INTERNATIONAL

Designation: F3427 – 20

Standard Practice for Documenting Environmental Conditions for Utilization with Exoskeleton Test Methods[1]

This standard is issued under the fixed designation F3427; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 When conducting test methods, it is important to consider the role that the environmental conditions play in measurement of exoskeleton safety and performance. Exoskeletons are designed to be operated both indoors and outdoors under conditions specified by the manufacturer. Likewise, end users of the exoskeletons will be using these exoskeletons in a variety of environmental conditions. When conducting and replicating ASTM Committee F48 test methods by exoskeleton manufacturers and users, it is important to specify and document the environmental conditions under which the exoskeleton is to be tested as there will be variations in system performance caused by the conditions, especially when comparing and replicating sets of test results. It is also important to consider changes in environmental conditions during the course of operations (for example, transitions between conditions). As such, environmental conditions specified in this document are static, dynamic, or transitional, or combinations thereof; with the exoskeleton stationary or in motion. This document provides brief introduction to the following list of environmental conditions that can affect performance of the exoskeleton:

1.1.1 Floor or ground surface;
1.1.2 Temperature;
1.1.3 Humidity;
1.1.4 Atmospheric pressure;
1.1.5 Lighting;
1.1.6 Air flow and quality;
1.1.7 External sensor emission;
1.1.8 Electrical interference;
1.1.9 Boundaries;
1.1.10 Additional categories, for example underwater, extraterrestrial, may also be added to this standard as the exoskeleton industry applications evolve in these areas.

1.1.11 This document then breaks down each condition into sub-categories so that the user can document the various aspects associated with the category prior to exoskeleton tests defined in ASTM Committee F48 test methods listed in Section 2. It is recommended that salient environment conditions be documented when conducting ASTM Committee F48 test methods.

1.2 The environmental conditions listed in 1.1 to be documented for exoskeleton(s) being tested are described and parameterized in Section 4 and allow a basis for performance comparison in test methods. The approach is to divide the list of environmental conditions into sub-conditions that represent the various aspects of the major category (for example, type-concrete within floor and ground surface). Where necessary, this document also provides guidelines (for example, grade levels and particulates) to document environmental conditions in an existing environment.

1.3 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.

1.4 *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.*

1.5 *This international standard was developed in accordance with internationally recognized principles on standardization 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]

E1155M Test Method for Determining F_F Floor Flatness and F_L Floor Levelness Numbers (Metric)
E1274 Test Method for Measuring Pavement Roughness Using a Profilograph
F3323 Terminology for Exoskeletons and Exosuits

[1] This practice is under the jurisdiction of ASTM Committee F48 on Exoskeletons and Exosuits and is the direct responsibility of Subcommittee F48.03 on Task Performance and Environmental Considerations.

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

2.2 *Other Standards:*

ANSI B101.3 Test Method for Measuring Wet DCOF of Common Hard-Surface Floor Materials [3]

ANSI/IEC 60529-2004 Degrees of Protection Provided by Enclosures (IP Code) [3]

BS 667:2005 Illuminance Meters – Requirements and Test Methods[4]

BS EN 12895: 2015 Electromagnetic Compatibility – Emissions and Immunity [4]

IEC 61000-4-1 Electromagnetic compatibility (EMC) – Part 4-1: Testing and measurement techniques – Overview of immunity tests [5]

IEC 61000-6 Emission Standards for Industrial Environments[5]

ISO 14644-1 Cleanrooms and associated controlled environments – Part 1: Classification of air cleanliness by particle concentration [6]

ISO 15469:2004 Spatial distribution of daylight – CIE standard general sky[6]

Mil-Stnd-462 EMI Emissions and Susceptibility [7]

3. Terminology

3.1 Many terms used within this document are defined as in Terminology F3323. The following terms and definitions are used within this document and are not defined within Terminology F3323.

3.2 *between area, n*—the area of the apparatus that is between different environmental conditions in a transitional environment (see *transitional*).

3.3 *change time, n*—amount of time to change from one environmental condition to another (only applies to dynamic environments).

3.4 *dynamic, adj*—when the environment changes over time within the test apparatus during a test.

3.4.1 *Discussion*—The amount of time it takes for the environment to change is called change time (see *change time*).

3.5 *emitter, n*—external radiation sources that can affect the exoskeleton performance, for example: multiple time-of-flight cameras, fork-lift pedestrian lights, structured light sensor, light detection and ranging sensors (LIDAR).

3.6 *static, adj*—when the environment is similar throughout the test apparatus for the duration of a test.

3.7 *transition distance, n*—amount of distance to change from one environmental condition to another, that is, the length of the between area (see *between area*).

3.8 *transitional, adj*—when the environment significantly differs in different areas within the test apparatus.

3.8.1 *Discussion*—The area between the different environmental conditions is called the between area (see *between area*).

4. Significance and Use

4.1 This section provides a description of the environmental conditions listed in Section 1 and describes the sub-conditions within each condition. Examples provided for many of the conditions and sub-conditions are provided as guidance only. Each of the conditions described should be evaluated and documented as set forth in Sections 5 – 7.

4.2 *Environment Consistency: Static, Dynamic, Transitional*

4.2.1 Static is when the environment is similar throughout the test apparatus. For example, there are minor fluctuations in temperature throughout the apparatus as shown in Fig. 1 and Fig. 2. Dynamic is when the environment significantly differs within the test apparatus. For example, when the temperature changes between repetitions as shown in Fig. 3. Transitional is when the environment significantly differs in different areas within the test apparatus as shown in Fig. 4. The intent here is to not give specific guidance, but to provide a high-level classification of a particular set of environmental conditions. If environment consistency is dynamic or transitional, or both, a report form (see Section 7) for each unique set of environmental conditions should be completed.

4.3 *Floor or Ground Surface:*

4.3.1 Exoskeleton mobility is affected by ground surface conditions including: surface texture/roughness, deformability,

[3] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

[4] Available from British Standards Institution (BSI), 389 Chiswick High Rd., London W4 4AL, U.K., http://www.bsigroup.com.

[5] Available from International Electrotechnical Commission (IEC), 3, rue de Varembé, 1st floor, P.O. Box 131, CH-1211, Geneva 20, Switzerland, https://www.iec.ch.

[6] Available from International Organization for Standardization (ISO), ISO Central Secretariat, BIBC II, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, http://www.iso.org.

[7] Available from U.S. Government Printing Office, Superintendent of Documents, 732 N. Capitol St., NW, Washington, DC 20401-0001, http://www.access.gpo.gov.

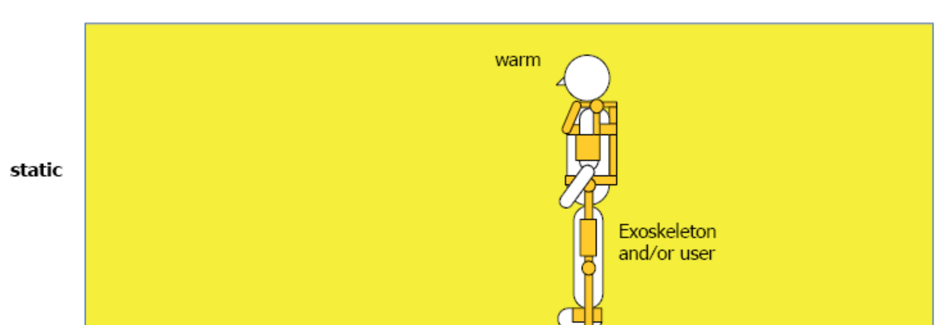

FIG. 1 Example of Static Environment Using Temperature

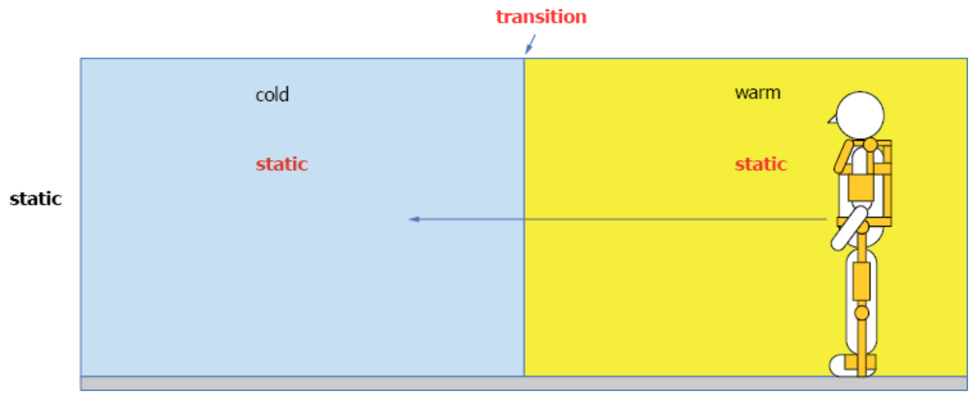

FIG. 2 Example of Static Environment Using Temperature and Showing a Transition Between Two Static Environments

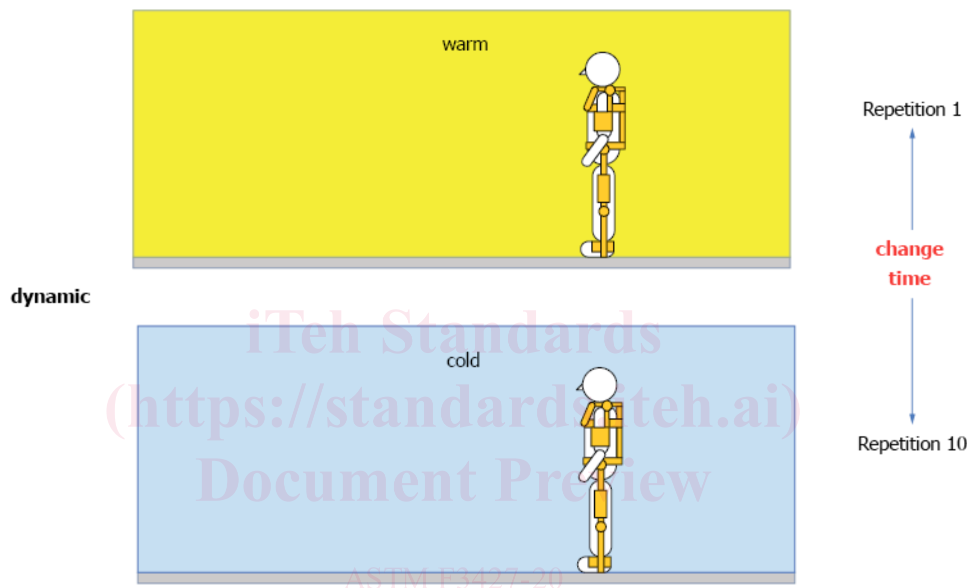

FIG. 3 Example of Dynamic Environment Using Temperature and Showing that the Environment Changed During the Test

slope or lack of flatness (that is, undulation). Ground surface conditions can affect the exoskeleton: traction, vibration affecting the electronics integrity, positioning, and stability.

4.3.2 *Type(s):*

4.3.2.1 Approximate type similar to the following examples where multiple floor types may be present and shall be indicated on the report form (for example, concrete, linoleum tile, carpet, dirt, grass, asphalt, wood plank, etc.).

4.3.2.2 Indicate floor anomalies within the test space (for example, floor grate, manhole cover, undetectable (by vehicle sensors) divots, transparent flooring, etc.).

4.3.3 *Coefficient of Friction:*

4.3.3.1 High (for example, brushed concrete, asphalt),

4.3.3.2 Moderate (for example, polished/sealed concrete, steel plates, packed dirt), and

4.3.3.3 Low (for example, icy, wet, lubricated, dry sand).

4.3.4 *Gap/Step*—Known infrastructure that could affect exoskeleton use and performance (see Fig. 5):

4.3.4.1 *Gap*—Length, width, depth, and angle of gap with respect to a reference frame.

4.3.4.2 *Step*—Length, width, depth, and angle of step with respect to a reference frame.

4.3.4.3 For each gap/step, a description of the gap/step should also be documented. Examples: sharp gap (between loading dock and truck) vs. rounded gap (pothole, floor divot); sharp step (square channel metal) vs. rounded step (cable or cable cover, speed bump/hump). A sharp gap and a rounded step are exemplified in Fig. 5.

4.3.5 *Deformability:*

4.3.5.1 *Rigid* (for example, concrete, asphalt);

4.3.5.2 *Semi-rigid* (for example, compacted dirt or gravel, wet sand, industrial carpet);

4.3.5.3 *Soft*—Malleable (for example, snow, mud, dry sand, padded carpet).

4.3.6 *Grade (ramp):*

4.3.6.1 *Level 1*—0 % to 3 % (for example, nominally flat floor);

4.3.6.2 *Level 2*—4 % to 7 % (for example, transitional ramp in factories);

4.3.6.3 *Level 3*—8 % to 10 % (for example, yard ramp = 8 % to 9 %);

4.3.6.4 *Level 4*—11 % to 15 % (for example, steep road grade);

4.3.6.5 *Level 5*—16 % and above.

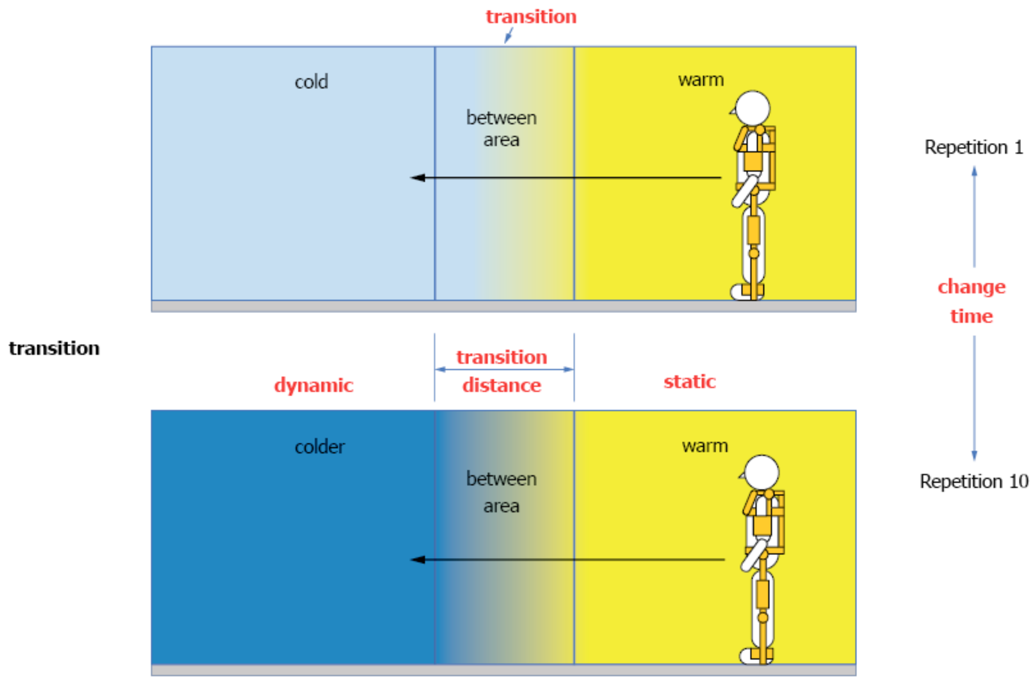

FIG. 4 Example of Transitional Environment Using Temperature Portions of the Environment may Remain Static or may be Dynamic (For example, Cold to Colder)

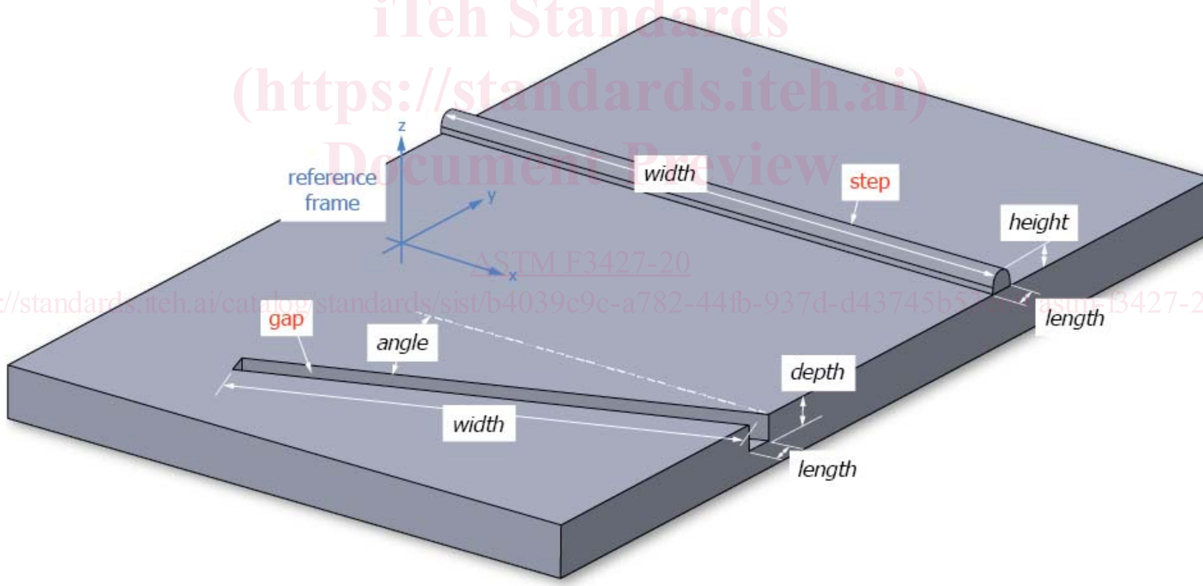

FIG. 5 Gap and Step

4.3.7 *Undulation (lack of flatness on the apparatus ground surface):*

4.3.7.1 *Flat*—0 mm to 6 mm variation over 3 m;

4.3.7.2 *Moderately flat*—More than 6 mm to 12 mm variation over 3 m;

4.3.7.3 *Non-flat*—More than 12 mm to 51 mm variation over 3 m;

4.3.7.4 *Outdoor*—More than 51 mm variation over 3 m.

4.3.8 *Particulates (document the type and describe):*

4.3.8.1 None (for example, dry, clean);

4.3.8.2 Fine (for example, cardboard dust, concrete dust);

4.3.8.3 Coarse (for example, sand, pebbles).

4.3.9 If more specificity of measurement is required, the following standards may be used:

4.3.9.1 *Deformability*—See Test Method E1274-18.

4.3.9.2 *Undulation*—See Test Method E1155M-14.

4.3.9.3 *Coefficient of Friction*—See ANSI B101.3 - 2012 which specifies use of a BOT-3000 drag-sled meter.

4.4 *Temperature:*

4.4.1 Temperature variability and extremes can affect the exoskeleton performance. Exoskeleton materials may also react to temperature (for example, retract, melt, transfer heat). The temperature exposure on the exoskeleton can be static, dynamic, or transitional, or combinations thereof while the exoskeleton is stationary or moving. Temperature ranges span from low to high extremes expressed in five categories. Temperature variations can affect onboard electronics, create condensation, cause hydraulic fluid viscosity, and reduce battery life and recharge rate.

4.4.2 *Temperature Levels (in °C):*

4.4.2.1 *Level 1*—Below 0° (for example, freezer);

4.4.2.2 *Level 2*—0° to 15° (for example, perishable storage);

4.4.2.3 *Level 3*—16° to 26° (for example, office, warehouse);

4.4.2.4 *Level 4*—27° to 49° (for example, warehouse);

4.4.2.5 *Level 5*—Above 49° (for example, foundries, forges).

4.5 *Humidity:*

4.5.1 Humidity refers to the amount of water vapor contained in the air around the exoskeleton. High humidity combined with dew point temperature causes condensation that can short electronics and affect other exoskeleton components. Greater than 60 % humidity causes a large increase in corrosion of metallic parts. Low humidity, on the other hand, will see a dramatic rise in static electricity and the need for adequate discharge.

4.5.2 *Relative Humidity Level:*

4.5.2.1 *Low*—Less than 30 %;

4.5.2.2 *Moderately Low*—31 % to 55 %;

4.5.2.3 *Moderately High*—56 % to 75 %;

4.5.2.4 *High*—Greater than 75 %.

4.5.3 *Dew Point Temperature*—The highest temperature at which airborne water vapor will condense to form liquid dew.

4.6 *Atmospheric Pressure:*

4.6.1 Atmospheric pressure can potentially affect the user or exoskeleton, or both, for example in high altitude areas. Atmospheric, or barometric, pressure is the measurement of pressure exerted by the weight of the atmosphere, or force per unit area, exerted against a surface by the weight of the air above that surface, which at sea level has a mean value of 101 kPa.

4.6.2 *Amount,* measured in kPa.

4.7 *Lighting:*

4.7.1 Various lighting conditions can potentially affect, for example exoskeleton materials or reflectance/absorption, or both, and in turn, exoskeleton-use safety and performance. Lighting sources can include ambient lighting, as well as direct light sources associated with exoskeleton application. Two setups for lighting include ambient or direct source(s) applied to the exoskeleton. Direct lighting can also include reflected light from a highly reflective surface and implies that the source is directed at the light-affected components of the exoskeleton (for example, materials, sensors). Indirect or ambient light includes lighting where the source is not directly applied to the light-affected components of the exoskeleton. Light intensity is divided into five levels exemplified through dark, typical indoor lighting, and full sunlight.

4.7.2 *Ambient Lighting Type:*

4.7.2.1 Exposed bulb (for example, fluorescent, can lights);

4.7.2.2 Spotlight (for example, directed away from the exoskeleton);

4.7.2.3 Sunlight (for example, the exoskeleton is tested in bright sunlight);

4.7.2.4 Reflected (for example, bulb directed at the ceiling);

4.7.2.5 Filtered (for example, diffused light through translucent glass).

4.7.3 *Directed Lighting Type:*

4.7.3.1 Exposed bulb (that is, no bulb cover);

4.7.3.2 Spotlight;

4.7.3.3 Sunlight (for example, the exoskeleton faces/moves towards low sun position);

4.7.3.4 Reflected;

4.7.3.5 Filtered;

4.7.3.6 Laser;

4.7.3.7 Light from another vehicle.

4.7.4 *Ambient Lighting Source Location*—Document light source location and elevation with respect to the exoskeleton (refer to Fig. 6); add a light symbol on the test method drawing in the appropriate location.

4.7.4.1 Elevation with respect to the exoskeleton or exoskeleton path.

4.7.4.2 Location with respect to the exoskeleton (add a light symbol on the test method drawing; for directional lighting only).

4.7.5 *Lighting Levels:*

4.7.5.1 *Level 1*—0 lx to 1 lx (for example, dark);

4.7.5.2 *Level 2*—2 lx to 99 lx (for example, dim);

4.7.5.3 *Level 3*—100 lx to 1000 lx (for example, office environment);

4.7.5.4 *Level 4*—1001 lx to 9 999 lx (for example, high intensity work light, spotlight);

4.7.5.5 *Level 5*—10 000 lx and above (for example, full sunlight).

4.7.6 *Spectrum*—Identify primary color and peak wavelength.

4.7.7 *Polarization*—Identify the polarizing source and angle with respect to a known reference (for example, world coordinates).

4.7.8 If more specificity of measurement is required, the following documents and standards may be used: "Recommended Light Levels" by National Optical Astronomy Observatory[8], which includes common/recommended indoor/outdoor light levels; British Standard, BS 667:2005; and ISO 15469:2004, which defines a set of outdoor daylight conditions linking sunlight and skylight for theoretical and practical purposes.

4.8 *Air Flow and Quality:*

4.8.1 Air flow and quality refers to the ability that an exoskeleton or exoskeleton-user, or both, is affected by air particulates or wind, or both, or that onboard exoskeleton sensor(s) are affected by the presence of precipitation or air particulates, or both. Air quality can also affect exoskeleton performance, for example heat transfer characteristics. Air

[8] "Recommended Light Levels," National Optical Astronomy Observatory, https://www.noao.edu/, accessed April 20, 2018.

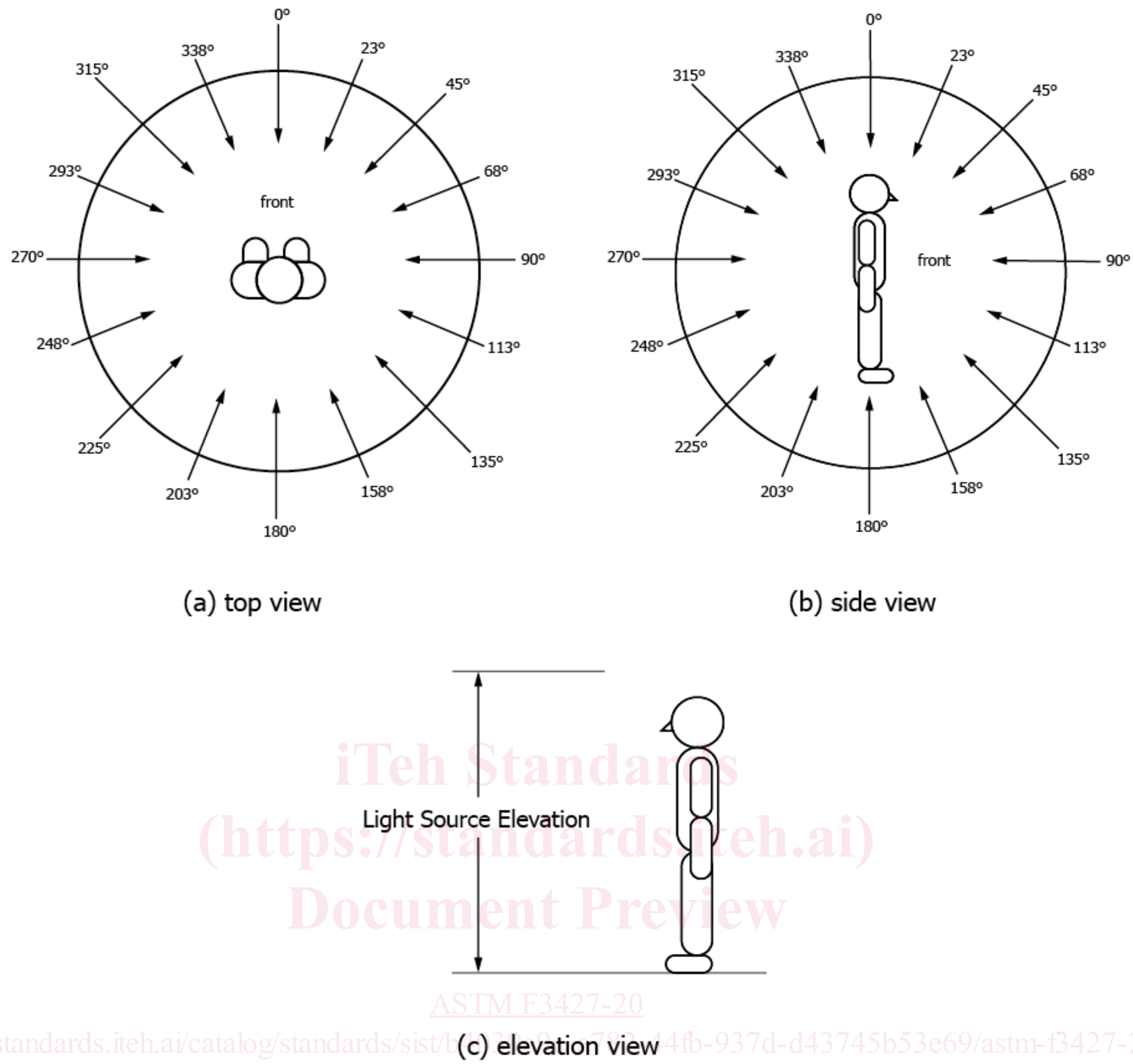

FIG. 6 Lighting Direction (a) Top View, (b) Side View and (c) Elevation View with Respect to the Exoskeleton

quality may affect the exoskeleton performance in terms of joint motion or electronics and automatic exoskeleton functionality, or both. Air quality depends upon the size and volumetric density of particulates in the air. For relative comparison, the average human eye cannot see particles smaller than 40 µm, fog from water vapor typically includes particle sizes from 5 µm to 50 µm, and dust particles are typically 0.1 µm to 100 µm. An ISO Class 1 cleanroom has no more than 10 particles larger than 0.1 µm in a cubic meter of air. Fog (water vapor) particle density of 1 amg allows human visibility of about 125 m at ground level.

4.8.2 *Air Velocity and Direction*—Document air flow source location and elevation with respect to the exoskeleton (refer to Fig. 6).

4.8.3 *Air Particle Density*—Optionally, measure the air particle size and volumetric density:

4.8.3.1 Clear (for example, clean room, no visible air particulates);

4.8.3.2 Moderate (for example, visible fog, dust, light to moderate rain/snow/fog);

4.8.3.3 Dense (for example, dust storm, heavy snow/rain/fog).

4.8.4 If more specificity of measurement is required, the following standards may be used: ISO 14644-1:2015 for air particle density (clear), and ANSI/IEC 60529-2004.

4.9 *External Sensor Emission:*

4.9.1 External emitters are outside of the exoskeleton (for example, from a nearby equipment source) and can potentially interfere with the exoskeleton sensor or control system. External radiation sources can affect the exoskeleton performance, for example: lasers, ultrasonics.

4.9.2 *External Emitter Configuration:*

4.9.2.1 Type of emitter(s);

4.9.2.2 Quantity of emitter(s).

4.9.3 *External Emitter Source Location*—Document emitter source location and elevation with respect to the vehicle (refer to Fig. 6):

4.9.3.1 Elevation with respect to exoskeleton or exoskeleton path;