An Investigation of Wind Pressure upon Surfaces.

Almost the only data which we have on the subject of wind pressure, were obtained by Prof. S. P. Langley, as published in the report of the Smithsonian Institute. Prof. Langley's work was carried on wholly with plane surfaces, and his results were all obtained by means of a whirling table, having a radius of thirty feet. The horizontal pressures were obtained by registering the extension of a calibrated spring, upon a revolving chronograph cylinder. The vertical pressures were obtained by using planes of different weights, and determining by electrical means, when the speed of the plane was just sufficient for the vertical component of the pressure developed, to raise its weight. Necessarily, there was considerable friction in such an apparatus.

The object of this thesis was to

make a study of wind pressures upon surfaces set at various angles to, and in different velocities of, a current of air, set in motion by means of a blower, and then to compare the results of such experiments with those obtained by Prof. Langley with his "whirling table."

The impossibility of using a "whirling table" at the Institute was apparent at the very outset, on account of lack of floor space. It was decided that the same results ought to be obtained by blowing a current of air, of known velocity, against a surface which was held stationary, as was obtained by moving the surface through the air, at the same speed.

The question at once arose regarding the source of this air supply. Since it would be very expensive to

install a new blower for this purpose, it was decided that the one located in the Engineering Laboratory Basement, and used for ventilating the building, could be utilized. At first sight, it seemed possible to locate the apparatus in some one of the flues, which conduct the air through the building. These, however, I found to be more or less filled with pipes, steam or otherwise, which would prevent a uniform flow of air through the flues, and which would also be in the way when making experiments. Thus I came to the conclusion that the only feasible method of getting the air supply, was to tap one of the flues at some convenient point, with a pipe of sufficiently large area, and to prevent the passage of the air in

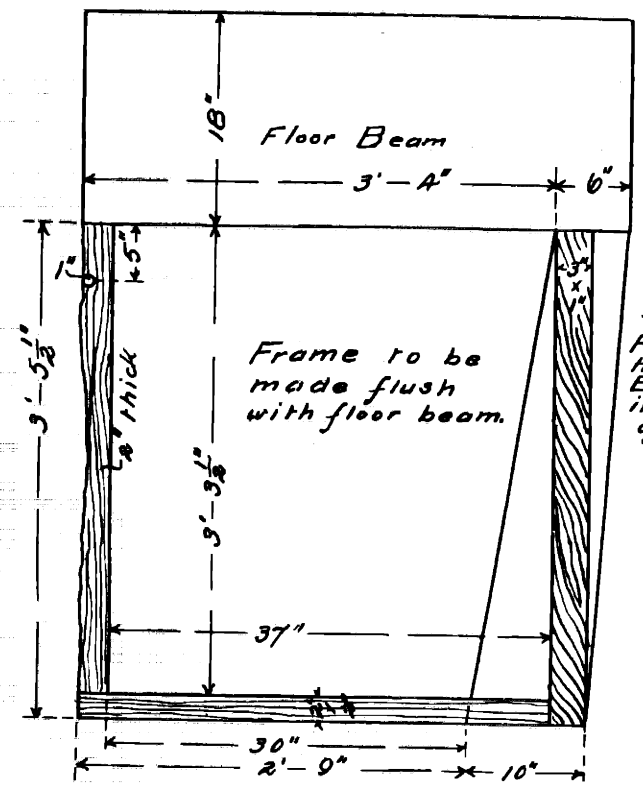
any direction except through the pipe, by means of dampers.

The most convenient place for tapping the flues, was found to be in the one which runs along the north side of the Basement, just beneath the floor. A galvanized iron pipe, three feet square, was let into the flue through the floor, between the Harris-Corliss engine and the Davis pump. This pipe was brought up perpendicularly from the floor, and then, by means of a long elbow, changed to a horizontal direction, leaving something over six feet head room beneath, and having its mouth in such a position that the air would be discharged over the pit. This pipe was published with a damper at the level of the floor, for shutting off the air when

not in use. For the dampers in the flues below I took measurements, and had wooden frames made to fit them leaving rectangular openings; then, after carefully locating the pipes from these frames, I designed and had constructed a set of dampers, the drawings of which accompany this thesis. Two of these dampers are held in place by means of wooden bars, dropped into catches made to receive them when the dampers are closed; the third damper located under the Harris-Corliss engine at the foot of the galvanized iron pipe, is held in a closed position by the mere pressure of the air upon it.

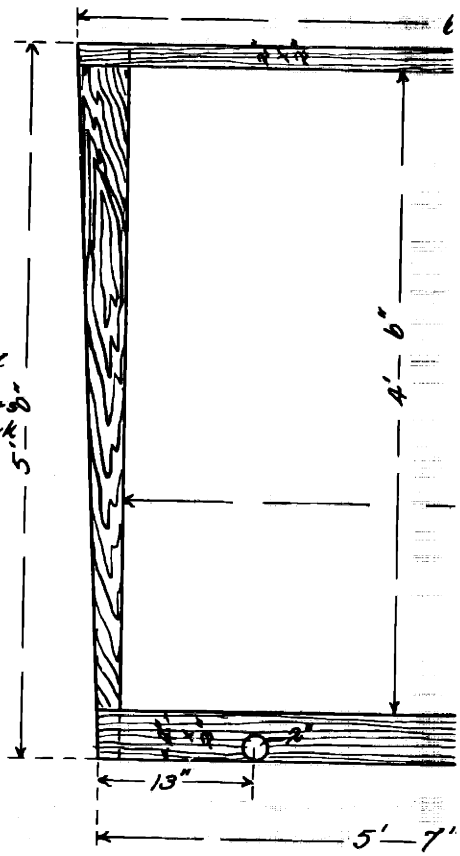
I decided to measure the velocity of the air flowing through the pipe, by means of a Casella anemometer belonging to the Engineering

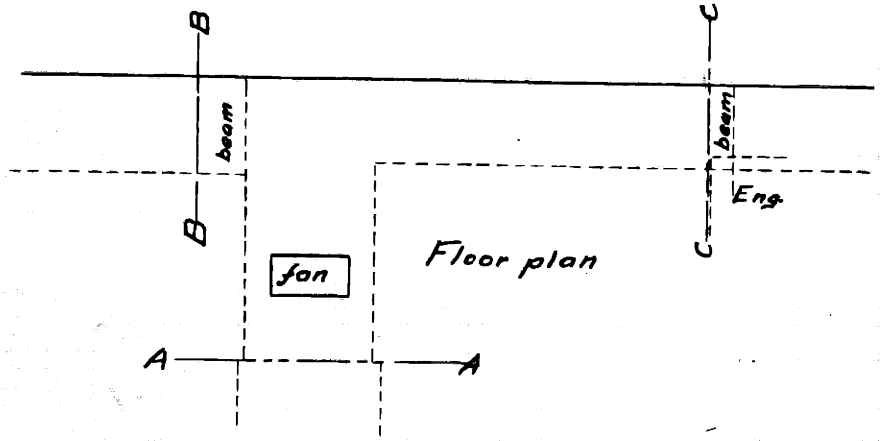
Section at CC.



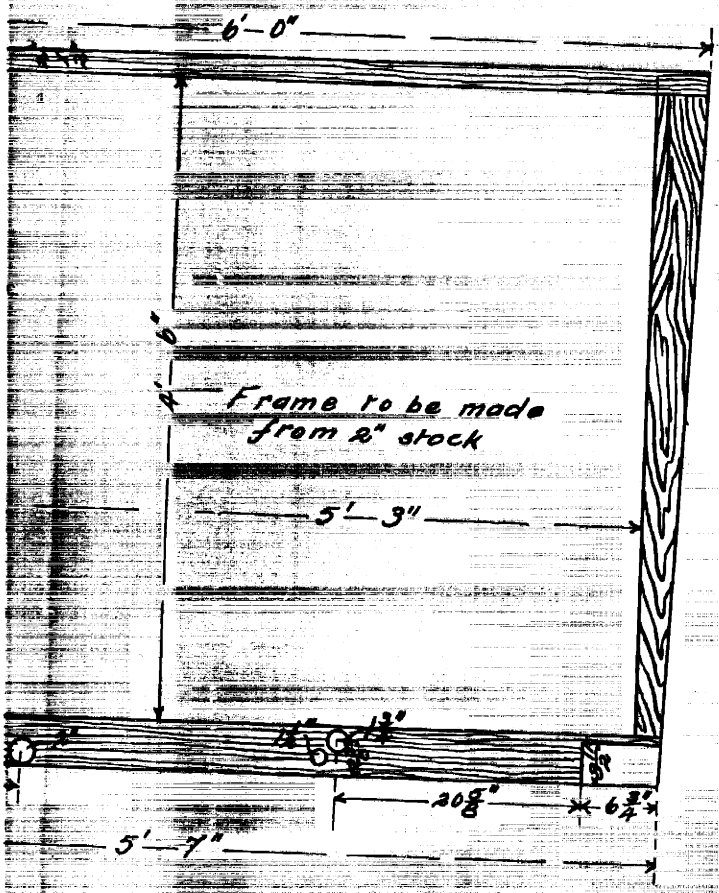
Foundation of Harris-Corliss Engine projects into flue 1" back of beam.

Section a





Section at A A.



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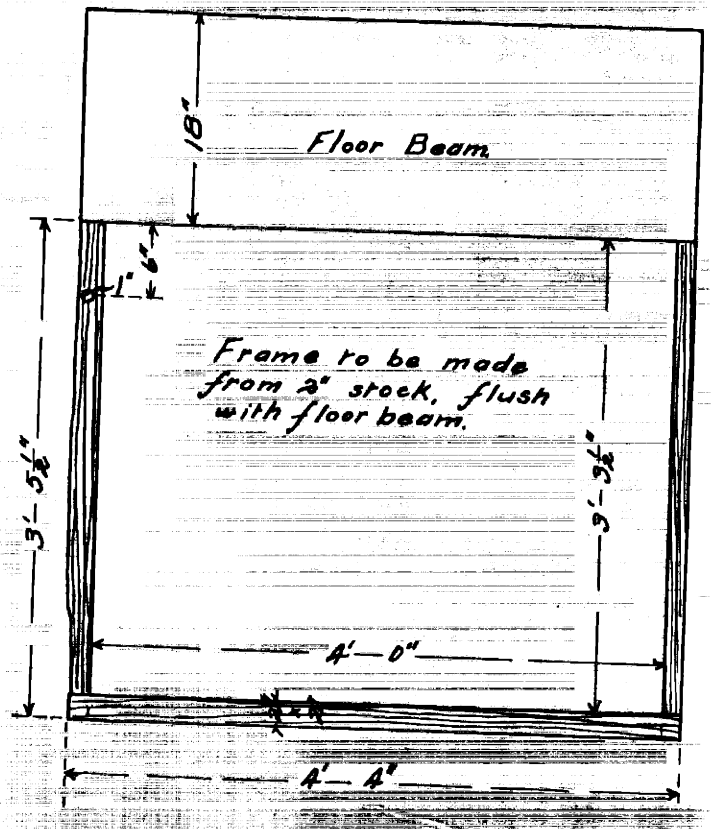
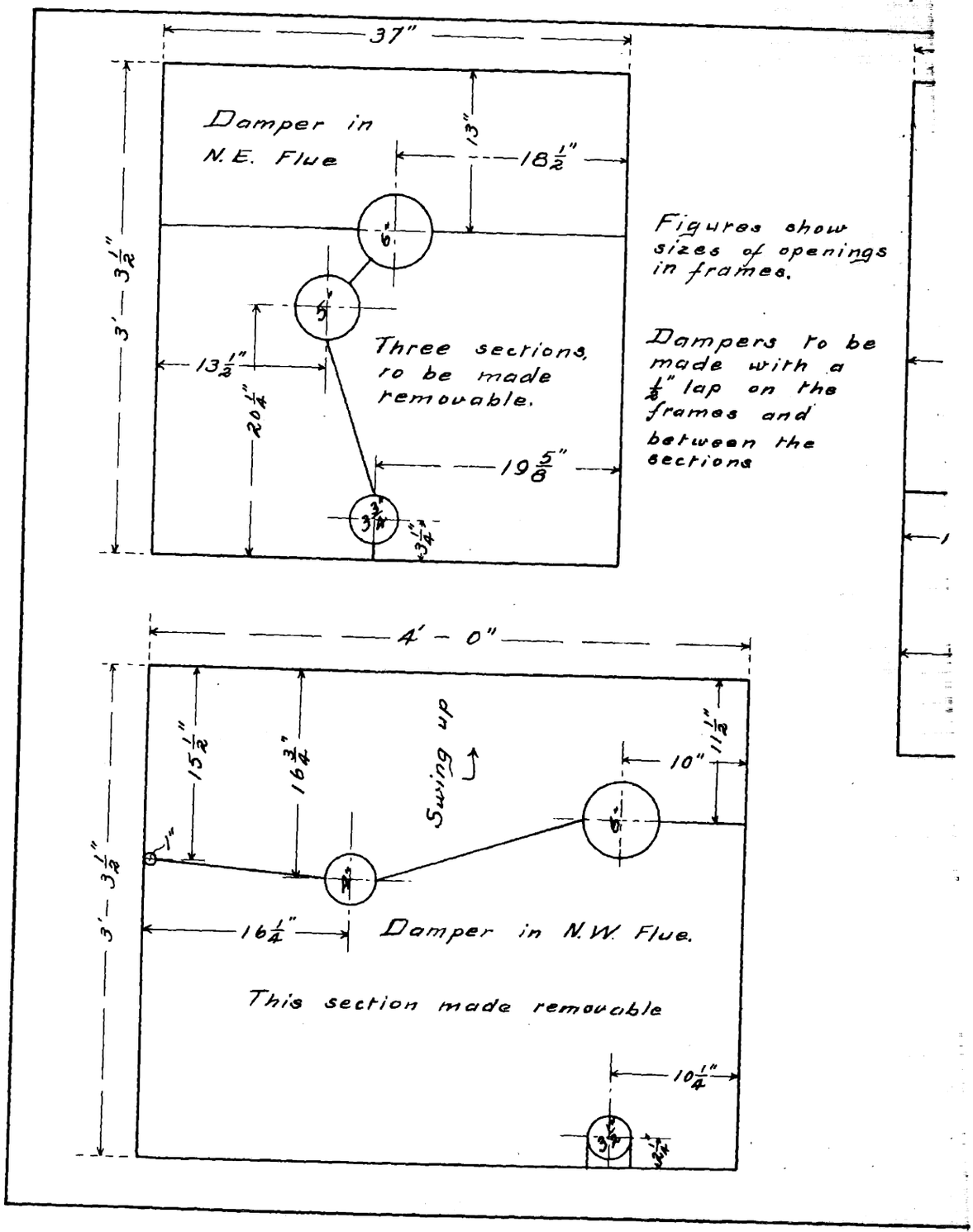


Wooden Frames for Dampers in Ventilating Flues of Engineering Building Mass. Inst. Tech.


37"
Damper in
N.E. Flue
13"
18 1/2"
3' - 3 1/2"
6"
5"
13 1/2"
20 1/4"
Three sections,
ro be made
removable.
19 5/8"
3 3/4"
3 1/4"
Figures show
sizes of openings
in frames.
Dampers ro be
made with a
1/8" lap on the
frames and
between the
sections
4' - 0"
15 1/2"
16 3/4"
Swing up
10"
11 1/2"
3' - 3 1/2"
16 1/4"
Damper in N.W. Flue.
This section made removable
10 1/4"
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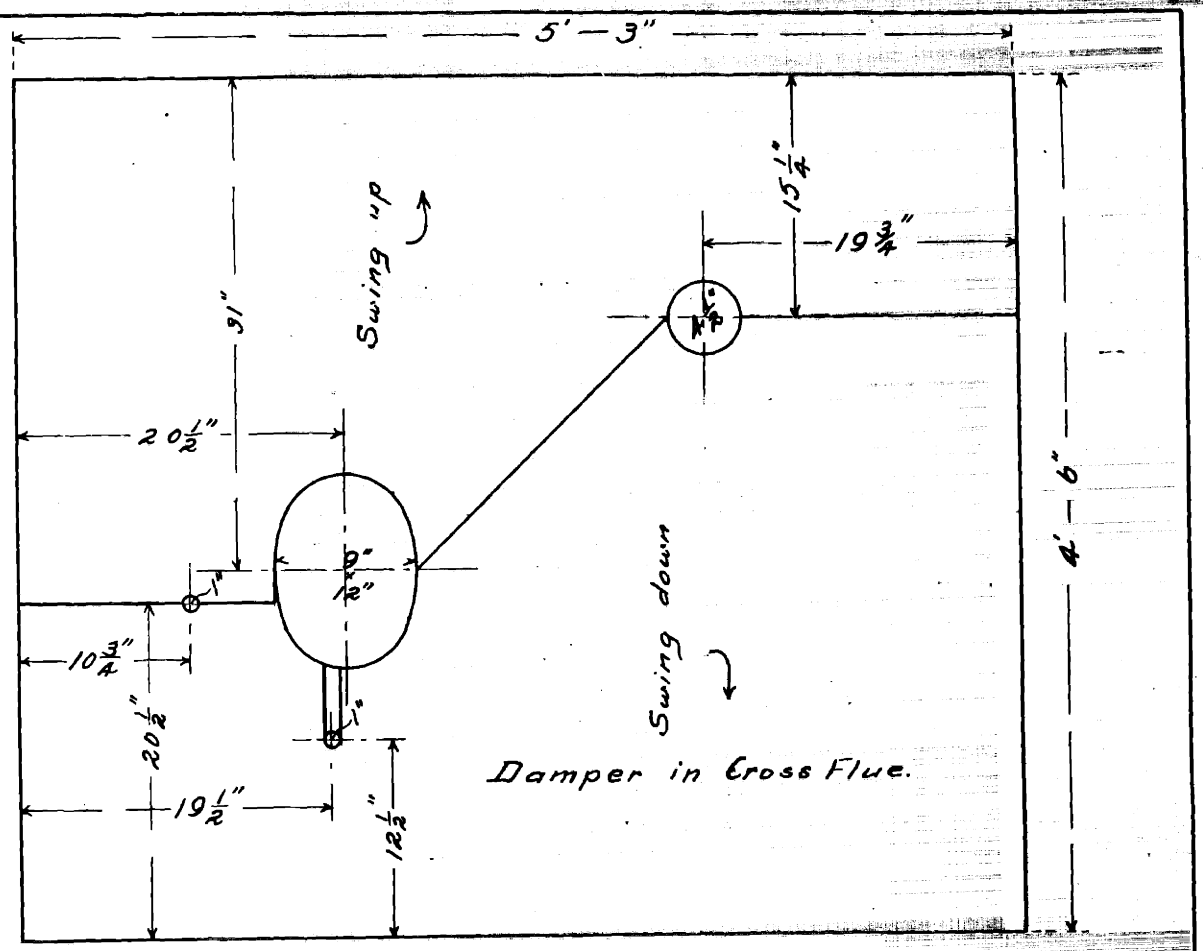
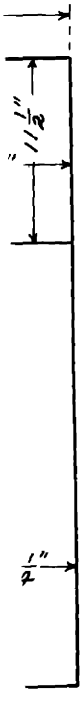




Dampers for Ventilating Flues in Basement of Engineering Bd'g.

Mass. Inst. Tech.

department. For this purpose, I calibrated it very carefully with a "flow of steam" apparatus.

Saturated steam had already been used in the Laboratory for calibrating an anemometer, but I found, when I tried to use it, that a considerable quantity of moisture condensed on the vanes of the instrument, and was thrown off by centrifugal force, thus imposing a condition which would not exist if air was being metered. The apparatus for using saturated steam was arranged as follows. A one and one half inch pipe was connected with a steam pipe at one end, and fitted with an orifice of known diameter, at the other. A gauge cock was fitted into the pipe, and a gauge attached,

by means of which, the pressure of the steam just back of the orifice could be obtained. Two valves were provided between the gauge and the steam supply, by means of which, the pressure back of the orifice could be brought to any desired point. The steam was discharged from the orifice into a piece of two and one half inch brass tube, open at the end. The joint at the orifice was carefully packed and shellaced, in order to prevent the suction of air.

After correcting the gauge, as shown in table I, by means of the mercury column in the Laboratory, it was placed in position, the anemometer was held up against the open end of the pipe, and steam was turned on. As was

before stated, the anemometer threw a considerable amount of moisture, I decided to superheat the steam.

Table I Gauge Corrections

Gauge Reading	Mercury Col. lbs.	Gauge Reading	Mercury Col. lbs.
20	20.4	50	50.0
25	24.4	55	55.5
30	30.4	60	60.3
35	35.5	65	65.3
40	40.5	70	70.0
45	45.6	75	74.7

Thermometer Corrections

0° −.2° 100° −.2

To do this, I put the two and one half inch pipe, conducting the steam from the orifice to the anemometer, inside a four inch galvanized iron pipe, which was to act as a hood, and which was provided with holes on the lower side, for the insertion of gas jets,

by means of which, the steam could be superheated. About four inches from the anemometer, I inserted a thermometer cup in the pipe in order to ascertain the amount of the superheat. In no case was the temperature allowed to reach one hundred and twenty degrees centigrade, on account of the danger of burning the anemometer. The temperature was governed by regulating the supply of gas to the burners. With this arrangement, after everything had become heated, no moisture was seen in the anemometer ring, and none was thrown from the vanes. Two different orifices were used, one, twenty-five hundredths of an inch in diameter, for the higher velocities, and the other, nineteen hundredths of an inch in diameter, for the lower velocities.

The method of conducting the experiments was to bring the pressure to some desired point, allow the steam to flow until its action became constant, then, to read the anemometer, and thermometer, every minute, for five consecutive minutes, using in the calculations, the average of the anemometer differences, and the average of the thermometer readings. The following method of calculation was used. The weight of steam, per minute, flowing through the orifice, was calculated by Napier's formula $G = \frac{F P_1 60}{70}$, G, being the weight of the steam in pounds per minute, F, the area of the orifice in square inches, and p_1, the absolute pressure.

The volume of the steam issuing from the superheating pipe,

and passing through the anemometer, was calculated by means of the equation

$$p v = 93.5\,T - 971\,p^{\frac{1}{4}}$$

in which, p is the pressure in pounds per square foot, in this case atmospheric pressure, since the discharge was into the air, v the volume in cubic feet of one pound, and T, the absolute temperature of the superheated steam in degrees Farenheit. Solving the equation for v, we obtain

$$v = \frac{93.5\,T - 971\,p^{\frac{1}{4}}}{p};$$

the total volume per minute will, of course, be the product obtained by multiplying this value by the number of pounds; that is, volume per minute $= v\,C_1$.

The velocity, at which the steam issued, is obtained by dividing this volume by the area of the pipe

in square feet. If A represent this area, then, velocity $= \frac{vG}{A}$.

Tests were made at thirteen different velocities, and, in each case, the velocity of the steam was calculated in the manner indicated above. The correction for the anemometer for any given speed, is the difference between the observed reading and the calculated velocity.

The data for all this work of calibration, together with the calculated velocity and correction in each case, may be found in table II. Having completed this table, a curve of corrections was plotted, using corrections for abscissas, and readings for ordinates. The readings extend over a range of from seven hundred and twenty feet per minute to three thousand two hundred and ninety-eight feet per minute, and the curve

enables us to get the correction for any reading between these limits. The plot follows table II.

Table II

Orifice 0.1900" Dia. Barom. = 29.55"

Steam Pressure	Anemom. Readings	Diff's.	Average	Temp. Deg's. C.	Average	Calcul. Velocity	Correc-rion.
20	1360			114.9			
	2095.	715		114.6			
	2820	725		114.4	114.9		
Cor. 20.4	3550	730	720	114.6	Cor. 114.7	700	−20
	4260	710		115.0			
	4980	720		115.9			
30	7010			115.3			
	7960	950		115.3			
	8900	940		115.5	115.3		
Cor. 30.4	9855	955	946	115.5	Cor. 115.1	902	−44
	0795	940		115.2			
	1740	945		115.2			
35	7580			115.5			
	8620	1040		115.8			
	9675	1055		116.0	115.3		
Cor. 35.5	0715	1040	1043	116.0	Cor. 115.1	1004	−39
	1745	1030		114.0			
	2795	1050		114.7			

Table II Cont.

Steam Pressure	Anemom. Readings	Diff's.	Average	Temp. Deg's C.	Average	Calcul. Velocity	Correc-rion.
40	7100			112.5			
	8260	1160		113.6			
	9390	1130		114.5			
Cor. 40.5	0540	1150	1150	115.0	114.2	1101	−49
	6750			115.4	Cor. 114.0		
	7900	1150		113.4			
	9060	1160		114.3			
Orifice	0.2500" Dia.					Barom. =	30.35"
20	5400			116.0			
	6670	1270		114.3			
	7950	1280		113.5			
Cor. 20.4	9240	1290	1280	113.2	113.5	1148	−92
	5750			113.2	Cor. 113.3		
	7030	1280		112.3			
	8310	1280		112.0			
25	0100			112.5			
	1620	1520		113.5			
Cor. 24.4	3135	1515	1516	115.5	114.4	1326	−190
	4645	1510		113.2	Cor. 114.2		
	6165	1520		114.2			
	7680	1515		117.5			

Table II Cont.

Steam Pressure	Anemom. Readings.	Diff's.	Average	Temp. Deg's C.	Average	Calcul. Velocity	Correction
30	9745			109.0			
	1450	1705		109.5			
Cor. 30.4	3150	1700	1701	110.7	110.8	1514	-187
	4860	1710		111.5	Cor. 110.6		
	6550	1690		111.8			
	8250	1700		112.3			
35	0190			114.4			
	2080	1890		114.7			
Cor. 35.5	3980	1900	1897	114.9	114.9	1704	-193
	5880	1900		115.0	Cor. 114.7		
	7780	1900		115.1			
	9675	1895		115.3			
40	9800			115.4			
	1900	2100		115.6			
Cor. 40.5	4015	2115	2105	115.9	116.0	1878	-227
	6115	2100		116.0	Cor. 115.8		
	8220	2105		116.3			
	0325	2105		116.6			

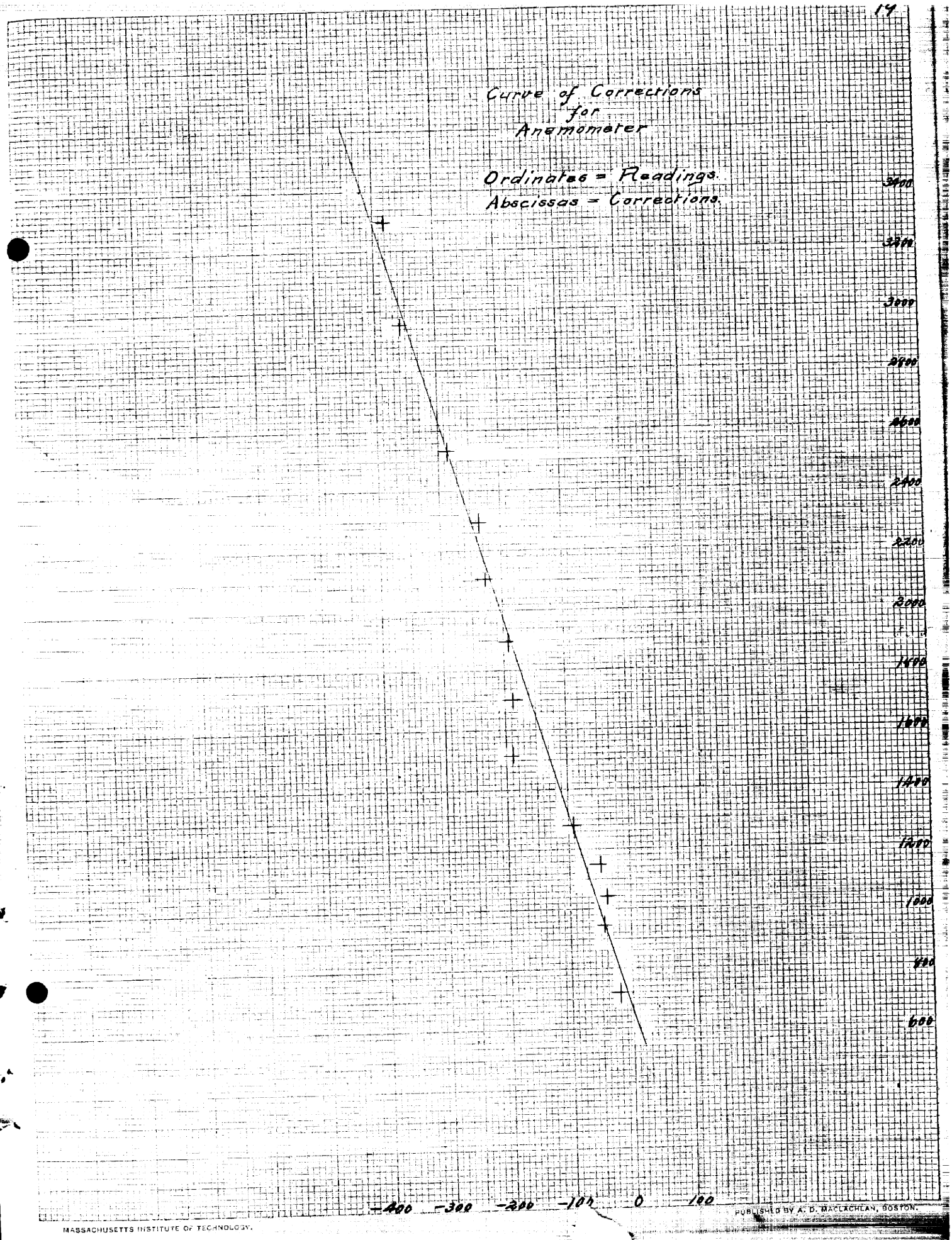
Table II Cont.

Steam Pressure	Anemom. Readings	Diff's.	Average	Temp. Deg's C.	Average	Calcul. Velocity	Correction
45	3860			117.0			
	6150	2290		117.4			
Cor. 45.6	8450	2300	2294	117.5	117.1	2058	−236
	0745	2295		116.9	Cor. 116.9		
	3040	2295		117.0			
	5330	2290		117.0			
						Barom. =	29.98"
50	3480			117.0			
	6010	2530		117.2			
	8550	2540		117.4			
Cor. 50.6	1090	2540	2534	117.6	116.7	2249	−285
	8930			116.5	Cor. 116.5		
	1450	2520		116.2			
	3990	2540		115.0			
60	9890			117.0			
	2840	2950		117.5			
Cor. 60.3	5790	2950	2954	118.3	118.2	2595	−359
	8750	2960		118.8	Cor. 118.0		
	1700	2950		118.8			
	4660	2960		119.0			

Table II Cont.

Steam Pressure	Anemom. Readings	Diff's	Average	Temp. Deg's C.	Average	Calcul. Velocity	Correction
70	8110			116.5			
	1200	3290		116.5			
Cor. 70.0	4700	3300	3298	116.5	116.5	2917	− 381
	8000	3300		116.5	Cor. 116.3		
	1290	3290		116.5			
	4580	3300		116.5			

The breaks in the anemometer readings are due to the fact that the steam was taken from the pipe which supplies the feed pumps of the boilers, so that, whenever there was a variation in the amount of steam required by the pumps, there was also a variation in pressure, and this had to be brought back to the original point, before the readings could be continued.



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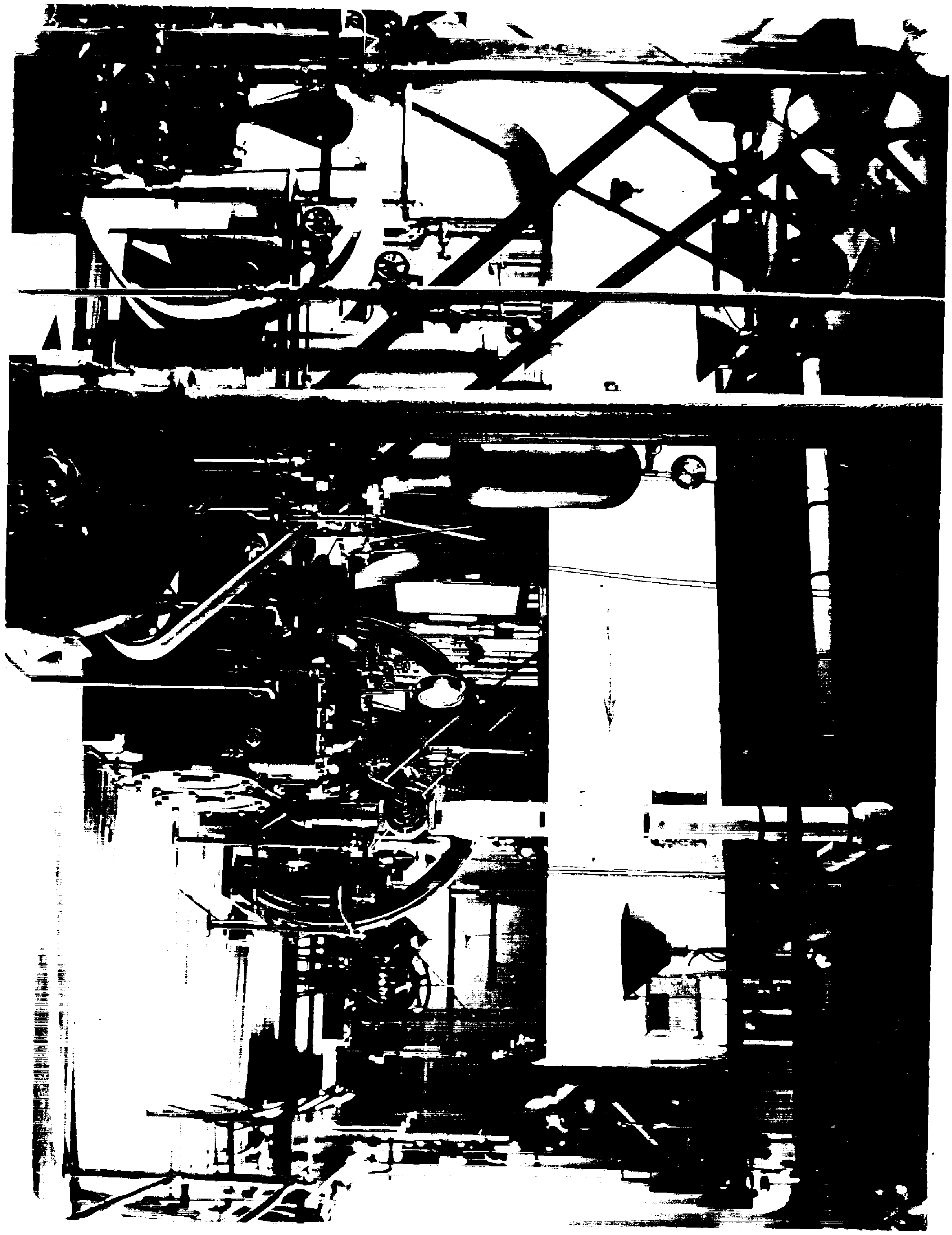
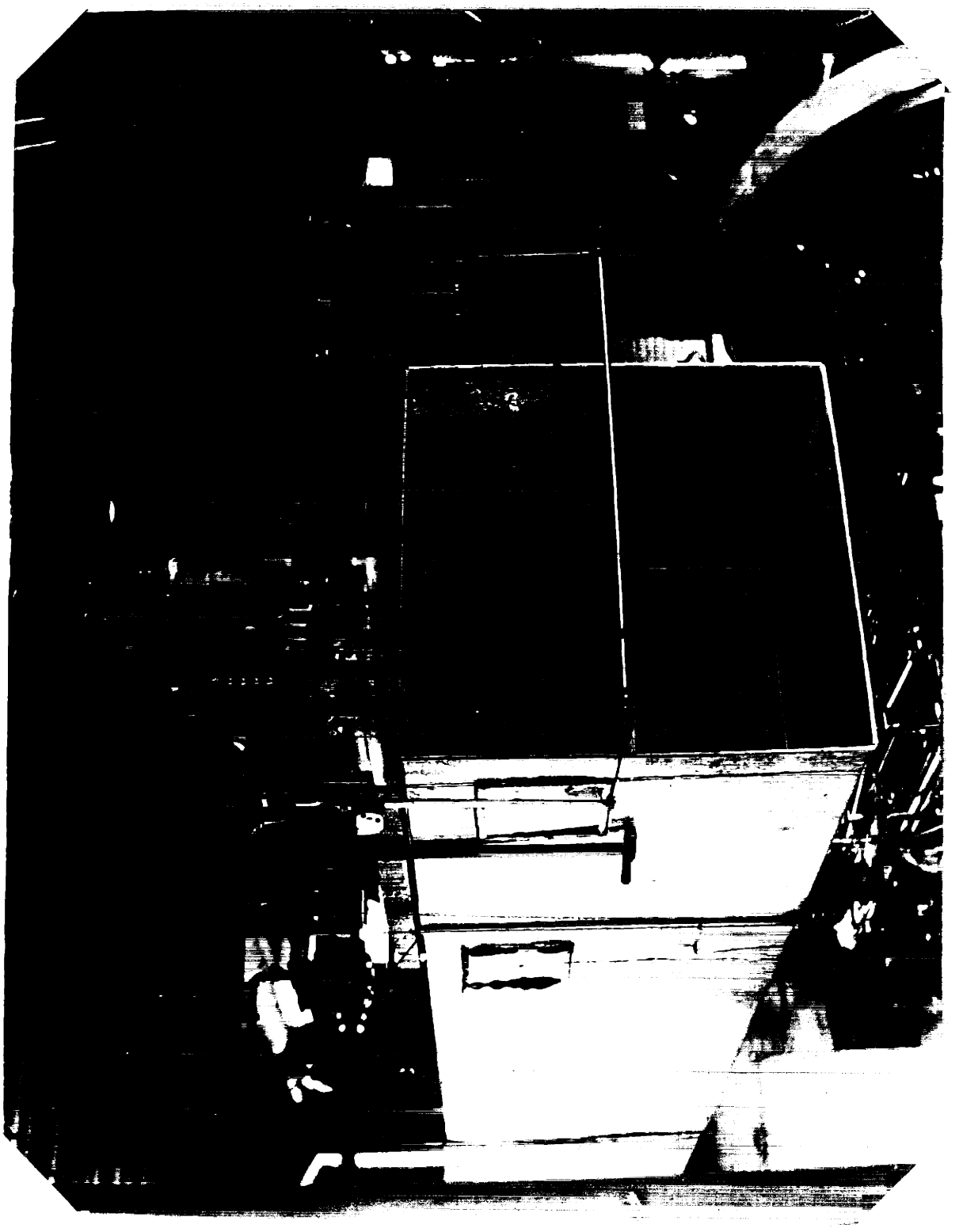
While this work on the anemometer was being performed, scales were being built by the Fairbanks Scale Company, to weigh the horizontal and vertical components of the wind pressure.

The vane, or plane, upon which the pressure was to be determined, was fastened to a shaft, flattened on one side to receive it, so that its center of gravity was over the center of the shaft. The shaft projects through holes cut in the sides of the pipe for that purpose, and the ends are supported by hanger rods from the lever on top of the pipe, which is connected with the scale beam weighing the vertical pressure.

These hanger rods are of such lengths, that the plane hangs in the middle of the pipe, and the



View showing galvanized iron tube and scales used in experiments. Flame outside.



View looking into bike, showing scales, [illegible] at an angle of 45° and anemometer.

scale is so located, that the shaft is about fifteen inches from the end of the pike.

The plane is arranged, so that when at an angle, the air blows over, instead of under it, thus exerting a vertical force downward, which can be weighed directly.

For weighing the horizontal component, a tie rod passes from each end of the shaft, to the vertical arms of two angle levers, which are arranged on each side of the pike, and rigidly connected above. On the horizontal arm of one of these angle levers, is fixed a scale beam, and by means of this, the horizontal force is weighed. Both scale beams weigh to grams. Everything about the scales is hung from knife edges, so that the friction is reduced

to a minimum. By means of this contrivance, the two components of the resultant pressure can be weighed simultaneously, and the action of the plane observed at all times. The plane used was of sheet steel, which I trimmed down to exactly one foot square. I also bevelled the edge which was towards the wind, and the one from which the air left the plane, so that there should be only sharp edges presented to the wind. The end of the shaft is clamped in a socket on the hanger rod, by means of a set screw, so that it can be set at any desired angle. The plane is set by means of triangles and a spirit level.

The first thing that I did was to try the anemometer in

different parts of the tube, in order to find out whether or not the velocity was the same all over the section in which the plane was located. Of course, in this experiment, the plane was removed from the tube. The following table contains the results obtained, giving the velocities, in feet per minute, found at the several points.

Table III

	Center of Pipe	8" Right of Center	8" Left of Center	8" Above Center	8" Below Center
	1500	1495	1480	1600	1405
	1510	1490	1490	1590	1395
	1495	1490	1495	1600	1390
	1490	1495	1500	1610	1400
	1495	1500	1500	1595	1400
Total	7490	7470	7465	7995	6990
Average	1498	1494	1493	1599	1398

In getting the results of this table, the indicated velocity, at any given location, was taken for one

minute. Then, the anemometer was moved to another location, and the velocity, for one minute observed there; then the anemometer was moved again, so that no two consecutive readings in the same column, were taken in succession. This was done in order to get average readings all over the pipe.

An inspection of table III. shows, that although the velocity is practically constant at points on a line drawn horizontally across the pipe, it varies considerably in a vertical direction, being about one hundred feet per minute more, at a point eight inches above the center, and about one hundred feet per minute less, at a point eight inches below the center, than it is directly at the center. This variation is probably due to the

band in the tube, already referred to. Since the variation is uniform, it is safe to assume as the velocity of the air impinging upon the blade, the mean of these varying velocities, that is, the velocity at the center of the blade.

Three tests were run with the blade inside the pipe; one on Apr. 29 with the blade making an angle α, with the direction of the air flow, of 30°, one on Apr. 30, with $\alpha = 15°$, and one on May 2, with $\alpha = 45°$. The data from these tests are found in tables IV, VI and VIII.

The shaft necessarily introduces an error into these results, so a correction for that is necessary. Three tests were run on the shaft alone, placed with its flat side at the same angles as when the blade was fastened to

it, and with the air flowing at as nearly as possible the same velocity. The results of these last tests are to be found in tables V, VII and IX. Now, since just two thirds of the shaft are exposed to the air when the plane is attached, it is assumed, that if we subtract from the scale readings when the plane is exposed to the air, two thirds of the scale readings when the rod alone is exposed, we shall have the true pressures upon the plane. In the tests with the plane, readings were taken every minute, for thirty minutes, of the anemometer, which was located where it recorded the mean velocity, and of the vertical and horizontal pressures upon the plane. In the tests upon the shaft alone, similar readings were taken every minute, for ten minutes only.

Table IV.

Plane, Angle α with wind = 30°. Apr. 29, 1896.

Anemometer Readings	Differences per min.	Vertical Pres. in grams	Horizontal Pres. in grams
0650		350	217
1950	1300	360	221
3260	1310	370	227
4560	1300	375	232
5890	1330	370	230
7210	1320	360	230
8570	1360	354	231
9880	1310	350	221
1180	1300	357	221
2495	1315	367	225
3800	1305	365	220
5100	1300	370	220
6405	1305	363	217
7705	1300	370	230
8990	1285	365	225
0280	1290	365	220
1610	1330	355	215
2890	1280	363	213
4200	1310	350	217

Table IV Cont.

Anemometer Readings	Differences	Vertical Pres. grams	Horizontal Pres. grams
5190	1290	362	231
6790	1300	367	219
8090	1300	360	228
9390	1300	365	227
0680	1290	365	223
1980	1300	365	223
3275	1295	361	222
4575	1300	357	221
5840	1265	355	216
7140	1300	356	215
8430	1290	352	213
9730	1300	355	214
Total	39080	1199	6884
Average	1302.7	361.3	222.1
Cor. Av'ge.	1206	337	201

Table V

Rod. $\alpha = 30°$

Anemometer Readings	Differences per min.	Vertical Pres. grams.	Horizontal Pres. grams.
6790		36	31
8090	1300	35	31
9450	1360	36	30
0765	1315	36	31
2070	1305	36	31
3360	1290	37	31
4670	1310	36	31
5970	1300	35	30
7270	1300	36	31
8555	1285	36	31
9855	1300	36	31
Total	13065	395	339
Average	1306.5	35.9	30.8
Cor. Avge.	1209	$\frac{2}{3}V = 24$	$\frac{2}{3}H = 21$

Table VI

Plane. $\alpha = 15°$ Apr. 30, 1896

Anemometer Readings	Differences	Vertical Pres. grams.	Horizontal Pres. grams.
5400		290	120
6720	1320	286	125
8050	1330	288	124
9375	1325	285	125
0700	1325	290	125
2030	1330	295	122
3350	1320	292	126
4690	1340	295	124
6030	1340	294	122
7380	1350	294	124
8710	1330	291	121
0030	1320	297	123
1350	1320	288	119
2675	1325	290	119
4000	1325	296	120
5325	1325	291	119
6640	1315	288	118
7950	1310	283	117
9265	1315	282	117

Table VI Cont.

Anemometer Readings	Differences	Vertical Pres. grams	Horizontal Pres. grams
0590	1325	287	117
		285	119
		292	119
		287	118
		285	119
7240		287	121
8550	1310	285	118
9900	1350	288	118
1240	1340	285	120
2560	1320	288	123
3885	1325	285	121
5215	1330	286	122
Total	33165	8955	3745
Average	1326.6	285.9	120.8
Cor. Av'g.	1226	279	107

Table VII

Rod. $\alpha = 15°$

Anemometer Readings	Differences	Vertical Pres. grams	Horizontal Pres. grams
5635		15	21
6960	1325	15	21
8280	1320	15	22
9630	1350	16	22
0955	1325	15	21
2280	1325	14	20
3595	1315	15	20
4935	1340	15	21
6260	1325	15	21
7590	1330	15	21
8910	1320	15	21
Total	13275	165	231
Average	1327.5	15	21
Cor. Av'g.	1227	$\frac{2}{3}V. = 10$	$\frac{1}{3}H = 14$

Table VIII

Plane. $\alpha = 45°$ May 2, 1896.

Anemometer Readings	Differences	Vertical Pres. grams	Horizontal Pres. grams
7310		+36	+33
8750	1440	+35	+39
0195	1445	+37	+38
1640	1445	+40	+41
3100	1460	+44	+43
4550	1450	+48	+45
6040	1490	+46	+46
7480	1440	+50	+46
8950	1470	+50	+48
0420	1470	+52	+52
1880	1460	+54	+53
3770	1490	+58	+60
4650	1480	+60	+62
6330	1480	+62	+63
7830	1500	+67	+66
9350	1520	+70	+71
0840	1490	+69	+70
2370	1530	+73	+75
3900	1530	+73	+74

Table VIII Cont.

Anemometer Readings	Differences	Vertical Pres. grams	Horizontal Pres. grams
5330	1430	473	474
6750	1420	472	474
8240	1490	470	471
9700	1460	469	468
11150	1450	461	460
2590	1440	458	458
4020	1430	456	455
5450	1430	451	450
6840	1390	447	449
8290	1450	445	444
9680	1390	444	443
1105	1425	445	443
Total	13795	14115	14114
Average	1379.8	455.3	455.3
Cor. Av'g.	1338	420	419

Rod.

Table IX
$\alpha = 45°$

Anemometer Readings	Differences	Vertical Pres. grams	Horizontal Pres. grams
8345		53	54
9785	1440	53	53
1240	1455	52	53
2700	1460	52	54
4150	1450	53	55
5615	1465	53	55
7060	1445	53	54
8515	1455	53	54
9955	1440	53	55
1400	1445	54	55
2850	1450	54	55
Total	14505	583	597
Average	1450.5	53	54.3
Cor. Av'g.	1381	$\frac{2}{3}V = 35$	$\frac{2}{3}H = 36$

From the comparison in table X, of the results of tables IV, VI and VIII, with those obtained by Prof. Langley, with a plane of the same size, set at the same angles and at the nearest velocities which he used, it

Table X

Source of Results	α	Velocity f.p.m.	Vertical Pressure	Horizontal Pressure
Table IV.	30°	1206	337	201
Prof. Langley	30°	1299	250	127
Table VI	15°	1226	279	107
Prof. Langley	15°	1791	250	68
Table VIII	45°	1338	420	419
Prof. Langley	45°	2244	500	492
		2008	500	516

will be seen that in the cases when the angle of elevation, α, of the plane was 30° and also when it was 15°, although the whirling table employed a higher velocity, the vertical and horizontal pressures, in both cases,

were considerably lower than those given by the blower apparatus; and while at the angle 45° Prof. Langley obtained much higher results, his speed was nearly double that which I used.

The formulæ which are most commonly used for finding the wind pressure upon an inclined surface, are those of Duchemin and Hutton; Duchemin's formula being

$$P = P_1 \frac{2 \sin \theta}{1 + \sin^2 \theta},$$

and Hutton's

$$P = P_1 (\sin \theta)^{1.84 \cos \theta - 1},$$

in both of which, P is the intensity of the normal pressure upon the surface, P_1, the intensity of the pressure upon a plane normal to the direction of the wind, and θ, the angle which the plane makes with the direction of the wind. In

these formulae, p, is commonly found by a pressure plate, or by Smeaton's formula

$$P = \frac{V^2}{200},$$

in which P is the pressure in pounds per square foot, and V, the velocity of the wind in miles per hour. For each of the three tests given in tables IV, VI and VIII, I calculated the pressure upon a plane normal to the wind, by Smeaton's formula, using the constant .005 as commonly given, and also the constant .0045, which agrees very closely with some experiments which I made later on. The values thus found I substituted in both Duchemin's and Hutton's formulae, thus finding the theoretical normal pressures upon the plane. Then, from the horizontal and vertical components

obtained in the experiments, represented by H and V respectively. I calculated the resultant pressure R, in each case, from the relation $R = \sqrt{V^2 + H^2}$, the angle θ which it made with the plane, from the relation $\cos(\theta - \alpha) = \frac{H}{R}$, α being as before, the angle which the plane makes with the wind; and, resolving this resultant pressure into components, normal and tangential to the plane, found the actual normal pressure. The results

Table XI.

	Velocity	Pressure on Plane Normal to Wind. (1) $P = .005V^2$ (2) $P = .0045V^2$		α	Resultant from Expt	Angle of Res. with Plane.
1	1206	425.96	383.37	30°	392.4	89°-11'-18.4"
2	1226	440.21	396.19	15°	298.8	84°-0'-59.5"
3	1338	524.31	471.88	45°	593.3	90°-4'-18.4"

	Normal Pressures				
	From Expt.	Duchemin. using p. from (1)	Duchemin. using p. from (2)	Hutton. using p. from (1)	Hutton. using p. from (2)
1	392.36	340.77	306.7	282.39	254.16
2	297.17	213.56	192.21	154.01	138.61
3	593.30	493.99	444.9	471.73	423.66

of these calculations are given in table XI. All velocities are expressed in feet per minute, and all pressures are in grams.

An examination of this table shows, that when the angle of incidence α of the plane is 45° the resultant pressure is very nearly normal to the surface, and that when α is 30°, the departure from the normal is less than one degree; but when α is diminished to 15° this departure from the normal becomes much greater, being nearly 6°. It will also be seen, that the normal pressure found by the experiments is much greater than that calculated by the formulæ of Duchemin and Hutton, using for p, the value found by Smeaton's formula, with the constant .005, and also with the constant .0045. The calculated results,

coming nearest to those obtained experimentally, are given by Duchemin's formula, substituting for p_1, the value found by using .005 in Smeaton's formula.

Since the values of the resultant pressures given in table XI are so much in excess of those calculated by the ordinary formulae, and since, in each of tables IV, VI and VIII, there is a considerable variation in the pressure readings, showing that there was more or less vibration, it was thought probable, that some of these differences might be due to the effect of the pipe, in holding the air together around the plane. Accordingly I set the scales in such a position that the rod to which the plane is attached hung 6" beyond the end of the pipe, with the plane,

as nearly as possible, in the center of the moving current of air. This brought the plane entirely outside the tube.

The moving body of air was calibrated in a plane 12" beyond the tube, in the same manner as that in which the tube was calibrated before, and the velocities, in feet per minute, at the different points chosen are compared, in table XII,

Table XII

Location during Exp'rs.	Center of moving air	9" right of center	9" left of center	9" above center	9" below center
1350	1335	1345	1335	1395	1300
1340	1330	1330	1330	1385	1295
1335	1345	1335	1335	1400	1290
1345	1350	1330	1350	1380	1270
1340	1355	1350	1345	1380	1280
Total 6710	6715	6690	6695	6940	6435
Av'g. 1342	1343	1338	1339	1388	1287

with the velocity at the point where

I wished to locate the anemometer during the experiments. From this comparison it is seen that the velocity is the same at the center of the section, 12" beyond the pipe, as it is in the center of the pipe, where the anemometer was to be located during the experiments; that the velocity is practically constant in a horizontal line across the section, as was found to be the case inside the pipe; and that in a vertical direction, the variation in the velocity is only about one half as much as it was inside the pipe.

All the tests given in the following tables, with the exception of the last, were run with the rod 6" from the end of the pipe. In the last test, that given in table XXXVII, the rod was 12" from the pipe.

In every case, a supplementary test was run upon the rod alone, in order to get the corrections for the scale readings when the plane was used. In each of the tests when $\alpha = 90°$, the velocity of the air against the rod, was greater than when the plane was attached, so that it was impossible to make the correction directly. A curve was plotted, using anemometer readings as abscissas, and pressures upon the shaft as ordinates, and by interpolating on this curve, I was able to obtain the pressures upon the rod, corresponding to the different velocities at which the tests upon the plane were run. This plot follows the tables of the tests.

In the following tables, readings were taken every half minute when $\alpha = 90°$; every minute at other angles.

Table XIII

Plane $\alpha = 30°$ May 5, 1896

Anemometer Readings	Differences	Vertical Pres. in grams	Horizontal Pres. in grams
8470		1290	222
9825	1355	1291	221
1170	1345	1289	220
2530	1360	1291	220
3890	1360	1291	221
5260	1370	1294	222
6625	1365	1295	222
8005	1380	1296	222
9390	1385	1296	223
0740	1350	1297	222
2095	1355	1296	223
3490	1395	1297	223
4860	1370	1299	223
6240	1380	1299	224
7620	1380	1299	224
9000	1380	1298	223
0365	1365	1299	222
1730	1365	1299	223
3110	1380	1300	224

Table XIII Cont.

Anemometer Readings	Differences	Vertical Pres. grams	Horizontal Pres. grams
4490	1380	1300	225
5855	1365	1300	225
7240	1385	1300	225
8610	1370	1301	225
0000	1390	1301	225
1375	1375	1302	225
2755	1380	1302	226
4140	1385	1303	226
5510	1370	1303	226
6895	1385	1303	226
8255	1360	1303	225
9630	1375	1302	225
Total	41160	40236	6928
Average	1372.0	1297.9	223.5
Cor. Av'g.	1264.	1277	206
Cor #2		354	

Table XIV

Rod. $\alpha = 30°$

Anemometer Readings	Differences	Vertical Pres. grams	Horizontal Pres. grams.
5760		31	26
7140	1380	31	27
8505	1365	30	26
9875	1370	30	27
1245	1370	31	28
2630	1385	32	26
3995	1365	32	27
5370	1375	32	26
6740	1370	32	26
8110	1370	32	26
9490	1380	31	25
Total	13730	344	292
Average	1373	31.3	26.5
Cor. Avg.	1265	$\frac{2}{3}V = 21$	$\frac{2}{3}H = 18$

Table XV

Plane $\alpha = 90°$ May 5, 1896

Anemometer Readings	Differences	Horizontal Pres. grams
2220		467
2890	670	468
3545	655	468
4210	665	467
4860	650	468
5530	670	468
6220	690	468
6825	605	469
7470	645	469
8155	685	470
8815	660	468
9475	660	467
0125	650	466
0795	670	465
1450	655	465
2110	660	464
3770	660	464
3440	670	464
4090	650	465

Table XV Cont.

Anemometer Readings	Differences	Horizontal Pres. grains
4750	660	465
5410	660	464
6065	655	464
7730	665	464
7400	670	465
8055	655	465
8720	665	464
9390	670	465
0045	655	465
0700	655	463
1375	675	464
2040	665	464
2700	660	465
3350	650	465
4030	680	465
4675	645	465
5355	680	465
6015	660	466
6690	675	466

Table XV Cont.

Anemometer Readings	Anemometer Differences	Horizontal Pres. grams
7350	660	467
8015	665	467
8675	660	466
9340	665	466
0000	660	465
0675	675	465
1320	645	465
1985	665	465
2655	670	465
3350	695	464
4000	650	465
4680	680	465
5300	620	465
5995	695	465
6640	645	465
7305	665	464
7985	680	464
8640	655	465
9300	660	465

Table XV Cont.

Anemometer Readings	Anemometer Differences	Horizontal Pres. grams
9975	675	466
0665	690	466
1335	670	465
2015	680	465
Total	39795	28399
Average	663.3	465.6
Avg. per min.	1326.6	465.6
Cor. Avg.	1225	409

Table XVI

Rod $a = 90°$

Anemometer Readings	Anemometer Differences	Horizontal Pres. grams
5240		90
5930	690	90
6635	705	89
7330	695	90
8035	705	90

Table XVI Cont.

Anemometer Readings	Anemometer Differences	Horizontal Pres. grams
8760	725	90
9440	680	90
0130	690	89
0840	710	89
1540	700	90
2230	690	90
2920	690	90
3625	705	90
4315	690	90
5010	695	89
5705	695	89
6390	685	89
7100	710	90
7780	680	90
8480	700	90
9190	710	90
Total	13950	1884
Average	697.5	89.7
Avg. per min.	1395	89.7

Table XVII

Plane $\alpha = 90°$ May 6. 1896.

Anemometer Readings	Anemometer Differences	Horizontal Pres. grams
2350		583
3130	780	582
3880	750	581
4650	770	581
5395	745	581
6175	780	580
6910	735	581
7675	765	581
8420	745	580
9180	760	581
9950	770	580
1700	750	580
1450	750	580
2200	750	579
2960	760	579
3720	760	579
4460	740	579
5225	765	579
5960	735	580

Table XVII Cont.

Anemometer Readings	Differences	Horizontal Pres. grams
6740	780	580
7480	740	581
8240	760	580
8970	730	580
9745	775	579
0480	735	580
1255	775	581
2015	760	580
2775	760	580
3530	755	581
4310	770	580
5080	730	579
5800	770	579
6545	745	580
7300	755	580
8050	750	579
8800	750	580
9550	750	581
0315	765	582

Table XVII Cont.

Anemometer Readings	Differences	Horizontal Pres. grams
1070	755	581
1840	770	582
2600	760	581
3340	740	581
4095	755	580
4865	770	580
5615	750	579
6380	765	579
7125	745	579
7895	770	580
8665	770	580
9430	765	580
0190	760	580
0955	765	580
1710	755	579
2480	770	581
3255	775	582
4020	765	581
4760	740	580

Table XVII Cont.

Anemometer Readings	Differences	Horizontal Pres. grams
5515	755	581
6265	750	580
7020	755	580
7780	760	581
Total	45430	35395
Average	757.2	580.2
Avg. per min.	151.4	580.2
Cor. Avg.	138.4	509

Rod. Table XVIII d=90°

Anemometer Readings	Differences	Horizontal Pres. grams.
1975		113
2755	780	113
3545	790	114
4330	785	114
5135	805	114

Table XVIII Cont.

Anemometer Readings	Differences	Horizontal Pres. grams.
5935	800	115
6725	790	115
7520	795	115
8310	790	115
9190	780	114
9885	795	115
0660	775	114
1420	760	114
2190	770	114
2975	785	115
3750	775	115
4540	790	115
5340	800	115
6135	795	115
6925	790	114
7715	790	115
Total	15740	2413
Average	787	114.9
Avg. per min.	1574	114.9

Table XIX

Plane $\alpha = 90°$ May 6, 1896.

Anemometer Readings	Differences	Horizontal Pres. grams
0860		168
1290	430	169
1690	400	169
2115	425	169
2520	405	169
2935	415	168
3340	405	170
3755	415	167
4150	395	167
4560	410	168
4960	400	167
5375	415	166
5780	405	166
6185	405	166
6580	395	165
6990	410	165
7390	400	165
7790	400	164
8180	390	163

Table XIX Cont.

Anemometer Readings	Differences	Horizontal Pres. grams
8575	395	161
8965	390	162
9360	395	162
9770	410	163
0175	405	163
0590	415	162
1010	420	164
1425	410	163
1830	410	163
2245	415	163
2645	400	163
3045	400	162
3435	390	162
3840	405	162
4250	410	163
4655	405	164
5075	420	164
5490	415	163
5890	400	162

Table XIX Cont.

Anemometer Readings	Differences	Horizontal Pres. grams
6300	410	162
6695	395	162
7090	395	162
7495	405	162
7905	410	163
8300	395	163
8715	415	163
9135	420	164
9545	410	163
9950	405	163
0350	400	162
0745	395	162
1140	395	162
1540	400	162
1945	405	162
2355	410	162
2755	400	162
3171	415	162
3565	395	161

Table XIX - Cont.

Anemometer Readings	Anemometer Differences	Horizontal Pres. grams.
3955	390	161
4355	400	162
4765	410	162
5170	405	163
Total	2405	9994
Average	401.2	163.8
Adj. per min.	851	164
Cor. Adj.	7851	1644

Table XX

Rod $\alpha = 90°$

Anemometer Readings	Anemometer Differences	Horizontal Pres. grams
0640		37
1085	445	37
1505	420	38
1950	445	37
2370	420	36

Table IX- Cont.

Anemometer Readings	Anemometer Differences	Horizontal Pressures grams
2810	+44	36
3225	+415	36
3645	+420	36
4160	+415	36
4485	+425	36
4915	+430	37
5325	+410	36
5755	+430	37
6195	+440	37
6620	+425	36
7050	+430	37
7485	+435	37
7910	+425	37
8330	+420	36
8750	+420	36
9105	+415	36
Total	4525	76.7
Average	+426.2	36.5
Avg. per min.	852	36.5

Table XXI

Plane $\alpha = 15°$ May 7 1896.

Anemometer Readings	Differences	Vertical Pres. grams	Horizontal Pres. grams
1650		1.8.	123
2030	.380	1181	123
3390	.360	1.80	122
4775	.385	1182	122
6150	.375	1.82	121
7510	.361	1.80	120
8885	.375	1.80	120
10275	.390	1.80	119
11650	.375	1.82	120
13030	.380	1.83	119
14410	.380	1.83	119
15800	.390	1.84	119
17180	.380	1.84	118
18565	.385	1.84	118
19945	.380	1.83	118
21330	.385	1184	119
22710	.371	1.84	119
24090	.380	1.83	119
25470	.380	1.82	119

Table XXI Cont.

Anemometer Readings	Differences	Vertical Pres. grams	Horizontal Pres. grams
6850	1350	1182	118
8240	1390	1181	118
9610	1370	1180	118
0975	1365	1180	118
2340	1365	1182	119
3710	1370	1184	119
5085	1375	1183	119
6450	1365	1181	117
7835	1385	1180	117
9215	1380	1181	117
0580	1365	1182	118
1950	1370	1182	118
Total	13300	36637	3693
Average	1376.7	1181.8	119.1
Cor. #1.	1208	1174	114
Cor #2		251	

Table XXII

Rod. $\alpha = 15°$

Anemometer Readings	Differences	Vertical Pres. grams	Horizontal Pres. grams
9350		12	22
1750	1390	12	22
2,15	1375	11	22
3480	1365	11	22
4870	1390	11	22
6250	1380	12	22
7625	1325	12	22
8990	1365	11	22
0375	1385	12	22
1745	1370	12	22
3,125	1380	11	22
Total	13775	127	242
Average	1377.5	11.5	22
Cor. Arc.	1269	$\frac{2}{3}V = 8$	$\frac{2}{3}H = 15$

Table XXIII

Plane $\alpha = +5°$ May 7, 1896.

Anemometer Readings	Differences	Vertical Pres. grams.	Horizontal Pres. grams
6150		1272	334
7450	1400	1272	334
8850	1400	1273	334
0235	1385	1274	335
1630	1395	1272	335
3020	1390	1272	336
4430	1410	1274	337
5830	1400	1273	337
7250	1420	1274	337
8650	1400	1274	338
0050	1400	1274	338
1450	1400	1274	337
2860	1410	1274	337
4275	1415	1275	337
5690	1415	1275	338
7100	1410	1274	338
8510	1410	1275	337
9920	1410	1275	338
1325	1405	1276	338

Table XLII Cont.

Anemometer Readings	Differences	Vertical Pres. grams	Horizontal Pres. grams
2730	1415	1275	337
4145	1400	1275	338
5535	1415	1276	338
6930	1395	1276	338
8330	1400	1275	338
9740	1410	1274	337
1140	1400	1275	337
2545	1405	1276	338
3960	1415	1276	338
5370	1410	1275	337
6770	1400	1275	338
8165	1395	1275	337
Total	42045	39505	10446
Average	1402.4	1274.3	337
Cor. Avg.	1291	1230	296
Cor $\frac{1}{2}$		307	

Rod

Table XXIV.

$\alpha = 45°$

Anemometer Readings	Differences	Vertical Pres. grams	Horizontal Pres. grams
+975		64	63
6390	1415	71	63
7790	1411	71	63
9185	1395	65	62
0580	1395	67	60
1945	1415	66	61
3340	1395	63	60
4740	1401	64	61
6110	1370	63	60
7505	1395	64	59
8900	1395	65	60
Total	13995	730	672
Average	1399.5	66.4	61.1
Cor. Nos.	128.7	$\frac{2}{3}1 = 44$	$\frac{3}{3}1 = 41$

Table XXV.

Plane $\alpha = 60°$ May 9, 1896

Anemometer Readings	Differences	Vertical Pres. grams	Horizontal Pres. grams
975		1,173	417
1,140	,390	1,174	4,16
2530	,390	1,174	417
3910	,380	,175	4,15
5310	,400	,176	418
6,715	,405	,176	419
8,120	,405	,175	419
9525	,405	1,180	422
0940	,415	1,182	425
2375	,435	1,186	430
3,750	,395	1,183	429
5200	,420	1,184	429
6600	,410	1,184	428
8000	,400	1,183	428
9400	,400	1,183	428
1,780	,380	1,183	427
2160	,380	1,182	427
3540	,380	1,178	425
4910	,370	1,176	422

Table XXV Cont.

Anemometer Readings	Differences	Vertical Pres. grams	Horizontal Pres. grams
6265	1355	1174	420
7620	1375	1173	420
9120	1350	1172	419
03,75	1355	1172	417
1735	1360	1172	415
3105	1370	1170	415
4461	1355	1171	415
5850	1370	1175	419
7225	1375	1175	419
8605	1380	1177	420
9995	1390	1176	422
1385	1390	1177	422
Total	41635	36495	13167
Average	1337.8	1177.3	421.5
Cor. Avg.	1279	1137	371
Cor #2		2147	

Table XXVI

Rod $\alpha = 60°$

Anemometer Readings	Differences	Vertical Pres. grams	Horizontal Pres. grams
0630		60	76
2035	1405	59	76
3415	1380	60	76
4800	1385	60	76
6211	1411	59	76
7580	1369	59	76
8985	1405	60	77
0390	1405	60	77
1790	1400	61	77
3165	1375	61	77
4550	1385	60	77
Total	13920	659	841
Average	1392	59.9	76.5
Cor. Avg.	1241	$\frac{2}{5}4 = 41$	$\frac{1}{5}14 = 51$

Table XXVII

Plane $\alpha = 30°$ May 9, 1896.

Anemometer Readings	Differences	Vertical Pres. grams	Horizontal Pres. grams
3275		1,7,	15,
44,0	,,35	,,72	,52
5555	1,45	,,72	,53
67,5	,,60	,,73	,53
7450	,,65	,172	154
9,30	,,50	,,72	,54
1190	1,60	,,73	,55
1345	,,55	1173	155
2511	,,45	1,74	,55
3645	,,35	,,72	,55
4180	,,35	1161	153
5901	,,20	,,71	,54
7140	1,40	1,73	155
8210	,,70	1176	157
9390	1180	1175	159
1570	1180	,,76	,59
,725	1155	,,72	160
2975	,,50	1,74	,61
4030	,,55	,,7,	160

Table XXVII Cont.

Anemometer Readings	Differences	Vertical Pres. grams	Horizontal Pres. grams
5180	.50	1.71	.59
5360	.50	.71	.59
5860	.55	.71	.61
6415	.61	.70	.55
6970	.55	.71	.59
7965	.65	.72	.59
8135	.71	.73	.60
8295	.61	.70	.55
8850	.55	.69	.57
9400	.50	1.70	.59
9965	.65	1.71	.59
10740	.75	1.73	1.60
Total	3.615	36.32	4.86
Average	.55.5	1.72	.56.6
Cor. Avg.	.56.	.66	.38
Cor. #2		2.43	

Table XXVIII

Rod. $\alpha = 30°$

Anemometer Readings.	Differences	Vertical Pres. grams	Horizontal Pres. grams
7040		24	28
8,95	1,55	25	28
9360	1,65	24	28
0520	1,60	23	28
1680	1,40	25	28
2835	1,55	25	28
3960	1,45	25	29
5,10	1,50	23	25
6260	1,50	24	28
7420	1,60	25	27
8575	1,55	24	28
Total	1,535	26,7	308
Average	1,53.5	24.3	28
Cor. Avg.	1,79	$\frac{2}{3}V = 16$	$\frac{2}{3}H = 19$

Table XXIX

Plane $\alpha = 45°$ May 9 1896.

Anemometer Readings	Differences	Vertical Pres. grams	Horizontal Pres. grams
3325		1.47	224
4470	1.145	1.47	225
5620	1.150	1.48	226
6775	1.155	1.49	226
7920	1.145	1.50	226
8060	1.140	1.50	226
9200	1.140	1.50	226
0350	1.150	1.49	226
1485	1.135	1.50	225
2630	1.145	1.50	224
3780	1.150	1.50	224
4910	1.130	1.49	224
6050	1.140	1.49	223
7190	1.140	1.48	222
8335	1.145	1.48	223
9475	1.140	1.48	224
0585	1.110	1.47	221
1725	1.140	1.47	223
2870	1.145	1.47	223

Table XXIX Cont.

Anemometer Readings	Differences	Vertical Pres. grams.	Horizontal Pres. grams
5030	1160	1.46	223
6190	1140	1.47	223
7325	1155	1.46	224
8475	1150	1.46	221
9620	1145	1.47	223
0750	1130	1.48	223
1895	1145	1.50	224
3030	1135	1.50	223
4185	1155	1.49	222
5345	1160	1.50	223
6495	1150	1.50	224
7640	1145	1.48	224
Total	34315	35600	6938
Average	1143.8	1.46.4	223.8
Cor. Avg.	1070	1122	199
Cor #2		199	

Table XXX

Rod. $\alpha = 45°$

Anemometer Readings	Differences	Vertical Pres. grams	Horizontal Pres. grams
4780		39	36
5925	1145	39	37
7080	1155	39	37
8220	1140	37	37
9360	1140	37	37
0510	1150	37	37
1675	1165	38	37
2830	1155	36	37
3970	1140	37	37
5115	1145	40	37
6245	1130	41	37
Total	11465	+29	+16
Average	1146.5	39	36.9
Cor. Adj.	1173	$\frac{1}{3}7 = 26$	$\frac{2}{3}H = 25$

Table XXXI

Plane $\alpha = 60°$ May 9 1896.

Anemometer Readings	Differences	Vertical Pres. grams	Horizontal Pres. grams
7950		1056	281
9,10	1,20	1,180	287
2010	1111	1170	281
1260	1150	1165	278
2320	1160	1167	272
3375	1175	1157	272
4510	1135	1151	279
5600	1140	1157	290
6810	1150	1158	292
7950	1150	1158	291
9125	1175	1159	292
0240	1145	1159	292
1375	1135	1157	293
2540	1165	1158	295
3690	1150	1190	294
4845	1155	1191	294
6010	1165	1190	292
7160	1150	1158	292
8315	1155	1159	294

Table XXXI Cont.

Anemometer Readings	Differences	Vertical Pres. grams	Horizontal Pres. grams
9471	1155	1157	293
1630	1161	1158	293
1791	1150	1157	294
2945	1165	1157	292
4115	1161	1158	292
5276	1160	1158	291
6430	1165	1159	291
7590	1150	1159	289
8745	1165	1057	290
9905	1160	1159	292
1160	1155	1059	292
2225	1165	1159	293
Total	34245	33663	8973
Average	11415	1165.9	292.5
Cor. Avg.	1169	1063	253
Cor $\frac{1}{2}$		140	

Mod. Table XXXII $\alpha = 60°$

Anemometer Readings	Differences	Vertical Pres. grams	Horizontal Pres. grams
4,700		34	56
5715	1015	34	55
6765	1150	35	56
7910	1145	35	55
9060	1150	34	55
10220	1160	34	55
11385	1165	34	56
12520	1135	35	56
13665	1140	35	55
15000	1140	34	56
16145	1145	35	55
Total	11445	379	610
Average	11445	34.5	55.5
Cor. Avg.	1071	$\frac{2}{3}V = 23$	$\frac{2}{3}H = 37$

Table XXXIII

Plane $\alpha = 15°$ May 12, 1896.

Anemometer Readings	Differences	Vertical Pres. grams.	Horizontal Pres. grams.
3,75		1122	82
5540	1165	1123	83
6720	1180	1126	83
7905	1185	1126	84
9100	1195	1126	83
10275	1175	1125	83
11450	1175	1125	82
12650	1200	1127	82
13830	1180	1127	82
15000	1170	1127	82
16180	1180	1126	83
17370	1190	1125	82
18540	1170	1125	81
19720	1180	1125	80
20900	1180	1123	80
22080	1180	1121	81
23255	1175	1121	81
24440	1185	1121	81
25630	1190	1124	80

Table XXXIII Cont.

Anemometer Readings	Differences	Vertical Pres. grams	Horizontal Pres. grams
6815	1,85	1,22	80
7985	1170	1,22	85
9150	1165	1,21	85
1330	1,80	1,23	85
1510	1180	1123	80
2685	1175	1,23	80
3855	1170	1,24	85
5020	1165	1,24	80
6190	1170	1123	80
7375	1185	1123	80
8540	1165	1,22	80
9705	1165	1120	80
Total	3533	3735	2515
Average	1177.7	1123.7	81.1
Cor. Avg.	1100	1109	68
Cor #2		186	

Table XXXIV

Rod $\alpha = 15°$

Anemometer Readings	Differences	Vertical Pres. grams	Horizontal Pres. grams
8410		23	20
9575	1165	24	20
10760	11185	23	19
11930	11170	23	21
13105	11175	23	20
14295	11190	23	21
15460	11165	23	21
16635	11175	23	21
17810	11175	23	20
18990	11180	23	21
20175	11185	23	20
Total	11765	254	219
Average	1176.5	23.1	19.9
Con. Avg.	1177	$\frac{V}{3}$ = 15	$\frac{2}{3}H$ = 13

Table XXXV

Plane $\alpha = 90°$ May 12, 1896.

Anemometer Readings	Differences	Horizontal Pres. grams
1115		322
1675	560	323
2220	545	323
2785	565	321
3330	545	321
3895	565	321
4435	540	322
5000	565	320
5550	550	320
6120	570	320
6660	540	320
7225	565	320
7770	545	321
8330	560	320
8875	545	320
9430	555	320
9975	545	320
0535	560	321
1090	555	321

Table XXXV Cont.

Anemometer Readings	Differences	Horizontal Pres. grams.
1650	560	320
2190	540	319
2750	560	319
3290	540	319
3850	560	319
4395	545	319
4940	550	318
5485	550	318
6045	550	318
6590	545	318
7150	560	318
7685	535	318
8240	555	317
8785	545	317
9340	555	317
9885	545	317
10440	555	317
11000	560	317
11545	545	317

Table XXXL Cont.

Anemometer Readings	Differences	Horizontal Pres. grams
2110	565	317
2650	540	317
3200	560	316
3755	545	316
4310	555	316
4870	560	317
5415	545	317
5965	550	316
6510	535	316
7065	555	317
7615	560	317
8155	540	317
8710	555	316
9260	550	317
9820	560	317
0370	550	316
0910	540	316
1450	540	317
2010	560	317

Table XXXV Cont.

Anemometer Readings	Differences	Horizontal Pres. grams
2555	545	317
3110	555	316
3670	560	316
4225	555	316
Total	3311	1264
Average	551.5	315.3
Adj. per min.	11.12	
Cor. Adj.	1135	277

Table XXXVI

Rod $\alpha = 90°$

Anemometer Readings	Differences	Horizontal Pres. grams
1085		60
1605	520	60
2150	545	59
2675	525	59
3225	550	60

Table XXXVI Cont.

Anemometer Readings	Differences	Horizontal Pres. grams
3755	530	60
4290	535	60
4835	545	60
5380	545	59
5915	535	59
6455	540	59
7005	550	60
7550	545	61
8080	530	60
8630	550	59
9160	530	59
9710	550	59
10265	555	59
10825	560	59
11375	550	59
11930	555	60
Total	11845	1250
Average	542.3	59.5
Avg. per min.	1154	59.5

Table XXXVII

Plane $\alpha = 90°$ May 19, 1896

Anemometer Readings	Differences	Horizontal Pres. grams
2000		241
2475	475	241
2930	455	212
3400	470	242
3860	460	242
4340	480	212
4800	460	241
5280	480	241
6735	455	241
6210	475	241
6680	470	242
7150	470	242
7635	485	242
8105	470	242
8560	455	242
9040	480	212
9500	460	241
9990	490	241
0440	450	241

Table XXXVII Cont.

Anemometer Readings	Differences	Horizontal Pres. grams
0920	480	241
1385	465	242
1860	475	242
2315	455	242
2790	475	243
3255	465	242
3730	475	242
4190	460	243
4680	490	243
5130	450	242
5620	490	242
6070	450	242
6540	470	242
6995	455	241
7475	480	241
7930	455	241
8390	460	241
8870	480	241
9350	480	242

Table XXXVII Cont.

Anemometer Readings	Differences	Horizontal Pres. grams
9815	+65	2+2
0290	+75	2+2
0750	+60	2+1
1235	+85	2+1
1685	+50	2+.
2150	+65	2+.
2620	+70	2+1
3100	+80	2+2
3585	+85	2+.
4070	+75	2+2
4540	+80	2+2
5015	+75	2+2
5475	+60	2+1
5930	+55	2+1
6385	+55	2+1
6860	+75	2+1
7325	+65	2+1
7890	+75	2+1
8265	+65	2+.

Table XXXVII Cont.

Anemometer Readings	Differences	Horizontal Pres. grams
8745	+80	242
9210	+465	242
9700	+490	242
0155	455	242
Total	28155	14737
Average	469.3	24.6
Avg. per min.	938.6	
Cor. Avg.	897	213

Table XXXVIII

Rod $\alpha = 90°$

Anemometer Readings	Differences	Horizontal Pres. grams
4960		46
5460	500	46
5925	465	47
6410	485	47
6885	475	47

Table XXXVIII Cont.

Anemometer Readings	Differences	Horizontal Pres. grams
7375	490	48
7840	465	47
8325	485	47
8810	475	48
9290	490	48
9765	475	47
0230	465	47
0715	475	47
1215	500	47
1690	485	47
2180	490	48
2665	485	48
3155	490	48
3640	485	48
4130	490	48
4615	475	47
Total	9645	993.
Average.	482.3	47.3
Avg. per min.	964.6	

In the first set of tests that was run, the scales were balanced each time for the rod and plane, and again for the rod alone; but in this first set of tests, a counterbalance was used so as to avoid disturbing the lever and rebalancing every time I wished to obtain the pressure on the rod.

The scales weighing the horizontal pressure balanced, either with or without the plane. The scales weighing the vertical pressure balanced without the plane, when 100 grams were fastened to the hanger rod; and when the plane was attached, and the 100 grams removed, they balanced at a scale reading of 923 grams, which, of course, and to be subtracted from the scale readings obtained during the experiments, in

order to get the true pressures. A summary of the results of the tests run with the lime outside the pipe is given in table XXXIX. This is followed by a summary of Prof. Langley's results in table XL, at the lowest velocities which he used, with the same size of lime.

The results given in table XLI were calculated in the same manner as those of table XI from the experimental data given in the summary.

Table XXXIX

Corrected Vel. f.p.m.	α	Vertical Pres. grams	Horizontal Pres. grams
1100	15°	186	68
1268	15°	251	104
1081	30°	243	138
1264	30°	354	206
1070	45°	199	199
1270	45°	307	296
1069	60°	140	253
1279	60°	214	371
787	90°	—	144
897	90°	—	213
1135	90°	—	277
1225	90°	—	419
1384	90°	—	509

Table XL

Velocity f.p.m.	a	Vertical Pres. grams	Horizontal Pres. grams.
1791	15°	250	68
1299	30°	250	127
1752	30°	500	285
1870	30°	500	267
2123	30°	500	262
2008	45°	500	516
2244	45°	500	492
1220	90°	—	247
1378	90°	—	385
1576	90°	—	452
1631	90°	—	508

Table XLI

	Velocity f.p.s.	Pres. on normal plane P=.005V² (1)	P=.0045V² (2)	α	Resultant Pressure	Angle of Res. with Plane
1	1100	354.4	318.9	5°	336.0	84°-54'-49"
2	1264	471.9	423.8	15°	271.7	82°-29'-40"
3	1181	342.2	308.0	30°	279.5	89°-35'-12"
4	1264	407.9	421.1	30°	359.6	89°-48'-22"
5	1170	335.3	301.8	45°	281.4	90°-0'-0"
6	1290	457.4	436.6	45	426.5	88°-56'-58"
7	1069	337.7	311.2	60°	269.2	88°-58'-30"
8	1279	473.	431.2	60°	428.3	89°-58'-42"
9	787	171.4	163.3	90°		
10	849.7	235.6	212.1	90°		
11	1135	313.1	281.7	90°		
12	1225	439.5	395.5	90°		
13	1354	561.0	504.9	90°		

Table XLI Cont.

	Normal Pressures.				
	By Exp'rs.	Duchemin p_1 from (1)	Duchemin p_1 from (2)	Hurton p_1 from (1)	Hurton p_1 from (2)
1	197.2	171.9	154.7	124.0	111.6
2	269.4	228.5	205.6	164.8	146.3
3	279.5	273.8	246.4	226.9	204.2
4	409.6	374.3	336.9	310.2	279.2
5	281.4	316.1	284.5	301.0	271.0
6	426.4	459.5	413.5	437.6	393.8
7	289.2	331.3	298.1	338.6	304.7
8	428.3	474.2	426.8	484.6	436.2
9	144				
10	213				
11	277				
12	459				
13	509				

A comparison of the results of table ~~XXXIX~~ with those of table XL shows that in every case the blower gave higher results than were obtained by Prof. Langley.

B.) comparing table XLII with table XI, it will be seen that somewhat lower results were obtained when the plane was outside the pipe, showing that the pipe did have some effect when the plane was inside.

An examination of table XLI. shows that when the angle of inclination is between 30° and 60°, the resultant pressure is very nearly normal to the plane, but when α is as low as 15° the departure from the normal is considerable, being in one case 5°-5'-11", and in the other case 7°-30'-20"; that for the

angles of 15° and 30°, the experiments gave a higher result than is given by the ordinary formula of Duchemin or that of Hutton; that for the angles of 45° and 60° Duchemin's formula, using the constant .015, gives higher results than is given by the experiments; and that for angles of 45° and below, Duchemin's formula gives higher results than Hutton's, but when the angle of inclination was 60°, the reverse was true.

A curve, given on page 94 was plotted having the velocities used in the experiments when $\alpha = 90°$, as abscissas, and pressures on a plane normal to the direction of the wind, calculated by the formula $P = .005 V^2$, as ordinates. Using the same abscissas, points were plotted, having for ordinates, the

pressures given by the experiments. These points were all found to be below the curve, so another curve was plotted, with the same abscissas, and with ordinates calculated by the formula $P = .0145 V^2$. This curve passed through the points, and can be called a representative curve. Therefore it can be said that for the range of velocities employed, with a plane normal to the wind, the experiments show that the pressure agrees very closely with that calculated by Duchemin's formula, using .0145 in place of .015. Whether or not the same is true for greater velocities remains to be shown by later experiments.