CEAS Aeronautical Journal (2023) 14:491–508
https://doi.org/10.1007/s13272-023-00640-7

ORIGINAL PAPER

Cabin aircraft comfort evaluation over high fidelity simulated flight

Antonio Esposito[1] · **Calogero Orlando**[1] · **Andrea Alaimo**[1]

Received: 18 July 2022 / Revised: 16 November 2022 / Accepted: 16 January 2023 / Published online: 27 January 2023

Abstract

The primary purpose of this paper is to investigate the possibility of using a Full Flight Simulator (FFS) as an experimental setup for passengers' comfort analysis. Results based on subjective measurements are thus presented to assess comfort levels experienced during a simulated flight. A preliminary investigation has been conducted on a sample of 125 candidates to gain insight into the elements influencing the comfort level perceived based on the participants' actual flight experience; this suggested that the seat configuration is of great importance. Then, the experiment carried out by means of the FFS have been conducted on a reduced sample of 20 candidates for economic and organizational reasons. The behaviour of the 65% of the candidates has been analysed in a seating configuration comparable to the seat of a business-class aircraft. While the experience of the remaining 35% has been studied in an economy-type seat arrangement. Although the main variable under consideration was the seat, several environmental parameters were also considered during the experimental tests to evaluate their effects on perceived comfort level. During each simulated flight, passengers have been subjected to different levels of light intensity, noise, temperature and vibration associated with the different flight phases. Subjective data were collected using a questionnaire concerning every parameter and submitted to the passengers for each flight phase. The aim of varying the environmental parameters inside the cabin was to look for a relation between the subjective comfort level and each comfort parameter. In addition to perceived comfort based on the questionnaire, statistical analysis with parametric and non parametric tests revealed significant effects of environmental variables.

Keywords Passenger comfort · Flight simulation · Subjective assessment · Cabin aircraft · Parametric and Nonparametric tests

1 Introduction

In the COVID-19 post-pandemic, people are regularly recovering their transport activity [1]; they travel for many reasons, such as work or pleasure. In this framework, the airplane is back one of the leading used transportation means whose use is constantly growing, determining a great business opportunity for airlines. Passengers choose airlines taking mainly into account some parameters that regard the flight itself, namely the price of the flight or the travel time. Other parameters that passengers consider to decide which airline they are flying with are related to marketing and previous comfort experience. Therefore, it is rightful to think of an increase in comfort to attract more passengers and create a possibility of financial growth for airlines [2]. Passenger comfort can be defined as a state of psycho-physiological balance between a human being and the environment surrounding him. It is always a subjective sensation of wellness [3]. It follows that the design of comfort is a challenging task from an engineering perspective since each passenger has its sensation of comfort, which in turn means that the comfort cannot be uniquely and quantitatively defined. Despite this difficulty, it is possible to design a passenger cabin by considering some essential parameters in the project's preliminary phase coming from the passenger's personal experience. For example, one possible approach is assessing passenger comfort based on different cabin layouts in terms of coatings, ergonomics, microclimate, noise and vibration levels, and ambient lighting. Thus, despite all the

✉ Antonio Esposito
antonio.esposito@unikore.it

Calogero Orlando
calogero.orlando@unikore.it

Andrea Alaimo
andrea.alaimo@unikore.it

[1] Faculty of Engineering and Architecture, Kore University of Enna, Cittadella Universitaria, 194100 Enna, Italy

new cabin design and construction technologies, the most critical design parameter to obtain “comfort” is the passenger experience.

The first part of this work describes the different parameters that affect cabin comfort. The influence that cabin lighting can have on passenger comfort has been discussed as well as the effects on comfort induced by the microclimatic conditions of the cabin in terms of air temperature and humidity. The dependence of comfort on noise and vibrations and the ergonomic aspects of the seat have also been considered.

The second section initially describes the syllabus of flight missions accounting for all possible environmental arrangements studied. Subsequently, the questionnaire for subjective analysis is detailed and presented; afterward, the section describes the tools used to measure the studied parameters and experimental setup with passenger seat configurations.

The third section presents and comments on the results collected from the experimental campaign. The flow model of data collection and analyses is initially introduced in the section; then, it follows the description of the sample and preliminary statistical analysis of collected responses. The results of experimental tests are analyzed regarding the seat configurations and the levels of light, temperature, noise, and vibration settings.

The conclusion section presents an overview of the results obtained and possible future developments.

1.1 Cabin comfort and ergonomics

The passengers spend several hours seated in airplanes while they are exposed to social, environmental and physical stimuli. The seat ergonomics, therefore, represents an important part of the perception of comfort. The seat comfort experience can be described in terms of a series of indexes such as “feeling relaxed and restored” or, on the contrary, having the “feeling of fatigue or heavy legs” [4]. However, it should be pointed out that the seat comfort experience is largely influenced by the passengers’ expectation of the flight along with their tendency to stay still or not during the flight. Moreover, it should also be mentioned that other important factors influencing seat comfort are the legroom area, the seat tilt adjustment and the environment of the cabin [5, 6].

De Looze et al. [7] distinguish three latent factors influencing sitting comfort and discomfort: the human, seat, and context levels. In particular, physical capacity and expectation affect the human; seat material features with aesthetic design influence the comfort; the environment and psychosocial aspects impact the context level. The scheme proposed by De Looze et al. was replaced by Hiemstra-van Mastrigt et al. [6] who focused their literature review on passenger seat comfort and discomfort in a human-product context interaction. Discomfort is associated with sensations of pain, soreness, and numbness and is driven by physical constraints in the design. Comfort, on the other hand, is related to feelings of well-being and relaxation and can be influenced by aesthetic appearance. For instance, at the context level, the physical environment has an influence on sitting discomfort and comfort, whereas, at the seat level, aesthetic design can influence sitting comfort. The models of De Looze et al. [7] contribute to understand the concepts of ‘comfort’ and ‘discomfort’, but they are useless for predicting either comfort or discomfort.

During the research, activity carried out by Kremser et al. [5], the subjects evaluated their feelings about the different tilt angle of the seat backrest and the available legroom spaces. At first, the passengers have been asked to rate on a Likert scale the agreement of the sentence with the flight scenario accounted for during the experimental campaign. In detail, the used Likert scale ranged from 1 (strongly disagree) to 5 (strongly agree). Successively, the passengers have been asked to rate their general level of wellness on a scale from1 (lowest level of wellness) to 10 (highest level of wellness). Correlating the subjective evaluations with the objective measures, it has been found that the wheelbase of the seats for maximum wellness varies from 34 to 42 inches and legroom space ranges from 32 to 40 inches, depending on the anthropometry of the passenger [6]. It has thus been found that comfort does not simply grow with a wider wheelbase, but there is a critical point where larger spaces for the legs lead to less wellness. The optimum seat inclination is heavily influenced by the knee-hip distance. The influence of visual perception on the general wellness of passengers was also shown. The spatial perception of subjects with a lower height can be governed by the feeling of being in limited spaces.

Many researchers have focused over the years on seat ergonomics as a fundamental element of comfort for the different transport means; among these, a recent work by Molenbroek [8] investigates changes in spaces over the past several decades and discusses the impact of those changes on seating in transport, with particular attention to airliners.

Therefore, the aim of the present study is to investigate whether it is possible to predict passenger seat comfort and discomfort on the basis of the context and seat characteristics. With respect to the experiment carried out in the present work, one of the seats employed has a position control, therefore it was decided to fix the distance between the seats equal to 38 inches in accordance with the results obtained by Kremser et al. [5].

Taking into account the aforementioned points, it can be concluded that there exist several parameters to be considered. However, since the aim of the present work is the overall comfort evaluation and considering that a “too long” questionnaire can weary and bore the passengers [9], nullifying the validity of a comfort subjective evaluation campaign, it has been decided to acquire seat comfort information by address just three questions to each passenger for each flight phase.

1.2 Cabin lighting comfort

The position of the cabin light, both direct for reading and indirect, is a factor that can positively or negatively influence passenger comfort. From an objective point of view, some factors that contribute to passengers' discomfort coming from the cabin light are the colour, the colour of the objects, the brightness, the intensity, the colour temperature, the contrast and the reflection of objects [10]. In particular, Vertamatti and Jurandir [10] arranged a regional aircraft simulator cabin lighting system with LEDs in such a way to control the lights colour among CW (cold white), RGB (red, green, blue) and WW (warm white). They asked the passengers to evaluate their perception of comfort underlighting combinations during the boarding, cruise, on-board service, and landing. The subjective evaluation was based on the psychometric method of Semantic Differential [10] with 15 pairs of adjectives. Participants evaluated their perception of lighting by marking a point on an unclassified line, with bipolar adjectives at the extremes. The points collected were converted into real numbers rounded to the tenth and then analysed statistically. The result of Vertamatti and Jurandir [10] research was that different colours could be used in different phases of flight to maximize the comfort level. In particular, the white colour light proved to be inadequate in many regards, while the orange and blue colours, in most evaluations, had satisfactory comfort indexes.

From a subjective point of view, the psychological effects of lighting should also be considered. For example, [11] and also [12] discuss how the colour of lighting can be used to influence the thermal comfort of the passenger. The discomfort also depends on the time of exposure and is obviously related to some factors such as age, the asymmetry of the visual system or the eyes movement [13, 14]. Using a cabin of a single-aisle aircraft under realistic condition, Albers et al. [12] examine whether the use of coloured light can influence a group of 199 aircraft passengers in terms of temperature sensations and the climate perception. Two lighting scenarios were combined with different temperatures, and results observed in the whole sample show a relationship between yellow and blue colour on climate perception. The results of Albers et al. [12] according to the analysis proposed by Winzen et al [11] lead us to next cabin comfort aspect.

In this work, to design the questionnaire, the semantic differential method was used. However, unlike the work conducted by Vertamatti and Jurandir [10], the focus of this work was on the light intensity, because analysis of the shade of colours would require changes to the simulator lighting system. Again, to lower the burden of the questionnaire, two questions for the evaluation of the cabin lighting have been asked to passenger for each flight segments.

1.3 Cabin climate comfort

The cabin climate is a primary factor that influences the comfort of passengers during a flight. Standards and guidelines relating to thermal comfort have been developed to define comfort limits for climatic parameters such as temperature, airspeed, humidity and air quality [15]. These Standards, however, refer to the experience of an "average passenger" and do not take into account the differences existing in feelings of comfort between, for example, women and men or different physiological health [16, 17]. Few literature reviews have been done on comfort related to the aircraft cabin environment [18].

Regarding the climatic awareness in the cabins of the aircraft, Marggraf-Micheel and Jaeger [19] reported differences in the assessment of climate parameters for different "types of climate". Possible causes are differences in metabolic rate, clothing and the asymmetry irradiation of the cabin. The individual difference seems to be the main factor, however, passengers that move the local air nozzle have been found to have a narrower acceptance threshold or a greater expectation regarding the cabin environment [20]. Maier and Marggraf-Micheel [21] show that air temperature significantly impacts thermal comfort compared to relative humidity and wind speed. However, recent studies [22–24] have shown that personalized air supply systems in the aircraft cabin can improve the air quality close to the passengers' seats. Winzen and Marggraf-Micheel [19] conducted a study on a model of Dornier 728 exposing 60 subjects to different thermal scenarios by varying the temperature, humidity and airspeed in the cabin. In their work Winzen and Marggraf-Micheel [19] proposed a working model according to which a certain climate situation is objectively affected by several parameters (e.g. temperature, air velocity, humidity), these parameters have an effect on the passengers and are perceived separately regarding their intensity (low or high). As a second step, an evaluation takes place, where the passengers determine how comfortable each parameter is. Thermal comfort can be derived from the integration of these evaluations. The analyses showed that a higher average cabin temperature during cruising seems to have induced the impression of having a lower airflow and air quality. However, passengers preferred the warmer scenario to the colder one. The results also confirmed that individual preferences related to climatic parameters influence how climate parameters are perceived. Finally, expectations regarding the climatic situation in a cabin of an airplane influenced feelings of comfort.

In this study, it was decided to consider two parameters: the temperature and air quality. The other two parameters humidity and air velocity proposed by Winzen and Marggraf-Micheel [19] were not considered. In fact, there are no adjustable nozzle vents near the passenger seats, therefore direct air-conditioning effect cannot be easily evaluated. In addition, the humidity level inside the simulator is constantly kept below 60% to avoid possible damage to the electronic equipment on board.

1.4 Cabin noise and vibration comfort

The noise level has a negative impact on the feeling of comfort and increases awareness of other aspects that compromise wellness, e.g. headache and fatigue [25]. Pennig et al. [26] examined the effect of cabin noise on passenger comfort during short-haul flights. The experiment considered three different Sound Pressure Levels - SPLs and three different frequencies representative of the positions of the seats during the cruise in the front, central and rear sections of the fuselage. To measure passenger comfort, cabin noise assessment and subjective wellness assessment during cabin noise exposure was considered. The acoustic comfort was measured using the technique of psychological evaluation of the semantic differential consisting of pairs of bipolar adjectives with a scale of seven points [27]. The feeling of wellness is measured globally by analysing three bipolar dimensions (“pleasure-displeasure”, “excitement-calm”, “insomnia-fatigue”) and on a level of 10 specific dimensions (e.g. “cheerfulness”). A close relationship was found between noise intensity and comfort in subjective evaluations; however, the passenger’s feeling of comfort was different depending on the frequency spectra corresponding to different seat positions in the cabin. With the same SPL, passengers exposed to noise with prevailing spectra in the rear of the cabin showed a greater level of comfort [26].

The problem of noise in the cabin is also closely connected to the problem of vibrations. In the work of Quehl [27], a fuselage mock-up was used and the passengers were subjected to various sound and vibration patterns during the simulation of a real aircraft cruising, to obtain a high degree of “ecological validity ”of the experiment. The acoustic and vibration signals were recorded at each location using microphones hanging from the ceiling and the accelerometers placed in the front part of the seats, while the subjective evaluations were obtained using the differential semantic approach with the polarities indicated in Table 1.2. The study also showed that assessments of the perceptual dimension of comfort (vibroacoustic) depend on the interaction between environmental sound and vibration. The sound pressure level contributed approximately 70% and the magnitude of the vibration about 30% to the comfort rating. From the passenger point of view, it is concluded that the comfort design for aircraft can still benefit from efforts towards a general reduction in sound and vibration, following the idea of “less is more” [27].

Similar considerations as the ones given at the end of previous sections can be drawn here. Only three questions about noise and vibration have been asked to each passenger for each flight phases to limit the influence of the questionnaire compilation on the flight comfort experience.

2 Syllabus, questionnaire and experimental set-up

2.1 Syllabus

To investigate the effects of different environmental parameters on the cabin comfort perception, the flight mission has been carried out considering different environmental scenarios in the Full Flight Simulator (FFS). In particular, to obtain the different cabin configurations, the temperature is let vary between two values, namely T_A and T_B, the ventilation in the cabin may be present or absent and two different types of seat, S_A and S_B are considered for each cabin light level taken into account. The diagram of the cabin configurations shown in Fig. 1 summarizes the different cabin and experimental setup arrangements that can be considered; each cabin configuration is indicated using an alphanumeric code as:

$$[L \in \{A,B\}] - \left[T \in \{T_A, T_B\}\right] - [V \in \{V,X\}] \qquad (1)$$

where box L indicates the level of cabin light during the cruise phases, box T indicates the value of cabin temperature (in Celsius degrees), box V gives indications about the

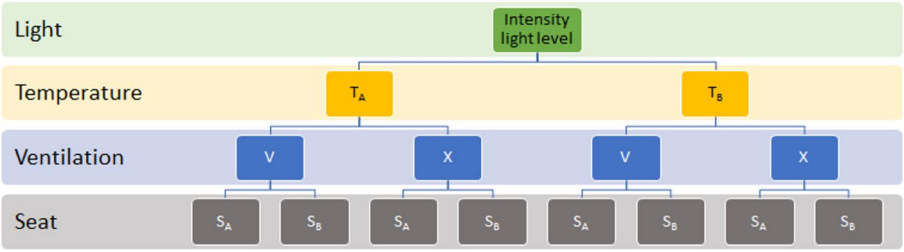


Fig. 1 Cabin configurations

presence (symbol V) or absence (symbol X) of the cabin ventilation. As example, the identification code of flight mission $A - 20 - X$ will designate level A of lighting in the cabin at an ambient temperature of 20°C with no ventilation.

Following the scheme of Fig. 1, a generic passenger can perform up to 8 flights corresponding to each climatic configuration of the cabin (temperature and ventilation) flying on two different classes of the seat, S_A and S_B. With the aim of acquiring data also on the influence of noise and vibration level, each flight will be split into four cruise phases characterized by different levels of noise and vibration. This is obtained, by means of turbulence models implemented on the simulator, and by different levels of perceived noise in the cabin, obtained by amplifying or reducing the aerodynamic and engine noise effect reproduced. Figure 2 shows the four cruise segment experimented during a simulated flight. The i-th phase starts at time t_{is} and finishes at time t_{ie} by freezing the simulation. Each flight phase lasts for 5 min. It is characterized by a combination of noise and vibration levels. After each flight phase, the passenger is asked to answer a questionnaire section; this easy the relationships between the subjective assessment of the comfort perceived during the flight phase and noise and vibration levels settings. The flight is preceded by the compilation of the registry section and a general information questionnaire named ’Q0’ referred to the Passenger Flying Experience. The questionnaire is shown in Appendix 1 and is described in the next subsection.

The complete flight mission includes taxiing, take-off, the climb up to cruising level, cruising in leveled straight flight, descent, approach, and landing. Regarding Fig. 2, from t_{1s} to t_{4e} will be carried out during the cruise in leveled straight flight. The Q1-Q4 questionnaires will be used to gain passengers’ comfort perception during these segments. The take-off and climb phase up to the cruise level and the approach and landing phase will also be evaluated using questionnaires called Q-Take-Off and Q-Landing, respectively. All the participants have experienced a complete flight mission sequence, including the preliminary phase and the time taken by the passengers to fill out the questionnaire, the execution of each test varying from 65 to 75 min.

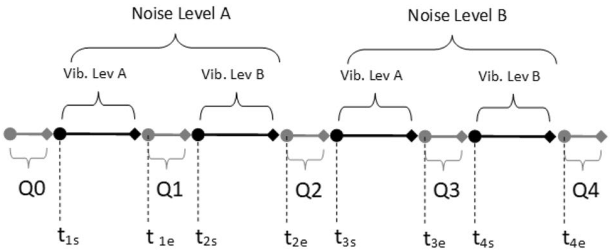


Fig. 2 Vibro-acoustic configuration during flight

2.2 Questionnaire

The subjective assessment of comfort in the cabin consists of nine questionnaires. The first part of the questionnaire is filled in by the passenger before the boarding phase starts. This questionnaire acquires all the information needed to classify the passenger based on anthropometric characteristics. Moreover, in the Q0 part the passengers are asked to give information about their general habits and perception of comfort during their real-flight experiences. In detail, passengers must indicate on a scale from 1 to 10 how much they like to travel by aeroplane and how high are their expectations from a flight. Then the passengers have to indicate the frequency with which they fly, what is the main reason for their flights (job, holidays etc..) and what they generally do during the journey (sleeping, eating, reading, etc...). Last, passengers mark the factors that most influence its perception of comfort during the flight choosing among pressure change, temperature, noise etc... A copy of the Q0 questionnaire is presented in Appendix 1. This part of the questionnaire can give additional information about the passenger population that characterizes the experimental campaign. In particular, the answers collected with respect to the perception of pre-flight comfort Q0 can be used to analyse the activities during a flight and the main contributions that can commonly influence cabin comfort. By acquiring a great number of questionnaires, this pre-flight information can potentially allow the identification of dominant features in the cabin’s design based on human perception of flight and can contribute to the human centred design of aircraft cabin. The Q-Boarding form will be filled in with the instructor’s support when the passenger takes place on the seat of the simulator, this form contains the identification code of the flight mission, as defined in the previous subsection. The other six cards, Q-Takeoff, Q1 to Q4, Q-Landing, are equal to each other and being compiled at the end of each flight sessions, described in Fig. 2. The form contains twelve assessments arranged into five sections, as summarized in Table 1.

For each of these questions, it is possible to state value in a range from 1 to 10 corresponding to graduated scale based on semantic differential LOW and HIGH, respectively. Finally, in the Q-END form, by means of keywords, the passenger can suggest from his experience, how to better estimate their comfort in the cabin. The questionnaires for the evaluation of comfort in the cabin are fully shown in Appendix 1.

2.3 Experimental set-up

This subsection briefly describes the sensors used in the Non Simulated Area (NSA) for the measurement of environmental parameters. The experimental set-up employed

Table 1 Questionnaire items

Topic area	*N*° Item	Items
Overall flight experience	2	The comfort experience of the flight has been. The pleasure of flying has been.
Cabin lighting	2	The comfort of cabin light has been. How adequate has been the illumination intensity?
Climate aspects	3	The comfort of cabin climate has been. The cabin temperature has been. The air quality has been.
Seat ergonomics	2	The seating comfort has been. The sensation of physical relaxation has been.
Noise and vibration	3	The noise and vibration comfort has been. The noise level has been.
		Your wellness rating is.

and described in this section allowed developing the experimental cabin comfort evaluation procedure.

The Sekonic L-758D Digital Master luxmeter was used to measure the lighting intensity in the cabin. The use of the exposure meter was limited to the preparatory phase. Data have been used to estimate a correlation between visual comfort and the cabin lighting level.

To measure the sound pressure level in the cabin, a Larson Davis Sound Track LxT sound level meter was used. The sound level meter has allowed us to accurately assess the sound pressure level perceived at the height of the passenger's head seated in the NSA.

The vibration level was measured by using monoaxial and triaxial accelerometers. These measures allowed the calculation of vibration levels and the motion sickness dose value. The environmental parameters were acquired in the two different seat positions inside the NSA. In particular, these are named (see Fig. 3) Seat-A (Economy type), the rear seat whose geometry is fixed and not movable; whereas Seat-B (Business type) designates the front seat that allows lumbar adjustment and temperature tuning.

Table 2 shows the preliminary acquisitions of environmental parameters that characterize each flight phase. In particular, the first value states the level A case for each parameter (described in Sect. 2.1), whereas in the round bracket is listed the level B.

The column of vertical axis acceleration reports the range of values acquired; it is noticeable that lower values characterize the take-off phase compared to the others segment. The accelerations for the Cruise 1 and Cruise 3 have the same levels as Cruise 2 and Cruise 4, but the latter segments present higher values due to the turbulence presence. The highest level is reached during the landing phase due to the touchdown accelerations.

Assuming the influence of the seat, in parallel to the comfort analyses presented in this work, the accelerations experienced by the human body during the different flight phases were analyzed. In this regard, a stochastic model has been developed [28].

3 Results

3.1 Flow working

The description of the results is anticipated by a subsection that presents the workflow used to collect and analyze the responses to the questionnaires. In particular, the main steps

Fig. 3 Seats configuration

Table 2 Settings Level-A and Level-B in round brackets

Flight phase	Cabin Light (Lux)	Noise (dBA)	Vertical acceleration (m/s^2)	Cabin Temperature (° C)
Takeoff and climb TO	30	72	0.08–0.12	18.0 (20.5)
Cuise C1	150 (100)	69	0.10–0.12	18.5 (21.0)
Cuise C2 (with turbulence)	150 (100)	69	0.12–0.15	19.0 (21.5)
Cuise C3	150 (100)	(63)	0.10–0.12	19.5 (22.0)
Cuise C4 (with turbulence)	150 (100)	(63)	0.12-0.15	20.0 (22.5)
Approach and landing LA	30	72	0.15–0.30	20.5 (23.0)

of research activities regarding data collection, analysis, and testing are highlighted in Fig. 4. During the first step, a preliminary investigation was conducted on candidates to gain insight into the elements affecting the comfort level perceived based on participants' past real flight experience. Step 1 of data collection contains the questionnaire Q0, which was also filled out by candidates who participated in the experimentation with FFS. The participants selected for the test phase on FFS filled out the other questionnaires during the different simulated flight phases, so the data collected based on the testing set-up were compared and analyzed. It is important to recall that it does not exist a univocal meaning of perceived comfort. Commonly, perceived comfort is associated with a condition of psycho-physical well-being that does not depend exclusively on individual parameters but on the interaction of multiple factors; among these, the environmental variables certainly play a not negligible role. Therefore, using an FFS to test the comfort perceived by the passenger is a proper test base to analyze these effects. It is also true that the simulation must be as realistic as possible. Thus, concerning comfort, the central hypothesis of the present work is to verify that the considered parameters flight configurations engender significant differences in perceived comfort.

3.2 Passengers pre-flight experience

As described in Sect. 2.2, the “Q0 passengers flying experience” (Q0 hereinafter) is a preliminary questionnaire filled out by the passengers containing general information useful to characterize the passenger population. More precisely, the central aspect of the questionnaire Q0 is to analyze the passenger population by means of their expectation based on their experience in past flights. The Q0 questionnaire is filled out by the participants before the boarding phase starts and has been also used as a form to collect preliminary information using a large sample. Based on these forewords, data collected on a sample of 125 responses, with 40 female and 85 male participants, are initially described. The characteristics of the sample in terms of age, height, weight, and responses to the item “How much do you like to fly” (Pleasure of flying) are listed in Table 3. First, collected data on factors influencing the aircraft comfort experience is described; successfully, a statistical analysis is reported. Then, the results of the Q0 questionnaire are used as a

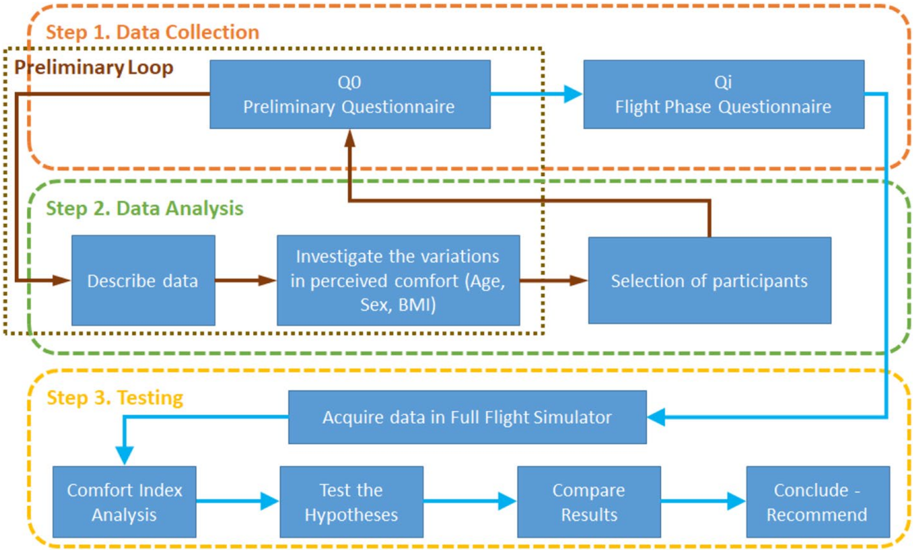


Fig. 4 Framework of methods of data collection and analysis

Table 3 Descriptive characteristics of participants who filled out the Q0 questionnaire

	Gender	Age	Height (cm)	Weight (kg)	Pleasure of flying
Mean	Female	22.3	164	59.6	8.59
	Male	22.9	178	78.6	8.54
Median	Female	22	164	57	9
	Male	22	176	79	9
Standard deviation	Female	3.45	6.86	9.39	1.55
	Male	3.17	6.52	13.3	1.85
Minimum	Female	18	151	41	4
	Male	18	163	48	1
Maximum	Female	30	180	84	10
	Male	30	194	115	10

valuable tool for selecting participants for the experimental phase to limit outliers and trouble effects.

The first question analysed is: "Which of the following activities occupy most of your time during flight?". In particular, for this question, passengers can select more than one activities. The highest percentage, equal to 23% of passengers, reports that they spend the time in flight looking out of the window. The 22% of passengers sleep, the 15% declares to think about personal matters, the 13% spend their time reading, the 10% entertains a conversation or use a mobile phone while a negligible number of passengers declares to spend the time for eating 3%. This result motivates the design and installation of simulated windows in the FFS to create a "simulated cabin" that can become very useful in estimating passengers' comfort, providing more sound information for the human-centered design of aircraft cabin comfort. This activity can be considered as possible future work. An alternative to a simulated window mockup, like a virtual environment, can also be examined. Recent advances in the Virtual Reality (VR) approach to human-centered design have shown the progress of this technology with regards to comfort assessment for preliminary aircraft interior design [29–31] and pilot training activities [32, 33]. Nevertheless, the use of currently available VR devices does not come without drawbacks introducing some important limitations due to the dissatisfaction felt by passengers [34], VR sickness, and physical discomfort [35], especially after a long period of flying on a VR simulator [36]. In addition to potential physical discomfort, practical limitations must be considered since the inertial measurement units installed in virtual reality devices are sensitive to movements and accelerations; thus, their use within a motion system is unworkable without a real-time software interface that links the actual and the virtual cabin movements.

Together with the general characteristics relating to the activities that occupy the passengers during the flight, in the Q0 questionnaire, the comfort perceptions associated with seven different features have been asked. In particular, the participants give their feeling concerning the pressure change, noise, vibration, temperature, seat, light, and motion importance parameters. The scale used in this case is based on five levels, from "Not Important" to "Of greatest Importance" see the Q0 questionnaire in Annex 1 for details. Collecting all the responses has allowed a detailed analysis of the main parameters influencing cabin comfort. Figure 5 shows, in percentage, the collected data for each parameter. For the sake of completeness, the data are listed in Table 4. It is also worth mentioning that results in Fig. 5 and Table 4 refer to the 125 participants' responses in an aggregate manner.

According to the passengers' perception, from the analysis of the answers, it is possible to highlight the importance of some parameters:

- for the pressure change, the higher percentage of passenger states that pressure changes is "Somewhat Importance". 24% of them declare the pressure change as "Very Important"; "Pressure change" thus has a medium to high importance on the passenger perception of comfort. This result can be important in the definition of the cabin altitude rate during the ascending and descending flight phases;
- for the noise, 31.4% of the passengers assert that the "Little Importance" while the "Very important" bar is equal to 28.1%. From the data collected, it seems that the noise is perceived conversely by the passengers, separating them between little and very important. These results could be related to the activities that occupy the passengers during the flight, those who like to sleep or read

Fig. 5 Pre-flight feeling of parameters influence on flight experience

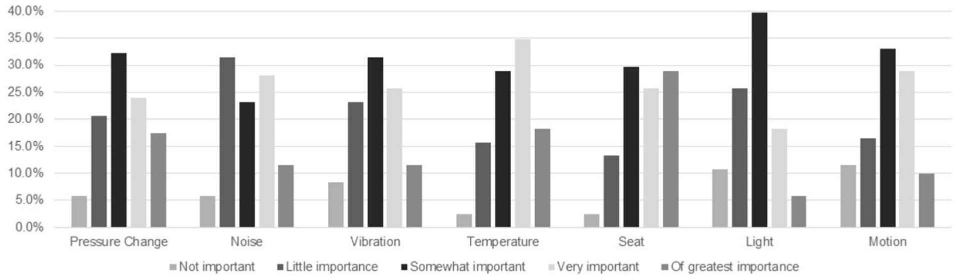


Table 4 Pre-flight feeling of parameters influence on flight experience

Label	P (%)	N (%)	V (%)	T (%)	S (%)	L (%)	M (%)
Not important (A)	5.8	5.8	8.3	2.5	2.5	10.7	11.6
Little importance (B)	20.7	31.4	23.1	15.7	13.2	25.6	16.5
Somewhat important (C)	32.2	23.1	31.4	28.9	29.8	39.7	33.1
Very important (D)	24.0	28.1	25.6	34.7	25.6	18.2	28.9
Of greatest importance (E)	17.4	11.6	11.6	18.2	28.9	5.8	9.9
$D + E$	41.3	39.7	37.2	52.9	54.5	24.0	38.8

P pressure, N noise, V vibration, T temperature, S seat, L light, M motion

maybe is more prone to silence, in contrast, those who prefer to eat or look out the window have a lower level of bother from a noisy environment;

- for the vibration parameter, the higher percentage of passenger states "Somewhat Importance". This result is in agreement with the responses collected for comfort importance level related to motion perception;
- for the temperature parameter, the lower percentage of passengers state the "Not Important" value, and the 34.7% assert that it is "Very Important". Looking the label "Very important" collected over the sample, 34.7% is the highest rate measured for the responses among observed parameters. The importance of climate comfort in the aircraft cabin is well-known from the literature, as well as the fact that the temperature comfort is strongly related to individual perception of it and can vary significantly from person to person;
- for the seat parameter, compared to the other parameters, none of the five measured levels (from A to E) show percentages higher than 30%. At the same time, looking at the level "Of greatest Importance", the highest rate of answers was collected with respect to the other parameters;
- the light parameter shows the highest value of passengers that declare "Somewhat Important". Its medium level of importance can be related to the fact that passengers prefer to do different activities during the flight; for some, the light intensity can be significant, while it is negligible for others.
- the last parameter taken into account is the motion, even though the 33.1% states "Somewhat Important" a percentage equal to 28.9% of passengers declare this parameter like "Very important". Thus, it has a medium-to-high level of importance in the comfort perception of passenger. It can be related to acceleration perceived during manoeuvres.

It can be concluded that, among the considered parameters, the seat is of remarkable importance. It is in fact the only parameter that has been classified as "Of greatest importance" by most part of passengers. This fact is also confirmed by the sum of the percentages given by the levels "Very Important" and "Of greatest Importance" (see Table 4 that reaching a value equal to 54.4%. More in detail, looking at Table 4, row $D + E$ it can be concluded that seat and temperature play a prominent role in comfort perception, followed by pressure change, noise, motion, and vibration, while lights have a secondary role. The results obtained put on evidence that it is most important to evaluate seat comfort perception during a flight. In this regard, the use of an FFS with a motion system able to give the highest level of accuracy and with the capability also to control the noise level, light intensity, and temperature support the proposed work.

3.2.1 Selection of participants to the FFS experiment session

The main results of the presents work are detailed in the subsequent sections according to the five topic area listed in Table 1. Nevertheless, the data are acquired on a sample of 20 participants selected from the 125 responses collected. The choice of a lower sample for the experimental campaign on the FFS lies in the need to limit the cost of the experiment to maximize the obtained results in this preliminary research phase. The choice of the reduced number of participants can not be done randomly, therefore, a statistical analysis of questionnaire responses was carried out.

The box plots referring to the sample split by gender are given in Fig. 6; these are based on the answers provided in Q0 for the parameters influencing cabin comfort . It is worth noting that a total of 125 responses were collected, however, data belonging to 14 of them were found to be outliers and thus were excluded from the subsequent analysis.

It is to be noted here that there exists a considerable disagreement, in the statistical research community, on the use of parametric or nonparametric statistical tests for the analyses of Likert rating scale data [37, 38]. Thus, in the present work, both approaches are presented, and in the preliminary analysis of Q0 are applied considering the gender difference shown in Fig. 6. More specifically, the nonparametric Mann–Whitney U test (MWU) and One-Way ANOVA parametric test are considered. The summary of results is presented in Table 5 in terms of p value. Data show a significant main effect between gender

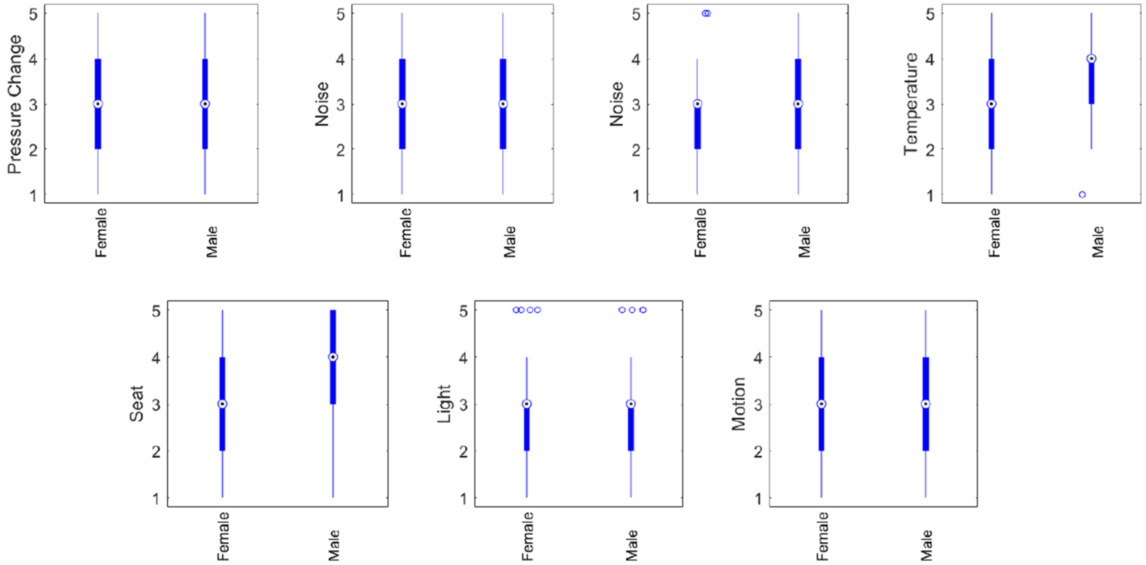


Fig. 6 Boxplot summary data of factors influencing the aircraft comfort experience

for the seat (p value < 0.001). Also, an effect close to a significant p value of 0.05 is obtained for the temperature and the light parameters. This result is not unexpected, considering that gender differences in thermal comfort and environmental satisfaction are proven for indoor environments [39].

Assuming the results of preliminary questionnaire Q0 the initial selection of only 20 male candidates among the participants for the experimental research phase was accomplished.

3.3 Overall comfort and seat comfort

Motivated by the preliminary results, one of the objectives of this study was the evaluation of seat comfort taking advantage of the FFS that, as seen before in Fig. 3, is equipped with two different types of seats, one economy type and one of business type. To accomplish such goal, the questionnaires (from “Q-Takeoff” to “Q-Landing”, see Annex 1) filled at the end of each flight segment are grouped according to the type of seat occupied by passengers and are analyzed separately.

3.3.1 Overall comfort

The two initial questions related to the overall comfort experience are first analyzed separately for passengers seated on the business and on the economy seat. These two questions are:

(a) The Comfort experience of the flight has been...
(b) The Pleasure of flying has been...

The results collected are shown in Fig. 7 for the Business seat and for the Economy type seat. The x-axis reports the six different flight phases from the take-off (TO) to the landing (LA) passing through the four cruises as described in Sect. 2. For each of these flight phases, the average of the collected responses was calculated and the standard deviation is also presented. For both the Business and Economy configurations it is possible to highlight a comparable tendency for both answers. In particular, it is distinctly apparent that the C2 cruise, flight segment with moderate turbulence and lighter SPL value, shows the greatest passengers discomfort value for both seating configurations. Analogous behaviour is noted in the C4 segment, however, in this latter case, the comfort level is higher than the C2 segment. A possible reason for this result can be associated with the perceived noise level. More in detail, looking at Table 6 that recalls the turbulence and noise levels during the flight phases, it appears that during the C4

Table 5 Mann–Whitney U test and one-way ANOVA test of Q0 questionnaire with gender grouping variable

Test	Pressure	Noise	Vibration	Temperature	Seat	Light	Motion
MWU	0.239	0.911	0.352	0.081	< 0.001	0.062	0.392
ANOVA	0.277	0.977	0.376	0.073	< 0.001	0.069	0.394

cruise the noise level is reduced by −6 dB compared to the C2 cruise configuration while the turbulence level is unchanged between C2 and C4. The perception of higher comfort, also in terms of pleasure, during the C4 phase can thus be due to the lower noise level in.

A further result to be commented is related to the perceived level of comfort during the landing sessions. The comfort level perceived during this segment is lower than both the take-off and the cruises without turbulence phases; this can be related to the higher acceleration levels to which the passengers are subjected during landing. Moreover, this result is independent of the seat type. Last, looking at the overall trend, it appears a reduction in both comfort and pleasure of flying from take-off to landing. This can be due to an increase of the tiredness of passengers because of flight duration.

In addition to the results shown in Fig. 7, a statistical analysis was performed. As discussed in Sect. 2.2 for each question, it is possible to state value in a range from 1 to 10. Concerning the questions on overall comfort (the first two questions of the questionnaire), and according to [40, 41], data were manipulated to test whether there is an influence of the seat configuration on the overall comfort experience. More in detail, data for general comfort were summed to data on pleasure perception. Thus, according to the results obtained by using the Q0 form, i.e. the importance of the seat in the perceived comfort, Mann–Whitney *U* test for independent samples and ANOVA test were performed to assess whether scores on the overall comfort indexes could be affected by the seat configuration. The statistical results are listed in Table 7. It is possible to note that, considering the sample of 20 participants, no one of the investigated flight phases presents a significant difference between seat configurations. This suggests that the seat configurations of the used FFS do not affect the overall comfort perception of the considered sample.

3.3.2 Seat comfort

The questions related to the seat comfort experience are here analyzed. These are:

(a) the seating comfort has been...
(b) the sensation of physical relaxation has been...

Figure 8 shows the comparison of the collected answers. Again, the answers have been analysed according to the type of seat. Observing Fig. 8, it can be seen that the influence of the flight phase is low on the seat comfort perception. The mean value trend varies between comfort levels 7 and 8 (corresponding the level 10 to “High” on the semantic scale). On the other hand, the question relating to the perceived

Fig. 7 General comfort and pleasure perception

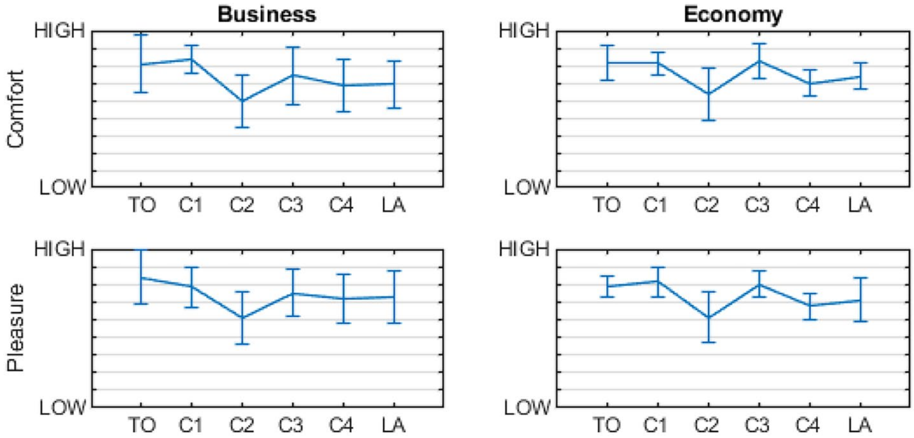


Table 6 Turbulence and Noise level during the flight phases experienced

Flight phase	TO	C1	C2	C3	C4	LA
Turbulence	Absent	Absent	Moderate	Absent	Moderate	Absent
Noise	Real flight	Real flight	Real flight	−6 dBA	−6 dBA	Real flight

Table 7 Significant test on the overall comfort questions for seat configurations

Test	TO	C1	C2	C3	C4	LA
MWU	0.384	0.570	0.409	0.087	0.375	0.963
ANOVA	0.394	0.719	0.306	0.086	0.310	0.966

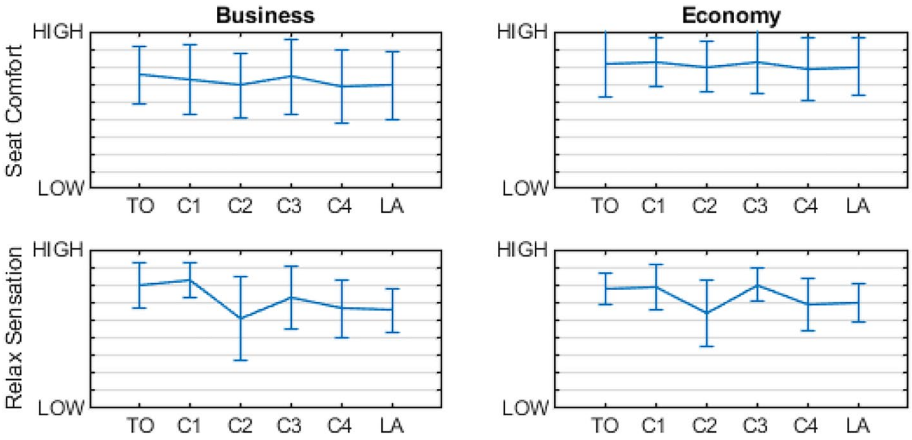


Fig. 8 Seat configuration evaluation

sensation of physical relaxation returns a behaviour similar to the question of pleasure analysed above in Fig. 7. It appears that the lowest mean value for the sensation of physical relaxation has been obtained during the C2 cruise phase. This allows us to argue that discomfort due to the turbulence added to the one caused by the actual noise level is also perceived as a lost of physical relaxation; it is ascribed to the seat comfort and strongly influence the overall flight comfort experience. This result fits both seat configurations. It is worth noting that the questions about the pleasure of flying and the one about the physical relaxation are not asked in progression (the question relating to the pleasure is the second one in the questionnaire while the question concerning relaxation is the ninth one). It can be inferred that the perception of overall comfort is not influenced by the seat comfort, which in turn is affected by noise and acceleration levels.

Again, to test if the seat configuration has a significant effect on the perception of comfort of the seat itself, both parametric and nonparametric analysis are performed. In Table 8 the statistical results in terms of p value for the parametric and nonparametric tests are listed. Again, considering the sample of 20 participants, it is possible to highlight that no significant difference between seat configurations is present during the considered flight phases. This result suggests that, at least for the analyzed sample, the comfort perceived by the participants is not a matter of the seat itself but the result of other factors. It is worth noting that, even if the seats resemble the business and economy configurations, the legroom space available in the current layout is not representative of an economy class or low-cost design (see Sect. 1.1 relating to the distance between the seats and results obtained by Kremser et al. [5]). This can motivates the obtained results. Thus, as a future development, it is possible to consider a mock-up that reduces the spaces for legroom to obtain a configuration more similar to the economy one.

3.4 Noise and vibration comfort

To analyse the section relating to the noise and vibration, the passengers in the business and the economy seat were considered subjected to the same ambient noise. Figure 9 shows the average value and the standard deviation of the collected answers. The construct was analyzed on the basis of the three following questions submitted:

(a) The noise and vibration comfort has been...
(b) The noise level has been...
(c) Your wellness rating is...

The TO, C1, C2 and LA phases were performed with noise levels compliant with real flight cabin noise, while during the flight phases C3 and C4 the noise level was reduced by –6 dBA. Analysis of the results shows that noise comfort has trend similar to the wellness experienced. Moreover, the trend of these parameters is alike the one of the seat and overall comfort shown in Figs. 7 and 8. This result can suggest that the noise associated with the turbulence influence not only the overall comfort perception but also the seat one (inevitably the main discomfort effect during the flight phase with turbulence is due to the vibrations). A different trend is shown by the noise level curve. For the analysis of distinct phases it is necessary to recognise

Table 8 Significant test for the seat configuration effect on seat comfort perception

Test	TO	C1	C2	C3	C4	LA
MWU	0.615	0.357	0.842	0.607	0.584	0.649
ANOVA	0.779	0.379	0.793	0.976	0.749	0.451

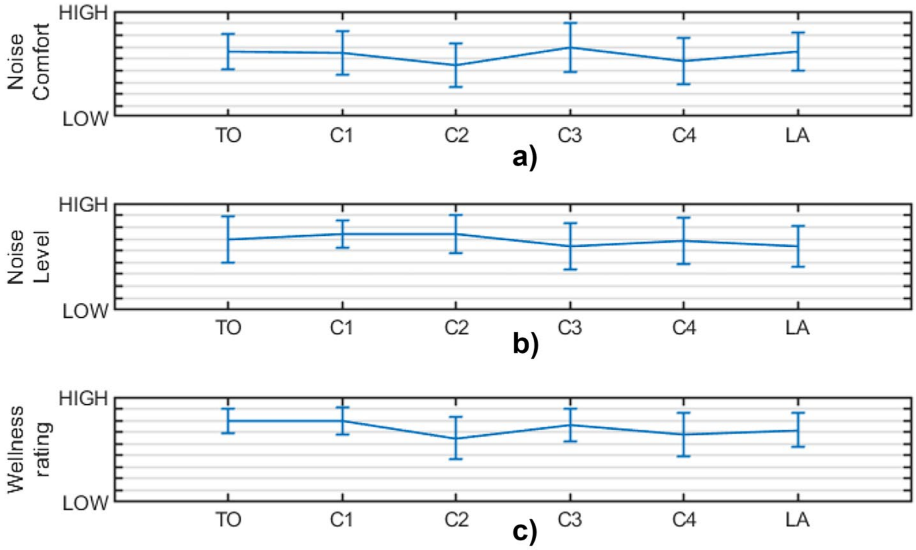


Fig. 9 Noise and vibration comfort evaluation

that during the flight segment with turbulence, flight phase C2, the noise level is the same as in phase C1. The same stands for flight phases C3 and C4 with −6 dbA of sound level (it is recalled that the level of turbulence in C4 is equal to C2). Although the passengers are able to perceive a decrease in sound intensity during flight phases C3 and C4, as reported in Fig. 9b, the perceived noise level during phases C2 and C4 (phases with turbulence) is higher than the C1 and C3 cruises. This result can be ascribed to the presence of turbulence since no change was made to the sound intensity levels during the phases C1-C2 and C3-C4. The result is supported by a decrease in comfort levels associated with general wellness rating during phases C2 and C4 as appears in Figs. 9a, c.

In addition to the comments on Fig. 9 that regards qualitative trends of perceived comfort, a statistical analysis is presented in Table 9 for the cruise phases. Considering that, from statistical tests, on seat questions, no difference emerged between the two configurations, the responses collected from passengers were cumulated in a single sample. For the analysis of noise and vibration perceived comfort, questions 10 and 12 of the questionnaire are used to check the presence of significant differences among the cruise phases. The reverse item number 11 (“The noise level has been…”) was excluded from the analysis for turbulence because it was not relevant and it was considered for noise by reversing the evaluation scale.

The data shown in Table 9 refer, on the left side, to the comparison of cruises C1 and C3 (characterized by the absence of turbulence) with C2 and C4 (phases with turbulence), respectively. Additionally, the sum of responses C1+C3 was compared to C2+C4, reporting significant differences among all samples tested. On the other hand, recalling the description of flight phases in Table 6, the right side reports the comparison among phases with real flight noise level versus flight segments with −6 dBA reduced noise level, see Table 2. The summary of results reveals a highly significant level for the perceived level of comfort due to turbulence. This suggests that the turbulence-induced motion is one of the factors that affect the comfort experience during the simulated flight. In contrast, no statistical significance is recognized between real noise and reduced noise level.

3.5 Light comfort

In a real flight, for safety reasons, during the Takeoff (TO) and Landing (LA) the ambient lights must be turned off, the same was done in the simulated flight. Since there are no windows inside the simulator, to avoid being in a fully dark environment a minimum light level equal to 30 lux was

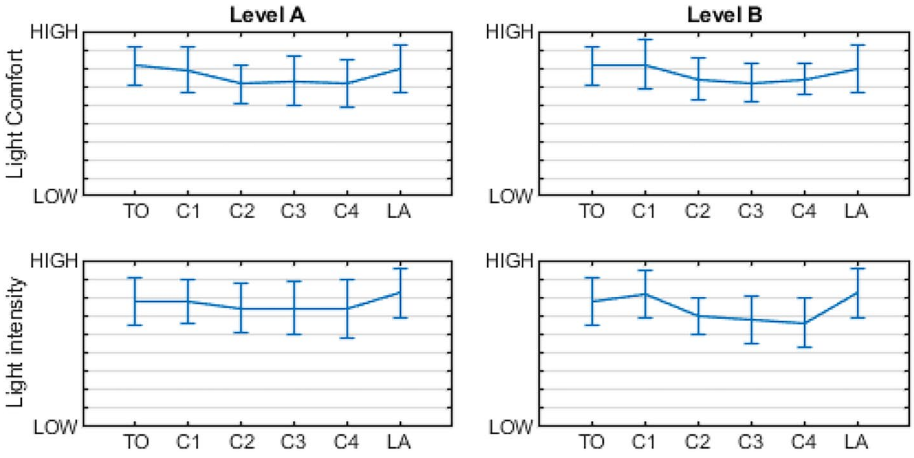
Table 9 Significant test for the noise and vibration items considering single and aggregated cruise flight phases

Test	Turbulence			Noise		
	C1 vs C2	C3 vs C4	C1 + C3 vs C2 + C4	C1 vs C3	C2 vs C4	C1 + C2 vs C3 + C4
MWU	0.004	0.046	< 0.001	0.524	0.557	0.699
ANOVA	0.006	0.029	< 0.001	0.253	0.443	0.605

Table 10 Light level during the flight phases

	TO	C1	C2	C3	C4	LA
Level A (Lux)	30	150	150	150	150	30
Level B (Lux)	30	100	100	100	100	30

Fig. 10 Light comfort evaluation



set for the TO and LA phases. On the other hand, the light intensity was maintained constant during the cruising segments. Table 10 lists the sequences of light intensity levels used during the experimental campaign; in particular Level A refers to a light intensity of 150 Lux and Level B refers to 100 Lux.

Figure 10 reports graphically the passengers' responses to the questions

(a) the comfort of cabin light has been...
(b) how adequate has been the illumination intensity?

in terms of mean value and standard deviation computed on sample. A general result regarding both illumination levels is the decrease in comfort level and in the adequacy of the illumination level between phase C1 and the subsequent phases C2, C3 and C4. Then both the comfort and the perception of adequate lighting condition increase in the landing segment. This result can suggest that the lower illumination level is perceived as comfortable during takeoff and landing. However, by the comparison between level A and B, it appears that almost equal values of illumination comfort are sensed by passengers with a slightly lower level of light intensity adequacy regarding the level B set. This can suggest that a lower light level can induce tiredness which is reflected in a reduction of the experienced "adequacy" of the cabin illumination. It is worth noting at this point that, as shown in Table 10, during the four different cruise phases C1-C4, no variation was made in the light intensity. Thus, the difference in the light comfort, reported in Fig. 10, can be due just to the passengers' perception and not to the actual light intensity settings. This can put into evidence that the illumination of cabin environment can have a reduced or secondary effect on passengers' comfort perception with respect to other parameters.

Table 11 Significant tests on the light level during the mission flight phases

Test	C1	C2	C3	C4
MWU ($\mu_A \neq \mu_B$)	0.762	0.611	0.175	0.109
MWU ($\mu_A > \mu_B$)	0.657	0.306	0.088	0.055
ANOVA	0.591	0.626	0.181	0.138

Statistical analyses to support the previous comments are presented in Table 11. Considering that the standards establish light levels during the Takeoff and Landing phases, these phases are excluded from the analysis. The results show that no significant difference appears from the Mann–Whitney *U* test or ANOVA test in the hypothesis of differences among mean values. However, considering the hypothesis that the mean value of comfort responses associated with illumination Level A is greater than that of Level B ($\mu_A > \mu_B$), it is obtained that the significance *p* value gradually reduces, demonstrating that the higher light level is perceived as more comfortable with the time extension of the flight test.

3.6 Temperature comfort

The section of the questionnaire concerning the climatic parameters consists of three different questions:

(a) The comfort of cabin climate has been...
(b) The cabin temperature has been...
(c) The air quality has been...

It is essential to point out that the seats are not configured with a personalized ventilation nozzles as in airplanes, but the air conditioning system is centralized and controls the ventilation in the NSA. Thus, during the experimental campaign, the conditioning system was set with a fixed flow intensity and not a rated temperature value. Given this circumstance, the ambient temperature inside the NSA grows about 2.5 °C for each hour of simulator activity, thus the analyses were classified based on the initial cabin temperature value. This temperature gradient is considered comfortable, and thus it can be assumed that it does not negatively affect the other comfort parameters [42].

More in detail, it was decided to organize the flight missions in two groups. The first group starts the flight with a cabin temperature higher than 20.5 °C, it is referred to as T_A in the following; the second group involves passengers who start the flight with an ambient temperature of 18.0 °C and complete it with a temperature lower than 20.5 °C, it is referred to as T_B.

Figure 11 shows the answers collected on the selected groups. Analysis of results highlights, for the flights carried out at a temperature higher than 20.5 °C, a lower level of comfort for all flight phases exception made for the Takeoff (TO). For this group, as the temperature increases from 20.5 up to 23 °C it is observed an overall decreasing comfort level from Take-off to landing phases. Observing the results collected for the second group, when the temperature varies from 18 to 20.5 °C, it can be evidenced that cabin climatic comfort trend is almost constant. This can allow to conclude that it is not the increase of temperature that induces a lowering of perceived comfort but the fact that cabin temperature is above 21° C.

With reference to the second question of the block "The cabin temperature has been. . . ", an increase on perceived temperature matches with a decrease in the level of climatic comfort for the T_A group. In particular, it can be observed an increase of temperature during the C4 segment which is reflected on a decrease of temperature. Regarding the T_B group, it is observed that the increase of temperature is only sensed during initial phases, then from C2 to LA the perceived cabin temperature is almost constant. Also this results is accordance with the cabin comfort trend.

The third question does not allow a comparative assessment since the conditioning system is disabled during the simulations. In fact, there are no significant differences between the two groups in terms of air quality. In both cases, the air quality level reduces during the flight mission. However, the air quality level perceived by the T_B group is higher than the T_A one, evidencing again that a temperature lower than 21 °C allows a higher comfort perception.

The comments inferred by Fig. 11 can be statistically proven. The results for the nonparametric MWU test and parametric ANOVA test reported in Table 12 reveal the significant differences among the air temperature arrangement for all the flight phases, but the take-off (TO), suggesting that temperature is another factor that affects the perceived comfort.

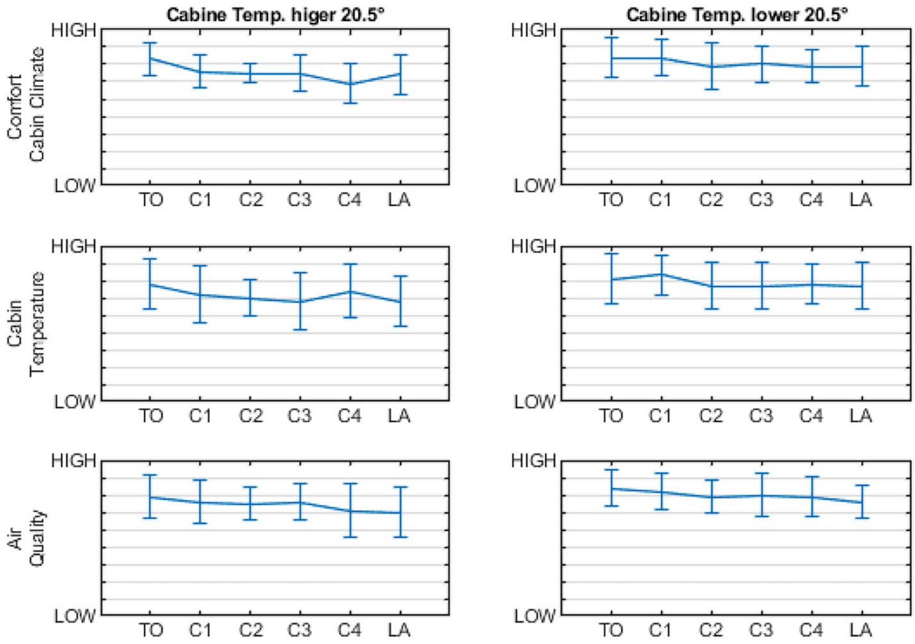


Fig. 11 Climate passengers' evaluation

Table 12 Significant tests between the cabin temperature conditions

Test	TO	C1	C2	C3	C4	LA
MWU	0.186	0.065	0.017	0.012	0.018	0.024
ANOVA	0.313	0.064	0.065	0.015	0.023	0.025

4 Conclusion

The objective of the present study was to investigate the influence of different aircraft cabin environmental parameters that can affect the levels of perceived comfort. Literature analysis has allowed the definition of several quantities influencing the flight comfort experience. The FFS installed at the M.A.R.T.A. center of the Kore University of Enna has been used as the set-up to carry out experimentation. A questionnaire has been developed to collect information regarding the passengers' flight comfort expectations and habits as well as their perception of comfort experienced during the simulated flight. The questions were constructed with non-numbered rating scales that exploit the semantic differential method. Questions range from overall comfort perception evaluation to seat, illumination, climatic, and noise and vibration comfort evaluations.

A preliminary investigation based on participants' past flight experience suggested that seat configuration may play an important role in the comfort experience; thus, passengers' comfort data were initially analyzed for two different seat configurations: one is a business-type seat, and the other one is economy-type. During the flight, passengers were subjected to the same conditions of light levels, temperature, noise, and vibrations. The results have shown that the seat comfort perception presents the same behavior as the overall flight comfort. The results obtained can be linked to the ergonomic aspects of the seat, considering the large legroom space set.

In particular, parametric and nonparametric tests agree with the statement that there isn't significant difference in the comfort levels perceived during the simulation between seats taken into account. Based on this, the passengers were considered a unique sample subjected to the same environmental conditions.

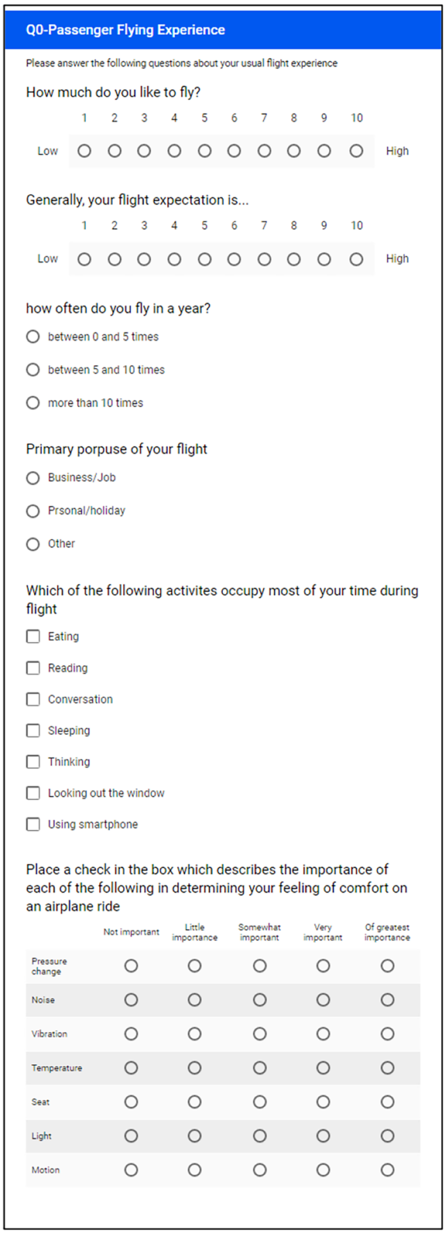
Results from analysis of noise and vibration items reveal that the candidates are more prone to evaluate as dis-comfortable the motion due to the turbulence compared to the noise level effect. It has been observed that passengers perceive the highest light levels as more comfortable with the prolongation of the simulated cruise. Regarding the climatic experience, it can be said that a perceived temperature higher than 21 °C reduces the cabin's climatic comfort.

It can be concluded that the developed questionnaire has confirmed the importance of research in evaluating the environmental effect on the overall comfort perception using the simulated flight as a preliminary benchmark. Statistical tests on responses have been useful to evidence the effect of other environmental parameters on passenger comfort. As such, the developed questionnaire can also become useful to assess the influence on the perceived comfort of design items/parameters such as novel seat configurations, alternative illumination, and climatic systems, as well as new lining materials characterized by higher noise transmission loss, among others.

Last, it can be obviously useful to enlarge the sample size to further increase the statistical significance of findings and to analyze passenger populations that differ from the studied one in terms of mean age and frequency of flight per year. The results of such an extended study could be applied in future studies to build a useful predictive model to foresee perceived comfort and discomfort at the preliminary design steps.

Appendix 1: Questionnaires

The left section shows the contents of the Q_0 questionnaire about passengers' general routines and perception of comfort during their flight experiences. The questionnaire Q_i shows on the right the twelve items used for evaluating cabin comfort over the flight phases.



Q0-Passenger Flying Experience

Please answer the following questions about your usual flight experience

How much do you like to fly?

	1	2	3	4	5	6	7	8	9	10	
Low	○	○	○	○	○	○	○	○	○	○	High

Generally, your flight expectation is...

	1	2	3	4	5	6	7	8	9	10	
Low	○	○	○	○	○	○	○	○	○	○	High

how often do you fly in a year?

- ○ between 0 and 5 times
- ○ between 5 and 10 times
- ○ more than 10 times

Primary porpuse of your flight

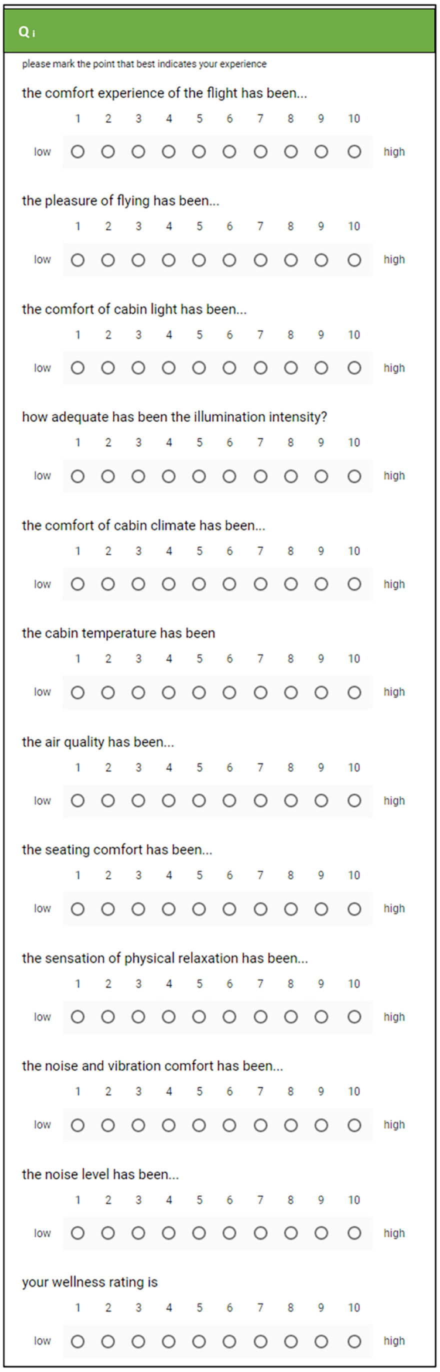
- ○ Business/Job
- ○ Prsonal/holiday
- ○ Other

Which of the following activites occupy most of your time during flight

- ☐ Eating
- ☐ Reading
- ☐ Conversation
- ☐ Sleeping
- ☐ Thinking
- ☐ Looking out the window
- ☐ Using smartphone

Place a check in the box which describes the importance of each of the following in determining your feeling of comfort on an airplane ride

	Not important	Little importance	Somewhat important	Very important	Of greatest importance
Pressure change	○	○	○	○	○
Noise	○	○	○	○	○
Vibration	○	○	○	○	○
Temperature	○	○	○	○	○
Seat	○	○	○	○	○
Light	○	○	○	○	○
Motion	○	○	○	○	○



Q_i

please mark the point that best indicates your experience

the comfort experience of the flight has been...

	1	2	3	4	5	6	7	8	9	10	
low	○	○	○	○	○	○	○	○	○	○	high

the pleasure of flying has been...

	1	2	3	4	5	6	7	8	9	10	
low	○	○	○	○	○	○	○	○	○	○	high

the comfort of cabin light has been...

	1	2	3	4	5	6	7	8	9	10	
low	○	○	○	○	○	○	○	○	○	○	high

how adequate has been the illumination intensity?

	1	2	3	4	5	6	7	8	9	10	
low	○	○	○	○	○	○	○	○	○	○	high

the comfort of cabin climate has been...

	1	2	3	4	5	6	7	8	9	10	
low	○	○	○	○	○	○	○	○	○	○	high

the cabin temperature has been

	1	2	3	4	5	6	7	8	9	10	
low	○	○	○	○	○	○	○	○	○	○	high

the air quality has been...

	1	2	3	4	5	6	7	8	9	10	
low	○	○	○	○	○	○	○	○	○	○	high

the seating comfort has been...

	1	2	3	4	5	6	7	8	9	10	
low	○	○	○	○	○	○	○	○	○	○	high

the sensation of physical relaxation has been...

	1	2	3	4	5	6	7	8	9	10	
low	○	○	○	○	○	○	○	○	○	○	high

the noise and vibration comfort has been...

	1	2	3	4	5	6	7	8	9	10	
low	○	○	○	○	○	○	○	○	○	○	high

the noise level has been...

	1	2	3	4	5	6	7	8	9	10	
low	○	○	○	○	○	○	○	○	○	○	high

your wellness rating is

	1	2	3	4	5	6	7	8	9	10	
low	○	○	○	○	○	○	○	○	○	○	high

Declarations

Conflict of interest The Authors declare no competing interests.

Informed consent Informed consent was obtained from all participants involved in the study. The activities with the FFS were approved by the Ethics Committee of Kore University Enna (protocol code 2510 date of 04/02/2022).

References

1. Christidis, P., Christodoulou, A., Navajas-Cawood, E., Ciuffo, B.: The post-pandemic recovery of transport activity: emerging mobility patterns and repercussions on future evolution. Sustainability **13**(11), 6359 (2021)
2. Vink, P., Bazley, C., Kamp, I., Blok, M.: Possibilities to improve the aircraft interior comfort experience. Appl. Ergon. Hum. Fact. Technol. Soc. **43**(2), 354–359 (2012)
3. Oborne, D.J.: Passenger comfort—an overview. Appl. Ergon. **9**(3), 131–136 (1978)

4. Vink, P.: Aircraft Interior Comfort and Design. CRC Press, Boca Raton (2016)
5. Kremser, F., Guenzkofer, F., Sedlmeier, C., Sabbah, O., Bengler, K.: Aircraft seating comfort: the influence of seat pitch on passengers' well-being. Work **41**(Supplement 1), 4936–4942 (2012)
6. Hiemstra-van Mastrigt, S., Groenesteijn, L., Vink, P., Kuijt-Evers, Lottie F.M.: Predicting passenger seat comfort and discomfort on the basis of human, context and seat characteristics: a literature review. Ergonomics, **60**(7):889–911 (2017)
7. De Looze, M.P., Kuijt-Evers, L.F.M., Van Dieen, J.A.A.P.: Sitting comfort and discomfort and the relationships with objective measures. Ergonomics **46**(10), 985–997 (2003)
8. Molenbroek, J.F.M., Albin, T.J., Vink, P.: Thirty years of anthropometric changes relevant to the width and depth of transportation seating spaces, present and future. Appl. Ergon. **65**, 130–138 (2017)
9. Rolstad, S., Adler, J., Rydén, A.: Response burden and questionnaire length: is shorter better? a review and meta-analysis. Value Health **14**(8), 1101–1108 (2011)
10. Vertamatti, E., Yanagihara, J.I.: Determination of lighting comfort in an aircraft cabin. In: 3rd International Conference on Engineering (2012)
11. Winzen, J., Albers, F., Marggraf-Micheel, C.: The influence of coloured light in the aircraft cabin on passenger thermal comfort. Light. Res. Technol. **46**(4), 465–475 (2014)
12. Albers, F., Maier, J., Marggraf-Micheel, C.: In search of evidence for the hue-heat hypothesis in the aircraft cabin. Light. Res. Technol. **47**(4), 483–494 (2015)
13. Van Bommel, W.J.M., Van den Beld, G.J.: Lighting for work: a review of visual and biological effects. Light. Res. Technol. **36**(4), 255–266 (2004)
14. Inkarojrit, V.: Balancing Comfort: Occupants' Control of Window Blinds in Private Offices. University of California, Berkeley (2005)
15. British Standard Institution. BS EN 04618–2013: Aerospace series—aircraft internal air quality standards, criteria and determination methods. BSI Standards Limited (2013)
16. Zhang, H., Huizenga, C., Arens, E., Yu, T.: Considering individual physiological differences in a human thermal model. J. Therm. Biol. **26**(4–5), 401–408 (2001)
17. Karjalainen, S.: Gender differences in thermal comfort and use of thermostats in everyday thermal environments. Build. Environ. **42**(4), 1594–1603 (2007)
18. Fan, J., Zhou, Q.: A review about thermal comfort in aircraft. J. Therm. Sci. **28**(2), 169–183 (2019)
19. Marggraf-Micheel, C., Jaeger, S.: Passengers subjective well-being in the aircraft cabin. Int. J. Psychol. **43**(3–4), 98 (2008)
20. Cui, W., Wu, T., Ouyang, Q., Zhu, Y.: Passenger thermal comfort and behavior: a field investigation in commercial aircraft cabins. Indoor Air **27**(1), 94–103 (2017)
21. Maier, J., Marggraf-Micheel, C.: Weighting of climate parameters for the prediction of thermal comfort in an aircraft passenger cabin. Build. Environ. **84**, 214–220 (2015)
22. Zítek, P., Vyhlídal, T., Simeunović, G., Nováková, L., Čížek, J.: Novel personalized and humidified air supply for airliner passengers. Build. Environ. **45**(11), 2345–2353 (2010)
23. Zhang, T.T., Li, P., Wang, S.: A personal air distribution system with air terminals embedded in chair armrests on commercial airplanes. Build. Environ. **47**, 89–99 (2012)
24. Bosbach, J., Lange, S., Dehne, T., Lauenroth, G., Hesselbach, F., Allzeit, M.: Alternative ventilation concepts for aircraft cabins. CEAS Aeronaut. J. **4**(3), 301–313 (2013)
25. Mellert, V., Baumann, I., Freese, N., Weber, R.: Impact of sound and vibration on health, travel comfort and performance of flight attendants and pilots. Aerosp. Sci. Technol. **12**(1), 18–25 (2008)
26. Pennig, S., Quehl, J., Rolny, V.: Effects of aircraft cabin noise on passenger comfort. Ergonomics **55**(10), 1252–1265 (2012)
27. Quehl, J.: Comfort studies on aircraft interior sound and vibration. PhD thesis, Universität Oldenburg, (2001)
28. Esposito, A., Lo Iacono, F., Orlando, C., Navarra, G., Alaimo, A.: Whole body vibration during simulated flight via uncertain models and interval analysis. Mech. Adv. Mater. Struct. 0(0):1–10 (2022)
29. De Crescenzio, F., Bagassi, S., Asfaux, S., Lawson, N.: Human centred design and evaluation of cabin interiors for business jet aircraft in virtual reality. Int. J. Interact. Des. Manuf. (IJIDeM) **13**(2), 761–772 (2019)
30. Walther, J.-N., Hesse, C., Biedermann, J., Nagel, B.: High fidelity digital cabin mock-up based on preliminary aircraft design data for virtual reality applications and beyond. In: AIAA AVIATION 2021 FORUM, p. 2775 (2021)
31. Ricci, G., De Crescenzio, F., Santhosh, S., Magosso, E., Ursino, M.: Relationship between electroencephalographic data and comfort perception captured in a virtual reality design environment of an aircraft cabin. Sci. Rep. **12**(1), 1–14 (2022)
32. Ahmed, S., Irshad, L., Demirel, H.O., Tumer, I.Y.: A comparison between virtual reality and digital human modeling for proactive ergonomic design. In: International Conference on Human–Computer Interaction. Springer, pp. 3–21 (2019)
33. Dymora, P., Kowal, B., Mazurek, M., Romana, S.: The effects of virtual reality technology application in the aircraft pilot training process. IOP Conf. Ser. Mater. Sci. Eng. **1024**(1), 012099 (2021)
34. Williamson, J.R., McGill, M., Outram, K.: Planevr: social acceptability of virtual reality for aeroplane passengers. In: Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems, pp. 1–14 (2019)
35. Butt, W., Idris, S., Ahmed, M.K.: Study and analysis of virtual reality and its impact on the current era. In: 2020 Seventh International Conference on Information Technology Trends (ITT), pp. 20–25 (2020)
36. Montalbano, C.J., Abichiv, J., Sikorski, E.: Employing a user-centered approach for evaluating a vr-based pilot training system. Proc. Hum. Fact. Ergon. Soc. Annu. Meet. **65**(1), 1104–1108 (2021)
37. Norman, G.: Likert scales, levels of measurement and the "laws'' of statistics. Adv. Health Sci. Educ. **15**(5), 625–632 (2010)
38. Harpe, S.E.: How to analyze likert and other rating scale data. Curr. Pharm. Teach. Learn. **7**(6), 836–850 (2015)
39. Indraganti, M., Humphreys, M.A.: A comparative study of gender differences in thermal comfort and environmental satisfaction in air-conditioned offices in Qatar, India, and Japan. Build. Environ. **206**, 108297 (2021)
40. Dillon, W.R., McDonald, R.: How to combine multiple items into a composite score. J. Consum. Psychol., 62–64 (2001)
41. Bergkvist, L., Rossiter, J.R.: The predictive validity of multiple-item versus single-item measures of the same constructs. J. Mark. Res. **44**(2), 175–184 (2007)
42. Lange, P., Dehne, T., Schmeling, D., Dannhauer, A., Gores, I.: Realistic flight conditions on ground: new research facility for cabin ventilation. CEAS Aeronaut. J., 1–20 (2022)