International Journal of Aviation, Aeronautics, and Aerospace

Volume 9 | Issue 3 Article 1

2022

Anthropometry Considerations in the Design and Evaluation of Flight Deck Displays and Controls: Literature Review

Robert Joslin
Embry-Riddle Aeronautical University - Worldwide, joslinr@erau.edu

Anthropometry Considerations in the Design and Evaluation of Flight Deck Displays and Controls: Literature Review

Cover Page Footnote

Research reported in this paper was conducted under the Flight Deck Program Directive/Level of Effort Agreement between the Federal Aviation Administration Human Factors Division (ANG-C1) and the Aerospace Human Factors Research Division (AAM-500) of the Civil Aerospace Medical Institute.

This literature review is intended to provide a compendium of the anthropometry considerations in the design and certification of displays and controls in aircraft flight decks. This document is not a compliance document and the references herein are frequently updated, hence they should be verified by the reader. The requirements and guidance related to anthropometric considerations for the design of flight deck displays and controls are interspersed throughout the Code of Federal Regulations (CFR), Advisory Circulars (AC), Policy Statements (PS), and industry standards accepted by the Federal Aviation Administration (FAA). The only body measurement stated in Title 14 of the Code of Federal Regulations (14 CFR) is that aircraft shall be designed for persons between the heights of 5’2” and 6’3” for airplanes (14 CFR §25.777) and 5’2” to 6’0” for helicopters (14 CFR §§29.777, 27.777). The origin of the “height” design requirements for airplanes and rotorcraft are the 1950’s vintage Civil Air Regulations [CAR §4b.353(c) and CAR §7.353(b)], which stated, in part, “This shall be demonstrated for individuals ranging from 5’2” to 6”0” in height.” These “design heights” remained in effect until 1975 when the regulation was changed, just for airplanes under 14 CFR §25.777(c), to “increase the maximum flight crewmember heights to be considered from 6’0” to 6’3” for the design of cockpit controls” (Cockpit Controls, 1975). The reason for this regulatory 3-inch increase in pilot stature, as explained in the U.S. Federal Register, was “because the average human height continues to increase…”.

However, a person’s standing height (stature) is irrelevant when it comes to aircraft cockpit design of displays/controls and pilot flight controls for the first and foremost reason that the pilot is in a seated position, other than during ingress and egress or when piloting lighter-than-air hot air balloons. Furthermore, pilots who share identical standing heights have a wide range of individual body measurements. Hence, the relevant body measurements are those that directly affect the pilot’s ability to see/read aircraft instruments, view the world outside the cockpit, and manipulate switches, knobs, and flight controls without restriction (Joslin, 2014).

The aircraft design requirement for a 5th percentile female to a 95th percentile male that have been accepted by the FAA and the aviation industry, is based on historical military standards. The design requirement is reaffirmed in Military Standard (Mil-Std)-1472H (2020) as the center 90% of the target user population. Mil-Std-1472H establishes general human engineering design criteria for military systems, subsystems, equipment, and facilities, except where provisions relating to aircraft design conflict with crew system design requirements. A design limit for the 5th percentile means that only 5% of the population has a shorter body dimension, hence 95% of the population would conceivably be accommodated. Conversely, a design limit for the 95th percentile means that 95% of the population has a shorter body dimension, hence only 5% of the population would conceivably be accommodated.

This literature review compiles the requirements and guidance along with recommendations that should be considered as related to anthropometry in the design and evaluation of flight deck displays and controls for all aircraft types certified under Title 14 CFR Parts 23, 25, 27, and 29. The 14 CFR regulatory requirements carry the force of law; hence compliance is mandatory unless an exemption, special condition, or equivalent level of safety (ELOS) is granted. The FAA develops ACs and PSs to provide additional information on how a *show of compliance* can be fulfilled. An AC describes an acceptable means, but not the only means, for complying with one or more related regulations and normally focuses on a specific system or function. Industry standards (e.g., ASTM, SAE, RTCA). In addition, the manufacturer/applicant can also propose their own means of compliance, which can consider recommendations and other best practices. Policy statements normally just provide general guidance on a single topic or issue, or acceptable practices on how to find compliance with a specific regulation. Applicable industry standards can be identified through Notices of Availability (NOA), or equivalent FAA documents, and should be consulted. The NOA is a relatively new process, especially for Part 25. The industry standards need to be invoked by the FAA and these are typically listed in the ACs and policy statements or Technical Standard Orders (TSO).

Anthropometrics, in the context of this literature review, is the pilot's ability to effectively physically interact with the displays and controls on the flight deck to include unrestricted movement of the flight controls, while maintaining an external view out-the-window when in the normal seated position with restraints fastened (as applicable) and wearing any required flight clothing. New or novel aircraft that do not have design airworthiness standards are certified as Special Class aircraft under Title 14 CFR § 21.17(b). Special Class aircraft include gliders, airships, and other non-conventional aircraft (e.g., unmanned aircraft systems, powered-lift, etc.). For these special classes, the applicable design airworthiness requirements may be extracted from 14 CFR Part 23/25/27/29 as relevant to the specific type design, supplemented by "special conditions" when there is no existing regulation that can be adapted for a specific aspect of the non-conventional design. The views and opinions expressed in this report are those of the author and do not necessarily reflect the official policy or position of the FAA.

The FAA regulatory requirements, guidance material, and recommendations for the anthropometry considerations in the design and evaluation of flight deck displays and controls were categorized as follows:

- Appropriate Representation of Pilot Population
- Design Eye Position
- Arrangement and Accessibility
- Modeling and Evaluations

Appropriate Representation of Pilot Population

Anthropometric databases for aviation applications were formally introduced in the 1940s and have matured beyond 1-D body measuring techniques (i.e., tape measure, calipers) to 3-D scanning technologies. The anthropometric database that has been used most broadly in aviation design over the last few decades for civilian and military aircraft of all types has been the *Anthropometric Survey of U.S. Army Personnel: Methods and Summary Statistics 1988* (Gordon et al., 1989; Joslin, 2014). The most recent large scale U.S. anthropometric study is the *2012 Anthropometric Survey of U.S. Army Personnel (ANSUR II)*, which provides 94 directly measured dimensions, 39 derived dimensions, and three-dimensional (3-D) head, foot, and full-body scans of 7435 men and 3922 women (Gordon et al., 2014). Although conducted between 1998 and 2001, the most recent large-scale anthropometric study of the European population is the *Civilian American and European Surface Anthropometry Resource (CAESAR)* which measured 4431 civilians from NATO countries providing 100 measurements, and 3-D scans of three postures (Robinette et al., 2002).

Statistically derived statistical methods can be applied to anthropometric data from a non-representative population, to match a target population (Nadadur & Parkinson, 2008). For example, the U.S military used statistical methods to apply the 1988 Anthropometric Survey of U.S. Army Personnel for the design of the Joint Primary Aircraft Training System (JPATS), and statistically derived anthropometric data from CAESAR for the Joint Strike Fighter (JSF) (Choi et al., 2009). Statistical methods can also be applied to forecast a future target population. NASA has extensive historical and current anthropometric data for their astronauts, however they recognized that the demographics and anthropometry of future astronauts may differ significantly, which highlighted a gap in identifying future design requirements for extended space travel, such as for the Constellation program. The anthropometric body measurement data for the 2015 NASA Constellation program for males and females between 35-50 years old were derived from the 1988 Anthropometric Survey of US Army Personnel, through linear regression statistical methods (NASA, 2010; 2007; Tillman, & McConville, 1991).

Digital Human Models (DHM), such as Safework™, RAMSIS™ and Ergo™, are used for dynamic manipulation of virtual/ mannequin representations of anthropometric databases, providing the capability to simulate the body measurements of any desired member of a target population. However, the limitation of the models is that they may not adequately replicate the body slouch or compression of body tissues exhibited by an actual human, nor any movement restrictions imposed by clothing and restraints (Horváth et al., 2005).

A valid anthropometric database applicable to the design of aircraft displays and controls is one that provides operationally relevant anthropometric measurements, beyond just stature, to include but not limited to functional reach, hand size, finger length, fingertip reach, buttock knee length, sitting knee-height, and sitting-eye-height. Normal secular (generational) changes, coupled with an increasingly diverse demographic, continues to change the body dimensions of the population. Although there are many variables associated with these changes, anthropologists, sociologists, and geneticists generally agree on a 20-30-year cycle for generational and demographic changes to become significant. This was evidenced by a U.S. Army anthropometric study that was conducted in 1995 to validate a 1988 study for the design and sizing of U.S. Army personnel equipment. The results indicated that the 1988 data were still valid, hence a 10-year threshold to update anthropometric data was considered too conservative (Gordon, 1996).

The most current anthropometric data for the U.S population can be obtained from the National Health and Nutrition Examination Survey (NHANES) conducted every 2 years by the National Center for Health Statistics (NCHS) in which a nationally representative sample of approximately 5,000 persons is surveyed as an interim supplement to the census data that is collected every 10 years. The limitations of this survey, as related to aircraft design, is that the number of body dimensions is insufficient, and the dimensions are not entirely relevant to a pilot seated in an aircraft cockpit. The NHANES survey only includes eight body measurements for adults: weight, standing height, upper leg length, upper arm length, mid-upper arm circumference, waist circumference, and sagittal abdominal diameter. However, since the data are typically the most current available, the NHANES survey is used often to validate that the test participants of a specific survey are representative of the United States population for the desired demographic.

A commonly used method to design complex workstations, but still not widely used as percentile, is the multivariate approach. This method is based on the boundary cases approach in conjunction with Principal Component Analysis (PCA), which is a multivariate statistical analysis that reduces the dimensionality of the problem. Using this technique, it is thus possible to infer real and accurate anthropometric data from the intended user population, and the body size and proportional variability among and between genders can be defined. This information can be used to create an anthropometric family of cases to better design an ergonomic crew station regarding geometry and layout, and to reach the desired accommodation range (da Silva et al, 2020).

Regulations

Part 23-Normal Category Airplanes

- The controls must be located and arranged so that the pilot, when seated, has full and unrestricted movement of each control without interference from either his clothing or the cockpit structure. (14 CFR §23.777(b))
- The pilot compartment, its equipment, and its arrangement to include pilot view, must allow each pilot to perform his or her duties, including taxi, takeoff,

climb, cruise, descent, approach, landing, and perform any maneuvers within the operating envelope of the airplane, without excessive concentration, skill, alertness, or fatigue. (14 CFR §23.2600(a))

Part 25-Transport Category Airplanes

- The controls must be located and arranged, with respect to the pilots' seats, so that there is full and unrestricted movement of each control without interference from the cockpit structure or the clothing of the minimum flight crew (established under Sec. 25.1523) when any member of this flight crew [from 5'2" to 6'3" in height] is seated with the seat fastened [belt and shoulder harness (if provided)]. (14 CFR §25.777 (c))

Part 27-Normal Category Rotorcraft

- Located and arranged with respect to the pilot's seats so that there is full and unrestricted movement of each control without interference from the cockpit structure or the pilot's clothing when pilots from 5′2″ to 6′0″ in height are seated. (14 CFR §27.777(b))

Part 29-Transport Category Rotorcraft

- Located and arranged with respect to the pilot's seats so that there is full and unrestricted movement of each control without interference from the cockpit structure or the pilot's clothing when pilots from 5′2″ to 6′0″ in height are seated. (14 CFR §29.777(b))

Guidance

Part 25-Transport Category Airplanes

- Height is not the only variable of interest, because people of the same height may have different lengths of arms, legs, etc. So, consideration must be given to various representative body proportions that fall within the height range identified in the regulation. (PS-ANM100-01-03A)
- Section 25.777 (in part) states that the flight deck must accommodate pilots from 5’2” to 6’3” in height. This means that pilots within this range should be able to reach all required controls, see all of the displays, and have sufficient clearance with the structure, panels, etc. (PS-ANM100-01-03A)

Part 27-Normal Category Rotorcraft

- Cockpit control location and arrangement, with respect to the pilot’s seat, must be designed to accommodate pilots from 5’2” to 6’0” in height. Pilots within this range should be able to reach and operate all required controls and have sufficient clearance with the structure, panels, etc. (AC 27-1B Chg 8, AC 27.777(a))
- It is important to conduct evaluations using individuals representing a range of potential user physical dimensions and users wearing different apparel, such as long-sleeved shirts, jackets, and gloves. (AC 27-1B Chg 8, MG 20(g)(2)(v)(B))
- Although the regulation requires compliance for a certain range of pilot heights, consider also using individuals from a fifth percentile female and a 95th

percentile male body stature. Consider using individuals that have a range of arm reach and seating statures within the selected population. (AC 27-1B Chg 8, MG 20(g)(2)(v)(B))

Part 27/29-Normal/Transport Category Rotorcraft

- Cockpit control location and arrangement, with respect to the pilot's seat, must be designed to accommodate pilots from 5'2" to 6'0" in height. Pilots within this range should be able to reach and operate all required controls and have sufficient clearance with the structure, panels, etc. (AC 29-2C Chg 8, AC 29.777(a))
- It is important to conduct evaluations using individuals representing a range of potential user physical dimensions and users wearing different apparel, such as long-sleeved shirts, jackets, and gloves. (AC 29-2C Chg 8, MG 20(g)(2)(v)(B))
- Although the regulation requires compliance for a certain range of pilot heights, consider also using individuals from a fifth percentile female and a 95th percentile male body stature. Consider using individuals that have a range of arm reach and seating statures within the selected population. (AC 29-2C Chg 8, MG 20(g)(2)(v)(B))

Part 23/25/27/29-Aircraft

- Design the controls to provide acceptable performance for a broad range of pilot physical attributes. The appropriate pilot representation is key in demonstrating compliance to the applicable regulations. For example, buttons that are too small for a given finger size can be prone to usability problems, such as finger positioning errors, finger slippage, inadequate feedback, insufficient label size, and inadvertent operation. (AC 20-175, 2-2(c)(1))
- Since human dimensions can vary greatly, the environment and use conditions should account for such variations. Some acceptable means of accounting for human size variations include: (a) Selecting individuals for testing based on reference to an anthropometric database. Anthropometric databases contain information collected from comparative studies of human body measurements and properties; (b) Supplementing physical mock-ups with computer anthropometrically-based models; or (c) Comparing physical measurements of control positioning relative to physical measurements in anthropometric databases. (AC 20-175, 2-2. (c)(3))

Recommendations

FAA Human Factors Design Standard

This document presents human factors design standards that are to be applied to new, modified, or updated air traffic control facilities, systems, and equipment that will be managed, operated, or maintained by the FAA. Although not specifically written for the design of aircraft and aircraft systems, it covers a broad range of universal human factors topics that pertain to input devices, automation, maintenance, controls, computer-human interface, workplace design, documentation, system security, safety, the environment, anthropometry, alarms, audio, and voice.

- Designers and human factors specialists shall draw upon the extremes of the larger male population distribution and the extremes of the smaller female population distributions to represent the upper and lower range values, respectively, to apply to anthropometric and biomechanics design problems. The use of separate male and female population data is a conservative approach that results in more inclusive design dimensions than the same percentiles would from a composite population. (HF-STD-001B, 5.12.1.1.3)
- Misperception of the typically sized person. A percentile value and its measurement value that pertains to a particular body part shall be used exclusively for functions that relate to that body part. The same percentiles values are not necessarily the same across all dimensions. Different human physical attributes from the same individual seldom have the same percentile ranking. For example, a 5th-percentile female in stature may have a 20th-or 40th-percentile arm length. Though there is some correlation among various physical attributes, the correlation is not strong across all measurements. (HF-STD-001B, 5.12.1.3.1)
- It is not acceptable to guess about human physical characteristics or to use the designer's own measurements or the measurements of associates. Application of appropriate anthropometric and biomechanics data is expected. (HF-STD-001B, 5.12.1.1.1)
- Limiting dimension at the 5th percentile. Limiting design dimensions, such as reach distances, control movements, display and control locations, test point locations, and handrail positions, that restrict or are limited by body or body part size, shall be based upon the 5th percentile of female data for applicable body dimensions. (HF-STD-0001B, 5.12.1.2.2)
- Summation of like percentile values for body components shall not be used to represent any human physical characteristic that appears to be a composite of component characteristics. The 95th percentile arm length, for instance, is not the addition of the 95th percentile shoulder-to-elbow length plus the 95th percentile elbow-to-hand length. The actual 95th percentile arm length will be somewhat less than the erroneous summation. To determine the 95th percentile arm length, one must use a distribution of arm length rather than component part distributions. (HF-STD-001B, 5.12.1.3.3)

MIL-STD-1472H

This standard establishes general human engineering design criteria for military systems and is applicable to the design of all systems, subsystems, equipment, and facilities, except where provisions relating to aircraft design conflict with crew system design requirements or guidelines of Joint Service Specification Guide-2010: Crew Systems.

- A central 90 percent accommodation design is one in which the multivariate central 90 percent of suitably clothed and equipped males of the target user population and the multivariate central 90 percent of suitably clothed and equipped females of the target user population will be able to use and fit the system to accomplish required physical tasks under consideration. The distribution of the 10 percent not accommodated by the design, including range of adjustment of system features, should be split evenly between the smaller and larger portions of the population. When design of the system requires simultaneous accommodation on multiple measures of the population, multivariate analysis methods are required to determine accommodation of the central 90 percent of users properly. When design of the system requires only univariate accommodation, design for the central 90 percent of users is achievable by using the conventional 5th to 95th percentiles on a single dimension. Any other central percentage population would be similarly calculated and evaluated. (MIL-STD-1472H, 3.2.10)
- Unless otherwise specified, the type of control selected, and the location of the motion envelopes shall accommodate the multivariate central 90 percent (95 percent preferred) of suitably clothed and equipped males of the target user population and the multivariate central 90 percent (95 percent preferred) of suitably clothed and equipped females of the target user population for body dimensions. (MIL-STD-1472H, 5.1.1.1.1.1)

Design Eye Position

The Design Eye Position (DEP) or Design Eye Reference Point (DERP) is a single point selected by the manufacturer/applicant from which a seated pilot achieves the required combination of outside visibility and instrument scan. The DEP is the principal dimensional reference point from which viewing distances and angular displacements are measured for primary/secondary field-of-view, while also ensuring accessibility to flight deck controls and displays.

Guidance

Part 23-Normal Category Airplanes

- The Human Factors Certification Plan (HFCP) should define a design eye reference point that will account for the range of expected pilot physical dimensions. The capability to provide an adequate view of the external environment is essential for safe operation. Evaluations should be conducted with individuals that represent a range of different human physical dimensions. Consideration should be given to seat adjustment capability as it accommodates the range of expected pilot physical dimensions. (PS-ACE100-2001-004)

Part 25-Transport Category Airplanes

- The HUD must be able to accommodate pilots, from 5′2″ to 6′3″ tall, while they are seated at the DEP with their shoulder harnesses and seat belts fastened, to comply with § 25.777.(AC 25-11B, App. F)

Recommendations

FAA Human Factors Design Standard

- In determining body position and eye position zones for seated (e.g., for the design of adjustable seats, visual envelopes, and display locations), a slump factor which accompanies relaxation should be taken into account. (HF-STD-001B, 5.12.2.2)

Arrangement and Accessibility

The arrangement of flight deck displays and controls so that they are accessible by pilots with varied body dimensions is critical to ensure that all tasks can be effectively accomplished in a timely manner without excessive workload.

Guidance

Part 23-Normal Category Airplanes

- If the ability to reset a circuit breaker or replace a fuse is essential to safety during flight, that circuit breaker or fuse must be located and identified so that it can be readily reset or replaced in flight. Discussion: The applicant may choose to use methods similar to those employed for § 23.777 to demonstrate the ability of the pilot to reach the specific circuit protective device(s). (PS-ACE100-2001-004)

Part 25-Transport Category Airplanes

- The flight deck environment includes the layout, or physical arrangement, of the controls and information displays. The layout should take into account the flightcrew requirements in terms of access and reach (to controls). (AC 25.1302-1, 5.8(d)(2)(a))
- For compliance with § 25.777, the flightcrew must be able to see, identify, and reach the means of controlling the HUD, including its configuration and display modes, from the normal seated position. (AC 25-11B, Appendix F.3.2.1)
- Section 25.777 (in part) states that the flight deck must accommodate pilots from 5’2” to 6’3” in height. This means that pilots within this range should be able to reach all required controls, see all of the displays, and have sufficient clearance with the structure, panels, etc. (PS-ANM100-01-03A)
- If the ability to reset a circuit breaker or replace a fuse is essential to safety during flight, that circuit breaker or fuse must be located and identified so that it can be reset or replaced readily in flight. Discussion: The applicant may choose to use methods similar to those employed for § 25.777 to demonstrate the ability of the pilot to reach the specific circuit protective device(s). (PS-ANM111-1999-99-2)

Part 27-Normal Category Rotorcraft

- The instruments should be arranged so that pilots can see critical information without moving their heads, and without undue distraction. Additionally, for instrument flight, 14 CFR §27/29.1321(b) requires grouping of the attitude, altitude, airspeed, and compass indicators in the standard "T." The design for the instrument location and arrangement, with respect to the pilot's seat, should accommodate pilots from 5'2" to 6'0" in height. Alternatively, a methodology to accommodate the 5th to the 95th percentile of male and female pilots may be used. Pilots within this height range should be able to see and, where necessary, reach and operate all of the displays. (AC 27-1B Chg 8, AC 27.1321(a))

Part 29-Transport Category Rotorcraft

- The instruments should be arranged so that pilots can see critical information without moving their heads, and without undue distraction. Additionally, for instrument flight, 14 CFR §27/29.1321(b) requires grouping of the attitude, altitude, airspeed, and compass indicators in the standard "T." The design for the instrument location and arrangement, with respect to the pilot's seat, should accommodate pilots from 5'2" to 6'0" in height. Alternatively, a methodology to accommodate the 5th to the 95th percentile of male and female pilots may be used. Pilots within this height range should be able to see and, where necessary, reach and operate all of the displays. (AC 29-2C Chg 8, AC 29.1321(a))

Part 23/25/27/29-Aircraft

- For aircraft that are designed for multi-crew operation, the incapacitation of one pilot must be considered in the determination of minimum flightcrew, per § 2X.1523. Any control required for flight crewmember operation in the event of incapacitation of other flight crew member(s), in both normal and non-normal conditions, must be viewable, reachable, and operable by flightcrew members, from the seated position. §§ 23.777(b), 25.777(c), 27.777(b), and 29.777(b)). [AC 20-175, 2-2.i] See also: AC 25.1302-1, 5.4(d), which is worded slightly differently.

Recommendations

FAA Human Factors Design Standard

- Reach envelope data shall be collected or modified for the tasks, motions, or functions to be accomplished by the reach. Fingertip touch results in the largest reach dimensions appropriate for touch controls. Other grasp functions would reduce the reach envelope. Two-handed operations, greater precision, and frequent or continuous operation would necessitate locating the task closer to the body. Bulky clothing could affect reach capabilities. Three factors can affect three-dimensional reach envelopes: the effects of different hand manipulation tasks, the effects of permitting torso and shoulder movement, and the effects of the seat back angle of the data collection apparatus. (HF-STD-001B, 5.12.4.3)

MIL-STD-1472H

- If emergency controls are located on touchscreens, the emergency controls shall be able to be reached by crewmembers with their harness or seat belt locked even if full arm extension is necessary. (MIL-STD-1472H, 5.1.3.1.13.3)

- Emergency displays and controls shall be located where they can be seen and reached immediately. (MIL-STD-1472H, 5.1.2.2.3.11)
- The most important and frequently used controls (particularly rotary controls and those requiring fine settings) shall have the most favorable position for ease of reaching and grasping. (MIL-STD-1472H, 5.1.1.3.3)

Modeling and Evaluations

Compliance testing identified in human factors certification plans normally begins with analysis of initial engineering studies and continues through modeling, simulation and aircraft ground/flight test evaluations. Engineering analysis is an integral part of showing compliance. It encompasses the full range of analytical techniques such as textbook formulas, computer algorithms, computer modeling/simulation, or structured assessments. (FAA, 2018) Some acceptable means of accounting for human size variations include supplementing physical mock-ups with computer anthropometrically-based models. (AC 20-175, 2-2c(3))

Guidance

Part 25-Transport Category Airplanes

- Mock-up evaluation: the applicant may use mock-ups as representations of the design, allowing participants to interact physically with the design. (AC 25.1302-1. 6.4(d)(6))
- Three-dimensional representations of the design in a computer aided design (CAD) system, in conjunction with three-dimensional models of the flight deck occupants, have also been used as “virtual” mock-ups for limited types of evaluations. Reach assessments, for example, can use either type of mock-up. (AC 25.1302-1. 6.4(d)(6))
- Example of a mock-up evaluation: one example might be an analysis to demonstrate that controls are arranged so flightcrew members from 1.58 m (5 ft., 2 inches) to 1.91 m (6 ft., 3 inches) in height can reach all the controls. This analysis should also consider differences in anatomy, such as functional arm reach, leg length, and other relevant body measurements. It may use computer generated data based on engineering drawings. The applicant may demonstrate results of the analysis in the actual aircraft. (AC 25.1302-1 §6.4(d)(7))
- While 14 CFR 25.777(c) directly addresses body height, other body dimensions, such as sitting height, sitting shoulder height, arm length, hand size, etc., can have significant effects on the geometric acceptability of the flight deck for pilots within the specified height range. These other dimensions do not necessarily correlate well with height or with each other. The method of compliance should reasonably account for these variables. The applicant may choose to use analytical methods, such as computer modeling of the flight deck and the pilots, for early risk reduction and to supplement certification evaluations using human subjects. Computer modeling allows for more control

over the dimensions of the pilot model, and thus, may allow the assessment of otherwise unavailable combinations of body dimensions. (PS-ANM100-01-03A, Appendix A)

- The applicant may propose a combination of computer-based reach analysis for the new controls, supplemented with a set of evaluations in the airplane flight deck, using people with a variety of body sizes and proportions. (PS-ANM100-01-03A)
- Components that are near the expected reach boundaries, as well as those that may be blocked by intervening objects (such as a control that is installed in front of the throttles), should be evaluated for reach. Potential knee contact with the lower edge of the main instrument panel may need to be evaluated for clearance, especially for tall pilots with long legs. (PS-ANM100-01-03A)
- Seat and rudder pedal adjustment ranges should be factored into evaluations of reach and clearance. (PS-ANM100-01-03A)
- Mock-ups typically are used for assessment of reach and clearance and, therefore, demand a high degree of geometric accuracy. Mock-ups have traditionally been physical representations of the design, which have allowed evaluators to interact physically with the design. In some cases, drawings of controls and indicators, placed on accurately positioned representations of instrument panels, can be beneficial in conducting reach assessments. Using data extracted from computer-aided design (CAD) systems, control panels can now be mocked-up physically in three-dimensional form (a process generally referred to as “stereo lithography”). These mock-ups can allow more precise evaluations of finger clearances, visibility of labels, etc. Three-dimensional representations of the design in a CAD system, in conjunction with three-dimensional models of the flight deck occupants, also have been used as “virtual” mock-ups for certain limited types of evaluations. For example, reach assessments using this technique can use either statistical samples of relevant body characteristics (for example, limb sizes, joint limits, etc.) or carefully chosen sets of specific combinations of body characteristics. In the latter case, attention should be given to selecting reasonable combinations of limiting characteristics (for example, a worst-case might be a 5’2” pilot with more than proportionally short legs). Care must be taken to determine if the model of the human reasonably represents actual human movement capabilities, especially at extreme body positions or near joint rotation limits. It is important to note that this type of virtual mock-up and, in fact, many types of mock-ups may be of even greater use during the design phase as part of engineering evaluations. They should only be used judiciously as a method of compliance (MOC) because they typically represent only certain features of the physical arrangement. For example, a control may be reachable in a given location, but, due to the means of actuation or forces required, it may be too difficult to use

when placed there. For many of the compliance issues typically evaluated in mock-ups, final compliance findings often can be found only in the actual airplane or a simulator. (PS-ANM100-01-03A)

- In the case of the trackball installation, it may be important to include people with relatively tall sitting height and short arms, as well as those with short sitting height and longer arms. (PS-ANM100-01-03A)
- If a new control is being added, have other similar controls been installed in the same location on other versions of this flight deck? Are there any other differences that might cause new reach or clearance issues to emerge? (PS-ANM100-01-03A)

Part 27-Normal Category Rotorcraft

- Applicants may use analytical methods, such as computer modeling of the cockpit or flight deck and the pilots, for early problem identification and risk reduction. Regardless of the analytical models used, demonstrate compliance either in a high- fidelity mockup, that accurately represents the actual rotorcraft, or in an actual rotorcraft. (AC 27-1B, MG 20(g)(2)(v)(B))
- Although the regulation requires compliance for a certain range of pilot heights, consider also using individuals from a fifth percentile female and a 95th percentile male body stature. Consider using individuals that have a range of arm reach and seating statures within the selected population. (AC 27-1B Chg 8, MG 20(g)(2)(v)(B))
- The applicant should have a cockpit design report, which documents the anthropometric suitability of the cockpit. Subsequent cockpit evaluations of control movement and location should be conducted with adjustable seats and/or controls positioned in a flight position for the subject pilot. Essential controls should be evaluated with the shoulder harness locked in the retracted position. Evaluation pilots should be aware of their individual anthropometric measurements and temper their assessments based on this information. Ideally, a new design should include evaluations by a range of different sized subject pilots. (AC 27-1B Chg 8, AC 27.777(b))

Part 29-Transport Category Rotorcraft

- Applicants may use analytical methods, such as computer modeling of the cockpit or flight deck and the pilots, for early problem identification and risk reduction. Regardless of the analytical models used, demonstrate compliance in either a high- fidelity mockup, that accurately represents the actual rotorcraft, or in an actual rotorcraft. (AC 29-2C Chg 8, MG 20(g)(2)(v)(B))
- Although the regulation requires compliance for a certain range of pilot heights, consider also using individuals from a fifth percentile female and a 95th percentile male body stature. Consider using individuals that have a range of arm reach and seating statures within the selected population. (AC 29-2C Chg 8, MG 20(g)(2)(v)(B))

- The applicant should have a cockpit design report, which documents the anthropometric suitability of the cockpit. Subsequent cockpit evaluations of control movement and location should be conducted with adjustable seats and/or controls positioned in a flight position for the subject pilot. Essential controls should be evaluated with the shoulder harness locked in the retracted position. Evaluation pilots should be aware of their individual anthropometric measurements and temper their assessments based on this information. Ideally, a new design should include evaluations by a range of different sized subject pilots. (AC 29-2C Chg 8, AC 29.777(b))
- Section 29.777(b) addresses the capability to operate a control through its full range of motion, considering potential interference from clothing and cockpit structures. This assessment can be accomplished simultaneously with the assessment for § 29.785(c) if the pilot is strapped into the seat wearing the lap belt and shoulder harness. (AC 29-2C Chg 8, AC 29.777(b))

Recommendations

FAA Human Factors Design Standard

- Use of correlation and multiple correlation data. When two or more human physical characteristics are applicable to a design problem, professionals should apply and interpret correlation statistics. Knowledge about distributions and intercorrelations among the distributions need to be factored into the use of these data. The relationships or correlations between specific body measurements are highly variable among the various human characteristics and may differ across samples and populations. For example, breadth measurements tend to be more highly correlated with weight than with stature. The degree of the relationship may be expressed by a correlation coefficient or "r" value. Although common percentile values may not be used to sum data across adjacent body parts, regression equations derived from the applicable samples can be used in constructing composite body measures. (HF-STD-001B, 5.12.1.5.3)
- Design Limits Approach is a method of applying population or sample statistics and data about human physical characteristics to a design so that a desired portion of the user population is accommodated. The steps are as follows: (a) Select the correct human physical characteristic and its applicable measurement characteristic (description) for the design problem at hand;(b) Select the appropriate population, representative sample, or rule information on the selected human physical characteristic and measurement description to apply to the design problem; (c) Determine the appropriate statistical point(s), usually percentile points from rule information or from the sample distribution(s) in order to accommodate a desired range of the human characteristic within the distribution of the user population; (d) Read directly or determine statistically the measurement value(s) that corresponds to the selected statistical point(s)

relevant to the population distribution.(e) Incorporate the measurement value as a criterion for the design dimension, or in the case of biomechanics data, for the movement or force solution in the design problem. (HF-STD-001B, 5.12.1.2)

- Many factors relate to the large variability observed in measures of the human body. These factors include: (1) body position, (2) age, health, and body condition, (3) sex, (4) race and national origin, (5) occupation, and (6) evolutionary trends. These factors affect future population sampling and encourage the use of the most recent data on the populations of interest. (HF-STD-001B, 5.12.2)
- There are several common errors to be avoided by designers when they apply anthropometric data to design. These are: (1) designing to the midpoint (50th percentile) or average, (2) the misperception of the typical sized person, (3) generalizing across human characteristics, and (4) summing of measurement values for like percentile points across adjacent body parts. (HF-STD-001B, 5.12.1.3)
- Misuse of the 50th percentile or of the average. The 50th percentile or mean shall not be used as design criteria as it accommodates only half of the users. When the population distribution is Gaussian (normal), the use of either the 50th percentile or the average for a clearance, at best, would accommodate half the population. (HF-STD-001B, 5.12.1.3.1)

MIL-STD-1472H

- Most designs require simultaneous accommodation of multiple dimensions as well as accounting for size and shape variability. In these cases, designers shall utilize other appropriate anthropometric methods. (a) Jointed or multivariate distributions of all relevant design variables. (b) Multivariate dimension reduction techniques such as principal component analysis. (c) Development of “boundary cases” on a multivariate accommodation envelope that represent the most limiting combination of dimensions. (d) Development of 3-D digital human models that represent multivariate “boundary cases” for use in appropriate modeling software. € Development of parametric accommodation models. (f) Morphometric or shape analyses on the corresponding vertices of a 3-D template matched to a database of 3-D human segment scans in order to quantify and visualize design relevant size and shape variation. (MIL-STD-1472H, 5.8.4.2.6)

References

Ahlstrom, V. (2016). *Human factors design standard* (DOT/FAA/HF-STD-001B). Atlantic City International Airport, NJ: Federal Aviation Administration William J. Hughes Technical Center.

da Silva, G. V., Zehner, G. F., & Hudson, J. A. (2020) Comparison of univariate and multivariate anthropometric design requirements methods for flight deck design application. *Ergonomics*, *63*(9), 1133-1149.

Choi, H. J., Zehner, G. F., Hudson, J. A., & Fleming, S. M. (2009, October). Trends in anthropometric measures in U.S. Air Force aircrew survey data. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 53*(10), 620-624.

Cockpit controls, 14 C.F.R. §27.777 (1964a).

Cockpit controls, 14 C.F.R. §29.777 (1964b).

Cockpit Controls, 40 F.R. 24808 (proposed June 10, 1995) (to be codified at 14 C.F.R. §25.777). https://www.govinfo.gov/content/pkg/FR-1975-06-10/pdf/FR-1975-06-10.pdf

Cockpit controls, 14 C.F.R. §25.777 (1978).

Cockpit controls, 14 C.F.R. §23.777 (2011).

Federal Aviation Administration. (2011). *Controls for flight deck systems* (Advisory Circular 20-175). U.S. Department of Transportation.

Federal Aviation Administration. (2013). *Installed systems and equipment for use by the flight crew* (Advisory Circular 25.1302-1). U.S. Department of Transportation.

Federal Aviation Administration. (2014). *Electronic flight deck displays* (Advisory Circular 25-11B). U.S. Department of Transportation.

Federal Aviation Administration. (2017). *Type certification* (Order 8110.4C Change 6). U.S. Department of Transportation.

Federal Aviation Administration. (2018a). *Certification of normal category rotorcraft* (Advisory Circular 27-1B Change 8). U.S. Department of Transportation.

Federal Aviation Administration. (2018b). *Certification of transport category rotorcraft* (Advisory Circular 29-2C Change 8). U.S. Department of Transportation.

Flightcrew Interface, 14 C.F.R. §23.2600 (2017).

Gordon, C. C., Churchill, T., Clauser, C. E., Bradtmiller, B., & McConville, J. T. (1989). *Anthropometric survey of U.S. Army personnel: Methods and summary statistics 1988*. Anthropology Research Project Inc. Yellow Springs OH.

Gordon, C. C. (1996). *US Army anthropometric survey database: Downsizing, demographic change, and validity of the 1988 data in 1996* (No. NATICK/TR-97/003). Army Natick Research Development and

Engineering Center.
Gordon, C. C., Blackwell, C. L., Bradtmiller, B., Parham, J. L., Barrientos, P., Paquette, S. P., ... & Mucher, M. (2014). *Anthropometric survey of US Army personnel: Methods and summary statistics* (No. NATICK/TR-15/007). Army Natick Soldier Research Development and Engineering Center.
Horváth, I., Zhang, B., Moes, N. C., & Molenbroek, J. (2005, January). Status of digital human body modeling from the aspect of information inclusion. In *International Design Engineering Technical Conferences and Computers and Information in Engineering Conference* (Vol. 47403, pp. 239-254).
Joslin, R. E. (2014). Examination of anthropometric databases for aircraft design. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *58*(1), 1–5.
Military Standard (MIL-STD) 1472H. (2020). *Department of Defense design criteria standard: Human Engineering*. Washington, DC: U.S. Department of Defense.
Nadadur, G., & Parkinson, M. B. (2008). Extrapolation of anthropometric measures to new populations. *SAE International Journal of Passenger Cars—Electronic Systems*, *1*(1), 567-573.
National Aeronautics and Space Administration. (2007). *Constellation program human-systems integration requirements-CxP 70024*. Author.
National Aeronautics and Space Administration. (2010). *Human integration design handbook-NASA/SP-2010-3407*. Author.
Policy Statement Number PS-ACE100-2001-004, Guidance for reviewing certification plans to address human factors for certification of part 23 small airplanes, August 29, 2002.
Policy Statement Number PS-ANM100-01-03A, Factors to consider when reviewing an applicant’s proposed human factors methods for compliance for flight deck certification, February 7, 2003.
Robinette, K., Blackwell, S., Daanen, H., Boehmer, M., Fleming, S., Brill, T., Hoeferlin, D., & Burnsides, D. (2002). *Civilian American and European surface anthropometry resource (CAESAR), final report, volume I: Summary.* AFRL-HE-WP-TR-2002-0169.
Tillman, B., & McConville, J. (1991). *Year 2015 astronaut population anthropometric calculations for NASA-Std-3000, Houston, TX*. NASA, Johnson Space Center