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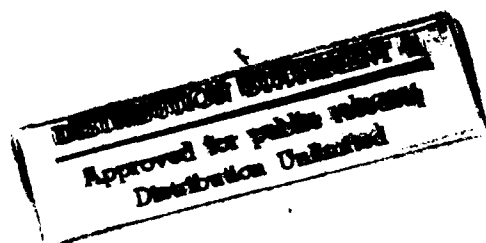


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DEVELOPMENT OF A STANDARD ANTHROPOMETRIC DIMENSION SET FOR USE IN COMPUTER-AIDED GLOVE DESIGN (U)

by

D. Hidson



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DEFENCE RESEARCH ESTABLISHMENT OTTAWA
TECHNICAL NOTE 91-22

Canada

October 1991
Ottawa

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Protective Sciences Division

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ABSTRACT

Anthropometric variables have always been measured with tapes and calipers and the data gathered have been the source material for designers and patternmakers in the development of NBCW protective equipment. This paper describes the re-assessment of the variables and dimensions under consideration and the construction of a new set of variables, for measuring hands, localized in three-dimensional space, that may be measured by traditional techniques but yet be suited to CAD/CAM applications. A set of fifty dimensions was devised and a datum from which to measure was defined. Data were taken from a small sample of hands and a computerized model constructed. Models may be constructed from fewer dimensions but there will be less variability in the resultant surface.

RÉSUMÉ

Les variables anthropométriques ont toujours été mesurées à l'aide de rubans et verniers et les données recueillies ont été une ressource de base pour les dessinateurs et modeleurs dans le développement d'équipement protecteur NBC. Ce document décrit la ré-évaluation des variables et dimensions en question et la construction d'un nouvel ensemble de variables, localisé dans un espace à trois dimensions, qui peut être mesuré avec des techniques traditionnelles mais aussi être adaptable pour des applications de CAO/FAO. Un ensemble de cinquante dimensions fut élaboré ainsi qu'un point de repère duquel les mesures sont définies. Les données furent prises d'un petit échantillonnage de mains et un modèle par ordinateur fut construit. Les modèles peuvent être construits à partir d'un plus petit nombre de dimensions mais la surface résultante aura moins de variabilité.



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EXECUTIVE SUMMARY

The design of protective equipment requires large amounts of accurate, anthropometric data which describes the dimensions and shape of the human body. The use of computers in engineering design demands that the data be suitable for entry into a computer and that the variables measured be useful and appropriate for a computer-aided design and manufacturing system. In this regard, location of the variables relative to a defined datum in three dimensions is important and is defined here. The purpose of the work here is to determine how many variables are required for the adequate definition of a hand-shape so relevant to glove design.

Fifty dimensions consisting of lengths, breadths and depths of the hand were taken at critical points using the anthropometric instruments. The data were modelled on a computer-aided design system and a fully three-dimensional computer model was created as proof of concept. More dimensions may be used in defining the shape of the hand to an arbitrary degree of accuracy, but the fifty one used here offer a good compromise.

1.0 INTRODUCTION

Articles of clothing and personal equipment are notoriously difficult to fit to a general population. Variations in human form, in size and shape, mean that any glove, helmet or shoe has to be made in a large range of sizes. This large range is also a result of the fact that any one item (e.g. a glove) may require more than one defining dimension (e.g. hand length and hand breadth) which leads to a rapidly expanding number of sizes for any given population that needs fitting.

The purpose of this paper is twofold: first, to review the extent of anthropometric information on hands available to researchers and designers and second, to describe the work done at DREO in devising a new set of anthropometric criteria for CW glove design that is compatible with computer-aided design and manufacturing (CAD/CAM) equipment.

The design, prototyping and testing of new equipment for defence of the soldier against chemical and biological weapons is part of the mandate of Chemical Protection Section at DREO. The glove is worn as part of the chemical warfare protective ensemble of mask, one-piece suit and overboots. The CW glove presently in service with the Canadian Forces was designed many years ago and consists of a knitted fabric base coated with a layer of protective rubber. It is thick and tends to exacerbate heat stress and reduce dexterity required for complex tasks. A light-weight version consisting only of polymer, but providing less chemical protection is available as well. The final objective of this work is to produce a inexpensive close-fitting, light-weight CB glove that offers excellent protection.

We shall first survey the current literature and then describe the design philosophy we used to construct a set of anthropometric variables that would capture the information required to model a hand and design a glove and that is compatible with CAD/CAM equipment and design techniques.

2.0 BACKGROUND

The use of anthropometry in protective equipment design has been reviewed at length (1) in a previous document. The data available were gleaned from either a few comprehensive surveys carried out by one or more branches of the American military, usually encompassing several thousand subjects, or a few surveys limited both in the scope of parameters and/or the number of subjects.

Most anthropometric surveys involve measurement of various parameters over the whole body (2) but some are specific to one particular area such as the head (3) or the hands (4). These parameters are measured with calipers and tape measures. The calipers are used for the point-to-point dimensions (usually small, straight lengths such as hand length or breadth) and the tape measure for the distances (usually long and curved dimensions such as head circumference or the various bitracion curvatures). More recent surveys such as the Anthropometric Survey of Canadian Forces Women (5) and the 1985 Anthropometric Survey of Canadian Forces Aircrew (6) contain the absolute minimum of hand measurements: the former only two (hand length and hand breadth) and the latter four (hand length, palm length, hand circumference-metacarpale and hand thickness at metacarpale III). While so few dimensions may be suitable for fitting gloves, they are completely inadequate for designing them where a much larger number of parameters has to be specified as, for instance, in the case where computer-aided design techniques are used.

A more recent report on the design of chemical defence gloves by Robinette and Annis (4) (of ARP - the Anthropological Research Project) uses twenty four dimensions for the hand. Although the report and the work done stems from the mid-1980s, the actual data gathering on the population was performed much earlier for other surveys (7,8). In the earlier survey by Garrett, more than fifty hand dimensions were measured. The Robinette report describes the selection of key dimensions for the design of chemical defence gloves. Not only does the key dimension determine which size a person will wear, it should be easily measured. Their report recommended two key dimensions for determining the size to be worn by the subject: hand length and hand circumference.

From the sampled population a set of glove sizes had to be determined. A two-dimensional plot of the data corresponding to the two variables under consideration showed the distribution of the variables and the correlation between them. Correlation between anthropometric parameters is notoriously weak. From this distribution one may determine the number of sizes required to fit the data given the quantitative difference between the sizes. This is where compromises between the number of sizes and the sizing intervals were made. In this case, the number of sizes chosen was nine. Once the number of sizes had been chosen, the sizing intervals were determined.

It was noted that the distribution of individuals within any given size category was not Gaussian but tended to cluster around the mean. The final design values were calculated from a "within-a-size" mean^a, the mid-size value, and the standard deviation, σ_s , where the subscript, s, denotes a subset of the total population.

^aSee Appendix A for a description of these terms.

Each size would then have a range of values to be accommodated (i.e. the mid-size value plus or minus some number of standard deviations e.g., $\pm 1.65\sigma_s$). Normally, the size for any particular dimension is chosen at the top end of a range with the understanding that a smaller person can wear a larger size but a large person cannot wear a smaller size. However, an exception was made in the situation with the chemical defence glove; a snug fit was very important and thus the mid-size value was chosen in almost all of the cases.

As the sexes differ in anthropometric proportion, the female data was used to determine the dimensions for the small sizes and the male data for the large sizes. For the medium sizes, both sets of data were used.

Dimensions were also provided for design parameters that included allowance for a one-millimeter thick liner. This affected the various circumferential measurements. Some length measurements were also affected.

2.1 DESIGN PROBLEMS FOR THE PATTERNAKER

The job of patternmaker is one of the last surviving craft industries. Great skill of eye and hand is required to take the diverse information available and turn it into a model for an anthropometrically-dimensioned hand.

Although many dimensions help to define a shape better, for complex shapes like the hand, the process of design leaves much to the designer. For an article like the glove, a stylized version of a hand, with all its surfaces and curves, has to be constructed from only twenty four measurements. Clearly, much is left for the designer to infer. Also, the differences between the sizes lead to compromises in the dimensions.

Before the introduction of computers, all the model making was performed using sculpting techniques in plaster and clay. Once a physical model had been constructed, the dimensions had to be checked against the master values to ensure that the variation was minimal. Where dimensions were missing, that is, where it is not clear where a dimension was to be located, some guesswork had to be used. Previous checks on the design dimensions of models and the resulting dimensions of the forms created from them have revealed significant differences (9).

One of the major difficulties of anthropometric modelling is the lack of correlation between the important variables. This means that when dimensions are taken and averaged with a view to generating dimensions for the various sizes, there is no guaranty that a person with a medium hand breadth, say, will have a medium

hand length. The generality of this condition adds to the complexity of fitting a certain population with a protective item and to the need for more sizes than might be apparent at a first glance.

When forms are made to define the shape of a face or hand, these forms are then used to design an item such as a respirator or glove. If any discrepancies are present in the critical dimensions of the form they will be transferred to the item being designed around it. The final product can be made only after a mold has been made from the glove or respirator model and this extra step allows more errors to be introduced.

3.0 INTRODUCTION OF CAD/CAM TECHNIQUES

The introduction of various techniques of computerization presents solutions to some of these problems while raising new questions at the same time. Data can be manipulated and transformed without introducing new errors but the requirements of computers mean that new types of data need to be considered and new variables measured.

Many techniques, such as sonic digitization and laser scanning, are available that can digitize three-dimensional objects including complex anthropometric shapes. These data can then be massaged and modelled with computer graphics to display fully surfaced models of the objects. A fully-surfaced model means that the defining curves and their resultant surfaces are mathematically defined in the computer and it is possible to locate any point on the surface. These shapes are required as data input for computer-aided manufacturing systems. This has been done with heads, feet (10) and even teeth (11). The problem of manipulating data and maintaining accuracy is essentially solved by the computer.

However, new problems arise when one is considering the use of computer models of anthropometric shapes. When protective equipment is being designed, whether gloves, masks or boots, it has to fit most of the target population group (usually 95% or more). This is not done by exact copying of anthropometric shapes or data but by the generation of a stylized rendition of the data. In some respects, this simplifies the problem and in others complicates it. It simplifies it to the extent that simpler surfaces can be used in computer models reducing memory requirements and computation times, but complicates it to the extent that the necessity of developing a variety of different sizes means that average dimensions have to be deduced from a large quantity of anthropometric data and these dimensions applied to a computer model.

3.1 DEFINITION OF NEW VARIABLES FOR QUANTIFYING HANDS

To begin, we considered the needs of the computer-aided design system for quantitative information. In the literature, most of these data defining hands consisted of point-to-point measurements and some measurements across arbitrary surface curves: in other words they were not well-localized in three-dimensional space. This made them difficult to apply to a computer-aided design process requiring accurate specification not only of the dimensions but of the spatial relationships between them measured from some datum.

With these considerations in mind, the design of a new protective glove was considered from the point of view of data required by a computer-aided design system. From this vantage point the anthropometric variables to be measured were determined. The variables need to be sufficient to define the size and shape of the fingers, the length, breadth and depth of the hand in several places (including the muscular portion of the thumb area) and to define the relationship of these variables to one another and to some established datum.

The datum was considered to be the primary wrist crease, that is the one closest to the hand. Two types of variable were considered: length/height measurements, that is measurements from the wrist crease to some point along the hand parallel to the fingers, and depth/breadth measurements, that is measures of the thickness of the hand or fingers and measures generally orthogonal to the first set. The complete set of variables is defined in Appendix B: Dimension Names for Required Variables. The variables are depicted in Figures 1 to 3.

The problem with previous data was that they were not inter-related definitively. Dimensions would exist in three-dimensional space but not be localized with respect to any datum. All the dimensions developed here for use with the CAD/CAM system are located with respect to the origin or the datum line. All the depth dimensions correspond to a measurement in the xy-plane showing location with respect to the datum.

3.2 NEW VARIABLES AND THE CAD/CAM DESIGN PHILOSOPHY

The origin was selected as the point on the outer wrist corner of the hand (see Figure 4) at the end of the wrist crease. With dimension #45 this defined the datum line. The complete set of dimensions used for the mock-up may be seen in Appendix C: Sample Measurements of the New Variables.

The dimensions were laid out in the xy-plane according to

their relationship to the datum. The values shown in the tables (see Appendix C) are not averages or means from a large sample, but values taken from one typical hand. This was because the purpose of the exercise was simply to prove the utility of the dimension set chosen, not to display any particular hand size. The dimensions may be seen in Figures 4 and 5. Dimensions in the xy-plane were taken with calipers. Measurements at the essential joints were included as required variables: these were widths, breadths and depths. The finger cross sections were not assumed to be circular so two variables (width and depth) could be used to define an ellipse. In certain cases an ellipse was a good deal more representative of the real shape of the cross section of a finger than a circle.

Figure 6 shows the depth dimensions in a trimetric view and their positions in space. The illustration shows the perimeter of the hand in the plane defining the mid-plane of the hand. The z-coordinates of the group ZPTS are taken as one-half the depth measurements. The group ZPTS includes all those data points that do not lie in the base plane, $z=0$.

The perimeter of the hand shape was constructed first and is shown in Figure 6 as the group PERIM. The term "group" here applies to a collection of entities in the computer model that can be manipulated as a single entity. In the previous illustrations (Figures 4 and 5), the terms DIM1 and DIM2 refer to the grouping of all the dimensioning terms and reference drafting notes. Points were generated where required in the mid-plane, which was defined as $z=0.000$. Then the perimeter was constructed with various lines, arcs and conic sections. The continuity of all the curves in the PERIM group was checked to ensure an uninterrupted boundary and a firm base from which the surfaces would be built. The perimeter curves were matched in continuity and gradient, that is, their first and second derivatives, at their intersection points.

The surfaces were constructed as sculptured surfaces and their defining curves were mostly conic sections or splines.^b The simplest possible surface was constructed between the generator curves. In other words, if further surface variation were required, more data would also be required to define other x, y, and z coordinates through which the surfaces would have to pass. Figures 7 and 8 show the finished surfaces. Wherever possible the gradients of the surfaces at the perimeter were defined as $(i,j,k)=(0,0,1)$ where i, j, and k are the direction cosines of generating curves at the perimeter. This helps to avoid undercut problems when machining the part with a three-axis CNC machine. This problem results from the fact that for any fixed three-axis CNC mill any surface must be a single-valued function of z. If the

^bSplines are those curves where each data point becomes a knot point.

surface folds over or under itself at any point, the machine tool quill will attempt to move the tool through part of the surface thus destroying other work. It also avoids the problems created by small hook-like formations at surface edges which may occur if gradients are incorrectly defined.^c It also ensures that there will be continuity in surface tangents and gradients when the mirror image is mated with this shape about the mid-plane.

4.0 CONCLUSIONS

The problems of anthropometric data gathering and the design of gloves have been examined solely from the point of view of the requirements of CAD/CAM techniques. The types and quantities of dimensions necessary for the design of an unambiguous computerized model were defined and sample measurements taken from an actual hand by means of the usual anthropometric devices. A perimeter defining the shape of the hand model was constructed and from the depth measurements, various points were located in three-dimensional space (the ZPTS group).

From these data, the surfaces were constructed showing that a model may be defined from the data set generated from the anthropometric measurements taken. More variation in the detail of the three-dimensional shape is possible if more data are provided. The model shown here was built from fifty dimensions. The perimeter shape was generated and the points in the z-direction were entered into the model. Curves were created to join all the data points and symmetrical surfaces used wherever possible. For a better fitting glove, more data from the palm area of the hand could be desirable, but locating the landmarks is difficult and it is doubtful that more than fifty dimensions will give a corresponding increase in ease of fit once a glove model has been designed.

The successful construction of a glove/hand model serves as a proof-of-concept for the new dimensions and their relevance to the CAD/CAM design philosophy. The number of dimensions may be increased or decreased according to the accuracy required. Certain dimensions cannot be eliminated from the sample because they are essential in defining the location of various dimensions and the spatial relationships between them.

^cIf the gradient is defined as $(i,j,k) = (0,0,-1)$ instead of $(0,0,1)$, the surface edge will be flipped through π radians.

5.0 ACKNOWLEDGEMENTS

I would like to thank Ms. Sylvia Wehrer of Rhodes & Associates for many fruitful discussions and for carrying out the anthropometric measurements.

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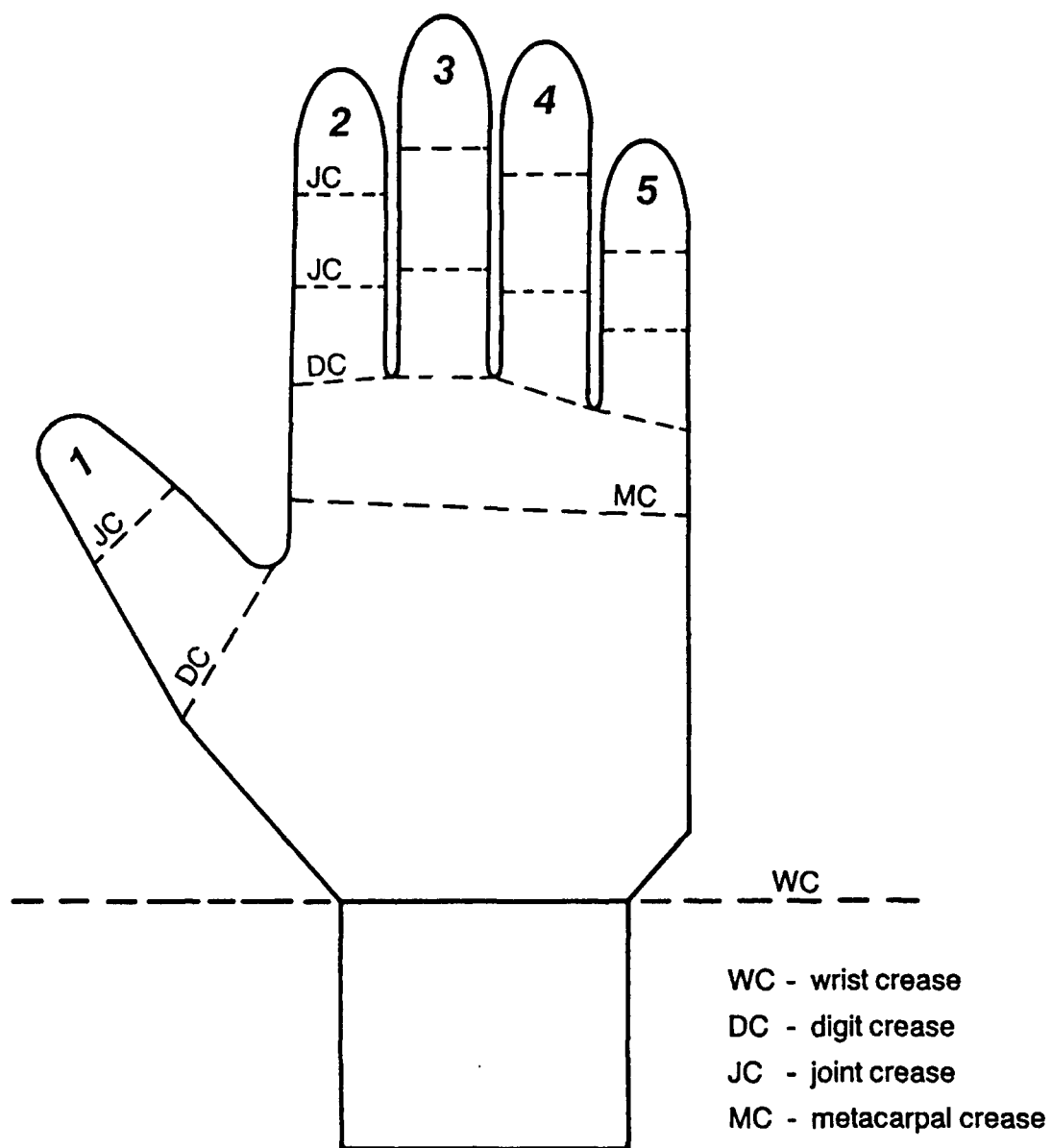


Figure 1: Digit and Crease Definition

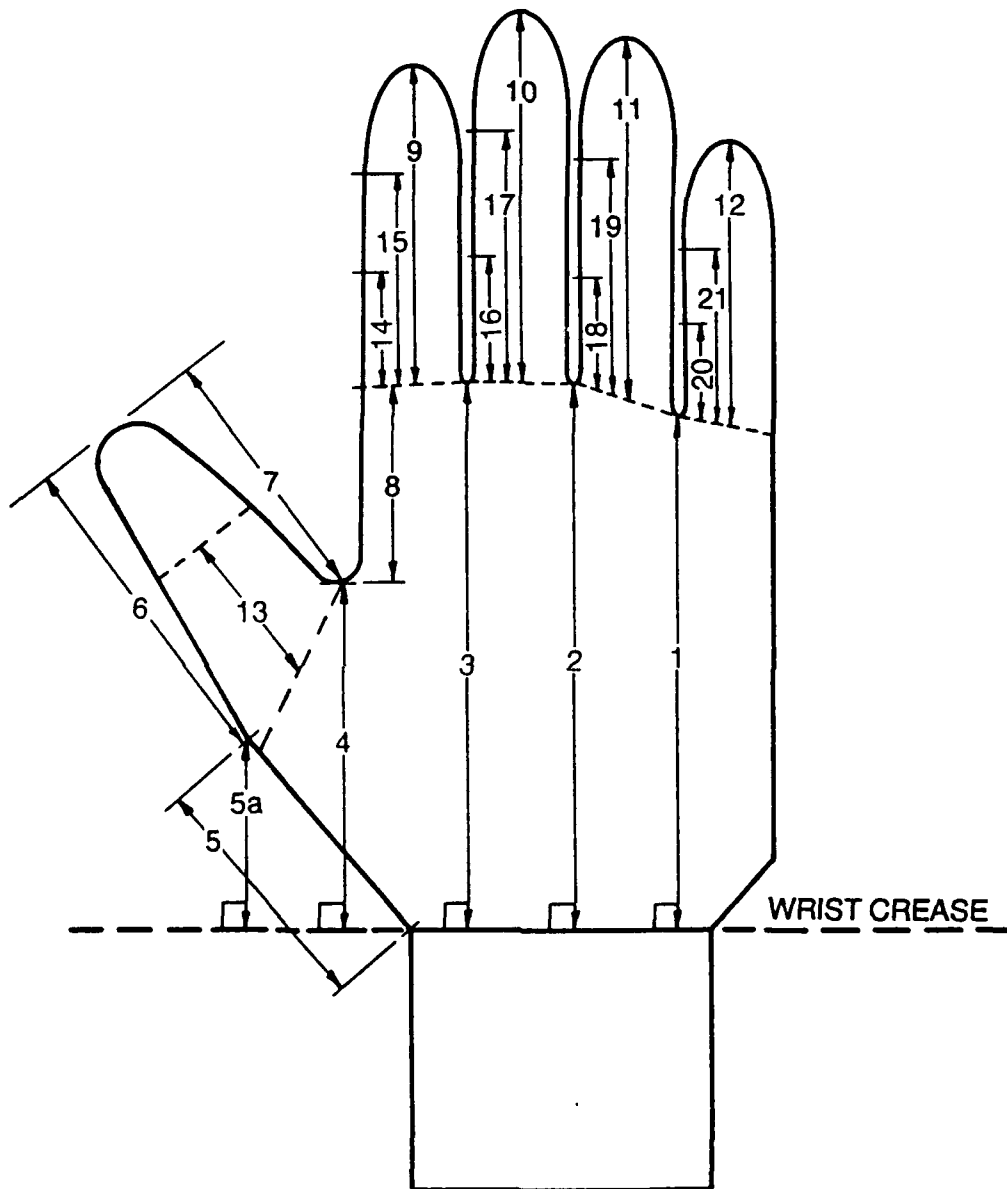


Figure 2: Planar Variables for the Hand

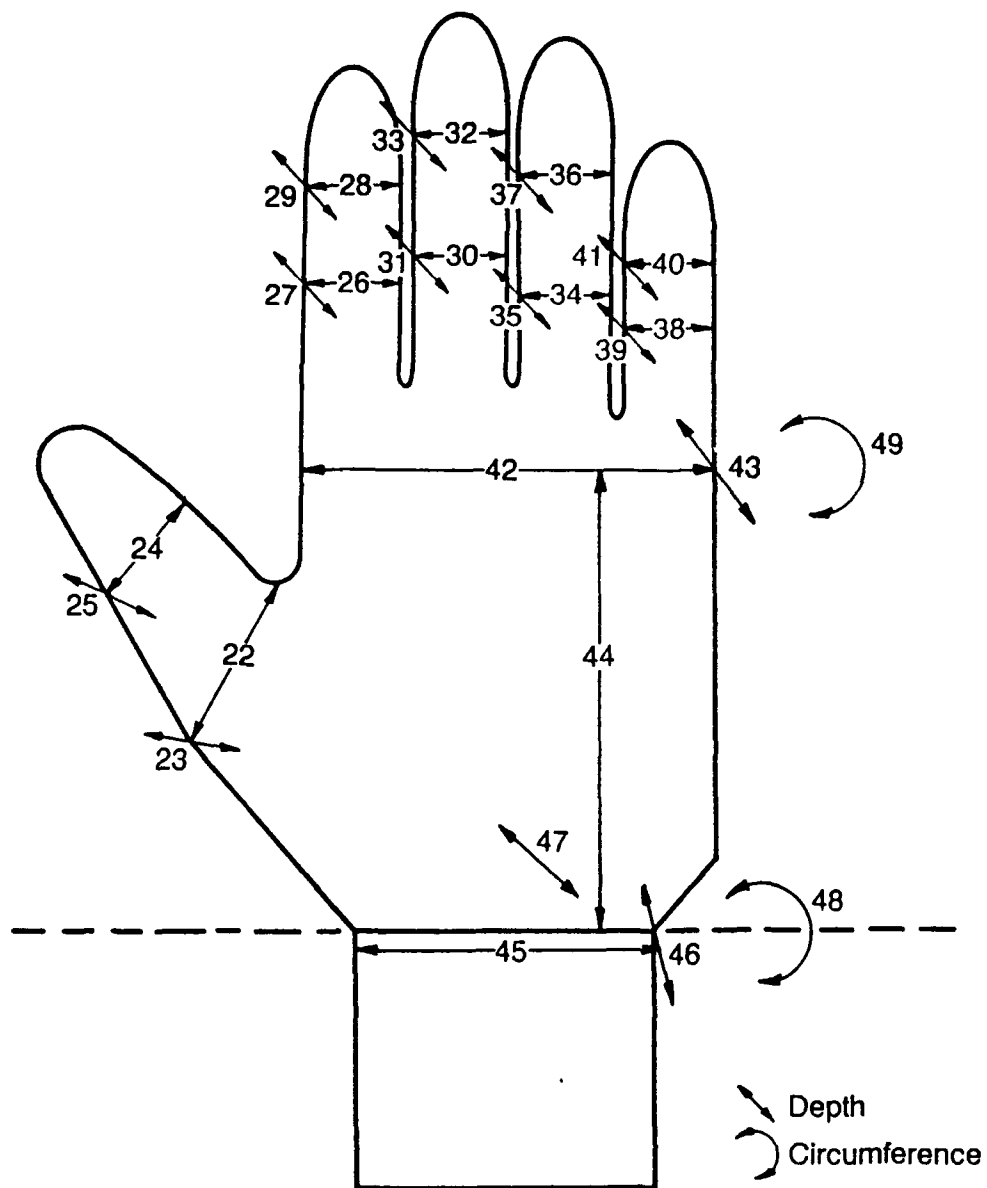


Figure 3: Depth and Circumference Variables for the Hand

Figure 1 is a plan view of the proposed road layout. The diagram shows a road with a curve and a straight section. Key dimensions and labels include:

- 147.08 (Total length of the straight section)
- 122.20 (Length of the first straight section)
- 106.81 (Length of the second straight section)
- 95.91 (Length of the third straight section)
- 83.00 (Length of the fourth straight section)
- 31.10 (Length of the fifth straight section)
- 14.80 (Length of the sixth straight section)
- 62.10 (Length of the seventh straight section)
- 31.10 (Length of the eighth straight section)
- 4.10 (Length of the ninth straight section)
- 4.10 (Length of the tenth straight section)
- 4.10 (Length of the eleventh straight section)
- 16.10 (Length of the twelfth straight section)
- 40.75 (Length of the thirteenth straight section)
- 66.30 (Length of the fourteenth straight section)
- 21.70 (Length of the fifteenth straight section)
- 1.00 (Length of the sixteenth straight section)
- ZPTS (Zoning Point of Tangency)
- PERIM (Perimeter)
- ORIGIN (Origin of the road layout)

13

MODEL: HAND1.PRT
 CONSTRUCTED FROM "NEW CONCEPT"
 DIMENSIONS (MM) LOCATION OF DATA
 POINTS IN THREE-DIMENSIONAL SPACE

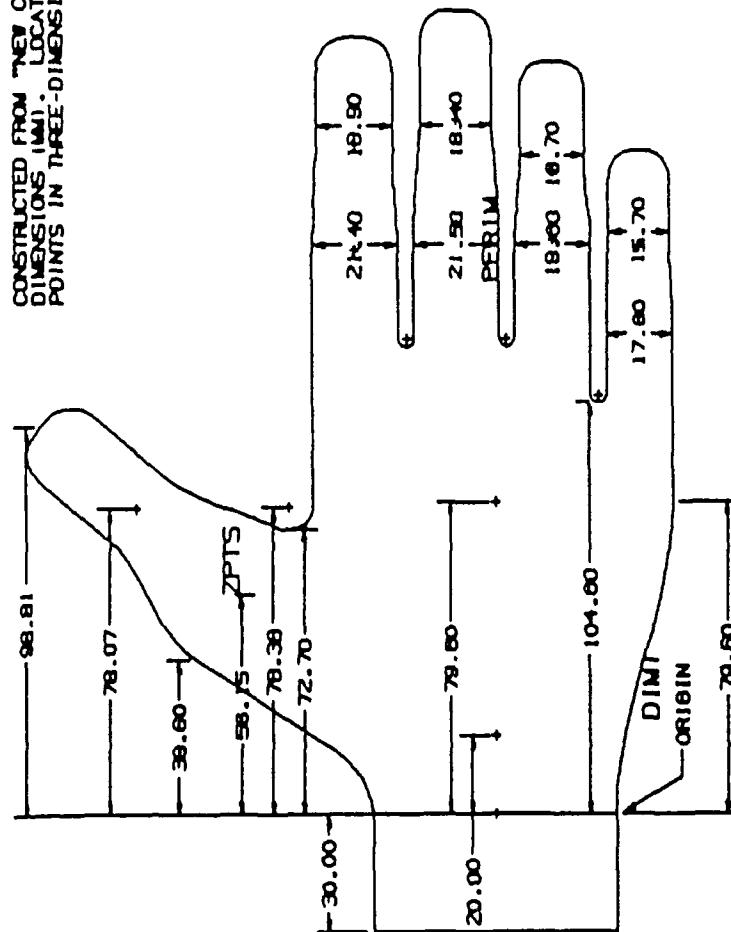


Figure 5: Dimensions Parallel to the y-axis

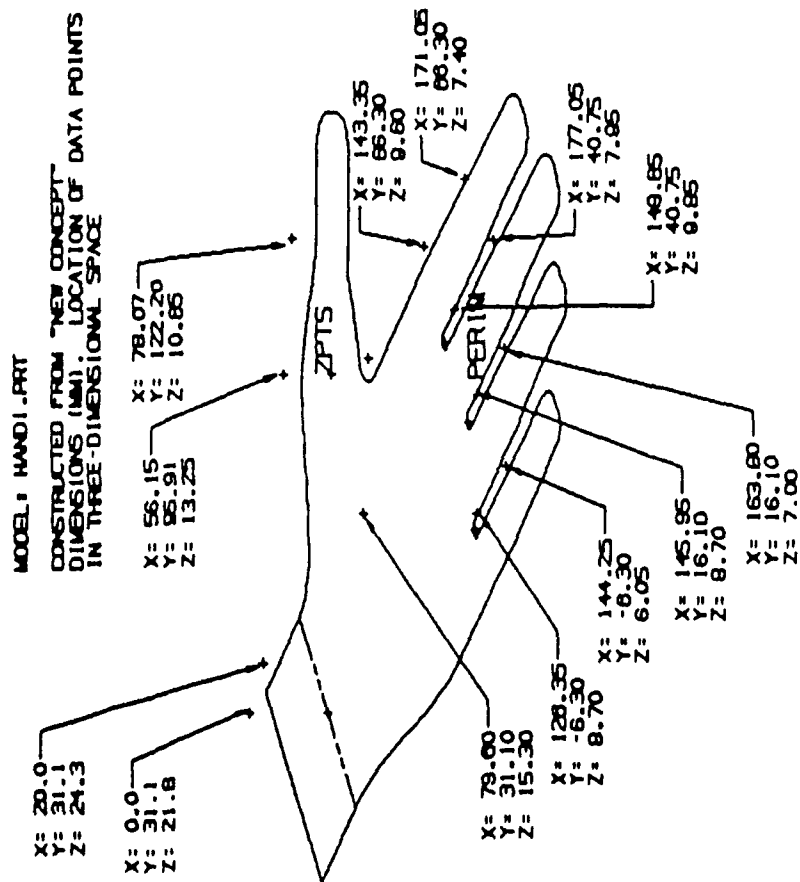


Figure 6: Depth Dimensions in Trimetric View

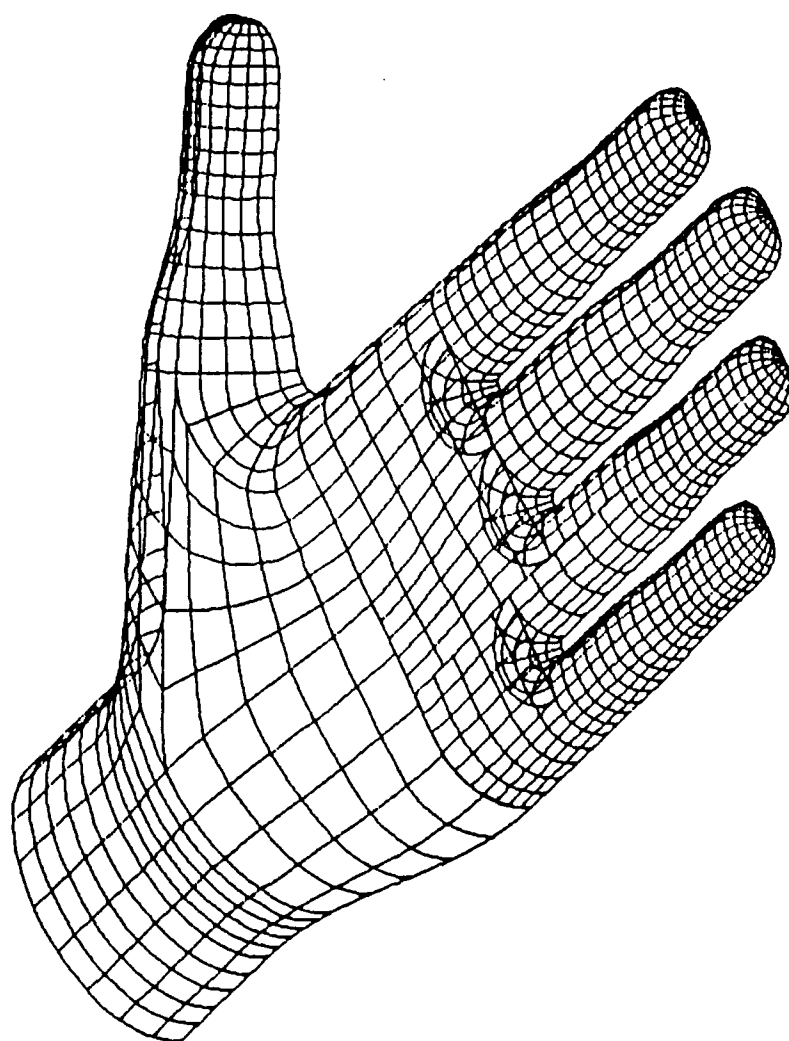


Figure 7: View of Surfaced Model (i)

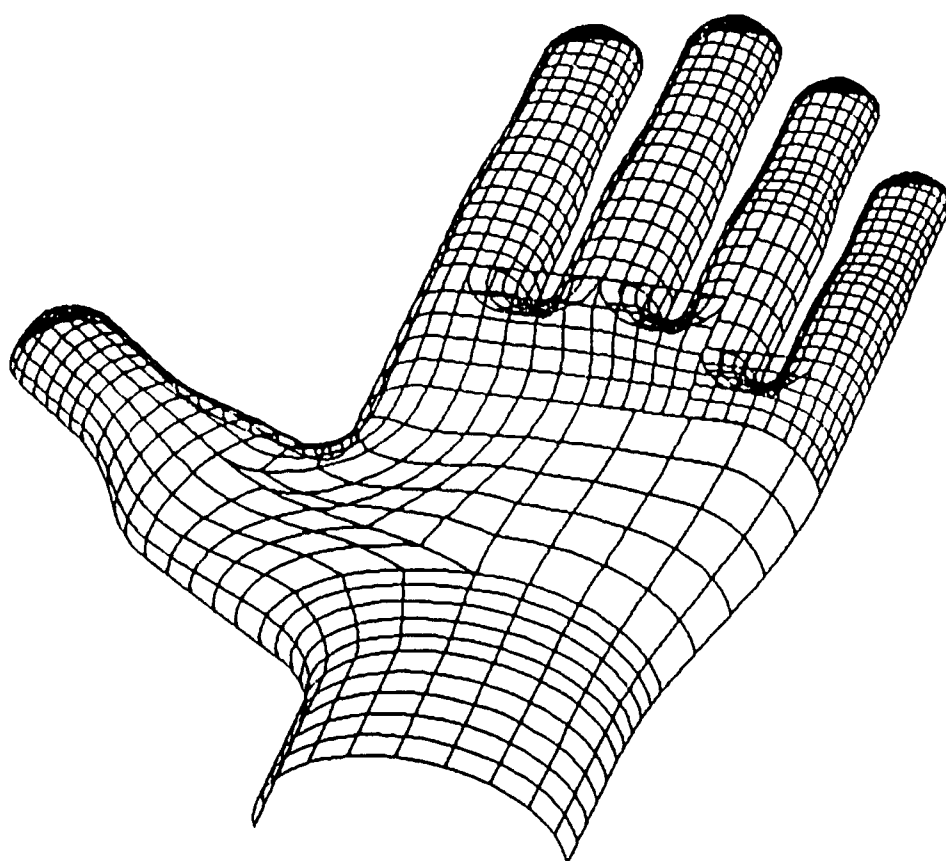


Figure 8: View of Surfaced Model (ii)

APPENDIX A

1. KEY DIMENSIONS

A key dimension is one which determines what size an individual will wear given that the sizing intervals have been resolved. The key dimensions should be measurements that are easily taken and repeatable to a high degree of confidence. Usually, for hands, the key dimensions are taken to be the hand length and hand breadth. Not only are these variables readily measurable, they show a significant statistical correlation one to another and to other important variables.

2. SIZING INTERVAL

Gloves are required to fit 95% of the population and the number of sizes needed to satisfy this condition depends on the interval between key dimensions in subsequent sizes. This is known as the sizing interval. There is no hard and fast rule that determines what the intervals should be, but practical and statistical considerations must play an important role. The number of individuals per size is determined by computer analysis of the anthropometric surveys and this number is a function of the key dimensions and the sizing intervals.

3. SIZE SUBSET

The size subset is the set of individuals whose values of key dimensions lie within a particular, specified range defined by the sizing interval.

4. MID-SIZE VALUES

When the size subset has been determined, the values of other dimensions to be used in the design process must be established. The values of all other relevant dimensions of individuals within the size subset can now be computed. These values constitute the basis of the design values for that particular size. But since the individuals within a single size category do not generally lie on a normal, or Gaussian, distribution curve, but tend to cluster around the mean, these values are modified according to a statistical procedure outlined by Robinette and Annis. The mid-size values are computed for each variable in a size category by means of multiple regression equations for all of the other variables using the above size category mid-points as predictors.*

*See Robinette and Annis report.

5. 'WITHIN-A-SIZE' STANDARD DEVIATION

In order to construct all the final design values for each variable in a particular size category, a modified standard deviation, the 'within-a-size' standard deviation is computed to be used with the mid-size value in a manner similar to the use of standard deviation with a mean value in a Gaussian distribution. The data set used for these calculations is the size subset discussed above in §3.

APPENDIX B

DIMENSION NAMES FOR REQUIRED VARIABLES

A. Length/Height Measurements:

Crotch Heights:

1. Perpendicular distance from the wrist center to the center of the finger crotch between digits 4 & 5.
2. Perpendicular distance from the wrist center to the center of the finger crotch between digits 3 & 4.
3. Perpendicular distance from the wrist center to the center of the finger crotch between digits 2 & 3.
4. Perpendicular distance from the wrist center to the center of the finger crotch between digits 1 & 2.

Digit Lengths and Other Digit Dimensions:

- 5a. Digit 1: the perpendicular distance from the wrist crease to the end of the metacarpal.
5. Digit 1: the distance from the wrist crease to the end of the metacarpal.
6. Digit 1: the distance from the end of the metacarpal to the finger tip.
7. Digit 1: the distance from the digit 1 crotch to the finger tip.
8. Digit 2: the distance from the digit 1 crotch to the digit 2 finger crease.
9. Digit 2: the distance from the finger crease to the digit tip.
10. Digit 3: the distance from the finger crease to the digit tip.

11. Digit 4: the distance from the finger crease to the digit tip.
12. Digit 5: the distance from the finger crease to the digit tip.

Joint Crease Heights:

13. The height from the digit 1 crease to the joint crease parallel to the axis through the center of the finger.
14. The height from the digit 2 crease to the first joint crease parallel to the axis through the center of the finger.
15. The height from the digit 2 crease to the second joint crease parallel to the axis through the center of the finger.
16. The height from the digit 3 crease to the first joint crease parallel to the axis through the center of the finger.
17. The height from the digit 3 crease to the second joint crease parallel to the axis through the center of the finger.
18. The height from the digit 4 crease to the first joint crease parallel to the axis through the center of the finger.
19. The height from the digit 4 crease to the second joint crease parallel to the axis through the center of the finger.
20. The height from the digit 5 crease to the first joint crease parallel to the axis through the center of the finger.
21. The height from the digit 5 crease to the second joint crease parallel to the axis through the center of the finger.

B. Depth/Breadth Measurements:

Digit Depth/Breadths:

22. The breadth of digit 1 at the metacarpal.

23. The depth of digit 1 at the metacarpal.
24. The breadth of digit 1 at the phalangeal.
25. The depth of digit 1 at the phalangeal.
26. The breadth of digit 2 at the proximal phalangeal.
27. The depth of digit 2 at the proximal phalangeal.
28. The breadth of digit 2 at the distal phalangeal.
29. The depth of digit 2 at the distal phalangeal.
30. The breadth of digit 3 at the proximal phalangeal.
31. The depth of digit 3 at the proximal phalangeal.
32. The breadth of digit 3 at the distal phalangeal.
33. The depth of digit 3 at the distal phalangeal.
34. The breadth of digit 4 at the proximal phalangeal.
35. The depth of digit 4 at the proximal phalangeal.
36. The breadth of digit 4 at the distal phalangeal.
37. The depth of digit 4 at the distal phalangeal.
38. The breadth of digit 5 at the proximal phalangeal.
39. The depth of digit 5 at the proximal phalangeal.
40. The breadth of digit 5 at the distal phalangeal.
41. The depth of digit 5 at the distal phalangeal.
42. The breadth of the palm at the metacarpal.
43. The depth of the palm at the metacarpal.
44. Metacarpal height (palmar view).
45. Wrist breadth.
46. Wrist depth.
47. Hand depth (2 cm from wrist crease at midline).

C. Circumferences:

48. Wrist circumference.

49. Metacarpale circumference.

APPENDIX C

SAMPLE MEASUREMENTS OF THE

NEW VARIABLES

Dimension Number	Value (mm)
---------------------	---------------

Crotch Heights

1	104.6
2	118.7
3	118.9
4	72.7

Thumb Dimensions

5a	39.6
5	58.9
6	70.0
7	58.9

Finger Lengths

8	48.0
9	77.4
10	84.2
11	78.2
12	62.1

Joint Heights

13	37.6
14	22.4
15	50.1
16	28.9
17	56.1
18	25.0
19	50.0
20	19.7
21	37.6

Digit Breadths

22	30.2
24	21.7
26	21.4
28	18.9
30	21.5
32	18.4
34	19.6
36	16.7
38	17.0
40	15.7

Digit Depths

23	26.5
25	19.0
27	19.2
29	14.8
31	19.7
33	15.9
35	18.2
37	14.0
39	17.4
41	12.1

Value

Hand & Wrist Measurements

42	91.8
43	30.6
44	79.6
45	62.2
46	43.6
47	48.6
48	172.0
49	215.0

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(highest classification of Title, Abstract, Keywords)

DOCUMENT CONTROL DATA

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1. ORIGINATOR (the name and address of the organization preparing the document. Organizations for whom the document was prepared, e.g. Establishment sponsoring a contractor's report, or tasking agency, are entered in section 8.) DEFENCE RESEARCH ESTABLISHMENT OTTAWA National Defence Ottawa, Ontario K1A 0Z4		2. SECURITY CLASSIFICATION (overall security classification of the document including special warning terms if applicable) UNCLASSIFIED	
3. TITLE (the complete document title as indicated on the title page. Its classification should be indicated by the appropriate abbreviation (S,C or U) in parentheses after the title.) DEVELOPMENT OF A STANDARD ANTHROPOMETRIC DIMENSION SET FOR USE IN COMPUTER-AIDED GLOVE DESIGN (U)			
4. AUTHORS (Last name, first name, middle initial) HIDSON, David			
5. DATE OF PUBLICATION (month and year of publication of document) OCTOBER 1991		6a. NO. OF PAGES (total containing information. Include Annexes, Appendices, etc.) 30	6b. NO. OF REFS (total cited in document) 11
7. DESCRIPTIVE NOTES (the category of the document, e.g. technical report, technical note or memorandum. If appropriate, enter the type of report, e.g. interim, progress, summary, annual or final. Give the inclusive dates when a specific reporting period is covered.) TECHNICAL NOTE			
8. SPONSORING ACTIVITY (the name of the department project office or laboratory sponsoring the research and development. Include the address.) DEFENCE RESEARCH ESTABLISHMENT OTTAWA National Defence Ottawa, Ontario K1A 0Z4			
9a. PROJECT OR GRANT NO. (if appropriate, the applicable research and development project or grant number under which the document was written. Please specify whether project or grant) 051LD		9b. CONTRACT NO. (if appropriate, the applicable number under which the document was written)	
10a. ORIGINATOR'S DOCUMENT NUMBER (the official document number by which the document is identified by the originating activity. This number must be unique to this document.) DREO TECHNICAL NOTE 91-22		10b. OTHER DOCUMENT NOS. (Any other numbers which may be assigned this document either by the originator or by the sponsor)	
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➤ Anthropometric variables have always been measured with tapes and calipers and the data gathered have been the source material for designers and patternmakers in the development of NBCW protective equipment. This paper describes the re-assessment of the variables and dimensions under consideration and the construction of a new set of variables, for measuring hands, localized in three-dimensional space, that may be measured by traditional techniques but yet be suited to CAD/CAM applications. A set of fifty dimensions was devised and a datum from which to measure was defined. Data were taken from a small sample of hands and a computerized model constructed. Models may be constructed from fewer dimensions but there will be less variability in the resultant surface.

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(23) * ANTHROPOMETRY
* COMPUTER-AIDED DESIGN
HUMAN FACTORS
PROTECTIVE EQUIPMENT
HAND,
GLOVE ←

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