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BRUISING AND ACCELERATION MEASUREMENTS IN APPLE PACKS

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SUMMARY

The impact testing of tray-packed apples has shown that bruising is more severe on the bottom than on the top layers. Acceleration measurements have shown that apples experience the highest accelerations in the top layer and that the magnitudes systematically decrease towards the bottom of the pack.

These apparently conflicting results have led to an understanding of the dynamic behaviour of apples in different positions in the pack. Apples in the lower layers are subjected to impacts from both above and below, so while fairly low accelerations are recorded at the centre, substantial bruising occurs at the contact points on the surface.

I. INTRODUCTION

Packaging is a major cost in marketing fruit and vegetables. An economic survey by the University of Queensland (1971) showed that packaging tomatoes costs more than growing them. The package cost for tomatoes in 1972 was 21% of the market price while for apples it was 33%.

The high incidence of fruit damage to apples and pears has been reported by Schoorl and Williams (1972, 1973). They showed that between 20 and 50% of apples were bruised.

The problem of high package costs, coupled with excessive fruit damage, clearly indicates a need for a better understanding of the basic mechanisms involved in damage to packaged fruit and vegetables. Several investigators have been active in this area. Schoorl and Williams (1972) have developed a mathematical model which describes the relation between fruit damage and drop height, number of drops and package type. The model describes the general bruise performance of the package during handling.

Arrivo (1968) has shown that the number of bruised apples and the volume of bruised tissue are greater in the bottom layers than in the top layers of tray packs. He also placed accelerometers in the middle and top trays and recorded average acceleration levels in the package of 20 and 30 g for drop heights of 18 and 30 in. respectively. By analysis, he showed that in a non-homogenous body, the acceleration should decrease from the base to the top of the pack, but that the variation would be small. On this basis Arrivo does not further investigate the behaviour of individual apples within the package and cites only average acceleration levels for the entire package.

Neither of these investigations sheds much light on the actual mechanisms involved and hence are of limited value in improving package design. The experiments described herein were carried out in order to gain insight into these mechanisms with the aim of formulating a physical description of the behaviour of individual apples within a pack.

II. BRUISING INVESTIGATIONS

A series of experiments was carried out to determine quantitatively the relationship between bruising level and position in package (that is, layer number) for both tray-packed cartons and pattern-packed wooden bushel cases. These package types were chosen since considerable difference in bruise protection was reported by Schoorl and Williams (1972).

(a) Materials and Methods

The fruit used were Delicious apples of $2\frac{7}{8}$ in. diam obtained from a commercial packing house, care being taken to select only bruise-free fruit. The internal dimensions of the tray-packed cartons were $19\frac{3}{4}$ in. x $11\frac{7}{8}$ in. x $11\frac{1}{2}$ in. and for the pattern-packed cases were 18 in. x $11\frac{1}{2}$ in. x $10\frac{1}{2}$ in. In each package type there were five layers and a 125 count.

Packages were subjected to a number of flat drops from various heights in randomized trials. The equipment used has been described by Holt and Schoorl (1973). The packages are firmly strapped on a rail-guided platen which impacts a solid rubber shock programmer. Each package was dropped from one of five heights at the following number of drops:

6 in. and 12 in.—1, 3, 9 and 27 drops
18 in.—1, 3 and 9 drops
24 in.—1 and 3 drops
48 in.—1 drop

Each observation was replicated once.

Bruise assessment on each fruit was conducted 3–4 days after dropping, a wedge section then being removed from the bruised area with the aid of a sharp knife. The largest bruise on each fruit was measured for the maximum diameter and depth of bruise. A fruit was considered "bruised" when a bruise of 0·8 in. diam and 0·2 in. depth was present, or if either dimension exceeded these values.

(b) Experimental Results

Although packages were dropped either once or a number of times, only the results obtained for single drops are reported here. There is no apparent change in trends with varying number of drops. The results for packs dropped once are shown in Tables 1 and 2.

TABLE 1

MEAN PERCENTAGE OF BRUISED APPLES IN EACH LAYER OF PACKS DROPPED ONCE FROM INCREASING HEIGHTS

Package Drop Height	Layers				
	1 (Top)	2	3	4	5 (Bottom)
Wooden Cases					
6 in.	2·1	0·0	14·4	4·1	6·4
12 in	12·0	20·0	26·0	30·0	32·0
18 in.	16·4	25·2	57·3	56·0	54·0
24 in.	28·3	48·0	68·0	83·8	86·8
48 in.	44·4	73·4	84·0	94·1	100·0
Tray Cartons					
6 in.	2·0	4·0	8·0	12·0	8·0
12 in.	0·0	2·0	15·0	26·0	22·4
18 in.	4·3	12·0	29·2	34·8	41·7
24 in.	4·0	12·4	40·5	44·0	68·0
48 in.	6·0	34·0	86·0	90·0	94·0

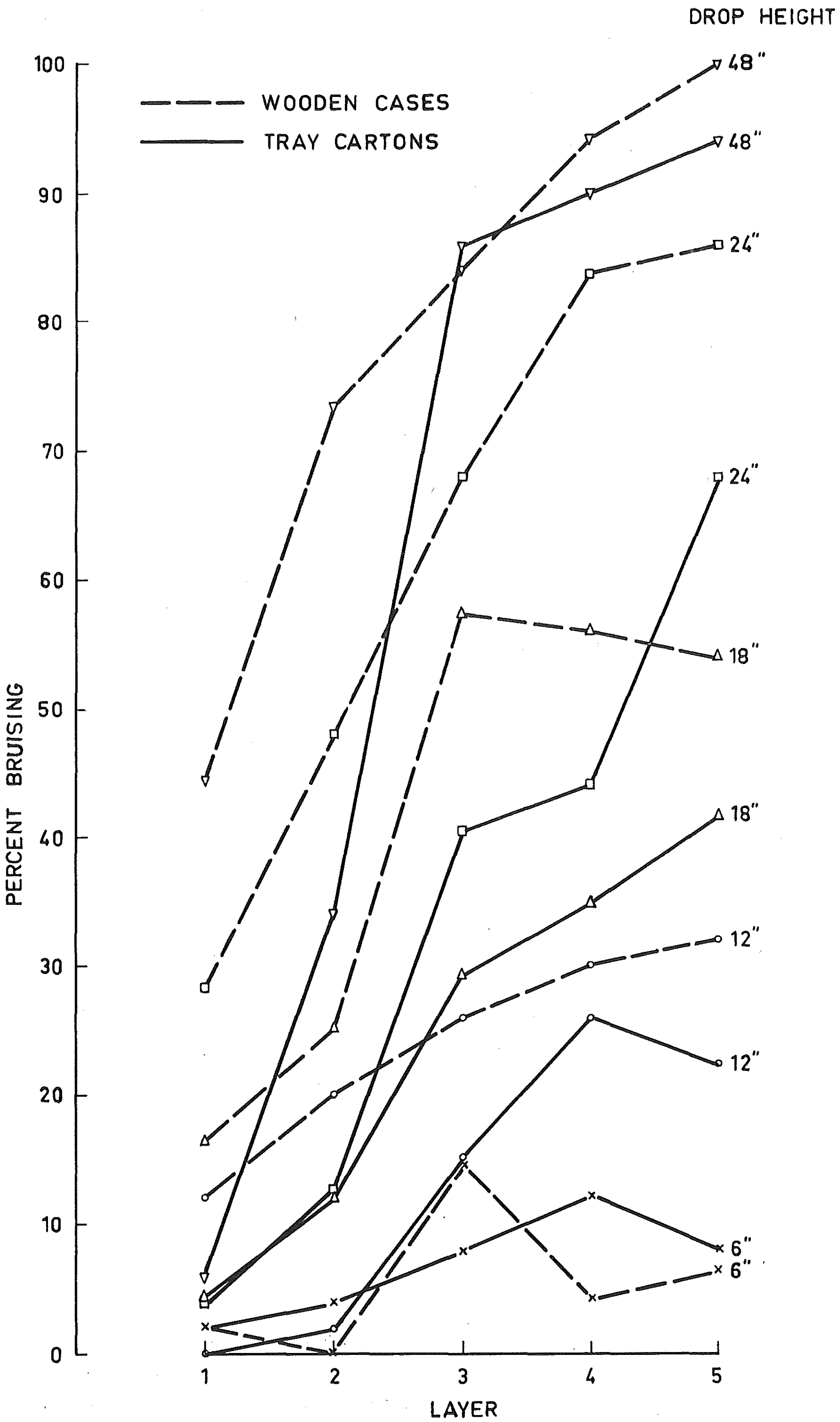

Fig. 1.—Percentage bruising in various layers in apple packs.

Table 1 shows the mean percentage of bruised apples in each layer in packs dropped from increasing heights. For both wooden cases and tray cartons there is a general progressive increase in the percentage of bruised apples from the top to the bottom layers for all drop heights. This is shown graphically in Figure 1.

Table 2 shows the average bruise size for bruised apples in each layer of the packs. In general, the diameter of the maximum bruise remains unchanged except for the fifth layer at the largest drop height, where the bruise measured resulted from apple-to-flat surface contact. The depth of bruise, on the other hand, increases with drop height and, where a sufficiently large number of apples was bruised (18 in drops and greater), appears to increase from the top to the bottom layers.

TABLE 2

BRUISE SIZE (DIAM. x DEPTH IN.) OF APPLES IN EACH LAYER OF PACK DROPPED ONCE FROM INCREASING HEIGHTS

Package Drop Height	Layers				
	1	2	3	4	5
Wooden Cases					
6 in.	8·0 x 2·0	0·0 x 0·0	10·0 x 3·5	10·0 x 4·0	9·0 x 3·0
12 in.	10·0 x 2·5	10·0 x 3·0	10·0 x 3·0	10·0 x 3·0	10·0 x 3·5
18 in.	10·0 x 2·5	11·0 x 2·5	11·0 x 3·5	11·0 x 4·0	11·0 x 4·0
24 in.	10·0 x 2·5	10·0 x 2·5	11·0 x 4·0	11·0 x 4·5	12·0 x 4·5
48 in.	11·0 x 3·0	11·0 x 5·0	12·0 x 5·0	13·0 x 5·5	17·0 x 6·5
Tray Cartons					
6 in.	12·0 x 3·0	8·0 x 3·0	9·0 x 3·0	10·0 x 3·0	10·0 x 2·5
12 in.	0·0 x 0·0	10·0 x 2·0	9·0 x 3·0	9·0 x 3·0	10·0 x 3·5
18 in.	9·0 x 2·0	10·0 x 2·5	11·0 x 3·0	10·0 x 3·5	10·0 x 4·0
24 in.	12·0 x 3·0	8·0 x 3·5	9·0 x 3·5	10·0 x 4·0	11·0 x 4·0
48 in.	12·0 x 2·0	11·0 x 4·0	11·0 x 4·5	12·0 x 5·0	14·0 x 6·0

It is also evident that the tray pack offers substantially better protection for all layers. This is particularly apparent for the top layer, where, for wooden cases, bruising varies from 2% to 44% while for the tray-pack cartons bruising varies from 2% to 6% over the same range of drop heights.

These results show that the percentage of bruised fruit, for both tray cartons and wooden cases, increases towards the bottom of the pack. Also, the maximum bruise size increases towards the bottom.

The effects of drop height, drop number and package type in this experiment have already been reported by Schoorl and Williams (1973) and can be represented by the relation

$$\ln \frac{y}{100} = 2 - \frac{2}{kh+0{\cdot}2} + 1{\cdot}0818 \ln x$$

where y is the percentage of fruit bruised, h the drop height in inches, x the number of drops and k a package constant.

III. ACCELERATION INVESTIGATIONS

The bruise results indicate that apples towards the bottom of the pack are subject to more severe impact conditions than those on the top. In an attempt to verify this an experiment was carried out to measure the acceleration experienced by apples in various layers in tray-pack cartons. The cartons were chosen in preference to packed cases because of the greater bruise variations from layer to layer.

(a) Materials and Methods

The fruit used were Granny Smith apples since this variety was readily available. The fruit size, tray-pack carton dimensions and drop tester were the same as reported for the previous experiment. Each package was dropped three times from one of four heights: 6, 12, 18 and 24 in. Each test was replicated once.

(b) Acceleration Measurements

Two small Bruel and Kjaer accelerometers type 4344 weighing 2g were connected to a Hewlett Packard dual-beam storage oscilloscope type 1210A through a Bruel and Kjaer preamplifier type 2625. The oscilloscope was externally triggered by a phototransistor just before the platen contacted the rubber shock programmer. Each accelerometer was placed in the core region of an apple by cutting the apple in half, pressing the accelerometer firmly into the flesh and then tightly taping the halves together. For each package two such apples were placed in the centre of two different layers. The package was dropped three times and then the accelerometers removed and placed in new apples for the next package. Despite careful handling this method of placement resulted in some disturbance of the pack.

(c) Experimental Results

The mean peak acceleration recorded for tray pack apples is given in Table 3. Photographs of typical acceleration-time traces for a drop height of 18 in. are shown in Figure 2.

For all drops the highest acceleration is recorded in the top layer. The accelerations in the top layer are three to four times those recorded in the bottom layer.

TABLE 3

MEAN PEAK ACCELERATION (g) OF FIVE LAYERS IN TRAY PACKS DROPPED REPETITIVELY THREE TIMES

Drop Height	Drop No.	Layers				
		1	2	3	4	5
6 in.	1	89	64	34	34	30
	2	110	73	52	45	32
	3	102	68	54	49	34
12 in.	1	128	79	70	54	55
	2	167	121	87	71	54
	3	172	123	83	77	65
18 in.	1	170	77	75	62	52
	2	232	132	99	85	64
	3	213	146	119	99	61
24 in.	1	170	93	66	59	72
	2	297	170	125	91	91
	3	391	195	116	108	108

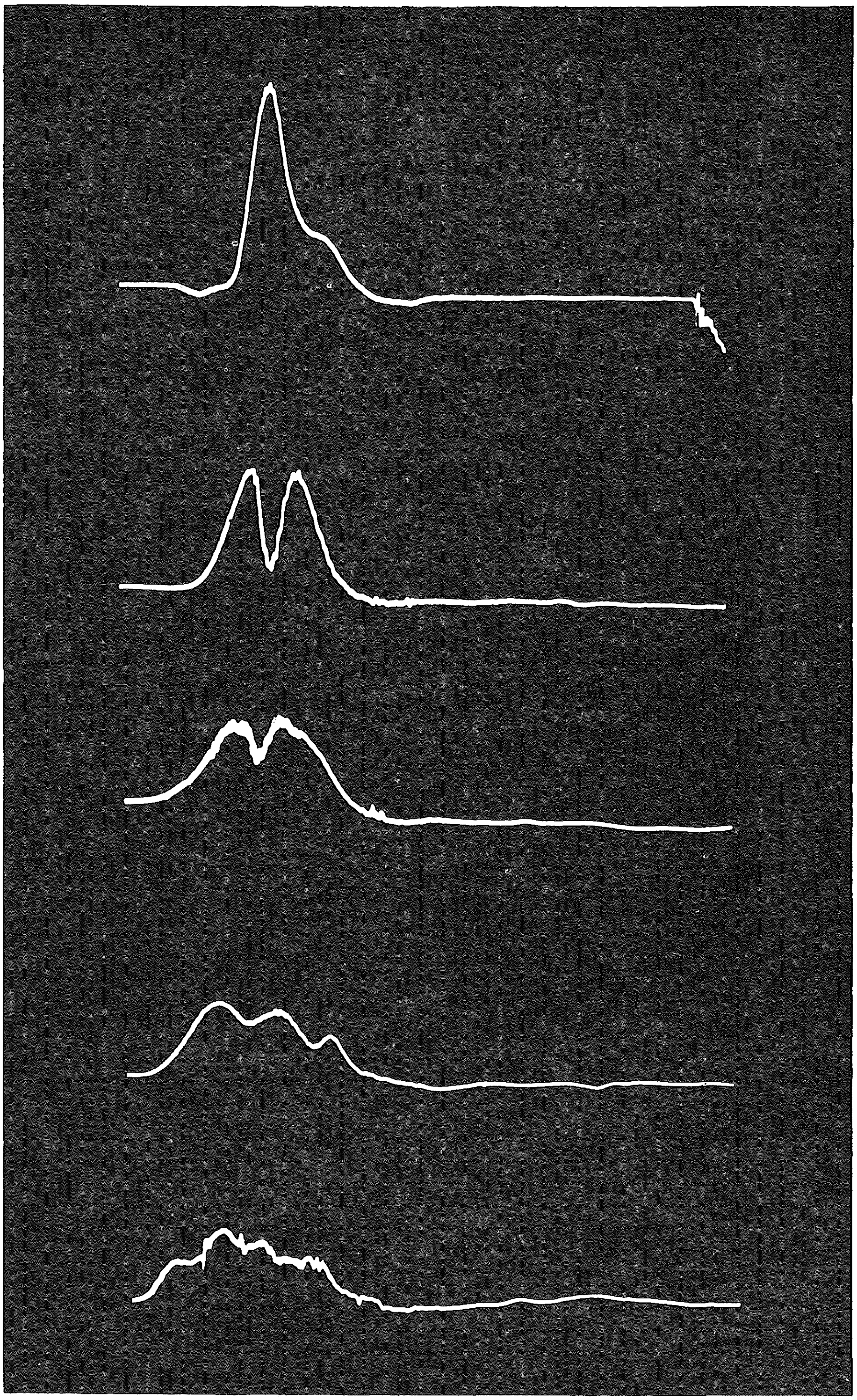

Fig. 2.—The shock wave form from top to bottom for five layers of apples in tray packs.

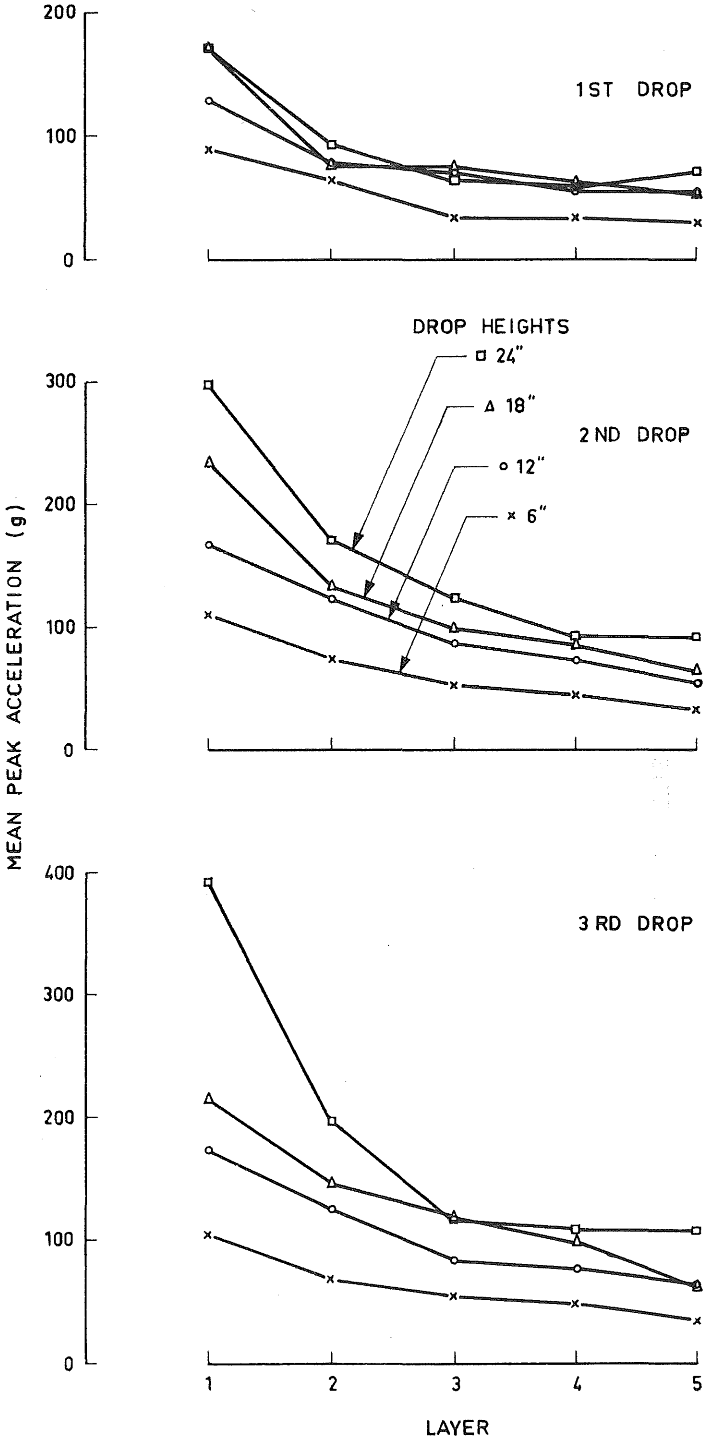

Fig. 3.—Peak acceleration of apples in various layers of tray packs dropped up to three times (layer 1 is the top layer).

There is a general decrease in acceleration towards the bottom of the pack as shown in Figure 3. This change in acceleration is less evident towards the bottom of the pack. Figure 3 also shows the effects of drop height and drop number. In general, accelerations increase with drop height and drop number.

The number of shock peaks for tray-pack apples are given in Table 4. The number of peaks increases from one for the top layer to four or five for the fifth layer. In general, the number of peaks and layer number—that is, position in the pack, correspond closely. The peak to peak shock duration time was recorded for layers 2, 3, 4 and 5. For layer 1, too few traces exhibited a second peak for any meaningful peak to peak measurements to be made. The effect of drop height, number of drops and layer number for the remaining layers is shown in Table 5. The peak to peak duration time was not influenced by the number of drops, position in the pack (layer number) or drop height, except for the 6 in. level, where the effect is small.

TABLE 4

NUMBER OF SHOCK PEAKS IN THE FIVE LAYERS OF TRAY PACKS WHEN DROPPED

Number of Peaks	Layers				
	1	2	3	4	5
1	20	..	..	..	..
2	14	19	1	..	..
3	..	4	20	14	1
4	..	1	3	17	12
5	..	..	..	1	12
6	..	..	..	..	4

TABLE 5

PEAK TO PEAK SHOCK DURATION TIME (SEC)

Treatment	Number of Readings	Mean	Sig Diffs.
Drop Height			
6 in.	24	4·2	
12 in.	9	3·7	6 in. > 12 in. (5% level)
18 in.	20	3·5	6 in. ⩾ 18 in. (1% level)
24 in.	24	3·7	6 in. > 24 in. (5% level)
Number of Drops			
1	23	4·0	No
2	27	3·9	Significant
3	27	3·6	Differences
Layer			
2	16	3·8	No
3	21	3·9	Significant
4	19	3·9	Differences
5	21	3·7	

IV. DISCUSSION

Bruising.—The bruising experiments show that apples in the lower layers of cartons and cases suffer more damage than those in the top layer. In fact, percentage bruising in the bottom layer may be from three to 15 times that in the top layer. Further, this increase in bruising is, in general, progressive down through the intermediate layers. There also appears to be an increase in bruise depth from the top to the bottom layers.

The effects on bruising of drop height, drop number and package type have been reported previously by Schoorl and Williams (1973).

Acceleration.—Acceleration measurements at the centre of individual apples in tray packs show that the top layer experiences the highest accelerations. Preliminary investigations with wooden cases have shown the same trend. Accelerations on the top layer are about three times those on the bottom layer. There is a general decrease in acceleration towards the bottom layer, with the largest decreases occurring over the top three layers. This trend is in direct contrast to that predicted by Arrivo (1968), who asserted that accelerations would be higher in the bottom layers than in the top and that there would be no large differences in magnitude.

The acceleration recorded in all layers increases with increasing drop height or severity of impact. The acceleration also increases with drop number, indicating some settling or stiffening of the pack under repeated impacts. This effect is most marked between the first and the second drop in the top layers and is no doubt influenced by the unavoidable disturbance that occurs during the placement of accelerometers. It has been observed that there is little, if any, change in acceleration for impacts after the third drop.

Shock Wave.—The shape of the shock wave for the various layers shows the apples in the bottom layer receive about four or five impacts indicated by the number of peaks on the shock wave whereas the top layer experiences only one impact. This trend is consistent for the intermediate layers. The traces show that, on impact, the bottom layer is the first to decelerate and is followed progressively by subsequent layers in a manner similar to shunting of railway wagons. The progressive delay in impact is clearly shown in Figure 2. Figure 2 also shows that the top apples are free to bounce while the movement of apples in subsequent layers is constrained by the layer above.

Conclusions.—The form and magnitude of the shock wave for the various layers, together with the bruising results, give some insight into the dynamic behaviour of apples in different positions in the pack. This behaviour is consistent with that of a column of apples with small spaces between each apple. As the platen of the drop tester strikes the shock programmer the bottom apples decelerate. At some time later the penultimate layer collides with the bottom layer and this process continues up through the pack, so the bottom layer receives multiple (four or five) impacts, while apples in the top layer bounce only once on the fruit below. This means that apples in layers other than the top can be struck from both above and below and, while little acceleration is recorded in the centre of the apple, appreciable penetration and hence bruising can occur at the points of contact. This accounts for the increase in bruising down through the pack and the decrease in acceleration levels.

The behaviour of apples in a pack subjected to impact has been described. It is proposed to develop a mathematical model for the system so that the effect of package variables such as fruit mechanical properties, number of layers, padding between fruit, etc. can be predicted.

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