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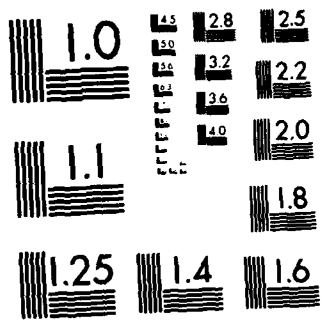

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Measurement of Lung Function Using the Magnetometer System

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Measurement of Lung Function Using the Magnetometer System.

Introduction

In the last few years, several investigators ~~[1,6,7,9,10,11,12]~~ have studied the idea of estimating lung volume by measuring the dimensional changes of the chest and abdomen during respiration. The prospect of being able to know the value of lung volume from information obtained noninvasively was intriguing.

The most common method of measuring the dimensional changes is to use magnetometer pairs. A more complete description of the principles of operation can be found elsewhere [7]. For the purpose of this report, it is sufficient to note that magnetometer pairs generate a voltage that is proportional to the change in their separation distance. The relationship between voltage and the change in separation distance is essentially linear over the separation distances measured in this study.

If one is to adequately infer lung volumes from the measurement of dimensional changes of the thorax and or abdomen, the following questions must be addressed:

1). What dimensional changes should be measured?

2). How are the dimensional changes related to lung volume changes?

3). How reliable can the dimensional changes be measured?

4). Does the relationship between dimensional changes and lung volume change from breath to breath, or with the respiratory maneuver?

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5). Does the relationship between lung volumes and dimensional changes differ from individual to individual?

We will attempt to answer many of the above questions, and will speculate on the answers to the others. Before describing our current experiments, however, it is worthwhile to review recent measurements with magnetometers.

The use of magnetometers in studying pulmonary ventilation was proposed by Mead et al. [7]. In this pioneering work, Mead and co-workers built upon an earlier study [6] in which they proposed that the abdomino-thoracic cavity could be treated as a two degree of freedom system (rib cage and abdomen), and that for isovolume maneuvers, volume change is nearly linearly related to changes in anteroposterior (AP) diameters. They showed [7] that, after calibration, the sum of magnetometer measured AP rib cage and abdominal diameters reflect lung changes closely. They recommended, therefore, that magnetometer measurements of minute ventilation would be useful where conventional (eg. spirometric) techniques were inconvenient.

Gilbert et al. [3] used the method proposed by Konno and Mead to investigate breathing patterns during CO_2 inhalation. The major change was their introduction of a new "calibration procedure" whereby the two magnetometer signals (chest and abdomen) were "scaled" graphically by-superimposing two breaths (an abdominal breath and a chest breath). In this way, they found that the "scaled-summed" magnetometer signal was linearly related to the spirometer volumes. The magnetometer-measured data was then used to construct tidal volume - ventilation curves for ten subjects.

In a later study, Gilbert et al. [4] used magnetometer-measured tidal volumes to show that conventional methods utilizing noseclips and mouthpieces alter the pulmonary parameters of : respiratory frequency, ventilation and tidal volume.

Grassino and Anthonisen [5] used magnetometers to examine the degree of distortion of the chest wall at functional residual capacity (FRC) during both high resistive inspiration and under external lateral compressions. In addition, they used magnetometer pairs to describe thoracic shape alterations while simultaneous regional volume distributions were measured with a Xeon technique. It is important to note that their studies were for isovolume maneuvers and that the results of Konno and Mead [6] were applicable.

Ashutosh et al. [2] used magnetometer-measured AP diametrical changes to study breathing patterns in both normal and COPD (Chronic Obstructive Pulmonary Disease) patients. They showed qualitatively that both abdominal and chest motions where synchronous with spirometrically measured breathing in all 10 normal subjects and in 7 of 17 COPD patients. In the other 10 COPD patients, the chest motion was found to be synchronous with spirometric volume, but the abdominal signal was asynchronous. It was further shown that, in general, the asynchronous pattern corresponded to a poorer patient prognosis. They concluded that recognition of this type of breathing pattern could be most helpful in initial patient assessment. Also, in an interesting application, they used the magnetometer signals to instruct patients to improve their breathing patterns by matching the magnetometer-measured breathing patterns with normal (desired) pattterns. This method was used to help wean patients off of ventilatory assist devices.

Sharp et al. [10], using what they call the "Konno and Mead method of thoracoabdominal partitioning of breathing", looked at 81 normal subjects to investigate whether variations related to sex and/or age differences exist. Using two magnetometer pairs (chest and abdomen), they found no major differences in relative contributions of rib cage/abdominal breathing between men and women, or between young and old during any respiratory act. In addition, they pointed out two most important points: first, that for rapid ventilatory maneuvers, the approximately linear relationship between volume change and AP diameter no longer prevails, although preliminary studies suggested that in these ranges magnetometer based information is still qualitatively useful; and second, that phase lags in the lateral and AP diameter changes (rib cage and abdomen) render useless any attempts to interpret phase relationships during maximal voluntary ventilation.

In summary, we notice that the aforementioned investigations have used two magnetometer pairs to qualitatively investigate the roles of the rib cage and abdomen in breathing. Now, we mention several investigators who report quantitative results on inferring lung volumes from magnetometer measured diametrical body surface changes.

Stagg et al. [11], again using two magnetometers, introduced both a new calibration method and a volume model from which tidal volumes could be inferred. They showed that it is possible to calibrate the magnetometers accurately during spontaneous breathing. However, they (like Sharp) pointed out that there was no reported evidence stating that chest wall displacements are linearly related to volume at the extremes of vital capacity. Thus, they concluded, that magnetometer measurements should be used within "moderate" volume ranges. They suggest the technique as an accurate means of measuring tidal volume and the time components of individual breaths.

They suggest four possible sources of error in the magnetometer based method: first, the calibration procedure; second, accurately defining the change in respiratory phase (expiration to inspiration); third, compression and decompression of thoracic gas at higher rates of ventilation, and fourth, cases of abnormal abdominothoracic distortion.

Robertson et al. [9] postulated three volume models (the first of which was analagous to Stagg) to quantitatively evaluate lung volume. They propsed that two additional magnetometer pairs (placed laterally at the same level as the AP) be used in the model. They showed that a four-magnetometer elliptical cylinder model gave the best results in quiet breathing and in vital capacity. They also point out that at the extremes of lung volume, the method <u>may</u> break down. Robertson reports an everpresent counterclockwise "looping" of the estimated volume at all tidal volume ranges. They suggest two possible reasons: first, "that different levels of the chest may behave differently in relation to the magnetometer between inspiration and expiration; they may lag behind or precede movements of the magnetometers". Second, the shift of blood to and from the extremities and thorax may be a factor. They conclude, however, that this method may be particularly well suited to studies of respiratory control and patient monitoring.

Ackerman [1], using the method of Robertson, automated the volume measurement on-line. He reports that breaths per minute, average tidal volume, and minute volume can be inferred and displayed at 15 second intervals while monitoring a patient. He reports results are accurate to within 10% of spirometric techniques.

Vawter [12], tested seven volume models (one being the same as the Robertson model) and showed that any two or three parameter model is adequate to predict volume for the breath from which the model constants are determined. He further reported that calibration should be done with a complex respiratory maneuver if the model is required to predict such complex maneuvers.

Although Vawter suggests that no one dimensional measurement is sufficient to predict volume changes, he does report that two anatomical sites (AP chest and AP abdomen) individually correlated 85% or higher with spirometric volume. He, as did Robertson, noted the "looping" or hysteresis of respiratory movement and suggested the need to consider it in any further studies.

Melissinos et al. [8] studied changes in abdominothoracic shape during forced vital capacity (FVC) maneuvers. Using four magnetometers at different sites than aforementioned, they reported that at the AP xiphi-sternal junction and AP manubrium site that diametrical changes with volume <u>are</u> useful indices of the motion of the anterior chest during FVC. They also note that measurements are accurate (from iso-volume calibration [6]) during spontaneous breathing and slow respiratory manuevers (20-80% vital capacity). They found changes in lateral xiphi-sternal magnetometers quite variable with subject. Also they report that AP abdominal changes <u>may</u> not be representative of the over-all movement of the anterior abdominal wall. Finally, they demonstrated substantial nonuniformites in regional abdominothoracic dimension changes during FVC, and that overall chest wall volume displacement cannot be accurately represented by the two common magnetometer positions (rib cage and abdominal) during FVC.

METHODS

In order to answer the questions posed above, we have conducted a series of experiments in which we measured simultaneously both dimensional changes and changes in lung volume.

Four magnetometer pairs were used to measure diametrical changes of the abdominothoracic cavity at eight anatomical sites. Consistent with previous studies, the midline, both AP and laterally, was chosen as a locus of possible placement sites. We note that the lateral magnetometers were placed just anterior to the the latissimus dorsi muscle. The eight sites chosen were : AP; M_1, just superior to the sternal arch; M_2, at the level of the xiphoid; M_3, midway between the xiphoid and umbilicus, and M_4, just inferior to the umbilicus. Laterally: M_5, at the level of the fourth rib; M_6, just inferior to the xiphoid level; M_7, midway between M_6 and M_8, and M_8 at the level of the umbilicus (Fig.1).

Eleven normal subjects (ages 19-29) with no prior pulmonary function testing experience were studied (table 1). The magnetometer pairs were taped securely in the above mentioned postions. Care was taken that the long axes (y_1 and y_2 see Fig. 2) were parallel to avoid rotational effects [12]. Proper alignment was obtained at the postion which generated a global minimum in voltage when one magnetometer was rotated with respect to the other.

Standing erect, each subject performed two separate breathing maneuvers: "quiet breathing" and "forced breathing" (ie., one vital capacity maneuver was performed at the middle of a quiet breathing sequence). A total of eight breathing tests, each of forty-five seconds duration were performed by each subject. Thus, two "quiet" and two"forced" breathing tests were performed at each of the eight magnetometer placement sites.

A given test consisted of the subject performing the particular maneuver by breathing into a spirometer (Model 840, Ohio Medical Products) with his nose clamped. The subject was instructed to minimize all unnecessary body motions. The spirometer and the four magnetometer signals were recorded simultaneously as voltage (output) versus time (Fig. 3). A Minc 11 Computer (Digital Equipment Company) was used to convert the five analog signals to digitized form, and then to store the data on floppy disk for later analysis. All programs were written in BASIC (Appendix 1), and the data sampling rate was 66.67 samples per second (ie. 13.33 samples per channel per second).

Quantitative data analysis consisted of two approaches: First, in order to investigate the relationship between spirometric data and the diametrical changes of the chest and the abdomen, as well as the cross relationship between various anatomical sites (M_1-M_8), correlation coefficients (ρ) for the respective data were calculated. Second, fourier analysis was used to represent the data (ie. a given breath) as a sum of sinusoidal components to study the influence of "phase" and "amplitude" on the correlation. Two authors [8,9] have speculated that "phase differences" may influence how well magnetometer based techniques can be used to infer volume information. In addition, the spectral analysis allowed us to ascertain whether the signals could be modeled by a simple harmonic function.

Since dimensional changes during expiration and inspiration may be different [9,12], each portion of the breathing maneuver was analyzed separately.

RESULTS

The correlation coefficients relating the spirometric results to each of the eight magnetometer placement positions are given for each subject (Appendix 2). It can be seen from these tables that for each subject, at least one AP position had a correlation with the spirometric data of greater than 0.9. In all subjects, except subject #9, the M_1 location has the highest correlation coefficient. Subject #9 is an abdominal breather which illustrates the need to allow for different subject types. Tables 2, 3, 4 and 5 list the averaged correlation coefficients $\pm$ standard deviations for correlation between spirometer-magnetometer position and cross correlations between the magnetometer positions. Gross observations from tables 2, 3, 4 and 5 show that the AP positions in each case correlate higher than their lateral counter parts. As can be seen, the M_1, position tends to correlate very well (> 0.95) with the spirometer. It is important to note that this high correlation is coupled with a very low standard deviation. On the other hand, we note poor correlation between the spirometer and the M_2 and M_6 positions (ie. AP and lateral xiphoid levels). Not only are the correlations ($.1610 < \rho < .4638$) very poor, but the scatter of the data is reflected by the large standard deviations (.3818 - .5982). Also, it is seen that negative correlations arise in the xiphoid data (subjects 6,7 in the AP position and subjects 6,9,10,11 in the lateral position). Determination of the cause of this poor correlation would require alternate measurement of the dimensional changes. It could be that paradoxical breathing is the cause or that the magnetometers in this position were subjected to rotational motions, to which the magnetometers are sensitive [12].

The only cross correlation between magnetometer sites (AP and lateral considered separately) with a 80% or higher correlation is between the M_3 and M_4 sites (84% and 83%). Also, note that the correlation between magnetometer pairs is much lower than between the magnetometers and the spirometer. If the correlations were high, then the measurements would be redundant and one of the pairs could be eliminated.

The correlation coefficients reported above were calculated from data sets of seven to twelve breaths (45 seconds) for each of the two maneuvers. In addition, we looked at correlation coefficients for individual breaths, and at the inspiratory and expiratory portions of single breaths. We found that, in general, the correlation coefficient for an individual breath was higher than that of the total breathing sequence, and as the number of breaths increased toward the total for that individual test, the correlation coefficients approached that of the total. These results are to be expected if there are breath to breath variations in the signals (and if the signals have only a small component of random noise). No significant patterns were observed in this result (Table 6).

In table 7 we show the correlation coefficients for each subject (AP positions only) for six individual breaths from a "quiet breathing" test. As can be seen from the averages $\pm$ standard deviations, position

M_1 has a high average correlation (>0.93) and a low standard deviation (.002 - .055). As in the above, the abdominal breather (subject #9) had the lowest M_1 correlation. Also, the M_2 position had the greatest variability and typically the largest scatter in the date. We observe, therefore, that breath to breath variations do not appear significant except in the M_2 position.

In the "forced breathing" manuever, the subject was instructed, at a particular instant, to (on his/her end resting expiratory volume) inhale as deeply as possible (i.e. to maximum inspiratory level) and then exhale totally. This can be seen in figure 3 in the eighth breath. In each of the above cases, the correlations were calculated based on either averaged breathing or on quiet breaths. In table 8, we show for each subject the AP correlation coefficients calculated from a single "forced breath". As can be seen, observation of the forced breathing results showed no remarkable differences from those of quiet breathing.

To investigate the dependence of volume on magnetometer measured dimensional changes we plotted one versus the other. In most every case, hysteresis was present showing differences between expiration and inspiration. We generated these plots (spirometer vs M_i, i = 1,2...8) for three breaths for each subject. In general, of the AP positions, it was the M_1 position which gave the least hysteresis and the M_2 position which corresponded to the most hysteresis (see Fig. 4). We note, however, that considerable variation in hysteresis was seen on a breath to breath basis (see Fig. 5). Similar results were observed laterally (Fig. 6). The degree of hysteresis is certainly reflected in the calculated correlation coefficients: this can be seen in figure 7 where three different plots are given with the corresponding correlation for that breath. Thus, we felt it beneficial to separate the breath into its inspiratory and expiratory portions and calculate the respective correlation coefficients. We show the results calculated over a single quiet breath in table 9. It is worthwhile to note that in each case where the total breath correlation is 0.99 or greater, the inspiratory and expiratory results are essentially the same, as expected. In the case shown, it is interesting that both subjects for which higher abdominal correlations occurred, (subject #9 and subject #11 for this breath) the expiratory results were correlated higher than the inspiratory (for all > 0.99). Conversely, the other nine subjects tended to have higher inspiratory results in cases where the results did differ.

The fourier analysis (Appendix 3) reveals that the amplitude of the first harmonic was normally 7 to 20 times as large as those for higher harmonics for both the spirometer and the M_1 magnetometer. The other magnetometers would not be adequately described using a single harmonic. In figure 8 we show a M_2 plot for a single breath, and the need for seven harmonics to adequately describe the curve. In fact, often for the xiphoid level, the first harmonic was not dominant.

We also give in table 10 the calculated correlation coefficients for the breath for which the fourier results are given. Generally, it is seen that in cases of high correlation the phase difference between spirometer and magnetometer position is lower. Looking at the magnetometer position which had the most dominant first harmonic (which tended to coincide with the highest correlation for that subject) we see no consistent pattern as to the dimensional changes lagging or leading the spirometric results. Thus, we can only say that variations from subject to subject are observable in this regard.

DISCUCSSION

Unfortunately, to date there exists no literature to which we can directly compare our results. There are, however, reported findings and/or speculations to which our results may be addressed.

Robertson et al. [9] and Melissinos et al. [8] suggest that different levels of the chest and abdomen, respectively, behave differently in relation to the magnetometer - volume results. We point out that each of the eight anatomical sites considered herein did yield different results in correlation, hysteresis and phase relationships. Thus we have shown that although within a given anatomical region correlations may be similar (eg. M_3 and M_4 vs S in tables 2,3), each site considered did behave differently. Coupling our results with those reported by Vawter [12] further substantiates this point.

Sharp et al. [10] and Robertson et al. [9] both mention that the difference in phase between volume and dimensional changes may influence the usefulness of the magnetometer-found data. Indeed this may well be true but may be difficult to quantify. Only the M_1 position yielded results in which a dominant first harmonic was seen, and as pointed out above, subject to subject variability renders this analysis quite useless in generating a general conclusion.

We conclude by emphasizing comments by Robertson et al. [9] and Ashutosh et al. [2] in that the usefulness of magnetometers in studying pulmonary function may indeed lie in the realm of patient assessment and patient monitoring. Certainly, information from M_1 and M_3 or M_4

positions is qualitatively useful. However, useful quantitative inference of lung volumes from magnetometer-measured dimensional changes for the general populus appears unlikely to be found.

Conclusions

In the introduction we posed five questions and feel we can now comment on them:

1) What dimensional changes should be measured. Positions M_1 and M_3 show the most promise.

2) How are the dimensional changes related to lung volume changes. The relationship is complex and nonlinear, and also exhibits phase shifts and hysteresis.

3-5) How reliable can the dimensional changes be measured. Even for a given subject there are breath to breath differences. Between subjects the pattern of dimensional changes is not predictable.

Our conclusion is that magnetometers are useful for quantitative measurement of dimensional changes but because of the complexity of respiration will likely only have qualitative value in inferring lung volume.

Acknowledgment

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Table 1. Physical Characteristics of Subjects

SUBJECT	SEX	HEIGHT (cm)	WEIGHT (kg)	CHEST (cm)	WAIST (cm)
1	F	(162)	(46.3)	(81.3)	(58.4)
2	M	(183)	(72.6)	(91.4)	(80.0)
3	M	(190)	(81.6)	(96.5)	(83.8)
4	M	(190)	(74.8)	(91.4)	(78.7)
5	M	(185)	(76.2)	(91.4)	(78.7)
6	F	(162)	(49.9)	(86.4)	(63.5)
7	F	(168)	(54.4)	(86.4)	(66.0)
8	M	(185)	(74.8)	(91.4)	(83.8)
9	M	(183)	(90.7)	(114.3)	(86.4)
10	M	(178)	(63.5)	(91.4)	(78.7)
11	M	(188)	(90.7)	(100.3)	(86.4)

Tables 2, 3, 4, 5. Averaged correlation coefficients over the test duration. S is for spirometer and $M_i (i = 1,2....8)$ is magnetometer location. Notice the higher correlations for the AP positions compared to the lateral sites. Also, note the relatively high M_1 and low M_2, M_6 correlations.

TABLE 2 AP QUIET BREATHING

	S	M_1	M_2	M_3	M_4
S	1±0				
M_1	.9505±.0510	1±0	symmetric		
M_2	.4638±.4118	.3764±.4169	1±0		
M_3	.7647±.1803	.6728±.2385	.6581±.3716	1±0	
M_4	.7999±.1455	.7104±.2307	.5659±.3224	.8422±.1428	1±0

TABLE 3 AP FORCED BREATHING

	S	M_5	M_6	M_7	M_8
S	1±0				
M_1	.9675±.0241	1±0	symmetric		
M_2	.4121±.3818	.3422±.4103	1±0		
M_3	.7945±.1150	.6917±.1527	.5227±.3238	1±0	
M_4	.6871±.1586	.5685±.1961	.4484±.2752	.8258±.1761	1±0

TABLE 4 LATERAL QUIET BREATHING

	S	M_5	M_6	M_7	M_8
S	1±0				
M_5	.6062±.5139	1±0	symmetric		
M_6	.1610±.5795	.1176±.5511	1±0		
M_7	.5803±.3959	.4176±.4808	.0858±.5153	1±0	
M_8	.4513±.5254	.3626±.4915	.2598±.6074	.4386±.4985	1±0

TABLE 5 LATERAL FORCED BREATHING

	S	M_5	M_6	M_7	M_8
S	1±0				
M_5	.5619±.5082	1±0	symmetric		
M_6	.3296±.5982	.0831±.6548	1±0		
M_7	.3555±.6198	.0794±.6002	.3194±.4766	1±0	
M_8	.5316±.5390	.2533±.5807	.4172±.4974	.4771±.4415	1±0

Table 6 AP cummulative breath correlation coefficients for subject #10. Note that the values approach the total as the number of breaths increases. Exact correspondence is not achieved due to incomplete breath portions at each end.

Number of Breaths	M1	M2	M3	M4
1	.9786	.6950	.9636	.6975
2	.9872	.9542	.9858	.8974
3	.9691	.8145	.9709	.6934
4	.9743	.6708	.9699	.6672
5	.9784	.6184	.9548	.6746
6	.9802	.5359	.9452	.6918
7	.9801	.5958	.9472	.7446
Last	.9799	.6073	.9453	.8184
TOTAL (from Appendix 2)	.9800	.6327	.9501	.8309

Table 7 AP correlation coefficients between spirometer and magnetometers for six individual breaths for each subject. Notice significant variations only in M_2 position.

SUBJECT 1

Breath #	1	2	3	4	5	6	AVG + SD.
M_1	.9943	.9924	.9965	.9859	.9869	.9677	.9873 $\pm$ .010
M_2	.7330	.9153	.8612	.9194	.9488	.9455	.8872 $\pm$ .082
M_3	.7938	.7128	.9286	.8702	.6305	.8504	.7977 $\pm$ .109
M_4	.6046	.6074	.6280	.6404	.8385	.8791	.7147 $\pm$ .116

SUBJECT #2

M_1	.9917	.9944	.9913	.9979	.9876	.9905	.9922 $\pm$ .004
M_2	-.2067	-.0136	-.2203	.4364	-.1368	.1806	.0081 $\pm$ .259
M_3	.8693	.9658	.8277	.9765	.9374	.9386	.9192 $\pm$ .058
M_4	.9706	.9940	.9247	.9941	.9764	.9812	.9735 $\pm$ .026

SUBJECT #3

M_1	.9849	.9843	.9921	.9933	.9948	.9908	.9900 $\pm$ .004
M_2	.5853	.6324	.8366	.6728	.8241	.9572	.7515 $\pm$ .143
M_3	.9468	.9757	.9898	.9841	.9912	.9937	.9802 $\pm$ .018
M_4	.7945	.9773	.9880	.9891	.9918	.9961	.9561 $\pm$ .079

SUBJECT #4

M_1	.9975	.9973	.9959	.9933	...	...	.9960 $\pm$ .002
M_2	.8896	.8783	.8564	.9247	...	...	.8873 $\pm$ .029
M_3	.9631	.9492	.9458	.9788	...	...	.9592 $\pm$ .015
M_4	.8987	.9531	.9871	.9572	...	...	.9490 $\pm$ .037

SUBJECT #5

M_1	.9442	.9234	.9551	.9581	.9725	.8983	.9419 $\pm$ .027
M_2	.9446	.9805	.9271	.9659	.9546	.9651	.9563 $\pm$ .019
M_3	.9562	.9816	.9529	.9908	.9777	.9771	.9727 $\pm$ .015
M_4	.9713	.9590	.9711	.9895	.9856	.9897	.9777 $\pm$ .012

SUBJECT #6

M_1	.9906	.9959	.9953	.9974	.9972	.9944	.9951 $\pm$ .002
M_2	.5938	-.0588	.0485	-.1482	.2152	-.7758	-.0208 $\pm$ .453
M_3	.9648	.7155	.9594	.9676	.8804	.8973	.8981 $\pm$ .097
M_4	.9629	.6785	.9516	.9552	.8816	.7841	.8689 $\pm$ .115

SUBJECT #7							
M_1	.9964	.9902	.9885	.9963	.9972	.9982	.9945 $\pm$ .004
M_2	-.9331	-.6511	.2943	.9136	.2874	-.5368	-.1043 $\pm$ .710
M_3	.9697	.8868	.8526	.9957	.9591	.9217	.9309 $\pm$ .054
M_4	.9896	.9187	.6794	.9729	.9658	.9857	.9187 $\pm$ .119
SUBJECT #8							
M_1	.9146	.9708	.9888	.9262	.9693	.9913	.9602 $\pm$ .032
M_2	.5116	.6896	.7786	.8107	.9004	.9275	.7697 $\pm$ .153
M_3	.8628	.6582	.8355	.8398	.9545	.9841	.8558 $\pm$ .115
M_4	.5478	.4092	.5868	.5822	.9237	.9571	.6678 $\pm$ .221
SUBJECT #9							
M_1	.9534	.9224	.8822	.9159	.9576	.9569	.9314 $\pm$ .030
M_2	.8300	.8505	.9074	.9395	.9759	.9556	.9099 $\pm$ .059
M_3	.9707	.9551	.9635	.9754	.9889	.9861	.9733 $\pm$ .013
M_4	.9685	.9846	.9899	.9886	.9932	.9715	.9827 $\pm$ .010
SUBJECT #10							
M_1	.9786	.9863	.9534	.9964	.9905	.9894	.9824 $\pm$ .015
M_2	.6949	.9518	.8867	.8838	.8882	.8787	.8640 $\pm$ .087
M_3	.9636	.9844	.9856	.9890	.9801	.9732	.9793 $\pm$ .009
M_4	.6975	.8892	.6231	.9794	.9729	.9845	.8558 $\pm$ .158
SUBJECT #11							
M_1	.9609	.9836	.8344	.9497	.9764	.9377	.9404 $\pm$ .055
M_2	.9131	.9914	.8977	.9219	.9497	.9079	.9303 $\pm$ .035
M_3	.9456	.9211	.9454	.9701	.9384	.9456	.9444 $\pm$ .016
M_4	.8217	.9741	.8562	.9602	.6584	.9878	.8764 $\pm$ .126

Table 8 AP Correlation coefficients for a single forced breath for each subject. Notice no remarkable differences from those of quiet breathing.

SUBJECT	M_1	M_2	M_3	M_4
1	.9975	.9782	.8801	.9275
2	.9829	.6253	.9213	.9537
3	.9888	.4612	.9698	.8537
4	.9964	.9564	.9381	.8221
5	.9706	.9789	.9169	.9198
6	.9935	.2457	.7463	.4557
7	.9826	-.7417	.8894	.8696
8	.9948	.4384	.8431	.9616
9		no measurements made		
10	.9844	.6871	.8938	.8866
11	.9555	.7147	.9204	.9243
Average	.9847±.013	.5343±.512	.8919±.062	.8574±.148

Table 9 AP Correlation coefficients for a single breath showing individual correlations for inspiration (I), expiration (E) and the total breath (T)

SUBJECT	TEST	M_1	M_2	M_3	M_4
1	I	.9964	.9524	.9964	.8491
	E	.9971	.9857	.9919	.9377
	T	.9948	.8823	.9837	.8279
2	I	.9989	.2029	.9981	.9978
	E	.9909	-.3788	.9001	.9784
	T	.9874	-.1569	.9352	.9756
3	I	.9951	.9739	.9945	.9957
	E	.9977	.7081	.9913	.9976
	T	.9948	.8240	.9912	.9917
4	I	.9975	.9608	.9853	.9764
	E	.9991	.9433	.9892	.9942
	T	.9973	.8783	.9491	.9531
5	I	.9562	.9859	.9944	.9961
	E	.9773	.9672	.9879	.9966
	T	.9551	.9270	.9529	.9711
6	I	.9997	.8623	.9989	.9949
	E	.9965	-.4624	.7004	.6487
	T	.9959	-.0588	.7155	.6785
7	I	.9973	.9598	.9954	.9949
	E	.9978	.9013	.9969	.9869
	T	.9963	.9136	.9957	.9728

8	I	.9962	.9822	.9967	.9966
	E	.9965	.9733	.9883	.9869
	T	.9913	.9275	.9841	.9570
9	I	.9811	.9311	.9784	.9976
	E	.9982	.9934	.9982	.9971
	T	.9582	.9568	.9865	.9722
10	I	.9974	.9479	.9956	.9851
	E	.9981	.7965	.9821	.9845
	T	.9964	.8838	.9890	.9794
11	I	.9781	.9699	.9601	.9851
	E	.9957	.9911	.9959	.9960
	T	.9404	.9267	.9544	.9879

Table 10 Correlation coefficients for the single breath for which the fourier results (Appendix 3) are given

SUBJECT	M_1	M_2	M_3	M_4
1	.9965	.8612	.9286	.6280
2	.9979	.4364	.9765	.9942
3	.9933	.6729	.9841	.9891
4	.9975	.8896	.9631	.8987
5	.8983	.9650	.9771	.9897
6	.9974	-.1482	.9675	.9552
7	.9963	.9136	.9957	.9729
8	.9913	.9275	.9841	.9571
9	.9224	.8505	.9551	.9846
10	.9534	.8868	.9856	.6231
11	.8344	.8977	.9454	.8562

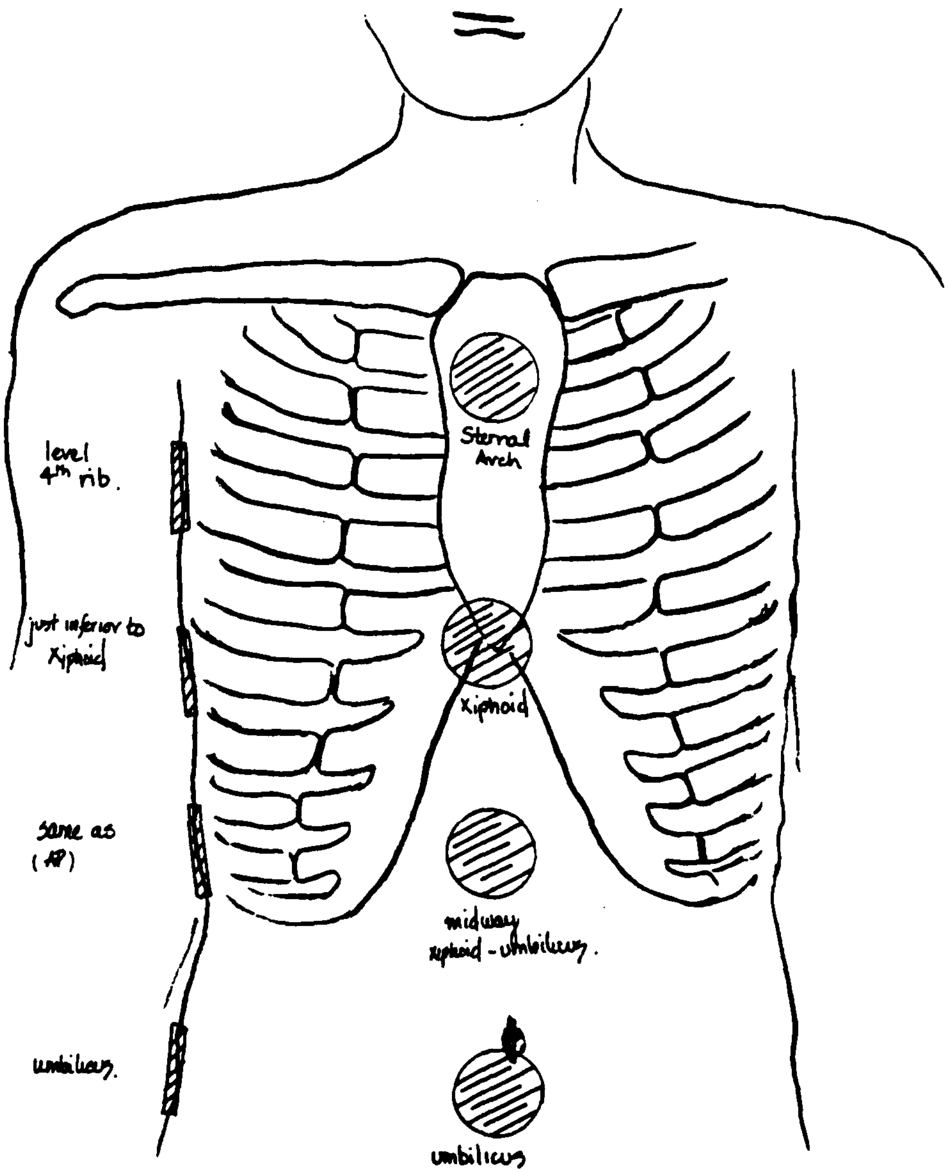


Figure 1. The eight anatomical magnetometer placements (M_i, $i = 1,2,\ldots 8$) are shown (see text).

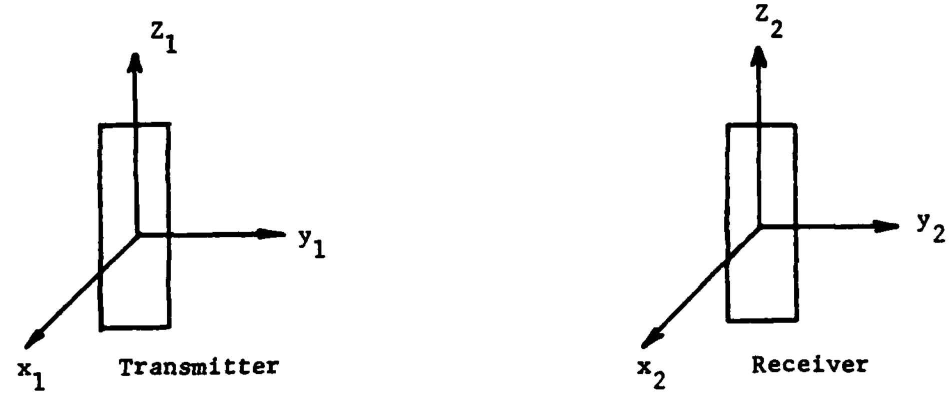


Fig 2. Axes for a given magnetometer pair (transmitter and receiver).

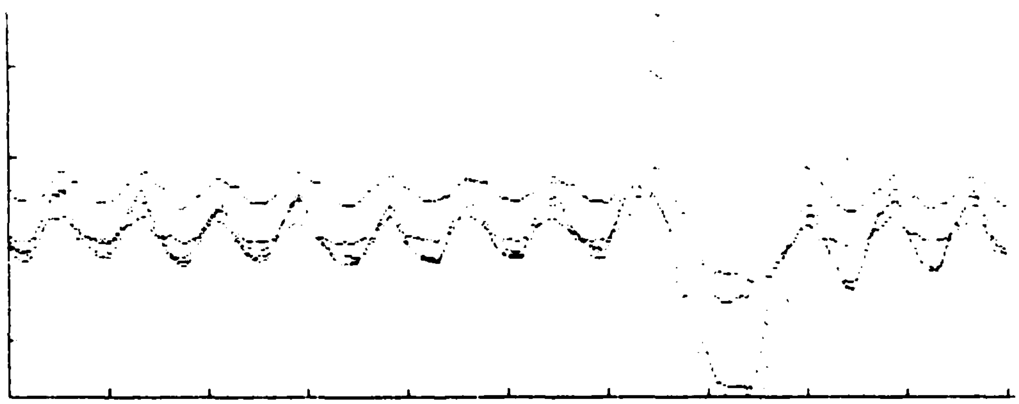


Figure 3. A typical time trace of the five signals (spirometer, M_1, M_2, M_3, M_4) for subject #5 during a forced breathing manuever is shown. Notice the maximal breath in the eighth breath see text for details.

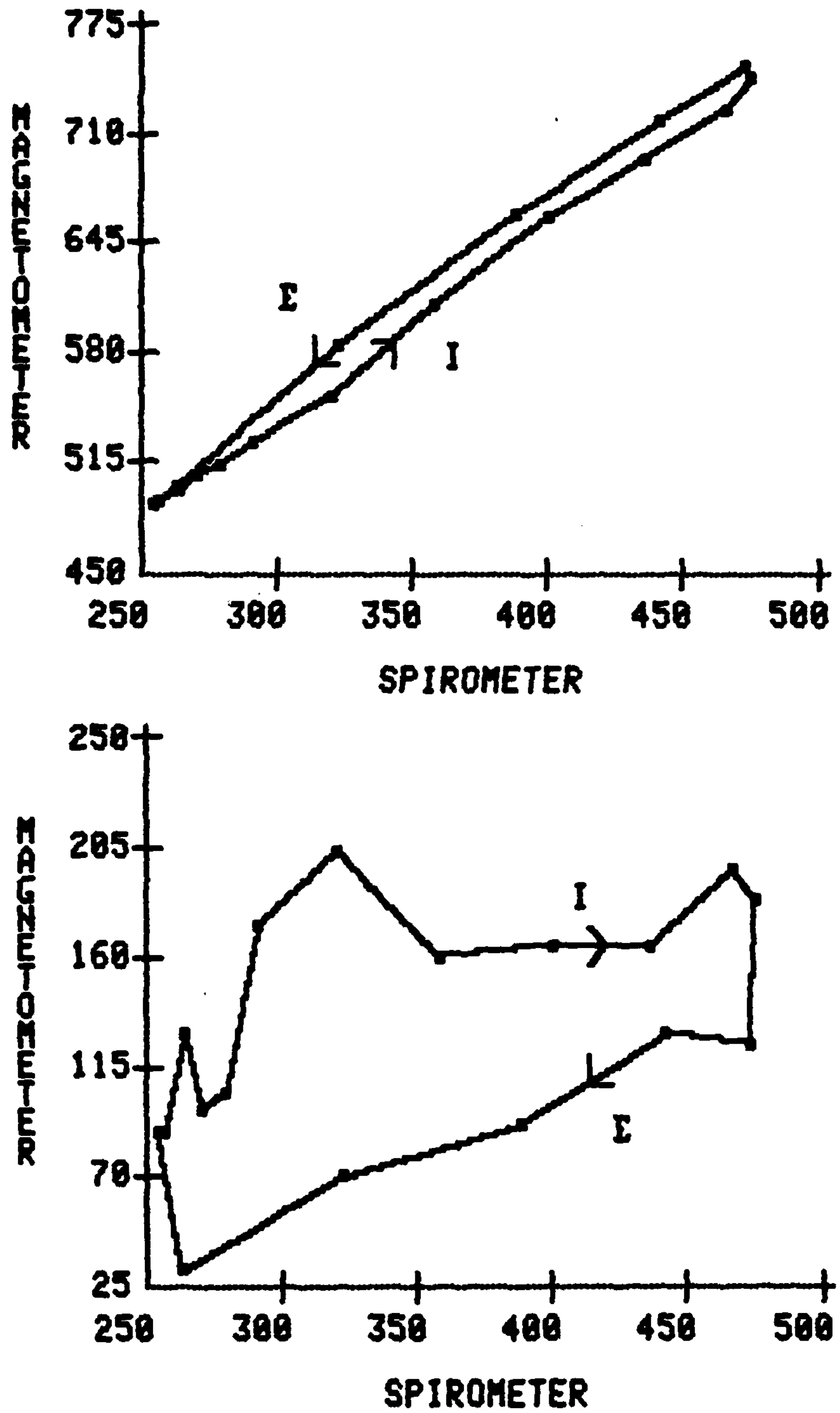
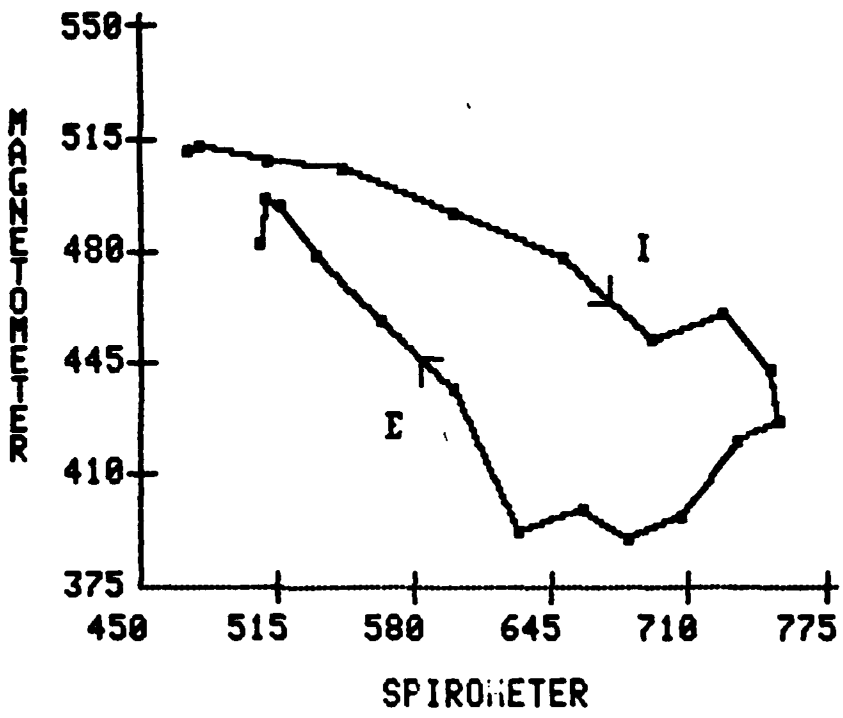
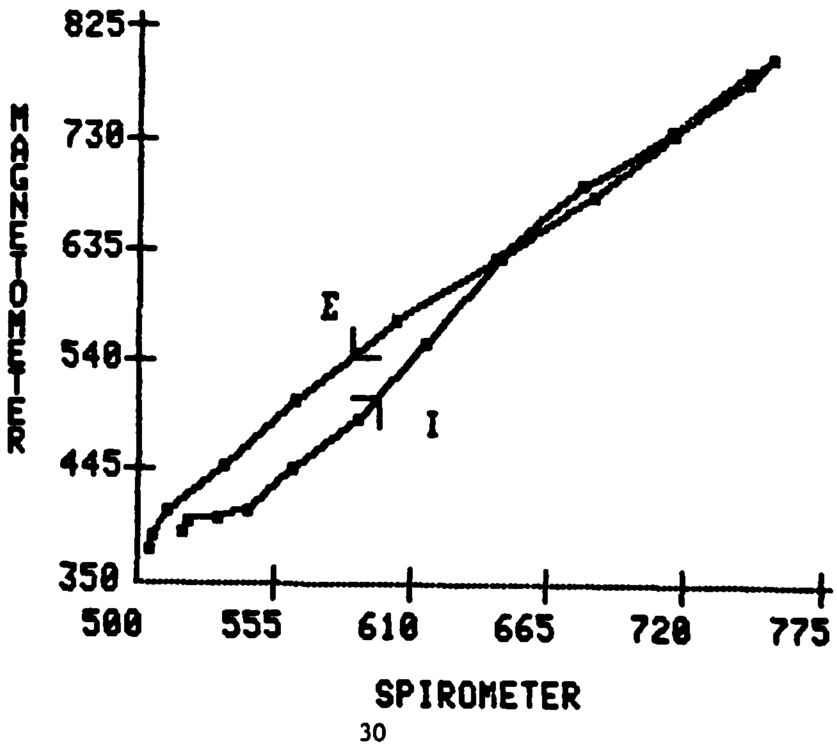
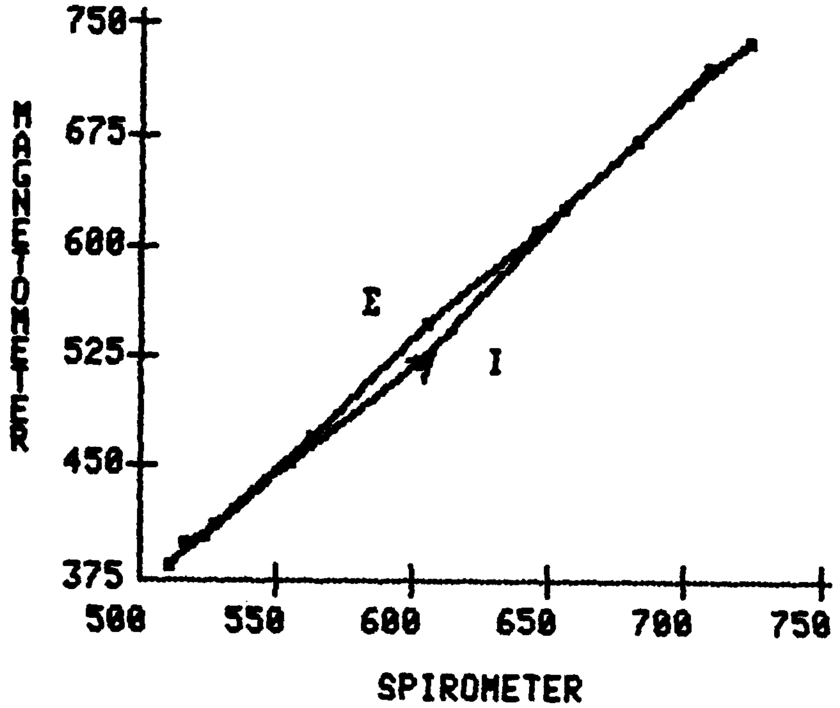


Figure 4. Hysteresis curves of a given breath for a typical subject. Notice the more pronounced hysteresis in the M_2 (bottom) position with respect to the M_1 (top) position. (Next page M_2(top), M_1(bottom)).


550
515
480
445
410
375
MAGNETOMETER
450
515
580
645
710
775
SPIROMETER
I
E


825
730
635
540
445
350
MAGNETOMETER
500
555
610
665
720
775
SPIROMETER
E
I



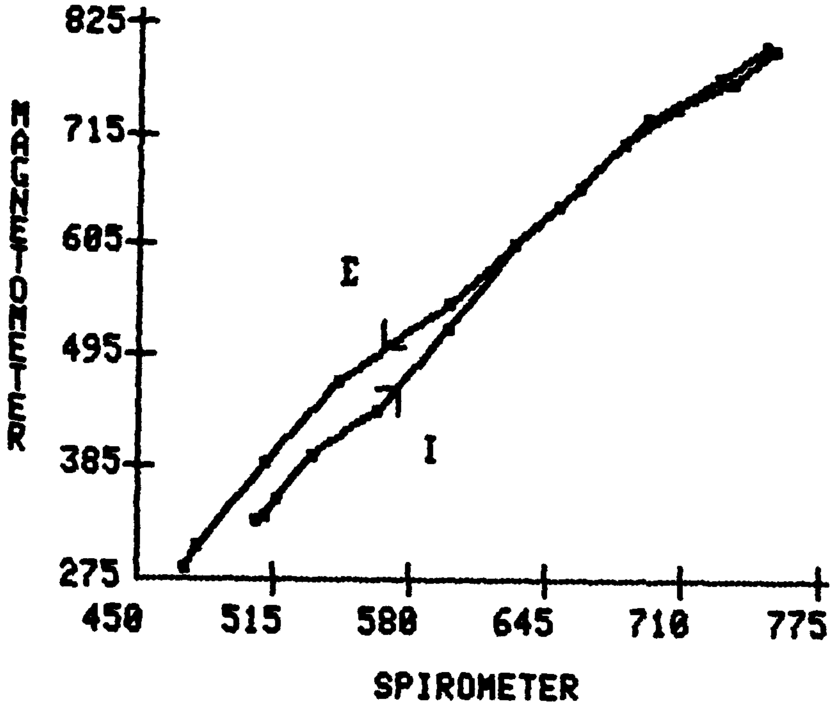
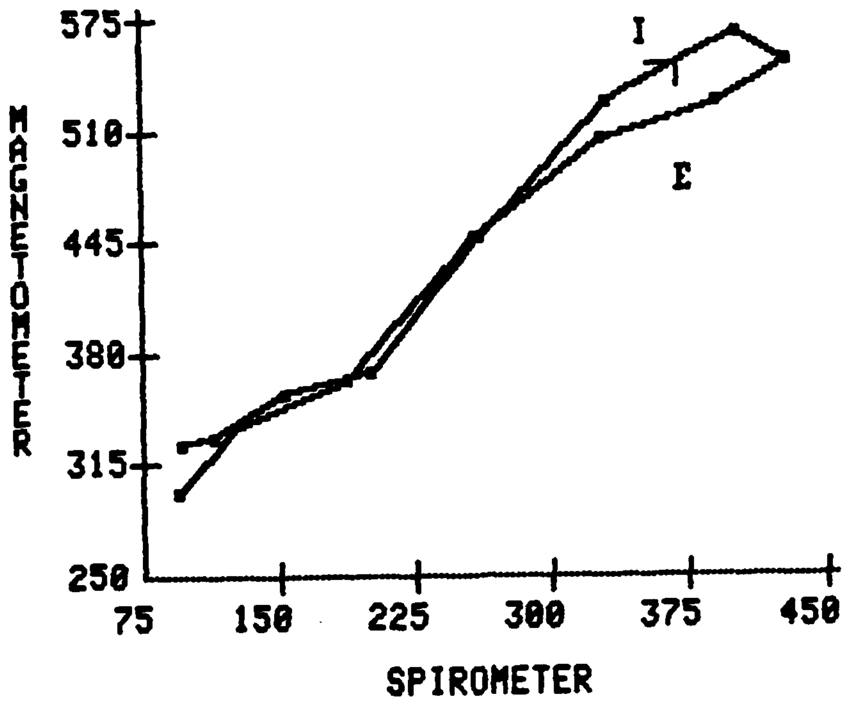
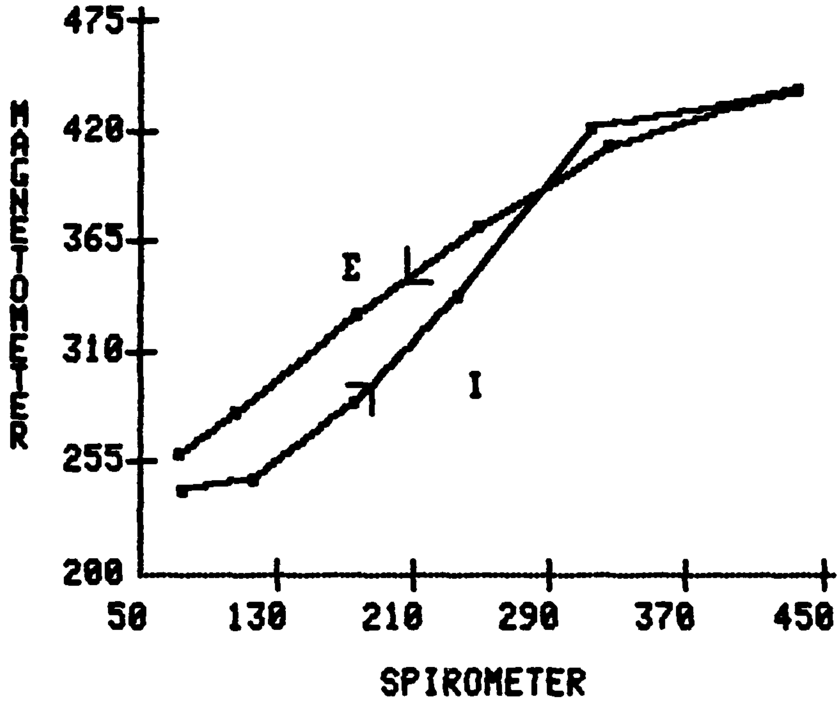


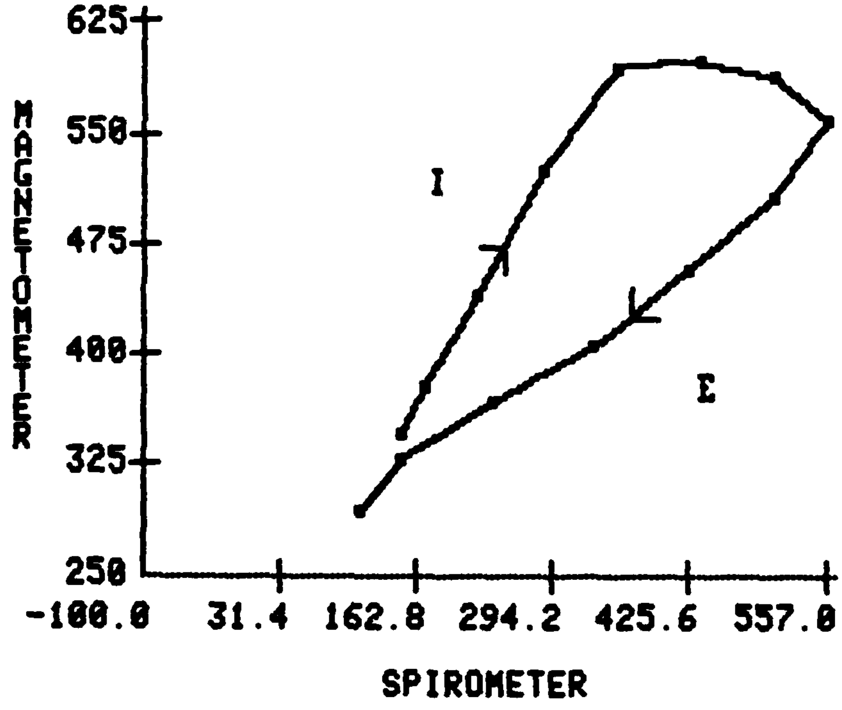
Figure 5. Hysteresis curves for a given subject showing two successive breaths at the M_1 position. Note the variations. Greater variations were seen in each of the other three AP positions on these breaths.

Figure 6. Lateral (M_6) position hysteresis curves showing significant variations on successive breaths (Three curves; continued next page).



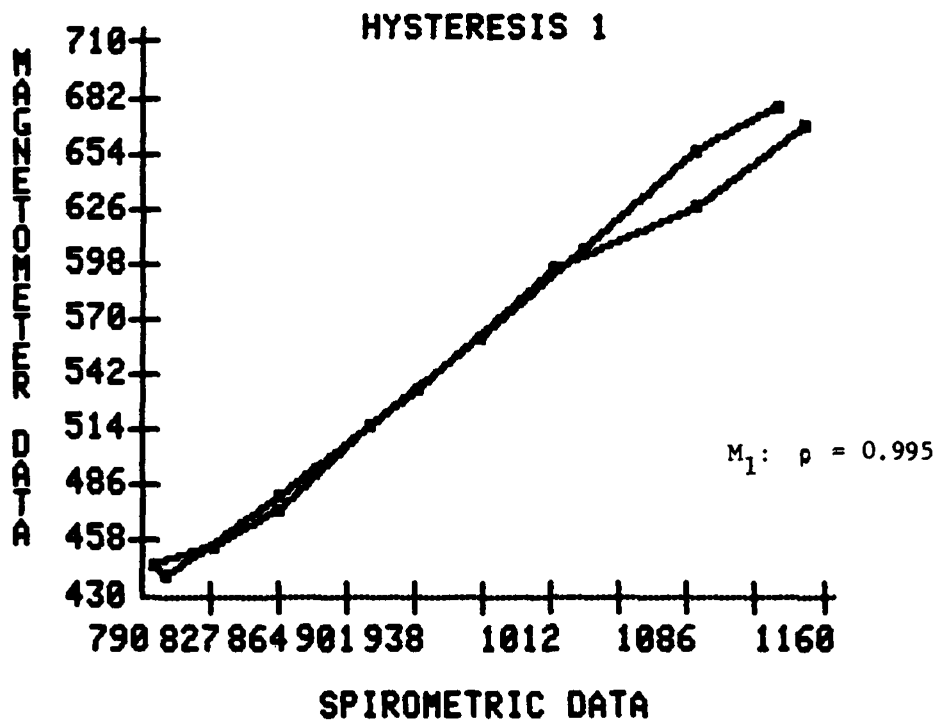


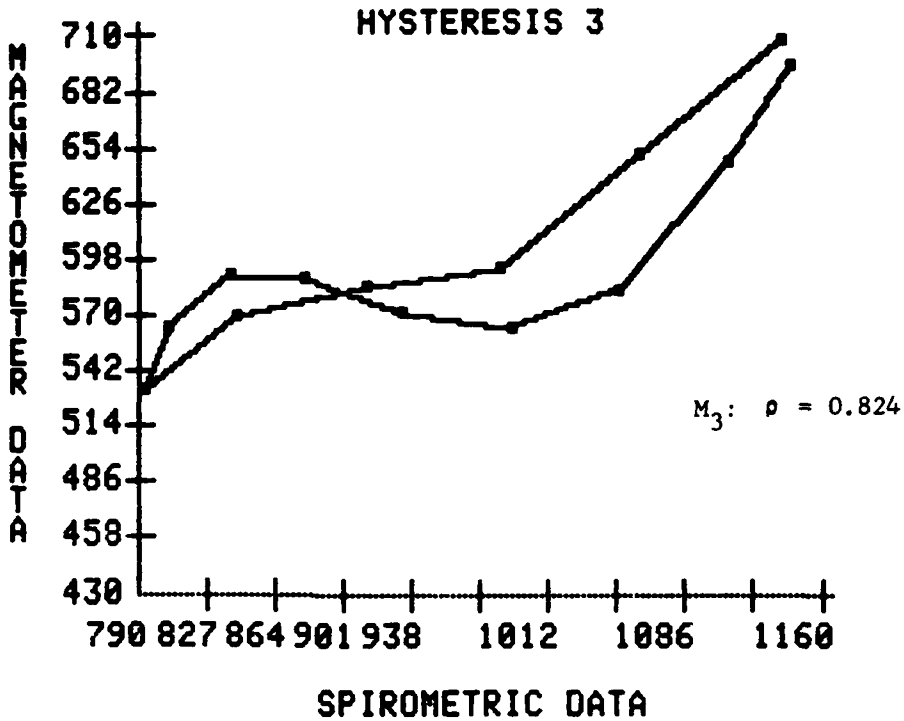
475
420
365
310
255
200
MAGNETOMETER
E
I
50
130
210
290
370
450
SPIROMETER

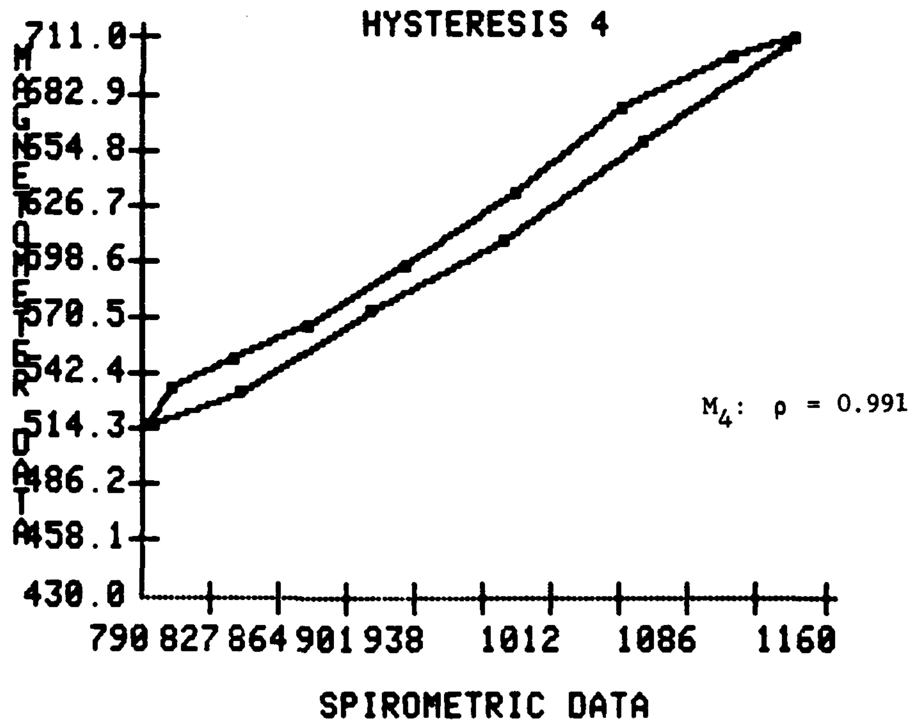


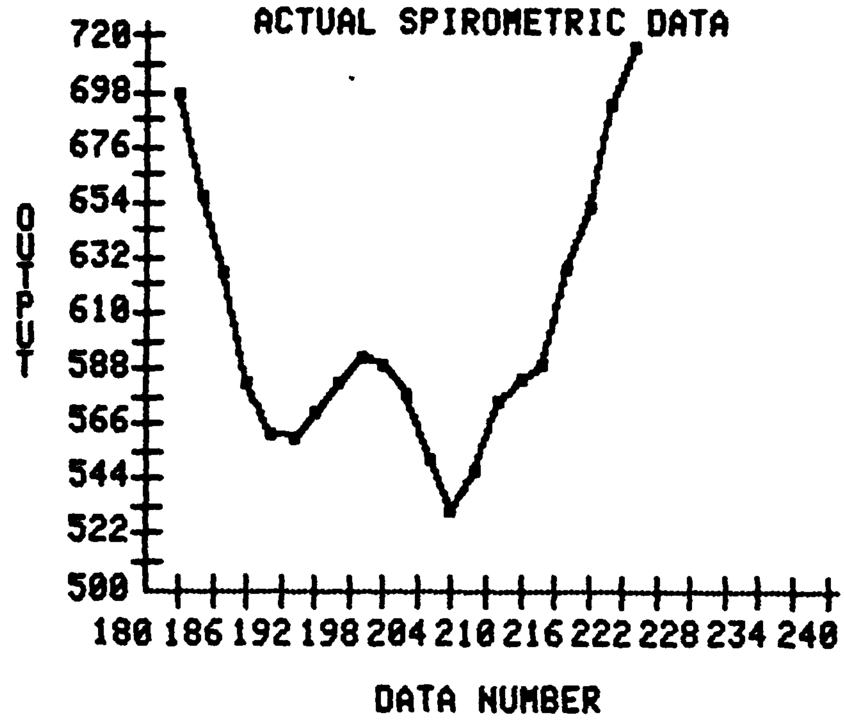
625
550
475
400
325
250
MAGNETOMETER
I
E
-100.0
31.4
162.8
294.2
425.6
557.0
SPIROMETER

Figure 7. Three hysteresis plots for a given breath, subject #3. We note the apparent correspondence between the amount of hysteresis and the calculated correlation coefficient. They are for M_1, M_3, M_4 respectively (continued next page).




HYSTERESIS 3
MAGNETOMETER DATA
710
682
654
626
598
570
542
514
486
458
430
790 827 864 901 938 1012 1086 1160
SPIROMETRIC DATA
M_3: ρ = 0.824


HYSTERESIS 4
MAGNETOMETER DATA
711.0
682.9
654.8
626.7
598.6
570.5
542.4
514.3
486.2
458.1
430.0
790 827 864 901 938 1012 1086 1160
SPIROMETRIC DATA
M_4: ρ = 0.991



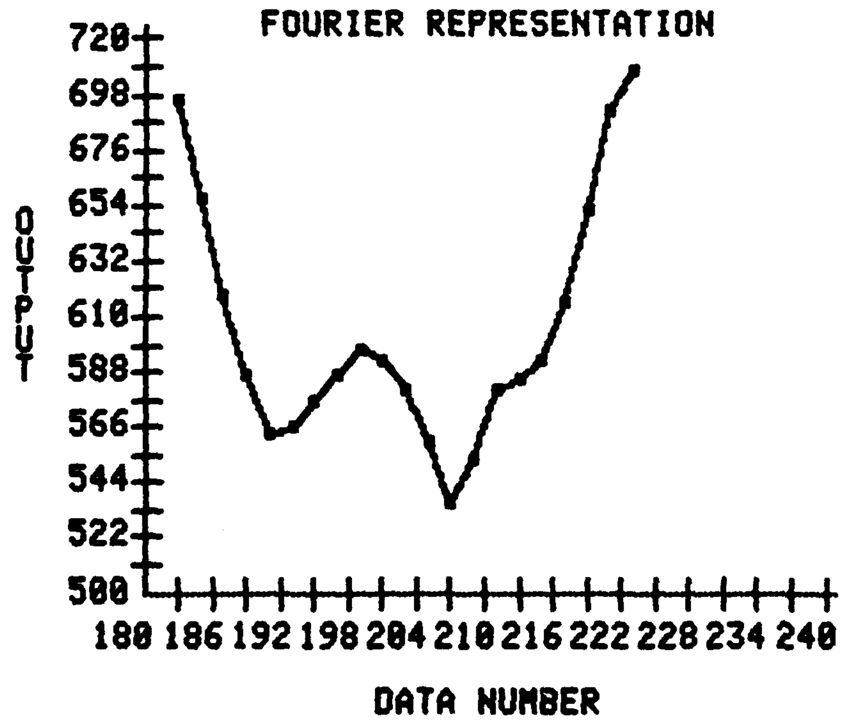


Figure 8. We show the actual and fourier representation of a M_2 vs time plot for a given breath. Seven harmonics were needed to accurately describe the curve.

Appendix 1

All data analysis and collection was performed on a Minc 11 with the controlling software written in the high level language, BASIC. The program listings as well as a brief program explanation are given below. The programs were written so as to "prompt" the user for the specific input as well as to instruct the user; this to allow other users to easily implement the programs on continued investigation.

A few points should be highlighted at this time. The test data files were stored as one dimensional integer arrays of three thousand data entries. They were stored as a sequence of spirometer, M_1, M_2, M_3, M_4 (or M_5, M_6, M_7, M_8) repeated 600 times. Approximately twenty four data files each of 3000 digitized points could be stored per secondary (data) diskette (Scotch, 8 inch, soft sector, double density, RX02 format).

In programs where individual breaths were analyzed (eg. ANALY3.BAS) the program asks for the spirometer file place (0 - 600) to define the given breath. This is exemplified in figure A.1. Thus by inputing any max/min value for the filplace, any breath, portion of a breath or sequence can be analyzed.

As a final note, all output data file names for output on disk drive 2 must be inputed before program execution. And, in the program listings, 1/2 stands for "<" and 1/4 stands for ">".

The programs are:

(1) LUNG - The program LUNG controlled the data collection process (eq. sampling rate, sampling time). 1 five simultaneous signals were converted to digitized form, stored, and graphed on the screen for a qualitative "look" at the data.

(2) ANALYP - The program ANALYP recalled the data file from storage (from LUNG) and calculated the correlation coefficients as given in Appendix 2. The results were both stored and displayed on the screen.

(3) RESLT2 - The program RESLT2 recalled the data stored by ANALYP for any number of subjects and averaged and gave standard deviations for the results (as given in tables 2-5).

(4) MCAL - The program MCAL allowed us to perform calibration tests on each magnetometer based on separation distances, rotational effects and adjustment of relative gain.

(5) SCAL - The program SCAL was used to obtain calibration curves for the spirometer as output vs volume.

(6) MAX 4 - The program MAX 4 was used to scan each data file to determine the relative maxima and minima fileplaces for use as described above. Due to the experimental nature of the data, abolute extrema were rare, and results were often doubled checked visually using MANGE2.

(7) MANGE2 - The program MANGE2 was used to visually inspect data and to generate cross plots (hysteresis curves).

(8) ANALY3 - ANALY3 is essentially the same as ANALYP except that one could keyboard control which breath or parts thereof that correlations were to be calculated. The results of MAX 4 were used here.

(9) The following "chained programs" were used to calculate the fourier coefficients (up to seven harmonics) for the given breath. They allowed visual inspection of the breath, calculation of the coefficients, visual comparison of the results (see Figure 8), normalization of results with respect to the spirometer and storage.

(i) FMAIN

(ii) FGRAPH

(iii) FCOEFF

(iv) FCOMP

(v) FNORM

(vi) FOUT

(vii) NSTORE

LUNG.BAS

```
10 B$=' ####     ######     ######     ######     ######     ######'
20 DIM M%(3000)   T=0
30 DISPLAY_CLEAR
40 PRINT '***************************************'
41 PRINT '* This program collects data from    *'
42 PRINT '* channels 0-4 and writes to a file  *'
43 PRINT '* or to the screen.                  *'
44 PRINT '***************************************'
45 PRINT "
50 PRINT \ PRINT 'Enter the filename for output '; \ LINPUT F$
55 PRINT 'Enter the file number 1-10'; \ INPUT F5
56 PRINT 'Enter the number of data points to be taken'; \ INPUT D1
58 PRINT "   PRINT "
59 PRINT 'note: did you substitute filename in #200'
60 PRINT \ PRINT \ PRINT 'Are you ready %RETURN%'; \ INPUT A$
70 PRINT \ PRINT 'input to begin after beep.....'
80 FOR J=1 TO 100 \ NEXT J
90 I=1
100 SCHEDULE('INTERVAL',1,140)
110 PRINT CHR$(7)
120 AIN(,M%(),D1,.075,0,5)
130 IF I=0 THEN 150 \ GO TO 120
140 I=0   RETURN
150 PRINT CHR$(7) \ PRINT  \ PRINT 'Input from channel 0-4 now complete.'
160 GRAPH(,,,M%())
165 PRINT "
170 PRINT 'Output to disk or to screen or do nothing (D or S or N)'; \ INPUT A$
190 IF A$='D' GO TO 200 \ IF A$='S' GO TO 230 \ IF A$='N' GO TO 270 \ GO TO 170
200 OPEN 'DK1:F.DAT' FOR OUTPUT AS FILE #F5
210 FOR K=0 TO D1-1 \ PRINT #F5,M%(K) \ NEXT K
220 CLOSE #F5 \ DISPLAY_CLEAR \ GO TO 270
230 DISPLAY_CLEAR
240 FOR K=0 TO D1/5-1 \ K%=5*K
250 PRINT USING B$,K%,M%(K%),M%(K%+1),M%(K%+2),M%(K%+3),M%(K%+4)
260 NEXT K
270 PRINT
290 DISPLAY_CLEAR\ STOP \ END
```

ANALYP.BAS

```
10 DIM M%(4,599),S(4),Q(4),T(4,4),C(4,4)
20 R=0   Z$='.DAT'   W$='#################'
28 PRINT '**********************************'
29 PRINT '* This program calculates the    *'
30 PRINT '* sum, the sum-squared and the   *'
31 PRINT '* correlation coefficients for  *'
32 PRINT '* channels 0-4                   *'
33 PRINT '**********************************'
34 PRINT "   PRINT "
40 PRINT    PRINT 'Enter the filename for input '; \ INPUT F$
45 PRINT 'Enter the file number 1-10';   INPUT F6
46 PRINT 'Enter the number of data points collected'; \ INPUT C1
47 PRINT    PRINT
48 PRINT ' note: did you substitute filename into #60'
49 C1=3000
50 OPEN F$&'0.DAT' FOR OUTPUT AS FILE #10
60 OPEN 'DK1:F.DAT' FOR INPUT AS FILE #F6
70 FOR J=0 TO C1/5-1 \ FOR I=0 TO 4 \ INPUT #F6,M%(I,J) \ NEXT I \ NEXT J
80 CLOSE #F6
90 FOR I=0 TO 4 \ S(I)=0
95 L=C1/5-1
100 FOR K=0 TO 4 \ T(I,K)=0 \ C(I,K)=0 \ NEXT K
110 FOR J=0 TO L \ S(I)=S(I)+M%(I,J) \ NEXT J
115 FOR K=0 TO I
120 FOR J=0 TO L \ PRINT '.'; \ T(I,K)=T(I,K)+1*M%(I,J)*M%(K,J) \NEXT J
125 NEXT K
130 FOR K=0 TO I \ C(I,K)=T(I,K)-S(I)*S(K)/(L+1) \ NEXT K \ NEXT I
135 FOR I=0 TO 4
140 Q(I)=SQR(ABS(C(I,I))) \ FOR K=0 TO I \ C(I,K)=C(I,K)/Q(I) \ NEXT K
145 NEXT I
146 FOR I=0 TO 4
150 FOR K=0 TO I \ C(I,K)=INT(C(I,K)/Q(K)*10000+.5)/10000 \ NEXT K
151 NEXT I
160 FOR I=0 TO 4 \ FOR K=I TO 4 \ T(I,K)=T(K,I) \ C(I,K)=C(K,I) \ NEXT K \ NEXT
I
165 PRINT \ PRINT W$ \ PRINT '#'
170 PRINT '#   '&F$&STR$(R)&Z$ \ PRINT '#' \ PRINT W$
190 PRINT \ PRINT '***SUM***' \ PRINT S(0),S(1),S(2),S(3),S(4)
205 PRINT \ PRINT '***INNER PRODUCT***'
210 FOR I=0 TO 4 \ PRINT T(I,0),T(I,1),T(I,2),T(I,3),T(I,4) \ NEXT I
225 PRINT \ PRINT '***CORRELATION COEFFICIENT***'
230 FOR I=0 TO 4 \ PRINT C(I,0),C(I,1),C(I,2),C(I,3),C(I,4) \ NEXT I
240 FOR I=0 TO 4 \ FOR J=0 TO 4 \ PRINT #10,C(I,J) \ NEXT J   NEXT I
245 CLOSE #10
246 PRINT 'AGAIN'; \ LINPUT H$
247 IF H$='A' THEN PRINT '***'
250 DISPLAY_CLEAR \ STOP \ END
```

RESLT2.BAS

```
10 DIM S(4,4),C(4,4),A(4,4),S1(4,4),D(4,4)
15 FOR K=0 TO 4 \ FOR L=0 TO 4 \ S(K,L)=0 \ NEXT L \ NEXT K
17 N=0
18 PRINT 'Enter the output filename'; \ LINPUT G$
20 PRINT 'Enter the input filename'; \ LINPUT F$
25 N=N+1
30 OPEN F$&'0.DAT' FOR INPUT AS FILE #5
40 FOR I=0 TO 4
45 FOR J=0 TO 4
50 INPUT #5,C(I,J)
55 NEXT J
60 NEXT I
70 CLOSE #5
80 FOR I=0 TO 4
85 FOR J=0 TO 4
100 S(I,J)=S(I,J)+C(I,J)
105 S1(I,J)=S1(I,J)+C(I,J)^2
110 NEXT J
120 NEXT I
170 PRINT 'Again?'; \ LINPUT A$
180 IF A$='Y' THEN 20
200 FOR K=0 TO 4
210 FOR L=0 TO 4
220 A(K,L)=S(K,L)/N
225 D(K,L)=SQR(ABS((S1(K,L)-N*A(K,L)^2)/(N-1)))
230 NEXT L
240 NEXT K
241 PRINT "   PRINT "
245 PRINT 'Wish to store this:'; \ LINPUT Q$
246 IF Q$='N' THEN 271
250 OPEN G$&'.DAT' FOR OUTPUT AS FILE #3
255 PRINT #3,'THE AVERAGE VALUES ARE:'
256 PRINT #3,' '
260 FOR I=0 TO 4 \ PRINT #3,A(I,0),A(I,1),A(I,2),A(I,3),A(I,4) \ NEXT I
262 PRINT #3,' '
263 PRINT #3,'THE STANDARD DEVIATIONS ARE:'
264 PRINT #3,' '
265 FOR J=0 TO 4 \ PRINT #3,D(J,0),D(J,1),D(J,2),D(J,3),D(J,4) \ NEXT J
270 CLOSE #3
271 DISPLAY_CLEAR \ PRINT 'AVERAGE VALUES ARE:' \ PRINT
272 FOR I=0 TO 4 \ PRINT A(I,0),A(I,1),A(I,2),A(I,3),A(I,4) \ NEXT I
273 PRINT " \ PRINT 'THE STANDARD DEVIATIONS ARE:' \ PRINT "
274 FOR J=0 TO 4 \ PRINT D(J,0),D(J,1),D(J,2),D(J,3),D(J,4) \ NEXT J
280 STOP \ END
```

MCAL.BAS

```
1 REM D1=SEPARATION DISTANCES, S1=AVG. VOLTAGE/DISTANCE
2 REM A3=MEAN DISTANCE,A4=MEAN VOLTAGE
3 REM B3=SLOPE, B4=INTERCEPT
10 REM THE PROGRAM NAME IS MCAL
20 REM ENTER CHANNEL #5 TO STOP
50 DIM D1(20),S1(20),V(100),V1(100)
55 DIM S(100),A1(20),A2(20),B1(20),B2(20)
60 I=0 \ M=20
62 PRINT '*********************************************'
63 PRINT '* This program allows calibration of the     *'
64 PRINT '* magnetometers voltage vs. separation dis-  *'
65 PRINT '* tance... a least squares fit can then be   *'
66 PRINT '* computed.                                  *'
67 PRINT '*********************************************'
68 PRINT " \ PRINT "
80 FOR K=0 TO M \ S1(K)=0 \ D1(K)=0 \ NEXT K
86 FOR K=0 TO 99 \ V(K)=0 \ V1(K)=0 \ NEXT K
100 I=I+1 \ J=0 \ A1(1)=0 \ A2(1)=0 \ B1(1)=0 \ B2(1)=0 \ B3=0 \B4=0
101 PRINT 'ENTER THE MAGNETOMETER NUMBER'; \ INPUT I1
102 I=I1
103 IF I=5 THEN 275
105 DISPLAY_CLEAR
109 PRINT '****************************'
110 PRINT USING 'SET UP MAGNETOMETER PAIR # .',I
111 PRINT '****************************'
114 PRINT "   PRINT "
120 PRINT 'ANOTHER SEPARATION DISTANCE Y or N'; \ LINPUT Q$
121 PRINT "
130 IF Q$='NO' THEN 232 \ IF Q$='N' THEN 232
131 J=J+1
140 PRINT 'PLEASE GIVE SEPARATION DISTANCE (inches)'; \ INPUT D
150 D1(J)=D
160 SCHEDULE('INTERVAL',10,200)
170 AIN('DISPLAY',V(),100,.1,I)
180 IF L=0 THEN 205
190 GO TO 170
200 L=0 \ RETURN
205 DISPLAY_CLEAR
210 FOR K=0 TO 99 \ V1(K)=V(K) \ S(K+1)=S(K)+V1(K)
215 NEXT K
220 S1(J)=S(K+1)/K
225 M=J
230 GO TO 120
232 PRINT "
233 PRINT ' DISTANCE    AVG. VOLTAGE'
234 PRINT "
235 FOR L=1 TO J \ PRINT D1(L),S1(L) \ NEXT L
236 PAUSE(5)
```

```
240 PRINT "   PRINT "
265 PRINT 'DO YOU WISH A LEAST SQUARES ANALYSIS:'; \ LINPUT L$
270 IF L$='YES' THEN  GOSUB 300
271 IF L$='Y' THEN  GOSUB 300
272 PRINT 'DO YOU WISH TO STORE THIS:'; \ LINPUT D$
273 IF D$='Y' THEN  GOSUB 480 \ IF D$='YES' THEN  GOSUB 480
274 DISPLAY_CLEAR
275 IF I%5 THEN 80 \ IF I=5 THEN STOP
300 REM THIS IS THE LEAST SQUARES SUBROUTINE
310 FOR K=1 TO M
320 A1(K+1)=A1(K)+D1(K)
330 A2(K+1)=A2(K)+S1(K)
340 NEXT K
350 A3=A1(M+1)/M
360 A4=A2(M+1)/M
370 FOR L=1 TO M
380 B1(L+1)=B1(L)+(D1(L)-A3)*(S1(L)-A4)
390 B2(L+1)=B2(L)+(D1(L)-A3) 2
400 NEXT L
410 B3=B1(M+1)/B2(M+1)
420 B4=A4-B3*A3
425 PRINT
430 PRINT 'THE SLOPE IS:'; \ PRINT B3
440 PRINT 'THE INTERCEPT IS:'; \ PRINT B4
450 PRINT "
465 PAUSE(15)
466 DISPLAY_CLEAR
470 RETURN
480 REM THIS IS A SUBROUTINE TO STORE DATA
490 PRINT 'ENTER THE DATA FILE NAME:'; \ LINPUT S$
500 OPEN S$&'.DAT' FOR OUTPUT AS FILE #3
510 FOR K=1 TO J \ PRINT #3,D1(K),S1(K) \ NEXT K
520 CLOSE #3
530 PRINT \  PRINT \  PRINT  \ PRINT
540 RETURN
```

SCAL.BAS

```
50 REM PROGRAM NAME IS SCAL
100 DIM A(100),A1%(100),A2(11),S(100),S2(11),S1(11),Z1(11)
120 PRINT '**************************************************'
121 PRINT '*                                                *'
122 PRINT '* This program calibrates input voltages in terms   *'
123 PRINT '*  of volume for the spirometer...begin at vol.=0   *'
124 PRINT '*                                                *'
125 PRINT '**************************************************'
130 REM DESIGNED TO INPUT 10 VOLUMES AND CALIBRATE (0-10)
140 J=0 \ I=1 \ S(0)=0 \ S2(0)=0 \ S1(0)=0 \ Z1(0)=0
150 SCHEDULE('INTERVAL',10,190)
160 AIN('DISPLAY',A1%(),100,.1,0,)
180 IF I=0 GO TO 190 \GO TO 160
190 I=0
200 FOR K=0 TO 99 \ A(K)=A1%(K) \ PRINT A(K) \ NEXT K
210 FOR L=0 TO 99 \ S(L+1)=S(L)+A(L) \ NEXT L
220 A2(J)=S(100)/100
225 DISPLAY_CLEAR
230 PRINT 'THE VOLUME MEASURED WAS:'; \ PRINT J
240 PRINT 'AVERAGE VOLTAGE WAS: '; \ PRINT A2(J)
243 PRINT ''
244 PRINT '***YOU HAVE TEN SECONDS TO INCREASE VOLUME***'
245 PAUSE(10)
246 PRINT CHR$(7)
250 I=1 \ J=J+1 \ S(0)=0
260 SCHEDULE('INTERVAL',10,190)
270 IF J%=11 THEN 285
280 RETURN
285 PRINT 'VOLUME          VOLTAGE'
286 FOR I=0 TO 10 \ PRINT I,A2(I) \ NEXT I
287 PRINT \  PRINT
290 REM NOW HAVE VOLTAGES VS VOLUME DATA
300 REM NEXT PERFORM LEAST SQUARES DATA REDUCTION
310 FOR J=0 TO 10 \ S2(J+1)=S2(J)+A2(J) \ NEXT J
320 V3=S2(11)/11
330 V4=5
340 FOR K=O TO 10 \ A(K)=(A2(K)-V3)*(K-V4) \ NEXT K
350 FOR K=0 TO 10 \ S1(K+1)=A(K)+S1(K) \ NEXT K
360 FOR K=0 TO 10 \ Z(K)=(K-V4)^2 \ NEXT K
370 FOR K=0 TO 10 \ Z1(K+1)=Z(K)+Z1(K) \ NEXT K
375 K=11
380 M=S1(K)/Z1(K)
390 B=V3-M*V4
400 REM VOLTS =VOLUME*M+B  ie. LINEAR RELATIONSHIP
410 REM USE EQN VOL=(VOLTS-B)/M
416 PRINT 'THE LEAST SQUARES INFORMATION IS:'
417 PRINT \ PRINT
420 PRINT 'THE SLOPE IS:'; \ PRINT M
430 PRINT 'THE Y INTERCEPT IS:'; \ PRINT B
440 PAUSE(20)
450 DISPLAY_CLEAR
460 STOP \ END
```

MAX4.BAS

```
1 REM
100 REM  This program allows one to find the relative extremum
101 REM   values in the spirometer data set
120 DIM M%(3000),S%(600),C1(50),C2(50)
125 DIM C3(50),C4(50)
130 B=0 \ D=0
140 OPEN 'DK1:JDH1.DAT' FOR INPUT AS FILE #3
150 FOR I=0 TO 2999
160 INPUT #3,M%(I)
170 NEXT I
180 CLOSE #3
190 REM
200 FOR K=0 TO 599 \ K%=5*K
210 S%(K)=M%(K%)
220 NEXT K
230 REM
240 FOR K=3 TO 595
260 T1=S%(K) \ T2=S%(K+1) \T3=S%(K+2) \ T4=S%(K-3) \ T5=S%(K+3)
270 IF T1<=T2 THEN IF T3<=T2 THEN IF T4<=T2 THEN IF T5<=T2 THEN B=B+1 \ C1(B)=K+
1
280 IF T1>=T2 THEN IF T3>=T2 THEN IF T4>=T2 THEN IF T5>=T2 THEN D=D+1 \ C2(D)=K+
1
290 NEXT K
300 IF B>D THEN J1=B
301 IF D>=B THEN J1=D
305 PRINT ' FILE PLACE    MAX       FILE PLACE          MIN'
306 PRINT \  PRINT
310 FOR J=1 TO J1 \ PRINT C1(J),S%(C1(J)),C2(J),S%(C2(J)) \ NEXT J
320 REM
325 PRINT    PRINT
330 PRINT 'WISH TO STORE MAX / MIN VALUES'; \ LINPUT S$
340 IF S$='N' THEN 380
345 PRINT     PRINT 'ENTER THE FILENAME PLEASE'; \ LINPUT F$
350 OPEN F$&'.DAT' FOR OUTPUT AS FILE #4
355 PRINT #4,' FILE PLACE    MAX       FILE PLACE          MIN'
360 PRINT #4,'***********************************************'
365 FOR J=1 TO J1    PRINT #4,C1(J),S%(C1(J)),C2(J),S%(C2(J)) \ NEXT J
370 CLOSE #4
380 PRINT \  PRINT
390 STOP \ END
```

MANGE2.BAS

```
1 REM Program name HELLO or MANAGE
5 REM THIS PROGRAM ALLOWS ONE TO OPEN A MAGNETOMETER DATA
6 REM  FILE AND ... GRAPH,TRANSFER OR DISPLAY THE DATA
7 REM note: must sub filename into #30 and #120
8 B$='  ####     #####     #####     #####     #####     #####'
10 DIM M%(3000)
11 DIM S%(600),Y%(600)
30 OPEN 'DK1:F2.DAT' FOR INPUT AS FILE #3
40 FOR I=0 TO 2999
50 INPUT #3,M%(I)
60 NEXT I
70 CLOSE #3
90 PRINT 'DO YOU WISH TO COPY FILE TO ANOTHER DISK'; \ LINPUT F$
100 IF F$='N' THEN 163
105 DISPLAY_CLEAR
110 PRINT 'PLACE NEW DISKETTE INTO DRIVE 2'
115 PAUSE(15) \ PRINT  \ PRINT
120 OPEN 'DK1:F.DAT' FOR OUTPUT AS FILE #5
130 FOR I=0 TO 2999
140 PRINT #5,M%(I)
150 NEXT I
160 CLOSE #5
163 PRINT \  PRINT \  PRINT
196 PRINT 'GRAPH THE RESULTS'; \ LINPUT G$
198 IF G$='N' THEN 205
199 GRAPH(,,,M%())
205 DISPLAY_CLEAR \ PRINT 'GRAPH SPIROMETRIC RESULTS'; \ LINPUT V$
210 IF V$='Y' THEN  GOSUB 325
211 PRINT 'DISPLAY THE NUMERICAL RESULTS'; \ LINPUT D$
212 IF D$='Y' THEN  GOSUB 385
215 PRINT 'WISH TO GRAPH HYSTERESIS'; \ INPUT H$
216 IF H$='N' THEN 320
217 PRINT 'ENTER DESIRED MAGNETOMETER FOR COMPARISION'; \ INPUT I
218 PRINT 'ENTER THE FILEPLACES DEFINING DATA RANGE'; \ INPUT M1,M2
230 FOR K=M1 TO M2 \ K%=5*K
240 S%(K)=M%(K%) \  Y%(K)=M%(K%+I)
250 NEXT K
260 GRAPH(,,Y%(),S%())
300 PRINT 'AGAIN'; \ LINPUT A$
305 DISPLAY_CLEAR
310 IF A$='Y' THEN 196
315 PRINT 'WISH TO STORE THIS'; \ LINPUT S$
316 IF S$='Y' THEN  GOSUB 500
320 STOP
325 REM SUBROUTINE
326 PRINT 'ENTER CHANNEL NO. 0-4'; \ INPUT M7
330 FOR J5=0 TO 599
335 S%(J5)=M%(J5*5+M7)
340 NEXT J5
```

```
350 GRAPH(,,,S%())
360 LABEL(,'SPIROMETRIC CURVE','.')
370 PAUSE(15) \ DISPLAY_CLEAR
380 RETURN
385 REM SUBROUTINE
390 FOR K=0 TO 599 \ K%=5*K
400 PRINT USING B$,K,M%(K%),M%(K%+1),M%(K%+2),M%(K%+3),M%(K%+4)
410 NEXT K
420 DISPLAY_CLEAR
430 RETURN
500 PRINT 'ENTER OUTPUT FILENAME'; \ LINPUT F$
510 OPEN F$&'.DAT' FOR OUTPUT AS FILE #3
520 FOR I=M1 TO M2
530 PRINT #3,I,S%(I),Y%(I)
540 NEXT I
550 CLOSE #3
560 RETURN
```

ANALY3.BAS

```
100 REM This program calculates correlation coefficients
110 REM  for inspiration/expiration parts of the data
200 DIM M%(3000),I%(525),E%(525)
210 DIM M1(25),C(2),M2(25)
220 REM
230 Z$='CHANNEL        INSPIRATION     EXPIRATION'
240 OPEN 'DK1:F.DAT' FOR INPUT AS FILE #3
250 FOR I=0 TO 2999
260 INPUT #3,M%(I)
270 NEXT I
280 CLOSE #3
290 PRINT 'Enter the number of MAX,MIN values'; \ INPUT B
300 FOR J=1 TO B
310 PRINT 'Enter the MAX,MIN fileplace'; \ INPUT M1(J),M2(J)
320 NEXT J
330 A1=0
340 FOR K=1 TO B-1
350 FOR C=M2(K) TO M1(K+1)
360 I%(A1)=M%(C*5)
370 A1=A1+1
380 NEXT C
390 NEXT K
400 A1=A1-1
410 A2=0
420 FOR K=1 TO B-1
430 FOR L=M1(K) TO M2(K)
440 E%(A2)=M%(L*5)
450 A2=A2+1
460 NEXT L
470 NEXT K
480 A2=A2-1
490 DISPLAY_CLEAR
500 PRINT 'WISH TO SEE EXPIRATION/INSPIRATION GRAPHS'; \ LINPUT E$
510 IF E$='N' THEN 560
520 REGION('UPPER',1) \ REGION('LOWER',2)
530 GRAPH(,,,I%(),2,,1) \ GRAPH(,,,E%(),2,,2)
540 LABEL(,'EXPIRATION','.',2) \ LABEL(,'INSPIRATION','.',1)
550 PAUSE(15) \ DISPLAY_CLEAR
560 PRINT \ PRINT
570 PRINT 'WISH TO CALCULATE CORRELATION COEFFICIENTS'; \ LINPUT C$
580 IF C$='N' THEN 1020
590 DISPLAY_CLEAR
600 PRINT Z$
610 PRINT \ PRINT
620 FOR M7=0 TO 4
630 P1=0 \ S1=0 \ S2=0 \ S3=0 \ S4=0 \A3=0 \ A4=0 \ D1=0 \ D2=0 \ N=0
640 C(1)=0 \ C(2)=0
650 FOR K=1 TO B-1
660 FOR C=M2(K) TO M1(K+1)
670 N=N+1
```

```
680 X=5*C \ Y=5*C+M7
690 S1=S1+M%(X)
700 S2=S2+M%(Y)
710 S3=S3+M%(X)^2
720 S4=S4+M%(Y)^2
730 Q1=M%(X) \ Q2=M%(Y)
740 P1=P1+Q1*Q2
750 NEXT C
760 NEXT K
770 A3=S1/N
780 A4=S2/N
790 D1=SQR(ABS(1/(N-1)*(S3-N*A3^2)))
800 D2=SQR(ABS(1/(N-1)*(S4-N*A4^2)))
810 C(1)=(1/(N-1))*((P1-N*A3*A4)/(D1*D2))
820 P2=0 \ R1=0 \ R2=0 \ R3=0 \ R4=0 \ A5=0 \ A6=0 \ D3=0 \ D4=0 \ M=0
830 FOR K=1 TO B-1
840 FOR C=M1(K) TO M2(K)
850 M=M+1
860 X=5*C \ Y=5*C+M7
870 R1=R1+M%(X)
880 R2=R2+M%(Y)
890 R3=R3+M%(X)^2
900 R4=R4+M%(Y)^2
910 Q3=M%(X) \ Q4=M%(Y)
920 P2=P2+Q3*Q4
930 NEXT C
940 NEXT K
950 A5=R1/M
960 A6=R2/M
970 D3=SQR(ABS(1/(M-1)*(R3-M*A5^2)))
980 D4=SQR(ABS(1/(M-1)*(R4-M*A6^2)))
990 C(2)=(1/(M-1))*((P2-M*A5*A6)/(D3*D4))
1000 PRINT M7,C(1),C(2)
1010 NEXT M7
1020 STOP \ END
```

FMAIN.BAS

```
100 REM Program name is FMAIN
120 COMMON M%(3000)
140 OPEN 'DK1:F2.DAT' FOR INPUT AS FILE #3
160 FOR I=0 TO 2999
180 INPUT #3,M%(I)
200 NEXT I
220 CLOSE #3
240 PRINT 'Wish to see spirometric curve'; \ LINPUT S$
260 IF S$='Y' THEN CHAIN 'FGRAPH.BAS'
280 PRINT 'Wish to calculate fourier coefficients'; \ LINPUT F$
300 IF F$='Y' THEN CHAIN 'FCOEFF.BAS'
320 PRINT 'Wish to print out FOURIER RESULTS?'; \ LINPUT R$
340 IF R$='Y' THEN CHAIN 'FOUT.BAS'
360 STOP \ END
```

FGRAPH.BAS

```
100 REM Program FGRAPH.BAS to be used with FMAIN.BAS and FCOEFF in chain
120 DIM S%(600)
140 COMMON M%(3000)
160 PRINT 'Which channel please'; \ INPUT C
170 FOR J=0 TO 599 \ S%(J)=0 \ NEXT J
180 FOR I=0 TO 599
200 S%(I)=M%(I*5+C)
220 NEXT I
240 GRAPH(,,,S%())
260 PAUSE(5) \ DISPLAY_CLEAR
280 PRINT 'AGAIN'; \ LINPUT A$
300 IF A$='Y' THEN 160
320 CHAIN 'FCOEFF.BAS'
```

FCOEFF.BAS

```
100 REM program FCOEFF.BAS
120 DIM A(5,7),B(5,7)
140 COMMON M%(3000),A1(4),G(5,7),P(5,7),N,N2,M1,M2
160 PRINT 'Enter number of harmonics to be found'; \ INPUT N2
180 PRINT 'Enter max datafile places to define data range'; \ INPUT M1,M2
200 N=M2-M1+1
220 FOR K=0 TO 4 \ FOR T=M1 TO M2 \ A1(K)=A1(K)+M%(T*5+K) \ NEXT T \ NEXT K
240 FOR K=0 TO 4 \ A1(K)=A1(K)/N \ NEXT K
245 FOR J=1 TO N2
250 FOR K=0 TO 4 \ A(K,J)=0 \ B(K,J)=0 \ NEXT K
255 NEXT J
260 FOR J=1 TO N2
280 FOR K=0 TO 4
300 FOR T=M1 TO M2
320 A(K,J)=A(K,J)+M%(T*5+K)*COS(2*PI*J*T/N)
340 B(K,J)=B(K,J)+M%(T*5+K)*SIN(2*PI*J*T/N)
360 NEXT T
380 NEXT K
400 NEXT J
440 FOR J=1 TO N2
460 FOR K=0 TO 4
480 A(K,J)=A(K,J)*2/N
500 B(K,J)=B(K,J)*2/N
520 G(K,J)=SQR(A(K,J)^2+B(K,J)^2)
540 P(K,J)=ATN(A(K,J)/B(K,J))
560 IF B(K,J)<0 THEN P(K,J)=P(K,J)+PI
580 NEXT K
600 NEXT J
620 CHAIN 'FCOMP.BAS'
```

FCOMP.BAS

```
100 REM program FCOMP.BAS
110 DIM S%(600),F%(600)
120 COMMON M%(3000),A1(4),G(5,7),P(5,7),N,N2,M1,M2
130 PRINT 'Wish to compare the results with original file'; \ LINPUT C$
135 IF C$='N' THEN 540
136 DISPLAY_CLEAR
140 PRINT 'Enter the channel # for comparison:'; \ INPUT M7
160 FOR T=M1 TO M2 \ F%(T)=0 \ NEXT T
180 FOR T=M1 TO M2
200 FOR J=1 TO N2
220 F%(T)=F%(T)+G(M7,J)*SIN(2*PI*T*J/N+P(M7,J))
240 NEXT J
260 F%(T)=F%(T)+A1(M7)
280 S%(T)=M%(T*5+M7)
300 PRINT S%(T),F%(T)
320 NEXT T
340 DISPLAY_CLEAR
360 REGION('UPPER',1) \ REGION('LOWER',2)
380 GRAPH(,,,S%(),2,,1) \ GRAPH(,,,F%(),2,,2)
400 LABEL(,'SPIROMETRIC RESULT one breath','.',1)
420 LABEL(,'FOURIER ANALYSIS REPRESENTATION','.',2)
440 PRINT 'The number of harmonics found is:',N2
460 PRINT \ PRINT 'CLEAR THE SCREEN?'; \ LINPUT Q$
480 PRINT 'AGAIN'; \ LINPUT A$
500 IF A$='Y' THEN 136
520 IF Q$='Y' THEN DISPLAY_CLEAR
540 CHAIN 'FOUT.BAS'
```

FNORM.BAS

```
100 REM program FNORM.BAS
120 COMMON M$(3000),A1(4),G(5,7),P(5,7),N,N2,M1,M2
140 PRINT 'Wish to print out normalized fourier results'; \ LINPUT R$
180 DISPLAY CLEAR
200 IF R$='N' THEN 510
220 PRINT '*** FOURIER ANALYSIS OF MAGNETOMETER DATA ***'
240 PRINT  \ PRINT
260 PRINT '      NORMALIZED AMPLITUDES'
280 PRINT
300 PRINT 'SPIROMETER     MAG1           MAG2           MAG3           MAG4'
310 G1=G(0,1)
320 FOR J=1 TO N2
341 PRINT G(0,J)/G1,G(1,J)/G(1,1),G(2,J)/G(2,1),G(3,J)/G(3,1),G(4,J)/G(4,1)
342 REM PRINT G(0,J)/G1,G(1,J)/G1,G(2,J)/G1,G(3,J)/G1,G(4,J)/G1
360 NEXT J
380 PRINT
400 PRINT '      NORMALIZED PHASE ANGLES'
420 PRINT
440 PRINT 'SPIROMETER     MAG1           MAG2           MAG3           MAG4'
450 P1=PI/2
455 N5=P1-P(0,1)
460 FOR J=1 TO N2
481 PRINT P(0,J)+N5,P(1,J)+N5,P(2,J)+N5,P(3,J)+N5,P(4,J)+N5
482 IF J=1 THEN 510
483 REM Now we are only looking at the first and dominate harmonic
500 NEXT J
510 PRINT 'Wish to store data on DK0:'; \ LINPUT S$
515 IF S$='Y' THEN CHAIN 'NSTORE.BAS'
520 STOP \ END
```

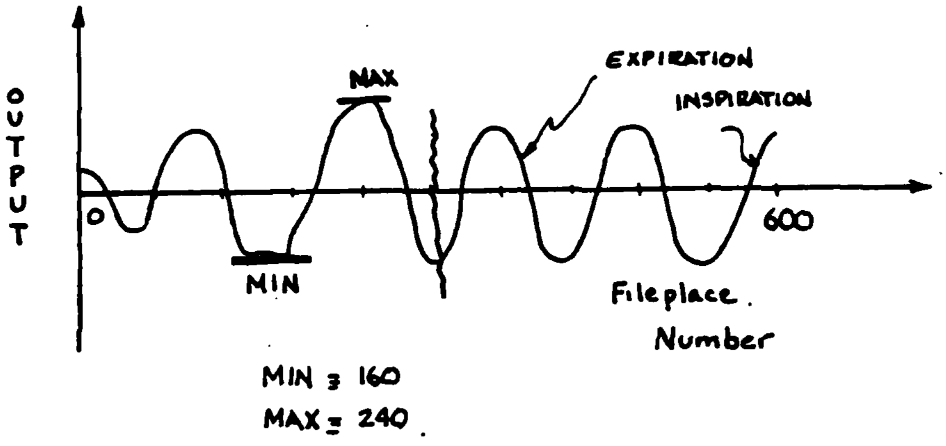
FOUT.BAS

```
100 REM program FCOMP.BAS
110 DIM S%(600),F%(600)
120 COMMON M%(3000),A1(4),G(5,7),P(5,7),N,N2,M1,M2
130 PRINT 'Wish to compare the results with original file'; \ LINPUT C$
135 IF C$='N' THEN 540
136 DISPLAY_CLEAR
140 PRINT 'Enter the channel # for comparison:'; \ INPUT M7
160 FOR T=M1 TO M2 \F%(T)=0 \NEXT T
180 FOR T=M1 TO M2
200 FOR J=1 TO N2
220 F%(T)=F%(T)+G(M7,J)*SIN(2*PI*T*J/N+P(M7,J))
240 NEXT J
260 F%(T)=F%(T)+A1(M7)
280 S%(T)=M%(T*5+M7)
300 PRINT S%(T),F%(T)
320 NEXT T
340 DISPLAY_CLEAR
360 REGION('UPPER',1) \ REGION('LOWER',2)
380 GRAPH(,,,S%(),2,,1) \ GRAPH(,,,F%(),2,,2)
400 LABEL(,'SPIROMETRIC RESULT one breath','.',1)
420 LABEL(,'FOURIER ANALYSIS REPRESENTATION','.',2)
440 PRINT 'The number of harmonics found is:',N2
460 PRINT      PRINT 'CLEAR THE SCREEN?'; \ LINPUT Q$
480 PRINT 'AGAIN'; \ LINPUT A$
500 IF A$='Y' THEN 136
520 IF Q$='Y' THEN DISPLAY_CLEAR
540 CHAIN 'FNORM.BAS'
```

NSTORE.BAS

```
100 REM program NSTORE.BAS
120 COMMON M%(3000),A1(4),G(5,7),P(5,7),N,N2,M1,M2
140 PRINT 'Enter the filename N(file).DAT'; \ LINPUT F$
160 OPEN F$&'.DAT' FOR OUTPUT AS FILE #5
180 PRINT #5,'*** FOURIER ANALYSIS OF MAGNETOMETER DATA ***'
200 PRINT #5,''
220 PRINT #5,'       NORMALIZED AMPLITUDES'
240 PRINT #5,''
260 PRINT #5,'SPIROMETER      MAG1            MAG2            MAG3            MAG4'
270 G1=G(0,1)
280 FOR J=1 TO N2
300 REM PRINT #5,G(0,J)/G(0,1),G(1,J)/G(1,1),G(2,J)/G(2,1),G(3,J)/G(3,1),G(4,J)/
G(4,1)
310 PRINT #5,G(0,J)/G1,G(1,J)/G1,G(2,J)/G1,G(3,J)/G1,G(4,J)/G1
320 NEXT J
340 PRINT #5,''
360 PRINT #5,'       NORMALIZED PHASE ANGLES'
380 PRINT #5,''
400 PRINT #5,'SPIROMETER      MAG1            MAG2            MAG3            MAG4'
410 P1=P(0,1)
415 N5=PI/2-P1
420 FOR J=1 TO N2
440 PRINT #5,P(0,J)+N5,P(1,J)+N5,P(2,J)+N5,P(3,J)+N5,P(4,J)+N5
450 REM PRINT #5,P(0,J)/P1,P(1,J)/P1,P(2,J)/P1,P(3,J)/P1,P(4,J)/P1
455 IF J=1 THEN 480
460 NEXT J
480 CLOSE #5
500 STOP \ END
```

Figure A.1 Schematic wave form illustrating the fileplace - data representation of a typical forty-five second trace. By specifying various maxima and minima values, we can analyze any breath(s).



Appendix 2

Correlation coefficients averaged over the entire test duration for each subject (four tables)

AP QUIET BREATHING

SUBJECT	$S-M_1$	$S-M_2$	$S-M_3$	$S-M_4$
1	.9756	.7029	.2859	.7602
	.9604	.6737	.4095	.5166
2	.9641	.0321	.7187	.8617
	.9733	.114	.8701	.9320
3	.9684	.5499	.8772	.9402
	.978	.5955	.9184	.9685
4	.9778	.6848	.8313	.8529
	.9942	.8666	.9516	.8994
5	.9287	.9487	.7817	.8928
	.9258	.8915	.8529	.8463
6	.9932	.1206	.7494	.7081
	.9923	-.1543	.7080	.7669
7	.9575	-.3899	.7365	.7554
	.9795	-.452	.7887	.7360
8	.9433	.4992	.7954	.5023
	.9611	.7998	.8759	.6865
9	.8081	.5431	.9005	.9243
	.8123	.8671	.9632	.9566
10	.9817	.7019	.8107	.9496
	.98	.6327	.9501	.8309
11	.9549	.3118	.5573	.8089
	.9000	.6635	.491	.5013

AP FORCED BREATHING

SUBJECT	$S-M_1$	$S-M_2$	$S-M_3$	$S-M_4$
1	.9849	.8845	.7125	.6538
	.9825	.4154	.5152	.7858
2	.9847	.3966	.8795	.9500
	.9742	.5829	.9202	.8796
3	.9562	.3586	.9099	.6506
	.9817	.0644	.7709	.6267
4	.9885	.8884	.8784	.6715
	.9873	.7373	.8222	.7403
5	.9344	.9608	.8360	.8589
	.9400	.9646	.7994	.8065
6	.9924	.0985	.6358	.3156
	.9493	.1685	.7157	.4737
7	.9747	-.1161	.7514	.7900
	.9815	-.4587	.8371	.8058
8	.9542	.3257	.7513	.5126
	.9672	.7193	.9250	.4977
9	.894	.083	.8755	.7737
	.9621	.0929	.9284	.8048
10	.9815	.6555	.8428	.6209
	.9914	.6953	.8102	.5193
11	.9433	.4500	.5396	.5653
	.9788	.0986	.8221	.8171

LATERAL FORCED BREATHING

SUBJECT	$S-M_5$	$S-M_6$	$S-M_7$	$S-M_8$
1	.9498	.8243	.4687	.8271
	.9232	.8563	-.2496	.8062
2	-.5975	.5453	.8145	.7288
	-.7195	.6283	.7250	.7511
3	.7910	.7788	.9334	.7523
	.8450	.8362	.9157	.8708
4	.9453	.8342	-.7874	.9471
	.7000	.8479	-.6118	.8523
5	.4483	.3807	.8277	.694
	.8778	.4090	.3967	.7428
6	.9745	-.0956	.813	.5289
	---	---	---	---
7	.9128	.5022	.8911	.5499
	.8807	.4291	.9126	.6256
8	.1717	.8939	.7823	.8789
	-.0776	.8987	.7360	.4747
9	.0314	.3034	.3671	.6653
	.6533	-.1091	.6391	.7598
10	.9323	-.8566	.3128	.7848
	.7259	-.4663	.1383	-.2513
11	.5952	-.6212	-.7816	-.9421
	.8375	-.8987	-.7784	-.8823

LATERAL QUIET BREATHING

SUBJECT	S-M_5	S-M_6	S M_7	S-M_8
1	.9260	.1024	.0612	.1375
	.9182	.1963	.2576	.1591
2	-.7599	.0007	.8106	.5375
	-.9163	.1814	.8882	.479
3	.8213	.4033	.9653	.9443
	.8459	.3365	.9423	.9572
4	.8483	.8142	.4001	.9183
	.8420	.7663	.2381	.9458
5	.9365	.3881	.9498	.9254
	.9325	.8679	.8903	.9508
6	.9671	-.4681	.8297	.015
	.9563	-.2238	.8528	-.002
7	.7661	.5974	.8628	.3024
	.6750	.5631	.7379	.4607
8	.1779	.6302	.2795	.2273
	.514	.8236	.3090	.0596
9	.5011	-.5108	.9380	.9391
	.659	-.2317	.6926	.9024
10	.9478	-.7823	.7529	.8037
	.7090	-.8433	.6728	.7586
11	.7596	.3045	-.1464	-.6463
	.3086	-.8804	-.4177	-.8461

Appendix 3

The fourier analysis results, one typical breath for each subject.

NAMY2.DAT

*** FOURIER ANALYSIS OF MAGNETOMETER DATA ***

NORMALIZED AMPLITUDES

SPIROMETER	MAG1	MAG2	MAG3	MAG4
1	1.53173	.277958	1.05395	.243016
.0818772	.135557	.153484	.438685	.20207
.0366824	.127475	.0547998	.190196	.151556
.0285365	.0706807	8.14475E-03	.0542658	.116529
.0117908	.0161791	7.58024E-03	.0500434	.0901269

NORMALIZED PHASE ANGLES

SPIROMETER	MAG1	MAG2	MAG3	MAG4
1.5708	1.55904	1.3449	1.57636	1.87677

NCGK2.DAT

*** FOURIER ANALYSIS OF MAGNETOMETER DATA ***

NORMALIZED AMPLITUDES

SPIROMETER	MAG1	MAG2	MAG3	MAG4
1	.745678	.0797519	.659867	.886666
.120703	.068604	.0306968	.133125	.139206
9.54317E-03	.0201517	.0705527	.104838	.0537833
.012031	.0231332	.0289273	.0291821	.0309087
6.71657E-03	.0191849	.023747	.0108346	9.70657E-03

NORMALIZED PHASE ANGLES

SPIROMETER	MAG1	MAG2	MAG3	MAG4
1.5708	1.54219	2.4549	1.60014	1.59252

NDAT2.DAT

*** FOURIER ANALYSIS OF MAGNETOMETER DATA ***

NORMALIZED AMPLITUDES

SPIROMETER	MAG1	MAG2	MAG3	MAG4
1	.676668	.202765	.889067	.551774
.158674	.0922115	.281772	.276767	.0951901
.0229658	.0191326	.0473572	.0825194	6.28071E-03
.0349847	.0147163	.0413403	.0667264	.0210197
.0174095	.0228745	.0156769	.0310486	.0209508

NORMALIZED PHASE ANGLES

SPIROMETER	MAG1	MAG2	MAG3	MAG4
1.5708	1.61464	1.68415	1.5423	1.43012

NJAG2.DAT

*** FOURIER ANALYSIS OF MAGNETOMETER DATA ***

NORMALIZED AMPLITUDES

SPIROMETER	MAG1	MAG2	MAG3	MAG4
1	1.07428	.450423	1.02361	.190903
.18042	.210806	.210626	.320047	.0730519
.0598286	.0254997	.0425669	.109846	.0476739
.0575806	.0417476	.0816732	.135963	.0318352
.0163215	.023997	.0103082	.0301155	.0224769

NORMALIZED PHASE ANGLES

SPIROMETER	MAG1	MAG2	MAG3	MAG4
1.5708	1.53719	1.82035	1.67781	1.63941

NJDH2.DAT

*** FOURIER ANALYSIS OF MAGNETOMETER DATA ***

NORMALIZED AMPLITUDES

SPIROMETER	MAG1	MAG2	MAG3	MAG4
1	.308159	.368654	1.28451	1.1958
.0590098	.027976	.106163	.259992	.129805
.049087	.0307273	.0438816	.126412	.0659156
.0124552	.0582475	.0301776	7.07686E-03	.0467637
.0188293	3.32966E-03	3.06696E-03	.0193889	3.98701E-03

NORMALIZED PHASE ANGLES

SPIROMETER	MAG1	MAG2	MAG3	MAG4
1.5708	1.18552	1.60638	1.72337	1.68595

NKGM2.DAT

*** FOURIER ANALYSIS OF MAGNETOMETER DATA ***

NORMALIZED AMPLITUDES

SPIROMETER	MAG1	MAG2	MAG3	MAG4
1	1.7058	.112815	.657055	.276472
.176537	.275889	.0844583	.144678	.0588457
.0380045	.0994377	.0753942	.0952208	.0317776
.0215485	.0150283	.036331	.0369434	.0122785
5.48140E-03	.0134287	.035262	.0299376	.0203154

NORMALIZED PHASE ANGLES

SPIROMETER	MAG1	MAG2	MAG3	MAG4
1.5708	1.62188	3.40169	1.67889	1.76207

NRSH2.DAT

*** FOURIER ANALYSIS OF MAGNETOMETER DATA ***

NORMALIZED AMPLITUDES

SPIROMETER	MAG1	MAG2	MAG3	MAG4
1	1.06612	.908002	1.90461	.984701
.320819	.310658	.386747	.569066	.205221
.109077	.125224	.036669	.178088	.0861792
.0493407	.0398869	.144349	.092692	.0625694
2.89136E-03	.0431166	.0213328	.0427264	.0186506

NORMALIZED PHASE ANGLES

SPIROMETER	MAG1	MAG2	MAG3	MAG4
1.5708	1.63064	1.2926	1.58333	1.40485

NRTO2.DAT

*** FOURIER ANALYSIS OF MAGNETOMETER DATA ***

NORMALIZED AMPLITUDES

SPIROMETER	MAG1	MAG2	MAG3	MAG4
1	.432942	.537349	1.03694	.444539
.0970627	.0260461	.149473	.218046	.106696
.038051	.0315812	.0828117	.0965678	.0354931
.0218677	6.65992E-03	.0321194	.0221177	.0294254
.0129702	.0140204	9.25482E-03	.0359399	.042443

NORMALIZED PHASE ANGLES

SPIROMETER	MAG1	MAG2	MAG3	MAG4
1.5708	1.68511	1.8608	1.65996	1.74555

NSMV2.DAT

*** FOURIER ANALYSIS OF MAGNETOMETER DATA ***

NORMALIZED AMPLITUDES

SPIROMETER	MAG1	MAG2	MAG3	MAG4
1	.443144	1.27092	1.40955	.835117
.111953	.119025	.455513	.30066	.162786
.0871499	.0470324	.26756	.198715	.102874
.0586643	.0484116	.149006	.122612	.0472155
.0339576	.0344445	.0944689	.0658373	.0283885

NORMALIZED PHASE ANGLES

SPIROMETER	MAG1	MAG2	MAG3	MAG4
1.5708	1.26516	2.04038	1.82385	1.6121

NTDK2.DAT

*** FOURIER ANALYSIS OF MAGNETOMETER DATA ***

NORMALIZED AMPLITUDES

SPIROMETER	MAG1	MAG2	MAG3	MAG4
1	.850661	.247883	1.22582	.450589
.188684	.213981	.0989264	.353044	.0604822
.0458051	.0573182	.0344821	.0998746	.0511678
.0660073	.0246433	.0493113	.114086	.0475755
9.45356E-03	.0349985	.0326862	.0718003	.0418472

NORMALIZED PHASE ANGLES

SPIROMETER	MAG1	MAG2	MAG3	MAG4
1.5708	1.85694	1.21839	1.48776	.72953

NWJD2.DAT

*** FOURIER ANALYSIS OF MAGNETOMETER DATA ***

NORMALIZED AMPLITUDES

SPIROMETER	MAG1	MAG2	MAG3	MAG4
1	.640421	2.03128	1.66554	1.08363
.0666984	.132997	.254743	.279774	.11212
.0428129	.0299331	.283275	.0197492	.182894
3.77183E-03	.0480178	.17451	.176451	.149901
.0205931	4.52137E-03	.082091	.0315118	.0437652

NORMALIZED PHASE ANGLES

SPIROMETER	MAG1	MAG2	MAG3	MAG4
1.5708	1.02658	2.00377	1.8433	1.13621

END

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