INFORMATICA ED EGITTOLOGIA

ALL'INIZIO DEGLI ANNI '90

a cura di

Francesco Tiradritti

BULZONI EDITORE

INDICE

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ON THE DISCOVERY OF THE ANCIENT EGYPTIAN MUSICAL SCALE

There is a lost link between the ancient Egyptian music and the music of other civilizations. This is due to the fact that there was no attempt to play the ancient Egyptian instruments and try to discover their features such as notes, scales, etc.

The instruments preserved in the museums are of two categories: the string and the wind instruments. The string instruments have, generally, an important difficulty which is, once they are mistuned, one cannot rediscover their original tuning position. On the contrary, the wind instruments keep their original tuning by keeping their dimensions and the position of their holes. Investigating these instruments would reveal a lot about the nature of the ancient Egyptian music and its characteristics. An important problem in the wind instruments is the nature of the Egyptian flute, normally played vertically. For this type of instruments the position of the mouth affects considerably the notes produced by the instrument. Fortunately, in the modern times, the Egyptian flute is played in the same way. That is why an Egyptian flute player would be the most suitable person to test such instrument.

In order to carry out this project, a team was formed from specialists of oriental music, history of music, computer systems specialists and music scientists under the supervision of the staff of the Egyptian Antiquities Organization (EAO). The team had the following objectives:

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1. Mahmoud Effat (Institute of Arabic Music, Academy of Arts, Cairo), Robert Cribbs (California State University, Sacramento), Fathi Saleh (Faculty of Engineering, Cairo University).

1 - Carrying precise measurement of all the wind instruments in the Cairo Egyptian Museum with two purposes: a) checking the old measurements carried by Dr. Hans Hickmann and b) completing the missing dimensions;
2 - Building physical models for the instruments, very similar to the existing ones. This is because most of the existing instruments are very fragile or partially damaged.
3 - Recording the musical sound from the different instruments (Whether the originals if they are in good shape and/or from the models). These recordings are to be carried on specially designed computer system capable of storing the music and perform complicated analysis on it.
4 - Trying to trace the relation between the ancient Egyptian music and the music of other civilizations, especially the Greek civilization which was very much affected by the Egyptian culture.

Motivation of the Project

Over a period of more than one hundred years, different scholars had tried to decypher the notes of the ancient Egyptian flutes, either through the mathematical calculation of the dimensions of the flutes or building physical models and try to play them. Because of the nature of the Egyptian flute, it has no reed and it needs special training to play it. Only Egyptian modern flute players has the ability to play with such instruments. The western scholars, lacking this ability, failed to play this instruments and their efforts in the analysis of ancient instruments came to a deadlock. Recently, a team was formed to execute this project which was mainly centered around a famous Egyptian flute player, Mr. Mahmoud Effat, and got the permission from the Antiquities Organization to carry out the project with the objective of getting answers to the following questions:

1 - Were the Greeks the first people to know the diatonic scale?
2 - What are the different musical scales played by the ancient Egyptians?
3 - What are the relation between the ancient Egyptian scales and other musical scales?

These question bare in mind that Pythagoras, the Greek mathematician, to whom the modern western musical scale is attributed, had lived in Egypt for 21 years and that the Greeks wrote a lot about the quality and perfection of the ancient Egyptian music.

The Work Program

Upon the approval of the head of Egyptian Antiquities Organization to carry out this project, a workplan was set having to accomplish the following steps:

1 - Investigating the available wind instruments at Cairo Museum.
2 - Selecting some instruments and building physical models for them.
3 - Recording the notes produced by some of the original instruments (that could be played) and all the replicas.
4 - The sound recording must be done on high quality tape recorder and also digitally on a computer system for scientific analysis.
5 - Carrying out some scientific analysis for the acoustic features of the instruments.
6 - Deduction of the results which should reveal the notes and the scales used by the ancient Egyptians and their relation with the present scales (Western and Arabic).
7 - Setting future plans for the continuation of the research.

The Available Wind Instruments at Cairo Museum

The available wind instruments at Cairo Museum (apart from the trumpets of king Tutankhamun) are all located in one showcase. Fig. 1 shows a photograph of this showcase with all the instruments inside. The following table summarizes the basic information available on these instruments whereby CG stands for the "Catalogue Générale" number, JE stands for "Journal d'Entrée" number and the JE Prov. stands for "Journal d'Entrée Provisoire" number:

Serial No.	CG	JE	JE Prov.	Date	Provenance
1	69811	44138		COPTIC	
2	69812	44138		COPTIC	
3	69813	27677	28/10/23/13		
4	69814	43328		M.K.	BENI HASSAN
5	69815	46157			SAQQARA
6	69816	46158			SAQQARA
7	69817	63745		XVIII	DEIR EL-MEDINA
8	69818	27345			AKHMIM
9	69819		27/10/23/4		
10	69821		27/10/23/1		
11	69822		27/10/23/2		
12	69823		27/10/23/3		
13	69824		28/10/23/2	FAYUM	
14	69825		28/10/23/3		
15	69826		28/10/23/4		
16	69828		28/10/23/6		
17	69829		28/10/23/7	FAYUM	
18	69830		28/10/23/8		
19	69831		28/10/23/9		
20	69832		28/10/23/10		
21	69833		28/10/23/11		
22	69834		28/10/23/12		
23	69837	27315		N.K.	DEIR EL-BEKHIT
24	69838		28/10/23/1		

The table indicates that there are 24 wind instruments in the showcase and that the date and the provenance information are missed for most of them. In fact, the wind instruments in this showcase are of two categories. The first one belongs to the "Nay", or Egyptian flute, a type of musical instruments without reed.

There are six "Nay"-flutes (CG 69814 to 69819) and they are the subject of this study). Four are made out of Nile bamboo and are similar in nature to those used by the Egyptians today. The remaining two are short "Nay"-flutes. One of them is made out of wood and the other is in metal.

The second category of wind instruments in the showcase belongs to the clarinet or oboe, instrument originally having reed. Unfortunately the reed is missing for all the 18 flutes displayed and it will be difficult to estimate the form and the dimensions of these reeds.

Characteristics of the Egyptian "Nay"-flute

The Egyptian "Nay"-flute is normally made out of Nile bamboo. The bamboo is characterized by the presence of nodes which tends to narrow the diameter of the air column at each node. These nodes are normally blocked in the case of raw bamboo rod. In the ancient Egyptian flutes, the nodes are fully cleared. In the modern Egyptian flute, all node are cleared except the last one at the blowing end (this feature allows the flutes to be blown to higher octaves than normal). The ancient Egyptians used to cut their flutes at the position of the nodes while the modern Egyptians cut their flutes in between the nodes. Finally the ancient Egyptians used very long flutes (about 90 cm.) while the modern Egyptians use relatively shorter flutes (30-60 cm.).

Some notes on the flute acoustics

The tone of a flute depends on the length of the air column. The theory of resonance states that given a tube opened from both sides, it will resonate at a frequency corresponding to a wave length that is equals to twice the length of the tube. Which means that (wave length) = (tube length) x 2. Fig. 2 shows a graphical representation of such a relation.

Parameters affecting air column length in a tube

The previous equation ignores several effects modifying and adding corrections to it. Some of these effects were discussed in Jeans 1938, Culver 1956 and Risset 1977 and some others were not treated, due to the special nature of the Egyptian flute. These effects can be summarized in the following:

1 - End of tube effect (open-end correction)
2 - Mouth piece effect (mouth correction)
3 - Material effect
4 - Hole effect (hole correction)
5 - The bamboo nodes effect
6 - The internal smoothness effect

The first three effects were treated in the studies mentioned above, while the last three effects were discussed in a special paper (see Effat and Saleh [under prep.]).

The Experiment

As said before, six wind instrument belong to the "Nay"-group, four are made out of bamboo (CG 69814 to 69817), one of wood (CG 69818) and one of bronze (CG 69818). The first step was to investigate these flutes, making accurate measurements and comparing the results with those of Hickmann 1949.

Table 1 shows the results of these measurements.

Table 1: Measured Dimensions of the flutes (cms)

Flute No.	1	2	3	4
CG No.	69814	69815	69816	69817
Total length	91.7	89.1	93.2	74.4
diam side A (mouth side)	1.7	1.5	1.7	1.6
diam side B	1.7	1.2	1.6	1.7
Number of holes	3	4	4	3
Distances of the holes from Side A (center)				
First	57.9	54.1	56.7	54.6
Second	64.0	60.0	63.7	61.3
Third	72.5	69.6	73.3	65.0
Fourth		76.4	81.7	
Distances of the nodes from Side A				
First	11.8	8.0	13.2	16.6
Second	29.6	18.5	28.1	32.5
Third	50.8	29.5	43.9	47.2
Fourth	70.9	43.0	59.2	61
Fifth	90.0	57.0	76.2	
Sixth		72.0		
Seventh		87.0		

The results of these measuments indicates that:

1 - three "Nay"-flutes belong to a same family caracterized by a length of about cm. 90 (looking as the dominant flute length at the time of the ancient Egyptians as indicated by different studies on the matter);

2 - only one "Nay"-flute has a shorter length (about 75 cm.);

3 - there are two flutes of shorter length, not made out of Nile bamboo;

4 - the obtained dimensions differ slightly from those of Hickmann 1949;
5 - Hickmann 1949 ignores the diameter of flute CG 69817 and states that the flute has a bad shape. The team found that this flute is better shaped than the three others;
6 - the other studies on the subjet did not take into account the measurement of the bamboo nodes.

After finishing the measurement and investigation task, the team decided the following:

1 - making exact model for all the four bamboo flutes in a similar material;
2 - making models for the wood and bronze flutes in plastic tubes;
3 - from investigations of the different studies, the team decided that only the bamboo flutes belong to the pharonic dynasties, while the other flutes probably date to the Ptolemaic period. The team decided not to stress on the results of these two flutes;
4 - the team found that only two original flutes can be played. The bronze flute and the flute number CG 69817 (dating to the Middle Kingdom), if restored. All other flutes were in bad conditions and too fragile to handle;
5 - the team solicited the Antiquities Organization to restore the mentioned flute and decided to carry out the experiment by playing the two original flutes and the six replicas.

In the third step the team entered the museum with two types of equipment:

- sound recording
- digital recording equipment on computer based system.

The first type of equipment was used to record the sound in a standard audio recording way for subjective (non engineers) analysis especially by musicians.

The second type of equipment was used to record the sound digitally on a computer media and then to treat it with special computer prepared for scientific analysis. The equipment records the signal digitally, loads it into the memory of the computer, apply fourier transforms to generate the frequency spectrum, from which the fundamental frequency of the note and all its harmonics are measured to the nearest one thousand of a Hertz.

Each flute, was played once as a sequence of possible notes of its scale and then played secondly as improvisation music on that scale.

Fig. 3 shows Mr. Effat playing the flute CG 69817 and fig. 4 shows Mr. Effat playing the flute CG 69819. Fig. 5 shows the computer display of the notes while playing. Fig. 6 shows the working team.

Subjective Results

Playing the different (bamboo) flutes produced the following notes that were identified by different music experts in a subjective test as follows:

Flute No.	1	2	3	4
CG	69814	69815	69816	69817
Type of Scale	Pentatonic (7 notes)	Diatonic (7 notes)	Diatonic (7 notes)	Diatonic
First note	F	F	F	A
Second	G	G	G	B
Third	-	Abb	*Ab	C
Fouth	Bb	Bb	Bb	D
Fifth	C	C	C	E
Sixth	D	D	D	F#
Seventh	-	Eb	*Eb	G
Eights	F	F	F	A

* These two notes are somewhere inbetween the flat and the 1/2 flat)

Note: 1/2 flat means a note that falls half way between the natural note and the flat (sometimes noted in case of arabic music as quarter tone). It is noted in this table as bb.

Measured Results

The measurement was carried for each flute as follows:

1. a sequence of notes is recorded within a total period of 15 seconds (corresponding to about 2 Mbytes of memory). Fig. 7 shows the computer printout of such signal for the flute CG 69817.
2. the one by one display of the notes is isolated and expanded for the analysis of that note. Fig. 8 shows the computer printout of an expansion of the note number 1 of Fig. 7;
3. a fourrier transform is applied to the isolated note signal in order to obtain the spectrum of the signal and its harmonic content. Fig. 9 shows the computer printout of the spectrum of the signal of Fig. 8;
4. the values of the maxima of the spectrum is normalised (such that the highest peak would equal to 50) and printed. Fig. 10 shows the printout of the spectral values.

It should be noted that the selection of range of the isolated note is very important. If this range is wide, it will includes some of the noise inbetween the notes and also the rise and fall of the notes. This would cause the appearance of many unwanted maxima in the spectrum. On the other hand, if the range is very narrow, it might fall in a range that is not really representing the average played frequency of the note.
Table 2 gives the computer frequency measurement in a com-

parative tabular form.
Table 3 gives the calculated frequency ratios of frequencies calculated with reference to the basic note. The table also shows these ratios for the natural scale.
Table 4 gives the calculated logarithmic (cents) values of the different notes.
Fig. 11 and 12 show graphic representations of these results.

Interpretation of Results

The results of these tables indicates the following:

1. they emphasise the subjective results with the following comments: a) the uncertain notes of the flute number CG 68916 are closer to the Arabic scale notes, b) the values of the flute CG 68917 frequences are flatter than the standard ratios;
2. the presence of a diatonic (seven notes) scale in three of these flutes;
3. the flute CG 69814 is from the Middle Kingdom and has been found at Beni Hassan. It gives an almost perfect pentatonic scale having the F as a base note and missing the third and seventh notes of the diatonic scale;
4. the flute CG 69817 is from the NK (XVIII dynasty) and has been found at Deir El-Medina. It plays a clear diatonic scale based on the A note. It gives a scale in A minor with the fourth note flatter than usual;
5. the flute CG 69815 is of unknown date and was found in Saqqara. It gives an almost perfect arabic seven note scale (with the third note half way between the A and Ab), also based on the F note. This suggests that the Arabic scale was originated at the time of ancient Egyptians and was used afterwards by the Persians who transfered it to the Arabic civilisation.
6. the flute CG 69816 is of unknown dating and was found also in Saqqara. It gives a scale very similar to that of CG 69815

flute, except for the fourth note that resulted a little ambigous in subjective test;
7. although the flutes CG 69815 and 69816 are of unknown dates, the shape and the length seem to indicate them as pure ancient Egyptian products. One of the extensions of this project is to carry out Carbon-14 dating test for these two flutes;
8. three out of the four flutes have almost the same length and consequently base note (F note). This base note corresponds to the lowest human natural singing sound.
9. investigating the frequency table shows very interesting result. The frequency values of the notes of the flute CG 69814 (pentatonic) and CG 69816 (diatonic) are very close to one another with one Hertz difference. Remembering that these two flutes are hundreds of years apart and hundreds of kilometers apart, this would suggest that there was a kind of a source of standard musical notes. (may be there was a sacred flute in a principal temple that was used as a yardstick). It is also interesting to note the similarity of frequencies of the first two notes of the flute CG 69817 and the third and fourth notes of the flute number CG 69816 (although one of them is F based and the other is A based).

Conclusion

The main objective of the project was to find out whether the ancient Egyptians knew the diatonic scale. The answer is more fascinating than the objective in the following sense:

- the ancient Egyptians had a pentatonic scale in the old time that developed at the beginning of the New Kingdom to seven note scale of A minor.
- the ancient Egyptian had, in addition to the diatonic scale, an Arabic seven note scale that was thought to have originated in Persia.

- there is a fascinating correlation between the frequencies produced from different flutes which suggests the presence of a means for calibration of these instruments.
- all these conclusions are stemmed from experimentation with only four flutes. The team thinks that extending the research work to a wider number of flutes (from different museums) would reveal more informations.

Acknowledgement

The authors would like to express their deep gratitude to Dr. M. Bakr, head of the Egyptian Antiquities Organization for giving the permission to carry out this project. Special thanks to Mr. M. Mohsen, general manager of Cairo Museum and Mrs. S. Abdelaal, assistant general manager, for their encouragement and technical support to carry out this work.

Thanks also goes to Dr. Bahaa Madkour for the photographic coverage of the project and the team of Cairo University: Dr. A. Darwish, H. El Kadi, H. Hussein and M. Elhady without whom this experiment could not have been realized efficiently.

Table 2: measured frequencies of notes produced by different flutes

Flute	CG 69814	CG 69816	CG 69817	CG 69815
	345.7	343.1		360.9
	390.7	390.4		401.2
		419.9	419.9	441.7
	468.5	468.8	468.4	489.3
	517.6	518.2	498.0	529.9
	585.1	583.7	540.5	605.4
		634.8	625.2	664.4
	683.6	703.1	687.3	772.9
	771.5	800.6	732.2	800.8
			839.5	

Table 3: calculated frequency ratios related to the base note

Flute	CG 69814	CG 69816	CG 69817	CG 69815
	1.00	1.00	1.00	1.00
	1.13	1.14	1.12	1.11
		1.22	1.19	1.22
	1.36	1.37	1.30	1.36
	1.50	1.51	1.49	1.47
	1.69	1.70	1.64	1.68
		1.85	1.74	1.84
	1.98	2.05	2.00	2.00
	2.23	2.33		2.22

Table 4: calculated logarithmic (cent) frequency ratio related to the base note

Flute	CG 69814	CG 69816	CG 69817	CG 69815
	0	0	0	0
	212	223	189	218
		349	295	350
	526	540	456	526
	699	714	690	665
	911	920	853	895
		1065	963	1056
	1180	1242	1199	1202
	1390	1467		1380

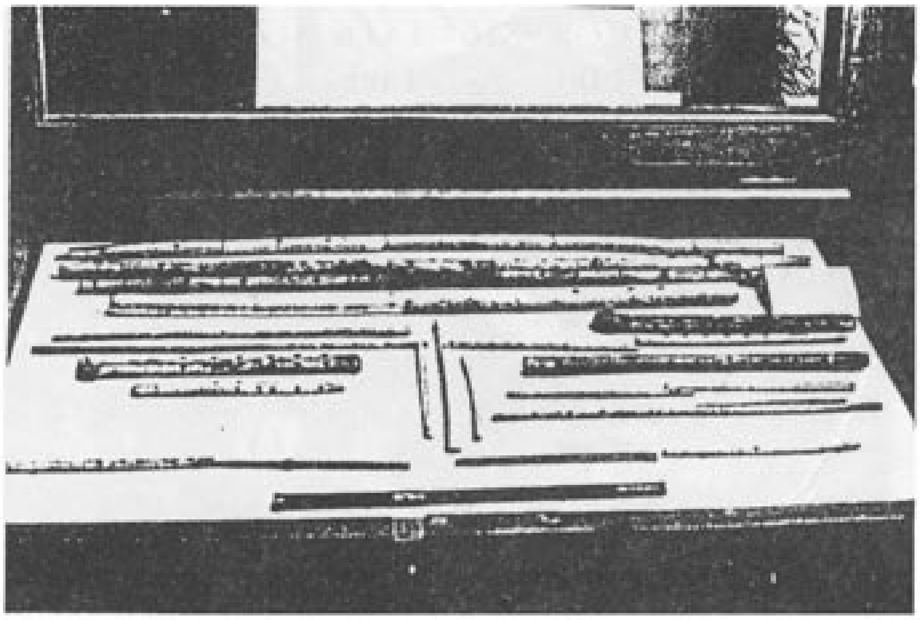

Figure 1 : Show case of the ancient Egyptian Flutes at Cairo Museum

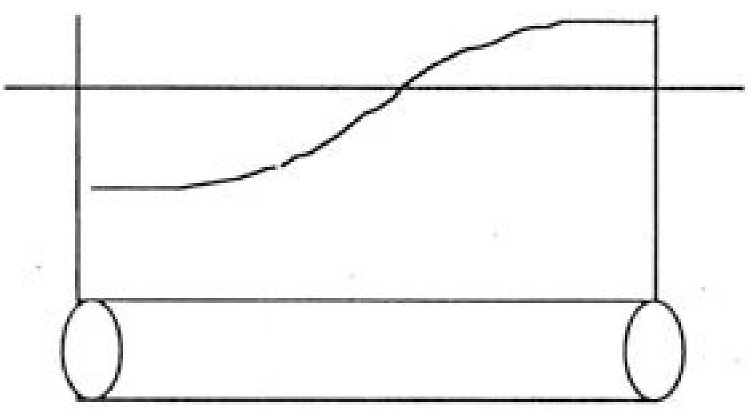

Figure 2 : Relation of the open ended tube to the Wave length

Figure 3 : Mr. Effat playing the flute No. 69817 (XVIII dynastry)

Figure 4 : Mr. Effat playing the flute No. 69819 (the Bronze flute)

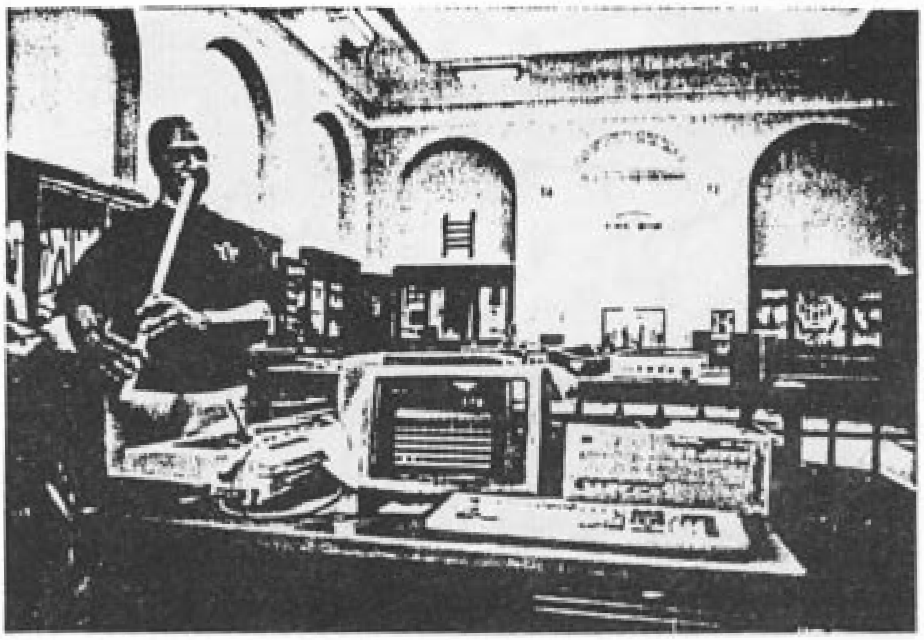

Figure 5 : Computer display of the note while playing

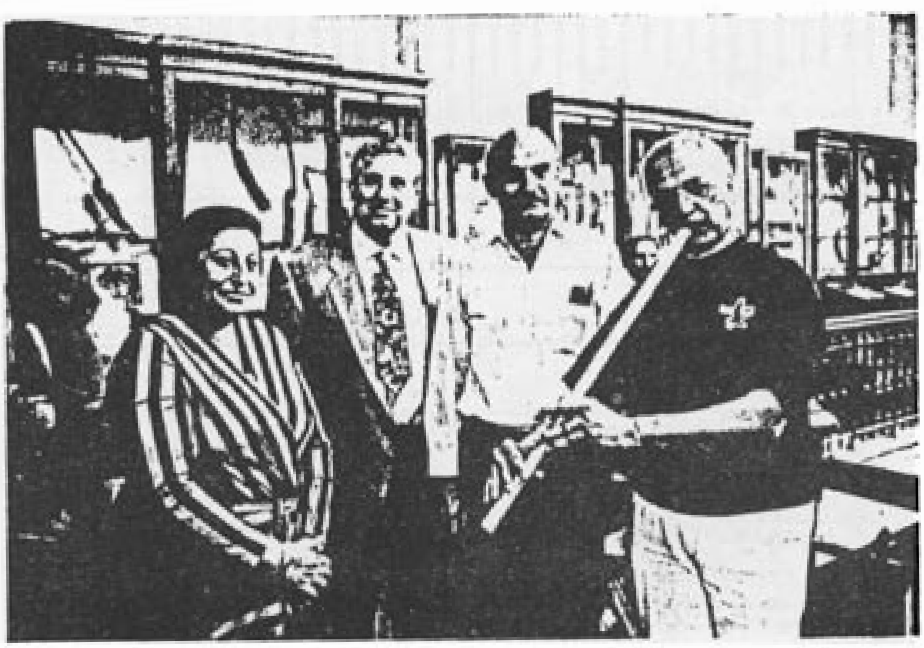

Figure 6 : The work team (from right to left Mr. Effat, F. Saleh, R. Cribbs, S. Abdelaal

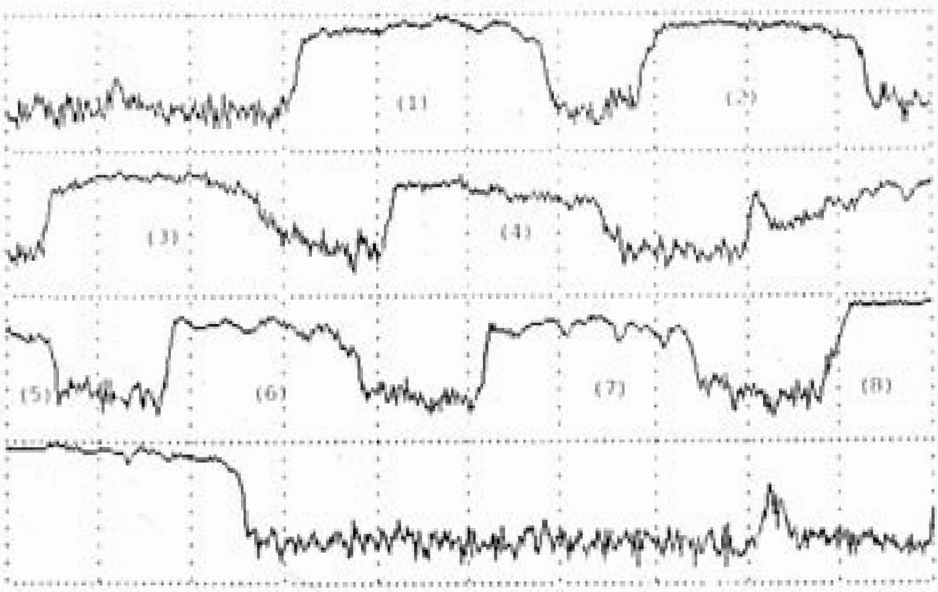

Figure 7 : Computer printout for notes played by flute No. 69817.

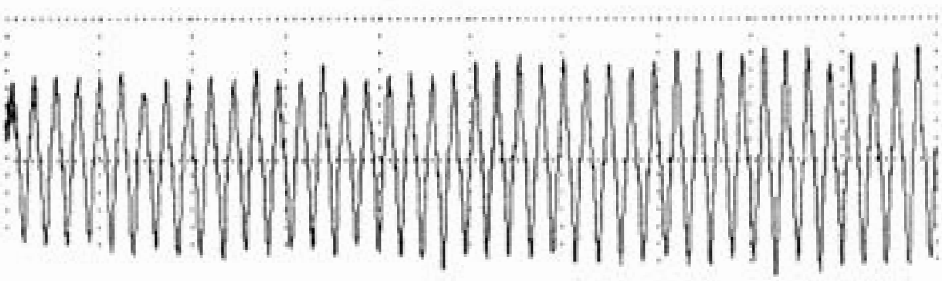

Figure 8 Expansion of note No. 1

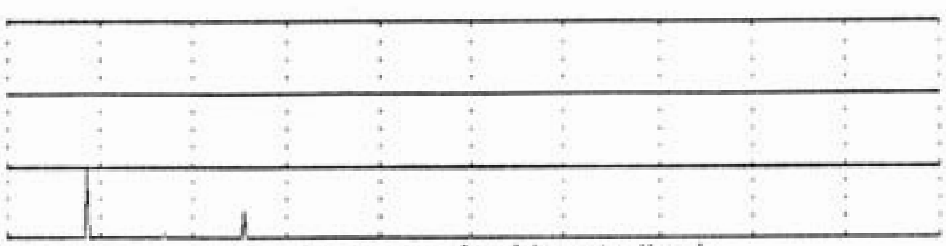

Figure 9 : Spectrum produced by note No. 1

NO	FREQ	AMPLITUDE (DB)
1	419.9651000	50.0001700
2	839.5721000	2.4834300
3	1260.2120000	16.9742600

Figure 10 : Spectral values of note number 1

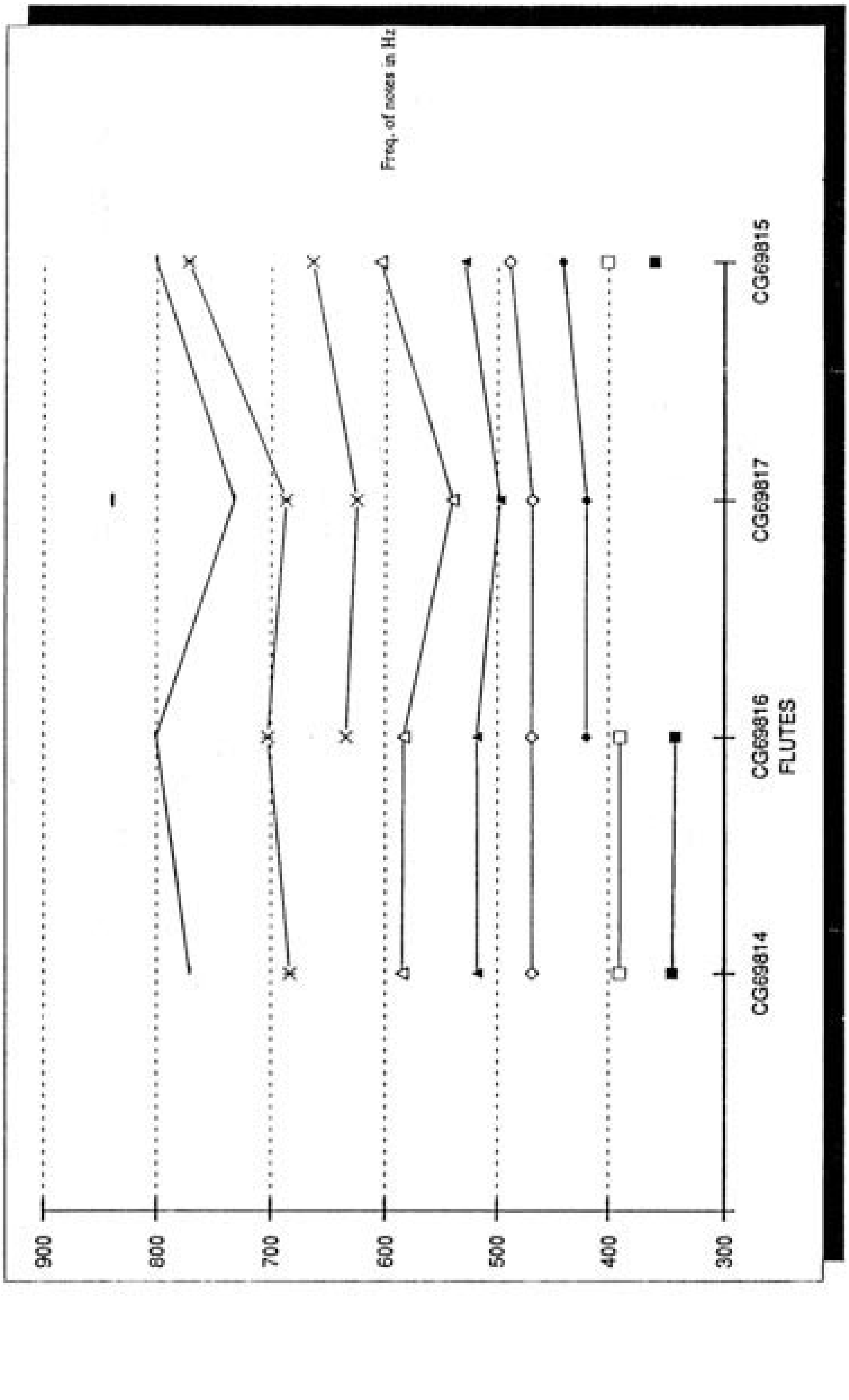

Figure 11. Graphic presentation of Table no. 2

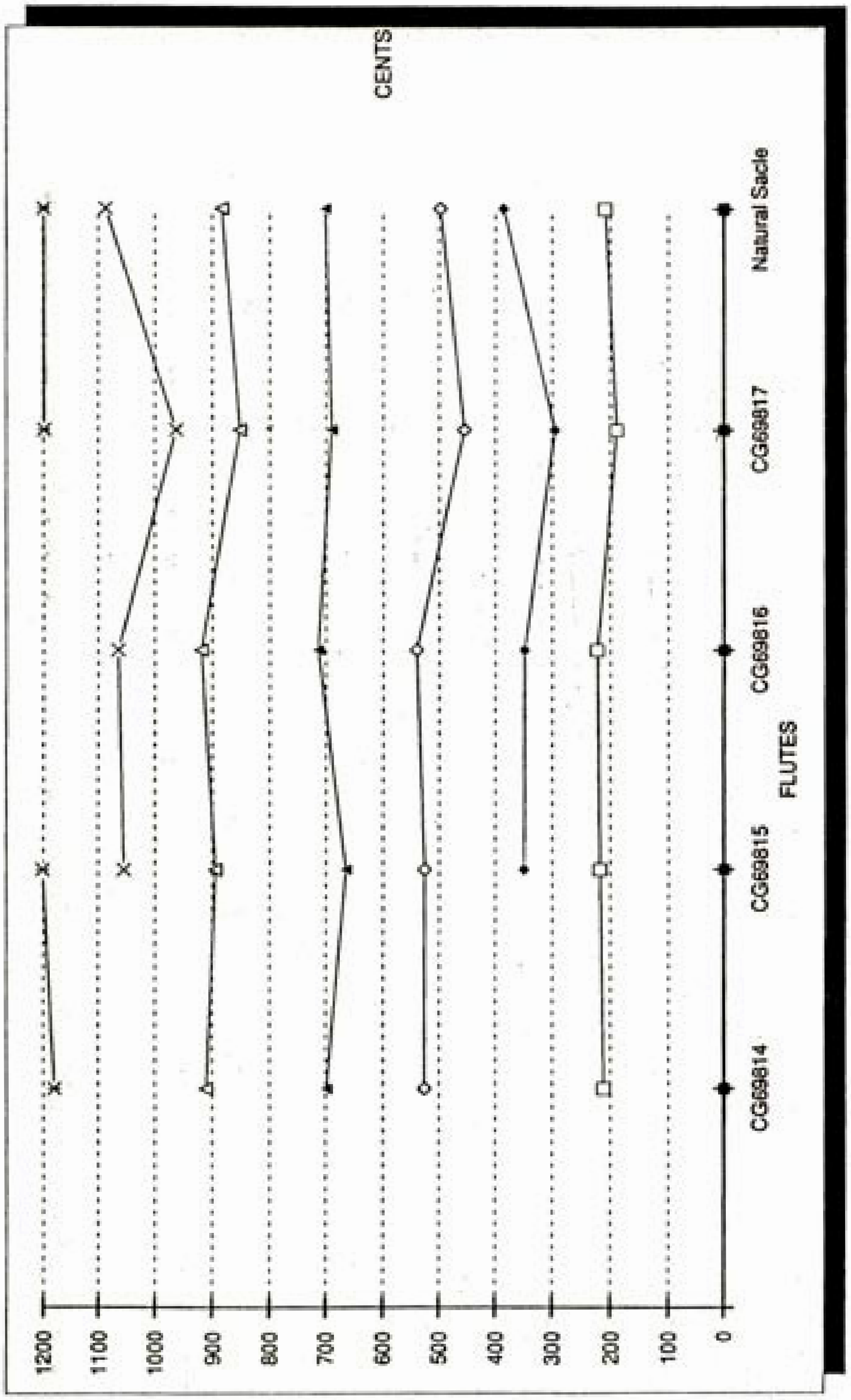

Figure 12. Graphic presentation of Table no. 4

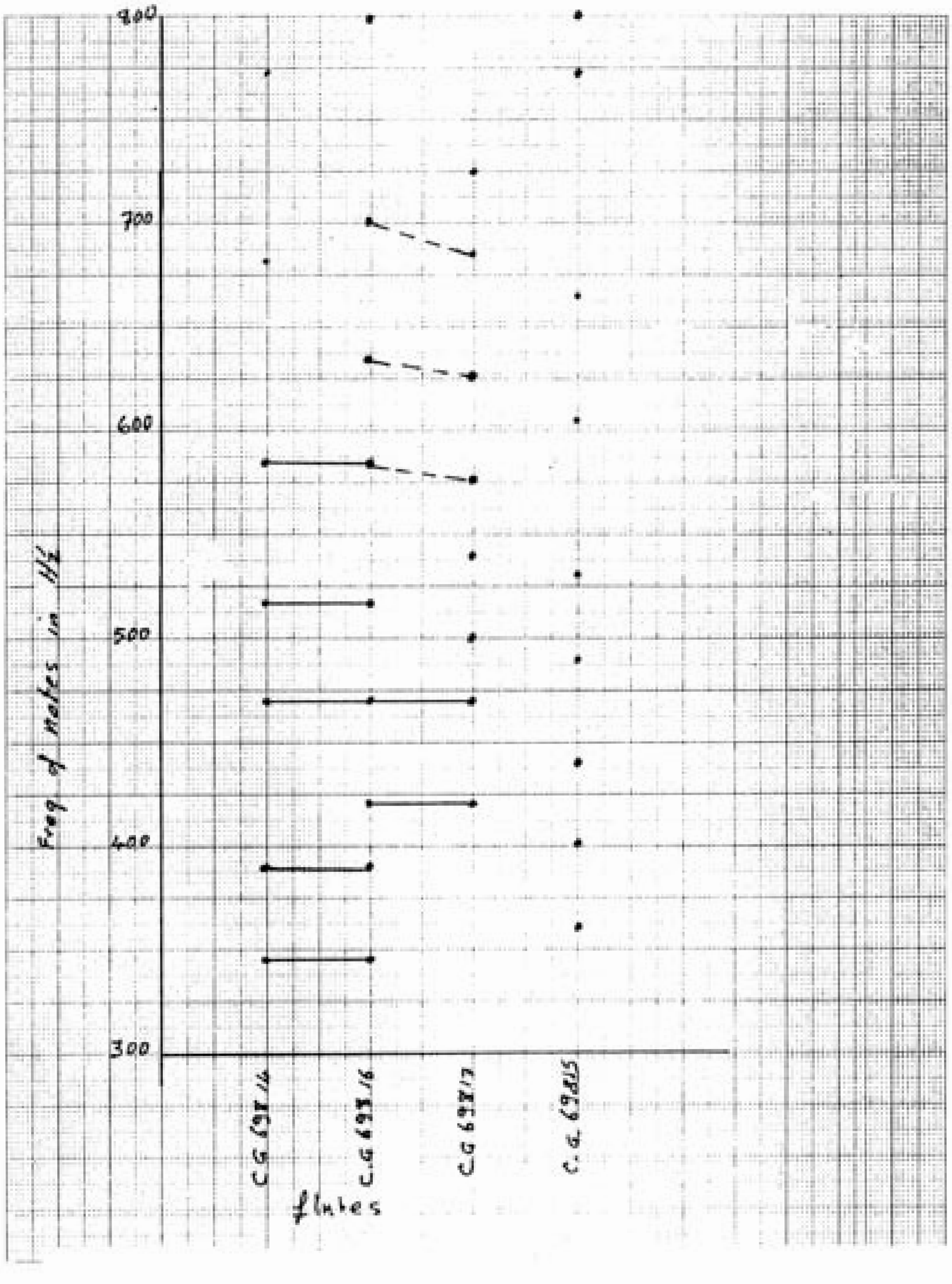

Figure 11. Graphic presentation of Table no. 2

(Lines Shows notes of great frequency correlation)

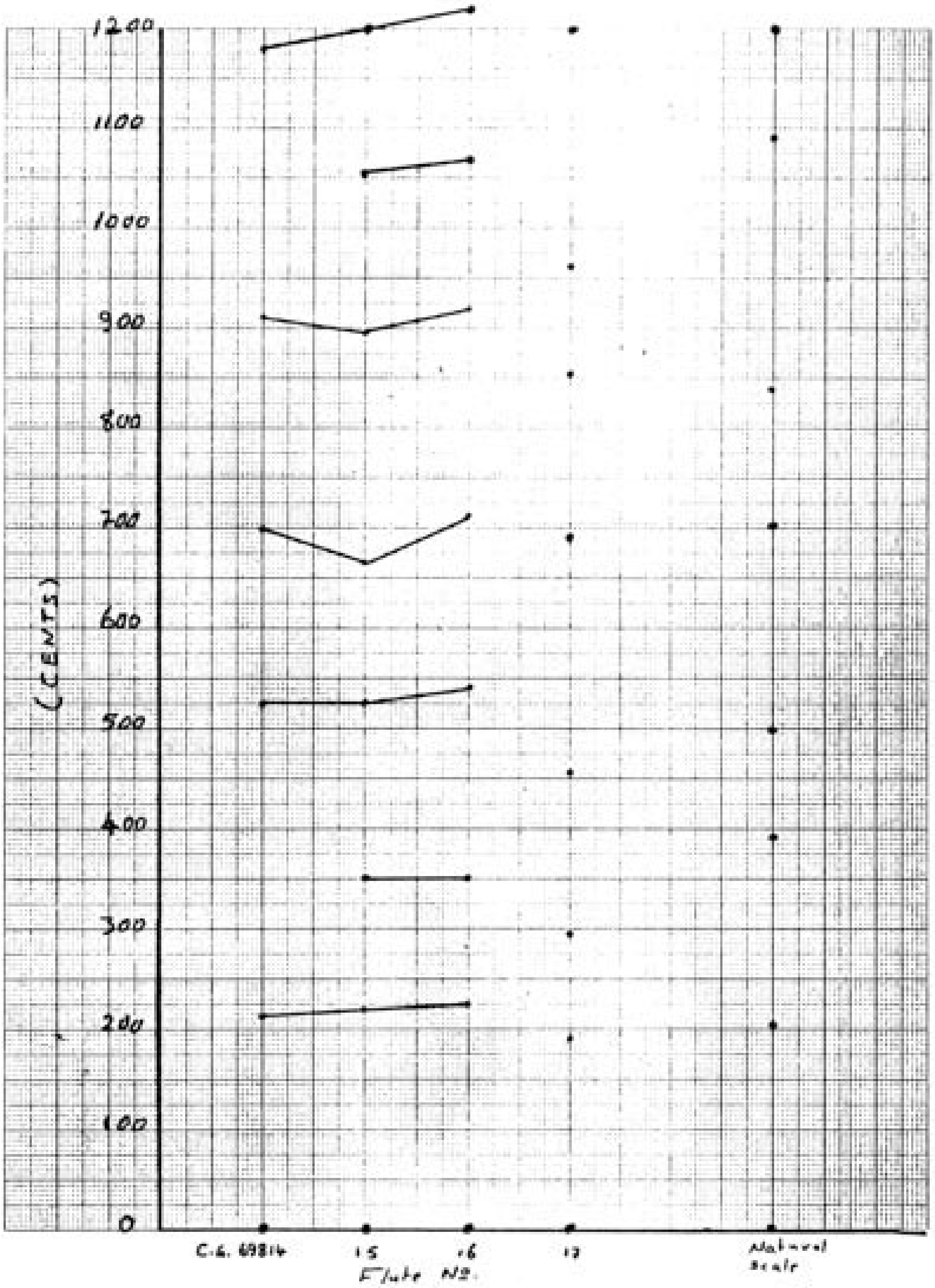

Figure 12. Graphic presentation of Table no. 4