



Designation: F3661 – 24

Standard Guide for Assessing Fit Accommodation of Exoskeletons for Manufacturers and Designers¹

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1. Scope

1.1 This guide covers guidelines and best practices in considering user fit and accommodation of exoskeletons. Accommodation refers to the ability of users to operate and maintain the exoskeleton safely and in the manner for the task(s) for which it was intended, as opposed to the exoskeleton users' fit to the environment (for example, using an exoskeleton while walking down the aisle of a plane). The manufacturer should specify the anthropometric characteristics of the population for which the exoskeleton was designed so that users may select the appropriate exoskeleton. This would include suggested language for identifying and clearly communicating relevant metrics regarding the fit and adjustment factors for their system, and may clearly specify the population who can use the exoskeleton safely. **Appendix X1** provides databases for determining population accommodation and **Appendix X2** provides an example of fit for a singular dimension. Lastly, this guide assumes the reader understands the fundamentals behind anthropometry and human biomechanics. The concepts in this guide may be appropriate for medical exoskeletons; however, medical exoskeletons have nuanced use cases which require a lot more specificity. While the guidance here may provide insight to the fit and accommodation of medical exoskeletons, the information herein is not exhaustive and should not replace treatment or oversight from a medical professional.

1.2 The values stated in SI units are to be regarded as standard. The values given in parentheses after SI units are provided for information only and are not considered standard.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.4 *This international standard was developed in accordance with internationally recognized principles on standard-*

ization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.

2. Referenced Documents

2.1 ASTM Standards:²

F3323 Terminology for Exoskeletons and Exosuits

F3527 Guide for Assessing Risks Related to Implementation of Exoskeletons in Task-Specific Environments

F3613 Practice for Recording the Exoskeleton Fit to the User

F3614 Practice for Recording the Exoskeleton User Information

2.2 Federal Standards:³

MIL-STD-1472 H Department of Defense Design Criteria Standard, Human Engineering

MIL-HDBK-1908 Department of Defense Handbook: Definitions of Human Factors Terms

2.3 ISO Standards:⁴

ISO 7250 Basic human body measurements for technological design

ISO 8559 Size designation of clothes

ISO 15537 Principles for selecting and using test persons for testing anthropometric aspects of industrial products and designs

ISO 20685 3-D scanning methodologies for internationally compatible anthropometric databases

3. Terminology

3.1 Definitions:

3.1.1 *accommodation, n*—the extent to which the physical requirements of the person, the task, and the workspace are met; it is the optimized status between the human and their

² For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at www.astm.org/contact. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

³ Available from U.S. Government Publishing Office (GPO), 732 N. Capitol St., NW, Washington, DC 20401, <http://www.gpo.gov>.

⁴ Available from International Organization for Standardization (ISO), ISO Central Secretariat, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, <http://www.iso.org>.

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immediate environment, where immediate environment begins with clothing or worn devices and extends to the workplace.

3.1.1.1 *Discussion*—This does not include cognitive accommodation, nor does it include accommodations for disabilities.

3.1.2 *anthropometry, n*—measured dimensions that describe the size and shape of the human body; these dimensions are often presented in the form of summary statistics that describe the range of body dimensions that are observed in a population.

MIL-HDBK-1908

3.1.3 *anthropomorphic exoskeleton, n*—an exoskeleton whose form mimics that of a human body or voluntary human motions.

3.1.4 *fit, n*—the extent to which an exoskeleton is the right shape and size to conform to the body of the wearer and allow the purpose of the user to be achieved; proper fit entails “equipment ease,” a term denoting the balance between the size of wearable equipment and the size of the wearer; there are two types of fit: dynamic and static.

3.1.4.1 *dynamic fit, n*—how the human and exoskeleton move and interact with each other through functional range of motion (ROM) activities and task performance, and is defined formally in the context of a specific activity.

3.1.4.2 *static fit, n*—the alignment between dimensions of the human and exoskeleton in one or a small number of predefined, standardized postures.

4. Significance and Use

4.1 Improperly fitted exoskeletons may cause discomfort, distraction, stress, disuse, accidents, and therefore, may cause unacceptable risk of injury or damage to the health of users (1).⁵ An improperly fitted exoskeleton can also cause a loss of cognitive fit and task failure. According to Ref (2), “Cognitive fit refers to supporting the perception–cognition–action decision process of the human when wearing the exosystem.” This characteristic is relevant to exosystem fit as the operator’s cognitive capability must be maintained such that operational tasks, including decision making, can be adequately performed. Thus, manufacturers and designers may consider user anthropometry and fit when designing exoskeletons. This guide provides a set of recommendations for considering the anthropometry (body size and shape) of the intended user population of an exoskeleton. These recommendations can provide guidance to designers on fit criteria. They will also facilitate the consistent (repeatable) estimation of accommodation rates. This guide further highlights important considerations in the design of exoskeletons which are impacted by human physical variation as well as range of motion and clearances, which are critical safety concerns. Additionally, anthropometric considerations also extend to kinematic and kinetic parameters; however, these concepts are beyond the scope of this guide. Lastly, this guide assumes the reader understands the fundamentals behind anthropometry and human biomechanics.

4.1.1 In estimating how much (that is, what percentage) of the population is accommodated by an exoskeleton, it is critical to use the appropriate anthropometric database. The anthropometric data upon which the design is based should match the target user population as closely as possible. This can be a challenge, particularly for civilian populations where detailed anthropometric data are often not widely available. A list of readily available anthropometric databases is provided in [Appendix X1](#). A limited number of civilian datasets are available in the public domain (that is, free). There are more extensive anthropometric datasets that are available for purchase.

4.1.2 When discussing accommodation, disproportionate disaccommodation is an essential conversation in the context of groups not considered. Disproportionate disaccommodation occurs when one group (for example, men) is accommodated at a rate different than that of other groups (for example, women) or at rates different than their relative presence in the overall population. Best practices of estimating fit include consideration of available anthropometric data and attention to subpopulations that may not be fully accommodated.

4.2 Considering anthropometry during exoskeleton design will result in information useful to end users. Information may include who may safely and effectively use an exoskeleton and how to correctly measure body dimensions to determine size requirements. Sizing information may also include criteria to determine if the exoskeleton is fitting properly and how to adjust the exoskeleton for a better fit. Possible limitations to the end user’s range of motion and guidance regarding the use of clothing, PPE, or other equipment may also be provided to the end user.

4.3 Not every element of this guide may be applicable to all exoskeletons, nor are the recommendations in this guide intended to be prescriptive (that is, manufacturers may already provide a variable level of adjustability inherent in the exoskeleton design which may be described in their guidance).

4.4 Static and dynamic fit are related to, but not the same as, comfort. Static fit refers to the alignment between dimensions of the human and exoskeleton in one or a small number of predefined, standardized postures, with no consideration of movement. An example of static fit is a user in a standing posture with their hands by their side. This would allow for shoulder breadth measurements to be taken. Dynamic fit, on the other hand, relates to the fit of the human and exoskeleton interaction with each other through functional range of motion (ROM) activities. An example of dynamic fit is a user moving the shoulder complex through the range of motion for flexion/extension and adduction/abduction. This would allow for changes in the shoulder complex to be noted and measured.

4.4.1 The environment is an important factor in dealing with evaluations of comfort or discomfort. According to Ref (3), discomfort was reported to be related to the physical characteristics of an environment. However; in the absence of discomfort, the user experiences a neutral subjective state. To notice comfort, something positive may be experienced, such as rest, security, relaxation, or indulgence; therefore, comfort and discomfort are considered two independent variables.

⁵ The boldface numbers in parentheses refer to a list of references at the end of this standard.

Nevertheless, in equipment evaluation, both discomfort and comfort can be related to an equipment's physical features (4, 5), albeit, comfort may also include the visual pleasure of a design as well (6, 7). For example, when wearing an exoskeleton, fit is a parameter of the exoskeleton. However, if the exoskeleton does not fit from an anthropometric perspective, this could mean discomfort from the exoskeleton device. Thus, the opposite of non-fitting or of discomfort would be fit and comfort.

5. Exoskeleton Anthropometric Design

5.1 Seven-Step Paradigm for Exoskeleton Anthropometric Design:

5.1.1 See Appendix X2 for an example of using the Seven-Step Paradigm (Fig. 1) to accommodate fit of a singular dimension.

5.1.2 Define Necessary Body Dimensions:

5.1.2.1 Selecting the required body dimensions to accommodate is a key step to ensuring user safety and comfort of the exoskeleton. What is the intended use of the exoskeleton? Is it for the lower body, a limb, the whole body, etc.? Does it provide stability, increase strength, reduce fatigue, or improve safety? How will the user interact with it? The answers to these questions help the designer identify which body dimensions need to be considered in the design. For example, sitting height is an important measure for cab design and hand width is a critical dimension for gloves. Furthermore, if designing a back exoskeleton, understanding the dimensions of the trunk, hips, thighs, waist, chest, and shoulders may be essential to the design. This would all depend on how the back exoskeleton would be coupled to the user and the required locus of assistive support to the user's back. Improper fit due to the selection of improper dimensions based on the desired design may lead to premature muscle activation, reduced anticipatory postural maintenance and proprioception, and a poor design. Defining

the correct dimensions in the beginning will reduce design risk as the design process progresses.

5.1.2.2 Measurements may be defined using standard anthropometric anatomical landmarks of the user population. Customarily, assessing anatomical landmarks requires palpation of the area of interest to find the correct bones. Performing such measurements requires a trained technician with the proper measurement tools and knowledge of how to palpate for the bony anatomical landmarks. It is recommended to seek out an expert in this field. Additionally, Practice F3614 provides further information on recording such metrics on the user.

5.1.3 Define Population Composition—Who are the intended users of the exoskeleton? Factors such as sex, age, race/ethnicity, and occupation are important considerations. Understanding the user population can guide sizing, adjustability, and ensure that the exoskeleton is appropriately designed for the intended users.

5.1.4 Define Population to be Accommodated—What fraction of the target user population will be able to use the design in the intended manner? Accommodation for 100 % of the population is usually infeasible. Typically, an appropriate fraction (for example, 95 % across multiple sizes) is accommodated, recognizing that there are tradeoffs in cost, safety, size of the apparatus, etc.

5.1.5 Obtain Reference Material Data—Finding data that appropriately represents the target user population is usually a challenge, particularly for civilian populations. This might include reviewing reference materials, particularly for measures such as strength and range of motion. Since multivariate analyses are necessary for properly estimating accommodation, detailed data rather than summary statistics are preferred. Having a detailed data set such as ANSUR II, where the measures are reported for each individual rather than in aggregate, allows the designer to consider the interactions of multiple measures simultaneously. Performing univariate

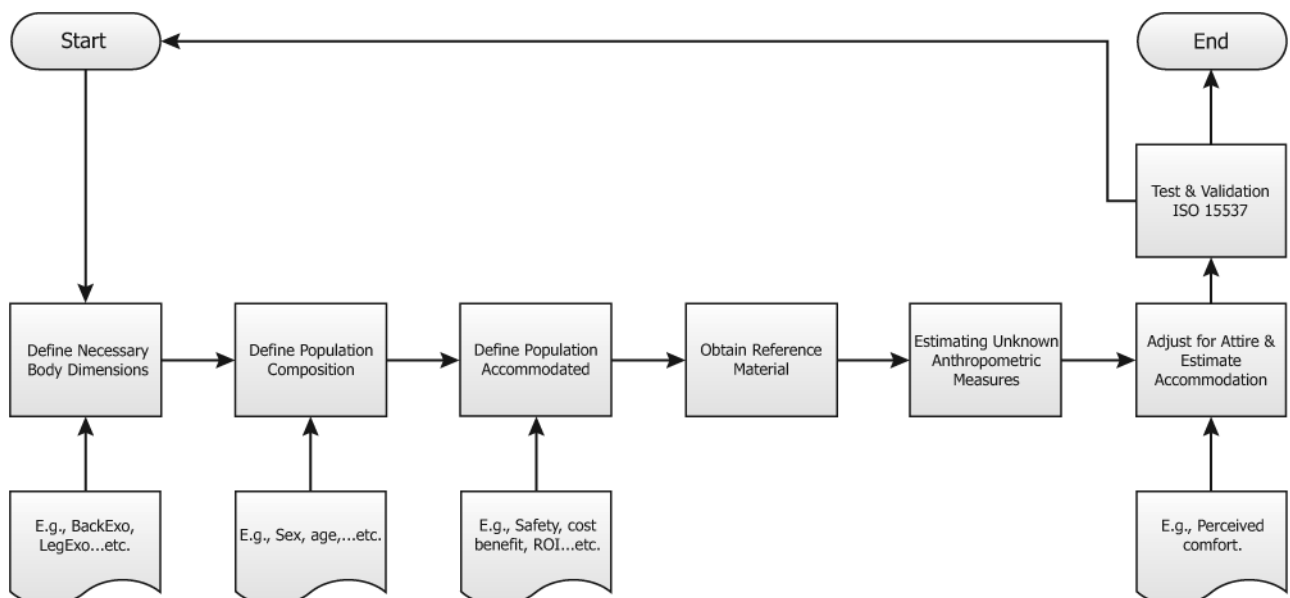


FIG. 1 Seven-Step Paradigm for Exoskeleton Anthropometric Design