5-7-2019

Designing Military Cockpits to Support a Broad Range of Personnel Body Sizes

Summer Lindsey

H. C. Neil Ganey

Meredith Carroll

Repository Citation

Lindsey, S., Ganey, H. N., & Carroll, M. (2019). Designing Military Cockpits to Support a Broad Range of Personnel Body Sizes. *20th International Symposium on Aviation Psychology*, 145-150. https://corescholar.libraries.wright.edu/isap_2019/25

DESIGNING MILITARY COCKPITS TO SUPPORT A BROAD RANGE OF PERSONNEL BODY SIZES

Summer Lindsey
Florida Insitute of Technology
Melbourne, FL
H. C. Neil Ganey
Northrop Grumman Corporation
Melbourne, FL
Meredith Carroll
Florida Institute of Technology

The Joint Primary Aircraft Training System (JPATS) body size cases provide aircraft designers access to representative Airmen anthropometric dimensions based on a database of air force personnel. To ensure new aircraft can support a broad range of pilot body sizes, designers can reference JPATS case numbers to assure adequate access to specific controls and clearances for ejection. JPATS cases 1 and 7 were added in response to the Air Force's goal to accommodate 95% of males and females. However, given that someone at the 90th percentile height may not have 90th percentile arm length, a far smaller percentage of accommodation than originally projected is actually achieved. This paper presents a discussion of the limitations of JPATS cases and past evaluation methods, and provides recommendations for methods to utilize during the design process to ensure next generation cockpits can accommodate a broader range of body sizes.

The Joint Primary Air Training System (JPATS) Program was developed to accommodate a large range of body types in military grade aircraft. This program sets requirements allowing a range of body sizes, from tall to short females, the ability to become military pilots. In 1996, United States Air Force (USAF) pilots were required to be within 64 to 77 inches tall – with a sitting height of between 34 to 40 inches. Due to these constraints, six percent of males, and over half of females were unable to become USAF pilots (Zehner, 1996). Anthropometric sizing is an issue for many military branches including USAF, the United States Navy (USN), and the United States Marine Corp (USMC).

The Cases

Zehner (1996) evaluated the range of anthropometric sizes of recent college graduates to derive a database of possible pilot body sizes. Based on his findings, JPATS cases 1 and 7 were built in response to the USAF goal to accommodate 95% of males and females. The addition of these cases expanded the range of acceptable height to between 58 and 77 inches tall, and sitting height to between 31 and 40 inches tall. The cases allow for an easy reference of body size. The USAF can reference these case numbers and require access to specific controls and specific head, shin and ejection clearances during Request for Proposal for new aircraft. The goal of accommodating 95% of the male and female population is good in theory; however, this creates a large amount of difficulties in the development phase for contractors and incoming extreme JPATS cases.

As the military includes more measurement requirements for the same individual e.g., thumb tip reach, sitting height and buttock-knee length, it limits the amount of the population that can actually fit into the percentages. Gordon, Corner and Brantley (1997) posit that if a requirement states that one individual must fit within the 5%-95% range for 5 different measurements, this may actually only accommodates 67% of the population. This issue arises due to the fact that an individual that falls within 90% height, may not necessarily fall within 90% thumb tip reach. Additionally, in a survey of USAF personnel, a pilot with 5th percentile height and weight is not actually a 5th percentile individual (Kennedy, 1986). Of this survey, only 1.3% of individuals were smaller than the 5th percentile in both dimensions. However, 9% of the population fell below 5% in either height or weight. These percentages can quickly become unrepresentative of pilots once percentiles are combined. As a result, a case 7 may be able to fly a particular aircraft; however, once an individual varies from these exact measurements in one or two categories, they are no longer accommodated. For instance, a case 7 may narrowly meet the requirements to reach critical safety controls, however an individual similar to a case 7 with longer legs would no longer be accomodated once the seat is adjusted back. Zenher (2002) discusses the concerns for larger pilots including overhead clearances, ejection envelopes, body interference with controls, body interference reaching for controls and shin clearance. On the other side of the spectrum, the largest concerns for smaller pilots include reaching emergency controls, external field of view, and full rudder and brake operating range. If a smaller case is in a harness locked position, it is important that all safety controls, primary flight controls and propulsion controls can be reached and that the operator has full operational range (MIL-STD 1333, 1987).

Gear being developed to support small female JPATS cases inside the cockpit also required modifications. For G-suits, women generally have larger hips and smaller waists then males. This would cause fit issues for incoming women, as many women must wear one size larger just to accommodate hip size. Modifications to three existing G-suit sizes are needed to support women pilots. These include reducing waist and calf circumferences, and shifting the abdominal bladder to the back instead of the front (Dooley, 1995). These reductions result in three new sizes which allow for 90% of the female population to be accommodated. However, this requires development of custom clothing in order to support new JPATS cases, and added cost. Further, considerations also must be given to these cases whenever additions are made in the cockpit. For instance, adding kneeboards for paper or an electronic flight bag (EFB) tablet has shown to have up to a 4.5% chance of a femur fracture for females in a T-38 during ejection compared to 2-3% for males (Perry, Burneka, & Stzelecki, 2015).

JPATS cases were developed over 30 years ago and their current applicability is in question. Over time and through new generations, average body sizes change. Research by Choi and Colleagues in 2011 found that while JPATS proportions still seem to fit the USAF population, individuals are becoming heavier overall. Tucker, Brattin, and Reason 2002 found that the reference databases for USN and USMC populations were non-representative of the actual population. It was found that the population consisted of mainly 4.7% female compared to the 40% female reference database. Furthermore, the population was shown to have some heavier individuals than the database stated. Twenty four percent of individuals were heavier than the highest weight in the database. Heavier individuals who are not considered during development can experience issues with safety gear, clothing, and even cockpit functionality such as center stick control (Tucker, Brattin, & Reason, 2002). The issues of body size variability, particularly when combining percentiles, as well as generational changes, makes it difficult for new aircraft designers. Further, significant body size differences were seen in Brazilian anthropometric data compared to U.S. data, as brazilian pilots were shown to have a shorter reach (Silva, Gordon, & Halpern, 2018). This is concerning as 28% of the USAF personnel are non-caucasian as of 2019, compared to 13% in 1996 when the JPATS cases were formed (Baseman, 1997; Air Force Personnel Center, 2018).

Legacy Aircraft

One of the largest concerns with allowing a larger percentile of males and females to become pilots, is the inability for legacy aircraft to support them. With respect to trainer aircraft, the T-38 is a common trainer aircraft for USAF pilots, however, only 47.1% of females will have a sufficient external field of view over the nose of the aircraft. The only way that many females can see over the nose is by adjusting their seat up all the way. However, this now prevents case 7 females from being able to reach the rudder pedals by multiple inches (Zehner, 2002). Small females are also unable to train in the T-38, due to the lack of reach to safety critical controls in a reel locked state and full rudder actuation. Considering all dimension categories together, only 27.2% of USAF female population and 86.9% of USAF male population can fly the T-38. However, the T-6 and T-37 allow a much higher percentage of the USAF population for safe flight. This includes full accomodation of female and male populations at the minimum size requirements or smaller. In addition, 86.3% of USAF females at the minimum size requirements or smaller are accomodated in the T-37 and 98.6% in the T-6 (Zehner, 2002). While these percentages support JPATS cases, they may not always be the appropriate training aircraft for the pilot's future career.

Zenher 2002 discusses the limitations with respect to fighter aircraft, the F-16 and F-15 still do not accommodate smaller females uch as case 7. This prevents case 7 females from pursuing a fighter pilot career path altogether. Such is also the case with respect to bomber and helicopter aircraft. It was also found that larger case pilots are also prevented from pursuing careers flying fighter aircraft or helicopters due to overhead clearances and/or leg clearances. Heavier pilots are able to fly bomber aircraft but are limited to training in the T-38. (Zehner, 2002).

Tucker, Brattin, and Reason (2002) discuss how USN and USMC legacy aircraft also encounter issues in an attempt to support 95% of the population. The T-44A, E-2C, and C-2A support less than 85% of the population. Additionally, the T-2C supports less than 54% of the population for the front cockpit. Each of these USN and USMC legacy aircraft exhibited issues supporting external FOV while also being able to reach controls in a locked hardness position. The T-2C also faced issues supporting heavier weighted individuals in order to safely eject. These legacy aircraft make it difficult for extreme JPATS case individuals to train, or safely operate in their particular aircraft. Due to the lack of accommodation of JPATS cases in existing aircraft, there is demand for new training and aircraft that can support extreme JPATS cases.

Moving Forward

Development for, and accommodation of, extreme JPATS cases cause an array of issues in existing and future aircraft. Numerous modifications have been made and current training aircraft are considered obsolete as they are unable to accomodate incoming JPATS cases. To truly allow 90% of the population to see and reach controls, have adequate external field of view, and have safe ejection clearances in future aircraft, there is a need to evaluate a large array of body sizes and variations of JPATS case measurements. Evaluation methods include measuring vision, clearances, reach tests and full range of motion for a large range of body sizes (Zehner, 2001). Ensuring these are researched appropriately and thoroughly during future aircraft test and evaluation can prevent the costs associated with issue correction during or after the production phase.

Manikins can be used in order to evaluate the impacts of ejection clearances as demonstrated in a study by Buhrman (1996). However, manikins that are representative of larger and smaller cases were shown to be less reliable for ejection tests. Particularly small JPATs manikins were shown to be less reliable for ejection impacts, showing different results under repeated tests. This can make it difficult to test the effectiveness of ejection seats using real-life ejection dummies that are representative of JPATS case 7. Furthermore, large case manikins were shown to exhibit larger seat forces than corresponding humans (Buhrman, 1996). The time to reach maximum velocity during ejection also varied from human data, which effects the calculations of injury possibilities. These variations indicate that manikin-tested ejection seats may be unsafe once used in a real-life situations.

Evaluation of the aircraft during development is vital to ensure accommodation of extreme JPATS cases. Crawford (2002) discusses how the USN utilizes 3D modeling in order to ensure that JPATS cases can be supported. A FaroArm is used to create a 3D rendering of the pilots performing certain tasks or reaching for particular controls. The FaroArm can be used in existing aircraft or used on a subject sitting in a seat similar to the one in the aircraft or a mockup of an aircraft in the development phase. The researchers can place the FaroArm rendering into CAD drawings in order to evaluate and predict possible issues during development. This method allows a controlled environment and does not require the actual aircraft in order to evaluate the reach and ejection envelopes which can allow more time and resources for evaluating a larger breadth of subjects (Crawford, 2000). However, the representativeness of digital human models requires repeated measurements, test, and evaluation. Whitestone, Hudson, & Rife (2018) evaluated the RAMSIS NextGen, a USAF tool that allows developers to test various cases, their reaches, positions and performance. The spinal data in the RAMSIS case sizes were not an accurate representation and failure to evaluate posture can lead to pain during prolonged flight. Through the use of 3D modeling and Luna fiber optic sensors, the researchers were able to correct the digital human models to a spinal position accuracy of 2mm. Robinette & Vietch (2016) stress the importance of still incoporating real human evaluations to evaluate not only accepted ranges and sizes, but to evaluate levels of pain, discomfort, pilot preferencess, and any potential improvements. The added benefit is that the anthropometric data from real human assessments can be added to virtual human databases to ensure the virtual anthropometric assessments are an accurate portrayal of the current military force.

Evaluating and discovering issues during the development phase can results in massive returns on investment. In past cases, these have ranged from -24% to 153% and even a 9,260% return on investment (Smith, 2015). However, when considering an aircraft that limits the population available to become pilots, it becomes more than just an investment decrement. This limits the pilots ability to pursue certain career tracks, and limits the manpower available to the military forces. The USN and USMC spend over one million dollars to train a jet aviator. Moreover, these costs can increase to three million if the aviator had to be reassigned, replaced, or was trained in a non-representative aircraft due to body size limitations (Tucker & Brattin, 2000). The JPATS program intends for a larger amount of the population to have the ability to become pilots. This comes with a large increase in test and evaluation resources and requires a much larger sample. For new aircraft in the developmental phase, evaluating an array of body sizes and types in large numbers is the most effective way to ensure 90% or more accommodation. However, pilots who approach the limits of JPATS extreme cases will always need to be fit-checked to see if they can be accommodated. While the possibility of all body type accommodation in aircraft is most likely improbable, the proper test and evaluation in early stages of development can help accommodate the more extreme percentiles.

References

Air Force Personnel Center. (2018). Military Demographics. Retreieved from https://www.afpc.af.mil/About/Air-Force-Demographics/

Baseman, L. (1997). Statistical digest. *United States Air Force.*

Buhrman, J. (1996). Impact testing of JPATS mankins. *Biodynamics and Biocommunications Division Wright-Patterson AFB.*

Choi, H., Coate, A., Selby, M., Hudson, J., Whitehead, C., Zehner, G., & Fleming, S. (2014). Aircrew sizing survey 2011. *Human System Integration Directorate, Wright-Patterson Air Force Base.*

Crawford, J. (2000). United states navy advanced crew station evaluation techniques. *Naval Air Warfare Center Aircraft Division Patuxent River MD.*

Dooley, J. (1995). Female acceleration tolerance enhancement. *Armstrong Laboratory.*

Gordon, C., Corner, B., & Brantley, D. (1997). Defining extreme sizes and shapes for body armor and load-bearing systems design: Multivariate analysis of U.S. Army torso dimensions. *U.S. Army Natick Research, Development and Engineering Center.*

Kennedy, K. (1986). A collation of United States Air Force anthropometry. *Harry G. Armstrong Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base.*

N.a. (1987). MIL-STD 1333 Aircrew station geometry for military aircraft. *Department of Defense.*

Perry, C., Burnecka, C., & Strzelecki, J. (2015). Biodynamic assessment of pilot knee-board configuration during simulated T-38 catapult acceleration. *United States Air Force Research Laboratory.*

Robinette, K. M. & Veitch, D. (2016). Sustainable sizing. *Human Factors, 58*(5). 657-664.

Silva, G. V., Gordon, C. C., & Halpern, M. (2018). Comparison of anthropometry of brazilian and US military population for flight deck design. *International Journal of Industrial Ergonomics, 64.* 170-177.

Smith. N. (2015). Examining the return on investment of test and evaluation. *Air Force Institute of Technology.*

Tucker, H. & Brattin, L. (2000). Current USN/USMC aircaft anthropometric compatibility issues and the “street to fleet” proposal. *Naval Air Warfare Center Aircraft Division Patuxent River MD.*

Tucker, H., Brattin, L., & Reason, W. (2002). Revised anthropometric restrictions for U.S. Navy and Marine Corps trainer and fixed wing nonejection aircraft and U.S. Coast Guard HU-25. *Naval Air Warfare Center Aircraft Division Patuxent River MD.*

Whitestone, J. J., Hudson, J. A., & Rife, B. (2018). Determining spinal posture for encumbered airmen in crewstations using the luna positioning sensor. *United States Air Force Research Laboratory.*

Zehner, G., (1996). Cockpit anthropometric accommodation and the JPATS Program. *SAFE Journal, 26*(3).

Zehner, G. (2001). Prediction of anthropometric accommodation in aircraft cockpits. *Crew Systems Interface Division, Wright-Patterson Air Force Base.*

Zehner, G., (2002). Body size accommodation in USAF aircraft. *United States Air Force Research Laboratory.*