The influence of the angle of attack on passenger comfort

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Abstract

The angle of attack (AOA) of an airplane changes the direction of the gravitational force on passengers and thereby might influence passengers' flying experience. However, the contribution of the AOA regarding comfort/discomfort is not fully explored. In this paper, we aim to fill this knowledge gap by identifying the relationships between the perceived comfort/ discomfort of passengers and the AOA of the plane during the take-off and climbing phases of a flight. An experiment is conducted in a Boeing 737 fuselage where 10 participants were recruited. Each participant experiences 3 setups of seats with different AOAs (3, 14 and 18 degrees) for 20 minutes, respectively. Participants were asked to complete several sets of questionnaires during each session, and their heart rate and the pressure on the seat and the backrest were recorded as well. Experiment results indicated that participants experienced 14-degree as the most comfortable angle with the lowest discomfort, which might be useful for airlines in setting up the take-off and climbing procedure.

Keywords

Seat inclination; comfort; take-off/climbing

Introduction

Passengers' comfort experience in flights is one of the key elements in selecting airlines (Balcombe et al., 2009). Previous studies have analysed factors influencing comfort/discomfort, e.g. space of the seat, in-flight service and noise (Brindisi & Concilio, 2008; Mellert et al., 2008)(Mellert et al., 2008). However, most discussions focused on the sitting comfort during the cruising stage of the flight, and only a few paid attentions to comfort of the passengers in the take-off and climbing phases. During these two phases, which may take up to 30 minutes, the plane has an inclination angle (angle of attack, AOA) to climb to the cruising height. According to the procedure recommended by Boeing, the AOA of a 737 plane varies between 15-18 degrees (Wakefield & Dubuque, 2009) in these phases. This angle changes the seat inclination angle with respect to the ground, and therefore changes the direction of the gravitational force of passengers' body against the seat. Furthermore, in these two phases, the backrest of the seat is put upright and the seat belt is often fastened, which might make it difficult for passengers to seek for a comfortable posture themselves.

The changed direction of the gravitational force may influence the pressure distribution between the body and the seat. Literature suggested that there is a relationship between pressure distributions and the discomfort experiences (Smulders et al., 2016). A large contact area between the seat pan and the human body often decreases discomfort. It is also confirmed that lower mean pressure and an even pressure distribution will create more comfort (Zemp et al., 2015). Besides, many studies have investigated that the inclination of the trunk may affect the physical state, muscular activities (Munoz & Rougier, 2011) as well as posture mobility (Cherng et al., 2009). However, these studies were mainly carried out in the clinical environment with the focus on patients. The combined effects on comfort/discomfort of healthy passengers in the take-off and climbing phases of a flight are still to be explored.

The aim of this research is to fill in the knowledge gap regarding the influence of inclination of the seat on comfort. The research question is: *What is the relationship between the comfort/discomfort experience of the passengers regarding the AOA of the plane during the take-off and climbing phases of a flight.*

Methods

Setup

An experiment was set up in the Boeing 737 fuselage at the Delft University of Technology (Fig.1). To simulate the scenario in a realistic context, two rows of seats were used in this experiment while participants sit in the middle of the second row. The seats were mounted to a large platform which can be adjusted to different inclination angles. The width of the seat was 17 inch and the pitch was 30 inches. Three inclination angles were tested in this experiment. The 3-degree was chosen to simulate the cruising stage, and the 14-degree and 18-degree were selected to simulate the minimal and maximal AOAs. The backrest was adjusted to the upright angle and the seat belt was always fastened as well. The experiment setup and the protocol were approved by the Human Research Ethical Committee (HREC) of Delft University of Technology.

Figure 1: Setup of the experiment

Figure 2: The measurement stool

Table 1: Anthropometric measurements of subjects

	Mean	SD
Age	25.9	1.81
Height	162.6	6.02
Weight	50	3.92
BMI	18.89	1.54
Hip breadth	368.1	21.64
Popliteal height	451.5	24.45
Buttock-popliteal depth	465.7	22.22

Participants & Measurements

Ten international participants (2 male and 8 female) joined the experiment. The mean age is 25.9±1.81. To acquire the anthropometric data, we used the measurement approach as described in DINED (Huysmans & Molenbroek, 2021) which includes the use of a stool (see Fig.2). Besides, the height and weight of participants were measured by a tape measure and a weighing scale, respectively. The measurement results and the calculated BMI values are presented in Table 1.

Two pressure mats (Brand: Xsensor) were put on the seat pan and backrest to measure pressure distribution data regarding the buttock and back of the subject, respectively. A pressure mat consists of 48 by 48 measuring cells; each has a size of 12.7 by 12.7 mm. Cameras were installed in the front and at the side of the subject to record the scenario as well as the movements of the subjects during the experiment. All participants wear a Scosche Rhythm24 armband at the left forearm. Their heart rate and the RR intervals were logged throughout the experiment.

A set of questionnaires, which includes a 10-likert scale overall comfort and discomfort questionnaire and a local postural discomfort (LPD) questionnaire was asked several times in the experiment (Anjani et al., 2021). In the comfort and discomfort questionnaire, participants are able to rate the perceived comfort and discomfort regarding the overall experience at a given time span. Using the LPD questionnaire, participants evaluate the perceived discomfort regarding different areas of body. In this experiment, besides all regions at the back of the body, participants are also able to rate the discomfort levels regarding different regions in the front of the body. For filling the questionnaire, participants were instructed that for a region(s) that she/he feels no discomfort, she/he can skip the question regarding this region(s). To avoid the effect on short term memory and to avoid the confusion of the word comfort and discomfort in different languages and cultures (Vink et al., 2021), we asked the question on comfort in the beginning, followed by the LPD questionnaire, and at the end of the questionnaire, we asked the question regarding the overall discomfort. Besides this set of questionnaires, participants were also asked to rank the 3 setups regarding comfort/discomfort levels after the experiment, i.e. after experiencing all setups.

Protocols

Two researchers hosted each experiment where they welcome the participants first. After a short introduction of the setup and the procedure of the experiment, the participants signed an informed consent. She/he then worn the Scosche Rhythm24 armband on the forearm, and sat on the seat with the first setup and fastened the safe belt. Before the start of the timer, the participant had several minutes to adapt to the setup as they did in the air travel. During this time, he/she completed questionnaire set 1 (incl. Comfort/discomfort questionnaire and LPD). As the AOA were adjusted to 3, 14 and 18 degrees in 3 setups, the sequence of the setups that the participant experienced was in a Latin square order. After finishing questionnaire 1, she/he sat for 20 minutes in total to simulate the duration of the take-off and climbing phases of a normal commercial flight. During this period, the participant completed questionnaire set 2 (same as the first set) after about 10 minutes. This took approximately 1 minute. Another 10 minutes after finishing the second set of questionnaires, she/he completed questionnaire set 3, which was the same as previous sets. In this period, the pressures on her/his buttock and the back were recorded in a 1 HZ frequency and her/his heart rate was continuously monitored and logged as well.

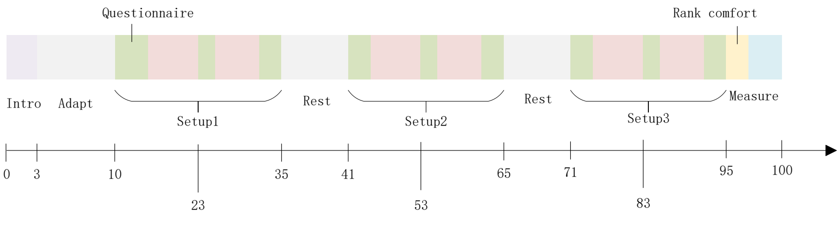

Figure 3: Experiment procedure

After finishing the first setup, he/she left the seat and took a 7-10 minutes break before experiencing the next setting. During the break, she/he was asked to walk along the aisle and had some water and snacks to “reset” the comfort/discomfort status. After a participant experienced all the 3 settings, her/his anthropometric data were measured by a researcher using the methods described in the previous section. Meanwhile, she/he was asked to rank the 3 setups regarding comfort/discomfort levels. Figure 3 illustrates the complete procedure of the experiment in a chronological order regarding a participant.

Data analysis

The collected data on heart rate, pressure (distributions), anthropometrics and results of the questionnaires were further analysed. For all logged RR intervals, a one-minute window was used to extract all HRV features using a self-developed Python program. The pressure recordings were processed by a self-developed program for calculating the mean pressure and the contact areas on the seat and the backrest, respectively.

All anthropometric data and the results of questionnaires were digitized in Excel where empty answers in the LPD questionnaires, they were filled in 0 by default. The mean values of the ratings of all subjects were calculated and the Wilcoxon signed rank test (using SPSS) was used (P<.05) to identify if there are differences between any two of the three conditions.

Results and discussion

Overall comfort/discomfort

Figure 4 presents the mean scores of overall comfort and discomfort of the 3 settings over time. Compared with the control group (3-degree), participants comfort levels decreased slightly in inclined settings. However, as the AOA gets larger, the perceived discomfort levels developed over time.

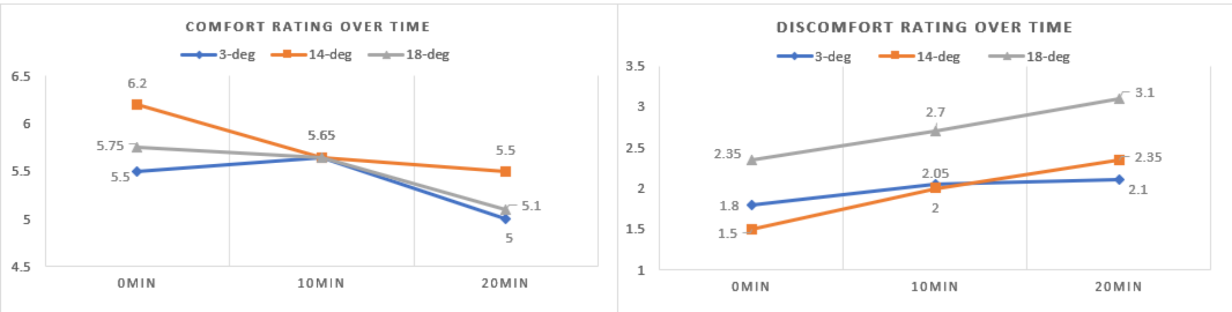

Figure 4: overall comfort/discomfort ratings over time under 3 settings

Table 3 Overall discomfort ratings under 3 settings for each subject

NO.	3-deg	14-deg	18-deg
1	3.5	5.5	4
2	3	0	1.5
3	22	18	24
4	3	4	7
5	8	7	9
6	6	5	15
7	3	8	6
8	6	4	3
9	4	3	8
10	1	4	4

Table 3 shows the mean overall discomfort scores for each condition regarding each subject. The Wilcoxon signed rank test shows that the perceived discomfort between 3- and 18-degrees AOA and between 14- and 18- degrees are significantly different ($p < .05$). However, regarding the 3-degree and 14-degree setups, there is no significant difference ($p=0.42$)

LPD questionnaire

Regarding discomfort on different body parts, results from LPD questionnaires (Figure 5) showed that the back of the neck and the lower waist scored highest on discomfort for all the 3 settings. It can also be noticed that with a larger AOA, more body parts of the participants get higher levels of discomfort.

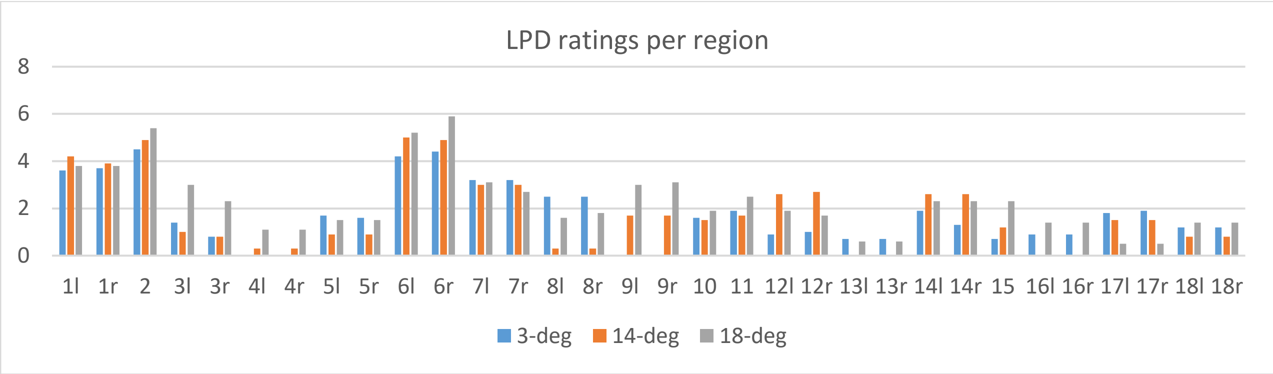

Figure 5: Average discomfort ratings in LPD questionnaires for 3 settings

HRV

The values of HRV features for each setting were computed with a 1-minute interval and averaged over 20-minutes to identify the correlations between the HRV features and comfort/discomfort ratings in 3 settings (Table 5). 3-degree setting had the lowest mean values compared with the other two regarding SDNN, pNN50, rMSSD and Mean NN. Mean HR was the highest under 3-degree condition. Yet for most features the relationships were not significantly different.

Table 5 HRV Features per setting

	3-deg	14-deg	18-deg
SDNN	55.3	60.4	58.3
pNN50	28.6	32.8	34.6
rMSSD	55.3	61.1	61.1
Mean NN	801.4	843.4	837.6
Mean HR	75.9	72.8	72.3

Pearson's correlation coefficients were calculated between the mean of HRV features of 10 subjects and the corresponding comfort/discomfort rating (Table 6). The results indicate that Mean NN and Mean HR were significantly correlated to both the comfort and discomfort ratings.

Table 6 Pearson' correlation of values of HRV features and subjective comfort/discomfort ratings at corresponding settings (**, p<.05; **, p< .01*)

Parameters	**discomfort**	**comfort**
SDNN	0.0756	0.2721
pNN50	0.1806	0.274
rMSSD	0.0733	0.329
Mean NN	0.5778**	-0.5079**
Mean HR	-0.5263**	0.4409*

Mean HR was also found to have a larger correlation to discomfort (r=.5263, p<.01) than comfort (r=.4409, p<.05). It was different to the results of the study of Beggiato et al. 2018. Mean NN was found to be significantly correlated to both comfort (r=-.5079, p<.01) and discomfort (r=.5778, p<.01). This is in accordance with previous studies, where it was found that the mean NN was correlated to physiological stress and physical pain (Terkelsen et al., 2005). This indicates that both stress and pain are the constructs of comfort and discomfort.

Table 7 Comfort ranking of 3 settings

	3-degree	**14-degree**	**18-degree**
Mean ranking	2.3	1.4	2.2

The comfort rankings given by participants after all three settings showed that they experienced the 14-degrees setting as most comfortable while the 3-degrees is the least comfortable. The rankings were consistent with the results of mean NN. Previous research found that sitting on a backward tilting seat may have benefits on pressure relief and increased blood flow (Sonenblum & Sprigle, 2011), which might be a possible explanation of this phenomena.

Pressure distribution

Table 8 presents the contact areas and mean pressure of these 3 settings, which are visualized in Figure 6. In the figure, the horizonal axis and the vertical axis stands for the index of the cells (48x48) in two directions and the colour represents the amplitude of the pressure. As expected, the mean pressure on the backrest increased as the angle becomes larger, while it decreases on the buttock. However, with respect to total force on the buttock, it increased slightly from 14-degree setting to 18-degree. It might mean that the supporting force from the floor on participants' feet changed, which may imply that participants changed their sitting posture. The contact areas on both the backrest and the buttock increased as the inclination angle gets larger. It can be inferred that people tend to sit more to the back of the seat in an inclined configuration, which results in larger contact areas.

Table 8: Contact area (cm^2), mean pressure (N/cm^2) and total force (N)

	Top			**Bottom**		
AOA	Contact area	Mean Pressure	Total	Contact area	Mean Pressure	Total
3-deg	887.1	0.118	104.7	1484	0.318	471.9
14-deg	1100	0.128	140.8	1555	0.275	427.6
18-deg	1161	0.138	160.2	1642	0.261	428.6

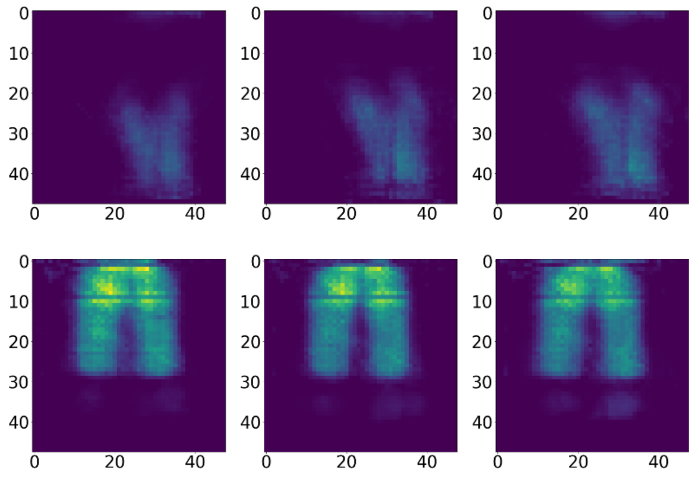

Figure 6: pressure map (left to right: 3-deg, 14-deg, 18-deg)

Limitations

This study was the first phase of the exploration where only a limited number of participants were recruited. The short stature of the population might explain that there were only a few participants that reported discomfort about the leg rooms. Besides, in the experiment, participants were allowed to talk as in the real flight, and the talking time and duration were not precisely controlled and recorded. This may have affected the perceived comfort/discomfort of participants.

Conclusion

In this research, 10 participants experienced 3 setups of the angle of attack (AOA) for 20 minutes. Subjective and objective measures indicated that the AOA is not linearly related to perceived comfort and discomfort of passengers. A certain degree of inclination might improve the feeling of comfort. Besides, it was found that 14-degree AOA is experienced as more comfortable than 18 degrees, which might be useful for airlines in setting up the take-off and climbing procedure.

References

Balcombe, K., Fraser, I., & Harris, L. (2009). Consumer willingness to pay for in-flight service and comfort levels: A choice experiment. *Journal of Air Transport Management*, *15*(5), 221–226. https://doi.org/10.1016/j.jairtraman.2008.12.005

Beggiato, M., Hartwich, F., & Krems, J. (2018). Using Smartbands, Pupillometry and Body Motion to Detect Discomfort in Automated Driving. *Frontiers in Human Neuroscience*, *12*. https://doi.org/10.3389/fnhum.2018.00338

Brindisi, A., & Concilio, A. (2008). Passengers' comfort modeling inside aircraft. *Journal of Aircraft*, *45*(6), 2001–2008. https://doi.org/10.2514/1.36305

Cherng, R. J., Lin, H. C., Ju, Y. H., & Ho, C. S. (2009). Effect of seat surface inclination on postural stability and forward reaching efficiency in children with spastic cerebral palsy. *Research in Developmental Disabilities*, *30*(6), 1420–1427. https://doi.org/10.1016/j.ridd.2009.07.002

Huysmans, T., & Molenbroek, J. F. M. (2021). *DINED / Anthropometry in design*.

Mellert, V., Baumann, I., Freese, N., & Weber, R. (2008). Impact of sound and vibration on health, travel comfort and performance of flight attendants and pilots. *Aerospace Science and Technology*, *12*(1), 18–25. https://doi.org/10.1016/j.ast.2007.10.009

Munoz, F., & Rougier, P. R. (2011). Estimation of centre of gravity movements in sitting posture: Application to trunk backward tilt. *Journal of Biomechanics*, *44*(9), 1771–1775. https://doi.org/10.1016/j.jbiomech.2011.04.008

Smulders, M., Berghman, K., Koenraads, M., Kane, J. A., Krishna, K., Carter, T. K., & Schultheis, U. (2016). Comfort and pressure distribution in a human contour shaped aircraft seat (developed with 3D scans of the human body). *Work*, *54*(4), 925–940. https://doi.org/10.3233/WOR-162363

Sonenblum, S. E., & Sprigle, S. H. (2011). The impact of tilting on blood flow and localized tissue loading. *Journal of Tissue Viability*, *20*(1), 3–13. https://doi.org/10.1016/j.jtv.2010.10.001

Terkelsen, A. J., Mølgaard, H., Hansen, J., Andersen, O. K., & Jensen, T. S. (2005). Acute pain increases heart rate: Differential mechanisms during rest and mental stress. *Autonomic Neuroscience*, *121*(1–2), 101–109. https://doi.org/10.1016/j.autneu.2005.07.001

Vink, P., Anjani, S., Udomboonyanupap, S., Torkashvand, G., Albin, T., Miguez, S., Li, W., Reuter, C., & Vanacore, A. (2021). Differences and similarities in comfort and discomfort experience in nine countries in Asia, the Americas and Europe. *Ergonomics*, *64*(5), 553–570. https://doi.org/10.1080/00140139.2020.1853248

Zemp, R., Taylor, W. R., & Lorenzetti, S. (2015). Are pressure measurements effective in the assessment of office chair comfort/discomfort? A review. *Applied Ergonomics*, *48*, 273–282. https://doi.org/10.1016/j.apergo.2014.12.010