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Thirty years of anthropometric changes relevant to the width and depth of transportation seating spaces, present and future

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ABSTRACT

This paper reports the results of an investigation into changes in body shape anthropometry over the past several decades and discusses the impact of those changes on seating in transport, especially airliners. Changes in some body shape dimensions were confirmed in a sample of students at TU Delft; several of the changes, e.g. hip breadth, seated, are relevant to the ongoing design of seating. No change in buttock knee length was observed.

The fit between current user anthropometry and current airline seat design, especially regarding seat width, was investigated. A comparison of the average current seat breadth with global anthropometric data suggests that accommodation may be problematic, with less than optimal width for passengers' shoulder and elbow widths.

1. Introduction

1.1. Changing anthropometry and seat size accommodation

This paper investigates anthropometric information relevant to the design of seating in transportation, especially for air transport. It first considers whether anthropometric data relevant to the design of seating are changing. It then looks at the current state of anthropometric accommodation in international economy-class airline seating.

It is well-established that humans' width and circumference measurements have been increasing at a greater rate than have heights for several decades. This can be seen in increases of body mass relative to height. The Body Mass Index (BMI) is defined as an individual's body mass in kilograms divided by the square of his or her height in meters. Finucane et al. (2011), in a study with more than 9 million participants, found that the average BMI of males worldwide has increased by 0.4 kg/m^2 per decade and that the average BMI of females has increased by 0.5 kg/m^2 per decade since 1980. Further details regarding the secular trend towards an increase in body dimensions relevant to the design of seating are presented in section 2 of this paper.

Consequently, updated anthropometry continues to be both relevant and necessary for the design of transport seating. Buttock to knee length, hip breadth seated, forearm to forearm breadth, and shoulder breadth are important dimensions for design of the distance between two seats and seat width, respectively, in aircraft, buses and trains (Roebuck et al., 1975). For passengers' comfort, aircraft seat design (Smulders et al., 2016) and seat widths and depths are identified as an important factor regarding passengers' perception of comfort (Ahmadpour et al., 2014). Seat widths may be subject to economic constraints to increase the number of seats within any given fuselage (Ahmadpour et al., 2014). However, this paper argues that the width of those seat designs should be expected to accommodate a reasonable proportion of the people sitting in them, especially for seating in long-duration flights.

1.2. Relevance of anthropometry to the design of the passenger seating space volume

This paper reemphasizes the concept of the seating space volume, defined by the width, length and seated height of passengers (Roebuck et al., 1975, Quigley et al., 2001). The desired dimensions of the seating space volume are those that concurrently accommodate a given proportion of all passengers on all three dimensions. However, only two of the three relevant dimensions of

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the seat space volume, width and depth, are discussed in detail in this paper while the height of the space is not.

One might arbitrarily define the dimensions of the seating space volume as the 95th percentile values of sitting widths, lengths and heights of the individuals who use various modes of transportation, especially airline seats (Quigley et al., 2001). It is important to note that, although 95th percentile values are used to define the space in this paper, this does not necessarily ensure exactly 95 percent accommodation. The method of estimating the accommodation achieved by combining these three 95th percentile dimensions (or indeed, of combining any percentile dimensions) is more completely described in Albin and Molenbroek (Albin and Molenbroek, 2016) and in section 4.3.1 of this paper.

1.2.1. Seating volume height

The height of the seating space is determined in this paper by the 95th percentile value of sitting height above the floor. Generally, this dimension is not directly measured and might be estimated by adding the 95th percentile values of popliteal height and sitting height. Although methods of interpreting the accommodation achieved by combining two percentile values has recently been described (Albin, 2017), this paper does not deal with the height of the seating space.

1.2.2. Seat pitch

Seat pitch is the horizontal distance between a point on a seat and the same point on the seat directly ahead of or behind it, for example, the distance between the front edges of two tandem seats (where one is behind the other).

The anthropometric dimension, buttock knee length, is relevant to establishing the seat pitch dimension in aircraft, buses and trains. If the horizontal thickness of the seat backrest at the level of the buttocks is added to the measurement of the buttock knee length, then the minimum seat pitch dimension while sitting can be calculated (Vink and Brauer, 2011). It must be emphasized that this should be considered as the minimum seat pitch dimension, as it does not allow space for movement; some additional depth should be added to afford clearances for garments and postural change and to enable entering and exiting the seat (Quigley et al., 2001). The longest buttock knee length reported in the ISO 7250-2 Technical Report is that of Dutch males, whose 95th percentile value for buttock knee length is 703 mm. Any changes in that anthropometry, such as a trend towards increasing buttock knee length, would imply that seat pitch would also need to increase to provide sufficient accommodation.

1.2.3. Seating space width

The width of the seating space varies with its height above the floor; in this paper, it has the width of the 95th percentile hip breadth seated value, female at the level of the seat surface; the 95th percentile elbow to elbow breadth, male at the level of the armrest, and the 95th percentile bideltoid shoulder width, male at the level of the shoulders. Clearly, hip breadth seated, bideltoid shoulder breadth and elbow to elbow breadth are relevant for the design of the width of bus, train and aircraft seats (Roebuck et al., 1975).

However, reducing seat width opens the possibility of seating more passengers next to each other (side by side) in the vehicle. For example, the basic seat plan for the Boeing 787 was a 2-4-2 (8 seats across) configuration. Except for Japan Air Lines and All Nippon Airways, most airlines chose a 3-3-3 (9 seats) configuration, which narrowed seat width to less than 457 mm (18 in) (Vink and Brauer, 2011). However, a narrower seat may not accommodate the hip breadth, seated, the elbow to elbow breadth or the shoulder width of a significant fraction of the intended users.

A convenience sample of 508 airline seat widths for 84 international airlines and various aircraft has been reported by Seatguru (Seatguru, 2016). The Seatguru seat pitch and seat width measurements (distance between the armrests) were reported to Seatguru by travellers and/or by the airlines (Carter, 2017). If more than one seat width or seat pitch value was given by Seatguru for an airline's aircraft, the minimum value was used to compute the overall average. The average and (standard deviation) of seat width on economy long-haul flights was 447.4 (15.5) mm and the average seat pitch was 816.0 (37.9) mm, or 17.6 (0.6) inches and 32.1 (1.5) inches for seat width and seat pitch, respectively. Although the Seatguru data are a sample of convenience, the average seat width between armrests reported in Seatguru is consistent with the average airliner seat width range of 430 mm–470 mm reported earlier by Ahmadpour et al. (2014) and an average airliner seat width of 436 mm reported by Goonetillike and Feizhou, (Goonetilleke and Feizhou, 2001).

The width of the seating space volume is partially determined by elbow to elbow breadth and/or shoulder breadth; these widths are critical in assessing the accommodation achieved by seat width design when people are seated side-by-side (Roebuck et al., 1975). Humans, particularly males, are somewhat wedge-shaped, and are wider at the shoulders and elbows than at the hips.

The anthropometric data in ISO 7250-2 (ISO, 2010) show that males' average shoulder breadth is 103 mm wider than their seated hip breadth and that females' shoulder breadth is 44 mm greater than their seated hip breadth.

This is a critical issue, as there may be insufficient space to accommodate passengers' shoulders in side-by-side seating, leading to concerns for passenger health and comfort. In such cases, the shoulders and elbows of a large passenger may overlap the seat boundaries into the seating space of the adjacent passengers. Changes in these width measurements would necessarily affect the anthropometric accommodation of transport seating.

The perception of intrusions or invasions into one's personal space are relevant to the design of seating (Li and Hensher, 2013). Evans and Winter (Evans and Wener, 2007) noted that this effect is so strong that many train passengers preferred to stand rather than sit in an open middle seat. They hypothesized that placing seats in pairs rather than three or more across might be preferable regarding a sense of maintaining inviolate one's perception of personal space. Vink et al. (2012) note that there are “clear relationships between comfort and legroom, hygiene, crew attention and seat/personal space” in aircraft. Gender may play an interesting role in the perception of personal space. For example, Fisher and Byrne (Fisher and Byrne, 1975) noted that females are more likely than males to perceive adjacent overlap as an intrusion into their personal space, while males are more sensitive to face-to-face intrusions. While the perception of personal space is an interesting and relevant topic in seating design, this paper only discusses anthropometric accommodation.

There are additional clearance dimensions of interest within the seating space volume. As examples, thigh height is important in defining the tray table height with respect to the seat pan height and elbow rest height relative to the seat pan is important in determining arm support heights. For seat pan height, the popliteal height is of interest and for seat pan length the buttock-popliteal length is relevant. Seated height above the floor defines the height of the seat space volume. These and other important seating dimensions, such as the height of the seat above the floor, allowances for tilted seat backs, tray tables, armrests, etc. are contained within the seating space. However, those dimensions are not discussed in detail in this paper, which focuses on the anthropometric dimensions that describe the length and width of the seating space volume.