AN INVESTIGATION OF MANUAL WORK METHODS AS ETIOLOGICAL FACTORS OF CARPAL TUNNEL SYNDROME

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ABSTRACT

Median nerve compression, in the majority of cases, is caused by either a build-up of pressure within the carpal tunnel or direct impingement of the nerve by the flexor tendons of the fingers. This report describes an investigation of the causal relationship between manual work methods requiring repetitive, forceful use of the hands and the incidence of employee carpal tunnel syndrome. Hand and wrist positions, as well as the corresponding force of exertions, were recorded in the plant for subjects performing various high and low incidence classifications of sewing operations. Statistical comparisons of the results of this data were used to determine the work method characteristics which may make an employee more susceptible to carpal tunnel syndrome.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

List of Figures - cont.

I. INTRODUCTION

The goal of this investigation was to identify specific work methods, which are associated with selected industrial sewing operations, that are factors of chronic wrist injuries in female employees. Based on these findings, existing and future jobs can be modified so as to eliminate these problem causing work methods and thereby reduce the incidence of occupational wrist injuries.

Frequencies and forces of selected hand exertions by persons performing jobs associated with high and low prevalence of CTS were determined by the use of the electromyograph (EMG) and of motion analysis of 8mm films. The comparison of these two types of jobs, coupled with pertinent information from existing literature concerning the types of hand positions and exertions that are believed to cause carpal tunnel syndrome, aided in the determination of the types of work methods that can cause carpal tunnel pathologies.

This report concerning job attributes is one phase of a two part project on carpal tunnel syndrome currently in progress. Part I involves a laboratory study of cadaver arms to determine the biomechanical properties of the wrist and hand. Part II is an in-plant investigation of personal and job attributes which affect the stress levels within the carpal tunnel. Personal attributes that are factors of occupational wrist injuries are being studied by Rabourn (1977).

RATIONALE FOR STUDY

In almost all industries throughout the world, tasks involving grasping and pinching requirements with the hands appear in a major percentage of the jobs in some form or another. Thus, it is no surprise that in 1971 the National Safety Council reported that hand and wrist injuries (excluding the fingers) accounted for seven percent of all lost time injuries during 1970 and accounted for four percent of the total workman's compensation claims that year. Undoubtedly most of these injuries are of the acute type, such as fractures, breaks, lacerations, etc., but in recent years more wrist and hand injuries of the chronic type are being reported. In certain industries where the jobs require workers to make extensive use of their hands in a repetitive and forceful manner, the incidence of chronic wrist injuries are even greater (Wehrle, 1976; Hymovich, 1966).

At the medium sized industrial upholstering facility where this in-plant investigation took place, Wehrle (1976) reported that the average incidence rate of carpal tunnel syndrome during the five year period from 1971 to 1975 was 10.3 injuries per million man hours worked. The workman's compensation and outside medical costs during this time averaged $43,385 per year, which encompassed 25% of this plant's total workman's compensation and outside medical cost during that period.

If carpal tunnel syndrome is diagnosed at an early stage, treatment such as a wrist splint and/or job restriction from highly stressful tasks can usually provide relief and complete recovery with no complications. However, if the disease is allowed to progress, loss of motor function as well as nocturnal numbness and burning pain may become so severe that the only remedy for relief is surgery; permanent residual after effects frequently persist after surgery (Cseuz, 1966). Therefore, defining and eliminating specific job attributes, that tend to cause CTS, is a preventative cure for the problems which accompany the syndrome.

Elimination of job attributes that cause CTS, and therefore reduction in the number of individuals who become inflicted with carpal tunnel syndrome, can also reduce other, more acute type of accidents to a lesser degree. A person with CTS tends to become increasingly weaker and clumsier as the disease progresses. This tends to make the whole body more susceptible to injury when performing tasks which require constant grip strength and dexterity of the hands, such as lifting a heavy box up onto a shelf. Sensory impairment on the lateral side of the hand which accompanies CTS (Turek, 1967) can also cause acute injuries by slowing down the immediate sensory feedback process which is essential for detecting when the hand is in a hazardous situation. CTS can also cause a decrease in productivity and work quality.

ORGANIZATION OF REPORT

Background information concerning forearm, wrist, and hand anatomy, the causes and effects of carpal tunnel syndrome, and the hypothesis of this report can be found in Chapter Two. The materials and methods used for in-plant data collection as well as data reduction techniques are outlined in Chapter Three. Analysis of all the data gathered along with the results of the investigation are described in Chapter Four. An interpretation of the results are discussed in Chapter Five and conclusions based on these results are contained in Chapter Six.

II. BACKGROUND

2.1 GENERAL ANATOMY OF WRIST

An understanding of the effects that various hand and wrist positions have on the carpal tunnel contents will be facilitated by a general anatomical description of the arm, wrist, and fingers.

The structural basis of the forearm is supplied by the radius and ulna bones which extend from the elbow joint to the wrist joint. The wrist joint itself consists of the eight carpal bones, while the palm of the hand contains the five metacarpal bones. Each of the four fingers has three distinct phalangeal bones whereas the thumb has only two (see Figure 2-1).

When the fingers are used to grasp an object, the closure of the fingers around and the force applied to the object is supplied by contraction of the flexor digitorum profundus (FDP) and the flexor digitorum superficialis (FDS) muscles located in the forearm. Flexion of the thumb is provided by the flexor pollicus longus muscle. These muscles, referred to as the extrinsic finger flexor muscle, attach to the bones of the fingers by means of tendons which originate in the lower forearm and extend through the wrist. The four profundus tendons are inserted into the distal phalanges and the four superficialis tendons into the middle phalanges (see Figure 2-2).

These tendons are included in tendon sheaths that provide lubrication to the tendons for ease of movement. Each tendon sheath (see Figure 2-3) has two layers, the pariethal and the visceral, between which is a synovial fluid that acts as the lubricant. The tendon sheaths for the index, long, and ring fingers extend from the distal phalanx to the midpalmar crease whereas the sheath for the little

Carpal Bones

Tm-Trapezium
S--Scaphoid
L--Lunate
Tq-Triquetrum
P--Pisiform
H--Hamate
C--Capitate
Td-Trapezoid

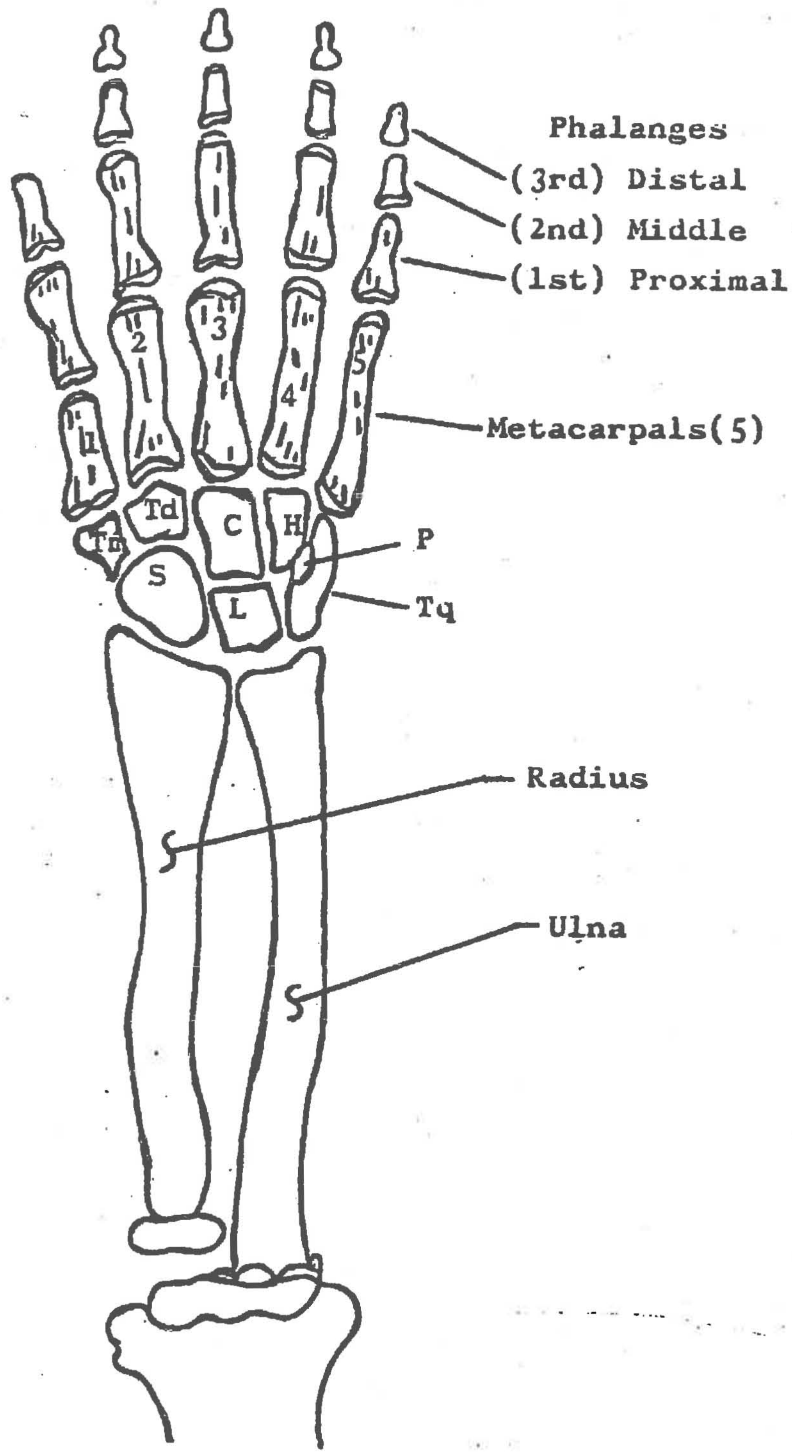


Figure 2-1: Bones of the Forearm, Hand, and Wrist (R.N. Gray, 1969).

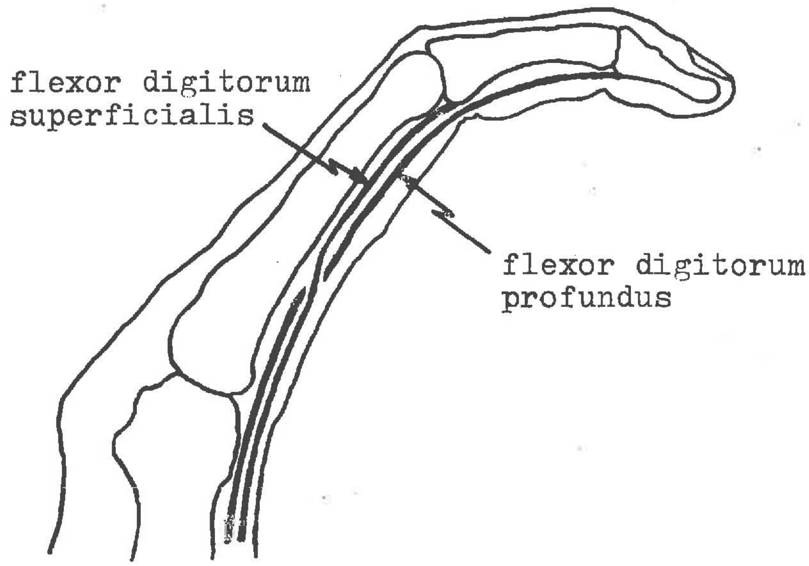


Figure 2-2: Insertion of Flexor Tendons (adapted from Armstrong, 1975).

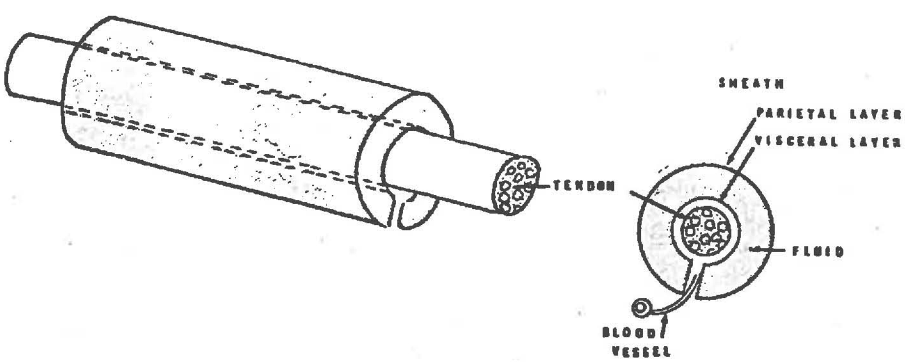


Figure 2-3: Tendon Sheath (Cailliet, 1971).

finger is continuous with the ulnar bursa (see Figure 2-4). The ulnar bursa forms three compartments, one superficial to the superficialis tendons, one between the superficialis and the profundus tendons, and one under the profundus tendons (Cailliet, 1971).

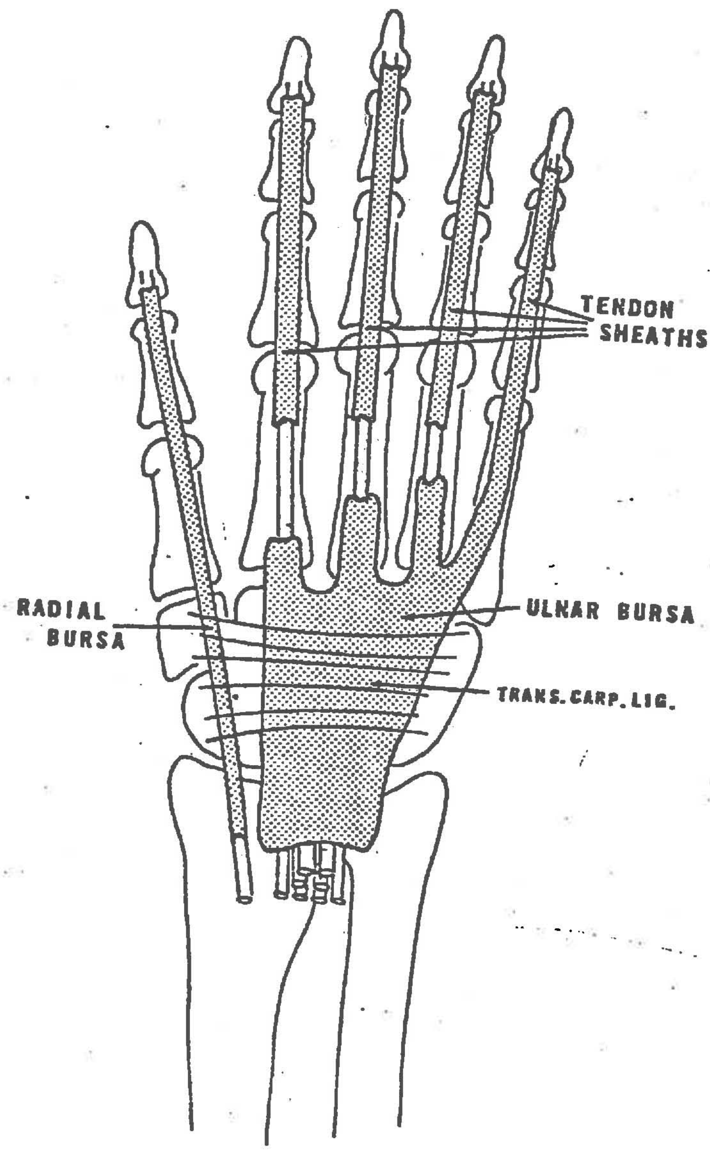


Figure 2-4: Tendon Sheaths of the Hand (Cailliet, 1971).

The wrist itself is a very complex and crowded structure with two axes of rotation. Since carpal tunnel syndrome is caused by compression of the median nerve within the wrist, only that part of the wrist aptly referred to as the carpal tunnel will be discussed. The carpal tunnel is bound on the dorsal side of the hand by the carpal bones which make up the wrist and across the anterior by the transverse carpal ligament (flexor retinaculum). See Figure 2-5. Within this tunnel is located the median nerve, the flexor digitorum profundus and superficialis tendon and the flexor pollicus longus tendon.

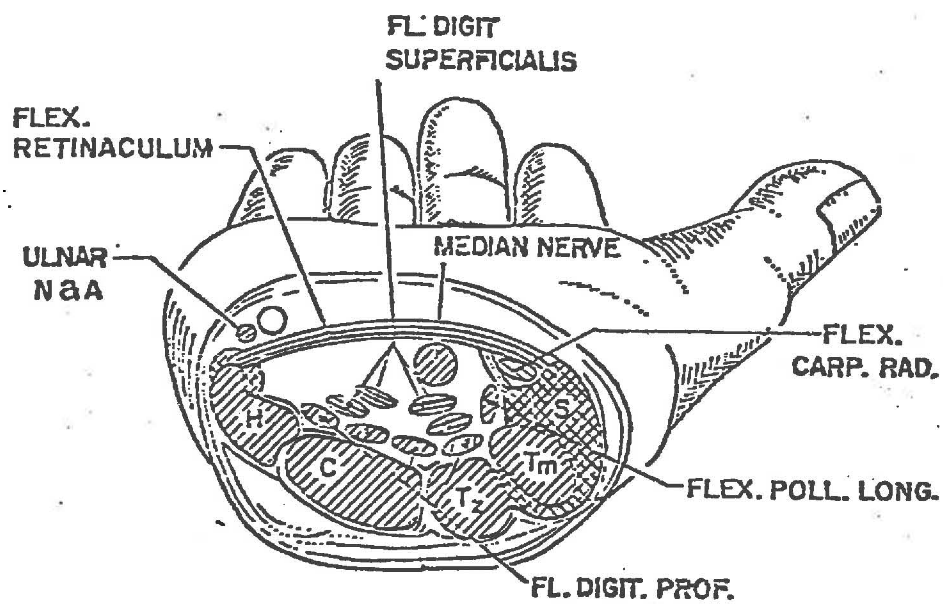


Figure 2-5: Contents of the Carpal Tunnel (adapted from Cailliet, 1971).

The median nerve lies superficial to the flexor tendons beneath the tense transverse carpal ligament, with the carpal tunnel being barely adequate to accommodate these structures (Turek, 1967). Throughout the literature there is disagreement between investigators about the actual position of the flexor tendons. Smith, et al., (1976) stated that the FDP tendons 2 and 3 are directly below the median nerve while all four FDS tendons lie to the ulnar side of the nerve. Robbins (1963) and Cailliet (1971) both show the FDS tendons 2 and 3 directly below the median, with tendons 4 and 5 positioned to the ulnar side.

The median nerve provides the brain with sensory information from the radial side of the hand, specifically the thumb, index, and long fingers as well as the radial half of the ring finger (see Figure 2-6). The nerve is also responsible for the autonomic and motor response function of the hand and fingers.

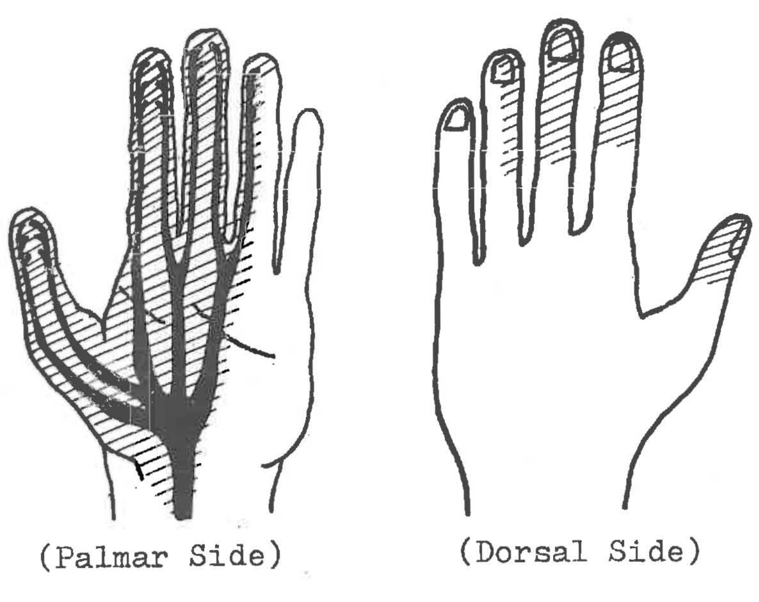


Figure 2-6: Median Nerve Sensory Pattern.

BIOMECHANICS

The loading of tendons and deviation of the wrist causes the tendons to be impinged upon the walls of the carpal tunnel. During extension of the wrist the flexor tendons are supported by the carpal bones whereas during flexion the tendons are supported by the transverse carpal ligament (Armstrong, 1975). Refer to Figure 2-7.

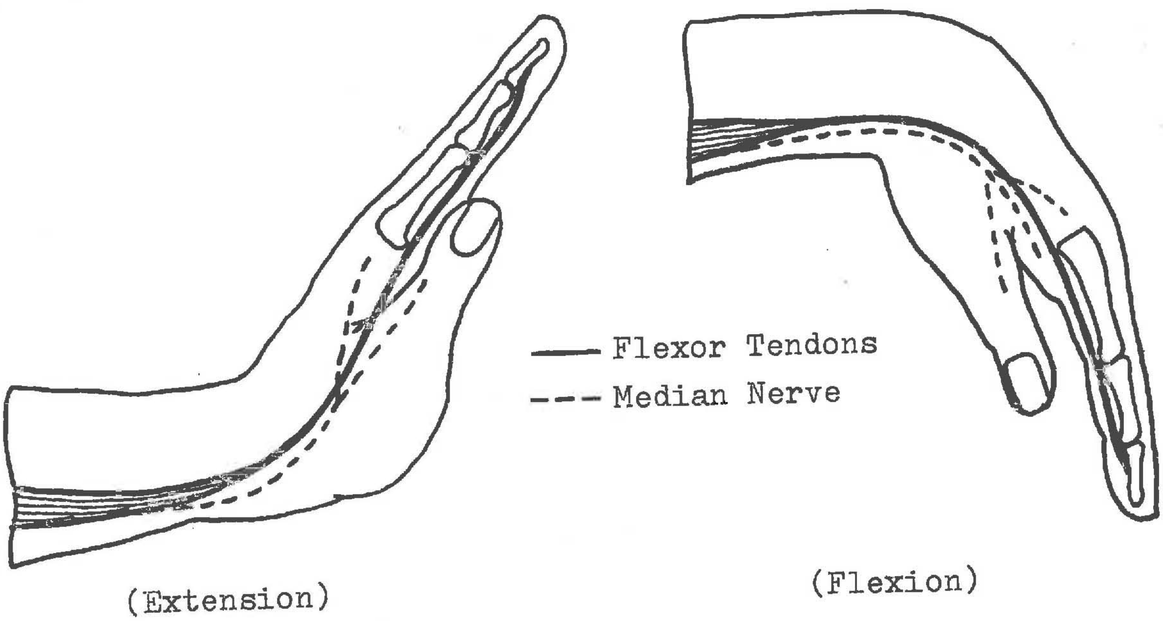


Figure 2-7: Wrist Deviation (adapted from Armstrong, 1975).

The tension that is developed in a tendon is dependent upon hand anthropometry as well as upon the external force exerted by the hand and fingers. Armstrong (1976) developed a biomechanical model of the wrist and finger to calculate the tendon tension and the load distribution and resultant force which the tendon exerts on the intra-wrist structures. Formulas were developed from which the tendon moment arm about a particular finger joint was calculated from the joint thickness. Thus, by knowing: 1) the external force exerted by the finger; 2) the position of the finger joints; and 3) the joint thickness; a free body diagram of the joint was used to calculate the tendon tension.

The tendon supporting structures (carpal bones and flexor retinaculum) act as anatomical pulleys, with the included angle of the area in contact with the tendon equal to the angle of wrist deviation (see Figure 2-8). Therefore, the resultant force exerted on the structure is expressed as:

$$\text{Resultant force} = 2F_{\text{tendon}}\,(\sin\theta)$$

where:

F_{tendon} = tendon tension force.

θ = angle the wrist is deviated from the neutral position.

The load along the tendon (force/arc length) can be calculated using the free body diagram of a belt and pulley system in Figure 2-9. Using basic mechanics, the following equation can be derived in order to find the load along the belt:

$$\text{Load (force/arc length)} = \frac{T}{r}e^{-\mu\theta}$$

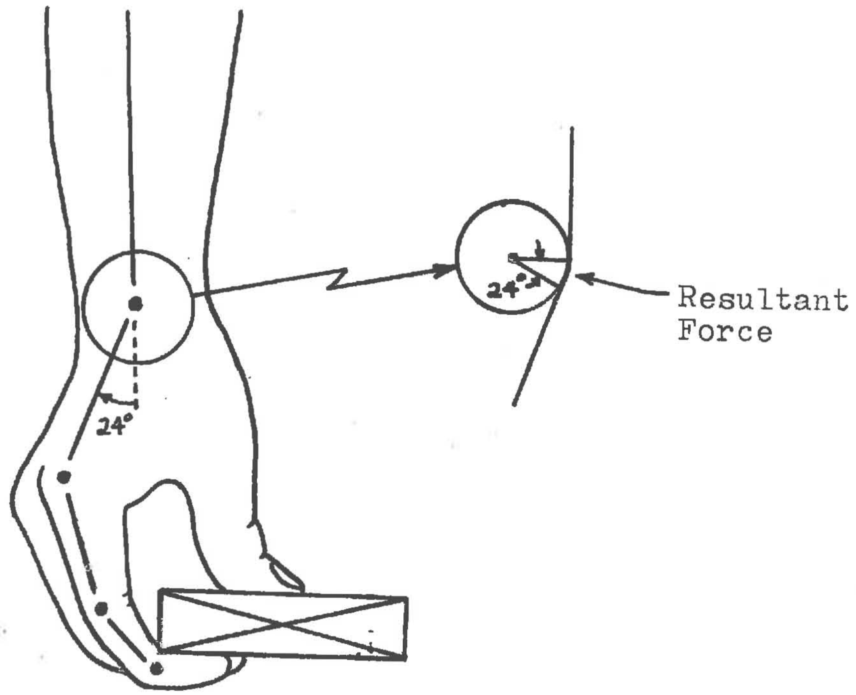
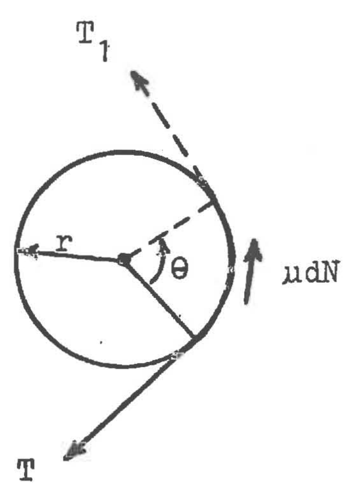


Figure 2-8: Area of Tendon Contact.



where: r = radius of pulley

θ = included angle of the area in contact

μ = coefficient of friction

T & T_1 = belt tension

μdN = force of friction

Figure 2-9: Belt and Pulley - Free Body Diagram.

Due to the synovial fluid which encapsulates the tendons, the coefficient of friction is essentially zero; Williams and Lissner (1977) reported a friction coefficient (u) of 0.012 between a tendon and its sheath. Thus the above equation reduces to:

$$\text{Load} = \frac{T}{r}$$

where:

T = tendon tension

r = trochlear radius

Armstrong (1976) developed formulas whereby the trochlear radii for the flexor digitorum superficialis and profundus tendons were determined based on the individual's wrist thickness.

Armstrong concluded that for a given load: 1) the tendon tension increases as the joint thickness decreases; 2) the total force on the intrawrist structures increases as the angle of deviation increases; and 3) the load distribution on inter-wrist structures increases as wrist thickness decreases.

Ulnar deviation of the hand can also subject the tendons to additional stresses while being forced to bend laterally (Tichauer, 1976). Refer to Figure 2-10.

Exertions of the hand can cause significant forces on intrawrist structures as well as the tendons themselves. Such forces on the tendons can cause inflammation of the flexor synovium. Inflammed flexor synovium in the confined space of the carpal tunnel can cause chronic pressure on the median nerve and hence, causes carpal tunnel syndrome. In

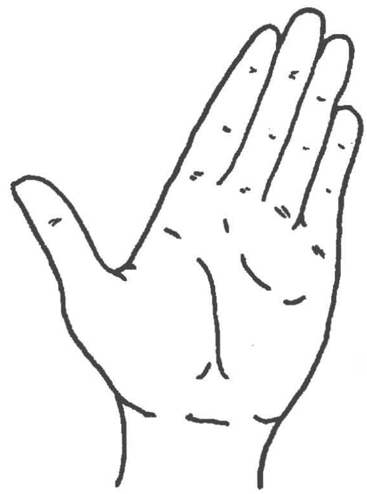


Figure 2-10: Ulnar Deviation of Hand.

addition, deviation of the wrist and exertions of the hand can cause acute pressure on the median nerve. Acute median nerve pressure can induce abrupt symptoms of carpal tunnel syndrome in a wrist with tenosynovitis.

Brain (1947), Tanzer (1959), and Smith (1976) have shown that both extension and flexion of the wrist cause inter-wrist pressure in the carpal tunnel to increase; this pressure in turn, causes compression of the median nerve. This principal is utilized in common carpal tunnel syndrome diagnostic tests such as: 1) Tinel's test, in which a gentle tap on the palmar side of the wrist causes pressure on the median nerve and hence, a tingling sensation in the areas of the hand innervated by the median nerve; 2) Phalen's test, in which relaxed flexion of the wrist for 30-60 seconds induces numbness and pain in the areas of the hand innervated by the median nerve; and 3) the modified Phalen's test, in which the fingers are forcibly pinched while the wrist is flexed.

2.2 CARPAL TUNNEL SYNDROME

There are numerous types of chronic wrist injuries from which individuals can suffer, but the type of injury which this report will be concerned with is a pathological condition referred to as "carpal tunnel syndrome," (CTS). CTS is described by Policoff (1971) as "numbness, tingling, and loss of sensation in the middle three fingers and swelling of the hand due to pressure upon the median nerve in the wrist."

Out of all wrist tunnel syndromes, compression neuropathy of the median nerve in the carpal tunnel is the most frequently encountered and the primary cause of numbness in the fingers (Phalen, 1972).

CAUSES OF CTS

Stemming from the fact that the carpal tunnel is normally a very crowded structure, it is reasonable to assume that any type of condition that leads to an increased volume within the tunnel, may cause median nerve compression and ultimately carpal tunnel syndrome. Yamaguchi (1965) decribed three factors which could facilitate overcrowding and cause nerve compression:

1. encroachment of bone into the tunnel,
2. thickening of the tendon sheaths (flexor synovialis),
3. space-occupying tumors, lesions or foreign bodies (see Figure 2-11).

Yamaguchi also stated that the most common cause of CTS was thickening of the flexor synovialis due to tenosynovitis, associated with rheumatoid arthritis, gout, diabetes, pregnancy, and other non-specific agents. It is these other non-specific tenosynovitis producing agents which are of interest when considering the job related causes of carpal tunnel syndrome.

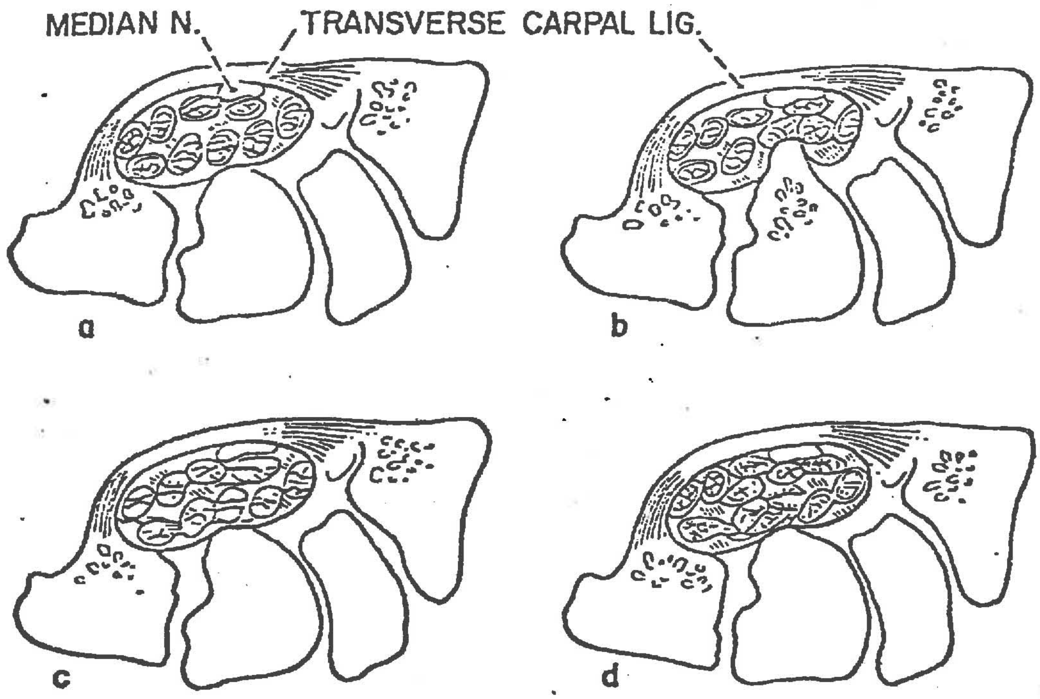


Figure 2-11: Mechanisms whereby the median nerve may be compressed in the carpal tunnel. (a) Normal relationship of the median nerve to the nine flexor tendons, tendon sheaths and transverse carpal ligaments. (b) Encroachment of bone into the tunnel producing secondary compression of the nerve. (c) Thickening of the tendon sheaths (flexor synovialis) producing compression of the nerve. (d) Foreign bodies, tumors and other space-occupying lesions in the carpal tunnel producing compression of the nerve. [From Yamaguchi, 1965.]

Tenosynovitis is a tendon disease whereby excessive repetitive movement or unphysiological stress may inflame the tendon sheaths and cause painful impairment of motion (Cailliet, 1971). Therefore thickening of the flexor synovialis within the carpal tunnel can be caused by prolonged forceful grasping movements, (Phalen, 1972), as well as by repetitive hand activity involving pinch and wrist flexion (Smith, 1976).

Aside from the fact that thickening of the flexor synovialis can induce CTS, the syndrome can also be produced by direct compression of the median nerve due to pressure from healthy flexor tendons. In certain types of hand and wrist positions the median nerve becomes pinched between the flexor tendons and the unyielding transverse carpal ligament.

The two wrist positions which are believed to subject the median nerve to carpal tunnel compression are flexion and extension.

Brain (1947) stated that there was little doubt that occupation is a causal factor of median nerve compression and suggested that jobs involving wrist extension can cause CTS due to increased pressure in the carpal tunnel. The rationale was based on cadaver studies which produced three times as much intra-tunnel pressure with the wrist in 90° extension than in 90° flexion. Similar results were found by Smith (1976).

However, a study of occupations (Tanzer, 1959) suggested that wrist flexion was more significant than extension in the cause of CTS, and the concensus of most authors substantiates this theory. Abbott and Saunders (1933) proposed that, even in normal persons, acute flexion of the wrist pinches the median nerve between the proximal margin of the transverse carpal ligament and the anterior border of the distal end of the radius. This can easily be visualized in reference to Figure 2-12, for if the hand is flexed, the flexor tendons are supported by the transverse carpal ligament and the median nerve is therefore clearly vulnerable to compression.

Tanzer (1959) agreed that flexion of the wrist is more apt to produce CTS, but hypothesized that simultaneous forceful flexion of the fingers added to the pressure on the median nerve with a force

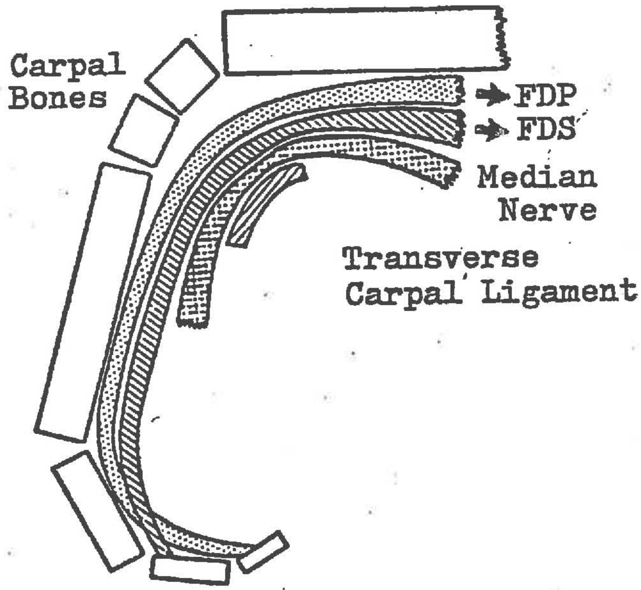


Figure 2-12: Wrist Flexion (Tanzer, 1959).

proportional to the degree of grasp exerted by the digits. This theory was tested (Smith, 1976) and results showed that tendon loading caused higher intra-wrist pressures with the hand flexed than in extension and was dependent on force magnitude and degree of flexion. This led to the conclusion that repetitive pinch while the wrist is in some degree of flexion, may play a significant role in CTS.

Attacks of tingling may develop during the day, often precipitated by certain manual activities, such as sewing, knitting, or writing (Turek, 1967; Tanzer, 1959). The actual numbness and tingling may not be noticed, though, until the hand has been rested for several hours after the activity.

Another hand position that probably is a causal factor of carpal tunnel syndrome is ulnar deviation. Deflection of the wrist toward the ulna, especially while rotating the hand in a flexing motion, creates conditions favorable to the development of tenosynovitis; according to

Tichauer (1976), this is mainly caused due to friction between the tendons while being forced to bend laterally.

EFFECTS OF CTS

Carpal tunnel syndrome usually affects the individual's dominant hand, since this hand gets most of the usage throughout the day and is usually used when high grip forces are required; however, when work methods dictate a particular hand for a specific part of a job cycle, that hand is most frequently affected. CTS can also appear bilaterally.

As mentioned previously CTS is a compression neuropathy and can cause permanent damage to the median nerve. In six of seven specimens the median nerve was found to flatten out around the proximal end of the carpal canal (Robbins, 1963).

A symptom of advanced carpal tunnel syndrome is thenar atrophy of the opponens pollicus brevis, abductor pollicus brevis, or flexor pollicus brevis muscles. These changes usually go unnoticed by the patient until nocturnal numbness becomes sufficient enough to awaken the individual during the night and causes the person to seek medical relief.

Sensory impairment is limited to the distribution of the median nerve, although it rarely involves all 3-1/2 fingers (Turek, 1967). Therefore, one of the many diagnostic tools used is a simple pin prick sensation test.

As the disease progresses, the individual becomes progressively weaker and clumsier due to atrophy and motor weakness of the thenar muscles. If the symptoms are detected at an early stage the effects can be reversed completely by fitting the employee with a splint to eliminate wrist flexion and putting her on a work restriction to limit the amount of pulling and pinching forces required (Wehrle, 1976). If the symptoms are not caught early enough and the disease progresses, the only relief is to surgically cut the entire transverse carpal ligament, thereby decreasing the pressure in the carpal tunnel and on the median nerve.

INDIVIDUAL FACTORS

Aside from various hand and wrist positions that are possible factors of carpal tunnel syndrome, other characteristics specific to an individual may also be causal factors of CTS. It is possible that susceptibility to CTS could be an inherited family trait, whereby anatomical variations may make the median nerve unusually vulnerable to conditions of stress which would be symptomless under other circumstances (Tanzer, 1959).

Two personal characteristics in particular have been found to be indicators of CTS vulnerability, namely, sex and age. Past studies have indicated that the majority of individuals developing CTS are females, with the most common ratio being 3:1, or 75% female involvement (Tanzer, 1959; Phalen, 1972), although ratios as high as 5:1 have been reported (Turek, 1967). Reasons for this higher female incidence may be due to the fact that rheumatic conditions of various types about the wrist (which can produce tenosynovitis) are more common in women than in men (Phalen, 1966), or simply due to the carpal canal being smaller in females than in males thereby making the median nerve more susceptible to compression (Yamaguchi, 1965).

The age of persons who have developed carpal tunnel syndrome range from early 20's up to middle 90's. The most common age though has been reported to be in the range between 30-50 years (Hymovich, 1966; Tanzer, 1967), with Phalen (1972) finding 58% of 384 cases to be within the 40-60 year age group.

Other individual factors that can cause tenosynovitis, and ultimately CTS, are pregnancy, gout, diabetes, and most of all rheumatoid arthritis. Rheumatoid arthritis is initially a disease of the synovium, and half of the patients with rheumatoid arthritis have a disease of the tendons that are enclosed in the sheaths (Cailliet, 1971). The disease causes pain and swelling that restricts finger movements and can be structurally detrimental to the hand.

Carpal tunnel syndrome is frequently associated with rheumatoid arthritis (Barnes, 1967; Chamberlain, 1970; and Herbison, 1973). Barnes (1967) found that 49% or 45 rheumatoid arthritis patients had abnormal electrodiagnostic tests and Herbison (1973) reported that 44% of 29 patients had CTS signs.

2.3 SUMMARY AND HYPOTHESIS

There are several causes of carpal tunnel syndrome which could be termed job related; therefore carpal tunnel syndrome can be considered as an occupational disease. Review of the existing literature has shown that occupations that require prolonged forceful grasping movements, repetitive hand activity, and ulnar deviation of the hand can lead to tenosynovitis in the wrist and ultimately CTS. Also, during flexion and extension of the wrist, pressure increases in the proximal end of the carpal tunnel, leading to possible median nerve compression. Finally, wrist flexion causes the median nerve to be compressed directly between the flexor tendons and the flexor retinaculum; the compression force increases proportional to the force exerted by the fingers.

The hypothesis to be tested in this report is:

> Frequency distributions of hand positions and forces are not the same in jobs associated with and without a high incidence of CTS. These differences are related to etiology of carpal tunnel syndrome and lie in the work methods employed.

The high incident job should contain a significantly greater percentage of the types of wrist positions and exertions previously set forth as CTS producing factors, based on existing literature.

All of the subjects used in this experiment were female, and when comparing two jobs all employees were matched as close in age as possible. The hypothesis assumes that other individual factors are not a prevalent cause of carpal tunnel syndrome, either acting alone or in conjunction with a particular work method.

III. MATERIALS AND METHODS

3.1 EXPERIMENTAL DESIGN

The major goal of this report is to investigate work methods in order to determine why some industrial sewing jobs have a higher incidence of carpal tunnel syndrome associated with them than others. Four different jobs were chosen, by the Industrial and Process engineering department at the plant, as high incident operations based on their existing CTS incident rate study. Four low incident jobs, each of which was similar to one of the high incident jobs, were then chosen such that the comparable jobs could be matched and analyzed on a one-to-one basis. Sixteen operators were chosen, two for each of the eight jobs mentioned, all of whom consented to being studied on a volunteer basis and signed consent forms (refer to the Appendix for a sample form). Table 3-1 gives a graphic representation of this job study design.

Table 3-1: Job Study Design.

Inc. \ Job	1	2	3	4
Low	S_1-S_2	S_3-S_4	S_5-S_6	S_7-S_8
High	S_9-S_{10}	S_{11}-S_{12}	S_{13}-S_{14}	S_{15}-S_{16}

The right or left hand was studied depending upon which hand had been most frequently affected with CTS on the high incident job.

In order to compare job methods, a motion analysis of hand and wrist postures as well as determination of the force of exertion was required. This was accomplished with the use of electromyography (EMG) and a super-8 movie camera. By filming a number of cycles of an operator performing her work, specific hand and wrist positions could be determined by means of a frame-by-frame analysis of the film. Six different types of hand positions were selected based on what was observed to be the most common positions used at this sewing facility, these being the 2, 3, or 4 finger pinch, the 4 fingers opposing the palm, the 4 finger press, and the hand press. Three example positions are shown in Figure 3-1.

Figure 3-1: Various Hand Positions.

Wrist positions were classified as either extended, neutral, or flexed, and either with or without ulnar deviation of the hand.

Synchronized with the film was the EMG electrical output, which monitored the activity of the subject's finger flexor muscles by means of surface electrodes placed on the medial forearm. Since EMG voltage vs. force of contraction is a linear relationship, each subject would only have to be calibrated using submaximal isometric contractions against a known force to establish the slope of the regression line

(DeVries, 1968). Because there are different slopes for different muscles, the subject would have to be calibrated at each of the six hand positions previously mentioned, so that separate regression lines could be calculated. Thus, the amount of force being exerted by the fingers could be determined and associated with the hand and wrist positions from the film. Frequency distribution for the hand and wrist postures, ulnar deviation, and the force exerted could then be generated and used for job comparison. This experimental design is described in more detail by Rabourn (1977).

3.2 SUBJECTS

All of the 16 employees who participated in this study volunteered freely and none of the subjects received any compensation for participating in the study, over and above their normal wages.

There were four criteria requirements for the selection of an operator, these were: 1) sex; 2) age; 3) job experience; and 4) history of carpal tunnel problems. All subjects were to be female since the majority of sewers at this plant are female and they also comprise the majority of workers who have developed CTS. Comparison of a male and female would lead to too much individual variation.

The age criteria pertained only to each of the groups of four sewers and not the group of 16 as a whole. An attempt was made to select 2 high and 2 low incident job employees that were approximately the same age, so as not to confound the data with this independent variable when the two jobs were compared.

The subject had to have enough experience on the particular operation such that she could sew using the normal methods to which she was accustomed and so that she could sew at the standard pace.

3.3 REFINED EQUIPMENT SET-UP

The objective of the data collecting equipment was to be able to simultaneously record RMS-EMG output and hand positions as the subject was performing her operation, while creating as little of a disturbance to regular plant working procedures as possible.

A schematic diagram of the equipment set-up is shown in Figure 3-2. Starting at the source of the signal, three Beckman monopolar surface electrodes pick up the electrical activity of the finger flexor muscles. This signal is input to a differential preamplifier which has a constant gain. The signal proceeds to the Heath A.C. Voltmeter which acts as a variable voltage amplifier and displays the amplified RMS signal. An unamplified raw EMG is connected straight to the Tektronix oscilloscope in order to check the signal for external noise and interference. The amplified RMS-EMG signal is then input to the Gould strip chart recorder for a permanent recording and also to one of two 1 V voltmeters placed near the point of operation in view of the camera. Both meters were fitted with a reflection needle and scale.

The second 1 V voltmeter is connected to the event marker on Channel 1 of the strip chart recorder, such that deflection of the event marker on the chart paper also deflects the meter. In this manner the movie film can be synchronized with the strip chart recording. A reflective sign with a 3 digit, 2 letter code is also filmed such that each operator can be easily identified.

A Nizo super-8 movie camera is used to film the operation, in order that hand and wrist positions as well as both 1 V meters and the identification sign can be recorded. To save on film usage an intervelometer was built such that the camera could be operated at 1 through

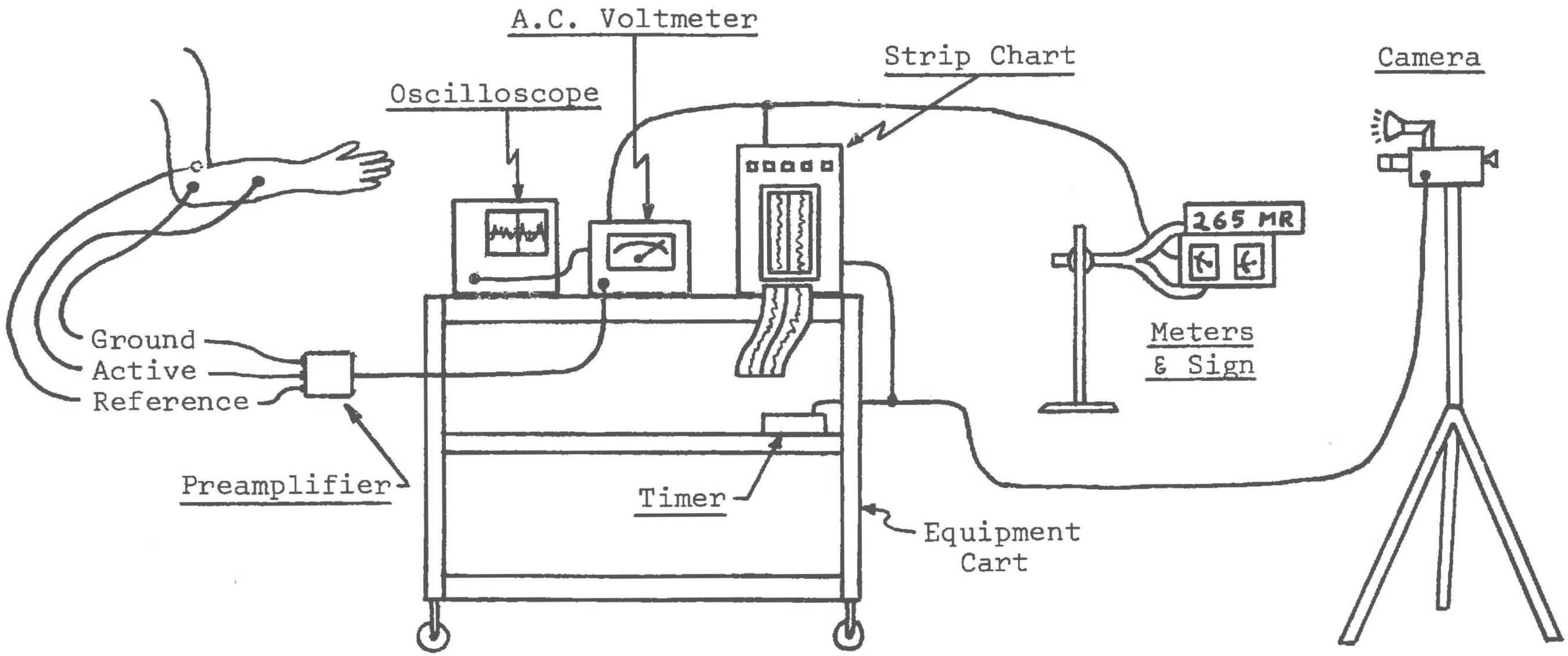


Figure 3-2: Equipment Schematic.

5 frames/second; 4 frames/second was used extensively during this study. The intervelometer also activated the event marker on Channel 2 of the strip chart every time a frame of film was taken.

A special hand dynamometer was also constructed (see Figure 3-3) such that each subject could be calibrated at known forces for all six of the previously mentioned hand positions. (Refer to the Appendix for a list of model and serial numbers for all equipment used.)

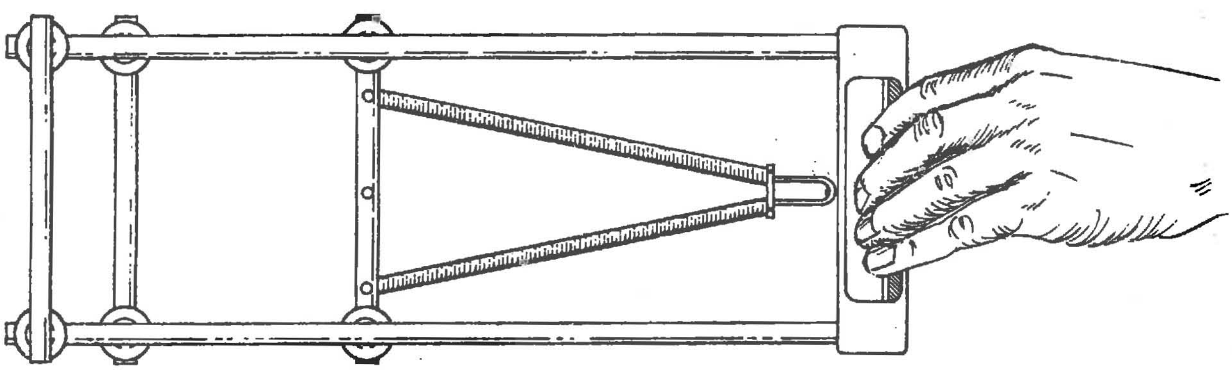


Figure 3-3: Hand Dynamometer. The fixture used to determine the relationship between the surface EMG of the medial forearm and hand force for selected hand positions.

3.4 PROCEDURE FOR DATA COLLECTION

The equipment cart was wheeled into the work area and placed in front of the workplace, with all displays facing away from the operator so she would be neither distracted nor exposed to feedback data while working. An important aspect in the procedure was to allow the operator to keep working as much as possible, thus the following set-up requirements were done without disturbing the operator. The two 1 V meters and reflective sign with the operator's code were set on the work surface in close proximity to the point of operation. The camera was then set up at the best possible vantage point and adjusted to include the hand to be studied, the two meters, and the reflective sign (see Figure 3-4).

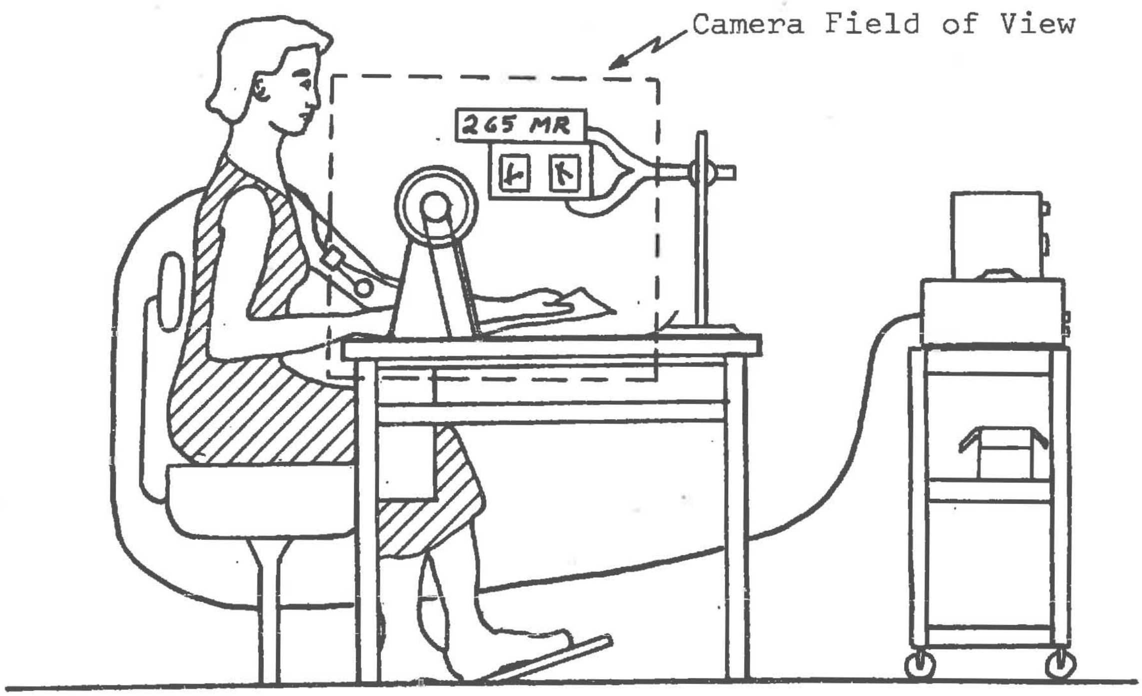


Figure 3-4: Workplace Set-Up.

Care had to be taken to ensure that the camera was in focus and that the meters had good reflectance without glare, otherwise the data would be worthless and the subject would have to be restudied at a later date. The electrodes were then cleaned, fitted with adhesive tabs, and filled with electrode paste.

The operator was then interrupted temporarily and the procedure of what was to be done was explained to her. The arm to be studied was then prepared by vigorously scrubbing both long sides of the elbow and the medial forearm to cleanse the skin of all oil and dirt. The three electrodes were placed over the prepared areas, checked for continuity with an ohmmeter, and plugged into the appropriate jacks of the preamplifier. With the hand and arm in a resting position, the oscilloscope was checked to ensure that there was not an excess of external interference in the signal. The signal was then checked as the subject made a fist and the sensitivity of the A.C. voltmeter was adjusted. To eliminate the electrode leads and preamplifier from interfering with the subject while working, the forearm and upper arm were wrapped with elastic bandages.

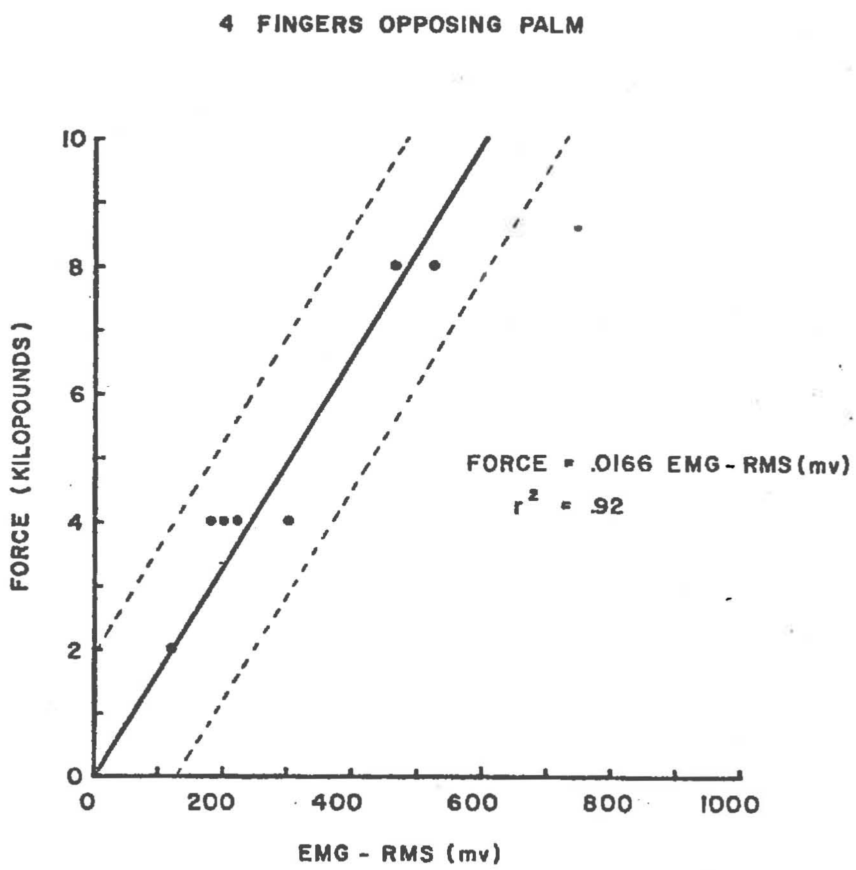
The subject was now ready to be calibrated using the hand dynamometer shown in Figure 3-3. She made a three second exertion using each of the six hand positions (4, 3, 2 finger pinch, 4 fingers opposing palm, 4 finger press, and hand press) at 4 kilopond (Kp) force, the EMG output of which was recorded on the strip chart. The subject was calibrated a second time in the same manner except that the experimenters' subjectively decided whether to use a 2, 4, or 8 Kp force.

The subject was then permitted to begin sewing normally and the camera was turned on (see Figure 3-4). The coordinating event marker was pushed for one second at the beginning of each cycle and randomly throughout the test. The operator was filmed for approximately two minutes, then the camera was switched to another position and another two minutes of film was taken.

The subject was interrupted once more and recalibrated twice at either 2, 4, or 8 Kp force, again at the experimenters' discretion.

The electrodes were then removed, equipment was gathered, and the workplace was vacated.

Analysis of the data began with the construction of calibration graphs, a total of six (one per each hand position) for a subject. The known calibration force was plotted on the abcissa vs. the EMG output on the ordinate. The corresponding data points were plotted and a straight line, intersecting the origin, was drawn to best fit the data points (see Figure 3-5). Thus, for a given hand position and EMG output, the corresponding force exerted by the fingers can be determined.



A sample plot of hand force versus the surface EMG of the medial forearm

Figure 3-5: Force Calibration Graph.

To facilitate the frame-by-frame data reduction, information from each frame of film, such as subject, frame number, EMG (uV), ulnar deviation, hand position, and wrist position was encoded directly on to an optical scan computer card. (See the Appendix for a sample card and data.) The reduced data could then be loaded directly into the computer for analysis.

In order to achieve statistically significant results, a sample size of at least 400 frames/subject was required (Rabourn, 1977). Also so as not to bias the data, the sample must consist of only complete job cycles. Thus, at least 400 frames were studied for each subject, but the total per subject varied.

IV. RESULTS

4.1 SUMMARY

The raw film data was analyzed frame by frame to determine hand positions and forces and wrist positions at 250 msec. intervals through the study period. Classifications and abbreviations, that will be used throughout this chapter, are shown for hand positions in Table 4.1a and for wrist positions in Table 4.1b. Hand and wrist position and hand force data are shown as a function of time in a sample operator's time plot in Figure 4.1. These plots were generated for all subjects and examined to be sure that all of the studied cycles of each subject were consistent. Also, comparison of the time plots for the two operators who performed the same job were used to check for inter-subject variability. The data was then summarized in histograms and statistically compared using analysis of variance and contingency analysis.

First, the pooled data for all 16 subjects was analyzed and then divided into two groups, one for the jobs associated with carpal tunnel syndrome and one for the jobs not associated with carpal tunnel syndrome. These results and analyses are presented in section 4.2. Next, the pooled data was separated into eight groups, each with two subjects pooled for each job. The results of analyses of these data are detailed in section 4.3. This hierarchy of analysis is shown in Figure 4.2.

4.2 ANALYSIS OF HIGH AND LOW INCIDENCE GROUPS

The analysis of the pooled data of all sixteen subjects was performed in order to obtain combined hand, wrist, and force frequency

Table 4-1: Classifications and Abbreviations.

Hand Positions
2P = 2 finger pinch
3P = 3 finger pinch
4P = 4 finger pinch
4OP = 4 fingers opposing palm
4PR = 4 finger press
HPR = hand press
HID = hidden hand
NIU = hand not in use

Table 4-1a

Wrist Positions	
HE = hyperextended	$\theta > -40^{\circ}$
E = extended	$-10^{\circ} \leq \theta \leq -40^{\circ}$
N = neutral (straight)	$-10^{\circ} \leq \theta \leq +10^{\circ}$
F = flexed	$+10^{\circ} \leq \theta \leq +40^{\circ}$
HF = hyperflexed	$\theta > +40^{\circ}$
HID= hidden wrist	

Table 4-1b

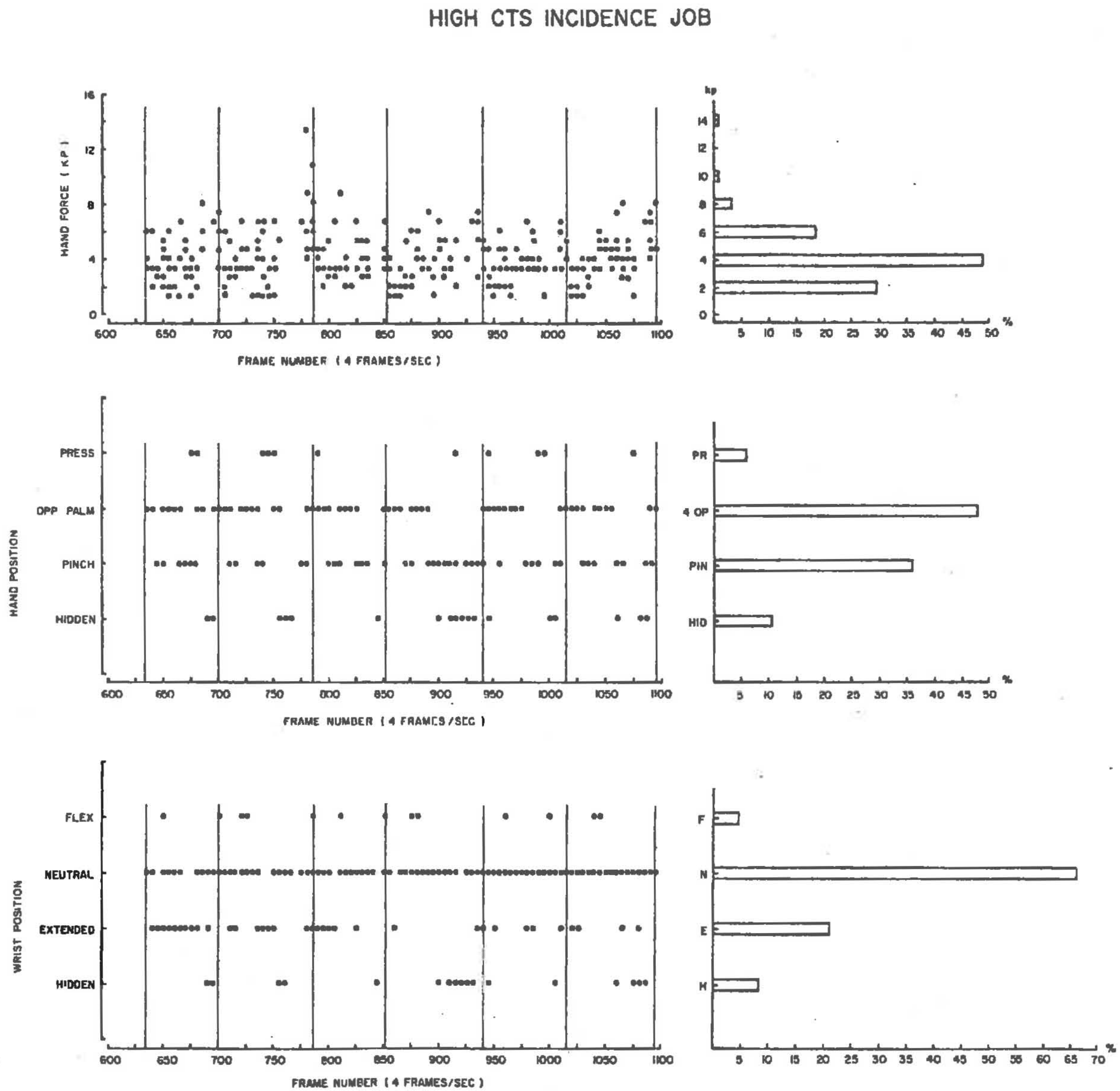


Figure 4-1a: Operator's Time Plot of All Cycles Studied.

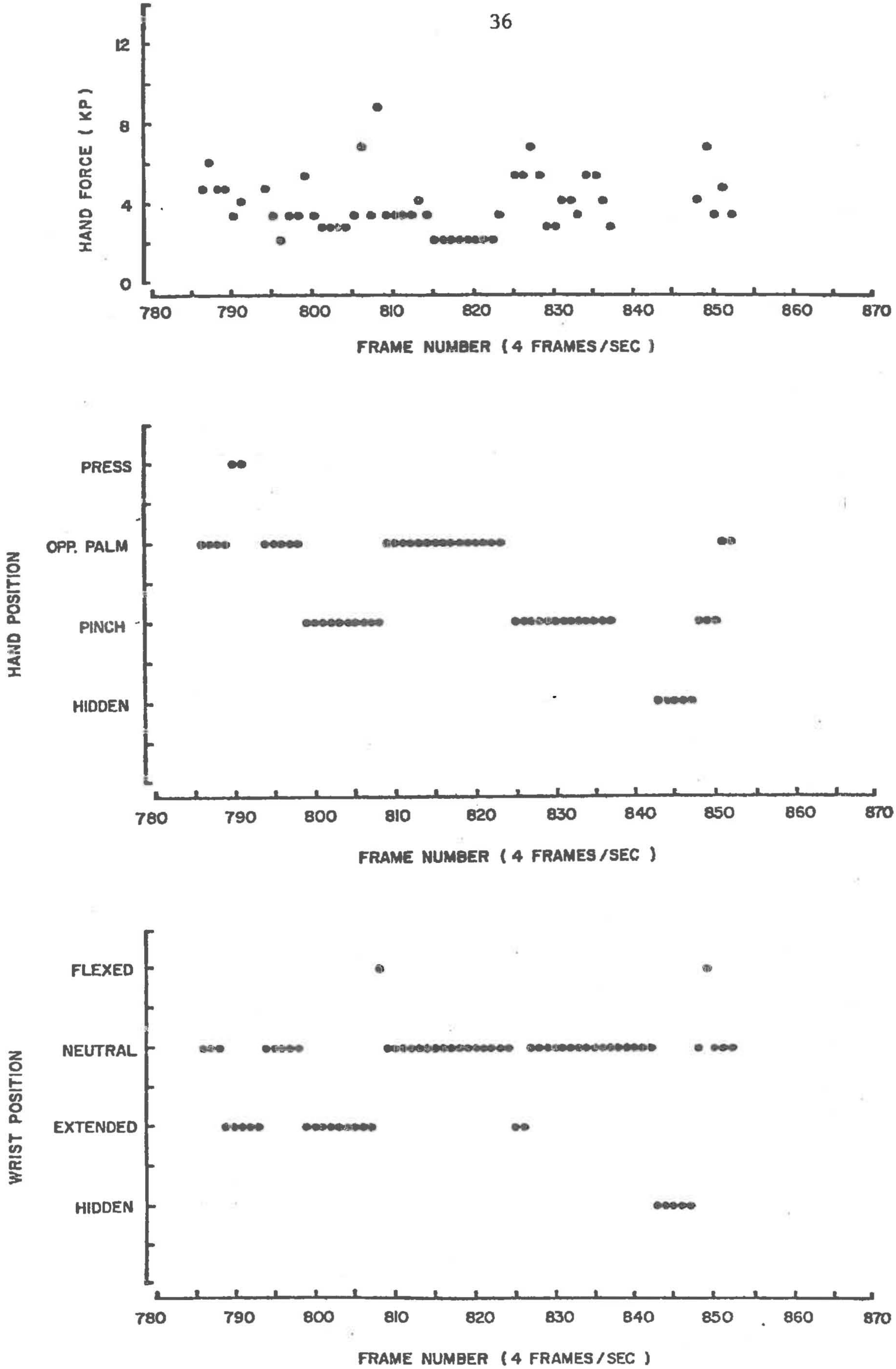


Figure 4-1b: Operator's Time Plot Expanded for One Cycle.

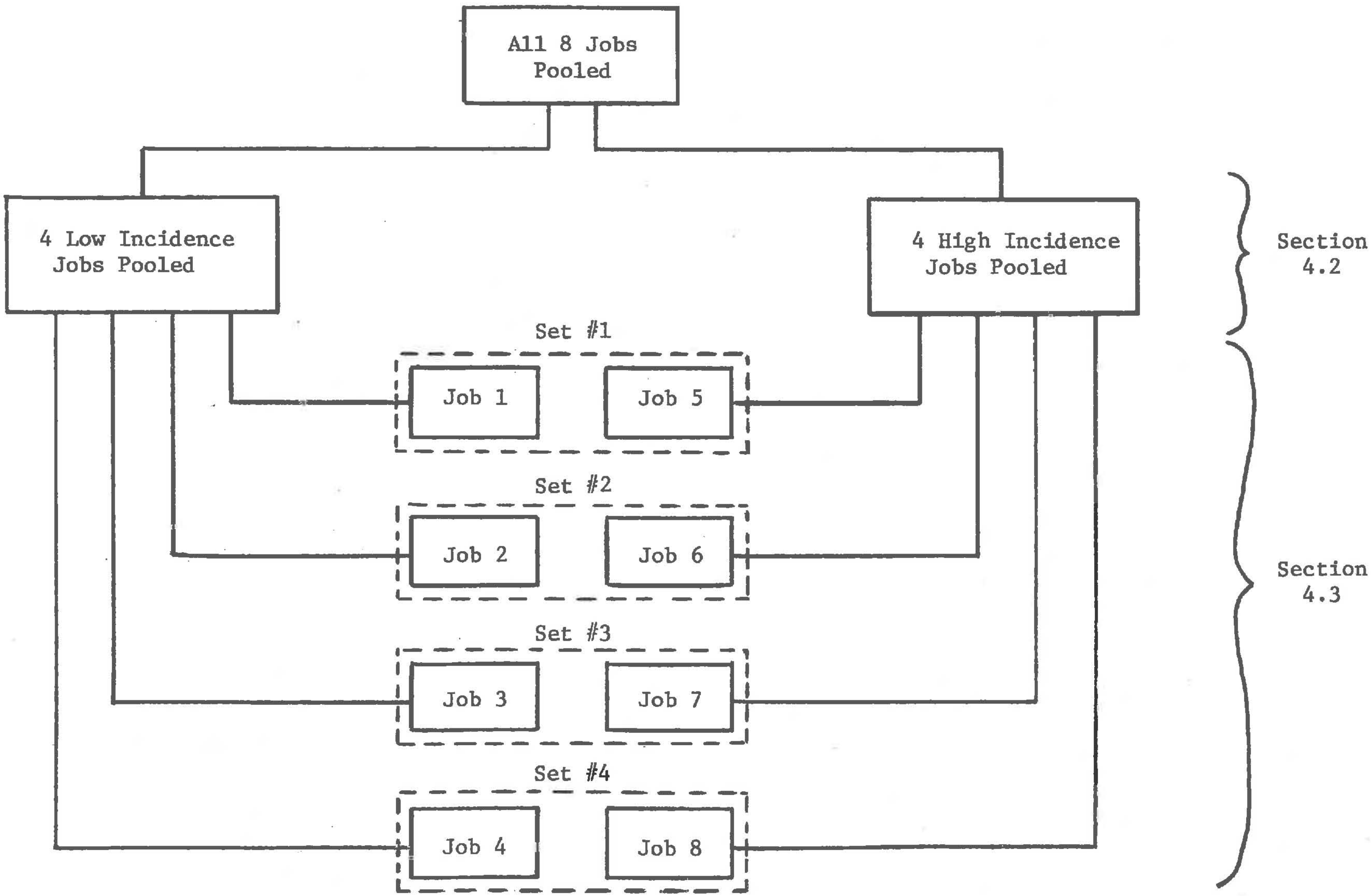


Figure 4-2: Hierarchy of Analysis.

distributions for all subjects. Histograms of: a) hand position; b) wrist position; and c) hand force for the pooled data of all sixteen subjects are shown in Figure 4-3. Frequencies are shown as total number of frames and as percentages of cycle time. The most frequently used hand positions by all subjects was the four finger pinch (24%), followed by the two finger pinch (20%) and the four fingers opposing palm (13%). The most frequent wrist position was neutral (53%) with extended wrists accounting for 20% and flexed wrists for 11.2%. The mean force exerted by all subjects was 4.18 kiloponds with a standard deviation of 3.70 Kp and skewness of 2.37.

Next, the data was separated into two groups, one with subjects who performed the high incidence classification of jobs and one with subjects who performed the low incidence classification of jobs, these permitted a comparison of the two job classes. These data are tabulated in Table 4-2 with the corresponding histograms shown in Figure 4.4.

These histograms of hand and wrist positions were compared statistically using contingency analysis as described by Goodman (1954) and Maxwell (1961); the histograms of hand forces were compared using a log normal or t statistic. The percentage, as well as the total number of frames for each hand and wrist position were compared for the subjects in the high and low incidence job classes, and are shown in a contingency in Table 4-3a and Table 4-3b. The 2, 3, and 4 finger pinch data were pooled into one category called "pinch"; similarly, the 4 finger and hand presses were lumped into a category called "press". Chi squared and coefficient statistics were calculated

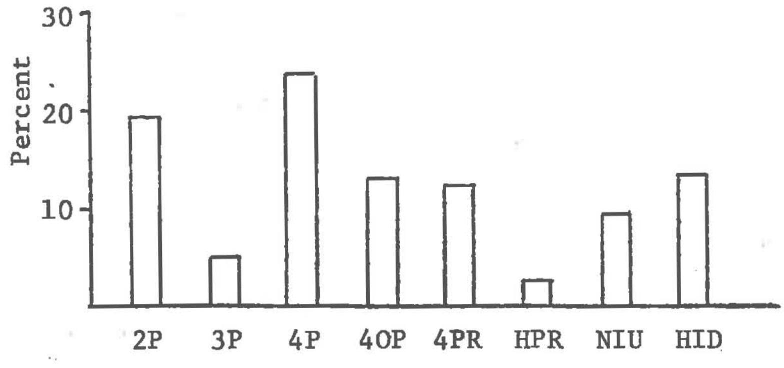


Figure 4-3a: Hand Position

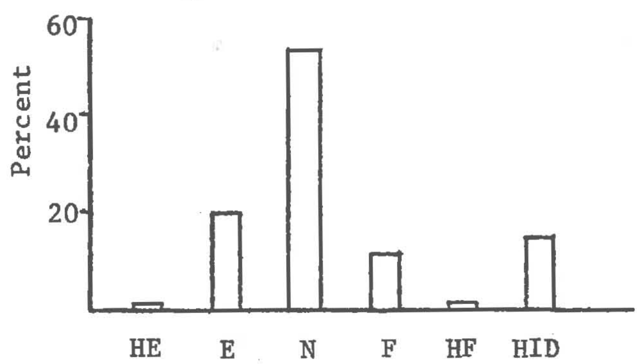


Figure 4-3b: Wrist Position

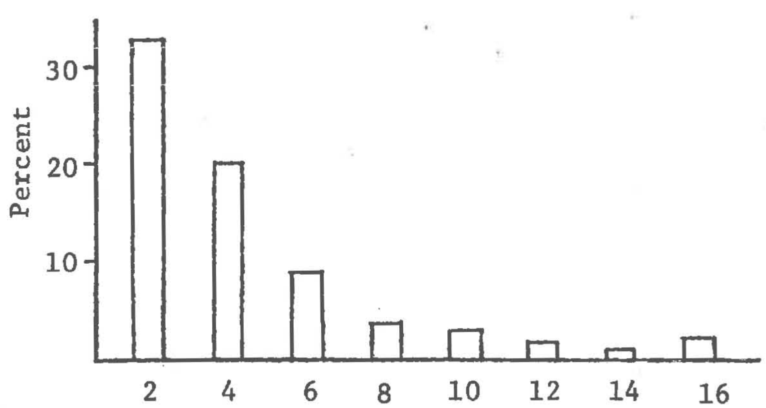


Figure 4-3c: Force (Kp)

Figure 4-3: Histograms for all Data Pooled.

Table 4-2: Pooled Data - All Forces

Table 4-2a: Hand Position

Job Incidence Class	Hand Position Class								
	2 pinch	3 pinch	4 pinch	4 opp. palm	4 press	hand press	hidden	not in use	total
Low	25.6% (902)	3.3% (116)	22.1% (780)	9.0% (317)	10.9% (383)	4.2% (148)	14.7% (515)	10.2% (358)	(3519)
High	13.5% (468)	6.9% (241)	25.6% (890)	17.5% (607)	14.5% (502)	1.0% (36)	12.3% (428)	8.7% (302)	(3474)
Total	19.6% (1370)	5.1% (357)	23.9% (1670)	13.2% (924)	12.7% (885)	2.6% (184)	13.5% (943)	9.4% (660)	(6993)

Table 4-2b: Wrist Position

Job Incidence Class	Wrist Position Class						
	HE	E	N	F	HF	Hid	Total
Low	.7% (23)	20.8% (734)	49.5% (1745)	10.5% (369)	1.1% (37)	17.4% (614)	(3522)
High	.5% (19)	19.0% (659)	55.7% (1936)	11.9% (413)	.9% (30)	12.0% (417)	(3474)
Total	.6% (42)	19.9% (1393)	52.6% (3681)	11.2% (782)	1.0% (67)	14.7% (1031)	(6996)

Table 4-2c: Force Exerted

Job Incidence Class	Hand Force (kiloponds)									
	0-5	6-10	11-15	16-20	21-25	26-30	Mis.	Mean	S.D.	Skew
Low	58.1% (2046)	15.0% (526)	1.7% (59)	.0% (0)	.0% (0)	.0% (0)	25.3% (892)	3.6	2.7	1.5
High	55.3% (1921)	16.0% (556)	3.6% (128)	2.7% (94)	.8% (27)	.3% (12)	21.2% (736)	4.8	4.4	2.2

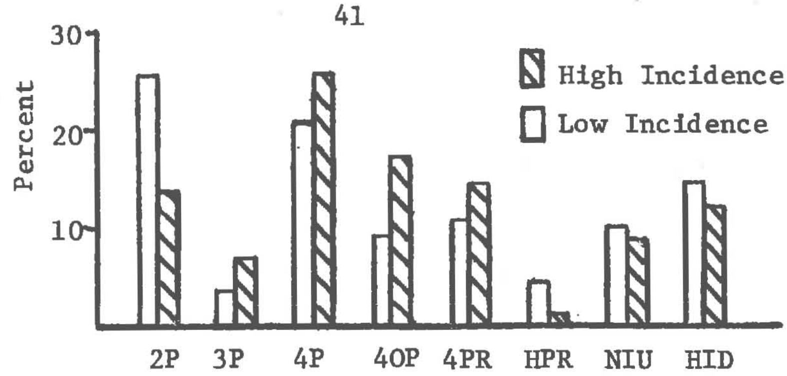


Figure 4-4a: Hand Position

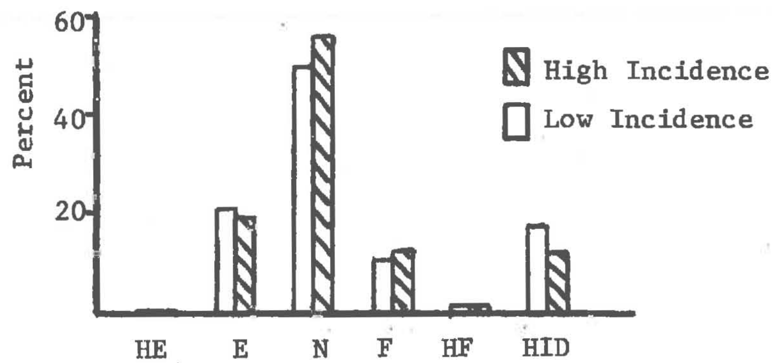


Figure 4-4 b: Wrist Position

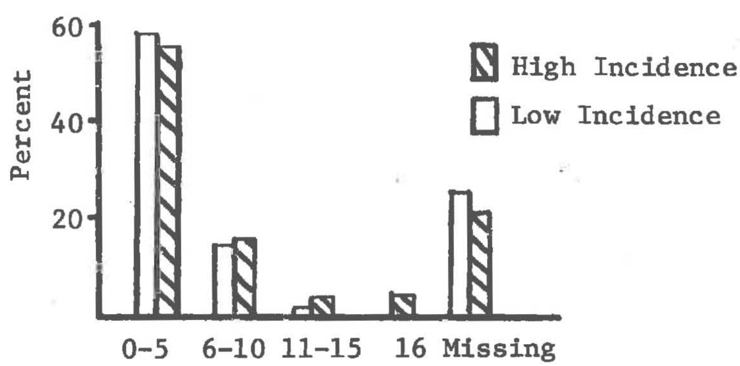


Figure 4-4c: Force (Kp)

Figure 4-4: Histograms for High and Low Incidence Data - All Forces

Table 4-3: Contingency Data - All Forces

Table 4-3a: Pooled Hand Positions

Job Incidence Class	Hand Position Class				
	Pinch	Op. Palm	Press	Hid	Total
Low	56.9% (1798)	10.0% (317)	16.8% (531)	16.3% (515)	(3161)
High	50.4% (1599)	19.1% (607)	17.0% (538)	13.5% (428)	(3172)
Total	53.6% (3397)	14.6% (924)	16.9% (1069)	14.9% (943)	(6333)

X^2 = 110.73, df = 3 contingency coeff. = .13

Table 4-3b: Pooled Wrist Positions

Job Incidence Class	Wrist Position Class				
	Ext.	Neut.	Flx.	Hid	Total
Low	21.5% (757)	49.5% (1745)	11.5% (406)	17.4% (614)	(3522)
High	19.5% (678)	55.7% (1936)	12.8% (443)	12.0% (417)	(3474)
Total	20.5% (1435)	52.6% (3681)	12.1% (849)	14.7% (1031)	(6996)

X^2 = 53.19, df = 3 contingency coeff. = .09

to test the null hypothesis that there is no relationship between the classification of hand positions and the classification of jobs, or between the classification of wrist positions and jobs.

The chi squared statistic was found to be highly significant at $\alpha \leq .00001$ for both hand and wrist position; however, the coefficient of contingency was found to be only .09 for wrist and .13 for hand positions. Therefore, the null hypothesis was rejected and it was concluded that there is a small but significant relationship between hand position and job classification as well as between wrist position and the job classification.

Based on the percent of total in Figure 4-4, the three most frequently used hand positions on the low incidence class jobs were the two finger pinch, four finger pinch, and four finger press respectively, whereas on the high incident class jobs the positions ranked four finger pinch, four fingers opposing palm, and four finger press. The three positions accounted for approximately 58% of their respective groups.

The most predominant wrist position in both low and high incidence classes was the neutral position. This was followed in the low incidence class by the extended and finally flexed wrist, with an almost identical percentage of extension and flexion in the high class as in the low.

The mean force exerted by the low incidence class was 3.59 Kp with a standard deviation of 2.66 Kp and a skewness of 1.50, contrasted to a high incidence class mean of 4.76 Kp and standard deviation and skewness of 4.41 Kp and 2.20 respectively. Based on a t test, this difference was found to be significant at $\alpha \leq .00001$.

In section 2.2 it was argued that forceful exertions as well as deviated wrist positions were etiological factors of carpal tunnel syndrome; therefore, the preceding analysis was repeated for only frames consisting of forceful exertions greater than 1 kilopond hand force.

The data was split into two groups, again corresponding to the high and low incidence jobs. The tabulated data is contained in Table 4-4, while histograms of the data are shown in Figure 4-5.

The hand and wrist position histograms for the two groups were compared using the contingency analysis described previously (refer to Table 4-5a and 4-5b). The chi squared statistic was again found to be significant at $\alpha \leq .00001$ for both positions and the coefficient of contingency was found to be .09 for wrist positions and .15 for hand positions. Therefore, the null hypothesis was rejected and a small but significant relationship was concluded to exist between the classification of hand and wrist position and the classification of jobs.

Based on the percent of total in Figure 4-5, the most predominant hand position on the low incidence jobs was the "pinch", followed by the "press" and then the four fingers opposing palm. The high incidence jobs contained mostly the "pinch" type of hand position also, but the second most frequent position was the four fingers opposing the palm followed by the "press".

For both the low and high incidence jobs, the most common wrist positions were the neutral, extended, and flexed wrists, respectively. The mean force exerted by the low group was 3.76 Kp with a standard deviation of 2.64 Kp; the high group mean force was 4.94 Kp with a standard deviation of 4.42 Kp.

Table 4-4: Pooled Data - Forces ≥ 1 Kp.

Table 4-4a: Hand Position

Job Incidence Class	Hand Position Class								
	2 pinch	3 pinch	4 pinch	4 opp. palm	4 press	hand press	hidden	not in use	total
Low	34.6% (858)	3.9% (96)	30.8% (764)	12.2% (302)	12.9% (319)	5.7% (142)	0% (0)	0% (0)	(2481)
High	16.5% (433)	8.7% (229)	32.8% (860)	23.0% (603)	17.5% (458)	1.4% (36)	0% (0)	0% (0)	(2619)
Total	25.3% (1291)	6.4% (325)	31.8% (1624)	17.7% (905)	15.2% (777)	3.5% (178)	0% (0)	0% (0)	(5100)

Table 4-4b: Wrist Position

Job Incidence Class	Wrist Position Class						
	HE	E	N	F	HF	Hid	Total
Low	0.6% (14)	25.6% (636)	56.7% (1407)	10.6% (263)	0.9% (23)	5.6% (138)	(2481)
High	0.6% (16)	22.3% (584)	60.1% (1574)	13.2% (347)	0.9% (24)	2.8% (74)	(2619)
Total	0.6% (30)	23.9% (1220)	58.5% (2981)	12.0% (610)	0.9% (47)	4.2% (212)	(5100)

Table 4-4c: Force Exerted

Job Incidence Class	Hand Force (kiloponds)									
	0-5	6-10	11-15	16-20	21-25	26-30	Mis.	Mean	S.D.	Skew
Low	76.4% (1896)	21.2% (526)	2.4% (59)	0% (0)	0% (0)	0% (0)	0% (0)	3.76	2.64	
High	68.8% (1802)	21.2% (556)	4.9% (128)	3.6% (94)	1.0% (27)	0.5% (12)	0% (0)	4.94	4.42	

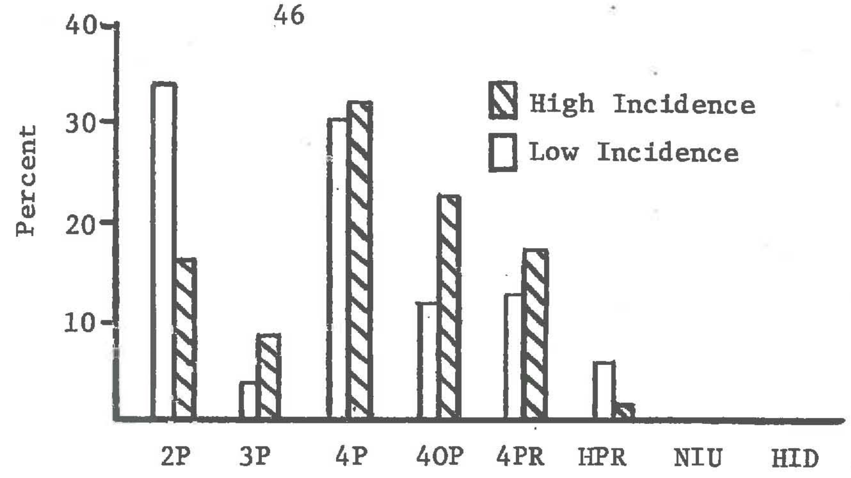


Figure 4-5a: Hand Position

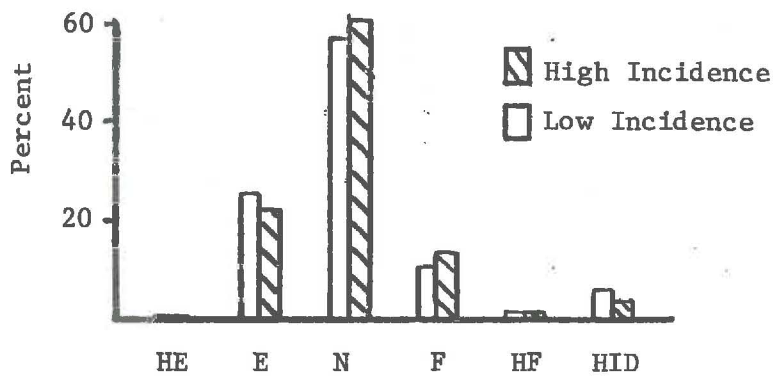


Figure 4-5b: Wrist Position

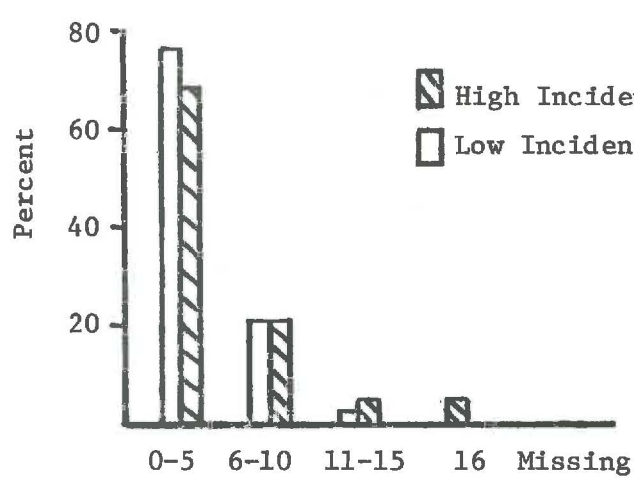


Figure 4-5c: Force (Kp)

Figure 4-5: Histograms for High and Low Incidence Data - Force $\geq$ 1 Kp

Table 4-5: Contingency Data - Forces $\geq$ 1 Kp.

Table 4-5a: Pooled Hand Positions

Job Incidence Class	Hand Position Class				
	Pinch	Op. Palm	Press	Hid	Total
Low	58.1% (1522)	23.0% (603)	18.6% (461)	.0% (0)	(2481)
High	69.2% (1718)	12.2% (302)	18.9% (494)	.0% (0)	(2619)
Total	63.5% (3240)	17.7% (905)	18.7% (955)	.0% (0)	(5100)

X^2 = 109.45, df = 2   contingency coeff. = .14

Table 4-5b: Pooled Wrist Positions

Job Incidence Class	Wrist Position Class				
	Ext.	Neut.	Flx.	Hid	Total
Low	26.2% (650)	56.7% (1407)	14.2% (371)	5.6% (138)	(2481)
High	22.9% (600)	60.1% (1574)	11.5% (286)	2.8% (74)	(2619)
Total	24.5% (1250)	58.5% (2981)	12.9% (657)	4.2% (212)	(5100)

X^2 = 37.97, df = 3   contingency coeff. = .09

4.3 ANALYSIS BY INDIVIDUAL JOBS

From the two groups of high and low incidence class jobs, each job in the high class was separated and matched with its corresponding similar job from the low incidence class. This generated four sets of high and low incidence classification of jobs, permitting a comparison to be made on a job-by-job basis (refer to Figure 4-2).

This first job by job analysis contained all of the data observed for each job. Tables 4-6a, b, and c contain the tabular data by job for percent involvement of hand and wrist positions, and force exerted; while Tables 4-6d, e, and f shows the data as the total number of frames observed. Table 4-7 contains lumped data by classifications. Each low incidence class job is matched and contrasted with its respective high incidence class job. Similarly, job contrasting histograms are shown for hand position in Figure 4-6 and for wrist position in Figure 4-7.

The hand and wrist position histograms for each job set were compared using the contingency analysis. The chi squared statistic and its level of significance as well as the coefficient of contingency statistic for each of the four job sets listed in Table 4-7 are shown in Table 4-8, for both hand and wrist position. It can be concluded for hand position that there is again a small but significant relationship between hand position and job classification for job sets 2, 3, and 4; whereas job set 1, with its contingency coefficient of .46, has an even greater degree of association. For job sets 1, 2, and 4 of the wrist position analysis, there is a significant relationship at $\alpha \leq .00001$ as well as a fair degree of association between wrist and job classification; however, job set 3 is significant only at $\alpha \leq .0003$.

Table 4-6: Data by Job - All Forces

Table 4-6a: Hand Position (Percent Involvement)

Job Number & Incidence Class	Hand Position Class								
	2 pinch	3 pinch	4 pinch	4 opp. palm	4 press	hand press	hidden	not in use	total
Low 1	43.9%	6.4%	25.1%	4.3%	1.2%	0.2%	10.9%	8.0%	
High 5	22.1%	11.4%	2.8%	36.6%	12.3%	0.5%	6.2%	8.0%	
Low 2	10.3%	3.0%	32.1%	15.0%	11.8%	2.3%	17.4%	7.9%	
High 6	10.7%	3.9%	22.9%	21.4%	8.5%	1.3%	25.1%	6.2%	
Low 3	18.7%	0.7%	11.9%	10.0%	18.5%	12.5%	15.4%	12.2%	
High 7	9.7%	6.6%	29.5%	4.0%	29.8%	2.3%	9.3%	8.8%	
Low 4	30.1%	3.0%	18.6%	6.5%	12.0%	2.4%	14.6%	12.5%	
High 8	11.2%	5.7%	48.0%	7.4%	7.0%	0.1%	8.7%	11.8%	

Table 4-6b: Wrist Position (Percent Involvement)

Job Number & Incidence Class	Wrist Position Class						
	HE	E	N	F	HF	Hid	total
Low 1	0.7%	32.1%	48.3%	5.9%	1.1%	12.0%	
High 5	0.0%	24.7%	62.9%	7.4%	0.2%	4.9%	
Low 2	1.4%	21.0%	37.3%	15.8%	2.3%	22.0%	
High 6	1.4%	14.2%	56.3%	6.6%	1.6%	20.0%	
Low 3	0.2%	19.3%	53.6%	10.0%	0.5%	16.3%	
High 7	0.2%	21.0%	59.9%	5.3%	0.3%	13.2%	
Low 4	0.2%	11.8%	59.1%	9.7%	0.3%	18.8%	
High 8	0.6%	15.9%	43.6%	28.7%	1.3%	10.0%	

Table 4-6c: Force Exerted (Percent Involvement)

Job Incidence Class	Hand Force (kiloponds)									
	0-5	6-10	11-15	16-20	21-25	26-30	Mis.	Mean	S.D.	Skew
Low 1	63.9%	16.7%	0.1%	0%	0%	0%	19.4%	2.9	2.1	1.0
High 5	33.9%	24.8%	12.9%	9.7%	3.1%	1.4%	14.3%	8.5	6.1	1.0
Low 2	40.2%	28.8%	4.8%	0%	0%	0%	26.4%	5.2	3.6	0.6
High 6	50.9%	15.0%	1.6%	0.9%	0%	0%	31.5%	3.9	2.9	1.8
Low 3	60.8%	9.7%	1.7%	0%	0%	0%	27.8%	3.6	2.3	1.9
High 7	73.9%	7.9%	0%	0%	0%	0%	18.1%	2.9	1.5	0.9
Low 4	68.2%	4.4%	0%	0%	0%	0%	27.5%	2.6	1.4	1.0
High 8	62.9%	16.1%	0%	0%	0%	0%	21.0%	3.6	2.2	0.7

Table 4-6d: Hand Position (Total Number of Frames)

Job Number & Incidence Class	Hand Position Class								
	2 pinch	3 pinch	4 pinch	4 opp. palm	4 press	hand press	hidden	not in use	total
Low 1	371	54	212	36	10	2	92	68	845
High 5	195	101	25	323	109	4	55	71	883
Low 2	95	28	296	138	109	21	160	73	920
High 6	93	34	199	186	74	11	218	54	869
Low 3	153	6	97	82	151	102	126	100	817
High 7	84	57	256	35	259	20	81	76	868
Low 4	283	28	175	61	113	23	137	117	937
High 8	96	49	410	63	60	1	74	101	854

Table 4-6e: Wrist Position (Total Number of Frames)

Job Number & Incidence Class	Wrist Position Class						
	HE	E	N	F	HF	Hid	total
Low 1	6	271	408	50	9	101	845
High 5	0	218	555	65	2	43	883
Low 2	13	194	344	146	21	203	921
High 6	12	123	489	57	14	174	869
Low 3	2	158	438	82	4	133	817
High 7	2	182	520	46	3	115	868
Low 4	2	111	555	91	3	177	939
High 8	5	136	372	245	11	85	854

Table 4-6f: Force Exerted (Total Number of Frames)

Job Incidence Class	Hand Force (kiloponds)									
	0-5	6-10	11-15	16-20	21-25	26-30	Mis.	Mean	S.D.	Skew
Low 1	539	141	1	0	0	0	164	2.9	2.1	1.0
High 5	299	219	114	86	27	12	126	8.5	6.1	1.0
Low 2	370	265	44	0	0	0	243	5.2	3.6	0.6
High 6	443	130	14	8	0	0	274	3.9	2.9	1.8
Low 3	497	79	14	0	0	0	227	3.6	2.3	1.9
High 7	642	69	0	0	0	0	157	2.9	1.5	0.9
Low 4	640	41	0	0	0	0	258	2.6	1.4	1.0
High 8	537	138	0	0	0	0	179	3.6	2.2	0.7

Table 4-7: Lumped Data by Job - All Forces.

Table 4-7a: Lumped Hand Position

Job Number & Incidence Class	Lumped Hand Position Class								
	Percent Involvement				Number of Frames				
	Pinch	Op. Palm	Press	Hid	Pinch	Op. Palm	Press	Hid	Total
Low 1	82.0%	4.6%	1.5%	11.8%	637	36	12	92	777
High 5	39.5%	39.8%	13.9%	6.8%	321	323	113	55	812
Low 2	49.5%	16.3%	15.3%	18.9%	419	183	130	160	847
High 6	40.0%	22.8%	10.4%	26.7%	326	186	85	218	815
Low 3	35.7%	11.4%	35.3%	17.6%	256	82	253	126	717
High 7	50.1%	4.4%	35.2%	10.2%	397	35	279	81	792
Low 4	59.3%	7.4%	16.6%	16.7%	486	61	136	137	820
High 8	73.7%	8.4%	8.1%	9.8%	555	63	61	74	753

Table 4-7b: Lumped Wrist Position

Job Number & Incidence Class	Lumped Wrist Position Class							
	Percent Involvement				Number of Frames			
	E	N	F	Hid	E	N	F	Hid
Low 1	32.8%	48.3%	7.0%	12.0%	277	408	59	101
High 5	24.7%	62.9%	7.6%	4.9%	218	555	67	43
Low 2	22.5%	37.4%	18.1%	22.0%	207	344	167	203
High 6	15.5%	56.3%	8.2%	20.0%	135	489	71	174
Low 3	19.6%	53.6%	10.5%	16.3%	160	438	86	133
High 7	21.2%	59.9%	5.6%	13.2%	184	520	49	115
Low 4	12.0%	59.1%	10.0%	18.8%	113	555	94	117
High 8	16.5%	43.6%	30.0%	10.0%	141	372	256	85

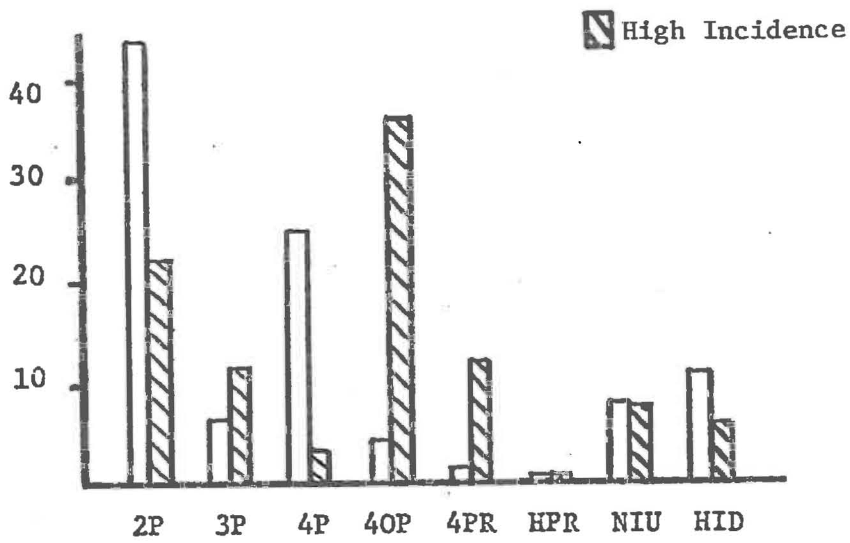


Figure 4-6a: Set 1 (Jobs 1 & 5)

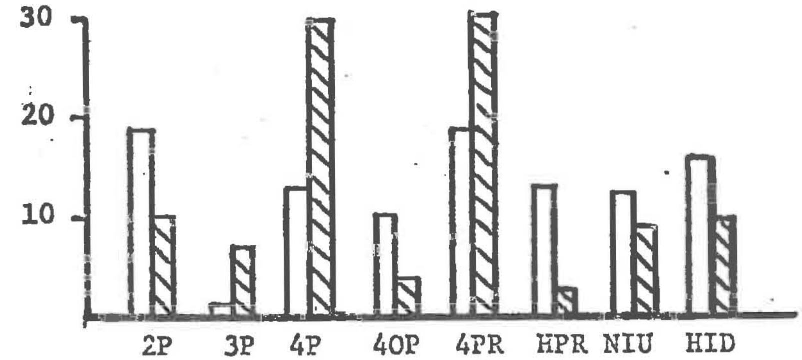


Figure 4-6c: Set 3 (Jobs 3 & 7)

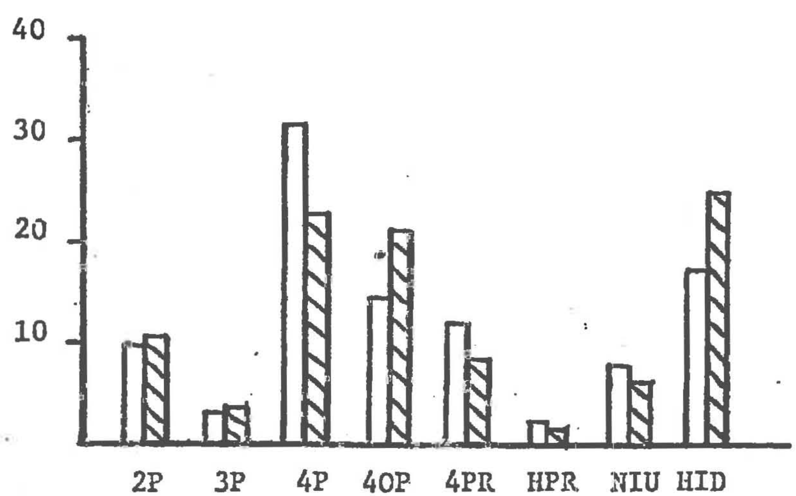


Figure 4-6b: Set 2 (Jobs 2 & 6)

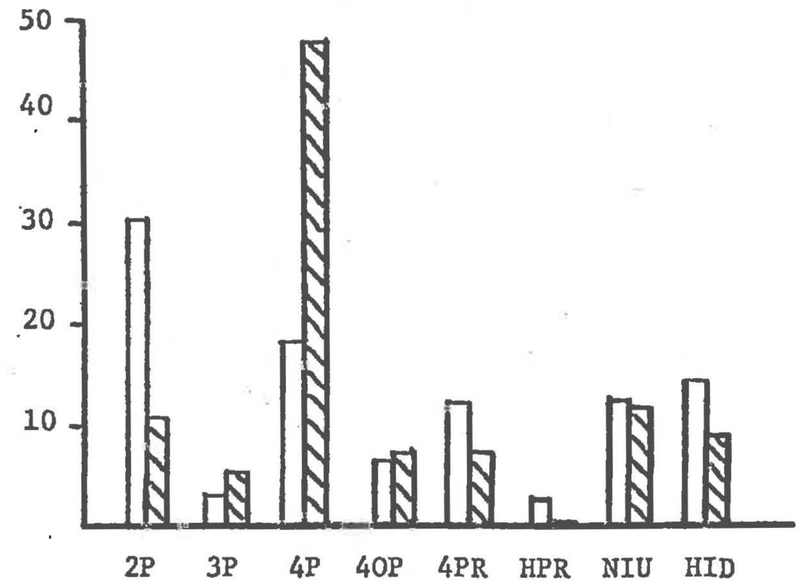


Figure 4-6d: Set 4 (Jobs 4 & 8)

Figure 4-6: Hand Position Histograms of Comparative Job Sets - All Forces.

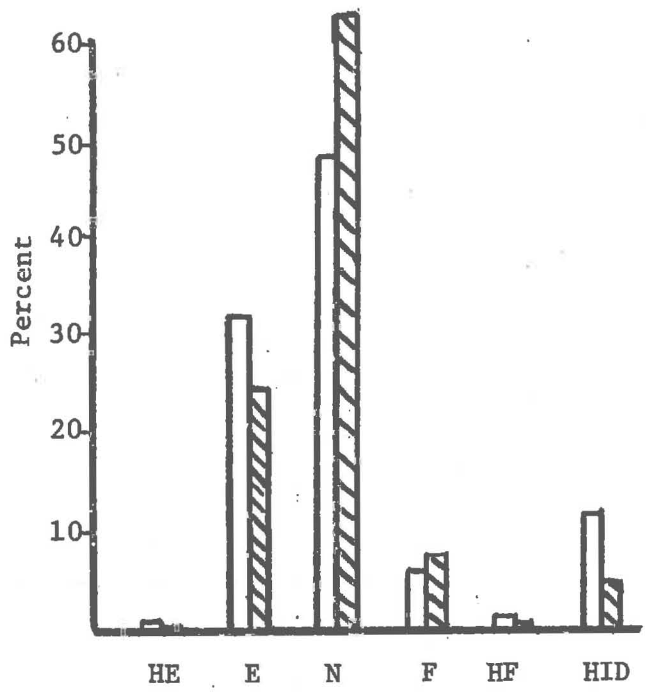


Figure 4-7a: Set 1 (Jobs 1 & 5)

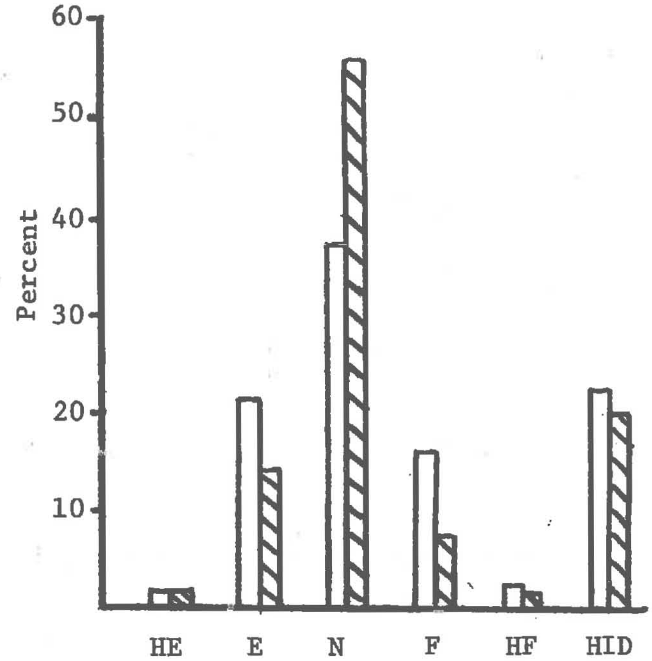


Figure 4-7b: Set 2 (Jobs 2 & 6)

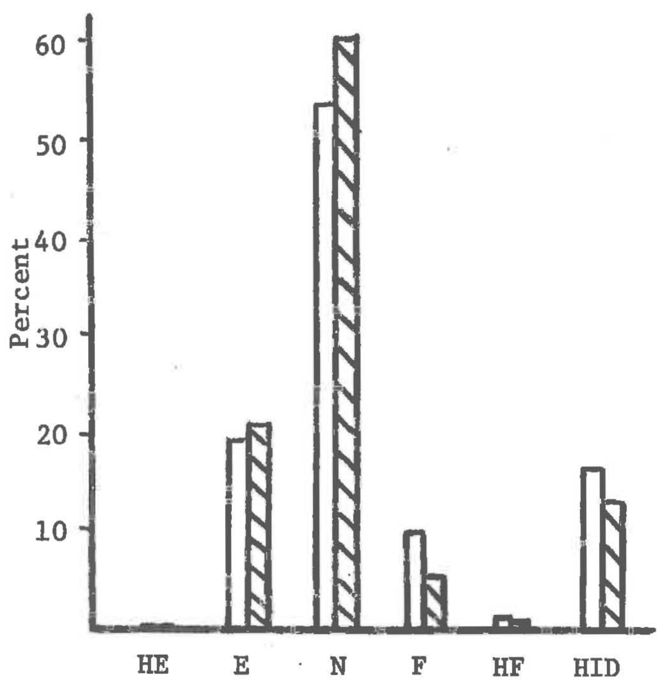


Figure 4-7c: Set 3 (Jobs 3 & 7)

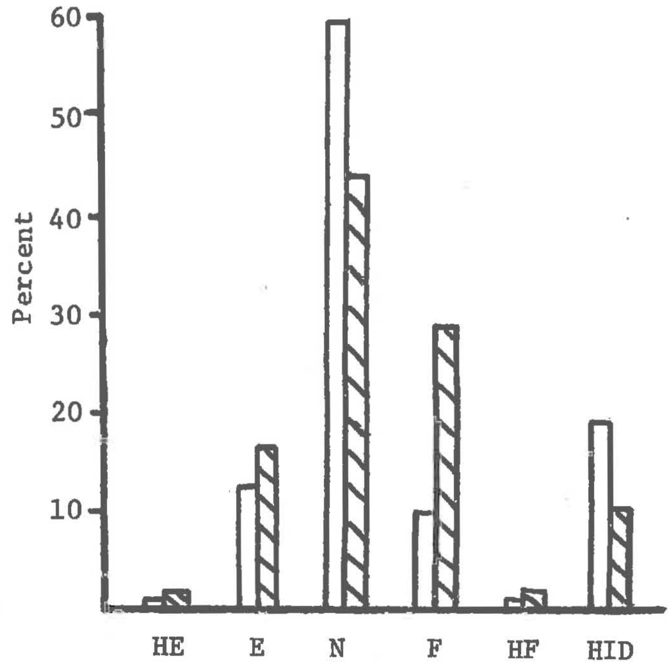


Figure 4-7d: Set 4 (Jobs 4 & 8)

High Incidence   Low Incidence

Figure 4-7: Wrist Position Histograms of Comparative Job Sets - All Forces.

Table 4-8: Contingency Data by Job Set - All Forces.

Table 4-8a: Hand Position

Matched Job Set	Summary of Contingency Analysis for Matched Jobs		
	Chi-Square	degree of freedom	Contingency Coef.
Set 1 (Jobs 1 & 5)	424.03*	3	.46
Set 2 (Jobs 2 & 6)	36.44*	3	.15
Set 3 (Jobs 3 & 7)	56.79*	3	.19
Set 4 (Jobs 4 & 8)	49.21*	3	.17

* significant at $\alpha \leq .00001$

Table 4-8b: Wrist Position

Matched Job Set	Summary of Contingency Analysis for Matched Jobs		
	Chi-Square	degree of freedom	Contingency Coef.
Set 1 (Jobs 1 & 5)	52.53*	3	.17
Set 2 (Jobs 2 & 6)	79.91*	3	.21
Set 3 (Jobs 3 & 7)	18.61**	3	.10
Set 4 (Jobs 4 & 8)	142.79*	3	.27

* significant at $\alpha \leq .00001$
** significant at $\alpha \leq .0003$

Table 4-9 summarizes the primary hand positions used for each job, based on the histograms shown in Figure 4-6. The only hand position common to portions of the high jobs and not to any of the low jobs is the 4 fingers opposing the palm.

From the histograms in Figure 4-7, contrasting the observed wrist positions per job, the dominant position for all four sets was the neutral wrist. In the first three sets, the second most frequent position was extension followed by flexion, for both high and low incidence class jobs; however, in set four the percentage of flexion and extension was nearly the same for the low incidence class job (#4), but the high incidence class job (#8) has a greater percentage of flexion as opposed to extension.

Stratification of force exertion levels are contrasted in Table 4-6c between the high and low class jobs for each of the four job sets. Comparison of the mean forces within job sets shows that there is less than a 1.3 Kp difference between the high and low incidence class jobs for sets 2, 3, and 4; but job set 1 has a 5.6 Kp higher force in the high class job (#5) than in the low class job (#1). Similarly, the standard deviation of job sets 2, 3, and 4 show less than a 0.8 Kp difference between the high and low class jobs; whereas the high class job in job set 1 has a 4.0 Kp greater standard deviation than its corresponding low class job.

For the same rationale as was stated in section 4.2, the analysis by job was repeated for only those frames consisting of forceful exertions greater than 1 kilopond hand force. Each low incidence class was matched with its corresponding high incidence class, to permit a by job comparison. These data are tabulated in Table 4-10a, b, and c as percent involvement

Table 4-9: Major Hand Position - By Job

Matched Job Set	Major Hand Position Usage	
	Low Incidence Jobs	High Incidence Jobs
Set 1 (Jobs 1 & 5)	2 pinch	4 opp. palm
Set 2 (Jobs 2 & 6)	4 pinch	4 pinch & 4 opp. palm
Set 3 (Jobs 3 & 7)	2 pinch & 4 press	4 pinch & 4 press
Set 4 (Jobs 4 & 8)	2 pinch	4 pinch

Table 4-10: Data by Job - Forces $\geq$ 1 Kp.

Table 4-10a: Hand Position (Percent Involvement)

Job Number & Incidence Class	Hand Position Class								
	2 pinch	3 pinch	4 pinch	4 opp. palm	4 press	hand press	hidden	not in use	total
Low 1	54.2%	7.6%	31.6%	5.3%	0.9%	0.3%	0%	0%	
High 5	25.8%	13.3%	3.3%	42.7%	14.4%	0.5%	0%	0%	
Low 2	14.8%	2.5%	45.9%	20.5%	13.4%	2.8%	0%	0%	
High 6	15.3%	5.9%	34.5%	32.4%	9.9%	1.9%	0%	0%	
Low 3	26.1%	1.1%	17.1%	13.7%	24.3%	17.8%	0%	0%	
High 7	12.4%	8.4%	37.0%	5.2%	34.2%	2.9%	0%	0%	
Low 4	41.8%	3.8%	27.1%	9.5%	14.4%	3.4%	0%	0%	
High 8	10.8%	6.1%	63.4%	9.7%	9.9%	0.2%	0%	0%	

Table 4-10b: Wrist Position (Percent Involvement)

Job Number & Incidence Class	Wrist Position Class						
	HE	E	N	F	HF	Hid	total
Low 1	0.6%	38.0%	54.0%	5.3%	1.1%	0.9%	
High 5	0%	26.6%	65.5%	7.7%	0.3%	0%	
Low 2	1.3%	25.6%	44.8%	16.9%	2.2%	9.3%	
High 6	1.9%	17.6%	65.9%	8.2%	1.7%	4.7%	
Low 3	0.2%	23.9%	63.0%	9.3%	0.4%	3.2%	
High 7	0.3%	25.3%	62.7%	6.2%	0.3%	5.2%	
Low 4	0.2%	14.3%	65.9%	10.9%	0%	8.8%	
High 8	0.5%	18.1%	45.0%	32.8%	1.6%	2.0%	

Table 4-10c: Force Exerted (Percent Involvement)

Job Incidence Class	Hand Force (kiloponds)									
	0-5	6-10	11-15	16-20	21-25	26-30	Mis.	Mean	S.D.	Skew
Low 1	78.3%	21.5%	0.2%	0%	0%	0%	0%	3.03	2.06	
High 5	39.5%	28.9%	15.1%	11.4%	3.5%	1.6%	0%	8.51	6.13	
Low 2	51.2%	41.9%	6.9%	0%	0%	0%	0%	5.51	3.46	
High 6	73.6%	22.6%	2.5%	1.4%	0%	0%	0%	4.06	2.89	
Low 3	83.6%	13.9%	2.4%	0%	0%	0%	0%	3.73	2.28	
High 7	89.9%	10.2%	0%	0%	0%	0%	0%	2.98	1.44	
Low 4	93.5%	6.7%	0%	0%	0%	0%	0%	2.77	1.31	
High 8	77.4%	22.6%	0%	0%	0%	0%	0%	3.52	2.10	

Table 4-10d: Hand Position (Total Number of Frames)

Job Number & Incidence Class	Hand Position Class								
	2 pinch	3 pinch	4 pinch	4 opp. palm	4 press	hand press	hidden	not in use	total
Low 1	355	50	207	35	6	2	0	0	655
High 5	195	101	25	323	109	4	0	0	757
Low 2	94	16	291	130	85	18	0	0	634
High 6	88	34	198	186	57	11	0	0	574
Low 3	148	6	97	78	138	101	0	0	568
High 7	84	57	251	35	232	20	0	0	679
Low 4	261	24	169	59	90	21	0	0	264
High 8	66	37	386	59	60	1	0	0	609

Table 4-10e: Wrist Position (Total Number of Frames)

Job Number & Incidence Class	Wrist Position Class						
	HE	E	N	F	HF	Hid	total
Low 1	4	249	354	35	7	6	655
High 5	0	201	496	58	2	0	757
Low 2	8	162	284	107	14	59	634
High 6	11	101	378	47	10	27	574
Low 3	1	136	358	53	2	18	568
High 7	2	172	426	42	2	35	679
Low 4	1	89	411	68	0	55	624
High 8	3	110	274	200	10	12	609

Table 4-10f: Force Exerted (Total Number of Frames)

Job Incidence Class	Hand Force (kilopons)									
	0-5	6-10	11-15	16-20	21-25	26-30	Mis.	Mean	S.D.	Skew
Low 1	513	141	1	0	0	0	0	3.03	2.06	
High 5	299	219	114	86	27	12	0	8.51	6.13	
Low 2	325	265	44	0	0	0	0	5.51	3.46	
High 6	422	130	14	8	0	0	0	4.06	2.89	
Low 3	475	79	14	0	0	0	0	3.73	2.28	
High 7	610	69	0	0	0	0	0	2.98	1.44	
Low 4	583	41	0	0	0	0	0	2.77	1.31	
High 8	471	138	0	0	0	0	0	3.52	2.10	

and in Tables 4-10d, e, and f as total number of frames, as well as by lumped classifications in Table 4-11. The corresponding histograms are shown in Figures 4-8 and 4-9.

The contingency analyses again was used to compare the histograms for each job set, and the pertinent data from these analyses are shown in Table 4-12. For hand position it can be stated that for job sets 2, 3, and 4 there is a small but significant relationship between hand position and job classification; whereas again job set 1, with a contingency coefficient of .47, has a greater degree of association. For wrist position job sets 1, 2, and 4 there is also a small but significant relationship; however job set 3 has a contingency coefficient of only .08 and is significant only at $\leq$ .0672.

From the hand position histograms in Figure 4-8, the high and low incident job in sets 2, 3, and 4 have the same ranked hand position frequencies (for set 2: Pinch-Opposing Palm-Press; for sets 3 and 4: Pinch-Press-Opposing Palm). Job set 1 however has the pinch as the most frequent low incident job position, while the most common high incidence job position is the 4 fingers opposing the palm.

The wrist position histograms (Figure 4-9) show the rank order for wrist position frequencies to be neutral, extended, and finally flexed for job sets 1, 2, and 3. Job set 4, however, has the same rank order for its low incidence job (neutral-extended-flexed); but the high incidence job's second most common position was flexed with extension ranking third.

The difference between the mean force of the high and low incidence job class was less than 1.4 Kp for job sets 2, 3, and 4; with the difference in job set 1 being 5.5 Kp higher in the high incidence class

Table 4-11: Lumped Data by Job - Forces ≥ 1 Kp.

Table 4-11a: Lumped Hand Position

Job Number & Incidence Class	Lumped Hand Position Class								
	Percent Involvement				Number of Frames				
	Pinch	Op. Palm	Press	Hid	Pinch	Op. Palm	Press	Hid	Total
Low 1	93.4%	5.3%	1.2%	0%	612	35	8	0	655
High 5	42.4%	42.7%	14.9%	0%	321	323	113	0	757
Low 2	63.2%	20.5%	16.2%	0%	401	130	103	0	634
High 6	55.7%	32.4%	11.8%	0%	320	186	68	0	574
Low 3	44.2%	13.7%	42.1%	0%	251	78	239	0	568
High 7	57.7%	5.2%	37.1%	0%	392	35	252	0	679
Low 4	72.8%	9.5%	17.8%	0%	454	59	111	0	624
High 8	80.3%	9.7%	10.0%	0%	489	59	61	0	609

Table 4-11b: Lumped Wrist Position

Job Number & Incidence Class	Lumped Wrist Position Class							
	Percent Involvement				Number of Frames			
	E	N	F	Hid	E	N	F	Hid
Low 1	38.6%	54.0%	6.4%	0.9%	253	354	42	6
High 5	26.6%	65.5%	7.9%	0%	201	496	60	0
Low 2	26.8%	44.8%	19.1%	9.3%	170	284	121	59
High 6	19.5%	65.9%	9.9%	4.7%	112	378	57	27
Low 3	24.1%	63.0%	9.7%	3.2%	137	358	55	18
High 7	25.6%	62.7%	6.5%	5.2%	174	426	44	35
Low 4	14.4%	65.9%	10.9%	8.8%	90	411	68	55
High 8	18.6%	45.0%	34.5%	2.0%	113	274	210	12

Table 4-12: Contingency Data by Job Set - Forces $\geq$ 1 Kp

Table 4-12a: Hand Position

Matched Job Set	Summary of Contingency Analysis for Matched Jobs		
	Chi-Square	degree of freedom	Contingency Coef.
Set 1 (Jobs 1 & 5)	408.33*	2	.47
Set 2 (Jobs 2 & 6)	23.26*	2	.14
Set 3 (Jobs 3 & 7)	38.05*	2	.17
Set 4 (Jobs 4 & 8)	15.65**	2	.11

* significant at $\alpha \leq .00001$
** significant at $\alpha \leq .0004$

Table 4-12b: Wrist Position

Matched Job Set	Summary of Contingency Analysis for Matched Jobs		
	Chi-Square	degree of freedom	Contingency Coef.
Set 1 (Jobs 1 & 5)	31.65*	3	.15
Set 2 (Jobs 2 & 6)	57.36*	3	.21
Set 3 (Jobs 3 & 7)	7.15**	3	.08
Set 4 (Jobs 4 & 8)	129.97*	3	.31

* significant at $\alpha \leq .00001$
** significant at $\alpha \leq .0672$

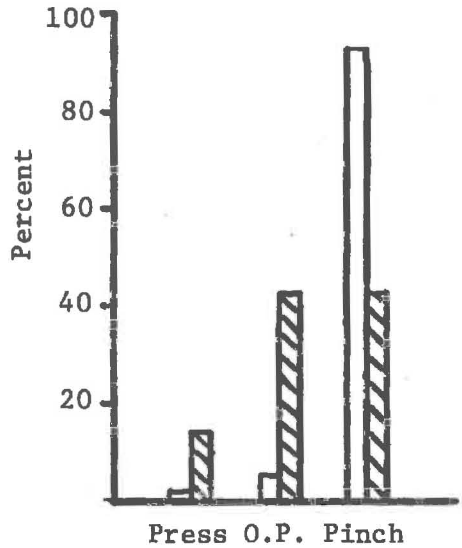


Figure 4-8a: Set 1

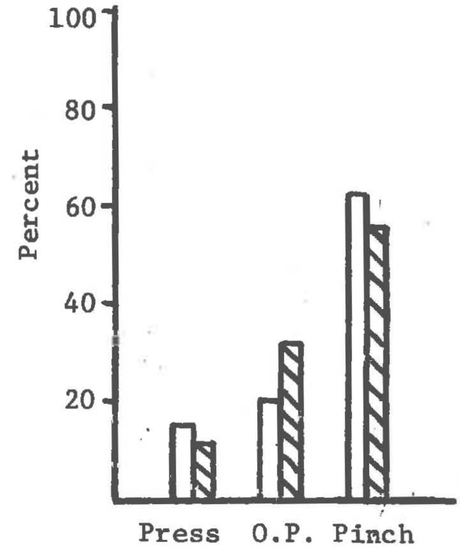


Figure 4-8b: Set 2

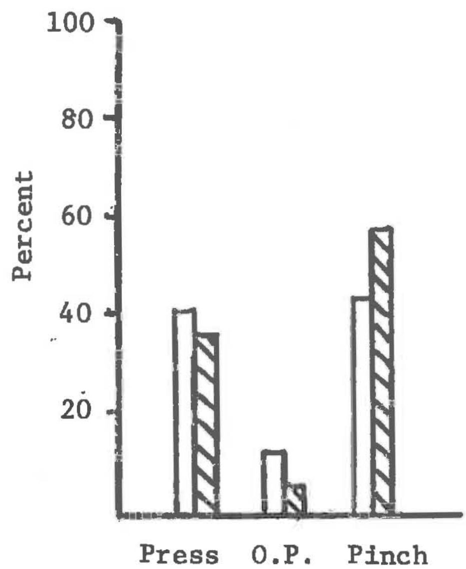


Figure 4-8c: Set 3

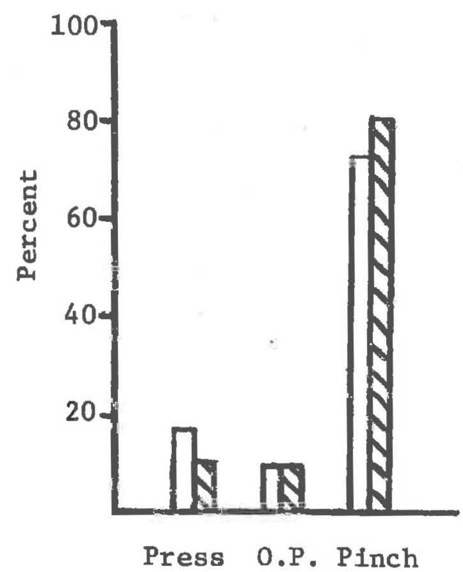


Figure 4-8d: Set 4

High Incidence

Low Incidence

Figure 4-8: Hand Position Histograms of Comparative Job Sets - Forces $\geq$ 1 Kp.

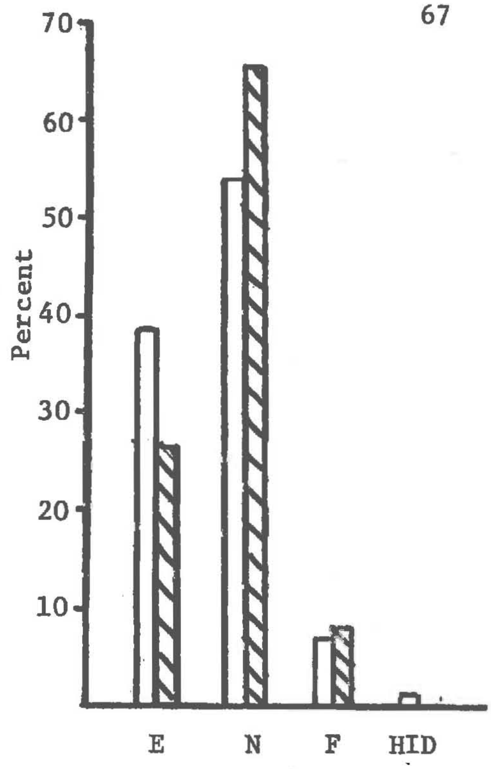


Figure 4-9a: Set 1

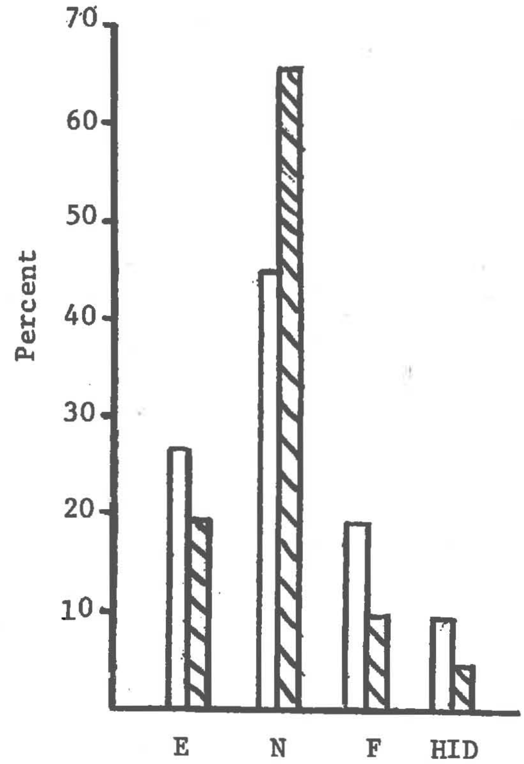


Figure 4-9b: Set 2

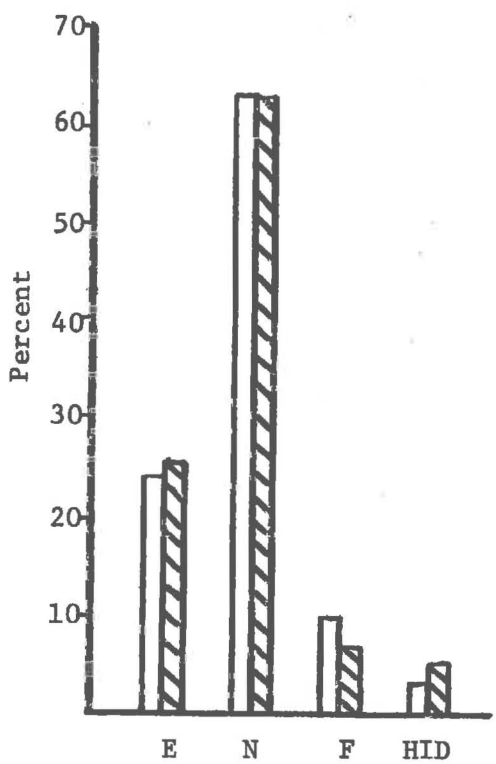


Figure 4-9c: Set 3

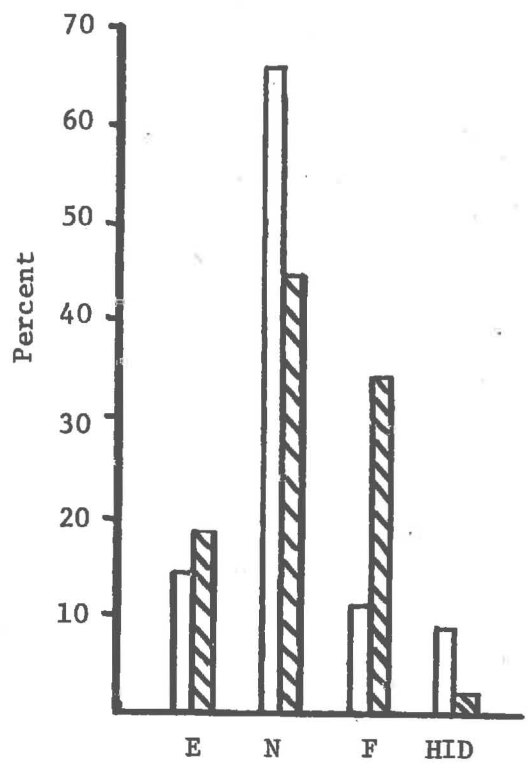


Figure 4-9d: Set 4

Figure 4-9: Wrist Position Histograms of Comparative Job Sets - Forces $\geq$ 1 Kp.

job. The difference between the standard deviations of the high and low incidence class job was 0.9 Kp in all job sets except job set 1 where the high incidence class job had a 4.1 Kp higher standard deviation.

V. DISCUSSION

5.1 EFFECTS OF HAND POSITIONS

All jobs, performed by the sixteen subjects in this experiment, required repetitive and forceful exertion of the hand and fingers throughout the entire workday. These types of hand requirements have been described by Phalen (1972) as causal factors of flexor synovialis inflammation and ultimately carpal tunnel syndrome.

The results and analysis of hand position frequencies, on both high and low incidence class jobs, attempted to determine if in fact specific repetitive hand positions were more prevalent in the high incidence class jobs, and therefore more predisposing to CTS.

From the comparison of all "low incidence pooled" and "high incidence pooled" data, there is a greater percentage (6.5%) of "pinch" positions in the low incidence class jobs; and a larger percentage (9.1%) of opposing palm positions in the high incidence class jobs. After stratifying the data to include only those hand positions with a corresponding force $\geq$ 1 kilopond, these differences become even more significant. There was an 11.1% difference between "pinch" positions (being higher in the low incidence class of jobs) and a 10.8% difference between "opposing palm" positions (being higher in the high incidence class jobs). See Table 5-1.

However, when analyzed on a job-by-job comparison the prevalence of pinch positions in the low incidence class and of opposing palm positions in the high incidence class is not consistent in all four job comparison sets. Based on the results presented in Table 4-7 for all forces $\geq$ 0 Kp and the results in Table 4-11 for all forces $\geq$ 1 Kp, there is a trend

Table 5-1: Hand Position Summary

Job Incidence Class	Hand Position Summary			
	Force ≥ 0 Kp		Force ≥ 1 Kp	
	Pinch	Op. Palm	Pinch	Op. Palm
Low	56.9% (1798)	10.0% (317)	58.1% (1522)	23.0% (603)
High	50.4% (1599)	19.1% (607)	69.2% (1718)	12.2% (302)
Difference	6.5%	9.1%	11.1%	10.8%

consisting of a higher percentage of pinch associated with the low incidence class jobs and opposing palm associated with the high incidence jobs.

Although comparison of the pooled and the job-by-job data indicates an association between frequent use of the 4 fingers opposing palm position and a high incidence class job, it cannot be stated that frequent use of the opposing palm position tends to cause carpal tunnel syndrome.

One reason for questioning the association between 4OP and CTS is that throughout this phase of the experiment only control (healthy) subjects were studied on both the high and low incidence jobs. From watching and talking to various operators, it is apparent that each individual has a different method for peforming the same job, ranging from slight to gross variations. Therefore, it is possible that, by observing healthy subjects on high incidence jobs, the experiment could become biased due to the studying of non-injurious methods.

A second reason for questioning the relationship between 4OP and CTS is that the amount of force and precision required by the job tends to dictate hand position. Napier (1956) stated that the "nature of the intended activity finally influences the pattern of the grip," and he distinguishes between the "power grip" and the "precision grip". In the "power grip" the combined fingers form one jaw of the clamp with the palm as the other jaw, with the fingers more or less flexed according to the size of the object. For a "precision grip" the thumb is abducted and rotated medially such that the pulp surface becomes directly opposed to the pulp surface of one or more of the digits.

Therefore, the four fingers opposing the palm position is more advantageous to use when high forces are demanded by the job. When dexterity and precision are required, a hand position such as the two, three, or four finger pinch suits the need more readily. Thus, four fingers opposing the palm may possibly not be associated with high CTS incidence but rather with high force requirements.

Therefore, there is a trend for high incidence class jobs to contain a higher percentage of four fingers opposing the palm than low incidence class jobs, and this hand position may or may not be a causal factor of carpal tunnel syndrome, for reasons stated above.

5.2 EFFECTS OF WRIST POSITIONS

Throughout the literature on carpal tunnel syndrome, as detailed in the Background chapter of this report, the consensus of the authors is that deviation of the wrist from the neutral (or straight) position, in either flexion or extension, causes increased pressure within the confines of the carpal tunnel (Abbott and Saunders, 1953; Smith, et al., 1976). This increased pressure from a flexed or extended wrist can cause compression of the median nerve and ultimately carpal tunnel syndrome, if the exposure is severe enough over a period of time.

Table 5-2 summarizes the results of wrist positions for both high and low incidence pooled data. Since both flexion and extension of the wrist are considered to be possible causes of median nerve compression, the data for these two classifications were lumped together. Upon analysis of all the data (forces $\geq$ 0 Kp) the frequency of the neutral wrist position was greater, by 6.2%, for the high incidence class jobs than for the low incidence class jobs; and the frequency of flexion and extension for the high and low incidence classes were approximately equal (a difference of only 0.7%). These results do not appear consistent with the previously mentioned theories from the existing literature associating wrist deviation and CTS, since it would be expected that high incidence class jobs be related to higher frequencies of flexed and extended position and smaller frequencies of neutral position than the low incidence class jobs.

However, Tanzer (1959) proposed that simultaneous forceful exertion of the fingers, while the wrist is in flexion, adds to the pressure on

Table 5-2: Wrist Position Summary

Job Incidence Class	Wrist Position Summary					
	Force ≥ 0 Kp		Force ≥ 1 Kp		Force = Top 10%	
	N	E & F	N	E & F	N	E & F
Low	49.5% (1745)	33.0% (1163)	56.7% (1407)	37.7% (936)	49.4% (175)	46.7% (166)
High	55.7% (1936)	32.3% (1121)	60.1% (1574)	37.1% (971)	57.1% (199)	36.9% (128)
Difference	6.2%	0.7%	3.4%	0.6%	7.7%	9.8%

the median nerve with a force proportioned to the force exerted by the digits; this theory was confirmed in experiments performed by Smith, et al., (1976). This relationship was also determined by biomechanical analysis (Armstrong, 1976) whereby the resultant intrawrist force is dependent upon both the force exerted by the finger tendons and by the angle of deviation of the wrist; refer to Chapter II.

It is, therefore, reasonable to assume that the effects of wrist position as a causal factor of CTS, are more significant as the force of exertion increases. Table 5-2 also contains the summary wrist position data at all forces $\geq$ 1 Kp, for high and low incidence job classes. Analysis of these results show that although the high incidence class still has a greater % of neutral wrists than the low incidence class, the difference has dropped from 6.2% to 3.4% as the wrist positions associated with forces less than 1 kilopond are eliminated. At this stratification level there was still no significant difference for flexion and extension between the high and low class jobs (0.6%).

There is an apparent trend that as low force exertions are eliminated the neutral wrist position becomes less frequent in high incidence job classes, and therefore positions such as flexion and extension should become increasingly more frequent. Due to this trend, a further stratification of the data was generated to include only the wrist positions associated with the top 10% of the force exertions for each subject. Although not formally presented in the Results chapter of this report, this summarized wrist data is shown in Table 5-2 for force = top 10%.

At this high force cutoff level, the aforementioned trend appears to have continued. This strata of the high incidence class data has a lower percentage of neutral wrist positions than the low incidence class, by a difference of 7.7%. The percentage of flexion and extension in the high force strata of the data is greater in the high incidence class than in the low incidence class, a difference of 9.8%.

Thus, it can be concluded from the literature that the effects of wrist flexion and extension on median nerve compression are accentuated by high finger forces. From the data it can be concluded that jobs associated with a high incidence of carpal tunnel syndrome tend to have a greater percentage of flexed and extended wrist positions at high levels than jobs associated with a low incidence of CTS.

5.3 EFFECTS OF FORCE EXERTED

From the previous discussion of the pathological influence of wrist positions, it is apparent that the amount of force exerted by the finger flexor tendons also has a direct bearing on the amount of pressure exerted on the intrawrist structures. An analysis of the force data presented in the Results chapter (see Tables 4-2c and 4-6c) showed that there was a significant difference ($\alpha \leq .01$) between the mean forces of the comparative high and low incidence jobs studied.

The average force of the pooled high and low incidence class data, as well as the average forces for each job, were analyzed and compared based on the assumption that hand forces are lognormally distributed, since they are bounded by zero and skewed toward high forces (see Figure 4-4c). A log transformation was achieved by taking the natural logarithm of each force datum. The average values of the transformed data were compared with a t-test, the results of which are shown in Table 5-3.

Since the degrees of freedom (dF) in all cases are greater than 120, the theoretical value of the t statistic, at $\alpha \leq .01$, is equal to 2.326. Since $|t_{calculated}| > t_{theoretical}$ for each high vs. low incidence comparison, it can be concluded that there is a significant difference between the mean forces of the high and low incidence pooled data, as well as between the high and low incidence individual job data for all four comparison sets. A negative t statistic indicates that the mean force of the high incidence job was larger than the mean force of the low incidence job; whereas a positive t statistic infers that the low incidence mean force was larger.

Job Incidence Class & Number	Statistics for Log Normal Force Distribution				
	Mean	Standard Deviation	Sample Size	t Statistic	dF
Low Pooled	3.6	2.7	2631	-9.686	5367
High Pooled	4.8	4.4	2738		
Low 1	2.9	2.1	681	-26.50	1436
High 5	8.5	6.1	757		
Low 2	5.2	3.6	679	5.516	1272
High 6	3.9	2.9	595		
Low 3	3.6	2.3	590	6.386	1299
High 7	2.9	1.5	711		
Low 4	2.6	1.4	681	-3.437	1354
High 8	3.6	2.2	675		

From the pooled data of all high vs. all low incidence class jobs it appears that jobs requiring high force exertions are associated with high incidence of carpal tunnel syndrome. Table 4-2c shows that 7.4% of the high incidence job exertions were greater than 11 Kp; whereas only 1.7% of the low incidence exertions were above this level.

Average force comparisons of all individual high vs. low incidence class jobs, do not follow the same trend as the comparison of the pooled data (see Table 4-6c). Comparison set 1 (jobs 1 & 5) has the most significant difference between mean forces, being 5.6 Kp higher for the high incidence job. The difference between mean forces of the remaining three comparison sets were all approximately 1 Kp, with two of the comparison sets having a greater force in the low incidence job.

Thus, the existing literature, as detailed in the Background chapter of this report, indicates that as the force exerted by the fingers is increased, so is the pressure within the carpal tunnel (refer to the resultant force equation, on page 13); thereby increasing the possibility for median nerve compression. From the data it can be concluded that there is an association between high job forces and a high CTS incidence job, based on lumped data. From the job by job comparisons it appears that if a large difference exists between mean forces, the higher mean force will be associated with the high incidence job; but for small mean force differences (approximately 1 Kp) the larger mean force could be associated with either the high or low incidence job. However, more research would be necessary to prove this assumption.

5.4 RECOMMEDATIONS FOR FUTURE ANALYSIS OF EXISTING DATA

Frequent ulnar deviation of the hand has been shown by Tichauer (1976) to cause tenosynovitis, which is a causal factor of carpal tunnel syndrome as discussed in Chapter II. It was not always possible to determine from the films if the wrist was adducted or abducted, since the range of motion in the corneal plane is very small and the camera viewing angles were not always at the best vantage point as far as ulnar deviation was concerned. Thus, enough data was not available to permit an analysis in this report.

The establishment of more detailed guideline criteria for determining the presence of ulnar deviation from these films, could possibly facilitate the acquisition of the missing ulnar deviation data. This would permit analysis of ulnar deviation frequency to determine its usage as an indicator of high carpal tunnel incidence.

Similarly, job description of the eight operations studied, with corresponding incidence rates and daily production standards, were to be supplied by the small upholstering facility where this study was performed; however, this information was not received in time to be incorporated into the Results and Discussion chapters of this report. This newly acquired data is supplied in the Appendix, and could be used in conjunction with the presented hand, wrist, and force data to further assist in the study of job related factors of carpal tunnel syndrome.

Finally, the results detailed in the first three sections of this chapter did not prove that there is a definite relationship between jobs associated with a high incidence of CTS and either hand position, wrist position, or force exerted; the results did in some cases establish apparent trends which would tend to validate the original hypothesis of this report (page 22). However, based on these findings, the hypothesis assumption that other individual factors are not a prevalent cause of CTS, either acting alone or in conjunction with a particular work method, is probably invalid and should be rejected.

Rejection of this hypothesis assumption would tend to explain some of the variations in the data (i.e., why a low incidence job could have a higher mean force than a comparable high incidence job). As detailed in the Biomechanics section of Chapter II, anatomical variations among different individuals can affect the intrawrist forces subjected onto the supporting structures of the wrist. Also hereditary individual deformities may predispose an individual to CTS (Tanzer, 1959), or conditions such as rheumatoid arthritis which has been frequently associated with CTS (Barnes, 1967). Refer to the report by Rabourn (1977) for more information and details concerning the effects of individual factors.

Thus, individual factors, in conjunction with work methods and demands (such as hand position, wrist position, and force required) are probably the causal factors of occupational carpal tunnel syndrome. The interaction between these two factors, job and individual, require further investigation and has the potential of helping to reduce the incidence of CTS in industry.

VI. CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

The following summary of conclusions is based on the Results and Discussion set forth previously in this report:

1. With the data stratified into high and low incidence groups, there is a distinct relationship associating high incidence jobs with a high frequency of the 4 fingers opposing the palm hand position, and associating the low incidence jobs with a high frequency of the pinch hand position (see Tables 4-3a, 4-5a, and 5-1). This same relationship appears in the job-by-job comparison, although not in every case (Tables 4-7a and 4-11a).

2. The association of hand position and carpal tunnel syndrome is questionable on two accounts:

   a) Different operators performing the same job tend to use different methods, and by studying healthy subjects it is possible that an interaction between the job and the employee might not have been seen, thus possibly biasing the data with non-injurious work methods.

   b) The job requirements of power and precision could bias the hand position data since the 4OP position is usually used more frequently when high forces are required and the pinch position used more frequently when the job demands precision.

3. As the data for wrist position is stratified to include only high exertion forces (refer to Table 5-2), there is a definite relationship showing a higher percentage of deviated (extended and flexed) wrists in the high incidence job class. Thus, it is concluded that jobs associated with a high incidence of CTS have a greater percentage of deviated (flexed and extended) wrist positions at high force levels than jobs associated with a low incidence of CTS.
4. From analyzing the job-by-job comparisons of high vs. low incidence job classes, it was assumed that a small difference between the mean forces of the two job classes (approximately 1 kilopond) cannot be used to distinguish a high incidence job from a low incidence job; but for larger mean force differences, the job with the highest mean force will usually be the high CTS associated job.
5. The effects of individual factors detailed in section 5.4, such as hand anthropometry, etc., cannot be discounted as causal factors of CTS; and these factors combined with the above job related factors are the major ingredients of occupational carpal tunnel syndrome.

6.2 RECOMMENDED FUTURE RESEARCH

Based on the experience and information acquired in this report on the job related factors of carpal tunnel syndrome, the following recommendations are proposed as areas for possible future study:

1. Attempt to develop a more accurate method for filming the hand to detect the occurrence of ulnar deviation, such that the frequency of ulnar deviation for the similar high and low

incidence jobs can be analyzed to determine if a relationship exists between the usage of ulnar deviation and carpal tunnel syndrome.

2. A more sensitive test is required to test the relationship between hand position and CTS, since the present analysis was subject to bias from other variables as explained previously. One such test might be to study a person known to be sensitive to CTS problems on a given operation, with instruction to perform the operation for the entire shift using a specified hand position (i.e., 4OP). Then run the operator through a series of diagnostic tests upon conclusion of the activity. Study the same operator on another day but specify an alternative hand position (i.e., pinch), and again perform the same battery of diagnostic tests. Results could then be compared to determine which hand position causes the most severe CTS symptoms. As stated previously, symptoms may not be noticed until the hand has been rested for several hours; hence, diagnostic tests should be performed twice, upon completion of work and again a few hours later.
3. A biomechanical analysis, as explained in Chapter II, could be performed contrasting the 4OP and the 4 pinch hand positions for a given force and wrist deviation angle. This analysis could be used to determine which hand position creates the largest intrawrist forces.

4. Make use of the time plot (shown in Figure 4-1b), corresponding super-8 film, and job description data to determine what part of an existing job may be causing high forces to be exerted (i.e., sharp radius), as well as what part of the cycle may cause awkward hand and wrist positions.
5. Make use of the same method as in #4 above to check out new job designs in order to determine where problems of high forces and awkward hand and wrist positions may occur; thus, enabling these bad designs to be modified before they reach the production floor. This type of preplanning analysis could eliminate any CTS producing job factors as well as reduce medical costs and the expensive costs associated with modifying an operation once it has been installed in the plants.

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APPENDIX

EMPLOYEE INFORMATION AND CONSENT FORM

I understand that I am being asked to participate in an investigation, conducted by the University of Michigan, to determine if there is a relationship between manual work and chronic wrist injuries. My inquiries about any matters concerning my participation in this investigation have been answered by the undersigned witness.

I acknowledge that I perform certain repetitive manual tasks which warrants my consideration in this investigation. My participation will include study of my medical and employment records, a clinical evaluation of my hand function which includes X-rays and nerve conduction tests, measurement of my hand dimensions and study of how I perform my job which includes an electromyographic study of my forearm and filming of my hands. These data will be recorded and treated in a confidential manner; these data will be analyzed to determine the cause of chronic wrist injuries.

My participation in this investigation is strictly voluntary. Whether or not I participate will not jeopardize my job assignment in any way. I may withdraw from this investigation at any time without fear of reprisals or prejudice against me.

I hereby consent to the release of information as a result of my participation. I understand that it will not be released in a personally identifiable form.

____
Signature of Employee

____
Date

The identity and relationship to any information in our possession (1) disclosed by participant in this project and (2) reported by him or derived from him during participation in this project will not be disclosed without his written consent except as required by law. Such information will be used for statistical and research purposes in a manner that no individual can be identified.

____
Witness (Medical Dept. Representative)

Equipment List

Tektronix 15 Mhz Oscilloscope
Model T922 Serial #B012284

Clevite Brush Mark 220 Recorder
Model 15 6327 50 Serial #0004580

Heath-Schlumberger AC Voltmeter
Model SM-5238 Serial #35194

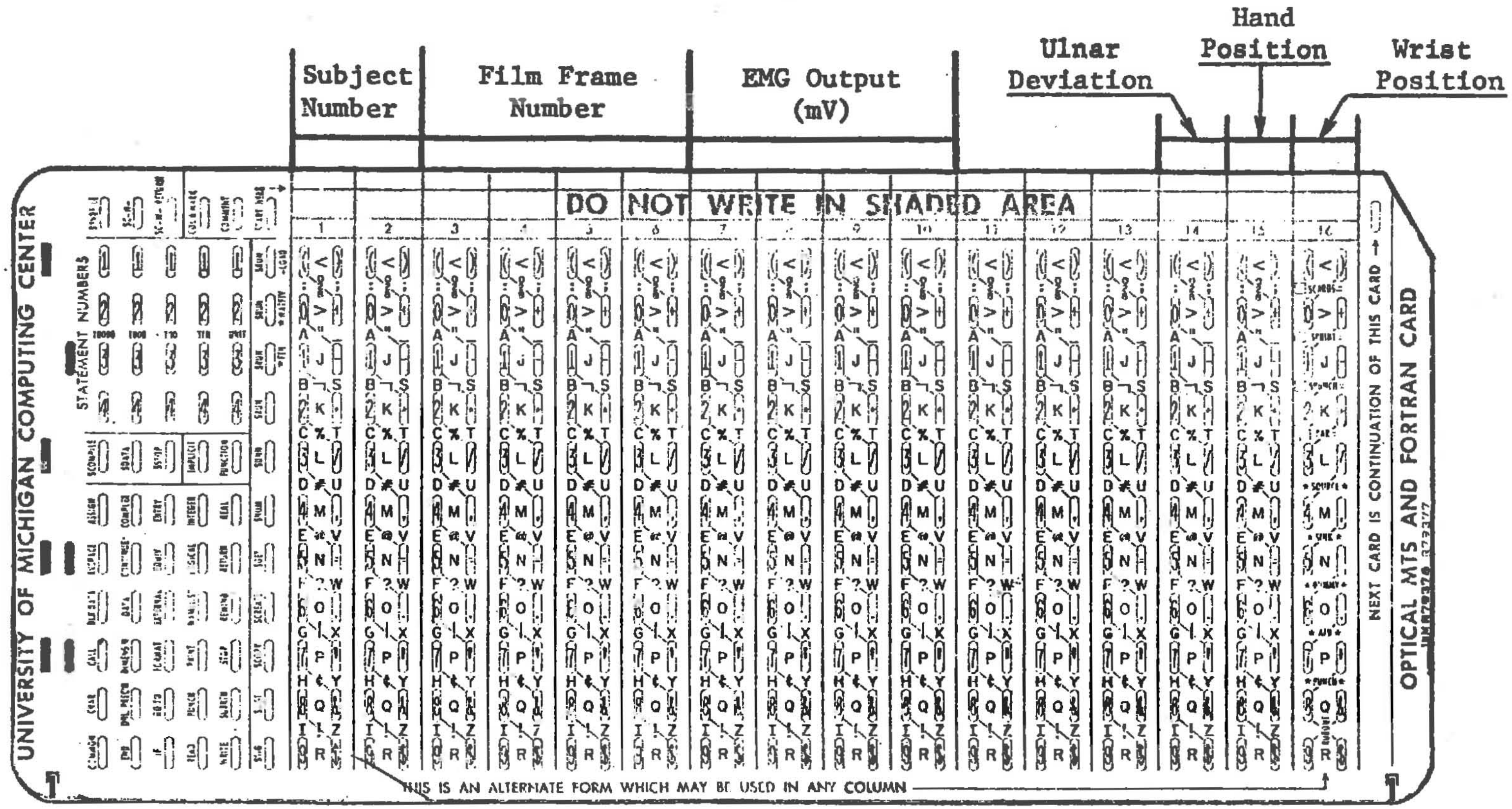
Nizo S480 Super-8mm Movie Camera
Serial Number 708876

Hewlett Packard Surface Electrodes

Beckman Electrode Electrolyte

University of Michigan Equipment:

- Camera Intervelometer (Timer)
- Hand Dynamometer (Calibrator)
- Preamplifier - 30 Gain
- Display Meters and Reflective Sign



Column 14: 0 = no deviation
1 = deviation

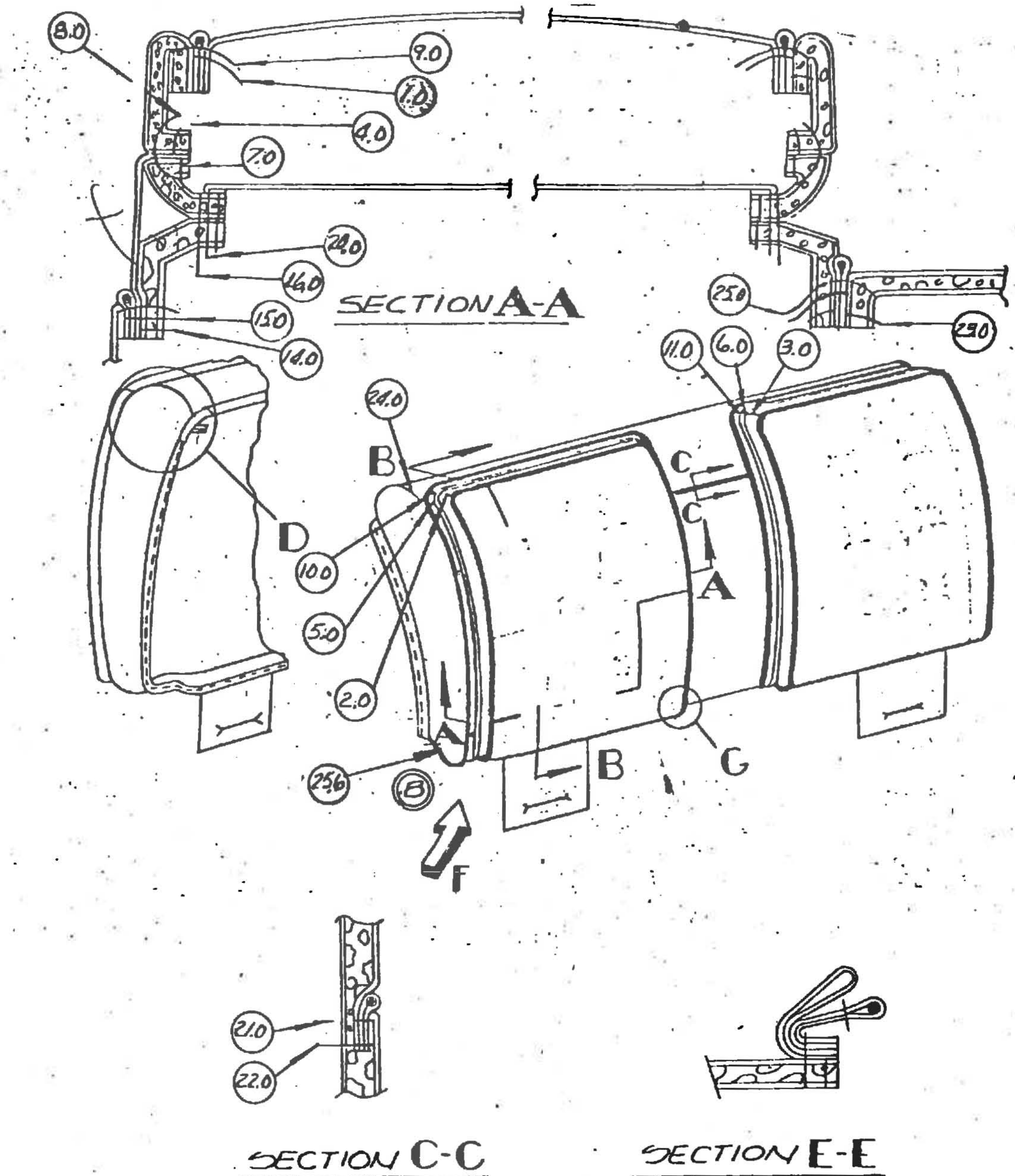
Column 15: 1 = hidden
2 = 2 pinch
3 = 3 pinch
4 = 4 pinch
5 = 4 op. palm
6 = 4 press
7 = hand press
9 = not in use

Column 16: 1 = hyperextended
2 = extended
3 = neutral
4 = flexed
5 = hyperflexed
6 = hidden

LOW INCIDENCE CLASS JOB DATA

Job Number:	1
Incidence Rate:	0
Job Description:	Join sew s/lace to top and sides of cover, insert trim.
Job Standard:	162/hour

Job #1



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15.0
14.0
SECTION A-A
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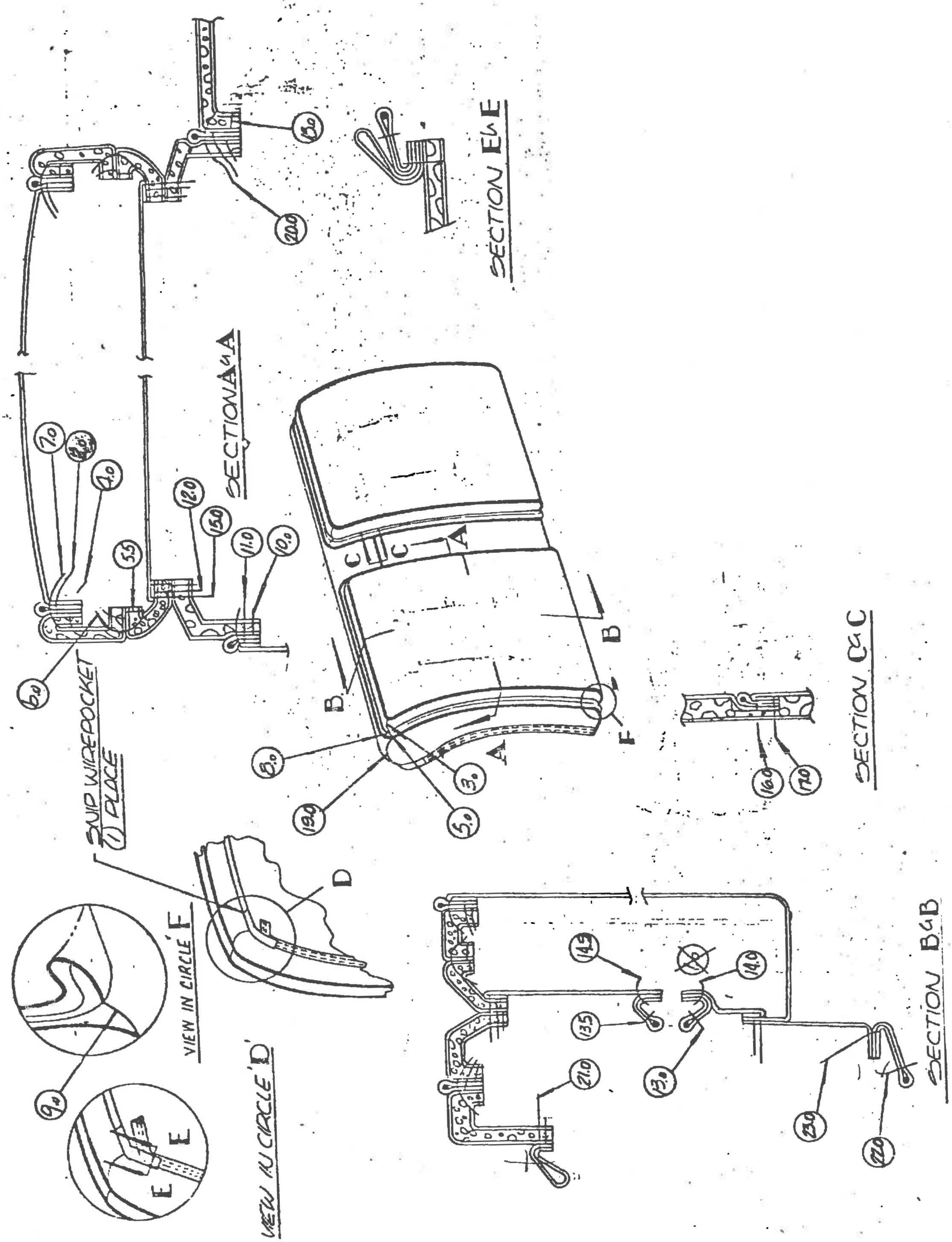
6.0
3.0
24.0
B
C
C
D
10.0
5.0
A
2.0
A
25.6
B
B
G
F
21.0
22.0
SECTION C-C
SECTION E-E

Job #1

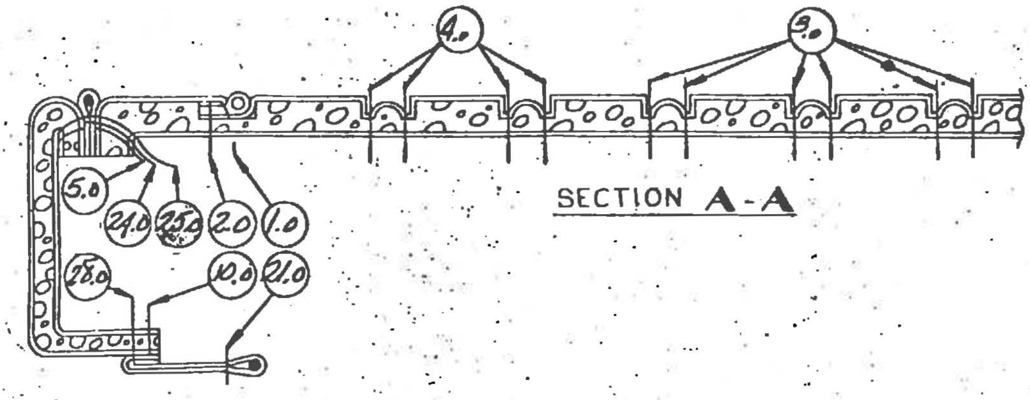
94



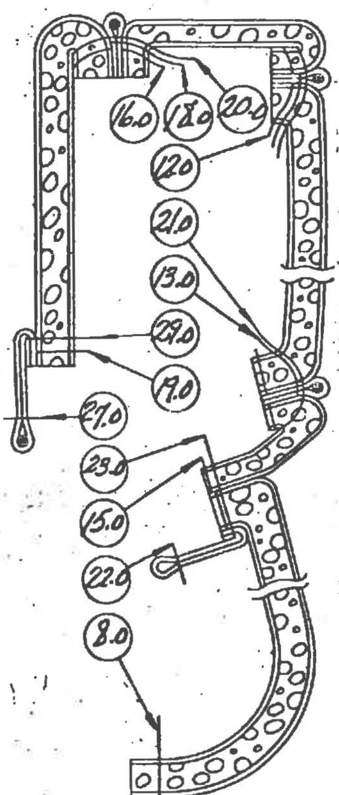
SECTION A-A
SECTION E-E
SECTION C-C
SECTION B-B
VIEW IN CIRCLE 'F'
VIEW IN CIRCLE 'D'
SNIP WIREPOCKET
(1) PLACE

LOW INCIDENCE CLASS JOB DATA

Job Number:	2
Incidence Rate:	0
Job Description:	Join sew side facing s/asm r & 1 to cover s/asm along s/lace - includes r & 1 end of cover upper s/asm (2 sews)
Job Standard:	73/hour



SECTION A-A



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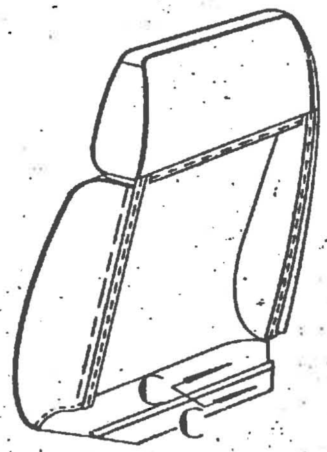
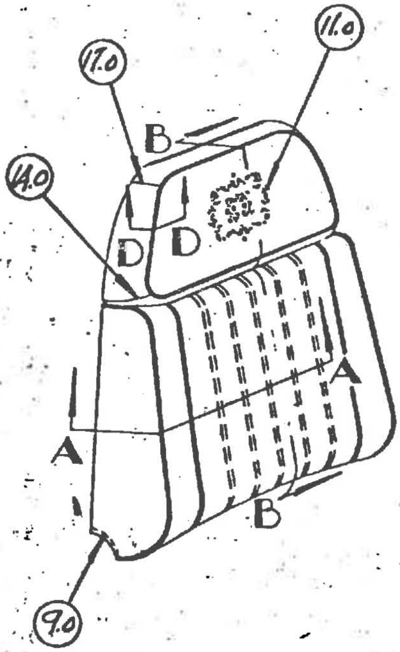
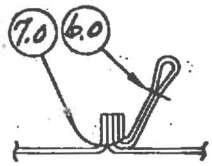
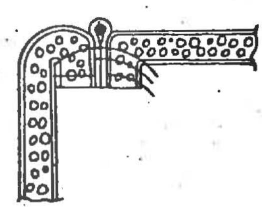






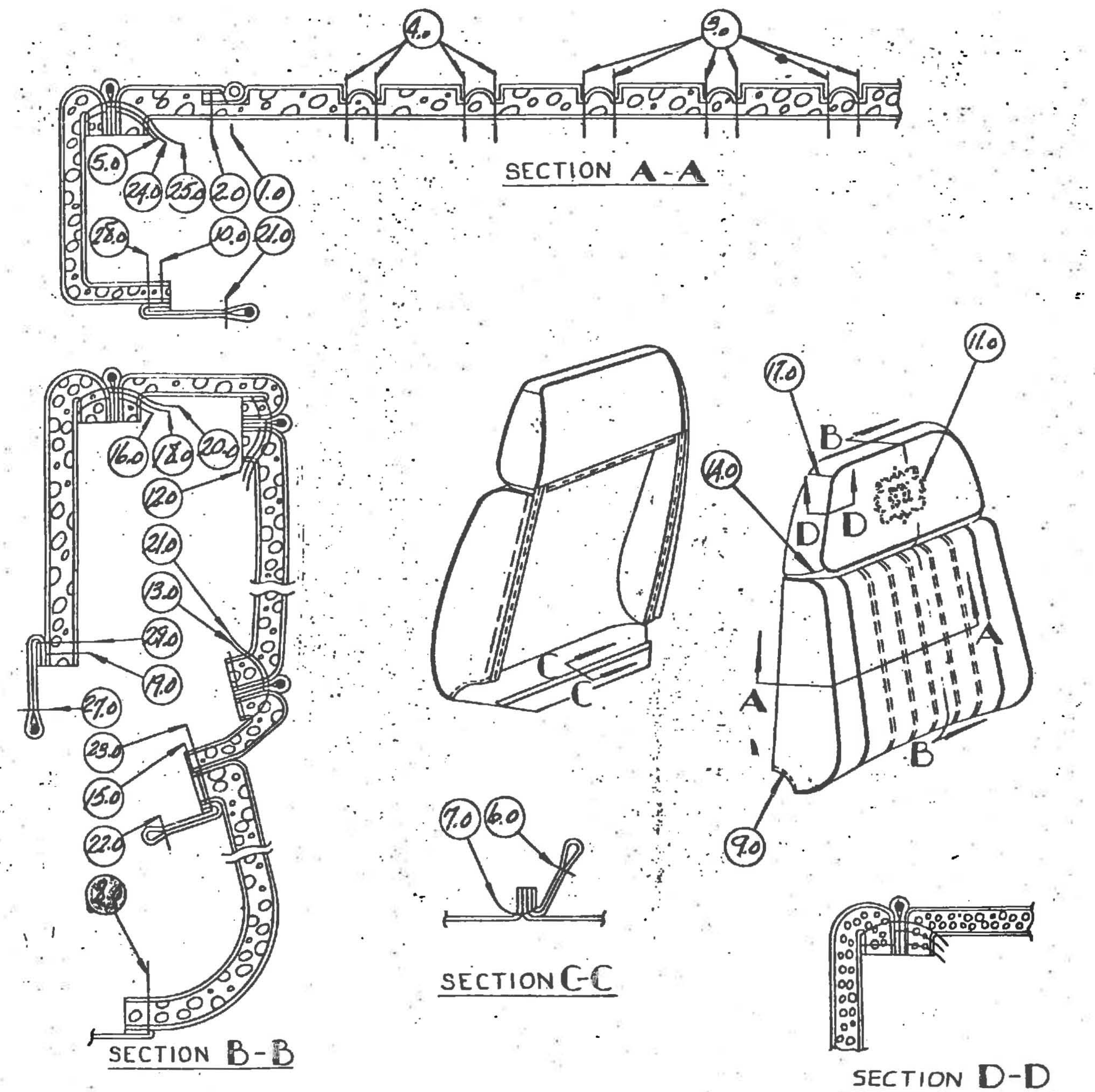
SECTION C-C



SECTION D-D

LOW INCIDENCE CLASS JOB DATA

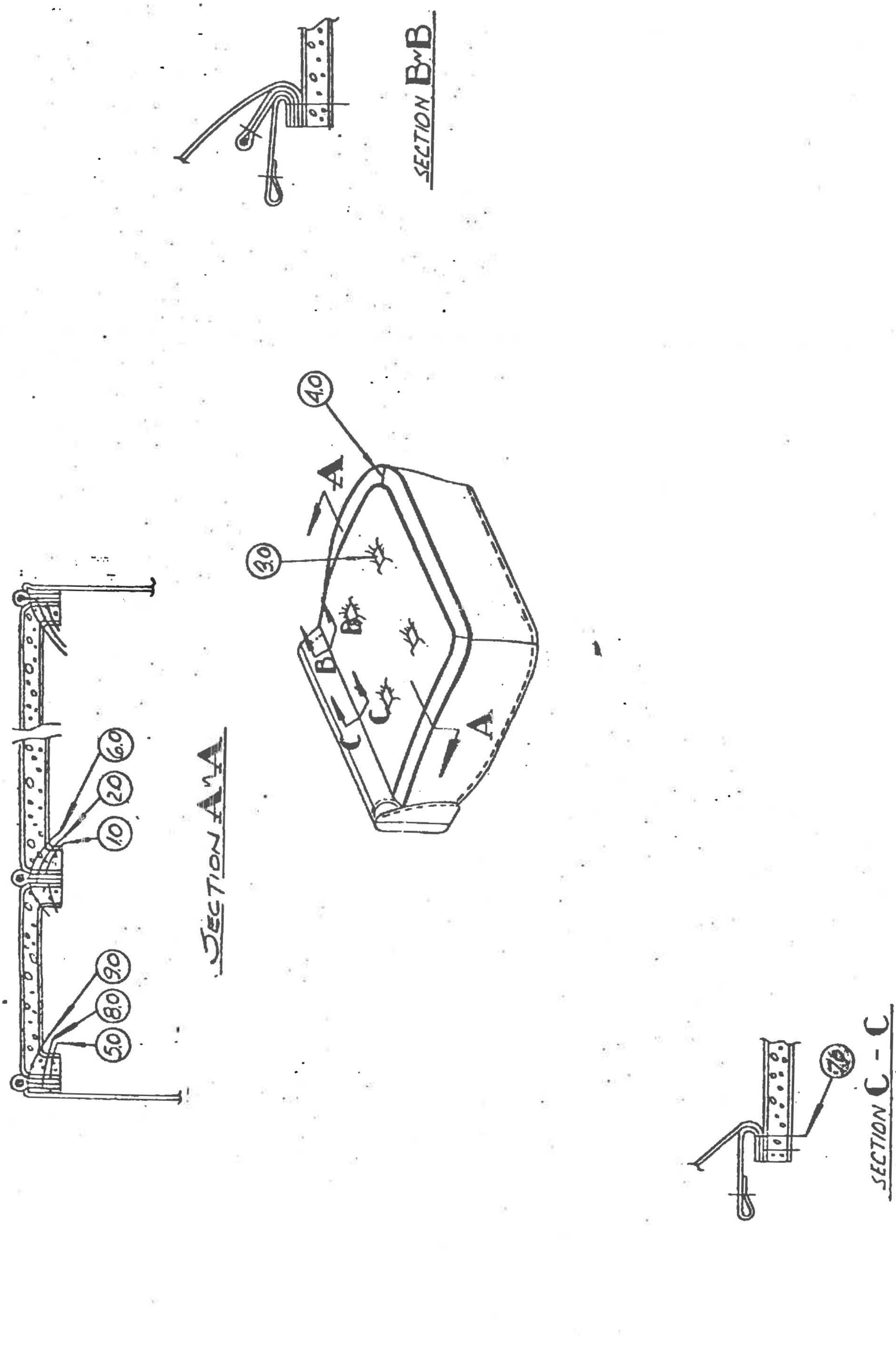
Job Number:	3
Incidence Rate:	0
Job Description:	Join sew bottom facing s/asm to cover lower s/asm
Job Standard:	249/hour


SECTION A-A
SECTION B-B
SECTION C-C
SECTION D-D

LOW INCIDENCE CLASS JOB DATA

Job Number:	4
Incidence Rate:	0
Job Description:	Join sew toe kick s/asm with rear facing end s/asm (artos cut) at outer end and pre-hemmed w/pkt at inner end to cover s/asm.
Job Standard:	133/hour

Job #4

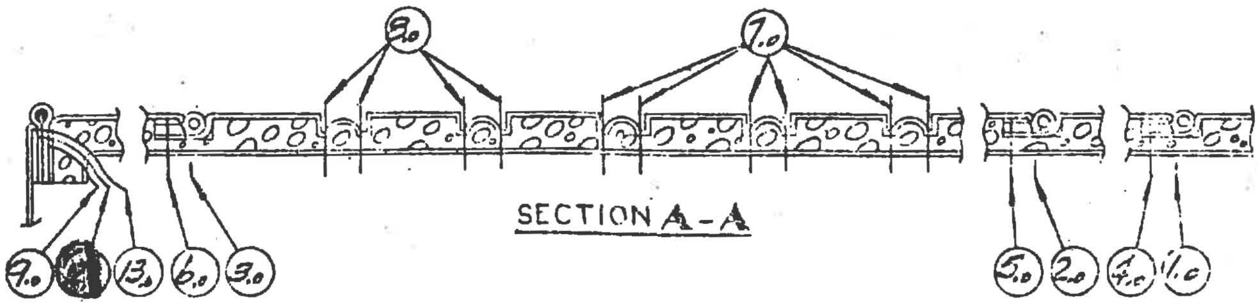


HIGH INCIDENCE CLASS JOB DATA

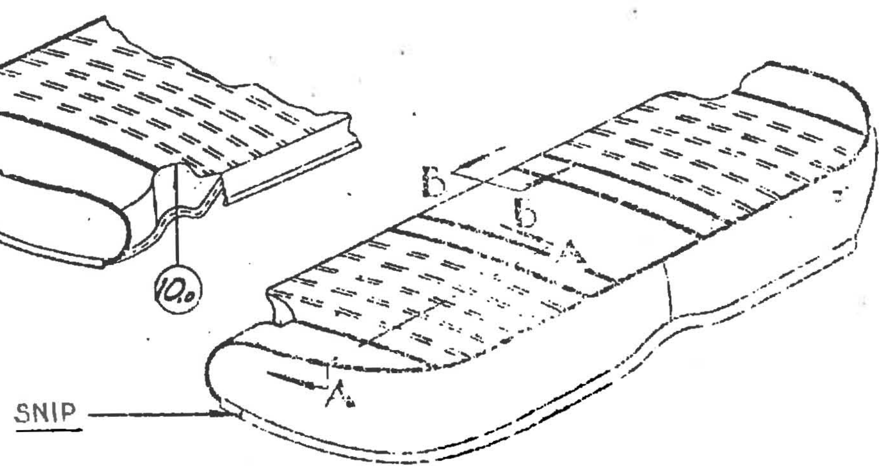
JOB NUMBER:	5
INCIDENCE RATE:	312/million man hours (1976)
JOB DESCRIPTION:	Join and sew side lace to front and side of cover subassembly.

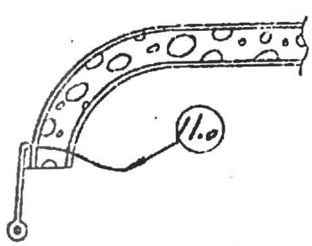
(1977 Incidence Rate: 252/million man hours)

Job #5



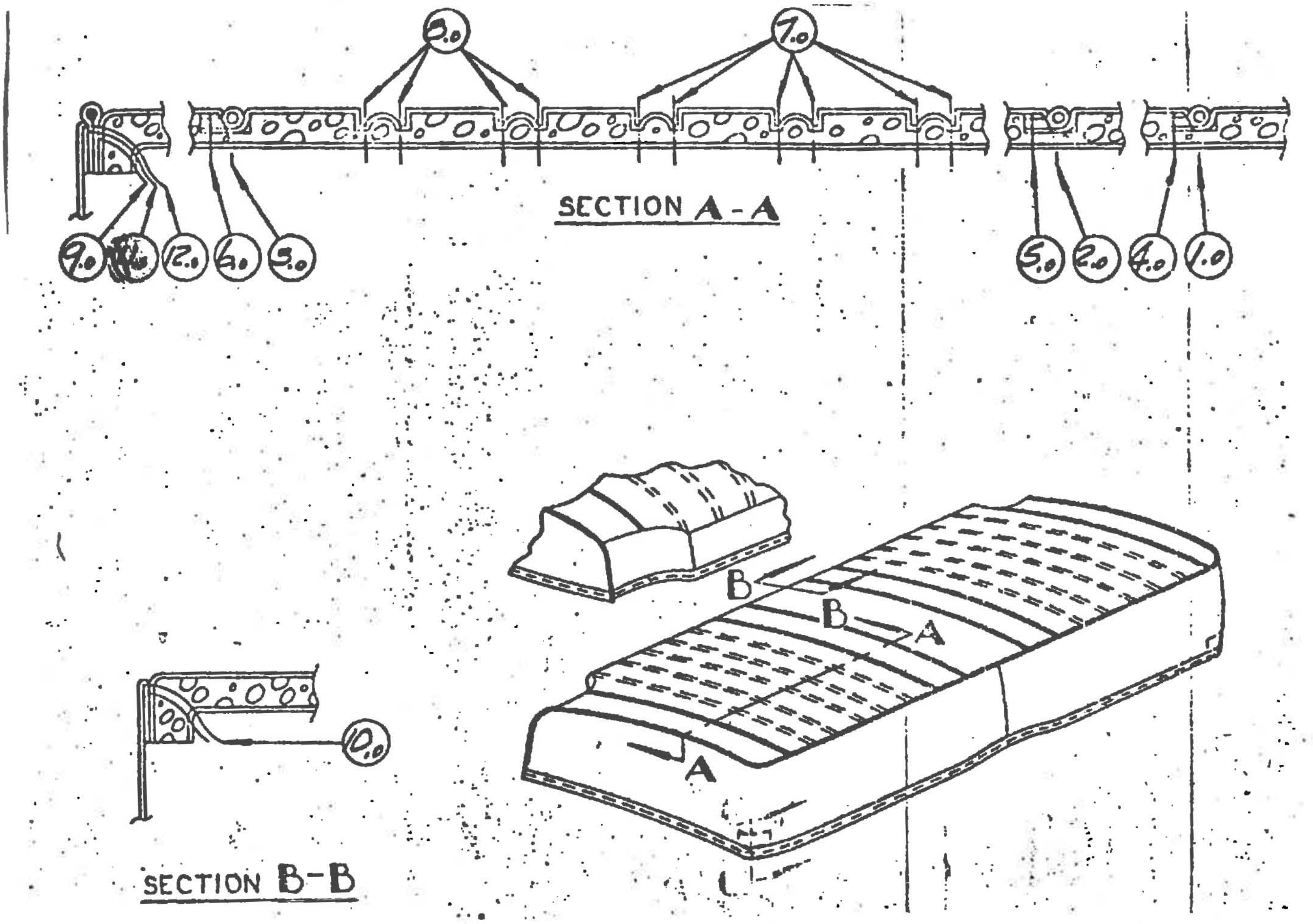
SECTION A-A



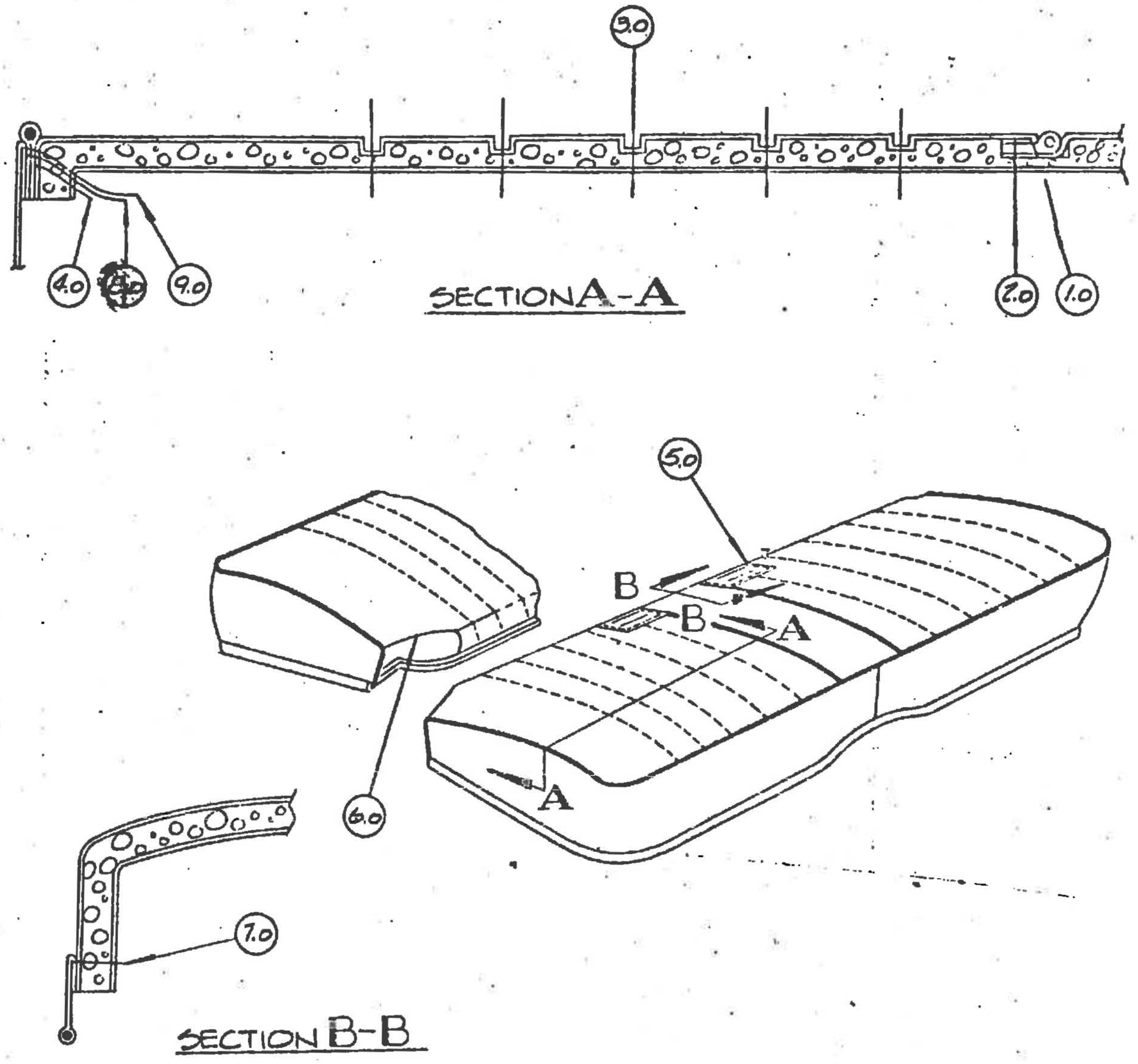


SECTION B-B

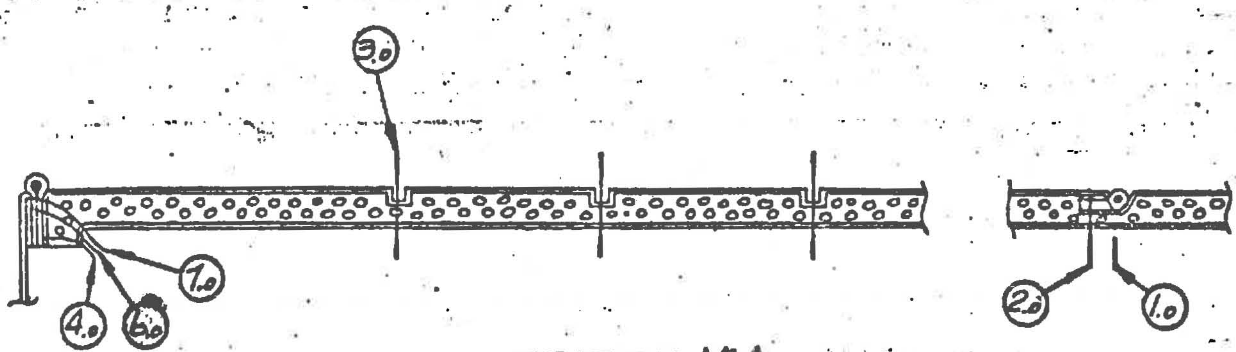
Job #5



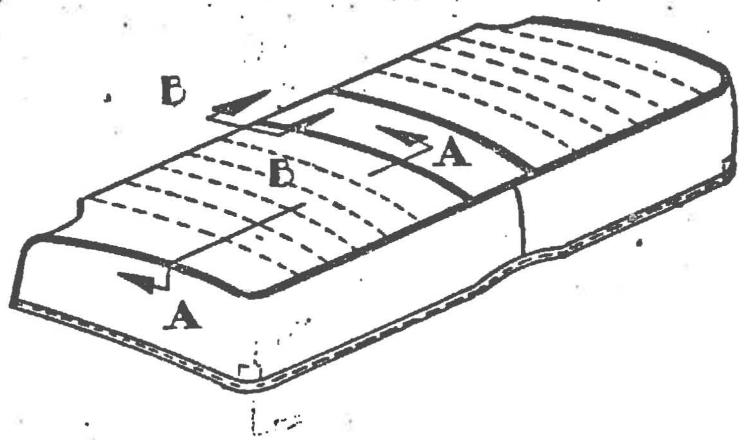
Job #5

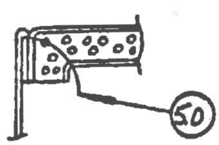


Job #5



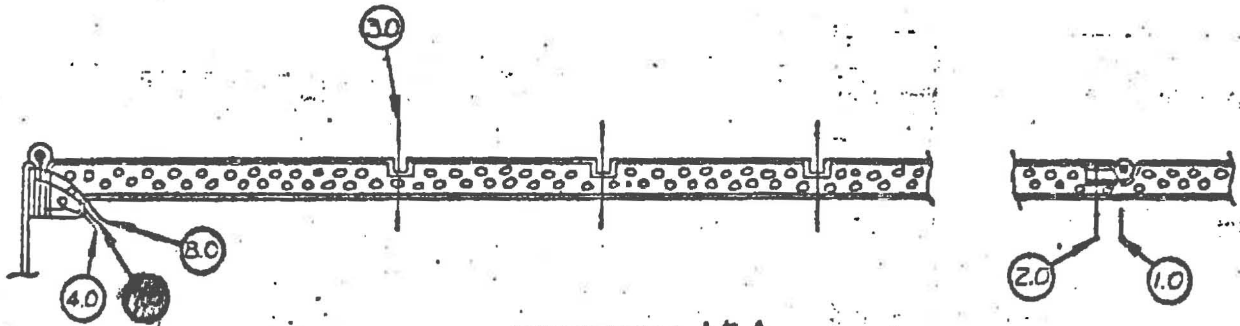
SECTION A-A



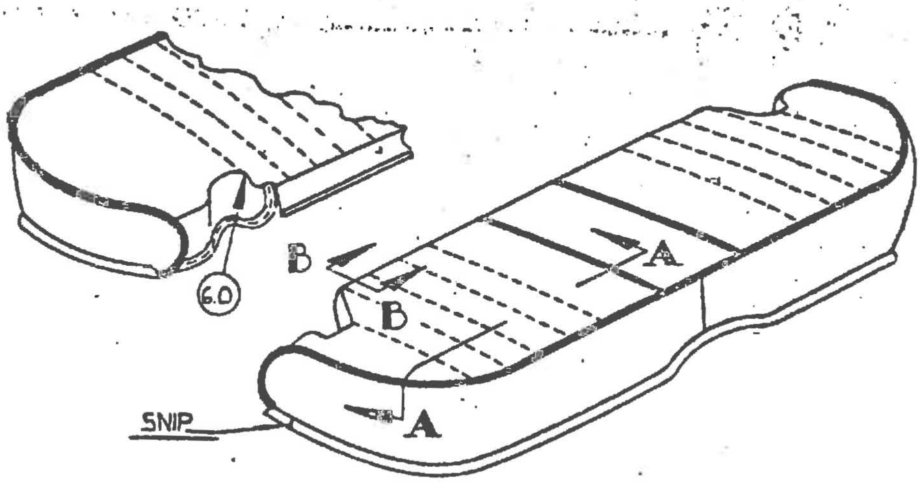


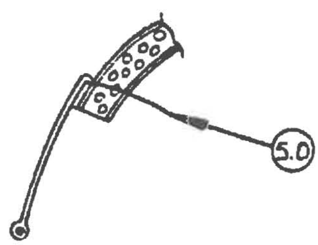
SECTION B-B

Job #5



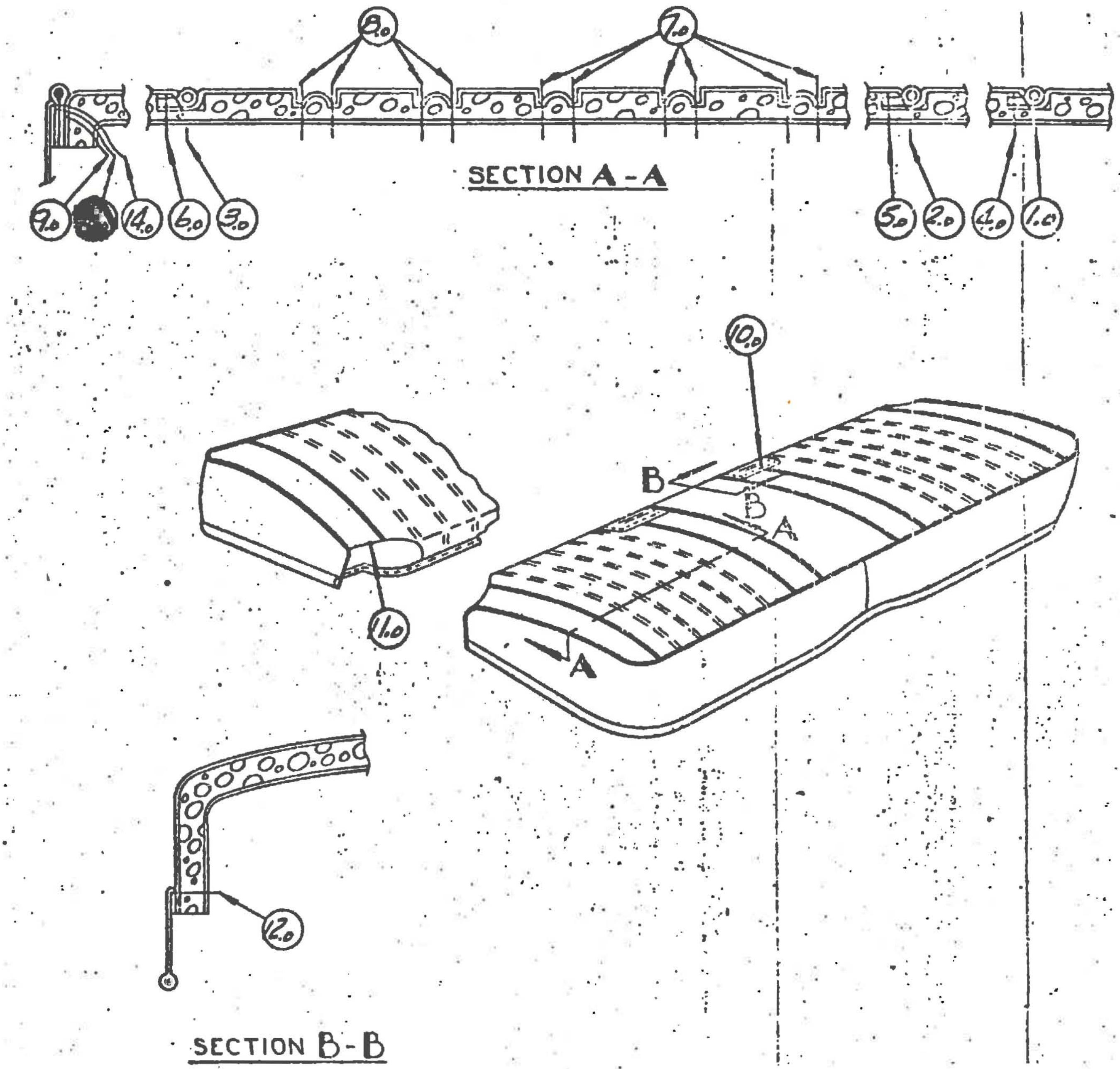
SECTION A"A





SECTION B"B

Job #5

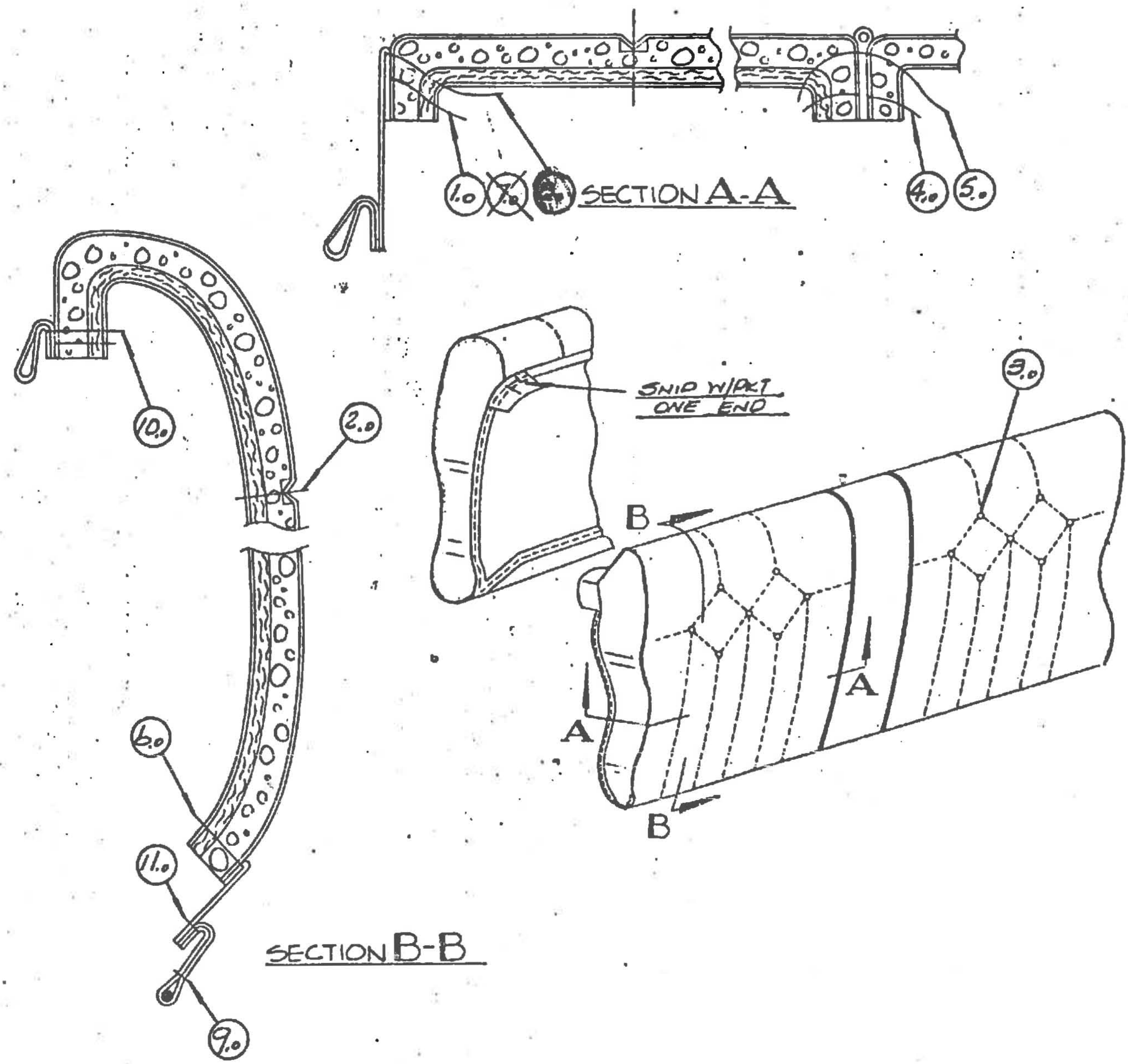

8.0
7.0
SECTION A-A
9.0
14.0
6.0
3.0
5.0
2.0
4.0
1.0
10.0
B
B
A
A
11.0
12.0
SECTION B-B

HIGH INCIDENCE CLASS JOB DATA

JOB NUMBER:	6
INCIDENCE RATE:	227/million man hours (1976)
JOB DESCRIPTION:	Join and sew side facing, right and left edge of cover subassembly.

(1977 Incidence Rate: -0-/million man hours)

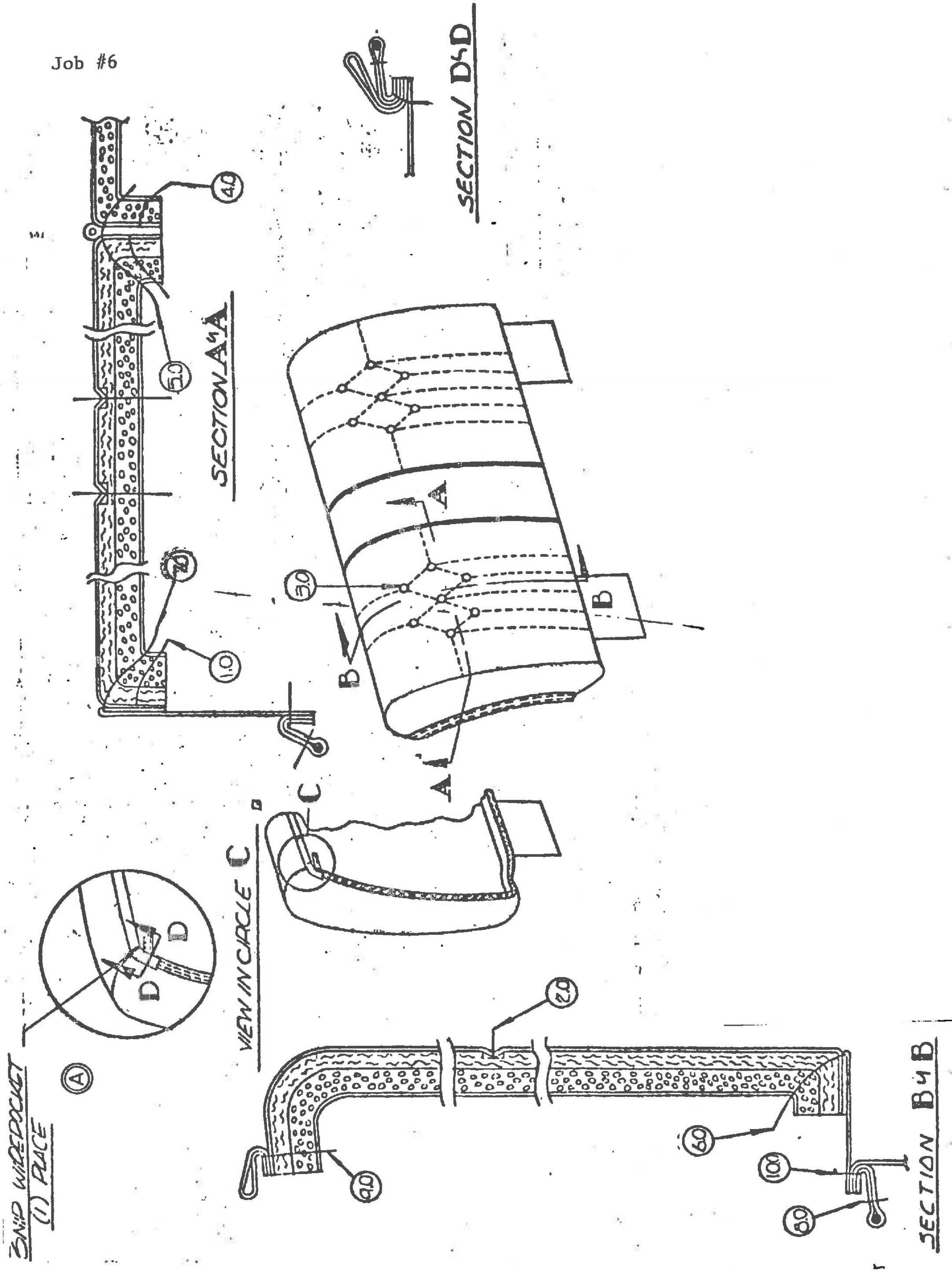
Job #6



1.0
7.0
SECTION A-A
4.0
5.0
SNIP W/PKT. ONE END
3.0
10.0
2.0
B
A
6.0
11.0
SECTION B-B
9.0

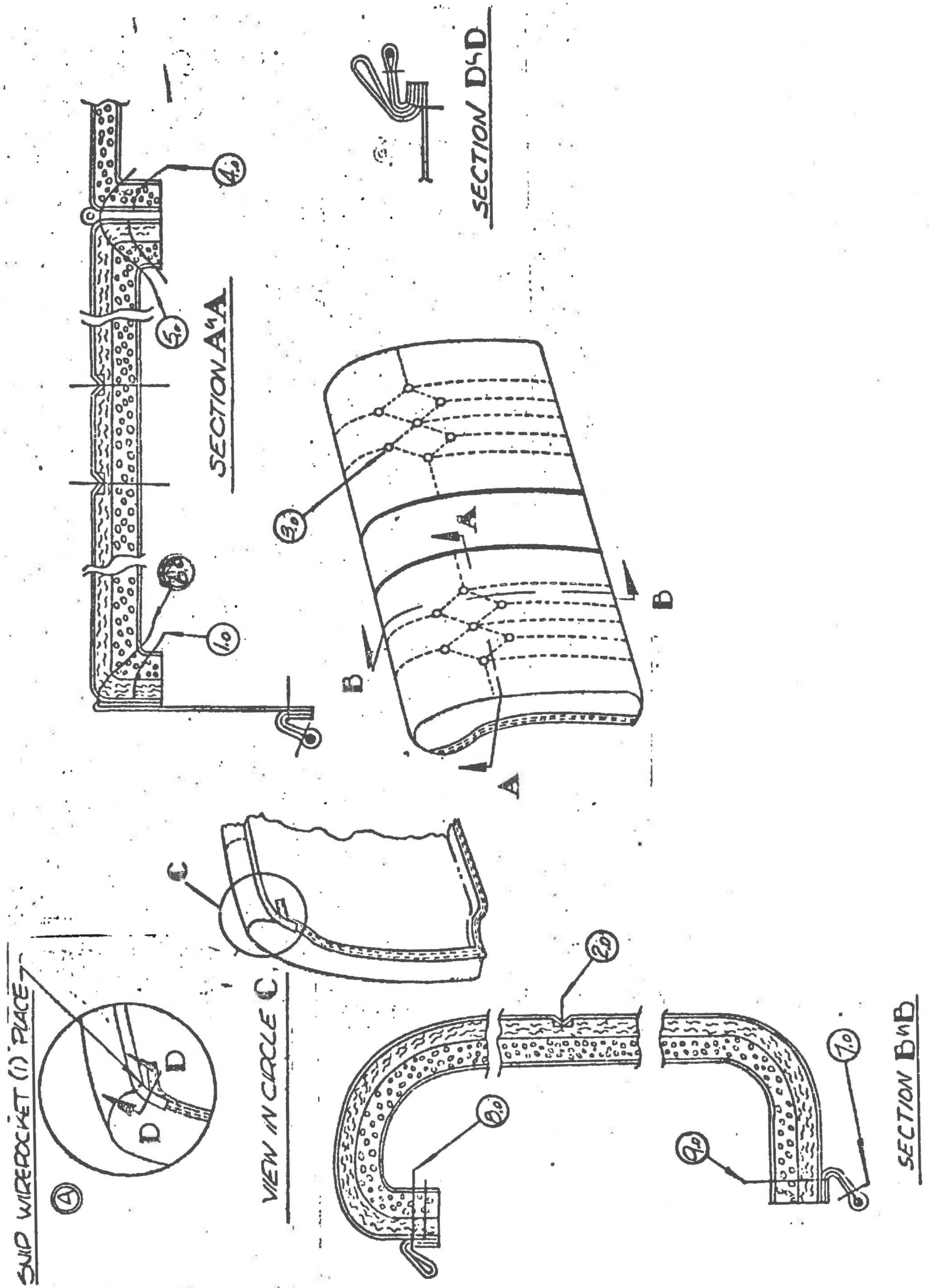
110

Job #6



SNIP WIREPOCKET
(1) PLACE
A
D
D
VIEW IN CIRCLE C
C
SECTION A-A
1.0
7.0
5.0
4.0
3.0
A
A
B
B
SECTION D-D
9.0
2.0
6.0
10.0
8.0
SECTION B-B

Job #6


SECTION A-A
SECTION D-D
SECTION B-B
VIEW IN CIRCLE C
SNIP WIREPOCKET (1) PLACE
1.0
2.0
3.0
4.0
5.0
9.0

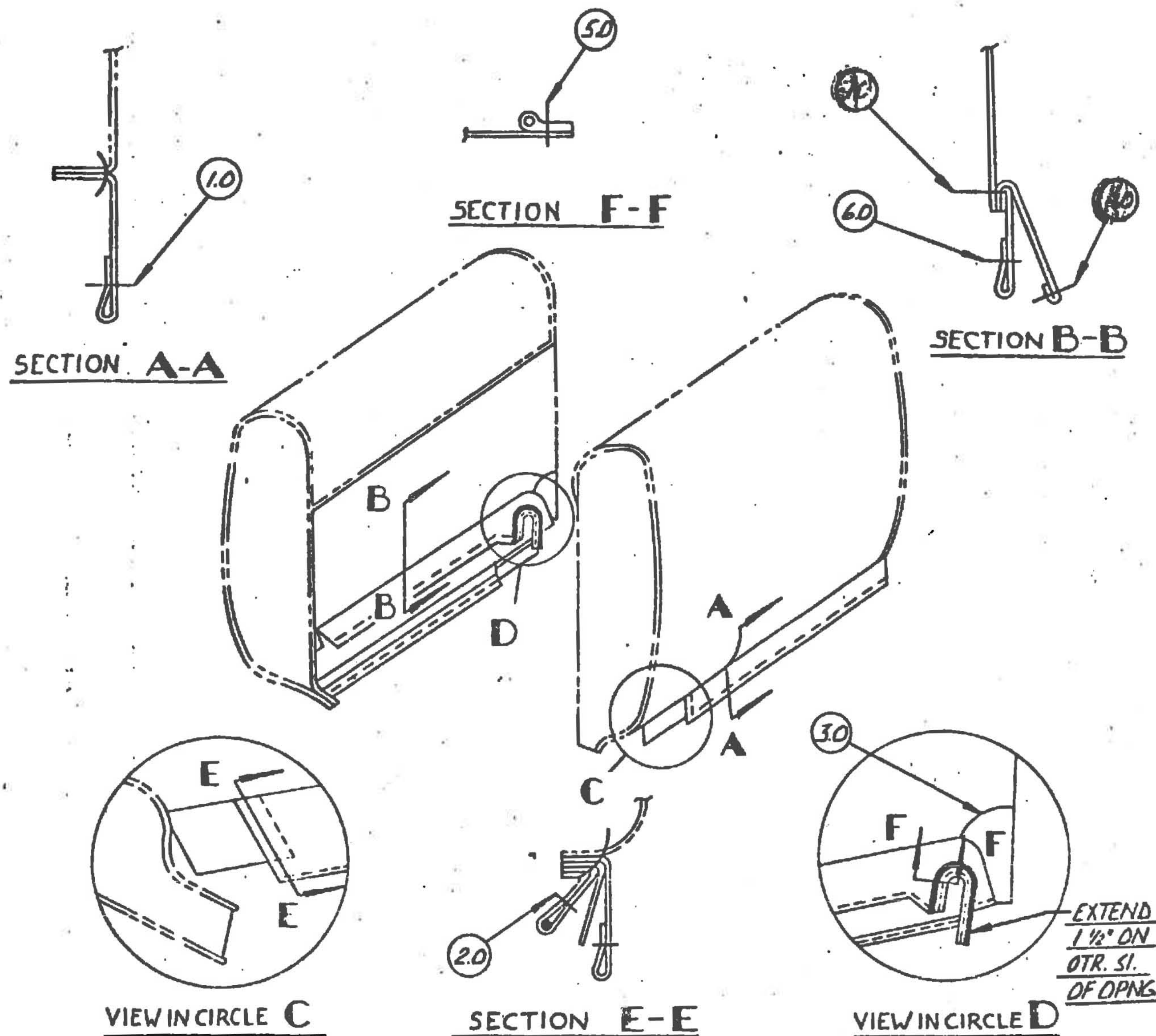
HIGH INCIDENCE CLASS JOB DATA

JOB NUMBER: 7

INCIDENCE RATE: 716/million man hours (1976)

JOB DESCRIPTION: Hem lower edge of rear lower facing subassembly. Join and sew rear lower facing extension trim to rear center trim. Join and sew rear lower subassembly wire pocket and extension tab to rear center subassembly.

(1977 Incidence Rate: 146/million man hours)

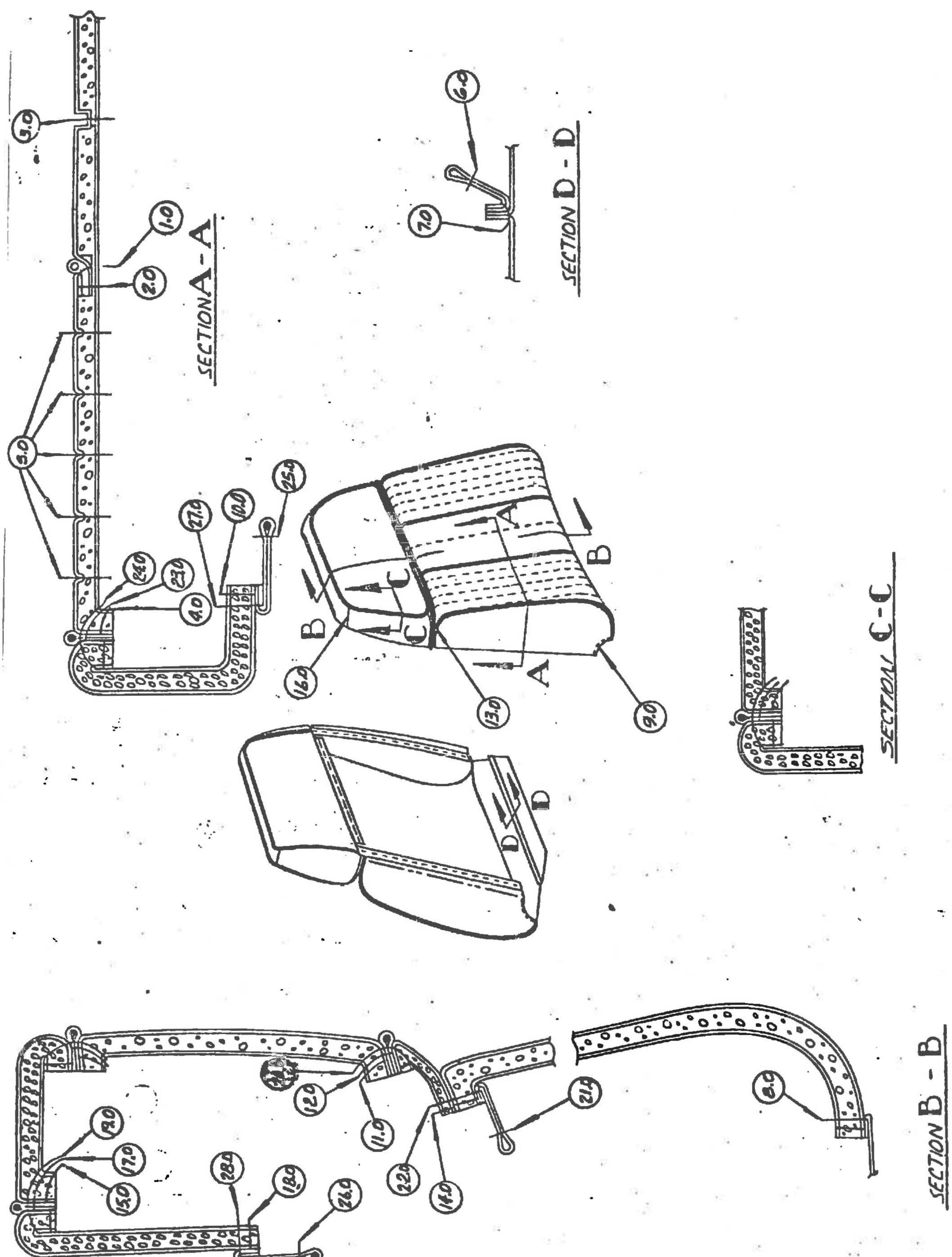

5.0
SECTION F-F
1.0
SECTION A-A
6.0
SECTION B-B
B
B
D
A
A
C
E
E
VIEW IN CIRCLE C
2.0
SECTION E-E
3.0
F
F
EXTEND
1 ½" ON
OTR. SI.
OF OPNG.
VIEW IN CIRCLE D

HIGH INCIDENCE CLASS JOB DATA

JOB NUMBER:	8
INCIDENCE RATE:	5019/million man hours (1976)
JOB DESCRIPTION:	Join cover upper sub-assembly with wire pocket to cover lower sub

(1977 Incidence Rate: -0-/million man hours)

Job #8


SECTION A-A
SECTION B-B
SECTION C-C
SECTION D-D
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
12.0
13.0
14.0
15.0
16.0
17.0
18.0
19.0
21.0
22.0
23.0
24.0
25.0
26.0
27.0
28.0
A
B
C
D