INDUSTRIAL SEATING

By

STERLING NEWELL FROST

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University of Oklahoma

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Thesis Approved:

S. Keith Adams
Thesis Adviser

Earl J. Ferguson

J. K. Boggs
Dean of the Graduate College

627039

PREFACE

The worker's chair is an important part of the work place layout in manufacturing operations. Use of a chair which does not provide adequate support for the body or maintain the proper operator-task relationship can cause undue fatigue and/or muscular discomfort. It is important that chair manufacturers be made aware of the design characteristics of good industrial seating.

Before a study of the proper design characteristics of improved seating can be undertaken, it is important that the investigator learn certain aspects of physiology, anatomy, and anthropometry. Not much information is available concerning the human engineering or biomechanical considerations of the worker-task relationship in industry. The purpose of this thesis is to present the design characteristics of a typical chair for use in industry which will accommodate a large majority of workers and minimize the problems of fatigue and muscular discomfort.

The author is particularly indebted to Dr. S. Keith Adams for his expert guidance, patience, and assistance in the preparation of this paper; and to the following for their assistance and the loan of material used in this study: The Western Electric Company; E. W. Hiatt, D. A. Heggie and other members of the Department of Biomechanics at the Western Electric Company, Kansas City Plant; and members of the Biomechanics Task Force, D. B. Powell and B. D. Johnson at the Western Electric Company, Oklahoma City Plant.

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CHAPTER I

INTRODUCTION

The problem of inadequate industrial seating has been ignored, or at least overlooked, for many years. Yet, it is an important feature in almost all work place layouts used in manufacturing operations. Disregard for the worker's needs can often be traced to ignorance on the part of equipment designers regarding essential features of good design. The purpose of this paper is to describe the design characteristics of a chair used in typical manufacturing operations. The design will adequately satisfy the needs of the worker population from the fifth to the ninety-fifth percentiles of physical stature according to McCormick (8, p. 352).

The Need Defined

The design criteria for seating vary according to the ultimate use of the chair. Considerable effort has been made to determine the optimal seat design for use in aircraft cockpits, space capsules, automobiles and aircraft passenger seats as reported in Woodson (12, p. 1-43) and McCormick (8, p. 380).

Certain features incorporated in chairs intended for use at other purposes have been found to be advantageous in chairs designed for manufacturing operations. To the best of the author's knowledge, there have been no studies specifically oriented toward designing a chair for industrial use other than those on which this paper is based.

Chairs properly designed for use in shop operations must be capable of providing adequate support for at least four hours of continuous usage without causing undue fatigue and muscular discomfort. Unless proper chairs are provided the operators, it is possible that many advantages produced through motion economy and work place design will not be realized.

Proper seating can help to reduce fatigue and eliminate the muscular soreness experienced by operators. The need for an improved chair can best be illustrated by two short examples. Both pertain to typical manufacturing operations observed at the Oklahoma City plant of the Western Electric Company where the author conducted research for this thesis.

Case Study No. 1

One of the operations required in the manufacture of a small magnetic coil is the splicing of a terminal wire to each lead wire from the coil. Several of the operators assigned to this task had complained of continual soreness in the left arm and shoulder and left side of the neck. Occasionally there were complaints of pain in the small of the back.

Observations revealed that the operators were required to work with the left arm elevated and the trunk of the body leaning slightly to one side as seen in Figure 1. Investigations revealed that this was caused by the design of the fixture and the inability of operators to adjust the height of their chairs.

The fixture was redesigned and the operator was provided with an adjustable height chair. The resultant change in operator's position can be seen in Figure 2. The operator can now sit with her elbows at her side and with the trunk of her body vertical.

After the changes were implemented, arm, shoulder and neck soreness were completely eliminated and there were no recurrences of pain in the small of the back. Over-all output improved slightly and performance was more consistent.

Case Study No. 2

All four operators assigned to a particular wire wrapping operation were complaining of soreness in the upper arms and across the shoulders. They also complained of sore and bruised backs. Two of the operators on this job had been off work several times because of back trouble.

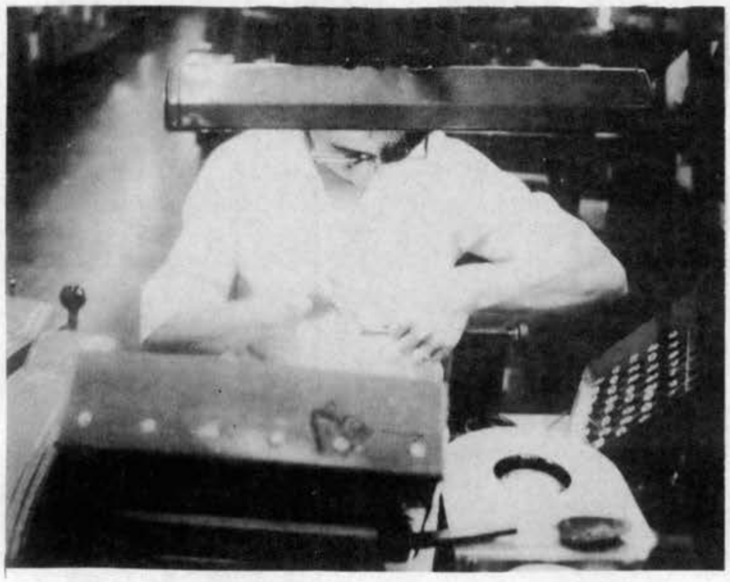

Figure 1. Operator Using Fixed Height Chair and Old Design Fixture

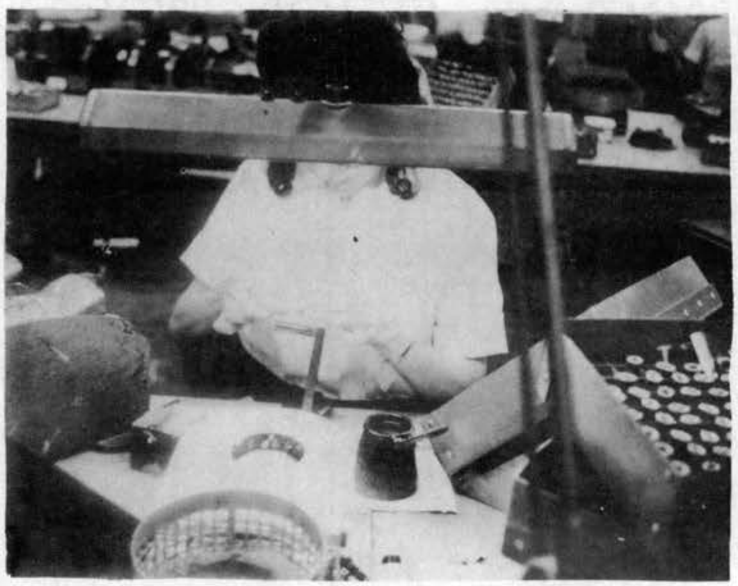

Figure 2. Operator Using Adjustable Height Chair and New Design Fixture

Investigation disclosed that the operators could not adjust the height of their chairs and would not continually lean against the six by fourteen inch wooden backrest on their chairs since they believed the backrest was the reason for the bruises on their backs.

The operators were provided with chairs which incorporate the features described in Chapters II and III. Within a few weeks the bruises on their backs had disappeared and there has been no more time off due to back ailments. Soreness in the upper arms and shoulders was minimized and the operators felt considerably less fatigued at the end of the work day.

These two short case studies describe the type of results in the improvement of operator comfort that can be achieved through improved seating. There may quite often be more than one factor involved as in Case Study No. 1. In these instances, all factors contributing to the specific problem must be considered to reach an optimal solution.

The function of this paper is to provide information on the design of a chair which will result in significant improvement in human comfort rather than an analysis of the costs and savings realized through the provision of such chairs. The type of results that can be expected from the provision of improved seating are: decreased fatigue and muscular discomfort, improved morale, decreased trips to medical, less absenteeism, and improved output and quality.

The change from one type of chair to another in almost all industrial situations will be to a better chair. This may result in some immediate effects in terms of efficiency increases but experience indicates that it is usually a product of the "Hawthorne effect" (an increase in productivity stimulated by additional attention from management rather than by changes in the work conditions) and performance soon returns to normal.

When permanent increases in efficiency and quality happen to occur, they tend to be so slight that they are difficult to verify. The most significant benefits are probably expressed in terms of decreased medical aid and absenteeism. A study to determine these results has not yet been conducted. Such a study would yield informative data and generate significant reductions in costs previously mentioned.

Basis for Recommendations

The features recommended in this paper for industrial seating are the result of experiments conducted in the Western Electric Company. The original chair design proposals were made by Dr. E. R. Tichauer, Professor of Industrial Engineering at Texas Technological College and Special Consultant on Biomechanics to the Western Electric Company.

Studies were conducted by the Department of Biomechanics and the various biomechanics committees in the Western Electric Company to determine the effectiveness of Dr. Tichauer's proposals. Based on empirical results and the subjective evaluation of operators, modifications in the chair design were made. The resulting structural features are presented in this thesis. The recommended design characteristics of the two main sections of the chair, the seat and the backrest, are discussed separately in Chapters II and III, respectively.

A cost analysis of the effects of poor seating has not been undertaken at this time even though the results would probably be significant. The difficulty of measuring indirect costs such as absenteeism, medical treatment and fatigue, rather than the nonexistence of these factors, prevents an engineering economic analysis of the problem. It is possible that the importance of a better chair design is best demonstrated in humanitarian achievements rather than by cost analysis. Similar situations occur in many phases of work in the field of Human Engineering.

CHAPTER II

THE CHAIR SEAT

The two basic purposes of a chair seat are: (a) to provide adequate support for the buttocks and thighs of the operator and (b) to maintain the proper operator-task relationship for the plane at which work is being performed. The seat design and seat height, respectively, determine the effectiveness of the chair in accomplishing these purposes. These two basic aspects will be discussed separately.

Seat Design

The three principle items considered in seat design are length, width, and contour. The objective is to establish criteria which will satisfactorily accommodate 95 per cent of the population.

Length

Seat length, defined as the distance from the front to the back of the seat, should be long enough to provide adequate support and yet not cut into the back of the operator's knee. Data given by McCormick (8, p. 352) indicate that the median seat length for men is 18.9 inches with a standard deviation of .96 inches. The median for women is shown as 18.2 inches with a 1.04 inch standard deviation. The ranges are 15.4 to 23.1 inches and 15.2 to 22.2 inches for men and women, respectively. From these data, a seat length of 16 inches would satisfy the support requirements of 95 per cent of the population and be short enough to allow proper bending of the knee in the seated position.

Width

Seat width should be sufficient to support the buttocks and allow a certain amount of side-to-side movement. Dimensions of the median hip breadth in seated position, found in McCormick (8, p. 352) are 15.3 inches for men and 14.6 inches for women. The ranges are 12.0 to 21.3 inches for men and 12.1 to 20.6 inches for women with standard deviations of 1.11 and 1.04 inches, respectively. It should be noted that the load bearing points of the bone structure in the buttocks are the ischial tuberosities. The ischial tuberosities are the oval masses at the bottom of the pubic bones and are the bony prominences in the buttocks while seated. Since they are not at the edge of the hips, some shifting of the edge of the hips past the edge of the seat does not physically punish the seated operator or cause a feeling of distress. Therefore, 16 inches is sufficient to provide adequate support for 95 per cent of the population and still allow some side-to-side movement.

Contour

Contour of the seat has received some publicity in recent years from chair manufacturers who claim to produce chairs designed with emphasis on "human engineering." The most popular designs which claim to be human engineered are the bucket seat and "form fitting" types. The bucket seat is very restrictive. Little or no side-to-side movement is possible. Long periods of sitting in a bucket seat, as experienced by an operator at an assembly position, can be very uncomfortable since a change in position is virtually impossible. The form fitting seats are made to fit the physique of a so-called "average" person. Virtually no one fits these dimensions exactly. The result is that extended periods of occupying one of these seats can be extremely uncomfortable. Those persons who are wider than the seat form have the feeling of being compressed as if they were in a funnel. Conversely, those persons with narrow features feel as if they are being split apart. Side-to-side movement is, of course, prohibited. In general, form fitting equipment is the least desirable. For example, what could be more "form fitting" than a shirt collar or pair of shoes a size too small?

The seat surface contour should be flat with a gently curved front and slight backward slope. A gentle "waterfall" slope on the front of the seat starting approximately three inches from the edge helps to prevent pressure to the popliteal area of the thigh which is directly back of the knee. On operators with short legs, the leading edge of a straight seat can cause undue pressure to the nerves and blood vessels on the underside of the thigh. The seat should slope backwards at an angle of four degrees to six degrees with the horizontal. This slight slope helps distribute some of the load onto the back of the seat.

The incorporation of an optional swivel feature on the seat may be advantageous when gross rotation of the trunk of the operator's body or extreme retraction (drawing back) of the elbow is required on the task. The stress to the shoulders and back will be reduced.

Additional worthwhile design considerations are that the seat be lightly padded and aerated. An aerated seat covering allows circulation of air which prevents the retention of body heat and perspiration. The covering will also eliminate the slick surface prevalent on most shop chairs. A slick surface gives the operator the sensation of sliding forward when she leans back, even though there is a slight backward slope to the seat. This will cause the operator to tighten her leg, stomach, and back muscles to overcome the insecure feeling and, therefore, provide an unnecessary element of fatigue.

Light padding will help distribute the load over a large area of the buttocks. Even though the flesh over the ischial tuberosities can withstand a large amount of pressure without restricting the blood supply, a light pad reduces the shock and discomfort to a specific area. If the seat is over padded, there is restriction of movement and air circulation as the buttocks sink into the padding. Should the padding break down, there is a good possibility that a bucket will be formed.

Seat Height

The most important function of a seat is to place the operator in the proper relationship to the task being performed. The bench top is not the principle plane of work at most manufacturing positions. There is usually a jig or fixture of variable height in which the task is being performed. The important dimension then becomes the distance from the top of the seat to the principle plane of work rather than to the bench top.

Variation in the body dimensions of operators prevents the establishment of a standard height chair which is satisfactory. The conventional chair height for use at a 30 inch high bench has been 18 inches for many years. This was supposed to fit the average man. The additional height of the heel on women's shoes was supposed to compensate for the difference in leg length and make 18 inches acceptable for women. The facts now are that women in factories generally wear shoes with no more heel height than that of men's shoes. The chair that was advertised to fit the average person really accommodates considerably less than fifty per cent of the total population.

Chairs are commercially available with two types of height adjustments. These include continuous and step adjustments. The continuous adjustment feature permits exact positioning for any height operator. However, experience shows that this is not always desirable for shop application. Many operators spend too much time making meaningless small adjustments trying to find a height that is "just exactly right" or to rediscover the position used before. After a period of use it is not unusual for the operators to cease trying to adjust the height each day unless the setting causes gross discomfort.

Step type height adjustments do not allow exact positioning by the operator. However, if the increments are approximately one-half inch to one inch in height, near optimum adjustment is possible. They also offer an advantage in that the operator can rapidly relocate a previously used position. Adjustments of this type are usually made in a very short time. Frequent time consuming small changes are discouraged.

The inability to adjust the seat height can result in the operator performing useless isometric work when the seat height is too low. Isometric work is performed in abducting the upper arm sufficiently to allow freedom of movement. Abduction of the arm means to move the arm sideways from the body. The angle of abduction is the included angle between the body and the upper arm.

What may appear to be a small change in the chair seat to work plane relationship can have a very large effect during assembly operations. For example, an increase of three inches in work surface height from the point where there is no abduction, can cause approximately a 35 to 40 degree angle of abduction in female workers. A good approximation of the angle of abduction can be obtained from the formula:

$$\text{Cos}X = B/A$$

where

X = angle of abduction

B = distance from shoulder to bench

A = distance from shoulder to elbow.

There is some disagreement among various authors, such as Heggie (6, p. 4) and Harrower (5, p. 224) as to the exact amount of increase in stress on the shoulder muscles and joint as a result of an increase in the angle of abduction. However, there is general agreement that increases in the angle produce considerable increases in strain. The result is that the operator uses energy performing isometric work rather than productive activities.

If the chair is too high, circulation in the lower leg is impaired by the seat pressing into the underside of the thigh. There are many cases of leg numbness and swollen feet due to the pressure against the nerves and blood vessels. Continued use of such a chair can lead to varicose veins. The most common way operators relieve the pressure is by sitting forward on the chair as in Figure 3. In this position, the operator either does not use the backrest and maintains posture with the body muscles or slumps back against the backrest and thereby increases the reach distance to the work area. Both situations are undesirable.

The ideal situation, of course, would be one in which the operator places both feet on the floor and still maintains the proper position with respect to the task being performed. This is rarely possible, however, since work benches are not adjustable in height. The frequent result is that the chair must be adjusted to a position so high that it is impossible for the operator to reach the floor when seated properly in the chair. It may be necessary in such cases to provide the operator with a footrest.

Figure 3. Common Method of
Relieving Pressure
to Back of Legs

Footrests

The most common type of footrest used in American industry today is a bar or rod mounted to the bench. This type of footrest is generally utilized by resting the foot so that the pressure is applied directly to the arch of the foot as seen in Figure 3. The arch is a very sensitive area on the foot. Nerves, blood vessels and tendons to the toes pass through the arch with very little protective tissue covering them. Continued pressure in this area can cause pain or numbness in the foot and leg.

Another problem with the bar type footrest is that it is not adjustable to fit the needs of different operators. The operator in Figure 3 is sitting forward in her chair to reach the footrest.

The properly designed footrest must be large enough to support both feet and have room enough for the operator to change the position of her feet occasionally. It must be adjustable in height to fit the needs of various operators. Interestingly, these are also characteristics of a proper chair.

CHAPTER III

THE BACKREST

The basic function of a backrest is to provide postural support for the upper portion of the operator's body. At the same time, it must not interfere when trunk movements and gross arm movements are required. The design of the backrest and the extent to which it can be adjusted determine the effectiveness of the backrest in accomplishing these purposes.

Backrest Design

The most common backrest design for chairs used at manufacturing operations is 14 inches wide and six to seven inches high. It generally has a concave curvature in the horizontal, is straight in the vertical and is made of bare metal or wood.

Many operations require that the elbows be retracted while performing the task. If the backrest is too wide, the operator may strike it when moving back her arm (see Figure 4). This may result in pain in the arm or hand if the ulnar nerve (often referred to as the "crazy bone") is struck. Operators soon become accustomed to this handicap

Figure 4. Common Backrest Design

and abduct the arm before starting back; however, this interference and unnecessary motion can be eliminated by proper design.

According to Dreyfuss (3, p. 32), the distance between the shoulder joints for the average male is 11.5 inches. The range is from 10.6 to 12.4 inches and includes the 97.5 and 2.5 percentiles. The range of the measurements for women is not given, but the average is shown as 10.8 inches. The use of a nine inch wide backrest eliminates the interference problem for approximately 95 per cent of the population. It should be slightly curved in the horizontal. This size backrest is wide enough to provide support across the entire lumbar region of the back on most operators. The lumbar region is commonly called the small of the back. There are five vertebrae numbered from lumbar 1 directly below the ribs to lumbar 5 immediately above the pelvic girdle.

Backrests designed with too great a dimension in the vertical do not give proper support. A large backrest may bridge the distance between the rib cage and the pelvic girdle. When this occurs, the natural curvature of the spine may be diminished as the lumbar curve seeks support.

A wide backrest that is positioned too high will pivot on the rib cage. Figure 4 demonstrates this condition. This may cause the bottom edge of the backrest to bruise the back in the area of the 2nd, 3rd, and 4th lumbar vertebrae (about waist high). If a wide backrest is positioned too low, it will pivot on the pelvic girdle. Pressure may then be placed on the 1st and 2nd vertebrae which are just below the ribs.

In either case described, considerable stress will be placed on the lumbar region of the back. Continued use of such a chair can cause severe irritation. An example of the resultant bruises from this situation are shown in Figure 5.

A backrest of approximately five inches high will give sufficient support to the spine and not interfere with the rib cage or pelvic girdle. In addition, the backrest should be padded enough to prevent sharp edges and provide a slight convex curvature in the vertical. The elimination of sharp edges will reduce stress to the back, particularly on those operators with a very prominent bone structure. The convex curvature will fit the concave of the spine better and be more comfortable.

The cover should be a smooth aerated material. Materials such as plastic and vinyl restrict the air flow and consequent dissipation of heat and moisture. Many operators will not fully utilize a backrest covered with a non-breathing material. Material with a rough surface has a tendency to cling to operators' clothing. This is very annoying.

The backrest should be mounted on a swivel to permit

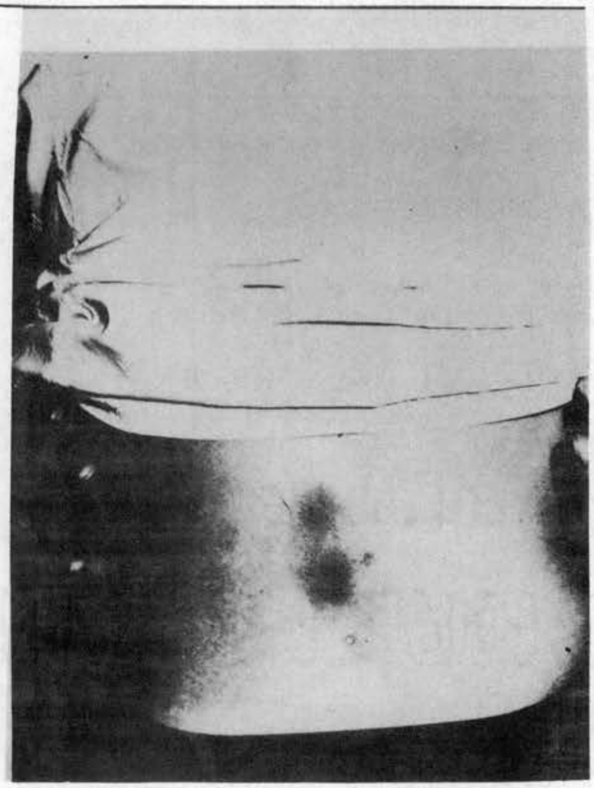

Figure 5. Back Bruise Caused by Backrest

adjustment to the contour of the spine. This feature is a standard item on many chairs. Unfortunately, the size of the backrest generally prevents it from being very effective. Several types of chairs are equipped with a threaded stop which may be used to hold the backrest at a fixed slope. What usually happens is that the stop is set at its limit and the operator rests against the edge of the backrest rather than make an adjustment.

It is also preferable to mount the backrest on a rigid support. A flexible support causes the backrest to creep up the operator's back when increased pressure is applied. The flesh is irritated by this rubbing action and may occasionally be pinched.

Backrest Adjustments

Three different adjustments must be possible to correctly accommodate various operators and tasks. They are: the horizontal location, the vertical position, and the angle between the seat and backrest.

An adjustment in the horizontal is necessary to allow for the large variations in the curvature of the spine. The variation is more pronounced in women and can be observed quite readily. Also, a horizontal adjustment may allow the use of a 16 inch seat length by an operator whose stature is so short that she would not be able to utilize the backrest otherwise.

The vertical adjustment is required because of the wide range of operator heights. The value found in McCormick (8, p. 352) for the mean shoulder height-sitting for women is 24.6 inches with a standard deviation of 3.02 inches. The median for men is 23.3 inches with a standard deviation of only 1.14 inches. According to Dreyfuss (3, pp. 33-35), the average is 23.7 inches for women and 24.3 inches for men. The vertical adjustment is probably the most critical of the backrest adjustments.

If operators are not properly trained, they will generally adjust the backrest too high. The tendency seems to be to provide support for the shoulders rather than the back. The result is that the backrest interferes with the movement of the scapula (shoulder blade). Figure 6 demonstrates this condition. In this position, the scapula may actually strike the backrest. The shoulder blade should be kept free so the muscles in the back can help when performing arm and shoulder movements. Many chairs are available with vertical adjustment of the backrest.

During the five to seven days prior to her menstrual cycle, the female operator retains body fluids. This causes some swelling in the abdominal region and an uncomfortable feeling when sitting in an erect position for long periods of time. The provision of a tilt mechanism to increase the angle between the chair seat and backrest allows the operator to recline and relieve some of the

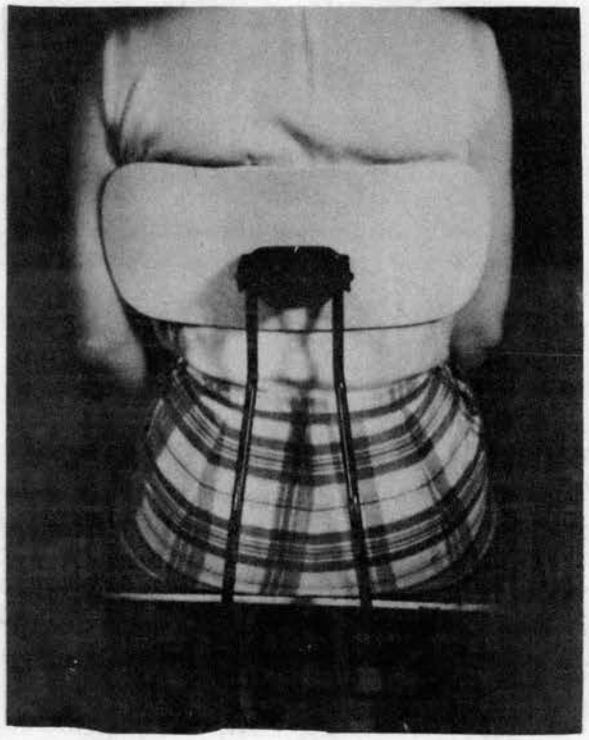

Figure 6. Backrest Interferes With the Movement of the Shoulder Blade

pressure. The normal included angle between the seat and backrest is approximately 95 to 100 degrees. Figure 7 demonstrates the body posture when the included angle is increased approximately 10 degrees. A more relaxed posture may also be beneficial when operating equipment such as a console type test set.

As the number of operations requiring the use of a microscope increases, consideration must be given to the provision of postural supports when the operator leans forward for sustained periods. Some postural support can be provided if the backrest is tilted forward.

Figure 8 shows the position of the operator when the backrest is tilted at an angle of about 85 degrees with the seat. It may also be necessary to provide padded armrests on which the operator can rest her elbows.

Operators will be found to vary the tilt of the backrest during the day to obtain a change of position. Two or three positions at approximately 10 degree steps are all that are required. This type adjustment is not incorporated in most chair designs and is a fairly expensive feature when available.

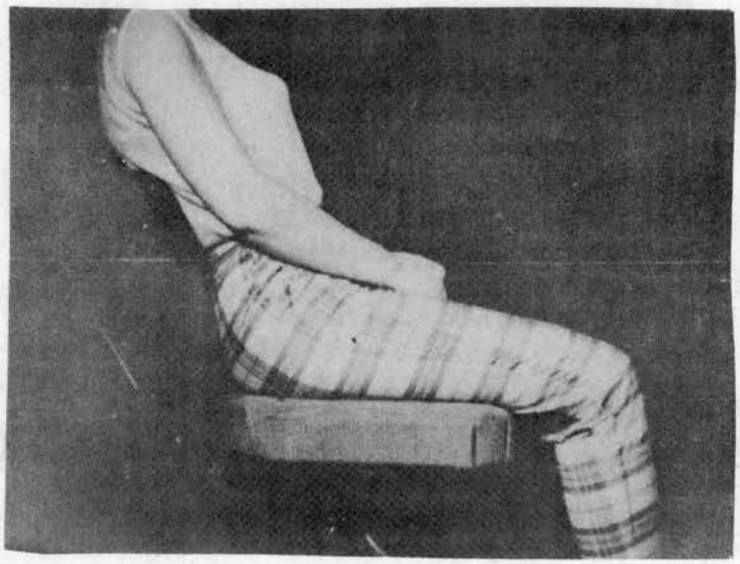

Figure 7. Backrest Position to Relieve Abdominal Pressure in Women

Figure 8. Backrest Position for
Microscopic Work

CHAPTER IV

SUMMARY AND CONCLUSIONS

The purpose of this thesis has been to describe the design characteristics of a chair for use in industrial manufacturing operations. The design will accommodate the needs of the 5th to the 95th percentiles of physical stature and minimize fatigue and physical discomfort.

Summary

A summary of the recommended design features is as follows:

Seat Size	- 16 inches long by 16 inches wide.
Seat Contour	- Flat with a gently curved front and a slight backward slope.
Seat Cover	- Lightly padded and covered with an aerated material.
Seat Height	- Adjustable in increments of one-half inch to one inch.
Backrest Size	- Five inches high by nine inches wide.

Backrest Contour	- Slight concave curve in the horizontal and slight convex vertical curve.
Backrest Cover	- Lightly padded and covered with an aerated material.
Backrest Support	- Rigid with swivel mounting.
Backrest Adjustments	- Continuous type adjustments of the horizontal location and vertical position. Step type adjustments for the angle between the backrest and chair seat.

Conclusions

The typical fixed height, wooden chair used in industry costs approximately \$15.00. A chair incorporating all the features suggested in this paper is not generally available. The few that have been purchased on special orders were relatively expensive and cost from \$40.00 to \$60.00. Chairs which include adjustable seat height, proper seat design and covering, correct backrest design, and vertical backrest adjustments were purchased for only about \$30.00.

The seat and backrest coverings are not generally provided on commercially available chairs, but it is not difficult or costly to get the manufacturer to supply them.

Adjustable seat height and vertical backrest adjustments are optional features on many chairs. The proper backrest design is slightly expensive since it generally requires that the manufacturer modify his present standard equipment.

The backrest tilt and horizontal location are the most expensive features since no provisions have been made for these considerations in present designs. Even if all features are ordered at a cost of $60.00 per chair, it should be remembered that the expense is not prohibitive if productivity is increased. An improvement of one per cent in the performance of an operator earning $2.00/hour and working 2000 hours per year will cover the additional cost of proper seating.

The costs of production time lost by an operator for trips to the medical department and the medical examination and treatment are relatively high. For example, a typical injury caused by improper seating generally requires approximately two or three visits to the medical department, which last about 30 minute each. The cost of medical examinations and treatment averages approximately $8.00 per visit by the operator. Based on an operator earning $2.00 per hour and an average of two and one-half trips to the medical department, the cost of production time lost and medical attention is $22.25 per injury. This is one-half of the additional expense of proper seating and does not include the cost of a reduced production pace due to pain.

For reasons previously stated, no survey data are available concerning the relative economic value of the various features discussed. It is the author's opinion that the adjustable seat height feature will provide the most immediate results since isometric work is generally reduced or eliminated as soon as the new chair is provided. Next are the backrest design, backrest adjustments, and seat design in that order. Backrest design changes can result in a fairly rapid reduction in back bruises. The effects of backrest adjustments and seat design are more difficult to determine.

Disregarding the economic aspects of the situation, the worth of improved industrial seating can be demonstrated in terms of humanitarian achievements. It must be remembered that most chairs are designed for the "average" man. If the seating in a particular situation is improper for the average, it is improper for at least 50 per cent of the population.

Suggested Areas of Further Study

One of the problems facing the engineer who is trying to convince management to provide better chairs for the shop operations is the lack of an estimate of the savings to be realized. Undoubtedly, a study to determine the effect of improved seating on the indirect costs mentioned previously would yield significant data useful in selling the program. If the results of such a study identified the relative value of the various design features, management might be convinced that the modification of existing chairs would be profitable even if the decision were made not to buy new chairs.

Considerable work has been done to determine the horizontal work area that is best suited for manual assembly operations. Based on personal experience, the author believes there is a vertical work range for operations requiring close eye-hand coordination in which fatigue is reduced. This range is probably only a few inches high. Information from a study of this factor would be valuable to equipment designers and engineers responsible for work place layouts.

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VITA

Sterling Newell Frost

Candidate for the Degree of

Master of Science

Thesis: INDUSTRIAL SEATING

Major Field: Industrial Engineering and Management

Biographical:

Personal Data: Born in Oklahoma City, Oklahoma, December 21, 1935, the son of Sterling J. and Eula W. Frost.

Education: Attended grade school and junior high school in Oklahoma City, Oklahoma; graduated from Central High School in Oklahoma City, Oklahoma, in 1952; received the Bachelor of Science degree from the University of Oklahoma, with a major in Industrial Management Engineering, in August, 1957; completed requirements for the Master of Science degree, with a major in Industrial Engineering and Management, at Oklahoma State University, in July, 1966.

Professional Experience: Joined the Western Electric Company in 1957 and is now a Department Chief, Industrial Engineering; since 1957 has been working in the Industrial Engineering organization; organized and implemented the Biomechanics Task Force at the Oklahoma City Plant; Senior member of the American Institute of Industrial Engineers and incoming President of the Oklahoma City Chapter for the 1966-67 year.