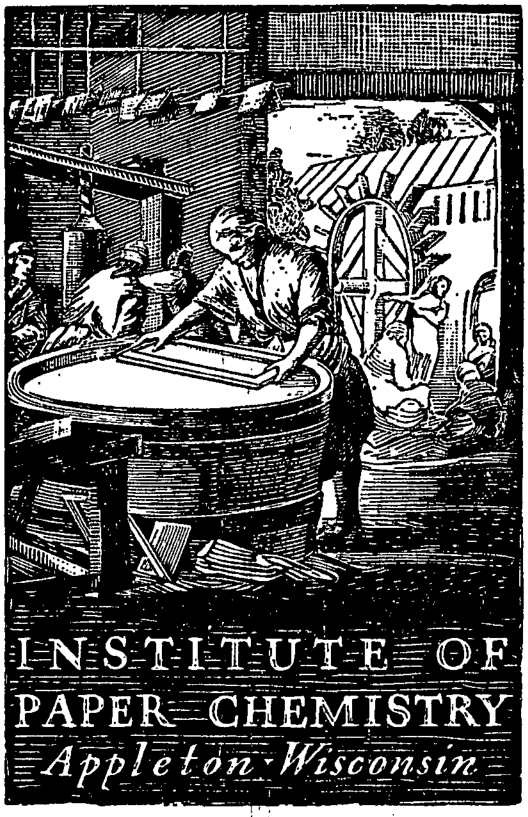
GENERAL



EVALUATION OF CORRUGATOR OPERATING CONDITIONS AND MEDIUM PROPERTIES WITH RESPECT TO HIGH-LOW FLUTE FORMATION

Project 2696-7

Report One

A Summary Report

to

FOURDRINIER KRAFT BOARD INSTITUTE, INC.

December 24, 1969

GENERAL

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

EVALUATION OF CORRUGATOR OPERATING CONDITIONS AND MEDIUM PROPERTIES WITH RESPECT TO HIGH-LOW FLUTE FORMATION

Project 2696-7

Report One

A Summary Report

to

FOURDRINIER KRAFT BOARD INSTITUTE, INC.

December 24, 1969

TABLE OF CONTENTS

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

EVALUATION OF CORRUGATOR OPERATING CONDITIONS AND MEDIUM PROPERTIES WITH RESPECT TO HIGH-LOW FLUTE FORMATION

SUMMARY

One of the limiting factors in the corrugating operation is the formation of high-low flutes. Excessive difference in the heights of successive flutes results in poor or no adhesion of the low flutes in the double-backing operation, thereby impairing the integrity of the corrugated board as a structure. Previous investigations indicate that high-low flute formation depends upon the properties of the medium being corrugated and upon the operating conditions used in fabricating the combined board. A study was undertaken to clarify the effects of certain corrugator operating variables on high-low flute formation. This information may help to identify the types of medium properties that govern high-lows, as well as provide operating guidelines for commercial corrugating plants faced with high-low problems.

Eight rolls of 26-lb. semichemical corrugating medium, representing mills of wide geographical distribution, were corrugated in combination with a "standard" 42-lb. single-face liner under various combinations of operating conditions. The operating variables studied were (a) web tension (0.5 and 1.75 lb./in.), (b) main steam shower pressure (0 and 21 p.s.i.), (c) corrugating roll pressure (187 and 420 lb./in.), (d) angle of take-off of single-faced board (0 and 20° above tangency), and (e) corrugating speed (300 and 450 f.p.m.). Average high-low, defined as the average absolute difference in height between successive flutes, was evaluated on a conditioned sample of A-flute single-faced board from each experimental corrugating run. It is shown that average high-low, as defined above, is approximately proportional to the relative

frequency of flute-height-differences exceeding three and five points – the latter are arbitrary criteria for excessive high-lows. Selected properties of the medium samples were evaluated for the purpose of checking equations developed in the allied Project 2696-6 describing the relationship between high-lows and medium properties.

Among the conclusions drawn from this study are the following:

1. Considering all medium samples, increasing the web tension from 0.5 to 1.75 lb./in. increased the average high-low by 0.39 $\pm$ 0.12 point (with 95% confidence). The effect was sensibly consistent for all mediums studied.

2. On the average, increasing the main shower pressure from zero to 21 p.s.i. decreased high-lows by 0.52 $\pm$ 0.12 point and the effect was consistent from medium-to-medium.

3. Increasing the corrugating roll pressure from 187 to 420 lb./in. decreased high-lows by 0.72 $\pm$ 0.12 point and the effect was consistent from medium-to-medium. This magnitude of decrease in average high-low corresponds to approximately 15 percentage points reduction in the relative number of flute-height-differences exceeding three points and 10 percentage points reduction in differences exceeding five points.

4. Increasing the angle of take-off of the single-faced web from tangency to 20° above the tangent at the pressure roll-corrugator roll nip had no important effect on high-lows. The effect was 0.06 $\pm$ 0.12 point (with 95% confidence), which includes no effect as a possibility.

5. Increasing the corrugating speed from 300 to 450 f.p.m. increased the average high-low by 0.25 $\pm$ 0.12 point considering all medium samples.

6. The results of this study are in good agreement with an earlier investigation (Project 2696-1).

7. The results cited above indicate that average high-low can be minimized by decreasing the web tension and corrugating speed and increasing the main steam shower pressure and the corrugating roll pressure. Elevating the angle of take-off of the single-face web by 20° above the normal tangential take-off appears to have no important effect on average high-low.

8. There were marked differences between the magnitude of average high-low among the eight mills at given corrugating conditions. Differences as great as one point in average high-low were exhibited by the eight medium samples, representing the major containerboard-producing areas of the country. One point difference in average high-low corresponds to about 20 percentage points difference in the relative frequency of flute-height-differences exceeding three points and 15 percentage points reduction of differences exceeding five points. This observation indicates that the properties of the medium, as well as operating conditions, influence the formation of high-low in corrugated board.

9. Selected properties of the medium were evaluated for the purpose of testing relationships between average high-low and medium properties, as developed in Project 2696-6. Six equations, each involving one or two medium properties, were tested. It was found that, on the average, each equation predicted average high-low for the samples of this study at least as well as it did for the samples of Project 2696-6. One of the more attractive equations involves tensile strength and Thwing formation of the medium. On the average, the high-low for the samples of the present study were predicted with 11% accuracy by means of this equation. The equation implies that high-low increase with increase in tensile strength and decrease with improved formation.

INTRODUCTION

Corrugating is a process that converts three or more relatively flexible paperboard webs into a composite material possessing markedly greater stiffness at relatively low weight. The primary requirement of the process is that it provide a product of satisfactory quality at a cost which is competitive with other packaging materials.

There have been many improvements in corrugating over the years, involving improvement of component quality, machine design and adhesives, all of which have tended to make the production of corrugated board more efficient and improve end-use performance. Two aspects of corrugating remain rather severe limitations, namely, runnability and high-lows, and they militate against further increases in production speeds and the associated increase in efficiency. "Runnability" refers to the ability of the medium to withstand the stresses and strains of corrugating without fracture of the flutes. "High-lows" refer to the differences in height of consecutive flutes. Excessive differences in flute height result in poor or no adhesion of the low flutes in the double-backing operation. This impairs the integrity of the composite structure (corrugated board) and may have adverse effects on its performance in container compression. The present investigation is concerned with high-lows.

Previous studies (1-3) have indicated that the tendency to form high-low flutes varies from medium-to-medium and with the operating conditions of the corrugator. The properties of the medium that govern high-low formation are not adequately known, although they are the subject of a concurrent investigation (Project 2696-6). Somewhat more is known about the effect of operating conditions on high-low formation, perhaps because it is more readily accessible to experimentation. There is likely some interplay between medium properties and corrugator operating variables in the sense that operational variables such as shower pressure, roll pressure, and web tension probably influence high-low formation by their action on the medium properties. For example, the amount of moisture absorbed at the steam showers may affect medium characteristics such as moldability, friction, or tension characteristics.

The objective of the present study is to clarify the effects of selected operational variables on high-low flute formation. The corrugator variables studied are: (a) web tension, (b) main steam shower pressure, (c) corrugating roll pressure, (d) angle of take-off of the single-faced board, and (e) corrugating speed. It is hoped that a clear understanding of the effects of operating variables will help identify the types of medium properties that govern high-low formation, as well as provide operating guidelines for commercial corrugating plants faced with high-low problems. While this is not the first investigation of these operating variables [see (3)], the present study benefited from the use of sound principles of the design of experiments, giving improved precision in the determination of the effects of the operating variables.

The number of samples of medium employed in the present study was not sufficiently large to carry out an effective development of the relationship between high-lows and medium properties. Selected properties of the medium were evaluated, however, and serve to test several relationships developed in the companion Project 2696-6.

MATERIALS

A 50-inch diameter, 12-inch wide roll of 26-lb. semichemical medium was selected from each of eight member mills, representing various geographical areas of the country. Based on earlier evaluation in the medium base-line study (Project 2694-2) the mediums exhibit average or above average runnability.

EXPERIMENTAL PROGRAM

Each of the eight rolls of 26-lb. medium was corrugated on the Institute's experimental corrugator with A-flute corrugating rolls and a "standard" 42-lb. kraft liner under various combinations of operating conditions. The operating variables under study and the levels investigated were as follows:

Operating Variable	Symbol	Levels Studied	"Normal" Level
Web tension	A	0.5, 1.75 lb./in.	0.5 lb./in.
Main steam shower pressure	B	0, 21 p.s.i.	14 p.s.i.
Corrugating roll pressure	C	187, 420 lb./in.	320 lb./in.
Angle of take-off of single-faced board	D	0°, 20°	0°
Corrugating speed	S	300, 450 f.p.m.	--

The "normal" levels listed above are those used in routine evaluations of runnability, as in the medium base-line study (Project 2694-2), and are shown for reference.

Web tension was monitored by means of a strain-gaged, cantilevered tension roll, illustrated in Fig. 1, and controlled to within ± 0.125 lb./in. by means of a remote-operated friction brake on the medium parent roll shaft.

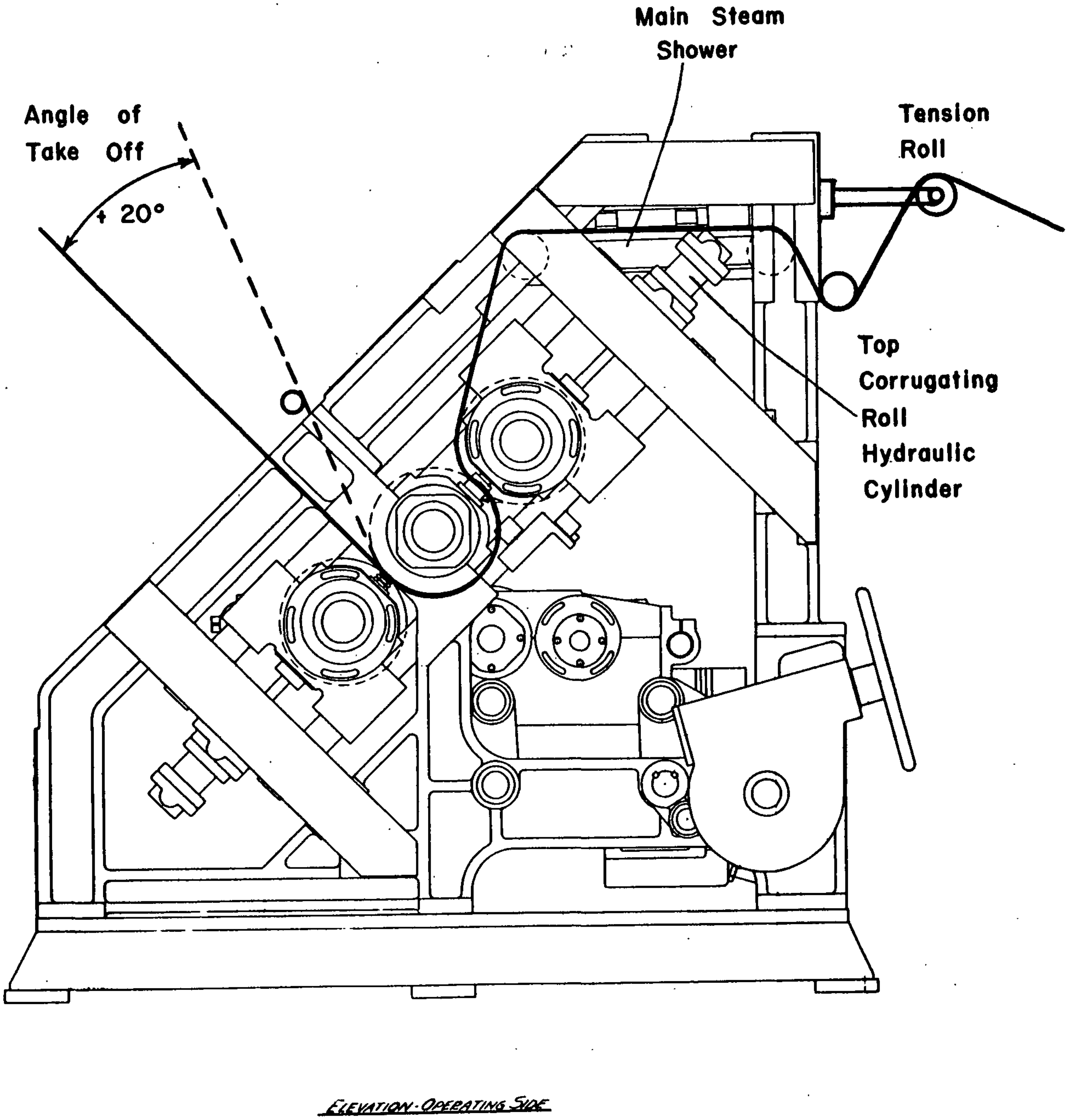


Figure 1. Experimental Corrugator

The main steam shower pressure was controlled to within ± 1 p.s.i. The medium preheater shower pressure was controlled in conjunction with the main shower pressure — zero and 1.5 p.s.i. on the preheater corresponding, respectively, to zero and 21 p.s.i. on the main showers. The corrugating roll pressure was controlled to within ± 10 lb./in. and the speed to within ± 10 f.p.m.

The angle of take-off of the single-faced web was either 0° (i.e., tangent at the nip of the lower corrugating roll and pressure roll), as illustrated in Fig. 1, or 20° above the line of nip tangency; a special idler roll was installed for the 20° angle.

Ten experimental runs were made on each roll of medium, as shown in Table I. This experimental design is a 1/2-fraction of a 2^4 factorial experiment (4,5) in the variables A, B, C and D — i.e., web tension, main shower pressure, roll pressure, and angle of take-off. A factorial experiment is one in which all levels of one variable are investigated at all levels of the other variables. For example, with four variables as above, each at two levels, there are 2 x 2 x 2 x 2 = 2^4 combinations of levels of the variables. Factorial experiments are efficient and are capable of revealing the interaction (or interplay) between variables. In the interest of economy it is possible to perform a fraction of the total number of trials, provided the trials are selected according to an appropriately balanced plan. A one-half fraction of a 2^4 factorial, for example, is comprised of 1/2 x 2^4 = 8 trials, suitably selected to reveal the major effects of the variables and the most probable interactions between them. The statistical notation employed in this relation is the usual notation for 2^M factorials (4,5). Variables such as tension, shower pressure, etc. are identified by upper case letters. Lower case letters and the parenthetical numeral (1) are used to identify specific combinations of the high and low levels of the different variables investigated in this study. Repeat determinations were made for Runs 4 and 5 to provide an estimate of experimental error. With a given roll of medium, the 10 runs were performed in random order, except that Run 3 was always performed first. The reason for this is that Run 3 was expected to be the most severe conditions from the standpoint of runnability, and it was necessary to be assured that the medium would run satisfactorily at these levels of the controlled variables before proceeding to the other runs of the fractional factorial design. In one instance (Roll 840) it was necessary to reduce the high level of web tension from 1.75 to 1.50 lb./in. in order for the sample to run without fracture. The experimental trials listed in Table I were performed at each of two speeds (300 and 450 f.p.m.), so that the overall experimental design for a given roll of medium is a $2 \times 2^4/2$ factorial design.

TABLE I

EXPERIMENTAL CORRUGATING RUNS

Run No.	Web Tension (A), lb./in.	Shower Pressure (B), p.s.i.	Corrugator Roll Pressure (C), lb./in.	Angle of Take-Off (D), degree	Statistical Name of Combination
1	0.5	0	187	0	(1)
2	1.75	21	187	0	ab
3	1.75	0	420	0	ac
4a	0.5	21	420	0	bc
4b	0.5	21	420	0	bc
5a	1.75	0	187	20	ad
5b	1.75	0	187	20	ad
6	0.5	21	187	20	bd
7	0.5	0	420	20	cd
8	1.75	21	420	20	abcd

The operating procedure was as follows: A 100-foot sample of medium was removed from the roll and stored for subsequent evaluation of material properties in connection with the second phase of this study. After taking a moisture sample from the medium web, the operating variables were set to their specified levels and the corrugator was brought up to 300 f.p.m. After steady state conditions were obtained at 300 f.p.m., a 100-foot sample of single-faced corrugated board was collected for subsequent evaluation of high-lows at this speed level. The speed then was elevated to 450 f.p.m. and, after steady state was obtained, a 100-foot sample of single-faced board was collected for evaluation of high-lows at 450 f.p.m. The corrugator was then brought back to zero speed, and the operating conditions set for the next scheduled run. After the tenth run a moisture sample was taken from the medium web, and a 100-foot sample of medium was removed and stored for subsequent use.

In the case of Roll 843, the complete factorial experiment in the A, B, C and D variables (16 runs) was performed to help clarify the assumptions implicit in the fractional factorial design employed with the other seven rolls of medium. The size of Roll 843 did not permit any replicate runs.

With one exception, corrugator variables other than those discussed above were held sensibly constant during the experimental runs, as shown in Table II. The one exception is the glue roll clearance and relative speed, which are not considered to have an affect on high-low corrugations. These variables were set at levels which have been found to be good operating practice with the Institute corrugator.

For the purpose of evaluating high-lows, twenty 5-square inch circular specimens were cut by means of a flat crush cutter at random intervals along

TABLE II

CORRUGATING CONDITIONS OTHER THAN VARIABLES UNDER STUDY

Medium Roll No.	Fabrication Date	Roll Temperature	Glue Roll: Relative Speed[b]	Glue Roll: Doctor Clearance, in.[c]	Glue Roll: Corrugating Roll Clearance, in.[d]	Starch Adhesive Characteristics: Viscosity sec. @ 100°F.	Starch Adhesive Characteristics: Gel Point, °F.	Starch Adhesive Characteristics: pH	Pressure Roll Pressure, lb./in.[e]
792	3-11-69	Standard[a]	95/95	0.012	0.012	30	138	12.3	210/187
843	3-21-69	Standard[a]	95/95	.013	.010	30	138	12.2	210/187
863	3-26-69	Standard[a]	95/95	.013	.010	30	139	12.2	210/187
840	3-27-69	Standard[a]	95/95	.013	.010	30	140	12.2	210/187
846	3-27-69	Standard[a]	95/95	.013	.010	30	140	12.2	210/187
833	3-27-69	Standard[a]	95/95	.013	.010	30	140	12.2	210/187
882	4- 7-69	Standard[a]	95/95	.013	.010	30	140	12.2	210/187
004	5-27-69	Standard[a]	95/35	.008	.010	35	138	12.2	210/187

[a] Top and bottom corrugating rolls, 340°F.; medium and liner preheater rolls, 360°F.; pressure roll, 360°F.

[b] First figure: 100 x transfer roll surface speed/bottom corrugating roll surface speed.
Second figure: 100 x doctor roll surface speed/transfer roll surface speed.

[c] Clearance between doctor roll and transfer roll.

[d] Clearance between lower corrugating roll and transfer roll.

[e] First figure: drive side. Second figure: operator side.

the 100-foot sample of single-faced board after standard conditioning. The flute height of five consecutive flutes in each circular specimen was measured by means of a special flute caliper equipped with a Federal dial indicator, giving a total of 100 flute height readings per sample. The dial indicator has a flat measuring foot, exerts a spindle force of 100 grams and is graduated to 0.0005 inch (0.5 point); readings were estimated to 0.0001 inch.

Selected properties of the eight rolls of medium were evaluated after standard conditioning. The purpose was to check several equations developed in Project 2696-6 describing the relationship between high-low formation and medium properties. "Start" and "end" samples of each roll of medium were evaluated in the following tests:

	Test	Procedural Details	No. of Readings or Specimens Per Roll Sample
1.	Basis weight	Toledo basis weight scale; 11 x 11-inch sheet	20
2.	Thickness	Cady micrometer	20
3.	Tension	Baldwin Universal tester; 1-inch wide x 7-inch span; 60-lb./min. test rate	10
4.	Formation	Thwing formation tester	6

DISCUSSION OF RESULTS

This study was conducted in two phases. The first phase speaks to the effects of selected operating variables on the formation of high-low flutes. The second phase, of a limited nature, is concerned with the relationship between the magnitude of high-lows and the properties of the corrugating medium. As a preliminary discussion of the results of these two phases, consideration is given in the following to a numerical measure of high-lows.

NUMERICAL CHARACTERIZATION OF HIGH-LOWS

"High-low" derives its name from the characteristic that two consecutive flutes are alternately high and low, or vice versa, relative to their mean height. A given alternating pattern exists for a period, is then upset and a new alternating pattern is set up; it frequently is one flute out of synchronization with the former pattern. It is the alternating nature of the high-low pattern that presents a problem in double-backing and causes the phenomenon to be a point of concern in the corrugating plant.

It seems appropriate to characterize high-lows in single-faced board in terms of the difference in height between a pair of consecutive flutes. Inasmuch as an increase in height from one flute to the next is of as much consequence as a decrease in height, the algebraic sign of the difference can be discarded. For five consecutive flutes, for example, the <u>average high-low</u> may be defined as

$$\bar{y}_4 = \frac{|h_2-h_1| + |h_3-h_2| + |h_4-h_3| + |h_5-h_4|}{4} \tag{1}$$

and, in general, for <u>n</u> flutes,

$$\bar{y}_{n-1} = \frac{|h_2-h_1| + \ldots + |h_n-h_{n-1}|}{(n-1)} = \frac{\sum_{i=1}^{n-1} |h_{i+1}-h_i|}{(n-1)} \tag{2}$$

In the present study, each circular specimen of single-faced board provided measurement of height for five consecutive flutes and hence four differences. The twenty circular specimens from a given experimental corrugator run therefore provided 100 flute measurements or 80 differences, and these were averaged to give a single average value $\bar{y}_{80}$ which was taken as the dependent variable (or response). It is termed average high-low throughout the report. The major objective of this investigation is concerned with determining the effects of five operating variables on average high-low, as defined above. Another objective, of secondary consideration because of the limited number of mediums is concerned with the relationship between average high-low and properties of the corrugating medium.

There are, of course, other arbitrary ways of characterizing high-lows. For example, one may count the number of differences, $\left|h_{i+1}-h_i\right|$, that exceed some value believed to be critical for adhesion at the double-backer, say, three points or five points. Clearly, board with a high frequency of excessively large differences is of poorer quality than board with a lower frequency.

Figures 2A and 2B illustrate the connection between a measure of this type and the average high-low defined in Equation (2), for the case of the data from this study (see Table XVII, Appendix II). The graphs show the relative frequency of flute-height-differences exceeding three and five points versus the average high-low for 128 experimental samples of single-faced board corresponding to the various runs performed on the eight rolls of medium. The scatter diagram indicates a reasonably close association between these two arbitrary measures of high-lows. Over most of the range the two measures of high-low are approximately proportional. The scatter undoubtedly reflects

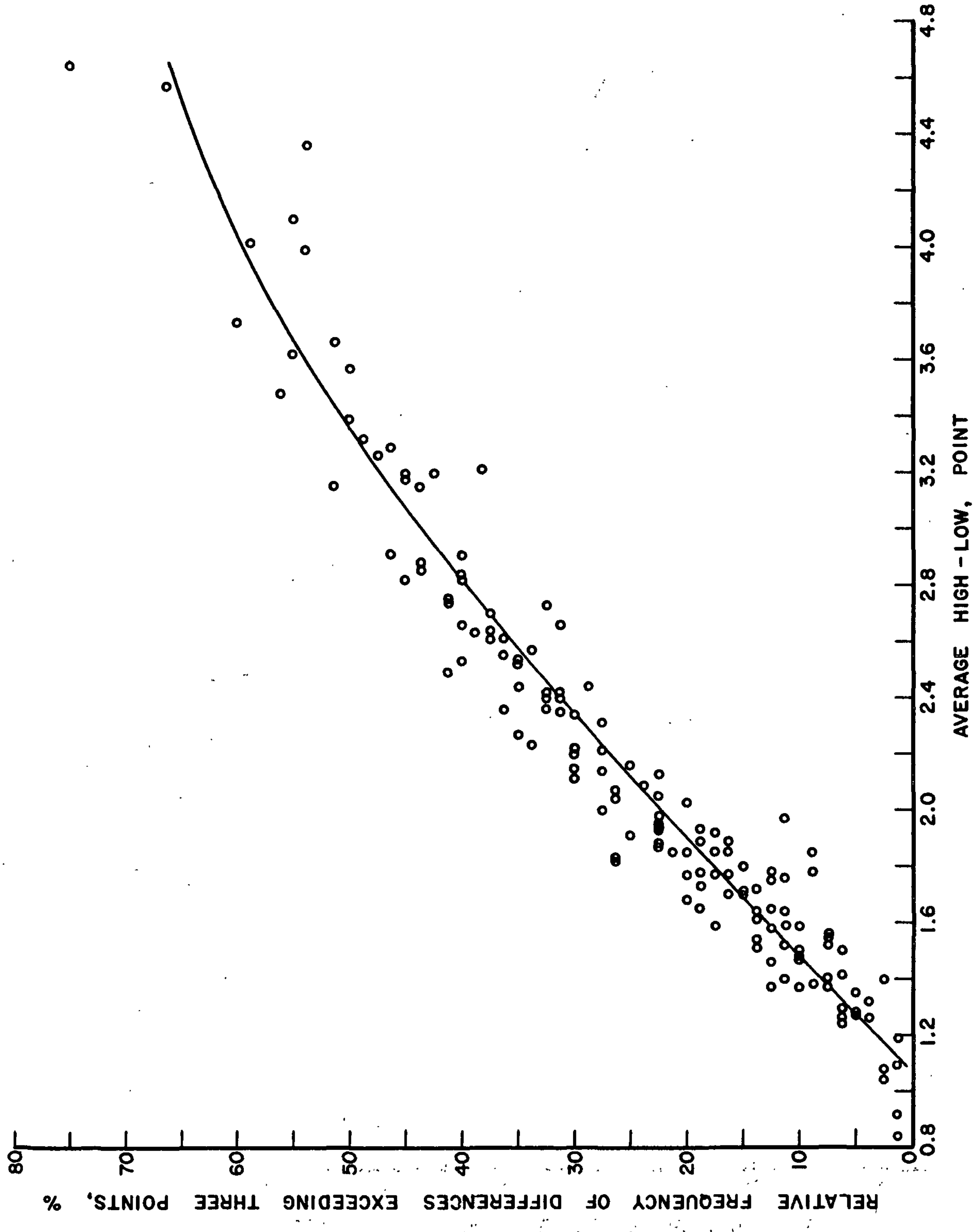


Figure 2A. Relationship Between Average High-Low and Relative Frequency of Consecutive-Flute-Height-Differences Exceeding Three Points (i.e., 0.003 Inch) for Single-Face Samples in this Study (Curves Fitted Visually)

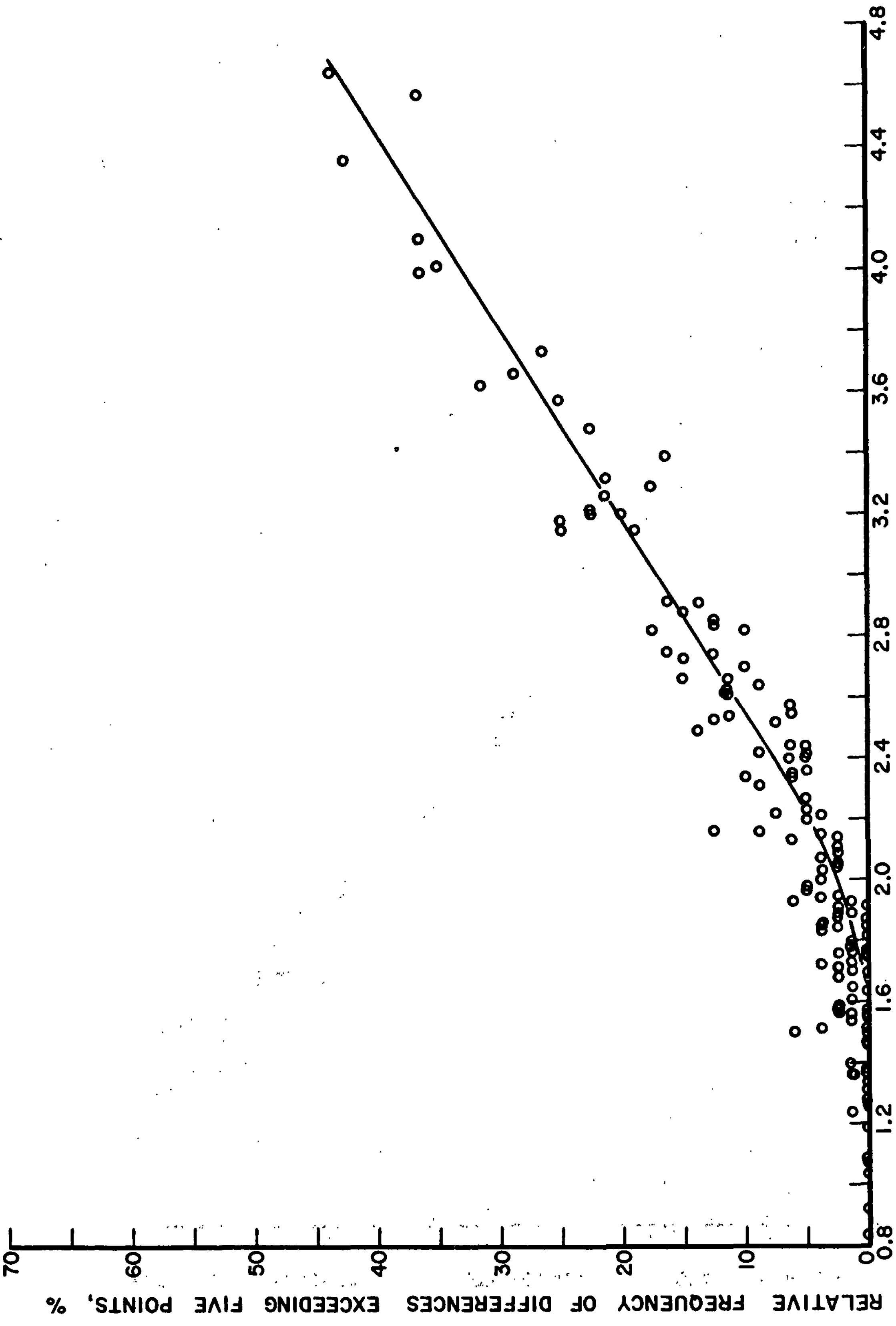


Figure 2B. Relationship Between Average High-Low and Relative Frequency of Consecutive-Flute-Height-Differences Exceeding Five Points (i.e., 0.005 Inch) for Single-Face Samples in this Study (Curves Fitted Visually) differences in standard deviation and shape of the distributions of flute-height-differences from sample-to-sample, as well as sampling variability. It seems clear, however, that generally the same assessment of high-low quality will be made with either method for characterizing high-lows provided the increment is not too subtle, say, on the order of at least a half-point or so on the average high-low scale. Average high-low is the easier statistic to work with, and this in part promoted its use in this study. Further work would be worthwhile, however, in defining an acceptable metric and statistic for high-lows which will accurately reflect this aspect of combined board quality.

Based on Fig. 2, the analysis of data in the present study proceeds on the premise that a reduction in average high-low corresponds to a reduction in the relative number of excessive flute-height-differences, and that this corresponds to better quality board from the high-low standpoint.

EFFECT OF OPERATING VARIABLES

Eight rolls of corrugating medium representing mills of wide geographical distribution were corrugated (A-flute rolls) with a standard liner on the Institute's experimental corrugator under a variety of operating conditions. The operating variables under study were web tension, main steam shower pressure, corrugating roll pressure, angle of take-off of the single-face web, and corrugating speed. Average high-low, defined as the average absolute difference in height between successive flutes, was evaluated on conditioned samples of single-faced board; the average is based on 80 differences in flute height (in 20 groups of four) over a 100-foot long sample. Table XVII in Appendix II lists the average high-low for each experimental run as well as the relative frequency of flute-height-differences in excess of three points.

Main Effects

The main effects of the operating variables, i.e., web tension, roll pressure, shower pressure, speed and angle of take-off, are shown in Table III (see Effects A, B, C, D, and S). It may be recalled that the main effect of a given variable is the average numerical change in the average high-low resulting from the change in a given operating variable – e.g., web tension. For example, with reference to the data for Roll 792 in Table III, the effect of increasing the web tension from 0.5 to 1.75 lb./in. was to increase the average high-low by 0.68 point. As a second example, the effect of increasing the shower pressure from zero to 21 p.s.i. was to decrease the average high-low for Roll 792 by 0.75 point. Both of these effects are statistically significant at the 0.05 level, as denoted by b footnote in Table III. Significance is indicated by the fact that the 95% confidence interval for the effect (see footnote in Table III) does not include zero; for example, the 95% confidence interval for the main effect of web tension with Roll 792 is 0.68 $\pm$ 0.32, i.e., from +0.36 to +1.00 point.

The effects of the five operating variables are also shown graphically in Fig. 3-7. Each figure shows the effect of one operating variable for each of the eight rolls and for the composite of all rolls, the latter corresponding to the right-hand column in Table III. Connection of the plotted points by straight lines is for the purpose of roll identification and is not meant to imply that the relationship is necessarily linear over the range of the operating variable studied.

It may be seen in Fig. 3 and Table III that increasing the web tension from 0.5 to 1.75 lb./in. increased the average high-low for each roll of medium.

TABLE III

EFFECT OF OPERATING VARIABLES ON AVERAGE HIGH-LOW

Effect Name		Roll No.:	Effect on Average High-Low, point								
			792	833	840	843	846	863	882	004	Composite
Main Effects											
A	Web tension, 0.5 to 1.75 lb./in.		+0.68[b]	+0.33[b]	+0.34[a,b]	+0.38[b]	+0.47[b]	+0.13	+0.39[b]	+0.42[b]	+0.39[b]
B	Shower pressure, 0 to 21 p.s.i.		-0.75[b]	-0.42[b]	-0.54[b]	-0.88[b]	-0.32	-0.49[b]	-0.50[b]	-0.23	-0.52[b]
C	Roll pressure, 187 to 420 lb./in.		-0.66[b]	-1.12[b]	-0.54[b]	-0.80[b]	-0.80[b]	-0.45[b]	-0.79[b]	-0.60[b]	-0.72[b]
D	Take-off angle, 0 to +20°		+0.06	+0.01	-0.08	+0.21	+0.25	0.00	-0.09	-0.06	+0.06
S	Corrugating speed, 300 to 450 f.p.m.		+0.23	+0.14	+0.26	+0.43[b]	+0.16	+0.30	+0.22	+0.28	+0.25[b]
Interactions											
AB	Tension x shower pressure		-0.17	0.00	-0.09	-0.28	-0.07	-0.20	-0.03	+0.01	-0.11
AC	Tension x roll pressure		-0.15	-0.12	0.00	-0.02	-0.27	-0.03	-0.17	+0.05	-0.09
BC	Shower pressure x roll pressure		+0.25	+0.25	+0.17	+0.62[b]	+0.39[b]	+0.28	+0.18	+0.12	+0.28[b]
AS	Tension x speed		-0.06	-0.12	0.00	+0.10	+0.04	-0.16	-0.09	-0.06	-0.05
BS	Shower pressure x speed		-0.21	-0.05	+0.11	-0.20	-0.32	-0.12	-0.02	-0.11	-0.11
CS	Roll pressure x speed		-0.22	-0.07	0.00	-0.38[b]	-0.20	-0.09	-0.26	-0.17	-0.17[b]
DS	Take-off x speed		+0.03	-0.02	-0.08	+0.14	+0.09	-0.09	+0.10	-0.06	+0.03
ABS	Tension x shower pressure x speed		-0.13	+0.13	+0.08	+0.05	-0.25	-0.07	-0.14	-0.02	-0.04
ACS	Tension x roll pressure x speed		-0.08	+0.18	+0.01	+0.05	-0.21	+0.13	+0.20	-0.14	+0.01
BCS	Shower pressure x roll pressure x speed		-0.12	+0.32	-0.08	+0.36[b]	+0.17	+0.09	+0.15	+0.18	+0.13[b]

[a]High level of web tension was 1.5 lb./in.

[b]Denotes significance at 0.05 level.

Note: 95% confidence intervals for each effect are:
$\pm$ 0.32 point for individual rolls
$\pm$ 0.12 point for composite of all rolls

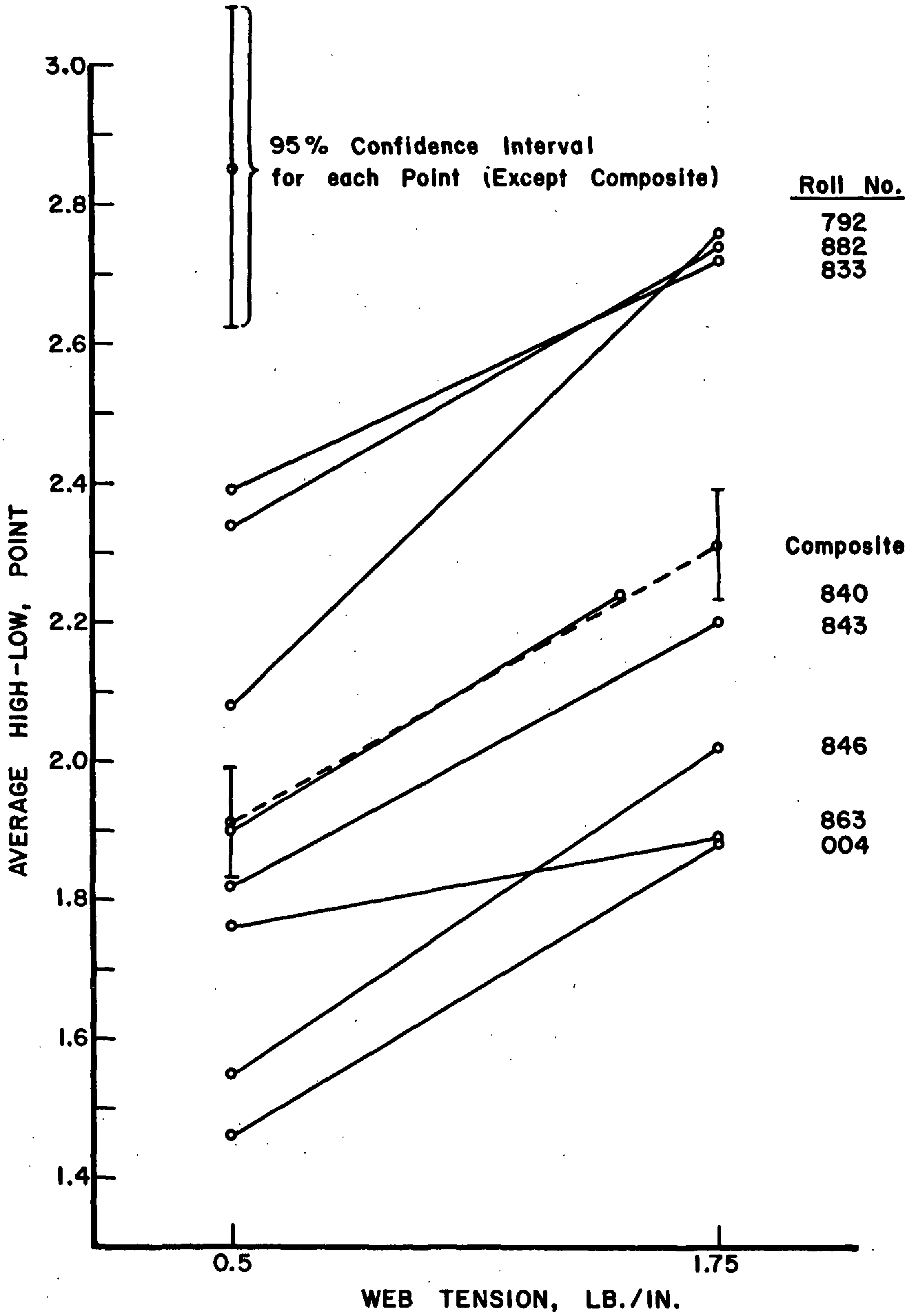


Figure 3. Effect of Web Tension on Average High-Low for Eight Rolls of Medium

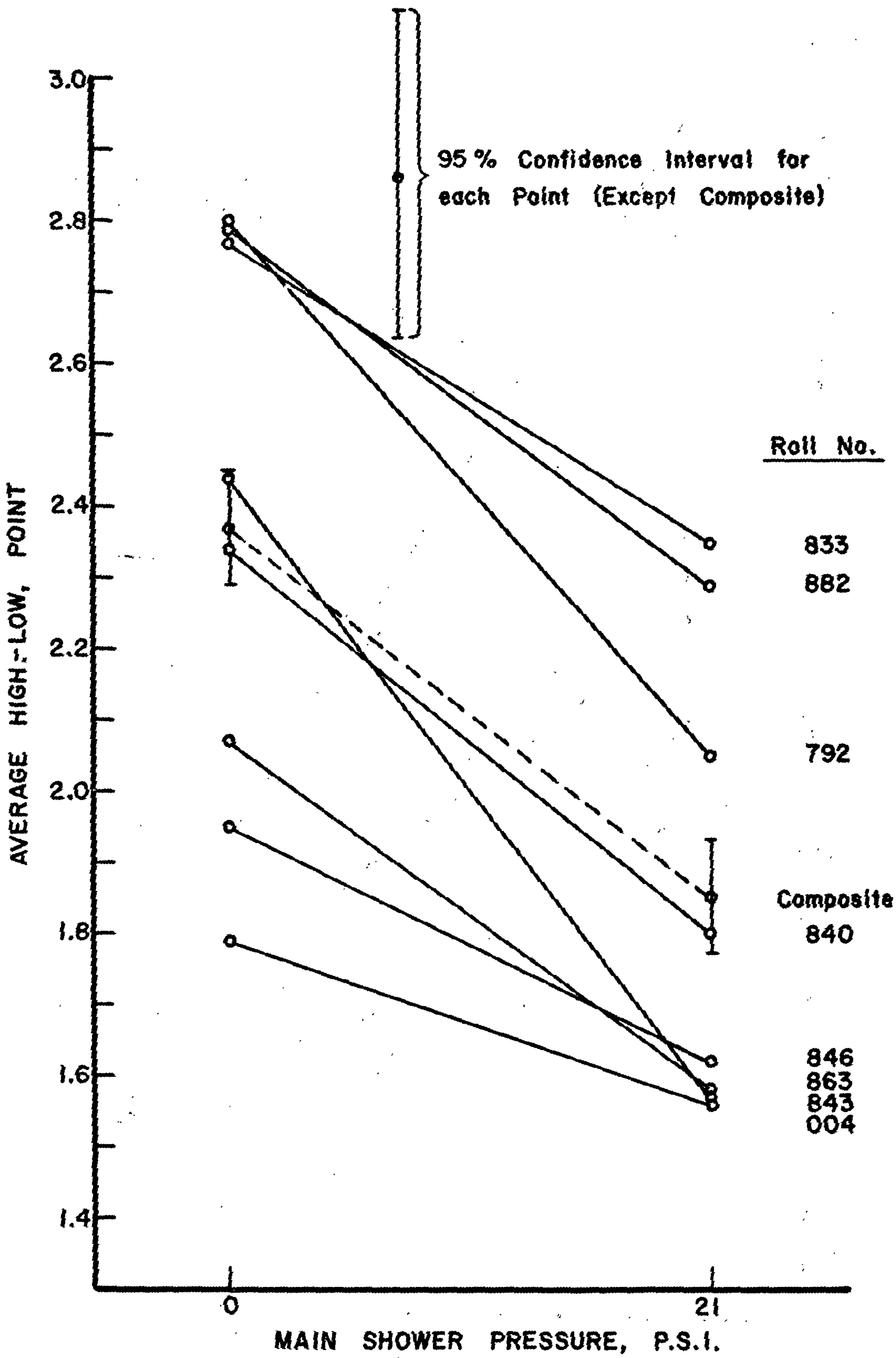


Figure 4. Effect of Main Steam Shower Pressure on Average High-Low for Eight Rolls of Medium

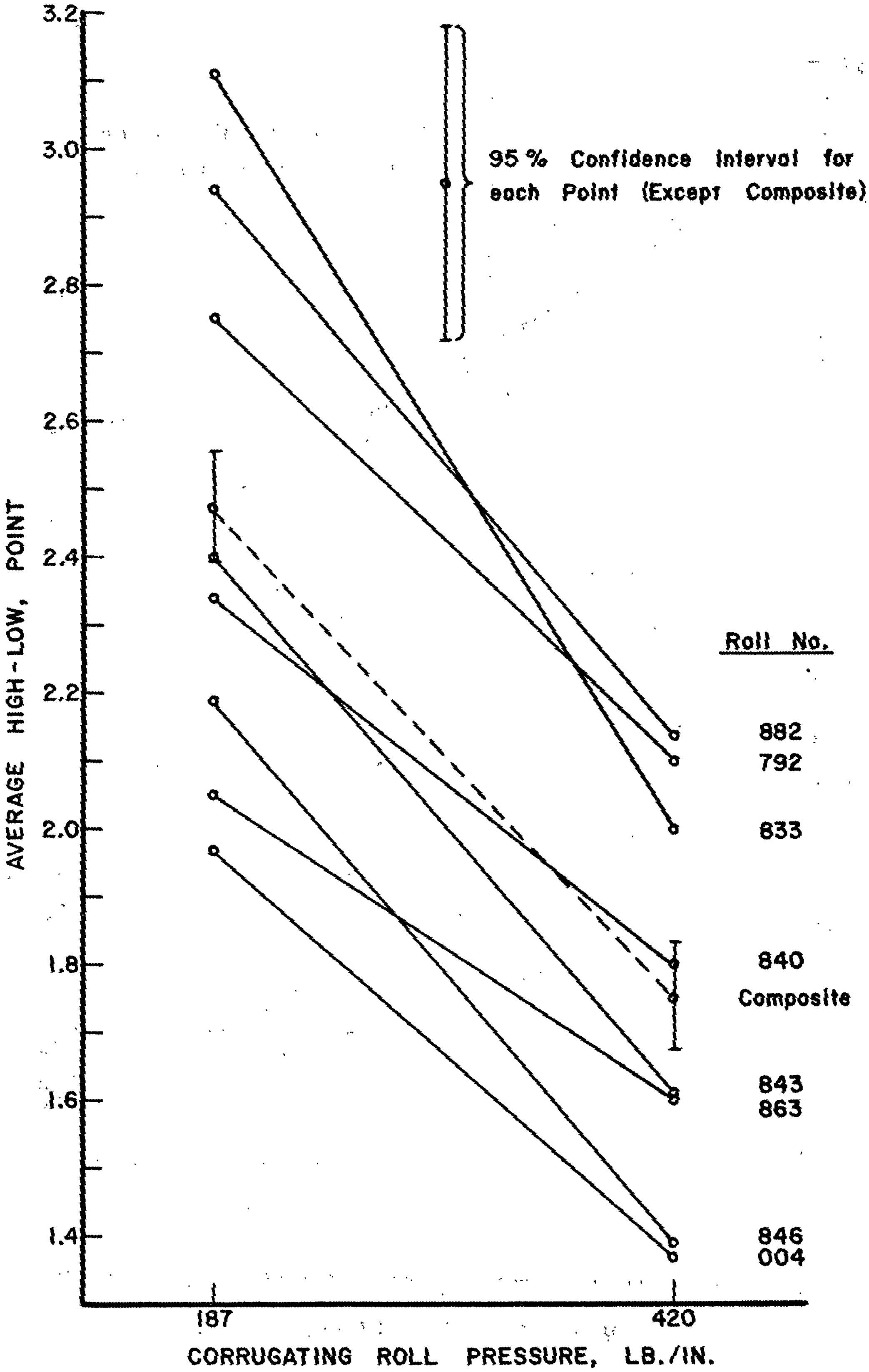


Figure 5. Effect of Corrugating Roll Pressure on Average High-Low for Eight Rolls of Medium

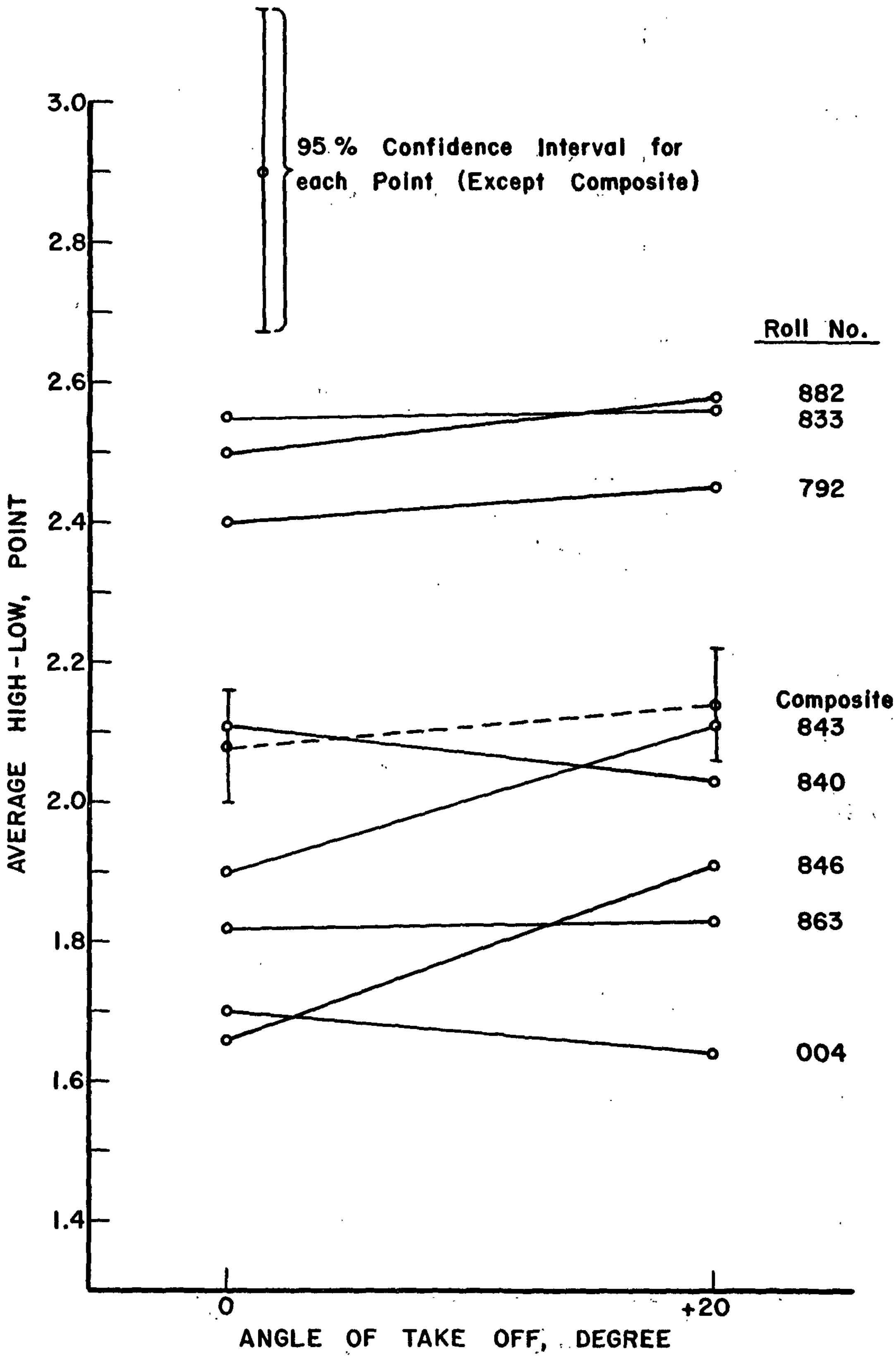


Figure 6. Effect of Angle of Take-Off of Single-Face Web on Average High-Low for Eight Rolls of Medium

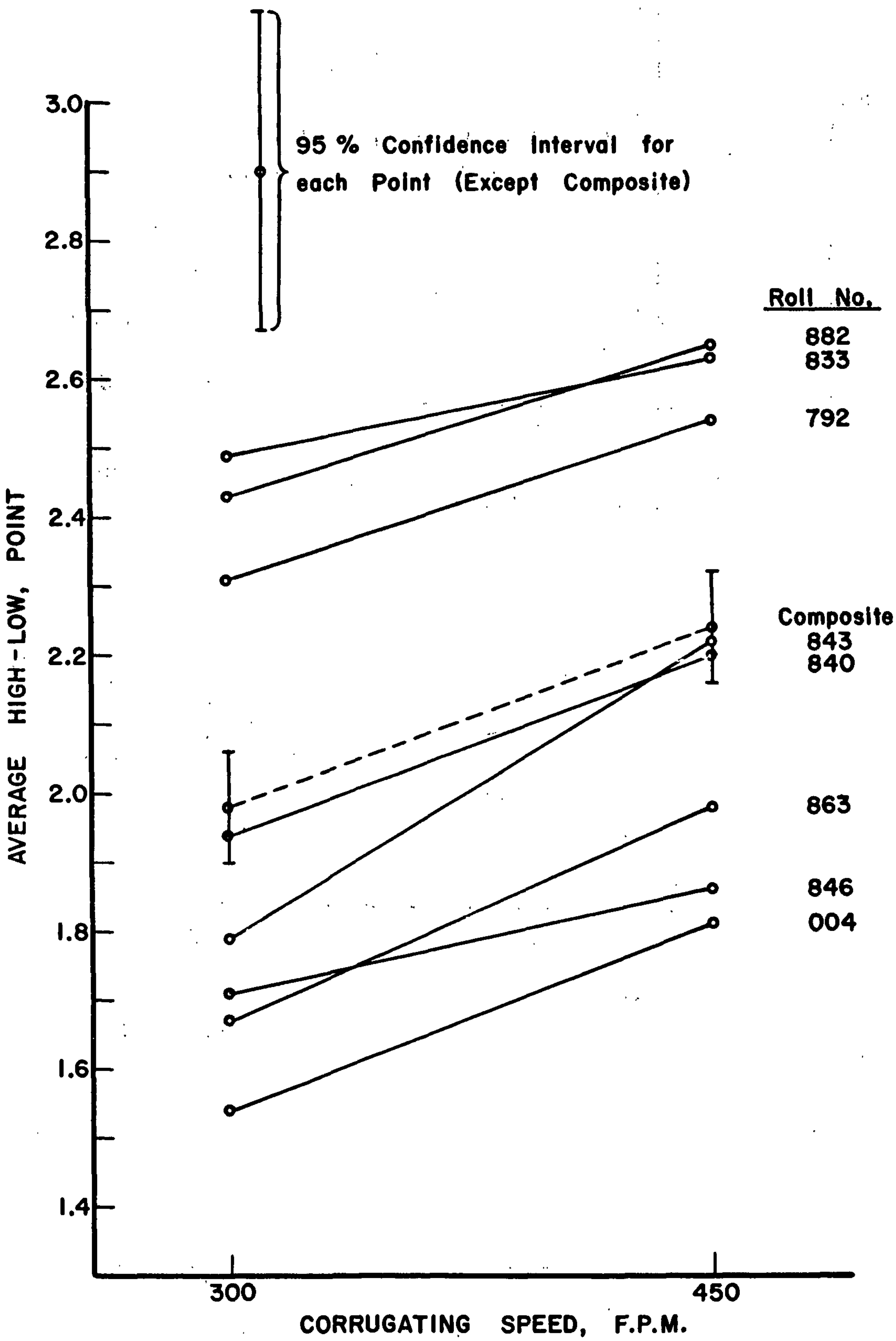


Figure 7. Effect of Corrugating Speed on Average High-Low for Eight Rolls of Medium

With the exception of two rolls, the curves exhibited similar slopes. The analysis of variance tabulated in Table XVI, Appendix I, shows that there was no interaction between web tension and corrugating medium rolls (AR); thus, the effect of web tension was essentially the same for each roll (that is, the slopes of the lines in Fig. 3 are parallel within experimental error). It is therefore appropriate to consider the effect of web tension for the composite of all rolls, namely, +0.39 point. That is, on the average, increasing the web tension from 0.5 to 1.75 lb./in. increased the average high-low of the eight mediums studied by 0.39 ± 0.12 point (with 95% confidence).

Figure 3 also provides graphic evidence of the differing magnitude of high-lows from medium-to-medium. Under a given set of corrugating conditions, differences of about one point in average high-low are exhibited by these eight rolls. One point difference in average high-low corresponds to a difference of approximately 20 percentage points in the relative frequency of excessive high-lows exceeding 3 points as may be seen in Fig. 2A, or approximately 15 percentage points in the relative frequency of excessive high-low exceeding 5 points (see Fig. 2B).

Figure 4 reveals that increasing the main steam shower pressure from zero to 21 p.s.i. decreased the average high-low by 0.52 ± 0.12 point, on the average. The effect of shower pressure was consistent from roll-to-roll to within experimental error as shown by the lack of a significant interaction between shower pressure and medium roll, BR, – see Table XVI, Appendix I.

As shown in Fig. 5, increasing the corrugating roll pressure from 187 to 420 lb./in. caused a consistently large decrease in average high-low. Averaged over all rolls the decrease was 0.72 ± 0.12 point. This was the largest effect observed in this study. It corresponds to approximately 0.3 point reduction for a 100 lb./in. increase in corrugating roll pressure (assuming a linear relationship).

To gain some appreciation for the consequences of a 0.72-point reduction in average high-low, reference may be made to Fig. 2A and 2B which show the relative frequency of flute-height-differences exceeding three and five points (arbitrary degrees of severity of high-lows) vs. average high-low for the samples in this study. As an example, it may be seen that in the neighborhood of 2.0 points for average high-low, a reduction of 0.72 point in average high-low would decrease the relative frequency of differences exceeding 3.0 points by about 15 percentage points and approximately 10% in the case of those exceeding 5 points, on the average.

An elevation of 20° in the angle of take-off of the single-face web had no significant effect (0.05 level) on average high-low (see Fig. 6). The lack of effect was consistent for the several rolls. The 95% confidence limits for the effect of angle of take-off are +0.06 ± 0.12, that is, -0.06 to +0.18 point, indicating that the true effect is unlikely to be large enough to be of technical importance. Negative angles of take-off (i.e., below the line of tangency at the nip of the pressure roll and lower corrugating roll) were not investigated.

Corrugating speed had a modest and consistent effect on high-lows for all rolls of medium (see Fig. 7). On the average, increasing the speed from 300 to 450 f.p.m. increased the average high-low by 0.25 ± 0.12 point.

Interactions

"Interaction" means that the effect of one variable depends upon the level of another variable. For example, an interaction (denoted UV) between variables U and V means that the effect of U on average high-low depends upon the level of V, or *vice versa*.

As may be seen in Table III there were significant interactions between shower pressure (B), corrugating roll pressure (C), and corrugating speed (S). These interactions are illustrated in Fig. 8-10. Figure 8 illustrates that the decrease in high-lows with increasing corrugating roll pressure was somewhat greater at zero shower pressure than at 21 p.s.i. shower pressure. The interaction is not severe, however, and does not vitiate the conclusions cited above that average high-low decreases with increase in (a) roll pressure and (b) shower pressure. Figure 9 illustrates a modest statistical interaction between roll pressure and corrugating speed.

Figure 10 shows the three-way interaction between shower pressure, roll pressure, and speed. It reveals that the severity of the aforementioned interaction between shower pressure and roll pressure (Fig. 8) in turn depends on the corrugating speed.

None of the interactions graphed in Fig. 8-10 involves a reversal in the effect of an operating variable, thus conclusions drawn in connection with Fig. 3-7 remain valid. The average effects of the several operating variables for the eight rolls of medium studied may be summarized as follows:

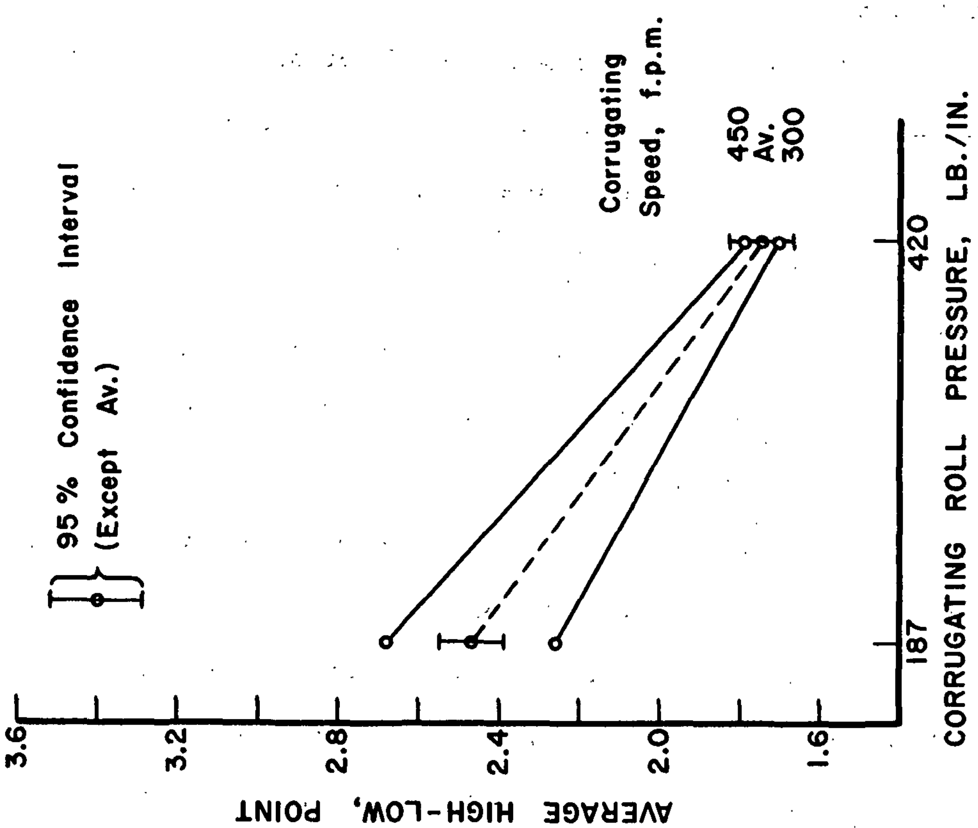


Figure 9. Interaction Between Corrugating Roll Pressure and Corrugating Speed

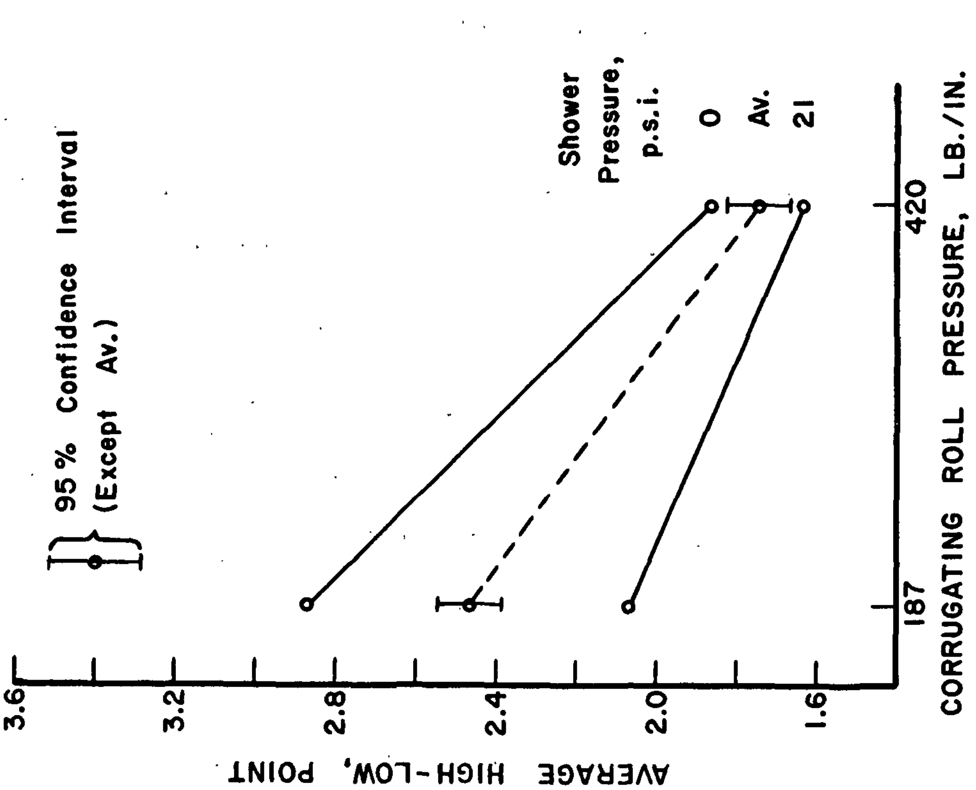


Figure 8. Interaction Between Steam Shower Pressure and Corrugating Roll Pressure

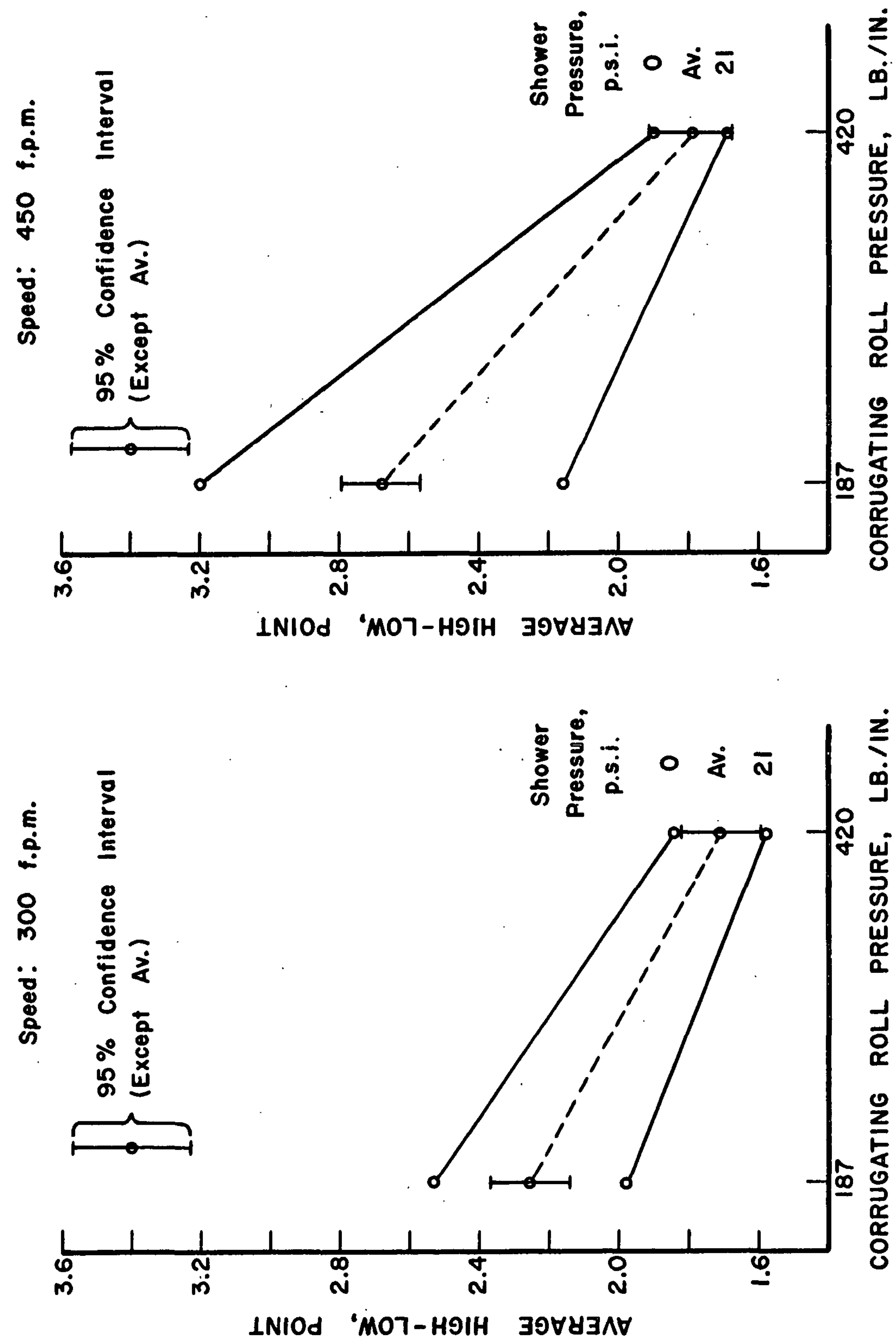


Figure 10. Interaction Between Steam Shower Pressure, Corrugating Roll Pressure and Corrugating Speed

Operating Variable	Change in Variable	Effect on Average High-Low[a]
Web tension	0.5 to 1.75 lb./in.	+ 0.39 point
Main shower pressure	0 to 21 p.s.i.	- 0.52 point
Corrugating roll pressure	187 to 420 lb./in.	- 0.72 point
Angle of take-off	0 to + 20°	+ 0.06 point
Corrugating speed	300 to 450 f.p.m.	+ 0.25 point

[a]All effects ± 0.12 point with 95% confidence.

These results indicate that the average high-low can be minimized by decreasing the web tension and corrugating speed and increasing the main steam shower pressure and the corrugating roll pressure. Elevating the angle of take-off of the single-face web by 20° above the normal had no important effect on average high-low.

Comparison with Previous Investigation

The operating variables investigated here were also studied earlier in Project 2696-1 (3). The earlier work involved four 26-lb. medium samples (three semichemical and one kraft). Generally speaking the precision of the earlier results was not as favorable as in the present study, and a number of the operating variables did not have a statistically significant effect (at the 0.05 level). This of course, should not be interpreted as proving that the variable had no effect, but rather that its effect was so imprecisely determined as to include zero effect as a possibility. It may be of interest, therefore, to estimate the effects from the earlier study and compare them with those discussed above. Since different levels of the operating variables were employed in the two studies, linear interpolation or extrapolation of the data from Reference (3) is employed to estimate effects comparable to those of the present work.

In the case of web tension, it is found by interpolation in Table XXII of Reference (3) that increasing the tension from 0.5 to 1.75 lb./in. increased the average high-low by 0.37 point, considering all four medium samples. This estimate agrees well with the effect (0.39 point) found in the present study.

The effect of main shower pressure in the earlier work [Table XXVIII of (3)] was a decrease of average high-low by 0.67 point for the four mediums as the shower pressure was increased from 0 to 21 p.s.i. (by interpolation). Again there is good agreement between studies, the present investigation giving 0.52 point decrease.

In the earlier study, increasing the corrugating roll pressure from 187 to 420 lb./in. decreased average high-low by 1.00 point [by interpolation in Table XXXVII of (3)] as compared with 0.72 point decrease in the current study. The earlier work indicated that virtually all of the effect occurred as the pressure was increased from 187 to 325 lb./in., with no further change in high-low from 325 to 420 lb./in. The earlier work involved five medium samples — including a 26-lb. semichemical medium in addition to those already mentioned.

The effect of a 20° angle of take-off on three mediums (two semi-chemical and one kraft sample) in the earlier study was to <u>decrease</u> average high-low by 0.21 $\pm$ 0.47 point with 95% confidence [by extrapolation in Table XLVI of (3)] whereas the present study indicated an <u>increase</u> of 0.06 $\pm$ 0.12. The two estimates are not significantly different and neither differs from zero.

Each of the abovementioned tables of data in Reference (3) provides an estimate of the effect of increasing the corrugating speed from 300 to 450 f.p.m. The four estimates range from +0.01 to +0.40 point. On the average, the effect of speed is +0.17 point, which agrees quite well with +0.25 point in the present study.

In general, therefore, the two studies are in quite good agreement in respect to the effect of five operating variables on high-low flutes. It seems clear from the two studies that, for the ranges of operating variables investigated, the corrugating roll pressure and the main shower pressure have the largest effect on high-lows and the angle of take-off has the least; web tension and corrugating speed have effects of intermediate magnitude. Severity of high-lows varies inversely as roll pressure and shower pressure, and directly as web tension and corrugating speed.

RELATIONSHIP BETWEEN HIGH-LOWS AND PROPERTIES OF THE CORRUGATING MEDIUM

A number of studies, including the present investigation, have shown that the magnitude of high-lows varies from medium-to-medium (1-3). This observation indicates that high-lows are governed by the physical properties of the medium as well as the operating conditions of the corrugator. Indeed, from one standpoint, an explanation of the importance of certain operating variables (e.g., shower pressure, roll pressure) in respect to high-lows may be approached in terms of their effect upon the properties of the medium. For example, shower pressure may be an important factor in high-low formation because of its effect on moldability and heat transfer of the medium.

At the present time there is no generally accepted description of the physical mechanism of the formation of high-low flutes. Research directed to gaining a clearer understanding, however, has been proposed for 1970, involving experimental study of the behavior of various elements of the corrugator (i.e., spectral analysis). For the present, research on high-lows depends upon empirical studies of the type reported here in respect to operating variables and in the concurrent, allied Project 2696-6 in respect to medium properties.

The work undertaken in the current study does not involve sufficiently extensive sampling of mediums to provide an effective empirical study of the relationship between high-lows and medium properties. The eight rolls of medium which were studied provide a good experimental base for the study of operating variables but are too few for the study of the effect of medium properties. Project 2696-6, on the other hand, employed some twenty medium samples in order to provide an adequate base for a study of medium properties.

The present investigation, however, does give an opportunity to check the relationships developed in Project 2696-6. It permits essentially an independent check of the relationships since the data reported here have not been used in their development.

Among a number of relationships developed in Project 2696-6 (6), the equations shown in Table IV of the present report appeared to be attractive from the standpoints of accuracy, frugality of number of properties, and consistency under different corrugating conditions. (Frugality is of concern since empirical relations often can be progressively improved by continued addition of independent variables beyond the point of physical relevance.)

The corrugating conditions termed "normal" and "adverse" in the two studies are compared in Table V. It may be seen that the main shower pressure and corrugating roll pressure for the "normal" condition were somewhat higher in

TABLE IV

RELATIONSHIPS BETWEEN AVERAGE HIGH-LOW AND PHYSICAL PROPERTIES OF MEDIUM

Eqt. No.	Equation[a]	Average Error, %[b] 2696-6 Absolute	2696-7 Absolute	2696-7 Algebraic
	Normal Corrugating Conditions			
1	$\underline{y} = 0.027\ \underline{TE} - 0.089\ \underline{FO} + 1.46$	15.4	8.6	+ 7.6
2	$\underline{y} = 0.0087\ \underline{TS} - 0.077\ \underline{FO} + 1.95$	16.2	9.8	+ 9.6
	Adverse Corrugating Conditions			
3	$\underline{y} = 0.066\ \underline{TE} + 0.30$	17.1	9.0	+ 4.4
4	$\underline{y} = 0.0230\ \underline{TS} - 0.452\ \underline{CA} + 6.50$	17.3	13.6	+11.5
	Composite			
5	$\underline{y} = 0.0478\ \underline{TE} - 0.102\ \underline{FO} + \begin{cases} 0.73 \text{ for Normal Conditions} \\ 2.10 \text{ for Adverse Conditions} \end{cases}$	16.6	10.8	+ 3.4
6	$\underline{y} = 0.0146\ \underline{TS} - 0.081\ \underline{FO} + \begin{cases} 1.63 \text{ for Normal Conditions} \\ 3.00 \text{ for Adverse Conditions} \end{cases}$	17.5	11.3	+ 4.2

[a] $\underline{y}$ = average high-low, pt.; $\underline{TE}$ = tensile strength, lb./in.; $\underline{TS}$ = tensile x stretch product, lb.-%/in.; $\underline{FO}$ = Thwing formation, unit; $\underline{CA}$ = thickness, pt.

[b] Error = (Predicted $\underline{y}$ − observed $\underline{y}$)100/(observed $\underline{y}$).

Project 2696-7 than in 2696-6. Based on the results in Reference (3), however, the differences in pressures would be expected to cause little or no difference in high-lows. That is, from Fig. 16 of Reference (3), an increase in shower pressure from 14 to 21 p.s.i. is expected to decrease high-lows by about 0.1 point; from Fig. 19 of (3) an increase in roll pressure from 327 to 420 lb./in. is expected to produce no difference in high-lows. The "adverse" conditions in the two investigations are nearly identical. The small disparity in web tensions (1.5 vs. 1.75 lb./in.) should cause less than 0.1 point difference in high-lows (see Table III of this report), and the difference in angle of take-off (15 vs. 20°) is inconsequential because angle had no important effect on high-lows.

TABLE V

CORRUGATOR OPERATING CONDITIONS IN TWO INVESTIGATIONS

Investigation	Web Tension, lb./in.	Main Shower Pressure, p.s.i.	Corrugating Roll Pressure, lb./in.	Angle of Take-Off, deg.	Speed, f.p.m.
		Normal Conditions			
Project 2696-6	0.5	14	327	0	300, 450
Project 2696-7	0.5	21	420	0	300, 450
		Adverse Conditions			
Project 2696-6	1.5[a]	0	187	15	300, 450
Project 2696-7	1.75[b]	0	187	20	300, 450

[a]Average for all medium rolls.

[b]One of eight rolls was at 1.5.

The relationships in Table IV were evaluated for the medium rolls of this study, whose physical properties are shown in Table VI. The average accuracy of each relationship is shown in Table IV for the two investigations. (The accuracy for individual samples is given in Appendix III.)

TABLE VI

PHYSICAL PROPERTIES OF MEDIUM ROLLS

Roll No.	Basis Weight, lb./1000 ft.^{2}	Thickness, pt.	Moisture Content, o.d., %	Thwing Formation, unit	M.D. Tensile Strength, lb./in.	M.D. Stretch, %	Tensile x Stretch Product	Average High-Low, pt. Normal Conditions	Average High-Low, pt. Adverse Conditions
792	26.6	10.8	4.0	11.65	50.0	1.95	97.5	1.64	3.78
833	26.4	9.8	3.8	7.85	47.0	1.35	63.4	1.80	3.68
840	25.9	11.0	5.6	9.55	36.7	1.45	53.2	1.53	2.87
843	26.6	9.8	5.4	13.45	51.7	1.75	90.5	1.34	3.60
846	26.1	9.8	4.3	13.85	41.8	1.50	62.7	1.24	3.08
863	26.0	10.0	7.5	11.60	44.4	1.25	55.4	1.55	2.62
882	26.8	10.0	4.4	11.80	50.4	1.85	93.1	1.84	3.62
004	26.6	10.0	4.4	15.85	39.8	1.15	45.7	1.11	2.30

As may be seen in Table IV, the empirical equations were somewhat more accurate for the eight rolls of medium in this investigation than they were for the twenty-one mediums from which they were derived. Consideration of the average algebraic error in Table IV indicates a systematic overestimation of high-lows for the eight rolls of this study; this may reflect some difference in experimental method between studies, although the techniques of corrugating and materials evaluation were nominally the same in both studies.

The relationship involving tensile strength and Thwing formation [Equation (5) in Table IV] appears to be a reasonably good predictor of high-lows. It implies that high-lows (a) decrease with better formation of the sheet, and (b) increase with increase in M.D. tensile strength of the medium.

INTERPRETATION OF RESULTS

The conclusions from this study, in so far as corrugating operating variables are concerned, are that high-lows increase with increasing web tension and corrugating speed and decrease with increasing main shower steam pressure and corrugator roll pressure. The magnitude of high-lows also varies with the medium being corrugated; it appears that high-lows decrease with improved formation of the medium and increase with increasing tensile strength of the medium.

The effects of the aforementioned operating variables are consistent with past investigations (3). While the mechanism of formation of high-lows is not really understood, a number of phenomenological explanations have been offered. For example, the fact that increasing web tension increases high-lows has been attributed to possible slippage of the fluted medium as it leaves the labyrinth (sometimes referred to as robbing of flutes already formed) and/or to more pronounced fluctuations in web tension which possibly may induce more pronounced fluctuations in flute height (3).

An increase in the main steam shower pressure increases the quantity of steam applied to the sheet and probably increases its temperature, thereby promoting more complete and more uniform molding of the flutes.

Increasing the pressure between the corrugating rolls would be expected to provide more complete, and possibly more uniform, molding or permanent set of the flutes. Increased roll pressure also may reduce the "jump" or drop action of the upper corrugating roll, to which Peters (7) has attributed high-low formation.

Increasing the corrugating speed probably reduces the heat transfer to the medium and also increases the jump action of the upper roll, both of which may be expected to lead to poorer molding of the flutes.

The indicated importance of formation of the medium supports Wilson's (3, 8) belief that uneven formation contributes to high-lows by causing different areas of the web to shrink at different rates, thereby inducing cockling. Uneven formation may also aggravate roll jump and increase high-lows in that way.

The empirical relationship between high-lows and tensile strength implies that increasing the tensile strength of the medium increases the magnitude of high-lows. This effect is difficult to explain, particularly since tensile strength is a failure property, and failure (or rupture) of the medium is not involved in the high-low phenomenon. It may be that the relationship between tensile strength and average high-lows may be more a function of prerupture stress-strain and recovery behavior than rupture. A consideration of high-low formation in the light of stress-strain loading and recovery may be a worthwhile approach for future research.

LITERATURE CITED

1. The Institute of Paper Chemistry. Behavior of fibrous and nonfibrous components in the corrugating operation. Parts IV, IV-A, IV-B, Progress Reports 4, 6, 7, Project 1108-22, March 15, 1962; March 26, 1962; June 5, 1962.

2. The Institute of Paper Chemistry. Behavior of fibrous and nonfibrous components in the corrugating operation. Part V, Progress Report 8, Project 1108-22, Dec. 1, 1964.

3. The Institute of Paper Chemistry. Effect of operational variables on runnability and high-low corrugations. Summary Report 1, Project 2696-1, Jan. 15, 1968.

4. Davies, O. L., Editor. The design and analysis of industrial experiments. p. 440 ff. New York, Hafner Publ. Co., 1965.

5. Hicks, C. R. Fundamental concepts in the design of experiments. p. 221 ff. New York, Holt, Rinehart and Winston, 1964.

6. The Institute of Paper Chemistry. Relationship between high-low flute formation and properties of the corrugating medium. Summary Report 1, Project 2696-6, Dec. 24, 1969.

7. Peters, W. Measuring forces that cause production problems. Pbd. Pkg. 46, no. 2:60-2 (Feb., 1961).

8. Wilson, H. W. An operator's thought on flute contour. Tappi 39, no. 7: 146-8A (July, 1956).

THE INSTITUTE OF PAPER CHEMISTRY

Robert C. McKee

Robert C. McKee
Chairman, Container Section

APPENDIX I

STATISTICAL ANALYSIS OF DATA

The experimental design shown in Table I is a one-half fraction of a 2^4 factorial (i.e., a 2^{4-1} factorial) in the factors web tension (A), main steam shower pressure (B), corrugator roll pressure (C), and angle of take-off (D). This design is economical of experimental effort since it requires only eight runs rather than the 16 runs required for a full factorial experiment in four variables. The price paid for the reduced number of runs is that necessarily some information is sacrificed, with the result that certain pairs of effects and interactions, which would be distinguishable in a full factorial, are confounded in the fractional factorial. The confoundings (or aliases) in this experiment (which is the principal fraction with defining relationship I = + ABCD) are as follows:

A + BCD
B + ACD
C + ABD
D + ABC
AB + CD
AC + BD
BC + AD

It is seen that the main effects are confounded with three-factor interactions. On the assumption that three factor interactions are negligible, this design provides estimates of the main effects A, B, C and D. Two-factor interactions are confounded pairwise. It is expected that D, angle of take-off, does not interact with web tension A, shower pressure B, or corrugator roll pressure C. Interactions between A, B and C may be expected to be more likely.

Under this assumption the design provides estimates of AB, AC and BC. It should be borne in mind, however, that CD = BD = AD = 0 is an assumption. There will necessarily be some question, therefore, whether what is termed a BC interaction, for example, is solely that or, on the other hand, a combination of BC and AD interactions or an AD interaction.

For each experimental run listed in Table I, single-faced board was fabricated at two corrugating speeds, S, (300 and 450 f.p.m.). Thus, the over-all experiment for a given roll of medium was a $2 \times 2^{4-1}$ factorial (and thus involves 32 runs, counting both speeds). To the seven effects listed above may be added the following: S, AS, BS, CS, DS, ABS, ACS and BCS. Experimental error was evaluated from replication of Runs 4 and 5, and the estimates of experimental error are shown in Table VII.

TABLE VII

ESTIMATES OF ERROR VARIANCE OF AVERAGE HIGH-LOW

Roll No.	Mean Value, pt.	Error Variance, pt.^{2}	Degrees of Freedom
004	1.67	0.0341	4
846	1.79	0.0719	4
863	1.83	0.0643	4
843[a]	2.01	0.0370	6
840	2.07	0.0608	4
792	2.42	0.1949	4
882	2.54	0.2348	4
833	2.56	0.1515	4
Composite	2.11	0.1021	34

[a]From 4 and 5-factor interactions.

An analysis of variance and evaluation of effects were calculated by the Yates algorithm (4, 5) programmed for an IBM System 360-40 digital computer as a part of this study. The results of the analysis of variance for seven of the eight rolls of medium are tabulated in Tables VIII to XIV.

In the case of the eighth roll (Roll No. 843) a full 2^5 factorial experiment without any replication was performed to shed light on the assumptions regarding interactions. The analysis of variance is tabulated in Table XV. It may be remarked that one of the three-factor interactions, ACD, showed up significant at the 0.05 level, suggesting that the main effect B (shower pressure) may not be free and clear of confounding in the fractional factorials for the other seven rolls. However, the ACD interaction, while significant, is not large relative to its alias B and may be spurious since 31 tests of significance are involved in Table XV and an error of the first kind might have occurred.

In addition to the analyses for the individual rolls, a composite analysis of all eight rolls was performed (an $8 \times 2 \times 2^{4-1}$ factorial) and is tabulated in Table XVI. In the case of Roll 843, only the eight combinations shown in Table I were used in the composite analysis; this leads to some disparity between the composite analysis and the individual roll analysis (Table XV) with respect to the estimates of effects for Roll 843. The disparities are not serious, however, and do not confuse the conclusions drawn from the study.

In all of the above statistical analyses the variables were treated as fixed factors. The responses for the repeat runs (a and b) of Runs 4 or 5 were averaged and treated as a single response. This results in a slight overstatement of the confidence intervals for the effects (by about 7%).

TABLE VIII

ANALYSIS OF VARIANCE FOR ROLL NO. 792

SOURCE	RESPONSE	EFFECT	DF	MEAN SQUARE	F
(1)	0.2540000E 01				
A	0.3410000E 01	0.6812500E 00	1	0.1856405E 01	18.2[a]
B	0.1700000E 01	-0.7512501E 00	1	0.2257506E 01	22.1[a]
AB	0.2440000E 01	-0.1712500E 00	1	0.1173062E 00	1.15
C	0.1830000E 01	-0.6562504E 00	1	0.1722657E 01	16.9[a]
AC	0.2520000E 01	-0.1462499E 00	1	0.8555609E-01	< 1
BC	0.1669999E 01	0.2512499E 00	1	0.2525060E 00	2.47
D	0.2339999E 01	0.5624998E-01	1	0.1265624E-01	< 1
S	0.2910000E 01	0.2337494E 00	1	0.2185551E 00	2.14
AS	0.4150000E 01	-0.6124985E-01	1	0.1500618E-01	< 1
BS	0.2200000E 01	-0.2137498E 00	1	0.1827558E 00	1.79
ABS	0.2660000E 01	-0.1337501E 00	1	0.7155633E-01	< 1
CS	0.2209999E 01	-0.2237500E 00	1	0.2002562E 00	1.96
ACS	0.2820000E 01	-0.8374989E-01	1	0.2805617E-01	< 1
BCS	0.1599999E 01	-0.1162499E 00	1	0.5405617E-01	< 1
DS	0.1770000E 01	0.2874982E-01	1	0.3306209E-02	< 1
AV.	0.2423124E 01				
ERROR			34	0.1021	

$F_{0.95,1,34} = 4.13$

A: Web Tension
B: Main Steam Shower Pressure
C: Corrugating Roll Pressure
D: Angle of Take-Off
S: Corrugating Speed

[a]Denotes significance at 0.05 level.

TABLE IX

ANALYSIS OF VARIANCE FOR ROLL NO. 833

SOURCE	RESPONSE	EFFECT	DF	MEAN SQUARE	F
(1)	0.2700000E 01				
A	0.3620000E 01	0.3325001E 00	1	0.4422252E 00	4.33[a]
B	0.2570000E 01	-0.4200002E 00	1	0.7056006E 00	6.91[a]
AB	0.3150000E 01	-0.4999995E-02	1	0.9999980E-04	< 1
C	0.2049999E 01	-0.1115000E 01	1	0.4972900E 01	48.7[a]
AC	0.2309999E 01	-0.1200000E 00	1	0.5760000E-01	< 1
BC	0.1719999E 01	0.2475001E 00	1	0.2450251E 00	2.40
D	0.1770000E 01	0.7500052E-02	1	0.2250031E-03	< 1
S	0.3730000E 01	0.1400013E 00	1	0.7840145E-01	< 1
AS	0.3740000E 01	-0.1200000E 00	1	0.5760000E-01	< 1
BS	0.2549999E 01	-0.5250013E-01	1	0.1102505E-01	< 1
ABS	0.2849999E 01	0.1325001E 00	1	0.7022500E-01	< 1
CS	0.1910000E 01	-0.6749976E-01	1	0.1822487E-01	< 1
ACS	0.2070000E 01	0.1774999E 00	1	0.1260248E 00	1.23
BCS	0.1889999E 01	0.3149999E 00	1	0.3968998E 00	3.89
DS	0.2270000E 01	-0.2499998E-01	1	0.2499995E-02	< 1
AV.	0.2556249E 01				
ERROR			34	0.1021	

$F_{0.95,1,34}$ + 4.13

A: Web Tension
B: Main Steam Shower Pressure
C: Corrugating Roll Pressure
D: Angle of Take-Off
S: Corrugating Speed

[a]Denotes significance at 0.05 level.

TABLE X

ANALYSIS OF VARIANCE FOR ROLL NO. 840

SOURCE	RESPONSE	EFFECT	DF	MEAN SQUARE	F
(1)	0.2400000E 01				
A	0.2929999E 01	0.3400000E 00	1	0.4624001E 00	4.53[a]
B	0.1679999E 01	-0.5425001E 00	1	0.1177225E 01	11.53[a]
AB	0.1849999E 01	-0.9499991E-01	1	0.3609993E-01	< 1
C	0.1610000E 01	-0.5400001E 00	1	0.1166400E 01	11.43[a]
AC	0.2129999E 01	0.2499938E-02	1	0.2499875E-04	< 1
BC	0.1389999E 01	0.1700000E 00	1	0.1155999E 00	1.13
D	0.1549999E 01	-0.7749999E-01	1	0.2402499E-01	< 1
S	0.2639999E 01	0.2574995E 00	1	0.2652239E 00	2.60
AS	0.2820000E 01	-0.4999757E-02	1	0.9999027E-04	< 1
BS	0.1969999E 01	0.1075000E 00	1	0.4622496E-01	< 1
ABS	0.2440000E 01	0.8499992E-01	1	0.2889994E-01	< 1
CS	0.1849999E 01	0.4999995E-02	1	0.9999980E-04	< 1
ACS	0.2360000E 01	0.7500052E-02	1	0.2250031E-03	< 1
BCS	0.1669999E 01	-0.8000004E-01	1	0.2560003E-01	< 1
DS	0.1849999E 01	-0.7749999E-01	1	0.2402499E-01	< 1
AV.	0.2071249E 01				
ERROR			34	0.1021	

$F_{0.95,1,34} = 4.15$

A: Web Tension
B: Main Steam Shower Pressure
C: Corrugating Roll Pressure
D: Angle of Take-Off
S: Corrugating Speed

[a]Denotes significance at 0.05 level.

TABLE XI

ANALYSIS OF VARIANCE FOR ROLL NO. 846

SOURCE	RESPONSE	EFFECT	DF	MEAN SQUARE	F
(1)	0.1889999E 01				
A	0.2360000E 01	0.4712502E 00	1	0.8883069E 00	8.70[a]
B	0.1639999E 01	-0.3237501E 00	1	0.4192566E 00	4.11
AB	0.2150000E 01	-0.7125008E-01	1	0.2030629E-01	< 1
C	0.1280000E 01	-0.7987498E 00	1	0.2552005E 01	25.0[a]
AC	0.1320000E 01	-0.2712501E 00	1	0.2943065E 00	2.88
BC	0.1160000E 01	0.3937501E 00	1	0.6201565E 00	6.08[a]
D	0.1870000E 01	0.2462500E 00	1	0.2425563E 00	2.38
S	0.2139999E 01	0.1562499E 00	1	0.9765607E-01	< 1
AS	0.3790000E 01	0.3875005E-01	1	0.6006263E-02	< 1
BS	0.1589999E 01	-0.3162502E 00	1	0.4000567E 00	3.92
ABS	0.1929999E 01	-0.2487501E 00	1	0.2475064E 00	2.42
CS	0.1400000E 01	-0.1962501E 00	1	0.1540564E 00	1.51
ACS	0.1410000E 01	-0.2137500E 00	1	0.1827562E 00	1.79
BCS	0.1309999E 01	0.1712500E 00	1	0.1173062E 00	1.15
DS	0.1349999E 01	0.8875000E-01	1	0.3150625E-01	< 1
AV.	0.1786874E 01				
ERROR			34	0.1021	

$F_{0.95,1,34} = 4.13$

A: Web Tension
B: Main Steam Shower Pressure
C: Corrugating Roll Pressure
D: Angle of Take-Off
S: Corrugating Speed
[a]Denotes significance at 0.05 level.

TABLE XII

ANALYSIS OF VARIANCE FOR ROLL NO. 863

SOURCE	RESPONSE	EFFECT	DF	MEAN SQUARE	F
(1)	0.1889999E 01				
A	0.2379999E 01	0.1337498E 00	1	0.7155603E-01	< 1
B	0.1370000E 01	-0.4862498E 00	1	0.9457555E 00	9.26[a]
AB	0.1780000E 01	-0.2037500E 00	1	0.1660562E 00	1.63
C	0.1400000E 01	-0.4487499E 00	1	0.8055059E 00	7.89[a]
AC	0.1759999E 01	-0.3124988E-01	1	0.3906220E-02	< 1
BC	0.1450000E 01	0.2837499E 00	1	0.3220561E 00	3.15
D	0.1360000E 01	0.1250148E-02	1	0.6251478E-05	< 1
S	0.2610000E 01	0.3037502E 00	1	0.3690566E 00	3.62
AS	0.2860000E 01	-0.1587499E 00	1	0.1008061E 00	< 1
BS	0.2000000E 01	-0.1187502E 00	1	0.5640645E-01	< 1
ABS	0.1509999E 01	-0.7125008E-01	1	0.2030629E-01	< 1
CS	0.1700000E 01	-0.8624995E-01	1	0.2975621E-01	< 1
ACS	0.1950000E 01	0.1262501E 00	1	0.6375635E-01	< 1
BCS	0.1650000E 01	0.9125006E-01	1	0.3330629E-01	< 1
DS	0.1540000E 01	0.9375012E-01	1	0.3515634E-01	< 1
AV.	0.1825624E 01				
ERROR			34	0.1021	

$F_{0.95, 1, 34} = 4.13$

A: Web Tension
B: Main Steam Shower Pressure
C: Corrugating Roll Pressure
D: Angle of Take-Off
S: Corrugating Speed
[a]Denotes significance at 0.05 level.

TABLE XIII

ANALYSIS OF VARIANCE FOR ROLL NO. 882

SOURCE	RESPONSE	EFFECT	DF	MEAN SQUARE	F
(1)	0.2610000E 01				
A	0.3339999E 01	0.3937500E 00	1	0.6201560E 00	6.08[a]
B	0.1940000E 01	-0.4962499E 00	1	0.9850559E 00	9.65[a]
AB	0.2910000E 01	-0.3124976E-01	1	0.3906190E-02	<1
C	0.2400000E 01	-0.7937500E 00	1	0.2520156E 01	24.7[a]
AC	0.2419999E 01	-0.1687500E 00	1	0.1139063E 00	1.12
BC	0.1809999E 01	0.1762497E 00	1	0.1242558E 00	1.22
D	0.2030000E 01	0.8625007E-01	1	0.2975629E-01	<1
S	0.3259999E 01	0.2187500E 00	1	0.1914063E 00	1.88
AS	0.3889999E 01	-0.9124994E-01	1	0.3330621E-01	<1
BS	0.2820000E 01	0.2374983E-01	1	0.2256217E-02	<1
ABS	0.2740000E 01	-0.1412501E 00	1	0.7980639E-01	<1
CS	0.2040000E 01	-0.2587500E 00	1	0.2678061E 00	2.62
ACS	0.2360000E 01	0.1962500E 00	1	0.1540561E 00	1.51
BCS	0.1879999E 01	0.1462498E 00	1	0.8555597E-01	<1
DS	0.2219999E 01	0.9625006E-01	1	0.3705629E-01	<1
AV.	0.2541874E 01				
ERROR			34	0.1021	

$F_{0.95,1,34} = 413$

A: Web Tension
B: Main Steam Shower Pressure
C: Corrugating Roll Pressure
D: Angle of Take-Off
S: Corrugating Speed
[a]Denotes significance at 0.05 level.

TABLE XIV

ANALYSIS OF VARIANCE FOR ROLL NO. 004

SOURCE	RESPONSE	EFFECT	DF	MEAN SQUARE	F
(1)	0.1639999E 01				
A	0.1910000E 01	0.4212501E 00	1	0.7098066E 00	6.95[a]
B	0.1559999E 01	-0.2287501E 00	1	0.2093064E 00	2.05
AB	0.1879999E 01	0.8749977E-02	1	0.3062482E-03	< 1
C	0.1080000E 01	-0.5962499E 00	1	0.1422055E 01	13.93[a]
AC	0.1730000E 01	0.4624987E-01	1	0.8556198E-02	< 1
BC	0.8800000E 00	0.1162499E 00	1	0.5405617E-01	< 1
D	0.1580000E 01	-0.6124996E-01	1	0.1500623E-01	< 1
S	0.2339999E 01	0.2787498E 00	1	0.3108058E 00	3.04
AS	0.2679999E 01	-0.6374979E-01	1	0.1625614E-01	< 1
BS	0.1589999E 01	-0.1137499E 00	1	0.5175612E-01	< 1
ABS	0.2160000E 01	-0.1624991E-01	1	0.1056238E-02	< 1
CS	0.1259999E 01	-0.1662501E 00	1	0.1105564E 00	1.08
ACS	0.1650000E 01	-0.1437500E 00	1	0.8265615E-01	< 1
BCS	0.1339999E 01	0.1762499E 00	1	0.1242560E 00	1.22
DS	0.1469999E 01	-0.6125022E-01	1	0.1500636E-01	< 1
AV.	0.1671874E 01				
ERROR			34	0.1021	

$F_{0.95,1,34} = 4.13$

A: Web Tension
B: Main Steam Shower Pressure
C: Corrugating Roll Pressure
D: Angle of Take-Off
S: Corrugating Speed

[a]Denotes significance at 0.05 level.

TABLE XV

ANALYSIS OF VARIANCE FOR ROLL NO. 843

SOURCE	RESPONSE	EFFECT	DF	MEAN SQUARE	F
(1)	0.2089999E 01				
A	0.2759999E 01	0.4162500E 00	1	0.1386112E 01	13.58[a]
B	0.1780000E 01	-0.6424999E 00	1	0.3302448E 01	45.9[a]
AB	0.1500000E 01	-0.3062500E 00	1	0.7503123E 00	7.35[a]
C	0.1469999E 01	-0.7325000E 00	1	0.4292449E 01	42.0[a]
AC	0.2030000E 01	-0.1237500E 00	1	0.1225124E 00	1.20
BC	0.1400000E 01	0.4250000E 00	1	0.1444999E 01	14.16[a]
ABC	0.1419999E 01	0.1562499E 00	1	0.1953122E 00	1.91
D	0.1889999E 01	0.5375010E-01	1	0.2311258E-01	<1
AD	0.2839999E 01	0.1950001E 00	1	0.3042001E 00	2.98
BD	0.1559999E 01	0.1087500E 00	1	0.9461242E-01	<1
ABD	0.1839999E 01	-0.6250000E-01	1	0.3125000E-01	<1
CD	0.1549999E 01	0.2125001E-01	1	0.3612502E-02	<1
ACD	0.2040000E 01	-0.2325000E 00	1	0.4324498E 00	4.24[a]
BCD	0.1639999E 01	-0.3124988E-01	1	0.7812440E-02	<1
ABCD	0.1370000E 01	-0.1749992E-01	1	0.2449978E-02	<1
S	0.3320000E 01	0.3850002E 00	1	0.1185801E 01	11.62[a]
AS	0.3709999E 01	0.1137499E 00	1	0.1035122E 00	<1
BS	0.2049999E 01	-0.1225001E 00	1	0.1200501E 00	1.18
ABS	0.1719999E 01	0.5875015E-01	1	0.2761264E-01	<1
CS	0.1650000E 01	-0.3150001E 00	1	0.7937999E 00	7.78[a]
ACS	0.1889999E 01	-0.2125013E-01	1	0.3612543E-02	<1
BCS	0.1270000E 01	0.2200001E 00	1	0.3872005E 00	3.79
ABCS	0.1770000E 01	0.1162500E 00	1	0.1081125E 00	1.06
DS	0.2360000E 01	0.1875013E-01	1	0.2812538E-02	<1
ADS	0.4360000E 01	0.1350000E 00	1	0.1457999E 00	1.43
BDS	0.1849999E 01	0.6625009E-01	1	0.3511259E-01	<1
ABDS	0.2490000E 01	-0.7000005E-01	1	0.3920004E-01	<1
CDS	0.1480000E 01	-0.1375020E-01	1	0.1512543E-02	<1
ACDS	0.1959999E 01	-0.8250022E-01	1	0.5445027E-01	<1
BCDS	0.1570000E 01	-0.1375008E-01	1	0.1512517E-02	<1
ABCDS	0.1889999E 01	0.4499996E-01	1	0.1619997E-01	<1
AV.	0.2016249E 01				
ERROR			34	0.1021	

$F_{0.95,1,34} = 4.13$

A: Web Tension
B: Main Steam Shower Pressure
C: Corrugating Roll Pressure
D: Angle of Take-Off
S: Corrugating Speed

[a]Denotes significance at 0.05 level.

TABLE XVI

ANALYSIS OF VARIANCE FOR COMPOSITE OF ALL MEDIUM ROLLS

Source	d.f.	Mean Square	F
A	1	4.9888	48.9[a]
B	1	8.5026	83.3[a]
C	1	16.4953	162[a]
D	1	0.1099	1.08
S	1	2.0377	20.0[a]
R	7	1.9947	19.5[a]
AB	1	0.3644	3.57
AC	1	0.2476	2.43
AS	1	0.0652	< 1
AR	7	0.0942	< 1
BC	1	2.5510	25.0[a]
BS	1	0.3949	3.87
BR	7	0.1806	1.77
CS	1	0.9505	9.31[a]
CR	7	0.1713	1.68
DS	1	0.0388	< 1
DR	7	0.0564	< 1
SR	7	0.0339	< 1
ABS	1	0.0608	< 1
ABR	7	0.0435	< 1
ACS	1	0.0062	< 1
ACR	7	0.0453	< 1
ASR	7	0.0291	< 1
BCS	1	0.5605	5.49[a]
BCR	7	0.1029	1.01
BSR	7	0.0748	< 1
CSR	7	0.0605	< 1
DSR	7	0.0261	< 1
ABSR, ACSR, BCSR	21	0.0888	--
ERROR	34	0.1021	--

Notes:

$F_{0.95,1,34} = 4.13$, $F_{0.95,7,34} = 2.30$

A: Web Tension
B: Main Steam Shower Pressure
C: Corrugating Roll Pressure
D: Angle of Take-Off
S: Corrugating Speed
R: Medium Roll
[a]Denotes significance at 0.05 level.

An estimate of experimental error is required for the tests of significance in the analysis of variance and for the construction of confidence intervals for the effects and means. Replicate runs (a and b) were performed for Runs 4 and 5 with each of seven rolls and provide an estimate of experimental error. It reflects variability in (a) equipment and operators conducting the runs, (b) material properties of a medium over the length of the roll, as well as (c) the variability in high-lows within and between test specimens.

Each roll provides a four degree-of-freedom estimate of experimental error variance, as shown in Table VII. In addition a six degree-of-freedom estimate was obtained from the full factorial for Roll 843 by "pooling" four- and five-factor interactions on the assumption that they are manifestations of experimental error rather than real effects. All of the abovementioned estimates were pooled to obtain a composite estimate, namely, $\underline{V}(\underline{e}) = 0.1021$ point^2 based on 34 degrees of freedom. This agrees favorably with a prior estimate given as $(0.36)^2 = 0.1300$ point^2 in Project 2696-1 [see Table LIV of Reference (3) for $\underline{N}_r = 80$ and $\underline{N}_t = 1$]. (It might be remarked that the variance of average high-low due to within-sample variability for a given run is 0.035 point^2, in the case of Roll 792 which was studied in detail in this regard. The experimental error is significantly greater than this within-sample variability, evidently because of variability in equipment, operators and material. This comparison illustrates the importance of replication of the experimental runs in studies of this type to avoid underestimation of experimental variability.)

There is a suggestion in the data of Table IV that the error variance increases with the magnitude of high-lows, thereby violating the requirement of homogeneity of error variance in the analysis of variance for the composite of all rolls (Table XVI). While it may be possible to find a transformation of the data to satisfy the homogeneity requirement, it was not attempted in this study. A consequence of inhomogeneity is that the significance of effects tends to be overstated for rolls with high average high-low and understated for rolls with low average high-low.

Confidence intervals (95%) for effects and means were calculated as follows:

Effects: $$\pm\, t_{.975,34}\sqrt{\frac{V(e)}{4R}} \qquad (3)$$

Means: $$\pm\, t_{.975,34}\sqrt{\frac{V(e)}{nR}} \qquad (4)$$

where $\underline{V}(\underline{e})$ = error variance = 0.1021 pt.^{2}

$\underline{t}$ = Student $\underline{t}$

$\underline{R}$ = number of rolls (1 or 8)

$\underline{n}$ = number of responses in mean (8 for main effect, 4 for two-factor interaction, 2 for three-factor interaction)

APPENDIX II

TABLE XVII

AVERAGE HIGH-LOW AND RELATIVE FREQUENCY OF FLUTE HEIGHT DIFFERENCES IN EXCESS OF THREE POINTS AND FIVE POINTS

Run Statistical Name[a]	No.[b]	Roll 792 Av.	Roll 792 % 3 pt.	Roll 792 % 5 pt.	Roll 843 Av.	Roll 843 % 3 pt.	Roll 843 % 5 pt.	Roll 833 Av.	Roll 833 % 3 pt.	Roll 833 % 5 pt.	Roll 882 Av.	Roll 882 % 3 pt.	Roll 882 % 5 pt.
300 f.p.m.													
(1)	1	2.54	35.0	11.3	2.09	23.8	5.0	2.70	37.5	10.0	2.61	36.3	11.3
ad	5a	3.62	55.0	31.3	2.84	40.0	12.5	3.15	43.7	25.0	3.29	46.3	17.5
ad	5b	3.20	45.0	22.5	--	--	--	4.10	55.0	36.3	3.39	50.0	16.3
bd	6	1.70	16.3	1.3	1.56	7.5	1.3	2.57	33.8	6.2	1.94	22.5	3.8
ab	2	2.44	28.8	6.2	1.50	10.0	6.2	3.15	51.3	18.8	2.91	46.3	13.8
cd	7	1.83	26.3	3.8	1.55	7.5	0.0	2.05	22.5	2.5	2.40	32.5	5.0
ac	3	2.52	35.0	7.5	2.03	20.0	3.8	2.31	27.5	8.8	2.42	32.5	5.0
bc	4a	1.75	12.5	0.0	1.40	7.5	0.0	1.78	8.8	0.0	1.77	17.5	0.0
bc	4b	1.59	10.0	0.0	--	--	--	1.65	18.8	1.3	1.85	17.5	0.0
abcd	8	2.34	30.0	6.2	1.37	12.5	1.3	1.77	16.3	0.0	2.03	20.0	3.8
450 f.p.m.													
s	1	2.91	40.0	16.3	3.32	48.8	21.3	3.73	60.0	26.3	3.26	47.5	21.3
ads	5a	4.64	75.0	43.7	4.36	53.8	42.5	3.48	56.2	22.5	3.21	38.2	22.5
ads	5b	3.66	51.3	28.8	--	--	--	3.99	53.8	36.3	4.57	66.3	36.3
bds	6	2.20	30.0	5.0	1.85	16.3	2.5	2.55	36.3	6.2	2.82	40.0	17.5
abs	2	2.66	31.3	15.0	1.72	13.8	3.8	2.85	43.7	12.5	2.74	41.3	12.5
cds	7	2.21	27.5	3.8	1.48	10.0	0.0	1.91	25.0	2.5	2.04	26.3	2.5
acs	3	2.82	45.0	10.0	1.89	16.3	1.3	2.07	26.3	3.8	2.36	32.5	5.0
bcs	4a	1.29	6.2	0.0	1.27	5.0	0.0	1.98	22.5	5.0	1.82	26.3	0.0
bcs	4b	1.92	17.5	0.0	--	--	--	1.80	15.0	1.3	1.93	22.5	1.3
abcds	8	1.77	20.0	1.3	1.89	18.8	2.5	2.27	35.0	5.0	2.22	30.0	7.5
Composite Av.:		2.42			2.01			2.56			2.54		

Run Statistical Name[a]	No.[b]	Roll 840 Av.	Roll 840 % 3 pt.	Roll 840 % 5 pt.	Roll 863 Av.	Roll 863 % 3 pt.	Roll 863 % 5 pt.	Roll 846 Av.	Roll 846 % 3 pt.	Roll 846 % 5 pt.	Roll 004 Av.	Roll 004 % 3 pt.	Roll 004 % 5 pt.
300 f.p.m.													
(1)	1	2.40	31.3	6.3	1.89	16.3	2.5	1.89	18.8	2.5	1.34	13.8	0.0
ad	5a	3.20	42.5	20.0	2.35	31.3	6.2	2.23	33.8	5.0	1.71	15.0	2.5
ad	5b	2.66	40.0	11.3	2.42	31.3	8.8	2.49	41.3	13.8	2.11	30.0	2.5
bd	6	1.68	20.0	5.0	1.37	10.0	2.5	1.64	11.3	0.0	1.56	7.5	0.0
ab	2	1.85	21.3	0.0	1.78	18.8	1.3	2.15	30.0	3.8	1.38	22.5	2.5
cd	7	1.61	13.8	1.3	1.40	11.3	0.0	1.28	5.0	0.0	1.06	2.5	0.0
ac	3	2.13	22.5	6.2	1.76	11.3	2.5	1.32	3.8	0.0	1.73	18.8	1.3
bc	4a	1.37	7.5	0.0	1.38	8.8	0.0	1.09	1.3	0.0	0.92	1.3	0.0
bc	4b	1.41	6.2	0.0	1.52	7.5	0.0	1.24	6.2	1.3	0.84	1.3	0.0
abcd	8	1.55	7.5	0.0	1.36	6.2	0.0	1.87	22.5	0.0	1.58	12.5	0.0
450 f.p.m.													
s	1	2.64	37.5	8.8	2.61	37.5	11.3	2.14	27.5	2.5	2.34	30.0	10.0
ads	5a	2.75	41.3	16.3	2.53	40.0	12.5	3.57	50.0	25.0	2.63	38.8	11.3
ads	5b	2.88	43.7	15.0	3.18	45.0	25.0	4.01	58.8	35.0	2.73	32.5	15.0
bds	6	1.97	11.3	5.0	2.00	27.5	3.8	1.59	11.3	0.0	1.59	17.5	2.5
abs	2	2.44	35.0	5.0	1.51	13.8	3.8	1.93	18.8	6.2	2.16	25.0	12.5
cds	7	1.85	11.3	2.5	1.70	15.0	0.0	1.40	2.5	1.3	1.26	3.8	0.0
acs	3	2.36	36.3	8.8	1.95	22.5	2.5	1.41	6.2	0.0	1.65	12.5	1.3
bcs	4a	1.88	22.5	0.0	1.78	12.5	0.0	1.04	2.5	0.0	1.19	1.3	0.0
bcs	4b	1.46	12.5	0.0	1.52	11.3	0.0	1.58	12.5	2.5	1.50	6.2	0.0
abcds	8	1.85	20.0	3.8	1.54	13.8	1.3	1.35	5.0	0.0	1.47	10.0	0.0
Composite Av.:		2.07			1.83			1.79			1.67		

[a]Variables are: A - Web tension, 0.5 and 1.75 lb./in.
B - Main steam shower pressure, 0 and 21 p.s.i.
C - Corrugating roll pressure, 187 and 420 lb./in.
D - Angle of take-off, 0 and 20°
S - Corrugating speed, 300 and 450 f.p.m.

[b]Suffixes a and b denote repeat trials.

APPENDIX III

TABLE XVIII

ACCURACY OF RELATIONSHIPS BETWEEN AVERAGE HIGH-LOW AND MEDIUM PROPERTIES

Roll No.	Corrugating Conditions		Error, %					
		Equation No.:	(1)	(2)	(3)	(4)	(5)	(6)
		Variables[a]:	TE, FO	TS, FO	TE	TS, CA	TE, FO	TS, FO
792	Normal		8.1	15.9			17.8	28.6
833	↑		12.7	7.8			20.8	6.6
840			4.6	9.6			- 1.3	6.8
843			23.8	27.0			36.5	38.9
846			9.4	15.2			6.1	14.8
863			4.8	- 0.7			7.5	- 3.2
882	↓		- 3.8	0.6			5.1	10.6
004	Normal		1.1	1.6			- 8.7	- 8.7
		Abs. Av.	8.6	9.8			13.0	14.8
		Alg. Av.	+ 7.6	+ 9.6			+10.5	+11.8
792	Adverse				- 4.8	2.7	-12.7	- 8.0
833	↑				- 7.6	- 4.1	- 3.7	-10.6
840					- 5.1	- 4.1	0.3	4.6
843					3.1	15.3	-11.2	-10.3
846					- 0.7	13.3	-12.8	- 9.3
863					23.2	24.2	15.9	9.5
882	↓				0.1	13.9	- 8.8	- 6.0
004	Adverse				27.1	30.8	3.6	3.6
		Abs. Av.			9.0	13.6	8.6	7.7
		Alg. Av.			+ 4.4	+11.5	- 3.7	- 3.3
				Abs. Av.			10.8	11.3
				Alg. Av.			+ 3.4	+ 4.2

[a] TE = Tensile strength; TS = Tensile x stretch product; FO = Thwing formation; CA = Caliper