Development of a Citrus Removal Device Using Oscillating Forced Air

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THE annual value and yield of the Florida citrus crop averaged 264 million dollars and 145 million boxes between 1960 and 1970 (reference 2). During the same period, annual production costs remained relatively constant while the per box cost of picking increased by 75 percent (Brooke 1970 and Spurlock 1971). In an effort to slow or halt this upward trend of picking costs, mechanical harvesting concepts have been under development over the last few years (Hedden et al. 1969). The concept discussed in this paper is intended for the harvest of citrus fruit destined for processing.

INITIAL DEVELOPMENT

The development of an oscillating, forced air concept for citrus fruit removal began in 1961 at the Agricultural Research and Education Center at Lake Alfred (Jutras and Coppock, 1963). Basically, the test machine (Fig. 1) discharged a 1-ft wide, vertical column of air into the tree. In the discharge, horizontal vanes were pivoted about their upstream edge and oscillated through an included angle of approximately 60 deg. This tended to create an oscillating, air blast in any exposed part of the tree. Air velocities between 8,600 and 10,000 fpm at the discharge, and 50 to 80 oscillations per minute, resulted in fruit removals as high as 95 percent in grapefruit. It was estimated that approximately 1 hp-hr of energy was required to remove a 90-lb box of fruit. Between 1963 and 1967, this same machine was tested to determine its ability to remove fruit and its effect on subsequent fruit yields (Whitney 1968 and 1970). Data from a 4-year experiment indicated maximum removals of 70 to 75 percent in oranges and 85 percent in grapefruit. Generally, subsequent yields were reduced about 5 percent in early and midseason fruit and 12 percent on late season fruit. The estimated energy input per 100 lbs of fruit removed was 1 hp-hr in grapefruit.

Also in 1963, FMC Corporation started developing the first of three machines which utilized the oscillating, forced air concept. In the subsequent discussion, these machines will be referred to as FMC-1, FMC-2, and FMC-3.

FMC-1

FMC-1 was tested in 1963 and 1964 and is shown in Fig. 2. Two, engine-driven, 44-in. vane axial fans forced approximately 120,000 cfm through a rectangular discharge 17 ft high. In most tests, the discharge width was 10 or 12 in. Percent removal tests were conducted to investigate different mechanisms for directing and oscillating air at the discharge to obtain optimum fruit removal. These mechanisms were vertical plates, horizontal plates, and wobble plates.

Tests with FMC-1 were made with either a total of two or four passes, respectively (one or two from each row middle), per tree at 1/2 mph ground speed. This was equivalent to an average total air blast exposure time per tree of 50 or 100 sec, respectively, with tree spacings of 20 ft in the row.

Wobble plates were tested initially. They were mounted on a rotating shaft which was positioned vertically and centered in the air discharge. The plates were elliptical in shape with their minor axis perpendicular to the shaft and the major axis forming an acute angle with the shaft. As the shaft rotated at a constant rpm, the discharged air was

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FIG. 1 Equipment used at the Agricultural Research and Education Center at Lake Alfred to develop an oscillating, forced-air stream.

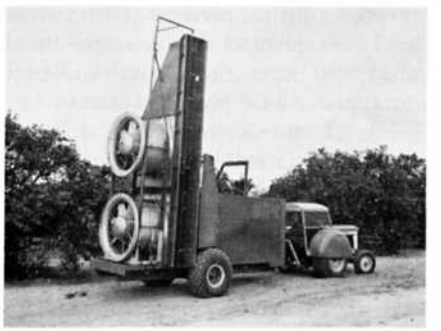

FIG. 2 FMC-1 with vertical plates.

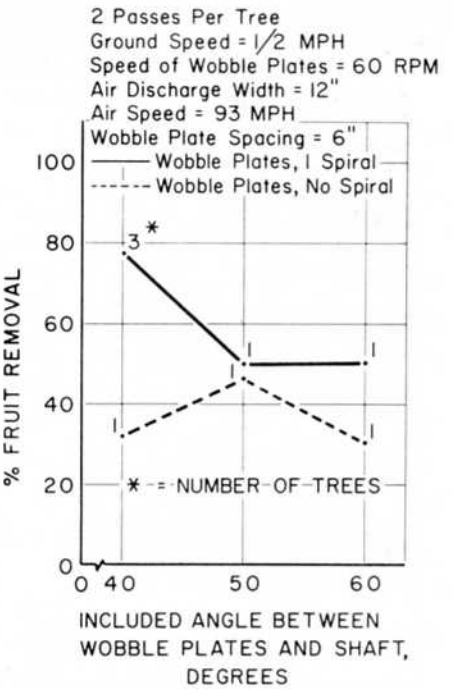

FIG. 3 Effect of included angle between wobble plates and shaft and wobble plate spiral of FMC-1 on percent removal in Valencia oranges (4/17-19/63).

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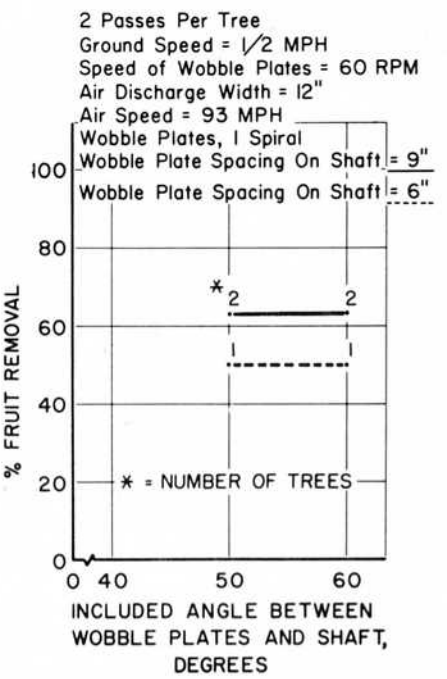

FIG. 4 Effect of included angle between wobble plates and shaft and wobble plate spacing of FMC-1 on percent removal in Valencia oranges (4/17-19/63).

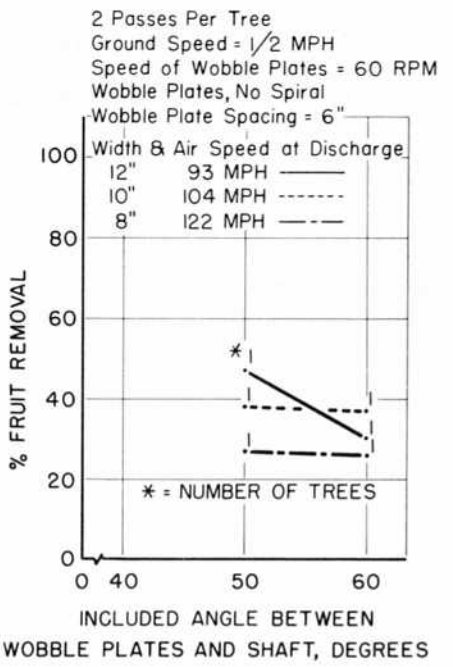

FIG. 5 Effect of included angle between wobble plates and shaft, air discharge width, and air speed at discharge of FMC-1 on percent removal in Valencia oranges (4/17-19/63).

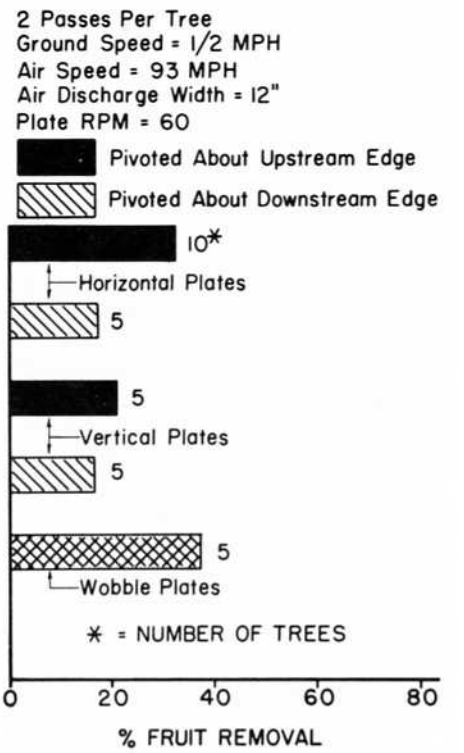

FIG. 6 Effect of type of plates on FMC-1 on percent fruit removal in Pineapple oranges (12/9-19/63).

alternately directed upward and downward. As with the oscillating horizontal plates described above, this tended to create an oscillating air blast in any exposed part of the tree.

Figs. 3, 4, and 5 show some of the initial fruit removal results in Valencia oranges. It should be pointed out here that the fruit removal data collected on the FMC-1 were not conclusive, but exploratory in nature to show trends. Fig. 3 shows the effect of angle between wobble plates and shaft and the spiral arrangement of the plates. With no-spiral, all plate minor axes were in the same vertical plane. With one-spiral, the minor axes of the plates were spaced equiangular about one revolution of the shaft. In effect, this represented one-spiral of a helix. One-spiral wobble plates performed slightly better than those with no-spiral. The 40 deg angle between wobble plates and shaft gave better removal than 50 deg or 60 deg. Fig. 4 shows that a 9-in spacing between plates resulted in better removal than did 6 in. With the no-spiral plates, better fruit removal performance was indicated (Fig. 5) with a wide discharge and lower air velocity as compared to a narrow discharge and high air velocity.

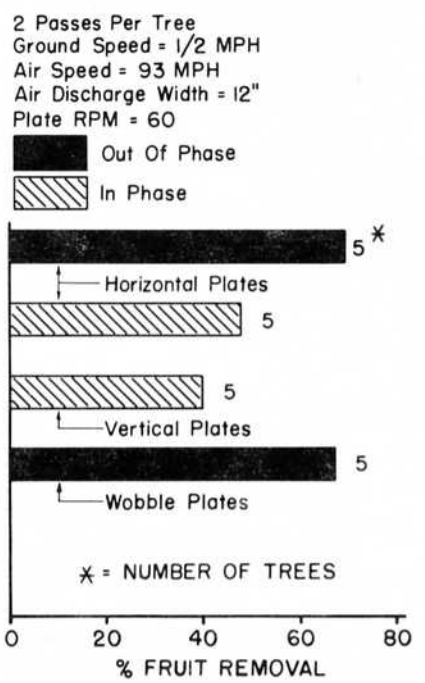

FIG. 7 Effect of type and phase of oscillators on FMC-1 on percent fruit removal in Marsh grapefruit (1/6-17/64).

Late in 1963, performance of vertical, horizontal, and wobble plates were compared on the FMC-1 in Pineapple oranges. Wobble plate performance was slightly superior (Fig. 6). Also, pivoting vertical or horizontal plates upstream removed a higher percentage than when they were pivoted downstream. In all subsequent tests, the vertical and horizontal plates were pivoted upstream.

Fig. 7 shows a slightly different arrangement tried in Marsh grapefruit. The horizontal plates were operated both in-phase and out-of-phase. In-phase, the angular orientation of all plates about their pivot shafts was identical at any given time. Out-of-phase, the angular orientation of each adjacent plate was different at any given time. More specifically, the plates were oriented equiangular about their pivot shafts so that the topmost and bottommost plates were always one cycle out-of-phase with respect to each other in their total oscillation (up to down to up). In-phase operation with the vertical plates was analogous to that of the horizontal plates. Performance of out-

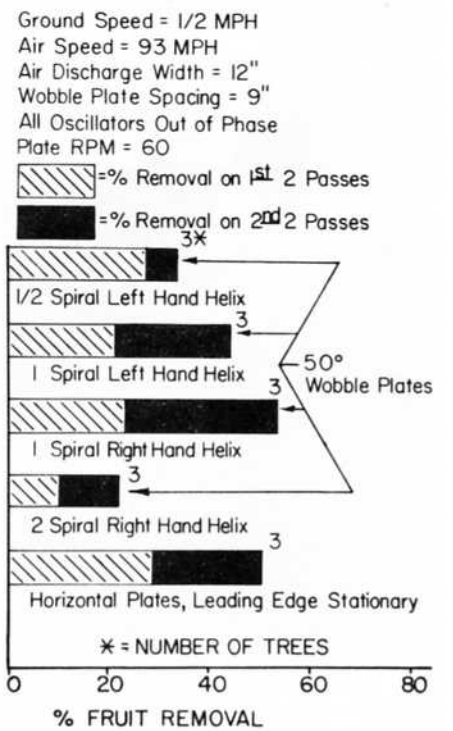

FIG. 8 Effect of number of spirals, type of helix, and type of plates on FMC-1 on percent fruit removal in Valencia oranges (4/2-8/64).

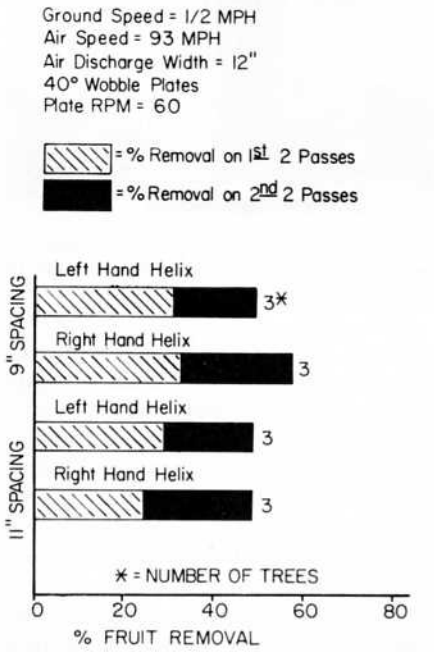

FIG. 9 Effect of direction of helix and wobble plate spacing, and number of passes of FMC-1 on percent fruit removal in Valencia oranges (4/9-13/64).

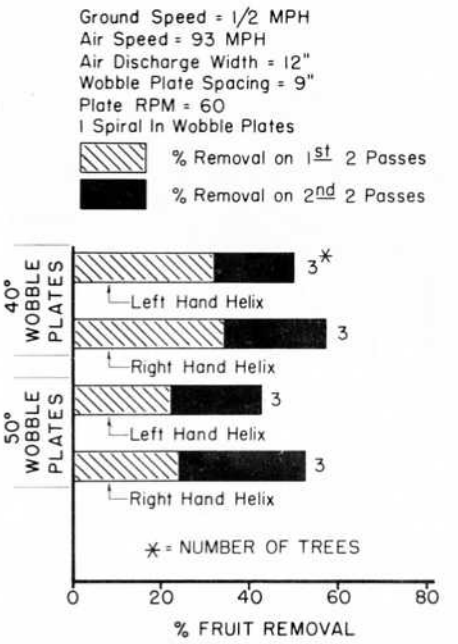

FIG. 10 Effect of number of passes, direction of helix, and included angle between wobble plates and shaft of FMC-1 on percent fruit removal in Valencia oranges (4/2-10/64).

FIG. 11 FMC-2 showing "wobble plates" in air outlet.

of-phase horizontal plates was comparable to the wobble plates and superior to in-phase horizontal and vertical plates. Fig. 8 compares the performance of different wobble plate arrangements and horizontal plates in Valencia oranges in 1964. The one-spiral wobble plates removed a higher percentage of fruit than did other wobble plate arrangements and was comparable to that of the horizontal plates. In Fig. 9, similar removal results are depicted for wobble plates with 9- and 11 in. spacing. Slightly higher removal was indicated in Figure 10 for 40 deg wobble plates.

Summarizing the results with FMC-1, the one-spiral wobble plates performed better than those with 2-, 1/2-, and no-spiral. Fruit removal with one-spiral wobble plates was comparable to horizontal plates, but superior to vertical plates. Both horizontal and vertical plates were pivoted about their downstream and upstream edges. Higher fruit removal was always associated with the latter arrangement. Fruit removal was better with a greater distance between wobble plates.

FMC-2

FMC-2 was constructed because a greater air discharge height was desirable for tall trees. It was tested in the 1964-65 season and is shown in Fig. 11. Air was forced through a rectangular discharge (10 in. wide by 20 ft high) by three engine-driven, vane axial fans. Wobble plates were mounted 9 in. apart at an included angle of 50 deg with their vertical supported shaft. Fig. 12 shows some results relating wobble plate shaft speed and percent removal. The most extensive tests were conducted in Pineapple oranges. 60 to 70 rpm provided a slightly better removal than did the higher and lower speeds for both two and four passes per tree. In Marsh grapefruit, rotating the wobble plate shaft at 70 or 80 rpm gave comparable results. Performance in Valencia oranges was best a 60 rpm with both two and four passes per tree.

Percent removal of the FMC-2 was greatly affected by its ground speed. Fig. 13 shows some results in Hamlin and Pineapple oranges. Removal in Hamlins at 1/6 and 1/4 mph was comparable at 91 percent. At 1/2 mph removal dropped off considerably to 62 percent. In Pineapple oranges, removal was slightly higher at comparable operating conditions of FMC-2. Four passes increased removal by 10 percent to 20 percent over that for two passes. In Fig. 14, grapefruit removal was approximately the same at 1/4 mph and 1/2 mph after 4 passes per tree. Results of removal in Valencias were similar to those in Hamlins.

Air speed at the discharge of FMC-2 affected its removal potential somewhat. Fig. 15 shows that optimum removal in Pineapple oranges was at air speeds of approximately 100 mph. Similar results were obtained in Valencias at a wobble plate shaft speed of 70 rpm.

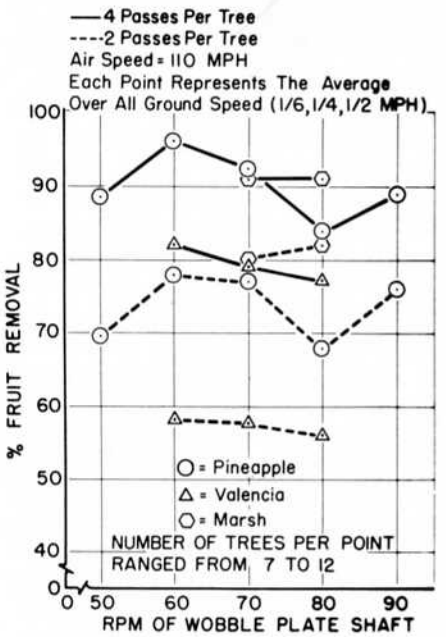

FIG. 12 Effect of revolutions per minute and number of passes of FMC-2 on percent fruit removal in Pineapple and Valencia oranges and Marsh grapefruit.

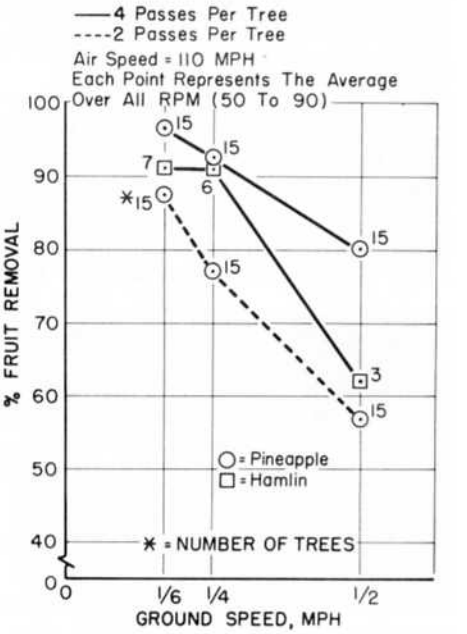

FIG. 13 Effect of ground speed and number of passes of FMC-2 on percent fruit removal in Pineapple and Hamlin oranges.

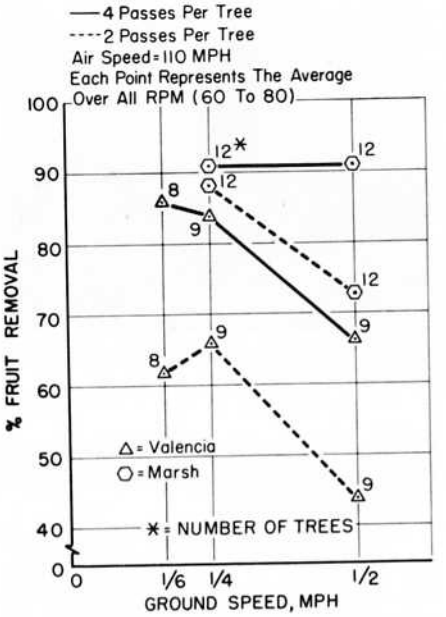

FIG. 14 Effect of ground speed and number of passes of FMC-2 on percent fruit removal in Valencia oranges and Marsh grapefruit.

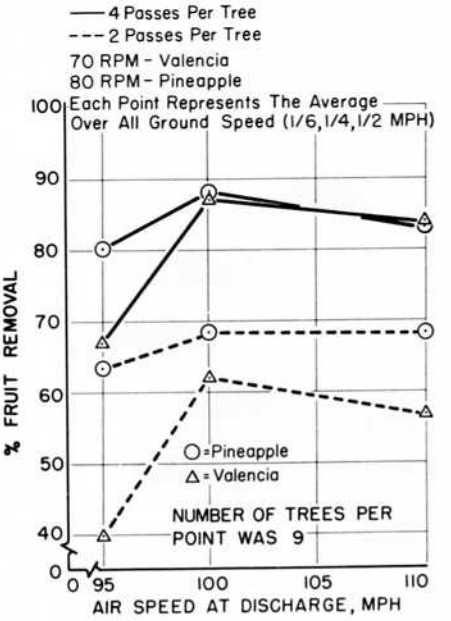

FIG. 15 Effect of air speed and number of passes of FMC-2 on percent fruit removal in Pineapple and Valencia oranges.

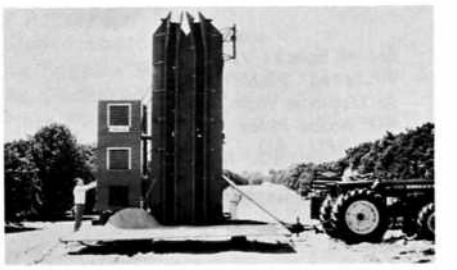

FIG. 16 Side view of FMC-3 with temporary catch frame attached and air discharges in converging orientation.

In summary, fruit removal with the FMC-2 was best when air was discharged at 100 mph and the wobble-plate shaft was rotated at 60 to 70 rpm. Fruit removal in oranges ranged from 86 percent in Valencias to 97 percent in Pineapples when the trees were exposed to the air discharge for approximately 300 secs (four passes at 1/6 mph). Fruit removal performance of the FMC-2, as well as the FMC-1, was poorest in the area of the tree most distant from the machine. Specifically, this area was in a vertical plane including the tree trunk line of the drive row and parallel to the direction of travel. In an attempt to improve the performance of the forced-air concept in this plane, greater air capacity was designed into FMC-3.

FMC-3

During the 1965-66 season, FMC-3 was tested (Fig. 16). It had essentially twice the air moving capacity of the FMC-2. The main components of the FMC-3 were two rectangular discharges and six, 34-in vane axial flow fans driven by three gasoline-powered industrial engines. Three fans supplied air to each discharge, approximately 10 in. wide and 20 ft high. In each discharge, wobble plates were mounted on a rotating vertical shaft, 9 in. apart and 50 deg with the shaft. The plates on each of the two shafts were mounted as one-spiral of a helix. Rotation of the shafts was synchronized at 70 rpm.

The first series of tests conducted with FMC-3 were designed to determine the relative orientation of the two discharges that would give maximum fruit removal and minimum apparent tree damage. Different orientations were achieved by two major adjustments—distance between discharges and relative direction of air discharges. Fig. 17 illustrates the adjustments. The distance between discharges, D, took on values of 39 and 56 in. The relative directions of discharges were converging, parallel, and diverging. Fig. 18 illustrates the effect of discharge orientation on fruit removal. For each of the air discharge orientations on the abscissa, and within each variety, the data were averaged over all distances, D between discharges. Fruit removal increased as the discharge orientation changed from diverging to parallel to converging. These data indicated that the percent fruit removal increased as the air moving capabilities were concentrated into one general area.

The second series of tests supplied information on the effect of ground speed on percent removal. Fig. 19 depicts the results in Valencia oranges and Marsh grapefruit. As expected, percent fruit removal was greatly affected

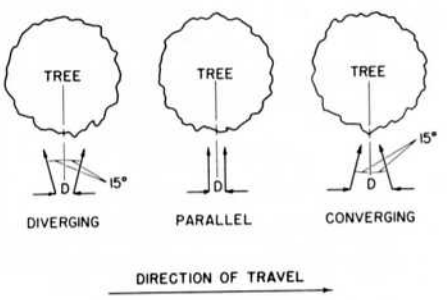

FIG. 17 Direction of air discharge and spacing, D, for the three discharge orientations.

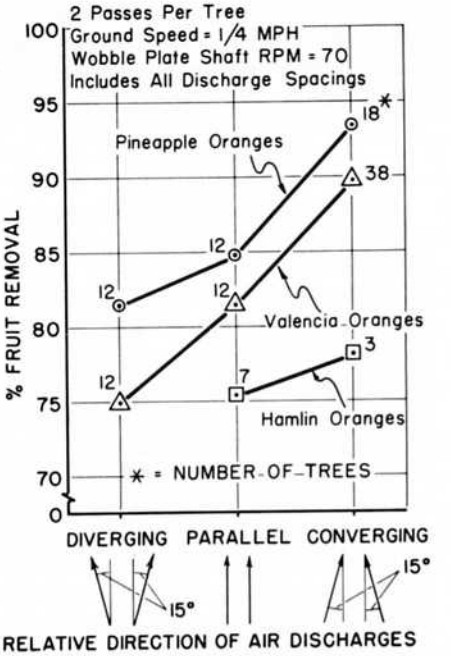

FIG. 18 Effect of relative direction of air discharges of FMC-3 on percent fruit removal.

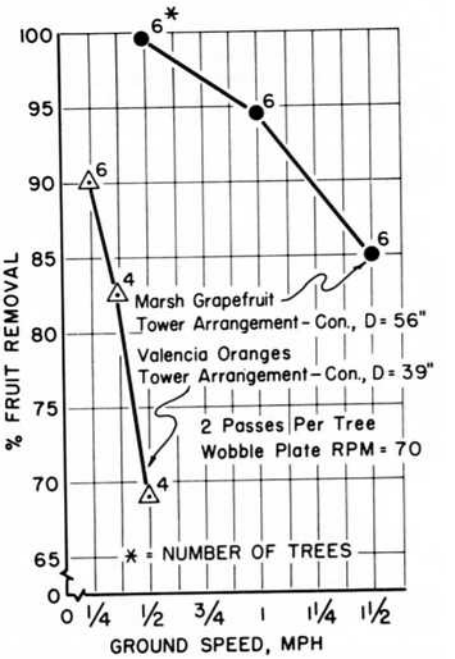

FIG. 19 Effect of ground speed of FMC-3 on percent fruit removal.