SCOOP CONDENSER TESTS AND INVESTIGATIONS

A Thesis

Submitted to
The Department of Naval Architecture
and Marine Engineering

by

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Massachusetts Institute of Technology
Cambridge May 15, 1940

Massachusetts Institute of Technology
Cambridge, Massachusetts
May 15, 1940

Professor George W. Swett
Secretary of the Faculty
Massachusetts Institute of Technology

Dear Sir;

We submit the accompanying thesis, " Scoop Condenser Tests and Investigations " in partial compliance with the requirements of the Massachusetts Institute of Technology for the Degree of Bachelor of Science.

Respectfully,

ACKNOWLEDGMENTS

The authors wish to express their appreciation for the help rendered by the following:

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Mr Peterson of the Model Shop

The Steam Laboratory Engineering Force

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OBJECT

The fundamental purpose of this paper is to present the results of tests on models of different designs of condenser scoop inlets in such a manner as to directly aid the designer in the choice and design of full scale scoops. In order to make the results of model tests as practical as possible, all data is so arranged that the essential variables may be entered directly in the plots and the best design of scoop for a particular installation readily determined.

INTRODUCTION

It is evident that the primary purpose of a scoop is to substitute the velocity power of a moving ship for the power necessary to operate a pump in forcing water through the circulating system. It is the function of a scoop to utilize the velocity power of the water moving by the hull in the most efficient manner. This efficiency may be measured and compared among different types of scoops in their various abilities to provide the necessary quantity of water for cooling at a definite velocity and against a certain static head drop. The best scoop is that one which will provide the greatest volume of water against a large static head over the greatest range of ship's speed. However, the best scoop for a particular circulating system cannot be determined from scoop characteristics alone but must be the one which best meets the requirements of the system as a whole. That is, it must be that scoop which most nearly approaches the performance of a pump which might be designed for the same purpose. Furthermore, the design of any scoop should not defeat its own purpose by causing such appendage resistance to be added to the hull that more power is necessary to overcome this resistance than would be needed to drive the pump.

The authors feel that previous investigations of condenser scoops, while providing valuable information for a comparison of various designs, do not present ready material to the designer. The results presented by Powell and Westgate in 1937 give comparative estimates of scoops with no reference to an overboard discharge. Their data is thus of use in comparing performances of scoops alone. The tests of Crawford and Hall in 1938 while including a discharge, are seriously limited by low capacity results and cover such high ship velocities that they are not generally applicable. Lastly, in his investigations, Schmidt used air as a fluid medium, testing the scoop inlets independently of the discharge and providing no method of simulating the static drop through the entire system. The authors feel that air may not be satisfactorily used in scoop analyses because of the pressure changes at scoop inlet and discharge which may be affected by the compressibility of air, the flow of air thus not simulating the actual flow of water.

Previous investigators, mentioned above, have made the outstanding contributions to the information available on the performance of condenser scoops. Each group has obtained data to be used for comparing the scoops tested, and in addition has suggested a method of presenting this data for design purposes. The test methods of the present authors were developed for a twofold purpose: to check the conclusions reached in previous investigations under the same conditions; and to obtain data which could be directly applied to design as well as comparison.

METHOD AND APPARATUS

Two distinct test methods were employed. The first technique was to discharge the flow from the scoops into a weighing tank. The second method was to construct an approximate model circulating system. All tests were conducted using part of the apparatus designed and built by Powell and Westgate in 1937 and described in their paper. Some changes were considered necessary.

The duct was lengthened 16 feet in order to increase the accessibility of the instruments and scoops. Glass panels were inserted in either side of the duct at the scoop so that the flow might be observed and photographed. These panels were also found essential in determining the minimum velocity possible without air entering the top of the duct. The Pitot tube used for determining duct velocity was placed about 4 1/2 feet ahead of the scoop. This location was considered necessary in order that any turbulence of flow caused by the large Pitot would not affect the flow at the scoop entrance.

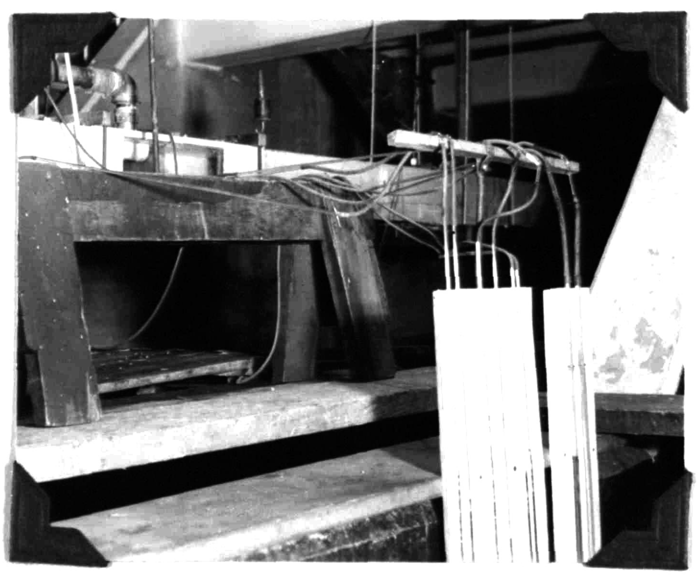
In discharging to the tank, flow from the scoop was controlled by means of a gate valve in the line. The system was about 4 feet long, consisting of radiator hose and brass tubing sections, its diameter being at no point less than 2 inches. It is assumed that no orifice action occurred in the tubing joints since the overall difference in diameters at no point except the gate valve differed by more than .08 inches.

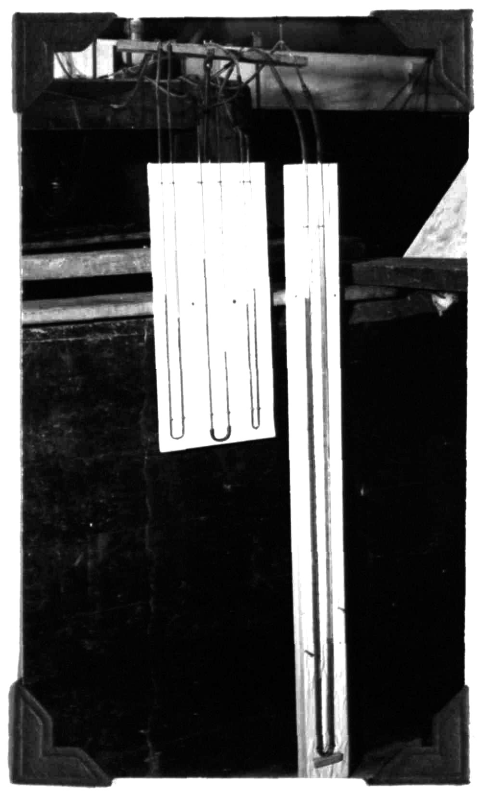
In discharging back to the duct, the model system consisted of the scoop and discharge located about 3 feet apart with the throttling gate valve inserted to offer resistance to the flow. A Pitot tube was mounted in brass tubing of the same diameter as the rest of the system and equipped with vanes to straighten any eddies which might be carried back from the injection. Velocities in the system were measured by this Pitot. A 45° discharge with a 1 1/2 inch lip was used throughout the tests.

The measuring instruments consisted of glass manometers using mercury as a medium. The Pitot measuring flow through the system had a small enough range so that a carbon tetrachloride manometer could be used. All manometer connections were carefully adjusted to eliminate any danger of air affecting the readings.

Originally, a Venturi meter was used in place of the small Pitot, but it was found that too much throttling action occurred and serious limitation of capacity resulted. The system in its final form presented very little resistance with the gate valve full open. Pipe bends and rubber hose were used to connect the various units.

Water was drawn through a discharge valve from a standpipe with the head maintained constant at 26 feet 4 inches. The duct velocity was controlled by means of the above valve. It is certain that this method of controlling duct velocity introduces no error in the readings because of the great distance from the valve to the scoop. The standpipe was supplied by a 24,000 G. P. M. pump. (For sketch see Crawford and Hall, Thesis, 1938.)

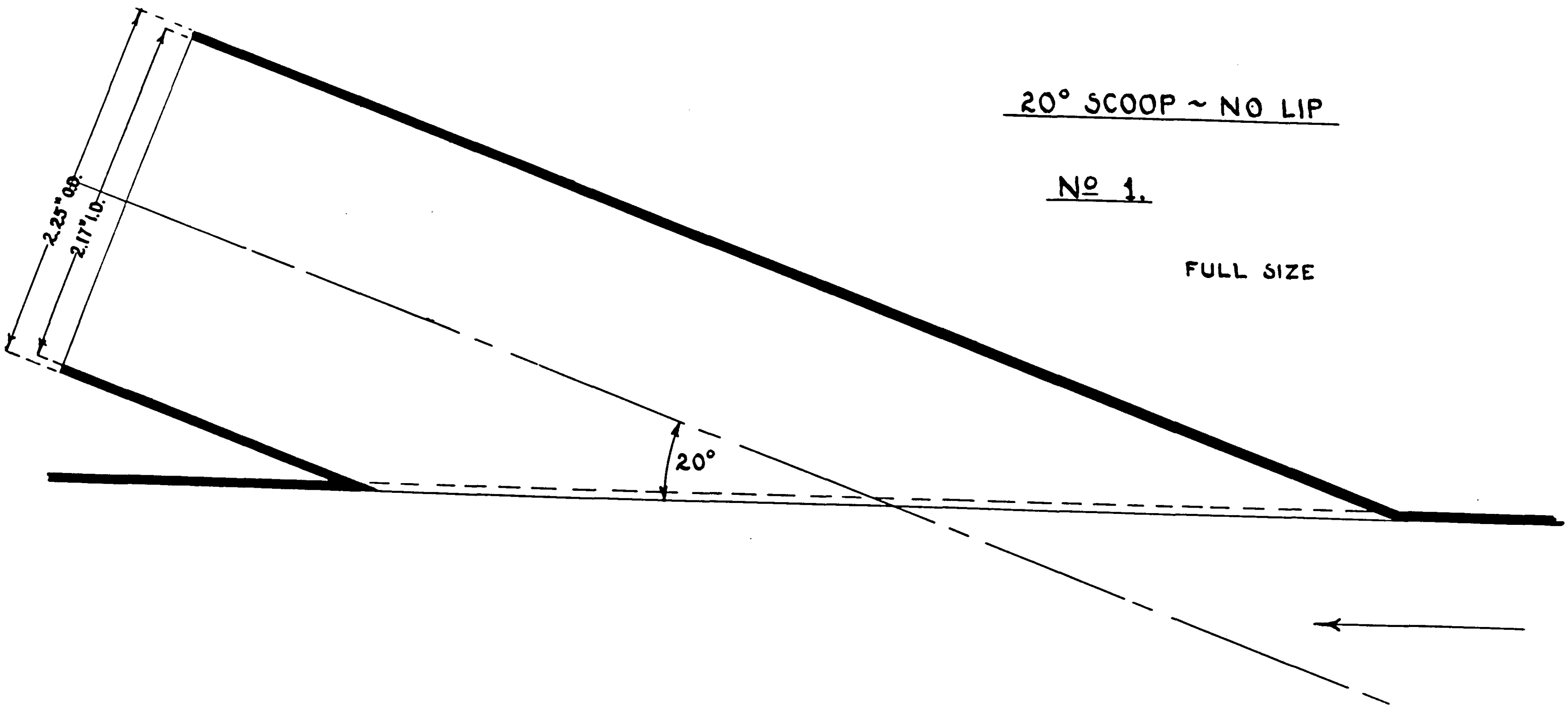




20° SCOOP ~ NO LIP

No 1.

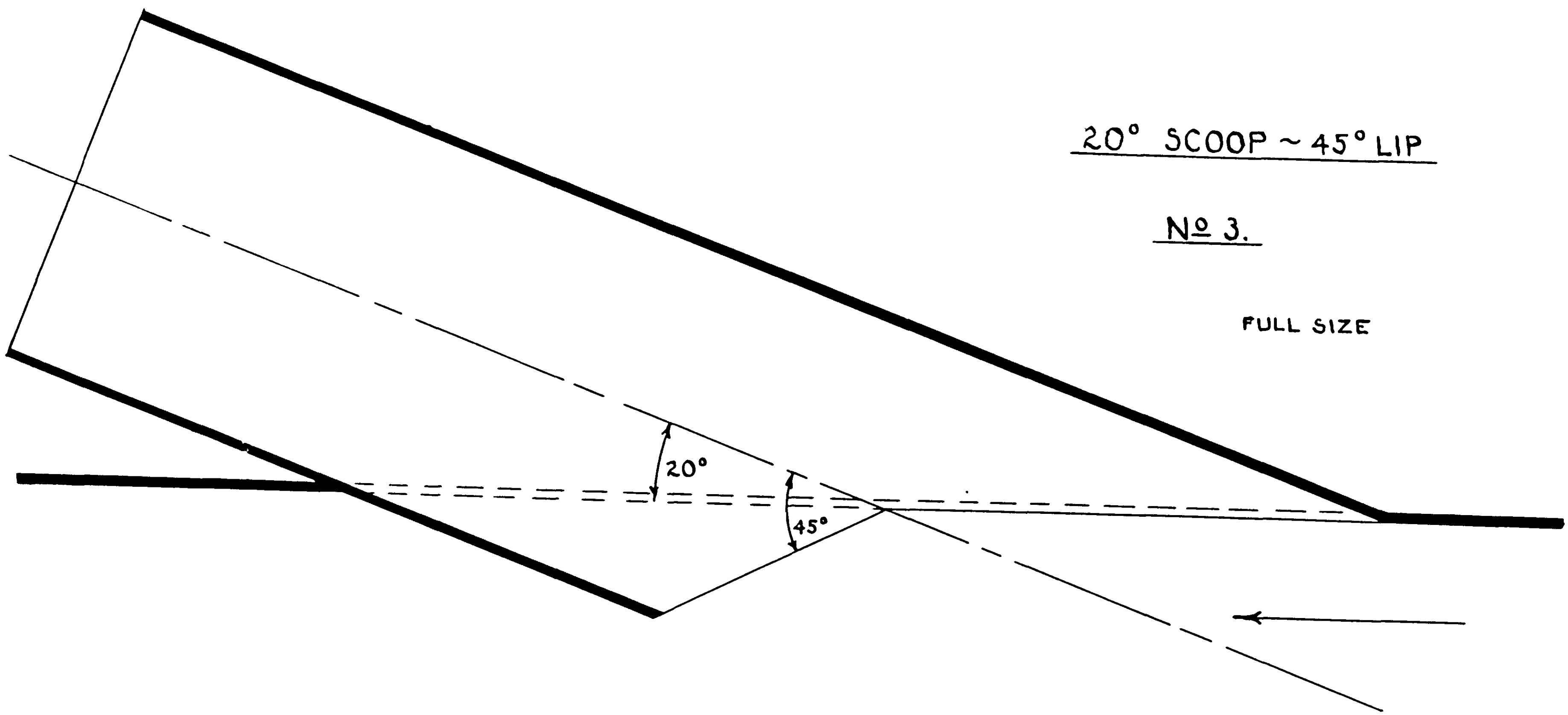
FULL SIZE



20° SCOOP ~ 45° LIP

№ 3.

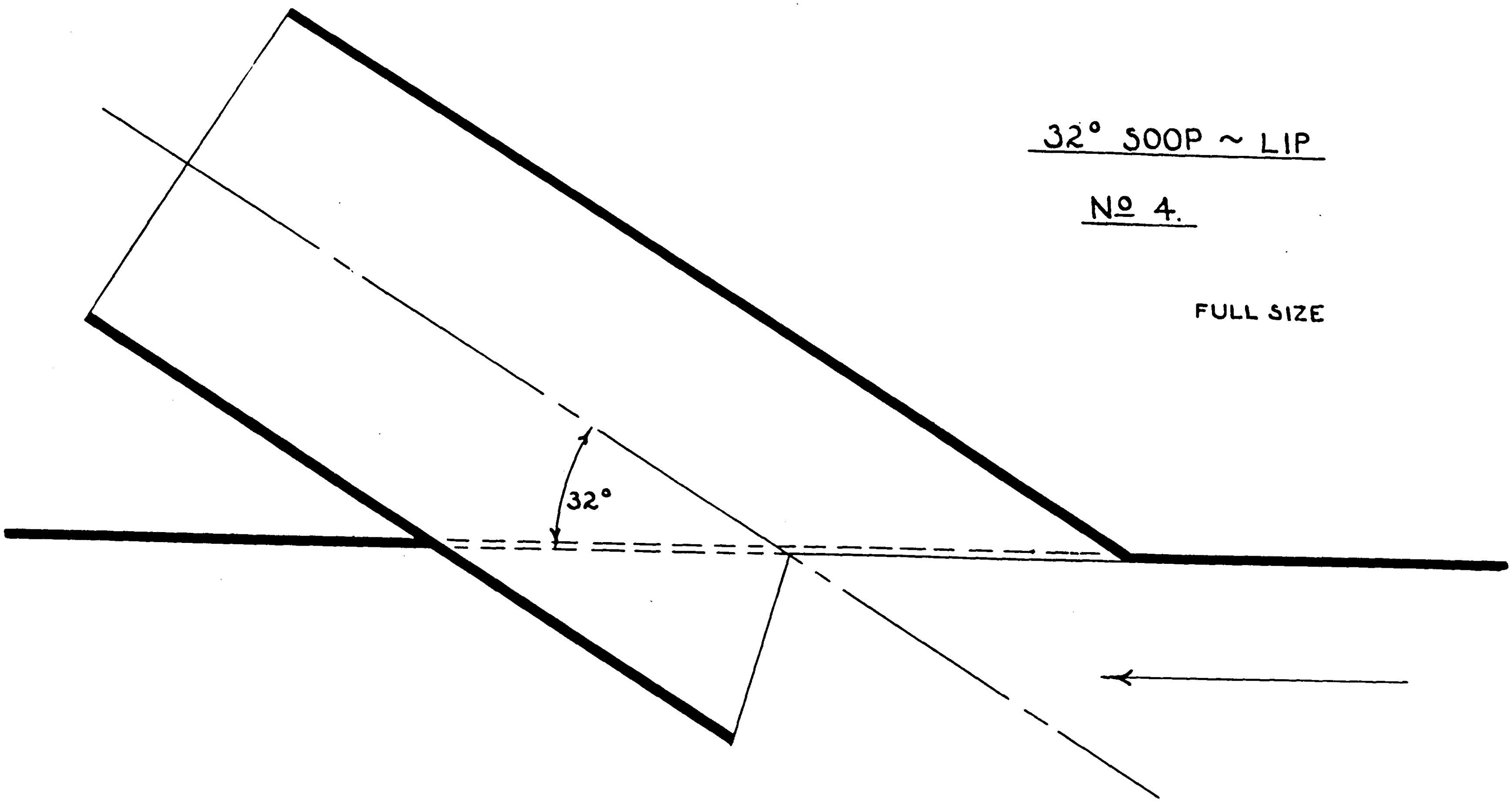
FULL SIZE

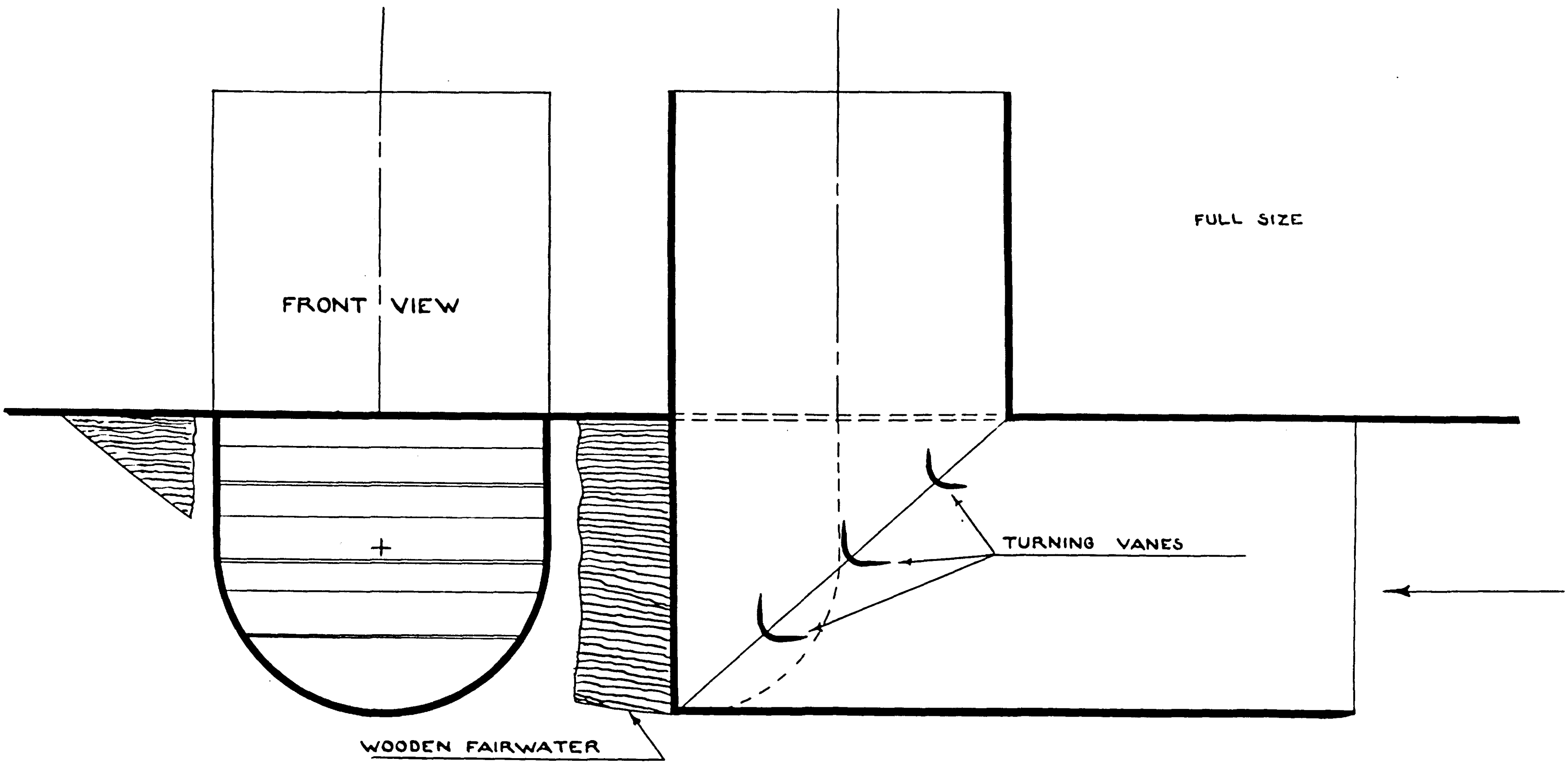


32° SOOP ~ LIP

No 4.

FULL SIZE



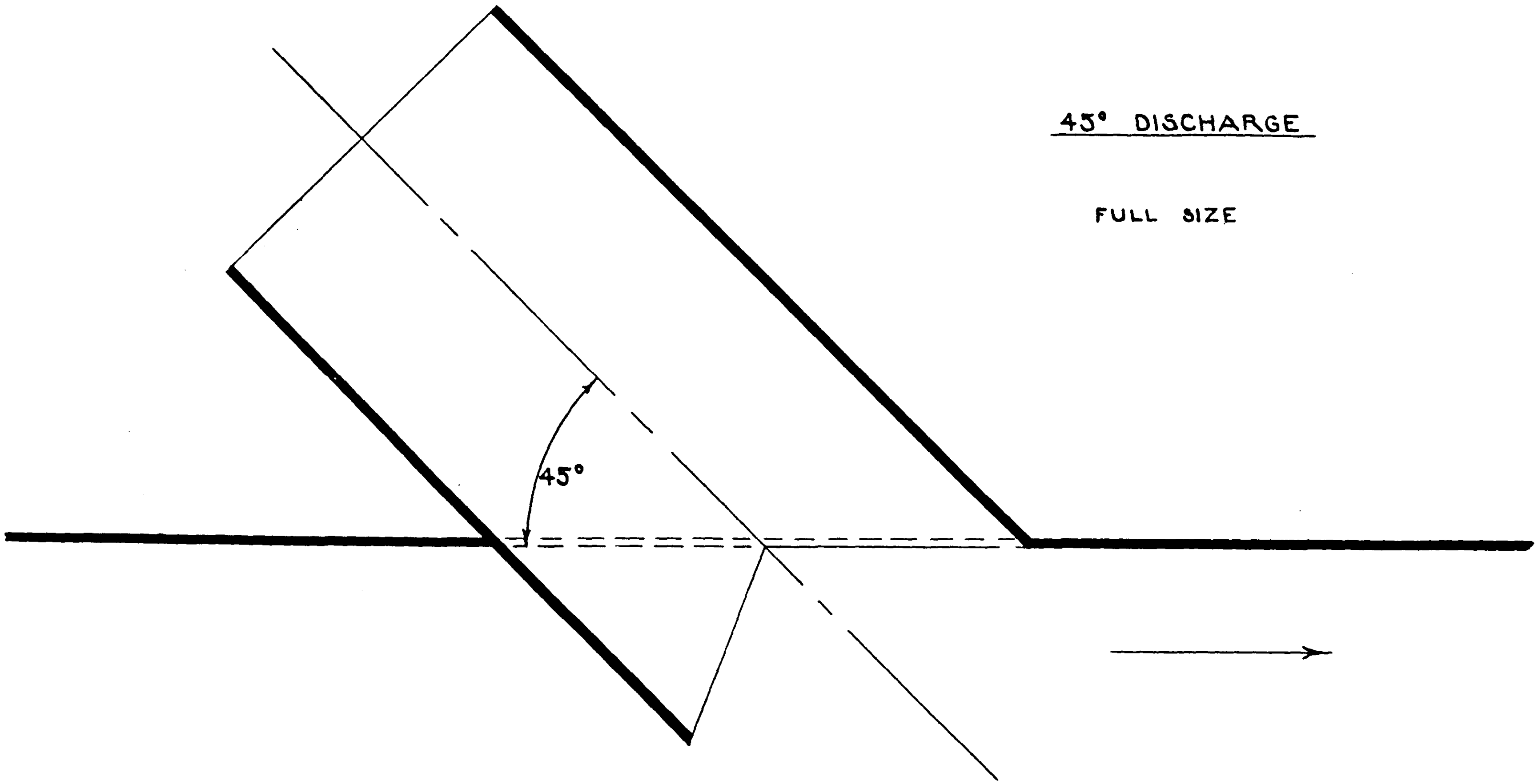


90° SCOOP

№ 5

45° DISCHARGE

FULL SIZE



CHECK ON PREVIOUS RESULTS

The two separate methods of testing result in two completely different sets of readings. The tank test data are useful in checking the results of previous investigations on the same scoops and are included for that reason alone. As has been noted, this method gives no quantitative results that may be applied to system design since the discharge is lacking. However, the information obtained and tabulated is of value in comparing the scoops on an arbitrary basis.

The form in which the 1937 data was presented prevents its comparison with either the 1938 results or the authors'. For the two scoops which may be compared, the 1938 conclusions were that the capacity of #3 is slightly greater than #1 and that the static heads developed in #3 were greater than those in #1. This is true in general for the range of duct velocities over which their investigations were made, but becomes decreasingly valid as the velocity in the duct decreases.

Because of the velocity ranges covered, #1 is the only scoop for which results may be quantitatively compared. The agreement on the same data is none too good. For a given duct velocity, the two trials should check on the value of (h ss - h sd) for the corresponding system velocity and capacity. As an example, referring to figure #17 in Crawford and Hall, at a duct velocity of 18.3 ft/sec and a system velocity of 6.88 ft/sec, the (h ss - h sd) value is 1.02 ft of H_2O. Interpolating the authors' results at the same velocities results in an (h ss - h sd) value of approximately .40 ft of H_2O. This is a disparity of about 50% in a figure that should not be greater than 20% in error allowing for experimental accuracy within 10% for both figures.

In contrast, however, the capacities of the scoop are in very close agreement, both being about 300 in^3/sec. The trend remains consistent throughout the two sets of data. The prevailing disagreement between the two results is in the value of (h ss - h sd). In explanation of this difference it is noted that the 1938 authors take no account of the difference in height between the two static measurements, duct and scoop, in applying instrument corrections to their readings. Inasmuch as the static pressure in the duct is without meaning unless referred to that in the scoop, this correction must be applied. From the photograph of the apparatus used by the 1938 authors it is evident that since the manometers were located above the points of measurement, this differential in height should be subtracted from the h ss readings. For scoop #1 this height is 5 1/2 inches of H_2O or .46 ft of H_2O. Applying the correction would leave a disparity in the two values of only .16 ft of H_2O

or agreement within 15%.

The authors suggest that in applying these previous data this correction be made.

METHOD OF PRESENTING DATA

The second method of obtaining data by use of a model system appears to the authors to be the most logical and easiest means of comparing scoop performance and of gaining design information. It is on the basis of tests made on model scoop systems that the conclusions of this paper are reached.

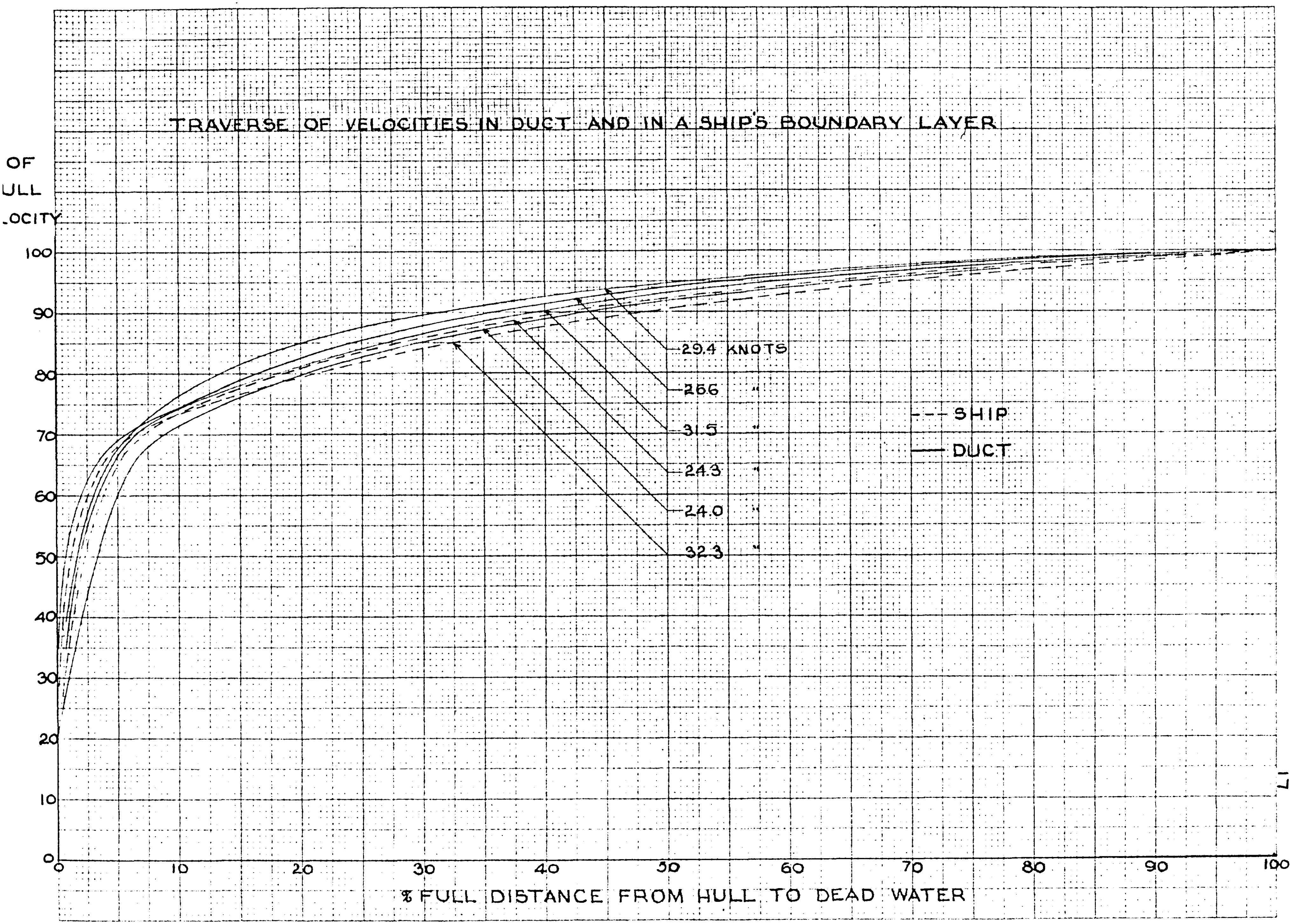
In previous tests, the data and results have been presented in such a manner that application to design involved a number of theoretical computations. Schmidt plotted his data against a parameter which he terms "percent of normal capacity", where "normal capacity" is dependent on the velocity of approach of the water to the scoop. Professor Burtner extended this method so that it might be applied to flush scoops. Use of this parameter involves an integration of the boundary layer velocities over a theoretical section of approach to determine the velocity of approach. Such a method was used by Crawford and Hall.

As to the basic assumption of "normal capacity", the authors found from visual examination of the flow, that streamlines for different scoops vary, and that the blanket assumption can not be made that constant approach conditions exist for all scoops. The parameter thus is purely arbitrary and another method of presenting results should be employed.

The above criticism is not intended to be destructive but shows what the authors wished to avoid in order to present results in the most practical form for design. Instead of using "normal capacity" and auxiliary pressure and velocity relations, the data were reduced to the three basic variables, the capacity of the scoop, the static head loss across the condenser system and the speed of the ship. The use of speed as a variable depends on a direct proportionality between conditions in the duct and those surrounding an actual ship in motion.

The essential determinant of dimensional proportionality between model scoops tested and full scale scoops as installed on board ship, is that the velocity distributions in the boundary layers of both model and full size installations are identical. That is, to the scale of each, the percent of total velocities must be the same at the same distance from the scoop entrance into the stream flow. In order to show that the velocity distribution in the test duct employed was consistent with full size conditions, a traverse of the duct was made and the data plotted along with the data taken in traverses of a ship's actual boundary layer. (Schmidt and Cox, A.S.N.E., vol 43, 1931, pp 435 - 466.) This plot appears on the following page.

To bring the duct traverse velocities into the range of the ship velocities a proportionality factor of 10 was


TRAVERSE OF VELOCITIES IN DUCT AND IN A SHIP'S BOUNDARY LAYER
OF
ULL
.OCITY
100
90
80
70
60
50
40
30
20
10
0
29.4 KNOTS
25.6 "
31.5 "
24.3 "
24.0 "
32.3 "
--- SHIP
—— DUCT
0
10
20
30
40
50
60
70
80
90
100
% FULL DISTANCE FROM HULL TO DEAD WATER

employed. The contours of the plot show that for any velocity between 24 and 32 knots the same curve applies for both duct and ship. That is, for that portion of the boundary layer into which a scoop will project, the same velocity distribution will obtain over the scoop entrance whether the scoop is a model or full scale. This agreement justifies the use of model data directly for full scale design.

A general survey of plotted results indicates that the data were consistent and uniform. The curves fair remarkably well and the trend is in agreement with an actual system model tested on board ship. (See fig.27, A.S.N.E. 1931, p 454.)

DISCUSSION OF RESULTS.

The data as presented in the curves of static head vs. capacity give some interesting information as to the performance of the various scoops. The results of scoop # 1 and #3 appear quite similar , as might be expected. The detrimental effect of the lip is seen from the lower heads produced in scoop # 3 at equal capacities and speeds as # 1. This difference is more noticeable at higher ship velocity ranges. For both these scoops the developed head varies relatively little with flow, and appears to be mainly dependent upon ship velocity.

On the other hand scoop # 4 shows a much steeper curve and the initial heads developed at no flow are higher than in either # 3 or # 1. However due to the greater slope of the curve the head value soon drops below the # 1 and # 3 values as the capacity increases.

Scoop # 5 develops considerably higher heads at low capacities than any of the other scoops. At the higher capacities the curves turn downward and there is a sharp decrease in head. Thus it would appear that for insallations at low speeds and high heads scoop # 5, or some similar design, would be best, while at high speed # 1 gives the best performance.

In drawing conclusions from these plots a number of facts must be stipulated. The size of the scoop may be altered without changing the head developed. The new capacity would be proportional to the model capacity by the ratio of the scoop areas. Thus the plots give actual performance up to approximately 12 knots, without the use of any proportionality factor. However as soon as velocities or heads above the plotted ranges are considered, a suitable λ must be applied to the data. Here again the capacity range may be changed by changing the scoop size and correcting the plotted or derived values, but the velocity and head values may be converted only by the Law of Similitude. (See Calculations for the relations.) Essentially then, the head and velocity ranges must be considered first, while the capacity can be adjusted later. This final adjustment will determine the size of scoop and injection line.

The curves of ship speed vs. capacity at a larger scale exemplify this argument. Data taken directly from the original curves were converted to the ranges required for high speed vessels. The capacities are for a 28 inch scoop and injection. The curves represent only part of the original data and therefore the comparison between scoops is not the same as for the original curves. At the highest velocities a 20° scoop with a small lip gives the highest capacity. In the middle velocity range a flush 20° scoop gives the best results, and at the lowest velocities the 90° scoop shows up best. Scoop number 4 gives an entirely different shaped curve than the others. The capacity becomes very high in the medium velocity range but also drops off very much at low speeds, and therefore would be considered impractical.

Before concluding a discussion of performance, a few words should be said on scoop efficiency. The terms used in the following argument are:

Q capacity
P pressure drop through system
P_s head developed in scoop
V ship velocity
R resistance which the scoop adds to hull resistance.
e_p pump efficiency
c_p propulsive coefficient of vessel

The ratio of Horse Power developed in the scoop to the H.P. added to the necessary ship driving power becomes QP/RV, which is a measure of scoop efficiency.

The ratio of H.P. necessary for a circulating pump to the S.H.P. added to the main unit becomes:

$$\frac{QP}{e_p} \cdot \frac{c_p}{RV}$$

If this value is less than 1.0 , use of a pump is indicated; if it is greater than 1.0 , theoretically a scoop should be fitted. However certain economic considerations of space, weight, and cost would reduce the critical point to a slightly lower value than 1.0 .

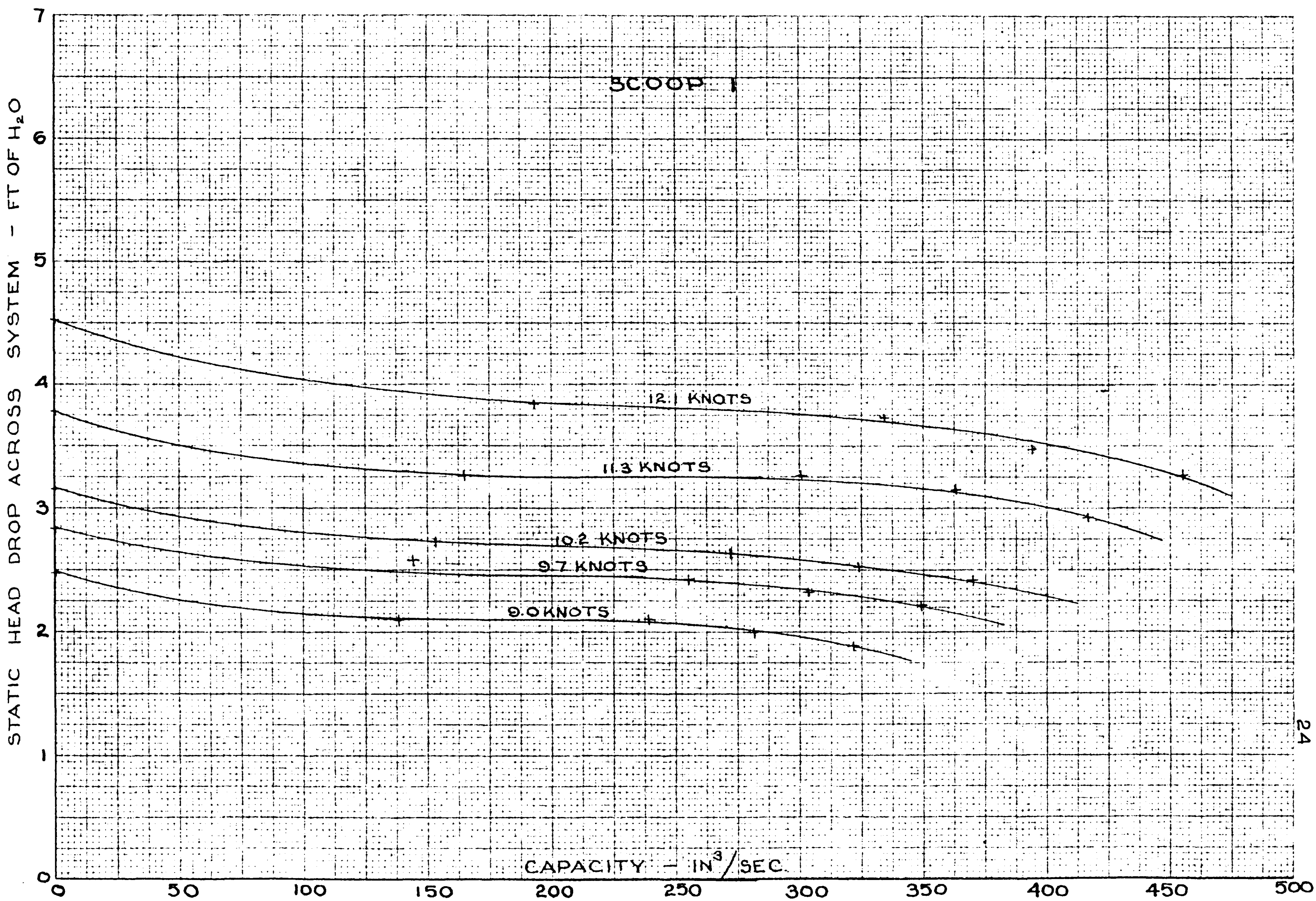
The percent of H.P. saved by adding a scoop to a regular pump circulating system would become :

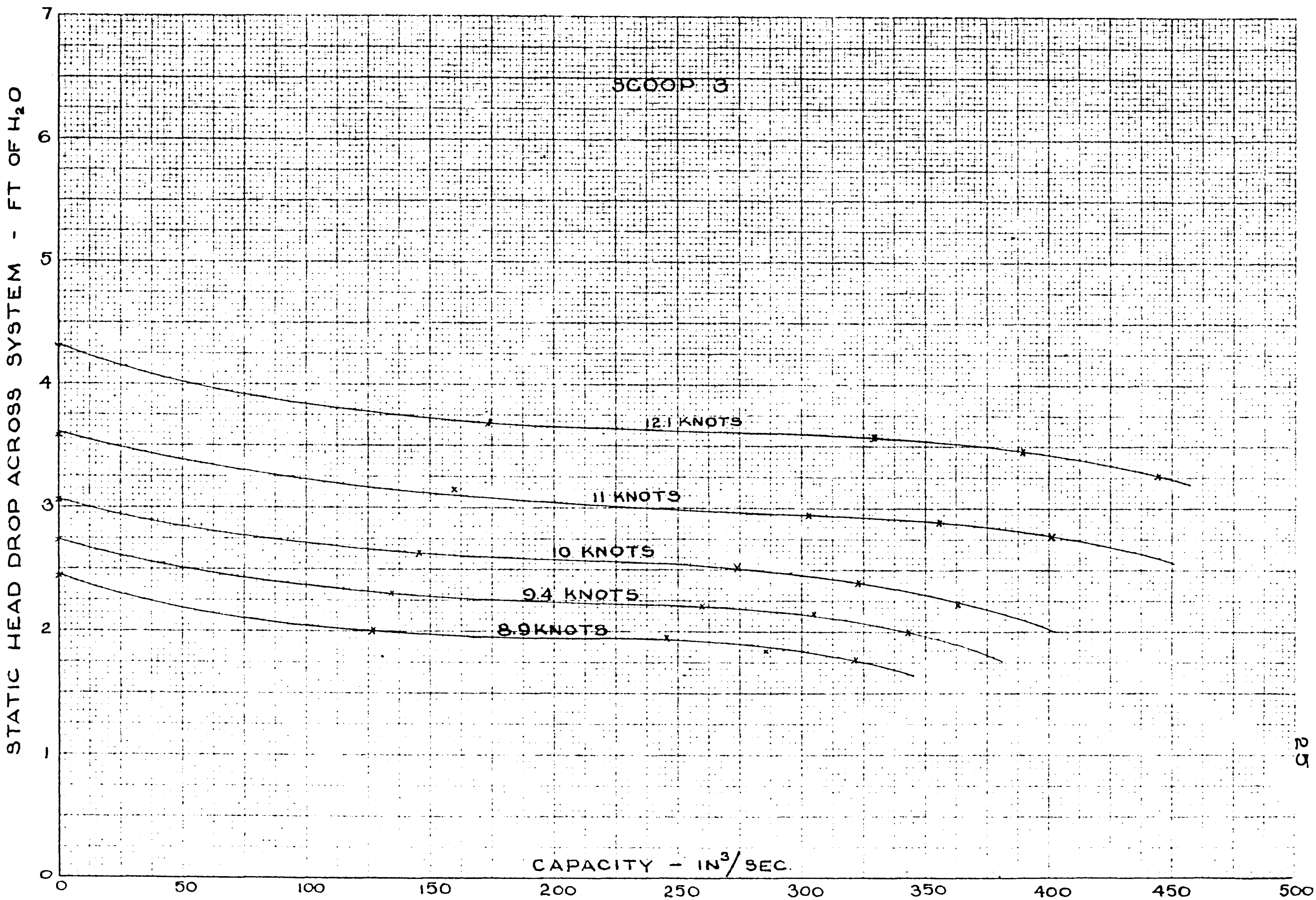
$$\frac{QP_s / e_p - RV / c_p}{QP / e_p} \quad (100)$$

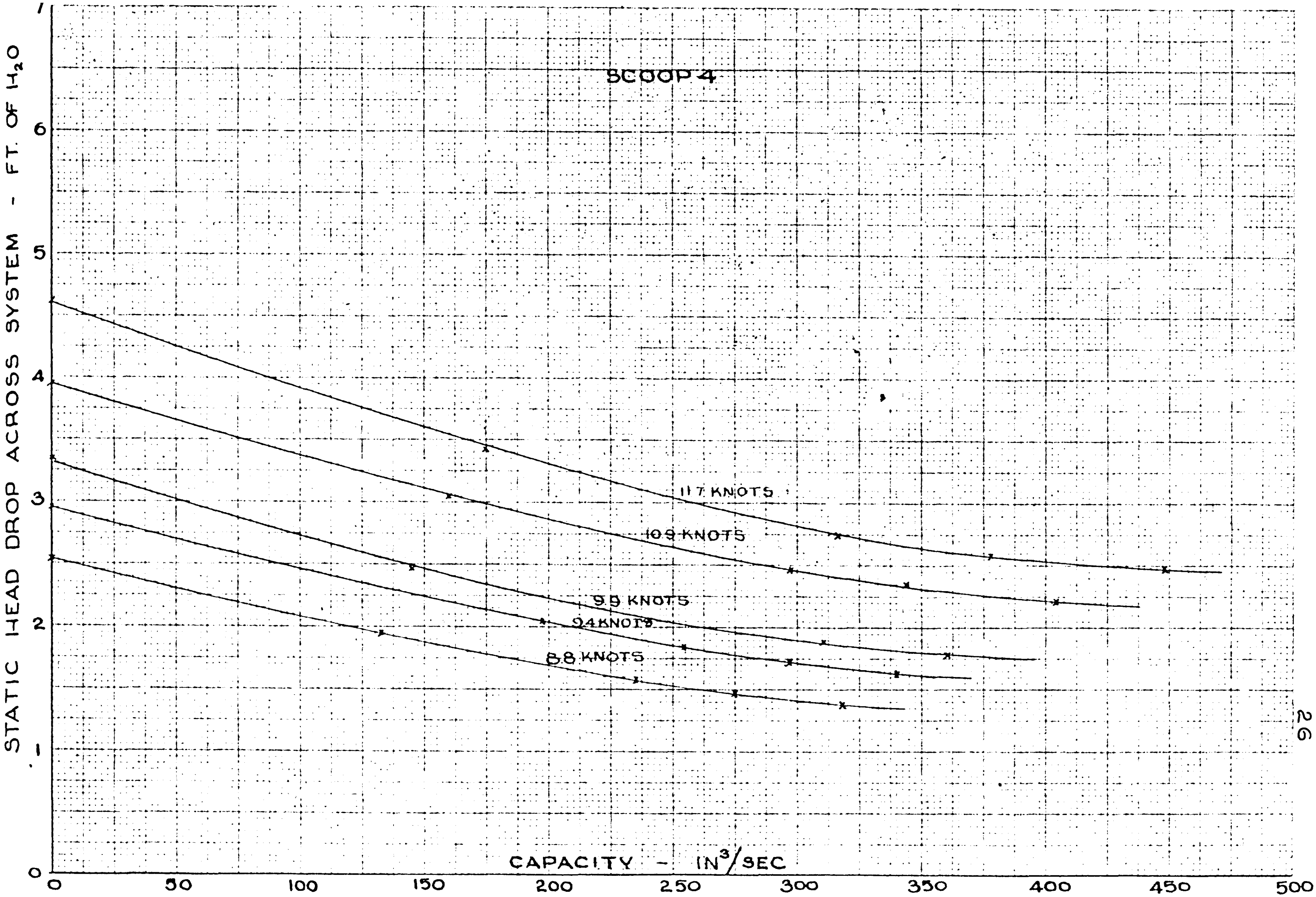
Again the economic factors would dictate the critical value which determines the utility of the scoop.

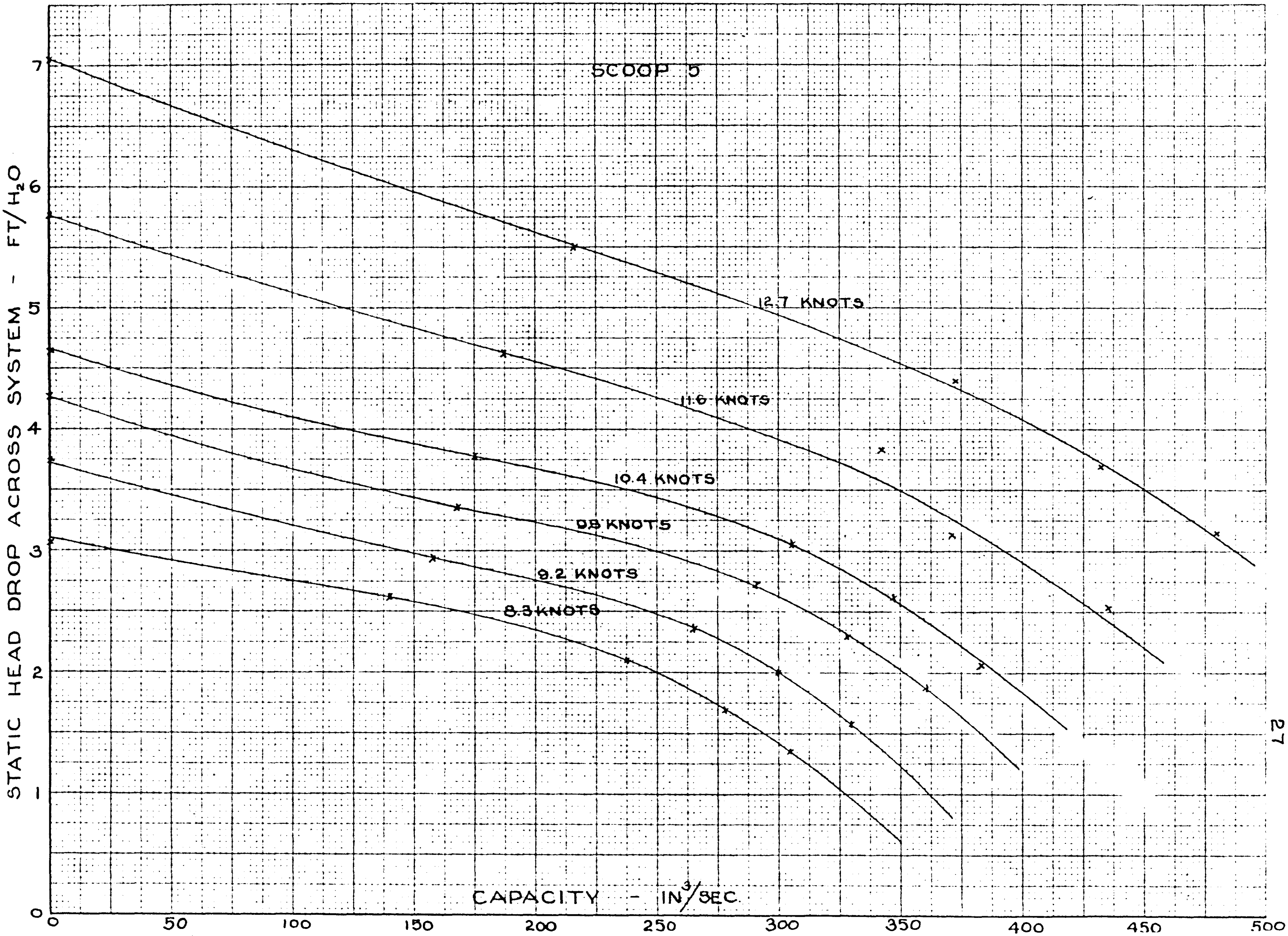
From these last considerations we find that the data available is not really sufficient for initial design. The circulating pump Horse Power of modern high vacuum installations is in the vicinity of 1 % of the main unit S.H.P., and therefore has some importance in the main unit design. Therefore, to be able to analyze fully the problem before the designer, it is necessary to know the appendage resistance of the scoop at various velocities of the hull and at various circulating water capacities. A scoop for a given vessel should be able to supply the required amount of circulating water at each given ship speed and also fulfill the external resistance specifications. The curves give information for the first proposition, but the data for the second problem is at present lacking.

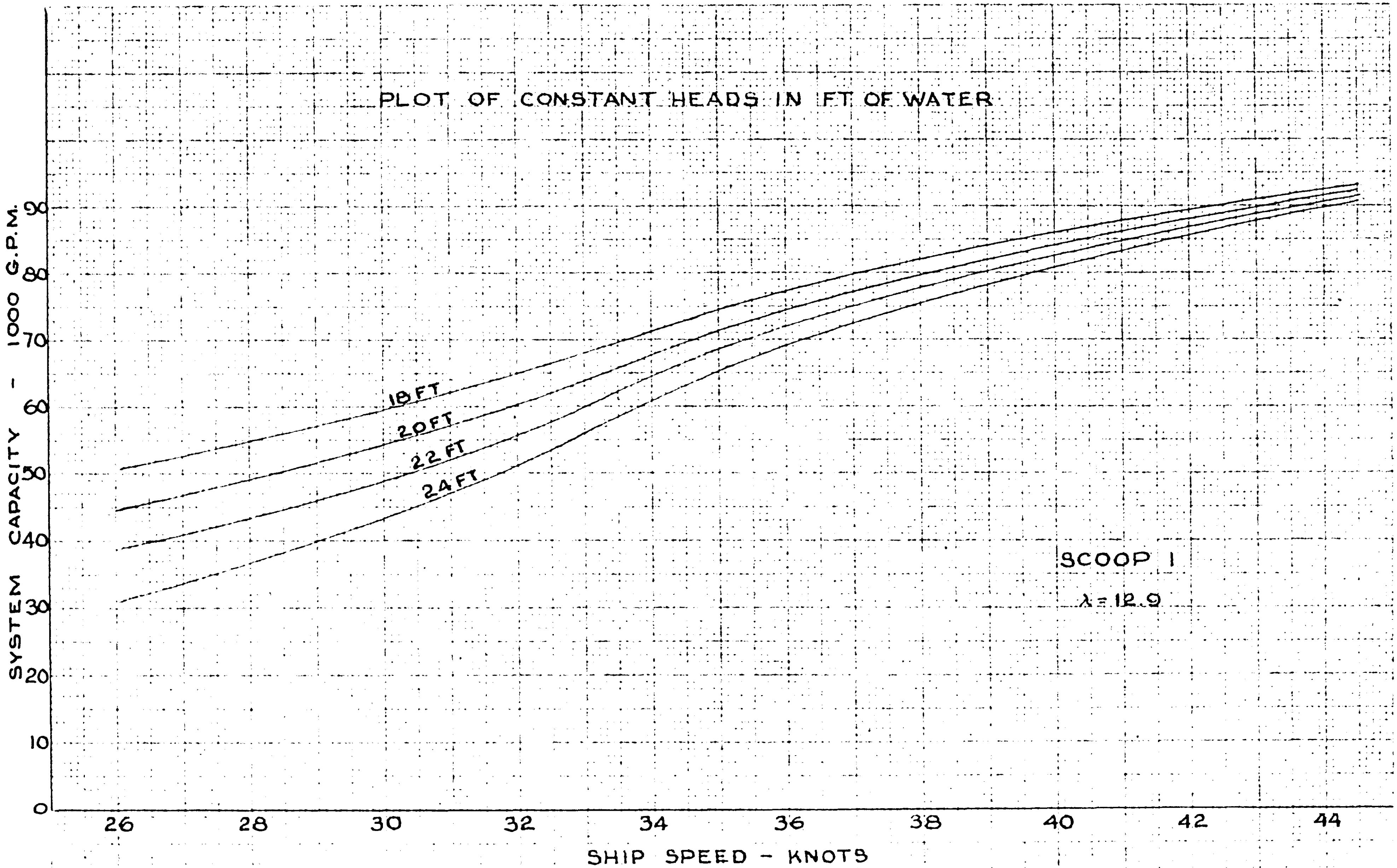
However, an examination of the photographs taken of all available scoops, including those not tested, will give some indication of the under water performance that may be expected.

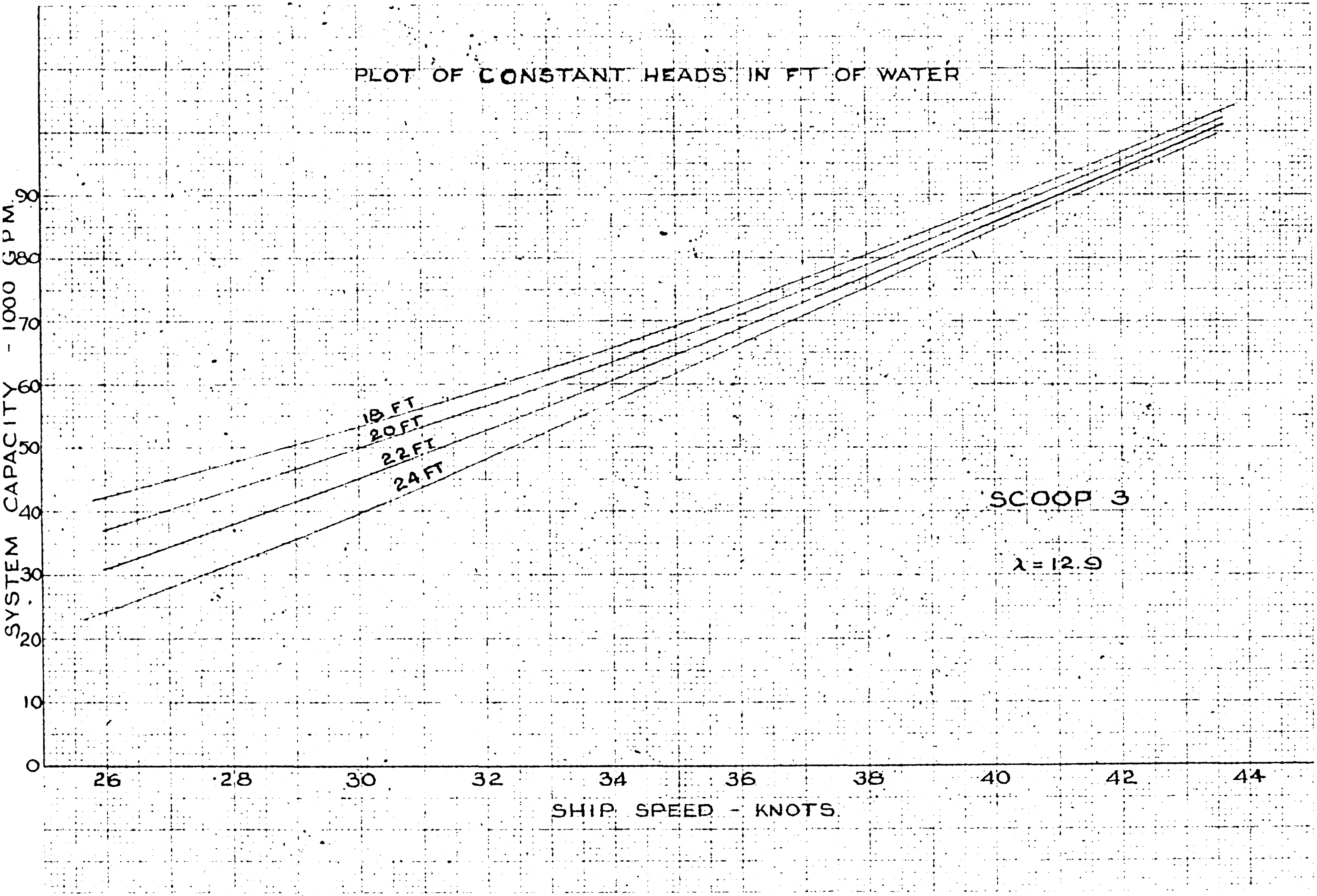

SCOOP 1
12.1 KNOTS
11.3 KNOTS
10.2 KNOTS
9.7 KNOTS
9.0 KNOTS
STATIC HEAD DROP ACROSS SYSTEM - FT OF H2O
CAPACITY - IN3/SEC
0
1
2
3
4
5
6
7
0
50
100
150
200
250
300
350
400
450
500

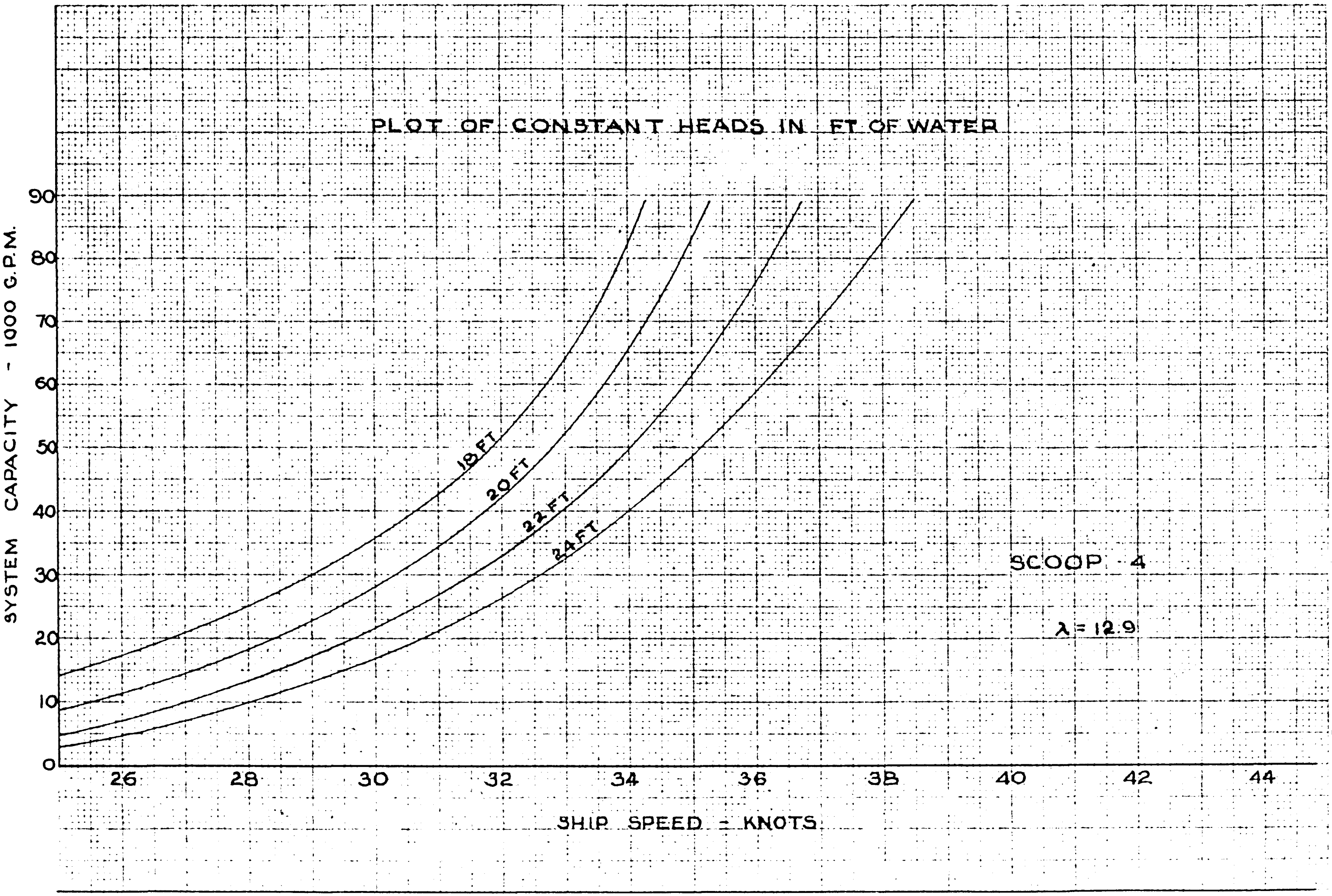

SCOOP 3
12.1 KNOTS
11 KNOTS
10 KNOTS
9.4 KNOTS
8.9 KNOTS
STATIC HEAD DROP ACROSS SYSTEM - FT OF H_2O
CAPACITY - IN^3/SEC.
0
1
2
3
4
5
6
7
0
50
100
150
200
250
300
350
400
450
500

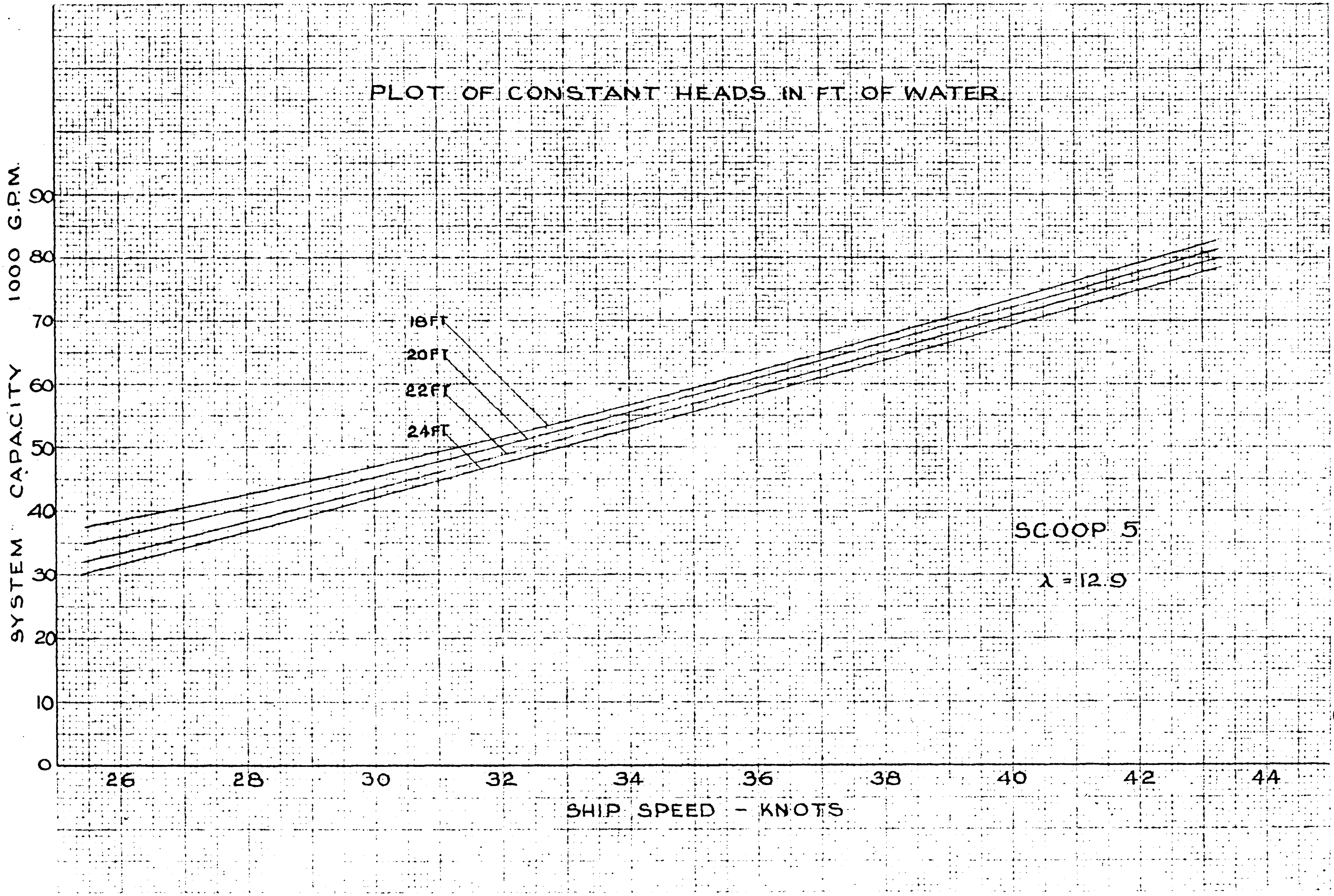

SCOOP 4
11.7 KNOTS
10.9 KNOTS
9.9 KNOTS
9.4 KNOTS
8.8 KNOTS
STATIC HEAD DROP ACROSS SYSTEM - FT. OF H2O
CAPACITY - IN3/SEC
0
1
2
3
4
5
6
7
0
50
100
150
200
250
300
350
400
450
500


SCOOP 5
12.7 KNOTS
11.6 KNOTS
10.4 KNOTS
9.8 KNOTS
9.2 KNOTS
8.3 KNOTS
STATIC HEAD DROP ACROSS SYSTEM - FT/H_2O
CAPACITY - $IN^3/SEC.$
0
1
2
3
4
5
6
7
0
50
100
150
200
250
300
350
400
450
500


PLOT OF CONSTANT HEADS IN FT OF WATER
18 FT
20 FT
22 FT
24 FT
SCOOP I
λ = 12.9
SYSTEM CAPACITY - 1000 G.P.M.
0
10
20
30
40
50
60
70
80
90
SHIP SPEED - KNOTS
26
28
30
32
34
36
38
40
42
44

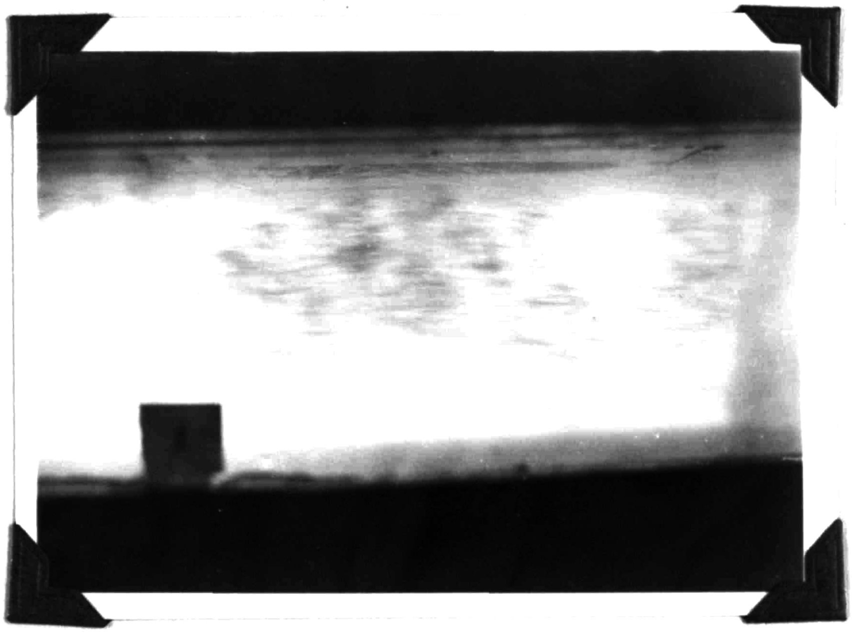

PLOT OF CONSTANT HEADS IN FT OF WATER
18 FT
20 FT
22 FT
24 FT
SCOOP 3
λ = 12.9
SYSTEM CAPACITY - 1000 GPM.
0
10
20
30
40
50
60
70
80
90
26
28
30
32
34
36
38
40
42
44
SHIP SPEED - KNOTS


PLOT OF CONSTANT HEADS IN FT OF WATER
SYSTEM CAPACITY - 1000 G.P.M.
0
10
20
30
40
50
60
70
80
90
SHIP SPEED - KNOTS
26
28
30
32
34
36
38
40
42
44
18 FT
20 FT
22 FT
24 FT
SCOOP 4
λ = 12.9


PLOT OF CONSTANT HEADS IN FT. OF WATER
18FT
20FT
22FT
24FT
SCOOP 5
λ = 12.9
SYSTEM CAPACITY 1000 G.P.M.
0
10
20
30
40
50
60
70
80
90
26
28
30
32
34
36
38
40
42
44
SHIP SPEED - KNOTS

PHOTOGRAPHS

In order to photograph the flow, air was introduced into the duct ahead of the scoop through a perforated tube. This tube was not in use during test runs.



Scoop number 1
(20° - no lip)

This photograph shows smooth flow from the duct into the scoop entrance with a slight outflow towards the end of the scoop opening. There is very little eddying and the flow is essentially unbroken. The indication would be that the scoop offers relatively little external resistance.

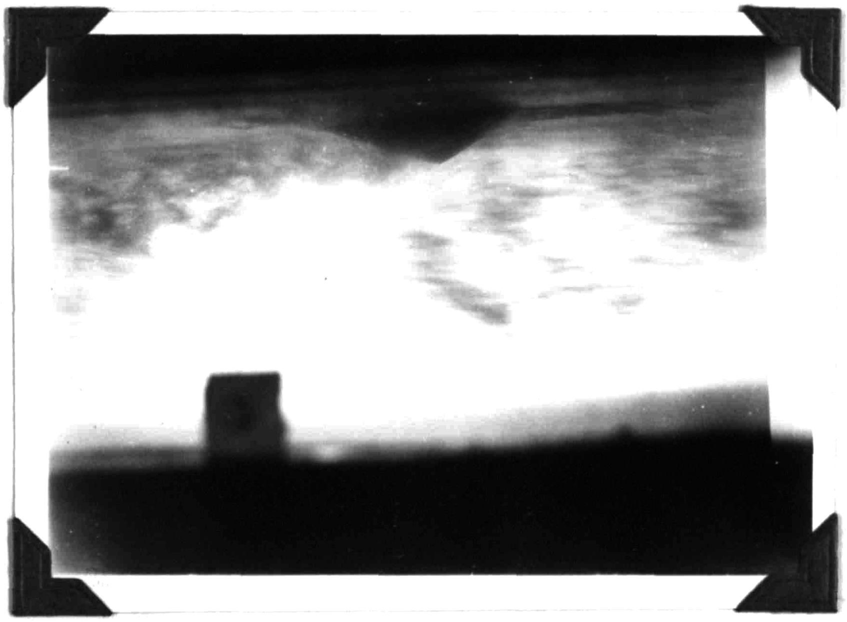
Scoop number 2

This is a 20° scoop with a slight lip and equipped with strainer plates. Because of the previous poor performance of this scoop it was not tested.

The photograph shows smooth flow into the forward part of the scoop but slight eddying at the lip projection and a small amount of water spilling over the sides and bottom. This spilling may be reduced by increased capacity in the scoop. The indication is that this scoop would give more eddy resistance than scoop number 1.

Scoop number 3

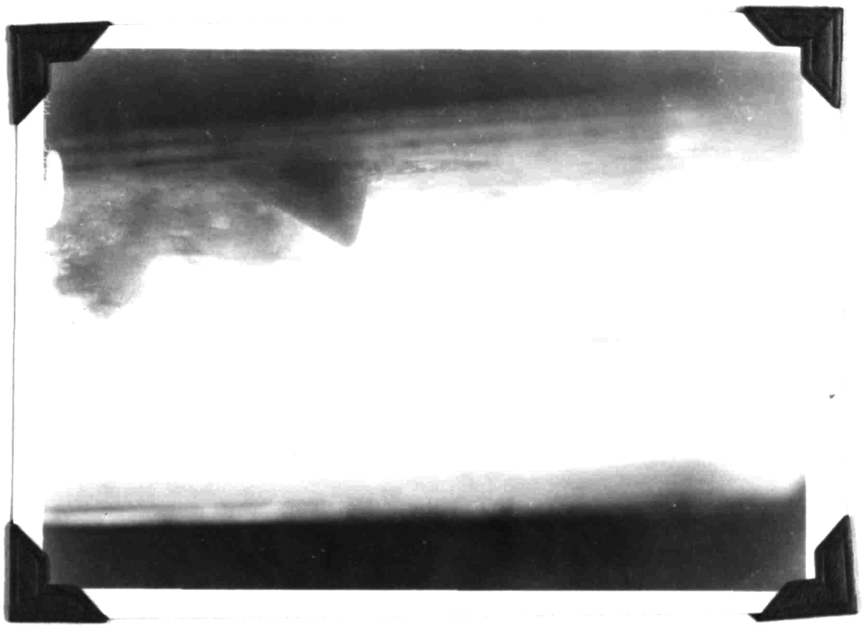
This is a 20° scoop with a medium lip.



The photograph shows fairly smooth flow into the forward part of the scoop opening but a slight downward flow and considerable eddying at the lip. The indication is that the scoop would have more eddy resistance than number 2.

Scoop number 4

This is a 32° scoop with a large lip projection.



The photograph shows clearly the effect of too abrupt a slope at the scoop inlet. The water, instead of turning smoothly into the forward part of the entrance, flows by until it hits the lip. This flow past the forward part of the opening is clearly seen by the formation of large stationary air bubbles at the initial entrance, indicating stagnant water due to too abrupt a slope of the scoop. This may explain the poor performance of scoop number 4. There is excessive eddying with water spilling over the sides and bottom of the lip. The indication is that this scoop would give the most eddy resistance of any tested.

Scoop number 5.

This is a 90° scoop with turning vanes and fairwater.

The photograph shows water spilling over the sides and bottom of the scoop entrance. This may be decreased by increased capacity. A fairwater at the back of the sçoop prevents any serious eddying, and it may be concluded that eddy resistance is slight. Due to the increased surface there will be a slightly greater frictional resistance.

Sample Design

It has previously been stated that the results of this thesis would be recorded in such a form as to aid the designer directly in his design of condenser scoops. The curves compiled by the authors can be used in two ways.

a. To find the desired size of scoop for a given scoop type so as to satisfy given condenser requirements of a ship.

b. Given a type and size of scoop , to predict its performance on the actual ship.

There are two methods of solving for scoop size for a given power installation. Method I. - Use the plots of system capacity vs. ship speed for a given scoop type (28" injection line , $\lambda = 12.9$) and correct the size of scoop for desired capacity. Method II.- Use plots of static head drop across the system vs. capacity for a given type scoop. Assume any λ which will bring the speed of the model into the range of the plots, or better assume a λ which will bring the speed of the model onto one of the constant speed contours.

Sample calculations for a given set of specifications are shown below for a flush 20° scoop and a 90° scoop with vanes. To predict the performance of a given scoop is merely the reverse procedure of the methods given above. The symbols used are:

λ = Linear proportion between ship and model.
V° = Model speed.
V = Ship speed.
Q° = Model capacity.
Q = Ship capcity.
A° = Model scoop area.
A = Ship scoop area.

Calculations:

Designer's data -
Ship speed = 30 knots
Req'd. cap.= 30,000 GPM.
Head loss = 18 ft. water

If a flush 20° scoop is desired -

Method I. Using the plot of system capacity vs. ship speed (constant head) for scoop # 1, enter at 18 ft. and 30 knots and read 59,000 GPM with a 28" injection.

$$\text{Capacity per unit area} = \frac{59{,}000}{\pi/4\ (28)^2} = \frac{30{,}000}{\pi/4\ (d)^2}$$

$$d = \sqrt{30{,}000/59{,}000}\ (28) = 20.0 \text{ inches.}$$

Method II. Using the plot of static head drop across the system vs. system capacity (constant speed) for scoop # 1. Assume a $\lambda = 9$

$$\sqrt{\lambda} = 3 \quad , \quad V/V^\circ = \sqrt{\lambda} = 3 \quad , \quad V^\circ = 10 \text{ knots.}$$

$$H = \lambda H^\circ \quad , \quad H^\circ = 18/9 = 2 \text{ ft. of water.}$$

Enter plot at 10 knots (interpolate) and 2 ft. static drop and read 435 in^3/sec.

Since the model scoop area = 3.7 in^2 , $Q°/A° = 117$ in^3/sec.
Q/A varies as $\sqrt{\lambda}$ and therefore Q/A = 351 in^3/sec.

$$Q\ (GPM) = \frac{30{,}000\ (231)}{60}\ in^3/sec.$$

$$A = \frac{30{,}000\ (231)}{351\ (60)} = 328 \text{ square inches} = \pi\, d^2/4$$

$$d = 20.4 \text{ inches.}$$

If a 90° scoop with vanes is desired -

Method I. Enter the plot of system capacity vs. speed (constant head) for scoop # 5. at 30 knots and 18 ft. and read off 47,000 GPM.

$$d = \sqrt{30{,}000/47{,}000}\ (28) = 22.3 \text{ inches}$$

Method II. Use the plot of static head drop across the system vs. capacity for scoop # 5. Instead of assuming any λ , let us use a λ which will bring us on a line in the plot so as to avoid interpolation. Let us use the 12.7 knot line.

$$30/12.7 = V/V° = \sqrt{\lambda} = 2.36 , \quad \lambda = 5.58$$

$$H/H° = \lambda , \quad H° = 18/5.58 = 3.24 \text{ ft. of water}$$

Enter plot with 3.24 ft. and 12.7 knots and obtain 470 in^3/sec. $\sqrt{\lambda}$ $Q°/A° = Q/A = 127\ (2.36) = 299$

$$A = \frac{30{,}000\ (231)}{299\ (60)} = 385 \text{ square inches}$$

$$d = \sqrt{4/\pi\ (385)} = 22.3 \text{ inches.}$$

It seems better to assume a λ which will give a value of speed which is plotted, when using Method II. , so as to avoid any interpolation.

From the diameters of injection line determined from the above calculations , it may be seen that the 20° scoop will give a lighter system and use slightly less space. However since the difference is slight, it would be wise to try the available and required circulating water capacity and heads at lower non-service speeds in order to see which scoop will be serviceable over the greatest ship speed range.

The one other major consideration is that of external resistance of the scoops. It may be assumed that the 90° scoop will have the greater appendage resistance. Therefore, unless the speed ranges differ very greatly, a 20.5 inch diameter flush scoop and injection line would be used for this vessel.

SCOOP CONDENSER DESIGN NOMOGRAMS.

These charts were developed on a theoretical basis as an aid to the design and prediction of scoop condenser systems. The explanation of assumptions and equations is given below.

Terminology:

Q = cubic ft./sec. flow through system

Δh = P = static pressure drop through system

V = ship velocity in knots.

a = scoop area in square inches.

K_1 = Constant of the condenser and piping.

K_2 = Constant of the scoop and discharge.

Basic Equations:

$$Q = K_1 \, a \sqrt{P} \qquad P = K_2 \, (V-v)^2$$

$$v = Q/a$$

<u>Note</u> :
Dimensional constants are omitted in these equations.

Plotted Equations:

I. $$\theta_1 = \frac{\sqrt{K_2}}{1 + \sqrt{K_2} \quad K_1}$$

II. $$\theta_2 = K_1 \, \theta_1$$

III. $$\sqrt{P} = \theta_1 V \qquad Q = \theta_2 \, a \, V$$

where θ_1 is a parameter governing pressure drop and θ_2 is a parameter governing capacity.

Ranges:

These charts are computed for use over the same ranges as the data found during these tests. The same Law of Similitude conversions may be applied to these charts for other changes.

Density Correction:

The scales are calculated for use with salt water conditions.. For use with water of other density, the following correction factors should be used:

r = lbs./cubic feet

$r_o = 64.$ = salt water

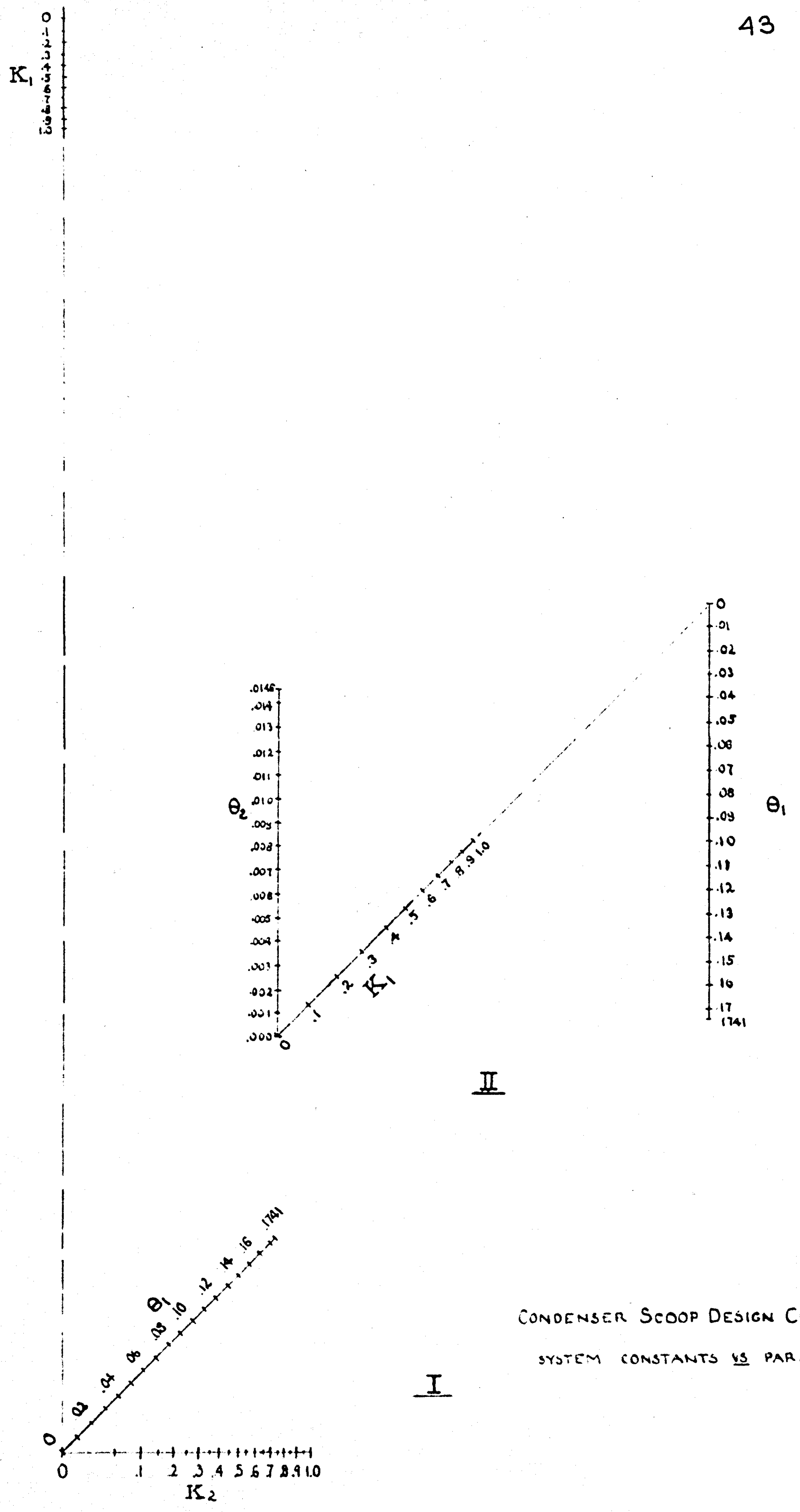
$P(r/r_o) = P\ (r/64)$ = P corrected.

$Q\sqrt{r/r_o} = Q\sqrt{r/64}$ = Q corrected.

If these factors are applied the system and scoop constants will be the same as for salt water.

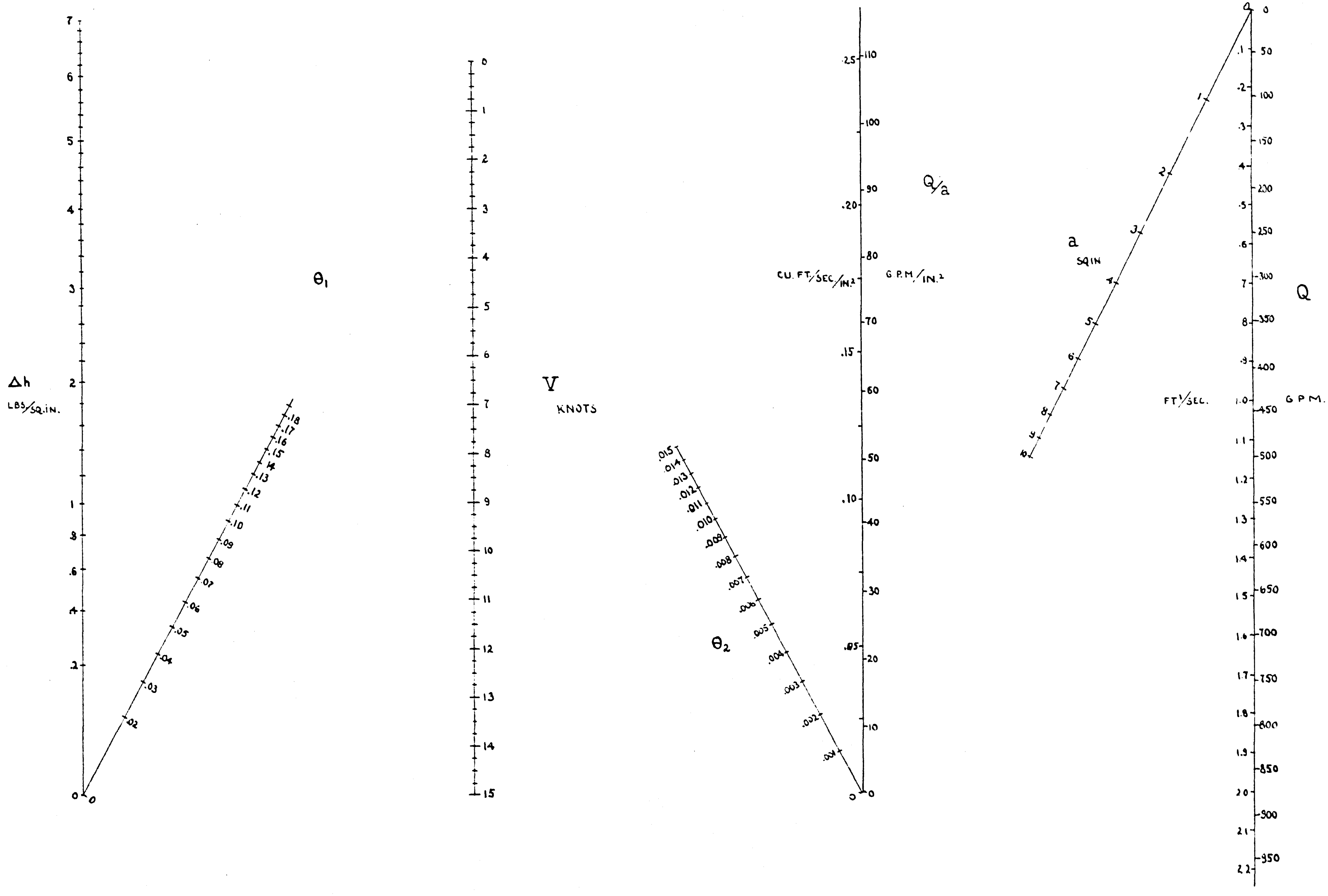
Determination of Constants:

The constants are determined by running test data through the chart system and coming out with the constant values. For design purpose the calculated head loss and required capacity and given ship speed may be used in the same manner.



CONDENSER SCOOP DESIGN CHARTS.

SYSTEM CONSTANTS VS PARAMETERS



III

CONDENSER SCOOP DESIGN CHARTS

PERFORMANCE DATA VS PARAMETERS.

E U P

RECOMMENDATIONS

The authors recommend:

that the system of presentation of data used in this paper be used in further investigations with the exception that Q/a instead of Q be plotted against ship speed to facilitate the calculations;

that tests be made on different model scoops of varying size to determine the exactness with which the Law of Similitude may be applied;

that complete tests be made on the appendage resistance of scoop and discharge systems at varying ship speeds and varying rates of flow;

that tests similar to those employed by the authors be used with varying types of overboard discharge.

APPENDIX

Symbols

V	Ship Velocity (units as given)
Q	System Capacity (units as given)
P	Pressure drop through system - ft of H_2O
P s	Pressure drop through system - in of Hg-in of H_2O
H vd	Velocity head in duct - in of Hg-in of H_2O
H vs	Velocity head in system - in of CCl_4-in of H_2O
h sd	Static head in duct referred to atmospheric pressure - ft of H_2O
h ss	Static head in scoop referred to atmospheric pressure - ft of H_2O
V s	Velocity in system - ft/sec
λ	Ratio of linear dimensions of full-size system to model.
a	Scoop cross sectional area - in^2

Traverse of Flume

Inches from top of flume	Velocities ft/sec			
1/2	13.0	12.7	11.0	9.7
3/4	13.5	13.2	11.9	10.4
1	14.7	14.0	12.5	10.9
1 1/4	14.9	14.1	12.9	11.1
1 1/2	15.5	14.6	13.1	11.3
1 3/4	15.7	14.7	13.2	11.8
2	16.0	14.9	13.5	12.0
2 1/4	16.1	15.2	13.6	12.2
2 1/2	16.2	15.3	13.8	12.4
2 3/4	16.4	15.4	13.9	12.7
3	16.6	15.5	14.0	12.7
3 1/4	16.7	15.5	14.1	12.8
3 1/2	16.8	15.7	14.2	12.9
3 3/4	16.8	15.7	14.2	12.9
4	16.8	15.7	14.2	12.7

Scoop Number 1 - Discharge to tank

V ft/sec	Q in^3/sec	h sd ft H_2O	h ss ft H_2O	V s ft/sec
18.40	398	1.88	2.03	8.98
18.40	346	1.88	2.20	7.80
18.40	297	1.88	2.25	6.69
18.30	160	1.88	2.37	3.60
18.30	0	2.10	2.37	.00
17.10	372	1.60	1.76	8.39
17.10	322	1.60	1.82	7.26
17.10	278	1.55	2.04	6.27
17.10	154	1.71	2.09	3.47
17.10	0	1.82	2.20	.00
15.80	344	1.33	1.48	7.76
15.80	297	1.33	1.58	6.70
15.80	258	1.33	1.64	5.82
15.80	143	1.33	1.64	3.22
15.80	0	1.38	1.70	.00
15.60	326	1.22	1.27	7.35
15.60	286	1.22	1.38	6.45
15.60	248	1.22	1.48	5.59
15.60	138	1.22	1.53	3.11
15.60	0	1.22	1.53	.00
14.00	309	1.06	1.17	6.96
14.00	274	1.06	1.17	6.18
14.00	236	1.06	1.33	5.32
14.00	134	1.06	1.38	3.02
14.00	0	1.22	1.44	.00

Scoop Number 3 - Discharge to tank

V ft/sec	Q in^3/sec	h sd ft H_2O	h ss ft H_2O	V s ft/sec
19.10	404	2.00	2.21	9.10
19.10	356	2.00	2.32	8.02
18.90	304	2.00	2.37	5.49
18.70	165	2.11	2.43	3.72
18.70	0	2.22	2.59	.00
18.00	378	1.62	1.88	8.53
17.80	330	1.62	1.94	7.45
17.80	286	1.62	2.10	6.44
17.80	145	1.62	2.10	3.27
17.80	0	1.62	2.10	.00
16.05	346	1.34	1.45	7.80
16.05	299	1.29	1.50	6.74
16.05	260	1.34	1.55	5.86
16.05	133	1.34	1.50	3.00
16.05	0	1.51	1.33	.00
15.20	329	1.13	1.28	7.42
15.20	293	1.18	1.39	6.60
15.20	255	1.24	1.50	5.75
15.20	135	1.24	1.61	3.04
15.20	0	1.24	1.67	.00
14.15	316	1.13	1.12	7.12
14.25	279	1.08	1.23	6.29
14.25	218	1.08	1.33	4.91
14.25	127	1.08	1.45	2.87
14.25	0	1.13	1.50	.00

Scoop Number 4 - Discharge to tank

V ft/sec	Q in^3/sec	h sd ft H_2O	h ss ft H_2O	V s ft/sec
19.50	415	2.12	1.63	9.35
19.60	355	2.23	1.85	8.00
19.60	302	2.18	2.22	6.80
19.60	169	2.23	2.43	3.82
19.50	0	2.45	2.71	.00
18.40	386	1.86	1.42	8.70
18.20	333	1.86	1.52	7.50
18.30	283	1.81	1.63	6.38
18.30	141	1.96	2.01	3.18
18.20	0	2.01	2.38	.00
16.65	343	1.42	1.08	7.74
16.60	300	1.42	1.18	6.76
16.65	260	1.42	1.23	5.87
16.65	142	1.42	1.83	3.20
16.65	0	1.70	1.96	.00
15.80	328	1.31	.87	7.40
15.80	286	1.31	1.02	6.45
15.80	250	1.31	1.18	5.64
15.80	136	1.31	1.46	3.07
15.40	0	1.36	1.63	.00
14.50	303	1.03	.74	6.84
14.50	269	1.03	.87	6.07
14.50	236	1.03	.92	5.33
14.50	132	1.14	1.18	2.97
14.50	0	1.35	1.42	.00

Scoop Number 5 - Discharge to tank

V ft/sec	Q in^3/sec	h sd ft H_2O	h ss ft H_2O	V s ft/sec
17.80	384	1.77	1.37	8.66
17.80	348	1.77	1.81	7.85
17.80	307	1.77	2.25	6.92
17.80	181	1.77	2.91	4.08
17.80	0	2.09	3.51	.00
16.70	367	1.55	1.32	8.28
16.70	329	1.55	1.65	7.41
16.70	296	1.55	2.14	6.68
16.70	170	1.60	2.91	3.83
16.70	0	1.82	3.23	.00
15.60	340	1.33	1.05	7.66
15.60	307	1.33	1.37	6.92
15.60	273	1.33	1.71	6.16
15.60	159	1.33	2.36	3.59
15.60	0	1.33	2.63	.00
14.95	325	1.16	.92	7.33
14.95	290	1.22	1.27	6.55
14.95	266	1.22	1.59	6.00
14.95	152	1.22	2.03	3.43
14.95	0	1.22	2.52	.00
14.00	306	1.00	.77	6.90
14.00	279	1.00	1.05	6.30
14.00	247	1.00	1.32	5.57
14.00	145	1.00	1.92	3.27
14.00	0	1.22	2.14	.00
13.00	284	.89	.61	6.41
13.00	260	.89	.83	5.87
13.00	230	.89	1.11	5.19
13.00	134	.89	1.49	3.02
13.00	0	.89	1.71	.00

Scoop Number 1 - Discharge to flume

H vd in Hg	H vs in CCl_4	P s in Hg	V ft/sec	Q in^3/sec	P ft H_2O
6.25	35.9	3.10	20.60	455	3.26
6.20	28.5	3.30	20.50	394	3.47
6.20	21.5	3.55	20.50	334	3.73
6.20	6.9	3.65	20.50	193	3.84
6.30	.1	4.30	20.70	0	4.52
5.40	31.3	2.80	19.10	417	2.94
5.40	24.8	3.00	19.10	363	3.15
5.40	18.0	3.10	19.10	301	3.26
5.40	5.8	3.10	19.10	165	3.26
5.40	.1	3.60	19.10	0	3.78
4.40	25.7	2.30	17.25	370	2.42
4.40	20.5	2.40	17.25	324	2.52
4.35	15.0	2.50	17.20	272	2.63
4.40	4.9	2.60	17.25	153	2.73
4.40	.1	3.00	17.25	0	3.15
3.90	23.2	2.10	16.30	349	2.21
3.95	18.2	2.20	16.35	303	2.31
3.95	13.4	2.30	16.35	255	2.42
3.95	4.3	2.45	16.35	144	2.57
3.95	.1	2.70	16.35	0	2.84
3.40	20.2	1.80	15.20	322	1.89
3.40	16.0	1.90	15.20	282	2.00
3.40	11.9	2.00	15.20	239	2.10
3.40	3.9	2.00	15.20	138	2.10
3.40	.1	2.35	15.20	0	2.47

Scoop Number 3 - Discharge to flume

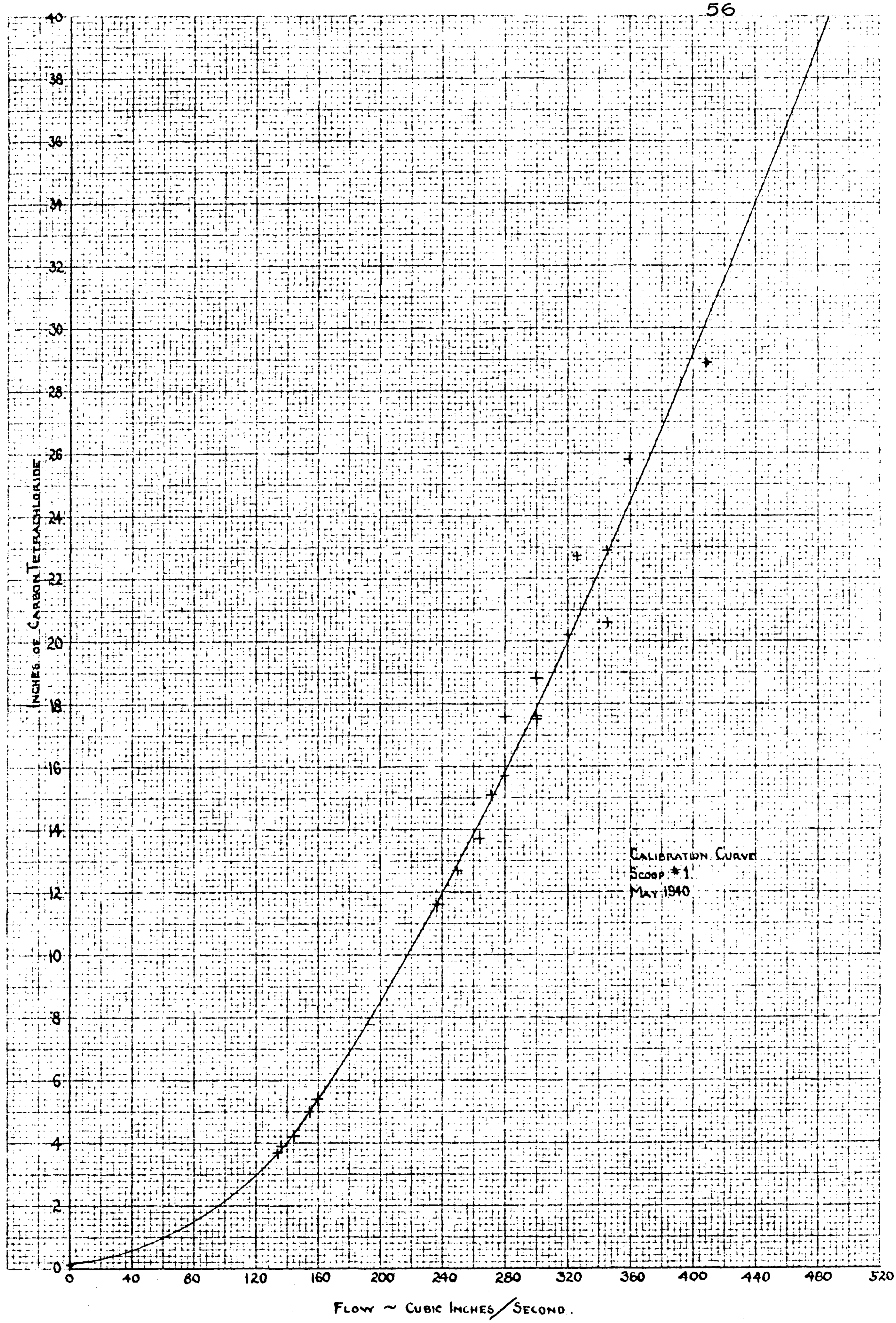
H vd in Hg	H vs in CCl_4	P s in Hg	V ft/sec	Q in^3/sec	P ft H_2O
6.30	36.4	3.10	20.60	444	3.26
6.20	28.6	3.30	20.50	389	3.47
6.20	20.8	3.40	20.50	329	3.57
6.20	6.1	3.50	20.50	174	3.68
6.10	.1	4.10	20.35	0	4.30
5.10	30.5	2.65	18.60	402	2.78
5.10	24.3	2.75	18.60	356	2.89
5.10	17.8	2.80	18.60	303	2.94
5.10	5.2	3.00	18.60	160	3.15
5.10	.1	3.40	18.60	0	3.57
4.10	25.2	2.10	16.70	363	2.21
4.20	20.0	2.25	16.85	322	2.36
4.20	14.5	2.40	16.85	274	2.52
4.20	4.4	2.50	16.85	146	2.63
4.20	.1	2.90	16.85	0	3.05
3.70	22.9	1.90	15.80	343	2.00
3.75	17.9	2.05	15.90	305	2.15
3.80	13.2	2.10	16.00	261	2.21
3.70	3.8	2.20	15.80	135	2.31
3.80	.1	2.60	16.00	0	2.73
3.30	19.9	1.70	14.95	322	1.79
3.25	15.8	1.75	14.85	286	1.84
3.30	11.5	1.85	14.95	243	1.95
3.30	3.4	1.90	14.95	127	2.00
3.30	.1	2.30	14.95	0	2.42

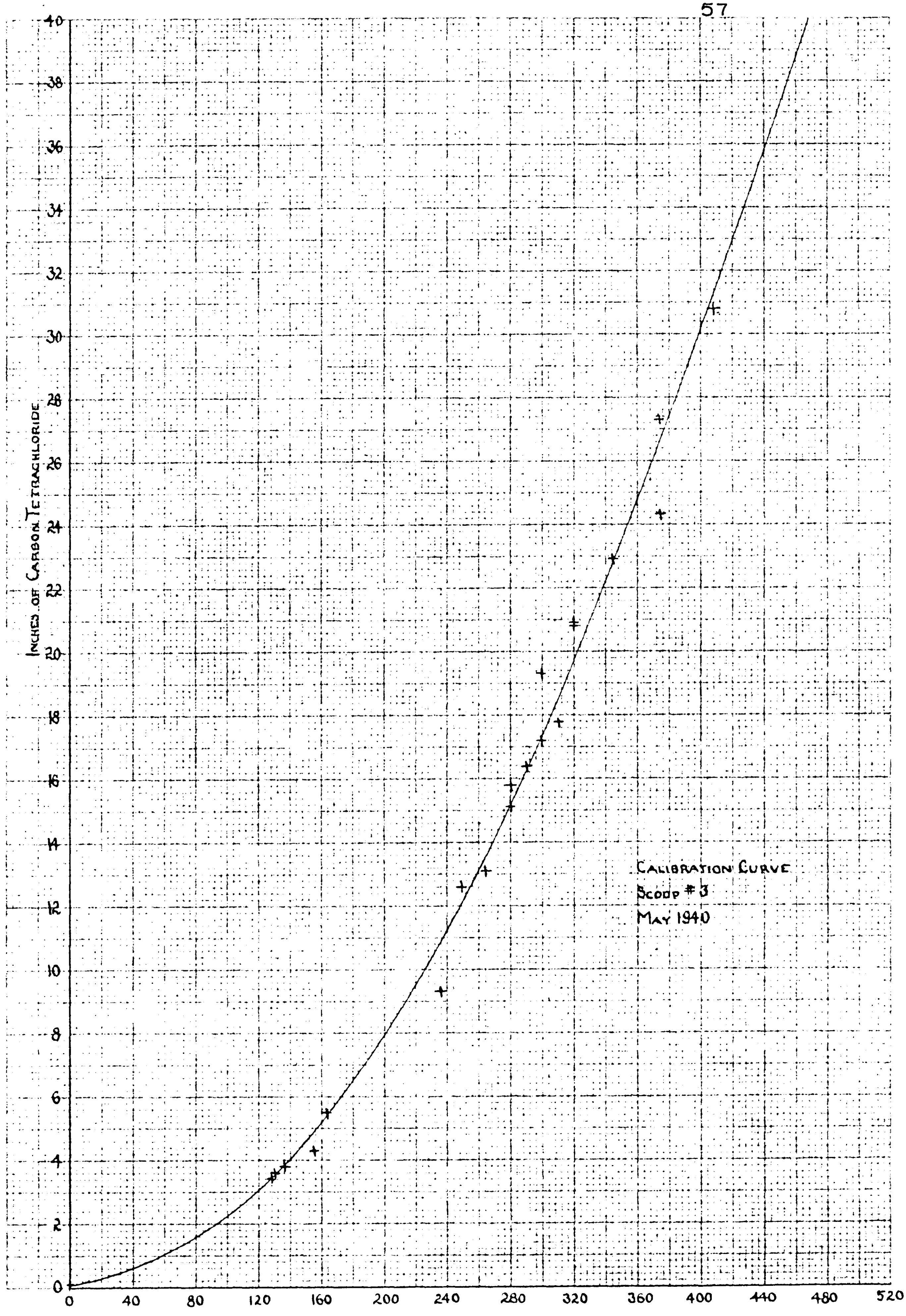
Scoop Number 4 - Discharge to flume

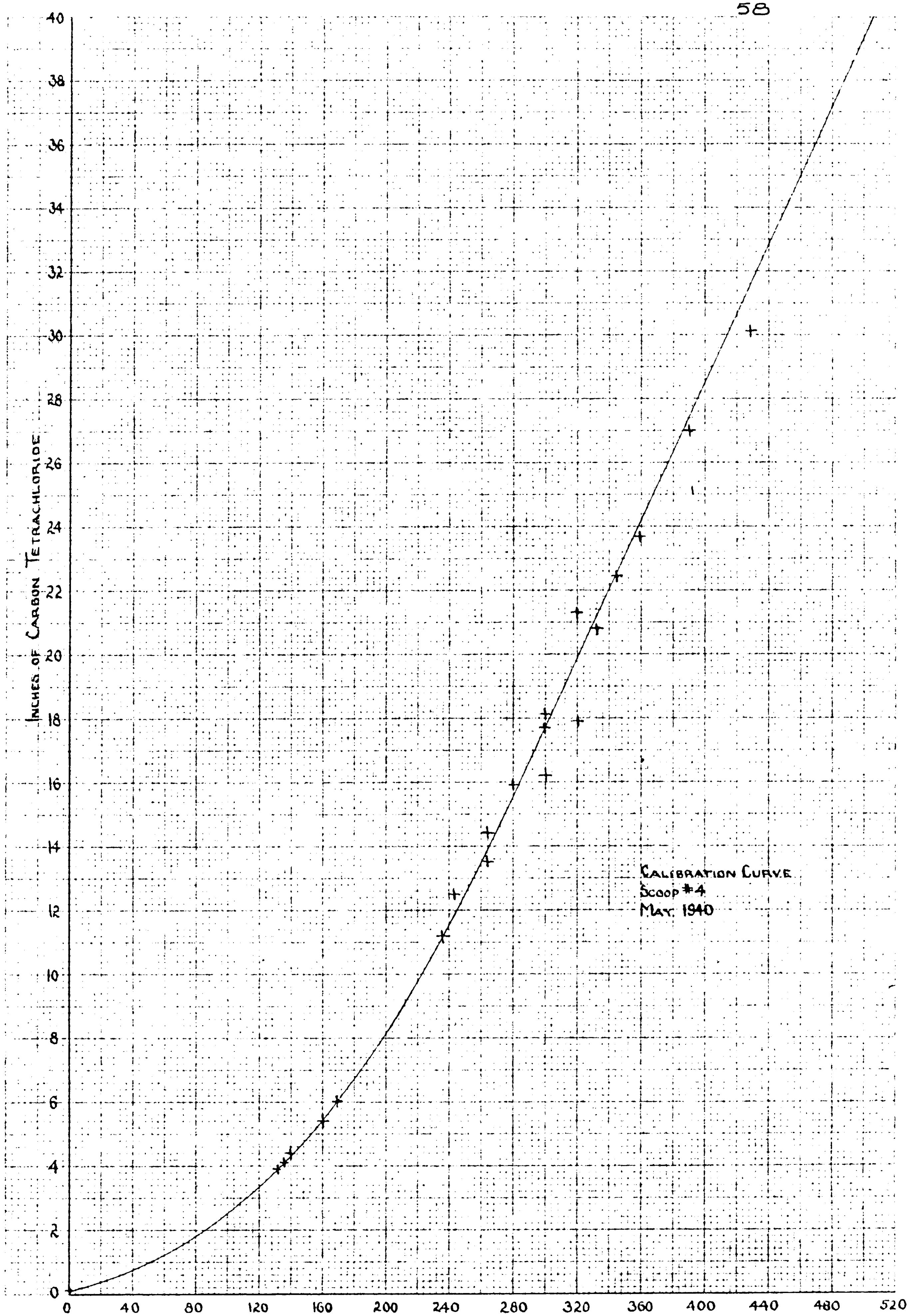
H vd in Hg	H vs in CCl_4	P s in Hg	V ft/sec	Q in^3/sec	P ft H_2O
5.80	32.8	2.35	19.80	449	2.47
5.80	26.1	2.45	19.80	378	2.57
5.75	19.5	2.60	19.70	316	2.73
5.80	6.3	3.25	19.80	174	3.41
5.65	.1	4.40	19.60	0	4.62
5.05	29.1	2.10	18.50	406	2.20
5.05	22.4	2.25	18.50	343	2.36
5.05	17.0	2.35	18.50	293	2.47
5.00	5.4	2.90	18.40	159	3.04
5.00	.1	3.75	18.40	0	3.94
4.10	24.1	1.70	16.70	359	1.78
4.20	18.8	1.80	16.85	310	1.89
4.20	14.1	1.95	16.85	266	2.04
4.15	4.6	2.30	16.75	145	2.42
4.10	.1	3.20	16.70	0	3.36
3.75	22.0	1.55	15.90	339	1.63
3.70	17.4	1.65	15.80	297	1.73
3.75	12.9	1.75	15.90	254	1.84
3.75	7.9	1.95	15.90	197	2.05
3.75	.1	2.80	15.90	0	2.94
3.30	19.7	1.30	14.95	318	1.37
3.30	15.0	1.40	14.95	275	1.47
3.30	11.2	1.50	14.95	236	1.58
3.30	3.9	1.85	14.95	132	1.95
3.30	.1	2.40	14.95	0	2.52

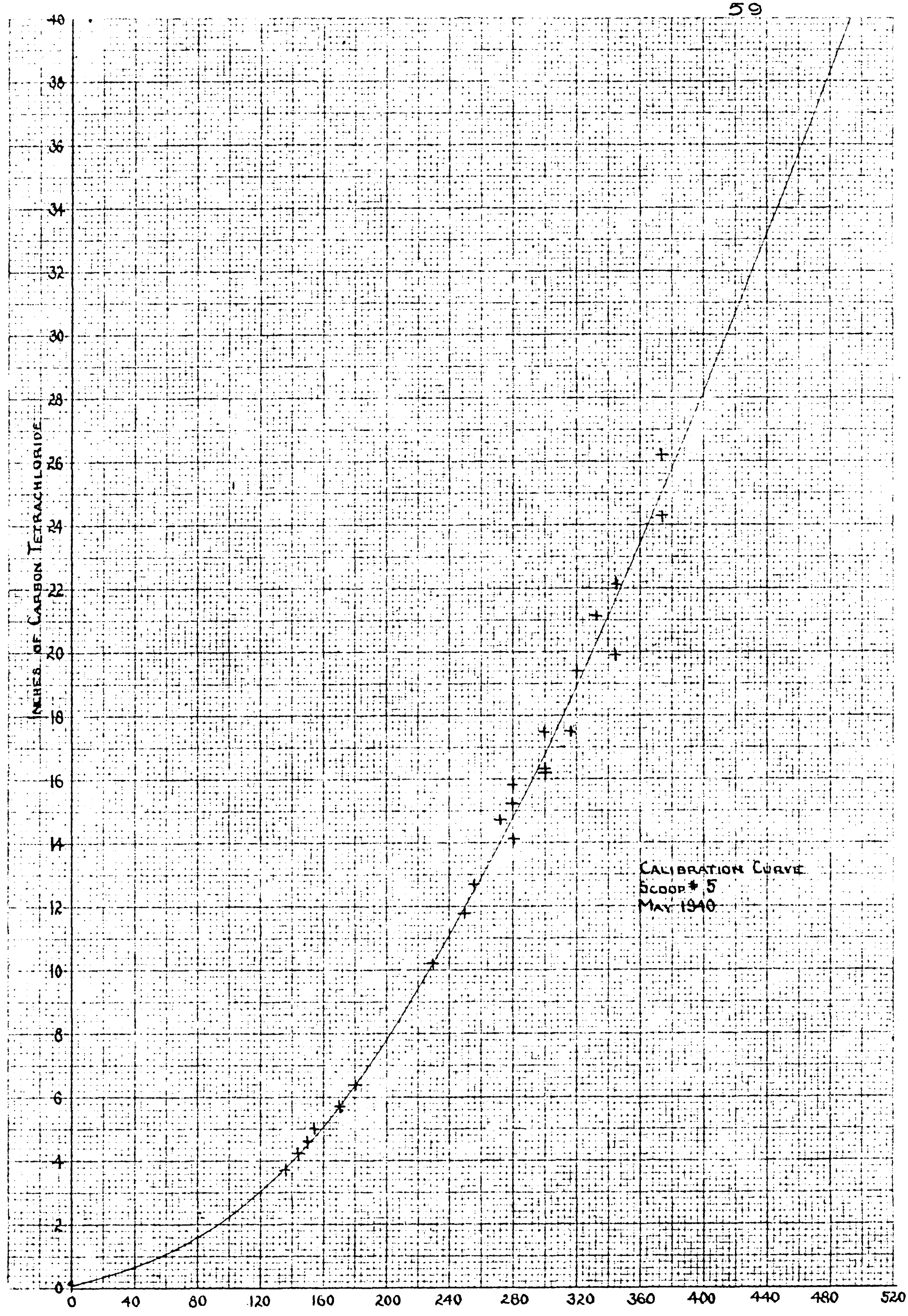
Scoop Number 5 - Discharge to flume

H vd in Hg	H vs in CCl_4	P s in Hg	V ft/sec	Q in^3/sec	P ft H_2O
6.70	37.9	3.00	21.30	480	3.15
6.80	31.9	3.50	21.50	433	3.68
6.80	24.6	4.20	21.50	373	4.41
6.75	8.8	5.25	21.40	217	5.50
6.80	- .3	6.70	21.50	0	7.05
5.75	32.2	2.40	19.70	436	2.52
5.70	26.9	3.00	19.65	371	3.15
5.70	21.2	3.65	19.65	342	3.83
5.70	6.7	4.40	19.65	188	4.62
5.65	- .1	5.50	19.55	0	5.77
4.55	25.9	1.95	17.55	382	2.05
4.60	22.0	2.50	17.65	348	2.62
4.60	17.2	2.90	17.65	305	3.05
4.55	6.0	3.60	17.55	176	3.78
4.45	0.0	4.45	17.35	0	4.67
4.00	23.5	1.80	16.50	361	1.89
4.05	19.7	2.20	16.60	328	2.31
4.00	15.8	2.60	16.50	291	2.73
4.00	5.3	3.20	16.50	166	3.36
4.00	0.0	4.10	16.50	0	4.30
3.50	20.4	1.50	15.40	334	1.57
3.45	16.7	1.90	15.30	300	2.00
3.40	13.1	2.25	15.20	263	2.36
3.50	4.8	2.80	15.40	158	2.94
3.50	0.0	3.60	15.40	0	3.78
2.90	17.3	1.30	14.00	305	1.36
2.85	14.5	1.60	13.90	277	1.68
2.90	10.9	2.00	14.00	238	2.10
2.90	4.0	2.50	14.00	140	2.62
2.90	.1	2.90	14.00	0	3.05


Calibration Curve
Scoop #1
May 1940
Inches of Carbon Tetrachloride
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
0
40
80
120
160
200
240
280
320
360
400
440
480
520
Flow ~ Cubic Inches/Second.


Inches of Carbon Tetrachloride
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
0
40
80
120
160
200
240
280
320
360
400
440
480
520
Calibration Curve
Scope # 3
May 1940


Inches of Carbon Tetrachloride
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
0
40
80
120
160
200
240
280
320
360
400
440
480
520
Calibration Curve
Scoop #4
May. 1940


Inches of Carbon Tetrachloride
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
0
40
80
120
160
200
240
280
320
360
400
440
480
520
Calibration Curve
Scoop # 5
May 1940

CALCULATIONS

I.

A summary of the general equations and constants used in the conversion of test data to plotted and noted data.

- - -

Velocity -

Pitot tube measurement. Mercury manometer with water above both mercury legs.

$$V = \sqrt{2gh} = \sqrt{(64.4)(13.6 - 1.0)\ h/12}$$
$$= 8.22\sqrt{h} \quad \text{ft./sec.}$$

H_{vs} -

Pitot tube measurements. CCl_4 manometer with water above both CCl_4 legs. Instead of calculating this velocity head and computing a discharge coefficient, the manometer readings were plotted directly against the timed discharge into a tank. (See calibration curves.)

Quantities -

These were read directly from the calibration curves in cubic inches per second.

Pressure Drop through the System -

Two static tubes were located at the injection and discharge. A mercury manometer with water above both mercury legs was used.

$$P = \frac{h\ (13.6 - 1.0)}{12} \quad \text{ft. of water}$$

Velocity in Scoop -

The quantity found from the calibration curve was divided by the scoop cross-sectional area to give the average velocity through the injection and the system. The area for all scoops was 3.7 square inches.

$$V_s = Q/(3.7)(12) \text{ ft./sec.}$$

Static Head in duct -

A mercury manometer was connected to the static tube of a pitot tube located in the center of the duct. There was water above the closed leg of the manometer, and a head of 7.7 inches of water in the leg open to the atmosphere. The pitot position was 26 inches above the median height of the mercury, which was at a scale reading of 9.1 inches.

$$(h_1 - h_2)(13.6) + (7.7)(1.0) = (9.1 - h_2) + 26 + h_{sd}$$

$$h_{sd} = \frac{13.6\ h_1 - 12.6\ h_2 - 27.4}{12} \quad \text{ft. of water.}$$

A further correction to the value of h_{sd} was necessary to refer it to conditions at the scoop static tube. This was done by subtracting the height of the scoop static tube above the pitot tube from the value of h_{sd} in feet of water.

Static head in scoop -

A mercury manometer with water in the closed leg and 6.5 inches of water in the open leg was connected to the static tube of the injection. The median mercury position was located at the 5.4 inch scale reading.

$$(h_1 - h_2)(13.6) + (6.5)(1.0) = (5.4 - h_2) + h_c + h_{sd}$$

where h_c is the height of the static tube above the median mercury position.

Scoop # 1. $h_c = 34.5$ inches

$$h_{sd} = \frac{13.6\ h_1 - 12.6\ h_2 - 33.4}{12} \quad \text{ft. of water}$$

Scoop # 3. $h_c = 35.0$ inches

$$h_{sd} = \frac{13.6\ h_1 - 12.6\ h_2 - 33.9}{12}$$

Scoop # 4. $h_c = 35.5$ inches

$$h_{sd} = \frac{13.6\ h_1 - 12.6\ h_2 - 34.4}{12}$$

Scoop # 5. $h_c = 34.5$ inches

$$h_{sd} = \frac{13.6\ h_1 - 12.6\ h_2 - 33.4}{12}$$

Constants -

1 knot = 6080.3/3600 = 1.685 ft./sec.

1 GPM = 231/60 = 3.85 cubic inches/ sec.

Specific gravity of water = 1.0 (62.4 lbs./cu.ft.)

II.

Considerations of proportionality factors .

- - -

In order to make the data determined from these tests on model scoops applicable to full size ships, Froude's Law , or the Law of Similitude, was applied to the test data. It was found that a λ of 12.9 gives a 28 inch diameter injection line, which is of the order of magnitude used on fast vessels. The ship speed and pressure drop through the system also are brought into usable ranges by this λ . The relations are as follow:

($V°, Q°, H°, a°$ are test data, $V, Q, H, a,$ are ship data.)

λ = ratio of linear dimensions of model and full size scoop.

$$V = V° \sqrt{\lambda} = V° \, (3.59)$$

$$Q = Q° \; \lambda^{2.5} = (600) \, Q°$$

$$H = H° \; \lambda = H° \, (12.9)$$

$$Q/a = (Q°/a°)\,(\lambda^{2.5}/\lambda^{2}) = Q°/a° \, (3.59)$$

This last relation is actually a velocity relation and the factor agrees with the ship velocity conversion. Any other λ may be applied to the test data to bring the ranges into suitable magnitude for the particular use in consideration.