Wind Machines

90 and 15 bhp machines compared for frost protection at Riverside

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Frost protection tests in the winter of 1951–52 at Riverside were run in 36 nights with wind machines of 15 bhp—brake horsepower—90 bhp, and 100 bhp engine driving a 33′ diameter propeller.

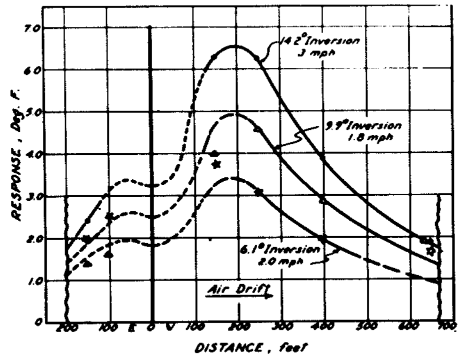
The tests revealed that under Riverside conditions the 15 bhp machine at 7½° downpitch angle does not have enough power to take advantage of strong temperature inversions.

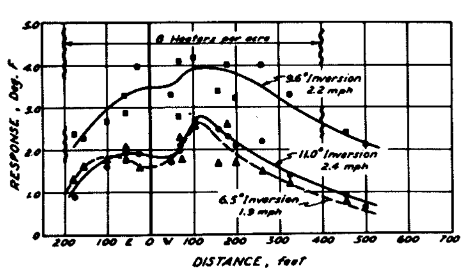
Using multiple wind machine protection for 2° F rise, it is estimated to take at least three 15 bhp machines to replace one 90 bhp machine.

The 15 bhp multiple wind machine protection would be a nearly uniform response while the 90 bhp machine would give a large percentage of 3° F and 4° F protection.

Full rotation provides frost protection over larger areas than oscillation when the smaller machine is used.

The combination of eight heaters per acre with a 15 bhp machine is about 1½° F better than the wind machine alone, and this heater support is needed when a 3°-protection is required.





Variation of temperature response versus distance along the line of airdrift. *Top:* diagram for the 1,050-pound thrust machine showing three curves of response lines nearly proportional to inversion. *Bottom:* diagram for the 240-pound thrust machine giving the curves of response for two inversions, showing very little gain from increased inversion. The top curve represents the combined response from small wind machines plus eight heaters per acre.

A good spacing of multiple 15 bhp machines is about 400′ by 550′.

The wind machine propeller sets in motion a stream of air which is actually a free jet before it reaches the tree tops. The outline of the jet is a cylindrical cone with the propeller located in the cone about three propeller diameters from the apex. The included angle of this cone is about 24°, and is independent of the origin of the jet, such as a nozzle or propeller. The cross-sectional area of the jet increases directly as the square of the distance. Therefore, the volume rate of flow increases directly with the distance. Since this increase in volume rate of flow must come from the surrounding air—which is drawn into and mixed with the rest of the jet—a free jet is a good mixing device.

As a result of the increased volume rate of flow and decreased velocity along the axis, the momentum—actually the rate of passage of momentum—remains constant throughout the entire length of the jet. If a flat plate, large enough to cover the whole cross-section of the jet, is placed in the jet anywhere along the axis, the force of the jet on the plate is the same no matter where the plate is placed along the axis. This force is equal to the thrust of the propeller. Therefore, thrust is the most significant measure of jet effectiveness. This single force, which can be measured at the tower, takes into account all the variations due to power, rpm—revolutions per minute—propeller diameter, and efficiency.

For the jet itself, all conventional turning-type power units are thrust units. Since thrust per horsepower can be increased by decreasing air-jet velocity—which involves larger propellers and more expensive transmissions—the best selection of propeller rpm and diameter depends on the minimum cost per pound of thrust.

The mean velocity of a stationary jet in free air decreases directly with distance from the apex of the equivalent jet dispersion cone.

When obstructed by trees, the decrease may be two or more times as rapid because of the forced broadening of the jet. The turning jet in free air also slows down more rapidly than the stationary because it encounters extra resistance in always moving sideways, biting into new air.

Helicopter blades on the right are 2¼ times as large as the standard propeller blades on the left and had a uniform turning speed 4½ min./360°, with no cold area at base of tower. The average of five tests in a 6.9° F inversion show the 2° F response from 200′ updrift to 400′ downdrift.

The spiral in free air has a characteristic geometric shape, the size of which can be described by some distance from the tower to the spiral blast after some characteristic time interval such as ⅛ turning period.

Inside the orchard where tree interference reduces the spiral, such measurement still provides a fair description of the shape of the spiral in the orchard. This can be used as an indication of tree interference comparing identical machines in an open young orchard and in old and dense orchards.

The machine tested had 15 bhp, 900 rpm electric motor with 9′ diameter two-bladed propeller—a thrust estimated at 240 pounds. The shaft was 32′ above ground, had a downpitch of 7½°. The steady turning times were adjusted to standard 4½ min./360°; 9 min./360°; and a fast travel of 2¼ min./360°.

The maximum temperature rise for the standard turning speed was slightly over 2½° F in a 6° inversion—temperature difference 40′ to 7′. This occurred 120′ downdrift. The distance to 1° F temperature rise was 350′ downdrift and less than 200′ updrift. The small machine did very little better in an 11° inversion.

In comparison, last year's test on the

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Relationship of Thrust and Shaft Horsepower for Wind Machines.

Well-proven propeller formulae give the following equation:

$$T = C\sqrt[3]{P^2D^2}$$

where T is the thrust of the propeller, C is a constant which depends only on the blade shape, pitch setting and air density, P is the shaft power and D is the propeller diameter.

This shows that for a given thrust, shaft power and propeller diameter can be traded on even terms—if the diameter is doubled, the power can be cut in half. One thing that the formula does not show is the great reduction in shaft rpm that goes along with such an increase in propeller diameter.

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90 bhp machine—1,050 pounds measured thrust—showed that the response in an 11° inversion was 50% better than in a 6.1° inversion. The poor gain by the small machine is due to its weaker penetrating power under the strong stability condition. Tests elsewhere indicate that a greater downpitch angle increases temperature response, but with reduced area.

When the small wind machine was used in combination with eight heaters per acre, the extra response was about 1½° F. This is equal to the gain reported last year for the big machine with 8½ heaters per acre. The 3° F total response for the big machine extends from 200′ updrift to over 700′ downdrift, while for the small machine the 3° F combined response extends from 100′ updrift to 350′ downdrift.

The 3° F response lines transverse to the air drift—for the small machine—are much less than the downdrift distance so the area proportions are about four to one. Under more severe conditions the big machine plus 8½ heaters per acre has a considerable area above 4° F response while the small machine plus eight heaters barely reaches the 4° F line.

Few tests have been run with two or more wind machines running simultaneously. The distance from the main recording station to the half-way point between machines is so great that few specific observations are available.

These observations show on the line transverse to the air drift more than 2° F rise where the response from a single machine is 1° F. This indicates that a fair estimate of combined response in overlapping patterns can be made by superposing two single machine response patterns. Overlapping the single patterns at the 2° F response line for a 90 bhp, 1,050-pound thrust, single-motor machine created a combined pattern with at least 4° F response midway between two machines spaced 700′ apart across air-drift. In this pattern a band exceeding 2° F rise was 600′ deep in the line of moderately fast air drift at Riverside.

It has not yet been determined whether overhead temperatures can be maintained full strength with a succession of wind machines in the line of drift, but estimates can be made assuming only small change in overhead temperatures.

On this basis superposition of dual response patterns in line of drift at the 1° F band depth indicates that a spacing of 950′ in line of air drift would provide orchard protection of at least 2° F at the coldest point between the four machines.

Thus the multiple protection indicates 16 acres for 90 bhp or 5.7 hp per acre—50% better than the 10½ acres of 2° F minimum protection afforded by a single machine. This pattern contains large percentages of 3° F and 4° F protection.

For the 15 bhp, 240-pound thrust, machines the advantage of multiple installation is more striking compared with single machines, but still calls for much closer spacing than is current practice.

Superposing the response patterns matching where each response would be 1¼° F, the transverse spacing would be 400′ and the in-line depth of 1° F response—on the half-way line between machines—would be 550′. This four-machine pattern is very uniform being nearly 2° F over most of the area. Thus with multiple installation the frost protection is five acres per machine—3 bhp per acre. This is very much better than the single machine which gives 2° F protection for only one acre under Riverside conditions.

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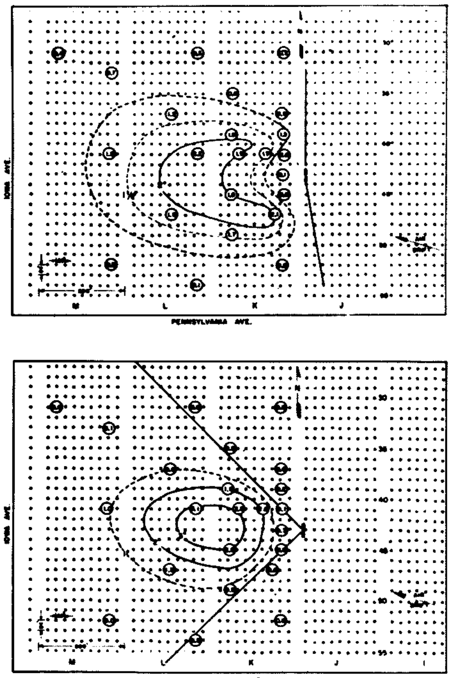

Area response for oscillating wind machines—240-pound thrust. *Top:* The 190° oscillation machine with a turning speed of 9 min./360°. Note *a*, the completely unprotected area under the machine, *b*, the small—0.7 acre—area of the 2° F response when the inversion was 13.7° F, and *c*, the maximum temperature response which is ½° F less than for full rotation. *Bottom:* The response to the 90° oscillation in a 15.4° F inversion with 2¼ min./360° turning speed. Again, the area directly under the machine is without protection. The area of 2° F protection is 0.9 acres. The maximum response is a little greater than for full rotation.

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Temperature response to wind-machine action. *Left:* a single 1,050-pound thrust, 90 bhp motor turning in the 4 min./180° downdrift and 1⅓ min./180° updrift. *Right:* a single 240-pound thrust, 15 bhp motor, turning uniformly 4½ min./360°.