Generation of design alternatives of vertical passenger seat for standing cabin concept in commercial transport aircraft

Norhafizah Dasuki, Fairuz I Romli* and Mohammad Yazdi Harmin

Department of Aerospace Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia.

fairuz_ir@upm.edu.my

Abstract. Standing cabin concept, whereby the passengers are transported during flight in their standing position, has been proposed as one of the measures to make flying more affordable to the mass public. The vertical seat, or also known as standing seat, is an essential element for the implementation of this new cabin concept as it will determine the compliance to the governing aviation regulations and also the level of safety and comfort for the passengers. Up until now however, there is no vertical seat design that has been approved for use inside the commercial transport aircraft cabin. Therefore, this study presents the generation of alternative designs for the vertical seat through the use of systematic engineering design methodology with the use of supporting design tools such as Quality Function Deployment (QFD) chart and Morphological Matrix. Five alternative concepts of the vertical passenger seat design have been developed for further assessment study to select the best one among them.

1. Introduction
The standing passenger cabin concept is one of the revolutionary solutions that have been proposed to increase the cabin capacity of commercial passenger transport aircraft in order to reduce flying cost per passenger. This idea has already been around for quite some time, with Spring Airlines, a low-cost airlines in China, been among the first to show high interest to implement the idea on its aircraft fleet back in 2006 [1]. In fact, a commercial pattern of what looks like a vertical stand for passenger cabin has been filed by Airbus, one of the main aircraft manufacturers in the world, in 2002 as depicted in Figure 1 [2]. In general, the standing cabin concept is readily in compliance with the current governing aviation regulations such as the ones imposed by the Federal Aviation Authority (FAA) and the Air Transport Association (ATA) that do not specify that the passengers must be seated during takeoff and landing phases, and do not impose any specific standard for seating comfort or arrangement inside the cabin [3]. A low-cost airline in Europe, Ryanair has been granted the regulatory approval to conduct a series of test flights with modified section of the passenger cabin on their aircraft as standing-only section in 2012 [4]. However, despite all these positive developments, there is still no standing cabin design that has been implemented or approved for commercial passenger transport aircraft until today.

There seems to be notable lack of published research study on this passenger cabin design concept and its implementation onboard of commercial passenger transport aircraft. In previous work done on this research topic, it has been highlighted that standing cabin concept can accommodate passengers with adequate comfort level [5] and its potential benefits to lower the flight cost per passenger is also discussed [6]. The results from the conducted public survey among Malaysian public have shown that
cabin concept has notable market support and acceptance [7]. Furthermore, a conceptual design of the vertical seat for application in standing cabin concept has been proposed as in Figure 2 [8]. The work presented in this paper is a continuation of the previous research work, whereby the design of vertical seat to support and secure the passengers in standing cabin concept is further explored and improved from previous design.

![Figure 1. Illustration of standing cabin in a pattern filed by Airbus [2]](image)

![Figure 2. Proposed vertical seat design by Mohammad Nor and Romli (2013) [8]](image)

2. Design alternatives generation process

Engineering product design process normally starts with the design requirement analysis [9]. In this step, the expectations and also preferences for the product to be developed with regards to its physical and functional aspects are identified and established. This is a very essential step that heavily dictates the probable success of the product design and development process because it determines whether the developed product design will match well with the market demands. There are several design aid tools that can be applied to aid the requirement analysis process and one of them is the Quality Function Deployment (QFD). QFD is a method that can be applied to satisfy the customers or stakeholders by translating their needs and preferences into design targets and quality assurance points for the product to be developed [10]. The main output of QFD method is a matrix known as House of Quality, which is essentially the conceptual map for the design process that establishes the underlying links between the customer requirements and the technical design parameters to satisfy them [11].
From the information summarized in the House of Quality, several essential design parameters and also functions of the product to be developed can be identified and focused on. Furthermore, from the information in the benchmarking section of the resultant House of Quality matrix, data on current competitor products in the market can be obtained and this can be utilized by product designers to set target performance and create market niche for the product under development. Using the information in QFD, another design aid tool called Morphological Matrix (MM) can then be applied to generate some alternatives for the product design. In short, MM is an assisting tool to help designers to explore the conceptual design space for the product, especially to encourage the search into new territories that are typically unexplored. Unlike other methods that can be heavily biased towards the designer's past experiences and also the previous or current successful designs in the market, MM can lead to more inventive process through random combinations of the possible solutions for each identified product attribute [12]. This allows the explored solution space to be extended outside the typical norm and may lead to the generation of new revolutionary ideas. However, each generated solution is assessed for feasibility and practicality before being considered further in the design and development process. MM has been accepted as a good means of recording the information on the possible solutions for the product design and facilitating the cognitive process of generating system-level design solution [13].

For this research study, summary of the design process applied up to the generation of alternative design concepts for the vertical seat is presented in Figure 3. A short public survey is conducted to the Malaysian public in order to obtain the customer requirements for the vertical seat design. In addition, interview sessions with few experts in related engineering industries, aviation authority and airlines are also done to gain some insights on their needs and requirements. All gathered information from the public survey and interview sessions has been summarized into the QFD matrix for the vertical seat as presented and discussed in Ref. [14], which is reproduced in Figure 4. Based on this information, MM for the vertical seat is constructed.

3. Generated design concepts
As previously mentioned, QFD is a well-accepted design tool that has been applied in many product design processes. From the data in the QFD shown in Figure 4, main design parameters and functions of the vertical seat for the standing cabin concept can be extracted. This information is then utilized to construct the MM for the vertical seat. All in all, six parameters or attributes for the vertical passenger seat design are identified: main seat structure, backrest, bottom seat pan, secure or safety mechanism, armrest and seat adjusting mechanism. Available options for each of them are identified, which have been obtained through literature review on existing designs and also from brainstorming process on new ideas and concepts. The constructed MM for the vertical passenger seat is shown in Figure 5.

Figure 3. Design methodology flowchart for this study
Based on the MM in Figure 5, several design alternatives can be generated for the vertical seat. An explanation on how this is done can be found in Ref. [15]. The total number of all possible solutions that can be derived from the MM is the product of multiplying degree of freedom for each dimension and rows of listed attributes, which amounts to 22,500 possible different design combinations. There are many ways that have been proposed to deal with this so-called "curse of dimensionality" whereby the total number of combinations grows exponentially with each additional degree of freedom in the MM. In this study, the traditional random mix-and-match of the options for each attribute is applied to generate the design alternatives. Several initial design concepts are randomly generated before they are
narrowed down to only five good designs to be seriously considered through a brainstorming process. This preliminary screening process is accomplished based on personal intuition and knowledge about existing designs.

3.1. Design Concept 1
One of the main driving factors for standing cabin concept is to increase the ability to accommodate more passengers in the same available cabin space. The vertical seat design in Concept 1, as shown in Figure 6, is selected for consideration to maximize number of passengers that can be accommodated inside the cabin space due to its design simplicity. Its main design structure uses a standard hollow cylindrical beam to reduce its overall structural weight. The seat's backrest is designed to support and provide comfort to the standing passengers. In addition, this vertical seat is also equipped with the adjustable seat pan and armrest to provide more comfort, particularly in relieving some of the body stresses caused by prolonged standing posture. Last but not least, a two-point safety belt mechanism is included for securing the passengers during flight.

3.2. Design Concept 2
Similar to the first concept, Concept 2 that is considered for design of the vertical passenger seat has also been driven by the notion of space-saving and more cabin accommodation capacity. The design concept is illustrated in Figure 7, which closely resembles a typical office chair. The main structure is a single cylindrical beam, with a hydraulic system installed within it for height adjustment capability. The seat pan and backrest is designed together as one unit, which means that the seat pan is fixed at a certain angle and is not adjustable. The adjustable armrests are provided to provide some comfort and support to passengers while they are standing. For safety mechanism, a three-point seat belt is installed to secure the passengers during flight.

3.3. Design Concept 3
The generated design Concept 3 for vertical passenger seat has been made primarily for high comfort and safety purposes. As can be observed in Figure 8, the primary seat structure looks bulky and rigid, providing strength and more stability to the seat. Apart from backrest and adjustable seat pan, it is also equipped with a headrest. The adjustable armrests are provided for additional support to the standing passengers and two-point seatbelt mechanism is installed to secure the passengers for safety purposes during flight. It should be noted that unlike the previous two concepts, this seat concept will be much heavier but stronger and steadier, which is expected to be able to provide more comfort (with less seat vibrations) and better safety support to the passengers. Moreover, with this seat concept, the number of standing passengers accommodated inside the cabin space will not be as many as those with previous two concepts.

![Figure 6. Generated design Concept 1 for the vertical seat](image1)
![Figure 7. Generated design Concept 2 for the vertical seat](image2)
![Figure 8. Generated design Concept 3 for the vertical seat](image3)
3.4. Design Concept 4
The main added element for the generated design Concept 4 for the vertical passenger seat is the sense of privacy. The main primary structure of the seat is shaped like a cocoon and instead of armrests, it is equipped with some sorts of a simple hand holder on both sides of the structure for the passengers to hold on for support during flight. Furthermore, a comfortable backrest and an adjustable seat pan are also equipped for the seat. A two-point seatbelt mechanism is also provided to secure the passengers. Similar to the previous Concept 3, this seat concept appears to be heavier and because of its structural shape, its manufacturing complexity and cost will be higher. Nevertheless, its advantages included the provision of more comfort to the passengers with the added privacy and less seat vibrations, with a stronger seat structure for safety. The use of cabin space to install this seat concept will also make it unable to fully maximize the available space for maximum number of standing passengers inside the cabin. The illustration of this concept is shown in Figure 9.

3.5. Design Concept 5
Last but not the least, the generated design Concept 5 of the vertical seat for the standing passengers looks more aesthetical than previous designs as depicted in Figure 10. It shares an almost similar main structural design like Concept 3 but it is lighter and curved. Similar to some of the previous concepts, it is equipped with a comfortable backrest, adjustable seat pan and also flexible armrests that can be adjusted up and down. Its safety mechanism is a two-point seatbelt to secure standing passengers. It is believed that this seat design can provide the level of safety and comfort much like previous Concept 3 and Concept 4, but with lighter weight and requires less space. The latter helps to add more possible accommodation of standing passengers in the cabin.

3.6. Further discussions
Once the design alternatives for the vertical seat have been generated, the next following step will be to evaluate them to select the best one among them. The evaluation criteria to be used in this process can be referred back to the established customer needs and requirements from previously constructed QFD chart for the vertical seat. By doing this, the chosen design concept for further development is ensured to be the closest one to meet most of the anticipated performance and characteristics by its stakeholders and end users. There can also be cases, especially with the purely randomize mix-and-match method from the MM, where none of the considered generated concepts is deemed suitable to be further developed based on evaluation results against its requirements. In such cases, the concept generation process from MM has to be reiterated and some new alternative design concepts are down
selected and evaluated. This continues until one design concept emerges as the most potentially good one for further development.

As noted from the five generated design alternative concepts, each of them has their own strengths and weaknesses that are hard to differentiate without using a proper evaluation technique. In addition, established customer needs and requirements that become the evaluation criteria can be conflicting to each other. Hence, systematic multi-criteria decision making techniques and tools are often applied for the design evaluation process like Pugh Analysis or Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS).

4. Conclusion
In this paper, few design alternative concepts of the vertical passenger seat for the standing cabin have been generated through a systematic design engineering process. Based on constructed QFD matrix for the vertical passenger seat in previous study, the information is utilized to construct the corresponding morphological chart. Five different design concepts are generated from the morphological chart by a random mix-and-match procedure. The next following step would be to evaluate these five concepts against the established customer requirements or needs in order to choose the best one among them for further development.

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