Project Number 119 August, 1930.

REPORT

ON

WIND PRESSURES ABOUT A BUILDING

and

ANALYSIS OF WIND STATISTICS OVER A FOUR-YEAR PERIOD

Prepared as a Thesis by W. A. Gardner

under the direction of J. E. Emswiler

DEPARTMENT OF ENGINEERING RESEARCH
UNIVERSITY OF MICHIGAN
ANN ARBOR

FOR

Detroit Steel Products Company

WIND PRESSURES ABOUT A BUILDING

and

ANALYSIS OF WIND STATISTICS OVER A FOUR-YEAR PERIOD

Prepared as a thesis by W. A. Gardner,

under the direction of J. E. Emswiler.

August, 1930

WIND PRESSURES ABOUT A BUILDING

and

ANALYSIS OF WIND STATISTICS OVER A FOUR-YEAR PERIOD

The allied subjects of Natural Ventilation and Wind Infiltration are shrouded in mystery which has only begun to be dispelled in the past few years. Practically all of the information available on the subject is empirical in nature and has not been verified by organized investigations. For small structures, such as dwelling houses and other buildings of equivalent size, a knowledge of wind effects is not of great importance, but in the large buildings which are becoming more and more numerous in the present-day industrial development, the matter of infiltration and aeration by natural means is one which deserves grave consideration.

The Department of Engineering Research of the University of Michigan has been carrying out a program of investigation of the priniciples of Natural Ventilation for several years, under the direction of Professor J. E. Emswiler. This work has been sponsored by the Detroit Steel Products Company, of Detroit, Michigan, makers of the Fenestra products, who have been pioneers in this type of investigation.

The program for the year 1929 included a study of the relationship between the velocity of the wind, and the pressures induced by this velocity on the lee and windward faces of a building, for the purpose of determining the infiltration of air due to these pressures, and also for the purpose of determining the total overturning moment exerted on a building by the wind. The records of the Detroit Station of the United States Weather Bureau were studied and the magnitude and velocity of the winds in that city during the months of December, January, and February, for the past four years were compiled.

The material of the report is presented in the following order:

1. Equipment for the work, including a resume' of some of the difficulties encountered in securing satisfactory equipment.

2. Procedure of the work, with a description of the disposition and operation of the apparatus.

3. Interpretation of the wind data taken with this apparatus.

4. An analysis of the records of the wind in Detroit.

5. Conclusions derived from the year's work.

EQUIPMENT FOR THE WORK

The nature of the work involved required apparatus not readily available on the open market, and much of it was built as required. It was found to be more satisfactory in the long run to build some of the instruments than to try to modify existing equipment, and this policy was followed as closely as possible.

Instruments for Recording Pressures.

The first piece of equipment necessary to secure data on the relation of the pressures at various points on a building was a recording pressure instrument. Several obstacles had to be overcome before a satisfactory device could be secured, and, while an account of these difficulties is not exactly relevant to the main purpose of this report, it is believed that a brief review of some of the major items may be of value to anyone engaged in similar work.

It was decided to have three recording pressure gauges in the set-up; one to be used for taking the velocity pressure of the wind, one for the windward pressure, and one for the leeward pressure on the building. These instruments were to take these pressures at three points around the building simultaneously, and their records would later be compared to establish the relationship of the various pressures. An instrument was required for this use which would record pressures ranging up to one inch of water, preferably in increments of .01" on a strip of paper in perfect synchronism with others of the same type. A minimum of inertia effect or lag was desired because of the rapid fluctuations in pressure incurred in working with the wind. In addition the instruments were to be as light as possible to facilitate transportation and use.

The Bachrach gauge used in the work described in the paper, "Pressure Differences across Windows in Relation to Wind Velocity", by J. E. Emswiler and W. C. Randall, American Society of Heating and Ventilating Engineers, October, 1929, was satisfactory in some respects, but could not be synchronized with any others, because it had a self-contained clock-work motor, and was also very heavy and bulky. It also lacked the continuous strip recording feature which was held to be very desirable. As there were no other commercial recording gauges of the desired type available in the fall of 1929, it was decided to build one in the Mechanical Laboratory shop.

Professor Emswiler designed a gauge, shown in Figure 1, which employed the well-known principle of a closed bell partially immersed in a liquid, whose position was varied by the pressure in an air space inside the bell, above the level of the liquid. A tube communicated with the air space inside the bell, and a counter-balance sustained the weight of the bell itself. It was planned to attach a pen to the movable bell, which would leave a record on a continuous strip of paper drawn along the outside of the container of the apparatus at a speed of about six inches per minute by a small synchronous motor. To prove the feasibility of the scheme, it was decided to build one with a two-inch diameter bell, giving a range of 1-1/2 inches of water head for 3 inches of displacement of the bell. This was done, but what at first appeared to be details of construction turned into stumbling blocks which delayed the whole program for the year. The mechanical counterbalance for the bell was a most annoying one. The first method employed was that of passing two thin cords over a light drum supported on small ball bearings. This mechanism failed through two hitherto unsuspected factors. The inertia of the drum itself was too great to enable the instrument to respond to slight variations in pressure, even though it was built of aluminum. Also, the ball bearings were not so smooth as had been anticipated, a sort of drag or catch in their movement was present, which persisted even after several hours of running-in at high speed.

The next attempt to eliminate drag in the movement of the bell was the substitution of a very light shaft for the ball bearing drum assembly. The shaft was supported in hardened cup and cone bearings, and had two thin disks with grooved edges for the cords mounted on it. While it was found that this reduced friction and inertia considerably, and the bell was noticeably more sensitive to slight pressure variations than formerly, it was still far from satisfactory, and was discarded.

In order to eliminate all mechanical friction, an experiment was tried in which the bell was suspended by a stiff wire to a wooden float immersed in mercury as in Figure 2. This gave a nearly constant buoyant force, as only one wire from the float up through the mercury varied the displacement of the mercury and the friction, when all parts were correctly alligned, was negligible. With this arrangement the apparatus was very sensitive to slight variations of pressure, but was easily deranged and was by no means portable. The minuteness of the forces available was shown very clearly when a pen was attached to the moving bell of the gauge, as it immediately destroyed the sensitivity of the apparatus merely by its friction on the paper. It was also noted that the drag of the liquid on the bell had considerable influence on the speed with which it responded to pressure changes, and that gasoline was a much better liquid for the purpose than water, due to its lower viscosity and affinity for the brass of the bell.

The mechanism for moving the strip of paper at a constant synchronous speed was developed without much trouble. The small 4-Watt synchronous motors made by the Warren Telechron Company for use in electric clocks, proved to be too small to drive the tension drum of the apparatus, but the larger 6 and 12-watt sizes made by the same firm were both found to be satisfactory. The shaft of these units turns over at one r.p.m. through a 3600:1 speed-reduction gear from the rotor of the motor, and was connected through an Oldham's coupling to the shaft of the roll which pulled the paper strip past the pen of the gauge.

As the principle of the bell type gauge had been proved to be satisfactory, the main objections were to the small magnitude of the forces available, and to the mechanical suspension of the bell first attempted, it was decided to double the diameter or the bell, thus quadrupling the force on its head, and to re-design the guage to incorporate a compact mercury suspension scheme. This was done as shown in Figure 4. The improved pressure element differed from the temporary mercury suspension job mainly in that the mercury was contained in an inner steel cup inside the water compartment, instead of above the bell, with a ring-shaped wooden float supporting the bell by means of three stiff steel rods. The system was made stable by a pendulum which ran through the pressure inlet tube with the bob hanging in a chamber below the gauge proper. One of these gauges was built by the Instrument Shop of the University, but when the model was completed, it was found to be faulty in some details of construction, and the time left to experiment was so short that it was impossible to set it up and try it out. It is thought that, if this line of experimentation were followed to a more fortunate conclusion, the gauge would be successful in its operation.

After the hydraulic gauge was abandoned, it was decided to try the element of a low-pressure gauge built by the Bristol Company, Waterbury, Conn., with the strip-moving mechanism driven by the synchronous motor as described above. An element which worked in the range of -.3 inch to +.7 inch head of water was secured, and had been successfully set up and calibrated when a bulletin from the Bristol Company announced a new line of instruments driven by the same synchronous motors that had been tried here. As the result of some correspondence with them, it was decided to buy their instruments and abandon efforts to develop any here, as the time left for experimenting was short. They provided us with gauges having a 10-inch circular chart, rotating once in 15 minutes, with a pressure range of -.3 inch to +.7inch of water. The strip recorders made by this company were too expensive, so eventually the circular chart type had to be used. One of the gauges was equipped with an air-tight iron case which, when tapped for pipe fittings made it possible to use it for a differential pressure recorder in connection with a pitot tube for determining wind velocity. The other two were in wooden cases for measuring total pressure only.

Auxiliary Equipment.

It was necessary to have some auxiliary equipment to use with the pressure gauges and all of this was built here. A Pitot tube which formed the tip of a wind vane so as to present the nose to the wind at all times was the most important of these auxiliaries. This device, shown in Figure 5, secured the velocity pressure which was recorded by the differential pressure gauge mentioned in the preceding paragraph. The tube was built according to A.S.H. & V.E. specifications, with an outer static-pressure tube of 5/8 inch diameter, and an inner total-pressure tube of 3/8 inch in diameter. The vane was of the split type which insured maximum stability and the assembly was mounted on ball bearings in order to insure maximum sensitivity.

It was originally intended to have the whole system of wind-pressure recorders operate automatically, and to do this the gauges were to be run only when the wind was in a specified direction, plus or minus five degrees. Accordingly, a commutator, Figure 3, was mounted on the wind-vane shaft, and, as it was not desirable to break the 110-volt circuit for the gauge motors at the point where the vane would be on top of the structure being studied, this commutator operated a relay. The relay was a simple type which operated on a 6-volt storage battery and broke the higher voltage circuit with a Mercoid switch unit mounted on a rocker arm.

PROCEDURE

The ideal situation for the work in this field would be an isolated building with no trees or other structure near by to influence the wind as it approached the building where the instruments were located. The nearest approach to this, however, that could be obtained was the tower of the Michigan Union Building. This is eight stories high, four of which are above the main part of the building, and is not equaled in height by any near-by obstructions. The roof of the tower is also easily accessible and the top room was vacant. These conditions, together with its proximity to the campus, made its use very desirable. The privilege of using the tower and the unoccupied top room was fortunately granted.

Disposition of Instruments.

The tower is square and is 28-1/2 feet on each side. The tower room is arranged as shown in Figure 6, with four windows on each face except the north and east sides, which are cut into by the stair wall. Two recording gauges, one for the leeward and one for the windward pressure, were placed inside this room and were connected by means of short rubber tubes to brass tubes set flush in boards cut to fit the window openings. This made it very easy to change the location of the instruments to meet any existing conditions, as it was necessary only to shut the window upon the board with the tube in it and then connect the gauge to it. The instruments were always placed as near the center of the face of the building as possible so as to secure a maximum value of the induced wind pressures.

The top of the tower is similar in plan to that of the tower room. It has a wide stone coping 3-1/2 feet high around the edge. The Pitot tube and vane were placed on the north-west corner of the tower, and the differential recording gauge was placed near it. As the shaft of the vane was five feet long, it is believed that the wind striking it was almost unaffected by the tower for directions ranging from SW to NE. This range of directions includes the prevailing winds for this locality.

The relays, battery, and other equipment were assembled in the tower room, and everything could be controlled from that point. The two pressure gauges in the tower room were usually on opposite sides of the tower so as to get a record of leeward and windward pressures simultaneously.

Direction Control of Gauges.

The original intention was to set the 10-degree segment of the commutator to suit the prevailing direction of the wind at the time the records were taken, and then let the control system stop and start the three motors in unison so that the three records would be perfectly synchronized when taken off the gauges. In theory this was all right, but in practice it did not work out perfectly. The synchronous motors used were of 2-watts capacity and their starting torque was so slight that variations in viscosity of the oil in the gear case containing the 3600-to-1 speed reduction were sufficient to influence the lag in starting. As a result, by the time the instruments had run the 15 minutes required to fill a chart, in the short intervals that the wind was in the right direction, the coldest instrument had a considerable lag compared to the warmer ones. This lag could not be distributed proportionally along the chart because of the unequal number of starts and stops at various parts of the charts. As perfect synchronization was necessary in these records, this inaccuracy could not be tolerated and steps were taken to eliminate it.

At first the charts, which resembled the sample set shown in Figures 7, 8, and 9, were resynchronized at every quarter revolution (6 hours on the arbitrary 24-hour scale). While this reduced the errors to one-fourth their former value, it entailed considerable trouble and delay during a run, and could not be considered as wholly satisfactory.

As the main difficulty was in the start-and-stop principle of automatic control, another attempt was made to record winds from only a prescribed direction and the motors were run continuously. This new scheme consisted of designing and building an automatic venting device which would open the total pressure line running to the differential gauge from the pitot tube at all times except when the wind was in the desired direction. When the commutator on the wind-vane shaft made contact, a solenoid was energized and dipped the end of a glass tube connected to the total-pressure line into a cup of mercury, thus allowing the differential gauge to operate in its normal fashion as long as the wind remained in the desired direction. This device and its connections are shown clearly in one of the photographs of the apparatus on the tower.

It was intended that this system of operation would give a velocity pressure chart of alternate sections of zero value and of the true value taken when the vent was open and when it was closed, respectively, during periods in which the wind was within the desired 10-degree range. However, the intervals of time in which the wind stayed with the 10-degree segment were so short that the record, instead of being alternate stretches of zero pressure, and fluctuating periods when the wind was acting on the gauge through the pitot tube, was composed almost entirely of up and down lines caused by the rapid opening and closing of the vent. A 20-degree segment was put on the commutator, but this change did not help materially as the travel of the pen was still very erratic. Some of the records taken by the methods outlined were satisfactory as regards accuracy, but their preparation into a usuable form was so laborious that they were superseded by a simpler system.

Continuous Records without Direction Control.

It was decided to sacrifice the feature of direction control in order to secure perfect synchronism and a more readable record. This was accomplished by disconnecting the commutator and installing a switch, which enabled the observer to start and stop all three instruments at will from either the tower room or the roof. When this was done, much of the previous difficulty disappeared at once and records were obtained which were much easier to compare and which matched perfectly in their timing. All three synchronous motors functioned properly when running steadily.

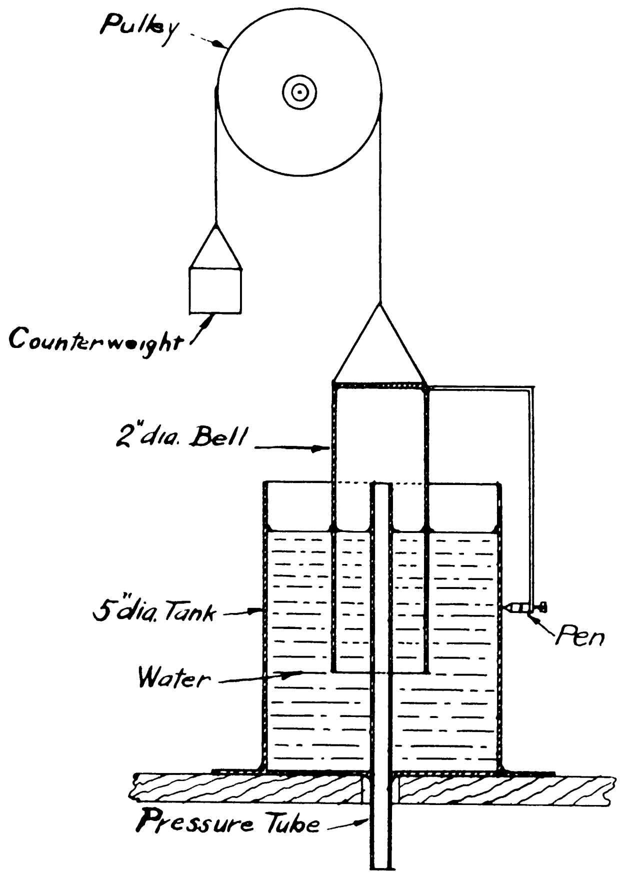
The curves traced by the pens of the instruments were much smoother when the charts were running steadily than when the direction control was in use, and the gain in accuracy and readibility more than offset the loss due to abandoning the selective function of the commutator.

The instruments, after having been installed in the tower, were checked against a sensitive Ellison Inclined Draft Gauge, and were found to be accurate within .01 inch head of water over their entire range. A static head was imposed upon both the Bristol and the Ellison gauges simultaneously by means of a variable column of water in this check up.

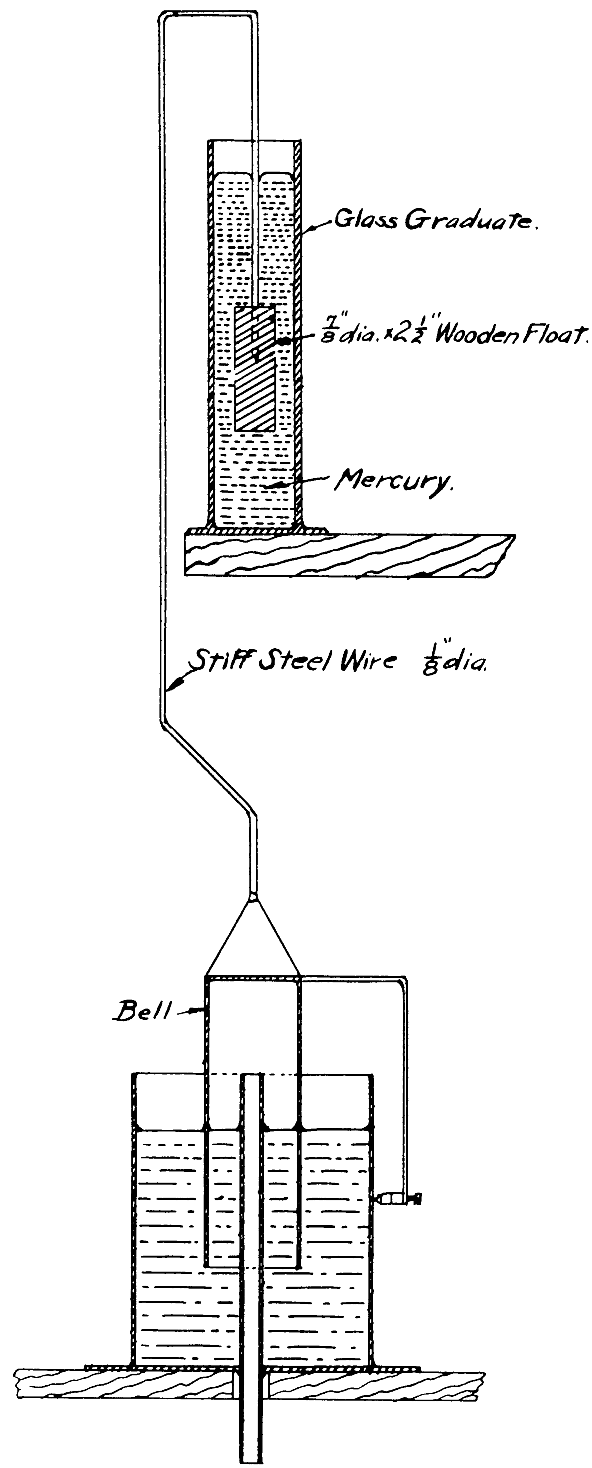
Variation of Conditions during Runs.

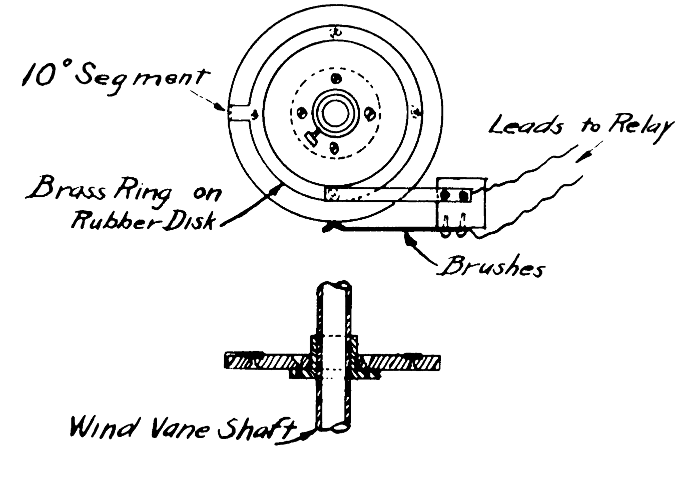
The greater part of the runs were made with the instruments disposed as follows: The differential gauge for determining the velocity pressure of the wind was on the northwest corner of the tower. The other two gauges in the tower room were located at the east and west faces of the building. This arrangement was satisfactory for nearly all conditions encountered, as the prevailing winds for the locality are southwest to north. The windows and door of the tower room were kept closed most of the time to simulate winter conditions in a building.

On one occasion, when there was a very high south wind, one of the gauges was shifted from the west to the south face and a few runs were made with this arrangement. Also, on this same day some experiments were made by opening various windows in the tower room and noting the subsequent effect on the gauges in the room. The results obtained were very interesting, and promise some further information on wind effects when gone into more exhaustively than was possible at this time.



ORIGINAL PRESSURE ELEMENT.
Fig. 1.

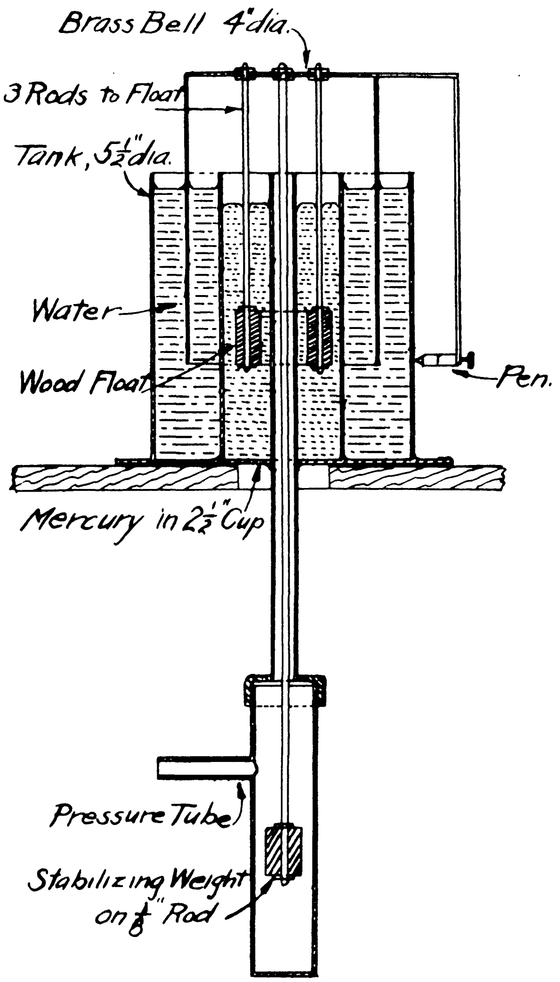




DIRECTION CONTROL COMMUTATOR
Fig. 3.

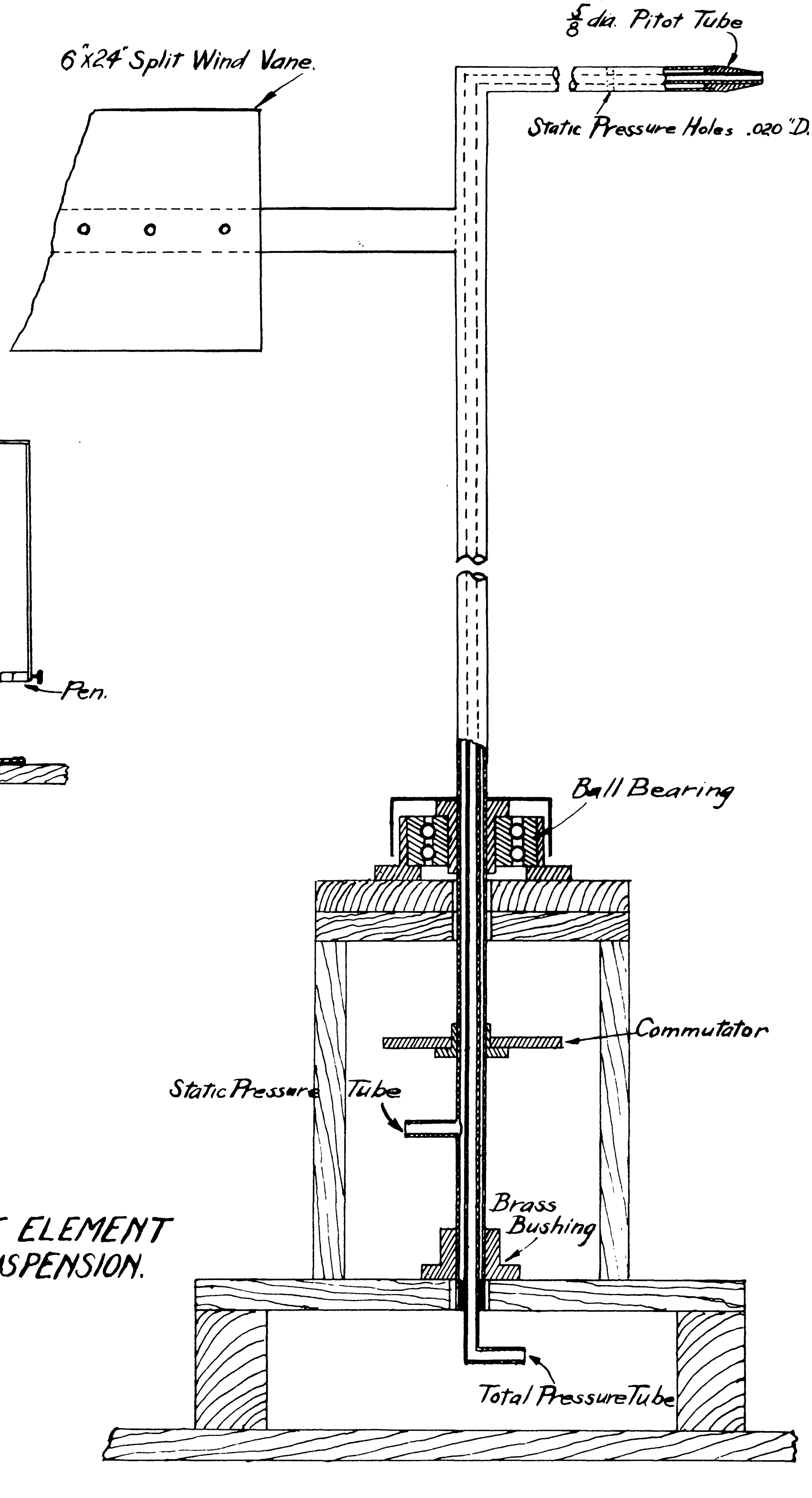
TEMPORARY MERCURY SUSPENSION ON PRESSURE ELEMENT.
Fig. 2.

SCALE - $\frac{1}{4}$" = 1"



IMPROVED PRESSURE ELEMENT WITH MERCURY SUSPENSION.

Fig. 4.



WIND VANE AND PITOT TUBE.

Fig. 5.

SCALE $\frac{1}{4}$"=1"

The Michigan Union, Ann Arbor, Michigan.

Interior of the Union Tower Room.

Rear View of the Union,
with Vane on Tower.

Direction Control on Vane.

Venting Device on Gauge.

Pitot Tube, Vane, and Bristol Gauge.

Control Station in the Union Tower Room.
Gauge Connected to the Window at the Left.

A Bristol's recording Vacuum and Pressure Gauge.

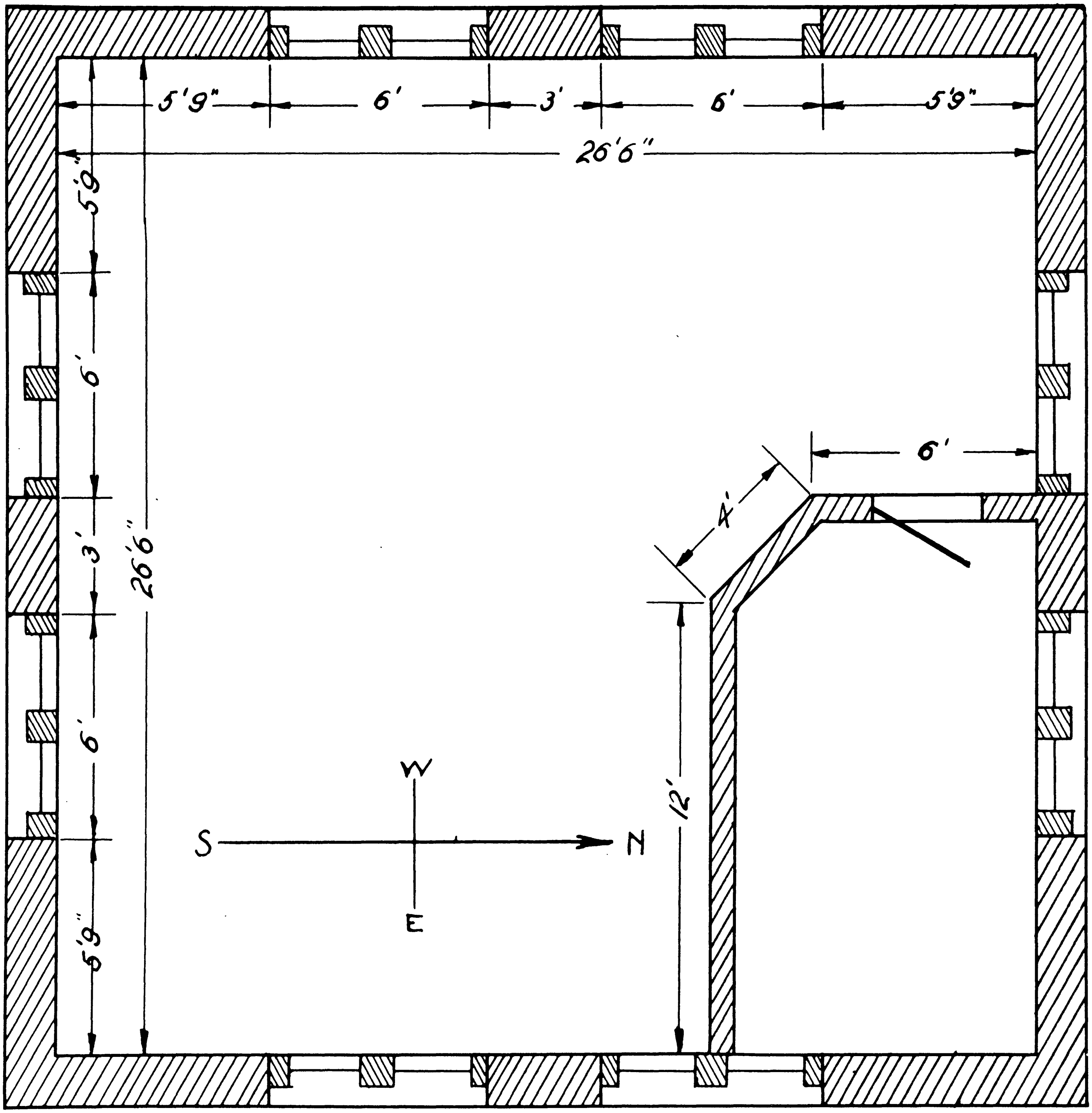


FIG. 6.

PLAN VIEW OF THE UNION TOWER, TOP FLOOR.

SCALE - 1/4" = 1'.

INTERPRETATION OF DATA TAKEN

A large number of charts were obtained by making runs whenever the wind conditions were suitable. As taken, the records were scarcely in a usable form, as the circular charts with only one curve on each were not readily comparable nor easy of interpretation. Each run, which is a term used throughout this report to describe a complete set of three charts which have been made simultaneously by the three recording gauges of the set-up, was therefore transcribed onto a system of rectangular coordinates. The three curves of a run are superimposed on the same sheets to permit easy comparison. It will be noted that there are two sheets of these curves for every run so transcribed as they could not be drawn to a proper scale on a single sheet. The second sheet of each run is marked "Cont'd" to designate it as the part corresponding to the P.M. section of the charts. A sample set of charts, Run "AB" is included with the transcribed curves (Figures 7, 8, and 9). These photostats are two-thirds the actual size of the original charts, which are ten inches in diameter. Thus the velocity pressure, windward pressure, and leeward pressure can be compared at a glance. The runs were grouped according to the direction of the wind and will be found to have been treated as groups rather than as individual runs.

Wind Normal to the Building.

The most important group of runs were those taken when the wind was blowing from a westerly direction. In this group, runs "v", "r", "Ac", "Ab", "d", and "k" have been taken as representative specimens, and the superimposed pressure curves from the three instruments are included in this section. In drawing these curves the arbitrary scale of hours found on the charts supplied with the instruments was used as one ordinate, and the head in inches of water as the other. As the instruments revolved once in 15 minutes instead of once in 24 hours, the horizontal scale reduces to one inch being equal to .783 of a minute instead of 1.25 hours, which it would be if the chart scale were true.

A study of the curves of these runs indicates at a glance that the windward pressure curve is very similar to the velocity pressure curve, and to a less marked extent the leeward pressure curve is much like the velocity pressure line. The velocity pressure was more subject to small fluctuations than either of the other two pressures, due to the variable nature of the wind, and the small amount of air involved in the transmission of these variations to the instrument. In the case of the two gauges in the tower room, the neutral or reference pressure in the room corresponds to the static pressure impressed on the outside of the pressure element of the differential gauge used for taking velocity pressures. However, it is not constant, nor nearly so as the static pressure is, and the effect of its variation on the record of the windward pressure gauge is as follows. A sudden increase in the windward head on the building finds the room, or reference pressure with a low value, and the pen on the guage registers the full difference between the windward pressure and room pressure; as the windward head persists the room pressure increases because of leakage on the windward face of the building, and the differential registered by the gauge becomes smaller. Hence, the curve traced by the pen jumps suddenly to some high value as a gust of wind hits the building, and slopes down gradually as the inner pressure builds up. In the meantime the true windward head may have been at a constant high value, but the gauge will have shown a steady decrease, due solely to the change in the reference pressure. The same thing applies to the leeward pressure, but here the effect is reversed, as an increase in the reference pressure increases the apparent suction registered by the gauge. The effect is not so noticeable in the case of the leeward pressure records because the heads registered were quite small at all times.

The response of the windward pressure to an increase in the velocity pressure is dependent upon the direction of the wind at the instant of increase. The more nearly normal the wind, the closer the agreement between the two curves, and vice versa. As it was previously explained that the directional control was given up in order to secure better charts, the directions noted on the accompanying curves are those of the prevailing winds during the runs, and are not to be taken as meaning that the wind was strictly confined to that given segment of the compass circle. As a rule, the higher the wind, the more unstable its direction is liable to be from minute to minute, while in the lower ranges the direction is notably more constant. Hence, the lack of agreement between windward and velocity pressures is most noticeable in the runs with higher heads recorded in them. Run "k", the curves of which will be found at the end of this section, is an exception to this rule, because it was taken while the direction control device was still in use.

The leeward head behaves in exactly the opposite way from the windward head, as it becomes more responsive to changes in velocity when the wind is not normal to the building than when it is normal. This is particularly well brought out in the curves of run "Ab". In the sections marked "1" and "2", which were one continuous stretch on the original charts, the wind changed from practically due west to northwest, and the hitherto fine agreement of the velocity and windward head curves was immediately broken up, while the agreement between the velocity and leeward head curves noticeably improved during this time. These effects agree with previously observed phenomena concerning wind effects on obstructions, as a wind at an angle of less than 90 degrees to the windward face produces a greater suction in the rear of the obstacle near the corner around which the wind is blowing than a normal wind does. Experiments with long structures have shown that the suction is higher near the windward corner than it is further along the leeward face, but in the case of this small square tower, the increase in suction was probably general when the wind swung around away from the normal angle.

The agreement between the various pressures recorded is interesting to note in the runs mentioned, but the original transcribed curves convey no quantitative idea of their actual relationship. Hence, it was decided to present their information in a modified form. To accomplish this it was necessary to construct a set of curves which would present the results of a comparison of the various pressures throughout the six runs included in this group, and would establish a relation between them. Accordingly, a set of axes were taken with the velocity head in inches of water as one ordinate, and the head induced by this velocity head on the windward and leeward faces of the building as the other ordinate. A large number of points were then plotted, and the paths of the curves on Figure 10 were determined. The points themselves are too numerous to be shown, but with six runs to work from there is every reason to believe that the curves shown are correct. The higher values of both the leeward and windward pressures were very definitely determined by the relation of the pressure curves in run "k", which was fortunately not only of high velocity, but limited to nearly a due west wind by the direction control.

It will be noted that the windward head curve is a straight line whose value is 80 per cent of the velocity head. The leeward head curve is steep at the lower part, where it equals about 40 per cent of the velocity head, but drops to around 15 per cent at the higher values of the velocity head. The third curve, called the "Total Head", is the sum of the windward and leeward heads, and is about equal in value to the velocity head. The total head exceeds the velocity head at some points, which seems to be an anomaly until it is considered that the windward head is a sort of piled-up mass of air, and the leeward head an attenuated region in the rough shape of a cone, and that it is not necessary that both be maintained by the same group of moving particles of air, but may be considered to be maintained by innumerable particles moving at a high velocity, which in this way may impart a total head to the pressure regions of more than their individual heads. At the higher values of the velocity head the total head drops off, due to the falling off of the slope of the leeward head curve.

In Figure 11 the curves of Figure 10 are shown again with the difference that the induced heads are drawn against the velocity in miles per hour instead of the velocity head itself. The relation between velocity and head in fluid flow, $V^2 = 2\ gh$, which reduces to $M = 45.5 \sqrt{p}$ for air at 70°F., where "M" is in m.p.h. and "P" in inches of water, was used for this transposition.

Only one position of the windward pressure recorder was used in any one of these runs as it was thought desirable to have a comparison between the value for the windward head in these experiments and that used in the A.S.H. & V.E. formula of $P = .00048\ M^2$. In Figure 12, therefore, the observed windward head, the maximum calculated head, and 68 per cent of the maximum calculated head, which is used as an average value by many designers, are all plotted against the velocity in m.p.h. The resulting curves show that the observed head lies between the other two in value, and approximates 80 per cent of the value of the maximum head given by the formula. One point readings cannot be considered as giving a true average of the pressure on the face of a wall, especially when the building is as irregular as the Union tower, but from these curves it would appear that the point selected was as nearly right as could have been found.

In the last of the set of curves based on this series of runs, Figure 13, the total displacing force of the wind on the building or the sum of the windward and leeward heads, was converted from inches of water to pounds per square foot, and plotted against the velocity. Then the value of the resistance that would be offered by a flat plate normal to the wind was computed from the well known formula $P = .0032\ AM^2$, when P is in pounds per square foot, A in square feet, and M in m.p.h. This formula is used extensively in aerodynamical work, and was originally determined by Eiffel in his research on the subject. It is given in Warner's "Airplane Design", and Monteith's "Simple Aerodynamics and the Airplane", with the coefficient .0032 as used here. When the flat plate resistance in pounds per square foot is also plotted against the velocity in m.p.h. it is seen that the two curves are very similar in form, but that the wind pressure is at all times less than the flat plate resistance. This is what might be expected, since a flat plate offers more opportunity for violent eddies and vortices to form immediately behind it than does a building with considerable depth. The resultant decrease in suction, or leeward head, behind a building is sufficient to account for the lower total displacing force, as evidenced in the curves shown. However, the agreement is closer than would at first be expected when the difference in the form of the two obstructions in the path of the wind is considered.

Winds Other Than Normal to the Building.

The runs when the wind was at angles other than 90 degrees to the face of the tower are not capable of being grouped together and analyzed as a whole, because of the varying effects resulting from slight changes in direction, and the virtual impossibility of obtaining duplicate records in the short time available. They will therefore be treated individually.

Run "y": Run "y" was taken when there was a very strong wind coming from 20 degrees west of south. To meet this condition the gauge in the tower room which was usually on the west side was moved to the south side of the room, the other gauge being left on the east side. As the wind was not normal to any one face, there was no way to get a strictly windward and leeward pressure relation, but in the titling of the charts, the south face is spoken of as "windward" and the east face as "leeward" because they most nearly satisfy normal conditions.

It will be seen from the pressure curves of run "y" that the run was remarkable in that high and low velocities occurred in quick succession. The windward pressure curve follows the velocity pressure curve quite closely, with no periods of marked divergence from the general trend of the velocity head line. This is what would be expected when it is considered that the wind was only 20 degrees from normal to the south face of the building most of the time, and that the general effects noted in the westerly runs were of the same character. However, the leeward head curve is quite different from any encountered before. It follows, or mirrors, the velocity head curve very closely, and the magnitude of the vacuum formed is greater than in any other case noted. As the wind swept around the southeast corner of the tower, a much greater vacuum was formed on the east face than when the flow was due west along the south side. The eddy currents formed were naturally more violent with this angling direction of the wind, and were more nearly comparable to those formed behind a thin, flat plate, than behind a building.

When the induced heads are plotted against the velocity head in Figure 14, the differences between a normal and an angling wind become very apparent. The windward head is less affected than the leeward. Instead of being 80 per cent of the velocity head, the windward now equals about 74 per cent, and is still a straight-line function. The leeward head curve, however, starts off as a straight line at lower values of the velocity head, and instead of decreasing its slope, increases it until the velocity head is .80 inch of water. The leeward head is .29 inch, or 36.2 per cent, instead of 15 per cent at a similar point in the case of the normal to building runs. The sum of the wind-ward and leeward heads is nearly equal to the velocity head throughout its range.

With the induced heads plotted against velocity instead of velocity head in Figure 15, the difference is still more clearly marked between these curves and those of normal winds. The sum of the leeward and windward heads does not equal the linear displacing force of the wind on the building, however, as the two faces considered are not opposite sides of the tower. It is also quite probable that if the instruments had been connected to different points along the east and south faces of the tower, the resultant curves would have had a different trend from those obtained with the gauges connected to as near the center of the faces as the window openings would permit, which was the case during this run. This is particularly true in the case of the leeward head curve, because of the non-uniform suction zone formed by the angling wind on the east face. The unusually wide range of the pressures obtained during this run made it possible to secure a large number of points by which to plot these curves, a circumstance which was quite fortunate. The windward pressure curve was not compared with the calculated value, and the displacing force observed was not drawn against the flat plate resistance because the cases were not analogous in this instance.

Runs "s" and "t": Runs "s" and "t" were made on the same day, and with the wind ranging from north to northwest. They do not fall into the normal class therefore, and are interesting because at some times the wind was almost parallel to the two faces of the building where the gauges were located.

In run "s", the agreement between the leeward and the velocity-head curves is perhaps the best of any run taken. With the horizontal axis as a horizon, the leeward-head curve appears to be a reflection of the velocity-head line, and follows its changes very faithfully. This is due to the more pronounced effect that an angling wind has upon the suction zone at the rear face of the building near the corner around which it sweeps than a normal wind has upon the suction zone extending across the whole read of the building. The windward pressure gauge evidently did not respond to the slight pressure built up until "5" on the time scale. After this point it functioned properly, and the agreement of the windward-head curve with the velocity-head curve is very good for the rest of the run. The range of pressures taken was not sufficient upon which to base curves giving the relationships established in other runs, as the maximum velocity head was only .20 inch of water.

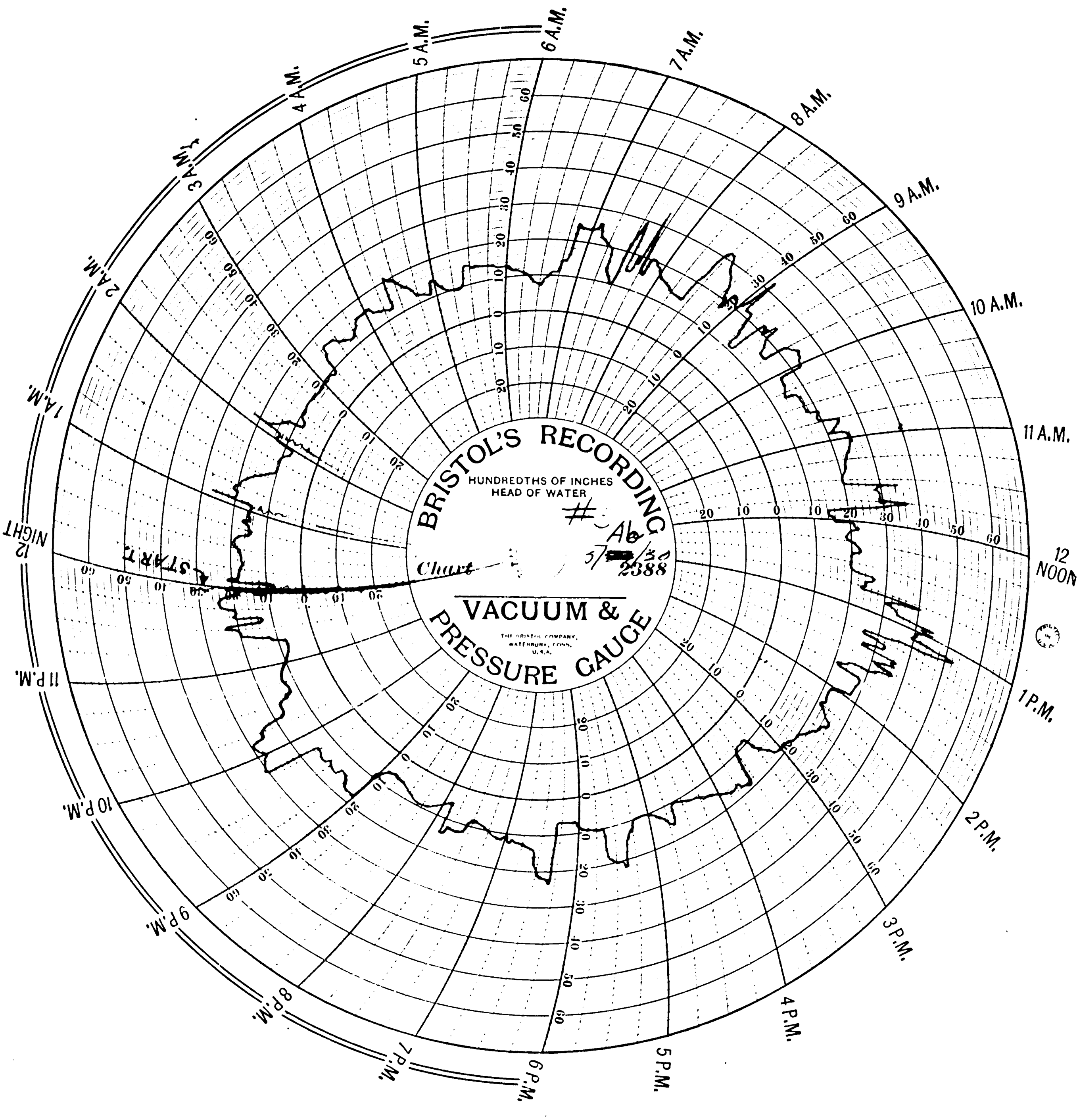
The first half of run "t" is without any particularly noteworthy features, but in the second sheet of the curves traced from the charts of this run, a very peculiar behavior of the windward head curve is apparent. With the velocity head ranging between .02 and .26 inch of water, the windward head hovers around the zero pressure line, rising only to .02 inch of water as a maximum and actually becoming -.02 inch at two points on the curve. The instrument was apparently not jammed or stuck, because minor fluctuations occurred during the time in which it registered zero plus or minus .01 inch of water.

The explanation of these phenomena lies in the fact that when the wind swings around to an angle of 15 degrees or less with the windward face of a building, the pressure on that face becomes negative rather than positive. This was observed in model tests made to determine certain facts concerning natural ventilation. It is interesting to have it substantiated by these results, though the exact angle of the wind at which the pressure changed over could not be determined in this case, as it was when models of buildings were used in a wind tunnel.

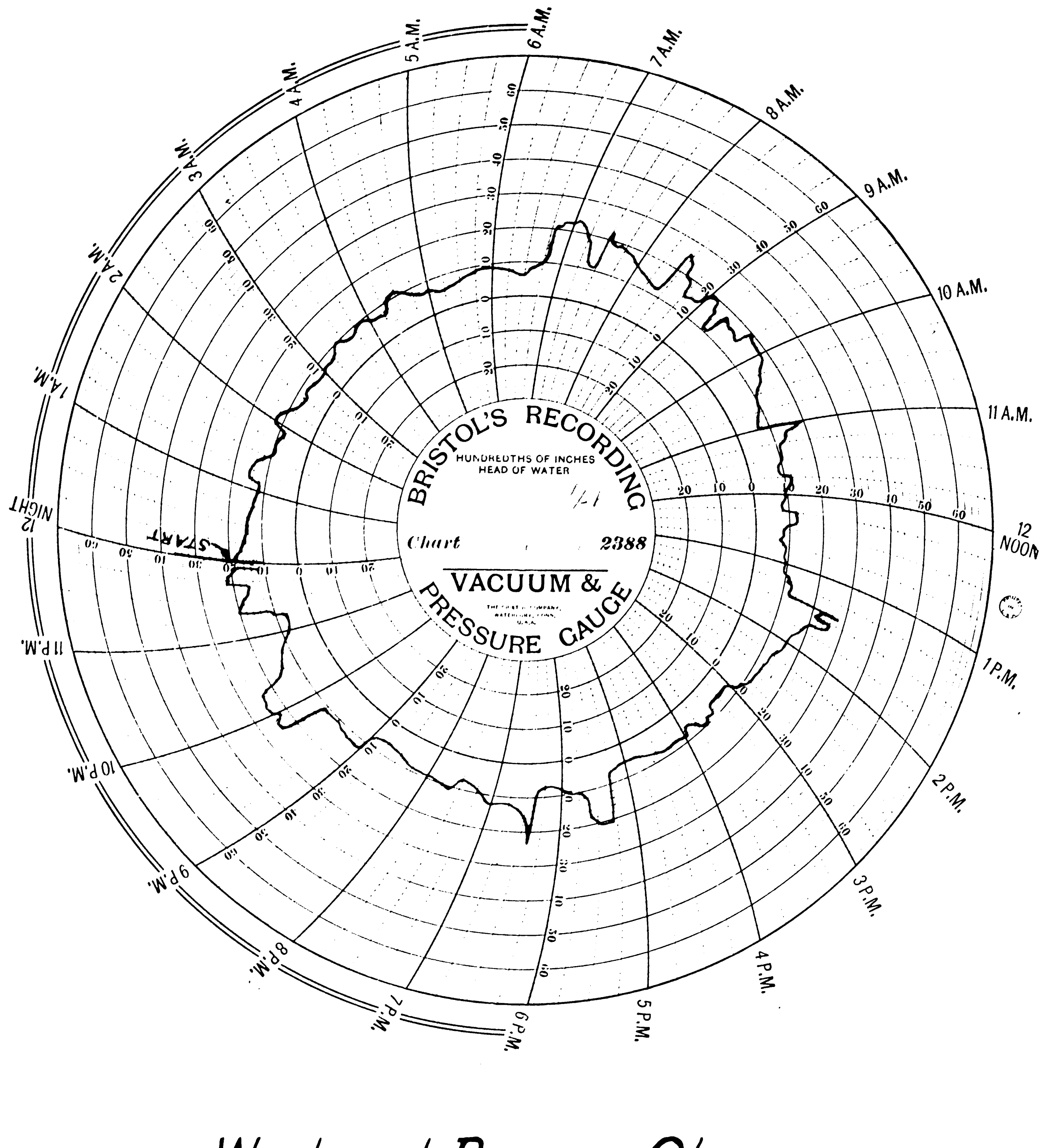
<u>Run "Aa"</u>: Run "Aa" was a special run made with the wind coming from S. 20° W., and with the south windows of the tower room all open and the pressure gauge on the south side of the room. The pressure line ran to an open

window and was fastened to a board placed as usual in the window opening. The velocity pressure was not taken during this run as the wind was so high that it was feared that permanent injury might be done to the gauge if it were connected. However, as this run was taken on the same afternoon as Run "Y", an idea of the velocity head may be obtained from that run, though they were higher yet for Run "Aa". With the windows on the windward side open, and all other openings in the room closed, it will be noticed that the windward-pressure curve roughly resembles a saw-tooth effect. A sudden gust of wind would build the pressure up immediately, then in a lull of the wind the pressure would gradually diminish until the next gust. The room seemed to act as a surge tank in a water circuit, the air within it being compressed by sudden large pressure jumps outside and then being released gradually within a period of about 10 seconds.

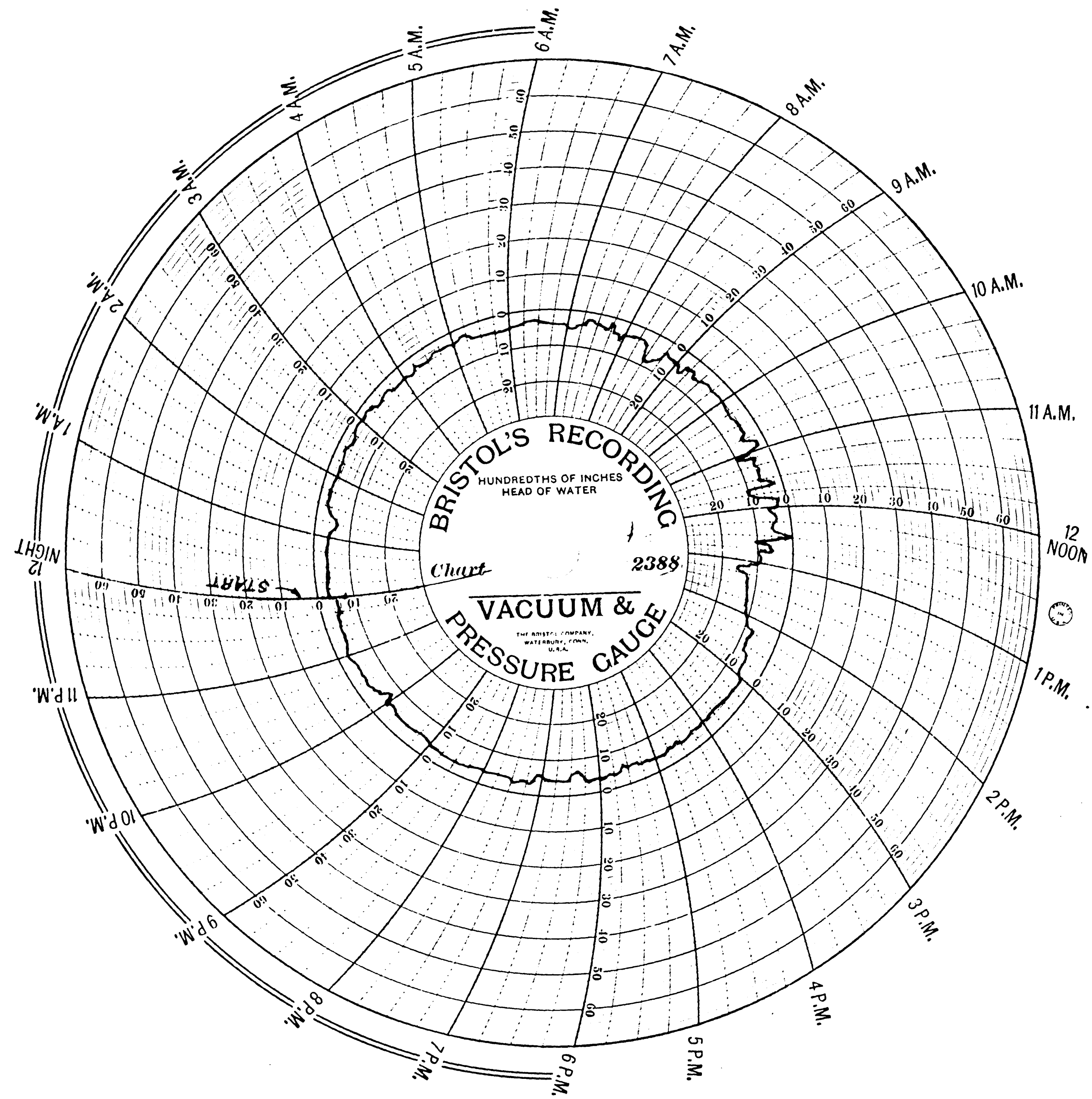
It is noteworthy that the pressure was at all times greater than zero, which shows that there was enough exfiltration from the room to maintain a pressure differential between the outer face of the window and the room immediately inside, as on opposite sides of a diaphragm in an orifice meter. This is certain, because if there were no flow through the windows, the pressure inside would have equalled that outside, and the gauge would not have responded at all. At one point on the curve, when the door was opened, the pressure remained nearly constant for a short time, as the flow through the room increased. Incidentally the pressure on the door, which opened outwards, was sufficient to require considerable effort to close it. When closed, the door was tight fitting, and all of the windows were equipped with metallic weather stripping, so it is probable that for an un-weather-stripped sash the base line of the pressure curve would have been higher in value.



Velocity Pressure Chart.
Run "Ab" 5/24/30 W to NW Wind.
Fig. 7.



Windward Pressure Chart.
Run "Ab" 5/24/30 W to NW Wind.
Fig. 8.



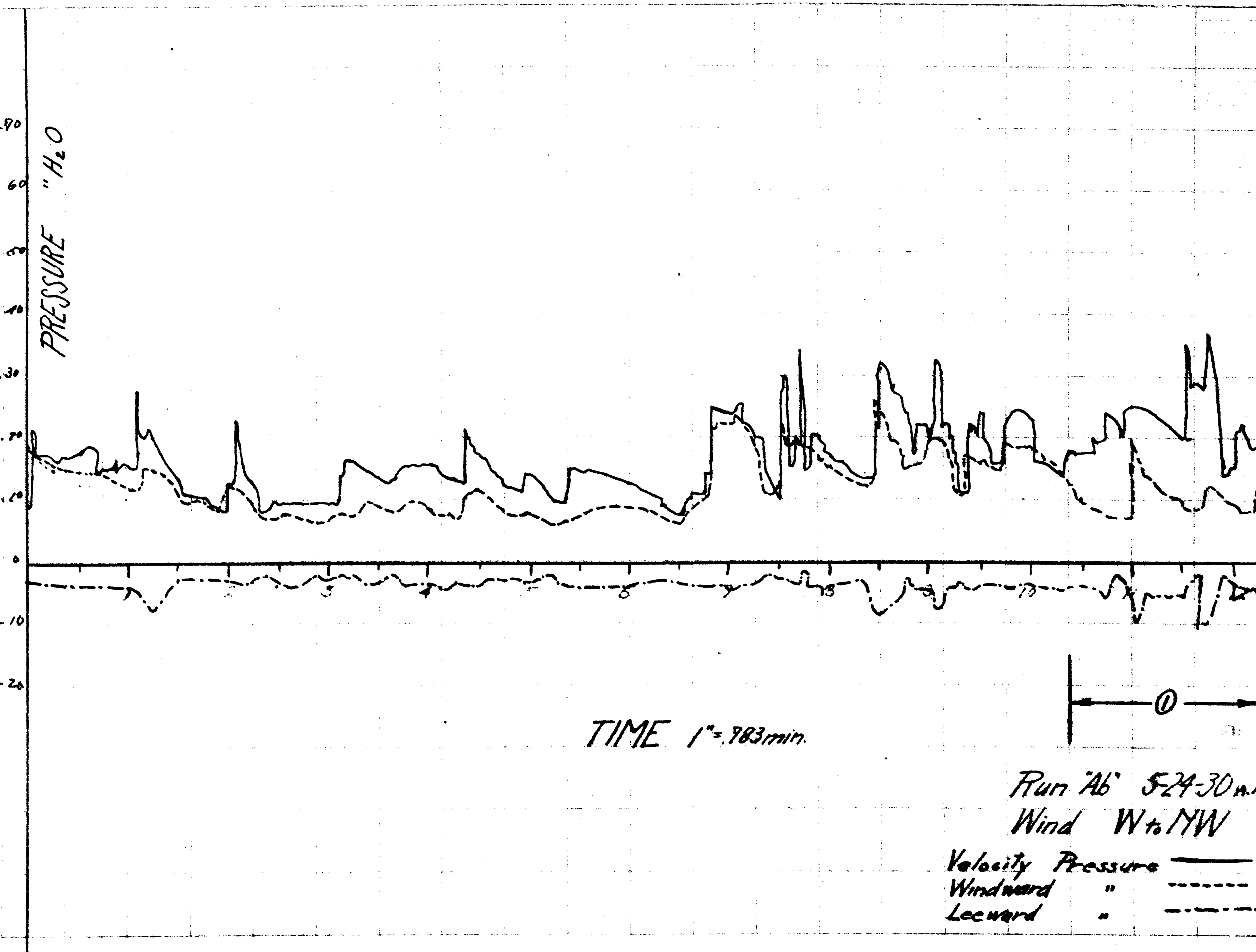
Leeward Pressure Chart.
Run "Ab" 5/24/30 W to NW Wind.
Fig. 9.

1

#3 —— Top
#2 –·– East
#1 ----- West

Run Ab 5/24/30

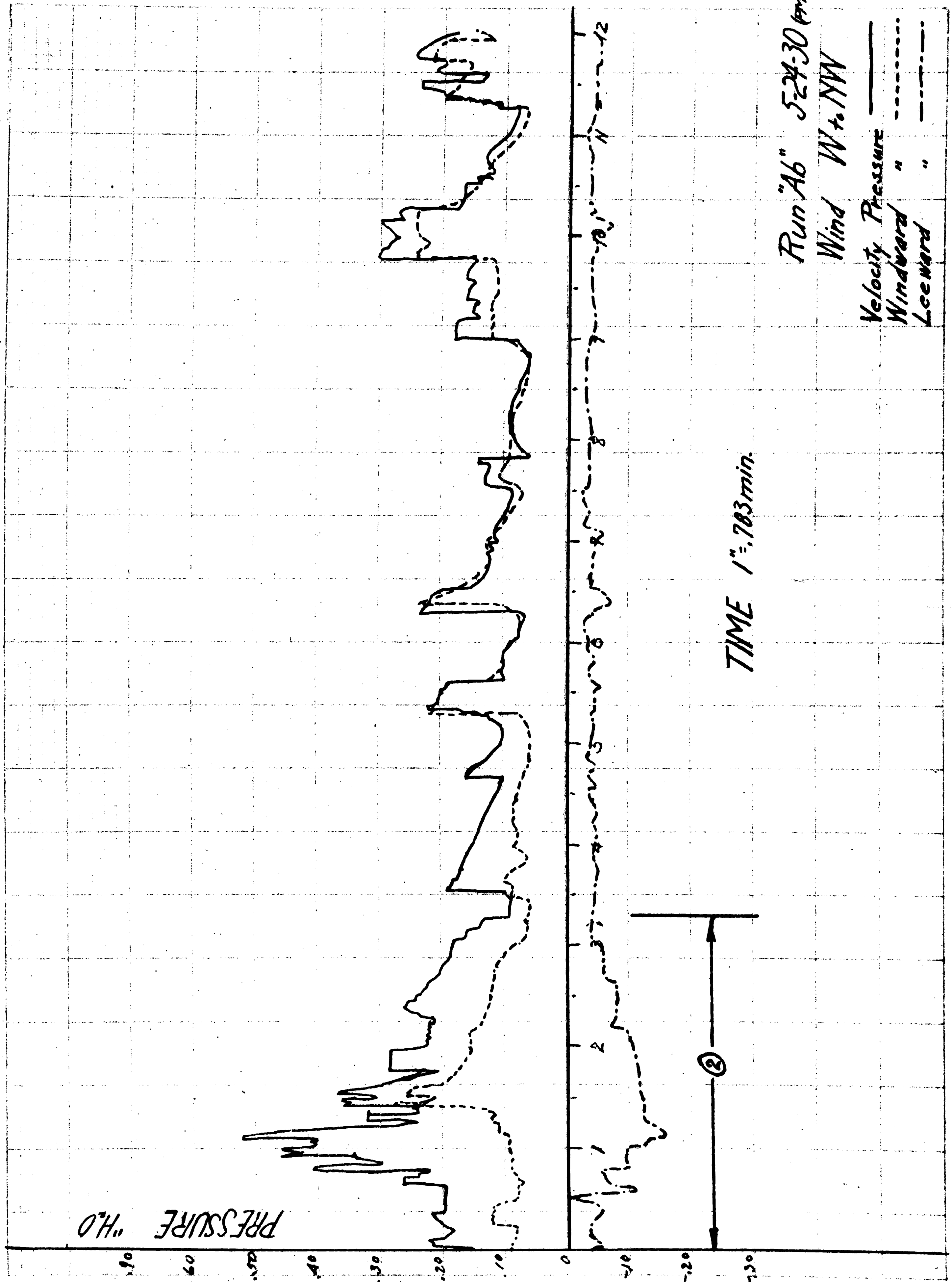
W to NW wind.



Run A6 5/24/30

W to NW wind.

#3 — Top
#2 ---- East
#1 ..... West



2

Accepted
Incorrect
Correction Due
Neatness

Course

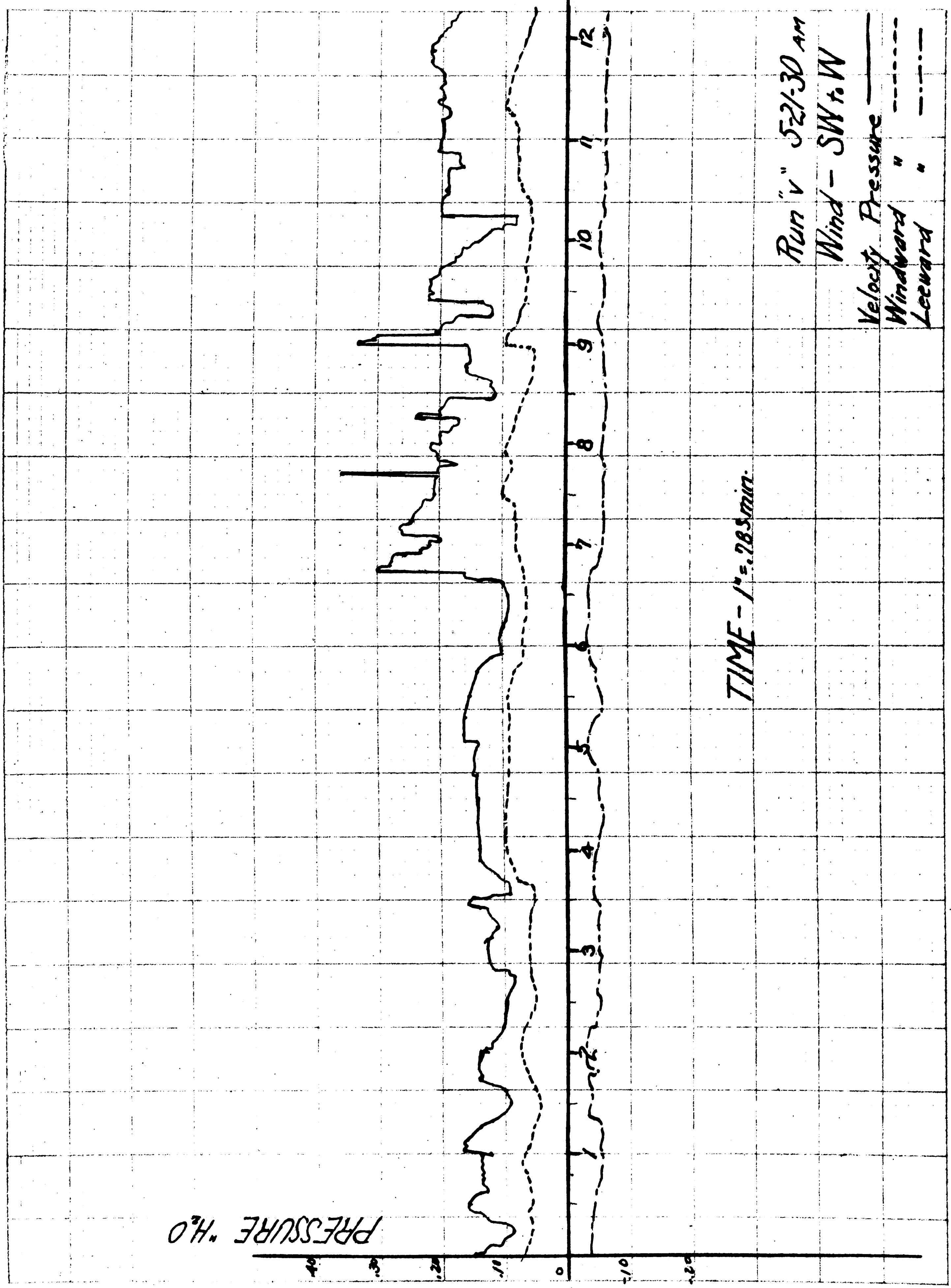
Sec. No.

Problem No.

Name
Date Due
Date Rec'd
Grade

Run "V" 5/21/30
SW to W

#3 — Top
#2 — E
#1 — W

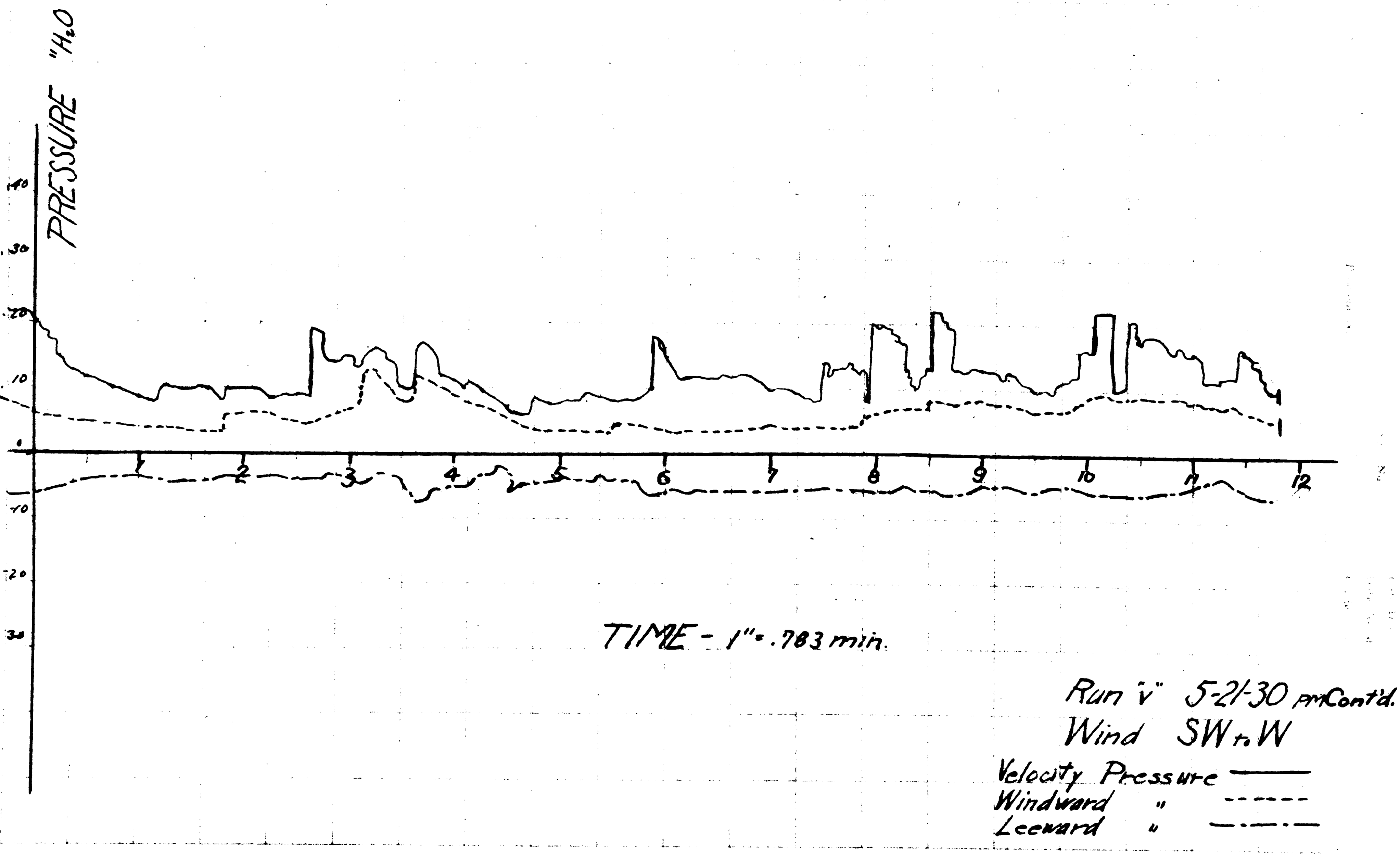


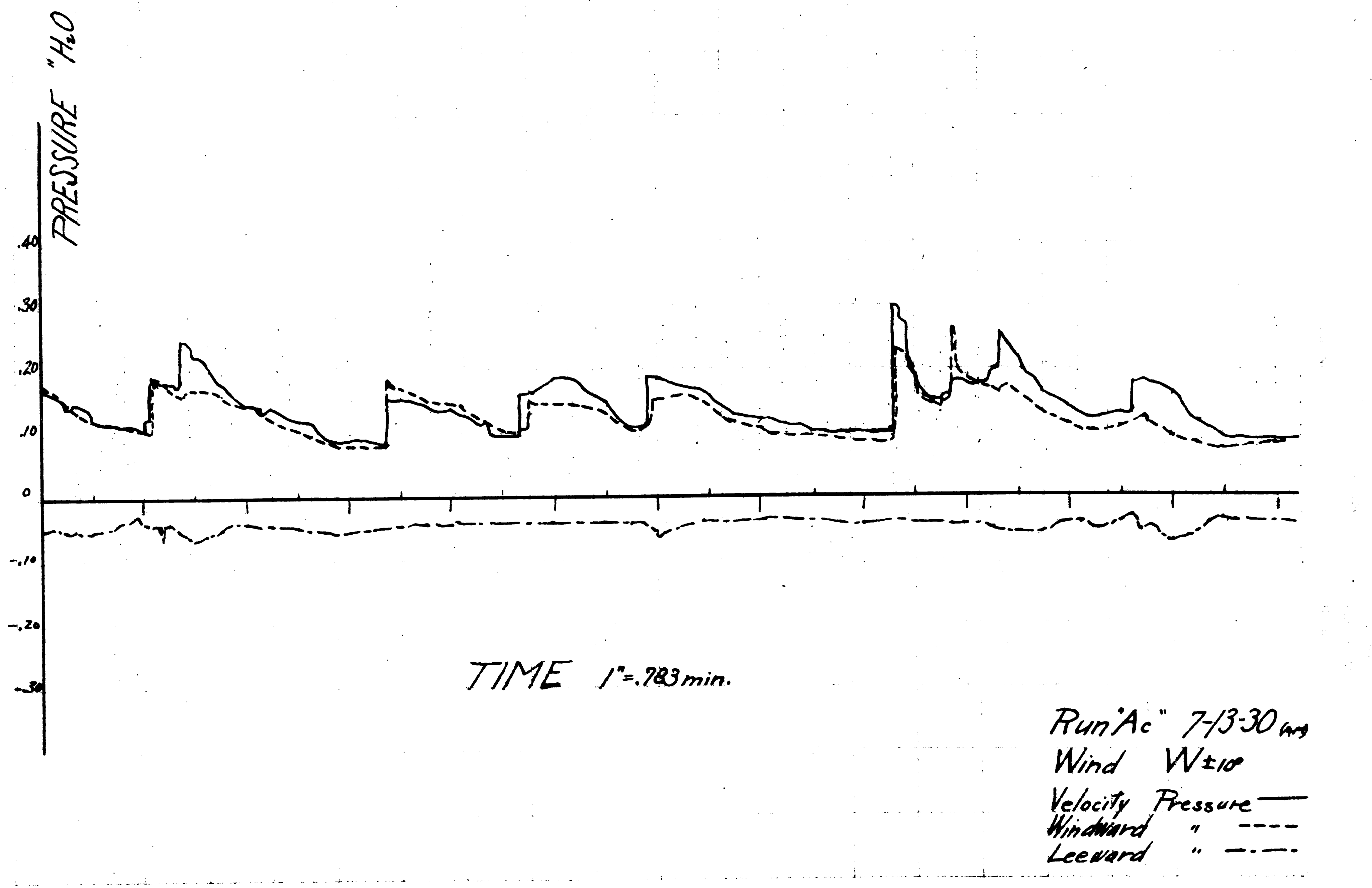
4

#3 — top
#2 — E
#1 — W

Run "V" 5/21

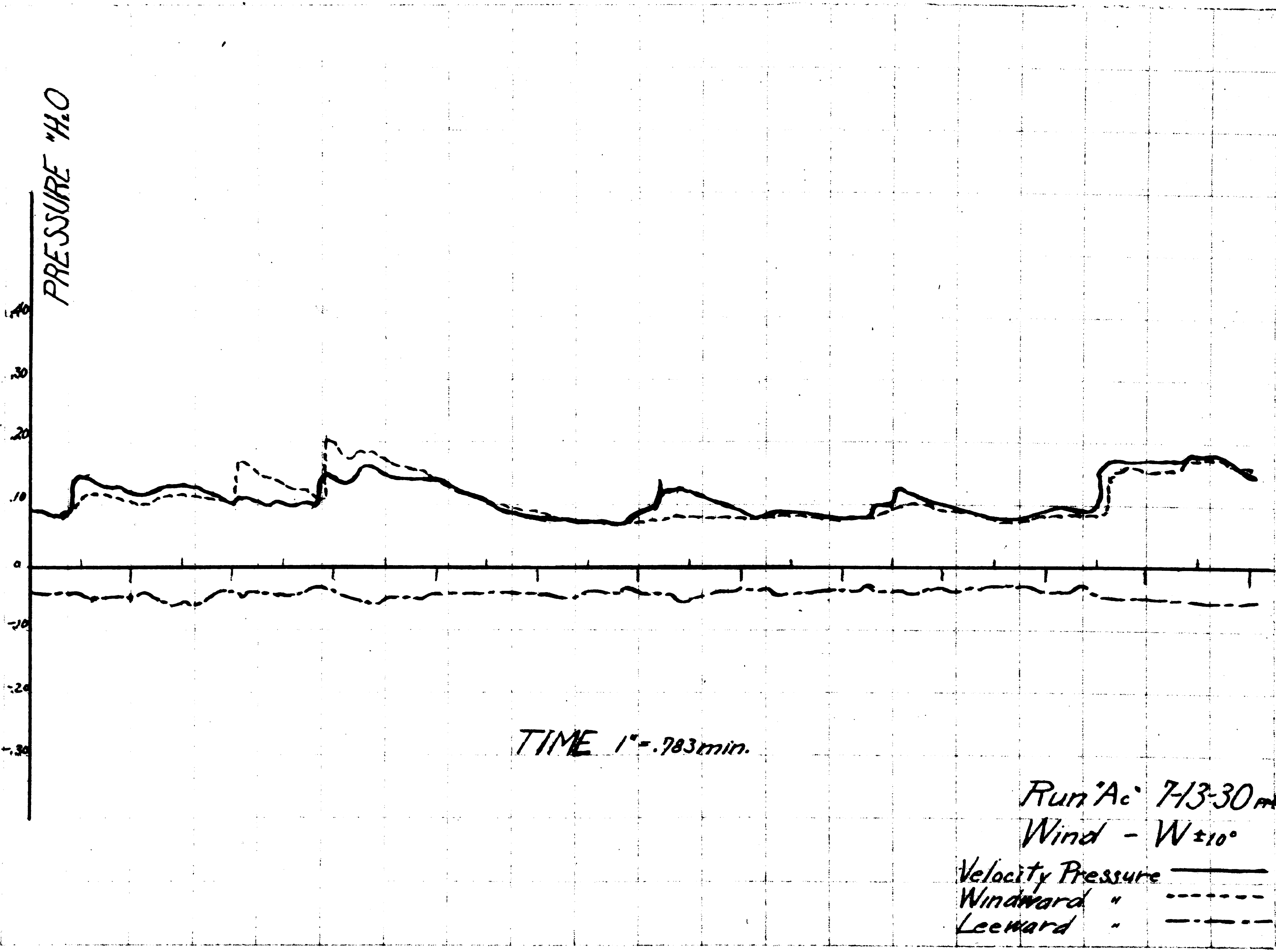
SW to W.





PRESSURE "H₂O
.40
.30
.20
.10
0
-.10
-.20
-.30
TIME 1" = .783 min.
Run "Ac" 7-13-30
Wind W±10°
Velocity Pressure
Windward "
Leeward "

6

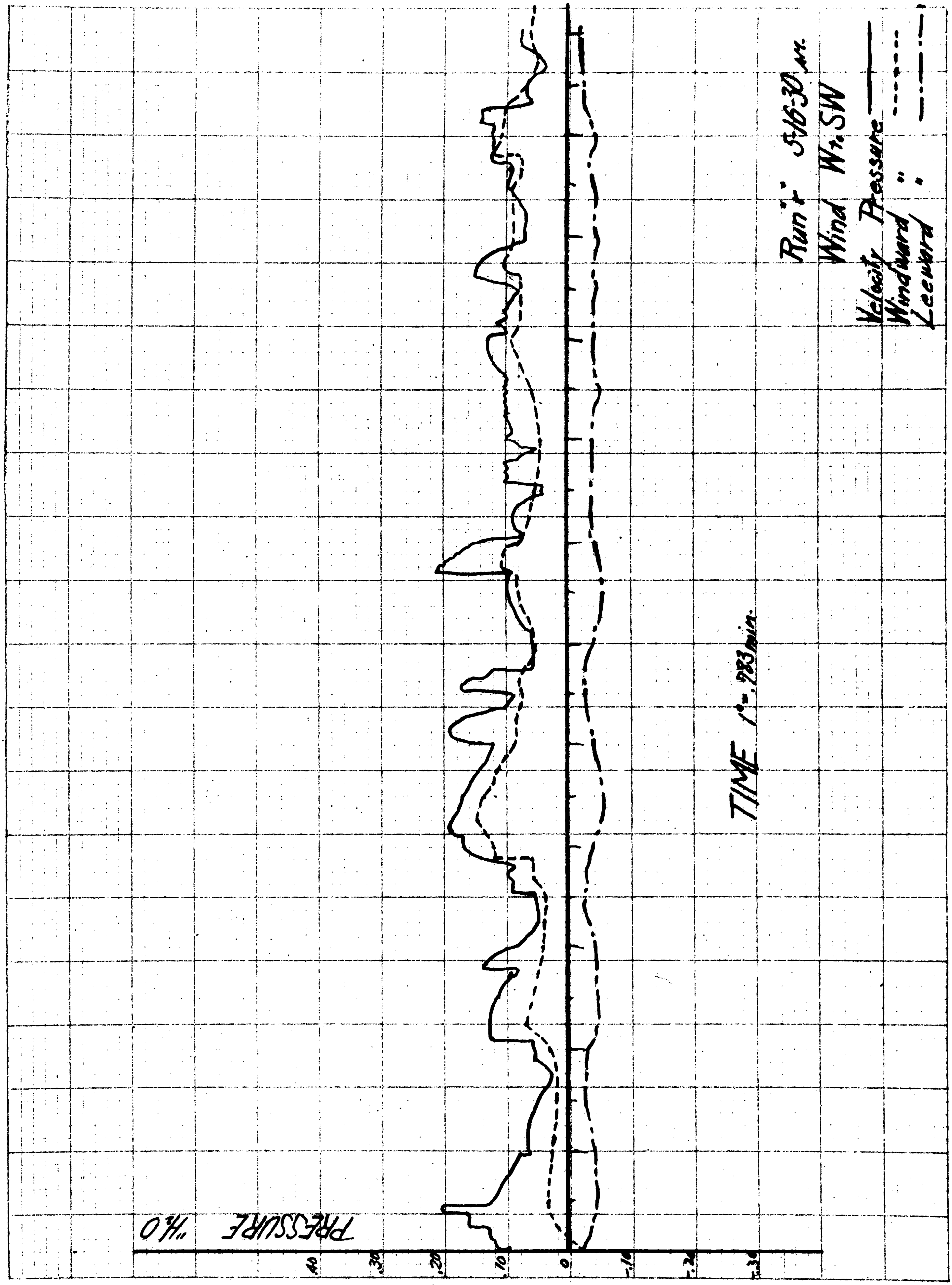

PRESSURE "H2O
.40
.30
.20
.10
0
-.10
-.20
-.30
TIME 1" = .783 min.
Run "Ac" 7-13-30 PM Cont'd.
Wind - W ±10°
Velocity Pressure
Windward "
Leeward "

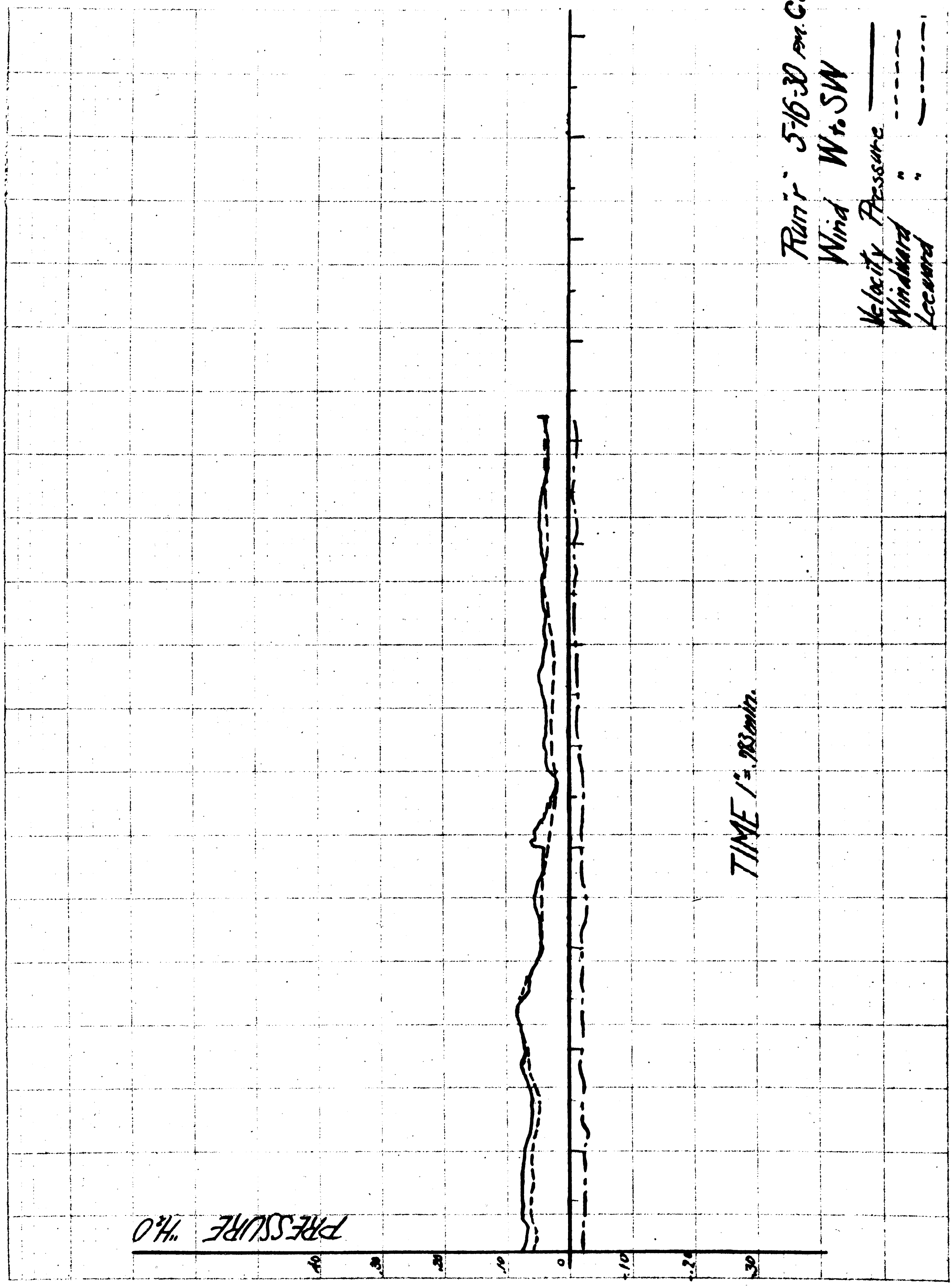
Accepted
Incorrect
Correction Due
Neatness

UNIVERSITY OF MICHIGAN
COLLEGE OF ENGINEERING

Sec. No.
Problem No.

Name
Date Due
Date Rec'd
Grade



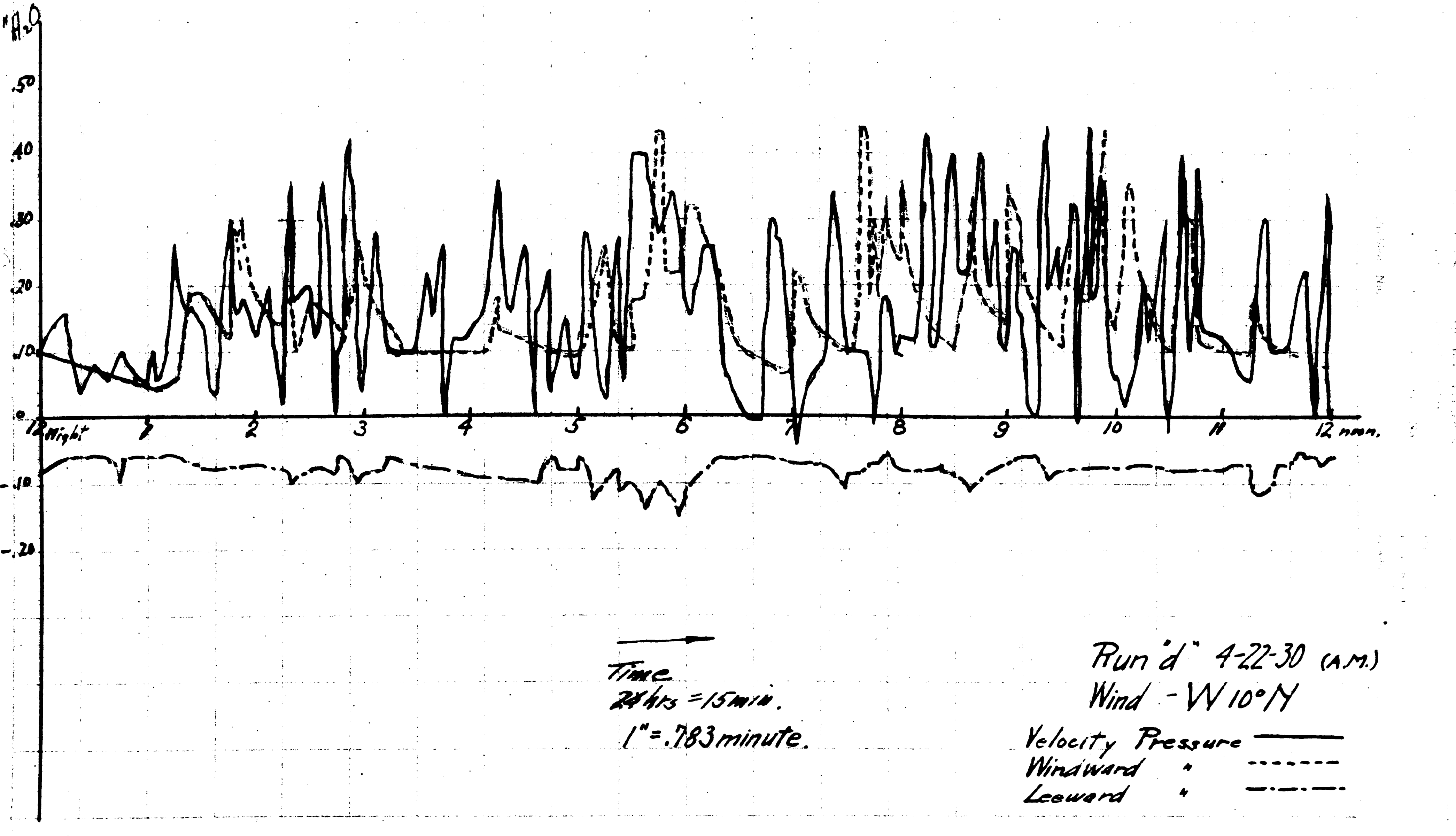


Run "r" 5-16-30 p.m. Cont'd.
Wind W to SW
Velocity Pressure
Windward "
Leeward "
TIME 1" = .983 min.
PRESSURE "H_2O
.40
.30
.20
.10
0
.10
.20
.30

8

9

Run "d" 4/22/30
12 night → 12 noon on charts

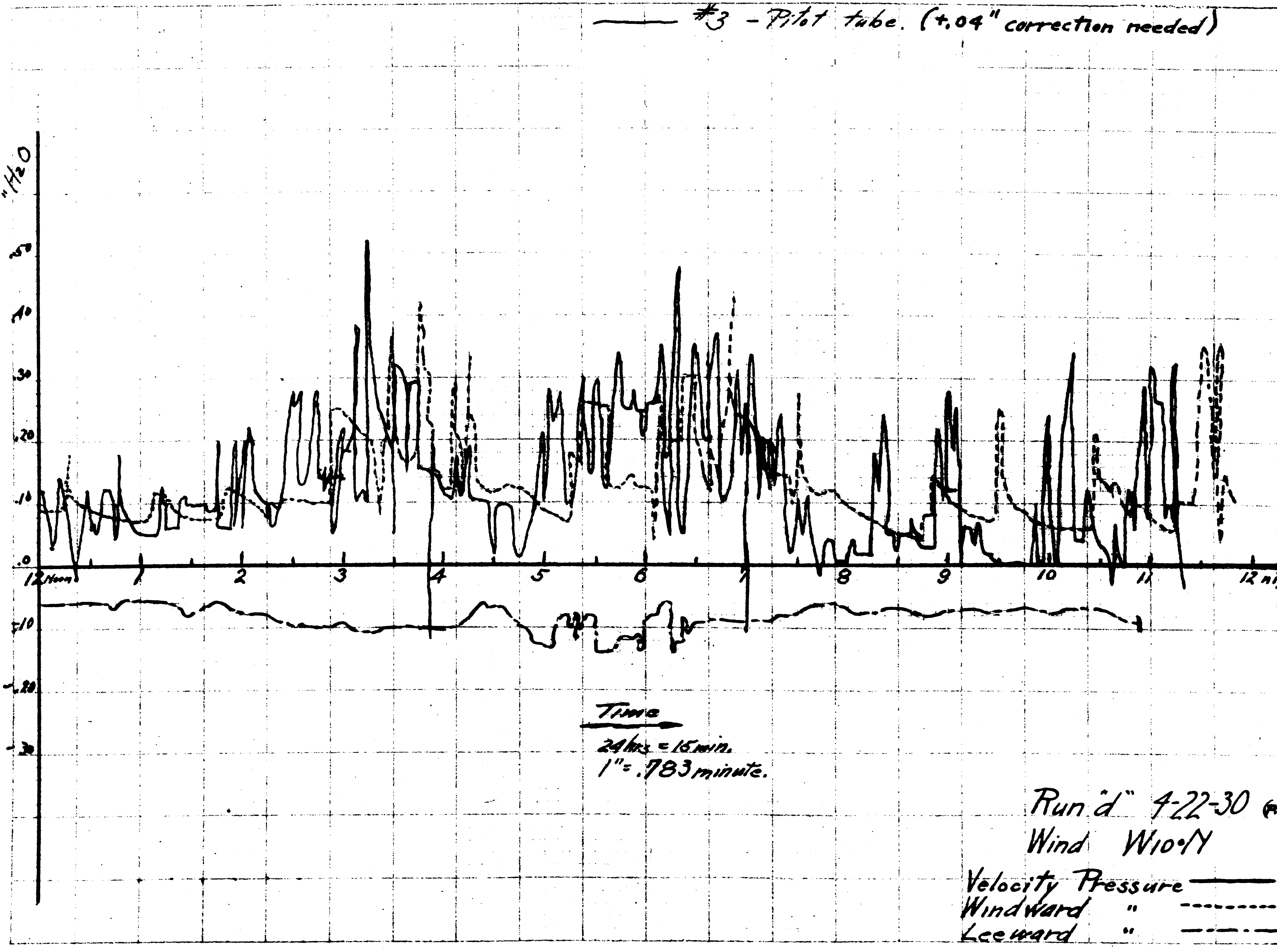


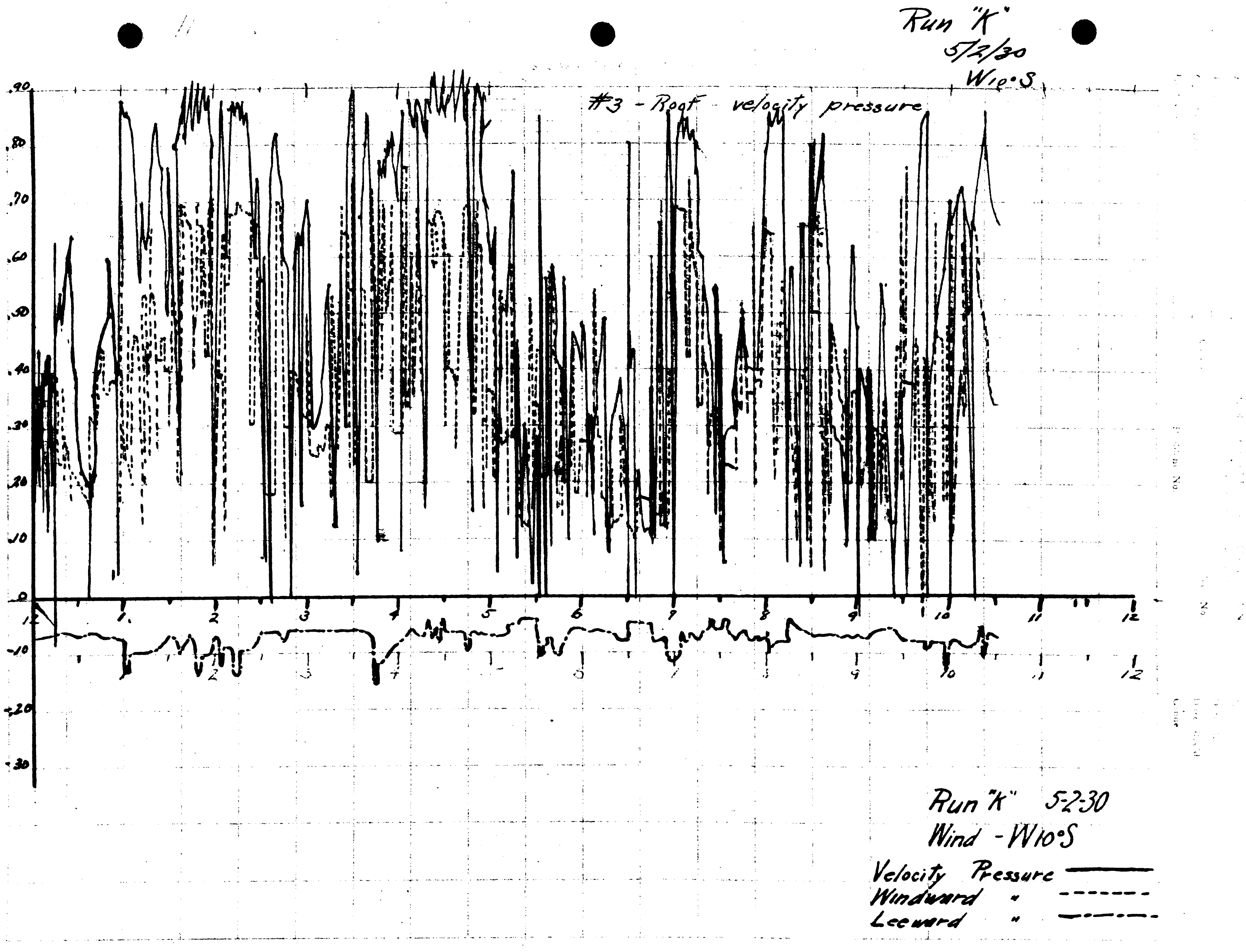
10

Run "d" 4/22/30
12 noon → 12 night on charts

STUDENTS SUPPLY STORE

Wind W10°N





Run "K"
5/2/30
W10°S
#3 - Roof velocity pressure
.90
.80
.70
.60
.50
.40
.30
.20
.10
0
-10
-20
-30
12
1
2
3
4
5
6
7
8
9
10
11
12
Run "K" 5-2-30
Wind - W10°S
Velocity Pressure
Windward "
Leeward "

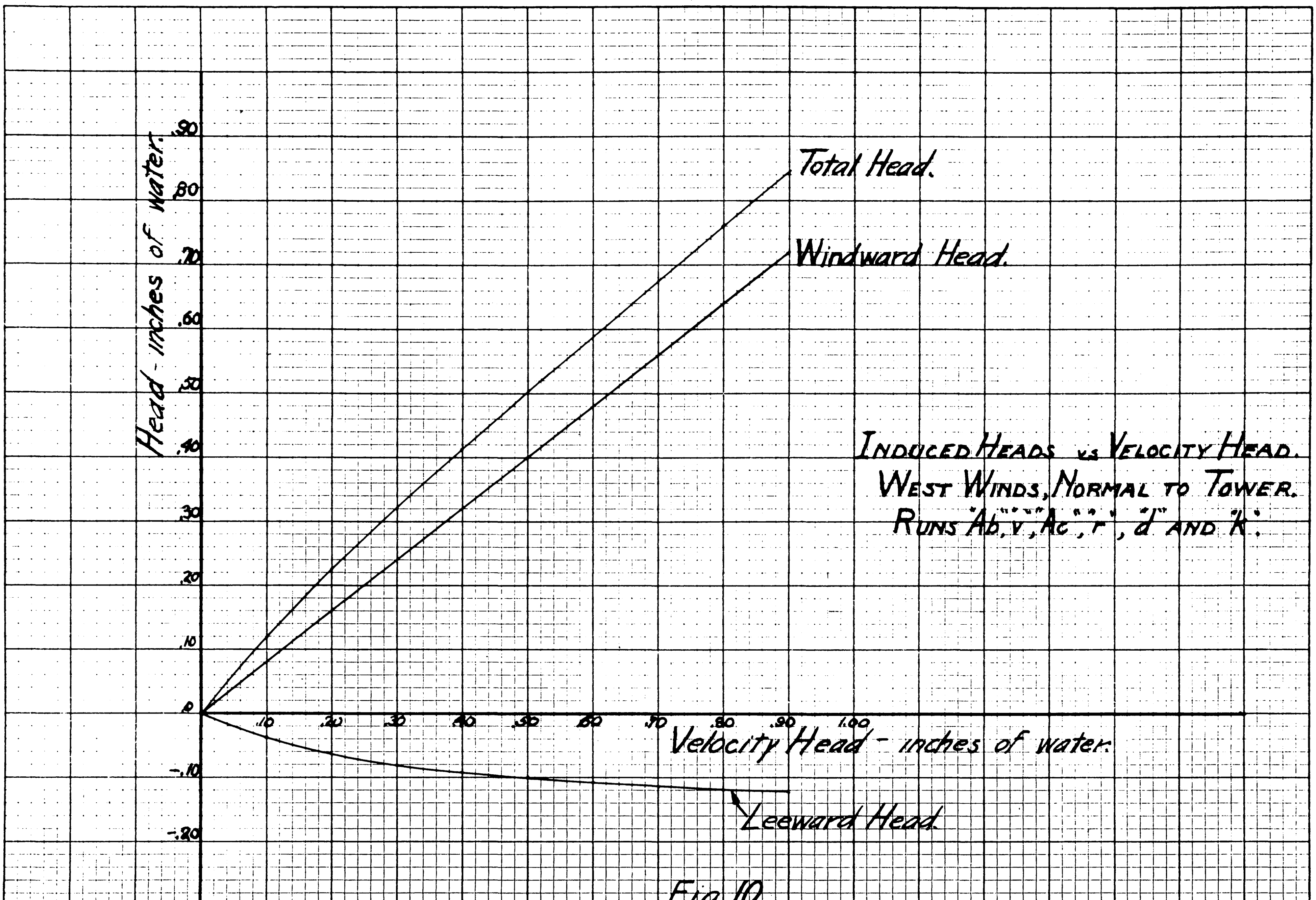

Total Head.
Windward Head.
Leeward Head.
INDUCED HEADS vs VELOCITY HEAD.
WEST WINDS, NORMAL TO TOWER.
RUNS "Ab," "v," "Ac", "r", "d" AND "k".
Head - inches of water.
Velocity Head - inches of water.
.90
.80
.70
.60
.50
.40
.30
.20
.10
0
-.10
-.20
.10
.20
.30
.40
.50
.60
.70
.80
.90
1.00

Fig. 10.

13

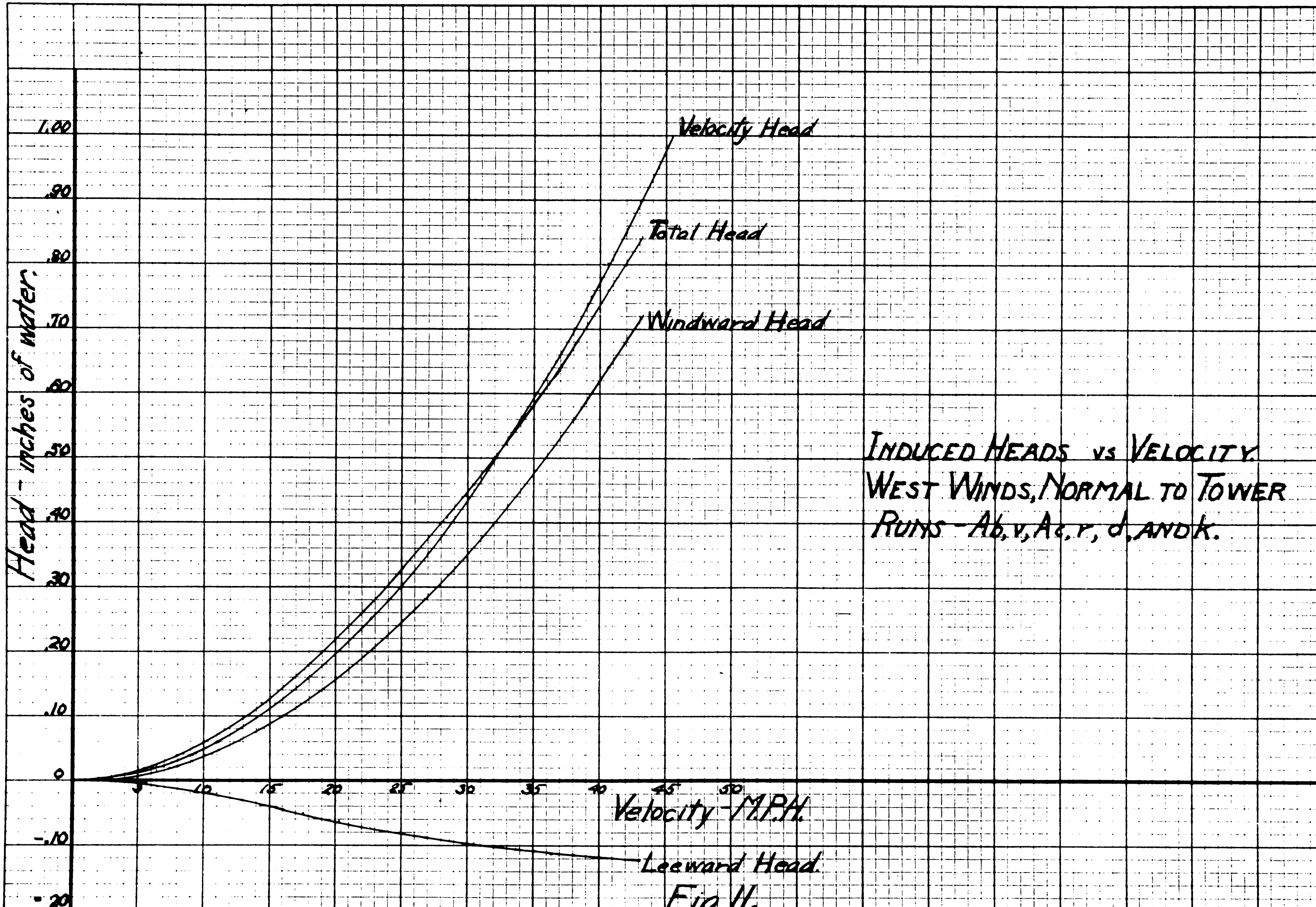
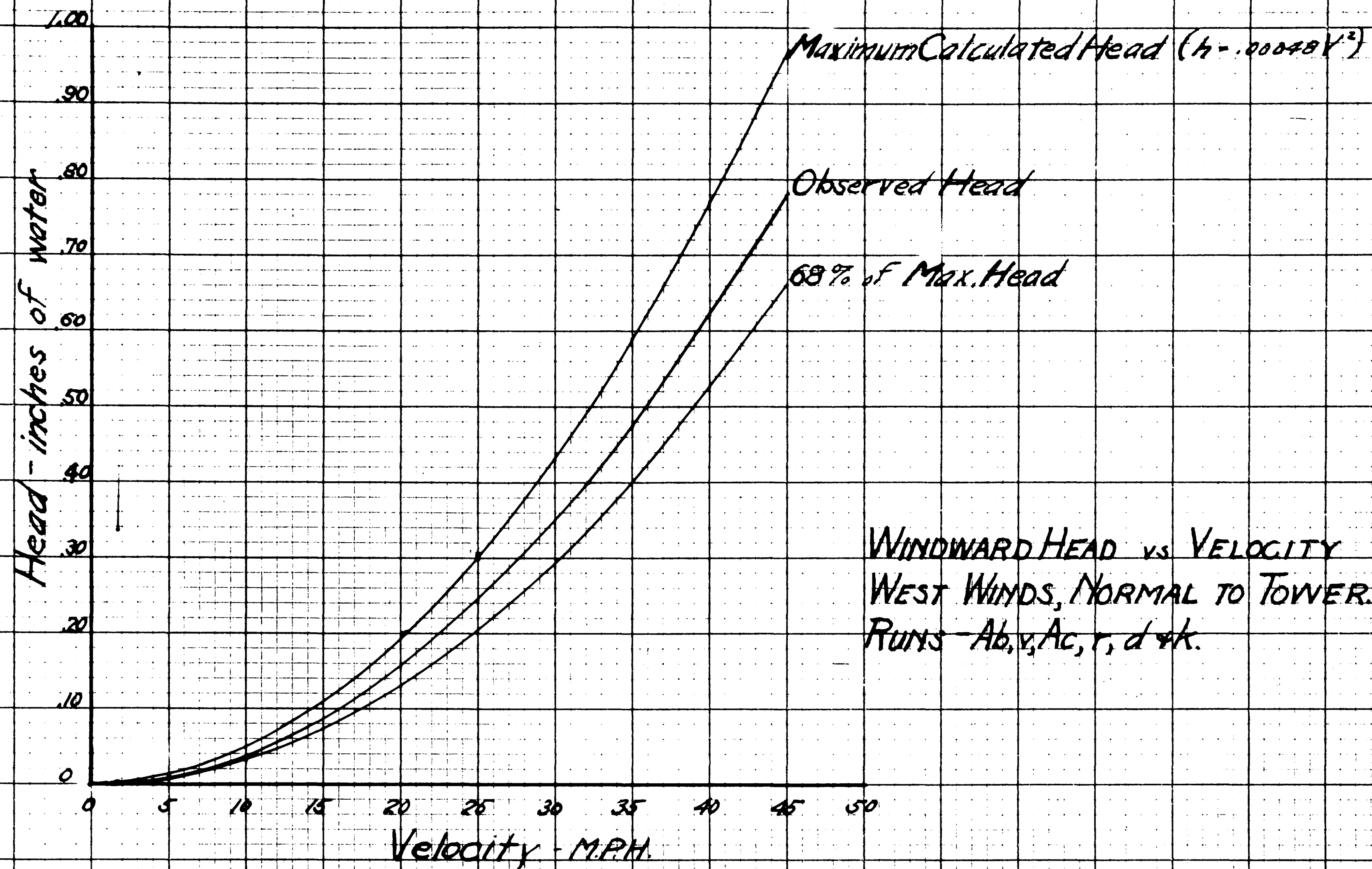

Induced Heads vs Velocity.
West Winds, Normal to Tower
Runs - Ab, v, Ac, r, d, and k.
Velocity Head
Total Head
Windward Head
Leeward Head
Head - inches of water.
Velocity - M.P.H.
1.00
.90
.80
.70
.60
.50
.40
.30
.20
.10
0
-.10
-.20
5
10
15
20
25
30
35
40
45
50

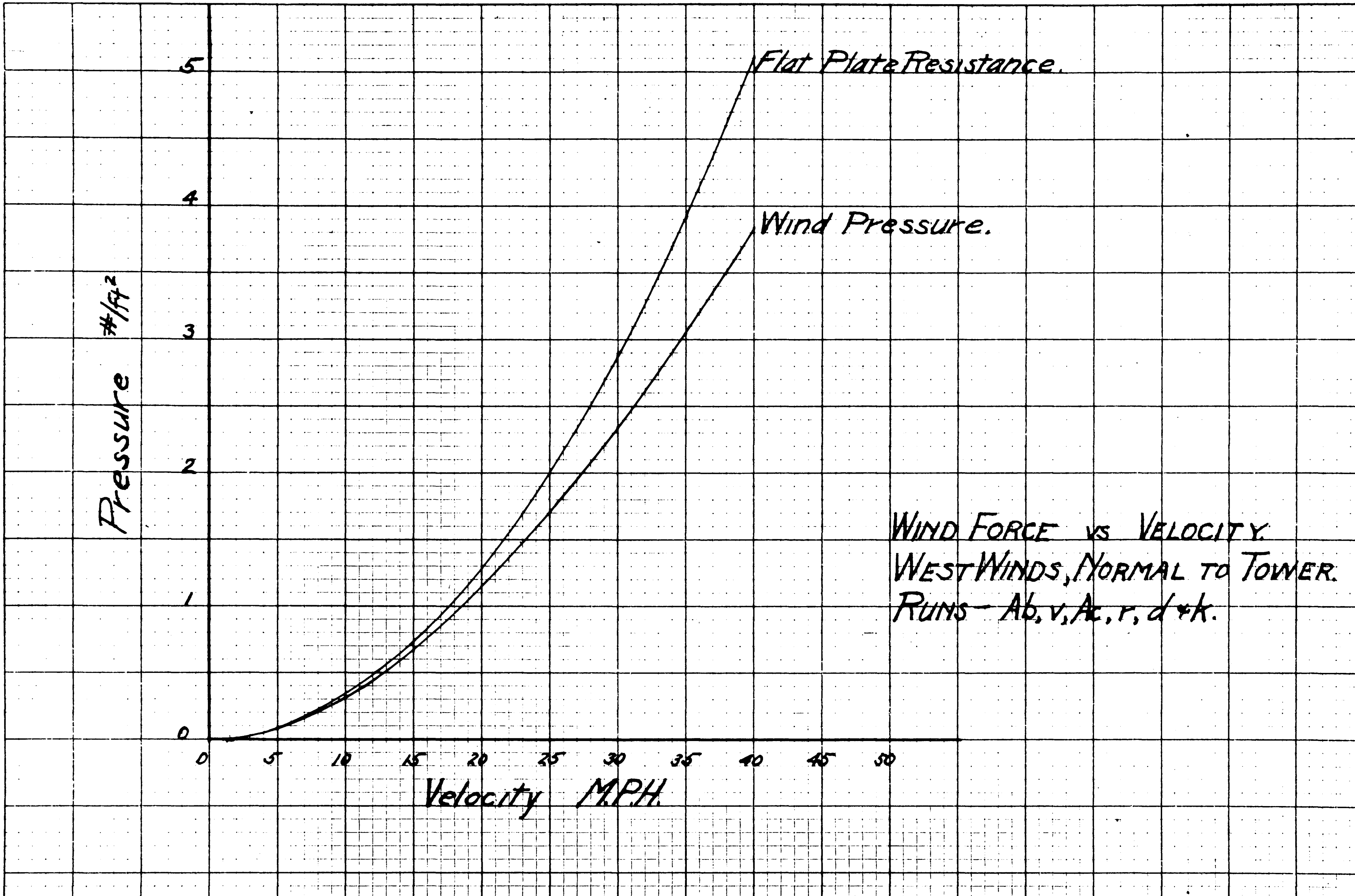
Fig. 11.

1-



Maximum Calculated Head (h = .00048V²)
Observed Head
68% of Max. Head
WINDWARD HEAD vs VELOCITY
WEST WINDS, NORMAL TO TOWER.
RUNS - Ab, v, Ac, r, d & k.
Head - inches of water
1.00
.90
.80
.70
.60
.50
.40
.30
.20
.10
0
0
5
10
15
20
25
30
35
40
45
50
Velocity - M.P.H.

Fig. 12



Flat Plate Resistance.
Wind Pressure.
Pressure #/ft²
Velocity M.P.H.
0
1
2
3
4
5
0
5
10
15
20
25
30
35
40
45
50
WIND FORCE vs VELOCITY.
WEST WINDS, NORMAL TO TOWER.
RUNS - Ab, v, Ac, r, d & k.

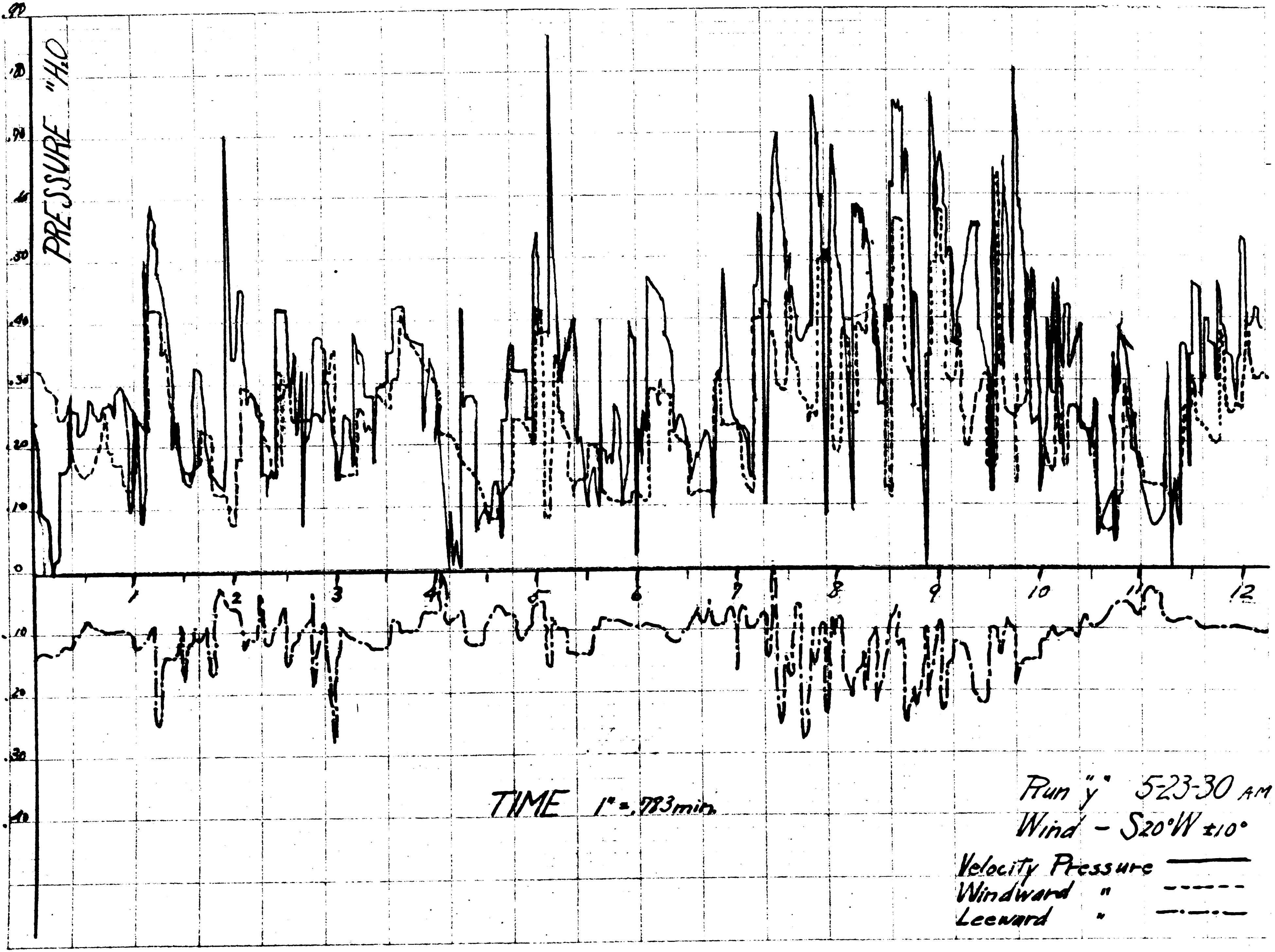
Fig. 13.

16

#3 — Top.
#2 — E
#1 — S

Run Y 5/23/30
S20°W ±10°

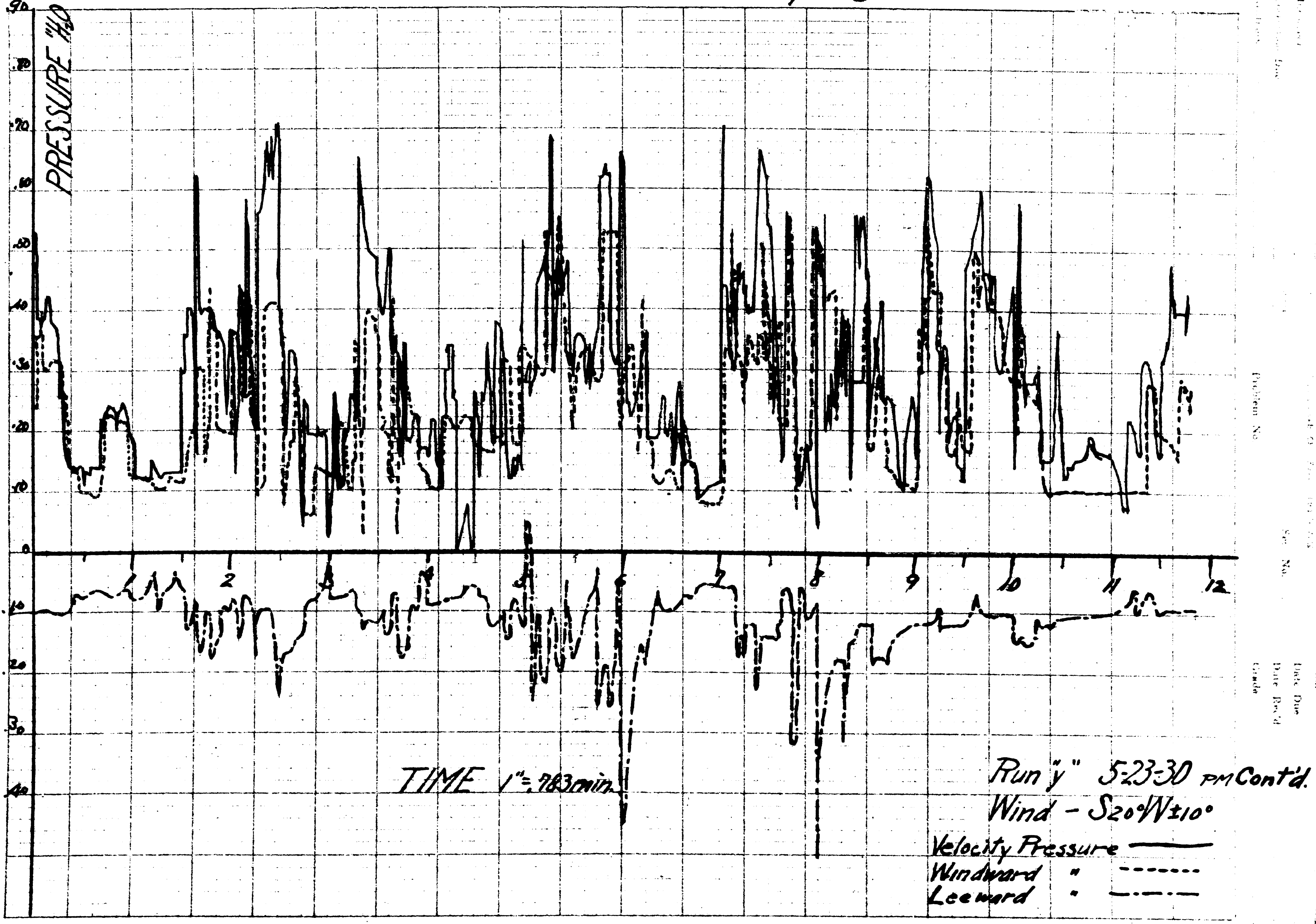
STUDENTS SUPPLY STORE

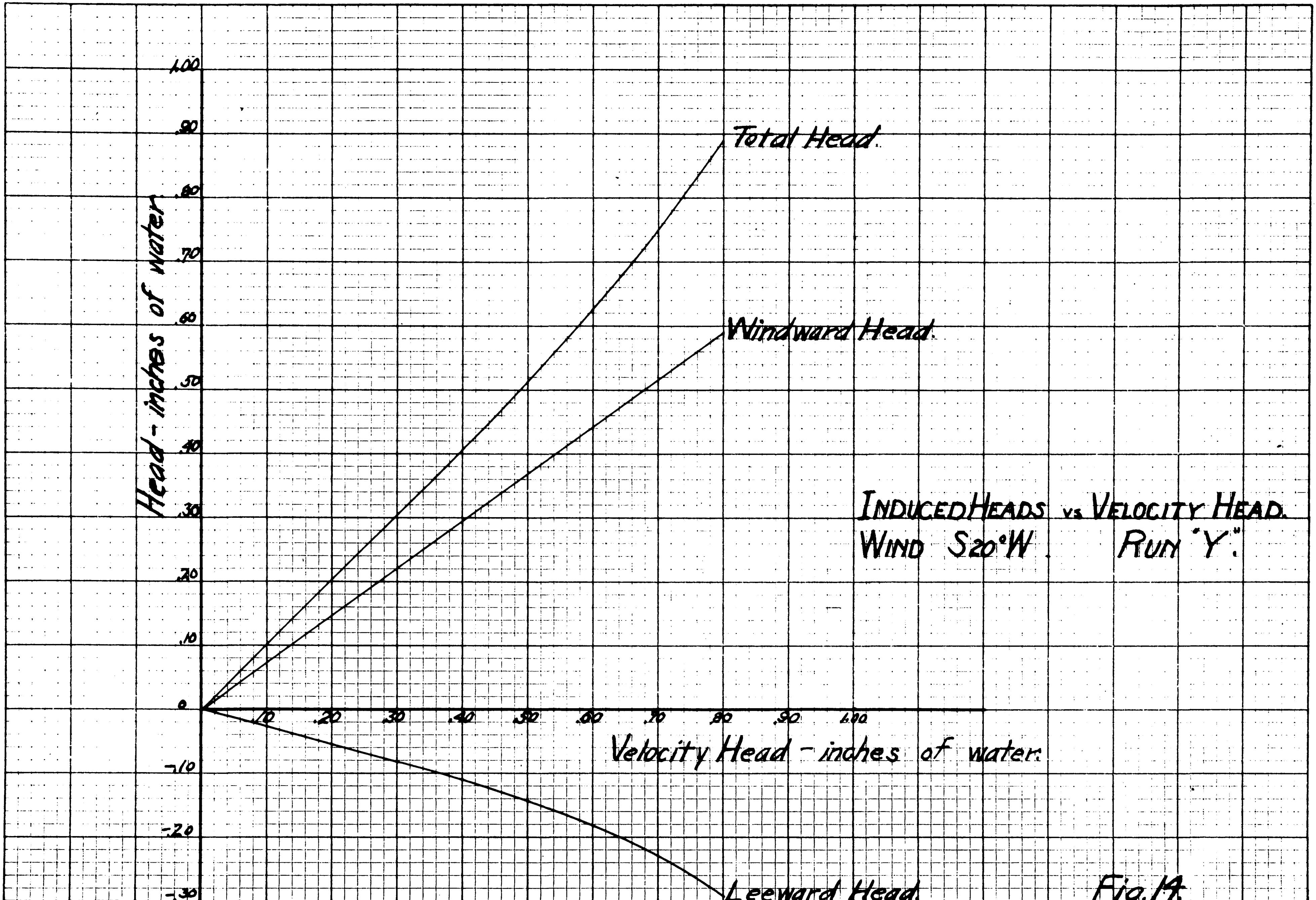


17

#3—Top
#2—E
#1—S

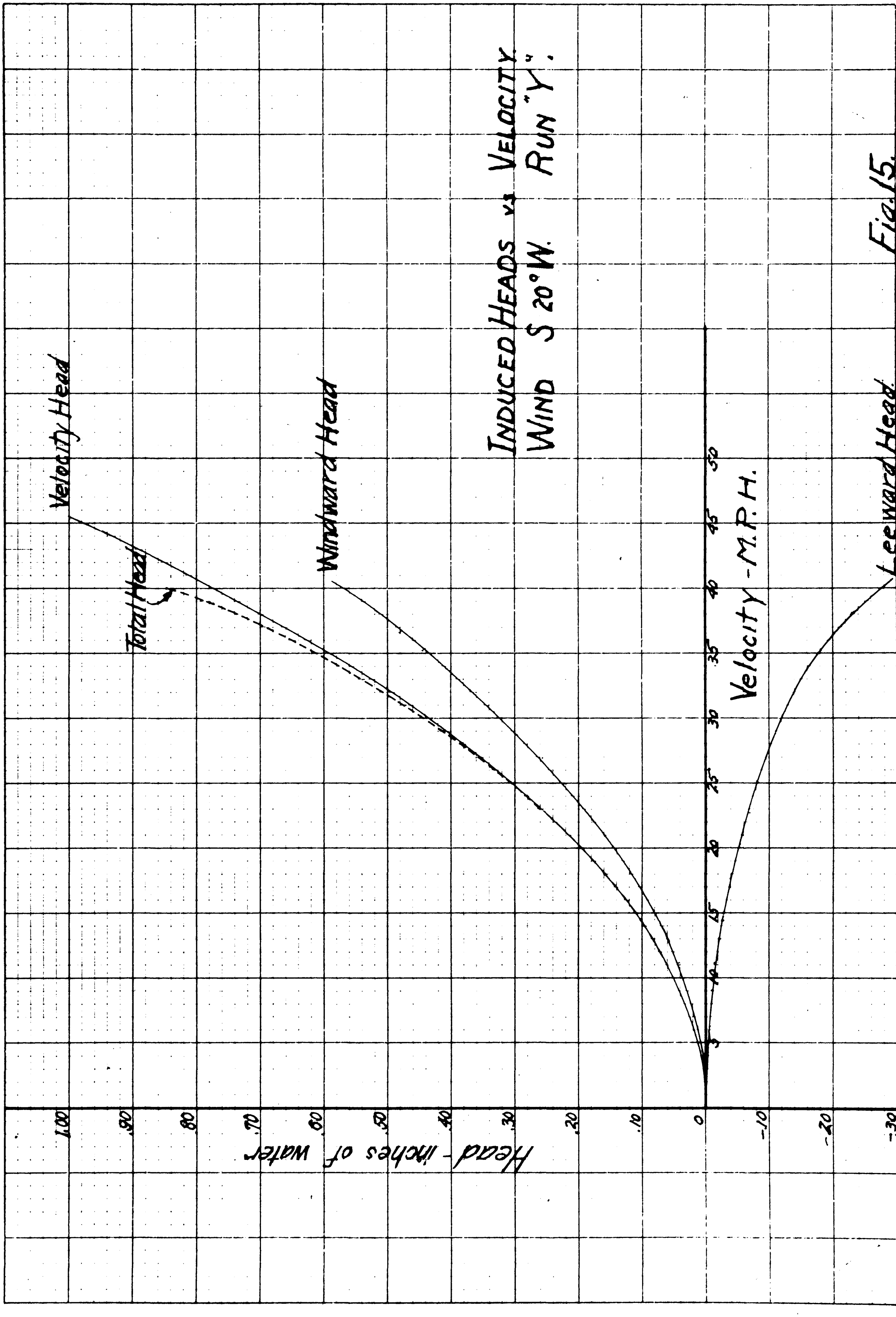
Run "Y" 5/23/30
S20°W ±10°





INDUCED HEADS vs VELOCITY HEAD.
WIND S20°W.
RUN "Y".
Total Head.
Windward Head.
Leeward Head.
Head - inches of water.
Velocity Head - inches of water.
1.00
.90
.80
.70
.60
.50
.40
.30
.20
.10
0
-.10
-.20
-.30

Fig. 14.

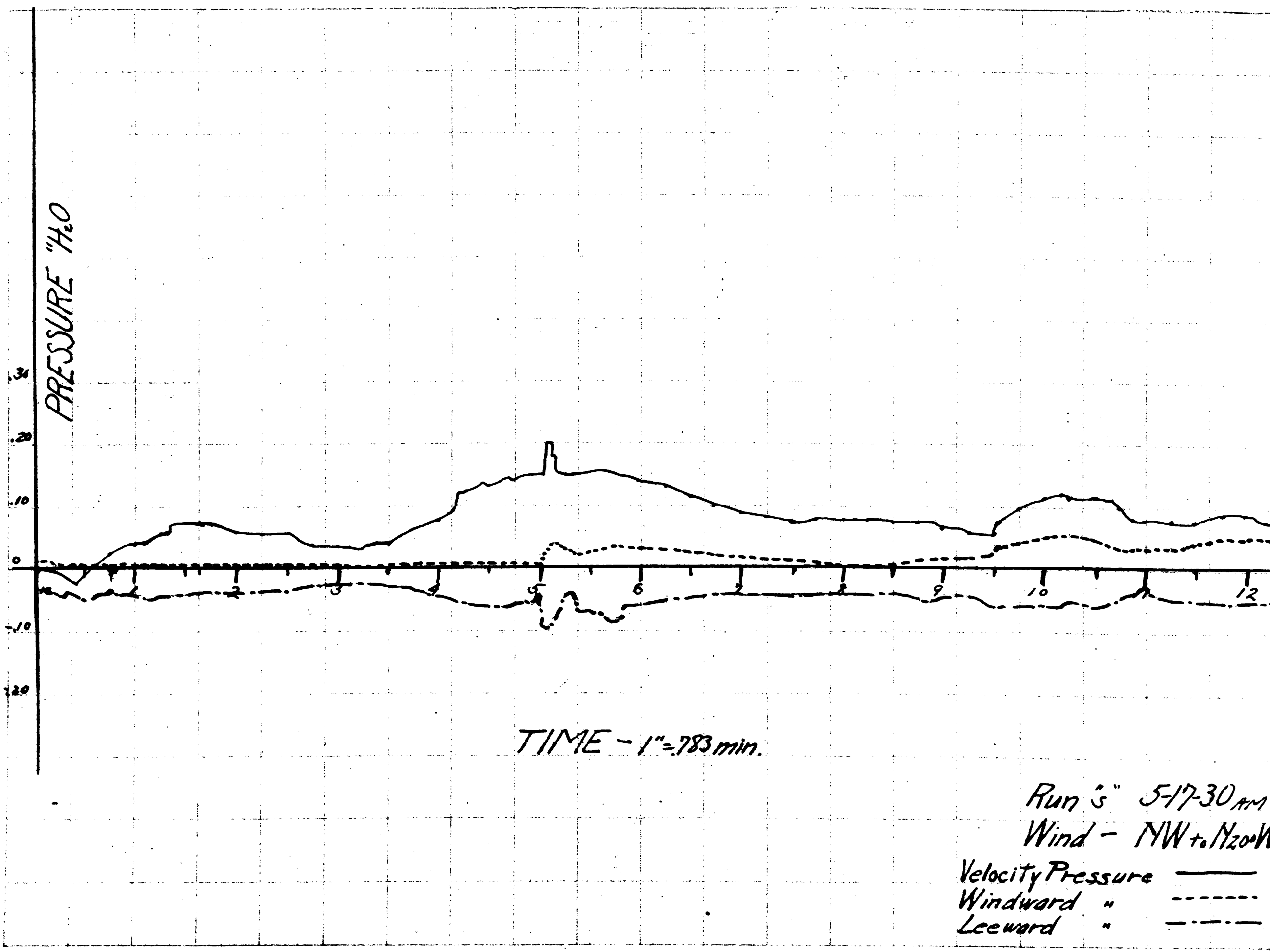


KEUFFEL & ESSER CO., N. Y. NO. 358-6
10 × 10 to the inch, 5th lines heavy.

20

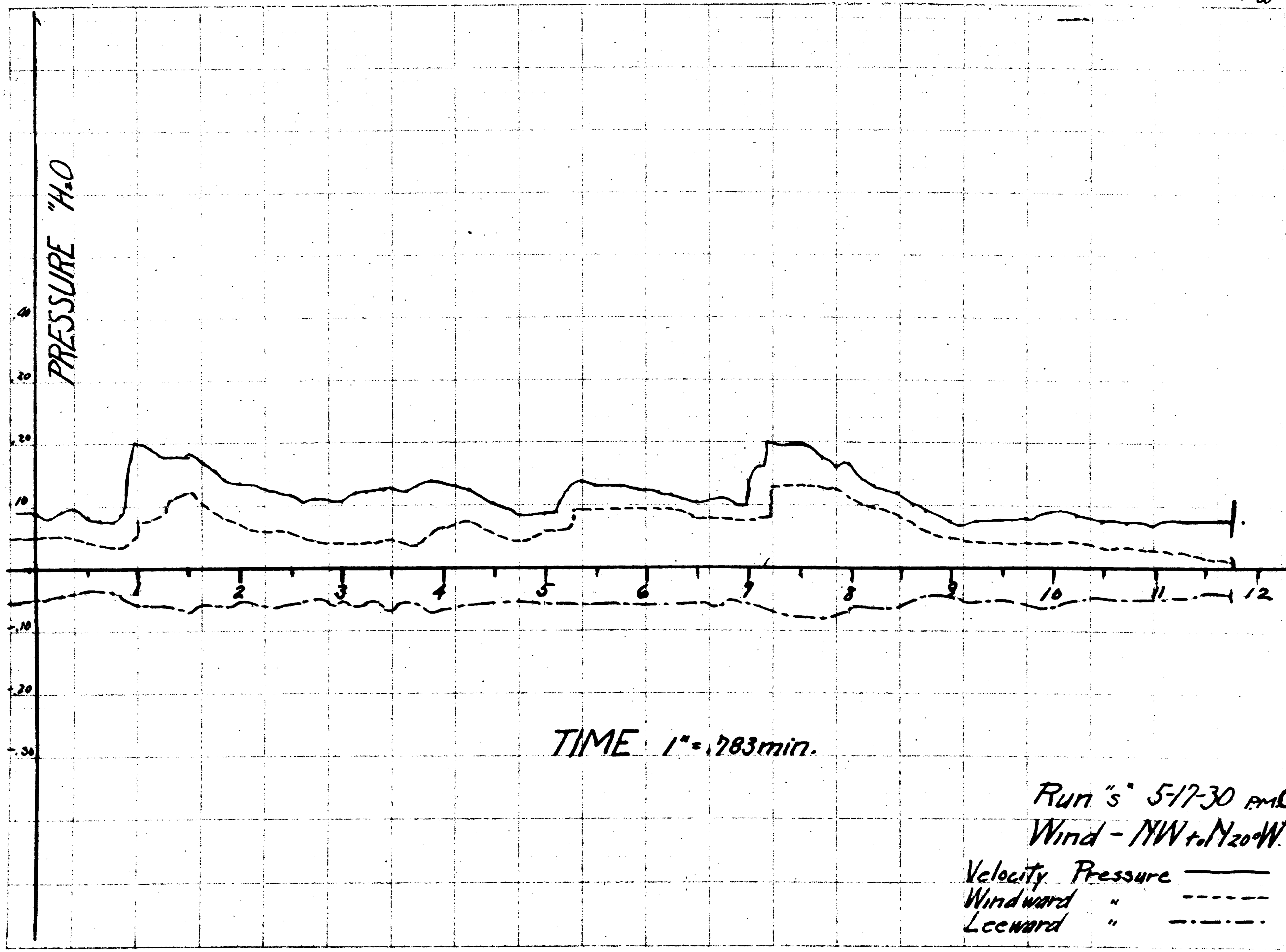
#3 — Top

Run "5" 5/17/
NW to N20°W



21

Run "S" 5/17/30
#3 — Top.
-·-
N20°W to NW



Accepted
Incorrect
Correction Due
Neatness

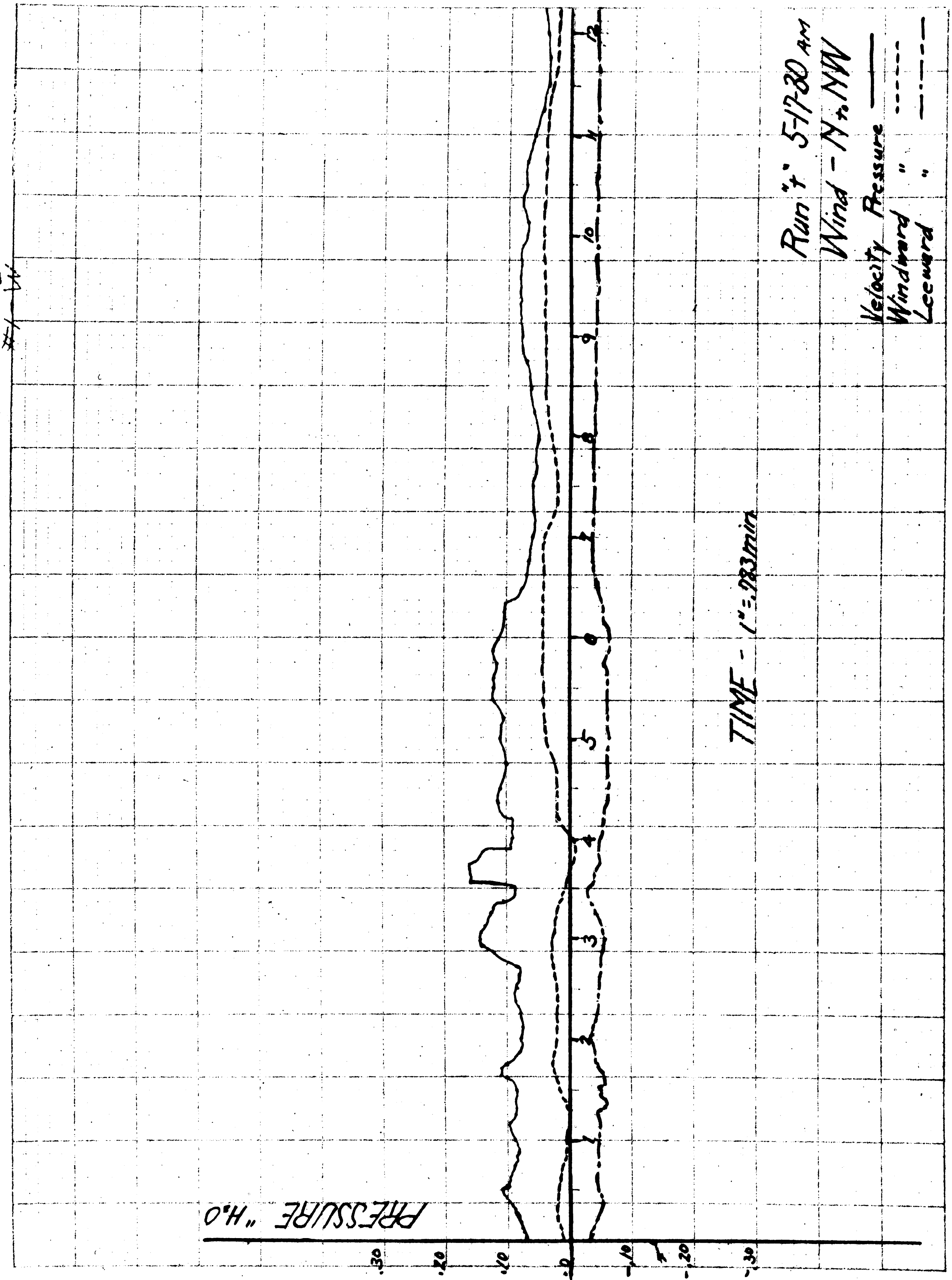
UNIVERSITY OF MICHIGAN
COLLEGE OF ENGINEERING

Course Sec. No

Problem No.

Name
Date Due
Date Rec'd
Grade

Run "t" 5/17/80 N to NW wind
#3 — Top
#2 — E
#1 — W



STUDENTS SUPPLY STORE

22

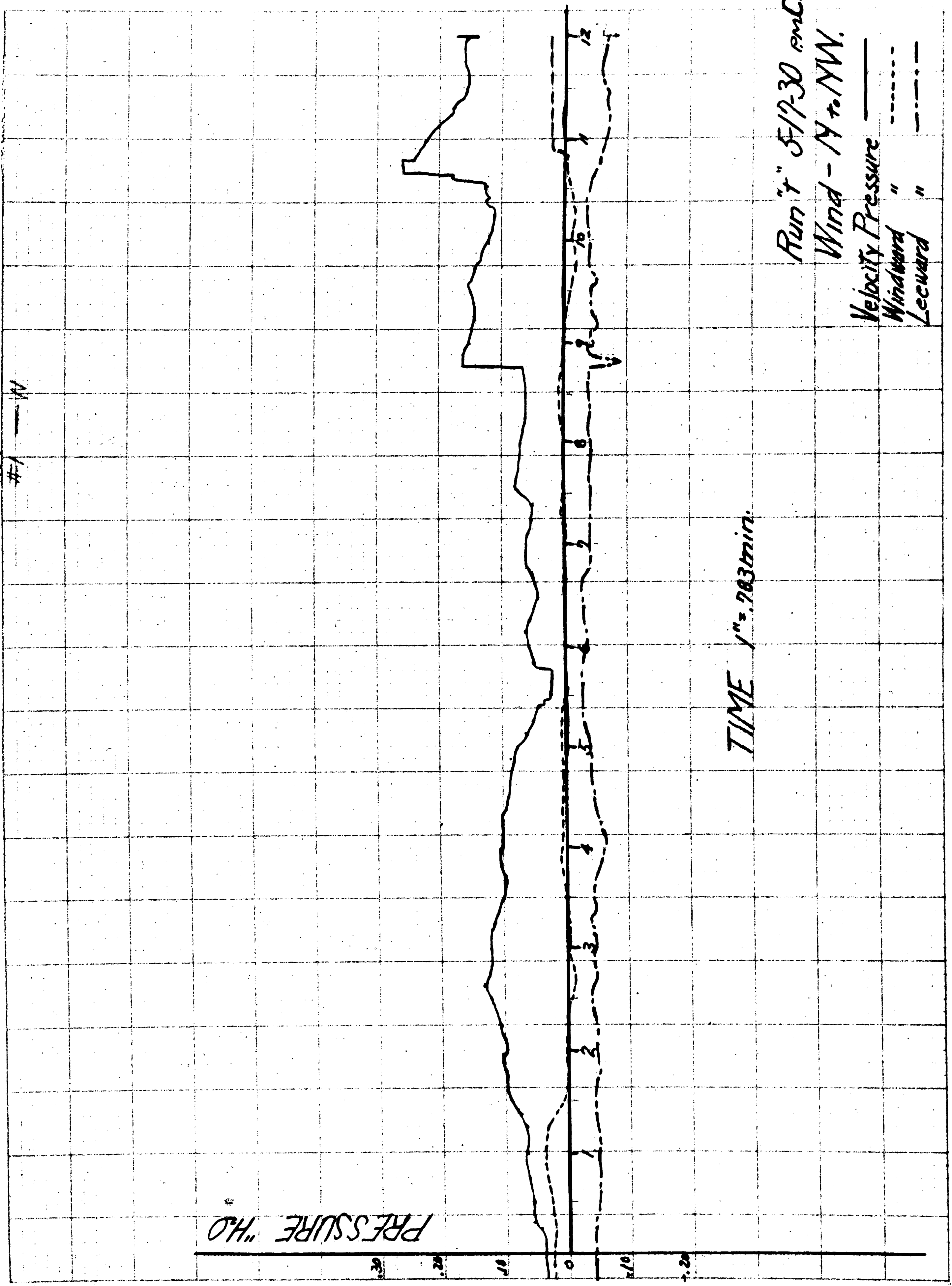
UNIVERSITY OF MICHIGAN

Accepted | Name
Incorrect | Date Due
Correction Due | Course | Sec. No. | Date Rec'd
Fairness | Problem No. | Grade

Run "7" 5/17/30
N & NW wind

#3 — Top
#2 — E
#1 — W

STUDENT'S SUPPLY STORE



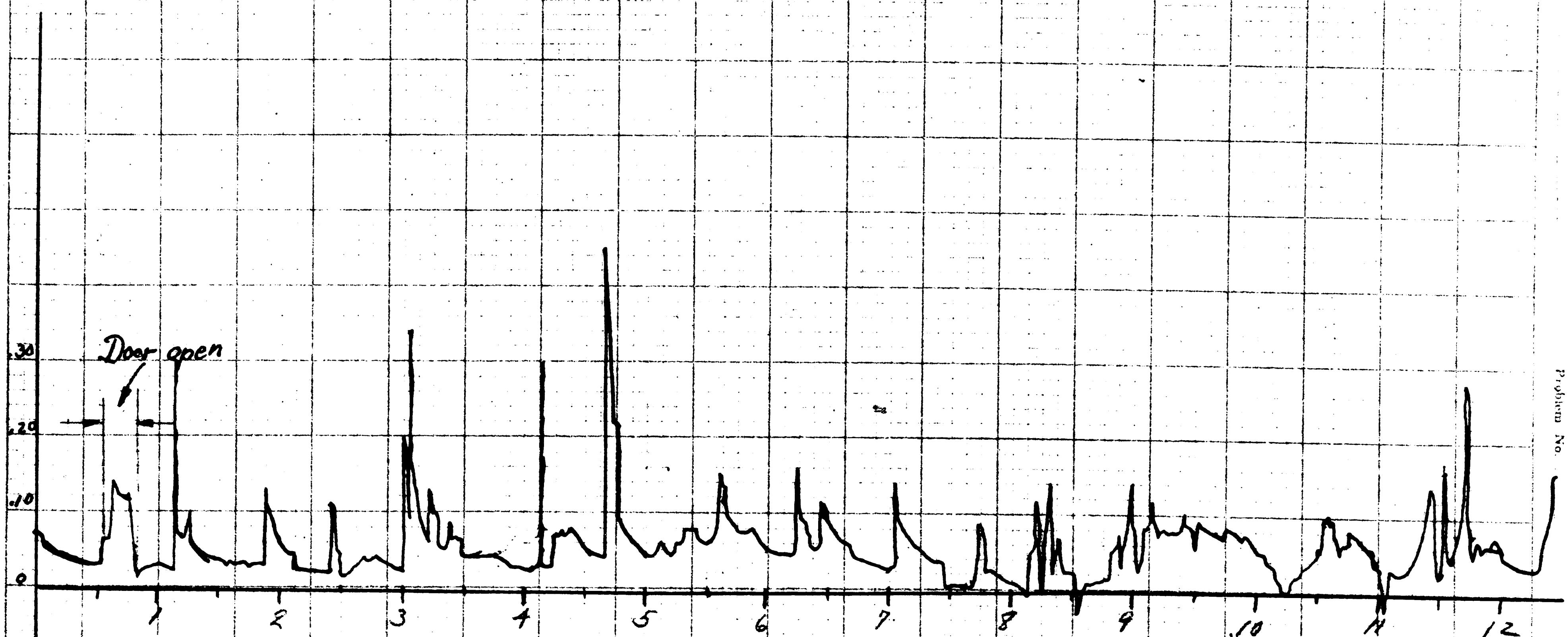
24

Run Aa special. 5/23/30

STUDENTS SUPPLY STORE #1 inst. on S. side.

S20°W ±10°

South Windows Open



A.M.

Run "Aa" 5/23/30
Wind S20°W
Pressure on S face, with
S windows open.

25

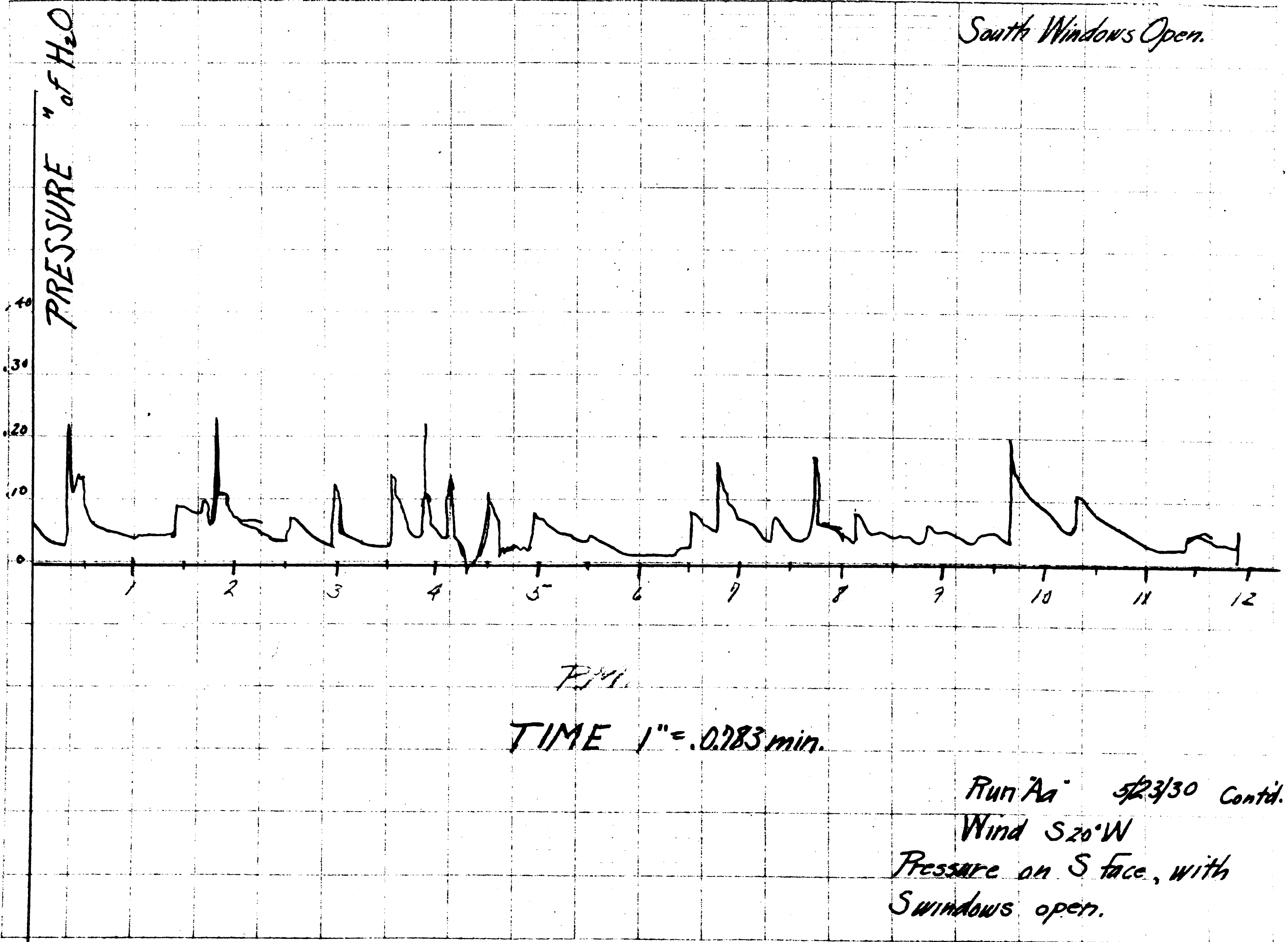
Run Aa special. 5/23/30

#1 inst. on S. side.

$S_{20}°W I 10°$

STUDENTS SUPPLY STORE

South Windows Open.



TIME 1" = .0783 min.

Run "Aa" 5/23/30 Cont'd.

Wind $S_{20}°W$

Pressure on S face, with S windows open.

RECORDS OF THE WIND IN DETROIT

It was thought desirable to secure some information regarding the past behavior of the wind, upon which predictions of future winds might be based. As Detroit was convenient and the local station of the Weather Bureau of the United States Department of Agriculture keeps a very complete record of the winds, it was decided to make use of their observations. Accordingly, through the courtesy of Mr. Conger, the chief meteorologist, records for the last four winters, 1926-27 through 1929-30, were studied for the three months of December, January, and February, and data taken on the daily average temperature and the velocity and direction of the wind for every hour of the day. The three months chosen are the coldest ones in the year, and are those during which the infiltration of air due to induced wind pressures is most important in the heating of buildings.

In its original condition the information gathered was of little direct value. Therefore, to make it more readable it was rearranged in the following manner: The anemometer records gave the direction of the wind by the four cardinal points of the compass or a combination of two adjacent points to indicate an intermediate direction, so the eight different directions noted in the log book were used as headings, and the number of hours per year, during the daylight hours of

6 a.m. to 6 p.m., that the wind blew in that direction with a velocity of 10 m.p.h. or more, was noted below. It was decided to restrict the compilation of this data to these hours, because the heating load of large buildings is greatest during the day and diminishes at night, when the majority of the occupants are away. Ten m.p.h. was set as the lower limit of the wind data as the pressures induced by winds of less than this velocity are practically negligible when considering infiltration. In Table I which presents this data two columns of figures will be found under each winter's heading in each direction. The left-hand figure gives the number of hours during that winter that the wind blew with the velocity given at the left of the page, while the right-hand column carries a running total of all the hours of wind at that and all higher velocities. The percentage of the total number of hours of wind of any direction for any one season is given at the bottom of the column for that winter, while the average percentage for four winters occupies the space below this, under the direction heading.

The percentage results are more vividly shown in Figure 16 where there is a graphical representation of the same figures shown in Table I. The octagon represents the eight directions, while the length of the bar erected on each side of the octagon represents the percentage of total wind in that direction for each season. The overwhelming predominance of southwest and west winds is surprising at first glance and, while the percentage in the various directions might be expected to taper off gradually from the prevailing southwest as it does in the clockwise direction, the sudden drop when going from southwest to south is very unusual. During the daylight hours of the winter of 1929-30 there was not a single hour during which the wind blew from the south with a velocity of 10 m.p.h. or more. If the winters of 1926-27 and 1927-28 were considered alone, the northwest winds would be more prominent than when all four winters are considered. This suggests the possibility of a false conclusion being drawn from four seasons' averages and also that an analysis over a longer period of time might be valuable. However, time did not permit of such an analysis when the distinct difference between the winters of 1927-28 and 1928-29 was noted.

Figure 16 gives a good idea of the general distribution of the wind in Detroit, but gives no clue as to velocity with which it blew in the various directions. The values for the four winters were averaged, therefore, and the distribution of total hours of 10 m.p.h. and above in each direction is shown in Figure 17. The totals for each direction are also split up to show the duration of winds of varying velocities. The first step out from the central octagon includes all those from 10 to 15 m.p.h., the next, those from 15 to 20 m.p.h., and so on.

The predominance of the southwest winds is again striking not only in quantity, but in winds of high velocity. There is more than half again as much southwest wind of over 20 m.p.h. than there is from all the other directions put together. A tendency for the higher winds to come from the southwest is shown by the fact that there is more west wind of 10-15 m.p.h. than there is southwest wind of that velocity range, while in all the other velocity ranges, the southwest exceeds the west winds. It would seem from these results that in planning to combat wind infiltration, the southwest and west wind would be the only ones to be considered in the Detroit district.

The temperatures for each direction were carefully averaged for the four seasons, and will also be found on Figure 17, at the ends of the wind-time figure. They are somewhat higher than might be expected for those months of the year, but the relative values of the northerly and southerly directions are what one would expect. The intermediate temperatures also follow a regular order, as the temperatures increase from north to south, both ways around the figure. Though it does not show in this figure, while the original data was being taken it was noticed that the days during which the highest winds were observed were not those of extremely low temperatures. In fact, the high winds were accompanied by moderate temperatures, and on the very coldest days the winds were not particularly high.

Thus the established practise of figuring infiltration for the highest winds and lowest temperatures observed in a locality would appear to be overly cautious, since the two worst conditions do not occur simultaneously.

Direction →	SW					W					NW				
Vel, MPH	26-27	27-28	28-29	29-30		26-27	27-28	28-29	29-30		26-27	27-28	28-29	29-30	
41		0 2	2	0	0	0	0 0	0 0	0 0	0		0	0	0	0
40		0 1	3	0	0		0	0	0	0		0	0	0	0
39		0 1	4	0	0		0	0	0	0		0	0	0	0
38		0 0	4	0	0		0	0	0	0		0	0	0	0
37		0 1	5	0	0		0	0	0	0		0	0	0	0
36		0 1	6 1	1	0		0	0	0	0		0	0	0	0
35	2	2 2	8 0	1	0		0	0	0	0		0	0	0	0
34	0	2 1	9 0	1 2	2	2	2 0	0 0	0 0	0		0	0	0	0
33	2	4 0	9 1	2 0	2	0	2 0	0 0	0 0	0		0	0	0	0
32	2	6 1	10 3	5 2	4	2	4 0	0 0	0 0	0		0	0	0	0
31	2	8 4	14 1	6 2	6	0	4 0	0 0	0 0	0		0	0	0	0
30	1	9 4	18 1	7 0	6	2	6 0	0 0	0 0	0		0	0	0	0
29	0	9 3	21 1	8 2	8	0	6 0	0 0	0 0	0		0	0	0	0
28	2	11 3	24 2	10 1	9	1	7 0	0 2	2 0	0	1	1 0	0 0	0 0	0
27	4	15 4	28 2	12 3	12	1	8 0	0 1	3 0	0	0	1 0	0 0	0 0	0
26	5	20 1	29 6	18 0	12	2	10 0	0 2	5 0	0	0	1 0	0 0	0 0	0
25	5	25 12	41 5	23 1	13	1	11 1	1 2	7 0	0	0	1 2	2 0	0 0	0
24	2	27 13	54 5	28 1	14	6	17 3	4 2	9 0	0	1	2 2	4 0	0 0	0
23	4	31 13	67 7	35 4	18	0	17 1	5 2	11 0	0	3	5 1	5 0	0 0	0
22	7	38 16	83 2	37 5	23	1	18 3	8 0	11 6	6	3	8 5	10 0	0 0	0
21	8	46 16	99 9	46 10	33	1	19 5	13 4	15 5	11	1	9 3	13 0	0 0	0
20	7	53 23	122 15	61 6	39	1	20 6	19 5	20 4	15	3	12 0	13 0	0 0	0
19	4	57 18	140 11	72 11	50	3	23 3	22 9	29 7	22	4	16 1	14 0	0 0	0
18	9	66 20	160 8	80 18	68	8	31 6	28 12	41 3	25	4	20 7	21 1	1 0	0
17	2	68 16	176 10	90 23	91	8	39 8	34 8	49 9	34	2	22 4	25 1	2 0	0
16	4	72 17	193 8	98 25	116	13	52 15	49 8	57 14	48	2	24 13	38 0	2 0	0
15	15	87 18	211 20	118 20	136	12	64 10	59 15	72 13	61	7	31 12	50 1	3 1	1
14	19	106 19	230 10	128 16	152	11	75 15	74 15	87 16	79	8	39 10	60 2	5 0	1
13	14	120 17	247 15	143 14	166	17	92 10	84 16	102 21	98	14	53 18	79 1	6 0	1
12	14	134 15	262 7	150 17	183	21	113 13	97 22	124 16	114	15	68 22	101 2	8 1	2
11	9	143 17	279 13	163 10	193	18	181 10	107 22	146 20	134	19	87 22	123 5	13 0	2
10	17	160 12	292 17	180 13	216	12	143 15	122 26	172 17	151	25	112 16	139 2	15 0	2
%	24.80	42.50	39.50	43.60		22.20	17.70	35.70	30.40		17.30	20.20	3.13	0.40	
Avg %	37.07					26.55					10.25				

Table. 1

Vel	N								NE								E							
	26-27		27-28		28-29		29-30		26-27		27-28		28-29		29-30		26-27		27-28		28-29		29-30	
40.																								
39																								
38																								
37																								
36																								
35																								
34																								
33																								
32																								
31																								
30																								
29																								
28																								
27									0	0	0	0	0	0	1	1								
26									0	0	0	0	0	0	1	2								
25									3	3	0	0	0	0	2	4								
24									2	5	0	0	0	0	1	5								
23									4	9	0	0	0	0	1	6								
22									5	14	0	0	0	0	4	10								
21	1	1	0	0	0	0	0	0	5	19	0	0	0	0	3	13	2	2	0	0	0	0	0	0
20	1	2	0	0	0	0	0	0	6	25	2	2	0	0	3	16	1	3	0	0	0	0	0	0
19	3	5	0	0	0	0	0	0	1	26	2	4	0	0	6	22	1	4	1	1	0	0	3	3
18	3	8	1	1	0	0	0	0	7	33	1	5	1	1	2	24	2	6	2	3	1	1	3	6
17	3	11	1	2	0	0	0	0	2	35	2	7	0	1	1	25	2	8	2	5	3	4	5	11
16	5	16	1	3	4	4	1	1	0	35	4	11	1	2	1	26	0	8	0	5	3	7	2	13
15	2	18	0	3	2	6	1	2	9	42	6	17	2	4	2	28	2	10	2	7	3	10	0	13
14	6	24	1	4	3	9	1	3	4	46	8	25	0	4	6	34	7	17	3	10	1	11	1	14
13	4	28	1	5	5	14	0	3	8	54	8	33	2	6	1	35	1	18	1	11	4	15	3	17
12	7	35	2	7	1	16	0	3	13	67	2	35	2	8	6	41	5	23	3	14	13	28	5	22
11	16	51	2	9	5	20	6	9	9	76	13	48	2	10	8	49	1	24	6	20	8	36	11	33
10	11	62	4	13	7	27	8	17	11	87	1	49	2	12	3	52	8	32	3	23	10	46	5	38
%	9.60		1.89		5.63		3.43		13.50		7.10		2.50		10.50		4.96		3.34		9.60		7.69	
Ave. %	5.13								8.4								6.39							

Table 1 (Cont.)

	SE								S							
Vel	26-27		27-28		28-29		29-30		26-27		27-28		28-29		29-30	
40																
39																
38																
37																
36																
35																
34																
33																
32																
31																
30																
29																
28																
27																
26																
25																
24									0	0	1	1	0	0	0	
23									0	0	0	1	0	0	0	
22									0	0	1	2	0	0	0	
21									0	0	0	2	0	0	0	
20	1	1	0	0	1	1	0	0	1	1	1	3	0	0	0	
19	1	2	2	2	0	1	0	0	0	1	0	3	0	6	0	
18	1	3	1	3	2	3	0	0	2	3	2	5	0	0	0	
17	0	3	2	5	1	4	0	0	1	4	0	5	0	0	0	
16	1	4	0	5	4	8	0	0	0	4	0	6	0	0	0	
15	1	5	2	7	3	11	0	0	0	4	1	6	0	0	0	
14	1	6	1	8	3	14	2	2	2	6	4	10	1	1	0	
13	5	11	4	12	3	17	4	6	2	8	2	12	0	1	0	
12	3	14	5	17	4	21	1	7	3	11	5	17	0	1	0	
11	4	18	4	21	1	22	7	14	5	16	3	20	0	1	0	
10	2	20	4	25	2	24	6	20	14	30	6	26	2	3	0	0
%	3.10		3.63		5.00		4.03		4.65		3.78		.63		0	
Ave. %	3.94								2.26							

Table 1 (Cont.)

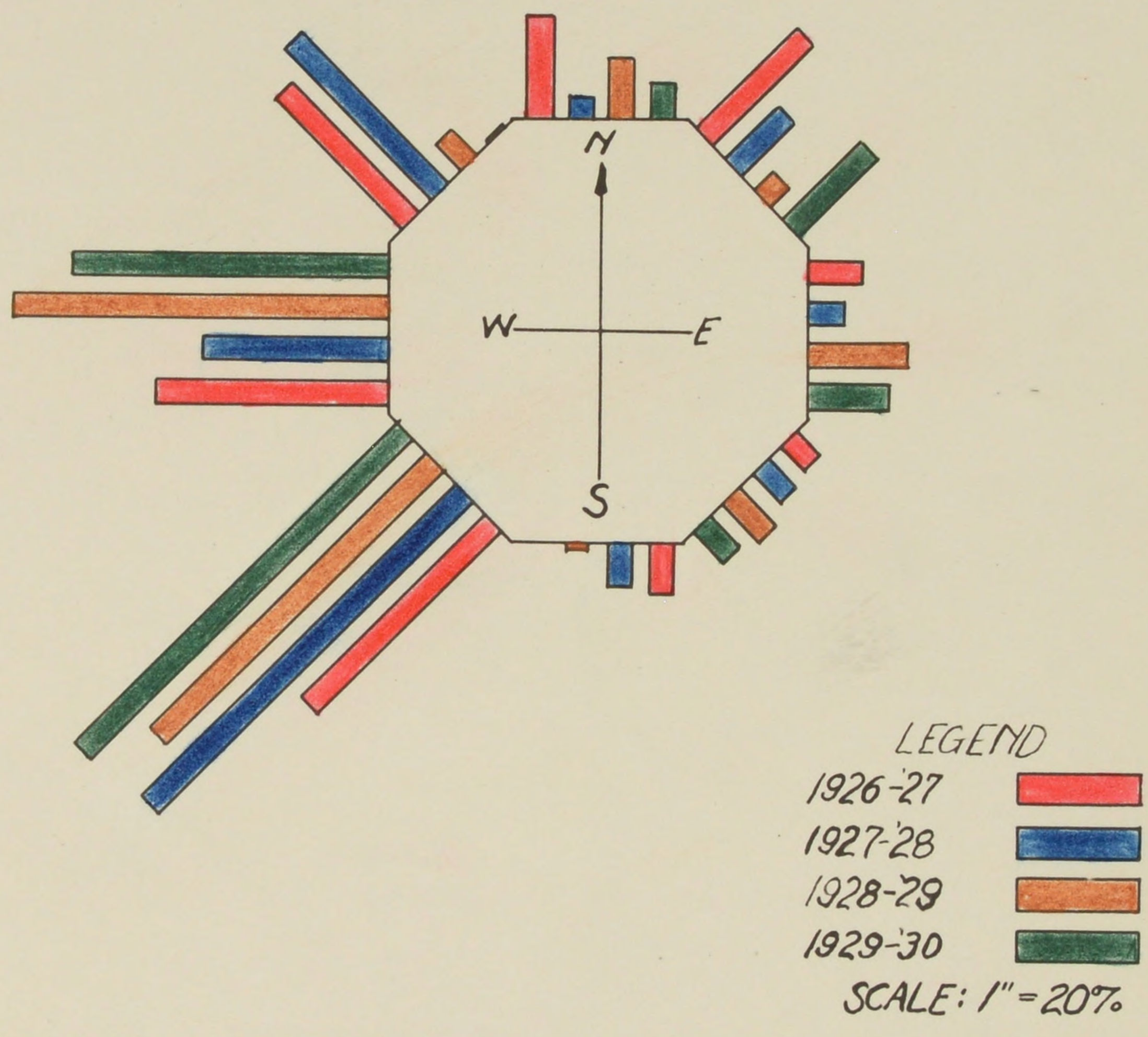


FIG. 16.

DISTRIBUTION OF WINDS
WITH A VELOCITY OF 10 M.P.H. AND OVER.
DURING DAYLIGHT HOURS OF DEC., JAN., AND FEB.
IN DETROIT, MICHIGAN.

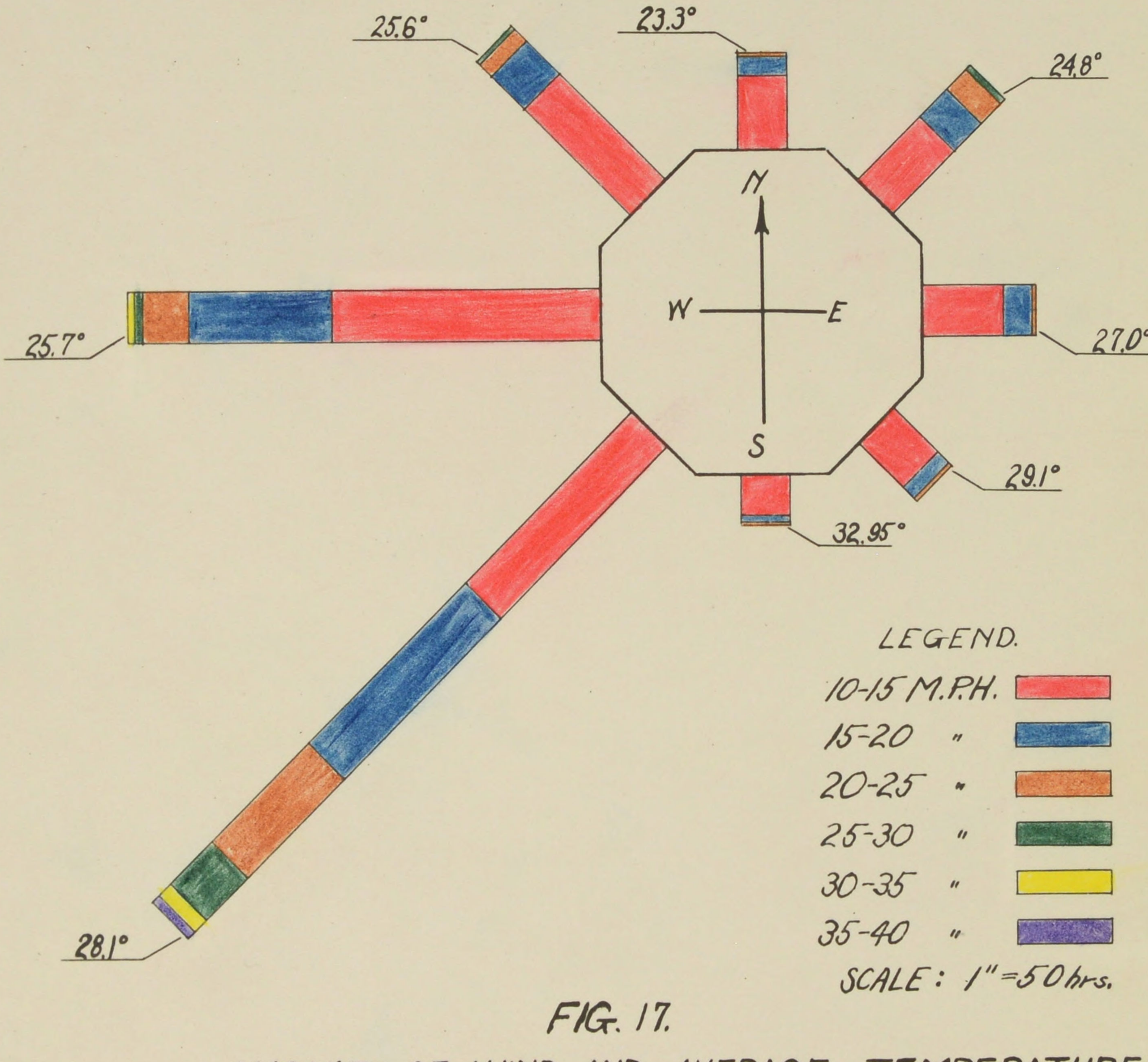


FIG. 17.

AMOUNT OF WIND AND AVERAGE TEMPERATURES FOR THE WINTERS 1926-27 THRU 1929-30. IN DETROIT, MICHIGAN.

CONCLUSIONS FROM THE YEAR'S WORK

From consideration of the results of the effect of the wind around a building it is apparent that when the wind is normal to a face of the building the windward pressure varies directly as the velocity head, and is equal to about 80 per cent of the velocity head. The leeward pressure does not vary directly as the velocity head, but is equal to about 13 per cent of the velocity head at the higher values of the velocity head. The total head induced by the winds is slightly greater than the velocity head until the velocity reaches 32 m.p.h., where it is equal to it. Above 32 m.p.h. the total induced head falls below the velocity head until at 43 m.p.h., the limit of the curves drawn, it is equal to about 93.5 per cent of the velocity head. The observed windward head falls between the maximum head calculated from the formula $p = .00048M^2$, and the value generally used by designers, which is 68 per cent of the maximum calculated head. The observed head is 80 per cent of the calculated head in these tests.

When the wind was not normal to the face of the building, the windward head was about 74 per cent of the velocity head, for a wind 20 degrees less than normal to the face. The leeward head is greater than in the case of the normal winds, as it equals 23 per cent at the higher ranges of the velocity head. The sum of the windward and leeward heads is equal to the velocity head up to a velocity of 25 m.p.h. and then rises slightly above the velocity head in value.

When the wind becomes nearly parallel to the face of a building, the windward pressure flustuates between positive and negative values. The critical angle for this change is with the wind at about 15 degrees to the face of the building.

With only the windward windows of a building open, there is still enough exfiltration from the room to maintain a pressure difference across the open windows which varies in value with the velocity of the wind and the air-tightness of the room.

The records of the winds in Detroit for the past four winters show that the west and southwest winds are the predominating ones for that vicinity; also that the latter are those having the higher velocities. The northwest winds are quite prominent, but the south winds are almost negligible in amount. The temperatures for the same period of time are fairly high, and refute the idea that high winds accompany low-temperature periods, as only moderate winds were observed during the cold snaps.

AIIM SCANNER TEST CHART # 2

Spectra

4 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:",./?$0123456789

6 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:",./?$0123456789

8 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:",./?$0123456789

10 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:",./?$0123456789

Times Roman

4 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:",./?$0123456789

6 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:",./?$0123456789

8 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:",./?$0123456789

10 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:",./?$0123456789

Century Schoolbook Bold

4 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:",./?$0123456789

6 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:",./?$0123456789

8 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:",./?$0123456789

10 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:",./?$0123456789

News Gothic Bold Reversed

4 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:",./?$0123456789

6 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:",./?$0123456789

8 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:",./?$0123456789

10 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:",./?$0123456789

Bodoni Italic

4 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:",./?$0123456789

6 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:",./?$0123456789

8 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:",./?$0123456789

10 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:",./?$0123456789

Greek and Math Symbols

4 PT ΑΒΓΔΕΞΘΗΙΚΛΜΝΟΠΦΡΣΤΥΩΧΨΖαβγδεξθηικλμνοπφρστυωχψζ≧∓",./≦±=≠°><⊁⊀>⩽≡

6 PT ΑΒΓΔΕΞΘΗΙΚΛΜΝΟΠΦΡΣΤΥΩΧΨΖαβγδεξθηικλμνοπφρστυωχψζ≧∓",./≦±=≠°><⊁⊀>⩽≡

8 PT ΑΒΓΔΕΞΘΗΙΚΛΜΝΟΠΦΡΣΤΥΩΧΨΖαβγδεξθηικλμνοπφρστυωχψζ≧∓",./≦±=≠°><⊁⊀>⩽≡

10 PT ΑΒΓΔΕΞΘΗΙΚΛΜΝΟΠΦΡΣΤΥΩΧΨΖαβγδεξθηικλμνοπφρστυωχψζ≧∓",./≦±=≠°><⊁⊀>⩽≡

White

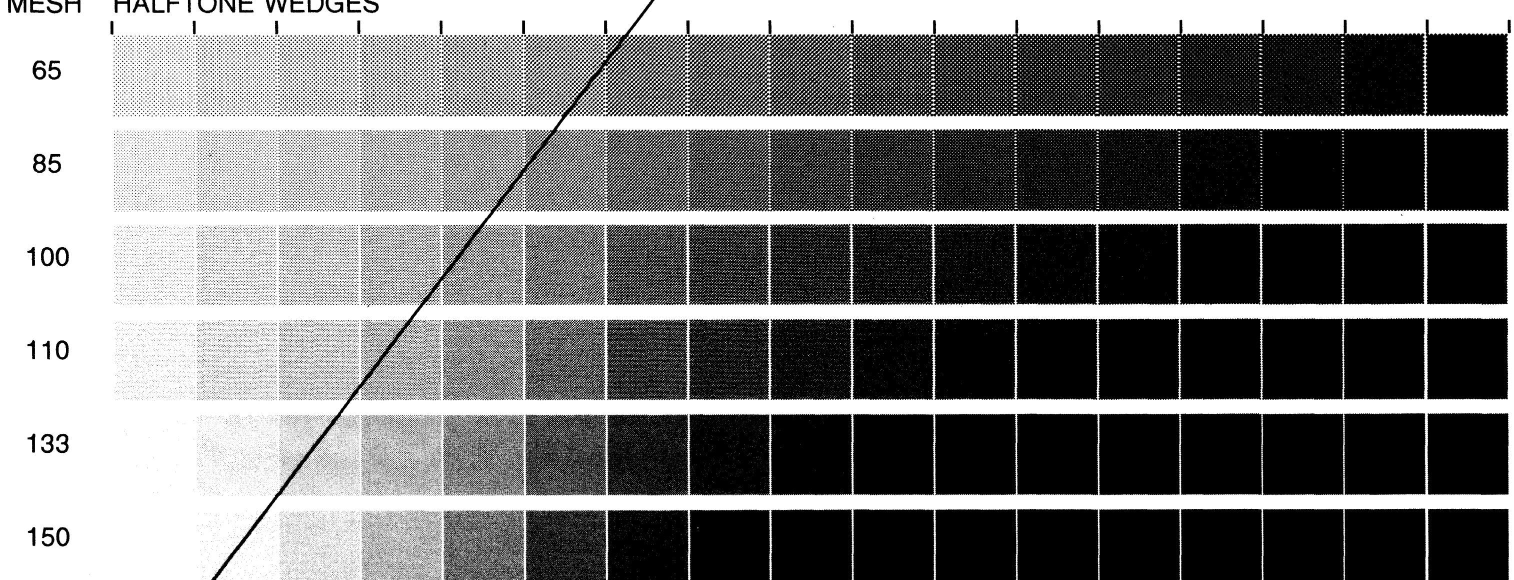
Black

Isolated Characters

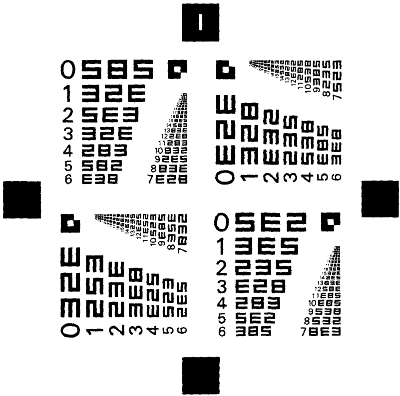
e	m	1	2	3	a
4	5	6	7	o	•
8	9	0	h	I	B

0123456 A4 Page 6543210

MESH HALFTONE WEDGES



RIT ALPHANUMERIC RESOLUTION TEST OBJECT, RT-1-71



PRODUCED BY GRAPHIC ARTS RESEARCH CENTER

ROCHESTER INSTITUTE OF TECHNOLOGY, ONE LOMB

MEMORIAL DRIVE, ROCHESTER, NEW YORK 14623