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SUMMARY OF ERGONOMICS RESEARCH FOR THE CREW CHIEF MODEL DEVELOPMENT (U)

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December 1989

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The voluntary informed consent of the subjects used in this research was obtained as required by Air Force Regulation 169-3.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

CHARLES BATES, JR.
Director, Human Engineering Division
Armstrong Aerospace Medical Research Laboratory

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This report describes ergonomic research accomplished by the University of Dayton Research Institute under Air Force Contract F33615-84-C-0519, in support of the CREW CHIEF and associated programs. The largest single effort described in this report is in the area of strength testing. More than 100,000 strength measures were made. Data collected were used to develop algorithmic models to predict strength capabilities for the various functions of the CREW CHIEF programs.

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SUMMARY

This report documents the research and development accomplished by the University of Dayton Research Institute (UDRI) under USAF Contract F33615-84-C-0519, "Techniques for Workplace and Maintenance Evaluation". The research was sponsored by the Harry G. Armstrong Aerospace Medical Laboratory (AAMRL) and the Air Force Human Resources Laboratory (AFHRL). The initial acquisition was for exploratory development and research to enhance maintainability and work station effectiveness of future Air Force weapons systems through the application of biomechanical engineering data and techniques. Specific attention was given to the flight line maintenance technician and assessment of limitations to maintenance task performance due to the physical characteristics of the technician or system design. This volume addresses the specific attention given to strength capabilities, clothed anthropometry and visual acuity as related to flight line maintenance activities.

Section 1 is an introduction to ergonomics research reported in this volume. Section 2 addresses the benchmark strength testing accomplished for developing predictors for strength modeling.

Sections 3 through 8 adress the experimentation accomplished in specific areas of strength testing. Appendices A and B cover the clothed anthropometry and visual acuity research in support of CREW CHIEF. Appendix C covers the Underwater research done in conjunction with Dr. Andrew J. Seter, Wright State University, School of Aerospace Medicine.

PREFACE

The research documented in this report was performed by the University of Dayton research Institute (UDRI) under USAF Contract F33615-84-C-0519, "Techniques for Workplace and Maintenance Evaluation", sponsored by the Harry G. Armstrong Aerospace Medical Research Laboratory (AAMRL) and the Air Force Human Resources Laboratory (AFHRL). The project number for this contract is 718408. AAMRL is the monitoring laboratory and Dr. Joe W. McDaniel of the AAMRL Workload and Ergonomics Branch is the project engineer. The principal investigator is Mr. Medhat Korna (UDRI).

Contributing authors for segments of this report are listed with the specific study which they were associated.

The editor would like to acknowledge the contributions of Dr. Joe W. McDaniel and Mr. Nilss Aume of AAMRL and Ms. Jill Easterly and Mr. John Ianni of AFHRL. The assistance of our subcontractor personnel, Drs. M.M. Ayoub and J.L. Smith of Texas Tech University, Lubbock, TX, Dr. John T. McConville and Mr. James Annis of Anthropology Research Project, Inc., Yellow Springs, OH, and Dr. S. Deivanayagam of Tennessee Technological University, Cookeville, TN are also gratefully acknowledged. The contributions of Dr. S. Keith Adams and Mr. Philip J. Peterson of Iowa State University for their work on the Electrical Connector studies are also acknowledged. The support in formatting and technical editing by Mrs. Stevie A. Hardyal and Ms. Trudy A. Grube, of UDRI, during the preparation of this manuscript is greatly appreciated.

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SECTION 1
INTRODUCTION[1]

Accessibility has been recognized as a major problem in maintaining aircraft, systems and equipment for some time. When new equipment is being designed the designer attempts to place those items with high failure rates or frequent inspection or servicing requirements in the most accessible locations, but the function of the component usually takes precedence in determining location. Also, when designing new equipment, the expected failure rates are estimates, and some times turn out to be far from accurate. Thus, if the failure rates are higher than expected for a specific component it may well be in an inaccessible location.

The inconvenient locations force maintenance technicians into uncomfortable and inefficient working postures such as kneeling, squatting, supine and prone. These are "everyday" working postures for maintenance technicians and since they are uncomfortable and less stable than the "normal" standing and sitting on a chair postures, are predictably less efficient. It can be readily observed that the time required to perform a task in such postures is longer than when standing or sitting. Likewise, the forces generated by the worker's strength will be of smaller magnitudes because of the less common directions of force and less stable support for the body.

The body's ability to generate force varies greatly with the direction of force. A combination of gravity and body posture causes this phenomenon. When possible, people tend to perform tasks with the trunk in a more or less erect posture while applying force to overcome gravity, as in lifting and lowering

1. Author: Dr. Joe W. McDaniel, Armstrong Aerospace Medical Research Laboratory

objects. Another frequent activity involves pushing and pulling, or exerting forces away from and toward the body. Lateral force exertions are usually minimized by facing the work. Tests confirm that the muscles produce relatively more force in the "normal" postures and force directions than in other less used postures and directions.

Ergonomics data are limited in supply and not familiar to most designers. Designers typically think of the more ideal circumstances when considering the maintainability of a design. They also tend to overestimate the strength capabilities of maintenance technicians, especially failing to discount strength due to awkward postures. If a significant portion of the maintenance technicians are not as strong as the designer assumes, tasks may be inadvertently created which are impossible for most technicians to perform.

1.1 MODELING CREW CHIEF STRENGTH

Many previous ergonomics strength models have failed in achieving their goals because model developers incorrectly assumed that all required data were available. There is a vast quantity of data available in the ergonomic literature, but most are not suited for development of a general purpose model. Most data are limited in the range of variables, sample size, applicability of the subjects to military populations, and non-availability of raw data. To model CREW CHIEF strength, data bases were required for material handling tasks and torque strength capabilities for wrenches and electrical connectors in the "everyday" working postures.

A seven step testing and modeling procedure was developed for the CREW CHIEF program. Due to the complexity and amount of data required for the CREW CHIEF model, it was not possible to gather all data on a representative sample of maintenance personnel. A benchmarking technique was developed to allow laboratory research to represent the population of workers. This procedure ensures that research data are representative of the Air Force maintenance population.

First, subjects were screened to represent the size and age of Air Force maintenance personnel. Since more than 99 percent of personnel doing manual maintenance work are 30 or younger, research subjects were limited to the age range of 18 to 30 years. The Air Force also has strict height and weight allowances defined by Air Force Regulation 160-43 which were also applied to research subjects. These restrictions may limit the utility of CREW CHIEF to represent older civilian populations, but Army and Navy personnel have almost identical characteristics.

Second, subjects were given benchmark strength tests. This battery of tests has been performed by large samples of Air Force maintenance and other personnel over the years. The benchmark tests are described in Section 2 of this report.

Third, body size measurements were made on each subject. For subjects tested at AAMRL, 69 measures were taken. At some of the off-site testing locations up to 20 measures, germane to the test being conducted, were made.

Fourth, the subjects' strength was measured in simulated working tasks. In most tests, 40 to 100 subjects were tested in each combination of variables. Treatments were randomized with suitable rest periods between strength measures. Some treatments were repeated at the beginning and end of each test session to verify the reliability of the subject's performance.

Fifth, the data were sorted, collated and edited. This process used both within subject and between subject relationships to identify outlying data values.

Sixth, the data were adjusted to represent the population of workers. This was accomplished using regression equations developed on large samples performing both the benchmark tests and some of the work tasks.

NOTE: The data reported in this volume have not been adjusted to represent the Air Force population. They are the data recorded from the subjects' exertions.

Seventh, the adjusted data were converted to algorithmic models for CREW CHIEF. When CREW CHIEF users define a task to be performed, the model determines the conditions which apply and select the appropriate strength models of male or female data. Predicted strengths for the 1st, 5th, 50th, 95th, and 99th percentiles are displayed.

1.2 STRENGTH RESEARCH

The largest single effort in the development of the CREW CHIEF strength models was gathering the research data, with more than 100,000 strength measures made. Table 1.1 shows combinations of variables and types of strength measured, with an "X" indicating that particular variable and type of strength was researched. In most cases an "X" represents a number of individual studies. For example, nine separate studies were conducted for tool torque, with variables of posture, different sizes and lengths of wrench handles, different types and sizes of wrenches, with and without gloves, loosening and tightening, different hand combinations (right, left and both), extensions and universal joint sockets, and different types and degrees of obstructing barriers.

Posture is an important variable when shifting the center of body mass effects the force generated. For example, in pushing or pulling, the body mass may be shifted by bending or straightening the elbows. In one study of pushing strength, men averaged

TABLE 1.1

VARIABLES TESTED IN CREW CHIEF STRENGTH STUDIES

(Reprinted from McDaniel, 1989)

VARIABLE	TOOL TORQUE	LIFT	PUSH & PULL	CARRY	HOLD & POSITION	ELECTRICAL CONNECTOR
GENDER	X	X	X	X	X	X
OBJECT HEIGHT	X	X	X		X	X
ORIENTATION	X	X	X		X	X
BARRIERS	X			X	X	X
HANDLE SIZE	X					X
ONE HANDED	X	X	X	X	X	X
TWO HANDED	X	X	X	X		
POSTURE						
STAND	X	X	X		X	X
SIT	X	X	X		X	
BEND	X	X	X	X	X	X
SUPINE	X	X	X			
PRONE	X	X	X			
SIDE	X	X	X		X	
KNEEL	X	X	X		X	
SQUAT	X	X	X	X	X	
WALK				X		
CRAWL			X	X		

An "X" indicates that a particular variable and type of strength variable were researched. The "X" usually indicates a number of individual studies were performed on a particular combination, with additional combinations of variables not shown in this table. More than 100,000 strength measures were made.

48 percent more and women 30 percent more when pushing with bent elbows versus straight elbows. A sonic digitizer was used to measure body posture in many of the strength studies. The sonic digitizer uses an array of 8 microphones surrounding the subject to reduce masking of body parts. Electric spark gaps are taped to the subject's joint centers or other anatomical features useful in tracking posture. The sonic digitizer measures the time delay between the generation of the spark and when each microphone detects the popping sound of the spark. The delay is translated into a slant range distance and the 3-D coordinates of the spark gap location is computed.

Posture is critically important in maintenance tasks where the object being maintained creates obstacles and forces the worker into restricted postures. When carrying, a low ceiling in a passage way or under the fuselage or wing of an aircraft can reduce the available strength as shown in Table 1.2. The lowering of the ceiling forces the worker into a bent, then a semi-squat and finally a crawling posture. At each progressively restrictive level, the amount of weight that can be carried is reduced. In a crawling posture (40% of stature) the carrying capability averages only 45 percent of the no restriction condition.

The effect of posture on weight lift capability is shown in Table 1.2 which shows that effective strength decreases when the body support becomes less stable. The values shown are the maximum weight (in boxes) people were able to lift from the floor to a shelf. The kneeling posture allows more mobility of the lower torso in adjusting the posture toward the load while still providing a stable support. Sitting provides a stable support but reduces the mobility of the lower body forcing the reach to the shelf to be farther. Squatting has little support, as the subject is supported by the balls of the feet and must exert some effort to maintain balance. The lying on the side posture has

TABLE 1.2

EFFECT OF POSTURE ON WEIGHT CARRYING CAPABILITY

(Reprinted from McDaniel, 1989)

CEILING HEIGHT	MALES	FEMALES
Unlimited	153	79
80%	146	73
60%	113	54
40%	64	41

Maximum weight (pounds) that can be carried in an 18 inch wide box with no handles while using two hands. The ceiling height was set to a percentage of stature. Values are averages.

TABLE 1.3

EFFECT OF POSTURE ON WEIGHT LIFT CAPABILITY

(Reprinted from McDaniel, 1989)

POSTURE	MALES	FEMALES
Standing	118	58
Kneeling	99	53
Sitting	92	49
Squatting	79	43
Lying, side	42	21

Maximum weight that can be lifted and placed on a shelf at chest height in a 24 inch wide box with no handles while using two hands.

little stability in the axis of load and requires the exertion of lateral forces to raise the weight.

Another example of the interaction of posture and force direction was found in measures of torque produced with a socket wrench. In a study of isometric (static) torque measured on 20 women and 20 men using a 1/2 inch square drive ratchet to turn a bolt with a 3/4 inch head, it was found that the least favorable location/orientation of the bolt head allowed only 15 percent of the torque produced in the most favorable location/orientation. In another wrench torque study where the subject had to reach over or around obstacles in the work place, the available strength was reduced up to 80 percent due to the obstacles.

As previously stated, strength testing was conducted in two areas, benchmark and task oriented testing. Both categories of strength testing were self-limiting, with the subject determining the maximum weight that could be lifted, duration of holding a weight, or the maximum force that could be applied. Subjects were told to stop the exertion at any time they felt over-stressed. No information regarding their performance was made available to any subject, or were they provided any information on other subjects' performance. All protocols and experimental plans were approved by the AAMRL Human Uses Resource Committee and all apparati were approved by the AAMRL Safety Office prior to any on-site experimentation. Off-site experimentation required the approval of protocols, plans and apparatus by similar agencies of the organization performing the study. Medical evaluations were made and volunteer consent forms obtained for all subjects prior to their participation in any study. Subsequent sections of this report will describe the testing in both areas.

SECTION 2

BENCHMARK STRENGTH TESTING

The purpose of the Benchmark Strength Tests was to provide a mechanism for adjusting the strength measures recorded in laboratory experiment to the Air Force population. The results of the Benchmark Strength Tests are not included in this volume. Data reported in this volume have not been adjusted to the Air Force population. They are the data recorded by the subjects during the experiment exertions.

In the initial phases only three benchmark strength measurements (the 6 Foot Incremental Weight Lift and Left and Right Hand Grip Strengths) were made. Relatively early in the project it was recognized that the range of values for these three strength measurements was insufficient to distribute the subjects' strength data across the USAF aircraft maintenance technician population.

To provide a better data base, seven strength tests were added for new subjects, and where possible, old subjects were recalled to take the additional strength tests. These tests were selected as they had previously been administered to large samples of the Air Force population. The added strength tests were:

- 38 cm Vertical Lift
- Elbow Height Vertical Lift
- One-Hand Pull
- Incremental Weight Lift to Elbow Height *
- Incremental Weight Lift to Knuckle Height *
- Seventy Pound Lift and Hold at Elbow Height *
- Forty Pound Lift and Hold at Elbow Height *

Asterisks indicate that these four tests were later discontinued as they were not good predictors of strength for the tasks studied and were highly correlated to the tests retained. Safety considerations were also a consideration in suspending the Incremental Weight Lifts to Elbow and Knuckle Height.

In addition to the Hand Grip Strength tests and the 6 Foot Incremental Weight Lift test, the One-Hand Pull, the Elbow Height Vertical Lift, and the 38 cm Vertical Lift were given to subjects as a basis for distributing predicted strength data across the Air Force maintenance population. The Air Force gives the Incremental Weight Lift to Six Feet test to all recruits and this test has been demonstrated to be highly correlated with manual material handling tasks. The other three tests have been given to numerous subjects in other studies and show good correlations to pushing, pulling and lifting tasks. 1066 males and 605 females performed the test in one study (McDaniel, et.al., 1983) and 527 subjects in another study (Ayoub, et.al., 1982).

2.1 INCREMENTAL WEIGHT LIFT TO SIX FEET

The test was originally designed to measure maximum lift capabilities of military personnel for determining assignment to jobs requiring significant physical strength. The apparatus has been used in several other studies. The apparatus is shown in Figure 2.1 and described in the following paragraph (McDaniel,et.al., 1983).

2.1.1 Incremental Weight Lift Test Apparatus

The apparatus for the Incremental Weight Lift Test is similar to exercise machines found in gymnasiums and health spas. The weights themselves can be coupled to a carriage assembly which moves vertically in heavy metal channels on ball-bearing rollers. The handles, which subjects hold to raise the weights, are attached to the carriage assembly, and are offset so that the subject is not near the moving carriage and weights. The weights are retained within the upright channels so there is no possibility of dropping the weights on one's foot.

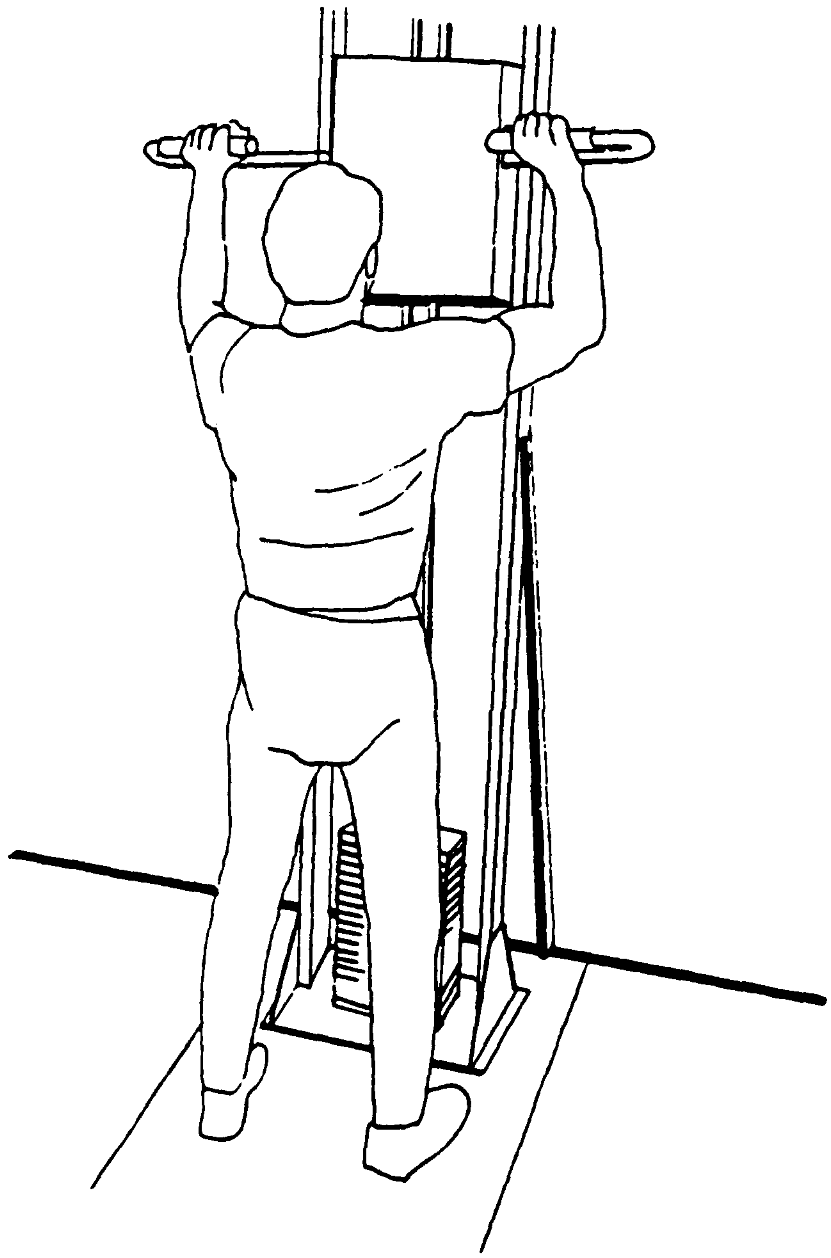


Figure 2.1 Incremental Weight Lift Test Device
(Reprinted from Ayoub, et.al., 1985a)

The handle and carriage assembly weigh 40 pounds, and from zero to 16 ten-pound weight plates can be coupled to the carriage assembly by inserting a metal pin beneath the number of weights to be lifted. The capacity of the apparatus is from 40 to 200 pounds in 10-pound increments. The weights themselves are obscured from the subject's view by a cover, shown removed in Figure 2.1. This prevents the subject from knowing how much weight he or she is lifting. The pin to select the weights is inserted from the back side of the apparatus, also out of the subject's view.

The handgrips are 1.25 inches in diameter, with a knurled surface designed for a positive grip. The handgrips, which rotate freely on the shaft, have an open area of 16 inches between the grips. This allows the subject's knees to clear the handgrips as weight is raised and lowered. The open area also prevents interference between the handles and the subject's head. The handles begin at a position one foot above the floor and can be raised to more than seven feet above the floor before contacting rubber bumpers. The subjects are not required to raise the handles above 6 feet, but an over-run area is desirable so that the weight is not constantly banged against the upper mechanical limit. The weight lift machine is free standing and is mounted on a 38 x 48 inch platform, which also serves as the standing surface for the subjects. The standing surface is carpeted, to provide a high-friction footing (McDaniel, et.al., 1983).

2.1.2 Incremental Weight Lift Test Procedures

The purpose of the Incremental Weight Lift Test is to measure maximum safe weight lift capability. The experimenter sets the weight test machine for a 40-pound lift and instructs the subject to assume the proper starting position, using an overhand grip with palms down, arms straight, knees bent, body as vertical as possible. The subject then raises the handles in one continuous movement to a height of six feet or more above the standing surface and then lowers the weight. The subject may stop at any time he or she has lifted their maximum weight.

The weight is increased to 50 pounds and the lift is repeated. The test is continued in this manner, increasing the weight by 10 pounds at each attempt until: the subject is unable to raise the weight to six feet, pauses in the lift for more than one second, the 200 pound weight capacity is reached, or the subject chooses to stop. The value of the last successful lift is recorded as the subject's maximum safe lift capability to six feet.

Except in such cases where a subject's grip slips, or a faulty lift was performed for reasons other than lack of strength, subjects are not routinely allowed a second attempt to lift any weight. Although, in many cases a second attempt might have been successful, limiting the test to one attempt eliminates such uncontrolled variables as motivation and technique. The subjects are not told how much they lift, that the starting weight is 40 pounds, or that the increments are 10 pounds. Knowledge of results are withheld to prevent subjects from competing with one another and prevent over-motivation on the part of individual subjects (McDaniel, et.al., 1983).

2.2 ONE HAND PULL TEST

The One Hand Pull test is an isometric (static) test to measure the amount of pull force that can be applied with the right hand, while pushing against an adjacent fixed surface with the left hand. Both the right pull grip and the left push plate are set at shoulder height.

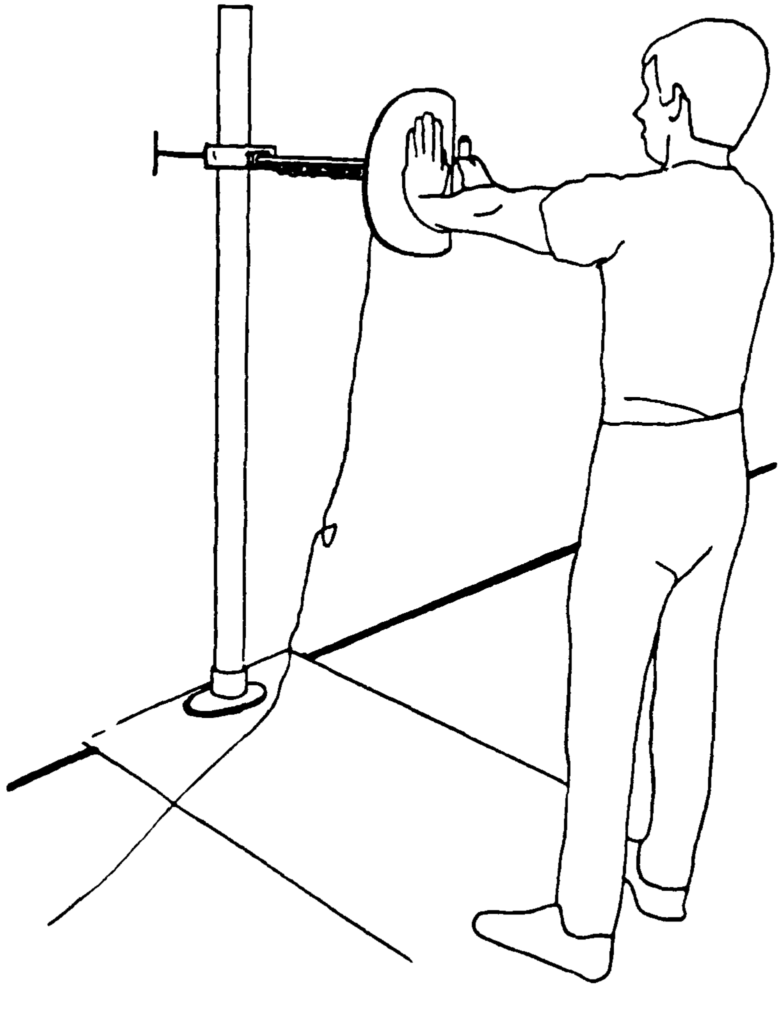


Figure 2.2 One Hand Pull Test Apparatus
(Reprinted from Ayoub, et.al., 1985a)

2.2.1 One Hand Pull Test Apparatus

The apparatus consists of a load cell attached to a vertical handle for pulling with the right hand. The cloth-wrapped vertical handle is 5 inches high and 1.125 inches in diameter. A plate is provided for the left hand to push against while pulling with the right hand. The mounting for the plate and the handle are movable in the vertical direction so they can be set at the shoulder height of each subject (Figure 2.2). Data collection can be from a direct, maximum reading load cell, or as used at AAMRL, through a computerized data acquisition system.

2.2.2 One Hand Pull Test Procedures

The experimenter sets the handle and pull plate at the subject's shoulder height (arms parallel to the standing surface). Subject is briefed to apply a steady force, reach his maximum and hold it steady for the remainder of the exertion. Subject grasps the handle with the right hand and places the palm of the left hand flat against the push plate. Subject steps away from the apparatus to arms reach distance, body erect, and feet parallel at approximately shoulder width. When the experimenter gives the signal to start, the subject pulls with the right hand and pushes with the left hand. At the end of the exertion, four seconds of force application, the subject releases the force on the apparatus.

The computerized data acquisition system provides data over the complete cycle of the test which can be used to identify peak values, means over various time periods, and ratios of peaks to means relative to time. It also provides a means of evaluating the consistency of the force application. That is, was force applied steadily until the maximum was reached, was the maximum force reached then held steadily for the rest of the exertion period, or was the force applied with a high spike and not sustained over the period of the exertion (Caldwell, et.al., 1974).

2.3 ELBOW HEIGHT VERTICAL LIFT TEST

The Elbow Height Lift Test is a static test to determine the amount of force that can be applied in a vertical (up) direction from the standing posture. In a previous study of Air Force personnel, 527 subjects were tested (Ayoub, et.al., 1982).

2.3.1 Elbow Height Vertical Lift Test Apparatus

The apparatus consists of a U shaped handle, connected by a chain and load cell to an eye bolt on the standing surface (Figure 2.3). There are two vertical cloth-wrapped hand grips, 6 inches high, 1.2 inches in diameter and 18 inches apart. The measurements can be taken from a direct, maximum reading load cell or with a computerized data acquisition system.

2.3.2 Elbow Height Vertical Lift Test Procedures

The height of the hand grips was adjusted to the elbow height of the subject. The subject stood erect and gripped the handles so that the upper arms are vertical and against the body, lower arms horizontal in front of the body, and at a distance from the load cell attachment so that the chain was vertical. At the experimenter's signal, the subject lifts vertically with the maximum possible force for the duration of the exertion.

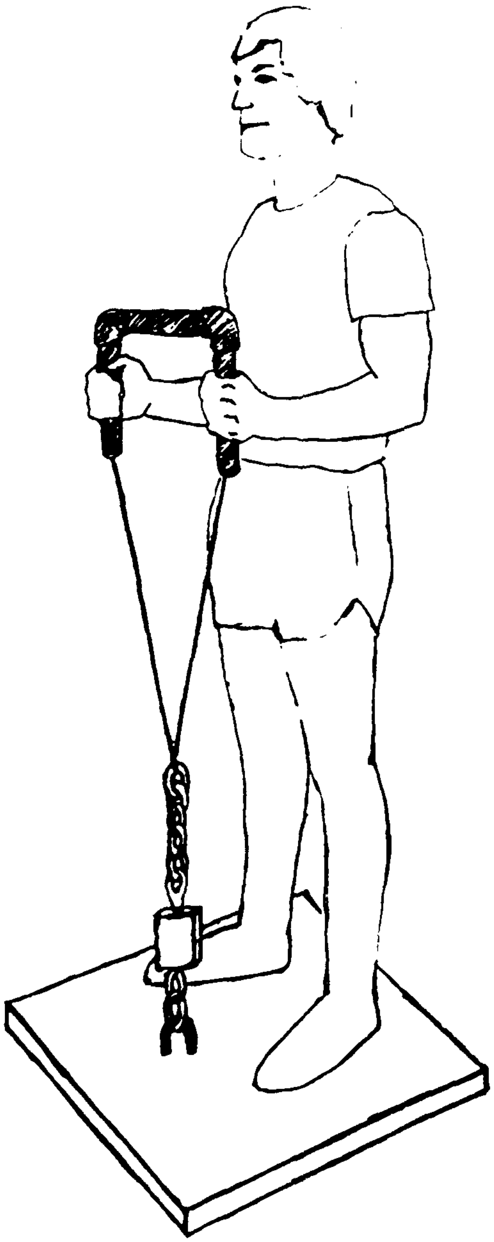


Figure 2.3 Elbow Height Vertical Lift Test Apparatus

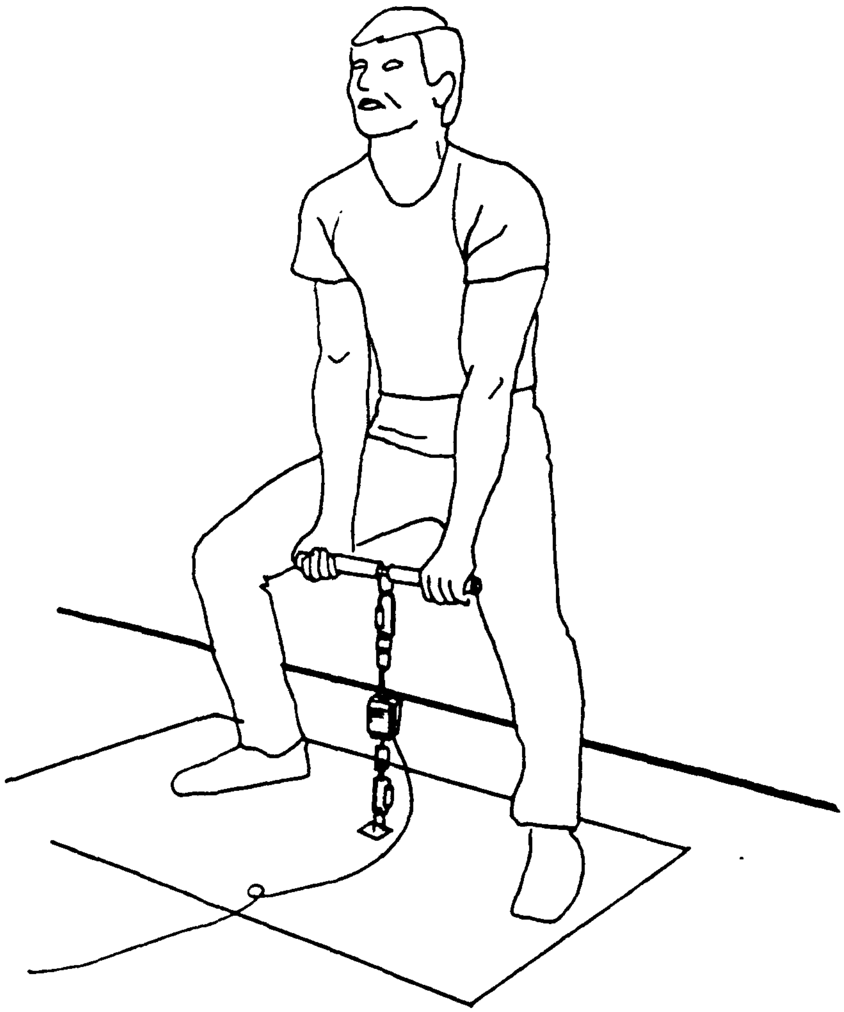


Figure 2.4 38 cm Vertical Lift Test Apparatus
(Reprinted from Ayoub, et.al., 1985a)

2.4 38 CM VERTICAL LIFT TEST

The 38 cm Vertical Lift test is a static test of the ability to apply maximum force in a lifting (up) direction. Ayoub's study (Ayoub, et.al., 1982) measured 527 Air Force personnel for this test.

2.4.1 38 cm Vertical Lift Test Apparatus

The apparatus consists of an eye bolt, load cell, chain and handle (Figure 2.4). The 1.2 inches diameter handle, is 16 inches long, wrapped with cloth tape to reduce hand slippage. A load cell is attached between the handle and eye bolt with the chain so the center of the handle is 38 cm above the standing surface. Force measurements may be taken from a direct, maximum reading load cell or with a computerized data acquisition system.

2.4.2 38 cm Vertical Lift Test Procedures

Subject grips the handle with an alternate over- and under-handed grip. Feet are placed on either side of the eye bolt, far enough apart so that there is no interference with the handle and the legs. Knees are bent with the trunk as erect as possible. At the signal, the subject pulls vertically (lifts) with maximum force possible for the duration of the exertion.

SECTION 3
SUMMARIES OF WRENCH TORQUE STUDIES

The Wrench Torque studies were conducted to determine the amount of torque subjects could apply to a bolt. Various combinations of postures, elevations, bolt orientations, wrench positions, hand(s) used, types and sizes of wrenches, direction of torque (loosen and tighten), gloves and obstacles were tested to simulate working conditions normally found in performing Air Force maintenance tasks.

3.1 ANTHROPOMETRY

A set of anthropometric measures was developed for the CREW CHIEF experiments (Figure 3.1). All measurements were made on subjects participating in the on-site Wrench Torque studies conducted at Wright-Patterson AFB, OH. A partial set of measurements was made at the off-site locations. Measurements made at the off-site locations are listed in the summary of the specific study.

3.2 TEST EQUIPMENT

There were four sets of test equipment used during the Wrench Torque studies; a Torque Dynamometer, a 3-D Sonic Digitizer, a Computerized Data Acquisition System, and a Video Recording System. All were used for the on-site studies, but only the Torque Dynamometer and Computerized Data Acquisition System at the off-site locations.

3.2.1 Torque Dynamometer

The torque dynamometer consists of a bolt attached to a force transducer. The mounting, attached to a vertical frame, can be adjusted vertically from 17.75 to 81 inches above the floor.

ANTHROPOMETRIC DATA

NAME:____________________________ DATE:____________

BIRTH DATE:_____________ SEX: M F

SUBJECT NO.:_________

1. AGE:_______

2: WEIGHT:__________(lbs)

3. INC WEIGHT LIFT:__________(lbs)

STANDING HEIGHTS

4. STATURE:_____________

5. EYE HEIGHT:__________

6. ACROMIAL HEIGHT:___________

7. CERVICALE HEIGHT:__________

8. SUPRASTERNALE HEIGHT:_________

9. SUBSTERNALE HEIGHT:__________

10. WAIST HEIGHT:_____________

11. ILIOCRISTALE HEIGHT:__________

12. ILIOSPINALE HEIGHT:___________

13. CROTCH HEIGHT:_______________

14. TROCHANTERIC HEIGHT:__________

15. PATELLA TOP HEIGHT:___________

16. TIBIALE HEIGHT:_______________

17. LAT MALLEOLUS HEIGHT:_________

ARM-HAND, STANDING

18. SHOULDER-ELBOW LENGTH:________

19. ACROMION-RADIALE LENGTH:_______

20. ELBOW-WRIST LENGTH:____________

21. RADIALE-STYLION LENGTH:_______

22. HAND LENGTH:_____________

23. HAND BREADTH:____________

24. WRIST-META III LENGTH:________

25. ELBOW-GRIP LENGTH:__________

26. THUMB-TIP REACH:______________

27. VERTICAL GRIP REACH:__________

28. SPAN:_________________________

TRUNK-TORSO, DEPTHS/BREADTHS

29. BIDELTOID BREADTH:_____________

30. BIACROMIAL BREADTH:____________

31. CHEST BREADTH:________________

32. CHEST DEPTH:__________________

33. WAIST BREADTH:________________

34. HIP BREADTH:__________________

35. BISPINOUS BREADTH:_____________

Figure 3.1 Anthropometric Measuring Form (Page 1 of 2)

SITTING MEASUREMENTS

36. SITTING HEIGHT: _______________

37. EYE HEIGHT, SITTING: ___________

38. ACROMIAL HEIGHT, SITTING: ______

39. KNEE HEIGHT. SITTING: _________

40. HIP BREADTH, SITTING: _________

41. BUTTOCK-KNEE LENGTH: __________

HEAD-FACE MEASUREMENTS

42. HEAD LENGTH: _________________

43. HEAD BREADTH: ________________

44. FACE(MENTON-SELLION) LENGTH: _______________

45. FACE(BIZYGOMATIC) BREADTH: _______________

46. BIOCULAR BREADTH: _____________

47. INTERPUPILLARY BREADTH: _______

CIRCUMFERENTIAL MEASUREMENTS

48. HEAD CIRCUMFERENCE

49. SHOULDER CIRCUM: ______________

50. BICEPS CIRCUM. FLX: ___________

51. FOREARM CIRCUM, FLX: __________

52. WRIST CIRCUM: ________________

53. HAND CIRCUM: _________________

54. CHEST CIRCUM: ________________

55. WAIST CIRCUM: ________________

56. HIP CIRCUM: __________________

57. THIGH CIRCUM: ________________

58. KNEE CIRCUM: _________________

59. CALF CIRCUM: _________________

60. ANKLE CIRCUM: ________________

OPTIONAL

61. FOOT LENGTH: __________________

62. FOOT BREADTH: _________________

SKINFOLDS

63. TRICEPS: __________________(mm)

64. SUBSCAPULAR ________________(mm)

65. SUPRAILIAC: ________________(mm)

66. MEDIAL CALF: _______________(mm)

GRIP

67. RIGHT 1: ___________________(kg)

68. RIGHT 2: ___________________(kg)

69. LEFT 1: ____________________(kg)

70. LEFT 2: ____________________(kg)

71. VERTICAL REACH STANDING/SHOES: ______________

72. VERTICAL REACH SQUATTING/SHOES: ___________

73. VERTICAL REACH KNEELING, ONE KNEES: ___________

74. VERTICAL REACH KNEELING, TWO KNEES: ___________

75. VERTICAL REACH SITTING: ____________________

76. AVERAGE GRIP LENGTH: __________

77. HAND DOMINANCE: R L

78. RACE/ETHNICITY: ________________

0 - NOT RECORDED
1 - WHITE
2 - BLACK
3 - ORIENTAL
4 - HISPANIC
5 - OTHER

Figure 3.1 Anthropometric Measurement Form (Page 2 of 2)

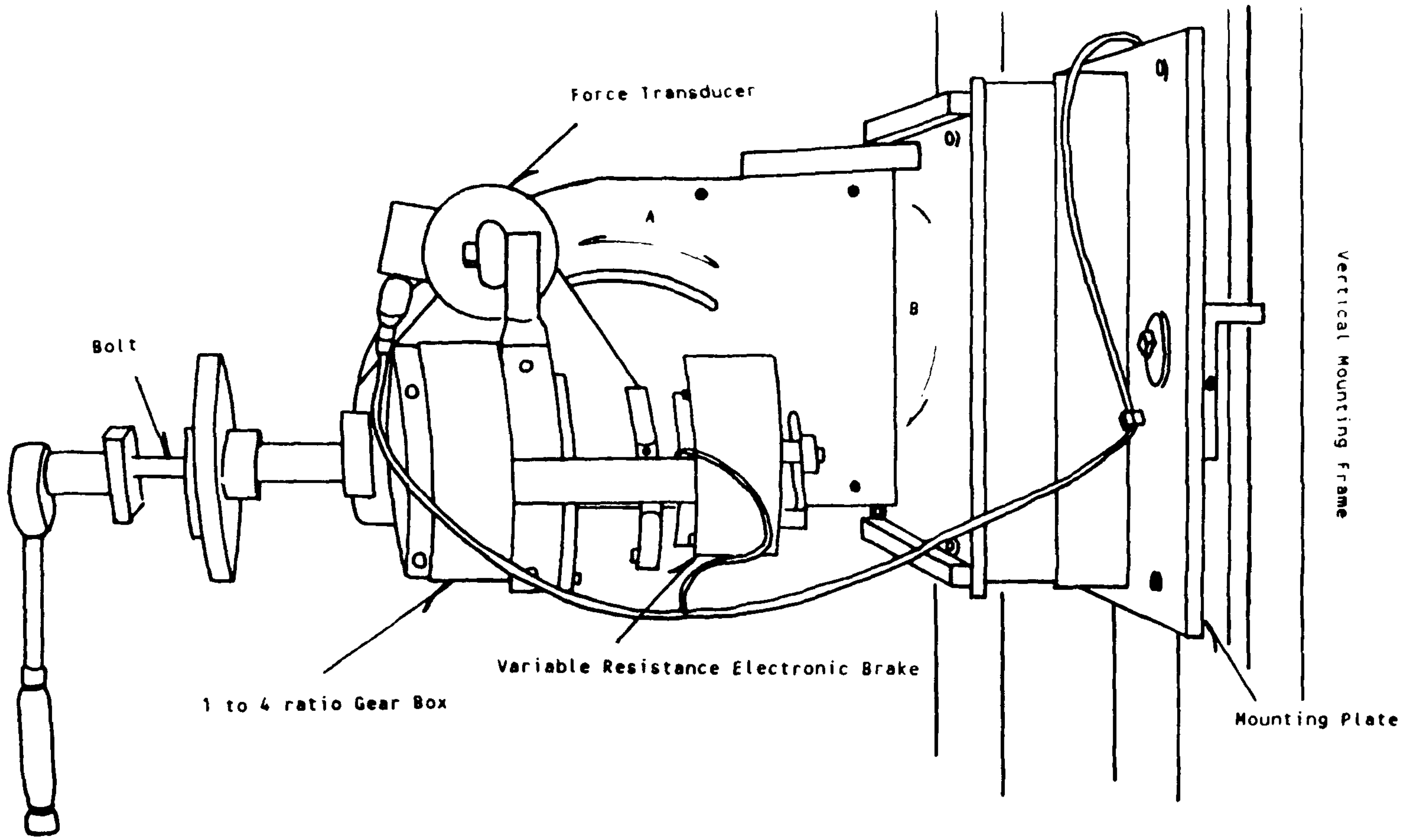
The mounting frame can be rotated in two planes (Figure 3.2) to provide the capability to maintain the three bolt orientations (Figures 3.3 through 3.5) relative to the body for all the 8 postures tested in the studies.

For the prone posture, a raised platform was placed so that the bolt would be below the subjects to simulate working conditions such as lying on the aircraft structure and reaching down to the point of work. For the C7 study, combinations of barriers were positioned between the subjects and the bolt to simulate working conditions requiring reaching over or around obstructions to the point of work. The bolt is stationary and isometric strength, as the force applied to the static wrench handle, is measured. The force was measured over a period of four seconds, and recorded in foot pounds of torque.

The static condition was chosen for measuring the force exerted because this approximates the conditions where maximum force is required in loosening or tightening a bolt in actual practice. When loosening a bolt, the maximum force is exerted just prior to the bolt and wrench moving. When tightening a bolt, the maximum force is applied at the end of the tightening process with minute movement of the bolt and wrench.

3.2.2 3-D Sonic Digitizer

The sonic digitizer uses electrical spark gaps to generate electrical sparks. The time delay between the generation of the spark and the detection of the sound of the spark by a microphone is measured. The delay is translated into a slant range distance from the spark gap to the microphone and the 3-D location of the spark gap can be computed. An array of 8 microphones (at the corners of a cube) surrounds the subject to reduce masking of the spark gaps' sound. The spark gaps are attached to the subject at anthropometric landmarks corresponding to the subject's joint centers, or other anatomical features useful in tracking posture.



A - 90 degrees Plane of Rotation

B - 360 degrees Plane of Rotation

Figure 3.2 Torque Dynamometer

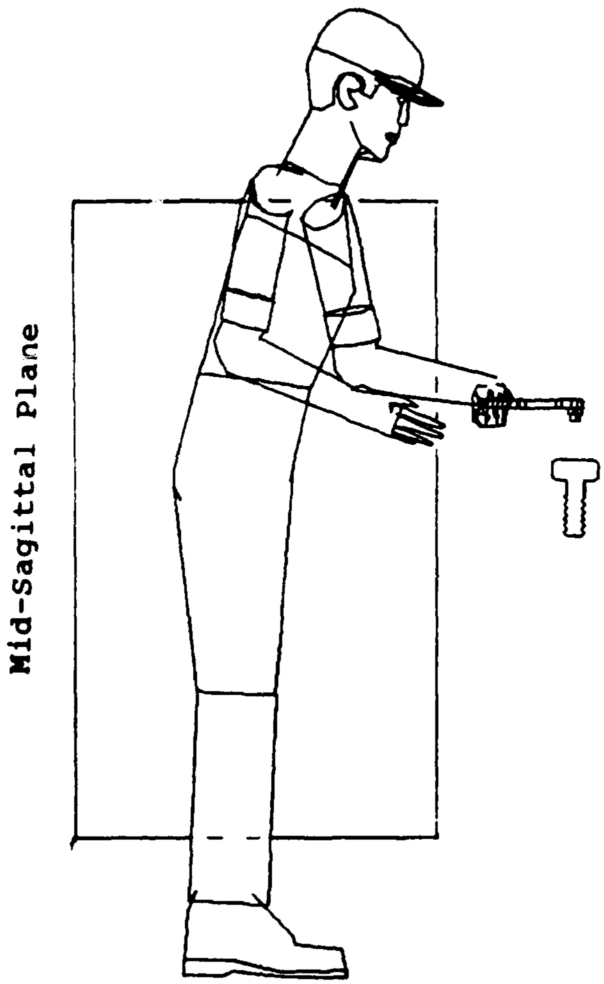


Figure 3.3 Vertical Bolt Orientation (Bolt size exaggerated to illustrate orientation)

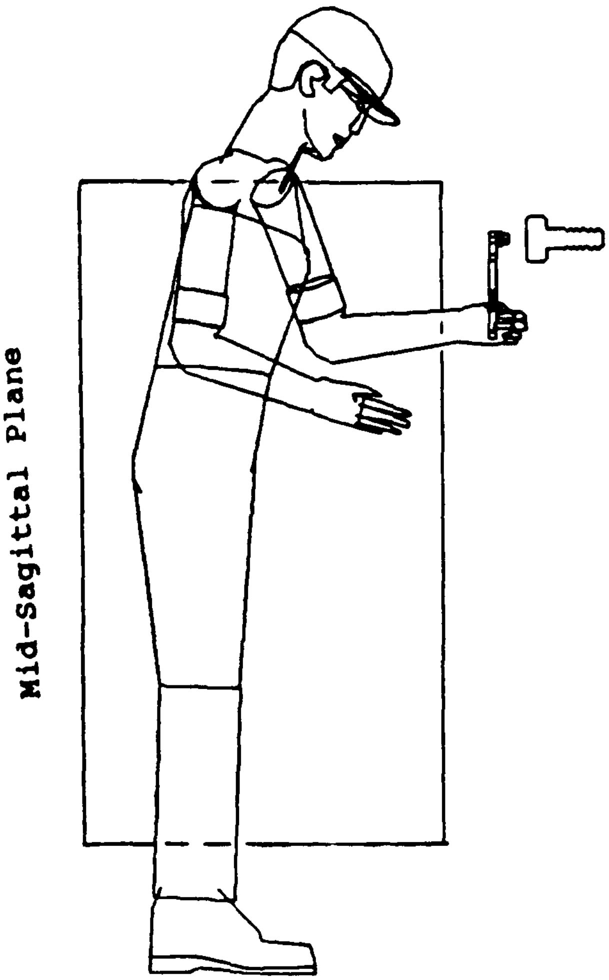


Figure 3.4 Facing Bolt Orientation (Bolt size exaggerated to illustrate orientation)

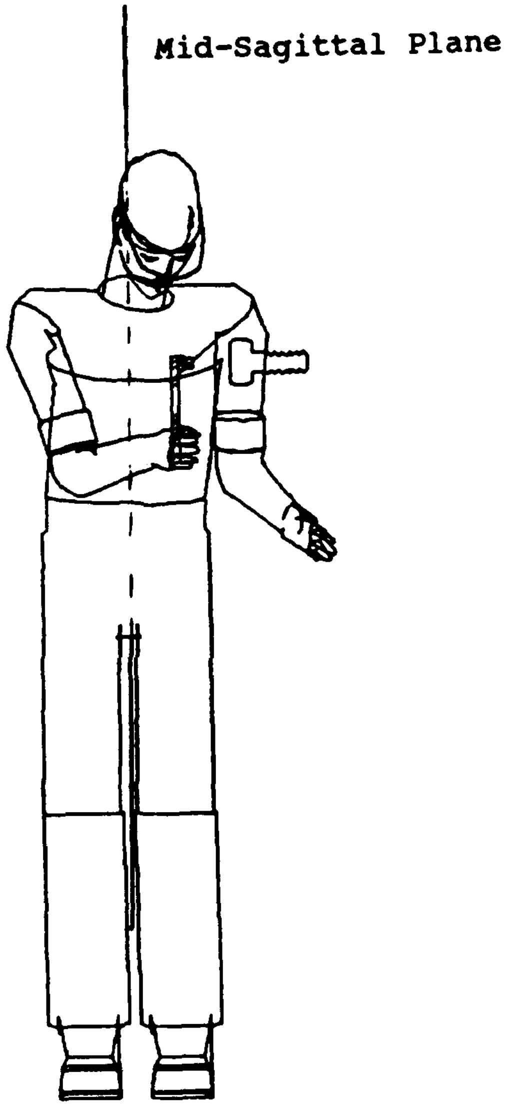


Figure 3.5 Transverse Bolt Orientation (Bolt size exaggerated to illustrate orientation)

For those wrench torque studies which collected data from the sonic digitizer, 12 body landmarks, which are listed below, were used to locate the sound emitters. The data were collected under the same file name as the strength data. Data were collected in the following format:

```
F1    xxxxx    xxxxx    xxxxx    xxxxx
 .      .        .        .        .
 .      .        .        .        .
 .      .        .        .        .
F12   xxxxx    xxxxx    xxxxx    xxxxx

B1    xxxxx    xxxxx    xxxxx    xxxxx
 .      .        .        .        .
 .      .        .        .        .
 .      .        .        .        .
B12   xxxxx    xxxxx    xxxxx    xxxxx
```

The F1 through F12 and B1 through B12 indicate that the data were collected from the front (F) or back (B) plane for the sound emitters 1 through 12. The four columns of up to five figures indicate the slant range from microphones A, B, C, and D of the designated plane (Figure 3.6). Data is recorded in centimeters and hundredths of centimeters (a data reading of 14368, equates to 143.68 centimeters).

Emitter Number   Landmark Description for Emitter Placement

1. Dorsal surface of right wrist, midway between the ulnar and radial styloid
2. Right humeral epicondyle
3. Right Acromion
4. Dorsal surface of left wrist, midway between the ulnar and radial styloid
5. Left humeral epicondyle
6. Left Acromion

7. Right lateral epicondyle femur
8. Right trochanter
9. Right lateral malleolus
10. Left lateral epicondyle femur
11. Left trochanter
12. Left lateral malleolus

3.2.3 Computerized Data Acquisition System

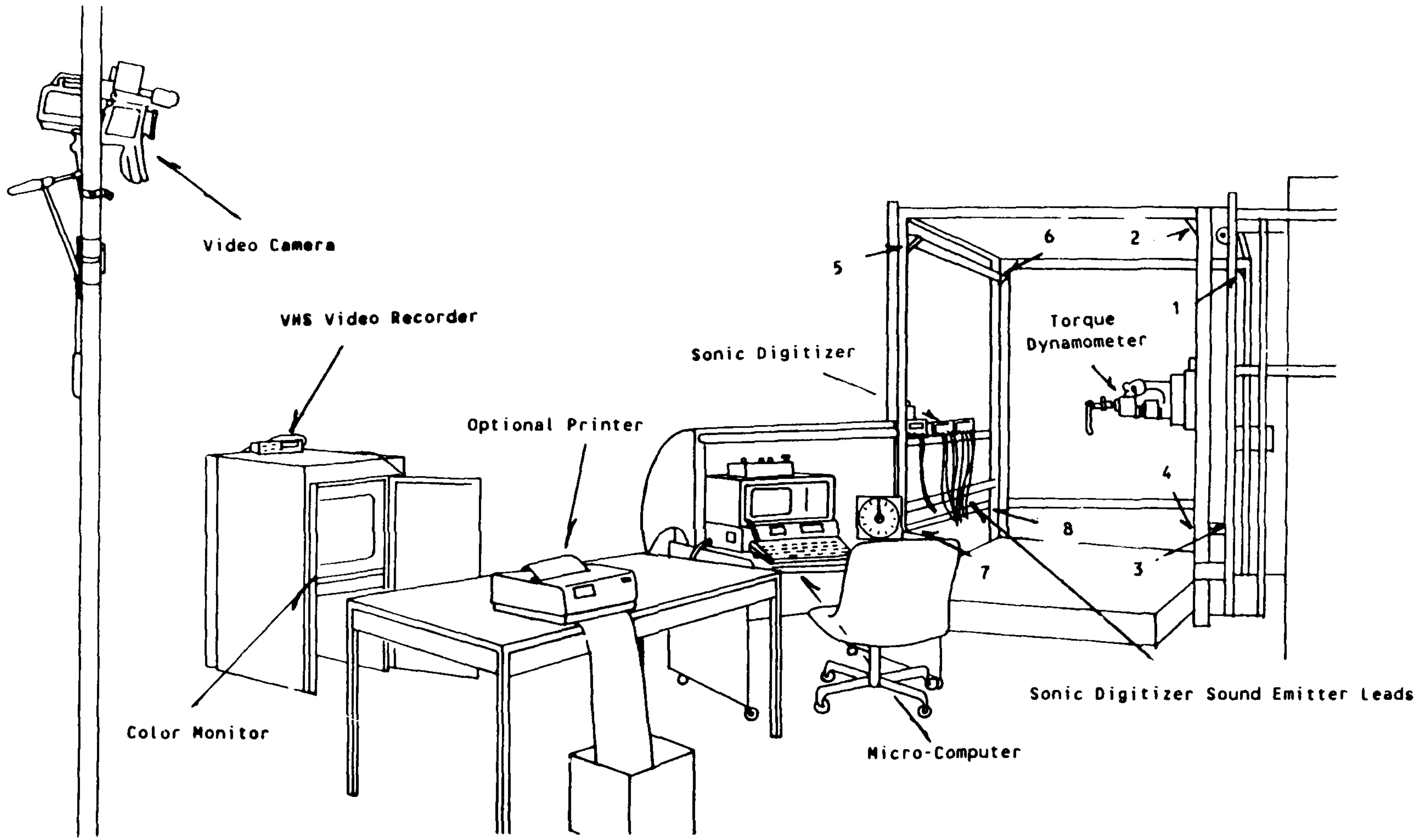
The computerized data acquisition system stores both the strength measures and the 3-D sonic digitizer data in memory as it is collected. After the trial, the data are saved on a floppy diskette and, optionally, printed on a printer.

3.2.4 Video Recording System

A video recording system consisting of a video camera, video tape recorder and a monitor was used to record the exertions for the on-site Wrench Torque studies. Figure 3.6 depicts the arrangement of the Torque Dynamometer, the 3-D Sonic Digitizer microphone array and the Video Recording system for the on-site Wrench Torque studies.

3.3 EXPERIMENTAL CONDITIONS

The conditions for each experiment varied. Some, such as subject selection criteria, remained relatively constant for all the experiments. Others were constant in one study and variable in another. For example, in one study posture might be a constant as only one posture was tested, while in another posture could be a variable as two or more postures were tested. The following were used in the Wrench Torque studies, but not all were used in each individual study. The summaries list which were used in that specific study, and which were constant and which were variable for that study.



1 - Front Plane Microphone B
2 - Front Plane Microphone D
3 - Front Plane Microphone A
4 - Front Plane Microphone C

5 - Back Plane Microphone C
6 - Back Plane Microphone A
7 - Back Plane Microphone D
8 - Back Plane Microphone B

Figure 3.6 Wrench Torque Studies Experiment Station

1. Subjects:

- Number: the number of male and female subjects participating in each study.

- Age: in all studies, the age range for subjects was 18 to 30 years. This corresponds to the age range of 99 percent of Air Force maintenance technicians who perform the majority of hands-on maintenance activities.

- Height/Weight: limiting height/weight restrictions as established by Air Force Regulation 160-43.

- Weight Lift: a minimum weight lift capability of 40 pounds on the 6 Foot Incremental Weight Lift test was required to participate in the study. Some Air Force maintenance career fields have weight lift requirements greater than 40 pounds, but all Air Force enlisted personnel are required to pass the test at the 40 pound level.

- Mixed Occupations: no particular skills or training were required for participation in the study.

- Pay: subjects were paid volunteers averaging $5.00 per hour. Informed consent was obtained prior to any testing.

- Handedness: right or left handed.

- No Physical Frailties: no physical frailties that would prevent a subject from participating in the study because of a possibility of injury or aggravation of an existing, or previously existing, condition.

2. Clothing:

- Shorts, T-shirt and Air Force boots, or
- Street clothes.

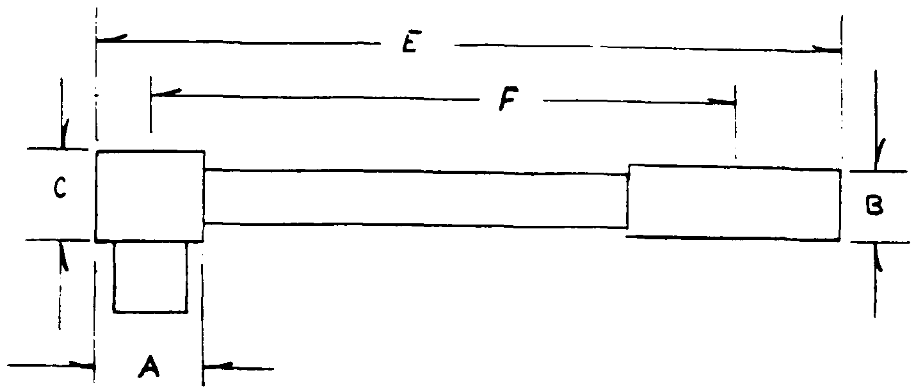
3. Testing Sessions:

- Number: number of sessions required to complete a study.
- Session Exertions: number of exertions in a session.
  Benchmark Exertions: specific exertions at the start and end of a session to verify subject's reliability. Described in each study summary.
  Test Exertions: the task exertions defined by the combinations of variable conditions. Accomplished in random order. Any anomalies to the randomization are described in the study summary.
  Rest Period: Rest time allowed between exertions to prevent fatigue becoming a factor.

4. Tools: various types and sizes of wrenches, extensions and universal joints (Figure 3.7 through 3.9). Those used in a specific study are listed in the study.

5. Posture: the 8 postures tested in the Wrench Torque studies. The subset of the 8 postures used in a specific study are included in the study summary.

6. Distance: the distance from the subject to the bolt head, relative to the subject's body such as a percentage of grip length. The specific distance(s)

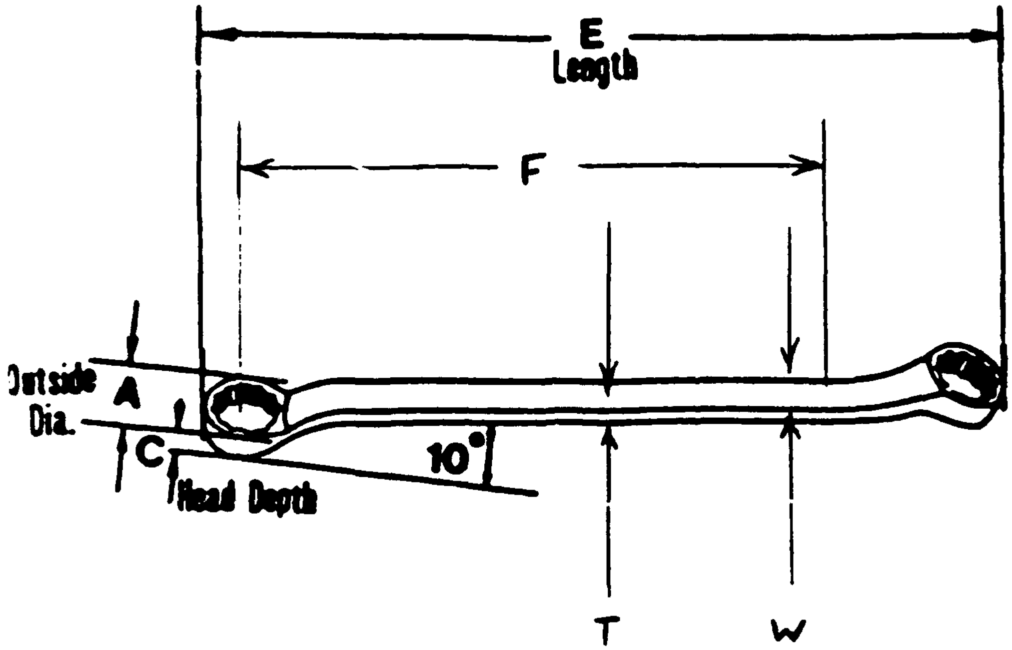


A = Head Diameter
B = Handle Diameter
C = Head Depth
E = Wrench Length
F = Moment Arm

Wrench Length	Handle	A	B	C (inches)	E	F
8 inch	Smooth	1 1/8	7/8	9/16	7 9/16	5 5/16
10 inch	Knurled	1 3/4	3/4	15/16	10 3/16	8
10 inch	Smooth	1 5/8	7/8	25/32	10 1/4	8
15 inch	Smooth	1 5/8	7/8	25/32	15	12 3/4

Nominal dimensions, may vary with manufacturers.

Figure 3.7 1/2 inch Drive Ratchet Wrenches

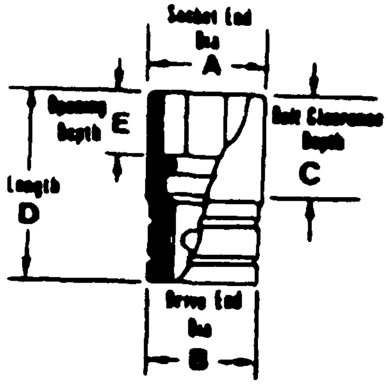


F = Moment Arm, T = Handle Thickness, W = Handle Width

Wrench Size	A	C	E (inches)	F	T	W
7/16 x 1/2	3/4	5/16	8 1/4	5 3/4	3/16	1/2
5/8 x 3/4	1	7/16	10 3/8	11 3/16	1/4	11/16

These are nominal dimensions. Dimensions vary from one manufacturer to another.

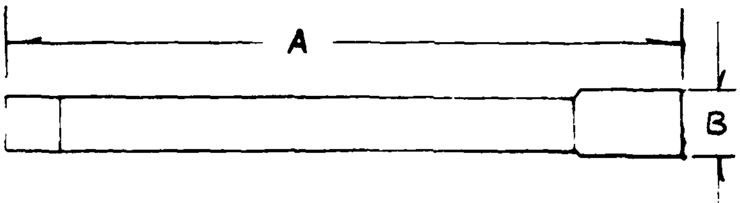
Figure 3.8 Box End Wrenches



Socket Size	A	B	C	D	E
			(inches)		
3/4 inch	1 1/16	31/32	7/8	1 1/2	1/2

Universal Joint 1/2 inch Drive by 1/2 inch Drive

Length - 2 11/16 inches. Head diameter - 29/32 inch.



Extensions

Size	A	B
	(inches)	
5 inch	5	7/8
10 inch	10	7/8

Nominal dimensions, may vary with manufacturers.

Figure 3.9 1/2 inch Drive 6-point Socket, Universal Joint and Extensions used in each study are identified in the study report. Figures 3.10 through 3.12 are examples of the method used to locate distances.

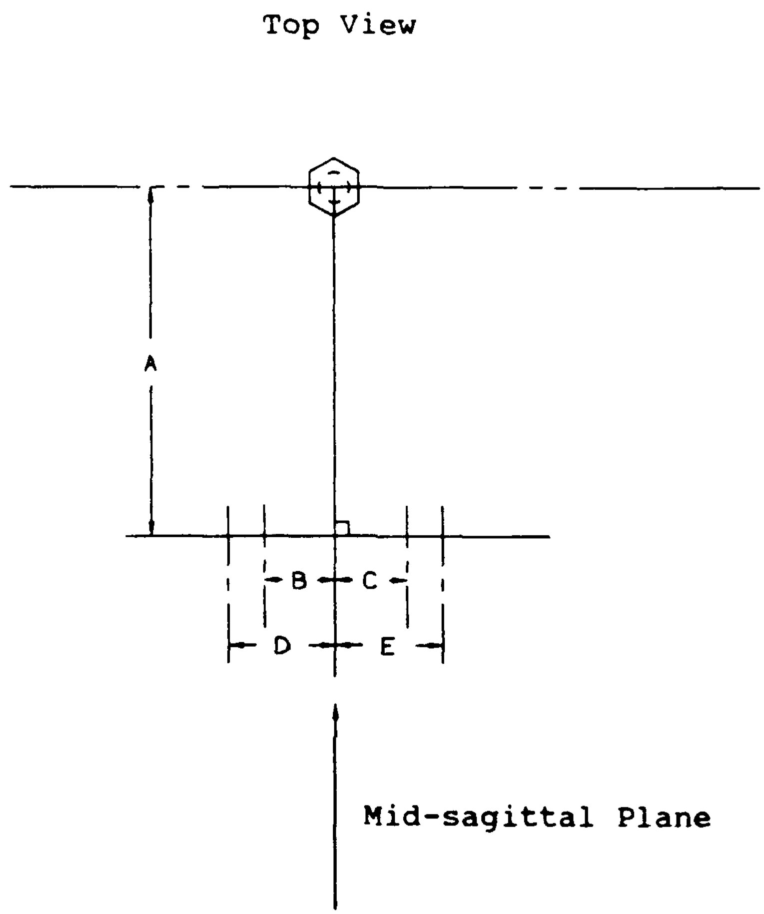
7. Bolt Head Elevation: the distance from the supporting surface to the center of the bolt head. Usually expressed as a percentage of the vertical reach for the posture(s) being tested.

8. Bolt Orientation: there were three bolt head orientations, established by the relationship of the bolt axis to the subject's mid-sagittal plane (Figures 3.4 through 3.6). This relationship holds regardless of the posture.

9. Wrench Handle Position: defined as a position in degrees around the bolt axis. There were either 4 positions at 90 degree intervals,or 8 at 45 degrees intervals. Because the bolt was oriented in three different planes, these handle positions change for each orientation as shown in Figure 3.13.

   NOTE: Figures 3.3 through 3.5 illustrate a standing subject with the wrench handle in the 180 degree position.

10. Hand Used: identifies the hand used to apply force to the wrench. Usually the right hand was used to apply torque to the wrench handle, with the left hand braced against the wrench head. For applications with the left hand the right hand was braced against the wrench head. A few tests were made with the right hand applying torque to the wrench handle and the left hand holding to test apparatus structure. When that situation exists it will be noted in the specific study report.



A = Distance from bolt

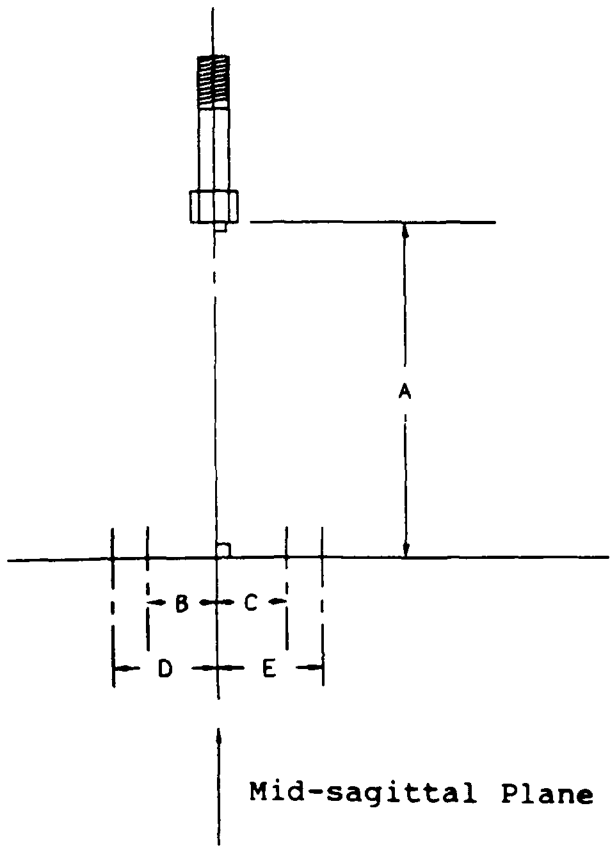
B and C = 50% of Biacromial Breadth
(locations for left and right foot markers)

D and E = 75% of Biacromial Breadth
(locations for left and right knee markers)

Mid-sagittal arrow head points in direction subject faces

Figure 3.10 Distance for the Vertical Bolt Orientation

Top View



A = Distance from bolt

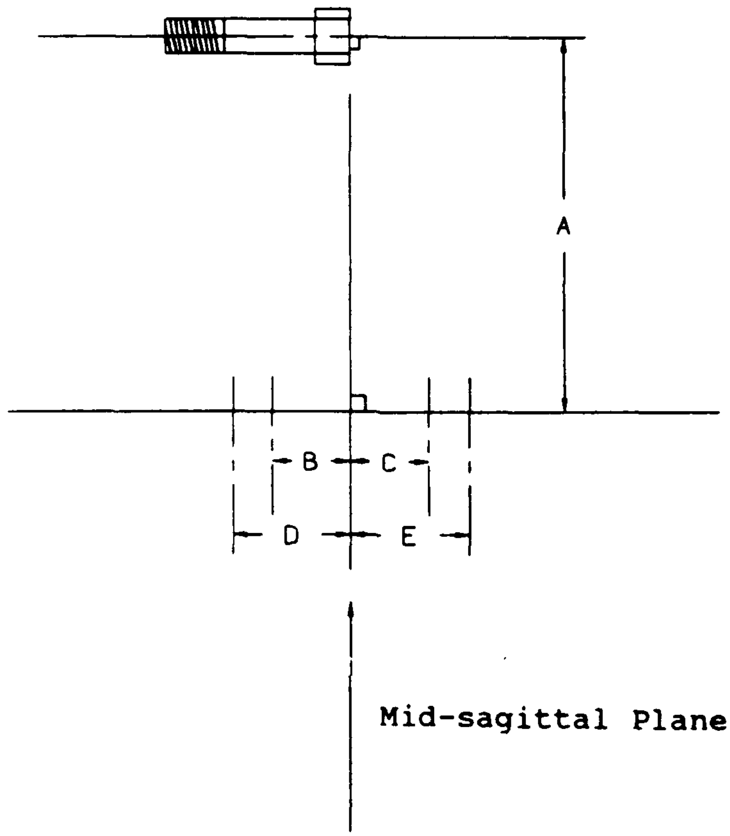
B and C = 50% of Biacromial Breadth
(locations for left and right foot markers)

D and E = 75% of Biacromial Breadth
(locations for left and right knee markers)

Mid-sagittal arrow head points in direction subject faces

Figure 3.11 Distance for the Facing Bolt Orientation

Top View



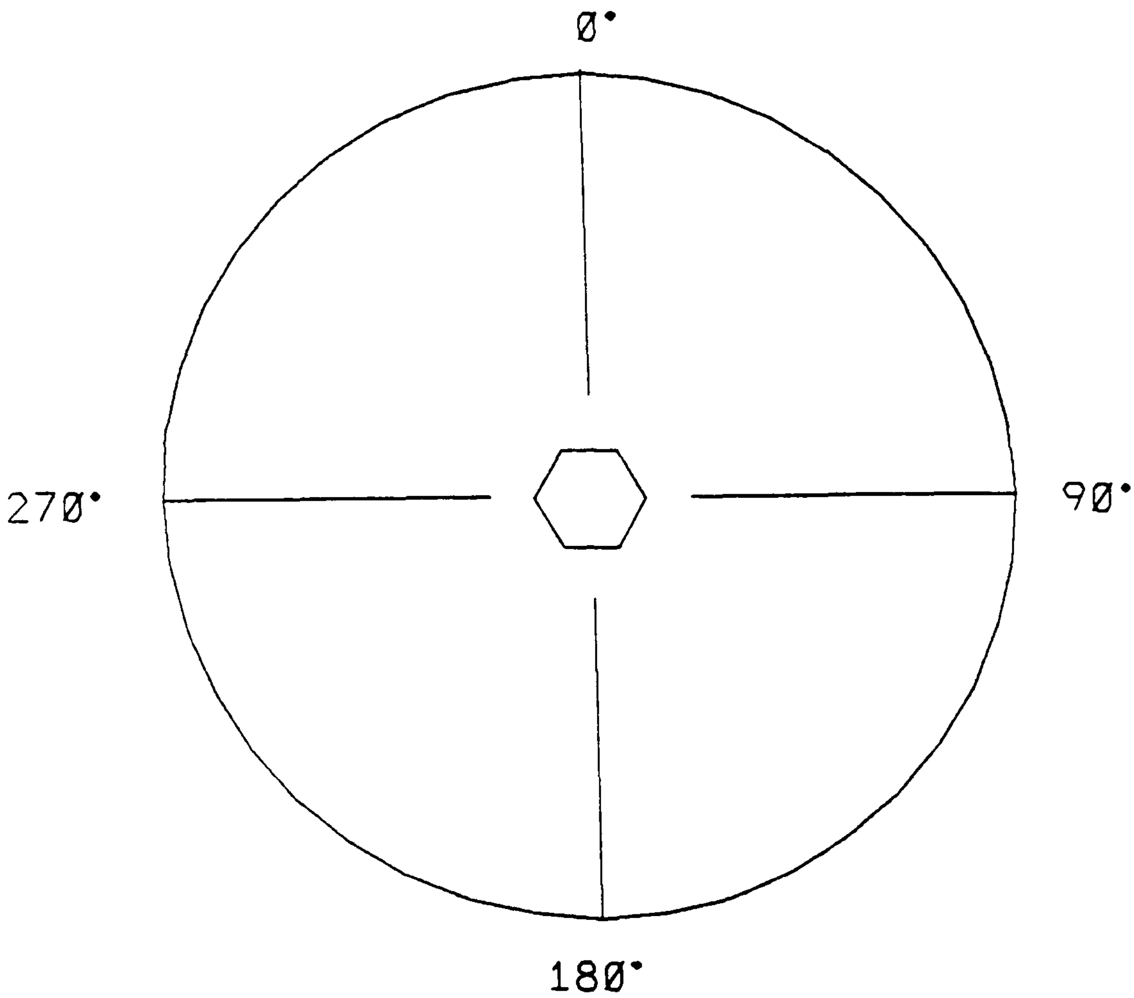
A = Distance from bolt

B and C = 50% of Biacromial Breadth
(locations for left and right foot markers)

D and E = 75% of Biacromial Breadth
(locations for left and right knee markers)

Mid-sagittal arrow head points in direction subject faces

Figure 3.12 Distance for the Transverse Bolt Orientation



Vertical Orientation - 0 degrees farthest away from subject and 180 degrees nearest.

Facing Orientation - 0 degrees at top and 180 degrees at the bottom.

Transverse Orientation - 0 degrees at top and 90 degrees farthest away from subject.

NOTE: Figures 3.3 through 3.5 illustrate a standing subject with the wrench handle in the 180 degree position.

Figure 3.13 Wrench Positions for Vertical, Facing and Transverse Orientations

11. Hand Covering: Bare hand or with one of two types of glove, work glove or chemical gloves. The work glove consists of leather shell with a wool insert liner. The chemical glove consists of three layers; a cotton liner and neoprene glove with an outer leather glove. The condition is described for the specific study.

12. Direction of Torque: Clockwise or Counterclockwise.

3.4 GENERAL PROCEDURES

The general procedures were the same for all the Wrench Torque studies. Bolt elevations and orientations were set. Subject was positioned at a specified distance from the bolt heads. For the standing, squatting and kneeling postures, one foot or knee (subject's choice) was placed on the distance line at the appropriate marker. Subjects were allowed to move the other forward or backward for a comfortable reach to the wrench handle. In most cases both were left on the distance line, but in those combinations of bolt head elevation and wrench position where a comfortable reach could not be attained with both on the distance line, one was moved. With a vertical bolt orientation, 85% bolt head elevation and 0 degrees wrench handle position, the foot or knee was usually moved slightly forward. For a vertical bolt orientation, 35% bolt head elevation and 180 degree position, one was usually moved slightly back. Experimenters did not allow the subjects to move the foot or knee to an extent that the basic posture was altered, or the alignment of the bolt axis was moved relative to the mid-sagittal plane. For the sitting posture, the subjects sat on a 12 inch high box, with the forward edge (nearest to the bolt) of the box at the distance line. Leaning the upper body toward or away from the bolt and wrench was allowed as long as it did not change the basic posture or body/bolt axis relationship. Force was applied to a static wrench handle for a period of four seconds. Usually, the right hand was used to apply to the wrench, with the left hand braced against the head of the wrench. In those cases where torque was applied with the left hand, the right hand was braced against the head of the wrench. In two experiments, C6 and C7, torque was applied with the right hand, with the left hand braced against a pole or barrier.

NOTE: The data reported in this volume have not been adjusted to represent the Air Force population. They are the data recorded by the subjects during experiment exertions.

■ WRENCH TORQUE STUDY, C1 ■

Maximum Voluntary Wrench Torque as a Function of Bolt Location, Wrench Position, and Body Posture.[2]

OBJECTIVE

To investigate the amount of torque which can be applied to a bolt by the maintenance technician in standing and squatting postures.

TEST EQUIPMENT

Torque Dynamometer

3-D Sonic Digitizer

Computerized Data Acquisition System

Video Recording System

CONDITIONS

<u>Constants</u>

- Subjects:
  Number: 19 Males, 18 Females
  Handedness: Right

- Clothing: Shorts, T-shirt and Air Force boots.

- Testing Sessions:
  Number: 3
  Session Exertions: 40
  Benchmark: 12
  Test: 28
  Rest Period: 2 minutes

2. Authors: C. Glenn Robbins and Donald L. Haddox (UDRI), and Dr. Joe W. McDaniel, (AAMRL).

- Tools: 1/2 inch drive ratchet 10 inch handle.
  3/4 inch 6-point socket.

- Distance: 50% of grip length

- Direction of Torque: Clockwise

<u>Variables</u>

- Postures: 2
  - Standing
  - Squatting

- Bolt Head Elevations: 3
  - Low - 35 % of vertical reach
  - Middle - 60 % of vertical reach
  - High - 85 % of vertical reach

- Bolt Orientations: 3
  - Vertical
  - Facing
  - Transverse

- Wrench Handle Positions: 4
  - 0 degrees
  - 90 degrees
  - 180 degrees
  - 270 degrees

- Hand Used: 2
  - Right - used with all postures and elevations.
  - Left - used only with standing posture and medium elevation.

Measures

- Isometric strength as the force applied to the static wrench handle by the subject. Force was measured with the torque dynamometer over a period of four seconds, and recorded in foot pounds.

- Body posture was measured with the Sonic Digitizer. The slant ranges from the microphones to the emitters, attached at the body landmarks, were recorded.

Benchmark Exertions

At the beginning and end of each session, a series of 6 exertions were performed, all at the 60% reach height elevation with the wrench at 90 degrees. One exertion was done for each bolt orientation (vertical, facing, transverse) in both postures (standing and squatting).

RESULTS

Tables 3.1 through 3.6 show the mean and standard deviation for each exertion. Males had larger scores than females in both postures. Means for males ranged from 20 to 75 ft. lb. and means for females ranged from 11 to 38 ft. lb. Scores for standing were consistently larger than for squatting. Overall, the 90 degree wrench position was the best and the 0 wrench position was the worst. Also, the lower the bolt, the higher the torque. Subjects produced slightly higher torque when using the right hand.

TABLE 3.1

FEMALES IN STANDING POSTURE

HEIGHT OF BOLT (% vertical reach)	ORIENTATION OF BOLT	POSITION OF WRENCH HANDLE (degrees)	N	MEAN (foot pounds)	STD (foot pounds)
85	FACING	0	17	14.5	4.1
		90	17	31.8	7.2
		180	17	22.3	6.6
		270	17	16.4	5.5
	TRANSVERSE	0	17	12.9	3.3
		90	17	28.1	7.3
		180	17	26.5	8.1
		270	17	17.6	3.5
	VERTICAL	0	17	16.1	4.7
		90	17	23.9	8.7
		180	17	13.6	3.9
		270	17	14.3	5.2
60	FACING	0	17	20.0	6.1
		90	17	30.2	8.4
		180	17	22.0	7.2
		270	17	17.5	4.3
	TRANSVERSE	0	17	22.1	8.3
		90	17	18.5	3.3
		180	17	31.1	9.1
		270	17	28.1	11.0
	VERTICAL	0	17	17.3	6.0
		90	17	30.9	10.2
		180	17	27.9	7.6
		270	17	18.0	6.0
35	FACING	0	17	20.3	5.6
		90	17	38.5	11.1
		180	17	17.0	6.2
		270	17	24.6	7.2
	TRANSVERSE	0	17	23.5	6.9
		90	17	29.1	8.1
		180	17	26.5	7.6
		270	17	37.5	14.7
	VERTICAL	0	17	17.4	5.2
		90	17	28.9	9.3
		180	17	26.3	6.8
		270	17	16.0	5.6

TABLE 3.2

FEMALES IN SQUATTING POSTURE

HEIGHT OF BOLT (% vertical reach)	ORIENTATION OF BOLT	POSITION OF WRENCH HANDLE (degrees)	N	MEAN (foot	STD pounds)
85	FACING	0	17	13.3	3.6
		90	17	31.3	8.6
		180	17	20.2	5.1
		270	17	16.9	5.3
	TRANSVERSE	0	17	12.5	3.5
		90	17	27.5	6.9
		180	17	23.6	8.4
		270	17	18.4	4.9
	VERTICAL	0	17	14.9	4.4
		90	17	25.1	8.5
		180	17	12.0	3.8
		270	17	11.6	3.7
60	FACING	0	17	18.1	5.5
		90	17	27.2	8.7
		180	17	25.0	6.6
		270	17	13.6	3.6
	TRANSVERSE	0	17	17.3	7.8
		90	17	20.4	5.6
		180	17	32.5	9.9
		270	17	29.1	8.5
	VERTICAL	0	17	15.6	4.6
		90	17	26.6	8.5
		180	17	21.0	7.9
		270	17	15.1	4.4
35	FACING	0	17	20.2	6.1
		90	17	31.1	9.3
		180	17	18.8	6.1
		270	17	18.7	7.0
	TRANSVERSE	0	17	21.0	6.7
		90	17	20.9	6.0
		180	17	28.9	7.1
		270	17	24.5	8.1
	VERTICAL	0	17	16.3	3.4
		90	17	27.2	7.6
		180	17	26.4	8.1
		270	17	15.3	3.8

TABLE 3.3

MALES IN STANDING POSTURE

HEIGHT OF BOLT (% vertical reach)	ORIENTATION OF BOLT	POSITION OF WRENCH HANDLE (degrees)	N	MEAN (foot	STD pounds)
85	FACING	0	19	27.0	10.2
		90	19	63.6	15.0
		180	19	41.9	10.3
		270	19	34.9	10.6
	TRANSVERSE	0	19	22.6	5.3
		90	19	60.5	14.1
		180	19	46.1	11.5
		270	19	42.7	17.3
	VERTICAL	0	19	21.6	6.1
		90	19	43.5	10.2
		180	19	22.9	6.1
		270	19	22.1	6.5
60	FACING	0	19	36.6	8.7
		90	19	57.7	17.0
		180	19	54.1	16.2
		270	19	38.2	17.0
	TRANSVERSE	0	19	43.4	13.3
		90	19	40.4	15.6
		180	19	67.1	18.0
		270	19	57.2	17.2
	VERTICAL	0	19	29.1	5.8
		90	19	59.0	15.4
		180	19	50.2	10.6
		270	19	38.1	13.9
35	FACING	0	19	39.8	14.0
		90	19	75.9	17.8
		180	19	33.8	10.1
		270	19	48.5	16.1
	TRANSVERSE	0	19	45.3	12.4
		90	19	53.7	21.2
		180	19	58.0	16.7
		270	19	62.6	19.9
	VERTICAL	0	19	31.6	12.2
		90	19	57.6	19.8
		180	19	55.8	18.0
		270	19	35.5	16.3

TABLE 3.4

MALES IN SQUATTING POSTURE

HEIGHT OF BOLT (% vertical reach)	ORIENTATION OF BOLT	POSITION OF WRENCH HANDLE (degrees)	N	MEAN (foot pounds)	STD (foot pounds)
85%	FACING	0	22	25.2	7.6
		90	22	64.9	13.4
		180	22	38.4	7.4
		270	22	30.3	9.2
	TRANSVERSE	0	19	23.0	8.3
		90	19	58.8	13.0
		180	19	46.5	16.6
		270	19	49.0	19.0
	VERTICAL	0	19	24.5	9.1
		90	19	38.1	8.6
		180	19	24.3	7.8
		270	19	20.3	5.0
60	FACING	0	19	34.2	10.7
		90	19	57.2	15.9
		180	19	57.0	16.1
		270	19	30.2	8.4
	TRANSVERSE	0	19	36.4	11.6
		90	19	44.3	14.0
		180	19	61.7	22.0
		270	19	55.0	20.2
	VERTICAL	0	19	27.3	11.3
		90	19	53.1	13.4
		180	19	39.4	12.0
		270	19	29.6	9.2
35	FACING	0	16	39.8	13.2
		90	16	60.8	18.5
		180	16	40.9	13.4
		270	16	34.1	9.6
	TRANSVERSE	0	19	38.1	10.4
		90	19	34.3	8.2
		180	19	61.4	18.6
		270	19	48.9	13.9
	VERTICAL	0	19	27.8	7.1
		90	19	56.1	17.1
		180	19	48.5	14.6
		270	19	29.8	10.5

TABLE 3.5

FEMALES USING LEFT HAND ON WRENCH HANDLE

ORIENTATION OF BOLT	POSITION OF WRENCH HANDLE (degrees)	N	MEAN (foot pounds)	STD (foot pounds)
FACING	0	17	25.2	7.4
	90	17	19.7	5.4
	180	17	18.3	4.9
	270	17	22.9	7.3
TRANSVERSE	0	17	21.2	8.026
	180	17	28.8	9.0
	270	17	27.1	10.6
VERTICAL	0	17	15.6	5.5
	90	17	22.2	5.9
	180	17	21.6	6.1
	270	17	25.2	7.8

TABLE 3.6

MALES USING LEFT HAND ON WRENCH HANDLE

ORIENTATION OF BOLT	POSITION OF WRENCH HANDLE (degrees)	N	MEAN (foot pounds)	STD (foot pounds)
FACING	0	19	44.2	11.8
	90	18	38.1	14.1
	180	19	41.7	10.7
	270	19	50.8	20.8
TRANSVERSE	0	19	45.8	14.0
	90	19	37.8	10.7
	180	19	56.0	13.7
	270	19	62.0	15.8
VERTICAL	0	19	37.1	8.8
	90	20	39.0	10.1
	180	19	37.5	7.4
	270	19	47.5	17.5

■ WRENCH TORQUE STUDY, C2 ■

Human Strength For Using Hand Tools[3]

OBJECTIVE

To determine torque strength as influenced by body position and wrench handle position at different bolt orientations.

TEST EQUIPMENT

Torque Dynamometer

Computerized Data Acquisition System

CONDITIONS

Constants

- Subjects:
  Number: 20 males, 20 females

- Clothing: Street clothes

- Testing Sessions:
  Number: 2
  Session Exertions: 36
  Benchmark: 6
  Test: 30
  Rest Period: 2 minutes

- Posture: Standing

- Distance: 50 percent of grip length

3. Dr. S. Deivanayagam, Linda Carlson, Rajagopalan Siddharthan, Chockalingam Rajagopal & Reinose Chacon (University of Texas at Arlington), C. Glenn Robbins & Donald L. Haddox, (UDRI), and Dr. Joe W. McDaniel, (AAMRL).

- Bolt Head Elevation: 60 percent of standing vertical reach

- Hand Used: Right

- Hand Covering: Bare handed

- Direction of Torque: Clockwise

Variables

Body Orientation was a variable used in only this study, and is established as shown Figure 3.14.

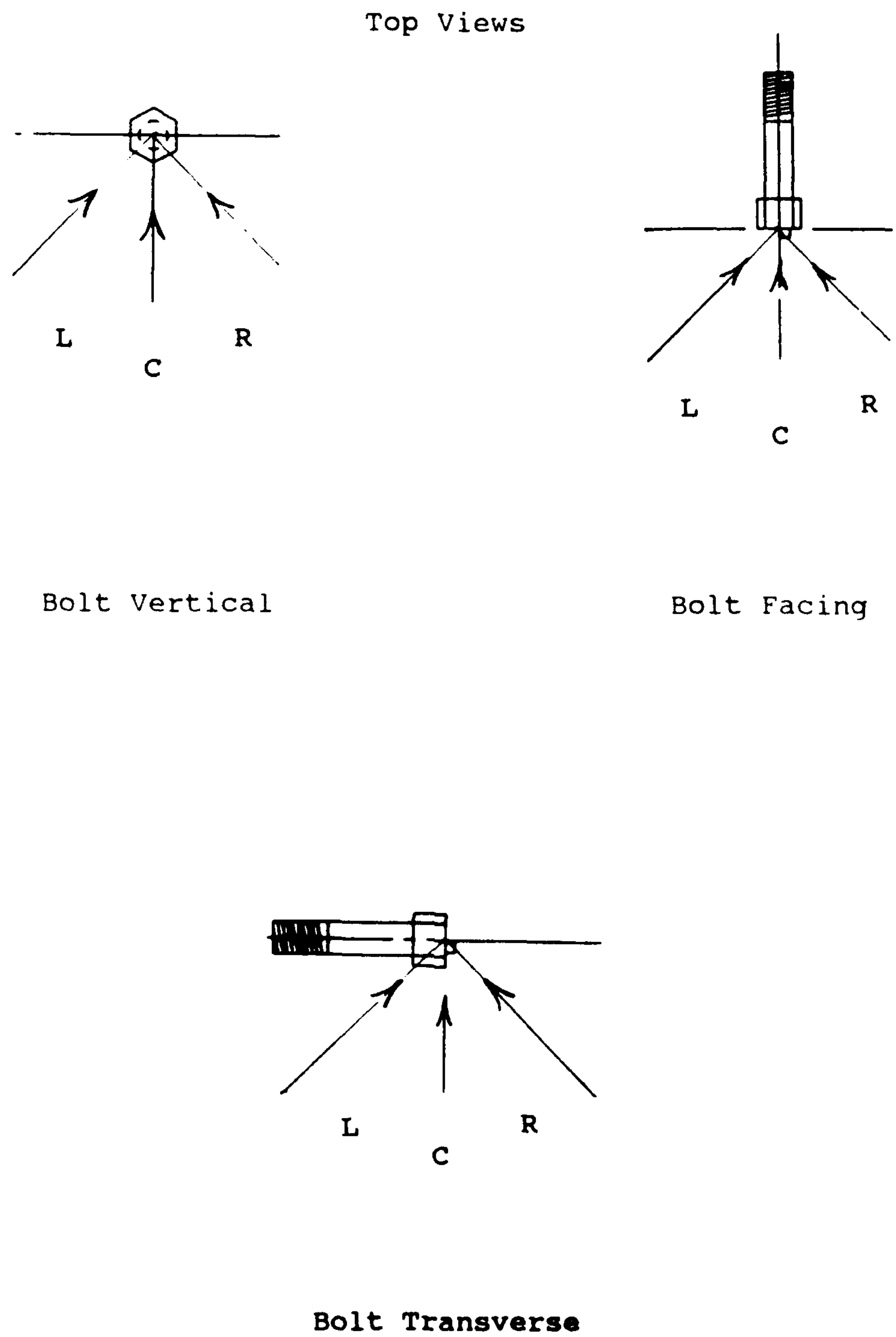
- Body Orientation: 3
  0 degrees, bolt centered on the body
  45 degrees to the right
  45 degrees to the left

- Tools: 2
  1/2 inch drive ratchet with 10 inch handle and 3/4 inch 6-point socket, without extension.

  1/2 inch drive ratchet with 10 inch handle and 3/4 inch 6-point socket, with 5 inch extension.

NOTE: The wrench with 5 inch extension was used only with the 0 degrees body orientation in combination with the 0, 90, 180, and 270 degree wrench handle positions.

- Bolt Orientation: 3
  Vertical
  Facing
  Transverse



Arrows indicate direction subject is facing
Transverse Right is the same as Facing Left

Figure 3.14 Body Orientations Relative to Bolt Orientation

- Wrench Handle Position: 8
  - 0 degrees
  - 45 degrees
  - 90 degrees
  - 135 degrees
  - 180 degrees
  - 225 degrees
  - 270 degrees
  - 315 degrees

NOTE: 45, 135, 225 and 315 degrees positions used only with the 0 degrees body orientation.

MEASURES

- Isometric strength as the force applied to the static wrench handle by the subject. Force was measured with the torque dynamometer over a period of four seconds, and recorded in foot pounds.

Anthropometric Measurements

The following anthropometric measurements were made for this study.

Age	Gender
Weight	Vertical Reach
Biceps circumference, flexed	Span
Forearm circumference, flexed	Stature
Acromial height	Trochanteric height
Tibiale height	Hand length
Lateral malleolus height	Hip breadth
Acromion-radiale length	Biacromial breadth
Radiale-stylion length	Grip length
Triceps skinfold	Subscapular skinfold
Medial calf skinfold	Suprailiac skinfold
Right grip strength	Left grip strength

Benchmark Exertions

At the beginning and end of each session, three standard exertions were performed at all three bolt orientations (vertical, facing and transverse). The wrench position was at 90 degrees, the body orientation at 0 degrees, and the wrench had no extension.

RESULTS

Tables 3.7 through 3.11 present the mean and standard deviation for each condition. Males produced higher torque than females. Overall, positioning the wrench at 135 degrees resulted in higher torque than the other positions. The least torque occurred at 315 degrees. The highest means for males and females occurred with the bolt transverse to the subject and the wrench handle at 180 degrees. The least means for males and females occurred when the bolt was vertical and the wrench was positioned at 315 degrees. The 5-inch extension on the ratchet wrench made no difference in torque. Also, offsetting the body (i.e., not centered on the bolt head) made no difference.

TABLE 3.7
MEANS AND STANDARD DEVIATIONS, FACING BOLT ORIENTATION

BODY ORIENTATION (degrees)	WRENCH HANDLE POSITION (degrees)	N	FEMALES (foot pounds) MEAN	FEMALES STD	MALES (foot pounds) MEAN	MALES STD
0	0	40	17.3	4.3	33.7	11.6
	45	20	18.8	5.0	35.1	14.4
	90	40	20.0	6.1	45.1	25.2
	135	20	22.7	6.0	53.3	22.7
	180	40	18.8	5.1	43.9	18.6
	225	20	16.1	6.1	35.4	18.2
	270	40	17.3	4.6	30.5	11.1
	315	20	16.2	4.4	29.4	11.4
45 LEFT	0	20	17.5	5.2	32.4	12.0
	90	20	19.2	5.6	37.6	13.0
	180	20	18.7	4.9	41.6	19.7
	270	20	21.4	7.7	36.2	13.4
45 RIGHT	0	20	19.5	6.3	37.9	12.6
	90	20	21.6	8.0	50.3	21.2
	180	20	19.5	5.5	44.3	16.8
	270	20	15.1	3.9	25.8	8.7

TABLE 3.8
MEANS AND STANDARD DEVIATIONS, TRANSVERSE BOLT ORIENTATION

BODY ORIENTATION (degrees)	WRENCH HANDLE POSITION (degrees)	N	FEMALES (foot pounds) MEAN	FEMALES STD	MALES (foot pounds) MEAN	MALES STD
0	0	40	19.4	5.4	38.8	13.8
	45	20	15.9	3.8	32.1	9.8
	90	40	17.1	5.0	31.0	10.7
	135	20	22.0	6.6	44.7	17.0
	180	40	26.1	9.2	56.1	19.1
	225	20	24.0	4.1	45.3	20.5
	270	40	24.0	7.6	54.7	18.9
	315	20	20.8	6.7	41.5	15.8
45 LEFT	0	20	17.2	5.0	34.2	10.1
	90	20	15.8	4.0	30.4	8.6
	180	20	24.8	6.0	55.8	22.4
	270	20	25.4	7.7	52.2	20.3

TABLE 3.9
MEANS AND STANDARD DEVIATIONS, VERTICAL BOLT ORIENTATION

BODY ORIENTATION (degrees)	WRENCH HANDLE POSITION (degrees)	N	FEMALES (foot pounds) MEAN	FEMALES STD	MALES (foot pounds) MEAN	MALES STD
0	0	40	14.2	3.3	27.0	8.8
	45	20	19.7	5.9	43.0	14.5
	90	40	24.5	6.9	56.5	19.6
	135	20	22.4	8.3	44.4	15.5
	225	20	16.2	4.3	36.1	10.0
	270	40	17.7	5.1	32.1	10.5
	315	20	11.4	2.5	20.1	5.8
45 LEFT	0	20	12.1	2.4	21.4	6.3
	90	20	21.0	5.6	45.7	17.4
	180	20	22.5	7.5	45.0	16.1
	270	20	17.0	4.0	34.1	12.1
45 RIGHT	0	20	20.4	5.4	42.5	14.7
	90	20	22.3	7.3	45.9	15.2
	180	20	15.6	3.4	37.9	13.6
	270	20	12.9	2.7	21.4	6.9

TABLE 3.10
WITH AND WITHOUT EXTENSION,
THREE BOLT ORIENTATIONS

USE OF EXTENSION	BOLT ORIENTATION	N	MEAN	STD	N	MEAN	STD
				(foot pounds)			
			FEMALE			MALE	
YES	FACING	38	18.3	5.6	38	40.5	16.3
YES	TRANSVERSE	43	21.1	7.7	45	43.0	19.2
YES	VERTICAL	33	17.9	7.8	53	39.9	17.6
NO	FACING	172	18.7	5.9	153	36.2	15.8
NO	TRANSVERSE	107	20.6	6.8	117	41.3	16.9
NO	VERTICAL	163	17.8	5.8	153	39.2	17.8

TABLE 3.11
WITH AND WITHOUT EXTENSION,
FOUR WRENCH HANDLE POSITIONS

USE OF EXTENSION	WRENCH POSITION	N	MEAN	STD	N	MEAN	STD
				(foot pounds)			
			FEMALE			MALE	
YES	0 degrees	30	17.1	4.5	30	36.2	15.0
YES	90 degrees	33	21.2	7.9	37	42.3	18.9
YES	180 degrees	27	21.0	9.3	35	49.4	19.2
YES	270 degrees	24	17.3	5.7	34	35.5	13.5
NO	0 degrees	83	17.3	5.3	77	33.4	12.7
NO	90 degrees	80	19.9	5.9	80	40.3	18.3
NO	180 degrees	90	20.1	6.6	66	47.2	17.3
NO	270 degrees	79	18.9	6.6	81	35.2	15.8

■ WRENCH TORQUE STUDY, C3 ■

Maximum Voluntary Wrench Torque as a Function of Bolt Location, Wrench Position, and Body Posture.[4]

OBJECTIVE

To investigate the amount of torque which can be applied to a bolt by the maintenance technician while in the postures of sitting and kneeling.

TEST EQUIPMENT

Torque Dynamometer

3-D Sonic digitizer

Computerized Data Acquisition System

Video Recording System

CONDITIONS

Constants

- Subjects:
  Number: 19 males, 18 females
  Handedness: Right

- Clothing: Shorts, T-shirt and Air Force boots

- Testing Sessions:
  Number: 1
  Session Exertions: 37
  Benchmark: 10
  Test: 27
  Rest Period: 2 minutes

4. Authors: C. Glenn Robbins and Donald L. Haddox, (UDRI) and Dr. Joe W. McDaniel, (AAMRL).

- Tools: 1/2 drive ratchet with 10 inch handle.
  3/4 inch 6-point socket.

- Distance: 50% of grip length

- Bolt Head Elevation: 60% of vertical reach

- Hand Used: Right hand

- Hand Covering: Bare handed

- Direction of Torque: Clockwise

<u>Variables</u>

- Postures: 3
  Sitting
  Kneeling on one knee
  Kneeling on two knees

- Bolt Orientations (3):
  Vertical
  Facing
  Transverse

- Wrench Handle Positions: 3
  0 degrees
  90 degrees
  180 degrees

MEASURES

- Isometric strength as the force applied to the static wrench handle by the subject. Force was measured with the torque dynamometer over a period of four seconds, and recorded in foot pounds.

- Body posture was measured with the Sonic Digitizer. The slant ranges from the microphones to the emitters, attached to the body landmarks, were recorded.

Benchmark exertions

At the beginning and end of each session, a series of five standard exertions were performed, all with the bolt head in the vertical orientation, the wrench at the 90 degree position, and at 60% reach height. One benchmark was performed in each of 5 postures: standing, squatting, sitting, kneeling (one knee), and kneeling (two knees).

RESULTS

Tables 3.12 through 3.17 present the mean and standard deviation for the test conditions. Torque values for all three postures tested in this study were generally lower than those observed in the standing posture in the first study. Torque values while kneeling on one knee were larger than those while sitting or kneeling on both knees. The largest means occurred with the bolt transverse to the subject and the wrench at 180 degrees. The smallest means occurred with the bolt vertical and the wrench at 0 degrees.

TABLE 3.12
FEMALES IN SITTING POSTURE

ORIENTATION OF BOLT	POSITION OF WRENCH HANDLE (degrees)	N	MEAN (foot pounds)	STD (foot pounds)
FACING	0	18	18.5	6.5
	90	18	26.9	9.0
	180	18	24.1	7.5
TRANSVERSE	0	18	20.6	7.4
	90	18	19.6	6.9
	180	18	32.1	10.2
VERTICAL	0	18	15.8	6.0
	90	18	28.3	10.6
	180	18	22.3	7.9

TABLE 3.13

FEMALES KNEELING ON ONE KNEE.

ORIENTATION OF BOLT	POSITION OF WRENCH HANDLE (degrees)	N	MEAN (foot pounds)	STD (foot pounds)
FACING	0	18	21.4	6.6
	90	18	29.2	11.0
	180	18	26.5	9.1
TRANSVERSE	0 DEG	18	18.1	7.0
	90 DEG	18	20.4	7.0
	180 DEG	18	30.9	15.9
VERTICAL	0 DEG	18	18.1	6.8
	90 DEG	18	26.5	10.9
	180 DEG	18	22.1	8.6

TABLE 3.14

FEMALES KNEELING ON BOTH KNEES

ORIENTATION OF BOLT	POSITION OF WRENCH HANDLE (degrees)	N	MEAN (foot pounds)	STD
FACING	0	18	18.6	4.8
	90	18	27.4	10.7
	180	18	23.8	6.9
TRANSVERSE	0	18	19.1	6.9
	90	18	20.3	6.9
	180	18	29.8	11.2
VERTICAL	0	18	14.4	4.7
	90	18	26.2	9.9
	180	18	24.0	8.6

TABLE 3.15

MALES IN SITTING POSTURE

ORIENTATION OF BOLT	POSITION OF WRENCH HANDLE (degrees)	N	MEAN (foot pounds)	STD
FACING	0	18	34.4	6.0
	90	18	51.5	10.0
	180	18	54.4	10.4
TRANSVERSE	0	18	33.7	7.2
	90	18	38.4	7.6
	180	18	58.6	14.7
VERTICAL	0	18	25.8	5.9
	90	18	49.1	12.5
	180	18	40.8	8.6

TABLE 3.16

MALES KNEELING ON ONE KNEE

ORIENTATION OF BOLT	POSITION OF WRENCH HANDLE (degrees)	N	MEAN (foot pounds)	STD
FACING	0	18	37.2	6.9
	90	18	56.4	15.0
	180	18	56.3	13.7
TRANSVERSE	0	18	37.0	9.6
	90	18	41.9	7.1
	180	18	61.6	14.9
VERTICAL	0	18	27.1	5.8
	90	18	52.7	15.5
	180	18	45.1	12.4

TABLE 3.17

MALES KNEELING ON BOTH KNEES

ORIENTATION OF BOLT	POSITION OF WRENCH HANDLE (degrees)	N	MEAN (foot pounds)	STD
FACING	0	18	35.5	6.2
	90	18	55.8	10.9
	180	18	53.7	12.4
TRANSVERSE	0	18	36.9	7.6
	90	18	40.9	7.3
	180	18	59.7	15.9
VERTICAL	0	18	24.9	4.9
	90	18	47.2	12.9
	180	18	43.4	9.1

WRENCH TORQUE STUDY, C4

Torque With Wrenches in Unusual Postures.[5]

OBJECTIVE

To measure maximum capability of producing torque with wrenches while in the postures of prone, supine, and lying on the side.

This study was performed in four sessions, one for the prone posture, one for the supine posture and two for the side posture. Prone was performed at the Tennessee Technological University (TennTU). Supine and side were performed at the AAMRL Ergonomics Laboratory. Each posture was considered as a block, and the exertions were randomized for each block. In this summary the variable conditions will be described for each posture block, as variable conditions were not constant in blocks.

TEST EQUIPMENT

Torque dynamometer

Subject positioning platform (used for the prone posture)

Computerized data collection system

CONDITIONS

<u>Constants</u>

- Subjects
  Number: 20 Males, 20 Females

- Clothing: Street clothing.

5. Dr. S. Deivayangam, Robert Finegan, Thomas Weaver and Ratnavelpandian Kanthasamy (TennTU), C. Glenn Robbins and Donald L. Haddox (UDRI), and Dr. Joe W. McDaniel (AAMRL).

- Testing Sessions:

  Number: 4

  One each for prone and supine and two for side postures.

  Session Exertions: Varied by posture

  Prone Session: 36

  Benchmark: 4

  Test: 32

  Supine Sessions: 36

  Benchmark: 4

  Test: 32

  Side Session: 28

  Benchmark: 4

  Test: 24

  Rest Period: 2 minutes for all sessions.

- Tools: 1/2 inch drive ratchet handle.
  3/4 inch 6-point socket.

- Hand Used: Right

- Hand Covering: Bare hand

- Direction of Torque: Clockwise

Variables

Prone Posture

- Distances: 2
  50 % of grip length
  75 % of grip length

- Bolt Orientations: 2
  - Vertical
  - Facing

- Wrench Handle Positions: 8
  - 0 degrees
  - 45 degrees
  - 90 degrees
  - 135 degrees
  - 180 degrees
  - 225 degrees
  - 270 degrees
  - 315 degrees

Supine Posture

- Bolt Orientations: 2
  - Vertical
  - Horizontal

NOTE: bolt orientation was relative to the support surface.

Vertical - the bolt axis was perpendicular to, and with bolt head pointing toward, the support surface. This corresponds to the Facing orientation depicted in Figure 3.4.

Horizontal - the bolt axis was parallel to the support surface and relates to the Vertical orientation in Figure 3.3, except that the bolt head pointed toward the feet instead of the head. Due to the construction of the apparatus, the subject could not be placed so that the bolt head pointed toward the subject's head.

- Distances: 2
  - 50 % of grip length + chest depth
  - 75 % of grip length + chest depth

- Wrench Handle Positions: 8
  - 0 degrees
  - 45 degrees
  - 90 degrees
  - 135 degrees
  - 180 degrees
  - 225 degrees
  - 270 degrees
  - 315 degrees

Side Posture

- Bolt Orientations: 3
  - Vertical
  - Facing
  - Transverse

- Bolt Elevations: 2, above the support surface
  - Biacromial breadth
  - 50 % of biacromial breadth

- Wrench Handle Positions: 8
  - 0 degrees
  - 45 degrees
  - 90 degrees
  - 135 degrees
  - 180 degrees
  - 225 degrees
  - 270 degrees
  - 315 degrees

MEASURES

- Isometric strength as the force applied to the static wrench handle by the subject. Force was measured over a period of four seconds, and recorded in foot pounds.

Anthropometric Measures

The full set of anthropometric measures were made on the subjects participating in the Supine and Side portions of the study at the AAMRL Ergonomics Laboratory. The following measurements were made on the subjects participating in the Prone portion at Tennessee Technological University.

Age	Sex
Race	Weight
Stature	Sitting Height
Trochanteric Height	Tibiale Height
Acromion-Radiale Length	Radiale-Stylion Length
Biacromial Breadth	Bitrochanteric Breadth
Lateral Malleolus Height	Grip Length
Vertical Reach	Grip Strength Right
Grip Strength Left	

Benchmark Exertions

At the beginning and end of each session, two standard exertions were performed. The posture was Standing, Bolt Orientation was Facing, Bolt Elevation was at 60 % of standing vertical reach, and two Wrench Handle Positions, 0 and 90 degrees were tested.

RESULTS

The means, standard deviations and sample size for each exertion are presented in Tables 3.18 through 3.23. Males produced more torque than females in all three postures. The range of mean torque values for males and females, respectively,

TABLE 3.18
FEMALES IN PRONE POSTURE

BOLT ORIENT	DISTANCE (% grip length)	WRENCH POSITION (degrees)	N	MEAN (foot pounds)	STD (foot pounds)
FACING	50	0	20	18.9	5.2
		45	20	16.5	2.2
		90	20	21.9	5.5
		135	20	15.5	3.9
		180	20	8.3	2.3
		225	20	13.9	4.4
		270	20	18.0	4.2
		315	20	18.1	3.2
	75	0	20	15.1	3.7
		45	20	17.0	2.9
		90	20	23.6	6.2
		135	20	12.8	3.5
		180	20	6.9	2.5
		225	20	12.6	3.4
		270	20	18.3	4.4
		315	20	19.5	4.3
VERTICAL	50	0	20	13.9	2.7
		45	20	17.1	4.6
		90	20	15.4	3.0
		135	20	18.5	4.9
		180	20	14.4	2.1
		225	20	9.8	2.1
		270	20	9.9	3.1
		315	20	10.4	2.4
	75	0	20	13.0	2.6
		45	20	15.6	3.7
		90	20	13.3	2.8
		135	20	15.1	3.3
		180	20	11.5	2.6
		225	20	8.4	1.6
		270	20	8.9	2.4
		315	20	9.5	2.6

TABLE 3.19
MALES IN PRONE POSTURE

BOLT ORIENT	DISTANCE (% grip length)	WRENCH POSITION (degrees)	N	MEAN (foot pounds)	STD (foot pounds)
FACING	50	0	20	35.1	9.3
		45	20	31.1	8.7
		90	20	42.1	14.7
		135	20	31.4	9.6
		180	20	15.3	5.8
		225	20	29.3	10.6
		270	20	33.5	8.4
		315	20	33.7	9.2
	75	0	20	29.9	10.4
		45	20	32.4	9.6
		90	20	47.0	22.2
		135	20	21.9	7.2
		180	20	11.8	4.0
		225	20	26.9	7.3
		270	20	39.9	14.0
		315	20	39.3	12.1
VERTICAL	50	0	20	25.0	7.3
		45	20	30.3	9.1
		90	20	28.8	8.2
		135	20	36.3	12.7
		180	20	28.5	8.0
		225	20	17.8	5.3
		270	20	16.4	3.3
		315	20	17.7	5.3
	75	0	20	23.5	6.0
		45	20	26.6	8.7
		90	20	25.4	6.9
		135	20	29.5	10.3
		180	20	21.9	5.8
		225	20	14.8	3.7
		270	20	14.2	3.0
		315	20	17.2	5.1

TABLE 3.20
FEMALES IN SUPINE POSTURE

BOLT ORIENT	DISTANCE (% grip length)	WRENCH POSITION (degrees)	N	MEAN (foot pounds)	STD
VERTICAL	50	0	20	11.9	3.0
		45	20	14.2	3.5
		90	20	20.0	4.1
		135	20	18.3	3.0
		180	20	22.9	5.7
		225	20	16.8	3.5
		270	20	20.0	4.3
		315	20	21.2	6.0
	75	0	20	10.1	2.9
		45	20	16.0	3.8
		90	20	21.6	4.9
		135	20	20.7	5.7
		180	20	17.9	4.2
		225	20	14.5	3.3
		270	20	29.6	9.1
		315	20	19.5	6.3
FACING	50	0	20	14.8	4.1
		45	20	18.8	5.1
		90	20	21.8	5.8
		135	20	21.0	5.1
		180	20	19.6	5.8
		225	20	15.7	4.1
		270	20	11.9	2.9
		315	20	13.0	2.4
	75	0	20	13.3	2.6
		45	20	17.4	4.7
		90	20	17.8	5.8
		135	20	16.6	3.4
		180	20	18.2	3.9
		225	20	14.7	3.6
		270	20	10.3	3.0
		315	20	11.4	3.1

TABLE 3.21
MALES IN SUPINE POSTURE

BOLT ORIENT	DISTANCE (% grip length)	WRENCH POSITION (degrees)	N	MEAN (foot pounds)	STD (foot pounds)
VERTICAL	50	0	20	17.6	5.6
		45	20	24.6	6.2
		90	20	32.0	9.4
		135	20	33.5	9.1
		180	20	33.2	9.6
		225	20	28.3	9.8
		270	20	48.2	15.4
		315	20	35.8	8.5
	75	0	20	15.2	4.1
		45	20	27.6	7.3
		90	20	36.8	11.4
		135	20	35.2	10.5
		180	20	24.6	5.7
		225	20	29.3	7.4
		270	20	68.4	22.3
		315	20	24.6	7.0
FACING	50	0	20	25.1	6.7
		45	20	30.9	8.7
		90	20	35.6	11.0
		135	20	34.5	9.1
		180	20	37.9	12.2
		225	20	29.6	7.9
		270	20	17.7	4.3
		315	20	19.9	5.8
	75	0	20	22.1	8.1
		45	20	26.6	7.2
		90	20	31.4	9.3
		135	20	28.4	6.1
		180	20	30.6	8.6
		225	20	23.9	7.2
		270	20	15.0	5.0
		315	20	18.4	6.5

TABLE 3.22
FEMALES IN SIDE POSTURE.

BOLT ORIENT	DISTANCE (% biacromial breadth)	WRENCH POSITION (degrees)	N	MEAN (foot pounds)	STD (foot pounds)
FACING	100	0	18	17.5	5.1
		45	18	20.3	7.1
		90	18	22.2	8.9
		135	18	26.8	10.9
		180	18	23.2	7.5
		225	18	11.5	2.5
		270	18	13.2	4.5
		315	18	13.3	2.9
	50	0	18	20.6	7.0
		45	18	23.4	9.4
		90	18	24.2	8.3
		135	18	20.3	5.4
		180	18	13.6	4.6
		225	18	13.4	4.1
		270	18	15.7	3.4
		315	18	19.5	5.1
TRANSVERSE	100	0	18	19.8	4.5
		45	18	13.0	3.4
		90	18	16.2	4.7
		135	18	20.8	5.5
		180	18	24.6	5.5
		225	18	20.9	5.0
		270	18	19.2	6.3
		315	18	22.7	7.7
	50	0	18	23.8	7.1
		45	18	15.9	4.2
		90	18	13.6	3.1
		135	18	14.0	3.8
		180	18	21.3	6.1
		225	18	25.7	7.6
		270	18	22.9	5.7
		315	18	17.6	5.9

(continued)

TABLE 3.22 (concluded)
FEMALES IN SIDE POSTURE.

BOLT ORIENT	DISTANCE (% biacromial breadth)	WRENCH POSITION (degrees)	N	MEAN (foot pounds)	STD (foot pounds)
VERTICAL	100	0	18	14.0	4.1
		45	18	19.3	5.4
		90	18	25.7	5.3
		135	18	21.0	4.2
		180	18	24.7	6.4
		225	18	26.0	6.5
		270	18	22.6	5.3
		315	18	17.2	5.3
	50	0	18	13.6	3.8
		45	18	18.4	5.6
		90	18	26.5	6.2
		135	18	17.0	5.1
		180	18	22.5	6.7
		225	18	27.4	7.3
		270	18	24.7	7.0
		315	18	17.3	3.2

TABLE 3.23
MALES IN SIDE POSTURE.

BOLT ORIENT	DISTANCE (% biacromial breadth)	WRENCH POSITION (degrees)	N	MEAN (foot pounds)	STD (foot pounds)
FACING	100	0	20	29.6	6.6
		45	20	33.5	9.3
		90	20	34.6	9.6
		135	20	43.6	13.3
		180	20	34.5	12.0
		225	20	22.4	7.3
		270	20	26.0	8.7
		315	20	26.5	7.5
	50	0	20	35.9	11.7
		45	20	38.4	13.8
		90	20	40.9	10.0
		135	20	37.0	12.7
		180	20	26.0	8.5
		225	20	24.7	8.8
		270	20	29.7	8.0
		315	20	35.9	9.8
TRANSVERSE	100	0	20	33.1	10.9
		45	20	21.9	5.9
		90	20	29.4	7.6
		135	20	34.7	8.6
		180	20	37.8	7.7
		225	20	33.4	6.7
		270	20	25.5	8.6
		315	20	47.8	20.9
	50	0	20	38.2	11.1
		45	20	26.9	7.4
		90	20	20.8	5.7
		135	20	23.8	6.4
		180	20	34.4	8.3
		225	20	40.5	10.5
		270	20	36.5	8.5
		315	20	33.0	8.0

(continued)

TABLE 3.23 (concluded)
MALES IN SIDE POSTURE.

BOLT ORIENT	DISTANCE (% biacromial breadth)	WRENCH POSITION (degrees)	N	MEAN (foot pounds)	STD (foot pounds)
VERTICAL	100	0	20	22.2	6.0
		45	20	32.3	9.5
		90	20	45.3	12.5
		135	20	38.9	9.2
		180	20	33.5	9.3
		225	20	39.3	8.9
		270	20	37.3	10.0
		315	20	29.0	7.4
	50	0	20	22.5	6.8
		45	20	31.1	8.3
		90	20	41.2	8.8
		135	20	34.1	7.8
		180	20	35.2	9.7
		225	20	44.1	12.0
		270	20	38.8	7.5
		315	20	31.5	10.2

are; 14.2 to 47.0 and 6.9 to 23.6 for the prone posture, 15.0 to 68.4 and 10.1 to 29.6 for the supine posture, and 20.8 to 45.3 and 11.5 to 27.4 for the side posture.

Slightly more torque was obtained when subjects were positioned at the near distance than at the far distance for the prone and side postures. Distance from the bolt had no effect in the supine posture. When in the prone posture, subjects obtained more torque when the bolt was in the facing orientation than when in the vertical orientation. Orientation of the bolt had little effect when subjects were in the supine and side postures. However, the effect of wrench position was dependent on the orientation of the bolt in all three postures, and in the side posture, distance from the bolt also effected the wrench position variable.

■ **WRENCH TORQUE STUDY, C5** ■

The Effect of Various Wrench Handles on Torque Capability [6]

OBJECTIVE

To measure the effect of different wrench handle shapes and sizes on torque capability.

TEST EQUIPMENT

Torque dynamometer

3-D sonic digitizer

Computerized data acquisition system

Video recording system

CONDITIONS

Constant

- Subjects:
  Number: 18 males, 17 females
  Handedness: Right

- Clothing: Shorts, T-shirt and Air Force boots

- Testing Sessions:
  Number: 2
  Session Exertions: 30
  Benchmark: 6
  Test: 24
  Rest Period: 2 minutes

- Posture: Standing

6. Authors: C. Glenn Robbins, Donald L. Haddox, and Cheryl A. Lai, (UDRI), and Dr. Joe W. McDaniel, (AAMRL).

- Distance: 50 % of grip length
- Bolt Head Elevation: 60 % of vertical reach
- Hand Used: Right
- Direction of Rotation: Clockwise

Variables

- Tools: 4

  1/2 inch drive ratchets with 10 inch handle
  3/4 inch 6-point socket
  Cylindrical smooth handle
  (0.87 inch handle diameter)
  Cylindrical knurled handle
  (0.75 inch handle diameter)
  3/4 inch box end wrench
  Handle: 10 3/8 inch long,
  11/16 inch wide, 1/4 inch thick
  1/2 inch box end wrench
  Handle: 8 1/4 inch long,
  1/2 inch wide, 3/16 inch thick

- Bolt Orientations: 3

  Vertical
  Facing
  Transverse

- Wrench Handle Positions: 2

To measure the effect of wrench handle shape and size on torque capability, the data from the C1 study were analyzed. The two wrench handle positions which had the Best (highest) and Worst (lowest) mean values for all subjects at the 60 % Bolt Elevation, and at each Bolt Orientation, were used to determine the Wrench Handle Positions for this study.

Best:

90 degrees for Vertical and Facing orientations

180 degrees for Transverse orientation

Worst:

000 degrees for all orientations

- Hand Covering: 2

  Bare handed

  Work glove

MEASURES

- Isometric strength as the force applied to the static wrench handle by the subject. Force was measured with the torque dynamometer over a period of four seconds, and recorded in foot pounds.

- Body posture was measured with the Sonic Digitizer. The slant ranges from the microphones to the emitters, attached to the body landmarks, were recorded.

Benchmark Exertions

At the beginning and end of each session, a series of three standard exertions were performed, all with the cylindrical, smooth handled ratchet without gloves. There was one exertion in each bolt orientation. In the vertical and facing orientations, the wrench handle was at 90 degrees. In the transverse orientation, the wrench handle was at 180 degrees.

RESULTS

Tables 3.24 through 3.31 present the mean and standard deviation of each test condition. Torque was larger with gloves when using either of the two wrenches with flat handles. However, gloves did not increase the torque for the two cylindrical handles. The largest torque values occurred when subjects were using the cylindrical smooth handle. The least torque was produced with the small flat handle.

TABLE 3.24

FEMALES USING WRENCH WITH CYLINDRICAL KNURLED HANDLE

ORIENTATION OF BOLT	POSITION OF WRENCH HANDLE (degrees)	USE OF GLOVES	N	MEAN (foot pounds)	STD (foot pounds)
FACING	0	NO	17	20.3	4.1
	0	YES	17	20.4	6.0
	90	NO	17	29.1	9.0
	90	YES	17	30.9	6.4
TRANSVERSE	0	NO	17	27.7	7.3
	0	YES	17	26.5	8.1
	180	NO	17	37.5	11.7
	180	YES	17	39.5	12.8
VERTICAL	0	NO	17	16.3	4.1
	0	YES	17	16.8	4.7
	90	NO	17	34.5	10.5
	90	YES	17	35.7	10.4

TABLE 3.25

FEMALES USING WRENCH WITH CYLINDRICAL SMOOTH HANDLE

ORIENTATION OF BOLT	POSITION OF WRENCH HANDLE (degrees)	USE OF GLOVES	N	MEAN (foot pounds)	STD (foot pounds)
FACING	0	NO	17	22.1	6.0
	0	YES	17	21.1	4.4
	90	NO	17	31.5	7.5
	90	YES	17	31.6	6.3
TRANSVERSE	0	NO	17	31.0	8.6
	0	YES	17	30.8	9.6
	180	NO	17	38.8	12.9
	180	YES	17	40.4	12.6
VERTICAL	0	NO	17	18.7	6.1
	0	YES	17	18.2	5.8
	90	NO	17	38.9	12.8
	90	YES	17	37.7	12.0

TABLE 3.26
FEMALES USING WRENCH WITH LARGE FLAT HANDLE
(3/4 inch box end)

ORIENTATION OF BOLT	POSITION OF WRENCH HANDLE (degrees)	USE OF GLOVES	N	MEAN (foot pounds)	STD (foot pounds)
FACING	0	NO	17	19.6	5.9
	0	YES	17	19.7	5.6
	90	NO	17	29.9	5.3
	90	YES	17	31.5	6.8
TRANSVERSE	0	NO	17	27.6	6.4
	0	YES	17	29.7	8.5
	180	NO	17	31.7	9.7
	180	YES	17	37.4	12.8
VERTICAL	0	NO	17	17.3	5.2
	0	YES	17	18.2	5.3
	90	NO	17	28.8	9.2
	90	YES	17	37.1	14.1

TABLE 3.27
FEMALES USING WRENCH WITH SMALL FLAT HANDLE
(1/2 inch box end)

ORIENTATION OF BOLT	POSITION OF WRENCH HANDLE (degrees)	USE OF GLOVES	N	MEAN (foot pounds)	STD (foot pounds)
FACING	0	NO	17	19.8	4.0
	0	YES	17	20.3	5.6
	90	NO	17	28.8	5.6
	90	YES	17	31.2	6.5
TRANSVERSE	0	NO	17	26.5	6.7
	0	YES	17	28.1	7.9
	180	NO	17	29.4	9.6
	180	YES	17	35.6	11.4
VERTICAL	0	NO	17	18.0	4.4
	0	YES	17	19.1	5.9
	90	NO	17	28.5	8.3
	90	YES	17	35.1	10.8

TABLE 3.28
MALES USING WRENCH WITH CYLINDRICAL KNURLED HANDLE

ORIENTATION OF BOLT	POSITION OF WRENCH HANDLE (degrees)	USE OF GLOVES	N	MEAN (foot pounds)	STD
FACING	0	NO	18	27.8	8.3
	0	YES	18	28.7	8.7
	90	NO	18	47.6	19.2
	90	YES	18	46.3	21.8
TRANSVERSE	0	NO	18	32.8	12.1
	0	YES	18	36.0	15.7
	180	NO	18	55.5	17.5
	180	YES	18	57.3	19.0
VERTICAL	0	NO	18	26.1	11.6
	0	YES	18	28.1	13.4
	90	NO	18	50.2	14.7
	90	YES	18	54.4	20.2

TABLE 3.29
MALES USING WRENCH WITH CYLINDRICAL SMOOTH HANDLE

ORIENTATION OF BOLT	POSITION OF WRENCH HANDLE (degrees)	USE OF GLOVES	N	MEAN (foot pounds)	STD
FACING	0	NO	18	34.8	11.1
	0	YES	18	30.9	10.0
	90	NO	18	49.1	16.0
	90	YES	18	52.0	20.4
TRANSVERSE	0	NO	18	41.3	16.5
	0	YES	18	39.7	14.0
	180	NO	18	64.3	24.1
	180	YES	18	61.0	20.5
VERTICAL		NO	18	27.6	6.9
	0	YES	18	28.4	9.3
	90	NO	18	52.5	19.4
	90	YES	18	56.4	24.2

TABLE 3.30
MALES USING WRENCH WITH LARGE FLAT HANDLE
(3/4 inch box end)

ORIENTATION OF BOLT	POSITION OF WRENCH HANDLE (degrees)	USE OF GLOVES	N	MEAN (foot pounds)	STD (foot pounds)
FACING	0	NO	18	27.3	8.7
	0	YES	18	26.5	11.6
	90	NO	18	43.0	13.5
	90	YES	18	46.2	17.3
TRANSVERSE	0	NO	18	33.1	10.8
	0	YES	18	32.3	16.9
	180	NO	18	42.7	15.5
	180	YES	18	43.8	18.5
VERTICAL	0	NO	18	25.9	11.1
	0	YES	18	25.8	9.9
	90	NO	18	40.0	11.6
	90	YES	18	46.8	18.2

TABLE 3.31
MALES USING WRENCH WITH SMALL FLAT HANDLE
(1/2 inch box end)

ORIENTATION OF BOLT	POSITION OF WRENCH HANDLE	USE OF GLOVES	N	MEAN (foot pounds)	STD (foot pounds)
FACING	0	NO	18	26.8	10.6
	0	YES	18	26.3	10.3
	90	NO	18	41.5	14.7
	90	YES	18	45.3	15.1
TRANSVERSE	0	NO	18	31.1	9.4
	0	YES	18	36.4	16.2
	180	NO	18	35.7	11.3
	180	YES	18	41.8	20.7
VERTICAL	0	NO	18	25.2	10.1
	0	YES	18	26.5	10.0
	90	NO	18	40.7	17.6
	90	YES	18	47.3	20.0

■ WRENCH TORQUE STUDY, C6 ■

Wrench Torque as a Function of Bolt Orientation, Distance, Wrench Position, and Handle Length[7]

OBJECTIVE

To investigate wrench torque capabilities at the far extremes of reach. Also, to determine the effect on torque of wrenches of different lengths.

TEST EQUIPMENT

Torque Dynamometer

Computerized Data Acquisition System

CONDITIONS

Constants

- Subjects:
  Number: 26 males, 26 females
  Handedness: Right

- Clothing: Street clothes

- Posture: Standing

- Testing Sessions:
  Number: 3
  Session Exertions: 34
  Benchmark: 6
  Test: 28
  Rest Period: 2 minutes

7. C. Glenn Robbins, Laura Meek, and John W. Quinn. (UDRI), Dr. S. Deivayangam, Robert Finegan, Thomas Weaver and Ratnavelpandian Kanthasamy, (TennTU), and Dr. Joe W. McDaniel, (AAMRL).

- Bolt Head Elevation: 60 % of vertical reach

- Hand Used: Right hand on wrench handle. Left not placed on wrench handle for this study. Left hand grasps adjoining structure.

- Hand Covering: Bare handed

Variables

- Tool and Handle Length: 3

  1/2 inch drive ratchet, 7 9/16 inch handle, with 3/4 inch 6-point socket

  1/2 inch drive ratchet, 10 1/4 inch handle, with 3/4 inch 6-point socket

  1/2 inch drive ratchet, 15 inch handle, with 3/4 inch 6-point socket

- Distance: 3

  50 % of grip length
  100 % of grip length
  125 % of grip length

- Bolt Orientation: 3

  Vertical
  Facing
  Transverse

- Wrench Handle Positions: 8
    - 0 degrees
    - 45 degrees
    - 90 degrees
    - 135 degrees
    - 180 degrees
    - 225 degrees
    - 270 degrees
    - 315 degrees

- Direction of Rotation: 2
    - Clockwise
    - Counterclockwise

NOTE: Exertions for all combinations were not tested. Table 3.26 shows the combinations of variables used to identify the exertions tested.

MEASURES

- Isometric strength as the force applied to the static wrench handle by the subject. Force was measured with the torque dynamometer over a period of four seconds, and recorded in foot pounds.

Anthropometric Measurements

Age	Sex
Race	Weight
Stature	Sitting Height
Trochanteric Height	Tibiale Height
Acromion-Radiale Length	Radiale-Stylion Length
Biacromial Breadth	Bitrochanteric Breadth
Lateral Malleolus Height	Grip Length
Vertical Reach	Grip Strength Right
Grip Strength Left	

TABLE 3.32
EXPERIMENTAL VARIABLE COMBINATIONS

BOLT ORIENTATION	DISTANCE % OF GRIP LENGTH	WRENCH HANDLE	WRENCH HANDLE LENGTH	DIRECTION OF TORQUE
VERTICAL [V]	50	90 180 270	7 9/16 10 1/4 15	CW CCW
	100 125	135 180 225	10 1/4	CW CCW
FACING	50	0 90 180	7 9/16 10 1/4 15	CW CCW
	100	45 90 135	10 1/4	CW CCW
TRANSVERSE	50	0 180 270	7 9/16 10 1/4 15	CW CCW
	100 125	225 270 325	10 1/4	CW CCW

Benchmark Exertions

At the beginning and end of each session, three standard exertions were performed. All used the 10 1/4 inch wrench at a bolt elevation of 60% of vertical reach, a distance of 50% of grip length, a wrench handle position of 90 degrees, and in the standing posture. One exertion was performed at each of the three bolt orientations: vertical, facing, and transverse.

RESULTS

Tables 3.33 through 3.40 present the means, standard deviations and sample size of each exertion. Males obtained higher torque values than females in all conditions. The mean torque values for males ranged from 8.5 to 60.1, and the range for females was 5.9 to 30.7.

Highest torque values were obtained in the Transverse orientation. In the Transverse orientation the highest values were with a wrench position of 270 degrees. In the Facing and Vertical orientations, subjects applied the most torque with the wrench in the 90 degree position. In general, the most torque was obtained with subject at the nearest distance to the bolt. There was no significant difference between the two farther distances. Also, as handle length increased, the amount of torque recorded increased. When the torque values were adjusted to compensate for the handle length, no differences were found.

TABLE 3.33
FEMALES, BOLT FACING

DISTANCE (% standing vertical reach)	WRENCH LENGTH (inches)	WRENCH POSITION (degrees)	N	MEAN TIGHTEN (foot pounds)	STD TIGHTEN (foot pounds)	MEAN LOOSEN (foot pounds)	STD LOOSEN (foot pounds)
50	15	0	26	14.8	3.5	14.2	2.9
		90	26	21.6	5.1	18.2	5.0
		180	26	15.3	4.1	16.6	4.0
	10.25	0	26	10.9	2.2	10.7	2.3
		90	26	15.7	2.9	13.3	4.2
		180	26	11.5	2.3	11.7	2.7
	7.5	0	26	8.6	2.0	8.0	2.1
		90	26	11.6	2.2	10.6	3.1
		180	26	9.7	2.4	7.7	2.4
100	10.25	45	26	12.8	2.7	9.3	2.9
		90	26	14.2	3.0	8.8	3.2
		135	26	12.5	2.6	9.0	2.7

TABLE 3.34
FEMALES, BOLT TRANSVERSE

DISTANCE (% standing vertical reach)	WRENCH LENGTH (inches)	WRENCH POSITION (degrees)	N	MEAN TIGHTEN (foot pounds)	STD TIGHTEN (foot pounds)	MEAN LOOSEN (foot pounds)	STD LOOSEN (foot pounds)
50	15.0	0	26	15.1	6.1	18.7	5.4
		180	26	24.1	7.4	16.0	5.1
		270	26	30.7	15.9	17.2	6.5
	10.25	0	26	10.5	4.0	12.6	3.2
		180	26	16.3	4.6	10.8	3.8
		270	26	20.9	7.8	11.9	3.7
	7.5	0	26	7.9	2.4	9.4	2.1
		180	26	11.2	3.4	9.1	2.7
		270	26	13.9	5.4	8.2	2.7
100	10.25	225	26	13.9	3.9	15.3	4.4
		270	26	16.2	6.2	11.8	2.8
		315	26	14.8	4.7	14.8	4.1
125	10.25	225	26	13.1	2.7	17.3	4.8
		270	26	14.7	4.5	12.4	4.7
		315	26	16.1	4.4	15.6	4.9

TABLE 3.35
FEMALES, BOLT VERTICAL

DISTANCE (% standing vertical reach)	WRENCH LENGTH (inches)	WRENCH POSITION (degrees)	N	MEAN TIGHTEN (foot pounds)	STD TIGHTEN (foot pounds)	MEAN LOOSEN (foot pounds)	STD LOOSEN (foot pounds)
50	15.0	90	26	20.0	6.4	15.1	6.0
		180	26	19.2	5.9	18.7	5.2
		270	26	11.7	4.7	17.6	4.6
	10.25	90	26	13.3	4.1	11.3	3.0
		180	26	13.2	3.8	12.9	2.8
		270	26	8.5	4.2	12.7	3.2
	7.5	90	26	10.4	2.9	9.1	2.5
		180	26	9.7	2.4	9.1	2.3
		270	26	5.9	2.6	9.7	1.8
100	10.25	135	26	12.8	3.4	14.3	4.3
		180	26	12.3	3.6	11.6	2.8
		225	26	12.8	3.2	12.4	2.8
125	10.25	135	26	11.8	3.0	15.0	4.7
		180	26	12.1	3.5	11.8	3.7
		225	26	13.4	3.4	11.4	2.4

TABLE 3.36
MALES, BOLT FACING

DISTANCE (% standing vertical reach)	WRENCH LENGTH (inches)	WRENCH POSITION (degrees)	N	MEAN TIGHTEN (foot pounds)	STD TIGHTEN (foot pounds)	MEAN LOOSEN (foot pounds)	STD LOOSEN (foot pounds)
50	15	0	26	22.6	6.4	22.3	7.8
		90	26	41.0	15.6	33.3	16.8
		180	26	27.1	11.0	28.7	12.1
	10.25	0	26	16.8	5.3	16.7	5.6
		90	26	27.6	12.3	25.9	13.2
		180	26	20.3	9.7	20.0	7.1
	7.5	0	26	12.4	3.6	12.2	4.4
		90	26	20.0	9.3	18.4	9.7
		180	26	15.6	5.2	13.3	5.0
100	10.25	45	26	20.7	8.1	16.8	10.0
		90	26	23.9	9.2	16.3	7.6
		135	26	21.3	7.5	15.4	6.7

TABLE 3.37
MALES, BOLT TRANSVERSE

DISTANCE (% standing vertical reach)	WRENCH LENGTH (inches)	WRENCH POSITION (degrees)	N	MEAN TIGHTEN (foot pounds)	STD TIGHTEN (foot pounds)	MEAN LOOSEN (foot pounds)	STD LOOSEN (foot pounds)
50	15.0	0	26	20.5	6.1	29.7	9.3
		180	26	36.8	10.7	23.7	8.7
		270	26	61.1	31.0	33.3	13.1
	10.25	0	26	14.3	3.7	19.2	5.3
		180	26	25.1	6.5	17.7	5.2
		270	26	40.0	19.0	20.7	8.2
	7.5	0	26	12.1	5.2	13.4	3.8
		180	26	16.6	4.3	14.1	4.0
		270	26	24.6	11.9	15.2	7.9
100	10.25	225	26	19.4	5.5	22.6	6.0
		270	26	28.1	14.2	21.5	9.9
		315	26	26.3	9.9	26.3	9.9
125	10.25	225	26	15.5	4.1	24.8	6.0
		270	26	23.4	6.8	20.5	7.7
		315	26	27.6	9.5	25.6	10.1

TABLE 3.38
MALES, BOLT VERTICAL

DISTANCE (% standing vertical reach)	WRENCH LENGTH (inches)	WRENCH POSITION (degrees)	N	MEAN	STD	MEAN	STD
				TIGHTEN (foot pounds)		LOOSEN (foot pounds)	
50	15.0	90	26	28.5	6.6	24.7	6.4
		180	26	31.2	9.0	29.1	8.0
		270	26	17.0	5.5	25.6	5.4
	10.25	90	26	20.0	5.2	19.9	5.1
		180	26	22.0	5.5	19.7	5.1
		270	26	11.1	3.0	19.3	4.4
	7.5	90	26	15.2	5.3	14.1	3.4
		180	26	15.2	3.9	14.4	4.2
		270	26	8.5	2.0	15.5	4.3
100	10.25	135	26	17.6	4.6	23.6	5.5
		180	26	20.0	5.9	17.2	5.3
		225	26	20.5	5.2	18.7	5.6
125	10.25	135	26	16.1	4.2	22.8	5.5
		180	26	19.4	5.5	16.6	5.1
		225	26	20.9	5.6	17.3	4.9

TABLE 3.39
CLOSE VS FAR REACH (10.25 INCH WRENCH), FEMALES

DISTANCE (% standing vertical reach)	WRENCH POSITION (degrees)	N	MEAN TIGHTEN (foot pounds)	STD TIGHTEN (foot pounds)	MEAN LOOSEN (foot pounds)	STD LOOSEN (foot pounds)
BOLT ORIENTATION, FACING						
50	90	26	15.7	2.9	13.3	4.2
100	90	26	14.2	3.0	8.8	3.2
BOLT ORIENTATION, TRANSVERSE						
50	270	26	20.9	7.8	11.9	3.7
100	270	26	16.2	6.2	11.8	2.8
125	270	26	14.7	4.5	12.4	4.7
BOLT ORIENTATION, VERTICAL						
VERT 50	180	26	13.2	3.8	12.9	2.8
125	180	26	12.1	3.5	11.8	3.7
100	180	26	12.3	3.6	11.6	2.8

TABLE 3.40
CLOSE VS FAR REACH (10.25 INCH WRENCH), MALES

DISTANCE (% standing vertical reach)	WRENCH POSITION (degrees)	N	MEAN TIGHTEN (foot pounds)	STD TIGHTEN (foot pounds)	MEAN LOOSEN (foot pounds)	STD LOOSEN (foot pounds)
BOLT ORIENTATION, FACING						
50	90	26	27.6	12.3	25.9	13.2
100	90	26	23.9	9.2	16.3	7.6
BOLT ORIENTATION, TRANSVERSE						
50	270	26	40.0	19.0	20.7	8.2
100	270	26	28.1	14.2	21.5	9.9
125	270	26	23.4	6.8	20.5	7.7
BOLT ORIENTATION, VERTICAL						
50	180	26	22.0	5.5	19.7	5.1
100	180	26	20.0	5.9	17.2	5.3
125	180	26	19.4	5.5	16.6	5.1

Wrench Torque Capabilities and Accessibility, with Workspace Limited by Barriers[8]

OBJECTIVE

To investigate wrench torque capabilities and working envelopes with barriers limiting accessibility to the workspace.

In this study, barriers were used to simulate the limitations on torque capability due to depth of reach from the edge of a work area and reaching around and over intervening objects. Barriers are classed as two types; Body and Box.

The Body barrier consisted of a horizontal bar (relative to the floor) which could be moved vertically and horizontally. The bar was positioned above the floor at 90 % of the subject's acromion height, which approximates chest height. The subject stood facing the bolt, with the bolt head aligned with the mid-sagittal plane. Subjects could lean into the bar to attain maximum reach but were required to keep both feet flat on the floor. The horizontal movement, toward and away from the bolt head, simulated different reach depths to the point of work.

The Box barriers consisted of one horizontal and one vertical bar, both positioned half way between the Body barrier and the bolt head. The vertical bar moved in four horizontal directions, right and left of the bolt head, and toward and away from the bolt head. This barrier was placed a prescribed distance to the right of the bolt head to simulate reaching "around" an obstructing object to the work point. The movement toward and away from the bolt head was used to position the bar at the mid-point between the Body barrier and the work point.

8. Authors: C. Glenn Robbins, William H. Harper, Laura Meek and John W. Quinn, (UDRI), and Dr. Joe W. McDaniel, (AAMRL).

The horizontal bar was positioned to simulate reaching "over" an obstructing object. The horizontal movement, toward and away from the bolt head was used to position the bar at the mid-point between the Body barrier and the work point. The vertical movement allowed the barrier to be set at a height that required the subject to reach "over" to the work point. For both reach types, "around" and "over", the subject maintained the same alignment of the bolt head and mid-sagittal plane as when the Box barrier was not used. That is, no movement to the right for the "around" reach, and the feet were kept flat on the floor for the "over" reaches.

The torque dynamometer was used to measure the work envelope for combination of variables. The electrical brake was set for a constant five pounds of resistance.

TEST EQUIPMENT

Torque dynamometer, equipped with electrical brake (to provide constant resistance while measuring work envelope) and potentiometers (to measure wrench handle position)

Computerized data acquisition system

3-D sonic digitizer

Video recording system - not used for all subjects. Priority for use was given to Push-Pull studies in progress at the same time.

PROCEDURES

The procedures were somewhat different than in other wrench torque studies. Subjects were in the standing posture, with the chest placed against the body barrier and the bolt head was centered on the subject's mid-sagittal plane. The subject was allowed to lean into the barrier, but maintained both feet flat on the floor, to obtain the maximum reach. The wrench handle was grasped with the right hand and the left hand grasped the body barrier structure. The edge of the hand farthest from the bolt head was aligned with the end of the wrench handle. The work envelope was measured with a clockwise motion.

While measuring the work envelope, the subject was allowed to rotate the hand around, or reverse the grip on the wrench handle to obtain the maximum work envelope. For example, if the initial grasp was with the palm down, the hand could be rotated around the handle so that the grasp was palm up as the wrench was moved. Or, if the initial grasp was with the thumb nearest the bolt head, the grip could be reversed (thumb away from the bolt head). The hand could be rotated or reversed as many times as required to obtain the maximum work envelope.

The Far body barrier distance was determined by moving the body barrier away from the bolt head until a 25 to 35 degree arc of movement was all that could be attained. The force applied to the wrench handle position at the mid-point of this arc was measured. For example, if the work envelope was thirty degrees, starting at 102 degrees and ending at 132 degrees, the wrench handle position was tested at 117 degrees. For the other two body barrier distances (Middle and Close) the body barrier was set at the prescribed percentage of the subject's arm length from the bolt head, and the work envelope was measured. If the subject could turn the wrench through a full 360 degrees, the force applied was measured at the 0, 90, 180 and 270 wrench handle positions. If a full 360 degrees of movement was not available, the program recorded the start and end points of the arc of movement. The wrench handle positions tested were the 45 degree positions nearest the beginning and end of the arc, if they were within, or not more than five degrees outside, the arc. Any 90 degree positions (0, 90, 180 and 270) that were within the arc were tested.

For example, if a work envelope of 173 degrees, starting at 56 and ending at 229 degrees, was recorded, the wrench handle positions tested would be 90, 180 and 225 degrees. The 45 degree position would not be tested as it lies more than 5 degrees outside the arc. The 225 degree position is tested as it is the nearest 45 degree position to the other end of the arc, and is within the arc.

A second example is a work envelope of 128 degrees, starting at 003 and ending at 131 degrees. The wrench handle positions tested are 0, 90 and 135 degrees. 0 and 135 degrees are the 45 degree points outside, but within 5 degrees of, the ends of the arc.

Basically, the same criteria were applied to the selection of wrench handle positions for the various Box barrier interference levels. With the Body barrier set at the two levels (Middle and Close), the vertical box barrier was moved to the right of the bolt head until an arc of 25 to 35 degrees was the maximum work envelope for the "around" reach. The mid-point of that arc was the wrench handle position tested for the High interference level. For the Forty, Medium and Low interference levels, the vertical barrier was set to the right of the bolt head at the prescribed distance, the work envelopes measured and the same criteria used to determine the wrench handle positions to be tested.

With the Body barrier set at the Middle and Close positions the horizontal box barrier was positioned to require the subject to reach "over" the barrier to the wrench handle. The High interference level was established by raising the horizontal box barrier until a 25 to 35 degree arc was the maximum obtainable work envelope. The mid-point of that arc was the wrench handle position tested. The horizontal box barrier was set the prescribed distance above the floor for the Medium and Low interference levels and the work envelope measured. The same criteria were applied for selection of the wrench handle positions to be tested.

The wrench handle positions to be tested for any set of variables could range from one, for the Far body and High box barriers, to five for a work envelope including two 45 and three 90 degree positions. The torque dynamometer was locked at each tested wrench handle position to measure the static force applied.

CONDITIONS

Constants

- Subjects:
  Number: 20 males
  Handedness: Right

- Clothing: Shorts, T-shirts and Air Force boots

- Testing Sessions:
  Number: 4
  Session Exertions: Variable
  Benchmark: 6
  Test: Variable
  Rest Period: 2 minutes

- Tools: 1/2 drive ratchet with 10 inch handle.
  3/4 inch 6-point socket.

- Posture: Standing

- Bolt Head Elevation: 60 % of vertical reach

- Hand Used: Right. Right hand applied torque, left hand grasped body barrier structure.

- Hand Covering: Bare handed

- Direction of Torque: Clockwise

- Body Barrier Height: 90 % of acromion height

- Body Barrier Distance: When used, the box barrier was always positioned half way between the body barrier and the bolt head.

Variables

- Bolt Orientation: 3
  - Vertical
  - Facing
  - Transverse

- Body Barrier Distance: 3
  - Far: (25 to 35 degree arc)
  - Middle: (65 % arm length)
  - Close: (35 % arm length)

- Box Barrier: 2
  - Used
  - Nor used

- Box Barrier Interference Level: 4

    High (25 to 35 degree arc)

    Forty

        40 % arm length for "around",

        Facing orientation only

    Medium

        70 % vertical reach for "over"

        30 % arm length for "around"

    Low

        65 % vertical reach for "over"

        20 % arm length for "around"

    None

        Box barrier not used for "straight" reaches.

- Reach Types: 3

    Straight

    Over

    Around

- Wrench Handle Position: Variable

    0 degrees

    |

    |

    359 degrees

    For the Far body barrier settings and for the High box barrier interference settings, the wrench handle position at the mid-point of the arc was tested.

    For the other barrier settings, the following 45 and/or 90 degree positions were tested. (The 45 degree positions were defined as 0, 45, 90, 135, 180, 225, 270, and 315. The 90 degree positions were defined as 0, 90, 180, and 270).

The 45 degree positions nearest the beginning and end of the arc (within the arc or no more than 5 degrees outside the arc.)

The 90 degree positions within the arc.

In those barrier configurations that allowed the subject to turn the wrench a full 360 degrees, the four 90 degree positions were tested.

MEASURES

- Isometric strength as the force applied to the wrench handle by the subject. Force was measured with the torque dynamometer over a period of four seconds, and recorded in foot pounds.

- Work envelope (degrees of wrench turn)

- Body posture was measured with the Sonic Digitizer. The slant ranges from the microphones to the emitters, attached to the body landmarks, were recorded.

Anthropometric Landmarks

15 body landmarks for sound emitter placement:

- Right acromion
- Right humeral epicondyle
- Dorsal surface of right wrist, midway between the ulnar and radial styloid

- Right trochanter
- Right lateral epicondyle femur
- Right lateral malleolus
- Left acromion
- Left humeral epicondyle
- Dorsal surface of left wrist, midway between the ulnar and radial styloid
- Left trochanter
- Left lateral epicondyle femur
- Left lateral malleolus
- Cervicale
- Suprasternale
- L3 Vertebra

Benchmark Exertions

Three standard exertions were performed at the beginning and end of each session, with no barriers. All were performed standing at 50% grip length from bolt head. The bolt elevation was 60% of vertical reach. The wrench position was 90 degrees. The bolt orientations were vertical, facing, and transverse; in that order.

RESULTS:

Tables 3.41 through 3.42 show the means for the largest torque values obtained for each of the combinations of distance and interference level for facing, transverse, and vertical bolt orientations. In all three bolt orientations there was a significant decrease in torque as the distance from the subject to the bolt increased. Also, in the vertical and transverse orientations, there was a significant decrease in torque as the level of interference increased. In the facing orientation, only the highest level of interference significantly decreased the amount of torque.

TABLE 3.41
BOLT FACING ORIENTATION

DISTANCE FROM BOLT	TYPE OF REACH	BOX BARRIER INTERFERENCE LEVEL NONE	LOW	MID	40%	HIGH
CLOSE	STRAIGHT	32.9				
	OVER	.	33.3	29.0	.	13.7
	AROUND	.	33.6	35.1	33.6	18.8
MIDDLE	STRAIGHT	23.8				
	OVER	.	23.1	22.6	.	10.0
	AROUND	.	25.9	27.6	25.9	13.4
FAR	STRAIGHT	9.2				

TABLE 3.42
BOLT TRANSVERSE ORIENTATION

DISTANCE FROM BOLT	TYPE OF REACH	BOX BARRIER INTERFERENCE NONE	LOW	MID	HIGH
CLOSE	STRAIGHT	53.0			
	OVER	.	34.7	31.7	23.1
	AROUND	.	51.8	43.3	11.0
MIDDLE	STRAIGHT	59.1			
	OVER	.	33.6	29.7	23.4
	AROUND	.	43.6	25.7	9.5
FAR	STRAIGHT	10.9			

TABLE 3.43
BOLT VERTICAL ORIENTATION

DISTANCE FROM BOLT	TYPE OF REACH	BOX BARRIER INTERFERENCE NONE	LOW	MID	HIGH
CLOSE	STRAIGHT	53.7			
	OVER	.	45.2	38.1	9.7
	AROUND	.	52.6	53.2	15.2
MIDDLE	STRAIGHT	63.1			
	OVER	.	38.2	26.0	9.0
	AROUND	.	54.4	27.6	13.6
FAR	STRAIGHT	10.2			

Torque Strength With Ratchet Wrench.
The Effect of an Extension and Universal Joint[9]

OBJECTIVE

To determine if the use of an extension and universal joint on a ratchet wrench causes a significant reduction in torque capability. The application of torque is somewhat different than with a ratchet wrench and socket only. With the ratchet and socket only, the bolt resists most of the force applied. With a universal and extension, both hands must be used, with one (the right in this study) applying the force to the ratchet handle and the other supplying the resistive force.

TEST EQUIPMENT

Torque dynamometer

Computerized data acquisition system

CONDITIONS

Constants

- Subjects:
  Number: 20 males, 20 females

- Clothing: Street Clothes

- Testing Sessions:
  Number: 3
  Session Exertions: 30
  Benchmark: 6
  Test: 24
  Rest Period: 2 minutes

9. C. Glenn Robbins and John W. Quinn (UDRI), Dr. S. Deivanayagam, Robert Finegan, Thomas Weaver and Ratnavelpandian Kanthasamy (TennTU), and Dr. J. W. McDaniel (AAMRL).

- Posture: Standing

- Distance: 50 % of grip length. When extension and universal for exertions in the Facing bolt orientation, the length of the extension and universal joint was added to 50 % of grip length so that the body and wrench relationship corresponded to that for the the same exertions without the extension and universal joint. Also, for the Transverse orientation exertions with extension and universal joint, the feet markers (reference Figure 3.12) were moved to the right to maintain the body and wrench relationship.
- Hand Used: Right, with left hand on wrench head

- Hand Covering: Bare handed

- Direction of Rotation: Clockwise

<u>Variables</u>

- Tools: 2

  1/2 inch drive ratchet, 10 1/4 inch handle, with 3/4 inch 6-point socket.

  1/2 inch drive ratchet, 10 1/4 inch handle, with 10 extension, universal joint, and 3/4 inch 6-point socket.

NOTE: When the extension and universal joint were used, subjects were instructed to keep the universal joint straight (the extension and universal joint axes aligned with the bolt axis) with the left hand while applying force with the right hand. The torque lost (equal to the cosine of the deflection angle) when working with the universal joint at an angle (the normal working situation) can be calculated.

- Bolt Head Elevation: 3
  - 35 % of vertical reach
  - 60 % of vertical reach
  - 85 % of vertical reach

NOTE: For exertions with the extension and universal joint in the Vertical bolt orientation, the percentages of vertical length were reduced by the length of the extension and universal joint. The relationship of the body and wrench then corresponded to those for the same exertions without the extension and universal joint.

- Bolt Head Orientations: 3
  - Vertical
  - Facing
  - Transverse

- Wrench Handle Positions: 4
  - 0 degrees
  - 90 degrees
  - 180 degrees
  - 270 degrees

MEASURES

- Isometric strength as the force applied to the static wrench handle by the subject. Force was measured with the torque dynamometer over a period of four seconds, and recorded in foot pounds.

Anthropometric Measurements

Age	Sex
Race	Weight
Stature	Sitting Height

Trochanteric Height	Tibiale Height
Acromion-Radiale Length	Radiale-Stylion Length
Biacromial Breadth	Bitrochanteric Breadth
Lateral Malleolus Height	Grip Length
Vertical Reach	Grip Strength Right
Grip Strength Left	

Benchmark Exertions

Three benchmark exertions were made at the beginning and end of each session. The exertions were in the Vertical, Facing and Transverse bolt orientations, ratchet and socket only, at 60 % of vertical reach, and at the 90 degree wrench handle position.

RESULTS

Tables 3.44 and 3.45 present the means, standard deviations, and sample size for each exertion. Males produced more torque than females. Both males and females produced less torque when using the extension and universal joint than when using only the ratchet wrench with socket. The range of mean values attained for the individual exertions when using the extension and universal joint was 66.2 % to 76.5 % for males, and 67.5 % to 88.2 % for females, of the mean values for the same exertions using the ratchet and socket only. Subjects produced more torque when the bolt was in the transverse orientation, and when the elevation of the bolt was in the middle and low height positions. The effect of wrench position was influenced by both the orientation and elevation of the bolt.

TABLE 3.44
MEANS AND STANDARD DEVIATIONS FOR FEMALES
WITH UNIVERSAL AND EXTENSION
AND WITH SOCKET

BOLT ORIENT	BOLT HEIGHT (% SVR)	WRENCH POSITION (degrees)	UNIVERSAL & EXTENSION N	UNIVERSAL & EXTENSION MEAN (foot pounds)	UNIVERSAL & EXTENSION STD (foot pounds)	SOCKET N	SOCKET MEAN (foot pounds)	SOCKET STD (foot pounds)
FACING	35%	000	20	13.5	5.0	20	15.6	5.1
		090	20	22.3	7.7	20	26.3	6.8
		180	20	12.8	2.7	20	15.1	4.3
		270	20	15.1	3.8	20	19.4	4.7
	60%	000	20	11.4	3.1	20	14.0	3.2
		090	20	15.1	2.9	20	17.3	4.6
		180	20	15.1	2.8	20	16.7	5.1
		270	20	10.5	2.5	20	14.2	3.7
	85%	000	19	11.8	3.1	20	13.0	2.7
		090	20	15.4	3.3	20	24.1	6.9
		180	20	14.9	3.3	20	18.2	5.3
		270	20	7.7	2.3	20	13.6	4.0
TRANS-VERSE	35%	000	20	15.9	2.3	20	19.9	5.4
		090	20	17.1	3.8	20	21.9	5.2
		180	20	16.8	2.3	20	21.5	4.3
		270	20	23.2	5.7	20	27.9	7.8
	60%	000	20	17.0	2.8	20	19.5	6.3
		090	20	13.5	2.4	20	14.7	3.0
		180	20	19.6	3.4	20	25.9	6.8
		270	20	16.2	3.7	20	21.3	5.0
	85%	000	20	11.5	2.2	20	12.2	2.5
		090	20	19.0	3.8	20	23.6	5.8
		180	20	17.6	3.6	20	22.8	6.2
		270	20	15.6	3.0	20	16.4	3.1
VERTICAL	35%	000	20	10.7	2.2	20	13.0	2.5
		090	20	14.0	2.9	20	20.3	4.9
		180	20	14.3	4.3	20	19.6	4.0
		270	20	10.4	2.0	20	12.4	2.9
	60%	000	20	11.4	1.3	20	11.4	1.4
		090	20	18.7	6.0	20	23.4	5.9
		180	20	14.9	3.4	20	19.9	4.8
		270	20	12.4	3.4	20	15.6	3.1
	85%	000	20	9.3	1.8	20	12.6	3.0
		090	20	16.9	4.7	20	21.0	6.4
		180	20	11.0	2.3	20	13.8	2.2
		270	20	11.3	2.7	20	14.2	3.2

TABLE 3.45
MEANS AND STANDARD DEVIATIONS FOR MALES
WITH UNIVERSAL AND EXTENSION
AND WITH SOCKET

BOLT ORIENT	BOLT HEIGHT (% SVR)	WRENCH POSITION (degrees)	UNIVERSAL & EXTENSION N	MEAN (foot pounds)	STD	SOCKET N	MEAN (foot pounds)	STD
FACING	35%	000	20	25.1	7.0	20	28.6	8.2
		090	20	47.6	13.5	20	60.8	24.4
		180	20	28.0	8.5	20	30.3	9.0
		270	20	27.3	7.0	20	38.7	11.1
	60%	000	20	24.5	8.3	19	26.7	8.4
		090	20	27.8	6.1	20	34.2	8.7
		180	20	32.5	11.1	20	36.5	12.2
		270	20	17.6	4.6	20	24.3	6.4
	85%	000	20	22.4	4.9	20	24.9	4.8
		090	20	32.5	10.7	20	56.5	20.8
		180	20	29.7	7.1	20	38.0	8.9
		270	20	13.9	3.2	20	24.4	7.6
TRANS-VERSE	35%	000	20	29.8	6.7	20	37.5	9.6
		090	19	27.6	7.0	20	35.4	9.1
		180	20	34.1	8.5	20	45.9	10.0
		270	20	42.3	12.4	20	63.0	22.7
	60%	000	20	33.7	10.5	20	35.0	7.3
		090	20	26.9	6.9	20	31.0	10.0
		180	20	40.0	10.4	20	51.9	17.2
		270	20	33.1	8.0	20	49.2	13.3
	85%	000	20	20.0	4.2	20	21.1	4.6
		090	20	38.1	10.5	20	47.1	9.3
		180	20	33.0	6.6	20	43.2	10.1
		270	20	29.6	7.5	20	35.7	9.0
VERTICAL	35%	000	20	21.9	6.3	20	24.9	5.4
		090	20	29.4	10.3	20	42.2	12.2
		180	20	31.4	8.4	20	41.5	10.4
		270	20	20.6	5.4	20	22.2	6.6
	60%	000	20	22.6	6.7	20	23.7	6.6
		090	18	40.2	15.4	19	45.1	16.6
		180	20	32.5	10.9	19	39.7	9.4
		270	20	20.8	5.9	20	29.2	7.3
	85%	000	20	16.4	4.0	20	21.1	5.6
		090	20	33.0	9.0	20	39.4	10.8
		180	19	23.7	6.1	20	28.3	6.1
		270	20	19.0	5.3	19	24.4	6.2

■ WRENCH TORQUE STUDY, C9 ■

Maximum Wrench Torque Capabilities,
with Bolt at Off-axis Orientations[10]

OBJECTIVE

To collect wrench torque data between the Vertical and Facing, and Vertical and Transverse, bolt orientations.

TEST EQUIPMENT

Torque dynamometer

Computerized data acquisition system

CONDITIONS

Constants

- Subjects:

  Number: 20 males, 20 females - Session 1
  15 males, 13 females - Session 2

  NOTE: Subjects in Session 2 all completed Session 1.

- Handedness: Right

- Clothing: Street clothes and Air Force boots

- Testing Sessions:

	Session 1	Session 2
Number: 2		
Session Exertions:	36	20
Benchmark:	4	4
Test:	32	16

Rest Period: 2 minutes

10. Authors: C. Glenn Robbins, Donald L. Haddox, William H. Harper and John W. Quinn (UDRI), and Dr. Joe W. McDaniel (AAMRL)

NOTE: Session 1 exertions were all clockwise and Session 2 exertions were all counterclockwise. Exertions were randomized by session.

- Tools: 1/2 inch drive ratchet, 10 inch handle, with 3/4 inch 6-point socket.

- Posture: Standing

- Distance: 50 % of grip length

- Bolt Head Elevation: 60 % of vertical reach

- Hand Used: Right

- Hand Covering: Bare handed

Variables

- Bolt Orientation: 4

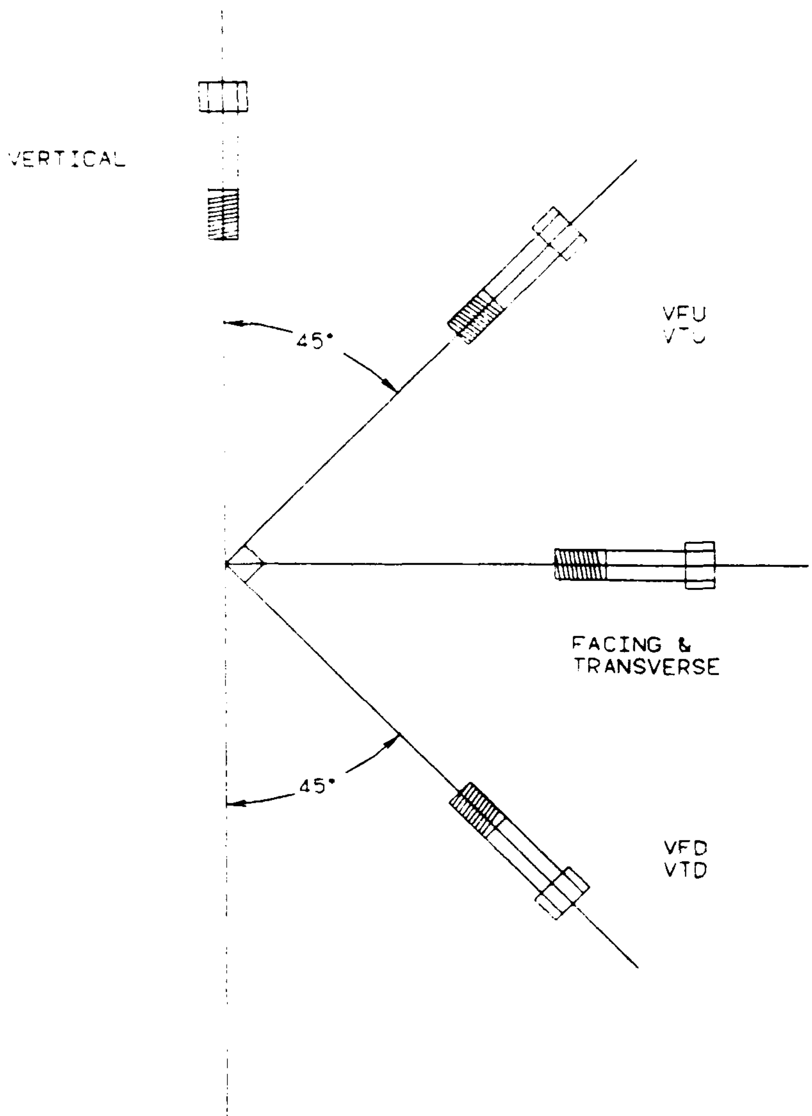
The bolt orientations are somewhat different than for the other studies. Figure 3.15 depicts the variations in bolt orientations.

Midway between vertical and facing, bolt head pointing up

Midway between vertical and facing, bolt head pointing down

Midway between transverse and vertical, bolt head pointing up

Midway between transverse and vertical, bolt head pointing down



For the VFU and VFD bolt orientations subjects were positioned as in the Vertical and Facing orientations (Figures 3.3 and 3.4).

For the VTU and VTD bolt orientations subjects were positioned as in the Transverse orientation (Figure 3.5).

Figure 3.15. Off-Axis Bolt Orientations

- Wrench Handle Positions: 8

0 degrees	45 degrees*
90 degrees	135 degrees*
180 degrees	225 degrees*
270 degrees	315 degrees*

* These wrench handle positions used only for the clockwise exertions in Session 1.

- Direction of Rotation: 2
  Clockwise
  Counterclockwise

MEASURES

- Isometric strength as the force applied to the static wrench handle by the subject. Force was measured with the torque dynamometer over a period of four seconds, and recorded in foot pounds.

Benchmark Exertions

At both the beginning and the end of each session two standard exertions were performed. Bolt orientation was Facing, at the 60 % Bolt Head Elevation. One was performed with the Wrench Handle Position at 0 degrees, and the other at 90 degrees.

RESULTS

Tables 3.46 and 3.47 present the means, standard deviations, and sample size for each exertion. Males produced more torque than females in all conditions. The mean torque values ranged from 28.2 to 69.4 for males, and from 13.9 to 36.3 for females. Of the bolt orientations used, subjects produced the most torque when the bolt was at the Midway between Vertical and Facing, Bolt Head Pointing Up (VFU) orientation.

TABLE 3.46
MEANS AND STANDARD DEVIATIONS WITH BOLT ORIENTATION
MIDWAY BETWEEN VERTICAL AND FACING

BOLT ORIENT	WRENCH POSITION (degrees)	FORCE DIRECTION	N	FEMALE MEAN (foot	STD pounds)	N	MALE MEAN (foot	STD pounds)
VFD	000	CCW	13	16.9	5.5	15	29.3	11.9
		CW	19	16.6	7.3	20	49.5	10.2
	045	CW	19	23.6	7.3	20	45.7	15.8
	090	CCW	13	24.0	9.8	15	39.1	13.2
		CW	19	18.9	7.0	20	55.1	19.8
	135	CW	19	19.1	6.1	20	38.0	12.8
	180	CCW	13	25.5	6.4	15	40.4	11.4
		CW	19	18.4	6.1	20	47.2	9.4
	225	CW	19	17.1	4.8	20	28.4	7.9
	270	CCW	13	18.7	5.0	15	29.3	10.7
		CW	19	13.9	3.2	20	34.6	8.1
	315	CW	19	15.9	4.8	20	32.4	10.9
VFU	000	CCW	13	20.3	5.6	15	34.0	12.1
		CW	19	17.7	3.1	20	33.0	7.2
	045	CW	19	25.6	8.0	20	43.8	8.9
	090	CCW	13	28.3	11.4	15	42.9	12.8
		CW	19	26.6	8.1	20	63.1	25.8
	135	CW	19	36.3	8.4	20	67.8	16.9
	180	CCW	13	22.0	5.8	15	34.3	9.0
		CW	19	27.5	7.7	20	69.4	20.6
	225	CW	19	28.0	14.1	20	48.4	14.7
	270	CCW	13	20.1	4.9	15	38.6	12.8
		CW	19	15.0	6.6	20	29.2	8.2
	315	CW	19	15.1	3.4	20	28.2	5.8

TABLE 3.47
MEANS AND STANDARD DEVIATIONS WITH BOLT ORIENTATION
MIDWAY BETWEEN VERTICAL AND TRANSVERSE

BOLT ORIENT	WRENCH POSITION (degrees)	FORCE DIRECTION	FEMALE N	FEMALE MEAN (foot pounds)	FEMALE STD (foot pounds)	MALE N	MALE MEAN (foot pounds)	MALE STD (foot pounds)
VTD	000	CCW	13	26.1	10.6	15	37.7	15.0
		CW	19	21.3	6.9	20	57.4	7.0
	045	CW	19	18.5	7.9	20	34.4	10.3
	090	CCW	13	15.4	5.5	15	26.5	5.7
		CW	19	14.6	2.7	20	39.6	7.6
	135	CW	19	19.1	6.0	20	37.8	11.6
	180	CCW	13	31.2	11.8	15	45.3	13.8
		CW	19	21.8	8.2	20	55.7	23.3
	225	CW	19	25.4	8.7	20	44.6	14.6
	270	CCW	13	28.2	9.7	15	43.8	14.4
		CW	19	22.0	9.9	20	51.2	24.5
	315	CW	19	21.2	6.9	20	35.4	14.8
VTU	000	CCW	13	23.3	8.1	15	40.0	10.7
		CW	19	21.2	6.2	20	45.3	6.3
	045	CW	19	18.1	4.5	20	32.2	6.9
	090	CCW	13	17.2	6.5	15	34.6	12.8
		CW	19	18.5	4.6	20	39.8	10.4
	135	CW	19	28.6	8.9	19	50.0	10.5
	180	CCW	13	29.2	9.4	15	45.0	12.5
		CW	19	27.3	6.7	20	72.2	16.3
	225	CW	19	28.9	9.1	19	46.2	13.7
	270	CCW	13	24.7	9.2	15	36.7	11.6
		CW	19	28.3	8.0	20	57.5	14.3
	315	CW	19	24.3	8.07	20	40.3	13.0

SECTION 4

SUMMARIES OF ELECTRICAL CONNECTOR STUDIES

A task frequently encountered in aircraft maintenance is connecting or disconnecting components of electrical and electronic systems. The attaching mechanisms commonly consist of a male and female multiple pin plug with a threaded securing ring. These studies used simulated threaded type connectors, of three different sizes. As with the wrench torque studies, the measurement of torque was made in a static condition, as it simulates the conditions where maximum torque is required, just before the securing ring reaches its full travel when tightening, or just before the ring starts to move when loosening. In each instance, the movement is microscopic at the point of maximum torque requirement.

Usually, the connector must be disengaged before the component can be removed, or engaged before the component is secured to its mounting. Frequently, connectors are behind the component or there are other objects interfering with accessibility, requiring the technician to reach around or over objects to the connectors. Clearances, and connector size, may also dictate that the optimum grip cannot be used. Conditions experienced during maintenance may require gloves to be worn while performing the task. The studies were designed to test the effects of the various combinations of connector size, direction of approach, grip type, location, gloves and obstacles on the torque capabilities of technicians to tighten or loosen connectors with the hand.

4.1 ANTHROPOMETRY

The set of anthropometric measurements listed in Figure 3.1 were made on all subjects who participated in studies conducted at the AAMRL Ergonomics Laboratory at Wright-Patterson AFB, OH. One study (I-3) was conducted at Iowa State University (ISU) at

Ames, Iowa and the anthropometric measures made at that site are listed in the summary of that study.

4.2 TEST EQUIPMENT

There were basically two components of the test equipment, an electrical connector strength testing device, and a computerized data acquisition system.

4.2.1 Electrical Connector Strength Testing Device

The electrical connector strength testing device (Figure 4.1) consisted of a vertical frame with a horizontal mounting plate which could be moved up and down. The simulated connectors were attached to the mounting plate. Torque applied by the hand to the simulated connectors was measured with a force transducer.

4.2.2 Computerized Data Acquisition System

The output of the force transducer was processed through a bridge amplifier and analog-to-digital converter to a microcomputer. The data were stored in memory as they were collected. After the trial, the data were saved on a floppy disk, or optionally, printed on a printer.

4.3 EXPERIMENT CONDITIONS

1. Subjects:

    - Number: the number of male and female subjects participating in each study.

    - Height/Weight: limiting height/weight restrictions as established by Air Force Regulation 160-43.

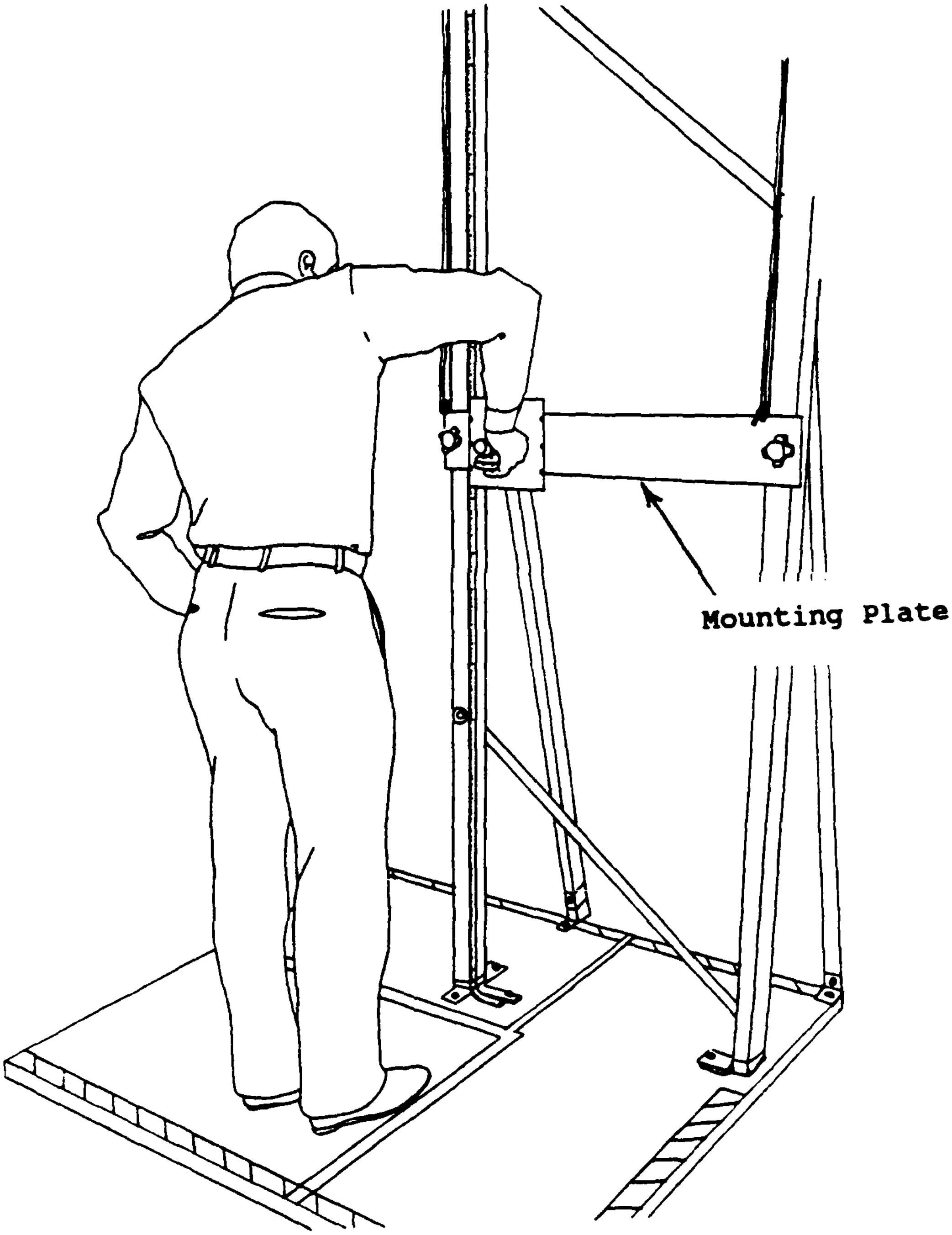


Figure 4.1 Electrical Connector Strength Testing Device
(Front Approach, at 60% Connector Elevation)

- Weight Lift: a minimum weight lift capability of 40 pounds on the 6 Foot Incremental Weight Lift test was required to participate in the study. Some Air Force maintenance career fields have weight lift requirements greater than 40 pounds, but all Air Force enlisted personnel are required to pass the test at the 40 pound level.

- Mixed Occupations: no particular skills or training were required for participation in the study.

- Pay: subjects were paid volunteers averaging $5.00 per hour. Informed consent was obtained prior to any testing.

- No Physical Frailties: no physical frailties that would prevent a subject from participating in the study because of a possibility of injury or aggravation of an existing, or previously existing, condition.

2. Clothing:

- Street clothes.

3. Testing Sessions:

- Number: number of sessions required to complete a study.

- Session Exertions: number of exertions in a session.

  Benchmark Exertions: specific exertions at the start and end of a session to verify subject's reliability. Described in each study summary.

Test Exertions: the task exertions defined by the combinations of variable conditions. Accomplished in random order. Any anomalies to the randomization are described in the study summary.

Rest Period: Rest time allowed between exertions to prevent fatigue becoming a factor.

4. Posture: Standing

5. Distance: The distance from the subject to the electrical connector, relative to the subject's body as a percentage of grip length.

6. Connector Elevation: The distance from the supporting surface to the center of the connector. Usually expressed as a percentage of the vertical reach for the posture being tested.

7. Approach Direction: The relationship of the body to the connector. Three approach directions were used, Front, Right and Back.
   - Front approach - the subject faced toward the mounting plate, with the connector aligned with the right edge of the right foot (Figure 4.1).

   - Side approach - the subject stood parallel to the mounting plate (Fig 4.2), with the connector aligned with the right edge of the right foot.

   - Back approach - the subject stood behind the mounting plate (Figure 4.3), with the connector aligned with the right edge of the right foot, and reached over the mounting plate to the connector.

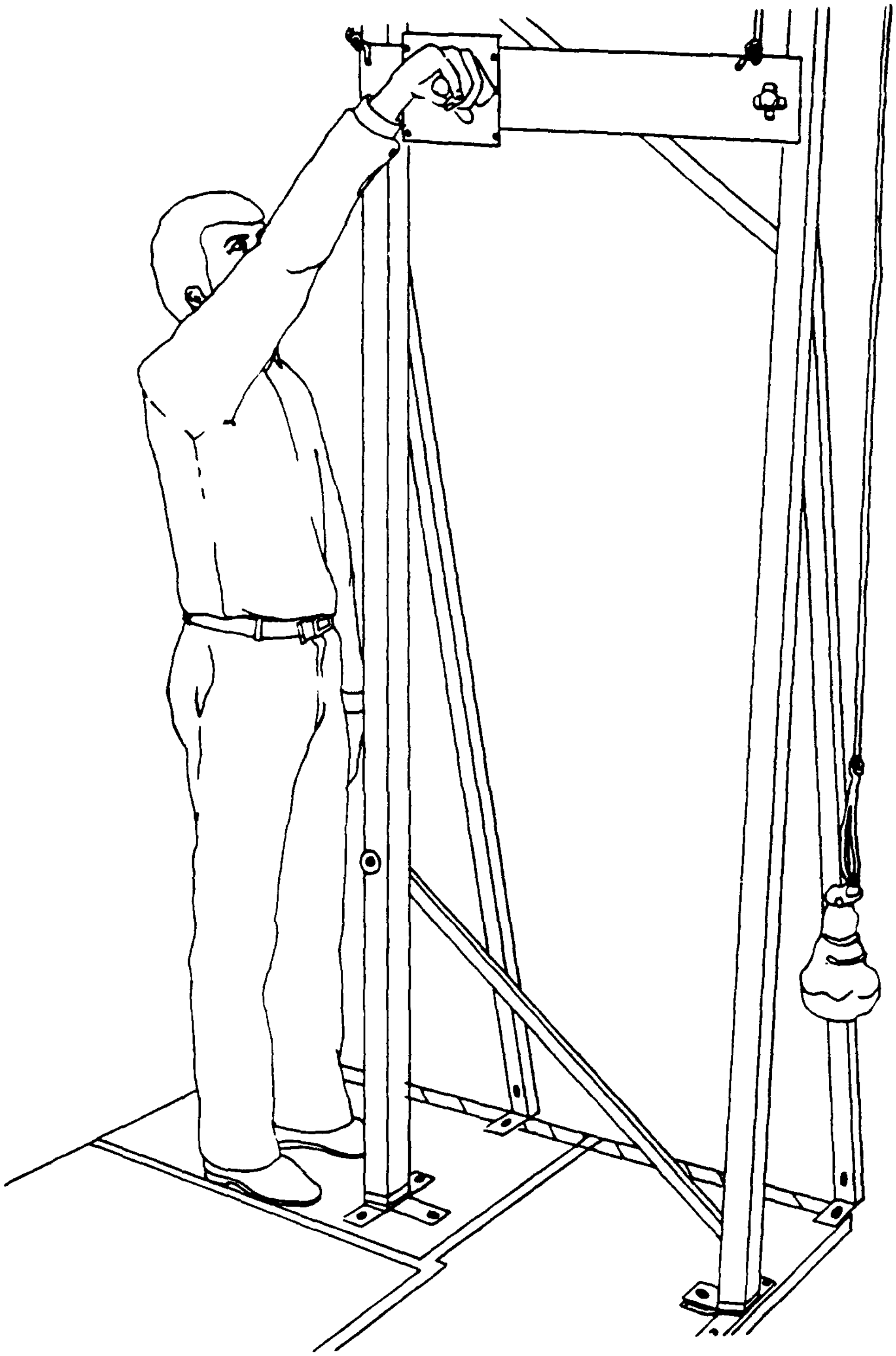


Figure 4.2 Side Approach, at 90% Connector Elevation

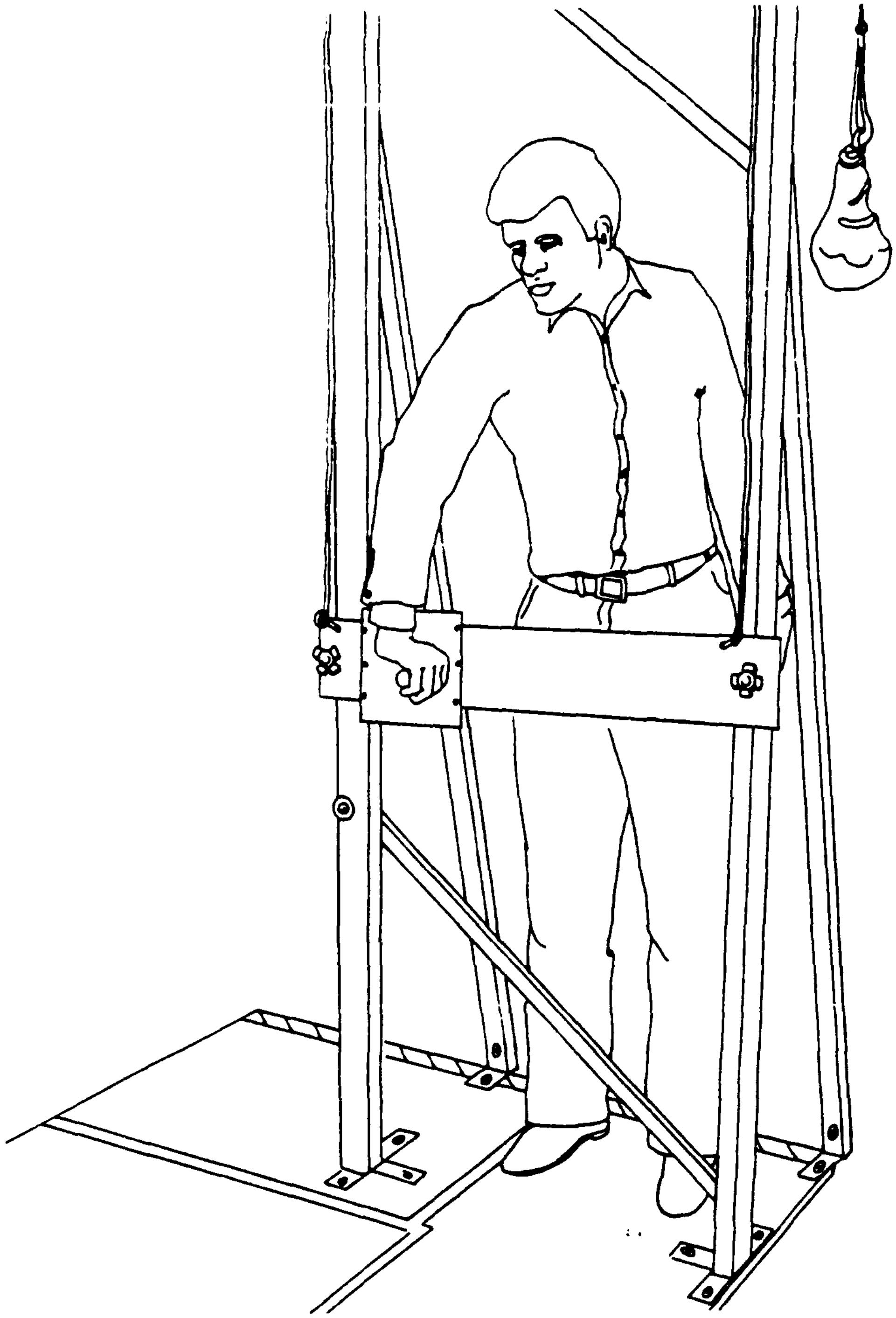


Figure 4.3 Back Approach, at 35% Connector Elevation

8. Hand Used: Identifies the hand used to apply force to the wrench.

9. Hand Covering: Bare hand or with one of two types of glove, work glove or chemical defense gloves. The work glove was a leather shell with a wool insert liner. The chemical glove consisted of three layers; a cotton liner, a neoprene glove, and an outer leather glove.

10. Grip Type: Full grip or finger tip grip.

11. Direction of Torque: Clockwise or Counterclockwise.

4.4 GENERAL PROCEDURES

Exertions were randomized. Connector elevation was set for the specified test. Subjects assumed the position for the specified direction of approach, with the proper hand covering and grip type, and the feet separated by biacromial breadth (shoulder width). Exertions were four second static trials which started when torque was applied to the simulated connector. Torque was sampled at a rate of 10 HZ and a tone signaled the end of the four second period.

Two calculations were used to determine the acceptability of the data for each exertion. The first was the ratio:

Peak in First Second/Mean of Last Three Seconds.

This ratio provided an indication of whether or not the exertion was stabilized within the first second, and whether or not the torque had dropped significantly before the end of the four second period. For the exertion to be acceptable, the ratio had to be within the range of .80 to 1.20.

The second calculation was the number of values in the last three seconds that were outside ±10 % of the mean for the last three seconds. This provided an indication of whether or not the torque application was relatively constant during the last three seconds of the exertion. For the exertion to be acceptable, no more than eight (8) values could be outside the ±10 % range.

■ ELECTRICAL CONNECTOR STUDY, I1 ■

Hand Torque Strength for Engaging and Disengaging Threaded Type Electrical Connectors[11]

OBJECTIVE

To determine maximum voluntary hand torque capability for combinations of connector sizes, approach directions, grip types, connector elevations, directions of torque application and hand coverings.

TEST EQUIPMENT

Electrical connector strength testing device

Computerized data acquisition system

CONDITIONS

Constants

- Subjects:
  Number: 17 males, 18 females

- Clothing: Street clothes

- Testing Sessions
  Number: 3
  Session Exertions: 48
  Benchmark: 8
  Test: 40
  Rest Period: 2 minutes

  NOTE: Whenever possible, 2 subjects were scheduled at the same time. Both subjects performed exertions in the same random order, with one resting while the other performed the exertion.

- Posture: Standing

11. Authors: Dr. S. Keith Adams and Philip J. Peterson (ISU), C. Glenn Robbins (UDRI) and Dr. Joe W. McDaniel (AAMRL)

- Distance: 50 % of grip length

- Hand Used: Right hand.

Variables

- Orientations: 3
  - Front
  - Side
  - Back (only with 60 % vertical reach)

- Connector Diameters: 3
  - 0.90 inches
  - 1.50 inches
  - 2.00 inches

- Connector Elevations: 2
  - 60 % of vertical reach
  - 85 % of vertical reach

- Grip Types: 2
  - Full grip
  - Fingertip grip

- Direction of Torque: 2
  - Clockwise
  - Counterclockwise

- Hand Covering: 3
  - Bare handed
  - Work glove
  - Chemical defense glove

NOTE: In order to reduce the overall number of exertions the subjects were divided into two groups for the gloved conditions. The first group performed half of the gloved exertions wearing work gloves and the other half wearing chemical defense gloves. The second performed the identical exertions but reversed the type of gloves used.

MEASURES

- Isometric strength as the force applied to the connector by the subject. Force was measured with a load cell over a period of four seconds, and recorded in inch pounds.

Anthropometric Measurements

The set of anthropometric measurements in Figure 3.1 were made for subjects participating in this study.

Benchmark Exertions

Four standard exertions were done at the beginning and end of each session. All were from the Front approach, with the 1.50 inches diameter connector, 60 % connector elevation, and bare handed. The four exertions were:

1. Full grip, clockwise
2. Full grip, counterclockwise
3. Fingertip grip, clockwise
4. Fingertip grip, counterclockwise

RESULTS

Tables 4.1 through 4.5 show the mean and standard deviation for each of the test conditions. The elevation, direction of approach, and direction of torque did not produce significant differences in torque. Likewise, the use of gloves made little difference. The size of the connector was significant, with torque increasing as the diameter increased. More torque could be produced with the full grip than with the fingertip grip. As in other strength studies, males produced significantly more torque than females.

TABLE 4.1
DIRECTION OF APPROACH, I1

DIRECTION OF APPROACH	FEMALES N	FEMALES MEAN (inch pounds)	FEMALES STD (inch pounds)	MALES N	MALES MEAN (inch pounds)	MALES STD (inch pounds)
BACK	432	11.9	9.5	408	17.1	15.7
FRONT	861	11.7	8.2	816	16.6	12.9
SIDE	864	13.6	10.3	816	19.7	16.7

TABLE 4.2
CONNECTOR ELEVATION, I1

CONNECTOR ELEVATION (% vertical reach)	FEMALES N	FEMALES MEAN (inch pounds)	FEMALES STD (inch pounds)	MALES N	MALES MEAN (inch pounds)	MALES STD (inch pounds)
85	864	12.7	9.6	816	18.1	14.9
60	1293	12.4	9.2	1224	17.9	15.3

TABLE 4.3
GLOVED CONDITION, I1

HAND COVERING	FEMALES N	FEMALES MEAN (inch pounds)	FEMALES STD (inch pounds)	MALES N	MALES MEAN (inch pounds)	MALES STD (inch pounds)
CHEM DEF	540	12.8	9.4	510	18.4	15.7
NO GLOVE	1077	12.0	9.3	1020	17.3	14.2
WORK	540	13.1	9.5	510	18.9	16.2

TABLE 4.4
DIRECTION OF TORQUE, I1

DIRECTION OF TORQUE	FEMALES N	FEMALES MEAN (inch pounds)	FEMALES STD (inch pounds)	MALES N	MALES MEAN (inch pounds)	MALES STD (inch pounds)
COUNTER-CLOCKWISE	1077	12.5	8.6	1020	17.8	14.1
CLOCKWISE	1080	12.5	10.1	1020	18.1	16.1

TABLE 4.5
CONNECTOR SIZE WITH GRIP TYPE, I1

SIZE OF CONNECTOR (inches)	TYPE OF HAND GRIP	FEMALES N	FEMALES MEAN (inch pounds)	FEMALES STD (inch pounds)	MALES N	MALES MEAN (inch pounds)	MALES STD (inch pounds)
2.0	FULL GRIP	360	27.5	8.4	340	43.2	15.5
2.0	FINGER-TIP	360	14.2	5.6	340	19.8	7.1
1.5	FULL GRIP	359	15.9	4.5	340	21.7	7.2
1.5	FINGER-TIP	360	9.2	3.0	340	12.8	4.2
0.9	FULL GRIP	358	4.4	1.4	340	5.2	1.6
0.9	FINGER-TIP	360	3.8	1.3	340	5.1	1.7

■ ELECTRICAL CONNECTOR STUDY, I2 ■

Hand Torque Strength for Engaging and Disengaging Threaded Type Electrical Connectors[12]

OBJECTIVE

To determine the effect of higher and lower connector elevations on torque capability.

TEST EQUIPMENT

Electrical connector strength testing device

Computerized data acquisition system

CONDITIONS

<u>Constants</u>

- Subjects:

  Number: 9 males, 9 females, all had participated in the Electrical Connector Study, I1.

- Clothing: Street clothes
- Testing Sessions

  Number: 1

  Session Exertions: 28

  Benchmark: 4

  Test: 24

  Rest Period: 2 minutes

- Posture: Standing

- Distance: 50 % of grip length

- Grip Type: Full grip

12. Authors: C. Glenn Robbins and Donald L. Haddox (UDRI) and Dr. Joe W. McDaniel (AAMRL)

- Hand Used: Right hand

- Hand Covering: Bare handed

Variables

- Approach Directions: 2

  Front

  Back (only with 35 % of vertical reach)

- Connector Diameters: 3

  0.90 inches

  1.50 inches

  2.00 inches

- Connector Elevations: 3

  35 % of vertical reach

  90 % of vertical reach

  95 % of vertical reach

- Direction of Torque: 2

  Clockwise

  Counterclockwise

MEASURES

- Isometric strength as the force applied to the connector by the subject. Force was measured with a load cell over a period of four seconds, and recorded in inch pounds.

Anthropometric Measurements

The set of anthropometric measurements in Figure 3.1 were made for subjects participating in this study.

Benchmark Exertions

Two standard exertions were done at the beginning and end of each session. All were from the Front approach, with the 1.50 inches diameter connector, at the 35 % connector elevation, in both torque directions (clockwise and counter clockwise)

RESULTS

Tables 4.6 through 4.9 portray the mean and standard deviation for the test conditions. As in the previous study (I1), the elevation, direction of approach, and direction of torque did not produce significant differences. Connector was significant, with torque increasing as the diameter increased. The apparent differences between direction of approach (Tables 4.6 and 4.1), connector elevation (Tables 4.7 and 4.2), and direction of approach (Tables 4.8 and 4.3) between the I1 and I2 studies are explained by the difference in grip type conditions for the two studies. Tables 4.1, 4.2 and 4.3 include data for both the full and fingertip grips, while Tables 4.6, 4.7 and 4.8 have only data for the full grip.

TABLE 4.6
DIRECTION OF APPROACH, I2

DIRECTION OF APPROACH	FEMALES N	FEMALES MEAN (inch pounds)	FEMALES STD (inch pounds)	MALES N	MALES MEAN (inch pounds)	MALES STD (inch pounds)
BACK	54	16.0	10.6	54	25.3	18.3
FRONT	162	16.2	10.9	162	24.2	17.1

TABLE 4.7
CONNECTOR ELEVATION, I2

CONNECTOR ELEVATION (% vertical reach)	FEMALES N	FEMALES MEAN (inch pounds)	FEMALES STD (inch pounds)	MALES N	MALES MEAN (inch pounds)	MALES STD (inch pounds)
35	108	15.9	10.7	108	25.5	18.3
90	54	16.2	10.9	54	24.4	16.7
95	54	16.7	11.1	54	22.4	16.1

TABLE 4.8
DIRECTION OF TORQUE, I2

DIRECTION OF TORQUE	FEMALES N	FEMALES MEAN (inch pounds)	FEMALES STD (inch pounds)	MALES N	MALES MEAN (inch pounds)	MALES STD (inch pounds)
COUNTER-CLOCKWISE	108	16.2	10.1	108	25.6	17.8
CLOCKWISE	108	16.1	11.5	108	23.3	16.9

TABLE 4.9
CONNECTOR SIZE WITH GRIP TYPE, I2

SIZE OF CONNECTOR (inches)	FEMALES N	FEMALES MEAN (inch pounds)	FEMALES STD (inch pounds)	MALES N	MALES MEAN (inch pounds)	MALES STD (inch pounds)
2.0	72	28.1	6.5	72	43.9	12.6
1.5	72	15.9	5.0	72	23.0	6.9
0.9	72	4.5	1.6	72	6.5	2.1

■ **ELECTRICAL CONNECTOR STUDY, I3** ■

Maximum Voluntary Hand-Grip Torque for Circular Electrical Connectors: The Effect of Obstructions[13]

OBJECTIVES

The objectives of this study are:

1. Develop a means of behaviorally identifying and specifying six levels of interference for the grip type employed in exerting hand torque in confined spaces.

2. Define and quantify the relationship between hand-grip torque and the six levels of interference.

3. Define and quantify the effects of interference by: adjacent connectors to the right and left of; adjacent connectors above, below, right and left of; and a flat surface located to the right or above, the grasped connector.

4. Investigate the effects of wearing work gloves under the interference conditions of objectives 2 and 3.

TEST EQUIPMENT

Electrical connector strength testing device

Computerized data acquisition system

CONDITIONS

Constants

- Subjects:
  Number: 18 males, 16 females

- Clothing: Street clothes

13. Authors: Dr. S. Keith Adams and Xiangiang Ma (ISU), C. Glenn Robbins (UDRI) and Dr. Joe W. McDaniel (AAMRL)

- Testing Sessions
  - Number: 3
  - Session Exertions: 52
    - Benchmark: 4
    - Test: 48
    - Rest Period: 2 minutes

- Posture: Standing

- Distance: 50 % of grip length

- Hand Used: Right hand

- Approach Direction: Front

- Connector Elevation: 60 % of vertical reach

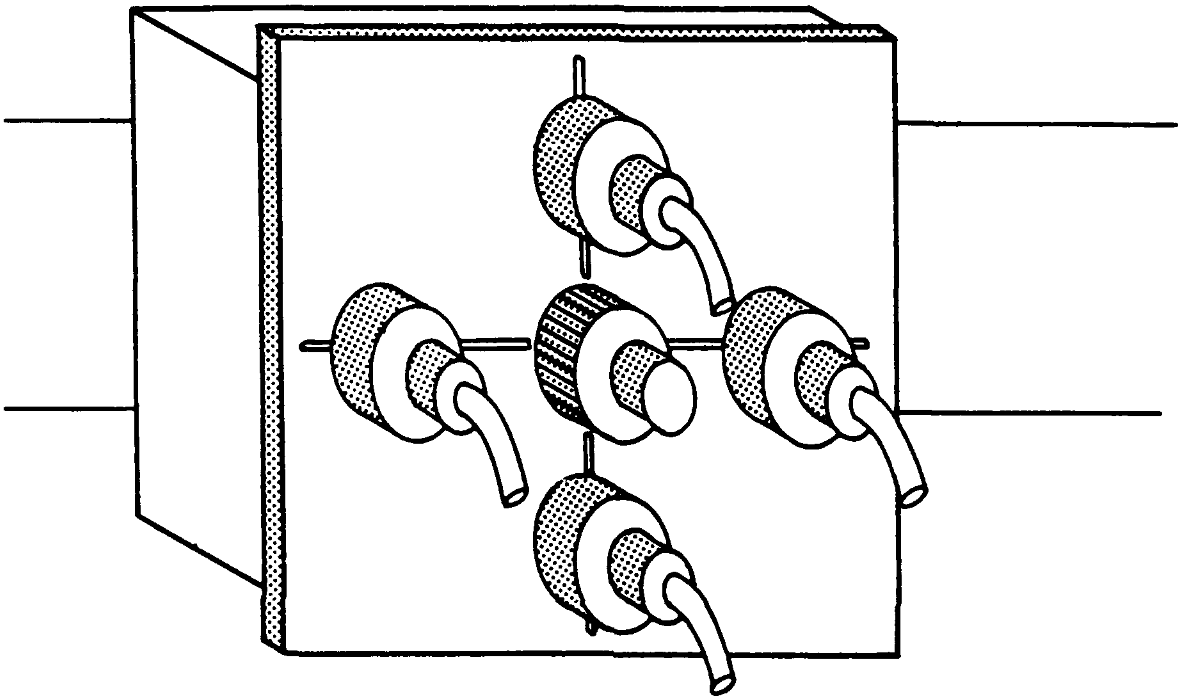
- Direction of Torque: Clockwise

Variables

- Connector Diameters: 3
  - 0.90 inches
  - 1.50 inches
  - 2.00 inches

- Hand Covering: 2
  - Bare Handed
  - Work Glove

- Obstruction Type: 4
  - Connectors, right and left
  - Connectors, above, below,
    right and left (Figure 4.4)
  - Flat surface, right (Figure 4.5)
  - Flat surface, below (Figure 4.6]



Test connector is in the center. Four obstructing connectors may be removed, or moved toward or away from the test connector to establish the prescribed level of interference. (reprinted from Adams, et. al., 1986)

Figure 4.4 Connector Obstruction

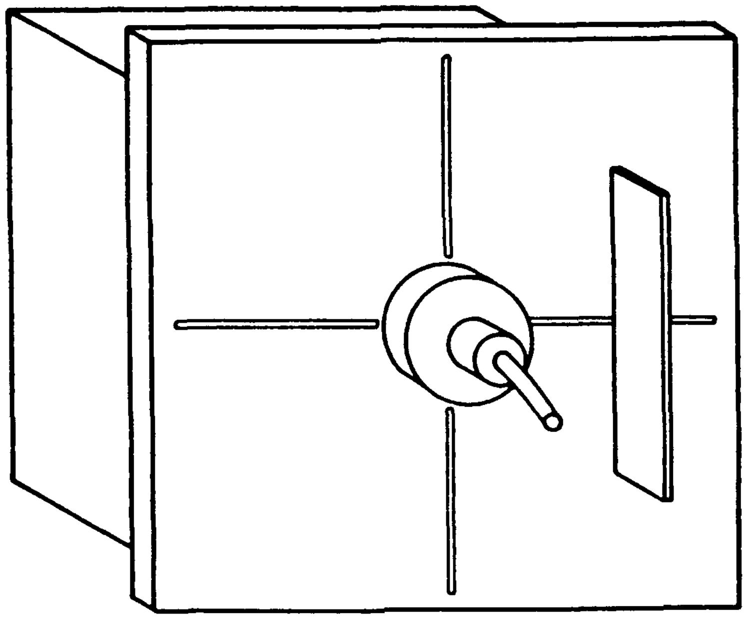


Figure 4.5 Flat Surface Obstruction, Right

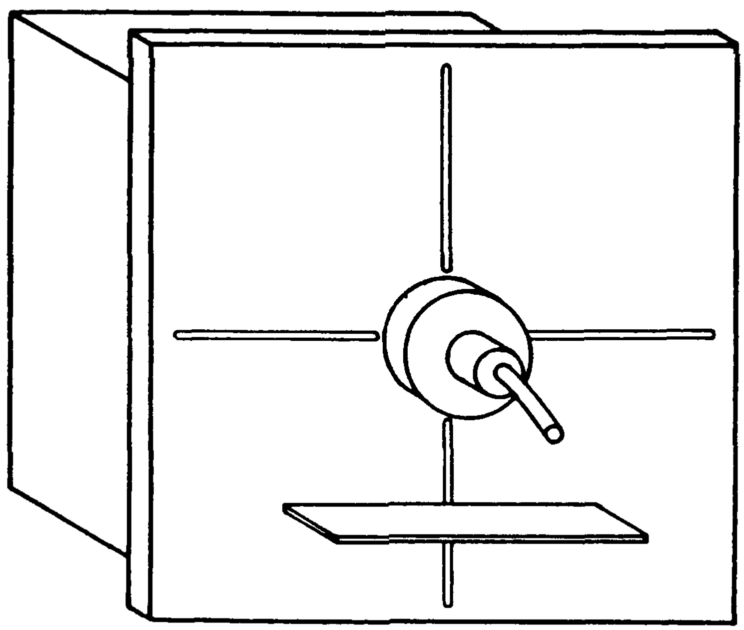


Figure 4.6 Flat Surface Obstruction, Below

Flat surface obstructions may be moved toward or away from the test connector to attain the prescribed level of interference. (Reprinted from Adams, et. al., 1986)

- Levels of Interference: 6

  1. **Unobstructed:** No perceptible contact with surrounding obstacles by any part of the hand while exerting static torque using a full wraparound grip.

  2. **First Noticeable:** First noticeable contact between the hand and surrounding obstacles while exerting static torque using a full grip. This usually occurs on the dorsal side of a metacarpal-phalangeal joint.

  3. **Moderate obstruction for full grip:** Very noticeable contact interference when using a full grip. Reconfiguration of the hand is necessary because of contact interference on the dorsal side of one or more metacarpal-phalangeal joints.

  4. **Loss of full grip:** Full grip replaced by fingertip grasp. Only a grip between the fingertips (usually the first and second digits, sometimes assisted by the third) is possible. No contact, or slight contact, between the proximal interphalangeal joints and surrounding obstacles occurs when using a fingertip grip.

  5. **Moderate obstruction for fingertip grip:** Very noticeable contact interference between the digits and surrounding obstacles while exerting static torque. Interference typically occurs at the proximal interphalangeal joints, limiting their flexion.

6. **Limit of fingertip grip:** Minimum clearance for which grasping between the distal phalanges of the first and second digits can be maintained while exerting static torque. There is practically no flexing of the proximal interphalangeal joint on the first and second digits.

PROCEDURES

Combinations of levels for the three connector diameters, four obstruction types and two glove effects were presented in random sequence. For each of these, the six levels of interference were tested in an ascending method of limits starting with the easiest (Level 1) and proceeding to the hardest (Level 6). Within each test, clearances were adjusted by moving the adjacent "dummy" connectors, or flat surface, closer until the next higher level of interference was achieved. The four second exertion was then performed.

MEASURES

- Isometric strength as the force applied to the connector by the subject. Force was measured with a force transducer over a period of four seconds, and recorded in inch pounds.

Anthropometric Measurements

The following set of anthropometric measures were made and recorded for subjects participating in this study.

Sex	Age
Weight	Stature
Hand Length	Hand Breadth
Wrist-Metacarpal Length	Wrist Circumference
Hand Circumference	Grip Strength
Average Grip Length	Reach Height

Benchmark Exertions

Two standard exertions were done at the beginning and end of each session. Both were from the Front approach, with the 1.50 inches diameter connector, at the 60 % connector elevation, 50 % grip length distance, and bare handed in the clockwise direction of torque. One was with the full grip, and the other with the fingertip grip.

RESULTS

The mean torques and standard deviations are presented in Tables 4.10 through 4.14. The results of this study are very similar to those of the previous connector torque studies, in both the magnitude of the torque values obtained and the effects of the experimental conditions. Males produced significantly more torque than did females in all conditions. The amount of torque increased significantly with each larger connector size and decreased as the amount of interference increased.

There was also a significant interaction between the size of the connector and the level of interference. The differences in torque due to the level of interference decreased with each smaller connector size. This result is very similar to the interaction found between connector size and grip type in the I1 study. As the level of interference increased, the subjects were forced to change from a full hand grip to a finger-tip grip. The type of obstruction used to create the interference had little effect on the subject's ability to exert torque on the connector, nor did the use of gloves.

TABLE 4.10
SIZE OF CONNECTOR

SIZE OF CONNECTOR (inches)	N	FEMALES MEAN (inch pounds)	STD	N	MALES MEAN (inch pounds)	STD
2.0	768	9.4	5.7	864	13.8	8.9
1.5	768	6.4	3.2	864	8.4	4.7
0.9	768	2.8	1.1	864	3.8	1.3

TABLE 4.11
GLOVES

GLOVE	N	FEMALES MEAN (inch pounds)	STD	N	MALES MEAN (inch pounds)	STD
NO	1152	5.9	4.1	1296	8.3	6.8
YES	1152	6.5	5.2	1296	9.0	7.4

TABLE 4.12
TYPE OF OBSTRUCTION

TYPE OF OBSTRUCTION	N	FEMALES MEAN	STD	N	MALES MEAN	STD
1	576	6.1	4.6	648	8.3	6.6
2	576	5.4	4.4	648	7.3	6.0
3	576	6.6	4.7	648	9.6	8.1
4	576	6.7	5.0	648	9.5	7.4

TABLE 4.13
LEVEL OF INTERFERENCE

LEVEL OF INTERFERENCE	FEMALES N	FEMALES MEAN (inch pounds)	FEMALES STD (inch pounds)	MALES N	MALES MEAN (inch pounds)	MALES STD (inch pounds)
1	384	8.9	6.3	432	13.5	10.6
2	384	7.9	5.7	432	11.3	8.4
3	384	6.6	4.7	432	9.0	6.4
4	384	5.1	2.9	432	6.6	3.4
5	384	4.6	2.7	432	6.0	3.1
6	384	4.1	2.3	432	5.5	3.0

TABLE 4.14
CONNECTOR SIZE AND LEVEL OF INTERFERENCE

SIZE OF CONNECTOR (inches)	LEVEL OF INTERFERENCE	FEMALES N	FEMALES MEAN (inch pounds)	FEMALES STD (inch pounds)	MALES N	MALES MEAN (inch pounds)	MALES STD (inch pounds)
	1	128	14.5	6.4	144	23.4	10.8
	2	128	12.7	6.0	144	19.1	8.6
2.0	3	128	10.3	5.2	144	14.4	6.8
	4	128	7.1	3.2	144	9.6	3.3
	5	128	6.3	3.1	144	8.5	3.3
	6	128	5.5	2.8	144	7.6	3.4
	1	128	9.1	3.8	144	12.9	5.5
	2	128	7.8	3.5	144	10.8	5.1
1.5	3	128	6.7	3.0	144	8.6	4.2
	4	128	5.3	2.0	144	6.5	2.2
	5	128	4.9	2.0	144	6.1	2.1
	6	128	4.3	1.7	144	5.7	2.2
	1	128	3.2	1.3	144	4.2	1.5
	2	128	3.0	1.1	144	4.1	1.4
0.9	3	128	2.8	1.1	144	3.8	1.3
	4	128	2.8	1.0	144	3.6	1.2
	5	128	2.7	1.0	144	3.5	1.1
	6	128	2.5	1.1	144	3.3	1.1

SECTION 5
SUMMARIES OF PUSH-PULL STUDIES

A series of studies were conducted to collect data on strength capabilities of maintenance technicians while pushing and pulling in various postures. Maximum voluntary force was applied to a static bar to simulate the maximum requirement when pushing and pulling objects. The maximum force requirement is at that instant just before inertia and friction are overcome and the object starts to move.

In some cases the maximum horizontal force component is attained with a relatively high vertical force component. In aircraft maintenance this can sometimes cause problems. For example, when pushing an electronic component into a close tolerance position in a rack, vertical forces may cause binding. Therefore, the push-pull forces were measured under two conditions of force application relative to horizontal and vertical forces. "Uncontrolled" force application, in which the maximum force was exerted regardless of the relationship of horizontal and vertical components, and "controlled" force application, in which the horizontal component was maximized and the vertical component was minimized. For the "controlled" condition the force was applied to a handle connected to the force bar by cables. Subjects were required to keep the cables as close to parallel with the floor as possible, to minimize the vertical component. Exertions in which any value of the vertical component was outside the range of ± 10 % of the horizontal component were rejected and redone.

5.1 ANTHROPOMETRY

The set of anthropometric measures in Figure 3.1 were made on all subjects participating in the Push-Pull studies.

5.2 TEST EQUIPMENT

The following test equipment was used in the PUSH-PULL studies.

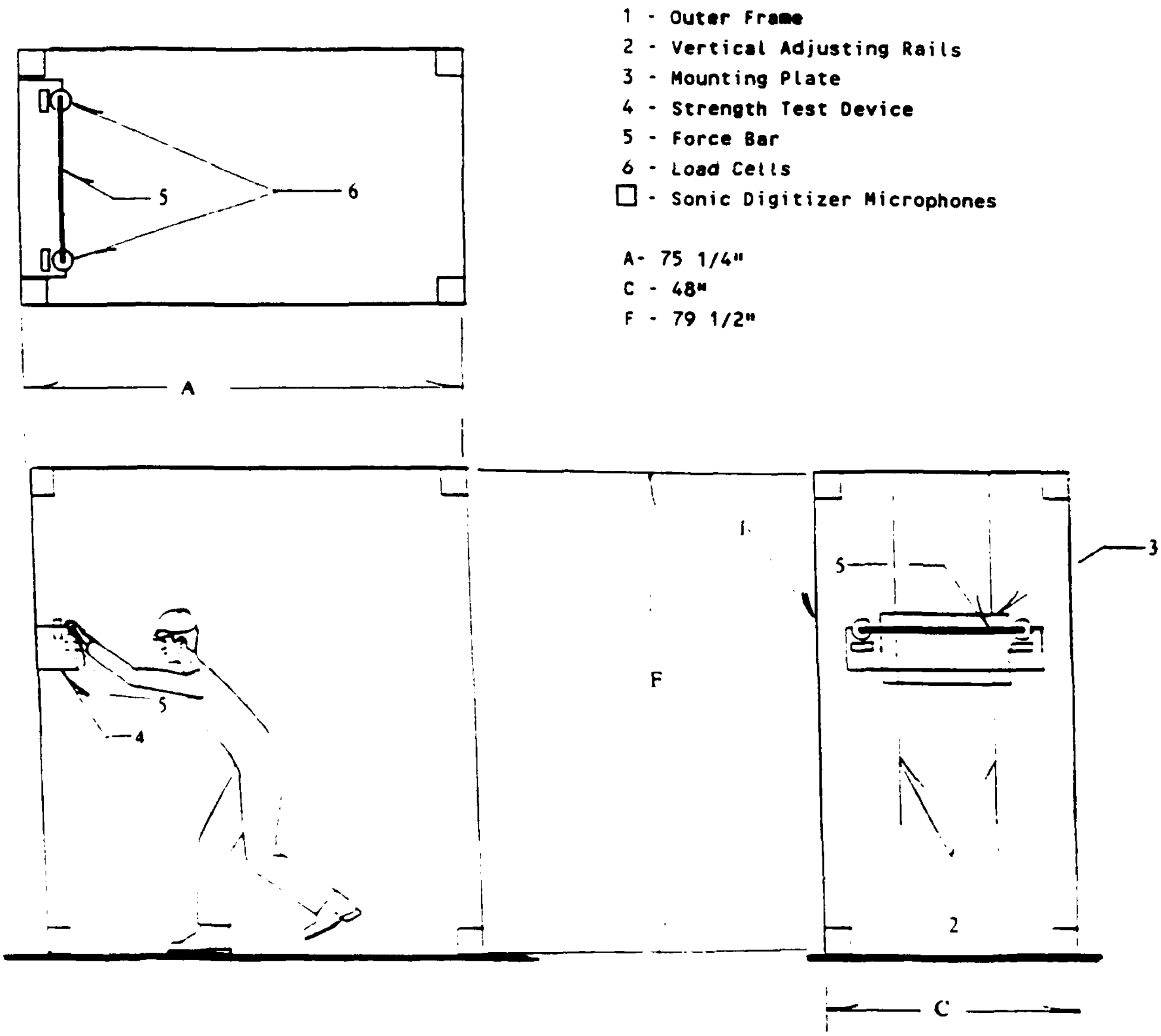
5.2.1 Push-Pull Strength Test Apparatus

The Push-Pull strength test apparatus (Figure 5.1) consisted of a frame work, with a vertically adjustable mounting plate. The floor was covered with anti-slip rubber matting. The strength test device consisted of a force bar and load cells attached to a bracket which was connected to the mounting plate. The force bar was 30 inches long, 1 1/8 inches outside diameter pipe, wrapped with cloth tape to reduce hand slippage. Four load cells, two mounted at right angles at each end of the force bar, were used to measure the horizontal and vertical components of the force applied. For the "controlled" force exertions, a 30 inches long, cloth tape wrapped, 1 1/8 inches outside diameter pipe, was connected to the force bar with cables. Eight microphones for the 3-D sonic digitizer were attached at the corners of the framework.

For the supine and prone postures, the force bar mounting was extended 28 inches from the vertical adjustment plate to provide adequate body clearances. Also, for the prone posture, an L shaped support platform, 30 inches above the floor, was added (Figure 5.2). The force bar was set at levels between the floor and the support platform. One portion of the support platform was adjustable to set the distance from the suprasternale to the force bar.

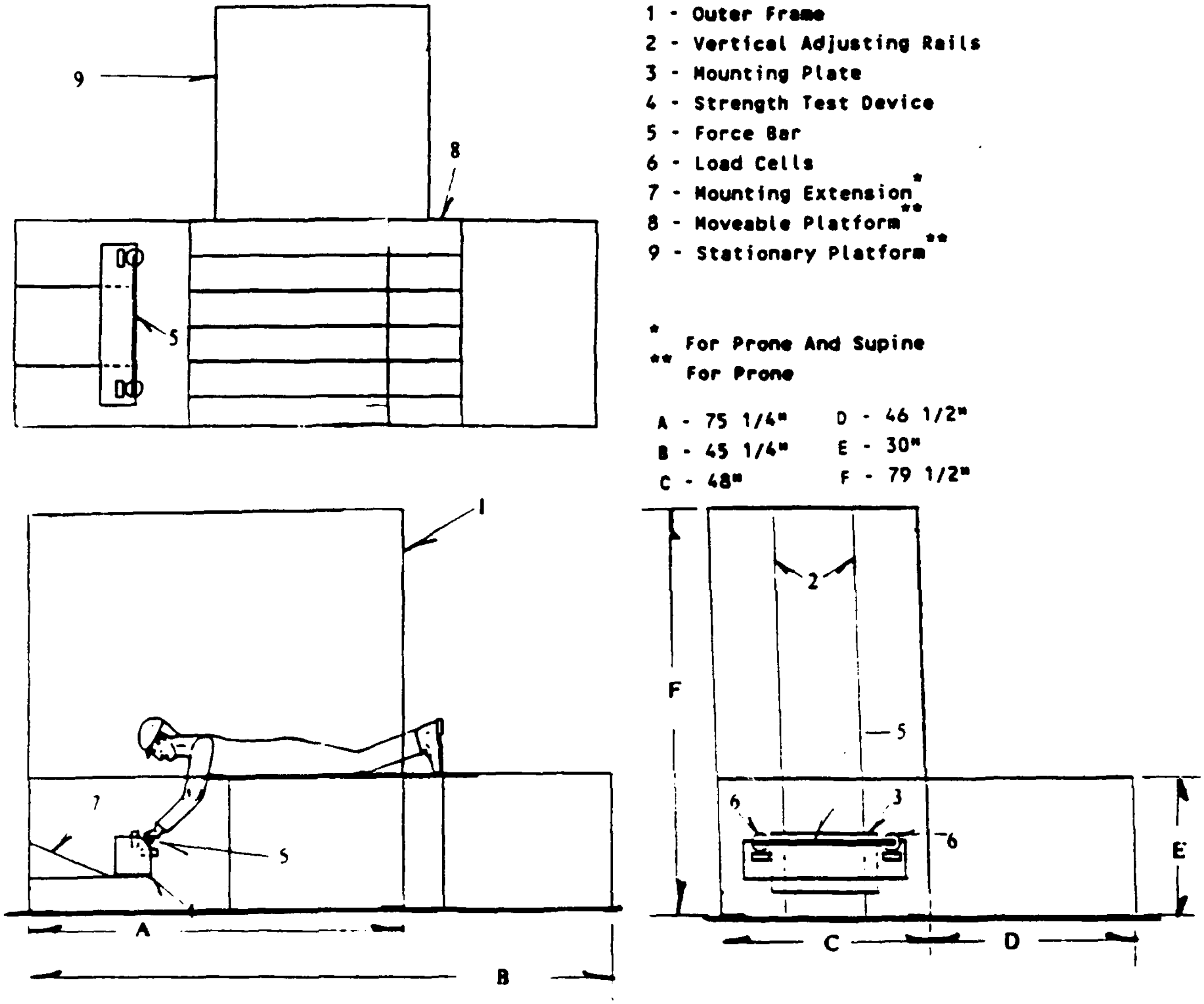
5.2.2 Computerized Data Acquisition System

Data from the load cells were measured at a sampling rate of 10 Hz and passed through a bridge amplifier and an analog-to-digital converter to a microcomputer. Data were stored in memory



The apparatus was used in this configuration for the upright (Standing, Sitting, Kneeling and Squatting) postures. The man-model is included in the side view for the Standing posture to show the relationship of a subject to the apparatus during a Pull exertion with Both hands. The Force Bar elevation is set at 65% of the subject's standing vertical reach, and the Distance at 35% of standing vertical reach. For the other upright postures, percentages of the vertical reach for the posture being tested were used to determine the elevation and distance for a particular exertion.

Figure 5.1 Push-Pull Strength Test Apparatus



The man-model is included in the Side view to show the relationship of a subject to the apparatus for an Under Body exertion. The Force Bar elevation is set at 45% (functional reach minus chest depth), and the Distance at 30% (functional reach), with Both hands used for the exertion. The relationship is the same for all Force Directions.

Figure 5.2 Push-Pull Strength Test Apparatus, With Platform for Prone Study during the exertion test period, saved to disk at the end of the exertion, and optionally, printed out. Sonic digitizer slant data were also stored in memory during the exertion, saved to disk after the exertion and optionally printed.

5.2.3 3-D Sonic Digitizer

The sonic digitizer uses electrical spark gaps to generate electrical sparks. The time delay between the generation of the spark and the detection of the sound of the spark by a microphone is measured. The delay is translated into a slant range distance from the spark gap to the microphone and the 3-D location of the spark gap can be computed. An array of 8 microphones (at the corners of a rectangle) surrounds the subject to reduce masking of the spark gaps' sound. The spark gaps are attached to the subject at anthropometric landmarks corresponding to the subject's joint centers, or other anatomical features useful in tracking posture.

Some Push-Pull studies collected data from the sonic digitizer. For those studies, 15 body landmarks, listed below, were used to locate the sound emitters.

Landmark Description for Emitter Placement

Emitter
Number

1. Right acromion
2. Right humeral epicondyle
3. Dorsal surface of right wrist, midway between the ulnar and radial styloid
4. Right trochanter
5. Right lateral epicondyle femur
6. Right lateral malleolus
7. Left acromion
8. Left humeral epicondyle

9. Dorsal surface of left wrist, midway between the ulnar and radial styloid
10. Left trochanter
11. Left lateral epicondyle femur
12. Left lateral malleolus
13. Cervicale
14. L3/L4 vertebrae interspace
15. Suprasternale

The data were collected under the same file name as the strength data. Data were collected in the following format:

F1	xxxxx	xxxxx	xxxxx	xxxxx
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
F15	xxxxx	xxxxx	xxxxx	xxxxx
B1	xxxxx	xxxxx	xxxxx	xxxxx
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
B15	xxxxx	xxxxx	xxxxx	xxxxx

The F1 through F15 and B1 through B15 indicate that the data were collected from the front (F) or back (B) plane for the sound emitters 1 through 15. The four columns of up to five figures indicate the slant range from microphones A, B, C, and D of the designated plane. Data is recorded in centimeters and hundredths of centimeters (a data reading of 14368, equates to 143.68 centimeters).

5.2.4 Video Recording System

A video recording system consisting of a video camera, video tape recorder and a monitor was used to record the exertions for the Push-Pull studies.

5.3 EXPERIMENTAL CONDITIONS

The following experimental conditions were used during the Push-Pull studies. Their applications were varied, being constants in some studies and variable in others. The constant and variable conditions are identified for each study.

1. Subjects:

   - Number: the number of male and female subjects participating in each study.

   - Age: in all studies, the age range for subjects was 18 to 30 years. This corresponds to the age range of 99 percent of Air Force maintenance technicians who perform the majority of hands-on maintenance activities.

   - Height/Weight: limiting height/weight restrictions as established by Air Force Regulation 160-43.

   - Weight Lift: a minimum weight lift capability of 40 pounds on the 6 Foot Incremental Weight Lift test was required to participate in the study. Some Air Force maintenance career fields have weight lift requirements greater than 40 pounds, but all Air Force enlisted personnel are required to pass the test at the 40 pound level.

- Mixed Occupations: no particular skills or training were required for participation in the study.

- Pay: subjects were paid volunteers averaging $5.00 per hour. Informed consent obtained prior to testing.
- No Physical Frailties: no physical frailties that would prevent a subject from participating in the study because of a possibility of injury or aggravation of an existing, or previously existing, condition.

2. Clothing:

   - Shorts, T-shirt and Air Force boots.

   - Street clothes.

   - Fatigue shirt with street clothes.

3. Testing Sessions:

   - Number: number of sessions required to complete a study.

   - Session Exertions: number of exertions in a session.

     Benchmark Exertions: specific exertions at the start and end of a session to verify subject's reliability. Described in each study summary.

     Test Exertions: the task exertions defined by the combinations of variable conditions. Accomplished in random order. Any anomalies to the randomization are described in the study summary.

Rest Period: Rest time allowed between exertions to prevent fatigue becoming a factor.

4. Posture: the postures tested in the Push-Pull studies. The subset of the postures used in a specific study are included in the study summary.
5. Distance: the distance from the subject to the force bar (or handle attached to the force bar by cables), relative to the subject's body, such as a percentage of grip length. The specific distances used in each study are identified in the study summary.

6. Force Direction: the direction of force application. Various identifiers were used depending on the requirements of the specific study. They are identified in each study summary.

7. Bar Elevation: the distance from the supporting surface to the center of the force bar. Usually expressed as a percentage of the subject's reach for the posture(s) being tested.

8. Elbow Angle: the elbow position was either straight or bent. While pushing, the elbow was bent to the maximum with the forearms as close to the body as possible. For pulling, the upper and fore arm were positioned so that the elbow angle was approximately a right angle.

9. Force Application: Uncontrolled (force applied directly to the force bar) or controlled (force applied to the force bar through cables).

10. Hand Used: identifies the hand(s) used to apply force.

5.4 GENERAL PROCEDURES

The variables for the exertion, such as force type, bar elevation, elbow angle, and distance were set. Subjects assumed the proscribed position and upon the experimenter's signal applied their maximum voluntary static force, in the proper direction, for a period of four seconds.

When a handle is significantly above or below shoulder level, pushing and pulling forces have a significant vertical force vector, as well as the desired horizontal force vector. In some push/pull tasks, it is not desirable to have a vertical force component. For example, when sliding an electronics box into a mounting rack, vertical forces can cause binding and/or misalignment. However, when pushing or pulling on a work stand, applying a vertical force to the handle is of no consequence.

In the uncontrolled vertical force condition, the subject pushed or pulled on an instrumented handle which could not move in any direction, hence both vertical and horizontal forces were measured. In the controlled vertical force condition, a second handle bar was attached to the fixed bar with steel cables. This "floating handle" was held at the same horizontal height as the fixed handle so that only horizontal forces transmitted through the steel cable to the fixed handle. In the controlled vertical push/pull test, the subject had to maintain the vertical stability of the handle, and was thus able to produce less horizontal force than was possible with the fixed handle.

In the push/pull studies for the Standing, Sitting, Kneeling, Squatting and Crawling postures exertions were measured with both controlled and uncontrolled vertical forces. For the Prone, Supine and Side postures, only uncontrolled vertical forces were measured.

■ PUSH-PULL STUDY, P1 (STANDING) ■

OBJECTIVE:

To investigate the capabilities to exert pushing and pulling forces in the standing posture.[14]

TEST EQUIPMENT

Push-Pull strength testing apparatus

Computerized data acquisition system

Video recording system

3-D sonic digitizer

CONDITIONS

Constants

- Subjects:
  Number: 20 males, 20 females

- Clothing: Shorts, T-shirt and Air Force boots

- Posture: Standing

- Testing Sessions:
  - Number: 4
  - Session Exertions: 28
  - Benchmark: 8
  - Test: 20
  - Rest Period: 2 minutes

14. Authors: C. Glenn Robbins, Donald L. Haddox, Mary W. Jones and Cheryl A. Lai (UDRI), and Dr. Joe W. McDaniel (AAMRL)

NOTE: The forty test exertions were randomized over two sessions. The first two sessions were with uncontrolled force exertions. Exertions were repeated in the same sequence for the third and fourth sessions, with controlled force application.

NOTE: All males did four sessions. 10 females did four sessions, and the remaining 10 did only two sessions. After the first 10 females were completed, it was found that the controlled force values, with the cable, could be accurately predicted from the uncontrolled force values.

- Hands Used: Both

Variables

- Force Direction: 2
  - Push
  - Pull

- Bar Elevation: 4
  - 35 % of vertical reach
  - 50 % of vertical reach
  - 65 % of vertical reach
  - 80 % of vertical reach

* Distance: 4

  From the bar, or handle, to the right foot position. Positive values are between the bar and the body, while negative values are on the opposite side of the bar from the body.

Push	Pull
15 % of vertical reach	-10 % of vertical reach
30 % of vertical reach	5 % of vertical reach
45 % of vertical reach	20 % of vertical reach
60 % of vertical reach	35 % of vertical reach

* Elbow Angle: 2

  Bent

  Straight

* Force Application: 2

  Uncontrolled

  Controlled

NOTE: The following combinations of variables were not performed as they were either impossible or impractical.

PUSH			PULL		
Bar Elevation	Distance	Elbow Angle	Bar Elevation	Distance	Elbow Angle
35%	45%	Bent	35%	20%	Bent
35%	60%	Bent	35%	35%	Bent
50%	45%	Bent	50%	20%	Bent
50%	60%	Bent	50%	35%	Bent
50%	15%	Straight	50%	-10%	Straight
65%	45%	Bent	65%	20%	Bent
65%	60%	Bent	65%	35%	Bent
65%	15%	Straight	65%	-10%	Straight
80%	15%	Bent	80%	20%	Bent
80%	30%	Bent	80%	35%	Bent
80%	45%	Bent	80%	35%	Straight
80%	60%	Bent			
80%	60%	Straight			

PROCEDURES

The strength testing device was set at the required bar elevation for the particular exertion. The distances from the bar, or handle, were marked on the floor for each subject. The subjects placed the ball of the right foot on the appropriate distance marker, with the mid-sagittal plane centered on the center line of the bar or handle. Force was transmitted through the right foot, with the left foot held slightly off the floor. During the push exertions, the left foot was held forward of the right foot as though preparing to step forward as the object moved. During the pull exertions, the left foot was held slightly behind the right foot as if preparing to step backward as the object moved (reference Figure 5.1). Both hands gripped the bar or handle, at biacromial breadth apart and with an overhand grip.

Elbows were set at the appropriate angle. For the "bent" elbow angle when pushing, the elbows were bent to the maximum with the body as close to the bar or handle as possible. When pulling, the elbow angle was maintained as close to a right angle as possible. Subjects applied their maximum voluntary force in the direction specified for a period of four seconds. Exertion started upon the experimenter's command, and ended with a tone single at the end of the four seconds.

MEASURES

- Isometric strength, as the force applied to the handle.

  Horizontal force component in pounds

  Vertical force component in pounds

  Resultant force in pounds

  Resultant angle in degrees

- Body posture was measured with the sonic digitizer. Slant ranges from the microphones to the emitters, at the landmarks, were recorded.

Anthropometric Measures and Landmarks

The anthropometric measures and landmarks listed in paragraphs 5.1 and 5.2.3 were used in this study.

Benchmark Exertions

At the beginning and end of each session the following four exertions were performed in the standing posture and with uncontrolled force application.

Force Direction	Bar Elevation	Distance	Elbow Angle
Push	65%	45%	Straight
Push	65%	30%	Bent
Pull	65%	5%	Straight
Pull	65%	5%	Bent

RESULTS

Tables 5.1 through 5.4 show the means and standard deviations for the horizontal force components, and sample size, for each exertion. Males produced greater pushing and pulling forces than females. Uncontrolled forces were greater than controlled forces for both males and females. The mean force values for males ranged from 16.3 for controlled pulls to 106.3 for uncontrolled pushes. For females the range was 11.6 for controlled pulls to 69.4 for uncontrolled pulls.

The effects of elbow position and foot distance were dependent on the force direction. Subjects could exert more force with straight arms when pulling, and with bent arms when pushing. Likewise, subjects could exert more force at the near distances when pulling, and at the far distances when pushing. Across all conditions, pushing and pulling were relatively equal. In general, as the height of the handle decreased, the force application increased. However, this trend was not found for pushing at the farther distances.

TABLE 5.1

PULL FORCES WITH VERTICAL FORCES CONTROLLED, P1

DISTANCE % grip length	BAR ELEVATION % vertical reach	ELBOW ANGLE	MALES N	MALES MEAN (pounds)	MALES STD (pounds)	FEMALES N	FEMALES MEAN (pounds)	FEMALES STD (pounds)
-10	35	BENT	20	80.5	30.2	20	36.3	21.9
		STRAIGHT	20	86.3	38.7	20	42.0	20.9
	50	BENT	20	62.8	15.1	20	42.3	11.6
	65	BENT	20	43.9	9.4	20	30.1	7.1
	80	BENT	20	29.8	13.2	20	18.1	7.7
		STRAIGHT	20	32.8	5.6	20	21.7	6.6
5	35	BENT	20	64.5	21.4	20	33.4	16.6
		STRAIGHT	20	73.1	25.8	19	35.5	20.8
	50	BENT	20	48.4	15.4	20	32.8	8.3
		STRAIGHT	20	60.7	11.5	20	41.6	10.8
	65	BENT	20	36.0	9.3	20	26.8	7.0
		STRAIGHT	19	42.2	7.2	20	31.1	8.8
	80	BENT	20	21.8	5.5	20	16.2	6.0
		STRAIGHT	20	26.5	5.2	20	19.1	5.4
20	35	STRAIGHT	20	58.0	18.5	20	36.2	11.5
	50	STRAIGHT	20	39.6	13.4	20	29.6	8.0
	65	STRAIGHT	20	29.1	6.5	20	22.8	4.4
	80	STRAIGHT	20	17.0	3.8	20	11.9	3.8
35	35	STRAIGHT	20	38.5	17.7	20	25.5	7.0
	50	STRAIGHT	20	25.9	13.7	20	19.3	6.1
	65	STRAIGHT	20	16.3	10.6	19	11.7	3.7

TABLE 5.2

PUSH FORCES WITH VERTICAL FORCES CONTROLLED, P1

DISTANCE % grip length	BAR ELEVATION % vertical reach	ELBOW ANGLE	MALES N	MALES MEAN (pounds)	MALES STD (pounds)	FEMALES N	FEMALES MEAN (pounds)	FEMALES STD (pounds)
15	35	BENT	20	43.9	13.2	20	25.3	8.7
		STRAIGHT	20	31.0	11.3	20	14.8	6.3
	50	BENT	20	37.8	9.5	20	27.3	6.8
	65	BENT	20	30.0	7.1	20	19.0	6.2
	80	STRAIGHT	20	20.2	9.3	20	11.6	3.7
30	35	BENT	20	53.3	18.4	20	30.8	14.2
		STRAIGHT	20	40.2	15.0	20	18.5	8.0
	50	BENT	19	53.2	10.4	20	37.1	10.2
		STRAIGHT	20	39.3	8.3	20	27.5	6.5
	65	BENT	20	40.7	6.4	20	28.3	6.2
		STRAIGHT	20	32.8	6.3	20	24.5	4.8
	80	STRAIGHT	20	27.9	4.1	20	18.3	4.2
45	35	STRAIGHT	20	44.9	14.2	20	22.8	11.8
	50	STRAIGHT	20	59.7	9.9	20	38.6	14.7
	65	STRAIGHT	20	46.8	6.2	20	35.2	7.3
	80	STRAIGHT	20	36.0	6.7	20	23.8	5.5
60	35	STRAIGHT	20	53.6	20.1	20	25.1	16.2
	50	STRAIGHT	20	84.0	14.2	20	58.5	17.9
	65	STRAIGHT	20	62.1	8.4	20	41.3	8.4

TABLE 5.3

PULL FORCES WITH VERTICAL FORCES UNCONTROLLED, P1

DISTANCE % grip length	BAR ELEVATION % vertical reach	ELBOW ANGLE	MALES N	MALES MEAN (pounds)	MALES STD (pounds)	FEMALES N	FEMALES MEAN (pounds)	FEMALES STD (pounds)
-10	35	BENT	20	98.0	32.0	20	58.2	25.0
		STRAIGHT	19	105.4	29.2	20	69.4	30.0
	50	BENT	20	67.1	11.9	20	48.8	12.2
	65	BENT	20	50.0	9.7	20	36.9	9.1
	80	BENT	19	33.1	8.0	20	27.1	7.4
		STRAIGHT	20	39.6	7.3	20	31.5	7.3
5	35	BENT	20	70.0	20.2	20	46.9	19.6
		STRAIGHT	20	71.1	25.6	19	45.2	22.7
	50	BENT	20	53.0	12.8	20	35.9	9.1
		STRAIGHT	20	63.1	13.2	20	41.9	11.2
	65	BENT	20	39.5	9.2	20	30.1	7.8
		STRAIGHT	20	50.4	9.3	20	37.8	10.9
	80	BENT	20	28.5	7.3	20	22.6	7.4
		STRAIGHT	20	35.4	7.0	20	28.5	6.8
20	35	STRAIGHT	20	59.8	21.6	20	40.7	19.8
	50	STRAIGHT	20	50.8	16.3	20	35.0	13.1
	65	STRAIGHT	20	40.4	11.4	20	30.8	9.2
	80	STRAIGHT	19	29.7	9.8	20	24.2	8.0
35	35	STRAIGHT	20	49.8	17.8	20	31.4	12.1
	50	STRAIGHT	20	42.8	14.9	20	28.1	10.8
	65	STRAIGHT	20	32.2	11.1	20	22.9	7.6

TABLE 5.4

PUSH FORCES WITH VERTICAL FORCES UNCONTROLLED, P1

DISTANCE % grip length	BAR ELEVATION % vertical reach	ELBOW ANGLE	MALES N	MALES MEAN (pounds)	MALES STD (pounds)	FEMALES N	FEMALES MEAN (pounds)	FEMALES STD (pounds)
15	35	BENT	20	50.3	29.4	20	25.1	9.0
		STRAIGHT	20	36.0	23.2	20	20.3	8.1
	50	BENT	20	49.4	13.5	20	35.4	12.5
	65	BENT	20	43.7	15.7	20	28.3	7.8
	80	STRAIGHT	20	27.8	16.4	20	18.0	7.5
30	35	BENT	20	67.8	25.8	20	38.6	15.1
		STRAIGHT	20	46.0	10.9	20	30.8	8.6
	50	BENT	20	76.0	24.7	20	43.8	14.4
		STRAIGHT	19	44.5	10.9	20	31.2	12.1
	65	BENT	20	56.6	15.8	20	39.0	11.0
		STRAIGHT	20	44.1	15.2	20	30.2	8.6
	80	STRAIGHT	20	46.5	17.0	20	37.4	11.2
45	35	STRAIGHT	20	64.5	16.7	20	39.8	11.3
	50	STRAIGHT	20	66.3	10.8	20	45.3	10.8
	65	STRAIGHT	20	67.3	17.6	20	50.3	15.7
	80	STRAIGHT	20	65.3	26.1	20	48.0	15.7
60	35	STRAIGHT	20	86.6	14.5	20	57.3	13.3
	50	STRAIGHT	20	99.1	20.0	20	61.3	17.5
	65	STRAIGHT	20	106.3	30.8	20	68.3	19.3

PUSH-PULL STUDY, P2 (SITTING),

OBJECTIVE

To investigate the push and pull forces that can be applied in the sitting posture.[15]

TEST EQUIPMENT

Push-Pull strength testing apparatus

Seat

Computerized data acquisition system

Video recording system

3-D sonic digitizer

CONDITIONS

Constants

- Subjects:
  Number: 19 males, 16 females

- Clothing: Shorts, T-shirt and Air Force boots

- Posture: Sitting

- Testing Sessions:
  Number: 1 or 2
  Session Exertions: 35
  Benchmark: 6
  Test: 29
  Rest Period: 2 minutes

15. Authors: C. Glenn Robbins, Donald L. Haddox, Mary W. Jones, Cheryl A. Lai (UDRI), and Dr. Joe W. McDaniel (AAMRL)

NOTE: The 29 exertions were randomized for one session. The exertions were performed in the same sequence for both sessions. The first session was accomplished with uncontrolled force application, and the second with controlled force application. 10 males and 10 females did both sessions. After the completion of both sessions by the 20 subjects, it was found that the controlled force application values could be predicted from the uncontrolled force application values. The remaining subjects performed only one session, with uncontrolled force applications.

- Hands Used: Both

<u>Variables</u>

- Force Direction: 2
  - Push
  - Pull

- Bar Elevation: 3
  - 15 % of vertical reach
  - 50 % of vertical reach
  - 65 % of vertical reach

- Distance: 3

  Measured from the bar, or handle, to the center of the seat.
  - 10 % of grip length
  - 25 % of grip length
  - 40 % of grip length

- Elbow Angle: 2
  - Straight
  - Bent

• Force Application: 2
  - Uncontrolled
  - Controlled

NOTE: The following combinations of the independent variables were not performed because they were either impossible or impractical. They were not performed for either the uncontrolled or controlled force applications.

Force Direction	Bar Elevation	Distance	Elbow Angle
Push	15%	10%	Bent
Push	15%	10%	Straight
Push	50%	10%	Straight
Push	50%	25%	Straight
Push	65%	10%	Straight
Pull	15%	10%	Bent
Pull	15%	10%	Straight

PROCEDURES

The strength testing apparatus was set at the required bar elevation for the particular exertion. The distances from the bar, or handle, had previously been marked on the floor. The centerline of the seat, parallel to the seat width, was set on the appropriate distance marker. The subjects seated themselves with their feet on either side of the seat for the Push exertions, or with both feet in front of the seat for the Pull exertions. Both hands gripped the bar, or handle, at biacromial breadth apart and with an overhand grip. Elbows were set at the appropriate angle. For the "bent" elbow angle when pushing, the elbows were bent to the maximum with the body as close to the bar or handle as possible. When pulling, the elbow angle was maintained as close to a right angle as possible. Subjects applied their maximum voluntary force in the direction specified for a period of four seconds. Exertion started upon the experimenter's command, and ended with a tone single at the end of the four seconds.

MEASURES

- Isometric strength, as the force applied to the handle.

  Horizontal force component in pounds

  Vertical force component in pounds

  Resultant force in pounds

  Resultant angle in degrees

- Body posture was measured with the sonic digitizer. Slant ranges from the microphones to the emitters, at the landmarks, were recorded.

Anthropometric Measures and Landmarks

The anthropometric measures and landmarks listed in paragraphs 5.1 and 5.2.3 were used in this study.

Benchmark Exertions

Three standard exertions were performed at the beginning and end of each session, all were performed with the straight elbow angle.

Force Direction	Posture	Bar Elevation	Distance
Push	Sitting	50%	40%
Pull	Sitting	50%	25%
Push	Standing	65%	45%

RESULTS

Tables 5.5 through 5.8 present the means and standard deviations for the horizontal force component, and sample size, for each exertion. Males exerted more pushing and pulling force than did females, in both the uncontrolled and controlled conditions. The males mean force values ranged from 15.3 for controlled pushes to 70.3 for controlled pulling.

The effects of elbow position and distance from the handle were dependent on the force direction. Pull forces were largest with arms straight and at the near distances. Push forces were largest with the arms bent and at the farther distances. Overall, pushing and pulling forces were greatest with the bar elevation at 50% of sitting vertical reach.

TABLE 5.5

PULL FORCES WITH VERTICAL FORCES CONTROLLED, P2

DISTANCE % grip length	BAR ELEVATION % vertical reach	ELBOW ANGLE	MALES N	MALES MEAN (pounds)	MALES STD (pounds)	FEMALES N	FEMALES MEAN (pounds)	FEMALES STD (pounds)
10	50	BENT	19	91.9	33.6	16	54.2	18.8
		STRAIGHT	19	105.1	30.8	16	66.5	23.6
	65	BENT	19	62.9	23.5	16	42.7	16.1
		STRAIGHT	19	62.7	20.6	16	35.2	8.2
25	15	BENT	19	51.0	12.7	16	27.4	8.8
		STRAIGHT	19	50.9	15.3	16	25.2	6.6
	50	BENT	19	100.9	33.2	16	57.4	19.6
		STRAIGHT	19	116.2	29.1	16	66.6	20.0
	65	BENT	19	64.2	21.5	16	40.6	14.5
		STRAIGHT	19	71.5	21.2	16	43.0	15.1
40	15	BENT	19	59.1	14.7	16	32.8	11.9
		STRAIGHT	19	54.4	13.4	16	30.4	6.8
	50	BENT	19	91.1	28.2	16	51.0	16.7
		STRAIGHT	19	111.5	30.6	16	61.9	18.0
	65	BENT	19	60.2	22.6	16	38.1	11.2
		STRAIGHT	19	68.7	21.5	16	41.3	13.1

TABLE 5.6

PUSH FORCES WITH VERTICAL FORCES CONTROLLED, P2

DISTANCE % grip length	BAR ELEVATION % vertical reach	ELBOW ANGLE	MALES N	MALES MEAN (pounds)	MALES STD (pounds)	FEMALES N	FEMALES MEAN (pounds)	FEMALES STD (pounds)
10	50	BENT	19	28.9	5.99	16	25.1	5.2
	65	BENT	19	21.2	4.6	16	16.2	2.9
25	15	BENT	19	44.6	13.2	16	25.2	8.9
		STRAIGHT	19	35.4	10.4	16	20.4	5.7
	50	BENT	19	36.4	9.2	16	27.7	6.2
	65	BENT	19	28.0	5.6	16	22.5	3.9
		STRAIGHT	19	15.3	4.1	16	13.4	2.9
40	15	BENT	19	44.0	12.1	16	24.2	9.6
		STRAIGHT	19	39.7	9.0	16	21.4	4.4
	50	BENT	19	44.5	11.6	16	33.7	7.1
		STRAIGHT	19	36.5	9.6	16	33.4	5.7
	65	BENT	18	33.5	7.5	16	26.6	3.7
		STRAIGHT	19	30.2	5.9	16	25.7	3.1

TABLE 5.7

PULL FORCES WITH VERTICAL FORCES UNCONTROLLED, P2

DISTANCE % grip length	BAR ELEVATION % vertical reach	ELBOW ANGLE	MALES N	MALES MEAN (pounds)	MALES STD (pounds)	FEMALES N	FEMALES MEAN (pounds)	FEMALES STD (pounds)
10	50	BENT	19	90.1	20.1	16	59.5	16.3
		STRAIGHT	19	105.9	25.7	16	66.8	14.1
	65	BENT	19	64.9	17.3	16	45.7	11.7
		STRAIGHT	19	78.3	17.3	16	53.9	8.8
25	15	BENT	19	73.0	33.1	16	39.5	17.0
		STRAIGHT	19	95.1	34.5	16	47.8	15.1
	50	BENT	19	95.9	15.7	16	62.1	18.5
		STRAIGHT	19	109.3	25.1	16	70.3	14.8
	65	BENT	19	72.2	19.3	16	50.1	11.4
		STRAIGHT	19	83.1	20.1	16	57.3	10.9
40	15	BENT	19	119.2	40.4	16	53.1	18.0
		STRAIGHT	19	131.4	48.1	16	67.2	29.9
	50	BENT	18	93.2	22.4	16	61.3	16.4
		STRAIGHT	19	105.3	23.0	16	65.8	16.0
	65	BENT	19	72.6	17.9	16	49.7	9.5
		STRAIGHT	19	84.0	18.3	16	58.1	9.6

TABLE 5.8

PUSH FORCES WITH VERTICAL FORCES UNCONTROLLED, P2

DISTANCE % grip length	BAR ELEVATION % vertical reach	ELBOW ANGLE	MALES N	MALES MEAN (pounds)	MALES STD (pounds)	FEMALES N	FEMALES MEAN (pounds)	FEMALES STD (pounds)
10	50	BENT	18	33.7	11.5	16	30.1	8.7
	65	BENT	18	23.6	7.6	15	18.0	3.9
25	15	BENT	19	48.6	18.7	16	33.1	11.5
		STRAIGHT	19	37.9	16.9	16	28.2	6.4
	50	BENT	18	54.8	20.7	16	38.9	14.4
	65	BENT	19	42.7	14.3	16	28.9	6.5
		STRAIGHT	19	25.0	7.5	16	20.8	5.1
40	15	BENT	19	53.6	16.5	16	38.3	10.7
		STRAIGHT	19	48.7	12.2	16	37.8	6.7
	50	BENT	19	59.9	22.2	16	38.7	9.0
		STRAIGHT	19	48.4	13.2	16	34.2	8.5
	65	BENT	19	56.7	17.6	16	37.5	7.0
		STRAIGHT	19	48.1	14.4	16	34.8	7.1

■ **PUSH-PULL STUDY, P3** ■

(KNEELING, SQUATTING & CRAWLING)

OBJECTIVE

To determine the maximum push-pull capabilities of aircraft maintenance technicians while kneeling, squatting or crawling.[16]

TEST EQUIPMENT

Push-Pull strength testing apparatus

Computerized data acquisition system

Video recording system

3-D sonic digitizer

CONDITIONS

Constants

- Subjects:

  Number: 20 males, 20 females

- Clothing: Shorts, T-shirt and Air Force boots

- Testing Sessions:

Number:	4
Session Exertions	36
Benchmark:	8
Test:	28
Rest Period:	2 minutes

16. Authors: C. Glenn Robbins, Donald L. Haddox, Cheryl A Lai, William H. Harper, Laura Meek and Mary W. Jones (UDRI) and Dr. Joe W. McDaniel (AAMRL)

NOTE: The 56 test exertions were randomized over two sessions. The order of the exertions were repeated, the first two sessions with uncontrolled force application and the third and fourth sessions with uncontrolled force application.

- Hands Used:
  Both for Kneeling and Squatting postures
  Right for Crawling posture

Variables

- Postures: 4
  - Kneel 1 - kneeling on one knee
  - Kneel 2 - kneeling on both knees
  - Squat
  - Crawl

- Force Directions: 2
  - Push
  - Pull

- Bar Elevations: 2
  - 15 % of average vertical reach
  - 50 % of average vertical reach

- Distances: 4
  - 0 % of average vertical reach
  - 20 % of average vertical reach
  - 40 % of average vertical reach
  - 60 % of average vertical reach

NOTE: The average vertical reach of the Kneel 1, Kneel 2 and Squat postures was used in this study, as the values of the vertical reach for each posture are very close.

- Elbow Angle: 2
  - Straight
  - Bent

- Force Application: 2
  - Uncontrolled
  - Controlled

NOTE: In the Crawling posture, 8 exertions were measured, in both force applications, for a total of 16 exertions. They were:

Force Direction	Bar Elevation	Distance	Elbow Angle
Push	15%	60%	Straight
Push	15%	40%	Bent
Push	50%	40%	Bent
Push	50%	60%	Straight
Pull	15%	60%	Straight
Pull	15%	40%	Bent
Pull	50%	40%	Bent
Pull	50%	60%	Straight

NOTE: Exertions for certain combinations of the variables were not performed due to their being impossible or impractical in some postures. They were not performed for either force application condition. The following exertions were not performed, as listed by posture.

Kneeling - one knee

Force Direction	Bar Elevation	Distance	Elbow Angle
Push	15%	0%	Bent
Push	15%	0%	Straight
Push	50%	0%	Bent
Push	50%	0%	Straight
Push	15%	60%	Bent
Push	50%	60%	Bent
Pull	15%	40%	Bent
Pull	50%	40%	Bent
Pull	15%	60%	Bent
Pull	15%	60%	Straight
Pull	50%	60%	Bent
Pull	50%	60%	Straight

Kneeling - two knees

Force Direction	Bar Elevation	Distance	Elbow Angle
Push	15%	0%	Bent
Push	15%	0%	Straight
Push	50%	0%	Bent
Push	50%	0%	Straight
Push	15%	40%	Bent
Push	50%	40%	Bent
Push	15%	60%	Bent
Push	15%	60%	Straight
Push	50%	60%	Bent
Push	50%	60%	Straight
Pull	50%	20%	Bent
Pull	15%	40%	Bent
Pull	15%	40%	Straight
Pull	50%	40%	Bent
Pull	50%	40%	Straight
Pull	15%	60%	Bent
Pull	15%	60%	Straight
Pull	50%	60%	Bent
Pull	50%	60%	Straight

Squatting

Force Direction	Bar Elevation	Distance	Elbow Angle
Push	15%	0%	Bent
Push	15%	0%	Straight
Push	50%	0%	Bent
Push	50%	0%	Straight
Push	15%	20%	Straight
Push	50%	20%	Straight
Push	15%	60%	Bent
Push	50%	60%	Bent
Pull	15%	20%	Bent
Pull	50%	20%	Bent
Pull	15%	40%	Bent
Pull	15%	40%	Straight
Pull	50%	40%	Bent
Pull	15%	60%	Bent
Pull	15%	60%	Straight
Pull	50%	60%	Bent
Pull	50%	60%	Straight

PROCEDURES

The distances from the bar, or handle, were marked on the floor for each subject. The required bar elevation was set for the exertion to be made. The following directions were used to position the subject, with the mid-sagittal plane aligned with the center line of the bar or handle.

- Kneeling - one knee: right knee and left foot on distance line for pushes and pulls

- Kneeling - two knees: push - right knee on distance line, left knee on, or slightly forward of, distance line

- Kneeling - two knees: pull - right knee on distance line, left knee on, or slightly aft of, distance line

- Squatting: push - right foot on distance line, left foot on, or slightly forward of, distance line

- Squatting: pull - right foot on distance line, left foot on, or slightly aft of, distance line

- Crawling: both knees on distance line, left palm on floor beneath the left shoulder

Subjects applied their maximum voluntary force for a period of four seconds. The exertion started upon the experimenter's command, and ended with a tone signal at the end of the four seconds.

MEASURES

- *Isometric Strength*, as the force applied to the bar or handle.

  Horizontal force component in pounds

  Vertical force component in pounds

  Resultant force in pounds

  Resultant in degrees

- Body posture was measured with the sonic digitizer. Slant ranges from the microphones to the emitters, at the landmarks, were recorded.

Anthropometric Measures and Landmarks

The anthropometric measures and landmarks listed in paragraphs 5.1 and 5.2.3 were used for this study.

Benchmark Exertions

The following three exertions were performed, under the uncontrolled force application condition, at the beginning and end of each session

Force Direction	Posture	Bar Elevation	Distance	Elbow Angle
Push	Sitting	50%	40%	Straight
Pull	Sitting	50%	25%	Straight
Push	Standing	65%	45%	Straight

RESULTS

Tables 5.9 through 5.12 present the mean and standard deviation for the horizontal force component, and sample size, for each exertion. Males produced greater forces than females in all postures, and uncontrolled were always greater than controlled forces. The range of mean force values for males and females, respectively, are: 32.4 to 77.7 and 20.1 to 59.8 in the Kneel 1 posture, 29.6 to 72.9 and 20.0 to 51.0 for the Kneel 2 posture, 19.3 to 112.0 and 16.8 to 96.4 for the Squatting posture, and 20.9 to 75.1 and 12.0 to 54.3 for the Crawling posture.

Higher forces were recorded in the Squatting and Kneel 1 postures than the Kneel 2 or Crawling postures. Averaged across all other variables, elbow angle had little effect in the Kneel 2 and Crawling postures. In the Kneel 1 posture, push forces were greater with bent arms and pull forces were greater with straight arms. In the Squatting posture, pull forces increased as the distance from the handle decreased and push forces increased as the distance increased. This was also the case for the Kneel 2 posture, although the effect was not pronounced. For Kneel 1 and Crawling postures, force increased as distance increased for both push and pull.

TABLE 5.9

PULL FORCES WITH VERTICAL FORCES CONTROLLED, P3

DISTANCE	BAR ELEVATION (% of average vertical reach)	ELBOW ANGLE	MALES N	MALES MEAN (pounds)	MALES STD (pounds)	FEMALES N	FEMALES MEAN (pounds)	FEMALES STD (pounds)
			KNEELING - 1 KNEE					
0	15	BENT	20	43.7	11.1	19	29.3	10.3
		STRAIGHT	20	51.1	16.0	19	33.6	11.7
	50	BENT	20	51.9	15.0	19	34.6	15.0
		STRAIGHT	20	55.0	12.0	19	40.6	7.4
20	15	BENT	20	51.2	10.9	19	31.4	9.8
		STRAIGHT	20	51.8	13.1	19	32.7	7.8
	50	BENT	20	47.7	16.7	19	34.7	9.0
		STRAIGHT	20	52.8	17.2	19	37.7	11.8
40	15	STRAIGHT	20	50.2	12.4	19	33.6	7.8
	50	STRAIGHT	20	48.0	20.6	19	33.4	12.1
			KNEELING - 2 KNEES					
0	15	BENT	20	38.6	8.7	19	28.3	8.1
		STRAIGHT	20	38.7	10.8	19	26.1	7.1
	50	BENT	20	32.4	9.2	19	24.8	4.6
		STRAIGHT	20	37.5	8.4	19	30.5	6.0
20	15	BENT	20	40.8	10.2	19	29.7	8.0
		STRAIGHT	20	42.0	11.4	19	30.5	6.0
	50	STRAIGHT	20	28.8	7.1	19	22.6	4.1

(continued)

TABLE 5.9 (concluded)

PULL FORCES WITH VERTICAL FORCES CONTROLLED, P3

DISTANCE	BAR ELEVATION (% average vertical reach)	ELBOW ANGLE	MALES N	MALES MEAN (pounds)	MALES STD	FEMALES N	FEMALES MEAN (pounds)	FEMALES STD
				SQUATTING				
0	15	BENT	20	65.7	22.9	19	43.4	15.7
		STRAIGHT	20	101.5	39.7	19	83.7	22.4
	50	BENT	20	43.9	12.0	19	29.9	7.1
		STRAIGHT	20	60.4	12.8	19	43.0	8.6
20	15	STRAIGHT	20	72.4	27.2	19	41.8	14.1
	50	STRAIGHT	20	40.5	15.1	19	26.3	8.1
40	50	STRAIGHT	20	27.9	11.9	19	18.5	9.4
				CRAWLING				
40	15	BENT	9	48.4	10.5	11	26.6	7.2
	50	BENT	9	33.7	6.0	11	20.0	6.5
60	15	STRAIGHT	9	56.7	15.2	11	37.8	11.5
	50	STRAIGHT	9	31.8	9.0	11	23.8	5.0

TABLE 5.10

PUSH FORCES WITH VERTICAL FORCES CONTROLLED, P3

DISTANCE (% average vertical reach)	BAR ELEVATION	ELBOW ANGLE	MALES N	MALES MEAN (pounds)	MALES STD (pounds)	FEMALES N	FEMALES MEAN (pounds)	FEMALES STD (pounds)
KNEELING - 1 KNEE								
20	15	BENT	19	42.6	11.7	19	27.9	13.7
		STRAIGHT	20	33.2	7.7	19	21.8	9.5
	50	BENT	20	46.0	11.2	19	30.3	9.3
		STRAIGHT	20	33.5	10.6	19	20.1	5.8
40	15	BENT	20	36.7	10.1	19	24.0	11.5
		STRAIGHT	20	32.4	9.6	19	20.1	5.2
	50	BENT	20	55.6	14.6	19	36.1	10.2
		STRAIGHT	20	45.6	13.8	19	32.8	9.0
60	15	STRAIGHT	20	60.4	13.5	19	45.6	11.9
	50	STRAIGHT	20	60.4	13.5	19	45.6	11.9
KNEELING - 2 KNEES								
20	15	BENT	20	45.1	10.5	19	27.9	12.2
		STRAIGHT	20	31.6	8.9	19	20.3	5.8
	50	BENT	20	55.5	15.3	19	37.1	12.2
		STRAIGHT	20	44.9	11.7	19	30.0	6.6
40	15	STRAIGHT	20	29.6	8.2	19	20.0	6.1
	50	STRAIGHT	20	60.5	15.1	19	39.0	11.0

(continued)

TABLE 5.10 (concluded)

PUSH FORCES WITH VERTICAL FORCES CONTROLLED, P3

DISTANCE (% average vertical reach)	BAR ELEVATION	ELBOW ANGLE	MALES N	MALES MEAN (pounds)	MALES STD (pounds)	FEMALES N	FEMALES MEAN (pounds)	FEMALES STD (pounds)
SQUATTING								
20	15	BENT	20	38.7	13.7	19	31.5	11.9
	50	BENT	20	22.7	7.7	19	17.3	4.0
40	15	BENT	20	37.8	10.3	19	23.9	9.7
		STRAIGHT	20	32.9	8.1	19	22.5	6.1
	50	BENT	20	32.0	9.8	19	23.8	5.2
		STRAIGHT	19	19.3	5.2	19	16.8	2.7
60	15	STRAIGHT	20	34.3	11.3	17	20.5	5.2
	50	STRAIGHT	20	37.2	11.0	19	31.1	5.8
CRAWLING								
40	15	BENT	9	24.0	8.8	11	18.4	11.1
	50	BENT	9	41.1	13.6	11	22.3	8.0
60	15	STRAIGHT	9	20.9	8.1	11	12.0	3.2
	50	STRAIGHT	9	55.2	12.5	11	32.3	9.1

TABLE 5.11

PULL FORCES WITH VERTICAL FORCES UNCONTROLLED, P3

DISTANCE	BAR ELEVATION (% average vertical reach)	ELBOW ANGLE	MALES N	MALES MEAN (pounds)	MALES STD (pounds)	FEMALES N	FEMALES MEAN (pounds)	FEMALES STD (pounds)
		KNEELING - 1 KNEE						
0	15	BENT	20	61.9	19.6	19	44.8	18.3
		STRAIGHT	20	62.8	19.0	19	53.6	19.1
	50	BENT	20	43.2	12.1	19	33.9	7.4
		STRAIGHT	20	51.0	1.7	19	43.6	9.8
20	15	BENT	20	50.4	16.1	19	42.7	14.1
		STRAIGHT	20	60.4	13.0	19	47.9	15.6
	50	BENT	20	46.7	14.1	19	33.6	9.7
		STRAIGHT	20	57.2	17.9	19	39.5	13.3
40	15	STRAIGHT	20	59.0	20.6	19	43.2	17.2
	50	STRAIGHT	20	53.8	19.3	19	39.4	16.1
		KNEELING - 2 KNEES						
0	15	BENT	20	50.6	17.3	19	39.3	12.0
		STRAIGHT	20	58.4	16.9	19	48.7	14.4
	50	BENT	20	33.0	8.8	19	28.5	3.9
		STRAIGHT	20	36.6	10.5	19	34.2	6.0
20	15	BENT	20	43.0	9.3	19	34.1	7.8
		STRAIGHT	20	41.6	10.2	19	34.2	7.6
	50	STRAIGHT	20	34.3	8.5	19	28.8	5.3

(continued)

TABLE 5.11 (concluded)

PULL FORCES WITH VERTICAL FORCES UNCONTROLLED, P3

DISTANCE	BAR ELEVATION (% average vertical reach)	ELBOW ANGLE	MALES N	MALES MEAN (pounds)	MALES STD (pounds)	FEMALES N	FEMALES MEAN (pounds)	FEMALES STD (pounds)
			SQUATTING					
0	15	BENT	20	95.0	37.2	19	75.8	26.8
		STRAIGHT	20	112.0	33.5	19	96.4	25.4
	50	BENT	20	52.3	18.0	19	38.6	9.4
		STRAIGHT	20	74.8	15.6	19	53.1	10.4
20	15	STRAIGHT	19	69.9	24.3	19	55.9	18.4
	50	STRAIGHT	20	52.9	14.1	19	39.0	8.7
40	50	STRAIGHT	20	40.8	12.2	19	30.8	6.5
			CRAWLING					
40	15	BENT	9	54.4	13.2	11	34.3	7.5
	50	BENT	9	43.7	9.1	11	31.7	4.5
60	15	STRAIGHT	9	63.0	15.8	11	44.4	10.9
	50	STRAIGHT	9	52.7	12.1	11	40.1	7.4

TABLE 5.12

PUSH FORCES WITH VERTICAL FORCES UNCONTROLLED, P3

DISTANCE (% average vertical reach)	BAR ELEVATION	ELBOW ANGLE	MALES N	MALES MEAN (pounds)	MALES STD (pounds)	FEMALES N	FEMALES MEAN (pounds)	FEMALES STD (pounds)
KNEELING - 1 KNEE								
20	15	BENT	20	58.4	12.1	19	40.8	13.1
		STRAIGHT	20	33.2	7.7	19	21.8	9.5
	50	BENT	20	58.4	17.4	19	41.8	14.2
		STRAIGHT	20	40.1	14.4	19	23.4	9.2
40	15	BENT	20	64.8	13.6	19	45.1	10.7
		STRAIGHT	20	60.2	13.3	19	43.7	10.1
	50	BENT	20	64.5	19.2	19	46.9	11.4
		STRAIGHT	20	57.6	14.3	19	41.4	11.2
60	15	STRAIGHT	19	73.3	15.1	19	54.3	11.1
	50	STRAIGHT	20	77.7	20.9	19	59.8	12.1
KNEELING - 2 KNEES)								
20	15	BENT	20	63.5	11.7	19	43.9	8.8
		STRAIGHT	20	64.0	11.0	19	44.1	8.6
	50	BENT	20	67.7	14.3	19	47.7	13.3
		STRAIGHT	20	59.6	20.1	19	35.9	10.7
40	15	STRAIGHT	20	72.9	20.2	19	51.0	11.8
	50	STRAIGHT	20	66.8	18.0	19	51.0	14.8

(continued)

TABLE 5.12 (concluded)

PUSH FORCES WITH VERTICAL FORCES UNCONTROLLED, P3

DISTANCE (% average vertical reach)	BAR ELEVATION	ELBOW ANGLE	MALES N	MALES MEAN (pounds)	MALES STD (pounds)	FEMALES N	FEMALES MEAN (pounds)	FEMALES STD (pounds)
			SQUATTING					
20	15	BENT	20	48.5	18.1	19	37.4	13.0
	50	BENT	20	41.6	11.5	19	28.7	12.7
40	15	BENT	20	63.1	17.1	19	43.8	12.3
		STRAIGHT	20	47.9	12.7	19	31.0	5.0
	50	BENT	20	51.0	13.4	19	37.6	9.3
		STRAIGHT	20	37.5	8.9	19	25.4	4.4
60	15	STRAIGHT	20	75.5	15.8	19	53.8	8.6
	50	STRAIGHT	20	75.0	20.0	19	56.2	11.4
			CRAWLING					
40	15	BENT	9	51.0	10.8	11	36.0	9.6
	50	BENT	9	57.2	14.3	11	36.9	10.8
60	15	STRAIGHT	9	68.3	18.0	11	45.3	11.2
	50	STRAIGHT	9	75.1	10.0	11	54.3	13.3

Pull forces were greater with the handle in the lower position, and push forces were greater with the handle in the higher position, for the Kneel 1, Kneel 2 and Crawling postures. In the Squatting posture, subjects produced greater forces when the bar was in the lower position for both pushing and pulling.

OBJECTIVE

To investigate the amount of push and pull forces that can be applied while in a supine posture.[17]

TEST EQUIPMENT

Push-Pull strength test apparatus

Foam rubber mat, for subjects to lie on for comfort and to prevent slipping

Computerized data acquisition system

Video recording system

CONDITIONS

Constants

- Subjects: 20 males, 20 females

- Clothing: Fatigue shirt with street clothes so subjects would have similar coefficient of friction

- Testing Sessions:
  - Number: 2
  - Session Exertions: 34
  - Benchmark: 4
  - Test: 30
  - Rest Period: 2 minutes

17. Authors: C. Glenn Robbins, Cheryl A. Lai, William H. Harper, Laura Meek, and Mary W. Jones (UDRI) and Dr. Joe W. McDaniel (AAMRL)

NOTE: The Behind the Head and Side exertions (12) were randomized in one block and the Over Body exertions (48) in another block. The randomized Behind the Head and Side exertions were performed at the start of the first session with 18 of the randomized Over Body exertions completing the first session. The remaining 30 randomized Over Body exertions were done in the second session.

- Posture: Supine

- Force Application: Uncontrolled

Variables

In this study there were sets of variables for each of the exertion types (Behind the Head, Side and Over Body). The variable descriptions for each exertion type, with diagrams relating the variables to the body, are listed separately.

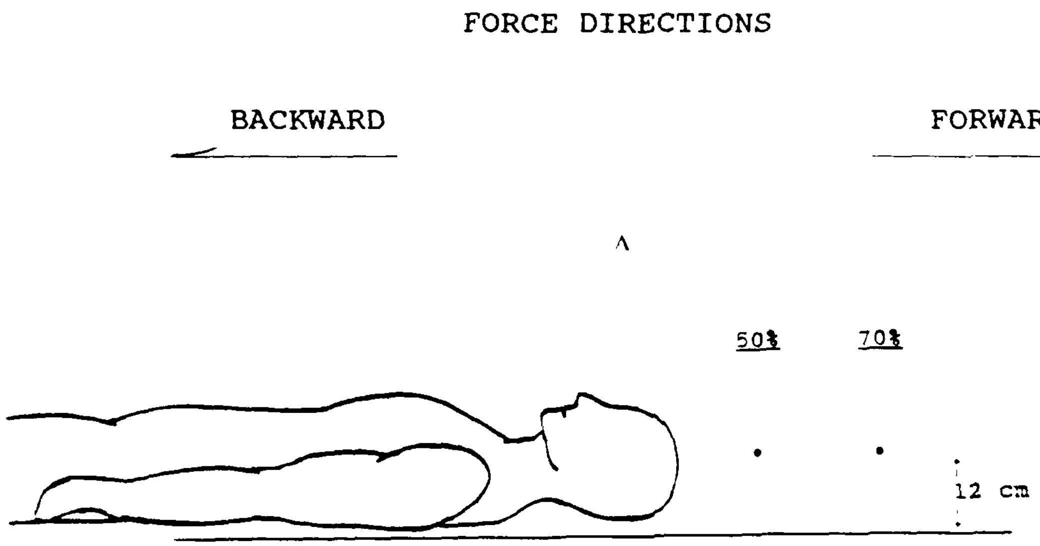
Behind the Head Exertions (Figure 5.3)

- Force Direction: 2
  Forward
  Backward

- Hand(s) Used: 2
  Right
  Both

- Bar Elevation: 1
  12cm - above the floor

- Distance: 2 (measured from suprasternale)
  50% of functional reach
  70% of functional reach



A - Distances

Figure 5.3 Diagram of Behind the Head Exertion Variables

Side Exertions (Figure 5.4)

- Force Direction: 2
  - Forward
  - Backward

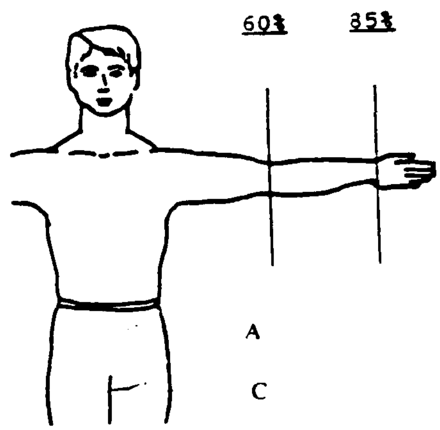
- Hand Used: 1
  - Right

- Bar Elevation: 1
  - 12 cm - above the floor

- Distance: 2 (measured from suprasternale)
  - 60% of 1/2 of arm span
  - 85% of 1/2 of arm span

FORCE DIRECTIONS

FORWARD ← → BACKWARD



A - Distances
C - 1/2 Span

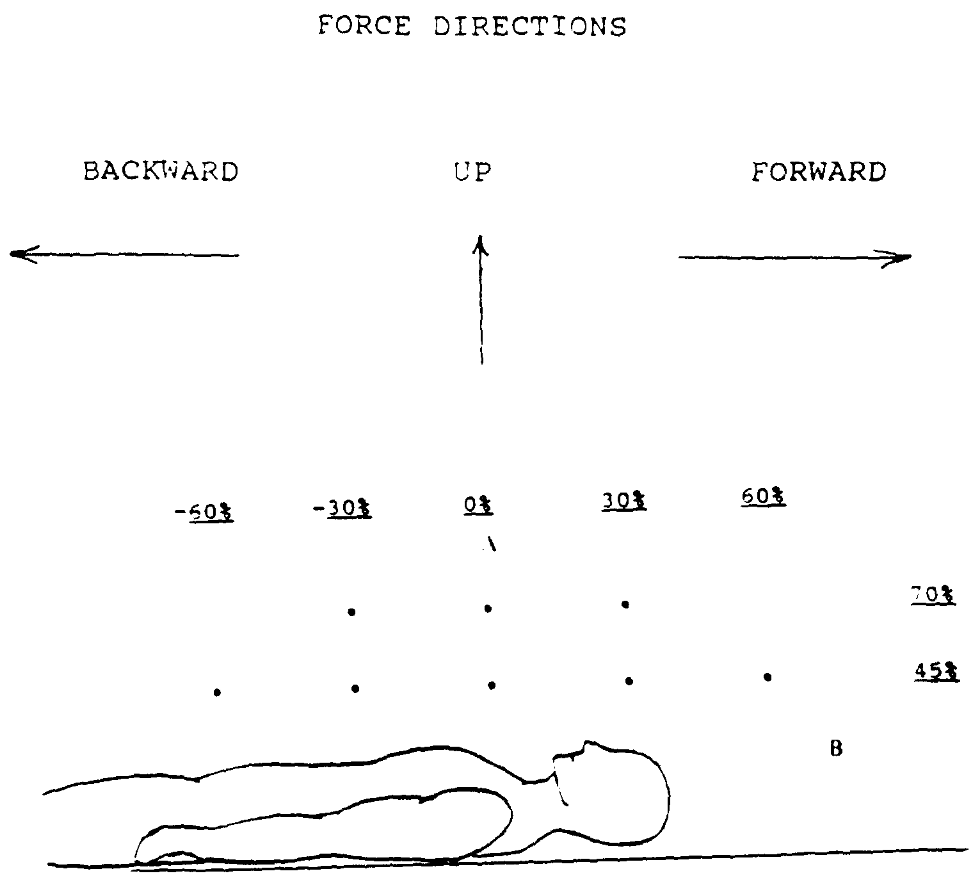
Figure 5.4 Diagram of Side Exertion Variables

Over Body Exertions (Figure 5.5)

- Force Direction: 3
  - Forward
  - Backward
  - Up

- Hand Used: 2
  - Right
  - Both

- Bar Elevation: 2 - measured from floor
  - 45% of functional reach
  - 70% of functional reach



A - Distances
B - Bar Elevations

Figure 5.5 Diagram of Over Body Exertion Variables

- Distances: from suprasternale

For 45% vertical height: 4
60% of functional reach
30% of functional reach
0% of functional reach
-30% of functional reach

For 70% vertical height: 3
30% of functional reach
0% of functional reach
-30% of functional reach

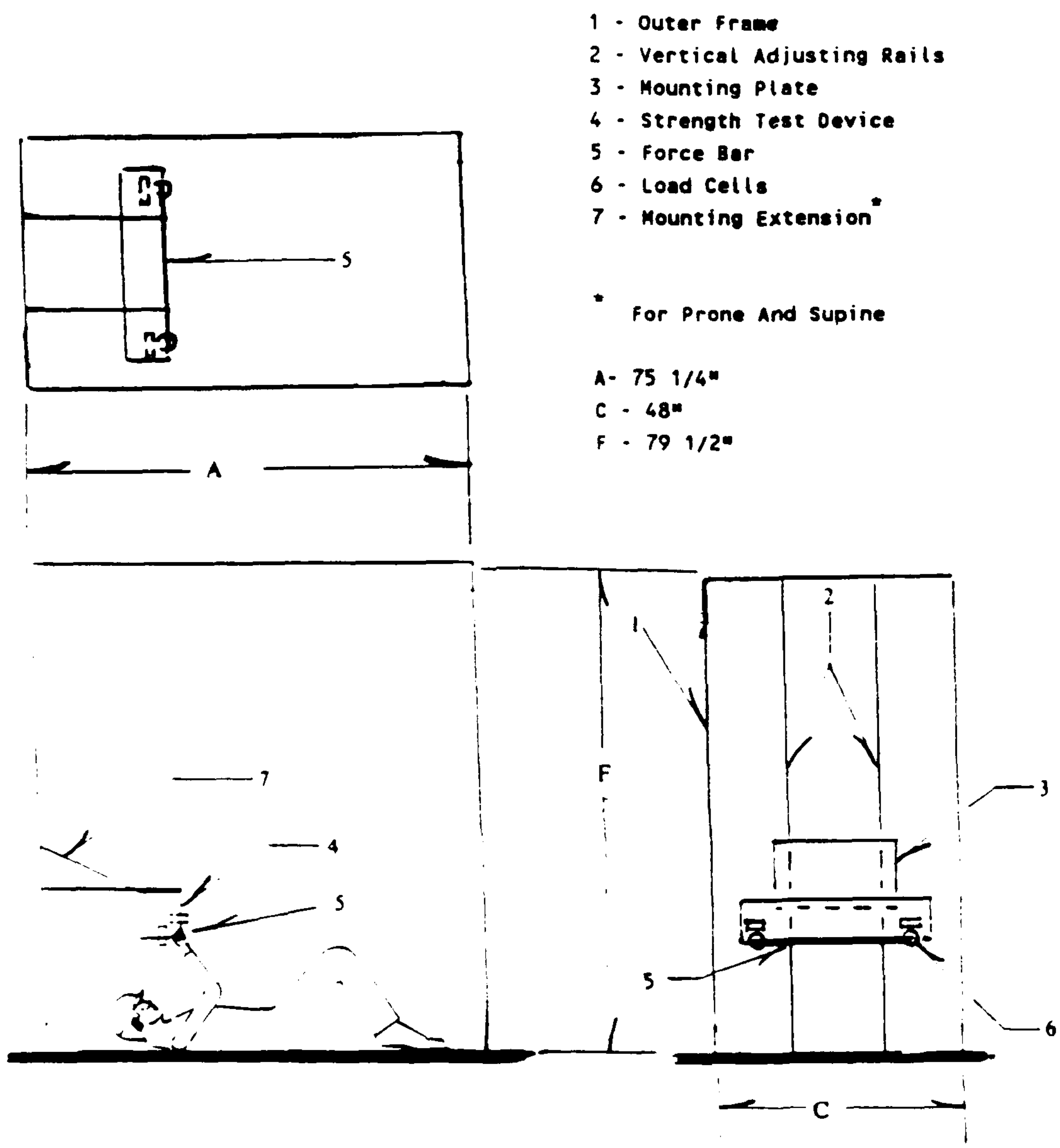
PROCEDURES

The distances were marked on the floor, with 0 % of functional reach directly under the bar. The bar was set for the exertion and the subject instructed on the hand and force direction conditions to be used. The subject was positioned for the exertion.

For the Over Body and Behind the Head exertions, the subjects laid on their backs with the length of the body perpendicular to the bar. The mid-sagittal plane was aligned with the center of the bar and the suprasternale aligned with the distance marker for the exertion (Figure 5.6).

For the Side exertions, the subject laid with the length of the body parallel to the bar and with the bar to the subjects' right. The mid-sagittal plane was aligned with the distance marker and the suprasternale with the approximate center of the bar.

When the required conditions were met, subjects applied their maximum voluntary static force to the bar for a four second period, starting on the experimenter's command. An audible tone signaled the end of the exertion period.



The apparatus was used in this configuration for the Supine posture. The man-model is included in the Side view to show the relationship of a subject to the apparatus for an Over Body exertion with Both hands. The Force Bar elevation and Distance were set at 45% and 30% of functional reach, respectively, for the example shown.

Figure 5.6 Strength Testing Apparatus, Supine Posture

MEASURES

- Isometric strength, as the force applied to the handle.

  Horizontal force component in pounds

  Vertical force component in pounds

  Resultant force in pounds

  Resultant angle in degrees
    Positive when resultant above horizontal
    Negative when resultant below horizontal

Anthropometric Measures

The anthropometric measures listed in paragraph 5.1 were used in this study.

Benchmark Exertions

Two benchmark exertions were performed at the beginning, and repeated at the end, of each session. Both exertions were Over Body Exertions, at a bar elevation of 70% of functional reach, with the distance at 0% of functional reach, using both hands. Force was applied in the Up direction for one exertion, and in the Forward direction for the other.

RESULTS

Tables 5.13 through 5.15 present the mean and standard deviation, and sample size, for each exertion. Males produced greater pushing and pulling forces than females in all conditions. The mean force ranged from 26.3 to 147.8 for males, and 16.3 to 78.0 for females. The effect of distance was dependent on the force direction. For horizontal forces (Forward and Backward), more force was obtained by subjects when the bar elevation was at the lower (45 %) position. Up forces were greater with the bar elevation at the higher (70 %) position. Up forces increased as the distance moved closer to the suprasternale. There was a

TABLE 5.13
MEANS AND STANDARD DEVIATIONS FOR OVER BODY EXERTIONS

BAR ELEVATION (% functional reach)	DISTANCE (% functional reach)	HAND USED	FORCE DIRECTION	FEMALE N	FEMALE MEAN (pounds)	FEMALE STD (pounds)	MALE N	MALE MEAN (pounds)	MALE STD (pounds)
45	-60	BOTH	BACK	20	55.7	17.3	20	92.8	43.5
		BOTH	FORW	20	44.2	14.3	20	70.0	18.3
		BOTH	UP	20	34.7	9.1	19	61.6	18.5
		RIGHT	BACK	20	34.2	12.1	20	57.7	20.8
		RIGHT	FORW	20	27.6	8.6	20	51.3	19.0
		RIGHT	UP	20	20.1	6.5	20	38.1	20.4
	-30	BOTH	BACK	20	37.1	11.1	20	57.1	22.2
		BOTH	FORW	20	36.6	7.8	19	64.9	16.9
		BOTH	UP	20	52.1	11.4	20	109.6	37.7
		RIGHT	BACK	20	20.7	6.7	19	32.8	12.3
		RIGHT	FORW	20	22.1	5.8	20	43.1	17.2
		RIGHT	UP	20	27.8	7.3	20	58.3	20.7
	0	BOTH	BACK	20	39.9	10.5	20	68.8	30.9
		BOTH	FORW	20	45.0	12.8	20	75.0	23.0
		BOTH	UP	20	43.2	13.3	20	107.2	36.8
		RIGHT	BACK	20	24.6	6.7	20	43.1	17.8
		RIGHT	FORW	20	27.1	6.3	20	54.5	23.8
		RIGHT	UP	20	20.6	6.2	19	42.9	21.8
	30	BOTH	BACK	20	41.8	9.7	20	71.7	25.2
		BOTH	FORW	20	41.4	11.6	20	74.6	25.0
		BOTH	UP	20	41.7	13.0	20	77.2	25.4
		RIGHT	BACK	20	31.4	10.5	19	55.4	22.1
		RIGHT	FORW	20	23.9	5.4	20	44.0	14.3
		RIGHT	UP	20	18.9	5.5	20	40.1	18.6
	60	BOTH	BACK	20	42.7	11.1	19	75.0	30.8
		BOTH	FORW	20	53.0	13.4	20	85.8	36.6
		BOTH	UP	20	27.5	8.2	20	57.0	16.7
		RIGHT	BACK	20	31.7	11.0	19	57.7	25.1
		RIGHT	FORW	20	33.4	12.5	20	48.3	21.8
		RIGHT	UP	20	16.4	5.2	20	29.4	9.0

(continued)

TABLE 5.13 (concluded)
MEANS AND STANDARD DEVIATIONS FOR OVER BODY EXERTIONS

BAR ELEVATION (% functional reach)	DISTANCE	HAND USED	FORCE DIRECTION	FEMALE N	FEMALE MEAN (pounds)	FEMALE STD	MALE N	MALE MEAN (pounds)	MALE STD
70	-30	BOTH	BACK	20	32.4	6.0	20	51.5	13.0
		BOTH	FORW	20	29.3	6.0	20	49.7	17.4
		BOTH	UP	20	59.6	25.2	20	122.9	44.6
		RIGHT	BACK	20	20.8	6.3	20	33.2	10.9
		RIGHT	FORW	20	17.8	4.0	20	29.3	11.8
		RIGHT	UP	20	29.1	7.3	19	55.2	17.7
	0	BOTH	BACK	20	31.1	7.0	20	46.8	14.7
		BOTH	FORW	20	28.7	7.1	20	49.3	18.4
		BOTH	UP	20	76.4	25.9	19	147.8	53.4
		RIGHT	BACK	20	18.7	4.3	20	32.1	9.1
		RIGHT	FORW	20	16.3	4.2	18	26.3	7.2
		RIGHT	UP	20	32.1	9.5	20	66.3	20.7
	30	BOTH	BACK	20	33.6	9.0	20	50.8	15.9
		BOTH	FORW	20	29.3	7.5	20	51.6	20.3
		BOTH	UP	20	78.0	29.3	20	128.5	47.9
		RIGHT	BACK	20	22.8	7.1	20	36.1	11.5
		RIGHT	FORW	20	19.2	6.1	20	32.9	16.3
		RIGHT	UP	20	38.0	17.0	19	69.0	23.0

TABLE 5.14
MEANS AND STANDARD DEVIATIONS FOR BEHIND HEAD EXERTIONS

BAR ELEVATION	DISTANCE (% functional reach)	HAND USED	FORCE DIRECTION	FEMALE N	FEMALE MEAN (pounds)	FEMALE STD	MALE N	MALE MEAN (pounds)	MALE STD
12 CM	50	BOTH	BACK	20	45.2	13.4	19	85.6	29.0
		BOTH	FORW	20	46.9	17.2	18	79.3	23.5
		RIGHT	BACK	20	30.2	9.3	19	51.0	12.9
		RIGHT	FORW	20	22.8	5.3	20	40.6	12.7
	70	BOTH	BACK	20	47.0	12.9	20	91.5	39.2
		BOTH	FORW	20	57.7	12.8	19	78.8	20.7
		RIGHT	BACK	20	35.7	12.8	20	63.6	19.1
		RIGHT	FORW	19	35.4	9.4	20	63.9	23.0

TABLE 5.15
MEANS AND STANDARD DEVIATIONS FOR SIDE EXERTIONS

BAR ELEVATION	DISTANCE (% of 1/2 span)	HAND USED	FORCE DIRECTION	FEMALE N	FEMALE MEAN (pounds)	FEMALE STD	MALE N	MALE MEAN (pounds)	MALE STD
12 CM	60	RIGHT	BACK	20	27.5	6.3	20	43.0	11.1
			FORWARD	20	26.7	7.8	20	45.6	12.9
	85	RIGHT	BACK	20	32.0	7.1	20	51.8	16.5
			FORWARD	20	30.9	9.6	20	53.5	17.0

slight tendency for Forward and Backward forces to increase as the distance moved away from the suprasternale. However, this did not hold true for all conditions.

■ PUSH-PULL STUDY, P5 PRONE ■

OBJECTIVE

To investigate the magnitude of push and pull forces that can be applied in the prone posture.[19]

TEST EQUIPMENT

Push-Pull strength test apparatus

Foam rubber mat, for subjects to lie on for comfort and to prevent slipping

Computerized data acquisition system

Video recording system

CONDITIONS

Constants

- Subjects: 20 males, 20 females
- Clothing: Fatigue shirt with street clothes
- Testing Sessions:

  Number: 2

  Session Exertions: 31

  Benchmark: 4

  Test: 27

  Rest Period: 2 minutes

Authors: C. Glenn Robbins, Cheryl A. Lai, William H. Harper, Laura Meek, and Mary W. Jones (UDRI) and Dr. Joe W. McDaniel (AAMRL)

NOTE: Exertions were randomized in three blocks. One block consisted of the Front of Head and the Side exertions. Another was the Under Body exertions at the 45 % bar elevation, and the other was the Under Body exertions at the 70 % bar elevation.

- Posture: Prone

- Force Application: Uncontrolled

Variables

There were different sets of variables for each of the three exertion types (Front of Head, Side and Under Body). The variable description, and diagrams for relationship of variables to the body, for each exertion type are listed separately.

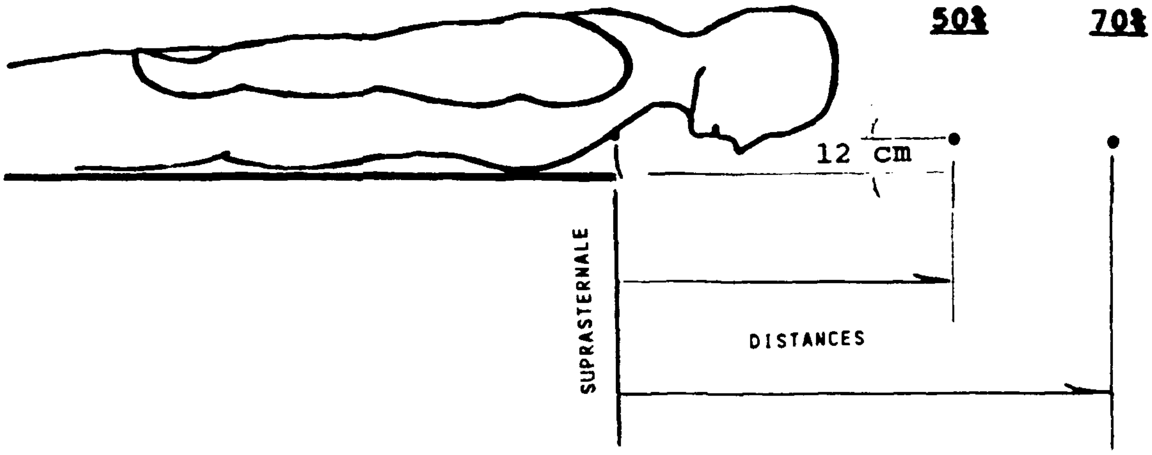
Front of Head Exertions (Figure 5.7)

- Force Directions: 2
  - Forward
  - Backward

- Bar Elevations: 1
  - 12 cm above the platform

- Distance: 2
  - 50 % of functional reach
  - 70 % of functional reach

- Hand Used: 2
  - Right
  - Both



Force Directions

Backward ⟵——————————⟶ **Forward**

Figure 5.7 Front of Head Exertions

Side Exertions (Figure 5.8)

- Force Directions: 2
  Inward Outward
- Bar Elevation: 1
  12 cm above the platform
- Distance: 2
  60 % of 1/2 arm span
  85 % of 1/2 arm span
- Hand Used: 1
  Right

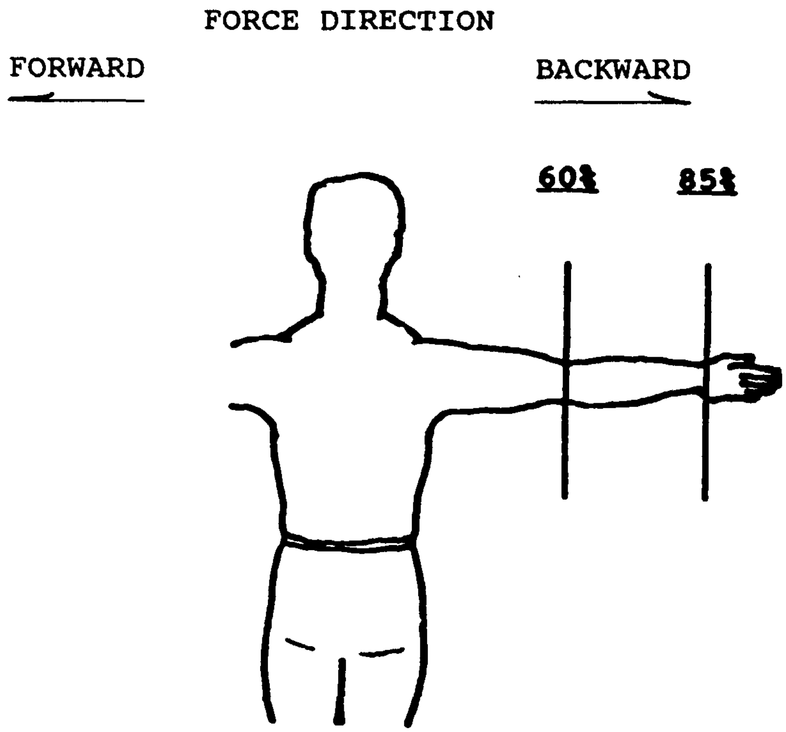


Figure 5.8 Side Exertions

Under Body Exertions (Figure 5.9)

- Force Directions: 3
  - Footward
  - Headward
  - Up

- Bar Elevations: 2
  - Measured down from top of platform

  45 % of functional reach minus chest depth
  70 % of functional reach minus chest depth

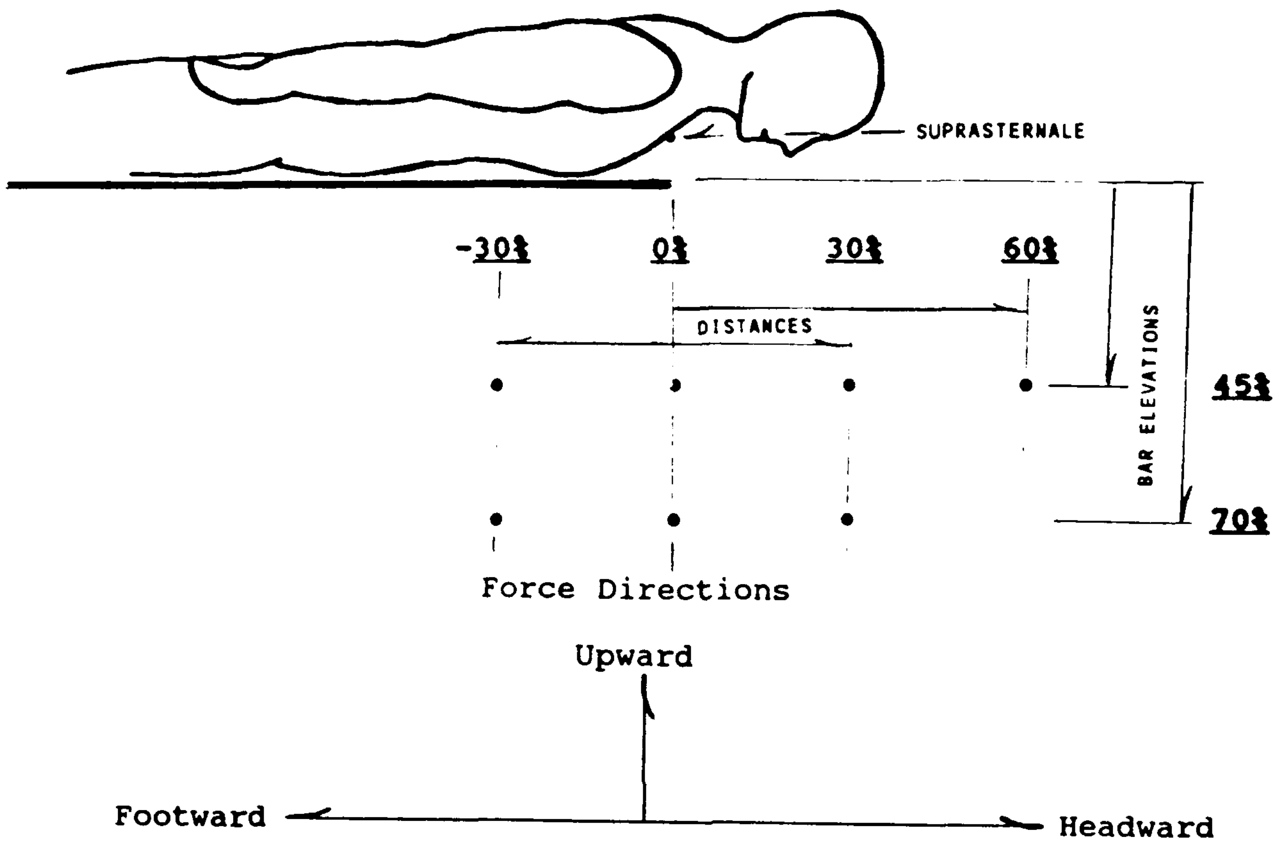


Figure 5.9 Under Body Exertions

- Distance:

  For the 45 % bar elevation
  - 60 % of functional reach
  - 30 % of functional reach
  - 0 % of functional reach
  - -30 % of functional reach

  For the 70 % bar elevation
  - 30 % of functional reach
  - 0 % of functional reach
  - 30 % of functional reach

- Hand Used: 2
  Right
  Both

PROCEDURE

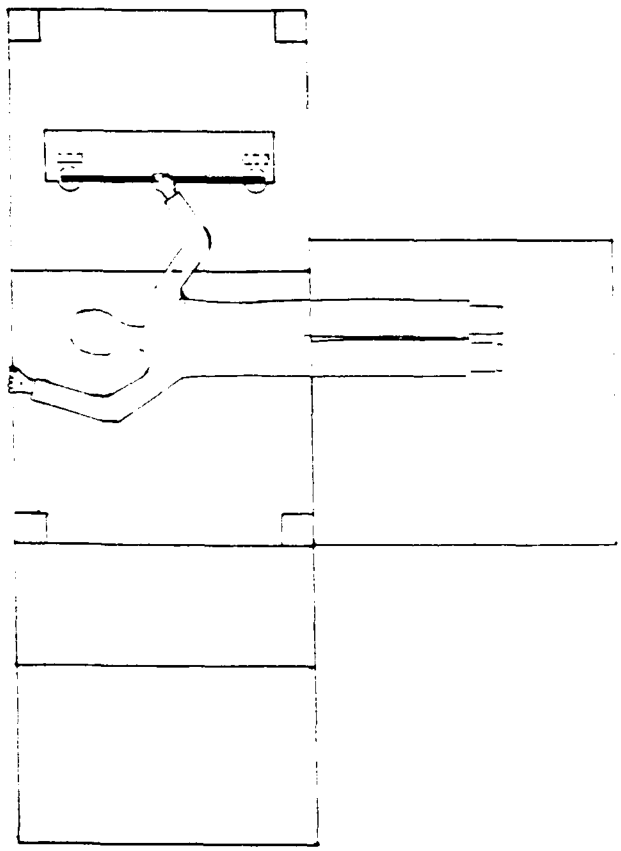
The distances were marked prior to the testing session. Bar elevations were set as required, and subject instructed on the force direction and hand conditions to be used. The subject was positioned for the exertion.

For the Front of Head exertions, the front edge of the platform (Figure 5.2) was aligned with the correct distance marker. The subject laid on the platform with the mid-sagittal plane aligned with the approximate center of the force bar. The suprasternale was aligned with the front edge of the platform.

For the side exertions the subject laid on the platform (Figure 5.10) parallel to the force bar, with the mid-sagittal plane aligned with the distance marker. The force bar was to the subject's right, and the suprasternale was aligned with the center of the force bar. The movable portion of the platform was set so that the edge of the platform nearest the force bar was aligned with the subject's armpit.

For the Under Body exertions, the front edge of the platform was set at the distance marker (reference Figure 5.2). Subject laid on the platform with the mid-sagittal plane aligned with the approximate center of the bar. The suprasternale was aligned with the edge of the platform. In some cases, the subject's body structure required that the suprasternale be slightly forward of the platform edge so that there was no interference with the arms when reaching down and footward to the force bar.

Once the exertion variable conditions were set, and the subject properly positioned, the subject applied maximum voluntary static force to the force bar for four seconds. The



This is basically the same as the Top View of Figure 5.2, with the man-model added to show the relationship of the subject and the Force Bar for Side exertions in the Prone posture. The only major change from Figure 5.2, is that the moveable platform has been moved away from the Force Bar. For the example shown, the Distance is set at 60% of 1/2 of arm span.

Figure 5.10 Side Exertion for the Prone Posture force application started on the experimenter's command and ended with the sounding of an audible signal. During the Right hand exertions, subjects were allowed to grasp the support platform with the left hand, and use the left hand to increase the right hand force.

MEASURES

- Isometric strength, as the force applied to the handle.

  Horizontal force component in pounds
  Vertical force component in pounds

  Resultant force in pounds
  Resultant angle in degrees

Anthropometric Measures

The anthropometric measures listed in paragraph 5.1 were used in this study.

RESULTS

Tables 5.16 through 5.21 present the means and standard deviations of the pushing and pulling forces. Males produced significantly greater forces then females in all conditions, with the female forces being between 50 and 65 percent those of the males.

Both males and females had significantly greater forces when using both hands than when using the right hand only. This was true for all conditions except for males during the Front of Head exertions with the force bar at 70% of their functional reach. This discrepancy was due to the ability of some males to grasp the edge of the platform with their left hand and generate additional force.

There was no difference in the amount of force due to the direction of force application. However, the forces obtained for the various force bar distance and height locations for the Under Body exertions differed depending upon the direction in which force was applied. When the direction of force was parallel to the body (both forward and backward), subjects could exert more force when the bar height position was 45% of functional reach then when it was 70%. The reverse was true when the direction of force was up toward the body. When the direction of force was forward, the greatest forces were obtained when the force bar distance was positioned back toward the subjects' feet. When the direction of force was backward, the greatest forces were obtained when the force bar position was forward toward the subjects' head. When the direction of force was upward, the greatest forces were obtained when the force bar was at 0%

The direction of force and the force bar distance had little effect on the subjects' ability to exert force for the Front of Head and Side exertions. The subjects were able to exert more force during the Front of Head exertions than during the Side exertions.

TABLE 5.16
UNDER BODY EXERTIONS
FOR ALL DISTANCES

HAND USED	FORCE DIRECTION	BAR HEIGHT	FEMALE N	FEMALE MEAN (pounds)	FEMALE STD (pounds)	MALE N	MALE MEAN (pounds)	MALE STD (pounds)
BOTH	FOOTWARD	45%	79	44.8	19.8	80	78.5	30.7
		70%	60	26.1	9.7	59	51.1	15.6
	HEADWARD	45%	80	43.6	16.1	80	74.1	23.8
		70%	60	31.0	10.0	60	53.4	14.5
	UP	45%	80	31.1	17.9	80	49.0	29.7
		70%	60	48.7	22.5	60	81.5	35.8
RIGHT	FOOTWARD	45%	78	28.9	13.0	79	54.3	20.2
		70%	60	17.6	6.2	60	33.3	10.7
	HEADWARD	45%	80	24.6	12.0	78	47.1	18.5
		70%	60	17.5	5.8	60	30.0	8.3
	UP	45%	79	18.8	8.4	80	32.6	15.2
		70%	60	28.4	11.1	60	50.4	17.2

TABLE 5.17
UNDER BODY EXERTIONS
FORCE DIRECTION - FOOTWARD

HAND USED	DISTANCE	BAR HEIGHT	FEMALE N	FEMALE MEAN (pounds)	FEMALE STD (pounds)	MALE N	MALE MEAN (pounds)	MALE STD (pounds)
BOTH	- 30%	45%	19	37.8	10.6	20	62.8	15.7
		70%	20	22.4	7.6	20	42.9	10.1
	0%	45%	20	34.5	9.7	20	60.3	13.6
		70%	20	23.6	7.3	20	45.4	9.6
	30%	45%	20	46.9	19.0	20	84.8	27.8
		70%	20	32.4	10.7	19	65.8	15.5
	60%	45%	20	59.7	25.6	20	105.9	35.8
RIGHT	- 30%	45%	19	24.3	7.2	19	48.8	11.3
		70%	20	15.7	5.0	20	28.7	10.1
	0%	45%	20	23.8	9.3	20	45.6	15.0
		70%	20	15.1	3.9	20	30.5	8.3
	30%	45%	20	26.5	11.5	20	51.3	19.2
		70%	20	21.9	7.0	20	40.6	10.0
	60%	45%	19	41.3	14.7	20	71.2	23.3

TABLE 5.18
UNDER BODY EXERTIONS
FORCE DIRECTION - HEADWARD

HAND USED	DISTANCE	BAR HEIGHT	FEMALE N	FEMALE MEAN (pounds)	FEMALE STD (pounds)	MALE N	MALE MEAN (pounds)	MALE STD (pounds)
BOTH	- 30%	45%	20	51.7	21.3	20	91.7	25.1
		70%	20	34.6	10.3	20	60.6	15.1
	0%	45%	20	32.7	12.0	20	55.9	10.7
		70%	20	24.7	5.6	20	43.1	8.3
	30%	45%	20	43.5	12.3	20	74.7	19.9
		70%	20	33.8	10.5	20	56.4	13.4
	60%	45%	20	46.4	10.9	20	74.3	23.1
RIGHT	- 30%	45%	20	27.2	10.2	19	50.3	12.8
		70%	20	19.0	5.9	20	34.2	10.1
	0%	45%	20	18.2	6.5	19	32.6	7.5
		70%	20	14.4	4.6	20	25.8	5.8
	30%	45%	20	23.1	10.4	20	44.1	12.9
		70%	20	19.2	5.8	20	30.0	6.3
	60%	45%	20	30.0	16.3	20	60.8	24.1

TABLE 5.19
UNDER BODY EXERTIONS
FORCE DIRECTION - UP

HAND USED	DISTANCE	BAR HEIGHT	FEMALE N	FEMALE MEAN (pounds)	FEMALE STD (pounds)	MALE N	MALE MEAN (pounds)	MALE STD (pounds)
BOTH	- 30%	45%	20	20.8	6.5	20	30.3	8.4
		70%	20	30.9	8.8	20	50.4	16.1
	0%	45%	20	51.5	21.5	20	84.7	33.5
		70%	20	66.0	24.5	20	115.5	33.7
	30%	45%	20	33.7	9.1	20	54.0	14.0
		70%	20	49.2	15.5	20	78.7	18.9
	60%	45%	20	18.5	5.3	20	27.1	7.0
RIGHT	- 30%	45%	20	16.1	5.8	20	27.1	8.7
		70%	20	20.7	5.6	20	39.0	9.4
	0%	45%	19	26.8	10.3	20	49.9	15.7
		70%	20	36.6	11.0	20	64.4	17.2
	30%	45%	20	19.8	5.0	20	33.8	9.5
		70%	20	27.8	9.7	20	47.7	13.3
	60%	45%	20	12.8	4.2	20	19.5	4.0

TABLE 5.20
FRONT OF HEAD EXERTIONS

HAND USED	DIRECTION	DISTANCE	FEMALE N	FEMALE MEAN (pounds)	FEMALE STD	MALE N	MALE MEAN (pounds)	MALE STD
BOTH	BACKWARD	50%	20	61.2	25.2	19	87.0	27.1
		70%	20	64.5	26.1	20	91.2	26.7
	FORWARD	50%	20	61.4	21.7	20	82.5	25.4
		70%	20	60.0	18.3	20	73.4	17.8
RIGHT	BACKWARD	50%	20	40.4	14.0	20	65.7	20.4
		70%	19	46.7	17.4	20	71.0	23.8
	FORWARD	50%	20	39.7	17.4	20	62.2	29.3
		70%	20	49.9	19.3	20	80.9	31.9

TABLE 5.21
SIDE EXERTIONS

FORCE DIRECTION	DISTANCE (% of half span)	FEMALE N	FEMALE MEAN (pounds)	FEMALE STD	MALE N	MALE MEAN (pounds)	MALE STD
BACKWARD	60%	20	35.1	14.5	20	50.4	18.5
	85%	20	40.0	15.7	20	58.8	21.7
FORWARD	60%	20	35.8	13.9	20	51.0	16.8
	85%	20	42.1	16.5	20	62.5	18.0

SECTION 6
LIFTING STUDIES

Two Lifting studies were performed at Texas Tech University (TTU), Lubbock, TX, to determine lifting strength capabilities of a representative sample of the population, in unusual postures, simulating some USAF aircraft maintenance activities. Tasks were developed, using containers of various sizes, some with handles, to simulate maintenance activities. Unlike the studies in previous sections, the lifting tasks were dynamic. The containers were constructed so that the total weight could be varied by removing or adding assorted lead weights. The weights were not marked with their weight, so that subjects did not know the total container weight.

Subjects were asked to work as hard as they could without becoming unusually tired, weakened, out of breath, or straining themselves (Snook, 1978 and Ayoub, et. al., 1982). Only the subject could adjust the workload. Subjects were encouraged to make as many adjustments as they felt necessary. When subjects indicated that they had reached their maximum acceptable weight for the lift, a single lift was accomplished at that weight to verify the lifting strength capability. The container was weighed after a successful single lift and that weight recorded as the lifting strength capability for that task and subject.

The task order was randomized and no specific method of lifting was suggested, as previous research had shown that a "free style" lifting was more appropriate than a structured lifting style (Ayoub, et. al., 1983). The number of sessions, and exertions per session, varied for each subject dependent upon the number of adjustments to the container weight for each task. Sessions were approximately two hours long.

6.1 ANTHROPOMETRY

The sets of anthropometric measurements made on the subjects were different for the two studies. The set for each study is listed in the summary for that study.

6.2 TEST EQUIPMENT

The test equipment consisted of various sizes of containers, some with handles, assorted lead weights to adjust the weight of the containers, platforms to lift from or to, an exercise bench, work bench, seat and scales. The container sizes and platform descriptions are included in the summary of each study.

6.3 EXPERIMENTAL CONDITIONS

The following experimental conditions were used during the Lifting studies. The constant and variable conditions used in each study are listed in the study summaries.

1. Subjects:

   - Number: the number of male and female subjects participating in each study.

   - Age: in both studies, the age range for subjects was 18 to 30 years. This corresponds to the age range of 99 percent of Air Force maintenance technicians who perform the majority of hands-on maintenance activities.

   - Height/Weight: limiting height/weight restrictions as established by Air Force Regulation 160-43.

   - Weight Lift: a minimum weight lift capability of 40 pounds on the 6 Foot Incremental Weight Lift test was required to participate in the study. Some Air Force maintenance career fields have weight lift requirements greater than 40 pounds, but all Air Force enlisted personnel are required to pass the test at the 40 pound level.

- Mixed Occupations: no particular skills or training were required for participation in the study.

- Pay: subjects were paid volunteers averaging $5.00 per hour. Informed consent was obtained prior to any testing.

- No Physical Frailties: no physical frailties that would prevent a subject from participating in the study because of a possibility of injury or aggravation of an existing, or previously existing, condition.

2. Clothing:

   - Street clothes (shorts, T-shirts and any shoes acceptable).

3. Posture: the postures tested in the Lifting studies. The subset of postures used in a specific study are included in the study summary.

4. Hand Used: identifies the hand(s) used to lift the container.

5. Container: the type container used for the specific lifting task. Dimensions and orientations are included in the study summary.

6. Container Orientation: the orientation of the container as the relationship of the length, depth and width.

7. Container Position: the container starting position for the lifts made from the side and supine postures.

8. Lift Height: vertical distance from the starting support surface of the container to the ending support surface of the container.

9. Leg Position: the leg positions for the lifts made from the side posture.

■ LIFT STUDY, F1 ■
(PRONE, SUPINE, STANDING and SIDE)

OBJECTIVE

To determine the lifting strength capabilities of a representative sample of the population on a series of lifting tasks in unusual postures simulating some USAF aircraft maintenance activities.[19]

TEST EQUIPMENT

Lifting platform

Exercise bench

10 inch high platform

Work bench

Container

Scales

CONDITIONS

Constants

- Subjects:
  Number: 50 males, 50 females.

- Clothing: Street clothes

19. Authors: Ayoub, M.M., Smith, J.L., Selan, J.L., and Fernandez, J.E. (TTU).

Variables

There were different combinations of variables used for each posture. The variables used for a posture are listed separately, and figures are included for clarification. The procedures for each task type are included in the text for the figures.

PRONE TASKS

Variables

- Posture: 1
  - Prone

- Hand Used: 2
  - Left
  - Right

- Container: 1
  - 10 " x 10 " x 12 ", with handle

- Lift Height: 1
  - From floor to lifting platform (Figure 6.1)

SUPINE TASKS

Variables

- Posture: 1
  - Supine

- Hand Used: 2
  - Right (Figure 6.2)
  - Both (Figure 6.3)

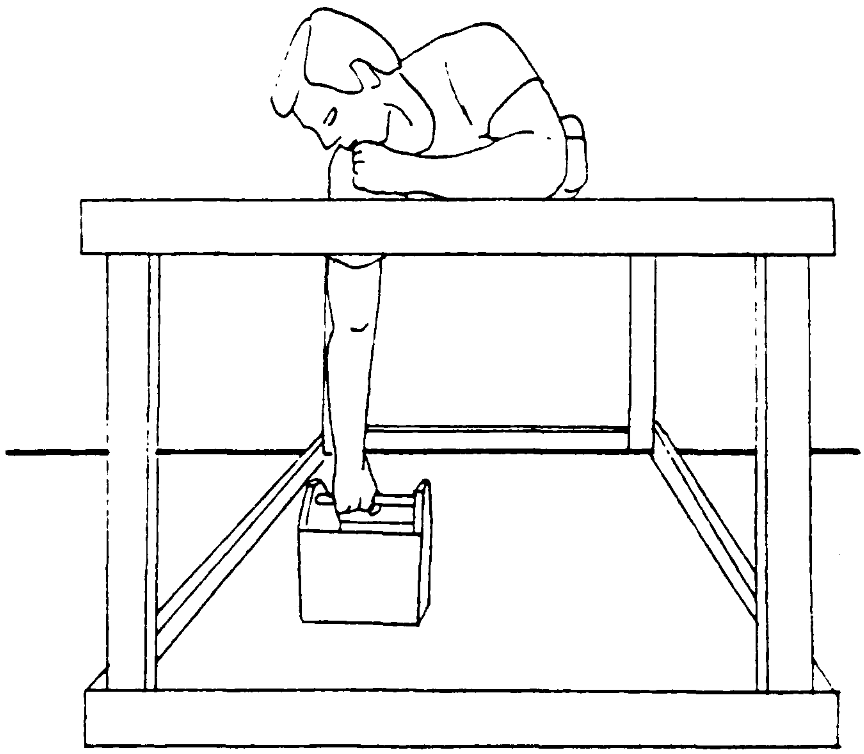


Figure 6.1 Diagram and Procedures for Prone Lifts

Subjects lay prone on a 4 foot high lifting platform and extended the arm through a 14 " x 14 " opening. Subject grasped the handle of a 10 " x 10 " x 12 " box and lifted it through the opening. Subject was allowed to prop up the body with the other forearm while lifting. The task was performed with the Right and the Left hand. (Reprinted from Ayoub, et. al., 1985a)

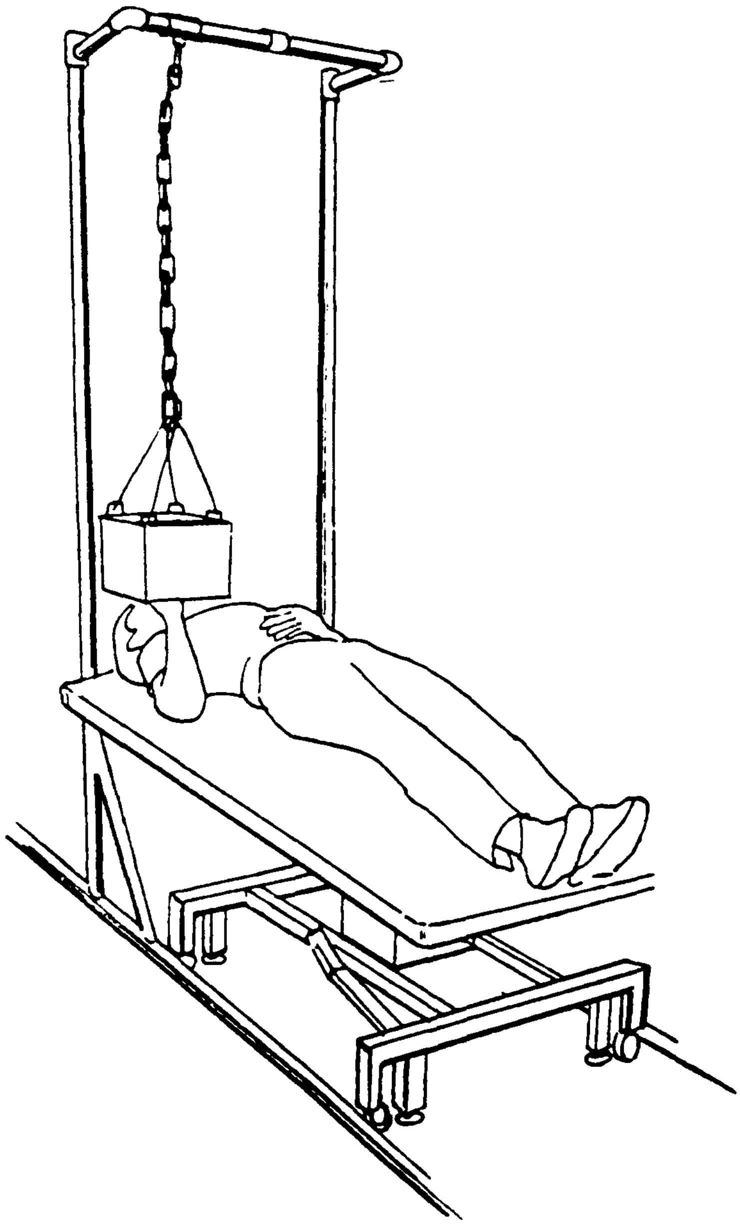


Figure 6.2 Diagram and Procedures for One Hand Supine Lifts.

Subjects lay supine on an exercise bench. The palm of the right hand was placed on the bottom of the 10 " x 10 " x 8 " box which was suspended over the subject's right shoulder. Subject lifted the box until the arm was fully extended. For the Close container position, subjects fully flexed the right arm and the box was suspended so that the bottom of the box was against the palm of the hand. For the Far container position, subjects extended the right arm and the box was suspended so that the bottom of the box was aligned with the subject's radiale. (Reprinted from Ayoub, et. al., 1985a)

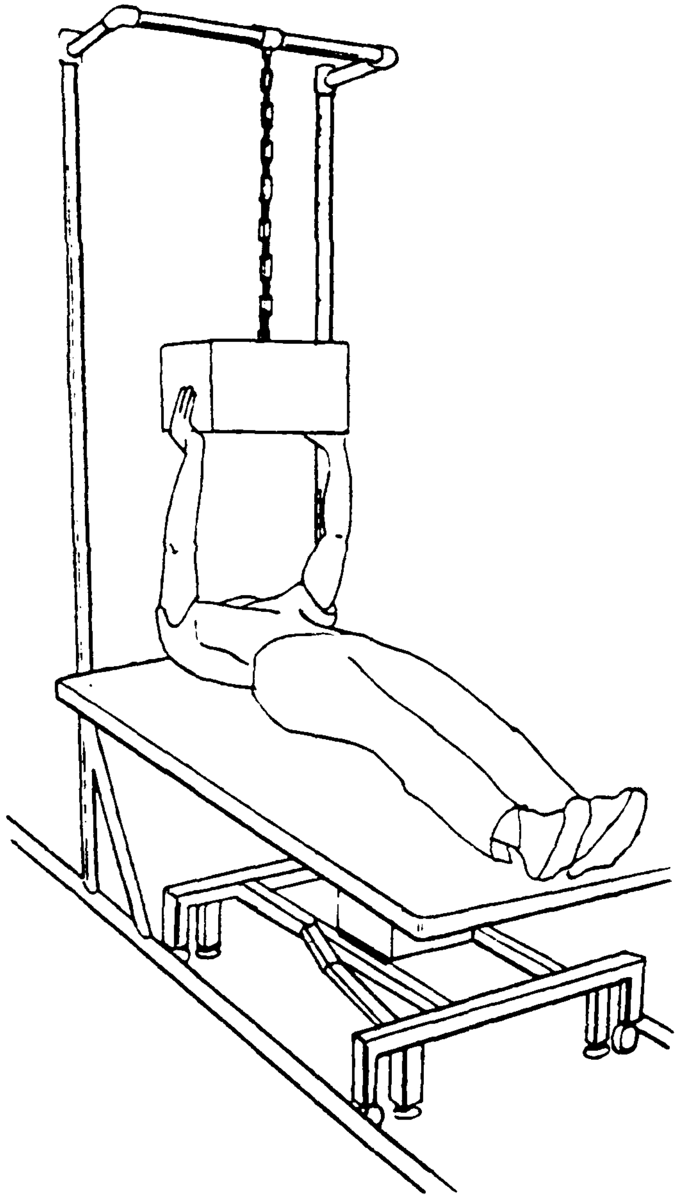


Figure 6.3 Diagram and Procedures for Both Hands Supine Lifts.

Subjects lay supine on the exercise bench and placed the hands on the bottom edges of an 18 " x 12 " x 10 " box suspended over the chest of the subject. Subjects lifted the box until the arms were fully extended. For the Close container position, the box was suspended as close to the chest as possible, with the subject still able to grasp the bottom edges. For the Far container position, the right arm was extended and the bottom of the box suspended in line with the subject's radiale

* Container: 2
  For Right Hand
  10 " x 10 " x 8 " (Figure 6.2)
  For Both Hands
  18 " x 12 " x 10 " (Figure 6.3)

* Container Position: 2
  Close
  Far
* Lift Height: 1 (full extent of the arms)

STANDING LIFTS

Variables

* Posture: 1
  Standing

* Hand Used: 1
  Right

* Container: 1
  24 " x 12 " x 11.75 ", with handle (Figure 6.4)

* Lift Height: 1
  30 " from floor to work bench

SIDE LIFTS

When the Side lifts were first accomplished, only one leg position (Straight) was planned. When these tasks were performed it was found that the subjects' bodies tended to roll when the lift was accomplished. The Top and 90° leg positions were added to determine which allowed the highest lifting strength. These two sets of tasks were done in conjunction with the second lifting study. Although some of the subjects were different

Figure 6.4 Diagram and Procedures for the Standing Lifts, to Work Bench Level (30 inches from floor).

Subject lifted a 24 " x 12 " x 11.75 " box, fitted with a handle parallel to the 24 " length of the box, at a height of 19 " from the bottom of the box. Lift was made with the right hand. The left hand could be placed on the work bench, or used to stabilize the box, but was not allowed to aid in the lift. (Reprinted from Ayoub, et. al., 1985a) than those performing the first study, they were representative of the population.

Variables

- Posture: 1
  - Side
- Hand Used: 2
  - Right
  - Both
- Container: 2
  - For Right hand
    - 15 " x 8 " x 5 ", with handle
  - For Both Hands
    - 8 " x 8 " x 8.5 "
- Container Position: 2
  - Close
  - Far
- Leg Position: 3
  - Straight (Figures 6.5 and 6.6)
  - Top (Figure 6.7)
  - 90° (Figure 6.8)
- Lift Height: 1
  - 10 inches

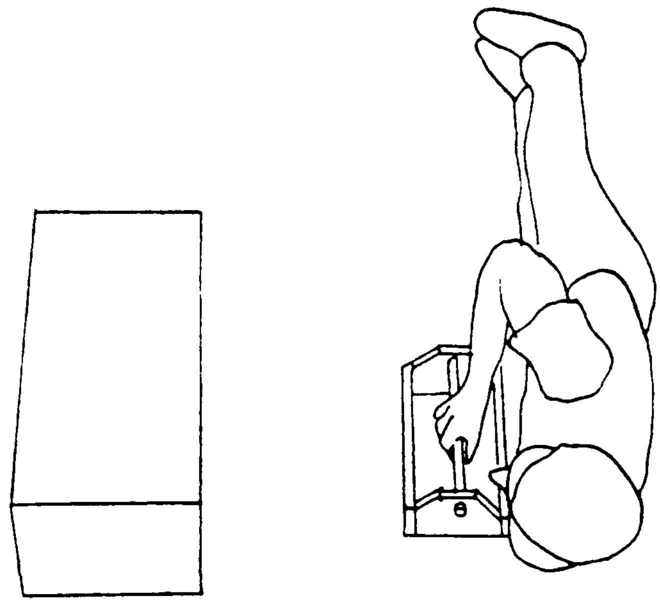


Figure 6.5 Diagram and Procedures for One Hand Side Lift, with Straight Leg and Close Container Positions.

Subjects lay on left side with body parallel to the 10 " high platform. Distance between platform and subject was subject's functional reach. Subject grasped the 15 " x 8 " x 5 " box handle with the right hand and lifted it onto the platform. For the Close container position, the rear edge of the box was placed against the subject's body. For the Far container position, the subject extended the right arm and the box was positioned such that the rear edge of the box was aligned with the radiale. (Reprinted from Ayoub, et. al., 1985a)

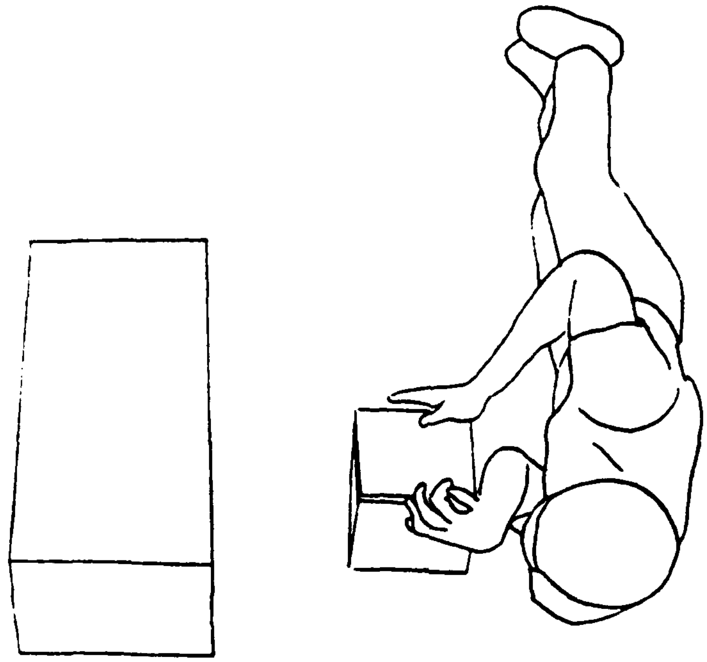


Figure 6.6 Diagram and Procedures for Both Hands Side Lifts, with Straight Leg and Close Container Positions.

Subjects lay on left side with body parallel to the 10 " high platform. Distance between platform and subject was subject's functional reach. Subjects grasped the 8 " x 8 " x 8.5 " box with both hands and lifted it onto the platform. For the Close container position, the box was placed against the hand of the flexed lower arm. For the Far container position, subject extended right arm and the box was positioned such that the rear edge of the box was aligned with the radiale. (Reprinted from Ayoub, et. al., 1985a)

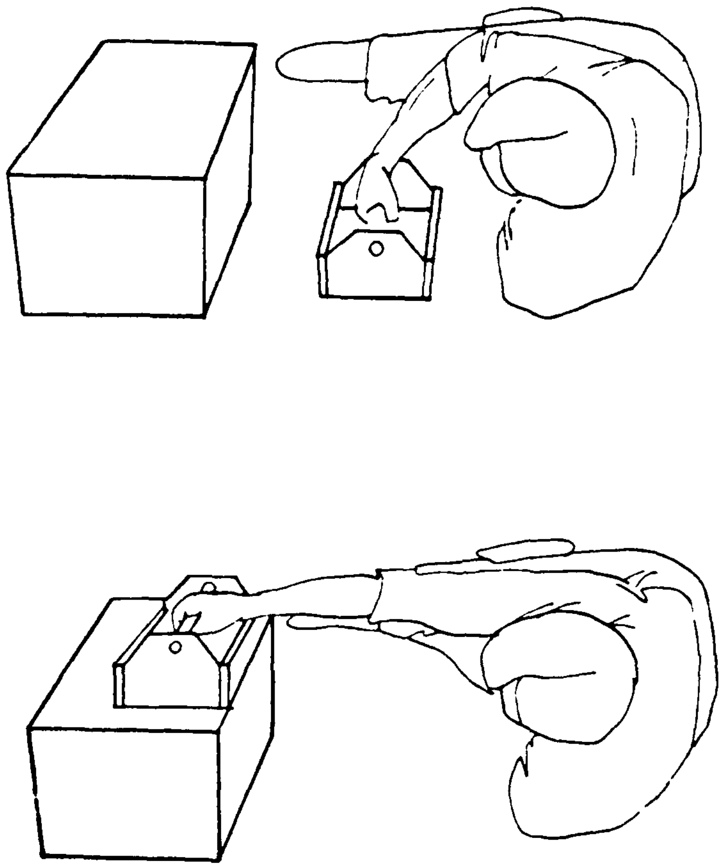


Figure 6.7 Diagram and Procedures for One Hand Side Lifts, with Top Leg and Far Container Positions.

Subjects lay on left side with body parallel to the 10 " high platform. Distance between platform and subject's body was subject's functional reach. Top leg was brought over and used as a brace. Subject grasped a 15 " x 8 " x 5 " box by the handle and lifted it onto the platform. For the Close container position, the rear edge of the box was placed against the subject's body. For the Far container position, the right arm was extended and the box placed such that the rear edge was aligned with subject's radiale. (Reprinted from Ayoub, et. al., 1985b)

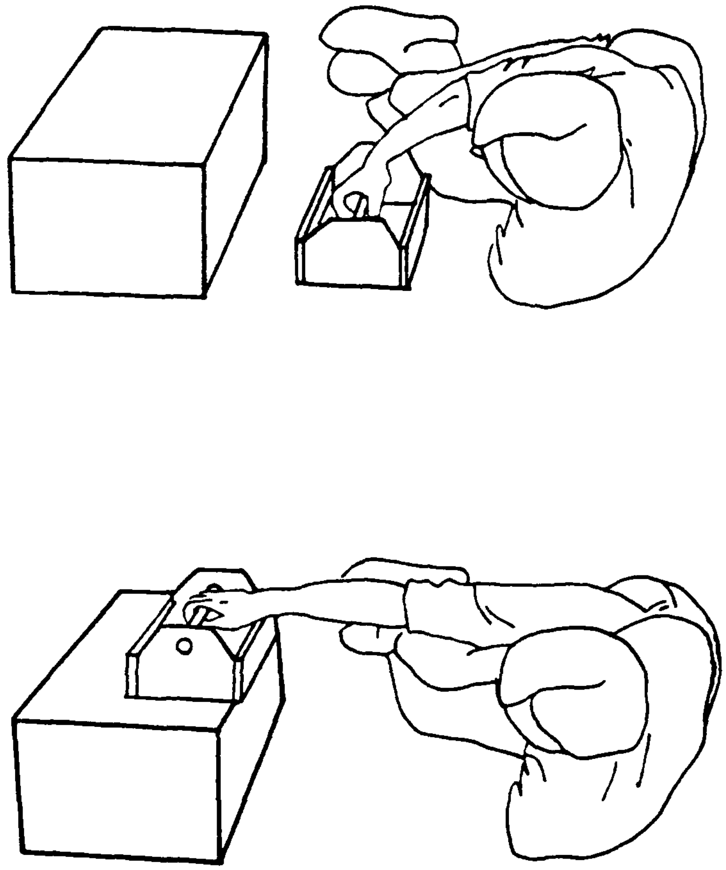


Figure 6.8 Diagram and Procedures for Both Hands Side Lifts, with 90° Leg and Far Container Positions.

Subjects lay with body parallel to the 10 " high platform. Distance between the platform and the subject's body was subject's functional reach. Subject positioned legs so that 90° angles were obtained at the trunk-thigh and at the knees. The 8 " x 8 " x 8.5 " box was grasped with both hands and lifted to the platform. For the Close container position, the rear edge of the box was placed against the hand of the lower flexed arm. For the Far container position, subjects extended the right arm and the box was placed so that the rear edge was aligned with the subject's radiale. (Reprinted from Ayoub, et. al., 1985b)

MEASURES

- Maximum acceptable weight, as determined by the subject, recorded in pounds.

Anthropometric Measurements

The following anthropometric measures were made on each subject participating in this study.

Height
Sitting height
Functional reach
Weight

RESULTS

The means and standard deviations for the Standing, Prone and Supine postures are listed in Table 6.1. Table 6.2 shows the mean and standard deviation for the Side posture. Subjects were able to lift the most weight from the the supine posture and the least from the side posture. More weight could be lifted when using both hands than when using only one. Subjects were able to lift more weight if the lift started at the Far container position than at the Close container position. For the Side postures the most weight could be lifted with body stabilized by the 90° Leg position. Males consistently lifted more than females.

TABLE 6.1
STAND, PRONE AND SUPINE LIFTS

POSTURE	HAND USED	CONTAINER POSITION	FEMALES N	FEMALES MEAN (pounds)	FEMALES STD (pounds)	MALES N	MALES MEAN (pounds)	MALES STD (pounds)
STAND	RIGHT		46	44.4	8.3	50	97.1	17.6
PRONE	LEFT		46	20.1	4.4	50	42.4	9.7
	RIGHT		46	20.9	4.2	50	43.3	10.2
SUPINE	RIGHT	CLOSE	46	21.2	5.4	50	43.8	12.8
		FAR	46	28.8	7.4	50	54.8	13.5
	BOTH	CLOSE	46	54.3	10.3	50	122.5	30.4
		FAR	46	65.5	11.4	50	147.5	35.1

TABLE 6.2
SIDE LIFTS

LEG POSITION	HAND USED	CONTAINER POSITION	FEMALES N	FEMALES MEAN (pounds)	FEMALES STD	MALES N	MALES MEAN (pounds)	MALES STD
STRAIGHT	RIGHT	CLOSE	46	14.6	3.2	50	30.7	7.0
		FAR	46	14.9	3.1	50	29.8	6.1
	BOTH	CLOSE	46	17.9	4.2	50	35.2	8.3
		FAR	46	19.9	4.7	50	40.0	8.9
TOP	RIGHT	CLOSE	46	15.9	3.2	45	31.9	5.8
		FAR	46	15.9	3.0	45	31.6	5.2
	BOTH	CLOSE	46	16.4	3.3	45	32.2	5.5
		FAR	46	16.1	2.9	45	31.6	6.0
90°	RIGHT	CLOSE	46	19.8	4.5	45	39.2	6.8
		FAR	46	21.4	4.8	45	41.6	6.2
	BOTH	CLOSE	46	20.1	3.9	45	39.4	8.2
		FAR	46	21.0	4.3	45	41.7	7.5

NOTE: All lifts were made to a height of 10 inches above the floor. Right hand lifts used the 15 " x 8 " x 5 " box, with handle. Both hand lifts used the 8 " x 8 " by 8.5 " box.

■ LIFTING STUDY, F2 ■
(STANDING, SITTING, SQUATTING and KNEELING)

OBJECTIVE

To determine the lifting strength capabilities of a representative sample of the population on a series of lifting tasks in unusual postures simulating some USAF aircraft maintenance activities.[20]

TEST EQUIPMENT

Lifting shelf - mounted on a vertically adjustable base. The shelf had dividers that were 1 inch wider than the length dimension of the container. Dividers were used for precision placement, which is commonly required in aircraft maintenance.

Containers

Seat

Scales

CONDITIONS

Constants

- Subjects:
  Number: 50 males, 50 females
- Clothing: Street clothes

20. Authors: Ayoub, M.M., Smith, J.L., Selan, J.L., Chen, H.C., Fernandez, J.E., Lee, Y.H., and Kim, H.K. (TTU)

Variables

Different combinations of variables were used for the Right hand and Both hands lifts. Variables used for each of the hand conditions are listed separately, and figures are included for clarification. The procedures for the tasks are contained in the text accompanying the figures.

Lifts with Both Hands

Variables

- Posture: 5

Standing	(Figure 6.9)
Sitting	(Figure 6.10)
Squatting	(Figure 6.11)
Kneel 1 - on one knee	(Figure 6.12)
Kneel 2 - on both knees	(Figure 6.13)

- Hand Used: 1

  Both

- Container: 1

  24 " x 12 " x 6"

- Container Orientation: 3

L x W x H	
24 " x 12 " x 6 "	(Figure 6.10)
12 " x 6 " x 24 "	(Figure 6.9)
6 " x 24 " x 12 "	(Figure 6.12)

- Seat: 1 (for Sitting posture only)

- Lift Height: 3

  35 % of subject vertical reach in test posture

  60 % of subject vertical reach in test posture

  85 % of subject vertical reach in test posture

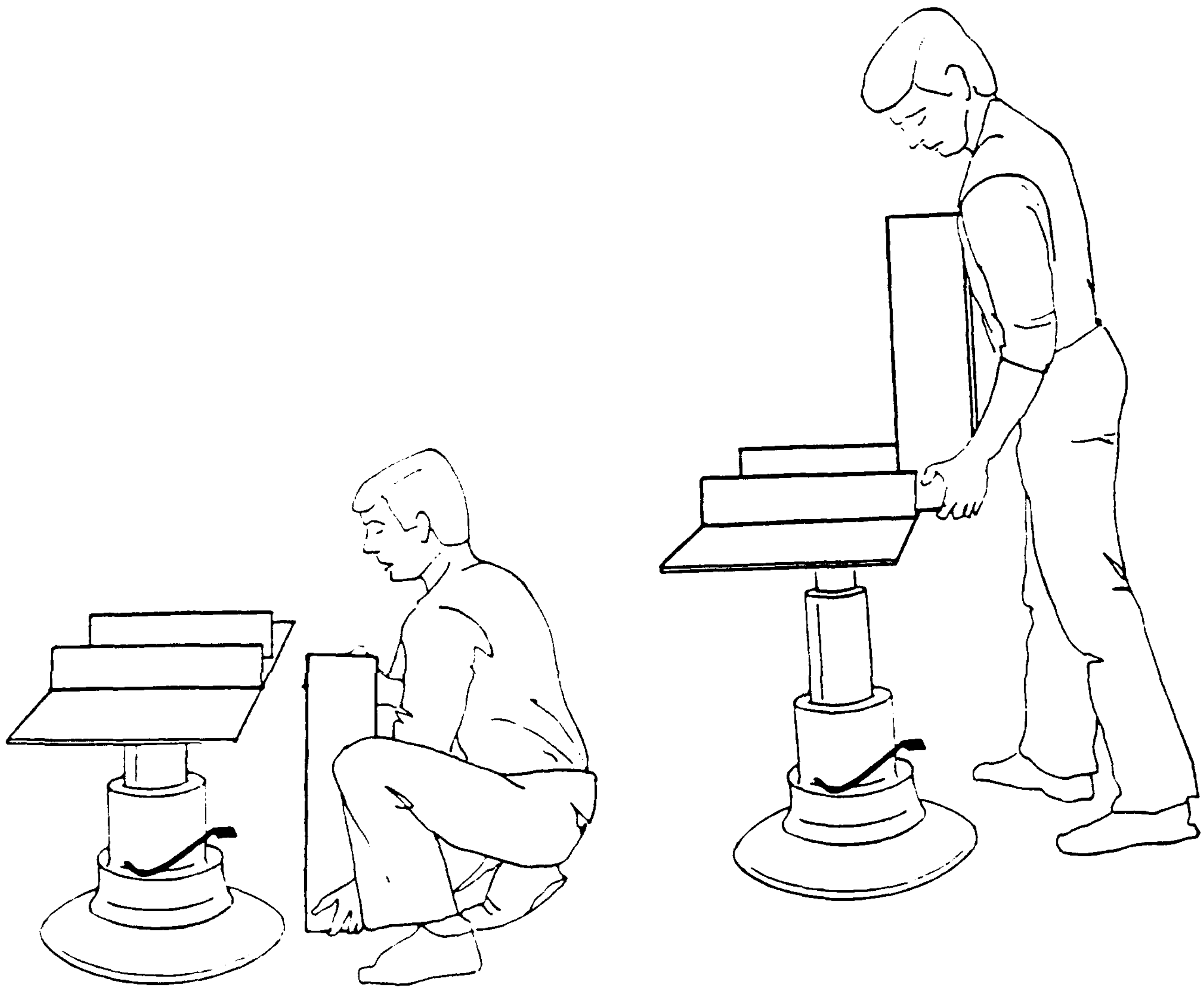


Figure 6.9 Standing Lift with Both Hands, with Container Oriented at 12 " x 6 " x 24 ".

Subject bent at knees, keeping back straight. Hand placement at subject's preference. Container lifted and placed on shelf without touching the dividers on either side of the container. Lifts were done to 35 %, 60 % and 85 % of subject's vertical reach for the posture being tested. (Reprinted from Ayoub, et. al., 1985b)

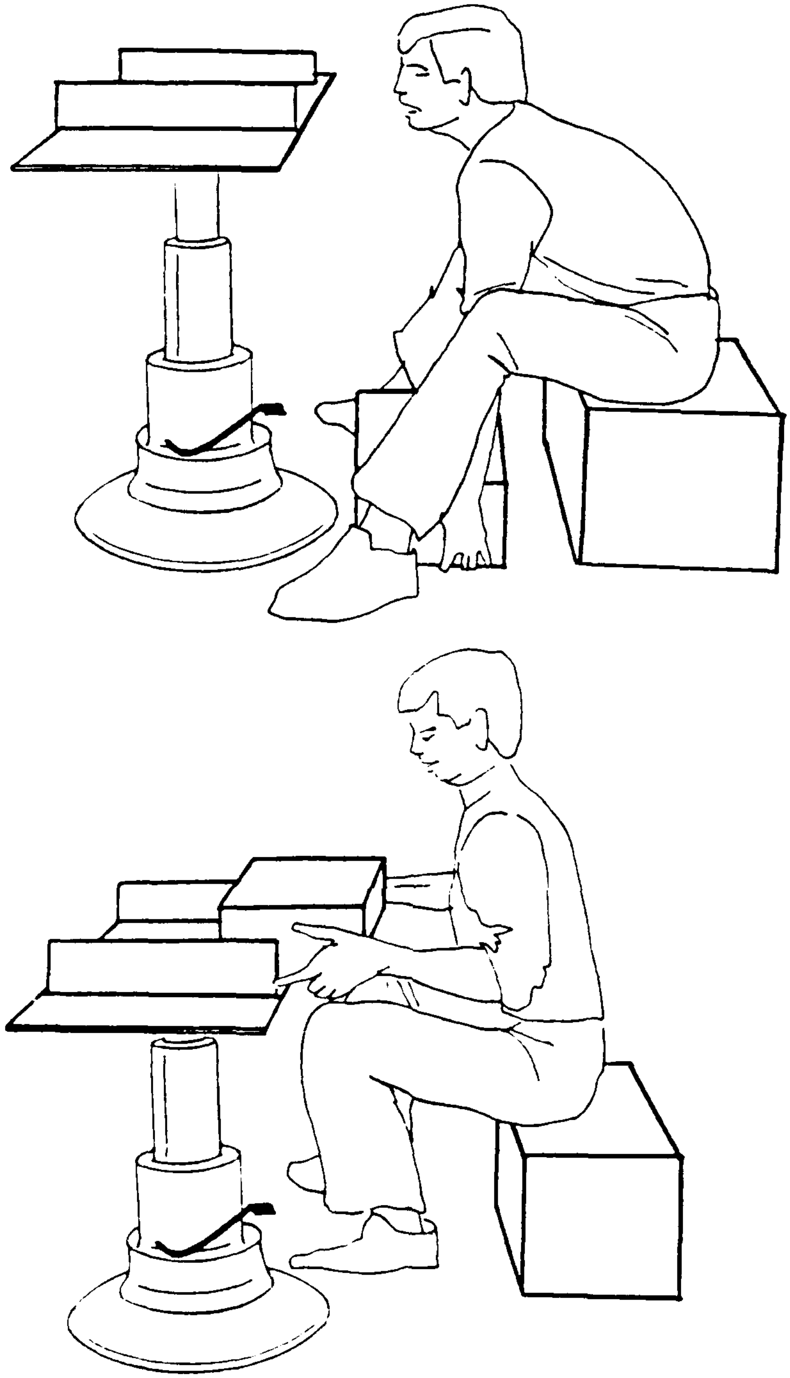


Figure 6.10 Sitting Lift with Both Hands, with Container Oriented at 24 " x 12 " x 6 ".

Subject sat on 12 " high seat. Hand placement was at subject's preference. Subject lifted container and placed on the shelf without touching the dividers on either side of the container. Lifts were done to 35 %, 60 % and 85 % of subject's vertical for the tested posture. (Reprinted from Ayoub, et. al., 1985b)

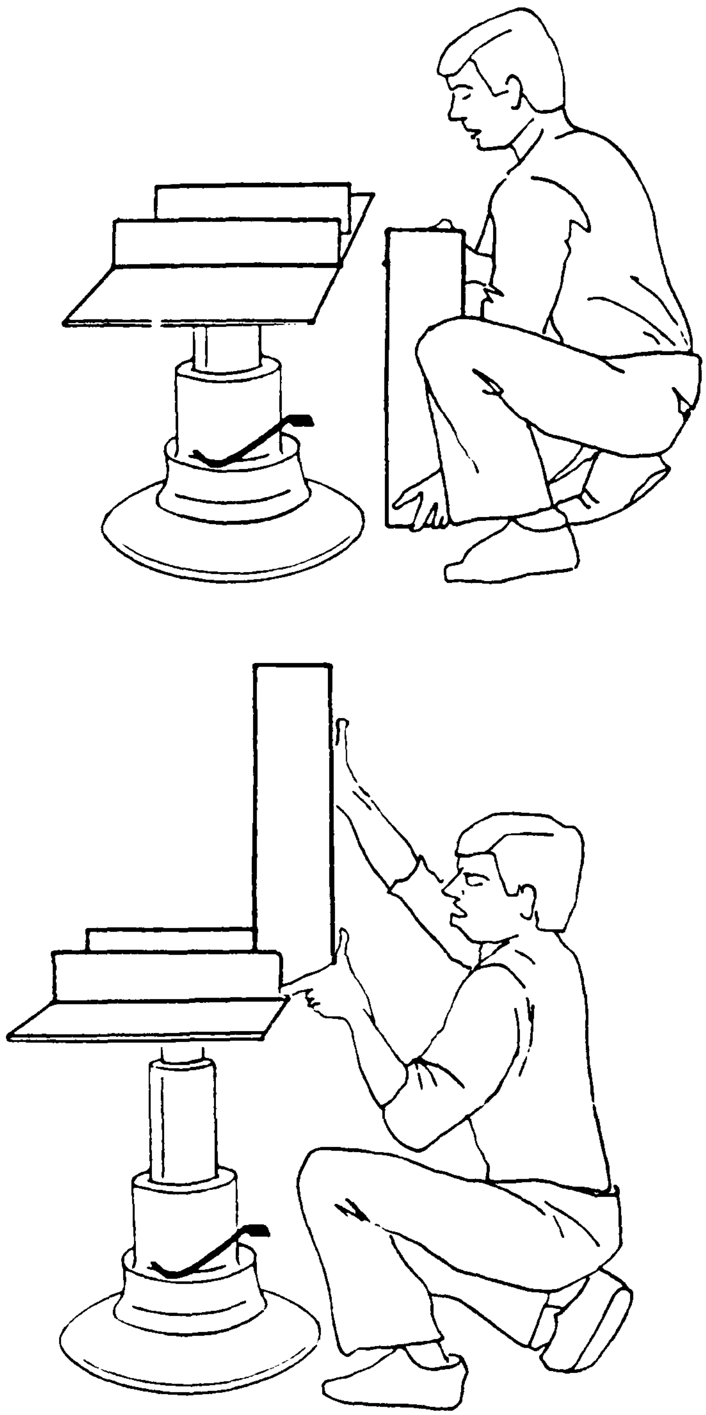


Figure 6.11 Squatting Lift with Both Hands, with Container Oriented at 12 " x 6 " x 24 ".

Subject assumed as comfortable a squatting posture as possible. Hand placement was at subject's preference. Container was lifted and placed on the shelf without touching the dividers on either side of the container. Lifts were done to 35 %, 60 % and 85 % of the subject's vertical reach for the tested posture. (Reprinted from Ayoub et. al., 1985b)

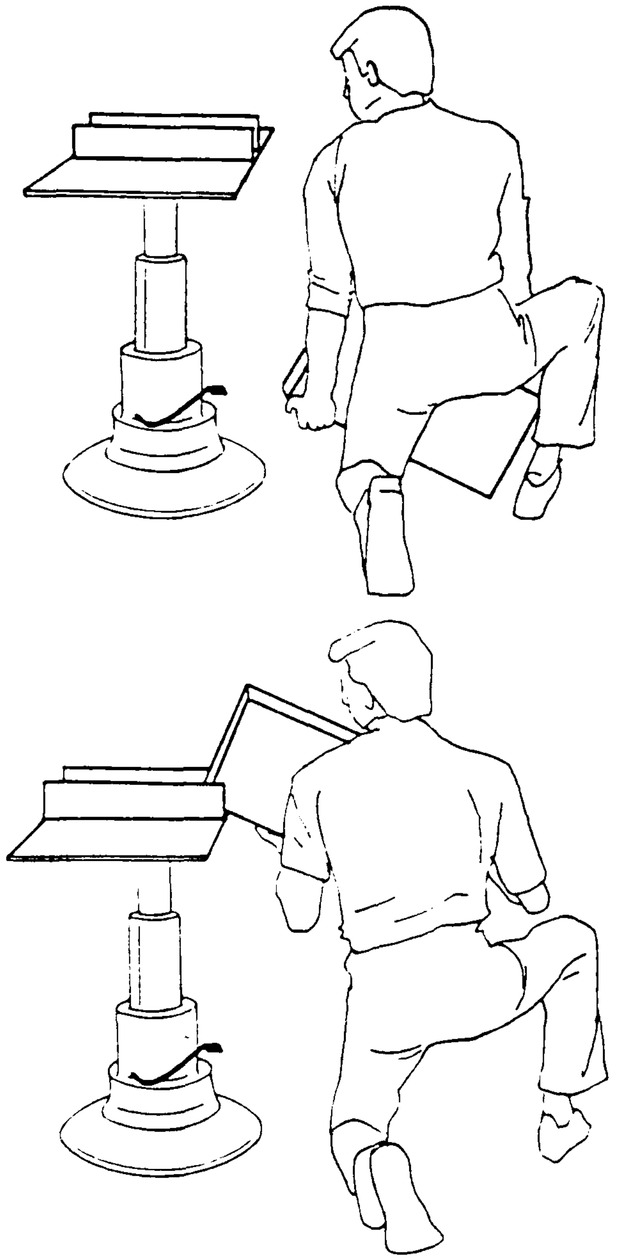


Figure 6.12 Kneel 1 Lift with Both Hands, with Container Oriented at 6 " x 24 " x 12 ".

Subject knelt with the left knee down and the right knee up. Hand placement was at the subject's preference. Container was lifted and placed on the shelf without touching the dividers on either side of the container. Lifts were done to 35 %, 60 % and 85 % of the subject's vertical reach for the tested posture. (Reprinted from Ayoub, et. al., 1985b)

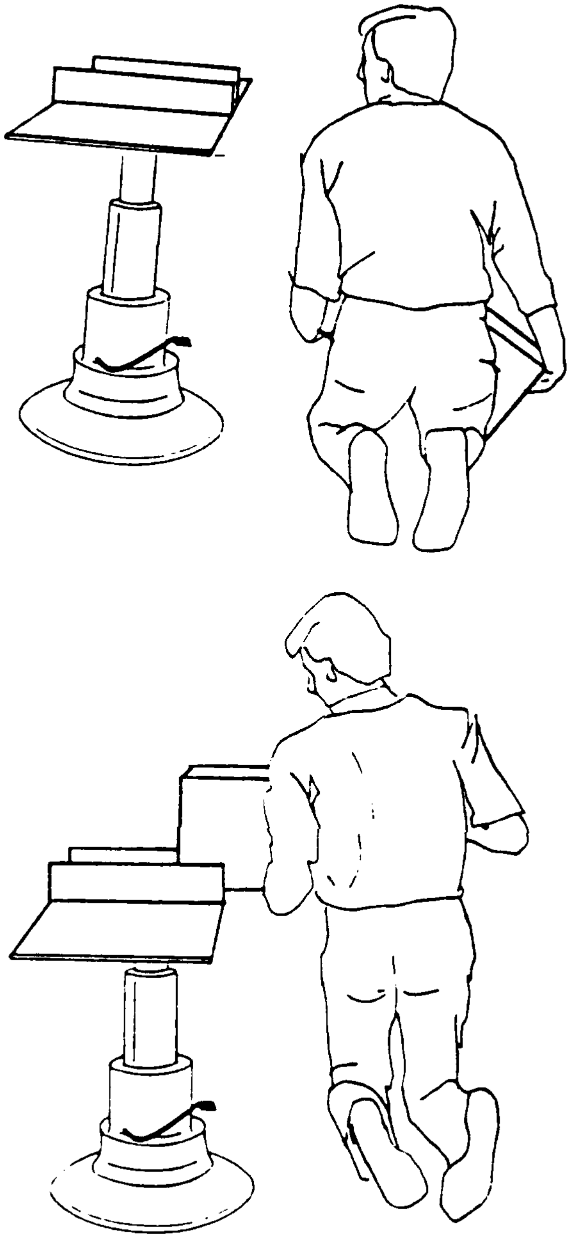


Figure 6.13 Kneel 2 Lift with Both Hands, with Container Oriented at 6 " x 24 " x 12 ".

Subject knelt with both knees on the floor. Hand placement was at subject's preference. Container was lifted and placed on the shelf without touching the dividers on either side. Lifts were done to 35 %, 60 % and 85 % of the subject's vertical reach for the tested posture. (Reprinted from Ayoub, et. al., 1985b)

Right Hand Lifts

Variables

- Posture: 5

Standing	(Figure 6.14)
Sitting	(Figure 6.15)
Squatting	(Figure 6.16)
Kneel 1	(Figure 6.17)
Kneel 2	(Figure 6.18)

- Hand Used: 1

  Right

- Container: 1

  10 " x 10 " x 11 ", with handle 10 " above bottom of container

- Lift Height: 3

  35 % of subject vertical reach in test posture

  60 % of subject vertical reach in test posture

  85 % of subject vertical reach in test posture

NOTE: 10 inches was subtracted from each subject's % of vertical reach for the tested posture to account for the height of the handle.

MEASURES

- Maximum acceptable weight, as determined by the subject, recorded in pounds.

Figure 6.14 Standing Right Hand Lift

Subjects lifted a 10 " x 10 " x 11 " box by grasping the handle with the right hand. Subjects were instructed to bend at the knees and lift while keeping the back as straight as possible. Subjects lifted box and placed it on the shelf without touching the dividers on either side of the box. Lift heights were set at 35 %, 60 % and 85 % of subject's standing vertical reach minus 10 ".

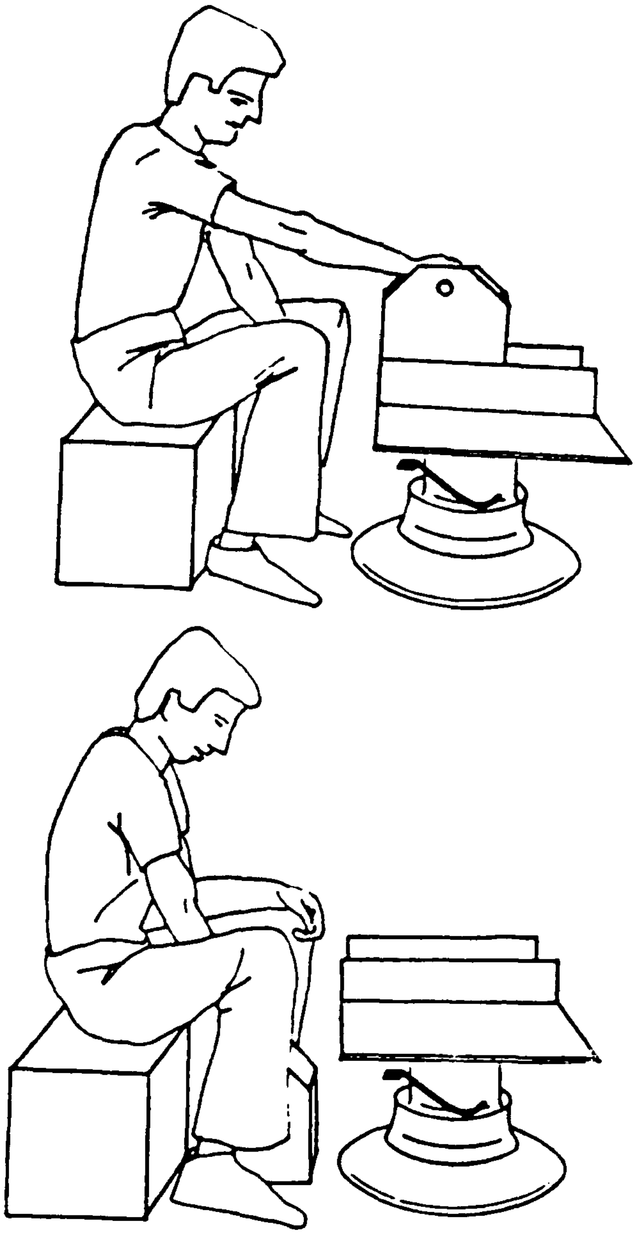


Figure 6.15 Sitting Right Hand Lift

Subjects sat on a 12 " seat and lifted a 10 " x 10 " x 11 " box by grasping the handle with the right hand. Subjects were instructed to lift with the back as straight as possible. Subjects lifted box and placed it on the shelf without touching the dividers on either side of the box. Lift heights were set at 35 %, 60 % and 85 % of subject's standing vertical reach minus 10 ".

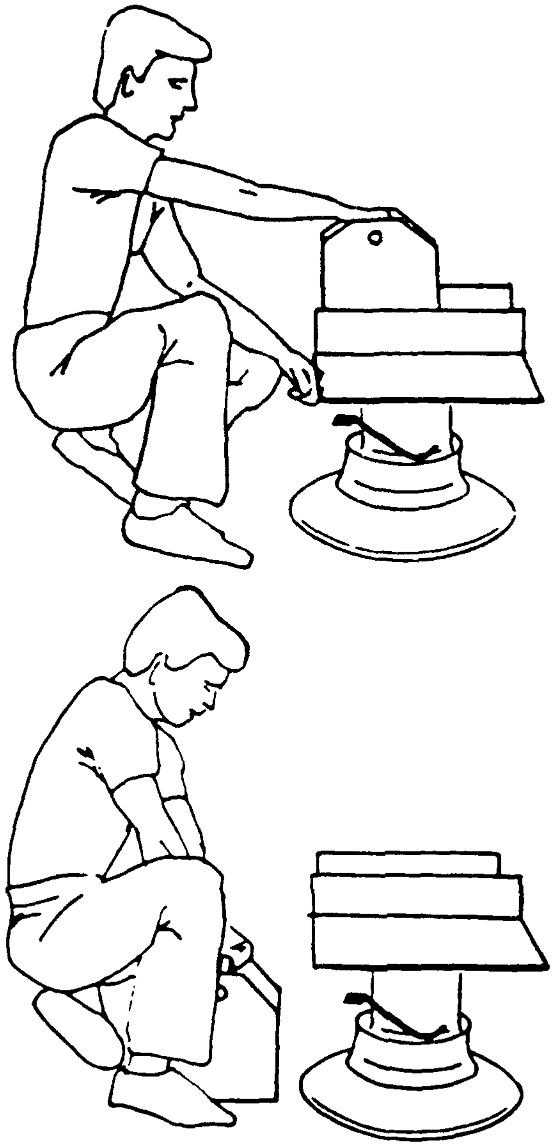


Figure 6.16 Squatting Right Hand Lift

Subjects squatted and lifted a 10 " x 10 " x 11 " box by grasping the handle with the right hand. Subjects were instructed to lift while keeping the back as straight as possible. Subjects lifted box and placed it on the shelf without touching the dividers on either side of the box. Lift heights were set at 35 %, 60 % and 85 % of subject's standing vertical reach minus 10 ".

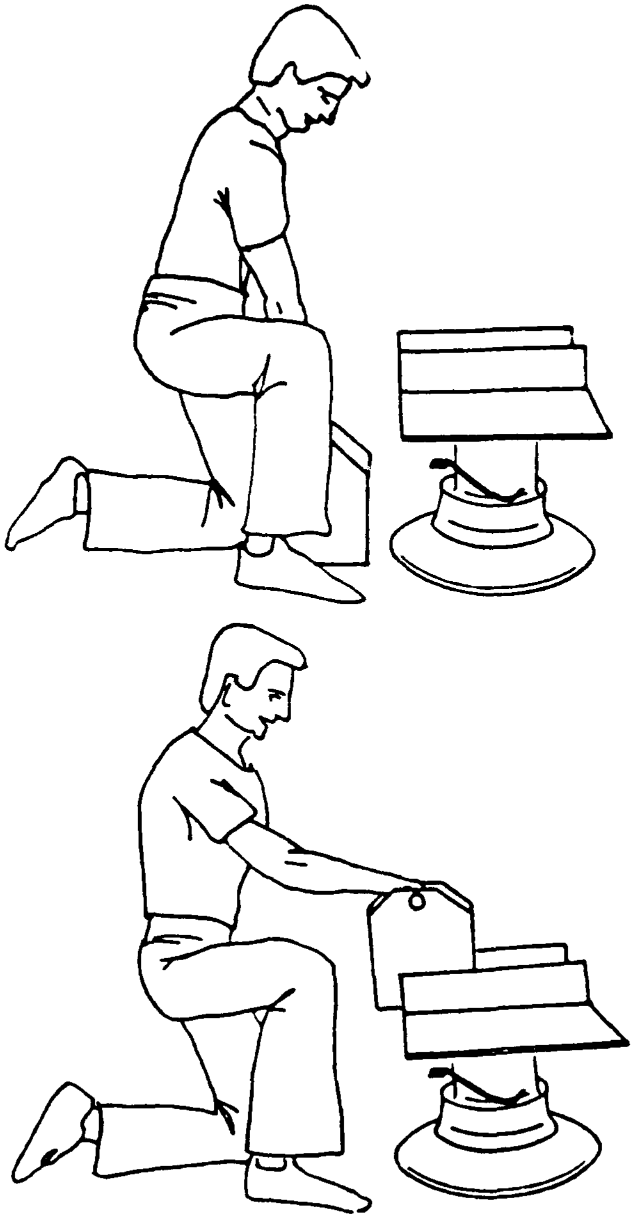


Figure 6.17 Kneel 1 Right Hand Lift

Subjects knelt on one knee and lifted a 10 " x 10 " x 11 " box by grasping the handle with the right hand. Subjects were instructed to lift while keeping the back as straight as possible. Subjects lifted box and placed it on the shelf without touching the dividers on either side of the box. Lift heights were set at 35 %, 60 % and 85 % of subject's standing vertical reach minus 10 ".

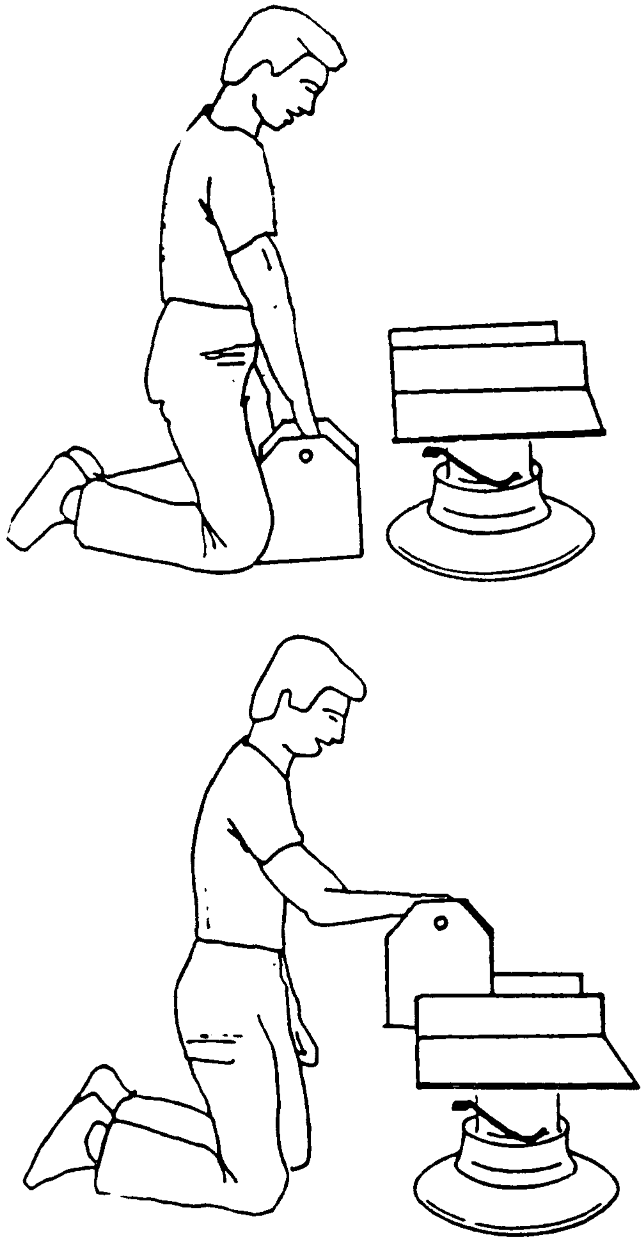


Figure 6.18 Kneel 2 Right Hand Lifts

Subjects knelt on both knees and lifted a 10 " x 10 " x 11 " box by grasping the handle with the right hand. Subjects were instructed to lift while keeping the back as straight as possible. Subjects lifted box and placed it on the shelf without touching the dividers on either side of the box. Lift heights were set at 35 %, 60 % and 85 % of subject's standing vertical reach minus 10 ".

Anthropometric Measures

The following anthropometric measures were made on the subjects participating in this study.

Stature	Asis Height
Weight	Crotch Height
Sitting Height	Trochanter Height
Eye Height	Patella Top Height
Acromion Height	Tibiale Height
Cervicale Height	Ankle Height (right and left)
Mastoid Height	Vertical Reach - Standing
Suprasternale Height	Vertical Reach - Sitting
Xyphoid Height	Vertical Reach - Squatting
Umbilical Height	Vertical Reach - Kneel 1
Iliac Height	Vertical Reach - Kneel 2

RESULTS

Tables 6.3 through 6.8 show the means and standard deviations for the exertions tested. In the Standing, Squatting, Kneeling and Sitting postures, subjects were capable of lifting the most weight while standing. The next best posture was Kneeling, with no significant difference between kneeling on one or both knees. The least weight lift capability was in the Squatting posture.

TABLE 6.3
LIFTS WITH BOTH HANDS, STANDING

LEFT HEIGHT (% vertical reach)	CONTAINER ORIENTATION (l x w x h)	MALES N	MALES MEAN (pounds)	MALES STD	FEMALES N	FEMALES MEAN (pounds)	FEMALES STD
	24x12x6	45	71.9	12.7	46	36.4	6.0
85	12x6x24	45	63.4	12.5	46	31.9	4.9
	6x24x12	45	74.9	12.9	46	36.9	5.0
	24x12x6	45	88.6	13.8	46	46.5	7.7
60	12x6x24	45	78.4	13.6	46	41.6	6.2
	6x24x12	45	90.6	13.3	46	45.9	6.7
	24x12x6	45	117.7	23.1	46	58.4	13.7
35	12x6x24	45	119.1	21.0	46	57.7	11.6
	6x24x12	45	118.0	23.4	46	56.1	9.8

TABLE 6.4
LIFTS WITH BOTH HANDS, SQUATTING

LIFT HEIGHT (% vertical reach)	CONTAINER ORIENTATION (l x w x h)	MALES N	MALES MEAN (pounds)	MALES STD	FEMALES N	FEMALES MEAN (pounds)	FEMALES STD
85	24x12x6	45	53.9	11.0	46	28.9	5.8
	12x6x24	45	46.6	11.0	46	25.2	6.0
	6x24x12	45	56.4	11.2	46	29.9	4.8
60	24x12x6	45	64.4	10.7	46	35.2	6.2
	12x6x24	45	62.4	11.8	46	33.2	4.9
	6x24x12	45	70.7	11.4	46	37.4	6.1
35	24x12x6	45	78.4	13.8	46	43.2	6.2
	12x6x24	45	75.6	13.4	46	40.8	6.8
	6x24x12	45	84.2	14.8	46	44.5	8.1

TABLE 6.5
LIFTS WITH BOTH HANDS, SITTING

LIFT HEIGHT (% vertical reach)	CONTAINER ORIENTATION (l x w x h)	MALES N	MALES MEAN (pounds)	MALES STD	FEMALES N	FEMALES MEAN (pounds)	FEMALES STD
85	24x12x6	45	61.7	12.6	46	32.0	5.9
	12x6x24	45	51.1	10.2	46	27.3	5.3
	6x24x12	45	59.1	10.7	46	31.0	5.2
60	24x12x6	45	73.6	11.6	46	39.3	6.7
	12x6x24	45	71.8	14.5	46	36.6	5.6
	6x24x12	45	70.9	10.5	46	38.8	6.3
35	24x12x6	45	90.4	16.7	46	49.3	9.5
	12x6x24	45	86.4	16.4	46	47.2	9.0
	6x24x12	45	86.8	14.2	46	46.6	8.8

TABLE 6.6
LIFTS WITH BOTH HANDS, KNEEL 1

LIFT HEIGHT (% vertical reach)	CONTAINER ORIENTATION (l x w x h)	N	MALES MEAN (pounds)	STD	N	FEMALES MEAN (pounds)	STD
	24x12x6	45	67.0	12.2	46	33.6	6.0
85	12x6x24	45	55.2	9.9	46	29.6	4.3
	6x24x12	45	66.3	11.3	46	34.9	4.2
	24x12x6	45	76.2	13.5	46	41.5	6.4
60	12x6x24	45	73.1	12.5	46	37.5	5.1
	6x24x12	45	80.0	14.8	46	42.5	6.3
	24x12x6	45	97.8	19.5	46	52.6	9.9
35	12x6x24	45	89.2	15.5	46	47.6	7.4
	6x24x12	45	99.6	20.7	46	52.2	10.1

TABLE 6.7
LIFTS WITH BOTH HANDS, KNEEL 2

LIFT HEIGHT (% vertical reach)	CONTAINER ORIENTATION (l x w x h)	MALES N	MALES MEAN (pounds)	MALES STD (pounds)	FEMALES N	FEMALES MEAN (pounds)	FEMALES STD (pounds)
	24x12x6	45	66.1	12.1	46	33.7	6.0
85	12x6x24	45	54.4	9.9	46	28.6	3.8
	6x24x12	45	65.6	11.5	46	35.7	5.4
	24x12x6	45	77.4	12.4	46	40.1	7.1
60	12x6x24	45	72.7	11.5	46	36.6	5.1
	6x24x12	45	79.7	14.3	46	42.9	5.4
	24x12x6	45	93.2	17.7	46	53.3	12.0
35	12x6x24	45	88.4	15.2	46	47.5	9.1
	6x24x12	45	101.8	19.5	46	52.9	8.4

TABLE 6.8
RIGHT HAND LIFTS

POSTURE	LIFT HEIGHT (% vertical reach)	MALES N	MALES MEAN (pounds)	MALES STD (pounds)	FEMALES N	FEMALES MEAN (pounds)	FEMALES STD (pounds)
STAND	85	45	36.5	6.6	46	20.7	3.2
	60	45	59.1	12.3	46	33.3	5.7
	35	45	130.8	33.7	46	65.1	17.4
SQUAT	85	45	30.4	4.8	46	16.5	2.9
	60	45	39.4	7.6	46	23.2	5.0
	35	45	64.2	13.3	46	33.4	6.6
SITTING	85	45	31.9	9.5	46	16.7	2.7
	60	45	40.7	7.3	46	23.0	4.9
	35	45	65.2	10.7	46	35.1	5.5
KNEEL 1	85	45	33.2	5.3	46	17.3	3.0
	60	45	43.2	9.3	46	26.0	6.0
	35	45	77.4	16.7	46	39.1	7.8
KNEEL 2	85	45	32.5	4.6	46	17.5	3.4
	60	45	44.2	9.1	46	26.4	5.5
	35	45	71.6	14.6	46	39.4	7.4

NOTE: % vertical reach heights were reduced by a constant of 10 inches to compensate for the height of the box.

SECTION 7

POSITION AND HOLD STUDY

Positioning a component and then holding it with one hand while the other hand is used to attach the component is a recurring task in aircraft maintenance. In most cases, a degree of precision is required in the positioning and holding. For example, holes in the component must be kept in alignment with the matching holes in the structure to allow fasteners to be inserted. The weight of the object has a bearing on the difficulty of the task. Arrangement of other components and aircraft structure in the work area also impacts on the task difficulty. Impeding components and structure can force the technician into awkward postures and positions. The Position and Hold study was performed to determine the ability of technicians to perform such simulated tasks.

The objective of the study was to determine the maximum weight that could be held, with the precision required, for a period of 60 seconds in various working postures. The postures tested were standing, sitting, squatting, kneeling and lying. The basic standing, sitting, squatting and kneeling postures were with the trunk erect. Barriers were used to force the subjects into modifications of the basic postures such as are required in everyday maintenance practice.

A 10 " x 10 " x 10" container was used to simulate the component. Weights could be added or removed in 10 pound increments to adjust the total weight. A 10.5 " x 10.5 " target was used to insure the alignment of the container, and the time on the target was timed. The target was set at various elevations, relative to each subject's standing vertical reach.

To simulate some of the typical aircraft maintenance tasks, four separate task types were developed.

1. Holding the container against a wall (vertical surface) with no restricting barriers.

2. Holding the container against a wall with a horizontal restricting barrier. The barrier was set at a vertical height to minimize the subject's ability to use the body to help support the container. It was used to simulate those conditions when aircraft structure or components prevent the technician from positioning the body to help support the component being held. An example, is the edge of an access opening to an equipment bay.

3. Holding the container against a wall with a ceiling (overhead) barrier. Used to simulate those cases where restricting structure or components result in a change in the the basic posture. For example, standing and holding a component against an overhead structure which is lower than the technician's stature, requiring the technician to alter the knee, hip or spine angles to hold the object in position.

4. Holding the container against a ceiling (overhead horizontal surface). The ceiling was adjustable in height, and by varying the height from the floor, required the altering of body segment angles from the basic posture being tested.

7.1 ANTHROPOMETRY

The following set of anthropometric measures were made and recorded for each subject participating in the study.

Stature	Xiphoid Height
Weight	Umbilical Height
Sitting Height	Asis
Functional Reach	Superiliac Height
Standing Vertical Reach	Crotch Height
Eye Height	Trochanter Height
Acromion Height	Patella Height
Cervicale Height	Tibiale Height
Mastoid Height	Suprasternale Height
Lateral Malleolus Height	

7.2 TEST EQUIPMENT

The following test equipment was used in the Position and Hold study.

7.2.1 Holding Apparatus

The holding apparatus consisted of framework with mounting plates for the target. A vertical target mounting plate was used for the hold against a wall tasks, and could be raised and lowered to set the target elevation. A horizontal mounting plate could be raised and lowered to set the target elevation for the overhead holding tasks. It was also used as the ceiling barrier for the against a wall holding tasks.

A horizontal barrier, for against a wall holding tasks, consisted of a 3/4 " thick by 6 " wide board, set between the subject and the target at a horizontal distance of 15 ". The barrier could be raised and lowered to restrict the subject's ability to use the body as an aid in supporting the container.

7.2.2 Container

The container was a 10 " x 10 " x 10 " metal box. Weights could be added or removed from the box to adjust the total weight. The maximum weight was 110 pounds.

7.2.3 Target

The target was 10.5 " by 10.5" metal plate, with a 0.75 inch wide metal frame surrounding it. Placing the container against the target depressed a microswitch immediately behind the target which activated the timing system. When the target was depressed by the container, it was level with the surrounding frame.

7.2.4 Computerized Timing System

The computerized timing system recorded the time-on-target, that period of time when the microswitch was depressed. If the microswitch was depressed but the container also touched the surrounding metal frame, the container was considered to be off target and time-off-target-1 was recorded. If during the test the microswitch was not depressed, time-off-target-2 was recorded. Because the normal degree of precision feedback (e.g., bolt would not go therefore object is misaligned) was lacking in the laboratory tasks, each of the time-off-target conditions had an auditory cue associated with it to inform subjects that they were off target. Subjects were allowed to use both hands to reposition the container and the time-on-target recording was continued. A digital counter was used to record the number of times the container was off target.

7.3 EXPERIMENTAL CONDITIONS

1. Subjects:

   - Number: the number of male and female subjects participating in each study.

- Age: in all studies, the age range for subjects was 18 to 30 years. This corresponds to the age range of 99 percent of Air Force maintenance technicians who perform the majority of hands-on maintenance activities.

- Height/Weight: limiting height/weight restrictions as established by Air Force Regulation 160-43.

- Weight Lift: a minimum weight lift capability of 40 pounds on the 6 Foot Incremental Weight Lift test was required to participate in the study. Some Air Force maintenance career fields have weight lift requirements greater than 40 pounds, but all Air Force enlisted personnel are required to pass the test at the 40 pound level.

- Mixed Occupations: no particular skills or training were required for participation in the study.

- Pay: subjects were paid volunteers averaging $5.00 per hour. Informed consent was obtained prior to any testing.

- No Physical Frailties: no physical frailties that would prevent a subject from participating in the study because of a possibility of injury or aggravation of an existing, or previously existing, condition.

2. Clothing:

- Street clothes.

3. Testing Sessions: were approximately 2 hours long, with a ten minute rest between tasks. Number of sessions varied, depending on the adjustments required to the total weight for each of the 55 tested tasks. Task order was randomized.

4. Task Type: the task types were identified in the introductory paragraph.

5. Posture: the 5 postures tested in the Position and Hold study.

6. Target Height: the distance from the floor to the target, expressed as a percentage of each subject's standing vertical reach.

7. Overhead Barrier (ceiling) Height: the distance from the floor to the ceiling, expressed as a percentage of each subject's standing vertical reach.

7.4 GENERAL PROCEDURES

The holding apparatus was set to match the parameters, such as target height, horizontal barrier, and ceiling height for the task to be tested. The subject assumed the required posture for the task. Container was loaded to a weight that the experimenter felt the subject could not hold on target for the required sixty seconds. The subject positioned the container against the target with both hands, held the container with the left hand and kept the right hand in the vicinity of the container, to simulate the right hand attaching the container to the mounting surface. If the audible signal sounded, indicating that the container was off target, subjects were allowed to use both hands to reposition the container.

While holding the container, subjects were allowed to indirectly support the weight of the container using their body to whatever extent the task allowed. For example, subjects could brace their arm against the trunk or leg to help to support the container. The exception to this was during the against the wall with horizontal barrier tasks, the barrier being positioned to require the container to be supported with the arm alone. Also, subjects were allowed, but not required, to wear a leather glove on the left hand while holding the container in position.

If the subject could not hold the container on-target for the required sixty second period during the first attempt, the weight was decreased in 10 pound increments and the trial repeated until the sixty seconds time-on-target was met, and that weight recorded as the subject's maximum position and hold weight. Conversely, if the subject did attain the sixty seconds time-on-target during the first attempt, the weight was increased in 10 pound increments, and the trial was redone until a weight was reached where the subject could not meet the sixty seconds time-on-target. At this time, the weight for the previous successful time-on-target was recorded as the subject's maximum position and hold weight.

■ POSITION AND HOLD STUDY ■

OBJECTIVE

To determine the maximum weight that could be positioned and held by a representative sample, in various postures and restraint conditions, while performing simulated aircraft maintenance activities.[21]

TEST EQUIPMENT

As described in paragraph 7.2.

CONDITIONS

Constants

- Subjects

  Number: 15 males, 17 females

- Clothing: Street clothes

Variables

There were different combinations of the following variables. The variable conditions used for each of the task types are listed in Tables 7.1 through 7.4

- Task Type
- Posture
- Target Height
- Ceiling Height

21. Authors: Ayoub, M.M., Smith, J.L., Selan, J.L., Kim, H.K., Lee, Y.H., and Chen, H.C. (TTU)

TABLE 7.1

AGAINST WALL, NO BARRIER

VARIABLE COMBINATIONS

POSTURE	TARGET HEIGHT (% of standing vertical reach)
STANDING	40, 60, 80 (Figure 7.1)
SITTING	20, 40, 60
SQUATTING	20, 40 60
KNEELING	20, 40, 60
LYING (on side)	20, 30

TABLE 7.2

AGAINST WALL, WITH HORIZONTAL BARRIER

VARIABLE COMBINATIONS

POSTURE	TARGET HEIGHT (% of standing vertical reach)
STANDING	40, 60, 80
SITTING	20, 40, 60
SQUATTING	20, 40, 60
KNEELING	20, 40, 60 (Figure 7.2)

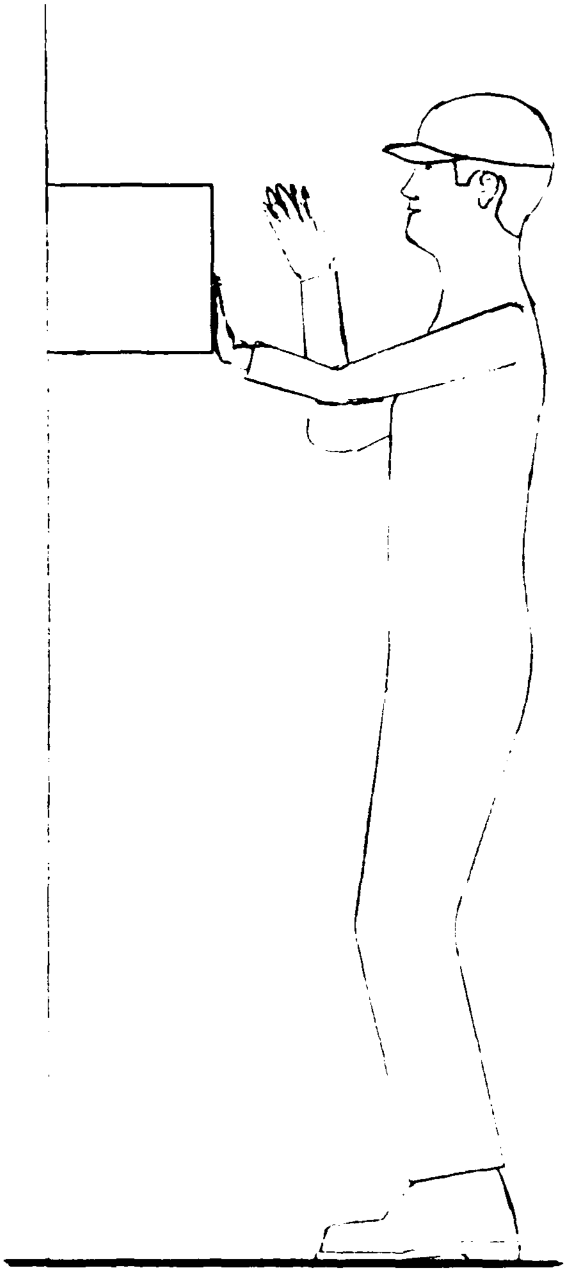


Figure [illegible]. Holding Against Wall, No Horizontal Barrier, No Ceiling Constraint, Standing, Target at 60% of Standing Vertical Reach

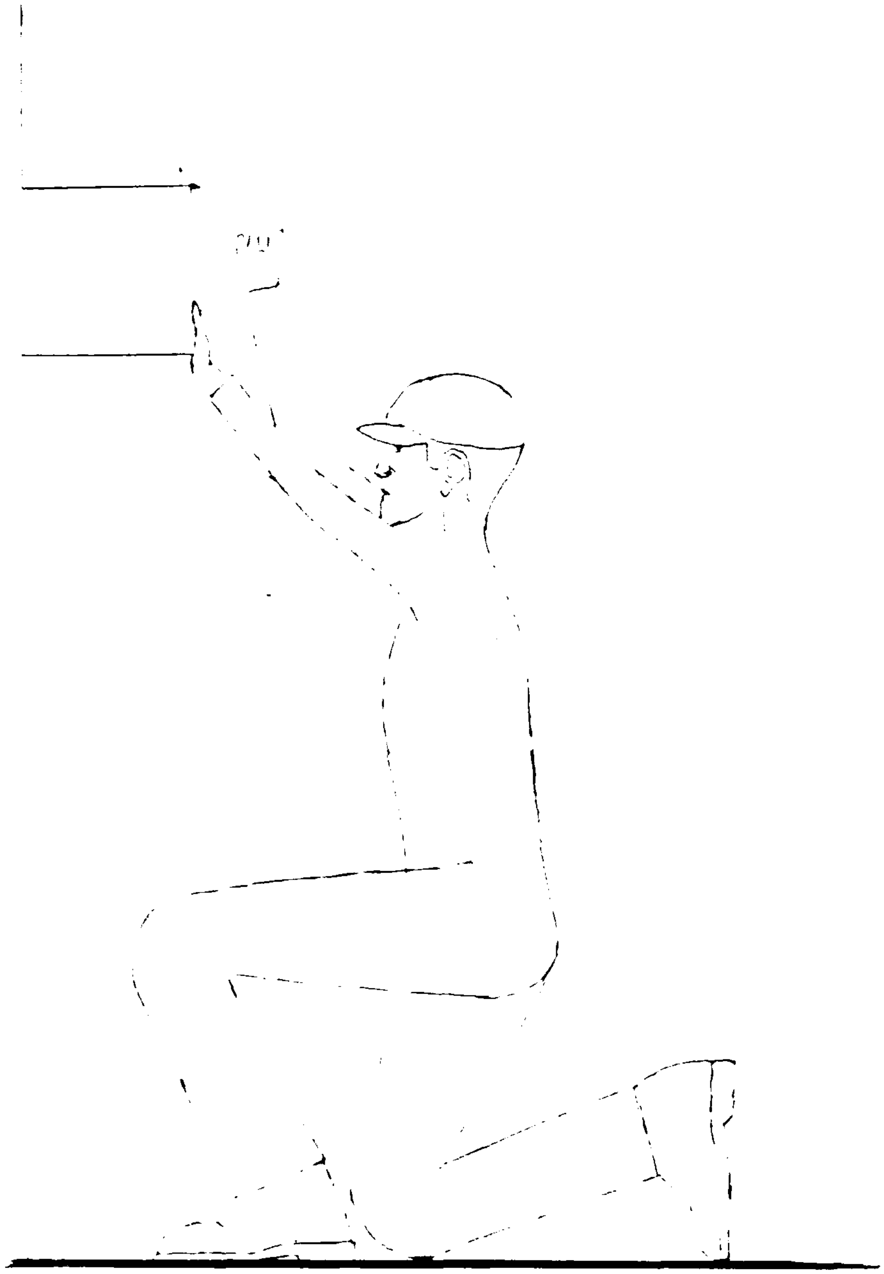


Figure 7.2 Holding Against Wall, with Horizontal Barrier, No Ceiling Constraint, Kneeling Posture, Target at 60% of Standing Vertical Reach

TABLE 7.3

AGAINST WALL, OVERHEAD BARRIER

VARIABLE COMBINATIONS

POSTURE	TARGET HEIGHT	CEILING HEIGHT	
	(% of standing vertical reach)		
STANDING	40	60	(Figure 7.3)
	50	60	
SITTING	20	30	
	30	40	
	20	40	
SQUATTING	20	30	
	30	40	
	20	40	
KNEELING	20	30	
	30	40	
	20	40	

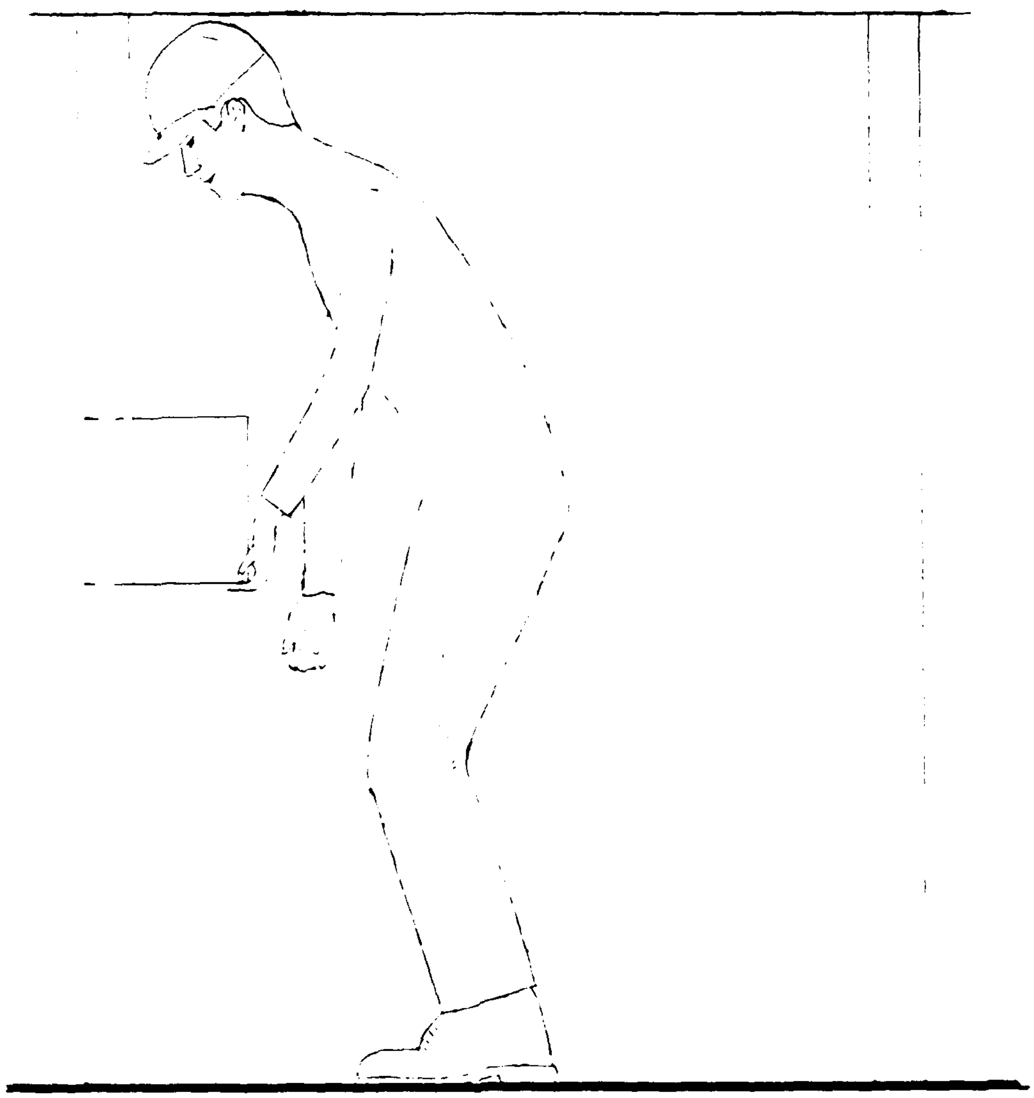


Figure 7.3 Holding Against Wall, No Horizontal Barrier, Ceiling Constraint at 60% of Standing Vertical Reach, Standing Posture, Target at 40% of Standing Vertical Reach

TABLE 7.4

AGAINST CEILING

VARIABLE COMBINATIONS

POSTURE	TARGET HEIGHT (% of standing vertical reach)
STANDING	60, 70, 80
SITTING	30, 40, 50, 60 (Fig 7.4)
SQUATTING	30, 40, 50, 60
KNEELING	30, 40, 50, 60, 70
LYING (on back)	20, 30

MEASURES

- Maximum weight held for successful completion (time-on-target of 57 to 60 seconds), recorded in pounds.
- Time-on-target, in seconds
- Time-off-target, in seconds
- Number of times off target

RESULTS

Tables 7.5 through 7.8 show the means and standard deviations of the maximum weight that could be held for sixty seconds for each task type. Males consistently held more weight than females. More weight could be held when there was no barrier interfering with the subject. More weight could be held against a wall than against a ceiling except when the subject was in the lying posture.

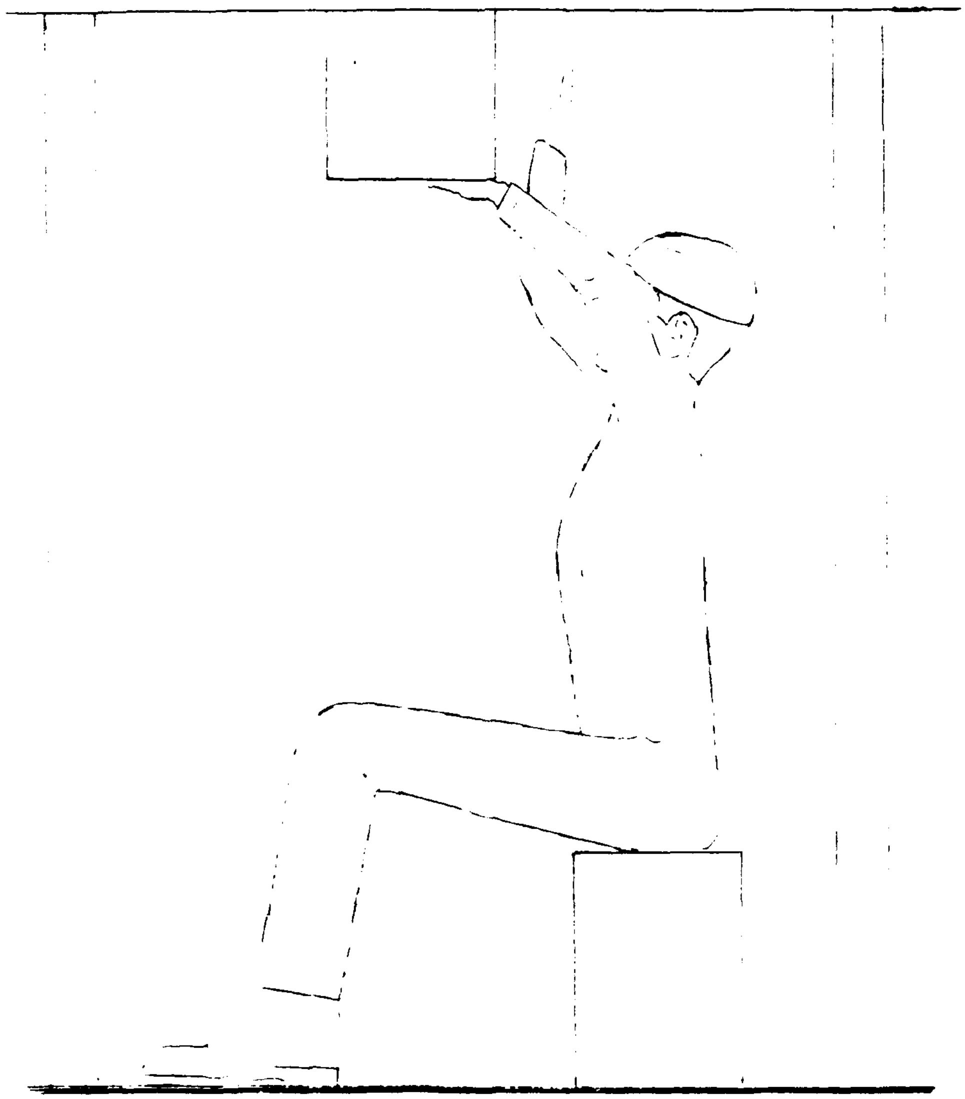


Figure 7.4 Holding Against Ceiling, Sitting Posture, Target at 60% of Standing Vertical Reach

TABLE 7.5

AGAINST WALL, NO BARRIER

POSTURE	TARGET HEIGHT (% of standing vertical reach)	MALES MEAN (pounds)	MALES STD	FEMALES MEAN (pounds)	FEMALES STD
STANDING	40	83.5	19.0	43.7	18.9
	60	79.5	22.4	44.2	16.1
	80	48.0	24.4	19.5	8.5
SITTING	20	96.0	16.7	51.6	18.6
	40	68.5	23.2	34.2	14.3
	60	39.5	17.3	14.7	7.0
SQUATTING	20	82.0	22.1	40.0	18.9
	40	56.0	22.1	26.3	13.4
	60	48.0	21.7	18.4	10.1
KNEELING	20	93.7	21.9	47.4	23.1
	40	66.5	26.4	34.7	14.3
	60	39.0	22.0	13.7	7.6
LYING	20	34.5	17.9	20.5	10.3
	30	35.0	19.6	15.3	8.4

TABLE 7.6

AGAINST WALL, HORIZONTAL BARRIER

POSTURE	TARGET HEIGHT (% of standing vertical reach)	MALES MEAN (pounds)	MALES STD (pounds)	FEMALES MEAN (pounds)	FEMALES STD (pounds)
STANDING	40	36.5	23.0	18.9	11.3
	60	69.5	22.1	35.8	11.2
	80	46.0	21.6	18.4	7.6
SITTING	20	40.5	26.1	21.6	11.7
	40	34.0	15.0	20.0	9.1
	60	40.5	18.2	18.4	6.9
SQUATTING	20	38.0	19.1	19.5	9.1
	40	27.5	13.7	12.8	7.5
	60	39.5	17.6	16.3	6.0
KNEELING	20	33.0	20.0	15.3	7.7
	40	53.5	22.8	31.1	12.8
	60	41.0	22.7	13.7	7.6

TABLE 7.7

AGAINST WALL, OVERHEAD BARRIER

POSTURE	TARGET HEIGHT	CEILING HEIGHT	MALES MEAN	MALES STD	FEMALES MEAN	FEMALES STD
	(% of standing vertical reach)		(pounds)		(pounds)	
STANDING	40	60	64.5	29.6	27.9	16.2
	50	60	66.5	19.8	27.9	10.3
SITTING	20	30	49.5	24.4	26.3	10.7
	20	40	83.5	29.4	43.1	21.6
	30	40	70.0	25.3	32.1	14.4
SQUATTING	20	30	52.5	23.6	28.4	16.8
	20	40	83.5	27.2	36.7	17.1
	30	40	62.5	28.6	34.2	14.3
KNEELING	20	30	56.5	28.9	24.2	15.0
	20	40	70.5	31.5	36.7	17.8
	30	40	54.5	24.2	27.4	14.1

TABLE 7.8

AGAINST CEILING

POSTURE	TARGET HEIGHT (% of standing vertical reach)	MALES MEAN (pounds)	MALES STD (pounds)	FEMALES MEAN (pounds)	FEMALES STD (pounds)
STANDING	60	51.5	28.0	28.4	11.2
	70	23.0	17.2	12.1	7.1
	80	30.6	23.6	11.7	5.1
SITTING	30	44.5	32.2	14.2	8.4
	40	41.0	17.7	18.4	7.6
	50	12.5	5.5	10.5	2.3
	60	22.0	20.2	10.5	2.3
SQUATTING	30	45.0	24.4	20.0	12.4
	40	25.5	19.9	10.5	2.3
	50	13.5	4.9	10.0	0.0
	60	22.0	14.7	12.8	7.5
KNEELING	30	41.0	27.3	19.5	12.2
	40	36.5	16.6	16.8	8.2
	50	16.0	8.2	10.0	0.0
	60	17.5	12.5	10.0	0.0
	70	29.0	19.7	13.1	7.5
LYING	20	17.0	8.0	10.6	2.4
	30	41.5	16.9	16.7	7.7

SECTION 8

CARRY STUDY

Maintenance technicians are frequently required to carry objects from one location to another. Carrying while walking is the most efficient posture. However, there are many situations which prevent carrying in an erect posture. For example, carrying beneath the wing or fuselage of, or inside of, an aircraft may require carrying while stooped or crawling. The Carry study was performed at Texas Tech University (TTU) to determine the carrying capacity in the erect and unusual postures.

The simulated carrying tasks were defined by the following postures, which were determined by ceiling constraints, set at a percentage of each subject's stature, to dictate the subject's posture.

1. Standing - ceiling height was set above each subject's stature.

2. Semi-stoop - ceiling height was set at 80 % of each subject's stature.

3. Full stoop - ceiling height was set at 60 % of each subject's stature.

4. Crawling - ceiling height was set at 40 % of each subject's stature.

8.1 ANTHROPOMETRY

The following set of anthropometric measures were made and recorded for each subject.

Stature	Eye Height
Weight	Mastoid Height
Sitting Height	Acromion Height
Functional Reach	Iliac Crest
Cervicale Height	Superiliac
Suprasternale Height	Trochanteric Height
Xiphoid Height	Patella Height
Umbilical Height	Tibiale Height
Crotch Height	Lateral Malleolus Height

8.2 TEST EQUIPMENT

The following test equipment was used in the completion of the Carry study.

Carry test station - The station was 10 feet long, consisting of a ceiling that could be raised and lowered to set the height for the five carries.

Containers - various sizes and handle configurations. Total weight could be adjusted by adding or removing weights.

Incremental Weight Lift Test Machine

8.3 EXPERIMENTAL CONDITIONS

The following conditions were used in the study as constants or variables.

1. Subjects:

- Number: the number of male and female subjects.

- Age: the age range for subjects was 18 to 30 years. This corresponds to the age range of 99 percent of Air Force maintenance technicians who perform the majority of hands-on maintenance activities.

- Height/Weight: limiting height/weight restrictions as established by Air Force Regulation 160-43.

- Weight Lift: a minimum weight lift capability of 40 pounds on the 6 Foot Weight Incremental Lift test was required to participate in the study. Some Air Force maintenance career fields have weight lift requirements greater than 40 pounds, but all Air Force enlisted personnel are required to pass the test at the 40 pound level.

- Mixed Occupations: no particular skills or training were required for participation in the study.

- Pay: subjects were paid volunteers averaging $5.00 per hour. Informed consent was obtained prior to any testing.

- No Physical Frailties: no physical frailties that would prevent a subject from participating in the study because of a possibility of injury or aggravation of an existing, or previously existing, condition.

2. Clothing:

   - Street clothes - shorts, T-shirts and any shoes acceptable.

3. Testing Sessions:

   - Number: number of sessions required to complete a study.

   - Rest Period: Rest time allowed between tasks to prevent fatigue becoming a factor.

4. Task Type: the task types defined by the Ceiling Elevation.

5. Ceiling Elevation: the distance from the supporting surface to the ceiling. Expressed as a percentage of each subject's stature.

6. Containers:
   Dimensions are length x width x height, in inches

   - A. 24 " x 12 " x 6 ", without handles.

   - B. 24 " x 12 " x 6 ", with handles at either end of the length.

   - C. 15 " x 10.5 " x 10.75 ", with one handle parallel to the length.

- D. 15 " x 8 " x 8 ", with one handle parallel to the length.

7. Hand Used: the hand(s) used to carry the container.

8.4 PROCEDURES

The container used, and its starting weight, depended on the task to be performed. In all cases the subjects were required to lift the container from the floor, carry it for a distance of 10 feet, and lower it to the floor. Subjects used freestyle lifting techniques, but were restricted to forward movement and duckwalking was not permitted. Subjects were not allowed to drag or slide the container on the floor.

The maximum weight carried by subjects was their voluntary maximum, with the experimenter asking subjects, after each successful carry, if they were safely able to carry more weight. If the answer was affirmative, the weight was increased by five pounds and the trial repeated, until the subjects judged they could not safely carry more weight, or the experimenter deemed the trial invalid based on the following criteria.

1. Sliding/dragging the container along the floor.

2. Dropping the container more than 3 inches from the floor.

3. Difficulty in lifting, carrying or lowering the container.

4. Staggering while lifting, carrying or lowering the container.

5. Physical overexertion as displayed by straining and/or verbal or facial expression.

The carrying procedures for the different task types were:

- Standing carry, with both hands - container held with both hands, lifted from the floor, carried in front of body for 10 feet using normal upright carrying posture, then lowered to the floor (Figure 8.1).

- Semi-stoop carry, with both hands - container held with both hands, lifted from the floor, carried in front of the body for 10 feet using a basically upright posture with slightly flexed neck and trunk to clear the ceiling, then lowered to the floor (Figure 8.2).

- Full stoop, with both hands - container held with both hands, lifted from the floor, carried in front of the body for 10 feet, and lowered to the floor. The carrying posture was a flexed neck and very flexed trunk and knees to clear the ceiling (Figure 8.3).

- Crawling, both hands _ container placed in front of the body in crawling position. Handles grasped by both hands, container lifted, moved forward, and lowered to the floor. Subjects then crawled forward to the container, with both hands in contact with the handles throughout the movement, and the lifting, moving forward and lowering was repeated until the container had been carried for 10 feet (Figure 8.4).

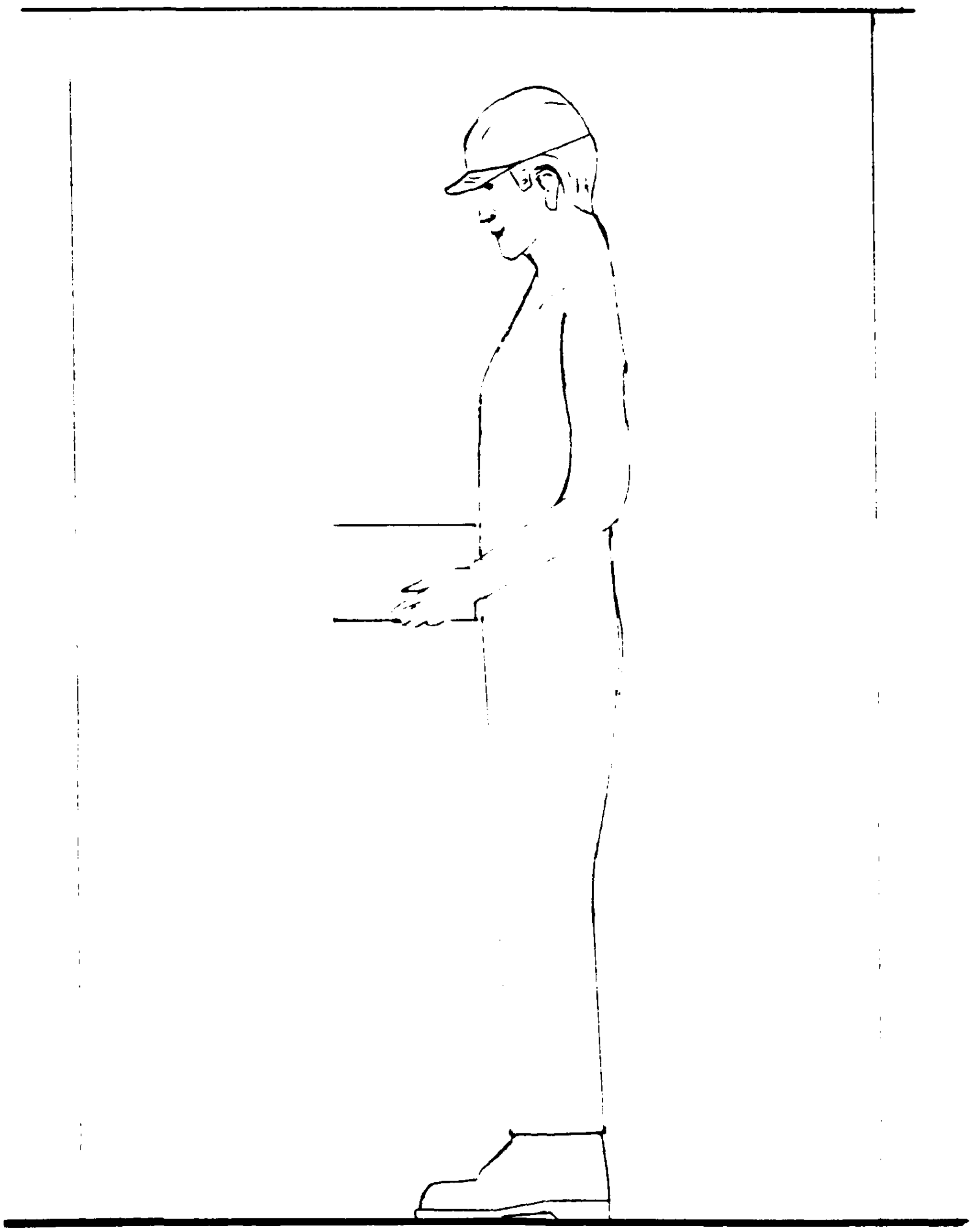


Figure 8.1 Standing Carry, with Both Hands
(Ceiling height is greater than stature,
(no obstruction).

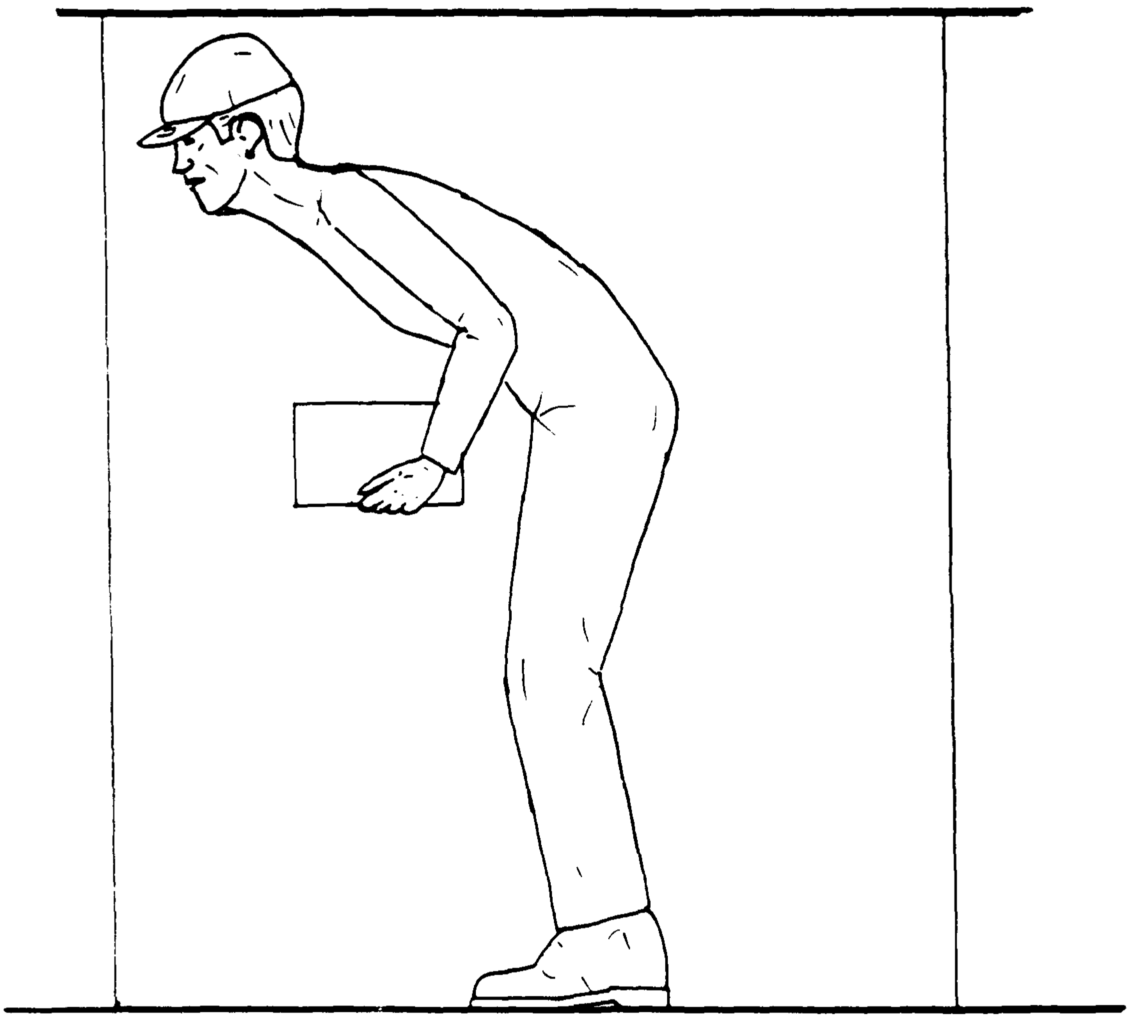


Figure 8.2 Semi-stoop Carry, with Both Hands
Ceiling height is 80% of stature.

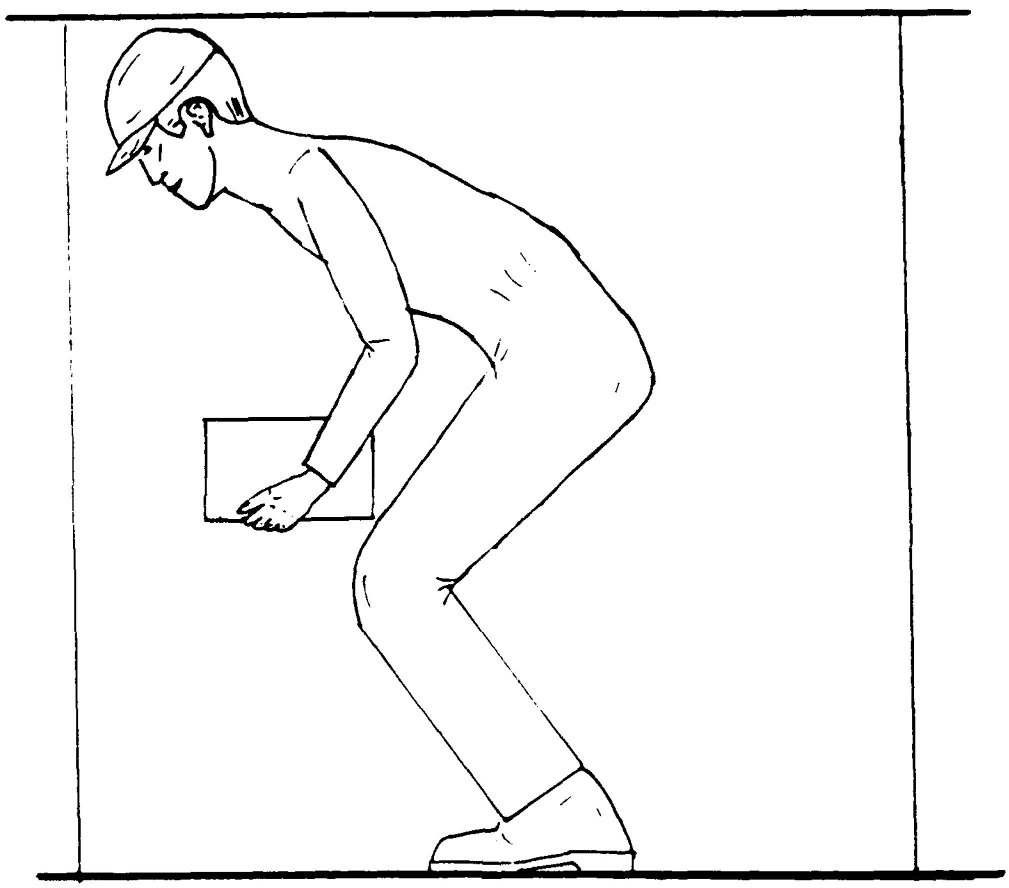


Figure 8.3 Full Stoop Carry, with Both Hands
Ceiling height is 60% of stature.

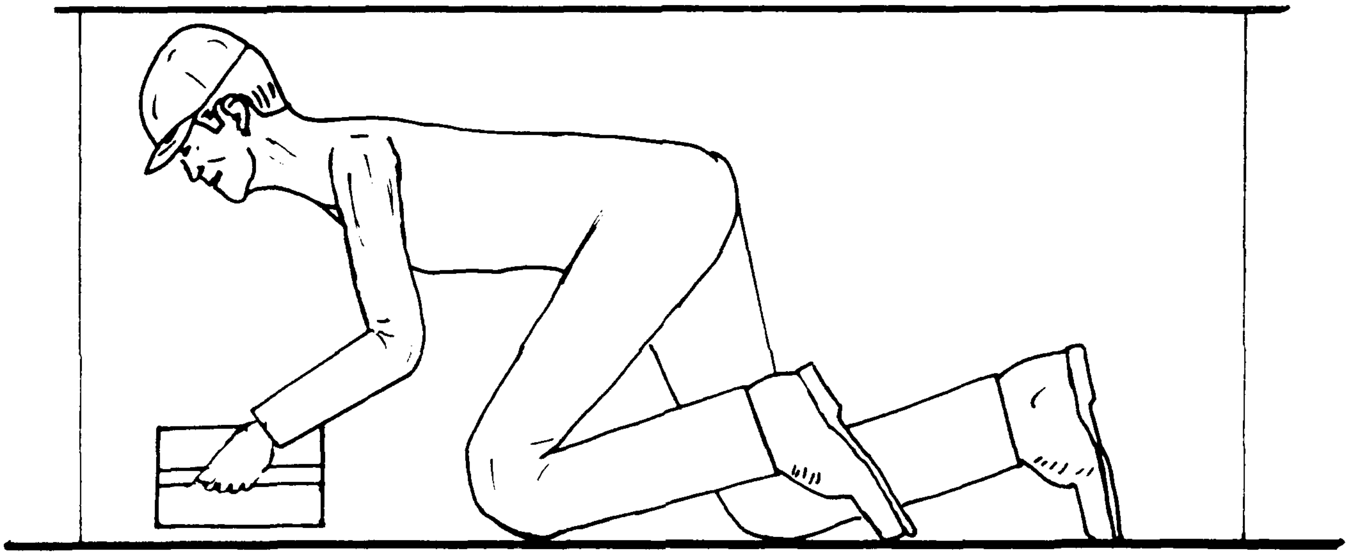


Figure 8.4 Crawling Carry, with Both Hands
Ceiling height is 40% of stature.

- Crawling, one hand - container placed on the subject's preferred side, container lifted with the preferred hand, moved forward and lowered to the floor. Subjects then crawled forward to the container, with the hand remaining in contact with the handle throughout the movement, and repeated the process until the container had been carried for 10 feet (Figure 8.5).

The starting weights of the container for each task were based on the subject's Incremental Elbow Lift (IEL) score. The Incremental Elbow Lift test was given to each subject on the Incremental Weight Lift Machine, using the following procedures.

A. Subject's elbow height was marked on the machine.

B. Subject faced the machine with the placed approximately shoulder apart.

C. Knees were bent, back erect and the handles grasped with an overhand grip.

D. Weight was lifted to elbow height, with a smooth motion and without the heels leaving the ground, and then smoothly lowered.

The starting weight for the Incremental Elbow Lift was the subject's maximum weight lifted during the Incremental Weight Lift to Six Feet (Paragraph 2.1). Weight was increased in ten pound increments until the subject was unable to lift the load to elbow height. The last weight successfully lifted to elbow height was recorded as the test score (IEL).

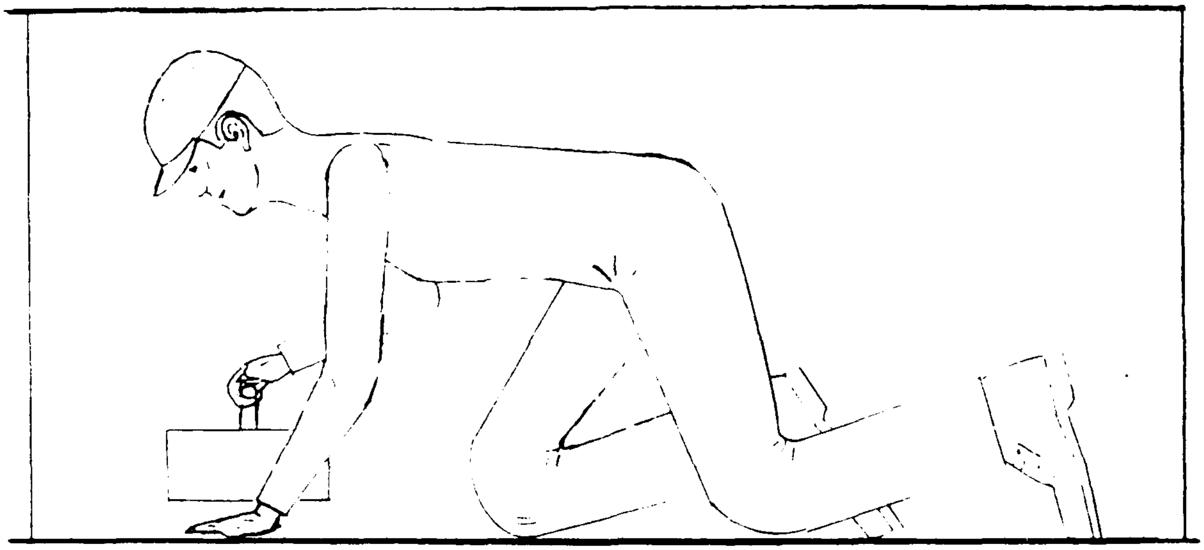


Figure 8.5 Crawling Carry, with One Hand
Ceiling height is 40% of stature.

The starting container weight for each of the task types was derived from the following table.

Task Type	Starting Weight Males	Females
Standing	IEL - 20 lb.	IEL - 10 lb.
Semi-stoop	IEL - 20 lb.	IEL - 10 lb.
Full stoop	IEL - 50 lb.	IEL - 20 lb.
Crawl	30 % of IEL	50 % of IEL

The weight carried for the last successful trial of a specific task was recorded as the maximum carrying weight. A 10 minute rest period was given after the completion of a task. The only rest between trials was while the container weight was being adjusted for the next trial. Tasks were performed in random order.

CARRY STUDY

OBJECTIVE

To determine maximum weight carrying capabilities of aircraft maintenance technicians during simulated maintenance tasks in unusual postures.[22]

CONDITIONS

Constants

- Subjects
  Number: 20 males, 19 females

- Clothing: Street clothes

- Testing Sessions:
  Number: varied with number of trials per task.
  Length: 2 hours
  Rest Period: 10 minutes between tasks.

Variables

There were different combinations of variables used for the different tasks. The variables used for each of the different task types are shown in Table 8.1.

- Task Type:
  Standing
  Semi-stoop
  Full-stoop
  Crawling

22. Authors: Ayoub, M.M., Smith, J.L., Chen, H.C., Danz, M.E., Kim, H.K., Lee, Y.H., and Ostrom, L.T. (TTU)

- Ceiling Height:

  Expressed as a percentage of each subject's stature

  - 100 % +
  - 80 %
  - 60 %
  - 40 %

- Container:

  Dimensions are length x width x height

  A. 24 " x 12 " x 6 ", without handles.

  B. 24 " x 12 " x 6 ", with handles at either end of the length.

  C. 15 " x 10.5 " x 10.75 ", with one handle parallel to the length, used for crawling with one hand by males.

  D. 15 " x 8 " x 8 ", with one handle parallel to the length, used for crawling with one hand by females.

- Hand Used:

  One

  Both

MEASURES

- Maximum voluntary weight in pounds.
- Stature in inches.
- Incremental elbow weight lift score in pounds.

TABLE 8.1

VARIABLE COMBINATIONS FOR THE FIVE TASKS

TASK TYPE	CEILING HEIGHT	CONTAINER	GENDER	HAND USED
STANDING	100 % +	A	BOTH	BOTH
SEMI-STOOP	80 %	A	BOTH	BOTH
FULL-STOOP	60 %	A	BOTH	BOTH
	40 %	B	BOTH	BOTH
CRAWLING	40 %	C	MALE	ONE
	40 %	D	FEMALE	ONE

RESULTS

Table 8.2 presents the mean and standard deviation for each task type. The standing carrying task (ceiling height 100 % + of stature) consistently resulted in the highest values. The crawling tasks (ceiling height at 40% of stature) resulted in smallest values. There was no significant difference in capabilities between crawling with one and two hands.

TABLE 8.2

MAXIMUM ACCEPTABLE CARRYING WEIGHT

TASK TYPE	CEILING HEIGHT (% stature)	HAND USED	MALES MEAN (pounds)	MALES STD (pounds)	FEMALES MEAN (pounds)	FEMALES STD (pounds)
STANDING	100 % +	BOTH	153.0	30.3	79.0	14.1
SEMI-STOOP	80 %	BOTH	146.5	26.5	73.3	11.2
FULL-STOOP	60 %	BOTH	113.3	27.5	54.0	12.6
CRAWLING	40 %	BOTH	64.3	8.8	41.5	5.9
	40 %	ONE	67.6	9.6	41.5	7.3

REFERENCES

Ayoub, M.M., Smith, J.L., Selan, J.L., and Fernandez, J.E. "Manual Materials Handling in Unusual Positions - Phase I". Final Report prepared for the University of Dayton Research Institute, 1985a (unpublished).

Ayoub, M.M., Smith, J.L., Selan, J.L., Chen, H.C., Fernandez, J.E., Lee, Y.H., and Kim, H.K. "Manual Materials Handling in Unusual Positions - Phase II". Final Report prepared for the University of Dayton Research Institute, 1985b (unpublished).

Ayoub, M.M., Denardo, J.D., Smith, J.L., Bethea, N.J., Lambert, B.K., Allen, L.R., and Duran, B.S. "Establishing Physical Criteria for Assigning Personnel to Air Force Jobs - Final Report" Air Force Office of Scientific Research, Contract No. F49620-79-C-006, September 1982 (unpublished).

Adams, S.K. and Ma, X. "Maximum Voluntary Hand-Grip Torque for Circular Electrical Connectors. The Effect of Obstructions". Final Report for the Air Force Office of Scientific Research. Contract No. F49620-85-C-0013/SB5451-0360, Subcontract No. S-760-0M6-008, December 1986 (unpublished).

Caldwell, L.S., Chaffin, D.B., Dukes-Dobos, F.N., Kroemer, K.H.E., Laubach, L.L., Snook, S.N., and Wassermann, D.E. A Proposed Standard Procedure for Static Muscle Strength Testing". American Industrial Hygiene Association Journal 35:4, pp. 201-206, April 1974.

McDaniel, J.W., Skandis, J.H., and Madole, S.W. "Weight Lift Capabilities of Air Force Basic Trainees". AFMRL-TR-83-0001, May 1983.

McDaniel, J.W. "Modeling Strength Data for CREW CHIEF ". Proceedings of the SOAR 89 (Space Operations, Automation and Robotics), NASA Johnson Space Center, Houston, TX, July 1989.

Snook, S.H. "The Design of Manual Handling Tasks". Ergonomics, Volume 2, No. 12, PP. 963-985, 1978.

APPENDIX A

CLOTHED ANTHROPOMETRY OF CREW CHIEF

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INTRODUCTION

The purpose of this report is to describe the data collection of clothed anthropometry in the on-going CREW CHIEF research project. The data on clothed subjects will be used in CREW CHIEF software to add increments of clothing to the enfleshed computer models of maintenance technicians.

Measurement of anthropometric dimensions on clothed subjects is not new, but it has been done relatively rarely in the context of military application. Surveys tend to be limited to small samples and specific clothing combinations (Johnson, 1984; White, et al., 1964; Garrett, 1968). Because clothing ensembles are so specific, and the equipment used with each varies so considerably (Johnson, 1984), it is not feasible to generalize data from a given survey for uses other than those specified.

In the present study, two clothing assemblages were used: Chemical Defense and Cold Weather. These were to represent the "worst case" clothing ensembles, in the sense that all other ensembles would add less bulk to the nude figure than these. Nevertheless, each clothing system is unique, and the data in this report should not be used to represent other clothing ensembles.

METHODS

The subjects for the present study were 10 males and 10 females drawn from the Synergy, Inc. Subject Pool. Each was briefed on the purpose of the study, received answers to any questions and signed a consent form. The basic anthropometric characteristics of the subjects are found in Table A.1. Table A.2 presents data from selected major U.S. anthropometric surveys for comparison with the CREW CHIEF subjects. Note that for stature, the CREW CHIEF males are slightly smaller, but that the CREW CHIEF females are slightly larger than the comparison

TABLE A.1

BODY SIZE OF SUBJECTS

MALES (N = 10)	MIN.	MAX.	MEAN	S.D.
STATURE (cm)	157.6	183.2	174.71	7.04
WEIGHT (lb.)	110.2	272.1	168.05	47.64
AGE (years)	18	25	20.60	1.91

FEMALES (n = 10)	MIN.	MAX.	MEAN	S.D.
STATURE (cm)	155.7	176.9	164.39	6.08
WEIGHT (lb.)	101.8	163.5	126.75	19.76
AGE (years)	19	26	21.40	2.37

TABLE A.2

MEANS AND STANDARD DEVIATIONS FROM MAJOR ANTHROPOMETRIC SURVEYS

MALES	USAF 1965 (n = 3869)		USAF 1967 (n = 2420)	
	MEAN	S.D.	MEAN	S.D.
STATURE (cm)	175.28	6.56	177.34	6.19
WEIGHT (lb.)	156.44	23.91	173.54	21.42
AGE (years)	22.8	6.47	30.03	6.31

FEMALES	USAF 1968 (n = 1905)		USAF 1977 (n = 1331)	
	MEAN	S.D.	MEAN	S.D.
STATURE (cm)	162.10	6.00	162.95	6.52
WEIGHT (lb.)	127.24	16.57	132.06	18.67
AGE (years)	23.43	6.45	23.61	5.40

samples. The males from the present study fall between comparison samples for mean weight, but the current females are just under the lower of the two mean weights listed. The CREW CHIEF subjects are younger than all the military survey samples listed. Thus, while subjects in this report are not exactly representative of any particular existing military sample, they are close enough that they could easily be individual members of the populations listed. All subjects had previously been measured for other CREW CHIEF studies, with original anthropometric measurements as shown in Figure A.1, so only supplemental nude measurements were needed (Figure A.2). Measurement descriptions for supplementary nude dimensions are given in Appendix A-A.

After the nude measurements were made, subjects dressed in their street clothes, and then donned either the Chemical Defense or the Cold Weather gear. The order of the two ensembles was random, but all subjects were eventually measured in both ensembles. Unfortunately, not every size of every item was available for use. Tables A.3 and A.4 show the available and missing sizes for both ensembles.

The Chemical Defense assemblage was worn over the subject's street clothes (minus shoes) to approximate the usual fatigues. Two female subjects #708 and #718, removed their skirts before donning the assemblage. Trousers were worn over both sets of boots, and elasticized cuffs secured the pant legs at the ankles. Liners and gloves were worn under the jacket.

Initially, subjects tried on appropriately sized trousers based on their own estimation of correct size and the investigator's judgments, and if necessary, exchanged for a larger or smaller pair. The trousers, which come in three sizes, with an adjustable waist, provided a satisfactory fit for all subjects.

ANTHROPOMETRIC DATA

NAME: ______________________ ____ DATE: ____________

BIRTH DATE: _____________ SEX: M F

SUBJECT NO.: _________

1. AGE: _______
2. WEIGHT: __________ (lbs)
3. INC WEIGHT LIFT: __________ (lbs)

STANDING HEIGHTS

4. STATURE: _____________
5. EYE HEIGHT: __________
6. ACROMIAL HEIGHT: ___________
7. CERVICALE HEIGHT: __________
8. SUPRASTERNALE HEIGHT: _________
9. SUBSTERNALE HEIGHT: __________
10. WAIST HEIGHT: _____________
11. ILIOCRISTALE HEIGHT: __________
12. ILIOSPINALE HEIGHT: ___________
13. CROTCH HEIGHT: ________________
14. TROCHANTERIC HEIGHT: __________
15. PATELLA TOP HEIGHT: ___________
16. TIBIALE HEIGHT: _______________
17. LAT MALLEOLUS HEIGHT: _________

ARM-HAND, STANDING

18. SHOULDER-ELBOW LENGTH: ________
19. ACROMION-RADIALE LENGTH: _______
20. ELBOW-WRIST LENGTH: ____________
21. RADIALE-STYLION LENGTH: _______
22. HAND LENGTH: _____________
23. HAND BREADTH: _____________
24. WRIST-META III LENGTH: ________
25. ELBOW-GRIP LENGTH: __________
26. THUMB-TIP REACH: ______________
27. VERTICAL GRIP REACH: __________
28. SPAN: ________________________

TRUNK-TORSO, DEPTHS/BREADTHS

29. BIDELTOID BREADTH: _____________
30. BIACROMIAL BREADTH: ____________
31. CHEST BREADTH: _________________
32. CHEST DEPTH: ___________________
33. WAIST BREADTH: _________________
34. HIP BREADTH: ___________________
35. BISPINOUS BREADTH: _____________

Figure A.1. Anthropometric Measurement Recording Sheet

SITTING MEASUREMENTS

36. SITTING HEIGHT: _______________

37. EYE HEIGHT, SITTING: ___________

38. ACROMIAL HEIGHT, SITTING: ______

39. KNEE HEIGHT. SITTING: _________

40. HIP BREADTH, SITTING: _________

41. BUTTOCK-KNEE LENGTH: __________

HEAD-FACE MEASUREMENTS

42. HEAD LENGTH: _________________

43. HEAD BREADTH: ________________

44. FACE(MENTON-SELLION) LENGTH: _______________

45. FACE(BIZYGOMATIC) BREADTH: _______________

46. BIOCULAR BREADTH: _____________

47. INTERPUPILLARY BREADTH: _______

CIRCUMFERENTIAL MEASUREMENTS

48. HEAD CIRCUMFERENCE

49. SHOULDER CIRCUM: ______________

50. BICEPS CIRCUM. FLX: ___________

51. FOREARM CIRCUM, FLX: __________

52. WRIST CIRCUM: _________________

53. HAND CIRCUM: __________________

54. CHEST CIRCUM: _________________

55. WAIST CIRCUM: _________________

56. HIP CIRCUM: ___________________

57. THIGH CIRCUM: _________________

58. KNEE CIRCUM: __________________

59. CALF CIRCUM: __________________

60. ANKLE CIRCUM: _________________

OPTIONAL

61. FOOT LENGTH: __________________

62. FOOT BREADTH: _________________

SKINFOLDS

63. TRICEPS: __________________(mm)

64. SUBSCAPULAR_______________(mm)

65. SUPRAILIAC: _______________(mm)

66. MEDIAL CALF: ______________(mm)

GRIP

67. RIGHT 1: __________________(kg)

68. RIGHT 2: __________________(kg)

69. LEFT 1: ___________________(kg)

70. LEFT 2: ___________________(kg)

71. VERTICAL REACH
STANDING/SHOES: ______________

72. VERTICAL REACH
SQUATTING/SHOES: ___________

73. VERTICAL REACH
KNEELING, ONE KNEES: ___________

74. VERTICAL REACH
KNEELING, TWO KNEES: ___________

75. VERTICAL REACH
SITTING: _____________________

76. AVERAGE GRIP LENGTH: __________

77. HAND DOMINANCE: R L

78. RACE/ETHNICITY: _______________

0 - NOT RECORDED
1 - WHITE
2 - BLACK
3 - ORIENTAL
4 - HISPANIC
5 - OTHER

Figure A.1 (cont'd). Anthropometric Measurement Recording Sheet

CREW CHIEF - SUPPLEMENTARY NUDE ANTHROPOMETRY
FOR CLOTHED ENFLESHMENT OF MODEL
(Refer to Original Data Blank for Other Measurements)

NAME ____________________ DATE ________________

SEX __________ AGE ____________ WEIGHT ___________

SUBJECT # ________________ CONSENT FORM _____________ (check)

DATE- ORIGINAL ANTHROPOMETRY ____________________

CIRCUMFERENCES

1. Neck - at base ____________ (cm)
2. Scye - right side ____________
3. Elbow - right max ____________
4. Chest - axillary ____________

DEPTHS/BREADTHS

1. Chest Depth - axillary ____________
2. Chest Breadth - axillary ____________
3. Waist Depth - at umbilicus ____________
4. Hip Depth - at max buttock ____________
5. Scye Depth - vertical ____________

HEIGHTS

10. Stature ____________
11. Axillary (anterior) ____________
12. Max Buttock Protrusion ____________
13. Midpatella ____________

Figure A.2. Recording Sheet for Supplemental Nude Measurements

TABLE A.3

CHEMICAL DEFENSE ENSEMBLE

Article	Sizes Available	Missing Sizes
Jacket	Medium, Large	X Small, Small X Large
Trousers	Small, Medium, Large	X Small, X Large
Leather Boots	6½, 7, 7½, 8, 9, 9½, 10, 11, 11½, 12	8½, 10½, 13
Chemical Defense Boots	Not Sized	N.A.
Glove Liner	Not Sized	N.A.
Chemical Defense Gloves	Small, Medium, Large	None
Respirator	Medium	Small, Large

TABLE A.4

COLD WEATHER GEAR

Article	Sizes Available	Missing Sizes
Trousers	24, 26, 28, 30, 32, 34, 40, 42	36, 38, 44, 46
Parka	XX Small, X Small, Large	Small, Medium, X Large, XX Large
Boot Liner	Medium	Small, Large, X Large.
Boots	Medium, Large, X Large	Small
Gloves	Medium	Small, Large

Jacket fit, however, was less than ideal for the smaller subjects, due to the limited available size range. Respirator fit was also poor for a number of females, causing discomfort after a short period of time. The remaining articles provided adequate fit in all but one case. Subject #15 was unable to fit into any Chemical Defense glove or the largest leather boots available. The subject wore his own size 13 boots during the measuring session. The specifications for military clothing do not indicate a method of assigning sizes to individuals.

With the exception of those women wearing skirts, subjects wore street clothes under Cold Weather garments. Trousers were tucked into the boots. Gloves were worn over the parka wrist. The Cold Weather trousers were sized by waist circumference and available in an adequate range of sizes. Male subjects were able to wear their normal pants sizes. Females generally required trousers slightly larger than waist circumference to accommodate hips. The limited supply of parkas resulted in less than optimal fit in many instances.

A large percentage of the subjects would likely have worn a medium sized parka if one had been available. Subjects wore the smaller parka if the garment was not too tight in the hip and chest area. The supply of Cold Weather boots was also inadequate. Even with liners, the medium proved too large for most females and some males.

After each subject was properly outfitted in the clothing ensembles the measurements were made. All measurements of the clothed subjects were taken by a single investigator. The descriptions of the clothed measurements are in Appendix A-B. The measurement recording sheet is shown in Figure A.3.

CREW CHIEF - CLOTHED ANTHROPOMETRY - MODEL ENFLESHMENT DATA

NAME ____________ DATE ____________ SUBJECT NO. ____________

SEX ____ M/F ____ AGE ____________ yrs WEIGHT ____________ kg/lbs

STATURE ____________ cm DATE-ORIGINAL ANTHROPOMETRY ____________

CLOTHING SIZES WORN:
COLD WEATHER - Parka____ Trouser____ Boots____ Gloves____

CD - Jacket____ Trouser____ Mask____ Boot____
Gloves____ Foot Wear Cover____

CIRCUMFERENCES	COLD WEATHER	C.D.
1. Head (if gear worn)	________cm	________cm
2. Neck (at base)	________	________
3. Shoulder (max deltoid)	________	________
4. Scye (right-max)	________	________
5. Elbow (right-max)	________	________
6. Wrist (right-max)	________	________
7. Chest (axillary level)	________	________
8. Waist (umbilicus level)	________	________
9. Hip (max buttock)	________	________
10. Thigh (at crotch level)	________	________
11. Knee (mid-patella)	________	________
12. Ankle (malleolus level)	________	________
DEPTHS/BREADTHS/LENGTHS/HEIGHTS		
13. Arm Depth (vertical at scye)	________	________
14. Chest Depth (axillary)	________	________
15. Waist Depth (umbilicus level)	________	________
16. Hip Depth (max buttock level)	________	________
17. Shoulder Breadth (max deltoid)	________	________
18. Chest Breadth (at axillary at scye)	________	________
19. Waist Breadth (umbilicus level)	________	________
20. Hip Breadth (max buttock level)	________	________
21. Hand Breadth	________	________
22. Hand Length	________	________
23. Foot Breadth	________	________
24. Foot Length	________	________
25. Stature	________	________
26. Axillary Height	________	________
27. Crotch Height	________	________

Figure A.3. Clothed Measurement Recording Sheet

RESULTS

As the emphasis in this report is not on body size of the clothed subject, but rather on the amount that body size is effectively changed by clothing, the measurements taken on the nude subjects are not included here. Instead, the measurements taken on the nude subjects have been subtracted from the measurements taken on the subjects when clothed to arrive at the difference (delta) between the two. This measurement can be said to be the body-size increment due to clothing. Summary statistics on the deltas are presented in Table A.5. As would be expected, the largest differences appear in the circumferences. For the Chemical Defense gear, the deltas for neck, scye and ankle circumferences are particularly large. In the case of the neck circumference, the clothed dimension includes the hood of the respirator. While this item is not produced from bulky fabrics, it is fastened about the shoulders in such a way that it does not follow the contour of the neck. The hood stands out from the neck, greatly increasing neck circumference.

Ankle circumference is another dimension whose large delta might be seen as surprising. This dimension is taken over the subjects' trousers, socks, leather boots, and, Chemical Defense boots and trousers. This combination of gear accounts for the large increase in size from nude to clothed.

It should be noted that the mean delta values for Axillary Height and Crotch Height are negative. This indicates that the clothed value is lower than the nude value. These two are the only dimensions in this battery which are measured from the floor to the underside of an anatomical structure. Because of this, when clothing is added, the effective underside becomes lower, and the value of the measurement is lower.

TABLE A.5

DIFFERENCES IN BODY SIZE BETWEEN NUDE AND CLOTHED CONDITIONS *
(values in centimeters)

VARIABLE	Δ CHEMICAL DEFENSE				Δ COLD WEATHER			
	Males n=10		Females n=10		Males n=10		Females n=10	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
Head Circ	4.81	.58	5.37	.68	24.98	2.65	23.22	4.06
Neck Circ	20.49	5.90	28.58	4.06	19.89	1.97	23.56	2.19
Shoulder Circ	7.37	2.16	9.49	2.61	12.85	3.68	17.08	3.99
Scye Circ	15.96	3.99	17.67	3.46	20.56	6.71	16.95	3.20
Elbow Circ	5.45	1.23	6.71	.92	12.19	1.64	12.77	2.87
Wrist Circ	8.41	1.26	9.05	1.62	7.79	1.41	11.13	2.90
Chest Circ	7.70	3.05	13.63	5.90	21.17	5.37	24.27	5.86
Waist Circ	11.30	3.94	15.73	3.47	29.92	6.67	28.63	5.48
Hip Circ	13.97	4.15	11.97	2.84	34.00	6.89	25.55	3.13
Thigh Circ	7.13	4.73	5.61	2.68	11.26	4.28	18.13	6.48
Knee Circ	9.55	2.49	8.92	2.39	16.66	2.25	17.57	3.94
Ankle Circ	18.33	2.98	18.60	3.08	16.58	3.63	16.00	.86
Arm Depth	7.15	2.01	5.88	1.87	7.47	2.53	4.62	2.14
Chest Depth	2.62	1.31	5.88	4.73	5.08	1.43	7.30	2.53
Waist Depth	3.19	1.82	5.83	.98	8.44	2.06	9.85	1.54
Hip Depth	2.78	.63	3.62	1.24	6.90	2.07	6.91	1.11
Shoulder Br	1.03	1.15	1.57	.86	1.98	1.68	3.80	1.64
Chest Br	1.87	2.08	2.43	4.14	4.71	3.17	4.84	4.27
Waist Br	1.85	1.52	3.18	2.10	5.21	1.58	6.72	2.44
Hip Br	3.22	2.16	3.36	1.49	8.11	3.10	7.49	2.07
Hand Br	.34	.18	.90	.30	2.28	.45	3.06	.72
Hand Length	.46	.40	.81	.72	1.42	.80	2.17	1.10
Foot Br	4.22	.81	4.66	.55	2.29	.57	2.88	.49
Foot Length	6.81	1.10	7.13	1.35	3.79	.90	5.75	.93
Stature	3.52	.89	3.63	.37	7.10	1.14	6.02	1.45
Axillary Ht	-5.11	1.84	-4.77	3.04	-7.72	3.71	-3.50	2.04
Crotch Ht	-6.85	3.68	-.95	2.23	-7.20	2.39	-.71	1.68

* Mean nude weight for males = 168.05 lb; SD = 47.64 lb
Mean nude stature for males = 174.71 cm; SD = 7.04 cm

Mean nude weight for females = 126.75 lb; SD = 19.76 lb
Mean nude stature for females = 164.39 cm; SD = 6.08 cm

In general, Cold Weather deltas are larger than Chemical Defense deltas due to the bulk of the fabric used in Cold Weather equipment. As before, the deltas of the circumferences are generally larger than for breadths, depths, or heights. A few dimensions deserve special mention.

Head circumference is dramatically increased with the donning of the Cold Weather ensemble. This is due to the very large hood, which extends well beyond the face for protection from the wind. The hood similarly affects Stature.

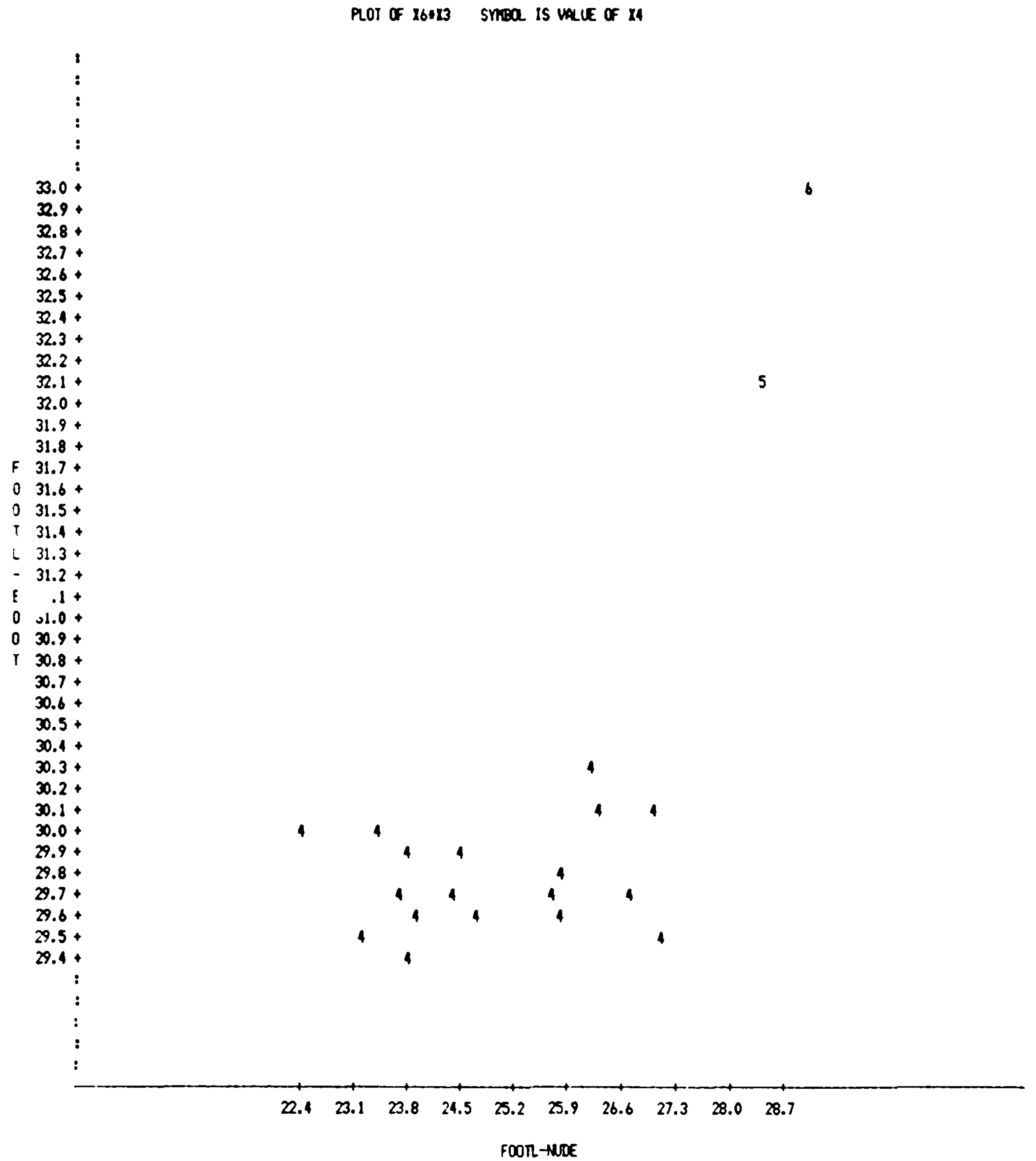
The Knee Circumference deltas are larger in the Cold Weather gear because for most subjects the trousers were long enough that folds accumulated at the knee, increasing the circumference. The Hand Circumference increase due to the Cold Weather mitten is much larger than the corresponding increase due to the Chemical Defense gloves. The nature of the glove is more form-fitting and that characteristic is demonstrated here.

The Cold Weather boots did not appear to be much influenced by the size of the foot. They fit closely enough that the mean deltas for the foot dimensions are lower in the Cold Weather gear than in the Chemical Defense boot combined with the standard leather boot.

As stated in the introduction, the purpose of this study of clothed anthropometry is to provide the best data which can be used to produce a computerized man-model of the aircraft maintenance technician. For most dimensions, that goal can be met by providing deltas, or increments, due to clothing to be added to the existing nude anthropometric data base to approximate the range of clothed body sizes for the maintenance technician. For some dimensions, however, adding an increment to the nude dimension may provide misleading results. There is a particular danger of this with the boots of the Cold Weather ensemble.

The boots and mittens share two characteristics which render the incremental approach less than optimal. First, they are constructed of materials which are heavy and relatively inflexible. Second, they both come in only a few sizes. These two characteristics affect the dimensions of the clothed subjects in such a way that the outside dimensions of the boot and glove may be determined more by their construction than by the foot or hand which is inside. Figures A.4 and A.5 show all 20 subjects (males and females combined) plotted with the nude foot dimensions on the horizontal axis and the clothed foot dimensions (boot) on the vertical axis. Note that the points on the plot are numerical designations for the size of the boot. The apparent variability of boot length and breadth measurements shown for those subjects wearing Size 4 can be accounted for by the slight give of the rubber boot edging and by measurement error. It is clear that the considerable variability in the size of the human foot has been reduced to a very small amount of variability contained in the three boot sizes.

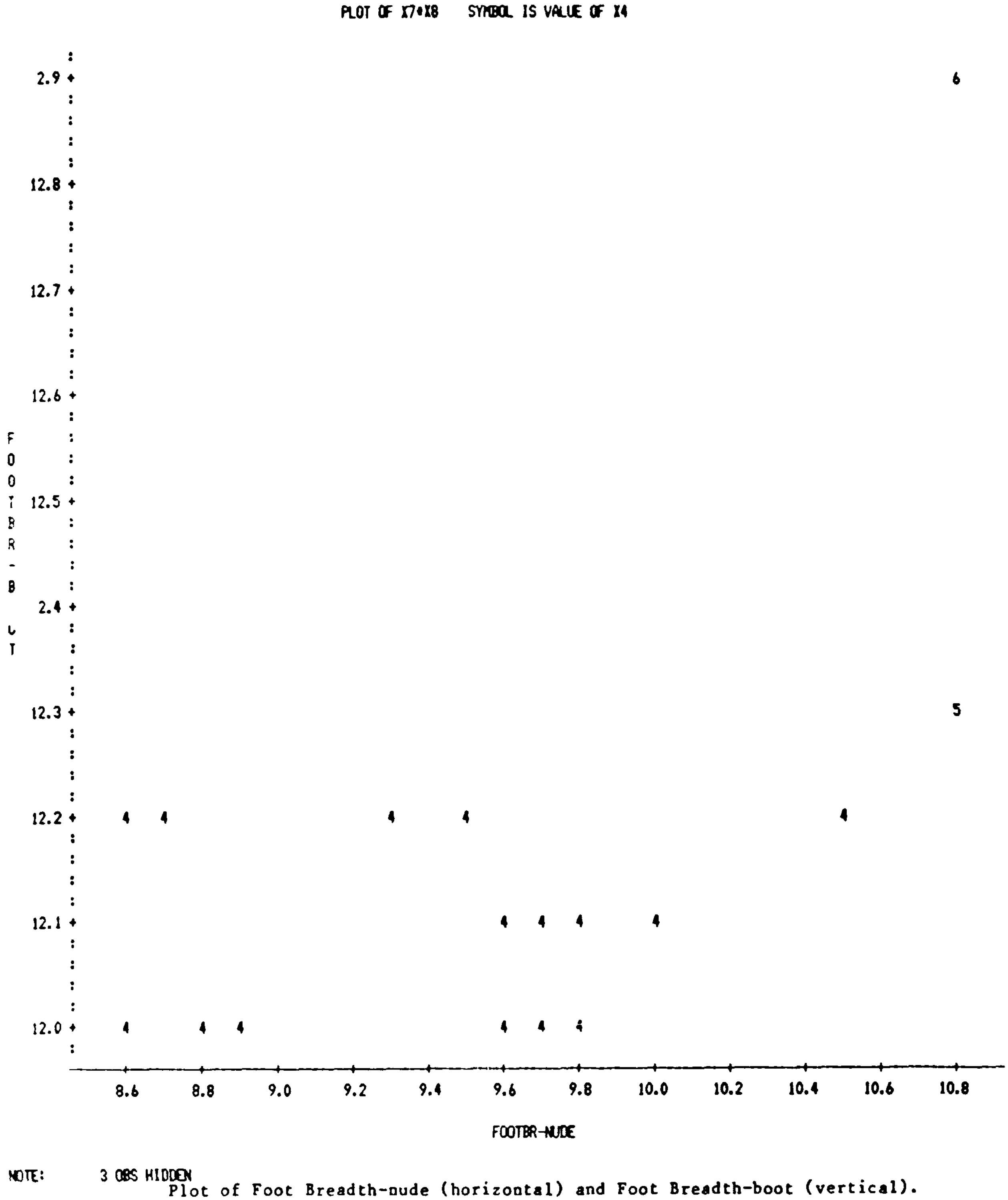
Many items of military gear are of course available in only a limited number of sizes. Would this argument not pertain to all such items? Figure A.6 shows Chest Circumference (nude) on the horizontal axis and Chest Circumference with the Cold Weather parka on the vertical axis. Again, the individual data points indicate size of the garment. It is clear that in this case, there is a rather smooth linear relationship between nude and clothed Chest Circumferences. That is, the clothed dimension increases as the nude dimension increases. Because of this linear relationship, adding an increment to the nude values would produce a distribution very similar to the distribution of clothed Chest Circumferences seen here. The size of the item appears to have little effect on the amount of the increment.



Plot of Foot Length-nude (horizontal) and Foot Length-boot (vertical).

4 = Medium Boot Size
5 = Large Boot Size
6 = X Large Boot Size

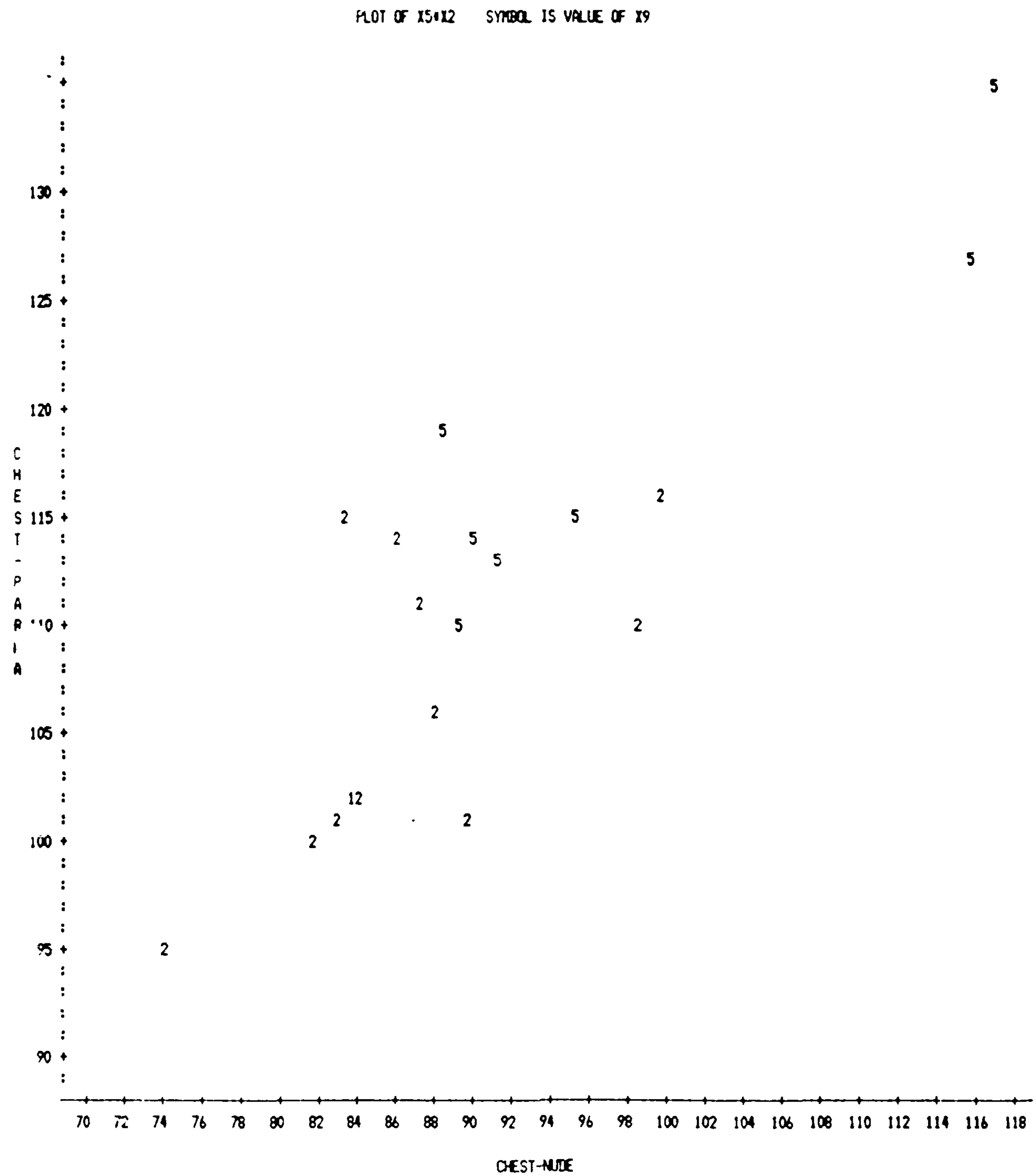
igure A.4. Plot of Foot Length (nude) vs. Foot Length (with boot)



Plot of Foot Breadth-nude (horizontal) and Foot Breadth-boot (vertical).

4 = Medium Boot Size
5 = Large Boot Size
6 = X Large Boot Size

Figure A.5. Plot of Foot Breadth (nude) vs. Foot Breadth (with boot)



Plot of Chest Circumference-nude (horizontal) and Chest Circumference with Cold Weather parka (vertical).

1 = XX Small parka size.
2 = X Small parka size.
5 = Large parka size.

Figure A.6. Plot of Chest Circumference (nude) vs. Chest Circumference (with Cold Weather parka)

The Chest Circumference, and dimensions like it, are well served by the incremental approach. **Foot Length and Foot** Breadth, on the other hand, would be better represented in the model if the distribution of the boot dimensions, rather than the distribution of foot dimensions, were used.

We originally supposed that the hand and mitten dimensions might follow the same pattern as foot and boot dimensions. Instead, Figures A.7 and A.8 show that the hand and glove dimensions are distributed more like chest circumference dimensions than like foot and boot dimensions. In Figures A-7. and A.8 data points are symbolized by the letter "M" to indicate that all individuals wore a medium mitten. The distribution of the points, however, does not suggest that the pattern would have been different had there been more sizes. We therefore recommend that the incremental approach be used for gloves when constructing the computer model

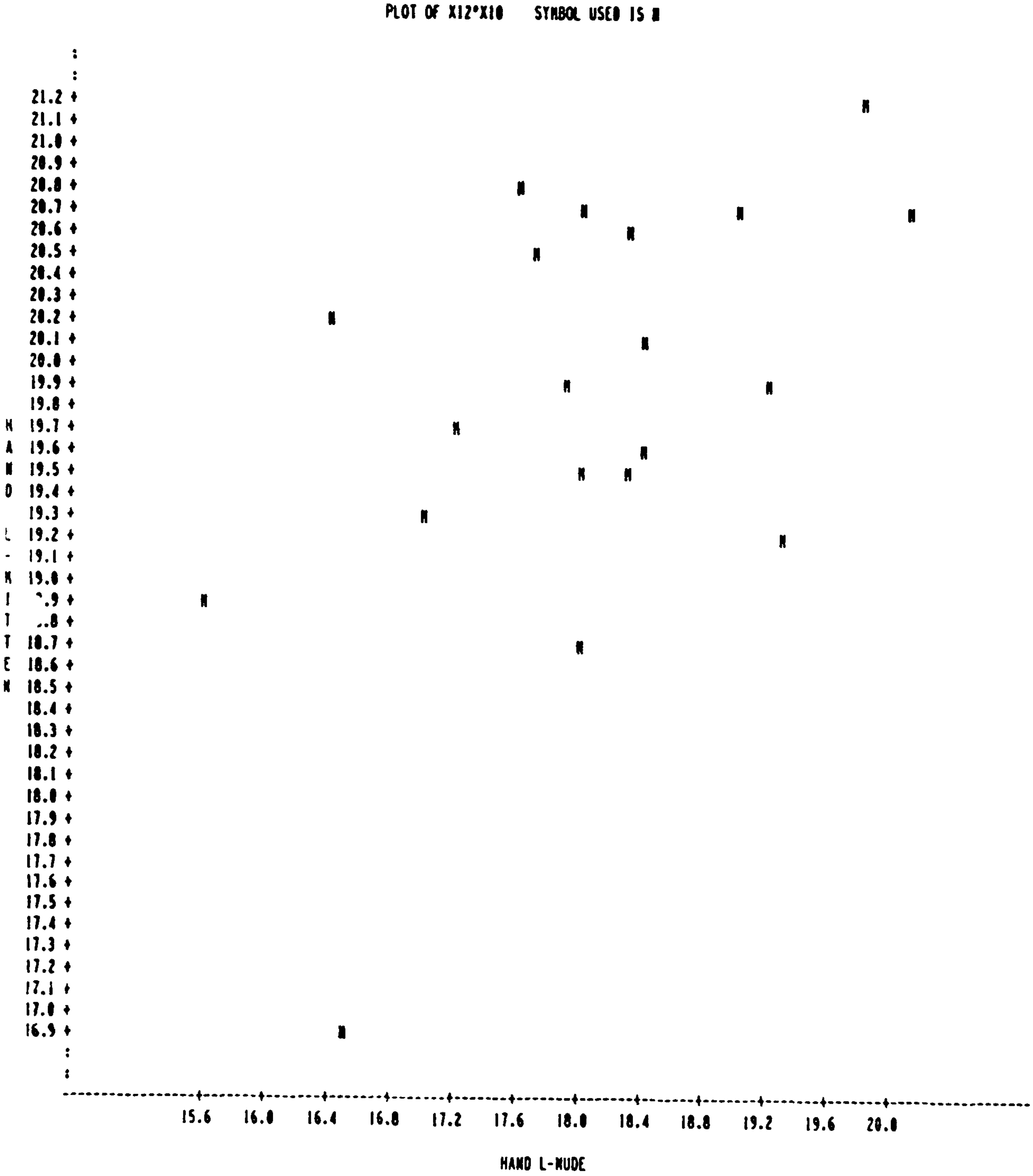
RELIABILITY

A reliability study was made and is reported in Appendix A-C.

SUMMARY AND CONCLUSION

A series of subjects were measured in Chemical Defense and Cold Weather clothing in order to determine what changes occur in human body dimensions due to the addition of clothing. The increments due to clothing are to be included in the clothed configuration of the CREW CHIEF computerized man-model. Lack of certain sizes of some garments precluded a detailed analysis, but basic incremental data were available and were included in tabular form.

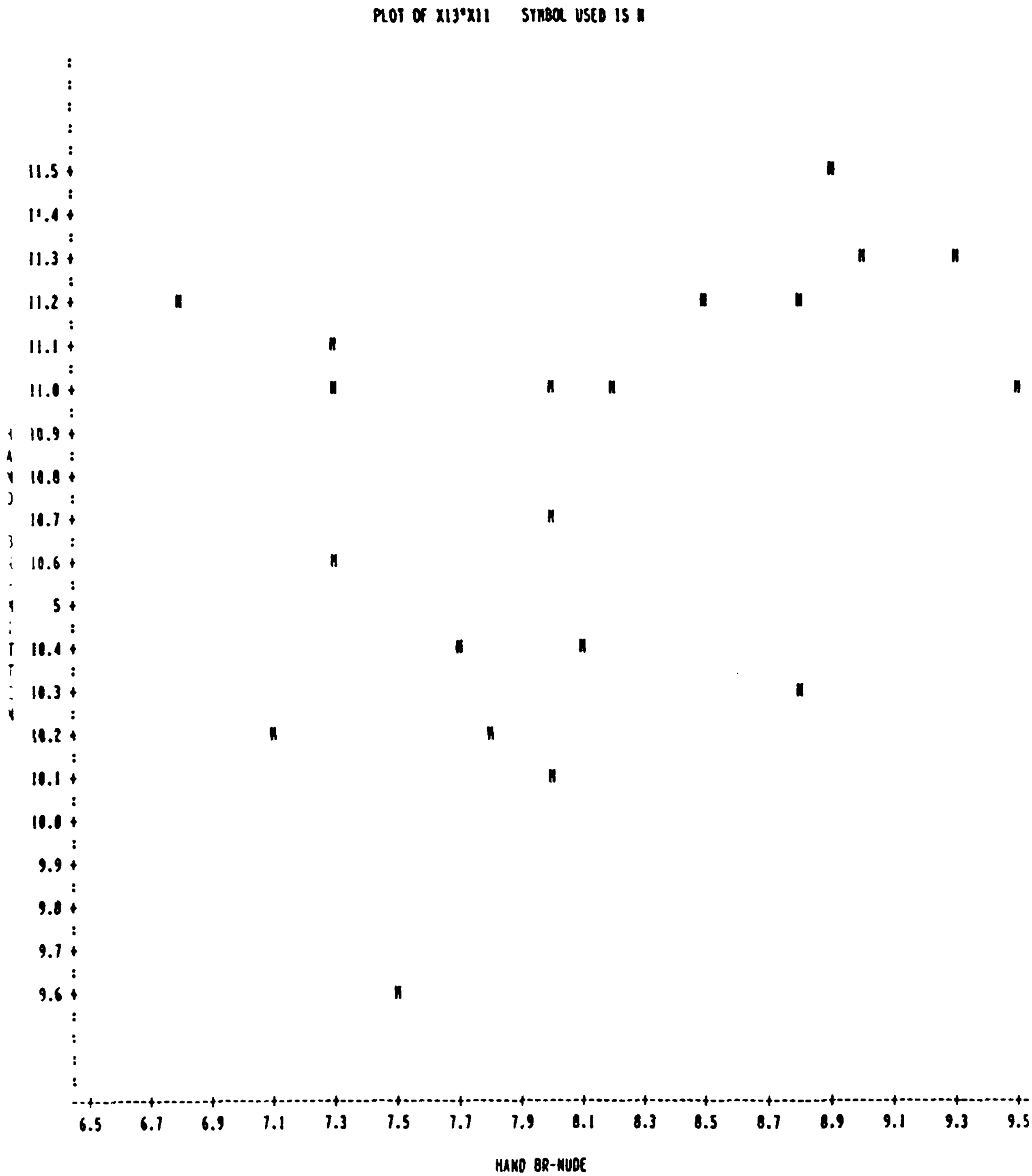
The increments found in the table should be added to the enfleshed computer model to simulate the clothed maintenance technician. The Cold Weather boot is constructed in such a way



Plot of Hand Length-nude (horizontal) and Hand Length-mitten (vertical).

M indicates medium mitten size.

Figure A.7. Plot of Hand Length (nude) vs. Hand Length (with mitten)



Plot of Hand Breadth-nude (horizontal) and Hand Breadth-mitten (vertical).

M indicates medium mitten size.

Figure A.8. Plot of Hand Breadth (nude) vs. Hand Breadth (with mitten) that the outside dimensions vary only slightly with the size of the foot inside it. Because of this, it was recommended that boot increments not be added to the enfleshed foot for modeling purposes, but that the dimensions of the boot itself (in each size) should be included in the model instead. Adding increments for clothing appeared to be an appropriate approach for all other items.

REFERENCES

1. Johnson, Richard F., Anthropometry of the Clothed US Army and Combat Vehicle Crewman NATICK/TR-84/034. Natick, Mass: US Army Natick R&D Command, 1984.

2. Garrett, J.W., Clearance and Performance Values for the Bare-handed and the Pressure-gloved Operator. AMRL-TR-68-24. Wright-Patterson AFB, OH: Aerospace Medical Research Laboratories, 1968.

3. White, R.M., Kobrick, J.L., & Zimmerman, T.R.; Reference anthropometry of the Arctic-equipped Soldier EPT-2. Natick, Mass: US Army Natick Laboratories, 1964

APPENDIX A-A

CLOTHED ANTHROPOMETRY
(all measurements over clothing)

BREADTHS

Chest Breadth - breadth of the chest where the garment side seams join the sleeves (midaxillary equivalent).

Foot Breadth - maximum breadth of the boot.

Hand Breadth - Maximum breadth of the glove, excluding thumb.

Hip Breadth - breadth of the hips (midaxillary line) at the level of the maximum protrusion of the buttock.

Shoulder Breadth - breadth of the shoulders measured at the level of the maximum protrusion of the deltoid muscles.

Waist Breadth - breadth of the waist (midaxillary line) at omphalion.

CIRCUMFERENCES

Ankle Circumference - Horizontal circumference just proximal to the medial and lateral malleoli.

Chest Circumference - horizontal circumference of the chest measured where the garment side seam joins the sleeve.

Elbow Circumference - circumference of the elbow at the point of the maximum bony diameter.

Head Circumference - circumference of the head passing above the ears and brow ridges.

Hip Circumference - horizontal circumference of the hips at the level of the maximum protrusion of the right buttock.

Knee Circumference - horizontal circumference of the knee at the midpoint of the patella.

Neck Circumference - circumference at the base of the neck (along neck-shoulder point). (Follows hood seam in Cold Weather gear).

Scye Circumference - vertical circumference at scye with the arm hanging freely at the side of the body.

Shoulder Circumference - circumference of the shoulders measured at the level of the maximum lateral protrusion of the deltoid muscles.

Thigh Circumference - circumference of the thigh at crotch level.

Waist Circumference - circumference of the waist at omphalion.

Wrist Circumference - circumference of the wrist passing just distal to the styloid process of the radius and ulna (Cold Weather gear). Circumference of the wrist passing over the elastic cuff of the jacket (Chemical Defense ensemble).

DEPTHS

Chest Depth - depth of the chest where the garment side seam joins the sleeve (arms slightly abducted).

Hip Depth - depth of the hips at the level of the maximum protrusion of the right buttock.

Scye Depth - vertical distance from the junction of the garment side seam and the sleeve to the top of the shoulder.

Waist Depth - maximum depth of the waist at omphalion.

LENGTHS

Foot Length - maximum length of the boot.

Hand Length - the distance from a line connecting the styloid processes of the radius and ulna to dactylion (maximum protrusion).

HEIGHTS

Axillary Height - distance from the standing surface to where the garment side seam joins the sleeve. Subject stands erect with heels together and arms relaxed at sides.

Crotch Height - distance from the standing surface to the "crotch" of the clothing. subject stands erect, feet approximately 20 cm apart.

Stature - distance from the standing surface to the top of the head. Subject stands erect, heels together, and with the head in the Frankfort plane.

APPENDIX A-B

DESCRIPTION OF THE SUPPLEMENTARY NUDE MEASUREMENTS AND THE CLOTHED MEASUREMENTS RELATED TO CREW CHIEF ENFLESHMENT NUDE ANTHROPOMETRY (SUPPLEMENTARY)

BREADTHS

Chest Breadth - horizontal breadth of the chest at the midaxillary line measured at the level of the axilla.

CIRCUMFERENCES

Chest Circumference - horizontal circumference of the chest measured at the axillary level.

Elbow Circumference - maximum circumference of the elbow (right) with the arm extended (relaxed) at the side of the body.

Neck Circumference - horizontal circumference of the base of the neck.

Scye Circumference - vertical circumference at scye with the arm extended (relaxed) at the side of the body.

DEPTHS

Chest Depth - maximum horizontal depth of the chest at the level of the axilla.

Hip Depth - horizontal depth of the hips at the level of the maximum protrusion of the right buttock.

Scye Depth - vertical distance from the anterior scye to the top of the shoulder (right side).

Waist Depth - maximum horizontal depth of the waist at omphalion.

HEIGHTS

Axilla Height - distance from the standing surface to the anterior scye. Subject stands erect, heels together.

Buttock Height - distance from the standing surface to the maximum protrusion of the right buttock. Subject stands erect with heels together.

Patella Height - distance from the standing surface to the midpoint of the patella. Subject stands erect with heels together.

Stature - distance from the standing surface to the top of the head. Subject stands erect, heels together, and head in the Frankfort plane.

APPENDIX A-C

RELIABILITY

INTRODUCTION AND METHODS

For most modeling purposes, the reliability of anthropometric data is more than adequate. For nude anthropometry, a generally acceptable level of reliability is that a repeated measure on the same subject, with the same investigator, at a single sitting, should be within 2 or 3 millimeters on linear dimensions, and within 3 or 4 millimeters on circumferential dimensions. This level of reliability is well within the requirements of computer modeling.

With clothed anthropometry, the reliability is lower. There are several reasons for this. The size of the clothing for an individual will affect the clothed dimensions. Some individuals will clearly be best fit in a specific size of, say, a jacket. Others, however, will be much closer to the border line between two sizes. How well the garment fits will affect all clothed dimensions.

An additional source of variation in the anthropometric dimension is actually donning clothing. The way the outerwear (Cold Weather, Chemical Defense) lies on the clothing beneath it is slightly different each time the subject puts it on. The folds of the clothing, especially the bulkier items, are dramatically affected by the "lay" of the item.

A third source of variation in our particular study is the subjects' own clothing, worn under the test garments. In the actual field situation, the maintenance technicians will be wearing fatigues, but these were not available to us. Instead, the subjects wore street clothes, which varied considerably in bulk and fit. Some wore sweaters, others shirts, and still others

T-shirts. Some wore tight-fitting jeans, while others had much more loosely fitting dress pants. The variety of clothing styles affected both the choice of size in the test garments, and the ultimate dimensions of the test garments.

Finally, the reliability of taking measurements on clothed subjects is affected by the difficulty in precisely locating landmarks and maintaining constant tape pressure.

Because of the differences in the level of reliability between nude and clothed anthropometry, we have made an effort to assess the reliability of the clothed anthropometry for this study. We anticipate that the results of the reliability study will be incorporated into the CREW CHIEF computer model as part of a range of acceptable values that the aircraft designer can use. Our approach to reliability assessment was to perform repeated measures on selected subjects. Table A.C.1 shows the breakdown of repeated measures.

TABLE A.C.1

REPEATED MEASURES
(number of subjects)

	Cold Weather	Chemical Defense
Males	6	4
Females	3	2

The small number of subjects in this study is insufficient to provide a definitive statement about the reliability of clothed anthropometry. However, there are statistical measures which allow us to quantify the reliability of a dimension as measured on these subjects. Specifically, the coefficient of reliability can be calculated as the correlation coefficient between the first and second set of measurements (Tanner and Weiner, 1949). If this correlation coefficient is squared,

$(r_{1,2})^2$ this provides the proportion of the total variability which is error free (Mueller and Martorell, 1985). Conversely, the quantity, $1 - (r_{1,2})^2$ gives the proportion of the total variability due to measurement error (Tanner ad Weiner, 1949). Another way of expressing measurement error in this context is to state that the within-subject variance comprises $1 - (r_{1,2})^2$ (%) of the between-subject variance (Mueller and Martorell, 1985).

The standard error of measurement (S.E.Meas.) is calculated using the correlation efficient (coefficient of reliability). In the present context, this is the most useful statistic because it is expressed in the same units as the original measurement. The formulation is as follows:

$$\text{S.E. Meas.} = \sigma\sqrt{1-r_{1,2}}$$

where σ is the standard deviation of the measurement in either the first or the second trial, and $r_{1,2}$ is the correlation coefficient between the first and second trial (Tanner and Weiner, 1949). This statistic is used as are other standard errors in that 95% of subsequent measurements should fall within ± 2 s.e.meas. of the "true" value for that individual.

CHEMICAL DEFENSE ENSEMBLE

Repeatability measures for each of the variables measured in the study are shown in the next several tables. In Table A.C.2, the data for the males in the Chemical Defense ensemble are presented. The first column, labeled Δ * mean, is the mean of the differences created by subtracting the value obtained on the first trial from the value obtained on the second. The range of these Δ means is from -2.10 cm (indicating that the first measurement was larger than the second by 2.10 cm) for hip circumference, to 1.06 cm (second measurement larger than the first) for neck circumference. The second column presents standard

TABLE A.C.2

REPEATED MEASURES
STATISTICS
Males - Chemical Defense Ensemble
n=5

	Δ * Mean (in cm)	ΔSD	Error Free $r^2_{1,2}$	Measurement Error $1 - r^2_{1,2}$	S.E.Meas. $\sigma\sqrt{1-r_{1,2}}$
Head Circumference	-0.08	0.71	0.82	0.18	0.46
Neck Circumference	1.06	3.03	0.25	0.75	1.52
Shoulder Circumference	-0.08	0.75	0.94	0.06	0.52
Scye Circumference	-1.80	1.09	0.99	0.01	0.12
Elbow Circumference	0.08	0.93	0.05	0.95	0.62
Wrist Circumference	0.40	0.51	0.67	0.33	0.37
Chest Circumference	0.72	2.40	0.44	0.56	1.82
Waist Circumference	-0.46	1.95	0.93	0.07	0.46
Hip Circumference	-2.10	3.54	0.72	0.28	2.18
Thigh Circumference	0.98	0.82	0.90	0.10	0.58
Knee Circumference	0.32	1.69	0.06	0.94	1.14
Ankle Circumference	-1.20	0.42	0.99	0.01	0.19
Arm Depth	-0.08	1.05	0.49	0.51	0.39
Chest Depth	-0.04	1.04	0.30	0.70	0.[illegible]1
Waist Depth	-0.88	1.80	0.01	0.99	1.05
Hip Depth	-0.78	1.05	0.50	0.50	0.48
Shoulder Breadth	0.38	0.48	0.94	0.06	0.25
Chest Breadth	-0.32	1.27	0.04	0.96	0.80
Waist Breadth	0.02	0.63	0.91	0.09	0.45
Hip Breadth	-0.60	2.64	0.43	0.57	1.22
Hand Breadth	0.10	0.10	0.95	0.05	0.06
Hand Length	-0.17	0.28	0.84	0.16	0.12
Foot Breadth	0.10	0.14	0.84	0.16	0.10
Foot Length	-0.45	0.40	0.93	0.07	0.24
Stature	0.42	0.29	1.00	0.00	0.18
Axillary Height	0.20	0.63	0.98	0.02	0.34
Crotch Height	0.90	1.00	0.97	0.03	0.64

*Δ = Trial 1 - Trial 2.

deviations for the same Δs . Note that in many cases the standard deviation is larger than the absolute value of the mean, indicating that, while the differences between measurements tend to cancel each other out (tend toward a mean of 0.00), the Δs for individual subjects may still be quite large.

The third column is labeled $(r_{1,2})^2$ which is simply the correlation coefficient of the first measurement with the second, squared. This figure is the amount of the variation (in %) in that measurement which can be said to be "error free". The values in this column range from 0.01 (indicating that measurement error accounts for almost all the variability in this dimension) for Waist Depth to 1.00 (indicating that all the variability is error free, or there is a perfect correlation between the first and the second measurement) for Stature. The fourth column, labeled $1 - (r_{1,2})^2$, is simply the complement of the third. This is the component (in %) of the variance due to measurement error. Its values range from 0.99 for Waist Depth to 0.00 for Stature.

The final column is labeled Standard Error of Measurement (S.E.Meas.) and is calculated as discussed above. As this value is expressed in the same terms as the dimension measured (cm), it is a useful gauge of the practical implications of the measurement errors. The values in this column range from 0.06 cm for Hand Breadth, to 2.18 cm for Hip Circumference. It should be noted, of course, that Hand Breadth is a much smaller dimension than Hip Circumference.

There were only two female subjects who were measured twice in the Chemical Defense configuration, so they are not presented separately. The largest mean difference for the females is -3.15 cm on Neck Circumference. The smallest is 0.05 cm on Foot Breadth.

The two sexes have been combined for Table A.C.3, which is in identical format to Table A.C2 for males. The means range from -2.07 cm on Scye Circumference to 0.70 cm for Crotch Height. The smallest absolute value difference is 0.03 cm for Hand Breadth. Both Scye Circumference and Stature have squared correlations of 1.00, indicating a lack of measurement error for those dimensions. The lowest squared error of measurement is 0.06 for Chest Breath. The highest standard error of measurement is 2.71 cm (Neck Circumference); the lowest is 0.11 cm (Scye Circumference).

Tables A.C.2 and A.C.3 can best be interpreted in light of Tables A.C.4 and A.C.5, which provide reliability estimates for the males and for the male/female combination, respectively. The first column of these tables shows the value of twice the standard error of measurement. When this value is subtracted from and added to the mean value, a range is produced which contains the "true" value 95% of the time that the measurement is taken. This range gives an estimation of the confidence in using this data. It is not true that these ranges always correspond in size to the size of the dimension. For example, twice the standard error of measurement for Stature is 0.36 cm, whereas the figure for foot length is 0.48 cm. The largest range is for Hip Circumference where the 95% confidence interval is from 102.66 through 111.38 cm. The smallest range is that of Hand Breadth, whose confidence interval is 8.81 to 9.05 cm. Most individuals accustomed to working with anthropometric data would be comfortable with the range for Hand Breadth. The same is not true of Hip Circumference. In general the measurements for which confidence is least are those about the trunk and circumferences on the leg. Generally, the best reliability comes from measurements on the head and the distal portions of the extremities.

Table A.C.5 displays the same kind of information as Table A.C.4, except it is for males and females combined. The greatest range is for Neck Circumference, although Hip Circumference is

TABLE A.C.3

REPEATED MEASURES
STATISTICS
Males/Females Combined - Chemical Defense Ensemble
n=7

	Δ * Mean (in cm)	ΔSD (in cm)	Error Free $r^2_{1,2}$	Measurement Error $1 - r^2_{1,2}$	S.E.Meas. $\sigma\sqrt{1-r_{1,2}}$
Head Circumference	0.69	1.47	0.73	0.27	1.04
Neck Circumference	-0.14	3.71	0.44	0.56	2.71
Shoulder Circumference	0.67	2.12	0.89	0.11	1.22
Scye Circumference	-2.07	1.16	1.00	0.00	0.11
Elbow Circumference	-0.27	0.96	0.36	0.64	0.47
Wrist Circumference	0.23	0.78	0.24	0.76	0.60
Chest Circumference	0.33	2.26	0.46	0.54	1.69
Waist Circumference	0.53	3.19	0.49	0.51	1.11
Hip Circumference	-1.37	3.31	0.58	0.42	2.48
Thigh Circumference	0.63	0.94	0.93	0.07	0.66
Knee Circumference	0.43	1.44	0.40	0.60	1.00
Ankle Circumference	-1.41	0.87	0.97	0.03	0.36
Arm Depth	0.09	1.07	0.47	0.53	0.75
Chest Depth	-0.07	0.96	0.31	0.69	0.71
Waist Depth	-0.57	1.63	0.02	0.98	0.93
Hip Depth	-0.41	1.09	0.55	0.45	0.63
Shoulder Breadth	0.64	0.66	0.90	0.10	0.47
Chest Breadth	0.39	1.59	0.06	0.94	0.90
Waist Breadth	0.19	0.80	0.84	0.16	0.58
Hip Breadth	-0.29	2.29	0.48	0.52	1.06
Hand Breadth	0.03	0.13	0.96	0.04	0.08
Hand Length	-0.32	0.32	0.95	0.05	0.13
Foot Breadth	0.08	0.15	0.91	0.09	0.10
Foot Length	-0.45	0.36	0.96	0.04	0.24
Stature	0.37	0.32	1.00	0.00	0.22
Axillary Height	0.45	0.87	0.98	0.02	0.61
Crotch Height	0.70	1.04	0.95	0.05	0.74

* Δ = Trial 1 - Trial 2.

TABLE A.C.4

RELIABILITY ESTIMATES
Males - Chemical Defense Ensemble
(in cm)
n=5

	2 S.E. Meas.	Range which includes true value 95% of the time
Head Circumference	.92	59.90 - 61.74
Neck Circumference	3.04	55.36 - 61.44
Shoulder Circumference	1.04	119.12 - 121.20
Scye Circumference	0.24	60.82 - 61.30
Elbow Circumference	1.24	31.10 - 33.58
Wrist Circumference	0.74	24.02 - 25.50
Chest Circumference	3.64	94.38 - 101.66
Waist Circumference	0.92	91.06 - 92.90
Hip Circumference	4.36	102.66 - 111.38
Thigh Circumference	1.16	62.60 - 64.92
Knee Circumference	2.28	42.64 - 47.20
Ankle Circumference	0.38	38.32 - 39.08
Arm Depth	0.78	19.98 - 21.54
Chest Depth	1.62	22.14 - 25.38
Waist Depth	2.10	20.10 - 24.30
Hip Depth	0.96	24.66 - 26.58
Shoulder Breadth	0.50	47.16 - 48.16
Chest Breadth	1.60	31.06 - 34.26
Waist Breadth	0.90	30.76 - 32.56
Hip Breadth	2.44	33.16 - 38.04
Hand Breadth	0.12	8.81 - 9.05
Hand Length	0.24	18.89 - 19.37
Foot Breadth	0.20	13.68 - 14.08
Foot Length	0.48	32.32 33.28
Stature	0.36	179.74 - 180.46
Axillary Height	0.68	127.87 - 129.23
Crotch Height	1.28	76.32 - 78.88

TABLE A.C.5

RELIABILITY ESTIMATES
Males/Females Combined - Chemical Defense Ensemble
(in cm)
n=7

	2 S.E. Meas.	Range which includes true value 95% of the time
Head Circumference	2.08	57.98 - 62.14
Neck Circumference	5.42	54.49 - 65.33
Shoulder Circumference	2.44	116.07 - 120.95
Scye Circumference	0.22	59.97 - 60.41
Elbow Circumference	0.94	30.77 - 32.65
Wrist Circumference	1.20	23.29 - 25.69
Chest Circumference	3.38	93.81 - 100.57
Waist Circumference	2.22	90.81 - 95.25
Hip Circumference	4.96	102.38 - 112.30
Thigh Circumference	1.32	61.18 - 63.82
Knee Circumference	2.00	42.61 - 46.61
Ankle Circumference	0.72	38.07 - 39.51
Arm Depth	1.50	18.91 - 21.91
Chest Depth	1.42	22.14 - 24.98
Waist Depth	1.86	20.47 - 24.19
Hip Depth	1.26	24.34 - 26.86
Shoulder Breadth	0.94	45.97 - 47.85
Chest Breadth	1.80	31.29 - 34.89
Waist Breadth	1.16	29.93 - 32.25
Hip Breadth	2.12	33.98 - 38.22
Hand Breadth	0.16	8.39 - 8.71
Hand Length	0.26	18.19 - 18.71
Foot Breadth	0.20	13.40 - 13.80
Foot Length	0.48	31.47 - 32.43
Stature	0.44	174.99 - 175.87
Axillary Height	1.22	124.10 - 126.54
Crotch Height	1.48	75.62 - 78.58

second. Hand Breadth again has the tightest confidence interval, and the overall pattern of confidence limits is the same.

COLD WEATHER GEAR

The analysis of reliability in the Cold Weather gear shows similar, though not identical, patterns to the Chemical Defense results. Table A.C.6 shows Δs statistics, correlations, and standards errors of measurement for the males. The smallest absolute mean difference is 0.00 cm for Foot Length. The largest mean difference is 2.80 cm on Chest Circumference. The second largest absolute mean difference is on Scye Circumference, with a value of -2.04 cm. The r-squared values range from 0.18 to 1.00 for Foot Breadth and Foot Length, respectively. Axillary Height also has a squared correlation coefficient of 1.00. The more interesting column, the Standard Error of Measurement, has values ranging from 0.06 cm for Foot Length to 4.42 cm for Chest Circumference.

The female Δ means and standard deviations are reported in Table A.C.7, but no further statistics are calculated. The number of females repeating in the Cold Weather ensemble was only three. Table A.C.8 reports the complete display for males and females combined. The patterns seen in the data are generally [illegible] same as in the males alone (Table A.C.6) except for Chest Circumference. The standard error of measurement for this dimension on the combined series is only 0.33 cm, much lower than that for males only. It may be that the fit across the chest was tighter in females, resulting in a more reliable measurement.

Tables A.C.9 and A.C.10 show the reliability estimates for males and males/females combined, respectively. The most impressive difference between the two tables is for the values of Chest Circumference already noted.

TABLE A.C.6

REPEATED MEASURES
STATISTICS
Males - Cold Weather Gear
n=5

	Δ* MeanΔ (in cm)	SD (in cm)	Error Free $r^2_{1,2}$	Measurement Error $1 - r^2_{1,2}$	S.E.Meas. $\sigma\sqrt{1-r_{1,2}}$
Head Circumference	-0.18	3.25	0.91	0.09	1.44
Neck Circumference	-0.90	2.15	0.39	0.61	0.99
Shoulder Circumference	1.76	4.23	0.94	0.06	2.13
Scye Circumference	-2.04	2.64	0.91	0.09	1.88
Elbow Circumference	1.34	1.74	0.89	0.11	1.21
Wrist Circumference	-0.22	0.59	0.79	0.21	0.41
Chest Circumference	2.80	5.62	0.79	0.21	4.42
Waist Circumference	1.16	1.40	0.99	0.01	0.67
Hip Circumference	1.52	1.40	0.99	0.01	0.97
Thigh Circumference	1.60	2.69	0.85	0.15	1.93
Knee Circumference	0.40	1.42	0.96	0.04	0.74
Ankle Circumference	0.30	0.57	0.96	0.04	0.40
Arm Depth	-1.20	2.62	0.42	0.58	1.99
Chest Depth	-0.20	1.34	0.98	0.02	0.18
Waist Depth	-0.70	1.19	0.95	0.05	0.84
Hip Depth	-0.06	0.88	0.99	0.01	0.35
Shoulder Breadth	-0.52	1.15	0.99	0.01	0.36
Chest Breadth	0.24	1.58	0.88	0.12	1.07
Waist Breadth	0.56	0.90	0.97	0.03	0.46
Hip Breadth	0.90	1.42	0.86	0.14	1.01
Hand Breadth	0.02	0.54	0.22	0.78	0.45
Hand Length	-0.12	0.49	0.57	0.43	0.37
Foot Breadth	0.40	0.41	0.18	0.82	0.10
Foot Length	0.00	0.12	1.00	0.00	0.06
Stature	1.73	3.38	0.89	0.11	2.21
Axillary Height	0.80	1.06	1.00	0.00	0.30
Crotch Height	1.17	0.97	0.95	0.05	0.53

*Δ = Trial 1 - Trial 2.

TABLE A.C.7

REPEATED MEASURES
STATISTICS
Females - Cold Weather Gear
(in cm)
n=3

	Δ Mean	Δ SD
Head Circumference	-0.03	1.11
Neck Circumference	-0.97	1.80
Shoulder Circumference	0.10	1.02
Scye Circumference	-2.33	2.09
Elbow Circumference	-0.83	0.69
Wrist Circumference	-0.17	0.39
Chest Circumference	0.13	0.53
Waist Circumference	-0.33	2.11
Hip Circumference	1.57	0.49
Thigh Circumference	1.47	2.90
Knee Circumference	-0.27	1.34
Ankle Circumference	-1.17	1.73
Arm Depth	-0.57	0.52
Chest Depth	-0.50	0.80
Waist Depth	0.30	1.06
Hip Depth	0.87	0.19
Shoulder Breadth	0.53	1.27
Chest Breadth	1.97	1.67
Waist Breadth	-0.57	0.74
Hip Breadth	-0.20	0.78
Hand Breadth	0.33	0.29
Hand Length	0.07	0.25
Foot Breadth	0.10	0.14
Foot Length	-0.20	0.08
Stature	0.07	0.40
Axillary Height	-0.27	1.28
Crotch Height	-0.17	0.90

TABLE A.C.8

REPEATED MEASURES
STATISTICS
Males/Females Combined - Cold Weather Gear
n=8

	Δ* Mean (in cm)	ΔSD (in cm)	Error Free $r^2_{1,2}$	Measurement Error $1 - r^2_{1,2}$	S.E.Meas. $\sigma\sqrt{1-r_{1,2}}$
Head Circumference	-0.13	2.67	0.86	0.14	1.52
Neck Circumference	-0.93	2.03	0.43	0.57	1.41
Shoulder Circumference	1.14	3.50	0.96	0.04	1.75
Scye Circumference	-2.15	2.45	0.90	0.10	1.75
Elbow Circumference	0.53	1.78	0.86	0.14	1.14
Wrist Circumference	-0.20	0.52	0.88	0.12	0.36
Chest Circumference	1.80	4.64	0.84	0.16	0.33
Waist Circumference	0.60	1.85	0.99	0.01	0.93
Hip Circumference	1.54	1.15	0.99	0.01	0.08
Thigh Circumference	1.55	2.77	0.80	0.20	1.87
Knee Circumference	0.15	1.43	0.97	0.03	0.70
Ankle Circumference	-0.25	1.35	0.77	0.23	0.99
Arm Depth	-0.96	2.12	0.56	0.44	1.58
Chest Depth	-0.31	1.18	0.95	0.05	0.35
Waist Depth	-0.32	1.24	0.93	0.07	0.88
Hip Depth	0.29	0.84	0.99	0.01	0.34
Shoulder Breadth	-0.13	1.30	0.94	0.06	0.86
Chest Breadth	0.89	1.81	0.83	0.17	1.30
Waist Breadth	0.14	1.01	0.93	0.07	0.61
Hip Breadth	0.49	1.33	0.85	0.15	0.95
Hand Breadth	0.16	0.48	0.21	0.79	0.39
Hand Length	-0.04	0.42	0.84	0.16	0.29
Foot Breadth	0.13	0.20	0.55	0.45	0.07
Foot Length	-0.09	0.15	0.99	0.01	0.07
Stature	1.01	2.70	0.93	0.07	1.77
Axillary Height	0.34	1.27	0.98	0.02	0.89
Crotch Height	0.60	1.15	0.96	0.04	0.77

*Δ = Trial 1 - Trial 2.

TABLE A.C.9

RELIABILITY ESTIMATES
Males - Cold Weather Gear
(in cm)
n=5

	2 S.E. Meas.	Range which includes true value 95% of the time
Head Circumference	2.88	78.80 - 83.56
Neck Circumference	1.98	58.40 - 62.36
Shoulder Circumference	4.26	128.52 - 137.04
Scye Circumference	3.76	62.44 - 69.96
Elbow Circumference	2.42	37.64 - 42.48
Wrist Circumference	0.82	24.46 - 26.10
Chest Circumference	8.84	110.24 - 127.92
Waist Circumference	1.34	117.86 - 120.54
Hip Circumference	1.94	129.22 - 133.10
Thigh Circumference	3.86	68.48 - 76.20
Knee Circumference	1.48	54.88 - 57.84
Ankle Circumference	0.80	38.76 - 40.36
Arm Depth	3.98	16.38 - 24.34
Chest Depth	0.36	29.30 - 30.02
Waist Depth	1.68	29.56 - 32.92
Hip Depth	0.70	32.98 - 34.38
Shoulder Breadth	0.72	50.14 - 51.58
Chest Breadth	2.14	35.68 - 39.96
Waist Breadth	0.92	36.64 - 38.48
Hip Breadth	2.02	39.84 - 43.88
Hand Breadth	0.90	10.10 - 11.90
Hand Length	0.74	19.79 - 21.27
Foot Breadth	0.20	12.37 - 12.77
Foot Length	0.12	31.03 - 31.27
Stature	4.42	174.38 - 183.22
Axillary Height	0.60	125.15 - 126.35
Crotch Height	1.06	71.04 - 73.16

TABLE A.C.10

RELIABILITY ESTIMATES
Males/Females Combined - Cold Weather Gear
(in cm)
n=8

	2 S.E. Meas.	Range which includes true value 95% of the time
Head Circumference	3.04	76.29 - 82.37
Neck Circumference	2.82	56.81 - 62.45
Shoulder Circumference	3.50	123.13 - 130.13
Scye Circumference	3.50	60.19 - 67.19
Elbow Circumference	2.28	36.06 - 40.62
Wrist Circumference	0.72	24.63 - 26.07
Chest Circumference	0.66	113.62 - 114.94
Waist Circumference	1.86	111.53 - 115.25
Hip Circumference	0.16	127.12 - 127.44
Thigh Circumference	3.74	69.42 - 76.90
Knee Circumference	1.40	53.13 - 55.93
Ankle Circumference	1.98	36.88 - 40.84
Arm Depth	3.16	16.20 - 22.52
Chest Depth	0.70	27.85 - 29.25
Waist Depth	1.76	28.09 - 31.61
Hip Depth	0.68	31.38 - 32.74
Shoulder Breadth	1.72	47.16 - 50.60
Chest Breadth	2.60	34.01 - 39.21
Waist Breadth	1.22	35.38 - 37.82
Hip Breadth	1.90	40.06 - 43.86
Hand Breadth	0.78	10.15 - 11.71
Hand Length	0.58	19.42 - 20.58
Foot Breadth	0.14	12.12 - 12.40
Foot Length	0.14	30.33 - 30.61
Stature	3.54	171.56 - 178.64
Axillary Height	1.78	121.96 - 125.52
Crotch Height	1.54	71.99 - 75.07

COMPARING RELIABILITY ON THE TWO ENSEMBLES

Tables A.C.5 and A.C.10 can be compared to provide an overall assessment of reliability differences between the two clothing systems examined in this report. Our initial impression was that the Cold Weather system, because of its bulk, had a lower reliability than the Chemical Defense ensemble. A comparison of Tables A.C.6 and A.C.10 demonstrates that this is not the case. Neither clothing ensemble is systematically better or worse than the other with respect to reliability of anthropometric measurements. On the dimensions with large differences in standard error of measurement, four were higher for the Cold Weather gear (Scye Circumference, Thigh Circumference, Arm depth, and Stature) and three were higher for Chemical Defense gear (Neck Circumference, Chest Circumference, and Hip Circumference). Thus reliability concerns should be shared equally for the two clothing systems.

SUMMARY

Reliability/reliability analysis on the Chemical Defense and Cold Weather ensembles have shown that for many dimensions in each system, the reliability of the measurement is considerably lower than that of nude anthropometry. The implications of these reliability checks are that the clothed anthropometry data (at least from these two clothing systems) cannot be used with the same assurance as traditional nude anthropometry. When using these values in a data base for the CREW CHIEF computer man-model, it is recommended that some allowance be made for large 95% confidence intervals.

REFERENCES

1. Mueller, William H. and Reynaldo Martorell. "How to Measure Measurement Error." Anthropometric Standardization Conference, Airlie House, Airlie, Va. October 28-29, 1985.

2. Tanner, J.M. and J.S. Weiner. "The Reliability of the Photogrammetric Method of Anthropometry, With a Description of a Miniature Camera Technique." American Journal of Physical Anthropometry, 7:145-186. 1949.

APPENDIX A-D

CLOTHED ANTHROPOMETRY FOR CREW CHIEF

FATIGUE JACKET

INTRODUCTION

This report is a supplement to the clothed anthropometry study reported in the main body of Appendix A. In the earlier study, ten male and ten female subjects were measured in Cold Weather and Chemical Defense ensembles to establish clothing enfleshment increments. This supplement establishes the clothing enfleshment increments for the fatigue jacket.

METHODS

In the initial study, investigators were unable to procure the complete range of sizes in either the Chemical Defense or Cold Weather ensembles. As a result, subjects occasionally received a less than optimal fit. The fatigue jackets were also available in a limited number of sizes (Table A.D.1), however, sizing guidelines were printed inside each jacket (Table A.D.2). Using this information and anthropometry records (Ref App A, Fig. A.1) investigators selected subjects who would get a "good fit" from the available jackets. Nine of the original twenty subjects fell within the suggested range for stature and chest circumference. Of the nine, six males and one female were available for remeasuring.

The anthropometric characteristics of the seven individuals available are found in Table A.D.3. Eleven subjects omitted from the study did not meet the 67 in. minimum height requirement specified by the sizing guidelines. As a result, those selected for remeasurement are on the average taller than subjects in the original study. The mean stature for males is about two

TABLE A.D.1

FATIGUE JACKETS AVAILABLE
(Through Individual Equipment Office)

Short	-	X-small
		Small
		Medium
		Large
Regular	-	X-small*
		Small*
		Medium*
		Large*
		X-large*
Long	-	Small
		Medium
		Large
		X-large

*Sizes procured for clothed anthropometry study.

TABLE A.D.2

FATIGUE JACKET SIZING GUIDELINES

Size	Accommodating (in inches)		# of Subjects
Small Regular	Height	67" - 71"	
	Chest Circ. (male)	33" - 37"	4
	Chest Circ. (female)	36" - 40"	1
Medium Regular	Height	67" - 71"	
	Chest Circ. (male)	37" - 41"	1
	Chest Circ. (female)	40" - 44"	
Large Regular	Height	67" - 71"	
	Chest Circ.	41" - 45"	1
X-Large Regular	Height	67" - 71"	
	Chest Circ.	45" or greater	0

TABLE A.D.3

BODY SIZE OF SUBJECTS

	Stature(cm)			Weight (lbs)			Age (yrs)		
	$\overline{X}$	SD	Range	$\overline{X}$	SD	Range	$\overline{X}$	SD	Range
Male n=6	176.33	3.05	176.30-181.10	168.42	36.46	145.00-239.25	21	1.41	19-23
Female n=1	174.30	--	------	158.50	--	-----	22	--	----
Original Sample: Males n=10	174.71	7.04	157.60-183.20	168.05	47.64	110.20-272.10	20.60	1.91	18-25
Original Sample: Females n=10	164.39	6.08	155.70-176.90	126.75	19.76	101.80-163.50	21.40	2.37	19-26

centimeters greater, while the female subject is almost ten centimeters taller. She is also significantly heavier than the mean of the previously sampled females. In fact, the height and weight values are closer to the original male sample mean. Military data sets presented in the main appendix are repeated in Table A.D.4 for comparison.

TABLE A.D.4

MEANS AND STANDARD DEVIATIONS FROM MAJOR ANTHROPOMETRIC SURVEYS

	MALES			
	MEAN	S.D.	MEAN	S.D.
	USAF 1965 (n = 3869)		USAF 1967 (n = 2420)	
STATURE (cm)	175.28	6.56	177.34	6.19
WEIGHT (lb.)	156.44	23.91	173.54	21.42
AGE (years)	22.8	6.47	30.03	6.31

	FEMALES			
	MEAN	S.D.	MEAN	S.D.
	USAF 1968 (n = 1905)		USAF 1977 (n = 1331)	
STATURE (cm)	162.10	6.00	162.95	6.52
WEIGHT (lb.)	127.24	16.57	132.06	18.67
AGE (years)	23.43	6.45	23.61	5.40

After briefing, subjects signed a consent form and donned the fatigue jacket over street clothes. Only two received a better fit in a size other than the one indicated by previously recorded stature and chest circumference. One of these two subjects had gained twenty-three pounds since his initial measurement and needed the next larger size. Standard leather boots, normally worn with fatigues, were not measured as part of the ensemble as the dimension of the boot is not altered by the foot inside.

The original data sheet (Ref App A, Fig A.3) was revised to reflect the absence of specialized gloves, head gear, or foot wear (Figure A.D.1). Only those dimensions changed by the addition of the fatigue jacket were measured. All dimensions were measured by the same anthropometrist responsible for the measurements with the Chemical Defense and Cold Weather garments. Complete measurement descriptions are found in Attachment 1 to this supplement.

RESULTS

Differences (deltas) were obtained by subtracting the nude dimension from the equivalent clothed dimension. As a rule, male female body size data is analyzed separately because of the differences in the body proportions. In this instance, the single female subject is included with the males for statistical analysis. Combining data is appropriate in this case as interest is not in the values for any given measurement, but rather in the increase or decrease caused by the fatigue jacket. Chemical Defense and Cold Weather deltas presented in the initial clothed anthropometry report have also been combined for comparison. Table A.D.5 shows the difference between clothed and nude dimensions. Deltas are greatest for the circumferences. Neck circumference delta is particularly large due to the jacket collar. Deltas for Chemical Defense and Cold Weather gear are even higher because of the hood and full face respirator. Depth and breadth measurements have considerably smaller deltas. Arm depth shows the greatest increase due to the clothing roominess in the scye area. It is notable that only six of the dimensions have a standard deviation of > 2. This is in part explained by the "good fit" received by all subjects. No one was measured in a garment that was too large or too small because the correct size was missing. As a result, there are a minimum number of outliers.

CREW CHIEF - CLOTHED ANTHROPOMETRY - MODEL ENFLESHMENT DATA

NAME__________ DATE__________ SUBJECT NO.__________

SEX ____M/F____ AGE__________yrs WEIGHT__________kg/lbs

STATURE__________cm DATE-ORIGINAL ANTHROPOMETRY__________

JACKET SIZE WORN: __________

CIRCUMFERENCES	FATIGUES
1. Neck (at base)	__________
2. Shoulder (max deltoid)	__________
3. Scye (right-max)	__________
4. Elbow (right-max)	__________
5. Wrist (right-max)	__________
6. Chest (axillary level)	__________
7. Waist (umbilicus level)	__________
8. Hip (max buttock)	__________

DEPTHS/BREADTHS	
9. Arm Depth (vertical at scye)	__________
10. Shoulder Breadth (max deltoid)	__________
11. Chest Breadth (axillary level)	__________
12. Waist Breadth (umbilicus level)	__________
13. Hip Breadth (max buttock level)	__________
14. Chest Depth (xiphoid level)	__________
15. Waist Depth (umbilicus level)	__________
16. Hip Depth (max buttock level)	__________

Figure A.D.1. Revised Clothed Anthropometry Measurement Recording Sheet

TABLE A.D.5

DIFFERENCES IN BODY SIZE BETWEEN NUDE AND CLOTHED CONDITIONS
(values in centimeters)

VARIABLE	ΔCHEMICAL DEFENSE n=20		ΔCOLD WEATHER n=20		ΔFATIGUE JACKETS n=7	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
Neck Circ	24.45	6.69	21.73	2.85	15.30	2.65
Shoulder Circ	8.43	2.69	14.97	4.50	10.31	3.64
Scye Circ	16.82	3.93	18.76	5.70	3.17	4.14
Flbow Circ	6.08	1.29	12.48	2.42	5.06	1.29
Wrist Circ	8.75	1.54	9.46	2.90	7.57	1.19
Chest Circ	10.67	5.70	22.72	5.98	10.61	3.93
Waist Circ	13.52	4.44	29.28	6.30	9.70	5.09
Hip Circ	12.97	3.79	29.78	6.99	10.13	4.39
Arm Depth	6.52	2.09	6.05	2.81	6.40	1.53
Chest Depth	4.25	3.93	6.19	2.39	1.56	1.05
Waist Depth	4.51	2.02	9.15	2.00	3.11	1.06
Hip Depth	3.20	1.10	6.91	1.70	2.53	0.93
Shoulder Br	1.30	1.08	2.89	1.94	1.56	1.59
Chest Br	2.15	3.38	4.78	3.86	0.04	0.92
Waist Br	2.52	2.00	5.97	2.25	0.26	1.30
Hip Br	3.29	1.90	7.80	2.73	1.61	1.18

CONCLUSION

Seven subjects were measured in fatigue jackets to provide modelers with the data to add fatigue clothing increments to the enfleshment of the CREW CHIEF man-model. As in any clothed anthropometry study, the data provided here is specific to the fatigue jacket and is not applicable to other clothing ensembles.

ATTACHMENT 1

CLOTHED ANTHROPOMETRY
(all measurements over clothing)

Breadths

Chest Breadth - breadth of the chest where the garment side seams join the sleeves (midaxillary equivalent).

Hip Breadth - breadth of the hips (midaxillary line) at the level of the maximum protrusion of the buttock.

Shoulder Breadth - breadth of the shoulders measured at the level of the maximum lateral protrusion of the deltoid muscles.

Waist Breadth - breadth of the waist (midaxillary line) at omphalion.

Circumferences

Chest Circumference - horizontal circumference of the chest measured where the garment side seam joins the sleeve.

Elbow Circumference - horizontal circumference of the elbow at the point of maximum bony diameter.

Hip Circumference - horizontal circumference of the hips at the level of the maximum protrusion of the right buttock.

Neck Circumference - circumference at the base of the neck (along neck-shoulder point). (Follows hood seam in cold weather gear).

Scye Circumference - vertical circumference at scye with the arm hanging freely at the side of the body.

Shoulder Circumference - circumference of the shoulders measured at the level of the maximum lateral protrusion of the deltoid muscles.

Waist Circumference - horizontal circumference of the waist at omphalion.

Wrist Circumference - circumference of the wrist passing just distal to the styloid process of the radius and ulna (Cold Weather). Circumference of the wrist passing over the elastic cuff of the jacket (C.D.).

Depths

Chest Depth - depth of the chest where the garment side seam joins the sleeve (arm slightly abducted).

Hip Depth - depth of the hips at the level of the maximum protrusion of the right buttock.

ATTACHMENT 1 (cont'd)

Scye Depth - vertical distance from the junction of the garment side seam and the sleeve to the top of the shoulder.

Waist Depth - maximum depth of the waist at omphalion.

APPENDIX B
VISUAL ACUITY STUDY

Authors

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VISUAL ACUITY STUDY

OBJECTIVE

Collect data on the limits of visual acuity. Data to be used to establish data bases to develop overlays for depicting the limits of visual acuity of maintenance technicians.

ANTHROPOMETRY

The set of anthropometric measures used in the Wrench Torque studies (Figure 3.1) were made for subjects participating in the Visual Acuity study.

TEST EQUIPMENT

Moving target with two degrees of freedom (azimuth and elevation). Target display was a seven element light emitting diode, character width and height (0.25 x 0.3 inches), with numbers 0 through 9. The walls, behind and around, the target display were covered with a light gray photographic background paper to reduce glare and provide a background void of any detail that might interfere with the subject's concentration on the target. Lighting was ceiling, flush mounted fluorescent fixtures with soft white plastic covers.

Adjustable chair, with head rest. The chair could be moved horizontally and vertically, and the seat back angle could be adjusted. The head rest could be adjusted up and down and forward and back.

Non-elastic head band to secure the head to the head rest in the desired position.

Random number generator.

Computerized data acquisition system.

Snellen eye chart.

CONDITIONS

Constants

- Subjects: 20 males, 20 females
  Vision Requirement: 20/40 vision without correction, as measured with the Snellen eye chart.

- Distance: 40.5 inches, measured from subject's sellion landmark (base of nose, between eyes) and target.

- Head Position: Head positioned against the head rest with the Frankfort plane (plane established by the three points of the sellion landmark and the two ear openings) parallel to the floor.

- Chair and Head Rest Position: Positioned so that the subject's sellion landmark coincided with the intersection of the azimuth and elevation axes of the target.

- Testing Sessions: 4

Variables

- Clothing: 4
  - Bare Headed
  - M-17 Chemical Defense Respirator
  - Cold Weather Parka, Fur Back
  - Cold Weather Parka, Fur Forward

PROCEDURES

The subject was seated in the chair, with the chair and head rest adjusted, so that with the Frankfort plane parallel to the floor, the sellion landmark coincided with the intersection of the azimuth and elevation axes of the target. The head was secured to the head rest with the head band.

For the measures made with the M-17 and the Cold Weather Parka in both configurations, the position of the head was established without the respirator or parka. Subjects then donned the respirator or parka, were re-seated and the head secured with the head band. For the parka, the head strap on the parka hood was adjusted to prevent the hood from sliding forward over the face during the testing session.

The high and low points of visual acuity at zero degree azimuth were determined. Subsequent measures were made at 10 degree intervals of elevation. For example, if the highest and lowest and points of elevation at zero degrees azimuth were +60° and -60°, the measures were made at +60°, +50°, +40°, +30°, 20°, +10°, 0°, -10°, -20°, -30°, -40°, -50°, and -60° elevation.

The sequence of measurement was from high to low, from the right and then from the left. The target was moved slowly from outside the field of vision until the subject could read the number on the target. Once the subject could read the number the target movement was stopped. At this point the experimenter changed the displayed number with the random number generator, and asked the subject to read the displayed number. If the subject could read four consecutive, randomly generated numbers, the target location was recorded. If the subject could <u>not</u> read the four consecutive, randomly generated numbers, the target was moved inward until the four consecutive, randomly generated numbers could be read.

A mild blurring of the numbers, as reported by the subject, was not considered a significant factor as long as the numbers could be read. If subjects reported severe blurring, double vision, or eye strain, they were allowed to rest their eyes until normal vision was recovered and then given the opportunity to read the numbers at the same location.

MEASURES

- Target location in degrees of azimuth and elevation

RESULTS

The collected data was edited and analyzed by UDRI personnel. Consideration was given to subject gender and size during the analyses. The angular limits were found to be consistent for the two genders and the various body sizes. The data were smoothed and one data set, applicable to both genders and all body sizes was developed. A set of overlays was developed from the data to depict the limits of visual acuity for maintenance technicians (Figures B.1 through B.3). The overlays depict the visual acuity limits for the four conditions tested, Bare Headed (the unobstructed base line), the M-17 Chemical Defense Respirator, and the Cold Weather Parka, with Fur Back and Fur Forward.

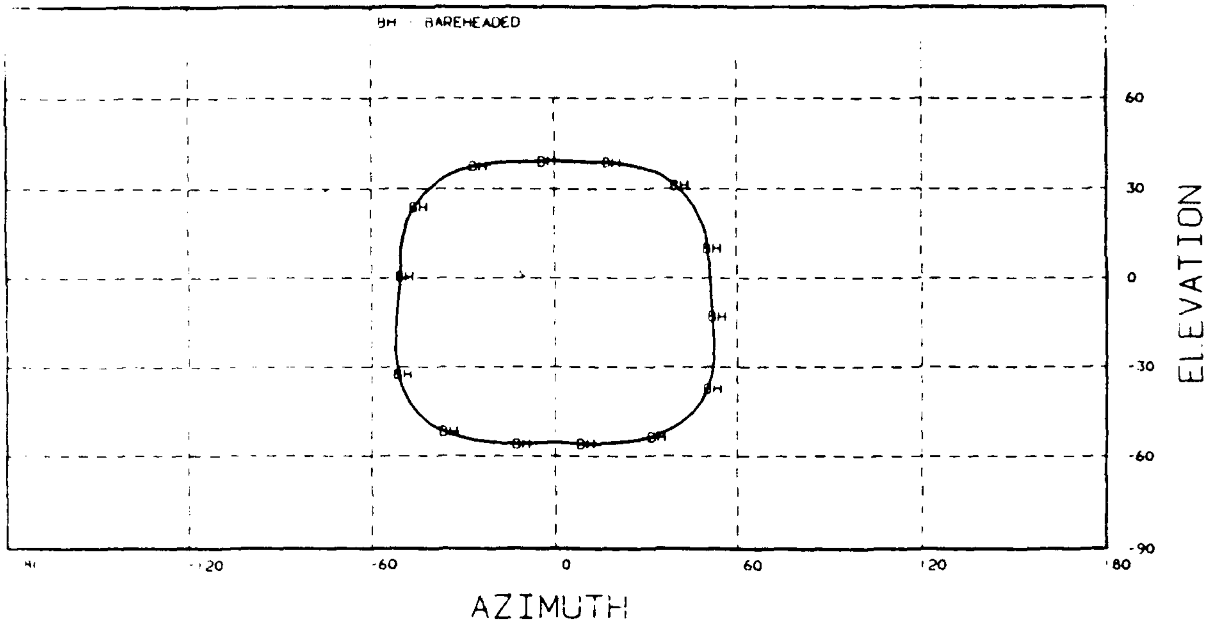

Figure P 1. Bareheaded Overlay (Base Line)

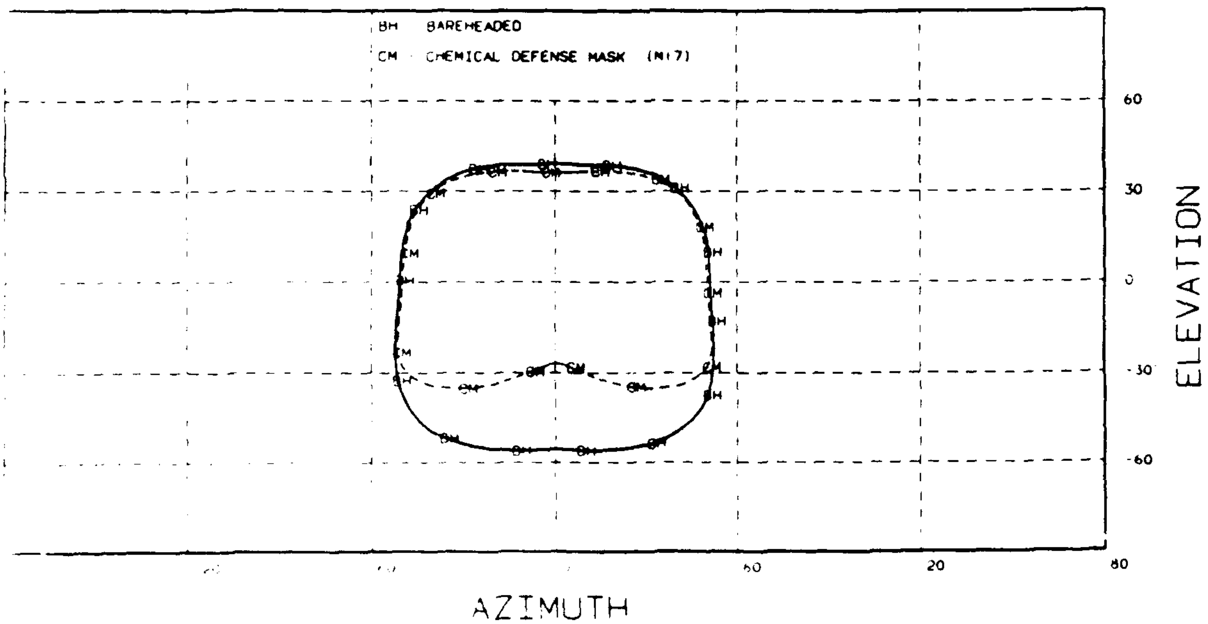

Figure B.2. Chemical Defense Overlay

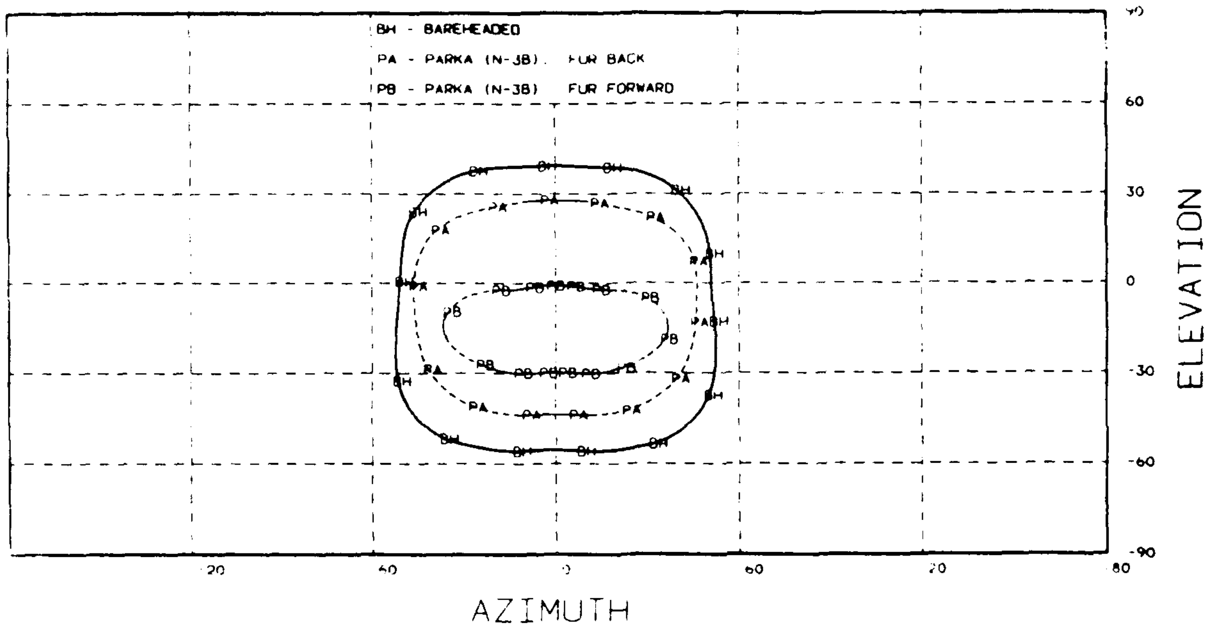

Figure B.3. Cold Weather Parka Overlay (Fur Back and Fur Forward)

APPENDIX C

UNDERWATER STRENGTH STUDY

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APPENDIX C
UNDERWATER STRENGTH STUDY

The purpose of this study was to measure strength in one gravity and simulated zero gravity environments. Strength in zero gravity has been poorly defined (Seter,1989). Certain tasks in space may call for sizable exertions or for unusual body positions. The inability to fully appreciate the factors that relate to force exertion in zero gravity may unduly limit astronaut performance. The influence of the use of hand and foot restraints, direction of exertion, position of task, and gender on strength in simulated zero gravity was examined.

The underwater environment allows the subjects to achieve neutral buoyancy as an approximation of zero gravity. In zero gravity, weightlessness allows for freedom of motion in all directions. If left unrestrained, an astronaut would simply push away from or pull towards the task at hand, as force was applied to perform the task. Restraints provide a surface against which to apply a stabilizing force during exertion. Foot restraints were used in this study to simulate the restraints available in space. The underwater environment does not fully simulate conditions in space. Water provides for increased resistance to motion. By limiting motion underwater, the effects produced by the resistance of water can be reduced. Therefore, the exertions of force in this study were isometric (static) maximum voluntary forces applied against a fixed handle by the subjects. Another reason for testing isometric strength, is that the maximum force required in performing most tasks occurs in a relatively static condition. For example, the maximum force required when loosening or tightening is usually just at the moment before the bolt starts or stops movement. The same condition applies to moving objects, the maximum force is required just before movement starts.

This study was developed in cooperation with the Harry G. Armstrong Aerospace Medical Research Laboratory (AAMRL) and the University of Dayton Research Institute (UDRI). The study was made as partial fulfillment of the requirements for the author's Master of Science work in Aerospace Medicine. The cooperation and support of AAMRL and UDRI was solicited as they were deeply involved in the development of strength data bases for the CREW CHIEF programs, including future applications for space maintenance. UDRI personnel fabricated the Underwater Strength Testing Device (Figure C.1), and assisted in the collection of the data.

C.1 ANTHROPOMETRY

The following set of anthropometric measures were made and recorded for all subjects participating in the study.

Weight	Stature
Acromial Height	Knee Height, Sitting
Biacromial Breadth	Hip Breadth, Sitting
Buttock-Knee Length	Hand Length
Radiale-Stylion	Chest Depth
Foot Length	Standing Vertical Reach
Acromion-Radiale Length	

C.2 TEST EQUIPMENT

The following test equipment was used in the data collection phase of this study.

- Underwater strength testing apparatus, with
  - 3 directional load cell
  - Feet restraints
- Computerized data acquisition system
- Self Contained Underwater Breathing Apparatus (SCUBA)
- Shoes for Simulated NASA Foothold (Figure C.2)

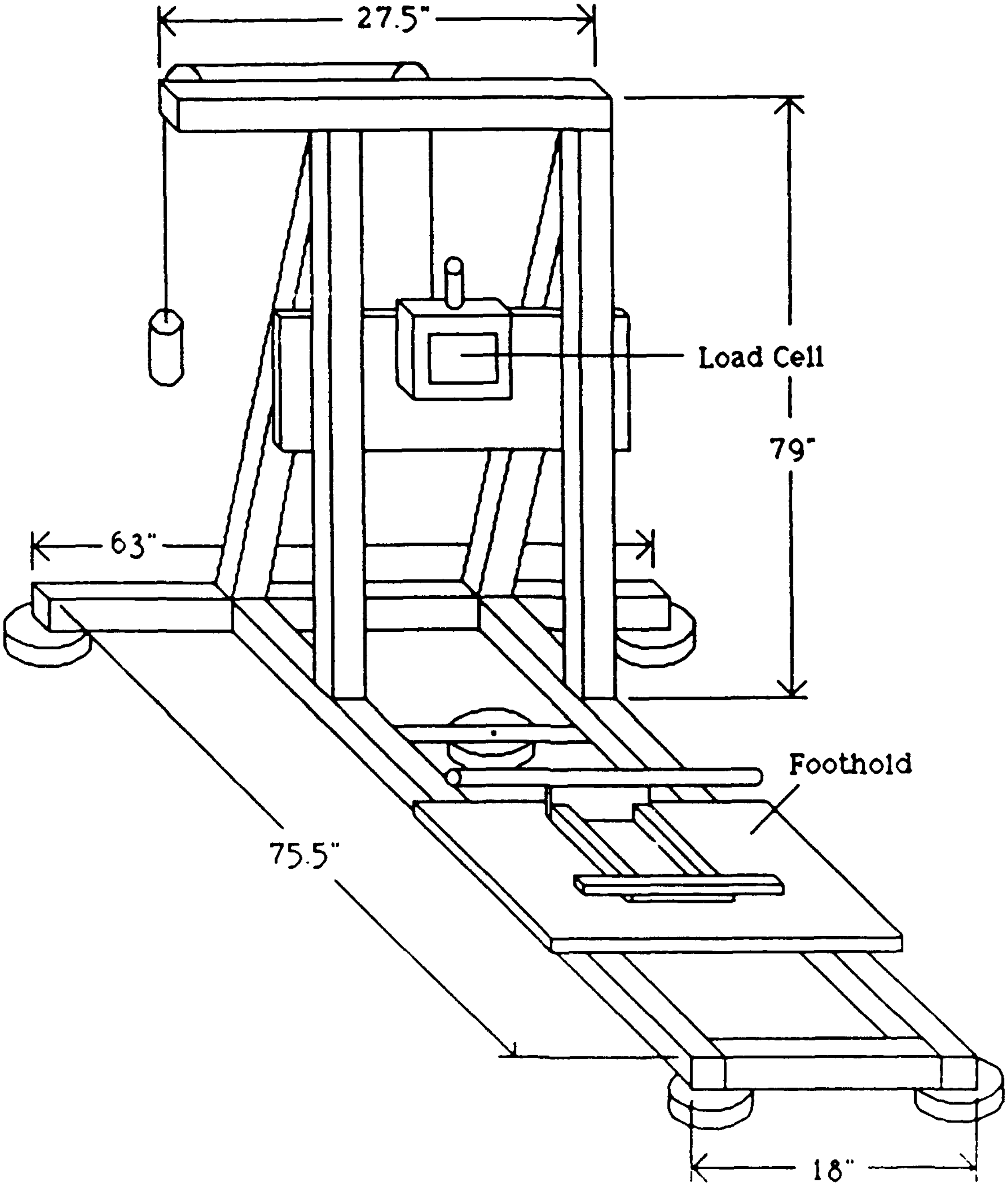

Figure C.1 Underwater Strength Testing Device
(Reprinted from Seter, 1989)

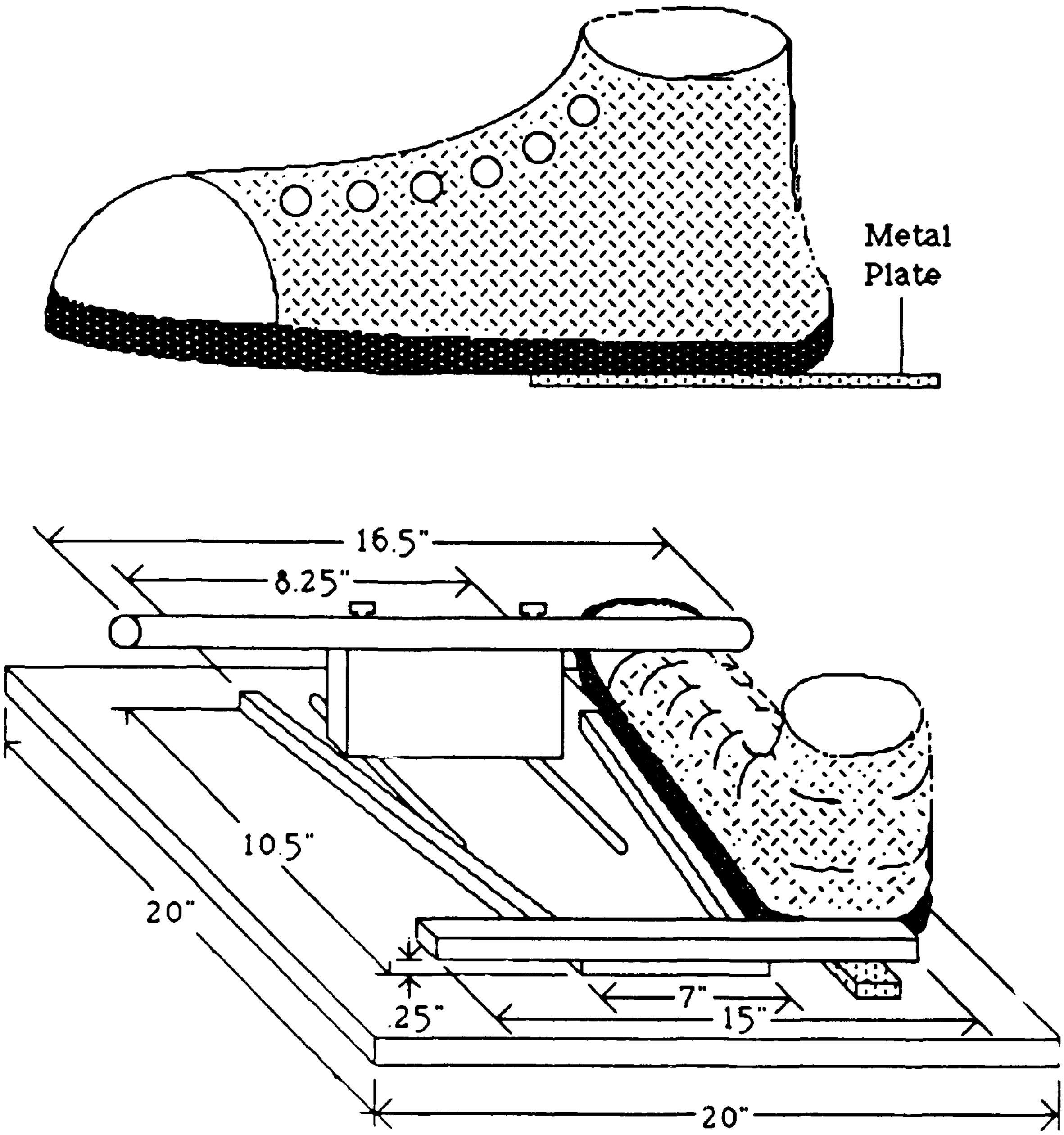

Figure C.2 Simulated NASA Foothold
(Reprinted from Seter, 1989)

C.3 EXPERIMENTAL CONDITIONS

The following conditions were used as constants, variables or as subject selection criteria.

1. Subjects:

- Number: the number of male and female subjects participating in each study.

- Weight Lift: a minimum weight lift capability of 40 pounds on the 6 Foot Incremental Weight Lift test was required to participate in the study. Some Air Force maintenance career fields have weight lift requirements greater than 40 pounds, but all Air Force enlisted personnel are required to pass the test at the 40 pound level.

- Mixed Occupations: all subjects were qualified SCUBA divers.

- Pay: subjects were paid volunteers averaging $5.00 per hour. Informed consent was obtained prior to any testing.

- No Physical Frailties: no physical frailties that would prevent a subject from participating in the study because of a possibility of injury or aggravation of an existing, or previously existing, condition.

2. Clothing:

- Swim suits and SCUBA apparatus.

3. Testing Sessions:

- Number: number of sessions required to complete a study.

- Session Exertions: number of exertions in a session.

  Benchmark Exertions: specific exertions at the start and end of a session to verify subject's reliability. Described in each study summary.

  Test Exertions: the task exertions defined by the combinations of variable conditions. Accomplished in random order. Anomalies to the randomization are described in the study summary.

  Rest Period: Rest time allowed between exertions to prevent fatigue becoming a factor.

4. Posture: standing

5. Foot Position: the horizontal distance from the center of the force handle to the foot position. Expressed as a percentage of each subject's vertical reach.

6. Handle Height: the vertical distance from the supporting surface to the center of the force handle. Expressed as a percentage of each subject's vertical reach.

7. Hand Hold: left hand either held the apparatus frame for bracing or was suspended at the side.

8. Hand Used: right hand used to apply force.

11. Force Direction: direction of force application.

C.4 GENERAL PROCEDURES

Four benchmark strength tests, Incremental Weight Lift to Six Feet, One Hand Pull, 38 cm Vertical Lift and the Elbow Height Vertical Lift, were performed by each subject. The apparatus and test procedures were as described in Section 2 of this volume.

Exertions were accomplished in the same random order for both the land and water session. The experimenter was a qualified SCUBA diver. At each underwater session, emergency procedures were explained and demonstrated.

The test apparatus was set at the correct foot position and handle height for the exertion. Subject was instructed as to the hand hold and force direction for the exertion. Subjects took the required position and on the experimenter's signal applied their maximum voluntary force in the direction specified for a four second period.

The computerized data collection system stored the data during the test. After the test the program computed and printed; the peak force value during the first second of the exertion, the mean force value during the last three seconds, the ratio of the peak in the first second to the mean of the last three seconds, and the number of occurrences during the final three seconds when the force value was greater or less than 10 % of the mean force value for the period. These data were used to determine the acceptability of the data, using the following criteria.

1, If the peak to mean ration was greater than ±20 %, the exertion was repeated.

2. If the force value was greater or less than 10 % of the mean force value more than 5 times, the exertion was repeated.

3. If more than one third of the total force was not in the direction requested, the exertion was repeated.

▪ SUMMARY OF UNDERWATER STRENGTH STUDY ▪

OBJECTIVE

To determine the available strength in a simulated zero-gravity environment.

TEST EQUIPMENT

As listed in paragraph C.2.

CONDITIONS

Constants

- Subjects
  Number: 16 males, 8 females

- Clothing: Swim suits and SCUBA apparatus.

- Testing Sessions:
  Number: 2 (1 on land, 1 underwater)
  Session Exertions: 30
  Rest Period: 1 minute

- Posture: Standing

- Hand Used: Right

Variables

- Foot Position: 2
  (percentage of vertical reach)
  Near - 15%   Far - 30%

- Handle Height: 3
  (percentage of vertical reach)
  Low - 50 %
  Middle - 65 %
  High - 80 %

- Force Direction: 4

Left	Fore
Right	Aft

- Hand Hold: 2
  Yes - With left hand holding apparatus for bracing
  No - With left hand at side

NOTE: Half of the subjects did 24 exertions at the Far distance, and half at the Near distance, at all 3 heights, all 4 directions and with both hand holds (3 x 4 x 2 = 24). Each subject did 6 exertions at the other foot distance, at all 3 heights and in two directions only (Push and Pull) for a total of 30 exertions.

MEASURES

- Isometric strength in pounds

RESULTS

The transfer, editing and analysis of data for these results was performed by UDRI personnel. Female mean strength capability was 47.7 to 70 percent of the male mean strength capability for the same exertions on land. Under water, the female mean strength capability was 47.4 to 62.9 percent of the male mean strength capability for the same exertions. The reduction of male mean strength capability from land to under water was 12.9 to 25.8 percent. The reduction of female mean strength capability from land to under water was 8.0 to 33.3 percent. Tables C.1 through C.4 show the values of mean strength exertions for male, female and the different conditions.

TABLE C.1

MEAN FORCE IN POUNDS FOR EACH HANDLE HEIGHT

ENVIRONMENT	GENDER	HANDLE HEIGHT		
		HIGH	MIDDLE	LOW
LAND	MALE	37.3	45.9	40.9
	FEMALE	18.7	23.4	20.9
WATER	MALE	32.5	36.5	35.1
	FEMALE	16.3	17.6	17.7

TABLE C.2

MEAN FORCE IN POUNDS IN ALL FORCE DIRECTIONS

ENVIRONMENT	GENDER	FORCE DIRECTION			
		BACK	FORE	LEFT	RIGHT
LAND	MALE	54.8	49.3	28.7	22.1
	FEMALE	29.0	25.2	16.8	13.0
WATER	MALE	44.1	42.4	24.5	19.2
	FEMALE	23.3	20.1	13.8	11.7

TABLE C.3

MEAN FORCE IN POUNDS WITH AND WITHOUT HAND HOLD

ENVIRONMENT	GENDER	HAND HOLD	
		NO	YES
LAND	MALE	24.0	52.8
	FEMALE	16.8	25.2
WATER	MALE	17.8	45.9
	FEMALE	11.2	23.2

TABLE C.4

MEAN FORCE IN POUNDS FOR EACH FOOT POSITION

MALES ONLY	FOOT POSITION	
ENVIRONMENT	FAR	NEAR
LAND	44.9	41.4
WATER	34.6	34.7

☆U.S.Government Printing Office: 1991—548-018/20223