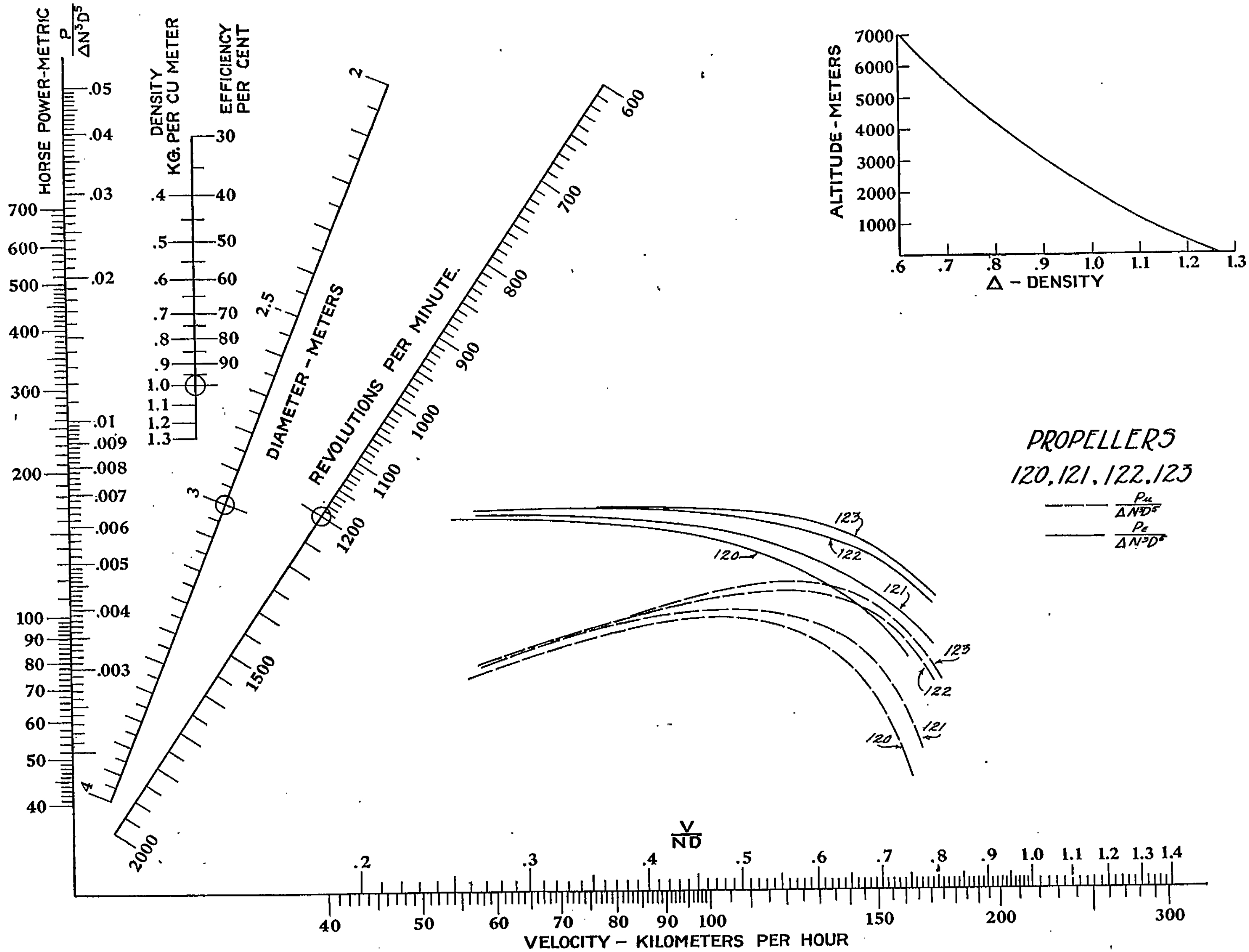

HORSE POWER-METRIC
$\frac{P}{\Delta N^3 D^5}$
DENSITY KG. PER CU METER
EFFICIENCY PER CENT
DIAMETER - METERS
REVOLUTIONS PER MINUTE
ALTITUDE - METERS
Δ - DENSITY
PROPELLERS
120, 121, 122, 123
$\frac{P_u}{\Delta N^3 D^5}$
$\frac{P_e}{\Delta N^3 D^5}$
$\frac{V}{ND}$
VELOCITY - KILOMETERS PER HOUR

PLATE XX.

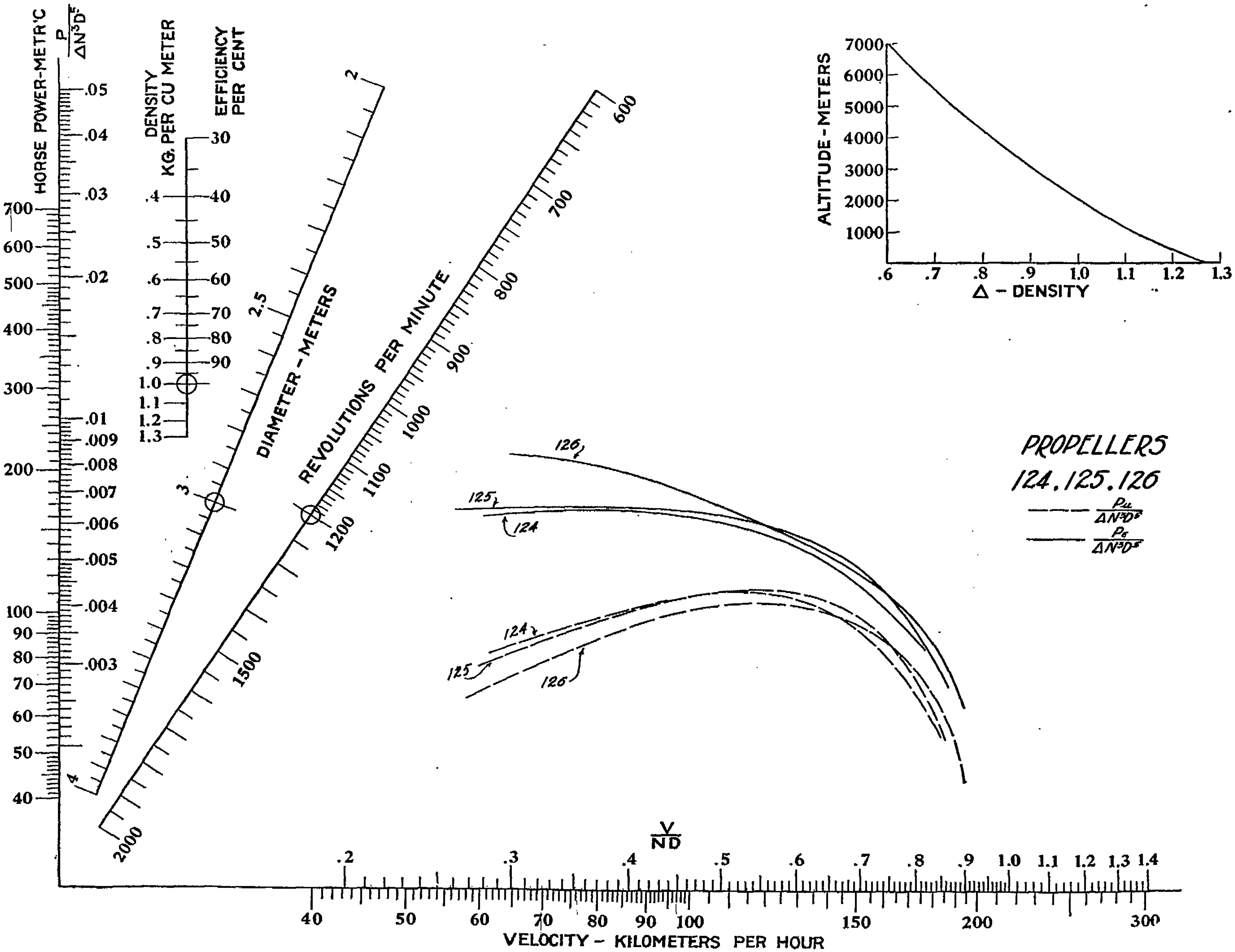

HORSE POWER-METRIC
P / ΔN³D⁵
DENSITY KG. PER CU METER
EFFICIENCY PER CENT
DIAMETER - METERS
REVOLUTIONS PER MINUTE
ALTITUDE - METERS
Δ - DENSITY
PROPELLERS
124, 125, 126
Pu / ΔN³D⁵
Pe / ΔN³D⁵
V / ND
VELOCITY - KILOMETERS PER HOUR

PLATE XXI.

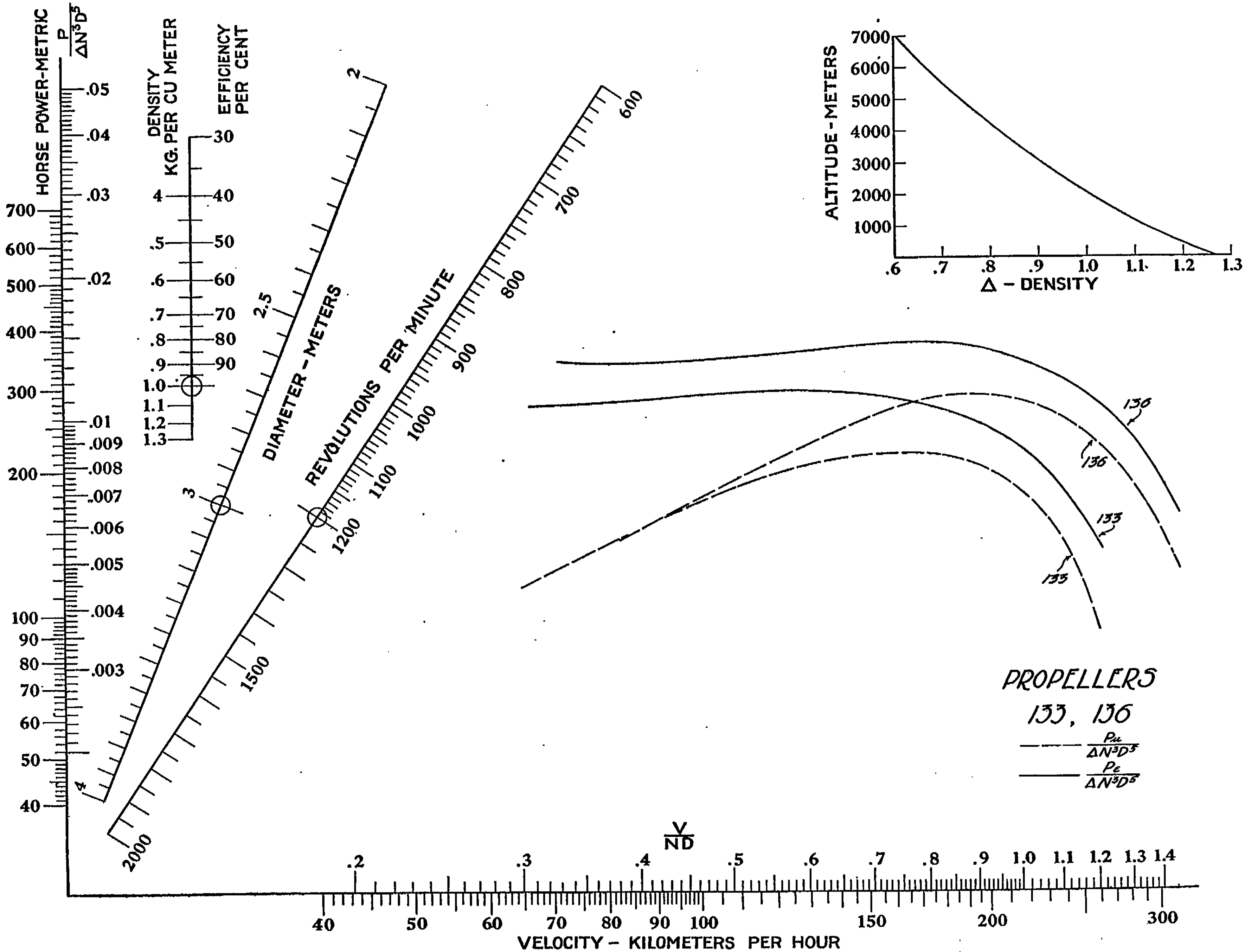

HORSE POWER-METRIC
P/ΔN³D⁵
DENSITY KG. PER CU METER
EFFICIENCY PER CENT
DIAMETER - METERS
REVOLUTIONS PER MINUTE
ALTITUDE - METERS
Δ - DENSITY
PROPELLERS
133, 136
Pu/ΔN³D⁵
Pe/ΔN³D⁵
V/ND
VELOCITY - KILOMETERS PER HOUR

PLATE XXII.

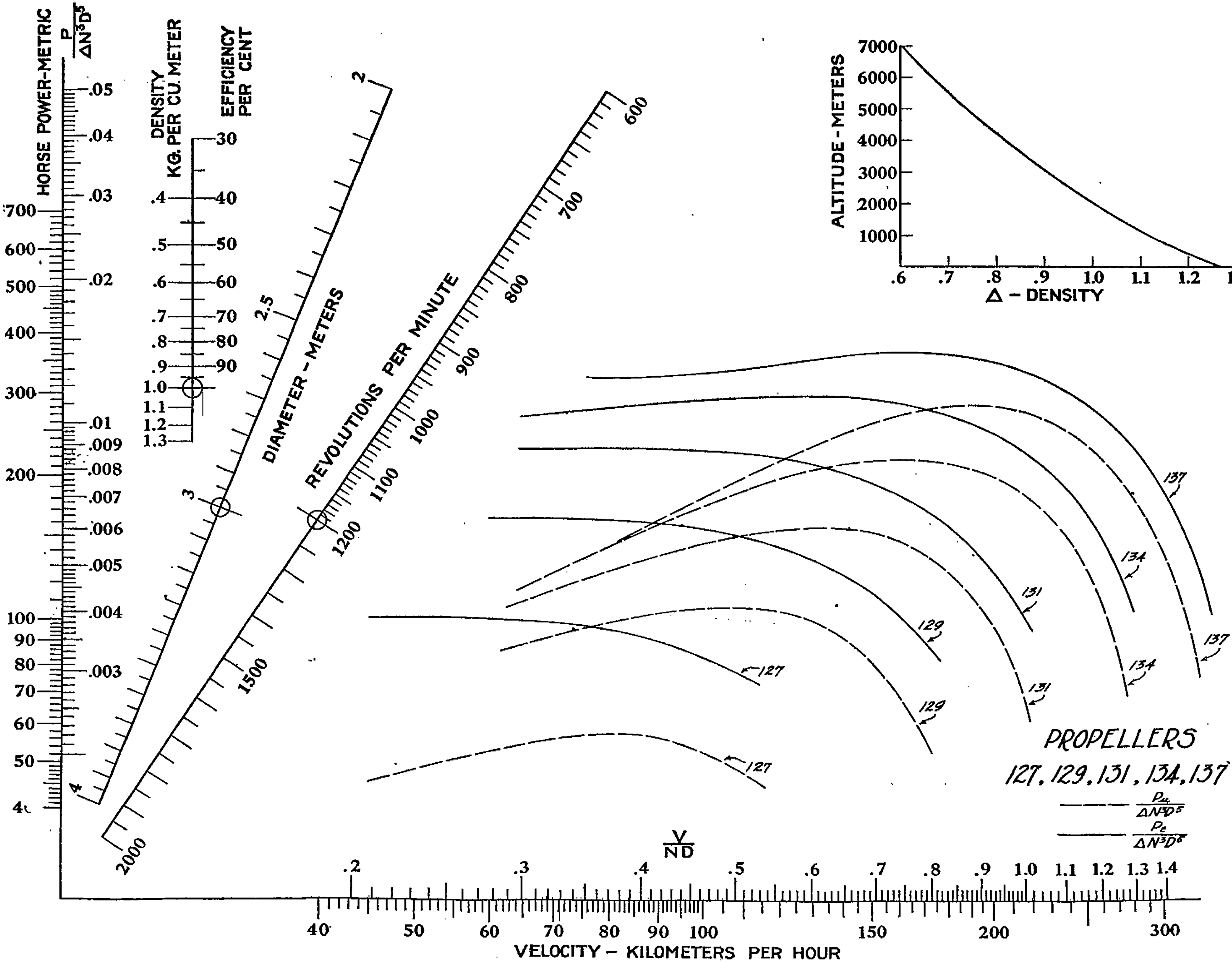

HORSE POWER-METRIC
$\frac{P}{\Delta N^3 D^5}$
DENSITY KG. PER CU. METER
EFFICIENCY PER CENT
DIAMETER - METERS
REVOLUTIONS PER MINUTE
ALTITUDE - METERS
Δ - DENSITY
PROPELLERS
127, 129, 131, 134, 137
$\frac{P_u}{\Delta N^3 D^5}$
$\frac{P_e}{\Delta N^3 D^5}$
$\frac{V}{ND}$
VELOCITY - KILOMETERS PER HOUR

PLATE XXIII.

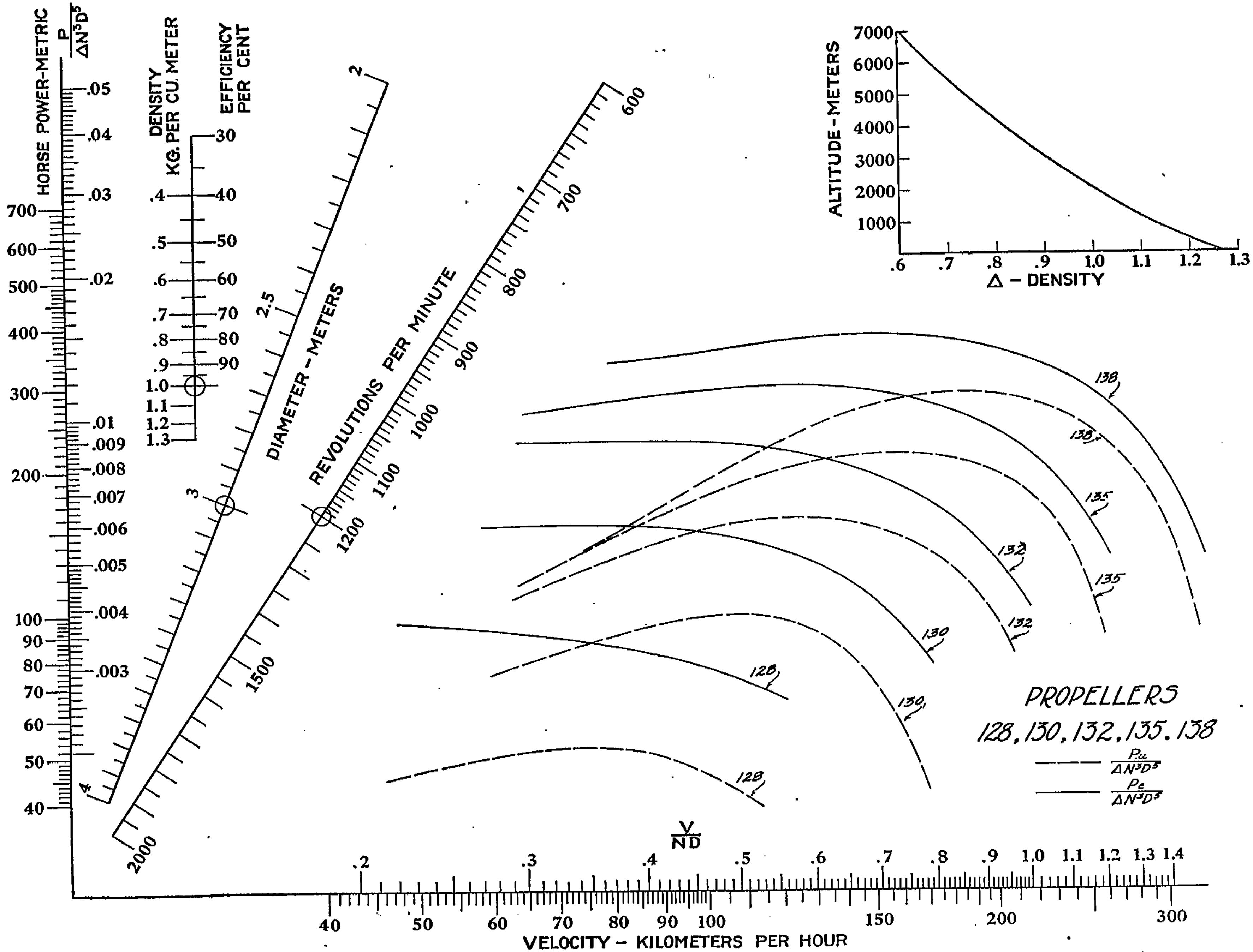

HORSE POWER-METRIC
$\frac{P}{\Delta N^3 D^5}$
DENSITY KG. PER CU. METER
EFFICIENCY PER CENT
DIAMETER - METERS
REVOLUTIONS PER MINUTE
ALTITUDE - METERS
Δ - DENSITY
PROPELLERS
128, 130, 132, 135, 138
$\frac{P_u}{\Delta N^3 D^5}$
$\frac{P_e}{\Delta N^3 D^5}$
$\frac{V}{ND}$
VELOCITY - KILOMETERS PER HOUR

PLATE XXIV.