Objective and Subjective Evaluation of a New Airplane Seat with an Optimized Foam Support

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Abstract Thanks to a fully adjustable experimental seat, data of the preferred seat profile and compressed seat pan surface were collected from 36 differently sized people. Parametric models were developed to predict optimal seat profile parameters such as seat height, seat pan length, back profile angle as well as optimal compressed seat pan surface (C-surface) in function of a sitter's body size for a given set of seat pan and back angles. Using a population simulation approach, the distribution of the preferred seat profile parameters could be estimated. We proposed a so-called 95%tile C-surface, which encompasses 95% of individually optimized compressed seat pan surfaces of a target sitter population, as foam support to reduce amount of foam while maintaining a good pressure distribution. The present study aimed to verify if seats with the proposed pre-shaped foam support could improve seating comfort for airplane passengers. The 95%tile C-surface was used to define two new seats with two different cushions with a same thickness of 45 mm, one slightly softer and the other harder. 19 volunteers, selected by stature and BMI, tested the two new seats and a reference existing seat randomly. After an assessment of initial discomfort for five different postures (neutral, erect, relaxed, frontal sleeping and side sleeping), participants were instructed to watch a TV series for 50 minutes to experience a longer sitting. A same questionnaire was used to assess both initial and longer-term discomfort. In addition to the contact forces measured by the experimental seat, contact pressures at the back and seat pan were also measured by two Xsensor pressure maps. Pressure distributions and postural changes during the long sitting were analysed. The two new seats were globally preferred with a lower discomfort rating than the existing reference seat in agreement with the number of postural changes during the long sitting watching a movie. Properly pre-shaped surface as the one we suggested could be used as foam support to reduce the amount of foam while maintaining seating comfort.

Keywords: Discomfort, Aircraft seat, Pre-shaped foam support, Pressure distribution, In-chair movements

1 Introduction

An airplane passenger seat, like other seats in transportation, is used by thousands or millions of people. The seat should be designed to accommodate the maximum number of a target population by taking into account the variability of body size as well as the environment's constraints. Aircraft seat manufacturers are facing two strong requirements from airline companies: to reduce seat weight while continuously increasing seating comfort. In order to provide quantitative guidelines for improving seat design, data of the preferred seat profile and compressed seat pan surface were collected in function of seat pan and backrest angle from a sample of differently sized participants using a reconfigurable experimental seat we built recently (Beurier et al., 2017). Parametric models were obtained to predict optimal seat profile parameters in function of a sitter's anthropometric characteristics, seat pan angle and seat back angle (Wang et al., 2018). Using a population simulation approach, a sample of 500 males and 500 females from the CAESAR US civil population (Robinette et al., 2002) were generated randomly based on the distribution of relevant anthropometric dimensions. The distribution of the preferred seat profile parameters, such as seat height, seat pan length, back profile angle as well as optimal compressed seat pan surface (C-surface), was obtained by virtual population simulation (Wang and Beurier, 2018). We proposed a so-called 95%tile C-surface, which encompasses 95% of individually optimized compressed seat pan surfaces of a target sitter population, as foam support to reduce amount of foam while maintaining a good pressure distribution. We have hypothesized that the optimal C-surface as foam support could:

- reduce the amount of foam needed for a pressure distribution
- use a uniform foam without varying foam thickness and stiffness, thus simplifying cushion manufacturing process

As the optimal seat profile and C-surface were obtained from an initial comfort assessment approach with a very short sitting experience, it is therefore necessary to verify if the proposed optimal seat parameters are well perceived for a longer sitting duration.

In the present study, two new seat configurations were defined based on the proposed optimal seat parameters. The objective of the present study was to evaluate these two new seat configurations with respect to an existing reference seat Z300. Our hypothesis is that the two new seats with an optimal profile and pre-shaped foam support surface should be better than Z300 in terms of both subjective perception and objective measurements.

2 Materials and methods

2.1 Participants

Nineteen subjects participated in the experiment. They were selected by stature and BMI (body mass index)

- 6 short females (3 with BMI<24 (FSH), 3 with BMI>30 (FSO))
- 6 average height males 3 with BMI<26 (MAH), 3 with BMI>30 (MAO))
- 7 tall males (4 with BMI<26, (MTH), 3 with BMI>29 (MTO))

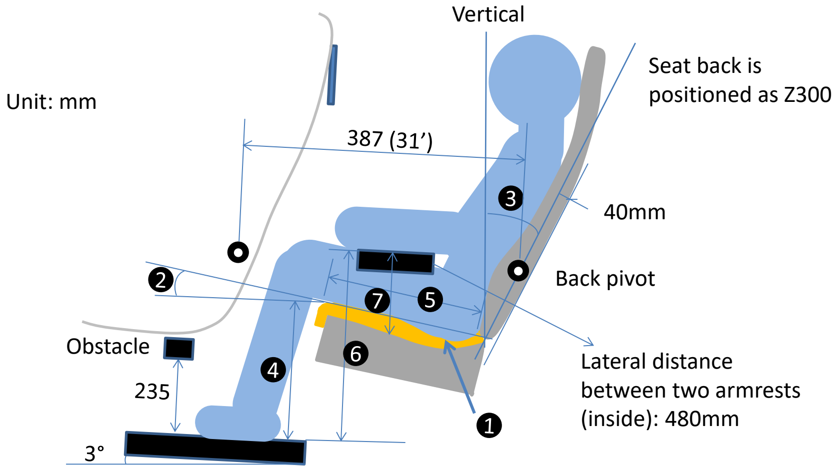
Prior to the experiment, participants were screened using a health questionnaire. They should already have a travel experience in an economics class long haul and be in good health condition for air travel. Participants who experienced any back injury or pain in the previous 3-months were excluded. The 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. Prior to experiment, main anthropometric dimensions such as stature, weight, sitting height etc. were measured for each participant. They were asked to dress with their own clothes for air travel.

2.2 Test conditions and experimental procedure

The optimal C-surface was used to define two seat configurations with a same pre-shaped support covered by two different foams with a thickness of 45 mm

- Cushion 5560: slightly softer
- Cushion 5580: slightly harder

The seat back of the reference seat Z300 was used for all test conditions. For the two new seat configurations, a slightly more inclined seat was used based on the preferred angles observed previously. Corresponding back angle was 22.4° slightly more reclined than Z300. The seat back was fixed on the upper support panel of the IFSTTAR experimental seat. Three seat pans could be put on the seat pan support of the experimental seat. In order to create a realistic environment, a frontal seat was added with an iPad tablet. Figure 1 shows the definition of the three tested seat configurations.



Cushion (1)	Seat pan angle (2)	Back angle (3)	Frontal edge height (4)	Seat pan length (5)	Armrest height (6)	Armrest height (7)
Z300	3.7°	20.0°	450	445	600	170+50*
5560	4.1°	22.4°	446	445	618	175+50*
5580	4.1°	22.4°	450	445	618	178+50*

Fig. 1. Definition of three seat configurations. Units are degree for angles and mm for length or height. A same Z300 seat back was used for all three seat configurations. All these parameters were measured when the seats were not occupied.

2.3 Experimental procedure and measurements

The experiment was organized in two sessions for each seat configuration: initial and long term assessment. An initial comfort was assessed for the 5 postures (Neutral, Relaxed, Erect, Frontal Sleeping, and Side Sleeping) during a short duration (<2 minutes). The posture 'neutral' was always tested the first and the responses from the questionnaire were collected. Four others were tested in a random order; only the global discomfort was rated. After the initial comfort assessment, participants were instructed to watch a TV series for 50 minutes. No specific instruction was given regarding the posture. After having watched the movie, the same questionnaire was proposed so that participants could assess the discomfort after a long term sitting experience.

Between two seat configuration tests, participants were asked to take a break of at least 10 minutes. Drinks and biscuits were proposed. The test order of these three conditions was randomized. The total duration including the welcoming and anthropometric measurements was about 4h30.

The questionnaire was composed of two parts, one for assessing the seat and the other for assessing body part discomfort. A multiple-choice question was designed for assessing the following seat parts: position of headrest and lumber support, seat pan length, seat pan cushion hardness, seat height, seat pan inclination, backrest inclination, space under the frontal seat, knee space, armrest position. The categorical partition scale CP50, from 0 (imperceptible) to 50 (extremely strong) or more (Shen and Parsons, 1997) was used for assessing the perceived discomfort of 8 body parts (neck, top, middle and low part of the back, buttock, middle and distal part of the thighs, calf) and the global perception.

In addition to the subjective responses from the questionnaire, the following objective variables during a trial were measured: contact forces at the foot support, seat pan, back support and armrests by the experimental seat, contact pressures at the back and seat pan by two Xsensor pressure-mapping systems (PX100.48.48.02, distance between two adjacent pressure cells 12.7 mm). The measurement frequencies for both experimental seat and pressure maps were respectively 25 and 2 hz for initial and long sitting sessions. Nine markers were attached on the shoulder, the belt, the knees and the shoes. Their positions were measured by a Vicon motion capture system at 30 Hz. A trigger device was used to generate starting and ending analog signals that could be recognized by both Vicon and force sensors from the experimental seat. In addition, a wand equipped with two markers visible by Vicon was used to press a specific area of the seat pressure pad for synchronizing Vicon and Xsensor measurements. All trials were also recorded by a video camera for visual inspection.

2.4 Data processing and analysis

The questionnaire responses were analyzed with help of STATGRAPHICS Centurion 18. Multi-factor ANOVA was performed on the CP50 ratings of the global discomfort as well as those of body parts, with explicative factors being sitting duration, seat configuration, and subject group. For the initial discomfort assessment, effects of sitting posture were also analyzed. For the categorical responses on the assessment of seat and its surrounding, contingency tables were generated and Chi-square test was used for comparing the responses between different test conditions and subject groups.

Concerning objective measures of seating discomfort, normal and shear forces on the seat pan as well as pressure distribution parameters for the neutral posture and postural changes or in-chair movements (ICM, Fenety et al., 2000, Sammonds, 2017) during the time of watching movie were investigated. Similar to the ones proposed by Zemp et al. (2016), more than 55 parameters were extracted from pressure distribution including peak pressure, mean pressure, standard deviation of pressure distribution, maximum gradient, mean gradient, standard deviation of the gradient, area for the whole contact area, the pressure profile and the four sub contact areas defined in Fig.2. Postural changes during the time of watching movie were detected by comparing the contact forces at the feet support, seat pan, back and armrests as well as in the row and column positions of centers of pressure (COP) on the seat pan and back between two adjacent frames. All contact forces were normalized by body weight. If one of these eight parameters had a change greater than their corresponding threshold, an ICM started until to the frame the changes of all eight parameters with respect to the previous frame became smaller than their respective thresholds. In the present work, the thresholds were 1% of body weight for the four contact forces and 1 unit (12.7 mm) in both row and column directions for two COPs.

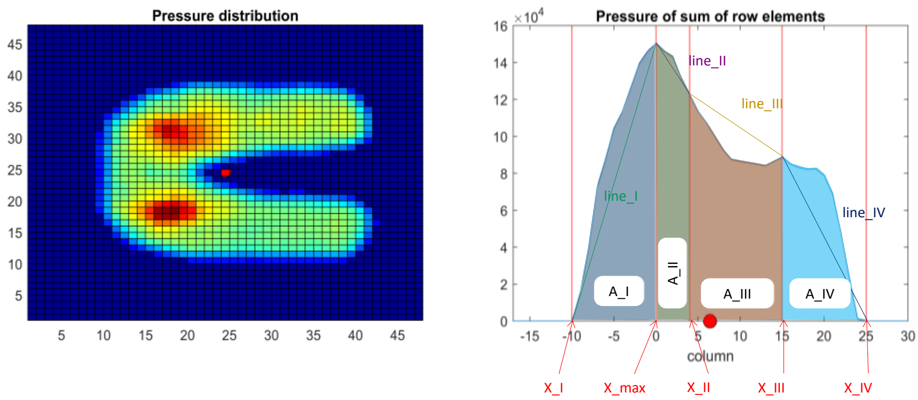


Fig. 2. Seat pan pressure distribution parameters. The pressure profile, defined as the sum of pressures by the sensors of each column, is centered at the peak pressure and divided into four sections. X_I and X_IV correspond to the border of the contact area, X_max the peak pressure position. X_II is the position of the point separating the two thigh contact areas. X_III is the mid point between X_II and X_IV.

3 Results

3.1 Questionnaire responses

Significant differences in initial discomfort CP50 ratings between 6 subject groups and 3 seat configurations were found. The seat configuration 5580 had the lowest discomfort rating, significantly lower than Z300. The subject group MAO (average height male obese) had the lowest discomfort whereas the groups MTO (male tall obese) and FSO (obese short female) had the highest discomfort. However, no significant difference in CP50 was found between five sitting postures. When comparing the initial CP50 ratings of the neutral posture with those after 50 minutes sitting; only sitting duration had a significant effect, whereas no effect was found for both subject group and seat configuration. Slightly but significantly higher discomfort rating was obtained after 50 minutes sitting. On average, the discomfort ratings were 15.9 and 19.7 respectively for initial and longer sitting assessments.

As for the global discomfort rating, sitting duration significantly affected the perception of all body parts except for the neck and calf. Higher discomfort was generally perceived for longer sitting. No significant difference between three seats was observed except for the neck. Significant differences between six subject groups were observed almost for all body parts except for the neck. Lower discomfort was perceived in the buttock and thigh for the participants with higher BMI.

Main effects of sitting duration, seat configuration and subject group were analyzed by comparing the frequencies of the categorical responses to the questions posed in the questionnaire. Concerning the effect of sitting duration, only the responses regarding the seat hardness differed significantly (P-Value=0.0193). Higher percentage of 'a little bit too hard' and 'too hard' were obtained after 50 minutes sitting. When comparing three seat configurations, only the responses concerning the seat hardness (P-Value=0.023), seat height (P-Value=0.006) and seat inclination (P-value=0.0106) significantly differed. The highest percentage of the responses 'good hardness' and 'good seat pan inclination' was obtained for 5580, followed by 5560 and Z300.

3.2 Seat pan contact force and pressure distribution parameters

The seat pan contact forces and pressure distribution parameters of the short sitting trials for the four left-right symmetric postures 'NE', 'RL', 'ER','FS' were analyzed. Participant group and posture affected most of these dependent responses. When comparing three seat configurations, normalized shear forces for 5580 and 5560 were 8.95% and 9.21% on average, significantly lower than Z300 (12.29%). They also more evenly distributed pressure with larger contact area, lower peak force, lower pressure standard deviation, larger contact area (A_III and A_IV) and higher gradient (Grad_IV_std) near the knees.

3.3 Postural changes

547 postural changes were identified over 57 trials (19 participants x 3 seats), with an average less than 10 changes per trial during a 50 minutes sitting. Depending on the pattern of force transfer between four body supports (seat pan, foot support, back and armrests) during a postural change, 27 types of ICM were identified. The first two most frequently observed movements corresponded to changing feet position, resulting in a small variation of contact force on the seat pan. They represent 48.1% of total number postural changes. These postural changes may not be of interest if postural changes due to sitting discomfort are supposed to relieve pressure of compressed body parts. By excluding the postural changes mainly implying feet movements, the numbers of postural changes for the configurations 5560 and 5580 were 82 and 86, well smaller than for Z300, which had 116 (Tab.1). When comparing six participant groups, MTH (male tall healthy) had the highest number of ICM with an average per trial of 7.42, followed by FSH (female short healthy), MTO (male tall obese).

Table 1. Numbers of postural changes and percentages by seat configuration and participant group. Postural changes mainly implying feet movements are excluded.

Configuration	*FSH (9*)*	*FSO (9)*	*MAH (9)*	*MAO (9)*	*MTH (12)*	*MTO (9)*	*Row Total (57)*
5560	23	6	10	8	18	17	82
	8.10%	2.11%	3.52%	2.82%	6.34%	5.99%	28.87%
5580	13	6	15	16	27	9	86
	4.58%	2.11%	5.28%	5.63%	9.51%	3.17%	30.28%
Z300	19	8	6	19	44	20	116
	6.69%	2.82%	2.11%	6.69%	15.49%	7.04%	40.85%
Column Total	55	20	31	43	89	46	284
	19.37%	7.04%	10.92%	15.14%	31.34%	16.20%	100.00%
Average per trial	6.11	2.22	3.44	4.78	7.42	5.11	4.98

* *Number of trials*

4 Concluding remarks

In the present work, two new airplane seats with an optimized foam support were compared with an existing reference seat by 19 differently sized volunteers. Both subjective and objective measures were investigated. The two new seats exhibited smaller shear force and more uniformly distributed pressure on the seat pan, as expected. Interestingly, lower number of postural changes during a 50 minutes siting was also observed for the new seats, though no significant difference in global discomfort rating were observed between new and existing seats after a 50 minutes sitting. Objective measures tended to show that the optimally pre-shaped foam support (Wang and Beurier, 2018) and preferred seat profile (Wang et al. 2018) we obtained experimentally are useful for improving design. Further studies are needed to optimize foam characteristics (density, thickness etc) in combination with the proposed pre-shaped foam support. Sitting duration longer than 50 minutes is certainly necessary for assessing proposed new seats.

Acknowledgments The work is partly supported by Direction Générale de l'Aviation Civile (DGAC project n°2014 930818).

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