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Effects of Airplane Cabin Interiors on Egress I: Assessment of Anthropometrics, Seat Pitch, and Seat Width on Egress

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16. Abstract Within the Federal Aviation Administration (FAA) Reauthorization Act of 2018, Pub. L. No. 115-254 § 577, Congress required that "...the Administrator of the Federal Aviation Administration shall issue regulations that establish minimum dimensions for passenger seats on aircraft operated by air carriers in interstate air transportation or intrastate air transportation, including minimums for seat pitch, width, and length, and that are necessary for the safety of passengers." This research project was developed to provide information to rule-makers within the FAA to meet this requirement. A total of 775 participants were recruited to assist with meeting two research objectives: first, to determine what percentage of the American population, based on anthropometric measurements, would be unable to sit in transport airplane passenger seats at the currently narrowest width and even narrower seat pitch. The second objective was to determine the effect of seat pitch and seat width on individual egress time. The study included 718 participants assigned to 12 groups who participated in up to four evacuations from the FAA's Flexible Aircraft Cabin Simulator (FlexSim), with various seat pitch and width combinations. Based on this study's results, currently flying seat pitches using seats of similar size or smaller than those used in this project can accommodate and not impede egress for 99% of the American population. This project also concluded that, similar to previous evacuation research, as long as ergonomic minimums are maintained, the transport airplane's interior configuration, including seat pitch and width, has not been shown to influence evacuations.					
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Effects of Airplane Cabin Interiors on Egress I: Assessment of Anthropometrics, Seat Pitch, and Seat Width on Egress

Introduction

Within the Federal Aviation Administration (FAA) Reauthorization Act of 2018, Pub. L. No. 115-254 § 577, Congress required "...the Administrator of the Federal Aviation Administration shall issue regulations that establish minimum dimensions for passenger seats on aircraft operated by air carriers in interstate air transportation or intrastate air transportation, including minimums for seat pitch, width, and length, and that are necessary for the safety of passengers.". This requirement came after many years of passenger advocacy groups calling on the FAA to do the same, with the rationale that the American public's physical dimensions have been getting larger and that seat size and available seated space (i.e., seat pitch) has been reduced. The FAA and the aviation industry have conducted a considerable amount of research on airplane evacuations; however, none of the research specifically focused on what effect airplane seat dimensions throughout the cabin may have on evacuation speed and safety. Indeed, one of the primary conclusions about airplane cabin interior factors and their effect on evacuations from the last major FAA evacuation research project involving human participants was that as long as ergonomic minimums were maintained, the effects of the interior cabin configuration leading to the exits were minimal (McLean et al., 2002). The McLean et al. (2002) project specifically addressed the interior cabin configuration adjacent to the type-III overwing exit; however, their conclusions have been extended to the rest of the aircraft cabin in arguments about why minimum seat size standards or spacing are not needed. Given the Congressional mandate, it was determined that more information was required to better inform rule-makers on how changes to seat dimensions or available space may affect evacuation speed and safety and to provide data on how anthropometric (i.e., physical size and dimensions) changes in the American population may affect the ergonomic minimums required within the airplane cabin.

This research project had two objectives to address the Congressional mandate as noted above. The first objective was to determine the percentage of the American population for whom ergonomic minimums are being violated at the lowest average seat spacing, and the percentage affected if that spacing was further reduced. Second, to determine what, if any, effect various seat pitch and width configurations have on the speed of a simulated airplane evacuation.

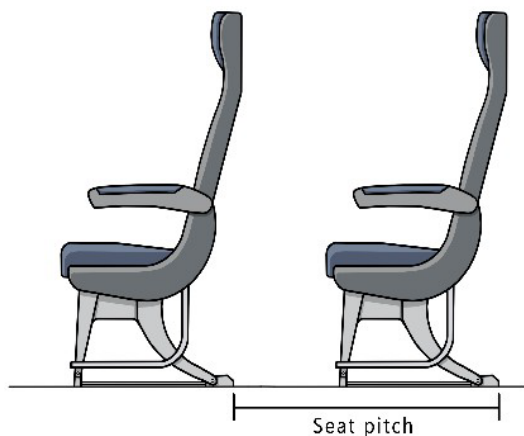
Seat Pitch vs. Available Space

A common misconception about the available occupiable space for a passenger onboard a transport category airplane involves the seat pitch dimension and how it relates to the available occupiable space. Seat pitch is the distance between a single point on an airplane seat (reference seat) to the same point on the airplane seat forward or aft of the reference seat, typically a fixed

point such as the aft foot or fitting where the seat attaches to the airplane floor (Figure 1). Seat pitch has become the focal point of public interest because, as seat pitch decreases, so apparently does the available occupiable space, and comparing the average seat pitch of the 1980s to the 2010s, there is a trend for decreasing seat pitch. However, the perception that less seat pitch equates to less space for passengers has a flawed underlying assumption that other seat dimensions have remained unchanged, which they have not.

Figure 1

Seat Pitch Measurement Diagram

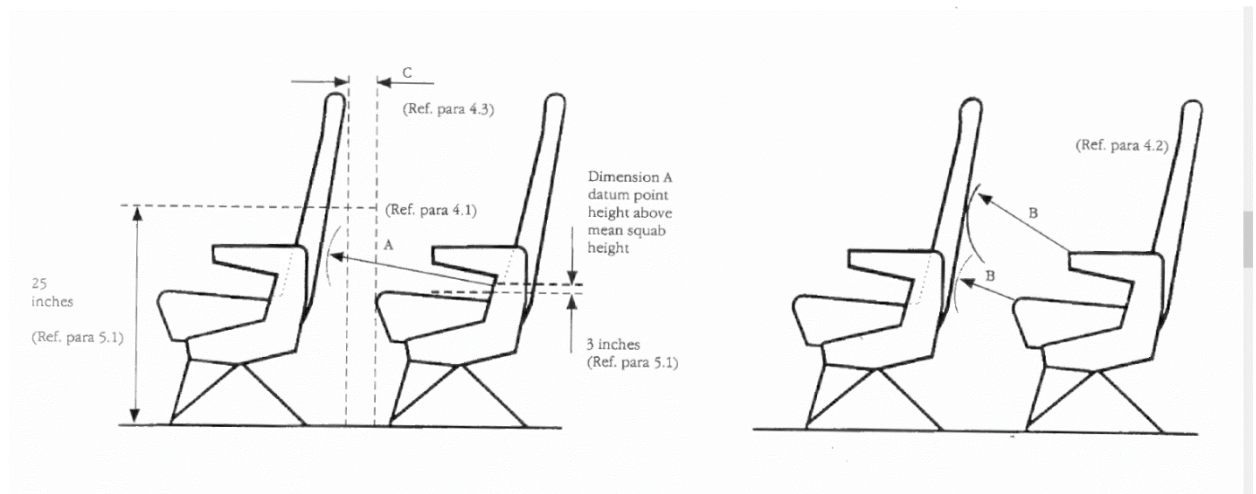


A comparison of airplane passenger seats from the mid-1900s to the 2000s reveals many physical differences that mirror changes in regulations, testing, and available materials and technology. These changes include seat leg placement and attachment points, the type and weight of structural materials used in seat construction, and the material for and thickness of the cushions on airplane seats. These changes were made to increase passenger safety and survivability in the event of an aircraft accident, and some of these changes resulted in seats that provide a high level of passenger safety while taking up less space and reducing the weight of the seat (Freed, 2013). Therefore, seat pitch (essentially the distance from one seat to the next) may stay the same, while differently designed seats offer more or less available occupiable space to the passenger. In addition to seat pitch, there is a more precise (if less intuitive) series of airplane seat measurements developed by the United Kingdom Civil Aviation Authority (UK CAA), which better defines the true variables of interest for determining the available occupiable space of an aircraft seat of any pitch. UK CAA airworthiness notice 61 (AN-64) describes these seat measurements as Dimensions A, B, and C (UK CAA, 1988). AN-64 defined Dimension A as measuring at the level approximately three inches above the seat cushion, the distance between the seat back and the back of the seat, or any fixed object in front of the seat. Dimension B was defined as the minimum distance between a seat and the back of the seat or other fixed

object in front of the seat. Dimension C was defined as the “vertically projected distance between seat rows or between a seat and any fixed structure forward of the seat” (UK CAA, 1988, p. 2, Section 4.3) (Figure 2).

Figure 2:

Visual Description of Dimensions A, B, and C



Note. From “Airworthiness Notice (AN) 64: Minimum Space for Seated Passengers” by the United Kingdom Civil Aviation Authority, 1988. In the public domain.

AN-64 also set minimum sizes for these dimensions, with Dimension A to be at least 26 inches (66.04 cm), Dimension B to be at least 7 inches (17.78 cm), and Dimension C to be at least 3 inches (7.62 cm). The criteria for seat dimensions established by AN-64 were withdrawn in November 2014 (Butcher et al., 2020); however, other regulations established similar criteria to ensure passengers' ability to be able to egress from airplane seats in the event of a crash. Specifically, UK CAA’s Dimension B has been established as 6 inches (15.24 cm) in a post-crash situation, and typically 9 inches (22.86 cm) in normal operations, to meet the requirement that deformed seats do not impede egress as required by 14 CFR 25.562(c)(8) (Emergency landing dynamic conditions; Appendix 2, 1988). Given the current FAA 14 CFR 25.562(c)(8) regulation and the trend that seat bottom length has remained approximately 18 inches (45.72 cm) for more than 30 years, it is unlikely that seat pitch would fall below 27 inches (68.58 cm) while Dimension A may fluctuate. Although the term “seat pitch” was used for this study and report for ease of communication, this report also provides information on Dimension A of the test articles. Note that the seats used in this project had larger constituent parts (e.g., thicker seat cushions) than newer “slim-line” aircraft seating (Freed, 2013; Limitations section of this report).

Expanding American Body Size

A comparison of the published National Health and Nutrition Examination Survey (NHANES) data and report data from 1988 (McDowell et al., 2009) to 2014 (Fryar et al., 2016) indicates that Americans have, on average, gained 14.77 lbs (6.7 kg) for males aged 20 years and older and 15.87 lbs (7.2 kg) for females aged 20 years and older. The average American waist size has grown from 37.48 inches to 39.96 inches (95.2 cm to 101.5 cm) for males aged 20 years and older and 34.88 inches to 38.15 inches (88.6 cm to 96.9 cm) for females aged 20 years and older. This growth may be impressive or depressing depending on reader inclination; however, given the previous discussion about available occupiable space and how airplane seat dimensions have changed over the years to provide more space while seat pitch has decreased, the average increase in Americans' girth and weight may not be the most valid physical dimensions to use to assess passengers' ability to evacuate. Indeed, other physical dimensions within the NHANES dataset, such as upper leg length and overall height, might be more pertinent in determining seat ergonomic minimums relevant to airplane evacuation. A review of the NHANES tables for the same 1988 to 2014 time period shows that upper leg length decreased by 0.39 inches (1 cm) for males aged 20 years and older and 0.59 inches (1.5 cm) for females aged 20 years and older, while overall height increased by 0.04 inches (0.1 cm) for males but remained unchanged, on average, for females.

While previous evacuation research surrounding the Type-III emergency exit has shown that, on average, increased girth leads to slower movement and evacuation speed of individuals (McLean et al., 2002), changing seat dimensions have not intersected with what might be thought of as hard ergonomic limitations, such as those derived from bone structure (height/leg length). However, those changing seat dimensions may appear to have intersected with softer ergonomics (i.e., fatty tissues). This intersection of seat dimensions (e.g., seat pitch) and softer ergonomics may seem alarming without understanding the previously discussed changes in actual occupancy space. With that understanding, and looking at the history of airplane evacuations, be they for certification, research, or real-life (precautionary and emergency), the FAA's response to previous calls for research and regulation from advocacy groups included the assertion that spacing issues were relevant to comfort (intersection of seat dimensions and softer ergonomics) rather than safety (intersection of seat dimensions and harder ergonomics). This study aims to ascertain the veracity of this position, with a focus on collecting a wider range of anthropometric data than previous evacuation research projects.

Historical Airplane Evacuation Research

The FAA, through the Civil Aerospace Medical Institute (CAMI; Oklahoma City, OK), in conjunction with the William J. Hughes Technical Center (Atlantic City, NJ,) has conducted airplane evacuation research since the 1960s to better understand and improve passenger

survivability (see the report by Mohler et al. (1965) for a review of early work at CAMI, see the report by Paskoff and Anderson (2016) for an index of historical research conducted at the FAA's Protection and Survival Laboratory). Much of this previous evacuation research, as well as research conducted at other institutions around the world, focused on exploring the evacuation of a transport airplane as a system, determining relevant variables within the system and their interactions while controlling as many extraneous variables as possible (McLean, 2001). Treating an airplane evacuation as a system has allowed researchers to gain an understanding of variables such as individual passenger attributes, crewmember actions, emergency lighting, egress assist means, passenger motivation, interior airplane configurations, use of personal breathing equipment, smoke obscured cabins, and exit size, as well as how these variables interact with each other to influence a successful (or not so successful) evacuation. The knowledge provided by the previous research influenced variable selection for the current research project and variables that could be ignored or at least controlled.

Previous evacuation research has shown that the individual attributes of passengers and learning effects can significantly contribute to variance found in airplane evacuation data, and evacuation performance tends to plateau (or lose variance) between evacuations after four to six evacuations (McLean & George, 1995a; McLean & George, 1995b; McLean, 2001). Two approaches have been explored to deal with this variance: trained vs. naïve evacuees. The use of trained evacuees, such as those in McLean and George, Parts I and II (1995a, 1995b), is beneficial for controlling unnecessary evacuation data variance. For example, comparing the evacuation data from a group of participants who had experienced six practice evacuations before their experimental trials would allow for much greater confidence in data analysis when looking at differences in evacuation times after experimental variables are introduced or manipulated. This would also allow the use of significantly fewer research participants in each study. However, the same previous research experience has shown that while the use of trained subjects may provide a "cleaner" result, the feedback received from the results of experiments using such a methodology—specifically that the use of trained participants was not representative of or generalizable to the general flying public—has led to the repetition of projects using a much larger sample of naïve participants to be more palatable to those critical of the research, though, in this specific example it produced similar if messier, results (McLean & George, 1995a, 1995b; McLean et al., 2002; McLean & Corbett, 2004). Given that history and the fact that using naïve evacuees requires a large number of participants, this project opted for the use of naïve participants for the evaluation of seat dimensions to allow for as much confidence in the generalizability of the results as possible.

Using evacuation slides contributes to variability within an evacuation system, as evacuees who have not encountered or used an airplane evacuation slide tend to hesitate at the airplane door before jumping, thus increasing their evacuation times. Some evacuees (e.g., typically young men) reduce their evacuation times after the first evacuation by engaging in potentially unsafe

egress techniques (e.g., launching onto the slide rather than stepping over the door threshold and onto the slide) (McLean et al., 1996, 1999). Evacuation slides are well designed to perform a specific function—to move passengers from the airplane door threshold to the ground quickly. Slides perform this function so well that there are risks to passengers such as friction burns and injuries from pile-ups at the bottom of slides due to passengers' inability to successfully (and correctly) dismount the slide. Given the above factors, the likely increase in evacuation time variability, the potential hazards, and because the current study was designed to evaluate cabin interior configurations on egress rather than exit configurations, this study excluded the use of evacuation slides.

Flight attendants are highly trained safety professionals who have accepted a role of responsibility and influence should an emergency event occur on an airplane. Previous research investigated what effects flight attendants have on evacuations and how much flight attendant assertiveness plays a role in facilitating a rapid egress event (Muir & Cobbett, 1995; McLean et al., 2002). Results indicate that cabin crew participation in evacuation research leads to better evacuee performance and increased fidelity to real-world evacuations. However, care must be taken when including flight attendants in an evacuation research project because they must remain consistent in their use of verbal commands (McLean et al., 2002). Given the benefits and effectiveness of flight attendants in previous evacuation studies, the current study requested and received the assistance of experienced and professional flight attendants from a major U.S. air carrier.

Passenger motivation is another crucial variable in evacuation research and has led to the use of three separately defined levels of motivation: no compensation, cooperative compensation, and competitive compensation. Research projects that manipulated participant motivation with extra payments show improved participant performance during egress events thought to be closer to real-world scenarios when compared to egress events during which no extra compensation was provided (Muir et al., 1989). Muir further refined this motivation manipulation by comparing a competitive approach (e.g., the first x number of participants to egress received more money) to a cooperative approach (e.g., if the group as a whole egressed within 90 seconds, all the participants received more money) and concluded that the cooperative approach more closely resembled a precautionary or certification evacuation while the competitive approach more closely resembled an actual airplane emergency evacuation (Muir & Cobbett, 1995). The cooperative approach also resulted in the fastest overall egress times, while the competitive approach was faster than no compensation at all. The faster egress times using the cooperative participation motivation approach were attributed to increased evacuee efficiency in the aisles and at the exits as the participants worked together instead of against each other. McLean and George (1995a, 1995b) explored cooperative/competitive compensation to manipulate participant motivation, and McLean and Corbett (2004) further explored the differences in performance between low motivation (i.e., no incentives) and high motivation with a refinement

of the competitive motivation approach by offering the first 30% of participants to evacuate, averaged over four trials, would receive double the pay they were offered for participation in the study. A critical issue throughout these participant motivation studies was that there tended to be a “tail” in evacuation times when using the competitive motivation approach. Participants near the end of an evacuation queue did not try as hard as they believed they would not receive a bonus, especially in studies that used a stringent motivation condition, such as the first 30% of participants to evacuate. The current study elected to use a competitive motivation manipulation strategy with a larger number of study participants than has been previously used in evacuation studies to minimize any “tails” in the data while at the same time maintaining the level of performance likely to be seen in an actual emergency evacuation.

Methods

Experimental Design

This study had two research objectives. The first objective was to determine what percentage of the American population, based on anthropometric measurements, would not be able to sit in transport airplane passenger seats at the currently narrowest and even narrower seat pitch. Second, this study sought to determine the effect of seat pitch and seat width on individual egress time.

The first question was addressed in two parts. First, this study collected an amount and type of anthropometric data from each participant that has not been collected in previous evacuation research performed at CAMI, with the intent to use these data for ergonomic analyses of current and future seat designs and use in various computer-modeling efforts. Second, this study asked all participants to sit in a seat mock-up that matched the narrowest seat pitch they would experience in the evacuation trials. They were also asked to sit in a seat mock-up of a narrower seat pitch than what would be presented in the evacuation trials or, presumably, in the active-duty fleet of commercial transport category airplanes. This extra step was selected to investigate what percentage of the population would be unable to sit, and thus be unable to fly, should the occupiable seat space (Dimension A) be further reduced.

The second research question (i.e., what effect, if any, does seat pitch and seat width have on individual egress time) was addressed by a 2 x 3 factorial design with two levels of seat width and three of seat pitch. The seat width was defined as the distance between the armrests' inner faces over the airplane seat. Two experimental seat widths were selected for this study: 16 inches (40.64 cm) and 18 inches (45.72 cm). These seat widths were selected based on data available through seatguru.com (which tracks and lists seat dimensions of airplane seats by airline, airplane type, and cabin configuration), representing the average seat widths for single-aisle, economy class seating at the time of project design (February 2019). Three experimental seat pitches were selected for this study: 32 inches (81.28 cm), 28 inches (71.12 cm), and 34 inches

(86.36 cm), and these sizes were based on data obtained from seatguru.com for the average, smallest, and largest seat pitch values found onboard economy class commercial transport airplanes at the time of the current study.

Ideally, to collect the best data for this design, all groups would experience all combinations of target variables for comparison. However, to account for learning effects and the need to simulate a naïve evacuation population and equipment limitations, this project used a pair of 2 x 2 factorial tests under the same umbrella project. Due to the potential for safety implications based on the findings of this project, the majority of the groups were assigned to experience the narrowest pitch condition (28 inch/71.12 cm pitch) in conjunction with the “control” pitch of 32 inches (86.36 cm). The 34-inch (86.36 cm) condition was selected to see what, if any, improvements in egress times could be achieved by increasing the seat pitch over the average. Twelve groups of 60 participants each were adequate to provide sufficient egress data to find an effect based on pretest power analysis, with eight groups experiencing the 32/28 comparison and four groups experiencing the 32/34 comparison.

Each group participated in four evacuations with experimental seat width, and seat pitch conditions counterbalanced to control for presentation effects. The principal investigators developed a seating chart to ensure that no participant sat within three rows closest to or farther from the exit more than once throughout the four evacuation trials to maintain participant motivation.

Facilities, Materials, and Staff

Location and Buildings

All research facilities are located on the FAA’s Mike Moroney Aeronautical Center (MMAC) campus in Oklahoma City, OK. The MMAC Visitors Center was used for participant arrival, initial check-in, briefing, and informed consent. Multiple rooms within CAMI (Building 13) were used. Anthropometric and seat mock-up data were collected in the Cabin Safety Research Team Lab (CAMI Room 127). The “High Bay” (CAMI Room 121) was used for participant staging, filling out pre-evacuation questionnaires, and mass participant debriefings. CAMI classroom 117 was a holding area for the pool of back-up participants if any of the evacuating participants were unable or unwilling to complete all four evacuation trials on a given day. The CAMI medical clinic (also located within Building 13) was on stand-by during the entirety of data collection on a given day to provide basic medical care to participants who sustained minor injuries.

Experimental Seat Mock-up

An experimental seat mock-up was built atop a 4-inch (10.16-cm) raised platform with carpet and an airplane seating track. Three sets of 3-abreast transport category airplane passenger seats were secured to the seat track with the first row as far forward on the platform as possible. The second row was secured to the platform at a 26-inch (66.04 cm) seat pitch, and the third row was secured to the platform at 28-inch (71.12 cm) seat pitch. CAMI acquired these airplane seats for use in a previous aircraft cabin simulator and, before that, the seats went through a service cycle in the flying commercial transport airplane fleet in the 1990s. The seats were used as references for developing the seats in the Flexible Aircraft Cabin Simulator (FlexSim) used in the evacuation portion of this study and resemble seats in the flying fleet. However, they are using older, thicker cushions than what has become the norm. The experimental seat mock-up was numbered using blue seat covers with the numbers embroidered on the headrest—numbers one to three in the first row (note that the seat cover for seat number two was removed to allow researchers and staff to evaluate participant interaction with the seatback in the narrowest seat pitch), numbers four to six in the second row, and numbers seven to nine in the third row (Figure 3).

Figure 3

Experimental Seating Mock-up



Flexible Aircraft Cabin Simulator

All evacuation trials were conducted in the FlexSim (Figure 4). The FlexSim was commissioned in 2014 as CAMI's newest and most versatile narrow-body aircraft cabin simulator. The FlexSim can be configured to resemble the interior dimensions of a range of narrow-body transport category aircraft by changing cabin width to simulate everything from four- to six-abreast seating. The FlexSim is equipped with individual airplane seats, rather than seat packs, to provide maximum flexibility in interior cabin configuration. For the current study, the FlexSim was configured into two distinct sections: (1) a control seat pitch section facing forward in the FlexSim, consisting of 11 seat rows in the 32-inch (81.28-cm) seat pitch configuration; and (2) the experimental seat pitch section, facing aft in the FlexSim, consisting of 11 seat rows placed in a 28-inch (71.12 cm) or 34-inch (86.36-cm) configuration depending on the experimental condition (Figure 5). Ramps were placed at the two exit doors (R1 for the control section, L4 for the experimental section) to facilitate rapid and safe participant egress. The control and experimental sections within the FlexSim were configured so that, from a participant's perspective, the egress pathway was the same for all four evacuation trials; participants traveled all the way forward and to the right to exit the FlexSim.

Figure 4

The Flexible Aircraft Cabin Simulator (FlexSim) During a Trial Day.



Figure 5

FlexSim Interior in the Experimental Configuration



Two large (10- x 20-foot) canopy tents were placed to the east of the FlexSim and served as a rallying point where participants completed post-evacuation trial surveys and were staged for preboarding in preparation for the next evacuation trial (see Figure 4).

The seat width was manipulated using arm-rest spacers fabricated by Newton Design, which built the FlexSim and the seats. The 1-inch (2.54-cm) thick thermoplastic spacers were formed to match the dimensions of and fit over the existing seat armrests to decrease the space between the armrests (Figure 6).

Figure 6

FlexSim Seats with Armrest Spacers Installed



Measurement Equipment

Two Health-O-Meter 500KL Digital Physician Scales were used to measure participant height and weight. We used 80-inch retractable body tape measures (Perfect Body) or 120-inch fabric tape measures (SumVibe; to accommodate larger girth participants) to measure participant girth. Two GPM Anthropometers were used to collect participant anthropometric measurements. Both anthropometers were calibrated before use for data collection. Two custom-built floor-to-knee measuring devices were used to collect leg length anthropometric data. These measuring devices consisted of a steel engineer's metric ruler modified for attachment and height range that was mounted to an aluminum footplate for stability and a handle for ease of movement and placement (Figure 7). These measuring devices were made in-house by CAMI Engineering Technicians and calibrated against existing rulers to ensure accurate measurements. Two custom-built bench seats, 17 inches (43.18 cm) high, were used to collect seated anthropometric data. These bench seats were built to match existing aircraft seat height, with tall, narrow backs to accommodate straight-backed posture measurements (Figure 8). Newton Design, Inc., made the bench seats.

Figure 7

Knee-to-floor Height Measurement Tool (front and side view)



Figure 8

Anthropometric Measurement Chair (front and side view)



Recording Equipment and Video

This project used 21 cameras to record the events of the research project and the evacuations. Thirteen of these cameras were GoPro Hero 3+ models that were a part of the FlexSim original equipment, 12 were used in the FlexSim itself, and one was used in CAMI Room 117 to record the participants sitting in the experimental seating mock-up. Four additional GoPro Hero 8 cameras were purchased and used inside the FlexSim for additional camera coverage of the evacuations. These cameras were owned, set-up, and maintained by the research staff for multi-angle coverage of the inside of the FlexSim during each evacuation. The CAMI iZone team provided primary timing camera coverage using four GoPro Hero 7 cameras: two cameras were inside the FlexSim, and two cameras were outside. iZone staff provided expertise in camera placement, setup, and maintenance throughout the evacuation trials. Additionally, iZone staff produced the timestamped video used for data breakdown and analysis.

General

Participants used clipboards and blue or black pens to complete paperwork throughout the study. Participants wore identification vests consisting of front and back panels of white canvas cloth with large, high-contrast color numbers on each side, shoulder straps, and tie on side straps. The vest number was the primary means of identification once an individual consented to participate in the study. Two 14-passenger busses shuttled participants to and from the MMAC Visitors Center and the CAMI building. Participants were given sanitary foot covers, on request, during the anthropometric measurements (all measurements were made with footwear removed). Boarding passes were made from colored paper and laminated to allow for writing, cleaning, and reuse. The colored boarding passes corresponded to one of the four evacuation trials and were derived from the principal investigators' seating chart. Two megaphones were used by the research staff and investigators when extra volume was required to communicate with participants. A total of 600 hair ties were used by participants to secure hair high on the head or to prevent obscuration of participant vest numbers. Four propane heaters were used on days and nights that were below comfortable temperatures—two large outside heaters for use in the canopy tents/rally point and two smaller heaters, safety rated for enclosed spaces, to provide additional heat near the FlexSim exit doors in addition to the FlexSim's integral heating system. Measurement reference photos for each of the anthropometric measurements taken in this project were developed for staff training and reference and posted at measurement stations for staff to show participants what was being measured and how (Figures 9-13).

Figure 9

Anthropometric Measurement Reference: Buttock-to-knee Length, Knee-to-floor Height.

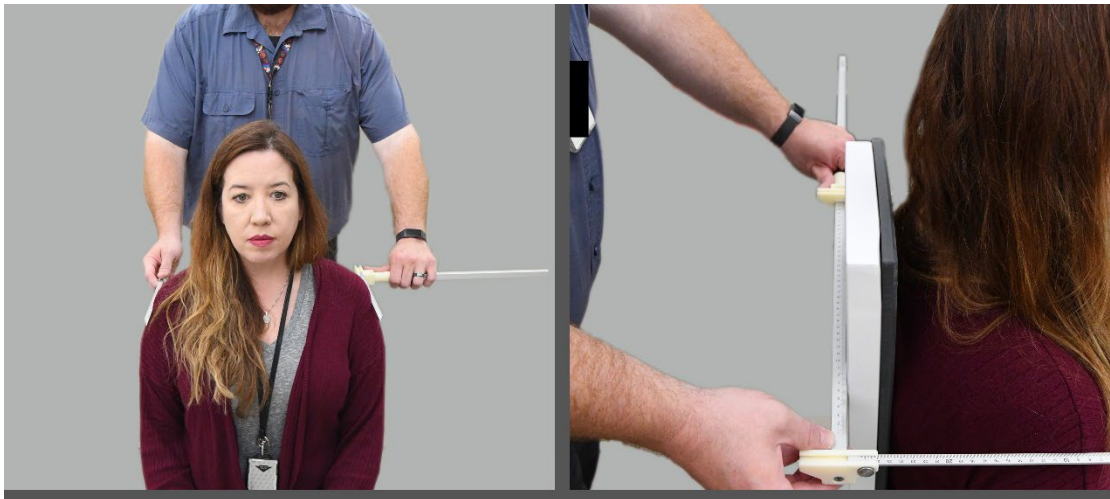


Buttocks-to-Knee Length/Knee Height, Sitting:

- * Seated, feet in line with thighs (apart), knees at 90°
- * Sit tall, look straight ahead with hands resting loosely on thighs

Figure 10

Anthropometric Measurement Reference: Shoulder Width.



Shoulder Width – Bideloid Breadth:

- * Seated, feet in line with thighs (apart), knees at 90°
- * Sit tall, look straight ahead with hands resting loosely on thighs
- * Flex elbows to 90°, hands straight, palms facing inward

Figure 11

Anthropometric Measurement Reference: Sitting Hip Width.



Hip Width, Sitting:

- * Seated, feet and knees together, knees at 90°
- * Sit tall, look straight ahead with hands resting loosely on thighs
- * Flex elbows to 90°, hands straight, palms facing inward

Figure 12

Anthropometric Measurement Reference: Waist Circumference.



Waist Circumference (Girth):

- * Stand tall
- * **Weight evenly distributed on both feet, heels together as much as possible
- * Point to belly button with LEFT index finger, once tape is in place let arms hang relaxed at the sides with shoulders relaxed

Figure 13

Anthropometric Measurement Reference: Height and Weight.



Standing Height/Weight:

- * Face forward and stand tall
- * Weight evenly distributed on both feet, heels together as much as possible
- * Shoulders relaxed, arms hang loosely at sides
- * Look straight ahead at target

Staff

A total of 47 FAA employees provided safety and research assistance for this study: two principal investigators, two members of the Cabin Safety Research Team, and 43 full-time FAA/CAMI employees excused from their regular work duties or working additional hours to support the study during regular business hours, on nights, and weekends. Except for the two principal investigators, all research staff wore high visibility vests for ease of identification, especially for the research participants. All research staff involved in collecting and recording anthropometric measurements participated in practice familiarization events to ensure consistency.

United Airlines provided six flight attendant qualified individuals to provide an extra layer of realism and safety to the evacuations. These individuals shouted a modified list of standard evacuation commands employed by flight attendants during real-world situations, and they monitored the evacuations as they progressed to help the research staff ensure participant safety.

Oklahoma City Airport Rescue and Fire Fighting personnel were present on each test day to act as additional evacuation safety monitors and first responders in the event of participant injury, including those requiring immediate aid or stabilization before transportation to a local hospital.

Participants

A contract personnel company recruited study participants from within the state of Oklahoma via an advertising campaign that used social and physical media. Participants received a base compensation of \$20 per hour for a five-hour commitment, with the opportunity to earn up to double the day's pay based on evacuation performance (up to a total compensation of \$200). The contractor was tasked to provide 12 groups of up to 75 participants to allow for a 25% attrition rate and still meet the requested 60 participants per test day. The contractor was also tasked to provide back-up/reserve participants should a participant become unwilling or unable to continue with the evacuation trials. The contractor was tasked to provide groups with approximately equal numbers of males and females, as well as groups whose participants consisted of no more than 40% in any single age decade (i.e., 18–30-year-olds, 31–40-year-olds, 41–50 year-olds, and 51–60 year-olds). The contractor was also tasked with ensuring that no participants who signed up were older than age 60 due to the increased risk of injury during physical activity.

Procedure

Measurement/Variable Definitions

All participant anthropometric data were recorded with the participants' footwear removed before measurement to ensure consistency and decrease variability introduced by different types of/height differences in footwear (e.g., sandals, flats, tennis shoes, boots, heels, and others). Participant standing and sitting postures and measurement procedures were taken or modified from available anthropometric measurement procedures published in the *Measurer's Handbook: US Army and Marine Corps Anthropometric Surveys, 2010-2011* (Hotzman et al., 2011). For all standing measurements, participants were instructed to adopt an "Anthropometric Standing" pose (Hotzman et al., 2011, p. 73, Section 6.1.1). For all sitting measurements, participants were instructed to adopt an "Anthropometric Sitting" pose (Hotzman et al., 2011, p. 74, Section 6.1.2) with the modification that participants' feet/knee heights were not manipulated to allow leg measurement geometry to reflect actual sitting in an aircraft seat. All anthropometric data were measured and recorded in standard metric units. All anthropometric measurements were taken by designated and trained research staff and recorded by designated and trained scribes. Each measurement was taken at least twice; measurement staff members were instructed to take additional measurements if the difference between measurements was greater than the allowed measurement error. The allowed measurement error ranges were taken from published anthropometric measurement guidelines (Hotzman et al., 2011).

Height: Participant height was measured using the Health-O-Meter 500KL Digital Physician Scale's built-in height measurement arm. Participants stood on the scale in the anthropometric standing pose with their back to the height measurement arm. The allowed height measurement error was 0.6 cm.

Weight: Participant weight was measured using the Health-O-Meter 500KL Digital Physician Scale. Participants stood on the scale in the anthropometric standing pose with their back to the height measurement arm. The allowed weight measurement error was 0.3 kg.

Girth: Participant girth was measured using an 80-inch (203.2-cm) retractable body tape measure or a 120-inch (304.8-cm) fabric tape measure depending on participant size. Participants indicated to the measurement staff the location of their navel (i.e., “belly button,” the anthropometric measuring landmark) then maintained the anthropometric standing pose while girth measurements were taken. The measurement staff positioned the measuring tape over this landmark and around the participant’s back with the measurement scribe checking the tape position to ensure that it was level. The allowed girth measurement error was 1.2 cm.

Shoulder Width: Participant shoulder width was measured using a GPM Anthropometer with participants sitting on an anthropometric bench seat in the anthropometric sitting pose. The measurement procedure was identical to that described in section 6.4.12 of the Measurer’s Handbook: US Army and Marine Corps Anthropometric Surveys, 2010-2011 (Hotzman et al., 2011, p. 88) with the exception that participants were instructed to press their backs as firmly as possible against the bench seat back to help maintain their posture. To ensure standardization and consistency, all measurements were taken on the participant’s right side. The allowed shoulder width measurement error was 0.8 cm.

Sitting Hip Width: Participant sitting hip-width was measured using a GPM Anthropometer with participants sitting on an anthropometric bench seat in the anthropometric sitting pose. The measurement procedure was identical to that described in section 6.4.52 of the Measurer’s Handbook: US Army and Marine Corps Anthropometric Surveys, 2010-2011 (Hotzman et al., 2011, p. 128), with the exception that participants maintained the anthropometric sitting pose with their elbows at 90°. To ensure standardization and consistency, all measurements were taken on the participant’s right side. The allowed hip-width measurement error was 0.6 cm.

Buttock-to-Knee Length: Participant buttock-to-knee (BtK) length was measured using a GPM Anthropometer with participants sitting on an anthropometric bench seat in the anthropometric sitting pose. The measurement procedure was identical to that described in section 6.4.20 of the Measurer’s Handbook: US Army and Marine Corps Anthropometric Surveys, 2010-2011 (Hotzman et al., 2011, p. 96), with the exception that participants maintained the anthropometric sitting pose with their elbows at 90°. One anthropometric caliper arm was placed on the back of the bench seat, and the other caliper arm was placed across the participant’s knee (maintaining a level anthropometer) per Handbook measurement procedure. To account for bench seat back thickness, 4.4 cm were subtracted from a participant’s BtK measurement. To ensure standardization and consistency, all measurements were taken on the participant’s right leg. Allowed BtK measurement error was 0.6 cm.

Knee-to-Floor Height: Participant knee-to-floor (KtF) height was measured using the previously described custom-built measurement devices with participants sitting on an anthropometric bench seat in the anthropometric sitting pose. The measurement procedure was

identical to that described in section 6.4.58 of the Measurer's Handbook: US Army and Marine Corps Anthropometric Surveys, 2010-2011 (Hotzman et al., 2011, p. 134), with the exception that participants maintained the anthropometric sitting pose with their elbows at 90°. A flat ruler was laid across the participant's knees (both knees) and provided a straight edge to measure knee height accurately on the custom-built floor-to-knee measuring device. To ensure standardization and consistency, all measurements were taken on the participant's right leg. Allowed KtF measurement error was 0.2 cm.

Seat Pitch: Seat pitch was defined as the distance between a fixed point on an airplane seat (reference seat) and the same fixed point on the seat in front of it. This study's airplane seat fixed point was the inboard (aisle-most) forward foot where it connected to the seat track on the FlexSim floor. Control seat pitch was 32 inches (81.28 cm), producing a Dimension A of 29 inches (73.66 cm). The two experimental seat pitches were 28 inches (71.12 cm) and 34 inches (86.36 cm). The "narrow," 28-inch (71.12-cm) experimental seat pitch produced a Dimension A of 25 inches (63.5 cm); the "wide," 34-inch (86.36-cm) experimental seat pitch produced a Dimension A of 31 inches (78.74 cm).

Seat Width: Seat width was defined as the distance between the armrests' inner faces over the airplane seat. The control seat width was 18 inches (45.72 cm); the experimental seat width was 16 inches (40.64 cm).

Group Egress Time: The study defined group egress time as the time from the start of the evacuation buzzer to when the last study participant completely exited the simulator. This time was calculated from the 60-frame-per-second timestamp on the evacuation videos and converted from base 60 to base 10 (seconds and milliseconds) for ease of analysis.

Individual Egress Time: Individual egress time was defined as the time from one participant's complete exit from the simulator to the next participant's complete exit from the simulator. This time definition has long been used in evacuation research studies as an indicator of evacuation flow and corresponds well to any difficulties participants may experience in reaching, traversing, or using an egress assist (e.g., evacuation slides) at an airplane exit.

Egress Assist Means: Ramps with handrails and surrounding ground padding (to cushion participant falls) were placed at the exit doors to aid participant egress once clear of the simulator exit door.

Passenger Motivation: An incentive protocol was used in which the first 70% of participants to egress during an evacuation trial received a \$25.00 bonus (a quarter of the study base pay rate). This motivation level was selected to increase participant competitive evacuation behavior while also enabling, with assigned seating for each evacuation trial, for approximately 99% of all participants to receive a bonus during the study. For example, if a participant was among the first 70% of participants to egress on each of the four evacuation trials, the participant received a total of \$200 for their participation and performance (i.e., \$100.00 base pay plus an additional \$25.00 for each evacuation trial).

Testing Procedure

Before the commencement of the research project, all procedures and documents were approved by the FAA's Institutional Review Board to ensure a reasonable safety and confidentiality level for all participants.

Before each testing day, the contractor providing the participants would coordinate their arrival and other requirements with the research team and MMAC security. Potential participants were informed of when and where to arrive and that they would be unable to bring anything onto the center other than identification and a means of getting into their vehicle once they were done with the day's activities. Participants were also instructed to wear tie-on shoes that covered their entire foot and wear long pants and tops appropriate for both work and the weather, as the evacuations were taking place in the winter months.

On arrival at the MMAC Visitor Center, participants were processed through security per FAA and MMAC procedures and provided with storage space for personal items that participants were unwilling or unable to leave elsewhere but were prohibited at the test site (e.g., cell phones). Once cleared through security, participants checked-in with the contractor, had their identities verified. They were counted to ensure a sufficient study population size and representation (i.e., a minimum of 60 participants, an approximately equal number of men and women, and sufficient age spread). The contractor was present to perform the day's research activities. After check-in, participants were escorted to a large conference room and given a pen and clipboard with the Pretest Information Form (Appendix A) and the Informed Consent document (Appendix B). Participants were instructed to complete the Pretest Information Form but not sign the Informed Consent document until briefed by the Principal Investigator. Once all the participants arrived, checked-in, and received their documents, the Principal Investigator read aloud an initial participant brief and the Informed Consent document. Once the brief was delivered, the Principal Investigator sat at a desk in the corner of the room (to afford some privacy) as each potential participant individually approached the Principal Investigator for the opportunity to ask questions before providing or declining their consent to participate in the study. Once both the participant and the Principal Investigator signed the Informed Consent document, the participant took the Pretest Information Form to a waiting research staff member who checked the form for completion and assigned the participant a numbered vest. The participant donned the vest, secured via side ties (both sides) by another research staff member, and then queued near the exit to be bussed to the CAMI building. The vest number was the primary identifier for a participant throughout the test day, and the overall study participant identification numbers were derived from a combination of the test day and vest number (i.e., 0101 for vest number 1 on the first test day; 1275 for vest number 75 on the 12th test day).

On arrival at the CAMI building, participants were escorted by research staff to the Cabin Safety Research Team Lab (CAMI Room 127) for anthropometric measurement by sex-matched research staff. Room 127 was divided into five stations: two stations (one male and one female) for measuring participant's height, weight, and girth; two stations (again, one male and one female) for the remaining anthropometric measurements (i.e., shoulder width, sitting hip-width, sitting buttock-to-knee length, and sitting knee-to-floor height); and one station for the experimental seat mock-up. All measuring stations had privacy screens so that only the participant being measured, the measuring staff member, and the recording scribe directly observed the measuring process. On entering the Cabin Safety Research Team Lab (CAMI Room 127), participants were instructed to go to the room's side corresponding to their gender and remove their footwear. Participants were called, one at a time, first to the height/weight/girth measurement area, then to the seated anthropometric measurements area. Once the seated measurements were complete, participants proceeded to the final station to re-don their footwear and participate in the experimental seat mock-up. At the seat mock-up, participants were asked, one at a time, to first sit in seat #8 (corresponding to the narrowest experimental seat pitch [28 inches; 71.12 cm]), and then attempt to sit in seat # 5 (corresponding to a seat pitch of 26 inches [66.04 cm] which was less than the narrowest experimental seat pitch). Once participants completed (or attempted to complete) sitting in the experimental seat mock-up, they were asked to complete the Experimental Seating Post-Test Questionnaire (Appendix C). Participants who were unable to sit in seat #8 received a blue copy of this questionnaire to indicate to the Principal Investigators that the participant was too large to fit in the simulator seats at the narrowest seat pitch. After measurement and experimental seating, participants were escorted by CAMI research staff to the High-Bay (CAMI Room #121) to complete their questionnaires and wait for their cohorts. Once all participants were measured and processed through the experimental seat mock-up, the Principal Investigators selected participants in excess of the 60 required for the evacuation trials and the participants who were unable to fit in the experimental seat mock-up and directed them to CAMI Room 117. Once in CAMI Room 117, the excess participants were held in reserve as substitutes if a selected participant was unwilling or unable to complete all four evacuation trials. Individuals too large to safely participate in the study were debriefed separately, paid for their time, thanked for their participation, and returned to the MMAC Visitor Center for release.

Once the excess participants were sequestered, the Principal Investigator entered the High Bay to give the pre-evacuation safety brief to the 60 selected participants. The safety brief included instructions on how to buckle the aviation passenger style seat belt. Participants were then led outside by CAMI research staff to the FlexSim for boarding and seat assignment.

Upon boarding the FlexSim, participants were given a boarding pass corresponding to their vest number, which directed them to a seat for the evacuation trial. Once all participants were seated, two research staff walked through the cabin, collecting boarding passes, verifying that

participants were in the correct seat, and visually checking that each participant had buckled their seat belt. Once complete, one of the two flight attendants also walked through the cabin performing a final visual seat belt check. The Principal Investigator then introduced the flight attendants, gave the final safety brief and the evacuation instructions, demonstrating the evacuation buzzer used as the “Go” signal. Participants were instructed that their egress path was “all the way forward and to the right” and treat the scenario/evacuation as if the plane was on fire. Participants were directed to follow flight attendant commands, egress as quickly as possible, and were reminded not to obstruct their vest number while exiting the simulator. Participants were told that should an evacuation trial needed to be stopped for safety reasons (e.g., to prevent serious injury), the evacuation buzzer would be activated again, and they were to cease movements (i.e., “freeze” in place). Finally, participants were instructed that once outside the simulator, they were to line-up in the order in which they had evacuated to ensure accurate calculation of bonus payments; CAMI research staff assisted in this effort to reinforce the recording activity performed by the participant recruitment contractor.

After completing an evacuation trial, participants were escorted to an area adjacent to the FlexSim to complete the Between Trial surveys (Appendix D). After the first evacuation and survey completion, CAMI research staff directed the participants to line-up in order of their vest numbers (lowest to highest) and re-board the FlexSim. The same boarding/pre-evacuation procedure (e.g., cabin walk-through, safety brief, and participant egress instructions) was repeated for each trial. After the second trial and once the Between Trial survey was completed, CAMI research staff escorted the participants back into the CAMI High Bay for a 30-minute break while the simulator was reconfigured for the third and fourth evacuations (i.e., the seat width was changed). Once the simulator reconfiguration was complete, the boarding and evacuation protocol was repeated for the remaining two evacuations. After the fourth and final evacuation and survey completion, CAMI research staff escorted the participants to the CAMI High Bay, where they completed the Post-Test Survey (Appendix E) and were debriefed by the Principal Investigator. During the debrief, participants were allowed to ask the Principal Investigators, the flight attendants, and the research staff questions. Once the debrief session was complete, and all questions answered, recruitment contract staff paid the participants their study base pay and any earned performance bonuses. Participants returned their vests and were offered a copy of the Informed Consent document, and were transported back to the MMAC Visitor Center to collect any personal items and return to their cars. The reserve participants, sequestered in CAMI Room 117 as potential substitutes, were released via the same procedure without the full debriefing in the High Bay. This allowed them to remain eligible as naïve candidates for participation on another test day.

Data Reduction/Analysis

Participant administrative data (e.g., general information and informed consent) and survey data were collected by pen and paper. Participant anthropometric data were entered into Microsoft

Excel and were the average of measurements within the acceptable error ranges for each specific anthropometric measurement. Participant free-form and Likert scale responses from the pretest information form, experimental seating post-test questionnaire, between-test surveys (up to four per participant), and post-test survey were divided among the Cabin Safety Research Team members for transcription into Microsoft Excel.

All video data were reviewed using Windows Media Player, using the advanced play speed settings to allow the research team to step through each video frame by frame. After establishing criteria for individual egress exit timing (described in Results – Individual Egress Times of this report), all four Cabin Safety Research Team members reviewed the same evacuation video individually, then compared their timings. This process was repeated until all timings were within two video frames to establish inter-rater reliability. After this, each team member was assigned 25% of the 48 evacuation videos to extract evacuation timings. Each reviewer was assigned one additional video also assigned to a separate reviewer for a crosscheck sampling of reviews to ensure inter-rater reliability of ± 2 video frames was maintained. All evacuation data points were entered into and collated in Microsoft Excel. All data were imported into IBM SPSS Statistics for Windows, Version 24.0. (Armonk, NY: IBM Corp.) for statistical analysis.

Results

Demographics

Overall: A total of 775 participants consented to participate in and be measured for this project. Four hundred seven participants (52.5%) identified as female, and the remaining 368 participants (47.5%) identified as male. Overall, the average participant age was 35.6 years, with a minimum of 18 and a maximum of 64¹ years (SD = 11.9 years). Table 1 lists the number of participants in each age group.

Of the 775 participants, two participants (0.3%; one 64-year-old man, one 24-year-old woman) did not provide information about their education level. Table 2 summarizes the education level for the remaining 773 participants.

¹ The inclusion of people over the age of 60 years old in the evacuations was an oversight issue not caught until approximately midway through the project during data entry by the PI. After reporting to and consultation with the IRB, tighter verification and checking of participant's ages during the consent and check-in process were implemented.

Table 1*Total Number of Participants per Age Group*

Age (years)	Frequency	Percent	Valid Percent	Cumulative Percent
18–30	293	37.8	37.8	37.8
31–40	213	27.5	27.5	65.3
41–50	160	20.6	20.6	85.9
51–60	105	13.5	13.5	99.5
61+	4	0.5	0.5	100.0
Total	775	100.0	100.0	

Table 2:*Participant Reported Education Level*

Education Level	Frequency	Percent	Valid Percent	Cumulative Percent
Some High School	15	1.9	1.9	1.9
High School Graduate	103	13.3	13.3	15.3
Some College	274	35.4	35.4	50.7
Associate degree	101	13.1	13.1	63.8
Bachelor degree	173	22.4	22.4	86.2
Graduate degree	107	13.8	13.8	100.0
Total	773	100.0	100.0	

Females: Female participants in the study ($n = 407$) ranged in age from 18 to 62 years old, with an average age of 37.1 years ($SD = 11.9$ years). Table 3 lists the number of female participants in each age group. Table 4 summarizes the reported education level of the 406 female participants who provided education information. One female participant in the 51–60 age group who reported her education level as “Some High School” admitted to one of the research staff that she could not read (i.e., functionally illiterate).

Table 3*Number of Female Participants per Age Group*

Age (years)	Frequency	Percent	Valid Percent	Cumulative Percent
18-30	132	32.4	32.4	32.4
31-40	115	28.3	28.3	60.7
41-50	92	22.6	22.6	83.3
51-60	65	16.0	16.0	99.3
61+	3	0.7	0.7	100.0
Total	407	100.0	100.0	

Table 4*Female Participant Reported Education Level*

Education Level	Frequency	Percent	Valid Percent	Cumulative Percent
Some High School	7	1.7	1.7	1.7
High School Graduate	48	11.8	11.8	13.5
Some College	130	32.0	32.0	45.6
Associate degree	60	14.8	14.8	60.3
Bachelor degree	94	23.2	23.2	83.5
Graduate degree	67	16.5	16.5	100.0
Total	406	100.0	100.0	

Males: Male participants in the study (n = 368) ranged in age from 18 to 64 years old, with an average age of 33.9 years (SD = 11.8 years). Table 5 lists the number of male participants in each age group. Table 6 summarizes the reported education level of the 367 male participants who provided education information.

Table 5*Number of Male Participants per Age Group*

Age (years)	Frequency	Percent	Valid Percent	Cumulative Percent
18-30	161	43.8	43.8	43.8
31-40	98	26.6	26.6	70.4
41-50	68	18.5	18.5	88.9
51-60	40	10.9	10.9	99.7
61+	1	0.3	0.3	100.0
Total	368	100.0	100.0	

Table 6*Male Participant Reported Education Level*

Education Level	Frequency	Percent	Valid Percent	Cumulative Percent
Some High School	8	2.2	2.2	2.2
High School Graduate	55	15.0	15.0	17.2
Some College	144	39.2	39.2	56.4
Associate degree	41	11.2	11.2	67.6
Bachelor degree	79	21.5	21.5	89.1
Graduate degree	40	10.9	10.9	100.0
Total	367	100.0	100.0	

Anthropometrics

This study collected a wide range of anthropometric measurements from all 775 participants. Table 7 summarizes the overall group anthropometric measurements (height, weight, girth, shoulder width, sitting hip breadth, sitting BtK, and sitting knee-to-floor height).

Table 7*Anthropometric Measurement Descriptive Statistics (Overall Group; N=775)*

	Range	Minimum	Maximum	Mean	Std. Deviation
Height (cm)	49.4	148.1	197.5	169.8	9.1
Weight (kg)	146.5	43.9	190.4	88.5	23.7
Girth (cm)	108.4	60.6	169.0	101.0	18.9
Shoulder Width (cm)	27.0	36.5	63.5	47.9	4.6
Hip Breadth (cm)	37.3	30.0	67.3	42.2	5.3
BtK (cm)	21.6	51.0	72.6	61.5	3.8
KtF (cm)	17.6	45.4	63.0	53.1	3.3
Valid N					

Note. BtK = buttock-to-knee length; KtF = knee-to-floor height.

Further refinement of these data allowed for easier comparison to the general U.S. population and anthropometric and ergonomic standards. The refinement separated the anthropometric data by gender and defined percentile profiles based on the collected data. These percentile profiles make it easier to discern what attributes define the average person per gender (i.e., the 50th percentile), as well as to define the generally largest average person (95th percentile male) and the smallest average person (5th percentile female) for anthropometric comparisons and ergonomic evaluations. Tables 8 and 9 summarize descriptive, and percentile definition statistics for female participants; Tables 10 and 11 summarize descriptive and percentile definition statistics for male participants.

Table 8*Female Participant Anthropometric Descriptive Statistics (N=407)*

	Range	Minimum	Maximum	Mean	Std. Deviation
Height (cm)	35.8	148.1	183.9	163.9	6.4
Weight (kg)	126.6	43.9	170.5	82.5	22.1
Girth (cm)	104.9	60.6	165.5	98.8	19.0
Shoulder Width (cm)	26.0	36.5	62.5	46.6	4.7
Hip Breadth (cm)	28.4	33.0	61.4	43.7	5.1
BtK (cm)	19.9	51.7	71.6	60.1	3.5
KtF (cm)	14.6	45.4	60.0	51.0	2.5

Note. BtK = buttock-to-knee length; KtF = knee-to-floor height.

Table 9*Female Anthropometrics Percentile Statistics (N=407)*

	Height (cm)	Weight (kg)	Girth (cm)	Shoulder Width (cm)	Hip Breadth (cm)	BtK (cm)	KtF (cm)
5	154.44	52.36	71.88	39.74	36.20	54.70	47.14
25	159.30	65.30	83.70	43.10	39.80	57.30	49.00
50	163.60	79.90	96.90	46.10	43.10	60.20	50.70
75	167.90	97.80	111.90	49.70	47.10	62.40	52.60
95	174.66	123.86	132.10	54.80	53.60	66.06	55.56

Note. BtK = buttock-to-knee length; KtF = knee-to-floor height.

Table 10*Male Participant Anthropometric Descriptive Statistics (N=368)*

	Range	Minimum	Maximum	Mean	Std. Deviation
Height (cm)	43.1	154.4	197.5	176.3	6.9
Weight (kg)	140.3	50.1	190.4	95.1	23.7
Girth (cm)	100.5	68.5	169.0	103.5	18.5
Shoulder Width (cm)	23.6	39.9	63.5	49.4	3.9
Hip Breadth (cm)	37.3	30.0	67.3	40.6	5.1
BtK (cm)	21.6	51.0	72.6	63.0	3.5
KtF (cm)	14.1	48.9	63.0	55.4	2.5

Note. BtK = buttock-to-knee length; KtF = knee-to-floor height.

Table 11*Male Participant Anthropometric Percentile Statistics (N=368)*

	Height (cm)	Weight (kg)	Girth (cm)	Shoulder Width (cm)	Hip Breadth (cm)	BtK (cm)	(KtF (cm))
5	165.30	62.69	77.00	43.55	33.40	57.40	51.30
25	171.73	78.13	89.50	46.63	37.30	60.83	53.73
50	176.00	91.35	102.00	49.20	39.95	62.80	55.30
75	180.50	109.15	115.00	51.90	43.18	65.10	57.10
95	188.43	141.46	139.00	56.64	49.36	69.66	59.31

Note. BtK = buttock-to-knee length; KtF = knee-to-floor height.

General Population: To compare study participants to the general U.S. population, the information collected by the U.S. Centers for Disease Control and Prevention for their NHANES is the most useful as it collects similar data points using similar methods as the current study. The NHANES data set is also more useful for comparison purposes than other available anthropometric data sets because it collects anthropometric data from a wide range of people within the U.S. population, not just a typically fit and healthy subset (such as military personnel), and the data are collected continuously. Finally, due to a lack of a database containing similar anthropometric information collected regularly from airline travelers (i.e., the flying public), this study comparison assumes that the general U.S. population well represents the flying public and that such a comparison is appropriate to see if the study population reasonably represents the U.S. flying public.

The following NHANES data were extracted from the raw data files from the 2017–2018 dataset released in March 2020 (NHANES Questionnaires, Datasets, and Related Documentation, 2020) (the most recent dataset available as of this writing). NHANES demographic and body measurement files were combined into a single database for analysis. From there, the NHANES data were filtered to exclude respondents younger than age 18 and older than age 60 to correspond to the current study’s participant population. NHANES data were also removed from the database for respondents who failed to provide body measurement data, age, and gender information. This process reduced the initial 9212 NHANES data set to 3847 NHANES respondents whose recorded information included their age, gender, and one body measurement point. Table 12 lists NHANES anthropometric data (Height, Weight, and Waist Circumference [Girth]), similar to those collected in the present study. Tables 13 and 14 summarize the percentile definition statistics for female and male respondents from the NHANES dataset. Table 15 compares the anthropometric data of the current study participants with that of the NHANES respondent dataset.

Table 12*NHANES Overall Group Anthropometric Descriptive Statistics*

	N	Range	Minimum	Maximum	Mean	Std. Deviation
Height (cm)	3609	57.5	138.3	195.8	167.3	10.0
Weight (kg)	3609	206.4	36.2	242.6	83.7	24.2
Girth (cm)	3468	113.1	56.4	169.5	98.8	18.2
Valid N	3462					

Note. NHANES = National Health and Nutrition Examination Survey.

Table 13*Female NHANES Anthropometric Percentiles*

		Height (cm)	Weight (kg)	Girth (cm)
N	Valid	1902	1902	1811
	Missing	113	113	204
Percentiles	5	149.70	49.20	70.92
	25	155.97	60.80	82.90
	50	160.80	73.20	94.60
	75	165.30	90.60	108.50
	95	172.59	124.80	131.24

Note. NHANES = National Health and Nutrition Examination Survey.

Table 14*Male NHANES Anthropometric Percentiles*

		Height (cm)	Weight (kg)	Girth (cm)
N	Valid	1707	1707	1657
	Missing	125	125	175
Percentiles	5	161.90	59.84	74.99
	25	169.30	73.60	88.15
	50	174.60	85.50	98.90
	75	179.60	101.90	110.50
	95	187.20	132.80	132.60

Note. NHANES = National Health and Nutrition Examination Survey.

Table 15*Comparison of Similar NHANES and Study Anthropometrics with Delta.*

Percentiles	Female								
	Current Study			NHANES Data			Delta		
	Height (cm)	Weight (kg)	Girth (cm)	Height (cm)	Weight (kg)	Girth (cm)	Height (cm)	Weight (kg)	Girth (cm)
50	163.60	79.90	96.90	160.80	73.20	94.60	2.8	6.7	2.3
95	174.66	123.86	132.10	172.59	124.80	131.24	2.07	-0.94	0.86
	Male								
	Current Study			NHANES Data			Delta		
	Height (cm)	Weight (kg)	Girth (cm)	Height (cm)	Weight (kg)	Girth (cm)	Height (cm)	Weight (kg)	Girth (cm)
50	176.00	91.35	102.00	174.60	85.50	98.90	1.4	5.85	3.1
95	188.43	141.45	139.00	187.20	132.80	132.60	1.23	8.65	6.4

Note. NHANES = National Health and Nutrition Examination Survey.

Experimental Seating Self-Report Questionnaire/Ability to Sit in Experimental Seating

All 775 study participants answered all the questions on the experimental seating post-test questionnaire. Responses from one participant were excluded from analysis due to the participant informing the research staff that she was unable to read – this participant was observed looking at other participants' questionnaires and asking a nearby participant to explain what was being asked in the questions.

Of the 774 valid self-reported responses to the question, “How many flights have you been on in the last 12 months”, 315 participants (41%) indicated they had been on no flight, 240 participants (31.3%) had been on one to three flights, 120 participants (15.6%) had been on four to six flights, 39 participants (5.1%) had been on seven to nine flights, and 50 participants (6.5%) had been on 10 or more flights within the last 12 months.

When asked to self-report how experienced participants felt when flying on passenger airplanes (1 = No Experience; 5 = Very Experienced), 52 participants (6.8%) indicated “none” (1), 76 participants (9.9%) indicated “little” (2), 227 participants (29.6%) indicated “some experience” (3), 199 participants (25.9%) indicated “experienced” (4), and 213 participants (27.8%) indicated “very experienced” (5).

Of the total 775 study participants, six (0.7%) were completely unable to sit in the experimental seat mock-up at the 28-inch (71.12 cm) seat pitch (i.e., the smallest experimental seat pitch). Of these six, one (participant 1057) participated in the evacuations, as this participant was not in a

group experiencing the 28-inch (71.12 cm) seat pitch as an experimental condition. Table 16 summarizes the demographics and anthropometrics of the six participants who were unable to fit in the 28-inch (71.12 cm) seat pitch mockup.

Table 16

Anthropometrics of Participants Unable to Sit in the 28-inch (71.12 cm) Seat Pitch Mock-up.

Participant ID	Age (years)	Gender	Height	Weight	Girth	Shoulder	Hip	BtK	KtF
0326	42	Male	175.2	175.4	164.0	63.5	56.7	68.5	56.4
0338	36	Male	191.0	144.5	125.3	58.5	50.6	71.1	62.2
0504	59	Male	186.7	116.3	154.5	62.0	53.1	76.5	60.1
0737	33	Male	178.9	190.4	169.0	62.2	60.6	74.5	58.6
0824	39	Female	163.3	170.5	165.5	62.3	61.4	73.3	55.0
1057	21	Male	181.4	167.8	153.7	53.7	57.1	75.0	59.0

Note. BtK = buttock-to-knee length; KtF = knee-to-floor height.

Excluding the six participants who were unable to sit in the 28-inch (71.12-cm) seat pitch and the one participant who was unable to read the survey questions, 56 participants (7.2%) self-reported that they were unable to sit in the 26-inch (66.04-cm) seat pitch experimental seat mock-up.

Responses from these 56 participants were also excluded from further analysis of the experimental seating post-test questionnaire. Tables 17 to 22 present the Likert Scale responses of the remaining 712 participants to questions about their opinions related to the ease of getting into and out of a 26-inch (66.04-cm) seat pitch and seat comfort.

Table 17

Responses to “On a scale of 1 (very difficult) to 5 (very easy), how easy was it to get into seat number 5 (middle row, middle seat)?”

Question: How easy was it to get into the 26-inch seat pitch?		
Response	Frequency	Percent
Very Difficult	158	22.2
Difficult	283	39.7
Neutral	172	24.2
Easy	73	10.3
Very Easy	26	3.7
Total	712	100.0

Table 18

Responses to “On a scale of 1 (very difficult) to 5 (very easy), how easy was it to get out of seat number 5 (middle row, middle seat)?”

Question: How easy was it to get out of the 26-inch seat pitch?		
Response	Frequency	Percent
Very Difficult	161	22.6
Difficult	266	37.4
Neutral	187	26.3
Easy	73	10.3
Very Easy	24	3.4
Missing	1	0.1
Total	712	100.0

Table 19

Responses to “On a scale of 1 (very uncomfortable) to 5 (very comfortable), how would you rate seat number 5 (middle row, middle seat)?”

Question: How comfortable was the 26-inch seat pitch?		
Response	Frequency	Percent
Very Uncomfortable	287	40.3
Uncomfortable	180	25.3
Neutral	170	23.9
Comfortable	51	7.2
Very Comfortable	24	3.4
Total	712	100.0

Table 20

Responses to “On a scale of 1 (very difficult) to 5 (very easy), how difficult do you think it would be for you to get out of seat number 5 (middle row, middle seat) quickly?”

Question: How difficult would it be to get out quickly from the 26-inch seat pitch?		
Response	Frequency	Percent
Very Difficult	257	36.1
Difficult	241	33.8
Neutral	127	17.8
Easy	64	9.0
Very Easy	23	3.2
Total	712	100.0

Table 21

Responses to “On a scale of 1 (very unsafe) to 5 (very safe), how safe do you think seat number 5 (middle row, middle seat) would be to use on a short (30 to 120 minute) flight?”

Question: How safe do you think the 26-inch seat pitch would be for a short 30 to 120-minute flight?		
Response	Frequency	Percent
Very unsafe	195	27.4
Unsafe	217	30.5
Neutral	200	28.1
Safe	71	10.0
Very Safe	26	3.7
Missing	3	0.4
Total	712	100.0

Table 22

Responses to “On a scale of 1 (very unsafe) to 5 (very safe), how safe do you think seat number 5 (middle row, middle seat) would be to use on a longer (2+ hour) flight?”

Question: How safe do you think the 26-inch seat pitch would be for a long (2+ hours) flight?		
Response	Frequency	Percent
Very unsafe	350	49.2
Unsafe	197	27.7
Neutral	114	16.0
Safe	32	4.5
Very Safe	16	2.2
Missing	3	0.4
Total	712	100.0

Group Egress Times

Group egress times provide a good starting point when looking at egress times in airplane evacuation research. Table 23 lists the overall group egress times for each trial. Due to participant recruitment issues and participant dropout, two of the 12 test days had fewer than the requested 60 participants per evacuation group; Test Day 1 had 54 participants, and Test Day 5 had 58 participants. Therefore, group egress times were adjusted to include only the first 54 participants out of the simulator. Table 24 lists the adjusted group egress times. Table 25 lists the adjusted group egress times and basic statistics for the first comparison group (test days 1–8/trials 1–32), sorted by experimental condition (i.e., seat pitch and seat width). Table 26 lists the

same information for the second comparison group (test days 9–12/trials 33–48). All times are in seconds.

Table 23

Overall Group Egress Times (in seconds) by Test Day and Egress Trial Order

Run	Test Day (N)											
	1 (54)	2 (60)	3 (60)	4 (60)	5 (58)	6 (60)	7 (60)	8 (60)	9 (60)	10 (60)	11 (60)	12 (60)
1	43.77	43.22	46.27	47.02	42.42	39.27	39.72	42.65	41.40	42.83	39.55	42.63
2	39.92	43.02	42.92	41.63	36.50	38.12	43.25	37.60	34.40	37.35	36.43	37.37
3	39.10	41.30	40.10	41.92	40.43	38.15	37.12	42.82	37.02	42.62	37.73	38.02
4	37.95	43.33	41.22	40.75	34.37	34.38	40.58	37.35	38.13	37.88	37.38	38.43

Table 24

Adjusted Group Egress Times (in seconds) by Test Day and Egress Trial Order

Run	Test Day (N = 54)											
	1	2	3	4	5	6	7	8	9	10	11	12
1	43.77	39.42	42.52	43.03	39.90	35.32	35.95	38.67	37.70	38.07	36.08	38.38
2	39.92	39.03	39.45	36.65	33.98	34.82	39.87	33.53	30.77	38.22	32.67	33.03
3	39.10	37.18	35.83	37.82	37.75	34.23	32.83	39.00	32.48	38.95	33.65	34.05
4	37.95	38.03	37.25	36.52	32.00	30.63	37.02	33.68	34.17	33.75	33.73	34.13

Table 25

First Testing Matrix Groups by Seat Pitch and Seat Width Combinations

Condition	Day (N=54)								Basic Descriptive Statistics		
	1	2	3	4	5	6	7	8	Min (Fast)	Mean	Max (Slow)
32/18	43.77	37.18	39.45	36.52	33.98	30.63	35.97	39.00	30.63	37.06	43.77
32/16	39.10	39.42	37.25	36.65	32.00	34.82	32.85	38.67	32.00	36.34	39.42
28/18	37.95	39.03	35.83	43.03	37.75	35.32	37.03	33.53	33.53	37.43	43.03
28/16	39.92	38.03	42.52	37.82	39.90	34.23	39.87	33.68	33.68	38.25	42.52

Table 26*Second Testing Matrix Groups by Seat Pitch and Seat Width Combinations*

Condition	Day (N=54)				Basic Descriptive Statistics		
	9	10	11	12	Min (Fast)	Mean	Max (Slow)
32/18	37.70	38.95	32.67	34.13	32.67	35.86	38.95
32/16	32.48	38.07	33.73	33.03	32.48	34.33	38.07
34/18	34.17	38.22	33.65	38.38	33.65	36.10	38.38
34/16	30.77	33.75	36.08	34.05	30.77	33.66	36.08

A factorial analysis of variance was performed to determine if any statistical differences existed in group egress times. The interaction between seat pitch and seat width did not statistically significantly affect egress times ($F(2,42) = .87, p = .43$), and neither did the main effects (at $p = .05$) for seat pitch ($F(2,42) = 2.90, p = .07$) and seat width ($F(1,42) = .83, p = .37$). The first eight groups did not show statistically significant differences in egress times based on the interaction of seat pitch and seat width, ($F(1,28) = .46, p = .50$), and the main effects of seat pitch ($F(1,28) = 1.02, p = .32$) and seat width ($F(1,28) = .002, p = .996$) did not significantly affect egress times. Groups nine to 12 also did not show statistically significant differences in egress times for interaction of width and pitch ($F(1,12) = .125, p = .73$) or the main effects of seat pitch ($F(1,12) = .027, p = .87$) or seat width ($F(1,12) = 2.39, p = .15$).

Individual Egress Times

Of the total 775 study participants, 718 (92.65%) participated in at least one of the four evacuations, with the majority ($n=707; 91.23\%$) participating in all four of their group's evacuations. Individual egress time analysis used a procedure from previous evacuation studies (McLean et al., 2002). Group egress times were deconstructed into individual egress times. Individual egress times were derived by analyzing each evacuation video to determine at what timestamp each participant completely exited the simulator (i.e., no part of their person or clothing was within the simulator doorway). Finally, a participant's timestamp was subtracted from the timestamp of the participant immediately preceding them out the simulator door. The times for the first participant to exit the simulator for a given trial (i.e., first-out-times) ranged from a minimum of 2.38 seconds to a maximum of 5.72 seconds with an average of 3.70 seconds ($SD = 3.70$ seconds), with a general trend that subsequent group evacuations had shorter first-out-times. Given that these first-out-times were the "zero point" of an evacuation trial and were essentially a measure of reaction time and evacuation speed for the first evacuee, they were excluded from further analysis. Thus, 48 individual egress times were removed from the initial individual egress times analysis, resulting in a total of 2,544 individual egress times (i.e., 53 participants \times four evacuation trials per test day \times 12 total test days).

The individual egress times were then screened for significant egress time outliers—egress times three standard deviations above or below the average group egress time for each combination of seat pitch and seat width. Using these outlier criteria, 34 individual egress times were removed, resulting in 2,510 individual egress times for final analysis. Outlier egress times ranged from 1.3 to 3.08 seconds. All removed egress times were greater than three standard deviations above the average group egress time (i.e., the outliers were slower than the group average); there were no individual egress times three standard deviations below the average group egress time. Appendix F provides a list of the removed egress times for all seat pitch and seat width combinations with the average group egress time and standard deviations for reference.

Once outlier times were removed, a multiple regression analysis was performed on the remaining 2,510 individual egress times to assess the relative significance of participant attributes (i.e., demographics and anthropometrics) to the average individual egress times for each participant. This analysis revealed that participant gender, girth, age, and KtF were significant predictors of average individual egress times ($R^2 = .146$, $F(4,711) = 30.476$, $p = .000$) and should be covariates in any further analyses. The statistical significance of gender, girth, and age is consistent with previous evacuation research results (McLean & Corbett, 2004), and the statistical significance of KtF is a new finding.

Individual Egress Times - Interaction of Seat Pitch and Seat Width

Two 2x2 Repeated-Measures Analysis of Covariance (RM-ANCOVA) were performed to determine if a significant interaction existed between seat pitch and seat width while accounting for the significant covariates of gender, girth, age, and KtF. Both RM-ANCOVAs were non-significant at the $p = .05$ level (Table 27). There were no significant differences in individual egress times due to seat pitch and seat width when accounting for the covariates of gender, girth, age, and KtF.

Table 27

RM-ANCOVA: Interaction of Seat Pitch and Seat Width on Individual Egress Times

Comparison				DF	Error DF	F	p	Means				N
32/18	32/16	28/18	28/16	1	289	0.74	0.39	0.611	0.615	0.612	0.622	294
32/18	32/16	34/18	34/16	1	132	0.06	0.81	0.551	0.546	0.580	0.552	137

Note. RM-ANCOVA = Repeated-Measures Analysis of Covariance; DF = degrees of freedom.

Individual Egress Times – Main Effect of Seat Pitch

Multiple RM-ANCOVAs were performed to evaluate the main effect of seat pitch on individual egress times while accounting for the previously identified covariates. Four separate ANCOVA's

were performed and all four were insignificant at the $p = .05$ level (Table 28). There were no significant differences in individual egress times due to seat pitch when accounting for the covariates of gender, girth, age, and KtF.

Table 28

RM-ANCOVA: Main Effect of Seat Pitch on Individual Egress Times

Comparison		DF	Error DF	F	p	Means		Delta	N
32/18	28/18	1	358	1.857	0.174	0.614	0.617	-0.003	363
32/16	28/16	1	369	1.024	0.312	0.612	0.628	-0.016	374
32/18	34/18	1	170	1.281	0.259	0.599	0.586	0.013	175
32/16	34/16	1	180	0.144	0.705	0.560	0.559	0.001	185

Note. RM-ANCOVA = Repeated-Measures Analysis of Covariance; DF = degrees of freedom.

Individual Egress Times – Main Effect of Seat Width

Multiple RM-ANCOVAs were performed to evaluate the main effect of seat width on individual egress times while accounting for the previously identified covariates. Three additional ANCOVAs were performed, and all three were insignificant at the $p = .05$ level (Table 29). There were no significant differences in individual egress times due to seat width when accounting for the covariates of gender, girth, age, and KtF.

Table 29

RM-ANCOVA: Main Effect of Seat Width on Individual Egress Times

Comparison		DF	Error DF	F	p	Means		Delta	N
32/18	32/16	1	537	0.610	0.435	0.594	0.599	-0.005	542
28/18	28/16	1	367	0.147	0.702	0.619	0.626	-0.007	372
34/18	34/16	1	176	0.160	0.690	0.579	0.556	0.023	181

Note. RM-ANCOVA = Repeated-Measures Analysis of Covariance; DF = degrees of freedom.

Discussion

This study addressed multiple questions within two specific domains: (1) the anthropometric makeup of the American flying public and (2) the evacuation safety implications of seat dimensions within transport category airplane cabins. Of note, a significant amount of collected data is not reported in this first in a series of reports. Future publications will report collected data not directly related to the seat pitch/seat width or anthropometric questions, such as the

participant questionnaire response, participant injuries, and instances of odd participant behavior observed during the evacuations.

Demographics and Anthropometrics

In addition to the research question investigating the ability of the flying public to sit in a range of seats either at or below the minimum seat pitch, this study also addressed questions and criticisms about the suitability of CAMI's standard practice of recruiting research participants from within the local Oklahoma population for evacuation research projects. The Principal Investigators for this study used a contract personnel service to locate and recruit research participants to ensure that CAMI researchers were not directly involved in nor influenced participant recruitment. In response to previous criticism over selective recruitment, CAMI researchers have maintained that CAMI's evacuation studies are conservative compared to the U.S. population because the Oklahoma population is typically larger, heavier, and can be assumed to be slower than the average U.S. population. Oklahoma is ranked as one of the heaviest states in the union, with 30% to 38% of adults classified as obese since 2011 (Centers for Disease Control and Prevention, 2020). Evidence that CAMI evacuation research participants are larger than the general U.S. population was seen in the CAMI Access to Egress studies of the 2000s (McLean et al., 2002) when CAMI data were compared with available contemporary U.S. population anthropometric data. This trend continued within the current study. Comparing study participant anthropometrics to the latest available NHANES data showed that, except for the 95th percentile female weight, the present study participants were slightly larger than the American public. While not as conservative as previous CAMI studies, wherein the participants were, on average, statistically larger and heavier than the general U.S. population at the time, this finding demonstrates that, anthropometrically, the current study population was slightly larger and heavier, and thus could be considered generally to move slower than the general U.S. population.

To address the research question concerning which body dimensions affect a person's ability to fit into an aircraft seat, this study found that six of 775 participants (less than 1%) were unable to fit in the experimental seat mock-up at the 28-inch (71.12-cm) seat pitch. With one exception, the anthropometrics of participants who were unable to sit in the experimental seat mock-up strongly correlated with BtK above the 95th percentile for both male and female participants. Upon video review, the one exception was a participant who was unable to sit mainly due to the interaction of weight, girth, and height, leading to an inability to traverse easily across the seats to reach and sit in the middle seat. This participant may have been able to sit in the aisle seat of the mock-up but would have found considerable difficulty attempting to sit in the FlexSim seats with their fixed armrests and spacers used to manipulate seat width experimentally.

The seats used in this study were modeled after an older design utilizing thicker seat cushions which provide less occupiable space (Dimension A) for a given seat pitch than is typical of those

currently flying². This, in turn, supports the conclusion that the study seats provided a conservative assessment of each seat pitch evaluated, since the space between rows they provide is less than provided by modern seats at the same pitch. However, without a formal survey of the Dimension A of the flying fleet, this report must itself be conservative in its generalizability (see Limitations, final paragraph). Even working within that limitation, the study findings indicate that the percentage of the flying public who would find it difficult to occupy a 28-inch (71.12-cm) seat pitch is extremely small. This percentage increased as seat pitch and Dimension A reduced, with 62 study participants (8%; six unable to fit in the 28-inch mock-up and 56 self-reporting the inability to fit in the 26-inch mock-up) being unable to sit in the 26-inch (66.04-cm) experimental set mock-up. The percentage of passengers who find it difficult to fit in an airplane seat could be higher still if the airplane is at full occupancy. A review of the video data showed many study participants had to move the seat backs forward in the 26-inch (66.04 cm) seat pitch configuration just to be able to access the seat and to sit—an option that would be curtailed in an actual airplane should the forward seats be occupied, and a possible detriment in an evacuation.

Seat Dimensions and Egress

Building on previous CAMI evacuation research findings, this study identified key participant characteristics that accounted for significant variation in egress times. In addition to previously identified characteristics of participant age, girth, and gender, this study identified participant KtF as a covariate of interest. Post hoc correlational analysis showed small positive correlations between the mean egress times and girth, age, and KtF—as these three measurements increased, egress times also increased. However, in contrast to previous CAMI research, male participants tended to have a higher average mean egress time than female participants. This was an interesting initial finding; however, additional post hoc correlational analyses indicated that there was a stronger positive correlation between girth and age for male participants and that the male participants were, on average, girthier than the female participants. A final post hoc analysis revealed that the study population conformed to previous findings in that, as female age and girth increased, their evacuation times increased (i.e., they become slower) when compared with similar age/girth combinations of male participants; there simply were fewer large, older female participants involved in this current study than previous CAMI evacuation studies.

For the second research question, this project achieved a conservative and comprehensive laboratory assessment of the effects of seat pitch and seat width on egress. Starting with an evaluation of group egress times, we found no significant statistical differences in egress time based on seat pitch, seat width, or a combination of the two. No statistically significant

² Informal field measurements taken by members of the research team between December 2018 and February 2020 found that the Dimension A of seats in the economy section of in-use aircraft were approximately 1 to 1.5 inches greater than the Dimension A of the seats used in this project.

difference in egress times was noted across the 12 groups as a whole or when breaking down the groups into sub-groups to evaluate different sets of the independent variables. Individual egress times were analyzed once outliers were removed, which, as shown in Appendix F, were concentrated in the individual egress times in the control seat pitch of 32 inches (86.36 cm; 16 outliers of a total of 38 outliers, or 47%). Both outlier removal and accounting for the variability attributed to participant individual differences increased statistical power and the ability to detect significant differences (if any) in individual egress times. The analyses indicated that, while there were differences in mean egress times among the different seat pitches and seat widths, the differences were so minuscule (tenths to ten-hundredths of a second) to be neither statistically nor practically significant.

Limitations

As discussed in McLean (2001), airplane evacuations are chaotic with many variables that can change and influence outcomes, and attempting to study everything in a single project is an exercise in futility. The factorial approach taken by the current study and by previous evacuation research studies is logical. By distilling individual variables critical to an evacuation and testing them in near-isolation, one can build, piece by piece, a picture of emergency evacuations and what variables critically affect the safety of the flying public. Examples of previously identified critical variables include equipment such as escape slides (McLean et al., 1996, 1999), aisle configuration and lighting (Muir & Cobbett, 1996), access to exits (McLean et al., 2002), or smoke inside the cabin (Muir et al., 1992). The current study followed the same factorial approach and isolated *only* seat pitch and seat width for study via live evacuations. The study findings are a small, but relevant, part of the many variables that influence real-world airplane evacuations.

Study results indicate that evacuations at a narrow seat pitch are safe for virtually all (99%) of the able-bodied population. However, the study results do not consider passenger comfort (or the lack thereof), which impacts a passenger's sense of well-being during a flight (Kremser et al., 2012). While this study did collect self-reported information on participants' feelings about their seating experiences, those data, along with the other self-reported data, will be presented in future reports. The current report focused on the safety aspect of seat pitch and seat width concerning evacuation time, just as the FAA's regulatory mandate focuses on the safety of the flying public. Ensuring passenger comfort is not within the FAA's regulatory mandate. Passenger comfort is left to the airlines, and a result of the choices passengers make when making travel arrangements.

Dimension A of airplane seats is arguably a better occupiable space measurement than seat pitch; however, the researchers were unable to find any published survey or study of Dimension A in any iteration of the flying fleet for a direct comparable reference to the Dimension A used in this project. The relationship between the Dimension A that were used in this project and the flying

fleet were instead inferred from a logical assessment. That assessment comparing modern seats (with typically thinner cushions and smaller/relocated tray tables and magazine storage) to the 1980s and 1990s era seats used for the experimental seating mock-up, and the FlexSim seats which were modeled on them. A formal survey of the Dimension A of the flying fleet, for reference, would allow for better generalizability of the findings of this study.

Conclusions

Following the factorial approach to evacuation research described by McLean (2001), the current study attempted to obtain an objective assessment of the influence of seat pitch and seat width on egress time. This study adds to the body of knowledge of previous airplane evacuation research with the findings of no discernable difference in evacuation times due to seat dimensions. Combined with this previous knowledge, a logical assessment shows that additional variables, that may have or have already been shown to influence evacuation times (e.g., evacuation slides) would mask seat dimension effects on egress times. The results of the current study support McLean et al. (2002), who indicated that as long as ergonomic minima are maintained, an aircraft's interior configuration does not have a significant impact on evacuations. Although, given the nature of new, emerging airplane interior configurations and designs, evacuation research should continue.

This study examined the previously mentioned ergonomic minima and found that the experimental seat pitches, which are similar to the seat pitches currently found on flying commercial large transport category aircraft, should provide protection and not impede egress for 99% of the general U.S. population. However, the results also indicated that reduction of Dimension A past the 28-inch (71.12-cm) seat pitch used in this study (Dimension A of 25 inches [63.5cm]) begins to have a detrimental impact on a larger percentage of the population, since more average-sized Americans are unable to fit in narrower seat pitches, which in turn may impede egress.

This study developed standard anthropometric data points and measurement procedures for use in future CAMI evacuation research studies. This standardization will facilitate developing a database for future projects with similar anthropometric data and will be available for use by researchers and manufacturers in the validation and verification of airplane evacuation computer models.

The study's findings confirm the NHANES data that the general U.S. population is getting larger and heavier, although this did not significantly impact egress time as expected based on previous research. However, the findings lend support for continued, ongoing evaluation of U.S. population anthropometric data, specifically for anthropometric data that may interact with airplane seat dimensions, because while airplane seat size may remain unchanged, passenger size and shape may change enough that ergonomic minima shift to being unfavorable for safe egress.

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Appendix A: Pre-Test Participant Information Form

As part of my participation in this project, I agree to provide the information requested below. This includes my age, gender, select recent health information, and evacuation history. I understand that my anthropometric information will be recorded by a trained member of the research staff. I understand that I may retrieve this information form should my participation in this project not be needed. **I certify that any information I provide is accurate to the best of my ability (Check One):** Yes _____ No _____

What is the highest level of education you have completed (**circle one**)?

- | | | |
|-------------------|------------------------------------|-----------------|
| Some high school | High school graduate or equivalent | Some college |
| Associates Degree | Bachelor's Degree | Graduate degree |

What is your age (in years)? _____

What is your gender? _____

Have you participated in evacuation research or training in the past (circle one)?
Yes No

Have you recently (within the last 6 months) undergone surgery related to your back, legs, feet, or ankles?
Yes No

Are you currently under the influence of alcohol or drugs (prescription or otherwise) which may affect your mobility or reaction time?
Yes No

Do you currently have trouble moving quickly?
Yes No

Do you suffer from a chronic condition which may affect your ability to evacuate an aircraft safely (such as dizziness, temporary loss of hearing, balance issues, etc)?
Yes No

Do you wish to continue your participation in this study?
Yes No

To be filled in by research staff

Participant Vest Number:

Appendix B: Informed Consent to Participate in Research Study

(FAA Evacuation Research Project 2019)

Principal Investigator (PI): **David Weed**, M.A., Civil Aerospace Medical Institute

Co-investigators: **Melissa Beben**, M.S., Civil Aerospace Medical Institute

Sponsors: **Federal Aviation Administration**

Contractor: **SGC23**

Invitation to Participate in Research Study

David Weed invites you to participate in a research study about the Effects of Seat Dimensions on Airplane Egress. This study is sponsored by the Federal Aviation Administration (FAA) and funded by the Fire and Cabin Safety Technical Committee Representative Group (F&CS TCRG), who have no financial interest in this study. This study is being conducted to partially meet requirements set forth in the FAA Reauthorization Act of 2018 (Public Law #115-254). The study will be conducted at the Mike Monroney Aeronautical Center (MMAC) Campus, Civil Aerospace Medical Institute (CAMI) Building, and the Flexible Aircraft Cabin Simulator (FlexSim), located adjacent to CAMI. The estimated total of participants who will take part in this study is at least 720 people, consisting of 12 groups of at least 60 participants each.

You have been hired by SGC23 as a possible research participant for this project. You have been selected as a possible participant in this study because you are a representative of the flying public, have no previous airplane evacuation experience, real or simulated, and are reasonably healthy, mobile, and not under the influence of any alcohol or drugs, prescription or otherwise, which may impair your mobility, cognition, or decision-making process, and are not receiving any form of disability payment. Any potential participant having previous airplane evacuation experience, and not reasonably healthy, mobile, or who is under the influence of any alcohol or drugs, prescription or otherwise, which may impair your mobility, cognition, or decision-making process, or receiving any form of disability payment may not participate in the study. Please take some time to consider these requirements and review this document. If you meet the requirements and decide to participate, after consideration and a verbal review with the researcher, please sign this form to show that you want to voluntarily take part. Please do not sign this document until you have fully reviewed it. Also, please keep in mind that, even after signing this document, you may withdraw from participation at any time.

Description of participant involvement

If you agree to participate in this study, your involvement will last approximately 5 hours. During this time, you will be asked to arrive at the MMAC Visitors Center, located at 6500 S. MacArthur Blvd, Oklahoma City, Oklahoma. You will be prohibited from bringing any extra items with you other than your identification and any keys for transportation. Cell phones and purses are explicitly forbidden and must be left in a vehicle or with the contractor representative for the duration of your participation in this project. At the MMAC visitors center you will receive a group briefing about this form and project and be given a chance to sign this form to signal your voluntary participation in this project. After signing, you will be given a participant number and transported to the CAMI building for anthropometric recording, including measurement of your height, weight, girth, shoulder width, sitting hip breadth, sitting knee to floor height, and sitting buttocks-to-knee length, and pre-test briefing. Next, you will go

to the Flexsim and participate in, at most, four simulated airplane evacuations, each with a flight attendant and slightly different cabin configurations. Each of these evacuations will be going through one designated floor level exit onto a ramp leading to grass or concrete. After the evacuations, you will be taken back to the CAMI building for debriefing, and transported back to the MMAC visitors center for any final paperwork with SGC23 before being dismissed.

Voluntary nature of the study

Participation in this research project is completely voluntary. You have the right to withdraw from this study at any point during or between trials without penalty or loss of benefits to which you are otherwise entitled. If you choose to withdraw before full completion of the study, you will be paid for the time worked by SGC23 as calculated from the time of initial briefing at the MMAC visitor's center, to the time of your withdrawal. If you choose to withdraw before the evacuation trials have started, you may request your demographic and anthropomorphic data be returned to you. If you choose to withdraw after participating in any evacuation trials, your data will be retained for the integrity of the research data already collected.

Potential Benefits

Your direct benefit for participating in this project is your payment from SGC23. You may qualify for an additional bonus for today's participation as well. This project will benefit aviation safety and the flying public as a whole by providing information to allow the FAA to maintain or improve safety on commercial aircraft.

Risks and discomforts

The researcher has taken steps to minimize the risk of this study. Even so, you may experience some risks related to your participation. Previous evacuation research has included participant injuries including bruises, lacerations, strains, sprains, and/or broken bones. These injuries have been the result of slips, trips, falls, over-vigorous inter-participant interaction, or a failure to properly navigate obstacles during an evacuation. You may experience discomfort during the anthropometric measurement portion of this project as a same sex researcher will measure around your waist with a tailor's tape measure, and, with an anthropometer, touch the tops of your shoulders, the front and top of one of your knees, and the sides of your hips while seated. You may also experience discomfort in the form of loud noises and uncomfortable simulated airplane seating during the simulated evacuation trials.

Compensation

You will be paid \$100 by SGC23 for your participation in this study. You have the possibility of earning a 25% bonus for each trial you are among the first 70% of participants to evacuate the FlexSim during the experimental trials for a potential to earn up to an additional \$100. If, during the testing today, it is determined that you have willfully or intentionally caused harm to another participant in the course of the evacuation trials, you will not be eligible for this bonus compensation.

Participant's Rights

You will not give up any legal rights or release any individual or institution from liability for negligence by signing this form and participating in this study. You have the right to withdraw from this study at any point during or between trials without penalty or loss of benefits to which you are otherwise entitled.

You have the right to be informed should any new findings develop during the course of this research project that may relate to your decision to continue participation.

By signing this form, you agree to allow still photographs and/or videos to be made as required during the research with the understanding that these records are the property of the U.S. Government. You will not be entitled to monetary or other benefits, now or in the future, for the use of this material.

You have the right to receive and keep a signed copy of this form for your records. You have the right to receive an electronic copy of any publications relating to this research project. You can contact the P.I. at the number provided at the bottom of this form.

Participation in this research project does not protect you from legal consequences should it be determined you have intentionally harmed another participant in the course of this project.

Cost to Participant

You will not incur any costs for participating in this research study.

Confidentiality

All paper records created during the course of this study will be kept in a locked file cabinet maintained by the Protection and Survival Laboratory, Cabin Safety Research Team, in the CAMI building. All records of this study will refer only to the participant number you will be assigned should you agree to participate in this study. Electronic data, including all audio-visual recordings, collected during this research project will be kept on a password protected, external storage drive, kept in a locked filing cabinet when not in use. All still photographs or videos used in publications related to this research project will have participant faces blurred or otherwise obscured to ensure participant confidentiality. In the event of any publication or presentation resulting from the research, no personally identifiable information will be shared. The recordings and data generated from this project may be used or distributed by the researchers without being required to obtain your consent in addition to this document.

All paper records and electronic data collected or generated from this project will be maintained, as stated above, for a minimum of 15 years at CAMI. After that time, if the records are deemed essential, they will be maintained at CAMI, otherwise they will be transferred to the National Archives in accordance with FAA order 1350.14B.

Observers from the FAA Evacuation Aviation Rulemaking Committee may or may not be observing this particular days trials. Any such observers will be required to remain sequestered from all research participants and will be bound by federal employment or nondisclosure agreement to federal regulations requiring confidentiality and other protections for human subjects.

By participating in this study, you are agreeing not to disclose any personal information about any other participants in this study that you may acquire through the course of your participation with the understanding that they will extend you the same courtesy.

Injury

Every effort to prevent injury as a result of your participation will be taken. It is possible, however, that you could develop complications or injuries as a result of participating in this research study. In the event of

injury during this research project, first aid will be provided by on-site first responders. Any required follow-on care will be coordinated by your contractor's representative and the first responders.

Participation and Withdrawal

Your participation in this study is voluntary and it is your choice whether to participate or not. You may decline or withdraw participation from the study at any time. The choice to decline or withdraw from the study will not cause any penalty or loss of any benefit to which you are entitled as described above.

David Weed, or another research staffer, may decide to stop or withdraw you from the study under certain circumstances without your permission. Some possible reasons that you may be removed from the study are such as; a risk or harm to your medical or psychological interest; not following the study instructions; intentionally causing harm to yourself or others; or other administrative reasons. In the event that your participation in the study ends early, you may request or you may be requested to speak to the principal investigator and/or contractor representative.

At any time during this research study, the principal investigator or research team will share any new information that may affect your health or well-being, and will discuss your continued participation in the study.

Contact Information

If you have questions about the study, please ask them before signing this form. You can ask any questions that you have about this study at any time.

For questions, concerns or complaints about this study, please contact the principal investigator, David Weed at 405-954-9218 (email: David.Weed@faa.gov) or research staff Melissa Beben at 405-954-7528 (email: Melissa.Beben@faa.gov).

If you feel that you have been treated unfairly, or you have questions regarding your rights as a research participant, you may contact the Civil Aerospace Medical Institute Institutional Review Board (a group of people who review the research to protect your rights) at 405-954-1000, Dr. Thomas Chidester.

Audio/Visual Records of Participants

- Audio/video will be used as a part of the study procedures.
- Upon complete of the study, these recordings will be retained for data analysis and may be used in presentations or publications related to this project.
- Please sign below if you are willing to be recorded.
- You will not be able to participate in this research project if you are not willing to be recorded

Printed Name of Participant

Signature of Participant

Date

Signature and Consent to be in the research study

I have been informed about the purpose, procedures, possible benefits and risks of this research study. I have read (or someone has read to me) this form, and I have received a copy of it. I have had the opportunity to ask questions and to discuss the study with an investigator. My questions have been answered to my satisfaction. I have been told that I can ask other questions any time. I voluntarily agree to participate in this study. I am free to withdraw from this study at any time without the need to justify my decision. If I withdraw, I will not lose any benefits to which I am otherwise entitled. I agree to cooperate with the principal investigator and the research staff and to inform them immediately if I experience any unexpected or unusual symptoms. I agree to not disclose any personal information about my fellow participants to anyone.

Participant: By signing this consent form, you indicate that you are voluntarily choosing to take part in this research.

Printed Name of Participant

Signature of Participant

Date

Investigator

Principal Investigator:

I have fully explained this study to the participant or his/her representative to the best of my ability. As a representative of this study, I have explained the purpose, the procedures, the possible benefits and risks that are involved in this research study. I have answered the participant's questions to his/her satisfaction before requesting the signature(s) above. I confirm that the individual has not been coerced into giving consent, and the consent has been given freely and voluntarily. There are no blanks in this document. A copy of this form has been given to the participant or his/her representative.

Printed name of Investigator

Signature of Investigator

Date

Time

**Appendix C: Evaluation of Aircraft Cabin Mock-up Seat #5 Post-test Questionnaire
(FRONT AND BACK)**

What is your participant number? _____

How many flights have you been on in the last 12 months?

0 1-3 4-6 7-9 10+

On a scale of 1 (no experience) to 5 (very experienced), how would you rate your experience at flying on passenger airplanes?

1 2 3 4 5
No Experience Some Experience Very Experienced

Were you able to sit in the seat number 5 (middle row, middle seat)? Yes No

On a scale of 1 (very difficult) to 5 (very easy), how easy was it to **get in to** seat number 5 (middle row, middle seat)?

N/A 1 2 3 4 5
Could not sit Very Difficult Neutral Very Easy

On a scale of 1 (very difficult) to 5 (very easy), how easy was it to **get out of** seat number 5 (middle row, middle seat)?

N/A 1 2 3 4 5
Could not sit Very Difficult Neutral Very Easy

On a scale of 1 (very uncomfortable) to 5 (very comfortable), how would you rate seat number 5 (middle row, middle seat)?

N/A 1 2 3 4 5
Could not sit Very Uncomfortable Neutral Very Comfortable

On a scale of 1 (very difficult) to 5 (very easy) how difficult do you think it would be for you to get out of seat number 5 (middle row, middle seat) quickly?

1 2 3 4 5
Very Difficult Neutral Very Easy

On a scale of 1 (very unsafe) to 5 (very safe), how safe do you think seat number 5 (middle row, middle seat) would be to use on a short (30 to 120 minute) flight?

1	2	3	4	5
Very Unsafe		Neutral		Very Safe

On a scale of 1 (very unsafe) to 5 (very safe), how safe do you think seat number 5 (middle row, middle seat) would be to use on a longer (2 hour+) flight?

1	2	3	4	5
Very Unsafe		Neutral		Very Safe

**FAA Evacuation Study 2019
Between Trials Survey**

What is your participant number? _____

What seat number were you sitting in? _____

Was it an aisle seat (next to the main aisle), a middle seat (between two other seats), or a wall seat (between the middle seat and the wall of the simulator)? **(Circle one)**

Aisle Seat Middle Seat Wall Seat

On a scale of 1 (very difficult) to 5 (very easy), how easy was it to **get in to** your seat in this trial?

1 2 3 4 5
Very Difficult Neutral Very Easy

On a scale of 1 (very difficult) to 5 (very easy), how easy was it to **get out of** your seat in this trial?

1 2 3 4 5
Very Difficult Neutral Very Easy

On a scale of 1 (very uncomfortable) to 5 (very comfortable), how would you rate the experimental seating arrangement?

1 2 3 4 5
Very Uncomfortable Neutral Very Comfortable

On a scale of 1 (very unsafe) to 5 (very safe), how safe do you feel the evacuation trial was?

1 2 3 4 5
Very Unsafe Neutral Very Safe

On a scale of 1 (very slow) to 5 (very fast), how fast do you think the evacuation trial went?

1 2 3 4 5
Very Slow Neutral Very Fast

On a scale of 1 (not helpful) to 5 (very helpful), how helpful do you think the flight attendants were during the evacuation?

1 2 3 4 5
Not Helpful Neutral Very Helpful

Appendix E: FAA Evacuation Study 2019 Configuration Post Test Survey

What is your participant number? _____

Of the trials you participated in, which one do you feel was the **most safe**?

1st 2nd 3rd 4th

Of the trials you participated in, which one do you feel was the **least safe**?

1st 2nd 3rd 4th

Of the trials you participated in, which one do you feel had the **most comfortable** seat?

1st 2nd 3rd 4th

Of the trials you participated in, which one do you feel had the **least comfortable** seat?

1st 2nd 3rd 4th

Of the trials you participated in, which one do you feel was the **easiest for you**?

1st 2nd 3rd 4th

Of the trials you participated in, which one do you feel was the **most difficult for you**?

1st 2nd 3rd 4th

On a scale of 1 (very unsatisfied) to 5 (very satisfied), how would you rate your satisfaction of **your performance** during these trials?

1 2 3 4 5
Very Unsatisfied Neutral Very Satisfied

On a scale of 1 (very unsatisfied) to 5 (very satisfied), how would you rate your satisfaction of **the flight attendants performance** during these trials?

1 2 3 4 5
Very Unsatisfied Neutral Very Satisfied

Thank you for your participation!

Appendix F: Removed outlier egress times

Determination of outliers was made by taking the mean and standard deviations of all individual egress times for each combination of seat pitch and width, finding those times that were above or below three standard deviations from the mean evacuation time. The following tables contain the means, standard deviations, and calculations of 3 standard deviations above and below the means for each combination of seat pitch and width. In addition to these descriptive statistics are lists of each participant and the time that was removed from each combination of seat pitch and width.

32/18				
-3	-0.1	SD 0.24	Participant	IET
-2	0.14		152	1.7
-1	0.38		156	1.4
Mean	0.62		324	2.67
+1	0.86		349	1.45
+2	1.1		826	1.67
+3	1.34		831	1.4
		850	1.67	
		1002	1.6	
		1036	2.9	
		1056	1.77	
		1149	1.92	
		1249	1.57	

32/16				
-3	-0.02	SD 0.22	Participant	IET
-2	0.2		141	1.67
-1	0.42		657	1.42
Mean	0.64		951	3.08
+1	0.86		1156	1.98
+2	1.08			
+3	1.3			

28/18					
				Participant	IET
-3		-0			
-2		0.19		152	1.57
-1		0.4	SD	224	2.37
Mean		0.61	0.21	240	1.5
+1		0.82		541	1.75
+2		1.03		545	1.42
+3		1.24		731	1.78
				847	1.32

28/16					
				Participant	IET
-3		0.01			
-2		0.22		152	1.67
-1		0.43	SD	255	1.83
Mean		0.64	0.21	313	2.03
+1		0.85		724	2.47
+2		1.06			
+3		1.27			

34/18					
				Participant	IET
-3		0			
-2		0.2		919	1.33
-1		0.4	SD	950	1.3
Mean		0.6	0.2	951	1.37
+1		0.8		1155	1.47
+2		1		1206	1.32
+3		1.2			

34/16					
				Participant	IET
-3		0			
-2		0.19		1042	1.35
-1		0.38	SD	1106	1.57
Mean		0.57	0.19		
+1		0.76			
+2		0.95			
+3		1.14			