# Designing a floor plan using aircraft seat comfort knowledge by aircraft interior experts

**Shabila ANJANI*, Yu SONG and Peter VINK[2*]**

Delft University of Technology, Landbergstraat 15, 2628 CE Delft, The Netherlands

* Corresponding author. E-mail address: S.Anjani@tudelft.nl

**Abstract** Recent research indicated that an 18"x30" aircraft seat resulted in nearly the same level of comfort as a 17"x34" seat, however, it took less space in the floor plan. Based on this research outcome, 88 experts in the field of aircraft interior were invited to make a floor plan of a part of a Boeing 777 aircraft. First, experts were informed by the outcomes of the research and then, they were asked to make the floor plan in groups of three. Participants were given the freedom to design an economy and/or first-class interior of the cabin (5.87m wide and 3.7 m long) where besides these two types of seats, an old business-class size seat of 20"x36" was introduced as well for more flexibilities in design. In total 29 floor plans were made and these plans were analysed to compared against the complexity of the operations, the number of passengers on board, the revenue of the airline, and the width of the aisle. Results showed that 14 groups opted for the economy seats, while the rest utilized a hybrid setup where the business class seats was used in the configuration. Among all plans, four groups opted for a combination of 20 18"x30" seats and 24 17"x34" seats, and the aisle width was 0.76 m. This floor plan fits the regulations and has the potential of the highest revenue at €1,108.

**Keywords:** Aircraft Seat, Pitch, Width, Comfort, Layout

## 1 Introduction

The airline industry is a competitive market where passengers demand for comfort at a low price. Airlines are adding different comfort features in order to be chosen by customers, but they also need to maintain a certain level of revenues for a sustainable business. Therefore, between of choices of offering maximum comfort to all passengers and making this an upgrade service feature, most airlines opt to the latter option, especially the low-cost carriers (LCCs) as: 1) the fares are low regardless of their service quality; and 2) by adding additional features, LCCs can get a revenue stream of 8-13% from service features [1]. Furthermore, Hunt and Truong [2] also recommended this upgrade feature for full-service carriers (FSCs), as it will affect passenger choice by giving an option to increase comfort for passengers who are willing to pay more.

Additional seat space is one of the highlighted upgrade features that is offered by airlines. Some airlines choose to provide longer seat pitches and wider seats throughout their economy class, while others have a special premium economy class which offers this feature. Lee and Luengo-Prado [3] found that having a larger seat space only for the premium economy is more profitable for the airline. This is because not all customers were willing to pay more for an upgraded legroom, as price was the third selection criteria for most airplane passengers [4]. This premium economy concept was also seen as an additional revenue stream since 4-6% of passengers were willing to upgrade a seat with extra space for €25-30 [1]. This upgraded seat space is a primary

factor for passengers to opt for premium economy [5]. Espino, Martín [6] also found that passengers flying for 2.5-3 hours were even willing to pay €38 for this extra seat space. This willingness to upgrade to economy plus class increased for medium-haul flights and was even higher for long-haul flights [5]. Moreover, researchers also identified that the demands for premium economy had grown quickly, causing several airlines expanding the size of this cabin [7].

Anjani, Li [8] found that comfort increases when increasing seat pitch. This study was later compared to increased comfort when extending seat width of 1 inch [9]. Comparison of the results indicated that increasing the width by 1-inch increases comfort more than increasing the pitch by 2 inches, though both require the same additional space in the floor plan. And for reaching the same level of the comfort score of this additional 1-inch in width, 4-inch increase in pitch direction is needed. Meanwhile, passengers were willing to pay an additional €22 for extra seat pitch and €29 for extra seat width, though these additions correlated negatively meaning that they were not willing to pay for both additions simultaneously [10]. Some care should be taking intyerpreting these data as what passengers say they will do might differ from really buying the extra's.

Besides those scientific discoveries, designers of the floor plan should also consider the complexity of the operations, the number of passengers on boards, the revenue of the airline, and aviation regulations (e.g. aisle width). All of these contribute to the complexity of designing the floor plan and selecting the types of seats for the premium economy class. This leads to the research questions of this paper: 1) Which seat layout is more preferred by experts for the economy class in their view? And 2) Which choice is more beneficial?

## 2 Literature Review

For airlines it is important to differentiate from other airlines also within the cabin [11]. One way of differentiating is adding premium economy or just a good economy class. In the assignment the good economy class is described and in this literature review the focus is on premium economy class. Premium economy class was introduced to prevent business passengers from downgrading too much and giving an option to high income leisure passengers to upgrade [7]. It provides a choice as an answer to most passenger dissatisfaction, which are seat comfort and legroom, luggage/flight disruptions and staff behaviours which occur in both LCCs and FSCs [12].

Adding a premium economy class itself adds the complexity to the operation of the airliner. A differentiation needs to be made not only in the seats but also in other services provided by the airline [7]. Adding two types of economy class options will increase this complexity further as it needs two different types of seats. Even though Boeing introduced open architecture which gives flexibility in the interior with lots of seat combinations, it costed two years of planning before installing and a considerable amount of man-hours were needed as well [13].

Kollmuss and Lane [14] found that in the US markets, the space for a first-class seat is 313% bigger than an economy seat, while a premium economy seats only occupies 29% more space than economy. This extra space could be beneficial as ticket prices of premium economy seats are higher, however, it was also found that the production cost of the seat is also 1.6 times more expensive than an economy class seats [7]. On the other hand, airlines also want to increase the number of seats in a cabin, as airplane manufactures predicted that adding another row in the airplane can reduce 5% of the seat cost per trip [15].

FAA regulates the size of the aisle to be minimum 15 inches for airplanes with more than 20 passengers. Some experts neglected this minimum. Though occupying larger space in the floor plan, a wider aisle may accelerate the (de)boarding process, as wide aisles enable people to pass each other during boarding. Another regulation Sec. 25.817 of the FAA regulates that there is a maximum of 3 seats beside each aisle per row, therefore the layouts with an additional floor is not possible.

## 3 Materials and Methods

Eighty-eight experts in the field of aircraft interior were asked to make a floor plan of a part of a Boeing 777 aircraft of 5.87m wide and 3.7 m long. 29 groups were made and 1 person left during the workshop. Each group was given a printed scaled aircraft floor plan and 2 types of economy seats to choose from (Figure 1**Error!**

**Reference source not found.**), and additional business class seat were given as a choice, if they wanted more flexibility. The sizes of two types of economy seats were 17" x 34" and 18" x 30", respectively, while the business class seats were 20" x 36". During the session, experts could put contours of the top view of the seat (including legroom) on top of the given floor plan according to different arrangement using their experience and/or creativity. The end results of the workshop were photographed and analysed based on aviation regulations and outcomes of previous studies. At the end of the session a general evaluation was made and experts were asked to give a reasoning for the decision. All floor plans were analysed and compared based on their manufacturing complexity, the potential of the total ticket price, the perceptual choice, the number of seats installed and the width of the aisle.

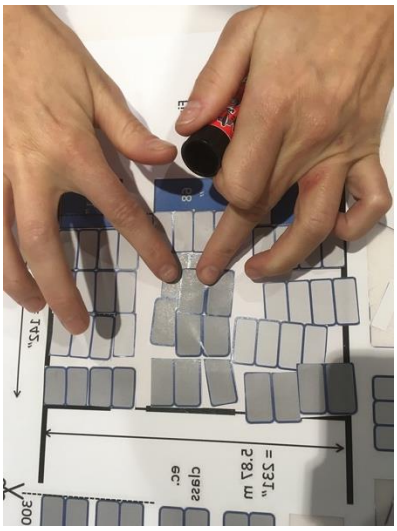

*Figure 1 Discussion process*

## 4 Results and Discussions

Twenty-nine floor plans were collected from this workshop (Figure 2).14 groups chose to only use the two types of economy class seats. These photographed floor plans were analysed based on the complexity of the operations, the number of passengers on boards, the revenue of the airline, and it might also bump some rules such as aisle width. Since this aircraft has 2 aisles, the sufficient aisle width would be 30 inches.

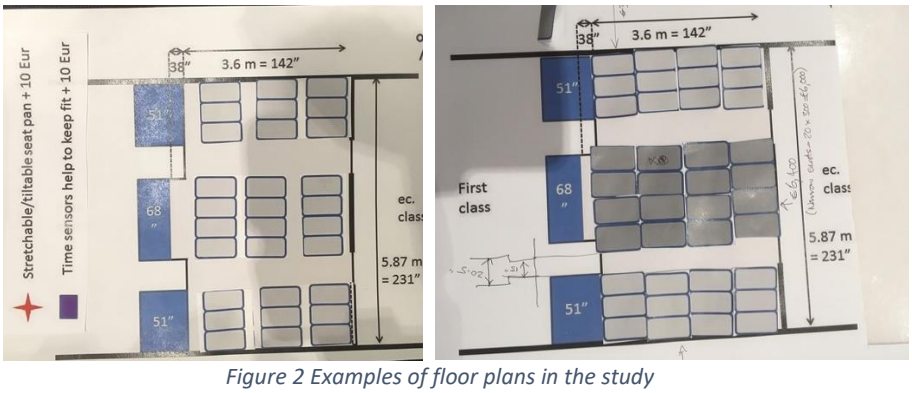


*Figure 2 Examples of floor plans in the study*

Each group was provided with three different types of seats. Adding different seat types would increase the operation complexity as it would change the process of the maintenance, booking, ticketing, etc. The number of seat types are included to give an overview of the complexity level of the operation.

The size choice of seats placed in the premium economy will affect the revenue of the airliner, as adding more seats can lead to price reduction per seat, but having an upgraded space could attract the passengers to pay more [10, 15]. Calculations of the potential total of additional revenue were made based on the price of Balcombe, Fraser [10]. Each 17"x 34" seats were valued €22 and the 18" x 30" seats were valued €29 additionally. This upgrade could be attractive for economy and premium economy passengers since 68.1% perceived legroom as the source of discomfort, while 50.7% had high discomfort on seat width [16]. The complexity level, the aisle width, the additional value of floor plans and numbers of seats were calculateed as Table 1.

**Table 1.** Calculation of floor plans

| *No.* | *18"x30"* | *17"x34"* | *Number of seat types* | *Aisle width (m)* | *Additional value* | *Seat Count* |
|---|---|---|---|---|---|---|
| 1 | 0 | 40 | 1 | 0.9 | €880 | 40 |
| 2 | 0 | 30 | 1 | 0.9 | €660 | 30 |
| 3 | 16 | 24* | 2 | 0.9 | €992 | 40 |
| 4 | 40 | 0 | 1 | 0.6 | €1,160 | 40 |
| 5 | 38** | 0 | 1 | 0.6 | €1,102 | 38 |
| 6 | 16 | 24 | 2 | 0.78 | €992 | 40 |
| 7 | 22** | 24 | 2 | 0.78 | €1,166 | 46 |
| 8 | 20 | 24 | 2 | 0.78 | €1,108 | 44 |
| 9 | 0 | 44 | 1 | 0.47 | €968 | 44 |
| 10 | 36 | 0 | 1 | 1.06 | €1,044 | 36 |
| 11 | 20 | 24 | 2 | 0.78 | €1,108 | 44 |
| 12 | 20 | 24 | 2 | 0.78 | €1,108 | 44 |
| 13 | 20 | 24 | 2 | 0.78 | €1,108 | 44 |
| 14 | 28 | 20 | 2 | 0.26 | €1,252 | 48 |

*) Seats were placed sideways
**) Layout contained a second storey

**Table 2.** Profit/loss calculation for each floor plan

| *Photo Number* | *Business class* | *Premium Economy* | *Cost (US$)* | *Revenue (US$)* | *Profit/Loss* | *Comply Regulations*** |
|---|---|---|---|---|---|---|
| 2 | 0 | 30 | 10.770 | 24.510 | 13.740 | ✓ |
| 25 | 21 | 13 | 20.753 | 36.892 | 16.139 | × |
| 16 | 7 | 28 | 15.414 | 31.633 | 16.219 | ✓ |
| 10 | 0 | 36 | 12.924 | 29.412 | 16.488 | ✓ |
| 24 | 19 | 16 | 20.298 | 36.841 | 16.543 | ✓ |
| 18 | 12 | 24 | 17.808 | 34.620 | 16.812 | ✓ |
| 27 | 24 | 12 | 22.692 | 39.828 | 17.136 | ✓ |
| 5 | 0 | 39* | 14.001 | 31.863 | 17.862 | × |
| 28 | 20* | 18 | 21.782 | 39.726 | 17.944 | × |
| 17 | 9 | 30 | 17.664 | 35.769 | 18.105 | × |
| 1 | 0 | 40 | 14.360 | 32.680 | 18.320 | ✓ |
| 3 | 0 | 40 | 14.360 | 32.680 | 18.320 | × |
| 4 | 0 | 40 | 14.360 | 32.680 | 18.320 | × |
| 6 | 0 | 40 | 14.360 | 32.680 | 18.320 | ✓ |
| 22 | 16 | 24 | 20.872 | 39.624 | 18.752 | × |
| 23 | 16 | 24 | 20.872 | 39.624 | 18.752 | × |
| 26 | 24 | 16 | 24.128 | 43.096 | 18.968 | × |
| 20 | 16 | 25 | 21.231 | 40.441 | 19.210 | ✓ |
| 21 | 16 | 25 | 21.231 | 40.441 | 19.210 | ✓ |
| 15 | 6 | 36 | 17.520 | 36.918 | 19.398 | × |
| 7 | 0 | 44* | 15.796 | 35.948 | 20.152 | × |
| 8 | 0 | 44 | 15.796 | 35.948 | 20.152 | ✓ |
| 9 | 0 | 44 | 15.796 | 35.948 | 20.152 | × |
| 11 | 0 | 44 | 15.796 | 35.948 | 20.152 | ✓ |
| 12 | 0 | 44 | 15.796 | 35.948 | 20.152 | ✓ |
| 13 | 0 | 44 | 15.796 | 35.948 | 20.152 | ✓ |
| 19 | 12 | 32 | 20.680 | 41.156 | 20.476 | × |
| 14 | 0 | 48 | 17.232 | 39.216 | 21.984 | × |
| 29 | 52* | 0 | 39.832 | 65.052 | 25.220 | × |

*) Layout contained a second storey
**) Regulations regarding the aisle width and additional store

In some plans, experts added an additional storey for more seats in the cabin. This did increase the numbers of seats, regulation wise it might not be possible since each aisle only allows three seats on each side of the aisle. One group placed the 17" x 34" seat sideways for fitting more seats in. However, it is not yet known the comfort level of the passenger in this type of seat as the orientation of the seat might also influence the comfort level. Four floor plans had an aisle width shorter than 0.76 m, which does not fit the FAA regulation. The floor plan with the highest additional revenue (€1,108) contains 20 seats of 18" x 30" and 24 seats of 17" 34". Four groups opted for this combination with 44 seats in total in the given section of the cabin.

Another comparison was made to see the potential revenue gained by combining business and premium economy class seats shown in Table 2. This calculation was based on a Boeing cost model [7]. The real cost per passenger was US$ 766 for business class and US$ 359 for premium economy. While the real revenue per passenger was US$ 1,251 and US$ 817 for business and premium economy, respectively. By comparing the potential revenue from all floor plans, it was found that having a cabin with premium economy is more profitable than just having business class seats or even combining them. Among all floor plans that are complying to the regulations, the variation with 44 premium economy class without business class was found to gain more profit. This might be due to the different space-profit ratio of the business class and premium economy class seats. Therefore, adding business class seat to this cabin section does not add to the profitability. Though, this calculation might change if the load factor of each class is added.

## 5 Conclusion and Future Works

This study tries to explore the potential of the floor plans of the economy cabin using two types of economy class seats. Aircraft interior experts were asked to make floor plans, which were analysed based on the complexity of the operations, the number of passengers on boards, the revenue of the airline, and its aisle width. 14 groups of experts used only the economy class seats. These floor plans were then photographed and the protentional additional revenues were calculated. The most profitable plan was using 20 seats of 17"x34" and 24 seats of 18"x30", resulting €1,108 with the highest seat count with 44 seats. Adding the business class seats to the floor plan did not increase the potential profit of the cabin section.

This study explores this seat configuration modelling by aircraft interior experts, where comfort was one of the main goals. Besides listed criteria, researcher also investigated aircraft seating layout by measuring load/unload time of passengers [17-20]. Another study also tries to model an aircraft seat configuration by maximizing customer satisfaction and in-flight safety as well as being profitable for the airliners [21]. They utilized tools such as digital human models, layout optimization, and a profit-maximizing constraint to their model for an optimal floor plan. Further studies are needed to understand the impact of having different types of seat in one cabin, its effect on loading and unloading process and optimizing the floor plan based on those understands.

**Acknowledgments** The authors want to thank the LPDP (Indonesian Endowment Fund for Education) Scholarship for funding the PhD work of Shabila Anjani and the participants in the workshop

## References

1. Daft, J. and S. Albers, *A profitability analysis of low-cost long-haul flight operations.* Journal of Air Transport Management, 2012. **19**: p. 49-54.
2. Hunt, J. and D. Truong, *Low-fare flights across the Atlantic: Impact of low-cost, long-haul trans-Atlantic flights on passenger choice of Carrier.* Journal of Air Transport Management, 2019. **75**: p. 170-184.
3. Lee, D. and M.J. Luengo-Prado, *Are passengers willing to pay more for additional legroom?* Journal of Air Transport Management, 2004. **10**(6): p. 377-383.
4. Brauer, K., *Presentation at the Aircraft Interior EXPO 2004*. 2004.
5. Kuo, C.-W. and R.-C. Jou, *Willingness to pay for airlines' premium economy class: The perspective of passengers.* Journal of Air Transport Management, 2017. **59**: p. 134-142.

6. Espino, R., J.C. Martín, and C. Román, *Analyzing the effect of preference heterogeneity on willingness to pay for improving service quality in an airline choice context.* Transportation Research Part E: Logistics and Transportation Review, 2008. **44**(4): p. 593-606.
7. Hugon-Duprat, C. and J.F. O'Connell, *The rationale for implementing a premium economy class in the long haul markets – Evidence from the transatlantic market.* Journal of Air Transport Management, 2015. **47**: p. 11-19.
8. Anjani, S., et al., *(In press) The effect of aircraft seat pitch on comfort.* Applied Ergonomics, 2018.
9. Anjani, S., et al., *The effect of 17" and 18" aircraft seat width on comfort*. 2019: Manuscript submitted for publication.
10. Balcombe, K., I. Fraser, and L. Harris, *Consumer willingness to pay for in-flight service and comfort levels: A choice experiment.* Journal of Air Transport Management, 2009. **15**(5): p. 221-226.
11. Vink, P. and K. Brauer, *Aircraft interior comfort and design*. 2011.
12. Sezgen, E., K.J. Mason, and R. Mayer, *Voice of airline passenger: A text mining approach to understand customer satisfaction.* Journal of Air Transport Management, 2019. **77**: p. 65-74.
13. Boeing. *787 Dreamliner by Design*. [cited 2019 3 June]; Available from: https://www.boeing.com/commercial/787/by-design/#/open-architecture.
14. Kollmuss, A. and J. Lane, *Carbon offsetting & air travel: Part 1: CO2-emissions calculations.* Stockholm: SEI., 2008.
15. Swan, W.M. and N. Adler, *Aircraft trip cost parameters: A function of stage length and seat capacity.* Transportation Research Part E: Logistics and Transportation Review, 2006. **42**(2): p. 105-115.
16. Greghi, M.F., et al., *Brazilian passengers' perceptions of air travel: Evidences from a survey.* Journal of Air Transport Management, 2013. **31**: p. 27-31.
17. Chung, C.A., *Simulation Design Approach for the Selection of Alternative Commercial Passenger Aircraft Seating Configurations.* Journal of Aviation Technology and Engineering, 2012. **2**(1).
18. Lusted, M., S. Healey, and J.A. Mandryk, *Evaluation of the seating of Qantas flight deck crew.* Applied Ergonomics, 1994. **25**(5): p. 275-282.
19. McLean, G.A., et al., *Effects of seating configuration and number of type III exits on emergency aircraft evacuation.* 1992.
20. Muir, H.C., D.M. Bottomley, and C. Marrison, *Effects of Motivation and Cabin Configuration on Emergency Aircraft Evacuation Behavior and Rates of Egress.* The International Journal of Aviation Psychology, 1996. **6**(1): p. 57-77.
21. Nadadur, G. and M.B. Parkinson, *Using Designing for Human Variability to optimize Aircraft eat Layout*, in *SAE International Journal of Passenger Cars - Mechanical Systems*. 2009, SAE International. p. 1641-1648.