October 17, 2001

CTFA Research Report

Development of Design Criteria for a 5-down Box

J. F. Thompson, R. T. Hinsch, D. C. Slaughter, C. H. Crisosto

INTRODUCTION

The California peach, plum, and nectarine industries are being requested to pack a significant volume of fruit in a new box with a 16" x 24" (5-down) or a 16" x 12" (10-down) footprint. Packers are using both returnable plastic (RPC) and corrugated fiberboard (F/B) boxes to satisfy this demand. This new design is typically a shallow box and a few years of limited commercial experience with the 5-down box indicates that it works well for tray-packed fruit.

However there are a number of unanswered questions about its feasibility when used under the industry's complete range of packs and handling conditions. There is only limited industry experience in using the box with volume-fill or bag packs. Vent design for forced-air cooling is complicated by the fact that palletized boxes are cross-stacked with this footprint and some designs do not have vent patterns that align when boxes are cross-stacked. Varying fruit density and size result in differing amounts of free space in the top of the boxes and a large free space can allow cold air to bypass fruit during cooling. Moisture loss may vary between different designs because of vent area differences and the fact that plastic does not absorb water, while corrugated does. Finally, box design, especially one with a large base, may influence vibration characteristics of the package and result in differing levels of damage protection from highway transport vibration damage.

PROJECT GOALS

This project compared the forced air cooling time, storage weight loss, vibration damage characteristics, and fruit holding capacity of several commercial implementations of the new 5-down and 10-down sized boxes for peaches, plums, and nectarines.

Procedure:

Fruit holding capacity was determined in nine tests with packed boxes of different sizes of peaches and nectarines taken from the packing lines of three packinghouses during the 2001 harvest season. Six tests with packed boxes of various sizes of plums were taken from two packinghouses, Table 1. Three forced air cooling and weight loss tests were conducted with peaches and nectarines. One test of vibration damage was conducted with peaches.

Description of boxes: California peaches, plums, and nectarines are generally packed in corrugated fiberboard boxes with outside base dimensions of approximately 12 x 20 inches. They are stacked 8 boxes per layer on 48 x 40 inch pallets. The experimental boxes are designed to be placed either 5 boxes per layer on a pallet, with nominal outside dimensions of 16 X 24 inches, or 10 boxes per layer on a pallet with nominal outside dimensions of 12 X 16 inches. Peaches and nectarines are packed in trays, 2 layers per box or volume filled with 25 pounds of fruit. Plums are packed in bulk (volume fill) with 28 pounds per box. Tray packed and volume filled fruit packed in CHEP or IFCO RPCs had an excelsior pad in the bottom of the box. The bottom pad used for volume fill RPCs had an attached paper liner that wrapped around the inside of the box and covered the top of the fruit. The sides of the paper were vented for air circulation. Peaches, plums, and nectarines are also packed in vented polyethylene bags. The RPC boxes had large amounts of ventilation area on the side and end panels. Corrugated fiberboard boxes had much lower levels of venting and vents did not align between cross-stacked boxes. A more complete description of the test boxes and bags is given in Table 2.

Table 1. Fruit varieties used for testing in 2001 season.

Fruit and cultivar	Size	Number of fruit per 16 pounds	Soluble solids (%)	Test date
Peaches/nectarines				
Summer Blush nectarines	40	28.8	12.0	6-Aug
Britany Lane peaches	40	34.4	--	12-Jun
Summer Lady peaches	42	32.0	16.0	25-Jul
Summer Lady peaches	56	43.2	12.0	25-Jul
Sweet Scarlet peaches	56	45.8	9.0	12-Jun
Summer Blush nectarines	64	47.2	14.0	6-Aug
September Red nectarines	64	48.3	13.5	9-Sep
September Sun peaches	64	52.3	11.5	19-Sep
Rose Diamond nectarines	72	66.1	12.0	12-Jun
Plums				
Aphrodite	35	30	13.0	10-Jul
Friar	40	38	14.0	16-Aug
Friar	50	49	10.5	16-Aug
Aphrodite	55	52	9.0	10-Jul
Aphrodite	65	59	11.6	10-Jul
Friar	70	70	9.0	16-Aug

Table 2. Description of containers used in 2001 tests.

Box type	Outside dimensions (In)	Tare weight (lb)	Inside volume (in^3)	Peaches* (in^3/lb)	Plums** (in^3/lb)	Side vent area (%)	End vent area (%)
8-down							
Fiberboard	19 1/2 x 12 x 7 1/2	1.9	1,501	60	54	5.7/3.3***	0
5-down							
Fiberboard	23 1/2 x 15 3/8 x 7	2	2,191	71	71	3.1	7.8
CHEP RPC	23 1/2 x 15 3/4 x 7	4	2,169	70	70	16.5	11.3
IFCO RPC	23 5/8 x 15 3/4 x 7 1/8	3	2,003	65	65	19.9	28
10-down							
Fiberboard	16 x 12 x 9 1/2	1.6	1,533	61	-	2	2.4
IFCO RPC	15 5/8 x 11 5/8 x 6	1.7	837	56****	-	34.5	29.3
Peach bags	16 x 10					5.5	
Plum bags	11 x 10					5.5	

*Peaches are packed with 25 pounds in the 8-down boxes and about 31 pounds in the 5-down boxes.

** Plums are packed with 28 pounds in the 8-down boxes and about 31 pounds in the 5-down boxes.

*** Venting is not standardized between packinghouses.

**** 15 pounds of peaches were packed in these 10-down boxes.

Fruit weight and depth ratios: Peaches and plums were packed (volume filled) into 5-down or 10-down RPCs, one layer at a time. The box was shaken by hand so that fruit would fill all of the space in a layer. The boxes were then weighed and the depth of the fruit measured. This procedure was followed for 1, 2, or 3 layers of fruit in the 10-down boxes and 1or 2 layers for the 5-down boxes. Also, the number of pieces of fruit per 16 pounds was determined for peaches and nectarines, and for 10 pounds of plums. The soluble solids concentration of the test fruit was also measured with a hand-held refractometer.

Cooling tests: Three cooling tests were conducted: 1) June 12 with size 46 'Brittany Lane' peaches, 2) July 11 with size 55 'Aphrodite' plums, and 3) August 7 with size 50 'O'Henry' peaches. RPCs designed for 5-down and 10-down on a pallet, and corrugated fiberboard boxes designed for 5-down and 10-down on a pallet were packed with peaches. The 5-down RPC and fiberboard boxes were each packed with 2 layers of trays, bagged (seven 4-pound bags), or volume filled with about 31 pounds. All volume filled RPCs had an aspen fiber bottom pad and a vented paper curtain that covering the side-walls and top of the pack. The 10-down RPCs were packed with about 15 pounds of fruit and the 10-down fiberboard boxes were packed with 25 pounds of fruit. Enough of each container and pack type was packed so that there were five layers of each on a pallet. Temperature data was collected in the three middle layers of boxes. The top and bottom layers of boxes for each type were used as buffer layers. One pallet of 2-layer tray pack and one pallet of volume fill fruit packed in "shoebox" 8-down boxes were also studied.

Five "T" type thermocouples were placed in each box layer of test fruit. Thermocouple junctions were about 3/8 " long and the tip of the junction was placed close to the pit of each fruit. Two thermocouples were placed in fruit near where air entered the pallet, one in a middle fruit and two in fruit near where air exited the pallet. The five thermocouples for each layer were connected in parallel to a single lead so that an average temperature was recorded for each layer of boxes. The fruit was allowed to warm slightly after packing, and then all of the test pallets were placed on a single forced-air tunnel. All fruit was cooled to at least 7/8ths of the difference between the beginning fruit temperature and the cooling air temperature. Air pressure in the tunnel was measured during cooling.

Weight loss: The fruit in ten replicate boxes for each combination of box and interior packing was weighed before the cooling tests. After cooling in the first and second tests, the fruit were placed in cold storage for 14 days, and weight loss for each package type was measured. The fruit were lost in the third test because of a communication error.

Vibration tests: After the second cooling test, additional boxes of fruit were taken to the Del Monte Research vibration laboratory in Walnut Creek, CA. The O'Henry peaches were placed in cold storage overnight. A column of ten boxes for each type was placed on the table and vibrated at 1/16 g-rms. The frequency was swept from 2 to 100 Hertz. An acceleration sensor secured to the center of the bottom of the top box was used to determine transmissibility and resonance. This test identifies frequencies, in the range commonly found in transport vehicles, where vibration is amplified as it is transmitted through a stack of boxes. Excessive amplification can lead to fruit damage in the upper layers of boxes in pallet loads.

Four boxes of each type were also placed on the vibration table in a single layer and vibrated for 1/2 hour at an average acceleration of 0.73 g-rms using a pattern of frequencies and acceleration to simulate long- distance transport. This test is based on ASTM Standard Practice D4169-94 with an assurance level I. All fruit was then taken to the University of California Kearney Agricultural Research Center in Parlier, stored for 7 days at 32°F followed by 7 days at 41°F and then and two days at 68°F. Fruit was considered bruised if had a bruised area greater than 1.4cm diameter circle.

RESULTS

Fruit weight and depth ratios for peaches and nectarines

A single layer of peaches or nectarines in a 5-down box weighs from 15 to 19 lbs depending on fruit size; larger fruit result in a heavier net weight, Figure 1. The layer was about 2.5 to 3.3 inches deep, Figure 2. Adding a second full layer increased weight to 27 to 35 lbs and depth to 4.7 to 6.0 in. All of these data are based on hand shaking the boxes, so they were well filled. Loose filling without shaking results in weights that were about 10% less than those described in the figures.

Volume filling peaches and nectarines to a 25-pound standard weight in the 5-down boxes resulted in a package that had less than 2 full layers for fruit sizes from 25 to 65. It appears that packing two full layers will result in a pack weighing more than 30 pounds for these sizes. The depth of this box must be great enough to accommodate 2 layers of fruit. Large fruit would require a depth of about 6 inches, while medium and small fruit will require a 5-inch depth. The currently used 8-down box has an inside depth of 7 1/4 inches, but it is not always filled to its maximum capacity.

In a 10-down box, volume filling 3 layers of peaches or nectarines resulted in a pack that weighed about 25 pounds for sizes greater than 35, Figure 3. More than 3 layers of fruit will be required to meet the 25-pound standard for the smaller sized fruit. The depth of a box of this size would probably be about 8 inches, Figure 4.

Weight and depth ratios for plums

Volume filling plums to a 28-pound standard in the 5-down boxes resulted in a package that had more than 2 layers but less than 3 full layers for fruit smaller than 45, Figure 5. A box depth of about 6 inches would be required, Figure 6. Three layers of plums volume filled in a 10-down box weighed between 20 and 23 pounds and had a depth of about 6 1/2 inches, Figures 7 and 8.

Truck capacity

Volume filled 5-down boxes held more fruit per box than the existing standard box and therefore a truck fully loaded with the new designs would have 18% to 24% fewer boxes of fruit than the standard. However, the corrugated fiberboard and CHEP boxes required more pallet loads to carry the same weight. (This is actually an advantage in the common 53' long refrigerated trailer because it is easier to correctly distribute weight with more than 20 pallets in the load.) The CHEP design RPC weighed slightly more than twice the standard so net fruit weight was reduced by about 6%.

The 10-down corrugated fiberboard box was 9 in deep and designed to hold 28 lb of fruit, so it had the same number of boxes per load and the same net fruit weight as the standard box. The IFCO design 10-down box held only 15 pounds of fruit per box and therefore required more boxes per load than the standard box and resulted in a lower net fruit weight per truck. A deeper design could eliminate most of the capacity disadvantages of the IFCO design.

Table 3. Truck capacity for standard and 5-down boxes. Pallet height was assumed to be 80 – 83 in and load weight was limited to approximately 44,000 lb.

Type of box	Net weight per box (lbs)	Tare weight per box (lbs)	Layers per pallet (number)	Boxes per pallet (number)	Boxes per truck (number)	Pallets per truck (number)	Fruit weight per truck (lbs)	Total Wt. per truck (lbs)
8-DOWN								
Corrugated	25	1.9	10	80	1600	20	40,000	43,840
5-DOWN								
Corrugated	31	2.0	11	55	1320	24	40,920	44,520
CHEP	31	4.0	11	55	1210	22	37,510	43,230
IFCO	31	2.6	13	65	1300	20	40,300	44,480
10-DOWN								
Corrugated	25	1.6	8	80	1600	20	40,000	43,360
IFCO	15	1.7	13	130	2600	20	39,000	44,220

Weight Loss

In three out of four comparisons, the peaches in the CHEP boxes had less weight loss during cooling and storage compared with fruit in the fiberboard boxes, Table 4. Further testing is needed to be able to draw a firm conclusion about the effect of the boxes on weight loss.

Table 4. Weight loss of peaches in two-week commercial storage.

Inner packaging	RPC (CHEP) (%)	Fiberboard (%)
Test 1		
Tray	1.19[a]	3.36
Bags	0.77	1.05[a]
Test 2		
Volume fill	0.76	1.24[a]
Bags	1.28[a]	0.60

[a] treatments within the same test having the same letter are not significantly different, Duncan's new multiple range test, alpha=0.05

Figure1. Effect of peach and nectarine size and number of fruit layers on net fruit weight in a 5-down box.

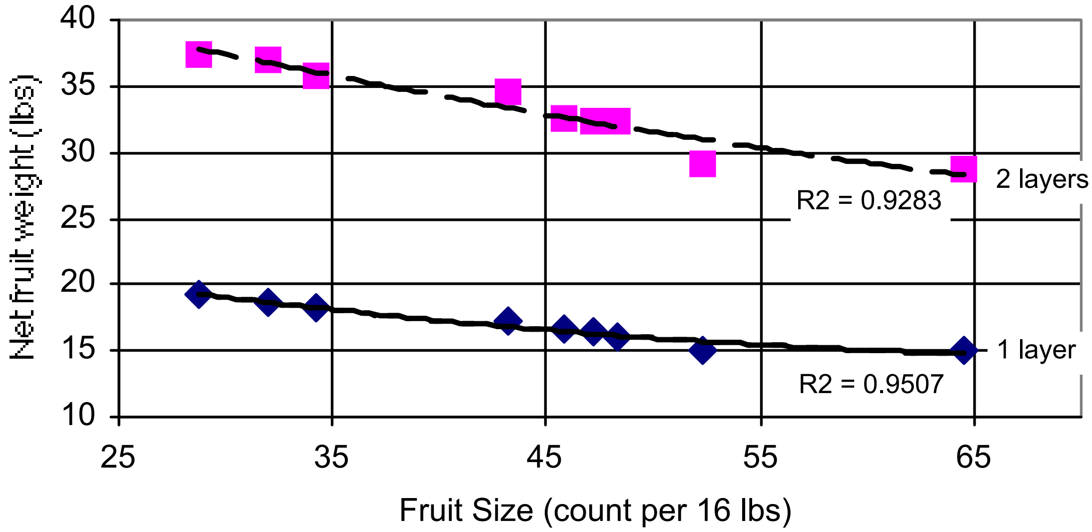


Figure 2. Effect of peach and nectarine size and number of layers on fruit depth in a 5-down box.

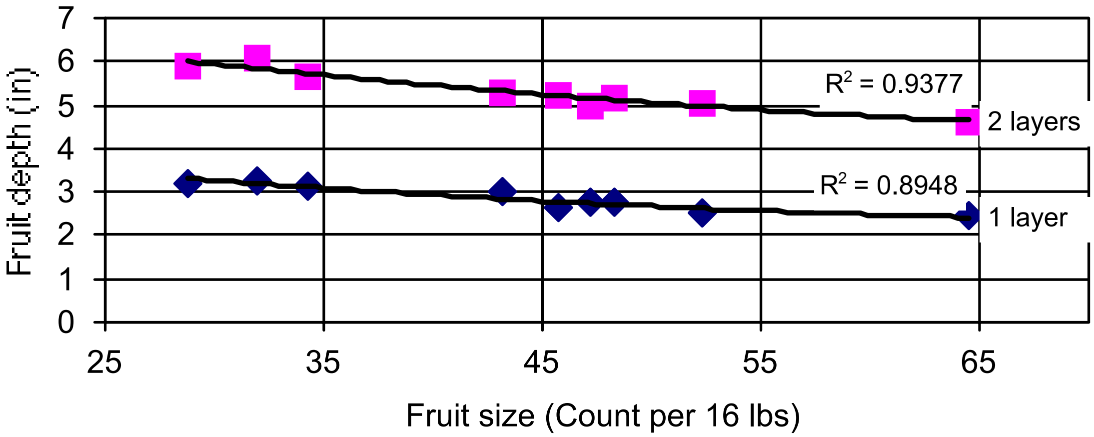


Figure 3. Effect of peach and nectarine size and number of layers on net fruit weight in a 10-down box

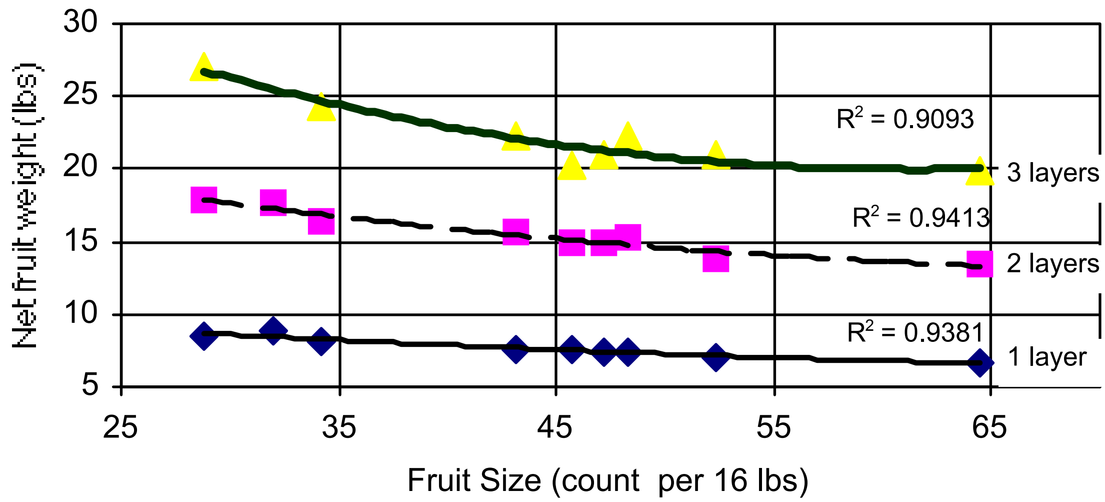


Figure 4. Effect of peach and nectarine size and number of layers on fruit depth in a 10-down box.

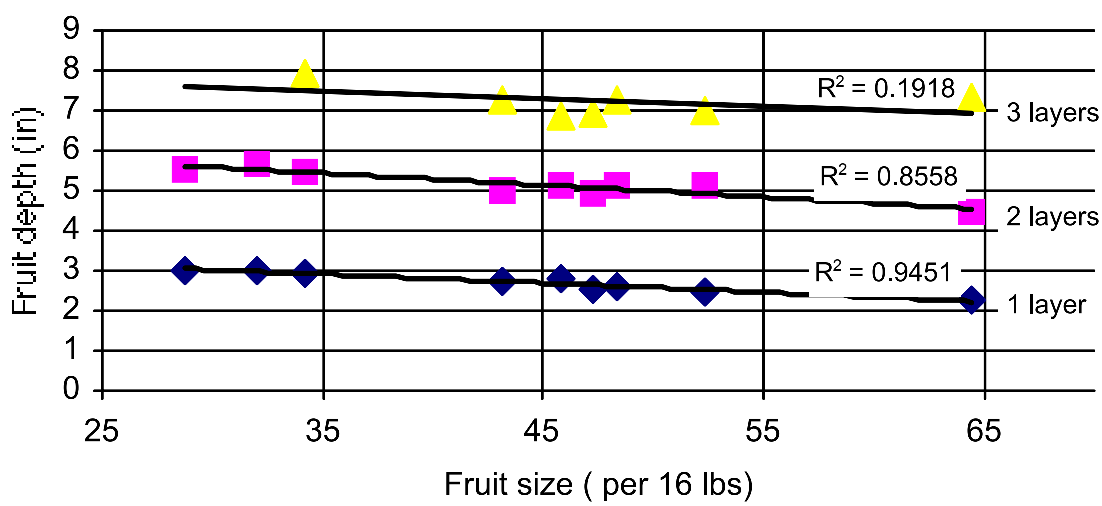


Figure 5. Effect of plum size and number of fruit layers on fruit weight in a 5-down box.

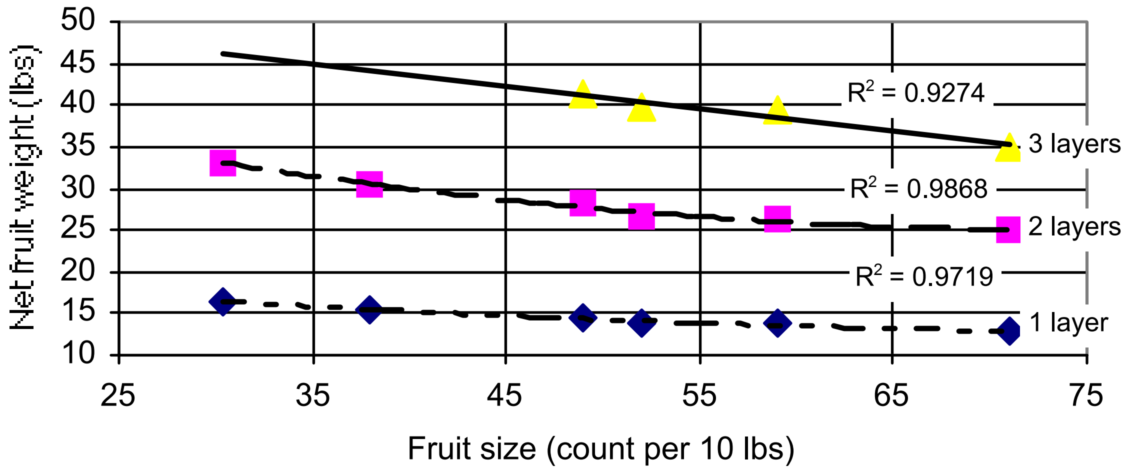


Figure 6. Effect of plum size and number of fruit layers on fruit depth in a 5-down box.

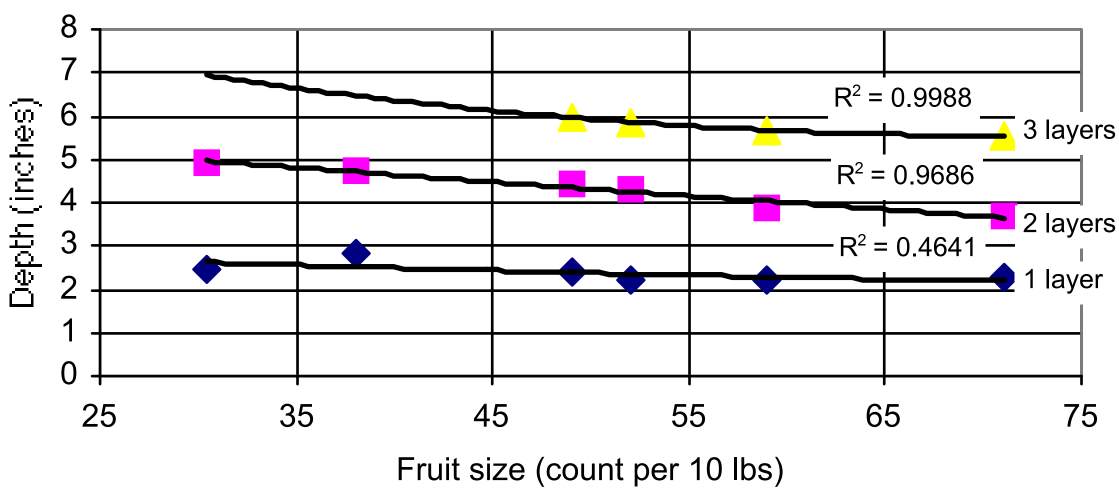


FIGURE 7. Effect of plum size and number of layers on net fruit weight in a 10-down box

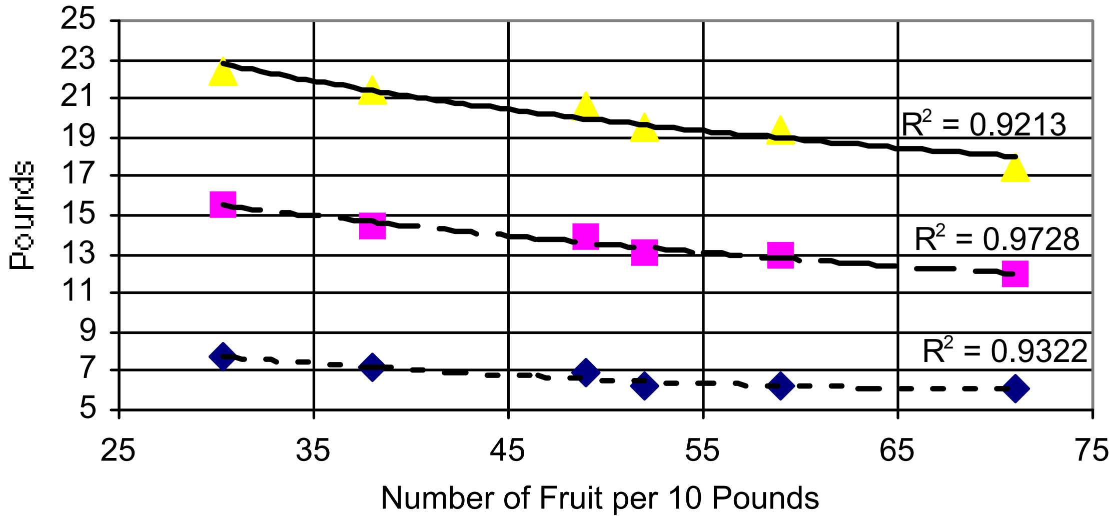
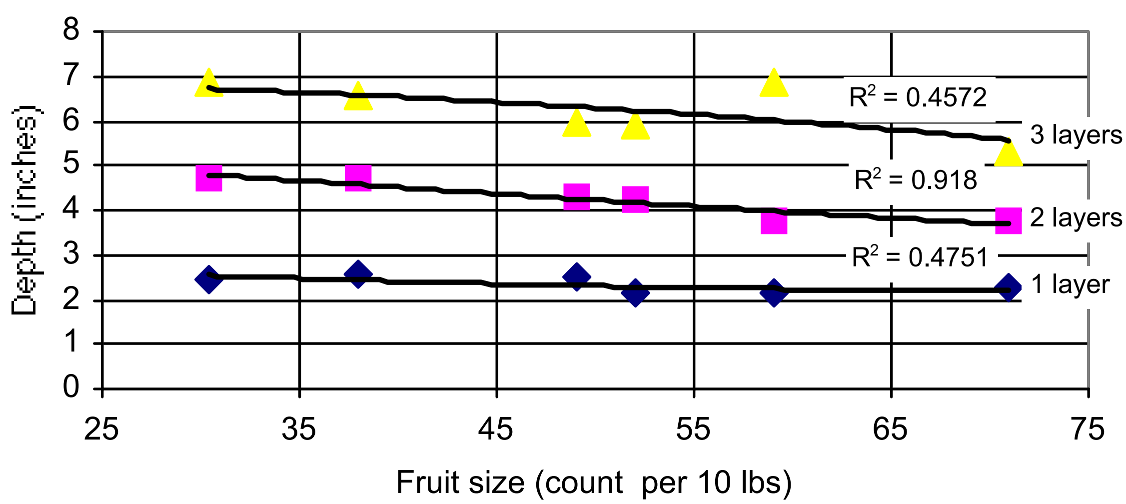


Figure 8. Effect of plum size and number of layers on fruit depth in a 10-down box.



Vibration Tests

The tests of columns of boxes showed that the RPC (CHEP) boxes with bottom pads and corrugated boxes had similar resonant frequencies and transmissibility (ratio of top box acceleration to table acceleration), Table 5. This implies that boxes of this size and made from either material will produce similar levels of acceleration of fruit in the topmost boxes. These boxes are the most subject to damaging levels of vibration in highway transport. However fruit damage may be different in the boxes due to differing interior surfaces.

The vibration tests, designed to simulate bruising to fruit in top boxes on pallets over steel spring suspended axles in a refrigerated trailer, showed that damage varied widely depending on the type of package. The volume filled control box had the least amount of damage, 3.5%, Table 6. The tray packed peaches in the 5-down RPC and the 5-down corrugated box also had low levels of damage and amount of bruised fruit was not significantly different than volume filled control box. Bagged peaches tended to have more damage than tray packed and bagged fruit in RPC boxes had slightly more damage than fruit in the control boxes.

Volume filled fruit in the RPCs (CHEP), either 5- or 10-down, had the highest levels of damage among the treatments tested, Tables 6 and 7. Testing with other fruits has shown that vibration bruising can be minimized by shipping it in air ride suspended trailers and by never loading damage susceptible fruit on the rear of a steel spring suspended truck. All of the RPC boxes had aspen fiber bottom pads and paper sidewall liners. These materials did not adequately prevent bruising damage.

Table 5. Vibration characteristics of corrugated and RPC fruit boxes.

Box	Resonant frequency	Transmissibility at resonance
5-down corrugated (FBA)	9.0	10.5
5-down RPC (CHEP)	10.5	10.0
10-down corrugated (FBA)	11.0	10.0
10-down RPC (CHEP)	11.0	10.0
8-down Bliss - control	10.5	12.0

Table 6. Percent bruised 'O'Henry' peaches after vibration in a simulated cross-country shipment.

	Tray (% bruised)	Bagged (% bruised)	Volume Fill (% bruised)
Fiberboard	9.5 [a,b,c]	9.6[a,b,c]	15.5[c]
RPC (CHEP) w/pads	3.6[a]	13.3[b,c]	26.4[d]
Fiberboard control	-	-	3.5[a]

[a-b] data with the same letters are not significantly different, Duncan's multiple range test, alpha=0.05

The 10-down corrugated fiberboard box had the least amount of bruising of the experimental boxes, and was not significantly different than the control 8-down corrugated box.

Table 7. Percent bruised 'O'Henry' peaches after laboratory vibration to simulated cross-country shipment.

	5-Down (% bruised)	10-Down (% bruised)
Fiberboard (FBA)	15.5[c]	7.1[a,b]
RPC (CHEP) w/pads	26.4[d]	29.1[d]
Fiberboard control	3.5[a]	--

[a-b] data with the same letters are not significantly different, alpha=0.05

Forced Air Cooling

Returnable plastic containers cool consistently faster than comparably sized corrugated fiberboard boxes, packed with the same internal packaging materials. The last test, conducted on August 7 with peaches, had the most complete range of treatments and demonstrated that the 5-down RPCs cooled in 21% to 29% less time than the corrugated fiberboard designs, Table 8. The actual cooling times in this test were fast compared to commercial conditions because we put only six pallets on a cooler that often has at least 12 pallets. The second test with plums shows similar relationships, Table 9. The rapid cooling of the RPCs is undoubtedly due to their high percent vent area compared with the corrugated fiberboard designs, although volume filled RPCs had a bottom pad and paper sidewall liners.

The data also show that the 5-down corrugated boxes cooled in 11% to 27% less time than the industry standard 8-down box and the 5-down RPC cooled in 30% to 44% less time than the 8-down box. The 10-down corrugated fiberboard box required the longest cooling time while the 10-down RPC cooled as fast as any treatment. The 8- and 10-down boxes tend to cause air to flow through more box walls than the 5-down design, resulting in more airflow restriction and longer cooling times, Figure 9. (Boxes for the current 8-down design have vents only on the side panels. This prevents the pallet from being turned 90 degrees, so that air would flow only through two rows of boxes instead of four, which might result in faster cooling times.)

In the 5-down boxes, there was no observable cooling time difference between tray packed and volume filled fruit. However this comparison was based on fruit in the top tray in the pack and we observed in the first test that bottom fruit in the corrugated fiberboard boxes required 60% more cooling time than fruit in the top tray. We observed no differences between top and bottom tray cooling times in RPCs. Bagged fruit always required more cooling time than tray or volume filled fruit.

Table 8. Seven-eighths cooling time for size 50 'O'Henry' peaches packed in 5, 8, and 10-down containers, August 7, 2001. Static pressure across pallets was 0.55 to 0.57 in of water column.

Box	Internal Packaging	Corrugated (hr)	RPC[1] (hr)
5-down	Tray	2.0[c]	1.6[a,b]
	Volume fill	2.2[c,d]	1.6[a,b]
	Bags	3.5	2.5
10-down	Volume fill	3.2	1.5[a]
8-down - control	Tray	2.2[d]	-
	Volume fill	2.8	-

[1] RPC boxes had aspen fiber bottom pads with paper sidewall liners.
[a-b] data with the same letters are not significantly different, Duncan's new multiple range test, alpha=0.05

Table 9. Seven-eighths cooling time for size 55 'Aphrodite' plums packed in 5-down containers, July 11, 2001 test.

Box	Internal Packaging	Corrugated (hr)	RPC (hr)
5-down	Volume fill	6.3	4.6
	Bags	9.1	7.1
8-down-control	Volume fill	9.0	--

The first cooling test was set up so that the cooling air flowed parallel to the 40" dimension, causing the vents in the corrugated boxes to be misaligned in the airflow path, Figure 9. (The corrugated box was specifically designed for air to flow parallel to the 48" dimension.) With this orientation RPCs cool in half the time required for corrugated fiberboard boxes to cool. Some shallow depth RPCs also have very limited end panel venting and may experience cooling time increase if oriented so that air must flow through cross stacked boxes.

Table 10. Seven-eighths cooling time for size 46 Britany Lane peaches packed in 5-down containers, June 12, 2001 test. Static pressure across pallets was 0.60 in. of water column.

Box	Internal Packaging	Corrugated (hr)	RPC (hr)
5-down	Tray	2.55	1.25
	Bags	5.17	2.53

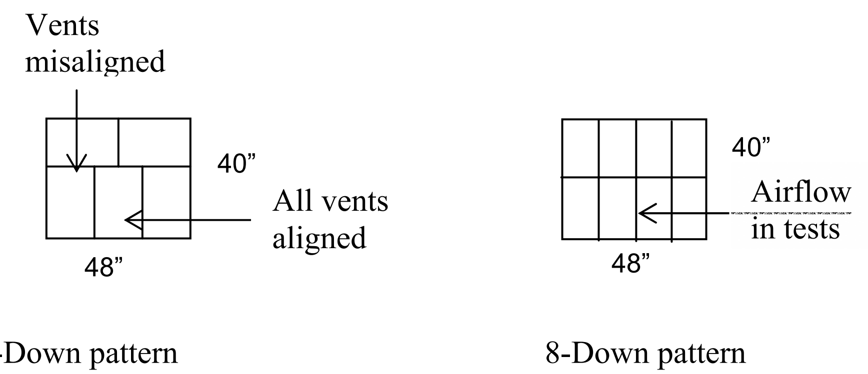


Figure 9. Airflow patterns and pallet orientation for cooling tests.

Two comparisons between bottom and top trays indicated that the bottom tray in corrugated boxes takes about twice as long to cool compared with the top tray, but there is very little difference in cooling times between top and bottom trays in the RPC boxes.

CONCLUSIONS

1. Volume filled peaches packed in the RPCs used in this test were excessively bruised during simulated shipment on the top layer of a pallet. Volume filled peaches in corrugated fiberboard boxes were also extensively bruised, but less so than those in the RPCs. If these boxes are volume filled they should be transported in trucks with air ride suspension. They should never be loaded on the rear of steel spring suspended truck.
2. Tray packed peaches packed in both RPC and corrugated fiberboard 5-down boxes had low bruising levels and no more bruising than the volume filled 8-down box.
3. Relationships between fruit size, net fruit weight and fruit depth were developed for peaches/nectarines and plums. These will allow the industry to select criteria for fruit weight and depth in volume fill packing for the new 5-down and 10 – down boxes.
4. Corrugated fiberboard boxes in the 5-down footprint cool 11% to 27% faster than the industry standard 8-down footprint box, when pallets are oriented so that the cooling air flows parallel to the 48" dimension of the pallet.
5. RPCs in the 5-down footprint require 21% to 29% less time for forced-air cooling compared with similarly sized and similarly packed corrugated fiberboard boxes. They cool in 27% to 43% less time than the standard 8-down design corrugated fiberboard box.
6. The 5-down boxes allow fewer boxes per truck while allowing the truck to carry the same fruit weight. However, the corrugated fiberboard and CHEP boxes will require more pallet loads to carry the same weight.

ACKNOWLEDGEMENTS

We appreciate the advice and logistical assistance provided by Scott Wallick, Weyerhaueser, Tacoma, WA; Mike Boersig, CHEP USA, Costa Mesa, CA; and Gary Van Sickle, California Treefruit Agreement, Reedley, CA and assistance in packing and fruit cooling provided by HMC Co. Kingsburg, CA; Fowler Packing Co., Fresno, CA; and Ballantine Produce, Reedley, CA.