An Ergonomics Approach to Evaluate the Use of Two Different Fixtures for Upholstering

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AN ERGONOMICS APPROACH TO EVALUATE THE USE OF TWO DIFFERENT
FIXTURES FOR UPHOLSTERING

by

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A furniture company in West Michigan proposed an evaluation of a new fixture that will be used in a repetitive manual stapling operation.

Numerous studies reveal that activities involving repetitive wrist motions cause inflammation in the median nerve that runs through the structure of the carpal wrist, causing a cumulative disorder known as Carpal Tunnel Syndrome (CTS). This syndrome is one of the most prevalent in industrial settings and service companies.

This study investigated if the use of a new design of a fixture had an impact on operators' performances. Three-dimensional comparative analysis was used to observe operators' wrist angular motions while stapling and using new and current fixtures. In addition, muscular strength and time involved in the particular task were analyzed.

Benefits identified through this study can be realized not only by the workers, but also by the employer.

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CHAPTER I

INTRODUCTION

Statement of the Problem

At the present time, technological changes and the
increased automation of industrial jobs require repetitive
manual tasks and high speed in order to keep up with rates
of production created by competitive pressures. In every
production line, parts or units are transported to differ-
ent workstations and they are progressively changed. In
these workstations, workers are assigned to perform specif-
ic manual tasks using specific tools. Automation has re-
duced the variety of tasks so that workers are limited to
performing only one manual task over and over during a
shift. Small groups of muscles and different wrist postures
are involved in these repetitive manual tasks. Although ex-
treme force may not be involved in manual tasks, extended
periods of grasping and pinching objects with bending
wrists cause stress in tendons. This stress damages nerves
and ligaments which pass through the carpal tunnel (see
Figure 1). Carpal Tunnel Syndrome (CTS) develops when the
median nerve becomes compressed as it passes through a
narrow tunnel in the carpal bones of the wrist (P. Panio,
1990). Activities that require active finger flexion with

Figure 1. Structure of the Carpal Tunnel.

Source: Vern Putz-Anderson (Eds).   (1988). <u>Cumulative</u>
           <u>trauma disorders: A manual for musculoskeletal</u>
           <u>diseases of the upper limbs.</u>   London: Taylor &
           Francis

the wrist flexed expose individuals to risk of CTS (Armstrong, 1986). People affected by CTS feel numbness, tingling and pain, resulting in an incapacity to work. Extreme cases can lead to surgery and permanent disability. CTS is one of the most common Cumulative Trauma Disorders (CTD). The rate of CTS has tripled in the last decade, causing pain not only to more workers but also to employers when they face workers compensation claims. The American Academy of Orthopaedic Surgeons estimates that CTD related injuries cost $27 billion a year in medical bills and lost of work days (Gabor, 1990).

Currently, manufacturing and service industries realize that they need to reduce the occurrence of CTD that cause damage to workers' health and performance, great variability in the rate of production and increased costs. However, not only automation and new technology, but also bad design of workstations and hand tools are the causes of CTD and increase the danger in workplaces.

Ergonomics is a discipline that assesses information about people's capacities and capabilities. This information is important not only for the design of workstations, fixtures and handtools, but also for addressing the improvement of the fit among people, machine and tasks as these pertain to productivity, health and safety. In the past years, industries have started to implement ergonomics programs in order to minimize the occurrence of CTD. Ergo-

nomics programs will include commitment, organization, comprehensive worksite analysis, strategies for preventing and controlling CTD and recommendations for change (Naderi and Baggerman, 1992).

Purpose of Study

In the past, several biomechanical models have been developed in order to analyze complex hand and wrist repetitive motions (Armstrong et al. 1979,1982; Keyserling 1986; Rawdin and Lin 1993). However, there is a need for three dimensional analysis to quantify wrist motion and kinematic factors, such as wrist angle and repetition (Marras and Schoenmarklin, 1993).

The main objectives of this study were to test whether or not the use of a new design of a fixture made a difference in operators' performances and to determine if indivuals were at risk of CTS. This research was based on three-dimensional (3-D) wrist data that was collected by obtaining wrist angular values. This angular data helped to identify the risk of CTS to the workers. With such information, preventive action should take place to minimize CTS occurrence.

Some research questions posed in this study were answered as the research progressed. These questions applied to the scene where workers started stapling parts for upholstery, using the current or the new fixture in the work-

station. The research questions answered were:

1. Is there a significant difference in the use of new fixtures and current fixtures and how wrist angular motions change?

2. Is there a significant difference in the time used?

3. Is there a significant difference in the number of staples to be used?

4. Does the new fixture minimize muscular activity and how is this activity reflected in each worker?

It was a goal of this study to become a tool for any ergonomics program that includes redesigning workstations and tools for people working in this industry at the present time.

CHAPTER II

REVIEW OF LITERATURE

History

Occupational injuries have been diagnosed for more than 200 years ago. In 1717, Bernandino Ramazini, an Italian physician, conceptualized the hazards in workplaces. He described how unnatural postures and repetitive motions could harm the perfect structure of the human body (Goldoftas, 1991). Later in the middle of the nineteenth century, Paget gave a full description of Carpal Tunnel Syndrome symptoms (Paget,1954). Since then, numerous studies have been done, but not in systematic manner. It was only fifty years ago that the compression of the median nerve was defined as a carpal tunnel disease (Brain, Wright and Wilkinson, 1947).

Anatomy of the Carpal Tunnel

The human body is a perfect composition of bones, muscles, nerves, tendons and ligaments. Bones are attached to each other by joints to provide motions of the articulated bones. Muscles that span the joints use the tendons to provide and transmit the force for moving bones.

The strong and flexible wrist joint and the hand are

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formed by a variety of bones, such as metacarpal in the palm, phalanges in the fingers and carpal in the wrist (Vern-Putz Anderson, 1988). Muscles in the front and back of the forearm and flexor tendons are responsible of the hand and finger movements. These flexor tendons have rope-like characteristics and are surrounded by tube-shape sheaths with a lubricating fluid. These sheaths enable tendons to retain position and move with minimum friction while muscles contract and relax during a movement (see Figure 2).

The carpal tunnel is a canal bordered by an arch of carpal bones and a dense carpal ligament by the palmar side, known as the extensor retinaculum (Huntley an Shannon, 1988). The extensor retinaculum ligament is a band with 20-30 mm wide and 1-2 mm thick. This ligament wraps and supports structures running through the tunnel. Like carpal bones, the extensor retinaculum is inelastic, limiting the tunnel capacity (Macdonald, Robertson and Erickson, 1988). Through the osteofibrous structure of the carpal tunnel passes the median nerve, four flexor digitorum profundus, four flexor digitorum superficialis and one flexor pollicis longus tendons (Tichauer and Howard, 1978). The median nerve furnishes sensory distribution to the palmar aspect of the thumb, index, middle and radial half of the full finger (Miller and Gregory, 1979).

Excessive use and unnatural positions of hand tendons
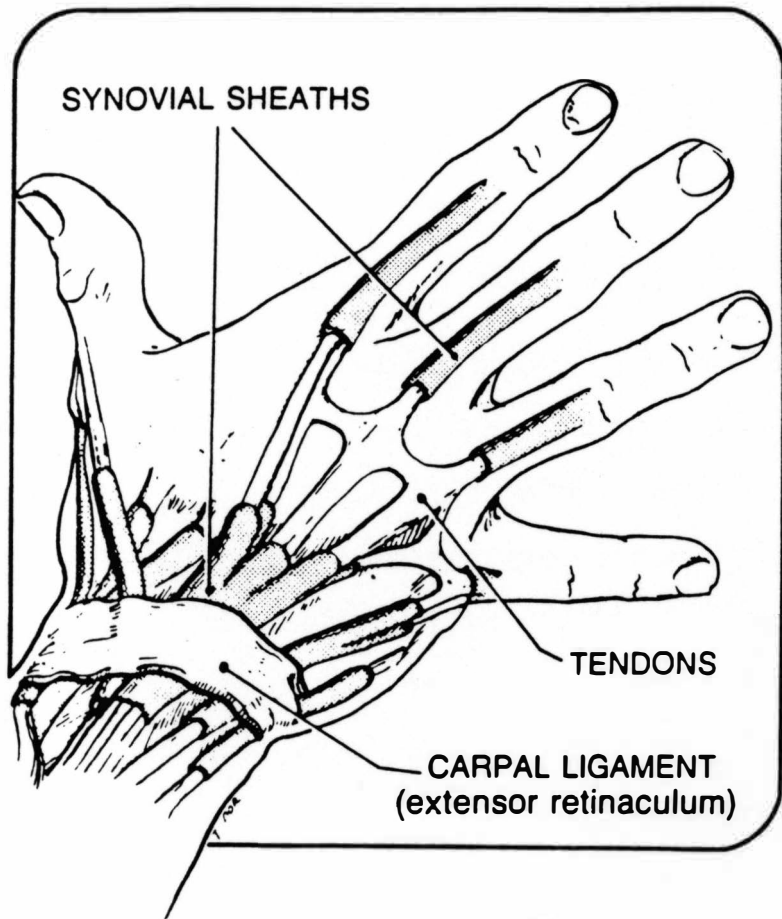
Figure 2. Carpal Ligament, Tendons and Synovial Sheaths.
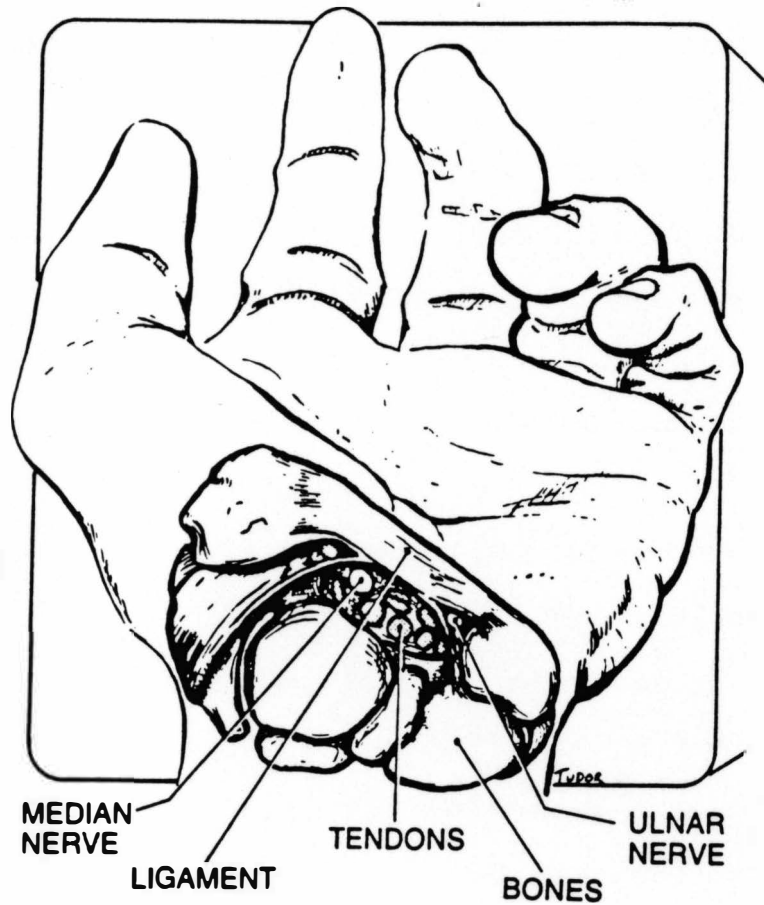
Source: Vern Putz-Anderson (Eds). (1988). <u>Cumulative
           trauma disorders: A manual for musculoskeletal
           diseases of the upper limbs.</u> London: Taylor &
           Francis

and bending of the wrists diminish lubrication of the tendon sheaths. This cause friction between the tendons and sheaths resulting in inflammation. Repeated episodes of inflammation will generate extraneous fibers that thicken tendon sheaths (Vern-Putz Anderson, 1988). Due to this thickening and the limited capacity of the tunnel, the median nerve also can be gradually damaged by getting squeezed or compressed, causing pain and impeding hand movement (Schenck, 1989).

Symptoms of the Injury

The compression of the median nerve as a result of tendon inflammation is known as Carpal Tunnel Syndrome (CTS). CTS is manifested as a specific pattern of neurological deficits that result in discomfort and impaired use of a hand. As a result of the median nerve damage, the sensory distribution is lost, producing discomfort and symptoms in the hand, such as, numbness, paresthesia, weakness, reduced temperatures and perspiration, lack of sensation and pain primarily in the fingers. Figure 3 shows darked areas on hands that are usually affected by CTS. People affected with the syndrome loose the capacity of grasping objects, holding things and performing simple manual tasks (Armstrong, 1983). In untreated cases, the progressing disorder will radiate pain into elbows, shoulders and the neck, with potential paralysis, cramps in the hands and arms, and

DORSAL SIDE

PALMAR SIDE

MEDIAN NERVE
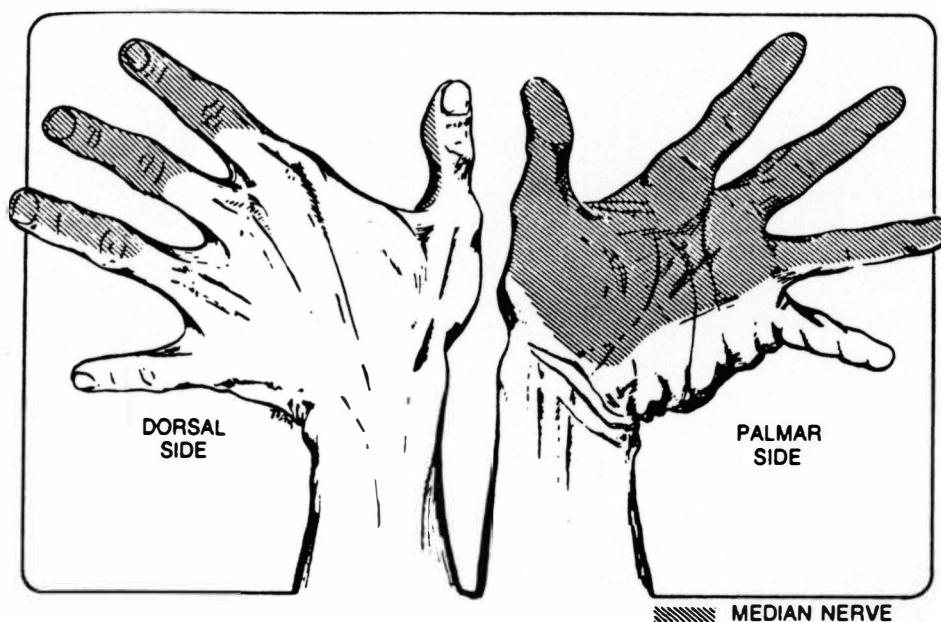
Figure 3. Shaded Areas Usually Affected by CTS.

Source: Vern Putz-Anderson (Eds). (1988). Cumulative trauma disorders: A manual for musculoskeletal diseases of the upper limbs. London: Taylor & Francis

swelling of the hands (Hoyt, 1984). Symptoms characteristically occur during the night. Most victims can awaken several times in one night. In some cases, temporary relief can be achieved by shaking the hand, rubbing it, changing its position or running warm water over it (Greenspan, 1988; Schenk 1989).

Risk Factors

Most of the manual industrial occupations involve considerable use of the hand and appeared to be predisposed to damage to the carpal wrist (Dionne, 1984). The result of numerous analyses and ergonomic studies reveals that CTS is most prevalent in jobs that require constant and forceful extension with frequent and large wrist deviations, such as, flexion, extension, ulnar deviation, radial deviation and a combination of these. Flexion and extension postures are shown in Figure 4. CTS has been found in assembly line workers and video display terminal users where tasks are performed with repetitive motions with wrists held at angle. Some studies found that speed of movements and incorrect posture while working should be counted (Luopajarvi et al., 1979). Another study found that median nerve compression can also be caused by a combination of forceful gripping and repetitive pounding with hands (Vern Putz-Anderson, 1988).
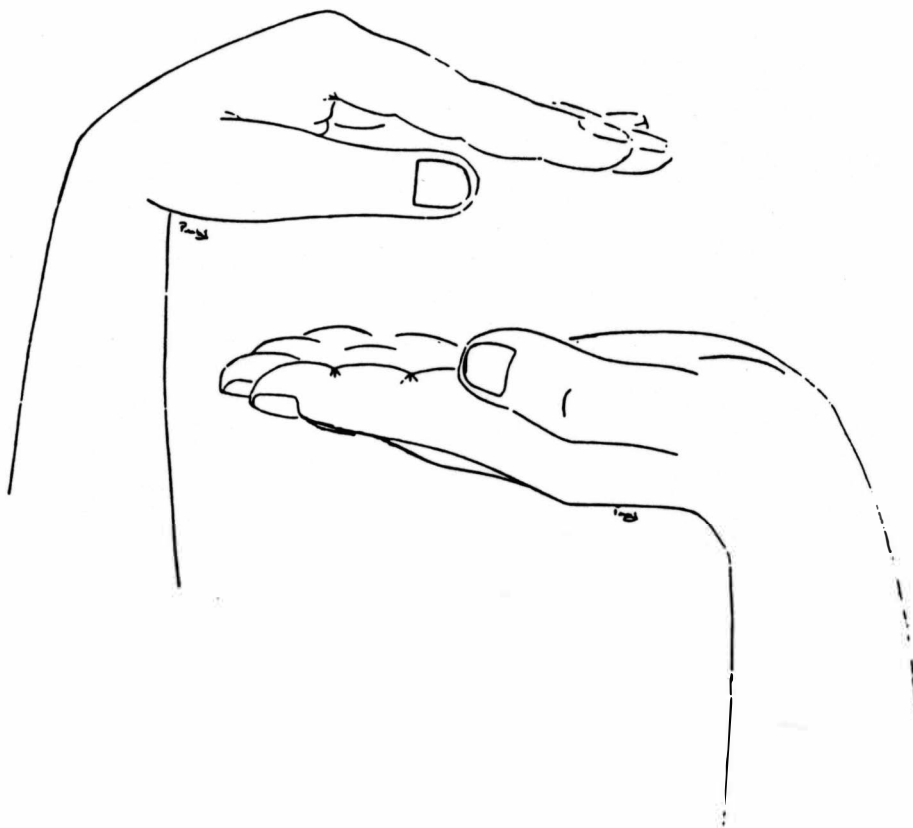
Figure 4. Flexion and Extension Hand Postures.

Wrist Position and Stresses

Deviations of the wrist side to side move the tendons against the inside of the carpal tunnel. The range of these motions produces significantly more stress than when the wrist is kept in a straight or neutral position (Armstrong, 1983).

Tichauer (1976) in his analysis of the work place recommends that wrists be kept straight while forearms and hands are rotated. He implies that continuous production jobs demanding flexion towards the ulnar, constitute a hazard to the working population. It is important to note that the length-tension relationship of contracting muscles is affected by wrist positions. As the angle of the joint increases or decreases with respect to its straight neutral position, there is a decrease in effective strength. This implies that more exertion or tendon tension must be required to do a task with a bent wrist than is required to do the same task with a wrist in a straight position (Vern Putz-Anderson, 1988). Finger flexion combined with a deviating wrist has also been found to compound tendon displacement and median nerve compression (Armstrong, 1983).

Smith, Sonstegard and Anderson (1977) have demonstrated the existence of compressive forces on the median nerve in simultaneous pinching and extreme wrist flexion. They determined that the hand is four to five times stronger in

a full grasp posture than in finger pinching posture, because the latest involves four to five times more tendon force and muscle strength.

Force Involved

The force applied on the palm and wrist to perform various occupational activities is another factor that contributes to the appearance of CTS. The amount of force to do a task depends on the design of the tool to be used and the size and shape of object that is to be moved or held. Following principles of mechanics, the amount of force exerted by fingers to hold an object is calculated by dividing the weight of the object by two times a coefficient of friction. Also, the amount of force exerted by the muscle of the forearm to the flexor tendons of the finger is related to the posture of the hand (Armstrong, 1986). The use of gloves also weakens worker strength and therefore more strength is required for a task (Armstrong 1983).

Wrist Angular Motion Involved in Manual Tasks

The wrist is a joint that draws angles between its proximal body segments: hand and forearm. Due to the vulnerability of the wrist, a continuous change of these angles over a long period of time severely stresses its structure.

During manual tasks, wrists generate an array of

stressing angular movement that are linked to many incidents of CTS in industry. Data from hand injuries suggests that it is essential to design handtools and fixtures with the purpose to maintain a natural position where the hand is held in line with the forearm, minimizing stress and continuous bending wrists (Bullock, 1990).

It is important to note that the movements of the hand and wrist are very complex and difficult to analyze. Hence, this research uses three dimensional movement to verify if the use of a new design of fixture allows the ideal straight wrist position.

Studies of the change in wrist angular movement showed a close relationship with a reduction of grip strength. Some examples of finger postures are shown in Figure 5 (Vern Putz-Anderson, 1988). Since the reduction of grip strength can be studied by measuring the flexor muscular activity from the forearm, this research studied the difference in a workers' muscular strength when they flexed fingers by pulling fabric edges from the cushion to be stapled. The experiment compared movements of stapling cushion parts when using a current and a new design of fixture.

The relationship of muscular activity and irregular hand motions has caught the attention of researchers and analysts. Wrist motion and hand postures have been the subject of many studies, all of them looking for solutions
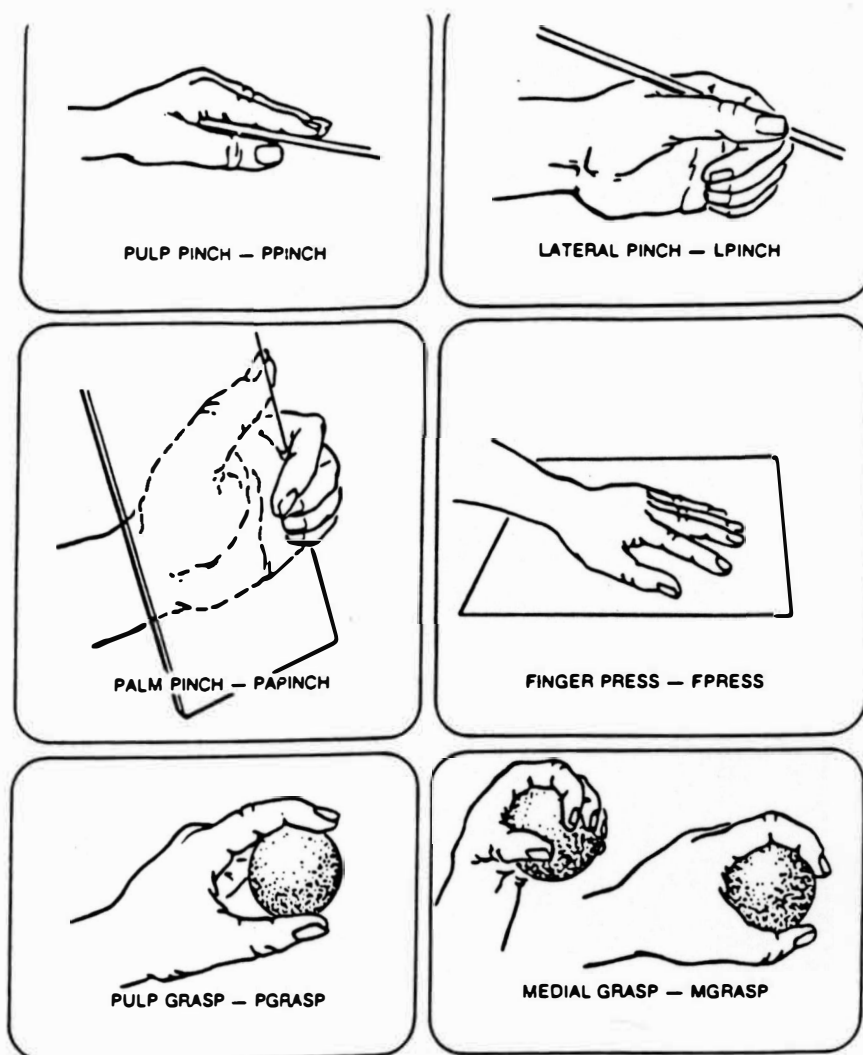
Figure 5. Finger Closing Postures.

Source: Vern Putz-Anderson (Eds). (1988). <u>Cumulative</u>
<u>trauma disorders: A manual for musculoskeletal</u>
<u>diseases of the upper limbs.</u> London: Taylor &
Francis

and strategies to minimize occupational injuries in the upper-body. Marras and Schoemarklin (1993) studied wrist motions that may influence tendon force in intensive hand work. They found that wrist accelerations in hand posture of flexion and extension are related to the risk of developing CTS.

CHAPTER III

METHODS AND PROCEDURES

Experimental Procedure

This research was conducted in conformance with Western Michigan University (WMU) policy that all research involving human subjects must have prior approval of the WMU Human Subjects Institutional Review Board. All participants in this research read and signed an information consent form that explained in detail the purpose of the experiment, equipment to be used, what was expected from this experiment and how data would be kept. A copy of the WMU Human Subject Institutional Review Board Subject is included in Appendix A.

Subjects

The present investigation was conducted in the Biomechanics Laboratory at Western Michigan University. The desired subjects in this experiment consisted of male and female furniture workers that performed the task of stapling fabric to back and seat cushion parts for the production of office chairs. Ten employees from a local furniture company volunteered to participate in the study. A workstation was installed in the biomechanics laboratory in

such a way that the subjects were able to staple cushion parts for upholstering in the same way that they performed in their daily eight hour work. Before any data collection and besides the information consent, these subjects were verbally informed about the purpose of the study and the performance of all the equipment to be used. In addition, subjects were told that no risk was associated with this experiment and it was their right to terminate participation at any time with no penalty.

Fixtures and Parts Description

For the staple operation, parts made of plastic come to the workstation with fabric and foam attached to them. In this particular case, back parts and seat parts were analyzed for the stapling task. The fixtures used in the experiment are listed in Table 1 and characteristics are shown in Figures 6,7,8.

Fixtures are made of plastic and are used to hold parts in the workstation. Because its shape, every part is held by its corresponding fixture. It is important to note that the purpose of using new fixtures is to be able to hold a part more tightly than a current fixture so that a worker will not need to pull (grasp) the fabric edges of the cushion to staple in the plastic part or frame of the hair.

Table 1

List of New and Old Fixtures Used for Cushion Parts

X N 2 3 0 S	New 230 fixture for cushion seat
X O 2 3 0 S	Old 230 fixture for cushion seat
X N 2 3 0 B	New 230 fixture for cushion back
X O 2 3 0 B	Old 230 fixture for cushion back
X N 5 3 0 B	New 530 fixture for cushion back
X O 5 3 0 B	Old 530 fixture for cushion back

Equipment

The furniture company provided a workstation for this experiment. It is shown in Figure 9. This workstation works with air pressure and has a round table that workers can rotate according to the need of the task. In addition, this workstation has pedals that permit workers to vertically adjust this table to their height.

The equipment utilized in this experiment permitted the subjects to staple parts for production of chairs in the same they way as they did as part of their normal full time job.

The handtool used for the manual task was a staple tool working with air pressure. Six fixtures were used: three of them in current use in the furniture company and three of them with a new design. Also, the new fixture used another fixture that was placed on top of the part, holding
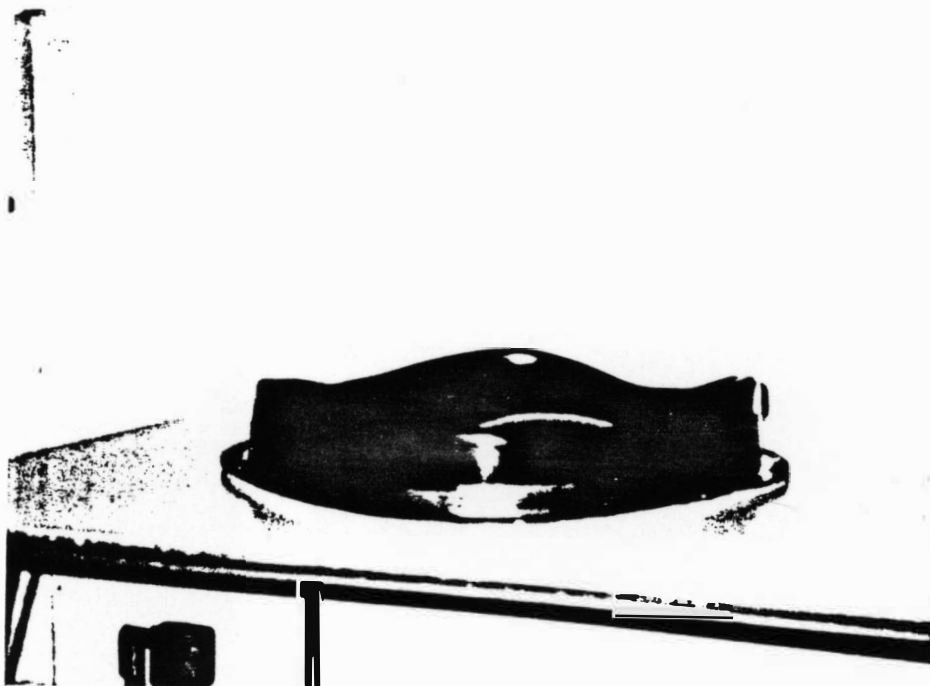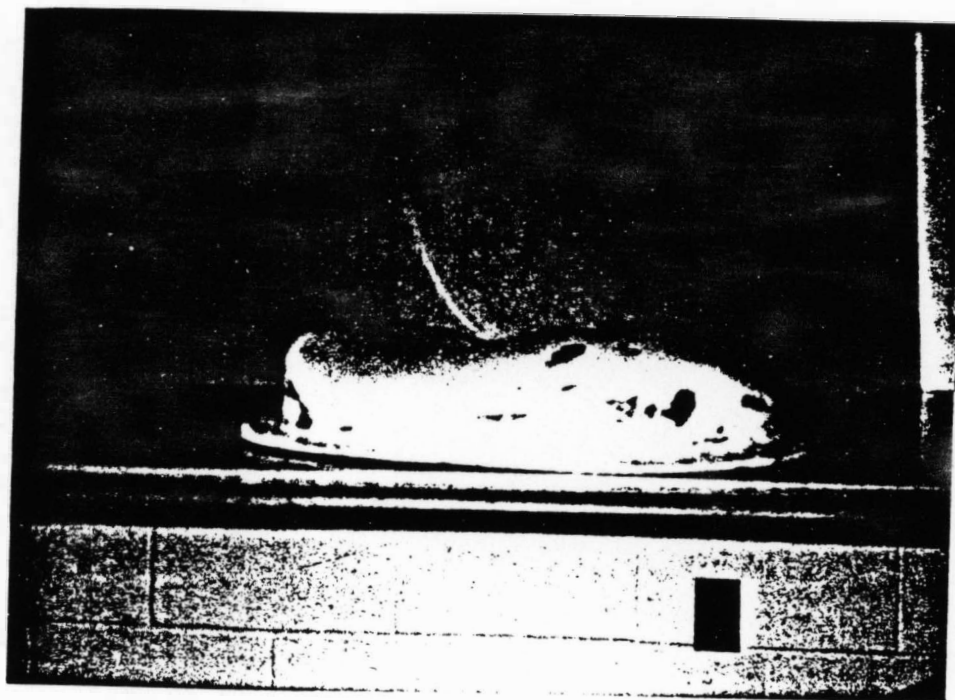
Figure 6. Old Fixture 230S (Top) and
          New Fixture 230S (Bottom).
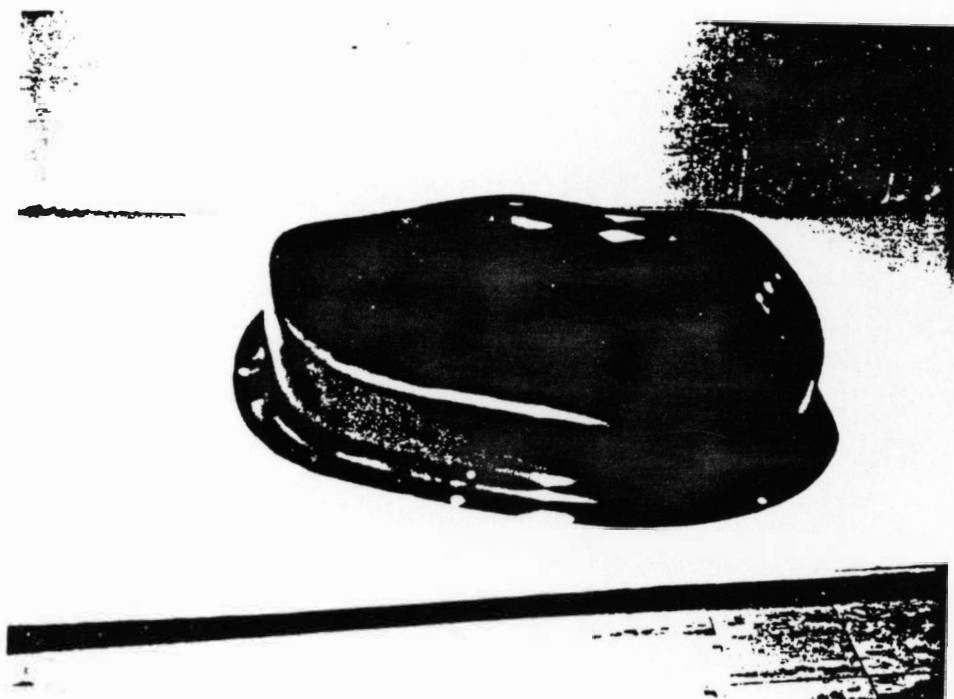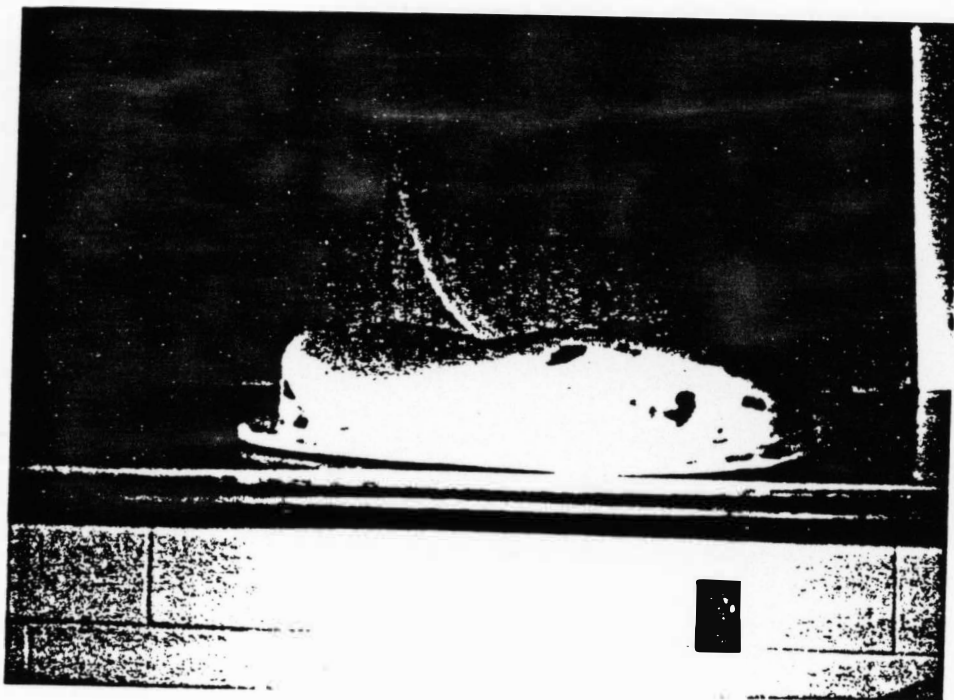
Figure 7. Old Fixture 230B (Top) and
New Fixture 230B (Bottom).
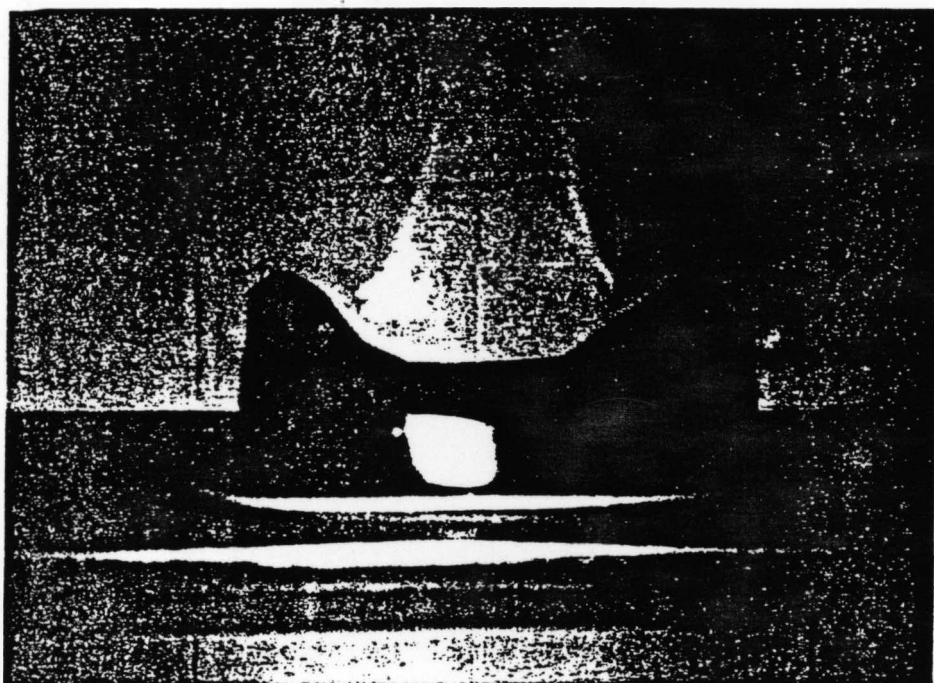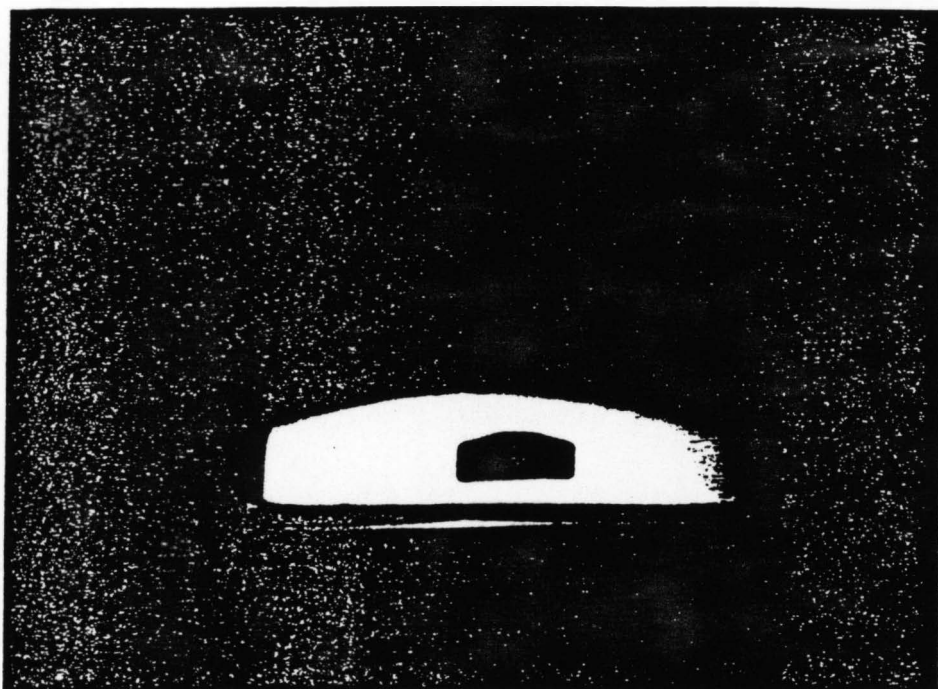
Figure 8. Old Fixture 530B (Top) and
New Fixture 530B (Bottom).

top

right

image

full

Figure
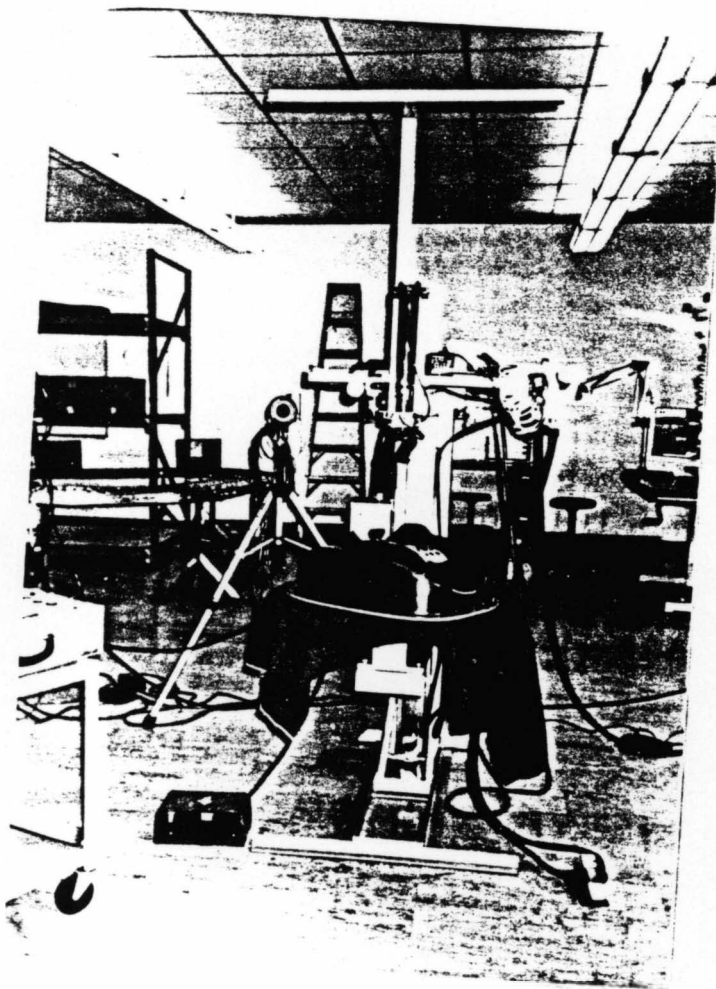
Workstation

Figure 9. Workstation.

the cushion very tight.

A videotape recorder was used to keep a record of the time involved during the manual tasks when using different fixtures. The videotape was used as a backup to refer to a particular analysis of operator or fixture.

Motion analysis system was the equipment used to collect three dimensional data. This system offered an integrated method to analyze a range of motions or multiple images. The system collected data in real time and offered high resolution graphics. Motion analysis equipment consisted of reflective markers, four video motion cameras, a video motion recorder, a video monitor, a videoprocessor, a host computer, a graphics workstation.

Muscle activity was recorded using electromyography. This technique has been used by many researchers to analyze muscular effort expended during manual tasks (Grandjean, 1988). The electrical activity of the flexor muscle in the forearm was recorded using a Lafayette Model #76409 EMG amplifier/EMG integrator. Three Lafayette 23mm diameter surface electrodes, Model #76623 transferred the electrical activity of the muscle. The output of surface electrodes was recorded by EMG equipment connected to motion analysis equipment for convenient automated collection of analog signals. Due to the capabilities of the videoprocessor, EMG analog signals were converted to digital signals for subsequent analysis (see Figure 10).
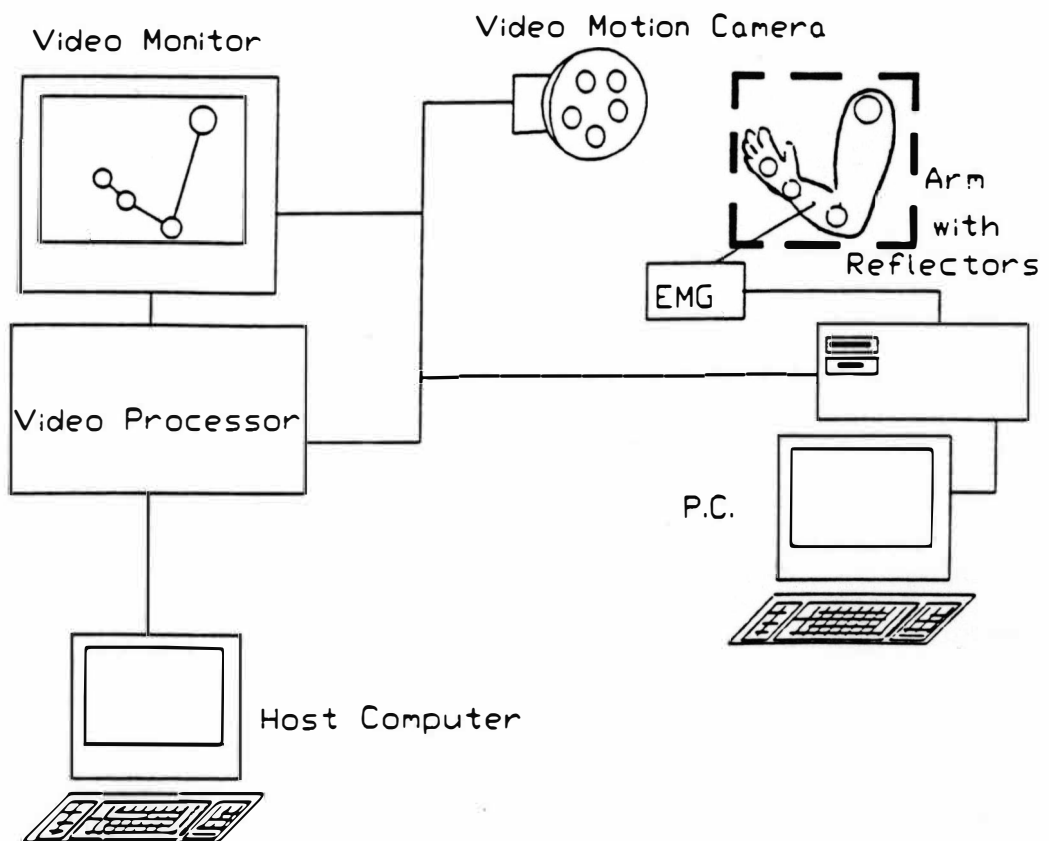
Figure 10. Motion Analysis Equipment and EMG.

Set Up of the Equipment

Before any data collection, the video camera recorder was placed in front of the area where subjects would staple parts. Motion equipment was set up in such a way that the data collected could be manipulated by computer software. Reflective markers were placed on the hand, wrist, elbow and shoulder of the left hand of the worker. Four video motion cameras were placed around the workstation to capture the reflection of these markers. This reflection was verified in the video monitor. In order to produce usable data, markers or reflectors had to be seen in the video monitor for every video motion camera. The system had the capability to hide other reflections using a reflection threshold. If some reflectors were not seen in the video monitor for a specific video motion camera, this camera had to be moved until all markers showed in the video monitor. The equipment was set up to record fifteen frames per second, usually called time frame. Default values were used for other functions of the motion analysis equipment. After these procedures, software in the host computer was called to start collecting data.

EMG Procedure

In order to collect EMG analog signals, electrodes had to be placed on the muscles that are involved in the activ-

ity to be analyzed. During the stapling task, individuals have to flex fingers to hold the fabric that have to be attached to parts. Since the flexor muscle from the foreman is responsible for the flexion of the fingers, this experiment wanted to investigate the activity of this muscle.

The subject's skin was cleaned with alcohol to reduce skin resistance and to increase the adhesive property of the electrodes. Muscle testing was used for correct electrode placement on the flexor muscle. Subjects were asked to flex their fingers to determine the right location of this muscle. Three electrodes were filled with electrode jelly to eliminate any air bubbles and were securely placed on the subject's left arm, one next to the elbow for grounding and the other two over the flexor muscle.

Data Collection

After the setup of motion analysis equipment, placement of the video camera and the EMG procedure, the first thirty second time frame of the task was registered in real time on the videoprocessor. Note that the motion analysis equipment performed a simultaneous collection of data matching video and analog data on time.

The total time involved in the task was recorded by video camera. The procedure was as follows:

1. Subject placed the fixture in the workstation, then the back or seat part over the fixture.

2. Subject pushed a button and workstation held fixture and part tightly.

3. Subject with a gun staple on the right side began stapling parts; motion analysis equipment started collecting data of the movement for thirty seconds with a rate of fifteen frames per second. The video camera recorder recorded the total activity of stapling to keep a record of time involved in the task in addition to serving as a backup.

4. During the task, subjects grasped and pulled the fabric edges of the cushion part towards the plastic part, stapled it and rotated the workstation's table. This continued until the task was completed (see Figure 11).

After the four cameras from motion analysis equipment recorded all the subject's movements, the analog data was stored in the computer. The videoprocessor converted the analog data into digital data, creating video files; a review of all the files was important to make sure that the video data collected was adequate and could be analyzed.

After reviewing the data, three dimensional analysis software was used. Expert Vision was the software used to manipulate the digitized video files frame by frame. Expert Vision offered a reconstruction of the data showing images in the host computer video screen images as seen by the four cameras. The motion could then be analyzed in a three dimensional plane. The four reflective markers placed on
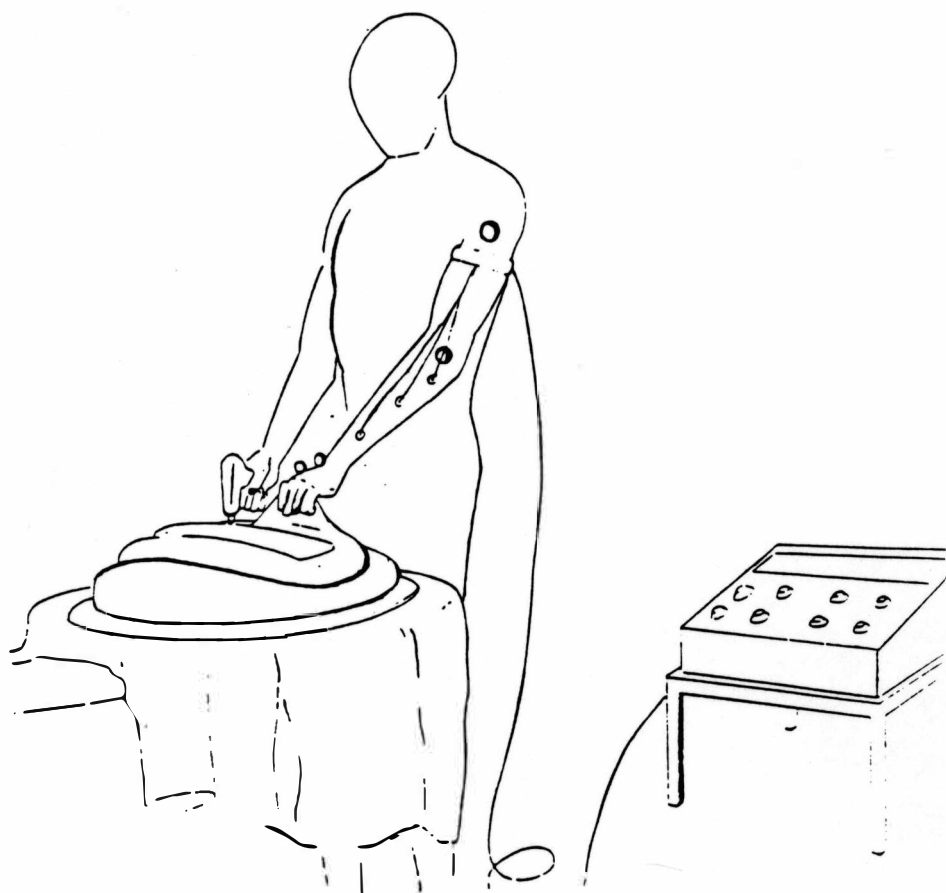
Figure 11. Worker Stapling Cushion Part.

the hand, wrist, elbow and shoulder were linked to form segments and were tracked. Tracking is a particular function of the software in which the position of the objects or segments moving in the three-dimensional space is calculated. This function creates files that can be manipulated for three dimensional analysis, such as angles, speed, linear acceleration. It is important to know that the track routine is tedious and long, but is an essential part of a three dimensional analysis. A example of a tracked file is shown in Figure 12.

Experimental Design

The determination of variability between current fixtures and new fixtures was determined by variability in angles wrists' workers data collected during the manual stapling task. In particular, this research used back and seat parts for the production of different models of chairs. Therefore the comparison for variability in the angular data was set by the use of three current fixtures and three new fixtures. The type of fixture to be used depended on the type of cushion part to be stapled. Every fixture had a number code pertaining to the part that was held. To keep the research data organized, letters were added to the codes. The first letter identified the operator. The second letter showed if the fixture was old (current fixture) or new. The last letter of the code showed if
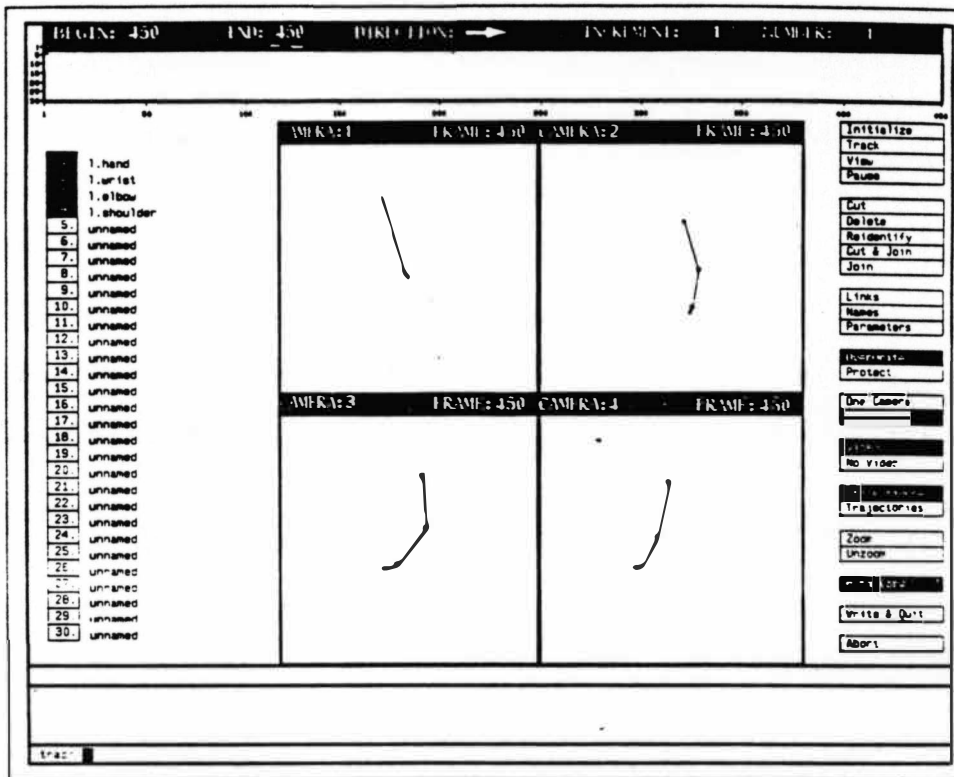
Figure 12. Left Arm Worker's Movement Tracked.

the fixture was used for back or seat cushion part. This explanation is shown in Figure 13.

```
X  N  2  3  0  S
                  ┌── S= CUSHION SEAT
                  └── B= CUSHION BACK
               └────── FIXTURE NUMBER
         └──────────── N= NEW FIXTURE
                       O= OLD FIXTURE
      └─────────────── OPERATOR IDENTIFICATION
                       (ANY LETTER)
```
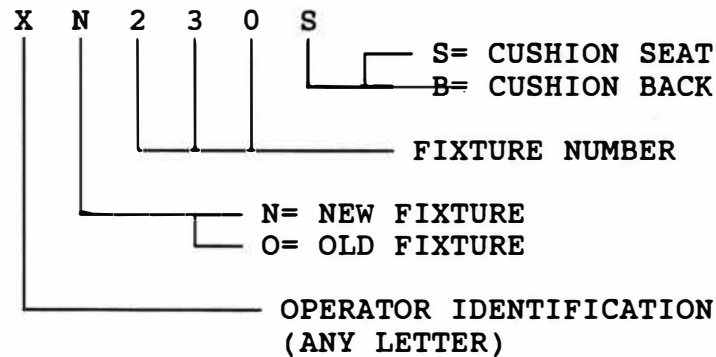
Figure 13.   Code Used for Fixture.

Analysis of variance (ANOVA) was used with a randomized complete block design. This design improved the accuracy of the comparison among fixtures by eliminating the variability among the operators. Randomized complete block design is the most widely used in experimental designs and helps to test operating characteristics of equipment and tools. In the experimental design, nine blocks corresponded to nine workers examined under an independent variable that was the wrist angular value. Six treatments corresponded to three new fixtures and three old fixtures.

The results of the randomized complete block design did not offer the difference between a pair of fixtures when a significant level for means was encountered. There-

fore, Duncan's test, a multiple range test, was used to find a difference between a pair of means (Montgomery, 1991). Wrist angular graphs were used to observe repetition of the wrist angle during the manual task (see Appendix B).

Randomized Block Design was also used to find if there was a significant difference in the amount of time to perform the manual task when using old and new fixtures.

A single factor ANOVA was used to calculate the difference in the number of staples used on the parts in the two different sets of new fixtures and old fixtures. In addition, single factor ANOVA model helped for an individual analysis for every worker's strength and wrist angular movement when using old and new fixtures.

CHAPTER IV

RESULTS AND DISCUSSION

The results of the statistical analysis will be presented and discussed in the following order: (a) wrists angular results, (b) time involved in the particular task, (c) number of staples used when using fixtures, and (d) EMG results for every operator.

Wrists Angular results

The wrist angle was based on the angle formed by the two planes. A plane was determined by a segment formed by the reflector markers: hand-wrist and wrist-elbow. Based on this information, Expert Vision software calculated wrists angle. The software was able to convert the angular data to a standard format data, enabling data to be used in any statistical software package. Minitab was used in this experiment. Minitab is a statistical package available at the VAXcluster at WMU. Minitab is a powerful statistical tool designed to analyze small to moderate size data collections. A single factor ANOVA was performed to analyze the possible variability between the set of old and new fixtures (see Table 2). The results displayed in Table 2 showed that at alpha 0.05 there was no significant difference in the use of old and new fixtures.

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Table 2

Analysis of Variance for the Wrist Angle
Old and New Fixtures

Source	DF	Sum Square	Mean Square	F-value
Fixtures	1	3.5	3.5	0.04*
Error	52	5009.5	96.3	
Total	53	5013.0		

* Not significant at 0.05 level

An analysis of the variance for a randomized complete block design was performed to determine if there was significant variability in the fixtures. This results are shown in Table 3.

The ANOVA displayed in Table 3 indicates that at alpha level of 0.05, there was a difference due to the fixtures. Consequently, a Ducans' test pairwise comparison was performed to find a pairwise variability in the fixtures. Ducans' test found differences on old fixtures O230S and O230B. It is important to note that the experiment was looking for comparative situations of old and new fixtures with the same number and the variability encountered did not help to the purpose of the experiment. The means of wrist angular data when using fixtures and the results of Ducan's test are presented in Table 4.

Note that randomization used applied to treatments

Table 3

Analysis of Variance for the Angular Wrist Experiment
Randomized Complete Block Design

Source	DF	Sum Squares	Mean Square	F-value
Fixtures (Treatments)	5	782.4	156.5	2.62 *
Operators (Blocks)	8	1840.1	230.0	3.85 *
Error	40	2390.5	59.8	
Total	53	5013.0		

* Significant at the 0.05 level.

(fixtures) within a block (operators), although an analysis of the F-value for blocks is also possible.

Variability in the blocks was found corresponding to the wrist angular means from the operators. Ducans' test showed the variability only among three operators. The means and significance difference in the wrist angle for operators when they stapled cushion parts using the six fixtures are shown in Table 5.

A single factor ANOVA with one degree of freedom was individually performed for every operator to observe more closely the difference between the new and the old fixtures. This analysis also helped to evaluate the wrist angular movement during the manual task. The results of these ANOVA presented in some cases significant variabili-

Table 4

Wrist Angular Means When Using Fixtures

Fixtures	Means (degrees)	Ducan's Test
N230S	143.3	
O230S	139.4	*
N230B	147.5	
O230B	150.7	*
N530B	147.2	
O530B	149.4	

* Significant different

ty. A summary of the single factor ANOVA analyses are shown in Table 6, Table 7, Table 8. Complete ANOVA results can be found in Appendix C.

It was shown that although the use of a new fixture was introduced as a different factor in the stapling task, the flexion of the wrist depended on the operators'performance. In fact, some subjects verbally commented that they did not like the new fixture because it caused them some problems. The design of the new fixture was like a deep bed for the cushion part. In some cases, the fabric border from the cushion part was stacked between the cushion part and the new fixture, enabling the operator to continue his/ her normal task and making him/her place the cushion part

Table 5

Wrist Angular Means of Operators

Operators	Means (degrees)	Ducan's Test
1	144.4	
2	134.1	
3	155.2	*
4	147.4	
5	144.8	
6	146.2	
7	141.8	
8	150.0	*
9	152.4	*

* Significant different to operator 2

over the new fixture. Further ANOVA analysis showed that the means of operators' wrist angular data when comparing old and new fixtures was the same. However, individual ANOVA for operators confirmed the variability among operators.

Time Involved in the Particular Task

The period of time used in this experiment was recorded from the videotape and calculated from the starting point when the operator started stapling until the operator

Table 6

Analysis of Variance Results of Wrist Angle's Operators
Means, Standard Deviation (SD), F-values for Fixtures

Operators	N230S Means (SD)	O230S Means (SD)	F-value
1	130.31 (35.68)	138.32 (34.98)	0.01
2	138.26 (24.94)	126.97 (43.30)	22.96*
3	152.19 (13.66)	152.04 (13.70)	0.03
4	150.05 (20.42)	155.19 (11.43)	20.60*
5	138.26 (24.94)	126.97 (43.30)	22.96*
6	142.42 (18.38)	146.49 (16.63)	11.94*
7	153.12 (17.10)	127.20 (49.55)	105.64*
8	138.61 (24.34)	139.65 (21.36)	0.46
9	146.69 (15.62)	142.11 (31.08)	7.79*

* Significant at 0.05 level.

stapled the last staple over the cushion part. The total
time employed for every operator during the stapling
task for each of the six fixtures is displayed in Table 9.

A single factor ANOVA was calculated for the time
involved in between the set of the new and old fixtures.
The results from the ANOVA are given in Table 10 show no
variability in the time utilized in stapling cushion parts
using the old and the new fixtures.

The randomized complete block design for the time in-

Table 7

Analysis of Variance Results of Wrist Angle's Operators
Means, Standard Deviation (SD), F-values for Fixtures

Operators	N230B Means (SD)	O230B Means (SD)	F-value
1	138.05 (40.90)	144.19 (40.48)	4.94
2	155.56 (10.54)	163.53 (5.98)	190.28*
3	142.12 (17.82)	140.36 (18.62)	2.06
4	158.42 (15.17)	156.60 (17.91)	2.66
5	152.16 (12.35)	153.09 (14.01)	1.11
6	146.03 (11.65)	146.38 (24.61)	0.07
7	156.70 (13.41)	156.92 (18.52)	0.04
8	135.30 (19.70)	147.93 (16.01)	110.82*
9	143.21 (27.21)	147.20 (15.41)	7.34*

* Significant at 0.05 level.

volved is shown in Table 11. The results showed that at alpha level 0.05 the time involved in the manual task was affected by the use of the fixtures. Also, variability was observed in the mean of time used by the operators. However, Ducan's test showed no variability in a pairwise comparison for the old and the new fixtures.

Number of Staples Used When Using Different Fixture

The number of staples used for every cushion part was

Table 8

Analysis of Variance Results of Wrist Angle's Operators
Means, Standard Deviation (SD), F-values for Fixtures

Operators	N530B Means (SD)	O530B Means (SD)	F-value
1	126.06 (51.54)	127.66 (40.31)	0.26
2	165.35 (4.34)	164.72 (7.94)	2.18
3	144.39 (12.27)	153.13 (17.80)	70.99
4	151.36 (20.09)	159.63 (18.87)	39.17*
5	149.90 (16.42)	148.51 (23.49)	1.05
6	143.42 (35.75)	141.47 (31.28)	0.76
7	151.51 (15.11)	154.49 (9.14)	12.30*
8	141.11 (12.39)	148.18 (11.11)	81.13*
9	151.30 (16.63)	146.82 (13.43)	19.78*

* Significant at 0.05 level.

obtained from the videotape played in slow motion. The result of the number of staples used for every operator is shown in Table 12. A single factor ANOVA was used to verify if the number of staples used with old and new fixtures was significantly different, as shown in Table 13. At alpha 0.05 level, the mean of the number of staples used was not significantly different when using old and new fixtures.

Table 9

Time Used in Stapling Manual Task
(minutes)

Operator	N230S	O230S	N230B	O230B	N530B	O530B
1	1.14	1.19	1.17	1.27	1.10	1.20
2	2.45	2.18	2.38	3.39	2.11	2.20
3	1.27	1.30	1.18	1.21	1.40	1.35
4	1.36	1.51	1.30	1.30	1.14	1.13
5	2.13	2.19	2.40	2.40	2.14	2.12
6	2.20	2.20	1.57	2.02	1.38	1.31
7	1.25	1.24	1.24	1.21	1.02	1.04
8	2.34	2.17	2.04	2.07	1.48	1.59
9	1.14	1.27	1.26	1.18	1.35	1.20
10	1.19	1.05	0.58	1.10	1.03	1.02

EMG Results for Every Operator

This experiment focused attention on the variability of every operator's EMG. In this way the pairwise mean analysis of old and new of a selected type of fixture was compared with single factor ANOVA. Tables 14, 15, and 16 show a summary of this analysis. The results displayed in these tables sometimes favor a new fixture and sometimes favor an old fixture. Furthermore, sometimes there was no difference between an old and new fixture for either seat or back.

Table 10

Analysis of Variance for Time
New and Old Fixtures

Source	DF	Sum Squares	Mean Square	F-value
Fixtures	1	0.058	0.58	0.20*
Error	58	16.951	0.292	
Total	59	17.009		

* Not significant difference at 0.05 level

Table 11

Analysis of Variance for Time Used in Stapling Task
Randomized Complete Block Design

Source	DF	Sum Squares	Mean Square	F-value
Fixtures	5	0.80	0.16	3.15 *
Operators	9	13.92	1.54	30.26 *
Error	45	2.29	0.05	
Total	53	17.01		

* Significant at the 0.05 level.

EMG graphs presented the muscular activity for every operator over the time. The peaks are associated with the contraction of the muscle during the manual task. Example of these graphs are included in Appendix D.

Table 12

Number of Staples Used in Stapling Manual Task

Operator	N230S	O230S	N230B	O230B	N530B	O530B
1	76	92	117	114	84	74
2	154	162	148	155	122	124
3	87	81	88	86	82	84
4	91	94	96	101	85	80
5	162	171	147	163	127	134
6	91	88	79	84	90	93
7	126	128	108	120	103	103
8	174	166	150	151	136	141
9	107	111	99	107	109	100
10	108	90	100	104	89	93

Discussion

Main Conclusions

Different manual tasks in industry were evaluated in number of research studies. Most of them concluded that the combination of awkward posture of the wrist, high force and repetitive movements was connected with symptoms of CTS (Silverstein, Fine, Armstrong, 1987; Jensen et al. 1983; Silverstein et al. 1986).

Table 13

Analysis of Variance for Number of Staples
Used in Stapling Task

Source	DF	Sum Squares	Mean Square	F-value
Fixtures	1	58	58	0.07*
Error	58	47022	811	
Total	59	47080		

* Not significant at 0.05 level

The complex movement of the hand and the need to analyze
wrist angle motion during tasks in industry, created the
need for using different equipment to record these complex
movements. Moore, Wells and Ranney in 1991, analyzed
repetitive manual tasks by using a wrist goniometer plus a
light weight non restricting glove transducer. In this way,
they were able to monitor complex hand movements in real
time. Marras and Schoenmarklin in 1993, used a wrist
monitor developed in the Biodynamics Laboratory at Ohio
State University. An industrial surveillance was performed
with this equipment, leading to a conclusion that the
dynamic measures of wrist motion, angular velocity and
acceleration can differentiate cumulative trauma disorders
levels.

Expanding on the number of studies of wrist angular

Table 14

Analysis of Variance Results of EMG Means, Standard
Deviation (SD), F-values for Fixtures

Operators	N230S Means (SD)	O230S Means (SD)	F-value
1	3232.1 (397.8)	3233.5 (482.2)	0.01
2	2475.6 (182.6)	2646.6 (265.3)	509.8 *
3	2106.4 (117.8)	2123.6 (150.7)	7.26*
4	2378.0 (57.89)	2377.0 (59.4)	0.26
5	4016.4 (113.4)	3963.8 (262.0)	57.60*
6	2544.92(494.0)	2454.2 (529.0)	28.27*
7	2278.31(306.7)	2405.4 (339.5)	138.98*
8	1990.7 (391.1)	1849.7 (388.7)	117.63*
9	1922.1 (222.9)	1854.3 (117.6)	130.16*

* Significant at 0.05 level.

motion in industry, this experiment used three dimensional
data to analyze more precisely wrist angular movement in
operators. The statistical analysis tried to verify the
significant differences in fixtures throughout of the wrist
angular movement. The results showed evidence that the
change of the wrist angle was caused by the operators and
a moderate stress in the means of the wrist angles was ob-
served in the results. In addition, the individual statis-

Table 15

Analysis of Variance Results of EMG Means, Standard
Deviation (SD), F-values for Fixtures

Operators	N230B Means (SD)	O23SB Means (SD)	F-value
1	3069.2 (400.0)	2987.1 (388.0)	39.07*
2	2544.1 (239.3)	2508.5 (180.9)	25.25*
3	2272.3 (163.1)	2135.1 (125.3)	400.24*
4	2447.3 (64.5)	2396.5 (59.4)	600.33*
5	4021.4 (113.5)	3857.2 (573.5)	140.03*
6	2705.8 (522.4)	2710.2 (521.0)	0.06
7	2697.3 (362.8)	2455.1 (397.4)	364.68*
8	1969.0 (327.3)	2455.1 (397.4)	1604.43*
9	1833.2 (91.7)	1871.9 (113.1)	127.24*

* Significant at 0.05 level

tical analysis executed for every operator showed that some
of them can be at future risk of CTS. Concluding results
are presented in Table 17 specifying wrist angle positions
held for each operator. Wrist angle values less than one
hundred forty degrees can be considered at severe stress;
values between one hundred fifty and one hundred sixty five
can be considered at moderate stress and values between one
hundred sixty five and one hundred eighty can be considered

Table 16

Analysis of Variance Results of EMG Means, Standard
Deviation (SD), F-values for Fixtures

Operators	N530B Means (SD)	O530B Means (SD)	F-value
1	3097.8 (279.8)	3147.5 (317.4)	24.86*
2	2498.3 (261.0)	2438.5 (128.3)	76.05*
3	2318.4 (238.2)	2262.1 (225.3)	26.50*
4	2474.3 (79.9)	2421.8 (67.6)	425.97*
5	3761.5 (529.4)	3788.7 (554.0)	2.27
6	2859.0 (399.8)	2650.2 (524.1)	180.27*
7	2164.6 (237.9)	2241.2 (265.9)	83.01*
8	2073.4 (443.9)	2054.2 (459.5)	1.63
9	2375.8 (484.5)	1898.8 (136.5)	1616.23*

* Significant at 0.05 level.

at optimal position. A few of the nine operators that were examined were not holding their wrists at a straight angle. By following the fifteen biomechanical work tolerances stated by Tichauer (1978), the wrist had to be kept in a straight position in order to avoid stress. For instance, operator one in Table 17 presented a wrist angle position at severe stress and therefore an action has to be taken to help this operator to improve his/her work performance.

Wrist operator graphs showed the constantly changing

Table 17

Operators' Results Respect to Fixtures and Angle Position

| | Fixtures | | | | | |
| | 230S | | 230B | | 530B | |
Oper.	Best Fixture	Angle Pos.	Best Fixture	Angle Pos.	Best Fixture	Angle Pos.
1	Equal	SS	Old	SS	Equal	SS
2	New	SS	Old	MS	Equal	O
3	Equal	MS	Equal	SS	Old	MS
4	Old	MS	New	MS	Old	MS
5	New	SS	Equal	MS	Equal	SS
6	Old	MS	Equal	SS	Equal	SS
7	New	MS	Equal	MS	Old	MS
8	Equal	SS	Old	SS	Old	SS
9	New	MS	Old	SS	New	MS

SS= Severe Stress (150-90 degrees)

MS= Moderate Stress (150-165 degrees)

O= Optimal Position (165-180 degrees)

values in the wrist angle over the time, verifying the variability found previously. This variability has been proven to stress the wrist. However implementation of an ergonomics program can control this variability and consequently, prevent the occurrence of CTS.

The time involved in the stapling task when using old

and new fixture showed no difference, but further analysis needs to be done in job site. It is important to consider that the site of the experiment where the data was collected and the equipment used can produce a relaxation or an intimidation among workers, thereby giving incorrect data.

The number of staples used remained unchanged for both situations using current and new fixtures.

Muscular activity encountered was variable. In fact, the lack of familiarity of the operator with the new fixture made them continue grasping and pulling harder the fabric edge of the cushion part when stapling and using the new fixture. Armstrong et al. in 1984 concluded that reducing grasping in manual tasks is decisive in reducing forces in the hand and wrist, and therefore, the new design of fixture can be a good tool if it is used in proper way.

CHAPTER V

SUMMARY AND RECOMMENDATIONS

Summary

The present study was conducted to evaluate the use of current fixtures and new fixtures that hold cushion parts in a stapling task.

Wrist angular data obtained from a three dimensional analysis was used to a provide statistical analysis. The variability in wrist angle's operators was actually found due to the operators performing the particular task. During the task, some operators held their left wrists in a stressed position and placed themselves at future risk of CTS.

Variability in the muscular activity was encountered in the operators in this experiment. These variable results reflected the ability of the operators to work better with old fixtures and the degree of comfort felt with this fixture. Thus, for some operators the old fixture was better.

The time and number of staples involved in the particular task remained almost constant in all conditions of stapling parts and using different fixtures.

Most of the statistical analysis results remained unchanged due to the fact that subjects were unfamiliar with

the use of the new fixture.

Recommendations

Recommendations drawn from this experiment are as follows:

1. It is recommended that the new fixture be used for a sufficient period of time to permit the workers to become familiar and comfortable using the new fixture.

2. The new fixtures should have handles for easy maneuvering in operations.

3. Change on the design of 530B fixture, height of laterals edges should be reduced to prevent workers from bending their wrists.

4. Workers performing the manual stapling of cushion parts bend their wrists constantly and, thus, variability of the wrist angle was encountered in operators. Therefore, an ergonomics wrist injury prevention program should be given to these workers. The ideal program should include appropriate training in using tools, equipment, posture and knowledge of CTS. Workers need to be informed about the factors that are related to the appearance of CTS, such as repetition, force and postures.

5. It is clear that the human body is not designed to perform the same task over a long period of time and that repetitive tasks have been identified as contributor

to CTS. It has been found that the work cycle of the manual stapling task is repeated over and over during a period ofeight hours. For this reason, implementation of rotation programs is necessary. An effective rotation program should assign workers to perform different movements in tasks generating a balance in the use of muscles.

6. Further studies need to be conducted after a period of training and more familiarity using the new fixture in order to assure the proper use of fixtures and to avoid symptoms of occurrence of CTS in the workers.

Appendix A

Human Subjects Institutional Review Board

Human Subjects Institutional Review Board

Kalamazoo, Michigan 49008-3899

WESTERN MICHIGAN UNIVERSITY

Date: June 30, 1993

To: Maria Roa

From: M. Michele Burnette, Chair

Re: HSIRB Project Number 93-06-03

This letter will serve as confirmation that your research project entitled "An ergonomic approach: Evaluation of a new fixture" has been approved following full review by the Human Subjects Institutional Review Board. The conditions and duration of this approval are specified in the Policies of Western Michigan University. You may now begin to implement the research as described in the approval application.

You must seek reapproval for any changes in this design. You must also seek reapproval if the project extends beyond the termination date.

The Board wishes you success in the pursuit of your research goals.

Approval Termination: June 30, 1994

xc: Wygant, IE

Informed Consent

This research study will fulfill the thesis require-
ment for Maria Roa to obtain a Master of Industrial
Engineering degree at Western Michigan University (WMU).
All data collection will take place in the Biomechanics
Laboratory at WMU

During manual tasks, a particular number of wrist
deviations and hand positions involving force can be
encountered. Specific motions are more stressful to the
wrist and hand than others. Extended period of motion such
as grasping and pinching objects with bending wrists cause
stress that damages nerves and ligaments causing a disorder
such as Carpal Tunnel Syndrome (CTS). CTS involves inflam-
mation of the nerve which runs through the arm, wrist and
hand.

This research aims to identify the difference between
old and new fixtures analyzing the wrist's movements and
stress. Subjects in this research will be asked to perform
their daily basic task. Four reflectors will be attached
with tape in the hand, wrist elbow, and shoulder to record
3-D movements. In addition, an attached surface electrode
will record activity and stress level of the forearm flexor
muscles using an electromyograph (EMG). Both reflector and
surface electrode will be attached to the subject's skin
using surgical tape. In addition, participant will be
verbally questioned if they have allergies to tape.

The performance of the left arm in operators will be video-
taped and information will be kept in the Biomechanics
Laboratory at Western Michigan University for further
analysis. Videotape will be erased after the completion of
the project (approximately 12 months). No confidential
records will be maintained for subjects participating in
this research and his/her employer.

Participation will require a time commitment of less than
2 hours.

Once angular wrist has been identified as stressful,
industrial tasks can be designed and/or modified to
minimize the occurrence of such exertions. Therefore, a
reduction in employee trauma and a reduction in CTS in the
work place, may be the result.

Subjects participating in this research are not at
risk of developing CTS. The EMG is a common procedure that
have been used in clinical settings, and presents no risk
to the participant.

Further information regarding this research, its purpose
and subject rights can be provided by:

Maria Roa   - Principle Investigator: 458-
0471

Dr. Robert Wygant - Faculty Advisor: 387- 3744
Participation in this research is voluntary and subjects
may discontinue participation at any time. Refusal to
participate will in no way involve penalties of any kind.
Subject _____
Date_____
               (signature)

Appendix B

Wrist Angular Graphs

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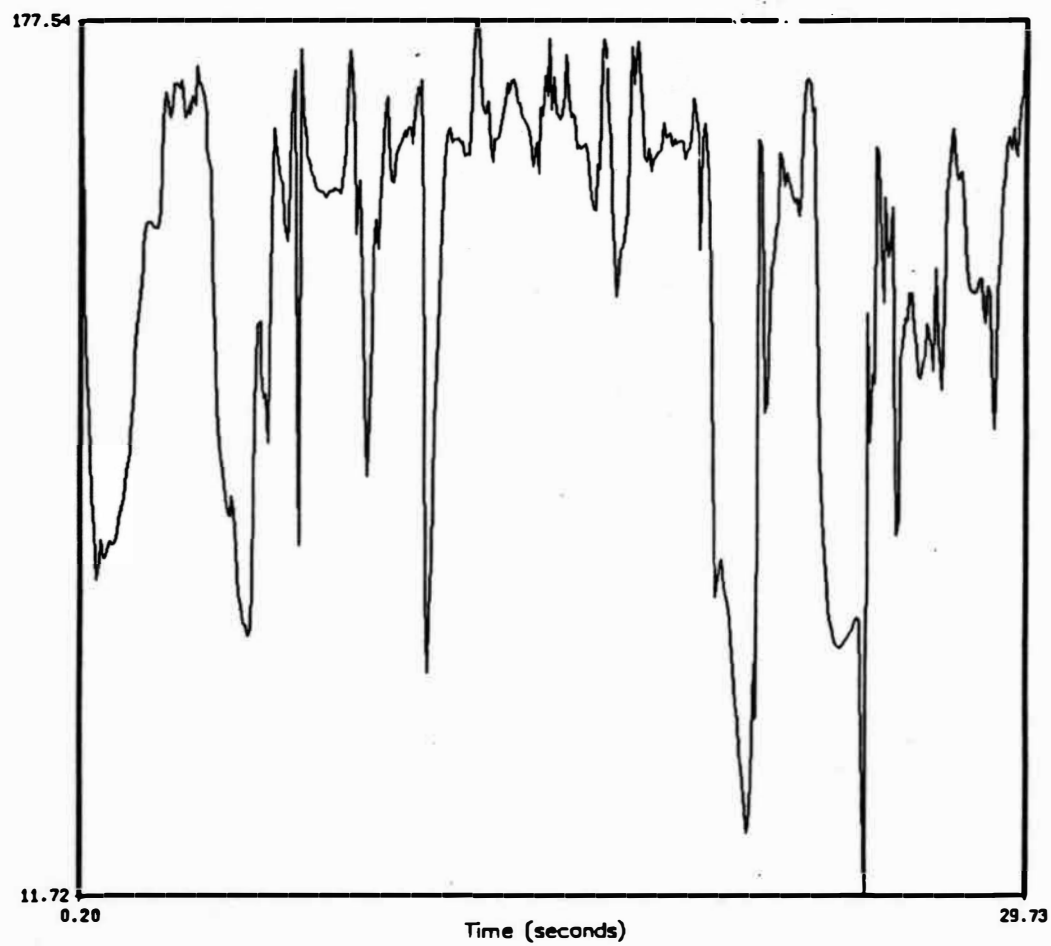
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60

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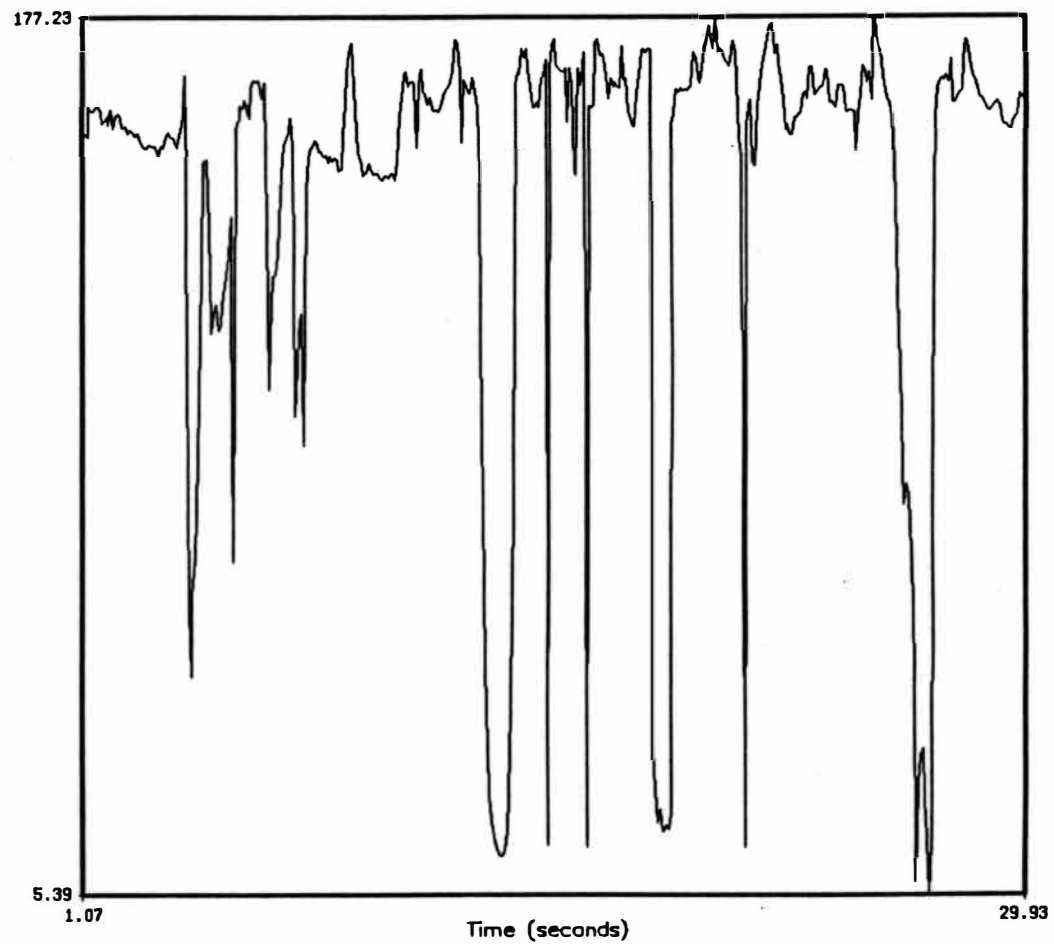
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Last Series: 1

177.54

11.72
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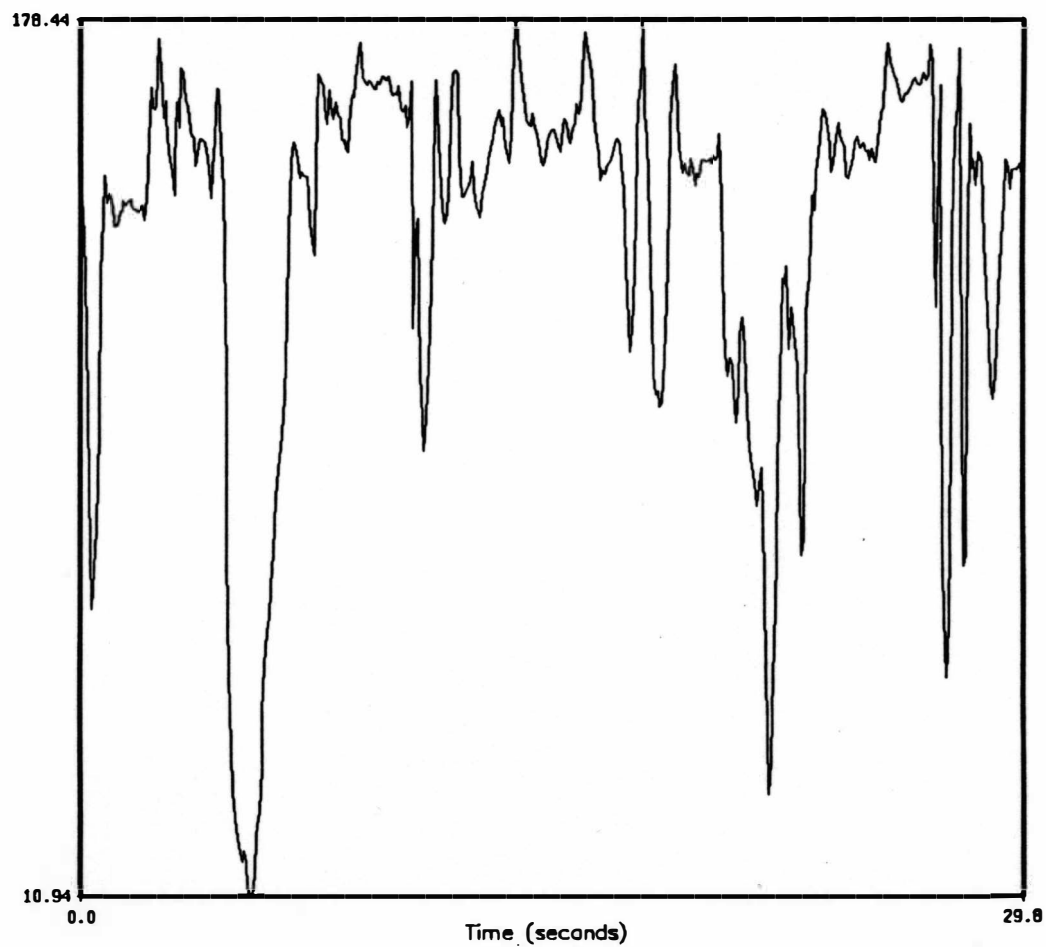
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63

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176.61

4.45

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Display Range:
  First Series: 1
  Last Series: 1

177.10

4.43

1.0   29.8
                    Time (seconds)

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    Last Series: 1

177.82

140.48

0.00

29.93

Time (seconds)

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175.36

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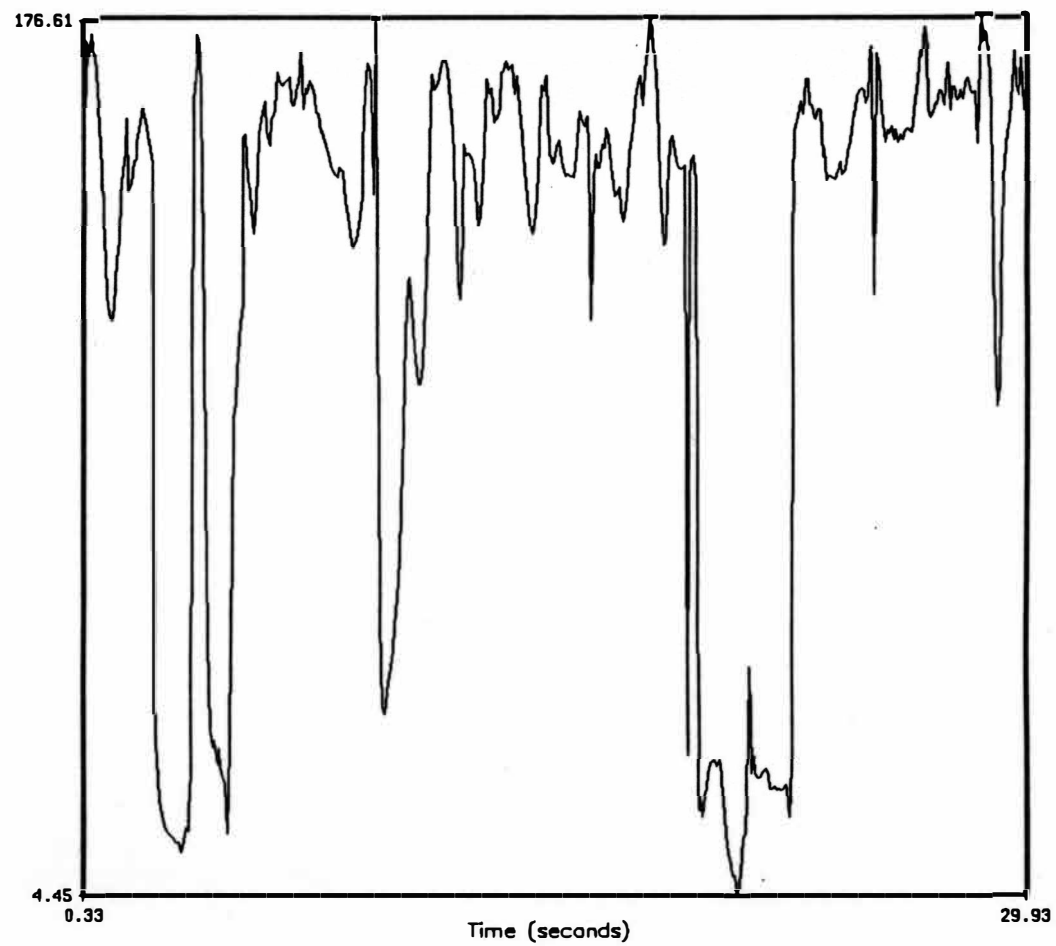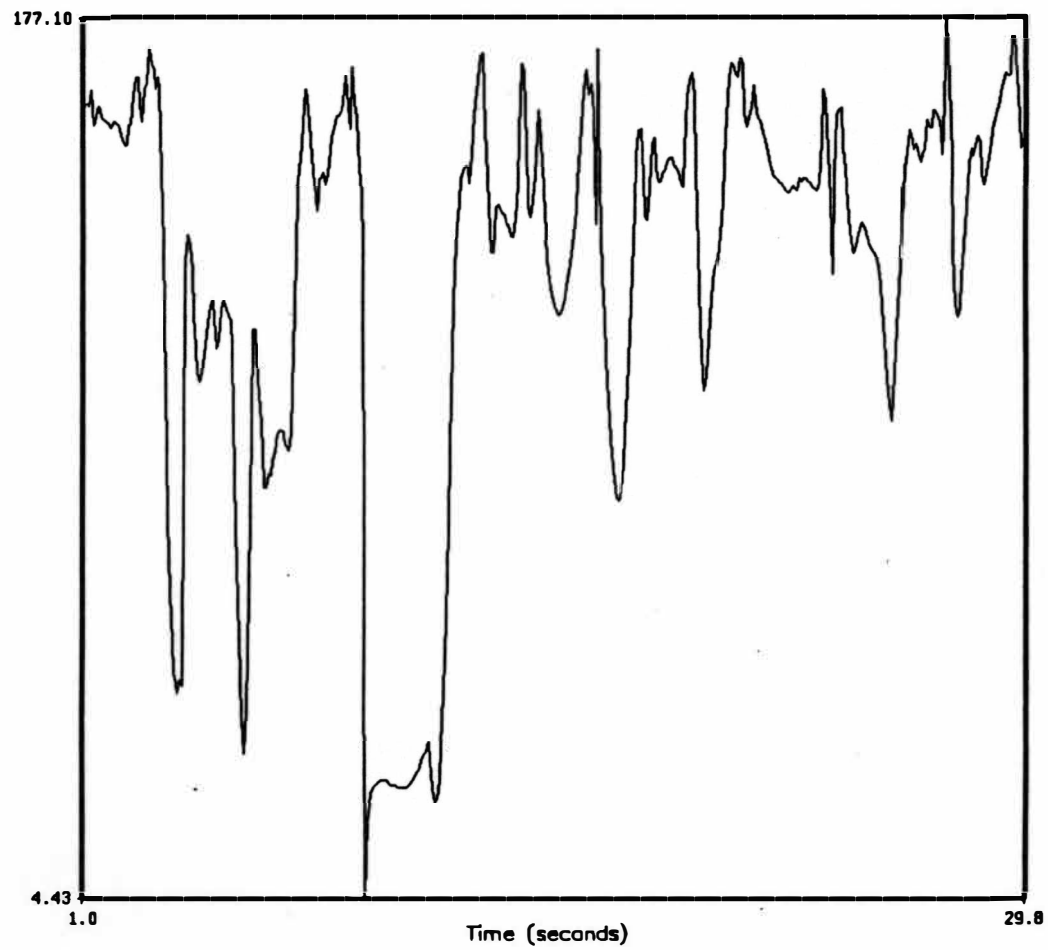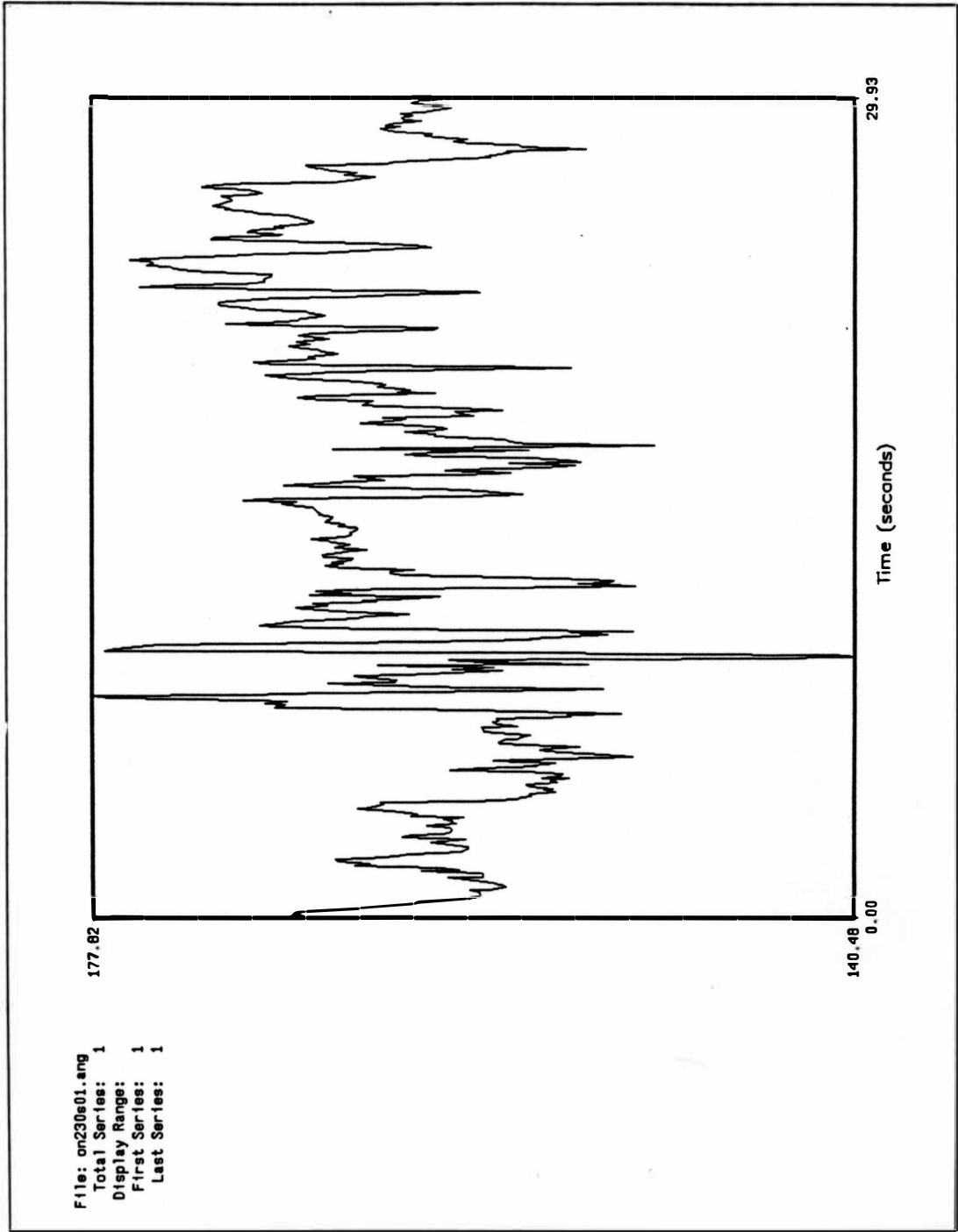
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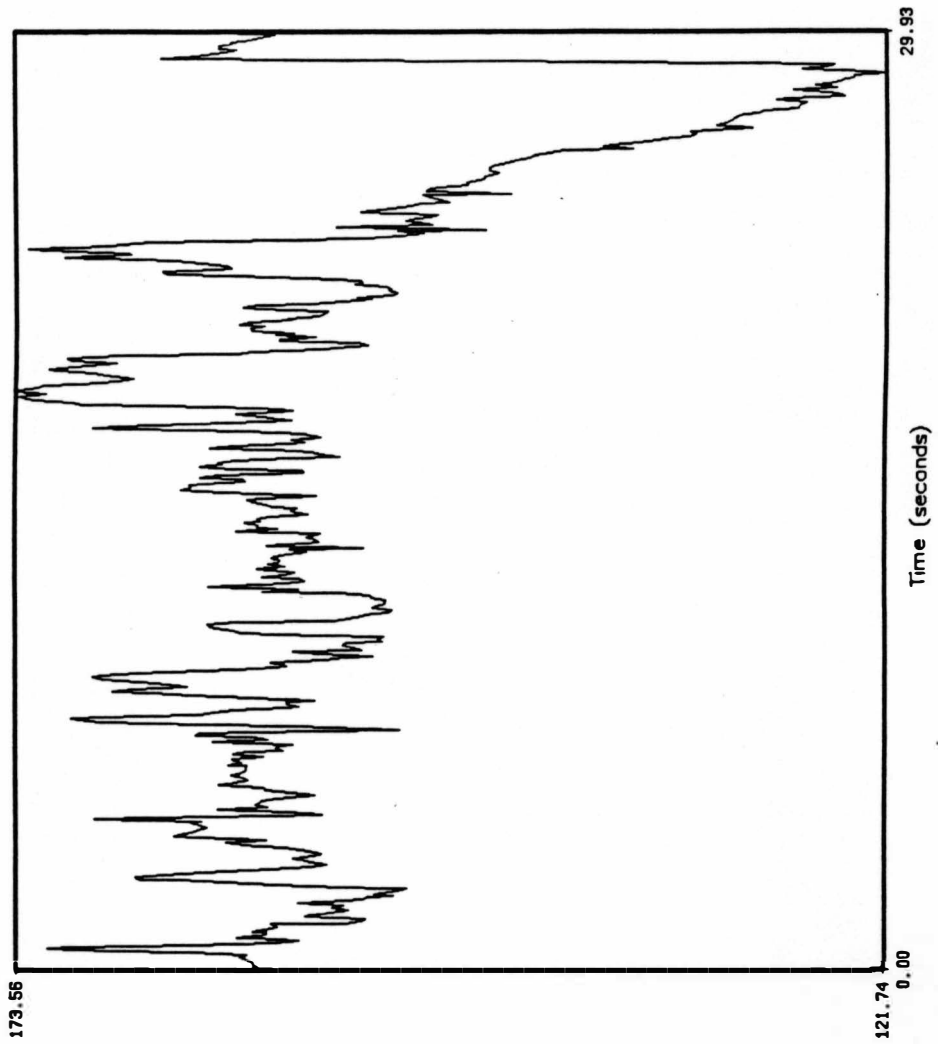
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Time (seconds)

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Time (seconds)

29.93

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174.93

150.54

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    Last Series: 1

178.97

120.27

0.07

Time (seconds)

29.93

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Last Series: 1

174.95

77.42
0.80   Time (seconds)   29.93

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  Display Range:
  First Series: 1
  Last Series: 1

Time (seconds)

File: go230b01.eng
Total Series: 1
Display Range:
First Series: 1
Last Series: 1

173.88

24.05

0.73   Time (seconds)   29.93

75

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Last Series: 1

176.61

86.16   0.80

Time (seconds)

29.87

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Display Range:
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178.81

33.83   0.00

Time (seconds)

29.73

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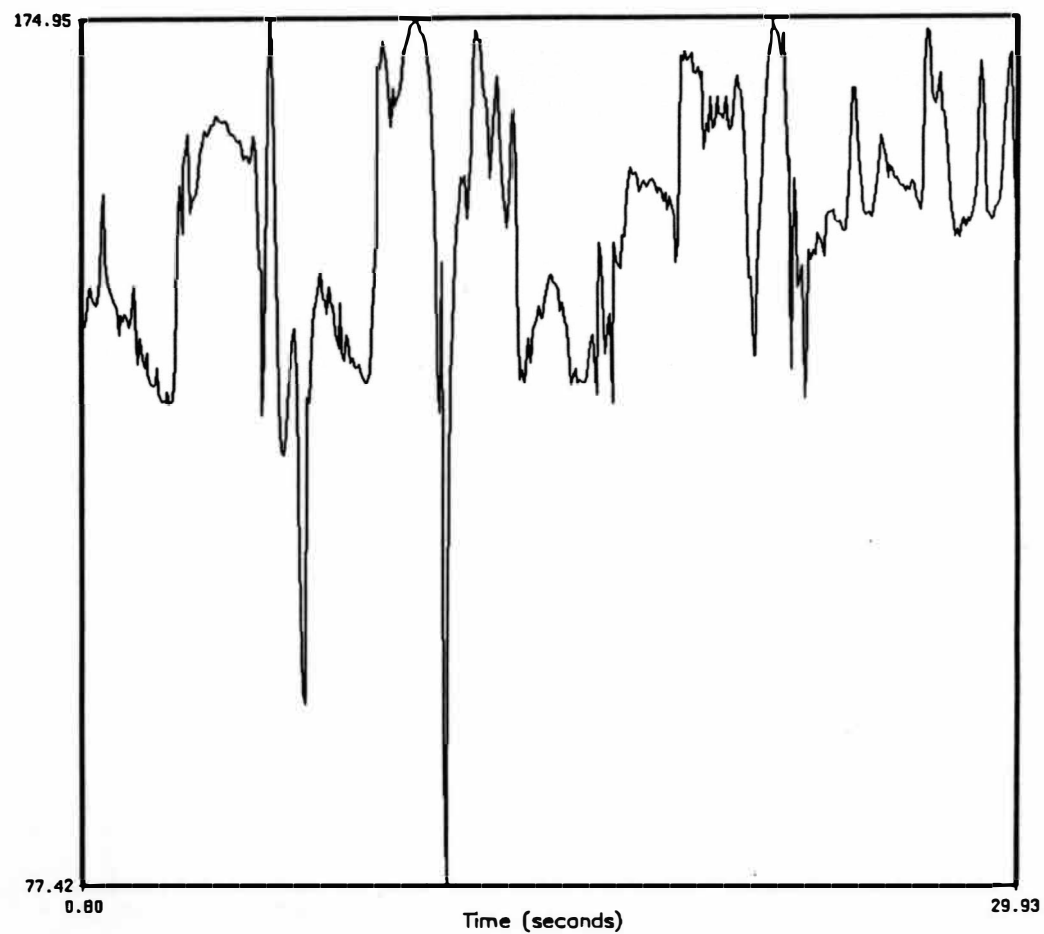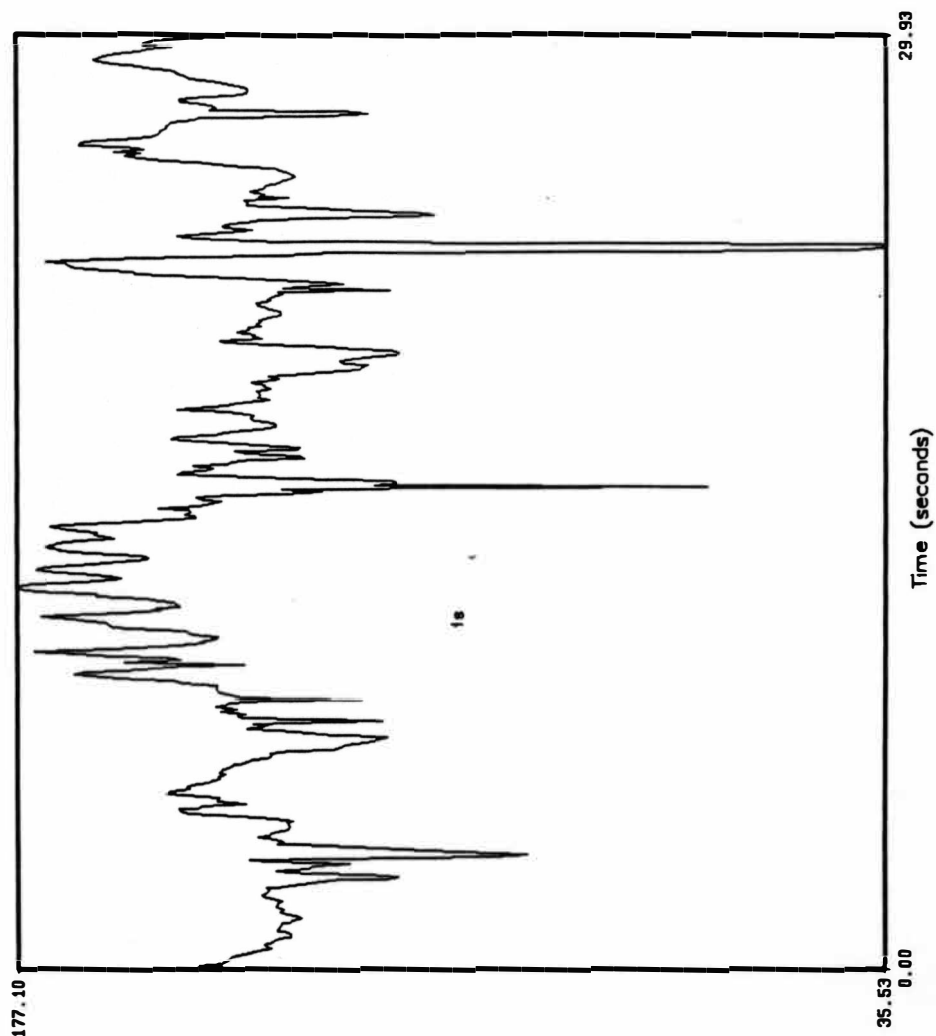
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89.20

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178.89

51.44

0.47   Time (seconds)   29.93

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  First Series: 1
  Last Series: 1
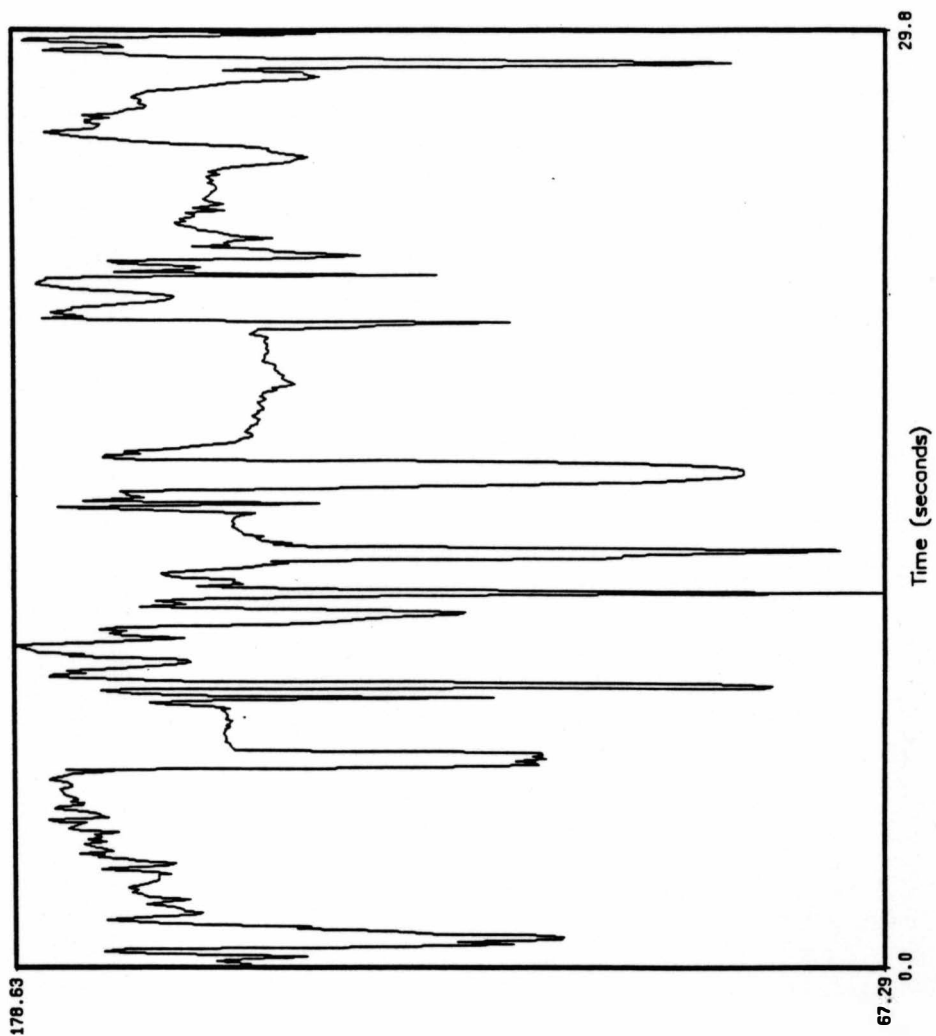
178.63

67.29

0.0

Time (seconds)

29.8

File: vo530b01.ang
  Total Series: 1
Display Range:
  First Series: 1
  Last Series: 1

176.80

66.39   0.80

Time (seconds)

29.73

83

File: ro230b01.ang
   Total Series: 1   178.12
Display Range:
   First Series: 1
    Last Series: 1

Time (seconds)

75.56   0.00   29.93
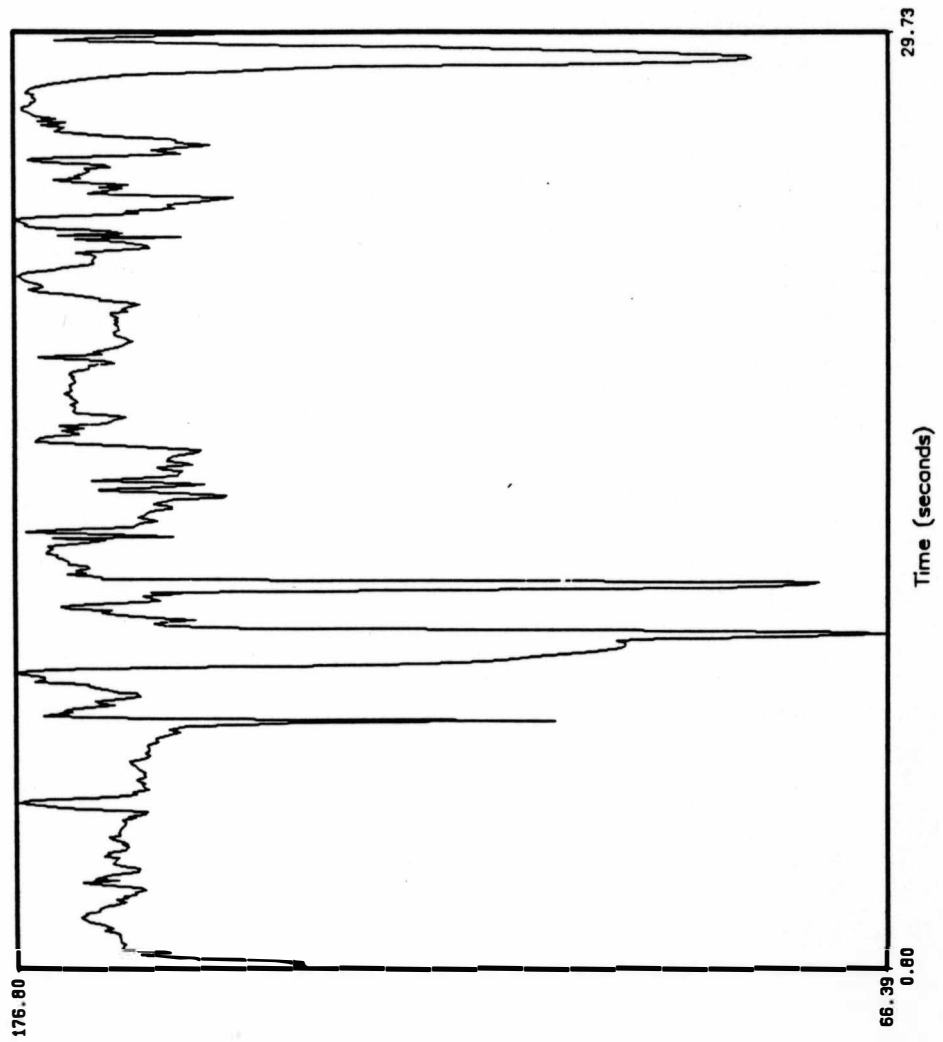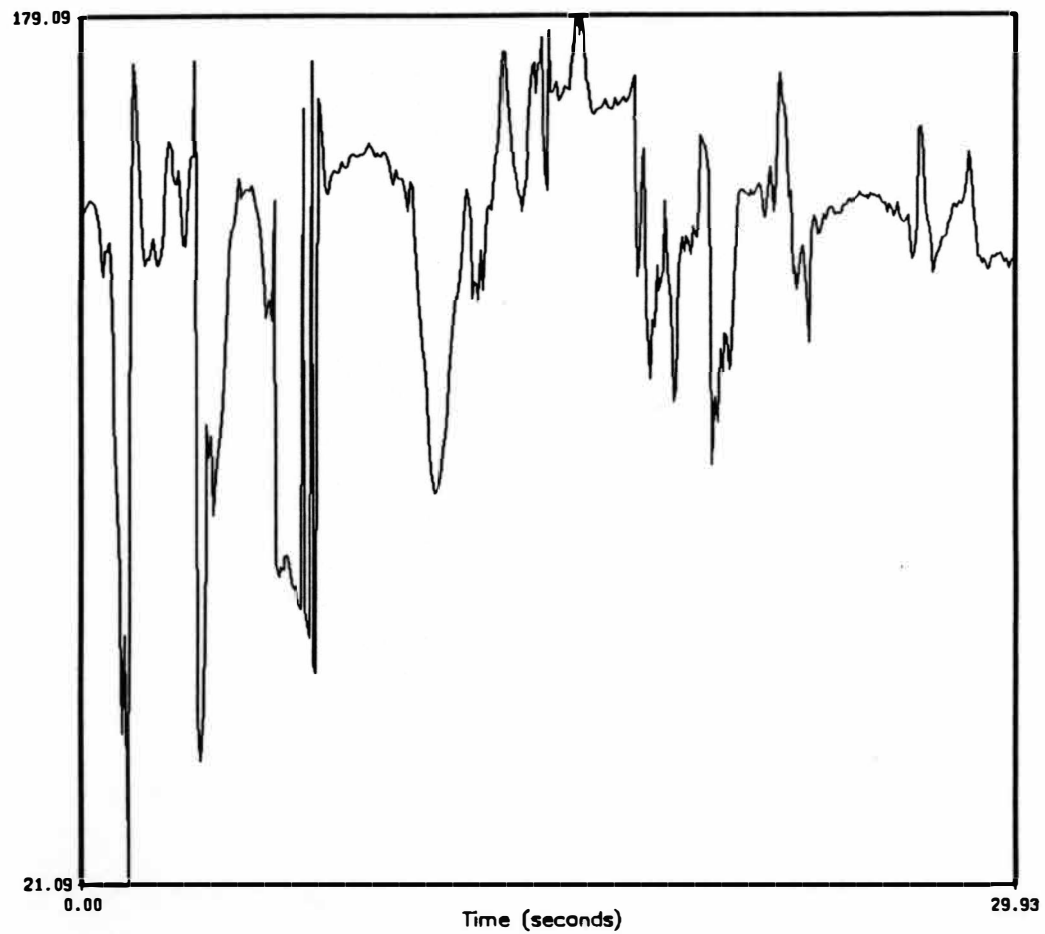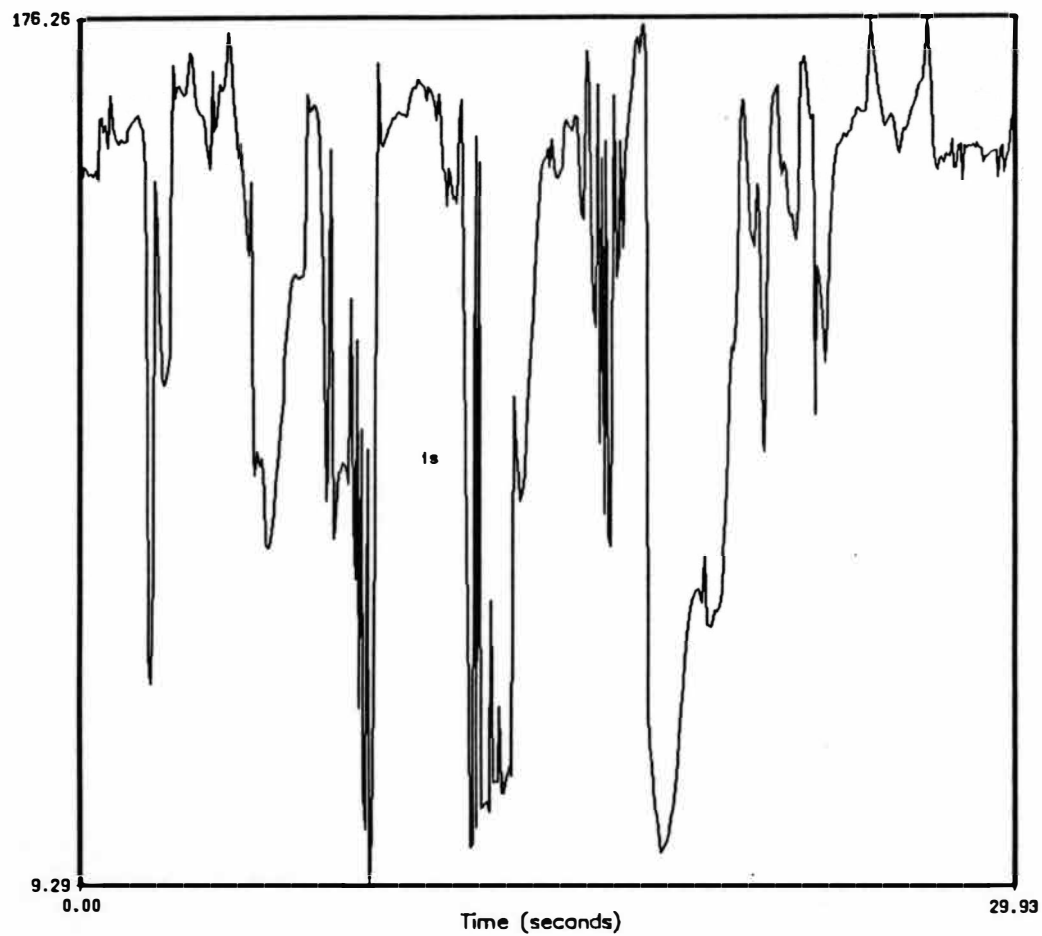
File: ro530b01.eng
   Total Series: 1
Display Range:
   First Series: 1
    Last Series: 1
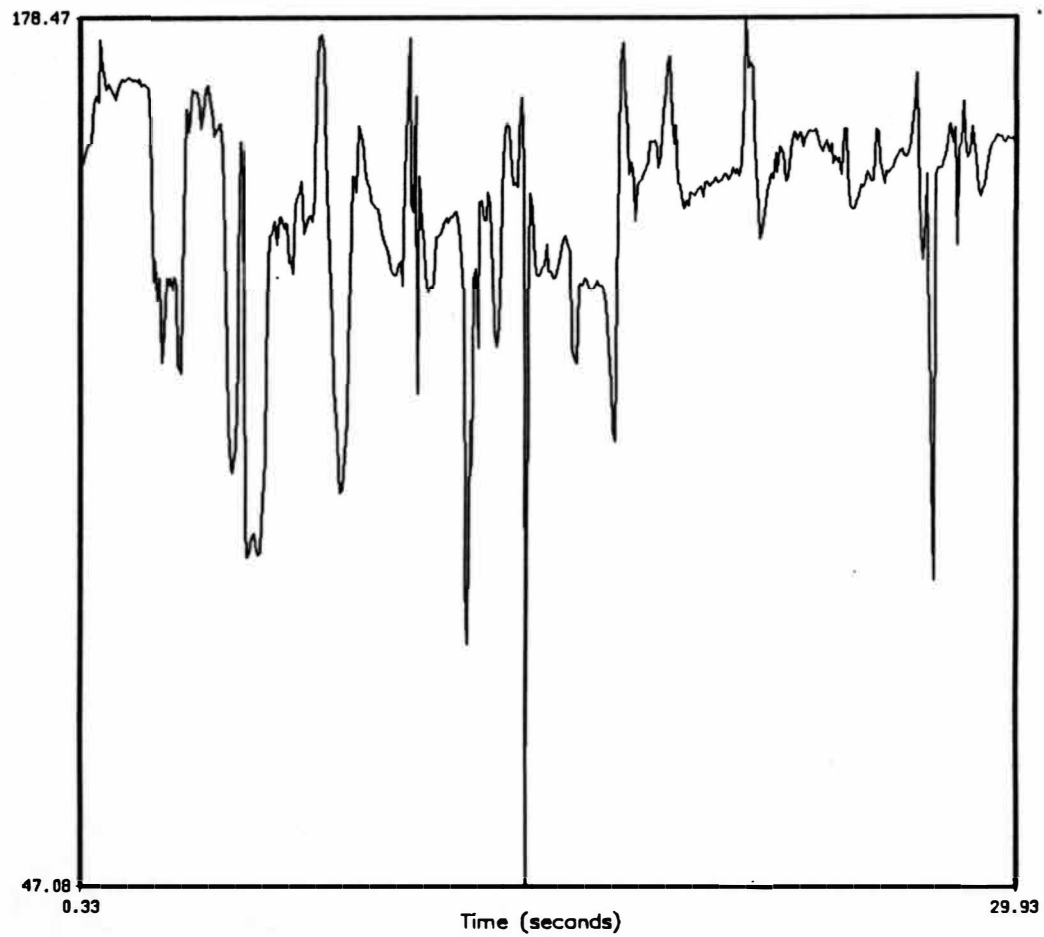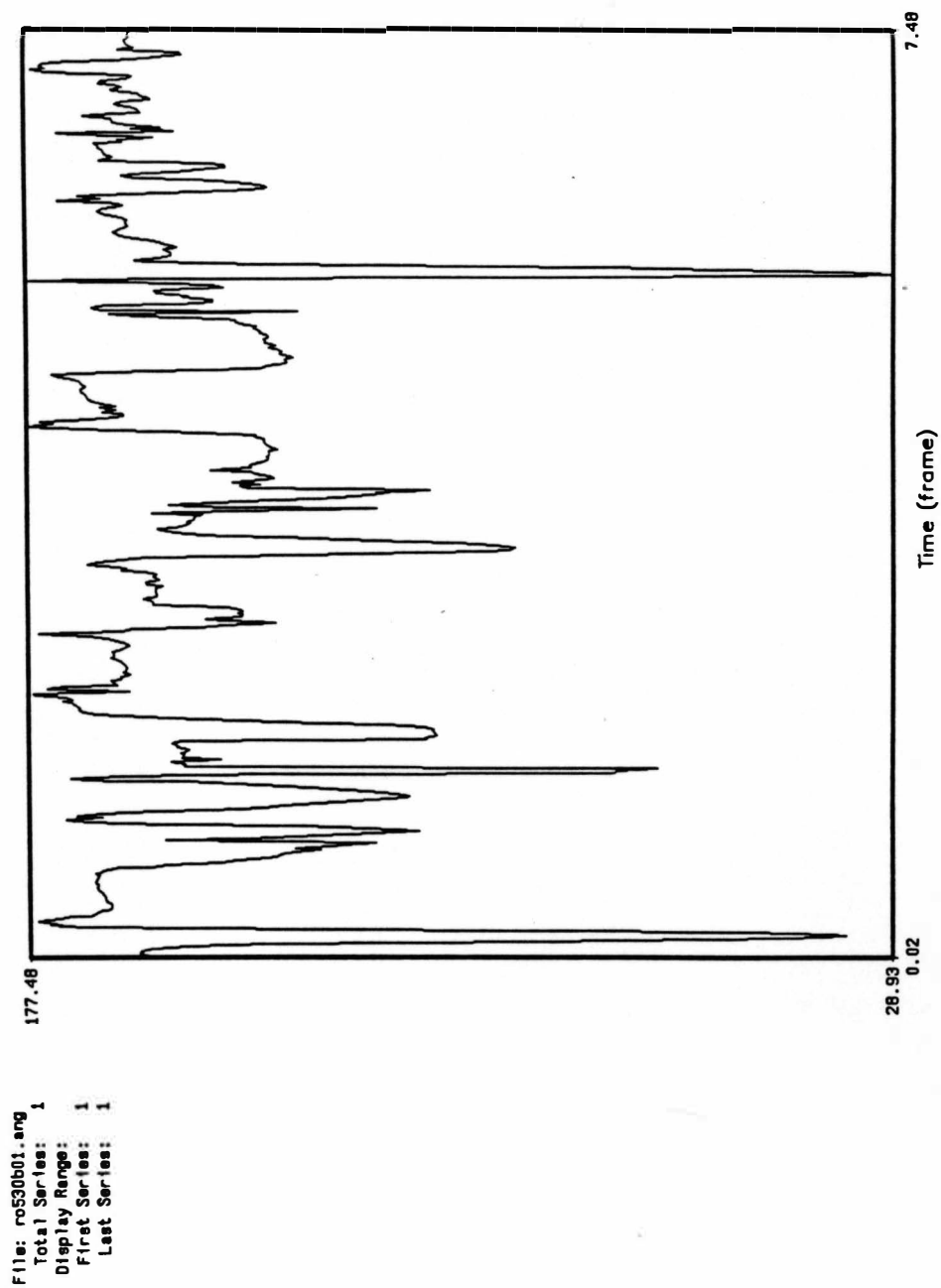
File: jn230s01.ang
Total Series: 1
Display Range:
First Series: 1
Last Series: 1

176.57

76.72
0.13   Time (seconds)   29.93

File: jo230s01.ang
Total Series: 1
Display Range:
First Series: 1
Last Series: 1

178.71

70.62
0.53   Time (seconds)   29.93
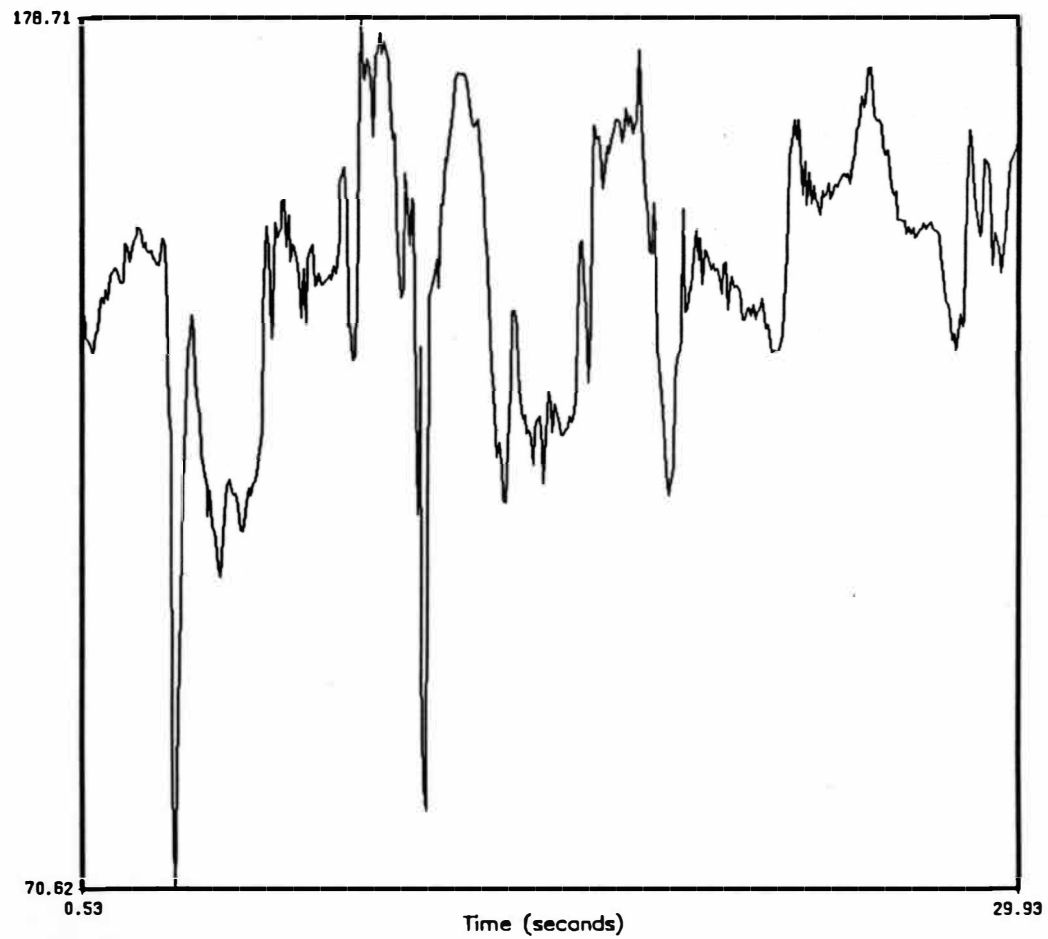
File: jn230b01.ang
Total Series: 1
Display Range:
First Series: 1
Last Series: 1

177.07

66.57

0.00   Time (seconds)   29.93

File: jo230b01.eng
  Total Series: 1
Display Range:
  First Series: 1
  Last Series: 1

179.55

11.33

0.0   Time (seconds)   29.8

File: jn530b01.ang
Total Series: 1
Display Range:
First Series: 1
Last Series: 1

176.71

5.89

0.13   Time (seconds)   29.93

95

File: mo530b01.ang
  Total Series: 1
Display Range:
  First Series: 1
   Last Series: 1

177.57

74.76

0.00

29.93

Time (seconds)

File: jo530b01.ang
  Total Series: 1
Display Range:
  First Series: 1
  Last Series: 1

Time (seconds)

177.56

39.81   0.00   29.93

File: fn230s01.ang
Total Series: 1
Display Range:
First Series: 1
Last Series: 1

177.51

86.46
0.00

Time (seconds)

29.93

File: fo230s01.ang
  Total Series: 1
Display Range:
  First Series: 1
   Last Series: 1

174.44

7.16
1.20

is

Time (seconds)

29.93

File: fn230b01.ang
Total Series: 1
Display Range:
First Series: 1
Last Series: 1

179.19

100.33
0.00   Time (seconds)   29.93

File: fo230b01.ang
Total Series: 1
Display Range:
First Series: 1
Last Series: 1

178.06

69.41
0.20

Time (seconds)

28.93

File: fn530b01.ang
Total Series: 1
Display Range:
First Series: 1
Last Series: 1

177.16

94.51

0.00   Time (seconds)   29.93

File: fo530b01.eng
Total Series: 1
Display Range:
First Series: 1
Last Series: 1

173.50

120.23 1.20

Time (seconds)

29.93

File: 1n230e01.ang
 Total Series: 1
Display Range:
 First Series: 1
 Last Series: 1

174.56

4.13

0.00   Time (seconds)   29.93

File: io230s01.ang
Total Series: 1
Display Range:
First Series: 1
Last Series: 1

177.63

70.78

0.00   Time (seconds)   29.93

File: in230b01.ang
Total Series: 1
Display Range:
First Series: 1
Last Series: 1

178.90

60.62

0.20   Time (seconds)   29.93

File: lo230b01.ang
  Total Series: 1
Display Range:
  First Series: 1
   Last Series: 1

178.00

81.05   0.20

29.93

Time (seconds)

File: fn530b01.ang
  Total Series: 1
Display Range:
  First Series: 1
  Last Series: 1

176.98

89.88

0.00

29.93

Time (seconds)

File: 1o530b01.ang
   Total Series: 1
   Display Range:
   First Series: 1
    Last Series: 1

177.35

100.60   0.00

Time (seconds)

29.87

File: mn230s01.ang
Total Series: 1
Display Range:
First Series: 1
   Last Series: 1

176.98

72.78 0.00

29.87

Time (seconds)

File: mo230s01.sng
  Total Series: 1
Display Range:
  First Series: 1
  Last Series: 1

178.04

17.45

0.00

Time (seconds)

29.93

File: mn230b01.ang
Total Series: 1
Display Range:
First Series: 1
Last Series: 1
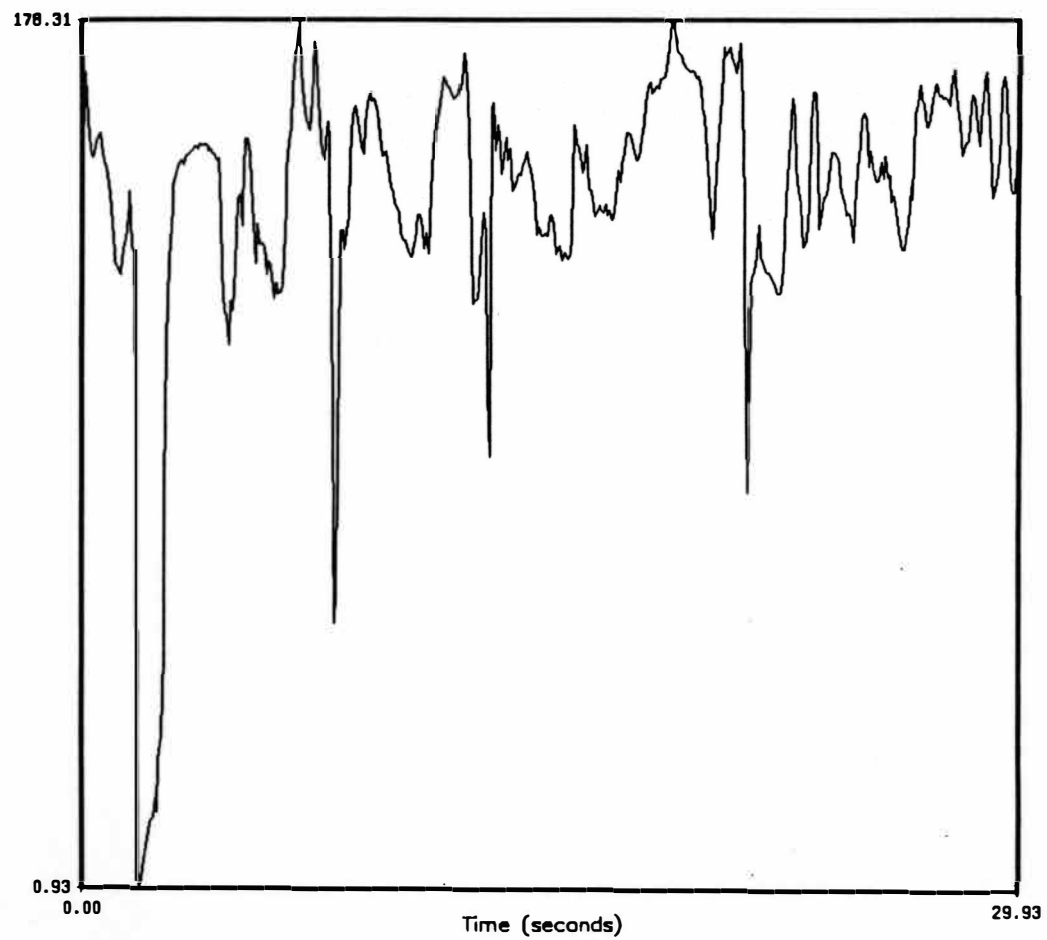
178.31

0.93

0.00   Time (seconds)   29.93

File: mo230b01.ang
Total Series: 1
Display Range:
First Series: 1
Last Series: 1

176.35

82.34

0.00   Time (seconds)   29.93

File: mn530b01.eng
  Total Series: 1
Display Range:
  First Series: 1
  Last Series: 1

Time (seconds)

179.12

95.43

0.00

29.93
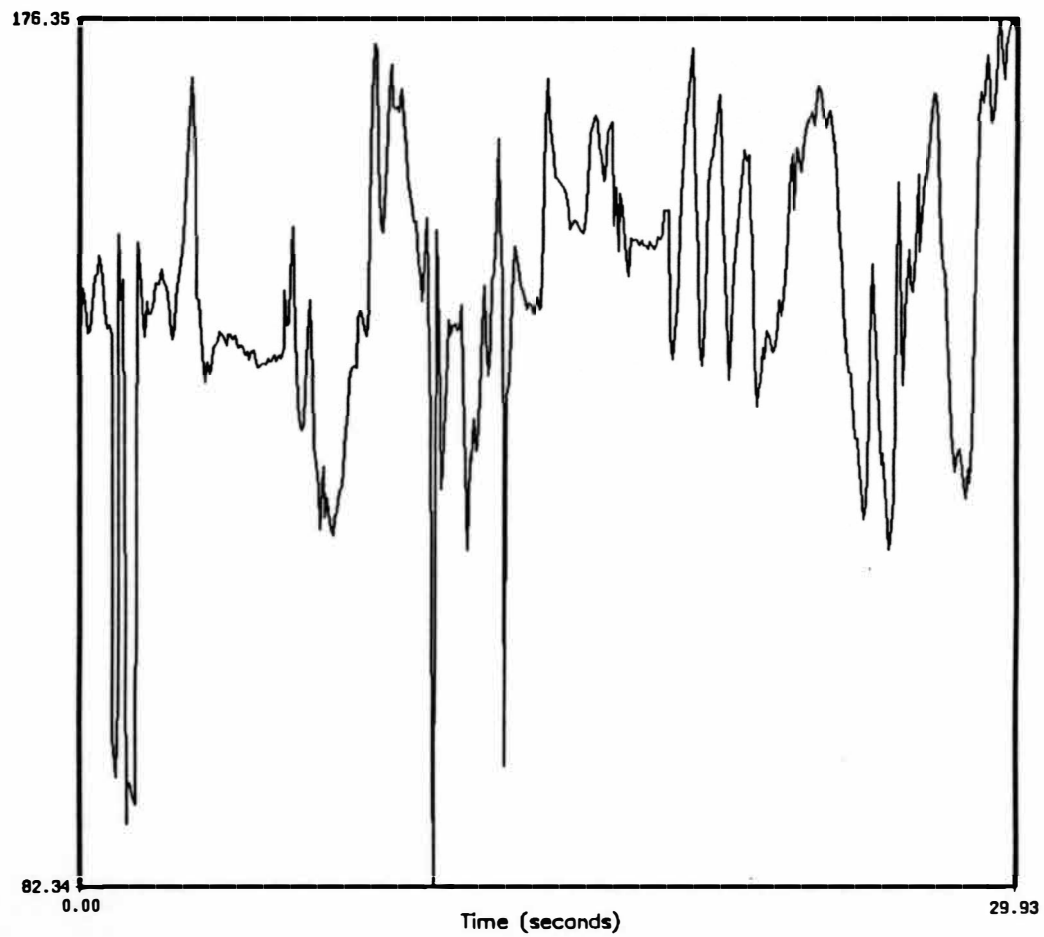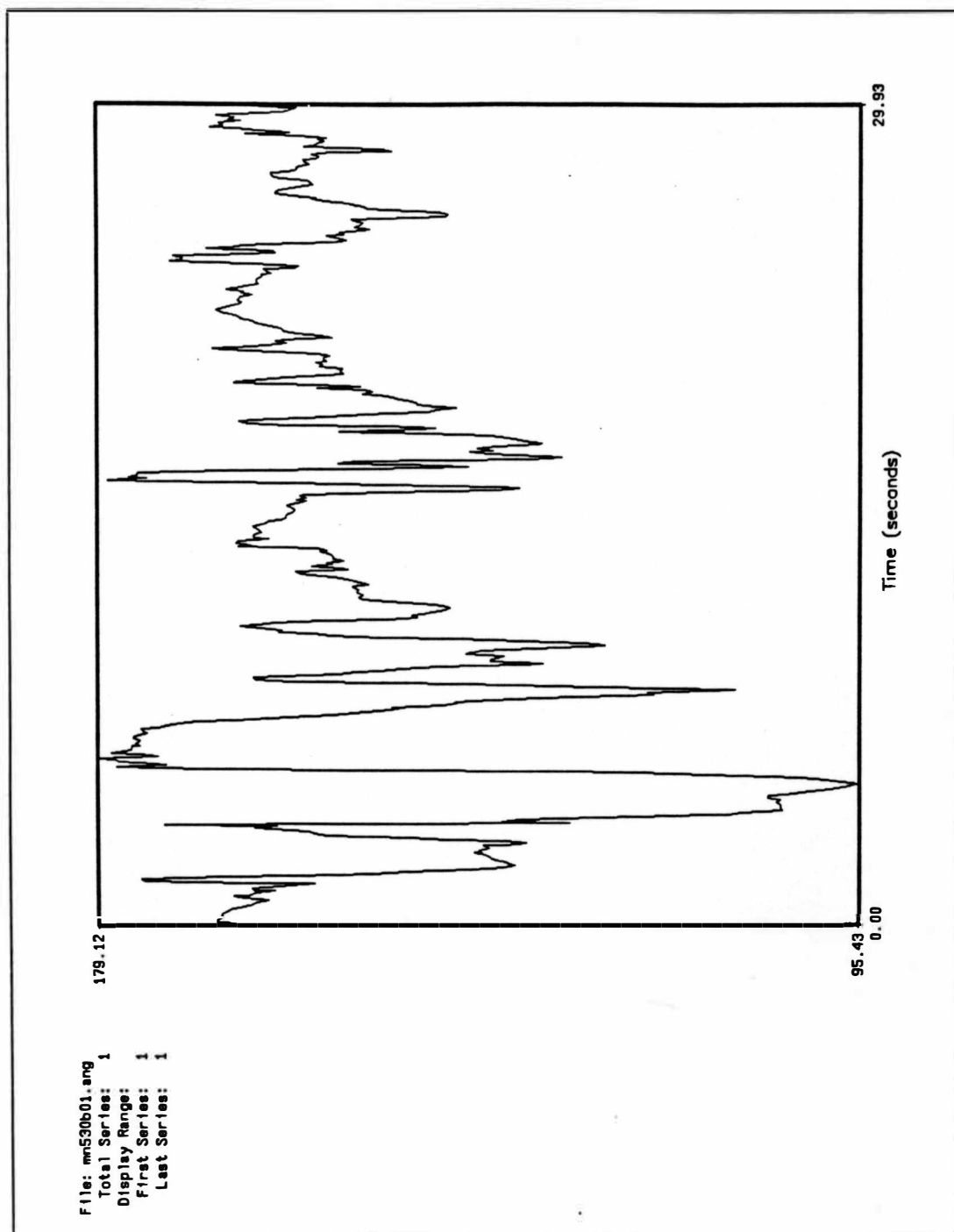
Appendix C

Statistical Analysis

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OPERATOR: M
ANALOG DATA: NEW AND OLD FIXTURE 230B

ANALYSIS OF VARIANCE ON C1

SOURCE	DF	SS	MS	F	p
C2	1	1350050	1350050	127.24	0.000
ERROR	3598	38174844	10610		
TOTAL	3599	39524892			

```
                                    INDIVIDUAL 95 PCT CI'S FOR MEAN
                                    BASED ON POOLED STDEV
LEVEL      N        MEAN    STDEV   --+---------+---------+---------+----
MN230B    1800     1833.2    91.7   (--*--)
MO230B    1800     1871.9   113.1                                 (--*--)
                                    --+---------+---------+---------+----
   POOLED STDEV =    103.0         1830      1845      1860      1875
```

ANGLE DATA: NEW AND OLD FIXTURE 230B

ANALYSIS OF VARIANCE ON C1

SOURCE	DF	SS	MS	F	p
C2	1	3589	3589	7.34	0.007
ERROR	898	439054	489		
TOTAL	899	442643			

```
                                    INDIVIDUAL 95 PCT CI'S FOR MEAN
                                    BASED ON POOLED STDEV
LEVEL      N        MEAN    STDEV   ------+---------+---------+---------+
MN230B     450     143.21   27.21   (-------*-------)
MO230B     450     147.20   15.41                   (-------*-------)
                                    ------+---------+---------+---------+
   POOLED STDEV =     22.11         142.5     145.0     147.5     150.0
```

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OPERATOR: M
ANALOG DATA: NEW AND OLD FIXTURE 530B

ANALYSIS OF VARIANCE ON C1
```
SOURCE      DF        SS         MS        F         p
C2           1  204769904  204769904  1616.23    0.000
ERROR     3598  455851456     126696
TOTAL     3599  660621376_
```

```
                                   INDIVIDUAL 95 PCT CI'S FOR MEAN
                                      BASED ON POOLED STDEV
LEVEL      N     MEAN    STDEV  -----+---------+---------+---------+-
MN530B   1800   2375.8    484.5                                    (*)
MO530B   1800   1898.8    136.5   (-*)
                                -----+---------+---------+---------+-
POOLED STDEV =    355.9         1950      2100      2250      2400
```

ANGLE DATA: NEW AND OLD FIXTURE 530B

ANALYSIS OF VARIANCE ON C1
```
SOURCE      DF        SS         MS        F         p
C2           1      4518       4518    19.78     0.000
ERROR      898    205173        228
TOTAL      899    209691
```

```
                                   INDIVIDUAL 95 PCT CI'S FOR MEAN
                                      BASED ON POOLED STDEV
LEVEL      N     MEAN    STDEV  ---+---------+---------+---------+---
MN530B    450   151.30    16.63                      (------*------)
MO530B    450   146.82    13.43   (------*------)
                                ---+---------+---------+---------+---
POOLED STDEV =     15.12       146.0     148.0     150.0     152.0
```

```
           4/12/93            Page 1
OPERATOR: M
ANALOG DATA: NEW AND OLD FIXTURE 230S

ANALYSIS OF VARIANCE ON C1
SOURCE      DF        SS         MS          F        p
C2           1    4134512    4134512    130.16    0.000
ERROR     3598 114287272      31764
TOTAL     3599 118421784
                                    INDIVIDUAL 95 PCT CI'S FOR MEAN
                                    BASED ON POOLED STDEV
LEVEL       N       MEAN      STDEV   --+---------+---------+---------+---
MN230S   1800     1922.1      222.9                              (--*--)
MO230S   1800     1854.3      117.6   (---*--)
                                      --+---------+---------+---------+--
POOLED STDEV =    178.2             1850      1875      1900      1925


ANGLE DATA: NEW AND OLD FIXTURE 230S

ANALYSIS OF VARIANCE ON C1
SOURCE      DF         SS         MS         F         p
C2           1       4711       4711      7.79     0.005
ERROR      896     541958        605
TOTAL      897     546669
                                    INDIVIDUAL 95 PCT CI'S FOR MEAN
                                    BASED ON POOLED STDEV
LEVEL       N       MEAN      STDEV   -+---------+---------+---------+----
MN230S     449     146.69      15.62                 (--------*-------
MO230S     449     142.11      31.08   (--------*---------)
                                      -+---------+---------+---------+---
POOLED STDEV =     24.59           140.0     142.5     145.0     147.5
```

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OPERATOR: I
ANALOG DATA: NEW AND OLD FIXTURE 530B

ANALYSIS OF VARIANCE ON C1

SOURCE	DF	SS	MS	F	p
C2	1	332487	332487	1.63	0.202
ERROR	3598	734370752	204105		
TOTAL	3599	734703232			

INDIVIDUAL 95 PCT CI'S FOR MEAN
BASED ON POOLED STDEV

LEVEL	N	MEAN	STDEV	----+---------+---------+---------+-
IN530B	1800	2073.4	443.9	(----------*---------)
IO530B	1800	2054.2	459.5	(---------*----------)

POOLED STDEV = 451.8

```
                      ----+---------+---------+---------+
                      2040      2060      2080      2100
```

ANGLE DATA: NEW AND OLD FIXTURE 530B

ANALYSIS OF VARIANCE ON C1

SOURCE	DF	SS	MS	F	p
C2	1	11241	11241	81.13	0.000
ERROR	896	124149	139		
TOTAL	897	135389			

INDIVIDUAL 95 PCT CI'S FOR MEAN
BASED ON POOLED STDEV

LEVEL	N	MEAN	STDEV	----+---------+---------+---------+-
IN530B	449	141.11	12.39	(--*---)
IO530B	449	148.18	11.11	(---*---)

POOLED STDEV = 11.77

```
                      ----+---------+---------+---------+
                      141.0     144.0     147.0     150.0
```

```
           4/12/93           Page 1
OPERATOR: I
ANALOG DATA: NEW AND OLD FIXTURE 230B

ANALYSIS OF VARIANCE ON C1
SOURCE       DF        SS        MS         F         p
C2            1 212649792 212649792   1604.43     0.000
ERROR      3598 476875200    132539
TOTAL      3599 689524992
                                  INDIVIDUAL 95 PCT CI'S FOR MEAN
                                  BASED ON POOLED STDEV
LEVEL        N      MEAN      STDEV  ----------+---------+---------+-----
IN230B    1800    1969.0      327.3  (*)
IO230B    1800    2455.1      397.4                                  (*)
                                  ----------+---------+---------+----
POOLED STDEV =     364.1               2100      2250      2400


ANGLE DATA: NEW AND OLD FIXTURE 230B

ANALYSIS OF VARIANCE ON C1
SOURCE       DF        SS        MS         F         p
C2            1     35699     35699    110.82     0.000
ERROR       892    287355       322
TOTAL       893    323053
                                  INDIVIDUAL 95 PCT CI'S FOR MEAN
                                  BASED ON POOLED STDEV
LEVEL        N      MEAN      STDEV  ---+---------+---------+---------+--
IN230B     447    135.30      19.70  (---*--)
IO230B     447    147.93      16.01                        (--*--)
                                  ---+---------+---------+---------+-
POOLED STDEV =     17.95          135.0     140.0     145.0     150.0
```

```
        4/12/93          Page 1
OPERATOR: I
ANALOG DATA: NEW AND OLD FIXTURE 230S

ANALYSIS OF VARIANCE ON C1
SOURCE      DF        SS        MS        F        p
C2           1  17883314  17883314   117.63    0.000
ERROR     3598 547025344    152036
TOTAL     3599 564908672
                                INDIVIDUAL 95 PCT CI'S FOR MEAN
                                BASED ON POOLED STDEV
LEVEL       N      MEAN     STDEV  ----+---------+---------+---------+--
IN230S    1800    1990.7    391.1                              (--*---)
IO230S    1800    1849.7    388.7  (---*---)
                                   ----+---------+---------+---------+-
POOLED STDEV =      389.9          1850      1900      1950      2000


ANGLE DATA: NEW AND OLD FIXTURE 230S

ANALYSIS OF VARIANCE ON C1
SOURCE      DF        SS        MS        F        p
C2           1       241       241     0.46    0.498
ERROR      898    471004       525
TOTAL      899    471245
                                INDIVIDUAL 95 PCT CI'S FOR MEAN
                                BASED ON POOLED STDEV
LEVEL       N      MEAN     STDEV  -+---------+---------+---------+-----
IN230S     450    138.61    24.34  (-------------*------------)
IO230S     450    139.65    21.36       (-------------*------------)
                                   -+---------+---------+---------+----
POOLED STDEV =      22.90        136.5    138.0     139.5     141.0
```

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OPERATOR : F
ANALOG DATA: NEW AND OLD FIXTURE 530B

ANALYSIS OF VARIANCE ON C1

SOURCE	DF	SS	MS	F	p
C2	1	5283869	5283869	83.01	0.000
ERROR	3598	229030112	63655		
TOTAL	3599	234313984			

INDIVIDUAL 95 PCT CI'S FOR MEAN
BASED ON POOLED STDEV

LEVEL	N	MEAN	STDEV	---+---------+---------+---------+---
FN530B	1800	2164.6	237.9	(---*--)
FO530B	1800	2241.2	265.9	(---*---)

```
                          ---+---------+---------+---------+---
POOLED STDEV =            252.3       2160      2190      2220
```

ANGLE DATA: NEW AND OLD FIXTURE 530B

ANALYSIS OF VARIANCE ON C1

SOURCE	DF	SS	MS	F	p
C2	1	1919	1919	12.30	0.000
ERROR	862	134481	156		
TOTAL	863	136400			

INDIVIDUAL 95 PCT CI'S FOR MEAN
BASED ON POOLED STDEV

LEVEL	N	MEAN	STDEV	--------+---------+---------+--------
1	432	151.51	15.11	(-------*-------)
2	432	154.49	9.14	(------*-------)

```
                          --------+---------+---------+--------
POOLED STDEV =     12.49       151.5     153.0     154.5
```

```
        4/12/93            Page 1
OPERATOR: F
ANALOG DATA: NEW AND OLD FIXTURE 230B

ANALYSIS OF VARIANCE ON C1
SOURCE      DF         SS          MS         F        p
C2           1    52807352    52807352    364.68    0.000
ERROR     3598   521006720      144805
TOTAL     3599   573814080
                                    INDIVIDUAL 95 PCT CI'S FOR MEAN
                                    BASED ON POOLED STDEV
LEVEL        N       MEAN      STDEV  ------+---------+---------+---------+
FN230B    1800     2697.3      362.8                                 (-*-)
FO230B    1800     2455.1      397.4  (-*-)
                                      ------+---------+---------+---------
POOLED STDEV =     380.5             2480      2560      2640      272


ANGLE DATA: NEW AND OLD FIXTURE 230B

ANALYSIS OF VARIANCE ON C1
SOURCE      DF         SS          MS         F        p
C2           1         10          10       0.04    0.846
ERROR      862     225324         261
TOTAL      863     225334
                                    INDIVIDUAL 95 PCT CI'S FOR MEAN
                                    BASED ON POOLED STDEV
LEVEL        N       MEAN      STDEV  ---------+---------+---------+-------
FN230B     432     156.70      13.41  (--------------*--------------)
FO230B     432     156.92      18.52    (--------------*--------------)
                                      ---------+---------+---------+------
POOLED STDEV =      16.17             156.0     157.0     158.0
```

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OPERATOR: F

ANALOG DATA: NEW AND OLD FIXTURE 230S

ANALYSIS OF VARIANCE ON C1

SOURCE	DF	SS	MS	F	p
C2	1	14545833	14545833	138.98	0.000
ERROR	3598	376581696	104664		
TOTAL	3599	391127552			

INDIVIDUAL 95 PCT CI'S FOR MEAN
BASED ON POOLED STDEV

LEVEL	N	MEAN	STDEV	
FN230S	1800	2278.3	306.7	(--*--)
FO230S	1800	2405.4	339.5	(--*--)

```
        --------+---------+---------+--------
            2300      2350      2400
```

POOLED STDEV = 323.5

ANGLE DATA: NEW AND OLD FIXTURE 230S

ANALYSIS OF VARIANCE ON C1

SOURCE	DF	SS	MS	F	p
C2	1	145144	145144	105.64	0.000
ERROR	862	1184295	1374		
TOTAL	863	1329439			

INDIVIDUAL 95 PCT CI'S FOR MEAN
BASED ON POOLED STDEV

LEVEL	N	MEAN	STDEV	
1	432	153.12	17.10	(--*---)
2	432	127.20	49.55	(--*---)

```
        -------+---------+---------+---------
            130       140       150
```

POOLED STDEV = 37.07

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OPERATOR   : J
ANALOG DATA: NEW OLD FIXTURE 530B

ANALYSIS OF VARIANCE ON C1

SOURCE	DF	SS	MS	F	p
C2	1	39169656	39169656	180.27	0.000
ERROR	3598	781779648	217282		
TOTAL	3599	820949312			

```
                                   INDIVIDUAL 95 PCT CI'S FOR MEAN
                                   BASED ON POOLED STDEV
LEVEL    N     MEAN    STDEV  -----+---------+---------+---------+-
JN530B  1800  2859.0   399.8                                  (--*---)
JO530B  1800  2650.4   524.1   (--*--)
                              -----+---------+---------+---------+-
POOLED STDEV =    466.1       2660      2730      2800      2870
```

ANGLE DATA: NEW AND OLD FIXTURE 530B
ANALYSIS OF VARIANCE ON C1

SOURCE	DF	SS	MS	F	p
C2	1	853	853	0.76	0.385
ERROR	894	1008893	1129		
TOTAL	895	1009747			

```
                              INDIVIDUAL 95 PCT CI'S FOR MEAN
                                 BASED ON POOLED STDEV
LEVEL    N     MEAN    STDEV  -------+---------+---------+---------
JN530B   448  143.42   35.75         (------------*----------)
JO530B   448  141.47   31.28  (------------*----------)
                             -------+---------+---------+---------
POOLED STDEV =    33.59       140.0     142.5     145.0
```

```
                    4/12/93          Page 1
OPERATOR:      J
ANALOG DATA: NEW AND OLD FIXTURE 230B

ANALYSIS OF VARIANCE ON C1
SOURCE      DF        SS         MS         F         p
C2           1      16930       16930      0.06      0.803
ERROR     3598  979975552      272367
TOTAL     3599  979992512
                                   INDIVIDUAL 95 PCT CI'S FOR MEAN
                                   BASED ON POOLED STDEV
LEVEL       N      MEAN    STDEV  ---+---------+---------+---------+---
JN230B    1800    2705.8   522.4    (--------------*---------------)
JO230B    1800    2710.2   521.4     (--------------*---------------)
                                   ---+---------+---------+---------+---
POOLED STDEV =      521.9         2685      2700      2715      2730


ANGLE DATA: NEW AND OLD FIXTURE 230B
ANALYSIS OF VARIANCE ON C1
SOURCE      DF        SS         MS         F         p
C2           1        27         27       0.07      0.785
ERROR      896     331752       370
TOTAL      897     331779
                                   INDIVIDUAL 95 PCT CI'S FOR MEAN
                                   BASED ON POOLED STDEV
LEVEL    N    MEAN   STDEV   --------+---------+---------+--------
JN230B  450  146.03   11.65  (--------------*-------------)
JO230B  448  146.38   24.61   (--------------*-------------)
                             --------+---------+---------+--------
POOLED STDEV =    19.24        145.2      146.4      147.6
```

OPERATOR: J
ANALOG DATA: NEW AND OLD FIXTURE 230S

ANALYSIS OF VARIANCE ON C1

SOURCE	DF	SS	MS	F	p
C2	1	7404204	7404204	28.27	0.000
ERROR	3598	942447808	261937		
TOTAL	3599	949851968			

INDIVIDUAL 95 PCT CI'S FOR MEAN
BASED ON POOLED STDEV

```
LEVEL   N    MEAN    STDEV  ---+---------+---------+---------+---
JN230S 1800  2544.9  494.0                          (-----*-----)
JO230S 1800  2454.2  529.0    (-----*----)
                             ---+---------+---------+---------+---
POOLED STDEV =    511.8         2440      2480      2520      2560
```

ANGLE DATA: NEW AND OLD FIXTURE 230S
ANALYSIS OF VARIANCE ON C1

SOURCE	DF	SS	MS	F	p
C2	1	3666	3666	11.94	0.001
ERROR	882	270895	307		
TOTAL	883	274561			

INDIVIDUAL 95 PCT CI'S FOR MEAN
BASED ON POOLED STDEV

```
LEVEL    N    MEAN   STDEV  -------+---------+---------+---------
JN230S  442  142.42  18.38  (-------*-------)
JO230S  442  146.49  16.63                    (-------*--------)
                            -------+---------+---------+---------
POOLED STDEV =   17.53         142.0     144.0     146.0
```

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OPERATOR: R
ANALOG DATA: NEW AND OLD FIXTURE 530B

ANALYSIS OF VARIANCE ON C1
SOURCE   DF   SS   MS   F   p
C2   1   666182   666182   2.27   0.132
ERROR   3598 1.056E+09   293559
TOTAL   3599 1.057E+09
                                    INDIVIDUAL 95 PCT CI'S FOR MEAN
                                    BASED ON POOLED STDEV
LEVEL   N   MEAN   STDEV   ------+---------+---------+---------+
RN530B   1800   3761.5   529.4   (---------*---------)
RO530B   1800   3788.7   554.0   (---------*---------)
                                    ------+---------+---------+---------
POOLED STDEV =   541.8   3750   3775   3800   382

ANGLE DATA: NEW AND OLD FIXTURE 530B

ANALYSIS OF VARIANCE ON C1
SOURCE   DF   SS   MS   F   p
C2   1   432   432   1.05   0.306
ERROR   888   364790   411
TOTAL   889   365222
                                    INDIVIDUAL 95 PCT CI'S FOR MEAN
                                    BASED ON POOLED STDEV
LEVEL   N   MEAN   STDEV   ---+---------+---------+---------+---
RN530B   445   149.90   16.42   (-----------*-----------)
RO530B   445   148.51   23.49   (-----------*-----------)
                                    ---+---------+---------+---------+--
POOLED STDEV =   20.27   147.0   148.5   150.0   151.5

```
        4/12/93          Page 1
OPERATOR: R
ANALOG DATA: NEW AND OLD FIXTURE 230B

ANALYSIS OF VARIANCE ON C1
SOURCE      DF        SS         MS        F        p
C2           1   24274344   24274344   140.03    0.000
ERROR     3598  623700672     173346
TOTAL     3599  647975040
                                    INDIVIDUAL 95 PCT CI'S FOR MEAN
                                    BASED ON POOLED STDEV
LEVEL       N       MEAN      STDEV  -+---------+---------+---------+----
 RN230B   1800     4021.4     133.5                                 (--*--)
RO230B    1800     3857.2     573.5   (--*--)
                                      -+---------+---------+---------+----
POOLED STDEV =    416.3             3840      3900      3960      4020


ANGLE DATA: NEW AND OLD FIXTURE 230B

ANALYSIS OF VARIANCE ON C1
SOURCE      DF        SS         MS        F        p
C2           1       193        193      1.11    0.293
ERROR      896    156227        174
TOTAL      897    156420
                                    INDIVIDUAL 95 PCT CI'S FOR MEAN
                                    BASED ON POOLED STDEV
LEVEL       N       MEAN      STDEV  -+---------+---------+---------+----
RN230B     449     152.16     12.35  (-----------*-----------)
RO230B     449     153.09     14.01          (-----------*-----------)
                                      -+---------+---------+---------+----
POOLED STDEV =    13.20            151.0     152.0     153.0     154.0
```

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```
                    4/12/93          Page 1
OPERATOR: R
ANALOG DATA: NEW AND OLD FIXTURE 230S

ANALYSIS OF VARIANCE ON C1
SOURCE      DF        SS        MS        F        p
C2           1   2489085   2489085    57.60    0.000
ERROR     3598 155480048     43213
TOTAL     3599 157969136
                                    INDIVIDUAL 95 PCT CI'S FOR MEAN
                                    BASED ON POOLED STDEV
   LEVEL      N      MEAN     STDEV  ---+---------+---------+---------+---
   RN230S  1800    4016.4     133.4                        (----*----)
   RO230S  1800    3963.8     262.0  (----*----)
                                    ---+---------+---------+---------+---
POOLED STDEV =     207.9            3960      3980      4000      4020


ANGLE DATA: NEW AND OLD FIXTURE 230S

ANALYSIS OF VARIANCE ON C1
SOURCE      DF        SS        MS        F        p
C2           1     28664     28664    22.96    0.000
ERROR      898   1121288      1249
TOTAL      899   1149952
                                    INDIVIDUAL 95 PCT CI'S FOR MEAN
                                    BASED ON POOLED STDEV
   LEVEL      N      MEAN     STDEV  ---+---------+---------+---------+---
   RN230S   450    138.26     24.94                     (------*-----)
   RO230S   450    126.97     43.30  (------*-----)
                                    ---+---------+---------+---------+---
POOLED STDEV =      35.34           125.0     130.0     135.0     140.0
```

OPERATOR: V
ANALOG DATA: NEW AND OLD FIXTURE 230B

ANALYSIS OF VARIANCE ON C1

SOURCE	DF	SS	MS	F	p
C2	1	2481360	2481360	452.97	0.000
ERROR	3598	19709808	5478		
TOTAL	3599	22191168			

```
                                    INDIVIDUAL 95 PCT CI'S FOR MEAN
                                    BASED ON POOLED STDEV
  LEVEL      N     MEAN    STDEV   -+---------+---------+---------+-----
  VN230B   1800   2474.3    79.9                                (-*-)
  VO230B   1800   2421.8    67.6   (-*-)
                                   -+---------+---------+---------+-----
POOLED STDEV =      74.0          2420      2440      2460      2480
```

ANGLE DATA: NEW AND OLD FIXTURE 230B

ANALYSIS OF VARIANCE ON C1

SOURCE	DF	SS	MS	F	p
C2	1	732	732	2.66	0.103
ERROR	884	243530	275		
TOTAL	885	244262			

```
                                    INDIVIDUAL 95 PCT CI'S FOR MEAN
                                    BASED ON POOLED STDEV
  LEVEL      N     MEAN    STDEV   -------+---------+---------+---------
      1    443   158.42    15.17               (---------*---------)
      2    443   156.60    17.91   (---------*---------)
                                   -------+---------+---------+---------
POOLED STDEV =     16.60           156.0     157.5     159.0
```

```
          4/12/93           Page 1
OPERATOR: V
ANALOG DATA: NEW AND OLD FIXTURE 230B

ANALYSIS OF VARIANCE ON C1
SOURCE      DF          SS          MS          F          p
C2           1       2327811     2327811     605.33     0.000
ERROR      3598      13836286       3846
TOTAL      3599      16164097
                                       INDIVIDUAL 95 PCT CI'S FOR MEAN
                                       BASED ON POOLED STDEV
LEVEL       N      MEAN    STDEV   -----+---------+---------+---------+-
VN230B    1800    2447.3    64.5                                      (-*)
VO230B    1800    2396.5    59.4    (-*-)
                                   -----+---------+---------+---------+-
POOLED STDEV =        62.0        2400      2416      2432      2448

ANGLE DATA: NEW AND OLD FIXTURE 230B

ANALYSIS OF VARIANCE ON C1
SOURCE      DF          SS          MS          F          p
C2           1          732        732       2.66       0.103
ERROR       884       243530       275
TOTAL       885       244262
                                       INDIVIDUAL 95 PCT CI'S FOR MEAN
                                       BASED ON POOLED STDEV
LEVEL     N     MEAN    STDEV   -------+---------+---------+---------
1        443   158.42   15.17           (---------*---------)
2        443   156.60   17.91   (---------*---------)
                               -------+---------+---------+---------
POOLED STDEV =       16.60       156.0     157.5     159.0
```

```
          4/12/93           Page 1
OPERATOR: V
ANALOG DATA: NEW AND OLD FIXTURE 230S

ANALYSIS OF VARIANCE ON C1
SOURCE      DF        SS        MS        F         p
C2           1        904       904      0.26     0.608
ERROR      3598   12341372     3430
TOTAL      3599   12342276
                                    INDIVIDUAL 95 PCT CI'S FOR MEAN
                                    BASED ON POOLED STDEV
LEVEL       N       MEAN      STDEV   --------+---------+---------+------
VN230S     1800    2378.0     57.8       (-------------*------------)
VO230S     1800    2377.0     59.4   (-------------*------------)
                                       --------+---------+---------+------
POOLED STDEV =      58.6              2376.0     2378.0     2380.0


ANGLE DATA: NEW AND OLD FIXTURE 230S

ANALYSIS OF VARIANCE ON C1
SOURCE      DF        SS        MS        F         p
C2           1       5639      5639     20.60     0.000
ERROR       852    233255      274
TOTAL       853    238895
                                    INDIVIDUAL 95 PCT CI'S FOR MEAN
                                    BASED ON POOLED STDEV
LEVEL       N       MEAN      STDEV   -------+---------+---------+--------
VN230S      427    150.05     20.42   (-----*-----)
VO230S      427    155.19     11.43                       (-----*-----)
                                       -------+---------+---------+--------
POOLED STDEV =      16.55             150.0      152.5      155.0
```

```
            4/12/93           Page 1
OPERATOR: G
ANALOG DATA: NEW AND OLD FIXTURE 530B

ANALYSIS OF VARIANCE ON C1
SOURCE      DF        SS         MS         F         p
C2           1    8469082    8469082    400.24    0.000
ERROR     1798   38045532      21160
TOTAL     1799   46514616
                                 INDIVIDUAL 95 PCT CI'S FOR MEAN
                                 BASED ON POOLED STDEV
LEVEL       N    MEAN     STDEV  ------+---------+---------+---------+
GN530B    1800   2272.3   163.1                              (*-)
GO530B    1800   2135.1   125.3  (-*-)
                                 ------+---------+---------+---------+
POOLED STDEV =    145.5         2150      2200      2250      2300


ANGLE DATA: NEW AND OLD FIXTURE 530B

ANALYSIS OF VARIANCE ON C1
SOURCE      DF        SS         MS         F         p
C2           1     16592      16592     70.99    0.000
ERROR      868    202862        234
TOTAL      869    219454
                                 INDIVIDUAL 95 PCT CI'S FOR MEAN
                                 BASED ON POOLED STDEV
LEVEL    N    MEAN    STDEV  --+---------+---------+---------+----
1      435   144.39   12.27  (----*---)
2      435   153.13   17.80                        (----*---)
                            --+---------+---------+---------+----
POOLED STDEV =     15.29     143.5     147.0     150.5     154.0
```

```
           4/12/93           Page 1
OPERATOR: G
ANALOG DATA: NEW AND OLD FIXTURE 230B
```

ANALYSIS OF VARIANCE ON C1

SOURCE	DF	SS	MS	F	p
C2	1	8469082	8469082	400.24	0.000
ERROR	1798	38045532	21160		
TOTAL	1799	46514616			

```
                                    INDIVIDUAL 95 PCT CI'S FOR MEAN
                                    BASED ON POOLED STDEV
LEVEL      N       MEAN    STDEV    -----+---------+---------+---------+-
GN230B    900     2272.3   163.1                                 (*-)
GO230B    900     2135.1   125.3    (-*-)
                                    -----+---------+---------+---------+
POOLED STDEV =     145.5           2150      2200      2250      2300
```

ANGLE DATA: NEW AND OLD FIXTURE 230B

ANALYSIS OF VARIANCE ON C1

SOURCE	DF	SS	MS	F	p
C2	1	684	684	2.06	0.152
ERROR	876	290972	332		
TOTAL	877	291657			

```
                                    INDIVIDUAL 95 PCT CI'S FOR MEAN
                                    BASED ON POOLED STDEV
LEVEL      N       MEAN    STDEV    ------+---------+---------+---------+
GN230B    439     142.12   17.82              (----------*----------)
GO230B    439     140.36   18.62    (----------*----------)
                                    ------+---------+---------+---------
POOLED STDEV =     18.23            139.5     141.0     142.5     144.
```

OPERATOR: G
ANALOG DATA: NEW AND OLD FIXTURE 230S

ANALYSIS OF VARIANCE ON C1

SOURCE	DF	SS	MS	F	p
C2	1	132870	132870	7.26	0.007
ERROR	1798	32898826	18297		
TOTAL	1799	33031696			

INDIVIDUAL 95 PCT CI'S FOR MEAN
BASED ON POOLED STDEV

LEVEL	N	MEAN	STDEV	
GN230S	900	2106.4	117.8	(-------*--------)
GO230S	900	2123.6	150.7	(--------*-------)

POOLED STDEV = 135.3   2100   2110   2120   2130

ANGLE DATA: NEW AND OLD FIXTURE 230S

ANALYSIS OF VARIANCE ON C1

SOURCE	DF	SS	MS	F	p
C2	1	5	5	0.03	0.870
ERROR	874	163659	187		
TOTAL	875	163664			

INDIVIDUAL 95 PCT CI'S FOR MEAN
BASED ON POOLED STDEV

LEVEL	N	MEAN	STDEV	
GN230S	438	152.19	13.66	(---------------*---------------)
GO230S	438	152.04	13.70	(---------------*---------------)

POOLED STDEV = 13.68   151.20   152.00   152.80   153

```
        4/12/93          Page 1
OPERATOR: O
ANALOG DATA: NEW AND OLD FIXTURE 530B

ANALYSIS OF VARIANCE ON C1
SOURCE      DF        SS        MS        F        p
C2           1    3216642    3216642    76.05    0.000
ERROR     3598  152176496      42295
TOTAL     3599  155393136
                                    INDIVIDUAL 95 PCT CI'S FOR MEAN
                                    BASED ON POOLED STDEV
LEVEL      N    MEAN     STDEV  ---------+---------+---------+-------
ON530B   1800   2498.3    261.0                          (--*---)
OO530B   1800   2438.5    128.3    (--*---)
                                  ---------+---------+---------+-------
POOLED STDEV =    205.7            2450      2475      2500


ANGLE DATA: NEW AND OLD FIXTURE 530B
ANALYSIS OF VARIANCE ON C1
SOURCE      DF        SS        MS        F        p
C2           1       89.9      89.9     2.18     0.141
ERROR      898    37127.6      41.3
TOTAL      899    37217.5
                                    INDIVIDUAL 95 PCT CI'S FOR MEAN
                                    BASED ON POOLED STDEV
LEVEL      N    MEAN     STDEV  --------+---------+---------+--------
ON530B    450  165.35    4.43             (----------*----------)
OO530B    450  164.72    7.94   (----------*----------)
                               --------+---------+---------+--------
POOLED STDEV =      6.43        164.50    165.00    165.50
```

```
           4/12/93            Page 1
OPERATOR: O
ANALOG DATA: NEW AND OLD FIXTURE 230B

ANALYSIS OF VARIANCE ON C1
SOURCE      DF        SS         MS         F         p
C2           1     1136001    1136001     25.25     0.000
ERROR     3598 161896352       44996
TOTAL     3599 163032352
                              INDIVIDUAL 95 PCT CI'S FOR MEAN
                                  BASED ON POOLED STDEV
LEVEL     N     MEAN    STDEV  -----+---------+---------+---------+-
ON230B 1800   2544.1    239.3                          (-----*------)
OO230B 1800   2508.5    180.9     (-----*------)
                              -----+---------+---------+---------+-
POOLED STDEV =    212.1      2505      2520      2535      2550

ANGLE DATA: NEW AND OLD FIXTURE 230B
ANALYSIS OF VARIANCE ON C1
SOURCE      DF        SS         MS         F         p
C2           1     13983.4    13983.4    190.28     0.000
ERROR      878     64521.1       73.5
TOTAL      879     78504.5
                              INDIVIDUAL 95 PCT CI'S FOR MEAN
                                  BASED ON POOLED STDEV
LEVEL     N     MEAN    STDEV  -----+---------+---------+---------+-
ON230B  440   155.56    10.54  (--*-)
OO230B  440   163.53     5.98                        (--*--)
                              -----+---------+---------+---------+-
POOLED STDEV =     8.57      156.0     159.0     162.0     165.0
```

4/12/93   Page 1
OPERATOR : O
ANALOG DATA: NEW AND OLD FIXTURE 230S

ANALYSIS OF VARIANCE ON C1

SOURCE	DF	SS	MS	F	p
C2	1	26436564	26436564	509.80	0.000
ERROR	3598	186579792	51857		
TOTAL	3599	213016352			

INDIVIDUAL 95 PCT CI'S FOR MEAN
BASED ON POOLED STDEV

LEVEL	N	MEAN	STDEV	
ON230S	1800	2475.2	182.6	(-*)
OO230S	1800	2646.6	265.3	(-*-)

```
                          ----------+---------+---------+-----
POOLED STDEV =  227.7        2520      2580      2640
```

ANGLE DATA: NEW AND OLD FIXTURE 230S

ANALYSIS OF VARIANCE ON C1

SOURCE	DF	SS	MS	F	p
C2	1	28664	28664	22.96	0.000
ERROR	898	1121288	1249		
TOTAL	899	1149952			

INDIVIDUAL 95 PCT CI'S FOR MEAN
BASED ON POOLED STDEV

LEVEL	N	MEAN	STDEV	
ON230S	450	138.26	24.94	(------*----
OO230S	450	126.97	43.30	(------*-----)

```
                          ---+---------+---------+---------+--
POOLED STDEV =  35.34        125.0     130.0     135.0     140.0
```

```
                    4/12/93            Page 1
OPERATOR        : C
ANALOG DATA     :   NEW AND OLD FIXTURE 530

ANALYSIS OF VARIANCE ON C1
SOURCE      DF          SS        MS         F        p
C2           1     2225119   2225119     24.86    0.000
ERROR     3598 322045536     89507
TOTAL     3599 324270624
```

ANALYSIS OF VARIANCE ON C1

SOURCE	DF	SS	MS	F	p
C2	1	2225119	2225119	24.86	0.000
ERROR	3598	322045536	89507		
TOTAL	3599	324270624			

```
                                    INDIVIDUAL 95 PCT CI'S FOR MEAN
                                      BASED ON POOLED STDEV
LEVEL       N      MEAN    STDEV  -------+---------+---------+---------.
CN530B   1800    3097.8    279.8  (----*-----)
CO530B   1800    3147.5    317.4                            (-----*-----)
                                  -------+---------+---------+---------
POOLED STDEV =     299.2             3100      3125      3150
```

ANGLE DATA: NEW AND OLD FIXTURE 530
ANALYSIS OF VARIANCE ON C1

SOURCE	DF	SS	MS	F	p
C2	1	550	550	0.26	0.612
ERROR	864	1849406	2141		
TOTAL	865	1849956			

```
                                    INDIVIDUAL 95 PCT CI'S FOR MEAN
                                      BASED ON POOLED STDEV
LEVEL     N    MEAN    STDEV   -----+---------+---------+---------+-
CN530B   433  126.06   51.54   (-------------*-------------)
CO530B   433  127.66   40.31        (-------------*-------------)
                              -----+---------+---------+---------+-
POOLED STDEV =     46.27      123.0     126.0     129.0     132.0
```

```
            4/12/93          Page 1
OPERATOR   : C
ANALOG DATA: NEW AND OLD FIXTURE FOR SEATS

ANALYSIS OF VARIANCE ON C1
SOURCE      DF          SS        MS        F        p
C2           1        1729      1729     0.01    0.925
ERROR     3598 706424768      196338
TOTAL     3599 706426496
                              INDIVIDUAL 95 PCT CI'S FOR MEAN
                              BASED ON POOLED STDEV
LEVEL       N    MEAN STDEV  ----+---------+---------+---------+--
CN230S   1800  3232.1 397.8  (----------------*-----------------)
CO230S   1800  3233.5 484.2   (----------------*----------------)
                             ----+---------+---------+---------+--
POOLED STDEV =     443.1      3216      3228      3240      3252


ANGLE DATA: NEW & OLD FIXTURE 230S

ANALYSIS OF VARIANCE ON C1
SOURCE      DF          SS        MS        F        p
C2           1       14241     14241    11.41    0.001
ERROR      886     1106088      1248
TOTAL      887     1120329
                              INDIVIDUAL 95 PCT CI'S FOR MEAN
                              BASED ON POOLED STDEV
LEVEL       N    MEAN STDEV  ---+---------+---------+---------+---
CN230S     444  130.31 35.68  (-------*-------)
CO230S     444  138.32 34.98                     (-------*-------)
                             ---+---------+---------+---------+---
POOLED STDEV =      35.33    128.0     132.0     136.0     140.0
```

4/12/93   Page 1
ANALOG DATA: NEW AND OLD FIXTURE FOR BACK'S CHAIRS
OPERATOR   : C

ANALYSIS OF VARIANCE ON C1
```
SOURCE      DF        SS          MS          F        p
C2           1    6066943     6066943     39.07    0.000
ERROR     3598  558684544      155276
TOTAL     3599  564751488
```

INDIVIDUAL 95 PCT CI'S FOR MEAN
BASED ON POOLED STDEV
```
LEVEL       N      MEAN      STDEV   --+---------+---------+---------+----
CN230B    1800    3069.2     400.0                          (----*----)
CO230B    1800    2987.1     388.0   (----*-----)
                                     --+---------+---------+---------+---
POOLED STDEV =     394.1           2975      3010      3045      3080
```

ANGLE DATA:
ANALYSIS OF VARIANCE ON C1
```
SOURCE      DF        SS          MS          F        p
C2           1      8181        8181      4.94     0.026
ERROR      866   1433818        1656
TOTAL      867   1441999
```

INDIVIDUAL 95 PCT CI'S FOR MEAN
BASED ON POOLED STDEV
```
LEVEL       N      MEAN      STDEV   -----+---------+---------+---------+-
CN230B     434    138.05     40.90   (--------*---------)
CO230B     434    144.19     40.48                (--------*---------)
                                     -----+---------+---------+---------+
POOLED STDEV =      40.69          136.0     140.0     144.0     148.0
```
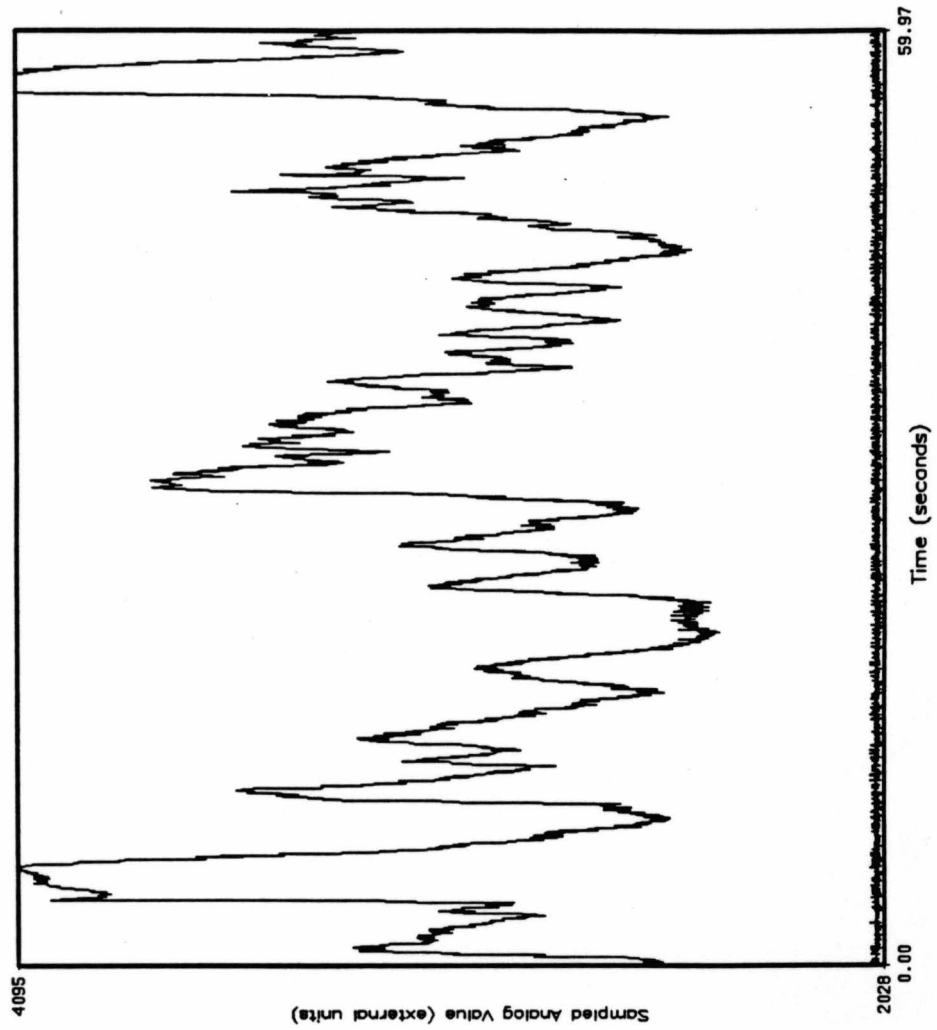
Appendix D

EMG Graphs

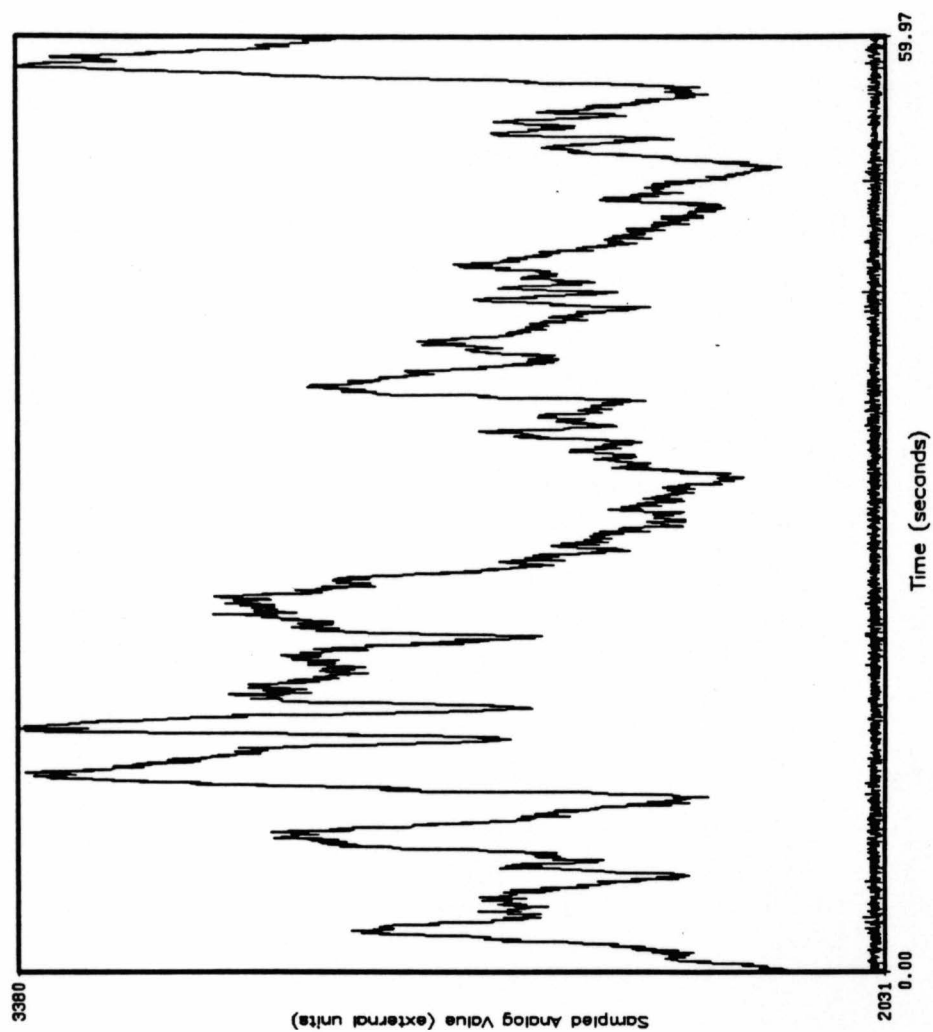File: cn230e01.ats
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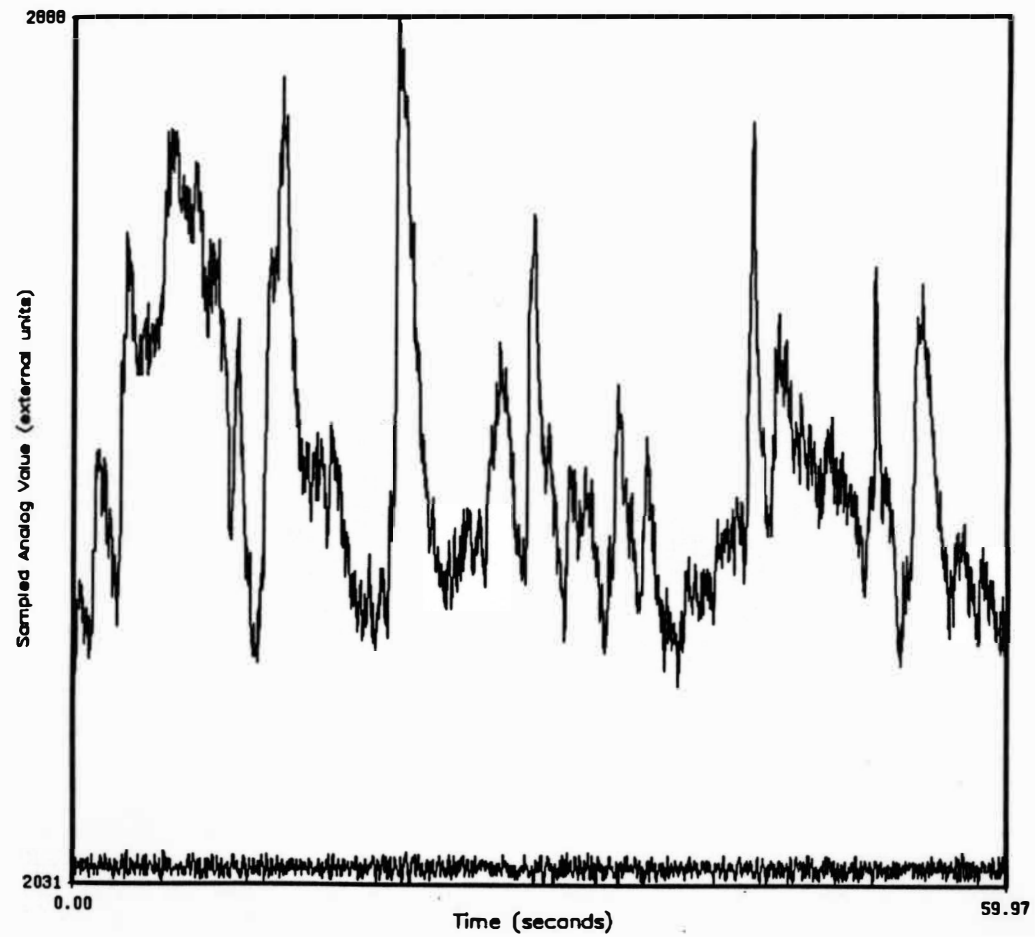
144
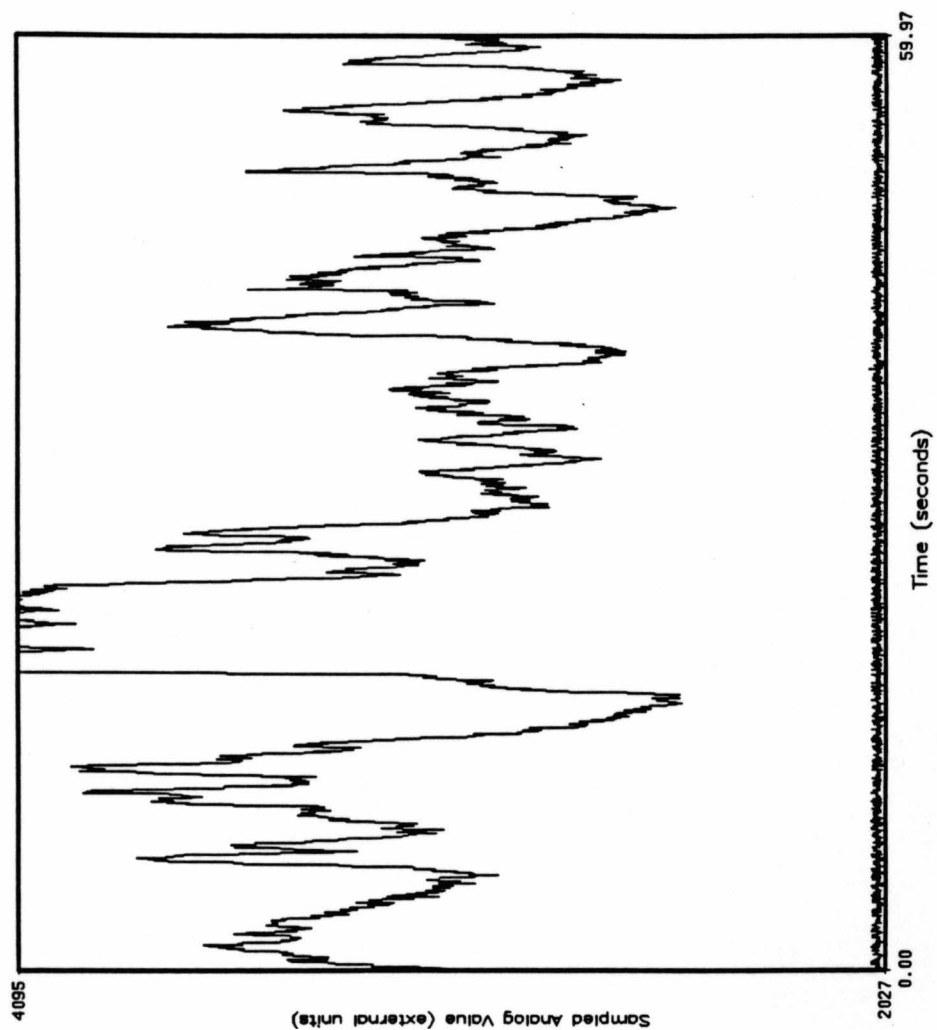
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Display Range:
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Last Series: 2

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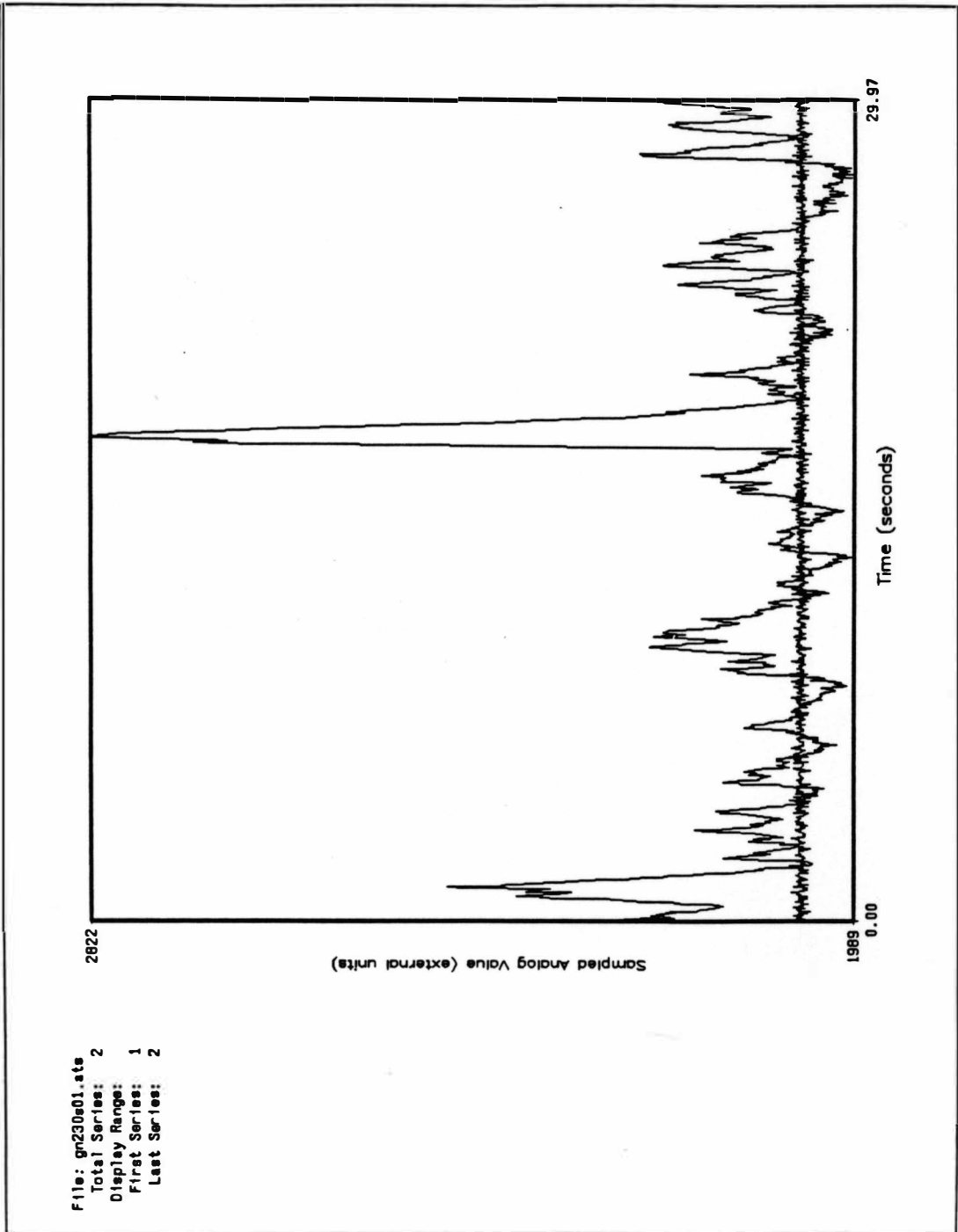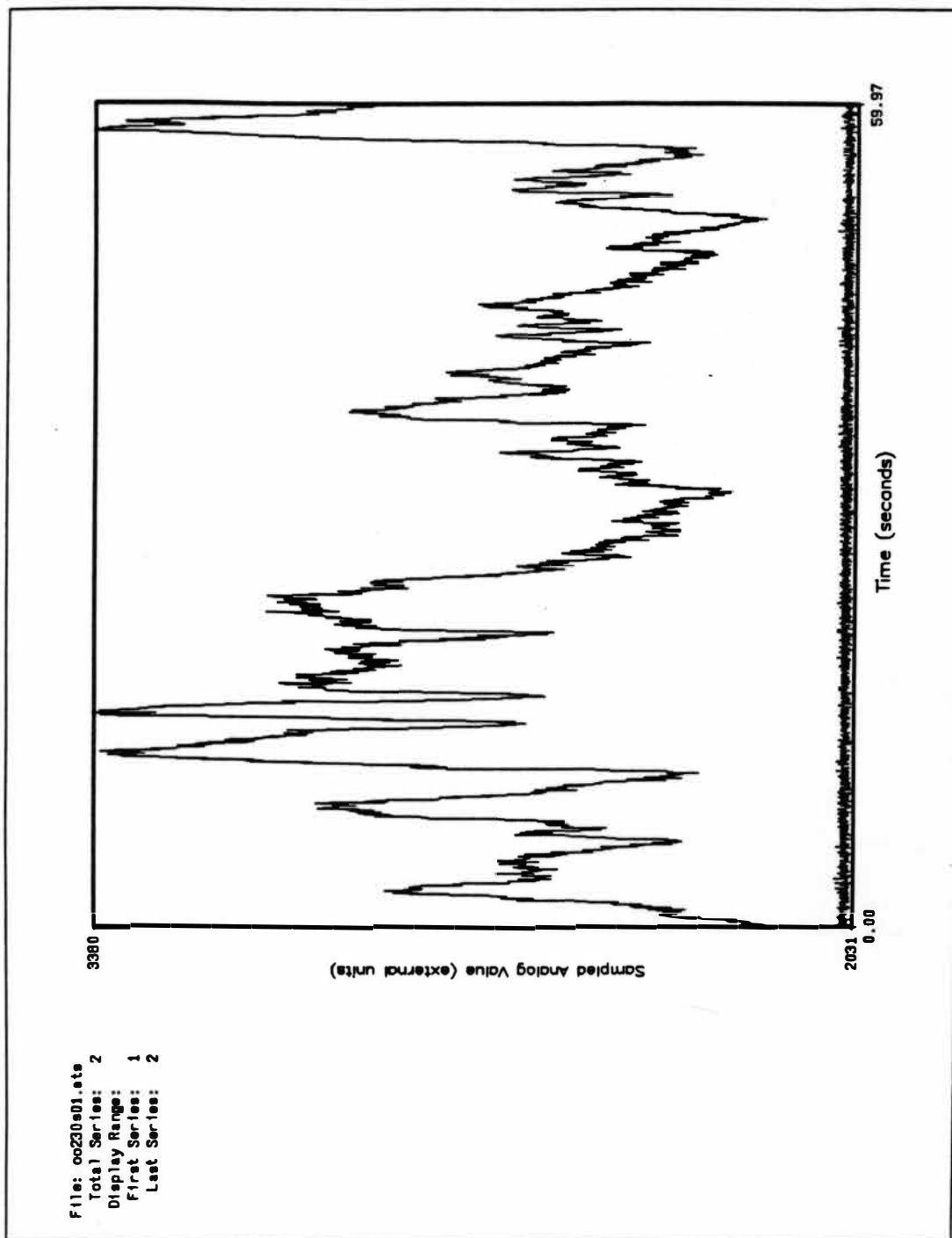Display Range:
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    Association.

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