PRESSURE DISTRIBUTION AND MYOELECTRIC ACTIVITY AS A FUNCTION OF SEATING PARAMETERS

A Thesis

Presented in Partial Fulfillment of the Requirements for the degree Master of Science School of the Ohio State University

by

Delia E. Treaster, B.A.

* * * * *

The Ohio State University

1986

Master's Examination Committee:

William S. Marras, Ph.D.
Patricia Wongsam, M.D.

Approved by

Advisor

Department of Industrial & Systems Engineering

DEDICATION

To Daniel, Allegra and Brian, always the center of my thoughts, I dedicate this effort.

ACKNOWLEDGEMENTS

I would like to thank my advisor, Dr. William S. Marras, for his continual advice, admonishments and encouragements throughout the lifespan of this project, from conception to completion. To Dr. Patricia Wongsam, Department of Physical Medicine, I wish to express my appreciation for her assistance and medical advice. To my subjects, who voluntarily submitted themselves for my experiment out of the goodness of their hearts, my heartfelt gratitude and guarantee of eternal anonymity. I would like to thank Dr. John Neuhardt and Fred Ruland for their assistance on the statistical analysis. To Shelby, Bob, Mike and Harold, the "boys in the shop", I extend my thanks for their aid and patient instructions during the design and construction of the experimental chair. For the support, encouragement, advice and friendship extended by numerous members of the ISE department, I thank you all.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

Chairs and related types of seating devices are among the most common and important fixtures found in society. They are found in virtually every work environment. These range from the strictly utilitarian flat-topped work bench to the plushly padded executive swivel chair. Astronauts, bulldozer operators, secretaries and school children all utilize chairs of some sort. Each has a different task to perform; thus each chair must be designed with that specific task in mind. For school-aged children, a properly designed chair is as integral to education as any school supply. A car seat obviously is designed with a different set of critera than an office chair.

It has been estimated that three-fourths of all work in industrial countries are considered sedentary The advantages of a seated work position over a standing one are obvious (Grandjean, 1982):

1. It takes the weight off the legs and reduces the static work performed by the leg muscles.

2. It requires less energy to maintain a sitting position.

3. It provides stability and thus allows the operator to have better control over the task being performed.

In addition to being in a seated position for most of the work day, the modern worker spends much of his/her non-working time in a seated position. Consider the typical day of a worker in a western society. He/she sits at breakfast, lunch and dinner; on the way to and from work via car, bus or train; and at home in the evening while watching television or reading. Many leisure activities are also performed while sitting: watching movies, plays, or concerts; attending sports events, etc.

Due to their ubiquity, proper chair design is essential. Poor chair design may hinder productivity; lead to discomfort and dissatisfaction; and aggravate existing medical conditions such as back pains. (Tichauer, 1978; Branton, 1969). Poorly designed seating devices promote poor sitting postures. Like many bad habits, poor sitting habits are acquired during childhood and carry over into adulthood, becoming more deeply ingrained with time (Floyd and Ward, 1976). According to McKenzie (1981), poor sitting posture is one of the three major predisposing factors in the etiology of low back pain. A poor sitting posture may be the primary cause of low back pain, or may exacerbate existing back pain.

Assessment of chair design can be performed in many ways. Shackel, Chidsey and Shipley (1976) have classified the assessment or measurement methods of seating research into four categories:

> 1. Anatomical and physiological factors--body size, shape and structure, related orthopaedic aspects and effects of prolonged pressure and other restrictions on physiological functions, all leading to comparisons and recommendations in terms of physical dimensions of the chairs.
>
> 2. Observations of body position and movement--closely related to the first area, but essentially different in that such aspects as the number, frequency and other characteristics of movements and changes of posture are the prime variables studied and often recorded, usually during "natural" and fairly lengthy sitting trials.
>
> 3. Observation of task performance--real or specially devised or controlled, work tasks are measured appropriately.
>
> 4. Subjective methods--under standardized

conditions the assessment and judgements are obtained by a controlled procedure.

None of these methods are considered superior to the others; all have their unique strengths. Therefore, the recommended approach would be to utilize a combination of assessment techniques.

This study will focus primarily on techniques from Category 1. There are a number of physiological measures which have been used in seating research. Some common ones are electromyographic recordings of the major trunk support muscles, which directly measures the physiological response of the lumbar region; and pressure measurements under the buttocks and thighs which indirectly assesses the physiological effects of various seating configurations. This study should be considered as one of the first steps in the extensive iterative process of designing, testing and evaluating chair designs.

CHAPTER 2

LITERATURE REVIEW: NORMAL SEATING

2.1 Seating Guidelines

Despite the multitude of uses for chairs, there are some common seating guidelines:

1. Avoid compression of thighs, which may restrict the blood flow to the lower extremities and pinch nerves, causing pain and numbness (Tichauer, 1978).

2. Avoid flattening the lumbar spine by providing a back rest for lumbar support.

3. Distribute weight equally on the weight bearing bony prominences in the buttocks (ischial tuberosities).

4. Allow adjustments to be made in the dimensions of the chair such as height and angle of inclination so as to accomodate different sizes of users.

Chairs should provide adequate support for the user, allow efficient performance of the desired task; permit changes in posture and be "comfortable" to the user (Andersson and Ortegren, 1974a; Branton, 1969).

Assessment of user comfort is difficult since there is no universally accepted definition of comfort (Lueder, 1983; Branton, 1976). Neither is there agreement on a reliable and precise technique of measuring chair comfort (Shackel, Chidsey and Shipley, 1976). Furthermore, comfort as is commonly considered may not be measurable (Branton, 1976); discomfort may be more readily measurable than comfort (Lueder, 1983). Subjective questionaires often require the user to evaluate chair comfort along a continuum. However, this technique presupposes that this information is relevant to specific design features and seat characteristics.

2.2 Effects of Seats on Sitting Posture

In the normal erect standing position, the vertebral column is curved when viewed in the lateral plane. The combination of curves are known as the cervical lordosis, thoracic kyphosis and lumbar lordosis. See Figure 1. Rotation of the pelvic girdle affects the shape of the lumbar spine. In order to maintain trunk balance during forward rotation of the

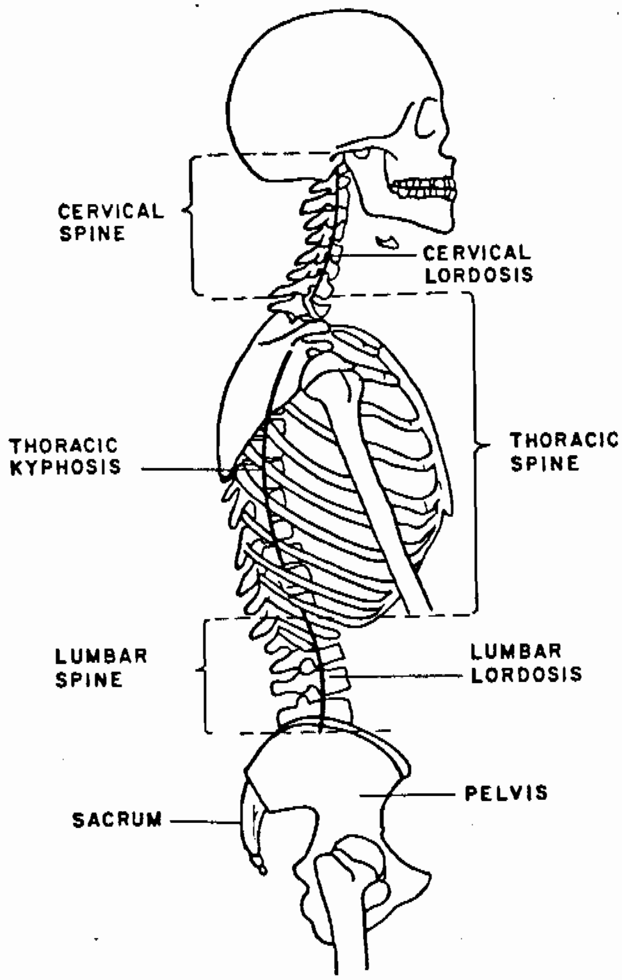


Figure 1. The Spine
(Chaffin and Anderson, 1984)

pelvis, an increase in the degree of lumbar lordosis is required. Backward rotation causes the lumbar spine to flatten and eliminates lordosis. This occurs in normal unsupported sitting, with knees and hips flexed (Chaffin and Andersson, 1984).

A good sitting posture is defined as one which preserves the spinal column in the normal curves seen in the erect standing position. This is known as the lordotic upright sitting posture. In this position, the pelvis is rotated forward, the lordotic curve of the lower lumbar spine is preserved and the center of gravity of the torso is in front of the ischial tuberosities. The posterior facets of the vertebrae are "locked" to stabilize the spinal column. See Figure 2.

A poor sitting posture is one in which the spine is fully flexed (McKenzie, 1981). This position places the posterior ligaments and other trunk support structures under the full load of the body weight. McKenzie (1981) describes the effects of a relaxed position:

> When a relaxed position is assumed for more than a few minutes, the muscular control required to hold the individual in that particular position diminishes, the body sags and the support is derived from the ligaments. Essentially, the muscles relax slowly in order to relieve themselves of the burden of opposing gravity or any other forces at work. In the fully relaxed postion, muscular activity stops and the stresses are transferred to the ligaments. The inherent elastic property of the ligaments is sufficient to support most positions with almost nil activity from the surrounding musculature. The ligaments are bearing nearly the entire load, which in the low back consists of the weight of the body above the level concerned.

The pelvis is rotated backwards, the lordotic curve of the lumbar spine is eliminated, and the center of gravity of the torso is above or behind the ischial tuberosities (Zachrow, 1984). This position is called the posterior or kyphotic sitting posture. See Figure 3.

The intervertebral discs form the articulations between the vertebrae. Each intervertebral disc consists of two parts: the semi-gelatinous nucleus pulposus in the center and the surrounding annulus fibrosus composed of concentric layers of collagen fibers. The hydrostatic properties of the disc allow it to absorb vertical shock by distributing the load

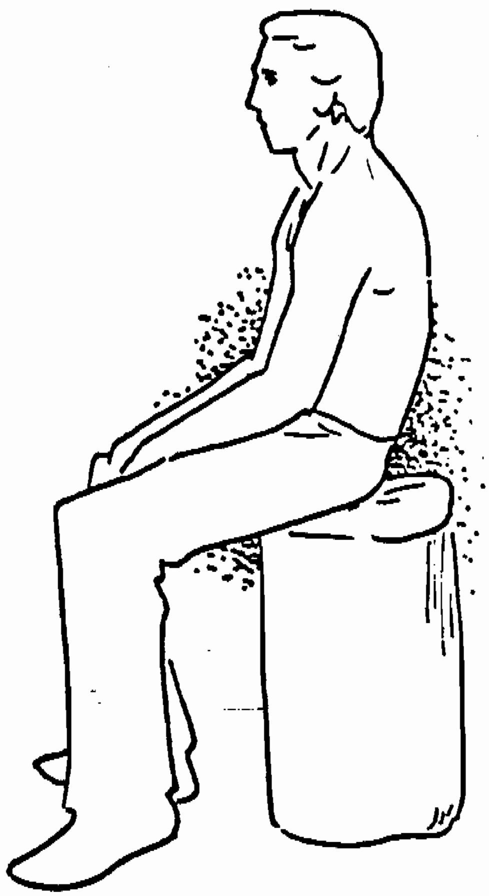


Figure 2. Kyphotic Posterior Sitting Posture (Zachrow, 1984)

Figure 3. Lordotic Posterior Sitting Posture (Zachrow, 1984)

radially in the horizontal plane to the innner annular wall. Increasing the intradiscal pressure increases the stress placed on the annulus, especially the posterior annulus. Sustained pressure may irrevocably damage the annulus as the weakened collagen and fibers begin to give way under the force of the nuclear material, to the extent that the nuclear material may be extruded from the disc. This seriously compromises the hydrostatic properties of the disc and impairs the flexibility of the spine. In the slouched or relaxed sitting position, with the spine fully flexed, the nuclei of the intervertebral discs are forced posteriorly, the intradiscal pressure increases, resulting in higher stresses on the posterior wall of the annulus.

Thus, flattening of the lumbar spine causes deformation of the lumbar discs and increases the intradiscal pressure. Andersson, et. al., (1974a,b,c,d,e,f), in a series of studies, measured the intradiscal pressure of the third lumbar disc of subjects during erect standing, and while seated in different chairs with differing backrest configurations. Disc pressure is greater when sitting than when standing, with disc pressure lowest in a recumbent position. Among unsupported sitting positions, the lowest pressure is in the erect or straight sitting position. See Figure 4.

It is unlikely that there is a single ideal posture for all people in all situations. Also, since no body posture can be maintained indefinitely, it is vital that the chair design permits changes in posture. The posture of the user can be affected by several factors--the design of the chair, individual sitting habits and the task to be performed. Chaffin and Andersson (1984) state:

> The height and inclination of the seat of the chair, combined with the position, shape and inclination of the back rest and the presence of other types of support, combine to influence the resulting posture. Obviously, it is important to provide not only a "good" chair, but a chair that is functionally adapted to the task of the occupant.

2.3 Seat Evaluation Methods

How is it possible to evaluate the "goodness" of a particular chair design? As previously stated, factors such as the user's characteristics, sitting habits,

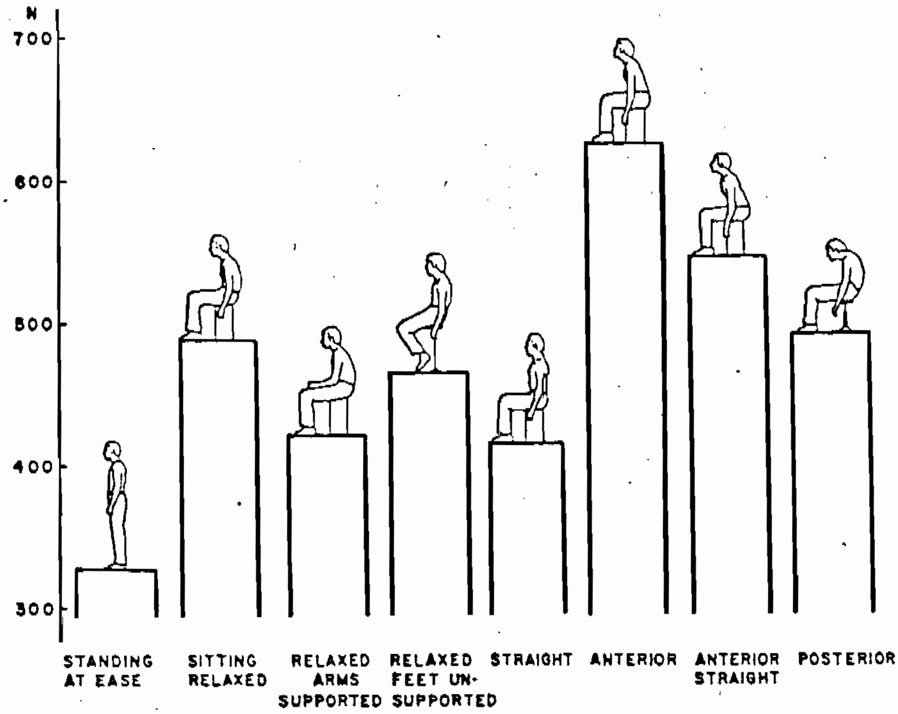


Figure 4. Disc Pressure Measurements--in standing and unsupported sitting postures. (Andersson, et al., 1974).

preferences and the task which is being performed should be given consideration in the final evaluation. These factors are difficult to analyze in a quantitative fashion.

2.3.1 Measuring Intradiscal Pressure

One factor which is easily quantified is intradiscal pressure which can be used as one indication of the goodness of a chair design. Based on the physiological evidence that increased intradiscal pressure is deleterious to the state of the disc, Andersson, et. al., (1974c,d,e,f) performed a series of experiments measuring intradiscal pressure under a variety of seating conditions. Intradiscal pressure was measured as the subjects sat in an experimental chair, office chair, wheelchair and car driver's seat. This technique of measuring disc pressure is invasive, since it requires that a needle transducer be inserted into a lumbar disc. As such, this technique may be objectionable to some subjects, and also requires the assistance of trained medical personnel. Many researchers question the validity of this measure since insertion of the needle tranducer into the disc may affect the disc pressure.

2.3.2 Measuring Myoelectric Activity

The amount of muscular effort needed to sustain a sitting posture may be another factor useful in the analysis of chair designs. This can be done by the use of electromyography techniques. Electromyography is the study of the combined electrical potentials generated when muscle fibers fire. It can be used to reveal the function or dysfunction of muscles, the recruitment pattern of motor units and the effects of fatigue, drugs, disease or neurological impairments. It is widely used by those whose work deals with muscles and movements.

Depolarization of the motor endplate causes depolarization of muscle fibers, resulting in a contraction. Carlo DeLuca states, in Basmajeno);756`, "The electromyographic signal is the electrical manifestation of the neuromuscular activation associated with contracting muscle ." The electrical activity is measured by recording electrodes, which convert ionic bioelectric current to electron current (Soderberg and Cook, 1984). As the magnitude of the depolarization wave changes, the signal picked up by the electrode likewise changes. Thus electromyography can provide unique insight into what a muscle actually does at any one moment.

Electromyographical (EMG) recordings are easily obtainable using either intramuscular electrodes or surface electrodes. Intramuscular electrodes, such as needle electrodes or fine-wire electrodes, provide an isolated pick up of an individual muscle, and are especially desireable in the study of deep muscles. However, the need to insert the electrode via a hypodermic needle may make this procedure unacceptable to many subjects. Also, the small area which is sampled may not be representative of the activity of the whole muscle group (Soderberg and Cook, 1984), thus the placement of the electrode is critical. Surface electrodes provide a non-invasive method of recording the EMG signal from superficial muscles. The pick up from these electrodes is global rather than localized, providing information about the gross activity of the underlying muscles, which is the major drawback to their use. Also, the overlying muscles present a problem in that they can interfere with the pick up of the desired muscles. Their chief advantage is their convenience; they are easily applied in a standardized manner with no discomfort to the subject; Care must be taken in the placement and orientation of the electrodes. Also the skin must be prepared so as to reduce the electrical resistance to a tolerable range.

2.3.3 Measuring Pressure Distribution

Another second factor which is easily quantified and non-invasive is the measurement of the pressure distribution under the weight-bearing areas of the body. Support for the seated individual is provided primarily in the buttocks region and thighs. The ischial tuberosities or "sitting bones" which are bony protruberances in the buttocks regions, are the major weight bearing structures. Because of this, the tissues directly overlying the ischial tuberosities are subjected to extremely high pressures. High pressure regions are associated with discomfort and pain. Ideally, areas of high pressure should be minimized, with the pressure distributed as uniformly as possible over the entire sitting region.

Rebiffe (1969) provided recommendations for the desired weight distribution of a person operating a motor vehicle. See Figure 5. Each line represents an equal pressure contour; these range from the maximum of 12.8 psi under the ischial tuberosities, to 1.4 psi at the outer extremity.

Many attempts have been made to quantify the sitting pressures. Swearingen (1962) measured sitting pressures by using absorbent paper placed ontop of inked corduroy cloth. Male subjects, wearing shorts, were seated upon the paper, creating an inked print. The density of the ink transfer was calibrated using a photometer. This procedure did not allow recording of pressures in excess of 10 psi due to the merging of the inked lines above that pressure. On the average, approximately half of the body weight was found to be concentrated on 8% of the sitting area, usually underneath or close to the tuberosities. The posture of the subjects during testing was not specified. Also, it was not specified as to how subjects were seated to prevent pressure artifacts before the final position was obtained. This method, crude as it is, presents one of the first attempts to measure the distribution of pressures under the thighs and buttocks

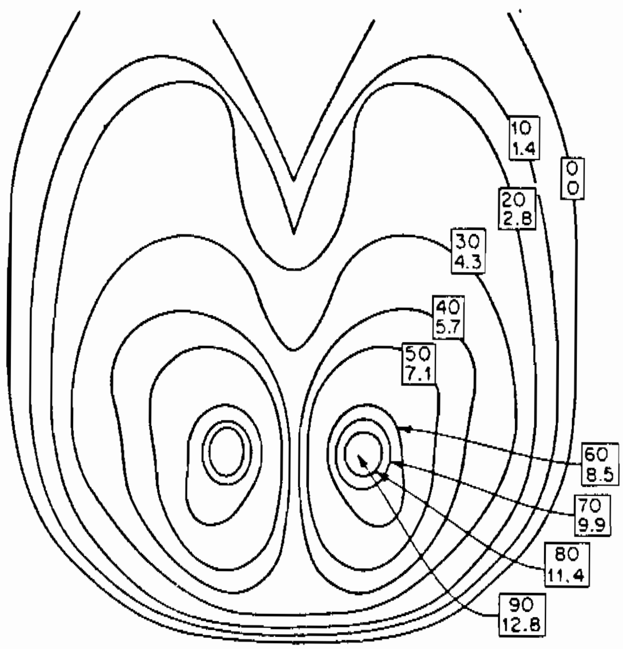


Figure 5. Recommended Seating Pressure Distribution. The upper value for each equal-pressure contour is g/cm^2 and the lower value is lb/in^2. (Rebiffe, 1969).

during sitting.

Other attempts to measure sitting pressures utilized pressure measuring devices placed under the ischial tuberosities. Bush (1969) used a single pressure transducer taped over the ischii and also under the thighs, just behind the seat edge. The accuracy of the complete system was estimated at +/- 10 psi. In this way, he was able to record the pressure with varying degrees of support for the feet and lower legs. His findings indicated that the highest ischial pressures occurred with feet supported, with pressures ranging up to 30 psi. His recommendation was to avoid feet support; however, the sitting position, specifically the degree of lumbar lordosis was not fully described. This, in combination with the test conditions, would seriously affect the data, and hence, interpretation of the results Zachrow (1984).

Holley, et. al., (1979) employed a small matrix of 10 pressure transducer cells taped over the ischial area. The error of the system was estimated at +/- 3 mm Hg. The subject was seated in the chair and a pressure reading taken. This experiment was used to assess the interface pressure for 6 different cushions commonly used for pressure relief for wheelchair users. Peterson and Adkins (1982) have reported the use of ischial pressures to "customize" wheelchair seat cushions. Fisher and Patterson (1983) also used transducers place beneath the ischial tuberosities for long term pressure recordings in spinal cord injured patients.

The sources of error associated with the use of pressure transducers are many-fold. The process of attaching the transducer to the sitting region is a potential source of error. If the transducer is affixed by adhesive tape, a pressure artifact may be created from the tension of the tape across the transducer. Placement of the transducer over the ischii is usually determined by palpatation of the skin while the subject is in a side-lying position; the subject is then moved to an upright sitting position. This shift may result in the transducer shifting offside of the ischii. Transducer thickness is another factor which was not addressed by any of the researchers, and the possibility of a pressure artifact due to the thickness of the transducer needs to be accounted for.

Patterson and Fisher (1979) investigated the accuracy of electrical transducers under various conditions. Their results showed that fairly accurate measurements are obtained using a rubber surface for loading, but when cloth was interposed between the rubber and transducer surfaces, large errors were seen. This indicates that clothing may interfere with pressure measurements. In addition, Patterson and Fisher found that an increase in variability occurred as the transducers were placed over firmer under-surfaces. The researchers cautioned that great care must be taken with positioning these transducers to avoid uneven loading.

An important factor in the use of transducers for measuring pressure on the sitting region is the correlation of the measured pressures with the actual pressures. Reddy, Palmieri and Cochran (1984) tested two types of transducers which are often used for clincial measurements of pressure; semiconductor transducers and pneumatic transducers. It was found that the pressure recorded by all the transducers was considerably higher than the applied pressure when tested on different surface types (gel-gel, gel-foam, gel-hard surface). The accuracy of the transducers seemed to be dependent on the type of interfacing material. One important factor affecting transducer performance was the enveloping property of the interfacing material (i.e. its "wrap-around" ability). The researchers also evaluated the accuracy of a pneumatic transducer placed beneath the thighs of human subjects as they were seated on cushions of varying thicknesses. The results indicated that pressure measurements via pneumatic or semiconductor transducers may be erroneous due to structural incompatibility between the interfacing materials; the load may be unbalanced, creating localized areas of high pressure. However, pressure measurements from patients seated on cushions was fairly accurate, since human flesh distributed the load evenly over the transducers.

Instead of measuring ischial pressures alone, some researchers have utilized a matrix of pressure sensitive devices under the entire sitting region. Drummond et. al., (1982) developed a micro-computer based pressure scanner, composed of 64 strain-gauge resistive transducers imbedded in an alumimum sheet to create a contour map of the seated pressure distributions. The transducers, arranged in an 8 x 8 matrix, were separated from each other by 3.8 cm. Due to the discrete nature of the data derived from the transducers, and the distance separating the transducers, the raw data obtained from the scanner was interpolated for 3 intermediate pressures between each transducer. This interpolation smoothed out the data and allowed contour plots to be constructed. The results for normal subjects showed the breakdown of pressure distributions as follows:

18% per ischial tuberosity

21% over each thigh

5% over the sacrum

remaining body weight was distributed evenly throughout the sitting region.

Garber, Krouskop and Carter (1978) devised a pressure evaluation pad (PEP) for monitoring and quantifying the pressure distribution of an individual seated on a cushion in a wheelchair. The sensing pad consisted of a 12 x 12 matrix of pneumatically controlled contact switches, each wired to a light on a readout display. Each of the 144 lights on the readout display represented a localized point of tissue pressure loading. The pad was used for comparison of the relative efficacy of various wheelchair pressure-relieving cushions. The pressure evaluation pad was placed between the subject and the cushion being evaluated. Air was pumped into the pad until all lights on the display were extinguished. The air was then slowly released until the first lights were turned on, at which point a pressure reading was taken. These initial lighted areas represented the maximum pressure. The remaining air was released in 20 mm Hg decrements, with pressure readings taken at each level. The accuracy of the pad for clinical use was estimated at 95%. The PEP has also been used to evaluated the effect of wheelchair cushions (Seymour and Lacefield, 1985); the effect of wheelchair cushion modification on pressure (Garber and Krouskop, 1984) and the relationship between body build and pressure distribution in wheelchair patients (Garber and Krouskop, 1982).

The methods which utilize matrices of pressure transducers provide discrete information of the pressure distributions. A single value is obtained from each transducer which is the average pressure over the surface of the transducer. Furthermore, interpolation is necessary to estimate pressure intensities between transducers. As mentioned earlier, transducer thickness is a factor which should be considered in evaluating the accuracy of the pressure measuring system. The thickness of the transducer may create artificially high pressure loading on the tissue or interfere with accurate measurements in other ways. Previously cited research by Patterson and Fisher (1979) and Reddy, Palmieri and Cochran (1984) indicate other problems associated with the use of pressure transducers for measuring the loading on human flesh.

A "wheelchair barograph" used by Mayo-Smith and Cochran (1981) provided a portable, adjustable device to identify high pressure regions clinically by means of light patterns and permitted continuous measurement of pressure. This barograph was installed in a wheelchair. The modified wheelchair utilized the optical principle of total internal reflection. High pressure regions appeared light and low pressure regions dark, with a gradient between the two. The high pressure regions were qualitatively identified with a wax pencil on the plexiglass grid beneath the seat, but the light intensities were not calibrated to standard units of pressure. The wheelchair barograph did not provide quantitative data on interface pressures; light intensities were not calibrated to known pressures. It had limited clinical application, only providing information regarding the distances between the ischial tuberosities, which allowed for rapid, accurate location of potential trouble spots on the seating surface.

A similar device, called a "pedobarograph" was developed by Minns and Sutton (1982) which utilized the same optical principles as the barograph by Mayo-Smith and Cochran described above. A videocamera recorded the pattern of light intensities, and by means of a gray scale to color converter, the researchers were able to quantify the light intensities to known pressure levels. The pattern of pressure distributions was not stored in a format which could be analyzed statistically. A Polaroid camera was used to make permanent copies of the pressure distribution displayed on the color monitor. This device was used to investigate the maximum pressures and pressure contours for both normal and paraplegic patients with pressure sores. The results showed maximal ischial pressures of 120 mm Hg for normal subjects, and up to 300 mm Hg near the pressure sores for paraplegics. Asymmetry of pressure distribution in some paraplegics was clearly seen using this device.

Most chairs and seating devices provide a backrest (those without backrests are known as stools and benches). The majority of the researchers cited above did not include the effects of a backrest on the pressure distribution. However, Zachrow (1984) recommended backrest inclinations of 15 degrees "to reduce lumbar disc pressure, to decrease myoelectric activity in the middle and lower back and help stabilize the trunk." Swearingen (1962) indicated that backrests function for stabilization rather than for weight bearing. He found that a 15 degree backrest inclination provided support for only 4% of the body weight. Significant increases in weight bearing of the back-rest did not occur until an inclination of 30 degrees had been reached. Andersson, et. al., (1974a) found that increasing the backrest inclination from 90 to 120 degrees decreased the myoelectric activity in the back muscles. Since backrests are important for comfort and are normally found with most chairs, it is important to consider the backrest inclination in the study of the pressure distribution.

The above literature presents various methods for measuring the pressure distribution under the weight bearing regions of the body; all of these methods had serious limitations. They did not provide continuous measurements of pressure; were not calibrated in terms of pounds per square inch or millimeters of mercury ; or the results were could not be statistically analysis. This research presents a technique for measuring pressure which is quantifiable and lends itself to statistical analysis. The custom-built experimental chair is based on the same optical principles of total internal reflection as the barograph by Mayo-Smith and Cochran (1981) and the pedobarograph by Minns and Sutton (1982). It is coupled with a computer system which allows the data to be permanently stored and analyzed. The experimental objective was to research the effect of seat pan and backrest inclinations on the distribution of pressure and myoelectric activity of the trunk support muscles.

CHAPTER 3

LITERATURE REVIEW: HANDICAPPED SEATING

The issue of pressure distributions in the sitting region is of particular concern to chronic wheelchair users. These individuals, due to the nature of their disability, remain in static seating postures for long periods of time. As such, they are at risk for the formation of decubitus ulcers or pressure sores. Pressure sores are characterized by an open wound with tissue necrosis or gangrene developing as a result of ischemia. These usually occur over weight bearing bony prominences with low soft tissue coverage. In the bed-lying patient, it is the tissue overlying the scapula, spinous processes, trochanters, sacrum, knees and heels which are at risk; in the seated patient, it is the areas over the ischial tuberosities and sacrum that pressure sores are most likely to develop (Houle, 1969; Peterson, 1976).

3.1 Costs of Pressure Sores

Houle (1969) reports that decubitus ulcers are a major problem for paraplegic patients, and if not cured may lead to sepsis, osteomyelitis, mutilating amputations and even death. He speculates that the cost of each ischemic ulcer is approximately $5,000; insurance companies estimate that one-fourth of the total medical expenses for spinal cord injured patients will be allocated for treatment of ischemic ulcers. It has been calculated that as much as one-third of a nurse's time may be spent treating pressure sores (McDougall, 1976). Krouskop (1983), stating that pressure sores are "one of the foremost obstacles in rehabilitation", estimated the cost per decubitus ulcers to be $5,000-$20,000. He reports statistics from the Veterans Administration: 50% of all quadriplegics and 30% of paraplegics will require hospitalization sometime during their lifetime for pressure related problems. Approximately one-fourth of these will die as a direct consequence of pressure sores. Krouskop cites research which estimates the total medical costs associated with curing pressure sores and the loss of patient productivity due to pressure sores to be greater than 2 billion dollars per year in the United States. Furthermore, the patients may experience increased deterioration in his/her overall state of health due to the imposed inactivity during the healing process. Pressure sores may persist for years if not treated properly (Isherwood, 1976).

3.2 Etiology of Pressure Sores

An unobstructed blood supply is necessary for healthy celluar metabolism. The blood supplies trophic substances and eliminates metabolic byproducts. Application of external pressure occludes the capillary blood flow, resulting in tissue anoxia. Lack of oxygen is one factor that ultimately lead to ulceration. (Reddy, Cochran and Krouskop, 1981). In addition, external pressure impairs the lymphatic system, leading to an accumulation of anaerobic waste products which exacerbate the effects of tissue damage due to anoxia. (Krouskop, 1983).

Analysis of the forces involved in the recumbent or seated person reveal two types of forces which can lead to pressure sore formation: compressive and shear forces. Compressive forces are perpendicular to the skin, and compress the tissues between the supporting surface and the bony prominence. Shear forces act parallel to the skin and by twisting or stretching the blood vessels, they occlude the supply of nutrients to the underlying tissues, causing necrosis (Holley, et. al., 1979). Patients sitting in a slumped position in wheelchairs experience shear forces at the sacrum as the body weight slides the sacrum and related muscles over the skin, which is held in place by frictional forces of the cushion covering.

Brand (1976) lists three etiological factors involved in pressure sores: 1) pressure ischemia--"low pressure sustained continuously for several hours" which obstructs the blood supply, causing local anemia; 2) mechanical stress--"direct mechanical disruption of tissues from a single exposure to a high level of pressure or shear"; 3) "tissue necrosis from repetitive moderate mechanical stress."

Daniel, et. al., (1981) investigated these primary etiological factors and concluded that the primary factor in the production of pressure sores is "pressure-induced ischemia". The researchers utilized the pig as the experimental animal, which is a fixed-skin animal (as opposed to loose- skin animals such as rabbits and dogs utilized by other researchers), and whose soft-tissue coverage is similar to man. Various levels of pressure were applied to the greater femoral trochanter, from 30-100 mm Hg, for time periods from 2-18 hours. Muscle damage was found to occur with high pressure, low duration; and low pressure, medium duration. Muscle and deep dermis damage occured with medium duration or low pressure, long duration. Muscle and full-thickness damage occured with long duration . The researchers concluded that muscle is extremely sensitive to ischemia, but skin is resistant to ischemia.

The interaction of time and pressure was initially investigated by Kosiak in a landmard study in 1959. He reported that pressure applied at 70 mm Hg for 2 hours produced pathological changes in rats; pressure at 60 mm Hg for 1 hour produced microscopic pathological changes in dogs. He concluded that ischemic ulcers occur at areas where external pressure exceeds capillary pressure and is maintained continuously for more than 60 minutes. The critical time may be less than 60 minutes if the area is exposed to prolonged repeated ischemia (Houle, 1969). He states that "ischemia caused by pressure greater than capillary pressure is the primary factor in the production of these ulcers." Various values of intracapillary blood pressure have been cited by researchers: 12-32 mm Hg (Landis, reported in Houle, 1969); 16-33 mm Hg (McLennan, reported in Houle, 1969); and 10-30 mm Hg (Krouskop, 1983). The value of 32 mm Hg is commonly used as the optimum value for pressure evaluation purposes (Scales, 1976; Holley, et. al., 1979; Fisher and Patterson, X872<.

Secondary factors which are often overlooked, contribute in varying degrees to the etiology of pressure sores. Krouskop hypothesizes that collage metabolism may be a critical factor in the formation of pressure sores. This may explain how factors such as increasing age and emotional stress which affect collagen synthesis play a role in pressure sore formation. Krouskop (1983) states:

> When the person is under emotional stress, the adrenal glands increase the production of glucocorticoids and it has been demonstrated that the formation of a stable collagen trihelix is inhibited under such conditions and again an unstable state can be created which makes the tissue more susceptible to pressure formation.

Increasing age also change collagen synthesis. Another factor is the lack of sensation: due to the lack of a feeling of pain, the patient is unaware of the pressure and the need to shift his/her weight. Likewise, the use of sedative drugs or a comatose condition of the patient, and the subsequent lack of movement which would otherwise redistribute pressure and alleviate areas of localized pressure. Moisture from incontingency may macerate the skin, causing it to be more susceptible to breakdown. Malnutrition and/or a low percentage of body fat are conditions in which the bones are more prominent.

3.3 Prevention of Pressure Sores

In normal healthy persons with full sensation, the pain and discomfort of being in one position too long will cause shifts in posture which alleviate pressure and effectively redistribute the pressure over the buttock region. Patients with spinal cord injuries, such as paraplegics and quadriplegics often lack sensation and thus are deprived of this built-in warning system. During their rehabilitation, they are taught to do push-offs in their wheelchairs periodically to relieve pressure. The usual time scale is one push-off lasting at least five seconds every ten to 15 minutes of sitting time (Malamet, Dunn and Davis, 1975). However, training does not ensure compliance and many wheelchair patients do not follow this regime. Various types of cushions have been developed in order to circumvent this problem. A cut-out cushion, designed by Key, Manley and Wakefield (1977, 1978-79) seems to be successful in treating these sores. A cut-out is made under the ischii so that most of the body weight is supported by the trochanter shelf and the thighs, which can withstand greater pressure due to their large surface areas (Pressure is inversely related to the total surface are in contact with the supporting surface; i.e. the greater the total surface area, the lower the pressure per given area.) The cut-out of the cushion is custom fitted to the individual by measuring the bi-ischial distance. The researchers reported an 89% success rate using this modification.

However, research by Houle (1969) provides evidence that cut-outs may not reduce ischial pressures below that critical level. Using hand molded rubber butterfly valves, he measured pressure under the ischii and 10 other positions of the buttocks region. The subjects were measured while seated on various types of wheelchair seats: plywood board; standard wheelchair sling seat; cutout 3" plastic foam; inflatable rubber contour pad; synthetic visco-elastic pad on wheelchair sling seat with plywood board and foam pad; mechanical drop seat; and alternating pressure pad. The highest average ischial pressure for the above conditions ranged from 77 mm to 135 mm Hg. It can be seen that the lowest pressure is more than double the recommended 32 mm Hg. None of these attempts at wheelchair modification were successful in reducing the ischial pressure to subcritical levels; thus the researchers concluded that wheelchair modifications alone are not a sufficient preventive measure.

It should be mentioned that there is no way to calculate the local stresses from overall tissue loads. Tissue is nonhomogenous--composed of layers of fat, fascia, muscle and bone. Stresses are distributed unevenly at these interfaces. Thus the measure pressure over a particular region does not mean that all of the tissue directly overlying the region experience that measured pressure (Brand, 1976).

Despite these attempts to evaluate seating devices, there is no way to accurately measure the applicability of the seating system for the patient a priori, that is, prior to seating the patient. The present method of seating wheelchair patients is largely by trial and error; a poor fit is diagnosed after the development of pressure sores (Wongsam, 1984). The problem of proper seating is compounded when the patient exhibits skeletal deformities such as scoliosis, hip dislocation and joint contractures, or abormal reflex patterns which promote deformities. Other patients have diminished physical and/or mental capabilities which interfere with their ability to perform prophylactic activities such as lift-offs or weight shifts at regular intervals which provide momentary relief or redistribution of sitting pressures. Naturally, most spinal cord injured patients would likewise be unable to perform such movements.

3.4 New Approaches and Attitudes

There has been a growing awareness of the needs of the handicapped population in this country in recent years. Legislation at both the state and federal level have been enacted which protect the rights of the handicapped, encompassing education and training, employment, health, welfare and other social services (Nickerson, 1978). New facilities are constructed, and existing ones modified, to provide greater accessibility to the handicapped. The intent of these efforts is to integrate, as much as possible, the handicapped individual as a functional member of society, and where feasible, promote independent living.

Partially as a result of these societal changes, and partly due to advanced technology, the chronic wheelchair users such as patients with spinal cord injuries, cerebral palsy and other forms of motor impairment, are spending more hours in the wheelchair to participate in daily activities (Krouskop, 1983). Hence it becomes increasingly urgent to find a solution to the management of pressure sores, a problem which has existed for hundreds of years.

Special seating clinics have been developed in rehabilitation facilities in order to provide individualized seating prescriptions. But there still is a need for an accurate way of evaluating or measuring the applicability of seating systems for the patient. This study examines one method of measuring pressure and it is hoped that the results may be applied towards seating concerns of the handicapped as well as the non-handicapped population.

CHAPTER 4

METHODS

4.1 Subjects

Eight nonhandicapped and one handicapped males participated as subjects in this experiment. The nonhandicapped subjects ranged in age from 22-29 years, with a mean of 27 years, and were in good physical condition. Their relevant anthropometric data are shown in Table 1. It should be noted that half of the eight subjects were at or above the 95% percentile in standing height (Chaffin and Andersson, 1984). Thus the sample size is not representative of the general population, since it consists only of males, and has a disproportionate percentage of tall subjects. This may limit the application of the results.

The handicapped subject, a male aged 30, had cerebral palsy with a high degree of scoliosis and pelvic obliquity. He had a recurring problem with a pressure sore forming under the right ischial

TABLE 1. Anthropometric Data

Subject	Age	Weight (lb)	Height (cm)	Skinfold Measurements Arm	Chest	Abdomen
1	26	176	187.8	10.0	5.5	7.5
2	24	158	173.3	9.3	4.7	16.2
3	29	204	175.0	17.6	20.0	47.0
4	23	200	197.9	21.0	22.0	30.0
5	29	135	172 9	9.0	10.0	22.0
6	29	205	191.1	21.0	5.0	27.0
7	29	160	178.7	17.0	28.0	20.0
8	22	235	194.5	21.0	5.0	24.0

tuberosity, although there was no sore present at the time of testing.

4.2 Experimental Design

The experiment utilized two seat angle conditions: 0 degrees (horizontal) and 10 degrees (inclined posteriorly), and 4 backrest angle conditions: 90 (vertical), 100, 110, and 120 degrees for a total of 8 test conditions. The backrest conditions were randomized within the seat conditions. The order of testing was randomly determined for the seat condition first, then the backrest condition. The order of testing for the backrest condition was the same within each seat condition. Each subject was tested once in each test condition. Dependent variables were the EMG signal of the latissimus dorsus and erector spinus muscles, recorded bilaterally, and the pressure distribution on the weight-bearing regions of the body (thighs and buttocks region and back region).

4.3 Equipment

Prior to the onset of testing, each subject was measured for relevant anthropometric data using Lange skinfold calipers from Cambridge Scientific Industries, and an anthropometer. Nine miniature Beckman silver-silver chloride surface electrodes were used for the EMG data. The recessed cup was filled with electrode gel to improve the electrical contact with the skin surface. The electrodes were attached with double faced collars. Preampliers increased the signal/noise ratio, then the signal was passed through shielded cables to the high pass (80 Hz) and low pass (1000 Hz) filters, and integrated over a 500 msec interval. Each data channel was sampled at 50 Hz for 3 seconds. The TZY signal was visually displayed on an oscilloscope to allow verification of the signal and allow detection of artifacts such as poor electrode contact or incorrect instrument settings. The data was converted from an analog signal to a digital one using an Issac 2000 Cyborg data acquisition system. It was plotted on a graphics terminal to permit visual validation, then stored for future processing. See

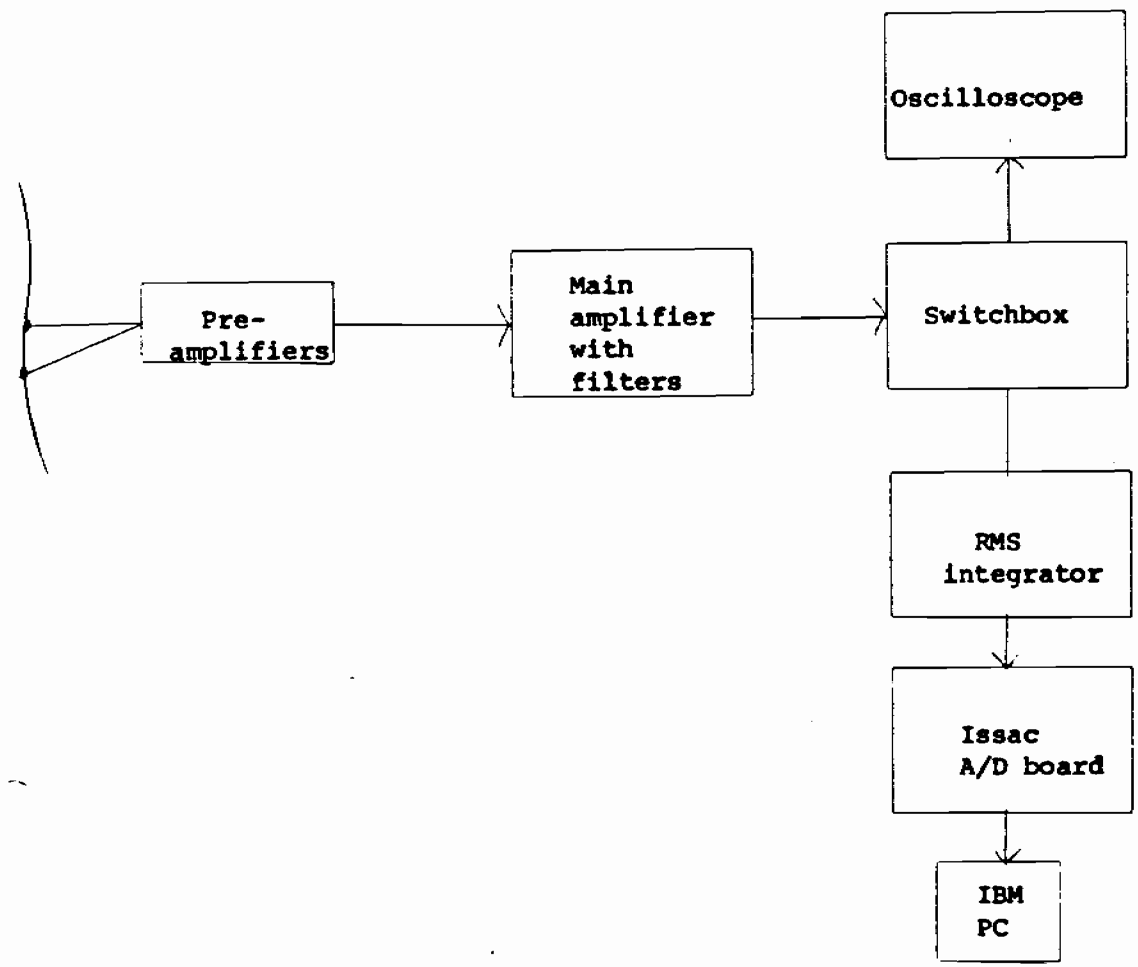


Figure 6. Schematic diagram of EMG signal processing

The pressure distribution of the buttocks and back areas were recorded on an experimental chair which is composed of a seat unit and a backrest unit linked together within a frame. See Figure 7. The seat unit was designed to allow anterior or posterior inclinations up to 30 degrees, and could be adjusted to accomodate various sizes of subjects. The seat unit also had adjustable footrests to provide support for the feet. The backrest unit likewise could assume a range of inclinations, from a vertically upright position at 90 degrees to a fully reclined position at 180 degrees. Both the seat unit and backrest unit could move independently of each other. See Figures 8 and 9.

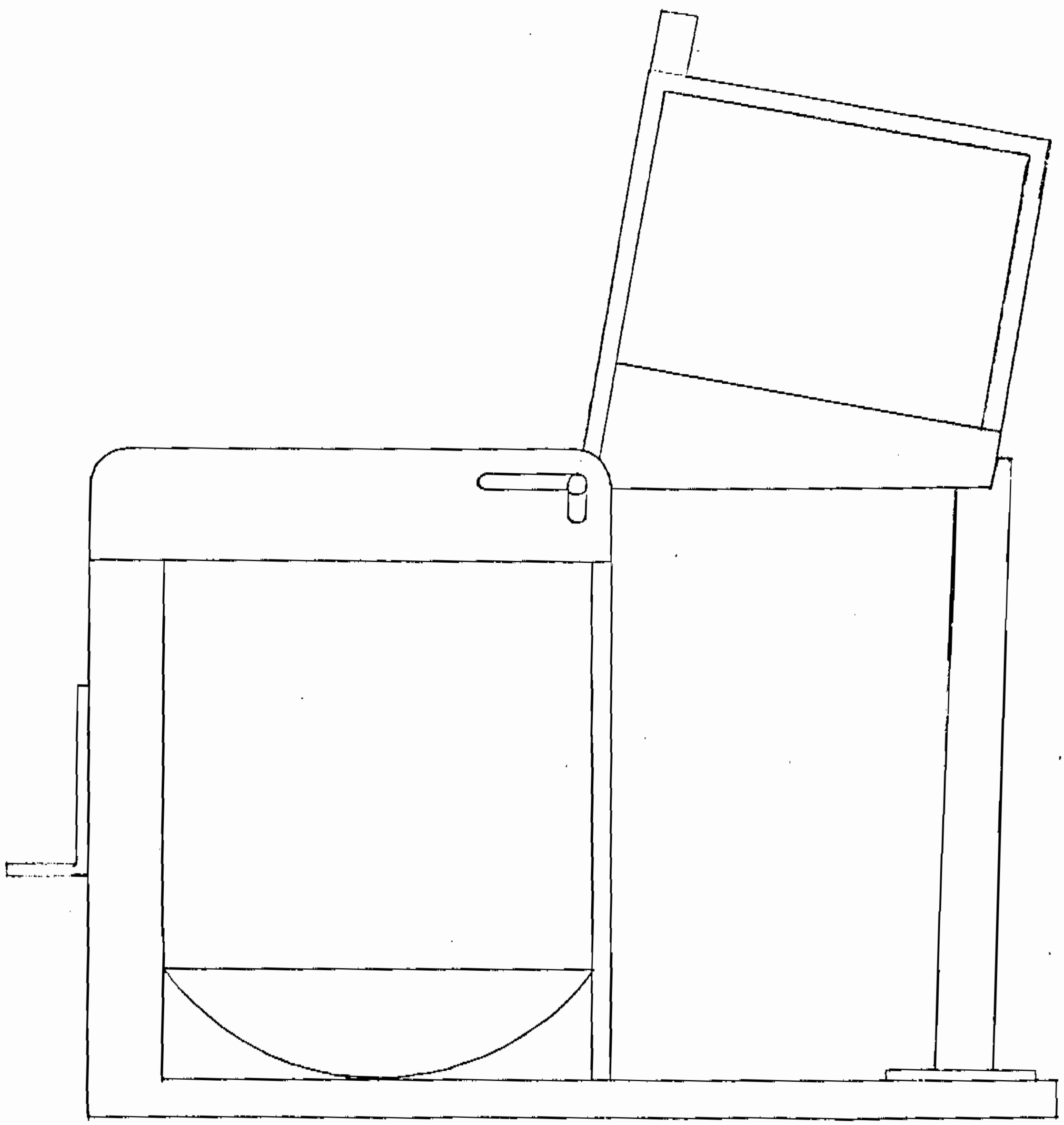


Figure 7. Experimental Chair

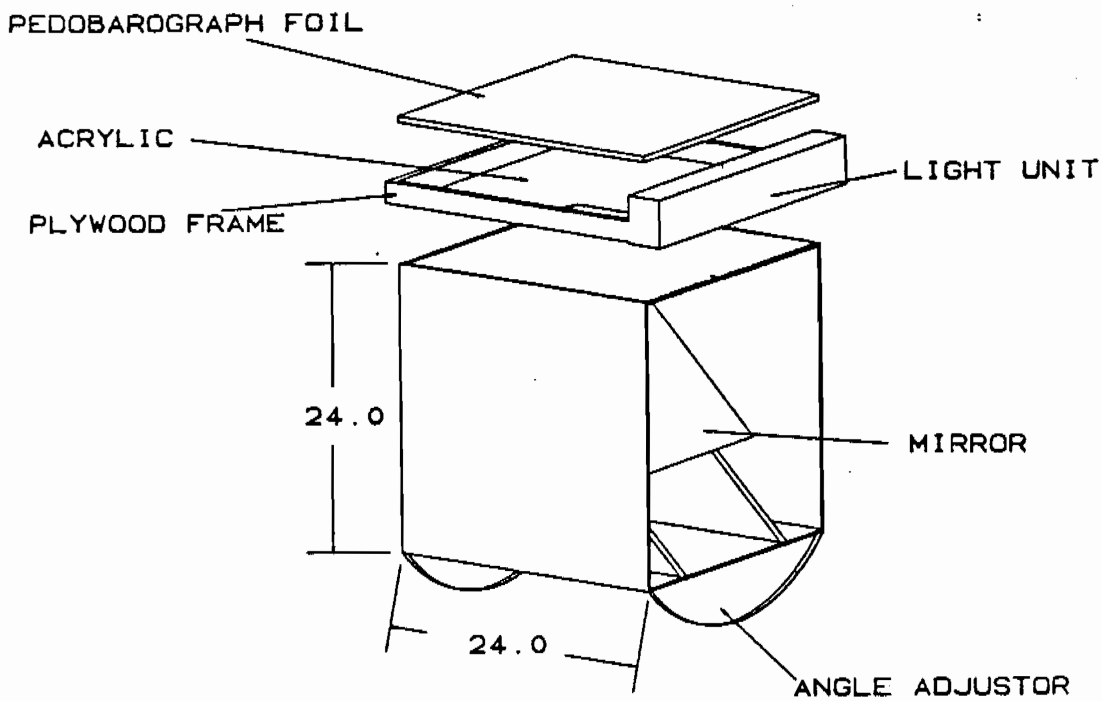


Figure 8. Seat Unit. (Courtesy of Ralph Greco)

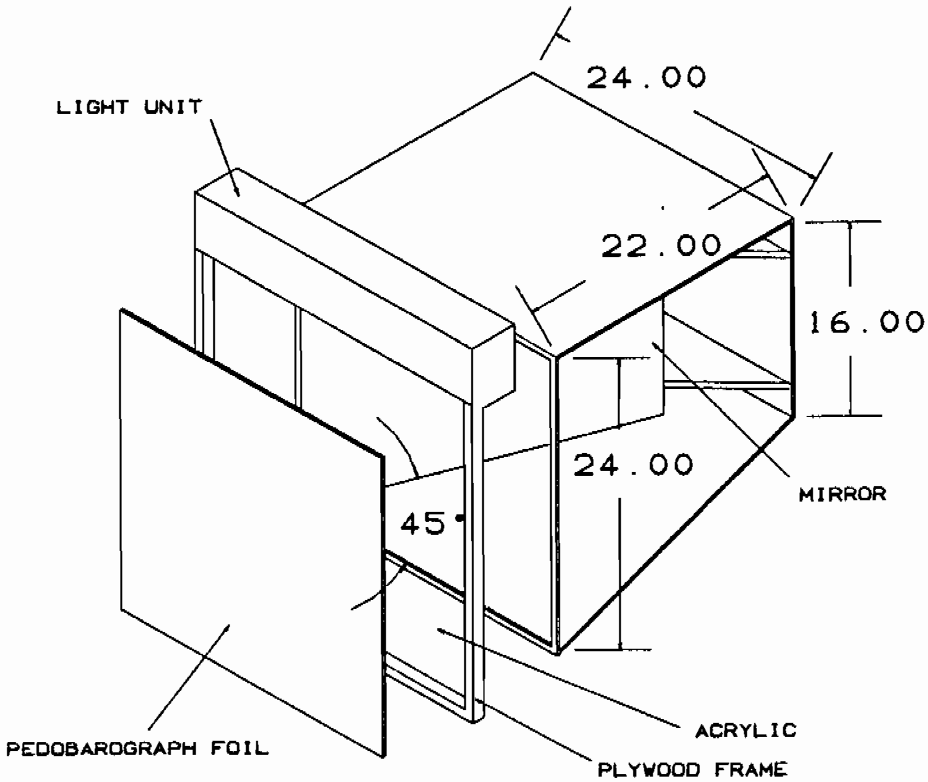


Figure 9. Backrest Unit. (Courtesy of Ralph Greco)

4.3.1 Total Internal Reflection

In Figure 10 a light beam is shown falling on the water surface-- the light beam is both reflected from the surface and refracted (bent) as it enter the water. The angles of incidence (0_1), of reflection ($0_1'$) and of refraction (0_2) are measured between the normal to the surface and the appropriate ray. As the angle of incidence is increased, the angle of reflection also increases, and the refracted ray moves closer to the surface until it lies along the surface. See Figure 11. For angles of incidence large than the critical angle 0_c, there is no refracted ray, and total internal reflrectin occurs. Total internal reflection only occurs when the light passes from a medium of higher refracter index to one of lower refractive index (Halliday and Resnick, 1970).

The pressure measuring apparatus utilized this principle of total internal reflection. The interface pressure distributions were measured from the seat and backrest surfaces, which were composed of 3/4" acrylic plastic sheets with one edge optically polished. A 24 inch, 15 watt fluorescent light was attached along that edge. The light which entered the acrylic sheet from the lighted edge was totally reflected internally between the top and bottom surfaces of the acrylic since acrylic is more optically dense (i.e. has a higher index of refraction) than air. Because none of the light was refracted out of the acrylic, it appears dark when viewed from the underside.

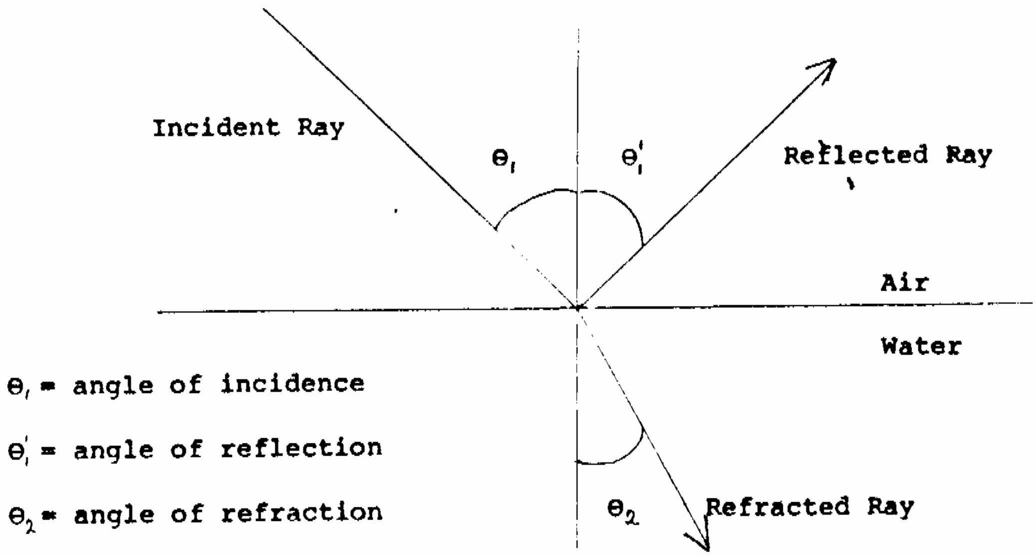


Figure 10. Reflection and Refraction of a Light Ray

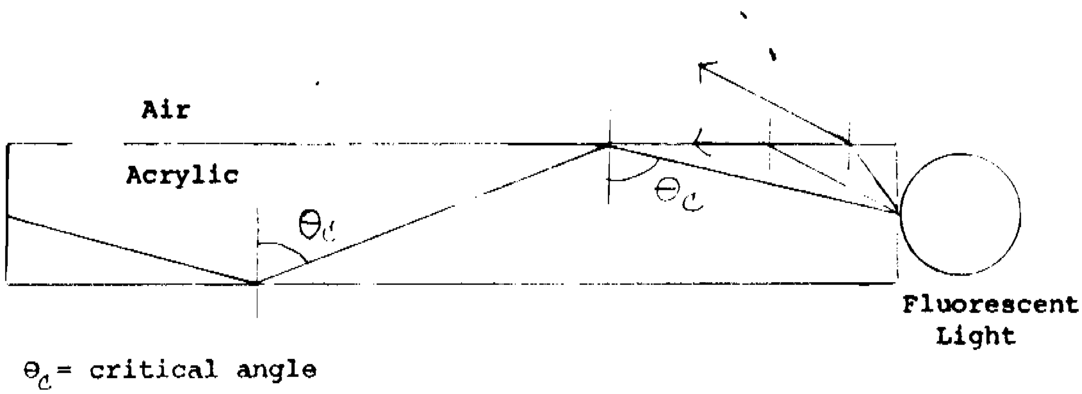


Figure 11. Total Internal Reflection

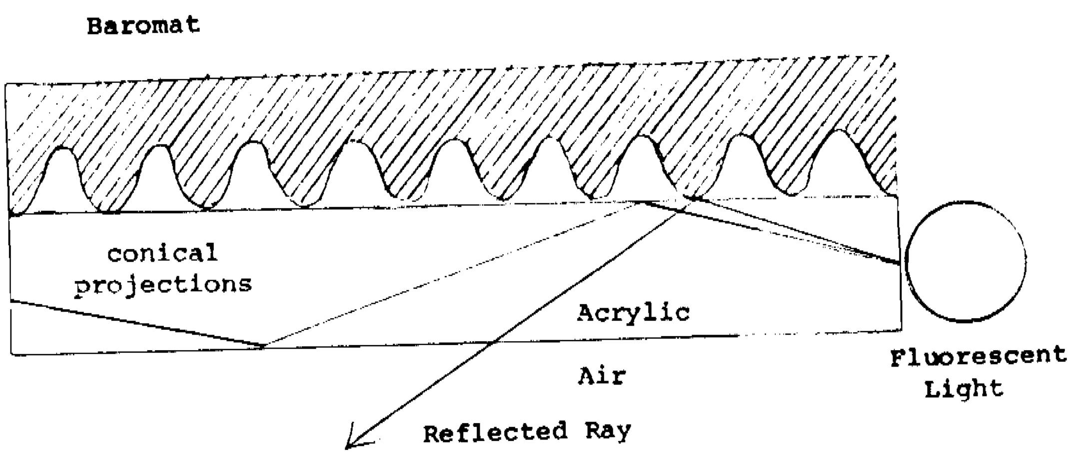
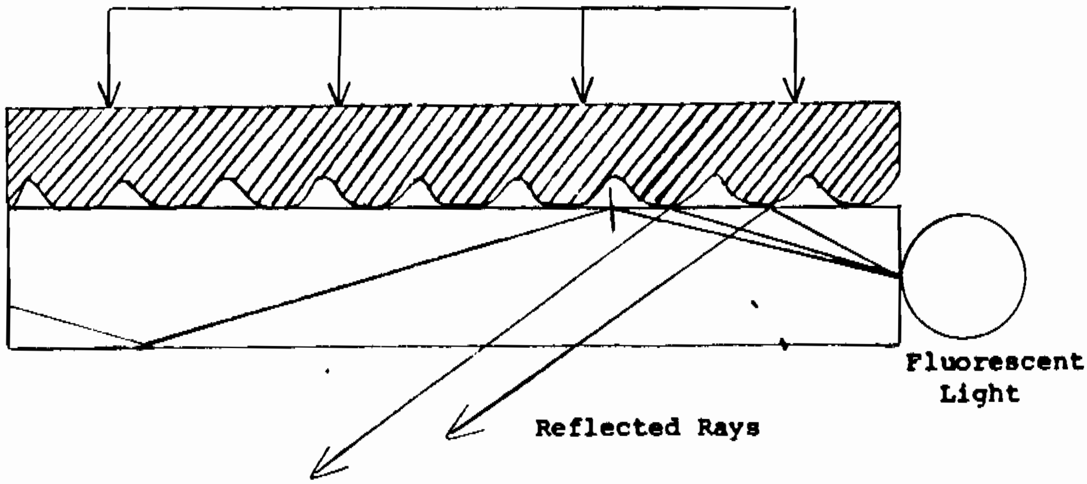
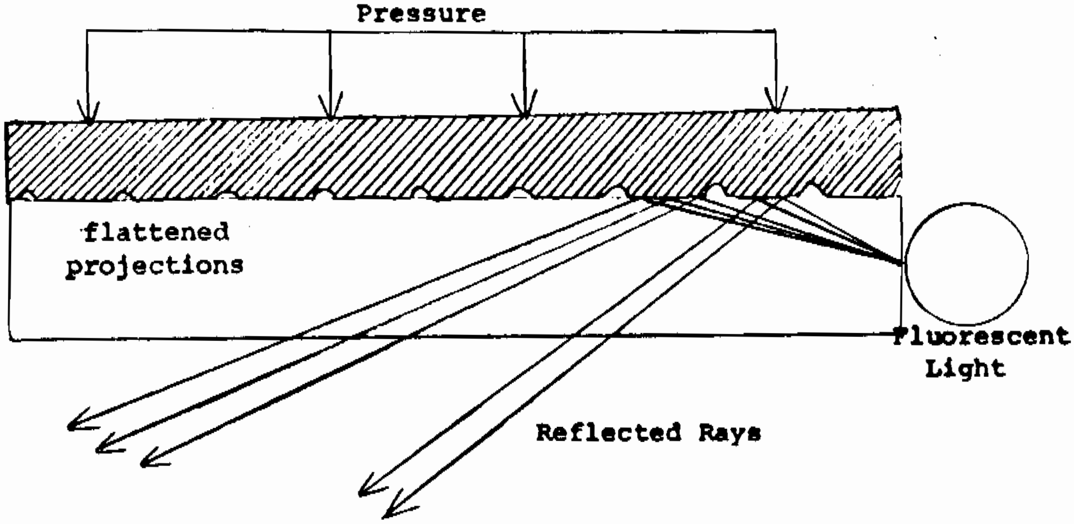


Figure 12. Effect of No Pressure

The acrylic was overlaid with a pedobarograph foil. The major requirement of a pedobarograph foil is that it has projections which can be deformed with pressure and increase the areas in intimate contact with the glass, resulting in an increase in the amount of light scattered. These projections may be either microscopic, as with untextured polyvinyl chloride (PVC) sheets, or macroscopic as with foam sheets. The deformation of the projections under pressure should be elastic, and should show little or no hysteresis (Smith, 1983). The pedobarograph foil used in this experiment was the Baromat (purchased from Biomechanics, La Mesa, Calif.) The Baromat is molded in 24 inch square sheets, using Dow Corning resin DC3110 room temperature vulcanizing silicon rubber. An imbedded nylon mesh provides tear resistance. Deformable conical projections are on one surface with a density of 400 per square inch, 30/1000" high, with the total thickness of the Baromat being 60/1000". It has been shown to have low hysteresis, good frequency response and neglible creep (Smith, 1983). It is able to record pressure up to 30 psi (Wirta, 1985). The points at which the foil come into contact with the acrylic (at the apex of the conical projections) caused the light to be reflected out of the bottom of the acrylic, and appeared as light areas on the underside. See Figure 12. As pressure is applied on the foil, the deformable projections were forced into more intimate contact with the acrylic, increasing the total contact area with the result that more light is refracted out of the bottom of the acrylic. See Figure 13. When viewed from the underside, these areas appeared as brightly lit spots, with intensity of light correlated to intensity of pressure. This technique of using critical light reflection to measure pressure intensities has been used in gait analysis (Betts, Franks and Duckworth, 1980a, b, c, d; Franks, Betts and Duckworth, 1983; Spiegel, et. al., 1985; Cahill, 1985). Mirrors positioned on the underside of the seat and backrest surfaces permited ease of viewing the pattern of high and low intensity areas.



Medium Pressure



High Pressure

Figure 13. Effect of Medium and High Pressure

4.4 Data Treatment

4.4.1 EMG Signal Processing

The EMG signal was boosted by the preamplifiers attached close to the subject; then it was sent through silver-shielded cables to the main amplifier. Following amplification, the EMG signal was low pass filtered (1 K Hz) and high pass filtered (80 Hz), then rectified. The rectified signal was integrated over a 500 msec integration window, then the root mean square (RMS) values were obtained. These were transferred to the ISSAC Cyborg data acquisition system, an A/D converter. THe sampling frequency of the integrated EMG signal was 50 Hz, for a three-second period. From there, the data was transferred to an IBM PC, where it was plotted on a color graphics monitor to check for artifacts in the EMG signal, then stored on diskettes for future analysis.

4.4.2 Videoimage Processing and Data Treatment

A JVC camera was used to record the image of the light intensities, along with an RCA video cassete recorder. A Trinitron color monitor displayed the image and allowed visual inspection of the image. To make this video information useful to a computer, it is necessary to digitally encode it and store the code in random access memory in a format that is relatd to the way it is displayed. The picture must be broken up into an array of discrete picture elements (pixels). Each pixel is stored as a binary equivalent of some brightness or gray level. A commercially available video digitizer (Video Van Gogh, by Tecmar, Inc.) was used to digitize the video image. Eight bits provide 256 gray levels; after the image is digitized, the data buffer contains a brightness value from 0 to 255 for each digitized dot or pixel, with 0 representing a black pixel and 255 representing the brightest white pixel. A digitized screen will have 250 horizontal x 240 vertical pixels. One frame per subject per test condition was digitized, and the data, in ASCII format, was stored on diskette and then transferred to the university mainframe computer system for statistical analysis. See Figure 14.

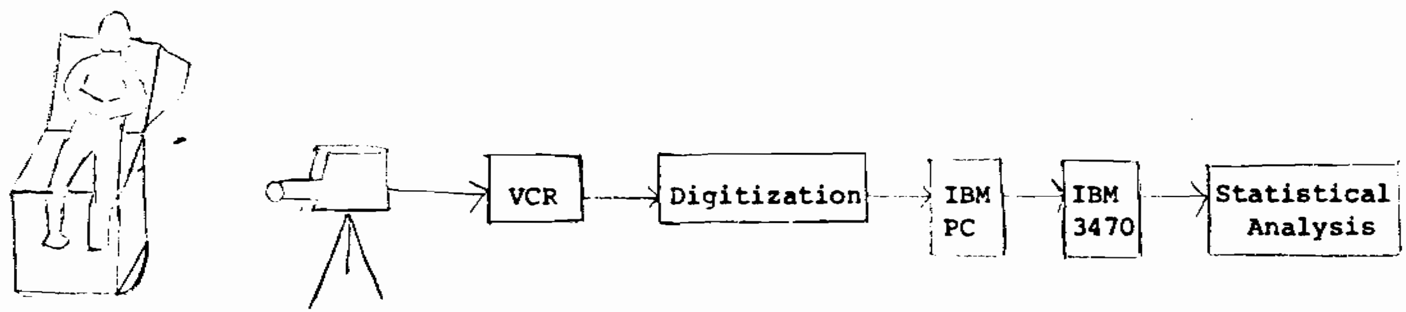


Figure 14. Schematic diagram of videoimage processing

After the pressure data had been digitized, a many-stepped analysis was performed on the digital data. See Figure 15 for a schematic diagram of the pressure data analysis. Three dimensional plots and contour plots were constructed for all test conditions for Subjects A and C, who represented the extremes in terms of percent of body fat (9% and 29%, respectively). These plots were constructed from the digital data, with values less than 20 eliminated as "noise". Because the data sets for the conditions were so large (more than 150,000 bytes, in some cases), it was necessary to reduce the data set considerably. Every fifth value along the x and y axes was used for plotting, and a running mean over 3 values was used to "smooth" the data. See Appendix D for the three-dimensional plots and contour plots for Subjects A and C.

For all subject, frequency histograms were constructed for the digital data. As before, all digital values below 20 were considered "noise" and eliminated from the analysis. A total of twenty intervals were used in the histograms; midpoints for the intervals were based on the pressure calibration curve (See Appendix B). Frequencies, cumulative frequencies, percentages, and cumulative percentages were calculated along with the histograms. The histograms provide a quick and easy way to assess distributional information about the data; the relative heights of the bars represent the relative density of observations in the interval.

Based on evaluation of the histogram data, it was decided to fit the data to the Weibull distribution. See Appendix D for a description of the characteristics of the Weibull distribution.

Plots were constructed of F(y) = cumulative percentage vs log y (where y represents the intervals, i.e. PSI levels from 1 to 20). The resultant slope and intercept from the plot provided estimates of the parameters:

Eq. 1 $\lambda = \exp\{-\text{intercept}/\text{slope})$

Eq. 2 $\theta = \text{slope}$

The plotting procedure was performed for all subject/condition combinations (for a total of 64 observations), obtaining λ and Θ for each. These empirically derived parameters, λ and θ, were then used to calculate quantiles. See Figures 16 and 17.

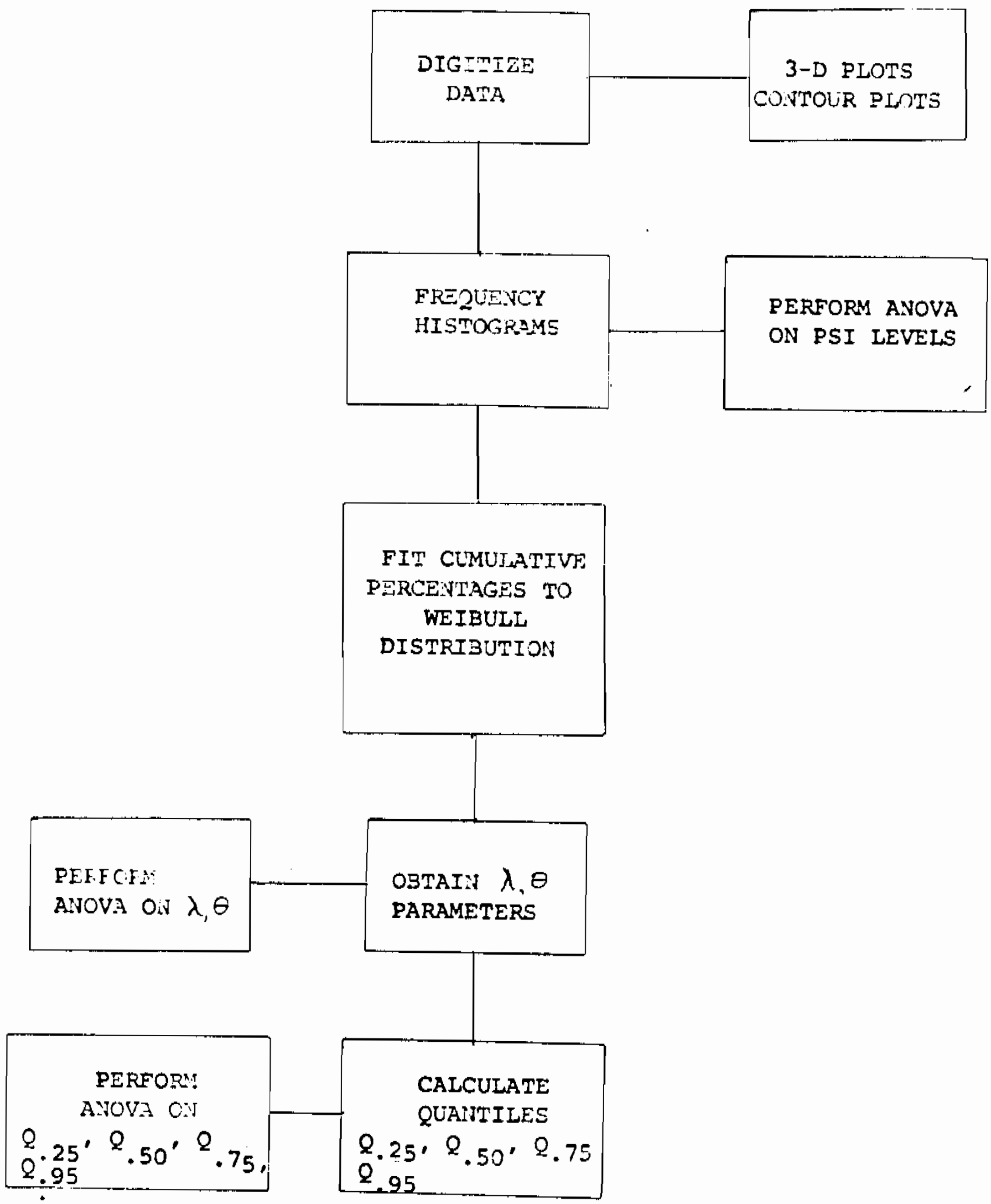


Figure 15. Schematic Diagram of Pressure Data Analysis

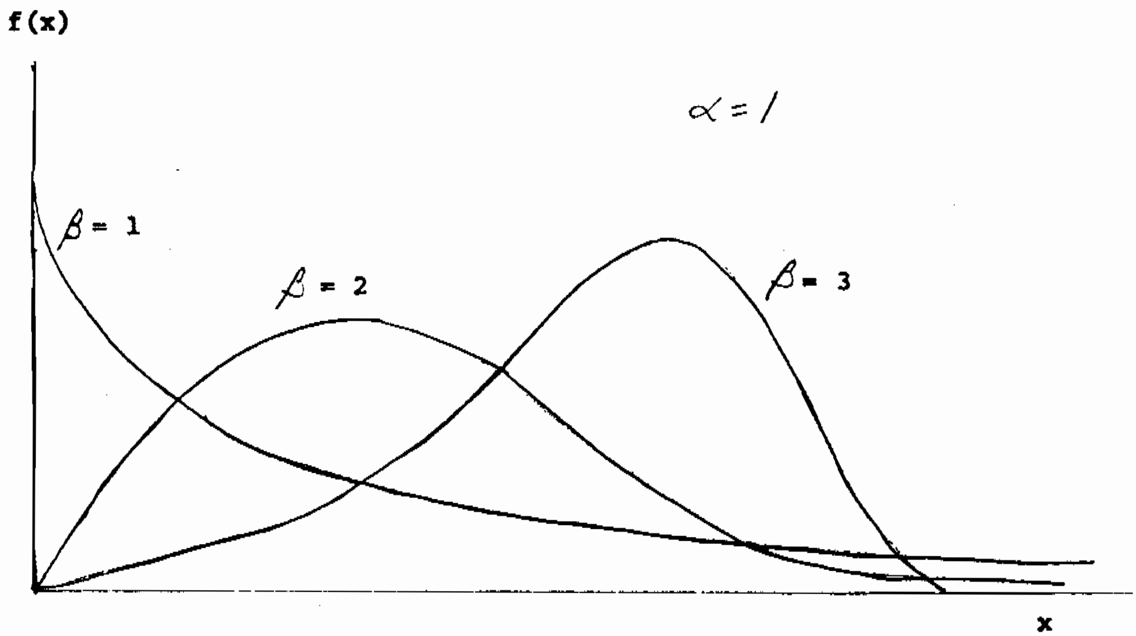


Figure 16. PDF of the Weibull Distribution with Varying Parameters

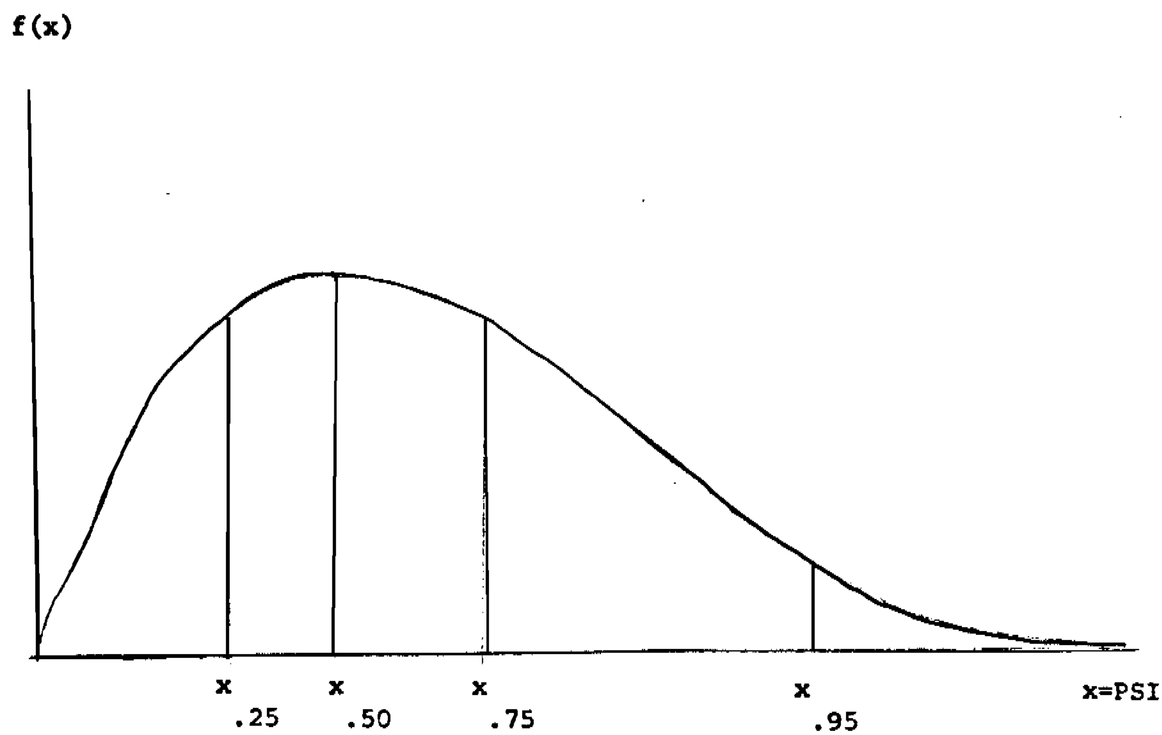


Figure 17. Quantiles of a Weibull Distribution

4.5 Procedure:

Each subject received standard verbal instructions regarding the purpose of the experiment, the experimental procedure and his participation in it, then signed a consent form. See Appendix A. Then the subject changed into gym shorts and anthropometric measurements were taken. Three skinfold measurements were used, all taken on the right side of the body: behind the upper arm, at the abdomen along the waistline, and on chest (adjacent to the nipple).' Six anthropometric dimensions were also taken (unilateral dimension were measured on the right side of the body): standing height, sitting height, shoulder breadth, seat breadth, popliteal length, and buttock-popliteal length. These measurements were used to determine body build characteristics.

The length of the seat pan of the experimental chair, and the length of the footrests were adjusted to fit the subject. Then preparations were made for recording the EMG's. The appropriate muscles were palpated and the sites marked for electrode placement.

After the skin had been cleaned with alcohol and lightly abraded, surface recessed electrodes were attached using double faced collars; the recess electrode cup was filled with electrode gel. Electrodes were placed bilaterally over the erector spinus and latissimus dorsus muscles. The resistance between electrode pairs was checked with an ohmmeter, then the preamplifiers and electrode cables were attached to the electrodes. The ground electrode was placed on the right side of the body, slightly above the waistline, at the L3 level. In all, 9 electrodes were used: 2 per muscle and 1 ground. See Figure 18.

In order to normalize the EMG data, a maximum voluntary exertion was performed with the subject pushing with his back against a bar connected to a Cybex Isokinetic Dynamometer. The subject then changed into a hospital gown, with the opening of the gown in back, and sat in the experimental chair in such a way that no portion of the hospital gown was interposed between the subject's body and the chair surface. This was done to avoid interference of the visual image by the pressence of seams and wrinkles in the clothing which were seen as lines of high luminance intensities.

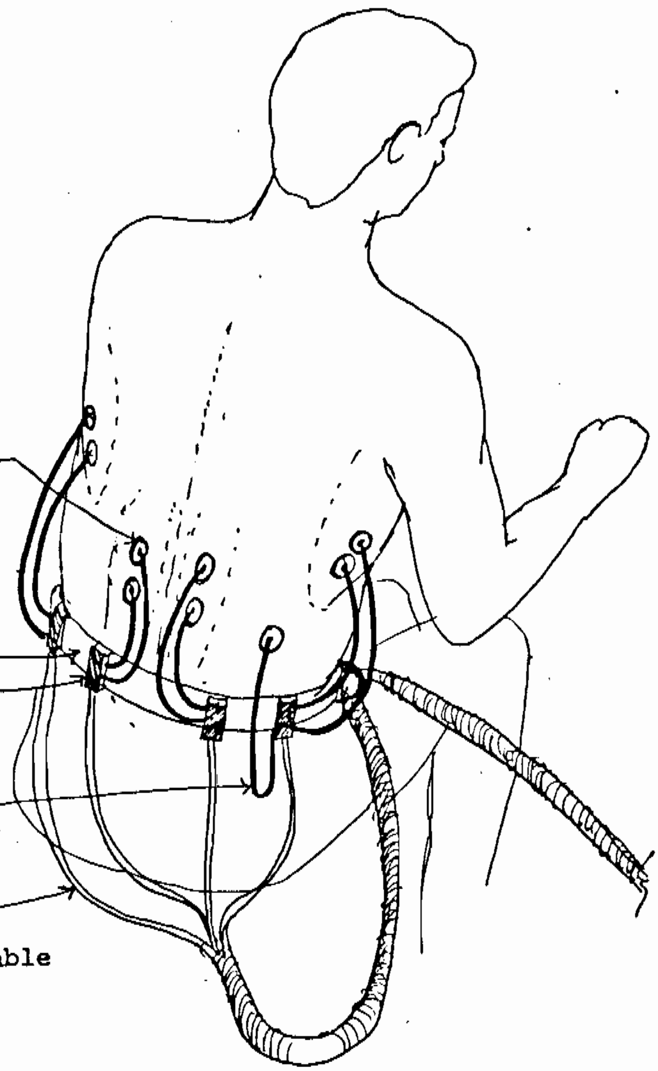


Figure 18. Electrode Placement on Subject. (Courtesy of Richard Schoenmarklin).

The subject was instructed to sit with the upper body leaning backwards against the backrest, with arms folded across the chest, head resting against the backrests, and legs supported by the footrests. He was to maintain this posture during the data recording interval. Deformation of the pedobarograph foil by the weight of the subject was recorded by a video camera from the underside of the seat and backrest units. This data was recorded sequentially, since there was only one video camera; the chair pressure was recorded first then the backrest pressure. The lights on the chair were then turned off and the EMG data for that position was recorded. This was done to prevent an experimental artifact caused by interference from the fluorescent chair lights. Ideally, all the data (the seat and back pressures, and EMG's) should be collected simultaneously, but due to the experimental constraints mentioned above, they were collected sequentially. The subject was instructed not to move until all the data for a particular position had been collected. Although there is a possibility that the subject may have shifted his position slightly during the recording interval, it is felt that this shift would be neglible since the position of the subject was neither arduous nor awkward and therefore would not be difficult to maintain. After all the data had been collected for a given position, the subject was instructed to get off the chair. This was done to allow the chair to be changed to the next test position, provide an opportunity for the subject to move about and to minimize the possibility of hysteresis (i.e. a time-loading effect caused by failure of the pedobarograph foil to return to its orginal state). of the pedobarograph foil. When the chair had been changed to the next position, the subject sat down again and the data collecting process was repeated. The room lights were turned off during the testing process to ensure a clear video image. A total of eight chair positions were tested.

After the completion of testing, the subject laid prone on a horizontal surface in order to record the resting TZYM

CHAPTER 5

RESULTS

5.1 Results of Pressure Data

In order to make inferences and draw conclusions regarding the plethora of experimental data, it was necessary to adopt a multi-phased analysis, with each phase providing slightly different information and interpretation. Before beginning any statistical analysis, it is important to initially preview the entire data set and assess any indications or trends in the data. The Weibull parameters, λ and θ, which indicate the spread or shaped of the distribution of data, provide succinct measures which essentially encapsulate the behavior of the entire data set. One can assess whether changes occur in the shape and spread parameters as a function of test conditions, and if so, in what direction these changes occur.

Once the overall trend had been analyzed to get the "big picture", a "finer-grained" analysis was performed. The data was split into sections and a systematic analysis was conducted for each section. This was done by using Weibull-derived quantiles and PSI levels to segment the data. Each quantile or PSI level was then analyzed separately.

5.1.1 Weibull Parameters

Fitting the cumulative percent of the histogram data to the Weibull distribution, as described in the Methods Sections and Appendix C, provided a valuable tool for analysis. Analysis of variance was performed on λ and θ, and the statistics are summarized in Table 2 for the seat data and Table 3 for the backrest data. It can be seen that for both seat and backrest data, the subject effect accounted for most of the variability. Post-hoc tests (using Duncan's procedure, with .05 significance level) show that seat angle 10° had lower λ and θ values than seat angle 0°. Thus, increasing the seat pan angle from 0 to 10 degrees reduced the variability (spread) and shifted the distribution to the left, resulting in a higher percent of the data at lower pressure levels. Conversely, increasing the backrest angle increased the variability and shifted the distribution to the right for the

TABLE 2 Seat Data

	θ	λ
Subject		
F-statistic	7.60	23.91
P-value	.0001 ***	.0001 ***
df	7	7
Seat		
F-statistic	3.01	1.76
P-value	.0890	.1904
df	1	1
Back		
F-statistic	4.30	2.44
P-value	.0018 ***	.5113
df	3	3
Seat*Back		
F-statistic	4.30	2.44
P-value	.0090 ***	.0751
df	3	3
R-Square	.6385	.7849

*** = significant at .01 level

TABLE 2. Seat Data (continued)

Post-hoc tests

	λ	Mean value	θ	Mean value
Subject				
	1	2.64	4	1.45
	2	2.51	3	1.44
	7	1.58	5	1.33
	4	1.51	2	1 22
	5	1.45	8	1.13
	8	1.41	6	1.01
	3	1.33	7	1.00
	6	1.29	1	.99
Seat				
	0	1.77	0	1.24
	10	1.66	10	1.15
Back				
	120	1.79	120	1.37
	100	1.75	110	1.16
	90	1.68	90	1.13
	110	1.64	100	1.11

TABLE 3 Backrest Data

	θ	λ
Subject		
F-statistic	3.25	12.95
P-value	.0066 ***	.0001 ***
df	7	7
Seat		
F-statistic	11.92	1.48
P-value	,0012 ***	.2300
df	1	1
Back		
F-statistic	4.65	6.07
P-value	.0062 ***	.0014 ***
df	3	3
Seat*Back		
F-statistic	1.70	0.90
P-value	.1804	.4468
df	3	3
R-Square	.5281	.7020

*** = significant at .01 level

TABLE 3. Backrest Data (Continued)

Post hoc Tests

Subject

λ	Mean value	θ	Mean value
4	2.93	3	1.37
8	2.63	5	1.34
2	2.53	8	1.34
5	2.28	4	1.32
6	1.69	1	1.27
7	1.47	6	1.20
3	1.34	2	1.13
1	1.32	7	.96

Seat

λ	Mean value	θ	Mean value
0	2.00	0	1.34
10	1.95	10	1.15

Back

λ	Mean value	θ	Mean value
120	2.35	120	1.40
110	2.09	110	1.26
100	2.00	100	1.20
90	1.63	90	1.11

backrest data, which reflected the greater percent of weight on the backrest as it was further reclined. The response of seat pressure to backrest changes was obscure; the post-hoc tests did not indicate any significant trend.

5.1.2 Quantiles

In addition to deriving shape and spread parameters from the Weibull distribution, one can generate quantiles which can then be used for analysis. The use of quantiles allowed the data to be systematically sectioned and the behavior of each section could be studied independently of the others. In particular, the upper and lower extremes (also called the "tails") of the distribution could be examined. A quantile is similar to the concept of percentile. The .85 quantile of a set of data, denoted as Q.85, is a number on the scale of the data that divides the data into two groups, so that a fraction .85 of the observations fall below and a fraction .15 fall above (Chambers, et. al., 1983). Bearing this definition in mind, it is clear that it is more desireable to have low values at each quantile, in order to fulfill the goal of minimizing or eliminating high pressures.

Table 4 shows the average values for the quantiles (seat data only), as a function of seat and backrest angles. Values were averaged over all subjects, marginal averages are included and the units are in PSI. Again, this allowed the data to be assessed and significaant trends to be noted before preceeding with further analyses. It can be seen that the worse cases occured at Seat 0°/Back 90° and Seat 10°/Back 100°. This was especially true at the higher quantiles (Q.95-Q.99). Both of these corresponded to a trunk/thigh angle of 90°; the implications of this observation will be discussed in further detail in the Discussion Section.

An analysis of variance and post-hoc analysis for the seat data was performed on the quantiles, with the results listed in Table 5. As seen previous, the subject effect was highly significant in all cases. Generally, at the higher quantiles, the back variable was significant. Post-hoc tests indicated that Back 110° and 120° had significantly lower values than Back 90° and 100°. This reflected the lessening of pressure

TABLE 4. Seat Data--Mean Values for Quantiles

(Units in PSI)

Seat	0				10				
Back	90	100	110	120	90	100	110	120	**Marginal Average**
Q.25	.48	.67	.69	.69	.61	.45	.43	.72	.59
Q.50	1.13	1.38	1.37	1.34	1.27	1.11	1.00	1.38	1.25
Q.75	2.23	2.48	2.35	2.27	2.35	2.28	2.05	2.33	2.29
Q.95	4.94	4.86	4.30	4.08	4.76	5.25	4.70	4.18	4.63
Q.96	5.33	5.13	4.55	4.31	5.09	5.69	5.08	4.41	4.96
Q.97	5.83	5.59	4.87	4.60	5.51	6.25	5.59	4.71	5.37
Q.98	6.55	6.17	5.31	5.01	6.12	7.06	6.31	5.31	5.96
Q.99	7.80	7.15	6.04	5.68	7.14	8.47	7.58	5.81	6.96
Marginal Average	4.29	4.19	3.59	3.50	4.11	4.57	4.09	3.58	

TABLE 5 Seat Data--Quantiles

	Q.25	Q.50	Q.75	Q.95	Q.96	Q.97	Q.98	Q.99
Subject (df=7)								
F-statistic	8.68	16.84	32.23	44.01	43.50	42.55	40.87	37.73
P-Value	.0001 ***	.0001 ***	.0001 ***	.0001 ***	.0001 ***	.0001 ***	.0001 ***	.0001 ***
Seat (df=1)								
F-statistic	3.78	2.84	0.67	0.84	1.14	1.53	2.05	2.82
P-value	.0576	.0984	.4181	.3642	.2909	.2221	.1584	.0997
Back (df=3)								
F-statistic	3.48	1.59	0.61	4.40	4.90	5.47	6.12	6.89
P-value	.0227 **	.2034	.6146	.0081 ***	.0047 ***	.0025 ***	.0013 ***	.0006 ***
Seat*Back (df=3)								
F-statistic	5.15	3.72	1.12	0.50	0.74	1.06	1.52	2.23
P-value	.0036 ***	.0174 **	.3493	.6846	.5346	.3732	.2205	.0962
R-Square	.6485	.7361	.8253	.8685	.8681	.8668	.8639	.8573

** = significant at .05 level
***= significant at .01 level

intensity in the buttocks as the backrest was inclined posteriorly.

Results of the ANOVA for backrest data are shown in Table 6. Since high pressure levels were not as critical in the backrest as in the seat pan, the higher quantiles (Q.96-Q.99) were not included. In addition to the subject effect, the back effect was significant at the .01 level, except for Q.95. Post-hoc tests supported the hypothesis that body weight was shifted to the backrest as it was reclined. In Q.25, Back 120° experienced 1.68% higher pressure than Back 90°.

TABLE 6 Backrest Data

	Q.25	Q.50	Q.75	Q.95
Subject				
F-statistic	12.16	12.97	12.70	11.22
P-value	.0001 ***	.0001 ***	.0001 ***	.0001 ***
df	7	7	7	7
Seat				
F-statistic	4.92	2.49	0.71	0.05
P-value	.0313 **	.1213	.4036	.8269
df	1	1	1	1
Back				
F-statistic	8.92	7.23	4.86	1.84
P-value	.0001 ***	.0004 ***	.0050 ***	.1530
df	3	3	3	3
Seat*Back				
F-statistic	1.32	1.07	0.74	0.48
P-value	.2773	.3697	.5342	.6980
df	3	3	3	3
R-Square	.7156	.7112	.6891	.6406

** = significant at .05 level
***= significant at .01 level

5.1.3 Subject and Trunk Angle

The angle between the trunk and upper thigh (referred to here as "trunk angle") was also used as the independent variable instead of the seat and backrest angles separately. Use of the trunk angle provided a single measure which incorporated the seat and backrest angles. Table 7 shows how seat and backrest angles related to trunk angle. Summary statistics for the quantiles are shown in Table 8, with subject and trunk angle as the independent variables. Post-hoc tests showed that subjects were always significant, and Trunk angle was significant at the low and high extremes of the quantiles (Q.25, Q.95-Q.99). Table 9 shows the corresponding statistics for the backrest data, with similar results to the seat analysis.

TABLE 7. Seat/Back/Trunk Angle

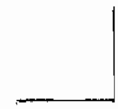
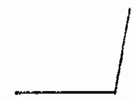
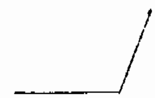
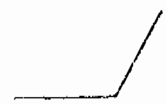
Seat	Back	Trunk	
0°	90°	90°	
0°	100°	100°	
0°	110°	110°	
0°	120°	120°	
10°	90°	80°	
10°	100°	90°	
10°	110°	100°	
10°	120°	110°	

TABLE 8. Seat Data--Trunk Angle

	Q.25	Q.50	Q.75	Q.95	Q.96	Q.97	Q.98	Q.99
Subject								
F-statistic	7.84	15.28	30.94	45.83	45.35	44.35	42.49	38.94
P-value	.0001 ***	.0001 ***	.0001 ***	.0001 ***	.0001 ***	.0001 ***	.0001 ***	.0001 ***
df	7	7	7	7	7	7	7	7
Trunk Angle								
F-statistic	4.77	2.36	0.17	3.80	4.48	5.27	6.22	7.42
P-value	.0024 ***	.0650	.9551	.0088 ***	.0035 ***	.0012 ***	.0004 ***	.0001 ***
df	4	4	4	4	4	4	4	4
R-Square	.5871	.6912	.8069	.8660	.8658	.8644	.8611	.8532

*** = significant at .01 level

TABLE 9 Backrest Data

	Q.25	Q.50	Q.75	Q.95
Subject				
F-statistic	12.69	13.48	13.07	11.34
P-value	.0001 ***	.0001 ***	.0001 ***	.0001 ***
df	7	7	7	7
Trunk Angle				
F-statistic	9.09	6.84	4.09	1.15
P-value	.0001 ***	.0002 ***	.0060 ***	.3443
df	4	4	4	4
R-Square	.7106	.7047	.6789	.6222

*** = significant at .01 level

5.1.4 PSI Levels

Instead of using quantiles of the cumulative Weibull distribution function as the dependent variables, the percent of data occurring at each PSI level was also employed as a dependent variable. This type of analysis may be more sensitive to small changes which otherwise would be obscured by the use of quantiles. However, the disadvantage is that random fluctuations, i.e. spurious noise, may be more likely to show up as significant effects. Therefore, one needs to consider results of both quantiles and PSI levels together. Table 10 shows the statistics for the ANOVA on the seat data for the PSI levels; Table 11 shows the corresponding back data. As seen in all of the previous analyses, the subject effect was consistently significant at the .01 level across all the PSI levels. The back effect was significant at high PSI levels, which is roughly analogous to the back significance at higher quantile values.

TABLE 10. Seat Data--PSI Levels

PSI:	1	2	3	4	5	10	11	12
Subject (df=7)								
F-statistic	7.47	3.96	5.74	24.85	31.51	14.00	15.80	9.77
P-value	.0001 ***	.0017 ***	.0001 ***	.0001 ***	.0001 ***	.0001 ***	.0001 ***	.0001 ***
Seat (df=1)								
F-statistic	0.33	2.70	0.88	0.29	1.32	1.31	0.45	0.04
P-value	.5672	.1071	.3535	.5955	.2563	.2583	.5065	.8335
Back (df=3)								
F-statistic	0.53	1.11	0.35	0.23	0.59	0.89	2.03	1.90
P-value	.6613	.3544	.7921	.8729	.6236	.4536	.1218	.1415
Seat*Back (df=3)								
F-statistic	0.61	0.18	0.22	1.51	2.37	0.16	0.10	0.27
P-value	.6132	.9074	.8805	.2236	.0823	.9212	.9592	.8487
R Square	.5336	.4116	.4662	.7855	.8249	.6765	.7056	.6046

*** = significant at .01 level

TABLE 10. Seat Data--PSI Levels (continued)

PSI:	13	14	15	16	17	18	19
Subject (df=7)							
F-statistic	15.63	6.81	10.14	9.39	6.07	4.77	4.67
P-value	.0001 ***	.0001 ***	.0001 ***	.0001 ***	.0001 ***	.0004 ***	.0005 ***
Seat (df=1)							
F-statistic	0.06	0.68	4.21	2.81	1.35	0.17	0.05
P-value	.8012	.4121	.0456 **	.0999	.2511	.6845	.8291
Back (df=3)							
F-statistic	4.25	5.04	4.41	4.88	2.70	5.03	3.05
P-value	.0096 ***	.0040 ***	.0080 ***	.0048 ***	.0555	.0041 ***	.0371 **
Seat*Back (df=3)							
F-statistic	2.06	1.42	2.32	1.30	2.26	1.53	0.45
P-value	.1177	.2469	.0867	.2867	.0929	.2180	.7204
R-Square	.7238	.5803	.6607	.6400	.5451	.5206	.4686

** = significant at .05 level
***= significant at .01 level

TABLE 11. Back Data--PSI Levels

PSI:	1	2	3	4	5	10	11	12
Subject (df=7)								
F-statistic	4.50	15.98	3.33	12.03	30.66	6.34	3.57	1.86
P-value	.0006 ***	.0001 ***	.0056 ***	.0001 ***	.0001 ***	.0001 ***	.0036 ***	.0973
Seat (df=1)								
F-statistic	3.81	0.33	4.27	6.89	6.99	2.53	3.81	2.01
P-value	.0568	.5694	.0442 **	.0116 **	.0111 **	.1181	.0569	.1622
Back (df=3)								
F-statistic	7.88	4.05	5.70	4.38	4.23	0.37	0.40	0.29
P-value	.0002 ***	.0120 **	.0020 ***	.0084 ***	.0099 ***	.7781	.7533	.8310
Seat*Back (df=3)								
F-statistic	0.84	0.38	0.31	1.10	1.43	0.32	0.16	0.34
P-value	.4784	.7695	.8166	.3579	.2450	.8128	.9220	.7936
R-Square	.5614	.7233	.4874	.6914	.8325	.5049	.3882	.2609

** = significant at .05 level
***= significant at .01 level

TABLE 11. Back Data--PSI Levels (continued)

PSI:	13	14	15	16	17	18	19
Subject (df=7)							
F-statistic	1.55	1.11	2.37	1.30	2.45	1.21	1.90
P-value	.1737	.3717	.0367 **	.2723	.0314 **	.3173	.0902
Seat (df=1)							
F-statistic	2.40	1.67	0.21	0.37	0.69	1.57	0.17
P-value	.1280	.2027	.6507	.5438	.4114	.2160	.6777
Back (df=3)							
F-statistic	0.42	0.25	0.21	0.27	0.36	0.59	1.25
P-value	.7393	.8621	.8899	.8455	.7849	.6228	.3032
Seat*Back (df=3)							
F-statistic	0.39	0.38	0.56	0.24	1.07	1.28	0.27
P-value	.7630	.7694	.6470	.8698	.3721	.2906	.8468
R-Square	.2461	.1909	.2844	.1861	.3151	.2459	.2730

** = significant at .05 level

5.2 Results of EMG Data

The results for the analysis of the EMG data are shown in Table 12. As seen in all the previous analyses, the subject effect was highly significant. Of the other independent variable, seat and back angles were significant for ESR and ESL at the .01 level. The latissimus dorsi (LDL, LDR) were not significant. Post-hoc tests indicate that increasing the backrest angle decreased the mean activity of ESL and ESR.

TABLE 12. EMG Data

	LDR	LDL	ESR	ESL
Subject (df=7)				
F-statistic	10652.68	403.22	61.62	20.39
P-value	.0001 ***	.0001 ***	.0001 ***	.0001 ***
Seat (df=1)				
F-statistic	0.91	0.54	12.80	22.06
P-value	.3459	.4645	.0013 ***	.0001 ***
Back (df=3)				
F-statistic	0.26	1.43	13.79	12.57
P-value	.8512	.2452	.0001 ***	.0001 ***
Seat*Back (df=3)				
F-statistic	0.13	1.20	0.15	0.19
P-value	.9388	.3214	.9271	.9017
R-Square	.9993	.9830	9149	.8131

TABLE 12. EMG Data (continued)

Post-hoc Tests

	ESR	ESL
Subject	8	8
	1	2
	2	4
	4	1
	7	6
		7
		5
Seat	10	10
	0	0
Back	90	90
	100	100
	110	110
	120	120

5.3 Results of Handicapped Subject's Data

The data for the handicapped subject are summarized in Table 12. With only one subject, it is not appropriate to perform statistical analyses; however it is useful to note gross changes in the variables as a function of seating parameters. Due to the nature of his disability, the subject did not perform a maximum voluntary exertion. Consequently, the EMG data is not normalized, but represents the mean activity of the muscles.

The spread parameter, λ , for the seat data increased as the backrest was inclined posteriorly, indicating a larger amount of spread or variability in the data. There was no corresponding shift in the shape parameter, θ, as seen with the normal subjects. For seat angle, λ was higher for the 0° seat angle than for the 10° seat angle, which again indicates increased variability.

For the backrest data, the opposite effect was observed. As the seat angle incresed, the variability increased. Unfortunately, no conclusions could be drawn about the effect of the backrest angles on backrest data. Likewise, there were no clear-cut trends observed for the shape parameter, θ, in the backrest data.

TABLE 13. Handicapped Subject Data

Seat:	0				10			
Back:	90	100	110	120	90	100	110	120
EMG (mean activity)								
LDR	.29	.29	.29	.33	.33	.38	.28	.23
LDL	.60	.65	.53	.56	.57	.84	.57	1.46
ESR	.32	.32	.31	.32	.32	.32	.31	.32
ESL	.26	.27	.25	.26	.26	.29	.26	.26
Weibull Parameters (seat)								
λ	1.26	1.75	1.83	1.58	1.25	1.28	1.41	1.75
θ	.62	.74	.69	.57	.53	.57	.65	.74
Weibull Parameters (back)								
λ	1.43	.73	.63	.73	.75	1.40	1.32	1.36
θ	.58	.50	.46	.49	.69	.67	.58	.62

Post-hoc Tests

	Seat Data	Back Data
	λ	λ
Seat	0	10
	10	0
Back	120	90
	110	100
	100	120
	90	110
	θ	θ
Back	110	90
	100	100
	120	120
	90	110

CHAPTER 6

DISCUSSION

6.1 Seating Research

The seated workplace as a whole should be adjusted to the worker. This adjustability encompasses the chair itself, the work surface height and workplace design, which facilitates worker performance, ensures good sitting posture and prevents physical disabilities.

The posture of the seated worker depends on several factors: the design of the chair, individual seating habits and the task being performed. Since these factors interact with one another, they all need to be taken into consideration in the design of the chair. Of course, individual seating habits are difficult to predict, but some of them can be estimated. For example, it is well-known that people slouch when sitting; this position is perceived as being more comfortable, and it reduces the EMG activity in the back muscles more than sitting erect. However, the slouched sitting posture stresses the intervertebral discs by increasing disc pressure.

Results from seating research show that providing a lumbar support relieves disc pressure. A reclining backrest reduces low back stress by reducing both disc pressure and EMG activity of the back muscles. The height of the work table should be optimal for the worker and the task being performed. If it is too high, it may cause uncomfortably large shoulder abduction angles. If it is too low, it may cause the worker to bend the neck and upper body to compensate. Either situation may affect the stability, comfort and/or productivity of the worker.

Another seating recommendation suggests distributing the body weight of the worker evenly over the buttocks and the backs of the thighs. This can be partially accomplished by providing adequate lower leg supports. If the weight of the lower legs is supported by the backs of the thighs, swelling of the legs and pressure on the sciatic nerve may occur. If the chair is too low, the weight of the upper body will be transferred to a small area overlying the ischial tuberosities, instead of being distributed on the entire seat surface interface. This condition of high pressure is uncomfortable to the worker, and if not relieved, may become acutely painful.

The worker will periodically shift positions while seated, in order to redistribute the weight and relieve high pressure points. The design of the chair should allow for these normal alterations in posture. However, excessive shifts in posture may indicate that the worker is experiencing abnormally high pressure concentrations. The worker may respond by frequent alterations in posture, or may get up and walk around. Or, he/she may pad the seat in an attempt to provide greater cushioning effect. This solution is unsatisfactory--the padding may slip and the worker would need to stop working to readjust it. Alternatively, the worker may choose to stand instead of sitting; which would create postural problems in a workplace designed for a seated worker.

For these reasons, it is important to provide a comfortable chair for the worker, one which distributes pressures as evenly as possible.

6.2 Significances of Research

Many of the previous studies which have measured seating pressure have been inadequate in that they did not provide continuous measurements of pressure, were not calibrated in standard units of pressure, or the results were not statistically analyzable. The use of pressure transducers or the Pressure Evaluation Pad (PEP) utilized by previous researchers produced discrete estimates of sitting pressure. It was necessary to extrapolate between the data points in order to estimate the intermediate pressures. Use of a "barograph" did provide a continous measurement of pressure. However, the light intensities were passed through a grey-scale to color converter, which could be calibrated to known pressure units, but was not stored in a form which could be analyzed statistically. Hence, quantification of observed differences in sitting pressure were not possible.

Studies of sitting pressure rarely incorporated the effect of a backrest. The importance of a backrest in chair design is well-documented. Also, the angle of the seat pan was not included in pressure studies, although an inclination of five or ten degrees posteriorly is often recommended.

This research utilized an experimental chair which was composed of a backrest unit and a seat unit which could move independently of each other. The backrest unit was capable of a full range of movement from 90° vertical to 180° horizontal. The seat unit was capable of tilting 30° anteriorly or posteriorly. Adjustable footrests provided lower leg support for a diversity of subject sizes. Both the seat and backrest units were capable of measuring pressure. The pressure measuring element was based on the physical principle of total internal reflection. This technique was adapted from gait analysis research and allowed pressure to be measured continuously over the entire region of interest, eliminating the need for interpolation. Coupled with a VCR system and a video digitizer, it was possible to analyze and store the pressure data for both units. Calibration to a standard unit of pressure (pounds per square inch, PSI) allowed the data to be converted to readily understandable units.

The analysis of data utilized the technique of curve fitting in order to measure changes in the distribution of pressure as the test conditions were varied. Fitting the data to the family of Weibull distributions, then using the resultant shape and slope parameters provided an effective way of reducing large amounts of data and providing sensitive dependent variable.

6.3 Subject Effect

Post-hoc tests showed that Subjects 1 and 2, with 5.3% and 5.7% body fat respectively, were most often significantly different from the other subjects. But paradoxically, Subject 5 who, with 7.6% body fat, was the third thinnest subject, was found to be most similar to Subjects 4 and 8, with 15.6% and 10.3% respectively.

These seemingly inconsistent results can be resolved by an examination of the methods of calculating specific gravity and body fat. There are several methods commonly used: Skinfold measurements may be used to calculate specific gravity, then percent of body fat may be derived from formulas or nomographs, based on the specific gravity. Alternatively, weight and height nomographs may be used for both specific gravity and percent of body fat. A third method is by calculating specific gravity based on water displacement by immersion in a water tank.

Accuracy of these methods are somewhat questionable, since they usually require a high degree of training, and even this does not ensure accurate results. The calculations for body fat, derived from skinfold measurements and height/ weight nomographs are shown in Figure 19. It can be seen that the derivation of body fat is highly variable. The accurate use of skinfold calipers requires several weeks of training prior to taking the experimental meaurements (Consolazio, 1963). Since the experimenter was probably not sufficiently trained in the use of the skinfold calipers, the body fat calculations based on skinfold measurements may be inaccurate. Also, the use of height/weight nomographs is limited, since the available nomographs are not applicable to the general population, but are limited to specific demographic groups (Pierson and Eagle, 1969).

The higher the percent of body fat an individual has, the greater the cushioning effect over bony prominences, and the more diffuse the resultant pressure. Thinner subjects lack the cushioning effect of body fat and would experience localized areas of high pressure intensities over bony prominences on weight-bearing regions of the body. In the buttocks region, this would be the area directly overlying the ischial tuberosities; on the back region, this would be the area overlying the scapula and spinous processes of the vertebrae.

In addition to the cushioning effect derived from body fat, a similar effect can be observed for individuals with a well developed muscular structure. Well-developed muscles, often found in healthy young males, would not be included in skinfold measurements, which by definition include only two thicknesses of skin and subcutaneous fat but not muscle or fascia (Consolazio, 1963). These types of subjects would have low skinfold measurements resulting in low estimation of body fat, leading one to believe that they are rather skinny, which in fact is not true at all. Thus, Subject 5, who had a low body fat value, was actually fairly muscular (he swam every day) and did not experience the high concentrations of pressure associated with thinner body types. The percent of body fat derived from height/weight nomographs show Subjects 4, 5 and 8 to have 15, 20 and 18% body fat respectively, which accounts for the similarities found in the post-hoc tests. See Figure 19 for a plot comparing the results of the two methods--skinfold measurements and height/weight nomographs .

Previous research by Garber and Krouskop (1982) examined the effects of body build on the locations, magnitude and gradient of pressure exerted by patients seated in wheelchairs. Subjects were classified as one of three body build types. Assessment of body build was based on scientific tables using height, weight, sex and age information. They found that thin patients had higher pressures over bony prominences and greater frequency of the maximum pressure occurring in a bony location than did the average weight or obese subjects.

Traditional seating guidelines recommend the inclusion of anthropometric data, such as sitting height, and upper and lower leg lengths, in seating design. The results of the above cited research indicate that body build is an additional factor which should also be included.

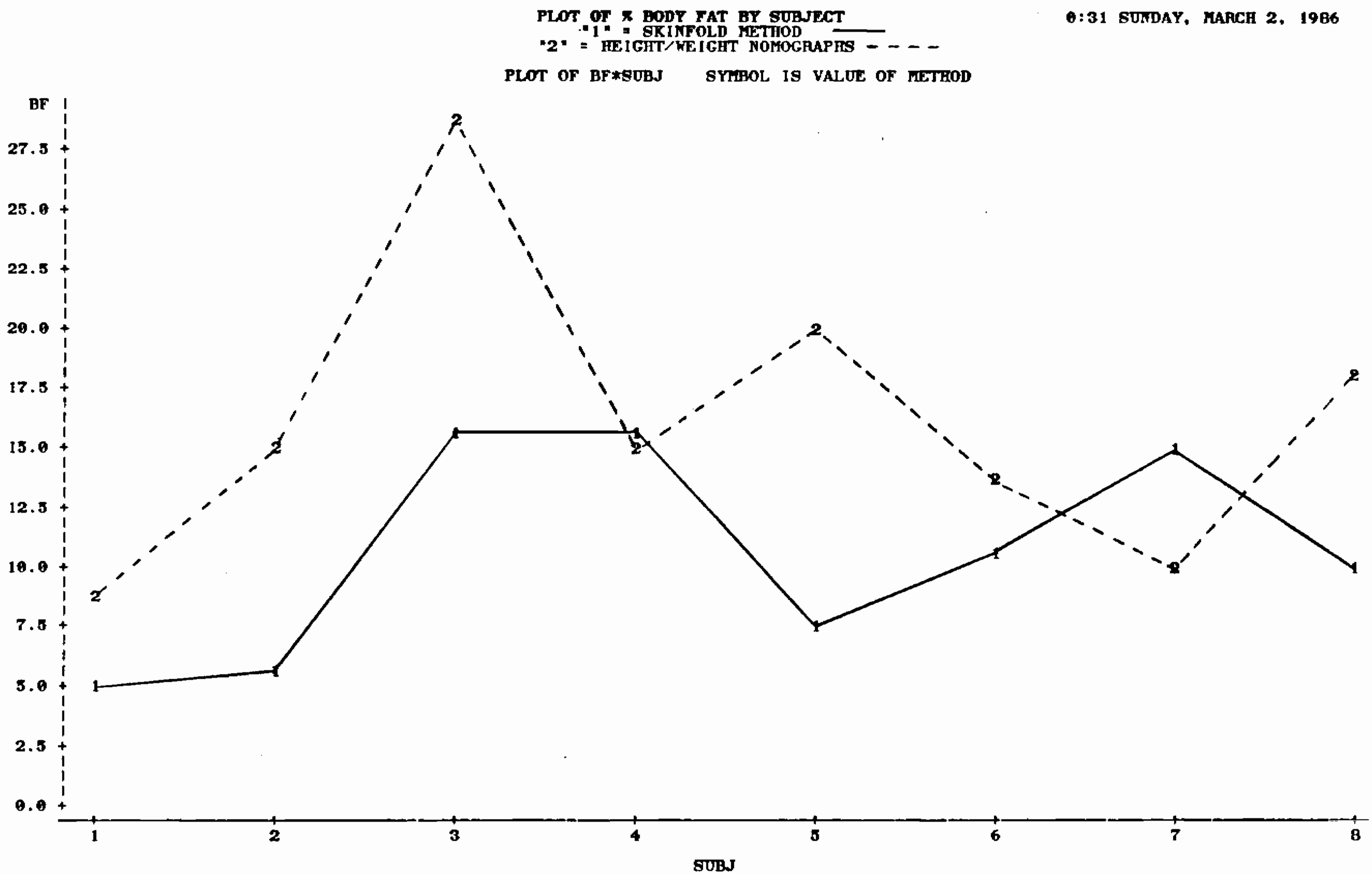


Figure 19. Plot of Body Fat vs Subject

6.4 Trunk Angle

As mentioned earlier in the Results Section, it is possible to consider the angle between the trunk and the upper thigh, referred to as the "trunk angle", as a dependent variable. This incorporates seat and backrest angles into a single measure and provides a supplementary analysis which may provide different information than the seat/backrest analysis. Figures 20-27 show the average quantile values for seat data plotted against trunk angles, for the two seat pan angles (1 = 0° Seat, 2 = 10° Seat). For 10° Seat, the values of the lower quantiles (Q.25-0.75) decrease as the trunk angle increases, reaching the lowest value at 100° trunk angle. For 0° Seat, the opposite occurs--the values increase dramatically from 90° to 100° trunk angle, then remain fairly constant or decrease slightly from 100° to 120°.

The sharp disparity between seat angles at 100° trunk angle can be due to the shift in the subject's center of gravity as the seat pan is inclined 10° posteriorly. Figures 29 and 30 show the sketches of the subject seated with 100° trunk angle. With a 10° posterior inclination in the seat pan, the subject's center of gravity is located more posteriorly than with 0° seat angle. This shift in the center of gravity accounts for the lower values at 10° Seat. At higher quantiles (Q.95-Q.99), the two seat conditions have similar values for the same trunk angles. Apparently it is the lower quantiles which are sensitive to shifts in the center of gravity.

No previous research has examined the interaction of seat and backrest angles, and changes in pressure distribution. The results of this analysis indicate that it is not sufficient to examine seat and backrest angles separately. In order to understand and interpret data correctly, it is necessasry to know what happens to the center of gravity by utilizing a measure such trunk angle.

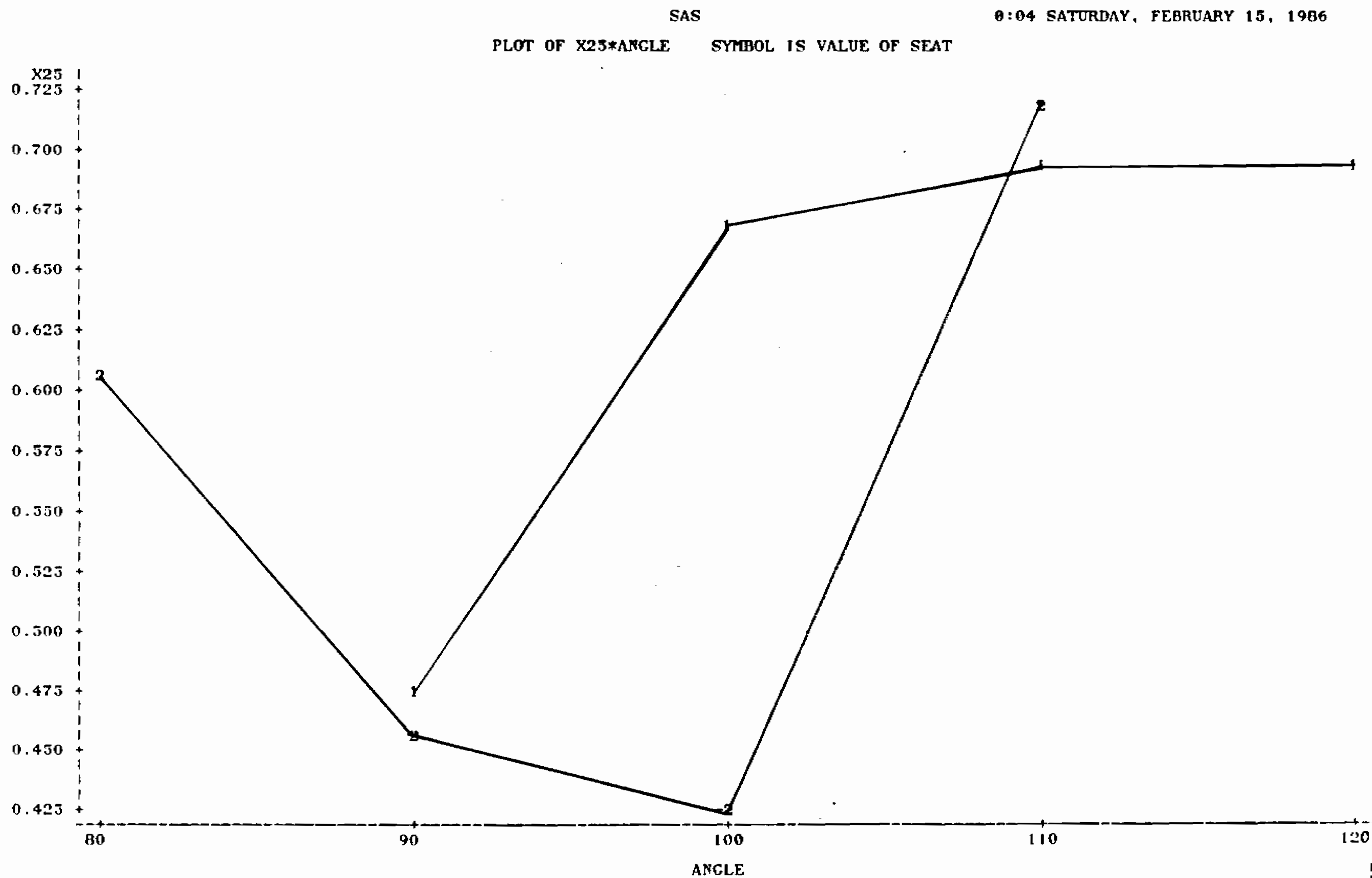


Figure 20. Q.25*Trunk Angle

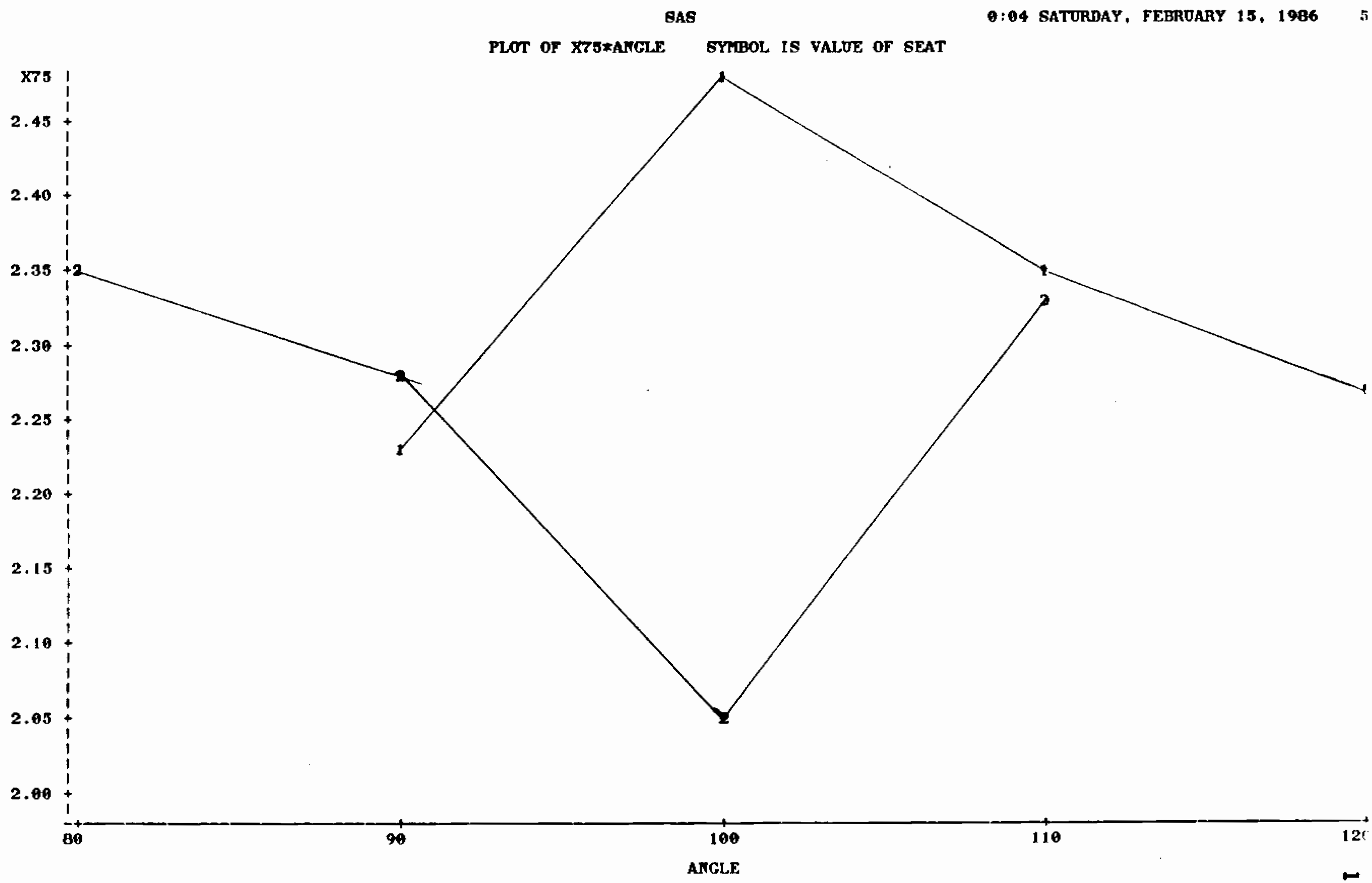


Figure 21. Q.50 * Trunk Angle

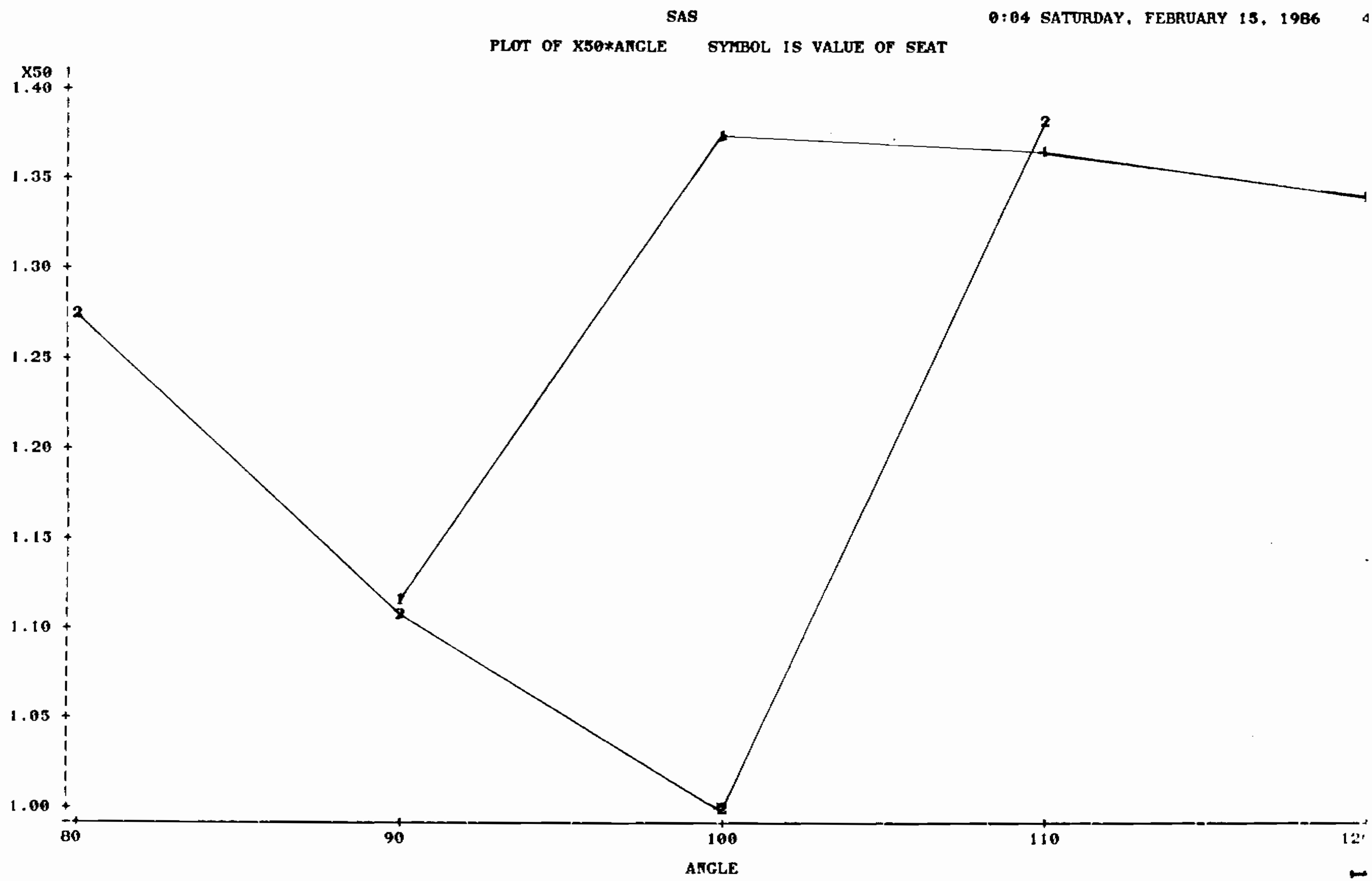


Figure 22. Q.75 * Trunk Angle

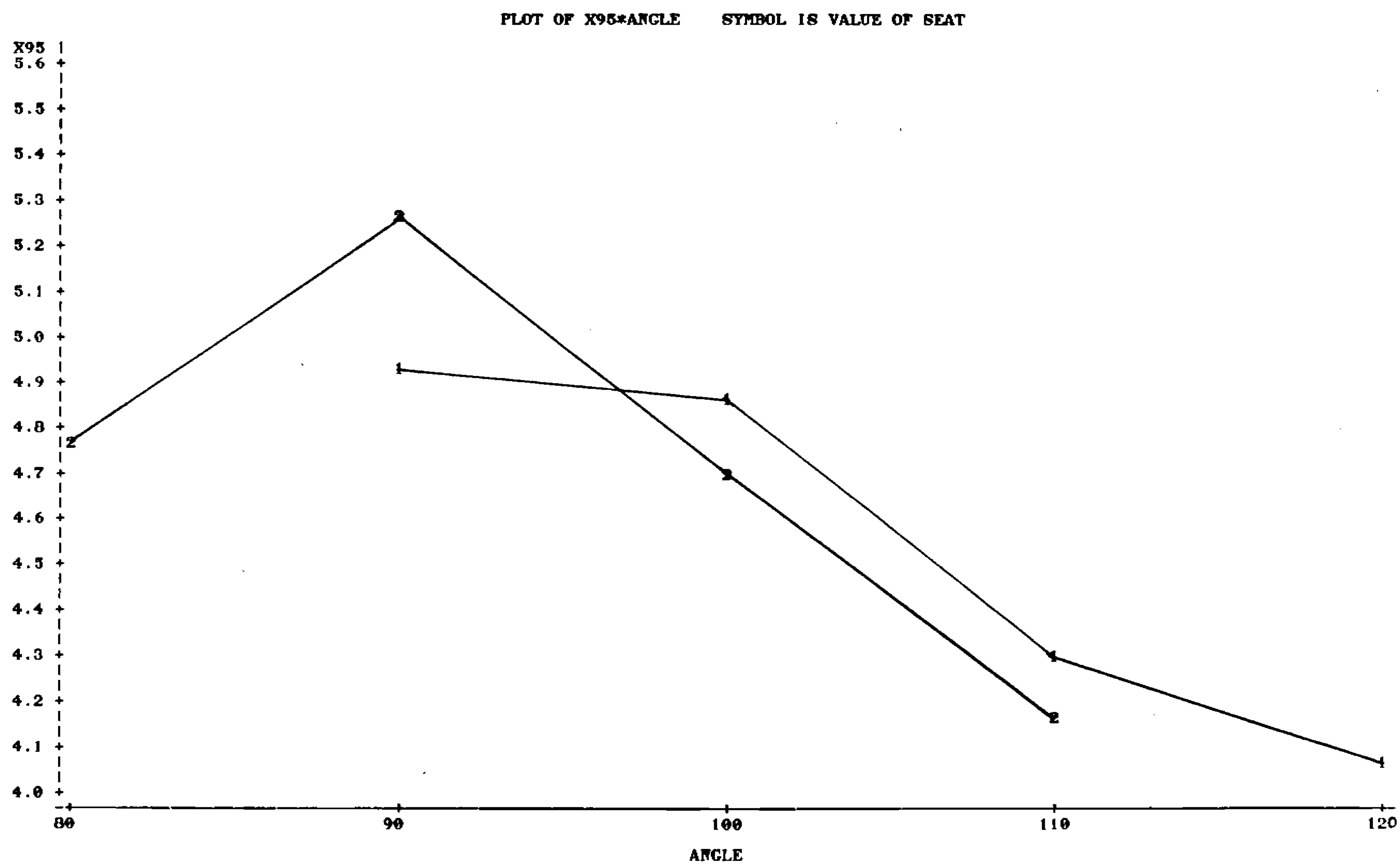


Figure 23. Q.95 * Trunk Angle

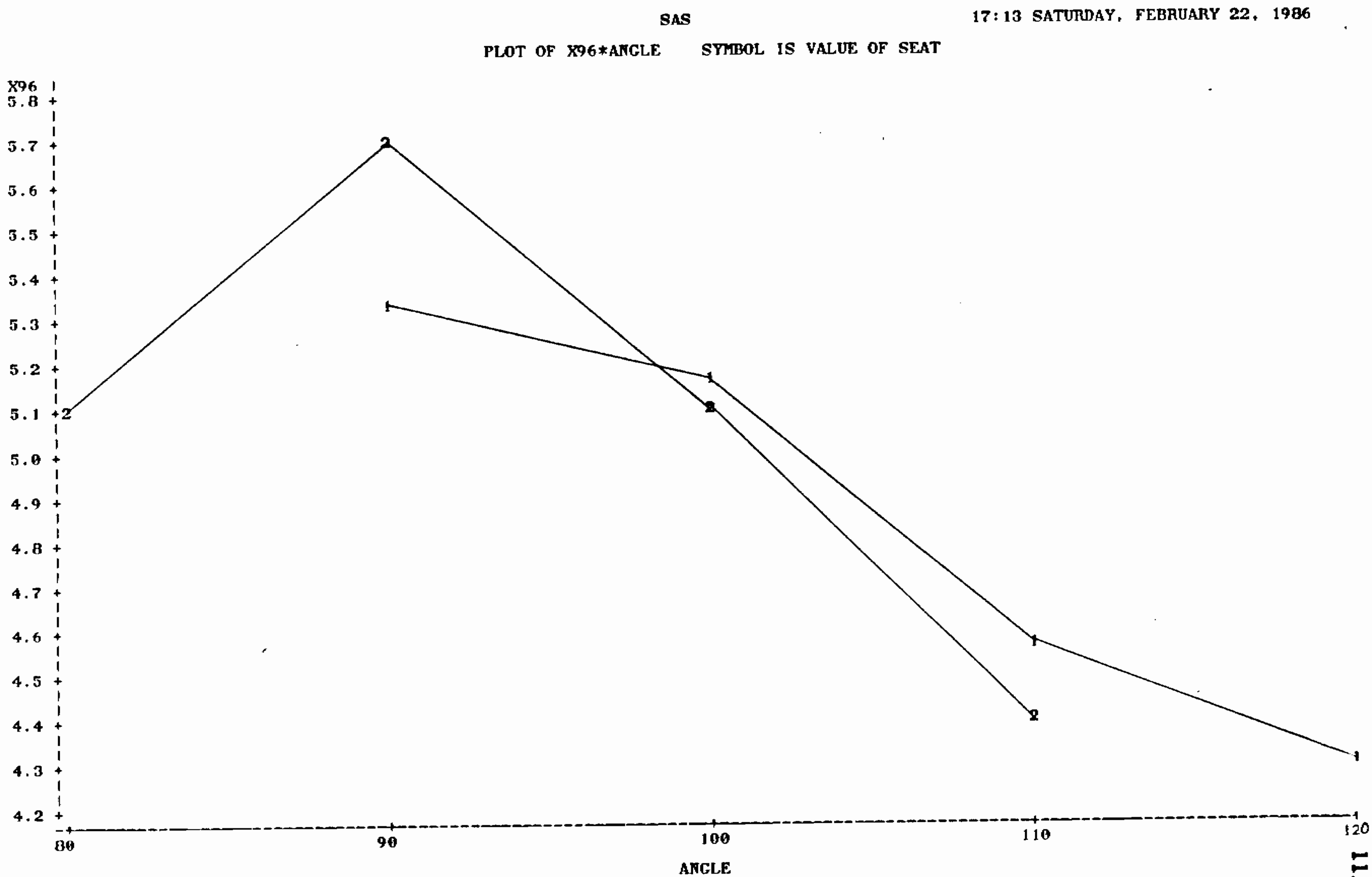


Figure 24. Q.96 * Trunk Angle

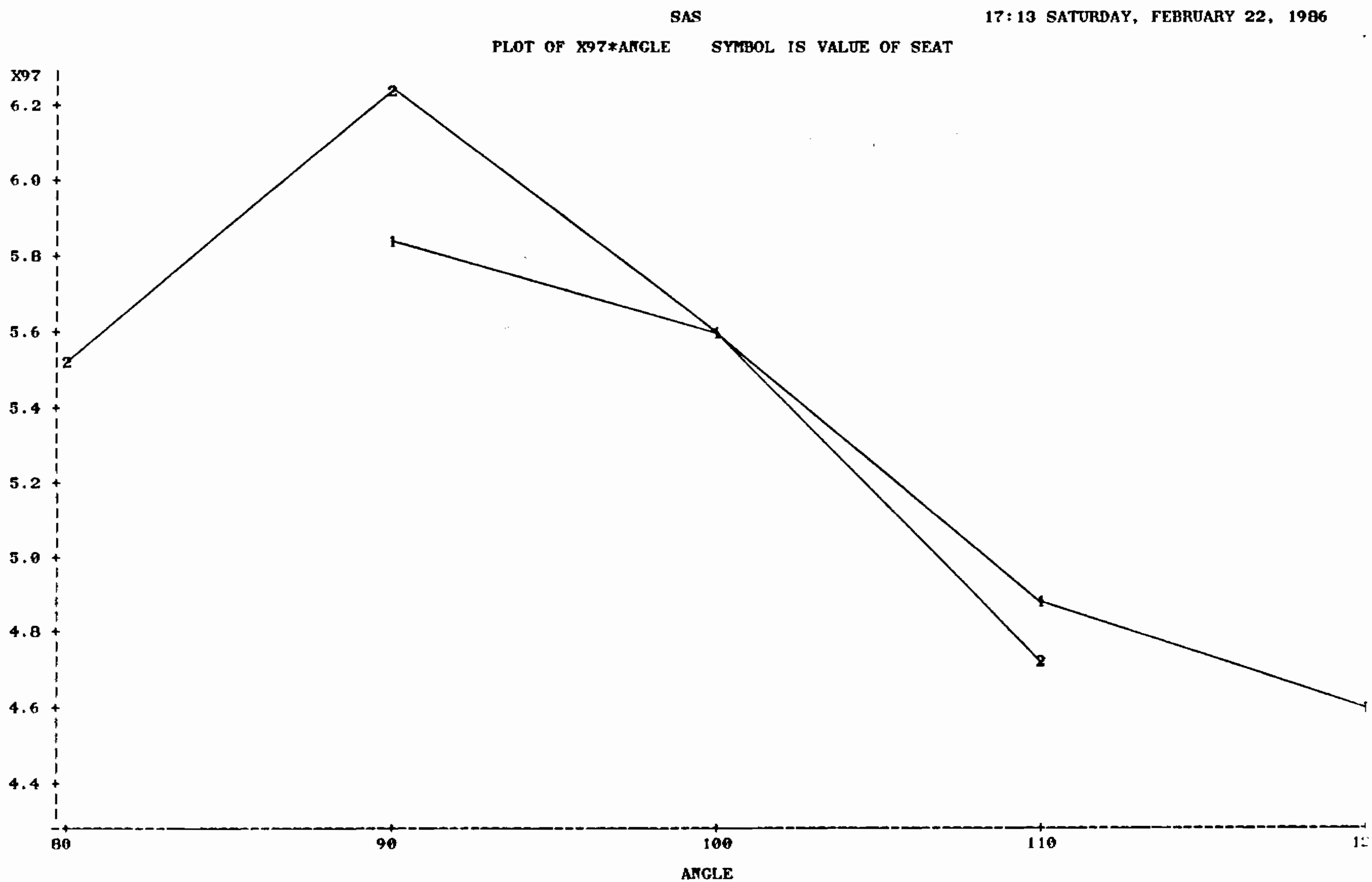


Figure 25. Q.97 * Trunk Angle

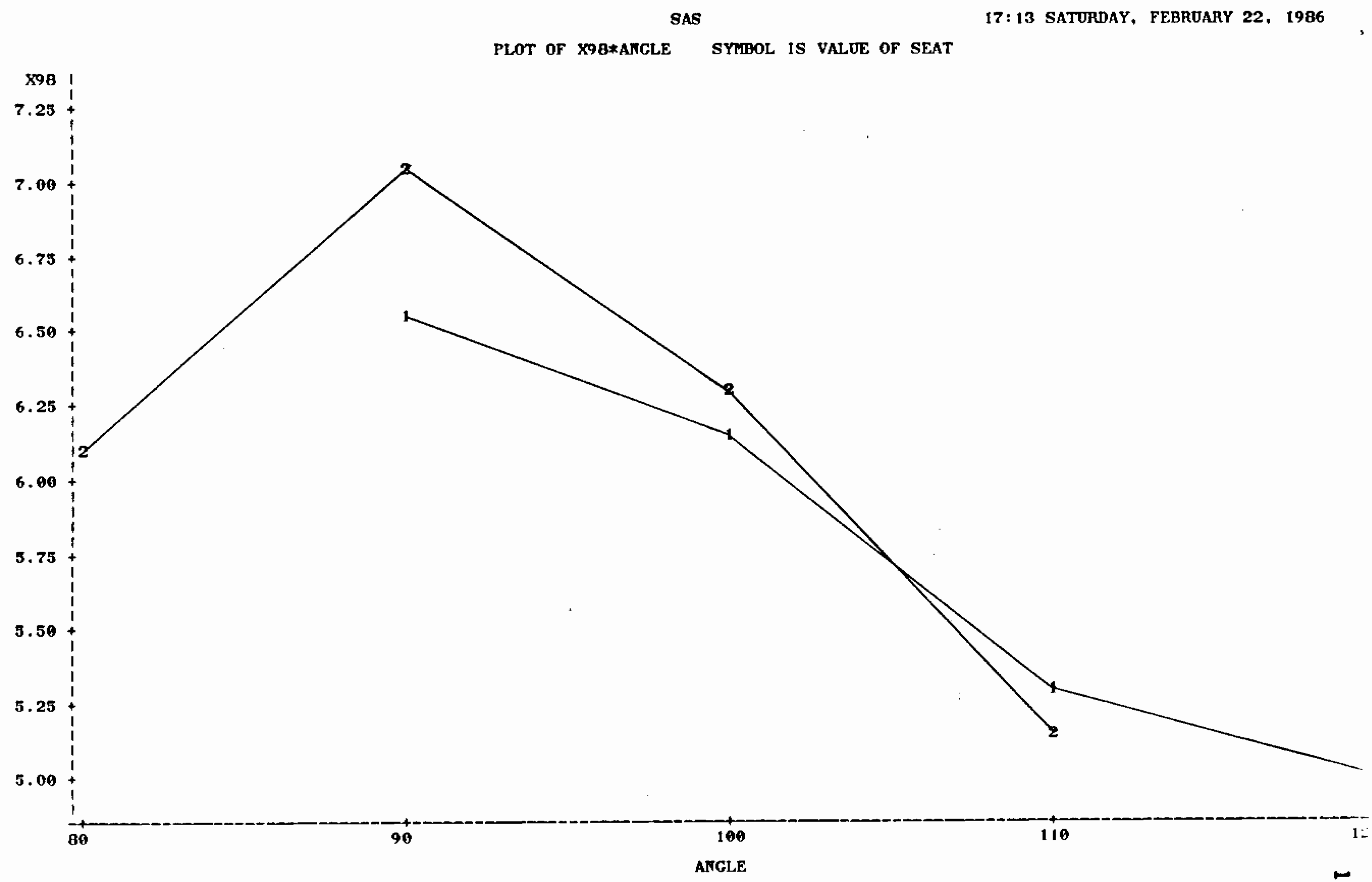


Figure 26. Q.98 * Trunk Angle

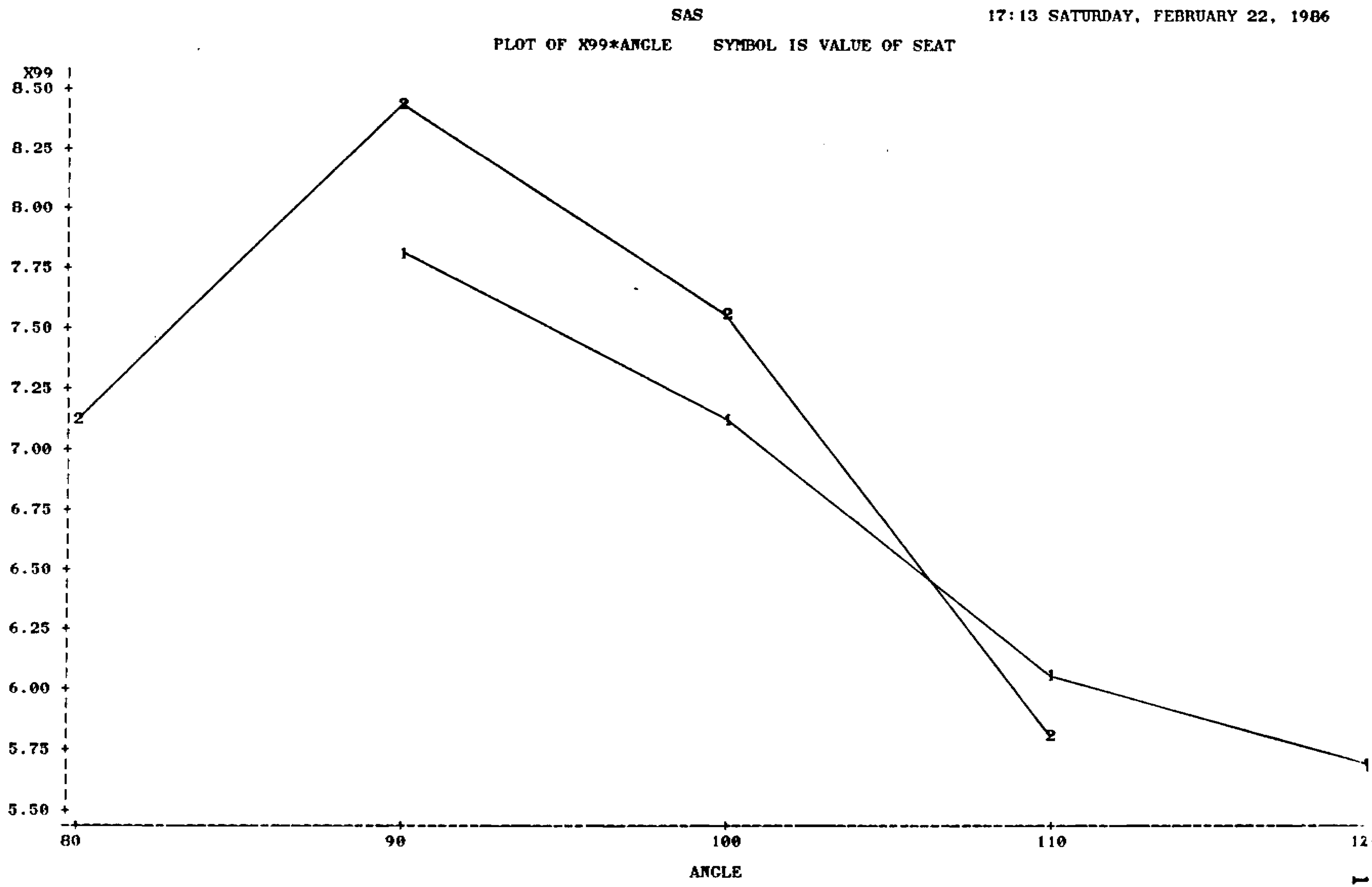


Figure 27. Q.99 * Trunk Angle

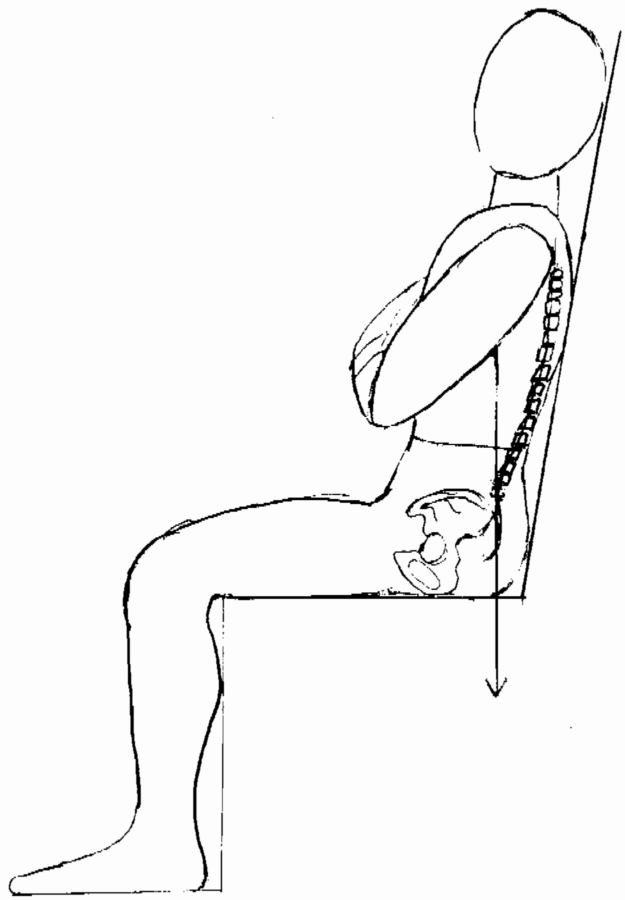


Figure 28. Subject at Seat 0°,Back 100°

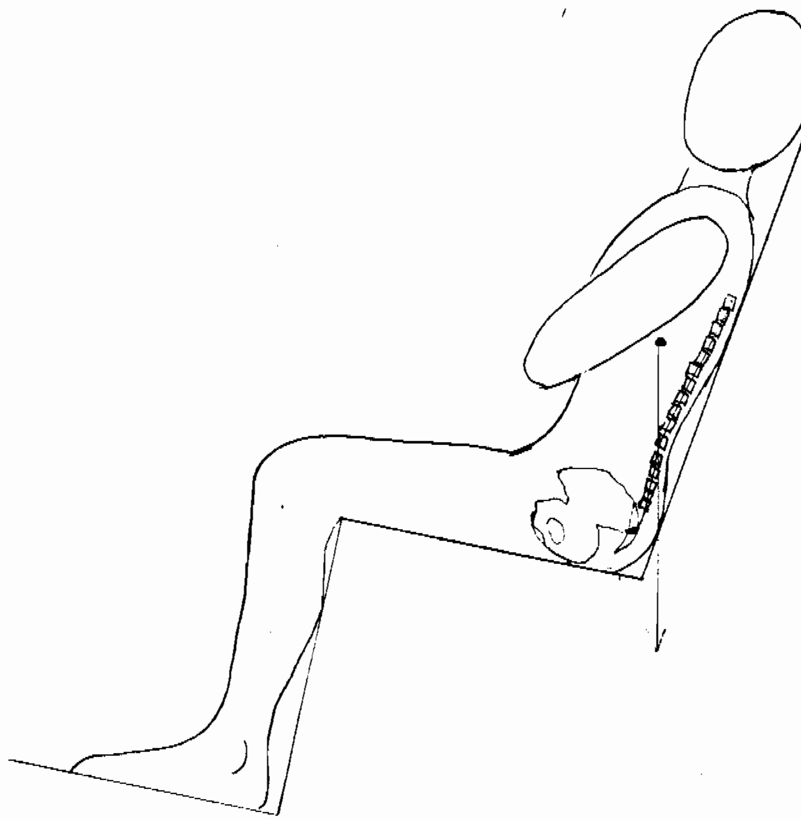


Figure 29. Subject at Seat 10°, Back 110°

6.5 EMG

The results of ANOVA for myoelectric activity showed that the latissimus dorsus muscle was not significant in any of the eight test conditions. This is not unexpected, since the latissimus dorsus probably isn't active during relaxed sitting. On the other hand, the erector spinus muscle was significantly involved. It should be noted that one subject was considered an outlier and excluded from the analysis of the left erector spinus muscle (ESL); the same subject plus two others were likewise excluded from the analysis of the right erector spinus muscle (FSR). This was due to the fact that the electrodes were improperly placed, as ascertained by the lack of recorded differences of the muscles in the eight test conditions.

Research by Andersson et. al., (1974a) indicates that the main factor influencing myoelectric activity of back muscles during sitting was the backrest inclination. If the backrest angles was increased there was always a decrease in activity in all muscles of the back. When the inclination reached 100´, the decrease was less pronounced. The results of this study support the decrease in myoelectric activity with increasing backrest angles. Increasing the seat pan inclination increased the myoelectric activity. This may be due to the fact that the 10° seat pan is "unnatural", and requires a greater level of muscular activity to stabilize the seating posture.

6.6 Recommendations for Chair Design

With the continous pressure data, concentric iso-pressure contour plots and three-dimensional plots were constructed, as shown in Appendix D. This provided a graphical means for locating the highest pressure points, and determining how the size and location of these points change as a function of seat and backrest angles. Rebiffe´s concentric iso-pressure contours show the recommended distribution of pressure on the buttocks and thighs (see Figure 5.), with the highest intensities associated with the ischial tuberosities. However, seating guidelines typically recommend even distribution of pressure and the elimination of localized areas of pressure, such as under the bony prominences.

The results of this study indicate that this was accomplished most effectively by increasing the backrest angle, with the maximum effect at 110° or 120° backrest angle. This finding is intuitively reasonable since more of the body weight was transferred from the seat pan to the backrest as the backrest angles was increased. The body weight would be equally distributed between the seat and backrest when the subject was fully reclined. Since pressure intensity is inversely related to the area it is distributed over, this horizontal position would optimize the distribution of pressure.

Naturally, with regards to task-related chair desings in which the user must perform a specific task, as opposed to relaxed sitting, one cannot make recommendations solely with the intent of optimizing the pressure distribution. The task itself provides additional constraints on chair design. In light of the results of this study, the chair should have a backrest which is capable of reclining to 110° or 120°, if this does not compromise user performance. This would allow the user to shift periodically into a more relax position, which also has the advantage of minimizing the pressure distribution.

6.7 Future Applications

The design of the experimental chair is such that it can be readily modified to test other seating conditions. With adjustable footrests, it would be easy to test the effect on pressure distribution of no lower leg supports, by allowing the feet to hang free. Raising the footrests has the effect of decreasing the knee flexion angle, and the increase in pressure under the ischial tuberosities could be quantified. The results of this type of research would have implications for those workplaces which constrain the worker to such positions. Since the distribution of pressure affects worker comfort, the results may indicate a need to redesign the chair, such as adding more padding or contouring the seat pan to eliminate high pressures. An alternative, though less satisfactory solution would be to provide more breaks so that the worker may get up and walk around to relieve localized areas of high pressure. For jobs which require the worker to utilize foot controls, such as truck drivers, it is important to known the effect of shifting the body weight to one side of the body, especially since these workers are also constrained to a limited sitting posture for long periods of times, with little freedom to move about.

Some other research topics are gerontological and gender considerations. Elderly people are physically and functionally different from the younger adult population. Changes occur in body composition--there is less subcutaneous fat, more intra-abdominal fat and more chest and upper arm fat. Hence, subjective perceptions of comfort, with regards to pressure on the buttocks and thighs, would change with age. Additionally, the changes which occur with increasing age differ for males and females. Females exhibit a greater concentration of body deposits in the buttocks and thighs whereas in males, the prime fat deposition site is in the abdominal region. These factors would affect the center of gravity of the individual, and indirectly, the distribution of pressure.

The effectiveness of various types of contoured seat pans could be investigated by modifying the surface of the experimental chair from a flat surface to a contoured surface. Likewise, this could be applied to measuring the effect of a contoured backrest or a lumbar support on the distribution of pressure on the region of the back. Results of this type of study would prevent the design of backrests which create uncomfortably high pressure points.

6.8 Parenthetical Notes

It should be noted, parenthetically, that a problem with visual "noise" existed in the pressure data processing system. "Noise" as defined by signal detection theory, is the sensory intensity which is not generated by the process being studied. The "signal" is generated by the process. During the filming process, the noise may have been within the videocamera itself, or in the random fluctuations in the intensity of the fluorescent lights on the experimental chair. This would cause erroneous values to be recorded as the luminance level for a given pixel. The noise distribution was assumed to be normal (Gaussian), in accordance to the Central Limit Theorem. The effect of noise was minimized by chosing a strict criterion or cutoff point for noise. In this study, any values below a 20 luminance level was considered noise and eliminated from the analysis.

6.9 Handicapped Subject

The lack of any consistent patterns in the handicapped subject's data is not surprising in light of the nature and severity of his disability. Having a high degree of pelvic obliquity as well as soft tissue contractures, he was not able to sit symmetrically on the experimental chair. Some seating positions were found to be uncomfortable due to his inability to stabilize his posture. Other positions, which were considered awkward or uncomfortable to the normal subject, he found comfortable because they countered his inherent sitting instability.

The present research has wide ranging implications in the area of adaptive seating. The experimental chair provided a quick way to quantify the pressure intensities actually experienced by the patient and the means of locating those areas of high pressure. This information is clinically useful in providing adaptive seating for the subject. But it is not possible to anticipate the subject's response to various seating configurations with respect to the magnitudes of pressure which would be experienced, or the way the pressure would be distributed. Nor are the conclusions, if indeed there are any, generalizable to other handicapped patients. Adaptive seating still requires highly individualized prescriptions in order to fully meet all the patient's seating requirements.

The usefulness of the equipment can be expanded by using it to measure the effectiveness of various types of seat cushions. By placing the cushion ontop of the seat unit, and seating the patient ontop of the cushion, medical personnel would be able to determine whether the cushion has "bottomed out" i.e. whether the weight of the patient has compressed the cushion to the point where it no longer is able to provide any cushioning effect. This could be accomplished simply by looking at the intensities of light created by the cushion. High light intensities correspond to high pressure intensities, which could be easily established by a quick visual inspection. Various thicknesses of cushions could be tested, starting with the thinnest, in order to determine the degree of cushioning needed by the patient, without incurring the unnecessary expense of over-prescribing the cushion needed. In a similar manner, it would be easy to determine when the cushion needs to be replaced, before the patient developes pressure sores.

CHAPTER 7

SUMMARY AND CONCLUSIONS

7.1 Recommendations

The results of this experimental study support the general consensus that increasing the backrest inclination is desireable. Doing so reduces the myoelectric activity of the erector spinae muscles. The inclination of the backrest is more effective in relieving high pressure points than the inclination of the seat pan. Increasing the backrest angle also results in a greater shift of the seating pressure to the backrest. This is verified by the behavior of the Weibull parameters, λ and θ of the backrest data. Both increase as the backrest angle changes from 90° to 120°. Increase in λ and θ indicate a greater spread in the distribution and a shift to higher pressure levels. Likewise, the values of the higher quantiles (Q.95-Q.99) for both seat and backrest data indicate that the backrest takes on high pressure as its angle increases.

The effect of the seat angle is more ambiguous. Often, the seat effect was not found to be significant. Evidence from the EMG analysis indicates that increasing the seat pan angle may be counterproductive in terms of reducing the activity of the back muscle.

The greatest source of variability is due to subject differences in the percent of body fat. Thus, in the design of seats, it is not possible to eliminate high pressure points olely by altering the seat pan and backrest angles; the physicl characteristics of the users must also be taken into account. Likewise, the handicapped subject´s data supports the concept that adaptive seating requires an individualized prescription.

7.2 Future Research

Many questions and concerns were generated as the result of this study. The problem of noise in the system needs to be resolved in order to gain greater accuracy for pressure calibration purposes, and to strengthen the conclusions regarding the high pressure levels and upper tails of the distribution of the pressure data. A more reliable and accurate measure of the amount of soft tissue coverage is needed to correlate subject data with body build. Present results indicate that this is a promising avenue of research. The relationship between trunk angle and the subject's center of gravity also deserves attention. The issues of center of gravity and bilateral symmetry should be explored further. All of these areas would increase our present knowledge of seating parameters and lead to better seat designs.

With regards to the handicapped aspect of the research, the measurement of seating pressures is only the first step in a long series of research into the issue of adaptive seating. Additional studies should be performed on the impact of asymmetrical sitting on the pressure distribution, quantifying the degree of scoliosis or pelvic obliquity and correlating this to the pressure distribution. This research questions have a particular urgency; without properly designed seating systems, the physically disabled individual is limited in his/her ability to lead an active and productive life.

APPENDIX: A

I hereby acknowledge that W. S. Marras has provided information about the procedure described above, about my rights as a subject, and he/she answered all questions to my satisfaction. I understand that I may contact him/her should I have additional questions. He/She has explained the risks described above and I understand them; he/she has also offered to explain all possible risks or complications.

I understand that, where appropriate, the U.S. Food and Drug Administration may inspect records pertaining to this study. I understand further that records obtained during my participation in this study may be made available to the sponsor of this study and that the records will not contain my name or other personal identifiers. Beyond this, I understand that my participation will remain confidential.

I understand that I am free to withdraw my consent and participation in this project at any time after notifying the project director without prejudicing future care. No guarantee has been given to me concerning this treatment or procedure.

In the unlikely event of injury resulting from participation in this study, I understand that immediate medical treatment is available at University Hospital of The Ohio State University. I also understand that the costs of such treatment will be at my expense and that financial compensation is not available. Questions about this should be directed to the Human Subject Review Office at 422-9046.

I have read and fully understand the consent form. I sign it freely and voluntarily. A copy has been given to me.

Date: ____________ Time ______ AM/PM Signed ______________________________

(Subject)

Witness(es) if Required ______________________

____

____

(Person Authorized to Consent for Subject - If Required)

I certify that I have personally completed all blanks in this form and explained them to the subject or his/her representative before requesting the subject or his/her representative to sign it.

Signed: ______________________________

(Signature of Project Director or his/her Authorized Representative)

Form HS-028A (Rev. 12/8'`

CONSENT TO INVESTIGATIONAL TREATMENT OR PROCEDURE

I, ______________, hereby authorize or direct W. S. Marras or associates or assistants of his or her choosing, to perform the following treatment or procedure (describe in general terms). attach electrodes to lower back, and be seated upon an experimental chair with an adjustable backrest, set and leg rests.
seat
upon myself (myself or name of subject).

The experimental (research) portion of the treatment or procedure is: to observe muscle activities and pressure from buttocks and thigh region during different sitting postures.

This is done as part of an investigation entitled: Pressure Measurements and Myoelectric Activity as a Function of Seating Parameters.

1. Purpose of the procedure or treatment: Determine amounts of pressure produced on different parts of the body during different sitting postures, and also the amount of muscle actitivty.

2. Possible appropriate alternative methods of treatment: Not to participate in study.

3. Discomforts and risks reasonably to be expected: Mild discomfort from sitting on a rigid surface.

4. Possible benefits for subjects/society: Knowledge of an optimal chair configuration which produces the least amount of muscular strain and least amount of pressure while sitting.

5. Anticipated duration of subject's participation: $2\frac{1}{2}$ to 3 hours.

APPENDIX B

PRESSURE CALIBRATION

The deformation of the pedobarograph foil under pressure was recorded as a series of digitized numbers, each ranging from 0 to 255, which represented the luminance levels. In order to quantify this deformation under various test conditions, it was necessary to calibrate the luminance level with known weights.

A small block of aluminum, with known dimensions, was placed on the surface of the seat unit of the experimental chair. It served as the base upon which known weights were placed, from one to twenty pounds, in one pound intervals. For each weight level, the deformation of the pedobarograph foil, which resulted in a unique pattern of light intensities, was recorded with a videocamera, and digitized as described earlier. The digitized values were averaged to obtain the average luminance level for each weight tested.

Several problems occurred which complicated this averaging proces. Due to a large amount of noise present in the system, it was difficult to exactly determine the area of interest. It was expected that the digitized PSI levels would look similar to Figure 30 in which the load bearing regions would be marked with nonzero values, and non-load areas marked with zero values. A sample of the digitized values of 1 PSI is shown in Figure 31. From this it can be seen that there are no sharply defined "edges". Thus it is unclear what are should be used in the averaging process. A second problem can be seen in Figure 32, a sample of digitized values at 15 PSI. There is a "blurring" effect at the edges, where the pressure deformation extends beyond the actual edges of the base.

The problem of obtaining average luminance values for the weight levels tested, was circumvented as follows: The approximate center of the area of the base located, then concentric square matrices were established and averaged over: 3x3 matrix, 5x5 matrix and 7x7 matrix. Three separated calibration curves were developed for each matrix, and a regression curve was fitted through these curves to get the final calibration curve shown in Figure 33.

Y/X :	103	104	105	106	107	108	109	110	111	112	113	114	115	116
152:	0	0	0	0	0	0	0	0	0	0	0	0	0	0
153:	0	0	0	0	0	0	0	0	0	0	0	0	0	0
154:	0	0	0	0	0	0	0	0	0	0	0	0	0	0
155:	0	0	0	0	0	0	0	0	0	0	0	0	0	0
156:	0	0	0	0	0	0	0	0	0	0	0	0	0	0
157:	0	0	0	23	35	22	28	24	30	27	0	0	0	0
158:	0	0	0	33	24	36	29	31	27	21	0	0	0	0
159:	0	0	0	30	25	22	29	25	24	35	0	0	0	0
160:	0	0	0	25	27	27	34	38	25	28	0	0	0	0
161:	0	0	0	27	21	26	33	37	26	29	0	0	0	0
162:	0	0	0	22	27	29	35	26	28	20	0	0	0	0
163:	0	0	0	28	26	35	30	32	38	25	0	0	0	0
164:	0	0	0	0	0	0	0	0	0	0	0	0	0	0
165:	0	0	0	0	0	0	0	0	0	0	0	0	0	0
166:	0	0	0	0	0	0	0	0	0	0	0	0	0	0
167:	0	0	0	0	0	0	0	0	0	0	0	0	0	0
168:	0	0	0	0	0	0	0	0	0	0	0	0	0	0
169:	0	0	0	0	0	0	0	0	0	0	0	0	0	0
170:	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 30. 1 PSI (Expected)

Y \ X	:	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117
152	:	0	0	0	0	0	0	0	0	0	0	0	21	0	0	0	0	0	0
153	:	0	0	0	0	0	18	0	0	0	11	0	0	0	0	0	0	0	0
154	:	0	0	0	0	0	0	0	0	0	37	0	19	0	37	0	0	0	0
155	:	0	0	0	0	0	1	0	39	0	24	0	25	0	24	0	0	0	0
156	:	0	0	0	0	0	12	0	32	0	21	18	39	0	5	0	0	0	0
157	:	0	0	0	0	0	6	8	8	16	37	24	35	37	38	0	0	0	0
158	:	0	0	0	15	0	16	0	18	24	30	13	20	40	2	0	0	0	0
159	:	0	0	0	0	0	16	26	12	4	56	31	30	39	15	0	0	0	0
160	:	0	0	0	5	4	0	0	38	25	0	35	48	51	0	0	0	0	0
161	:	0	0	0	17	18	40	3	42	8	46	17	48	46	0	0	0	0	0
162	:	0	0	0	0	23	32	0	29	0	32	20	35	47	0	0	0	0	0
163	:	0	0	0	0	28	0	24	2	36	25	40	27	20	17	0	0	0	0
164	:	0	0	0	0	28	0	47	0	20	0	52	0	44	0	0	0	0	0
165	:	0	0	0	0	7	0	9	0	50	21	30	0	38	0	7	0	0	0
166	:	0	0	0	0	0	0	8	0	17	0	28	0	40	0	3	0	0	0
167	:	0	0	0	0	6	0	4	0	0	0	0	0	3	0	0	0	0	0
168	:	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
169	:	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
170	:	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 31. 1 PSI (Actual)

Y \ X	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117
152	131	0	13	0	94	0	26	0	0	0	50	0	128	0	0	0	0	0
153	0	0	172	0	144	0	172	0	38	39	170	40	169	0	0	0	0	0
154	104	0	160	0	201	0	188	115	139	29	127	43	153	75	35	0	0	0
155	0	154	216	147	156	83	154	119	146	128	129	123	136	84	64	0	0	0
156	27	82	143	158	195	101	151	112	139	142	163	130	149	66	31	0	0	0
157	0	127	153	190	205	211	142	150	198	149	181	167	174	158	49	0	0	0
158	159	128	195	153	223	214	233	184	140	185	183	159	159	128	22	0	0	0
159	88	173	169	185	145	167	199	207	200	184	189	149	136	85	0	1	0	0
160	0	0	150	211	133	137	211	143	148	137	135	139	177	136	31	84	0	0
161	0	161	174	204	151	134	214	172	129	186	128	169	161	156	45	0	4	0
162	75	31	209	184	152	211	192	163	140	180	188	131	120	112	0	0	0	0
163	0	110	125	182	160	176	187	170	128	192	128	150	145	122	0	0	0	0
164	6	105	170	225	140	219	88	213	121	121	138	169	131	128	0	0	0	0
165	0	84	159	139	134	191	96	198	99	116	0	164	75	150	0	0	0	0
166	0	85	150	179	0	188	185	159	140	149	26	148	0	122	0	0	0	0
167	0	126	43	174	128	185	30	172	0	144	0	92	46	92	0	18	0	0
168	0	66	79	158	0	117	16	137	0	164	0	34	0	78	0	0	0	0
169	0	70	0	139	0	80	0	131	0	140	0	23	0	10	0	0	0	0
170	0	92	0	0	0	29	0	0	0	20	0	8	0	121	0	0	0	0

Figure 32. 15 PSI (Actual)

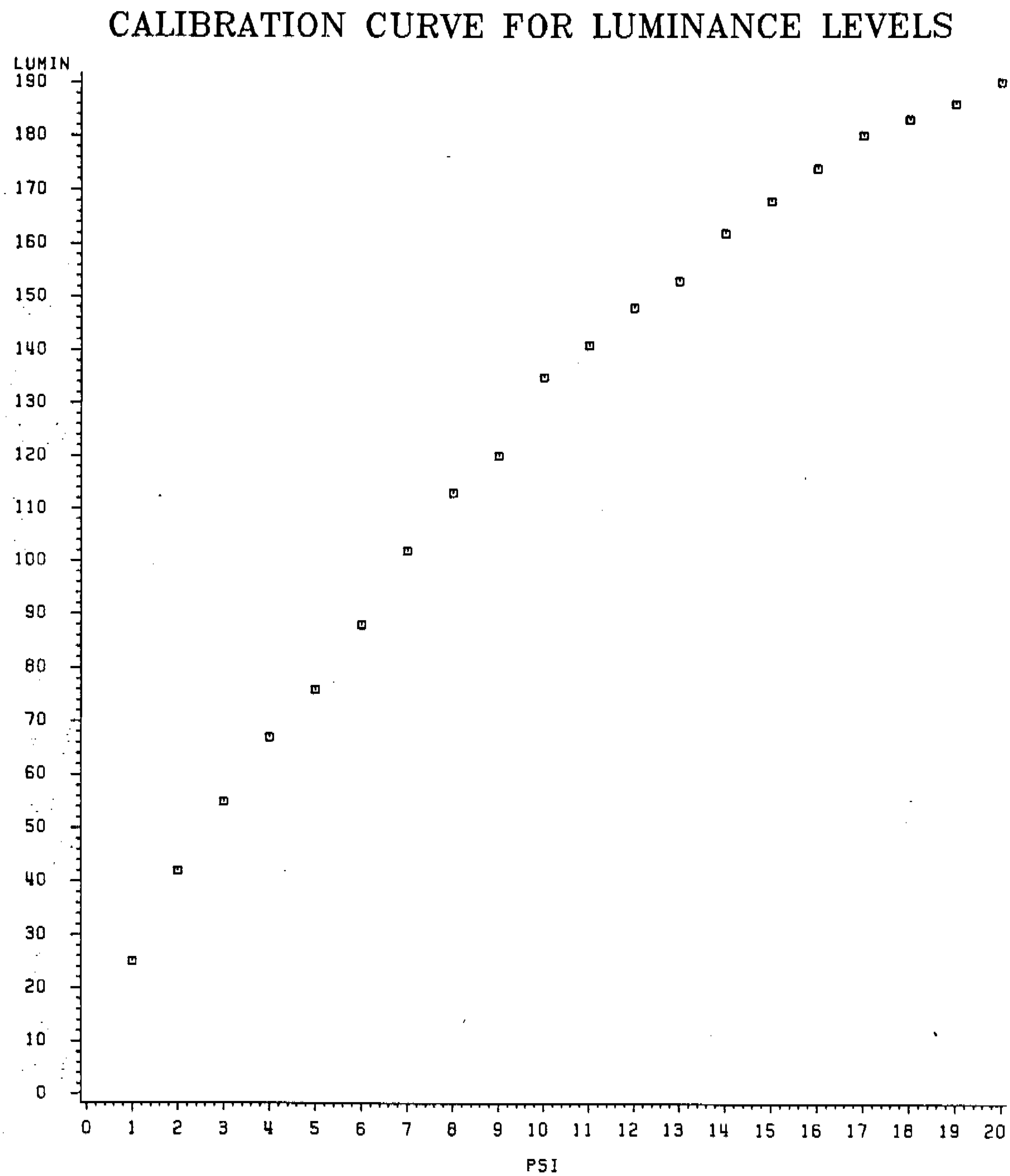


Figure 33. Calibration Curve.

APPENDIX: C

WEIBULL DISTRIBUTION

At the heart of probabilistic statistical analysis is the assumption that a set of data arises as a sample from a distribution in a class of probability distributions. The reasons for making distributional assumptions about data are several (Chambers, et. al., 1983):

1. If a set of data can be described as a sample from a certain theoretical distribution, say a normal distribution, then there is a valuable compactness of description for the data. For example, in the normal case, the data can be succinctly described by giving the mean and standard deviation and stating that the empirical (sample) distribution of the data is well approximated by the normal distribution.

2. Distributional assumptions can lead to useful statistical procedures, such as analysis of variance and least squares.

3. The assumptions allow characterization of the

sampling distribution of statistics computed during analysis. Inferences and probabilistic statements can be made about unknown aspects of the underlying distribution. For example, assuming the data are a sample from a normal distribution allows the use of the t-distribution to form confidence intervals for the mean of the theoretical distribution.

4. The distribution of a set of data can sometimes shed light on the physical mechanisms involved in generating the data.

Analyses based on specific distribution assumptions about data are not valid if the assumptions are not met to a reasonable degree. To test distributional assumptions about data, the data should be "fitted" to the assumed distribution.

The Weibull distribution is a general distribution for continuous nonzero random variables, and can take into account a wide variety of parameters and shapes. A random variable is said to have a Weibull distribution with parameters λ and θ ($\lambda > 0$, $\theta > 0$) if X has a continuous distribution with the following

p. d.f.:

Eq. 3 $$f(x \mid \lambda, \theta) = \frac{\theta}{\lambda^{\theta}} x^{\theta-1} e^{\left(-\frac{x}{\lambda}\right)^{\theta}} \quad \text{for } x>o$$

$$0 \quad \text{for } x<=0$$

(DeGroot, 1975). The Weibull distribution function, in closed form, is as follows:

Eq. 4 $$F(y \mid \lambda, \theta) = 1 - \exp\{-(y / \lambda)^{\theta}\}$$

The parameters λ and θ indicate the spread and shape of the distribution, respectively. High values of λ indicate a larger spread or greater variability in the distribution; as θ --> 3, for a fixed λ, the distribution approaches the normal distribution. Figures 34-39 show plots of the distribution with and θ varying systematically from 1-3.

WEIBULL DISTRIBUTION
1 THETA = 3 LAMBDA = 1
2 THETA = 3 LAMBDA = 2
3 THETA = 3 LAMBDA = 3

0:06 FRIDAY, FEBRUARY 21, 1986

PLOT OF Y*X SYMBOL IS VALUE OF VERSION

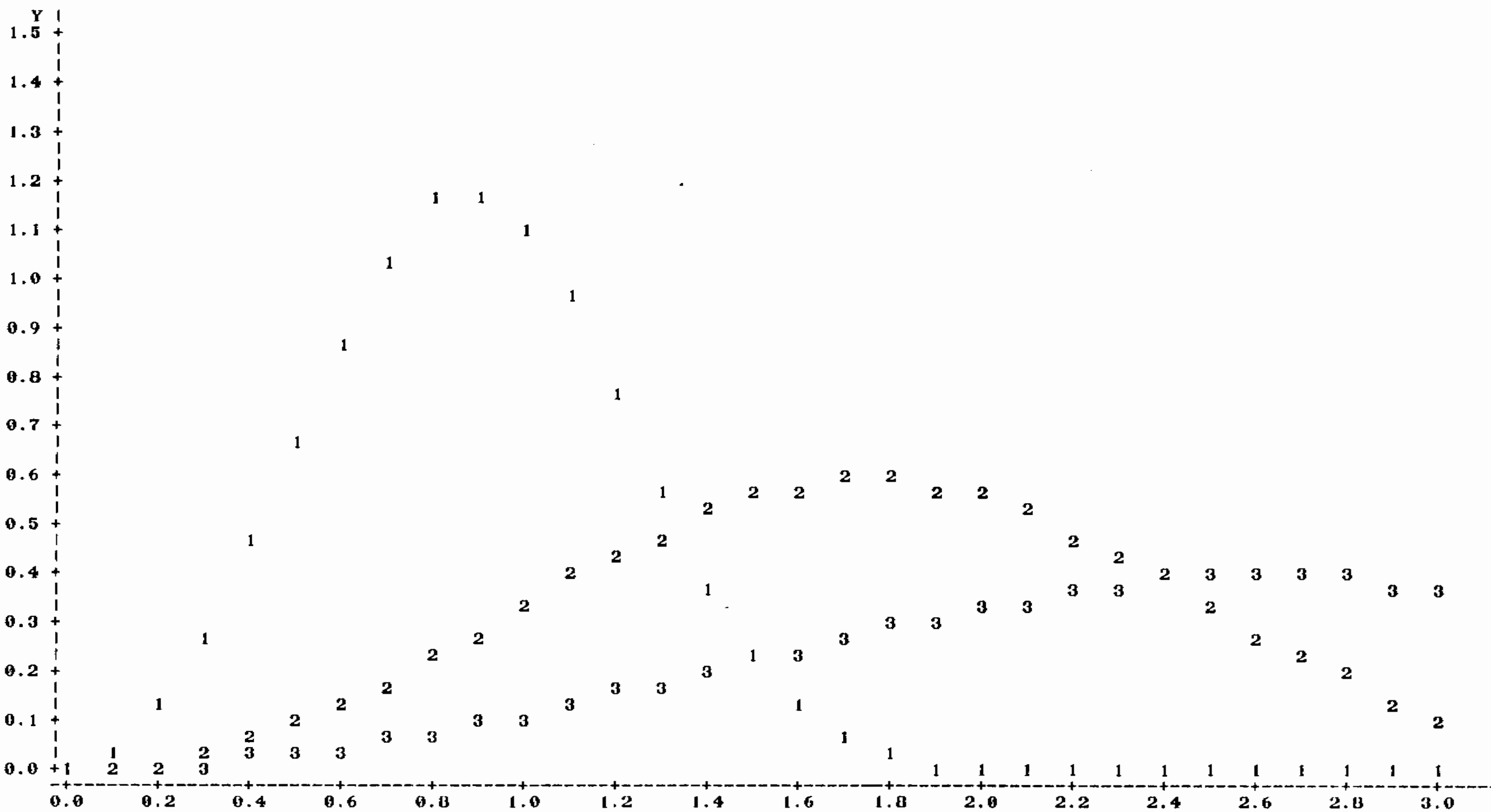


Figure 34. Weibull Distribution: $\theta=1$, $\lambda=1$ 3

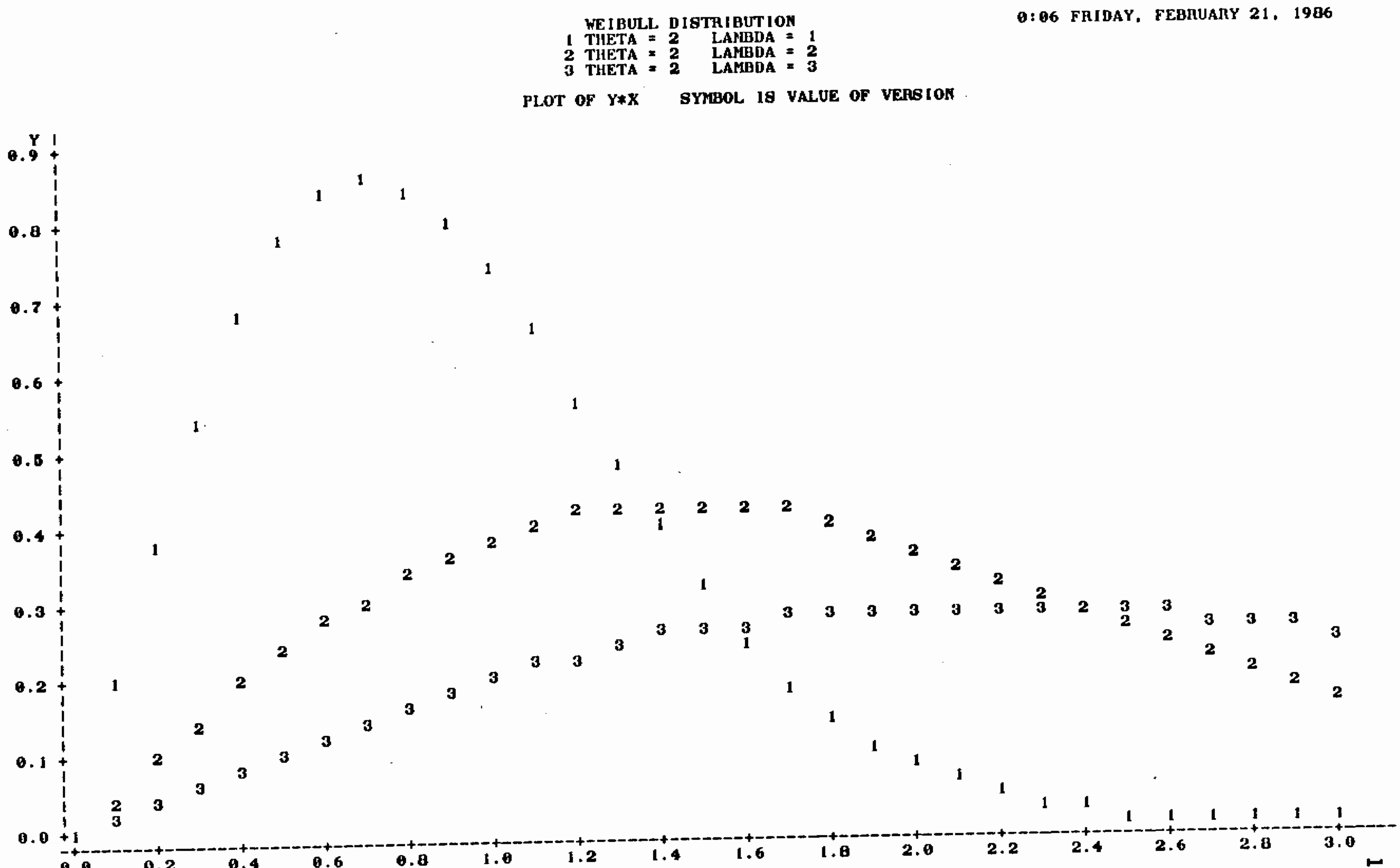


Figure 35. Weibull Distribution: $\theta=2$, $\lambda=1-3$

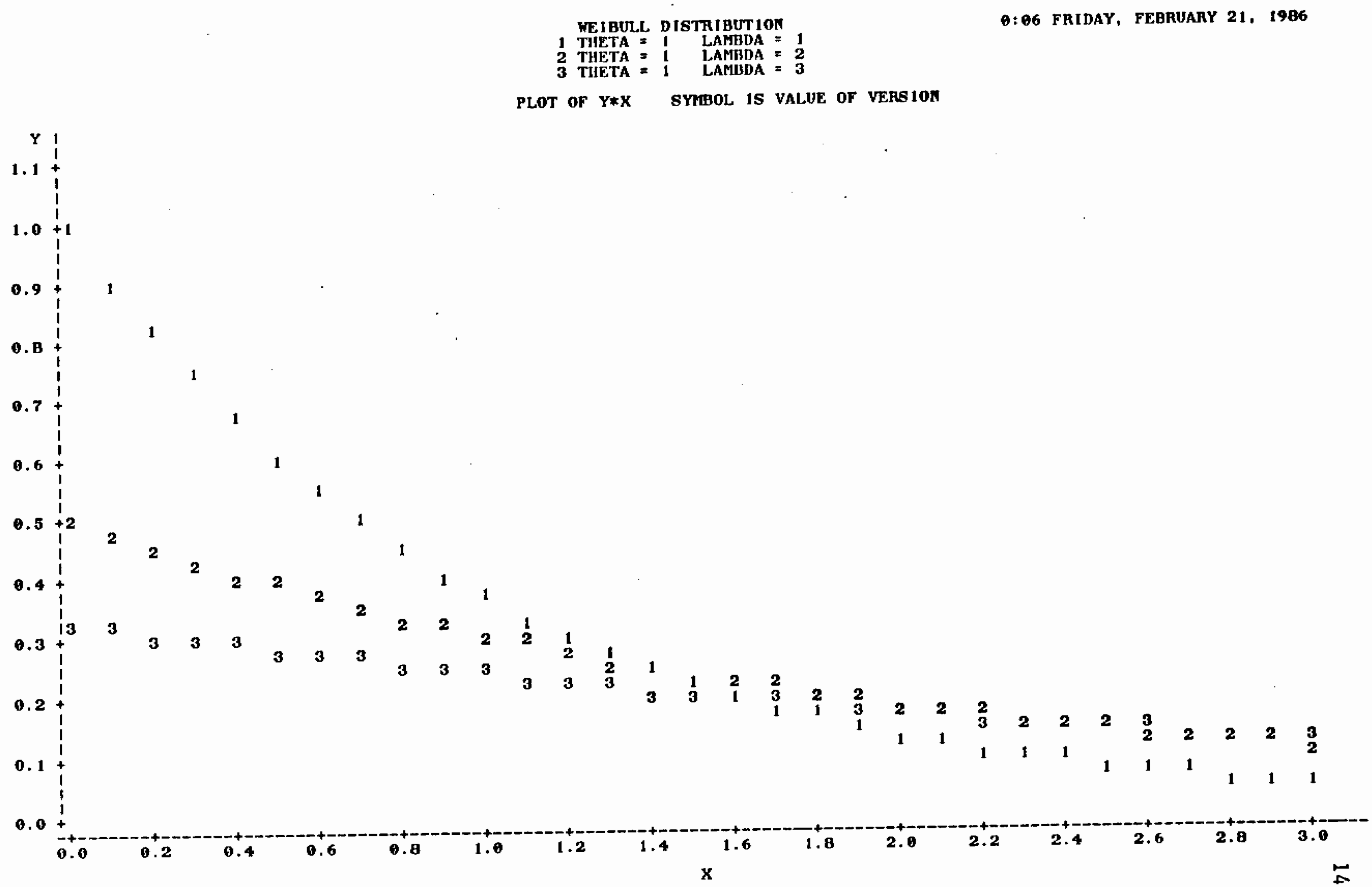


Figure 36. Weibull Distribution: $\theta=3$, $\lambda=1-3$

WEIBULL DISTRIBUTION
1 THETA = 1 LAMBDA = 1
2 THETA = 2 LAMBDA = 1
3 THETA = 3 LAMBDA = 1

0:06 FRIDAY, FEBRUARY 21, 1986

PLOT OF Y*X SYMBOL IS VALUE OF VERSION

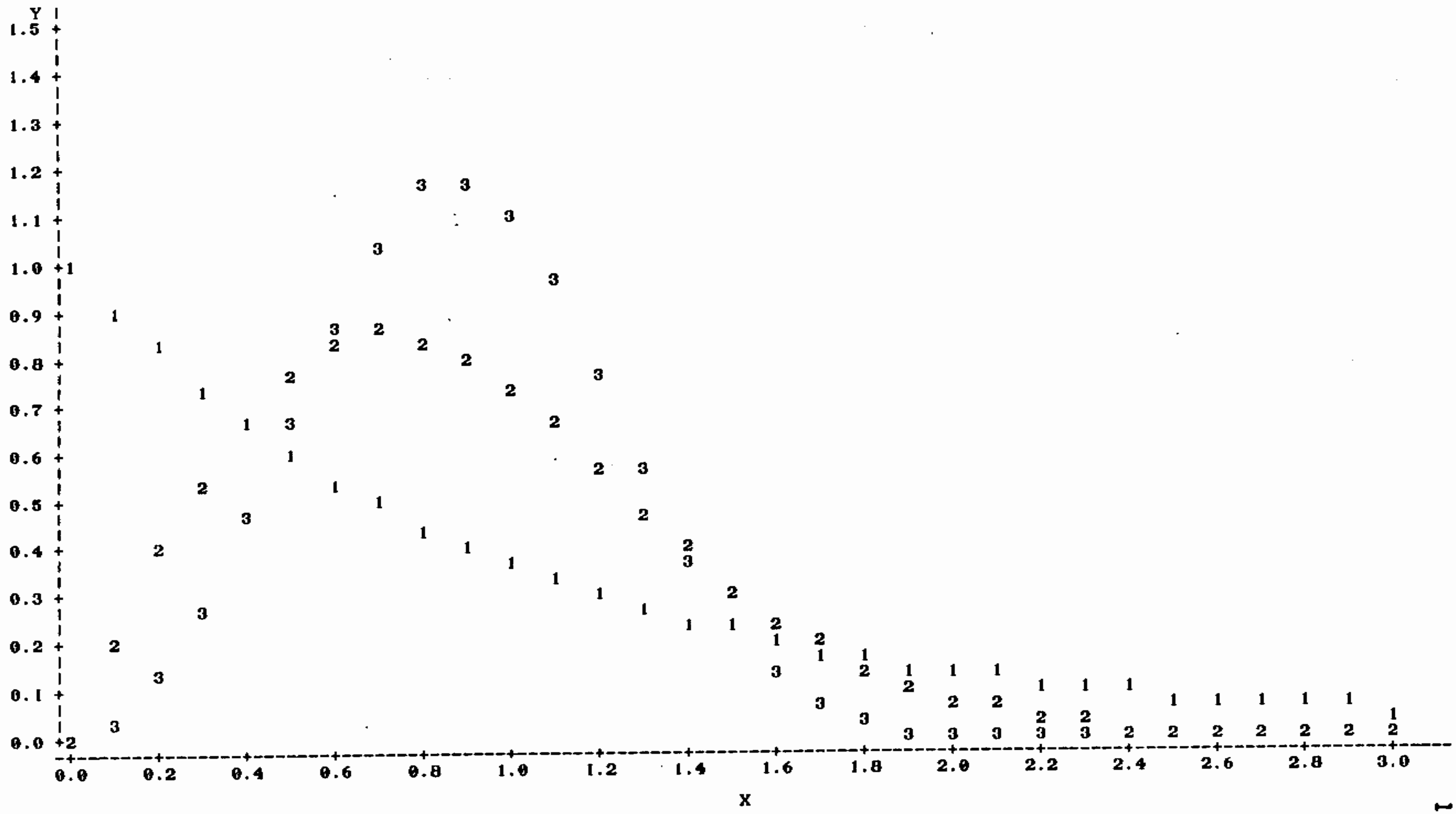


Figure 37. Weibull Distribution: θ=1-3, λ=1

WEIBULL DISTRIBUTION
1 THETA = 1 LAMBDA = 2
2 THETA = 2 LAMBDA = 2
3 THETA = 3 LAMBDA = 2

0:06 FRIDAY, FEBRUARY 21, 1986

PLOT OF Y*X SYMBOL IS VALUE OF VERSION

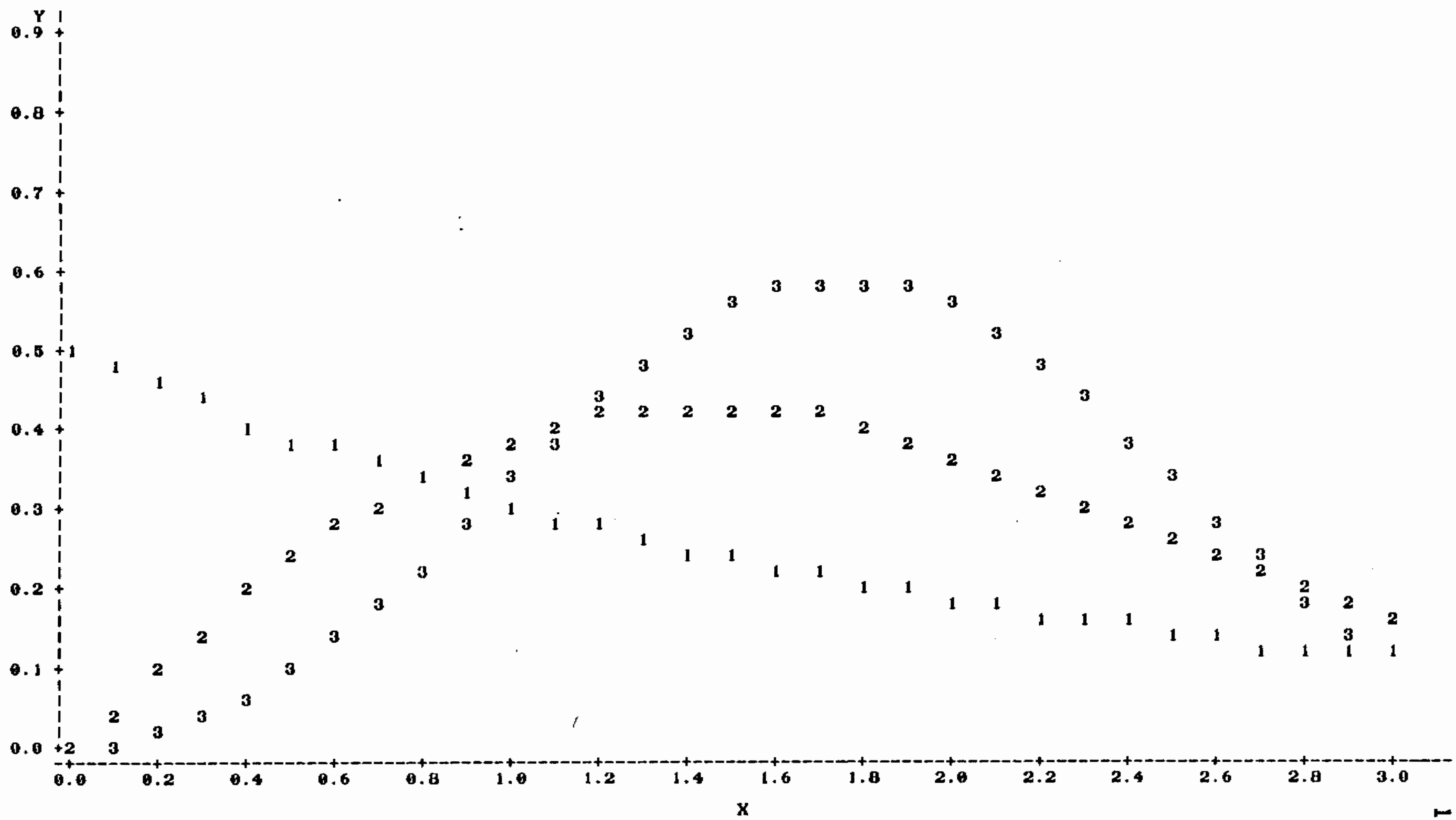


Figure 38. Weibull Distribution: θ=1-3, λ=2

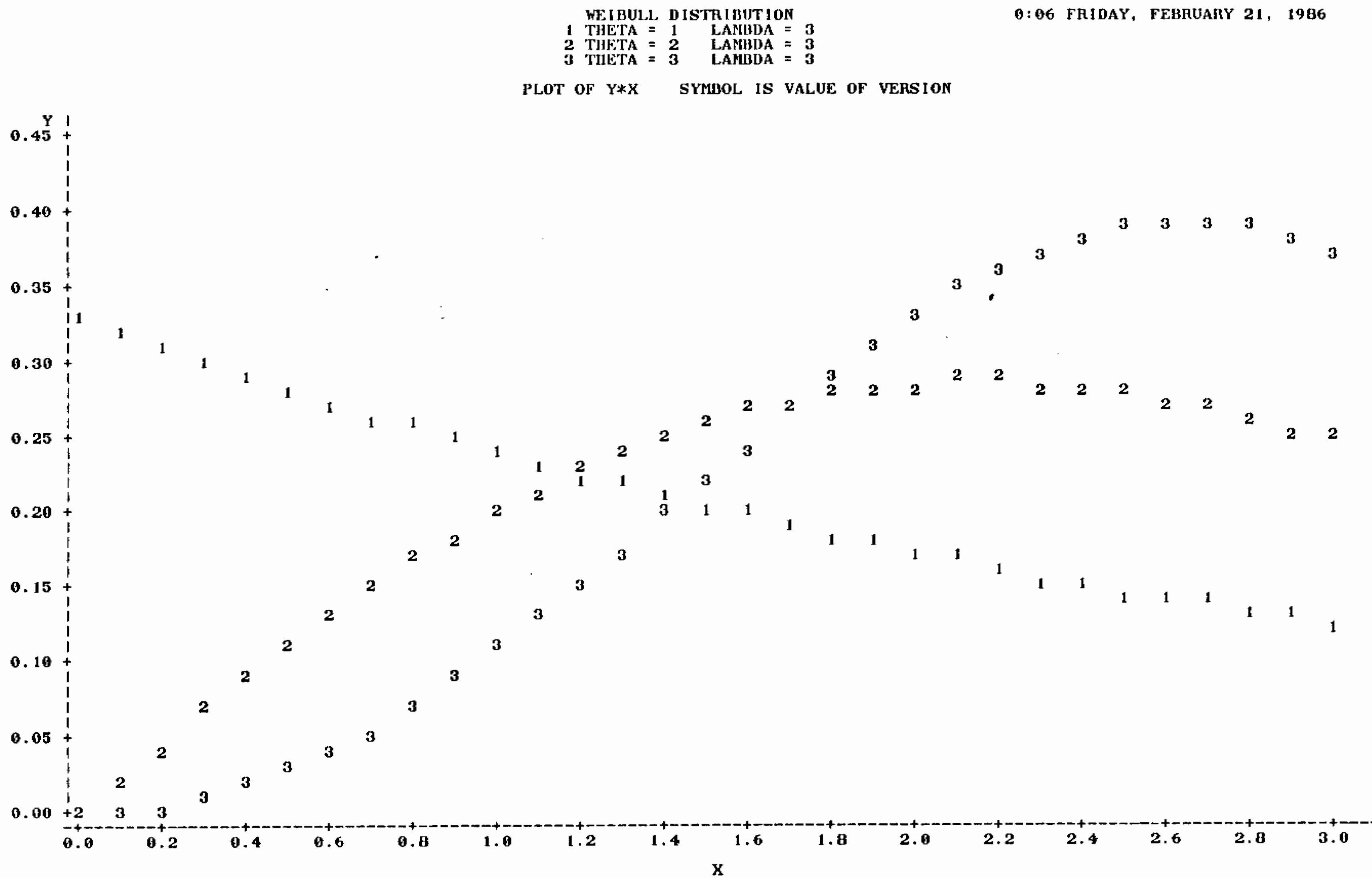
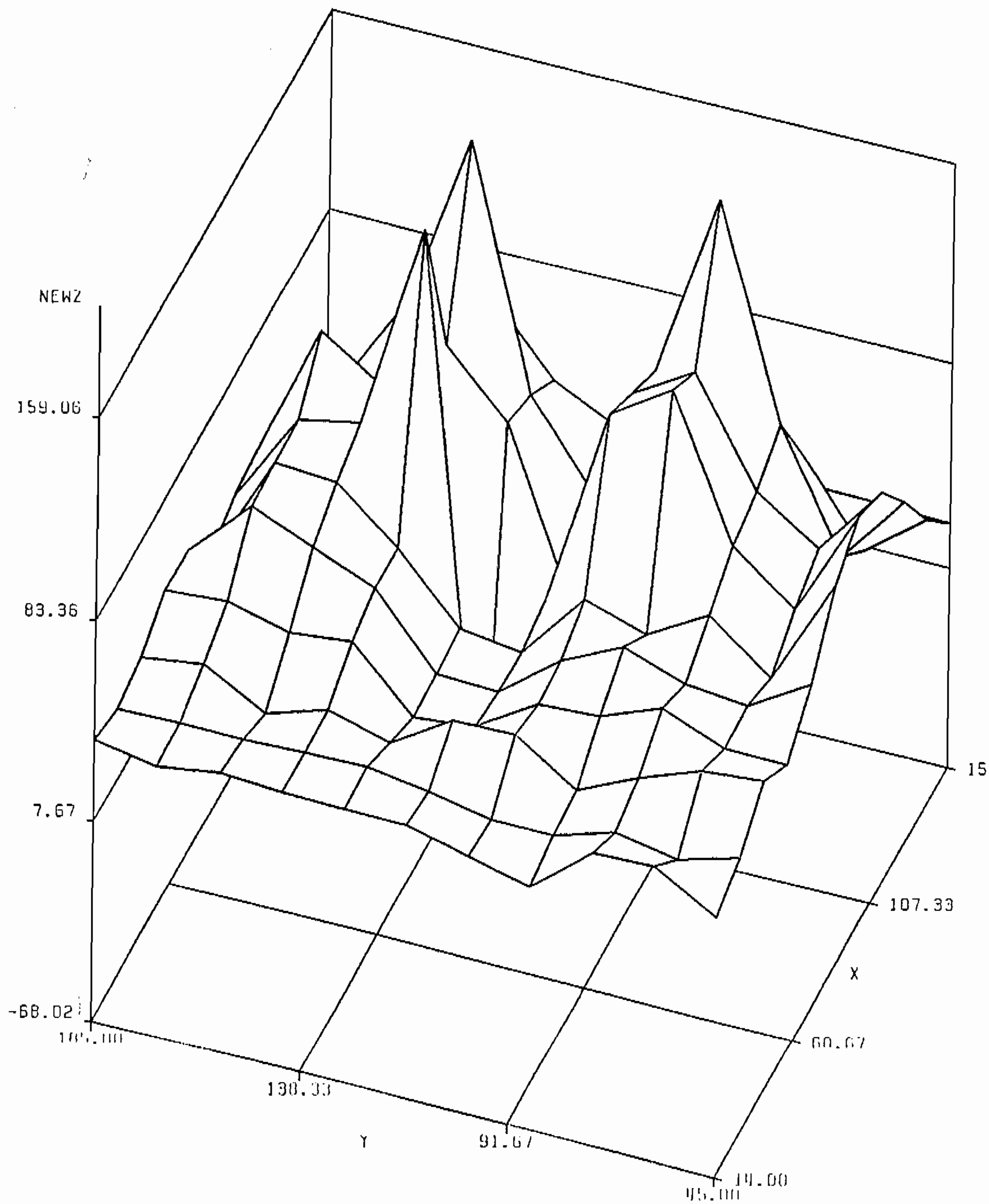


Figure 39. Weibull Distribution: $\theta=1-3$, $\lambda=3$

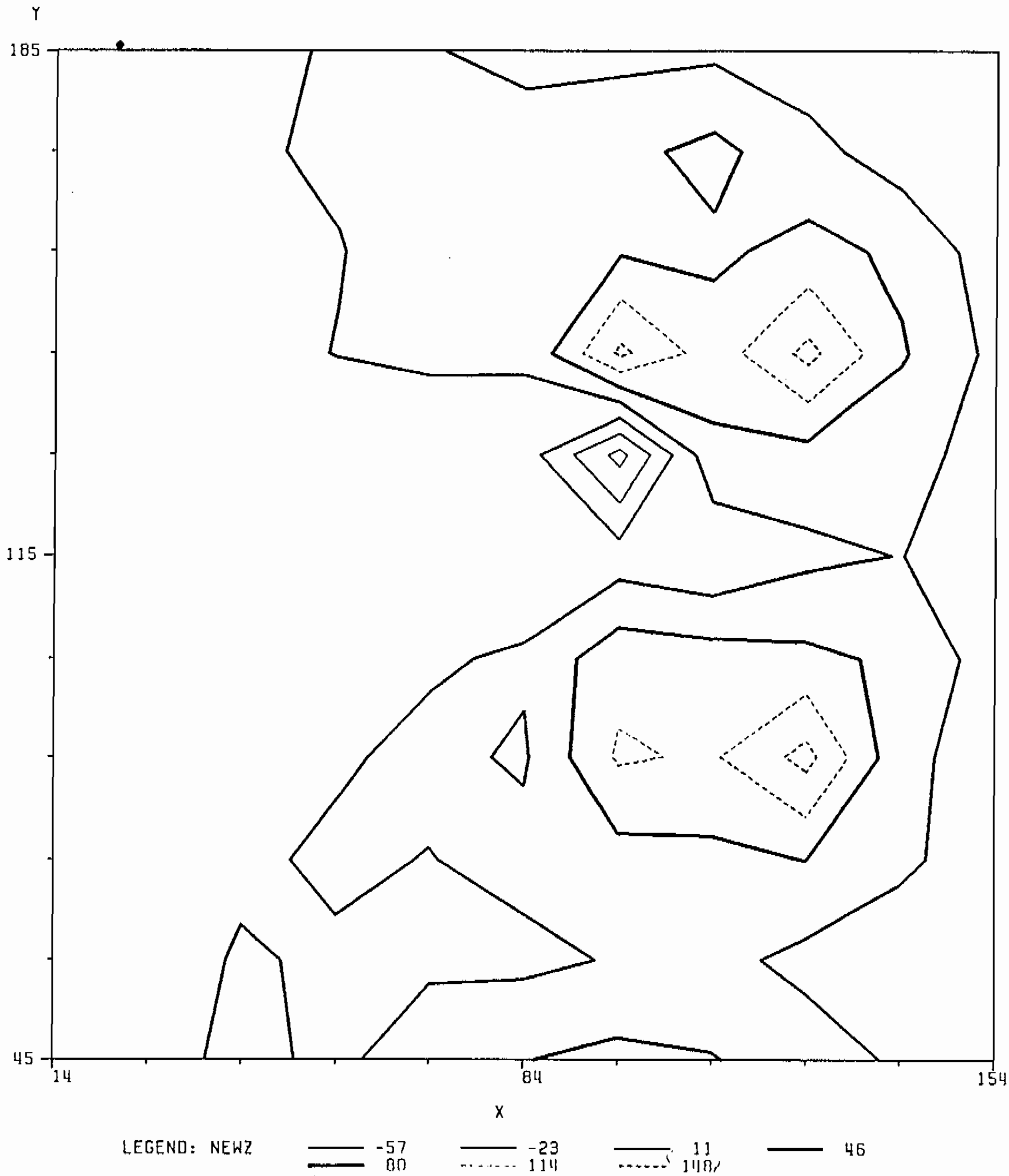
APPENDIX D

```
                 SUBJECT A--SEAT PRESSURE--HISTOGRAM OF PRESSURE INTENSITY
                                          SEAT=0
                                        BACK = 90

                                    FREQUENCY BAR CHART
MIDPOINT
   Z                                                                                        FREQ   CUM.   PERCENT    CUM.
                                                                                                   FREQ            PERCENT
      |
  25  |************************************************************************             3619   3619    24.46    24.46
      |
  42  |*********************************************************************                3458   7077    23.37    47.83
      |
  55  |*********************************************************                            2852   9929    19.28    67.11
      |
  67  |********************************                                                     1600  11529    10.81    77.92
      |
  76  |***********************                                                              1163  12692     7.86    85.78
      |
  88  |****************                                                                      796  13488     5.38    91.16
      |
 102  |**********                                                                            520  14008     3.51    94.67
      |
 113  |****                                                                                  183  14191     1.24    95.91
      |
 120  |***                                                                                   127  14318     0.86    96.77
      |
 135  |**                                                                                     96  14414     0.65    97.42
      |
 141  |*                                                                                      34  14448     0.23    97.65
      |
 148  |*                                                                                      28  14476     0.19    97.84
      |
 153  |*                                                                                      30  14506     0.20    98.04
      |
 162  |*                                                                                      27  14533     0.18    98.22
      |
 166  |                                                                                       18  14551     0.12    98.34
      |
 174  |                                                                                       17  14568     0.11    98.46
      |
 180  |                                                                                        5  14573     0.03    98.49
      |
 183  |                                                                                        6  14579     0.04    98.53
      |
 186  |                                                                                        6  14585     0.04    98.57
      |
 190  |****                                                                                  211  14796     1.43   100.00
      |
      --------+--------+--------+--------+--------+--------+--------+--------+--------+
             400      800     1200     1600     2000     2400     2800     3200     3600

                                       FREQUENCY
```

SUBJECT A -- SEAT PRESSURE
SEAT = 0
BACK = 90

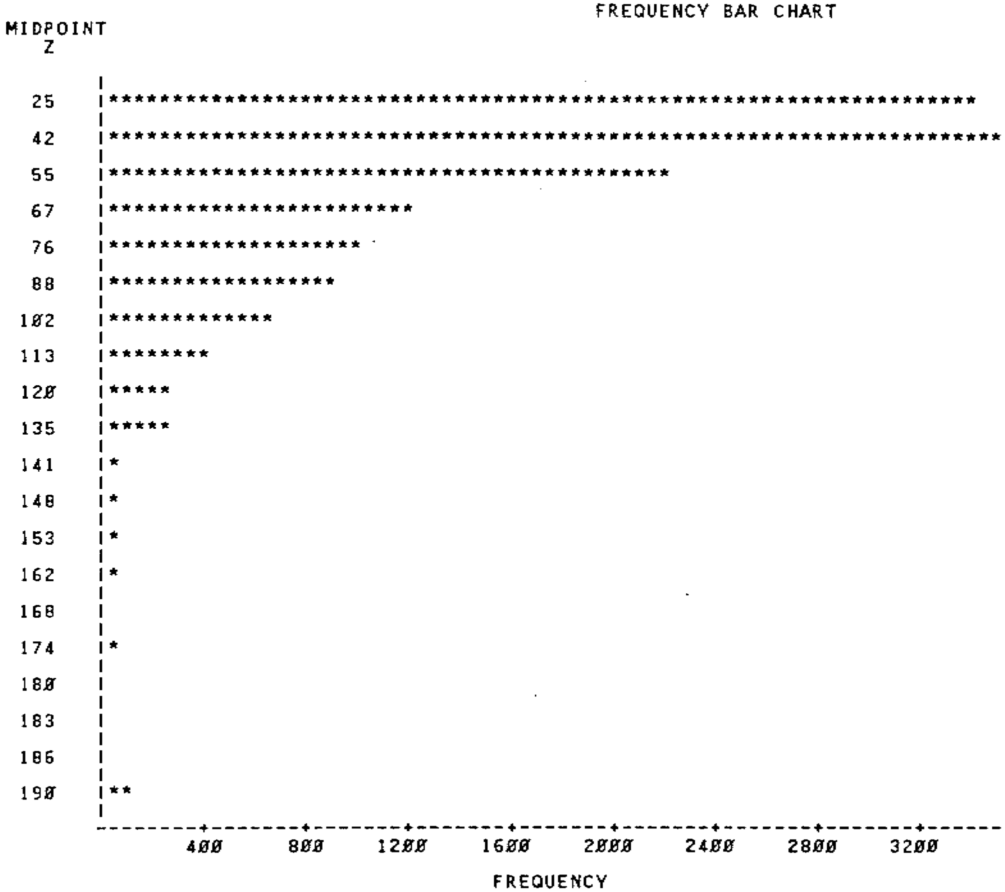


# SUBJECT A -- SEAT PRESSURE
SEAT = 0
BACK = 90



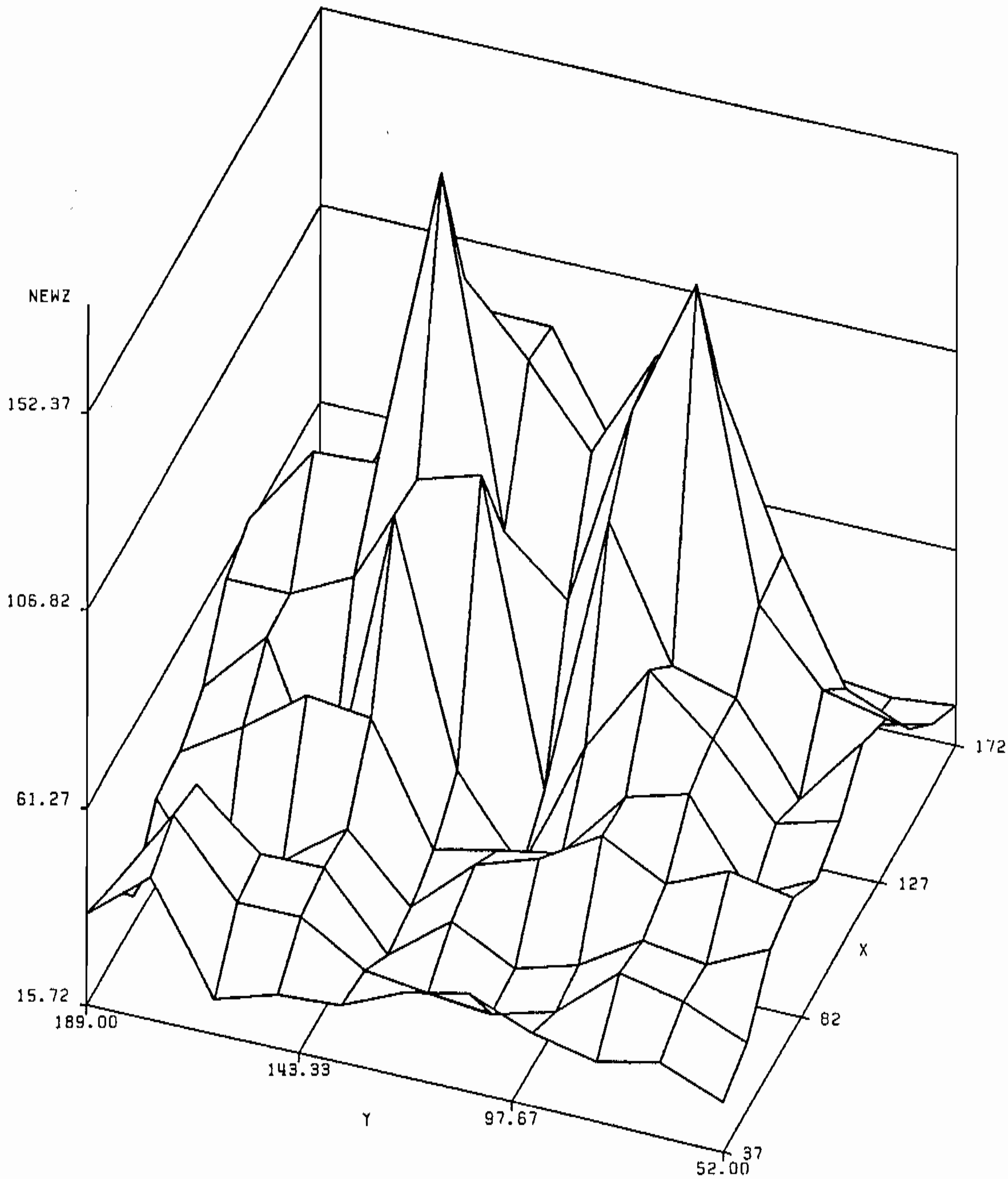
SUBJECT A--SEAT PRESSURE--HISTOGRAM OF PRESSURE INTENSITY
SEAT=Ø
BACK = 1ØØ

FREQUENCY BAR CHART

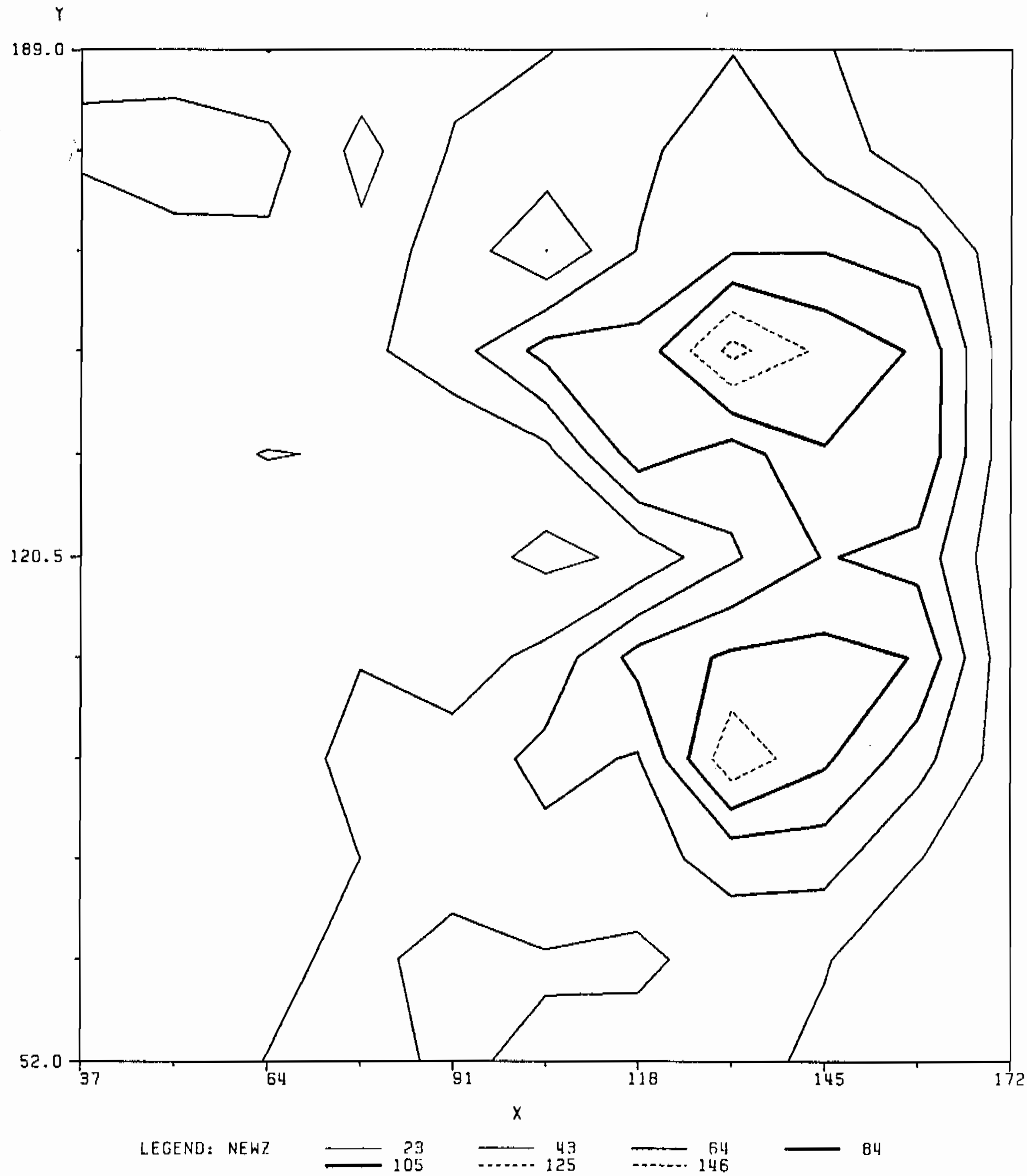


MIDPOINT Z	FREQ	CUM. FREQ	PERCENT	CUM. PERCENT
25	3395	3395	24.Ø1	24.Ø1
42	3494	6889	24.71	48.73
55	2222	9111	15.72	64.44
67	12Ø4	1Ø315	8.52	72.96
76	994	113Ø9	7.Ø3	79.99
88	9ØØ	122Ø9	6.37	86.36
1Ø2	667	12876	4.72	91.Ø7
113	377	13253	2.67	93.74
12Ø	239	13492	1.69	95.43
135	235	13727	1.66	97.Ø9
141	67	13794	Ø.47	97.57
148	6Ø	13854	Ø.42	97.99
153	46	139ØØ	Ø.33	98.32
162	55	13955	Ø.39	98.71
168	23	13978	Ø.16	98.87
174	28	14ØØ6	Ø.2Ø	99.Ø7
18Ø	14	14Ø2Ø	Ø.1Ø	99.17
183	11	14Ø31	Ø.Ø8	99.24
186	23	14Ø54	Ø.16	99.41
19Ø	84	14138	Ø.59	1ØØ.ØØ

SUBJECT A -- SEAT PRESSURE
SEAT = 0
BACK = 100

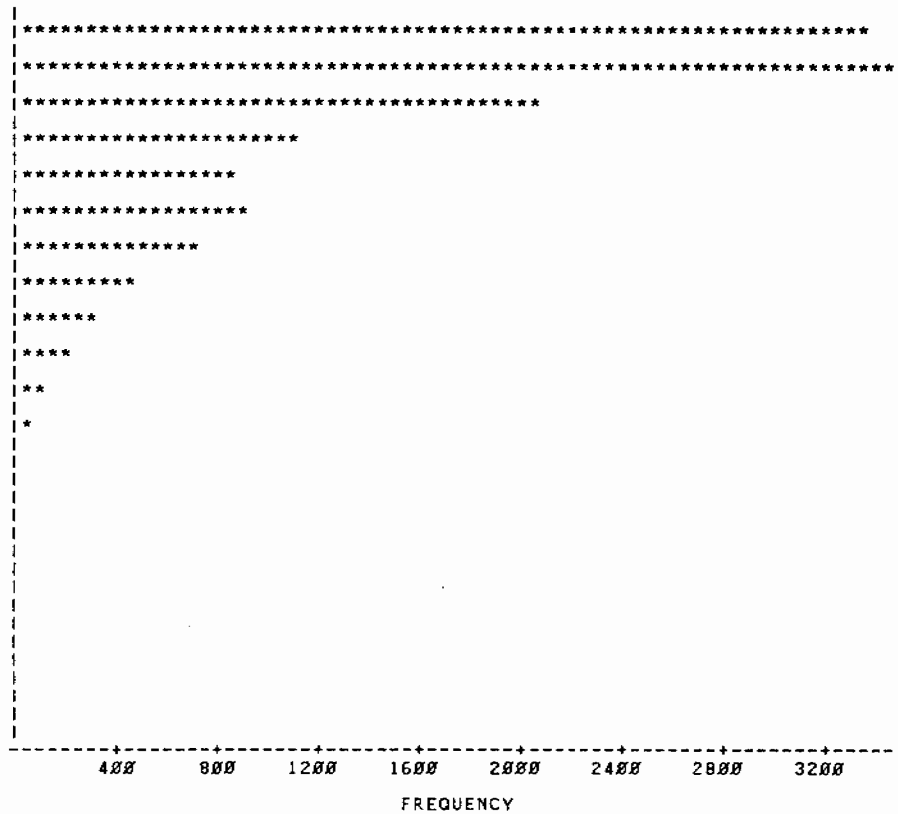


SUBJECT A -- SEAT PRESSURE
SEAT = 0
BACK = 100



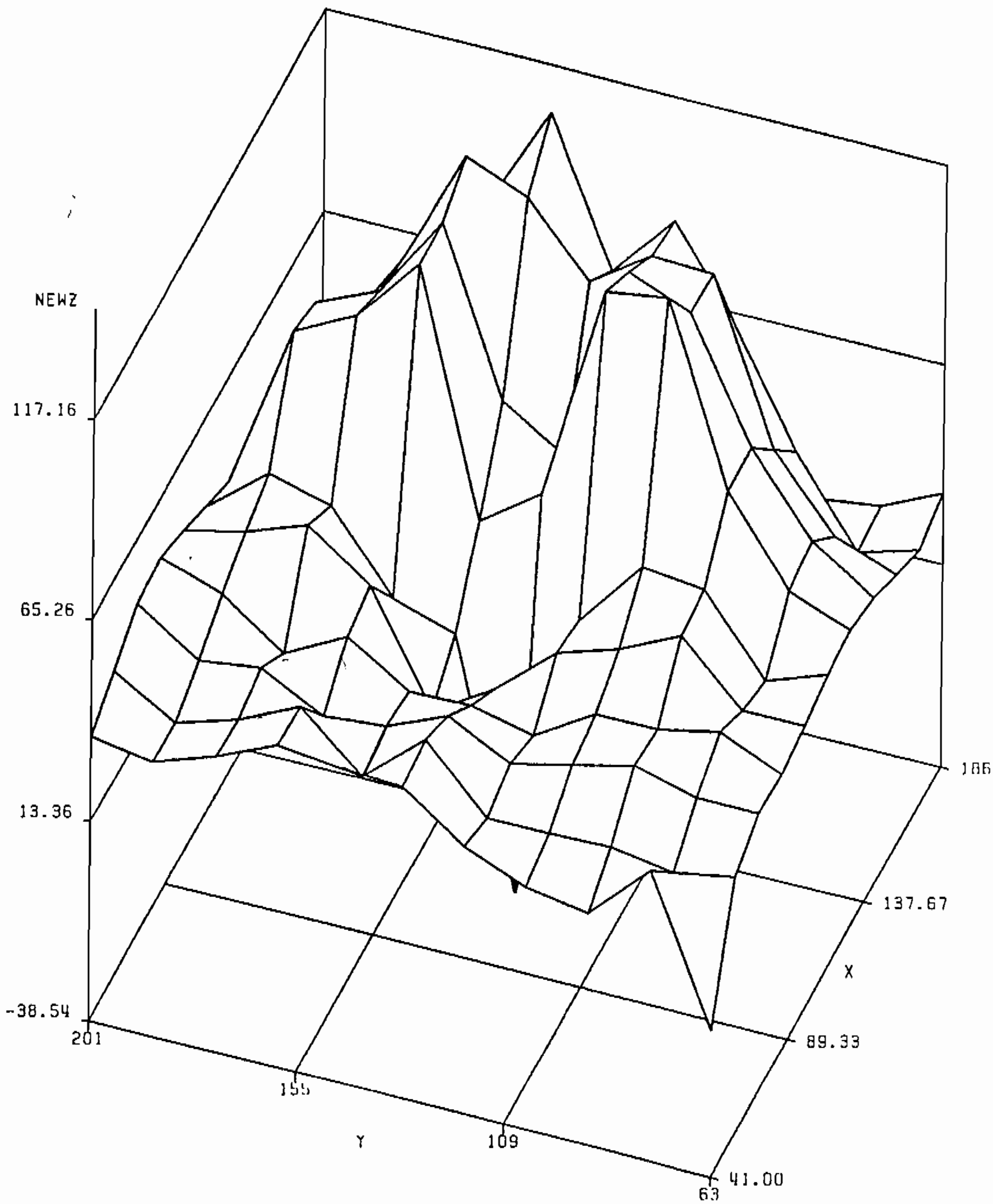
SUBJECT A--SEAT PRESSURE--HISTOGRAM OF PRESSURE INTENSITY
SEAT=Ø
BACK = 11Ø

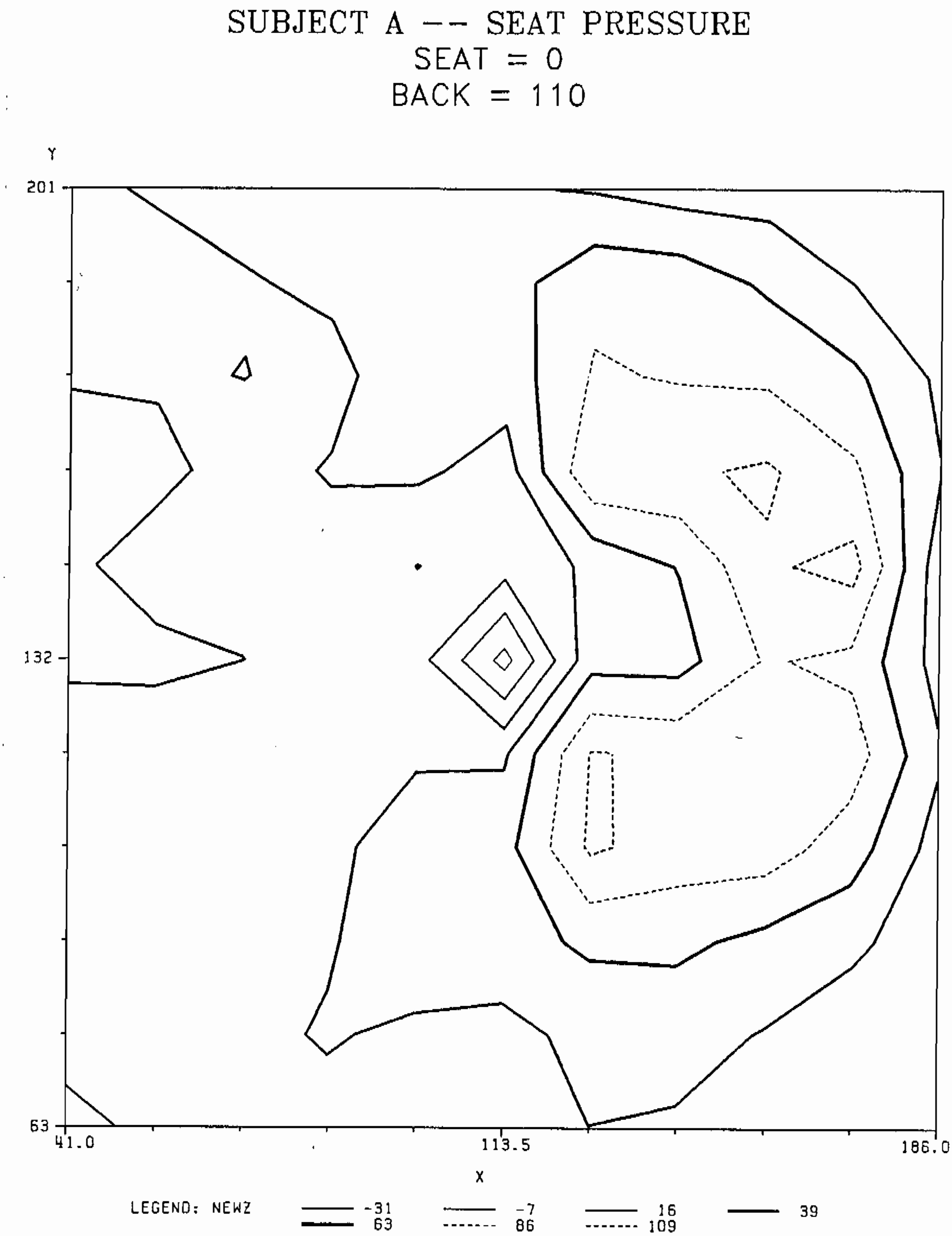
FREQUENCY BAR CHART



MIDPOINT Z	FREQ	CUM. FREQ	PERCENT	CUM. PERCENT
25	3331	3331	24.6Ø	24.6Ø
42	346Ø	6791	25.55	5Ø.15
55	2Ø7Ø	8861	15.29	65.44
67	1Ø83	9944	8.ØØ	73.44
76	872	1Ø816	6.44	79.88
88	884	117ØØ	6.53	86.4Ø
1Ø2	698	12398	5.15	91.56
113	428	12826	3.16	94.72
12Ø	317	13143	2.34	97.Ø6
135	223	13366	1.65	98.71
141	84	1345Ø	Ø.62	99.33
148	62	13512	Ø.46	99.79
153	18	1353Ø	Ø.13	99.92
162	11	13541	Ø.Ø8	1ØØ.ØØ
168	Ø	13541	Ø.ØØ	1ØØ.ØØ
174	Ø	13541	Ø.ØØ	1ØØ.ØØ
18Ø	Ø	13541	Ø.ØØ	1ØØ.ØØ
183	Ø	13541	Ø.ØØ	1ØØ.ØØ
186	Ø	13541	Ø.ØØ	1ØØ.ØØ
19Ø	Ø	13541	Ø.ØØ	1ØØ.ØØ

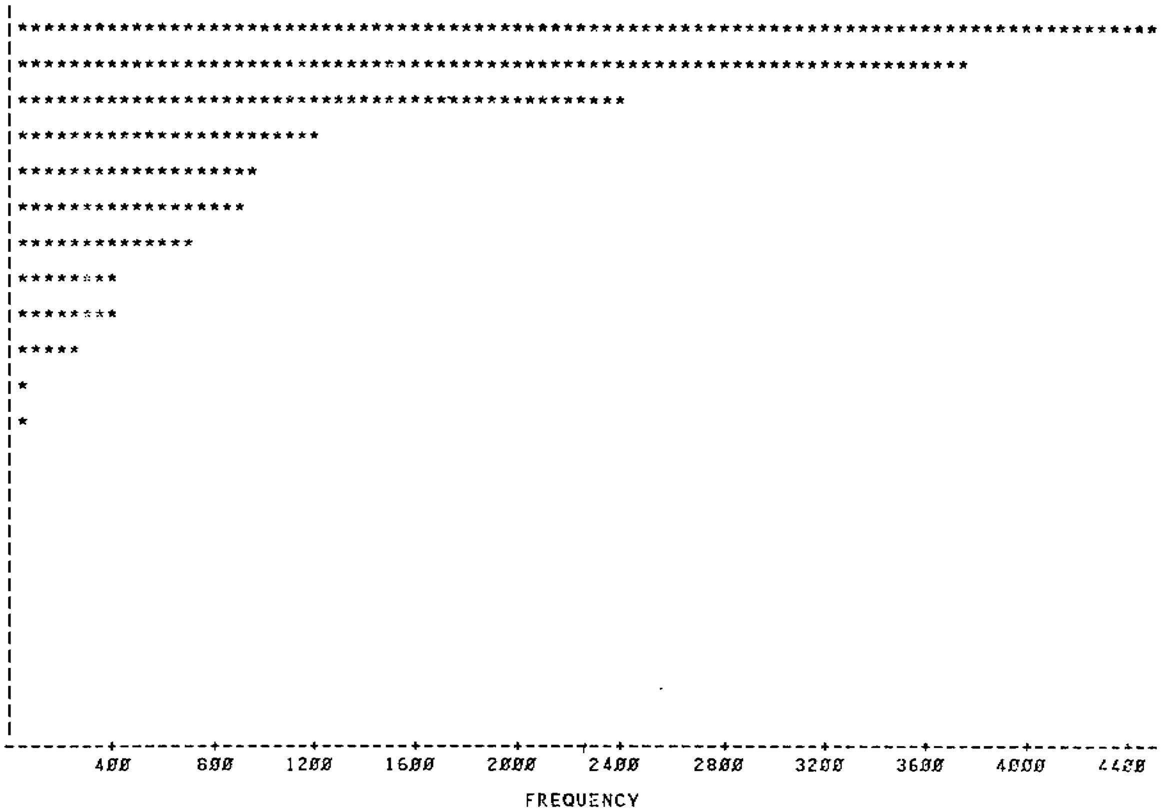
SUBJECT A -- SEAT PRESSURE
SEAT = 0
BACK = 110




SUBJECT A -- SEAT PRESSURE
SEAT = 0
BACK = 110
Y
201
132
63
41.0
113.5
186.0
X
LEGEND: NEWZ
-31
-7
16
39
63
86
109

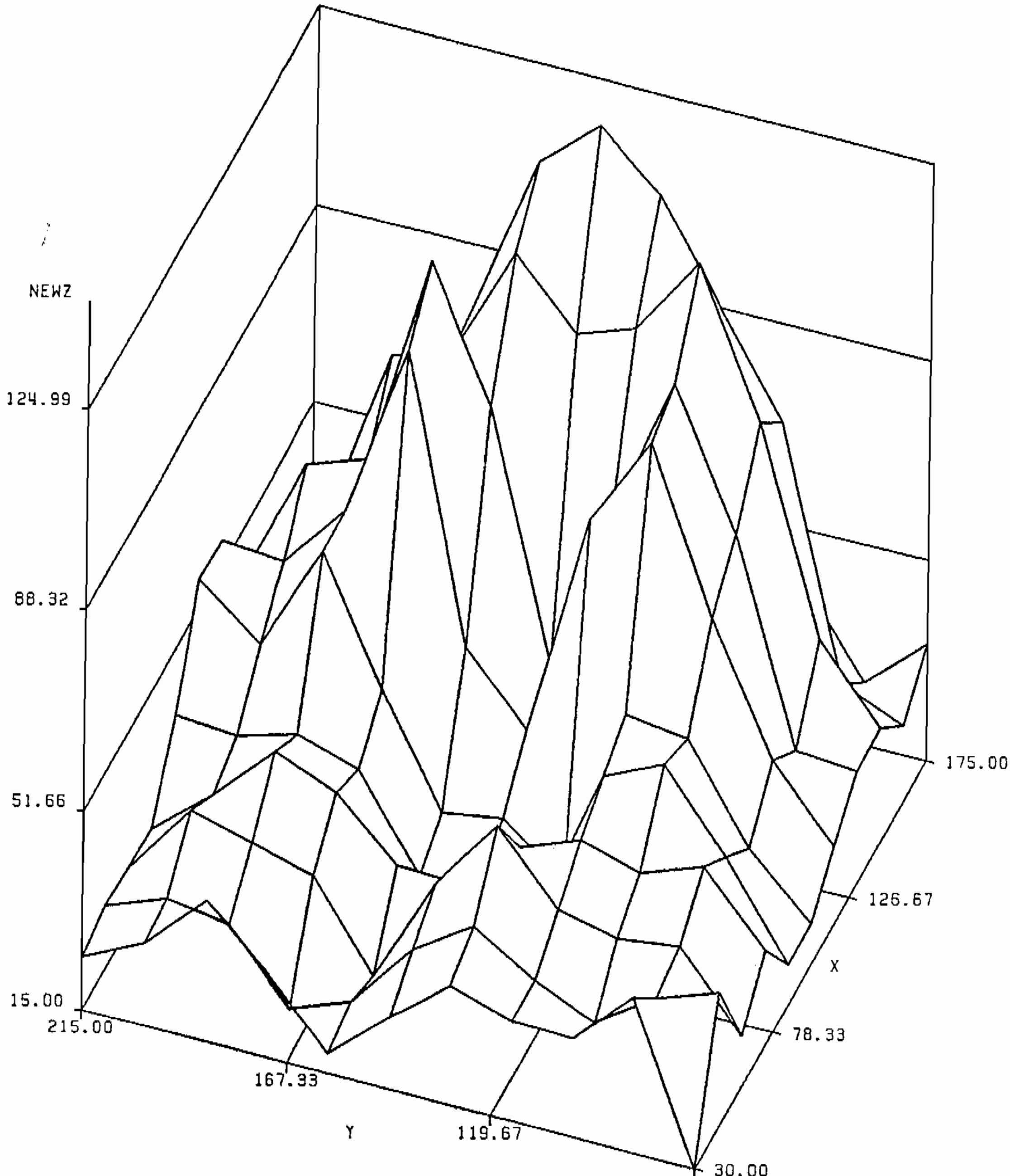
SUBJECT A--SEAT PRESSURE--HISTOGRAM OF PRESSURE INTENSITY
SEAT=0
BACK = 120

FREQUENCY BAR CHART

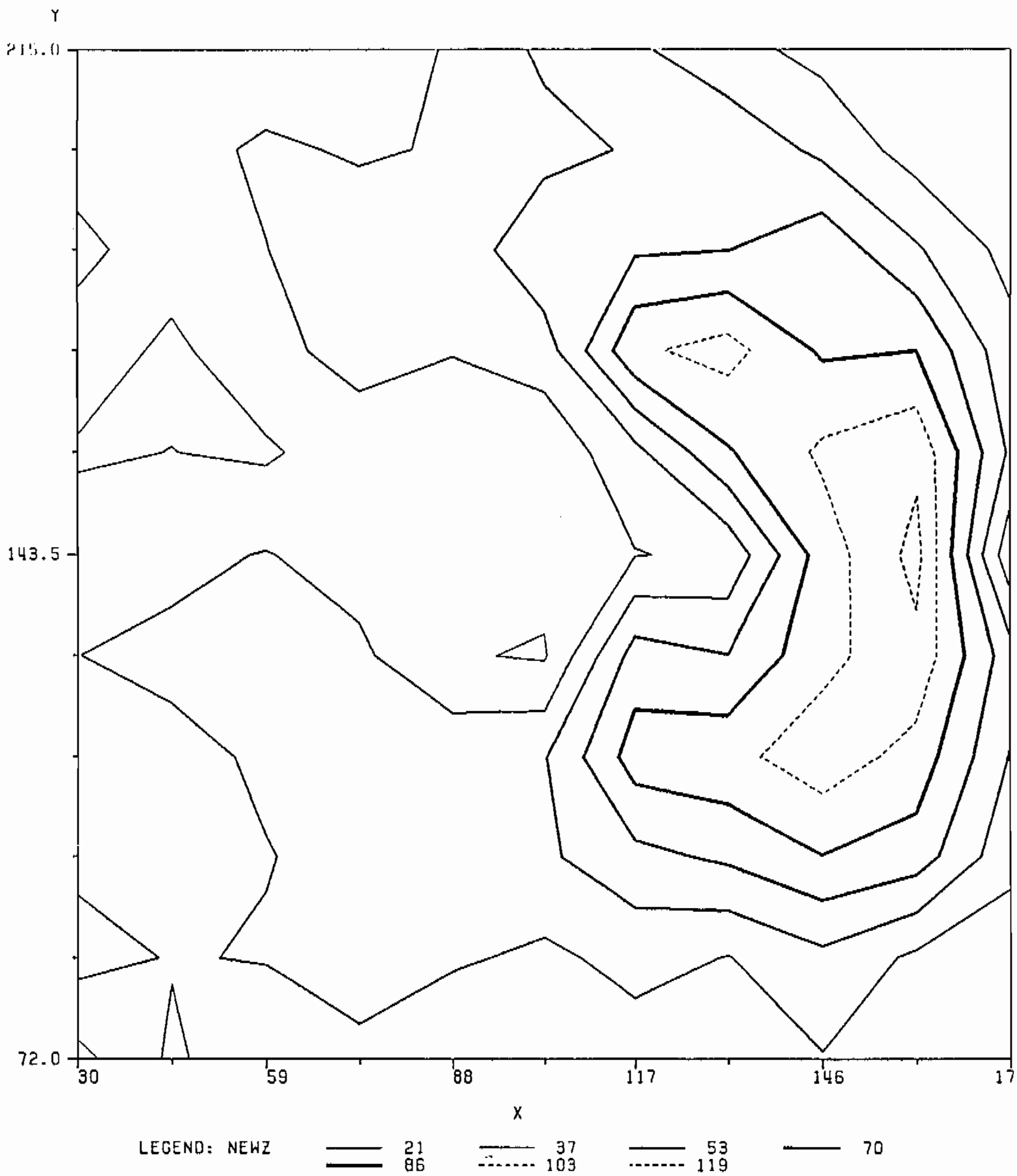


MIDPOINT Z	FREQ	CUM. FREQ	PERCENT	CUM. PERCENT
25	4486	4486	28.87	28.87
42	3768	8254	24.25	53.12
55	2387	10641	15.36	68.49
67	1185	11826	7.63	76.12
76	959	12785	6.17	82.29
88	882	13667	5.68	87.96
102	706	14373	4.54	92.51
113	401	14774	2.58	95.09
120	385	15159	2.48	97.57
135	249	15408	1.60	99.17
141	69	15477	0.44	99.61
148	33	15510	0.21	99.83
153	23	15533	0.15	99.97
162	4	15537	0.03	100.00
168	0	15537	0.00	100.00
174	0	15537	0.00	100.00
180	0	15537	0.00	100.00
183	0	15537	0.00	100.00
186	0	15537	0.00	100.00
190	0	15537	0.00	100.00

SUBJECT A -- SEAT PRESSURE
SEAT = 0
BACK = 120

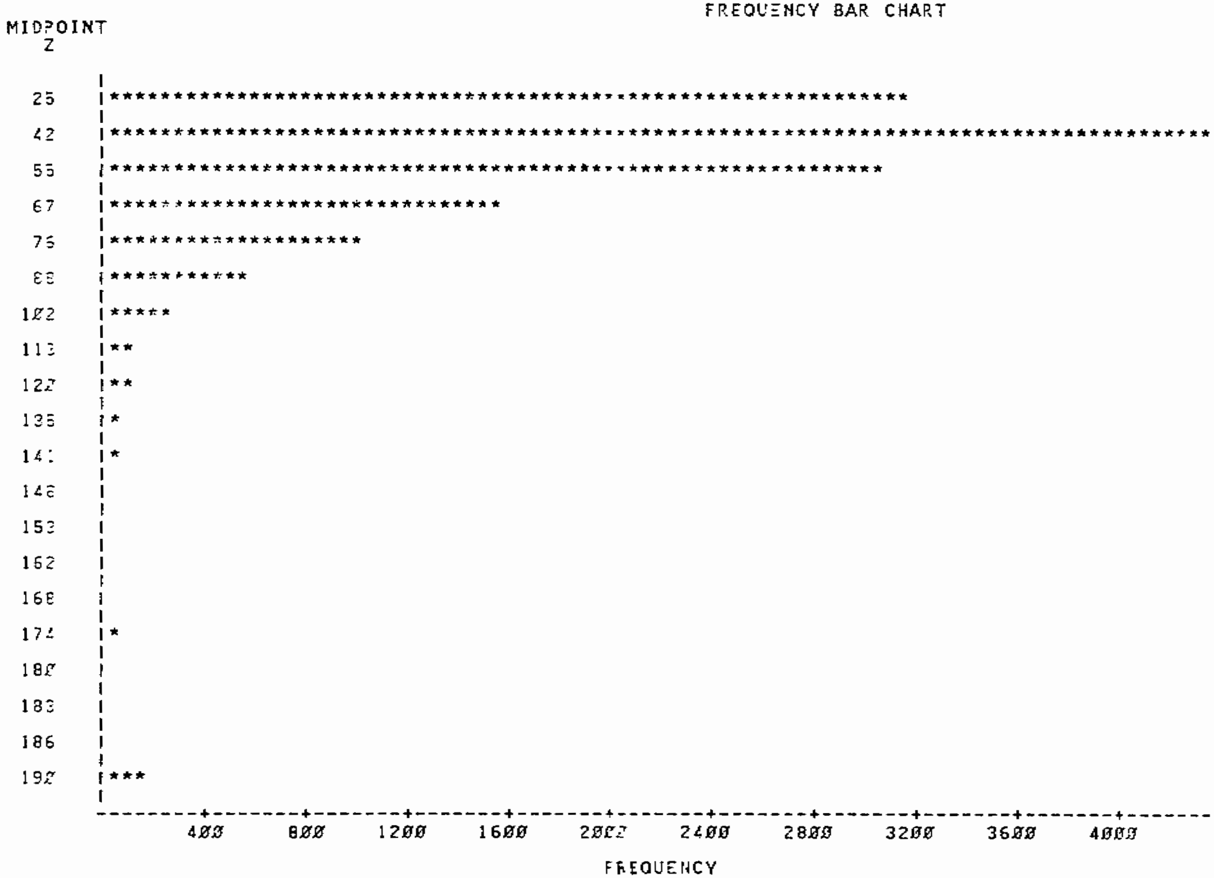


# SUBJECT A -- SEAT PRESSURE
SEAT = 0
BACK = 120



SUBJECT A--SEAT PRESSURE--HISTOGRAM OF PRESSURE INTENSITY
SEAT=10
BACK = 90

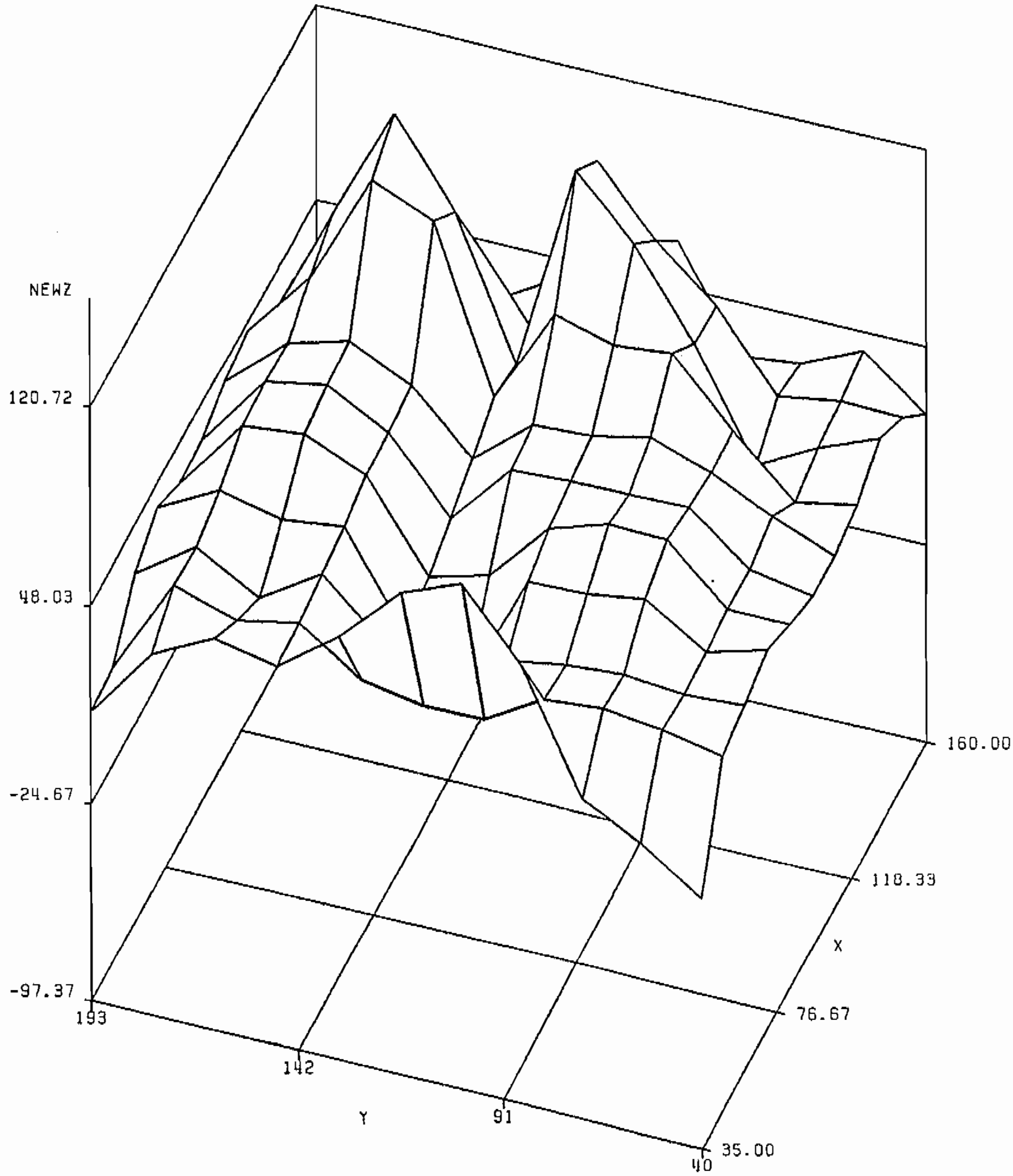
FREQUENCY BAR CHART



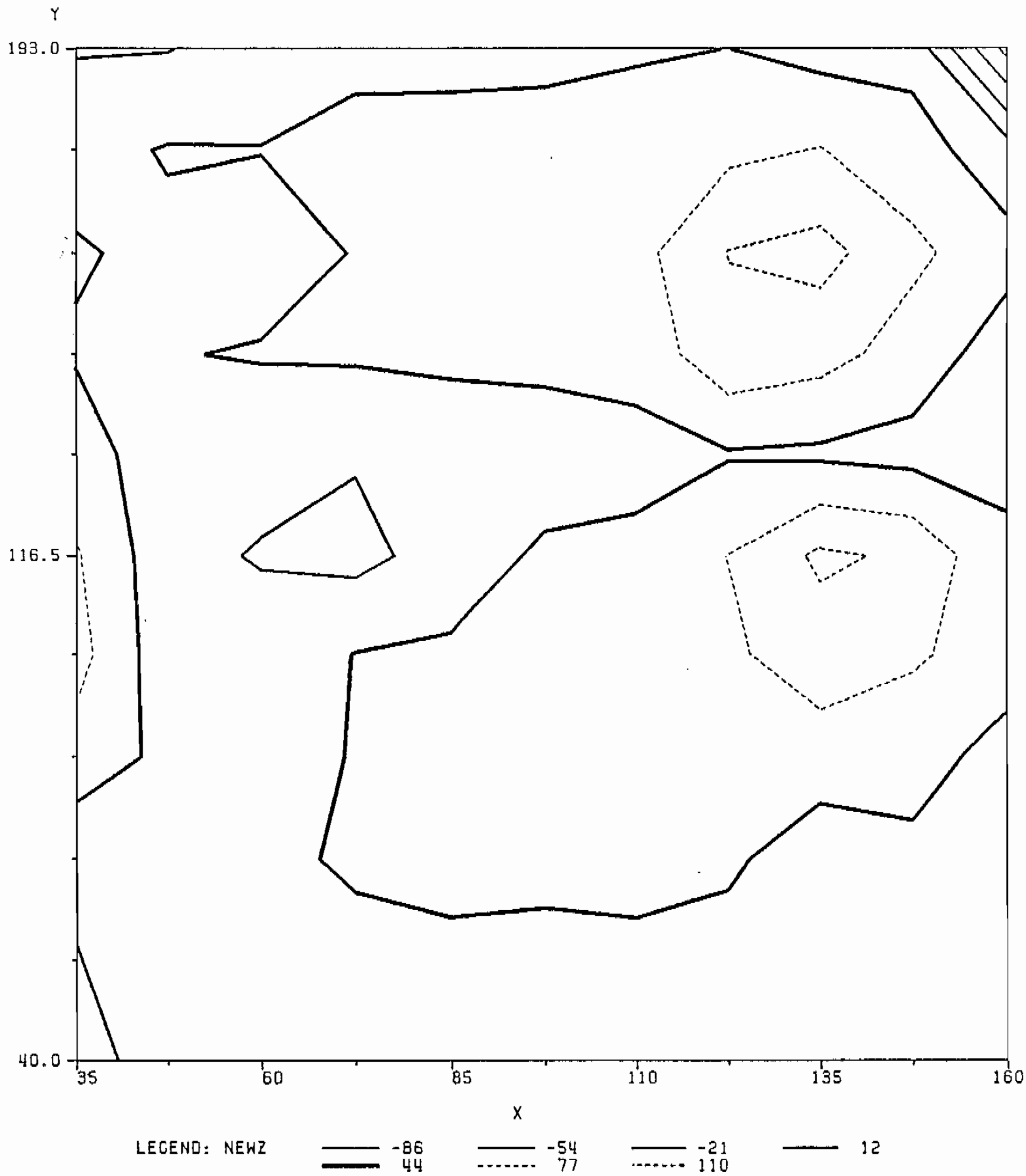
MIDPOINT Z	FREQ	CUM. FREQ	PERCENT	CUM. PERCENT
25	3170	3170	21.85	21.85
42	4356	7526	30.03	51.88
55	3059	10585	21.09	72.96
67	1534	12119	10.57	83.54
75	1009	13128	6.96	90.49
88	562	13690	3.87	94.37
102	250	13940	1.72	96.09
113	116	14056	0.80	96.89
122	79	14135	0.54	97.44
135	66	14201	0.45	97.89
141	27	14228	0.19	98.08
146	12	14240	0.08	98.16
153	17	14257	0.12	98.28
162	21	14278	0.14	98.42
168	14	14292	0.10	98.52
174	25	14317	0.17	98.69
180	8	14325	0.06	98.75
183	6	14331	0.04	98.79
186	9	14340	0.06	98.85
192	167	14507	1.15	100.00

SUBJECT A -- SEAT PRESSURE

SEAT = 10
BACK = 90

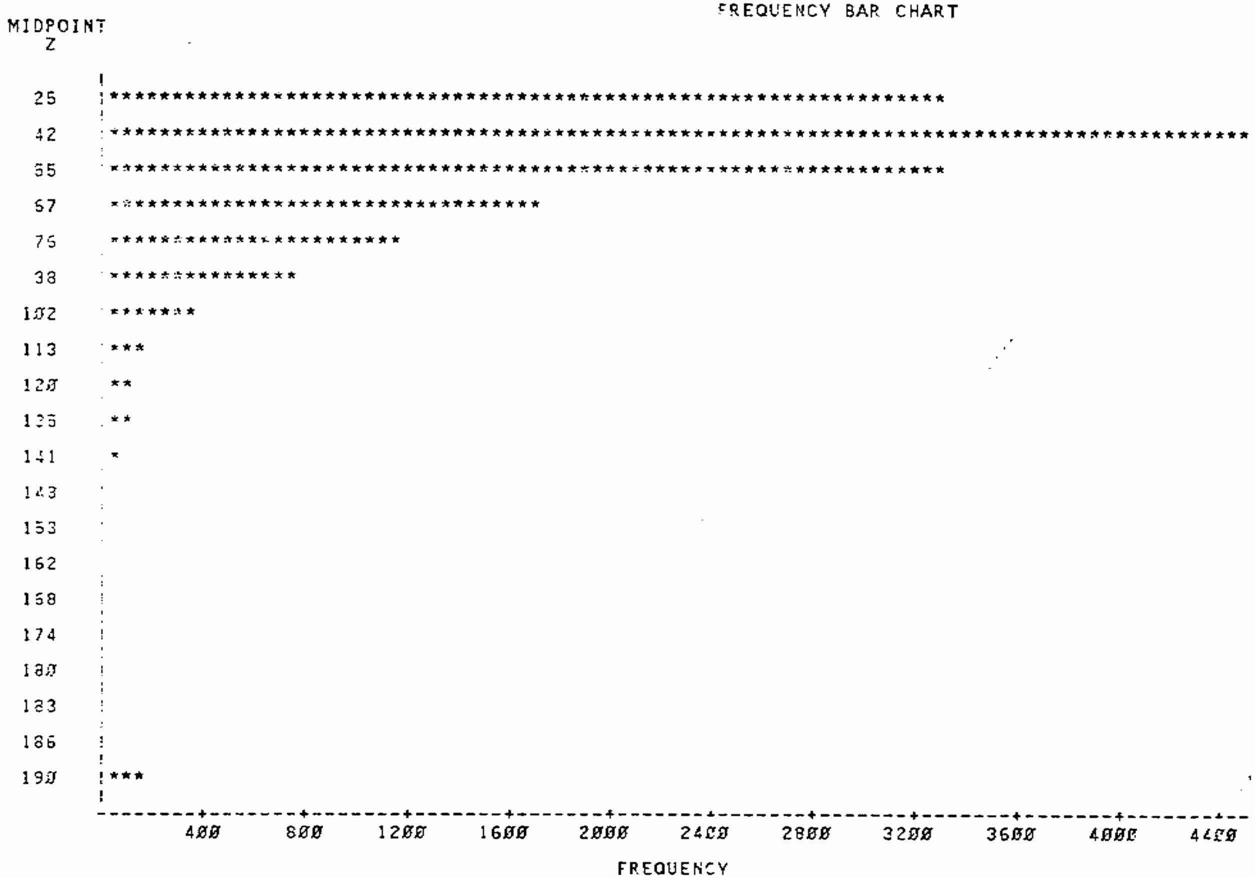


# SUBJECT A -- SEAT PRESSURE
SEAT = 10
BACK = 90



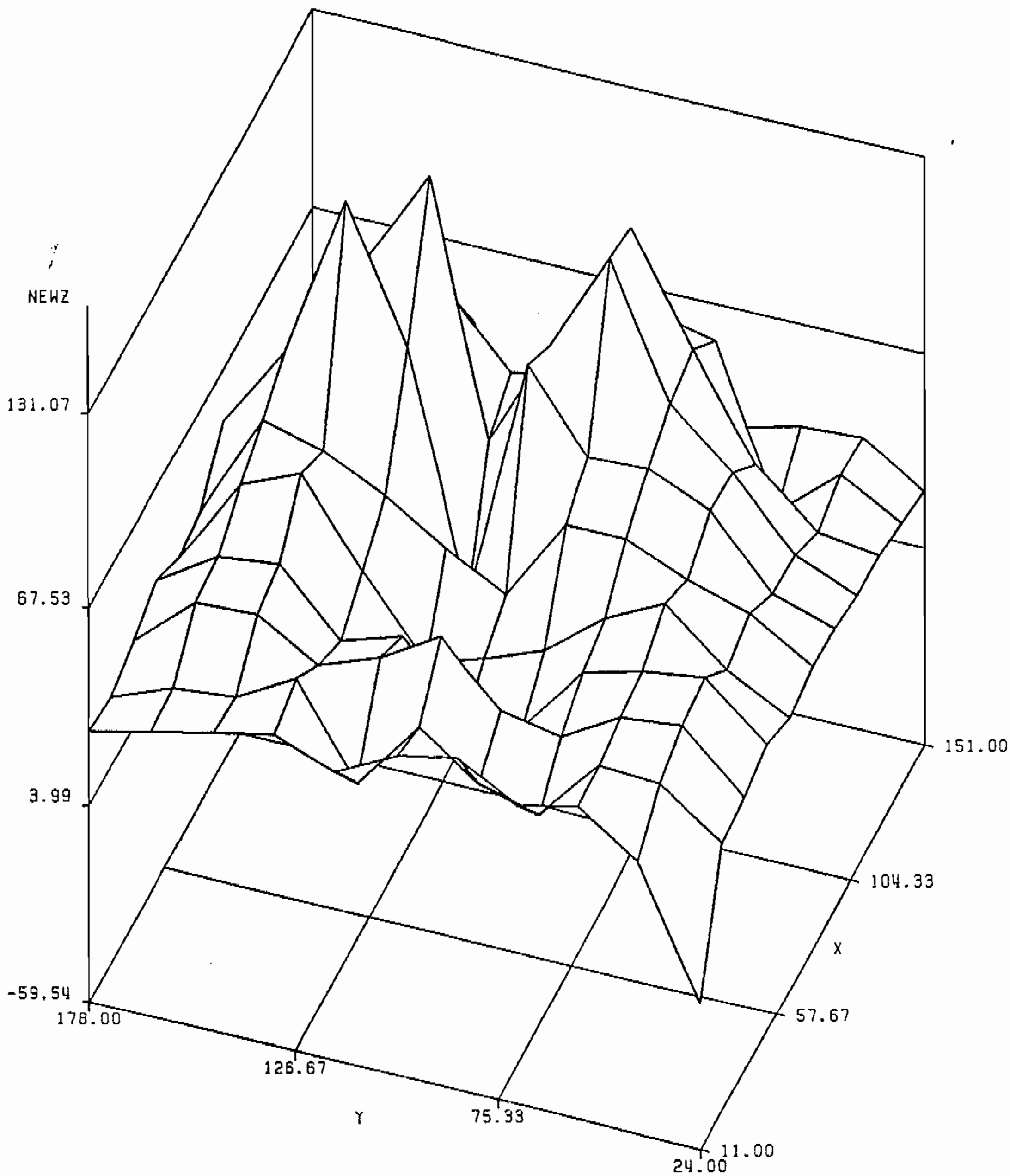
SUBJECT A--SEAT PRESSURE--HISTOGRAM OF PRESSURE INTENSITY 6
SEAT=10 16:38 SUNDAY, FEBRUARY 2, 1986
BACK = 100

FREQUENCY BAR CHART

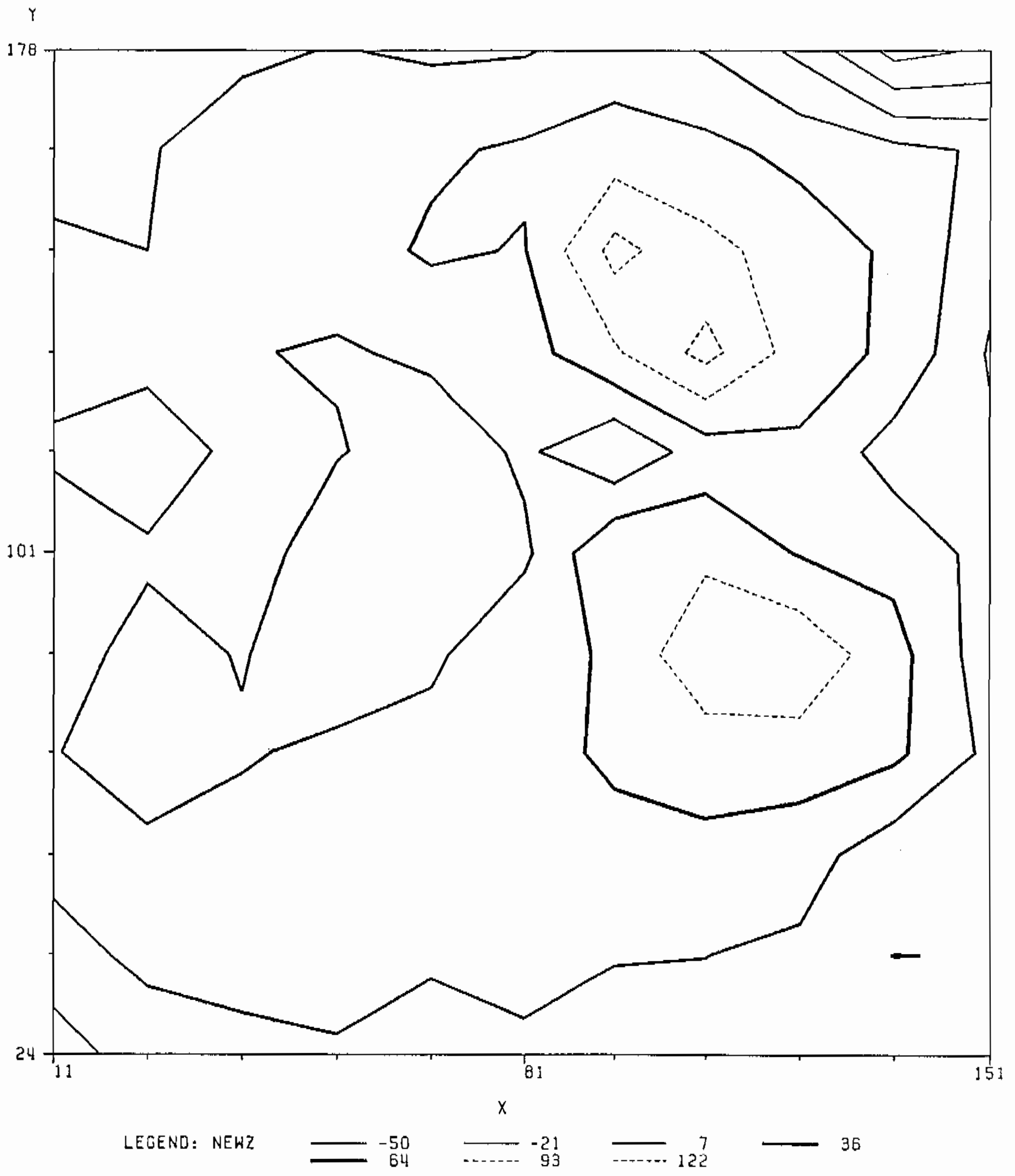


MIDPOINT Z	FREQ	CUM. FREQ	PERCENT	CUM. PERCENT
25	3305	3305	21.14	21.14
42	4519	7824	28.90	50.04
55	3279	11103	20.97	71.00
67	1679	12782	10.74	81.74
75	1126	13908	7.20	88.94
38	743	14651	4.75	93.69
102	330	14981	2.11	95.80
113	159	15140	1.02	96.82
120	107	15247	0.68	97.51
135	78	15325	0.50	98.00
141	36	15361	0.23	98.23
143	19	15380	0.12	98.36
153	24	15404	0.15	98.51
162	18	15422	0.12	98.63
158	15	15437	0.10	98.72
174	17	15454	0.11	98.83
180	7	15461	0.04	98.87
183	2	15463	0.01	98.89
186	10	15473	0.06	98.95
190	164	15637	1.05	100.00

SUBJECT A -- SEAT PRESSURE
SEAT = 10
BACK = 100



SUBJECT A -- SEAT PRESSURE
SEAT = 10
BACK = 100



SUBJECT A--SEAT PRESSURE--HISTOGRAM OF PRESSURE INTENSITY
SEAT=10
BACK = 110

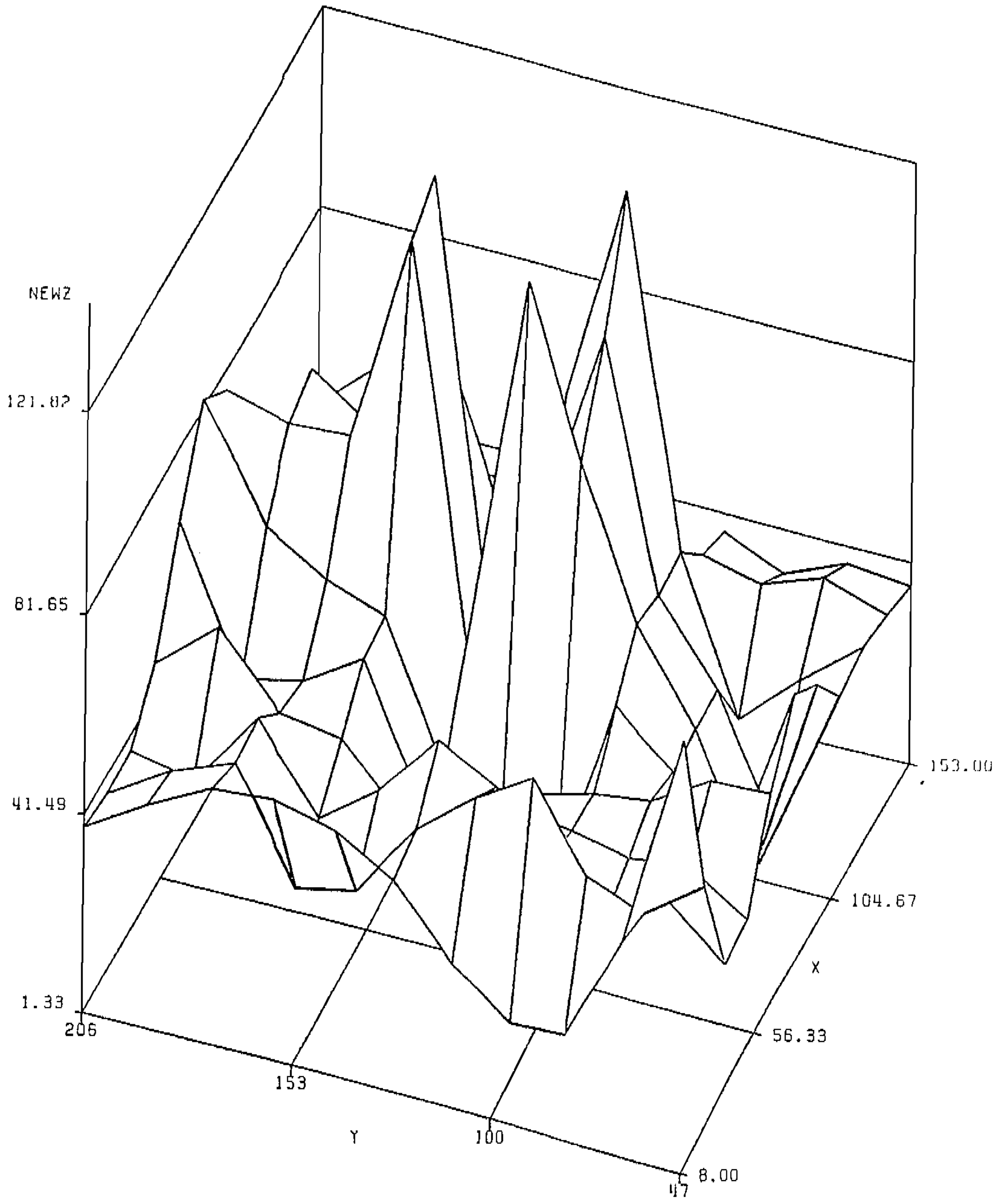
16:38 SUNDAY, FEBRUARY 2, 1986 7

FREQUENCY BAR CHART

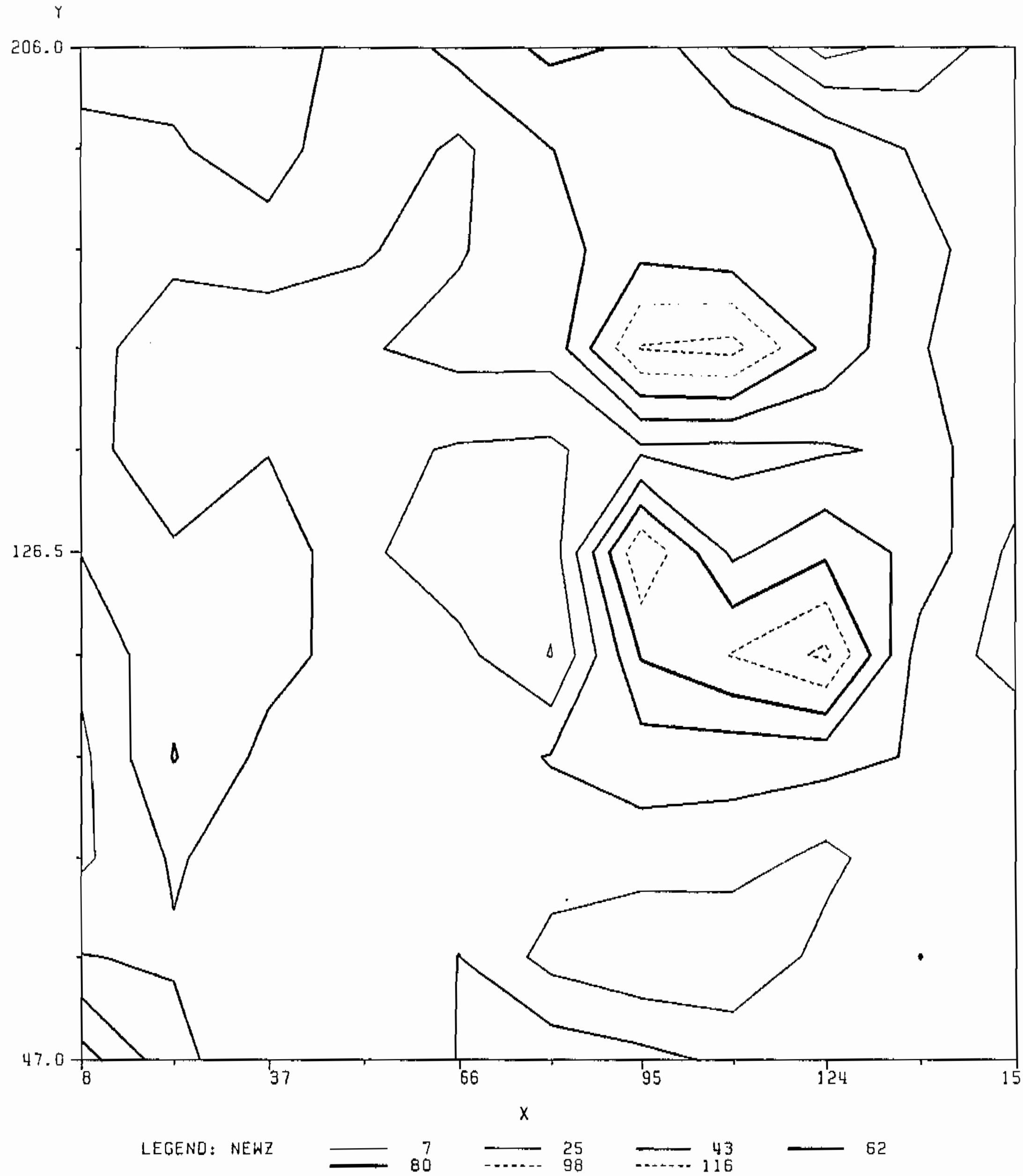
```
MIDPOINT
   Z                                                                                                       FREQ   CUM.   PERCENT    CUM.
                                                                                                                  FREQ             PERCENT
       |
  25   |****************************************************************************                       3802   3802    29.23    29.23
  42   |****************************************************************************************           4404   8206    33.86    63.10
  55   |********************************************                                                       2181  10387    16.77    79.87
  67   |********************                                                                               1002  11389     7.70    87.57
  76   |*************                                                                                       643  12032     4.94    92.52
  88   |********                                                                                            379  12411     2.91    95.43
 102   |***                                                                                                 166  12577     1.28    96.71
 113   |*                                                                                                    67  12644     0.52    97.22
 120   |*                                                                                                    49  12693     0.38    97.60
 135   |*                                                                                                    54  12747     0.42    98.02
 141   |                                                                                                     24  12771     0.18    98.20
 148   |                                                                                                     15  12786     0.12    98.32
 153   |                                                                                                     14  12800     0.11    98.42
 162   |                                                                                                     11  12811     0.08    98.51
 168   |                                                                                                     17  12828     0.13    98.64
 174   |                                                                                                     17  12845     0.13    98.77
 180   |                                                                                                     11  12856     0.08    98.85
 183   |                                                                                                      2  12858     0.02    98.87
 186   |                                                                                                     10  12868     0.08    98.95
 190   |***                                                                                                 137  13005     1.05   100.00
       |
       --------+--------+--------+--------+--------+--------+--------+--------+--------+--------+--------+
              400      800     1200     1600     2000     2400     2800     3200     3600     4000     4400

                                    FREQUENCY
```

172

SUBJECT A -- SEAT PRESSURE
SEAT = 10
BACK = 110

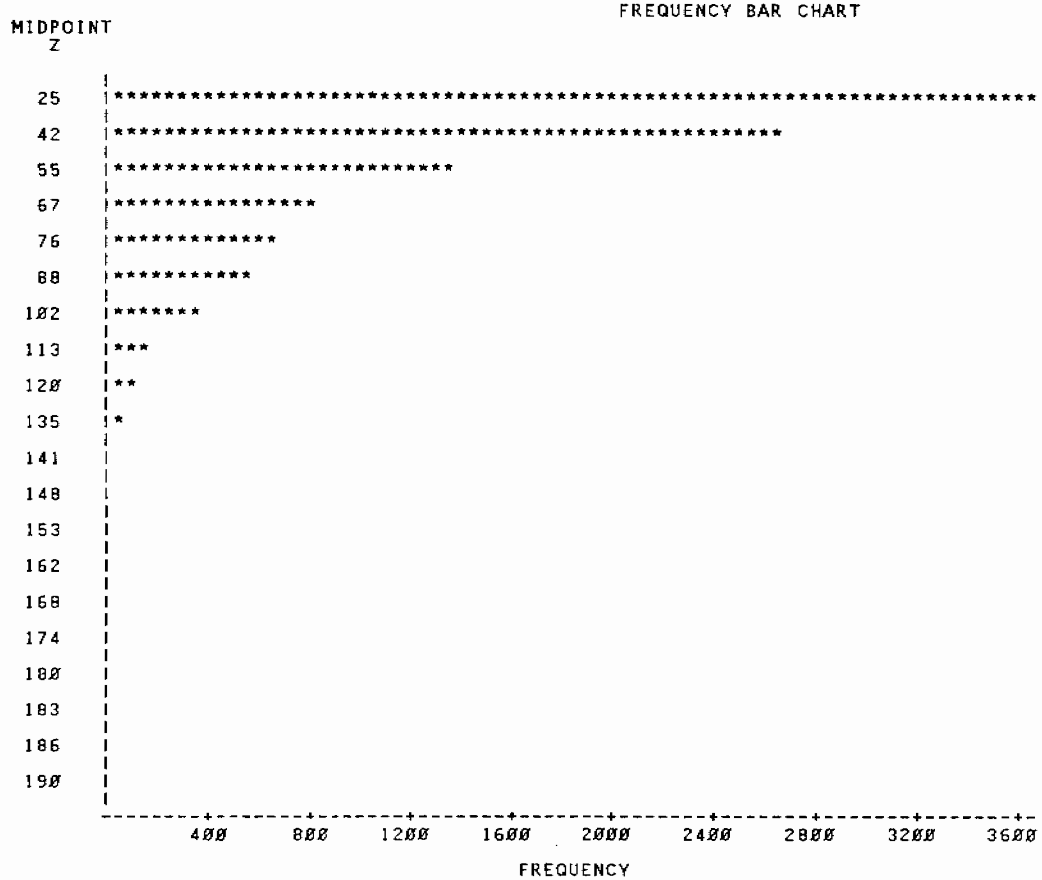


# SUBJECT A -- SEAT PRESSURE
SEAT = 10
BACK = 110



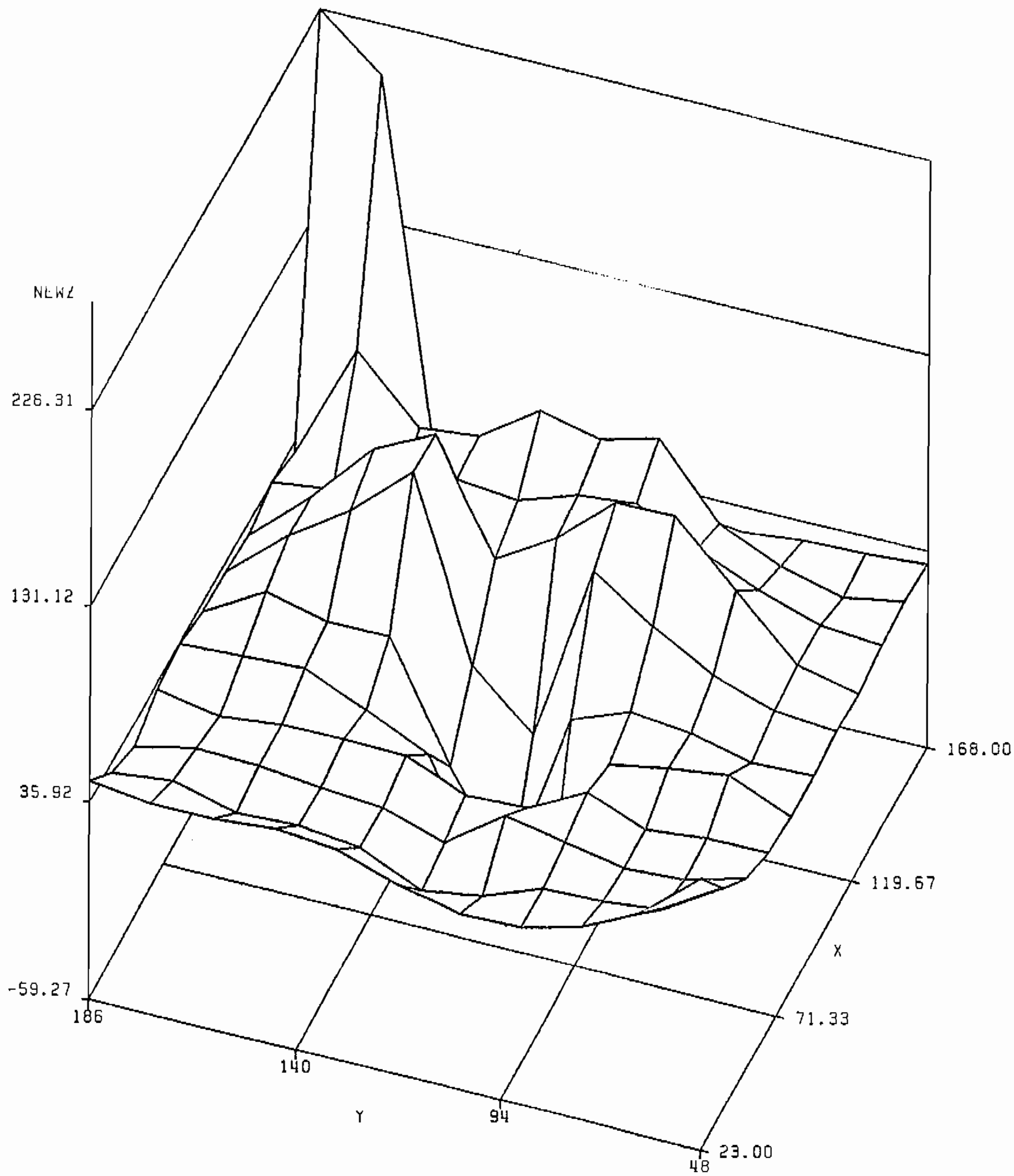
SUBJECT A--SEAT PRESSURE--HISTOGRAM OF PRESSURE INTENSITY
SEAT=10
BACK = 120

FREQUENCY BAR CHART

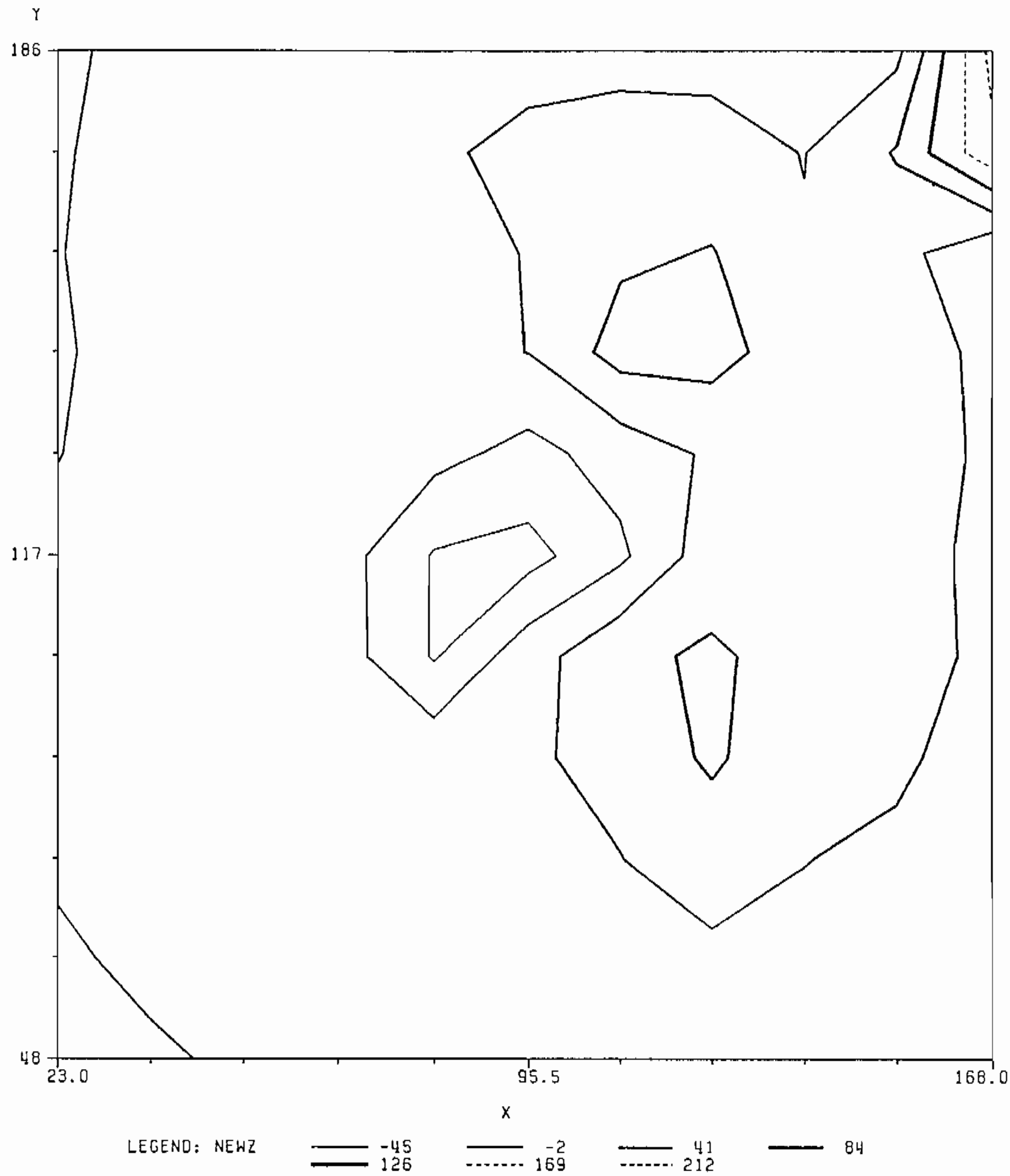


MIDPOINT Z	FREQ	CUM. FREQ	PERCENT	CUM. PERCENT
25	3644	3644	35.25	35.25
42	2637	6281	25.51	60.76
55	1349	7630	13.05	73.81
67	807	8437	7.81	81.61
76	659	9096	6.37	87.99
88	553	9649	5.35	93.34
102	344	9993	3.33	96.66
113	129	10122	1.25	97.91
120	76	10198	0.74	98.65
135	70	10268	0.68	99.32
141	17	10285	0.16	99.49
148	13	10298	0.13	99.61
153	15	10313	0.15	99.76
162	7	10320	0.07	99.83
168	10	10330	0.10	99.92
174	6	10336	0.06	99.98
180	2	10338	0.02	100.00
183	0	10338	0.00	100.00
186	0	10338	0.00	100.00
190	0	10338	0.00	100.00

SUBJECT A -- SEAT PRESSURE
SEAT = 10
BACK = 120

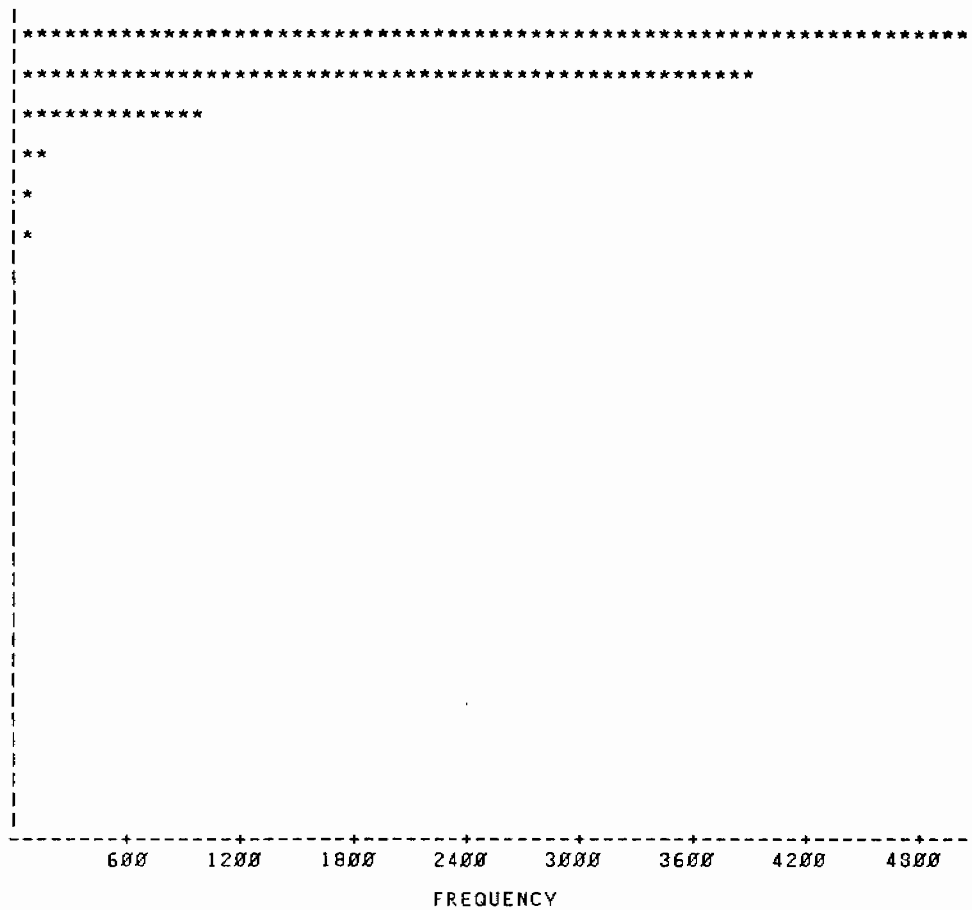


SUBJECT A -- SEAT PRESSURE
SEAT = 10
BACK = 120



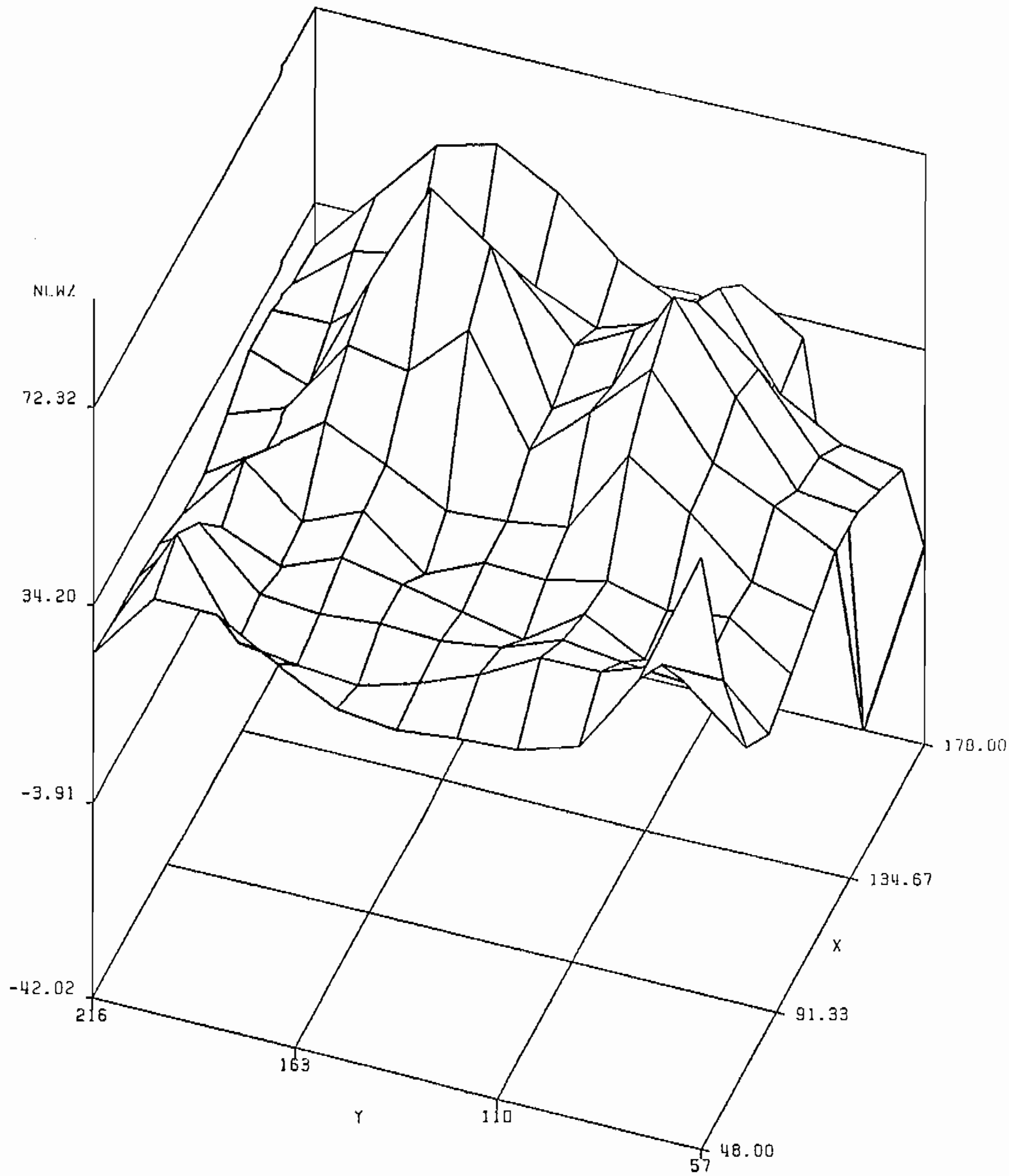
SUBJECT C--SEAT PRESSURE--HISTOGRAM OF PRESSURE INTENSITY
SEAT=Ø
BACK = 9Ø

FREQUENCY BAR CHART

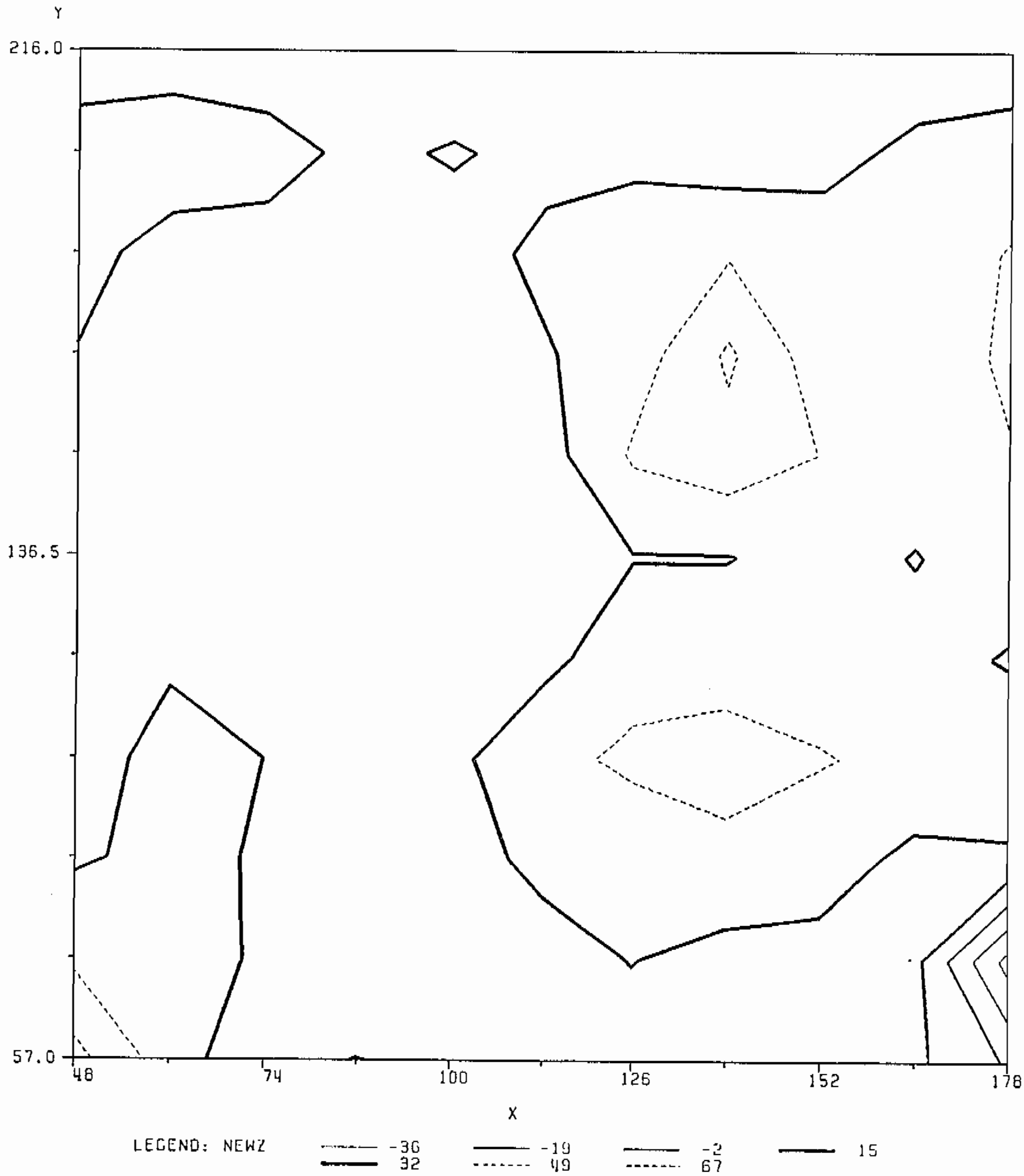


MIDPOINT Z	FREQ	CUM. FREQ	PERCENT	CUM. PERCENT
25	5014	5014	48.86	48.86
42	3929	8943	38.29	87.15
55	1001	9944	9.75	96.90
67	169	10113	1.65	98.55
76	86	10199	0.84	99.39
88	48	10247	0.47	99.85
102	14	10261	0.14	99.99
113	1	10262	0.01	100.00
120	0	10262	0.00	100.00
135	0	10262	0.00	100.00
141	0	10262	0.00	100.00
148	0	10262	0.00	100.00
153	0	10262	0.00	100.00
162	0	10262	0.00	100.00
168	0	10262	0.00	100.00
174	0	10262	0.00	100.00
180	0	10262	0.00	100.00
183	0	10262	0.00	100.00
186	0	10262	0.00	100.00
190	0	10262	0.00	100.00

SUBJECT C -- SEAT PRESSURE
SEAT = 0
BACK = 90

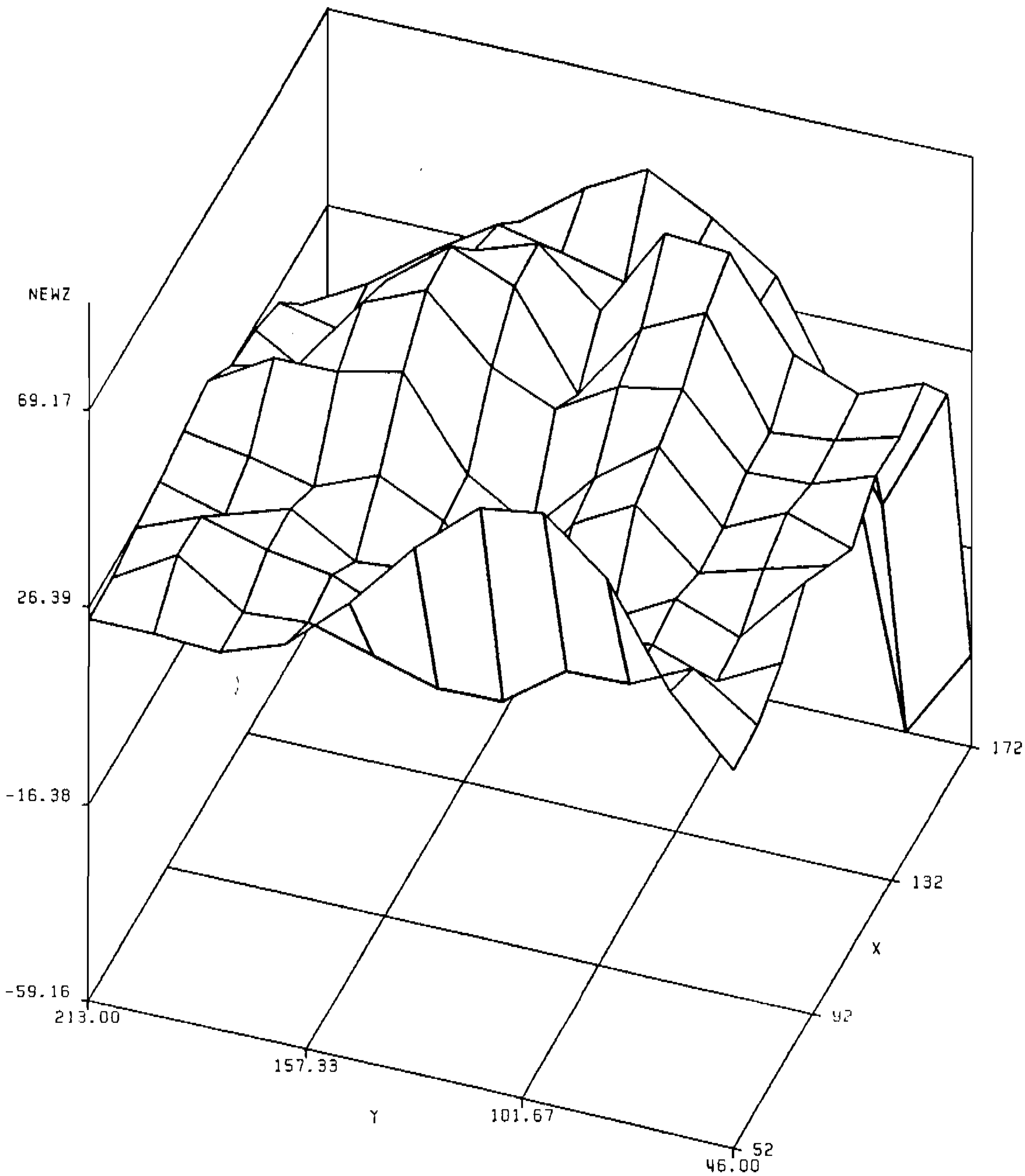


# SUBJECT C -- SEAT PRESSURE
SEAT = 0
BACK = 90



```
                  SUBJECT C--SEAT PRESSURE--HISTOGRAM OF PRESSURE INTENSITY
                                          SEAT=0
                                        BACK = 100

                                    FREQUENCY BAR CHART
MIDPOINT
   Z                                                                                      FREQ   CUM.    PERCENT    CUM.
                                                                                                 FREQ              PERCENT
          |
  25      |********************************************************************************  4802   4802    48.37     48.37
          |
  42      |**********************************************************                        3484   8286    35.09     83.46
          |
  55      |***********************                                                           1363   9649    13.73     97.19
          |
  67      |***                                                                                243   9892     2.45     99.64
          |
  76      |                                                                                    35   9927     0.35     99.99
          |
  88      |                                                                                     1   9928     0.01    100.00
          |
 102      |                                                                                     0   9928     0.00    100.00
          |
 113      |                                                                                     0   9928     0.00    100.00
          |
 120      |                                                                                     0   9928     0.00    100.00
          |
 135      |                                                                                     0   9928     0.00    100.00
          |
 141      |                                                                                     0   9928     0.00    100.00
          |
 148      |                                                                                     0   9928     0.00    100.00
          |
 153      |                                                                                     0   9928     0.00    100.00
          |
 162      |                                                                                     0   9928     0.00    100.00
          |
 168      |                                                                                     0   9928     0.00    100.00
          |
 174      |                                                                                     0   9928     0.00    100.00
          |
 180      |                                                                                     0   9928     0.00    100.00
          |
 183      |                                                                                     0   9928     0.00    100.00
          |
 186      |                                                                                     0   9928     0.00    100.00
          |
 190      |                                                                                     0   9928     0.00    100.00
          |
          ----------+---------+---------+---------+---------+---------+---------+---------+
                   600      1200      1800      2400      3000      3600      4200      4800

                                         FREQUENCY
```

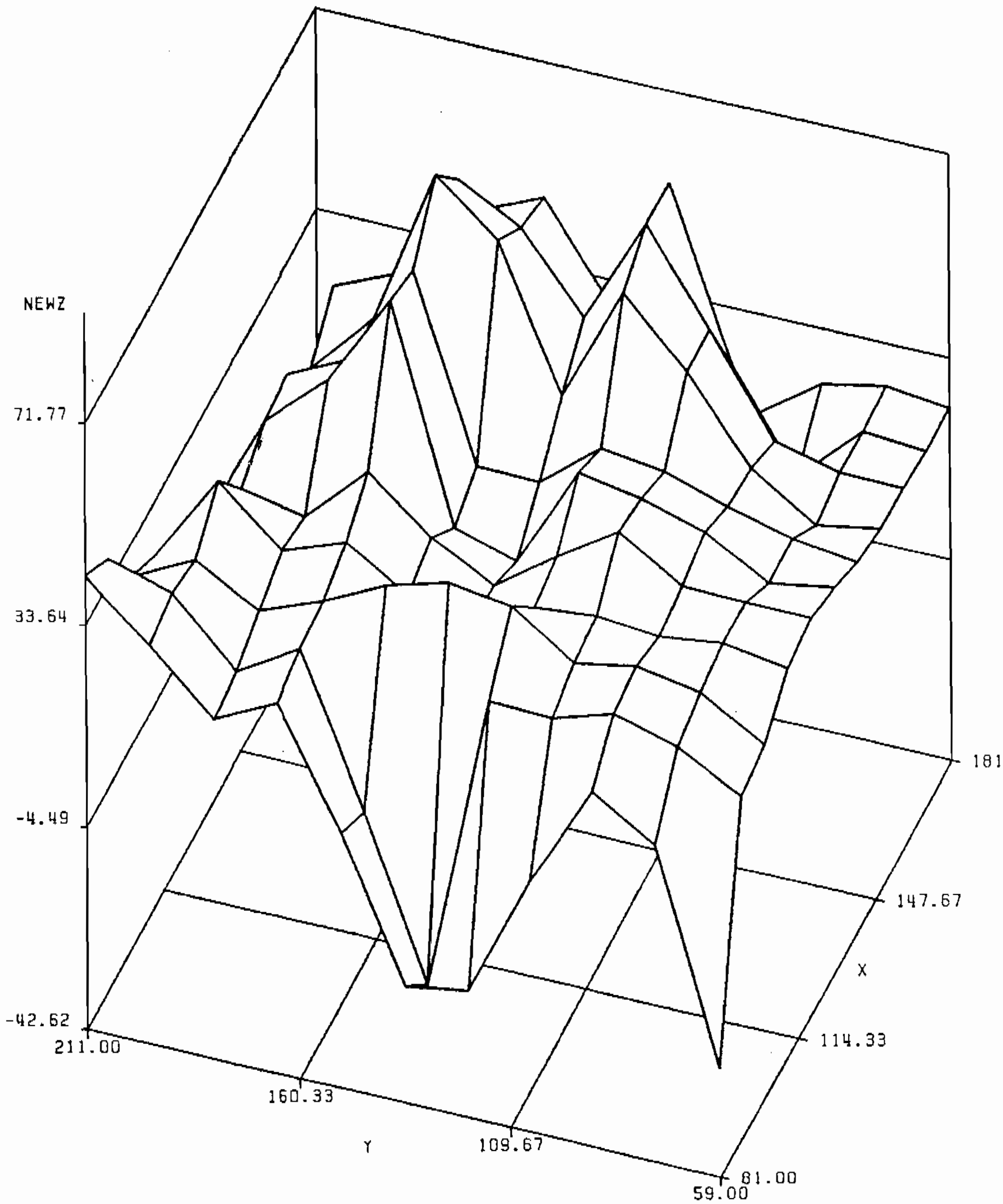
# SUBJECT C -- SEAT PRESSURE
SEAT = 0
BACK = 100



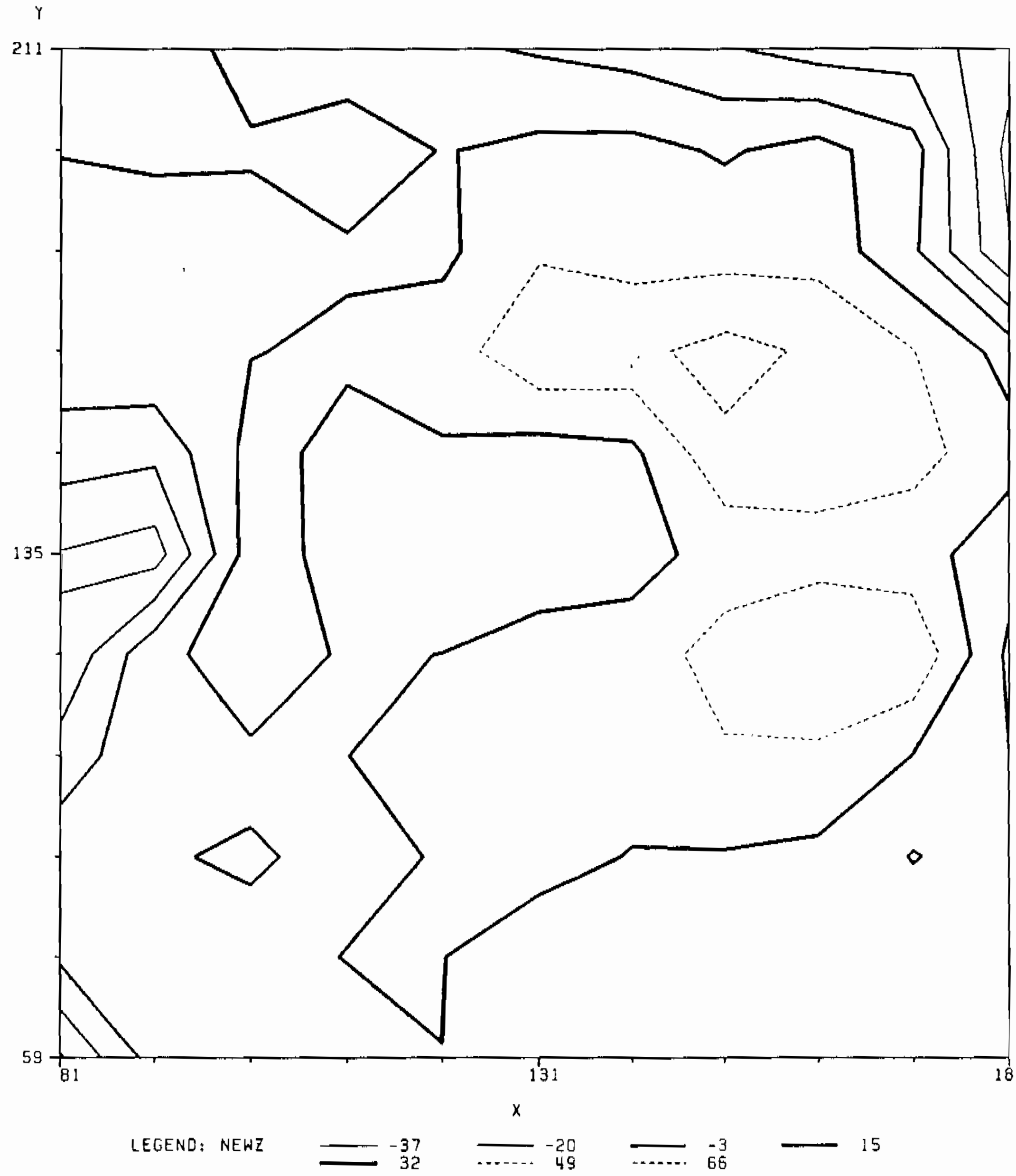
SUBJECT C -- SEAT PRESSURE
SEAT = 0
BACK = 100

```
             SUBJECT C--SEAT PRESSURE--HISTOGRAM OF PRESSURE INTENSITY
                                      SEAT=Ø
                                    BACK = 11Ø

                                FREQUENCY BAR CHART
MIDPOINT
   Z                                                                           FREQ   CUM.   PERCENT    CUM.
                                                                                      FREQ             PERCENT
        |
   25   |********************************************************************  3376   3376    41.13     41.13
        |
   42   |******************************************************                2709   6085    33.00     74.13
        |
   55   |***************************                                           1349   7434    16.43     90.56
        |
   67   |**********                                                             503   7937     6.13     96.69
        |
   76   |****                                                                   208   8145     2.53     99.22
        |
   88   |*                                                                       60   8205     0.73     99.95
        |
  102   |                                                                         4   8209     0.05    100.00
        |
  113   |                                                                         0   8209     0.00    100.00
        |
  120   |                                                                         0   8209     0.00    100.00
        |
  135   |                                                                         0   8209     0.00    100.00
        |
  141   |                                                                         0   8209     0.00    100.00
        |
  148   |                                                                         0   8209     0.00    100.00
        |
  153   |                                                                         0   8209     0.00    100.00
        |
  162   |                                                                         0   8209     0.00    100.00
        |
  168   |                                                                         0   8209     0.00    100.00
        |
  174   |                                                                         0   8209     0.00    100.00
        |
  180   |                                                                         0   8209     0.00    100.00
        |
  183   |                                                                         0   8209     0.00    100.00
        |
  186   |                                                                         0   8209     0.00    100.00
        |
  190   |                                                                         0   8209     0.00    100.00
        |
        --------+-------+-------+-------+-------+-------+-------+-------+----
               400     800    1200    1600    2000    2400    2800    3200

                                 FREQUENCY
```

SUBJECT C -- SEAT PRESSURE
SEAT = 0
BACK = 110



SUBJECT C -- SEAT PRESSURE
SEAT = 0
BACK = 110



SUBJECT C--SEAT PRESSURE--HISTOGRAM OF PRESSURE INTENSITY
SEAT=Ø
BACK = 12Ø

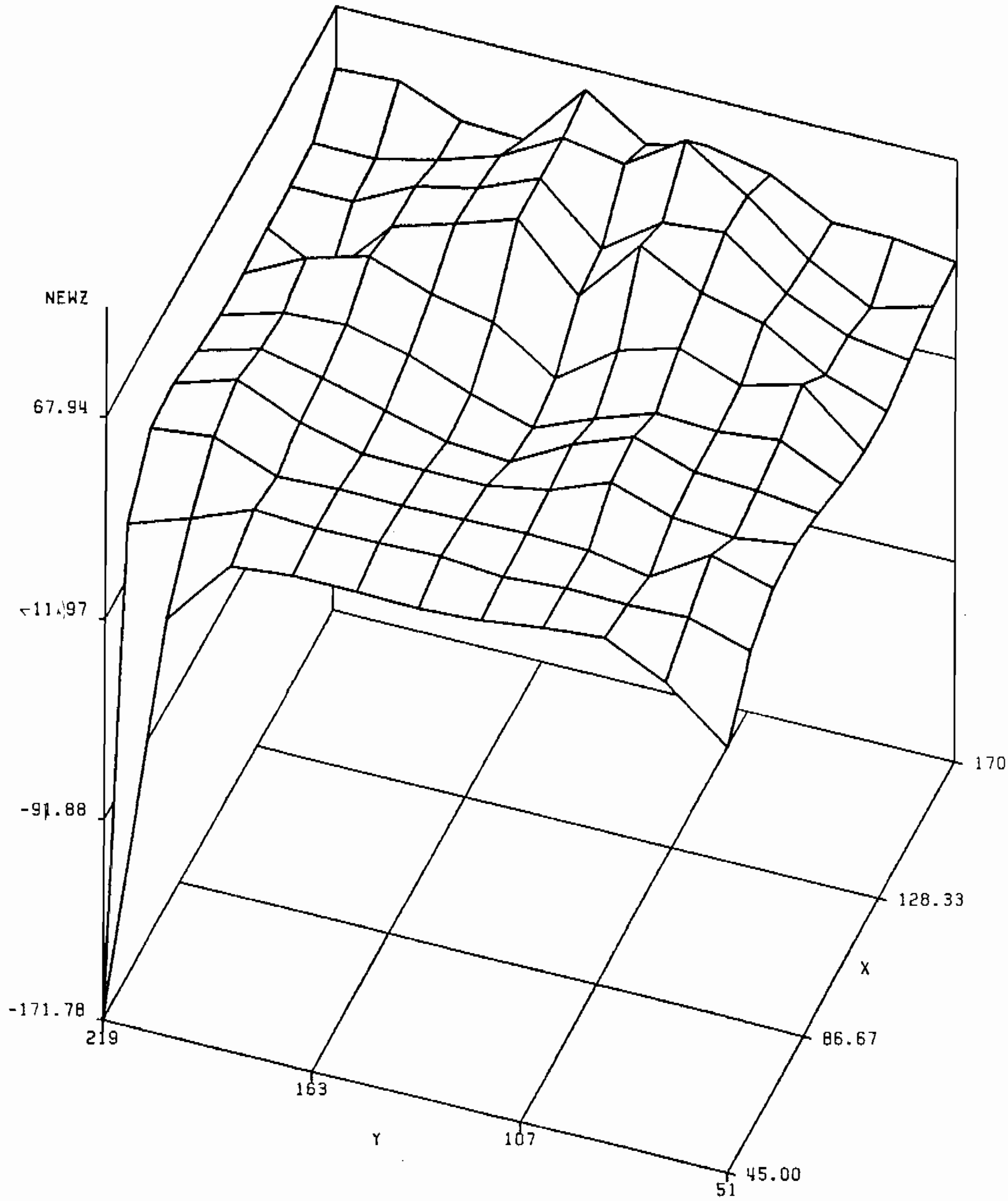
FREQUENCY BAR CHART

MIDPOINT Z		FREQ	CUM. FREQ	PERCENT	CUM. PERCENT
25	**	4683	4683	43.75	43.75
42	**	3783	8466	35.34	79.Ø8
55	***********************	17Ø8	1Ø174	15.96	95.Ø4
67	******	447	1Ø621	4.18	99.22
76	*	83	1Ø7Ø4	Ø.78	99.99
88		1	1Ø7Ø5	Ø.Ø1	1ØØ.ØØ
1Ø2		Ø	1Ø7Ø5	Ø.ØØ	1ØØ.ØØ
113		Ø	1Ø7Ø5	Ø.ØØ	1ØØ.ØØ
12Ø		Ø	1Ø7Ø5	Ø.ØØ	1ØØ.ØØ
135		Ø	1Ø7Ø5	Ø.ØØ	1ØØ.ØØ
141		Ø	1Ø7Ø5	Ø.ØØ	1ØØ.ØØ
148		Ø	1Ø7Ø5	Ø.ØØ	1ØØ.ØØ
153		Ø	1Ø7Ø5	Ø.ØØ	1ØØ.ØØ
162		Ø	1Ø7Ø5	Ø.ØØ	1ØØ.ØØ
168		Ø	1Ø7Ø5	Ø.ØØ	1ØØ.ØØ
174		Ø	1Ø7Ø5	Ø.ØØ	1ØØ.ØØ
18Ø		Ø	1Ø7Ø5	Ø.ØØ	1ØØ.ØØ
183		Ø	1Ø7Ø5	Ø.ØØ	1ØØ.ØØ
186		Ø	1Ø7Ø5	Ø.ØØ	1ØØ.ØØ
19Ø		Ø	1Ø7Ø5	Ø.ØØ	1ØØ.ØØ

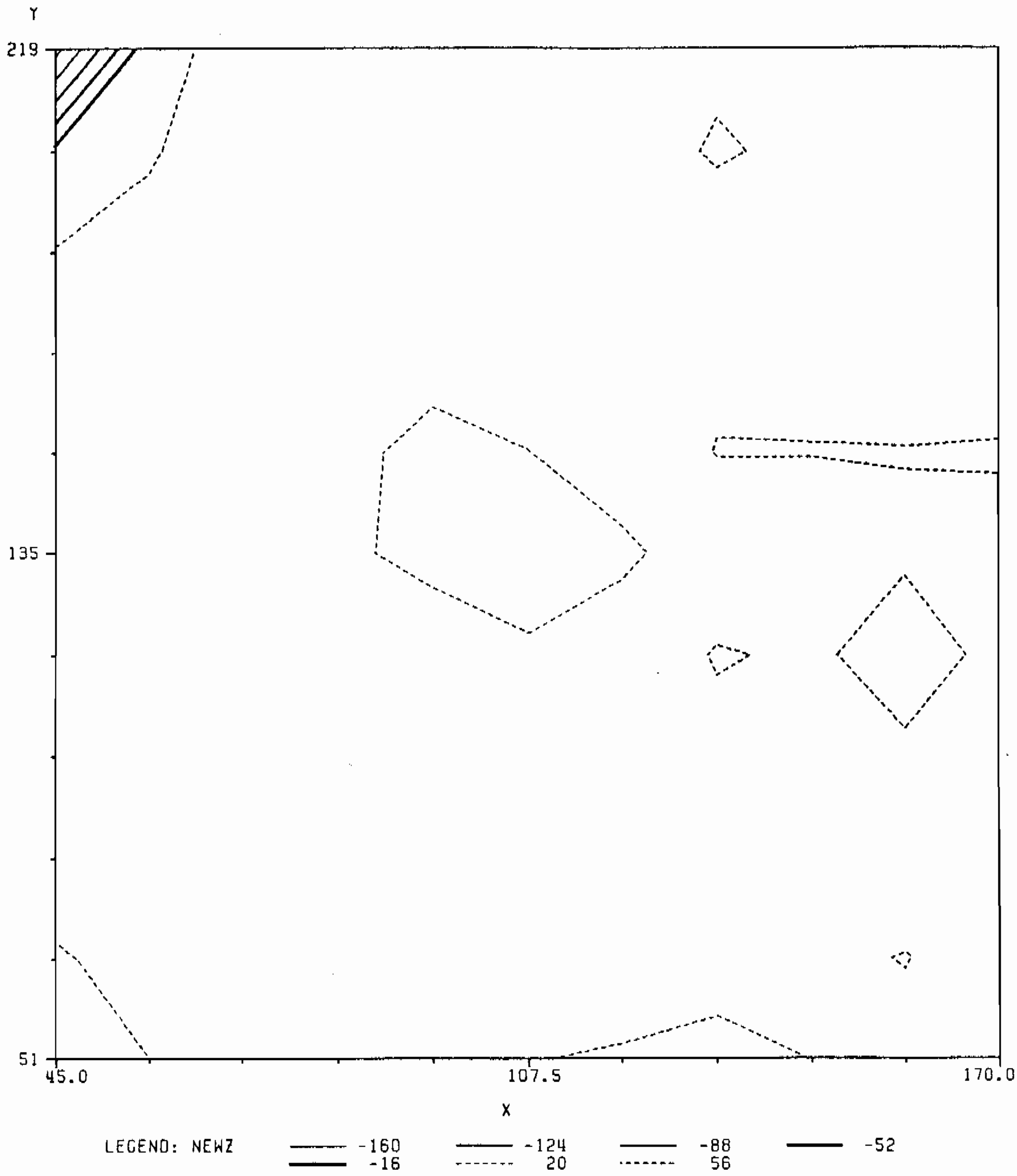
600 1200 1800 2400 3000 3600 4200

FREQUENCY

SUBJECT C -- SEAT PRESSURE
SEAT = 0
BACK = 120



# SUBJECT C -- SEAT PRESSURE
SEAT = 0
BACK = 120



SUBJECT C--SEAT PRESSURE--HISTOGRAM OF PRESSURE INTENSITY
SEAT=10
BACK = 90

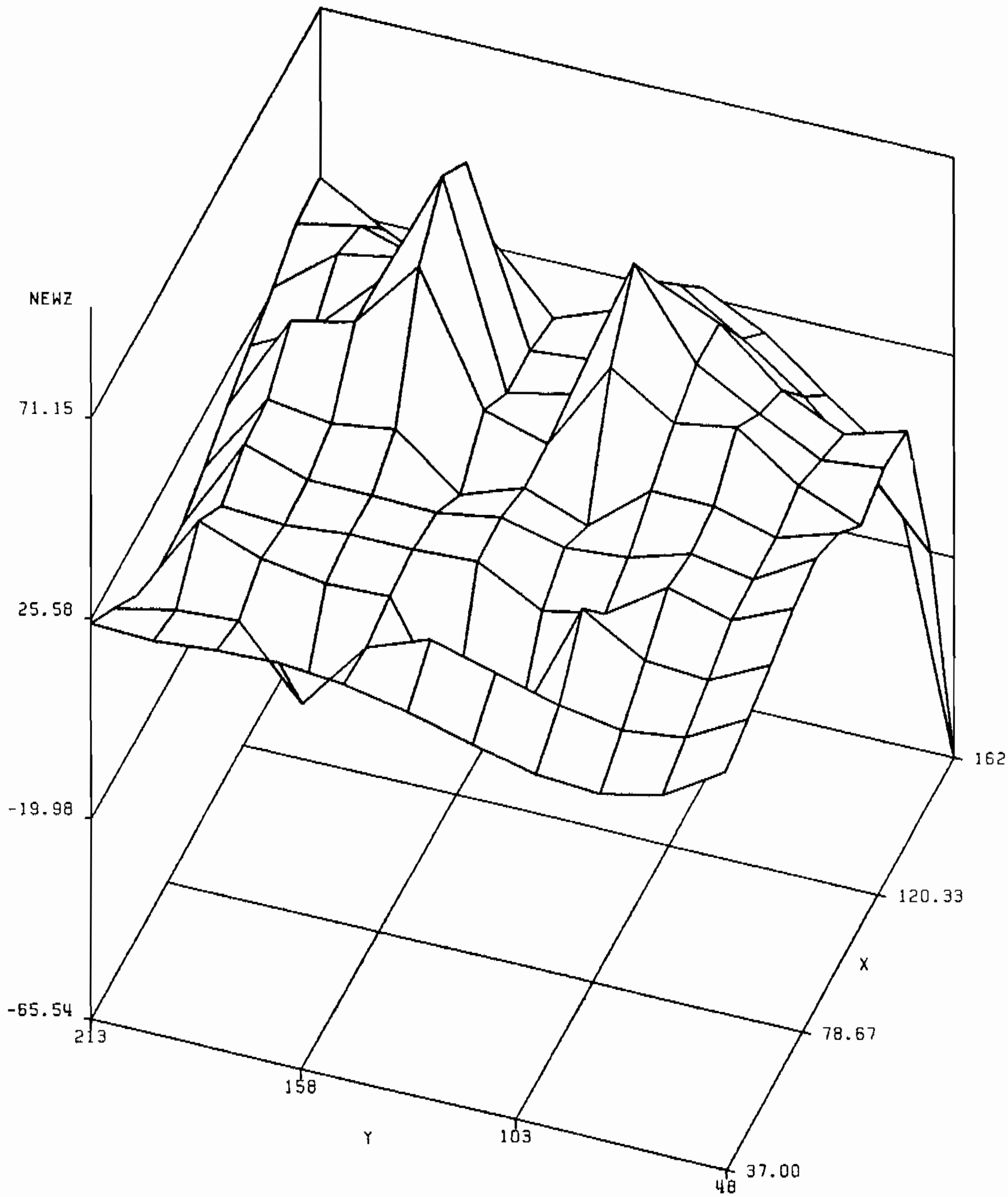
FREQUENCY BAR CHART

MIDPOINT Z		FREQ	CUM. FREQ	PERCENT	CUM. PERCENT
25	***	5750	5750	57.61	57.61
42	***	3245	8995	32.51	90.12
55	********	634	9629	6.35	96.47
67	**	173	9802	1.73	98.21
76	*	92	9894	0.92	99.13
88	*	57	9951	0.57	99.70
102		26	9977	0.26	99.96
113		4	9981	0.04	100.00
120		0	9981	0.00	100.00
135		0	9981	0.00	100.00
141		0	9981	0.00	100.00
148		0	9981	0.00	100.00
153		0	9981	0.00	100.00
162		0	9981	0.00	100.00
168		0	9981	0.00	100.00
174		0	9981	0.00	100.00
180		0	9981	0.00	100.00
183		0	9981	0.00	100.00
186		0	9981	0.00	100.00
190		0	9981	0.00	100.00

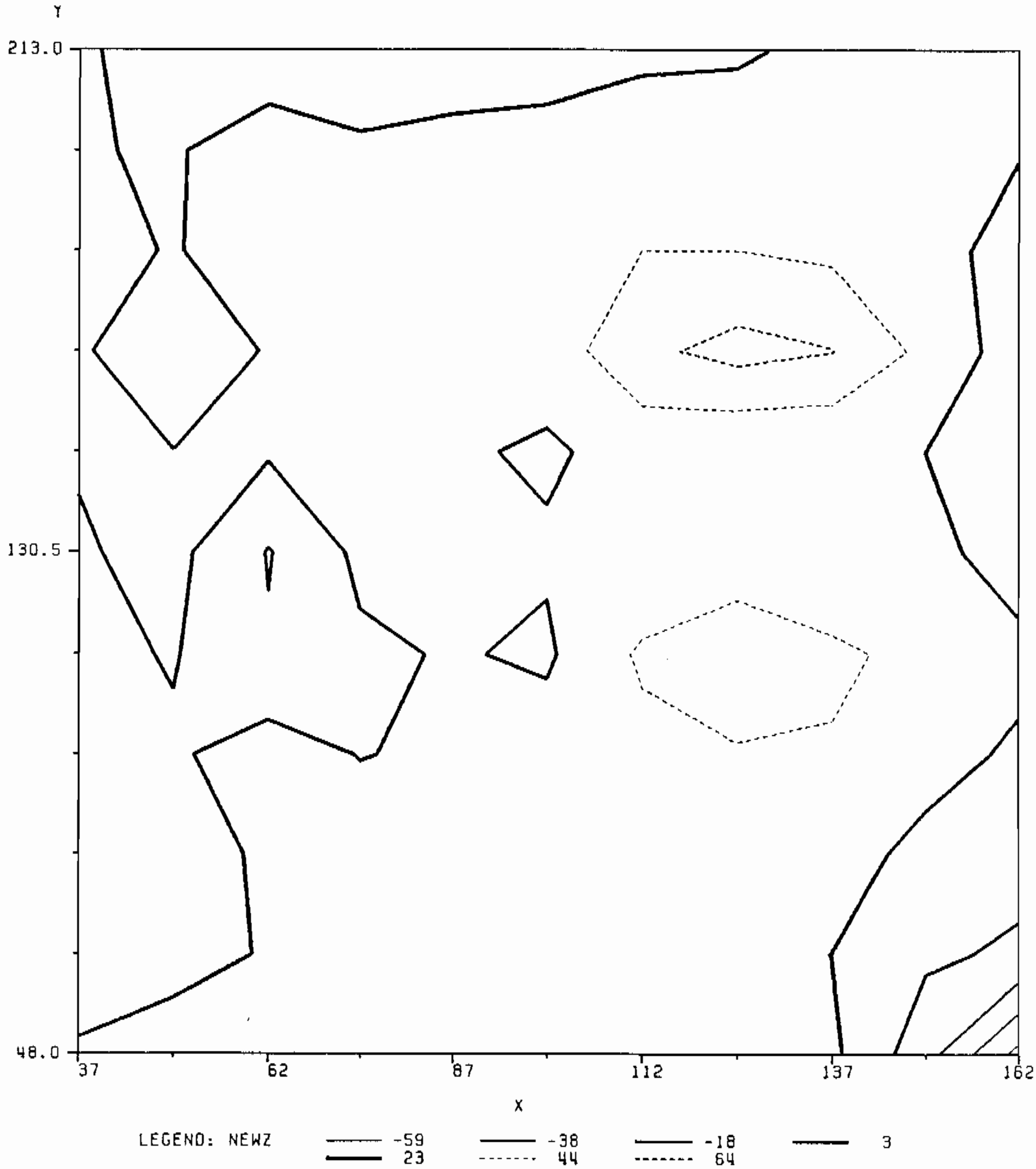
600 1200 1800 2400 3000 3600 4200 4800 5400

FREQUENCY

SUBJECT C -- SEAT PRESSURE
SEAT = 10
BACK = 90

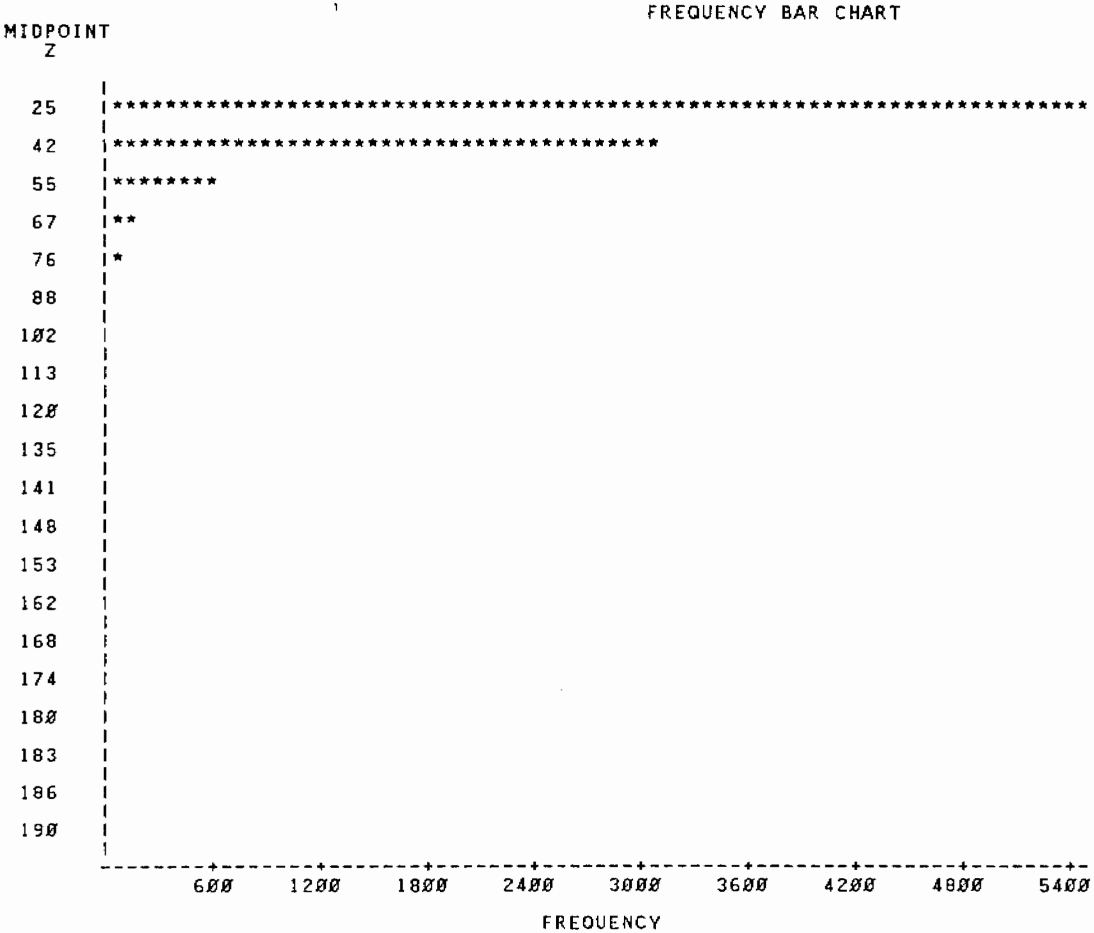


# SUBJECT C -- SEAT PRESSURE
SEAT = 10
BACK = 90



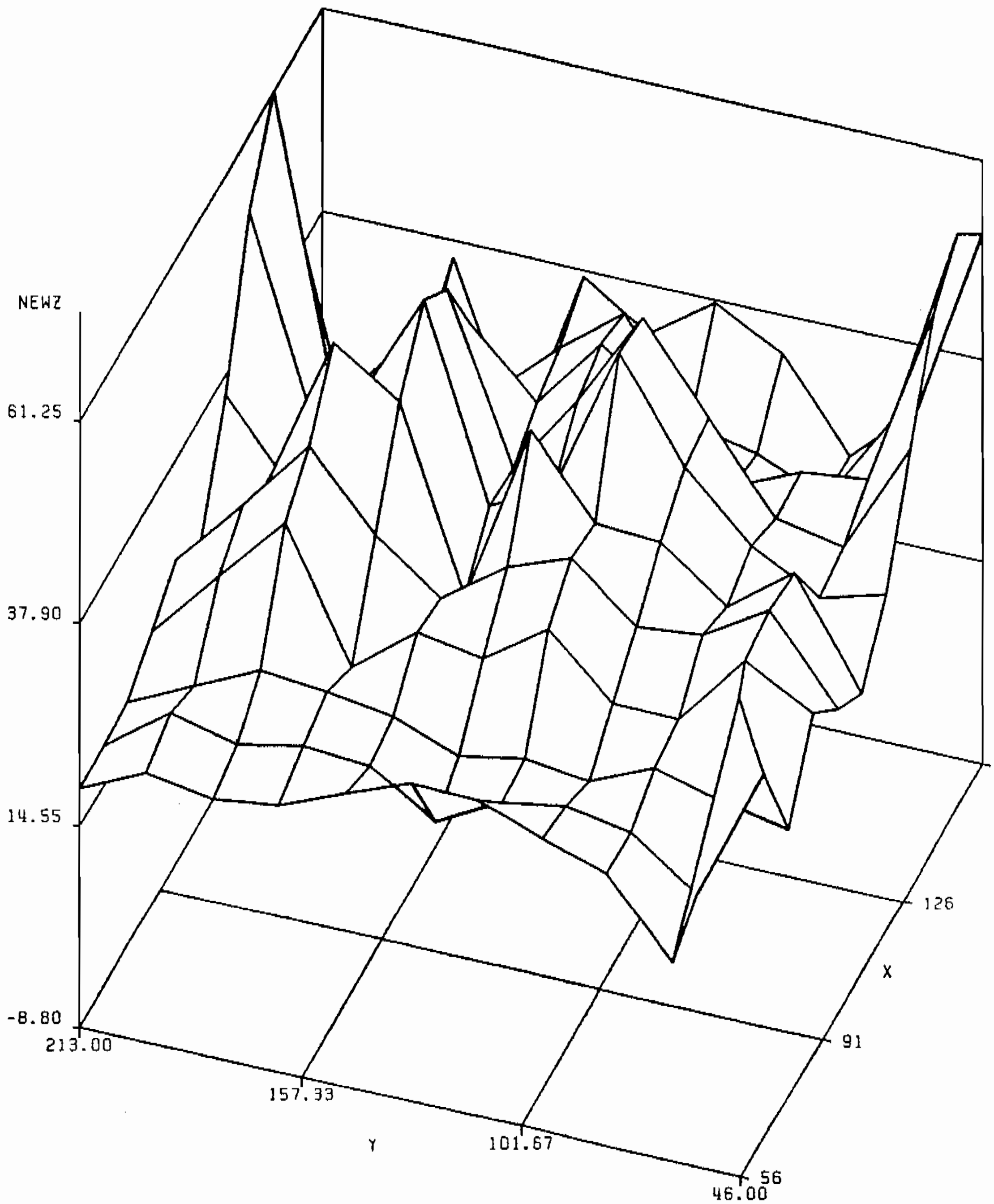
SUBJECT C--SEAT PRESSURE--HISTOGRAM OF PRESSURE INTENSITY
SEAT=10
BACK = 100

FREQUENCY BAR CHART

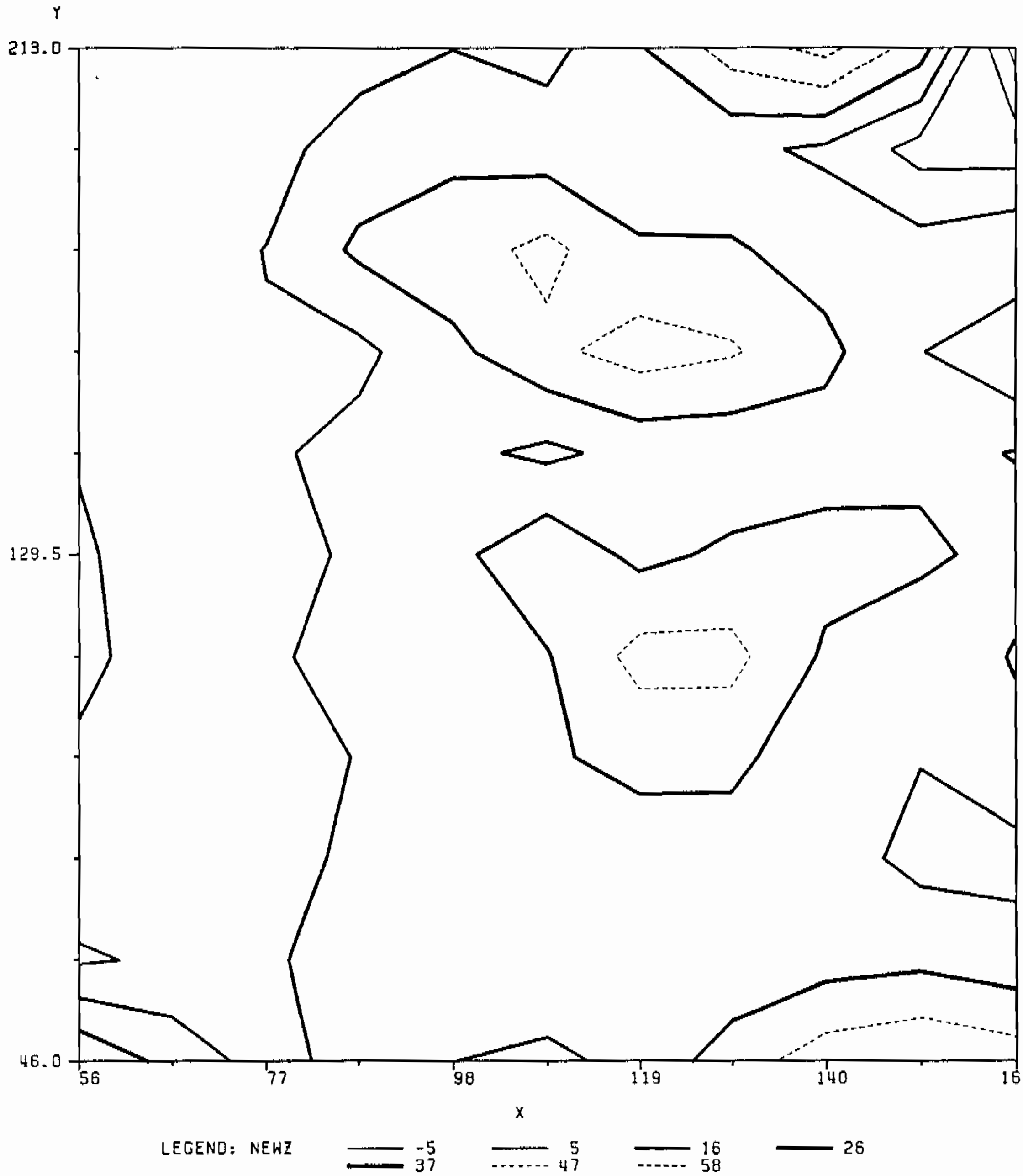


MIDPOINT Z	FREQ	CUM. FREQ	PERCENT	CUM. PERCENT
25	5446	5446	58.13	58.13
42	3085	8531	32.93	91.06
55	606	9137	6.47	97.52
67	140	9277	1.49	99.02
76	53	9330	0.57	99.58
88	36	9366	0.38	99.97
102	3	9369	0.03	100.00
113	0	9369	0.00	100.00
120	0	9369	0.00	100.00
135	0	9369	0.00	100.00
141	0	9369	0.00	100.00
148	0	9369	0.00	100.00
153	0	9369	0.00	100.00
162	0	9369	0.00	100.00
168	0	9369	0.00	100.00
174	0	9369	0.00	100.00
180	0	9369	0.00	100.00
183	0	9369	0.00	100.00
186	0	9369	0.00	100.00
190	0	9369	0.00	100.00

SUBJECT C -- SEAT PRESSURE
SEAT = 10
BACK = 100



SUBJECT C -- SEAT PRESSURE
SEAT = 10
BACK = 100

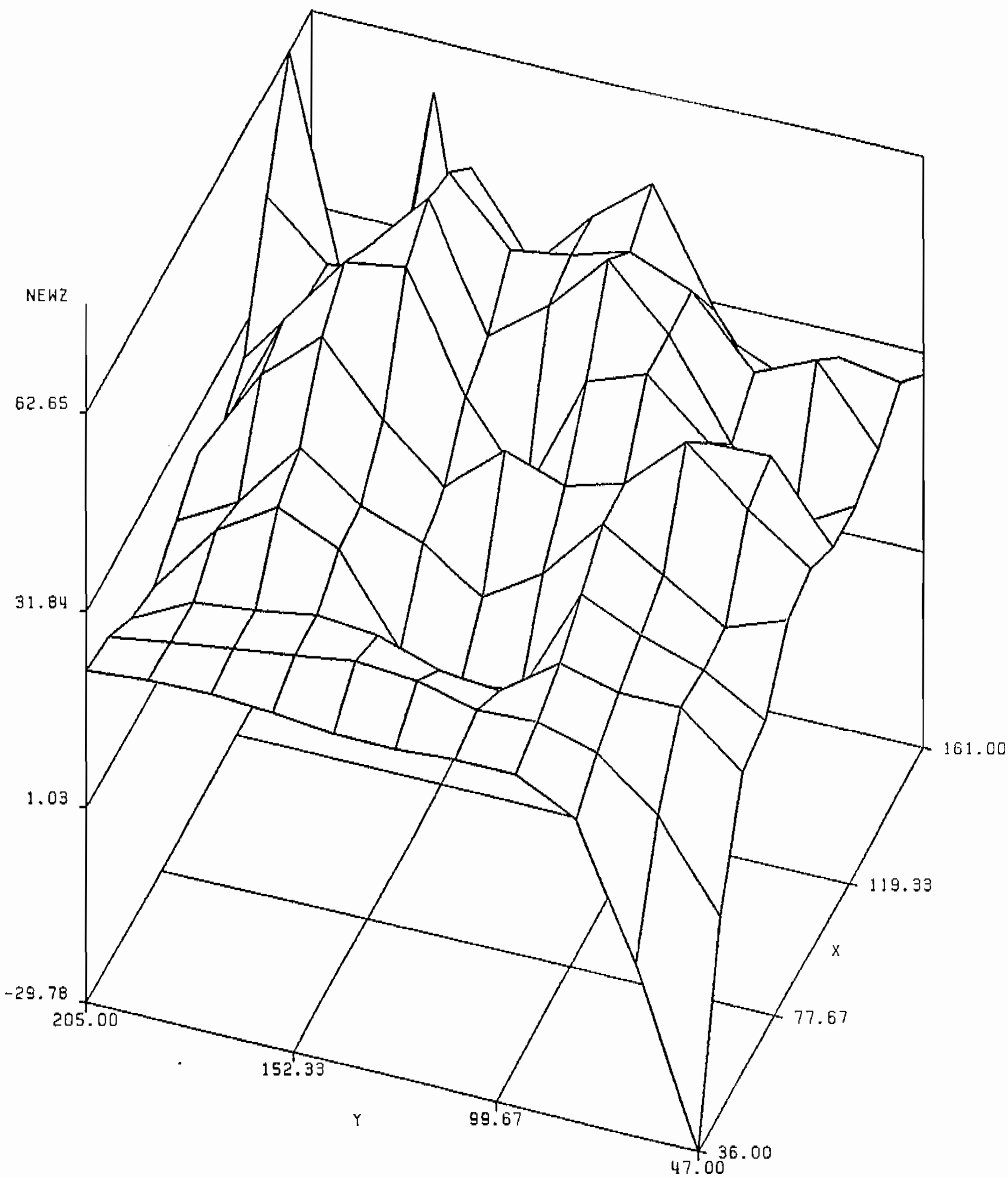


SUBJECT C--SEAT PRESSURE--HISTOGRAM OF PRESSURE INTENSITY
SEAT=1Ø
BACK = 11Ø

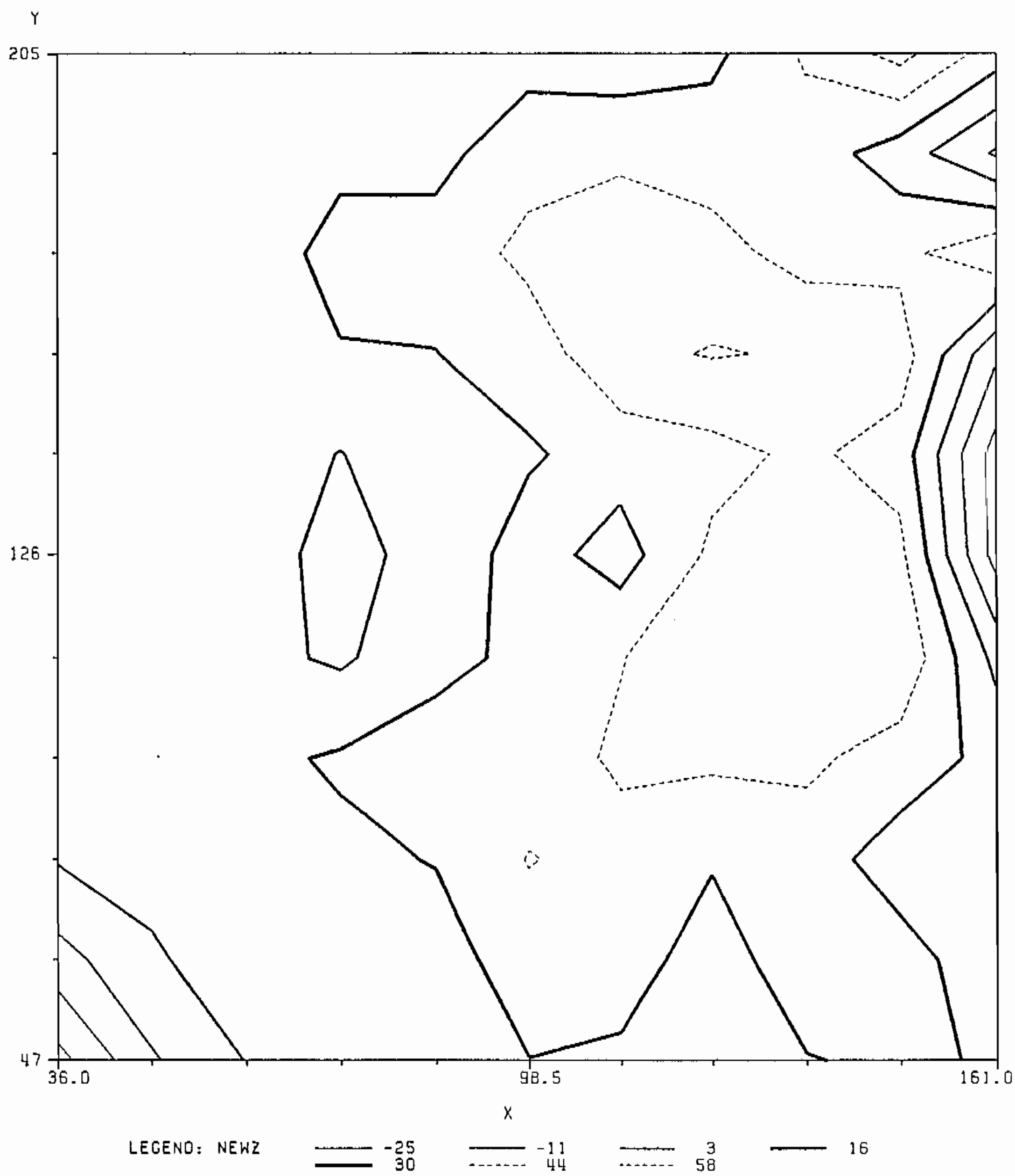
FREQUENCY BAR CHART

```
MIDPOINT
   Z                                                                                              FREQ   CUM.   PERCENT    CUM.
                                                                                                         FREQ             PERCENT
        |
  25    |*******************************************************************************          3939    3939   38.56     38.56
        |
  42    |*******************************************************************************          3952    7891   38.69     77.26
        |
  55    |***********************************                                                      176Ø    9651   17.23     94.49
        |
  67    |*********                                                                                 432   1ØØ83    4.23     98.72
        |
  76    |**                                                                                        123   1Ø2Ø6    1.2Ø     99.92
        |
  88    |                                                                                            8   1Ø214    Ø.Ø8    1ØØ.ØØ
        |
 1Ø2    |                                                                                            Ø   1Ø214    Ø.ØØ    1ØØ.ØØ
        |
 113    |                                                                                            Ø   1Ø214    Ø.ØØ    1ØØ.ØØ
        |
 12Ø    |                                                                                            Ø   1Ø214    Ø.ØØ    1ØØ.ØØ
        |
 135    |                                                                                            Ø   1Ø214    Ø.ØØ    1ØØ.ØØ
        |
 141    |                                                                                            Ø   1Ø214    Ø.ØØ    1ØØ.ØØ
        |
 148    |                                                                                            Ø   1Ø214    Ø.ØØ    1ØØ.ØØ
        |
 153    |                                                                                            Ø   1Ø214    Ø.ØØ    1ØØ.ØØ
        |
 162    |                                                                                            Ø   1Ø214    Ø.ØØ    1ØØ.ØØ
        |
 168    |                                                                                            Ø   1Ø214    Ø.ØØ    1ØØ.ØØ
        |
 174    |                                                                                            Ø   1Ø214    Ø.ØØ    1ØØ.ØØ
        |
 18Ø    |                                                                                            Ø   1Ø214    Ø.ØØ    1ØØ.ØØ
        |
 183    |                                                                                            Ø   1Ø214    Ø.ØØ    1ØØ.ØØ
        |
 186    |                                                                                            Ø   1Ø214    Ø.ØØ    1ØØ.ØØ
        |
 19Ø    |                                                                                            Ø   1Ø214    Ø.ØØ    1ØØ.ØØ
        |
        --------+-------+-------+-------+-------+-------+-------+-------+-------+-------
               4ØØ     8ØØ    12ØØ    16ØØ    2ØØØ    24ØØ    28ØØ    32ØØ    36ØØ

                                  FREQUENCY
```

SUBJECT C -- SEAT PRESSURE
SEAT = 10
BACK = 110



SUBJECT C -- SEAT PRESSURE
SEAT = 10
BACK = 110

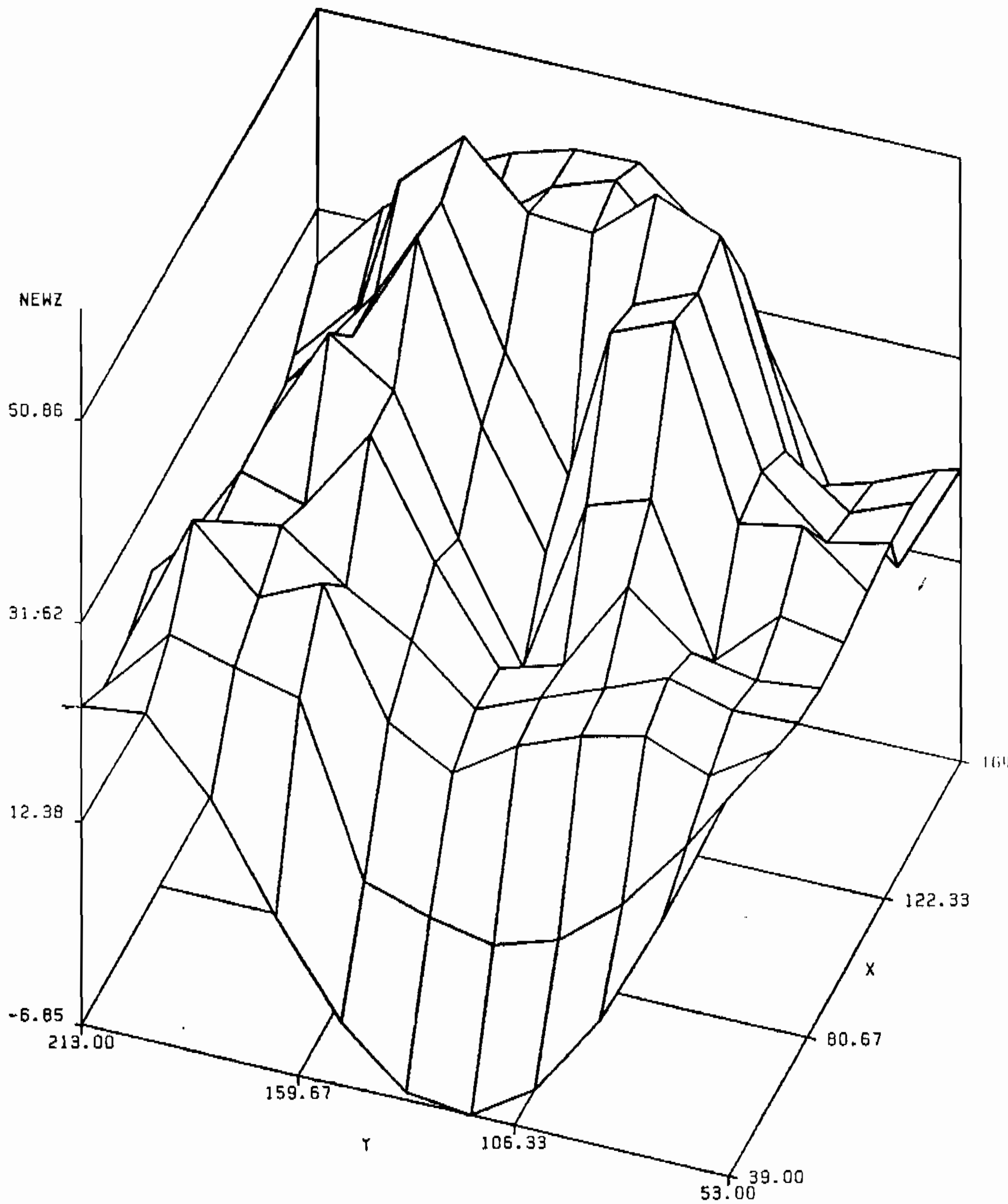


SUBJECT C--SEAT PRESSURE--HISTOGRAM OF PRESSURE INTENSITY
SEAT=1Ø
BACK = 12Ø

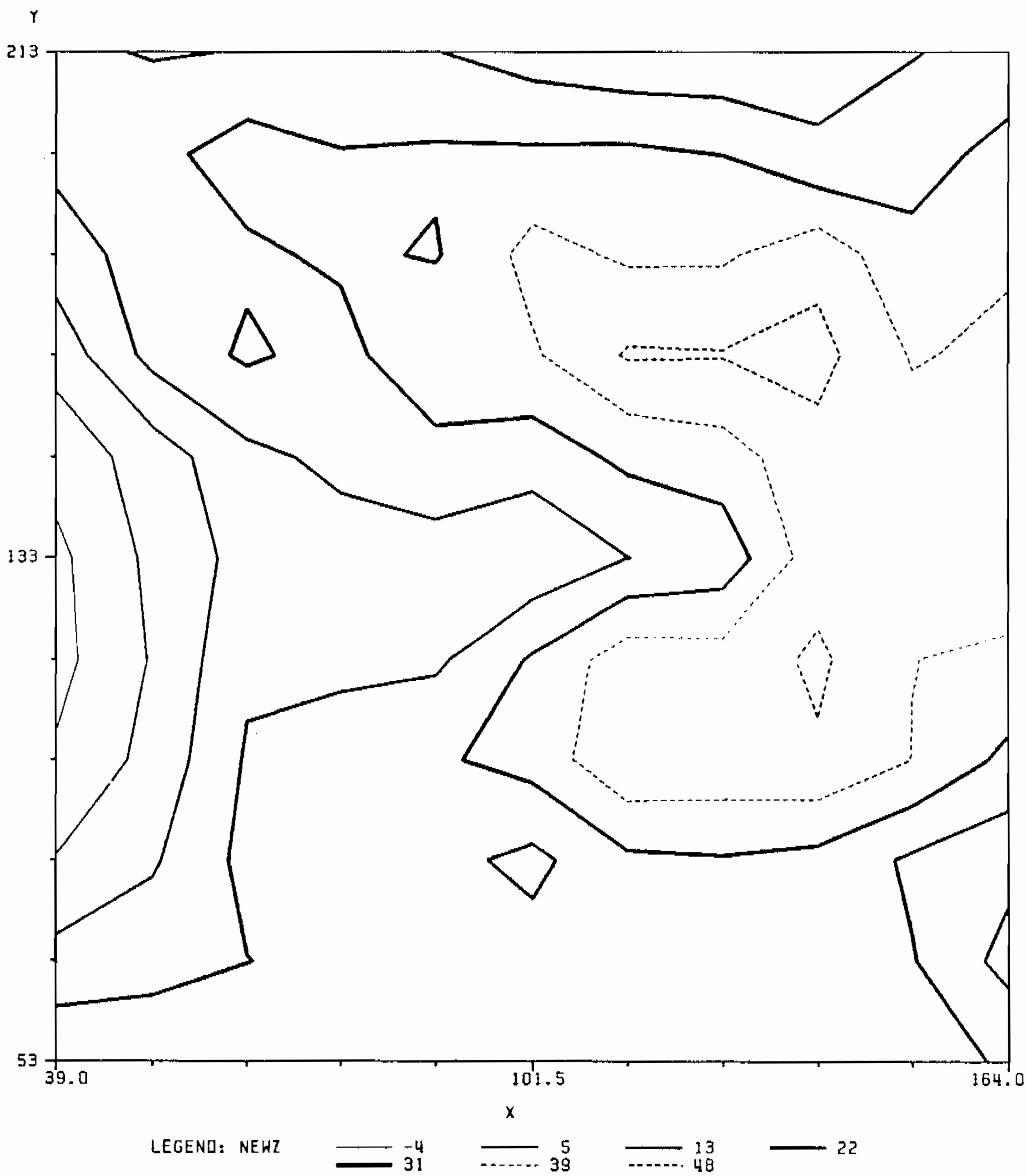
FREQUENCY BAR CHART

```
MIDPOINT
   Z                                                                                                   FREQ   CUM.   PERCENT    CUM.
                                                                                                              FREQ             PERCENT
        |
   25   |*****************************************************************************************    4434   4434    46.85    46.85
        |
   42   |***************************************************************************                  375Ø   8184    39.62    86.48
        |
   55   |***********************                                                                      1143   9327    12.Ø8    98.55
        |
   67   |***                                                                                           125   9452     1.32    99.87
        |
   76   |                                                                                               12   9464     Ø.13   1ØØ.ØØ
        |
   88   |                                                                                                Ø   9464     Ø.ØØ   1ØØ.ØØ
        |
  1Ø2   |                                                                                                Ø   9464     Ø.ØØ   1ØØ.ØØ
        |
  113   |                                                                                                Ø   9464     Ø.ØØ   1ØØ.ØØ
        |
  12Ø   |                                                                                                Ø   9464     Ø.ØØ   1ØØ.ØØ
        |
  135   |                                                                                                Ø   9464     Ø.ØØ   1ØØ.ØØ
        |
  141   |                                                                                                Ø   9464     Ø.ØØ   1ØØ.ØØ
        |
  148   |                                                                                                Ø   9464     Ø.ØØ   1ØØ.ØØ
        |
  153   |                                                                                                Ø   9464     Ø.ØØ   1ØØ.ØØ
        |
  162   |                                                                                                Ø   9464     Ø.ØØ   1ØØ.ØØ
        |
  168   |                                                                                                Ø   9464     Ø.ØØ   1ØØ.ØØ
        |
  174   |                                                                                                Ø   9464     Ø.ØØ   1ØØ.ØØ
        |
  18Ø   |                                                                                                Ø   9464     Ø.ØØ   1ØØ.ØØ
        |
  183   |                                                                                                Ø   9464     Ø.ØØ   1ØØ.ØØ
        |
  186   |                                                                                                Ø   9464     Ø.ØØ   1ØØ.ØØ
        |
  19Ø   |                                                                                                Ø   9464     Ø.ØØ   1ØØ.ØØ
        |
        --------+-------+-------+-------+-------+-------+-------+-------+-------+-------+-------+-
               4ØØ     8ØØ    12ØØ    16ØØ    2ØØØ    24ØØ    28ØØ    32ØØ    36ØØ    4ØØØ    44ØØ

                                            FREQUENCY
```

# SUBJECT C -- SEAT PRESSURE
SEAT = 10
BACK = 120

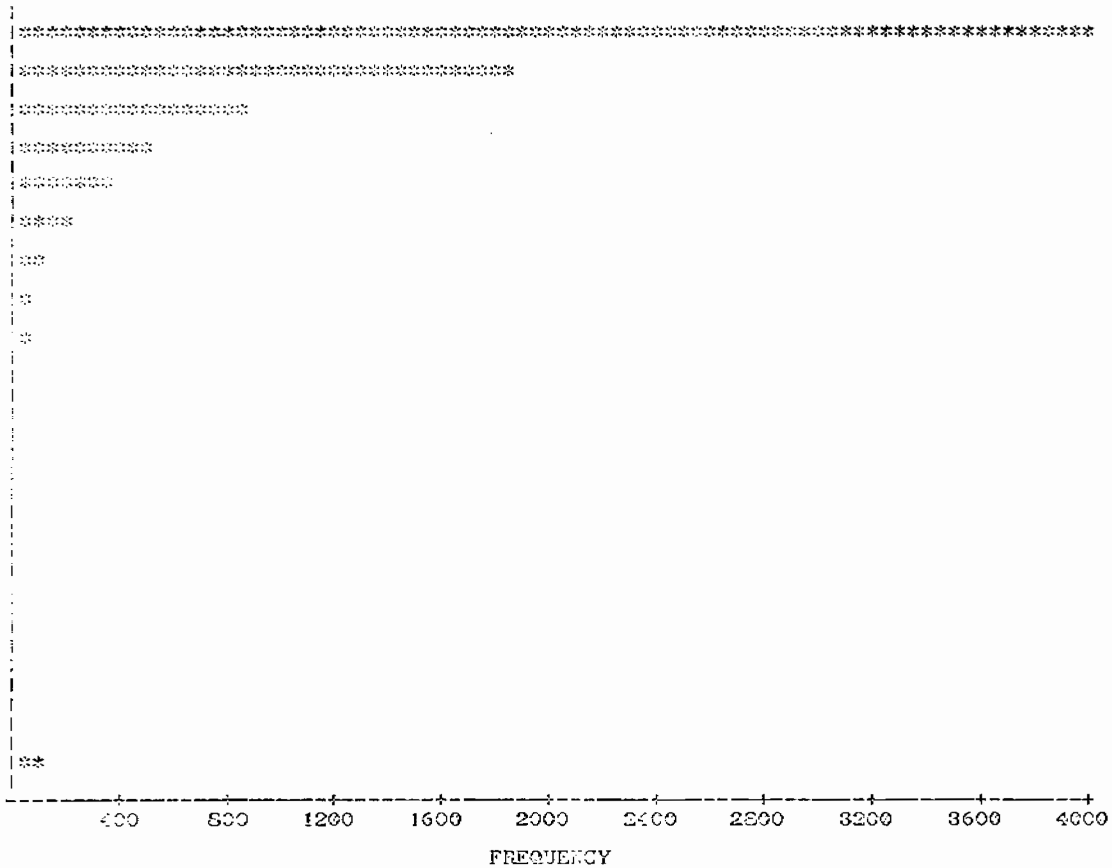


# SUBJECT C -- SEAT PRESSURE
SEAT = 10
BACK = 120



SUBJECT I--SEATING PRESSURE--HISTOGRAM OF PRESSURE INTENSITY 9:51 MONDAY, FEBRUARY 24,
SEAT=0
BACK = 90

FREQUENCY BAR CHART



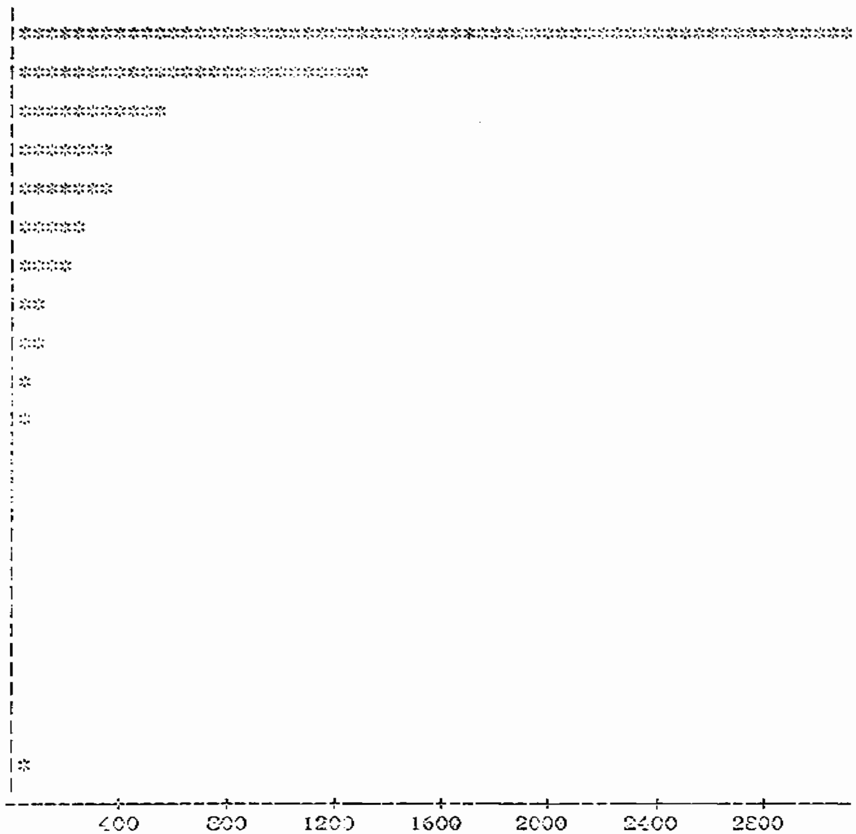
MIDPOINT Z	FREQ	CUM. FREQ	PERCENT	CUM. PERCENT
25	4001	4001	48.86	48.86
42	1867	5868	22.80	71.66
53	863	6731	10.54	82.20
67	519	7250	6.34	88.53
75	367	7617	4.48	93.02
83	197	7814	2.41	95.42
102	93	7907	1.14	96.56
113	48	7955	0.59	97.14
129	45	8000	0.55	97.69
133	21	8021	0.26	97.95
141	14	8035	0.17	98.12
148	14	8049	0.17	98.29
153	10	8059	0.12	98.41
162	9	8068	0.11	98.52
163	4	8072	0.05	98.57
174	10	8082	0.12	98.69
180	8	8090	0.10	98.79
183	6	8096	0.07	98.86
186	8	8104	0.10	98.96
190	85	8189	1.04	100.00

SUBJECT I--SEATING PRESSURE--HISTOGRAM OF PRESSURE INTENSITY 9:51 MONDAY, FEBRUARY 24, 1986 2

SEAT=0

BACK = 100

FREQUENCY BAR CHART

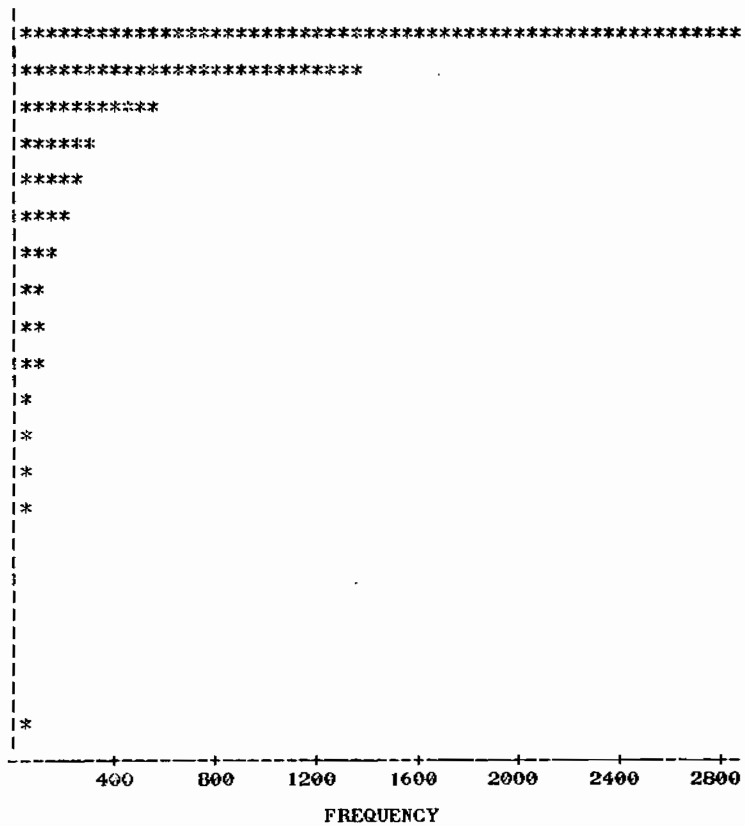


MIDPOINT Z	FREQ	CUM. FREQ	PERCENT	CUM. PERCENT
25	3085	3085	47.67	47.67
42	1314	4399	20.30	67.97
55	542	4941	8.37	76.34
67	357	5298	5.52	81.86
76	338	5636	5.22	87.08
89	264	5900	4.08	91.16
102	185	6085	2.86	94.02
115	106	6191	1.64	95.66
120	103	6294	1.59	97.25
135	65	6359	1.00	98.25
141	27	6385	0.42	98.67
148	23	6409	0.36	99.03
155	4	6413	0.06	99.09
162	10	6423	0.15	99.24
168	2	6425	0.03	99.27
174	2	6427	0.03	99.30
180	2	6429	0.03	99.34
183	2	6431	0.03	99.37
186	1	6432	0.02	99.38
190	40	6472	0.62	100.00

SUBJECT I--SEATING PRESSURE--HISTOGRAM OF PRESSURE INTENSITY
SEAT=0
BACK = 110

3
9:51 MONDAY, FEBRUARY 24, 1986

FREQUENCY BAR CHART



MIDPOINT Z	FREQ	CUM. FREQ	PERCENT	CUM. PERCENT
25	2845	2845	46.28	46.28
42	1339	4184	21.78	68.05
55	564	4748	9.17	77.23
67	310	5058	5.04	82.27
76	230	5288	3.74	86.01
88	203	5491	3.30	89.31
102	130	5621	2.11	91.43
113	97	5718	1.58	93.01
120	96	5814	1.56	94.57
135	97	5911	1.58	96.15
141	41	5952	0.67	96.81
148	25	5977	0.41	97.22
153	26	6003	0.42	97.64
162	42	6045	0.68	98.32
168	21	6066	0.34	98.67
174	15	6081	0.24	98.91
180	9	6090	0.15	99.06
183	7	6097	0.11	99.17
186	12	6109	0.20	99.37
190	39	6148	0.63	100.00

```
                 SUBJECT I--SEATING PRESSURE--HISTOGRAM OF PRESSURE INTENSITY
                                           SEAT=0                                      9:51 MONDAY, FEBRUARY 24
                                         BACK = 120

                                      FREQUENCY BAR CHART
MIDPOINT
   Z                                                                    FREQ    CUM.   PERCENT    CUM.
                                                                                FREQ            PERCENT
         |
   25    |*******************************************************       2762    2762    49.86     49.86
         |
   42    |**********************                                        1111    3873    20.05     69.91
         |
   55    |*********                                                      425    4298     7.67     77.58
         |
   67    |*****                                                          246    4544     4.44     82.02
         |
   76    |****                                                           216    4760     3.90     85.92
         |
   88    |***                                                            166    4926     3.00     88.92
         |
  102    |**                                                             122    5048     2.20     91.12
         |
  113    |**                                                              75    5123     1.35     92.47
         |
  120    |*                                                               64    5187     1.16     93.63
         |
  135    |*                                                               73    5260     1.32     94.95
         |
  141    |*                                                               32    5292     0.58     95.52
         |
  148    |                                                                22    5314     0.40     95.92
         |
  153    |                                                                21    5335     0.38     96.30
         |
  162    |                                                                21    5356     0.38     96.68
         |
  168    |*                                                               28    5384     0.51     97.18
         |
  174    |                                                                17    5401     0.31     97.49
         |
  180    |                                                                12    5413     0.22     97.71
         |
  183    |                                                                 9    5422     0.16     97.87
         |
  186    |                                                                13    5435     0.23     98.10
         |
  190    |**                                                             105    5540     1.90    100.00
         |
        ---------+---------+---------+---------+---------+---------+------
                400       800       1200      1600      2000      2400

                                   FREQUENCY
```

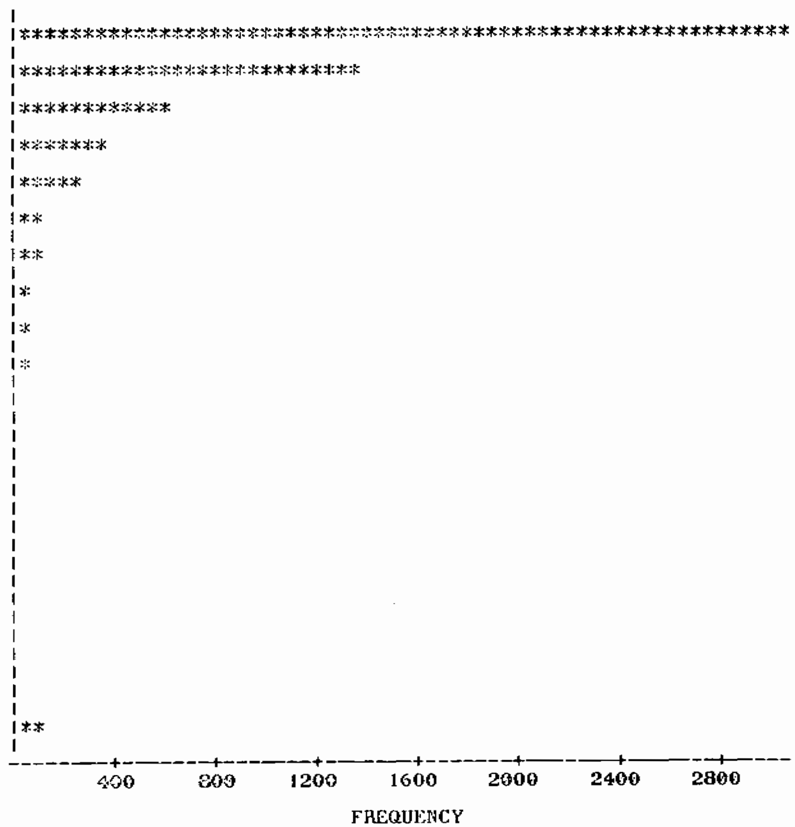
```
                    SUBJECT I--SEATING PRESSURE--HISTOGRAM OF PRESSURE INTENSITY
                                      SEAT= 10                                          9:51 MONDAY,
                                      BACK = 90

                                      FREQUENCY BAR CHART
MIDPOINT
   Z                                                                          FREQ   CUM.   PERCENT    CUM.
                                                                                     FREQ             PERCENT
        |
  25    |***************************************************************     3170   3170    50.19    50.19
        |
  42    |*****************************                                       1454   4624    23.02    73.21
        |
  55    |************                                                         576   5200     9.12    82.33
        |
  67    |******                                                               304   5504     4.81    87.14
        |
  76    |****                                                                 192   5696     3.04    90.18
        |
  88    |**                                                                   112   5808     1.77    91.96
        |
 102    |**                                                                    93   5901     1.47    93.43
        |
 113    |*                                                                     51   5952     0.81    94.24
        |
 120    |*                                                                     43   5995     0.68    94.92
        |
 135    |*                                                                     52   6047     0.82    95.74
        |
 141    |                                                                      15   6062     0.24    95.98
        |
 148    |                                                                      18   6080     0.28    96.26
        |
 153    |                                                                      24   6104     0.38    96.64
        |
 162    |*                                                                     33   6137     0.52    97.17
        |
 168    |                                                                      13   6150     0.21    97.37
        |
 174    |                                                                      20   6170     0.32    97.69
        |
 180    |                                                                      10   6180     0.16    97.85
        |
 183    |                                                                       6   6186     0.09    97.94
        |
 186    |                                                                       5   6191     0.08    98.02
        |
 190    |***                                                                  125   6316     1.98   100.00
        |
        ---------+-------+-------+-------+-------+-------+-------+--------
                400     800    1200    1600    2000    2400    2800

                                  FREQUENCY
```

SUBJECT I--SEATING PRESSURE--HISTOGRAM OF PRESSURE INTENSITY 9:51 MONDAY, FEBRUARY 24, 1986 6

SEAT=10

BACK = 100

FREQUENCY BAR CHART

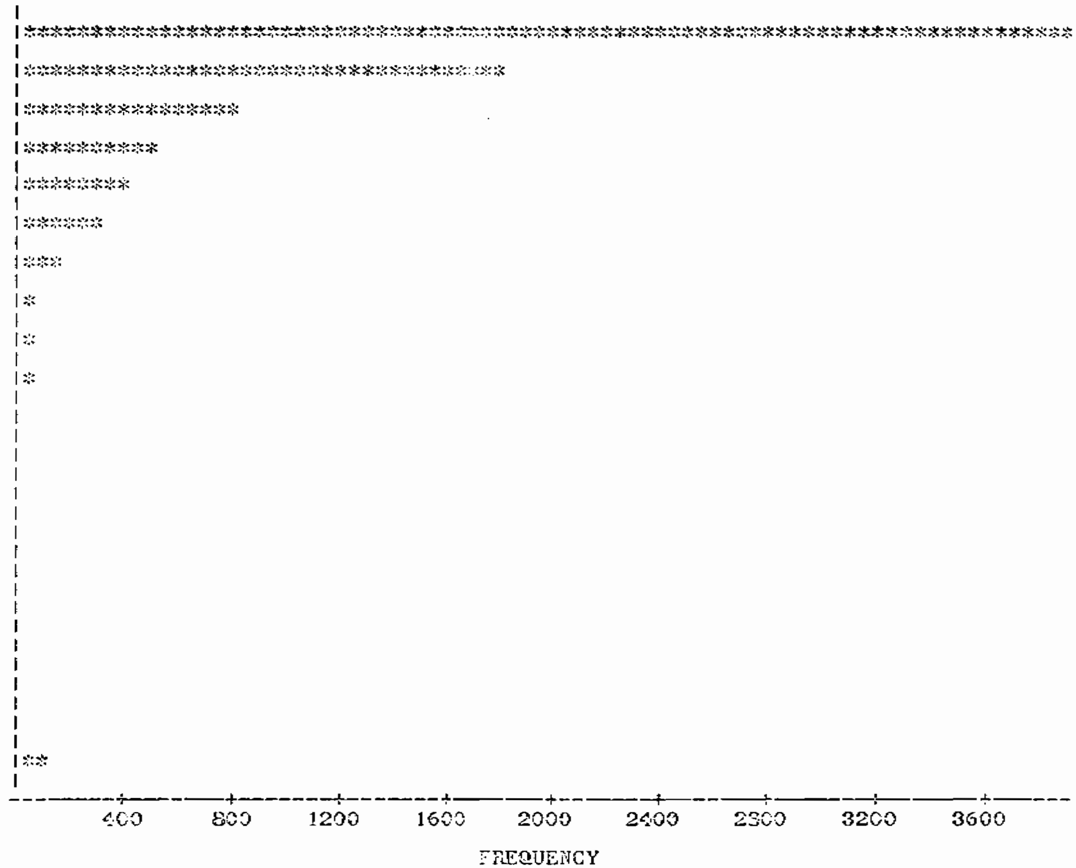


MIDPOINT Z	FREQ	CUM. FREQ	PERCENT	CUM. PERCENT
25	3060	3060	49.89	49.89
42	1351	4411	22.02	71.91
55	611	5022	9.96	81.87
67	341	5363	5.56	87.43
76	238	5601	3.88	91.31
88	123	5724	2.01	93.32
102	84	5808	1.37	94.69
113	32	5840	0.52	95.21
120	41	5881	0.67	95.88
135	41	5922	0.67	96.54
141	20	5942	0.33	96.87
148	20	5962	0.33	97.20
153	18	5980	0.29	97.49
162	17	5997	0.28	97.77
168	10	6007	0.16	97.93
174	12	6019	0.20	98.13
180	7	6026	0.11	98.24
183	12	6038	0.20	98.43
186	5	6043	0.08	98.52
190	91	6134	1.48	100.00

SUBJECT 1--SEATING PRESSURE--HISTOGRAM OF PRESSURE INTENSITY
SEAT= 10
BACK = 110

9:51 MONDAY, FEBRUARY 24

FREQUENCY BAR CHART

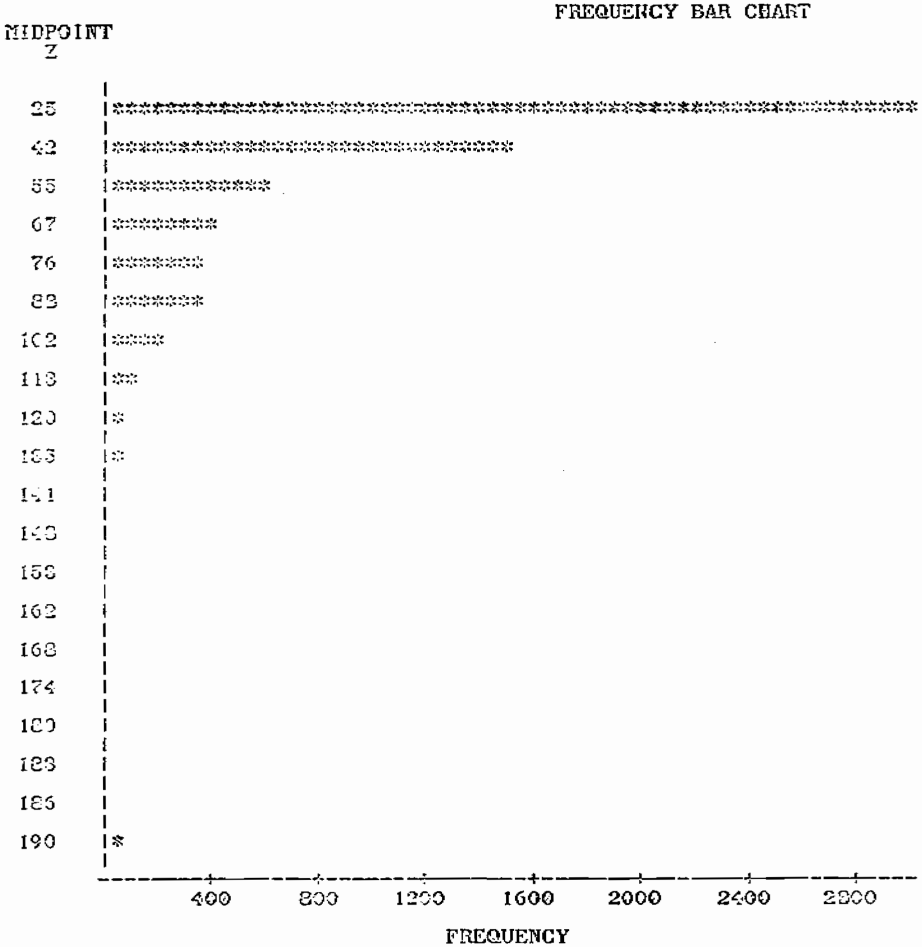


MIDPOINT Z	FREQ	CUM. FREQ	PERCENT	CUM. PERCENT
25	3899	3899	47.98	47.98
42	1821	5720	22.41	70.38
55	789	6509	9.71	80.09
67	478	6987	5.88	85.97
76	407	7394	5.01	90.98
88	312	7706	3.84	94.82
102	157	7863	1.93	96.75
113	51	7914	0.63	97.38
120	36	7950	0.44	97.82
135	29	7979	0.36	98.18
141	8	7987	0.10	98.28
148	12	7999	0.15	98.43
158	13	8012	0.16	98.58
162	10	8022	0.12	98.71
168	5	8027	0.06	98.77
174	10	8037	0.12	98.89
180	3	8040	0.04	98.93
183	7	8047	0.09	99.02
186	3	8050	0.04	99.05
190	77	8127	0.95	100.00

SUBJECT I--SEATING PRESSURE--HISTOGRAM OF PRESSURE INTENSITY 9:51 MONDAY, FEBRUARY 24, 1986 8

SEAT=10
BACK = 120

FREQUENCY BAR CHART



MIDPOINT Z	FREQ	CUM. FREQ	PERCENT	CUM. PERCENT
25	3014	3014	45.11	45.11
42	1497	4511	22.41	67.52
55	603	5114	9.03	76.55
67	383	5497	5.73	82.28
76	335	5832	5.01	87.29
88	334	6166	5.00	92.29
102	189	6355	2.83	95.12
113	97	6452	1.45	96.57
120	66	6518	0.99	97.56
133	66	6584	0.99	98.55
141	18	6602	0.27	98.82
148	3	6605	0.04	98.86
153	6	6611	0.09	98.95
162	5	6616	0.07	99.03
168	6	6622	0.09	99.12
174	7	6629	0.10	99.22
180	3	6632	0.04	99.27
183	1	6633	0.01	99.28
186	1	6634	0.01	99.30
190	47	6681	0.70	100.00

LIST OF REFERENCES

Andersson, B.J.G., and Ortengren, R. "Myoelectric Back Muscle Activity During Sitting." Scand. J. Rehab. Med. Suppl. 3:73-90, 1974a.

Andersson, B.J.G.; Jonsson, B., and Ortengren, R. "Myoelectric Activity in Individual Lumbar Erector Spinae Muscles in Sitting. A Study with Surface and Wire Electrodes." Scand. J. Rehab. Med. Supple. 3:91-108, 1974b.

Andersson, B.J.G.; Ortengren, R., Nachemson, A., and Elfstrom, G. "Lumbar Disc Pressure and Myoelectric Back Activity During Sitting. Part I. Studies on an Experimental Chair." Scand. J. Rehab. Med. 6:104-114, 1974c.

Andersson, B.J.G., and Ortengre, R. "Lumbar Disc Pressure and Myoelectric Back Muscle Activity During Sitting. Part II. Studies on an Office Chair." Scand. J. Rehab Med. 6:115-121, 1974d.

Andersson, B.J.G., and Ortengren, R. "Lumbar Disc Pressure and Myoelectric Back Muscle Activity During Sitting. Part III. Studies on a Wheelchair." Scand. J. Rehab. Med. 6:122-127, 1974e.

Andersson, B.J.G.; Ortengren, R.; Nachemson, A.; and Elfstrom, G. "Lumbar Disc Pressure and Myoelectric Back Activity During Sitting. Part IV. Studies on a Car Driver's Seat." Scand. J. Rehab. Med. 6:128-133, 1974f.

Basmajian, John V. Muscles Alive. 4th ed. Baltimore, Md.: The Williams & Wilkins Co., 1978.

Betts, R.P.; Duckworth, T.; and Austin, I.G. "Critical Light Reflection at a Plastic/Glass Interface and its Application to Foot Pressure Measurements." J. Medical Engineering and Technology. 4:136-142, 1980a.

Betts, R.P.; Franks, C.I.; Duckworth, T.; and Burke, J. "Static and Dynamic Foot-Pressure Measurements in Clinical Orthopaedics." Medical and Biological Engineering and Computing. 18:674-684, 1980b.

Betts, R.P.; Franks, C.I.; and Duckworth, T. "Analysis of Pressures and Loads Under the Foot. Part I. Quantitation of the Static Distribution Using the PET Computer." Clin. Phys. Physiol. Meas. 1:101-112, 1980c.

Betts, R.P.; Franks, C.I.; and Duckworth, T. "Analysis of Pressure and Loads Under the Foot. Part II. Quantitation of the Dynamic Distribution." Clin. Phys. Physiol. Meas. 1:113-124, 1980d.

Brand, P.W. "Pressure Sores--The Problem." in Bedsore Biomechanics, ed. R.M. Kenedi, J.M. Cowden, and J.T. Scales. Baltimore, Md.: University Park Press, 1976.

Branton, P. "Behavior, Body Mechanics and Discomfort." in Sitting Posture, ed. E. Grandjean. London: Taylor & Francis, Ltd., 1969.

Bush, Charles A. "Study of Pressures on Skin Under Ischial Tuberosities and Thighs During Sitting." Arch. Phys. Med. and Rehab. 50:207-213, 1969.

Cahill, Patrick. Personal communication, 1985.

Chaffin, Don B.; and Andersson, Gunnar, B.J. Occupational Biomechanics. New York: John Wiley & Sons, Inc., 1984.

* Chambers, John M.; Cleveland, William S.; Kleiner, Beat; and Tukey, Paul A. Graphical Methods For Data

Analysis. Murrary Hill, New Jersey: Bell Telephone Laboratories, Inc. 1983.

Consolazio, G. T. Physiological Measurements of Metabolic Functions In Man. New York: McGraw Hill, 1963.

Daniel, Rollin K.; Priest, Derek L.; and Wheatley, David C. "Etiologic Factors in Pressure Sores: An Experimental Model." Arch. Phys. Med. Rehab. 62:492-498, 1981.

* DeGroot, Morris H. Probability and Statistics. Reading, MA.: Addison-Wesley Publishing Company, Inc. 1975.

Drummond, Denis S.; et. al., "A Study of Pressure Distributions Measured During Balanced and Unbalanced Sitting." J. of Bone and Joint Surgery. 64:1034-1039, 1982.

Fisher, S.V.; and Patterson, P. "Long Term Pressure Recordings Under the Ischial Tuberosities of Tetraplegics." Paraplegia 23:99-106, 1983.

Floyd, W. F.; and Ward, Joan S. "Anthropometric and Physiological Considerations in School, Office and Factory Seating." in Sitting Posture, ed. E. Grandjean. London: Taylor & Francis, Ltd. 1976.

Franks, C.I.; Betts, R.P.; and Duckworth, T. "Microprocessor-Based Image Processing System for Dynamic Foot Pressure Studies." Medical and Biological Engineering and Computing. 21:566-572, 1983.

Garber, Susan Lipton; Krouskop, Thomas A.; and Carter, R. Edward. "A System for Clinically Evaluating Wheelchair Pressure-Relief Cushions." American Journal of Occupational Therapy. 32:565-570, 1978.

Garber, Susan Lipton; and Krouskop, Thomas A. "Body Build and Its Relationship to Pressure Distribution in the Seated Wheelchair Patient." Arch. Phys. Med. Rehab. 63:17-20, 1982.

Garber, Susan Lipton; and Krouskop, Thomas A. "Wheelchair Cushion Modification and Its Effect on Pressure." Arch. Phys. Med. Rehab. 65:579-583, 1984.

Grandjean, E. Fitting the Task to the Man. London: Taylor & Francis, Ltd. 1982.

Haliday, David; and Resnick, Robert. Fundamentals of Physics. New York: John Wiley Sons, Inc. 1974.

Holley, L.K.; Long, J.; Stewart, J.; and Jones, R.F. "A New Pressure Measuring System for Cushions and Beds--With a Review of the Literature." Paraplegia. 17:461-474, 1979.

Houle, Rollin J. "Evaluation of Seat Devices Designed to Prevent Ischemic Ulcers in Paraplegic Patients." Arch. Phys. Med. Rehab. Oct.:587-594. 1969.

Isherwood, P.A. "The Use of Chemically Dried Air in the Treatment of Chronic Ulcers." in Bedsore Biomechanics, ed. R.M. Kenedi, J.M. Cowden, and J.T. Scales. Baltimore, Md.: University Park Press, 1976.

Key, A.G.; Manley, M.T.; and Wakefield, E. "Pressure Redistribution in Wheelchair Cushion for Paraplegics: Its Application and Evaluation." Paraplegia, 16:403-412, 1978-1979.

Krouskop, Thomas A. "A Synthesis of the Factors that Contribute to Pressure Sore Formation." Medical Hypotheses 11:255-267, 1983.

Lueder, Rani Karen. "Seat Comfort: A Review of the Construct in the Office Environment." Human Factors

25:701-711, 1983.

Malament, Irwin B.; Dunn, Michael E.; and Davis, Ross. "Pressure Sores: An Operant Conditioning Approach to Prevention." Arch. Phys. Med. Rehabil. 56:161-165, 1975.

Manley, M.T.; Wakefield, E.; and Key, A.G. "The Prevention and Treatment of Pressure Sores in the Sitting Paraplegic." S. African Medical Journal. 52:771-774, 1977.

Mayo-Smith, W.; and Cochran, G.V.B. "Wheelchair Cushion Modification: Device for Locating High-Pressure Regions." Arch. Phys. Med. Rehab. 62:135-136. 1981.

McDougall, A. "Clinical Aspects of Bed Sore Prevention and Treatment." in Bedsore Biomechanics, ed. by R.M. Kenedi, J.M. Cowden, and J.T. Scales. Baltimore, Md.: University Park Press. 1976.

McKenzie, R. A. The Lumbar Spine: Mechanical Diagnosis and Therapy, Waikanae, New Zealand: Spinal Publications, Ltd. 1981.

Minns, R. J.; and Sutton, R. A. "Pressures under the Ischium detected by Pedobarograph." Engineering in Medicine. 11:111-115, 1982.

Nickerson, Raymond S. "Human Factors and the Handicapped." Human Factors, 20:259-272, 1978.

Patterson, R.P.; and Fisher, S.V. "The Accuracy of Electrical Transducers for the Measures of Pressures Applied to the Skin." IEEE Transactions on Biomedical Engineering. 26:450-456, 1979.

Peterson, M.J.; and Adkins, H.V. "Measurement and Redistribution of Excessive Pressures During Wheelchair Sitting--A Clinical Report." Physical Therapy. 6:990, Smith, David M. "A New Pedobarograph Foil-Baromat" London: University College, Bioengineering Centre. Report 1983.

Soderberg, Gary L.; and Cook, Thomas M. "Electromyography in Biomechanics." Physical Therapy. 64:1813-1819, 1984.

Spiegel, P. et. al., "Dynamic Foot Pressure Measurements in Normal Subjects." (abstract) Orthopedic Biomechanics Lab; Mayo Clinic, Rochester, Mn. 55905. 31st. Annual ORS, Las Vegas, NV. Jan. 21- 24, 1985.

Swearingen, J.J.; Wheelwright, C.D.; and Garner, J.D. "An Analysis of Sitting Areas and Pressures of Man." Civil AeroMedical Research Institute. Jan. 1962.

Tichauer, E.R. The Biomechanical Basis of Ergonomics. New York: John Wiley & Sons, Inc., 1978.

Wirta, Roy. Personal communication, 1985.

Wongsam, Patricia. "Adapted Seating." Inter-Clinic Information Bulletin. 20:1-9, 1985.

Zacharkow, Dennis. Wheelchair Posture and Pressure Sores. Springfield, Ill.: Charles C. Thomas, Publisher, 1984.