ENGINEERING RESEARCH INSTITUTE
UNIVERSITY OF MICHIGAN
ANN ARBOR

FINAL REPORT

MODEL STUDY OF THE STACKS FOR THE WEST SIDE POWERHOUSE

R. H. SHERLOCK
Professor of Civil Engineering

E. J. LESHER
Associate Professor of Aeronautical Engineering

Project 2252

DOW CHEMICAL COMPANY
MIDLAND, MICHIGAN

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SUMMARY

By referring to Table II and to the photograph of run A9X, it will be seen that with the present 104-foot stacks, the gas plume will not clear the elevator under any condition if the wind is from the west or southwest, unless the wind velocity is so low that it is approaching the conditions of calm.

The photograph B4X shows that when the wind is from the south-west, with a 157 ft - 3 in. stack, the bottom of the plume will clear the top of the elevator house by more than 15 feet, and that conditions will be worse than that during only 370 hours per year if average operation is assumed for the entire year, and 1180 hours per year if minimum operations are assumed for the entire year. Photographs B5X and B6X show that this condition will improve as the wind velocity decreases.

If the stack height is increased to 163 ft - 3 in., photograph C1X and Table II show that the clearance between the bottom of the plume and the top of the elevator house will be increased by approximately the increased height of the stack, that is, that the clearance will be increased to somewhat more than 20 feet. Photographs C2 and C3 show that the situation is improved for the lower wind velocities.

Photograph B10X shows that when the wind is from the west, the bottom of the plume will clear the top of the elevator house by more than 15 feet and that the conditions will be worse than that for only 280 hours per year, if average operation is assumed for the entire year. Photographs B11X and B12X show that the condition improves for lower wind velocities.

Photograph C13 shows that when the wind is from the west, the bottom of the plume will clear the top of the elevator house by a little more than 20 feet, that is, that the clearance between the house and the bottom of the plume will be increased by approximately the increased height of the stacks.

It is not known how the data based on the Saginaw Airport will change the number of hours per year in Table II. A supplement will be issued after the data are received from the U. S. Weather Bureau and the computations have been made.

FINAL REPORT

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FOR THE WEST SIDE POWERHOUSE

INTRODUCTION

Contract

Under date of April 26, 1954, a contract was executed between the Dow Chemical Company and the University of Michigan to proceed with this study. It was intended to provide information from wind-tunnel tests upon which to base the selection of the height for a new stack to replace three short, existing stacks. The various steps between the original inquiry of December 23, 1953, and the final execution of the contract are set forth in a Progress Report dated July 12, 1954. An additional Progress Report for the month of June was likewise submitted. The progress of the work as given in those reports will not be repeated here.

Program

Information regarding the dimensions of the old stacks and of the proposed new stack, together with the operating conditions and the dimensions of the plant buildings, were obtained at conferences in Midland and in Ann Arbor. A fairly complete set of architectural drawings was obtained, together with a number of sheets of computations by Mr. H. L. McNally. Table I shows the information upon which the testing program was based. The model was made to a scale of 1 to 150 as shown on a set of three drawings 24" x 36" which was submitted to the client for approval on May 28. The drawings are not included in this report. Five wind directions were to be tested. Two series of tests were outlined. Series A was for the purpose of checking the performance of the old stacks, whose height was 104 feet above the ground (Elev. 87 ft), and Series B was for testing the performance of the proposed new stack which was to take the place of the three old stacks. The new stack was to have a height of 157 ft 3 in. above the ground. In conference with Mr. McNally it was decided to use a stack-gas velocity of 33 fps at 295° F as representative of average operating conditions, and a velocity of 15 fps at 237° F as representing the minimum operating conditions.

Mr. McNally came to Ann Arbor on July 28 to observe the running of the tests. At this conference it was decided to add Series C, which was to be the same as Series B except that the stack height would be increased to 163 ft - 3 in. It was also decided to restrict the observations for Series B and C to the west and south-west wind directions, and for Series A to the south-west direction only.

WIND TUNNEL

The investigation was conducted at the University of Michigan in a wind tunnel which is 8 ft wide by 5 ft 4 in high, with a venturi working section approximately 14 ft long, as shown in the accompanying photographs. The velocity of the approaching undisturbed wind was usually kept at 30 fps, but due to the difficulty of getting consistent manometer readings at the higher velocity ratios, particularly of Series B and C, the wind velocity was sometimes reduced to 20 fps, with corresponding adjustments in the velocity of the stack gases.

The smoke consisted of a mixture of oil vapor and steam and was emitted from the stacks at a temperature of approximately 70° F. The details and assembly of the smoke generator are not given in this report, and likewise the details of its operation are omitted. However, this information is available if desired. The changes in the ratio of the gas velocity to the wind velocity were obtained by varying the gas velocity. The smoke plume was photographed through a plate-glass window against a grid on the far side of the tunnel using an exposure of one second.

MODEL

The model was made of pattern-makers grade of white pine to a scale of 1 to 150. The smoke was transmitted through a measuring orifice into a stilling chamber inside the boiler house model, and thence through an equalizing screen to the stacks.

STACK GAS BEHAVIOR

Under favorable weather conditions the plume from a smoke stack having adequate height will rise gradually as it flows downwind, and the gases will be dispersed until only a negligible concentration prevails in the atmosphere. Unfortunately, however, there are several adverse natural influences which arise occasionally to disturb this orderly dispersion of the stack gases. In this particular case, the adverse influences are of aerodynamic origin. With the old stacks, which are only 104 feet high, the photographs which are made in the wind tunnel show that the stack gases are emitted into the turbulent mass of air which is deflected over the building. The gases are quickly brought to the roof and to the ground in the lee of the plant building. This occurs in the wind tunnel even at relatively low wind velocities and checks with the behavior observed at the phototype in the field.

In Series B and C, where the stacks are 157 and 163 feet, respectively, the gases as shown in the photographs appeared to emerge from the top of the stacks above the vortex sheath which separates the turbulent mass of air over the building from the more smoothly flowing air above it. Nevertheless, the gases were brought to the ground within a thousand feet of the stack, except at low wind velocities.

The aerodynamic downwash shown in Series B and C occurs in two steps, the first of which is caused by the eddies at the tip and in the wake of the stacks. If this first step brings the gases low enough so that they penetrate the vortex sheath over the building turbulence, the gases will be brought to the ground or even to the top of the plant building. If, however, the emerging gas had had sufficient momentum to escape the adverse eddies created by the stack, and if the stacks had projected high enough above the turbulence of the buildings, the gas plume would have flowed downwind and would have been dispersed. The gas would not have been brought to the ground unless it had encountered the large-scale meteorological effects of vertical atmospheric mixing.

TEST METHODS

The calibration for wind speed in the tunnel and for the velocity of the emerging smoke followed practices which are standard in this laboratory for this kind of work. The constriction of the tunnel area by the model presented no special problem. Each of the illustrative photographs included in this report shows a single "run" which was made in the tunnel under conditions of controlled wind velocity, gas velocity, and with the gas temperature reduced to an exit temperature of approximately 70° F. Each series of runs was checked by repeating the entire series. A total of 129 data runs were made as well as about 30 calibration and practice runs. The photographs for 15 typical runs are shown in this report as listed in Table II.

Since it was easier to control the stack-gas velocity than to change the wind velocity, a constant wind velocity was used in the tunnel for all runs and the various velocity ratios were obtained by varying the stack gas velocity. This is a well validated procedure in our work. During each run, smoke was emitted at the proper velocity from the stack for a period of about 15 seconds, from which one particular second was selected for the time exposure of the camera. The one-second exposure was too long to show the instantaneous structure of the plume; instead, it gave an integrated history of the plume for a period equivalent to about three minutes at the plant site and made it possible to choose an envelope which was representative of the position of the bottom of the plume with each particular velocity ratio.

Usually, the position of the plume is identified by the minimum height to the bottom of the plume at approximately 2000 feet downwind from the stacks. In this case, however, the interference of the building turbulence and of the turbulence created by the elevator housing brings the gases to the ground so quickly that usual procedures are ineffective, and it is not possible to draw curves of behavior. Reliance must be placed on an inspection of the plume and the manner in which the gases avoid contact with the elevator housing and with the electrical switching structures to the east of the building.

It will be noted that the ratio of the velocity of the stack gases to the velocity of wind is computed only after both velocities have been reduced to an equivalent velocity at 70° F. This gives a measure of the ratio of the favorable momentum of the stack gases to the adverse momentum of the wind. It is important that these velocities always be referred to these standard conditions rather than to the operating temperatures.

TEST RESULTS

A portion of the testing program dated May, 1954, is repeated here for easy reference. The underlying data were arrived at during conferences in Midland and in Ann Arbor. It was originally expected that the wind velocity in the tunnel could be maintained constant for all tests at a velocity of 30 fps for all runs. However, it was found advisable to change to a tunnel velocity of 20 fps for certain of the runs in order to obtain the control necessary for good photographic results. All of these cases are clearly indicated on the original log sheets.

TABLE I

Testing Program

Model Scale = 1:150

(See 24" x 36" Drawings, Sheets 1, 2, 3)

Wind directions, N, NW, W, SW, and S
All runs will be numbered consecutively regardless of the Series in which they occur. This includes calibration runs. Velocity of tunnel wind V_W = 30 fps unless otherwise noted.

SERIES A

Smoke from 2 stacks G only. Stacks F, H, and J are wooden dummies.
Stack Height = 104' (8.32") above Elev. 87' = Elev. 191'
Stack Diameter = 7'ID (0.56")
Stack gas velocity V_s' = 33 fps at 295° F (Aver.)
V_s = 23.2 fps at 70° F
V_s' = 15 fps at 237° F (Min.)
V_s = 11.5 fps at 70° F

SERIES B

Smoke from 1 proposed new stack only. Stacks, F, G, H, and J are wooden dummies.
Stack Height = 157'-3" (12.58") above Elev. 87' = Elev. 244'-3"
Stack Diameter = 14'ID (1.12")
Stack gas velocity V_s' = 33 fps at 295° F (Aver.)
V_s = 23.2 fps at 70° F
V_s' = 15 fps at 237° F (Min.)
V_s = 11.5 fps at 70° F

SERIES C

(Same as Series B except that Stack Height = 163'-3")

A total of 129 data runs were made. There is a separate photograph for each run. All these photographs are mounted three on a page, and opposite each photograph the identifying information is given. All such sheets are included in a looseleaf notebook which is filed in the office of the authors.

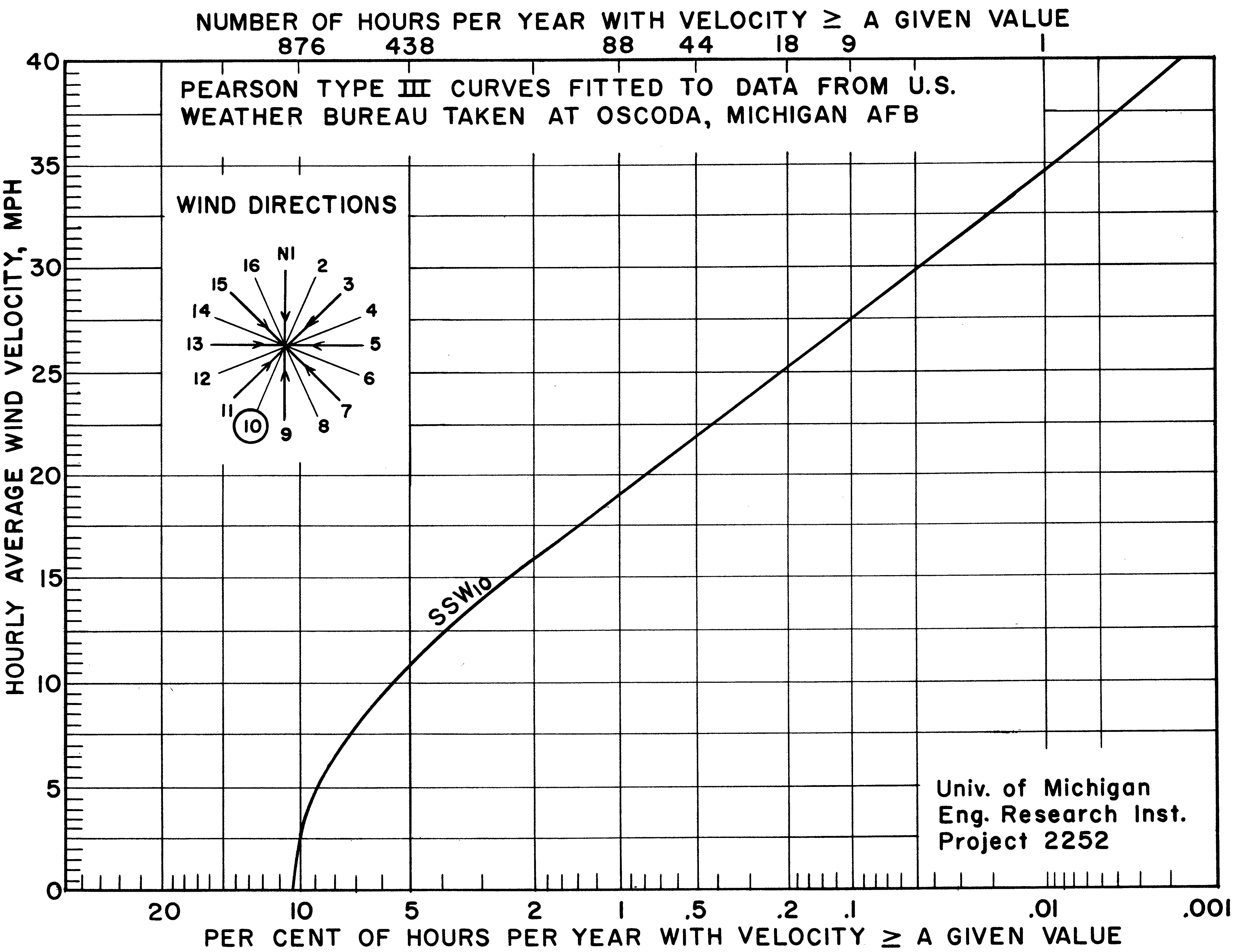
NUMBER OF HOURS PER YEAR WITH VELOCITY ≥ A GIVEN VALUE
876 438 88 44 18 9 1
PEARSON TYPE III CURVES FITTED TO DATA FROM U.S. WEATHER BUREAU TAKEN AT OSCODA, MICHIGAN AFB
WIND DIRECTIONS
N1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
SSW10
HOURLY AVERAGE WIND VELOCITY, MPH
0 5 10 15 20 25 30 35 40
20 10 5 2 1 .5 .2 .1 .01 .001
PER CENT OF HOURS PER YEAR WITH VELOCITY ≥ A GIVEN VALUE
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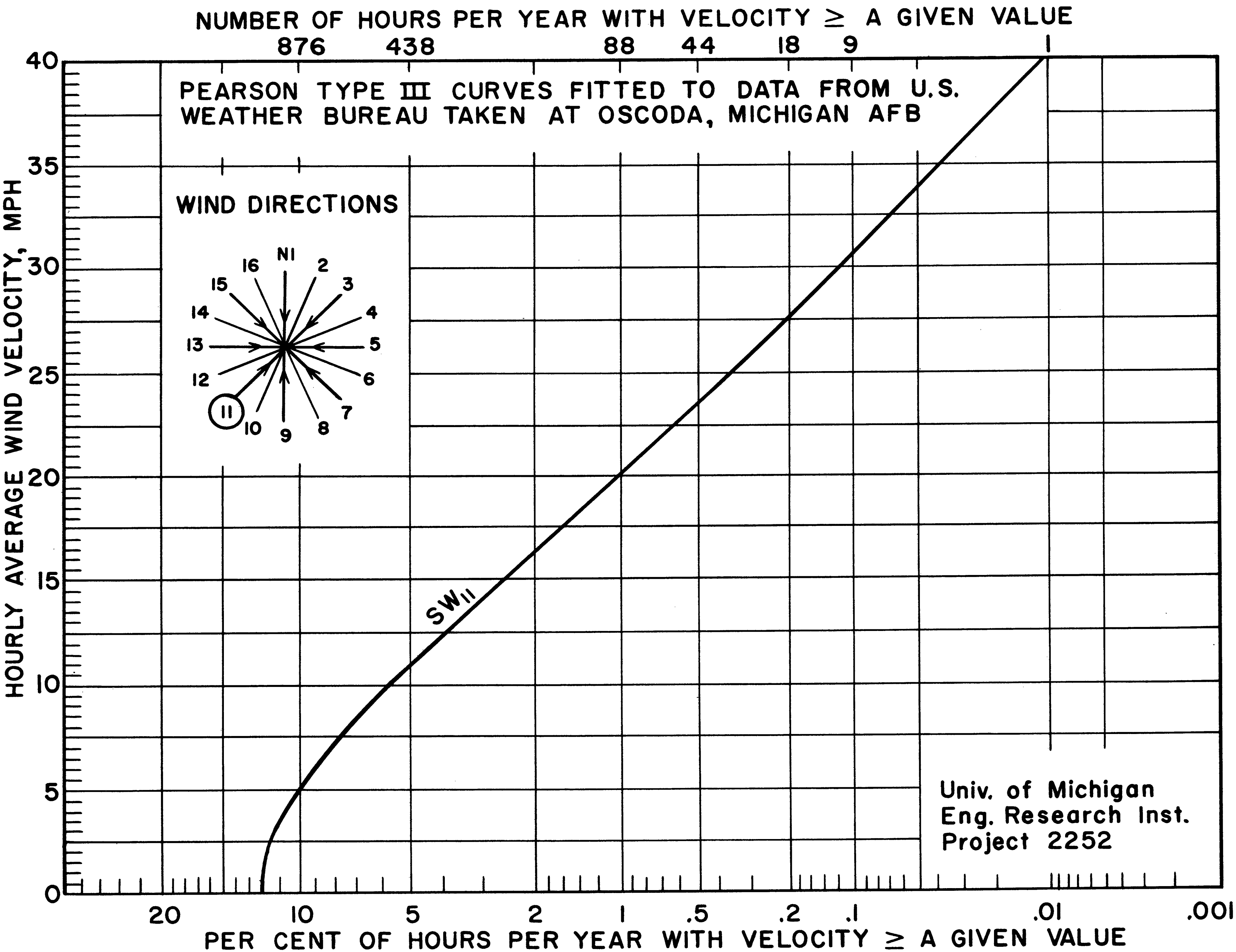
FIG. 1.



NUMBER OF HOURS PER YEAR WITH VELOCITY ≥ A GIVEN VALUE
876 438 88 44 18 9 1
PEARSON TYPE III CURVES FITTED TO DATA FROM U.S. WEATHER BUREAU TAKEN AT OSCODA, MICHIGAN AFB
WIND DIRECTIONS
N1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
SW11
HOURLY AVERAGE WIND VELOCITY, MPH
40 35 30 25 20 15 10 5 0
Univ. of Michigan
Eng. Research Inst.
Project 2252
20 10 5 2 1 .5 .2 .1 .01 .001
PER CENT OF HOURS PER YEAR WITH VELOCITY ≥ A GIVEN VALUE

FIG. 2.

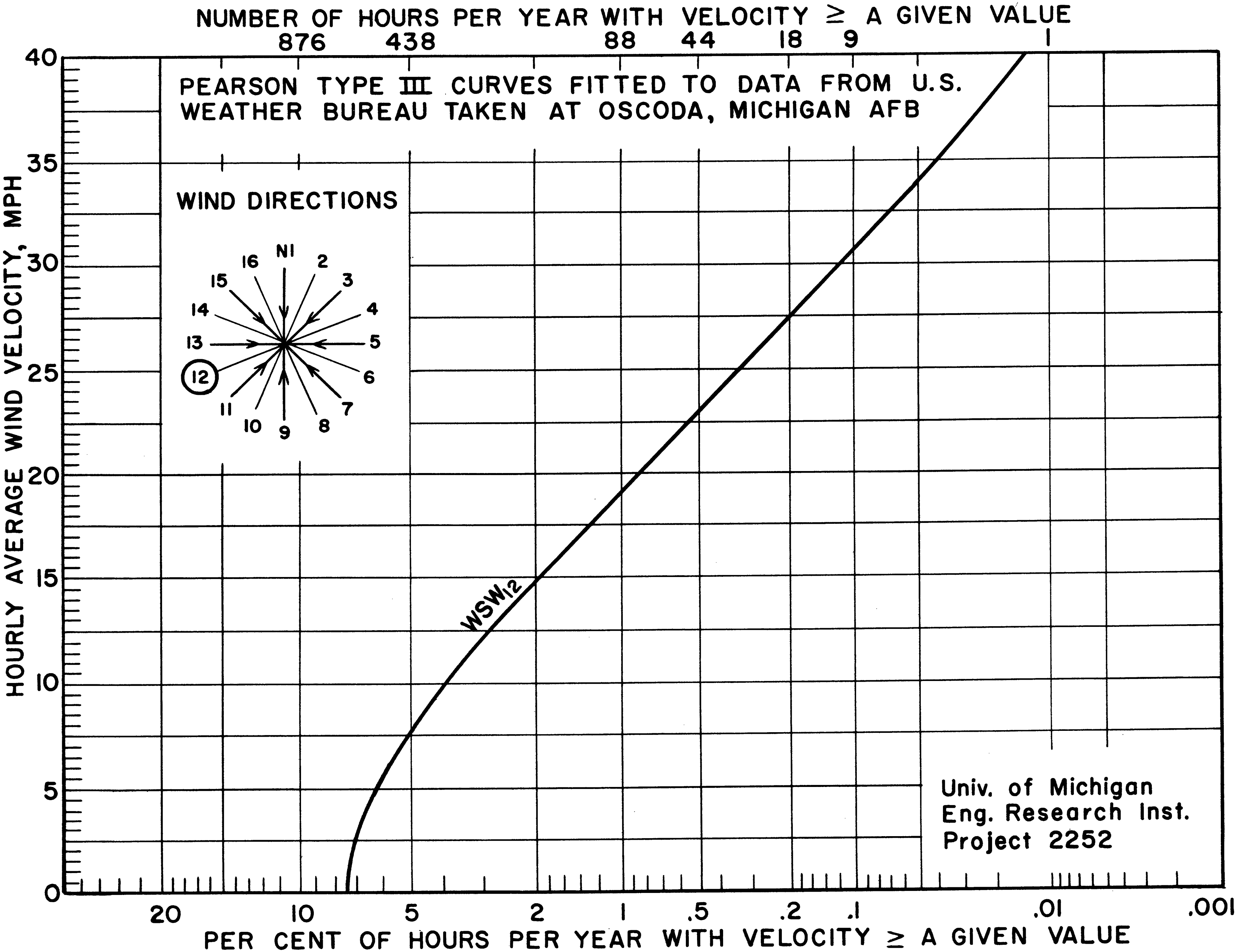

NUMBER OF HOURS PER YEAR WITH VELOCITY ≥ A GIVEN VALUE
876 438 88 44 18 9 1
PEARSON TYPE III CURVES FITTED TO DATA FROM U.S.
WEATHER BUREAU TAKEN AT OSCODA, MICHIGAN AFB
WIND DIRECTIONS
N1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
WSW12
Univ. of Michigan
Eng. Research Inst.
Project 2252
HOURLY AVERAGE WIND VELOCITY, MPH
0 5 10 15 20 25 30 35 40
20 10 5 2 1 .5 .2 .1 .01 .001
PER CENT OF HOURS PER YEAR WITH VELOCITY ≥ A GIVEN VALUE

FIG. 3.

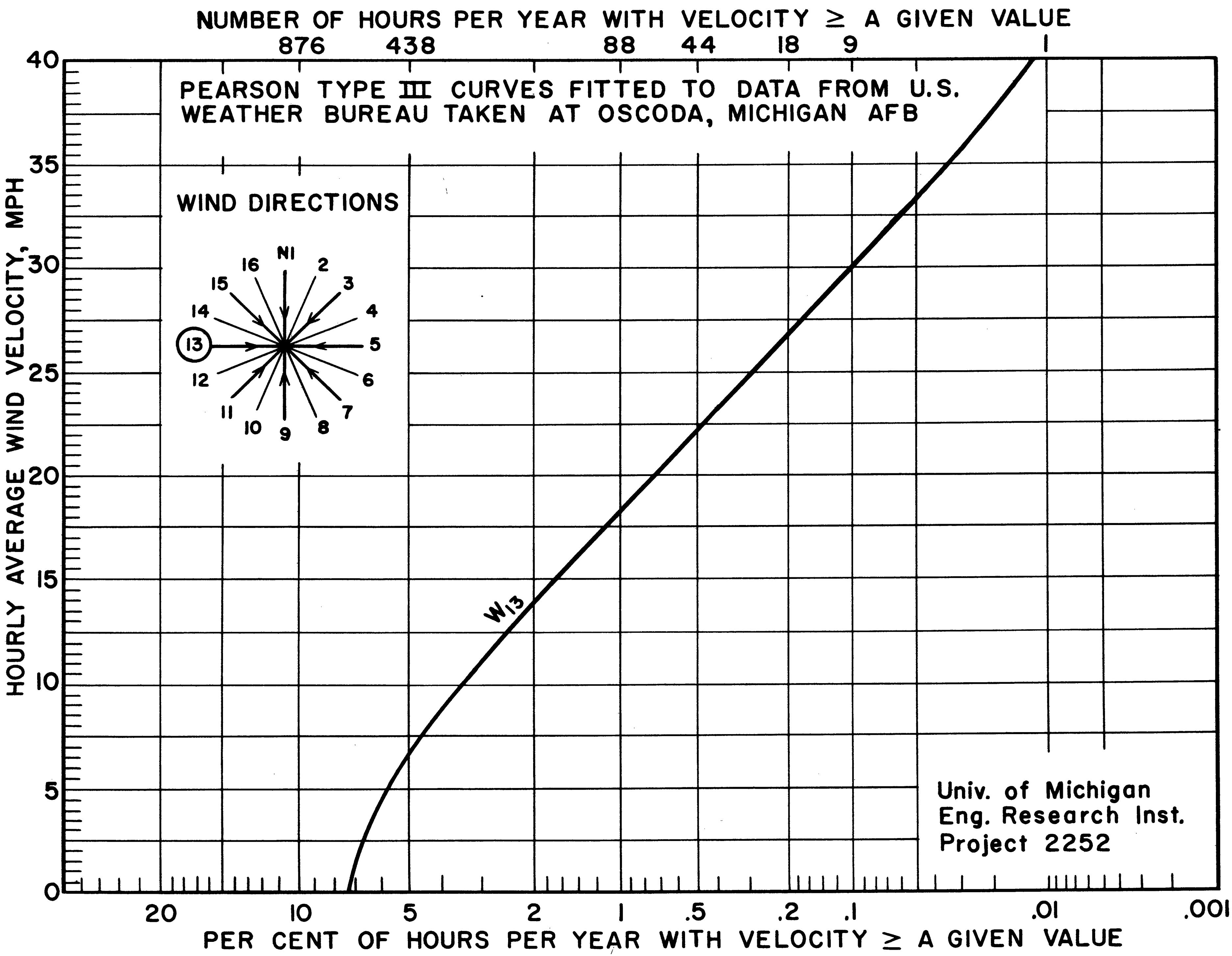

NUMBER OF HOURS PER YEAR WITH VELOCITY ≥ A GIVEN VALUE
876 438 88 44 18 9 1
PEARSON TYPE III CURVES FITTED TO DATA FROM U.S.
WEATHER BUREAU TAKEN AT OSCODA, MICHIGAN AFB
WIND DIRECTIONS
N1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
W13
HOURLY AVERAGE WIND VELOCITY, MPH
0 5 10 15 20 25 30 35 40
20 10 5 2 1 .5 .2 .1 .01 .001
PER CENT OF HOURS PER YEAR WITH VELOCITY ≥ A GIVEN VALUE
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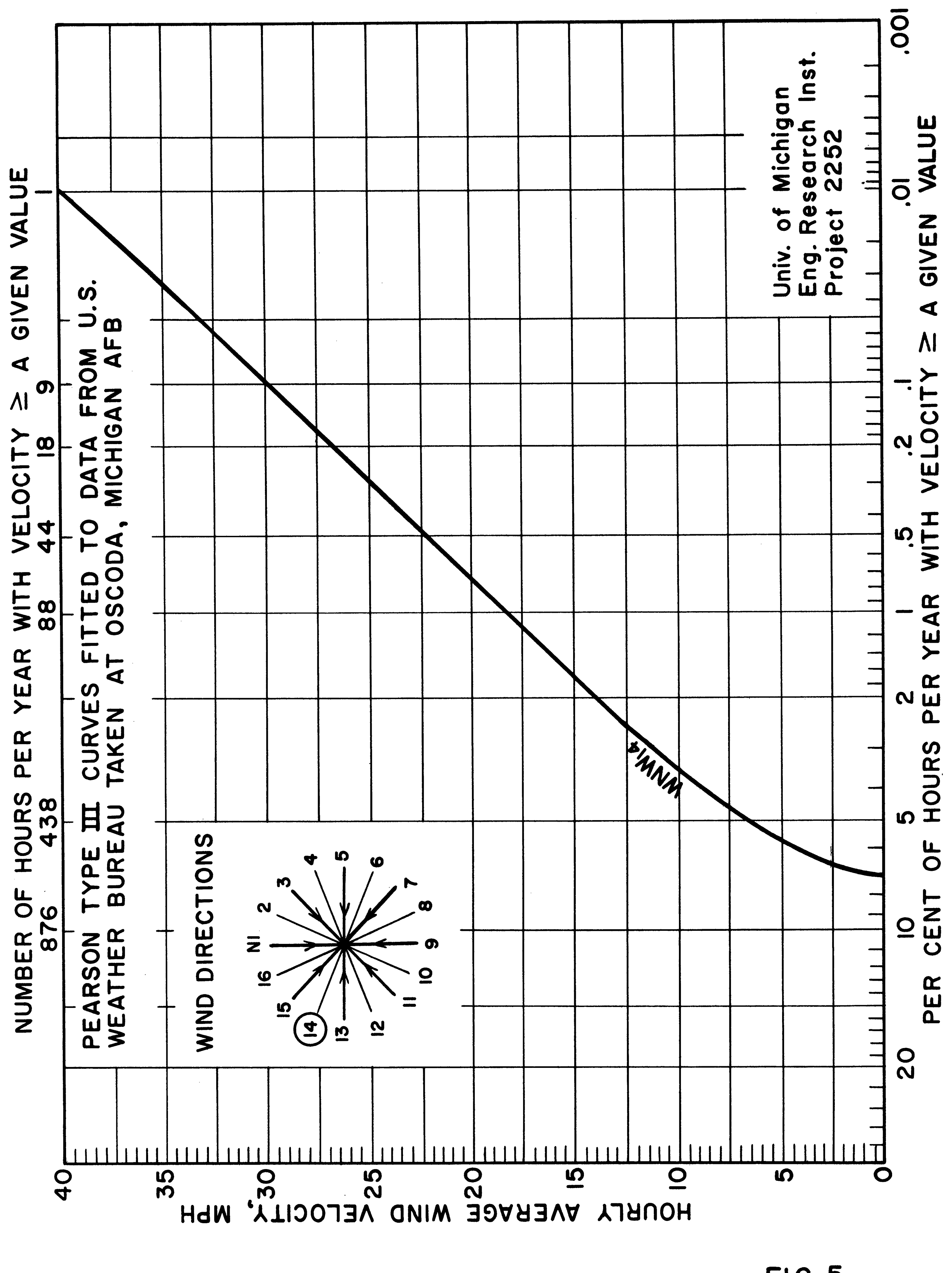
FIG. 4.



NUMBER OF HOURS PER YEAR WITH VELOCITY ≥ A GIVEN VALUE
876
438
88
44
18
9
1
PEARSON TYPE III CURVES FITTED TO DATA FROM U.S.
WEATHER BUREAU TAKEN AT OSCODA, MICHIGAN AFB
Univ. of Michigan
Eng. Research Inst.
Project 2252
WIND DIRECTIONS
N1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
WNW14
HOURLY AVERAGE WIND VELOCITY, MPH
40
35
30
25
20
15
10
5
0
PER CENT OF HOURS PER YEAR WITH VELOCITY ≥ A GIVEN VALUE
20
10
5
2
1
.5
.2
.1
.01
.001

FIG. 5.

Wind-Velocity Record

In order to correlate the results obtained in the wind tunnel with the history of the wind at Midland, it was necessary to obtain records from the United States Weather Bureau. The nearest first-order station is at the Tri-City Airport, which is identified by the Weather Bureau as the Saginaw Airport. These records, however, are not on I.B.M. cards, and it is necessary to transcribe them before they can be reproduced. Consequently, the U. S. Weather Bureau sent us the records from the Air Force Base at Oscoda, Michigan, as being the nearest first-order station from which records are available on I.B.M. cards. An order was placed, however, for the records to be transcribed to I.B.M. cards for the Tri-City Airport, but these have not yet been received at the time of writing this report. If they are later received, a supplement to the report will be sent to the client so that he may fill in the information for Saginaw winds in Table II.

The U. S. Weather Bureau records are reported for 16 wind directions, as shown on Figs. 1 to 5. Each Fig. shows, for one wind direction, the annual percentage of hours with velocity equal to, or greater than, any particular value of wind velocity. A Pearson Type III statistical curve was fitted to the data in all cases. An example of how to read the curves is as follows: Figure 1 shows that during 0.10 percent of all the hours of an average year the wind will be from the SSW and its velocity will be equal to or higher than 27.5 mph. Since there are 8760 hours in a year this means that the wind will be from the SSW and will have a velocity equal to or greater than 27.5 mph during 8.76 hours per year.

On this project we are interested only in winds from the west and south-west octants of the compass. For this reason, Figs. 1 to 5 were used in the following manner: It was assumed that the south-west octant would contain all the hours shown from direction 11 and half of the hours from directions 10 and 12, and that the west octant of the compass would contain all the hours from direction 13 plus half of the hours from directions 12 and 14. This is the procedure that was used in filling out the hours per year in Table II.

Velocity Ratio vs Critical Wind Velocity

Table II is divided into two horizontal subdivisions within each of which information is given for velocity ratios of 1.0, 2.0, and 3.0. The velocity ratios are always given in terms of equivalent velocities reduced to 70° F. Under average operating conditions, the gas emerges from the stack at 33 fps and at 295° F. When the volume of gas emerging per second is reduced to a volume at 70° F, the corresponding velocity of the emerging gas will be 23.2 fps. When the velocity ratio has a value of 1.0 then both the stack-gas velocity and the wind velocity, reduced to 70° F, have a value of 23.2 fps or

15.8 mph. A similar computation is made for other velocity ratios and for both minimum and average operating conditions as shown.

TABLE II

SUMMARY OF TYPICAL WIND-TUNNEL RUNS
CHOSEN TO ILLUSTRATE THE EFFECT OF
STACK HEIGHT AND VELOCITY RATIOS ON
THE BEHAVIOR OF THE STACK GAS

V_s/V_w	Wind Dir.	Wind Velocity, V_w		Hours Per Year				Run Numbers		
		Minimum Operation	Average Operation	Oscoda Wind Min.	Oscoda Wind Ave.	Saginaw Wind Min.	Saginaw Wind Ave.	Stack Ht. 104'	Stack Ht. 157'-3"	Stack Ht. 163'-3"
1.0		7.8 MPH	15.8 MPH	1180	370			A7X	B4X	C1X
2.0	SW	4.0	7.9	1660	1170			A8X	B5X	C2X
3.0		2.6	5.3	1780	1510			A9X	B6X	C3X
1.0		7.8 MPH	15.8 MPH	800	280			---	B10X	C13X
2.0	W	4.0	7.9	1110	810			---	B11X	C14X
3.0		2.6	5.3	1180	1000			---	B12X	C15X

Table II shows that for the wind from the south-west and with a velocity ratio of 1.0, the critical wind velocity would vary from 7.8 mph at minimum operation to 15.8 mph at average operation, and that the behavior of the gas plume for a 104-foot stack would be as shown in the photograph A7X. A proper reading of the curves shown in Figs. 1, 2, and 3 indicates that if minimum operation were to continue for an entire year, and if the records at the Oscoda air base are used, the conditions would be as shown in the A7X photograph or worse, during 1180 hours per year. But if average operation is assumed for the entire year, the behavior of the plume will be as shown in photograph A7X, or worse, during only 370 hours per year. However, if the height of the stack is changed to 157 ft-3in.,the behavior of the plume will be as shown in photograph B4X, or worse, during these same numbers of hours per year. If the stack height is changed to 163 ft - 3 in.,then the behavior will be as shown in C1X, or worse, for these same numbers of hours per year.

This same meaning should be attached to each of the other horizontal lines in Table II. For example, if the height of the stack is 157 ft-3 in., the conditions shown in photograph B6X, or worse, will occur for 1780 hours per year if minimum operation is assumed for the entire year, or for 1510 hours per year if average operation is assumed for the entire year. The true conditions of operation will, of course, lie somewhere between the minimum and an unspecified maximum. The average operating condition gives the best basis for future estimation, but the minimum operating condition gives a basis for anticipating the worst behavior.

15 pages of mounted pictures follow here.

See ERI File Copy