WIND-TUNNEL STUDY OF WIND RESISTANCE OF ROOFING SHINGLES

by

J. A. Peterka* and J. E. Cermak**

for

Owens-Corning Fiberglas Corporation
Technical Center
Granville, Ohio 43023

Fluid Mechanics and Wind Engineering Program
Fluid Dynamics and Diffusion Laboratory
Department of Civil Engineering
Colorado State University
Fort Collins, Colorado 80523

CSU Project 2-95470

February 1983

*Associate Professor
**Professor-in-Charge, Fluid Mechanics and
Wind Engineering Program

ACKNOWLEDGEMENTS

This investigation was funded by Owens-Corning Fiberglas. Mr. Glenn Lamb of Owens-Corning Fiberglas was responsible for initiation of the study and valuable input during design and execution of the study. Mr. Jim Garrison and Mr. Hank Weber were responsible for conducting the test. Mr. Coby Howell took the still photographs.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

This study was undertaken at the request of Owens-Corning Fiberglas (OCF) for the purpose of developing improved wind testing procedures for roofing shingles. Previous testing procedures used a technique developed at least in part at Underwriters Laboratory in which a jet of air was directed horizontally at close range onto a shingled panel set to a typical roof slope. This test suffers from a lack of realism: The physical mechanisms which produce shingle uplift on houses subjected to natural winds are not simulated in any real way by the Underwriter's test. Laboratory tests at OCF using the Underwriters's test procedure had failed to adequately show a difference in performance between shingles which were expected to have a significant difference in performance when installed on houses subjected to real winds.

The purpose of this study was threefold: 1) to review the published literature to determine what work had been performed in the past which would be useful to the current task and to further development of wind performance appraisal techniques, 2) to develop an improved testing procedure and use it on shingles supplied by OCF, and 3) to use the results of the first two parts of the study to recommend further research which would benefit future development and wind resistance testing of shingle products. Sections 2-6 provide the results of these three parts of the investigation.

2. LITERATURE REVIEW

As was expected, the literature review determined that research has not been published which provides a complete understanding of roof shingle failure and the responsible physical mechanisms. A large number of papers and reports are available which address, in some measure, the problem of roof loads due to wind. From this literature some indication of roof wind pressures and qualitative wind flow characteristics responsible for shingle failure can be deduced. What is missing is the quantitative connection between approach wind flow characteristics, detailed building geometry, fluctuating wind magnitude and direction just above the shingles correlated with uplift pressure on the shingles, and the ability of a particular shingle to resist the combination of local velocity and uplift pressure.

The literature cited below is not complete for every category in which references are grouped. Several of the most important citations are provided from each type of study which adds additional understanding to the problem. Because of the missing connections cited above, further citation in each category would not add materially to the understanding or benefit derived from the literature survey. The survey was limited to wind effects, particularly those which would be of value in providing a quantitative evaluation. Some references were included at the request of the OCF representative.

A number of references have reported on full-scale wind loads on small buildings--one outcome was a measurement of wind pressures on the roof. References 1-3 describe results of wind pressure measurements on a single story, pitched roof test house at Aylesbury, England. This field data probably represents the best field data available on a small building, although some of the test runs have been shown since the original data was published to be out of calibration. References 4 and 5 describe limited field data for pressures on two small buildings including roof tops. These buildings include a residential house and a mobile home. Instrumentation problems slightly limit the usefulness of these data. Reference 6 describes integrated uplift pressures on the entire flat roof of a small test building built for that purpose. Reference 7 presents full-scale wind loads on greenhouses in England. Data in references 1-7 provide full-scale pressures acting locally or integrally on roof systems. Many of the flow mechanisms responsible for roof loads are described or implied in these references.

A variety of pressure measurements have been made on small building roofs in wind tunnels. Some measurements have been performed in wind tunnels of the aeronautical type where the characteristics of the atmospheric wind were not simulated, for example references 8-11. These data suffer from an inaccurate representation of the flow field and thus have a distorted measurement of roof pressures.

Procedures have been developed over the past twenty (20) years which permit accurate modeling of fluctuating pressures on building models using boundary-layer wind tunnels 12-14. Reference 15 was probably the first boundary-layer wind-tunnel measurement of wind pressures on a small building. This data was obtained to compare with the field measurements of reference 4 (which also includes some of the data from reference 15). Reference 16 reports on wind pressures on low-rise buildings. This data was obtained for use in design of metal buildings. References 17-19 show wind-tunnel measurements on models of the house at Aylesbury for which field measurements were reported in references 1-3. Additional measurements of a model of the Aylesbury house were made at Colorado State University which have not been published. All of these measurements at model scale compare well with the full-scale data where proper care was obtained in the modeling of the atmospheric winds. Wind-tunnel tests provide an economical way to obtain large amounts of data quickly. Field tests tend to be more expensive, of longer duration, and more limited in scope.

Measurements of roof pressures on more than 150 buildings have been made at model scale at Colorado State University on buildings under design. These references are not specifically listed here. In addition, basic research into the nature of fluctuating pressures on buildings, references 20-23, have brought a clearer understanding of the mechanism and methods for quantitative assessment of peak local pressures on buildings.

Uplift pressure on a roof is not the only mechanism which causes shingle uplift. Local velocity just above the shingle is also a contributing factor. Few tests are available which define the wind field just above the roof level, although overall flow structures over a roof are reasonably well understood in a qualitative way from many flow visualization studies which are not typically published. The few measurements where wind velocity close to the roof was a factor in the measurement were obtained in boundary-layer wind-tunnel tests to determine the scouring and blow off characteristics of roof gravel on flat roofs. These data are reported in references 24-29. The references concentrated on the influence of approach velocity, building aspect ratios and parapet height on the movement of roof gravel of various sizes. Reference 27 provides a design procedure for gravel size selection. The primary flow mechanism involved in gravel blowoff on a flat roof, the roof vortices which originate at the building corners, also exist on sloped shingled roofs. The data in references 24-29 is certainly qualitatively applicable to the shingle uplift case but may not be quantitatively applicable.

Some references provide a general understanding of wind flow over buildings and relate damage experience or recommend wind loads for smaller buildings. Among these sources are references 30-34. Their primary usefulness to the shingle failure problem is in the qualitative understanding of failure mechanisms.

The standard sources of wind loads on buildings are local wind load codes. These are often based on one of the major codes such as the Uniform Building Code, Standard Building Code, or American National Standards Institute Standard A58.1. Data used by these codes and standards are usually based on references such as those cited above. Because each locality has a different basic wind speed, it is necessary to determine the local wind speed for design use. Until recently, most wind data for the continental U.S. was derived from reference 35 based on a Type II extreme value analysis of fastest mile wind records. A more recent wind analysis using a Type I extreme value analysis of fastest mile wind speeds, reference 36, incorporates a longer record of data and a more appropriate analysis procedure for noncoastal areas. In coastal areas for less frequent winds (50 or 100 year recurrence interval), reference 37 provides a wind analysis for hurricane winds. References 36 and 37 should provide an adequate basis for establishing the variability in basic wind speeds in the U.S. except in those areas where winds of special character exist which are not adequately defined by National Weather Service stations.

A few references have shown the influence of roof cover porosity on the pressure loads on those porous covers. Reference 38 addresses this area for roof tiles, a major roofing material in Europe. For a porous roof cover, the negative uplift is rapidly neutralized by pressure response on the underside of the cover so that the cover material (tiles, pavers, gravel, etc.) do not see the full uplift forces which might be predicted by pressure loads measured on an impermeable surface. Shingles may benefit from the same phenomena; however, we are not aware of measurements of pressures on each side of a shingle.

Laboratory testing of roof shingles for wind, exclusive of wind-tunnel tests, have been at a rather primitive state. Test procedures developed by Underwriters Laboratory and ASTM are described in references 39-41. As mentioned earlier, these tests aim a jet of air directly at a sloping shingled surface at close range. These tests do not include important flow mechanisms which are important at a field site. Apparently no calibration of these test procedures against field performance has been published.

The conclusion to be made from the review of published literature is that a large amount of data exists which may be of qualitative use in identifying wind flow features which are responsible for shingle failure. However, data of direct quantitative use in the shingle failure problem are quite sparse.

3. SHINGLE BLOW OFF EXPERIMENT

In coordination with OCF representative Glenn Lamb, an experiment was designed to test the wind damage and blowoff characteristics of shingles including a somewhat more realistic test procedure than has been standard in the past. Two major elements were changed in the test procedure: 1) the entire shingled test panel was enveloped in a turbulent flow to improve the way in which the wind flowed over the shingles, and 2) the tests were run at two temperatures, 75°F and 35°F, to observe the influence of ambient temperature. Enveloping the test panel in the flow eliminated the unrealistic flow in previous tests in which a jet was directed at close range onto a specific course of shingles. The improved flow cannot, however, be considered to be completely representative of full-scale flow conditions. Section 5 addresses this point in more detail. Because field experience has indicated that cold shingles were more susceptible to wind damage than room temperature shingles, probably due to increased shingle brittleness, 35°F tests were included with the expectation of higher damage rates at the lower temperature. Shingles tested were standard, three tab, seal down asphalt covered with ceramic granules in various colors having organic and fiberglass felt bases. In addition to OCF shingles from several production plants a few tests were made with competitive shingles.

Decks measuring 36 x 48 in. with a 5/8 in. A-C plywood surface on a frame of 2 x 4 in. lumber, Figure 1, were prepared and shingled under the supervision of the OCF representative. Completed shingle decks were placed in the 5.5 x 5.5 m section of the wind tunnel immediately downstream of the heat exchanger so they would be at the tunnel operating temperature (75°F or 35°F) when they were installed for testing. Care was taken to avoid shingles sealing together so that each test would represent the worst case.

Decks were mounted on a support frame, Figure 2, at the downstream end of the Meteorological Wind Tunnel (MWT), Figures 3 and 4, on a turntable which permitted them to be rotated for yaw angles of 0° and 45°. The support frame held them at a pitch of 4 in 12 and permitted each deck to be held with carriage bolts and wing nuts to permit rapid change.

A copper-constantan thermocouple was inserted under the fourth course of shingles to measure the shingle temperature and a second thermocouple was mounted nearby to give the air temperature. These were connected to a Brown-Honeywell temperature indicator. Air temperature was also recorded at the upstream end of the test section. Figure 5 shows typical traces of the control room tracings during both low and room temperature runs.

Temperature variations (32°F to 43°F) during successive low temparature runs were virtually identical (Figure 5a). Temperatures of the thermocouple imbedded in the deck itself showed a rise during the runs from 33°F to 41°F. Air temperature at the testing position varied from 35°F to 43°F. Differences between temperatures at the deck and those measured at the stilling chamber just upstream of the test section were consistent with the expected heat gain of the air as it moved down the test section and farther from the heat exchanger.

Control of the temperature for the 75°F runs was less regular. Because the laboratory temperature was slightly less than the desired test temperature, some heating was required at the lower speeds. As soon as the energy input from the fan caused the air temperature to exceed 75°F, the controls would switch abruptly to cooling which gave a rather sudden drop in temperature. When the machine controls switched to heating, the temperature would rise equally rapidly. Temperatures varied from 66°F to 81°F and the pattern was somewhat erratic (Figure 5b).

Velocity was measured with a pitot-static tube mounted just upstream of the test position and connected to an MKS electronic differential pressure meter. The velocity in feet per second (fps) was obtained from the following formula:

$$U = 54\sqrt{\Delta p}$$

U = fps, Δp = differential pressure in mm Hg.

Table 1 gives the conditions and time duration for each test run. By the use of these times, two runs could be recorded on a single hour-long TV cassette tape.

Table 1. Test Conditions for Each Test Run

Elapsed Time	Δp	ft/sec	mi/hr
00	0.66	44	30
01	1.18	59	40
03	1.84	73	50
08	2.66	88	60
13	3.62	103	70
18	4.72	117	80
23	Stop wind & permit shingles to relax for several minutes		
25	Enter tunnel, inspect deck, take pictures, describe damage, etc.		
29-30	End test		

No attempt was made to write down tables of data as the tests progressed. Rather each run was recorded on 3/4 in. TV cassette tapes using a JVC camera with a Sony recorder and monitor. Time from the start of each run and the Δp, in mm Hg, appear in a corner of the TV screen. A commentary was added at appropriate moments during each run and during an examination of the shingle deck after each run. Still photographs in both black and white and color slides were made of the whole deck and details as appropriate at the end of each run. Still photographs were not made for runs 1 through 9.

The test program, comprising 53 runs, is listed in Table 2. Each deck had a 4-part label for identification. The label was visible in the videotape. The label indicated the run sequence number, the nominal ambient temperature in degrees Fahrenheit, the shingle manufacturing location and type, and the repeat number for a particular sample of shingle. A yaw angle of 0 degrees indicated approach wind normal to the shingle courses; a yaw angle of 45 degrees indicated an approach wind at 45 degrees to the shingle courses.

At the conclusion of the test runs, mean velocity and turbulence intensity profiles were obtained at 6 locations on the centerline of the wind tunnel for the 0 degree yaw angle case to document the flow characteristics. Profile locations are shown in Figure 6. Profiles are shown in Figure 7 and are listed in Table 3. The approach flow in the wind tunnel had a turbulent boundary-layer about 20 inches thick with a uniform flow of about 2 percent turbulence intensity above that level. Turbulence intensity is defined as the root mean square of the along-wind velocity fluctuations about the mean velocity divided by the local mean velocity. Profile C shows a flow deceleration immediately in front of the shingle deck. Profiles over the top of the shingle deck, D-F, show a local boundary-layer on the deck developing from about ½ in. at D to almost 3 in. at location F. No evidence of flow separation on the deck surface was observed in the velocity profiles.

Table 2. Test Program

Run #	Air Temp.	Deck Label	Yaw Angle	Date Completed
1.	35°F	1-35-JAX STD-1	0°	12-2-82
2.	"	2-35-ORGANIC-1	"	"
3.	"	3-35-DEN IMP-1	"	"
4.	"	4-35-JAX STD-2	"	"
5.	"	5-35-DEN IMP-2	"	"
6.	"	6-35-ORGANIC-2	"	"
7.	"	7-35-DEN IMP-3	"	"
8.	"	3-35-ORGANIC-3	"	"
9.	"	9-35-JAX STD-3	"	"
10.	75°F	10-75-DEN IMP-4	"	12-3-82
11.	"	11-75-ORGANIC-4	"	"
12.	"	12-75-JAX STD-4	"	"
13.	"	13-75-ORGANIC-5	"	"
14.	"	14-75-JAX STD-5	"	"
15.	"	15-75-DEN IMP-5	"	"
16.	"	16-75-JAX STD-(6)	45°	12-6-82
17.	"	17-75-DEN IMP-(6)	"	"
18.	"	18-75-ORGANIC-(6)	"	"
19.	"	19-75-DEN IMP-(7)	"	"
20.	"	20-75-JAX STD-(7)	"	"
21.	"	21-75-ORGANIC-(7)	"	"
22.	35°F	22-35-JAX STD-(8)	"	12-7-82
23.	"	23-35-DEN IMP-(8)	"	"
24.	"	25-35-JAX STD-(9)	"	"
25.	"	25-35-ORGANIC-(8)	"	"
26.	"	26-35-ORGANIC-(9)	"	"
27.	"	27-35-DEN IMP-(9)	"	"
28.	"	28-35-JAX STD-(10)	"	"
29.	"	29-35-ORGANIC-(10)	"	"
30.	"	30-35-DEN IMP-(10)	"	"
31.	"	31-35-WALTHAM-1	0°	12-9-82
32.	"	32-35-BRKVLLE STD-1	"	"
33.	"	33-35-JESSUP-1	"	"
34.	"	34-35-ORGANIC-1	"	"
35.	"	35-35-WALTHAM-2	"	"
36.	"	36-35-DEN STD-1	"	"
37.	"	37-35-BRKVLLE STD-2	"	"
38.	"	38-35-JESSUP-2	"	"
39.	"	39-35-MEDINA-1	"	"
40.	"	40-35-WALTHAM-3	"	"
41.	"	41-35-BRKVLLE P-1	"	"
42.	"	42-35-JM-1	"	12-10-82
43.	"	43-35-ATLANTA-1	"	"
44.	"	44-35-ATLANTA-2	"	"
45.	"	45-35-TAMKO-1	"	"
46.	"	46-35-JM-2	"	"
47.	"	47-35-ELK-1	"	"

Table 2 (continued).

Run #	Air Temp.	Deck Label	Yaw Angle	Date Completed
48.	"	48-35-GAF-1	"	"
49.	75°F	49-75-WALTHAM-4	0°	12-13-82
50.	"	50-75-JESSUP-3	"	"
51.	"	51-75-BRKVLLE STD-3	"	"
52.	"	52-75-WALTHAM-5	"	"
53.	"	53-75-BRKVLLE STD-4	"	"

Note: Run 49 was inadvertently erased on the TV tape and is documented only in the still pictures.

Table 3. Velocity Profile Printouts

RESULTS FOR PROFILE - P5470A DEC 14, 1982

REFERENCE VELOCITY = 31.45 FPS

EXPONENT = .1133 LOG INTERCEPT = 1.333
RMS ERR = 3.5%U(HMAX) MAX ERR = 6.3%U(HMAX)
HREF = 49.96 IN U(HREF) = 33.55
HMAX = 49.96 IN U(HMAX) = 33.55

DATA POINT	HEIGHT IN	UMEAN FPS	U-RMS FPS	TURB INT PERCENT
1	2.00	22.18	2.391	10.79
2	3.99	24.13	2.203	9.13
3	6.01	25.92	2.180	8.41
4	7.99	27.33	1.891	6.92
5	10.06	28.52	1.672	5.86
6	12.01	29.66	1.510	5.09
7	14.05	30.66	1.211	3.95
8	16.05	31.32	.885	2.83
9	18.01	31.66	.546	1.72
10	22.03	31.79	.277	.87
11	25.98	31.77	.247	.78
12	30.00	31.72	.245	.77
13	33.95	31.69	.241	.76
14	38.01	31.76	.242	.76
15	41.99	31.81	.271	.85
16	45.98	31.86	.345	1.08
17	49.96	31.45	.818	2.60

RESULTS FOR PROFILE - P5470B DEC 14, 1982

REFERENCE VELOCITY = 32.22 FPS

EXPONENT = .1478 LOG INTERCEPT = 1.278
RMS ERR = 2.2%U(HMAX) MAX ERR = 4.7%U(HMAX)
HREF = 50.01 IN U(HREF) = 33.81
HMAX = 50.01 IN U(HMAX) = 33.81

DATA POINT	HEIGHT IN	UMEAN FPS	U-RMS FPS	TURB INT PERCENT
1	2.00	19.97	2.785	13.95
2	4.00	23.06	2.262	9.81
3	6.02	24.69	2.341	9.48
4	8.06	25.70	2.134	8.31
5	10.01	27.13	2.009	7.41
6	12.03	28.15	1.795	6.38
7	14.00	29.00	1.632	5.63
8	16.03	29.54	1.413	4.78
9	18.02	30.15	.991	3.29
10	22.02	30.79	.432	1.40
11	26.01	30.93	.281	.91
12	30.01	31.26	.263	.84
13	34.02	31.62	.259	.82
14	37.96	32.01	.263	.82
15	41.98	32.37	.294	.91
16	45.97	32.56	.406	1.25
17	50.01	32.22	.986	3.06

Table 3 (continued).

RESULTS FOR PROFILE - P5470C DEC 14, 1982

REFERENCE VELOCITY = 39.91 FPS

EXPONENT = .1180 LOG INTERCEPT = 1.342
RMS ERR =18.1%U(HMAX) MAX ERR =41.5%U(HMAX)
HREF = 48.08 IN U(HREF) = 34.68
HMAX = 48.08 IN U(HMAX) = 34.68

DATA POINT	HEIGHT IN	UMEAN FPS	U-RMS FPS	TURB INT PERCENT
1	2.00	27.31	2.635	9.65
2	4.00	29.49	2.179	7.39
3	6.05	30.98	2.039	6.58
4	8.04	32.11	1.911	5.95
5	10.01	30.97	1.813	5.85
6	12.05	29.16	1.535	5.27
7	14.01	24.59	1.235	5.02
8	15.95	18.03	1.014	5.63
9	17.95	16.48	1.003	6.08
10	22.02	25.65	.527	2.05
11	26.03	35.05	.372	1.06
12	30.00	37.67	.314	.83
13	33.98	38.60	.314	.81
14	37.97	39.29	.303	.77
15	42.04	39.67	.331	.83
16	46.00	39.91	.384	.96
17	48.08	40.04	.531	1.33

RESULTS FOR PROFILE - P5470D DEC 15, 1982

REFERENCE VELOCITY = 29.35 FPS

EXPONENT = .0350 LOG INTERCEPT = 1.417
RMS ERR = 2.5%U(HMAX) MAX ERR = 4.0%U(HMAX)
HREF = 9.99 IN U(HREF) = 28.29
HMAX = 9.99 IN U(HMAX) = 28.29

DATA POINT	HEIGHT IN	UMEAN FPS	U-RMS FPS	TURB INT PERCENT
1	.25	24.59	3.855	15.68
2	.50	26.61	1.121	4.21
3	.74	26.37	1.003	3.80
4	1.00	26.20	.789	3.01
5	1.50	25.93	.747	2.88
6	1.98	25.86	.637	2.46
7	2.96	26.29	.463	1.76
8	3.96	26.61	.339	1.27
9	6.00	27.61	.299	1.08
10	8.00	28.76	.240	.83
11	9.99	29.35	.232	.79

Table 3 (continued).

RESULTS FOR PROFILE - P5470E DEC 15, 1982

REFERENCE VELOCITY = 0.00 FPS

EXPONENT = .0452 LOG INTERCEPT = 1.452
RMS ERR = 2.3%U(HMAX) MAX ERR = 5.1%U(HMAX)
HREF = 10.00 IN U(HREF) = 31.43
HMAX = 10.00 IN U(HMAX) = 31.43

DATA POINT	HEIGHT IN	UMEAN FPS	U-RMS FPS	TURB INT PERCENT
1	.25	25.00	2.785	11.14
2	.51	27.52	2.074	7.54
3	.77	28.97	1.231	4.25
4	1.02	29.32	.807	2.75
5	1.53	29.59	.572	1.93
6	2.00	29.61	.568	1.92
7	3.00	29.88	.387	1.29
8	3.99	30.05	.328	1.09
9	5.97	30.29	.265	.87
10	8.01	30.62	.248	.81
11	10.00	30.89	.234	.76

RESULTS FOR PROFILE - P5470F DEC 15, 1982

REFERENCE VELOCITY = 33.68 FPS

EXPONENT = .0593 LOG INTERCEPT = 1.500
RMS ERR = 5.6%U(HMAX) MAX ERR = 9.7%U(HMAX)
HREF = 9.96 IN U(HREF) = 36.24
HMAX = 9.96 IN U(HMAX) = 36.24

DATA POINT	HEIGHT IN	UMEAN FPS	U-RMS FPS	TURB INT PERCENT
1	.25	25.61	3.254	12.71
2	.53	29.53	3.026	10.25
3	.79	32.57	2.351	7.22
4	1.04	34.36	1.408	4.10
5	1.54	35.05	.572	1.63
6	2.03	35.07	.496	1.41
7	3.01	34.96	.357	1.02
8	4.01	34.71	.310	.89
9	5.99	34.28	.276	.80
10	7.99	33.98	.268	.79
11	9.96	33.68	.266	.79

4. RESULTS OF THE TESTS

The videotapes of test runs were given to OCF for their detailed analysis of the results. Presented here are some typical results as documented with still photographs and detailed comments of videotape results by the OCF representative. Results ranged from tabs bent up with little damage to the tabs, Figure 8 top, to nearly complete blow off, Figure 8 bottom.

Damage to bent shingles ranged from minimal to severe. Cracking was observed on both top and bottom surfaces particularly on organic shingles, Figure 9. Staple pull through was a common mode of damage, Figure 10 top, in which the staple remained in position while the top shingle pulled up. Pull throughs were often accompanied by tearing of the shingle, Figure 10 top and bottom, with or without blow off of a portion of a shingle. Pull through at one location permitted more local deformation of the shingle which in turn resulted in higher wind forces on that portion of the shingle. As a result, pull through at an adjacent staple often resulted.

Wind damage to shingles was reasonably consistent from run to run with repeat measurements of decks with similar shingles behaving in a similar way. Differences between shingle types were evident at both 75°F and 35°F with damage generally occurring for lower wind speeds at the colder condition. Figures 11a and b show post-run photographs of decks with four different shingle types at 75°F and 0° yaw. One sample shows considerable damage while the other three had differing degrees of crack damage. Decreasing severity of damage was usually associated with increased quality of shingle. These photographs were made before the shingles had relaxed back to the surface. Figures 12a and b show typical post-test results for four different shingles at 35°F and 0° yaw. Significantly more damage was evident for the low temperature case as compared to the room temperature case.

The remainder of the analysis of data runs is contained in a discussion of results which were obtained from a detailed review of the videotapes by Mr. Glenn Lamb, the OCF representative. His comments are reproduced in the Appendix in full for completeness of this report.

5. DISCUSSION OF THE FLUID MECHANICS OF SHINGLE BLOW OFF

Observation of shingle blow off experiments in combination with velocity measurements, flow visualization experiments (discussed below) and the authors' previous experience in analyzing fluid flows provided some understanding of the fluid mechanical forces at work in shingle uplift and blow off.

Flow visualization provided a direct observation of the flow field characteristics. Titanium dioxide smoke was released from sources in the flow field to provide a marker for fluid passing the release point. Figure 13 top shows smoke being released from sources at two elevations just in front of a shingled deck at 0° yaw (front edge of the deck normal to the approaching flow) with wind velocity below the level where shingle lifting occurs. The upper smoke trace is deflected up and over the deck without contacting the deck surface. The lower smoke trace was placed so that it would impinge on the front edge of the shingle deck. This flow is seen to separate, or detach, slightly from the top of the deck as it rounds the corner onto the top of the deck and to reattach to the deck a short distance from the leading edge. A careful examination of the separation region showed it to be 1/16 or 1/8 of an inch in thickness and an inch or so in length. A different deck geometry would have produced a different size of separation region.

Separated flow regions are commonly found in wind flows about buildings or other bluff bodies. These separated flow regions may be quite small in extent with the flow reattaching to the body surface downwind or may be quite large with the separation streamline never returning to the body. Flow within the separation region, often called a separation bubble, is of much lower velocity than the flow outside the bubble and is in the opposite direction to the outer flow near the body surface. The local pressure on the body under a separated flow is negative, or outward acting, tending to pull the surface out toward the flow. In the case of the separated flow above the leading edge of the shingle deck, this upward acting pressure will tend to lift the lead shingle. As wind velocity increases, the uplift force will increase roughly as the square of the approach velocity until the uplift is sufficient to lift the shingle. The local pressure on the shingle surface of the test panel behind the separation/reattachment area should be positive, or tending to hold the shingles down. On a full-scale structure, the areas of negative pressure associated with flow separation will be much larger due to the presence of side walls which will increase the area coverage and intensity of uplift pressure within the separated region; in some cases the entire roof is enveloped in uplift pressures.

Once the front shingle has lifted due to the pressures described above, the separated flow region is greatly increased in extent and intensity of uplift pressure as shown in the flow visualization photograph of Figure 13 bottom. Reattachment did not occur until the 3rd or 4th course. Flow impinging on the upward side of the uplifted shingle provides a positive pressure which adds to the uplift negative pressure on the top side of the shingle. Only the stiffness of the shingle prevents the shingle from folding over completely since aerodynamic forces on both top and bottom of the shingle are tending to force it up.

The mean pressures on the shingle deck from the fourth course up in the bottom photograph of Figure 13 could be either positive (downward acting) or negative (upward acting). Turbulence developed in the separated shear layer (the thin region of high velocity gradient between the high speed separated flow and the low speed bubble) combined with turbulence in the approach flow may induce a fluctuation about the mean pressure sufficiently large that at any location on the rear of the deck the pressure oscillates in time between positive and negative pressures. As approach velocity is further increased, a negative pressure fluctuation on a shingle in that region will become sufficiently large that it will lift the shingle. That lifted shingle would then be subject to the same aerodynamic forces as the first shingle and would tend to remain in a raised position.

Pressures under the separated flow bubble in the lower photograph of Figure 13 are negative and, except near the actual separation point, of fairly low magnitude. This low negative pressure is of insufficient size to lift additional shingles under the bubble.

The mechanism for shingle uplift is illustrated in Figure 14 in which a sequence of photographs shows shingle uplift patterns at every 10 mph wind speed from 30 to 80. Initially the first course is raised (30 mph) and bent backwards (40, 50 mph). At 40 and 50 mph the separated shear layer probably does not reattach until the 5th or 6th course. By 60 mph, the first course of shingles has bent back sufficiently to permit an earlier reattachment of the shear layer. This in combination with larger pressure fluctuations due to the higher wind speed resulted in shingle uplift in the 5th and 6th courses. By 70 and 80 mph, the uplift pressures have increased on the 4th course sufficiently to lift shingles there. The lifting mechanism described above may be somewhat simplified from the actual mechanisms at work.

A useful exercise would be to estimate the wind pressures on an uplifted shingle. The easiest case is probably the 30 mph wind speed shown in Figure 14. The first course is lifted so that it is nearly normal to the approach flow. The velocity profiles of Figure 8 indicate that the velocity approaching the leading edge is nearly the same as that measured at the reference velocity location, 30 mph. At 30 miles per hour at an elevation of approximately 5000 ft (the laboratory elevation) the stagnation pressure of the wind, $0.5\ \rho V^2$, is about 2.0 psf. The drag coefficient for the uplifted shingle might be in the range of 1.3-1.8 (based on the authors' previous experience in measuring drag coefficients) resulting in a net pressure acting on the shingle of 2.6 to 3.6 psf. If the exposed area of the shingle subject to this pressure is 5 x 12 in., then the force on each uplifted tab is 1.1 to 1.5 lb. The drag coefficient for this case is in some doubt, so the forces could be somewhat outside the range calculated. For higher wind speeds, the drag coefficient for the bent shingles would only be a guess. At 80 mph, if a drag coefficient of 0.5 is assumed for the first course of shingles, the net pressure on the lead shingle would be about 7.0 psf resulting in a net force of about 2.9 lb acting normal to the shingle surface.

When the deck was oriented at 45 degrees to the approach flow, a somewhat different flow mechanism was involved. Figure 15a top shows smoke flow across the shingle surface at a wind speed too low to lift a shingle. A small separation/reattachment zone was observed at the leading edge as before. This separated zone, however, had a stronger circulation within the bubble. A similar zone was observed along the upwind side edge. Although of very small extent on the deck, this separation/reattachment zone is analogous to the classical delta wing vortex observed on aircraft. On a full-scale house with side walls, the upward flow at the roof edge rolls up into a delta wing type vortex of greater strength and larger roof area than observed for this study where the deck had no sidewalls below it. As wind speed was increased across the deck, the first course of shingles rose due to similar forces as for the 0° yaw case. The lower photograph of Figure 15a shows the flow with shingle raised. A very strong vortex was observed. This vortex would be expected to increase wind pressures on the shingle. For the same wind speed, the wind flow over the top of the vortex is shown in Figure 15b top. This flow impinges on shingles downstream tending to hold them down. The area on the middle left of the bottom photograph of Figure 15b is the area of flow impingement seen in the top photograph. Shingle uplift was not observed in this region.

The smoke visualization for both the 0° and 45° yaw showed wind flow patterns with similar structure, but not always similar magnitude, to those observed about full-scale buildings and about model buildings in a boundary-layer wind tunnel which simulates natural winds. The mechanisms for shingle uplift and damage are thus probably similar to those acting on full-scale structures. Because of the differences in magnitude, the wind speeds at which damage occurred in the wind tunnel may not be directly related to wind speeds in the full-scale for similar damage. Relative performance of one shingle in comparison to another in the wind tunnel, however, should be similar to full-scale experience.

6. RECOMMENDATIONS FOR FURTHER WORK

Testing accomplished during this study showed that wind-tunnel evaluation of shingle performance is a consistent technique which can differentiate between shingles whose wind resistance in the prototype is expected to be different. It can thus be used as a tool for product development.

Additional wind-tunnel testing could improve product development capability in two ways. First, further development of the current testing procedure could improve similarity in flow structure between the test deck and full scale so that better prediction of shingle performance could be obtained. Second, a series of more basic studies could be undertaken to determine actual uplift forces on shingles and relate those forces to site wind conditions, building geometry, building orientation and influence of nearby structures. This latter program might lead to risk prediction charts for individual buildings at different sites. This program might also identify load reduction schemes to inexpensively reduce shingle damage at vulnerable locations on roofs.

REFERENCES

1. Eaton, K. J. and J. R. Mayne, "The Measurement of Wind Pressures on Two-Storey Houses at Aylesbury," Building Research Establishment Current Paper, CP 70/74, July 1974.

2. Eaton, Keith J., John R. Mayne, and Nicholas J. Cook, "Wind Loads on Low-Rise Buildings - Effects of Roof Geometry," Proceedings of the 4th International Conference on Wind Effects on Buildings and Structures, Heathrow, 1975.

3. Eaton, K. J., J. R. Mayne, and N. J. Cook, "Wind Loads on Low-Rise Buildings - Effects of Roof Geometry," Building Research Establishment Current Paper, CP 1/76, January 1976.

4. Marshall, R. D., "A Study of Wind Pressures on a Single-Family Dwelling in Model and Full Scale," National Bureau of Standards Technical Note 852, October 1974, 40 p.

5. Marshall, Richard D., "The Measurement of Wind Loads on a Full-Scale Mobile Home," prepared for Division of Energy, Building Technology and Standards, Office of Policy Development and Research, Department of Housing and Urban Development, Washington, D.C., NBSIR 77-1289, September 1977.

6. Mehta, Kishor C. and Soo-Il Kim, "Wind Loads on Flat Roof Area through Full-Scale Experiment," prepared in cooperation with Division of Engineering, National Science Foundation, Institute for Disaster Research and Department of Civil Engineering, Texas Tech University, Lubbock, TX, September 1977.

7. Wells, D. A. and R. P. Hoxey, "Measurements of Wind Loads on Full-Scale Glasshouses," Jnl. of Wind Engineering and Indus. Aerodynamics, 6 (1980), pp. 139-167.

8. Chien, Ning, Yin Feng, Hung-Ju Wang, and Tien-To Siao, "Wind-Tunnel Studies of Pressure Distribution on Elementary Building Forms," Iowa Institute of Hydraulic Research, State University of Iowa, Iowa City, 1951.

9. Howe, J. W., "Wind Pressure on Elementary Building Forms Evaluated by Model Tests," Civil Engineering, May 1952, pp. 330-334.

10. Leutheusser, Hans J., "Influence of Architectural Features on the Static Wind Loading of Buildings," in Proceedings of Technical Meeting Concerning Wind Loads on Buildings and Structures, Building Science Series 30, November 1970, 169 p.

11. Kelnhofer, Wm. J., "Influence of a Neighboring Building on Flat Roof Wind Loading," 3rd Int. Conf. on Wind Effects on Buildings and Structures, 1971, Tokyo.

12. Cermak, J. E., "Laboratory Simulation of the Atmospheric Boundary Layer," AIAA Jl., Vol. 9, September 1971.

13. Cermak, J. E., "Applications of Fluid Mechanics to Wind Engineering," A Freeman Scholar Lecture, ASME Jl. of Fluids Engineering, Vol. 97, No. 1, March 1975.

14. Cermak, J. E., "Aerodynamics of Buildings," Annual Review of Fluid Mechanics, Vol. 8, 1976, pp. 75-106.

15. Cermak, J. E. and K. J. Dreher, "Wind Pressures on a House Roof," U.S.-Japan Research Seminar on Wind Loads on Structures, Kyoto, Japan, 9-13 September 1974, CEP74-75JEC-KJD10.

16. Davenport, A. G., D. Surry, and T. Stathopoulos, "Wind Loads on Low Rise Buildings: Final Report of Phases I and II - Part 1 - Text and Figures," Boundary Layer Wind Tunnel Faculty of Engineering Science, The University of Western Ontario, London, Ontario, Canada, August 1977, second edition, November 1977, BLWT-SS8-1977.

17. Holmes, J. D. and R. J. Best, "Further Measurements on Wind Tunnel Models of the Aylesbury Experimental House," James Cook University of North Queensland, Wind Engineering Report 4/78, October 1978.

18. Tieleman, H. W. and T. A. Reinhold, "Wind Tunnel Model Investigation for Basic Dwelling Geometries," Department of Engineering Science and Mechanics, Virginia Polytechnic Institute and State University, Blacksburg, Virginia, VPI-E-76-8, May 1976.

19. Apperley, L., D. Surry, T. Stathopoulos, and A. G. Davenport, "Comparative Measurements of Wind Pressure on a Model of the Full-Scale Experimental House at Aylesbury, England," Jnl. of Industrial Aerodynamics, Elsevier Scientific Publishing Co., Amsterdam, The Netherlands, 1980.

20. Peterka, J. A. and J. E. Cermak, "Wind Pressures on Buildings--Probability Densities, Jl. Structural Division, ASCE, 101 (1975), pp. 1255-1267.

21. Stathopoulos, T., "PDF of Wind Pressures on Low Rise Buildings," Jl. Structural Division, ASCE, 106 (1980), pp. 973-990.

22. Melbourne, W. H., "Turbulence Effects on Maximum Surface Pressures--A Mechanism and Possibility of Reduction," Wind Engineering, Proceedings of the Fifth International Conference, J. E. Cermak ed., Pergamon Press, 1980.

23. Peterka, J. A., "Selection of Local Peak Pressure Coefficients for Wind Tunnel Studies of Buildings," to be presented at the Sixth International Conference on Wind Engineering, Gold Coast, Australia, March 1983.

24. Kind, R. J., "Estimation of Critical Wind Speeds for Scouring of Gravel or Crushed Stone on Rooftops," National Research Council Canada, Ottawa, Laboratory Technical Report, LTR-LA-142, January 1974.

25. Kind, R. J., "Wind Tunnel Tests on Some Building Models to Measure Wind Speeds at which Gravel is Blown Off Rooftops," National Research Council Canada, Ottawa, Laboratory Technical Report, LTR-LA-162, June 1974.

26. Kind, R. J., "Tests to Determine Wind Speeds for Scouring and Blowoff of Rooftop Gravel," in Proceedings of the Fourth International Conference on Wind Effects on Buildings and Structures, Keith J. Eaton editor, Cambridge University Press, Heathrow, 1975.

27. Kind, R. J. and R. L. Wardlaw, "Design of Rooftops Against Gravel Blow-Off," National Research Council Canada, Ottawa, NRC No. 15544, September 1976.

28. Kind, R. J., "Further Wind Tunnel Tests on Building Models to Measure Wind Speeds at which Gravel is Blown Off Rooftops," National Research Council Canada, Ottawa, Laboratory Technical Report, LTR-LA-189, August 1977.

29. Kind, R. J. and R. L. Wardlaw, "Model Studies of the Wind Resistance of Two Loose-Laid Roof-Insulation Systems," National Research Council Canada, Ottawa, Laboratory Technical Report, LTR-LA-189, May 1979.

30. Newberry, C. W. and K. J. Eaton, Wind Loading Handbook, Department of the Environment, H.M.S.O., London, 1974.

31. Scruton, Christopher and Cyril William Newberry, "On the Estimation of Wind Loads for Building and Structural Design," Proceedings, Institution of Civil Engineers, 25, Paper No. 6654, 1963.

32. Eaton, K. J. and J. B. Menzies, "Roofs, Roofing and the Wind," Building Research Establishment Current Paper, CP 75/74, August 1974.

33. Menzies, J. B., "Wind Damage to Buildings," Building, 35, August 27, 1971, pp. 67-76.

34. Marshall, R. D., "A Guide to the Determination of Wind Forces," presented at Regional Meeting on Development of Design Criteria and Methodology for Low-Rise/Low-Cost Buildings to Better Resist Extreme Winds, Center for Building Technology, Institute for Applied Technology, National Bureau of Standards, Washington, D.C.

35. Thom, H.C.S., "New Distributions of Extreme Winds in the United States," Jnl. of the Structural Division, ASCE, Vol. 94, No. ST7, Proceedings Paper 6038, July 1968, pp. 1787-1801.

36. Simiu, Emil, Michael J. Changery, and James J. Filliben, "Extreme Wind Speeds at 129 Stations in the Contiguous United States," NBS Building Science Series 118, National Bureau of Standards, March 1979.

37. Batts, E. M., M. R. Cordes, L. R. Russel, J. R. Shaver, and E. Simiu, "Hurricane Wind Speeds in the United States," NBS Building Science Series 124, National Bureau of Standards, 1980.

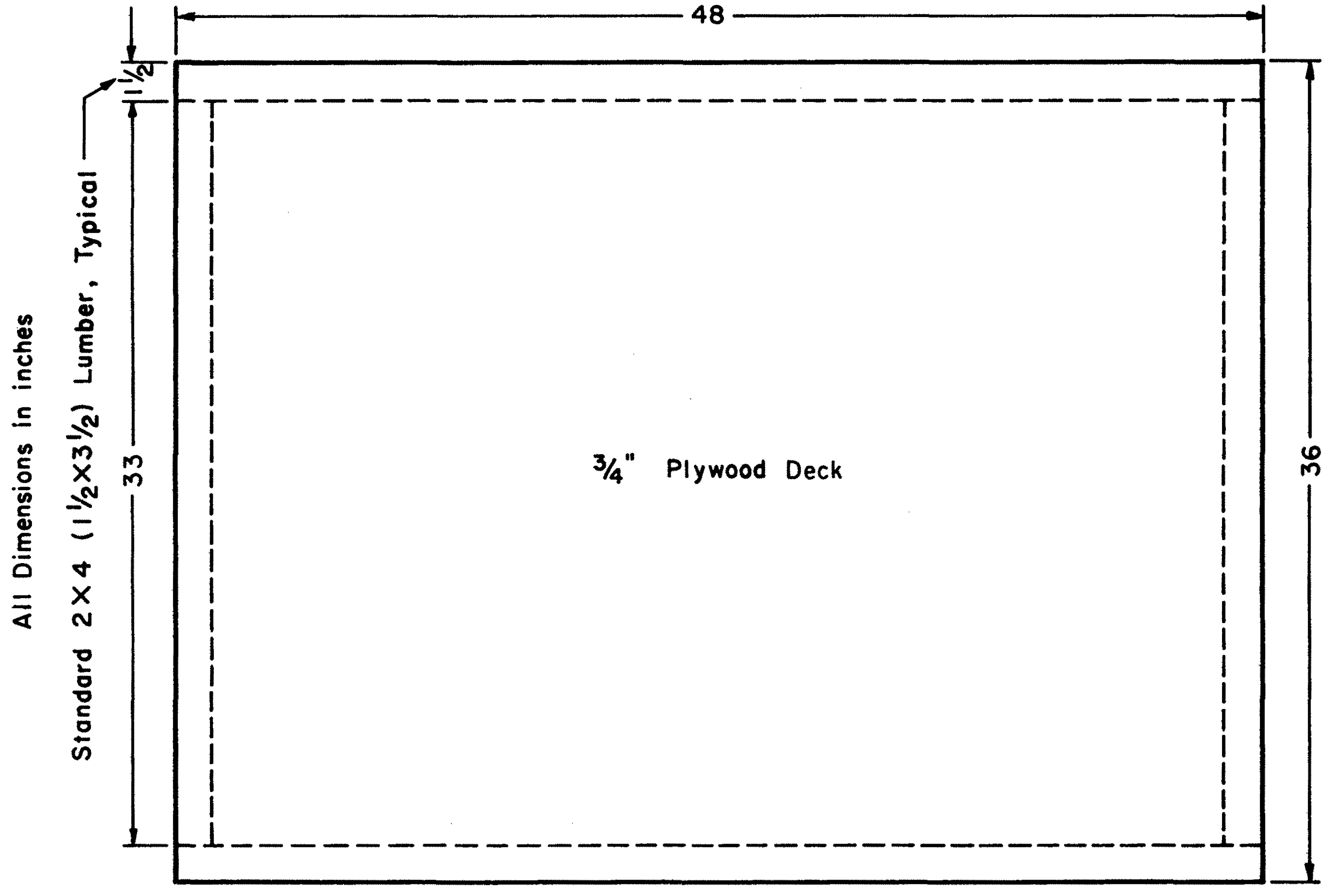
38. Kramer, C., H. J. Gerhardt, and H.-W. Kuster, "On the Wind-Loading Mechanism of Roofing Elements," presented at 3rd Colloquium on Industrial Aerodynamics, Aachen, June 14-16, 1978, Journal of Industrial Aerodynamics, 4(1979), pp. 415-427.

39. "Standard Test Method for Wind-Resistance of Asphalt Shingles," American National Standard, ANSI/ASTM D 3161-76.

40. Benjamin, I. A. and J. A. Bono, "Wind-Resistance Tests of Roof Shingles and Roof Assemblies," Engineering Properties of Roofing Systems, ASTM STP 409, Am. Soc. Testing Mats., 1967, p. 110.

41. Cullen, William C., "Wind Resistance of Asphalt Shingle Roofing," in New Building Research, Fall 1960.

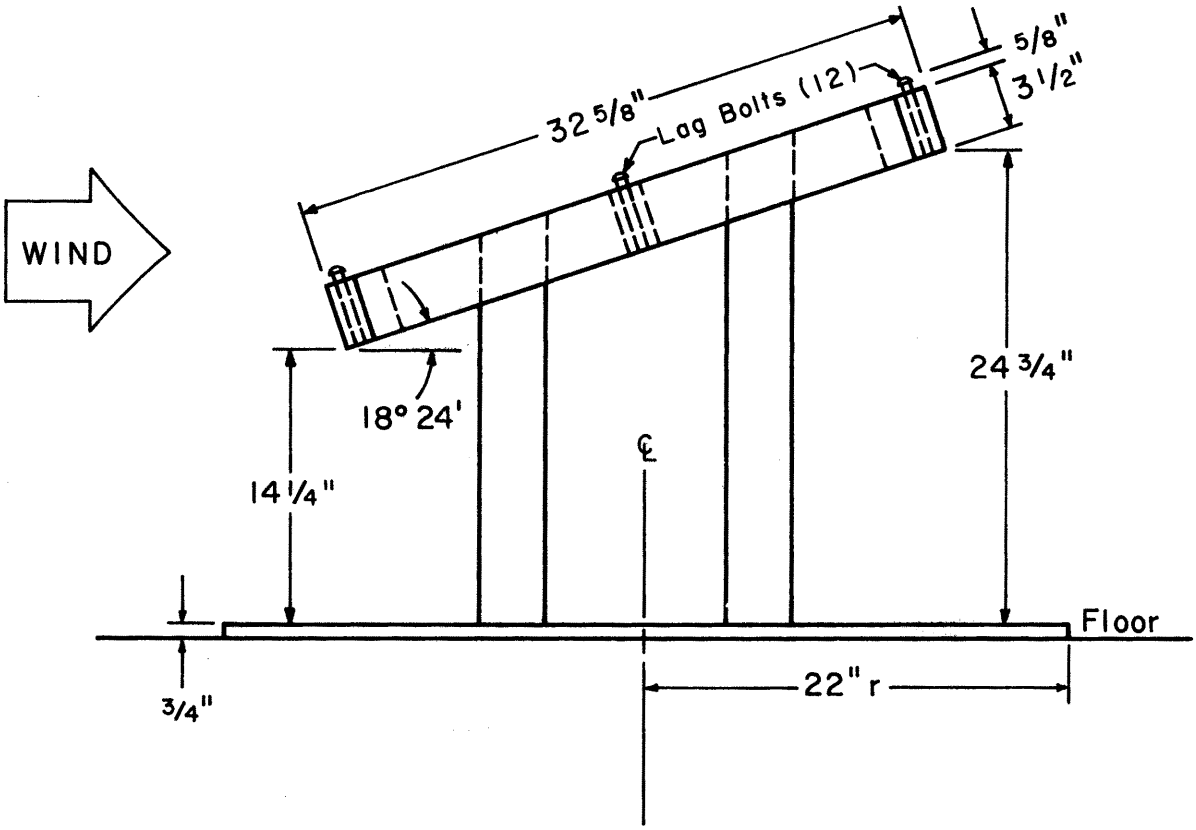
FIGURES



OWENS CORNING SHINGLE ROOF PANEL CONSTRUCTION

SCALE ~ 1 : 8

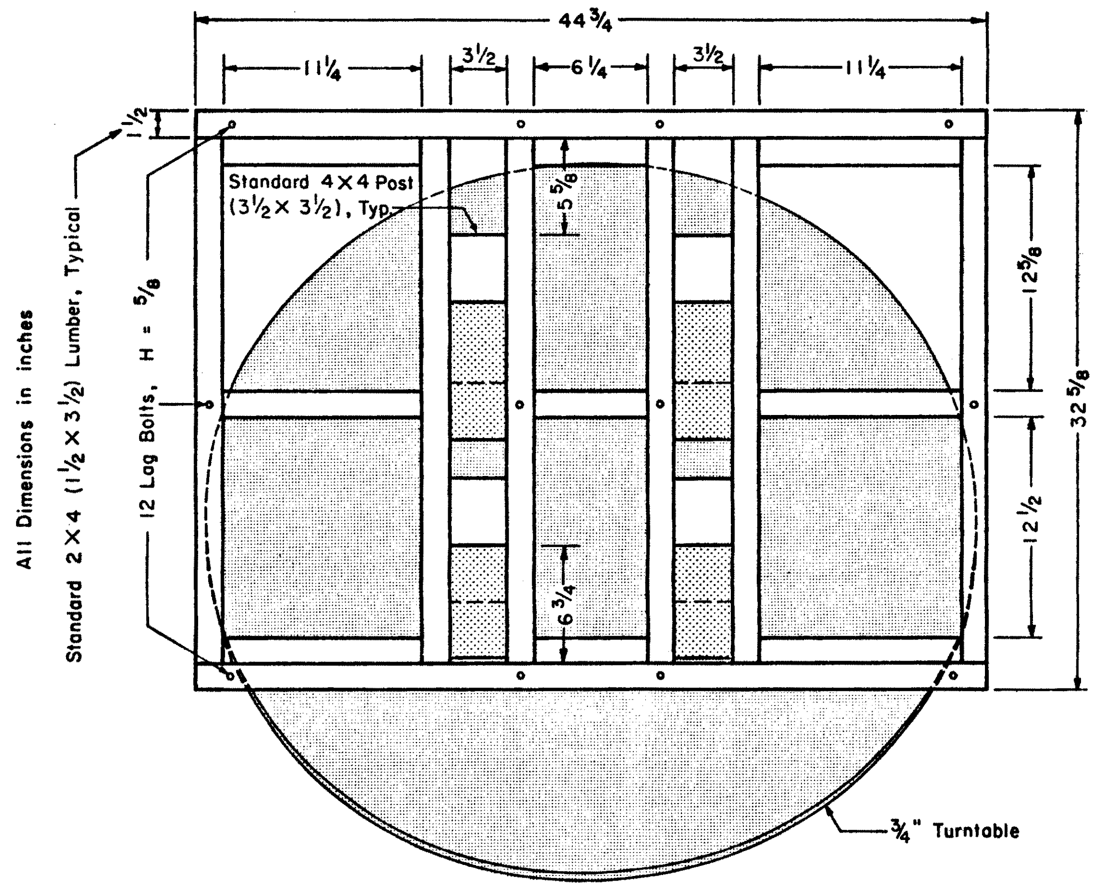
Figure 1. Construction Details for Shingle Test Decks



SIDE VIEW, TEST STAND

Stand Constructed of 1 1/2" X 3 1/2" Lumber and 3 1/2" Square Posts.

Figure 2a. Test Stand to Support Shingle Decks



OWENS-CORNING SHINGLE TEST STAND CONSTRUCTION

SCALE ~ 1 : 8

Figure 2b. Test Stand to Support Shingle Decks

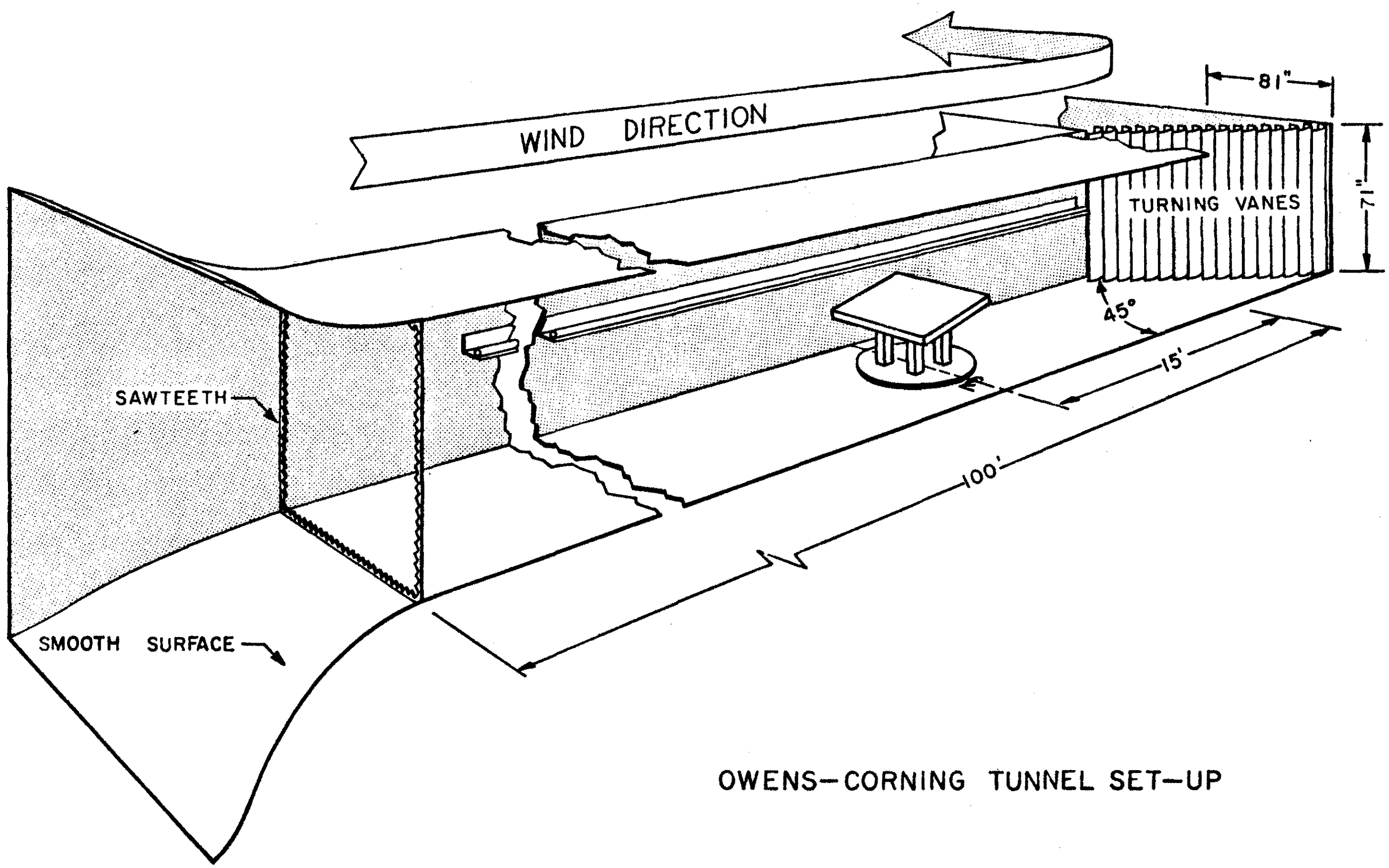
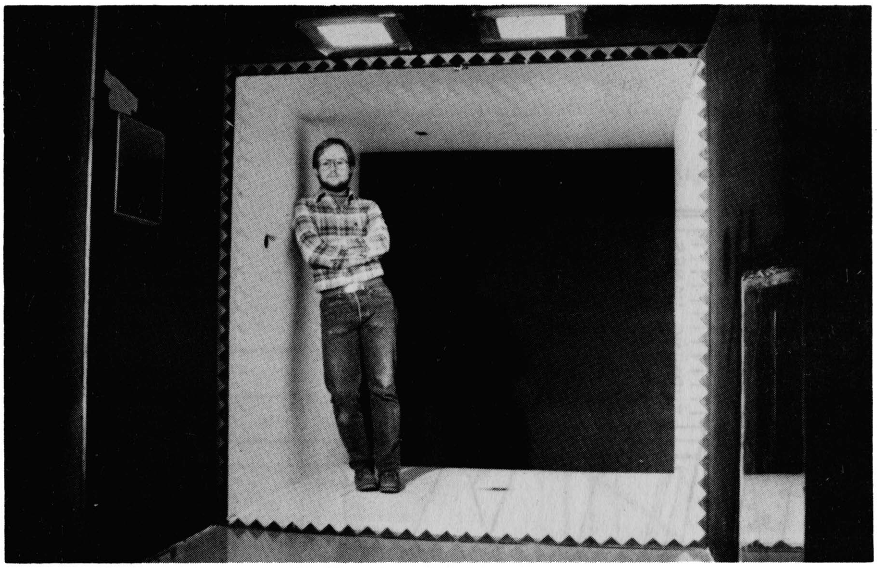
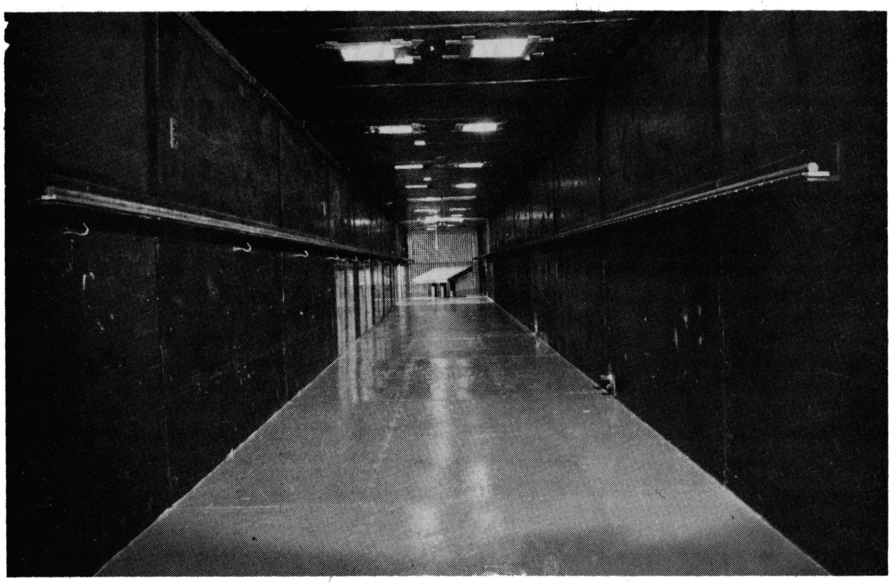


Figure 3. Wind-Tunnel Configuration for Shingle Tests

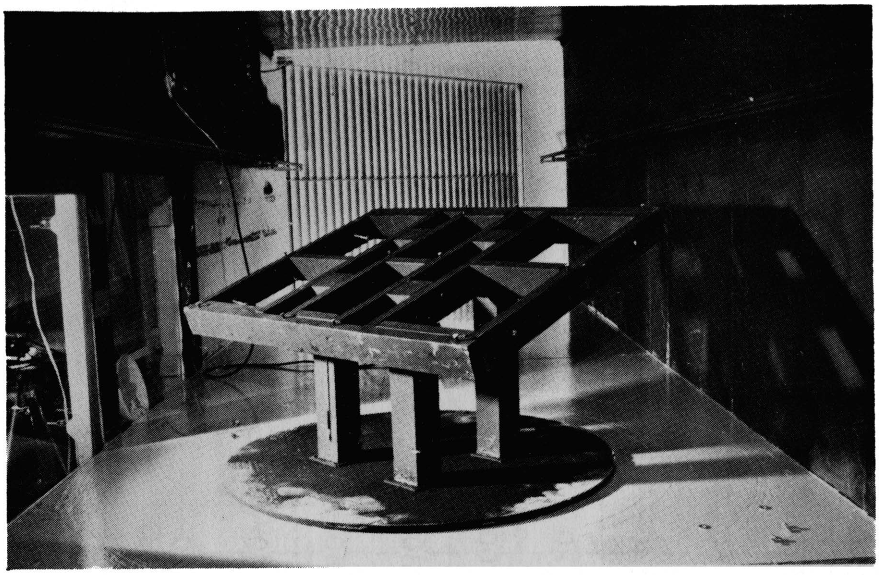


Test Section Entrance Looking Upwind

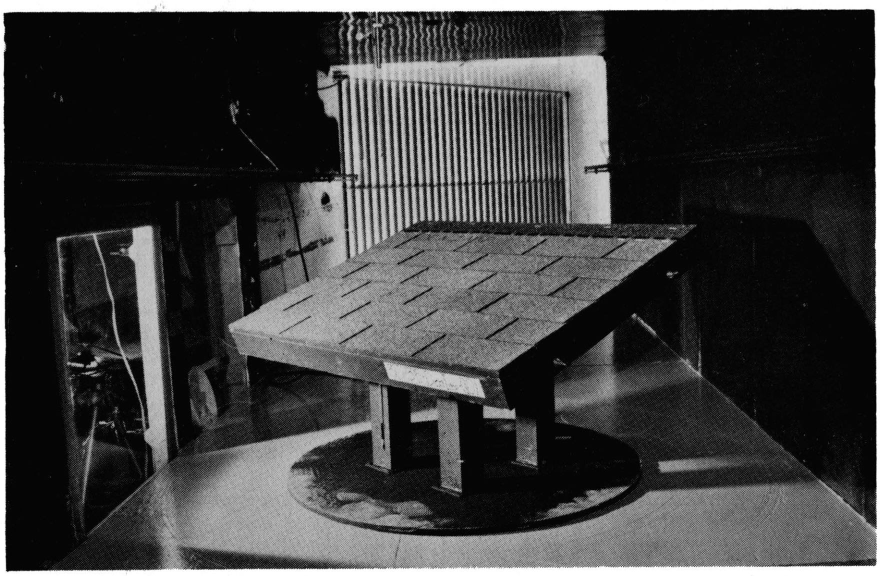


Test Section Looking Downwind

Figure 4a. Photographs of Test Configuration



Test Stand without Shingle Deck



Test Stand with Shingle Deck at Yaw = 45 Degrees

Figure 4b. Photographs of Test Configuration

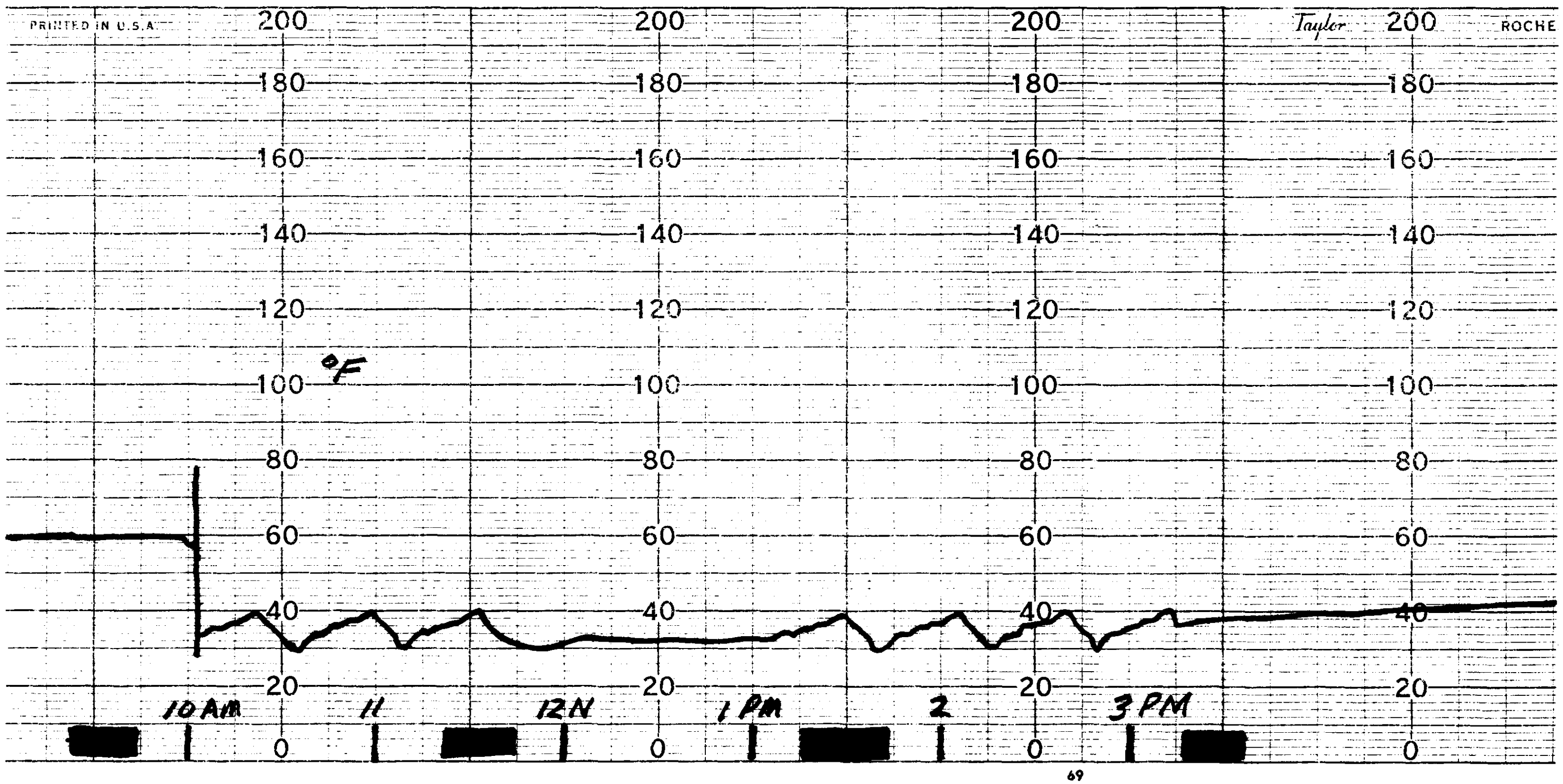


Figure 5a. Typical Temperature Record for Cold Test

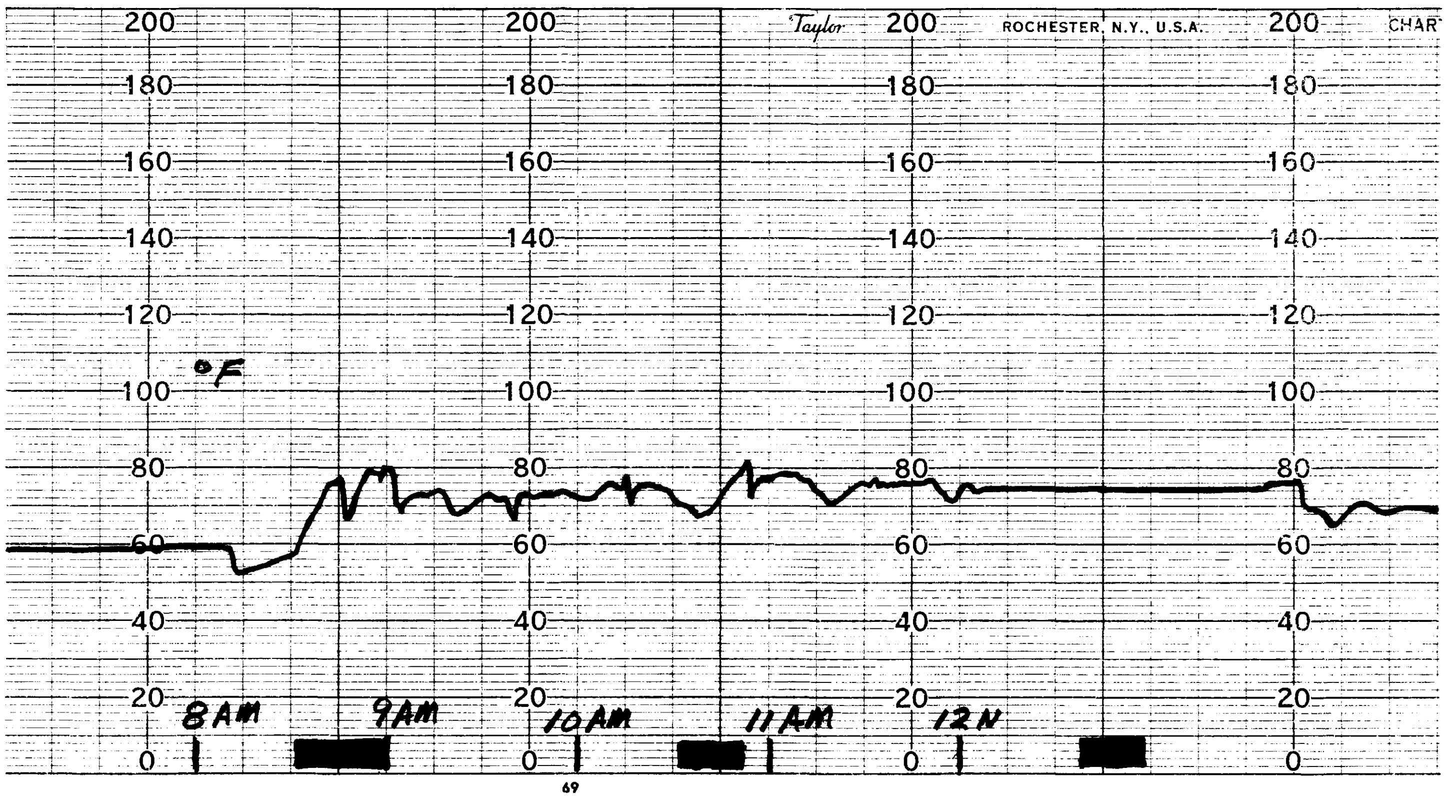


Figure 5b. Typical Temperature Record for Room Temperature Test

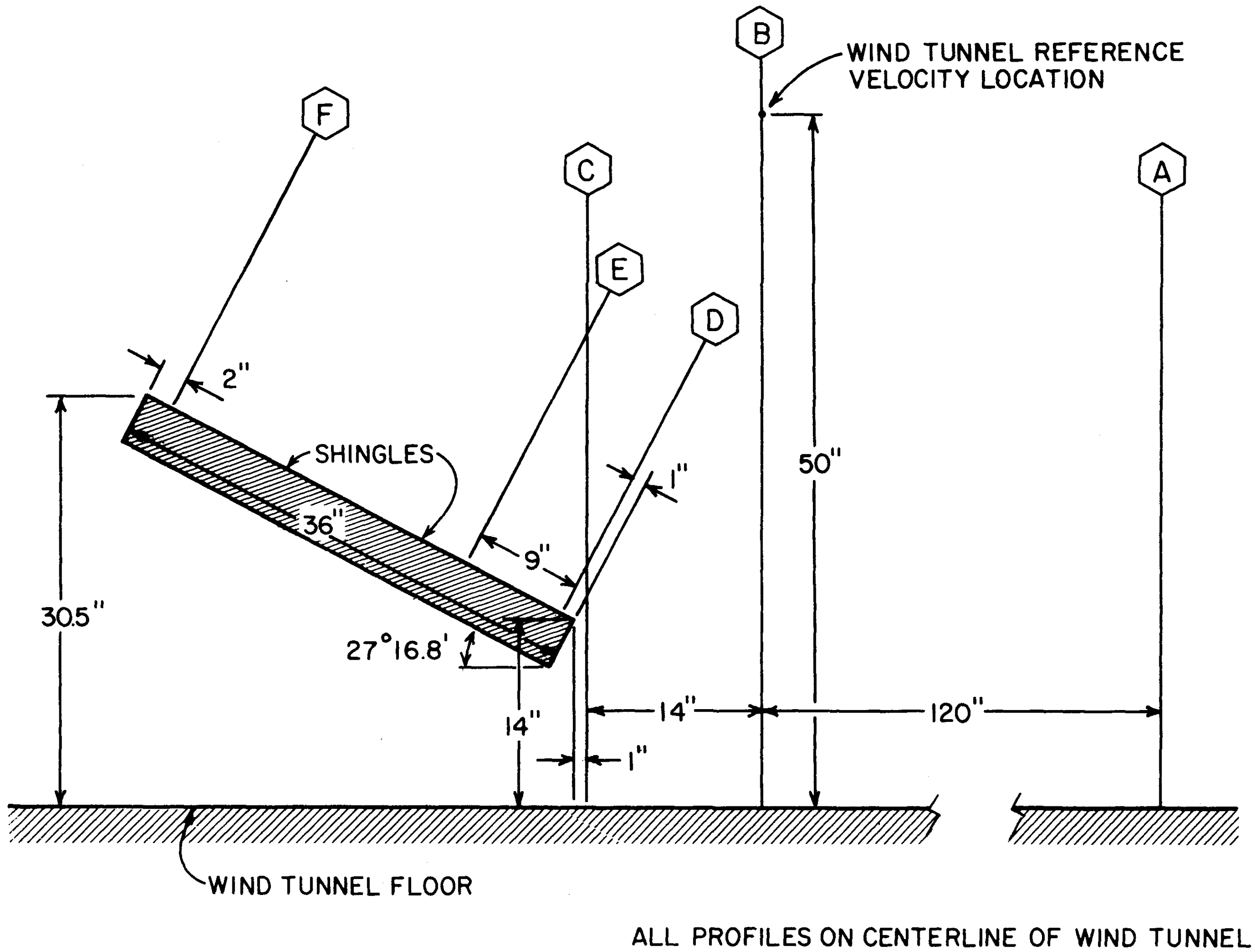


Figure 6. Velocity Profile Locations

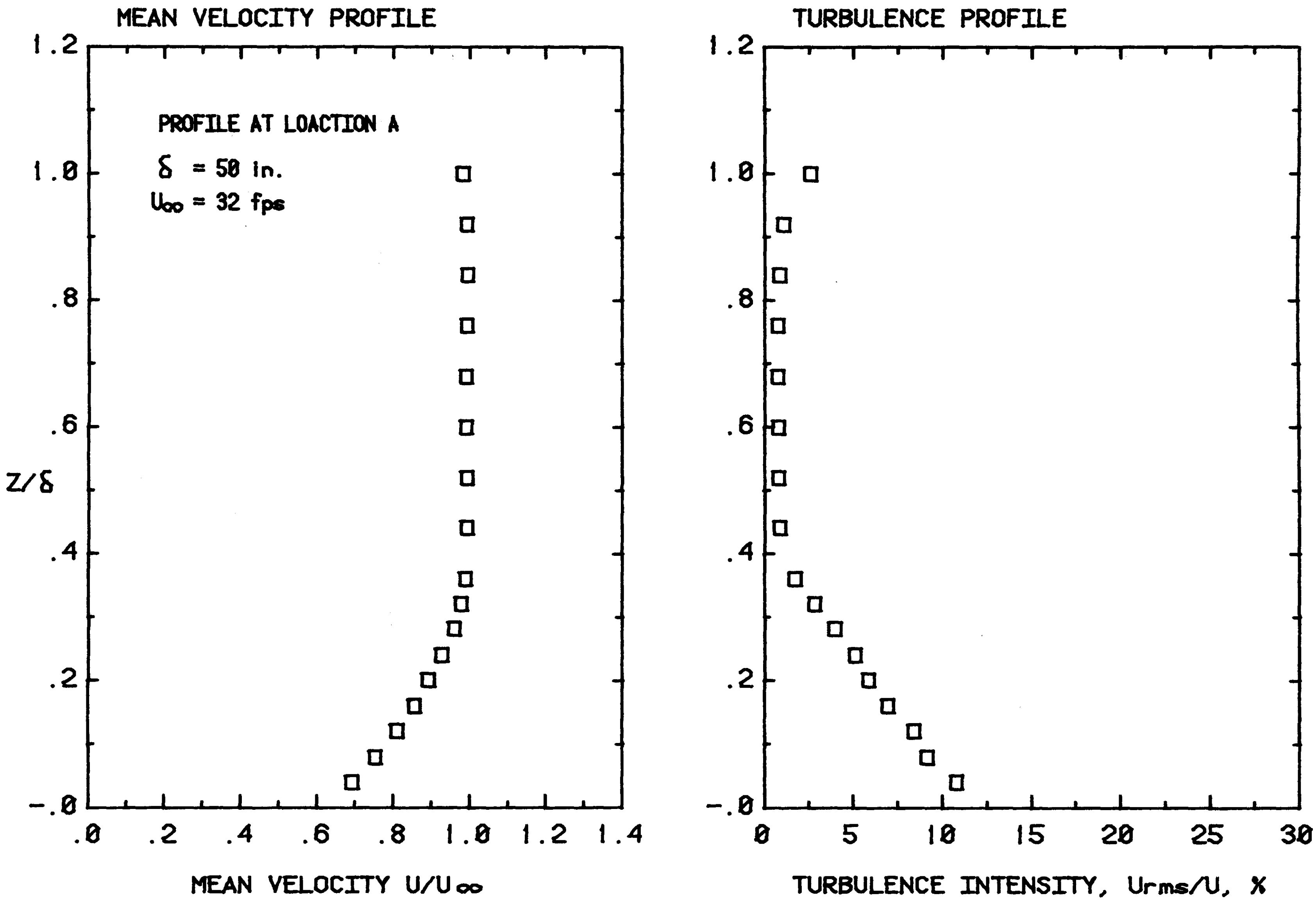


Figure 7. Mean Velocity and Turbulence Intensity Profiles near the Test Deck

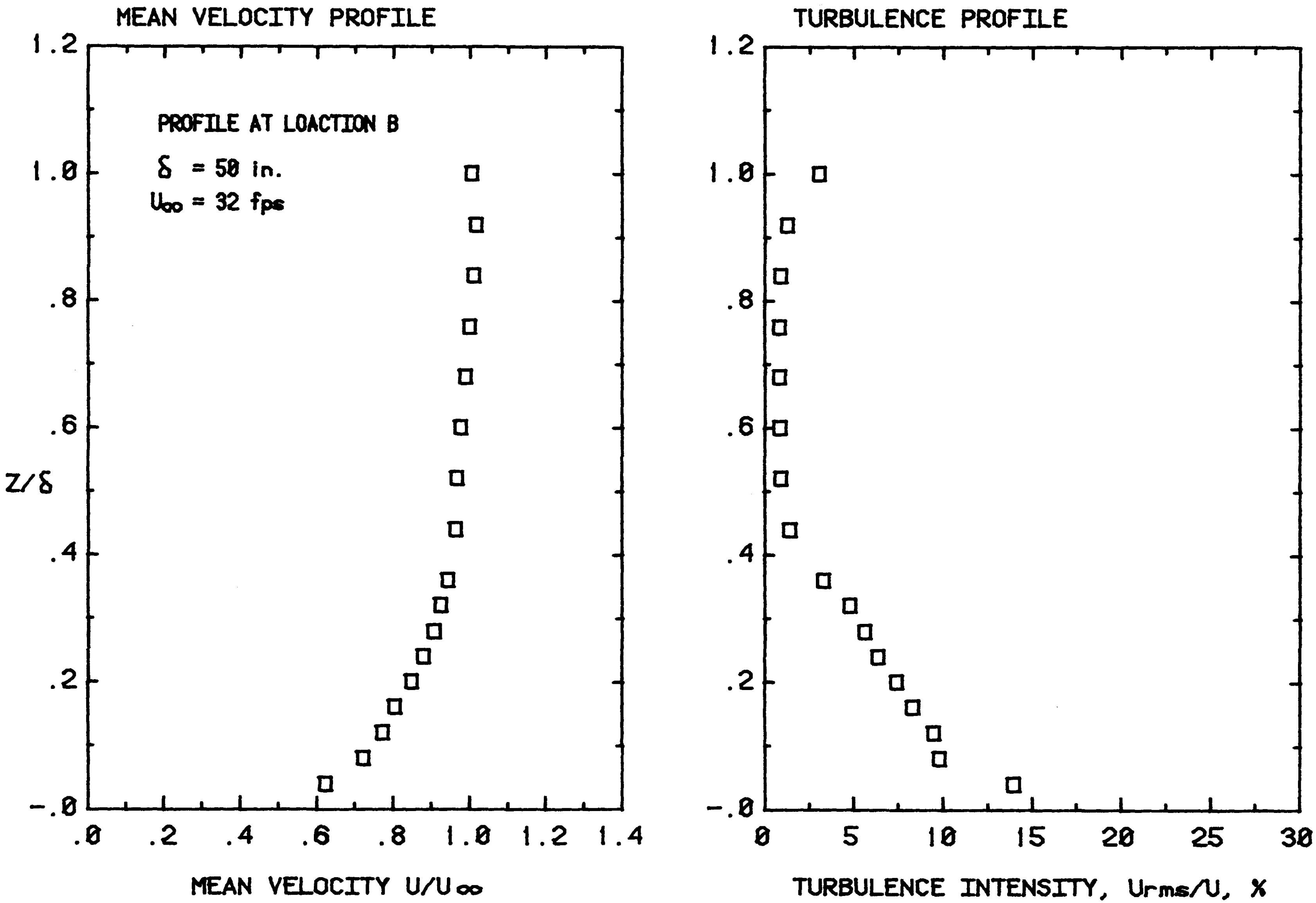


Figure 7. Mean Velocity and Turbulence Intensity Profiles near the Test Deck

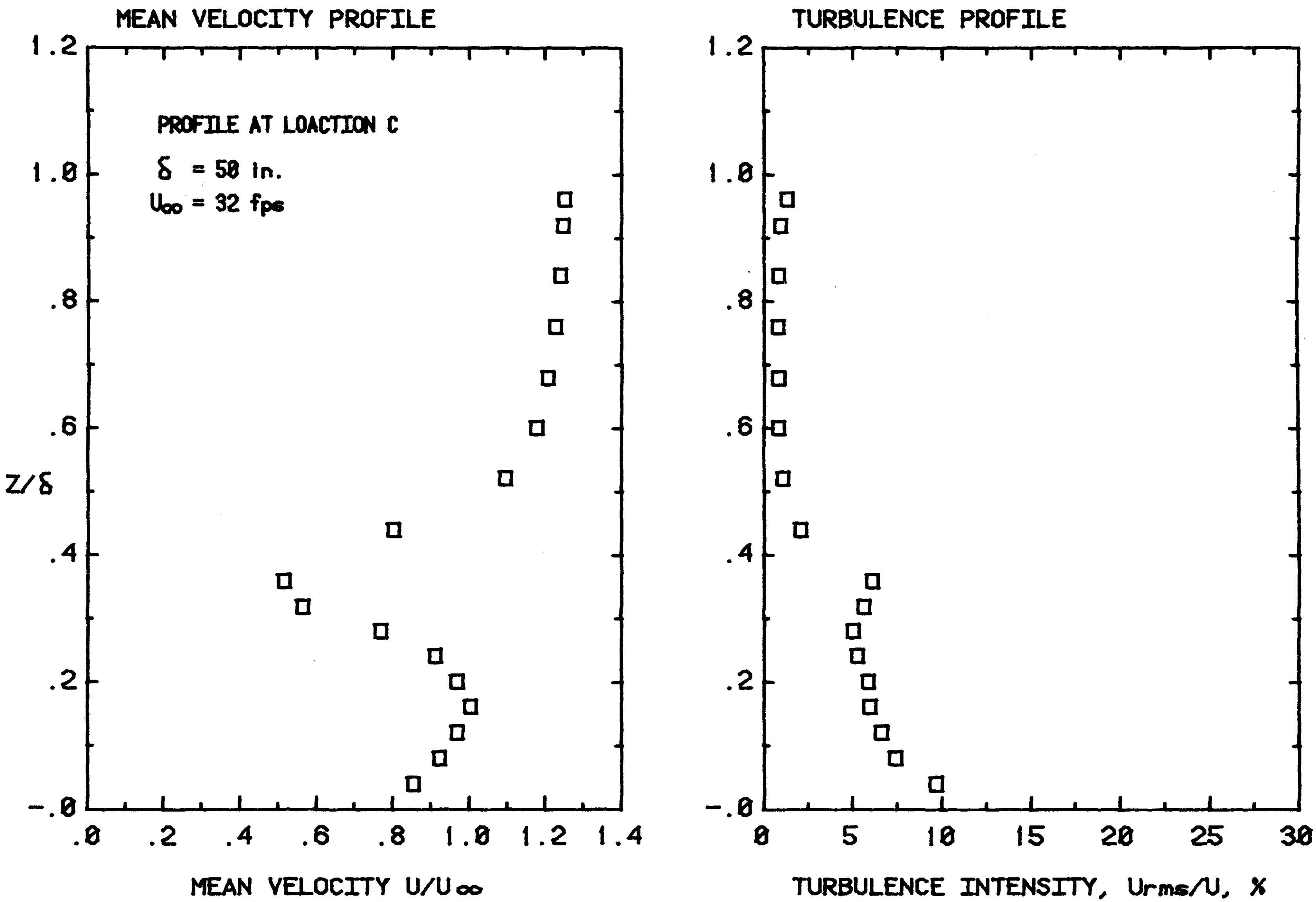


Figure 7. Mean Velocity and Turbulence Intensity Profiles near the Test Deck

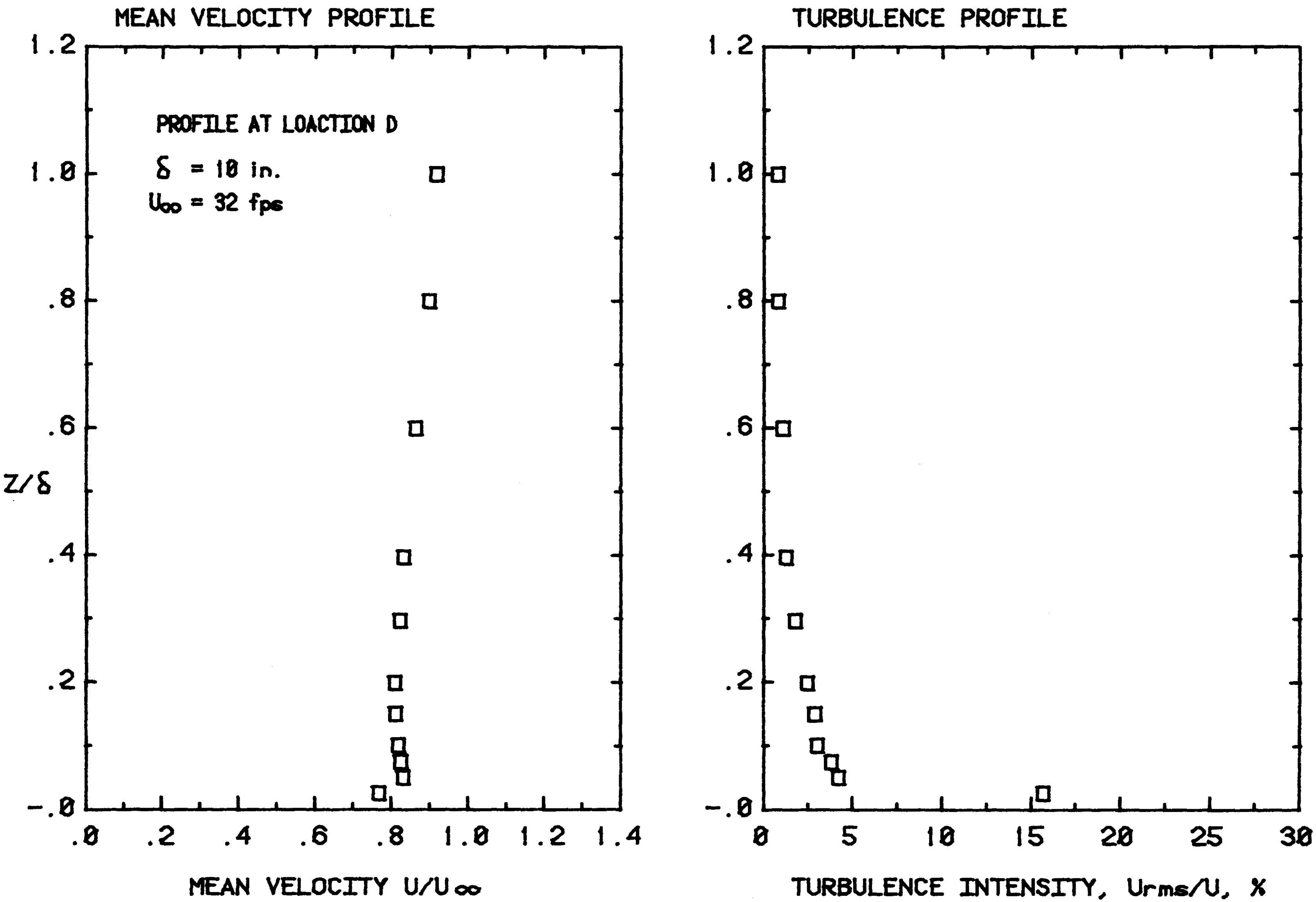


Figure 7. Mean Velocity and Turbulence Intensity Profiles near the Test Deck

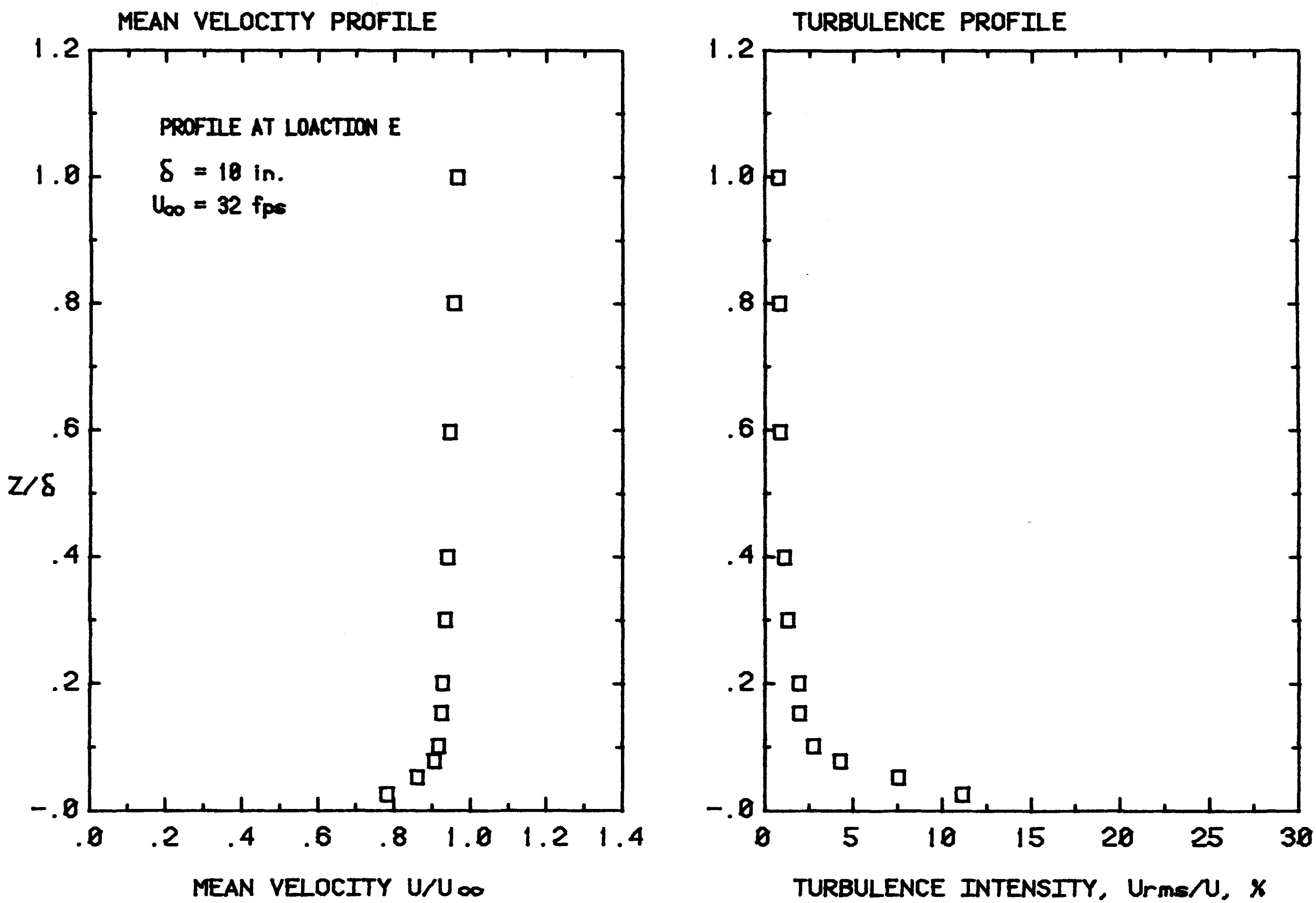


Figure 7. Mean Velocity and Turbulence Intensity Profiles near the Test Deck

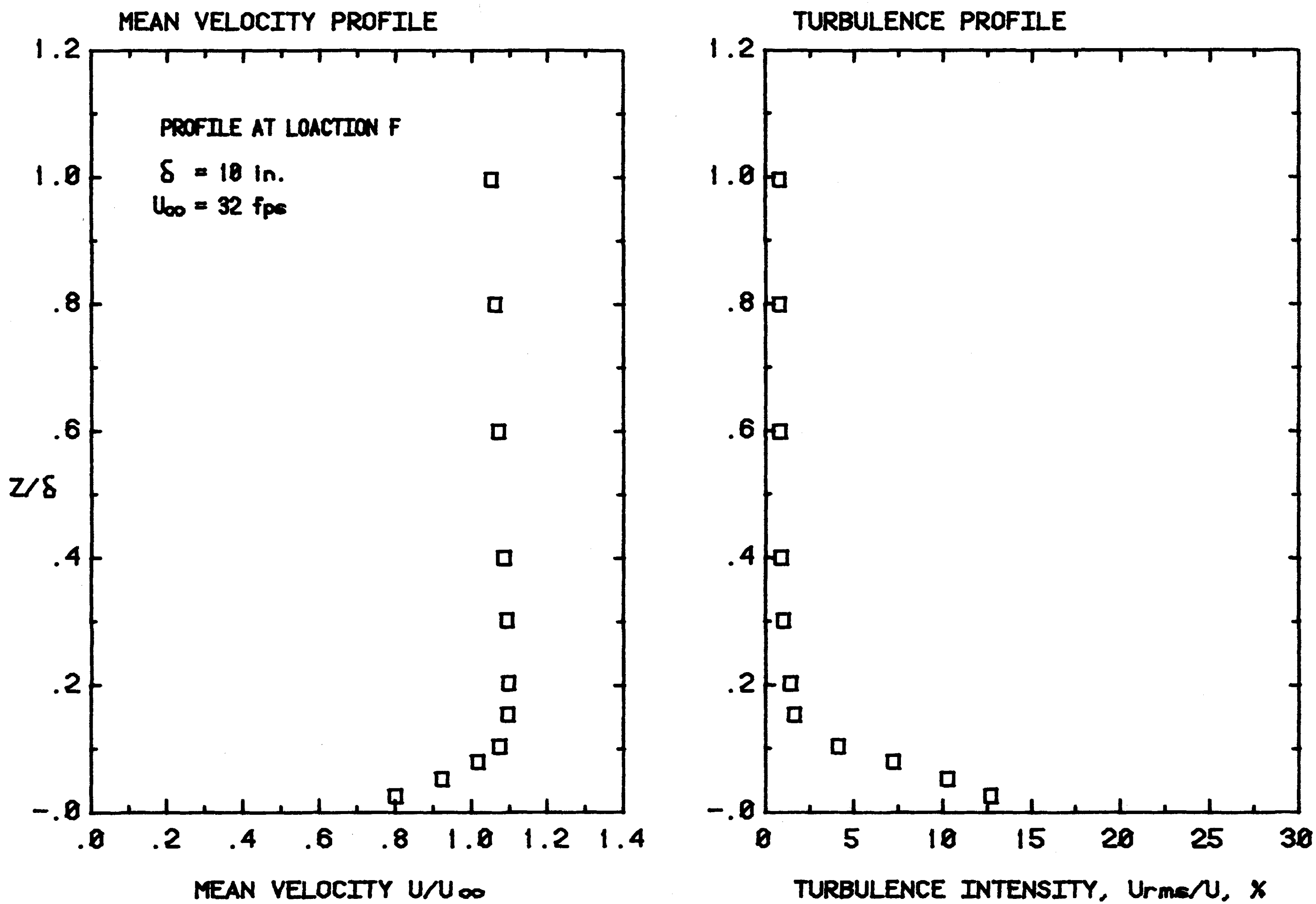
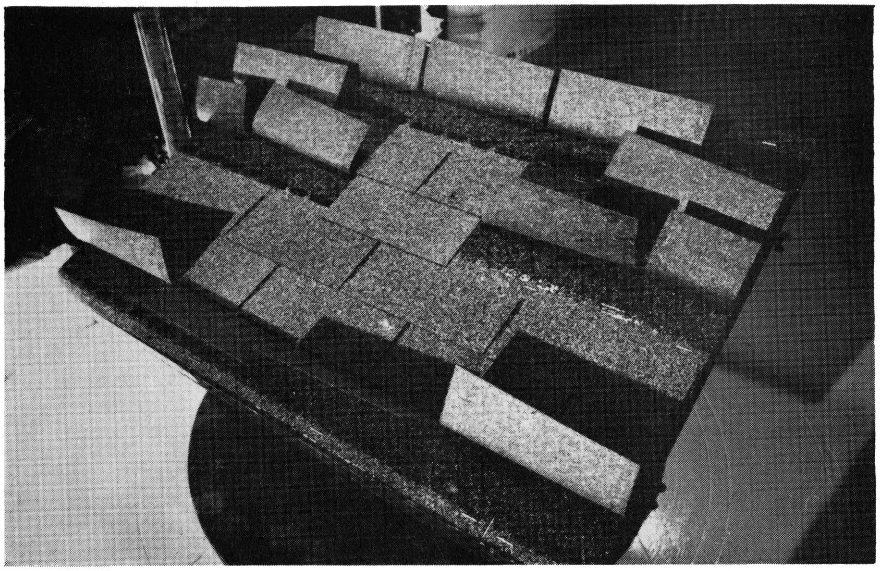
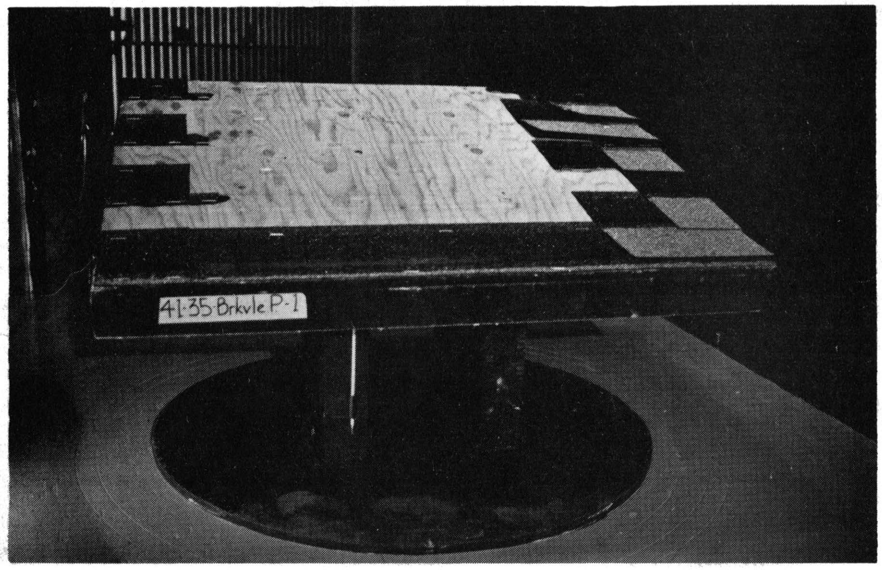


Figure 7. Mean Velocity and Turbulence Intensity Profiles near the Test Deck

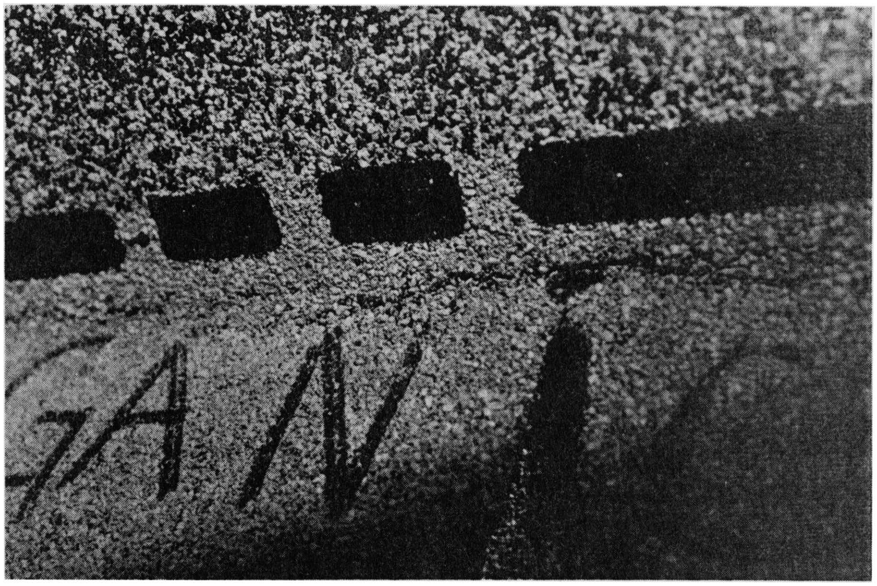


Deck 10-75-DEN IMP-4

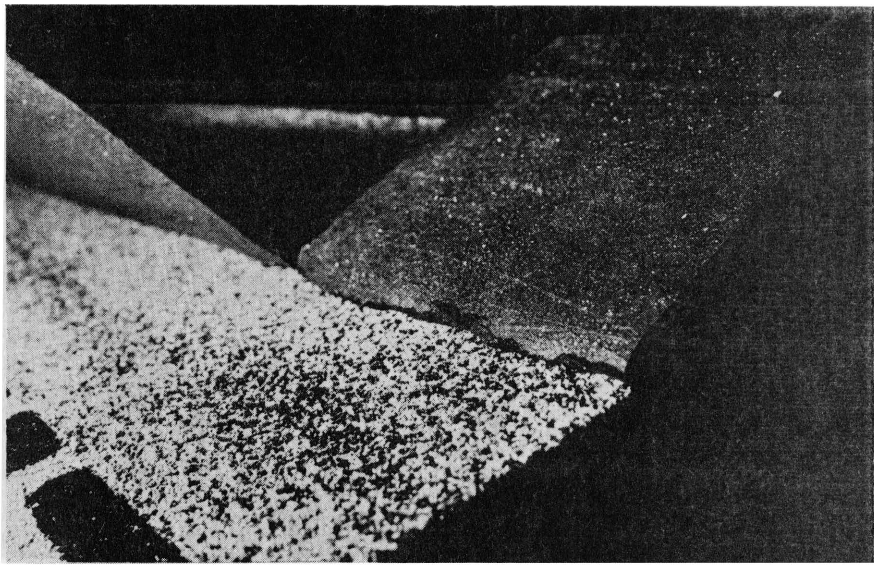


Deck 41-35-BRKVLEP-1

Figure 8. Range of Wind Damage at the End of a Run

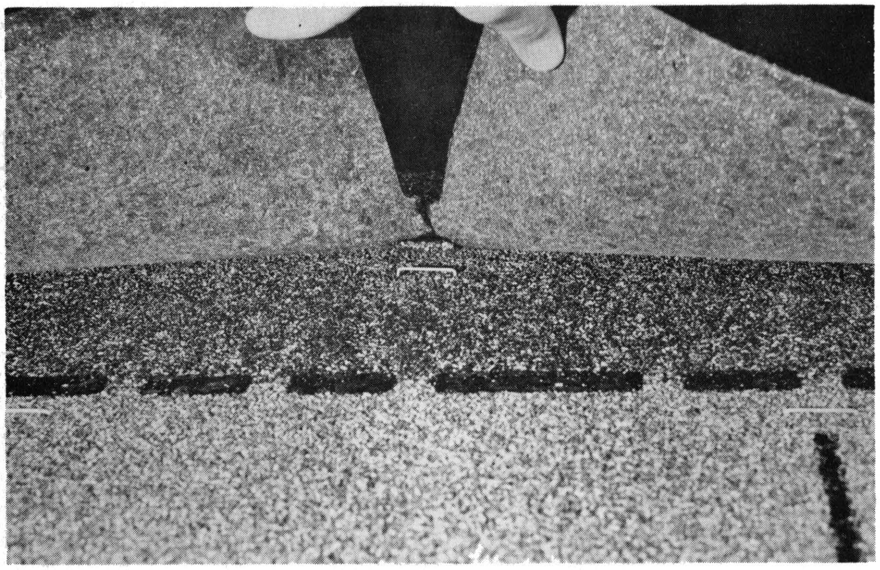


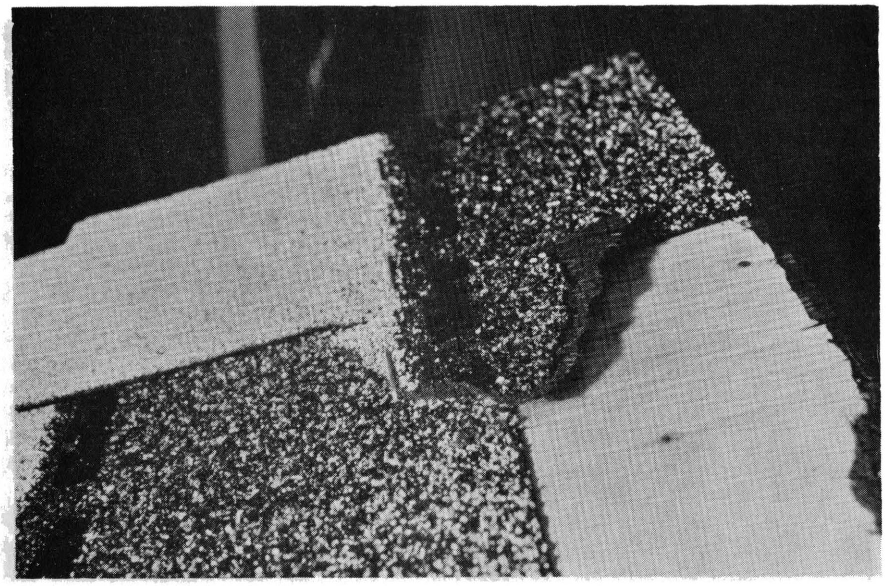
Deck 21-75-ORGANIC-(7)



Deck 25-35-ORGANIC-(8)

Figure 9. Cracking in Bent Shingles

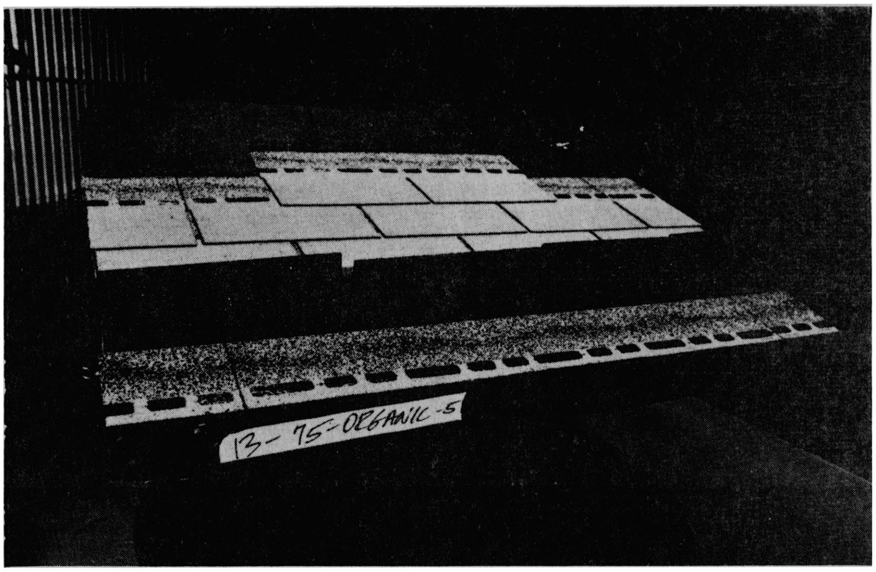




Deck 22-35-JAX STD-(8)

Figure 10. Staple Pullthrough and Shingle Tearing

Deck 52-75-WALTHAM-5



Deck 13-75-ORGANIC-5

Figure 11a. Results for Typical Runs at 75°F

Deck 14-75-JAX STD-5

Deck 15-75-DEN IMP-5

Figure 11b. Results for Typical Runs at 75°F

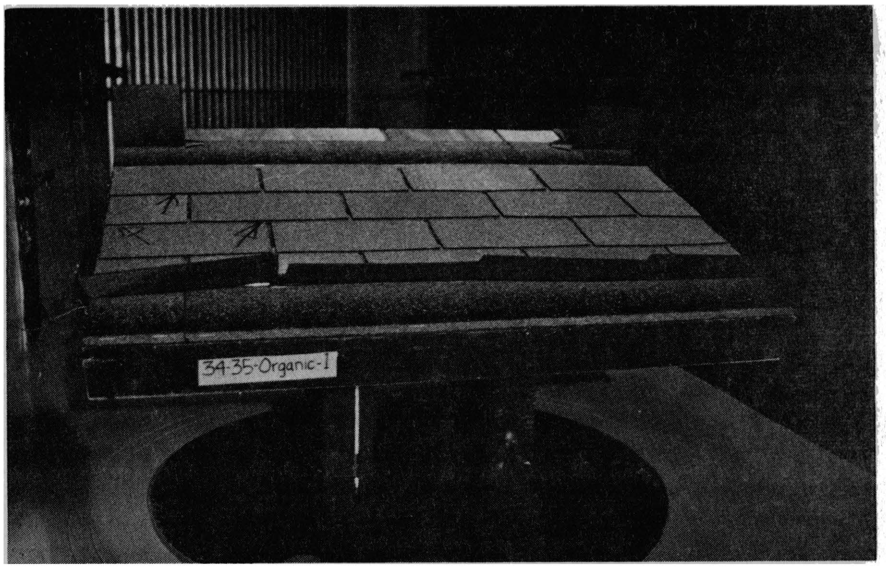


Figure 12a. Results for Typical Runs at 35°F

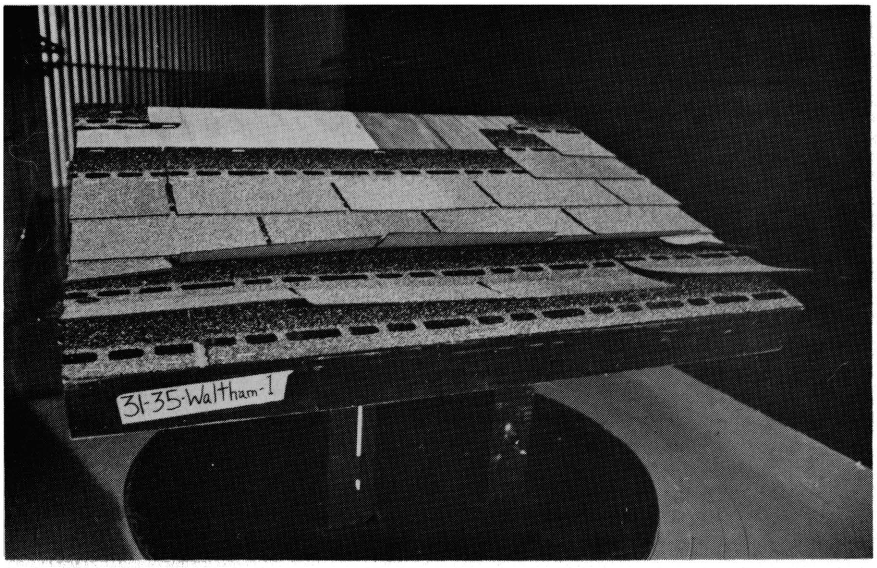
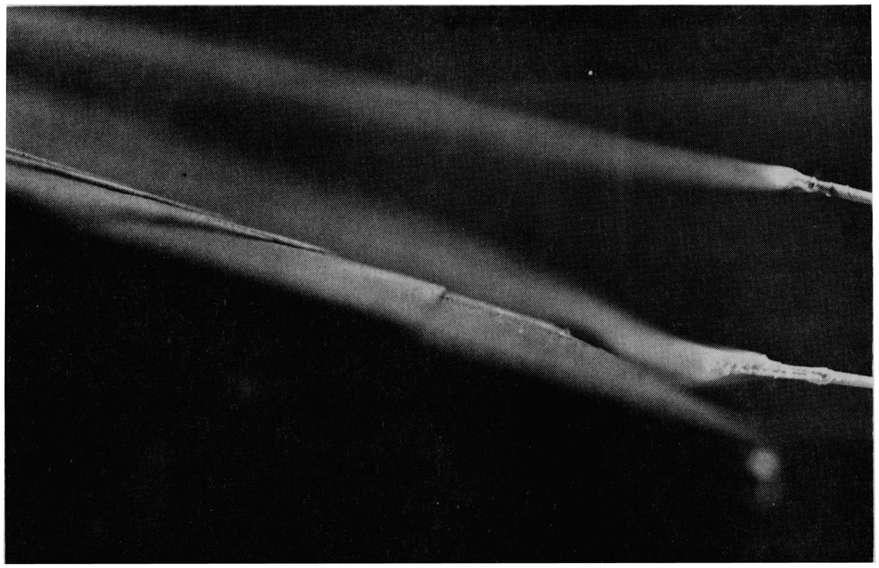
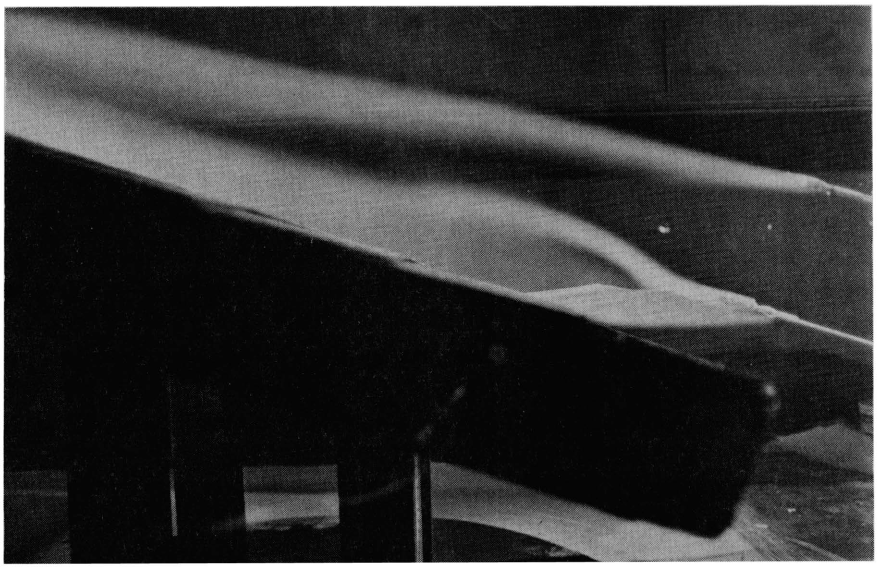


Figure 12b. Results of Typical Runs at 35°F

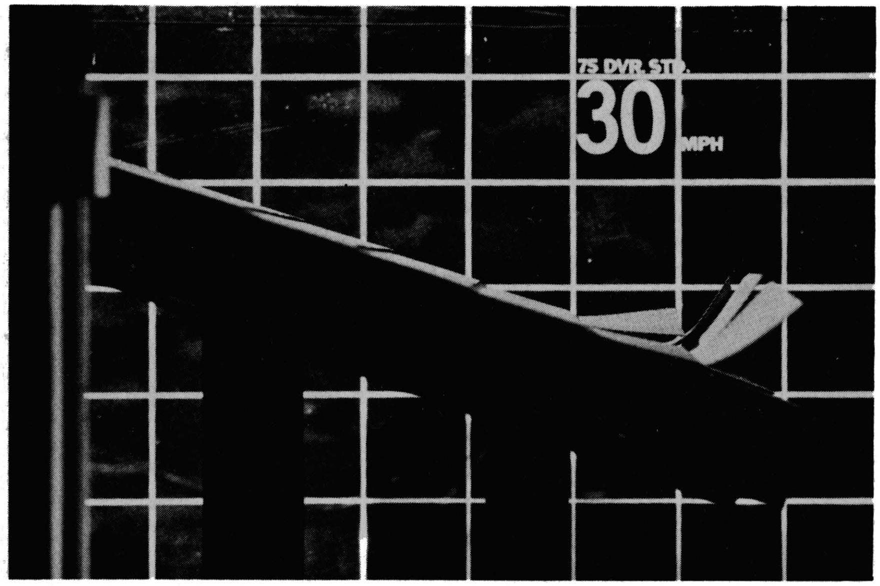


Before Shingle Uplift



After Shingle Uplift

Figure 13. Flow Visualization for 0° Yaw



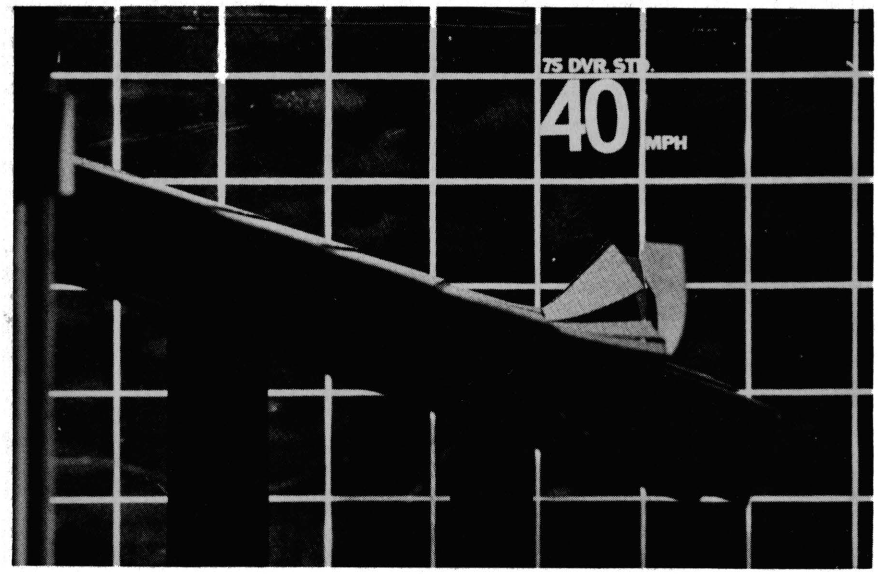
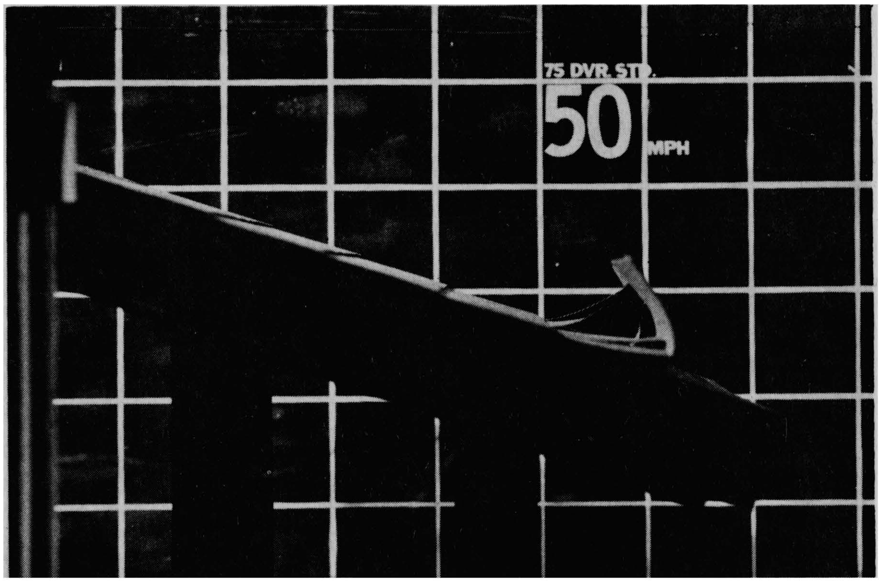


Figure 14a. Sequence of Shingle Lifting with Increasing Wind Speed



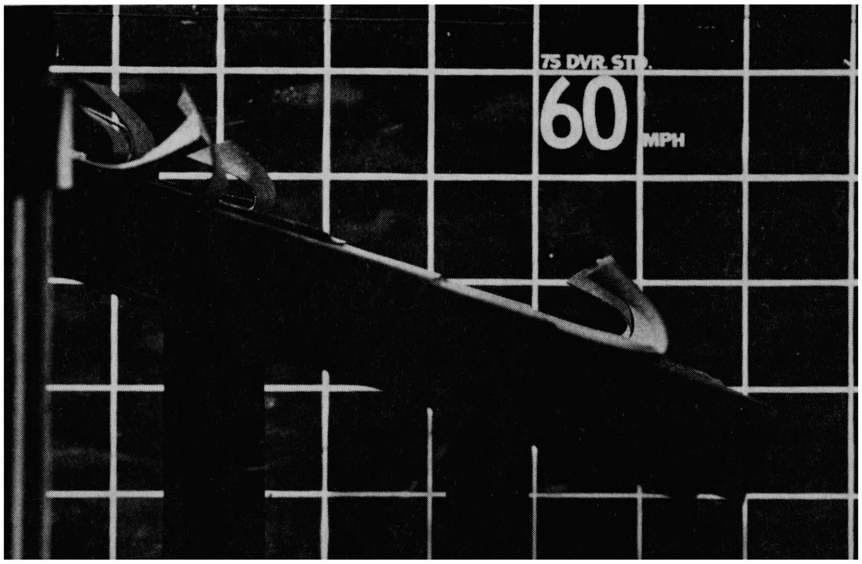


Figure 14b. Sequence of Shingle Lifting with Increasing Wind Speed

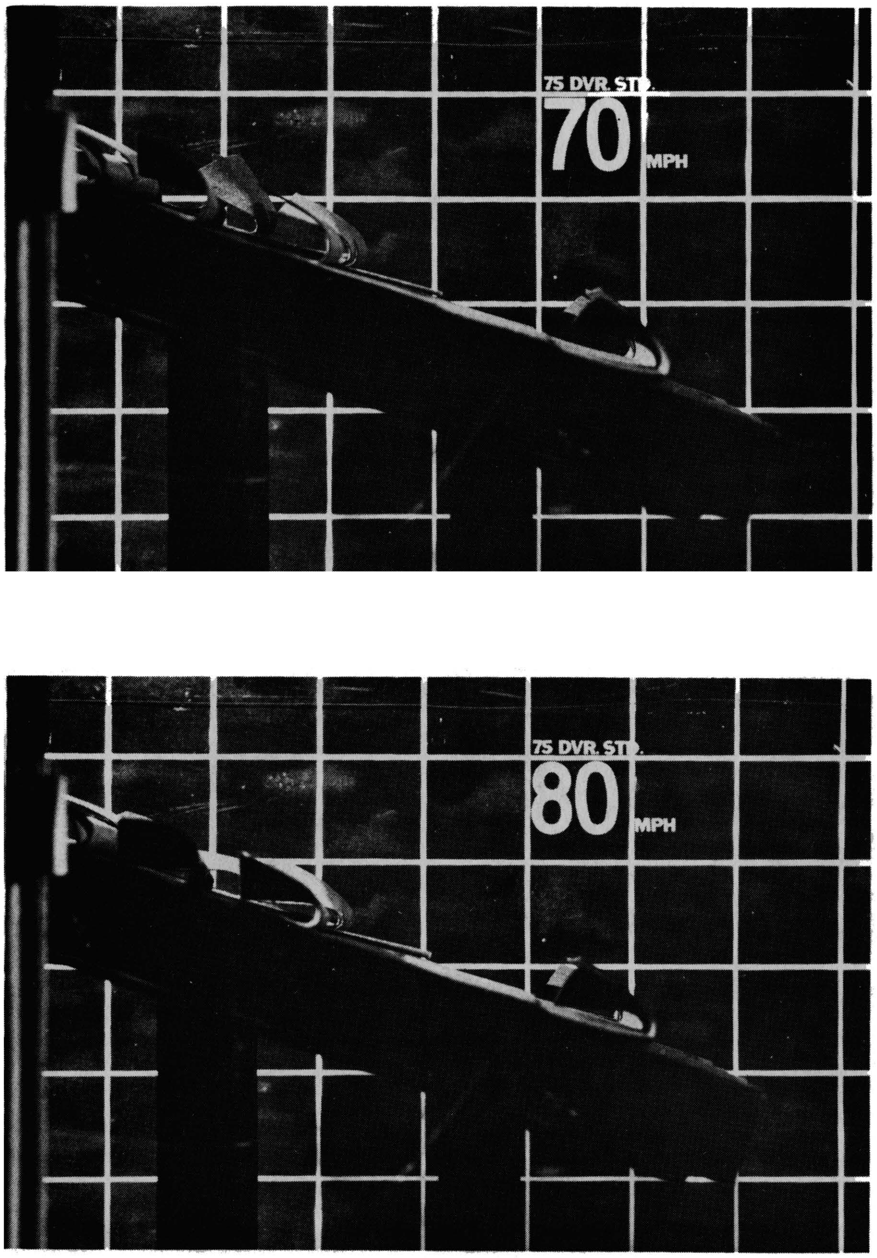


Figure 14c. Sequence of Shingle Lifting with Increasing Wind Speed

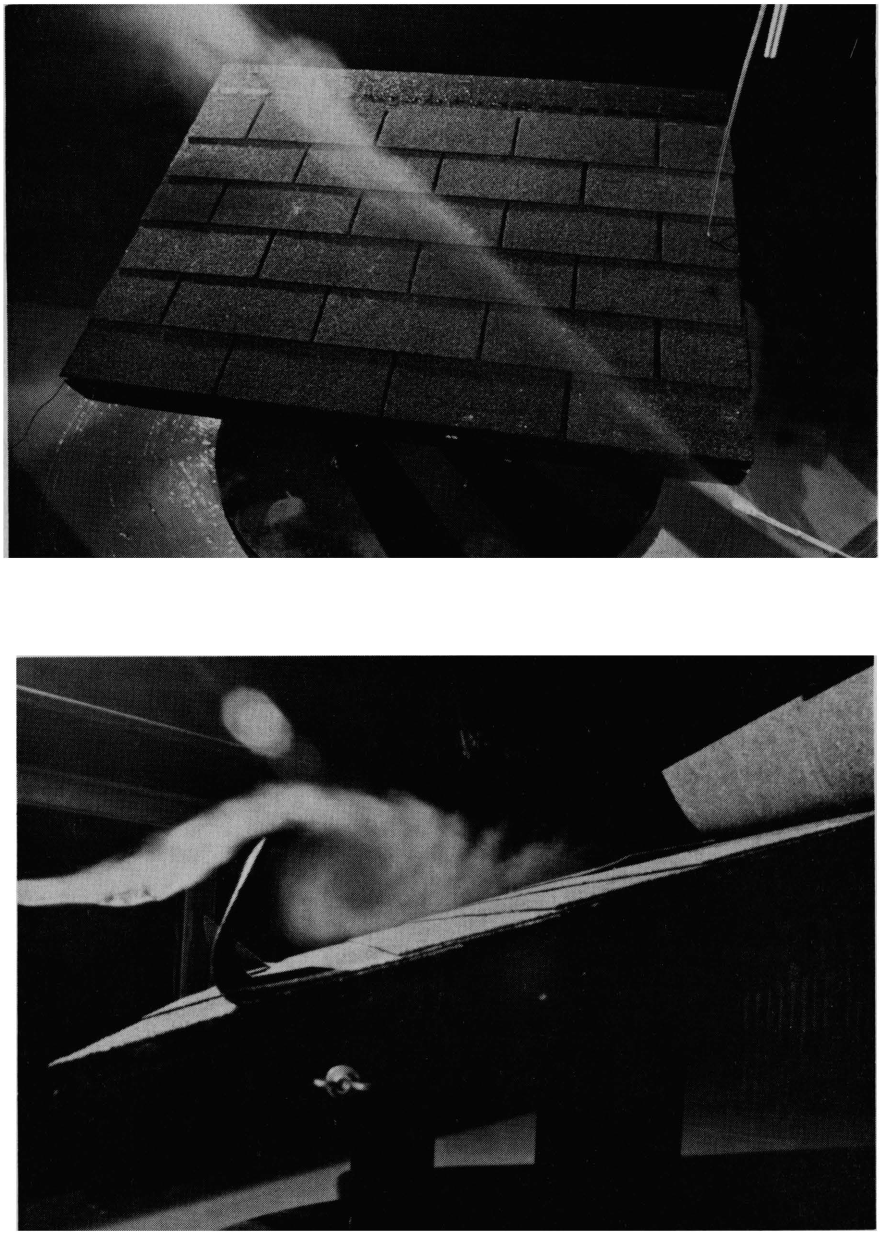


Figure 15a. Flow Visualization for 45° Yaw

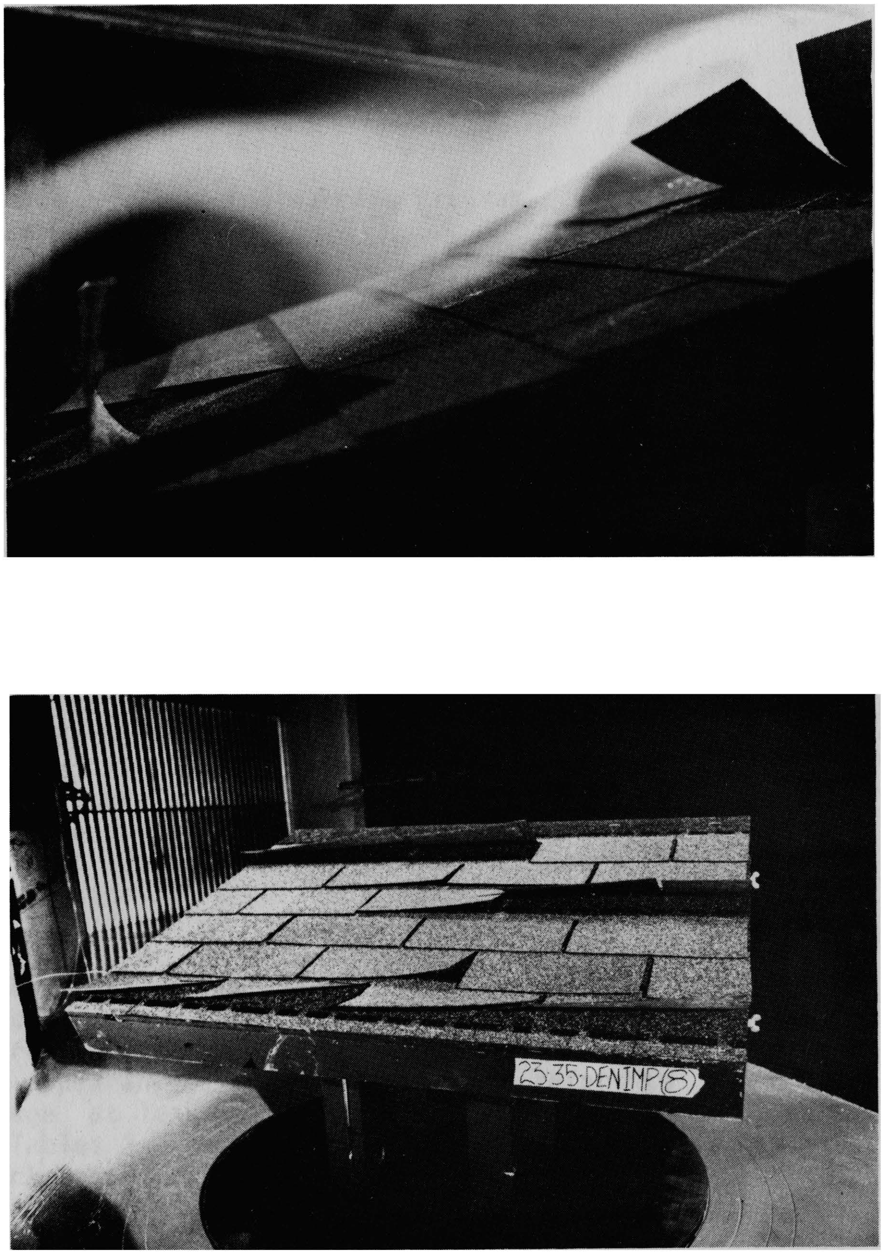


Figure 15b. Flow Visualization for 45° Yaw

APPENDIX

ANALYSIS OF VIDEOTAPE RESULTS

by

Glenn Lamb, Owens-Corning Fiberglas

January 13, 1983

Dr. Jack E. Cermak
Fluid Mechanics and Wind Engineering Program
Foothills Campus
Colorado State University
Fort Collins, CO 80523

Dear Dr. Cermak,

The following is my analysis of the wind tunnel testing results made after viewing the testing on videotape. My evaluation is made from a roofing perspective rather than a fluid dynamics/stress analysis point of view. I hope that you will be able to provide this latter analysis.

My analysis is heavily weighted towards damage sustained by the shingles, and, to a lesser degree, the flexibility of the shingles. I have summarized the results in 7 tables, which are placed at the end of the text. The first 6 tables breakdown the results by individual shingle, temperature of the testing, and orientation of the deck to the wind. The page preceeding Table 1 is a key for the notation in the tables. "Slight Damage" refers to minor tears (less than 1/2 inch long) or initiation of a pull through. (A pull through refers to the shingle pulling free of the staple. The staple barbs are usually visible beneath the tab before a pull through occurs). Since this amount of damage is minimal and has little effect on roof performance, I do not include it in my discussion. "Serious Damage" has a significant effect on roof performance either in terms of accelerated weathering, leaking, or appearance. "Multiple Damage" refers to the occurrence of serious damage at least twice during any given minute of the testing sequence. Tables 1-6 summarize the extent of damage as described above for each deck tested. The tables further breakdown damage by wind speed and course (first course and fifth or sixth course). Table 7 summarizes the degree of tab lift by wind speed for all of the shingles tested. This is very subjective, but does highlight the effect of cold temperature and the differences in flexibility of the various shingles.

Results of Main Program: Organic, Standard and Improved Shingles

Organic shingles were included in this experiment to provide reference material. They are often the standard against which the newer fiber glass shingles are judged. Historically, they have been very good wind performers. Their performance in the wind tunnel was also very good. These shingle were very stiff, especially at 35 F. They also resisted lifting from the deck much more than the fiber glass shingles as can be seen in Table 7. Damage usually occurred at 70 mph for both 35 F cases. At 75 F, damage occurred at 50 to 80 mph. Although the organic shingles usually did not suffer extensive damage, the type of damage sustained was serious from a performance standpoint. These shingles tended to bend back with the wind stiffly rather than flexibly, and occasionally cracked and creased when bent back more than about 90 degrees. On several occasions, the tab simply broke off. The loss of granules associated with this type of damage would provide areas of accelerated weathering and poor appearance. Due to their stiffness, the organic shingles were slow to recover to their original position on the deck at the end of the test. This was aggravated by the cracking.

The performance of the fiber glass shingles was clearly differnt than that of the organic shingles. The Standard and the Improved shingles were more flexible at both 35 and 75 F (see Table 7). The type of failure was also different. The fiber glass shingles usually failed by either pulling through or by tearing. Serious cracking and creasing was rare. At the end of testing, the fiber glass shingles recovered or returned to their original position on the deck faster than the organic shingles.

The difference in performance between the Standard and the Improved products was also very clear. Although the Standard shingles were less flexible than the Improved shingles, especially at 35 F, the striking difference was in their lack of strength. Standard shingles experienced all types of damage: tearing, pull throughs, blow-offs and occasional cracking. Usually when a pull through occurred, subsequent tearing or pull throughs would soon follow. Examination of Tables 1-4 shows the numerous multiple failures, many of which included blow-offs. At 35 F, damage usually occurred at 60 mph on the 0 degree orientation decks and 70 mph on the 45 degree decks. At 75 F, failures were less extensive, but occurred sooner- 50 and 60 mph, respectively.

The performance of the Improved shingles was outstanding. In my opinion, the improvement made in these shingles, which is proprietary, was the major contributor to superior wind performance. Damage was minimal. In all of the testing, multiple damage occurred once. Also, wind speeds were higher before damage occurred. On the 0 degree orientation decks, no damage occurred at 35 F, and one pull through occurred at 70 mph at 75 F. On the 45 degree decks, two pull throughs occurred at 70 mph at 35 F, and one cracked tab occurred at 80 mph at 75 F. In addition to the excellent strength of these shingles, they were noticeably more flexible than any of the others. They lifted higher for a given wind speed at both temperatures. They also bent back easily and sustained no cracking or creasing. In fact, at the high wind speeds, the tabs would often lay back on themselves.

Before discussing the additional shingles tested, a comment on the validity of the above testing is in order. The original plan for the Standard and Improved shingles was to make both shingles at the same roofing plant so that as many manufacturing variables as possible would be the same. However, due to the timing of the testing and lack of important materials, the Standard shingles were made in a different roofing plant. Consequently, there are differences between the Standard and Improved shingles that have nothing to do with the improvement made, but which show up in the testing. As I have viewed the tapes, I am convinced that the dramatic difference in performance between the Standard and Improved shingles can be safely attributed to the improvement that we have made in the Improved shingles. The additional shingles tested confirm this conclusion as will be noted shortly.

Results of the Variety of Shingles

Since the testing went so smoothly and efficiently, there was time to test 12 additional shingles: 8 OCF products and 4 competitive products. The OCF products represented a variety of process and material differences, but they were grouped three ways: 1 organic shingle, 3 which had properties similar to the Standard shingles, and 4 which had properties comparable to the Improved shingles. The results from this testing agreed very well with the results from the main program. At 35 F, the organic shingle was very stiff and sustained damage at 70 mph. The shingles from Waltham, Brookville (Std) and Atlanta generally sustained first damage at 60 mph and it was usually multiple damage. The shingles from Denver (Std), Jessup, Brookville and Medina had less damage and it usually occurred at 70 mph. The Brookville and Medina shingles had multiple damage. Except for two early pull throughs, the Denver and Jessup shingles were outstanding. At 75 F, the Waltham shingles had continual damage, beginning at 40 mph. The Brookville Standard shingles had considerable damage, beginning at 50 mph. The one Jessup deck sustained no damage.

Results of the Competitive Shingles

While little is known about the material and physical properties of the competitive shingles, it appears, based on this very small sampling, that these shingles were more comparable to the Standard shingles. Naturally, this is good for Owens-Corning. It indicates that our standard shingles are competitive in the marketplace, and that our Improved shingles could be clear industry leaders in wind performance.

Discussion of Test Parameters

35 F versus 75 F

There were several differences attributable to temperature. The shingles were less flexible at 35 F. For a given wind speed, the tabs lifted less at 35 F than at 75 F. Damage was more extensive at 35 F with multiple damage occuring frequently. However, damage occurred sooner (at a lower wind speed) at 75 F, and was distributed among all wind speeds.

0 versus 45 Degree Orientation

Damage occurred sooner on the 0 degree decks (60 vs 70 mph). The big difference was involvement. On the 0 degree decks, only the first and fifth or sixth courses were usually affected by the wind. (Occasionally, the outside tabs on the 4th and 5th courses would be lifted by 75 F, high wind). On the 45 degree decks, all the courses except the second course were affected by the wind. There appeared to be slightly more damage on the 45 degree decks.

Test Protocol

The time table of the testing consisted of 1 minute at 30 mph, 2 minutes at 40 mph, and 5 minutes at each of 50, 60, 70 and 80 mph. With one exception, no damage occurred during the 30 and 40 mph segments of the test. Occasional damage occurred at 50 mph. The majority of the damage occurred at 60 and 70 mph. About 20% of the damage occurred at 80 mph. About 50% of the damage occurred during either the first minute after a speed change or in the last minute before a change. The rest of the damage was sustained during minute 2, 3, 4 of the 5 minute segment. My feeling is that this was a good choice of testing protocol. The only drawback I see is that the shingles had a chance to gradually be lifted by the wind as wind speed increased. Future work might include a more demanding protocol such as gusting or larger step changes in speed.

Conclusion

Everything about the testing program was excellent. The results were very conclusive. Selection of temperatures, deck orientation, protocol, etc., contributed to the excellent results. The tunnel itself performed very well. Hank Weber and his crew, Jim Garrison and Coby Howell provided very expert assistance and were the major reason why everything went so smoothly. They were also most enjoyable to work with. And, of course, your experience and knowledge combined with that of Dr. Peterka cannot go unmentioned.

I am eagerly awaiting your final report. I will be especially interested in your comments on the fluid dynamics of the testing- flow visualization, velocity profiles, etc. I am also interested in your comments on the forces involved in causing shingle damage. Hopefully, the sum total of all of this will enable us to formulate a viable approach to further work.

Best regards,

Glenn D. Lamb

cc W.W. Lincoln

Key to wind-tunnel results

-	Slight damage
	staple barb visible slight tear in cutout (<½ inch)
X	serious damage
	tear around staple large tear (>½ inch) staple pull through cracking/creasing tab or shingle blow off
(X)	multiple damage
	two or more of the above in the same minute
course	Damage generally occurred on the 1st and 5th or 6th courses. Damage on each course is shown for each deck.

Table A1. Organic, Standard, Improved: 35°F, 0° Orientation

Wind Speed minutes into test		40 mph 1	2	50 mph 3	4	5	6	7	60 mph 8	9	10	11	12	70 mph 13	14	15	16	17	80 mph 18	19	20	21	22
Shingle	Course																						
Organic 1	5th			No Damage																			
	1st																						
Organic 2	6th														—	X			(X)				—
	1st																						
Organic 3	6th												X					X					
Jax Std 1	6th								(X)														
	1st													(X)				(X)					
Jax Std 2	5th									(X)	X			X									
	1st													(X)									
Jax Std 3	6th									X	X												
	1st											X		(X)									
Den Imp 1	6th			No Damage																			
	1st													—									
Den Imp 2	5th			No Damage																			
	1st			No Damage																			
Den Imp 3	6th																					—	
	1st										—												

Table A2. Organic, Standard, Improved: 35°F, 45° Orientation

Wind Speed minutes into test		40 mph 1	2	50 mph 3	4	5	6	7	60 mph 8	9	10	11	12	70 mph 13	14	15	16	17	80 mph 18	19	20	21	22
Shingle	Course																						
Organic 8	6th																X				(X)	X	
	1st																X			—	X		
Organic 9	6th														X								
	1st																						
Organic 10	6th																X						
	1st																						
Jax Std 8	6th														(X)		(X)						
	1st														X	X	(X)		X				
Jax Std 9	6th																			(X)			
	1st																(X)		(X)		(X)		X
Jax Std 10	6th													(X)									—
	1st														X	—		(X)	(X)				(X)
Den Imp 8	6th														X								
	1st																			X			
Den Imp 9	6th									—					—	—			X				
	1st																		—				
Den Imp 10	6th								—		—				(X)								
	1st														(X)								

Table A3. Organic, Standard, Improved: 75°F, 0° Orientation

Wind Speed minutes into test		40 mph 1	 2	50 mph 3	 4	 5	 6	 7	60 mph 8	 9	 10	 11	 12	70 mph 13	 14	 15	 16	 17	80 mph 18	 19	 20	 21	 22
Shingle	Course																						
Organic 4	6th			X						_		_								X		X	
	1st																						
Organic 5	6th				X									(X)						X			
	1st																						
Jax Std 4	6th													X					X				
	1st				X																		
Jax Std 5	6th			X		_																	_
	1st																						
Den Imp 4	6th																						
	1st			No Damage																			
Den Imp 5	6th																						
	1st	_													X								

Table A4. Organic, Standard, Improved: 75°F, 45° Orientation

Wind Speed		40 mph		50 mph					60 mph					70 mph					80 mph				
minutes into test		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Shingle	Course																						
Organic 6	6th						X																X
	1st																						X
Organic 7	6th							_				(X)			(X)								
	1st																						
Jax Std 6	6th													(X)									
	1st									_	X												
Jax Std 7	6th			No Damage															_				
	1st																						
Den Imp 6	6th			No damage																			_
	1st																						
Den Imp 7	6th																						X
	1st																						

Table A5. Variety of Shingles: 35°F, 0° Orientation

Wind Speed	minutes into test	40 mph		50 mph					60 mph					70 mph					80 mph				
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Shingle	Course																						
Organic 1	6th														(X)						_		X
	1st																		(X)	_			
Waltham 1	6th-5th				(X)			X	(X)	X													
	1st									(X)			(X)	X		_							_
Waltham 2	5th										_												
	1st									X		(X)		X									X
Waltham 3	5th								(X)		_												
	1st													(X)									_
Brookville Std 1	6th								(X)						X								
	1st											X	X	(X)				_		_			
Atlanta 1	6th											_	X		_								
	1st														(X)				X		X		X
Atlanta 2	6th									X						(X)							
	1st														X		_			X			_

Table A5 (continued).

Wind Speed	minutes into test	40 mph		50 mph					60 mph					70 mph					80 mph				
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Den Std 1	6th							_	(X)														
	1st														–								
Jessup 1	5th																						
	1st			No damage																			
Jessup 2	6th																						
	1st													–		X							
Brookville P1	6th												(X)										
	1st													(X) wholedeck peels									
Medina P1	6th													(X)		X							
	1st														X	(X)	_	X̄					
JM 1	6th						–		(X)		X			(X)				X					
	1st								X		X			X	X								X
JM 2	5th										–												
	1st													_	(X)								
Elk 1	6th																	X					
	1st								(X)		–												–
GAF 1	6th								(X)														
	1st									(X)													
Tamko 1	6th								X			–											X
	1st									X													–

Table A5 (continued).

Wind Speed minutes into test	40 mph 1	2	50 mph 3	4	5	6	7	60 mph 8	9	10	11	12	70 mph 13	14	15	16	17	80 mph 18	19	20	21	22
Brookville Std 2 6th							–	(X)				–										
1st								X					(X)	(X)								

Table A6. Variety of Shingles: 75°F, 0° Orientation

Wind Speed		40 mph		50 mph					60 mph					70 mph					80 mph				
minutes into test		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Shingle	Course																						
Waltham 4	6th			Unknown timing-2 tabs blown off, large tear, 2 6" tabs cracked																			
(lost tape)	1st								staple tear														
Waltham 5	6th	X		X					_					X			_		X				(X)
	1st																						_
Brookville Std 3	6th													X					(X)				X
	1st																		(X)	(X)	(X)		
Brookville Std 4	6th		_	X																			(X)
	1st			_			X									X			X			_	
Jessup 3	6th			No Damage																			
	1st																						

Table A7. Average, Approximate Angle of Lift from Deck, 0° Orientation

Temperature		35°F			75°F		
Wind Speed	mph	40	50	60	40	50	60
Shingle	Course						
Organic	top	<15°	15°	30°	15°	120°	n/a
	bottom	15°	30°	45°	45°	90°	n/a
Standard	top	<15°	45°	60°	45°	120°	150°
	bottom	15°	30°	60°	30°	90°	120°
Improved	top	30°	60°	90°	45°	120°	180°
	bottom	30°	60°	90°	60°	150°	180°
Waltham	top	15°	45°	60°	60°	120°	135°
	bottom	30°	45°	60°	30°	90°	120°
Brookville Std	top	15°	45°	--	60°	120°	150°
	bottom	15°	45°	--	60°	120°	150°
Atlanta	top	15°	45°	90°			
	bottom	30°	45°	60°			
Den Std	top	15°	30°	90°			
	bottom	30°	30°	60°			
Jessup	top	15°	45°	90°	90°	120°	>120°
	bottom	30°	30°	60°	90°	120°	150°
Brookville D	top	<15°	15°	30°			
	bottom	15°	30°	30°			
Medina P	top	15°	30°	45°			
	bottom	15°	30°	45°			
JM	top	15°	45°	90°			
	bottom	15°	30°	90°			
Elk	top	15°	45°	--			
	bottom	15°	30°	--			
GAF	top	<15°	30°	--			
	bottom	15°	30°	--			
Tamko	top	15°	60°	90°			
	bottom	15°	45°	90°			

Table A7. Average, Approximate Angle of Lift from Deck, 0° Orientation

Temperature		35°F			75°F		
Wind Speed	mph	40	50	60	40	50	60
Shingle	Course						
Organic	top	<15°	15°	30°	15°	120°	n/a
	bottom	15°	30°	45°	45°	90°	n/a
Standard	top	<15°	45°	60°	45°	120°	150°
	bottom	15°	30°	60°	30°	90°	120°
Improved	top	30°	60°	90°	45°	120°	180°
	bottom	30°	60°	90°	60°	150°	180°
Waltham	top	15°	45°	60°	60°	120°	135°
	bottom	30°	45°	60°	30°	90°	120°
Brookville Std	top	15°	45°	--	60°	120°	150°
	bottom	15°	45°	--	60°	120°	150°
Atlanta	top	15°	45°	90°			
	bottom	30°	45°	60°			
Den Std	top	15°	30°	90°			
	bottom	30°	30°	60°			
Jessup	top	15°	45°	90°	90°	120°	>120°
	bottom	30°	30°	60°	90°	120°	150°
Brookville D	top	<15°	15°	30°			
	bottom	15°	30°	30°			
Medina P	top	15°	30°	45°			
	bottom	15°	30°	45°			
JM	top	15°	45°	90°			
	bottom	15°	30°	90°			
Elk	top	15°	45°	--			
	bottom	15°	30°	--			
GAF	top	<15°	30°	--			
	bottom	15°	30°	--			
Tamko	top	15°	60°	90°			
	bottom	15°	45°	90°			