TESTS ON MODELS OF CONDENSER SCOOPS

A Thesis Submitted to
The Department of Naval Architecture
and Marine Engineering

by

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Cambridge May 1937

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May 1937

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

Dear Sir:

The accompanying thesis, "Tests on Models of Condenser Scoops", is submitted in compliance with the requirements of the Massachusetts Institute of Technology for the degree of Bachelor of Science.

Respectfully yours,

C O N T E N T S

Acknowledgments

The writers desire to express their sincere appreciation of the helpful cooperation received from the staff of the Institute; in particular Professor J. J. Eames, Professor Evers Burtner and Mr. Carl Engstrom, and the operating personnel of the Institute shops and laboratories. Also the following students have been of assistance in conducting the tests: Charles Gidley, George Cary and John Haponik.

Object

The object of this thesis was to test model condenser scoops in order to obtain performance data for comparison and design.

The design and construction of suitable testing apparatus was a prerequisite to carrying on the tests.

General Considerations

Within the last few years the extensive use of high vacuum condensing equipment on shipboard has directed the attention of marine engineers to the problem of obtaining ample and efficient circulation of the cooling water. To this end, the means of producing the head necessary to overcome the hydraulic resistance of condenser water boxes, tubes, and associated piping has been under close scrutiny. In general there are three methods in use for producing this head:

Circulating pumps only

Scoop installations with auxiliary pumps for slow speeds and manoeuvring

Pump with assisting scoop.

The first is the usual type of equipment fitted in merchant vessels. In the second group above, the pump is used only for slow speeds or manoeuvring, the scoop providing the entire head at cruising speeds. In the last type, the pump is run continuously, the scoop acting only as an aid. Scoops are merely openings in the ship's shell so fitted and shaped that the relative motion between ship and water causes a flow into it. Such installations are to be found in naval craft and

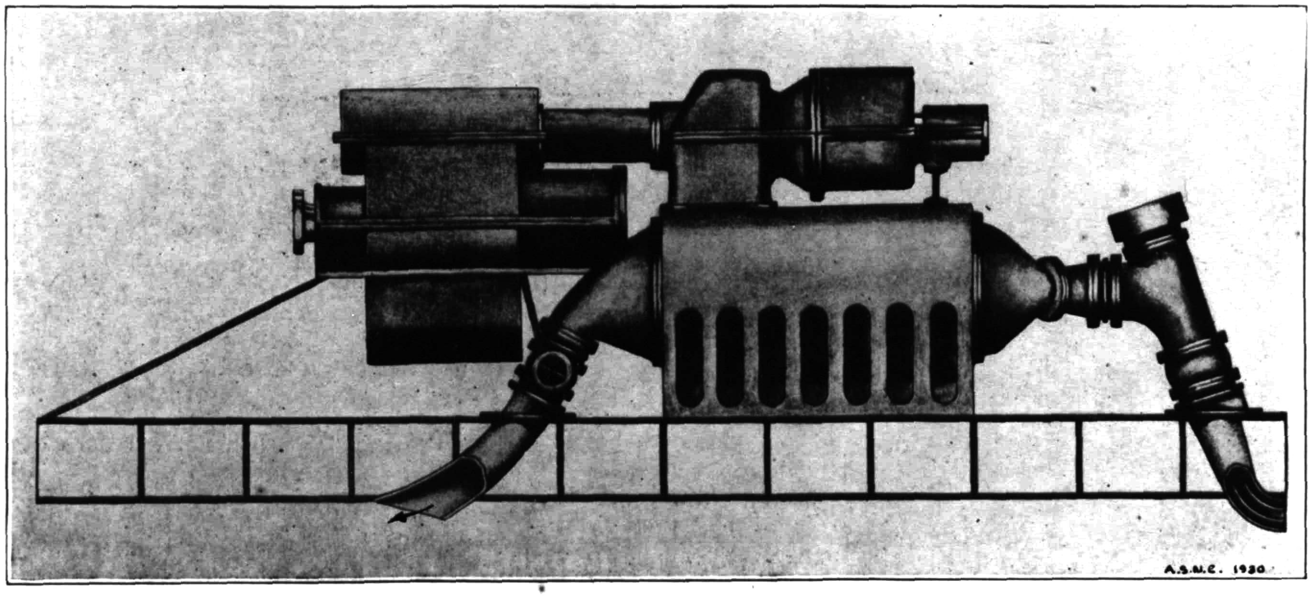


FIG. 1

fast merchant vessels. Sectional elevations of several scoops are shown in Figures (3) to (6) and a sketch of a typical arrangement of the complete system is shown in Figure (1).

It will be noted that there may be some effect due to the overboard discharge. Conceivably, this may produce either a suction head or a back pressure, obviously undesirable, on the condenser, depending on its design.

One would expect, however, that the injection scoop would have a greater influence on the performance of the condenser system, yet in spite of widespread application, especially in naval work, very little data of use to the designer is available. The various ship yards have, of course, trial results from which some inferences may be drawn, but in general there are so many variables that failure or success cannot be attributed to any one of them.

The only published data known to the writers that is at all capable of use in design and comparison of various shapes of scoops is contained in two engineering publications.

The first is a series of papers by Mr. H. F. Schmidt before the American Society of Naval Engineers, dating from 1930 and appearing in the Journal of that body. Mr. Schmidt has been primarily interested in a divergent form of scoop. This is not the case with actual scoops which are usually of cylindrical form. His experimental work was on both injections and overboard discharges. The tests on each were conducted separately in an air blast.

The second is an investigation by Professor S. Uchimaru and Mr. S. Kito of the University of Tokyo reported in the Journal of the Faculty of Engineering, 1935. This work is of rather academic interest.

Apparently there exists a very real lack of information and data on features of design covering variations in:

Angle of incidence
Projection of lip
Shape of lip and scoop
Fairing of certain portions
Strainer plates and splinter vanes.

It would seem desirable to investigate each of these items separately, since much general data may be obtained with a minimum of experimental work.

A circulating pump and a scoop both consume power. In the former it is steam or electricity. In the latter it appears as increased resistance of the ship. Estimates of the efficiency of the respective systems vary widely. Therefore, if measurement of the resistance of the scoop were possible very valuable light might be shed on this factor.

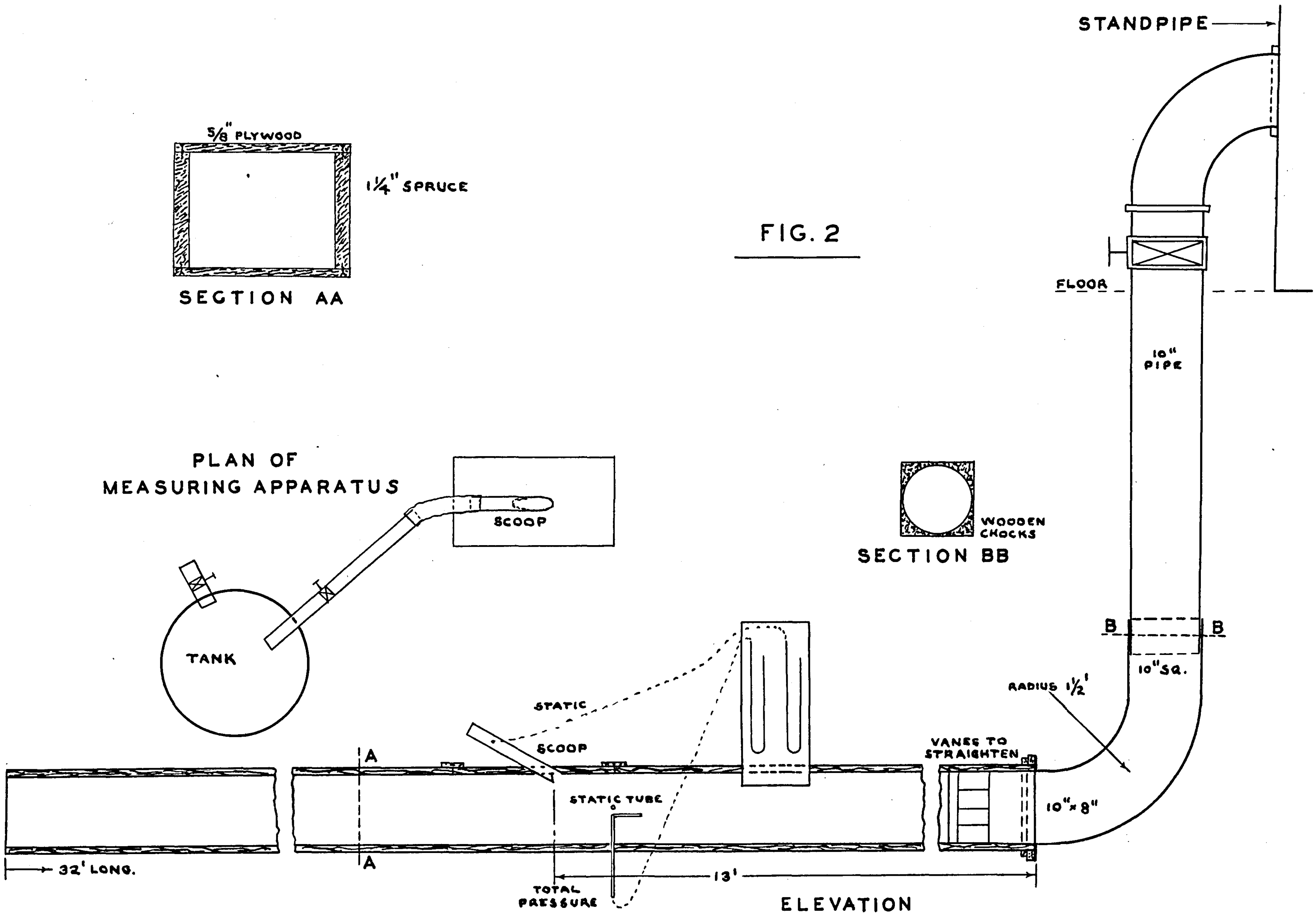
Preparation and Description of Apparatus

When the writers first attacked the problem it was their intention to test both injection and discharge scoops together with the attached waterboxes. These were to be made of wood and connected by a venturi meter in place of the condenser. Each of the variables, including the shape of the waterbox was to be changed in its turn so that each might have been investigated separately. The size of scoop was to be small, approximately one inch in diameter. Fluid media of both air and water were considered. Since measurable pressure readings were unobtainable with air because of limitations of wind apparatus, the use of water was made necessary. Much time was spent in determining what apparatus was available.

A large standpipe in the Mechanical Engineering Laboratory, into which discharged a steam driven centrifugal pump of 24,000 g.p.m. capacity was selected as the most satisfactory source of water supply.

The possibility of obtaining larger flows of water with this equipment than originally expected led to the adoption of models of about 2 inches diameter, which were expected to yield more satisfactory results.

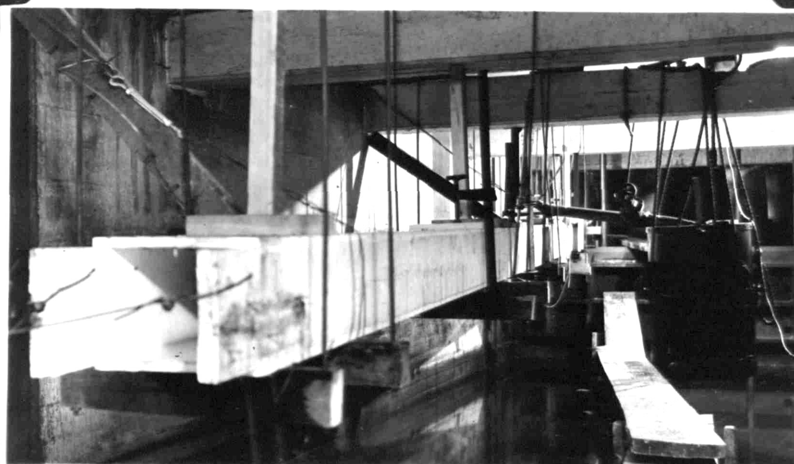
FIG. 2



STANDPIPE
5/8" PLYWOOD
1¼" SPRUCE
SECTION AA
FLOOR
10" PIPE
PLAN OF
MEASURING APPARATUS
SCOOP
TANK
WOODEN CHOCKS
SECTION BB
B
B
10" SQ.
RADIUS 1½'
STATIC
SCOOP
A
A
VANES TO STRAIGHTEN
10" × 8"
STATIC TUBE
32' LONG.
13'
TOTAL PRESSURE
ELEVATION

An application of Froude's law of comparison showed that a maximum speed of twenty feet per second should occur in the box. Simple hydraulic calculations showed that this could be obtained with an arrangement similar to figure (2) which shows diagrammatically the set-up used in the actual tests.

This apparatus (Plate I) consisted of a box with the scoops mounted in a removable section of the cover. It was erected over a water channel which ordinarily takes the discharge from the standpipe and always contains about six feet of water. This made it necessary to support the box from the overhead floor and beams and the sides of the channel which extend up to them. Both tension and compression members were used so that there resulted a very strong and vibrationless mounting. In addition guy wires were fastened to the box to take up longitudinal thrust. The attached elbow was guyed by horizontal wires and vertical rods in order to take up its reaction. The box was made long so that there could be a considerable latitude in placing the scoop with respect to the elbow without danger of effect from the open end. Straightening vanes consisting of 6 inch lengths of 2 inch sheet metal tubing were placed in the box near the elbow. A piece of 1/4 inch mesh wire screening was placed after these. The inside surface of the box was



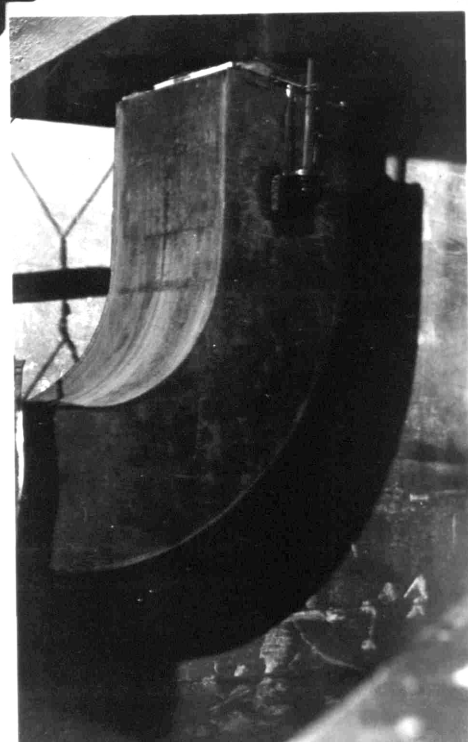
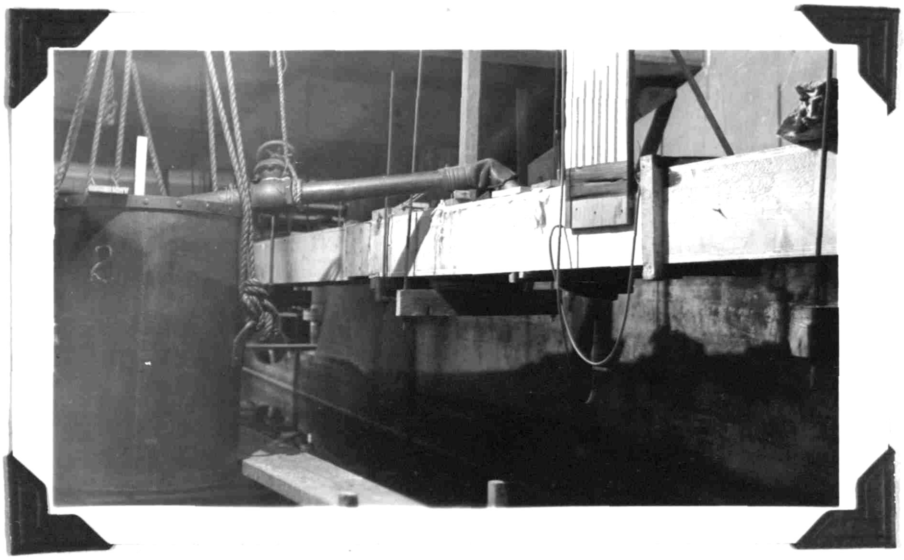


PLATE Ia



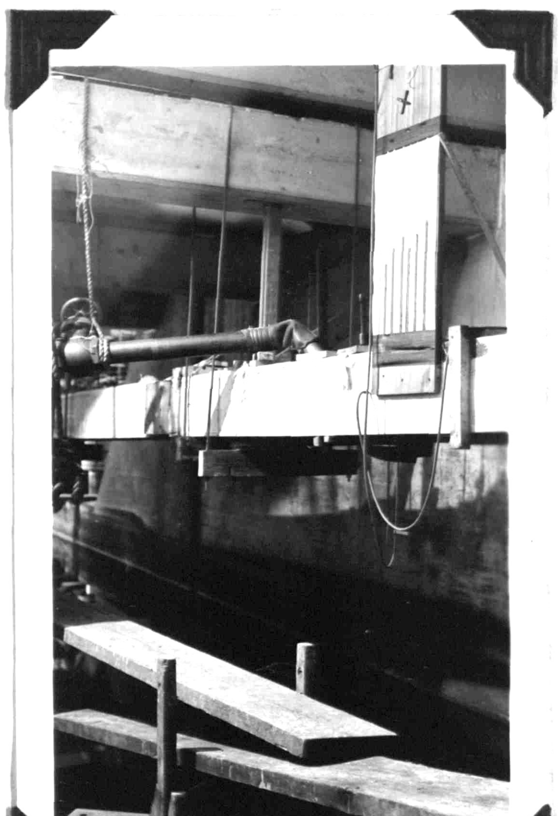


PLATE Ib

planed and given a coat of flat paint, followed by a coat of gloss, so that the surface was very smooth. The box was constructed and erected by the writers.

The elbow was welded up of 1/4 inch steel plate, the work being done outside.

The apparatus for measuring the scoop discharge consisted of a cylindrical tank fitted with a quick opening valve. This was suspended from the overhead beams. A wooden scale was clamped to the side whereby the level could be read.

The discharge from the box flowed into the channel, that from the scoop into the tank through a length of pipe and a valve which was connected to the scoop by a section of automobile innertube wired to each part.

A manometer board was mounted on the box.

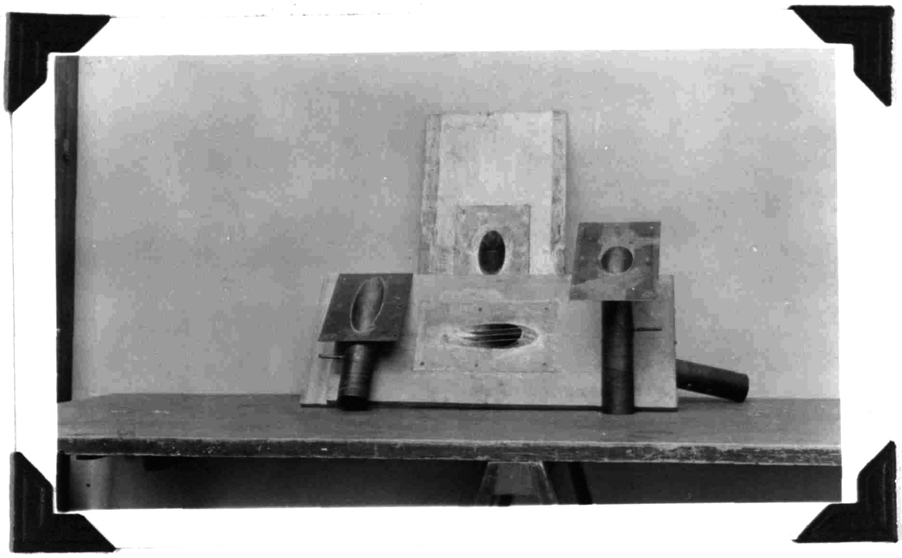
The scoops themselves were constructed of brass tubing 2 1/4 inches O. D., .04 inch wall. They were mounted on brass plates by means of soldering. Figures (3) to (6) and Plate (II)

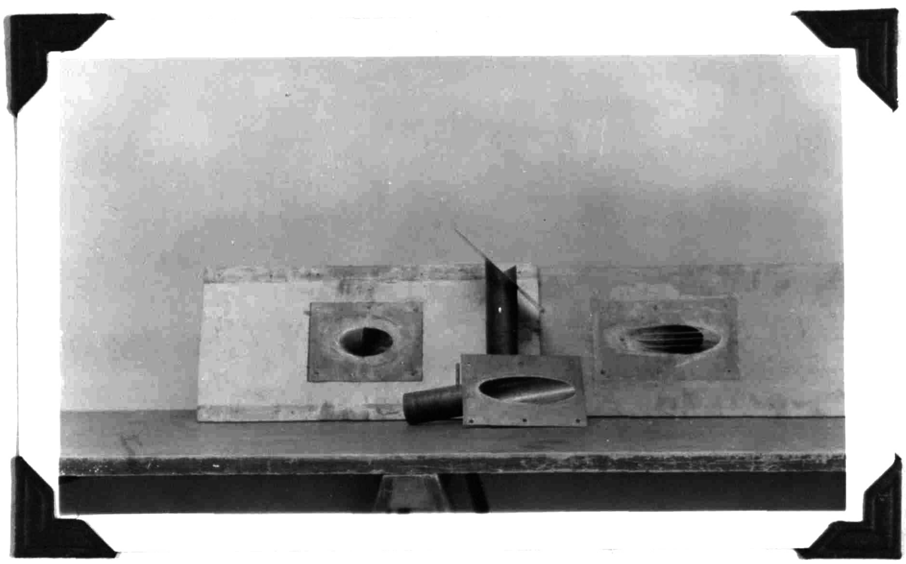
Observations of transverse velocity distribution were made at two longitudinal positions in the box. Static pressures were also obtained at these points. Figure (7). These readings determined the placing of the scoops which was at a point that simulated actual ship conditions as nearly as possible.

Traverses at several velocities were made at the point selected for the scoops, namely, 12 feet from the elbow. These curves are given in figure (8).

The removable section was clamped in place with steel clamps.

A leak developed in the side of the box due to a drying check. This was closed by clamping with more clamps.





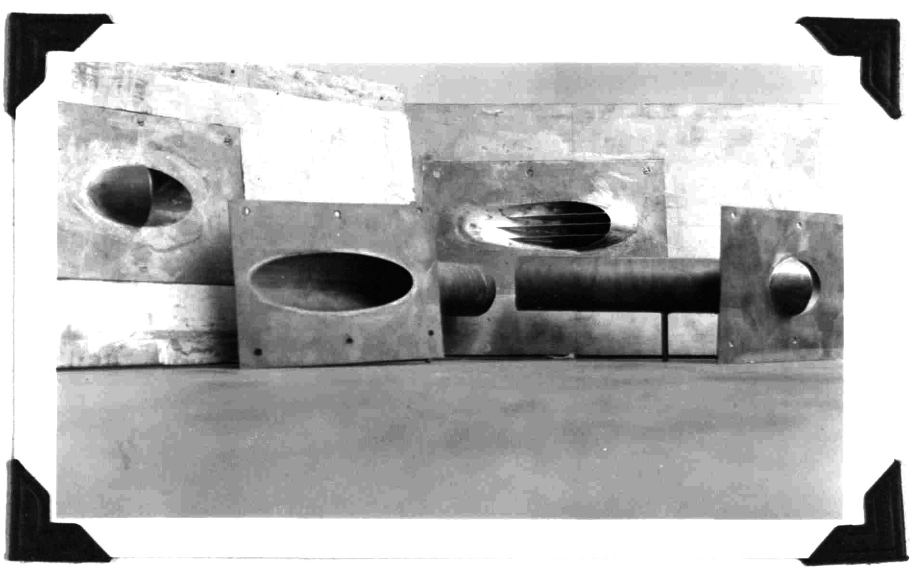


PLATE II

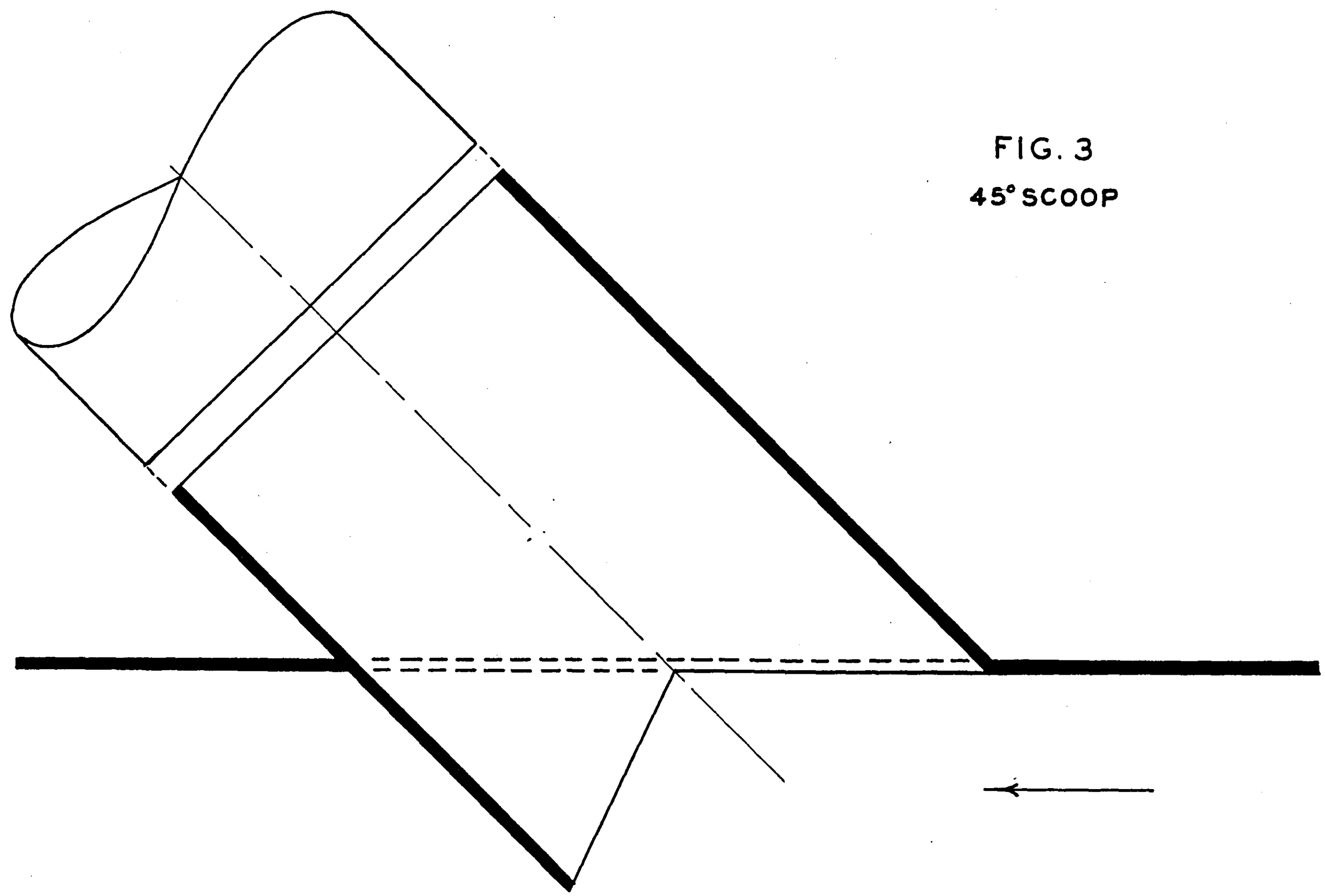


FIG. 3
45° SCOOP

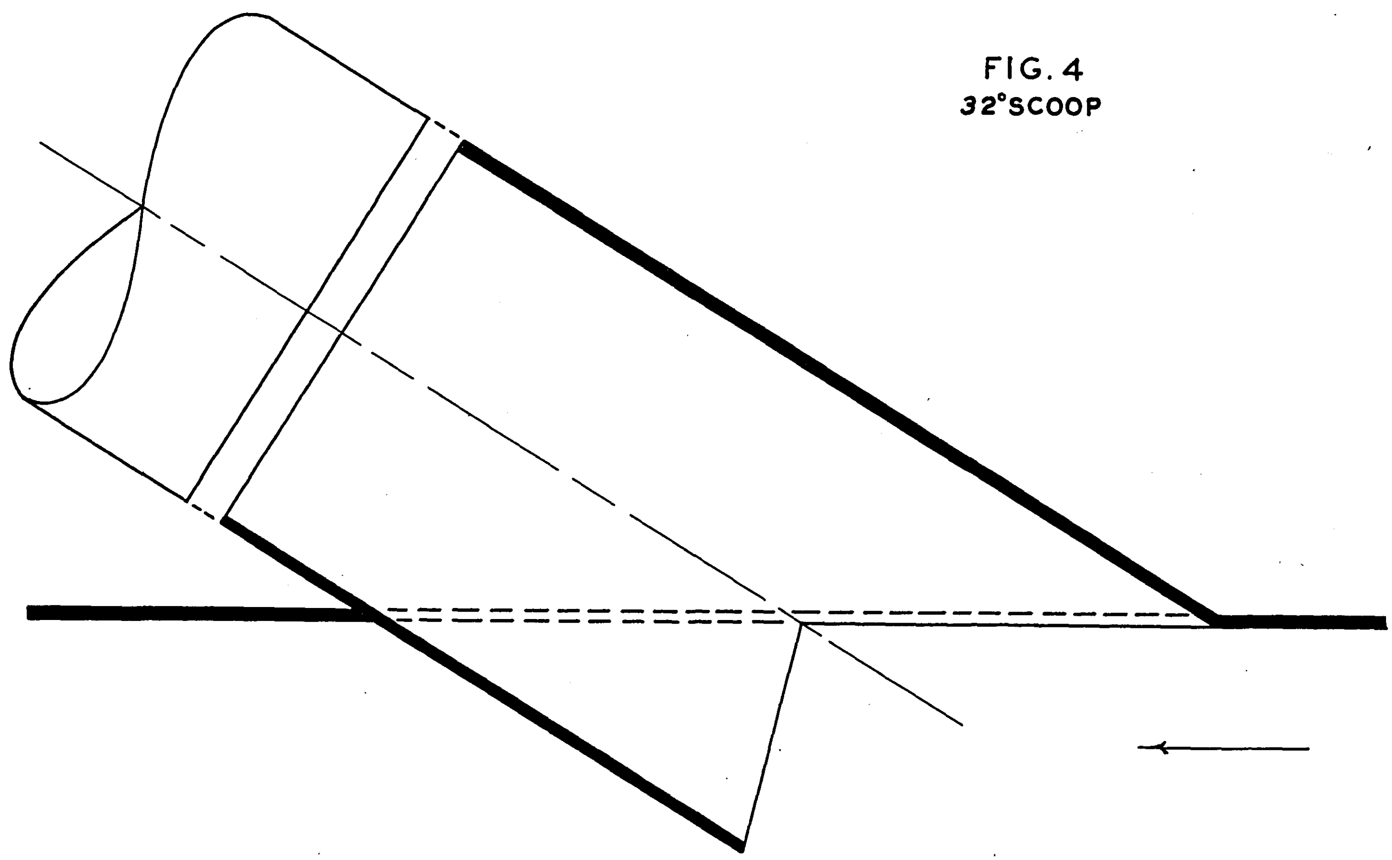
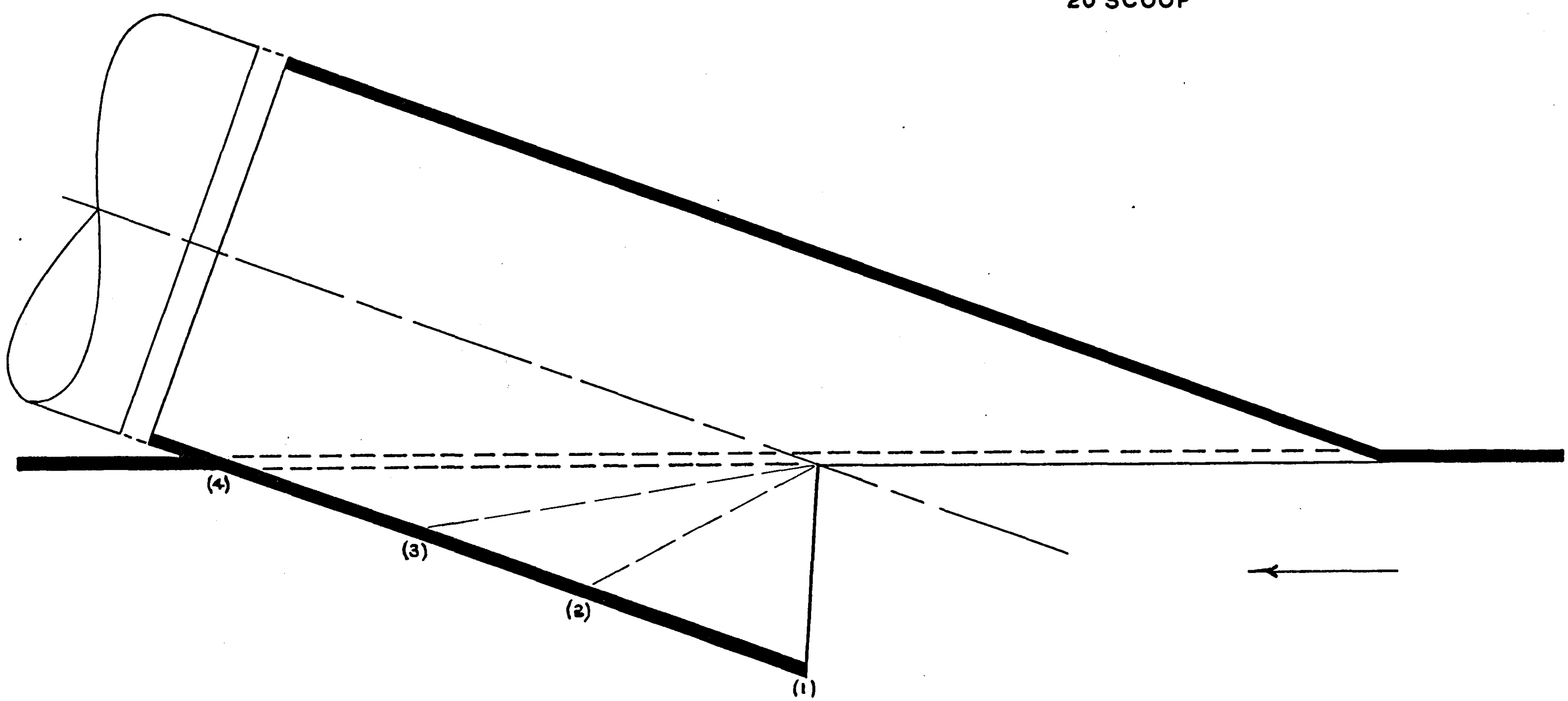


FIG. 4
32°SCOOP

FIG. 5
20°SCOOP



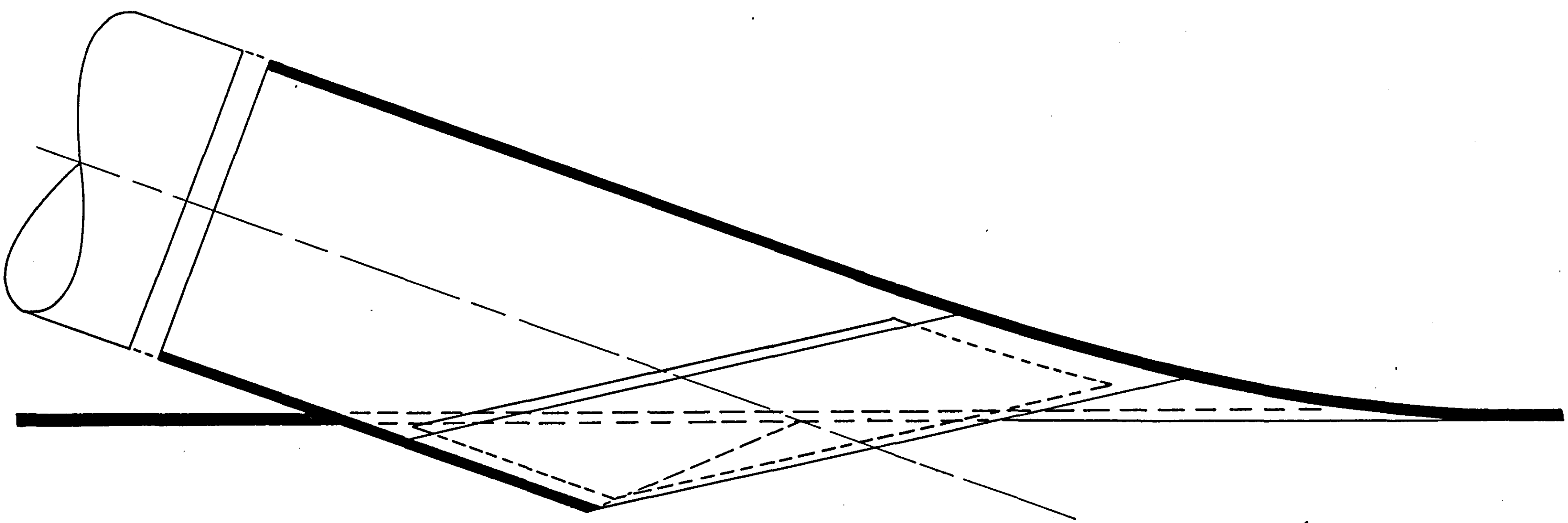
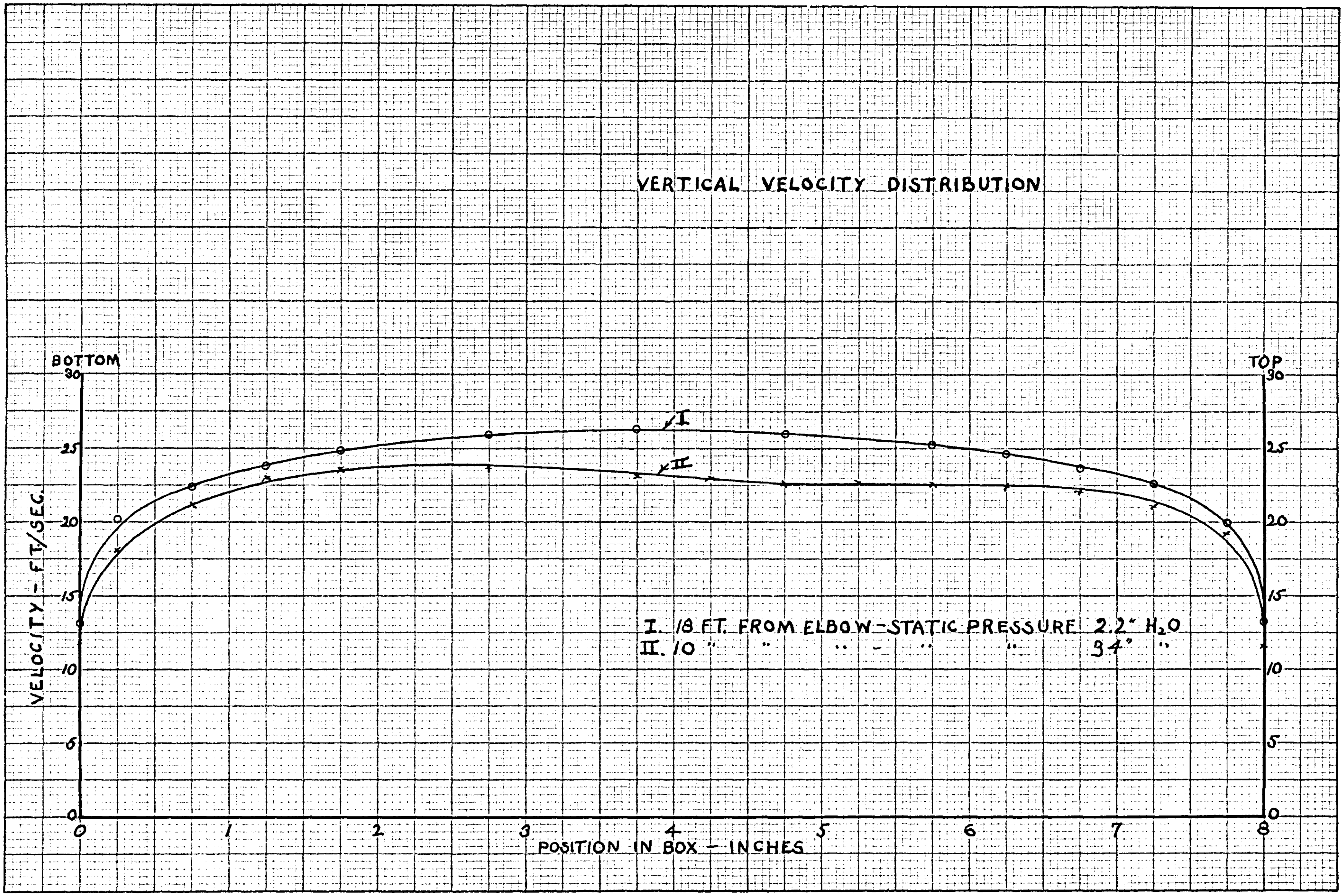
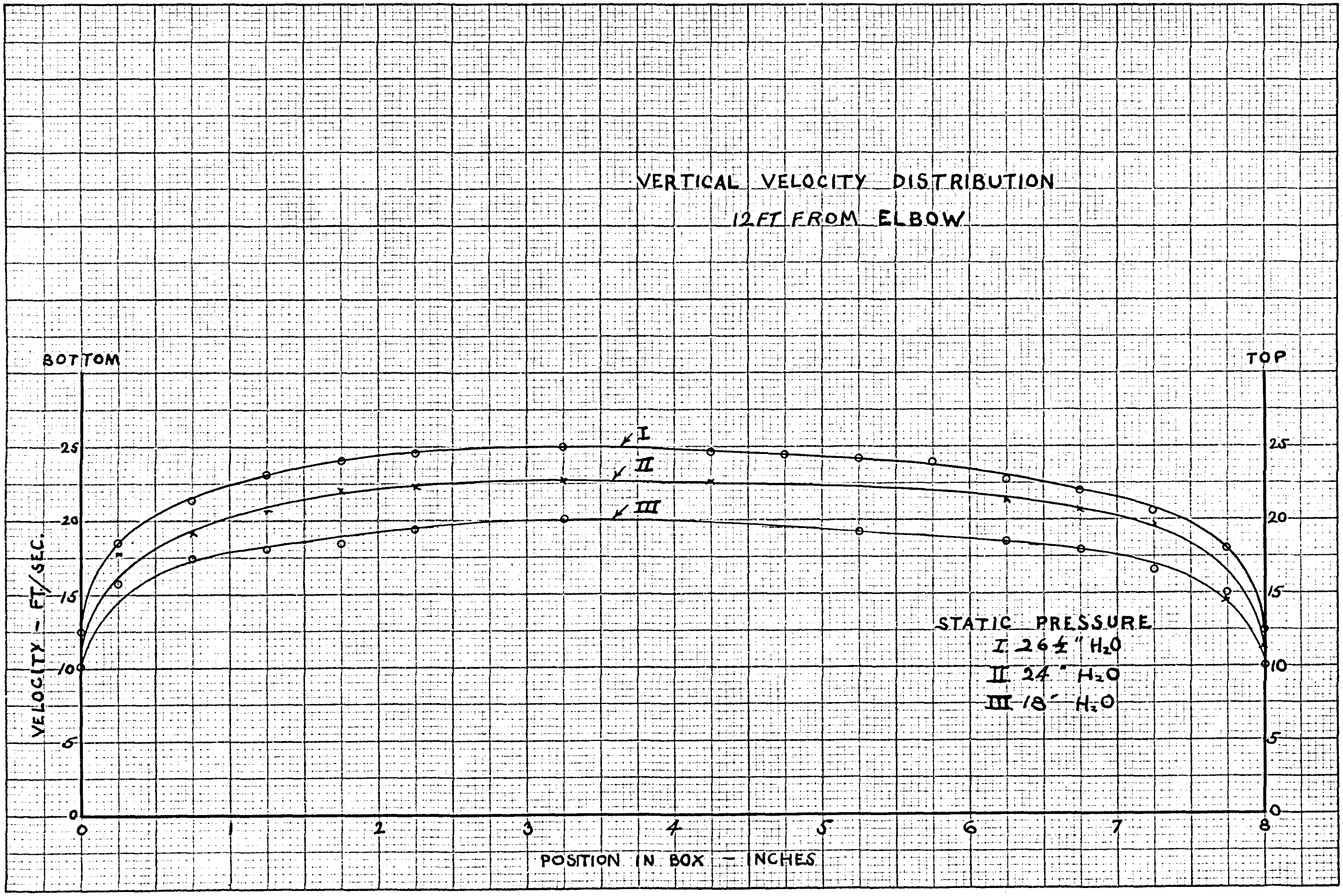


FIG. 6
20° SCOOP
FAIRED



VERTICAL VELOCITY DISTRIBUTION
BOTTOM
TOP
VELOCITY - FT/SEC.
30
25
20
15
10
5
0
I
II
I. 18 FT. FROM ELBOW - STATIC PRESSURE 2.2" H_2O
II. 10 " " " - " " 3.4" "
0
1
2
3
4
5
6
7
8
POSITION IN BOX - INCHES

FIG. 7



VERTICAL VELOCITY DISTRIBUTION
12 FT FROM ELBOW
BOTTOM
TOP
I
II
III
STATIC PRESSURE
I 26½" H₂O
II 24" H₂O
III 18" H₂O
VELOCITY - FT/SEC.
POSITION IN BOX - INCHES

FIG.8

Test Procedure

In testing the scoops the usual procedure was to fill the standpipe so that there was a head of about twenty six feet on the box. The standpipe has a large channel on top which has an area of about 500 square feet. This enabled an easy control of the head since a large variation in flow caused only a small variation in head. The pump was run constantly at about one-third capacity, which was slightly more than the quantity passing through the box. This excess was bypassed into the channel by means of permanent valves located on the standpipe. Variations of flow in the box were obtained by manipulating the gate valve in the piping to the box. An accompanying change was made in the bypass valves to compensate for it. Readings of discharge from the scoops were made at several different degrees of throttling in the discharge line and at three or four velocities in the box. The following runs were made:

45° Scoop
✓32° Scoop
20° Scoop - large lip, indicated by (1), Fig. (5)
✓20° Scoop - medium lip, (2), Fig. (5)
20° Scoop - small lip, (3), Fig. (5)
✓20° Scoop - no lip, (4), Fig. (5)
20° Scoop, with faired entrance
20° Scoop, faired, and with three strainer plates.

Because of the great amount of time required by the above, no work on discharges was attempted. A pitot tube two inches from the bottom of the box which read on a mercury manometer was used to determine the total head in the box. A static tube in the box was read by the simple expedient of holding the attached rubber hose high enough so that flow from it just stopped.

The static head in the scoop was measured at a point six inches from the entrance by means of another mercury manometer. These manometers were arranged to be vented at the beginning of each run. The velocity head in the scoop was later calculated from the discharge readings. The readings were obtained by recording with a stopwatch the time necessary to fill the measuring tank to a certain height.

Several unforeseen events occurred during the course of these experiments. One difficulty experienced was bursting of the rubber tube in the scoop discharge line. After this occurred the first time, a cord binding was used. Due to clogging, the straightening vanes broke loose and proceeded to run through the box, damaging box, pitot tube and scoop. After this happened once due to a large foreign object in the line, it took place again for no apparent reason, this time with less disastrous results but bursting the rubber tube once more. The vanes were replaced and made fast by through rods of three-sixteenths inch material, the rubber hose put back doubled, and a large mesh screen placed over the opening into the standpipe. No further trouble was experienced.

RESULTS OF TESTS - CURVES

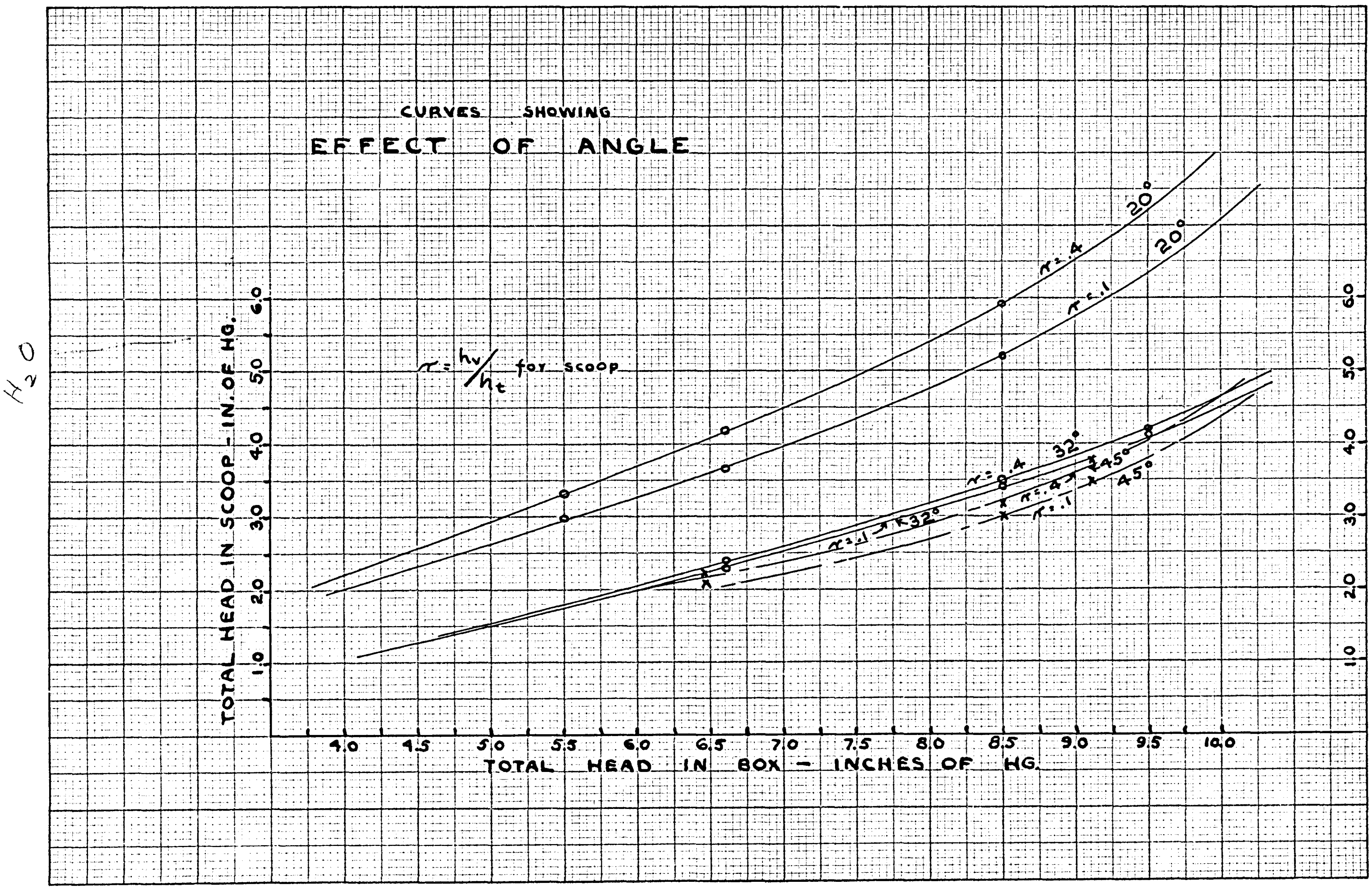

CURVES SHOWING
EFFECT OF ANGLE
r = hv/ht for scoop
r = .4
r = .1
20°
20°
32°
45°
r = .4
r = .1
r = .4
r = .1
32°
45°
TOTAL HEAD IN SCOOP - IN. OF HG.
TOTAL HEAD IN BOX - INCHES OF HG.
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
1.0
2.0
3.0
4.0
5.0
6.0
H2O

FIG. 9

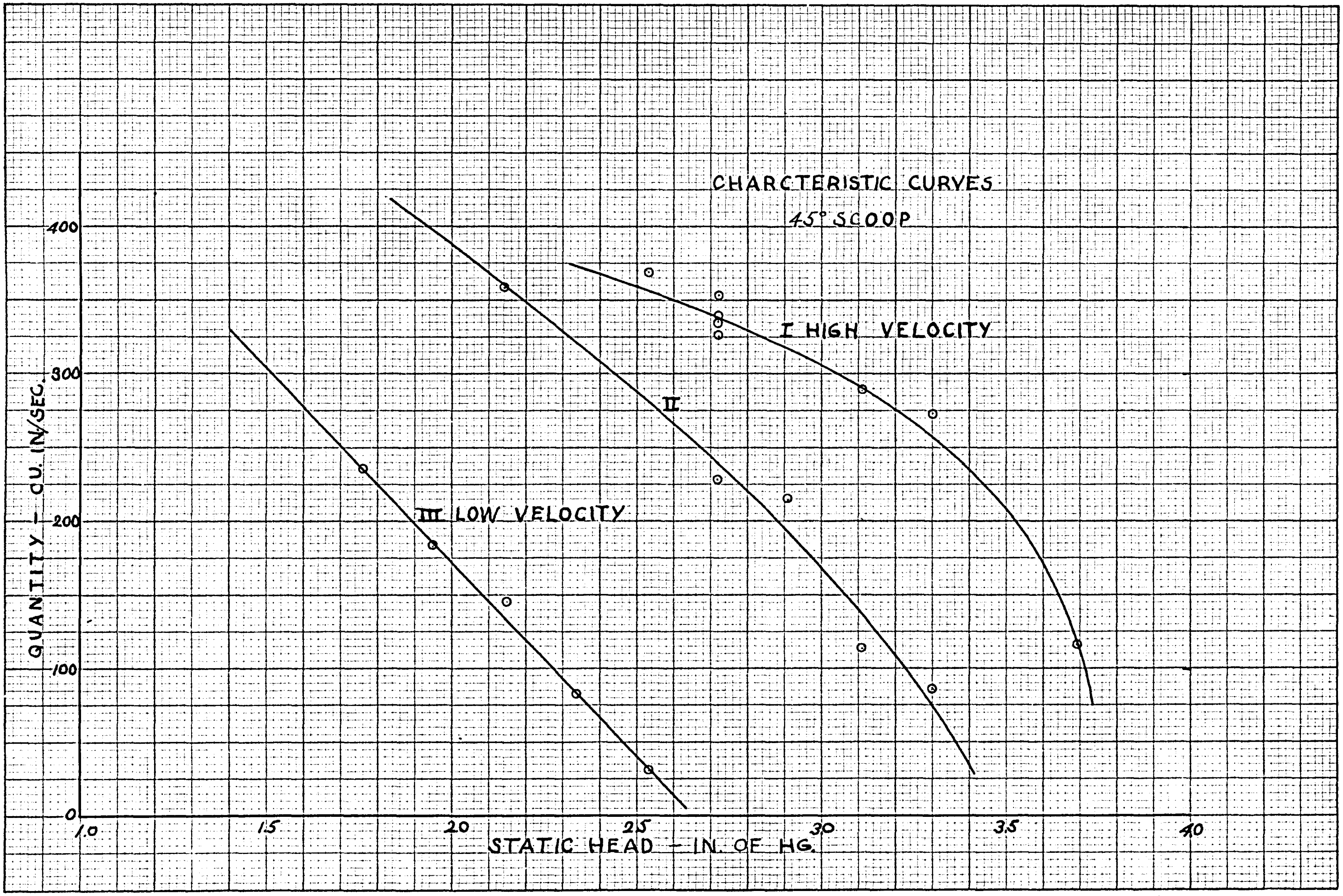

CHARCTERISTIC CURVES
45° SCOOP
I HIGH VELOCITY
II
III LOW VELOCITY
QUANTITY — CU. IN/SEC.
400
300
200
100
0
1.0
1.5
2.0
2.5
3.0
3.5
4.0
STATIC HEAD — IN. OF HG.

FIG. 10

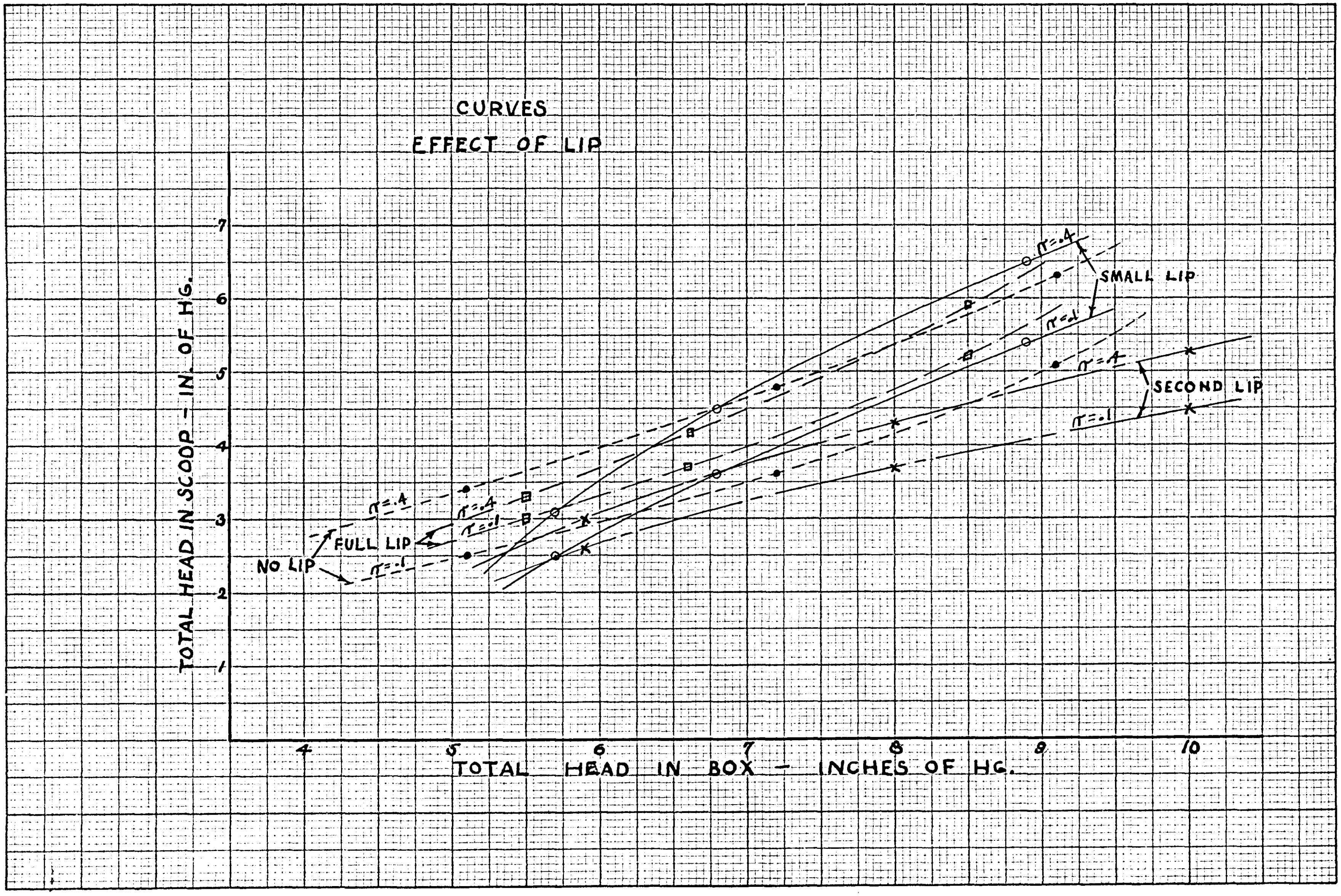
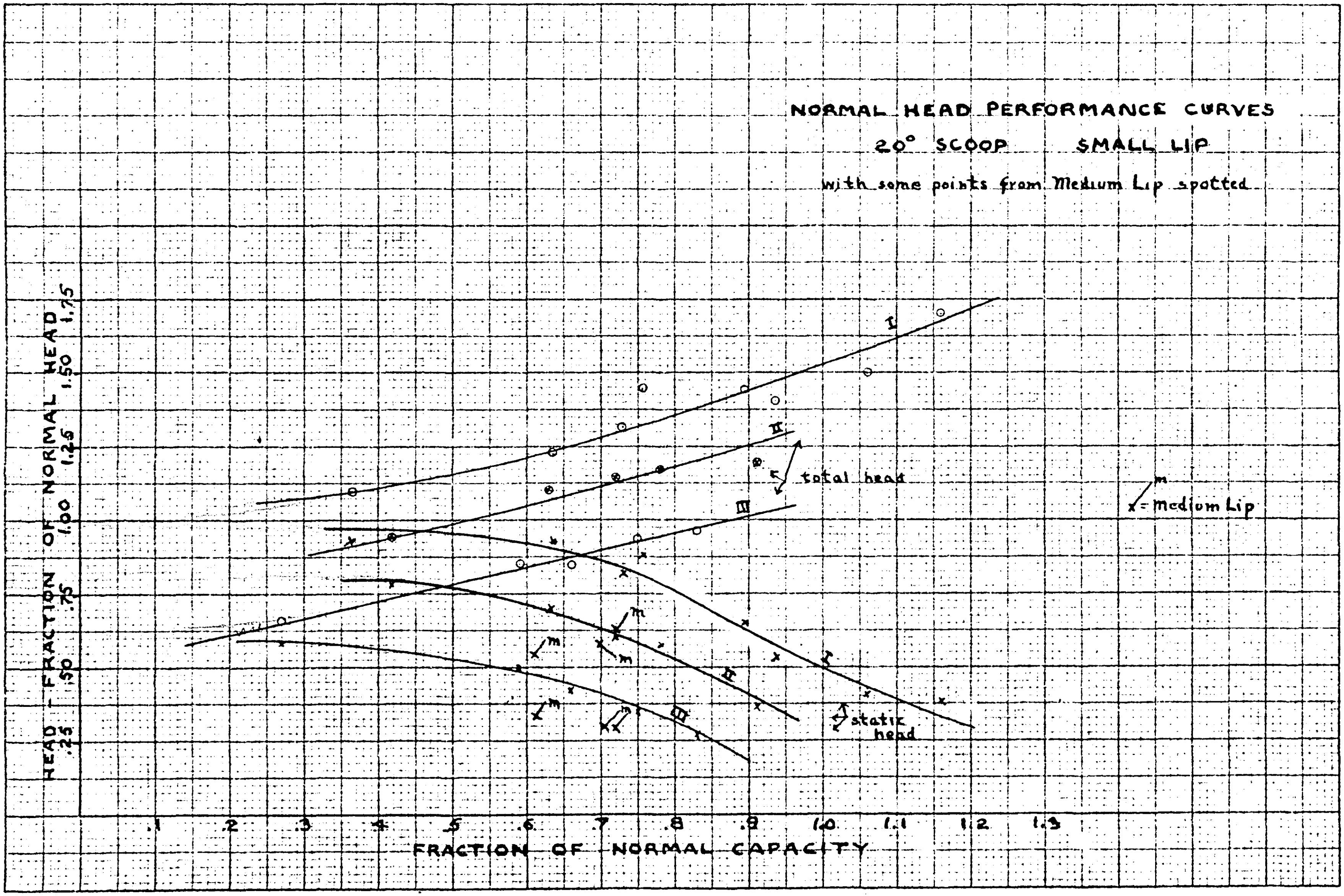

CURVES
EFFECT OF LIP
TOTAL HEAD IN SCOOP – IN. OF HG.
TOTAL HEAD IN BOX – INCHES OF HG.
1
2
3
4
5
6
7
4
5
6
7
8
9
10
SMALL LIP
SECOND LIP
FULL LIP
NO LIP
r=.4
r=.1
r=.4
r=.1
r=.4
r=.1
r=.4
r=.1

FIG. 11



NORMAL HEAD PERFORMANCE CURVES
20° SCOOP SMALL LIP
with some points from Medium Lip spotted
x = Medium Lip
total head
static head
I
II
III
HEAD - FRACTION OF NORMAL HEAD
.25
.50
.75
1.00
1.25
1.50
1.75
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
1.1
1.2
1.3
FRACTION OF NORMAL CAPACITY

FIG. 12

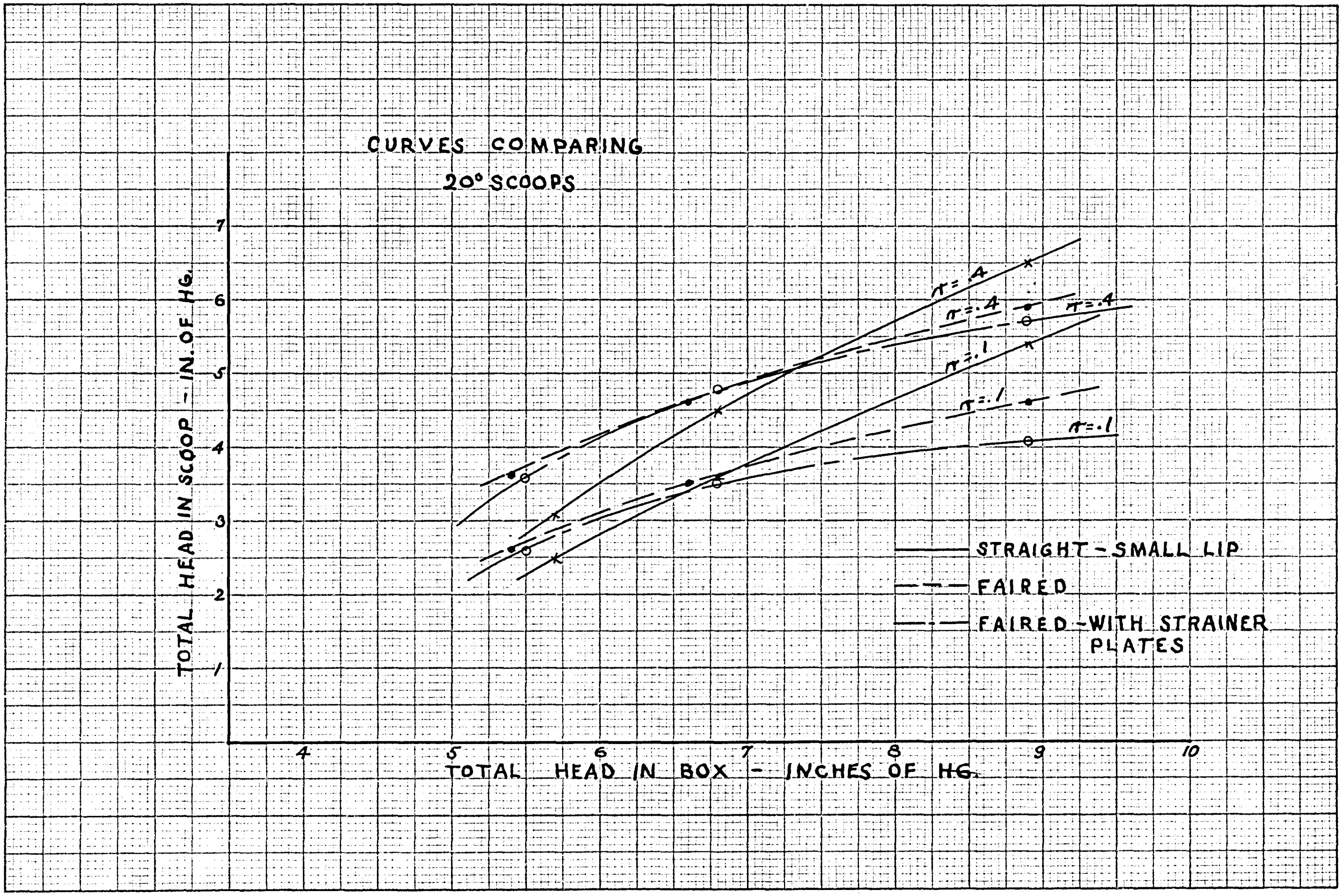

CURVES COMPARING
20° SCOOPS
TOTAL HEAD IN SCOOP - IN. OF HG.
TOTAL HEAD IN BOX - INCHES OF HG.
1
2
3
4
5
6
7
4
5
6
7
8
9
10
r = .4
r = .4
r = .4
r = .1
r = .1
r = .1
STRAIGHT - SMALL LIP
FAIRED
FAIRED - WITH STRAINER PLATES

FIG. 13

Discussion of Results

In analyzing the results it is very necessary to realize that the number and accuracy of the results which are finely plotted in the curves are such as to make it necessary to regard them as general trends rather than detailed values. The accuracy in measuring the quantity of flow per unit time in the scoop was very good, probably within two percent. More difficulty was experienced in measuring the heads. The mercury manometers should have been larger so as to damp out some of the wild fluctuation. Additional vanes in the box might be of help. The usual fluctuation in reading was about one-tenth inch plus or minus for the scoop and two-tenths plus or minus in the box although higher fluctuations were often to be found. This allowed reading to tenths of inches, and since the quantities read varied from about four tenths to four inches in scoop and from two and a half to five in the box, the accuracy would not be too good. However, it was customary to use scoop static pressure as an independent variable when running the tests so that a fair degree of consistancy was maintained. A series of curves of scoop static pressure vs discharge rate has been drawn in figure (10) and designated as "Characteristic Curves". This is essentially a plot of corrected data and it will be noted that a fairly satisfactory line may be put through each set of points.

These curves might prove to be the basis of an interesting study if time permitted.

In obtaining the value of total head in scoop for the curves of scoop head vs box head, Fig. (9) to (13), a curve of "h_t" vs "r" was drawn, thus giving points on the former curve that represent all the experimental points. Obviously since the value of scoop head varies with the ratio, velocity to total heads in scoop ($r=h_v/h_t$), any comparisons must be at corresponding values of this ratio. Therefore, sets of curves for r=.4 and r=.1 have been drawn.

During the test runs several observations were noted that might be mentioned. Venting the top of the manometer columns at the beginning of each run to remove any air bubbles is an absolute necessity. It is well to check at the end by venting again. This rule should be rigidly followed. A question was raised as to whether the static tube in the scoop was too near disturbed flow conditions to record properly. As a check a second tube was used on one scoop about eighteen inches from the scoop entrance. The difference between the two positions read simultaneously was negligible.

It was further noted that if the discharge throttle was just barely cracked open a maximum static pressure occurred with a tendency to fall off if valve was completely closed or opened more. The effect was not positive enough to record.

Mr. Schmidt (A.S.N.E., 1930) used an interesting system of plotting his results as noted in the Appendix under Normal Head. Curves based on this system for the twenty degree scoop are shown in figure (12). At the lower box velocities the magnitudes from these tests are very close to Mr. Schmidt's although no detailed analysis is undertaken since the scoops in these and Mr. Schmidt's tests are not particularly comparable.

The authors did not consider this system a desirable form in which to present the results of their tests for three reasons:

1) At no lip the normal capacity, etc. has no meaning.

2) The writers will not subscribe to a proposition that fractions of normal capacity and head are the only variables. This is borne out by the three distinct curves obtained in figure (12) which shows definitely that box velocity, which corresponds to ship velocity is also a variable factor. This is not considered in the normal head procedure.

3) The time required for the calculations would have been prohibitive.

The writers absolutely do not wish to express condemnation of the normal head method of expression. The system they have adopted is far from perfect. Very likely a normal head based on some function of scoop diameter would prove very satisfactory. Certainly the surface velocity distribution should be taken into consideration in comparing tests from different experimenters. However, it would seem well to leave the lip projection out of such a system of notation as this is only an incidental variable to the whole scoop, and if lips are to be compared, this seems most important. In the original applications there were no variations of lip.

A further comparison of these results shows that as box velocity approaches a speed determined by laws of mechanical similitude the fraction of normal head increases greatly. This may indicate that the point of greatest efficiency has not been reached, althouth certain designers feel that the scoop may in service be running above the point for maximum efficiency. However, it is definitely felt by most engineers that there will be an optimum velocity of approach to the scoop.

The best means of comparing the scoops tested is by a close inspection of the curves. A few points are deemed worthy of mention here however. The effect of angle is clearly shown in that the 20° scoop is far superior. This is only to be expected from a consideration of the hydraulic flow into the scoop. Cavitation is indicated by the rapid drop in head between 20° and 32° with a slow drop between 32° and 45°.

In general a small lip seems to be preferable, but not in all instances. The scoop with no lip proved rather remarkably good. The full lip did not perform as well as expected. This may be explained by the fact that at certain speeds the lip caused a back flow in the scoop, much in the manner suggested by Mr. Schmidt in his first paper. It must be emphasized that these tests were not accurate enough to make very fine differentiation in scoop performance, but it is evident that lip is not an extremely important variable.

The results for the faired scoop do not show a startingly good performance at any time. The authors are inclined to rather discount this test since the scoop was made up by hammering the brass tubing. Consequently the surface was rough even after liberal use of a file. Also the fitting of the scoop into the base plate was difficult and resulted in a somewhat irregular scoop. These effects, it is felt, must cut down the efficiency of the scoop, but there is no way of estimating this with a worth while degree of certainty; there could be nothing more than a good guess.

With the strainer plates added a decrease in head amounting upwards to ten percent is to be noted. The maximum loss is at high heads and at lower heads the loss is less. This is to be expected since the lost head probably varies with about the square of the velocity.

Smoothness of running is an important factor in scoops from the standpoint of vibration, errosion, structural strain on condensing apparatus, general efficiency (influenced by cavitation) and other factors. The faired scoops were noticeably smoother running than the others.

In regard to design, the authors would suggest that the easiest solution would be to arbitrarily select a form and size of scoop and calculate the head and discharge to be expected, based on mechanical similitude and the ship's speed. They believe this should yield a satisfactory solution and several determinations would show the proper size scoop. It is to be expected that Froude's law will hold as shown by Professor Uchimaru and Mr. Kito in their paper.

CONCLUSIONS

In order to carry out work that would lead to a successful fulfilment of the original object it was necessary to construct the apparatus as previously described. This proved very satisfactory for the purpose, although suggestions have been made as to improvements in the equipment which should make it still more so.

The main object of the thesis has been nicely met in regard to the following points:

1) Comparison of scoops with various angles
2) Comparison of the same scoop with different lip projections
3) Finding results for effect of strainer plates
4) Data obtained suitable for design of some unfaired scoops.

In addition the effect of faired entrance was investigated although the results were not as satisfactory, as previously explained. The method of forming the faired scoop, that is by hammering it in the annealed condition around a wooden form, is thought to be perfectly all right with a little more time and experience.

Since, to the authors' knowledge, no experiments covering the range of conditions embodied in the results have been carried out before, they may well form the basis upon which futher experiments and investigations may build a detailed knowledge of the actions of condenser scoops. The authors would like to suggest the following fields for future study:

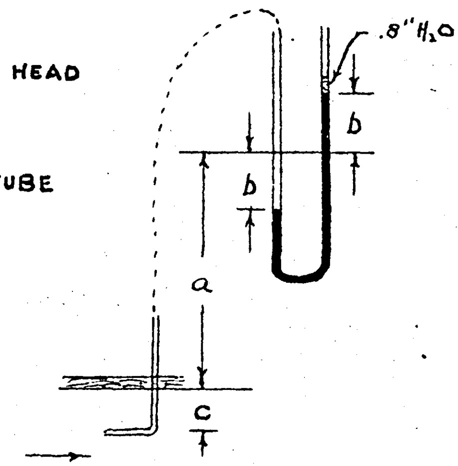
1) Continuation of the present work, obtaining data enough for cross curves, checking more faired scoops, strainer plates, splinters, etc.
2) Test discharges.
3) Investigate form for efficient condenser waterboxes.
4) Visual investigation of flow in vicinity of scoop.
5) Development of a more satisfactory method of reporting results.
6) Measurement of thrust reaction of scoops.
7) Cavitation study by means of a low-pressure box.

In general, these last two may be said to require rather elaborate set-ups and much painstaking labor. The present investigators suffered from a serious lack of time, but it is only through at least a partial disregard for such limitations that worthwhile work may be consummated in the particular field of condenser scoops and the general field of fluid mechanics or the universal field of engineering.

APPENDIX

SAMPLE COMPUTATIONS

VELOCITY DISTRIBUTION CALCULATIONS



CORRECTIONS AND ADDITIONS TO TOTAL HEAD READING TO OBTAIN VELOCITY HEAD

1. FOR DIFFERENCE IN LEVELS OF PITOT TUBE AND MANOMETER

$$+a - b + c$$

2. FOR WATER ON OPEN MANOMETER COLUMN

$$+.8''$$

3. FOR STATIC HEAD, h_s

$$-(h_s + c)$$

TOTAL ADDITION

$$a - b + c + .8 - h_s - c \quad \text{INCHES OF } H_2O$$

SAMPLE CALCULATION

FOR RUN I. 18' FROM ELBOW

$$\text{CORRECTION} = (6.2 - b + .8 - 2.2)\left(\frac{1}{13.6}\right)$$

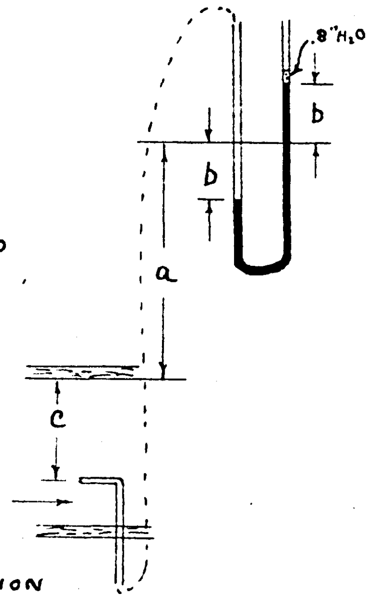
$$= \frac{4.8 - b}{13.6} \quad \text{INCHES OF HG}$$

$$\text{VELOCITY} = \sqrt{2GH} \quad \text{FT/SEC}$$

$$= 8.54\sqrt{H} \quad \text{H IN INCHES HG}$$

H	CORR	h_v	V
5.3	.2	5.5	20.1

VELOCITY DISTRIBUTION - Cont.



CORRECTIONS AND ADDITIONS TO TOTAL HEAD READING TO OBTAIN VELOCITY HEAD. PITOT TUBE INSERTED FROM BOTTOM. AS BEFORE

ADD $a - b + c + .8 - h_s - c$ IN OF H_2O

$a = 13.2"$

TOTAL HEAD CORRECTION

AT STANDARD PITOT POSITION : $c = 6"$

ADD $a - b + 6 + .8$

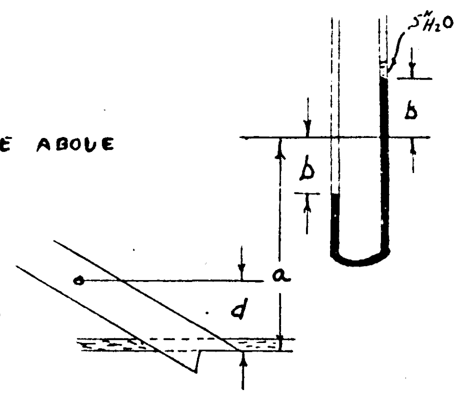
ADJUSTING FOR SCOOP POSITION

$a - b + 6 + .8 - 6$

$\simeq (14 - b)\frac{1}{13.6}$ " OF Hg.

(THIS ADJUSTS FOR STATIC HEAD TO ENTRANCE OF SCOOP)

SCOOP STATIC CORRECTIONS



ADD $a + .5 - b - d$ " H_2O

$a = 11\frac{1}{4}$ (CONSTANT)

d = Hgt. OF STATIC TUBE ABOVE TOP (I.S.) OF BOX

EXAMPLE:

FOR 45° SCOOP AT $H_s = 2.0$

$d = 3\frac{1}{2}"$

$\therefore$ Add $11\frac{1}{4} + .5 - 1.0 - 3\frac{1}{2} = 7\frac{1}{4}$ " H_2O

$\simeq .53"$ Hg.

SCOOP DISCHARGE + HEAD

EXAMPLE - 45° SCOOP, 1st READINGS.

AREA TANK = $\pi \frac{d^2}{4}$; d = 2' ∴ A = 452 □"

VOLUME = $\Delta h \times A$ = 31 × 452 = 14,020 "³

QUANTITY = $\frac{V}{t}$ = $\frac{14,020}{38}$ = 369 "³/sec

VELOCITY IN SCOOP = $\frac{Q}{A_{sc}}$: $A_{sc} = \frac{\pi d^2}{4} = \frac{\pi}{4}(2.16)^2 = 3.66$ □"

∴ vel. = $\frac{369}{3.66}$ = 101 INCHES/SEC.

VELOCITY HEAD IN SCOOP: $h_v = \frac{vel^2}{2g}$

$h_v = \frac{vel^2}{2 \times 386 \times 13.6}$ INCHES OF Hg.

$h_v = \frac{101^2}{2 \times 386 \times 13.6}$ = .971 "Hg.

STATIC HEAD - CORRECTED PER PREVIOUS EXAMPLES.

TOTAL HEAD = $h_s + h_v$ = 2.53 + .971 = 3.5 " Hg. = h_t

RATIO "r" = h_v/h_t = $\frac{.971}{3.5}$ = .28

NORMAL HEAD CALCULATIONS

NORMAL CAPACITY CALCULATIONS

1) TAKE PROJECTED (VERTICAL) VIEW OF LIP, DIVIDE INTO ELEMENTS, FIND AREA OF EACH ELEMENT. FIND VELOCITY AT CENTER OF ELEMENT FROM VELOCITY DISTRIBUTION CURVES. QUANTITY PASSING EACH ELEMENT = AREA x VEL. TOTAL FLOW = Σ ELEMENT FLOWS.

EXAMPLES BELOW:

I. 20° SCOOP - SMALL LIP (3/8")

ELEMENT	AREA	1. FAST BOX VEL. VEL	1. FAST BOX VEL. CAP	2. MED. VEL. VEL.	2. MED. VEL. CAP.	3. SLOW VEL. VEL	3. SLOW VEL. CAP
①	.157	206	32.4	194	30.5	180	28.3
②	.150	199	29.9	187	28.0	174	26.1
③	.142	188	26.6	178	25.2	165	23.4
④	.120	174	20.9	162	19.5	151	18.1
⑤	.053	152	8.1	144	7.6	138	7.4
	□"	"/sec.	cu. in/sec.				

$\Sigma A = .622$ $\quad \Sigma q_1 = 117.9$ ''³/sec. $\quad \Sigma q_2 = 110.8$ $\quad \Sigma q_3 = 103.3$

CHECK: $\Sigma A = \frac{1}{2}$ ELIPSE

$$\therefore \Sigma A = \tfrac{1}{2} \times .7854 \times d_{scoop} \times 2(\text{LIP})$$

$$= \tfrac{1}{2} \times .7854 \times 2.13 \times 2 \times \tfrac{3}{8} = .625 \text{ □"}$$

2) NORMAL VELOCITY = AVERAGE ACROSS LIP

$$= \frac{\Sigma q}{\Sigma A_{LIP}}$$

Ex: FAST RUN = $\frac{117.9}{.625}$ = 189 "/sec = v_m

MED. " = $\frac{110.8}{.625}$ = 177 "/sec

SLOW " = $\frac{103.3}{.625}$ = 165 "/sec

3) NORMAL HEAD = HEAD ≙ NORMAL VEL

$$h = \frac{v^2}{2g}$$

Ex: FAST 3.40 " Hg = h_m

MED 2.99

SLOW 2.59

4) NORMAL CAPACITY = TOTAL SCOOP AREA x v_m

Ex: FAST = 3.66 x 189 = 690 cu. in/sec = Q_m

MED. = 3.66 x 177 = 650

SLOW = 3.66 x 165 = 605

5) EXPRESS HEADS AND CAPACITIES AS FRACTIONS OF THE NORMAL VALUES.

TABULATED DATA AND RESULTS

Vertical Velocity Distribution

Tabulated Data and Results

I 18" from elbow static press. 2.2" water

P	H	Corr.	h_v	V
Position from bottom inches	Uncorrected total head "Hg	Corrected + Static "Hg	Velocity Head "Hg	Velocity Ft/Sec.
.25	5.3	.2	5.5	20.1
.75	6.7	.1	6.8	22.3
1.25	7.7	.1	7.8	23.9
1.75	8.4	0	8.4	24.8
2.75	9.3	0	9.3	26.0
3.75	9.5	0	9.5	26.3
4.75	9.3	0	9.3	26.0
5.75	8.8	0	8.8	25.4
6.25	8.3	0	8.3	24.6
6.75	7.6	.1	7.7	23.7
7.25	6.8	.1	6.9	22.5
7.75	5.3	.2	5.5	20.1

II 10' from elbow - static press. 34" water

P	H	Corr	h_v	V
.25	8.9	4.4	4.5	18.1
.75	10.6	4.4	6.2	21.2
1.25	11.8	4.5	7.3	23.0
1.75	12.1	4.5	7.6	23.6
2.75	12.2	4.5	7.7	23.7
3.75	11.9	4.5	7.4	23.2
4.25	11.7	4.4	7.3	23.0
4.75	11.4	4.4	7.0	22.6
5.25	11.4	4.4	7.0	22.6
5.75	11.4	4.4	7.0	22.6
6.25	12.2	4.4	6.8	22.3
6.75	11.1	4.4	6.7	22.1
7.25	10.5	4.4	6.1	21.1
7.75	9.5	4.4	5.1	19.3

Vertical Velocity Distribution (continued)

I

P	H	Corr	h_v	V
.25	5.8	1.1	4.7	18.5
.75	7.4	1.2	6.2	21.3
1.25	8.4	1.2	7.4	23.2
1.75	9.2	1.2	8.0	24.2
2.25	9.6	1.3	8.3	24.6
3.25	9.8	1.3	8.5	25.0
4.25	9.6	1.3	8.3	24.6
4.75	9.4	1.2	8.2	24.5
5.25	9.2	1.2	8.0	24.2
5.75	9.0	1.2	7.8	23.9
6.25	8.2	1.2	7.0	22.6
6.75	7.8	1.2	6.6	22.0
7.25	7.0	1.2	5.8	20.6
7.75	5.6	1.1	4.5	18.1

II 12' from elbow - static press. 24" water

P	H	Corr	h_v	V
.25	5.2	.9	4.3	17.8
.75	6.0	.9	5.1	19.3
1.25	6.8	1.0	5.8	20.6
1.75	7.6	1.0	6.6	22.0
2.25	7.8	1.0	6.8	22.3
3.25	8.0	1.0	7.0	22.6
4.25	8.0	1.0	7.0	22.6
6.25	7.2	1.0	6.2	21.3
6.75	6.8	1.0	5.8	20.6
7.25	6.2	.9	5.3	19.6
7.35	3.8	.9	2.9	14.5

III 12' from elbow - static press. 18" water

P	H	Corr	h_v	V
.25	3.8	.4	3.4	15.8
.75	4.6	.4	4.2	17.5
1.25	5.0	.5	4.5	18.1
1.75	5.2	.5	4.7	18.5
2.25	5.6	.5	5.1	19.3
3.25	6.0	.5	5.5	20.1
5.25	5.6	.5	5.1	19.3
6.25	5.2	.5	4.7	18.5
6.75	4.8	.5	4.3	17.8
7.25	4.2	.4	3.8	16.7
7.75	3.4	.3	3.1	15.0

Tabulated Data and Results
45° Scoop

	h	V	t	h_v	H_s	h_s	h_t	r
	Incr. of ht. of water in tank "	Volume cubic inches	Time sec.	Vel. head " of Hg.	Scoop static head read. " of Hg.	Corr. static head " of Hg.	Scoop total head " of Hg.	h_v/h_t
1	31	14,020	38	.971	2.0	2.53	3.5	.28
2	30	13,570	40	.816	2.2	2.72	3.5	.23
3	30	13,570	38	.885	2.2	2.72	3.6	.24
4	32	14,470	43	.800	2.2	2.72	3.5	.23
5	28	12,660	39	.754	2.2	2.72	3.5	.22
6	28	12,660	44	.588	2.6	3.11	3.7	.16
7	26	11,750	43	.529	2.8	3.30	3.8	.14
8	26	11,750	101	.096	3.2	3.69	3.8	.026

Total head in box: 8.4" uncorrected; 9.1" Hg. Corrected
Static head 26.5" of H_2O
At $r = .4, h_t = 3.5$; at $r = .1, h_t = 3.8$

1	23	10,400	29	.915	1.6	2.14	3.1	.30
2	27	12,200	53	.369	2.2	2.72	3.1	.12
3	28	12,660	59	.328	2.4	2.91	3.2	.10
4	25	11,300	100	.091	2.6	3.11	3.2	.028
5	28	12,660	147	.053	2.8	3.30	3.4	.015

Total head in box: 7.8" Hg. total unc; 8.5" corrected
Static: 24" water
At $r = .4$, $h_t = 3.0$; at $r = .1, h_t = 3.2$

1	24	10,850	46	.396	1.2	1.76	2.2	.18
2	23	10,400	57	.238	1.4	1.95	2.2	.11
3	26	11,750	80	.153	1.6	2.15	2.3	.065
4	21	9,500	118	.046	1.8	2.34	2.4	.020
5	10	4,520	173	.005	1.8	2.53	2.5	.0

Total pressure in box: 5.6" Hg. unc., 6.4" Corrected
Static = 18" water
At $r = .4, h_t = 2.1$ At $4 = .1, h_t = 2.2$

1	12	5,420	50	.084	.4	.99	1.07	.075
2	12	5,420	60	.058	.4	.99	1.05	.057

Total head in box = 2.3" uncorrected. Static = 7" water

Tabulated Data and Results
32° Scoop

	h	V	t	h_v	H_{sc}	h_s	h_t	$h_v/h_t=r$
1	31	14,020	32	1.4.	2.2	2.76	4.2	.34
2	30	13,570	36	1.02	2.6	3.15	4.2	.24
3	30	13,570	47	.593	2.8	3.34	3.9	.15
4	30	13,570	48	.568	3.0	3.53	4.1	.14
5	30	13,570	62	.341	3.2	3.73	4.1	.083
6	29	13,100	79	.195	3.4	3.92	4.1	.048

Static head in scoop at no discharge 3.6" uncorrected
Total head in box: 8.8" uncorrected, 9.5 corrected.
Static head : 25" of water
At r=4, h_t = 4.2. At r = .1, h_t = 4.1

1	30	13,570	35	1.09	1.8	2.38	3.5	.31
2	30	13,570	39	.859	2.0	2.57	3.4	.25
3	29	13,100	40	.763	2.2	2.76	3.5	.22
4	30	13,570	56	.416	2.4	2.96	3.4	.12
5	21	9,490	72	.124	2.6	3.15	3.3	.038

Static head in scoop at no discharge 2.8" uncorrected
Total head in box: 7.8" uncorrected, 8.5" corrected.
Static head: 23" of water
At r = .4, h_t = 3.5. At r = .1, h_t = 3.4

1	30	13,570	42	.740	1.0	1.61	2.4	.31
2	30	13,570	50	.522	1.2	1.80	2.3	.23
3	29	13,100	59	.350	1.4	1.99	2.3	.15
4	31	14,020	93	.162	1.6	2.18	2.3	.070

Static head in scoop at no discharge 1.8" uncorrected
Total head in box: 5.8" uncorrected, 6.6" corrected.
Static head: 17" of water
At r = .4, h_t = 2.4. At r = .1, h_t = 2.3

1	18	8,140	33	.399	.4	1.03	1.4	.28
2	15	6,780	34	.276	.6	1.22	1.5	.18

Static head in scoop at no discharge .8" uncorrected
Total head in box 1.8" uncorrected. Static, 10" water

Tabulated Data and Results
20° Scoop - Full Lip

	h	V	t	h_v	H_{sc}	h_s	h_t	r
1	30	13,570	21.5	2.85	2.6	3.26	6.1	.45
2	30	13,570	21.5	2.85	2.6	3.26	6.1	.45
3	31	14,020	24	2.43	2.8	3.45	5.9	.41
4	30	13,570	26.5	1.87	3.2	3.84	5.7	.33
5	31	14,020	29	1.66	3.4	4.03	5.7	.29
6	31	14,020	32.5	1.32	3.6	4.22	5.5	.24

Head in box: total uncorrected 7.8", corrected 8.5"
Static 22" and 24" water
Scoop static at no disch. 3.8" Hg.uncor,4.3"corr.
At r =.4, h_t = 5.9". At r = .1, h_t = 5.2"

	h	V	t	h_v	H_{sc}	h_s	h_t	r
1	30	13,570	25.5	2.00	1.6	2.30	4.3	.47
2	30	13,570	27	1.79	1.8	2.49	4.3	.42
3	30	13,570	29	1.56	2.0	2.68	4.2	.37
4	30	13,570	34.5	1.09	2.2	2.87	4.0	.27
5	30	13,570	41.5	.76	2.2	3.06	3.8	.20
6	30	13,570	38	.904	2.4	3.06	3.9	.23

Head in box : total uncorr. 5.8", total corr. 6.6"
Static 15" and 18" ofwater
Scoop static at no discharge 2.6" uncorr.
At r = .4, h_t = 4.2. At r = .1, h_t = 3.7"

	h	V	t	h_v	H_{sc}	h_s	h_t	r
1	30	13,570	31	1.37	1.2	1.91	3.3	.42
2	30	13,570	28	1.69	1.2	1.91	3.6	.47
3	30	13,570	33	1.19	1.4	2.10	3.3	.36
4	30	13,570	56	.630	1.8	2.49	3.1	.20

Head in box: total uncorr. 4.6", total corr. 5.5"
Static 15" and 18" water
Scoop static at no discharge 2.6 uncorr.
At r = .4, h_t = 3.3. At r = .1, h_t = 3.0"

	h	V	t	h_v	H_{sc}	h_s	h_t	r
1	30	13,570	32	1.28	1.0	1.71	3.0	.43

Head in box: total uncorrected 3.8",Static 10"
Scoop static at no discharge 1.2" uncorr.

Tabulated Data and Results
20° Scoop - Medium Lip

	h	V	t	h_v	H_{sc}	h_s	h_t	r
1	30	13,570	25	2.08	2.6	3.26	5.3	.39
2	30	13,570	28	1.66	2.8	3.45	5.1	.32
3	30	13,570	32	1.28	3.0	3.64	4.9	.26
4	30	13,570	38	.903	3.2	3.84	4.7	.19
5	30	13,570	53	.465	3.4	4.03	4.5	.10

Total head in box: uncorrected 9.4, corrected 10.0"
Static 22" water scoop discharging, 27" without
Scoop static uncorrected 3.6 at no discharge
At r = .4, h_t = 5.3" at r = .1, h_t = 4.5"

1	30	13,570	31	1.37	2.2	2.87	4.2	.33
2	30	13,570	31	1.37	2.2	2.87	4.2	.33
3	30	13,570	47	.593	2.6	3.26	3.9	.15
4	30	13,570	73	.245	2.8	3.45	3.7	.066
5	30	13,570	80	.205	2.8	3.45	3.6	.057

Head in box: uncorrected total 7.2", corrected 8.0"
Static 19" and 24" as above
Scoop static uncorrected 3.0 at no discharge
At r = .4, h_t = 4.3". At r = .1, h_t = 3.7"

1	30	13,570	37	.952	1.2	1.91	2.9	.33
2	30	13,570	36	1.10	1.2	1.91	3.0	.37
3	30	13,570	42	.740	1.4	2.10	2.8	.26
4	30	13,570	42	.740	1.4	2.10	2.8	.26

Head in box: uncorrected total 5.0" corrected 5.9"
Static 12" and 16"
Scoop static at no discharge 1.6"
At r = .4, h_t = 3.0". At r = .1, h_t - 2.6"

Tabulated Data and Results
20° Scoop - Small lip

	h	V	t	h_v	H_{sc}	h_s	h_t	r
1	30	13,570	17	4.53	2.2	2.87	7.40	.61
2	30	13,570	19	3.62	2.4	3.06	6.7	.54
3	30	13,570	21	2.95	2.8	3.45	6.4	.46
4	30	13,570	22	2.69	3.2	3.84	6.5	.41
5	30	13,570	28	1.66	3.8	4.41	6.1	.27
6	30	13,570	26	1.92	4.0	4.61	6.5	.29
7	30	13,570	31	1.37	4.2	4.80	6.2	.22
8	30	13,570	54	.448	4.2	4.80	5.3	.085

Head in box: total, 8.2" uncorrected, 8.9" corrected.
Velocity hd. at 2" = 6.9"Hg
Velocity = 22.4 ft/sec.
Static, 22 and 29" water
Scoop static head at no disch. = 4.2
At r= .4, h_t = 6.5". At r = .1, h_t = 5.4"

	h	V	t	h_v	H_{sc}	h_s	h_t	r
1	30	13,570	23	2.47	1.4	2.10	4.6	.54
2	30	13,570	27	1.79	2.0	2.68	4.5	.40
3	30	13,570	29	1.56	2.2	2.87	4.4	.35
4	30	13,570	33	1.19	2.4	3.06	4.3	.28
5	30	13,570	50	.526	2.6	3.26	3.8	.14

Head in box: total uncorrected 6.0, corrected 6.8
Velocity hd 5.4, Vel.= 19.9 ft/sec
Static, 13" and 20" water
Scoop static head at no disch. 2.6" uncorr.
At r = .4, h_t = 4.5". At r = .1, h_t = 3.6"

	h	V	t	h_v	H_{sc}	h_s	h_t	r
1	30	13,570	27	1.79	.8	1.52	3.3	.54
2	30	13,570	30	1.44	1.0	1.72	3.2	.45
3	30	13,570	34	1.13	1.2	1.91	3.0	.38
4	30	13,570	38	.904	1.4	2.10	3.0	.30
5	18	8,140	50	.189	1.6	2.29	2.5	.076

Head in box: total 4.8 uncorrected, 5.7" corrected, Vel. hd. 4.5"
Velocity 18.1 ft/sec. Static 11" and 16" water
Scoop static at no discharge 1.6 uncorrected
At r = .4, h_t = 3.1". At r = .1, h_t = 2.5"

Normal Head Performance Curves

Tabulated Calculations
Small lip (3/8"), 20° Scoop

I At Box total head = 8.9"; Static head = 22" water equivalent to 1.6" of Hg.

In the tables below h_s and h_t have been adjusted to compensate for static head in the box

h_s	h_t	Q/Q_n	h_s/h_n	h_t/h_n
1.3	5.8	1.16	.38	1.71
1.4	5.1	1.04	.41	1.50
1.8	4.8	.936	.53	1.41
2.2	4.9	.894	.65	1.44
2.8	4.5	.703	.82	1.32
3.0	4.9	.757	.88	1.44
3.2	4.6	.635	.94	1.35
3.2	3.7	.364	.94	1.09

II At Box total head = 6.8"Hg. Static head = 1.0"Hg

1.1	3.6	.91	.37	1.20
1.7	3.5	.78	.57	1.17
1.8	3.4	.72	.60	1.14
2.1	3.3	.63	.70	1.10
2.3	2.8	.42	.77	.94

III At Box total head = 6.8"Hg. Static head = .8" Hg.

.7	2.5	.83	.27	.96
.9	2.4	.75	.35	.93
1.1	2.2	.66	.42	.85
1.3	2.2	.59	.50	.85
1.5	1.7	.27	.58	.65

Tabulated Data and Results
20° Scoop - No Lip

	h	V	t	h_v	H_{sc}	h_s	h_t	r
1	30	13,570	21	2.95	2.6	3.26	6.2	.48
2	30	13,570	23	2.47	3.2	3.84	6.3	.39
3	30	13,570	26	1.95	3.6	4.22	6.2	.32
4	30	13,570	33	1.19	3.8	4.41	5.6	.21
5	30	13,570	74	.238	3.8	4.41	4.7	.051

Total head in box: uncorrected 8.4, corrected 9.1"
Static 23" water scoop discharging, 29" without
Scoop static uncorrected 3.8 at no disch.
At r = .4, h_t = 6.3. At r = .1, h_t = 5.1

1	30	13,570	24	2.26	1.8	2.49	5.7	.40
2	30	13,570	27	1.79	2.2	2.87	4.7	.38
3	30	13,570	33	1.19	2.4	3.06	4.3	.28
4	30	13,570	55	.432	2.6	3.26	3.7	.12

Head in box: uncorrected total 6.4", corrected 7.2"
Static 17" and 23" as above.
Scoop static uncorrected 2.6 at no disch.
At r = .4, h_t = 4.8". At r = .1, h_t = 3.6"

1	30	13,570	29	1.56	1.2	1.91	3.5	.44
2	30	13,570	30	1.44	1.2	1.91	3.4	.42
3	30	13,570	35	1.07	1.4	2.10	3.2	.33
4	30	13,570	35	1.07	1.4	2.10	3.2	.33
5	30	13,570	54	.447	1.6	2.29	2.7	.17

Head in box: uncorrected total 4.4", corrected 5.1"
Static 12" and 16"
Scoop static at no discharge 1.6"
At r = .4, h_t = 3.4". At 4 = .1, h_t = 2.5"

Tabulated Data and Results
20° Scoop - Faired Entrance

	h	V	t	h_v	H_{sc}	h_s	h_t	r
1	30	13,570	24	2.26	3.0	3.64	5.9	.38
2	30	13,570	25	2.09	3.2	3.84	5.9	.35
3	30	13,570	36	1.01	3.4	4.03	5.0	.20
4	30	13,570	51	.811	3.4	4.03	4.8	.17
5	30	13,570	94	.580	3.4	4.03	4.6	.13

Heads in box: total uncorrected 8.2, total corr., 8.9,
Static 24"-29" water
Scoop static at no discharge 3.4 uncorrected.
At r = .4, h_t = 5.9, at r = .1, h_t = 4.6

	h	V	t	h_v	H_{sc}	h_s	h_t	r
1	30	13,570	28	1.66	2.2	2.87	4.5	.37
2	30	13,570	40	.916	2.4	3.06	4.0	.23
3	24	10,850	52	.804	2.4	3.06	3.9	.20
4	30	13,570	61	.742	2.4	3.06	3.8	.19

Heads in box: total uncorr. 5.8, total corr. 6.6,
Static 18" + 24" water
Scoop static at no discharge 2.6" uncorrected
At r = .4, h_t = 4.6. At r = .1, h_t = 3.5

	h	V	t	h_v	H_{sc}	h_s	h_t	r
1	30	13,570	34	1.13	1.6	2.29	3.4	.33
2	30	13,570	53	.796	1.6	2.29	3.1	.26
3	18	8,140	56	.774	1.8	2.49	3.2	.24
4	18	8,140	58	.761	1.8	2.49	3.2	.24

Heads in box: total uncorr. 4.6, total corr. 5.4
Static 12" + 18" H_2O
Scoop static at no discharge = 1.8 uncorrected
At r = 4, h_t = 3.6. At r = .1, h_t = 2.6

Tabulated Data and Results
20° Scoop-Faired with Strainers

	h	V	t	h_v	H_{sc}	h_s	h_t	r
1	28	12,660	25	1.81	3.0	3.64	5.5	.33
2	28	12,660	50	.455	3.0	3.64	4.1	.11
3	28	12,660	31	1.17	3.0	3.64	4.8	.24
4	28	12,660	62	.295	3.2	3.84	4.1	.072
5	28	12,660	62	.295	3.2	3.84	4.1	.072

Heads in box: total unc. 8.2,total corr. 8.9
Static 23" and 30" H_2O
Scoop static at no discharge 3.2" unc.
At r = .4, h_t = 5.8. At r = .1, h_t = 4.1"

	h	V	t	h_v	H_{sc}	h_s	h_t	r
1	28	12,660	27	1.56	2.4	3.06	4.6	.34
2	28	12,660	29	1.35	2.4	3.06	4.4	.31
3	28	12,660	34	.990	2.4	3.06	4.1	.24
4	28	12,660	42	.644	2.4	3.06	3.7	.17
5	28	12,660	53	.406	2.4	3.06	3.5	.11

Head in box: total uncorr. 6.0, total corr., 6.8
Static 19" and 25" H_2O
Scoop h_s at no discharge = 2.6 uncorr.
At r = .4, h_t = 4.8". At r = .1, h_t = 3.5"

	h	V	t	h_v	H_{sc}	h_s	h_t	r
1	28	12,660	36	.880	1.6	2.29	3.2	.27
2	28	12,660	54	.392	1.6	2.29	2.7	.15
3	28	12,660	68	.246	1.6	2.29	2.5	.098
4	20	9,040	71	.114	1.8	2.49	2.6	.044
5	28	12,660	82	.169	1.8	2.49	2.6	.065

Head in box: total unc. 4.6, total corr. 5.5
Static 15" and 18" H_2O
Scoop h_s at no discharge 1.8" unc.
At r = .4, h_t = 3.7". At r = .1, h_t = 2.6"

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