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Anthropometric and HFE Design Criteria
for Tactical Unmanned Ground Vehicle
Operation and Maintenance

Patricia M. Burcham

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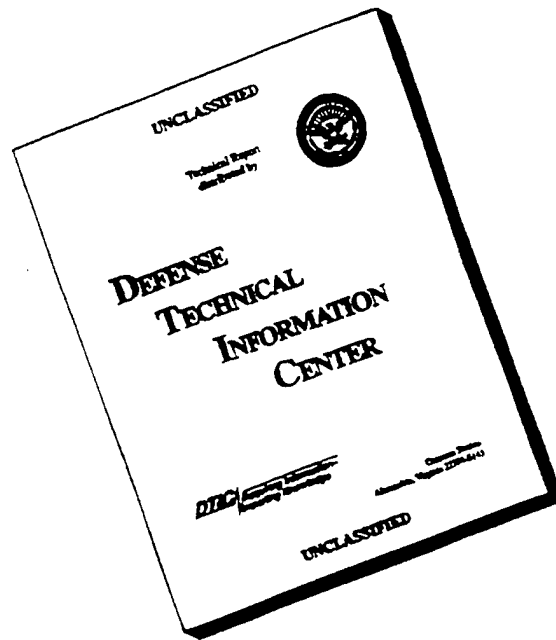
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Patricia M. Burcham
Human Research & Engineering Directorate

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Abstract

A literature search was conducted to address tactical unmanned ground vehicles' (TUGV) anthropometric and human factors engineering (HFE) design criteria for operation and maintenance of TUGVs to allow modeling of the TUGV. Human physical weights and space claims are discussed for the 5th percentile female through the 95th percentile male.

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ANTHROPOMETRIC AND HFE DESIGN CRITERIA FOR TACTICAL UNMANNED GROUND VEHICLE OPERATION AND MAINTENANCE

BACKGROUND

An integrated product and process development (IPPD) effort at the Unmanned Ground Vehicle/Systems Joint Project Office (UGV/SJPO) identified a number of issues concerning existing tactical unmanned ground vehicles (TUGV) requirements and constraints. These issues address specification of human attributes and capabilities to allow modeling of the TUGV with operator representation. The Human Research & Engineering Directorate (HRED) of the U.S. Army Research Laboratory (ARL) was tasked to provide human physical weights and space claims applicable for TUGV operations and maintenance. This report is in support of TUGV acquisition program Phase 0 activities during fiscal year (FY) 96. The following report provides information to address Study No. TUV-010, TUGV Issue 141.

FINDINGS

MIL-STD-1472D (Department of the Defense, 1989).

Anthropometry (paragraph 5.6)

General (paragraph 5.6.1)

Design and sizing shall ensure accommodation, compatibility, operability, and maintainability by the user population. Generally, design limits shall be based upon a range from the 5th percentile female to the 95th percentile male values for critical body dimensions, as appropriate, except for special populations. For any body dimension, the 5th percentile values means that 5% of the population will be equal to or smaller than that value, and 95% will be larger; conversely, the 95th percentile value indicates that 95% of the population will be equal to or smaller than that value and 5% will be larger. Therefore, use of a design range from the 5th to 95th percentile values will theoretically provide coverage for 90% of the user population for that dimension. When two or more dimensions are used simultaneously as design parameters, appropriate multivariate data and techniques should be used. The limited anthropometric data presented in Appendix A, Figures A-1 through A-4 and Tables A-1 through A-4 are intended to provide general design guidance only.

Anthropometric Data (paragraph 5.6.2)

The anthropometric data presented in Appendix A, Tables A-1 through A-4 are nude body dimensions; data are given in centimeters, with equivalent values in inches beneath in parentheses. The anthropometric data shown in these tables were compiled and collated from several sources. The data about "General Forces - Male" were compiled from the 1988 Anthropometric Survey of U.S. Army Personnel (ANSUR), the 1966 Anthropometric Survey of U.S. Marines, and the 1965 Anthropometric Survey of U.S. Air Force male officers and enlisted personnel. Data voids and omitted line numbers within these tables represent measurements that were not taken or for data not available.

PART I. WORK SPACE DESIGN FOR TUGV OPERATORS

Work Space Design

General (paragraph 5.7.1)

Unless otherwise noted, the following criteria apply to ground installations and as practical, to airborne and shipboard installations.

Kick Space (paragraph 5.7.1.1)

All cabinets, consoles, and work surfaces that require an operator to stand or sit close to his or her front surfaces shall contain a kick space at the base at least 100 mm (4 inches) deep and 100 mm (4 inches) high to allow for protective or specialized apparel.

Handles (paragraph 5.7.1.2)

Handles on cabinets and consoles shall be recessed whenever practical to eliminate projections on the surface. If handles cannot be recessed, they shall be designed so that they shall neither injure personnel nor entangle clothing or equipment.

Work Space (paragraph 5.7.1.3)

Whenever feasible, free floor space of at least 1.220 m (4 feet) shall be provided in front of each console. For equipment racks that require maintenance, free floor space shall be provided in accordance with the following criteria.

Depth of Work Area (paragraph 5.7.1.3.1)

Clearance from the front of the rack to the nearest facing surface or

obstacle shall not be less than 1.070 m (42 inches). The minimum space between rows of cabinets shall be 200 mm (8 inches) greater than the depth of the deepest drawer (equipment).

Lateral Work Space (paragraph 5.7.1.3.2)

The minimum lateral work space for racks having drawers or removable equipment shall be as follows (measured from the drawers or equipment in the extended position):

a. For racks having drawers or removable items weighing less than 20 kg (44 pounds): 460 mm (18 inches) on one side and 100 mm (4 inches) on the other.

b. For racks having drawers or removable items weighing more than 20 kg (44 pounds): 460 mm (18 inches) on each side.

Space Between Rows of Cabinets (paragraph 5.7.1.3.3)

The minimum space between rows of cabinets shall be 200 mm (8 inches) greater than the depth of the deepest drawer or cabinet.

Storage Area (paragraph 5.7.1.3.4)

Adequate and suitable space shall be provided on consoles or immediate work space for the storage of manuals, work sheets, and other materials that are required for use by the operational or maintenance personnel.

Seated Operations

Work Surface Width and Depth (paragraph 5.7.3.1)

A lateral work space of at least 760 mm (30 inches) wide and 400 mm (16 inches) deep shall be provided whenever practical.

Work Surface Height (paragraph 5.7.3.2)

Desk tops and writing tables shall be 740 to 790 mm (29 to 31 inches) above the floor, unless otherwise specified.

Writing surfaces (paragraph 5.7.3.3)

When a writing surface is required on equipment consoles, it shall be at

least 400 mm (16 inches) deep and should be 610 mm (24 inches) wide, when consistent with operator reach requirements.

Seating

Compatibility (paragraph 5.7.3.4.1)

Work seating shall provide an adequate supporting framework for the body relative to the activities that must be performed. Chairs to be used with sit-down consoles shall be designed to be operationally compatible with the console configuration.

Vertical Adjustment (paragraph 5.7.3.4.2)

Provision shall be made for vertical seat adjustment from 380 to 535 mm (15 to 21 inches) in increments of no more than 25 mm (1 inch) each.

Back Rest (paragraph 5.7.3.4.3)

A supporting back rest that reclines between 1745 and 2005 mrad (100° and 115°) shall be provided. The back rest shall engage the lumbar and thoracic regions of the back, and shall support the torso in such a position that the operator's eyes can be brought to the "eye line" with no more than 75 mm (3 inches) of forward body movement.

Cushioning (paragraph 5.7.3.4.4)

When applicable, both the back rest and seat shall be cushioned with at least 25 mm (1 inch) of compressible material and provided with a smooth surface.

Arm Rests (paragraph 5.7.3.4.5)

Unless otherwise specified, arm rests shall be provided. Armrests that are integral with operators' chairs shall be at least 50 mm (2 inches) wide and 200 mm (8 inches) long. Modified or retractable arm rests shall be provided when necessary to maintain compatibility with an associated console and shall be adjustable from 190 to 280 mm (7.5 to 11 inches) above the compressed sitting surface.

Knee Room (paragraph 5.7.3.5)

Knee and foot room that equals or exceeds the following minimum dimensions shall be provided beneath work surfaces:

- a. Height: 640 mm (25 inches). If fixed foot rest or a foot-operated control

is provided, this dimension shall be increased accordingly.

b. Width: 510mm (20 inches)

c. Depth: 460 mm (18 inches)

Display Placement, Normal (paragraph 5.7.3.6)

Visual displays mounted on vertical panels and used in normal equipment operation shall be placed in an area between 150 and 1170 mm (6 and 46 inches) above the sitting surface.

Display Placement, Special (paragraph 5.7.3.7)

Indicators that must be read precisely and frequently shall be placed in an area between 360 and 890 mm (14 and 35 inches) above the sitting surface and no farther than 530 mm (21 inches) laterally from the centerline.

Warning Displays (paragraph 5.7.3.8)

For consoles at which operators sit, which require horizontal vision over the top, critical visual warning displays shall be mounted at least 570 mm (22.5 inches) above the sitting surface.

Control Placement, Normal (paragraph 5.7.3.9)

All controls mounted on a vertical surface and used in normal equipment operation shall be located between 200 and 860 mm (8 and 34 inches) above the sitting surface.

Control Placement, Special (paragraph 5.7.3.10)

Controls requiring precise or frequent operation shall be mounted between 200 and 740 mm (8 and 29 inches) above the sitting surface.

Control Working Positions (paragraph 5.7.4)

Anthropometric data for the design and sizing of work spaces involving standing, sitting, stooping, kneeling, and supine positions are presented in Appendix A, Table A-5, and illustrated in Appendix A, Figure A-5. Fifth and 95th percentile values for men and women are given for various body dimensions in both centimeters and inches. (The data are based on measurements of 300 Army women and 106 Army men in 1977; therefore, differences in several measurements common to Table A-5 and tables of paragraph 5.6 should be resolved in favor of

the latter tables.) Suitable allowances should be made for heavy clothing or protective equipment when required. In no case shall clearance dimensions be less than the 95th percentile values for men or limiting dimensions be more than the 5th percentile values for women, shown in Table A-5.

Operational and Maintenance Ground and Shipboard Vehicles (paragraph 5.12)

General (paragraph 5.12.1)

Handles, levers, pedals, knobs, and work space dimensions shall be designed to enhance effective vehicle operation by suitably clothed and equipped users with relevant body dimensions varying between 5th and 95th percentiles.

Seating (paragraph 5.12.2)

Dimensions and Clearances (paragraph 5.12.2.1)

Seating for vehicle operators should follow the dimensions and clearances recommended in Figures A-6 and A-7 and Table A-6 as applicable.

Vertical Adjustment (paragraph 5.12.2.2)

If the seat's height above the floor is variable, requirements for leg room and footrest will also vary. When the seat is adjusted higher, there will be more leg room and larger footrest angles.

Horizontal Adjustment (paragraph 5.12.2.3)

Seats shall adjust at least 150 mm (6 inches) in the fore-aft direction.

Back Rest Angle (paragraph 5.12.2.4)

Back rest angle should not be more than 1920 mrad (110°) from horizontal. If only the lumbar area is supported, the back rest angle of tilt should be 1660 to 1745 mrad (95° to 100°) for operators in an alert position.

Seat Pan (paragraph 5.12.2.5)

The seat pan shall be flat and made from a rigid material.

Seat Padding (paragraph 5.12.2.6)

Seat padding should be kept to a minimum, but it should be resilient enough to keep the operator's body from contacting the seat bottom during severe vibration. Seat padding made of foam-type material should be adequately ventilated.

Seat Belts (paragraph 5.12.2.7)

All administrative type vehicles shall have safety seat belts. Seat belts should be installed on other type vehicles except when they interfere with operational requirements.

Controls (paragraph 5.12.3)

Design (paragraph 5.12.3.1)

Controls shall be designed so as not to be adversely affected by distortion, shock, or vibration of the vehicle.

Steering (paragraph 5.12.3.2)

In case of power steering assist failure, the steering gear shall afford the operator sufficient mechanical advantage to guide the vehicle during an emergency stop or during low speed operation.

Pedals (paragraph 5.12.3.3)

Foot pedals shall be designed to accept the weight of the operator's foot without initiating control action.

Helander (1981)

The most important controls should be positioned where they are easily reached. Refer to Appendix A, Figure A-8, for the optimum and maximum hand and foot control space. The following factors determine importance:

- a. Frequency and duration of use.
- b. Accuracy and speed of operation required.
- c. Ease of manipulation in terms of force, precision, and speed.

The most important controls should be located at a height between the operator's waist and shoulder and within a radius of 16 inches from the normal working position. They should be grouped together, preferably to the right front of the operator (to be operated by the right hand). When this is not possible, they can also be positioned to the left front.

Controls that are used less frequently and are less important should be located within 20 inches of the normal work position. Controls that are used infrequently may be placed to the side. These might be covered, mounted behind hinged doors, or recessed into the instrument panel to reduce distraction and prevent inadvertent operation.

Recommendations and Conclusions

Work space design requirements for the operator are provided in accordance with MIL-STD-1472. The optimum and maximum hand and foot control space criteria are provided in accordance with Helander/SAE J898. Anthropometric dimensions are provided for guidance of design for both the operator and maintainer. These design criteria should aid in the design effort of TUGV operator to include accommodations of the 5th percentile female through 95th percentile male.

PART II. WORK SPACE DESIGN AND LIFTING LIMITS FOR TUGV MAINTENANCE

Whole Body Access (paragraph 5.7.8.3)

Dimensions for rectangular access openings for body passage shall not be less than those dimensions shown in Appendix A, Figure A-9. Minimum diameter for circular hatches shall be 760 mm (30 inches). Diameters of oval hatches in armored vehicles shall not be less than 430 and 710 mm (17 and 28 inches). When rescue of personnel may be required because of environmental hazards (e.g., toxic fumes) within the work place, larger access openings for two-person ingress and egress may be necessary. Where "step down" through a top access exceeds 690 mm (27 inches), appropriate foot rests or steps shall be provided.

Accessibility (paragraph 5.9.4)

Structural Members (paragraph 5.9.4.1)

Structural members or permanently installed equipment shall not visually or physically obstruct adjustment, servicing, removal of replaceable equipment, or other required maintenance tasks. Panels, cases, and covers removed to access equipment shall have the same

access requirements as replaceable equipment. Mounting provisions shall be directly, visually, and physically accessible by the maintainers. Unless required by security considerations, no special tools shall be required for removal or replacement.

Large Items (paragraph 5.9.4.2)

Large items that are difficult to remove shall be so mounted that they will not prevent convenient access to other items.

Use of Tools and Test Equipment (paragraph 5.9.4.3)

Checkpoints, adjustment points, test points, cables, connectors, and labels shall be accessible and visible during maintenance. Sufficient space shall be provided for the use of test equipment and other required tools without difficulty or hazard.

Rear Access (paragraph 5.9.4.4)

Sliding, rotating, or hinged equipment to which rear access is required shall be free to open or rotate its full distance and remain in the open position without being supported by hand. Rear access shall also be provided to plug connectors for test points, soldering, and pin removal when connectors require such operations. Aircraft-installed equipment shall be configured for one-sided access.

Relative Accessibility (paragraph 5.9.4.5)

Mission-critical items that require rapid maintenance shall be most accessible. When relative criticality is not a factor, items requiring most frequent access shall be most accessible.

High Failure Rate Items (paragraph 5.9.4.6)

High failure rate items should be accessible for replacement without removing non-failed items. Mechanical replacement items shall be removable with common hand tools and simple handling equipment.

Skills (paragraph 5.9.4.7)

Access to items maintained by one technician should not require removal of critical equipment maintained by another technician, particularly when highly specialized skills are involved.

Access Openings and Covers (paragraph 5.9.9)

Application (paragraph 5.9.9.1)

An access shall be provided whenever frequent maintenance operations would otherwise require removing a case or covering, opening a fitting, or dismantling an item of equipment.

Self-Supporting Covers (paragraph 5.9.9.2)

Hinged access covers that are not completely removable shall be self-supporting in the open position. The cover in the open position shall not obstruct required visual or physical access to the equipment being maintained or to related equipment during maintenance. Self-supporting covers should be capable of being opened and closed with one hand. Covers shall be secured to withstand wind gusts, vibrations, or other environmental effects as specified by system requirements.

Labeling (paragraph 5.9.9.3)

Each access should be labeled with nomenclature for items visible or accessible through it, nomenclature for auxiliary equipment to be used with it, and recommended procedures for accomplishing operations. Accesses should be labeled with warning signs, advising of any hazards existing beyond the access and stating necessary precaution. Opening or removing an access cover shall not remove or visually obstruct any hazard warning. If instructions applying to a covered item are lettered on a hinged door, the lettering shall be properly oriented to be read when the door is open. Warning notices shall be clear, direct, and attention getting and have a 25% larger letter height than any detailed instructions that follow.

Rounding (paragraph 5.9.9.4)

Cover and access edges shall be rounded to preclude hand injury or clothing damage.

Physical Access (paragraph 5.9.9.5)

Arm and Hand Access (paragraph 5.9.9.5.1)

Access openings provided for adjusting and handling interior equipment shall be sized to permit the required operations and shall provide an adequate view of the item being manipulated. All blind arm and hand access shall require approval of procuring authority.

Opening Covers (paragraph 5.9.9.5.1.1)

Access covers shall be equipped with grasp areas or other means for opening them. When operations will require opening and closing the covers while gloves or special clothing is worn, opening provisions shall accommodate the gloves or special clothing.

Reach Access Dimensions (paragraph 5.9.9.5.1.2)

The dimensions of access openings for arms, hands, and fingers shall be made for clearance of the operator's gloved or mittened hand, or special clothing as appropriate (see Appendix A, Figure A-10). Shape of access shall allow easy passage of equipment, body appendage, or tools as appropriate. Shape of access shall permit passage of all equipment that must be replaced through the opening, allowing for protuberances, attachments, and handles on the equipment.

Tool Access Dimensions (paragraph 5.9.9.5.1.3)

Access openings shall be large enough to operate tools required for maintenance of the equipment reached through the access.

Remove and Replace Dimensions (paragraph 5.9.9.5.1.4)

Opening size for removal and replacement of equipment shall allow for handling clearance for bare hand or gloved hand as appropriate.

Guarding Hazardous Conditions (paragraph 5.9.9.5.1.5)

If a hazardous condition, such as exposed conductors energized with dangerous voltages or currents, exists behind the access, the physical barrier over the access shall be equipped with an interlock that will de-energize the hazardous equipment when the barrier is open or removed. Both the presence of the hazard and the fact that an interlock exists shall be noted on the equipment case or cover so that it remains visible when the access is open.

Type of Opening (paragraph 5.9.9.5.1.6)

When physical access is required, the following practices shall be followed in order of preference:

- a. An opening with no cover unless this is likely to degrade system performance, safety, or nuclear, biological, chemical (NBC) contamination survivability.

b. A hand-operated (latched, sliding, or hinged) cap or door where dirt, moisture, or other foreign materials might otherwise create a problem.

c. A cover plate that opens quickly using 1/4 turn captive fasteners if a cap will not meet stress requirements or space prevents a hinged cover.

d. When captive fasteners cannot be used because of stress, structure, or pressurization, screw down cover tightly. Use minimum number of interchangeable screws to fasten door.

Visual Access (paragraph 5.9.9.6)

When visual access is required, the opening shall provide a visual angle sufficient to view all required information at the normal operating or maintenance position. The maintainer should be provided unrestricted visual access from the work station without bending. When bending is required, frequency and time in the bent position shall not cause fatigue. When visual access only is required, the following practices shall be followed in order of precedence:

a. An opening with no cover except when this might degrade system performance or NBC survivability.

b. A transparent window if dirt, moisture, or other foreign materials might otherwise create a problem.

c. A break-resistant glass window if physical wear, heat, or contact with solvents would otherwise cause optical deterioration.

d. An opaque cover that opens quickly if glass will not meet stress or other requirements.

Access Cover Attachment (paragraph 5.9.9.7)

Covers shall be attached with the fewest number of fasteners that are the simplest to operate. Fasteners shall be operable by hand or by common hand tools in that order of preference. Small, removable covers shall be attached to structure or otherwise retained to prevent loss.

Accessibility (paragraph 5.9.10.6)

The heads of mounting bolts and fasteners should be located on surfaces

readily accessible to the maintainer. Both hand and tool access shall be provided to the unthreaded or loosened fastener.

Unit Design for Efficient Handling (paragraph 5.9.11)

Rests and Stands (paragraph 5.9.11.1)

When required to support operations or maintenance, functions, rests, or stands on which units can be placed, including space for test equipment, tools, technical orders and manuals, should be provided. When permitted by design requirements, such rests or stands shall be part of the basic unit, rack, or console chassis.

Extensions (paragraph 5.9.11.2)

Extensions and connected appurtenances, accessories, utilities, cables, wave guides, hoses, and similar items shall not interfere with removing, replacing, or carrying an item. If such extensions and connected appurtenances interfere with these tasks, they shall be easily removed or disconnected from the equipment before handling. Easy disconnection shall consist of hand-operable quick disconnect or standard hand tool operable disconnects in that order of preference.

Weight (paragraph 5.9.11.3)

Lifting Limits (paragraph 5.9.11.3.1)

The weight limits in Table 1, conditions A and B, shall be used as maximum values in determining the design weight of items requiring one person lifting with two hands. Double the weight limits in Table 1 shall be used as the maximum values in determining the design weight of items requiring two person lifting, provided the load is uniformly distributed between the two lifters. If the weight of the load is not uniformly distributed, the weight limit applies to the heavier lift point. When three or more persons are lifting simultaneously, not more than 75% of the one-person value may be added for each additional lifter, provided that the object lifted is sufficiently large that the lifters do not interfere with one another while lifting. When it is not possible to define the height to which an object will be lifted in operational use, the limit in which the object is lifted to shoulder height shall be used rather than the more permissive bench height value. The values in Table 1 are applicable to objects with or without handles.

Table 1
Design Weight Limits

Handling function	Male and Female Population		Male Only Population	
	(kg)	(lb)	(kg)	(lb)
A. Lift an object from the floor and place it on a surface not greater than 1.525 m (5 ft) above the floor.	16.8	37	25.4	56
B. Lift an object from the floor and place it on a surface not greater than 915 mm (36 in.) above the floor.	20.0	44	39.5	87
C. Carry an object 10 meters (33 ft) or less.	19.0	42	37.2	82

Lifting Frequency (paragraph 5.9.11.3.2)

The equipment weight limits in Table 1 are not for repetitive lifting as found, for example, in loading and unloading transport vehicles. If the frequency of lift exceeds one lift in 5 minutes or 20 lifts per 8 hours, the permissible weight limits shall be reduced by $(8.33 \times \text{LF})$ percent, in which LF is six lifts per minute, then the maximum permissible weight is reduced by 50% ($8.33 \times 6 = 50$).

Load Size (paragraph 5.9.11.3.3)

The maximum permissible weight lift limits in Table 1 are applicable to an object uniform mass distribution and a compact size not exceeding 460 mm (18 inches) wide, and 300 mm (12 inches) deep (away from the lifter). This places the hand holds at half the depth, or 150 mm (6 inches) away from the body. If the depth of the object exceeds 610 mm (24 inches), the permissible weight shall be reduced by 33%. If the depth of the object exceeds 910 mm (36 inches), the permissible weight shall be reduced by 50%. If the depth of the object exceeds 1.220 m (48 inches), the permissible weight shall be reduced by 66%.

Obstacles (paragraph 5.9.11.3.4)

The values in Table 1 assume that there are no obstacles between the person lifting and the shelf, table, bench or other surface on which the object is to be placed. When there is a lower protruding shelf or other obstacle limiting the lifter's approach to the

desired surface, the weight limit of the object shall be reduced by 33% for an obstacle protruding 300 mm (12 inches), 50% for an object protruding 460 mm (18 inches), and 66% for an obstacle protruding 610 mm (24 inches). If the allowable weight must be reduced by both oversize load considerations, only the more restrictive single value shall apply; two reductions shall not be applied.

Carrying Limits (paragraph 5.9.11.3.5)

The weight limit in Table 1 Condition C shall be used as the maximum value in determining the design weight of items requiring one person to carry objects a distance as great as 10 m (33 feet). The maximum permissible weight for carrying also applies to an object with a handle on top, such as a tool box, which usually is carried at the side with one hand. Double this weight carrying limit shall be used as the maximum value in determining the design weight of items requiring two-person carrying, provided the load is uniformly distributed between the two carriers. When three or more persons are carrying a load together, not more than 75% of the one-person value may be added for each additional person, provided that the object is sufficiently large that the workers do not interfere with one another while carrying the load. In all cases involving carrying, it is assumed that the object is first lifted from the floor, carried a distance of 10 m (33 feet) or less, and placed on the floor or another surface not higher than 915 mm (36 inches). If the final lift is to higher height, the 1.525-m (5-foot) lift height applies as the limiting case.

Carrying Frequency (paragraph 5.9.11.3.6)

The reduction formula expressed in paragraph 5.9.11.3.2 shall be applied to repetitive carrying in the same manner as for load size.

Object Carry Size (paragraph 5.9.11.3.7)

The reduction formula expressed in paragraph 5.9.11.3.3 shall be applied to size of objects to be carried in the same manner as for load size.

User Population (paragraph 5.9.11.3.8)

Unless otherwise specified by the procuring activity, the values in Table 1 for male and female population shall apply to any object to be lifted or carried manually. When the procuring activity specifies that the object is to be lifted or carried only in a combat environment, the male only population will be applied.

Labeling (paragraph 5.9.11.3.9)

Items weighing more than the one-person lift or carry values for male and female population of Table 1 shall be prominently labeled with weight of the object and lift limitation, that is, mechanical or power lift is required, hoist and lift points shall be provided and clearly labeled.

Recommendations and Conclusions

Lifting limits and access design requirements are provided in accordance to MIL-STD-1472. Anthropometric dimensions are provided for guidance of design for both the operator and maintainer. These design criteria should aid in the design effort of the TUGV maintainer to include accommodations of the 5th percentile female through 95th percentile male.

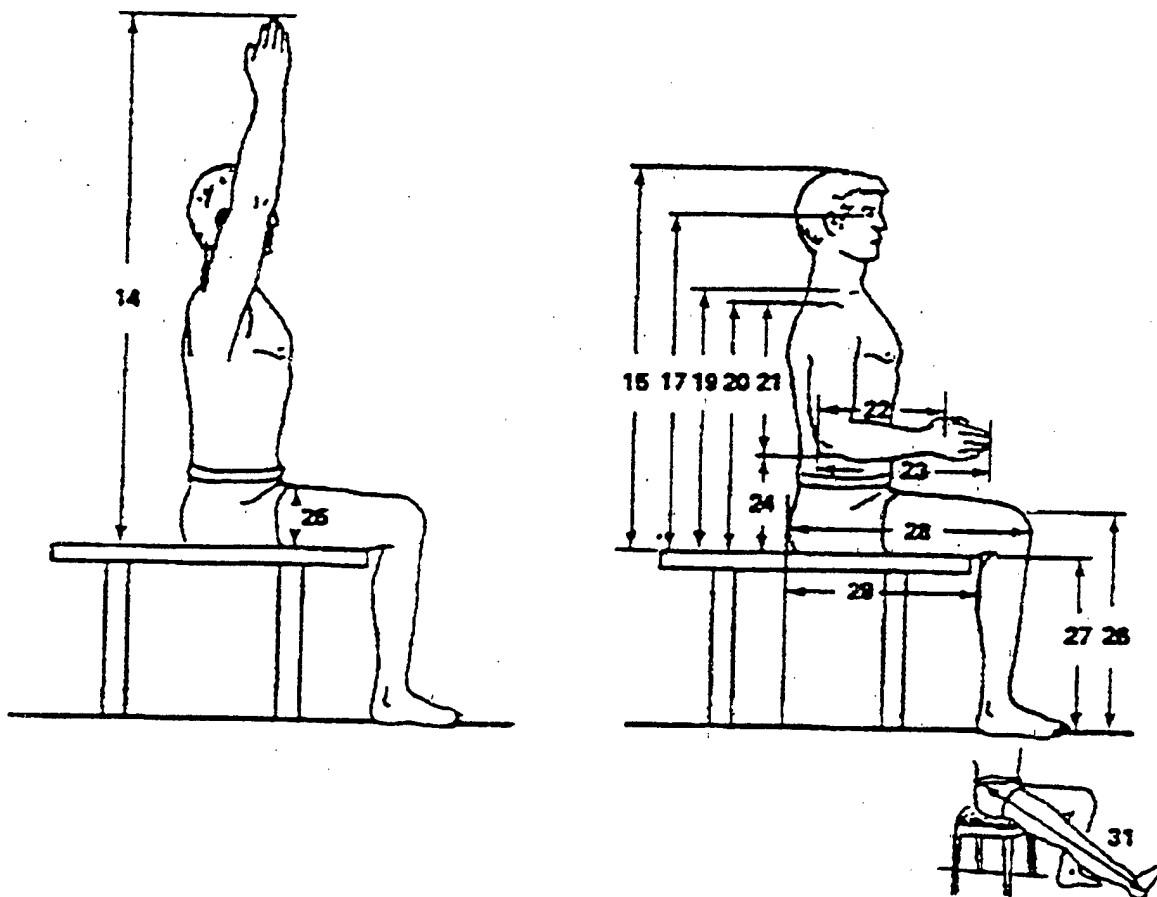
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Helander, M. (ed.) (1981). Human factors/ergonomics for building and construction. John Wiley & Sons.

APPENDIX A

FIGURES



Dimension 16 — Sitting eye height (relaxed) is not shown on figure.

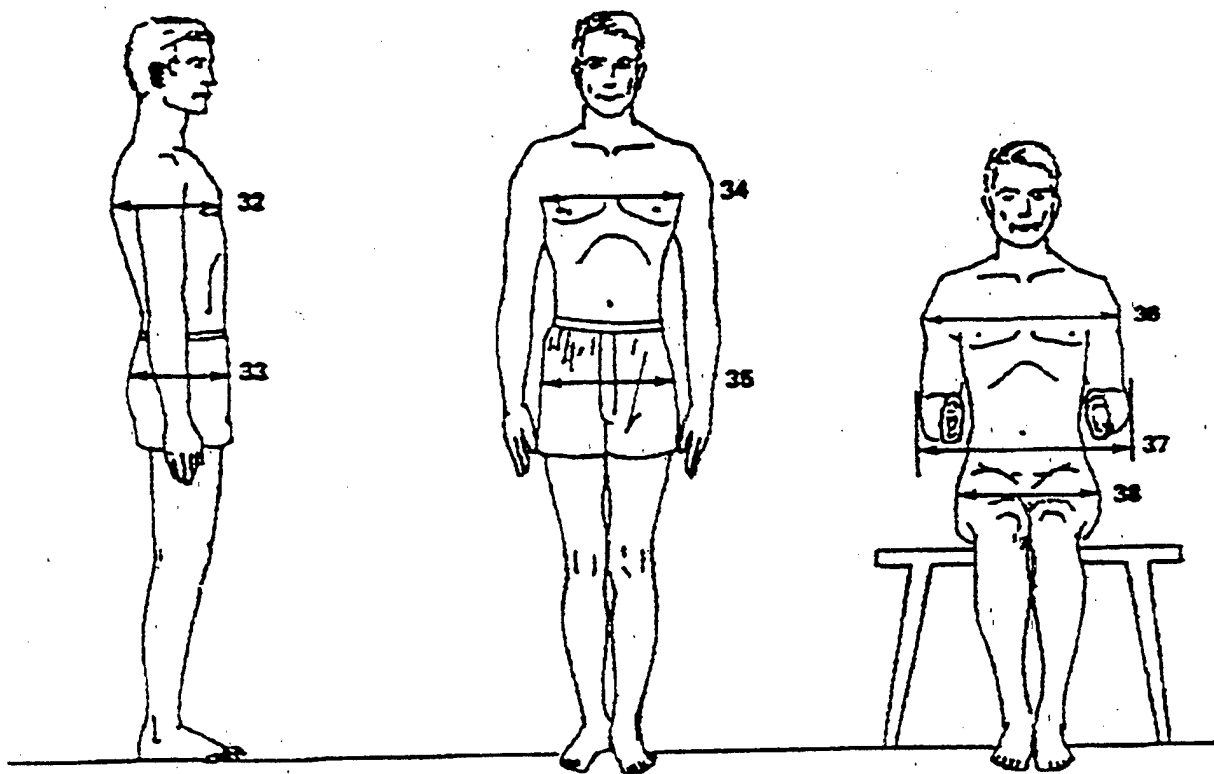
Dimension 30 — not used.

Figure A-1. Seated body dimensions.

Table A-1

Seated Body Dimensions - General Forces

Percentile Values in Centimeters (Inch Equivalents in Parentheses)				
	5th Percentile		95th Percentile	
	Male	Female	Male	Female
14 VERTICAL ARM REACH, SITTING	128.6 (50.6)	123.3 (48.5)	153.2 (60.3)	141.8 (55.8)
15 SITTING HEIGHT, ERECT	85.2 (33.5)	79.5 (31.3)	97.2 (38.3)	91.0 (35.8)
16 SITTING HEIGHT, RELAXED		78.9 (31.1)		89.7 (35.3)
17 EYE HEIGHT SITTING, ERECT	72.9 (28.7)	68.5 (27.0)	85.2 (33.5)	79.4 (31.3)
19 MID-SHOULDER HEIGHT	57.2 (22.5)	53.9 (21.2)	68.6 (27.0)	63.1 (24.8)
20 SHOULDER HEIGHT, SITTING	54.9 (21.6)	50.9 (20.0)	64.6 (25.4)	60.4 (23.8)
21 SHOULDER-ELBOW LENGTH	34.0 (13.4)	28.3 (11.1)	40.2 (15.8)	36.5 (14.4)
22 ELBOW-GRIP LENGTH	33.2 (13.1)	30.0 (11.8)	39.1 (15.4)	35.8 (14.1)
23 ELBOW-FINGERTIP LENGTH	44.4 (17.5)	40.6 (16.0)	52.4 (20.6)	48.3 (19.0)
24 ELBOW REST HEIGHT	18.4 (7.2)	17.6 (6.9)	28.6 (11.3)	26.9 (10.6)
25 THIGH CLEARANCE HEIGHT	13.7 (5.4)	10.4 (4.1)	19.0 (7.5)	18.0 (7.1)
26 KNEE HEIGHT, SITTING	50.0 (19.7)	47.4 (18.7)	60.6 (23.9)	56.0 (22.0)
27 POPLITEAL HEIGHT	39.5 (15.6)	35.1 (13.8)	50.0 (19.7)	44.1 (17.4)
28 BUTTOCK-KNEE LENGTH	55.2 (21.7)	53.2 (20.9)	66.7 (26.3)	64.0 (25.2)
29 BUTTOCK-POPLITEAL LENGTH	45.6 (18.0)	43.5 (17.1)	54.6 (21.5)	52.8 (20.8)
31 FUNCTIONAL LEG LENGTH	100.2 (39.4)	93.3 (36.7)	116.9 (46.0)	109.4 (43.1)



Dimension 39 — not used

Figure A-2. Depth and breadth dimensions.

Table A-2

Depth and Breadth Dimensions - General Forces

Percentile Values in Centimeters (Inch Equivalents in Parentheses)				
	5th Percentile		95th Percentile	
	Male	Female	Male	Female
32 CHEST DEPTH*	20.4 (8.0)	20.9 (8.2)	28.0 (11.0)	27.8 (10.9)
33 BUTTOCK DEPTH	21.2 (8.3)	18.4 (7.2)	28.6 (11.3)	26.5 (10.4)
34 CHEST BREADTH	27.8 (10.9)	25.0 (9.8)	36.7 (14.4)	31.5 (12.4)
35 HIP BREADTH, STANDING	30.5 (12.0)	30.8 (12.1)	38.3 (15.1)	38.8 (15.3)
36 SHOULDER (BIDELTOID) BREADTH	41.8 (16.5)	38.2 (15.0)	53.5 (21.1)	47.2 (18.6)
37 FOREARM-FOREARM BREADTH	47.7 (18.8)	41.5 (16.3)	62.1 (24.4)	52.8 (20.8)
38 HIP BREADTH, SITTING	31.1 (12.2)	33.8 (13.3)	41.3 (16.3)	43.3 (17.0)

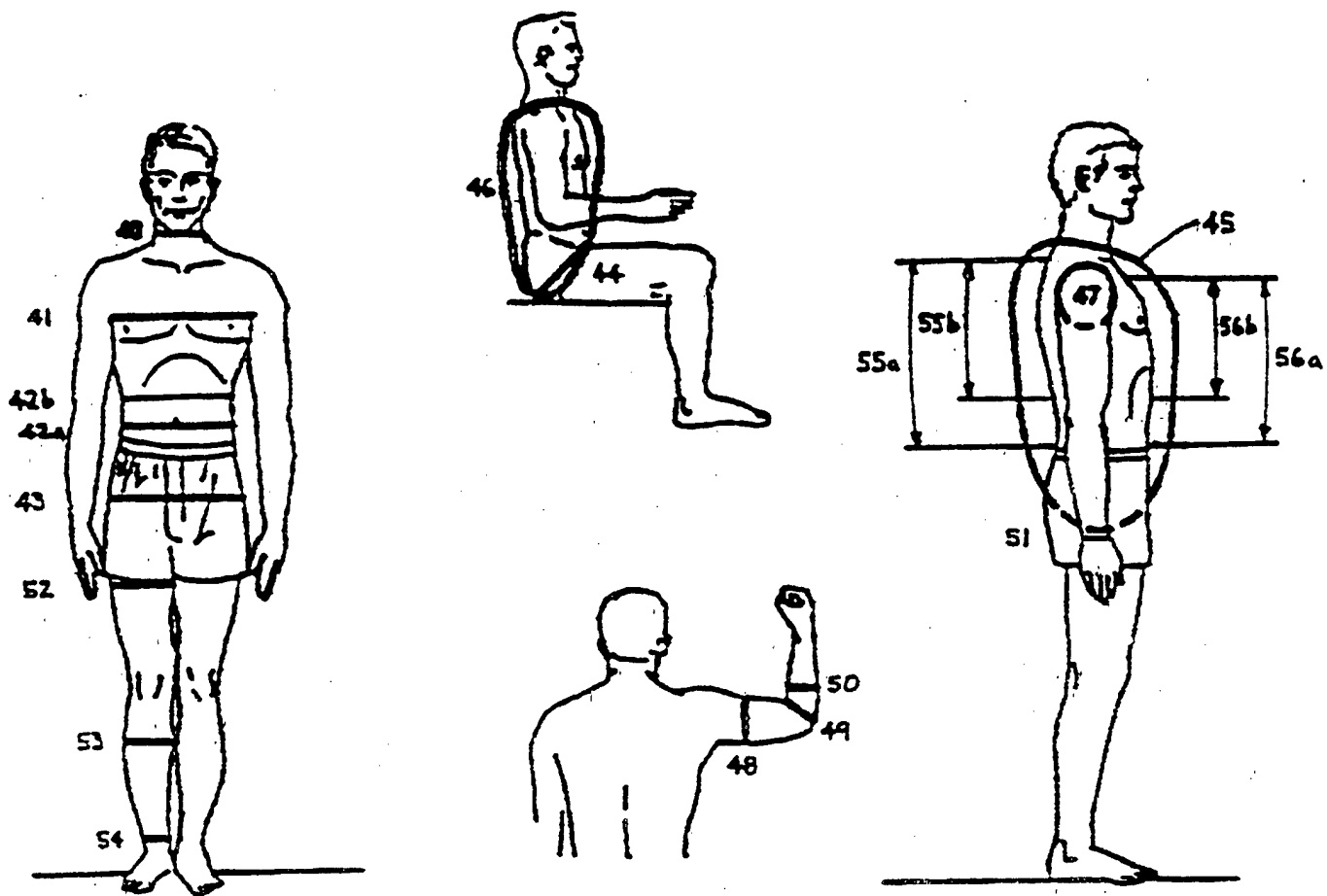


Figure A-3. Circumferences and surface dimensions.

Table A-3

Circumferences and Surface Dimensions - General Forces

Percentile Values in Centimeters (Inch Equivalents in Parentheses)				
	5th Percentile		95th Percentile	
	Male	Female	Male	Female
40 NECK CIRCUMFERENCE	34.7 (13.7)	29.2 (11.5)	41.6 (16.4)	36.7 (14.4)
41 CHEST CIRCUMFERENCE*	85.5 (33.7)	81.4 (32.0)	111.3 (43.8)	102.2 (40.2)
42a WAIST CIRCUMFERENCE (OMPHALION)	70.2 (27.6)	67.6 (26.6)	101.6 (40.0)	94.6 (37.2)
42b WAIST CIRCUMFERENCE (NATURAL INDENTATION)	71.9 (28.3)	59.5 (23.4)	98.4 (38.7)	84.3 (33.2)
43 HIP (BUTTOCK) CIRCUMFERENCE, STANDING	86.7 (34.1)	85.8 (33.8)	109.0 (42.9)	107.0 (42.1)
45 VERTICAL TRUNK CIRCUM- FERENCE, STANDING	150.6 (59.3)	142.0 (55.9)	180.7 (71.1)	166.3 (65.5)
47 ARM SCYE CIRCUMFERENCE	39.9 (15.7)	33.6 (13.2)	49.8 (19.6)	41.2 (16.2)
48 BICEPS CIRCUMFERENCE, FLEXED	27.7 (10.9)	23.3 (9.2)	38.5 (15.2)	32.1 (12.6)
49 ELBOW CIRCUMFERENCE, FLEXED	25.3 (10.0)	21.8 (8.6)	35.0 (13.8)	30.0 (11.8)
50 FOREARM CIRCUMFERENCE, FLEXED	26.5 (10.4)	23.0 (9.1)	33.6 (13.2)	27.9 (11.0)
51 WRIST CIRCUMFERENCE	15.7 (6.2)	13.8 (5.4)	18.8 (7.4)	16.3 (6.4)
52 UPPER THIGH CIRCUMFERENCE	49.1 (19.3)	48.7 (19.2)	67.9 (26.7)	65.7 (25.9)
53 CALF CIRCUMFERENCE	32.7 (12.9)	31.5 (12.4)	42.1 (16.6)	39.1 (15.4)
54 ANKLE CIRCUMFERENCE	20.0 (7.9)	18.6 (7.3)	25.0 (9.8)	23.3 (9.2)
55a WAIST (OMPHALION) - BACK LENGTH	43.5 (17.1)	40.4 (15.9)	52.3 (20.6)	48.5 (19.1)
55b WAIST (NATURAL INDENTATION) BACK LENGTH	37.4 (14.7)	32.7 (12.9)	45.1 (17.8)	44.3 (17.4)
56a WAIST (OMPHALION) - FRONT LENGTH	35.9 (14.1)	35.5 (14.0)	45.7 (18.0)	42.8 (16.9)
56b WAIST (NATURAL INDENTATION) - FRONT LENGTH	31.0 (12.2)	27.5 (10.8)	38.1 (15.0)	36.9 (14.5)

*Bust circumference for women

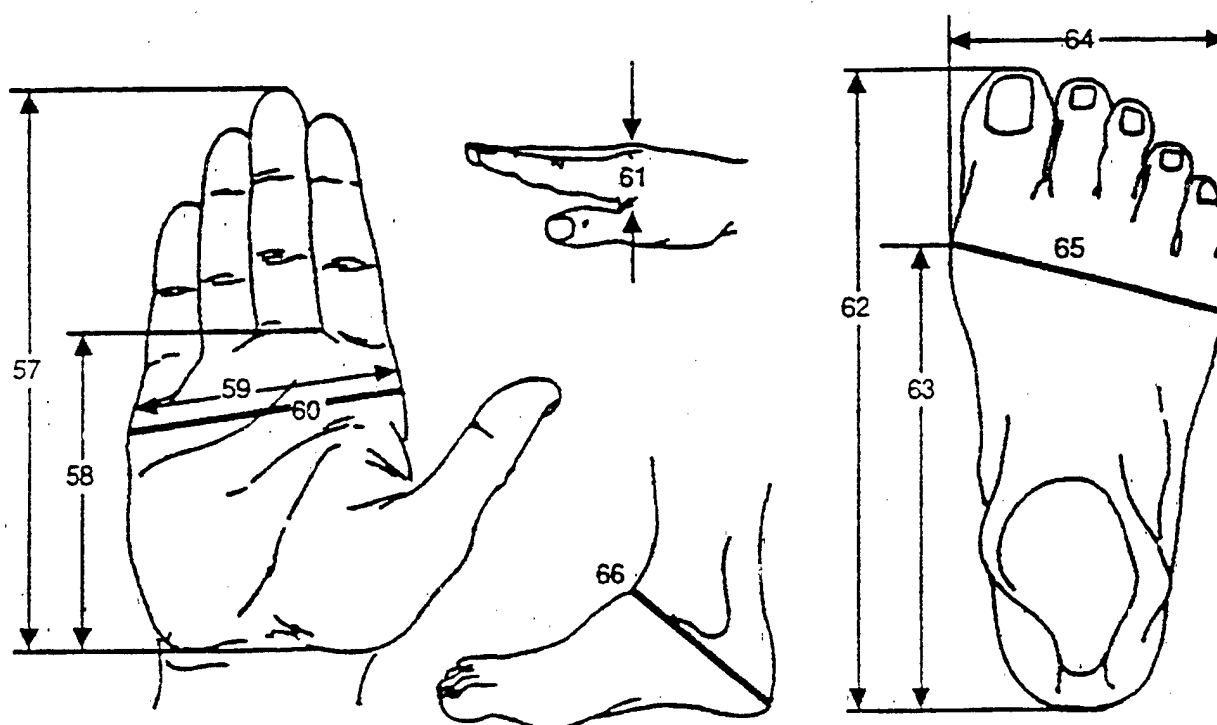


Figure A-4. Hand and foot dimensions.

Table A-4

Hand And Foot Dimensions - General Forces

Percentile Values in Centimeters (Inch Equivalents in Parentheses)				
	5th Percentile		95th Percentile	
	Male	Female	Male	Female
57 HAND LENGTH	17.5 (6.9)	16.5 (6.5)	21.1 (8.3)	20.1 (7.9)
58 PALM LENGTH*	9.6 (3.8)	9.0 (3.5)	11.7 (4.6)	10.8 (4.3)
59 HAND BREADTH	8.2 (3.2)	6.9 (2.7)	9.8 (3.9)	8.6 (3.4)
60 HAND CIRCUMFERENCE	19.9 (7.8)	16.8 (6.6)	23.5 (9.3)	20.0 (7.9)
62 FOOT LENGTH	24.6 (9.7)	22.2 (8.7)	29.2 (11.5)	26.5 (10.4)
63 INSTEP LENGTH	17.9 (7.0)	16.4 (6.5)	21.4 (8.4)	19.5 (7.7)
64 FOOT BREADTH	9.0 (3.5)	8.0 (3.1)	11.0 (4.3)	9.8 (3.9)
65 FOOT CIRCUMFERENCE	22.9 (9.0)	20.5 (8.1)	27.3 (10.7)	24.2 (9.5)
66 HEEL-ANKLE CIRCUMFERENCE	31.3 (12.3)	28.1 (11.1)	36.9 (14.5)	33.0 (13.0)

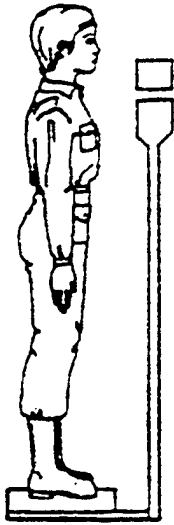
* Data for males were compiled from the 1966 survey of U.S. Army Men, the 1966 survey of U.S. Marines, and the 1965 survey of U.S. Air Force Men. Data for females were compiled from the 1977 survey of U.S. Army Women and the 1968 survey of U.S. Air Force Women.

Table A-5

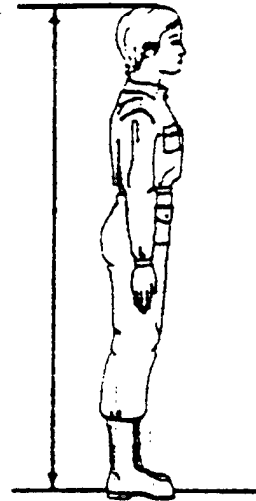
Anthropometric Data for Common Working Positions

	PERCENTILE VALUES IN CENTIMETERS			
	5th PERCENTILE		95th PERCENTILE	
	MEN	WOMEN	MEN	WOMEN
1. WEIGHT – CLOTHED (KILOGRAMS)	58.6	48.8	90.2	74.6
2. STATURE – CLOTHED	168.5	156.8	189.0	178.7
3. FUNCTIONAL REACH	72.6	64.0	86.4	79.0
4. FUNCTIONAL REACH, EXTENDED	84.2	73.5	101.2	92.7
5. OVERHEAD REACH HEIGHT	200.4	185.3	230.5	215.1
6. OVERHEAD REACH BREADTH	35.2	31.5	41.9	37.9
7. BENT TORSO HEIGHT	125.6	112.7	149.8	138.6
8. BENT TORSO BREADTH	40.9	36.8	48.3	43.5
9. OVERHEAD REACH, SITTING	127.9	117.4	146.9	139.4
10. FUNCTIONAL LEG LENGTH	110.6	99.6	127.7	118.6
11. KNEELING HEIGHT	121.9	114.5	136.9	130.3
12. KNEELING LEG LENGTH	63.9	59.2	75.5	70.5
13. BENT KNEE HEIGHT, SUPINE	44.7	41.3	53.5	49.6
14. HORIZONTAL LENGTH, KNEES BENT	150.8	140.3	173.0	163.8
	PERCENTILE VALUES IN INCHES			
	5th PERCENTILE		95th PERCENTILE	
	MEN	WOMEN	MEN	WOMEN
1. WEIGHT – CLOTHED (POUNDS)	129.1	107.6	198.8	164.5
2. STATURE – CLOTHED	66.4	61.8	74.4	70.3
3. FUNCTIONAL REACH	28.6	25.2	34.0	31.1
4. FUNCTIONAL REACH, EXTENDED	33.2	28.9	39.8	36.5
5. OVERHEAD REACH HEIGHT	78.9	73.0	90.8	84.7
6. OVERHEAD REACH BREADTH	13.9	12.4	16.5	14.9
7. BENT TORSO HEIGHT	49.4	44.4	59.0	54.6
8. BENT TORSO BREADTH	16.1	14.5	19.0	17.1
9. OVERHEAD REACH, SITTING	50.3	46.2	57.9	54.9
10. FUNCTIONAL LEG LENGTH	43.5	39.2	50.3	46.7
11. KNEELING HEIGHT	48.0	45.1	53.9	51.3
12. KNEELING LEG LENGTH	25.2	23.3	29.7	27.8
13. BENT KNEE HEIGHT, SUPINE	17.6	16.3	21.1	19.5
14. HORIZONTAL LENGTH, KNEES BENT	59.4	55.2	68.1	64.5

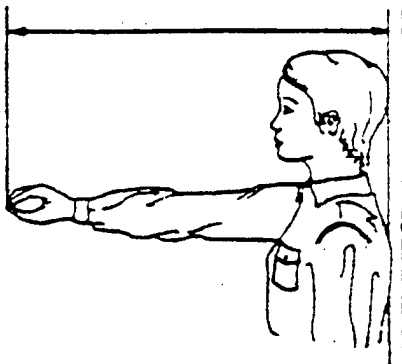
*See Figure 29 for illustration of each measurement.



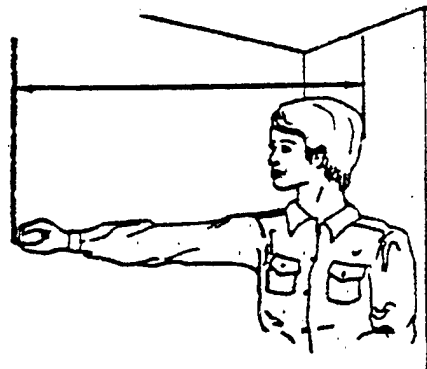
- ① **WEIGHT (CLOTHED)**
WEARING FATIGUES &
COMBAT BOOTS; STANDING
IN CENTER OF SCALE



- ② **STATURE (CLOTHED)**
STANDING ERECT; HEELS
TOGETHER; WEIGHT DIS-
TRIBUTED EQUALLY ON BOTH
FEET. MEASURED FROM STANDING
SURFACE TO TOP OF HEAD.

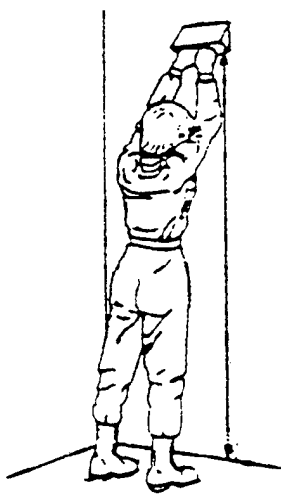


- ③ **FUNCTIONAL REACH – STANDING
ERECT; LOOKING STRAIGHT
AHEAD; BOTH SHOULDERS AGAINST
WALL; RIGHT ARM HORIZONTAL.**
MEASURED FROM WALL TO TIP OF
INDEX FINGER

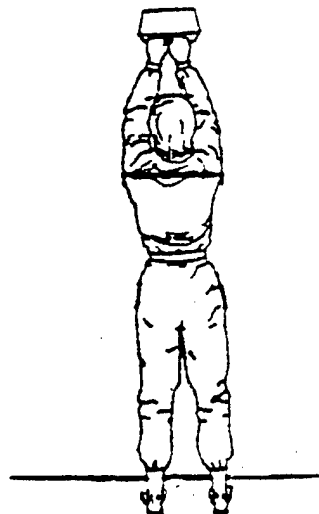


- ④ **FUNCTIONAL REACH, EXTENDED—
STANDING ERECT; LOOKING STRAIGHT
AHEAD; RIGHT SHOULDER EXTENDED
AS FAR FORWARD AS POSSIBLE WHILE
BACK OF LEFT SHOULDER FIRMLY
AGAINST WALL; ARM HORIZONTAL.**
MEASURED FROM WALL TO TIP OF
INDEX FINGER.

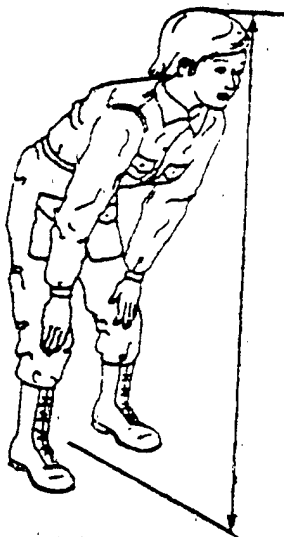
Figure A-5. Anthropometric data for work spaces.



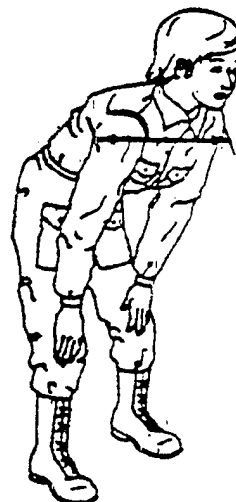
- ⑤ **OVERHEAD REACH HEIGHT** –
STANDING WITH HEELS 23 cm
APART AND TOES 15 cm FROM
WALL; ARMS EXTENDED OVER-
HEAD WITH FISTS TOUCHING
AND AGAINST WALL; 1st
PHALANGES HORIZONTAL.
MEASURED FROM FLOOR TO
HIGHEST POINT ON 1st PHALANGES



- ⑥ **OVERHEAD REACH BREADTH** –
STANDING WITH HEELS 23 cm APART
AND TOES 15 cm FROM WALL; ARMS
EXTENDED OVERHEAD WITH FISTS
TOUCHING AND AGAINST WALL; 1st
PHALANGES HORIZONTAL. MEASURED
HORIZONTALLY ACROSS ARMS OR
SHOULDERS, WHICHEVER IS WIDER.



- ⑦ **BENT TORSO HEIGHT** –
STANDING WITH FEET 30 cm APART;
BENDING OVER AND PLACING PALMS OF
THE HANDS ON KNEECAPS; ELBOWS AND
KNEES LOCKED; LOOKING FORWARD;
HEAD TILTED AS FAR BACK AS POSSIBLE.
MEASURED FROM FLOOR TO TOP OF HEAD.

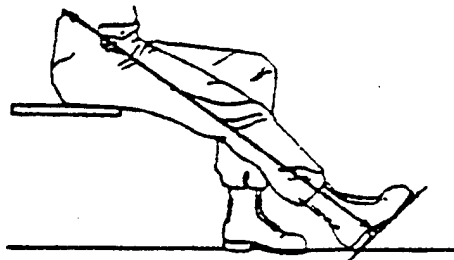


- ⑧ **BENT TORSO BREADTH** –
STANDING WITH FEET 30 cm APART;
BENDING OVER AND PLACING THE PALMS
OF THE HANDS ON KNEECAPS; ELBOWS
AND KNEES LOCKED; LOOKING FORWARD;
HEAD TILTED AS FAR BACK AS POSSIBLE.
MEASURED AS MAXIMUM HORIZONTAL
DISTANCE ACROSS SHOULDERS.

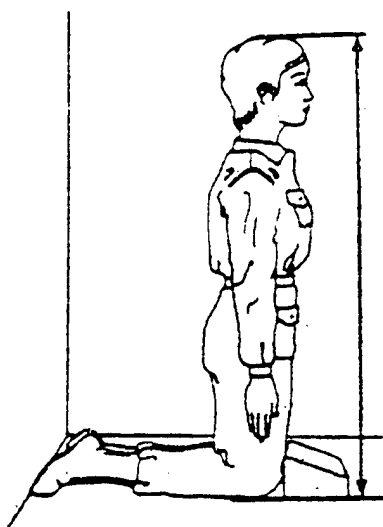
Figure A-5. Anthropometric data for work spaces (continued)



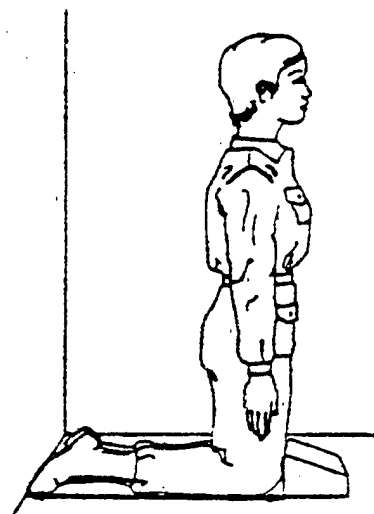
- ⑨ **OVERHEAD REACH, SITTING** – SITTING ERECT; RIGHT SIDE AGAINST WALL; RIGHT ARM EXTENDED UPWARD WITH PALM FLAT AGAINST WALL AND FINGERS EXTENDED. MEASURED FROM SITTING SURFACE TO TIP OF MIDDLE FINGER.



- ⑩ **FUNCTIONAL LEG LENGTH** – SITTING ERECT ON EDGE OF CHAIR; RIGHT LEG EXTENDED FORWARD WITH KNEE STRAIGHTENED. MEASURED FROM HEEL ALONG AXIS OF LEG TO POSTERIOR WAIST.

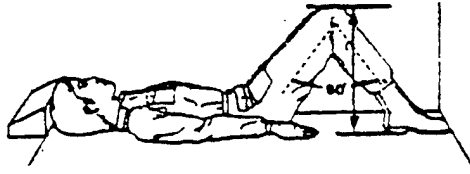


- ⑪ **KNEELING HEIGHT** – KNEELING WITH TOES EXTENDED AND LIGHTLY TOUCHING REAR WALL; TORSO ERECT WITH ARMS HANGING LOOSELY AT SIDES. MEASURED FROM FLOOR TO TOP OF HEAD.

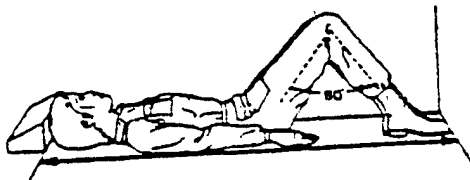


- ⑫ **KNEELING LEG LENGTH** – KNEELING WITH TOES EXTENDED AND LIGHTLY TOUCHING REAR WALL; TORSO ERECT WITH ARMS HANGING LOOSELY AT SIDES. MEASURED FROM WALL TO ANTERIOR PORTION OF BOTH KNEES.

Figure A-5. Anthropometric data for work spaces (continued)



- 13 BENT KNEE HEIGHT, SUPINE —
LYING SUPINE; KNEES RAISED UNTIL ANGLE
BETWEEN UPPER AND LOWER LEGS APPROX-
IMATES 60° ; TOES LIGHTLY TOUCHING WALL.
MEASURED FROM FLOOR TO HIGHEST POINT
ON KNEES.



- 14 HORIZONTAL LENGTH, KNEES BENT —
LYING SUPINE; KNEES RAISED UNTIL
ANGLE BETWEEN UPPER AND LOWER LEGS
APPROXIMATES 60° ; TOES LIGHTLY
TOUCHING WALL. MEASURED FROM WALL
TO TOP OF HEAD.

Figure A-5. Anthropometric data for work spaces (concluded)

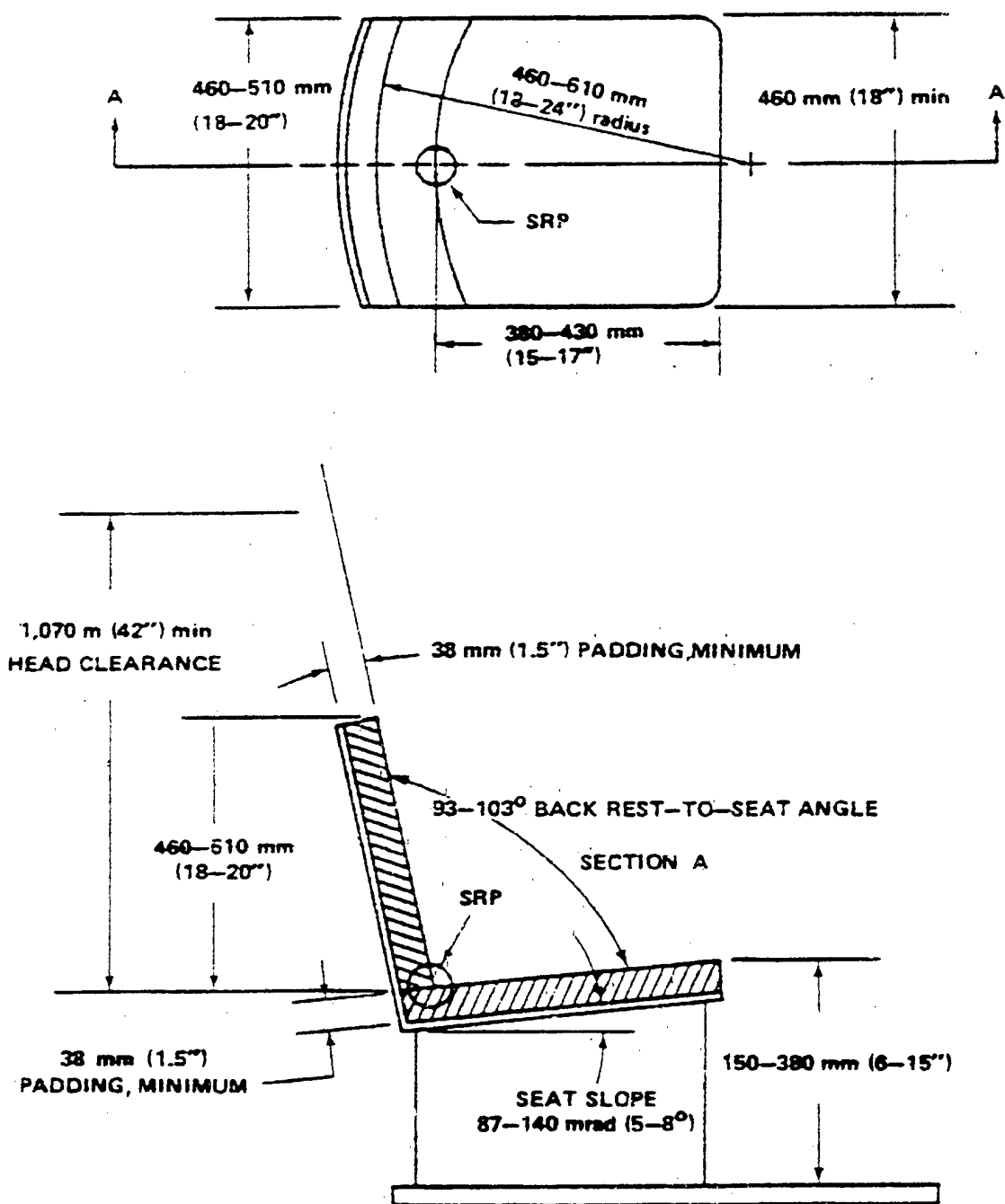


Figure A-6. Dimensions for vehicle operator's seat.

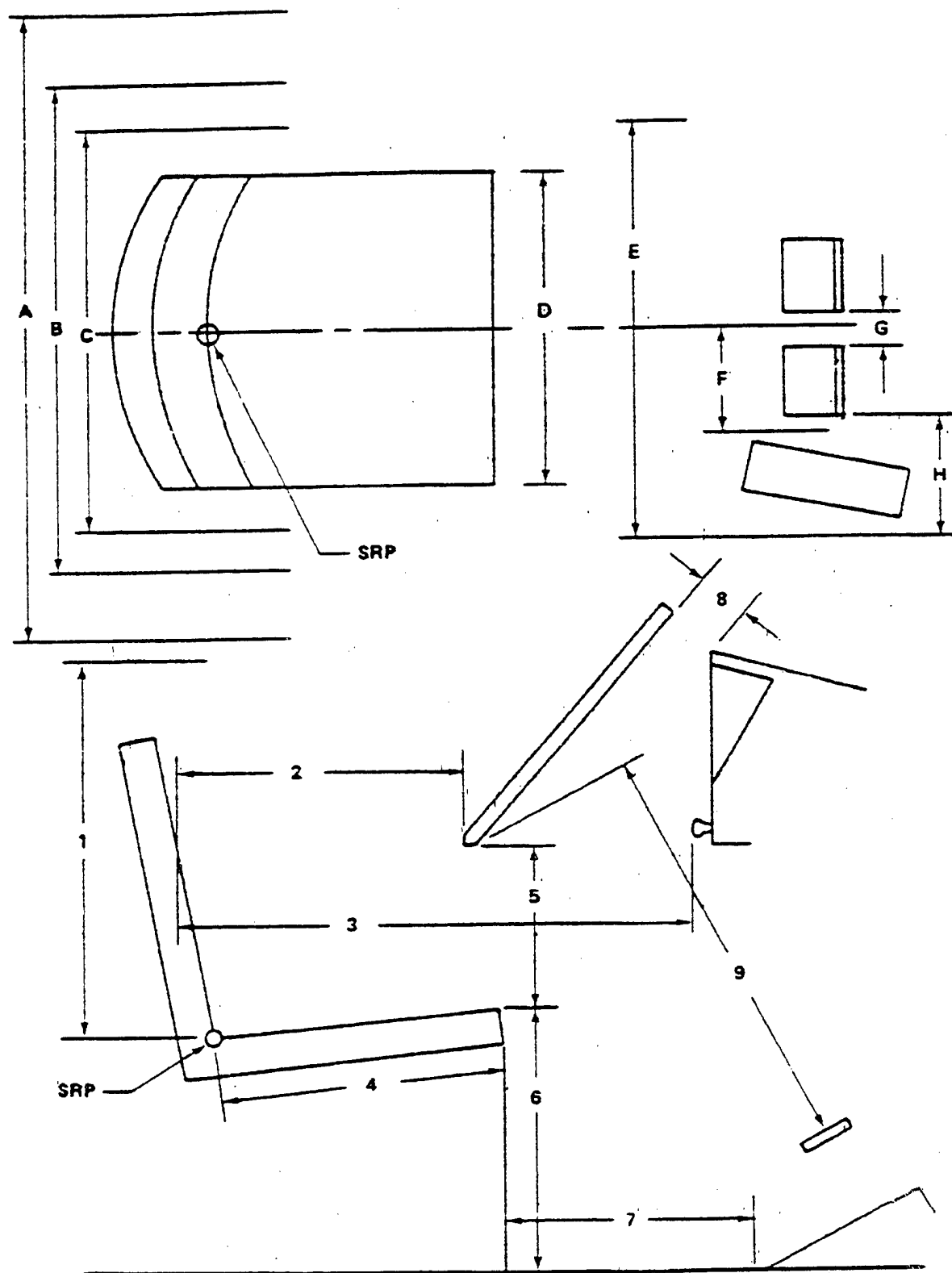


Figure A-7. Recommended clearances around equipment operator's station (see Table A-6).

Table A-6

Recommended Clearances Around Equipment Operator's Station to Accommodate the 95th Percentile Soldier Dressed in Arctic Clothing (operator seat in rear-most position [Figure A-9])

A. ELBOW (DYNAMIC)	910 mm (36 in.)
B. ELBOW (STATIC)	710 mm (28 in.)
C. SHOULDER	580 mm (23 in.)
D. KNEE WIDTH (MINIMUM)	460 mm (18 in.)
E. KNEE WIDTH (OPTIMUM)	610 mm (24 in.)
F. BOOT – PROVIDE ADEQUATE CLEARANCE TO OPERATE BRAKE PEDAL WITHOUT INADVERTENT ACCELERATION OPERATION	150 mm (6 in.)
G. PEDALS (MINIMUM)	50 mm (2 in.)
H. BOOT – PROVIDE ADEQUATE CLEARANCE TO OPERATE ACCELERATOR WITHOUT INTERFERENCE BY BRAKE PEDAL	150 mm (6 in.)
1. HEAD (SRP TO ROOF LINE)	1070 mm (42 in.)
2. ABDOMINAL (SEAT BACK TO STEERING WHEEL)	410 mm (16 in.)
3. FRONT OF KNEE (SEAT BACK TO MANUALS/CONTROLS ON DASH)	740 mm (29 in.)
4. SEAT DEPTH (SEAT REFERENCE POINT TO FRONT EDGE OF SEAT PAN)	410 mm (16 in.)
5. THIGH – UNDER SIDE OF STEERING WHEEL TO SEAT PAN	240 mm (9.5 in.)
6. SEAT PAN HEIGHT	380 mm (15 in.)
7. BOOT (FRONT OF SEAT PAN TO HEEL POINT OF ACCELERATOR)	360 mm (14 in.)
8. MINIMUM MITTEN CLEARANCE AROUND STEERING WHEEL	75 mm (3 in.)
9. KNEE – LEG – THIGH (BRAKE – CLUTCH PEDAL) TO LOWER EDGE OF STEERING WHEEL	660 mm (26 in.)

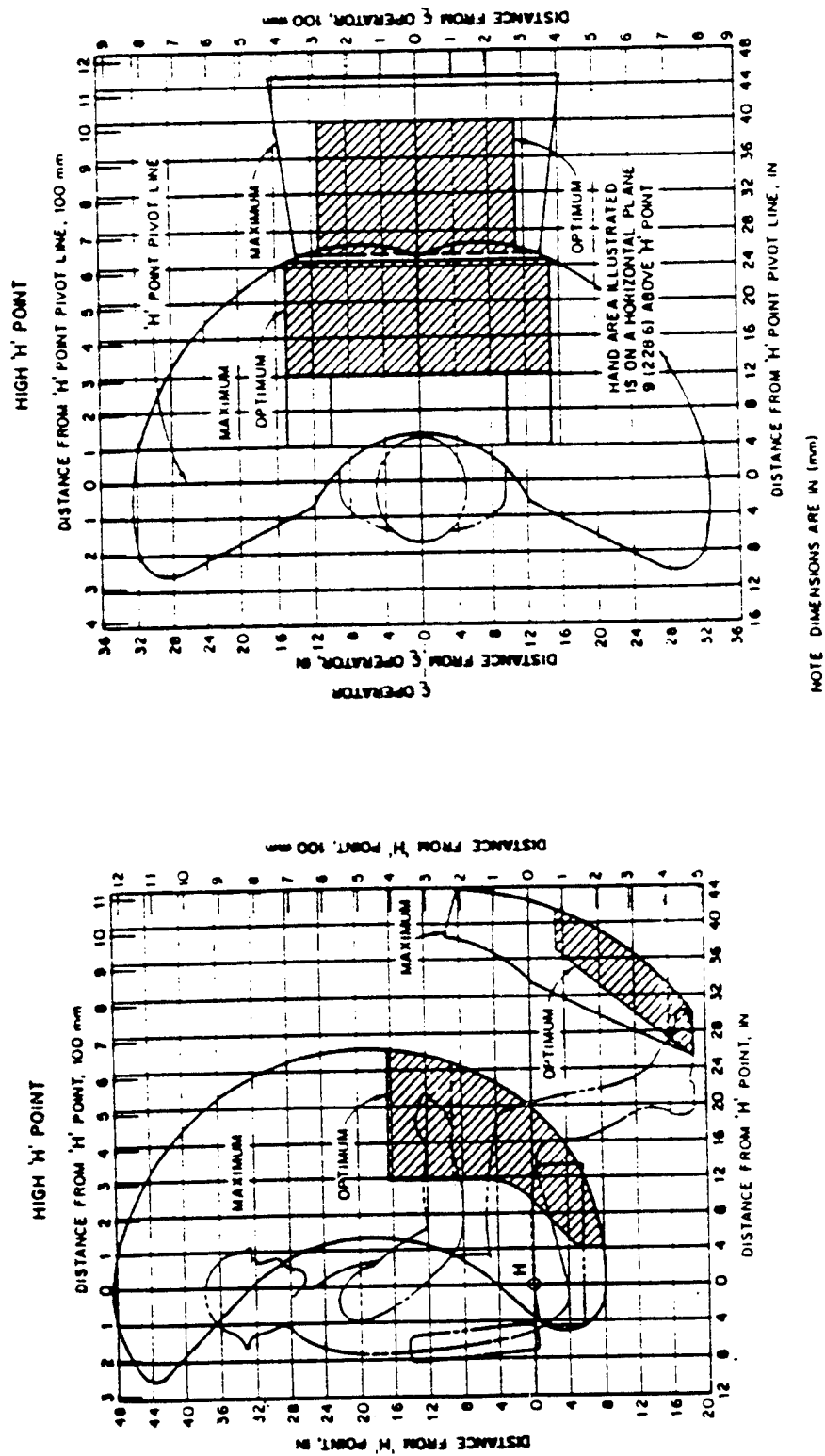
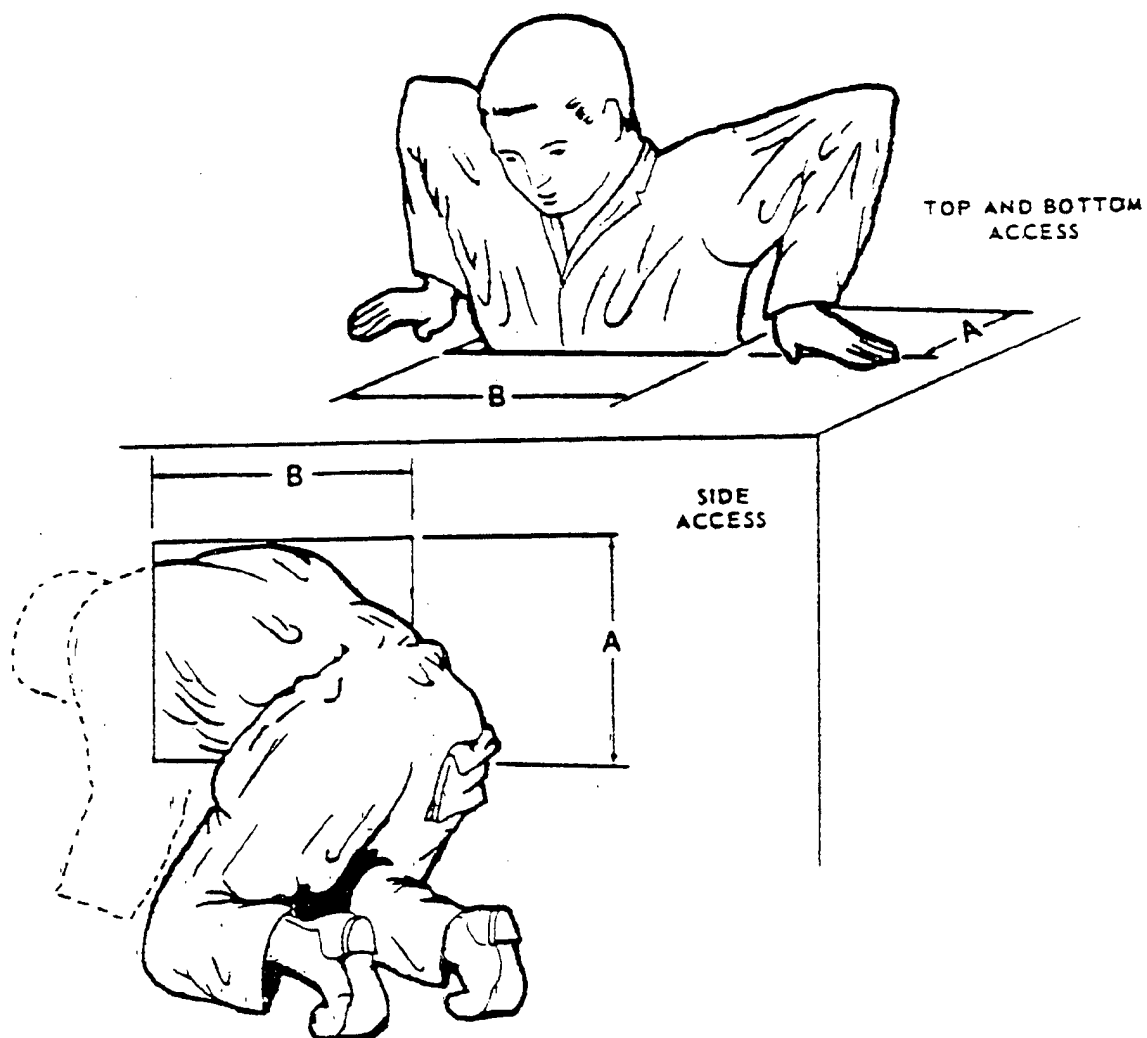


Figure A-8. Optimum and maximum hand and foot control space for high hip-point (H) location. (The figure illustrates a 95th percentile U.S. male construction worker with the seat in the rear position of fore-and-aft adjustment. Provision of 4-inch adjustability accommodates 90% of the operator population [source: SAE J898 Recommended Practice, SAE, 1980].)



DIMENSIONS	A. DEPTH		B. WIDTH	
	CLOTHING			
TOP AND BOTTOM ACCESS	LIGHT	BULKY	LIGHT	BULKY
	330 mm (13 in.)	410 mm (16 in.)	580 mm (23 in.)	690 mm (27 in.)
SIDE ACCESS	660 mm (26 in.)	740 mm (29 in.)	760 mm (30 in.)	860 mm (34 in.)

NOTE: DIMENSIONS SHOWN BASED ON MALE DATA.

Figure A-9. Whole body access opening.

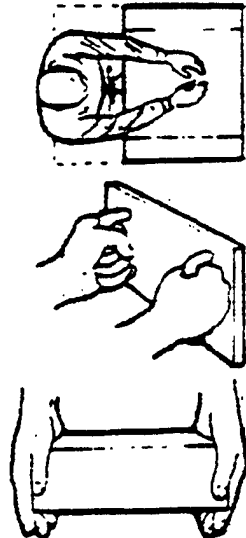
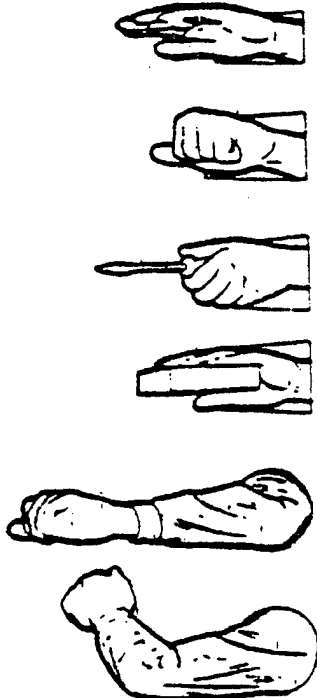
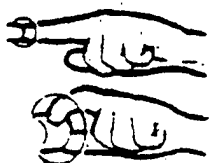
MINIMAL TWO-HAND ACCESS OPENINGS WITHOUT VISUAL ACCESS																																																																																
<u>Reaching with both hands to depth of 150 to 490mm:</u> Light clothing: Width: 200mm or the depth of reach* Height: 125mm Arctic clothing: Width: 150mm plus 3/4 the depth of reach Height: 180mm <u>Reaching full arm's length (to shoulders) with both arms:</u> Width: 500mm Height: 125mm <u>Inserting box grasped by handles on the front:</u> 13mm clearance around box, assuming adequate clearance around handles <u>Inserting box with hands on the sides:</u> Light clothing: Width Box plus 115mm ± Height: 125mm or 13mm around box* Arctic clothing: Width: Box plus 180mm ± Height: 215mm or 15mm around box* *Whichever is larger. ±If hands curl around bottom, allow an extra 38mm for light clothing, 75mm for arctic clothing.																																																																																
MINIMAL ONE-HAND ACCESS OPENINGS WITHOUT VISUAL ACCESS																																																																																
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<u>Push button access:</u> Bare hand: 32mm dia Gloved hand: 38mm dia <u>Two finger twist access:</u> Bare hand: object plus 50mm Gloved hand: object plus 65mm																																																																																

Figure A-10. Arm and hand access dimensions in millimeters.

MINIMAL TWO-HAND ACCESS OPENINGS WITHOUT VISUAL ACCESS

Reaching with both hands to depth of 6 to 19.25 inches:

Light clothing:	Width:	8" or the depth of reach*
	Height:	5"
Arctic clothing:	Width:	6" plus 3/4 the depth of reach
	Height:	7"

Reaching full arm's length (to shoulders) with both arms:

Width:	19.5"
Height:	5"

Inserting box grasp by handles on the front:

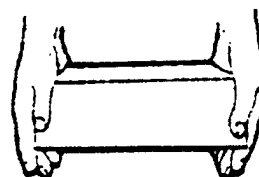
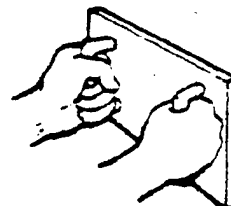
1/2" clearance around box, assuming adequate clearance around handles

Inserting box with hands on the sides:

Light clothing:	Width:	Box plus 4.5"
	Height:	5" or 0.5" around box*
Arctic clothing:	Width:	Box plus 7"
	Height:	8.5" or 0.5" around box*

* Whichever is larger.

: If hands curl around bottom, allow an extra 1.5" for light clothing, 3" for arctic clothing.



MINIMAL ONE-HAND ACCESS OPENINGS WITHOUT VISUAL ACCESS

Empty hand, to wrist:

	Height	Width
Bare hand, rolled:	3.75"	sq or dia
Bare hand, flat:	2.25"	x 4.0" or 4.0" dia
Glove or mitten:	4.0"	x 6.0" or 6.0" dia
Arctic mitten:	5.0"	x 6.5" or 6.5" dia

Clenched hand, to wrist:

Bare hand:	3.5"	x 5.0" or 5.0" dia
Glove or mitten:	4.5"	x 6.0" or 6.0" dia
Arctic mitten:	7.0"	x 8.5" or 8.5" dia

Hand plus 1" dia object, to wrist:

Bare hand:	3.75"	sq or dia
Gloved hand:	6.0"	sq or dia
Arctic mitten:	7.0"	sq or dia

Hand plus object over 1" in dia, to wrist:

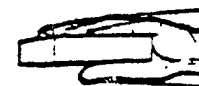
Bare hand:	1.75"	clearance around object
Glove or mitten:	2.5"	clearance around object
Arctic mitten:	3.5"	clearance around object

Arm to elbow:

Light clothing:	4.0" x 4.5" or 4.5" dia
Arctic clothing:	7.0" sq or dia
With object:	Clearances as above

Arm to shoulder:

Light clothing:	5.0" sq or dia
Arctic clothing:	8.5" sq or dia
With object:	Clearances as above



MINIMAL FINGER ACCESS TO FIRST JOINT

Push button access:

Bare hand:	1.25" dia
Gloved hand:	1.5" dia

Two finger twist access:

Bare hand:	object plus 2.0" dia
Gloved hand:	object plus 2.5" dia



Figure A-10. Arm and hand access dimensions (continued).

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