SNOW CONTROL WITH VORTEX AND BLOWER FENCES

by

Brett N. Meroney and Robert N. Meroney*
Colorado State University
Fort Collins

Proceedings of Conference on
A Multidisciplinary Approach to Snow Engineering
Santa Barbara, California
10-15 July 1988

Sponsored by

Engineering Foundation,
American Society of Civil Engineers, and
National Science Foundation

Fluid Mechanics and Wind Engineering
Civil Engineering Department
Colorado State University
Fort Collins, Colorado

---

* Professor, Civil Engineering
Director, Fluid Dynamics and Diffusion Laboratory

CEP88-89BNM-RNM-1

SNOW CONTROL WITH VORTEX AND BLOWER FENCES

Brett N. Meroney and Robert N. Meroney[1]

ABSTRACT

Blower fences (jet roofs) and vortex style blower fences were examined in a small windtunnel to examine their ability to prevent snow deposition downwind. A series of experiments were performed to evaluate optimum fence geometries, fence orientations, and comparative performance characteristics. Forty five combinations of blower-fence height and fence angle were tested to determine optimum blower fence proportions. A blower fence located 1.5 times its table width above the ground at an angle of attack of 15° appeared optimum. Additional runs were performed on a delta-wing vortex fence. The structure was constructed from an equilateral triangle oriented at a 15° angle into the wind. Tests over a range of fence heights from 0.25 to 0.75 triangle heights supported at the delta-wing centroid did not identify a strong dependence of fence performance on wing height above the ground. The vortex fence generally out-performed the blower fence tested. Scaled fences were also tested around a model house to eliminate snow deposition over driveway surfaces. The blower fences eliminated drifts which otherwise developed in the absence of protection.

INTRODUCTION

Most conventional snow fences are designed to produce preferential deposition of snow in the sheltered area behind the fence. Accumulation of drifting snow in these regions protect downwind areas through a process of attrition of particles from the air stream near the ground. An alternative approach is to devise a structure which protects a downwind region through an increase in surface scour. The table-top type blower fence is designed to accelerate the wind flow, locally by diverting the wind flow downward through a constriction between the blower roof and the ground. A vortex-style blower fence produces counter-rotating vortices which align axially with the wind and increase surface stresses downwind.

This paper reviews the physical principals and experience associated with such fences, discusses simulation concepts required to develop fence design criteria through physical modeling, and presents the results of an experimental program to optimize the size and shape of such devices.

Blower Fences

Blower fences made from panels mounted on vertical supports and inclined with the higher end toward the prevailing wind have been variously called "pupitre" or "Pultdächer" (desks or desk roofs)," "Düsendächer," "toits," "blower roofs," "snow blowers," or "jet roofs." They are used frequently when the snow-bearing wind varies little in direction, and they are especially useful when the quantity of snow is large enough to swamp the ordinary type fence.

In the winter of 1946-47, staff at the Canadian Army base at Fort Churchill, Manitobe, noted that during a blizzard the area lying underneath the wings of aircraft parked facing the wind was blown clear of snow. Subsequently, army personnel and the Department of Highways in Ontario carried out a program during the winter of 1948-49 to evaluate the performance of blower fences at nine separate locations along Canadian highways (Fraser, 1949, 1950). Conventional vertical slat snow fences were supported on steel fence posts, inclined at various angles, and arranged with the lower edge at various heights and distances from the roadway. Some 3.3 km (10,850 lineal feet) of fence were constructed at sites ranging from 0 to 5 m (0 to 17 ft) from the roadway, 0.75 to 1.2 m (2.5 to 4 ft) above ground, 30^o to 60^o inclination to the horizontal, and along flat roadway or 3 m (10 ft) deep highway cuts. Although many of the fences were buried under accumulated snow from plows, three fences kept roadway centers free in cuts normally filled 2.5 to 3.5 m deep by blizzards, and others worked well until they were plowed under.

Fraser (1949, 1950) concluded that the installations were definitely beneficial at top of slope locations and worked well at flat road locations when not plowed under. No definite relationship was determined between inclination angle, height, and effectiveness. Several other authors like Pugh (1950), Pugh and Price (1965), Mellor (1965), Schaerer (1972), and Verge and Williams (1981) mention blower fences briefly, but they conclude such devices are often difficult to support in high winds, can produce worse drifting if the wind blows in a direction opposite to that expected, and flatter inclination angle may allow snow to build up on the roof.

Blower roofs can provide effective modification or prevention of snow cornices along mountain ridges. Unstable snow cornices frequently trigger avalanches in recreation areas, and the avalanches present serious safety problems. Montagne et al. (1968) constructed ten jet roof fences along the Bridger Range in Southwestern Montana during thee winters of 1965-68 incorporating various designs, inclinations and materials. Hopf and Bernard (1963) reported avalanche control experience in the Austrian Tirol using baffles and jet fences. They concluded,

a. An efficient construction technique used a solid 2.4 x 3 m (8 x 10 ft) solid panel mounted on two upright posts by pivot bolts. The structures were guyed to the ground using no. 9 gauge wire and 1.2 m (4 ft) cement rebar anchor pins. It took about 4 hrs for two men to erect each fence at a materials costs of $25 (1968 US dollars),

b. Multiple jet roofs should be separated no wider than the width of the panel,

c. Jet roofs consisting of panels with open slats have proven less effective than solid panels; however, open slats avoid accumulation of snow on the panel top,

d. Jet roofs are best in areas where snow does not accumulate in windless storms, and

e. The most efficient inclination angle is parallel to the angle of the lee slope. Steeper angles dig out a sharp cup-shaped hollow in the snow to the lee of the structure, but a secondary cornice accumulated beyond the hollow.

Montagne et al. (1968) erected a full-sized jet roof on a level field which was not snow covered. They used cup anemometers to measure winds speeds upwind and downwind from the center of the jet roof. Downwind accelerations were maximized with inclination angles between 10° and 20°. A measured 12% increase in wind speed in the lee of the fence was associated with a 20% increase in frictional drag or scour along the ground. The researchers also repeated their study in a wind tunnel using a 1:48 scale model. Measurements over a range of wind speeds produced similar results, but percent changes in wind speed were less.

Dawson and Lang (1979) prepared a numerical simulation of jet roof geometry for snow cornice control. Their two-dimensional marker-and-cell program solved the laminar Navier-Stokes equations for regions of recirculation above the jet roof and stagnation zones along the ground. They concluded an inclination angle of -9.5° produces the minimum stagnation and recirculation regions. They recommended the fence be located at the ridge line, nearly parallel to the lee slope, with the upwind fence edge directly over the hill crest.

Another design used to remove snow is the "kolktafeln" or vertical baffles with undergaps of 1 m (3 ft) (Wopfner and Hopf, 1963). Japanese scientists report such fences incorporating air-foil shaped turning vanes are effective, but they are more expensive and difficult to maintain (Japanese Construction and Mechanical Assoc., 1987). Sometimes buildings or radar stations have been elevated above the snow surface on poles or extensible columns (Strom et al. 1962; Mellor, 1965; Sherwood, 1967). The expectation was that air accelerating beneath the structures would sweep the base free of snow. Unfortunately, stagnation regions downwind of the bluff shaped elevated obstacles produced accelerated deposition and large drifts eventually swamped the structures.

Vortex Style Blower Fence

Longitudinal vortices aligned with the wind are known to persist for great distances without dissipation. A fence designed to generate a pair of counter-rotating vortices will sweep the snow to the side away from the fence centerline. The vortices are similar to two weak tornadoes laying parallel to the ground. Tangential velocities beneath the vortices create high surface shear stresses which exceed the values required for snow movement. In the near wake the regions of highest local shear stress are directly under the vortices. Further downstream, the entrained air causes the regions of maximum shear stress to merge to the wake centerline.

Iverson et al. (1974) considered the vortices generated by a short horizontal wing suspended above a particulate surface of uniform depth. Twin eroded streaks developed downwind of the airfoil. Later the streaks merged except for a triangular particle deposit just downstream of the wing. Such vortices generated by short jet roof fences may explain their effectiveness; indeed, a series of short separated jet roof fences may be more effective than one continuous fence.

Strong vortices are known to be generated by delta-wing shaped triangles inclined at about 30° to the approaching wind field. Some inventors have suggested using such devices to channel high speed winds into wind mills (Walters et al., 1976); whereas other designers suggest using vortex generators to mix and dilute hazardous gases at ground level (Kothari and Meroney, 1982). A rotating vortex generator snow fence should be effective for all wind orientations and may provide long range downstream protection.

SIMULATION OF DRIFTING SNOW

Simple wind tunnel experiments using fine particles such as sawdust, mica, sand, borax, glass-beads, and even ice-particles or snow have yielded useful information on the shapes and dimensions of drifts near buildings, roads, and mountain ridges. Some experiments have attempted to satisfy similitude requirements, at least partially. In other experiments, modeling laws have been ignored. The exact similitude requirements for scale modeling of drifting snow problems are not met at small scales because of the large number of modeling parameters that cannot be satisfied simultaneously (Strom et al., 1962; Odar, 1965; Mellor, 1970; Kind, 1980; Iverson, 1980a, 1980b, 1981).

Many researchers emphasize the importance of modified Froude number, $Fr = U/(g(sg-1)L)^{1/2}$, where U is a characteristic wind velocity and sg is the specific gravity of the snow relative to air. But Iverson (1980a) argues that for similarity in final drift shape and growth rate a mass-transport rate parameter and an aerodynamic roughness parameter govern drifting behavior:

$\rho U^2/(2 \rho_p gH) \{1 - (U_o/U)\}$, transport rate parameter,

$A_1^2 (D_p/H)(U_*/U_{*t})^2$, equivalent roughness,

where A_1 is dimensionless threshold friction speed (Froude number with friction speed as characteristic velocity), U_o is the threshold wind speed, U_* is the surface friction speed, U_{*t} is the threshold friction speed, ρ is the air density, and ρ_p is the particle density.

Since the present study primarily was concerned with particle movement in the immediate vicinity of sharp-edged fences and buildings, an effort was made to develop reasonable approach profiles of wind and turbulence. Asymptotic drift shape was evaluated rather than growth rate or drift development time.

MODEL BLOWER FENCE AND VORTEX GENERATOR EXPERIMENTS

Three sets of experiments were performed to evaluate blower and vortex fence performance. First, a 50% porous conventional snow fence was compared to full-scale snow measurements performed by Tabler (1979) and wind-tunnel glass-bead measurements made by Iverson (1980b). Second, a series of tests were performed to examine the influence of fence dimensions on snow removal performance, and, third, a study was performed to compare relative ability of various snow fences to clear areas about a model building.

Experimental Techniques and Equipment

Experiments were performed in a small open-circuit blower tunnel, test section dimensions 20 x 61 x244 cm (Figure 1). The approach wind profile was produced by an upwind set of spires, barrier, and a surface layer of particles. Additional particles were added to the airstream at the front of the tunnel using a particle dispersal bin. A sand trap was placed at the end of the wind tunnel to collect particles moving beyond the test section. Velocity profiles were measured with a conventional Prandtl pitot-static tube and pressure transducer. Wind speeds were set using a calibrated drag sphere anemometer.

Validation and optimization experiments were performed with a fine sand of average diameter 0.115 mm (size range 0.08 to 0.2 mm), and model building studies were performed using fine detergent-grade borax powder (approximate diameter 0.1 mm). When the tunnel was run without obstacles or fences present, the 25 mm bed of particles remained flat with minor ripples (2.5 mm) over the 1 m test length in the wind tunnel. Adding particles at the beginning of the test section maintained bed depth within 3 mm.

Conventional Snow Fence Experiment

A 1:100 scale model of a 50% porous horizontal-slat vertical snow fence was placed above a 25 mm bed of fine sand. The 29 mm high fence was located 66 cm from the vortex spires, had a 25 mm subsand barrier and a 5 mm gap (16% open area) at the bottom of the fence. The wind speed at fence height was set at 4.5 m/sec (10 mph), and the model fence was allowed to accumulate sand for nine hours. Sand depth measurements were taken up- and downstream from the fence every hour.

Within 3 hours the drift had reached its average height, 1.2H at x = 6H, and after 6 hours the sand extended the drift downwind to about x = 27H. Figure 2 demonstrates that the modeled drift profile replicated the full scale snow drift measurements of Tabler (1979), the 1:25 scale measurements performed on a frozen lake-bed using real snow by Tabler (1981), and the 1:100 scale model studies by Iverson (1980) using glass-beads.

Blower Fence Measurements

A 1:50 scale model of a blower fence was installed above the sand surface about 66 cm downwind from the vortex spires. The roof width (W) was 45 mm by 153 mm long. It was supported by two vertical end plates which permitted pivoting the roof to various inclination angles (0° to 30°). The lee edge of the fence roof was placed at various heights (H) above the undisturbed sand bed, (H/W = 0.75 to 2.1). Sixteen combinations of inclination angle and lee height were examined in some 45 test runs. Each test lasted three hours, and sand depths were measured at the end of each hour out to distances 25W downwind of the blower fence.

All fences removed sand downwind and prevented subsequent accumulation. Angles greater than 22.5° tended to immediately scour out a hole immediately downwind of the fence, but then further downwind the surface was very uneven, and large drifts appeared relative to the new average depth (Figure 3). The 15° table top inclination removed great amounts of sand and left the surface much smoother and almost ripple free (Figure 4). Given a criteria based on the minimum and maximum scour which occurs over the 25W fetch examined it appears that a 15° table inclination arranged with its lee edge 1.5W above the particle surface produces maximum protection in the fence wake (Figure 5). An optimum table inclination of 15° agrees with the full-scale wind speed experiments performed by Montagne et al. (1968). Their experiment was only performed for a H/W ratio of 0.5; thus, they may have found even greater effects by raising their table top.

Vortex Generator Measurements

A 1:50 scale model of a delta-wing vortex generator was also installed above the sand surface about 66 cm from the entrance spires. The wing was formed of an equilateral triangle 102 mm on a side, (triangle height, TH = 88 mm). One tip was inclined upwind at an angle of 15°. The lee edge of the generator was placed at various initial heights above the sand bed (H/TH = 0.28 to 0.73). Only four heights were examined in some 12 test runs. Each test lasted three hours, and the sand depths were measured at the end of each hour out to distances 12TH downwind of the vortex generator.

The maximum scour produced by the vortex generator was slightly greater then than produced by the optimum blower fence, and the minimum scour measured was very similar. Over the range of generator heights examined no optimum position appeared; thus, any moderate height is suitable, but, intuitively, heights greater than 2TH seem extreme (Figure 6).

Building Area Protection Experiments

A 1:75 scale model of a typical two-story Ft Collins home was installed downwind of the entrance spires. The model included surrounding trees, fences, and an upwind house. Snow was known to drift across the front of the house and driveway for winter storms approaching from the west. In these experiments borax was used as a snow simulant. Experiments were performed without any mitigation technique, and using inclined vertical-slat model snow fences with 50% porosity, model hedges, model blower fences (15° inclination), and model vortex generators. Comparisons were made between snow patterns around the model and full-size house. Snow drifts and scour regions formed during several storms from the 1978-1980 snow seasons compared very well. Drifts appeared across the front of the house and driveway, around two Austrian pine trees just downwind of the driveway, and over the patio at the rear of the house. Scour areas occurred at the rear of the house and immediately behind the downwind corner of the front of the house.

Model snow fences and hedge rows placed along the upwind property line accumulated snow downwind; however, the drifts produced actually increased snow deposition across the front of the model house and driveway. Two blower fences, placed just upwind of the driveway, swept the driveway and downstream area completely free of particles for westerly winds. For northwesterly winds (blower fences at a 45° angle to the approach wind) the fences only cleared one/third of the driveway and permitted drifts to form across the garage doorway.

CONCLUSIONS

Properly proportioned blower fences and vortex generators provide effective protection from excessive snow deposition out to distances of 25 times characteristic fence heights or widths. Such fences perform most effectively in regions where storms approach predominately from one direction and snow falls under windy conditions. Nearby or upwind vegetation and obstructions will reduce the effectiveness of these devices.

Acknowledgements

The authors wish to express their appreciation for access to the library on snow information at the Rocky Mountain Field and Range Experiment Station, Fort Collins, collected by Dr. M. Martinelli, USDA Forest Service (Retired).

REFERENCES

Dawson, K.L. and Lang, T.E., 1979, "Numerical Simulation of Jet Roof Geometry for Snow Cornice Control," USDA For. Serv. Res. Pap. RM-206, 19p.

Fraser, C., 1949, "An attempt to control snow drifting by the use of an elevated, inclined snow fence," Research Council of Ontario REport, No. 5-2-49.

Fraser, C., 1950, "Experiments with Elevated, Inclined Snow Fence on Ontario Roads," Roads and Construction, April 1950, pp. 88-90, 115-117.

Hopf, J. and Bernard, J., 1963, "Windbeeinflussend Bauten in der Lawinen-verbauung und-vorbeugung, (Wind control structures in avalanche defence and prevention)," Mitteilunger der Forstlichen Bundes-Versuchsanstalt Mariabrunn, 60, pp. 605-681. Also see National Research Council of Canada Technical Translation 1348, Ottawa, 1968.

Iverson, J.D., 1980a, "Wind-Tunnel Modeling of Snow Fences and Natural Snow-Drift Controls," Proceedings of 37th Eastern Sonw Conference, Peterborough, Ontario, Canada, pp. 106-124.

Iverson, J.D., 1980b, "Drifting-Snow Similitude - Transport-Rate and Roughness Modeling," Journal of Glaciology, 26, pp. 393-403.

Iverson, J.D., 1981, "Comparison of Wind-Tunnel Model and Full-Scale Snow Fence Drifts," Journal of Wind Engr. and Ind. Aerody., 8, pp. 231-249.

Iverson, J.D., Greeley, R., White, B.R., and Pollack, J.B., 1974, "Eolian Erosion on the Martian Surface; Part 1: Erosion Rate Similitude," Icarus, 26, pp. 321-331.

Japanese Construction and Mechanical Engineering Association (editors), 1988, Handbook of Snow Drift Control Engineering, Morikita Publishing Co., Tokyo, 527 pp.

Kind, R.J., 1981, "Snow Drifting," Handbook of Snow: Principles, Processes, Management and Use, D.M. Gray and D.H. Male, editors, Pergamon Press, New York, pp. 338-359.

Mellor, M., 1965, "Blowing Snow," Cold Regions Science and Engineering Part III, Section A3c, AD630328, 85 pp.

Mellor, M., 1970, "A Brief Review of Snowdrifting Research," Snow Removal and Ice Control Research, U.S. Army Cold Regions Research and Engineering Laboratory, Special Report 115,pp. 196-209.

Montagne, J., McPartland, J.T., Super, A.B., and Townes, H.W., 1968, "The Nature and Control of Snow Cornices on the Bridger Range Southwesern Montana," USDA Forest Service, Wasatch National Forest, Alta Avanalanche Stud. Cent., Misc. Rep. No. 14, 23 pp.

Odar, F., 1965, "Simulation of Drifting Snow," U.S. Army Cold Regions Research and Engineering Laboratory, Research Report 174, 16 pp.

Pugh, H.Ll.D., 1950, "Snow Fences," Dept. of Scientific and Industrial Research, Road Research Laboratory, Technical Paper No. 19, 52 pp.

Pugh, H.Ll.D., and Price, W.I.J., 1954, "Snow Drifting and the Use of Snow Fences," Polar Record, 7, No. 47, pp. 4-23.

Schaerer, P.A., 1972, "Control of Snow Drifting about Buildings," Canadian Building Digest, CBD146, pp. 146-1 to 146-4.

Sherwood, G.E., 1967, "Preliminary Scale Model Snowdrift Studies Using Borax in a Wind Duct," U.S. Naval Civil Engineering Laboratory, Fort Hueneme, CA, Project No. Y-FO11-11-01-025, 16 pp.

Strom, G.H., Kelly, G.R., Keitz, E.L., and Weiss, R.F., 1962, "Scale Model Studies on Snow Drifting," U.S. Army Snow Ice and Permafrost Research Establishment, Research Report 73, 50 pp.

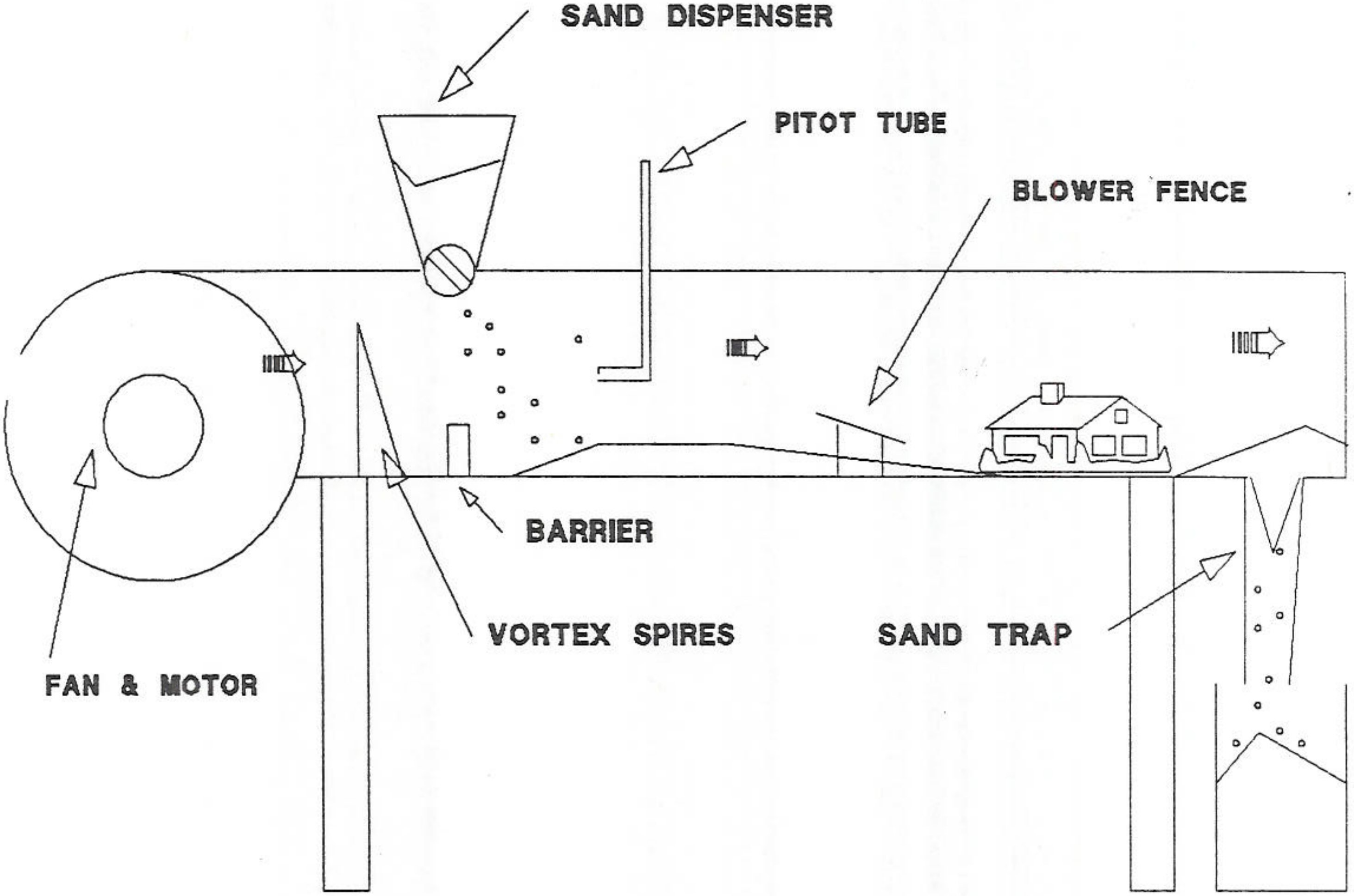
Tabler, R.D., 1981, "Geometry and Density of Drifts Formed by Snow Fences," J. Glaciol., 26, No. 94.

Tabler, R.D., 1981, "Self-similarity of wind profiles in blowing snow allows outdoor modelling," J. Glaciol., 26, No. 94.

Verge, R.W. and Williams, G.P., 1981, "Drift Control," Handbook of Snow: Principles, Processes, Management and Use, D.M. Gray and D.H. Male, editors, Pergamon Press, New York, pp. 630-647.

Walters, R.E. and Fanucci, J.B., 1976, "Innovative Wind Machines, Executive Summary and Final Report," Department of Aerospace Engineering, U. of West Virginia, 215 pp.

Wopfner, H. and Hopf, J., 1963, " Versuche mit Kolktafeln an der Schneeforschungsstelle Wattener Lizum (Tirol) in den Jahren 1950-1955 (Tests with baffles at the Wattener Lizum Snow Research Station (Tyrol) in the years 1950-1955)," Mitteilungen der Forstlichen Bundes-Versuchanstalt Mariabrunn, 60 , pp. 633-665. Also see National Research Council of Canada, Technical Translation 1348, Ottawa, 1968.


SAND DISPENSER
PITOT TUBE
BLOWER FENCE
BARRIER
VORTEX SPIRES
SAND TRAP
FAN & MOTOR

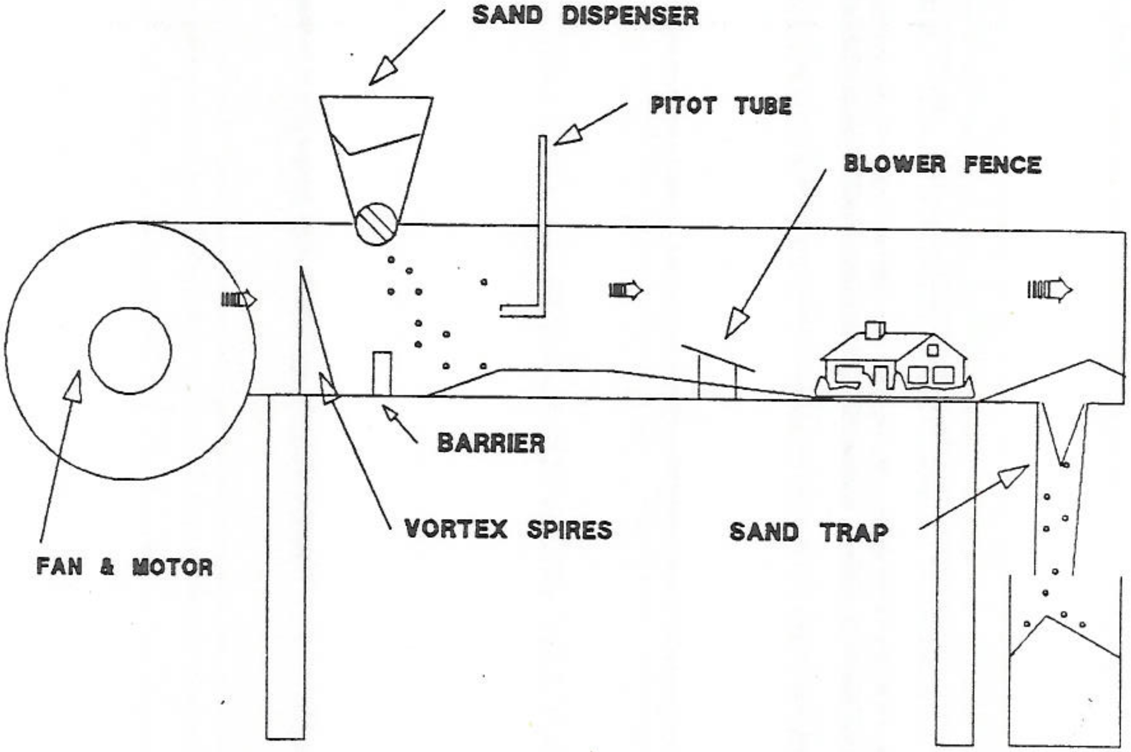


Figure 1 Schematic of open-circuit snow-drift wind tunnel

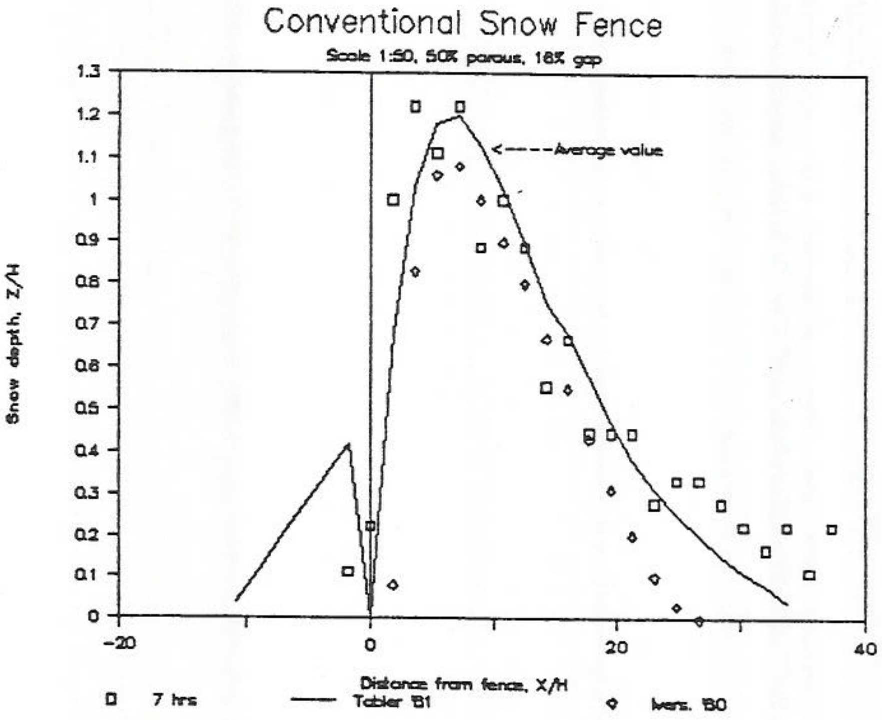


Figure 2 Particle depths deposited downwind of a 50% horizontal-slat Wyoming type snow fence with a 16% undergap.

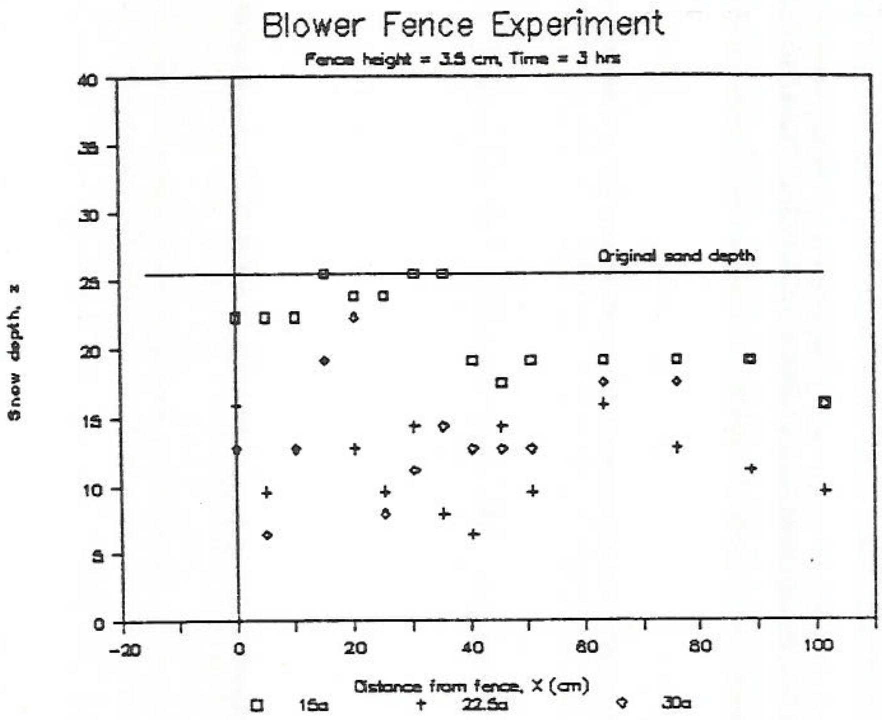


Figure 3 Blower fence performance at 3.5 cm height, various table-top inclination angles.

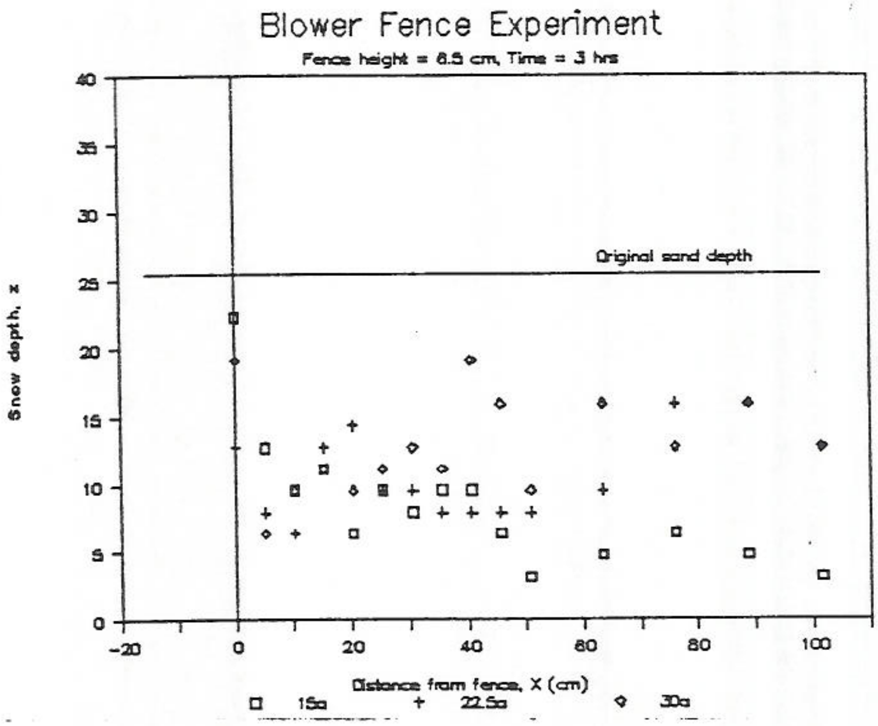


Figure 4 Blower fence performance at 6.5 cm height, various table-top inclination angles.

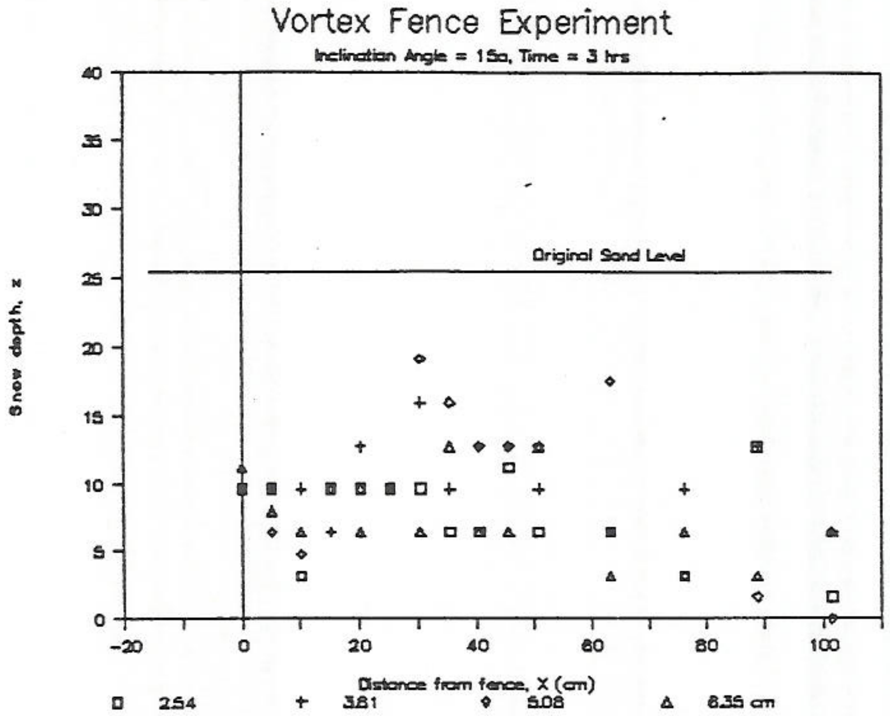


Figure 5 Vortex fence performance at various delta-wing heights.