

Wind Machines

1953 report on frost protection tests in California citrus groves

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Two or four large wind machines running together provided a greater temperature response per machine than one alone in citrus frost protection tests made in Riverside during the 1952-53 winter. The responses depended on the spacing of the machines.

Multiple installation of 72 bhp—brake horse power—turning-jet machines showed weak combination effect for the 600' spacing. The left graph on this page shows that the combination effect was good, however, on the same spacing for one machine of 72 bhp and the other 93 bhp. Furthermore, the right graph on this page shows that the 4° F band between these two was raised to 5° F when two more 72 bhp machines were added 600' further updrift. All these large machines turn through the westerly 180° in four minutes and the easterly 180° in 1 1/3 minutes and the spacing is closer than usual because of the strong natural cold-air flow at Riverside, but in the Satcoy area—with big machines 1,320' apart—

heaters have to be lit early between the machines. This means that here the separation is so great there is only a slow radial outflow from complete rings which quietly meet instead of cross agitation by intersecting jets.

A study of the effect of choice of propeller diameter on the over-all cost of frost protection shows that propellers, or fans, much larger in diameter than those being used at present, can be more economical. For any given area of protection, such machines will cost more to build because of the greater expense of the larger propellers and of the addition of reduction gears to provide the low-speed, high-torque drive required. The saving in over-all cost comes from lower power and demand charges which, over the years of operation, will tend to offset the higher first-cost. Another advantage of the large propellers is that they will be much quieter in operation. The performance of cooling-tower fans without enclosures was found to be inefficient.

In making a preliminary choice of blade design for a wind machine propeller a good figure-of-merit is thrust coefficient divided by the three-fourths power of the power coefficient. The thrust and power coefficients are characteristics of the geometrical shape of the blades. They are somewhat similar to the lift and drag coefficients of an airplane wing. Since they are relatively independent of size and speed, they can be determined quite satisfactorily from laboratory tests of a scale model or of the full-size propeller at reduced speed and power such as arranged for at Davis.

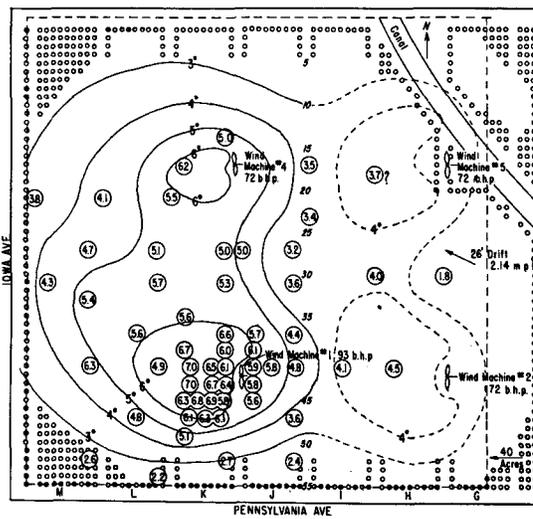
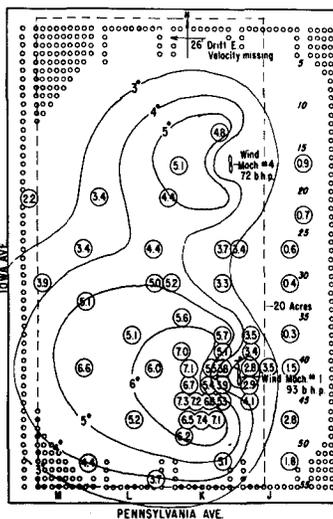
This figure-of-merit—intermediate between the ratios for given revolution-per-minute, and given diameter—takes into account, very roughly, propeller efficiency and the propeller and reduction gear costs. The final choice of fan design should rest on detailed analyses—including the estimated performance and cost—of several different preliminary designs. It appears at present that the optimum design of fan probably will have two blades of sheet metal construction. The blades should be rather narrow for their length, have at least a moderate amount of taper toward the tip, and should employ a low-cambered, low-drag airfoil section.

Tests with fixed three-blade helicopter wind machines showed very high response at the base of the machine but the area enclosed by the 2° F response line was smaller than that produced by the small turning-jet machine tested last year.

The machine tested this year—the Therm Retain—was a vertical shaft helicopter wind machine, with three 10' blades, each set at 45° above horizontal. There was a remarkable 8° F response at the machine and the 2° response line covered about 3/4 acre in a 12° F inversion—difference between temperatures at 40' and at 7' above ground. For the 18 bhp input this figures 24 hp per acre.

The California tests confirm pioneering work done in Australia with a fixed two-bladed flat helicopter machine and the Australian conclusions are of considerable value to California research workers and growers.

The Australian design used an 11 hp 21' diameter propeller blowing straight down, turning 147 rpm 25' above ground. Their 1951 report showed 0.46 acres with 2° F response or better. They found, however, that by tilting the axis 62° from the vertical, the area protected 2° F increased 58% to 0.73 acre. This best response for a fixed blast figures 15 bhp per acre. The 62° tilt corresponds to a down-pitch of 28°, and when they followed California practice and rotated the tower top 360° in one minute, the 2° protection area increased to 1.34 acres—namely 8.2 hp per acre. Probably a greater area would have shown the 2°-or-

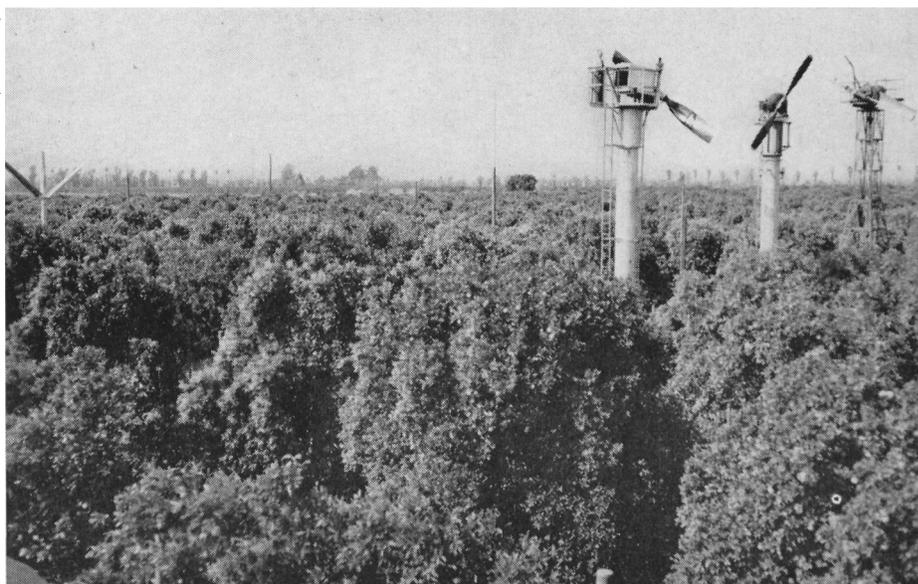


Left. Plot of temperature response from two large, single-motor wind machines 600' apart in 20 acres of citrus where the inversion was 13° F. Note the 4° F band of protection bridging across between machines. Because of the strong cold-air drift at the Citrus Experiment Station all these machines turn 180° in four minutes with the drift and 180° in 1 1/3 minutes when opposing the drift. **Right.** Plot of average temperature response from four large, single-motor machines operating simultaneously in 40 acres of citrus at Riverside when the inversion was 11° F. Note that the two 72 bhp machines on the right act almost independently but serve to raise the minimum temperature between the next two machines to 5.0° F. The 2° F response line was outside the 40 acres equipped with recording electric thermometers. Although this appears to be adequate protection, heaters had to be lit throughout this orchard twice in February, 1953.

more response had the turning speed been slower because they had a good high-thrust design.

Australian tests comparing response in a deciduous orchard with the above findings for citrus showed an increase of 78% of area within a rise of 2° F in the deciduous orchard when the base temperature rise was 8° F, presumably in an inversion of 10° F to 12° F. Since these results of fixed helicopter type machines have also been confirmed in tests in England, it seems clear that fixed machines spreading the air the whole 360° in all directions simultaneously inherently have a more limited area of 2° response than the turning-jet machines. Probably the best explanation of the advantage of the turning jet—which carries a much longer distance—is that the beneficial effect of forced heat transfer during the time of blast lingers in quiet air for the few minutes between blasts.

In a weak inversion, 6° F, the 4.3° F temperature rise at the base of the Therm Retain was 3/4 the inversion, and the acreage covered by a fixed degree rise of 1° F was less than that for the 12° F inversion tests almost in the proportion of inversion decrease. The 2° F area was less than proportionate. A stronger inversion than 12° F cannot, however, be expected to increase the area covered in direct proportion, because the Australians found a maximum area response limited in strong inversions apparently by the increased tendency for the warm air to rise. To investigate the physical barrier between the protected area and the surrounding colder orchard a rough test was made with a bubble-producing apparatus. A sharp angular up-flow 50' to 70' from the machine was found, showing that the outflowing warm air



The four wind machines tested in 1953. The 93 hp machine reported is between the two with large propellers whose tests are not completed. The other 72 hp machines are not in view. The fixed helicopter machine is visible above the trees at the extreme left. Three of the eight masts for measuring overhead temperatures and velocities are also visible.

was riding up over the surrounding, cold orchard air.

No tests were made at Riverside on multiple installations of helicopter-type machines but again the Australian report can be referred to for a test with two fixed helicopter machines run simultaneously and individually. No interference was found at a machine spacing of 240 feet. This means that there were cold spaces between machines when there was one 11 bhp machine for each 1.3 acres.

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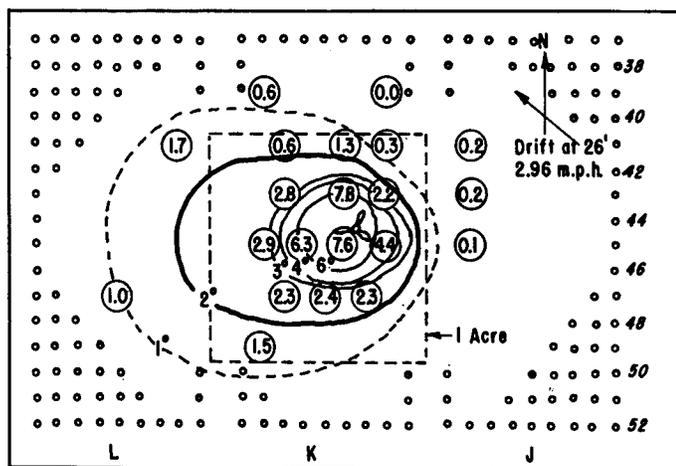
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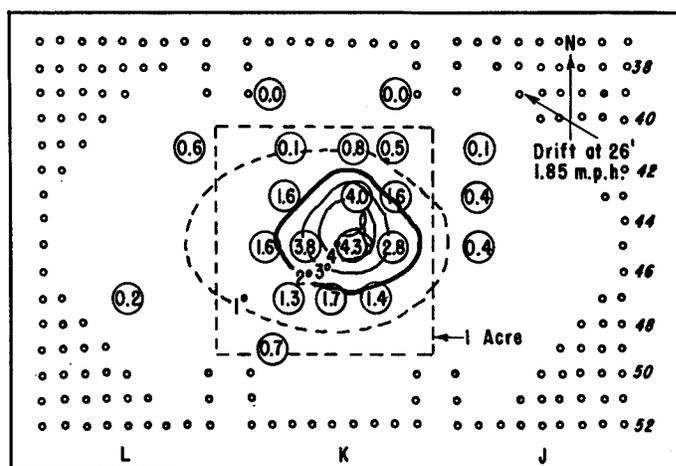
C. E. Barbee, Associate Specialist, and H. B. Schultz, Assistant Specialist, Department of Agricultural Engineering, co-operated in the field work of this study.

The above progress report is based on Research Project No. 400-U and on the 1952 report by D. E. Angus, Commonwealth Scientific and Industrial Research Organization, Melbourne, Australia.

The Therm Retain Wind Machine tested in the studies reported here, was generously loaned by the manufacturer.



PENNSYLVANIA AVENUE



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Left. Plot of average temperature rise around an 18 bhp fixed three-blade helicopter machine in a mature citrus orchard at Riverside. The air at 40' above ground was 12° F warmer than at 7'. A very strong response was found at the base of the machine but only 3/4 acre protected 2° F or more. Right. Plot of average temperature rise around the fixed helicopter machine in a weak inversion, 6° F, showing that the 1° F response line corresponds to the 2° F in the graph on the left. However, the maximum temperature at the base is a higher proportion of the inversion.