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A COMPARATIVE ANALYSIS OF WIND-TUNNEL AND ATMOSPHERIC AIR-FLOW PATTERNS ABOUT SINGLE AND SUCCESSIVE BARRIERS

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Abstract--Atmospheric wind velocities were measured aft of a single and a series of three successive snow fences and compared to velocities measured aft of models of the fences placed in a wind tunnel. Results indicate the wind-tunnel approach gives a reasonable estimate of the effectiveness of full-scale surface barriers under atmospheric conditions. It is also shown that a series of three successive barriers is not enough to obtain a beneficial accumulative ground effect. A general lessening of velocity with distance traveled over the successive barriers indicates, however, that an accumulative effect might be obtained in a system containing a larger number of successive barriers extending for a great length. The barriers are shown to increase the velocity fluctuations of the wind from two to nine times at different locations aft of a single barrier. Maximum fluctuations in a series of successive barriers were found to occur at the 0.5-ft elevation aft of the second barrier.

Introduction--This study compares results from field and wind-tunnel investigations for one phase of the wind-erosion problem, namely, the use of artificial barriers. Field investigations of the wind-erosion problem and of methods for its control are perhaps the most obvious approach; they have, however, the disadvantages of high cost, dependence on weather, and inapplicability of the data to all regions. These disadvantages have led to the use of wind-tunnel methods. Qualitative evaluation of wind-tunnel data is a most perplexing problem. The primary objectives of this study were to determine: (a) whether the effect of surface barriers, such as windbreaks, on the atmospheric wind could be evaluated in a wind tunnel using models; (b) the accumulative effects on the air flow with successive barriers; (c) the effectiveness of barriers when approached by oblique winds; (d) the effects of single and successive barriers on the velocity fluctuations or eddies formed aft of each barrier; and (e) the effectiveness of the snow fence selected for this study.

Experimental equipment--The atmospheric wind study was conducted on an ungrazed Buffalograss pasture near Wakeeney, Kansas, in the Spring of 1953. The pasture had a uniform slope toward the south giving the wind an unobstructed approach for a distance of several miles. The roughness of the surface remained relatively constant throughout the study. Slat snow fence four feet high with a density of approximately 40 pct was attached to steel posts spaced 20 ft apart and placed on the location as shown in Figure 1. The orientation of the snow fence took advantage of the predominance of south-southwest winds. A 60-ft or 15-height spacing of the barriers was maintained throughout the experiment. A center stake position was used when measuring perpendicular winds. Positions to either side of the center line were for oblique winds.

The laboratory experiments were conducted in a wind tunnel described previously [ZINGG and CHEPIL, 1950]. The working section was a 16-ft length beginning 36 ft downwind from the fan. The floor of the tunnel was covered with sieved gravel, 1/6 to 1/4 inch in diameter. A turbulent boundary layer several inches deep was developed beyond the 36-ft point. Four galvanized tin model snow fences, each three feet long, were built on a scale of one inch equals one foot. These fences were placed in the tunnel singly and in groups of four. The spacing interval of 15 heights used for the atmospheric studies was maintained in the tunnel.

Velocities in the field were measured at 0.5, 1, 2, 4, and 6 ft above the ground elevation. All velocities except the unobstructed atmospheric wind were measured with Pitot tube-alcohol manometer combinations. The unobstructed wind was measured and recorded with Friez conical three-cup anemometers and a rebuilt triple register approximately 100 yards windward and away from the fence.

Procedure--Selected atmospheric winds with average velocities of 13.1 to 24.1 mph at the six-foot height were measured. Replicate velocity traverses were made aft of both the single and successive barriers under conditions of perpendicular and oblique wind directions. The unobstructed wind velocities were recorded simultaneously. In addition, 14 samples of open wind were taken with each Pitot tube-manometer combination over ten-minute periods to provide check data.

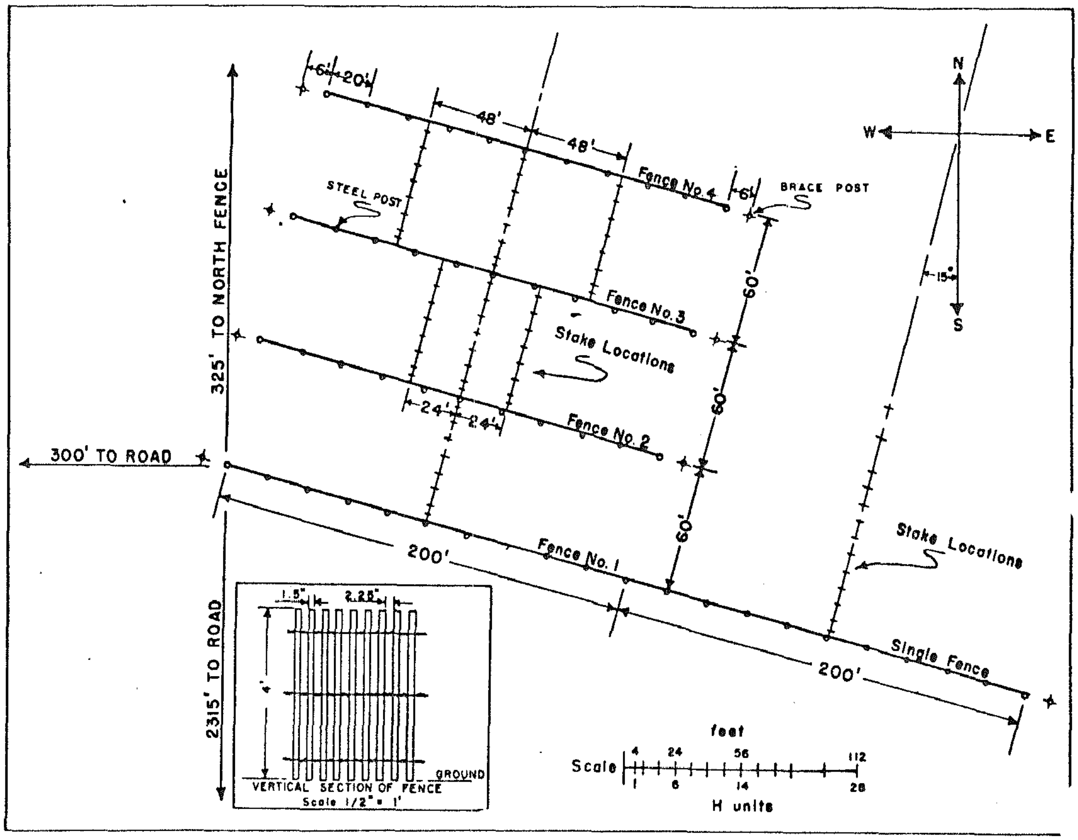

Fig. 1--A map of the snow fence location used to study air-flow patterns

A complete velocity traverse consisted of taking instantaneous velocities at 30-sec intervals for ten-minute periods at 13 locations aft of the single fence and eight locations aft of each successive barrier. Three Pitot tube-manometer combinations were placed abreast at each station aft of the single fence. For successive barriers one instrument was placed at corresponding locations aft of fences 1, 2, and 3. All velocities were secured simultaneously and related to the corresponding ten-minute open-wind velocity.

Procedures for the wind-tunnel study were identical to those of the field with the exception that no oblique wind data were obtained, and velocities were measured at 12 vertical heights at 18 locations aft of the single fence. All tests in the tunnel were run in duplicate at wind speeds of 17.5 and 27.6 mph as measured in the center of the tunnel. These velocities were slightly higher than the 13.1- to 24.1-mph velocities existing for the atmospheric wind tests. Previous wind-tunnel studies of air-flow patterns about vertical plates [WOODRUFF and ZINGG, 1952] have shown, however, that the ratio of the velocity aft of the plate to the velocity at the same location in the clear tunnel is constant irrespective of the level of wind movement. The flow pattern in terms of this ratio, therefore, would not be affected by the magnitude of the velocities used.

Check data--Check data were obtained to determine whether operators, time lag, or some other variable could consistently cause one instrument to be read differently from another. The combined results of all check readings consistently show the following average ratio with respect to the anemometer: 1.017, 0.921, and 0.937 for instruments 1, 2, and 3, respectively. All data were adjusted, therefore, in accordance with these factors.

Effect of barriers on the air-flow pattern--The effects of the barriers on the air-flow pattern are shown in Figures 2, 3, and 4. These profiles were obtained by plotting the dimensionless ratios z/H and V_f/V_o, where

z = elevation above surfaces upon which barriers were placed
H = height of snow fence (four inches in model, four feet in prototype)
V_f = velocity aft of fence (V_f for atmosphere is ten-minute average)
V_o = velocity in open tunnel or unobstructed atmospheric wind

Vertical and horizontal distances on the profile maps are shown in terms of barrier heights H.

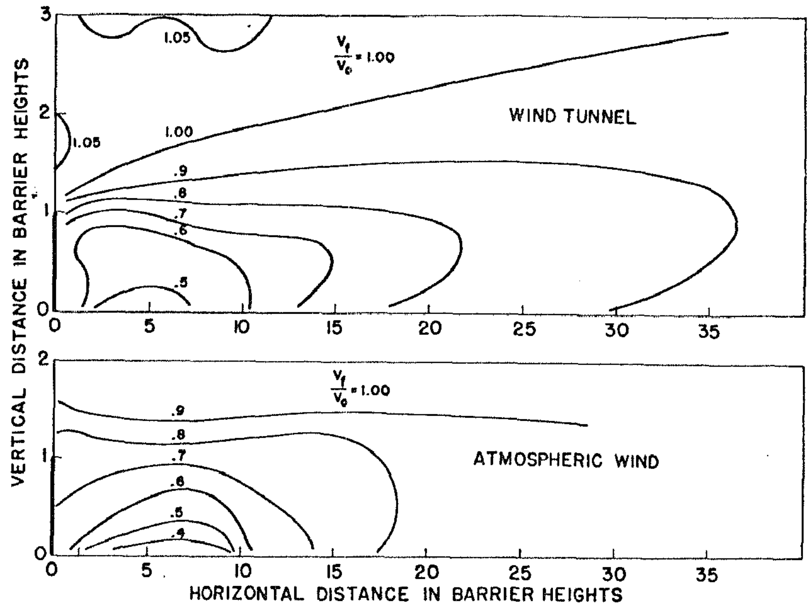

Fig. 2--Velocity ratios V_f/V_o obtained in vicinity of a single snow fence placed in the wind tunnel and in atmospheric winds

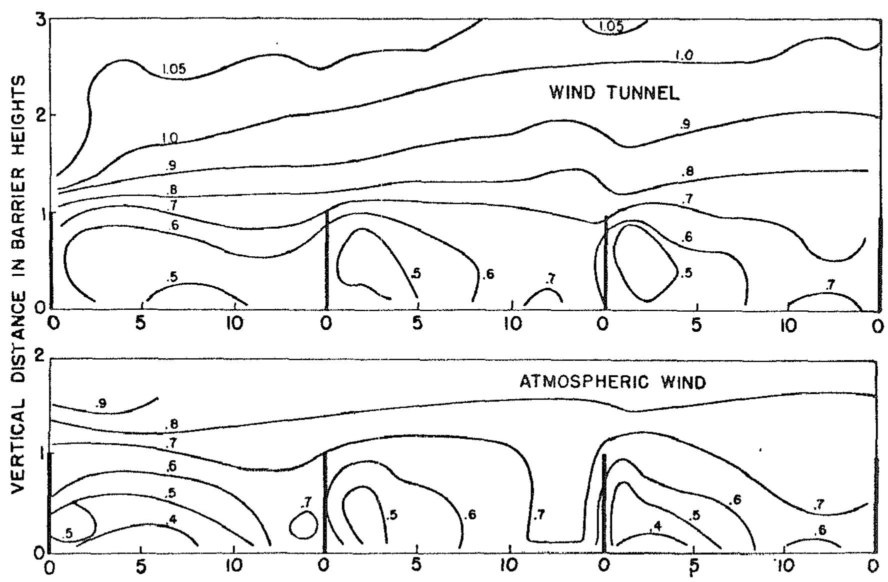

Fig. 3--Velocity ratios V_f/V_o obtained in vicinity of four successive snow fences placed in the wind tunnel and in atmospheric wind

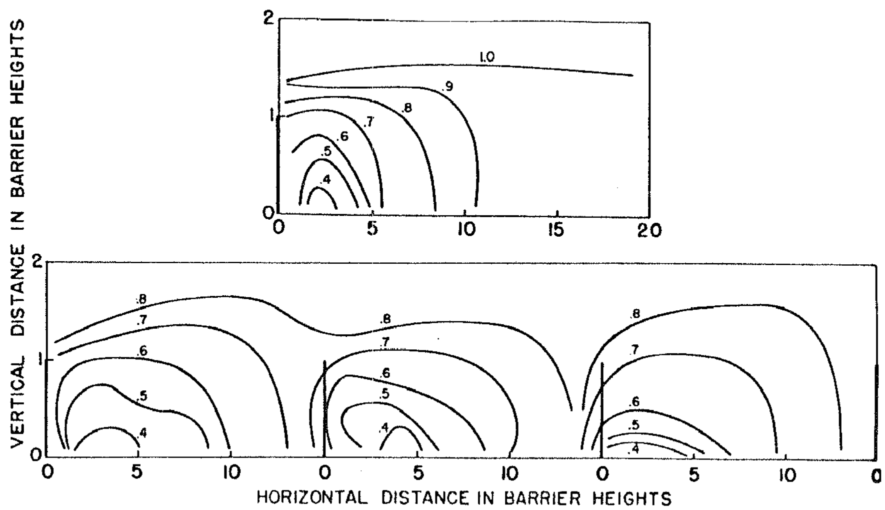

Fig. 4--Velocity ratios V_f/V_0 obtained in vicinity of a single and four successive snow fences placed in oblique atmospheric winds

In general, the wind tunnel and atmospheric profiles are nearly the same behind both the single and successive barriers (Fig. 2 and 3). The extent of influence of the barriers at a height of 0.1 H is similar in the model and the prototype. The contour lines for the single fence are the averages of seven trials in the atmospheric wind and two trials in the wind tunnel. The successive fence profiles are averages of four field trials and two wind-tunnel trials.

The patterns in Figure 4 are for oblique winds aft of the single and successive barriers. They are averages of five southeast winds for the single fence and of one southeast and one northwest wind for the successive fences.

Effect of barriers on velocity fluctuations--The coefficient of variation $\sigma/\bar{u}$, where σ is the standard deviation of the instantaneous 30-sec velocities about the mean $\bar{u}$ for a ten-minute period, was used to gage the magnitude of the fluctuations. The curves of Figure 5 were obtained by plotting the quantity $\sigma/\bar{u}$ with respect to z, the height above the ground. Curves are shown for open wind and

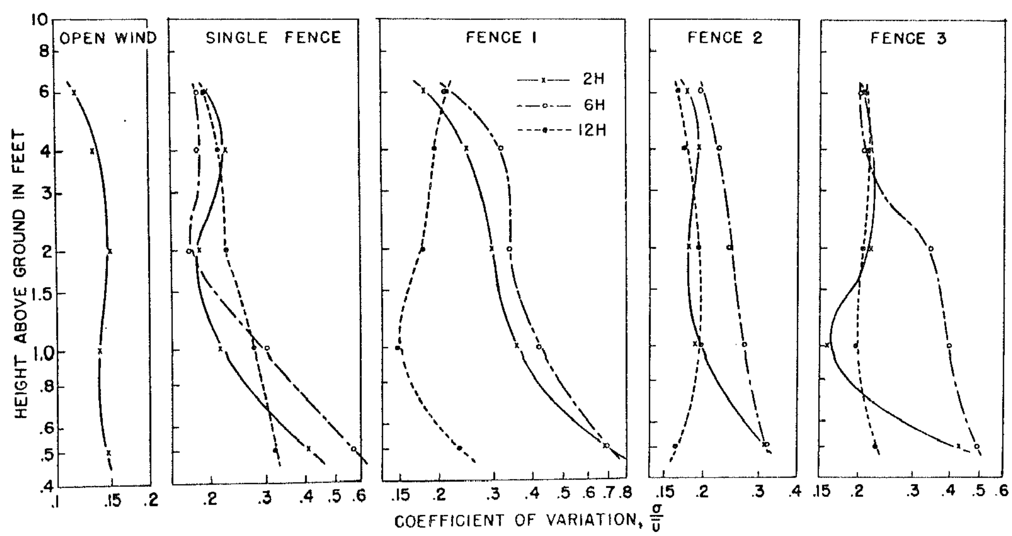

Fig. 5--A plot showing the coefficient of variation $\sigma/\bar{u}$ at various heights for open winds and for winds aft of single and successive snow fences for one wind from 10h 00m to 17h 25m on May 28, 1953

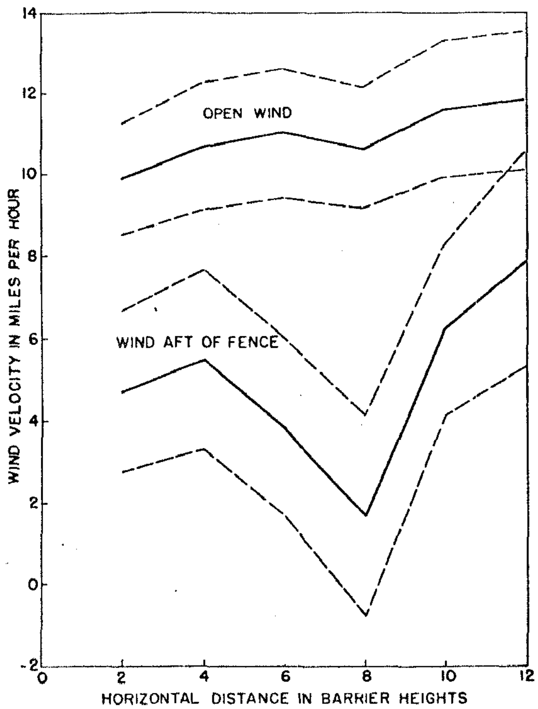

Fig. 6--A comparison of average, maximum, and minimum velocities at the 0.5-ft elevation for open wind and locations aft of a single snow fence; velocities used were obtained from 16h 25m to 17h 25m on May 28, 1953

for locations of 2 H, 6 H, and 12 H aft of the single and each successive barrier for one day of testing.

Average, maximum, and minimum velocities for both open wind and locations aft of the single barrier at the 0.5-ft elevation are shown in Figure 6. The maximum and minimum velocities were calculated from the velocity fluctuation data.

Discussion and conclusions--The results indicate that wind-tunnel approaches give reasonable estimates of the ground protection afforded by surface barriers under atmospheric conditions (Fig. 2 and 3). Statistical standard error of difference between means tests applied to tunnel ratios and to atmospheric ratios for both single and successive barriers showed no significant difference between means of the entire patterns in either case. This overall similarity of results between tunnel and atmosphere demonstrates rather close correspondence of behavior between model and prototype, even though the so-called 'model rules' were not strictly adhered to. Values of the Reynolds number, using the barrier height as the characteristic length, ranged from 48×10^4 to 88.2×10^4 for the atmospheric tests and from 5.3×10^4 to 8.4×10^4 for the tunnel tests. Previous studies using plates placed in a turbulent boundary layer [WOODRUFF and ZINGG, 1952] and artificially roughened pipes [ROUSE, 1938, pp. 241-244] have shown, however, that at this range of Reynolds numbers the drag coefficient becomes independent of the number, thus inferring similarity of flow patterns.

Interpretation of the results of the tests to determine possible accumulative effect from the use of successive barriers is dependent upon the vertical zone being considered. Results between the fences in the zone from the ground to the height of the barriers for both the tunnel and atmosphere actually indicate slightly more ground protection aft of the upwind barriers than aft of the downwind barriers. On the other hand, all the ratio lines above the barriers tend to rise in the interval extending from the first to last barrier (Fig. 3). This would indicate an adjustment toward a lower velocity above the fence with distance. A continuation of this trend over a larger number of successive fences would probably mean that the effect would extend down to the height interval between fences, thus giving an accumulative effect from use of successive barriers. In view of these results the following conclusions may be drawn: (1) Three or four successive barriers are not enough to create a beneficial accumulative surface effect on the air flow. (2) An accumulative effect for a system containing a larger number of successive barriers is indicated.

The results leading to the first conclusion are similar to those obtained by NAGELI [1943] in making measurements over two sets of three successive shelter belts. He indicates a progressively lessened protection aft of the belts in a downwind direction for a set of young belts 5.5 m high. He also shows the third belt in a series of three older belts ten to 12 m high offers the least protection and the second gives the most protection. Previous studies of air flow about shelter belts or other barriers to the wind flow have not included a sufficient number of successive barriers to substantiate the second conclusion. It appears reasonable, however, when the fences are considered to be roughness elements of great magnitude affecting the wind flow as do smaller surface roughness elements, that is, the separation boundary is moved up an appreciable distance above the ground leaving a quieted zone in the rougnness wake.

The results of the oblique-wind tests shown in Figure 4 indicate that the single barrier provides approximately one-half the protection obtained when the wind approaches the barrier perpendicularly. The protection from successive barriers is lessened by about two barrier-heights