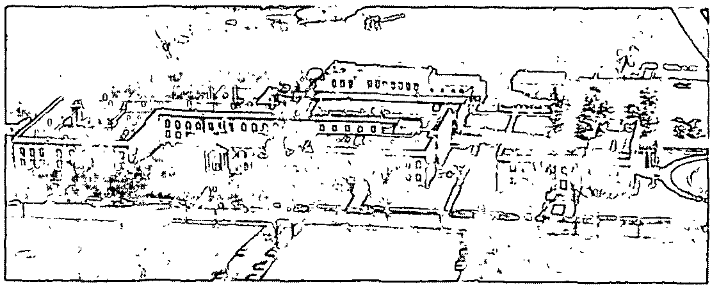

THE INSTITUTE OF PAPER CHEMISTRY, APPLETON, WISCONSIN

STUDY OF FACTORS AFFECTING TOP LOAD BOX DEFLECTION

Project 2698

Report One

A Progress Report

to

FOURDRINIER KRAFT BOARD INSTITUTE, INC.
TECHNICAL DIVISION

December 28, 1973

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

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TABLE OF CONTENTS

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SUMMARY

This two-phase study is directed toward the broad objective of developing ways of predicting the top load compression performance of corrugated boxes with inner packing and/or partial load bearing contents. This requires consideration of both the strength and deflection of the box and inner packing as well as headspace. Because box deflection is one of the main factors, the specific objective of this study was to investigate factors affecting top load box deflection and to develop equations for predicting box deflection so that boxes for new applications could be engineered.

The total box deflection may be regarded as being comprised of two parts; namely, (1) the deflection in the flap scoreline regions, and (2) the deflection between scoreline regions-midpanel area. For this study, it was assumed that when boxes and tubes of the same size are tested, the tube deflection is a measure of the midpanel deflection. Therefore, the difference between box and tube deflection is a measure of the flap scoreline deflection.

In Phase I, a very limited comparison of box and tube deflection results showed the following:

1. As expected, the scoreline portion of the deflection accounts for the major portion of the total box deflection. On the average, the scoreline deformation amounted to 92.5, 90.9, and 87.3% of the total box deflection for the A-, C-, and B-flute samples in the study. As one consequence, box depth has only a small effect on box deflection and its effect tends to be overshadowed by the flap scoreline effects.

2. The flap scoreline deformations were not significantly affected by box depth.
3. Total box deflection appears to be primarily related to flute size because of the dominant effect of scoreline behavior.

In a second phase of the study, correlations between maximum box deflection, box dimensions, and combined board (C.B.) properties, were studied, using data for a wide array of commercially manufactured box samples. These results indicated that:

1. Top load box deflection is best related to combined board properties which are highly dependent on flute size — specifically, (1) combined board caliper, (2) the composite flexural stiffness, and (3) the product of cross direction (CD) edgewise compression and caliper squared. Neither box depth nor perimeter were highly correlated to box deflection. Thus, these results were in qualitative agreement with the results for Phase I.
2. For the overall data, a small improvement in prediction accuracy was achieved by also considering box depth or edgewise compression strength in conjunction with board caliper.
3. It was also observed that box deflection variability is much greater than the variability in box load. For example, the average coefficients of variation were 6.7 and 11.1% for load and deflection, respectively. Much of the deflection variability is believed to originate in variations in the deflection in the flap scoreline regions. High deflection variability must contribute to variations in the warehouse stacking performance of boxes.

INTRODUCTION

The deflection of a box under load can be important in a number of use applications. For example, for packages consisting of a box, inner divider, and load-bearing product, it is desirable to interrelate the load-deflection curves for these three elements so as to obtain optimum stacking performance.

In principle, the strength of the box plus inner packing can be calculated from the separate load-deflection curves of the box and inner packing considered separately — making appropriate allowance for headspace and other factors. This approach is cumbersome and does not lend itself to simple calculation. It is believed that fairly accurate estimates of combined strength could be made in the following way:

1. Utilize present equations for box strength (1).
2. Develop equation relating maximum box deflection to (a) the basic properties of the combined board, and (b) box dimensions.
3. Develop equations relating strength and deflection of inner packing to (a) basic properties of the combined board, and (b) dimensions and configuration of inner packing.
4. Develop equations relating the separate strengths of box and inner packing (making allowance for the relative deflections of box and inner packing as well as headspace) to the combined strength of the box plus inner packing. This must include consideration of the fact that the inner packing is loaded through the top and bottom flap areas of the box.

The broad objective of the above is to provide data relative to the service behavior of the box plus inner packing as related to the properties of the board used in its manufacture. It is believed that future years will see even greater efforts to control packaging costs. Package designs will be scrutinized more closely to promote more efficient utilization of materials. Consequently, the corrugated industry will need more information on the performance of the complete package to better serve its markets and meet its competition.

With the above in mind, a very limited study was undertaken to explore ways of predicting box deflection at maximum load. The work was divided into two phases. Phase I involved a limited comparison of the maximum deflection of tubes and boxes of the same size. As discussed later, the difference between the tube and box deflections may be regarded as an estimate of the deflection occurring in the flap scoreline region of the box. In the second phase, correlations between top load box deflection, box dimension, and combined board properties were studied using data for a wide array of commercial box samples.

BACKGROUND CONSIDERATIONS

TOTAL TOP LOAD BOX DEFLECTION

It is known that an appreciable fraction of the total vertical deflection of a box occurs in the area near the flap scorelines. Consequently, it appears that the total deflection may be regarded as being comprised of two parts as schematically illustrated in Fig. 1. Deflections e_s are associated with deformation in the scoreline region at top and bottom of the box. The deflection e_p accounts for the strain in the portion of the panel between but not including the scoreline areas.

Thus, as a first approximation, it is suggested that Equation (1) would hold when a given load is applied to the box.

$$e = e_p + 2\ e_s \tag{1}$$

where e = total box deflection

e_p = deformation in area adjacent to vertical scoreline but excluding scoreline region at top and bottom

e_s = deformation in scoreline region

FACTORS AFFECTING e_p

The strain in the mid-depth region is probably quite uniform over most of the box depth in the region adjacent to the vertical scorelines because no appreciable bowing of the panel occurs in this region. Thus, the total deflection in the mid-depth region should be directly related to (1) the effective depth (d_p) over which the strain is sensibly uniform and (2) the unit strain (ε_p) of the combined board which, in turn, is related to the applied load (P_p) and the compression stiffness of the combined board (S_p). Thus, e_p may be defined as follows:

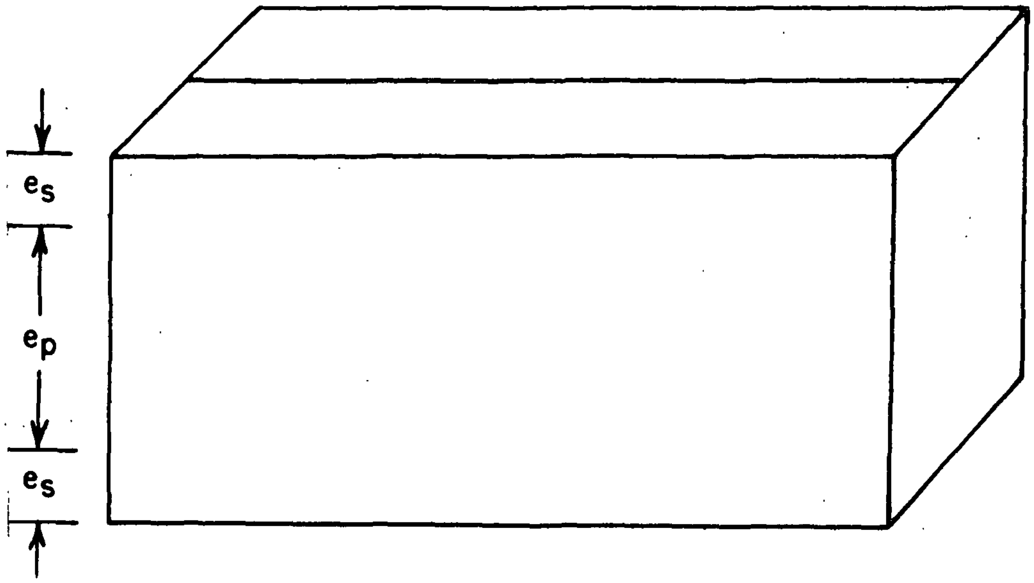

Figure 1. Schematic Drawing of Box Deflection Regions

$$e_p = \varepsilon_p d_p = (P_p/S_p) d_p \qquad (2)$$

or, if d_p is approximately equal to the box depth (D), then

$$e_p \doteq \varepsilon_p D \doteq (P_p/S_p) D \qquad (3)$$

At box loads before much bowing occurs, the load applied to the box is approximately uniformly distributed around the perimeter. Hence, under these conditions, P_p would equal the box load per unit of perimeter. As bowing and buckling occur, the load distribution on the perimeter becomes nonuniform and P_p is related to but not equal to the total box load per unit of perimeter. At high applied load levels, the stresses are above the proportional limit so S_p is no longer equal to the "elastic" stiffness.

According to theory, when maximum box load is attained, P_p is equal to the ultimate compression strength of the corrugated board (P_{my}). Also, ε_p should equal the ultimate compression strain of the corrugated board (ε_{my}). Thus, at maximum load, Equation (3) may be written as follows:

$$e_p \doteq \varepsilon_{my} D \qquad (4)$$

Equation (4) indicates that the ultimate compression strain of the combined board must be evaluated in order to estimate the e_p component of the total box deflection. Furthermore, aside from minor differences in compression stiffness between flute sizes, e_p is not affected by flute size. This implies that the differences in box deflection between flute sizes are associated with the second term in Equation (1) — i.e., the amount of scoreline deflection.

FACTORS AFFECTING SCORELINE DEFORMATION $\underline{e}_{\underline{s}}$

The scoreline deformation involves the "squaring-off" and crushing of the board in the scoreline region. For this reason, it can be expected to depend highly on the flute size of the board. Other factors which might affect the amount of scoreline deformation include box squareness, type and severity of flap score, and box dimensions. The role that material properties play in affecting the scoreline deformation is not very amenable to analysis. However, it seems possible that the edgewise compression stress-strain property of the combined board or its components may be a factor.

MATERIALS

For Phase I, boxes and tubes were constructed from three samples of 200-lb series board — one A-, one C-, and one B-flute sample.

In the second phase of the study, correlations between top load box deflection, box dimensions, and combined board properties, were obtained using data for 63 commercial box samples. The data were taken from Compression Report 75.

BOX AND TUBE FABRICATION — PHASE I

The A- and C-flute boards were fabricated into RSC boxes and tubes having perimeters of 35, 55, and 75-inches and depths of 9, 13, 17, and 21 inches. Because of a shortage of material, the B-flute boxes and tubes were made up in only two perimeters; namely, 35 and 55 inches. The same four depths were employed at each perimeter for the B-flute tubes and boxes. Only three boxes and three tubes were constructed in each size from each sample due to sample limitations.

A 3-point flap score contour was used for the flap scorelines of the boxes. The vertical scorelines were made with a V male *vs.* flat scoreline contour. Both boxes and tubes were made with a glued manufacturer's joint. The tubes were cut to depth using a sharp saw.

TESTING

All materials were preconditioned at less than 35% RH, 73°F and conditioned at least 48 hours at 50% RH, 73°F prior to test. The top load box and tube compression tests were carried out at a rate of 0.5 inch/minute.

Edgewise compression, flexural stiffness, and caliper tests were carried out on the combined board.

DISCUSSION OF RESULTS

PHASE I. STUDY OF SCORELINE DEFLECTION

As mentioned previously, total box deflection may be regarded as being comprised of two parts. They are (1) the deflection ($\underline{e}_{\underline{s}}$) of the scoreline region at top and bottom of the box, and (2) the deflection ($\underline{e}_{\underline{p}}$) in the panel region between flap scorelines. These are referred to as scoreline and midpanel deflections or strains in the following discussion.

For this study, it is assumed that when combined board tubes and boxes of the same size are tested, the tube deflection is a measure of the midpanel deflection ($\underline{e}_{\underline{p}}$). Therefore, the difference between box and tube deflection is a measure of the scoreline deflection ($\underline{e}_{\underline{s}}$).

A limited comparison of box, tube, and scoreline deflections is shown in Table I for A-, C-, and B-flute samples. The effects of depth and perimeter are illustrated in Fig. 2 and 3, and a statistical analysis of the data is contained in Table II. In interpreting the data, it should be kept in mind that the average box and tube deflections are based on only three replicate tests for each size and sample.

As expected, the scoreline deformation is much greater than the tube deflections. For example, on the average, the scoreline deflection amounted to 92.5, 90.9, and 87.3% of the total box deflection for the A-, C-, and B-flute samples, respectively. Thus, the scoreline deflection accounts for the

TABLE I

EFFECT OF DEPTH AND PERIMETER ON BOX, TUBE, AND SCORELINE DEFLECTION

Depth, in.	A-Flute Perimeter, in. 35	55	75	Av.	C-Flute Perimeter, in. 35	55	75	Av.	B-Flute Perimeter, in. 35	55	Av.
					Box Deflection, in.						
9	0.74	0.72	0.73	0.73	0.61	0.59	0.64	0.61	0.44	0.41	0.42
13	0.89	0.82	0.66	0.79	0.70	0.57	0.57	0.61	0.48	0.42	0.45
17	0.92	0.86	0.67	0.82	0.75	0.64	0.59	0.66	0.47	0.48	0.48
21	0.77	0.75	0.66	0.73	0.70	0.64	0.61	0.65	0.49	0.51	0.50
Av.	0.83	0.79	0.68	0.77	0.69	0.61	0.60	0.63	0.47	0.46	0.46
					Tube Deflection, in.						
9	0.052	0.044	0.038	0.045	0.046	0.039	0.035	0.040	0.044	0.041	0.042
13	0.059	0.052	0.045	0.052	0.056	0.055	0.053	0.055	0.053	0.053	0.053
17	0.068	0.062	0.055	0.062	0.057	0.062	0.063	0.061	0.064	0.067	0.066
21	0.081	0.065	0.065	0.070	0.077	0.077	0.072	0.075	0.076	0.076	0.076
Av.	0.065	0.056	0.051	0.057	0.059	0.058	0.056	0.058	0.059	0.059	0.059
					Scoreline Deflection, in.[a]						
9	0.69	0.67	0.69	0.69	0.56	0.55	0.61	0.57	0.40	0.37	0.38
13	0.83	0.77	0.61	0.74	0.65	0.52	0.57	0.58	0.42	0.36	0.39
17	0.86	0.79	0.62	0.76	0.70	0.58	0.53	0.60	0.40	0.42	0.41
21	0.69	0.68	0.59	0.65	0.63	0.56	0.54	0.58	0.41	0.44	0.42
Av.	0.77	0.73	0.63	0.71	0.64	0.55	0.56	0.58	0.41	0.40	0.40
					Scoreline Deflection, %[b]						
9	92.9	93.9	94.8	93.9	92.4	93.4	94.5	93.4	90.1	90.0	90.0
13	93.3	93.6	93.1	93.3	92.0	90.4	90.8	91.1	88.9	87.3	88.1
17	92.7	92.8	91.8	92.4	92.5	90.4	89.6	90.8	86.4	86.2	86.3
21	89.5	91.3	90.1	90.3	89.1	87.9	88.3	88.4	84.3	85.1	84.7
Av.	92.1	92.9	92.4	92.5	91.5	90.5	90.8	90.9	87.4	87.2	87.3

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[a] Box deflection minus tube deflection.

[b] Scoreline deformation divided by box deflection times 100.

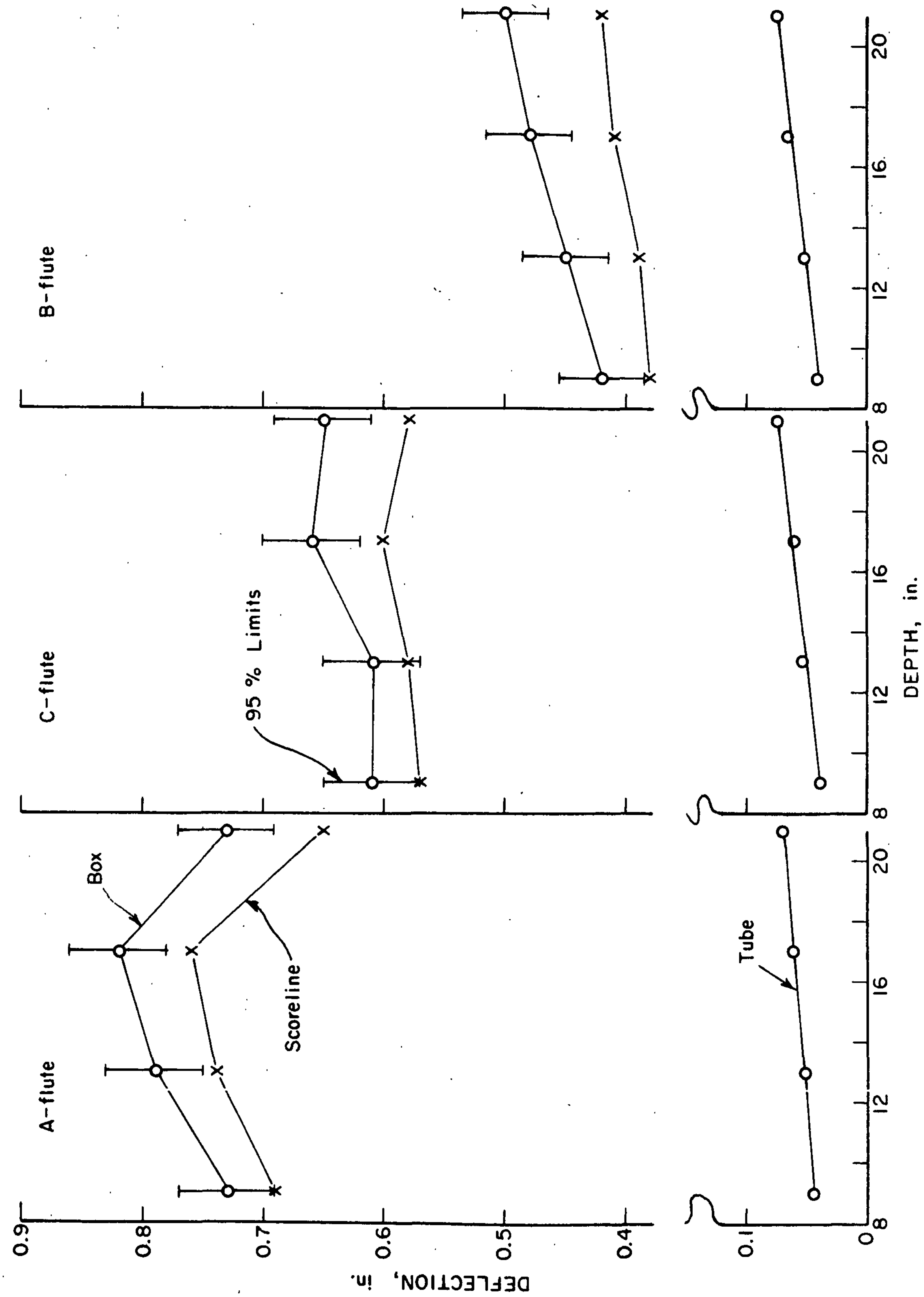

Figure 2. Effect of Depth on Box, Tube, and Scoreline Deflections

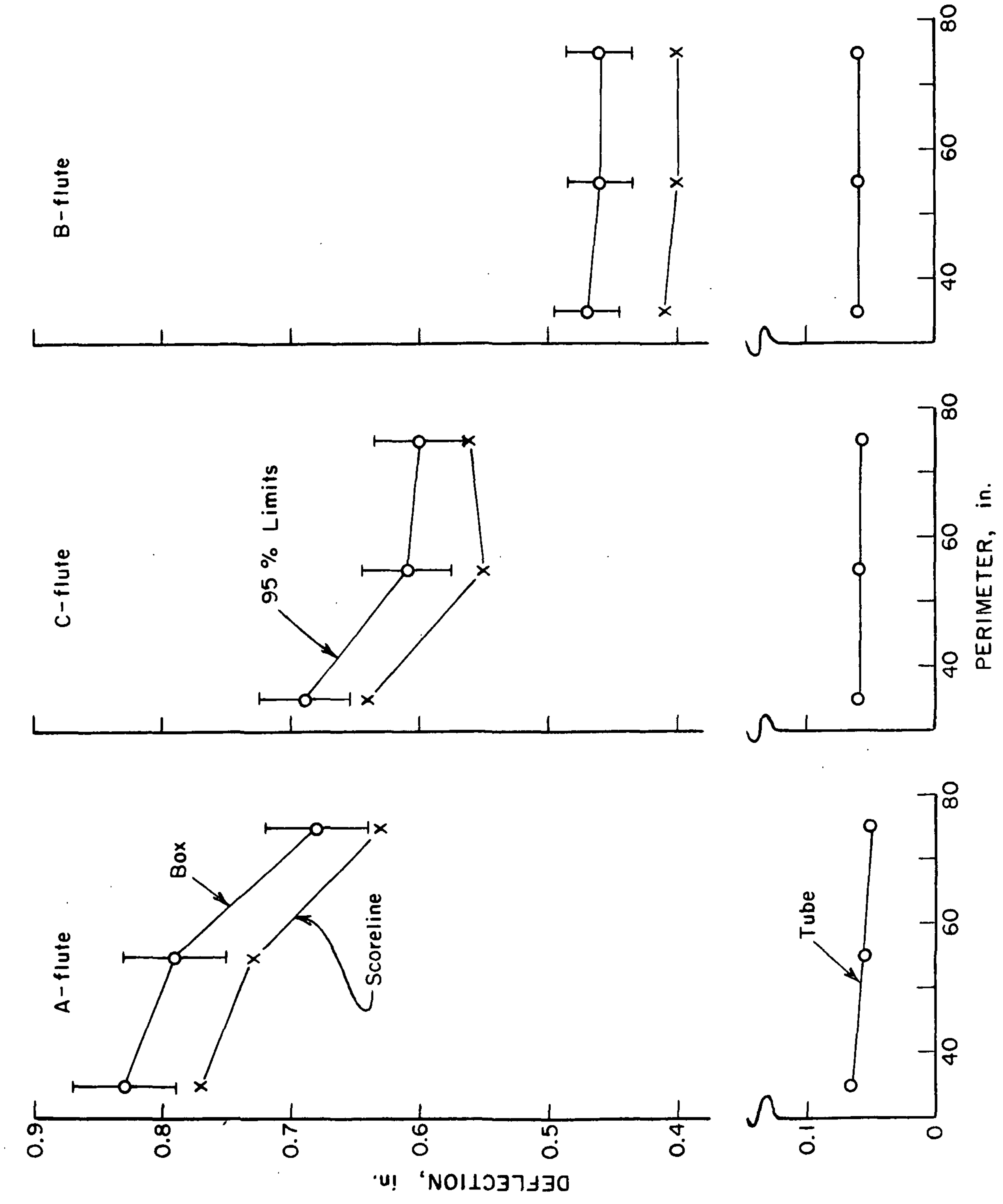

Figure 3. Effect of Perimeter on Box, Tube, and Scoreline Deflections

TABLE II

STATISTICAL ANALYSIS OF DEFLECTION RESULTS

	Box Deflection			Tube Deflection			Scoreline Deflection		
Source of Variance	DF	Mean Square (x 10^{-2})	F	DF	Mean Square (x 10^{-4})	F	DF	Mean Square (x 10^{-2})	F
				A-Flute					
Between depths (D)	3	1.82	4.37[a]	3	11.18	110.35[a]	3	0.64	1.72
Between perimeters (P)	2	7.26	17.46[a]	2	6.55	64.65[a]	2	2.02	5.48[a]
D x P interaction	6	1.09	2.62[a]	6	0.14	1.38	--	--	--
Residual	24	0.42	--	24	0.10	--	6	0.37	--
				C-Flute					
Between depths	3	0.55	1.42	3	19.11	73.15[a]	3	0.06	0.24
Between perimeters	2	2.91	7.46[a]	2	0.46	1.77	2	0.78	3.35
D x P interaction	6	0.61	1.56	6	0.35	1.34	--	--	--
Residual	24	0.39	--	24	0.26	--	6	0.23	--
				B-Flute					
Between depths	3	0.61	3.60[a]	3	12.97	73.96[a]	3	0.060	0.81
Between perimeters	1	0.07	0.41	1	0.01	0.04	1	0.025	0.34
D x P interaction	3	0.23	1.37	3	0.08	0.43	--	--	--
Residual	16	0.17	--	16	0.18	--	3	0.074	--

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[a] Significant at 0.05 level or more.

major portion of the box deflection at maximum load. It appears that much of the variability in box deflection, and possibly in box load, originates in flap scoreline behavior.

An analysis of variance indicated that the scoreline deflections were not significantly affected by box depth. Also, perimeter did not significantly affect the scoreline deformations for the B- and C-flute samples; however, the A-flute scoreline deformations showed a significant decrease with increased perimeter. Taken as a whole, the results suggest that the scoreline deflection is not strongly affected by either box depth or perimeter (except possibly A-flute). Additional confirmatory testing would be helpful here because of the low number of replications used in this preliminary study.

As mentioned previously, the tube deflections are assumed to be a measure of the deflection occurring between the flap scorelines — i.e., the midpanel deflections. The results show that the tube deflections significantly increased with increasing depth as expected. However, despite their high statistical significance, the increases in tube deflection with increasing depth were relatively small in practical terms. For example, for a change in depth from 9 to 21 inches, the average tube deflection increases were 0.025, 0.035, and 0.034 inch for the A-, C-, and B-flute samples, respectively. Thus, while increases in box depth should result in larger box deflections due to the midpanel strains, the effect on box deflections will be small (except for large depth differences) and can easily be obscured by differences in flap scoreline behavior.

Because of the small magnitude of the tube deflections, small differences in ultimate edgewise compression strain of the combined board from sample-to-sample would not be expected to have a large effect on box deflections in so far as midpanel strains are concerned.

The relatively low magnitude of the midpanel deflection apparently arises because the ultimate edgewise compression strain for linerboard is much lower than its stretch in tension. For example, Setterholm and Gertjejansen (2) reported an ultimate strain in compression of 0.00526 inch/inch (0.522%) in the cross direction for linerboard whereas the stretch in tension was 0.0460 inch/inch (4.60%). Thus, the ultimate strain in compression was almost 10 times less than in tension. In this study, the tube strains (deflection/depth) averaged for the three samples were as follows:

Tube Depth, inch	Tube Strain, inch/inch
9	0.0047
13	0.0041
17	0.0037
21	0.0034

In rough terms, the tube strains are quite low and of the same magnitude as reported in the cited article. The decreasing trend with depth is probably due to localized deformation at the loaded edges of the tubes which would be expected to increase in magnitude at low tube depths.

Figure 4 shows the average box, scoreline, and tube deflections plotted against combined board caliper. As would be expected, the box and scoreline deformation were essentially proportional to caliper — i.e., flute size. The tube deflections were not affected by flute size because the ultimate edgewise compression strain of the combined board should be about the same for the three flutes — disregarding secondary effects.

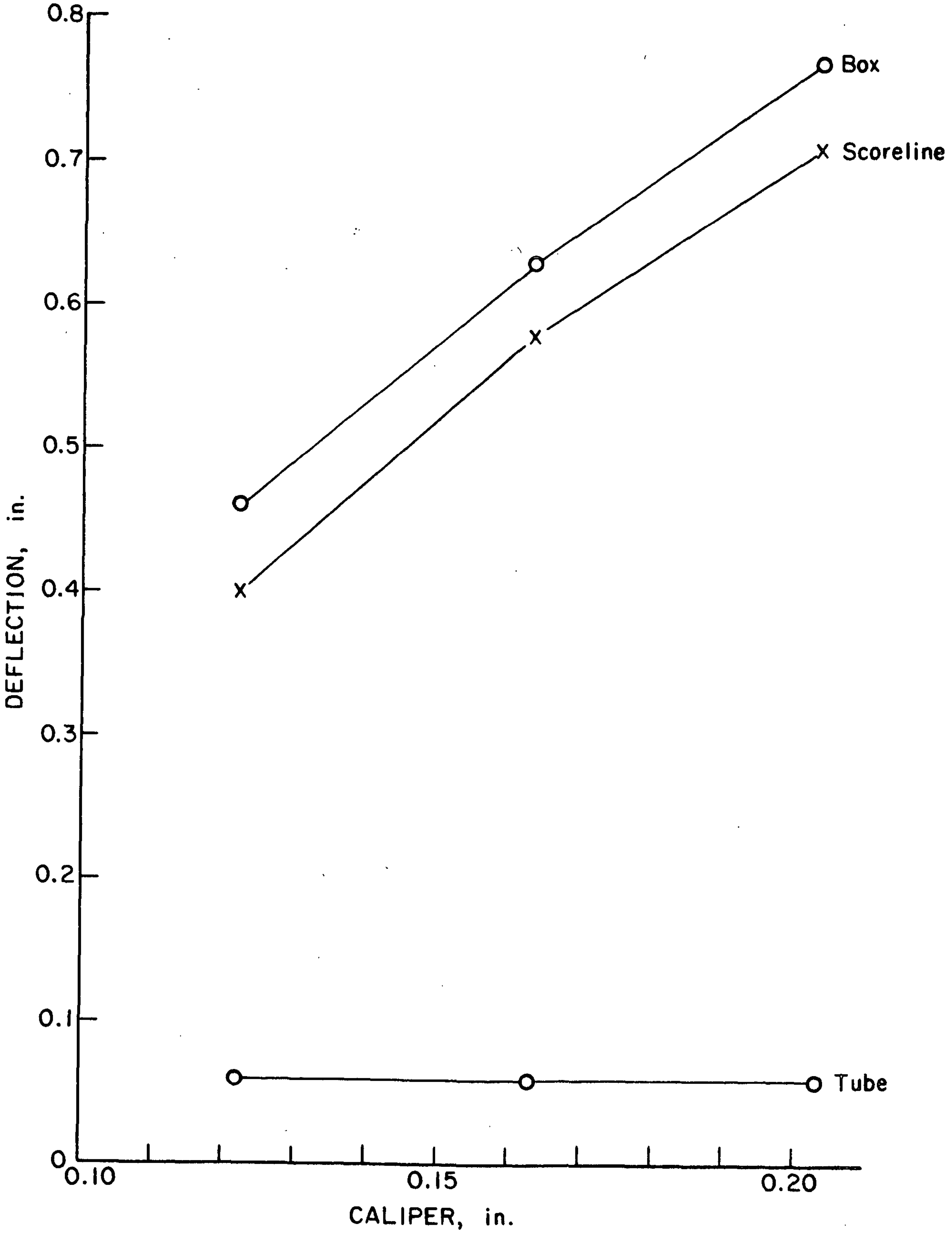

Figure 4. Effect of Combined Board Caliper on Box, Tube, and Scoreline Deflections

Briefly summarizing the Phase I results indicate the following:

1. As expected, the scoreline deformation accounts for the major portion of the box deflection.
2. The scoreline deformations were not significantly affected by box depth and generally not by perimeter.
3. Total box deflection appears to be primarily related to flute size because of flap scoreline behavior.

PHASE II. BOX DEFLECTION VS. C.B. CHARACTERISTICS AND BOX DIMENSIONS

The box and combined board (C.B.) data are shown in Table III. When the coefficients of variation for maximum box load and deflection are compared, it may be noted that box deflections are considerably more variable than box loads. For example, for the 63 box samples the average coefficients of variation were 6.7 and 11.1% for load and deflection, respectively. Moreover, the deflection coefficients of variation ranged up to 26.1% and for one-third of the samples were greater than 14.7%. High deflection variability must contribute to variations in warehouse stacking performance of palletized corrugated boxes.

High variability also results in wide confidence limits on the average deflection. For this reason, it was decided to carry out the correlations between box deflection, dimensions, and C.B. characteristics in two ways, namely, (1) for the entire array of 63 samples, and (2) restricted to the 42 samples where the deflection coefficient of variation was less than 12.5%.

The simple correlations between maximum box deflection and various characteristics are listed in Table IV. The data for the low variability samples shows that highly significant correlations with deflection were

TABLE III

MECHANICAL AND DIMENSIONAL PROPERTIES OF COMBINED BOARD AND BOXES

	Box Properties							Combined Board Properties			
	Top-Load Box Compression										
Code	Load, $\underline{P}$, lb	Coeff. of Variation, %	Deflection, in.	Coeff. of Variation, %	Box Depth, $\underline{D}$, in.	Loading Perimeter, $\underline{Z}$, in.	Type of Mfr.'s Joint	Caliper, $\underline{H}$, in.	Edgewise Compression, $\underline{P}_{\underline{my}}$, lb/in.	Comp. Flex. Stiffness, lb-in.	Flat Crush, psi
A-Flute Box Deflection — Coefficient of Variation is <12.5%											
2046	880	4.9	0.572	5.5	23.750	57.50	Taped	0.214	45.80	134.0	30.8
2341	949	7.4	0.634	5.4	22.250	79.00	Taped	0.199	40.40	120.0	40.0
2345	946	3.5	0.618	6.0	22.250	79.00	Glued	0.199	43.30	122.0	36.1
1176	772	5.2	0.646	8.9	14.750	44.50	Taped	0.207	44.00	141.0	31.3
1146	912	5.9	0.560	3.5	14.000	56.00	Taped	0.208	46.70	128.0	33.0
1167	994	6.9	0.614	10.4	6.750	63.50	Taped	0.207	45.60	139.0	31.4
1163	938	6.5	0.602	3.4	8.750	65.00	Taped	0.209	45.90	130.0	36.3
2315	1024	4.9	0.600	5.0	11.375	80.50	Stitched	0.206	45.70	119.0	32.0
2303	1120	4.6	0.608	4.6	10.250	99.00	Stitched	0.202	47.60	126.0	42.0
2397	1013	6.7	0.542	2.4	14.125	84.00	Taped	0.216	46.00	144.0	29.6
2402	1015	7.0	0.565	2.7	17.750	67.00	Taped	0.215	42.50	137.0	29.2
2095	1496	8.5	0.680	12.2	15.375	86.75	Taped	0.195	63.70	175.0	32.2
2099	1918	4.4	0.726	4.0	31.250	116.50	Taped	0.224	67.10	171.0	29.4
2054	1717	5.5	0.554	3.4	31.000	120.00	Stitched	0.215	59.90	185.0	40.0
2155	1663	5.6	0.722	4.4	28.250	134.00	Stitched	0.223	61.10	215.0	33.8
A-Flute Box Deflection — Coefficient of Variation is 12.5% or Greater											
1192	564	7.9	0.496	26.1	7.750	34.50	Stitched	0.197	41.20	121.0	33.3
1188	660	5.6	0.664	18.8	15.750	46.50	Taped	0.200	37.30	117.0	35.6
1184	770	10.0	0.602	22.1	17.750	49.50	Taped	0.207	43.70	141.0	33.8
2324	951	6.2	0.626	21.9	17.250	54.00	Taped	0.203	45.40	131.0	41.4
1172	925	11.9	0.556	19.9	11.500	66.00	Taped	0.207	42.40	140.0	29.0
1180	678	5.5	0.636	23.0	14.750	32.50	Stitched	0.217	50.50	115.0	32.2
1197	862	3.6	0.706	21.3	12.500	38.00	Taped	0.216	48.30	125.0	32.8
2041	814	6.3	0.768	18.2	16.250	40.50	Taped	0.218	50.00	159.0	27.5
2373	1280	10.9	0.644	26.0	13.250	72.00	Taped	0.225	57.10	190.0	29.8
C-Flute Box Deflection — Coefficient of Variation is <12.5%											
2211	489	10.9	0.356	6.0	12.250	40.50	Taped	0.152	34.10	62.3	28.4
2081	616	5.1	0.450	2.3	9.375	44.75	Taped	0.162	40.70	96.0	44.2
2228	768	8.3	0.406	5.6	10.500	47.00	Glued	0.166	47.50	84.1	41.7
2207	689	4.1	0.384	4.3	7.250	53.25	Taped	0.164	40.30	78.3	48.2
2076	792	9.8	0.500	8.7	7.750	53.50	Taped	0.166	42.60	103.0	48.4
2058	810	9.5	0.494	4.4	10.500	54.00	Taped	0.158	43.80	93.1	47.8
2365	799	6.6	0.482	11.4	11.125	56.00	Taped	0.152	43.30	73.8	30.9
2215	625	8.8	0.384	9.9	11.250	57.50	Taped	0.161	41.90	78.4	40.8
2145	960	4.2	0.480	5.7	11.750	57.50	Glued	0.162	52.30	84.3	59.8
2171	901	5.9	0.542	6.7	7.250	58.25	Glued	0.161	48.40	88.3	66.6
2090	971	5.3	0.498	12.1	16.250	72.75	Taped	0.161	49.00	82.6	48.6
2094	914	8.2	0.464	9.5	20.500	79.25	Taped	0.160	45.20	81.0	44.8
2369	1170	3.9	0.548	3.2	14.125	66.50	Taped	0.180	61.70	128.0	36.9
2033	1126	8.6	0.512	5.0	22.750	76.50	Taped	0.172	63.30	116.0	38.0
2050	1407	9.9	0.498	10.2	16.000	79.50	Taped	0.185	71.10	148.0	35.6
2103	1206	8.8	0.506	9.8	18.250	87.50	Taped	0.172	56.60	108.0	42.4
2086	1296	6.4	0.652	11.2	15.000	40.00	Stitched	0.176	78.90	126.0	48.4

TABLE III (Continued)

MECHANICAL AND DIMENSIONAL PROPERTIES OF COMBINED BOARD AND BOXES

	Box Properties							Combined Board Properties			
	Top-Load Box Compression										
Code	Load, P, lb	Coeff. of Variation, %	Deflection, in.	Coeff. of Variation, %	Box Depth, D, in.	Loading Perimeter, Z, in.	Type of Mfr.'s Joint	Caliper, H, in.	Edgewise Compression, P_{my}, lb/in.	Comp. Flex. Stiffness lb-in.	Flat Crush, psi
C-Flute Box Deflection — Coefficient of Variation is 12.5% or Greater											
2219	636	8.9	0.352	18.3	10.500	32.25	Glued	0.162	43.90	75.8	48.1
2167	597	6.3	0.410	18.3	5.750	43.75	Glued	0.164	40.80	70.7	48.1
2176	671	10.3	0.472	25.3	6.750	32.50	Glued	0.160	40.60	81.5	51.4
2107	841	6.8	0.574	18.0	10.250	43.50	Taped	0.161	48.80	101.0	47.1
2150	831	5.6	0.588	14.7	10.625	64.25	Glued	0.158	45.50	78.2	54.8
2398	793	5.9	0.351	19.3	8.125	62.00	Taped	0.169	40.20	90.0	34.4
2111	961	5.5	0.538	21.3	12.250	49.75	Taped	0.172	57.10	120.0	46.9
2141	1066	3.2	0.512	14.9	11.000	55.50	Stitched	0.184	68.50	139.0	47.8
2137	1028	9.5	0.560	17.8	17.000	44.00	Stitched	0.174	72.70	126.0	48.4
B-Flute Box Deflection — Coefficient of Variation is <12.5%											
2349	615	5.8	0.400	4.4	22.000	57.50	Taped	0.119	43.40	38.8	45.3
2353	626	4.6	0.352	6.4	24.125	40.00	Taped	0.126	43.50	48.4	49.1
2311	769	4.4	0.366	4.0	13.125	49.50	Glued	0.124	48.40	48.0	54.4
2001	730	5.9	0.356	10.5	11.500	57.00	Stitched	0.124	47.40	41.3	49.0
2005	735	2.8	0.364	11.1	11.500	57.00	Stitched	0.124	45.80	41.4	48.2
2029	654	9.8	0.444	9.1	21.750	57.50	Taped	0.124	47.70	46.6	41.0
2319	744	4.6	0.352	4.9	9.500	63.25	Glued	0.121	48.90	41.3	57.8
2307	872	4.0	0.360	3.5	9.000	68.00	Stitched	0.123	49.70	52.7	57.0
2062	1086	4.3	0.450	11.5	12.000	48.00	Taped	0.140	69.90	80.3	51.3
2240	801	7.5	0.398	4.1	10.625	48.50	Taped	0.145	63.10	82.3	45.2
B-Flute Box Deflection — Coefficient of Variation is 12.5% or Greater											
2009	589	6.6	0.488	19.8	14.625	52.13	Glued	0.122	46.00	69.3	48.0
2182	999	8.3	0.608	20.3	22.500	54.50	Stitched	0.139	64.20	79.5	46.2
2248	994	9.4	0.454	14.9	18.625	73.25	Stitched	0.148	63.40	74.1	43.8

obtained with (1) combined board caliper, (2) the composite flexural stiffness $\sqrt{D_x D_y}$, and (3) the product of CD edgewise compression and caliper squared ($P_{my} H^2$). These properties are highly dependent on flute size though, within a given flute, they generally increase with board weight. The three properties were about equally well related to deflection.

TABLE IV

CORRELATION BETWEEN MAXIMUM BOX DEFLECTION, DIMENSIONS AND C.B. CHARACTERISTICS

	Property	Correlation Coefficient (r)[a]	
		Low Var. Samples (N = 42)	All Samples (N = 63)
1.	Box depth	0.37	0.35
2.	Box perimeter	0.58	0.30
3.	Length/width ratio	-0.17	-0.28
4.	C.B. Edgewise compression (CD) (P_{my})	0.33	0.26
5.	C.B. Caliper (H)	0.86	0.79
6.	Composite flexural stiffness ($\sqrt{D_x D_y}$)	0.88	0.80
7.	$P_{my} H$	0.78	0.70
8.	$P_{my} H^2$	0.86	0.79
9.	Flat crush	-0.52	-0.50

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[a] 0.05 Significance levels; N = 42, r = 0.30; N = 63, r = 0.25.

The correlation of box depth with box deflection was statistically significant but low in magnitude (r = 0.37). This appears to result because the deflections in the flap scoreline regions overshadow the small changes in deflection due to changes in box depth as shown by the results in Phase I.

A somewhat higher coefficient of 0.58 was obtained with perimeter. This may result from the fact that the boxes of larger perimeter were generally made from A- or C-flute board.

A low but significant coefficient was also obtained for flat crush (*r* = 0.52). This apparently results because flat crush is generally highest for B-flute and lowest for A-flute.

The results for all the samples generally exhibited the same trends as the low variability sample results. However, the magnitudes of the coefficients were usually somewhat lower. The lower coefficients are caused, in part, by the fact that the average deflections for the high variability samples have much wider confidence limits — i.e., the sample average is a poorer estimate of the population average.

Thus, the simple correlations indicate that top load box deflection is best related to C.B. properties which are highly dependent on flute size — namely, C.B. caliper, the composite flexural stiffness or the quantity $P_{my} H^2$. Using each of these properties in turn, stepwise multiple regressions were carried out to determine if the correlations could be improved by the addition of depth, perimeter, length/width ratio and two factor interactions of these properties. Little or no improvement in correlation was obtained, thus confirming that box dimensions do not have a strong effect on box deflections.

Tables V and VI show a number of two and three factor regression equations obtained using various properties with (a) caliper, (b) $\sqrt{D_x D_y}$, or (c) $P_{my} H^2$. Table V contains the results obtained for the low deflection variability samples and Table VI shows the corresponding results for all samples.

TABLE V

MULTIPLE REGRESSIONS BASED ON LOWER DEFLECTION VARIABILITY SAMPLES
($N = 42$)

Number	Equation	Significance (0.05 Level) Var. 1	Var. 2	Var. 3	Mult. Corr. Coeff.	Av. Pred. Error, %
1	$DF = 0.02 + 2.83H$	Yes	--	--	0.863	8.41
2	$DF = 0.01 + 2.72H + 0.0018d$	Yes	No	--	0.869	8.36
3	$DF = -0.08 + 2.73H + 0.0024\ P_{my}$	Yes	Yes	--	0.889	8.02
4	$DF = -0.09 + 3.11H + 0.0015\ F_c$	Yes	No	--	0.868	8.37
5	$DF = -0.08 + 2.68H + 0.0022\ P_{my} + 0.0009d$	Yes	Yes	No	0.890	7.97
6	$DF = -0.14 + 2.90H + 0.0023\ P_{my} + 0.0009\ F_c$	Yes	Yes	No	0.891	7.99
7	$DF = 0.28 + 0.0022\sqrt{D_x D_y}$	Yes	--	--	0.877	8.24
8	$DF = 0.27 + 0.0022\sqrt{D_x D_y} + 0.0002d$	Yes	No	--	0.877	8.23
9	$DF = 0.29 + 0.0022\sqrt{D_x D_y} - 0.0003\ P_{my}$	Yes	No	--	0.878	8.20
10	$DF = 0.27 + 0.0022\sqrt{D_x D_y} + 0.0001\ F_c$	Yes	No	--	0.877	8.24
11	$DF = 0.29 + 0.0022\sqrt{D_x D_y} - 0.0003\ P_{my} + 0.0003d$	Yes	No	No	0.878	8.20
12	$DF = 0.30 + 0.14\ P_{my}H^2$	Yes	--	--	0.862	9.15
13	$DF = 0.30 + 0.14\ P_{my}H^2 - 0.0007d$	Yes	No	--	0.863	9.12

Note: Symbols are as follows:

DF = Max. top load deflection
H = C.B. caliper
d = Box depth
F_c = Flat crush
P_{my} = CD edgewise compression
$\sqrt{D_x D_y}$ = Geometric mean of MD and CD flexural stiffness

TABLE VI

MULTIPLE REGRESSIONS BASED ON ALL SAMPLES
(N = 63)

Number	Equation	Significance (0.005 Level) Var. 1	Var. 2	Var. 3	Mult. Corr. Coeff.	Av. Pred. Error, %
14	$DF = 0.05 + 2.72H$	Yes	--	--	0.788	10.42
15	$DF = 0.02 + 2.58H + 0.0034d$	Yes	Yes	--	0.808	9.97
16	$DF = -0.07 + 2.68H + 0.0024\ P_{my}$	Yes	Yes	--	0.818	10.05
17	$DF = -0.07 + 3.04H + 0.0015\ F_c$	Yes	No	--	0.793	10.35
18	$DF = -0.07 + 2.59H + 0.0020\ P_{my} + 0.0023d$	Yes	Yes	No	0.826	9.78
19	$DF = -0.13 + 2.86H + 0.0023\ P_{my} + 0.0008\ F_c$	Yes	Yes	No	0.819	9.96
20	$DF = 0.29 + 0.0022\ \sqrt{D_x D_y}$	Yes	--	--	0.802	10.13
21	$DF = 0.27 + 0.0021\ \sqrt{D_x D_y} + 0.0016d$	Yes	No	--	0.807	9.99
22	$DF = 0.29 + 0.0022\ \sqrt{D_x D_y} - 0.0002\ P_{my}$	Yes	No	--	0.802	10.10
23	$DF = 0.29 + 0.0022\ \sqrt{D_x D_y} - 0.00008\ F_c$	Yes	No	--	0.802	10.13
24	$DF = 0.29 + 0.0022\ \sqrt{D_x D_y} - 0.0005\ P_{my} + 0.0018d$	Yes	No	No	0.807	9.90
25	$DF = 0.31 + 0.133\ P_{my}H^2$	Yes	--	--	0.787	10.94
26	$DF = 0.30 + 0.130\ P_{my}H^2 + 0.0007d$	Yes	No	--	0.788	10.94

Note: Symbols are as follows:

DF = Max. top load deflection
H = C.B. caliper
d = Box depth
F_c = Flat crush
P_{my} = C.D. edgewise compression
$\sqrt{D_x D_y}$ = Geometric mean of MD and CD flexural stiffness

Table V shows that small but significant improvements in correlation were obtained using caliper and CD edgewise compression strength (P_{my}). It seems likely that the scoreline deflection will depend somewhat on the compression characteristics of the board — hence, this would explain the significance of the P_{my} term. As one consequence, it suggests that scoreline deformation and, hence, box deflection, increases somewhat as board weight increases.

Using all the box data, Table VI shows that small but significant improvements in correlation were obtained using caliper and either depth or P_{my}. An additional small improvement was effected in Equation (18) using all three properties but the depth factor failed to attain statistical significance.

Based on the above, it appears that Equations (14) or (20) involving either caliper or $\sqrt{D_x D_y}$ are the simplest equations to use to predict maximum top load box deflection. A small improvement in prediction accuracy can be effected by also including box depth or P_{my} in conjunction with board caliper [see Equations (15), (16), and (18)]. The inclusion of depth has a logical basis but it must be admitted that the gain in prediction accuracy is rather small.

The equations in Tables V and VI provide a way to estimate box deflections. As mentioned previously, it is believed that as a broad objective it should be possible to develop ways of predicting the compression behavior of boxes with inner packing and/or load-bearing product. Box deflection is one of the factors that must be considered in working toward this objective.