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Effects of seat parameters and sitters' anthropometric dimensions on seat profile and optimal compressed seat pan surface

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ABSTRACT

Designing one seat for multi-sitters and multi-activities is challenging especially in a very restrained aircraft economy class cabin. In this paper, the effects of seat parameters and sitters' anthropometric dimensions on seat profile and optimal compressed seat pan surface were studied using a newly built multi-adjustable experimental seat. The 'optimal' seat pan contact surface was obtained by controlling the height of 52 cylinders so that the normal contact force was distributed to all cylinders as evenly as possible. With 13 other motorized adjustments controllable by a computer, individual seat profile in the symmetry plane such as seat height, seat pan length, seat pan angle, lumbar protrusion and headrest position were also studied. Data were collected from 36 men and women of varying body size testing 40 seat configurations. Parametric models were obtained for predicting seat profile and optimal compressed seat pan seat surface in function of seat pan and back rest angles for two sitting postures. It is expected that the proposed parametric models provide necessary reference values in seat development for a better fit of a target population of sitters with large varying body size.

1. Introduction

According to an online survey by Ahmadpour et al. (2014) on a sample of 158 people who just had a long-haul trip (> 4 h), the seat was the most frequently mentioned factor (among the 22 features in the aircraft cabin) which had an influence on passenger comfort. From the analysis of 10,032 reports of passengers flying in 2009 mentioned in Vink and Brauser (2011), it was concluded that the seat had a substantial influence on the comfort experience, though leg room, hygiene and crew were found to be more influential. Interestingly the illustrations and comments by passengers reported in Vink and Brauser (2011) are quite indicative for seat related problems for some passengers: too short seat pan length, too narrow seat width, no free should space, no living space when the frontal seat is fully reclined, no seat support for side sleeping, etc. These are good examples demonstrating that designing one seat for multiple sitters and multiple activities is challenging especially in a very restrained aircraft economy class cabin.

Hiemstra-van Mastrig et al. (2017) proposed a conceptual model arguing that perceived seating comfort and discomfort is due to the interaction between human (anthropometry), seat and context (activities). The interaction was characterized by three mediating variables: sitting posture, interface pressure and movement. Guided by the conceptual model, they conducted an extensive literature review focusing on the relationships between anthropometry, seat characteristics and the activities of passengers, on perception of comfort and discomfort; the goal was to understand how subjective perception is influenced by the three mediating variables. Despite a large amount of investigations on seating comfort/discomfort, it was concluded that statistical evidence between these relationships is still lacking for supporting seat designers and purchasers to make informed decisions. Human seat interaction is highly complex and seating comfort/discomfort depends on many factors such as sitter's anthropometry, posture, seat geometry, material proprieties and their interactions. As most of existing studies were carried out using a real seat or an experimental seat with limited possibilities of varying design parameters (see the review by Reed et al., 1994 and Hiemstra-van Mastrig et al., 2017), it is difficult to isolate the effects of one particular seat parameter and to look at its interaction with other variables. As pressure mapping is the primary experimental facility for investigating seating comfort, many researchers investigated the relationships between seat discomfort and pressure distribution (De Looze et al., 2003; Zemp et al., 2015). However, contact shear force is rarely investigated thought shear is also generally suggested as an important factor affecting seat discomfort (Goossens et al., 1994; Goossens and Snijders, 1995; Zhang and

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Roberts, 1993). Lack of current literature on shear force and quantitative guidance regarding seat design led us to the development of a multi-adjustable experimental seat. The experimental seat had a seat pan surface made up of 52 cylinders, whose height was adjustable to control contact force distribution. All adjustments were motorized except for those for the arm rests. The experimental seat was also fully instrumented allowing the measurements of seat geometric positions as well as all contact forces. A detailed description can be found in the paper by Beurier et al. (2017).

The present study aimed to develop seat design guidelines for airplane economy class seats, based on the data collected using the newly designed experimental seat. Due to large amount of collected data, only the data concerning the seat geometric parameters were analyzed in the present study. Parametric models were obtained for predicting seat profile and 'optimal' compressed seat pan seat surface in function of seat pan and back rest angles for two sitting postures.

2. Materials and methods

2.1. Participants

Thirty-six participants (18 males, 18 females), aged from to 19–56 years old, were recruited based on their body mass index (BMI) (healthy 18.5–25, obese > 30) and stature (small, medium and tall). Stature, sitting height to stature ration and BMI of the participants are summarized in Table 1. Three stature groups were 154–157 cm, 162–166 cm and 170–175 cm for females; 168–171 cm, 176–180 cm and 185–190 cm for males. A total of 12 groups were formed after considering sex, stature and BMI (3 individuals per group). Prior to the experiment, participants were screened using a health questionnaire. Participants who experienced any back injury or pain in the previous 3-months were excluded. The experimental protocol was approved by IFSTTAR (French Institute of Science and Technology for Transport, Development and Networks) ethics committee and informed consent was given prior to experiment.

2.2. Multi-adjustable experimental seat

The experimental seat (Fig. 1) was composed of four main structural components: the supporting frame (A), seat back frame (B), seat pan frame (C) and foot support (D). The supporting frame (A) was mounted on four wheels and its orientation ranged from −5° to 5° (relative to the ground) with help of an electric actuator. The backrest frame (B) articulated with the (A) frame around a lateral axis (y-axis) passing through the reference point of the experimental seat, named PRC ('Point de Référence du Conformateur'). The position and orientation of the seat pan frame (C) in xz plane was controlled by three electric actuators attached to the main structure (A). The foot support (D) had a rectangular surface with a width of 500 mm and a length of 600 mm. It could be adjusted both in x and z directions by two electric actuators.

Table 1
Summary statistics of stature, sitting height to stature ratio (RatioSH) and body mass index (BMI) of the 36 participants.

	N		Average	SD	Minimum	Maximum	Range
Females		Stature (mm)	1633	78	1510	1760	150
	18	RatioSH (×100)	52.24	1.17	49.4	53.8	4.4
		BMI (kg/m^2)	28.5	8.3	19	44.3	25.3
Males		Stature (mm)	1788	77	1680	1930	250
	18	RatioSH (×100)	52.04	1.14	50	53.9	3.9
		BMI (kg/m^2)	27.4	5.3	19.3	35.7	16.4
All		Stature (mm)	1710	109	1510	1930	420
	36	RatioSH (×100)	52.14	1.14	49.4	53.9	4.5
		BMI (kg/m^2)	27.9	6.9	19	44.3	25.3

The experimental seat had thirteen adjustable parameters (Fig. 1b) directly controlled by a computer. Adjustable features included: fore-aft (x) and vertical position (z) of the foot support, the seat pan and the three back supports; seat pan inclination and backrest inclination. Two armrests (E) were also available and adjusted manually. Force sensors were mounted to measure contact forces in xz plane on the foot support, seat pan, three back supports and two armrests. The seat pan surface was composed of a matrix of 52 cylinders, each had a circular flat freely rotatable head of 60 mm in diameter. Each cylinder was equipped with a tri-axial force sensor, enabling the measurement of both normal and tangential forces. The height of each cylinder was adjustable with a maximum stroke length of 40 mm and pressure distribution could be controlled by changing seat pan surface shape. Fig. 2 shows a subject sitting in the experiment seat and the matrix of 52 cylinders simulating seat surface. A more detailed description can be found in Beurier et al. (2017).

Pressure distribution on the contact surface was controlled using a uniform coupling law relating normal force and position for each cylinder. The coupling law enabled us to distribute normal contact force as uniformly as possible among the 52 cylinders within their maximum stroke length. For a given normal contact force on the seat surface (F_n^{SP}), a target mean force ($\overline{F}_n^{SP}$) was estimated as $F_n^{SP}/(0.75*52)$ considering that approximately ¼ of the seat surface was not in contact with the buttock or thighs. Each cylinder lowered its height once its contact force (F_n^i) reached to the target force $\overline{F}_n^{SP}$, while it maintained its position when $F_n^i \leq \overline{F}_n^{SP}$. The movement of the cylinders had a limitation of 40 mm in stroke length, therefore the compressed seat surface and corresponding force distribution depended on the initial height of the cylinders. To maintain symmetry amongst the cylinders, their position was controlled with respect to the seat symmetry plane XZ, meaning that left cylinders had the same height as their corresponding right ones.

2.3. Experimental conditions and procedure

Participants were instructed to test a total of 40 seat positions that simulated an economy class seat. The H-point location of an existing airplane seat following SAE J826 (2008) was used to define the position in x of the middle support with X_MS_L being fixed at 135 mm, and the position in z of the seat pan support with Z_SP_L = −98 mm. Two backrest angles from the vertical (A_SB = 10°, 20°) and three seat pan angles (A_SP = 0°, 5°, preferred) were used to define 6 A_SP/A_SB combinations. For each combination, 5 conditions were tested successively in the following order:

1 *Reference position with the initial cylinder height of 20 mm (CH = 20 mm)*. This position was used to determine seat pan length, foot support height and armrests position for each participant. The three backrest panels were positioned at specific anatomical points (occipital bone, T9 and L3). Their position in x was fixed at 135 mm in the seat back LCS. The seat pan length (X_SP_L, Fig. 1b) was fixed until there was approximately 70 mm (hand width) between the popliteal (behind the knee) and the front of the seat pan. Participants were asked to keep their back in contact with the lower and middle supports. The foot support was adjusted (Z_FS, Fig. 1b) until the knees were set at approximately 90°. Participants were also asked to place a rectangular foam of 100 mm (in thickness) between the knees to reduce postural variation (Fig. 2a). The foam was not used as seat cushion but only to standardize the seated posture. The armrests were self-positioned by subjects. Once participants were fitted to the seat, they were instructed to step off the experimental seat to zero all the force sensors. They were then asked to reposition themselves back on the experimental seat and look forward without use of the upper support. Measurements were recorded at a rate of 20 Hz for 1.25 s.