THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

BEHAVIOR OF FIBROUS AND NONFIBROUS COMPONENTS IN THE CORRUGATING OPERATION

PART IV. ANALYSIS OF COMMERCIAL BOARDS FOR HIGH-LOW CORRUGATIONS

Project 1108-22

Report Four

A Progress Report

to

FOURDRINIER KRAFT BOARD INSTITUTE, INC.

March 15, 1962

TABLE OF CONTENTS

	Page
SUMMARY	1
INTRODUCTION	3
GENERAL PROCEDURE	7
Samples	7
Evaluation	8
Individual Flute Height	8
Caliper of Medium at Various Locations in a Flute	9
Caliper of Corrugating Medium	9
DISCUSSION OF RESULTS	10
A-Flute Single-Faced Board	10
B-Flute Single-Faced Board	19
C-Flute Single-Faced Board	32
Comparison of Different Flutes	45
LITERATURE CITED	46

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

BEHAVIOR OF FIBROUS AND NONFIBROUS COMPONENTS IN THE CORRUGATING OPERATION

PART IV. ANALYSIS OF COMMERCIAL BOARDS FOR HIGH-LOW CORRUGATIONS

SUMMARY

Studies carried out at The Institute of Paper Chemistry have shown that board made on the Institute's experimental corrugator always exhibited alternately high and low flutes. The periodicity exhibited by these boards in contrast to random high-low corrugations suggests that the mechanism of corrugating and/or single-facing may introduce a regular pattern of high-low corrugations. Inasmuch as the above observations represented the behavior obtained with only one corrugator, a study was undertaken to determine if the behavior noted above is selective to one corrugator or representative of corrugated board in general. Accordingly, sixteen samples of commercially produced single-faced board were examined for height of individual flutes, average, maximum, and minimum difference in the height of consecutive flutes, the variation in caliper of the medium in a given formed flute, and finally the caliper of the corrugating medium. Each sample consisted of three locations across the corrugator--namely, front, center and back.

The results of this study indicate the following:

1. All the samples of single-faced board used in this study exhibited a distinct pattern or periodicity of alternately high and low flutes.

2. The maximum difference between consecutive flutes varied with the corrugator and the position on the corrugator. There appeared to be no correspondence across the machine relative to the magnitude of the difference in consecutive flute height.

3. On the average, A-, B-, and C-flute boards exhibited about the same variability relative to average and maximum difference in consecutive flute height.

4. There appears to be no trend towards a relationship between the high-low flute profile and the variation in the caliper of the corrugating medium.

5. The determination of caliper at the side walls and tips of the flute showed that, es expected, the greatest pressure (as evidenced by nonrecoverable transverse strain) takes place at the flute tip. The side walls also evidence some nonrecoverable strain. There is an indication that one side wall may undergo greater deformation than the other, indicating greater applied pressure.

6. The results of this study indicate that the mechanism of corrugating and/or single-facing introduces a periodicity of high-low flutes. It may be speculated further that the variation in the height of the "highs" and "lows" may be due to the quality of the medium or the corrugating technique. In other words, the material and corrugating effect on high-low corrugations may be superimposed on a basic high-low profile imposed by the corrugating or single-facing mechanism. It is believed that an understanding of the mechanism through which the corrugating or single-facing mechanism imposes a periodicity of "high-low" corrugations will help to understand the causes of high-low corrugations.

INTRODUCTION

One of the goals of the fundamental study of the mechanism of corrugating and the behavior of the fibrous and nonfibrous components in the corrugating operation is the determination of the cause of high-low corrugations. The opinion is held by some that high-low corrugations are formed in the corrugating labyrinth as a result of medium being "robbed" from flutes already formed. If such were the case, it would be anticipated that the presence of "high-low" corrugations would be randomly dispersed throughout the board in keeping, possibly, with the variability in frictional and strain characteristics of the medium. Studies carried out at The Institute of Paper Chemistry using the experimental corrugator (1) have shown that single-faced board produced on this machine, which is commercially acceptable, always exhibits variation in the height of consecutive flutes regardless of type of flutes. The degree of variation increases with speed, and varies with the type of medium. Normally the difference in flute height is not discernible to the eye. More important is the manner in which the high-low flutes are arranged--generally a definite periodicity in which alternate flutes are "high" or "low" as the case may be. Typical flute height profiles are shown in Fig. 1 and 2. It may be seen from the data plotted in Fig. 1 and 2 that on those occasions when a "low" flute is followed by an even lower flute, the sequence of high-low flutes changes place although the periodicity is continued. That is, the flutes which would have been "high" flutes by the previous sequence have now become "low" flutes and vice versa. It may be speculated that possibly the mechanism of corrugating and single-facing may introduce the periodicity or pattern of consecutive flutes being of different height and that the variation in the height of the "high" or "low" flutes is more a function of the material or condition of operation. If this is so, it may be anticipated that the mechanism of corrugating induces a certain degree of high-low configuration to the flutes normally and that high-low corrugations become bothersome only when the difference in flute height reaches such a magnitude that adhesion on the double-backer is impaired unless the board is crushed, both of which adversely affect the quality of the combined board.

The above results and hypothesis are based on the behavior observed on The Institute of Paper Chemistry's experimental corrugator and it was considered advisable to determine if the experimental corrugator used at the Institute was representative of the general behavior encountered on regular production equipment. Accordingly, samples of single-faced board obtained from regular production-run board were requested of the Fourdrinier Kraft Board Institute membership. The single-faced board samples received were evaluated for consecutive flute height together with other pertinent data.

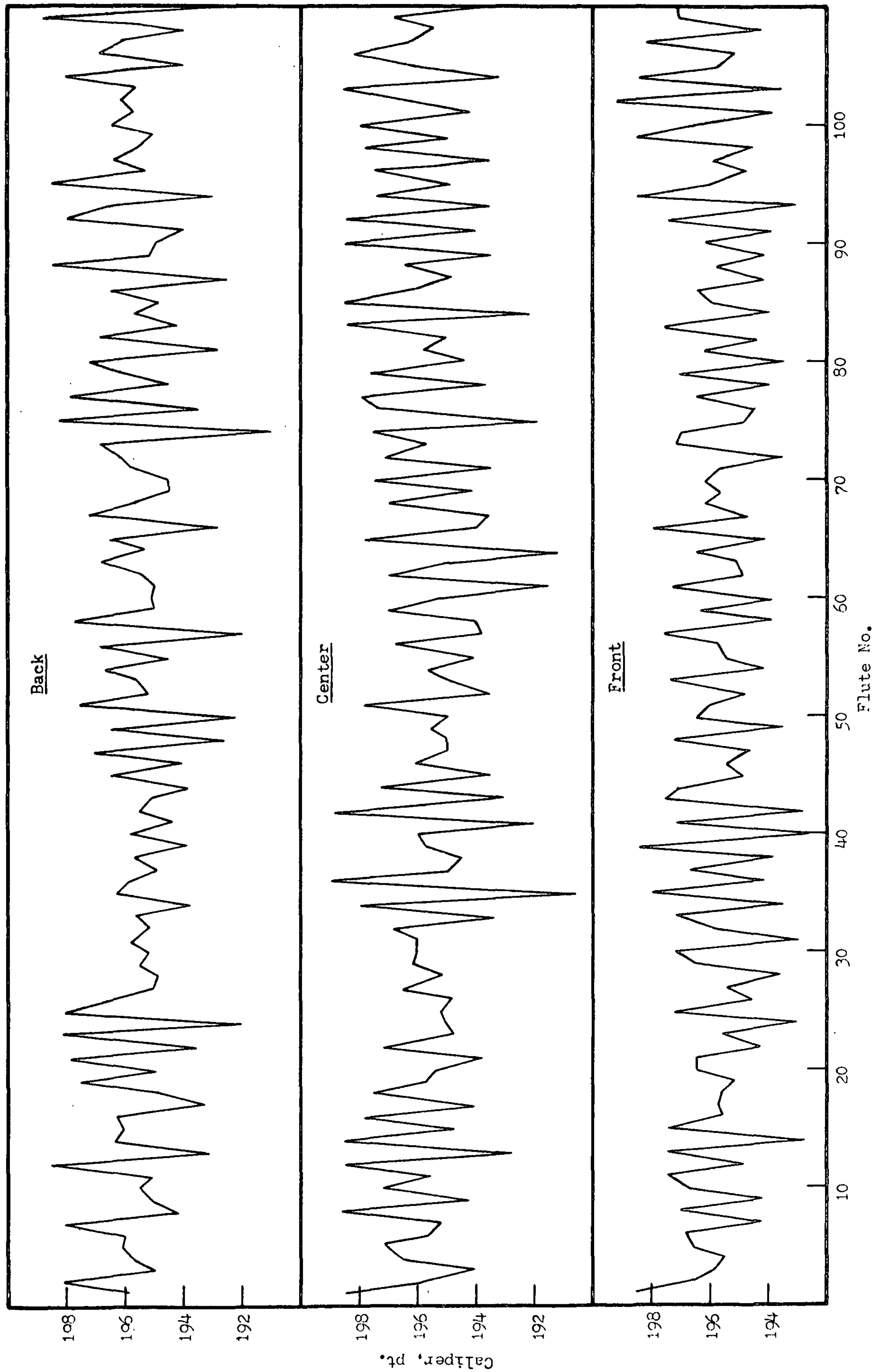

Figure 1. Flute Height Profile
(A-Flute)

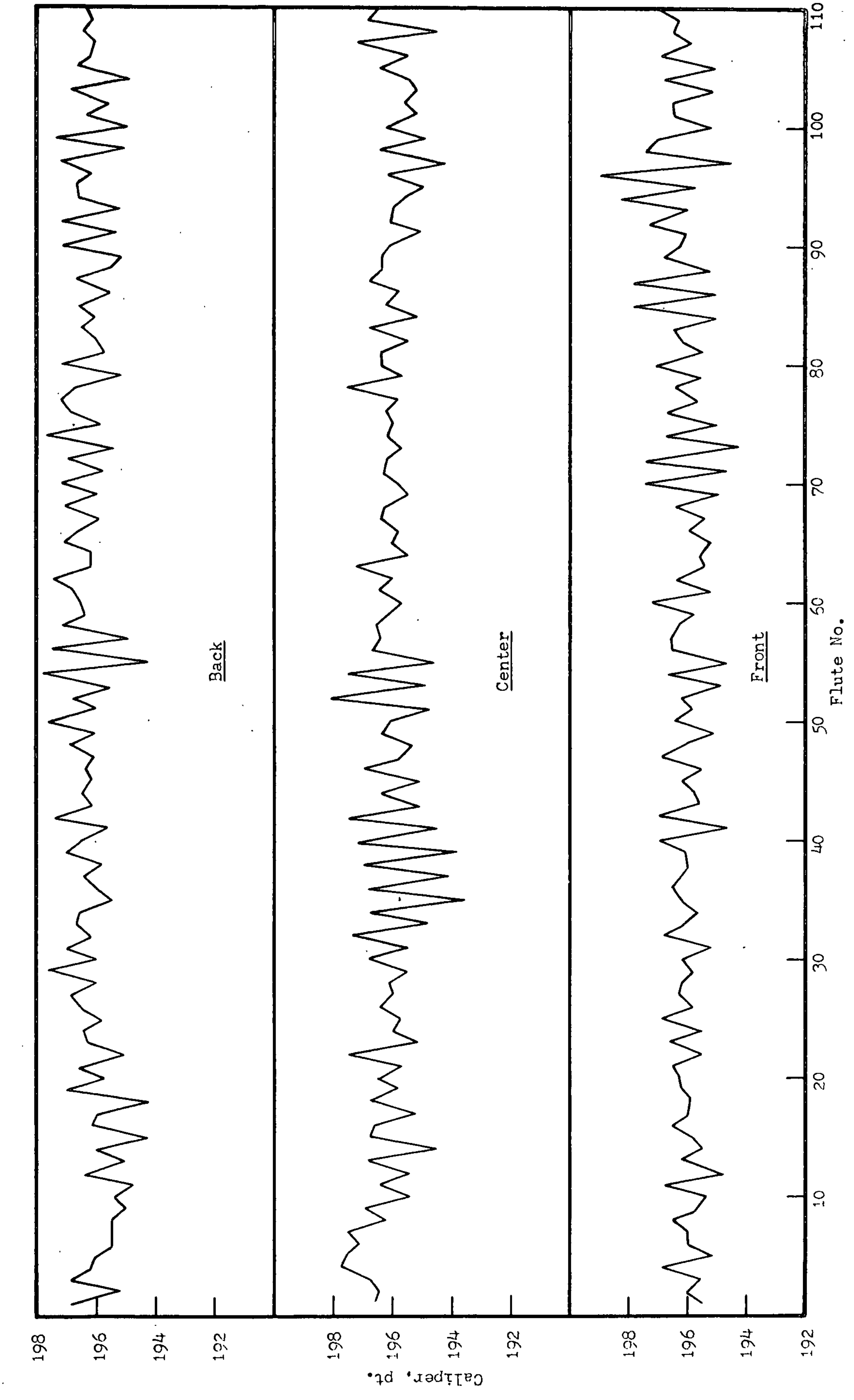

Fig. 2. Flute Height Profile
(A-Flute)

GENERAL PROCEDURE

SAMPLES

The following request for samples was directed to each member company of the Fourdrinier Kraft Board Institute, Inc.:

> "In connection with our study of the mechanics of corrugating and the behavior of the fibrous and nonfibrous materials during corrugating, we are in need of samples of single-faced board and the medium with which it was made. We would like to have commercial-run samples from each of the following types of corrugators:
>
> A-flute
> B-flute
> C-flute
> C-39-flute
>
> The samples of single-faced board should be taken as follows. Cut sample of single-faced board full width of corrugator and approximately five feet long. Draw a heavy pencil or ink line in the valley of a <u>given</u> flute near one end of the strip from front to back. Cut strips <u>12</u> inches wide by five feet representing the front, center, and back of the corrugator, and identify as to front, center, and back samples, corrugator speed, and medium roll number. Be sure to include the marked flute. Equivalent size samples of corrugating medium taken from the same roll as was used in the manufacture of the single-faced board should be taken corresponding to the front, center, and back side of the roll and should be marked with the roll number. Care should be exercised in taking the samples of single-faced board samples so as not to crush the flutes inasmuch as we intend to determine and compare the height of the individual flutes.
>
> We would like to have one sample of each type of flute which you have available. It will be helpful if you will also specify the type of fluted rolls on which each sample is made.
>
> Protect from crushing and ship flat to The Institute of Paper Chemistry--mark Project 1108-22."

It may be noted that the samples were to be so taken as to permit comparison of identical flute heights at three locations across the width of the corrugator. A total of sixteen samples of combined board and auxiliary samples were submitted by four different companies representing eight different box plants. The number of samples in each flute is set forth in Table I.

TABLE I

SAMPLES SUBMITTED

Code No.	Flute	Number of Consecutive Flutes Measured	Corrugating Speed, f.p.m.
A-1	A	180	450
A-2	A	165	225
A-3	A	175	380
B-1	B	240	420
B-2	B	228	200
B-3	B	230	300
B-4	B	190	
B-5	B	255	200
B-6	B	25	
C-1	C-42	210	550
C-2	C-39	166	
C-3	C-39	221	200
C-4	C-39	204	
C-5	C-39	25	320
C-6	C-39	25	
C-7	C-39	25	

EVALUATION

Each of the three 1 x 5-foot strips of single-faced board per sample was tested in accordance with the following procedure. The start or point of reference was the marked flute; thus, comparison across the machine on corresponding flutes could be made as well as in the machine direction.

Individual Flute Height

One caliper measurement was made on each of the flutes in each five-foot strip except in a few cases wherein the number was reduced to twenty-five flutes in the interest of economy. In a few cases strips longer than five feet were evaluated. Also, in certain cases the full five feet were not evaluated because the board was damaged.

A special caliper was used for these measurements. The instrument consisted of a bench-type thickness gage with a pressure foot 3/8 inch in diameter and an anvil consisting of a plane circular surface two inches in diameter. The pressure foot is attached to a dial indicator which can be read to 0.001 inch. The load on the pressure foot is 100 ± 10 grams. A caliper determination is made by inserting the single-faced board between the pressure foot and the anvil so that the foot rests on a single-flute without touching either of the adjacent flutes. The 3/8-inch diameter of the pressure foot permits it to contact only one flute. The specimen is pressed gently against the anvil, and the reading recorded. Each consecutive flute in the five-foot strip was measured in this way.

Caliper of Medium at Various Locations in a Flute

The first twenty-five flutes in each strip were also evaluated for the caliper of the medium at three points in the flute. These were flute tip and each side wall or shank. These measurements were performed as follows: One-inch long sections of each of the first twenty-five flutes per sample were carefully cut out. A piece of 0.08-inch drill rod was attached to the lower anvil of the special thickness gage or caliper device. The caliper at the three locations in a given flute was measured by placing the flute over the drill rod, lowering the pressure foot and recording the caliper. The pressure foot was then raised and the flute section rotated about the rod to the desired location and the operation was repeated. The twenty-five individual readings at each location were then averaged to give the recorded values of caliper.

Caliper of Corrugating Medium

Samples of corrugating medium equivalent to the single-faced board samples were requested with each sample of single-faced board. The caliper of the medium corresponding to the front, center, and backside of the single-faced board sample was obtained by measuring the caliper at 0.5 inch intervals on each five-foot strip using the special caliper device described above. The reported caliper is the average of the one hundred twenty readings.

DISCUSSION OF RESULTS

As mentioned previously, all single-faced board produced on the Institute's experimental corrugator exhibits "high-low" corrugations although the magnitude of the "high-low" is not discernible necessarily by visual inspection. In addition, the board exhibits a periodicity in that generally alternate flutes are high or low. Samples of single-faced board obtained from commercial runs are evaluated in this study for the purpose of determining whether the caliper profile described above is characteristic of all corrugated board or associated with the Institute's experimental corrugator. The sixteen samples of commercial board investigated in this study consisted of three A-flutes, six B-flutes, and seven C-flutes.

A-FLUTE SINGLE-FACED BOARD

The results of the individual flute height determinations for the three A-flute samples are tabulated in Table II together with the average difference in flute height, caliper of the medium at the tip and side walls as well as the caliper of the corrugating medium. The height of the individual flutes are graphically displayed in Fig. 3, 4, and 5 to show the flute height profile. It may be noted that in all cases the front, center, and back strip of each sample exhibited the same general flute height profile, i.e., a periodicity of "high-low" flutes. With few exceptions, consecutive flutes are alternately high and low. In the case of Sample A-1, the board formed on the back side of the machine exhibited the largest variation in flute height. On the other hand, Samples A-2 and A-3 exhibited the

TABLE II

CALIPER RESULTS ON A-FLUTE SINGLE-FACED BOARD AND MEDIUM

Location on Corrugator	Sample A-1 Front	Sample A-1 Center	Sample A-1 Back	Sample A-2 Front	Sample A-2 Center	Sample A-2 Back	Sample A-3 Front	Sample A-3 Center	Sample A-3 Back
Flute height, pt.									
No. of flutes measured	180	180	180	165	165	165	175	175	175
Average	196.4	196.0	194.9	193.9	194.0	195.0	195.4	194.4	195.5
Maximum	198.5	198.4	198.2	198.2	199.0	197.2	197.4	199.0	198.0
Minimum	193.2	192.8	190.6	190.2	188.0	192.5	191.8	187.3	191.0
Difference in consecutive flute height, pt.									
Average	0.7	1.0	1.5	1.4	2.6	1.0	1.4	1.8	1.2
Maximum	5.0	5.0	6.0	6.6	8.4	3.8	4.7	8.0	4.6
Minimum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Caliper of fluted member, pt.									
Leading side wall									
Average	9.6	9.4	9.0	11.1	11.2	11.0	9.1	9.2	9.4
Maximum	10.0	10.0	9.5	12.5	12.2	12.4	9.6	10.0	10.4
Minimum	9.0	8.8	8.5	9.5	9.0	9.6	8.5	8.2	8.5
Flute tip									
Average	8.2	8.2	7.4	6.5	7.4	5.9	6.7	7.4	6.8
Maximum	9.2	9.2	8.8	7.2	8.1	6.1	7.5	8.3	7.8
Minimum	6.7	7.7	6.7	6.1	7.0	5.6	5.7	6.5	6.0
Trailing side wall									
Average	9.7	9.6	9.2	10.1	10.2	10.7	10.1	9.8	9.9
Maximum	11.0	10.5	10.2	11.6	12.0	11.8	11.0	10.7	11.0
Minimum	9.1	8.8	8.5	9.0	8.8	9.2	8.7	8.5	9.0
Corrugating medium caliper, pt.									
Average	10.0	9.9	10.0	11.7	10.9	10.4	10.7	9.9	10.1
Maximum	10.6	10.7	10.6	12.6	12.8	11.8	11.9	10.5	11.6
Minimum	9.4	9.4	9.1	10.8	10.0	10.0	9.4	9.2	9.2

largest variation in flute height in the board made in the center of the corrugator. The magnitude of the differences in flute height for the center strips of Samples A-2 and A-3 is such that difficulty might be anticipated at the double-backer unless the "dancer" roll is set to compensate in which case the higher flutes would tend to be flattened out slightly.

When the caliper measurements on the medium are compared with the height of consecutive flutes, it may be noted that the variation in caliper is not only much less than the variation in consecutive flute height but there appears to be no clear relationship between flute height and caliper of the medium. Flute height, of course, is a function of not only the flute geometry but also the caliper of the medium at the flute tips which is considerably less than the corrugating medium caliper. As may be seen in Table II, the variations in the caliper of the tip of the flute is considerably less than the variation in flute height.

A comparison of the average caliper at the flute tip and the two side walls indicate that in all cases the board at the flute tip exhibits much greater plastic flow (nonrecoverable transverse compression strain) than the board at the side walls of the flute. Further, on two of the three samples, the leading side walls were subjected to greater transverse compression than the trailing side wall as evidenced by the greater loss in caliper. Sample A-2 exhibited the reverse behavior. The method used in this study to determine the leading and trailing side wall was somewhat arbitrary and this may reflect the behavior noted for Sample A-2. The results show, however, that one side wall receives greater pressure than the other in the corrugating and single-facing operation.

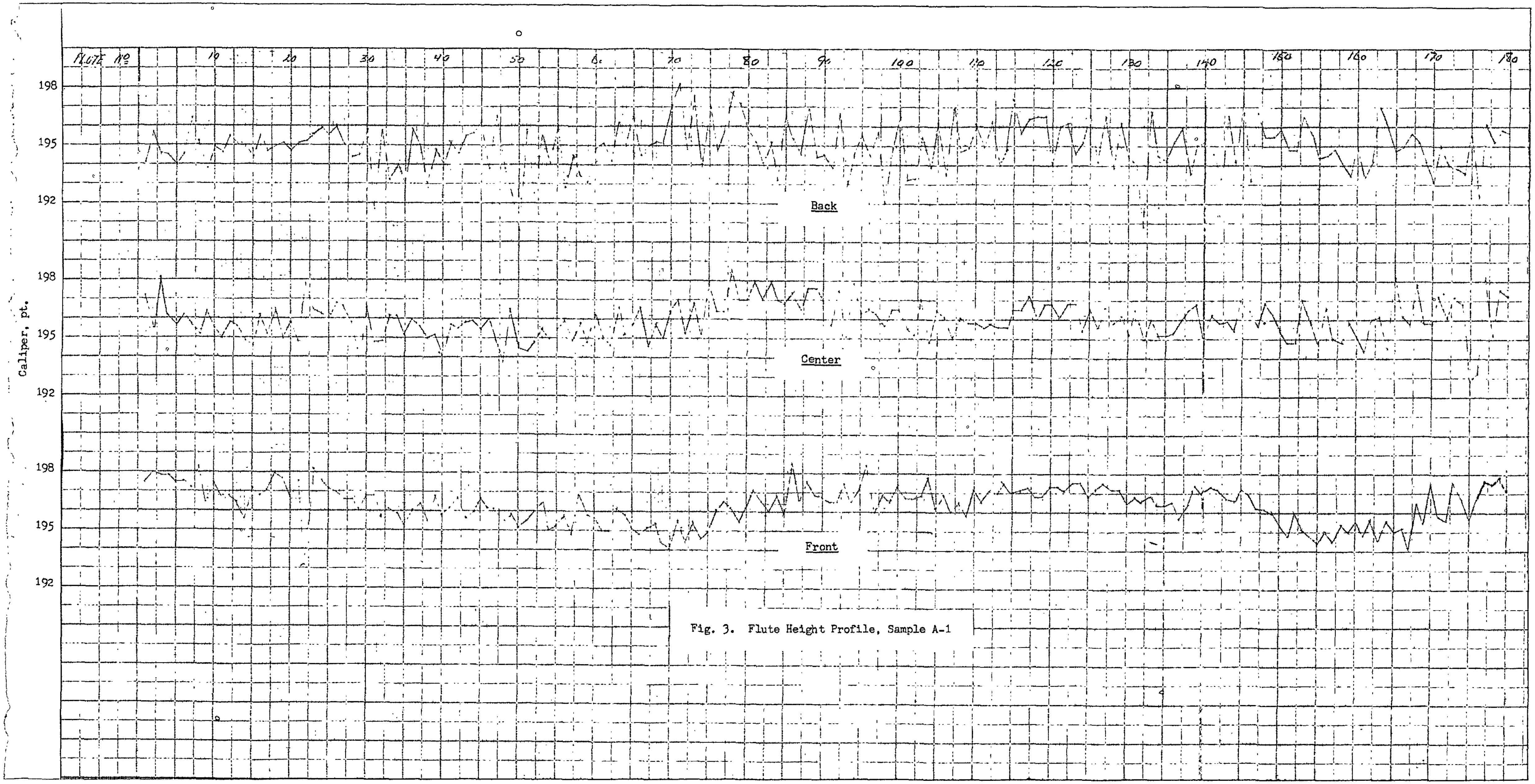

Fig. 3. Flute Height Profile, Sample A-1

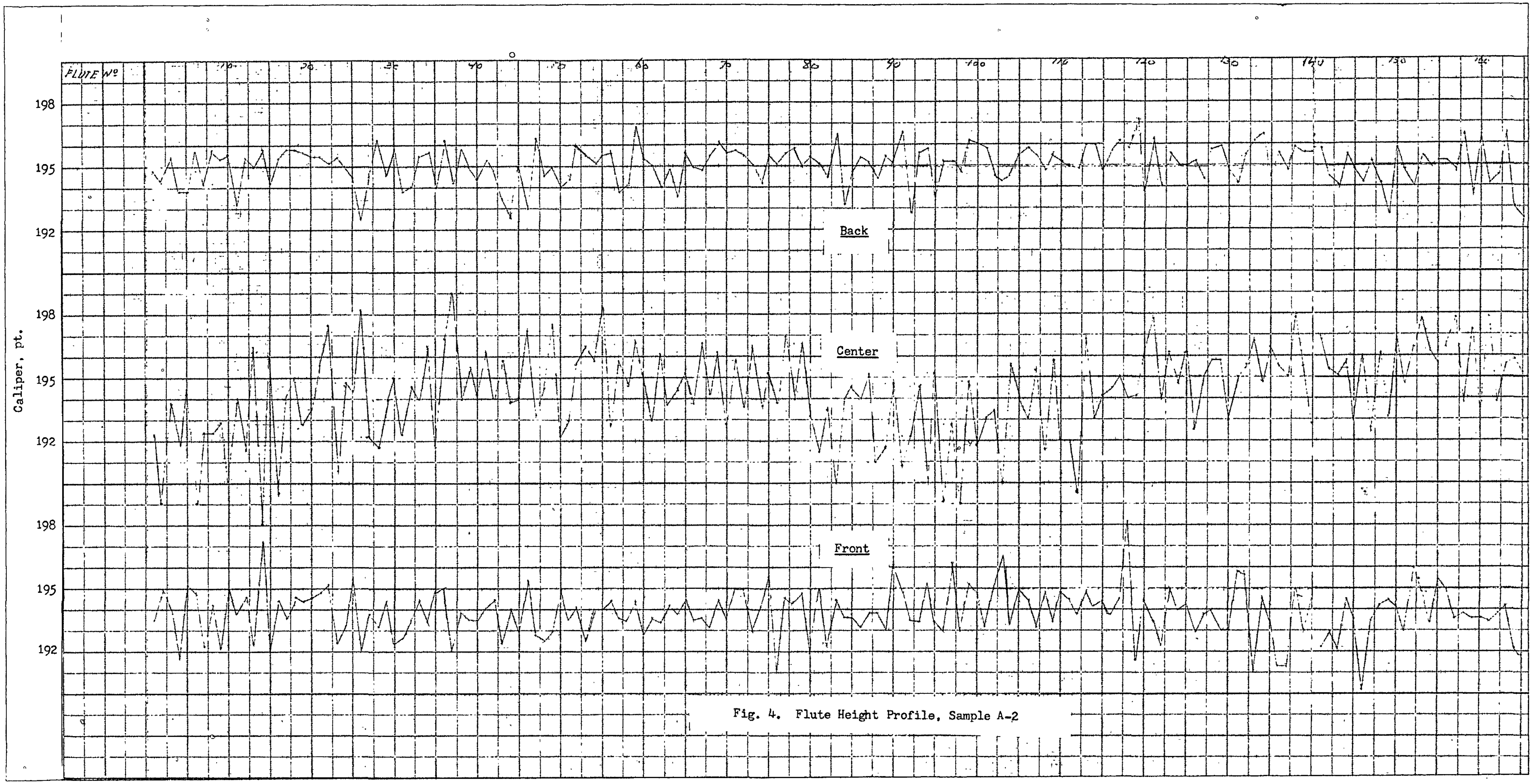

Fig. 4. Flute Height Profile, Sample A-2

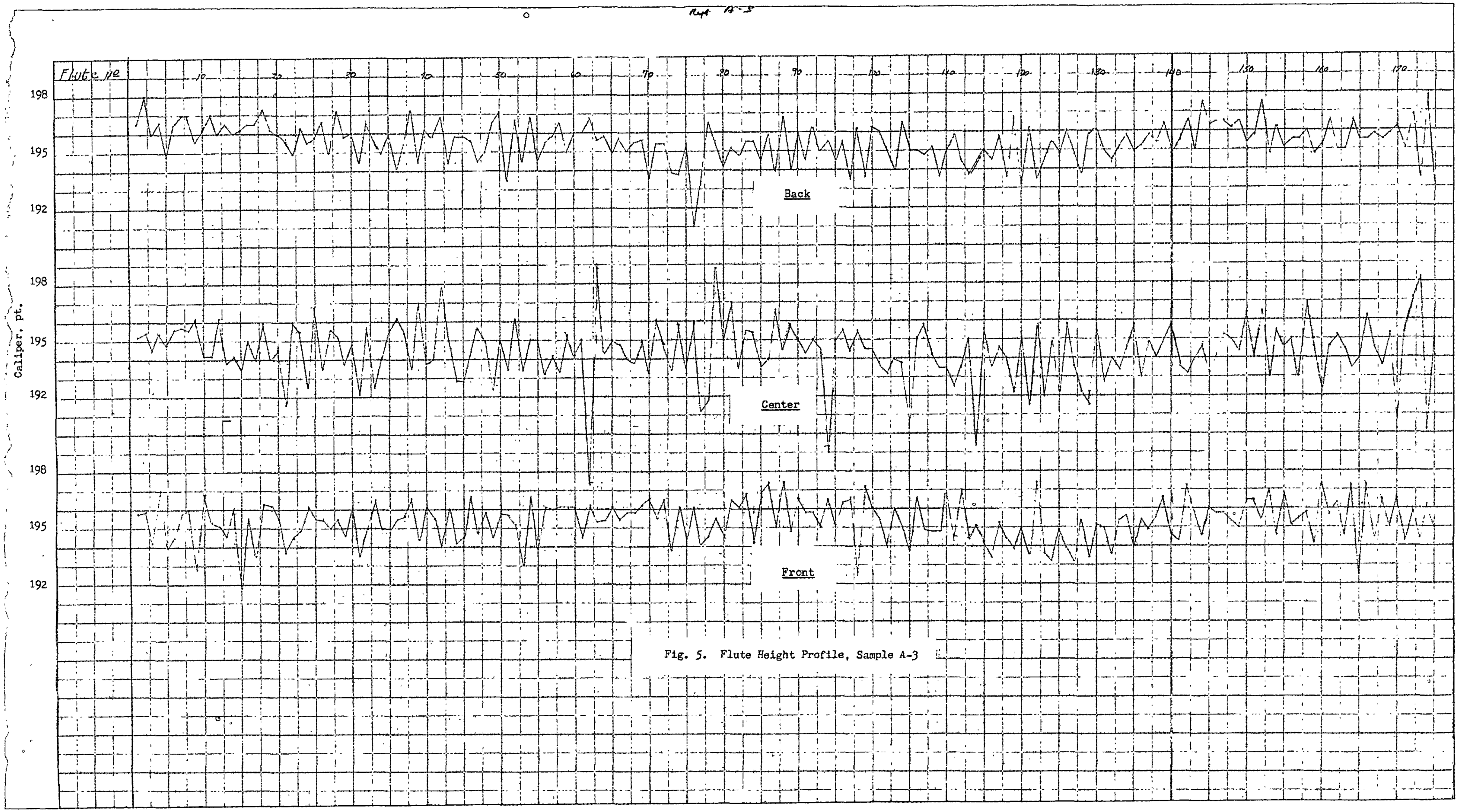

Fig. 5. Flute Height Profile, Sample A-3

B-FLUTE SINGLE FACED-BOARD

The results obtained on the six samples of B-flute single-faced board are tabulated in Table III and the flute height data are plotted in Fig. 6 through 11 to show the flute height profile of consecutive flutes. It may be noted that the flute height of consecutive flutes varies depending on the corrugator and/or the position across the corrugator; however, they all show the same general pattern of high-low periodicity noted for the A-flute samples. When the profiles for the individual samples are considered, it may be seen that in the case of Sample B-1, the front strip exhibited considerably less variation than the center or back strip. This is reflected also by the average difference in consecutive flute height results tabulated in Table III. By contrast with some of the other samples, the profiles for Sample B-2 are very good in that there are no large differences in consecutive flute height and the variability present appears to be about the same for the various positions across the corrugator. Samples B-3 and B-4 exhibit about the same general profile relative to position; however, the variation in consecutive flute height is considerably more noticeable than in Sample B-2. When the profiles for Sample B-5 are compared, it may be observed that the front and center location profiles are good in that the variation in flute height is relatively low whereas the profile for the back side sample indicates considerably greater variation in flute height. Sample B-6, represented by far fewer flute measurements, exhibits much more uniform flute profile for front and back than for center. Thus, it appears that the occurrence of the extreme variation in consecutive flute height is not associated with a given location on the corrugator. Studies carried out at the Institute have indicated this same trend.

TABLE III

CALIPER RESULTS ON B-FLUTE SINGLE-FACED BOARD AND MEDIUM

Location on Corrugator	Sample B-1 Front	Sample B-1 Center	Sample B-1 Back	Sample B-2 Front	Sample B-2 Center	Sample B-2 Back	Sample B-3 Front	Sample B-3 Center	Sample B-3 Back	Sample B-4 Front	Sample B-4 Center	Sample B-4 Back	Sample B-5 Front	Sample B-5 Center	Sample B-5 Back	Sample B-6 Front	Sample B-6 Center	Sample B-6 Back
Flute height, pt.																		
No. of flutes measured	240	240	240	228	228	228	230	230	230	190	190	190	255	255	255	254	254	254
Average	105.8	105.1	105.3	112.1	114.2	111.8	108.9	108.2	109.3	114.2	115.3	115.5	113.1	117.9	112.7	105.3	104.9	107.1
Maximum	108.2	111.0	108.5	113.5	116.3	113.4	110.8	110.2	112.0	115.8	116.9	117.4	115.0	120.0	115.5	106.9	108.2	108.8
Minimum	103.5	101.2	102.3	110.6	112.5	110.4	106.5	105.2	107.1	112.0	113.0	112.0	111.5	115.5	109.4	103.4	99.8	105.8
Difference in consecutive flute height, pt.																		
Average	0.9	1.9	1.3	0.7	0.8	0.7	1.0	1.1	1.1	1.1	1.1	1.2	0.6	0.7	1.5	0.8	1.2	0.4
Maximum	3.8	7.0	5.4	2.5	2.5	2.4	2.9	3.6	4.2	2.8	3.3	4.2	2.4	2.8	5.1	2.3	4.3	2.7
Minimum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Caliper of fluted member, pt.																		
Leading side wall																		
Average	7.9	8.6	8.8	8.9	9.4	8.6	9.0	8.6	9.1	9.3	9.8	10.1	7.4	8.1	6.3	8.5	8.1	8.2
Maximum	8.5	10.6	9.6	10.5	10.6	9.8	10.2	10.0	10.0	10.5	10.8	10.8	10.0	9.0	8.4	9.2	9.0	9.4
Minimum	7.3	7.5	8.2	7.8	7.8	7.5	8.5	8.0	7.8	8.0	9.0	9.2	5.0	7.0	5.2	7.4	7.3	7.4
Flute tip																		
Average	6.6	7.6	6.8	7.6	7.0	7.4	6.4	6.6	6.6	6.4	7.0	7.3	7.1	7.5	8.0	5.9	7.3	6.7
Maximum	7.6	8.5	7.6	8.4	7.5	8.2	7.2	8.0	7.8	7.0	7.4	8.2	7.8	8.2	8.8	6.6	8.1	7.1
Minimum	5.4	7.0	6.0	6.5	6.1	6.9	6.0	5.5	5.9	6.0	6.7	6.9	6.6	7.0	7.3	5.4	6.8	6.4
Trailing side wall																		
Average	8.4	9.0	8.6	8.6	9.6	8.6	9.9	9.2	9.1	9.3	9.7	10.0	7.4	8.1	8.6	7.2	8.3	8.3
Maximum	9.2	10.2	10.3	10.0	11.0	9.7	11.2	10.4	10.7	10.5	11.0	10.9	10.0	8.8	10.5	9.0	9.0	9.4
Minimum	7.6	8.0	7.8	7.4	8.1	7.6	8.2	8.0	8.0	8.0	8.6	9.1	6.4	7.5	7.5	6.3	7.5	7.4
Corrugating medium caliper, pt.																		
Average	9.3	9.0	9.0	10.1	10.6	10.0	10.7	9.8	10.2	10.9	10.5	11.0	10.6	10.7	10.5	10.3	9.9	9.4
Maximum	9.8	10.2	9.6	11.5	11.8	12.0	11.5	10.4	12.0	11.6	11.5	11.8	12.3	12.6	11.6	11.2	10.8	10.5
Minimum	9.0	8.9	8.6	9.5	9.7	9.5	9.8	9.2	8.6	10.0	9.9	10.2	10.0	10.0	10.0	9.5	9.1	9.2

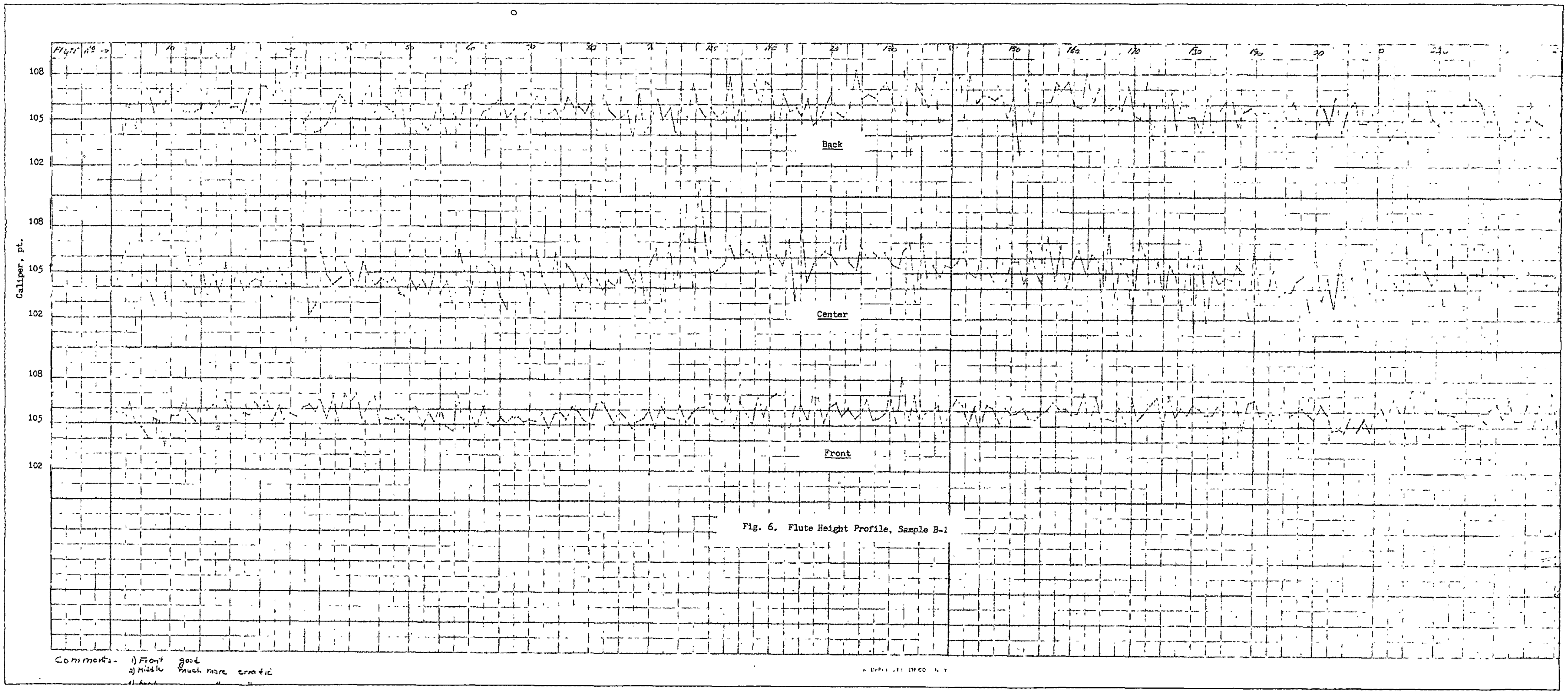

Fig. 6. Flute Height Profile, Sample B-1

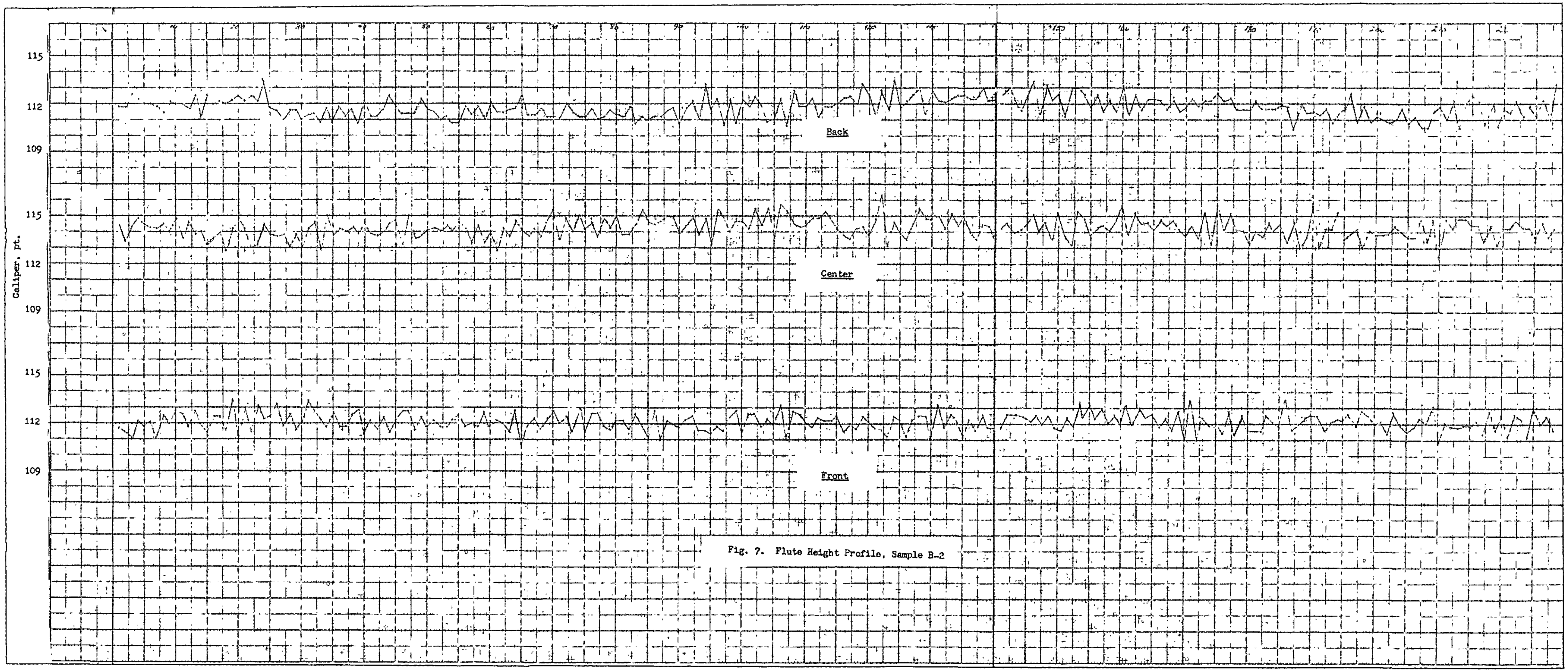

Fig. 7. Flute Height Profile, Sample B-2

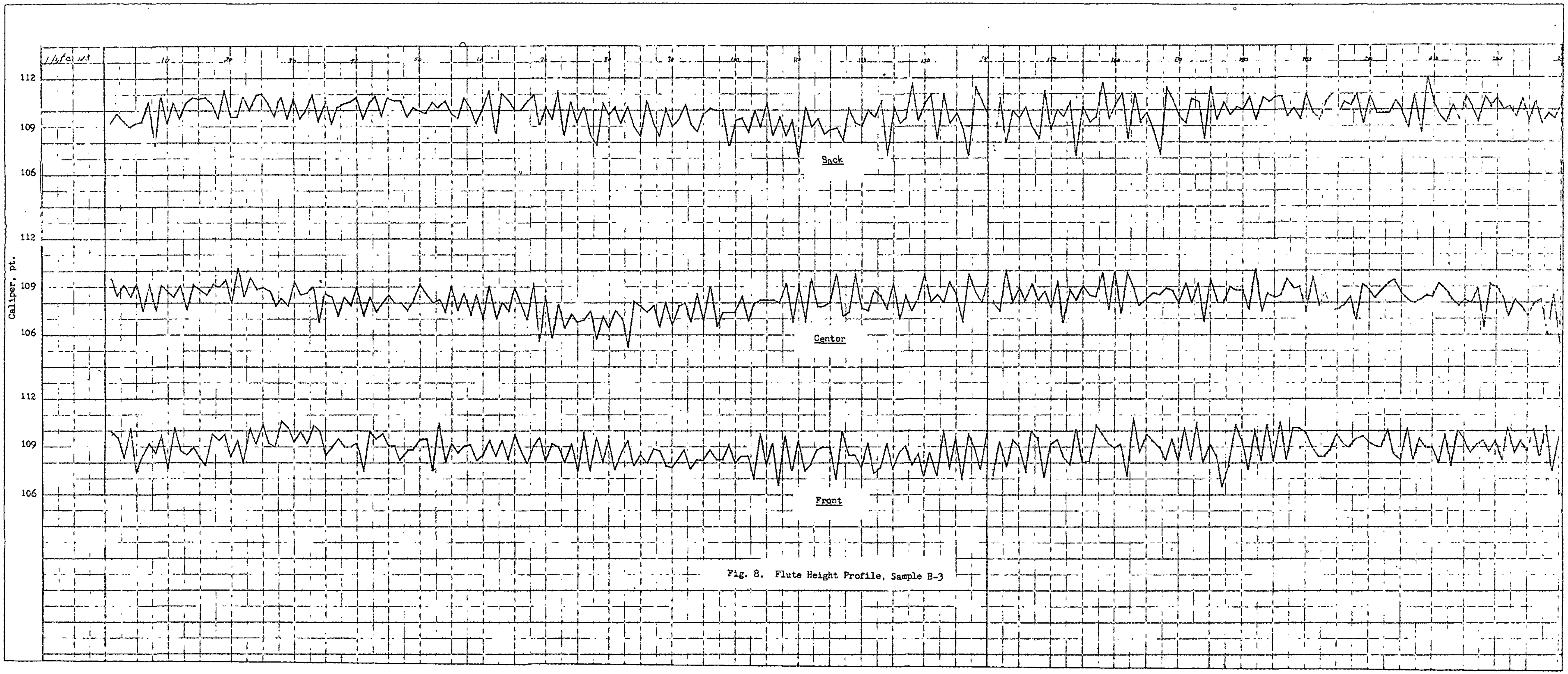

Fig. 8. Flute Height Profile, Sample B-3

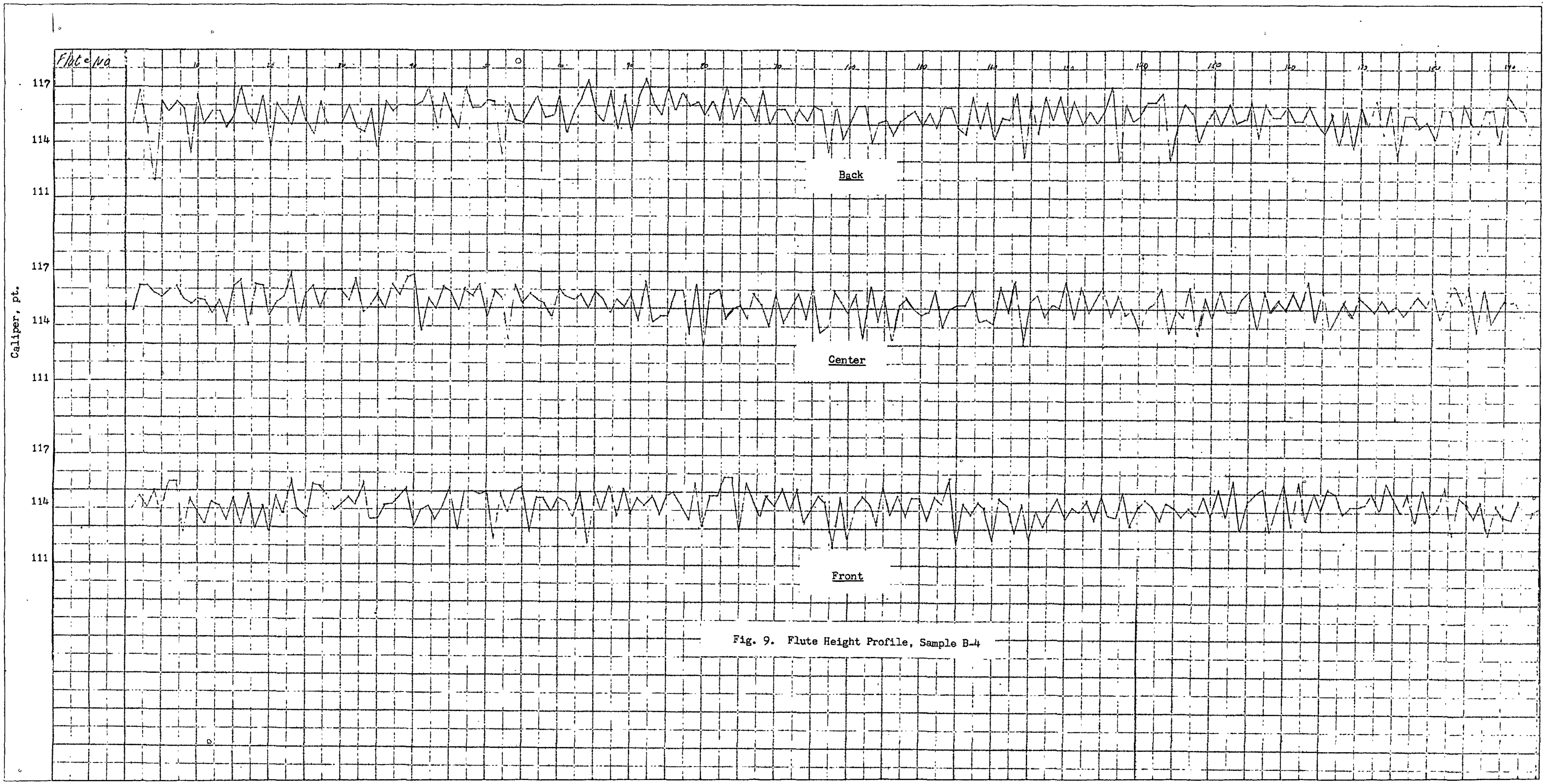

Fig. 9. Flute Height Profile, Sample B-4

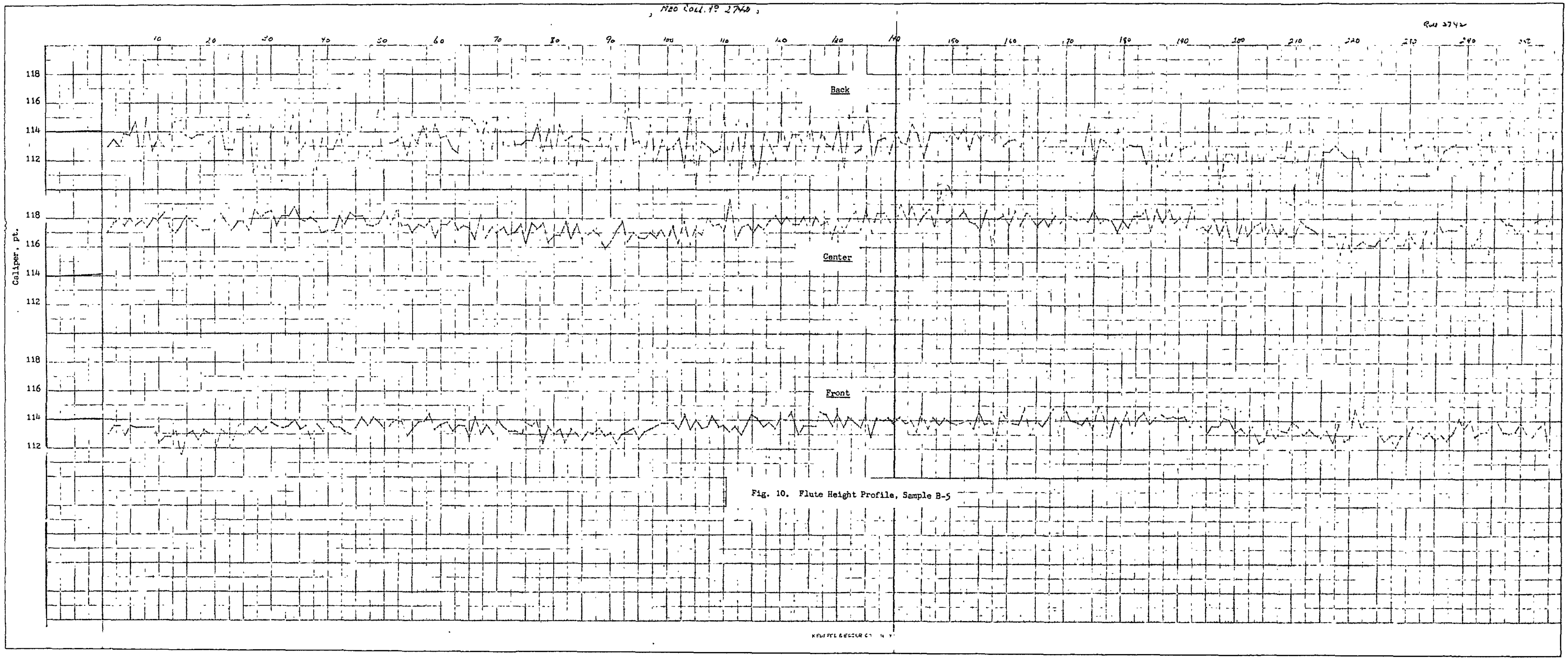

Fig. 10. Flute Height Profile, Sample B-5

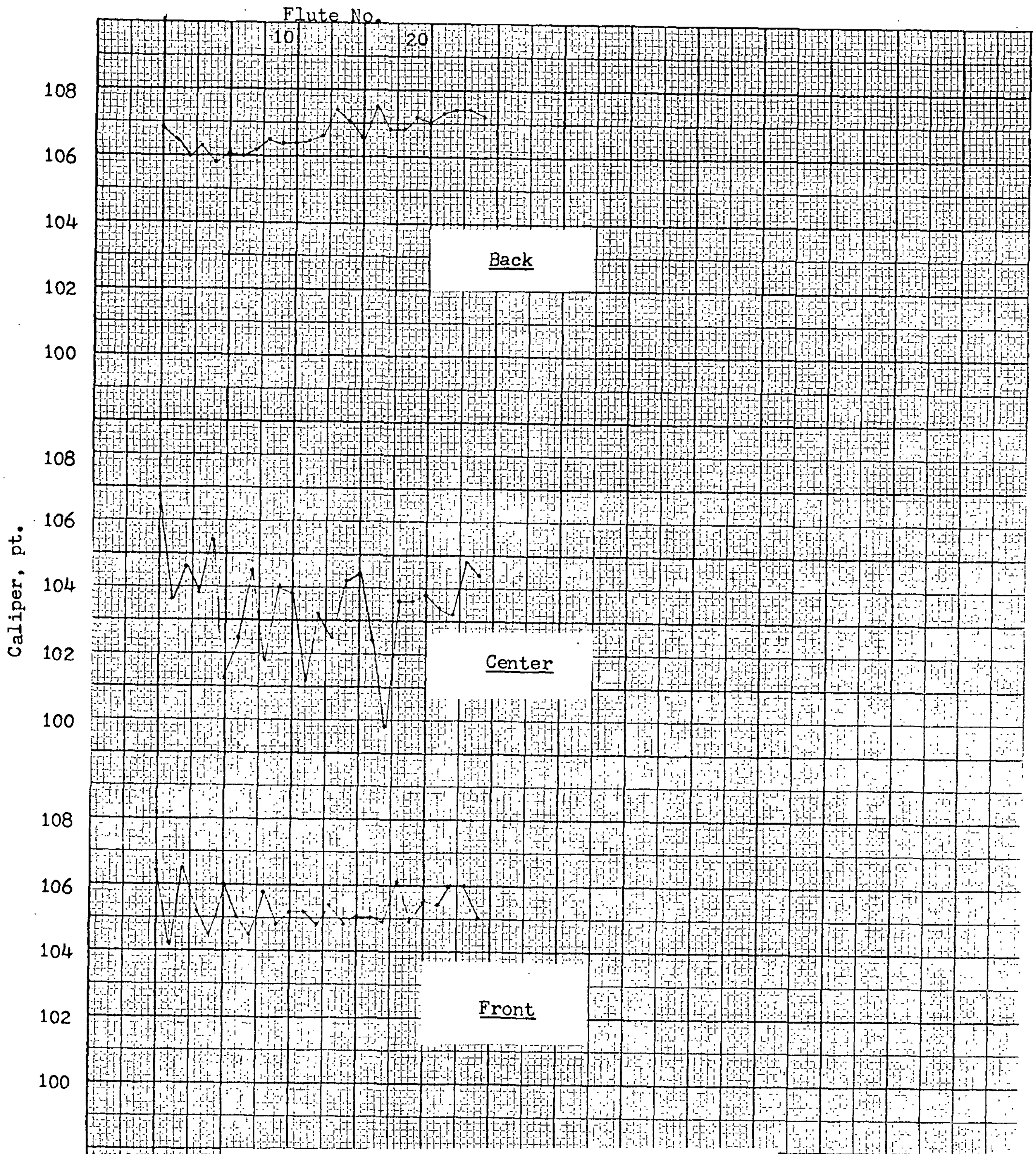

Fig. 11, Flute Height Profile, Sample B-6

When the variability in medium caliper as represented by the range is considered, it may be noted that there appears to be no relationship between medium caliper variations and the variability in the different heights of consecutive flutes either within or between samples. Similarly, the average caliper of the single-faced board does not appear to be related to the difference in height of consecutive flutes.

The caliper results obtained on the fluted member show, as would be expected, that the flute tip is subjected to more pressure and exhibits more permanent set than the side wall portions of the flute. On the other hand, the side walls are subjected to pressure and exhibit permanent set as evidenced by the caliper loss.

C-FLUTE SINGLE-FACED BOARD

The C-flute samples were predominantly C-39 as there were six samples of C-39 and only one sample of regular C-flute (Sample C-1, 42 flutes per foot). The results obtained on the C-flute samples are tabulated in Table IV and the flute profiles are graphically presented in Fig. 12 through 18. As in the case of the A- and B-flute samples, all the C-flute samples indicate the same general pattern or periodicity relative to the height of consecutive flutes, although the magnitude of the difference in flute height varies between samples and within a given sample. The profile for the regular C-flute does not appear to materially differ from the C-39 samples. As in the case of the other fluted samples, there appears to be no clear relationship between the variation in the caliper of the medium and the variation in the height of consecutive flutes.

The C-flute samples exhibited the same behavior as noted for the A- and B-flute samples relative to caliper loss at the tip and side walls of the flute.

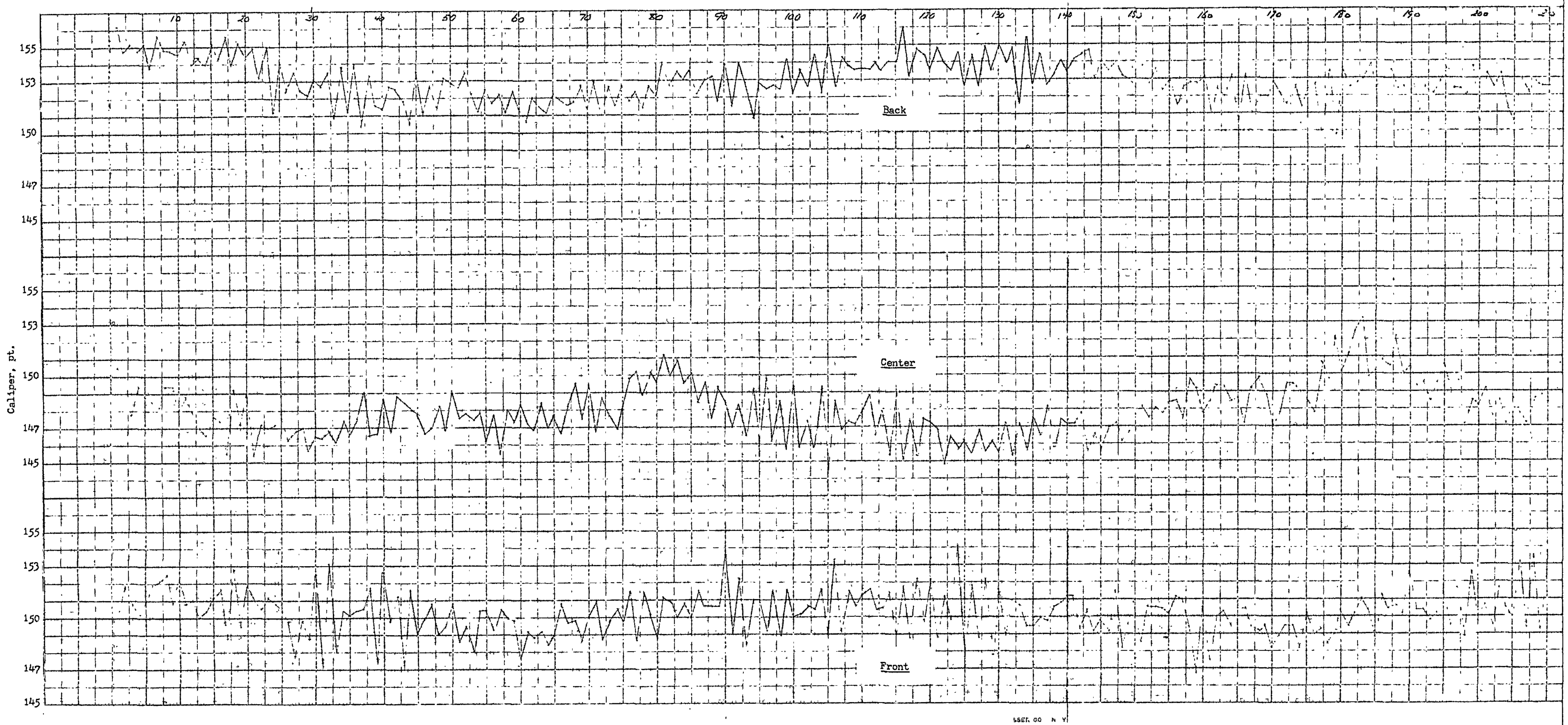

Fig. 12. Flute Height Profile, Sample C-1

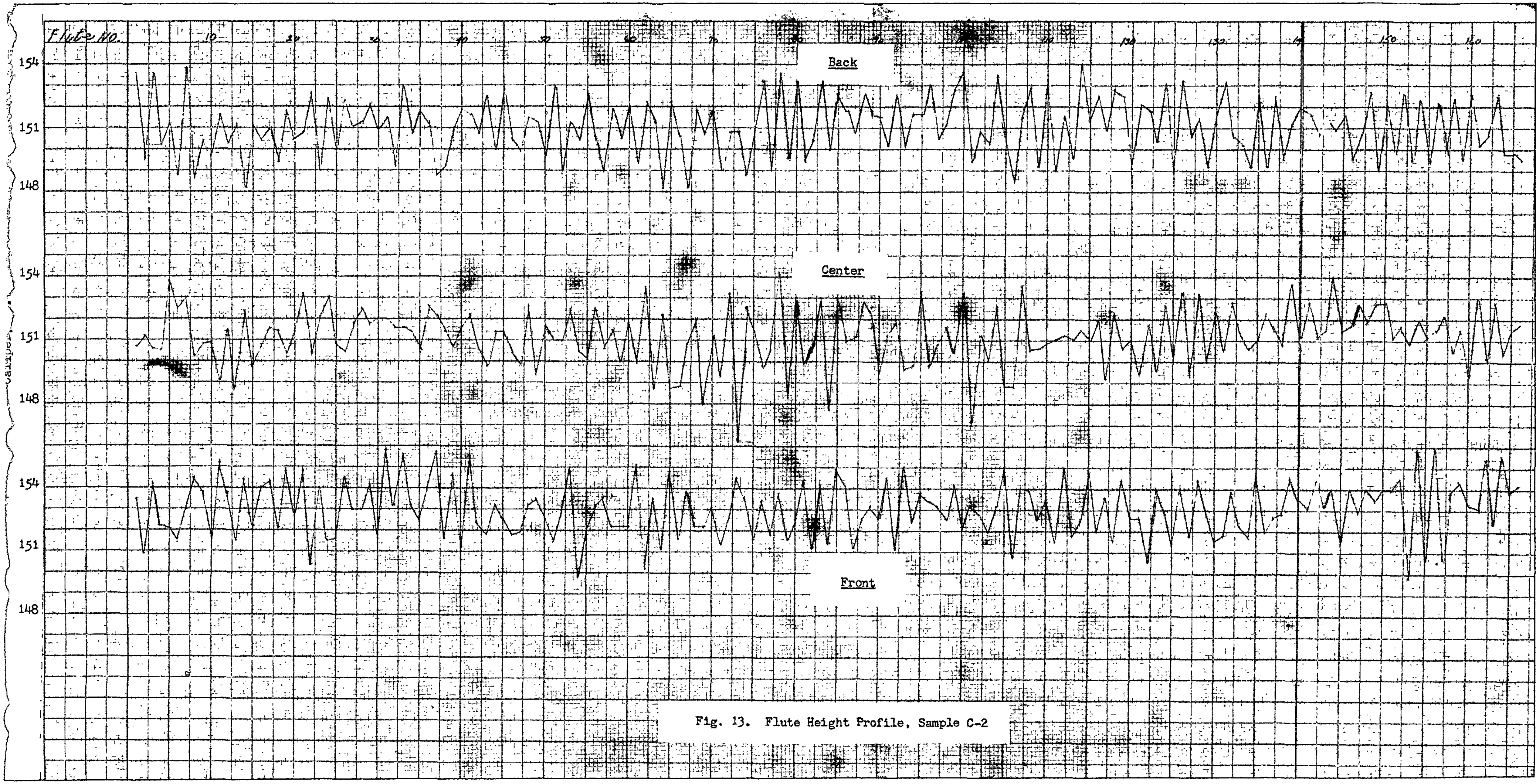

Fig. 13. Flute Height Profile, Sample C-2

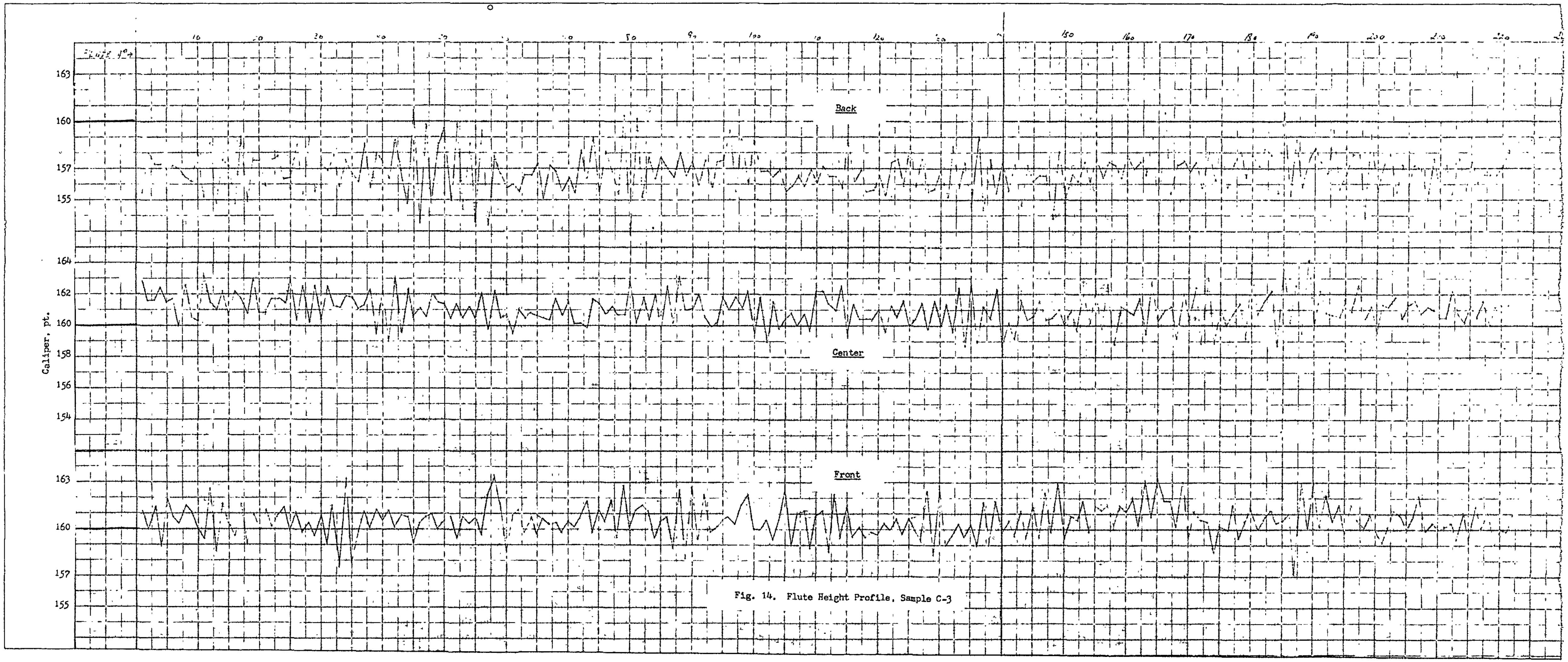

Fig. 14. Flute Height Profile, Sample C-3

TABLE IV

CALIPER RESULTS ON C-FLUTE SINGLE-FACED BOARD AND MEDIUM

Location on Corrugator	Sample C-1 Front	Sample C-1 Center	Sample C-1 Back	Sample C-2 Front	Sample C-2 Center	Sample C-2 Back	Sample C-3 Front	Sample C-3 Center	Sample C-3 Back
Flute height, pt.									
No. of flutes measured	210	210	210	166	166	166	221	221	221
Average	150.3	148.1	153.0	153.1	151.2	151.0	161.4	160.1	156.1
Maximum	152.6	153.2	156.2	156.0	154.2	153.9	163.2	164.1	160.7
Minimum	146.7	144.5	149.7	149.8	146.3	148.2	157.2	158.7	153.5
Difference in consecutive flute height, pt.									
Average	1.6	1.3	1.1	1.9	1.8	2.1	1.5	1.4	2.0
Maximum	6.4	4.3	3.8	6.0	6.9	5.0	5.8	4.3	7.0
Minimum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Caliper of fluted member, pt.									
Leading side wall									
Average	9.3	9.8	10.3	9.0	9.3	9.6	11.9	11.2	12.3
Maximum	11.2	10.5	12.5	10.2	10.4	11.0	13.0	12.0	13.0
Minimum	8.0	9.1	7.0	8.4	8.6	8.9	11.0	10.0	11.0
Flute tip									
Average	6.1	6.9	5.2	8.4	7.6	7.8	9.4	9.2	9.5
Maximum	8.5	7.8	6.2	8.7	8.3	8.7	10.0	9.8	10.0
Minimum	5.0	6.0	4.6	7.8	7.2	7.2	8.3	8.5	8.5
Trailing side wall									
Average	9.7	9.7	10.6	9.6	9.1	8.7	11.5	12.1	9.8
Maximum	11.2	11.2	12.5	10.2	10.1	10.0	12.2	12.8	10.8
Minimum	8.4	9.0	8.8	8.9	8.3	8.0	10.8	10.9	9.2
Corrugating medium caliper, pt.									
Average	9.4	9.6	10.3	11.5	10.9	11.0	14.5	14.7	14.1
Maximum	10.5	10.2	11.8	12.2	11.7	12.5	15.7	16.4	15.3
Minimum	9.4	8.4	9.8	10.9	9.8	10.0	13.4	13.8	13.3

Location on Corrugator	Sample C-4 Front	Sample C-4 Center	Sample C-4 Back	Sample C-5 Front	Sample C-5 Center	Sample C-5 Back	Sample C-6 Front	Sample C-6 Center	Sample C-6 Back	Sample C-7 Front	Sample C-7 Center	Sample C-7 Back
Flute height, pt.												
No. of flutes measured	204	204	204	25	25	25	25	25	25	25	25	25
Average	150.6	153.7	151.9	155.8	156.0	155.9	145.5	144.0	145.4	152.8	152.5	152.6
Maximum	153.5	155.1	153.6	157.1	158.0	157.4	147.2	145.7	147.2	154.6	153.0	154.1
Minimum	148.1	151.5	150.4	153.3	153.5	153.6	143.5	141.8	143.1	150.4	151.6	151.6
Difference in consecutive flute height, pt.												
Average	0.9	1.0	0.6	1.5	2.3	1.3	1.2	1.2	1.2	1.4	0.5	0.6
Maximum	2.7	3.5	3.1	3.8	4.1	3.8	3.3	2.0	2.6	4.2	1.3	1.6
Minimum	0.0	0.0	0.0	0.1	0.1	0.0	0.2	0.0	0.0	0.0	0.0	0.0
Caliper of fluted member, pt.												
Leading side wall												
Average	8.6	9.3	7.0	9.1	8.7	9.3	9.0	9.5	9.2	8.0	8.0	8.1
Maximum	9.8	10.0	7.2	10.0	9.2	9.8	9.7	10.2	10.0	8.5	8.5	8.6
Minimum	8.2	8.7	6.5	8.5	8.0	8.5	8.2	8.8	8.5	7.6	7.5	7.6
Flute tip												
Average	5.6	6.8	6.5	6.1	6.6	5.7	5.5	5.8	6.1	6.4	6.6	6.5
Maximum	6.4	7.0	6.8	6.5	7.1	6.3	6.4	7.0	6.3	6.8	6.8	7.1
Minimum	5.4	6.5	6.1	5.8	6.1	5.5	5.1	6.6	5.9	6.1	6.1	6.1
Trailing side wall												
Average	6.5	9.2	9.7	9.3	9.4	9.8	8.6	9.2	8.2	8.5	8.3	8.7
Maximum	7.5	10.0	10.2	10.3	10.5	10.5	9.1	10.0	9.5	9.0	8.9	9.6
Minimum	5.3	8.5	9.0	9.1	8.3	9.0	8.0	8.4	7.4	8.0	8.0	8.0
Corrugating medium caliper, pt.												
Average	11.0	11.0	10.5	10.3	10.0	10.8	10.5	10.2	10.5	10.7	10.2	10.4
Maximum	11.7	11.6	11.8	10.3	10.5	11.4	11.7	10.5	10.4	11.2	10.6	11.2
Minimum	10.5	10.4	9.7	9.8	9.5	10.0	10.0	9.6	9.2	10.2	9.9	9.7

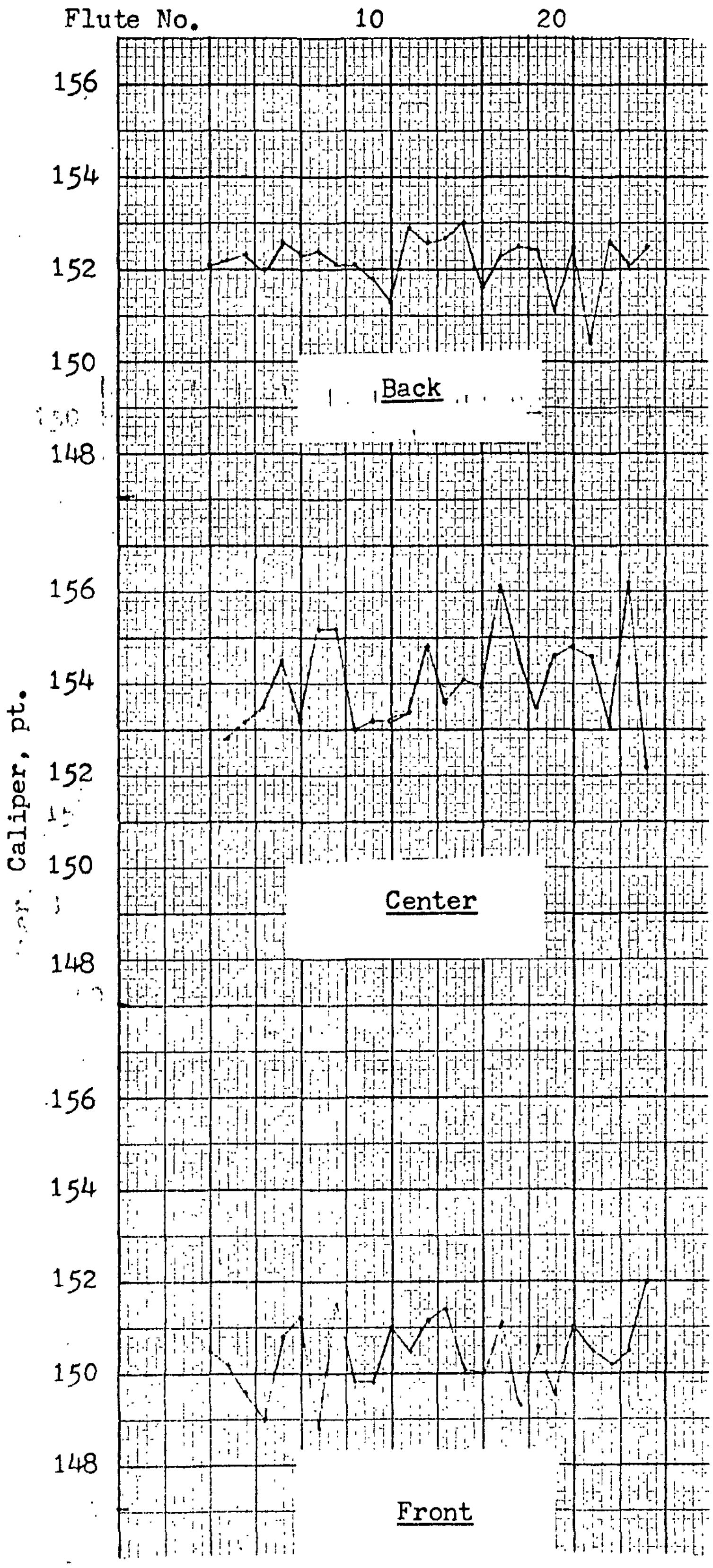

Fig. 15. Flute Height Profile, Sample C-4

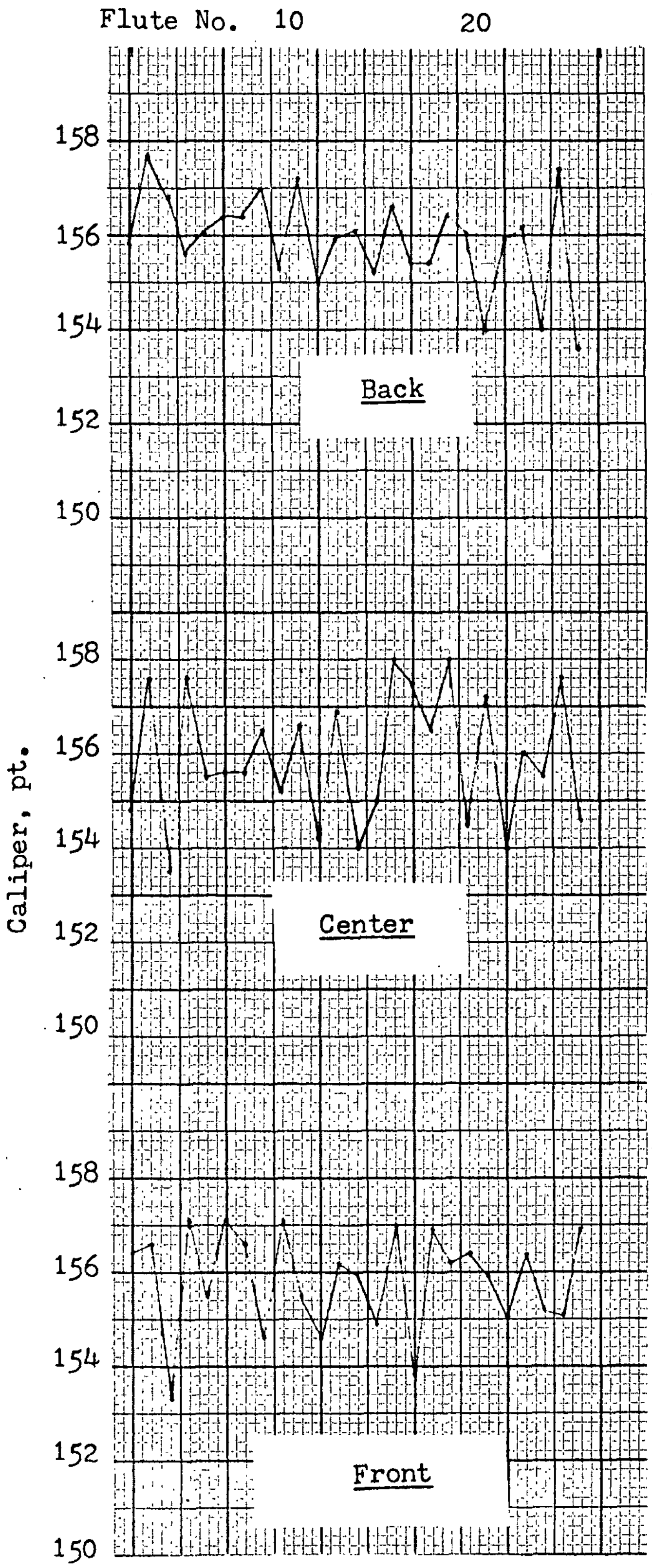

Fig. 16. Flute Height Profile, Sample C-5

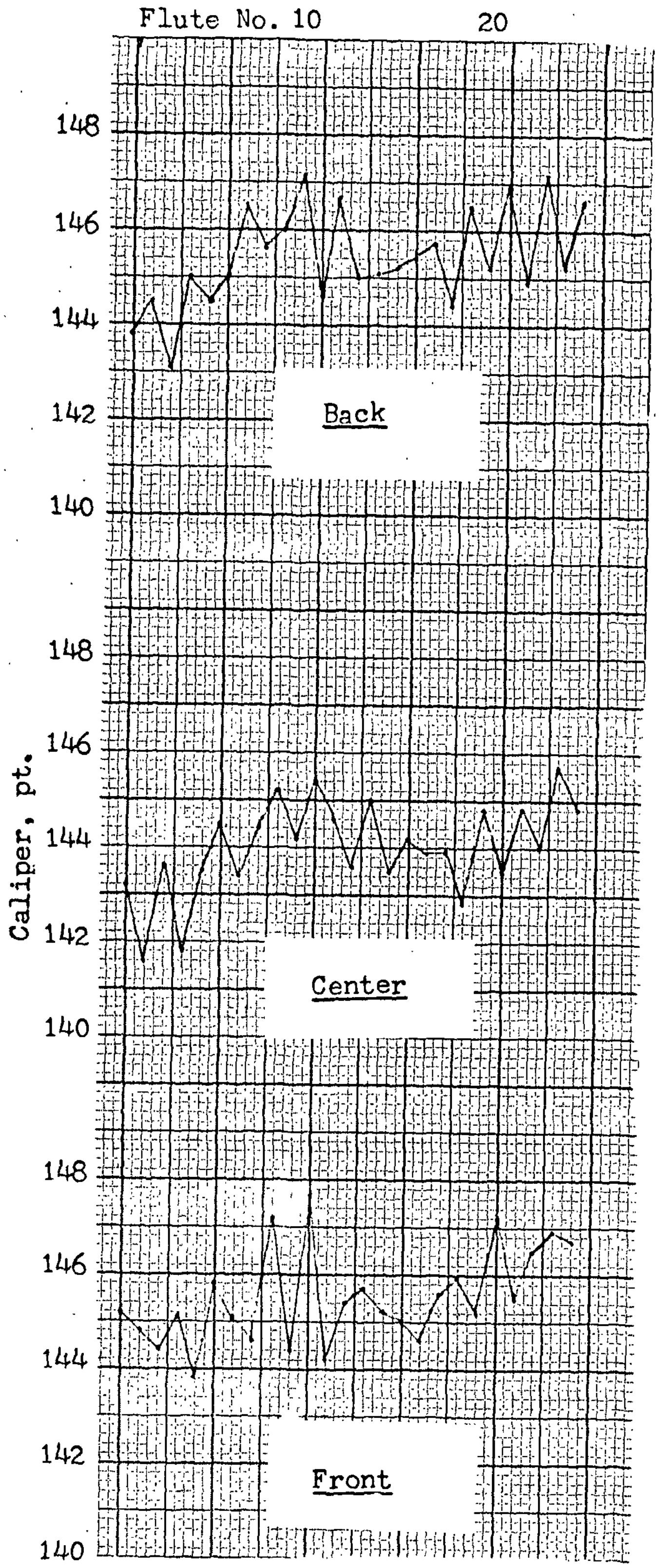

Fig. 17. Flute Height Profile, Sample C-6

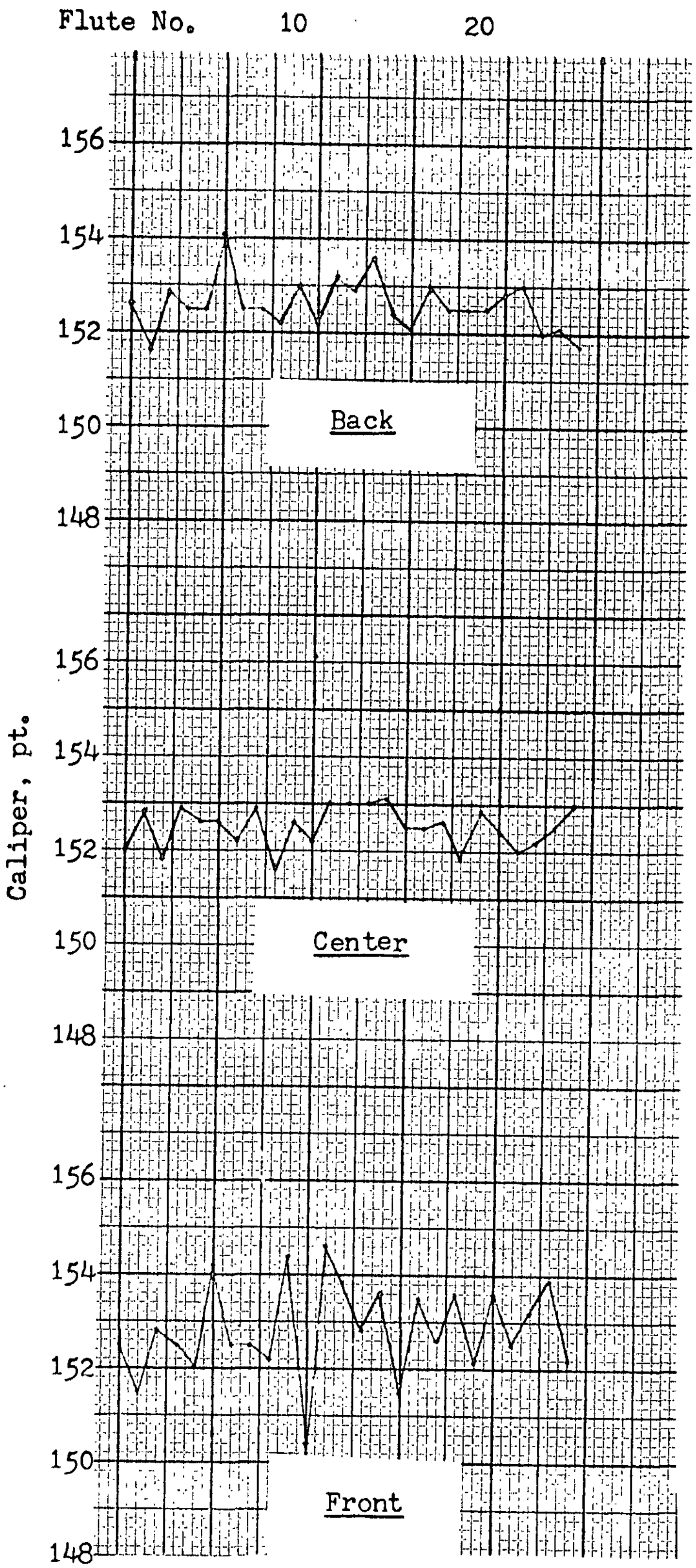

Fig. 18. Flute Height Profile, Sample C-7

COMPARISON OF DIFFERENT FLUTES

When the flute profiles for the various samples are compared on a flute basis, it may be seen that the periodicity of "high-low" flutes was independent of the type of flute. The average as well as maximum difference in the height of consecutive flutes also appear to be fairly independent of the type of flute as may be seen from the averages and maximum differences tabulated in Table V.

TABLE V

DIFFERENCE IN CONSECUTIVE FLUTE HEIGHT

Flute Size \ Sample No.	1	2	3	4	5	6	7	Composite Average
	Average Differences, pt.							
A	1.1	1.7	1.5	--	--	--	--	1.4
B	1.4	0.7	1.1	1.1	0.9	0.8	--	1.0
C	1.3	1.9	1.6	0.8	1.7	1.2	0.8	1.3
	Maximum Differences, pt.							
A	5.3	6.3	5.8	--	--	--	--	5.8
B	5.4	2.5	3.6	3.4	3.1	3.1	--	4.2
C	5.0	6.0	5.9	3.1	3.9	2.6	2.4	6.3

The periodicity relative to consecutive flutes being alternately high and low was exhibited by all the commercial samples. This phenomenon confirms that the behavior noted for board made on the Institute's experimental corrugator represents normal behavior. Further, the absence of any relationship between the caliper of the medium or the type of flute and the variation in consecutive flute height suggests that the corrugating and/or the single-facing operation introduces a pattern of alternate flutes being high and low. In addition, it may be speculated that the variation in the height of the high or lows may be associated with the quality of the medium or the corrugating technique. If this hypothesis is correct, it may be projected that the high-low corrugations which are referred to in commercial practice may have their beginning as a result of the high-low profile introduced by the corrugating or single-facing operation. The board becomes objectionable or unsatisfactory only when the magnitude of the high-low corrugations reaches an excessive amount believed to be due to either (a) material quality, (b) operation of the corrugator or (c) a combination of both. The foregoing is, of course, speculative and it needs to be established just how much is due to the geometry of corrugating, quality of medium, and the conditions of corrugating. It appears obvious that the high-lows are not solely a function of the quality of the corrugating medium because the pattern of flute height is too definite and, therefore, appears induced rather than random as would be the case if quality of the medium were the sole cause.

LITERATURE CITED

1. The Institute of Paper Chemistry. Supplementary report on caliper of single-faced board. Project 1108-17. Progress Reports 46, 48, 50, 52, 54, 56, 58, 60, 62, 64, 66, 68, 70, 72, 74, 76, 78, 80, 82, 84 to the Fourdrinier Kraft Board Institute. (July 1, 1959 - Feb. 1, 1961).

THE INSTITUTE OF PAPER CHEMISTRY

C. N. Smith, Research Assistant
Container Section

R. C. McKee, Chief, Container Section