UNIVERSITI PUTRA MALAYSIA

CONCEPTUAL DESIGN OF VERTICAL SEAT IN COMMERCIAL TRANSPORT AIRCRAFT FOR STATIC CONDITION FLIGHT

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By

AHMAD REDZMAN BIN MOHAMAD NOR

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia as in fulfilment of the requirement for the degree of Master of Science

CONCEPTUAL DESIGN OF VERTICAL SEAT IN COMMERCIAL TRANSPORT AIRCRAFT FOR STATIC CONDITION FLIGHT

By

AHMAD REDZMAN BIN MOHAMAD NOR

July 2016

Chairman : Fairuz Izzuddin bin Romli, PhD

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The number of people travelling by air has increased from year to year. This situation can be attributed to the rise of low cost airlines, which offer cheaper flight tickets and make air travel affordable to more people. However, offering cheap flight tickets is also hard to maintain amid increasing competition and fluctuating market factors like fuel prices. It is believed that one way to keep the flight cost per passenger low is by increasing the cabin capacity. Several cabin arrangement and seat designs have been proposed to some level of success but the discomfort level of the passengers has also increased. To counter this problem, the "standing cabin" concept is proposed where passengers will be transported in their standing position instead of sitting inside the cabin. This way, the number of passengers that can be accommodated onboard the cabin per flight will be increased. In addition, because they are standing, the issue of small legroom space will not be a problem anymore. A central part of the standing cabin concept is the vertical seat to support passengers during flight. Thus far, there is no vertical seat that has been widely used in commercial transport flights due to several factors. Therefore, this research aims to propose a conceptual design of such vertical seat. Based on the market study and literature review, several design criteria of the vertical seat have been identified. They are used to select the baseline design to be developed further among three alternative concepts that have been designed. The chosen vertical seat design is then sized according to anthropometric data and prepared using Computer Aided Design software, CREO PARAMETRIC. Further sizing through parametric design study and also safety compliance analysis of its static structural strength to the governing aviation regulations are done using Finite Element Analysis software, ABAQUS. The structural strength of the resultant conceptual vertical seat design in this study has been shown to be in compliance with static condition flight specifications as outlined by aviation regulations. Furthermore, it has been demonstrated that the use of the proposed vertical seat in a full standing cabin set-

up leads to an increase of 21% in cabin capacity for a Boeing B737-300 aircraft. Further study on improving the proposed vertical seat design, especially in testing for its performance in dynamic condition flight, is recommended in future.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Master Sains

REKABENTUK KONSEPSI KERUSI MENEGAK DALAM PESAWAT PENGANGKUTAN KOMERSIAL BAGI KONDISI STATIK PENERBANGAN

Oleh

AHMAD REDZMAN BIN MOHAMAD NOR

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Jumlah penumpang pengangkutan udara semakin meningkat dari tahun ke tahun. Situasi ini boleh dikaitkan dengan peningkatan syarikat penerbangan tambang murah yang menawarkan harga tiket penerbangan yang lebih murah dan menjadikan lebih ramai orang mampu menggunakan pengangkutan udara. Namun, penawaran tiket penerbangan yang murah sukar untuk dikekalkan dengan keadaan persaingan yang meningkat dan faktor pasaran yang tidak menentu seperti harga minyak. Dipercayai bahawa salah satu cara untuk mengekalkan kos operasi penerbangan rendah bagi setiap penumpang adalah dengan meningkatkan kapasiti kabin. Beberapa susunan kabin dan rekabentuk kerusi telah berjaya dicadangkan tetapi tahap ketidakselesaan penumpang turut meningkat. Untuk mengatasi masalah ini, konsep "kabin berdiri" telah dicadangkan di mana penumpang akan diangkut dalam keadaan posisi berdiri dan bukan dalam keadaan duduk di dalam kabin seperti sekarang. Dengan cara ini, jumlah penumpang yang boleh ditampung di dalam kabin untuk setiap penerbangan akan meningkat. Selain itu, memandangkan penumpang akan berdiri, isu mengenai ruangan untuk kaki yang kecil tidak akan timbul. Perkara utama bagi konsep kabin berdiri adalah kerusi menegak untuk menyokong penumpang ketika penerbangan. Ketika ini, masih belum ada rekabentuk kerusi menegak yang digunapakai di dalam penerbangan komersial secara menyeluruh disebabkan beberapa faktor. Oleh itu, kajian ini bertujuan mencadangkan satu rekabentuk konsepsi bagi kerusi tersebut. Berdasarkan kajian pasaran dan literatur, beberapa kriteria untuk kerusi menegak ini telah dikenalpasti. Kriteria ini digunakan bagi memilih rekabentuk asas di antara tiga rekabentuk alternatif yang dihasilkan untuk dibangunkan seterusnya. Pensaizan reka bentuk kerusi menegak yang terpilih kemudian dibuat berdasarkan data antropometri dan disediakan menggunakan perisian rekabentuk berbantukan komputer, CREO PARAMETRIC. Pensaizan selanjutnya melalui kajian parametrik rekabentuk dan analisis kepatuhan keselamatan untuk kekuatan statik struktur mengikut keperluan peraturan penerbangan dilakukan menggunakan perisian analisis unsur terhingga, ABAQUS. Kekuatan struktur bagi rekabentuk konsepsi akhir kerusi menegak yang dicadangkan dalam kajian ini telah ditunjukkan mematuhi spesifikasi kondisi statik penerbangan seperti

digariskan oleh peraturan penerbangan. Selain itu, penggunaan kerusi menegak ini di dalam konsep kabin berdiri sepenuhnya bagi pesawat Boeing B737-300 juga menunjukkan peningkatan kapasiti kabin sebanyak 21%. Kajian selanjutnya untuk menambahbaik rekabentuk kerusi menegak ini, terutamanya dari segi pengujian prestasi dalam kondisi dinamik penerbangan, adalah disyorkan pada masa depan.

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Last but not the least, I am forever grateful to my family for their great understanding and patience during my studies.

I certify that a Thesis Examination Committee has met on **21 July 2016** to conduct the final examination of **Ahmad Redzman Bin Mohamad Nor** on his thesis entitled" **CONCEPTUAL DESIGN OF VERTICAL SEAT IN COMMERCIAL TRANSPORT AIRCRAFT FOR STATIC CONDITION FLIGHT** " in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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Declaration by graduate student

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Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

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Name of Member of Supervisory Committee: Rizal Bin Zahari

Signature: ______________________
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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

LCC	Low Cost Carrier
FSC	Full Service Carrier
IATA	International Air Transport Association
MAB	Malaysia Airport Berhad
FAA	Federal Aviation Authority
FAR	Federal Aviation Regulation
JAR	Joint Aviation Regulation
CAD	Computer Aided Design
FEA	Finite Element Analysis

CHAPTER 1

INTRODUCTION

1.1 Commercial Air Transport Market

The commercial aviation industry has been progressing over the years. Today, more and more people are keen to travel by air, which is evident in Figure 1.1 where the number of passengers using aircraft as their mode of travel is on steady increasing trend between years 1950 to 2011. Moreover, Airbus and Boeing companies, the two major aircraft manufacturers in the world, have predicted an exponential growth of flying passengers between the years 2011 to 2030 [1].

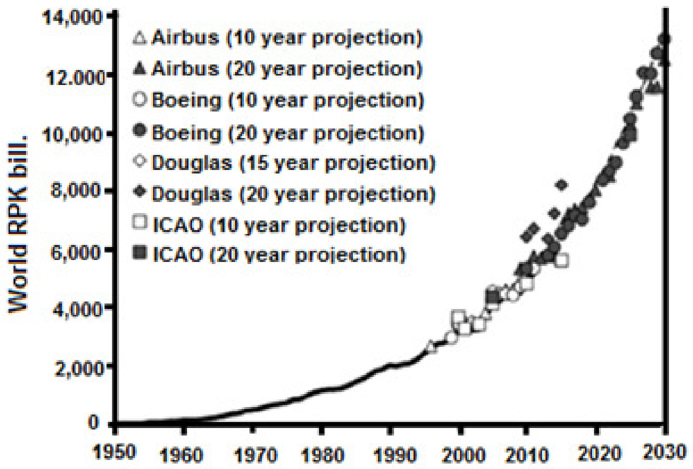

Figure 1.1: World passenger revenue passenger-km, historical (1950-2011) and projection [1]

One factor that can be attributed to rapid growth of airlines industry is the rising number of Low Cost Carriers (LCCs). Cheaper ticket prices offered by LCCs have opened up a few new flying passengers' market segments by attracting people who may otherwise think that the cost of flying is too high for them. Demand for LCCs has been increasing. From August 2003 and August 2012, the number of seat capacity has risen from 150 million to 350 million worldwide [2]. The lower cost of flight tickets and value for money are two main factors that attract people to use LCCs [3]. This is achieved by removing non-essential onboard services like complimentary cabin foods, in-flight entertainment system and also business class seating. In addition, LCCs cut their overhead costs by operating from the remote airports that offer much lower landing fees compared to those airports that are located nearer to the city centre. It can be noted that aircraft cabin for LCCs often has minimum comfort features. Luxury items such as passengers' seat with seat-back video screen, reclining seats and blinds are typically removed. As most of targeted flight segments for LCCs are those in shorthaul category, sacrificing extra comfort, in-flight entertainment and foods are rarely seen as a big deal for their passengers.

In order for LCCs to have a profitable operation, they rely heavily on having high load factors for each of their serving flights. As their main competitive strength is lower ticket prices, their primary challenge is to maintain a low operational cost amid the instability of the other market factors. In addition, increasing number of operating LCCs also raises the competitive level of the market. Table 1.3 shows the current number of operating LCCs in the world by region. As can be observed, most number of LCCs is within the Asian region, which includes the domestic Malaysian market.

One of the dominant market factors to airlines operation is the jet fuel price. Figure 1.4 shows the fuel cost and its consumption by the U.S. carriers from January 2000 until September 2014. As can be seen, the graph indicates that fuel cost per gallon for domestic and international flights is less than USD1 in 2000 but by the month of September 2014, the cost of fuel has gone up by roughly 300%. Though currently the worldwide fuel price has reduced, it is nonetheless expected to increase back again if based on its historical trend. The instability of fuel price, especially when it sharply increases, is indeed a challenge to keep the flight operational cost low.

Table 1.1: Numbers of Operating LCCs Worldwide [4]

Region	Number of LCCs
Africa	9
South America	6
Oceania	1
North America	12
Middle East	7
Asia	59
Europe	27
South America	5

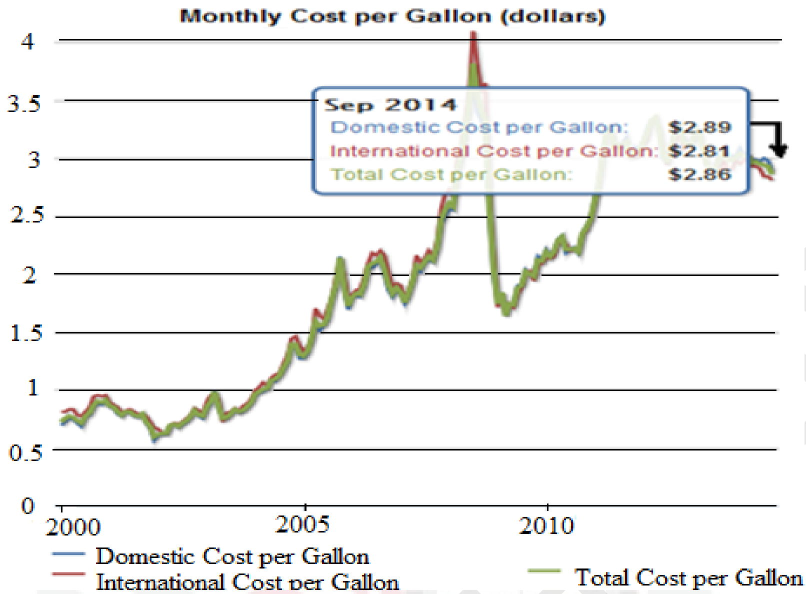

Figure 1.2: Airline fuel cost and consumption (US Carriers) [5]

Additionally, airlines are facing a stiffer competition from other available means of public transportation. To date, tremendous improvement of road infrastructures and high-speed rail services has enabled buses and trains to become significant competitors to airlines, especially LCCs. Based on data by United States' Bureau of Transportation Statistics as shown in Table 1.2, large numbers of people tend to choose to domestically travel by ground road highways instead of taking flights. This situation can be attributed to several reasons but the fact domestic flight market in the United States is among the biggest and many people still tend to choose other transportation means to travel even with plethora of choices of LCCs serving the domestic routes is a concern. In other words, operation of airlines especially LCCs has to be more competitive to attract more flying customers.

Table 1.2: Mode of Transport in the United States in 2005 [5]

Mode of Passenger Transport	Passenger-miles (millions)	Percentage
Highway - Total	4,884,557	88.79%
Air Carriers	583,689	10.61%
Rail - Total	30,972	0.56%
Other Modes	2,091	0.04%

Travel time savings used to be the ultimate advantage of paying higher price for the flight ticket as compared to using other cheaper public transports. However, with rapid improvement of ground facilities and their operational efficiency, the gap in travelling time between air and ground transportation is gradually shrinking. A good example is the development of high speed train. For London to Paris route, it now takes about 2 hours and 20 minutes using Eurostar high speed train, with a cost as low as USD100. For the same route by flight, LCC's EasyJet airline will take about 1 hour and 10 minutes, and can cost up to USD165.

All in all, in order to remain competitive and maintain profitable operation, airlines are actively searching for new ways to keep their operational cost low amid market uncertainties. Apart from the reduction of onboard luxury services as applied by many LCCs in their operation, one of the ways to reduce flight ticket price for passengers is by increasing the cabin capacity of the current aircraft. It has been hypothesized that having a bigger cabin capacity (hence more onboard passengers per flight) can notably reduce the flight operational cost per passenger [6]. With this notion, several proposals have been made for cabin arrangements and also passengers' seat designs to make way for a high-density cabin.

1.2 Increasing Cabin Capacity per Flight to Reduce Cost

An airline seat supplier, Zodiac Seat France [7] has proposed a new airline cabin seat arrangement called "Economy Class Cabin Hexagon" as shown in Figure X1. The concept of this Hexagon Seat arrangement is by placing the passenger seats in different directions. The objective of this new cabin arrangement is to increase cabin density (hence number of passengers per flight). The Hexagon Seat arrangement design can potentially improve passenger "shoulder and arm area" and by this way seat can be placed much closer to each other. The Hexagon seat itself can be folded upright to make easy exit for passengers during emergency situation. However, it is believed this concept can also tend to make passengers feel uncomfortable, especially when they are trying to sleep or eating because they are facing each other.

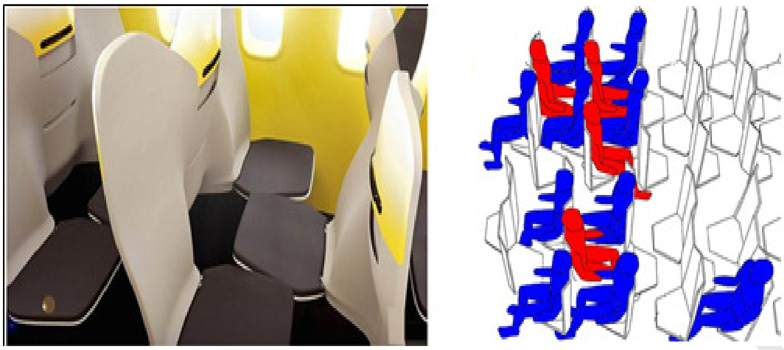

Figure 1.3: Economy class cabin Hexagon [7]

On the other hand, Boeing has also launched a denser seat seating for their Boeing 737 aircraft that is called 737 MAX 200 [8]. The seats are made thinner than the current conventional seats. The thinner or skinny seat will make high cabin density airplane possible as shown in Figure 1.4 and its layout in Figure 1.5.

Figure 1.4: Skinny seat [8]

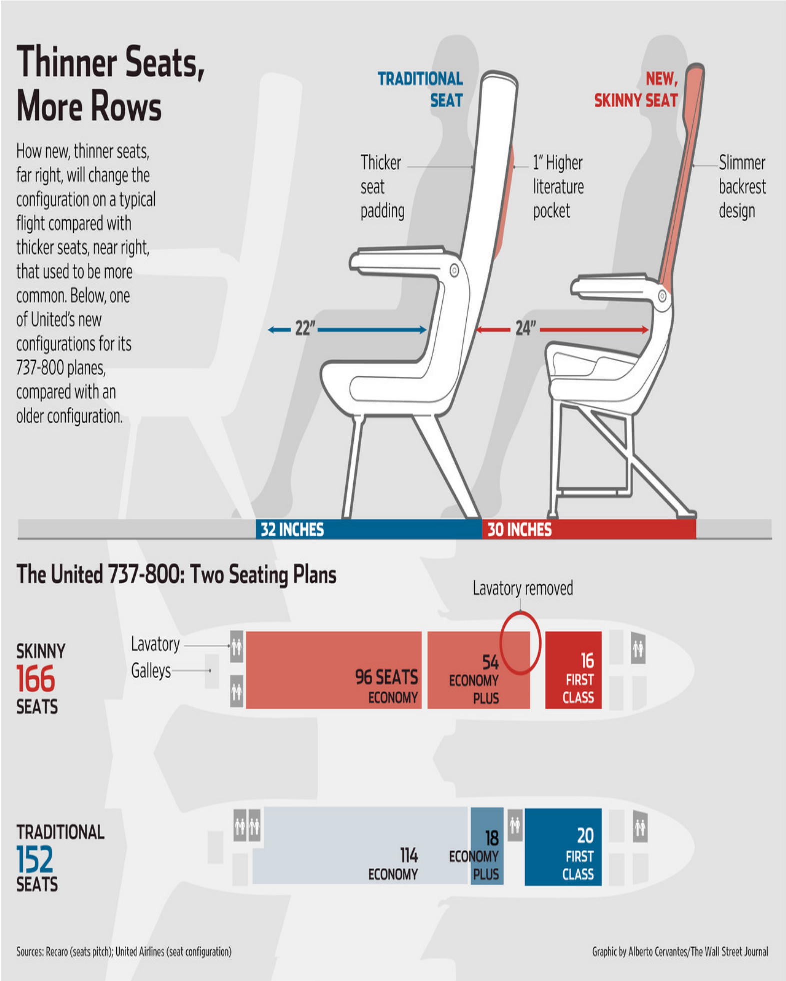

Figure 1.5: Skinny seat layout inside aircraft cabin [8]

This skinny seat used in Boeing 737-800 (Figure 1.4) can reduce the sitting pitch and therefore increase numbers of passengers' seats inside the cabin. It has been projected that it can increase the cabin capacity up to a total of 166 seats but with a pitch of only 30 inches, down from 32 inches of current conventional seats [8]. This does not bode well with the passengers. Based on a study, passengers' perception of space, leg room and seat width account for 60% of the average traveller's sense of comfort [9]. Since passengers are seated, legroom space is very important for their comfort, especially for tall people.

While several other cabin arrangements and new conventional seat designs have been also proposed to achieve high-density cabin, issues and concerns regarding the passengers' comfort and airlines' profitability are still ongoing. Hence, there is a need to find new revolutionary cabin concept that can both help the airlines to reduce their flight cost per passenger by increasing the cabin capacity and at the same time maintain a good flying experience for the passengers. A much more revolutionary and innovative idea of the cabin design that is thought to be a good alternative to resolve this issue is the "standing cabin" concept, which is further discussed in following section. Since the issue of reduced legroom is essential for many passengers' when they are seated, it is hard to increase cabin capacity with the conventional seated cabin arrangement without sacrificing their legroom comfort. On the other hand, when the passengers are standing, the issue of reduced legroom to increase the cabin capacity is no longer a primary problem. However, it is important for passengers to be adequately supported to ensure their safety is not compromised and also reduce their fatigue feeling from standing within the flight duration.

Key Note: It is difficult to increase cabin capacity with conventional seated arrangement without reducing the legroom space for passengers (hence lowering flying comfort). The “standing cabin” concept is believed to be able to provide a better alternative solution to this problem.

1.3 Standing Cabin Concept

Standing cabin, as the name readily suggests, is a cabin concept where the passengers are transported during flight in their standing position instead of the normal seating arrangement, as illustrated in Figure 1.5. This idea has already been around for some time. A LCC in China, Spring Airlines has started to look at the possibility of having standing-only passenger cabin on their aircraft in 2009. It is anticipated that such cabin design can increase the onboard capacity by about 40% than that of the conventional cabin design and reduce cost by as much as 20% [6]. In 2012, a major LCC in Europe, Ryanair has picked up on the idea and conducted a series of test flights with a modified section of passenger cabin on their aircraft fleet as standing-only section [10]. This development is seen as an indication that standing cabin idea is growing in acceptance by the public and airlines, though there are still several issues that need to be addressed and resolved before it is fully ready for implementation in commercial flights.

A study on the ergonomics of the standing cabin highlights that the standing posture will not pose a significant health risk to passengers in comparison to current sitting posture inside the cabin for short range flights [11]. In fact, standing can actually provide better posture for human body. Thus contrary to negative perception on standing cabin concept as health risk and also uncomfortable for passengers, it could actually be a more comfortable and efficient way of transporting people inside the aircraft cabin for short flight. Natural standing over prolonged periods is a common situation in daily life and it is not fatiguing, even if it is restricted within limited area of standing space like in the standing cabin concept [12]. Another study by Callaghan and McGill [13] concluded that standing posture is a good rest from sitting due to favourable change in the lumbar spine posture and shift in loading of posture-dependent passive tissues.

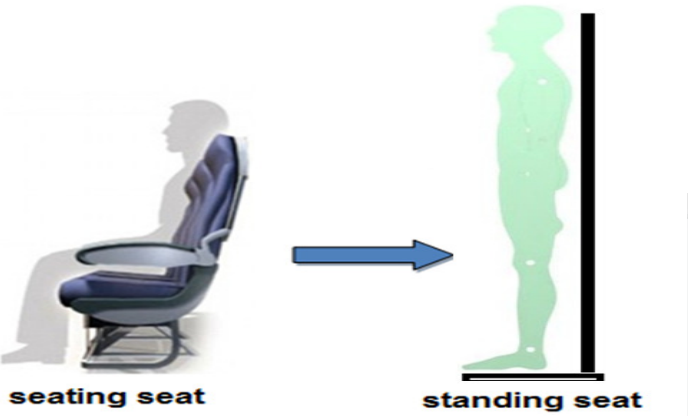

Figure 1.6: Standing seat inside aircraft cabin

It goes without saying that safety is always a paramount issue in commercial aviation. To ensure this, vertical seat design and standing cabin arrangement will still have to comply with the currently applied standards by the aviation regulatory bodies. For such very-high-density seating concept, it must be able to ensure that all passengers can evacuate the aircraft cabin within the allowable time limits during any emergency cases. In addition, the vertical seat design needs to pass all required tests to ensure that it can provide the necessary level of protection and passengers' restraint as outlined by the crashworthiness requirements. The materials used in building the seats also need to be tested and has to comply with the required criteria such as non-flammable and non-toxic. In a nutshell, the seat design needs to satisfy the requirements for aircraft seat as outlined in FAR/JAR Part 23 Regulation.

As of today, there is no vertical seat design or standing cabin arrangement that has been approved for commercial transport use. In addition, no major study that has been published on the vertical seat designs for standing cabin is found in public domain. Nonetheless, it is encouraging to note that such standing seats are not illegal by the current standards of several governing aviation bodies. In terms of regulation, standing cabin concept is principally legal by current standards of major governing aviation authorities. Federal Aviation Authority (FAA) does not specify that passengers have to be in their sitting position during take-off and landing while the Air Transport Association (ATA) does not enforce specific standards for seat comfort or seating configuration onboard the cabin [14]. According to current aviation rules, it is adequate if it can be proven that passengers have been properly secured by a certified mechanism, even if they are standing during take-offs and landings. This cabin concept is suitable for domestic air transportation market because most domestic flights are within two hours duration, which is suggested as a good duration for its application [14]. A study conducted for domestic Malaysian flight markets indicates that flight ticket prices can be reduced by as much as 26% when using the standing cabin concept [15]. This is due to increased number of passengers that can be accommodated inside the cabin. By having the passengers stand during travel, the standing seat pitch between passengers can be reduced as shown in Figure 1.7.

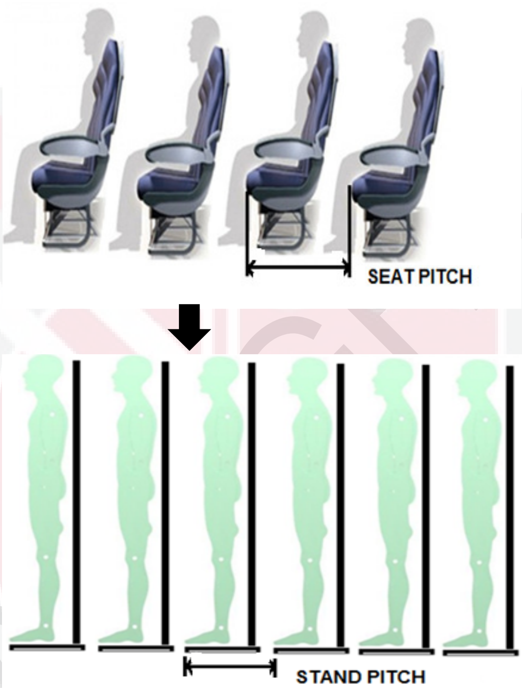

Figure 1.7: Standing pitch less than seating pitch

Even though the idea of a standing cabin concept has been floating around for some time, it is unfortunate that very few studies have been done on its implementation to commercial air transportation.

1.4 Research Scope Definition

One of the key elements required for successful implementation of standing cabin concept in commercial transport aircraft is the vertical seat to support passengers while they are standing during flight. Thus far, there is no vertical seat design that has been approved for use on commercial transport aircraft although the idea of the standing cabin concept has been around for nearly a decade. In fact, during the literature study done for this research, no formal detailed study on any design and development of vertical seat for this purpose is found in public domain. This is a clear research gap that must be addressed to enable the realization of the standing cabin concept.

Identified Research Gap: There is no vertical seat design thus far that has been fully studied in the literatures and approved for use on commercial transport aircraft.

1.4.1 Scope Limitations

The complete design and development study of a vertical seat for standing cabin concept is a very wide research area. In this study, some limitations are applied to the problem scope to better refine its focus and aligned it with the expected workload of a Master's degree.

Firstly, this study only covers the conceptual phase of the vertical seat design and development process. This means that this thesis research work does not include any prototype development or experimental testing. The research is limited to computer modelling of the proposed design concept and also design simulation testing or demonstration using available software tools to show its compliance to the identified design requirements. The test for safety will only cover the specifications for static condition flight.

Secondly, the sizing and dimensioning of the proposed vertical seat design is mainly tailored to the features of Asian passengers. This helps to simplify the design and development process. Since the standing cabin concept works well for LCCs and the Asian region has been shown to have the biggest number of LCCs, this design simplification is rather justifiable. Nonetheless, the sizing and dimensioning of the vertical seat can be easily extended or reduced to cater for different passengers' features.

Last but not least, it should be noted that the focus of this research is on the conceptual design of the vertical seat and not the standing cabin. Although simulation of the arrangement of the proposed vertical seats in the standing cabin set-up is provided, no work is done on demonstrating the feasibility and viability of the standing cabin implementation for LCCs. Hence the detailed study on how the standing cabin concept will affect the airlines' operation can be considered to be out of the scope of this thesis research study.

1.4.2 Research Objectives

Up until this point, the need for a working vertical seat design to effectively support the implementation of standing cabin concept has been sufficiently established. Furthermore, the scope of this study has also been clarified in previous section. In short, this research is narrowed down to development of a vertical seat design concept for use in the standing cabin of commercial transport aircraft. This is summarized in the following purpose statement for this thesis work.

The purpose of this thesis to develop a conceptual design of a vertical passenger seat that can support the future implementation of the standing cabin concept in commercial transport aircraft.

In corroboration with the above work intent, following research objectives are set up based on the identified requirements and aviation regulations for current aircraft seat designs. It should be noted that the research objectives are essential to ensure that the proposed vertical seat design concept satisfies operational and safety requirements that have been outlined for commercial transport aircraft operation.

Research Objective 1: The vertical seat design should enable increased capacity of existing commercial transport aircraft with the same available passengers' cabin space for better operational profitability.

Research Objective 2: The vertical seat should be designed in compliance with aviation regulations and able to provide adequate support for the standing passengers such that their safety is not compromised during flight operation.

1.5 Thesis Organization

The overall structure for this thesis documentation is as follows. This first chapter has built the case for relevance of this research study by explaining its motivation. In addition, the study scope has been outlined by defining its limitations and research objectives that guides the development of proposed vertical seat design. Chapter 2 reports upon the literature review that has been done to identify available information and state-of-the-art technologies to aid in the vertical seat design and development. The review is conducted based on the research questions, which are tailored to research objectives in Chapter 1. Based on the gained knowledge, the research hypothesis for this study is presented in Chapter 3, along with planned research methodology to test this hypothesis. Chapter 4 presents the details of the steps in deriving the final proposed design of the vertical seat. Lastly, this thesis document concludes with Chapter 5, which contains assessment on the achievement of the research objectives and also the final discussion on this research work and suggested future work.

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