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The Military Anthropometry Resource Companion (MARC): Overview and Sample Use Cases

by Christopher Garneau

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14. ABSTRACT
The Military Anthropometry Resource Companion (MARC) is an interactive analysis tool that provides complete body size data and related analytical resources. MARC may be used to explore traditional anthropometric data and calculate percentiles for any given dimension and value, compare characteristics of available datasets, and find accommodation dynamically given certain constraints on measures of anthropometry and demographics. MARC encompasses two components: a front-end graphical user interface and an underlying analytical engine implemented as an R package called MARCR (Military Anthropometry Resource Companion in R). This technical note primarily focuses on the analytical engine—specifically, a description of the data underlying MARCR, a description of the methods of analysis and associated assumptions, and an overview of current capabilities. This report also discusses examples of simple use cases and the steps to complete tasks.

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Military Anthropometry Resource Companion, MARC, anthropometry, physical accommodation, Human Systems Integration, HSI, human factors engineering

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1. INTRODUCTION

The Military Anthropometry Resource Companion (MARC) is an interactive analysis tool that provides complete anthropometric (body size) data and related analytical resources. MARC complements available guidance relevant to designing or evaluating an artifact or environment for physical accommodation (e.g., Military Standard [MIL-STD]-1472 [Department of Defense, 2020]) as well as other tools for physical accommodation assessment (e.g., digital human modeling). MARC may be used to explore traditional anthropometric data and calculate percentiles for any given dimension and value, compare characteristics of standard reference datasets against each other or newly collected data, and find accommodation dynamically given certain constraints on anthropometry and demographics. MARC is developed by the U.S. Army Combat Capabilities Development Command (DEVCOM) Analysis Center (DAC).

MARC encompasses two tools—a front-end graphical user interface and an underlying analytical engine implemented as an R package called MARCR (Military Anthropometry Resource Companion in R). This technical note primarily focuses on the analytical engine—specifically, a description of the quantitative/numeric data underlying MARCR, a description of the methods of analysis and associated assumptions, and an overview of current capabilities. This report also discusses examples of various use cases and the steps to complete tasks.

2. BACKGROUND

2.1 Motivation

Considering the spatial requirements of the Soldier in the design of vehicles, equipment, weapons, and other systems ensures fit, safety, and performance. Detailed databases of reference anthropometry for the military have been made publicly available and may be used to inform required adjustability, reach, clearance, and other parameters for materiel (see Section 3.1). MIL-STD-1472, *Department of Defense Design Criteria Standard: Human Engineering* (Department of Defense, 2020) establishes requirements for considering the user in the design of materiel for the United States military and recommends use of jointed anthropometric distributions or digital human modeling (DHM) as appropriate methods for solving problems with many dimensions. Despite this broad guidance, specific quantitative methods for applying anthropometry to design and evaluation activities are largely left for the reader to seek out from alternate sources.

2.2 Background: MARC and MARCR

MARC was initially envisioned as a companion tool to MIL-STD-1472 to fill the aforementioned analytical gap, and had the following main objectives:

1. Provide a calculator that can properly account for multiple measures of anthropometry when determining accommodation.
2. Offer multiple, user-selectable sources of anthropometry from multiple services (e.g., U.S. Army Anthropometric Survey [ANSUR], ANSUR II, U.S. Marine Corps ANSUR [MC-ANSUR]).
3. Encourage appreciation of the effect of clothing and equipment by including sample clothing/equipment margins.
4. Incorporate several features for use in an evaluation context:
    a. Aid anthropometric data collection via a guided interface with definition of measures to be collected (e.g., relevant body landmarks)
    b. Ensure adequacy of study sample by comparing collected data points with reference data (e.g., ANSUR)
    c. Enable real-time system evaluation given prototype dimensions and relevant anthropometry (e.g., for checking clearances).

Given these objectives, it was envisioned that the app would find use in several roles, including: (1) interpreting requirements, (2) getting values for design, (3) encouraging appreciation for the effect of clothing and equipment on Soldier space accommodation, and (4) collecting data and analyzing performance of a design in real time, with respect to physical accommodation, during an evaluation effort. In addition to supporting these specific activities, another important outcome is that the app would help structure the process for applying anthropometric data for design and evaluation, as well as provide ready access to complete and accurate anthropometric data.

MARC has undergone development and revision since 2014, across three main versions. These are briefly reviewed in the next three subsections.

2.2.1 MARC Version 1: Web App Only

The first version of MARC provided a GUI with functionality that encompassed all four objectives. It was written as a web app using a combination of HTML and JavaScript—which limited its utility for more complex analyses. Figures 1 and 2 show screenshots of this first version.

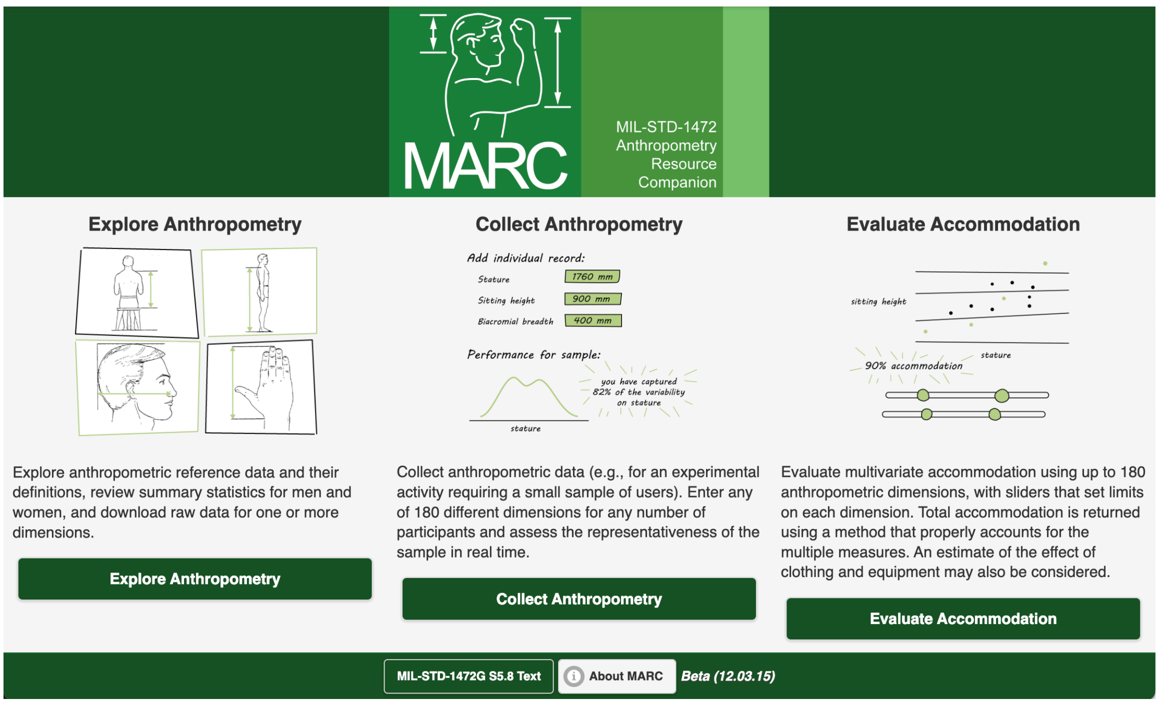

Figure 1. Home screen of MARC v1

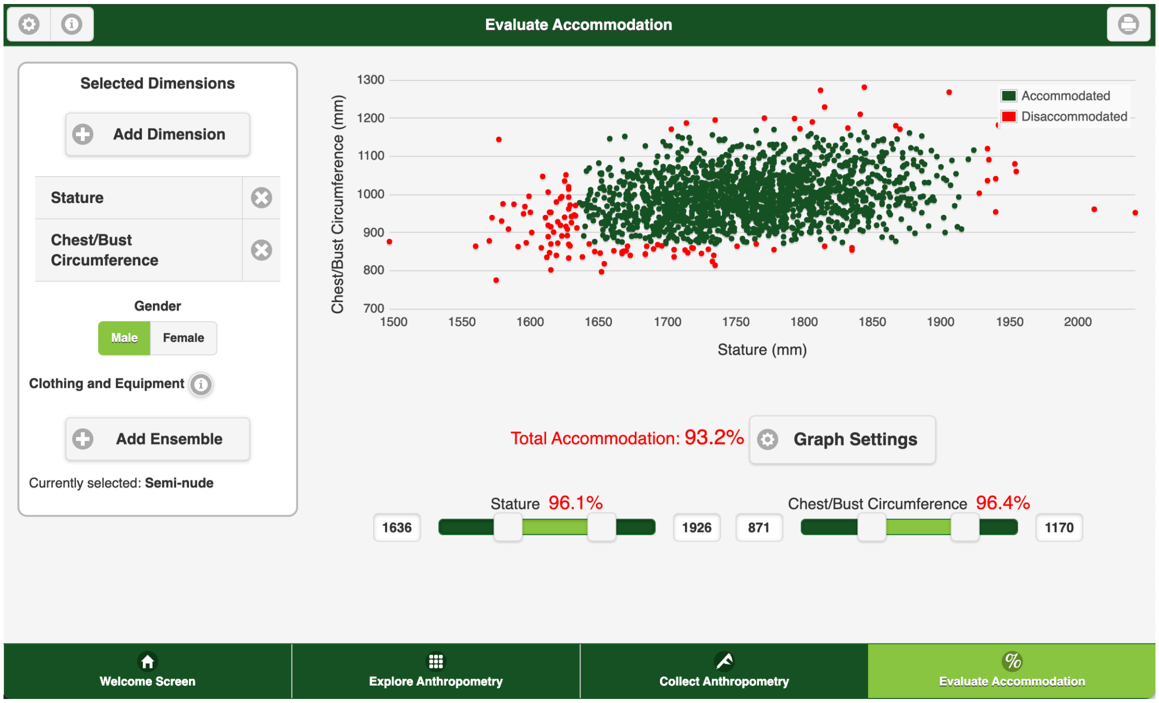

Figure 2. "Evaluate accommodation" view in MARC v1

2.2.2 MARC Version 2: Web App and R Package

With Version 2, MARC was split across two related applications: a newly designed web app similar to Version 1 (with analyses implemented within the app using JavaScript) and a new R package for more complex or scripted analyses in the R environment (MARCR). Figures 3 and 4 show screenshots of the Version 2 web app.

In Version 2, the data collection objective (objective no. 4) was broken out into a separate app called the Anthropometry Collection Tool. This split allowed MARC to focus strictly on the analysis of anthropometric data.

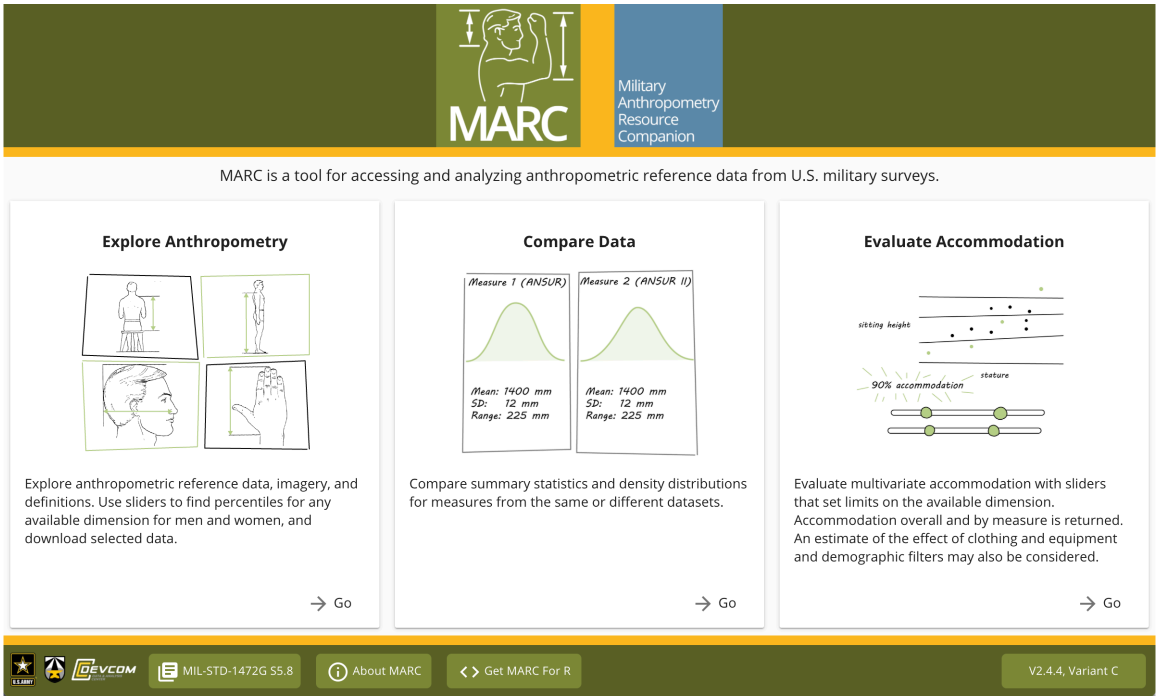

Figure 3. Home screen of MARC v2

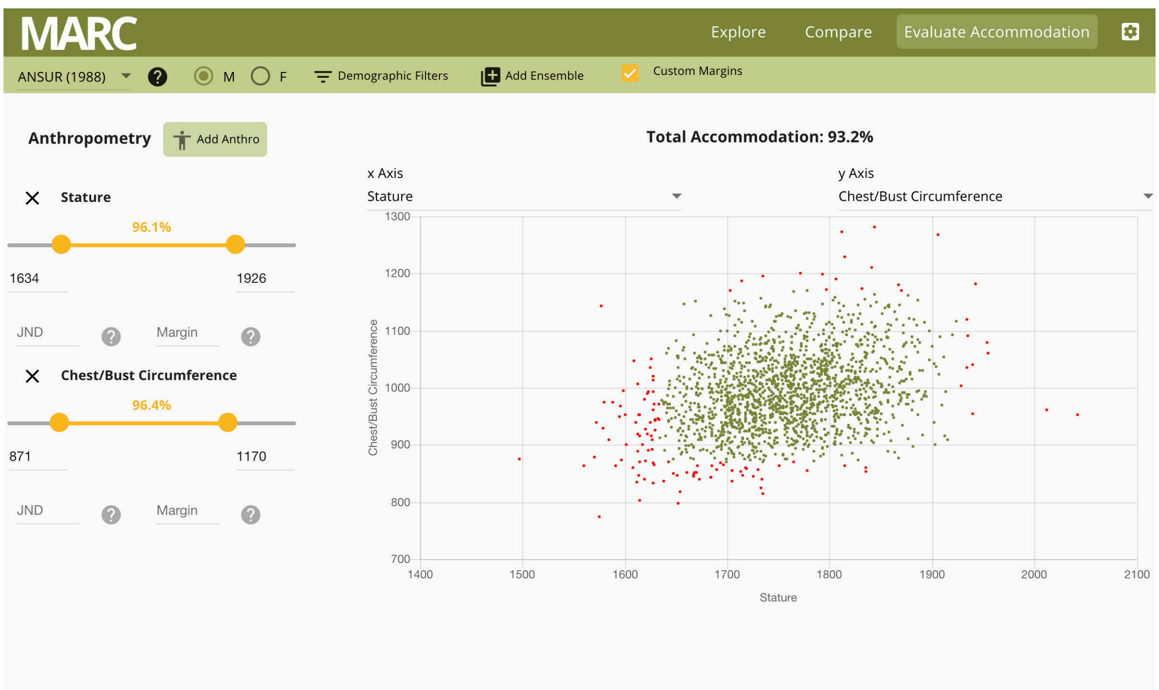

Figure 4. “Evaluate accommodation” view in MARC v2

2.2.3 MARC Version 3: R Package and R Shiny App

With Version 3, MARC analysis functionality is unified within the R environment. The MARCR package continues from Version 2, but a new R Shiny application has been developed to interface with it. Development of the Shiny application was informed by work on a related Shiny application called the Human Systems Integration (HSI) Metric Tradespace Exploration Environment (Garneau, 2022). Figures 5 and 6 show screenshots of the Version 3 MARC Shiny application.

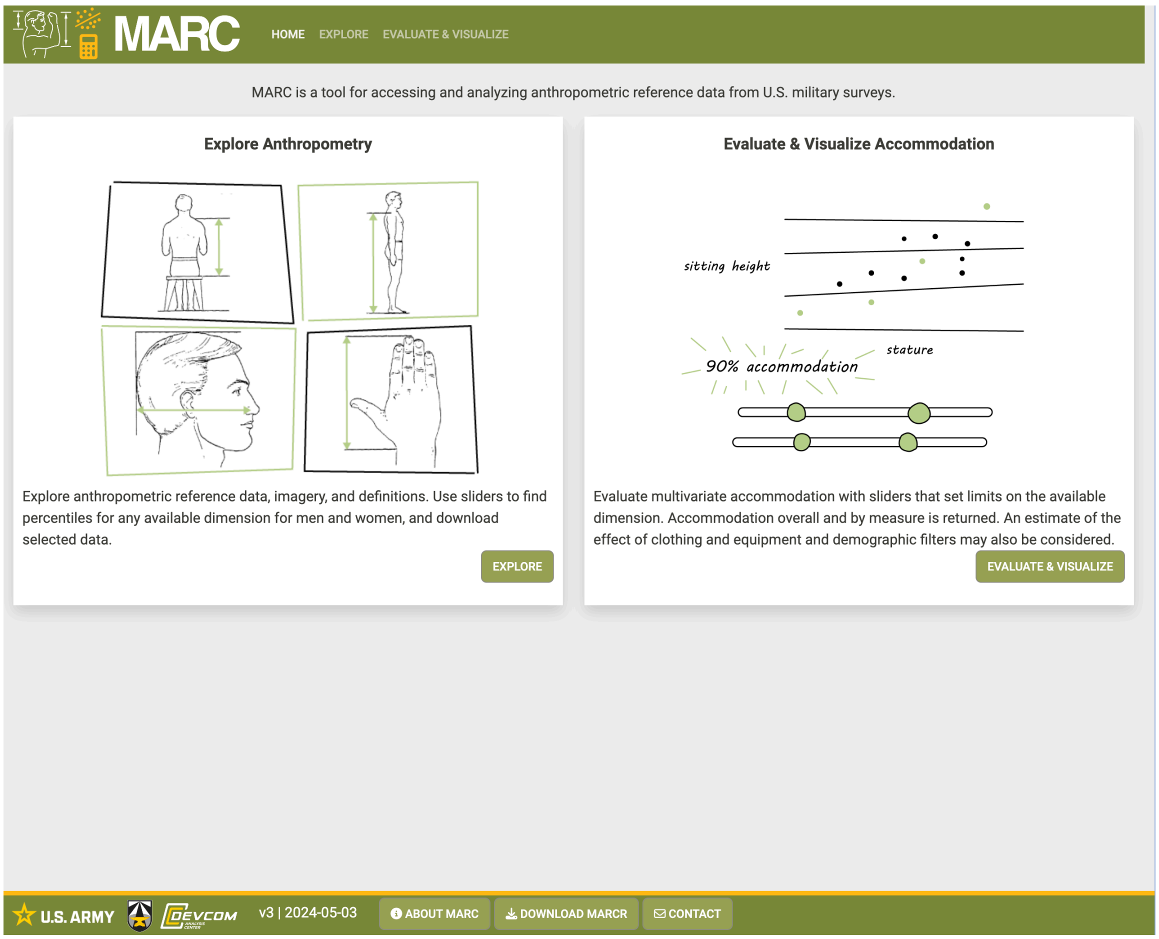

Figure 5. Home screen of MARC Shiny

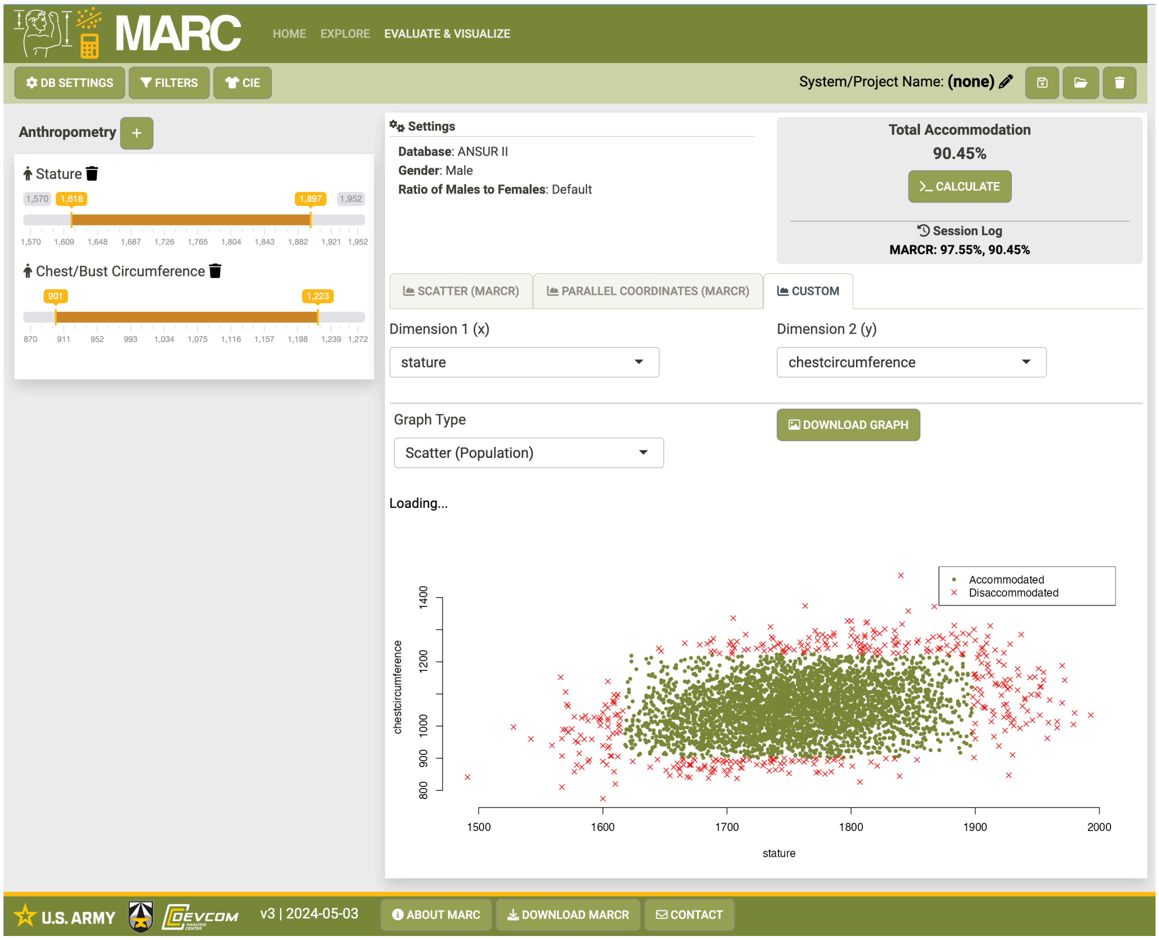

Figure 6. “Evaluate accommodation” view in MARC Shiny

One capability of the MARC Shiny application that is not present within the MARCR engine is the ability for data to be augmented with additional offsets that simulate the effect of clothing and individual equipment (CIE) on certain dimensions (e.g., Garlie and Choi, 2014). User-defined custom margins may be applied as well. Including the effect of CIE usually serves to lower overall accommodation rates due to increased physical space requirements.

Future revisions of MARC’s Shiny version may introduce additional capabilities. For instance, work is under way to expand the analysis capabilities of MARC by allowing an anthropometric dimension (or combination of dimensions) to be mapped onto physical system dimensions using various schema (one-to-one, statistical model, addition/subtraction, etc.). Limitations would then be placed on the physical system dimensions to assess accommodation. This modification will allow MARC to expand beyond providing only anthropometric reference data and analysis to also enabling an analyst to directly apply the anthropometric data to the design or evaluation of a system, and thus provide a more flexible complement to other tools for physical accommodation analysis—for instance, DHM software like Jack (Process Simulate Human[*]) or RAMSIS[†]. See Kozycki (2018) for a discussion of the application of DHM to military systems.

Allowing for the mapping of reference data to system dimensions will also facilitate incorporation of statistical preference models for specific applications (e.g., highly reclined seating [Reed and Ebert, 2020]). Statistical models capture user preference and behavior in laboratory conditions and enable verification of analyst assumptions and results. When a relevant statistical model is available for the type of system in use, incorporating its results into an analysis strengthens the ability to validate and justify design or evaluation recommendations. It is anticipated that MARC will include a library of some available preference models and applications and will allow straightforward expansion as new models become available.

Any new anthropometric datasets or changes to analytical methodology would likely be implemented in MARCR, not the MARC Shiny application. A copy of the current MARCR documentation is provided in Appendix A.

2.3 Scope of this Report

Given its use within the latest MARC Shiny application and its availability as a standalone package, the remainder of this report focuses on the MARCR analytical engine as encompassing the overall analytic approach of MARC. MARC and MARCR are used interchangeably in subsequent sections unless otherwise noted.

[*] https://static.sw.cdn.siemens.com/siemens-disw-assets/public/7IMuCIBsulgLwTiGLMpDZo/en-US/Siemens_SW_Process_Simulate_Human_Fact_Sheet.pdf

[†] https://www.human-solutions.com/en/products/ramsis-general/index.html

3. MARC DATA AND ANALYSIS METHODS

3.1 Anthropometric Datasets

MARC capitalizes on the U.S. military's investment in large surveys of anthropometric data that have been conducted at various times in the last 50 years. Specifically, the following datasets are currently available in MARC:

1. 1966 U.S. Army Anthropometry (see White and Churchill, 1971).
2. 1988 Anthropometric Survey of U.S. Army Personnel (ANSUR) (see Gordon et al., 1989).
3. 2010 Anthropometric Survey of U.S. Marine Corps Personnel (MC-ANSUR) (see Gordon et al., 2013).
4. 2012 Anthropometric Survey of U.S. Army Personnel (ANSUR II) (see Gordon et al., 2014).

These data were collected by the DEVCOM Soldier Center (SC)—formerly Natick Soldier Research, Development, and Engineering Center (NSRDEC). Description of data collection methods and summary statistics for each survey are in the source documents. For the 2012 ANSUR II data—the most current and comprehensive data available for the design of materiel for U.S. Army Soldiers—the dataset provides dozens of traditional body dimensions characterized by gender, component, age, race, and military occupational specialty (MOS).

Table 1 provides a snapshot of the parameters of each study. Study personnel, methods, and measure definitions differed among the surveys, with the exception of the MC-ANSUR and ANSUR II data that were collected over approximately the same time period by the same measurers using the same methodology.

Table 1. Characteristics of datasets included in MARC

	No. individuals sampled	No. traditional dimensions	No. derived dimensions	3D scans[a]	Notes
1966 Army	6682 men	70	N/A	No	Survey did not include women
1988 ANSUR	1774 men, 2208 women	132	60	No	48 head and face dimensions were collected by means of an automated headboard
2010 MC-ANSUR	1301 men, 620 women	94	39	Yes	. . .
2012 ANSUR II	7435 men, 3922 women	94	39	Yes	Working dataset includes 4082 men, 1986 women

[a] 3D scan data are not available in MARC; to inquire about these data or analyses derived from these data, contact DEVCOM SC.

Additional datasets may be readily added to MARC in the future as they are available.

3.2 Types of Analyses and Associated Methodology

The calculations performed interactively in MARC are possible because of the large datasets available (see Section 3.1). MARC does not rely on published reports of summary statistics, instead performing all calculations of percentiles and other metrics in real time using the full dataset.

MARCR implements the functions described in this section. MARCR is not available in any of the R package repositories but may be requested from DAC or downloaded from the MARC Shiny GUI. This report describes algorithms in MARC in general terms, not using specific R functions (unless otherwise noted).

MARC enables various kinds of analysis for a variety of use cases, but essentially performs four types of calculations on the selected dataset:

1. Determination of the percentile associated with a specified value for a single dimension.
2. Determination of the value associated with a specified percentile for a single dimension.
3. Determination of the level of (percent) accommodation associated with specified limits on the values of multiple dimensions.
4. Determination of values associated with certain levels of accommodation for multiple dimensions.

Each type of calculation is discussed in the following sections.

3.2.1 Calculation Types 1 and 2: Percentiles

Calculations for Types 1 and 2 are fairly straightforward. Type 1 uses the data associated with a dimension and a $quantile$ function. Suppose the data for stature for the 1988 ANSUR set are saved as a comma-separated list in a variable called $stature$. Then, to determine the value (called val) associated with a specified percentile (called $prctile$ in units of %), the following function is used:

$$val = quantile(stature, \frac{prctile}{100})$$

To perform this calculation in reverse (Calculation Type 2), MARC looks for the location of the target value in the string of sorted values belonging to the dimension of interest in the dataset. For instance, if the target value is in position 150 of a 1500 element string, then its associated percentile is estimated as 10%. This type of calculation is possible because of the large number of samples for each dimension, and the fact that samples are ordered by value from smallest to largest. This calculation is implemented in MARC as follows.

Using the same nomenclature as shown previously, where `prctile` is the parameter of interest given `val`, the following R code snippet sorts the stature string from smallest to largest and then brackets `val` by finding the index of the values immediately before and after the target value (there may be multiple individuals with the target value). These indices are called `istart` and `iend`, respectively. This snippet performs this calculation to return `prctile` for stature:

```
var stature_sorted = stature.sort(function(a, b){return a-b});
istart=0;
iend=stature.length-1;

while (stature_sorted[istart]<val){
    istart++;
}

while ((stature_sorted[iend])>val){
    iend=iend-1;
}

return Math.round((istart+iend)/(2*stature.length)*1000)/10;
```

With stature for males in the ANSUR II dataset as an example, a value of 1669 mm is the 408th entry for 4081 males. Thus, $val = 1669$ returns $prctile = 10\%$ in the snippet above.

3.2.2 Calculation Types 3 and 4: Accommodation

Accommodation is a term that refers to the percentage of the target user population whose body dimensions and/or preferred system settings are included when limitations are placed on individual dimensions. Calculations for Types 3 and 4 assess accommodation and are slightly more complicated than Types 1 and 2. Type 3 calculations require the simultaneous consideration of two or more dimensions (as selected by the user) to determine accommodation.

While it may seem trivial, an important assumption for the assessment of accommodation in MARC is that an individual need only be disaccommodated on one dimension to be disaccommodated overall (one failure out of three fails all). As an example of this treatment of disaccommodation in practice, if an individual is taller than the high limit on stature, it does not matter if their shoulder breadth and weight fall within acceptable limits because they are already disaccommodated by their stature. By default, there is no allowance for disaccommodation; a fraction of a millimeter greater or less than the set limits on any of the dimensions is considered disaccommodation. However, consideration of *just noticeable difference* (JND) is possible in MARC and is discussed later.

Another important observation informing this methodology is that there exists substantial variability in the proportion of individuals. While there exist strong correlations between various length dimensions and (separately) girth dimensions, one dimension does not perfectly predict another. Thus, there is no nth-percentile person; each individual is composed of measurements with varying percentiles (Moroney and Smith, 1972).

To perform the Type 3 calculations, MARC first iterates through each individual in the data to determine which (if any) individuals exceed the set limitations on any of the dimensions. If each individual is not disaccommodated by the set limits, it increments a counter for the number of accommodated individuals on the given dimension.

The following code snippet illustrates the MARC Type 3 algorithm. As MARC loops through the population, it assesses the dimensions of each individual in comparison to the limits. For each accommodated individual, MARC increments `accom_[dimension]` by 1; otherwise, a flag called `disaccom_flag` is set to true. As long as the `disaccom_flag` flag is false (i.e., all measures are accommodated), MARC increments a counter for the total number of accommodated individuals overall (called `accom_total`) by 1. Once the loop has completed, the accommodation rates for each of the dimensions under consideration as well as the overall rate of accommodation are available by dividing the counter totals by the total number of individuals in the data. The following R code snippet illustrates this algorithm for the stature and shoulder-breadth dimensions across the data with `pop_size` number of individuals with user limits set as `min_cutoff_stature`, `max_cutoff_stature`, `min_cutoff_shoulder_breadth`, and `max_cutoff_shoulder_breadth`:

```
accom_stature = 0;
accom_shoulder_breadth = 0;
accom_total = 0;
disaccom_flag = false;

for (i=0; i<pop_size; i++){
    if ((stature[i]>min_cutoff_stature) &&
(stature[i]<max_cutoff_stature)){
          accom_stature = accom_stature + 1;
    } else {
          disaccom_flag = true;
    }
if ((shoulder_breadth[i]>min_cutoff_shoulder_breadth) &&
(shoulder_breadth[i]<max_cutoff_shoulder_breadth)){
          accom_shoulder_breadth = accom_shoulder_breadth + 1;
```

```
    } else {
          disaccom_flag = true;
    }

    if (disaccom_flag == false){
          accom_total = accom_total + 1;
    }
disaccom_flag = false;
}

accom_stature = (accom_stature*100/pop_size).toFixed(1);
accom_shoulder_breadth = (accom_shoulder_breadth*100/pop_size).toFixed(1);
accom_total = (accom_total*100/pop_size).toFixed(1);
```

These calculations are performed every time the user makes an adjustment to any of the dimension limits so that accommodation rates update in real time. That is, each time a user moves the limits on a slider in the MARC Shiny app and taps “Calculate” (see Figure 6), MARC executes these functions with the updated values. When run at the R console, the output of the `marc_accom` MARCR function appears according to the following format:

```
[1] "<Database>  -->  <Gender>"
[1] "With filter(s) on [  <filters> ], sample size is  <n>"
[1] "<measure1> ( <measure1_low> - <measure1_high> ):  P1 %"
[1] "<measure2> ( <measure2_low> - <measure2_high> ):  P2 %"
[1] "Accommodation rate for these  <number>  measure(s) is:  P3 %"
```

For Type 4 calculations, MARC does not assume or enforce “central accommodation”—that is, disaccommodation of an equal number of people greater than and less than the limits of accommodation. If a user wishes to find the “central 90%” for accommodation, they adjust the small and large values of relevant dimensions until an approximately equal portion of Soldiers are disaccommodated at each end of the relevant distributions.

Thus, for Type 4 calculations it is left to the user to experiment by trial and error to find values that yield the desired rate of accommodation (as determined by the Type 3 calculation discussed previously). As a result, there is a large number of combinations of values that would yield a specified level of accommodation.

3.3 Demographic Filtering

In addition to the four types of calculations, MARC enables additional data analysis capability through filtering (discussed in this section) and consideration of sensitivity (discussed in the next section).

MARC permits inclusion or exclusion of certain subsets of individuals by the available demographic variables. For the ANSUR II/MC-ANSUR data, these variables are age, race, MOS, and component. If a filter (or filters) is applied, MARC looks for and retains only the individuals in the dataset that match the filter parameters. These filters are often helpful when targeting specific user characteristics (e.g., specific MOS) with an evaluation or assessing trends within the data and may facilitate analysis of populations other than the U.S. military (see Nadadur et al., 2016) for a technique that synthesizes anthropometry for global user populations using U.S. Army data).

A caveat to the use of filters is that some parameters or combinations of parameters may result in very few observations. In these cases, MARCR (as well as the MARC Shiny GUI) displays a warning indicating the sample size being used for analysis.

3.4 Just Noticeable Difference

For accommodation analyses with multiple dimensions, MARC enables consideration of scenarios for which users may be insensitive to a small amount of disaccommodation of the relevant anthropometry. This is captured in an analysis by specification of *just noticeable difference (JND)*.

JND is an amount of disaccommodation a person may experience just before they begin to notice. Including the effect of JND serves to increase overall accommodation rates. Any consideration of JND should be supported by relevant literature, research, or test data to ensure that users are not being inappropriately disaccommodated. Generally, JND is associated with an outcome measure, like a user's preferred seat height or their judgment of the adequate amount of clearance to perform required functions. As such, there are methods for empirically measuring JND and then accounting for it in modeling. See Garneau and Parkinson (2013) for an in-depth discussion of JND as it relates to physical accommodation analyses.

JND is generally not associated directly with the anthropometric measures themselves—however, it may be included in anthropometric modeling (e.g., with MARC) insofar as the anthropometric measures are used as a proxy for the required system dimensions for estimating accommodation. For instance, to assess approximate population accommodation for a driver's physical space requirements, sitting height might be used as a rough approximation for the necessary hip point to ceiling height distance, biacromial breadth an approximation of required seat width, and buttock to knee length an approximation for knee clearance. Including a small, reasonable amount of JND for these measures (e.g., ¼–½ in.) can help assess the trade space—but should also be accompanied by adequate discussion of assumptions and contextualized with similar analyses that exclude the JND sensitivity factor. The analyst should also consider whether slight amounts of disaccommodation might lead to a degradation in performance, comfort, or safety over sustained use.

3.5 Combined Gender Analyses

For the data sources listed in Section 3.1, anthropometric datasets are available for each gender separately. However, it is often necessary to perform analyses for a combined population. A common target is 85% male/15% female, as that approximates characteristics of Soldiers for many systems/MOSs. MARCR provides functionality for performing combined gender analyses, as described next.

As with other MARCR functionality, the large datasets facilitate straightforward analysis—in this case, via sampling/reweighting. For similar applications, sampling with replacement might be the technique of choice. However, to preserve the characteristics of the source distributions, a technique is deployed using oversampling wherein the observations for each gender are repeated a given number of times to achieve the desired proportion in the combined population. Only specified measures of interest are sampled to create the combined dataset to reduce processing time.

The following notation describes relevant variables:

- pM (pF): desired proportion of males (females) in combined population
- nM (nF): number of males (females) in source population
- wM (wF): weighting factor for males (females) in combined population
- k: weighting factor
- SF: user-defined "speed factor" specifying number of significant figures to retain for k

The following steps are performed to create a combined dataset with the approximate desired proportion of males and females.

1. Reduce male and female source datasets to required dimensions
2. Solve for k in the following equation:
$$k\frac{n_M}{n_F} = \frac{p_M}{1 - p_M}$$
3. Round k to the number of significant figures given by SF, then convert the decimal to a fraction (e.g., 0.3 becomes 3/10)
4. Given that $k = \frac{w_M}{w_F}$, build the combined data by weighting/counting each male in the source dataset by w_M and each female by w_F (e.g., for $k = 0.3$, $w_M = 3$, and $w_F = 10$).

Once the combined, reweighted dataset has been created, the desired analysis may be performed using the techniques in Section 3.2.

The "speed factor" mitigates a potential downside to this methodology, which is that a combined gender analysis can take some time (up to a few minutes) to compute—even using modern hardware. This is due to the potentially very large size of the combined dataset for analysis and limiting k to the indicated number of significant digits can help reduce required precision (and thus the weighting factors) to speed up calculation of results. For instance, the weighting factors for $k = 0.3$ are 3 and 10 for males and females, respectively, whereas the weighting factors for $k = 0.33$ are 33 and 100. The computing time for $k = 0.3$ will be faster than $k = 0.33$.

3.6 Data Visualization

In general, visualizing data for which many dimensions (i.e., more than two) are relevant is challenging. This is particularly evident for the analysis of physical accommodation, which may involve demographic variables, many dimensions of anthropometry, consideration of behavior or preference, and scenarios involving various limitations or combinations of clothing and equipment. The following types of visualizations are provided as built-in capabilities in the MARCR package:

- *Histogram/Probability Density*: This graph is used to visualize the distribution of the population across a single anthropometric measure.
- *Scatter Plot*: This graph shows the individual data points wherein one measure is plotted against another; disaccommodation is depicted by coloring the disaccommodated points red.
- *Parallel Coordinates Plot*: This multidimensional visualization shows the relationships among many variables plotted on parallel vertical axes; traces for each data point intersect the parallel coordinates. Disaccommodation is depicted by coloring the disaccommodated traces red.

For a complex analysis, using only a single plot produced by MARC will probably be insufficient. When presenting an analysis to a decision-maker, it is often insightful to provide multiple plots showing the same data from different perspectives. In some cases, it may be necessary to manipulate the anthropometric data and then generate custom multidimensional plots to convey the nuances of the data for a given situation.

4. SAMPLE USE CASES

This section covers a few simple use cases for MARC and provides sample MARCR commands that may be used in each scenario, along with the associated R output and plots generated by MARCR. Any parameters that are not specified when writing a function uses the default values. The default values are given in the MARCR documentation (Appendix A).

4.1 Clearance (Single Dimension Analysis)

Scenario: A designer would like to know the minimum size of a circular hatch to ensure adequate clearance for 99% of the population of users, which have been identified as being characterized by the ANSUR II (2012) database. The hatch opening has been measured in centimeters.

Assumptions: This is a univariate (one-dimension) problem—find the largest breadth dimension to ensure that nearly all users may exit a hatch. The designer is unsure whether shoulder breadth (males) or hip breadth (females) will be the limiting factor, so both will be checked. The designer will perform calculations assuming a semi-nude condition without clothing or equipment (i.e., ANSUR and ANSUR II survey conditions).

Solution: This problem would make use of the `marc_prctile()` function to find the percentiles. The function and R console output for each measure is as follows:

- For 99th percentile male shoulder breadth:

```
marc_prctile(calcType=1,value=0.99,db=2,measure="bideltoidbreadth",
gender="male",filters=NA)
[1] "ANSUR2 --> male"
[1] "For bideltoidbreadth, a percentile of 99 gives a value of 593"
```

- For 99th percentile female hip breadth:

```
marc_prctile(calcType=1,value=0.99,db=2,measure="hipbreadth",
gender="female",filters=NA)
[1] "ANSUR2 --> female"
[1] "For hipbreadth, a percentile of 99 gives a value of 423"
```

The largest of these values is 59.3 cm for the 99th percentile male shoulder breadth, and so the hatch must have a minimum diameter of 59.3 cm to accommodate 99% of the population in the semi-nude condition. Figures 7 and 8 show the probability density plots for bideltoid breadth for males and hip breadth for females, respectively, with the desired percentile value annotated.

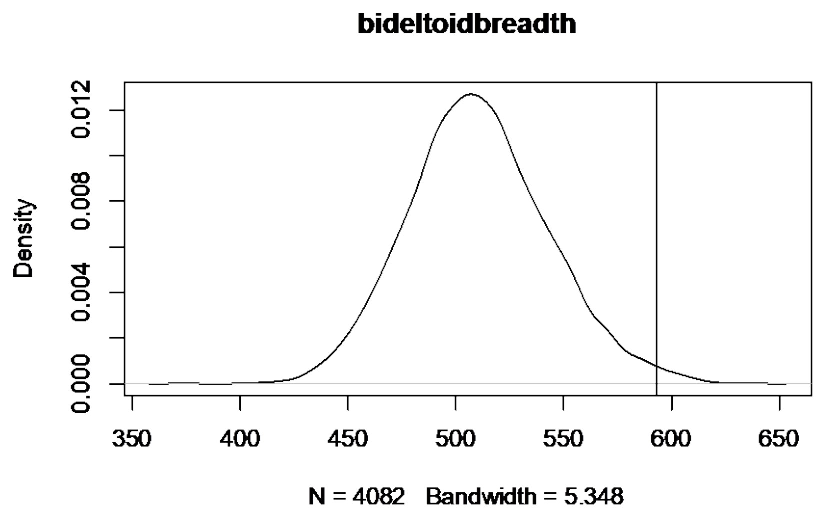

Figure 7. **Probability density plot for bideltoid breadth (male) for ANSUR II dataset, with the 99th percentile value annotated by the vertical line**

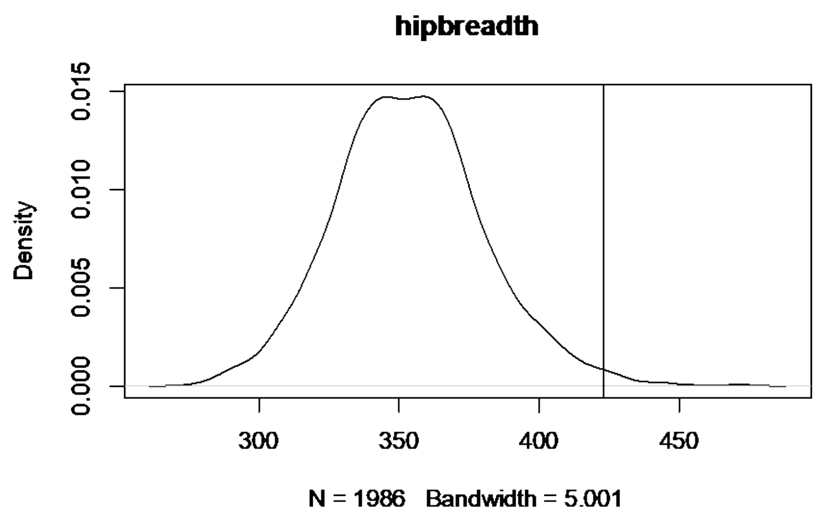

Figure 8. **Probability density plot for hip breadth (female) for ANSUR II dataset, with the 99th percentile value annotated by the vertical line**

4.2 Anthropometry Trends over Time (Secular Trends)

Scenario: A program manager is unsure whether an update to a legacy Army system with a hatch designed in the 1990s needs to be reconfigured to enlarge the opening to achieve adequate accommodation today.

Assumptions:

- Since this component affects emergency egress, assume that it was originally designed for the 99th percentile value for male shoulder breadth.
- The legacy system was likely designed for the ANSUR (1988) data.
- Shoulder breadth is the limiting factor (as discussed in Scenario 1; this also implies that only male anthropometry are necessary for this analysis).
- For the sake of comparison, assume only anthropometry is of concern and there is not any additional clothing or equipment to consider.

Solution: This problem would make use of the `marc_prctile()` function to find the percentiles. The function and R console output for each condition is as follows:

- For 99th percentile male in 1988:

```
marc_prctile(calcType=1,value=0.99,db=1,measure="BIDELTOID_BRTH",
gender="male",filters=NA)
[1] "ANSUR1 --> male"
[1] "For BIDELTOID_BRTH, a percentile of 99 gives a value of 550.54"
```

- For equivalent male percentile in 2012:

```
marc_prctile(calcType=2,value=550.54,db=2,measure="bideltoidbreadth",
gender="male",filters=NA)
[1] "ANSUR2 --> male"
[1] "For bideltoidbreadth, a value of 550.54 gives a percentile of
88.78"
```

Nomenclature for measures changed from 1988 to 2012 and can be checked with the `marc_names()` function, supplied with the `db=1` or `db=2` parameter. Figures 9 and 10 show the probability density plots for males in the ANSUR and ANSUR II data, respectively, with the 99th percentile annotated for the ANSUR plot and the equivalent value (551 mm) annotated in the ANSUR II plot.

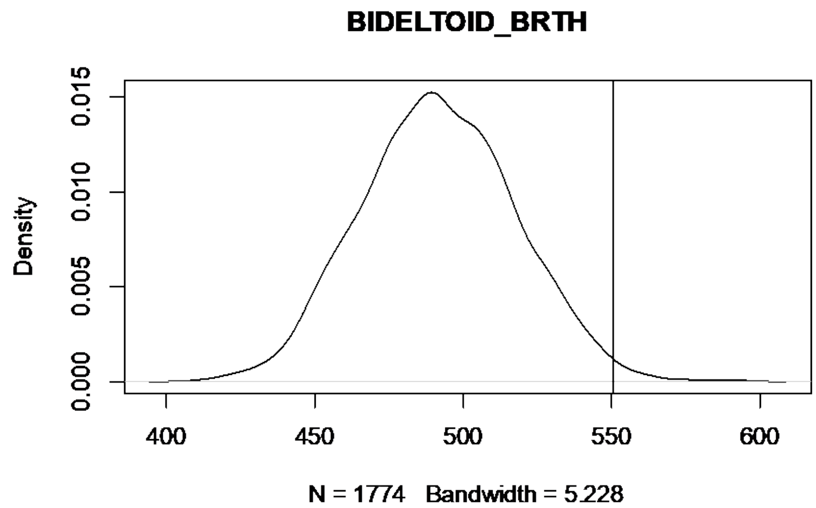

Figure 9. Probability density plot for bideltoid breadth (male) for ANSUR dataset, with the 99th percentile value annotated by the vertical line

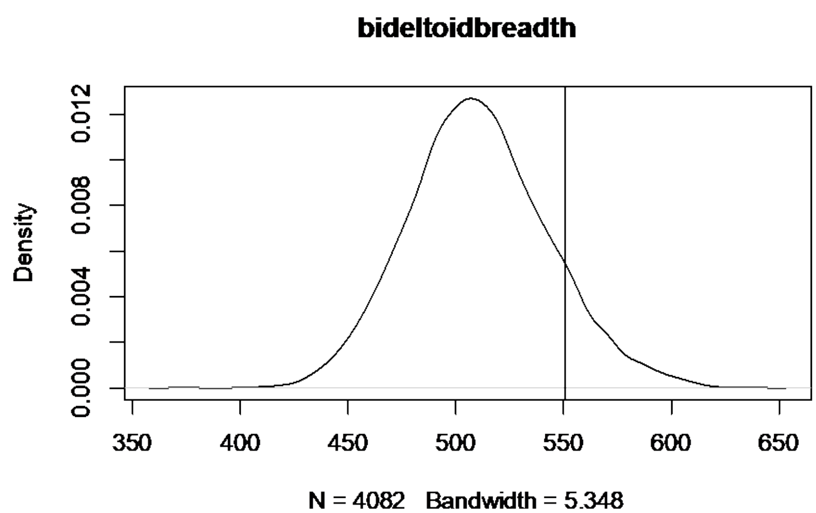

Figure 10. Probability density plot for bideltoid breadth (male) for ANSUR II dataset, with the equivalent value from Figure 9 (551 mm) annotated by the vertical line

The increase in bideltoid breadth from 1988 to 2012 is an example of a secular trend, a change that occurs over a period of time. For a variety of reasons, the size of Soldiers has changed in several key ways over the past 50 years. Moreover, while not considered in this analysis, the introduction of women in combat roles has changed the requirements for the physical design of relevant systems and these systems may not perform as well as originally intended. Comparisons using MARCR provide a mechanism to explore the effect of gender, demographic, and secular trends.

In this example, using the original (1988) 99% cutoff for bideltoid breadth would yield an accommodation rate of only 89% today (2012), which is inadequate for an emergency egress. Modern clothing and equipment have made Soldiers safer, but also come with added bulk and heft. Considering the effect of this equipment is almost certain to further degrade the accommodation performance of this system. The DEVCOM SC monitors secular and demographic trends via periodic surveillance studies to determine if a new data collection effort is warranted, or if corrections need to be made to existing data (Parham et al., 2021).

4.3 Driver Workstation Accommodation (Multiple Dimension Analysis)

Scenario: An analyst would like to know the percentage of current male Soldiers that are accommodated when limitations on the range of shoulder breadth and buttock–knee length are set according to limitations of the driver workstation in a legacy system. The limits are:

- Sitting height: up to 95 cm
- Shoulder breadth: up to 55 cm
- Buttock–knee length: 55 to 70 cm

Assumptions: The analyst will use the ANSUR II (2012) data since this is the most current survey of Soldiers available. No filters will be applied, and disaccommodation will be considered binary (no allowance for JND).

Solution: This problem would make use of the `marc_accom()` function to find the total accommodation rate, as follows:

```
marc_accom(db=2,measures=c("sittingheight","bideltoidbreadth",
"buttockkneelength"),measureRange=c(0,950,0,550,550,700),filters=NA,
gender="male")
```

This function yields the following R console output:

```
[1] "ANSUR 2  -->  male"
[1] "sittingheight ( 0 - 950 ):  82.02 %"
[1] "bideltoidbreadth ( 0 - 550 ):  88.76 %"
[1] "buttockkneelength ( 550 - 700 ):  98.53 %"
[1] "Accommodation rate for these  3  measure(s) is:  73.57 %"
```

Figures 11 and 12 show the scatter and parallel coordinates plots generated by MARCR for the inputs provided. These plots color-code the individuals in the ANSUR II data according to their accommodation—individuals shown as blue are accommodated and red are disaccommodated. For Figure 11, MARCR selects the first two dimensions provided to use as the horizontal and vertical axes to generate the plot, but all dimensions are used to determine accommodation; thus, some points are shown as red below the cutoffs because they are disaccommodated by the third dimension (buttock–knee length).

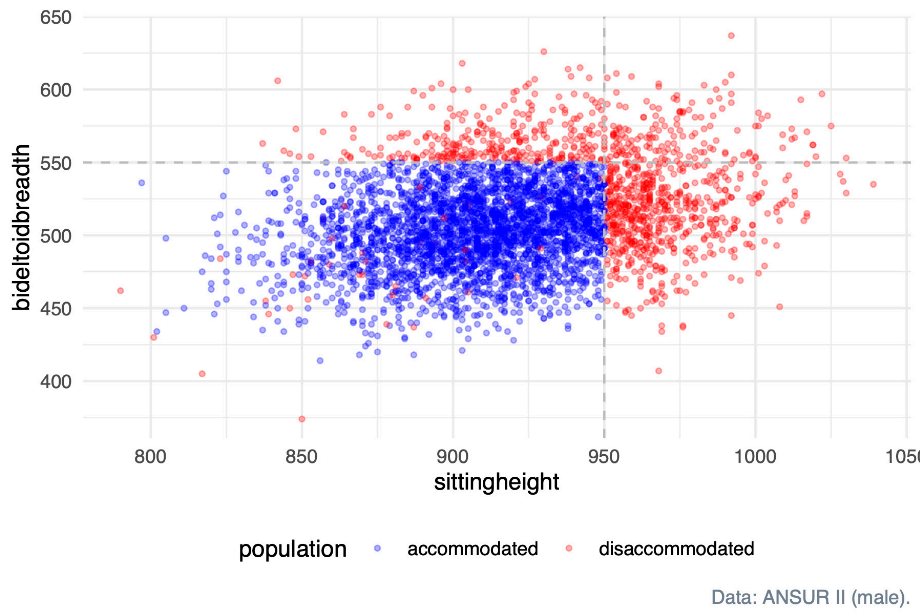

Figure 11. Scatter plot showing accommodated and disaccommodated individuals in the ANSUR II (male) data according to the limits provided (shown by dashed lines)

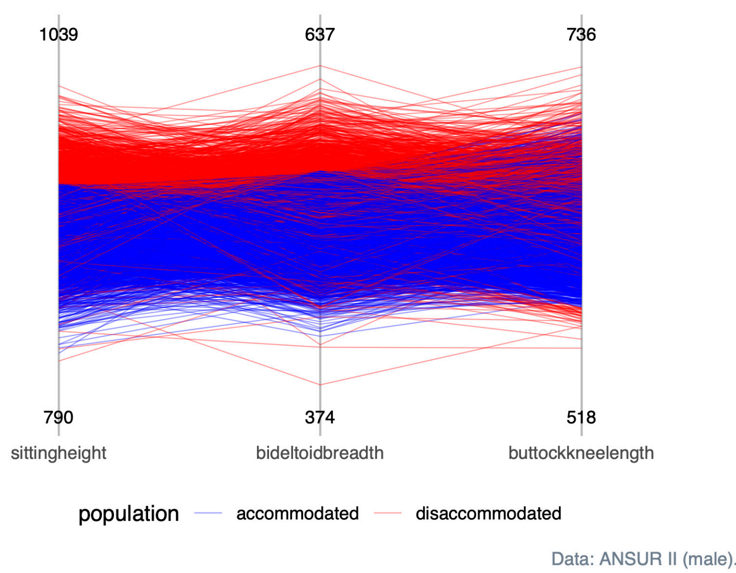

Figure 12. Parallel coordinates plot showing accommodated and disaccommodated individuals in the ANSUR II (male) data according to the limits provided

This type of analysis is particularly useful when bounding a problem to set the space envelope for initial requirements, or to validate and/or quantify an analysis performed with DHM software. For the latter, it is important to consider the context, assumptions, and goals of the analysis. As a modeling and simulation tool, DHM may be used early in the acquisition lifecycle to determine potential issues affecting accommodation before any prototypes are constructed—particularly if 3D CAD geometry is available using a similar system or notional geometry for the proposed system. It may also be used for evaluation of accommodation once a design is nearing completion and/or has been finalized. In either case, the DHM analyst is often looking at certain considerations, including clearance issues (e.g., projections into the driver workstation), visibility issues, and an approximate evaluation of fit considering assumed posture(s) for a set of clothed and equipped digital manikins. However, it is difficult to produce quantitative assessments of population accommodation using DHM alone, and this is where MARC serves to fill an analytical gap. Key dimensions measured from the digital environment (e.g., distance from hip point to ceiling or available space for knee clearance) may be entered into MARC to determine resulting quantitative estimates of population accommodation.

4.4 Combined/Multistep Analysis

Sometimes it may be useful to combine multiple MARCR functions for analysis, as in the following scenario.

Scenario: Consider the case for which an analyst would like to know the accommodation rate when stature and sitting height are set to their respective 5th to 95th percentile values for a combined, evenly split male–female ANSUR II population (with a Regular Army filter applied).

Solution: This problem would make use of both the `marc_prctile()` and `marc_accom()` functions, as follows:

```
measures = c("stature", "sittingheight")
limit_low = 0.05 # percentile
limit_high = 0.95 # percentile

marc_accom(
      gender = "combined",
      pM = 0.5,
      measures = measures,
      filters = c("component", "==", "\"Regular Army\""),
      measureRange = c(
            marc_prctile(
                  value = limit_low,
                  measure = measures[1],
                  gender = "combined",
```

```
                pM = 0.5,
                filters = c("component", "==", "\"Regular Army\""),
                makePlot = FALSE,
                verbose = FALSE
            ),
            marc_prctile(
                value = limit_high,
                measure = measures[1],
                gender = "combined",
                pM = 0.5,
                filters = c("component", "==", "\"Regular Army\""),
                makePlot = FALSE,
                verbose = FALSE
            ),
            marc_prctile(
                value = limit_low,
                measure = measures[2],
                gender = "combined",
                pM = 0.5,
                filters = c("component", "==", "\"Regular Army\""),
                makePlot = FALSE,
                verbose = FALSE
            ),
            marc_prctile(
                value = limit_high,
                measure = measures[2],
                gender = "combined",
                pM = 0.5,
                filters = c("component", "==", "\"Regular Army\""),
                makePlot = FALSE,
                verbose = FALSE
            )
        )
)
```

This combination of functions yields the following R console output:

```
[1] "ANSUR2 --> combined with a split of 50% males "
[1] "For the combined population, males have a weight of 481 and females have a weight of 1000."
[1] "With filter(s) on [  component ], sample size is  2039720"
[1] "stature ( 1547 - 1846 ):  90.19 %"
[1] "sittingheight ( 813 - 965 ):  90.24 %"
[1] "Accommodation rate for these  2  measure(s) is:  85.33 %"
```

In this case, a combined gender population necessitates reweighting and the respective weights are shown with the output.

The functions in MARCR are intended to provide flexibility to an analysis and may be combined in many different ways to build more complex analyses. For instance, `marc_data()` may be used to return the vector of values for any anthropometric dimension and `marc_names()` provides the measure names for any of the given databases. Taken together, these functions allow users to create custom plots and more easily compare and integrate data across the different datasets. The MARC Shiny application combines these various functions in different ways to interact with the anthropometric data for various kinds of analyses.

5. CONCLUSION

Using accurate data and the best available techniques for modeling physical accommodation yields designs that perform as expected across the physical variability in Soldiers (and Warfighters across the other services as data are available). There are always various factors that compete against the physical space available for users (e.g., overall system size/weight, placement of controls and other equipment). Effective quantitative models enable appropriate trade-offs against these competing factors to optimize system performance for the Soldier. MARC is a tool that assists HSI practitioners in analyzing and applying anthropometric data to the design or evaluation of systems, equipment, or environments. Existing as both an R package (MARCR) and GUI application (MARC Shiny), MARC provides a data resource, calculators, and other tools for interacting with, analyzing, and visualizing anthropometric data. This technical note reviewed the data underlying MARCR, the methods of analysis and associated assumptions, and current capabilities. This report also discusses examples of simple use cases and the steps to complete tasks.

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Appendix A – Military Anthropometry Resource Companion in R (MARCR) Documentation

A.1 MARCR (v1.05): Implementation of the Military Anthropometry Resource Companion (MARC) as an R package

A.1.1 Description

MARC is a tool developed by the U.S. Army for accessing and analyzing anthropometric (body size) reference data from U.S. military surveys. Calculations use techniques that capitalize on the large sample size of the included datasets.

A.1.2 Dataset Characteristics

This version of MARCR includes three datasets: the 1988 U.S. Army Anthropometric Survey (ANSUR) data, the 2012 Army ANSUR II data, and the 1966 Army Men data.

- **ANSUR.** 1987–1988 anthropometric survey of Army personnel; 1774 men and 2208 women were sampled to match the proportions of the active-duty Army of 1988. Dimensions include 132 standard measurements, 60 derived dimensions, and 48 head and face dimensions.
- **ANSUR II.** A comprehensive anthropometric survey of U.S. Army Soldiers, completed in 2012 by the Natick Soldier Research, Development and Engineering Center (NSRDEC). There were 94 directly measured dimensions; 39 derived dimensions; and 3D head, foot, and full-body scans obtained on each subject in this study. The sample consisted of 7435 men and 3922 women (including Active Duty, National Guard, and Army Reserve Soldiers).
- **Army 1966.** Archival data from the 1966 U.S. Armed Forces anthropometric surveys of 1966. There were 70 measurements collected from 6682 Army men. Data should be used with caution due to older measurement definitions and are primarily included in MARC for historical comparison.

A.1.3 MARCR Functions

- **`marc_accom`** Function that returns accommodation given specified measure(s) with given parameters
- **`marc_prctile`** Function that returns percentile/value of a single specified measure with given parameters
- **`marc_names`** Function that returns available names for `measures` when given a specified database
- **`marc_data`** Function that returns and displays raw data when given a specified database and gender.

A.2 marc_accom(): Accommodation Rate Given the Specified Parameters

A.2.1 Description

Function that returns accommodation given specified measure(s) with given parameters.

A.2.2 Usage

```
marc_accom(
  db = 2,
  measures = c("stature", "sittingheight"),
  measureRange = c(1000, 1800, 850, 1000),
  gender = "male",
  pM = 0.5,
  speed = 3,
  jnd = NA,
  filters = c("primarymos", "==", "\"11B\"", "component", "==", "\"Regular
Army\""),
  makePlots = TRUE,
  verbose = TRUE,
  returnType = "list"
)
```

A.2.3 Arguments

db	dataset to use: 1 for ANSUR, 2 for ANSUR 2, 3 for Army 1966
measures	names of measurements in this format: c(<measure1>,<measure2>,...)
measureRange	specify min/max (inclusive) in this format: c(<measure1_min>,<measure1_max>,<measure2_min>,<measure2_max>,...)
gender	may be 'male', 'female', or 'combined'; note that a combined gender analysis may be substantially slower than a single-gender analysis
pM	proportion of males in a combined gender analysis; must be between 0.01 and 0.99
speed	number of significant figures to use for weight factor in a combined gender analysis; a smaller value for speed yields faster results
jnd	specify value to use for just noticeable difference in this format: c(<measure1_jnd>,<measure2_jnd>,...); set 0 values or specify jnd=NA to disregard (note that setting NA for any value will disregard JND overall)
filters	apply filters on ANSUR 2 data for age, component, dodrace, or primarymos; use format: c(<filter>,<comparator>,<value>) or specify filters=NA if none
makePlots	set to TRUE to get a color-coded scatter plot with axes given by the first two measures, and a parallel coordinates plot for all measures; plots are saved to the plots folder in the working directory
verbose	set to TRUE to get text summary, set to FALSE to return accommodation rate only
returnType	set to 'percent' to get percent value of accommodation or 'list' for a list containing the subsets of the population that are accommodated and disaccommodated

A.2.4 Value

Either accommodation rate or accommodated/disacommodated subset of population, as specified by `returnType`

A.2.5 See Also

`marc_prctile()` to find percentile/value of a single specified measure with given parameters, `marc_names()` for measure names to use in the `measures` vector, `marc_data()` for available raw data

A.3 marc_prctile(): Percentile/Value of a Single Specified Measure with Given Parameters

A.3.1 Description

Function that returns percentile/value of a single specified measure with given parameters.

A.3.2 Usage

```
marc_prctile(
  calcType = 1,
  value = 0.5,
  db = 2,
  measure = "stature",
  gender = "male",
  pM = 0.5,
  speed = 3,
  filters = c("primarymos", "==", "\"11B\"", "component", "==", "\"Regular
Army\""),
  makePlot = TRUE,
  verbose = TRUE
)
```

A.3.3 Arguments

calcType	determines type of calculation: 1 is give percentile get value, 2 is give value get percentile
value	value of the measure in either percentile or mm
db	dataset to use: 1 for ANSUR, 2 for ANSUR 2, 3 for Army 1966
measure	name of measurement
gender	may be 'male', 'female', or 'combined'; note that a combined gender analysis may be substantially slower than a single-gender analysis
pM	proportion of males in a combined gender analysis; must be between 0.01 and 0.99
speed	number of significant figures to use for weight factor in a combined gender analysis; a smaller value for speed yields faster results
filters	apply filters on ANSUR 2 data for age, component, dodrace, or primarymos; use format: c(<filter>,<comparator>,<value>) or specify filters=NA if none
makePlot	set to TRUE to get a density distribution for the measure; plot is saved to the plots folder in the working directory
verbose	set to TRUE to get text summary, set to FALSE to return percent/value only

A.3.4 Value

Either percentile (in percentage) or value

A.3.5 See Also

marc_accom() to find accommodation given specified measure(s) with given parameters, marc_names() for measure names to use in the measures vector, marc_data() for available raw data

A.4 marc_names(): Available Measure Names

A.4.1 Description

Function that returns available names for measures when given a specified database. Can also look up display name and description for any given measure.

A.4.2 Usage

```
marc_names(db = 2, name_lookup = NA, ...)
```

A.4.3 Arguments

db	dataset to use: 1 for ANSUR, 2 for ANSUR 2, 3 for Army 1966
name_lookup	dimension name to search for within specified database

A.4.4 Value

List of measurements; if "name_lookup" is provided, a list with "display_name" and "description" will be returned for the given "name_lookup"

A.4.5 See Also

`marc_prctile()` to find percentile/value of a single specified measure with given parameters, `marc_accom()` to find accommodation given specified measure(s) with given parameters, `marc_data()` for available raw data

A.5 marc_data(): Available Raw Data

A.5.1 Description

Function that returns and displays raw data when given a specified database and gender.

A.5.2 Usage

```
marc_data(db = 2, gender = "male", viewData = FALSE, ...)
```

A.5.3 Arguments

`db`	dataset to use: 1 for ANSUR, 2 for ANSUR 2, 3 for Army 1966
`gender`	may be `'male'` or `'female'`
`viewData`	whether or not to show data when called; may be `TRUE` or `FALSE`

A.5.4 Value

List of raw data

A.5.5 See Also

`marc_prctile()` to find percentile/value of a single specified measure with given parameters, `marc_accom()` to find accommodation given specified measure(s) with given parameters, `marc_names()` for measure names to use in the `measures` vector

LIST OF ACRONYMS

3D	three-dimensional
ANSUR	U.S. Army Anthropometric Survey
CAD	computer-aided design
CIE	clothing and individual equipment
DAC	DEVCOM Analysis Center
DEVCOM	U.S. Army Combat Capabilities Development Command
DHM	digital human modeling
GUI	graphical user interface
HSI	Human Systems Integration
HTML	Hyper Text Markup Language
JND	just noticeable difference
MARC	Military Anthropometry Resource Companion
MARCR	Military Anthropometry Resource Companion in R
MC-ANSUR	U.S. Marine Corps ANSUR
MIL STD	Military Standard
MOS	military occupational specialty
NSRDEC	Natick Soldier Research, Development, and Engineering Center
SC	Soldier Center