PAP-823

Vortex-Tube Sandtrap Tests for 1935

May 1934

by

Carl Rohwer
W.E. Code
I.R. Brooks

Return to Carl Rohwer
Experiment Station
Colo A and M College
Ft Collins Colo

UNITED STATES DEPARTMENT OF AGRICULTURE
Bureau of Agricultural Engineering
S. H. McCrory, Chief
Division of Irrigation
W. W. McLaughlin, Chief

VORTEX-TUBE SANDTRAP TESTS FOR 1933

by

Carl Rohwer, W. E. Code, L. R. Brooks

UNITED STATES
DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

Division of Irrigation
Fort Collins, Colorado
December 2, 1949

Mr. E. W. Lane
U. S. Bureau of Reclamation
Denver Federal Center
Denver, Colorado

Dear Mr. Lane:

I am sending you the copy of the report on Vortex Tube Sand Traps that you asked to see when you were here recently.

I wrote to Mr. Clyde about this report and he said that you were free to use the material so long as it was not released to the public. I know that you are familiar with the rules regarding the use of material of this sort.

When you have finished with the report please send it back to me as it is the only copy we have.

Very truly yours,

CARL ROHWER, SENIOR
IRRIGATION ENGINEER

CR:lb

UNITED STATES DEPARTMENT OF AGRICULTURE
Bureau of Agricultural Engineering
S. H. McCrory, Chief

Progress Report

VORTEX-TUBE SANDTRAP TESTS FOR 1933

by

Carl Rohwer, W. E. Code, L. R. Brooks

Prepared under the direction of
W. W. McLaughlin, Chief
Irrigation Division
Bureau of Agricultural Engineering

Based on data gathered under a cooperative agreement between the Bureau of Agricultural Engineering and the Colorado Experiment Station.

Fort Collins, Colorado

May, 1934

UNITED STATES DEPARTMENT OF AGRICULTURE
BUREAU OF AGRICULTURAL ENGINEERING

IN YOUR REPLY PLEASE
REFER TO FILE No. ________

June 9, 1934

Mr. R. L. Parshall,
Hotel California,
El Centro, California.

Dear Mr. Parshall:

I am sending you a copy of the progress report on the sand trap experiments for 1933. This is practically the same as the copy which I had with me when I came to El Centro but it includes the tables and diagrams.

Very truly yours,

Carl Rohwer.

Associate in Irrigation
USDA

CR:AA

Saw Sam this morning. He would like to have a vortex tube tried in the wood flume crossing one of the canals in the valley. You probably know which one he means. If you have a simplified design for desilting the All American canal, he would like to have a copy. Sam says he advised you to write to Priest about transferring the man from Yuma.

Weather cool and dry, some rain early in week. Have been painting and cleaning up cargo transportation equip. Planning to start to Bellevue this week.

Glad you are having cooler weather.

Rohwer

Progress Report (1) on Vortex-Tube Sandtrap Tests for 1933

by

Carl Rohwer, W. E. Code, and L. R. Brooks

The study of the vortex-tube sandtrap was started in 1930 and since that time different types of tubes have been tested under various conditions. These tests indicated that the device would remove sand and silt carried as bed load, but there were many uncertainties as to the conditions which produced the greatest efficiency in sand removal. Tests made in 1932 showed that the tube had great carrying power. However, the methods adopted for making some of the observations did not prove satisfactory, and as a result it was not possible to interpret the results obtained accurately. A more complete study of the vortex-tube was planned for 1933, and after considering various methods of making observations, a new method was devised which it was hoped would give more accurate results or at least more consistent ones.

The study made during 1933 consisted of the determination of the speed of rotation and the velocity of translation of the water in straight and taper tubes set at various angles with the axis of the flume when operated under different flow conditions. Observations were

(1) This report was prepared under the direction of W. W. McLaughlin, Chief of the Division of Irrigation of the Bureau of Agricultural Engineering. The work was carried on under a cooperative agreement between the United States Department of Agriculture and the Colorado Experiment Station and is the continuation of a series of experiments started by R. L. Parshall, Senior Irrigation Engineer, in charge of the Irrigation Investigations in Colorado.

also made on the effectiveness of the tubes in removing sand and silt under these conditions, both by visual tests and by quantitative measurements. In addition some special tests were made to determine the effect of changing the level of the lower lip of the tubes.

The vortex-tube sandtrap consists of a tube with an opening along the upper side. The tube is placed in the bed of the canal transversely to the direction of flow in the channel but with the horizontal line of flow approximately tangent to the surface of the tube at the upstream edge or lip of the opening. The downstream edge of the opening in the tube is bent down so as not to obstruct the flow of the water. The downstream end of the tube is connected with an outlet channel or sluiceway to carry away the discharge from the tube. The design of the tube is shown by the cross-section of two tubes of different diameters in figure 1.

When the water in the canal flows over the opening along the side of the tube it causes the water in the tube to rotate and since the water in the tube has a velocity along the axis of the tube caused by the discharge through the outlet of the tube, the combination of the two velocities results in a spiral motion of the water in the tube which is similar to a horizontal vortex. The rate of rotation is high enough under certain conditions to cause an air core to form in the water in the center of the tube.

Particles of sand, silt or gravel moving as bed load along the bottom of the canal come in contact with the rotating water in the tube as soon as they pass across the

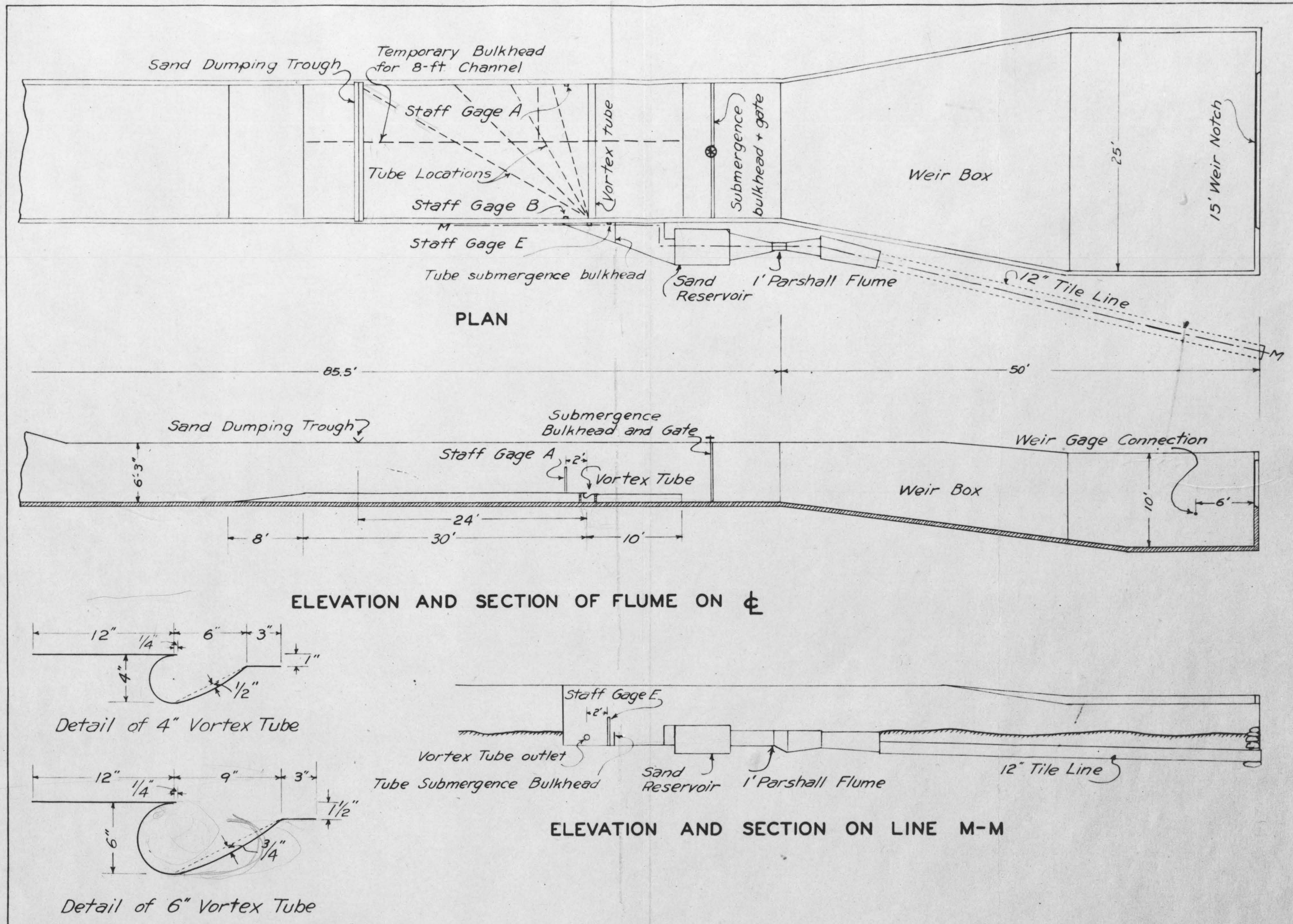

Sand Dumping Trough
Temporary Bulkhead for 8-ft Channel
Staff Gage A
Vortex tube
Submergence bulkhead + gate
Tube Locations
Weir Box
25'
15' Weir Notch
Staff Gage B
M
Staff Gage E
Tube submergence bulkhead
Sand Reservoir
1' Parshall Flume
12" Tile Line
M
PLAN
85.5'
50'
Sand Dumping Trough
Submergence Bulkhead and Gate
Staff Gage A
2'
Vortex Tube
Weir Gage Connection
6'3"
Weir Box
10'
6'
24'
8'
30'
10'
ELEVATION AND SECTION OF FLUME ON ℄
12"
1/4"
6"
3"
1"
4"
1/2"
Detail of 4" Vortex Tube
12"
1/4"
9"
3"
1 1/2"
6"
3/4"
Detail of 6" Vortex Tube
Staff Gage E
2'
Vortex Tube outlet
Tube Submergence Bulkhead
Sand Reservoir
1' Parshall Flume
12" Tile Line
ELEVATION AND SECTION ON LINE M-M

FIGURE 1

lip of the tube. Gravity pulls the sand into the tube because the sand is no longer supported by the bed of the canal when it passes over the lip of the tube. The spiral motion keeps the sand caught in suspension and also carries it out through the outlet of the tube.

The percentage of sand caught and the percentage carried out depend on various factors. The determination of the factors and their influence is the purpose of this study.

Description of Laboratory.

This study was made at the Bellvue laboratory, (See Fig. 1.) which consists of a concrete channel 85.5 feet long 14 feet wide and 6.25 feet deep connected at the downstream end with a weir box 50 ft. long and 10 ft. deep at the lower end of which was installed a 15-foot Francis weir with 5-foot end and bottom contractions. The upper end of the channel is attached to the sand gate of the Jackson ditch in the Poudre river from which the water for the experiments is obtained. The water is discharged back into the river after passing through the flume.

In order to carry on the experiments on the sandtraps, some changes had to be made in the laboratory. A level floor was built in the flume which extended 30 feet upstream from the vortex-tube. The elevation of this floor was about 12 inches above the floor of the flume. Downstream from the tube the floor was extended 8 feet. The level of the downstream floor was made to conform to the elevation of the lower lip of the vortex-tube. In the case of the taper tubes it was necessary to give the downstream floor a small transverse slope because the drop over the tube decreased with the diameter of the taper tube. A water-tight bulkhead was built between the upstream and the downstream floor in order to eliminate the possibility of leakage under the tube. The bulkhead was moved to conform to the line of the tube each time the angle of the tube setting was changed. Plate 1 is an interior view of the flume.

The water discharged from the vortex-tube was taken through the wall of the flume through a hole cut on the river side. This water was carried by a channel to a stilling pool about 4 feet wide and 6 feet long with its bottom 11 inches below the level of the channel. The sand carried out by the vortex-tube was caught in this box. After passing through the stilling pool the water was measured by a one-foot Parshall flume which was attached to the downstream side of the box. The lower end of the Parshall flume was connected with a 12" tile-line which carried the water back to the river. A general view of the arrangement is shown in plate 2.

The amount of water in the flume was regulated by the sandgate and the wasteway at the upper end of the flume. The maximum head that it was possible to draw through the sandgate was approximately 100 cubic feet per second. On some occasions the water supply in the river available for the tests was not sufficient to provide a satisfactory depth in the 14-foot flume. Under these conditions the width of the flume was narrowed to 8 feet by installing a partition 8 feet from the river side of the flume. In order to have

Plate 1. Interior view of flume showing
6-inch straight vortex-tube in place.

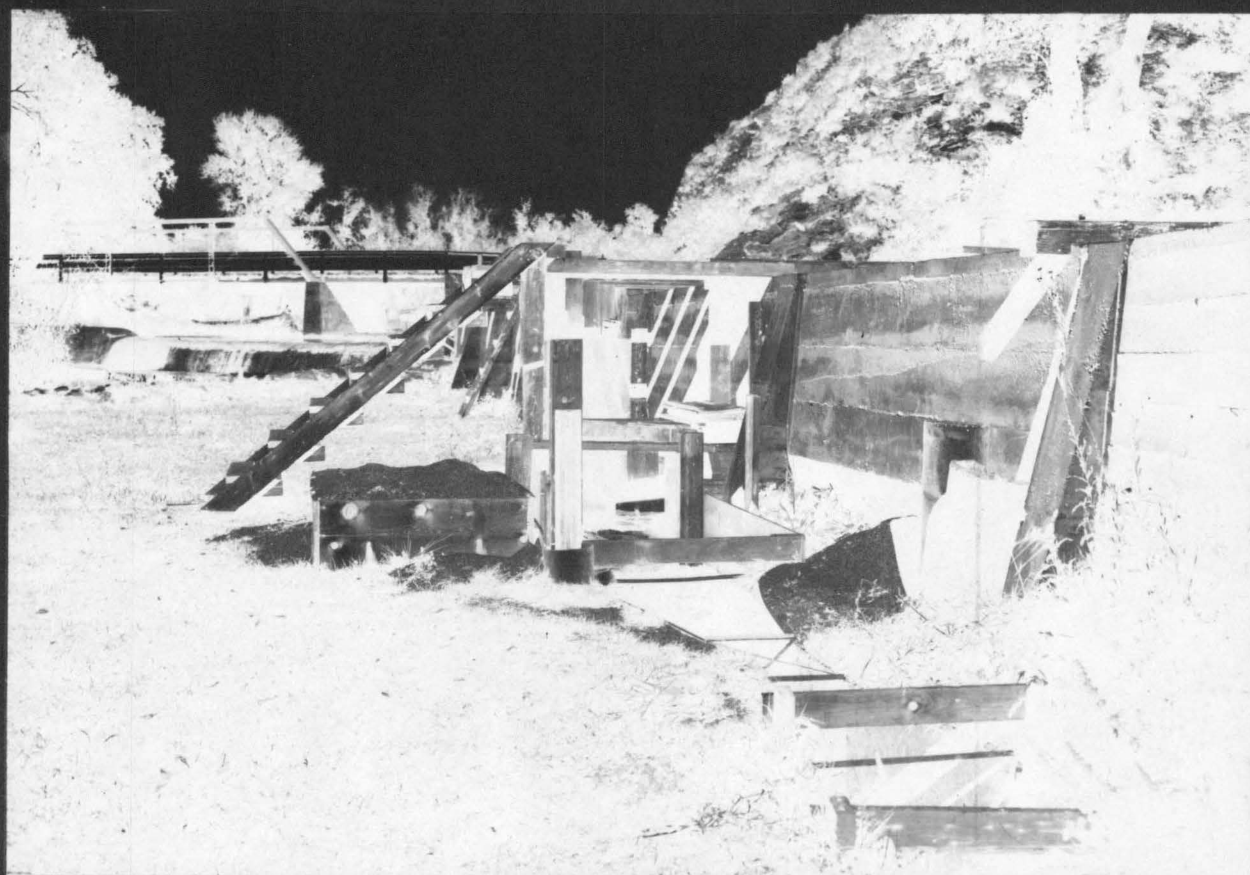


Plate 2. Exterior view of flume showing auxiliary channel and Parshall measuring flume.

comparable flume widths for all settings of the tubes, it was decided to test the tubes in both widths of the flume even though sufficient water was available for the 14-foot flume. The depth of the water flowing in the flume was controlled by a bulkhead with flashboards and a screw-gate as shown in figure 1. The level in the discharge channel from the vortex-tube was regulated by flashboards at the point indicated in the figure.

The vortex-tubes tested were of two types: One with a uniform diameter throughout and the other with a taper section decreasing as the distance from the discharge outlet increased. The first tests were made on a 12-inch diameter straight tube, but it was discovered that the discharge through this tube was too great to be economically feasible, so it was decided to use smaller tubes. For the straight tubes a 6-inch diameter was chosen and for the taper tubes a 6-inch diameter was adopted for the outlet end and a 4-inch diameter for the small end of the tubes. Sections of the tubes are shown in figure 1. These same diameters were used regardless of the increase in length of the tube due to changing the angle of the setting. When the flume width was reduced to 8 feet the tubes were not changed. The partition was built across the tube and the hole in the tube was stopped by a plug at the partition.

Method of Conducting Tests

The observations on each tube at each setting were made to cover as wide a range of discharges as was possible with the water available in the river. Each setting was usually tested at four different quantities of flow and for each quantity the tube was tested under three different conditions. One test was made with unobstructed flow in the flume and free discharge from the vortex-tube. This was designated as the "free-flow" condition. One test was made with unobstructed flow in the flume, but with the discharge from the vortex-tube submerged. This was known as the "tube submerged" condition. The third test was made with the flow from the tube unobstructed, but with the flow in the flume retarded by the flashboards and regulating gate in the bulkhead. This was known as the "flume submerged" condition. The degree of submergence adopted during each test was determined by observation of the action of the tube. In each case the submergence was not increased beyond the point where some action was still shown by the tube.

Observations were made on the velocity of translation through the tube and the rate of rotation in the tube. The quantity of water flowing over the tube and that discharged by the tube were measured. The depth of water upstream and downstream from the tube and in the outlet channel from the tube was determined. In addition visual observations were made on the action of the tube and quantitative measurements on the sand removed from the flume by the vortex-tubes on one series of tests on each tube at each setting.

During the tests made previously, the translation velocity in the tube was determined by the rate of travel of beeswax balls sliding on tight wires located at the axis of the tube. This method was found to be unsatisfactory because of the frictional resistance of the ball on the wire and also because of the uncertain action of the ball at low velocities. Several methods of improving the accuracy of these measurements were considered, but it was finally decided to use a small meter with special propellers. It is obvious, since the water in the tube is rotating at the same time it is moving toward the outlet, that the ordinary propeller meter will not measure the velocity directly. To overcome this difficulty a right- and a left-hand propellere were made for the meter, one of which registered the rotation due to the velocity plus the rotation caused by the spiral motion of the water and the other of which measured the rotation due to the velocity minus the rotation caused by the spiral motion of the water. The meter, which is of the Hoff type, and the propellers are shown in plate 3.

The two propellers were made as nearly identical as possible except that the pitch of the one was the opposite of the pitch of the other. It seems reasonable to assume then that the spiral motion of the water in the vortex tube will accelerate the rotation of one propeller just as much as it retards the rotation of the other. Hence the following equations result:

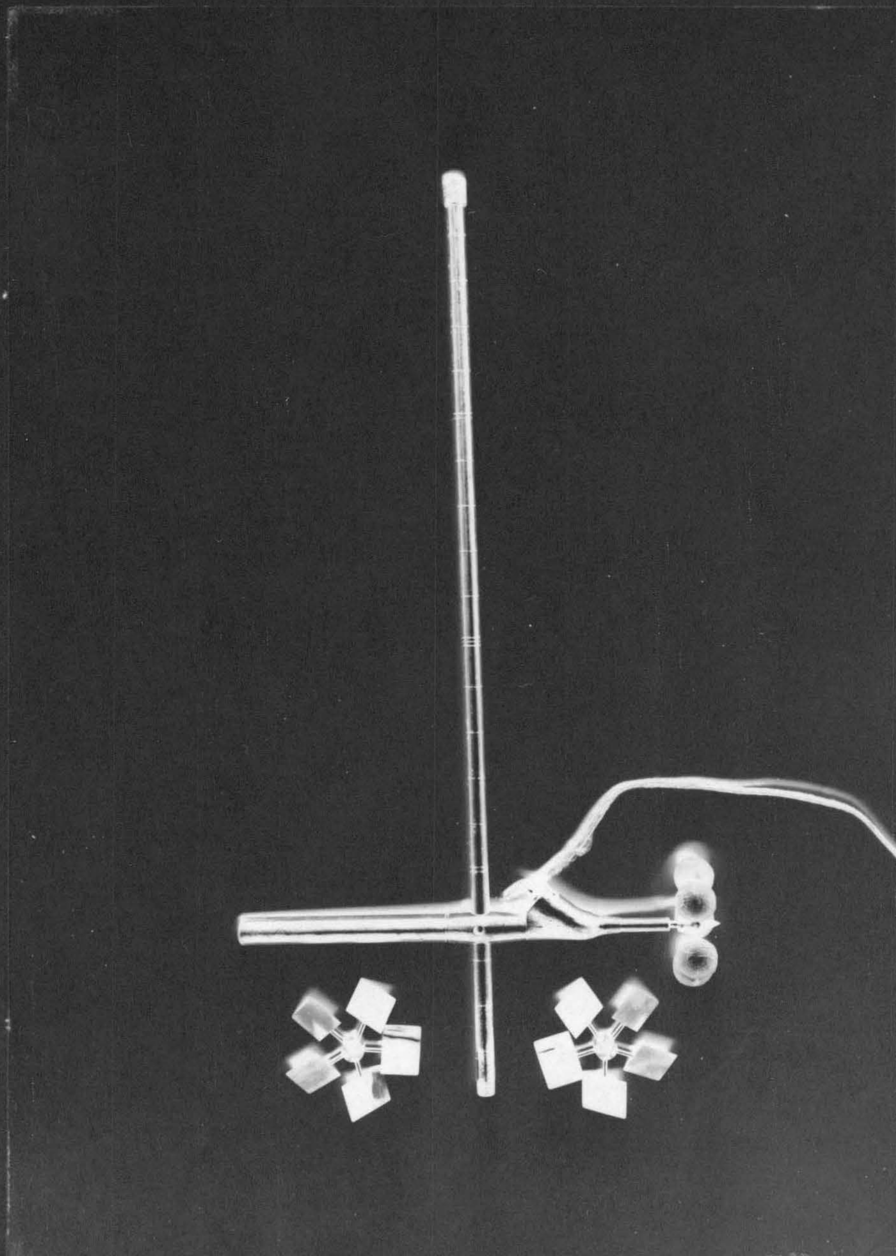


Plate 3 - Hoff meter with different types of propellers for determining the rate of rotation and the velocity of translation.

$$R_1 = R_v + R_r \text{ and} \text{---------------}(1)$$
$$R_2 = R_v - R_r \text{------------------}(2)$$

in which R_1 and R_2 are the observed rates of rotation of the propellers.

R_v, the rate of rotation due to velocity alone and

R_r, the rate of rotation due to the spiral motion of the water in the tube.

It is readily seen that by adding the two equations together, that $R_v = \frac{R_1 + R_2}{2}$. This is the rate of rotation due to the velocity of translation in the tube. By substituting this value in the rating table for the meter the velocity of translation is obtained.

The meter with the right-and left-hand propellers was rated on several occasions and the results are shown in figure 2. Two diameters of propeller were used. The first two had a diameter of 5 inches but when it was discovered that smaller vortex tubes would have to be used on account of the large amount of water passing through the 12-inch tube, the diameter of the propellers was reduced to 4 inches so that they could be used in the smaller tubes. It will be observed that the ratings of the two propellers are identical except in the case of the second rating of one of the 5-inch propellers. This difference was probably caused by the fact that one of the propellers was injured while in use and had to be repaired. As shown in the figure the rating made after the propeller was repaired did not agree with the previous rating. Apparently some change was made in the meter when repairing it. The velocities for the tests made under this condition were approximated by converting the observed rates of rotation into velocity from the respective rating curves and then solving in the same manner as before.

A series of tests was made for the purpose of checking the accuracy of the right-and left-hand propellers in determining the velocity of translation in the 12-inch vortex-tube. The comparison was made by timing a piece of coal through the tube. Five trials were made in each test and it was observed that there was a wide variation in the time required for the coal to move through the tube. The tests showed, however, that in most cases the maximum velocity of the coal agreed quite closely with the velocity determined by the right-and left-hand propellers. No check tests were made on the smaller tubes, so it is not known whether the velocities measured are accurate, but it was observed that the velocities at the different stations were quite consistent.

The rate of rotation of the water in the tube was measured with a ball propeller in the same manner as the tests made in previous years except that a larger propeller was used. The ball propeller is shown in plate 3.

This propeller was also used on a Hoff type meter. The rotation of the propeller was unaffected by the translation velocity of the water because only symmetrical spherical surfaces were exposed to the water. The rate of rotation could be determined also from the observations with the right and left handed propellers as a study of equations 1 and 2 will show. By subtracting the second equation from the first it is then easy to obtain $R_r = \frac{R_1 - R_2}{2}$, which gives the rate of rotation of the water in terms of the observed revolutions of the right-and left-hand propellers in the tube.

The results of the tests on the rates of rotation in the tubes were computed by both methods. A comparison of the results obtained in the two ways showed that in most instances they checked fairly well. There were, however, wide variations in some cases. In general, it may be said that the largest deviations occurred when the flume was submerged and the tube outlet free. There was also a tendency for the deviation to be greater when the angle of the tube was farthest from 90 degrees. No conclusion was drawn as to which method gave the most accurate results, but as the use of the ball propeller gave direct results it was adopted for making the study of the rate of rotation in the tubes.

The observations on the rate of rotation and the velocity of translation were made at two foot intervals throughout each tube beginning at one wall of the flume and ending at the other. In order to save time, all the observations with each propeller were completed before starting with the next. As the flow usually remained quite uniform throughout the period of each test it was thought that this expedient would not affect the results materially.

The discharge of the flume below the vortex-tube was measured by the 15-foot Francis weir in the weir box. This weir was equipped with two hook gages for measuring the head which read to the thousandth of a foot. Readings were taken twice during each test and the means were used in determining the discharge. The water passing through the tube was measured by a one-foot Parshall flume. The flume was equipped with a hook gage reading to thousandths of a foot, similar to those used on the weir. Two readings were also taken on this gage during each test. The Parshall flume discharge and the Francis weir discharge were added together to obtain the quantity flowing in the flume above the vortex tube.

Staff gages were located in the flume above and below the vortex tube for the purpose of measuring the depth at these points. A staff gage was also located in the channel carrying the water from the vortex tube.

The location of the gages is shown in figure 1. The gages in the flume did not prove satisfactory because the high velocity of the water made reading the water levels difficult. Depth readings were taken also on the floor of the flume at two foot intervals six inches back from the upper lip of the tube. The average of these depths was used in computing the velocity of the water over the vortex tube and also the degree of submergence of the outlet of the vortex tube. The gage in the outlet from the tube was in quieter water and consequently could be read accurately.

Whenever the water was clear enough to see the tube, observations were made on the action of the sand in the tube by throwing a shovelful of sand into the flume above the tube and then watching to see whether it was caught by the tube and if caught how rapidly it was carried out. Quantitative determinations of the effectiveness of each tube in removing sand were made on one group of tests in each setting. In order to make the results comparable, the tests were made under as nearly similar conditions as to flow as was possible to obtain with the water available. The observations were made on the free flow, tube submerged, and the flume submerged conditions. In making the tests a definite quantity of sand was dumped into the flume from a V-shaped trough which distributed the sand uniformly across the channel. The trough was placed twenty-four feet from the outlet of the tube at the beginning when the tubes were set at right angles to the axis of the flume and this distance was increased as the angle of the tubes decreased until it was 29 feet when the tubes were at an angle of 30 degrees with the axis of the flume.

After dumping the sand into the flume a definite period was allowed to elapse and at the end of this time the sand remaining in the tube and that caught in the sand basin were measured. All the measurements were made volumetrically, but care was exercised to see that the determinations were made on uniformly consolidated material.

There was at times some sand from the river running in the flume. The amount of this sand was determined by measuring the sand caught in the sand basin in a definite time, usually 15 minutes. Each observation was then corrected by a proportionate amount of this quantity based on the ratio of the time of the observation to the time of the tare test.

Results of Tests

The results of the tests are given in tables 1 to 5 inclusive. The observations on each angle at which the tubes were placed in the flume are recorded in

Table 1 Vortex Tube Data. Axis of Tube at 90 Degrees with Stream Flow
Bellvue Hydraulic Laboratory 1933

Test No.	Condition*	Discharge Flume Sec-ft	Discharge Tube Sec-ft	Tube Percent	Critical Depth Feet	Flume Mean Depth Feet	Mean Velocity Ft/sec	Mean Rotation R.P.M.	Mean Translation Ft/sec	Head on Tube Feet	Remarks
	4-inch to 6-inch taper tube in 14-foot channel										
175	FF*	52.97	1.72	3.3	.76	.68	5.55	68	1.20	1.14	Rocks jump tube. Sand deposits between Sta. 0 and 2.
176	TS*	50.45	.51	1.0	.74	.69	5.25	53	.64	.19	Translation plus and minus between Sta. 0 and 2.
177	FS*	49.87	2.43	4.9	.73	1.03	3.45	40	1.13	1.35	Sand deposits between Sta. 0 and 2.
178	FF	62.58	1.78	2.8	.85	.74	6.02	74	1.22	1.19	Sand deposits between Sta. 0 and 2.
179	TS	62.66	.60	1.0	.85	.75	5.97	53	.60	.19	Sand deposits between Sta. 0 and 2.
180	FS	61.76	2.61	4.2	.84	1.20	3.67	48	1.30	1.50	Some sand at Sta. 0 and from 3 to 8. None at Sta. 2.
181	FF	19.69	1.19	6.1	.39	.38	3.80	69	1.16	.96	Sand deposits Sta. 0 to 8.
182	TS	19.56	.37	1.9	.39	.39	3.54	46	.67	.17	Sand deposits Sta. 0 to 8.
183	FS	19.35	1.88	9.7	.39	.61	2.26	26	1.04	1.03	Sand deposits Sta. 0 to 7.
184	FF	19.23	1.16	6.0	.39	.36	3.87	70	1.19	.95	Tube a little more active than #181.
185	FF	10.23	.93	9.1	.25	.26	2.80	62	1.22	.92	Sand deposits Sta. 0 to 4. From Sta. 6 to 8 less active than 4 to 6.
186	TS	10.21	.44	4.3	.25	.25	2.92	46	.74	.16	Sand deposits Sta. 0 to 8.
187	FS	10.52	1.51	14.3	.26	.43	1.76	14	.70	.89	Sand deposits from 0 to 11.
188	FF	47.77	1.63	3.4	.71	.65	5.23	71	1.15	1.13	Sand deposits Sta. 0 to 2.
189	FF	35.92	1.48	4.1	.59	.54	4.73	73	1.08	1.06	Sand deposits Sta. 0 to 6.
	6-inch straight tube in 14-foot channel										
190	FF	77.80	1.80	2.3	.98	.85	6.56	53	1.30	1.29	Sand deposits in tube Sta. 0 to 2.
191	TS	77.47	.62	.8	.98	.87	6.36	34	.53	.21	Sand deposits in tube Sta. 0 to 2.
192	FS	75.49	2.68	3.6	.97	1.40	3.86	33	1.18	1.68	Sand deposits in tube Sta. 0 to 9.
193	FF	43.05	1.52	3.5	.67	.60	5.15	56	1.12	1.10	
194	TS	43.09	.79	1.8	.67	.60	5.13	43	.70	.31	
195	FS	44.06	2.39	5.4	.67	.98	3.21	29	1.10	1.29	Sand deposits Sta. 0 to 12.
196	FF	27.11	1.36	5.0	.49	.46	4.22	54	1.01	1.00	Sand deposits Sta. 0 to 6.
197	TS	27.18	.71	2.6	.49	.46	4.24	46	.64	.27	
198	FS	27.19	2.07	7.6	.49	.73	2.65	20	.93	1.13	
199	FF	100.71	2.52	2.5	1.17	1.36	5.30	42	1.13	1.67	
200	FF	88.40	1.88	2.1	1.08	.95	6.66	57	1.32	1.39	Sand trapped but coal jumps over.
201	TS	77.40	.63	.8	.98	.88	6.26	37	.63	.30	
202	FS	75.31	2.66	3.5	.96	1.43	3.76	34	1.03	1.73	
203	FF	10.73	.92	8.6	.26	.26	2.90	48	.92	.90	Sand deposits Sta. 0 to 8.
204	TS	10.73	.53	4.9	.26	.29	2.69	36	.60	.22	Sand deposits Sta. 0 to 6. Mill tailings, 0 to 3.
205	FS	10.67	1.49	14.0	.26	.44	1.74	11	.60	.94	Sand deposits Sta. 0 to 11.

Table 2 Vortex Tube Data. Axis of Tube at 75 Degrees with Streamflow

Test No.	Condition*	Discharge Flume Sec-ft	Discharge Tube Sec-ft	Tube Percent	Critical Depth Feet	Flume Mean Depth Feet	Mean Velocity Ft/sec	Mean Rotation R.P.M.	Mean Translation Ft/sec	Head on Tube Feet	Remarks
	6-inch straight tube in 14-foot channel										
206	FF	65.52	1.94	3.0	.88	.79	5.96	67	1.90	1.24	
207	TS	65.76	.50	.8	.88	.80	5.86	44	1.06	.21	
208	FS	64.35	2.68	4.2	.87	1.22	3.75	42	1.30	1.54	
209	FF	48.31	1.74	3.6	.72	.64	5.36	71	1.62	1.10	Sand deposits Sta. 0 to 5. Catches nearly all.
210	TS	48.07	.48	1.0	.72	.66	5.20	44	.95	.24	Sand deposits Sta. 0 to 6. Catches nearly all.
211	FS	47.50	2.51	5.3	.71	1.01	3.36	31	1.14	1.37	Sand deposits Sta. 0 to 10. Action weak.
212	FF	26.39	1.45	5.5	.48	.45	4.23	56	1.41	1.00	Sand deposits Sta. 0 to 5. Fairly active.

Table 2 continued

Test No.	Condition	Discharge Flume Sec-ft	Discharge Tube Sec-ft	Tube Percent	Critical Depth Feet	Flume Mean Depth Feet	Mean Velocity Ft/sec	Mean Rotation R.P.M.	Mean Translation Ft/sec	Head on Tube Feet	Remarks
	6-inch straight tube in 14-foot channel (continued)										
213	TS	28.54	.45	1.6	.51	.48	4.27	45	.91	.20	Sand deposits Sta. 0 to 6. Some jumps. Action fair.
214	FS	28.20	2.09	7.4	.50	.74	2.70	24	1.06	1.16	Sand deposits Sta. 0 to 12. Catches everything. Action weak.
215	FF	11.79	1.02	8.6	.28	.28	3.02	59	1.19	.90	Sand deposits Sta. 0 to 6.
216	TS	11.66	.36	3.1	.28	.27	3.06	38	.64	.17	Sand deposits Sta. 0 to 9.
217	FS	11.64	1.48	12.7	.28	.35	2.40	19	.83	.91	Milltailings deposit Sta. 0 to 11.
	6-inch straight tube in 8-foot channel										
218	FF	30.75	1.64	5.3	.78	.69	5.57	139	1.99	1.22	
222	TS	19.55	.42	2.2	.57	.53	4.63	58	.93	.21	
223	FS	18.57	2.11	11.4	.55	.70	3.33	41	1.45	1.11	
224	FF	42.17	1.88	4.5	.95	.86	6.14	130	2.22	1.34	Very active. Rocks jump over.
225	TS	42.55	.74	1.7	.96	.87	6.14	64	1.21	.30	Action very good, some sand jumps.
226	FS	41.79	2.47	5.9	.94	1.06	4.91	70	1.72	1.45	Action good, no sand in tube, same jumps.
	6-inch straight tube in 8-foot channel with lips level										
219	FF	31.02	1.91	6.2	.78	.74	5.22	135	1.87	1.22	
220	TS	20.75	1.13	5.4	.59	.58	4.48	74	1.61	.26	No sand deposits, catches all.
221	FS	18.71	2.40	12.8	.55	.75	3.12	53	1.47	1.13	Sand deposits Sta. 0 to 6.
	4-inch to 6-inch taper tube in 8-foot channel										
227	FF	18.60	1.46	7.8	.55	.50	4.65	140	2.04	1.06	Action excellent. Rocks jump.
228a	TS	18.59	.41	2.2	.55	.50	4.68	81	1.07	.20	Action excellent. Rocks jump.
228b	FS	18.64	2.13	11.4	.55	.68	3.40	56	1.45	1.10	
229	FF	7.38	1.01	13.7	.30	.28	3.36	127	1.58	.91	Action excellent. Rocks jump.
230	TS	7.38	.41	5.6	.30	.28	3.25	67	.93	.18	Action very good. Some rocks jump.
231	FS	8.38	1.75	20.9	.32	.47	2.24	47	1.10	.97	Sand deposits Sta. 0 to 5.
232	FF	61.69	2.15	3.5	1.22	1.11	6.95	182	2.55	1.52	
233	TS	61.61	.97	1.6	1.22	1.10	7.00	118	1.64	.33	
234	FS	58.60	2.78	4.7	1.18	1.33	5.50	85	1.96	1.67	
235	FF	34.76	1.81	5.2	.83	.74	5.90	157	2.37	1.20	Very active. Some sand and rocks jump.
236	TS	34.98	.54	1.5	.84	.77	5.70	96	1.33	.22	Action good. Some sand and rocks jump.
237	FS	34.84	2.41	6.9	.84	.97	4.50	67	1.60	1.37	
	4-inch to 6-inch taper tube in 14-foot flume										
238	FF	65.32	1.98	3.3	.88	.81	5.80	56	2.06	1.25	Action good. Some sand jumps.
239	TS	65.60	.66	1.0	.88	.81	5.76	49	1.33	.23	Action good.
240	FS	66.22	2.96	4.5	.89	1.60	2.97	22	1.24	1.93	
241	FF	46.34	1.78	3.8	.70	.65	5.06	56	1.85	1.12	Action good. Rocks jump.
242	TS	46.08	.73	1.6	.70	.66	5.02	45	1.36	.26	Fairly active. Rocks jump.
243	FS	43.36	2.66	6.1	.67	1.24	2.49	17	1.05	1.58	
244	FF	31.66	1.56	4.9	.54	.53	4.30	50	1.68	.99	Action fair.
245	TS	31.51	.47	1.5	.54	.51	4.42	43	1.17	.19	Action fair.
246	FF	11.76	1.03	.9	.28	.27	3.09	46	1.47	.91	Action fair. Gravel deposits Sta. 0 to 5 but not fine sand.
247	TS	11.76	.37	3.1	.28	.27	3.15	37	.98	.15	Action fair. Gravel deposits Sta. 0 to 5 but not fine sand.
248	FS	11.95	1.62	13.6	.28	.43	1.99	16	.84	.94	Action weak. Mill tailings deposit Sta. 0 to 7.

Table 3 Vortex Tube Data. Axis of Tube at 60 Degrees with Stream Flow
Bellvue Hydraulic Laboratory 1933

Test No.	Condition	Discharge Flume Sec-ft	Discharge Tube Sec-ft	Tube Percent	Flume Critical Depth Feet	Flume Mean Depth Feet	Mean Velocity Ft/sec	Mean Rotation R.P.M.	Mean Translation Ft/sec	Head on Tube Feet	Remarks
	6-inch straight tube in 14-foot channel										
249	FF	16.58	1.18	7.1	.35	.33	3.55	39	1.52	.94	Not very active but no deposits.
250	TS	16.71	.40	2.4	.35	.33	3.62	30	1.04	.17	Action fair. Some sand collects 0 to 9.
251	FS	16.55	1.74	10.5	.35	.54	2.19	12	.70	1.04	Action poor.
252	FF	23.61	1.40	5.9	.45	.42	4.06	34	1.57	1.00	No deposits. Not very active 0 to 4.
253	TS	24.46	.67	2.7	.46	.42	4.19	32	1.28	.22	Slow action Sta. 0 to 7.
254	FS	23.28	1.98	8.5	.44	.75	2.23	11	.89	1.22	
271	FF	98.02	1.92	2.0	1.15	1.04	6.75	76	2.22	1.58	
272	TS	95.63	1.17	1.2	1.13	1.03	6.61	65	1.90	.29	
273	FS	92.88	2.82	3.0	1.11	1.71	3.88	38	1.09	2.15	Water muddy. Sand collects in tube interfering with meter.
274	FF	48.75	1.96	4.0	.72	.66	5.29	55	2.08	1.16	
275	TS	47.76	.61	1.3	.71	.66	5.17	57	1.36	.20	Sand running but tube clean.
276	FS	45.08	2.36	5.2	.69	1.16	2.76	17	1.02	1.64	
277	FF	29.89	1.50	5.0	.52	.49	4.40	55	1.68	1.04	
278	TS	30.20	.40	1.3	.52	.48	4.48	37	1.23	.16	
279	FS	29.46	2.04	6.9	.52	.80	2.65	37	.97	1.27	
	6-inch straight tube in 8-foot channel										
255	FF	17.60	1.29	7.3	.53	.46	4.73	119	1.61	1.07	Very active. Some rocks jump.
256	TS	17.52	.38	2.2	.53	.46	4.72	57	.97	.17	Very active. Some rocks jump.
257	FS	15.69	1.96	12.5	.49	.74	2.66	31	1.19	1.24	No action Sta. 0 to 6.
258	FS	12.55	1.78	14.2	.42	.56	2.79	34	1.15	1.08	No action Sta. 0 to 5.
259	FF	7.32	.80	10.9	.30	.26	3.47	156	1.29	.97	Action fine.
260	TS	7.33	.36	4.9	.30	.27	3.43	55	.75	.18	Action fine--a little slow 0 to 5.
261	FS	7.38	1.52	20.6	.30	.39	2.37	35	.89	.92	Sand deposits Sta. 0 to 6.
	6-inch straight tube in 8-foot channel with lips level										
262	FF	8.09	1.42	17.6	.32	.30	3.40	84	1.43	.85	Sand deposits Sta. 0 to 3.
263	TS	8.00	.72	9.0	.31	.30	3.33	27	.95	.07	Sand deposits Sta. 2 to 4. Action fair.
264	FS	7.30	1.58	21.6	.30	.38	2.43	71	1.09	.89	Sand deposits Sta. 0 to 5.
265	FF	15.90	1.78	11.2	.50	.47	4.27	119	1.81	.99	Fairly active, no deposit.
266	TS	15.87	.77	4.9	.50	.49	4.07	46	1.03	.07	Action slow, rocks collect Sta. 2 to 4.
267	FS	15.80	2.02	12.8	.49	.65	3.05	43	1.30	1.11	Action weak, sand deposits Sta. 0 to 6.
268	FF	64.21	2.70	4.2	1.26	1.27	6.32	131	2.02	1.71	
269	TS	63.53	1.31	2.1	1.25	1.31	6.06	61	1.20	.22	
270	FS	59.53	2.94	4.9	1.20	1.88	3.95	48	1.64	2.32	
	4-inch to 6-inch taper tube in 14-foot channel										
280	FF	88.66	2.22	2.5	1.07	1.00	6.42	86	2.28	-.81	Handling large quantities of sand from river.
281	TS	82.04	1.34	1.6	1.02	.93	6.30	89	2.18	.37	Handling large quantities of sand from river.
282	FS	77.92	2.67	3.4	.99	1.37	4.06	68	1.36	1.79	
283	FF	50.21	1.96	3.9	.74	.64	5.56	77	2.07	1.14	
284	TS	49.93	1.17	2.3	.73	.66	5.40	92	1.85	.30	

Table 3 continued.

Test No.	Condition	Discharge Flume Sec-ft	Discharge Tube Sec-ft	Tube Percent	Critical Depth Feet	Flume Mean Depth Feet	Mean Velocity Ft/sec	Mean Rotation R.P.M.	Mean Translation Ft/sec	Head on Tube Feet	Remarks
4-inch to 6-inch taper tube in 14-foot channel (continued)											
285	FS	48.84	2.34	4.8	.72	1.04	3.36	26	1.15	1.48	
286	FF	27.27	1.40	5.1	.49	.44	4.43	82	1.79	1.04	
287	TS	27.27	1.10	4.0	.49	.44	4.43	74	1.68	.29	
288	FS	26.15	2.02	7.7	.48	.82	2.28	13	.90	1.34	
289	FF	12.78	1.02	8.0	.30	.25	3.67	82	1.57	.88	Action good 0 to 2, slow and sand deposits 2 to 5, excellent 5 to 14
290	TS	12.74	.66	5.2	.30	.28	3.28	62	1.30	.19	Action same as #289.
291	FS	12.71	1.45	11.4	.30	.36	2.52	16	.73	.92	No action 0 to 8, feeble 8 to 12, carried only small amt. mill taili
4-inch to 6-inch taper tube in 8-foot channel											
292	FF	12.60	1.21	9.6	.43	.37	4.26	161	1.69	.98	Action excellent. Some rocks jump.
293	TS	10.56	.79	7.5	.38	.33	3.98	123	1.44	.24	Action excellent. Some rocks jump.
294	FS	10.51	1.71	16.3	.38	.55	2.38	32	1.03	1.06	Practically no action 0 to 4, feeble 4 to 6, good 6 to 8.
295	FF	20.60	1.47	7.1	.59	.50	5.12	122	1.83	1.08	Action excellent. Some rocks jump.
296	TS	20.59	.92	4.5	.59	.50	5.12	89	1.65	.22	
297	FS	20.33	1.94	9.5	.59	.70	3.61	33	1.18	1.20	
298	FF	6.74	.84	12.5	.28	.25	3.40	146	1.51	.95	
299	TS	6.74	.52	7.7	.28	.24	3.44	109	1.21	.19	Action excellent. Some rocks jump.
300	FS	6.72	1.42	21.1	.28	.32	2.58	46	.89	.86	Sand deposits 0 to 6.
301	FF	64.75	2.21	3.4	1.26	1.08	7.52	235	2.48	1.52	
302	TS	64.71	1.05	1.6	1.26	1.09	7.41	119	1.54	.25	
303	FS	63.80	2.84	4.5	1.26	1.59	5.01	53	1.89	1.99	
304	FF	47.06	2.00	4.3	1.03	.87	6.79	176	2.09	1.40	Action fine. Rocks jump.
305	TS	47.20	.63	1.3	1.03	.88	6.72	88	1.36	.16	Action fine but sand stops in outlet.
306	FS	44.12	2.66	6.0	.98	1.52	3.62	64	1.36	1.93	Action feeble 0 to 5 but sand does not deposit.

Table 4 Vortex Tube Data. Axis of Tube at 45 Degrees with Stream Flow
Bellvue Hydraulic Laboratory 1933

Test No.	Condition	Discharge Flume Sec-ft	Discharge Tube Sec-ft	Tube Percent	Flume Critical Depth Feet	Flume Mean Depth Feet	Mean Velocity Ft/sec	Mean Rotation R.P.M.	Mean Translation Ft/sec	Head on Tube Feet	Remarks
	6-inch straight tube in 14-foot channel										
307	FF	26.57	1.40	5.3	.48	.39	4.85	88	1.82	.98	Action good 0 to 4, slow 4 to 9, good 9 to 11, excellent 11 to 14.
308	FF	75.11	2.30	3.1	.96	.79	6.82	133	2.57	1.27	Action fine, some slowing up from 6 to 8.
309	TS	76.05	.89	1.2	.97	.80	6.79	113	2.25	.18	Action good but slows up 7 to 10 and at outlet.
310	FS	74.53	2.88	3.9	.96	1.43	3.71	68	1.25	1.83	Action stopped 0 to 4, feeble 4 to 11, fair 11 to 14.
311	FF	47.03	1.90	4.0	.71	.56	5.95	115	2.28	1.03	Action good, least 7 to 9, most rocks jump.
312	TS	47.91	.76	1.6	.71	.58	5.96	95	2.00	.17	Action good, slows down near Sta. 8 and at outlet.
313	FS	46.36	2.43	5.2	.70	.93	3.58	29	1.08	1.33	Action poor, very feeble 0 to 8, better 8 to 12, good 12 to 14.
314	TS	27.64	.94	3.4	.49	.41	4.86	85	1.70	.26	Action good.
315	FS	27.46	2.06	7.5	.49	.61	3.23	19	.89	1.07	Very little action 0 to 12, fair 12 to 14.
	6-inch straight tube in 8-foot channel										
316	FF	86.89	2.82	3.2	1.54	1.31	8.27	206	2.67	.81	Action very fast.
317	TS	85.95	1.62	1.9	1.54	1.33	8.10	190	2.11	.43	Action very fast.
318	FS	85.00	3.19	3.8	1.52	1.83	5.80	71	1.43	2.20	
319	FF	63.46	2.42	3.8	1.25	1.06	7.50	254	2.54	1.56	Very active.
320	TS	63.35	1.44	2.3	1.25	1.07	7.38	181	2.25	.36	Very active.
321	FS	62.45	2.91	4.7	1.24	1.48	5.26	60	1.04	1.93	
322	FF	39.05	1.96	5.0	.90	.75	6.51	205	1.99	1.21	Very active. Rocks and some sand jumps.
323	TS	39.09	.99	2.5	.90	.75	6.52	181	1.51	.29	Very active but slows up at outlet.
324	FS	37.60	2.50	6.6	.88	.95	4.95	35	.87	1.35	Action slow, fairly good 6 to 8.
325	FF	23.73	1.52	6.4	.65	.54	5.46	163	1.57	1.12	Very active.
326	TS	24.57	.78	3.2	.66	.56	5.52	156	1.32	.28	Very active, slows up at outlet. Rocks jump.
327	FS	24.49	2.30	9.4	.66	.84	3.66	38	.78	1.31	Nearly no action except 7 to 8.
328	FF	10.45	.98	9.4	.38	.32	4.12	139	1.13	.99	Action uniform and excellent.
329	TS	10.39	.58	5.6	.38	.31	4.18	140	.92	.23	Action excellent
330	FS	10.44	1.80	17.2	.38	.38	3.47	17	.41	.86	Action poor, only fine dirt carried out.
	6-inch straight tube in 8-foot channel lips level										
331	FF	50.26	2.82	5.6	1.31	1.01	6.24	187	1.82	1.43	Action excellent, catches everything.
332	TS	50.35	1.96	3.9	1.32	1.02	6.15	107	1.60	.42	Action excellent, slight tendency to slow up at outlet.
333	FS	50.31	2.79	5.5	1.07	1.30	4.84	123	1.51	1.72	Action slow but no deposits.
334	FF	32.34	2.36	7.3	.80	.75	5.38	119	1.62	1.21	Action good.
335	TS	32.02	1.80	5.6	.79	.76	5.30	113	1.31	.39	Action fine 6 to 13,deposits at 13 but moves out.
336	FS	31.11	2.48	8.0	.78	.98	3.96	81	1.35	1.39	Action slow 0 to 6, fair 6 to 8.
337	FF	10.23	1.68	16.4	.37	.33	3.90	146	1.30	.85	Action good
338	TS	10.14	1.21	11.9	.37	.33	3.83	116	1.18	.15	Action fair, slows up and deposits at Sta. 4.
339	FS	10.13	1.86	18.4	.37	.50	2.53	57	1.13	1.02	Practically no action 0 to 6, some 6 to 8.

Table 4 continued.

Test No.	Condition	Discharge Flume Sec-ft	Discharge Tube Sec-ft	Tube Percent	Critical Depth Feet	Flume Mean Depth Feet	Mean Velocity Ft/sec	Mean Rotation R.P.M.	Mean Translation Ft/sec	Head on Tube Feet	Remarks
	4-inch to 6-inch taper tube in 8-foot channel										
340	FF	40.71	2.14	5.3	.93	.77	6.64	183	2.32	1.19	Action very fast, larger particles jump out.
341	TS	41.63	1.14	2.7	.94	.79	6.57	221	2.18	.30	
342	FS	38.50	2.48	6.4	.89	1.00	4.79	35	.93	1.40	Action very slow 0 to 6, fair 6 to 8.
343	FF	62.10	2.48	4.0	1.23	1.06	7.35	217	2.90	1.52	Very active, rocks jump.
344	TS	62.18	1.46	2.3	1.23	1.06	7.34	256	2.47	.34	Action excellent, some sand and gravel jumps.
345	FS	62.12	2.89	4.6	1.23	1.43	5.44	61	.98	.89	Action fair 0 to 2, very slow 2 to 6, fair 6 to 8.
346	FF	23.70	1.63	6.9	.65	.52	5.68	190	1.99	1.08	Action very good, slows at Sta. 6.
347	TS	23.58	.99	4.2	.65	.53	5.59	179	1.85	.29	Very active, some sand jumps.
348	FS	22.81	2.28	10.0	.63	.86	3.32	25	.94	1.28	Action very slow 0 to 7.
349	FF	10.53	1.14	10.8	.38	.31	4.25	110	1.72	.98	Action good, sand jumps only at upper end.
350	TS	10.51	.87	8.3	.38	.31	4.22	104	1.67	.19	Action excellent, some sand jumps 0 to 5.
351	FS	10.45	1.77	16.9	.38	.40	3.27	13	.60	.96	No action.
	4-inch to 6-inch taper tube in 14-foot channel										
352	FF	54.07	1.96	3.6	.77	.62	6.18	128	2.70	1.14	Very active.
353	TS	53.63	1.30	2.4	.77	.64	6.04	140	2.47	.31	Action very good, some sand jumps.
354	FS	52.46	2.44	4.7	.76	1.06	3.54	40	1.23	1.50	Action very slow.
355	FF	19.12	1.15	6.0	.39	.32	4.24	98	1.77	1.00	Fairly active, a little slow near center.
356	TS	19.11	.93	4.9	.39	.32	4.20	97	1.85	.19	Action fair, slow 4 to 8.
357	FS	18.85	1.92	10.2	.38	.61	2.21	13	.82	1.14	Action weak.

Table 5 Vortex Tube Data. Axis of Tube at 30 Degrees with Stream Flow
Bellvue Hydraulic Laboratory 1933

Test No.	Condition	Discharge Flume Sec-ft	Discharge Tube Sec-ft	Tube Percent	Critical Depth Feet	Flume Mean Depth Feet	Mean Velocity Ft/sec	Mean Rotation R.P.M.	Mean Translation Ft/sec	Head on Tube Feet	Remarks
	6-inch straight tube in 14-foot channel										
358	FF	50.77	1.94	3.8	.74	.52	6.94	155	3.02	1.06	Action good, some sand lost.
359	TS	51.37	1.13	2.2	.75	.54	6.85	138	2.82	.21	Uniformly fairly active.
360	FS	55.85	2.42	4.5	.77	.97	3.97	51	1.47	1.47	Action slow, sand deposits.
361	FF	37.32	1.63	4.4	.60	.43	6.22	138	2.60	1.03	Action good, slower at center.
362	TS	37.01	1.12	3.0	.60	.43	6.09	128	2.51	.29	Action good.
363	FS	36.20	2.21	6.1	.59	.74	3.48	32	1.23	1.29	Catches everything, slow discharging.
	6-inch straight tube in 8-foot channel										
364	FF	43.15	2.38	5.5	.97	.74	7.25	171	2.33	1.16	Very active, some sand lost.
365	TS	43.35	1.33	3.1	.97	.74	7.33	152	2.03	.23	Very active, some sand lost.
366	FS	43.37	2.74	6.3	.97	1.19	4.56	67	1.25	1.64	Fairly active, sand slows down at 3rd points
367	FF	29.62	2.08	7.0	.75	.54	6.80	155	2.47	1.05	Very active.
368	TS	29.50	1.23	4.2	.75	.54	6.85	148	2.13	.22	Very active, some sand lost.
369	FS	29.24	2.42	8.3	.75	.87	4.20	47	.96	1.35	Action weak, sand deposits.
370	FF	16.20	1.49	9.2	.50	.36	5.66	127	1.75	.92	Very active, some sand lost.
371	TS	16.17	.97	6.0	.50	.37	5.51	120	1.67	.24	Very active.
372	FS	16.02	2.00	12.5	.50	.60	3.31	16	.75	1.16	Action poor.
	6-inch straight tube in 8-foot channel with lips level										
373	FF	39.29	2.73	6.9	.91	.85	5.80	154	1.79	1.29	Action good, but less than with drop. Catches sand well.
374	TS	39.03	1.74	4.5	.90	.86	5.66	143	1.66	.28	
375	FS	43.14	2.78	6.4	.97	1.24	4.35	95	1.48	1.72	Fairly active, no deposit.
376	FF	30.46	2.56	8.4	.77	.73	5.24	139	1.78	1.23	Fairly active.
377	TS	30.43	1.80	5.9	.77	.74	5.17	126	1.59	.33	Fairly active.
378	FS	30.32	2.48	8.2	.76	.91	4.16	104	1.41	1.41	Fairly active, no deposit.
379	FF	16.77	2.16	12.9	.51	.47	4.42	119	1.55	1.01	Fairly active.
380	TS	16.87	1.77	10.5	.52	.48	4.40	107	1.48	.32	Fairly active, no deposit.
381	FS	16.83	2.12	12.6	.52	.66	3.20	89	1.12	1.19	Action poor, sand deposits.
	4-inch to 6-inch taper tube in 14-foot channel										
382	FF	37.36	1.54	4.1	.60	.42	6.35	180	2.85	1.04	Fairly active, some sand jumps.
383	TS	39.02	.99	2.5	.62	.44	6.32	167	2.81	.20	Action good.
384	FS	39.51	2.22	5.6	.63	.78	3.61	47	1.40	1.32	Inactive at 3, 5, 7½, and 11.
385	FF	27.26	1.33	4.9	.49	.34	5.75	143	2.60	1.00	Very active, slow place near Sta. 6.
386	TS	27.31	.73	2.7	.49	.35	5.61	146	2.35	.15	Slow place 4 to 6.
387	FS	27.40	1.88	6.9	.49	.47	4.18	71	1.47	1.02	Active at places, inactive between.

Table 5 continued.

Test No.	Condition	Discharge Flume Sec-ft	Discharge Tube Sec-ft	Tube Percent	Critical Depth Feet	Flume Mean Depth Feet	Mean Velocity Ft/sec	Mean Rotation R.P.M.	Mean Translation Ft/sec	Head on Tube Feet	Remarks
	4-inch to 6-inch taper tube in 8-foot channel										
388	FF	38.70	2.28	5.9	.90	.66	7.33	272	2.58	1.08	Very active.
389	TS	38.40	1.24	3.2	.90	.67	7.15	242	2.29	.15	Very active.
390	FS	38.20	2.58	6.8	.89	1.16	4.12	41	1.00	1.67	Action slow, no deposits.
391	FF	29.60	2.06	7.0	.75	.53	6.93	265	2.68	.97	Very active.
392	FF	17.49	1.58	9.0	.53	.37	5.94	151	2.27	.95	Very active, carries large rocks.
393	TS	17.57	1.31	7.5	.53	.38	5.81	162	2.34	.26	Very active, carries large rocks.
394	FS	17.62	2.02	11.5	.53	.57	3.86	20	.41	1.12	Action poor, sand deposits.
395	TS	28.92	1.26	4.4	.74	.53	6.87	245	2.54	.22	Very active.
396	FS	28.76	2.18	7.6	.74	.70	5.17	88	1.12	1.17	Action poor, sand deposits Sta. 11 and 12.

* FF stands for free flow; TS, tube submerged; and FS, flume submerged.

separate tables, but the data on the straight and taper tubes for all flow conditions are combined in each table. The flume discharge given is the sum of the Francis weir discharge and the Parshall flume discharge. The tube discharge is the quantity passing through the outlet of the tube into the auxiliary channel to the river. It was measured by the one-foot Parshall flume in the outlet channel. The percentage of flow passing through the tube is the ratio of the discharge of the tube to the total quantity flowing in the flume measured in percentage. Both the flume discharge and the weir discharge were taken from discharge tables computed by the formulas for the respective devices.

The critical depth given in the tables is a limiting condition of flow. For each quantity of flow and each width of flume there is but one critical depth. It is that depth at which the velocity head is just equal to one half the depth. The values given in the tables were computed by the formula $d_c = \sqrt[3]{\frac{\left(\frac{Q}{T}\right)^2}{g}}$ in which d_c is the critical depth, Q the discharge, T the width of the flume, and g the acceleration due to gravity. All the units are in feet. These values are given because the critical depth seems to be a definite line of demarcation between satisfactory and unsatisfactory action of the tube. When the depth is less than critical the action is generally quite good and when it is greater than critical the action is poor. The mean depths in the tables are the means of the point gage determinations parallel to the axis of the tube and 6 inches from the edge of the lip. When compared with the critical depth they show whether the depth is above or below critical and indicate whether the action of the tube will be satisfactory of not. The mean velocity in the tables is the average velocity in the flume 6 inches back from the lip of the tube. It was obtained by dividing the flume discharge by the product of the width of the flume and the mean depth.

The mean rotation is the average of the observations on the rotation of the water in the tube made at two-foot intervals with the ball turbine. In a few instances the ball turbine was too large for the small end of the taper tubes. The rate of rotation derived from the right-and-left hand propellers was used where available to supply the information lacking. Otherwise the portion of the tube in which measurements could not be made was eliminated. The mean translation velocity is the average of the results of the observations made with the right-and-left hand propellers at two-foot intervals on the velocity of the tube. Before the small diameter propellers were made, observations could not be taken in the small end of the taper tubes because the diameter of the propellers was greater than the diameter of the taper tubes at this point. The translation velocity in the small end of the taper tubes was small relative to that of the outlet end and for this reason only the portion of the tube in which observations could be made was considered in determining the mean velocity.

The head on the tube is measured from the level of the water in the flume to the level of the water in the outlet channel. The level of the water in the flume was determined from the mean of the depth readings on the lip of the tube and the level of the water in the outlet channel was obtained from the mean reading of the staff gage in the outlet channel. The difference between the two means referred to the same datum is the head on the tube. This difference is significant only when the tube outlet is submerged. It is obvious that when the tube is flowing free that the distance the water level in the auxiliary channel is below the bottom of the outlet tube will have no effect on the discharge through the tube.

Under "remarks" are given the observations on the action of the tube. These observations were made with few exceptions whenever possible, but when the water was muddy it was impossible to see what was going on in the tube.

The study of these data indicates that there is a tendency for the rate of rotation and the velocity of translation to increase as the angle of the tube with the axis of the flume decreases. Casual comparison does not, however, show that there is any appreciable difference between the straight and taper tubes. The data on the operation of the tubes show that the action is good when the tube and flume are operating under the free flow condition and that it is also good under ordinary conditions of submergence of the tube outlet. Retarding the velocity in the flume seems to inhibit the action in the tubes. Comparison on the basis of the critical depth in the flume shows that the action in the tube is good when the depth in the flume is less than critical, and is poor in most instances when the depth is greater than critical.

The variations in the results obtained are brought out more clearly by the plots of the data, figures 3 to 12, which show the variation of the rate of rotation and the velocity of translation with the velocity in the flume for each setting of the tubes. The observations on the different types and lengths of tubes and the condition of flow are grouped together and are indicated by different symbols. These diagrams show in general that both the rate of rotation and the velocity of translation for each setting of the tubes increase with the velocity of flow in the flume. They show also that the rate of increase of these factors with the increase in velocity in the flume increases as the angle of the tube decreases with relation to the axis of the flume. In other words, for a definite mean velocity in the flume, the rate of rotation and the velocity of translation increase as the angle of the tube decreases. There are no conspicuous differences shown by the different conditions of flow by the plots

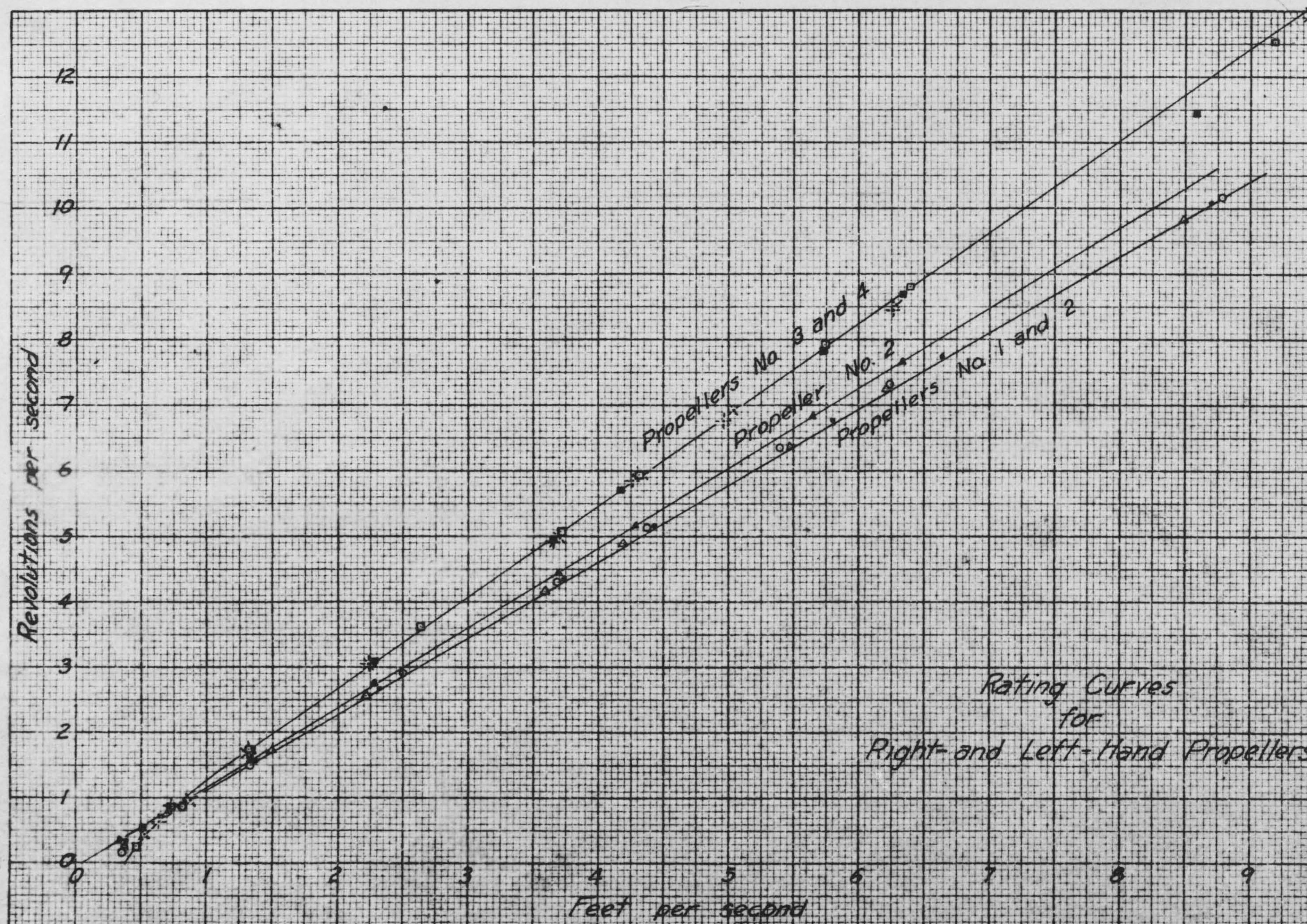

Revolutions per second
Feet per second
Propellers No. 3 and 4
Propeller No. 2
Propellers No. 1 and 2
Rating Curves
for
Right- and Left-Hand Propellers
0
1
2
3
4
5
6
7
8
9
10
11
12

FIGURE 2

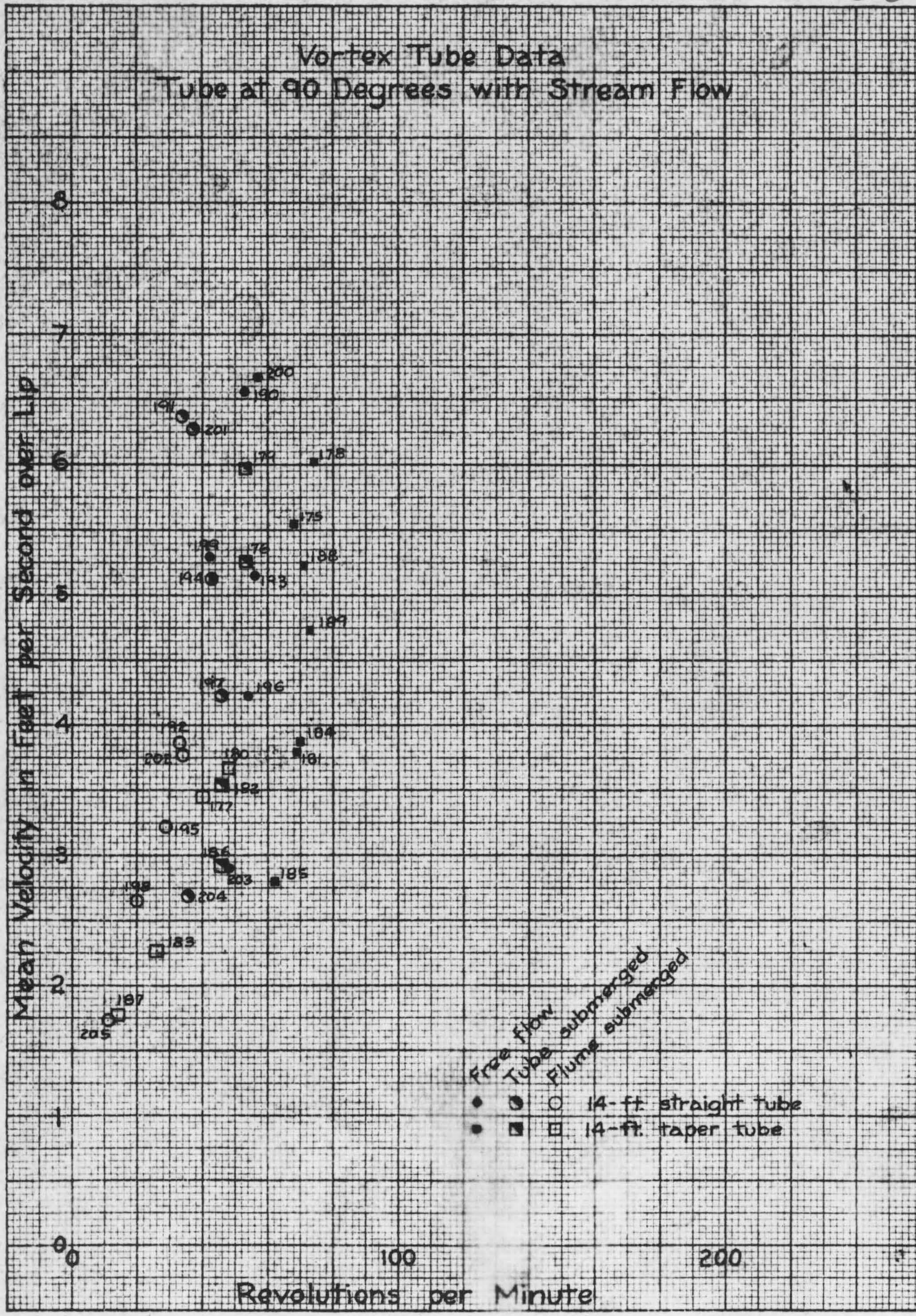

Vortex Tube Data
Tube at 90 Degrees with Stream Flow
Mean Velocity in Feet per Second over Lip
Revolutions per Minute
0
1
2
3
4
5
6
7
8
0
100
200
Free flow
Tube submerged
Flume submerged
14-ft. straight tube
14-ft. taper tube
200
190
191
201
179
178
175
199
176
198
194
193
189
197
196
192
184
202
181
180
182
177
195
186
203
185
198
204
183
187
205

FIGURE 3

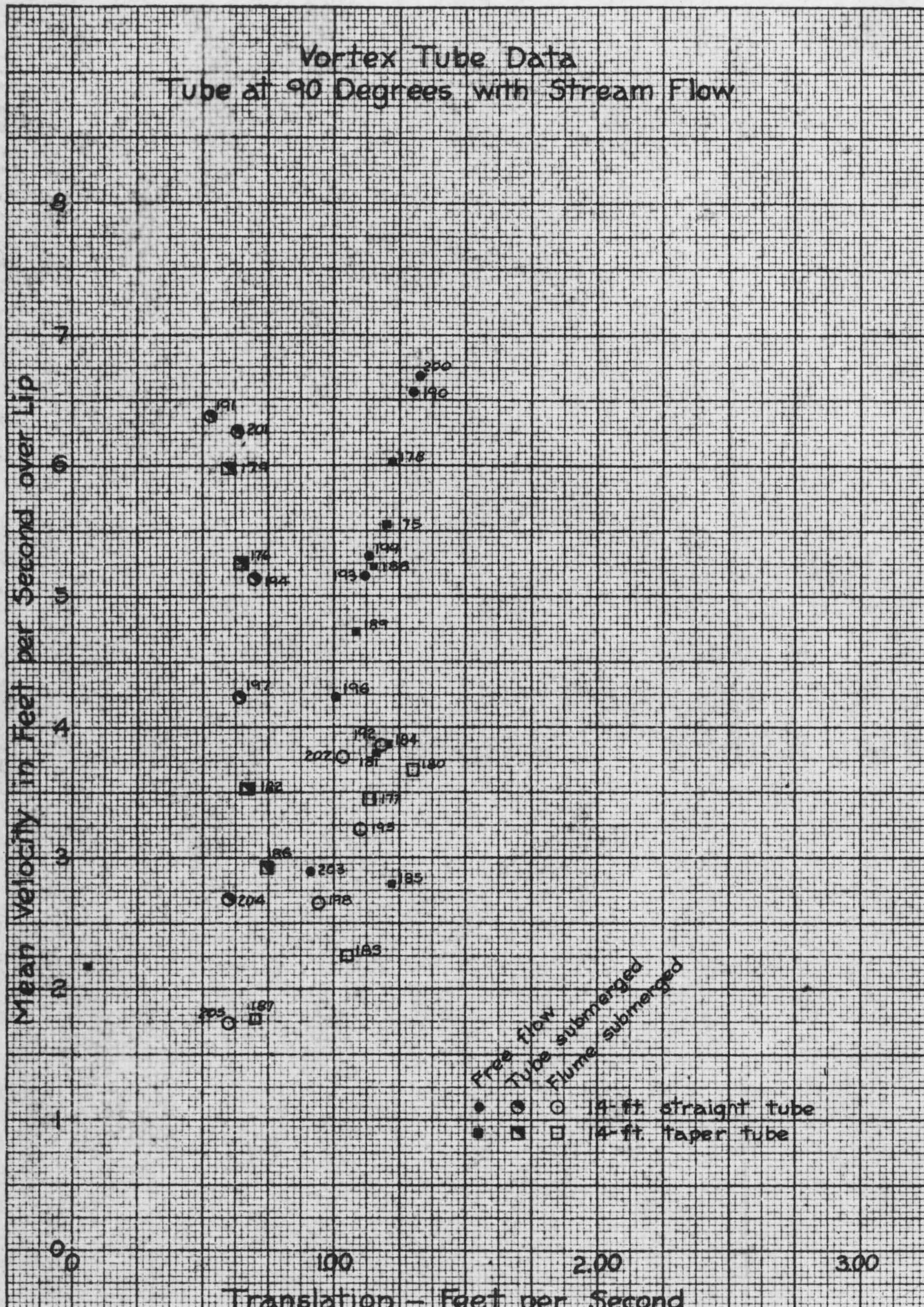

Vortex Tube Data
Tube at 90 Degrees with Stream Flow
Mean Velocity in Feet per Second over Lip
Translation – Feet per Second
0
1.00
2.00
3.00
Free flow
Tube submerged
Flume submerged
14-ft. straight tube
14-ft. taper tube

FIGURE 4

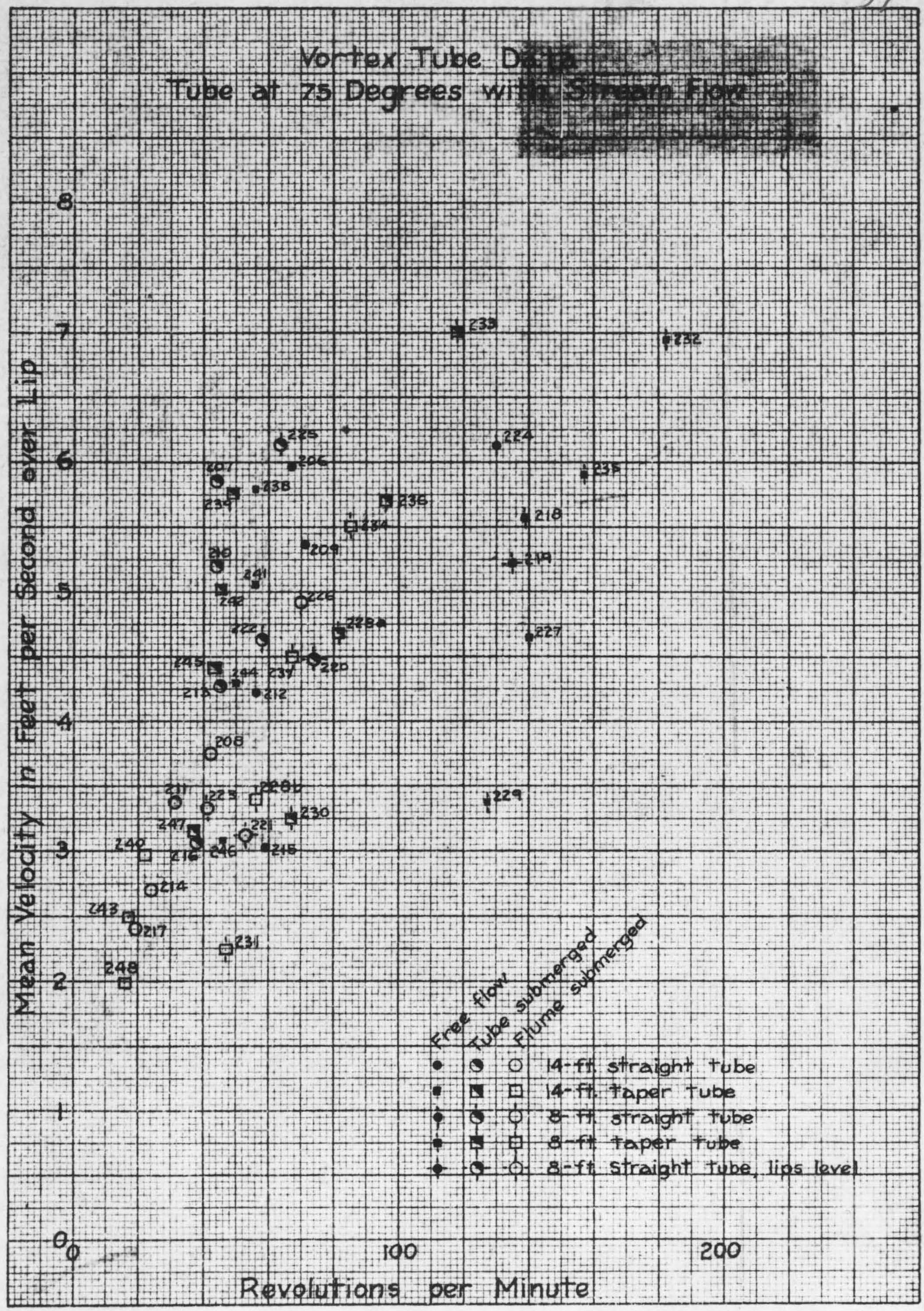

Vortex Tube Data
Tube at 75 Degrees with Stream Flow
Mean Velocity in Feet per Second over Lip
Revolutions per Minute
0
100
200
1
2
3
4
5
6
7
8
Free flow
Tube submerged
Flume submerged
14-ft straight tube
14-ft taper tube
8-ft straight tube
8-ft taper tube
8-ft Straight tube, lips level

FIGURE 5

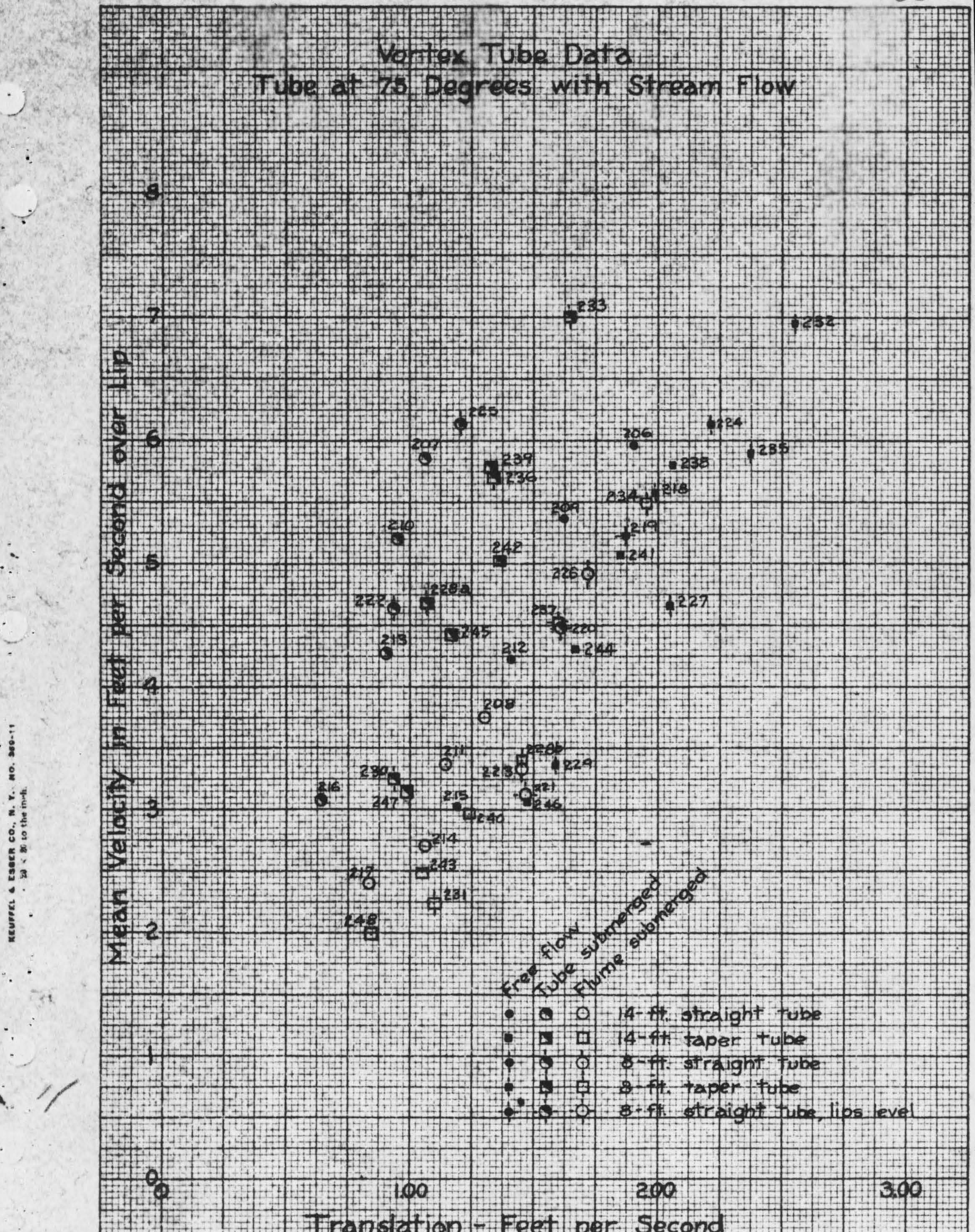
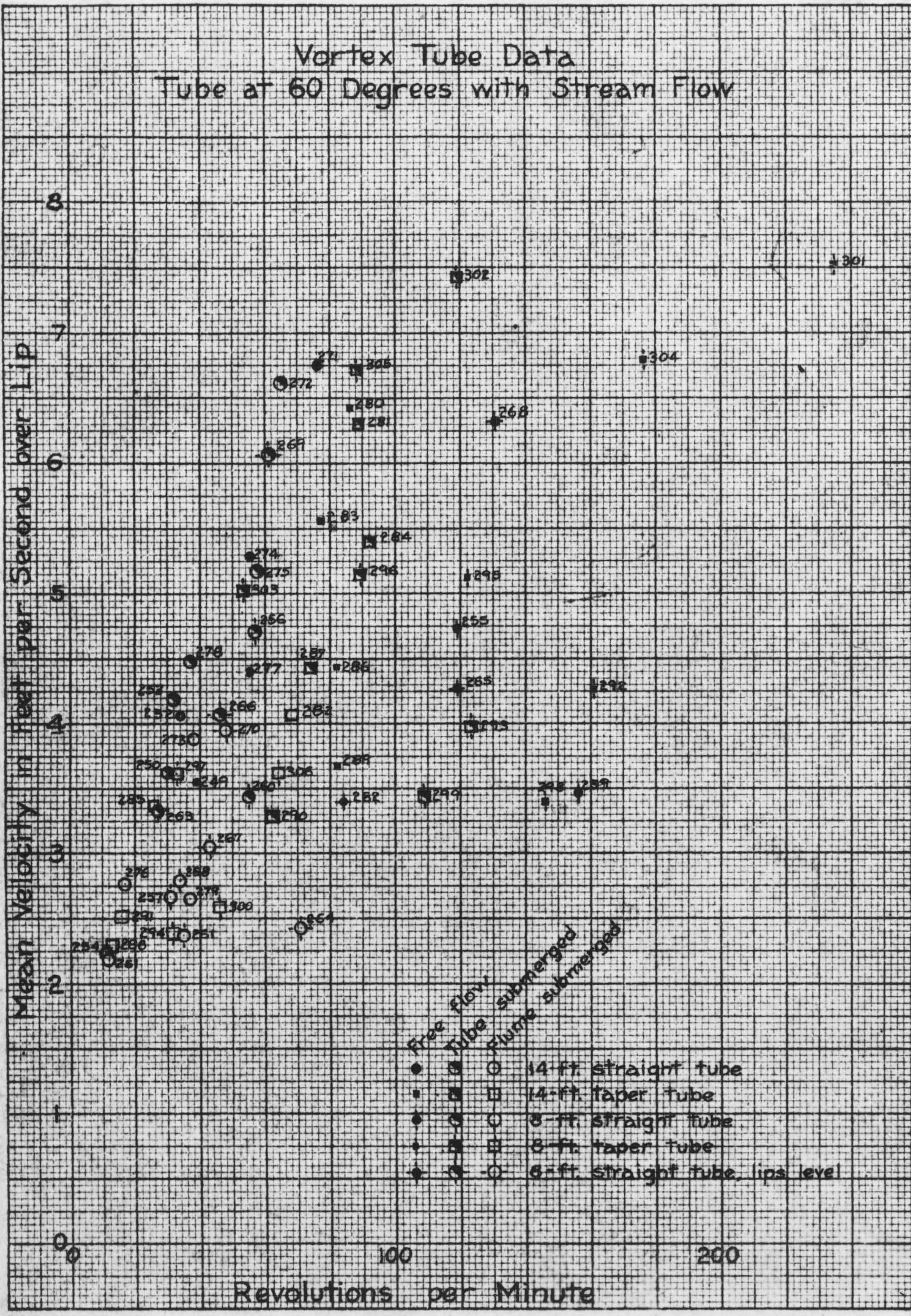
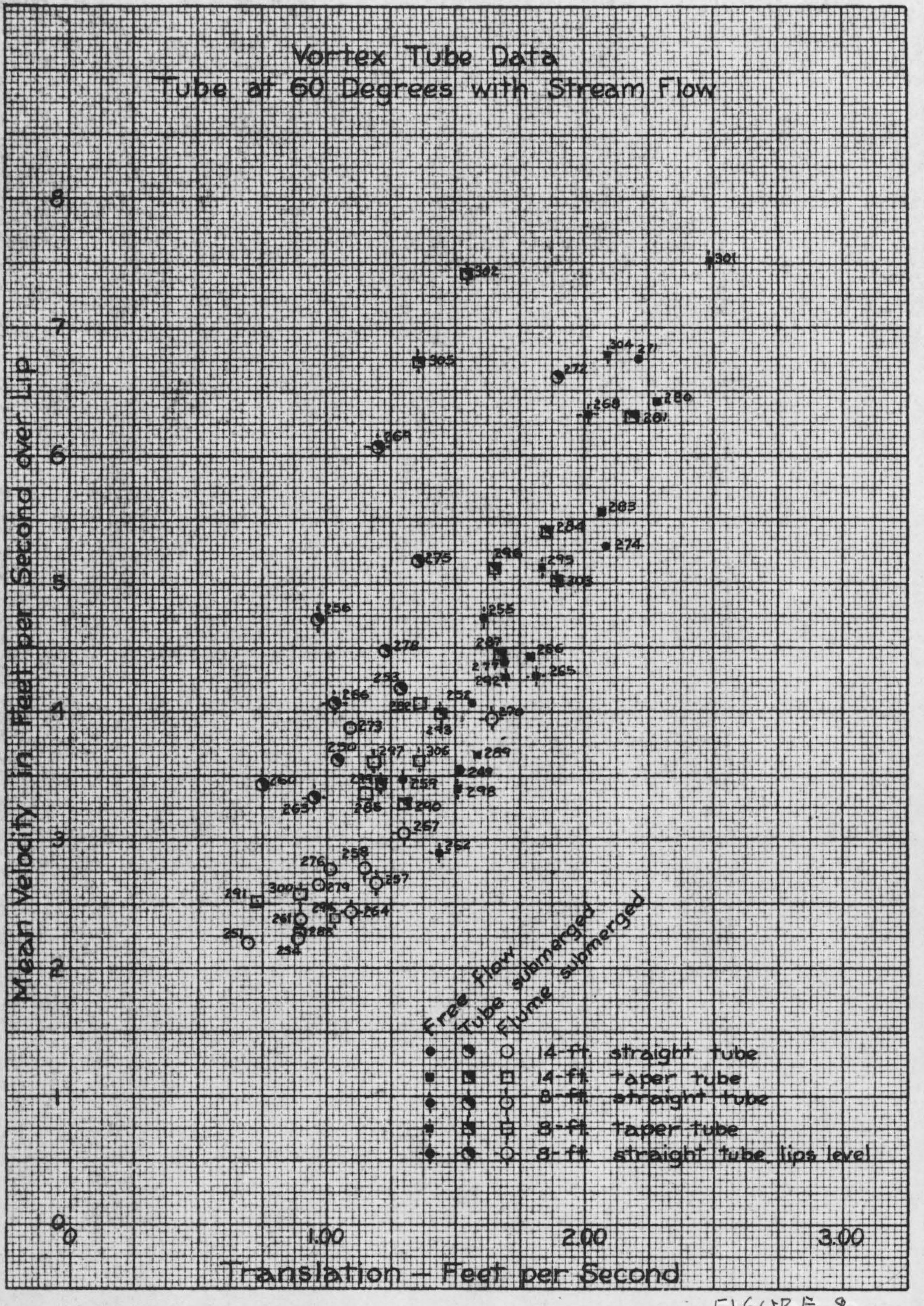

Vortex Tube Data
Tube at 75 Degrees with Stream Flow
Mean Velocity in Feet per Second over Lip
Translation - Feet per Second
0
1.00
2.00
3.00
1
2
3
4
5
6
7
8
Free flow
Tube submerged
Flume submerged
14-ft. straight tube
14-ft. taper tube
8-ft. straight tube
8-ft. taper tube
8-ft. straight tube, lips level
KEUFFEL & ESSER CO., N. Y. NO. 359-11
10 × 10 to the inch

FIGURE 6



Vortex Tube Data
Tube at 60 Degrees with Stream Flow
Mean Velocity in Feet per Second over Lip
Revolutions per Minute
Free flow
Tube submerged
Flume submerged
14-ft. straight tube
14-ft. taper tube
8-ft. straight tube
8-ft. taper tube
6-ft. straight tube, lips level

FIGURE 7



Vortex Tube Data
Tube at 60 Degrees with Stream Flow
Mean Velocity in Feet per Second over Lip
Translation – Feet per Second
0
1.00
2.00
3.00
1
2
3
4
5
6
7
8
Free Flow
Tube submerged
Flume submerged
14-ft. straight tube
14-ft. taper tube
8-ft. straight tube
8-ft. taper tube
8-ft. straight tube lips level

FIGURE 8

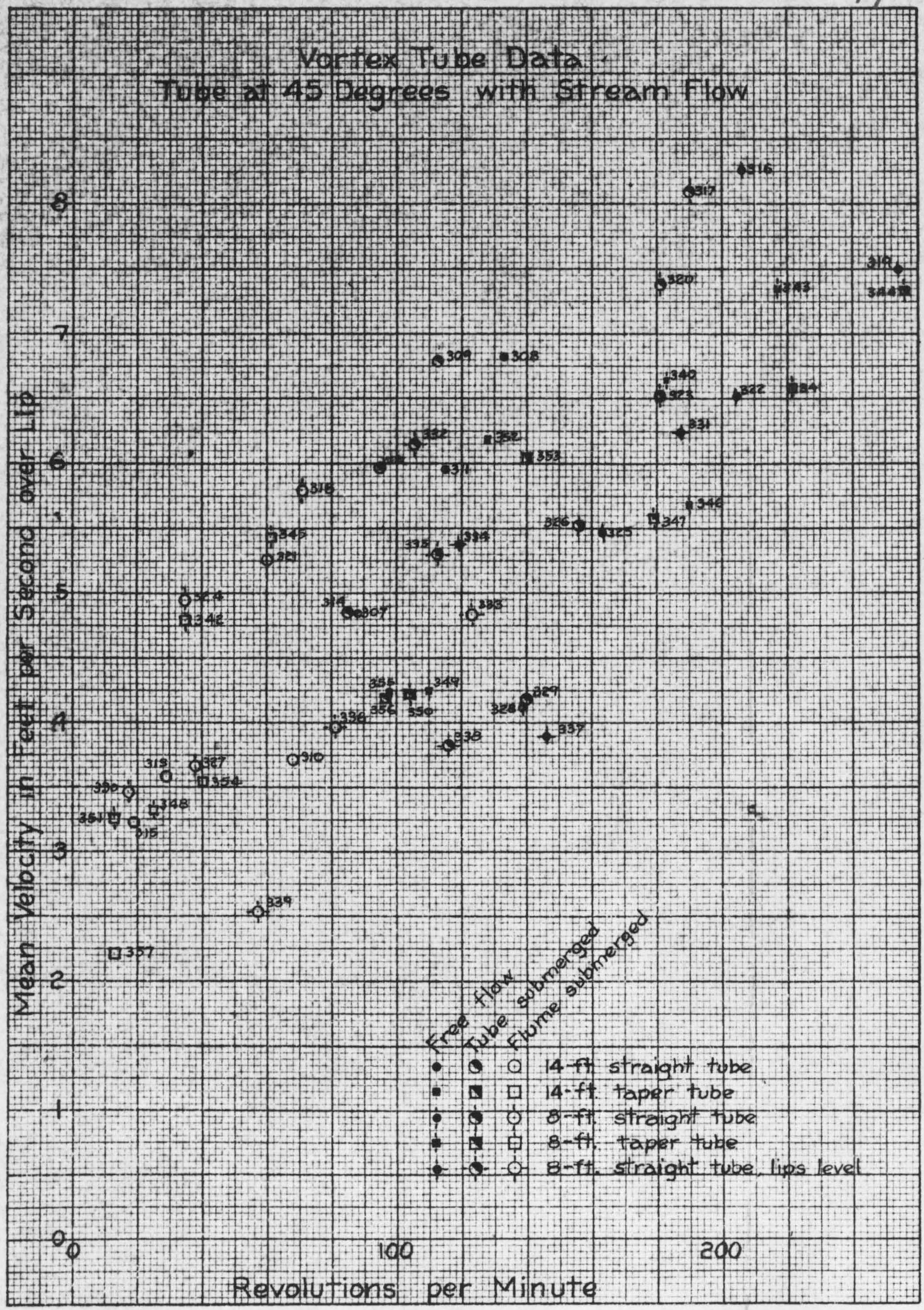
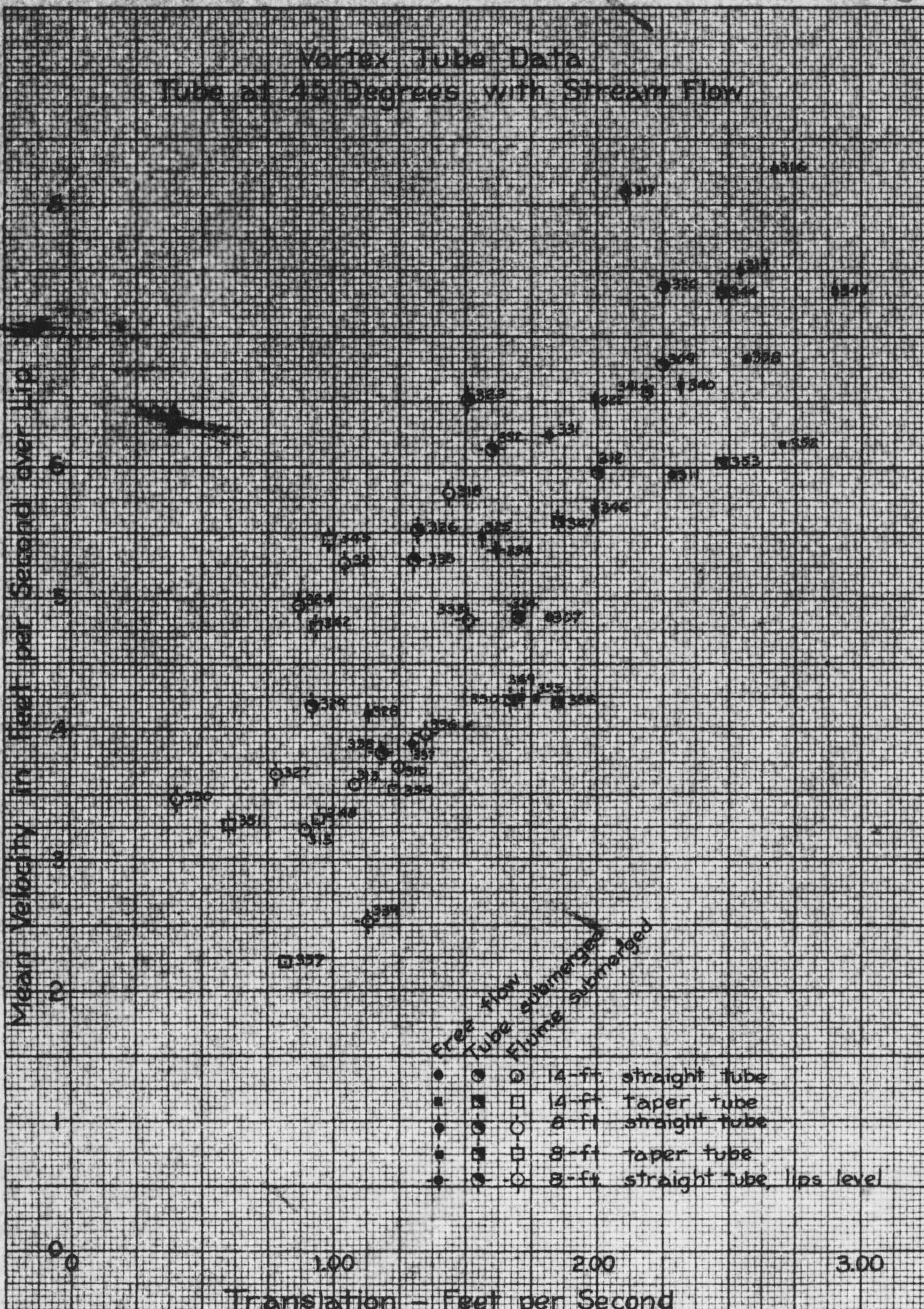
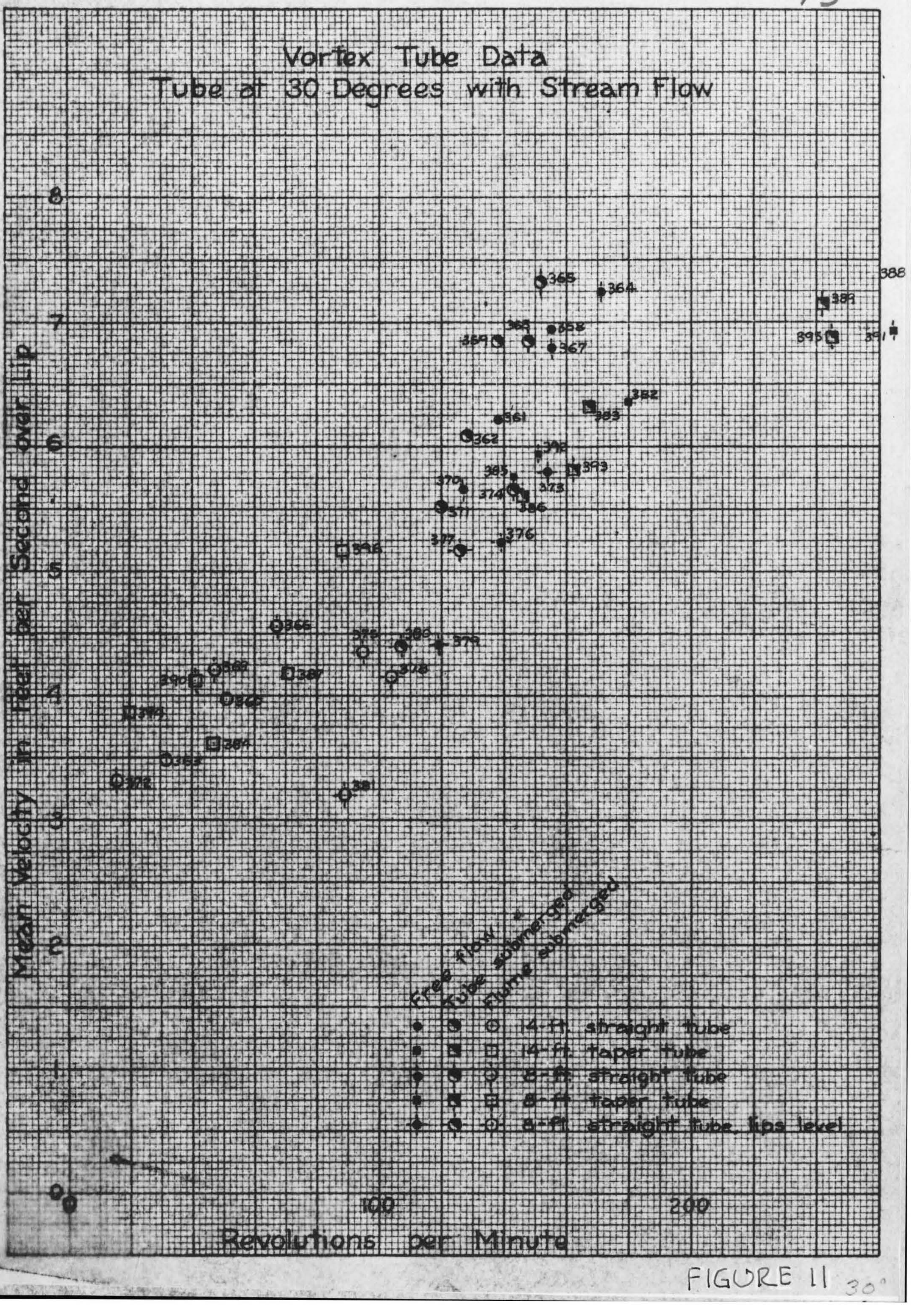

Vortex Tube Data
Tube at 45 Degrees with Stream Flow
Mean Velocity in Feet per Second over Lip
Revolutions per Minute
0
100
200
1
2
3
4
5
6
7
8
Free flow
Tube submerged
Flume submerged
14-ft. straight tube
14-ft. taper tube
8-ft. straight tube
8-ft. taper tube
8-ft. straight tube, lips level
316
317
319
320
343
344
309
308
340
323
322
324
331
332
352
353
311
318
346
326
325
347
345
335
334
321
324
342
314
307
333
355
349
356
350
328
329
336
338
337
310
313
327
354
330
348
351
315
339
357

FIGURE 9



KEUFFEL & ESSER CO., N. Y. NO. 359-11
20 x 20 to the inch.

FIGURE 10



Vortex Tube Data
Tube at 30 Degrees with Stream Flow
Mean Velocity in Feet per Second over Lip
Revolutions per Minute
0
100
200
1
2
3
4
5
6
7
8
Free flow
Tube submerged
Flume submerged
14-ft. straight tube
14-ft. taper tube
8-ft. straight tube
8-ft. taper tube
8-ft. straight tube, lips level

FIGURE 11 30°

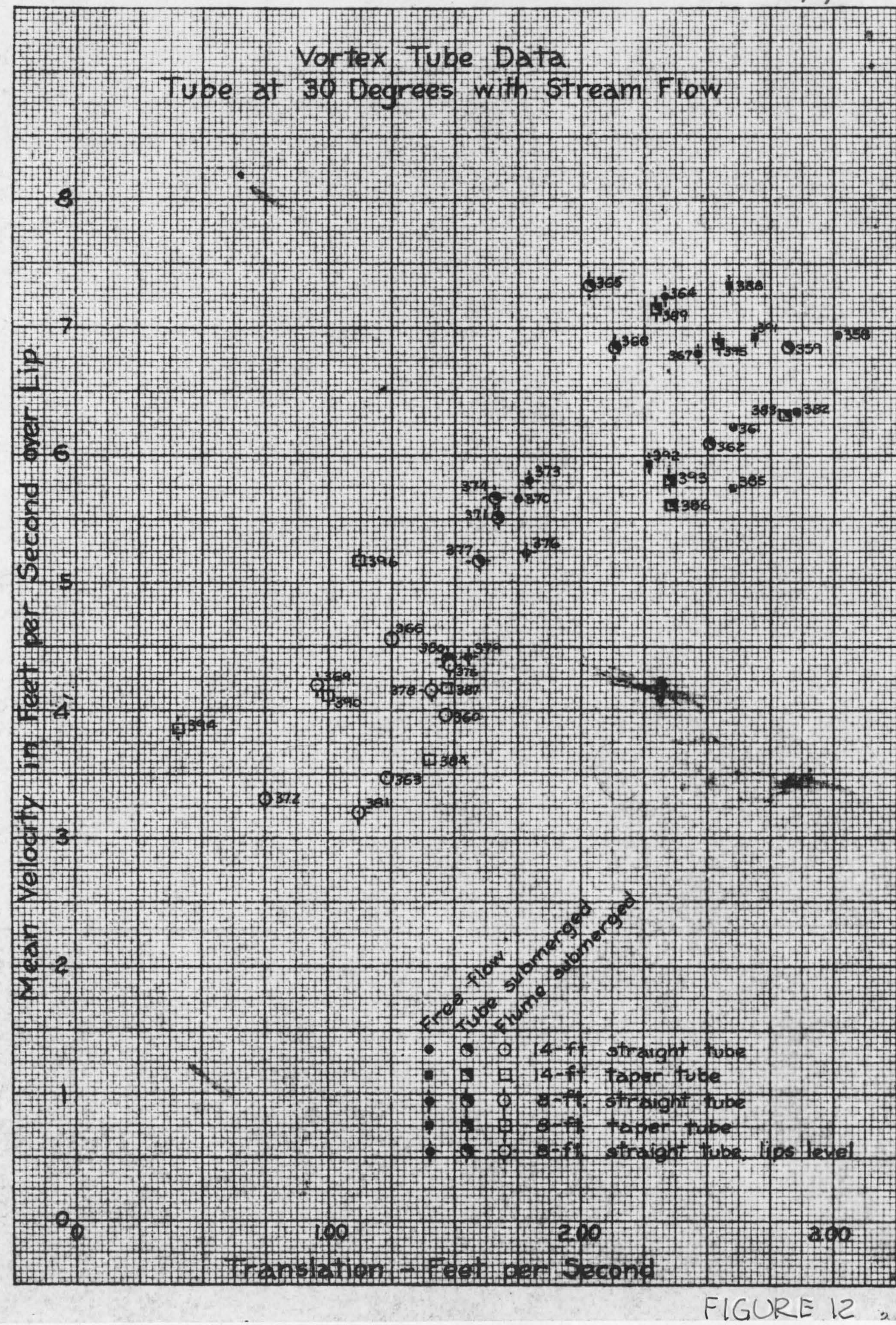

Vortex Tube Data
Tube at 30 Degrees with Stream Flow
Mean Velocity in Feet per Second over Lip
Translation - Feet per Second
0
1.00
2.00
3.00
1
2
3
4
5
6
7
8
Free flow
Tube submerged
Flume submerged
14-ft. straight tube
14-ft. taper tube
8-ft. straight tube
8-ft. taper tube
8-ft. straight tube, lips level

FIGURE 12

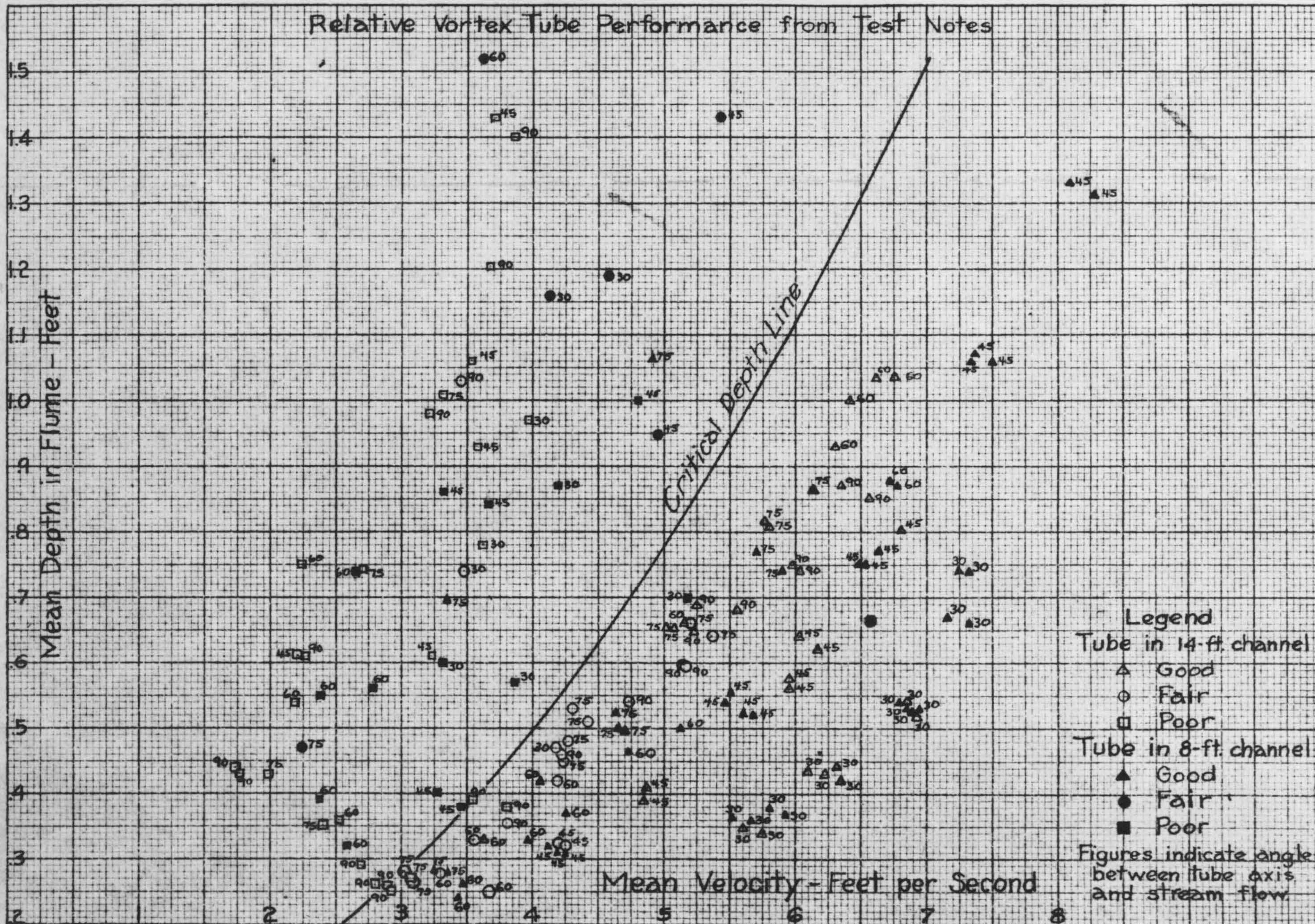
except that the data for the condition when the flume was submerged are on the lower end of the group of points, and the data for the free flow condition are on the upper end in each plot.

It was thought that the rotation in the tubes might be caused by the water in the flume sliding over the water in the tubes in such a manner that the water in the tubes would act as a roller and consequently would have a peripheral speed equal to or approaching the velocity of the water in the flume. The comparison of the average peripheral speed of the water in the tubes with the velocity of the water in the flume was made for each test, and it was found that the peripheral speed of the water in the tubes was much lower than the velocity of the water in the flume being less than half in most instances. In general, the peripheral speed increased as the flume velocity increased, but it was so much less that it is doubtful whether the rotation of the water in the tubes can be attributed to the sliding action of the water in the flume.

Comparison of the results of the rotation tests on the straight and taper tubes shows that the rotation and the translation are approximately the same for the 75 and 90 degree angles. For angles less than 60 degrees both the rate of rotation and the velocity of translation are faster for the taper tube. This would indicate that the taper tube is more active than the straight tube. This superiority is not shown by the tests on the efficiency of the tubes in removing sand. It should be pointed out that the tests on the 90 degree angle and some of those on the 75 degree angle were made with the five-inch propellers whereas the remaining tests were made with the four-inch propellers.

The data were plotted also to show how the action in the tube varied with the mean velocity in the flume at various depths. All the data where observations as to the activity of the tube were recorded, were used. The observations were classified as "good", "fair," and "poor." No distinction was made between the straight and taper tubes, but the observations on the 14-foot channel were separated from those on the 8-foot channel and the angle was indicated on each plotted point. The results are shown in figure13.

The curve drawn in the figure is the critical depth line. This line divides the plotted points into two groups. To the left of the line are the observations where the action of the tube was poor and to the right are those where the action of the tube was fair or good. For some reason there is a zone along this critical depth line where there are no points. This is probably owing to the fact that it is difficult to run water at the critical depth except where a control occurs. The plot shows also that the higher the velocity is at any depth, the more active the tube becomes. Another thing shown is that these velocities increase as the angle between the



Relative Vortex Tube Performance from Test Notes
Mean Depth in Flume - Feet
Mean Velocity - Feet per Second
Critical Depth Line
Legend
Tube in 14-ft. channel
Good
Fair
Poor
Tube in 8-ft. channel
Good
Fair
Poor
Figures indicate angle between tube axis and stream flow

FIGURE 13

tube and the axis of the flume decreases. This may be caused by the fact that the tube acts as a spillway which would tend to speed up the water. The smaller the angle, the longer the tube would be, and consequently the longer the spillway also.

The percentage of water passing through the tube into the auxiliary channel varied with the condition under which the tube was operating. The largest percentage passed through the tube when the flume was submerged and the tube was discharging under the freeflow condition. The smallest percentage passed through the tube when the outlet was submerged and the flume was operating under the free flow condition. When both the tube and the flume were operating under the freeflow condition, the percentage passing through the tube was intermediate between the two conditions mentioned previously. The extreme range of percentages for all conditions was from 0.8 to 21.6. The large percentages were for very small flows. In most of the tests the percentages passing through the tube were definitely under 5 percent.

The data on the observations on the efficiency of the tubes in removing sand are given in table 6. The table shows the conditions under which the tests were made and the results of the tests. It will be observed that the tare corrected in accordance with the time required for the test was all subtracted from the amount of sand passing through the tube.

the tube. Some of the sand remaining in the tube probably came from that carried by the water from the river and should have been deducted from the amount remaining in the tube. Since there was no accurate method of dividing the tare between the two amounts, all was subtracted from the amount of sand passing through the tube, as this would be the least favorable to either condition. A large amount of sand remaining in the tube would be just as unsatisfactory as to have a small amount of sand pass through the tube.

The data in table 6 show that generally the largest proportion of sand was removed when operating under the free-flow condition, and that the least amount was removed when the flume was submerged. When the tube outlet was submerged, the amount removed was about the same as when operating under the free-flow condition. The data show also that there was little if any difference between the results obtained with the straight and the taper tubes, but the 8-foot tubes removed slightly more sand in proportion to their length than the 14-foot tubes. The angles of the tubes apparently did not affect the results except when the tubes were at right angles to the axis of the flow. For this condition the tubes are definitely less efficient than when set at a smaller angle. The results of the observations made when the lower lip of the tube was at the same elevation as the upper lip are conspicuously better than those for any other condition. Even those tests made when the flume was

Table 6 Summary of Tests Showing Percentage of Sand Removed by Tubes Under Different Conditions

Date	Condition	Type of Tube	Flume Width	Discharge Flume	Discharge Tube	Ratio	Flume Depth	Diff in Head	Flume Velocity	Time	Dumped	In Tube	Thru Tube	Tare	Net in Tube	Thru Tube
			Feet	Sec-ft	Sec-ft		Feet	Feet	Ft/sec	Min	Bkts	Bkts	Bkts	Bkts	Bkts	Percent
7/24/33	FF*	12" straight, 90°	14	48.24	4.24	8.8	.72	.61	4.79	8	6	----	5.33	.29	5.04	84
7/24/33	TS*	"	14	47.29	2.23	4.7	.71	.40	4.75	8	6	3.9	2.00	.29	1.71	28
7/24/33	FS*	"	14	47.46	6.00	12.6	.86	.31	3.94	8	6	3.0	3.00	.29	2.71	45
7/31/33	TS	4"-6" taper, 90°	14	38.12	1.23	3.2	.62	.42	4.39	9	6	2.0[a]	3.00	.07	2.93	49
7/31/33	FS	"	14	34.39	2.15	6.3	.84	1.03	2.92	15	6	4.3	1.10	.12	.98	16
7/31/33	FF	"	14	35.92	1.48	4.1	.61	1.14	4.20	9	6	2.0	2.95	.07	2.88	48
7/31/33	FF	"	14	35.92	1.48	4.1	.62	1.14	4.14	15	-	---	.12	---	----	--
8/2 /33	FF	6" straight, 90°	14	74.28	1.80	2.4	.95	1.40	5.58	18	-	---	.49	---	----	--
8/2 /33	FF	"	14	71.10	1.77	2.5	.95	1.39	5.35	15	6	.7	3.67	.41	3.26	54
8/2 /33	FF	"	14	43.26	1.52	3.5	.70	1.16	4.41	15[b]	6	.7	3.70	.41	3.29	55
8/ 5/33	TS	"	14	34.94	.76	2.2	.60	.38	4.16	10	6	1.3	3.40	.27	3.13	52
8/ 5/33	FS	"	14	34.40	2.16	6.3	.82	1.19	3.00	20	6	.4	2.00	.54	1.46	24
8/10/33	FF	6" straight, 75°	14	31.73	1.51	4.8	.57	1.10	3.98	15	-	---	.03	---	----	--
8/10/33	FF	"	14	32.36	1.51	4.7	.57	1.10	4.05	9	6	.9	3.90	.02	3.88	65
8/11/33	TS	"	14	38.72	.82	2.1	.64	.34	4.32	10[d]	6	.8	4.10	.02	4.08	68
8/11/33	FS	"	14	32.34	2.12	6.6	.74	1.15	3.12	15	6	3.2	2.40	.03	2.37	39
8/15/33	FF	6" straight, 75° c	8	19.49	1.79	9.2	.60	1.04	4.06	10	4	.0	3.62	.02	3.60	90
8/15/33	TS	" c	8	20.47	1.12	5.5	.60	.27	4.26	10	4	.1	3.80	.02	3.78	94
8/15/33	FS	" c	8	19.65	1.68	8.6	.76	1.16	3.23	10	4	1.8	2.10	.02	2.08	52
8/16/33	FS	6" straight, 75°	8	18.57	2.11	11.4	.71	1.12	3.27	90	-	---	.02	---	----	--
8/16/33	FS	"	8	21.97	1.55	7.1	.62	1.12	4.43	8	4	0	3.30	0	3.30	83
8/16/33	TS	"	8	21.18	.43	2.0	.61	.26	4.34	10	4	.1	3.27	0	3.27	82
8/16/33	FF	"	8	21.74	1.48	6.8	.61	1.16	4.46	10	4	0	3.12	0	3.12	78
8/22/33	FF	4"-6" taper, 75°	8	21.85	1.54	7.0	.62	1.14	4.41	8	4	0	3.36	0	3.36	84
8/22/33	TS	"	8	21.69	.50	2.3	.61	.30	4.44	5	4	0	3.22	0	3.22	80
8/22/33	FS	"	8	21.44	2.20	10.3	.77	1.16	3.48	13	4	.75	3.03	0	3.03	76
8/24/33	FF	4"-6" taper, 75°	14	13.40	1.09	8.1	.37	.94	2.59	15	6	.25	4.85	0	4.85	81
8/24/33	TS	"	14	12.48	.45	3.6	.35	.20	2.55	10[d]	6	1.15	4.05	0	4.05	67
8/24/33	FS	"	14	7.57	1.42	18.8	.33	.86	1.64	18	6	4.32	1.35	0	1.35	22
8/30/33	FF	6" straight, 60°	14	25.96	1.43	5.5	.49	1.00	3.78	15	6	0	4.87	0	4.87	81
8/30/33	TS	"	14	25.43	.37	1.5	.48	.24	3.78	15[d]	6	.50	4.70	0	4.70	78
8/30/33	FS	"	14	24.92	2.05	8.2	.80	1.29	2.23	28	6	4.05	1.30	0	1.30	21
9/ 5/33	FF	6" straight, 60° c	8	16.26	1.85	11.4	.50	1.00	4.07	10	4	.09	4.02	.03	3.99	100
9/ 5/33	TS	" c	8	16.61	.70	4.2	.53	.12	3.92	10	4	.32	3.58	.03	3.55	90
9/ 5/33	FS	" c	8	16.36	2.00	12.2	.67	1.14	3.05	17	4	1.50	2.34	.04	2.30	58
9/ 5/33	FF	" c	8	16.09	1.78	11.1	.52	1.05	3.87	15	-	----	.04	---	----	--
9/13/33	FF	6" straight, 60°	14	33.32	1.59	4.8	.61	1.20	3.90	10	6	----	5.42	.03	5.39	90
9/13/33	FF	"	14	36.58	1.68	4.6	.66	1.13	3.96	15	-	----	.25	---	----	--
9/13/33	TS	"	14	36.65	.23	.6	.66	.26	3.97	10	6	1.25	1.20	.17	1.03	17[h]
9/13/33	FS	"	14	35.05	2.17	6.2	.94	1.42	2.66	15	6	4.40	1.40	.25	1.15	19

Table 6 continued

Date	Condi-tion	Type of Tube	Flume Width	Discharge Flume	Discharge Tube	Ratio	Flume Depth	Diff in Head	Flume Velo-city	Time	Dumped	In Tube	Thru Tube	Tare	Net	Thru Tube
			Feet	Sec-ft	Sec-ft	percent	Feet	Feet	Ft/sec	Min	Bkts	Bkts	Bkts.	Bkts	Bkts	Percent
9/16/33	FF	4"-6" taper, 60°	14	39.49	1.66	4.2	.65	1.12	4.34	9	6	0	5.45	.15	5.30	88
9/16/33	FF	"	14	39.19	1.63	4.2	.64	1.12	4.37	15	-	-	.37	---	----	--
9/16/33	TS	"	14	39.39	1.02	2.6	.65	.32	4.33	10	6	-	4.72	.25	4.47	74
9/16/33	FS	"	14	36.72	2.15	5.9	.88	1.36	2.98	11	6	3.10	2.38	.27	2.11	35
9/19/33	FF	4"-6" taper, 60°	8	20.19	1.49	7.4	.59	1.17	4.28	13	4	0	3.35	0	3.35	84
9/19/33	TS	"	8	20.37	.91	4.5	.59	.31	4.31	11	4	0	3.50	0	3.50	88
9/19/33	FS	"	8	20.18	2.00	9.9	.79	1.28	3.19	13	4	1.25	2.35	0	2.35	58
9/19/33	FF	"	8	20.26	1.45	7.2	.59	1.17	4.29	15	-	----	0	-	----	--
9/27/33	FF	6" straight, 45°	14	62.05[e]	2.12[e]	3.4	.74[e]	1.09[e]	5.99	15	-	----	.07	-	----	--
9/27/33	FF	"	14	62.05	2.12	3.4	.74	1.09	5.99	12	6	0	4.63	.06	4.57	76
9/27/33	FF	"	14	62.30	2.13	3.4	.75	1.09	5.93	11	6[f]	0	4.75	.05	4.70	78
9/27/33	TS	"	14	61.95	1.31	2.1	.75	.25	5.90	10	6	0	4.71	.05	4.66	78
9/27/33	FS	"	14	59.35	2.60	4.4	1.18	1.58	3.59	10	6	3.42	2.05	.05	2.00	33
9/29/33	FF	6" straight, 45°	8	32.41	1.81	5.6	.60	1.15	6.76	12	4	0	3.18	.01	3.17	79
9/29/33	TS	"	8	32.54	1.13	3.5	.62	.31	6.56	10	4	0	3.14	.01	3.13	78
9/29/33	FS	"	8	31.50	2.45	7.8	1.04	1.47	3.79	10	4	1.81	2.03	.01	2.02	51
9/29/33	FF	"	8	32.41[g]	1.81[g]	5.6[g]	.60[g]	1.58[g]	6.76	15	-	----	.01	---	----	--
10/3/33	FF	6" straight, 45° c	8	22.47	2.27	10.1	.59	1.05	4.76	11	4	0	3.88	0	3.88	97
10/3/33	TS	" c	8	21.96	1.43	6.5	.59	.19	4.66	11	4	0	3.78	0	3.78	94
10/3/33	FS	" c	8	22.09	2.26	10.2	.84	1.30	3.29	9	4	1.75	2.23	0	2.23	56
10/3/33	FF	" c	8	22.05	2.22	10.1	.58	1.04	4.75	15	-	----	0	-	----	--
10/7/33	FF	4"-6" taper, 45°	8	30.37	1.86	6.1	.60	1.12	6.32	13	4	0	3.24	0	3.24	81
10/7/33	TS	"	8	30.76	1.09	3.5	.60	.26	6.41	10	4	0	3.12	0	3.12	78
10/7/33	FS	"	8	29.83	2.41	8.1	1.01	1.41	3.69	10	4	1.90	1.97	0	1.97	49
10/7/33	FF	"	8	30.83	1.84	6.0	.60	1.12	6.42	15,	-	----	0	-	----	--
10/10/33	FF	4"-6" taper, 45°	14	57.16	2.03	3.6	.77	1.11	5.30	9	6	0	4.22	.12	4.10	68
10/10/33	FF	"	14	55.94	1.95	3.5	.72	1.14	5.55	15	-	-	.22	---	----	--
10/10/33	TS	"	14	58.19	.98	1.7	.76	.16	5.46	10	6	0	4.28	.15	4.13	69
10/10/33	FS	"	14	54.49	2.31	4.2	.96	1.36	4.06	12	6	1.72	3.39	.17	3.22	54
10/17/33	FF	6" straight, 30°	14	43.32	1.79	4.1	.54	1.18	5.74	15	-	----	.50	---	----	--
10/17/33	FF	"	14	43.79	1.84	4.2	.54	.88	5.79	11	6	0	4.67	.37	4.30	72
10/17/33	TS	"	14	44.07	.93	2.1	.56	.06	5.62	10	6	0	4.53	.33	4.20	70
10/17/33	FS	"	14	42.82	2.46	5.7	1.04	1.55	2.94	16	6	4.75	.82	.53	.29	05
10/19/33	FF	6" straight, 30°	8	42.74	2.45	5.7	.80	1.09	6.68	10	4	0	3.22	.05	3.17	79
10/19/33	TS	"	8	45.33	1.15	2.5	.80	.07	7.08	10[d]	4	0	3.35	.05	3.30	82
10/19/33	FS	"	8	41.77	2.79	6.7	1.28	1.73	4.08	10	4	1.81	2.13	.05	2.08	52
10/19/33	FF	"	8	42.39	2.38	5.6	.81	1.08	6.54	15	-	----	.08	---	----	---

Table 6 continued

Date	Condition	Type of Tube	Flume Width	Discharge Flume	Discharge Tube	Ratio	Flume Depth	Diff in Head	Flume Velocity	Time	Dumped	In Tube	Thru Tube	Tare	Net	Thru Tube
			Feet	Sec-ft	Sec-ft		Feet	Feet	Ft/sec	Min	Bkts	Bkts	Bkts	Bkts	Bkts	Percent
10/23/33	FF	6" straight, 30° c	8	43.05	2.76	6.4	.98	1.45	5.49	11	4	0	3.54	.04	3.50	88
10/23/33	TS	" c	8	42.90	1.92	4.5	.98	.40	5.47	10	4	0	3.64	.03	3.61	90
10/23/33	FS	" c	8	42.15	2.76	6.5	1.28	1.75	4.12	15	4	.50	3.25	.08	3.17	79
10/23/33	FF	" c	8	42.22	2.76	6.5	.98	1.35	5.38	15	-	---	.05	---	----	--
10/27/33	FF	4"-6" taper, 30°	14	41.39	1.65	4.0	.54	.89	5.48	10	6	0	4.55	.01	4.54	76
10/27/33	TS	"	14	42.30	.98	2.3	.54	.04	5.60	10	6	0	4.45	.01	4.44	74
10/27/33	FS	"	14	41.96	2.29	5.5	.80	1.34	3.75	15	6	3.85	1.62	.01	1.61	27
10/27/33	FF	"	14	42.49	1.72	4.0	.54	.90	5.62	15	-	----	.01	---	----	--
11/ 3/33	FF	4"-6" taper, 30°	8	28.89	1.95	6.8	.62	.82	5.82	10[d]	4	0	3.36	.01	3.35	84
11/ 3/33	TS	"	8	28.73	1.19	4.1	.62	.09	5.80	10	4	0	3.07	.01	3.06	76
11/ 3/33	FS	"	8	27.45	2.33	8.5	.85	1.33	4.03	15	4	1.30	2.25	.01	2.24	56
11/ 3/33	FF	"	8	28.49	1.96	6.9	.62	.87	5.74	15	-	----	.01	---	----	--

Note.--

* FF stands for Free Flow; FS, Flume submerged; and TS, Tube submerged.
(a) Amount left in tube from record of free flow test.
(b) Two minute interval between dumping of first and second half of sand.
(c) Upper and lower lips level.
(d) Time interval estimated.
(e) Records taken from test following.
(f) Sand dumped in slowly.
(g) Set same as suceeding free flow run.
(h) Sand came is so fast it clogged outlet.

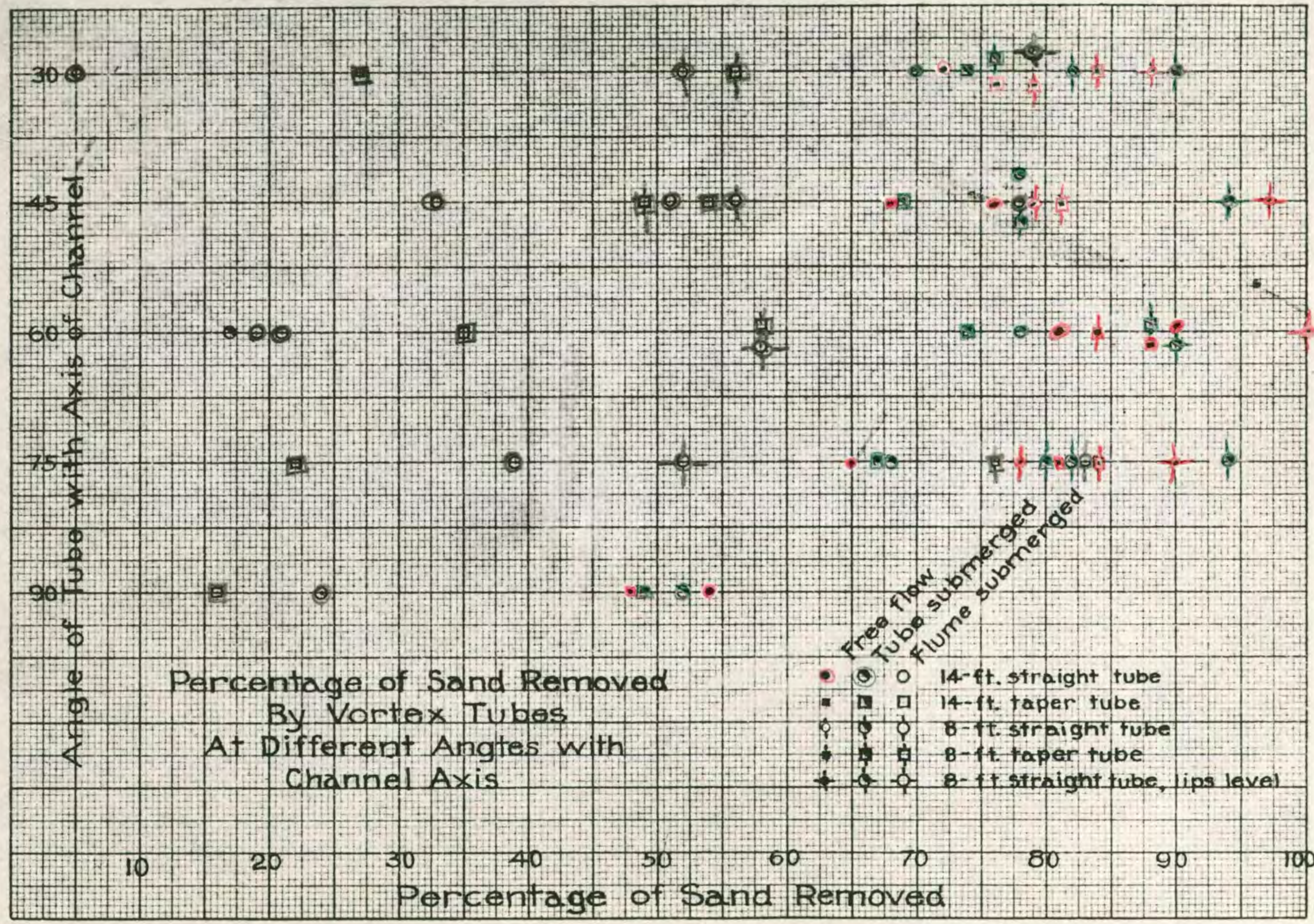

Percentage of Sand Removed
By Vortex Tubes
At Different Angles with
Channel Axis
Angle of Tube with Axis of Channel
30
45
60
75
90
Percentage of Sand Removed
10
20
30
40
50
60
70
80
90
100
Free flow
Tube submerged
Flume submerged
14-ft. straight tube
14-ft. taper tube
8-ft. straight tube
8-ft. taper tube
8-ft straight tube, lips level

FIGURE 14

submerged show a high percentage of efficiency in removing sand.

The data in table 6 have been plotted in figure 14 which shows the percentage of sand removed by the tubes when set at different angles. The symbols indicate the condition of flow, type of tube, and width of flume. This diagram shows graphically the facts brought out by the study of the data in table 6, and in addition it reveals how the observations are distributed with reference to the percentage of sand removed. Nearly all the points fall to the right of the 50 percent line and a large number fall in the zone beyond the 70 percent line.

These data show clearly that under proper conditions, the tubes will remove 80% of the bed-load and if two tubes are installed, the second tube should remove 80 percent of the remaining 20 percent or 16 percent, making a total of 96 percent which would be very satisfactory. This is based on the assumption that the 20 percent passing the first tube is just as easy to trap as the bed-load was originally.

Summary

The method of using right-and-left-hand propellers on a Hoff meter to determine the velocity of translation yielded consistent results. The absolute accuracy of the method could not, however, be determined. Comparative tests made by timing visible suspended matter in the tubes agreed reasonably well with the observations by the propeller method.

The average rates of rotation in the tube by the ball turbine checked the results obtained by the right-and-left-hand propellers quite closely when the tubes were set at an angle of more than 45 degrees with the axis of flow in the channel, but the agreement was not so good when the angle was less than 45 degrees.

The rate of rotation and the velocity of translation both increase as the velocity increases and the rate of increase is greater as the angle between the tube and the axis of the flume decreases.

The velocity of translation and the rate of rotation are slightly higher for the taper tube than the straight tube, particularly when the angle between the tube and the axis of the channel is small.

The tubes are most efficient in removing sand, when operating under the free-flow condition, that is, when both the tube and the flume are flowing free. Moderate submergence of the tubes has little effect on the efficiency, but submerging the flume reduces the efficiency materially.

The tubes are most active when the depth of the water in the flume is less than critical. The percentage of water passing through the vortex tube varied with the conditions but for most of the tests it was less than 5 percent.

The straight and taper tubes are about equally efficient in removing sand. Raising the lower lip of the straight tube, however, materially increases the efficiency of the tube.

The angle of the tubes apparently has little effect on the efficiency for angles less than 90 degrees. The efficiency at the 90 degree angle is definitely less than at the other angles.

Under proper condition, the tubes will remove from 70 to 90 percent of the bed-load carried by the flume.

Recommendations

As a result of these tests it is recommended that observations be made on the effect of raising the tubes so as to reduce the depth at the tube and to increase the velocity. It is believed that more tests should be made on the effect of changing the level of the lower lip on the efficiency of the tube.