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Aircraft interior and seat design: priorities based on passengers' opinions

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For many years, comfort has been an important factor for passengers in choosing the airline and the aircraft (Brauer, 2006) and it makes sense to design a comfortable interior and seat to attract passengers. It might not only be important to feel comfortable during the flight but also feeling comfortable about the flight (Vink, 2020). Decision influencing factors in the future of mobility might incorporate new elements such as sustainability, and future travel may have a requirement to use more sustainable solutions. Many sustainable aircraft concepts use some form of propeller drive in the engine (IATA, 2019). In more sustainable travel options, the same comfort rules might apply to customer satisfaction. Therefore, it is important to study the relevant comfort factors for usage of more sustainable turboprop and electric propeller airplanes.

According to Krist (1993) and Bubb et al. (2015), comfort is established by six factors: anthropometry, climate, sound, vibrations, illumination and smell. Bouwens et al. (2018) showed that among 183 passengers, ‘anthropometry’ was the most important factor influencing comfort, meaning that the legroom and seat width are insufficient for the size of different human body parts. The second most important factor was ‘noise,’ which is mainly the sound that the engines and aerodynamics produce. However, the sound of a crying baby and fellow passengers can be annoying as well (Lewis et al., 2016). The third factor was temperature, which could be too low or high. It could also be local temperature that is annoying, like cold feet or a draft in the neck. Smell, illumination, and vibration were mentioned as fourth, fifth, and sixth factors. It is interesting to see that the importance of the factor is dependent on the activity of the passengers (Bouwens et al., 2016); for example, the third most important factor while sleeping was ‘temperature’ and while watching in-flight entertainment (IFE) it was light. Some studies also mention the “proximity of others” as the overall most important factor for comfort (e.g., Lewis et al., 2017), but many mention physical space (e.g., Vink et al., 2012).

As anthropometrics is often the most important factor, it might be good to look more in detail which seat element needs attention. In Table 1, the opinion of 246 passengers on several seat elements is shown (Bouwens, 2018). It is probably no surprise that leg room is mentioned as number one, e.g., Vink et al. (2012) reported the same result. The bottom cushion, which is number two, also needs attention. Asking the same group what needs to be improved, resulted again in legroom as number one, and overall space and cushion as number two and three (see Figure1).

Table 1

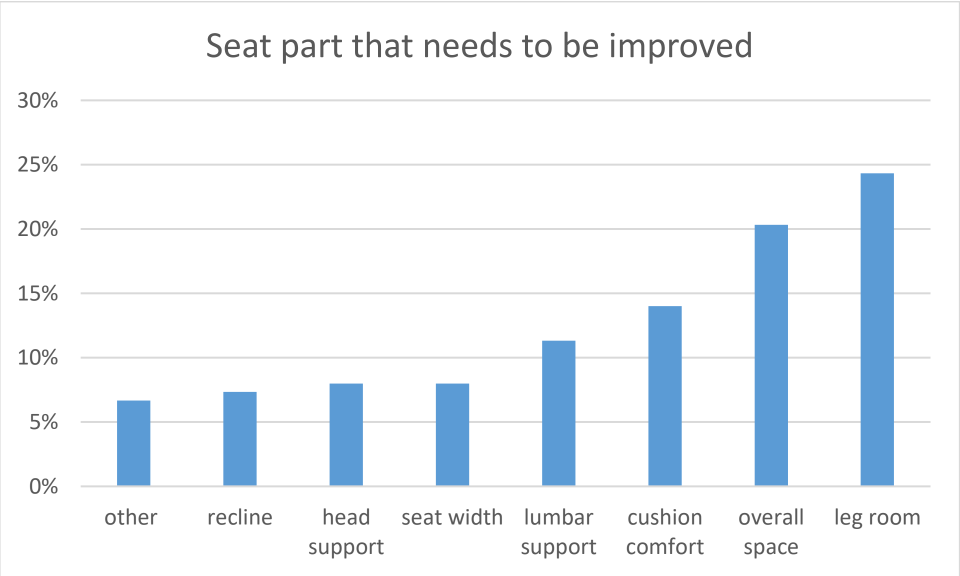
Importance of Different Airplane Seat Features for Perceived Comfort According to 246 Passengers (Bouwens, 2018)

1. leg room
2. bottom cushion
3. foot space
4. seat width
5. head support
6. lumbar support
7. Recline
8. Armrest
9. head side support
10. tray table
11. foot rest*

Note. 1=most important/11= least important. **for Asian travellers foot rests are more important and comes just after head side support.*

Figure 1

Percentage of the 246 Passengers That Stated That This Part of the Seat Needed to be Improved



Sustainability seems to become more important for aircrafts. Electric propeller aircrafts are in development aiming at closer to zero emission, and several have already been flown as demonstrators. This process is already on its way as current cargo turboprops will be changed to use hydrogen fuel using conversion kits (Mandel, 2021), which includes a fuel cell and an electric powertrain to

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replace conventional turboprop engines. Thus, there might be more electric propeller driven airplanes coming. However, a serious issue for the adoption of the turboprop aircraft is the comfort experience of the passenger, primarily because the noise and vibration inside a turboprop cabin (Mansfield et al., 2021) might play a larger role in the overall comfort experience.

For instance, the noise levels in the cabins of turboprop aircraft are typically 10 to 30 decibels louder than commercial jet noise levels (Kincaid et al., 1997). For a turboprop the noise is derived from a combination of the engine power source and noise arising from the passage of blades past the wing. To study the priorities of passengers in the factors influencing comfort data two experiments were completed in which the sound of propellers was apparent. The question in this analysis is: *is the order of importance of different comfort factors as contributors to aircraft interior comfort experienced different in propeller aircrafts in comparison to known data of jet aircrafts?*

Method

Two experiments were carried out. In one experiment, 33 participants (average age 24.5 years (19-37); length 1.751 m (1.60-1.92)) sat in a Boeing 737 interior in six rows. Five rows were occupied by 30 participants (3x3 next to each other in 31" pitch). In the front row, three participants were located on one side and had more legroom. The Boeing 737 stayed on the ground and a flight of 70 minutes was simulated. A speaker simulating a turboprop flight was located just behind the passengers, a screen in the front of the cabin showed a video of the flight. Passengers had to complete several questionnaires and did not leave their seat. After 35 minutes, a drink was served. Three times during the "flight" (during ascent, cruise, and descent) the question was asked "please mark the three factors most contributing to your experienced level of discomfort: temperature, noise, lighting, air quality, vibration, seat and space". To apply the results in the CLEANSKY 2 ComfDemo project temperature and air quality are separated in this study. In the study of Bouwens et al. (2018) climate was defined as one element. Norrefeldt et al., 2021 also measured humidity, carbon dioxide (CO_2), Total Volatile Organic Compounds, and temperature and studied comfort regarding air quality separately from comfort regarding temperature. The same question was asked for comfort three times. Per factor, the percentage of persons mentioning the factor was calculated. A Cochran Q test for repeated measures with binary outcomes ($p<.05$) was used to see if the factor differed from the other sample points in the simulated flight (across all measurement points and in direct comparisons of t1 vs t2, t2 vs t3, and t1 vs. t3).

Figure 2
Participants on their way to the Test Flight in an ATR72

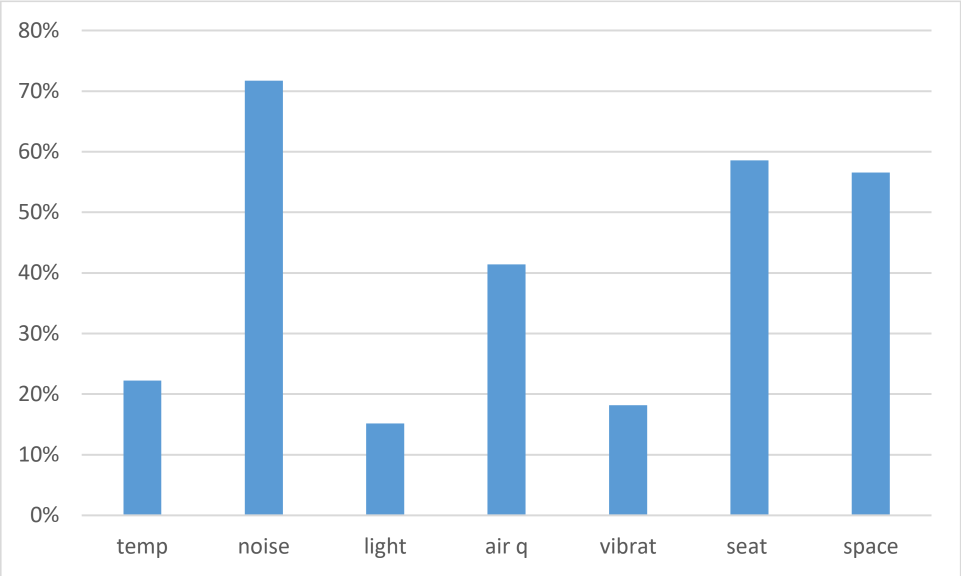
The second experiment was a flight of 70 minutes in an ATR72 turboprop with 30 minutes at a cruising altitude of 17,000 feet (see Figure 2). The seats were 2x2 (so no middle seat) with 35” pitch, creating more legroom than usually experienced in regional flights. The aircraft had passenger capacity of 60; experimenters also travelled on the flights. Two flights with 52 and 45 passengers respectively were completed. After the flight, the passengers were asked the same question: “please mark the three factors most contributing to your experienced level of discomfort: temperature, noise, lighting, air quality, vibration, seat and space”. Again, the same question was asked for comfort. Per factor, the percentage of individuals mentioning the factor was calculated.

Results

In the first experiment, there was no significant difference between the three recorded comfort/discomfort scores. So, during the simulated flight no significant changes were observed. The percentage of participants mentioning the factors influencing discomfort over all three recordings is shown in Figure3. Noise in this case is the most dominant factor, followed by seat and space.

Figure 3

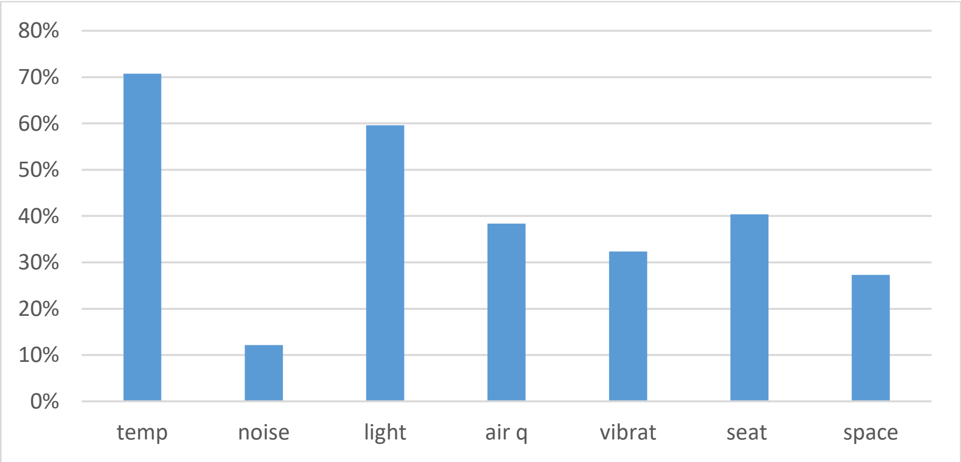
The Percentage of the 33 Passengers Mentioning the Factor Related to ***Discomfort*** *Averaged Over the Three Times That it was Sampled in the Test in the 737 Cabin (air q=air quality)*



The factor influencing comfort that was most mentioned was temperature (see figure 4), followed by light and seat.

Figure 4

The Percentage of the 33 Passengers Mentioning the Factor Related to ***Comfort*** *Averaged Over the Three Moments it was Recorded (air q=air quality)*



In the second experiment 94 participants ((35 females, 49 males, average age 33.86 (SD 14.31). average length 1,755 m (SD 0,102), average BMI 23.60 (SD 3.24) completed the questionnaire (a further 5 were incomplete and excluded from the analysis). Again, noise was the dominant factor influencing discomfort (see Figure 5), followed by seat and vibration. For comfort space followed by lighting and temperature were the factors mentioned mostly related to comfort as Figure6.

Figure 5

*Percentage of the 94 Passengers That Report This Factor Influencing **Discomfort** After the Flight*

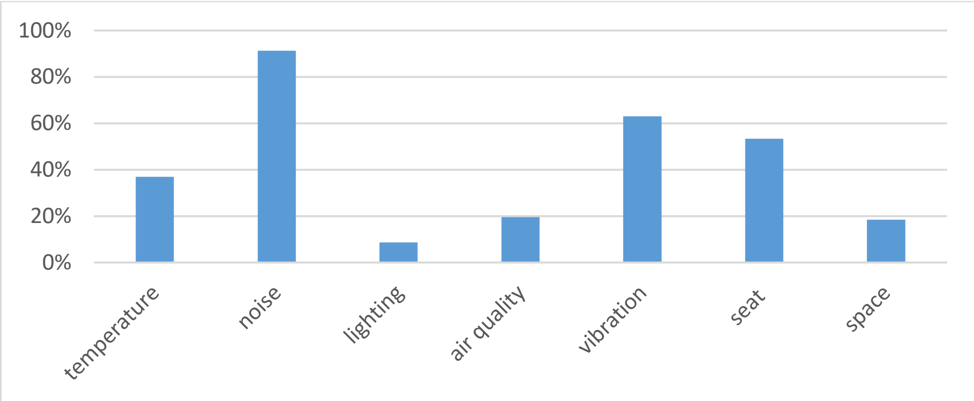
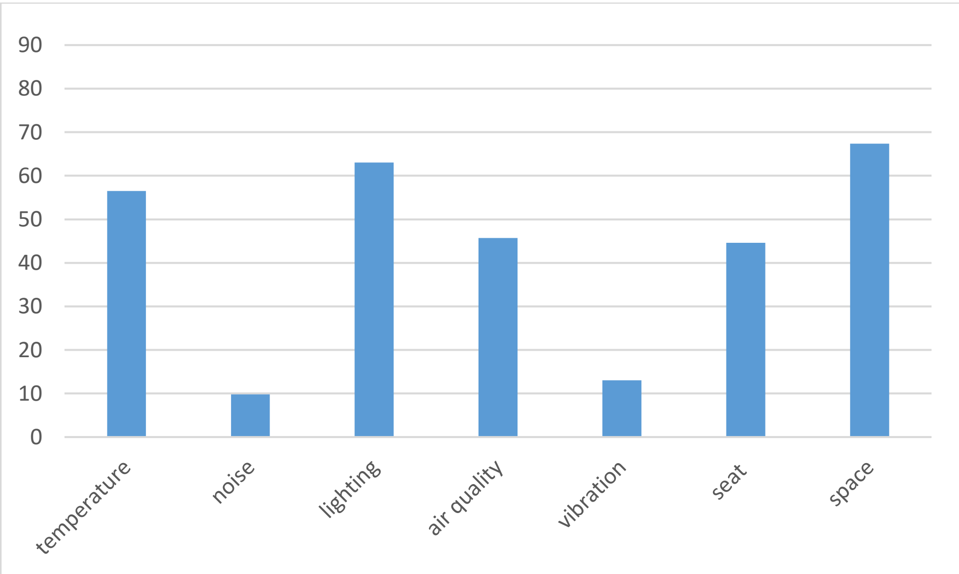


Figure 6

*Percentage of the 94 Passengers That Report This Factor Influencing **Comfort** After the Flight*



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Discussion

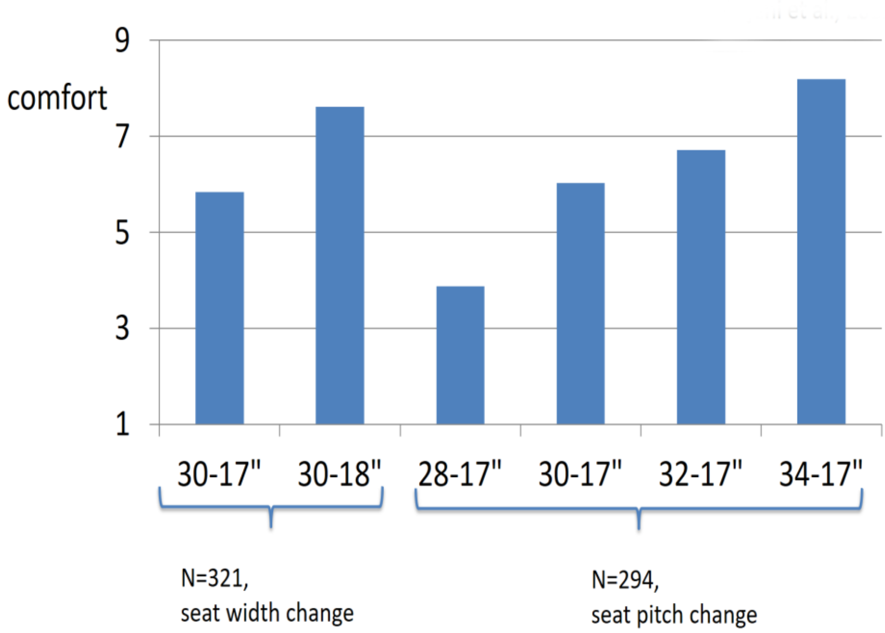
Anthropometry

In current jet aircrafts anthropometry (the fit between human and seat) is the main point related to comfort according to Bouwens et al. (2018), while in our research the seat was number two regarding discomfort and three or four regarding comfort. Bouwens et al. (2018) used a different approach and studied airplanes in general. As most airplanes are jets, turboprops did not get much attention in their study. In their approach passengers had to choose between two factors and select the most important one. Based on that way of studying the factor most mentioned was anthropometry. In our study, comfort and discomfort were separated. First the question on discomfort was asked and passengers could mention the most ‘annoying’ factor first and then participants could mention the factor contributing to comfort. The anthropometrics having most influence in jet airplanes is also confirmed in other studies (e.g. Vink et al., 2012; Kremser et al., 2012). Also, in the propeller driven airplane the seat is very important as it is the second most important factor related to discomfort and the third related to comfort. Within the seat, the legroom and cushion need attention, as they are the two with most importance of different airplane seat features for perceived comfort according to 246 passengers (Bouwens, 2018). Hinninghofen and Enck (2006) also identified that seat comfort is associated with seat pitch, seat width, legroom and quality of upholstery.

Kuo and Jou (2017) described that seat pitch and seat width are primary factors for passengers to upgrade to the premium economy class based on their previous experience. Anjani et al. (2021) found that comfort increases when the pitch gets larger. In figure 6 a pitch of 28” with a seat width of 17” is related to a very low comfort (score 4), while a pitch of 30” with a seat width of 17” gives a just acceptable comfort score of 6. Widening the seat has a large effect. At a seat, pitch of 30” an 18” seat width gives a significantly better score than a 30” pitch and 17” wide seat and it is better than a 32” pitch with a 17” wide seat. Differences in pitch size can explain the difference in importance of the seat ‘factor’ on comfort and discomfort in the second test compared to previous research. The pitch in the second test was relatively large (35”), which might influence the priorities as well. It is unknown whether passengers contribute the larger pitch to the seat or space. The relatively large pitch could have increased the feeling of “spaciousness” and/or the ‘anthropometry and these two are related.

Figure 6

Comfort Score on a Scale from 0-10 (10=extreme comfort) for Different Pitches and Seat Widths (Anjani et al., 2021)



Noise

It seems that in turboprops the noise is the factor that needs most attention. This is in line with other studies on turboprop airplanes (e.g. Mansfield et al., 2021; Vink et al., in press). Cabin noise can increase the awareness of symptoms such as swollen feet and headache (Mellert et al., 2008), but can also cause differences in comfort experience and mood (Pennig et al., 2012). Therefore, for future propeller aircrafts it might be wise to look at noise reduction systems. Already in 1997, Kincaid et al. (1997) stated that noise levels in the cabins of turboprop aircraft are louder than commercial jet noise levels. The turboprop noise spectrum is dominated by multiple harmonically related tones. Active structural acoustic control and engine synchronisation is a method to reduce noise, but also other systems like noise dampening material and noise cancelling headphones might be helpful. Mechanical options might be: changing the frequency of the harmonics by changing the propeller (e.g., by the number of blades) or change the propeller position such that there is less aerodynamic interaction with the rest of the airframe.

Vibration

Vibration is mentioned as third factor influencing discomfort. The probable vibration sources in a turboprop are the engine, blade passage frequency (BPF), air conditioning system, boundary flow, and aircraft

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mechanical systems (Bagherzadeh & Salehi, 2021), and vibration is a major contributor to the internal cabin noise. Although the seated human is especially sensitive to vertical vibration in the 5-10 Hz range, vibration and shock should be attenuated as much as possible, as in practice the lower and higher frequencies might influence the feeling of comfort as well (Wilder et al. 1994), especially at low magnitudes (Morioka & Griffin, 2006). The seat and seat cushion materials play an important role in attenuating high frequency vibration. New designs that have vibration absorption capabilities with lighter sustainable materials might improve the passengers' comfort in the sustainable aviation of the future.

Light and Temperature

For the total comfort experience light and temperature are important as well. Temperature is often mentioned in the literature regarding comfort (Bazley, 2015). Ranging from 21°C to 31.7°C on continental flights, the temperature in an airplane cabin varies significantly (Pang et al., 2014). The temperature does not only vary between flights, it varies also at different heights in the cabin, among which simultaneous cold feet and hothead discomfort is a frequent complaint (Park et al., 2011). Aircraft cabins can also be cold during boarding, before engines are started, if the aircraft has had time to lose heat since its previous flight. Providing passengers with the right means to control their body temperature (e.g., nozzles and blankets) might contribute to a better comfort experience, the crew can play a role as well in controlling the temperature and the ventilation system.

All Factors

Although the outcomes of this research suggest optimizing the cabin interior for noise or anthropometry and using a hierarchical order of factors influencing (dis) comfort, Bouwens (2018) discusses that optimizing every single element in the environment is probably not wise. Mellert et al. (2008) show that neck complaints are more noticed in noisy airplanes and McMullin (2013) showed that passengers rated their seats better (while these were the same) in the Boeing 737 sky interior compared with a traditional Boeing 737 interior. Hiemstra-van Mastrigt (2015) suggested that people could be distracted from discomfort by having a nice conversation. Kahn (2003) discusses that the presence of background noise is considered positive by train riders, as it masks other sounds like conversations between other passengers. In addition, a strong stimulus might create 'masking effect' regarding comfort (Huang and Griffin, 2012). Therefore, the combination of factors should be studied. But since, in this situation the impact of noise on discomfort is shown to be very large in a turbo-propeller airplane and on longer flights (more than 70min. as in the test) this impact might be even larger. It is wise to treat noise with higher importance and first reduce the noise to a level mostly influencing comfort and not discomfort.

A disadvantage of researching comfort and discomfort factors with questionnaires is that participants might not be aware of the single causes and their interdependency for their discomfort or comfort. Often humans are not aware of the environment (Vink, 2014), and in the process of becoming aware of elements in the environment mistakes can be made, like in the already mentioned study of Mellert et al. (2008) where noise was not remembered and neck pain and swollen feet were experienced instead. Another example is the already mentioned study of McMullin (2013). On the other hand, other studies show the importance of anthropometrics in the economy class of jet airplanes and noise in turboprops as well. Apparently, these are relevant matters.

Overall, in fact many factors influencing comfort and discomfort should be taken into account, as they are not independent and might even compensate each other. Further research is needed in this field to see how these factors interrelate. Aggerwal et al. (2021) showed that with the increase in noise levels and vibration magnitudes the overall human discomfort increased, indicating a cross-modal interaction. For the other factors these kinds of studies are needed as well to understand the interaction between different factors and their relationship with comfort. Further analyses will be done in the ComfDemo project and will include comfort evaluations, passengers' attitude and preconditions with reported (dis)comfort factors to show a more complete picture

Conclusion

In designing new electrical propeller aircrafts attention is needed for the sound in the cabin. There are ways to reduce the noise with noise cancelling or by designing the sound to be less unpleasant. In propeller and jet airplanes the seat and pitch needs attention in relationship with the anthropometrics. For anthropometrics, there is enough knowledge on what the comfort scores are of various economy class pitches and seat widths. However, many factors influencing comfort and discomfort should be taken into account, as they are not independent and might even compensate each other.

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