Gender Inequality in Aircraft Design

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The first modern United States civilian aircraft, the Boeing 247, was built in 1933 (Historical, 2020), and one of the first United States military combat aircraft, the Boeing B-17 Flying Fortress, was built in 1935 (Richman, 2020). Females, however, were not legally allowed to join civilian pilot training programs until 1972 in the US (Davey, 2000), and they were not legally allowed to fly in US military combat missions until 1993 (Smithsonian, 2018). This means that for almost 40 years, males were the only legal operators of all aircraft.

To understand the significance of this time period gap, it is important to note the history of where the rules for designing the aircraft come from. Military Standards (MIL-STDs) are rules put in place by the Department of Defense (DoD) to maintain standard operations within the military. The act of standardizing design and parts within militaries became popular during World War II when American aircraft parts were not compatible with British aircraft, making quick repairs impossible. By the 1980s, there were over 30,000 military standards addressing every aspect of a product imaginable. The sheer volume of specifications and standards established by the DoD has created restrictions on incorporating new technology into design and some argue that the standards need to be recertified to fit today's design requirements.

A crucial standard for the context of this research is the Design Criteria Standard for Human Engineering, or MIL-STD-1472. Written in 1968, when only men were flying aircraft, this standard contains all the specifications for aircraft sizing down to the predicted length of a pilot's fingertips (DOD, 1999). It is necessary to note that males and females universally have different anthropometric measurements, such as height, weight, and body circumference. Clearly those with a smaller body size may face difficulties when operating machinery designed and built for larger sized humans. Another topic that works together with anthropometric data when addressing the recertification of military standards is human factors. Human factors is the study of "human characteristics, expectations, and behaviors in the design of items which people use" (Davey, 2000). Simply put, the pilot must be physically and mentally capable of flying the machine, otherwise a mission is compromised, and a very expensive piece of technology becomes useless.

This research seeks to determine if gender inequality in aircraft cockpits can be ameliorated by the recertification of the rules and regulations which control their design. The reason for calling these design issues a gender inequality is because the standards and specifications were initially established with an average male body size in mind. Female body sizing was not, and is still not, incorporated in the guidelines, therefore the issue falls into the category of gender inequality. Keeping in line with the topic of aircraft design, the technical project is to design a state-of-the-art Light Attack Aircraft (LAA) that can operate from austere fields for the 2021 AIAA Undergraduate Design Competition.

Case Context for Inequality

Small stature bodies, which include around 95% of females and 25% of males, may have the following issues when in a cockpit: difficulties with forward vision over the nose of the aircraft, struggle with leg reach to rudder controls, and struggle with arm reach to the control panel (Zehner, 2000). A recent study done by a US Air Force aviator explains how the branch is still using "aircrew height standards that are based on a 1967 anthropometric survey that accounts for only males" (Ruttenber, 2020). In Figure 1, the red dotted line shows the cutoff point for a minimum height requirement that is still in effect today in the USAF. This minimum height automatically eliminates 43% of females, who wish to be aviator candidates, from joining the US Air Force. Not only do small statured bodies experience difficulties when flying, but sometimes they are barred from flying all together.

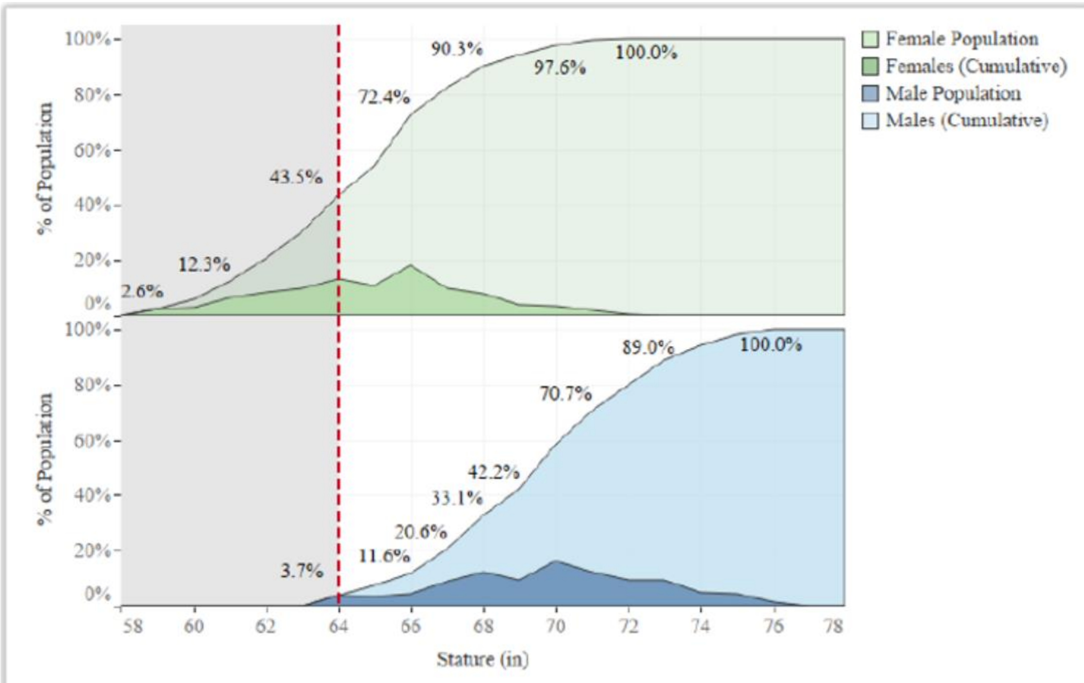

Figure 1: Population curves based on height for males and females in the US Air Force (Ruttenber, 2020)

Another example of a physical restriction is the Joint Primary Aircraft Training Systems (JPATS) used in the military. JPATS regulates how humans interact in an aircraft cockpit after it has been designed. Before the 1994 Defense Authorization Bill was passed, people were barred from pursuing any aviation career in the military if they did not *fit* into the JPATS cockpit. Here, fit means being able to properly reach panel buttons, reach rudder pedals, and see over the nose of the plane simulator without using outside cushions/boosters. Smaller statured people could surely fit inside of the simulators, that was not the issue. It came down to whether the technology was sized in a way that was too large for the smaller statured body to operate it with no issues. This information indicated that even once legal hurdles were jumped to give females equal opportunity in the aviation industry, the physical hurdles are a whole separate issue. As female pilots began receiving military missions in the 1993, they unfortunately found that because of JPATS requirements, “the aircraft associated with these assignments precluded the directive from being implemented” (Weber, 2000, 242). This had an extreme influence over females and small statured men who wished to be aviators at the time.

The MIL-STD-1472 for human engineering design criteria and the FAA human factors handbook also contain specifications that are not inclusive of female pilots. The MIL-STD-1472 has gone through eight revisions since it was first published in 1968, but almost every specification that has a description with the word ‘female’ in it just says that the requirement “should be corrected, where applicable, for females” (DOD, 1999). This is positive in that the standard acknowledges that changes need to be made to eliminate gender limitations in arm, hand, thumb-finger and foot controls (Sections 5.4.4.2 and 5.4.4.3), but it does not provide measures of change for smaller bodies. Also, the verbiage in Regulations 5.6.4. recognizes that the strength of the pilot must be assessed differently for males and females but does not specify how it needs to be assessed differently (DOD, 1999). The FAA safety handbook on human factors (HF) addresses what fields of study HF covers and how HF applies differently to males and females. It states that someone who has a smaller body “may be able to perform more efficiently with equipment that is tailored to their size”, suggesting that a one-size design will not fit all pilots that have to use the aircraft (FAA, 2008).

Not only do military standards, JSSGs, and FAA regulations need updating for interior cockpits sizing, but there is a case that all human factors regulations on advanced aviation technologies need recertification. A report done by the Center of Applied Human Factors in Aviation (CAHFA) stated that standards pertaining to aircraft cockpits and maintenance interfaces, air traffic control interfaces, and supporting aviation facilities all need updating as a system and not individually in order to properly recertify the standards (Hennessy, 1993). Updating only the aircraft cockpit standards may not solve the greater issue of outdated human factors regulations. These examples seek to shed light on why this research should be a concern to others. Human factors engineering is an essential part of designing any piece of technology and "ignoring human factors considerations in the rest of the aviation system will create weak links in the chain" (Hennessy, 1993). Because the population of pilots has significantly changed from only male pilots when much of the design criteria was established in 1968, an update is long overdue.

Theoretical Lenses

The two frameworks I will use for this research topic are the Social Construction of Technology (SCOT) and inclusive design. SCOT is the idea that technological development can be explained as a social process (Pinch & Bijker, 2008). Social groups that encounter a problem with a technology can voice their concerns and then the construction of technology should be improved to reflect the needs of society. In a chapter from the book, *The Social Construction of Technological Systems*, Pinch and Bijker placed the cause of evolution of the Penny Farthing Bicycle on social groups that demanded the design be altered so that they could utilize the artifact (Pinch & Bijker, 2008). While considering the development of the bicycle, the authors treat gender as a characteristic to define distinct social groups who use the artifacts, and then they explain the opposing interpretations of the bicycle in terms of gender. In the case of the Penny Farthing Bicycle, the development was "better explained by including a separate social group of feminine cycle-users" because if the relevant social groups are not properly described, "the function of the artifact with respect to each [user]" cannot be refined and fixed (Pinch & Bijker, 2008). It is critical to understand who uses an artifact and how the said users must use it.

Pinch and Bijker also define what a 'problem' constitutes in the SCOT process. They say a problem is "defined as such only when there is a social group for which it constitutes a 'problem'" (Pinch & Bijker, 2008). Breaking it down, this quote means that there is not a problem in a design until a user says there is a problem. Until a problem is voiced, a design is considered successful in its function. In the case of females using the bicycles, they could not ride the artifact like men did because their clothing prohibited them from straddling the center of the bike. The example of the bicycle can be easily translated to aircraft design. SCOT recognizes females as a relevant social group that operate aircraft. SCOT will consider the fact that females are encountering issues with a technology and it will provide an approach for solving gender inequality in aircraft design.

Inclusive design, the second framework, suggests that all designs need to "consider the full range of human diversity with respect to ability, language, culture, gender, age, and other forms of human difference" (OCAD, 2018). Inclusive design recognizes that a one-size-fits-all does not apply in the design of all technologies, artifacts, and systems. The three aspects that define a successful inclusive design are recognizing diversity and uniqueness, utilizing inclusive processes and tools, and creating a broader beneficial impact (OCAD, 2018). Inclusive design can be further explained with Papanek's design function complex.

The function complex defines six different aspects of design: use, need, telesis, association, aesthetics and method. The most relevant aspects for achieving inclusive aircraft design are need and association. Papanek claims that "design has satisfied only evanescent wants and desires, while the genuine needs of man have often been neglected by the designer" (Papanek, 1973). Satisfying the psychological and intellectual needs of a human is "more difficult and less profitable" so some designers choose to ignore it (Papanek, 1973). This can be argued as a reason why there are still gender inequalities in aircraft design today. As for association, Papanek explains the example of tiny transistor pocket radios that were primarily utilized by teenagers in the 1970s. He claims that it is possible to tailor technologies to "differing needs and wants of various socio-economic groups and thus force new acceptance areas into being" but it can be a difficult process (Papanek, 1973). The biggest hurdle to jump when altering the association of something is facing psychological conditioning, which "predisposes [humans], or provides [humans] with antipathy against a given value" (Papanek, 1973). His argument of humans associating a certain artifact or technology with one type of user is a case for why the change towards inclusive aircraft designs for females is slow moving. Applying inclusive design to this research topic is an obvious fit. Cockpit designs need to consider female body sizes to be truly inclusive of all users. No person should be discouraged from pursuing a job because the size of their body limits them from performing successfully. The design of cockpits can become inclusive once the military standards and FAA regulations are recertified.

Research Question and Analysis Methods

This paper addresses the question: Could gender inequality in aircraft design be ameliorated with the recertification of rules and regulations which control the design? This question is poignant, as gender inequality prohibits and discourages people with different body types from pursuing a career as a pilot. A large reason why the inequality is still present today can be traced back to the original rules and specifications established to control the design of aircraft, and the fact that the updates made to them over the last 50 years have not incorporated the anthropometric sizing of average females. (History, 2020).

To gather information on the physical difficulties female pilots have faced while in the cockpit of military and civilian aircraft, I sent a survey to several experienced pilots found via

LinkedIn Pilot Group. Survey questions included (1) what types of aircraft they fly/flew, (2) how tall they are, (3) if they experienced (a) struggle with arm reach to controls, (b) limited sight lines or difficulties with forward vision over the nose, (c) leg reach to foot pedal limitations while in cockpits, (d) difficulties operating other cockpit equipment and (4) if they experienced any other noteworthy physical difficulties. Two UVA alumni, Sarah Franks and Ashley Henderickson, helped expand the survey pool by sharing the survey with their fellow female aviator social groups on Facebook and by email-push.

The evidence was analyzed through content analysis and historical comparisons. The method of content analysis was used to find common difficulties and suggest specific updates in the regulations to give females the most inclusive designs. A historical comparison was also done to see if older aircraft pose more difficulties than recently designed aircraft.

Results & Analysis

There were 77 survey participants who, collectively, have piloted 315 different aircraft spanning the commercial, military, and general aviation industries. The data collected indicated that the majority of participants do struggle with the four topics listed in the survey, and it answered the question of whether the design standards should be updated to accommodate all aviator body types. The difficulties conveyed in the survey responses were examined through content analysis to see if responders indicated any of the same issues, and then suggestions to update the design standard are made. A historical analysis was also done to see if design updates made on the most flown aircraft by participants shows any indication that time could be a natural promoter of inclusive design.

Content Analysis

The survey results, seen in Table 1, showed that females do struggle with reaching control panel buttons, seeing over the nose of aircraft, reaching rudder foot pedals, and operating other equipment in the cockpit area. Many responders found personalized remedies to solve these issues, such as using booster seat cushions to help increase their sight lines and back cushions to help them reach foot pedals. Some simple design change that I believe could make a difference for people struggling with these sizing issues is demanding (1) more flexible seat belts so pilots can stretch their arms father to reach control, (2) a longer track for the pilot seat so it can be pushed forward more to reach the pedals, and (3) a seat elevator to help with limited sight lines.

Table 1: Results of the Pilot Survey

Survey Question	**Participants that Said 'Yes'/ Total Participants**
Struggle with arm reach to controls	25/77
Struggle with vision limitations	53/77
Struggle with leg reach to rudder pedals	42/77
Struggle operating other cockpit equipment	27/77

The main reason for experiencing arm reach issues was either having short arms or a short torso as this restricts them from being able to reach trim tabs and operate overhead panel buttons. When the reach is not physically possible from their seat, sometimes they are forced to unbuckle or unstrap midflight. A direct quote describing these issues can be seen in Figure 2.

"On the Airbus 320 family, I couldn't reach the aft overhead panel while buckled into my seat. When I was first assigned to that fleet, we had a procedure that required resetting a system after every engine start. I had to unbuckle, and stretch upwards every, single flight. I pulled a muscle in my left shoulder from twisting and reaching every leg of the flight. The ache never healed until the procedure changed, about 6 months later." (5 foot, 2.5 inches)

Figure 2: A description of arm leach limitations from a survey participant.

The main examples of vision limitations, including one described in Figure 3, were being unable to see over the nose, unable to see over the glareshield, and unable to see anything in front of the plane during climb. In addition, when they sit on cushions to help correct the vision limitations, they may hit their head on sun visors ultimately creating more problems while trying to correct for one crucial limitation.

“Not just [seeing] over the nose, but also the instruments – being closer to the yoke means the yoke and panel “dash” obscure view of the instruments. In fact, we had the panel in the Cessna 414 reorganized to provide for proper instrument scan.” (5 foot, 1 inch)

Figure 3: A description of vision limitations from a survey participant.

Participants who experienced leg reach limitations claimed it is primarily because seats will not slide far enough forward for their legs to reach the pedals. Figure 4 contains a quote from a participant describing her method of dealing with leg reach struggles.

“Cannot reach them without the seat fully forward, with pillows underneath me and behind my back. Even then in some simulators I can barely reach the pedals. It's the same in the aircraft.”(5 foot, 2 inches)

Figure 4: A description of leg leach limitations from a survey participant.

An assortment of responses regarding struggles operating other equipment are as follows: not having the upper body strength to close doors, being unable to reach shoulder straps behind a seat, being unable to reach controls once the shoulder strap is on, having difficulties with opening and seeing into fuel valves, having difficulties with manually extending and retracting flaps or landing gear, and struggling with the strength to use the tow bar manually. An additional struggle mentioned by several survey responders is seen in Figure 5.

"I found the oil dip stick was over tightened by previous pilots at times and difficult to unscrew. I started carrying my own pliers to help unscrew the dip stick." (5 foot 3 inches)

Figure 5: A description of a survey responder's struggles operating other cockpit equipment.

Although the majority of participants have faced difficulties while flying, there were women that said they have not experienced any difficulties listed in the survey. 19 participants answered 'no' to every question, indicating zero issues with fitting in cockpits. Possibilities as to why participants responded with zero physical sizing issue could be that they are taller, they are operating tailored aircraft, or they are unaware that they are, in fact, facing difficulties. When these participants went through pilot training, they may not have been told what their sightlines should be, or they may not be aware what the proper leg and arm reach lengths should be.

Another crucial part of the survey was asking for the participants' height. The heights of all survey participants are seen in Figure 6, and the average height is 5 feet 5 inches. The number of participants that are 5 foot 4 inches or shorter is 39. This means that according to USAF anthropometric requirements, 50.6% of the surveyors are not tall enough to be an aviator in the Air Force (Ruttenber, 2020). The average height of the 19 participants who stated that they have no physical difficulties with cockpit sizing is 5 feet 7.5 inches, and the average height of survey participants that indicated experiencing at least one sizing difficulty, or in other words all the participants excluding the 19 'no' participants, is 5 feet 4 inches. This suggests that the participants who responded with having no sizing difficulties are generally taller and may fit the 1968 male anthropometric sizing guidelines.

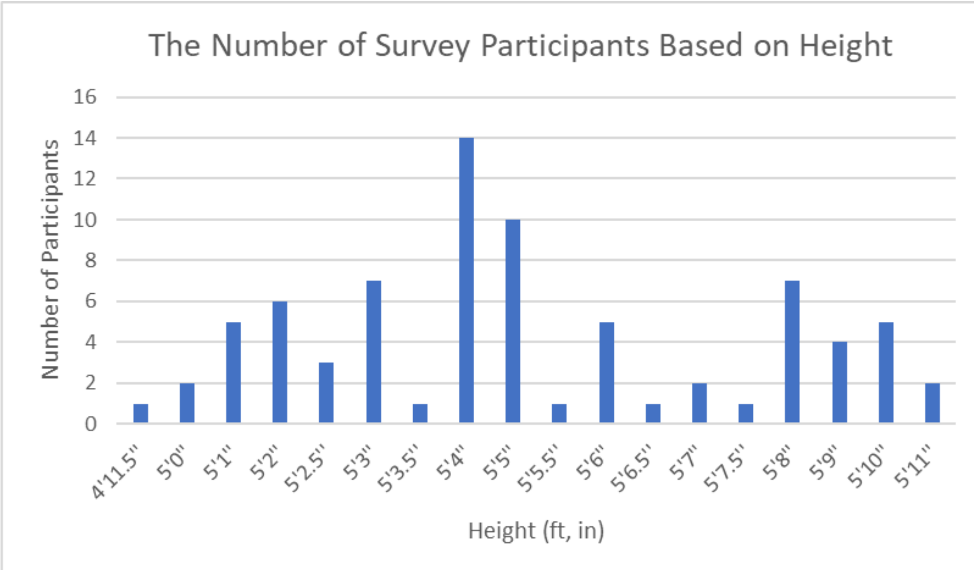

Figure 6: A column chart of survey participants' heights.

Historical Comparison

After filtering through the responses and running a historical analysis study, it is not conclusive that older aircraft are less likely to have an inclusive fit compared to newer aircraft. This is to say that aircraft built in the 1960s and aircraft built in 2020 will likely cause the same types of physical sizing issues for small statured bodies. Of the 315 aircraft flown by the participants of this survey, the most common aircraft was the Cessna 172 (C172) with 44 of the 77 participants listing it as one that they have operated. The C172 was first designed in 1955 by Textron and over 44,000 have been manufactured since (Goyer, 2012). Textron has made updates to the design almost every decade to implement improvements and new technologies, yet four women specifically left comments complaining about vision limitations in the C172. I believe this rules out the possibility that time has been a natural improver for aircraft design. This raises the question of whether recertifying design standards is the *only* way to make steps toward inclusive designs. The survey overwhelmingly suggested that females face sizing issues due to the designs of the aircraft and the updating of design specifications is the key to creating design inclusivity for the entire population of pilots.

Discussion

My results confirmed the work of Zehner in his dissertation *Prediction of Anthropometric Accommodation in Aircraft Cockpits,* and the work of Weber in the article Manufacturing Gender in Commercial and Military Cockpit Design (Zehner, 2000 and Weber, 1997). Both case studies suggested that females had arm reach issues, leg reach issues, struggle operating certain equipment in the cockpit, and issues with vision over the nose and control panels. My results showed that these issues are in fact happening and that the historical dating of when aircraft are built does not play a role in whether the cockpit is more suited to small statured bodies. As it has been 50 years since females were allowed to fly and they still have issues fitting properly into numerous models of aircraft, it can be concluded that the design sizing standards are the cause.

Like the Social Construction of Technology theory says, "there is not a problem, until someone says there is a problem" and these survey responses could not emphasis more that there is a lack of inclusive design (Pinch & Bijker, 2008 and OCAD, 2018). For designs to pass the conceptual build stage, standards and specifications have to be fully fleshed out to ensure each aspect is compliant with the rules. Since the rules do not demand items such as the suggested changes listed in the *Results - Content Analysis* section, the private, civil, and military aircraft in flight will never be updated under the current system for struggling pilots and these fixes will not trend in future designs. These simple design changes could make a world of difference for pilots who are already under the stress of trying to fly an aircraft carrying precious cargo. A pilot should not be worrying about their personal booster seat cushion, which helps them with vision limitations, potentially restrict them from being able to reach the rudder pedals. Military Standards and FAA regulations need to be updated not only for the sake of inclusivity and equality, but also for the sake of safety.

There are several caveats to this research. It is obvious that one size cockpit does not fit all. This suggests that people who are 6 foot 2 inches will not fit the same way as someone who is 5 foot 2 inches in an aircraft. In the same breath, it also does not mean that every person who is 5 foot 2 inches fits the same way in a cockpit. In addition to that, people that are above average height and weight likely experience sizing issues too, so it is difficult to make a blanket statement that shorter humans experience more sizing issues than other groupings of anthropometric sizes. The vocabulary of the research question is intentionally targeting females as they are typically shorter than males, and because the historical aspect of this topic shows that male bodies are the average sizing model for aircraft cockpits. This, however, does mean that physical sizing issues do not span genders. At a higher level, I am also unaware if design recertifications are currently underway.

In the future, I would specifically ask survey responders if they think updating the design standards could fix the issues they are facing. I would also be interested to hear what other improvements they think could be made to solve the physical issues. Creating three separate surveys for military, commercial, and general aviation pilots could provide more insight than the research process used here. Expanding the survey and asking more targeted questions would have allowed me to draw more conclusions on my research question.

I would like to focus on human factors engineering and design in my future career. Individualization and detail are big passions of mine and I hope that this project will propel me into tackling other types of design limitation projects. I chose this topic out of personal interest as I am only 5 foot 2 inches and faced difficulties flying the flight simulator in the UVA Mechanical Engineering building. I was curious if other petite females faced the same issues and I overall found it to be true. Although there were 19 women who said they face no physical issues, I still found it so disheartening to read the detailed comments about pain and forced crash-landings because some women could not fly the planes properly due to their body size. Learning about military standards and the process of certifying a design will also be very beneficial for my future.

Conclusion

The survey results and new design suggestions in no way solve the greater issue, but hopefully shed light on the situation. There are indeed physical limitations for shorter statured females, and it can be implied that this also holds for short statured males. I believe the recertification of design standards and specifications could ameliorate these difficulties. Getting rid of height minimums is also necessary to create inclusive cockpit design. Designing to be more inclusive with a height minimum still in place overlooks part of the issue. The next steps for this research are continued whistleblowing and networking. If updates are eventually made to design standards, aviators that fly the updated aircraft will need to be polled to see if the updates do provide help. Cockpit design regulations need to be updated so the baseline sizing ranges from average female to average male anthropometric measurements. Flying an aircraft is no easy task, and a pilot should not encounter more difficulties due to the size of their body.

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