



AENSI Journals

Australian Journal of Basic and Applied Sciences

ISSN: 1991-8178

Journal home page: www.ajbasweb.com



Impact of Standing Cabin Concept on Takeoff Gross Weight

Fairuz I. Romli, Ahmad Redzman Mohammad Noor

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

ARTICLE INFO

Article history:

Received 25 January 2014

Received in revised form 12

March 2014

Accepted 14 April 2014

Available online 25 April 2014

Keywords:

Vertical seat, standing cabin, aircraft cabin, transport aircraft

ABSTRACT

The market competition between airlines today has basically changed towards the affordability of their air transportation service. In other words, airlines are competing to lower their ticket prices as to capture the high demands from the leisure and business travellers, who are also price-sensitive customers, while still maintaining a reasonable profits margin. Theoretically, by having more passengers onboard the aircraft, the flight ticket price can be lowered since the imposed operational costs can be shared by more passengers per flight. To achieve this, an idea of standing cabin, where passengers are transported in the aircraft cabin in their upright position, has been proposed to reduce operational flight cost per passenger. However, this condition will only work if the resultant operational costs can be maintained at the same level as in the conventional cabin arrangement or increase at a lower rate than the additional number of passengers. Since operational costs of an aircraft can be directly related to its weight, this study is aimed to highlight the impact of standing cabin concept on the takeoff gross weight as to verify the sought-after potential benefit of a lower cost per passenger.

© 2014 AENSI Publisher All rights reserved.

To Cite This Article: Fairuz I. Romli, Ahmad Redzman Mohammad Noor., Impact of Standing Cabin Concept on Takeoff Gross Weight. *Aust. J. Basic & Appl. Sci.*, 8(4): 375-382, 2014

INTRODUCTION

Today, air transportation has become an essential means of travelling. This situation is the result of increasing global networking and businesses that necessitates people to travel from one point to another in a much shorter time. Instead of being an exclusive travel option that is mostly aimed for the rich like in the past, air transportation has progressively become a common travel mode as the flight services are made more affordable by the rising numbers of low-cost airlines. With this shift in the market, the competitive landscape between airlines has also changed. The focus is now primarily placed on having cheaper flight operations to enable them to offer reduction in their flight ticket prices. By doing so, they can capture bigger spectrum of market demands across different social and economic classes, which largely consists of price sensitive travellers. For instance, by 1999, low-fare-no-frills airlines captured 25% of domestic US travel market (Mason, 2000). In Europe, low-cost carriers have transported about 20.7 million passengers in 2000 and the numbers are on increasing trend since then (Dobruszkes, 2006). All these highlight the existing high demands for cheap air transportation options.

However, due to the increased saturation of the low-cost model airlines in the current market, the search for innovative means to obtain a competitive edge against other competing airlines becomes important. There have been many researches done on improving the efficiency of the airlines' operation and management to reduce costs. On the aircraft manufacturers' end, new technologies and improved design options have been explored and developed for better flight performances. One idea that has been considered is standing cabin concept, in which the passengers are proposed to be accommodated in the aircraft cabin during flight in their standing position instead of current seating arrangement. Among the first to pursue this idea is Spring Airline, one of the low-cost airlines in China. The airline intended to have standing-room only passengers cabin onboard its Airbus A320 aircraft. It was expected to increase the number of passengers that can be accommodated in the cabin by 40% more than current conventional cabin and reduce the operational costs by as much as 20% (Romli and Dasuki, 2013). Inspiration behind this idea comes from the public ground transportation modes like buses and trains, whereby passengers can be standing throughout the journey. Another low-cost carrier operating in Europe, Ryanair has picked up the idea and is seriously pushing for approval from governing aviation authorities to implement it. In 2012, the airline has successfully obtained approval to operate a series of 100 trial

Corresponding Author: Fairuz I. Romli, Department of Aerospace Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia.
Email: fairuz_ir@upm.edu.my

flights, in which the last five rows of seats in their passenger cabin were removed to allow up to 50 passengers to stand for their one-hour flights (Kerridge, 2012). The ticket price for this standing seat was offered at only £2 per person. This is evidently a giant step towards the implementation of this cabin concept in future commercial transport aircraft.

Currently, very few information is publicly available for evaluating the potential of this standing cabin concept in airlines' operation. A preliminary study was conducted for the domestic Malaysian flight markets indicates that the flight ticket prices can be reduced as much as 26% using this standing cabin concept (Romli and Dasuki, 2013). Though big assumptions are made in that study, it nevertheless highlights the potential of implementing the standing cabin concept for commercial transport aircraft. This paper aims to present a deeper analysis on the implementation of the standing cabin design for commercial transport aircraft by focusing on its potential impact on the takeoff gross weight of the aircraft. The takeoff gross weight is a highly interested parameter in aircraft design since it is an effective general indicator to the flight performances and costs of the aircraft. A common rule of thumb is that the reduction in the aircraft's takeoff gross weight will translate into improvements in its flight performances and costs (i.e. both production and operating costs). This is the reason why it is always preferred during the conceptual aircraft development stages to have an aircraft design with a low gross weight for a given mission profile.

Standing Cabin Concept:

The standing cabin, also known as vertical seating cabin, is a concept of cabin design arrangement where the passengers are primarily transported in their standing position throughout the flight. A graphical depiction of this cabin concept is illustrated in the following Figure 1. Apart from enabling the airlines to fit in more passengers into the passengers' cabin of their fleet, it is also highly expected that the vertical seats will be thinner and lighter than the current cabin seats. Hence this will also help to improve the flight performance and also operational costs in the long run through the savings of fuel costs. Actually, the idea of a vertical passenger seat for the aircraft cabin has been around since 2006, which is visualized to be comprised of a vertical bench with shoulder harnesses and arm rests. Back then, major aircraft manufacturers such as Airbus are reportedly considering such cabin concept to help increase the profit margin for airlines. With the high fuel prices, having more passengers per trip with reduced seat weight can help to increase the revenue for airlines by holding down the overall fuel consumption for their operation (Elliot, 2006).

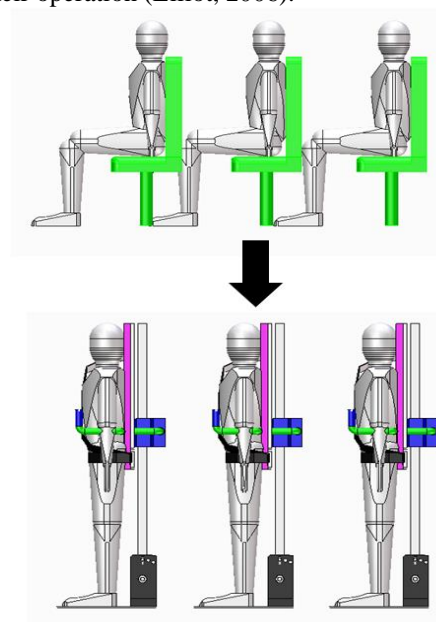


Fig. 1: Standing Cabin Concept (Romli *et al.*, 2014).

Aviointeriors Company, one of the world's leading aircraft seat and interiors manufacturers, has unveiled their proposal of vertical seat design. The seat, which is called SkyRider, was first promoted at the Aircraft Interiors Expo Americas 2010 in Long Beach, California. As depicted in Figure 2, SkyRider is developed as an ultra-high density seat to enable reduction of ticket prices while maintaining a sound profit to low-cost airlines. The seat design is then said to be already in final stages of testing (Platt, 2010). For SkyRider concept, even with the reduced seat pitch, it is expected that the appropriate passengers' comfort level can be maintained. It should be noted that in this seat design, the passengers are not transported in their full standing position like in the original idea of standing cabin. Instead, their seating position is rather similar to riding a motor-scooter.



Fig. 2: SkyRider Prototype Seat Design (Sorrel, 2010).

Apart from the seat design, the passengers' safety factor is a paramount issue in commercial aviation industry. For the standing cabin concept, which is effectively a high-density cabin design, it has to ensure that all passengers can be evacuated from the cabin within the required time in any emergency cases. On top of that, the seats have to undergo tests before they can be certified in accordance to the underlying safety and crashworthiness requirements. The material used in building the seats also needs to be tested and has to comply with the required criteria like non-flammable and non-toxic. In a nutshell, the seat design needs to comply with the requirements for the aircraft seat as outlined in the FAR/JAR Part 23 Regulation. As of today, no vertical seat design or standing cabin arrangement has been approved for commercial transport use. Nonetheless, it is good to acknowledge that the standing cabin concept is in fact legal by current standards of several governing aviation authorities. Federal Aviation Authority (FAA), for instance, does not specify that passengers have to be in sitting position during takeoffs and landings (Elliot, 2006). It is enough to prove that the passengers are properly secured by some certified mechanisms, even if they are standing during takeoffs and landings. The Air Transport Association (ATA) also does not impose specific standards for seat comfort or seating configurations (Elliot, 2006), meaning that the standing cabin concept is very much a possibility for future commercial short-haul flights.

However, having more passengers onboard can also have adverse effects on the aircraft performance mainly due to the potential increase in the gross weight of the aircraft. This is particularly true in the case of turning existing conventional aircraft cabin into a standing passenger cabin. If the weight of the vertical seats is not made adequately lighter than that of the current conventional seats, it can offset the benefits of the increase in cabin capacity with the increased weight of the passengers and their baggage. It is said that the vertical seats will typical be lighter than the normal seats. However, the overall effects from standing cabin concept remains to be fully analysed.

Takeoff Gross Weight Estimation:

Takeoff gross weight of an aircraft is its total weight at the beginning of its intended mission. In short, takeoff gross weight can be broken down into the weights of crew, payload and fuel, and also aircraft's empty weight. The payload weight corresponds to the passengers and their baggage, and/or cargo. On the other hand, the empty weight covers all else that are not considered as part of crew, payload and fuel weight. By this definition, the mathematical equation for the takeoff gross weight, W_0 can be written as in Equation (1).

$$W_0 = \frac{W_{\text{crew}} + W_{\text{payload}}}{1 - \left(\frac{W_{\text{fuel}}}{W_0}\right) - \left(\frac{W_{\text{empty}}}{W_0}\right)} \quad (1)$$

While the weight of crew and payload, W_{crew} and W_{payload} respectively, can be easily estimated by knowing the number of onboard crew and the intended payload capacity (i.e. number of passengers or cargo volume), the fuel and empty weights are usually estimated from empirical equations that are derived from historical data of existing aircraft. Raymer has outlined a structured method to estimate fuel and empty weights of the aircraft that is applied for this study (Raymer, 1992). Empty weight fraction of a commercial transport aircraft with a fixed sweep wing, which is the focus in this study, can be estimated using Equation (2). This equation is statistically derived based on historical trends of available aircraft in the market and the value of variable A will also depend on the materials used for the aircraft design.

$$\frac{W_{\text{empty}}}{W_0} = A(W_0)^{-0.06} \quad (2)$$

Meanwhile, for fuel weight estimation, it is closely tied to the intended mission profile for the aircraft. Typical mission profile for a commercial transport aircraft used for this study is illustrated in the following

Figure 3. Fuel weight fraction can be estimated as in Equations (3) and (4). Note that in Equation (3), the common 6% of additional fuel for emergency cases (i.e. for reserve flight segments) has also been included.

$$W_{\text{fuel}} = 1.06 \left(1 - \frac{W_x}{W_0} \right) W_0 \quad (3)$$

$$\frac{W_x}{W_0} = \left[\begin{array}{l} \text{Takeoff Weight Fraction} \times \text{Climb Weight Fraction} \\ \times \text{Cruise Weight Fraction} \times \text{Loiter Weight Fraction} \\ \times \text{Landing Weight Fraction} \end{array} \right] \quad (4)$$

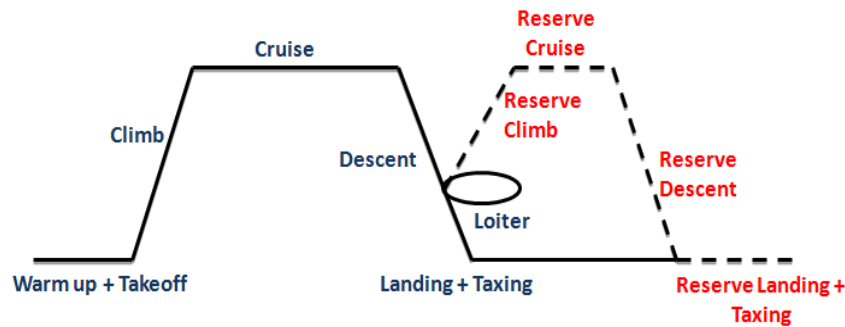


Fig. 3: Typical Mission Profile for Commercial Transport Aircraft.

As can be implied from Equation (4) and Figure 3, the commercial transport flight mission can be broken into several major stages. Estimated values for the takeoff weight fraction, climb weight fraction and the landing weight fraction are all given in (Raymer, 1992), and they are tabulated in Table 1. Meanwhile, for cruise and loiter weight fractions, they can be calculated based on the specified mission profile using Equations (5) and (6), respectively, where the variables R = range, V_∞ = velocity, E = endurance, (L/D) = lift-to-drag ratio and TSFC = thrust specific fuel consumption.

$$R = \frac{V_\infty}{TSFC} \frac{L}{D} \ln [\text{Cruise Weight Fraction}] \quad (5)$$

$$E = \frac{1}{TSFC} \frac{L}{D} \ln [\text{Loiter Weight Fraction}] \quad (6)$$

Table 1: Typical Values of Weight Fractions.

Mission Segment	Weight Fraction
Takeoff	0.970
Climb	0.985
Landing	0.995

Using the calculated value of the fuel weight from Equation (3) and estimated empty weight from Equation (2), the takeoff gross weight of the aircraft can be iteratively found through Equation (1). The iteration is done until the value of the takeoff gross weight converges. A MATLAB program is developed based on the outlined procedure in to facilitate iterative calculations of the aircraft takeoff gross weight.

Sample Case Study: Boeing 737-300 Cabin:

The standing cabin concept is ideally more applicable in serving short-haul flights with duration between only one to two hours. This is mainly constrained by the anticipated tolerable flight time that passengers can withstand in such standing position. To compare the standing cabin arrangement with that of the conventional seats, the cabin of Boeing 737-300 aircraft is selected as a reference platform. This choice is based on the notion that the Boeing 737 aircraft is one of the most common models currently used to serve short-haul flight routes. Using the existing cabin size and dimension of this aircraft, cabin arrangement can be derived for the standing cabin concept. No vertical seat design has been certified thus far for use in commercial transport aircraft. In addition, there is no formal study that has been published on the vertical seat design is found in the public domain. Airbus had been considering the idea of a standing cabin for their aircraft since early 2000's and in fact, they had filed a pattern over their proposed concept (Angerani *et al*, 2002). However, not much detail has been made available regarding that vertical seat design. For this study, conceptual design of the vertical seat that is proposed by Mohammad Noor and Romli as shown in Figure 4 will be used for the standing cabin. Dimensions of this vertical seat are roughly estimated from the anthropometric data of people from several countries, which

suggest that the overall height and width of each of the vertical seat are set to 1.7 meters and 0.5 meters, respectively (Romli and Dasuki, 2013).

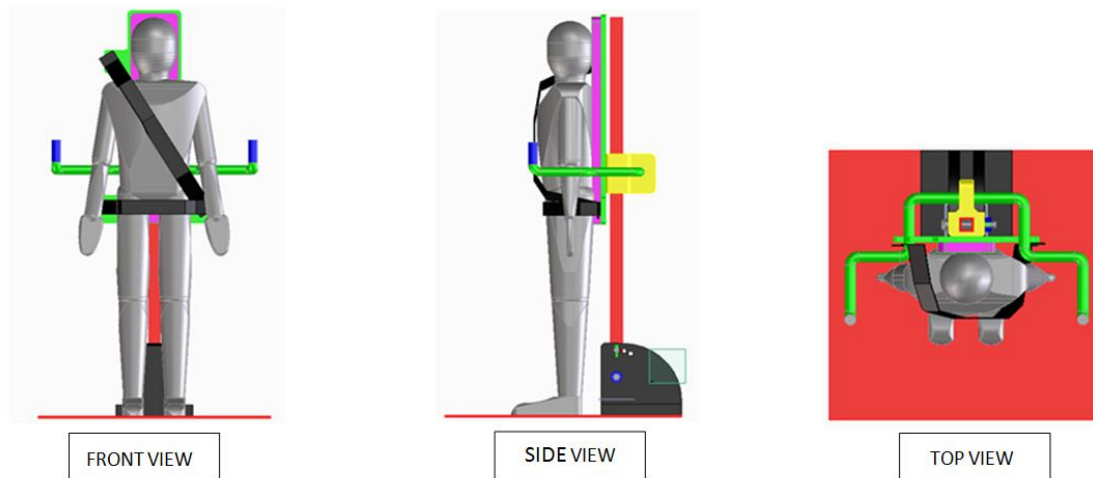


Fig. 4: Three-view drawing of vertical seat design concept (Mohammad Noor and Romli, 2013).

Based on the current cabin size and dimension of this aircraft, an alternative layout is derived for the standing cabin concept. The development of the proposed standing cabin concept takes into account several criteria of safety regulations imposed by FAR on design parameters like the minimum required seat dimension, seat pitch and aisle width. Since the passengers are now standing instead of sitting, the pitch between seats can be reduced as there is no need for a big legroom. The SkyRider seat from Aviointeriors is advertised to be able to be squeezed into the cabin with only 23-inch pitch, a sharp reduction from the typical 30-inch seat pitch between the rows (Platt, 2010). A side-by-side comparison between the normal and vertical seats in a typical 30-inch pitch cabin arrangement is shown in Figure 5, which indicates the extra space available between the rows for vertical seats. This means that the pitch can be further reduced and this enables more rows of vertical seats to be implemented into the passengers' cabin.

However, it should be noted that the main challenge is to fit the vertical seats into the aircraft cabin due to the height of the cabin as illustrated in Figure 5. Since the shape of the cabin cross-section is not rectangular, low height towards the sides of the cabin makes it impossible to have the vertical seats close to the cabin's wall. One way to remedy this is to remove the overhead bins and place them at the side as shown in Figure 5. Using this convention and taking into account the FAA regulations such as required aisle width and emergency procedures, arrangement for the standing cabin is constructed. If a totally new aircraft is being designed with standing cabin concept, it can be assumed that the height of the cabin can be adjusted accordingly to install the vertical seat as close as possible to the wall to accommodate the maximum number of seats. This would mean that the room for cargo space underneath the cabin floor might be reduced but for short flights with such cabin arrangement, passengers can be expected not to bring too much baggage onboard. But for this study, in order to make direct comparison to the existing Boeing B737 aircraft, the cabin space is taken as it is and only the vertical seats are re-fitted in place of the normal ones.

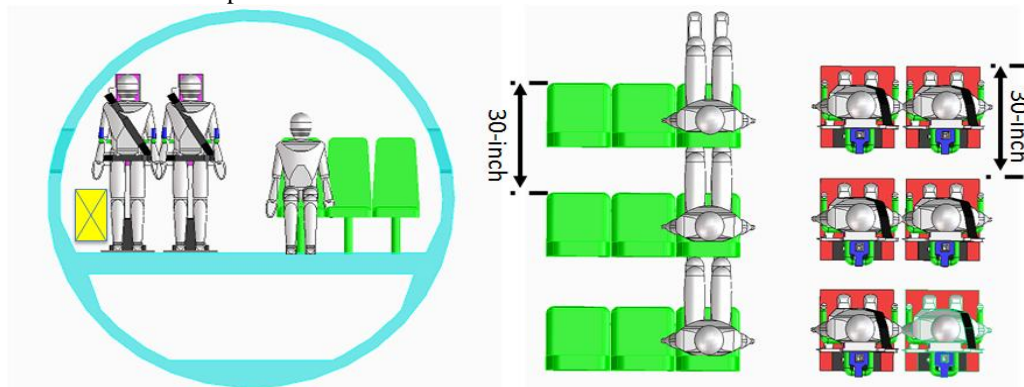


Fig. 5: Comparison of normal and vertical seat arrangement.

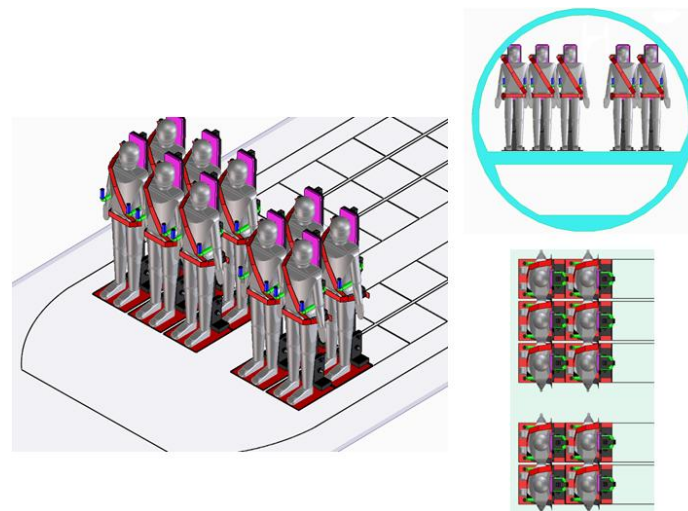


Fig. 6: 3 + 2 standing cabin arrangement (Romli *et al.*, 2014).

In the design simulation for the standing cabin arrangement, it is found that the seat pitch can be reduced to as little as only 20 inches. With the 3 + 2 arrangement as illustrated in Figure 6, the total number of seats that can be accommodated in the cabin has increased by 21% to 180 seats in comparison to that in normal seating arrangement. This increase in number of passengers may offset the weight savings from using lighter vertical seats and affect the performance of the aircraft, which is the focus of this study. With the advancement in materials technology, the weight of passengers' seats onboard the aircraft cabin is getting lighter as years go by. For instance, at 2013 Aircraft Interiors Expo in Germany, one of the displayed new economy-class seat has been advertised to weigh as light as 4 kg, which is supposed to be half of the weight for traditional airliner seats (Dubois, 2013). On the other hand, the vertical seat for standing cabin has been expected to weigh about 6.8 kg lighter than the normal seat (Elliot, 2006), which should come about to just around 1.2 kg per seat.

Before the new takeoff gross weight with standing cabin concept is estimated using the constructed MATLAB program, it needs to be validated first with the published information for Boeing B737-300 aircraft. The weights of the Boeing B737-300 aircraft as available in public domain are tabulated in Table 2.

Table 2: Weights of Boeing B737-300 Aircraft.

Weight Type	Value
Maximum Takeoff Mass	62,820 kg
Maximum Operating Empty Mass	32,700 kg
Maximum Fuel Mass	14,410 kg

Several assumptions have to be made in this calculation. As suggested by Raymer, the mass of each passenger and crew can be taken as 81.65 kg (including their carry-on luggage) and 18.15 kg each of checked luggage in the cargo hold (Raymer, 1992). With a maximum capacity of 149 people onboard in 1-class seating and typical crew size of seven people, the mass of cargo is estimated to be of 141.2 kg. Using the information in Table 2, the value of variable *A* in Equation (2) for Boeing 737-300 is calculated as 1.06. Furthermore, based on available information in the public domain, other assumptions that have been made for several parameters are tabulated in Table 3.

Table 3: Estimated Design and Performance Parameters.

Parameter	Value
Thrust Specific Fuel Consumption	0.0001642 /s
Lift-to-Drag Ratio	17.5
Maximum Flight Range	4204 km
Cruise Velocity	780 km/h

Using this data, the takeoff weight estimation program is run in MATLAB to validate its output results. Note that, the maximum range advertised for Boeing B737-300 is assumed to cover the emergency and loiter portions of the mission profile. This means that no additional emergency fuel is to be included in Equation (3). The comparison of the results is shown in Table 4, where it shows only a rather insignificant 0.279% of error in average between the calculated and the actual values for the Boeing B737-300 aircraft. This indicates the reliability and goodness of the MATLAB program for this study.

Now, to account for the modifications in the normal seating to the proposed standing cabin arrangement, the primary differences will be on the payload and empty weights of the aircraft. Having more passengers onboard

will increase the weight of payload due to their body and luggage weights. On the other hand, the replacement of the normal seats with the much lighter standing seats may reduce the overall operational empty weight. As discussed before, the standing cabin arrangement can fit a total of 180 passengers, which amounts to 18,662.6 kg of onboard payload (assuming the same number of crew) using the body weight and luggage assumptions as done previously. In addition, replacing 149 normal seats with 180 standing seats can be expected to save about 976 kg of empty weight based on previously discussed weight savings, which is around 0.03% of the current empty weight. The fuel weight and the overall empty weight is a function of the total takeoff gross weight, hence they have to be estimated through the weight estimation procedure. As the aircraft's external design is not notably changed and only the passenger cabin is modified, all performance parameters are taken to remain the same. Considering these changes, the weight estimation program is executed and the results are as tabulated in Table 5.

Table 4: Comparison between Actual and Calculated Weights for Boeing B737-300 Aircraft.

Weight	Actual Value	Calculated Value	% Error
Maximum Takeoff Mass	62,820 kg	62,963 kg	0.227
Maximum Operating Empty Mass	32,700 kg	32,798 kg	0.299
Maximum Fuel Mass	14,410 kg	14,455 kg	0.311

Table 5: Estimated Weights for Boeing 737-300 Aircraft with Standing Cabin Arrangement.

Weight	Value
Maximum Takeoff Mass	69,593 kg
Maximum Operating Empty Mass	34,953 kg
Maximum Fuel Mass	15,977 kg

As indicated by the results in Table 5, the weights of the aircraft can be expected to increase for the standing cabin in comparison to the current normal seating arrangement. However, the increase is not significant and is just roughly about 10.5% as highlighted in the comparison Table 6.

Table 6: Comparison of Weights.

Weight	Normal Cabin	Standing Cabin	% Increase
Maximum Takeoff Mass	62,963 kg	69,593 kg	10.5
Maximum Operating Empty Mass	32,798 kg	34,953 kg	6.6
Maximum Fuel Mass	14,455 kg	15,977 kg	10.5

Conclusion:

As the current market faces the increased saturation of the low-cost model airlines, the search for innovative means to obtain a competitive edge against other competing airlines becomes important. To further reduce costs, and hence the charging flight ticket to the flying customers, the idea of standing cabin concept in which the passengers are accommodated in the aircraft cabin in their standing position instead of current seating arrangement during flight is being considered. It is expected that the flying cost will be lower per passenger as it is distributed to larger number of paying people. However, having more passengers onboard can also have adverse effects on aircraft performance mainly due to the potential increase in the gross weight of the aircraft. This is particularly true in the case of turning existing conventional aircraft cabin into a standing passenger cabin. If the weight of the vertical seats is not made adequately lighter than that of current conventional seats, it can offset the benefits of the increase in cabin capacity with the increased weight of the passengers and their baggage. It is said that the vertical seats will typical be lighter than normal seats. As shown by the results of the study, the takeoff gross weight of the aircraft is indeed expected to increase with the standing cabin arrangement. Since the takeoff gross weight is often used as the design indicator of the cost, it can be taken to mean that the cost will also increase. Nevertheless, the increment in weight is estimated to be just around 10.5% and should be easily balanced back by the increase in 21% of total passenger capacity. A more detailed analysis on the cost will be done in the future to solidify the advantages of having this standing cabin design in commercial transport aircraft.

ACKNOWLEDGEMENT

The author is grateful to Universiti Putra Malaysia, Malaysia for supporting this research work under the grant GP-IBT/2013/9407100.

REFERENCES

- Angerani, J.G., A. Baatz, S. Hiesener and H. Merensky, 2002. Airbus Deutschland GmbH, Hamburg, Patent. No. US 6,467,728 B2, Date of Patent: 22 October 2002.
- Dobruszkes, F., 2006. An Analysis of European Low-Cost Airlines and Their Networks. *Journal of Transport Geography*, 14: 249-264.

Dubios, T., 2013. New Airliner Seat Sheds Weight and Parts Count, Available: <http://www.ainonline.com/aviation-news/ain-air-transport-perspective/2013-04-15/new-airliner-seat-sheds-weight-and-parts-count> [Accessed: December 2013]

Elliot, C., 2006. One Day, That Economy Ticket May Buy You a Place to Stand. Available: <http://www.ny-times.com/2006/04/25/business/25seats.html> [Accessed: December, 2013].

Kerridge, S., 2012. Ryanair – Approval for Standing Only Cabin Areas. Available: <http://blog.france-airport-guide.com/2012/04/ryanair-approval-for-standing-only.html> [Accessed: December, 2013].

Mason, K.J., 2000. The Propensity of Business Travellers to use Low Cost Airlines. *Journal of Transport Geography*, 8: 107-119.

Mohammad Noor, A.R. and F.I. Romli, 2013. Conceptual Design of Vertical Passenger Seat for Standing Cabin in Commercial Transport Aircraft. *Journal of Advanced Management Science*, 1: 344-348.

Platt, C., 2010. Saddle Up: World's Smallest Airline Seat Unveiled. Available: <http://www.smh.com.au/travel/travel-news/saddle-up-worlds-smallest-airline-seat-unveiled-20100914-15ad6.html> [Accessed: December, 2013].

Raymer, D.P., 1992. *Aircraft Design: A Conceptual Approach*, American Institute of Aeronautics and Astronautics, Inc., Washington D.C.

Romli, F.I. and N. Dasuki, 2013. Preliminary Study of Standing Cabin Concept for Domestic Commercial Flights in Malaysia. *Proceeding of 2nd International Conference on Advances in Mechanical and Aeronautical Engineering*, Bangkok, Thailand.

Romli, F.I., A.R. Mohammad Noor and N. Dasuki, 2014. A Study on Potential Standing Cabin Effects in Improving the Competitiveness of Low-Cost Airlines. *International Journal of Engineering and Technology*, 6: 304-308.

Sorrel, C., 2010. World's Most Cramped Airline Seat to Launch Next Week. Available: <http://www.wired.com/gadgetlab/2010/09/worlds-most-cramped-airline-seat-to-launch-next-week> [Accessed: December, 2013].