WIND EFFECTS ON SKI TRAILS

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Abstract

The ski trails facing into the wind direction and those that are above tree line are particularly susceptible to being scoured of their snow cover, which causes hazardous skiing conditions. A two year study supported by the New England Regional Commission was started in July, 1970, to find novel wind barrier techniques to reduce the scouring effect of the wind and induce snow deposition. For this study an "air table" was devised which is an open channel through which air is forced by a 60" diameter fan whose speed can be changed to simulate various wind speeds. Tests on models simulating ski trails indicate that narrow, winding trails with short runs into the prevailing winds can greatly reduce wind erosion. A wind barrier in the form of a "lifting body" shape similar to a delta winged aircraft, properly oriented, has been tested on the "air table." These tests indicate that this barrier has the ability to induce snow deposition into drifts of larger volume than conventional snow fences. Depending on the orientation and the number of barriers, one, two or three drifts are possible. Tests of larger scale models under actual wind conditions are now being conducted at Sugarloaf Mountain, Kingfield, Maine and Wildcat Mountain, Pinkham Notch, New Hampshire.

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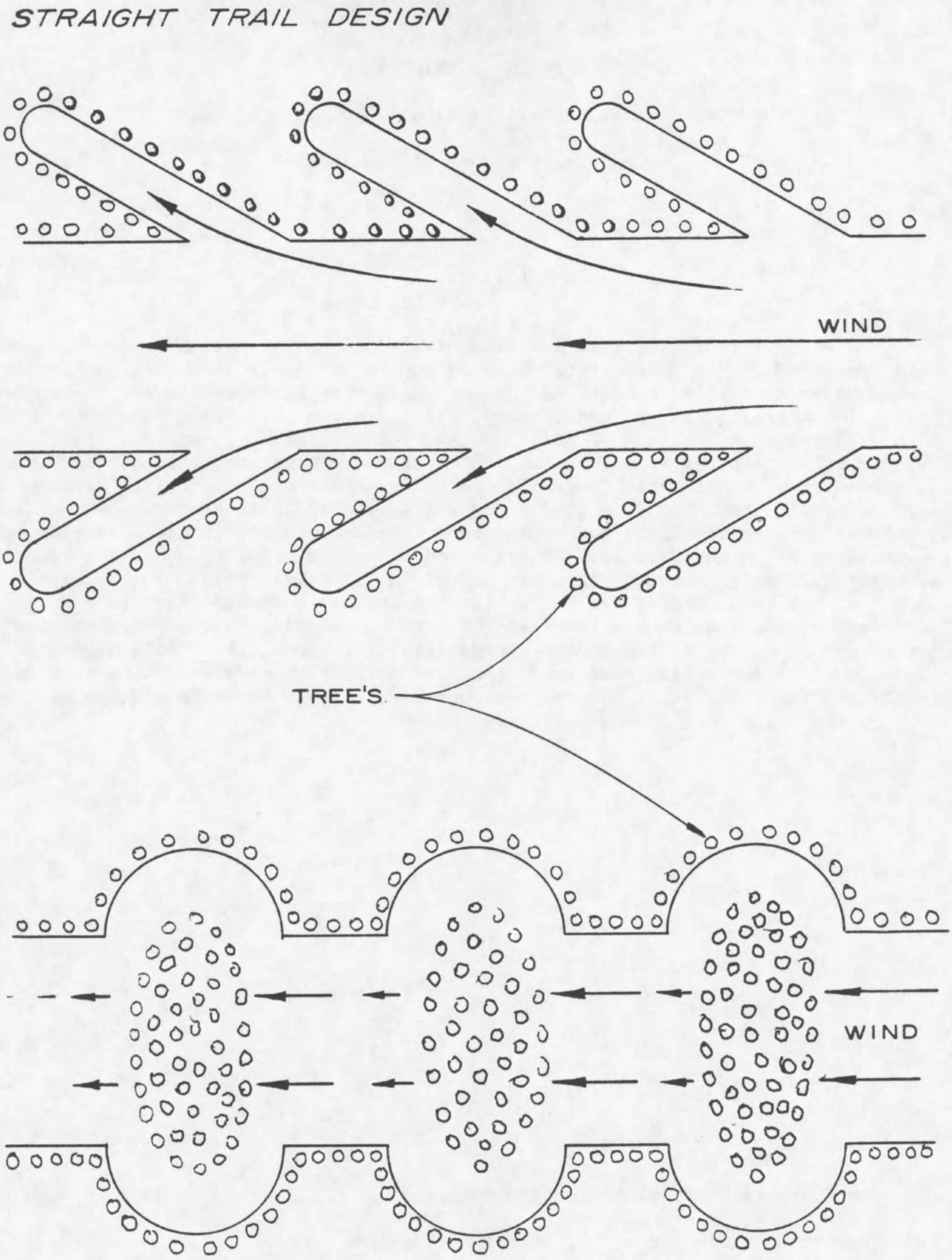


FIGURE 1 STRAIGHT TRAIL DESIGNS

INTRODUCTION

A number of studies have been concerned with the problems of snow drifting and snow mechanics. Mellor(1) has reviewed the subject of blowing snow considering the physical causes and processes. Radok(2) described the processes of deposition and erosion of the snow by the wind. Most of the studies have been concerned with the design of snow fences for reducing deposition near roads and buildings.(3) Dyunin(4,5) outlined a method of calculating the velocity and the related snow transport characteristics behind porous barriers. Shelter Belt studies(6) show experimentally determined velocity and snow deposition patterns behind various forest groupings in the Midwest. Schmidt(7) has developed design parameters for using snow fences to deposit snow on ski slopes, especially above tree line. However, in the author's discussions with Eastern ski area operators, it has been established that snow fences tend to fly apart in the high winds prevalent at higher elevations making snow fences difficult to use in exposed locations.

A two year study supported by the New England Regional Commission (NERC) was undertaken to determine the problems associated with snow deposition on ski slopes, as well as investigate novel techniques for snow deposition and wind control on ski slopes.

RESULTS AND DISCUSSION

A simulation facility called a wind channel or air table was constructed to allow scale models of ski trails and wind barriers to be tested. The air table used a 60" fan driven by a 7.5 H.P. gasoline engine to provide high velocity air. The air was directed over a scale model of a ski trail. Plywood sides confined the flow; however, the top was open to simulate the real case of the mountainside, where the air can move over the top without the compression that would occur in a confined wind tunnel section. Ground lime or commercial borax (#3) was used to simulate snow, greenhouse stakes (1/8" diameter) simulated trees and indoor-outdoor carpet simulated the ski trail surface. Wind velocities were measured with an Alnor velometer at various locations and heights above the trails.

The initial work on the air table consisted of determining the influence of trail shape on wind velocities near the trail surface. Straight trails into the wind have high wind velocities, which cause scouring the entire length of the trail. It is possible that straight trails can be improved if the trails are made to diverge in the dominant wind direction to act as a diffuser rather than converge as is often the case. It should be noted that because of friction from the trees on the trail sides, the velocity was lower on the trail edges and this is why snow deposits there even when the trail runs in the direction of the wind. Short shallow bends in the trail had little effect on the wind near the trail surface. In fact, there might be more scouring at the corners where the flow has to accelerate to turn the corner. Sharp corners with a finite trail length perpendicular to the wind were the only designs effective in reducing wind velocities on the trail. In this case, the loss in pressure energy to turn the corner was more than for it to diffuse through the trees or to go over the trees at the bend and hence the wind would not follow the trail. In some cases, long trails into the wind are unavoidable. In these cases, some wind protection could be obtained by leaving small groves of dense trees in the trail with avenues on both sides for skiers (Figure 1). The groves of trees will cause the wind to diffuse into the trees along the edge of the trail. The avenues must be fairly narrow, with sharp curves and the trees must be fairly dense to prevent the wind from moving around or through the blockage. Thus, the trees prevent the trail from acting like a channel for the wind.

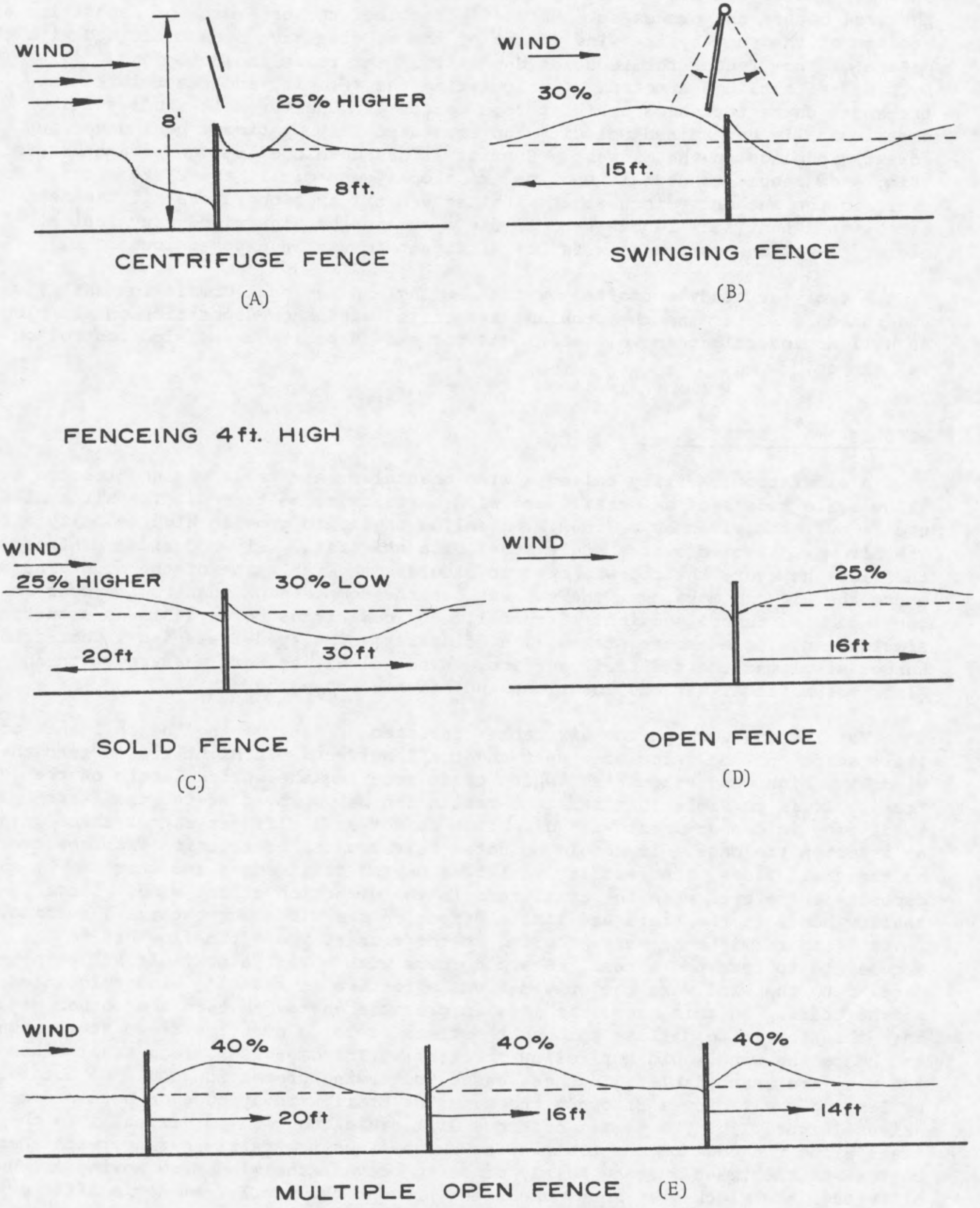


FIGURE 2 BARRIER CONFIGURATIONS TESTED DURING WINTER

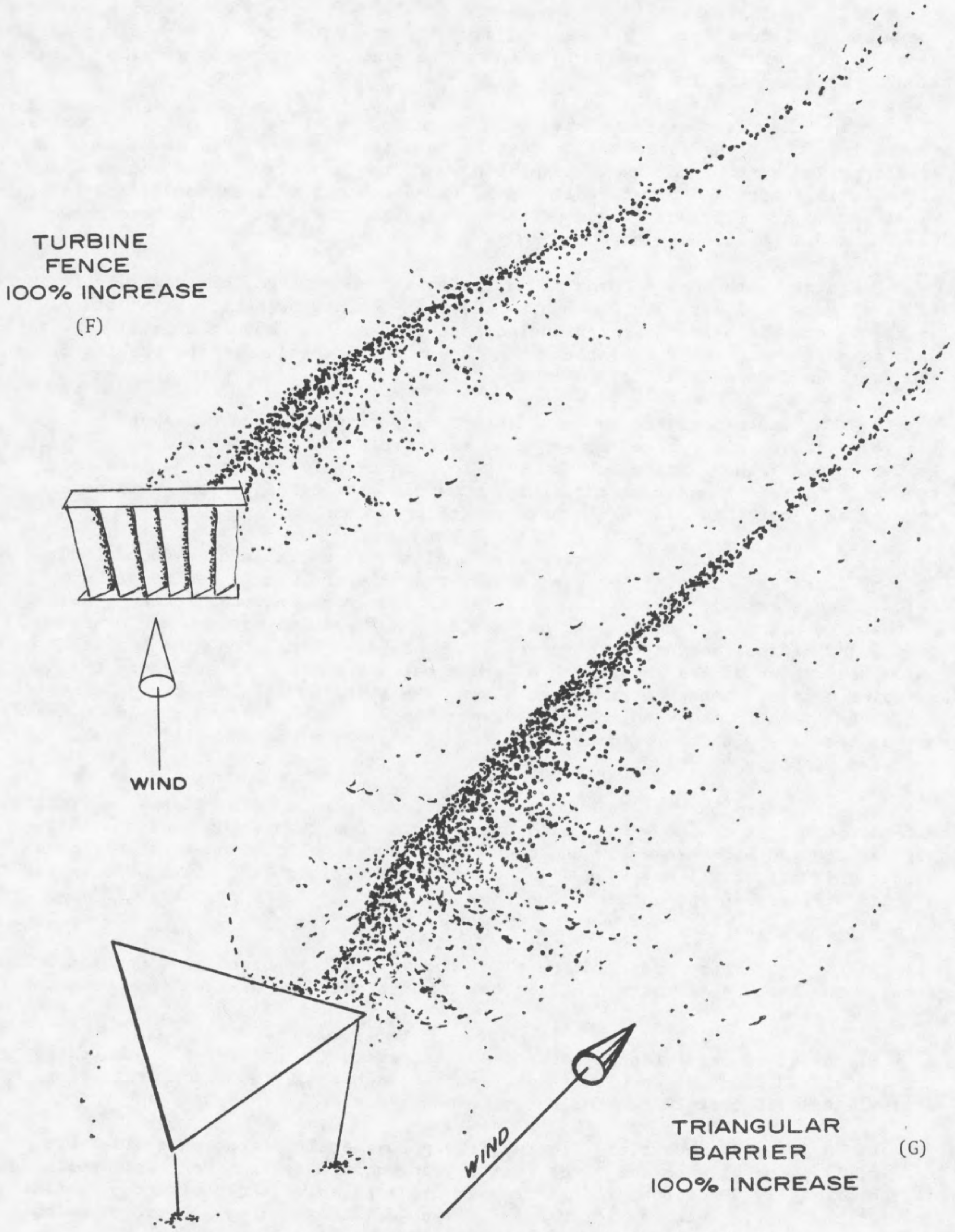


FIGURE 2 BARRIER CONFIGURATIONS TESTED DURING WINTER

Another possibility is to open up the edges of the trail and provide room for the wind to diffuse into the trees and deposit snow which can be farmed out as needed. Care must be taken not to open up the trail too much and provide increased flow in the main trail.

During the first winter tests, full scale models of several barriers conceived during the summer were erected for testing in a field in Lee, New Hampshire. The area received a number of snow storms; however, the majority of the storms came with little drifting and were followed by rain, so that a crust formed and later winds caused no drifting. These results emphasized the need to simulate snow blowing and deposition on the air table.

One storm with some blowing and drifting snow deposited approximately 18 inches of level snow fall with 30-50 m.p.h. winds from the northwest after the storm. (Note all snow depositions refer to increase or decrease above the level snow fall data taken the day after the storm when the snow had settled.) The results from the test barriers were as follows:

A. The fence designed to centrifuge snow particles (Figure 2a) and move the wind over the barrier worked somewhat as expected. The snow deposited in a narrow band in back of the barrier but was only four inches higher than the level of snowfall in the open part of the field. Changing the opening size would have some effect, but this design did not seem to be promising.

B. The swinging fence (Figure 2b) consisted of sections of plywood, four feet by four feet, mounted to swing freely from the top with a solid barrier below. There was some deposition in front but scouring occurred in back. Based on these results a new design was devised to make the wind move up and over the ground and diffuse behind the barrier. This new design has the hinge point below the center of the sheet with a weight below the hinge to stabilize the swinging member. Hence, as the wind blows, the swinging sections are at a negative angle of attack to the wind and will divert the wind upwards rather than downwards as was the case with the original barrier. The angle of attack will decrease as the wind velocity increases.

C. The solid barrier (Figure 2c) had a four inch deposit of snow in front extending 20 feet upwind. The solid barrier had some deposition near the back but was scoured 6 inches below the open field snow level for some distance downwind. This effect was noted in all the ski areas visited last winter. Whenever a solid barrier was encountered, the snow deposited in front of the solid barrier.

D. A regular snow fence (figure 2d) had very little or no snow deposition in front. The back had a four inch high drift which extended sixteen feet downwind from the fence.

E. A set of three fences located 45 feet apart (Figure 2e) had open field snow levels in front of each but had 8 inch, 8 inch and 7 inch high drifts for approximately 16 feet in back of each, respectively.

F. A triangular barrier (Figure 2f) (approximately 6 feet on a side) was made of 1/4 inch plywood set three feet off the ground in the front and inclined at approximately 30 degrees to the ground with a negative angle of attack (point lower than base). This barrier had an 18 inch drift extending 50 feet downwind.

The drift was in line with the apex and leveled off on either side to the open field level at the overall width of the barrier. This effect seems to be partially due to diffusion of the wind (reduced wind velocity) behind the barrier, but mainly due to the influence of vortices or small tornados formed along the edges of the triangular barrier.(8) This effect was noted when smoke was released in front of the barrier to make the wind patterns around the triangular barrier visible. In these studies, the wind took the smoke introduced at the leading edge of the triangle and accelerated it under the barrier while spinning the air flow in a vortex. The smoke showed that the wind behind the barrier was moving and diffusing at nearly the same angle as the inclination of the barrier.

G. A regular snow fence two rows high had a 13 inch drift extending more than 12 feet downwind. There was no drift in front.

H. A fence made like a flat row of turbine blades (Figure 2g) had no deposition in front and had a 15 inch high drift that extended downwind in back at an angle to the fence which was at the same angle as the fence boards made with the wind. Changing the angle of the boards changed the angle of the drift.

I. Plastic snow fence was used in experiments to change the porosity of trees, but did not have significant influence on snow deposition. The plastic fence was used on Cannon Mountain on a lower trail; however, in high winds the material vibrated, causing the abrasion and failure wherever it touched trees. This vibration may also cause much less effective turbulence than a fixed barrier of equal porosity, which may explain the lack of snow deposition behind the plastic fence.

The winter results tended to indicate that if snow deposition is desired in front of the barrier, a solid barrier is needed. However, if deposition is desired in back of a barrier, a porous barrier is required. This means that trees should be somewhat porous on the windward side of a ski trail and they should be relatively solid on the leeward side of the trail. The triangular barrier gave good deposition characteristics for long distances downwind and was investigated further. The advantage of the triangular shape over a standard snow fence is that large triangles may be placed above the ski trails where they would not interfere with skiers while still causing good drifting and wind protection. These triangles might be made out of light weight materials such as canvas so that they could be easily erected and adjusted. The triangles must be well supported, however, as the wind forces tend to lift them.

TRIANGULAR BARRIERS

The triangular barrier has a different mode of operation than the conventional snow fence. The triangular barrier is similar to an airplane wing and creates flow patterns in the air like those which an airplane would produce(8). As previously noted, when a triangle is oriented with the point facing into the wind and at some positive (point up) or negative (point down) angle of attack, a pressure difference is formed between the two faces, with a windward face having a higher pressure than the leeward face. The pressure difference occurs because air flowing across the leeward side must accelerate, which causes a reduction in pressure on that side. Air flowing across the windward side decelerates, which causes an increase in pressure. Due to the pressure difference, air will flow around the leading edges of the triangle, which initiates the vortices or small tornadoes which are carried downstream by the wind from each edge of the triangle (9). The vortices thus formed cause the snow particles to move in a circular pattern, perpendicular to the wind direction. They are carried by the wind and deposited where the vortices interact with each other and the ground.

The strength (size and velocity) of the vortices will increase as the angle of attack increases up to a point where the flow fails to follow the contour of the triangle and separates. Separation causes a region of highly turbulent motion, which greatly reduces the pressure difference and causes a reduction in the strength and/or possible elimination of the vortices. The angle of attack at which separation occurs is dependent upon wind velocity, and decreases as velocity increases.

AIR TABLE TESTS

Model triangles were tested on the air table described previously to determine the shape and orientation which produced the largest drift. Borax was sifted into the air stream behind the propellar and ahead of the barrier for a fixed period of time. The resulting drift was photographed and the volume of the drifted material was determined. The air table surface and weather conditions tended to affect the drifts formed by borax used to simulate snow and introduce some errors in the measurements of drift size and volume. Humidity affects the borax used to simulate snow. When the humidity is high, the borax is heavier and more adherent and gives greater than normal drift volumes. In addition, the indoor-outdoor carpet used to simulate the trail surface increases in roughness as it is used, which also increases drift volume. The boundary layer on the sides of the air table causes a drift to form along the side similar to drifting caused by trees on the side of a ski trail. This drift must be discounted when taking volume measurements. However, the general shape of the drift is not affected by the air table or weather conditions and only changes as the triangle shape and orientation change.

EFFECT OF TRIANGLE SHAPE

Model triangles were tested for the most effective shape by examining their drifting characteristics. The triangles were oriented with a negative angle of attack of 20° (point down) and with the point facing the wind; both on the ground and two inches off the ground (wind velocity of 15 mph). These results were compared to the drift formed by a standard 50% density snow fence model (3 1/2" high, 10" long) which produced a drift in scale with observed and published results for full sized snow fences.

The equilateral (10" base) and obtuse (10" base, 6" height) triangles (Figures 3a, 3b) produced nearly identical drifts which had triangular cross sections and were about seven inches wide the full length of the drift and extended 120" (from the point of the triangle to the end of the test area). The volume of snow in the drift was considerably more than in the drift formed by the snow fence.

The very obtuse triangle (15" base, 6" height) (Figure 3c) produced a wide, short, shallow drift in back when the point of the triangle was on the ground, and a longer but shallower drift with the point off the ground. Similar drifting occurred with an equilateral triangle (10" base) (Figure 3d) which had three inches of the point cut off to produce a trapezoidal shape. These shapes did not seem to produce the large trailing vortices and therefore did not produce a long drift.

The acute triangle (10" base, 13 1/2" height) (Figure 3e) produced a long, narrow drift similar to that of the equilateral triangle, but not as large. The V shaped triangles (10" equilateral with a triangular cut out on the base) (Figures 3f, 3g) produced drifts similar to that of the equilateral triangle, but smaller and they tended to erode away rapidly after they were deposited.

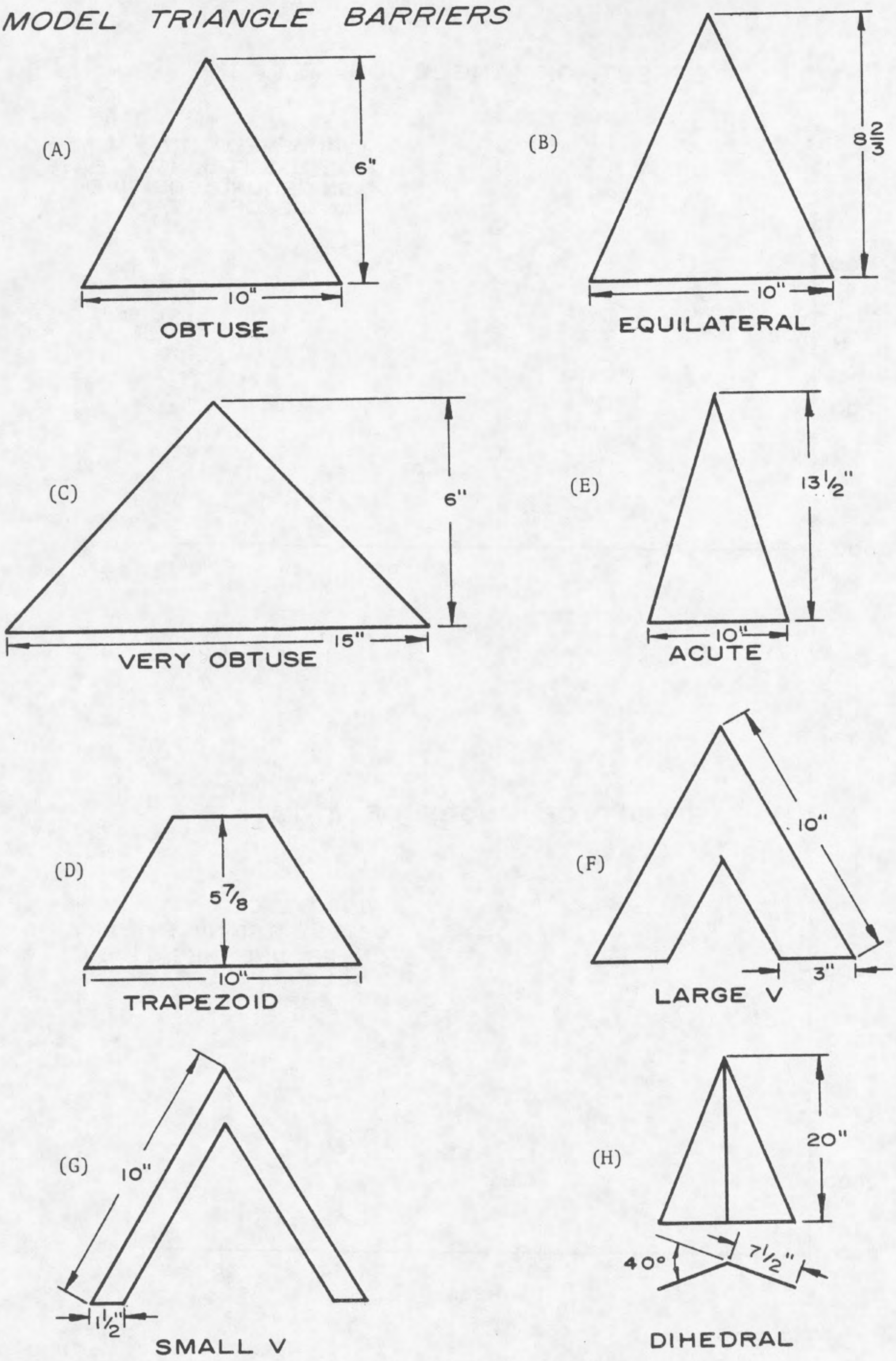
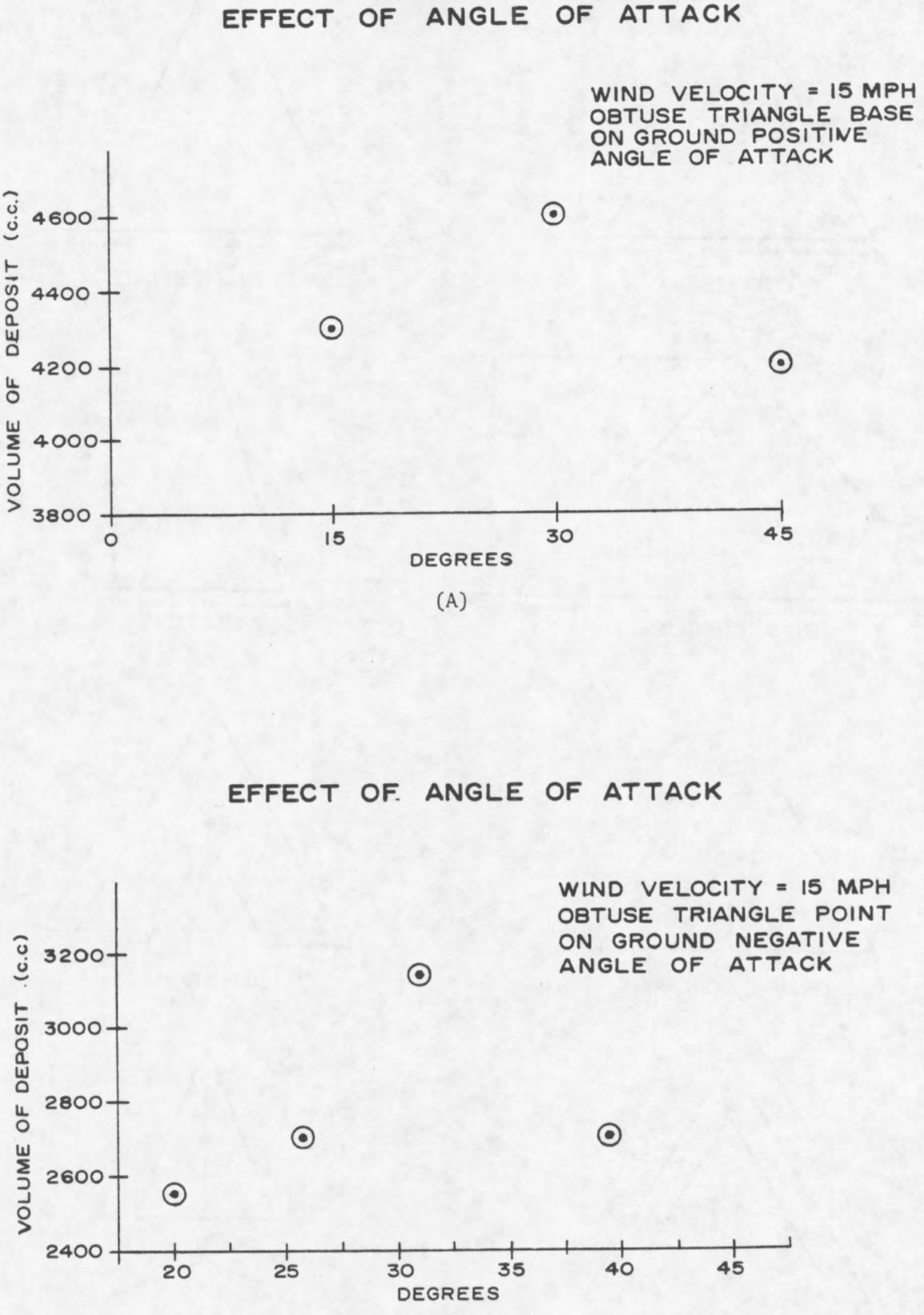


FIGURE 3 MODEL BARRIERS TESTED



(A)

(B)

FIGURE 4 EFFECT OF ANGLE OF ATTACK ON TRIANGULAR BARRIER DEPOSITION

The dihedral triangle (15" base, 20" height, with a 40° bend along the center line) (Figure 3h) produced a very small drift when placed with the concave side down and produced no drift with the concave side up. This shape may be effective where drifting is undesirable because it deflects the particles back up into the airstream.

The equilateral and obtuse triangles produced the largest drifts in these tests. The obtuse triangle gave the greatest drift volume for its surface area and is therefore the most economical for construction. Hence, further tests concentrated on this shape (10" base, 6" height obtuse triangle) to determine its optimum orientation.

EFFECT OF ANGLE OF ATTACK

The best drifting from the obtuse triangle appeared to occur at a positive or negative angle of attack of about 30° at a wind velocity of 15 miles per hour (Figure 4a, 4b). A study of the pressure differences between the top and bottom of the triangle indicated that at any angle greater than 30 degrees separation will occur. The angle at which separation occurs is dependent on wind velocity. The strength of the vortexs formed and therefore, the deposition appear to be greatest at an angle which is slightly less than the angle at which separation occurs.

The obtuse triangle was tested with both the point and the base facing the wind, for both positive and negative angles of attack. With the point facing the wind and a negative angle of attack, the single long, narrow drift was formed as before (Figure 5a). With the point facing the wind and at a positive angle of attack, a double drift formed (Figure 5b). A drift started at each rear corner of the triangle and extended to the end of the test area. The drift widened out as it extended back so that it covered a very large area and contained a high volume of material. With the base facing the wind and at a positive angle of attack, a double drift was formed as before, but it did not have as much volume as those drifts formed by triangles with the point facing into the wind. With the base facing the wind and at a negative angle of attack, no drift formed.

EFFECT OF ELEVATION

The obtuse triangle was tested to find how the drift volume was effected by triangle elevation above the ground at a wind velocity of 15 miles per hour. At a positive angle of attack of 30°, the largest volume double drifts appeared to occur with the base two inches off the ground (Figure 6a). At a negative angle of attack of 30°, the largest volume single drift appeared to occur with the point two inches off the ground (Figure 6b).

EFFECT OF HILL ANGLE

The angle of the hill does not affect the drifting, provided the angle is constant over a large area. In this case, the wind will flow parallel to the hill surface as it would on level ground. Roughness of the hill surface affects the wind velocity near the ground and has a strong effect on local velocities near the triangle which will affect snow deposition.

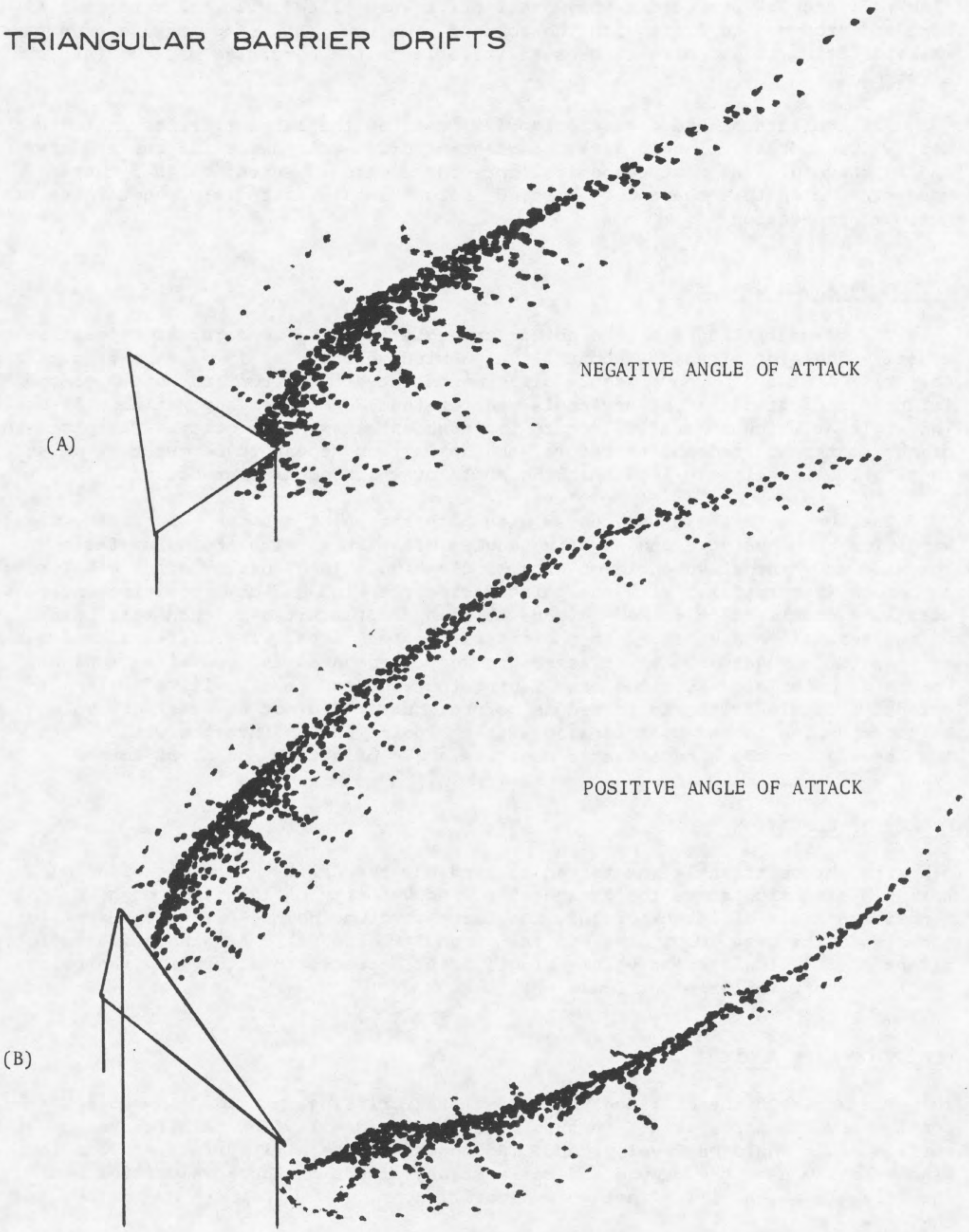
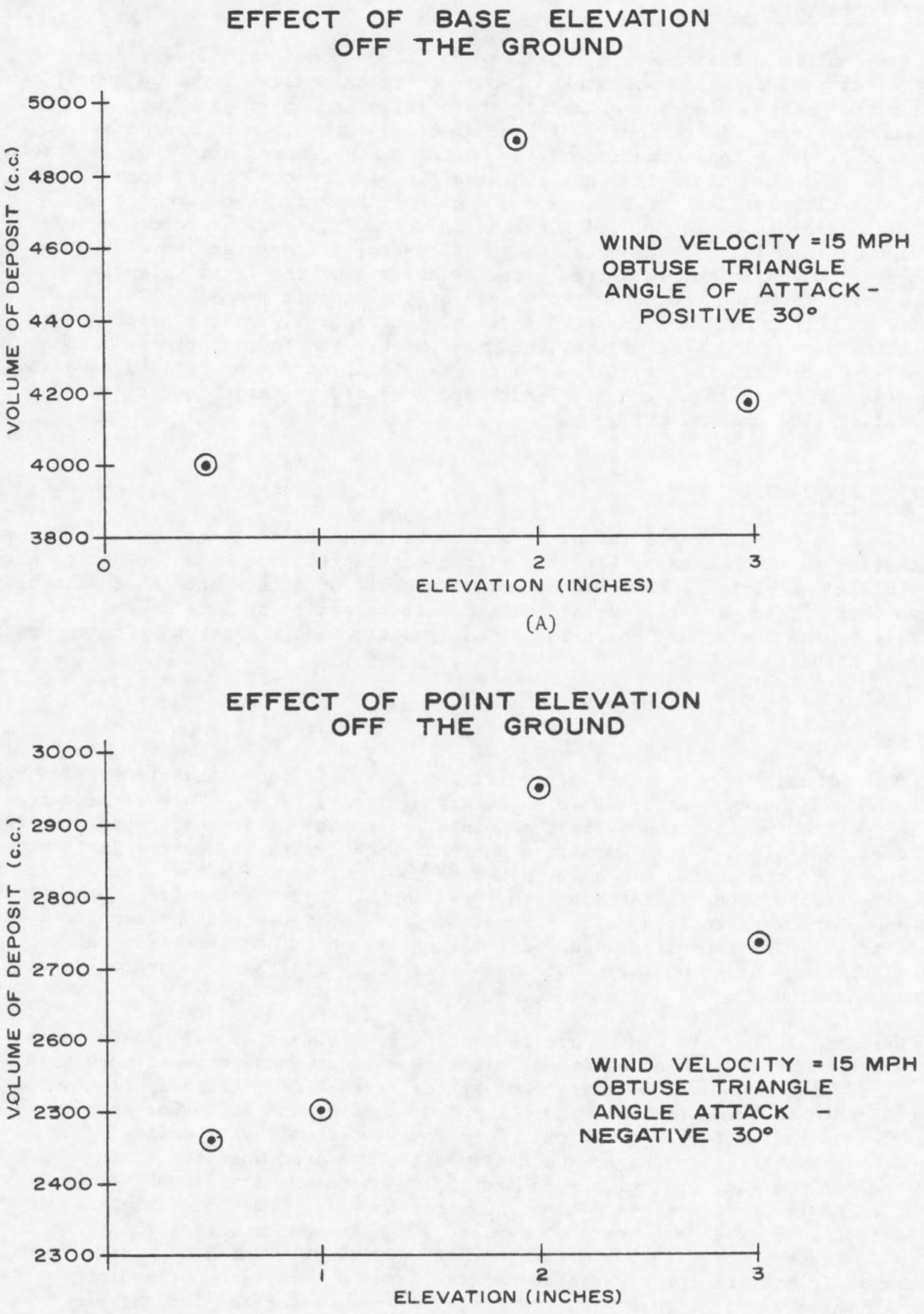


FIGURE 5 TRIANGULAR BARRIER DRIFT CONFIGURATIONS



(A)

(B)

FIGURE 6 EFFECT OF TRIANGULAR BARRIER ELEVATION ON DEPOSITION

MULTIPLE CONFIGURATIONS

Many multiple triangle and triangle-snow fence combinations were tried at a wind velocity of 15 miles per hour. Two or three triangles placed on top of each other with the base of one overlapping the point of the next gave poor results. Placing snow fences in various positions around a triangle with a negative angle of attack hindered the formation of the vortices and reduced drifting. A combination of two obtuse triangles, one 10 inches in back of the other, both at a positive angle of attack of 30°, gave a double drift which was larger than one triangle alone could produce but less in volume than drifts formed by two individual triangles. Setting the second (leeward) triangle at a negative angle of attack produced a triple drift (a double drift from the first triangle and a single drift from the second). The volume of the deposit was not significantly greater than that obtained from two individual triangles, but the drifting was more uniform over the area of influence than with most configurations. Two obtuse triangles placed side by side at a positive angle of attack of 30° and separated by a distance equal to their base length produced a very large center drift plus two smaller side drifts.

SUMMARY OF TRIANGLE TESTS

Based on the air table tests, it was concluded that the best configurations for testing on the mountains were the single obtuse triangle with the point facing the wind and at either a positive or negative angle of attack and the combination of two obtuse triangles side by side with positive angles of attack, and one triangle behind the other, the first with a positive and the second with a negative angle of attack.

FULL SCALE TESTS

This winter two obtuse triangles (20 foot base, 12 foot height) were erected on the edge of an exposed trail at Sugarloaf Mountain, Maine. They are located one 20 feet behind the other with the points facing the predominate wind direction. The first triangle has a 30° positive angle of attack with the base 4 feet above the ground and the second has a 30° negative angle of attack with point 4 feet above the ground. On Wildcat Mountain, New Hampshire, two triangles of the same size and shape were located below a straight section of trail at an exposed bend in the trail. The triangles were located in a side by side manner separated by 20 feet and each had a positive 30° angle of attack with the base approximately 4 feet above the ground.

Results so far this winter are incomplete due to the lack of blowing snow, however, some data has been obtained. It appears that whenever a triangular shape is exposed to the wind at some angle of attack, even if the triangle is not pointed directly into the wind (if the wind comes from a direction different than the triangle was set up for) a drift will form downwind from the triangle. This indicates that the triangles are partially effective even when there are variations from the optimum wind direction. The triangles on the mountains were originally set at an angle of attack of 30°. At this setting, a 4 1/2 foot maximum depth and 50 foot long drift was produced by one of the triangles on Sugarloaf and the two triangles on Wildcat. The drifts formed very quickly which may indicate the greater efficiency of the triangular barrier. The drifts were not as long as expected which is probably due to too large an angle of attack for the wind velocities present (up to 70 mph). The angle has since been reduced to about 20° and another storm is needed to test this configuration.

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