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PREDICTING PACKAGE COMPRESSION STRENGTH

GEOMETRY EFFECT

Project 3806

Final Report

A Progress Report

to the

CONTAINERBOARD AND KRAFT PAPER GROUP
OF THE AMERICAN FOREST AND PAPER ASSOCIATION

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PREDICTING PACKAGE COMPRESSION STRENGTH

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OBJECTIVE

Part A. To verify the modified box compression estimating model developed under Project 3746, in 1992, with commercial boxes.

Part B. To evaluate the model's applicability to internal partition and divider structures.

SCOPE

Part A. To provide the commercial documentation portion of this project involved having five volunteer box plants produce corrugated packaging of various sizes from a common lot of corrugated sheets produced at that box plant. Each of the five box plants used a different grade of corrugated so as to have a range of board strengths represented, including double-wall and heavy weight medium grades. The package dimensions among the five plants ranged from 36 x 36 x 30 inches to 12 x 6 x 6 inches. The testing included ECT, flexural stiffness, caliper, and box compression.

Part B. To evaluate the application of the model to inner packing such as dividers and partitions included two, four, and six cell designs. Three grades of corrugated were used with varying box heights and perimeters. The analysis of the data obtained from this work should be adequate to demonstrate the applicability of the model. The testing included ECT, flexural stiffness, caliper, and tube compression.

Summary and Conclusions

Continuing research to improve the predictability of compressive strength of corrugated boxes has been directed toward cost efficient packaging. Earlier work by McKee et al.[1] led to the development of a box compression predicting model (commonly referred to as a formula or equation) that has been used effectively by the industry for the last 30 years. This model was limited to a narrow range of box heights and perimeters as well as critical panel sizes and perimeter/height aspect ratios. Commercial production of boxes in the present market demands the ability to predict compression strengths well outside the limitations of that era in 1963.

The current Project 3806 and its immediate predecessor (Project 3746)[2] were directed toward developing sufficient data to allow a modification of the original McKee model to reflect the compression characteristics of both smaller and larger corrugated boxes than used in the development of that model. Considerable progress was made in Project 3746 with the addition of another parameter to the original McKee model that considers the effects of the individual panel widths, heights, and number of panels. The data presented in this current project support the use of individual panel dimensions in the calculation of compression strength for both boxes and partitions but donot appear to be the final answer. The predicted compression strengths still exhibit a wide range of values using the modified equation. The larger disparities seem to be at the higher compressive load levels. Other parameters that could be added to the model need to be looked at, possibly such as the effect of a corner factor, height to width aspects, initial panel curvature, and others. This analysis of the data to produce modifications to the model was intended to be looked at in one of the next phases of this work. Only after a complete analysis of the data will we be able to determine which aspect of box design will be needed to be added to the model.

The problems associated with the procurement of commercial box samples require that a concerted effort must be made with the box plants to expedite the acquisition of additional samples for future studies. It is in their interests that these efforts have been directed.

Whether or not future work is continued, the importance of predicting box performance will be an important part of cost-effectiveness in the industry.

Part A - Verification of the Modified Box Compression Estimating Model Using Commercial Boxes

I. Summary and Conclusions

The data developed from testing five sets of boxes made by five different container plants for six sets of data pose a challenge to the researchers to interpret. The predicted box compression from the original and modified McKee equation resulted in a wide range of values compared to the actual test results.

The small number of samples in this phase, 30 in all, yielded predicted compression data, using the Modified McKee Model **from Project 3746, Final Report, dated February 15, 1993**, that had some variation from the actual compression tests notably at the higher compression strengths. These predictions were substantially improved from the original and simplified models determined by McKee in 1963.[1] The modified was better in predictions than the original or the simplified formulas and was consistent for all four sets of single-wall ECT Grade conditions.

Calculated values for double-wall board, using the modified model were consistently closer to the actual compression as compared to either the original or simplified formula. The predicted strengths for the original and the simplified formulas, for the most part, were consistently higher by as much as 63% and 89% in one of the sets of double-wall boards. This same set showed only 43% higher for the modified formula.

Flexural stiffness plays an important part in actual compression resistance as larger panel size and/or height can reflect buckling tendencies not visible on smaller panels or height of container.

The information gathered to date on this project does suggest that an additional term or terms may be required in order to improve the accuracy of the modified equation. Whether the exponents need adjusting is unknown at this time. Panel size is more sensitive to its flexural stiffness value in contributing to box compression. The various configurations used in this project suggest that the additional terms may include, and not be limited to, a corner factor, height to perimeter aspect, individual panel height to width aspect, initial panel curvature, and others.

The original project contemplated five stages with Project 3806 completing Stage 3. Two additional stages were visioned necessary to obtain a commercially viable and accurate prediction model for the industry. Stage 4 was proposed to involve laminated structures at an estimated cost of $80K, and Stage 5 was intended to refine all the data for the final equation at a cost of $50K. These figures would need to be revised as the complications of the ranges of box compression variability show the need for more analysis.

II. Introduction

Over the years there have been numerous comments from the converting divisions of CKPG member and nonmember companies concerning the lack of predictive accuracy of the original 1963 McKee Box Compression Model. The deficiencies appeared to be related to the newer package designs, wider ranges in box sizes, and to the new linerboard and medium combinations being used to address Performance Packaging issues.

With the above in mind, this project was intended to address the various parameters of commercial box production so as to provide the industry with a better tool for evaluating the comparative cost effectiveness of the wider range of materials and designs being used in the marketplace.

With the cooperation of the CKPG task group assigned to oversee this project, several converting plants local to the Atlanta area were identified as willing to participate in the preparation of the needed boxes. Since these plants are in commercial production of the grades of board needed, IPST was given the assurance that the board samples could be obtained without delay. In real-life though, it required several months of juggling schedules at each of the converting plants to find the machine time to make the corrugated sheets and then the boxes for the sizes necessary to meet the needs of the project.

III. Background

(From New Project Proposal to CKPG August 1991)
"Totally empirical box compression estimating charts were developed over 50 years ago by major corrugated box users, such as Colgate and P&G, to assist their packaging engineers in designing cost efficient compression packaging. Robert C. McKee,[1] IPC/IPST, published an equation in 1963 that could be used to predict compression strength of RSC style boxes from the fundamental combined board strength properties of Edge Crush Test and Flexural Stiffness. The only package geometry factor that was included in the early model was the box size expressed as the total perimeter of the box.

All of these published box compression estimating methods were restricted to RSC style containers. Qualitative studies have demonstrated that the observed package compression strength is affected by the ratio of the box width (aspect ratio) and by the package height below some critical dimension. These effects have not been sufficiently quantified so as to allow their application over the full range of package usage. Compression strength predicting models have not been developed for more complex packaging, such as the bliss styles, die-cut styles, and inner packing.

As package users continue to stress the need for more efficient compression packaging, there will be an increased interest in and application of non-RSC style designs. Such non-RSC packaging will include the bliss style boxes, internal dividers and partitions, complex folded die-cut designs, and boxes utilizing a combination of corrugated board grades. The development of sophisticated package setup equipment capable of handling complex style packaging has helped to accelerate this trend. The recent modifications to Item 222/Rule 41 will add to this momentum.

An improved model for package compression that can handle changes in the packaging geometry and style in a generic manner, which the current models cannot do, would expand our ability to deal with the broader issues of corrugated packaging compression performance."

IV. Experimental Technique

1. Source of the Commercial Boxes

The commercial box compression verification experimental design as approved by CKPG was to spread the test box sample procurement across the spectrum of local Atlanta area box plants and converters. Each converter would make a given ECT grade of board that would be subsequently made into RSC style boxes covering six different box sizes. The following board grades are those selected for inclusion in this study:

1) SW 150 psi Mullen or 26 lb/in ECT
2) SW 200 psi Mullen or 32 lb/in ECT
3) Same as 2) above except with Heavy Weight Medium
4) SW 275 psi Mullen or 44 lb/in ECT
5) DW 350 psi Mullen

Each grade of board was to be made from the same roll-stock at a given converting plant and, if possible, from the same location on the corrugator, from either the front or back, within a minimal time frame, and at normal commercial corrugating speeds and conditions. This was intended to keep the board stock and machine variables to a minimum.

The various grades and box sizes are tabulated in Table 1 and Appendix A. Also included in Table 1 are the identities of the plants who ultimately provided the needed boxes. We need to thank them for their contribution to this project. The procurement of samples for a research project is a difficult job for both the researcher and the box plant. Only by being there for the production of the board and the making of the boxes can one fully appreciate the vast problems involved.

TABLE 1

Commercial Box Verification
Experimental Design
Package and Blank Sheet Sizes

	Box Dimensions (L X W X D), Inches	Sheet or Blank Size (Including MJ tab), Inch
Set 1	26 ECT Grade	Stone Container Corp., Lithonia, GA
	12 X 6 X 8	38 X 12
	12 X 6 X 15	38 X 21
	12 X 12 X 15	50 X 27
	24 X 6 X 8	62 X 12
	24 X 6 X 15	62 X 21
	24 X 12 15	74 X 27
Set 2	32 ECT Grade	Willamette Industries, Griffin, GA
	24 X 8 X 6	66 X 14
	24 X 8 X 15	66 X 23
	24 X 8 X 24	66 X 32
	24 X 24 X 6	98 X 30
	24 X 24 X 15	98 X 39
	24 X 24 X 24	98 X 48
Set 3	32 ECT Heavy Med.	Union Camp Corp., Forest Park/ Lithonia, GA
	24 X 8 X 6	66 X 14
	24 X 8 X 15	66 X 23
	24 X 8 X 24	66 X 32
	24 X 24 X 6	98 X 30
	24 X 24 X 15	98 X 39
	24 X 24 X 24	98 X 48
Set 4	44 ECT Grade	Georgia-Pacific, Cleveland, TN
	24 X 10 X 6	70 X 16
	24 X 10 X 15	70 X 25
	24 X 10 X 24	70 X 34
	36 X 10 X 20	94 X 30
	36 X 30 X 20	134 X 50
	36 X 30 X 30	134 X 60
Set 5	51 ECT DW Grade	Mead Corp. Atlanta, GA
	24 X 12 X 6	74 X 18
	24 X 12 X 15	74 X 27
	36 X 12 X 20	98 X 32
	36 X 12 X 30	98 X 42
	36 X 36 X 20	146 X 56
	36 X 36 X 30	146 X 72

The procurement of the commercial boxes took place over the course of several months. As each volunteer plant indicated an acceptable date for the runs, the IPST project co-ordinator scheduled personnel time so as to be present at the fabrication runs for the board as well as the runs at the flexos' where the board stock was made into the desired boxes. In one instance, where arrangements for a precise date for both operations could not be arranged, IPST opted to be on-site for the flexo runs only.

2. Notes on the Fabrication Runs

The corrugator runs to provide the board were initially specified to be made at commercial production speeds, if possible at 600 to 800 ft/min, with no splices or other machine adjustments made during the run. Also, since the flap scores were to be placed in the sheet stock at the time of corrugating the scheduling became more difficult. Our short runs of less than 50 sheets made it doubly difficult to arrange. It was noted that in almost every case the board supplied was produced at or near a roll change, often times with the corrugator operating at less than 100 feet per minute. In one case, the board was rejected by the plant manager because it had numerous spliced sections and was heavily warped due to several stops and slow converting speeds. The replacement board in this case was only a little better as the next machine order was forcing the closing of our sampling window.

In order to improve the scheduling on each corrugator, IPST agreed to allow the use of off-machine scoring for the flap scores, usually in the plants quality control lab. This allowed the manufacture of enough sheets of sufficient size for all the box designs in the shortest period of time. It was noted that corrugator production speeds were still quite slow during the time our corrugated sheets were taken. The occurrence of a splice (liner or medium roll change) during the time our unscored box blanks were taken was noted several times. The corrugated sheets were then taken to the lab, trimmed, and the flap scores positioned at the same time.

At the time the initial request was made for the board runs, each plant was asked to supply the board in a specific ECT grade range, as previously shown in Table 1. Mediums and liners that would meet the desired level of combined board ECT were to be used. In every case IPST representatives were assured by the plant contacts that these parameters were being met. However, once the board and boxes were produced and returned to the IPST's lab it was determined that the ECT levels were 30 to 75% higher than the specified grade level. We had anticipated only 20 to 30% higher test values.

This higher level of ECT was not desired nor planned. But it is the way of the real world. When a specification is made by a customer for a certain grade level of board, it is in the best interests of the converter to supply a board that exceeds the requested level. Normally, the grade supplied would be to guarantee that the ECT test minimum would be higher than the requested level, taking into account the variability of the board.

3. Notes on the Flexo Runs

The scheduling of the flexo runs was equally difficult as the interruption of regular production often required extra shifts to be called in for the running of our box blanks. In several instances, a flexo that had not been in use for some weeks or months was put on line for our runs.

We had tried to anticipate the needs of the flexo crew in the setup of each box run. Our request was for 25 good boxes after the flexo operation. Most plants allowed about 30 blanks for each size and run, five blanks to make the actual flexo setup settings and 25 for the run. Each plant contact assured us only five waste blanks were needed to make a precise setup. Actually 20 blanks or more were needed before any machine was running at peak (a very nebulous term) performance. Some of the smaller box sizes required the dismantling of portions of the flexos' to allow the feed systems to operate or the addition of auxiliary devices and guides. These modifications took several hours to accomplish and always prolonged the actual flexo run window.

Another specification made early in the experimental design was not to use scoring clearances. These are normally needed to allow for takeup in the scores and to help insure box squareness. The reason for not using these additional tolerances was to keep the perimeter of the finished boxes in even inch dimensions. Fractional variations in dimensions were initially considered to be a nuisance in the calculations using the box performance model. This resulted in the folded flat box coming off the flexos' having a misaligned manufacturing joint that resulted in a skewed box when setup.

In addition, several flexos' did not have the ability to trim the length of the blank at the MF joint, so each blank in these instances had to be manually trimmed prior to the flexo run. Other flexos' needed a full two-inch trim to produce the desired box MF joint parameter.

The two-inch allowance for the manufacturer's joint on all the boxes became only one and a half inch on several of the flexo's because that was the only size cutters available. Also, the flap notch cuts varied with each flexo setup from the normal 3/8 inch to a wide 1/2 inch. We used what was normally available on each flexo setup for boxes of the sizes we were making. We were given the choice of canceling the runs or using what was available.

Most flexo operators made it a point to check the caliper of the board before and after the flexo operation. Caliper losses occur in the feed system and if not properly set could crush and damage the flutes. Differences in the before and after were always less than 2 mils according to the information we received. Flexo operators seemed less concerned with the other operations of the machine that grabbed, kicked, folded, and glued each blank.

The glued manufacturer's joints, from each flexo operation, did not always have the same glue spread, and were not always lapped with the short panel. In one plant, all the joints had to be glued manually after going through the flexo. Even then the process was dependent on the available box plant personnel who had to be closely guided in this operation.

4. Preparation of Boxes for Testing

As each plant production run was completed the finished boxes were removed by truck to the IPST Test Lab. Here they were sorted and culled. In all cases there, were enough "good" boxes for the compression tests.

We had to carefully cull the more severely damaged boxes in the IPST lab and were able to obtain the needed number for the box compression and other board tests. Visibly damaged boxes exhibited dents, crushed flutes, and CD (cross direction) creases, caused by the flexo operation. Only about 30% of all the boxes overall were relatively free of defects.

After setting aside the 10 boxes for compression, five additional boxes were carefully selected to be cut and sampled for physical characteristics. The experimental design called for every box size to be measured for caliper and ECT (CD edgewise compression strength). Only the largest box in each grade was to be tested for flexural stiffness.[2] The areas for testing on each box were to come only from the side panels and not from any of the flaps.

Each box for compression testing was preconditioned and conditioned according to TAPPI Method T-402 prior to setup. To secure the box for compression testing, metal staples (applied with a pneumatic powered device) were used on both top and bottom flaps. Sufficient staples were used to hold the inner flap in a normal sealed position during the compression test. The staples were placed at least one inch away from a scoreline, and a tool was devised to hold the inner flap in position during the stapling operation.

V. Experimental Results

1. Grade Verification

The five grades of board used in this work are as previously identified in Table 1. To determine the construction of each board sample, known areas of each of the boards were soaked in water to separate the facings. Each of the component samples was then air dried and weighed to determine the actual liner and medium grade weights used. These data are presented in Table 2. It is immediately evident that the medium and liner basis weights were not consistent with the desired ECT grade levels. This will be discussed in more detail in a later section.

TABLE 2

Determination of Component Basis Weight

Set#	Grade of Board Burst	ECT	Measured Basis Weight, lb/Msq ft DF Board	SF Liner#1	SF Med#1	SF Liner#2	SF Medium#2	DF Liner
1	150 SW	26	115	33.9	26.4			44.5
2	200 SW	32	134	44.2	34.7			42.7
3	200 SW	32 (Hvy.Med.)	117	35.4	33.8			35.2
4	275 SW	44	149	54.8	28.3			56.1
5	350 DW	51	210	42.9	28.6	45.5	28.2	42.2

2. ECT Testing

A board sample for ECT testing, representative of each box size and grade weight, was set aside during the selection of boxes for compression testing. Each size of boxes was sampled to determine the uniformity of board strengths within each of the various box sizes made at a given plant. ECT values, if highly variable within for any box size, were to have required additional tests on that box size for Pin Adhesion and Flexural Stiffness to help determine a reason for the variability. Even though some variability was noted in the ECT values for one grade, no additional testing to determine the cause was done at this time.

From each box size and grade weight, 10 ECT specimens, 2 inch x 2 inch were cut using a Billerud pneumatic twin knife specimen cutter. With CKPG committee approval, each specimen was then cut to a one-inch wide neck-down configuration using a TMI neck-down cutter. (The original experimental plan was to have used the standard wax reinforced loading edges, but due to time and budget constraints, it was necessary to go with the neck-down method.) The TMI cutter used was loaned to IPST for use on this project by Willamette Industries.

ECT compression testing was performed on a rigid platen compression tester at a test rate of 10 mm/min. The test data from the ECT determinations are shown in Table 3.

The same support blocks used normally to align waxed edge specimens were used with the neck-down specimens to align them properly at the initiation of each test. All failures occurred in the neck-down portion when the maximum load had been reached. There was no crushing of the unwaxed loading edges for any of the specimens tested.

3. Flexural Stiffness Testing

The five different grades of boards used in this study were evaluated for flexural stiffness following TAPPI Method T-820. These test samples were only taken from the largest size boxes in each board grade. (The larger sample boxes were usually the only box size that allowed for the needed specimen length in the CD dimension.) These results are given in Table 4.

Five boxes were selected from the largest set size in each ECT grade. The flaps were removed and two opposite side panels were selected for testing. Each flexural stiffness specimen was cut from as near the center portion of the panel as possible. Ten specimens were cut for each direction to a two-inch width and as long as the panel width or height. This was especially important for the double-wall sample which required a 24-inch test span for testing as compared with a 12-inch span for all the single-wall samples. The TAPPI test method is not sufficiently detailed and resulted in some initial data being generated that indicated very low flexural stiffness values along with high variability. Retests using higher loads reduced the variability and raised the stiffness values into the

TABLE 3

Summary of ECT, Neck-down specimens

	Board Grade Burst	Requested ECT Level	Box Size		Caliper, pts	ECT, lb/in
Set 1	150 SW	26	12X6X8	AV	161.79	46.83
				SD	1.15	1.93
			12X6X15	AV	161.00	44.32
				SD	1.14	2.18
			12X12X15	AV	160.43	46.78
				SD	1.42	1.57
			24X6X8	AV	163.16	47.79
				SD	1.58	1.73
			24X6X15	AV	160.55	46.29
				SD	1.15	2.06
			24X12X15	AV	161.30	45.35
				SD	.63	2.25
				Average	161.37	46.23
Set 2	200SW	32	24X8X6	AV	154.53	44.18
				SD	2.38	2.36
			24X8X15	AV	155.46	45.09
				SD	1.42	2.81
			24X8X24	AV	159.96	46.03
				SD	.70	1.85
			24X24X6	AV	158.95	45.89
				SD	2.32	1.87
			24X24X15	AV	154.74	43.23
				SD	2.58	3.27
			24X24X24	AV	160.61	47.49
				SD	.64	1.28
				Average	157.38	45.32
Set 3	200SW	32	24X8X6	AV	154.21	42.48
				SD	2.37	1.32
			24X8X15	AV	155.65	41.88
				SD	2.10	2.39
			24X8X24	AV	159.01	52.53
				SD	.89	2.25
			24X24X6	AV	157.44	44.03
				SD	1.30	2.02
			24X24X15	AV	157.56	50.30
				SD	2.81	3.12
			24X24X24	AV	157.92	45.82
				SD	1.48	2.66
				Average	156.97	46.17
Set 4	275 SW	44	24X10X6	AV	169.30	59.09
				SD	1.23	3.53
			24X10X15	AV	170.12	65.04
				SD	.74	3.79
			24X10X24	AV	167.52	60.15
				SD	2.83	4.57
			36X10X20	AV	169.65	62.88
				SD	1.81	3.05
			36X30X20	AV	170.17	64.27
				SD	1.80	2.10
			36X30X30	AV	168.79	64.20
				SD	2.19	5.38
				Average	169.26	62.60
Set 5	350 DW	51	24X12X6	AV	308.31	65.56
				SD	3.38	5.01
			24X12X15	AV	308.21	66.55
				SD	2.41	3.03
			36X12X20	AV	301.14	73.66
				SD	4.09	4.97
			36X12X30	AV	308.94	68.90
				SD	2.25	5.74
			36X36X20	AV	308.58	70.99
				SD	5.23	4.05
			36X36X30	AV	310.65	67.91
				SD	4.74	5.44
				Average	307.64	68.93

Table 4

Summary of Flexural Stiffness from Side Panels Only

(Large boxes, size 6 only)

Flexural Stiffness, lb.-in.

		Spec.1	2	3	4	5	6	7	8	9	10	Sample Average	Standard Deviation (n-1)
Set 1	Dx	114.7	110.6	110.0	107.0	110.0	102.5	91.9	95.3	93.2	98.6	103.4	8.2
	Dy	47.5	50.8	50.3	46.7	49.5	47.5	56.9	49.4	47.5	47.4	49.3	3.0
Set 2	Dx	133.4	123.2	130.8	136.7	143.8	124.6	128.0	116.9	112.5	116.3	126.6	9.9
	Dy	46.5	46.2	46.8	46.0	44.5	47.5	47.2	45.5	47.6	46.7	46.4	.9
Set 3	Dx	110.2	112.2	110.5	119.2	109.6	103.3	100.4	101.3	103.2	104.0	107.4	5.9
	Dy	41.4	40.4	44.5	44.2	42.6	43.8	42.1	46.8	44.3	42.6	43.2	1.8
Set 4	Dx	185.6	190.5	185.1	194.2	184.8	179.4	168.3	176.0	166.0	181.7	181.2	9.0
	Dy	87.7	92.4	87.5	96.0	79.8	96.0	89.2	95.0	86.1	89.0	89.9	5.1
Set 5	Dx	1222.9	1126.3	1200.0	1127.6	1227.3	1194.0	1306.5	1141.7	1238.8	1155.0	1194.0	61.1
	Dy	540.0	496.2	510.0	481.6	509.1	510.8	496.2	510.0	510.0	496.2	506.0	15.3

expected range.

4. Box Compression

Actual compression testing of the commercial boxes was performed on an Emerson Compression Tester following TAPPI Method T-804. The results from these tests are given in Table 5. Each box was made up just prior to testing using metal staples to close the flaps. The testing was performed at a test rate of 0.5 in/min, and deflection at failure was measured from the 50-lb preload at the start of each test. A 100 lb preload was used with the double-wall boxes.

Table 5

Summmary of Commercial Box Compression Results

Set	Spec#: Size, in. (L x W x D)	1	2	3	4	5	6	7	8	9	10	Sample Average lb	Standard Deviation (n-1)
		Box Compression, lb											
1	12X6X8	584	537	566	446	495	514	525	582	627	539	541.5	51.31
	12X6X15	502	538	606	526	582	574	590	544	515	521	549.8	35.69
	12X12X15	749	605	639	663	622	666	764	711	698	712	682.9	52.91
	24X6X8	559	536	524	566	552	542	513	607	521	597	551.7	31.48
	24X6X15	597	560	603	558	552	546	551	554	557	551	562.9	20.01
	24X12X15	754	678	740	694	705	716	783	735	748	730	728.3	30.96
2	24X8X6	834	870	879	848	787	848	805	850	801	861	838.3	31.01
	24X8X15	638	698	657	582	608	710	654	669	653	619	648.8	39.18
	24X8X24	655	702	633	627	700	694	656	709	684	692	675.2	29.94
	24X24X6	1133	1138	1215	1012	1038	1088	1116	1051	1040	1079	1091.0	60.90
	24X24X15	893	824	653	804	826	868	751	905	833	693	805.0	82.91
	24X24X24	1054	1019	937	928	1055	816	810	849	834	964	926.6	96.14
3	24X8X6	872	867	821	776	805	682	772	789	935	775	809.4	69.53
	24X8X15	619	587	604	618	592	586	535	606	607	547	590.1	28.42
	24X8X24	648	641	661	747	692	658	702	667	637	615	666.8	38.02
	24X24X6	1188	1090	1146	1111	1018	1154	1187	1149	1198	1117	1135.8	54.54
	24X24X15	830	831	888	870	909	717	740	734	780	799	809.8	67.22
	24X24X24	840	763	718	746	710	719	656	653	774	639	721.8	62.41
4	24X10X6	1314	1298	1300	1303	1218	1189	1302	1247	1234	1177	1258.2	51.73
	24X10X15	1119	1119	1138	1087	1126	1078	1127	1151	1168	1093	1120.6	28.39
	24X10X24	1067	1155	1127	1088	1054	1170	1157	1058	1133	1138	1114.7	43.95
	36X10X20	1142	1292	1123	1100	1111	1090	1261	1172	1181	1239	1171.1	71.35
	36X30X20	1244	1435	1540	1268	1473	1475	1291	1440	1342	1353	1386.1	100.37
	36X30X30	1347	1206	1252	1358	1437	1448	1334	1273	1477	1347	1347.9	88.11
5	24X12X6	1908	1975	2170	2317	2087	1643	1872	2131	1736	2335	2017.4	232.36
	24X12X15	1379	1395	1489	1331	1435	1325	1505	1402	1468	1305	1403.4	70.36
	36X12X20	1391	1482	1530	1264	1261	1252	1495	1362	1351	1351	1373.9	101.04
	36X12X30	1425	1424	1375	1569	1387	1498	1420	1456	1435	1420	1440.9	56.36
	36X36X20	1857	1844	2032	1715	1660	1706	1787	1650	1975	1990	1821.6	141.18
	36X36X30	1707	2190	1627	1856	1684	1599	1562	1685	2112	2025	1804.7	227.37

VI. Calculation of Predicted Compression Load

Using the data from Tables 3 and 4, the calculation of predicted compression strength was undertaken using the three variants of the McKee Equation listed below.

Simplified McKee Equation[1]:

$$P= 5.87*(Pm)*[(H)^{0.508}]*[(Z)^{0.492}]$$

Original McKee Equation:[1]

$$P = 2.028[(Pm)^{0.746}]*((Dx*Dy)^{0.127}]*[(Z)^{0.492}]$$

Modified McKee Equation: (Ref. Report 3746)

$$P = 1.014[(Pm)^{0.746}]*[(Dx*Dy)^{0.127}]*[\Sigma(W)^{0.492}]*[1.593*[(d)^{-0.236}]]$$

Where

P = Box Compression, lb
H = Combined board caliper, inches
Pm= CD ECT Edge Crush Test Strength, lb/in.
Dx= MD Flexural Stiffness, in-lb.
Dy= CD Flexural Stiffness, in-lb.
Z = Box Perimeter, in.
W = Width of Each Panel, in.
d = Box Depth, in.

ECT (Pm) values for each box size were used in each of the calculations, while the single flexural stiffness value obtained only for the largest box was used for all calculations in that grade of board. These calculations using all three models of the McKee Equation are presented in Tables 6 and 7.

VII. Comments and Conclusions

The data obtained from the testing of the five sets of boxes and the six data points from each set of different panel widths, box heights, and perimeters demonstrated a number of anomalies that made it difficult to form definitive conclusions.

Table 6

Commercial Boxes
Summary of Physical Characteristics

Set	Perim. in.	Depth in.	d/z (1)	ECT lb/in	SD	Flex. Stiff. MD lb.-in.	SD	CD lb.-in.	SD	Strength Factor (2)	Actual Box Comp. lbs
1	38	8	.21	46.83	1.93	103.4		49.3		52.13	541.5
	38	15	.39	44.32	2.18	103.4		49.3		50.03	549.8
	50	15	.30	46.78	1.58	103.4		49.3		52.09	682.9
	62	8	.13	47.79	1.73	103.4		49.3		52.92	551.7
	62	15	.24	46.29	2.06	103.4		49.3		51.68	562.9
	74	15	.20	45.35	2.25	103.4	8.2	49.3	3.0	50.89	728.3
2	66	6	.09	44.18	2.36	126.6		46.4		50.82	838.3
	66	15	.23	45.09	2.81	126.6		46.4		51.59	648.8
	66	24	.36	46.03	1.85	126.6		46.4		52.39	675.2
	98	6	.06	45.89	1.87	126.6		46.4		52.28	1091.0
	98	15	.15	43.23	3.27	126.6		46.4		50.00	805.0
	98	24	.24	47.49	1.28	126.6	9.9	46.4	.9	53.63	926.6
3	66	6	.09	42.48	1.32	107.4		43.2		47.90	809.4
	66	15	.23	41.88	2.39	107.4		43.2		47.38	590.1
	66	24	.36	52.53	2.25	107.4		43.2		56.11	666.8
	98	6	.06	44.03	2.02	107.4		43.2		49.19	1135.8
	98	15	.15	50.30	3.12	107.4		43.2		54.33	809.8
	98	24	.24	45.82	2.66	107.4	5.9	43.2	1.8	50.67	721.8
4	70	6	.09	59.09	3.53	181.2		89.9		71.86	1258.2
	70	15	.21	65.04	3.79	181.2		89.9		77.19	1120.6
	70	24	.34	60.15	4.57	181.2		89.9		72.82	1114.7
	94	20	.21	62.88	3.05	181.2		89.9		75.26	1171.1
	134	20	.15	64.27	2.10	181.2		89.9		76.50	1361.0
	134	30	.22	64.20	5.38	181.2	9.0	89.9	5.1	76.44	1350.6
5	74	6	.08	65.56	5.01	1194.0		506.0		122.86	1849.8
	74	15	.20	66.55	3.03	1194.0		506.0		124.25	1403.4
	98	20	.20	73.66	4.97	1194.0		506.0		134.02	1373.9
	98	30	.31	68.90	5.74	1194.0		506.0		127.50	1440.9
	146	20	.14	70.99	4.05	1194.0		506.0		130.38	1821.6
	146	30	.21	67.91	5.44	1194.0	61.1	506.0	15.3	126.13	1804.7

(1) D/Z Aspect ratio, Depth to Perimeter
(2) Strength Factor: (Pm)^0.746*(Dx*Dy)^0.127

Table 7

Commercial Boxes
Calculation of Predicted Box Strength

Set	Perim. in.	Depth in.	d/z	Actual Box Comp. lbs	S.D.	Predicted.... Simplified lbs	Simplified /Actual %diff	Original lbs	Original /Actual %diff	Modified lbs	Modified /Actual %diff
1	38	8	.21	541.5	51.31	652.5	20.50	633.0	16.89	599.0	10.62
	38	15	.39	549.8	35.69	616.0	12.04	607.5	10.49	495.6	-9.85
	50	15	.30	682.9	52.91	742.9	8.78	723.9	6.01	603.2	-11.68
	62	8	.13	551.7	31.48	850.8	54.21	817.6	48.19	752.5	36.40
	62	15	.24	562.9	20.01	817.4	45.21	798.4	41.83	633.5	12.55
	74	15	.20	728.3	30.96	875.7	20.24	857.8	17.78	709.1	-2.64
2	66	6	.09	838.3	31.01	789.0	-5.88	809.6	-3.42	812.9	-3.03
	66	15	.23	648.8	39.18	807.7	24.50	822.0	26.70	664.8	2.47
	66	24	.36	675.2	29.94	836.6	23.90	834.7	23.63	604.2	-10.51
	98	6	.06	1091.0	60.90	1009.9	-7.43	1011.7	-7.27	1056.9	-3.12
	98	15	.15	805.0	82.91	938.6	16.59	967.7	20.21	814.3	1.16
	98	24	.24	926.6	96.14	1050.6	13.38	1037.9	12.01	781.7	-15.64
3	66	6	.09	809.4	69.53	758.0	-6.36	763.1	-5.72	766.2	-5.34
	66	15	.23	590.1	28.42	750.6	27.21	754.9	27.94	610.6	3.47
	66	24	.36	666.8	38.02	951.8	42.74	894.0	34.07	647.1	-2.95
	98	6	.06	1135.8	54.54	964.3	-15.10	952.0	-16.18	994.5	-12.44
	98	15	.15	809.8	67.22	1102.0	36.08	1051.4	29.83	884.7	9.26
	98	24	.24	721.8	62.41	1005.0	39.23	980.7	35.87	738.6	2.33
4	70	6	.09	1258.2	51.73	1137.9	-9.56	1178.5	-6.34	1198.5	-4.74
	70	15	.21	1120.6	28.39	1255.6	12.05	1266.0	12.97	1037.2	-7.44
	70	24	.34	1114.7	43.95	1152.1	3.36	1194.2	7.13	875.7	-21.44
	94	20	.21	1171.1	71.35	1401.3	19.65	1427.0	21.85	1071.3	-8.52
	134	20	.15	1361.0	100.37	1707.9	25.49	1726.9	26.89	1360.2	-.06
	134	30	.22	1350.6	88.11	1699.0	25.79	1725.6	27.76	1235.1	-8.55
5	74	6	.08	1849.8	232.36	1759.3	-4.89	2070.8	11.95	2125.1	14.88
	74	15	.20	1403.4	70.36	1785.7	27.24	2094.3	49.23	1731.2	23.36
	98	20	.20	1373.9	101.04	2242.7	63.23	2593.7	88.78	1969.8	43.38
	98	30	.31	1440.9	56.36	2125.2	47.49	2467.5	71.25	1703.0	18.19
	146	20	.14	1821.6	141.18	2662.6	46.17	3070.0	68.53	2422.0	32.96
	146	30	.21	1804.7	227.37	2555.7	41.61	2970.0	64.57	2129.3	17.99
						ABS Ave:	24.86		28.04		11.9

Five different box plants supplied the boxes of varying heights and box perimeters. ECT grade values of 26, 32, 32 with heavy weight medium, 44, and 51 (DW) were obtained from the suppliers as shown in Table 1.

While the basic project plan did not call for basis weight determinations, the wide variations in the data prompted the researchers to determine the actual basis weights to better understand the causes and effects on the ECT test results. These determinations are given in Table 2. Please note that unbalanced liners appear to have been used for the 26 ECT grade, a 33# medium combined with 42# liners for the 32 ECT grade, and the heavy medium 32 ECT grade actually used lighter weight liners and medium than the regular 32 ECT grade board. The fact that each grade came from a different box plant means that each converter used the material that they normally be supplied to a customer for that grade even if it appears to fall outside our project's design parameters.
Table 3 results indicated the 26 ECT grade level with an average of 46.2 lb/in was nearly 78% greater than what was anticipated for a minimum commercial order. The 32 ECT grade was 41.6% greater than the minimum required. The 44 ECT grade was 42.3% more than the minimum, and the 51 ECT grade was 35.2% above its minimum.

Table 7, giving the actual compression results compared to the original McKee formula and modified McKee formula, portrays the wide range of variations where the modified is the closest approximation to the actual box compression.

The 26 ECT group prediction is within a range of +36% to a -12% from the actual. The 32 ECT group prediction is in a range of +2% to more than -15% of the actual. The 32 ECT with heavy medium and the 44 ECT predictions also show similar differences, but up to 21% or more less than the actual box compression results. The 51 DW ECT group predictions were all higher than the actual by up to 43%. See also Figures 1, 2, 3. It is interesting to note that the heavy weight medium for the same box construction did not significantly improve the top to bottom compression. Actual compression values for the most part were somewhat lower for the added medium weight. The predicted values for the original formula ranged from -15.1% to +42.7% of the actual compression, while the modified was much closer with a range of -12.4% to +9.2%. This is indicative of the value in pursuing the refinements needed in the modified equation to make it even more useful to industry.

Figure 1 shows the data plot of the 30 sets of boxes comparing the actual compression test results with the values from the simplified McKee formula. These data show an R^2 equal to 0.817. Figure 2 shows the same type of data format only using the original McKee formula. This set of data has an R^2 of 0.814. The plot in Figure 3 using the modified McKee formula derived in Report 3746 exhibits an R^2 of 0.896. This clearly indicates that the modified formula yields the closest data match. Future work must be done to clear up some of the terms in the modified equation to make it mathematically balanced.

Figure 1
Commercial Boxes
Comparison of Observed vs. Predicted Compression Strength
Simplified Formula

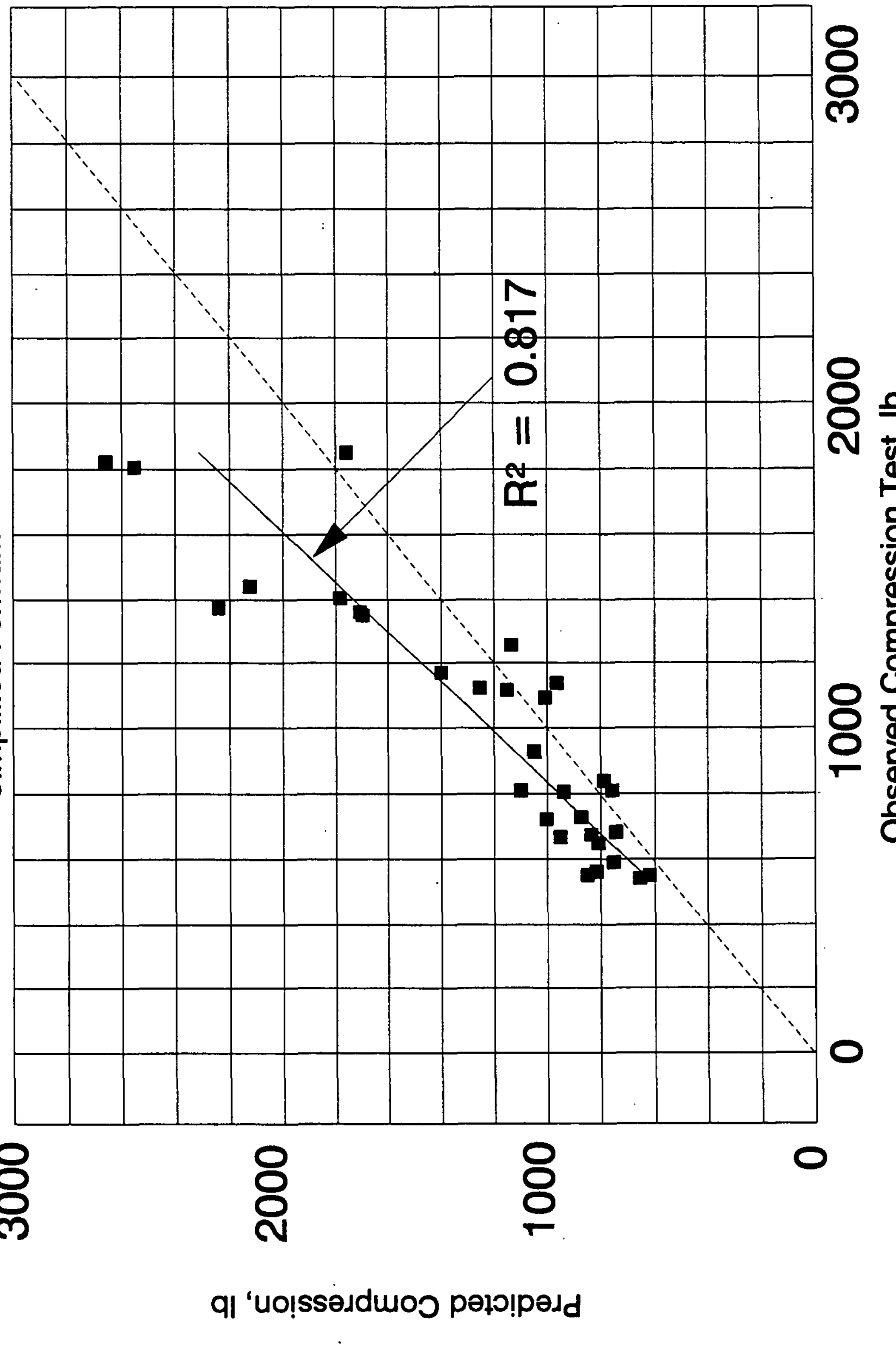


Figure 2
Commercial Boxes
Comparison of Observed vs. Predicted Compression Strength
Original Formula

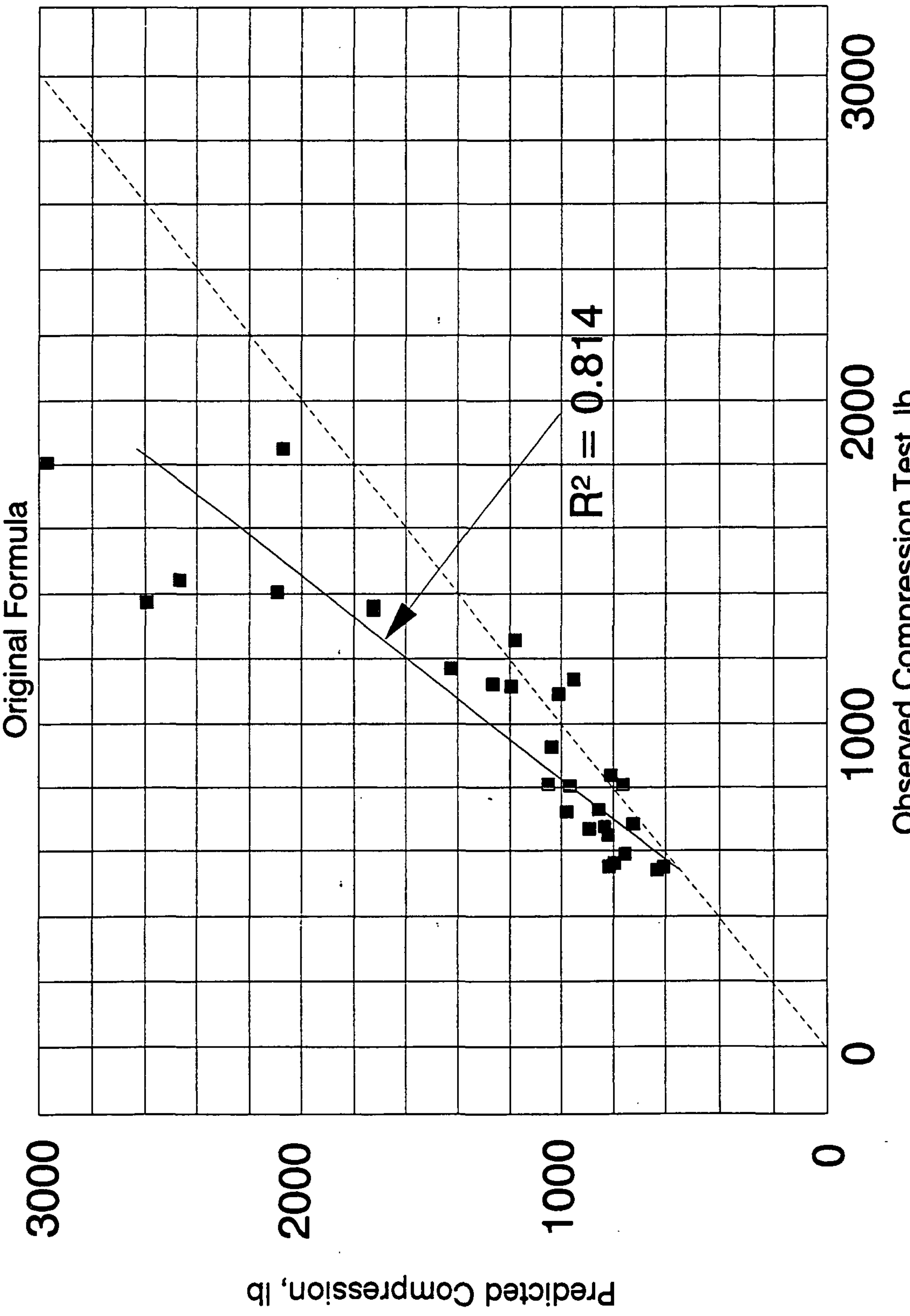
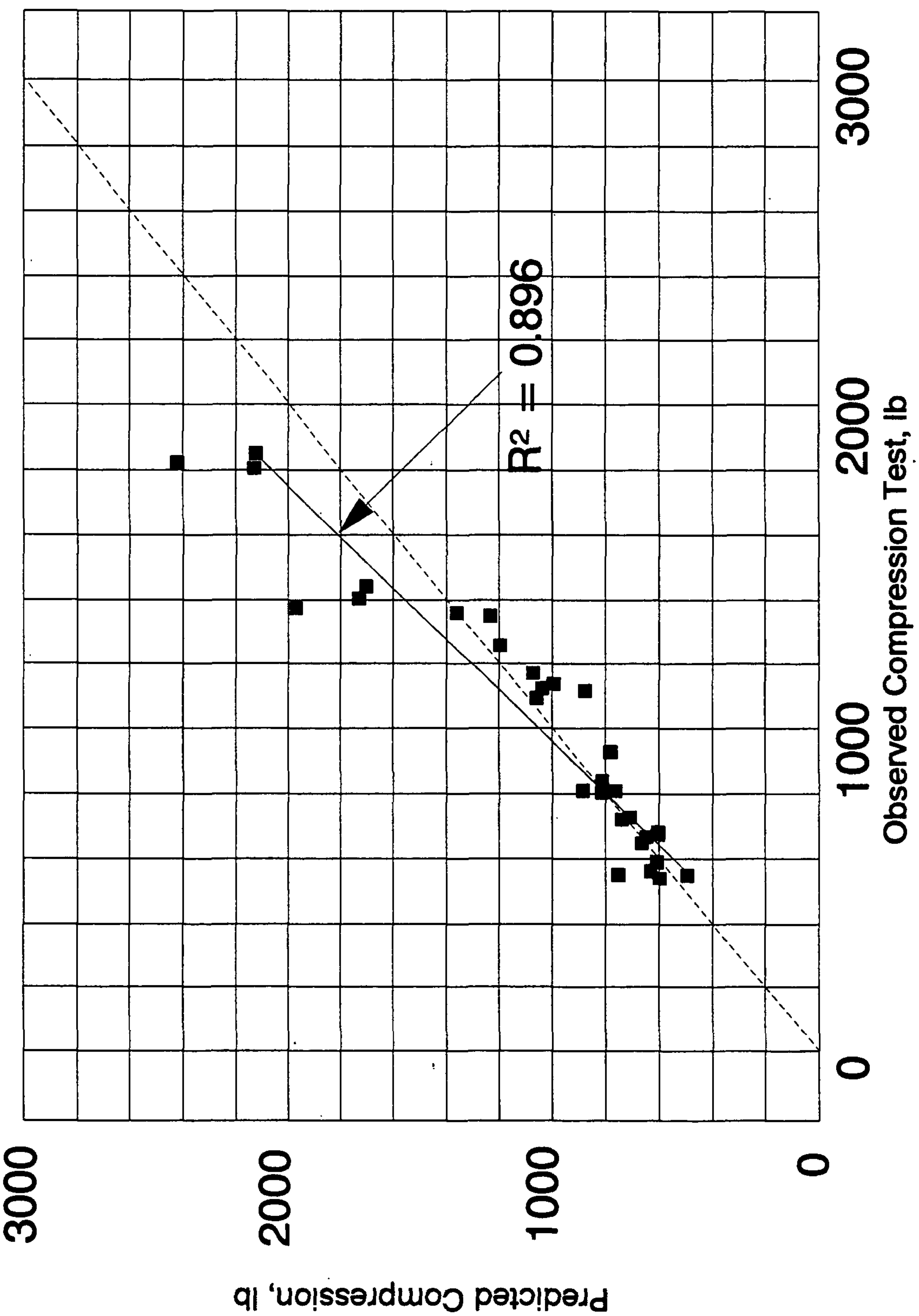


Figure 3
Commercial Boxes
Comparison of Observed vs. Predicted Compression Strength
Modified Formula



It is entirely possible that these are "normal" data since the test results represent a limited number of samples, only five sets of structures of corrugated boxes and six compression values from each set. Additional analysis is required, and IPST has supplied the committee leader and interested committee members with copies of the data.

There are two more stages of the original project to improve the prediction model. These include laminated structures for Stage 4 and a total refinement of the compression model for Stage 5. Stage 4, a one year project had an estimated cost of $80K, and Stage 5, in the final year, had an estimated cost of $50K. Both of these would need to be evaluated again since the information developed to date needs more analysis in an effort to warrant recommendations of the committee to continue with the original plan.

PART B - Application of the Box Compression Estimating Model to Internal Partitions and Divider Structures

VIII. Summary

Compression failure in partitions as well as boxes is governed by the compression resistance of the structure and its ability to resist buckling. On small panel sizes of partitions, the influence of flexural stiffness is minor compared to large panels. The data on all panels yielded results where the actual compression values were significantly different than the predictions of the original McKee formula as well as the modified formula.

In all cases of the 26 ECT through the 44 ECT on the partitions, the original Mckee and the modified McKee predictions were more than the actual compression values on the smaller depth and number of panels by about 20% to as much as 49%. Lower predictions were made for the larger panels, depths, and perimeters, and ranged from -23% and greater differences.

It appears that the database is too small for any precise adjustments to the model since the predicted values covered a wide range from higher than actual to considerably less than actual when using either formula for predicting compression. The changing values from positive to negative over the testing format of actual compression values compared to predicted values suggest that an additional term or terms are needed to improve the accuracy.

Consideration must be given to the value of the constants in each formula as they reflect a converting plants efficiency and would need to be adjusted upwards or downwards as required.

The recommendations of the committee for continued research on the final two phases are vital to this project, particularly the final Stage 5 for critical analysis of all the data to improve the accuracy of the modified McKee equation.

It is suggested that future compression studies address the issue of partitions in conjunction with empty and filled cartons. The interaction of the partition with the carton is an important aspect of the compression characteristics of the total package.

IX. Introduction

The application of the compression model to inner packing such as dividers is of interest as these add-on features to a corrugated carton can affect its compressive qualities. This phase of the project is an exploration of some common designs used in the industry and our attempt to fit the compression model to the data. The experimental plan was to make up dividers having 2, 4, and 6 cells associated with various perimeters and depths. The board stock was taken from the material remaining from the earlier work done under Project 3746.

X. Experimental Technique

1. Source of Board Stock

Single-wall sheet stock remaining from Project 3746 was selected for this work. The three grades of board used had already been characterized, and the summary of that work is shown in Appendix B.

Corrugated sheets of the required sizes had been previously obtained from three different commercial box plants. Three grades of the single-wall corrugated were selected to cover a range of ECT compression strength levels (26 lb/in, 32 lb/in, and 44 lb/in ECT grades). The body scores and the specialized required board cutting needed to produce the various packaging partitions were made with a sample die-cutting table.

2. Die Cutting of Partitions

Selected sizes of the partitions are given in Appendix C, and in Table 8. In Appendix D, the die-cut layouts are presented to help give the reader an understanding of the divider configuration.

Arrangements were made with Tom Santelli at the Georgia Pacific Technology Center in Roswell to use their die table for the preparation of the partitions. Georgia Pacific's Data Technology Die Table was used to cut the partitions with great precision and uniformity. Again, no scoring allowances were used in the dimensions. The die-cut sheets were kept intact during transport and storage until the time of testing. The actual patterns used for the die-cutting procedure are to be found in Appendix E for each of the nine partition configurations.

Table 8

Sample Preparation Plan for Partitions

Code	Perimeter	Aspect Ratio L TO W	Partition Size Length in.	Partition Size Width in.	Partition Size Depth in.	Aspect Ratio depth /perim.	Blank Size Length in.	Blank Size Width in.	Blank Stock Remaining from P ECT Grade Blank lb/in Nominal	in.
26 lb ECT Grade Level TWO CELL PARTITION										
A	48	1:1	12	12	8	.17	24	16	26	
B	72	1:1	18	18	8	.11	36	16	26	
C	48	1:1	12	12	16	.33	24	32	26	
FOUR CELL PARTITION										
D	72	1:1	9	9	8	.11	36	16	26	
E	96	1:1	9	9	16	.17	48	16	26	
F	72	1.67:1	15	9	8	.11	36	32	26	
SIX CELL PARTITION										
G	96	1:1	15	15	8	.08	48	16	26	
H	72	1.5:1	12	8	16	.22	36	32	26	
I	96	1.3:1	15	11.5	16	.17	48	32	26	
32 lb ECT Grade Level TWO CELL PARTITION										
A	48	1:1	12	12	8	.17	24	16	32	
B	72	1:1	18	18	8	.11	36	16	32	
C	48	1:1	12	12	16	.33	24	32	32	
FOUR CELL PARTITION										
D	72	1:1	9	9	8	.11	36	16	32	
E	96	1:1	9	9	16	.17	48	16	32	
F	72	1.67:1	15	9	8	.11	36	32	32	
SIX CELL PARTITION										
G	96	1:1	15	15	8	.08	48	16	32	
H	72	1.5:1	12	8	16	.22	36	32	32	
I	96	1.3:1	15	11.5	16	.17	48	32	32	
44 lb ECT Grade Level TWO CELL PARTITION										
A	48	1:1	12	12	8	.17	24	16	44	
B	72	1:1	18	18	8	.11	36	16	44	
C	48	1:1	12	12	16	.33	24	32	44	
FOUR CELL PARTITION										
D	72	1:1	9	9	8	.11	36	16	44	
E	96	1:1	9	9	16	.17	48	16	44	
F	72	1.67:1	15	9	8	.11	36	32	44	
SIX CELL PARTITION										
G	96	1:1	15	15	8	.08	48	16	44	
H	72	1.5:1	12	8	16	.22	36	32	44	
I	96	1.3:1	15	11.5	16	.17	48	32	44	

3. Partition Setup for Compression Testing

As each partition panel was folded in preparation for testing, the main centerfold was made so as to place the single-face liner side out. This resulted in smoother cell folds to be made at all the remaining scores. Regardless which way the initial fold was made, the centerfold at the score always resulted in a panel height lower than the adjacent cell panels. This resulted in most of the compression force being placed on the cell panels before the center panel at the fold took on its share of the load.

In the setup of each partition, 1/2 inch wide cellophane tape "straps" were used to hold the various sections of the partition in place just prior to the actual compression testing. These tape straps were used to bridge and secure the panels only at the loading edges on both the top and bottom of each divider.

The procedure for testing the partitions was the same as that used for the commercial boxes. TAPPI Method T-804 was used with the preload of 50 pounds as the starting point for measuring the deflection under load.

XI. Experimental Results

The results from the partition compression tests are shown in Tables 9, 10, and 11. It is readily noted that the deflection at peak load for these partition designs ranged from 0.05 to 0.34 inches with the average being close to 0.10 inches. A summary of the calculated or predicted partition strength using the original and modified McKee equations is shown in Table 12. A plot of the data generated, a combination of the partition results and the out of range data from the tubes tested in Project 3746, by the modified McKee equation is presented in Figure 4. The R^2 value was determined to be 0.758.

If the data for the commercial boxes tested in the first section of this report are added to that given in Figure 4, the plot in Figure 5 is presented that gives an R^2 value of 0.805.

When just the partition data are looked at, we see the plot in Figure 6 that gives us an R^2 of 0.884, substantially better than when the data from the tubes and boxes are included.

Figure 7 is an informational presentation of the total data generated in Project 3746 for the various sizes and configurations of tubes for that work. The R^2 value was determined to be 0.911.

When all the data from the current work are added to the previous data, we see the plot in Figure 8 that is only slightly poorer than that given in Figure 7 as the R^2 value is only reduced to 0.875.

Table 9

Tabulation of Partition Tests

26 lb ECT Grade Level

Sample Code:	A		B		C		D		E		F		G		H		I	
Size-Perimeter:	48		72		48		72		96		72		96		72		96	
Height or Depth:	8		8		16		8		8		16		8		16		16	
No. of Cells:	2		2		2		4		4		4		6		6		6	
ECT Level	Load	Defl.	Load	Defl.	Load	Defl.	Load	Defl.	Load	Defl.	Load	Defl.	Load	Defl.	Load	Defl.	Load	Defl.
	lb.	in.	lb.	in.	lb.	in.	lb.	in.	lb.	in.	lb.	in.	lb.	in.	lb.	in.	lb.	in.
26	381	.08	539	.06	437	.08	1320	.11	1629	.08	1224	.15	1381	.1	1091	.16	1447	.17
	413	.28	525	.06	443	.26	1211	.08	1636	.09	1218	.12	1519	.09	1111	.14	1436	.15
	443	.34	507	.05	480	.09	1205	.09	1618	.09	1183	.1	1398	.1	1138	.14	1443	.12
	447	.19	517	.07	434	.22	1310	.12	1549	.09	1148	.19	1433	.3	1191	.15	1452	.14
	437	.07	515	.09	422	.11	1233	.09	1652	.11	1250	.18	1506	.11	1168	.13	1509	.16
	425	.2	497	.07	454	.09	1225	.1	1625	.08	1198	.15	1441	.11	1197	.16	1541	.15
	411	.1	468	.06	456	.09	1242	.09	1673	.08	1283	.14	1426	.12	1190	.14	1500	.17
	408	.22	485	.06	452	.09	1308	.08	1546	.11	1214	.16	1481	.08	1200	.14	1429	.18
	437	.23	500	.06	381	.05	1215	.09	1656	.07	1190	.12	1469	.09	1198	.13	1465	.14
	422	.22	507	.04	395	.08	1185	.09	1620	.09	1139	.15	1509	.12	1148	.15	1496	.16
Average	422	.193	506	.062	435	.116	1245	.094	1620	.089	1205	.146	1456	.122	1163	.144	1472	.154
SD(N-1)	20.0	.087	20.2	.013	29.6	.068	49.0	.013	42.2	.013	43.6	.028	48.0	.064	39.5	.011	37.3	.018

Table 10
Tabulation of Partition Tests
32 lb ECT Grade Level

Sample Code:	A		B		C		D		E		F		G		H		I	
Size-Perimeter:	48		72		48		72		96		72		96		72		96	
Height or Depth:	8		8		16		8		8		16		8		16		16	
No. of Cells:	2		2		2		4		4		4		6		6		6	
ECT Level	Load	Defl.	Load	Defl.	Load	Defl.	Load	Defl.	Load	Defl.	Load	Defl.	Load	Defl.	Load	Defl.	Load	Defl.
	lb.	in.	lb.	in.	lb.	in.	lb.	in.	lb.	in.	lb.	in.	lb.	in.	lb.	in.	lb.	in.
32	577	.08	723	.07	623	.38	1645	.13	2047	.13	1521	.15	1841	.11	1479	.16	1935	.16
	645	.34	755	.07	584	.09	1584	.12	2072	.09	1572	.13	1867	.1	1431	.14	1880	.15
	595	.06	723	.09	620	.09	1608	.15	2144	.08	1517	.16	1824	.1	1447	.15	1848	.17
	593	.07	725	.09	550	.33	1636	.12	2089	.09	1566	.17	1839	.1	1416	.13	1891	.15
	591	.38	736	.08	617	.1	1662	.25	2095	.09	1606	.15	1931	.09	1434	.14	2015	.15
	645	.4	754	.1	627	.09	1651	.11	2190	.1	1525	.13	1861	.1	1468	.13	1864	.14
	559	.22	739	.05	570	.36	1620	.12	2097	.09	1608	.16	1931	.1	1512	.15	1865	.18
	583	.08	742	.07	614	.09	1588	.13	2115	.1	1492	.14	1828	.11	1350	.14	1974	.16
	594	.31	726	.09	587	.09	1570	.12	2106	.11	1525	.13	1806	.1	1485	..14	1910	.16
	585	.28	735	.07	595	.09	1496	.13	2014	.09	1553	.14	1822	.11	1472	.14	1902	.15
Average	597	.222	736	.078	599	.171	1606	.138	2097	.097	1549	.146	1855	.102	1449	.142	1908	.157
SD(N-1)	27.6	.138	12.0	.015	25.8	.129	49.4	.041	48.7	.014	39.1	.014	43.9	.006	45.3	.010	52.7	.012

Table 11
Tabulation of Partition Tests
44 lb ECT Grade Level

Sample Code:	A		B		C		D		E		F		G		H		I	
Size-Perimeter:	48		72		48		72		96		72		96		72		96	
Height or Depth:	8		8		16		8		8		16		8		16		16	
No. of Cells:	2		2		2		4		4		4		6		6		6	
ECT Level	Load	Defl.	Load	Defl.	Load	Defl.	Load	Defl.	Load	Defl.	Load	Defl.	Load	Defl.	Load	Defl.	Load	Defl.
	lb.	in.	lb.	in.	lb.	in.	lb.	in.	lb.	in.	lb.	in.	lb.	in.	lb.	in.	lb.	in.
44	884	.06	975	.09	741	.14	2235	.39	2663	.10	2008	.17	2302	.14	2044	.20	2592	.19
	837	.28	1060	.11	753	.16	2078	.12	2967	.11	2052	.23	2479	.13	2030	.18	2561	.17
	773	.10	966	.10	829	.49	1973	.17	2875	.13	2019	.17	2416	.13	2005	.24	2614	.17
	864	.07	1066	.07	771	.27	2022	.13	2799	.11	2144	.18	2242	.14	2037	.19	2558	.18
	793	.06	963	.07	833	.48	2068	.21	2904	.10	2103	.21	2290	.14	2154	.19	2394	.19
	830	.29	1028	.14	803	.11	1976	.16	2875	.10	2083	.16	2454	.15	2062	.18	2615	.19
	782	.09	996	.10	759	.29	2108	.12	3016	.10	2106	.20	2456	.16	2157	.50	2523	.16
	816	.07	1038	.08	776	.24	2047	.15	2724	.10	2037	.22	2381	.15	2116	.30	2626	.19
	827	.08	1042	.10	801	.48	2071	.19	2715	.15	1942	.25	2525	.15	1958	.30	2445	.18
	766	.09	956	.22	781	.14	2168	.11	2869	.17	2035	.15	2476	.13	1883	.17	2458	.25
Average	817	.12	1009	.11	785	.28	2075	.18	2841	.12	2053	.19	2402	.14	2045	.25	2539	.19
SD(N-1)	39.02	.088	42.5	.044	31.2	.152	81.1	.082	113.8	.025	58.3	.033	94.8	.010	85.3	.102	81.2	.025

Table 12

Summary of Predicted Box Compression Strength
Partitions and Tubes

ECT Level	No. of Cells or sides	No. of Panels	Perimeter in.	Depth in.	Aspect Ratio D/P	Actual Compression lb	Predicted... Original Equation lb	% Diff. Original/ Actual	Modified Equation lb	%Diff Modified/ Actual
Two-, Four-, and Six-celled Partitions										
26	2	6	48	8	.17	422	520	23.1	621	47.0
26	2	6	72	8	.11	506	635	25.5	758	49.8
26	2	6	48	16	.33	435	520	19.4	527	21.1
26	4	14	72	8	.11	1245	635	-49.0	1172	-5.9
26	4	14	96	8	.08	1620	731	-54.9	1353	-16.5
26	4	14	72	16	.22	1205	635	-47.3	995	-17.4
26	6	14	96	8	.08	1456	731	-49.8	1334	-8.4
26	6	14	72	16	.22	1163	635	-45.4	979	-15.9
26	6	14	96	16	.17	1472	731	-50.3	1132	-23.1
32	2	6	48	8	.17	597	713	19.5	851	42.7
32	2	6	72	8	.11	736	870	18.3	1039	41.2
32	2	6	48	16	.06	599	713	19.1	723	20.7
32	4	14	72	8	.11	1606	870	-45.8	1607	.0
32	4	14	96	8	.08	2097	1003	-52.2	1854	-11.6
32	4	14	72	16	.22	1549	870	-43.8	1364	-11.9
32	6	14	96	8	.08	1855	1003	-46.0	1828	-1.5
32	6	14	72	16	.22	1449	870	-40.0	1341	-7.5
32	6	14	96	16	.17	1908	1003	-47.5	1552	-18.7
44	2	6	48	8	.17	817	1017	24.4	1214	48.6
44	2	6	72	8	.11	1009	1241	23.0	1482	46.9
44	2	6	48	16	.33	785	1017	29.6	1031	31.4
44	4	14	72	8	.11	2075	1241	-40.2	2291	10.4
44	4	14	96	8	.08	2841	1430	-49.7	2645	-6.9
44	4	14	72	16	.22	2053	1241	-39.5	1945	-5.2
44	6	14	96	8	.08	2402	1430	-40.5	2607	8.5
44	6	14	72	16	.22	2045	1241	-39.3	1913	-6.4
44	6	14	96	16	.17	2539	1430	-43.7	2214	-12.8

Four-, Six-, and Eight-sided Tubes

These data from Project 3746 Final Report (data where prediction error was greater than 10%)

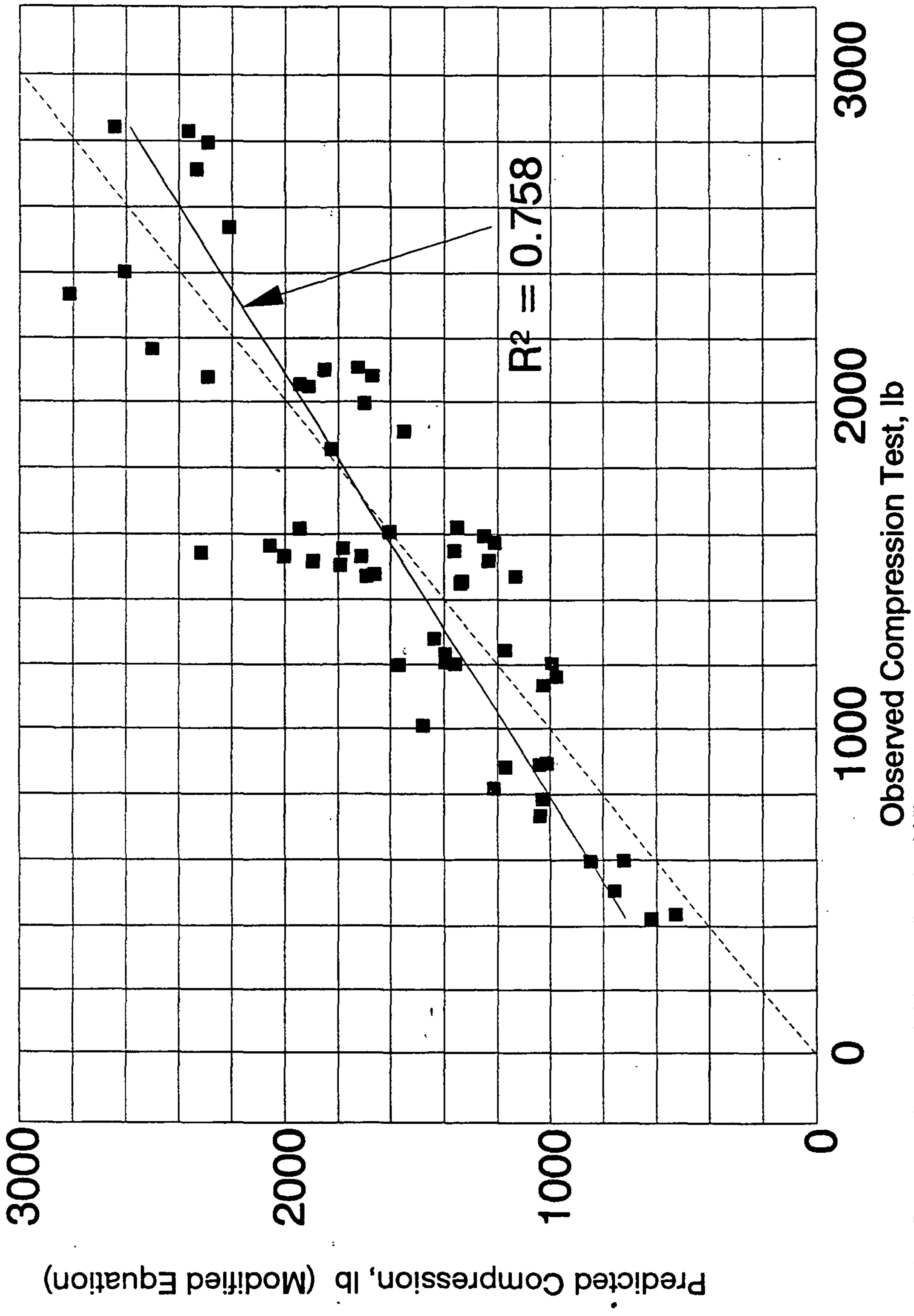
ECT Level	No. of Cells or sides	No. of Panels	Perimeter in.	Depth in.	Aspect Ratio D/P	Actual Compression lb	Note 1 (Original Formula Only) lb	% Diff. Original/ Actual	Modified Equation lb	%Diff Modified/ Actual
26	1:1	4	48	5	.07	1134	520	-54.1	1028	-9.4
26	2:1	4	72	5	.25	1519	635	-58.2	1236	-18.7
26	1:1	4	72	5	.47	1594	635	-60.2	1252	-21.4
26	3:1	4	72	5	.10	1574	635	-59.7	1213	-22.9
26	6s	6	32	5	.07	889	426	-52.1	1041	17.0
26	8s	8	32	5	.07	882	426	-51.7	1171	32.7
26	8s	8	32	8	.16	895	426	-52.4	1013	13.2
26	8s	8	48	5	.07	1207	520	-56.9	1396	15.7
32	2:1	4	72	5	.16	1994	870	-56.4	1701	-14.7
32	1:1	4	72	5	.10	2106	870	-58.7	1724	-18.1
32	3:1	4	72	5	.31	2078	870	-58.1	1670	-19.6
32	6s	6	32	5	.10	1233	584	-52.6	1397	13.3
32	8s	8	32	5	.07	1199	584	-51.3	1572	31.1
32	8s	8	32	8	.16	1202	584	-51.4	1360	13.2
32	8s	8	48	5	.10	1615	713	-55.9	1947	20.6
44	2:1	4	32	5	.16	1472	833	-43.4	1692	14.9
44	3:1	4	32	5	.25	1477	833	-43.6	1663	12.6
44	3:1	4	32	8	.16	1280	833	-34.9	1439	12.5
44	1:1	4	32	5	.07	1532	833	-45.6	1713	11.8
44	2:1	4	72	5	.07	2713	1241	-54.3	2334	-14.0
44	1:1	4	72	5	.25	2829	1241	-56.1	2366	-16.4
44	3:1	4	72	5	.16	2796	1241	-55.6	2292	-18.0
44	6s	6	32	5	.07	1563	833	-46.7	2061	31.9
44	6s	6	32	8	.25	1554	833	-46.4	1784	14.8
44	6s	6	48	5	.16	2163	1017	-53.0	2502	15.7
44	8s	8	32	5	.10	1542	833	-46.0	2318	50.3
44	8s	8	32	8	.16	1533	833	-45.7	2006	30.9
44	8s	8	32	10	.16	1517	833	-45.1	1897	25.1
44	8s	8	32	15	.07	1505	833	-44.7	1793	19.1
44	8s	8	48	5	.25	2334	1017	-56.4	2817	20.7
						ABS Ave:		45.2		19.8

Note 1: Used average values from all sheet sizes for ECT and Dx, Dy in the calculations for the Original Formula

Figure 4

Partition and Tube(*) Performance

Comparison of Observed vs. Predicted Compression Strength

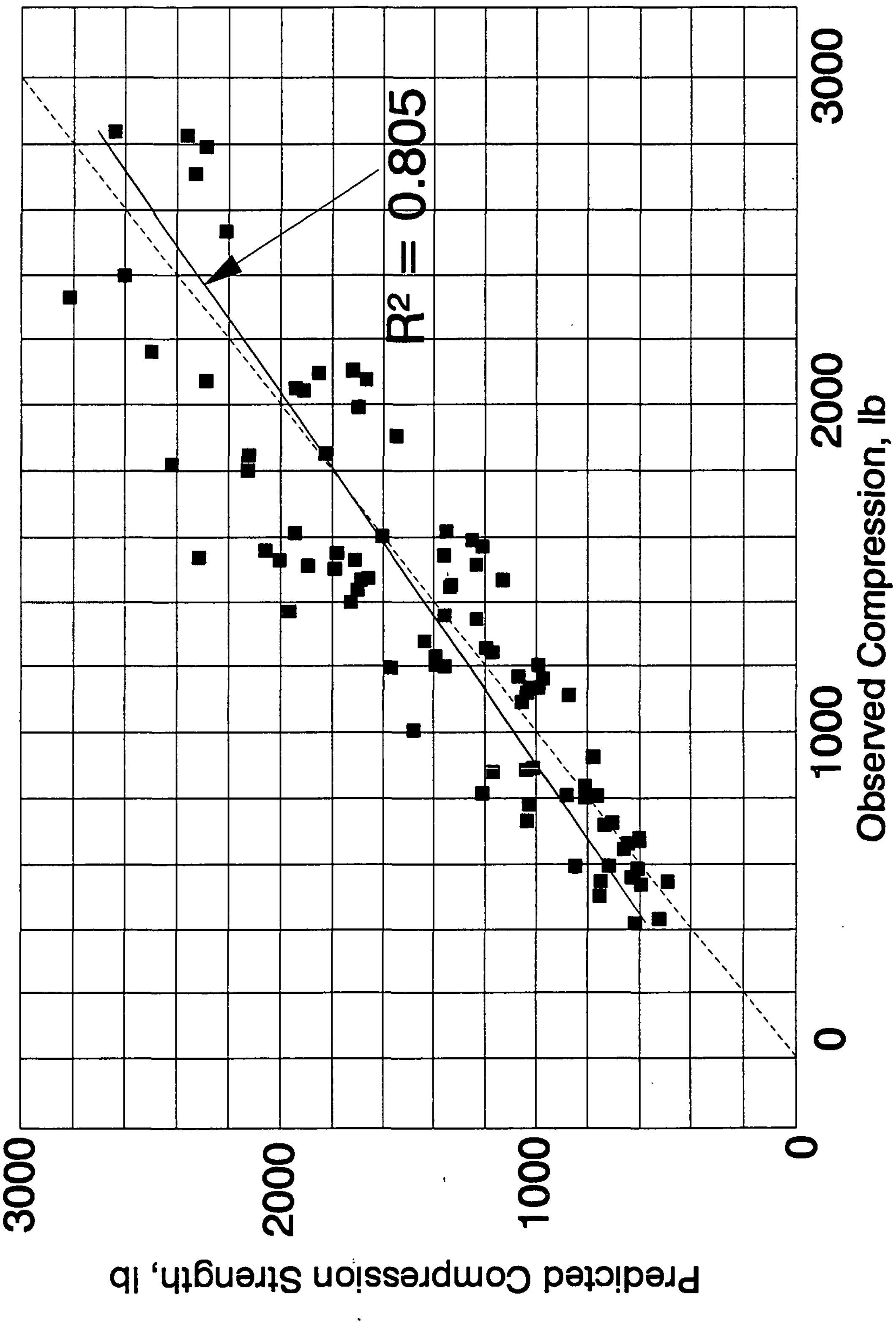


* Data from Project 3746 that exceeded the 10% allowed variability

Figure 5

Summary of Commercial Boxes, Partitions, and Tubes*

Modified Formula



* From Project 3746, data exceeding +/-10% variability

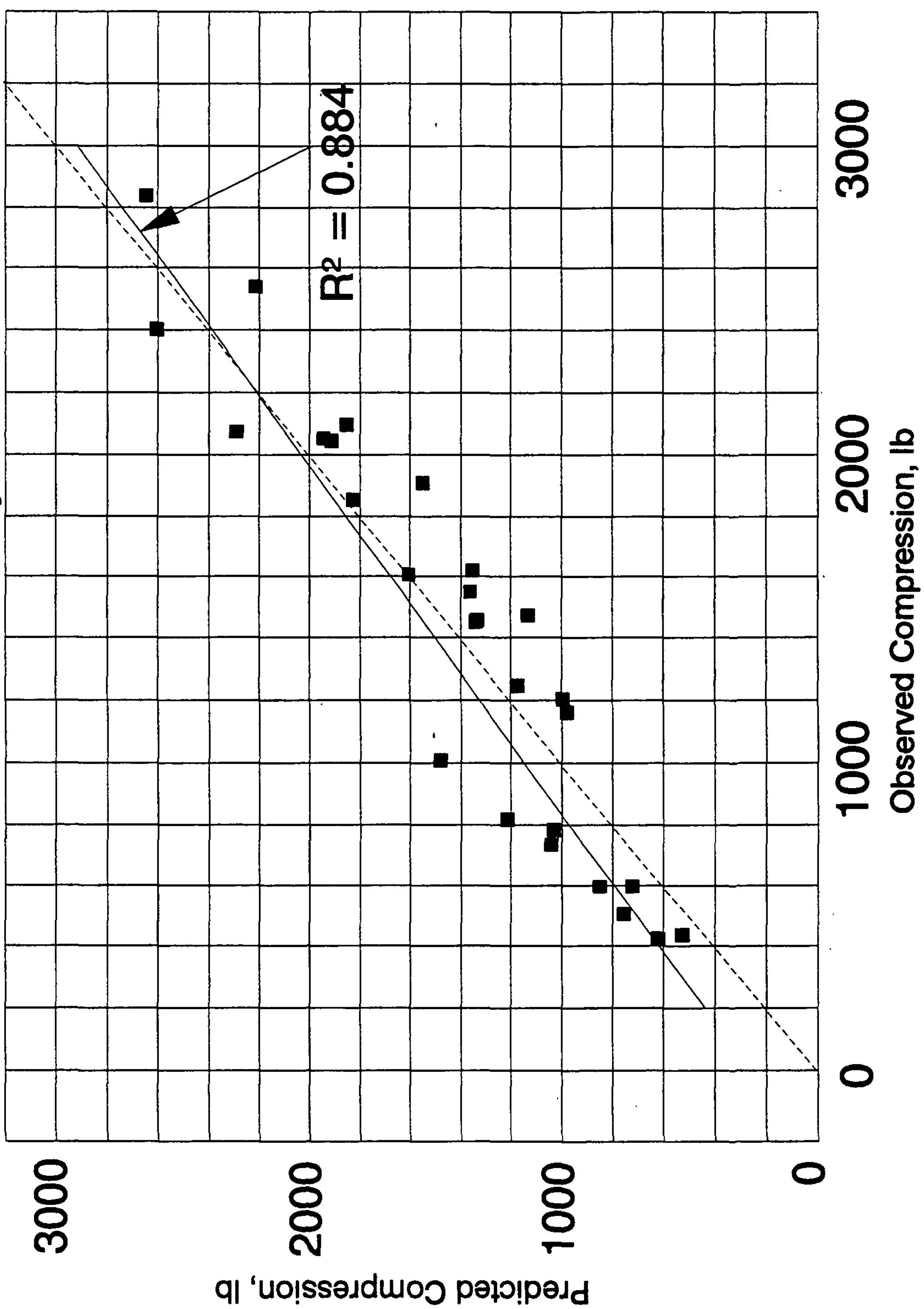


Figure 6
Comparison of Observed vs. Predicted Compression Strength
Modified Formula
Partitions Only

Figure 7
Comparison of Observed vs. Predicted Compression Strength
Modified Formula
All Data as Reported in Project 3746

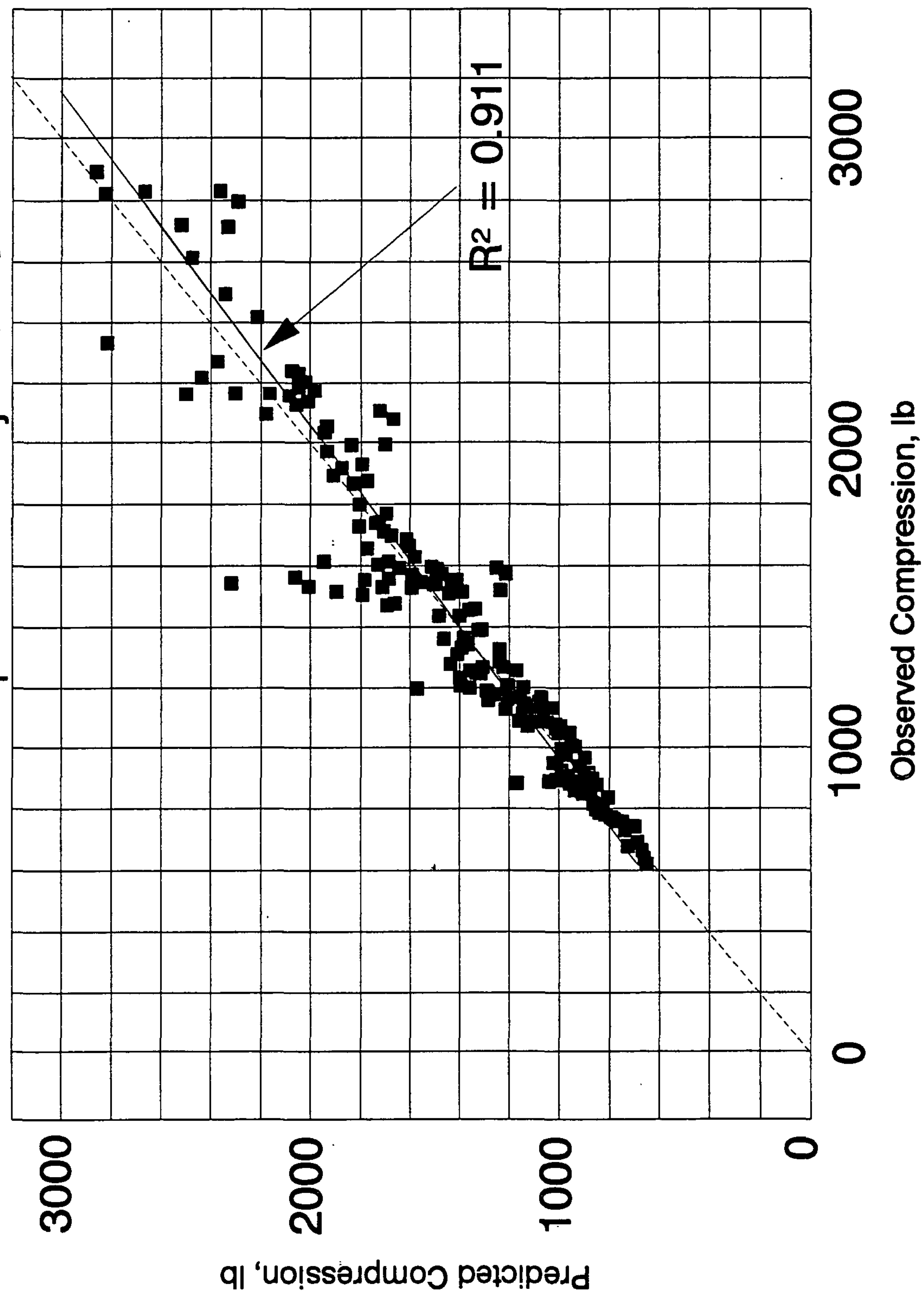
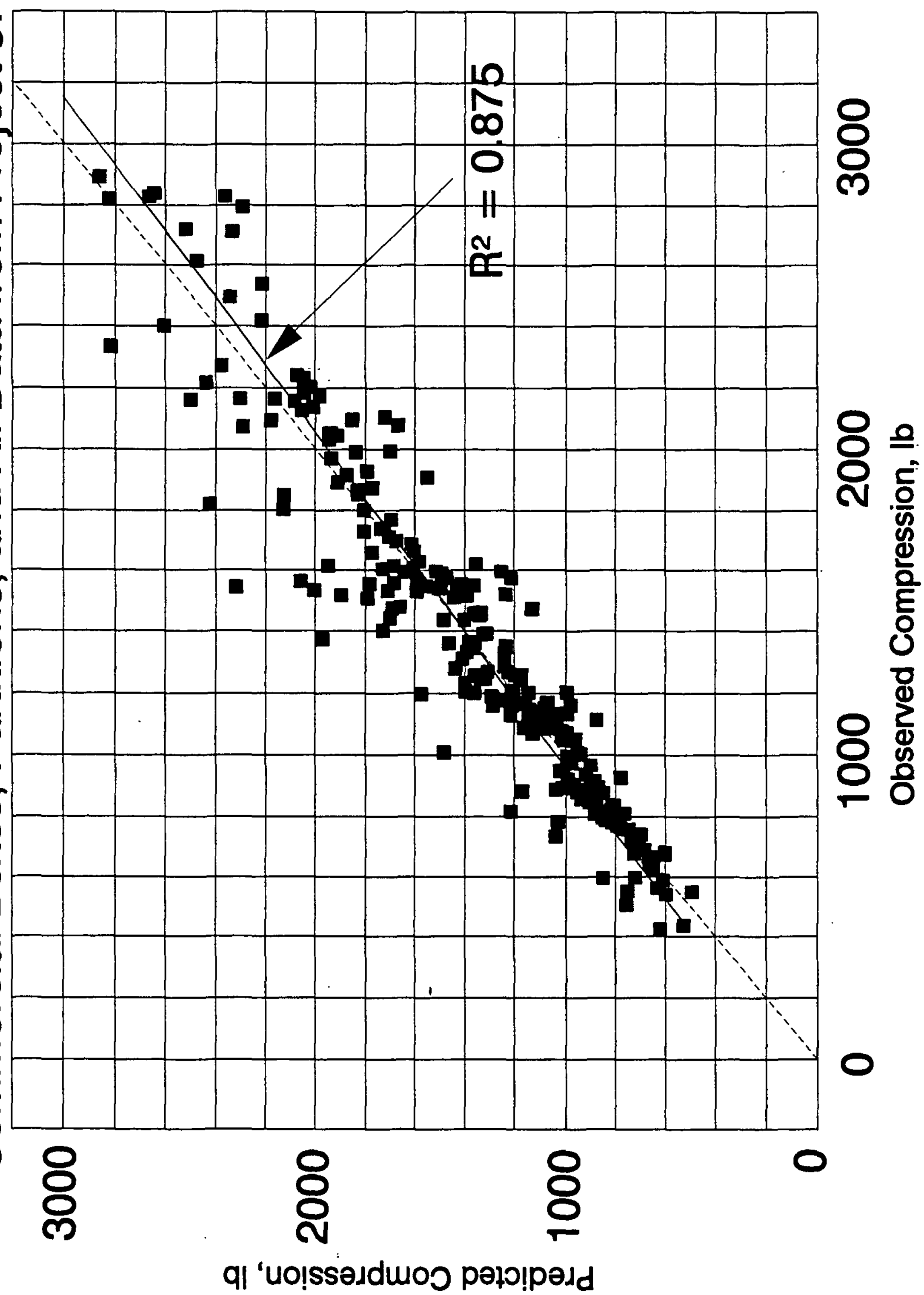


Figure 8
Comparison of Observed vs. Predicted Compression Strength
Modified Formula
Commercial Boxes, Partitions, and All Data from Project 3746



XII. Conclusions

The data obtained demonstrate very significant variations in the compression load readings from actual test values to those predicted by the original McKee formula as well as the modified formula. In the three categories of ECT of the combined board used for the construction of the panels, 26, 32, and 44 pounds per inch, the smaller attributes of perimeter, height, and number of panels yielded higher predicted compression than the actual compression test values.

The increased perimeter, height, and panels registered lower compression readings for the original McKee formula, while the modified formula was essentially closer to the actual compression test values.

Compression failure is essentially governed by the compression resistance of the structure and its ability to resist buckling. Panel size and flexural stiffness are contributing factors that must be accounted for in any predictive formula. The data appear to indicate that adjustments may be needed in the exponential values of the terms in the modified formula or possibly an additional term or terms to further refine its predictive value.

The concept of the project was designed to extract as much information as possible to improve the predictive value of the modified formula. The information gathered may not have a large enough database to adjust the necessary terms in the formula.

The data to date confirmed what was hypothesized as to the probability of adjustments in the terms of the modified predictive McKee formula. All the data are in the report, and those that possess computer statistical programs may want to manipulate the information and seek appropriate adjustments for the modified formula.

The information gathered to date on this project suggests that an additional term or terms may be required in order to improve the accuracy of the modified equation. Whether the exponents need adjusting is unknown at this time. Panel size is more sensitive to its flexural stiffness value in contributing to box compression. The various configurations used in this project suggest that the additional terms may include, and not be limited to, a corner factor, height to perimeter aspect, individual panel height to width aspect, initial panel curvature, and others.

XIII. References

1. McKee, R.C.; Gander, J.W.; Wachuta, J.R. "Compression Strength Formula for Corrugated Boxes." Paperboard Packaging: 149-159, August 1963.

2. Batelka, J.J.; Smith, C.N.; "Package Compression Model" AFPA Project 3746, Final Report, February 15, 1993.

3. McKee, R.C.; Gander, J.W.; Wachuta, J.R. "Flexural Stiffness of Corrugated Board." Paperboard Packaging: December 1962.

Appendix A

EXPERIMENTAL DESIGN
COMMERCIAL VARIFICATION OF MODIFIED BOX COMPRESSION
MODEL ACCOUNTING FOR PACKAGE SIZE

			PACKAGE LENGTH, INCH								
			12			24			36		
			PACKAGE HEIGHT, INCH								
BOX PLANT & BOARD GRADE		BOX WIDTH, INCH	6	15	24	6	15	24	10	20	30
	I 150 SW **	6	X	X		X	X				
		12		X			X				
	II 200 SW **	8				X	X	X			
		24				X	X	X			
	III 200 SW *	8				X	X	X			
		24				X	X	X			
	IV 275 SW **	10				X	X	X		X	
		30								X	X
	V 350 DW	12				X	X			X	X
		36								X	X

* = WITH HEAVY WEIGHT MEDIUM.
** = OR NEW, REDUCED BASIS WEIGHT CONSTRUCTION COMPRESSION GRADES.

Appendix B

COMBINED BOARD TEST VALUES
FOR THE 26 LB/IN ECT ITEM/RULE GRADE

BOX PERIM (IN.)	STATIST. PARAMETER	ECT (LB.IN)	FLEXURAL STIFFNESS (IN-LB)		CALIPER (IN)	PIN ADHESION (LB)	
			MD	CD		SF	DF
72	NO. TESTS	25	15	15	20	20	20
	AVERAGE	32.0	107.6	39.4	161	97.3	87.7
	SIGMA	1.322	10.34	3.637	1.040	9.631	11.46
48	NO. TESTS	25	15	15	20	20	20
	AVERAGE	31.4	101.9	42.4	161	106	89.3
	SIGMA	1.459	18.14	2.476	2.007	8.839	5.192
32	NO. TESTS	25	15	15	20	20	20
	AVERAGE	31.9	101.3	41.9	161	94.1	81.5
	SIGMA	1.180	20.08	4.739	1.234	9.819	6.100
ALL	NO. TESTS	75	45	45	60	60	60
	AVERAGE	31.8	103.6	41.2	161	99.1	86.2
	SIGMA	1.331	16.59	3.886	1.505	10.54	8.628

Appendix B

COMBINED BOARD TEST VALUES
FOR THE 32 LB/IN ECT ITEM/RULE GRADE

Page 2 of 3

BOX PERIM (IN.)	STATIST. PARAMETER	ECT (LB.IN)	FLEXURAL STIFFNESS (IN-LB)		CALIPER (IN)	PIN ADHESION (LB)	
			MD	CD		SF	DF
72	NO. TESTS	25	15	15	20	20	20
	AVERAGE	44.2	135.3	58.6	167	110	100
	SIGMA	1.528	13.48	3.710	1.293	3.275	7.070
48	NO. TESTS	25	15	15	20	20	20
	AVERAGE	43.9	134.4	61.6	167	104	102
	SIGMA	1.481	9.59	3.851	0.923	3.284	4.054
32	NO. TESTS	25	15	15	20	20	20
	AVERAGE	42.4	136.7	59.4	166	109	106
	SIGMA	1.499	10.28	3.461	1.100	4.368	6.689
ALL	NO. TESTS	75	45	45	60	60	60
	AVERAGE	43.5	135.4	59.9	166	108	102
	SIGMA	1.687	11.03	3.829	1.242	4.390	6.463

Appendix B

COMBINED BOARD TEST VALUES
FOR THE 44 LB/IN ECT ITEM/RULE GRADE

Page 3 of 3

BOX PERIM (IN.)	STATIST. PARAMETER	ECT (LB.IN)	FLEXURAL STIFFNESS (IN-LB)		CALIPER (MILS)	PIN ADHESION (LB)	
			MD	CD		SF	DF
72	NO. TESTS	25	15	15	20	20	20
	AVERAGE	55.0	255.9	102.9	188	128	118
	SIGMA	2.816	16.15	6.877	1.152	3.268	4.168
48	NO. TESTS	25	15	15	20	20	20
	AVERAGE	58.2	278.0	103.9	186	124	119
	SIGMA	3.484	15.82	10.32	1.974	10.120	4.095
32	NO. TESTS	25	15	15	20	20	20
	AVERAGE	57.0	263.0	115.7	184	128	122
	SIGMA	4.980	6.855	20.76	2.150	6.198	3.483
ALL	NO. TESTS	75	45	45	60	60	60
	AVERAGE	56.5	265.6	107.5	186	127	120
	SIGMA	3.402	16.26	14.84	2.343	7.281	4.189

Appendix C

EXPERIMENTAL DESIGN COMPRESSION PREDICTION OF PARTITIONS AND DIVIDERS

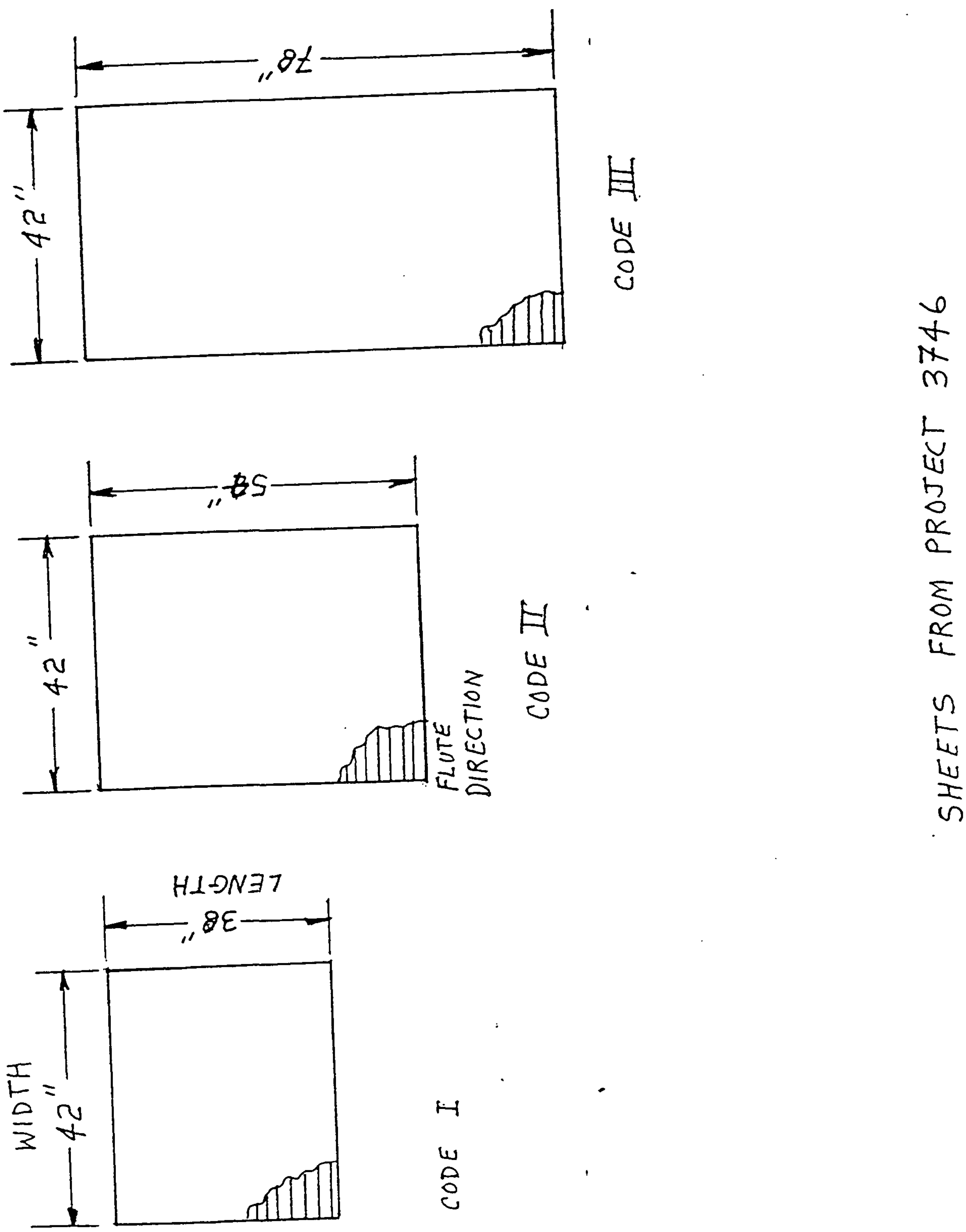
		TOTAL PERIMETER, INCH					
		48		72		96	
		HEIGHT, INCH					
NUMBER OF CELLS	ITEM 222 ECT BOARD GRADE LB/IN	8	16	8	16	8	16
2	26	X	X	X			
2	32	X	X	X			
2	44	X	X	X			
4	26			X	X	X	
4	32			X	X	X	
4	44			X	X	X	
6	26				X	X	X
6	32				X	X	X
6	44				X	X	X

Appendix D (1 of 5)

EXPERIMENTAL MATERIAL DESIGN

CELLS	TRIMMED SHEET SIZE				CODE
	WIDTH	Height	LENGTH	Perim	
2	16	8	24	48	A
2	16	8	36	72	B
2	32	16	24	48	C
4	16	8	36	72	D
4	16	8	48	96	E
4	32	16	36	72	F
6	16	8	48	96	G
6	32	16	36	72	H
6	32	16	48	96	I

Appendix D (2 of 5)

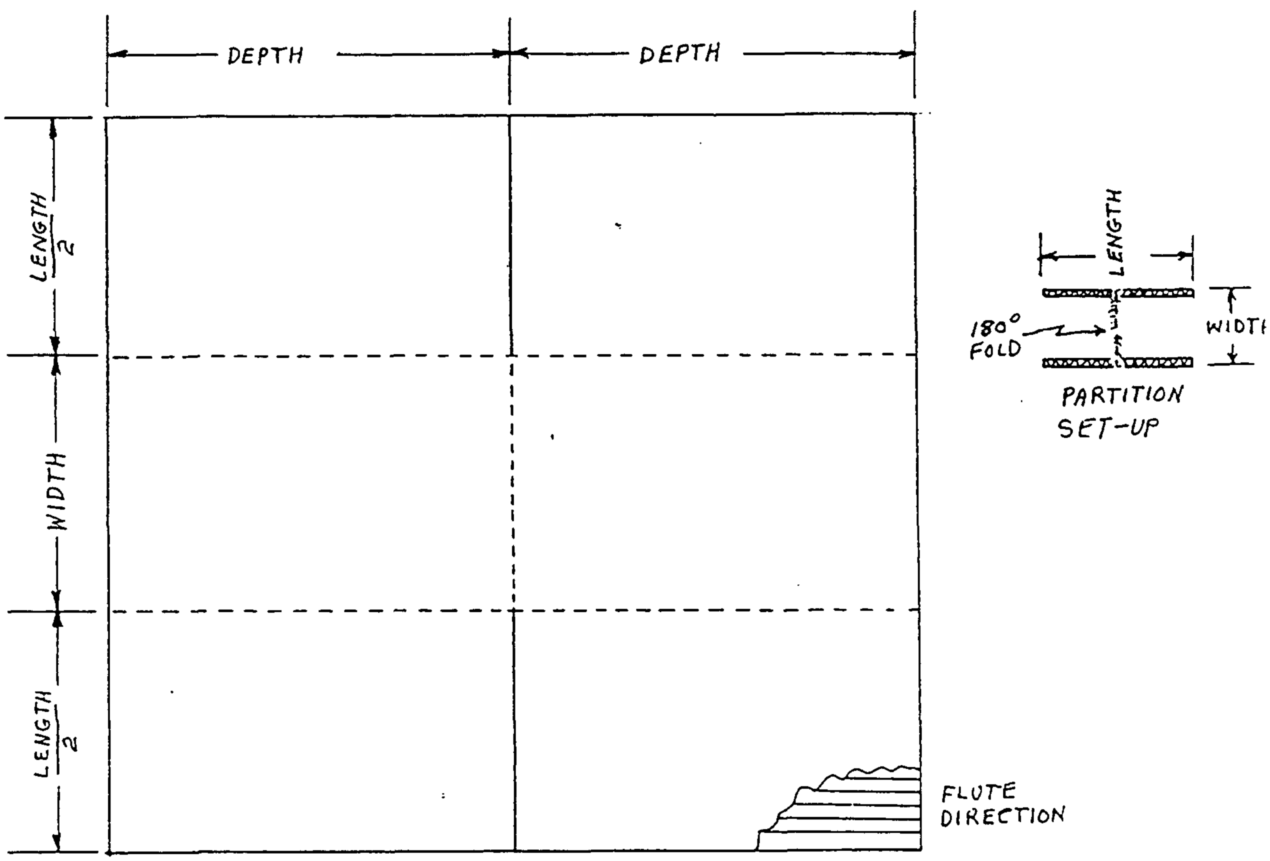


Appendix D (3 of 5)

TWO CELL PACKAGE

	PROJECT DESIGN		STRUCTURE			SHEET (W/O TRIM ALLOW.)	
	PERIM. (IN.)	HEIGHT (IN)	LENGTH (IN.)	WIDTH (IN.)	DEPTH (IN.)	WIDTH (IN.)	LENGTH (IN)
A	48	8	12	12	8	16	24
C	48	16	12	12	16	32	24
B	72	8	18	18	8	16	36

3806



SHEET WIDTH = 2 (DEPTH)

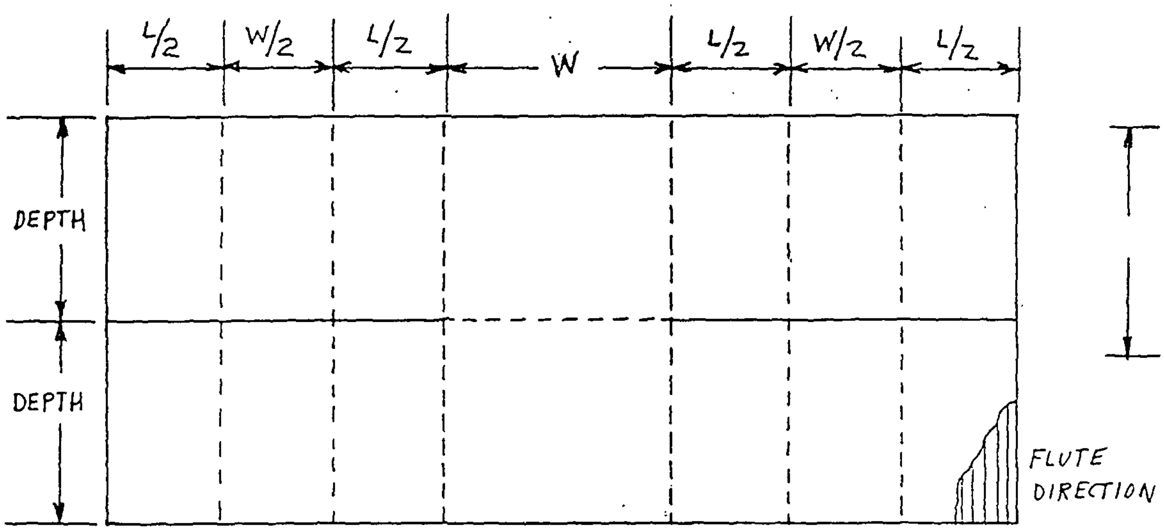
SHEET LENGTH = WIDTH + LENGTH

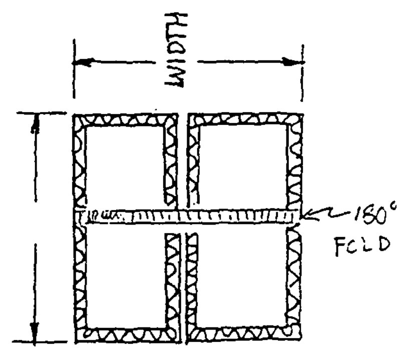
TWO CELL PACKAGE

Appendix D (4 of 5)

FOUR CELL PACKAGE

	PROJECT DESIGN		STRUCTURE			SHEET (W/O TRIM ALLOW.)	
	PERIM. (IN.)	HEIGHT (IN.)	LENGTH (IN.)	WIDTH (IN.)	DEPTH (IN.)	WIDTH (IN.)	LENGTH (IN.)
D	72	8	9	9	8	16	36
F	72	16	9	9	16	32	36
E	96	8	15	9	8	16	48





SHEET WIDTH = 2 (DEPTH)

SHEET LENGTH = 2 (LENGTH) + 2 (WIDTH)

W = SET-UP PACKAGE WIDTH

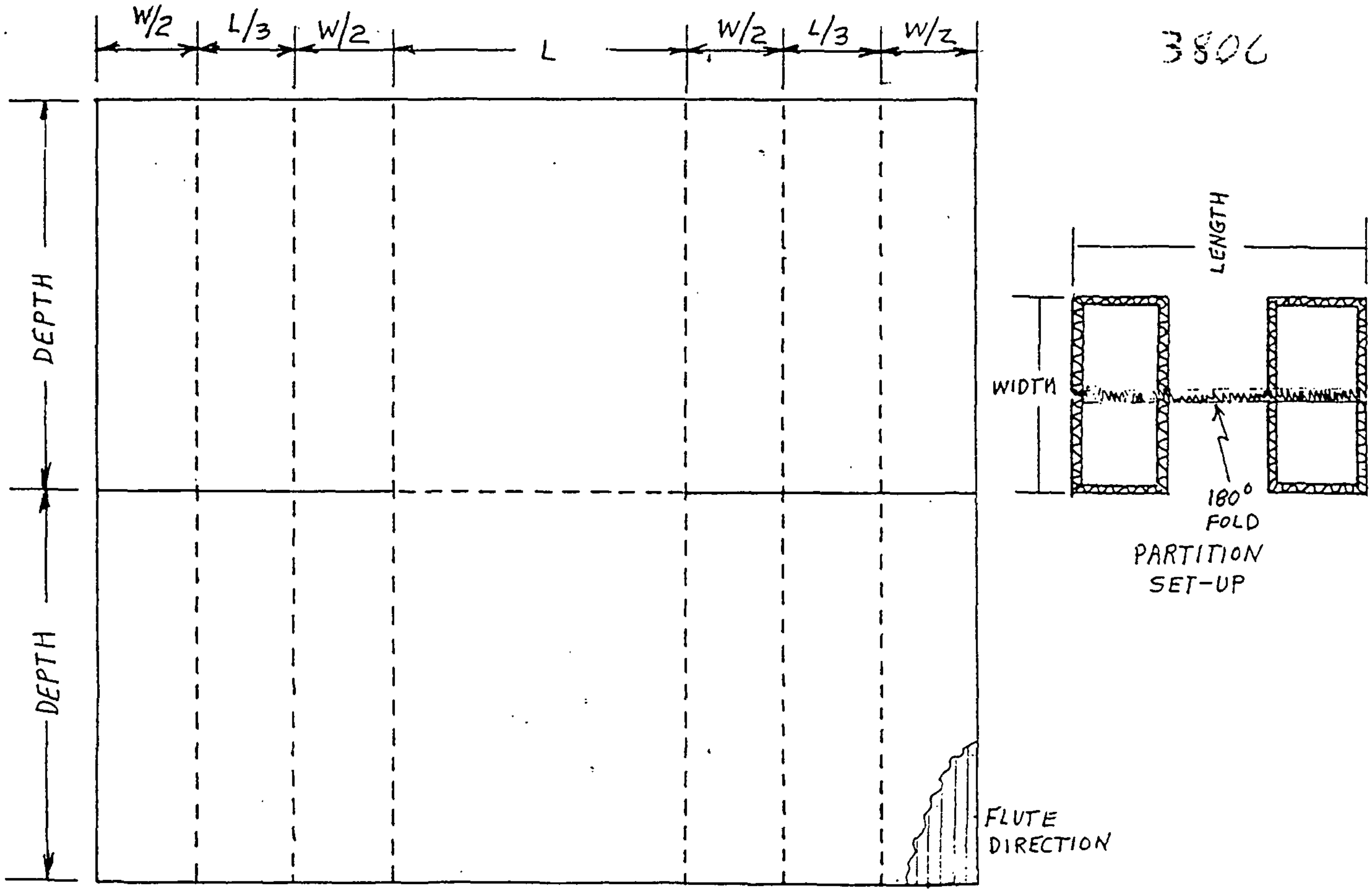
L = SET-UP PACKAGE LENGTH

Appendix D (5 of 5)

SIX CELL PACKAGE

	PROJECT DESIGN		STRUCTURE			SHEET (W/O TRIM ALLO	
	PERIM. (IN.)	HEIGHT (IN.)	LENGTH (IN.)	WIDTH (IN.)	DEPTH (IN.)	WIDTH (IN.)	LENGTH (IN.)
H	72	16	12	8	16	32	36
G	96	8	15	11.5	8	16	48
I	96	16	15	11.5	16	32	48

3806



W = SET-UP PACKAGE WIDTH

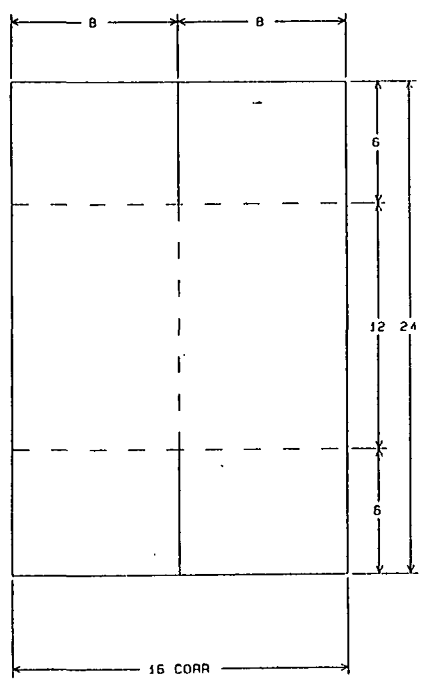
SHEET WIDTH = 2(DEPTH)

Appendix E (1 of 9)

Customer: GEORGIA-PACIFIC
Style: DIVIDER: Institute of Paper Science
CAD Design #: 5500015
Notes: Dimensions for A
Comments:

Board: C-Flute Singlewall
Inches of Rule: 136
Box I.D.: 12 x 12 x 8
Blank Size: 16 x 24

Date: Mar-18-93
Sq. Ft. 2.667
Direction of Corr: Horiz
Project #:



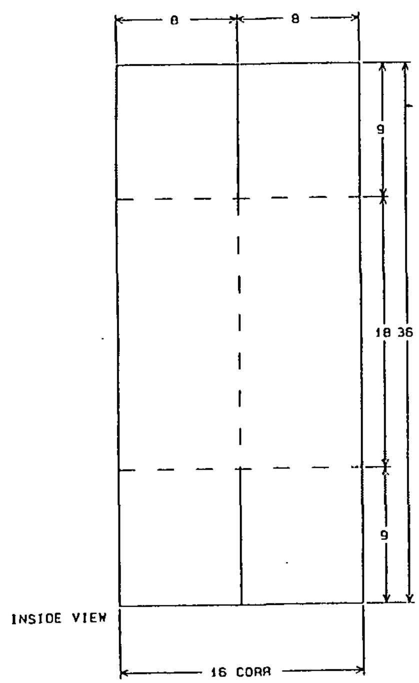
INSIDE VIEW

Appendix E (2 of 9)

Customer: GEORGIA-PACIFIC
Style: DIVIDER: Institute of Paper Science
CAD Design #: 5500016
Notes: Dimensions for 8
Comments:

Board: C-Flute Singlewall
Inches of Rule: 172
Box I.D.: 18 x 18 x 8
Blank Size: 16 x 36

Date: Mar-18-93
Sq. Ft. 4.000
Direction of Corr: Horiz
Project #:

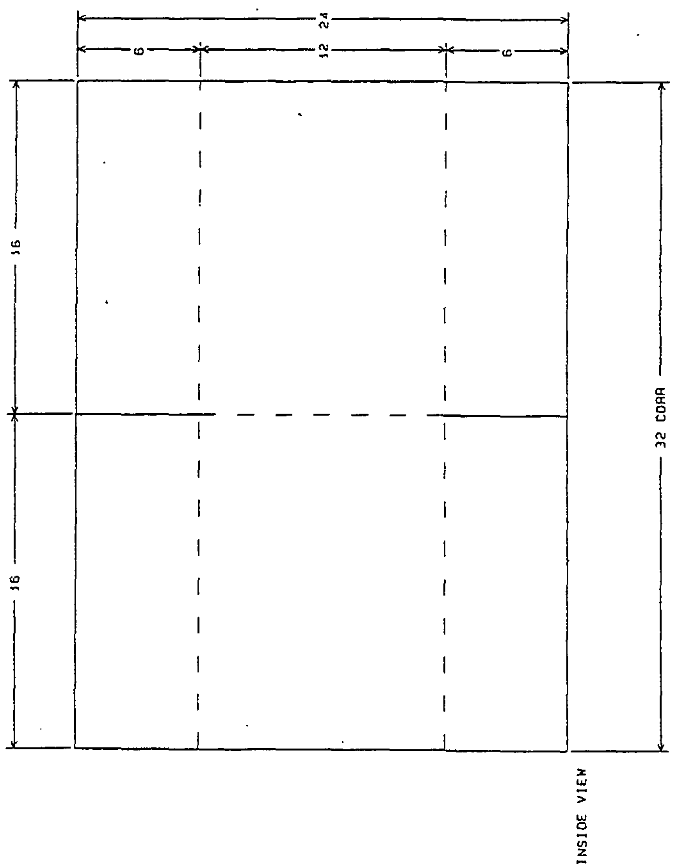


Appendix E (3 of 9)

Customer: GEORGIA-PACIFIC
Style: DIVIDER; Institute of Paper Science
CAD Design #: 5500017
Notes: Dimensions for C
Comments:

Board: C-Flute Singlewall
Inches of Rule: 200
Box I.D.: 12 x 12 x 16
Blank Size: 32 x 24

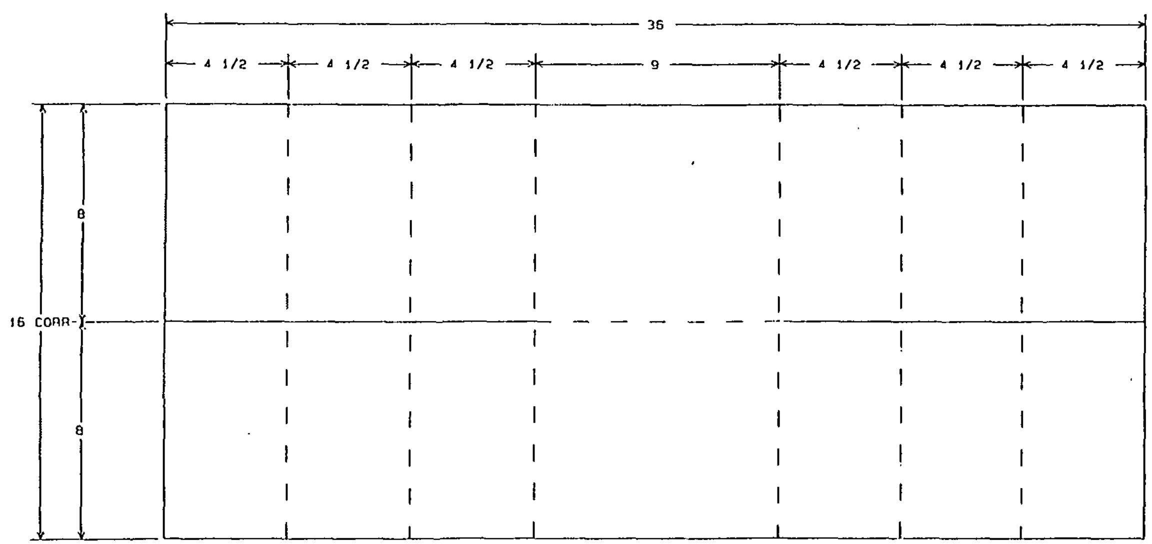
Date: Mar-18-93
Sq. Ft. 5.333
Direction of Corr: Horiz
Project #:



Appendix E (4 of 9)

Customer: GEORGIA-PACIFIC	Board: C-Flute Singlewall	Date: Mar-18-93
Style: DIVIDER; Institute of Paper Science	Inches of Rule: 236	Sq. Ft. 4.000
CAD Design #: 5500018	Box I.D.: 9 x 4 1/2 x 8	Direction of Corr: Vert
Notes: Dimensions for D	Blank Size: 16 x 36	Project #:
Comments:		

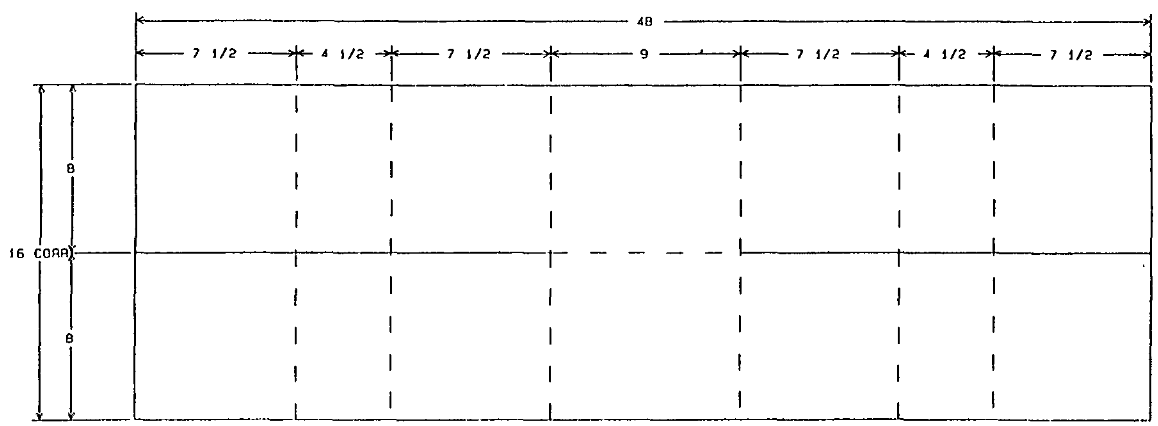
INSIDE VIEW.



Appendix E (5 of 9)

Customer: GEORGIA-PACIFIC	Board: C-Flute Singlewall	Date: Mar-18-93
Style: DIVIDER; Institute of Paper Science	Inches of Rule: 272	Sq. Ft. 5.333
CAD Design #: 5500019	Box I.D.: 9 x 7 1/2 x 8	Direction of Corr: Vert
Notes: Dimensions for E	Blank Size: 16 x 48	Project #:
Comments:		

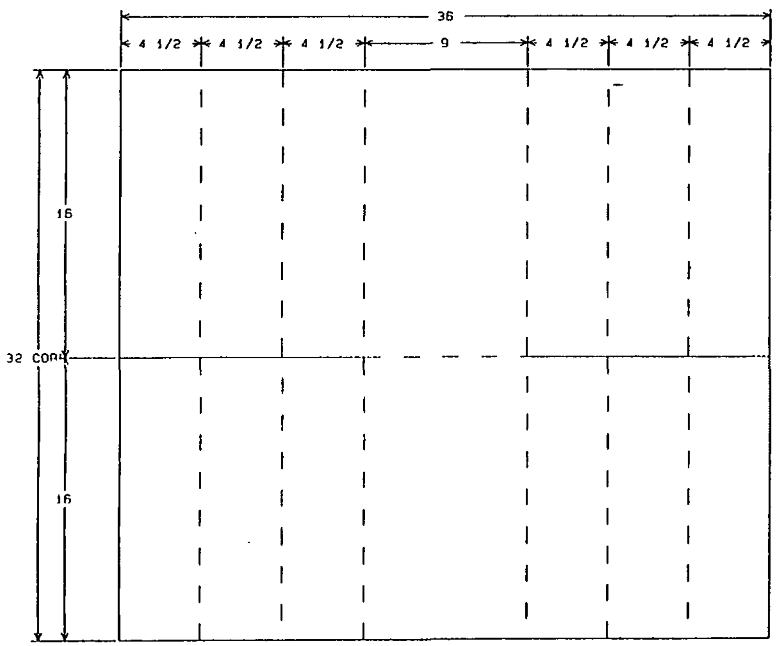
INSIDE VIEW.



Appendix E (6 of 9)

Customer: GEORGIA-PACIFIC	Board: C-Flute Singlewall	Date: Mar-18-93
Style: DIVIDER; Institute of Paper Science	Inches of Rule: 364	Sq. Ft. 8.000
CAD Design #: 5500021	Box I.D.: 9 x 4 1/2 x 16	Direction of Corr: Vert
Notes: Dimensions for F	Blank Size: 32 x 36	Project #:
Comments:		

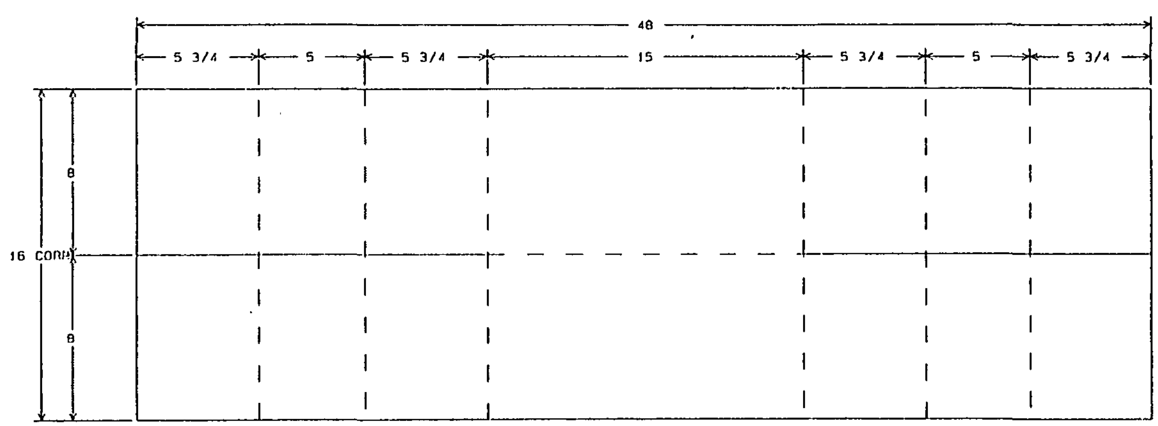
INSIDE VIEW.



Appendix E (7 of 9)

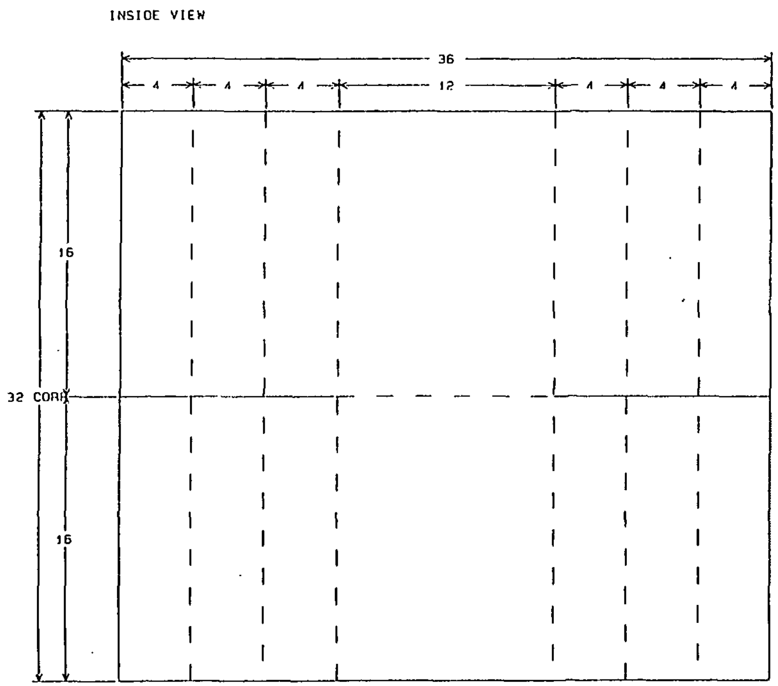
Customer: GEORGIA-PACIFIC	Board: C-Flute Singlewall	Date: Mar-18-93
Style: DIVIDER; Institute of Paper Science	Inches of Rule: 272	Sq. Ft. 5.333
CAD Design #: 5500022	Box I.D.: 15 x 5 3/4 x 8	Direction of Corr: Vert
Notes: Dimensions for G	Blank Size: 16 x 48	Project #:
Comments:		

INSIDE VIEW.



Appendix E (8 of 9)

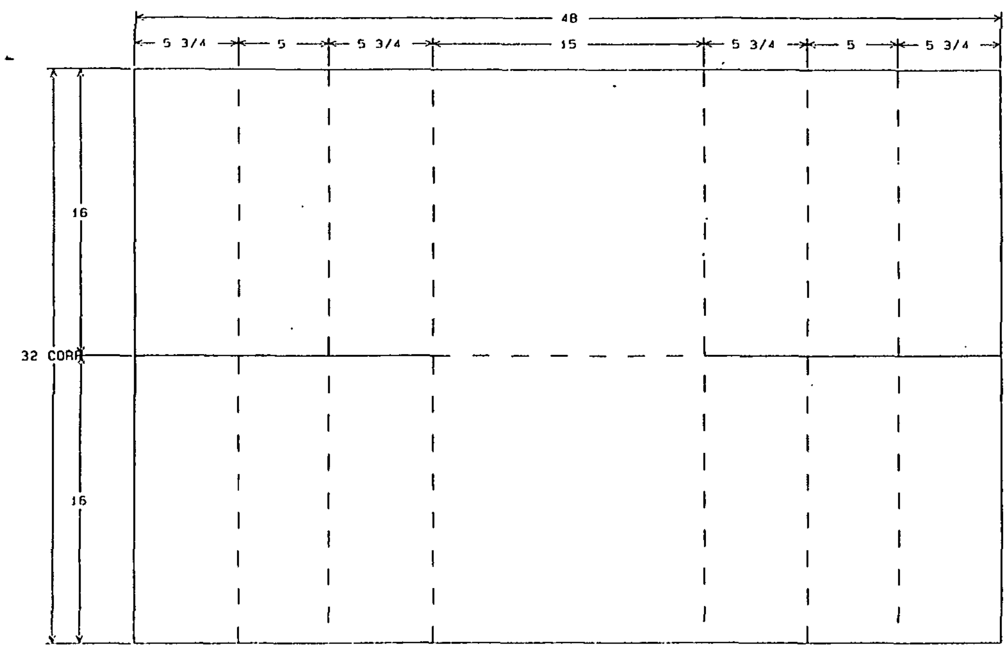
Customer: GEORGIA-PACIFIC	Board: C-Flute Singlewall	Date: Mar-18-93
Style: DIVIDER; Institute of Paper Science	Inches of Rule: 364	Sq. Ft. 8.000
CAD Design #: 5500023	Box I.D.: 12 x 4 x 16	Direction of Corr: Vert
Notes: Dimensions for H	Blank Size: 32 x 36	Project #:
Comments:		



Appendix E (9 of 9)

Customer: GEORGIA-PACIFIC	Board: C-Flute Singlewall	Date: Mar-18-93
Style: DIVIDER: Institute of Paper Science	Inches of Rule: 400	Sq. Ft. 10.667
CAD Design #: 5500024	Box I.D.: 15 x 5 3/4 x 16	Direction of Corr: Vert
Notes: Dimensions for I	Blank Size: 32 x 48	Project #:
Comments:		

INSIDE VIEW



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